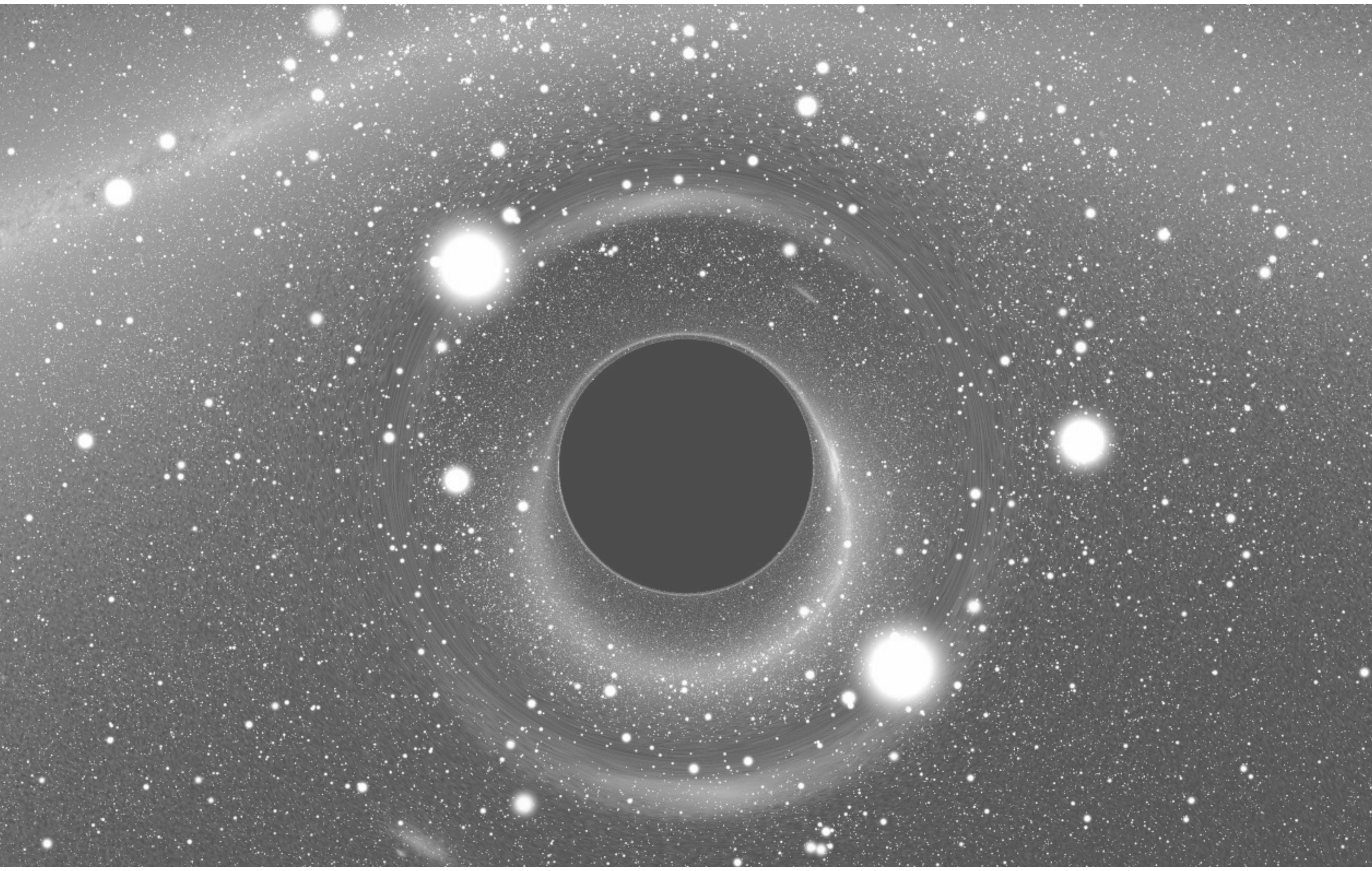
ACTIVITY REPORT
2017-2021



ASTROPARTICULE ET COSMOLOGIE

Released: February 2022

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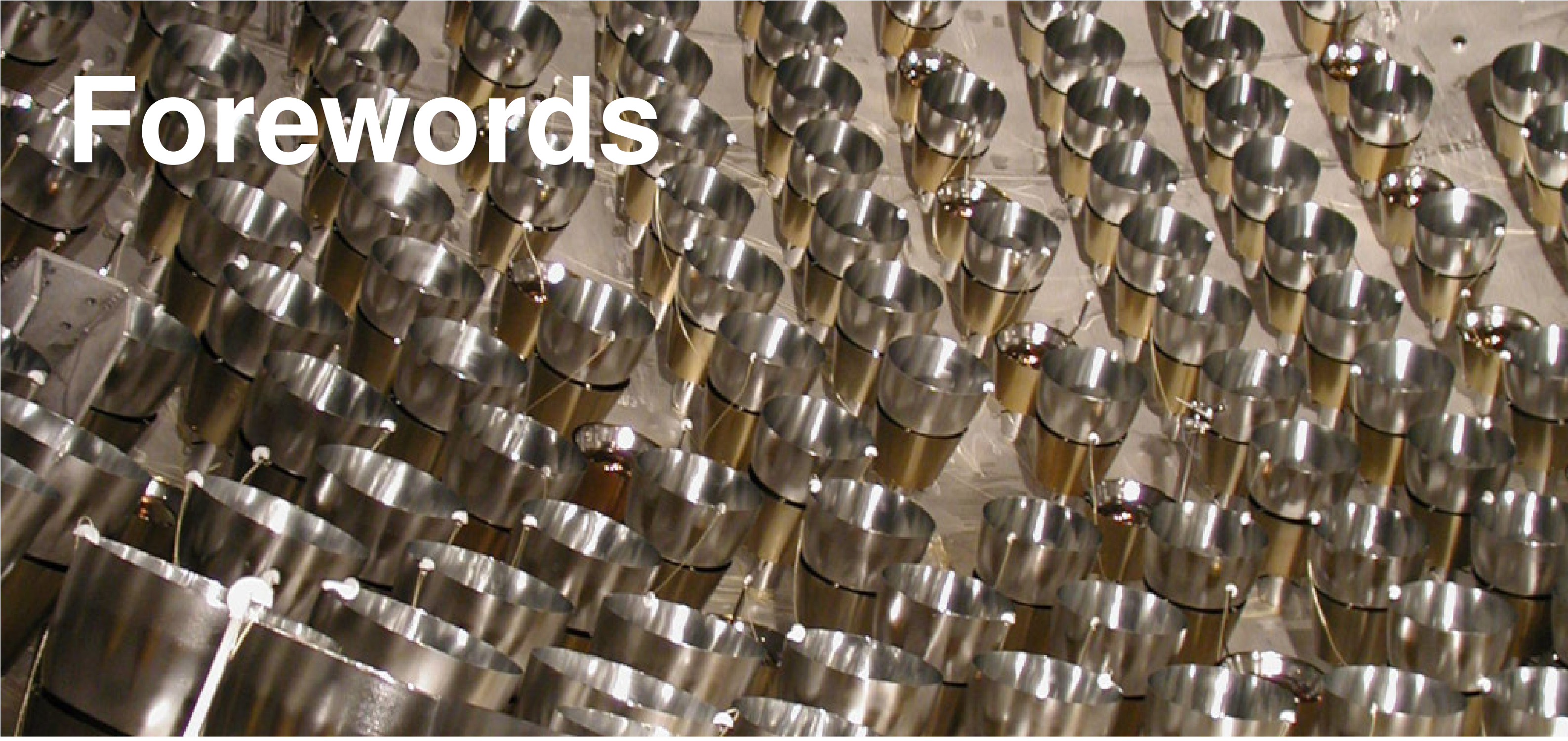
Forewords



Laboratoire Astroparticule et Cosmologie (APC) is a joint research unit (Unité Mixte de Recherche (UMR)) created in 2005. This structure is managed by Université de Paris, CNRS (represented by three of its institutes: mainly IN2P3, and also INSU and INP), CEA/Irfu (DSM/IRFU), the Observatoire de Paris, and the French space agency (CNES).

APC is organized into five main teams that develop research in the following scientific areas:

- Cosmology – The Cosmology team works on various aspects of cosmology, from theory to instrumentation, with the study of the cosmic microwave background and the understanding of dark energy as two central themes.
- Gravitation – The Gravitation team contributes to gravitational-wave astronomy using ground-based and spaced-based detectors, and related fields.
- High-Energy Astrophysics – The High Energy Astrophysics team studies violent phenomena in the Universe with a multi-wavelength (ranging from X- to gamma-rays) and multi-messenger approach, including neutrinos, charged cosmic rays, and gravitational waves.
- Neutrinos and dark matter – The Neutrinos and dark matter team focuses on various aspects related to the neutrino physics (such as the determination of parameters governing neutrino oscillations) and dark matter direct detection. Since 2021, it comprises a new axis on Higgs boson physics. For this reason, the team has now been renamed "Particles".
- Theory – The Theory team develops theoretical models in all the above themes and in close contact with the experimental teams.

A key aspect of APC is the presence of five technical departments, which provide the technical expertise required by the projects. They are organized according to their different skills: Mechanics, Electronics & micro-

Antoine Kouchner, Director of the Laboratoire AstroParticule et Cosmologie electronics, Instrumentation, Information Technology and Project quality assurance. Their work develops within and around the François Arago Centre (FACe) (a data management center), four laboratories (millimetric wavelength, photodetection, optics, integration and tests), and two workshops (mechanics and assembly hall).

Three structures are closely associated to the laboratory:

1. Paris Center for Cosmological Physics. Founded by George Smoot (2006 Physics Nobel Prize and APC member since Feb 2010), PCCP was created in 2010 with the support of the University of Paris and IN2P3. In order to provide future funding for the Centre, an endowment fund was created (Fonds de dotation pour la Formation et la Recherche en Physique de l'Univers), based on the model of a similar foundation created by George Smoot in Berkeley.

2. LabEx UnivEarthS. Together with IPGP and AIM, APC is one of the founding members of the LabEx UnivEarthS, an interdisciplinary alliance awarded a grant of about 1 M€ per year since 2011. This initiative develops an extensive program of interdisciplinary collaborations, notably with the geosciences.

3. APPEC functional centre. The AstroParticle Physics European Consortium (APPEC) regroups the European funding agencies involved in astroparticle projects. Through the EU funded ERA-Net ASPERA (2006-2012) [1], it has developed a roadmap for astroparticle physics in Europe, which has been key in providing adequate effort for the large projects of the discipline. APC is a functional centre of APPEC hosting its strategy activities and interdisciplinary programs.

[1] https://www.aspera-eu.org

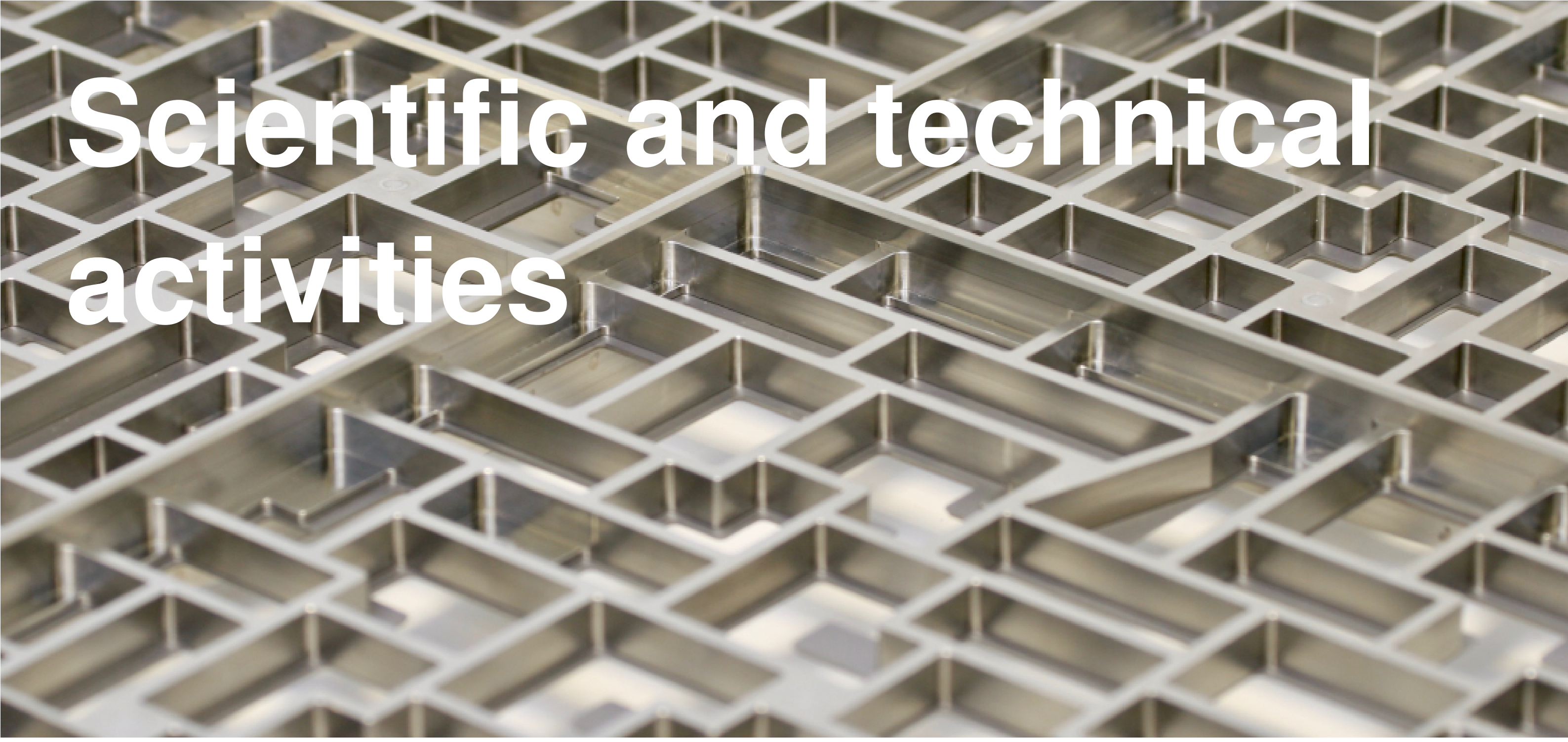
As an associate institute, APC has close connections with Observatoire de Paris. For instance, APC is a partner of the the regional program of Ile-de-France "Domaine d'Interêt Majeur" (DIM) ACAV+ coordinated by Observatoire de Paris. This program is a major locus for interaction and coordination of the regional astrophysical community. APC is one of the stakeholders in the new program DRIM Origines recently submitted to the region Ile de France.

At the international level, APC is embedded in a large network of international centres of excellence in Astroparticle Physics. APC has been key in establishing a new International Research Lab (IRL) in Berkeley: the Pierre Binetruy Centre [2] whose head is a former APC member. It is also worth mentioning the special role of APC in the creation of AstroCeNT [3] in Warsaw, a new excellence center in astroparticle physics that APC is supporting via scientific collaborations and supervision actions.

[2] https://www.cpb.in2p3.fr

[3] https://astrocent.camk.edu.pl

Scientific and technical activities



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Cosmology

Resp: K. Ganga

The APC Cosmology group works on a number of aspects of cosmology, from theory to instrumentation. There are two overarching themes to the group of roughly equal size: optical and infrared surveys, and the Cosmic Microwave Background (CMB). In addition, there are various smaller efforts. At the moment, the large optical and/or infrared projects on which we work are the Vera C. Rubin Observatory, and the Euclid Satellite. For the CMB, the large projects we work on are QUBIC, the Simons Array and Observatory, and *LiteBIRD*.

The Cosmology group is composed of 20 permanent researchers (6 CNRS with 5 IN2P3and 1 INP; 5 University; 2 CEA/Irfu; 1 Observatory; 5 Emeritus and 1 Benevol), 12 doctoral students, and 6 postdocs. Another dozen or so APC members are affiliated with the Cosmology group (i.e. this is their “second affiliation” or they are engineers working with the Cosmology Group). We have a mailing list with approximately 50 recipients, which includes group members as well as others such as external affiliates, associates, and the like, and we have nominally weekly meetings, though we will skip meetings where there is nothing significant to report or a number of people are out of the office.

The group addresses its scientific priorities using both ground-based and space-based platforms. Below we discuss these two axes in turn.

Ground-based efforts

APC has been involved in a number of ground-based experiments in the past. For example, QUAD and Polarbear in the CMB, and BOSS in the optical. Today, the group is part of the Rubin, Simons and QUBIC experiments, each of which is described in the following.

Vera C. Rubin Observatory

The Vera C. Rubin Observatory, previously referred to as the Legacy Survey of Space and Time (LSST), is an astronomical observatory currently under construction in Chile. The Rubin Observatory hosts a wide-field telescope with an 8.4-meter primary mirror that will scan the entire sky every 3 nights. Its main task will be to conduct a 10-year deep survey of the southern hemisphere, called the Legacy Survey of Space and Time (LSST), which will enable breakthroughs in many astrophysical fields, cosmology in particular.

Figure 1: July, 2021 drone photo of the Rubin Observatory summit facility (provided by Dome Surveyor, Oscar Rivera) showing advancement to near 100% on the dome cladding completion as well as closure of the louvers, rear door, and shutters. Sublocation: Cerro Pachón, Chile. Credit: Rubin Obs/NSF/AURA

France, through IN2P3, has been involved for the last decade in the construction of the LSST Camera. At APC, the technical contribution of the camera has been focused on the software for the filter exchange system (FES), a part of the camera that takes care of swapping filters during the night and ensures the precise (re-)positioning of each filter.

As of October 2021, There are five permanent researchers and professors in the APC Rubin group, two permanent engineers, one postdoc, one non-permanent engineer, and two students. Our largest technical contributions to LSST are focused on the construction of its camera: the architecture and development of the camera control and command systems and development of the filter exchange subsystem. We also do scientific coordination for the French camera construction. Principal scientific themes are galaxy clusters, joint analyses and cross-correlations between different probes, and gravitational lensing.

Filter Exchange System The FES is a complex online system designed to complete a dozen of filter exchanges every night for 10 years, and conceived by five IN2P3 labs : APC, LPNHE (Paris), CPPM (Marseille), LPSC (Grenoble), and LPC (Clermont-Ferrand). It is composed of 3 sub-systems: the filter loader, the autochanger and the carousel (see figure 2). All three are controlled by a common software called the Filter Control System (FCS).

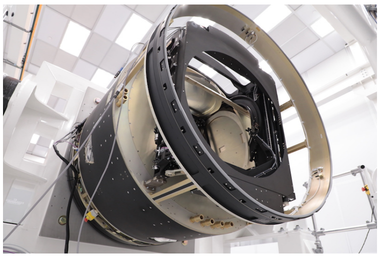

Figure 2: Picture of the assembled LSST camera under testing. One can catch a glimpse of the filter exchange system with the dummy filters inside – IR2 clean room – SLAC, California – December 2019. Credit: Gaëlle Shifrin, CNRS/IN2P3

APC has been deeply involved in the construction since the beginning of the project around 2010, and has taken the lead on the development of the FCS software, written in Java. We have also been contributing to the larger Camera Control System (CCS), the distributed system that controls most of the operations and communications related to the hardware of the LSST camera and which is mainly developed at SLAC, California.

During summer 2019, the French team tested and validated a standalone production-ready version of the FES that concluded successfully (see photo on figure 3). The subsystems were then sent to SLAC, California for an integration into the full camera body, which happened between November 2019 and February 2020.

After a long pandemic break that prevented live-support from French people, travel resumed in September-October 2021, allowing the whole FES team to tune the system and starting validating both the hardware and the software directly on the camera body and with the true filters. This resulted in a huge improvement of the timing of a full filter exchange, reaching a value well below the specification of 90 seconds from the project.

Figure 3: Snapshot of happy engineers after the completion and success of the filter exchange tests with the production-ready FES, before shipment to California – LPNHE clean room, September 2019

Key figures

The Filter Exchange System engineering team was awarded the *Cristal collectif du CNRS 2021.* Françoise Virieux is listed among the recipients of this award. [See https://www.cnrs.fr/fr/personne/changeur-de-filtres-lsst]

Weak lensing science The cosmological probe on which we focus in these surveys is weak gravitational lensing. Gravitational lensing corresponds to the deflection of light from distant sources (background galaxies) due to the bending of space-time by matter along the line of sight, resulting in distortions and displacements of their image. The statistical study of weak gravitational lensing distortions at large scales provides a "mapping" of the matter (dark or visible) between the observer and source (more accurately, the effect of coherent deformation described here is called cosmic shear).

This type of measurement gives a window on the properties and the evolution of cosmic structures as well as the geometry of the Universe. Its study can therefore bring higher constraints on the origin of the current accelerated expansion of the Universe that led to the notion of dark energy. In the absence of systematic errors, weak lensing is even recognised as the single most constraining probe of dark energy. As such, it is one of the main science drivers for a survey like the LSST and Euclid.

Weak lensing correlations are statistically inferred by associating the measured shapes of numerous galaxies, meaning that weak lensing estimates of the matter distribution generally improve with the number of well-measured galaxy shapes, as long as the uncertainties can be controlled. To address one of the challenges set by the shape measurements on the images of the coming surveys, our group has started to develop an approach based on Bayesian neural networks. The development of this type of analysis has lead us to build new collaborations, leading to the defense of an ANR project *AstroDeep*. The BNNs offer a formalism to quantify and propagate uncertainties associated with deep neural networks models and also with the data themselves, which are both key for cosmological analyses. As such their study and the construction of a full shear analysis relying on them is one of the goals of our team.

We have demonstrated the feasibility of their use, first in a simple context for Euclid,[4] and then in a configuration with several simulated galaxies per image in a recent publication for LSST and Euclid.[5] This work is still part of an ongoing effort in the LSST Dark Energy Science Collaboration (DESC [6]). A first PhD thesis has taken place in the group (B. Arcelin, defense in Sep 2021) bringing forth these progresses with two main contributions based on Bayesian deep learning methods while tackling the effect of blending of galaxies, which is an effect we have to address in large and deep ground surveys like the LSST. The first avenue to address this problem is a deblending algorithm which uses a deep generative network called variational autoencoder. This neural network allows to learn a prior for the generation of isolated galaxy images. The latter is used in a second network to perform the deblending of the centred galaxy on images of simulated galaxies. Using this analysis, we have been able to show that the pixel joint analysis of LSST and Euclid data decreases the median error on galaxy shape reconstruction from 8 to 47%. An iterative process is then designed in order to separate all the galaxies in an image going through detection, classification and deblending of sources and this work is currently pursued.

[4] Alexandre Boucaud et al. "Photometry of high-redshift blended galaxies using deep learning". In: *MNRAS* 491.2 (2020), pp. 2481–2495. arXiv: 1905 . 01324 [astro-ph.GA].

[5] Bastien Arcelin et al. "Deblending galaxies with variational autoencoders: A joint multiband, multi-instrument approach". In: *MNRAS* 500.1 (2020), pp. 531–547. arXiv: 2005.12039 [astro-ph.IM].

[6] https://lsstdesc.org

Tested on images extracted from the DC2 simulation, generated within the DESC to prepare for the analysis of futures images taken by LSST, this method shows an improvement of 70 to 120 % on the median ellipticity error compared to the generic method used in the current LSST pipeline.

Additional work by B. Arcelin proposed a neural network allowing for the direct estimation of galaxy shape and redshift parameters from DC2 images, without going through the deblending. This neural network allows for a precise measurement of these parameters, even when sources are blended, and can be compared to the ones obtained with deblending. This other axis will also be developed further in our group in the next few months.

Supporting grants

2019–2024	ANR **AstroDeep** – PI: E. Aubourg – https://astrodeep.net
2021–2024	PhD grant B. Biswas - Marie Skłodowska-Curie Actions (MSCA) - COFUND Horizon 2020

Team

B. Arcelin, E. Aubourg, J. Bartlett, B. Biswas, A. Boucaud, C. Doux, J. Errard, K. Ganga, K. Grishin, A. Guinot, S. Mei, C. Roucelle, T. Sainrat, F. Virieux, J. Zeghal

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Simons Observatory

The Simons Observatory (SO) is a new Cosmic Microwave Background (CMB) experiment and one of the leading Stage-III experiments worldwide. It grew from a merger of two major Stage-II experiments: the POLARBEAR/Simons Array and Atacama Cosmology Telescope collaborations. SO is under construction at the same site as POLARBEAR/Simons Array, the Cerro Toco in Chile. It is due to achieve first light in 2022 and start scientific observations in the early 2023.

Figure 4: Overview of the SO site (Credits: D Kellner)

The team at APC has had central role in the data analysis and scientific exploitation of the previous generation, POLARBEAR observations. We took part in the design, deployment, calibration, map-making and cosmological interpretation of POLARBEAR data sets. Historically, POLARBEAR was the first experiment which delivered direct evidence in favor of the presence of the B-mode at small angular scales. In the period covered by this report our main achievements include

- the first iterative delensing using polarized data sets [The POLARBEAR collaboration (2020)].
- the demonstration of the rotating half wave plate, which is a crucial element for future experiments such as CMB-S4 and LiteBIRD.
- the publication of independent upper limits on the inflationary tensor-to-scalar ratio [The POLARBEAR collaboration (2019, 2021 in prep)].

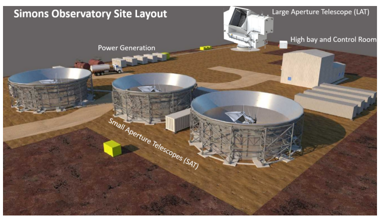

Figure 5: An artist's impression of the SO layout

The Simons Array is an evolution of the POLARBEAR project, which features three POLARBEAR telescopes, furnished with ~ 21,000 TES detectors sensitive to polarization in four frequency bands: 90, 150, 220 and 280GHz. The project, based on a high sensitivity and a strong control of instrumental systematics, aims at constraining the tensor-to-scalar ratio with a statistical sensitivity $\sigma(r = 0) \sim 0.006$, about half of the current sensitivity [The Bicep/Keck collaborations (2021)]. Its angular resolution allows the measurement and characterization of gravitational lensing, and in particular the setting of constraints on late Universe cosmological parameters such as the total mass of neutrinos. As of 2021, the three SA telescopes are operating, and the instrument is under commissioning.

The POLARBEAR/Simons Array experiments will pave the way to the third generation experiment, SO, at the same site. Its initial configuration will have three small-aperture 0.5-m telescopes (SATs) and one large-aperture 6-m telescope (LAT), with a total of 60,000 cryogenic bolometers. The SATs will target the largest angular scales observable from Chile, mapping around 10% of the sky to a white noise level of 2 μK-arcmin in combined 93 and 145 GHz bands, to measure the primordial tensor-to-scalar ratio, r, at a target level of σ(r)=0.003. The LAT will map around 40% of the sky at arcminute angular resolution to an expected white noise level of 6 μK-arcmin in combined 93 and 145 GHz bands, overlapping with the majority of the sky area of the Legacy Survey of Space and Time (LSST) on the Vera C. Rubin Observatory sky region. It will also partially overlap with the Dark Energy Spectroscopic Instrument (DESI) field of view.

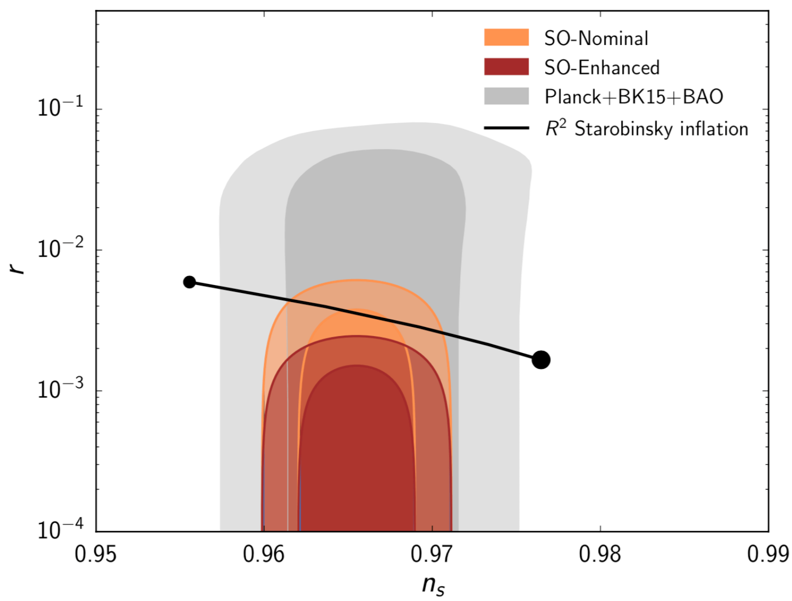

Figure 6: Projection of SO performances in constraining inflationary parameters. From `https://simonsobservatory.org/primordial/`.

SO key science goals include the characterization of primordial perturbations, the measurement of the number of relativistic species and the mass of neutrinos, the test for deviations from a cosmological constant, the improvement of our understanding of galaxy evolution, and the constraint of the duration of reionization. With up to ten times the sensitivity and five times the angular resolution of the Planck satellite, and roughly an order of magnitude increase in mapping speed over currently operating ("Stage 3", like SA) experiments, SO will measure the CMB temperature and polarization fluctuations to exquisite precision in six frequency bands from 27 to 280 GHz. The high-resolution sky maps will constrain cosmological parameters derived from the damping tail, gravitational lensing of the CMB, the primordial bispectrum, and the thermal and kinematic Sunyaev-Zel'dovich effects, and will aid in delensing the large-angle polarization signal to measure the tensor-to-scalar ratio. The survey will also provide a legacy catalog of 16,000 galaxy clusters in the nominal SO mission, and more than 20,000 extragalactic sources.

Design optimization and forecast The team played an important role in the definition of the science goals of the project and design of its instruments. This work has been summarized in the article [The Simons Observatory (2018)]. In particular we have co-led the work on the impact of the foregounds on the science performance of the experiment.

Data analysis, from raw data to science The team has had an important role in the development, testing and validation of map-making techniques suitable for the Stage-III (and beyond) class experiments. In particular, we have developed a publicly-available, massively parallel software package MAPPRAISER [El Bouhargani et al (2021)]. Such codes are the backbones of any CMB data analysis pipelines and our code, developed under the auspices of the SO Pipeline Working Group, is one of the two codes currently under the development by the SO project and arguable the most advanced one. This effort was supported in part by a multi-disciplinary ANR project, B3DCMB.

Since the inception of the project in 2016 we have continuously co-led the SO Working Group focused first on the optimization of the SATs design and operation in the presence of galactic foregrounds, instrumental systematics and gravitational lensing. Most recently, this group, still under our co-leadership, has been developing data analysis tools aiming at extracting of the B-mode signal from the SAT data. In addition to central contribution to the foreground cleaning and characterization of inflationary science, APC is involved in the study and exploitation of SZ clusters as well as the cross correlation of its data sets with other projects such as Rubin, Euclid and DESI.

Calibration and other activities The team is involved in delivering a high frequency (280GHz) calibration source which will be flown on a drone above the SATs, with the goal of calibrating the pointing, optical response, polarization angles of the detectors and bandpasses. This has been funded by a Émergences grant from the Université de Paris Idex.

The team has been deeply involved in the governance of the SO project and had several organizational positions. These include a membership of the Theory and Analysis Committee (TAC), the collaboration and membership committees, talk panel, analysis working group co-leads, etc.

More information about SO can be found at the Simons Observatory website.[7]

[7] https://simonsobservatory.org/.

Supporting grants

2018-22 ANR B3DCMB - PI : R. Stompor – http://b3dcmb.in2p3.fr

2018-22 ANR BxB - PI: F. Boulanger (ENS) – https://anr.fr/Project-ANR-17-CE31-0022

Team

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Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

QUBIC

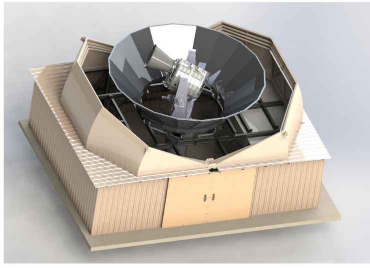

Figure 7: Artist view of QUBIC on the alt-azimuth mount in the shelter, as will be installed in early 2022 at the observing site at 5000m a.s.l. near San Antonio de los Cobres, Salta Province, Argentina

The Q & U Bolometric Interferometer for Cosmology (QUBIC)[8] is a novel kind of polarimeter optimized for the measurement of the B-mode polarization of the CMB, which is one of the major challenges of observational cosmology. The signal is expected to be of the order of a few tens of nK, prone to instrumental systematic effects and polluted by various astrophysical foregrounds which can only be controlled through multichroic observations.

[8] J. -Ch. Hamilton et al. "QUBIC I: Overview and ScienceProgram". In: *JCAP* (2020). arXiv: 2011.02213 [astro-ph.IM].

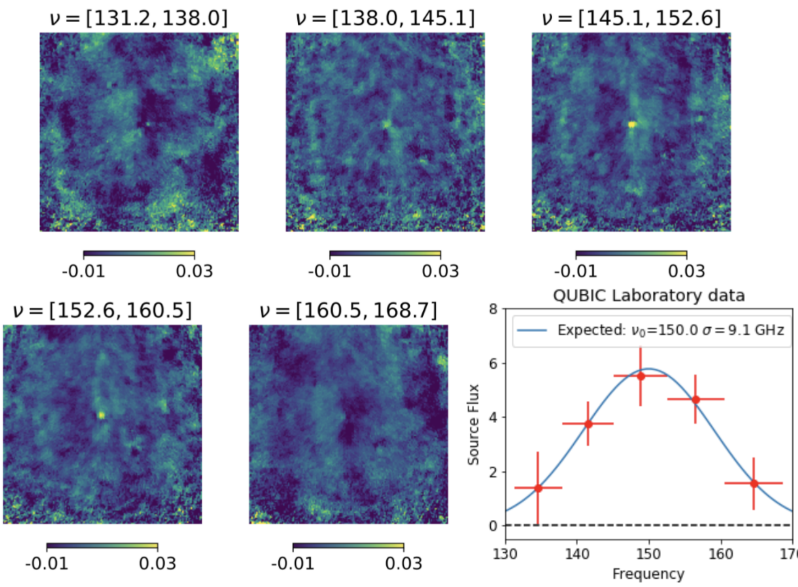

Figure 8: Reconstructed images of our artificial calibration source using spectral imaging in 5 sub-bands. The source was set to 150 GHz. The measured intensity of the source is shown on the right as a function of frequency (red points) while the expected spectral resolution (8 GHz) is superimposed in blue (no fitting).

QUBIC is designed to address these observational issues with a novel approach that combines the advantages of interferometry in terms of control of instrumental systematic effects with those of bolometric detectors in terms of wide-band, background-limited sensitivity. The QUBIC synthesized beam has a frequency-dependent shape that results in the ability to produce maps of the CMB polarization in multiple sub-bands within the two physical bands of the instrument (150 and 220 GHz). These features make QUBIC complementary to other instruments and makes it particularly well suited to characterize and remove Galactic foreground contamination.

In QUBIC, pairs of back-to-back horns act like pupils of a Fizeau interferometer forming fringes on the focal plane equipped with bolometers. This is the optical equivalent of a correlator in classical interferometry. BI performs this over a wide-band, at low cost, with a sensitivity comparable to that of a classical imager,[9] with the possibility of self-calibration as in

[9] J. -Ch. Hamilton et al. "Sensitivity of a bolometric interferometer to the cosmic microwave backgroud power spectrum". In: *A&A* 491.3 (2008), pp. 923–927. arXiv: 0807.0438 [astro-ph].

a classical interferometer.[10] Thanks to the frequency dependence of its synthesized beam, QUBIC can perform spectral imaging with $\Delta\nu/\nu$ 0.05.[11] This has been demonstrated with real data in the laboratory[12] as shown in Fig. 8 from.[13] This is a key feature for foreground contamination control, unique to Bolometric Interferometry.

End-to-end simulations with three years of integration, assuming perfect foreground removal as well as stable atmospheric conditions showed that we can achieve polarization maps depth of 2.7 and 3.7 μK.arcmin at 150 and 220 GHz respectively. This results in a statistical sensitivity to the effective tensor-to-scalar ratio (including primordial and foreground B-modes) $\sigma(r) = 0.015$[14]).

After a phase of R&D on subsystems, the QUBIC collaboration began building the Technological Demonstrator (TD) in 2016. It is the same as the Full Instrument (FI) but with fewer detectors (256 at 150 GHz instead of 2048 at 150 and 220 GHz), and with fewer horns (64 instead of 400). The TD was then integrated at APC laboratory starting in 2018 and went through a detailed calibration and testing phase throughout 2019 and 2020. A review, organized in 2020 by CNRS/IN2P3, with INFN, highlighted the innovation from this first ever Bolometric Interferometer, assessed the concept's capabilities as "excellent" and found the spectro-imaging feature "of utmost utility for foreground control". QUBIC was shipped to Argentina in mid-2021 and is now operational, cooled-down and undergoing tests and training of the Argentinean teams in our integration laboratory in Salta, Argentina. The next step is the installation of the TD on its 5000m a.s.l. site in Argentina (3h drive from Salta). A control building in San Antonio de los Cobres (45 min drive) is already operational, while the works on the site are underway. The installation on-site is scheduled for early 2022 and will be shortly followed by commissioning and data taking with the QUBIC-TD. The upgrade to the QUBIC-FI is anticipated in 2023 after one year of operations with the TD.

Team

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Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Space-based efforts

In space-based work, *Planck* was a flagship project at APC, and the group has also been involved in balloon measurements such as those by Archeops. Today, *Euclid* and LiteBIRD are the main satellite missions on which the group works (though there are also smaller contributions to balloon-based efforts as well). The laboratory also played a leading role in the study of a European post-Planck CMB space mission, for polarization observations (CORE space mission), and for CMB polarized spectroscopy (in the

[10] M. -A. Bigot-Sazy et al. "Self-calibration: an efficient method to control systematic effects in bolometric interferometry". In: *A&A* 550 (2013), A59. arXiv: `1209.4905 [astro-ph.IM]`.

[11] L. Mousset et al. "QUBIC II: Spectro-Polarimetry with Bolometric Interferometry". In: *JCAP* (2020). arXiv: `2010.15119 [astro-ph.IM]`.

[12] S. A. Torchinsky et al. "QUBIC III: Laboratory Characterization". 2020.

[13] Torchinsky et al., "QUBIC III: Laboratory Characterization".

[14] Hamilton et al., "QUBIC I: Overview and ScienceProgram".

context of the ESA Voyage-2050 process).

Euclid

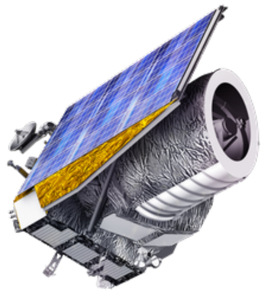

Figure 9: An artist's rendition of Euclid

Euclid is ESA's flagship cosmology mission dedicated to constraining the nature of dark energy. It uses two primary probes - gravitational lensing and galaxy clustering - plus additional probes based on galaxy clusters and cross-correlations of large-scale structure with the CMB. In June 2010, the Cosmology group joined the consortium that proposed the concept to ESA. The Agency selected *Euclid* in 2012 as its Medium 2 mission. The launch is planned for 2023.

Euclid's instrument suite consists of an optical imager with a broad single band (VIS), and a near infrared imager with three photometric bands and a grism spectrograph (NISP) optimized to detect the hydrogen H-alpha line in emission from galaxies at redshifts around unity. Surveying the extragalactic sky, *Euclid* will measure the shapes of over one billion galaxies for gravitational lensing studies, and spectroscopic redshifts of 50 million galaxies for galaxy clustering measurements. *Euclid*'s high quality imaging and infrared photometry from space, and its redshift survey, complement the deep, six-band optical imaging survey by the ground-based Rubin Observatory's Legacy Survey of Space and Time (LSST). The combination of *Euclid* and LSST will enable science beyond the scope of either alone.

The cosmology group has positioned itself at the interface of the two surveys to take full advantage this complementarity. Similar to the group's strategy in CMB science, using a combination of the space-based *Planck* and ground-based QUBIC and Polarbear, we aim to use the synergy between *Euclid* and LSST observations to advance our scientific objectives. Building on its recognized expertise with galaxy clusters and CMB observations, the team focusses on galaxy clusters and cross-correlations with the CMB as cosmological probes, which are complementary to gravitational lensing and galaxy clustering.

The *Euclid* team contributes to both the project's scientific development and, employing the laboratory's technical services, its infrastructure. We contribute to and hold scientific responsibilities in the Galaxy Cluster, Galaxy Evolution and Local Universe Science Working Groups (SWGs), and we lead the Cluster SWG Key Project on evaluating the cluster survey selection function. Working with colleagues at CEA/Irfu, we proposed a novel cluster mass measurement technique and used it in a pipeline for the cluster cosmology likelihood analysis. This work led to two Ph.D.theses completed in 2020 (C. Murray, APC, and E. Artis, CEA) and associated papers. R. Kou joined the team as doctoral student in 2020 and is working on cross-correlations of *Euclid* large-scale structure measurements and the CMB.

The team scientists hold responsibilities in the coordination of the Galaxy Cluster SWG and the Distance Measurements Work Package. We lead several papers within the Pre-Launch Key Projects in the Galaxy Cluster, Galaxy Evolution and Local Universe SWGs. The scientist and engineering team is responsible for the CODEEN platform, and for the scientific coordination of the French Science Data Centre at CCIN2P3. The CODEEN platform allows more than 1500 developers in 14 countries to work collaboratively, an critical contribution to the mission's infrastructure. We develop software for the *Euclid* Science Ground Segment, including development of the external data simulator and integration of LSST images into the pipeline, and for the estimation of cluster galaxy luminosity and mass functions.

We study the first epochs of cluster assembly using current observations of clusters and proto-clusters at $z > 1.5$ in preparation of the *Euclid* surveys. In the Local Universe SWG, we are developing a pipeline to measure galaxy distances up to ~100 Mpc. We develop Deep Neural Network for cluster detection and cosmology. In this context, we obtained funding from Université de Paris for the project AIR (Artificial Intelligence for Research; 2020-2022, PI: J. Bartlett), a Chair for S. Mei's arrival at APC (2021-2022), and a PSL project (2019-2021, PI: S. Mei). We hired one postdoctoral fellow and an intern, who developed deep convolutional networks for cluster detection. Our results show that our networks are more efficient than conventional methods for detecting galaxy clusters and for estimating their properties. With the arrival of a new Ph.D. student, K. Grishin, we are extending this work to Bayesian neural networks, in collaboration with the AstroDeep team.

The laboratory's involvement in the preparation of *Euclid* includes:

- Co-coordination of the Galaxy Clusters SWG (J. Bartlett), and leadership on the Cluster Selection Function Pre-Launch Key Project and on Pre-Launch Key Project papers in the Galaxy Cluster and Galaxy Evolution SWGs focussed on clusters and proto-clusters at $z > 1.5$ and the role of environment in galaxy evolution.

- Coordination of the Distance Measurements Work Package in the Local Universe SWG (S. Mei). This includes development of the pipeline for measuring surface brightness fluctuations in local galaxies (< 100Mpc).

- Simulation and integration of LSST images into the *Euclid* Science Ground Segment. This is central to the photometric redshift estimation for each of the more than one billion galaxies detected by *Euclid*, and it is critical to the weak analysis and galaxy cluster analysis.

- Responsibility for the CODEEN collaborative platform, with FACe engineers providing essential support.

- Responsibility for the scientific coordination of the French Science Data Centre at CCIN2P3.

- Responsibility for developing algorithms to measure cluster galaxy luminosity and mass functions for the Science Ground Segment, and leadership on the paper describing the algorithms and their validation within the Pre-Launch Key Projects.

- Evaluation of the impact of cosmic rays on the performance of the infrared detector, applying our experience from the *Planck* mission.

Eight CNRS or faculty researchers work and/or have responsibilities in the mission, three post-docs and one student are working on scientific preparation, and twelve technicians and engineers (among them three fix-term engineers funded by CNES) develop and maintain software for the Science Ground Segment.

Euclid Science Ground Segment The team is in charge of SIM-EXT (production of pixel image simulations of ground-based astronomy surveys) and EXT-LSST (calibration and euclidization of external data) software development activities. Ground-based multi-band surveys, such as the Rubin Observatory's LSST, are required for accurate photometric redshifts. The Rubin field will cover two-thirds of the *Euclid* survey area, providing critical data in the southern parts of the sky. While an agreement on the exchange of data between the two experiments is in progress, the team has already developed software to render and process raw LSST-like pixel images within the ground segment environment.

CODEEN The team is in charge of the software development platform COllaborative DEvelopment ENvironment (CODEEN) for the *Euclid* mission in France. CODEEN is a central web based infra, relying on Jenkins engine, allowing the continuous integration and deployment of software delivered through Gitlab by the Euclid Developers' community. CODEEN complies with EDEN. It covers: source code extraction, binaries generation, bindings generation, Data Model and software documentation generation, quality check and dashboards, unit, smoke and pre-integration tests and dashboards, software packaging, software distribution repository update.

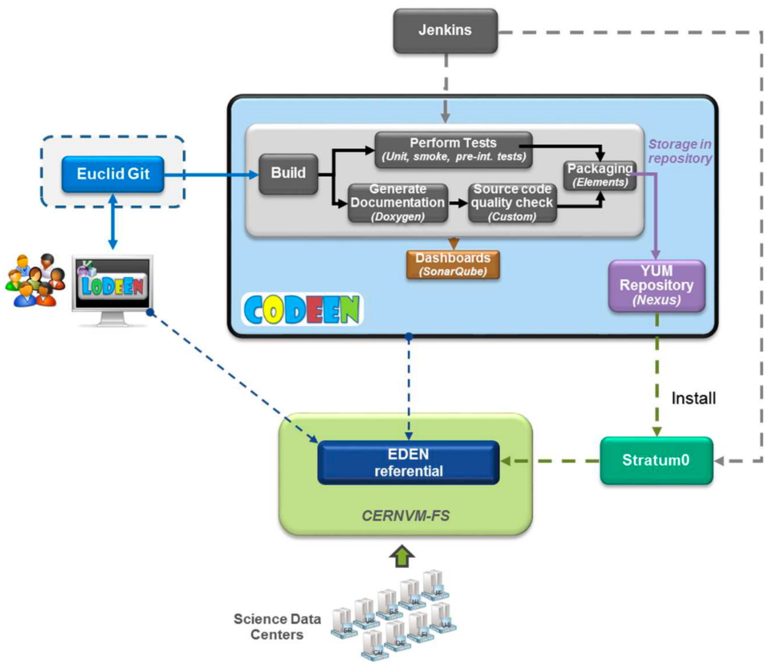

Figure 10: CODEEN is at the core of the *Euclid* Development Environment

A first version of the platform was installed at end of 2012 at the former FACe. Since 2018, the platform is hosted on the OpenStack cloud at CCIN2P3, the French Science Data Center (SDC).

Supporting grants

2021-2022	Chaire Université de Paris – Simona Mei
2020-2022	Project AIR - Université de Paris (PI: Bartlett)
2012-2022	CNES Research grants for galaxy clusters (PI: Bartlett) and proto-clusters studies (PI: Mei)
2010-2022	CNES grants for the Euclid Ground Segment development and maintenance, CODEEN (Project manager: Cécile Cavet)

Team

A. Afanasiev, E. Aubourg, J. Bartlett, A. Boizard, A. Boucaud, H. Bretonnière, C. Cavet, J.-M. Colley, R. Fahed, K. Ganga, S. Ilic, R. Kou, M. Le Jeune, S. Mei, J. Pollack, C. Rosset, M. Souchal, S. Zappino.

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

LiteBIRD

Lite (Light) satellite for the studies of B-mode polarization and Inflation from cosmic background Radiation Detection (LiteBIRD) is a Japan-led space mission aiming at constraining primordial cosmology and fundamental physics via high precision measurement of the Cosmic Microwave Background (CMB) polarization. LiteBIRD is a strategic large-class mission in Japan and is strongly supported in Europe by French (CNES) and Italian (ASI) space agencies. The launch is expected in the late 2020s using JAXA's H3 rocket and the mission will survey the full sky from its vantage point at L2. LiteBIRD will map the CMB polarization over the full sky with unprecedented precision. Its main scientific objective is to carry out a definitive search for the signal from cosmic inflation, either making a discovery or ruling out well-motivated inflationary models. The measurements of LiteBIRD will also provide us with an insight into the quantum nature of gravity and other new physics beyond the standard models of particle physics and cosmology. To reach these goals LiteBIRD will carry out observations over three years, scanning the full sky in 15 frequency bands between 34 and 448 GHz with three telescopes, to achieve a total sensitivity of 2.16 μK-arcmin with a typical angular resolution of 0.5° at 100 GHz. Beyond the use of more than 4,000 TES detectors, LiteBIRD design is also based on a high control of instrumental systematic effects, in particular via the use of three continuously rotating half-wave plates.

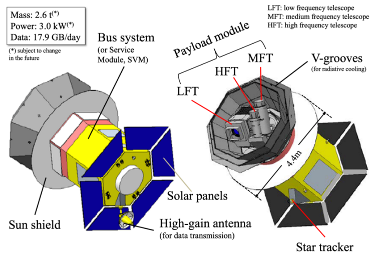

Figure 11: Conceptual design of the LiteBIRD spacecraft. The payload module (PLM) houses the low-frequency telescope (LFT), the medium-frequency telescope (MFT), and the high-frequency telescope (HFT). From Hazumi et al. 2021

APC has central hardware and data analysis contributions to the project:

- thermal architecture – thermal architecture responsibility has been transferred from LESIA to APC in 2021;
- instrumental and astrophysical systematic effects, modeling and correction – APC plays a central role in the modeling, simulations and

derivation of calibration requirements. The team is also expert in the modeling, characterization and removal of galactic foregrounds, which are the main limitation to the detection of primordial gravitational waves;

- data analysis and cosmological interpretation – APC is also performing the cosmological analysis on the systematic-corrected and foreground-cleaned CMB maps;
- theory – although not official LiteBIRD members, several APC researchers are studying the performance of LiteBIRD in constraining inflationary or other exotic early Universe scenarios.

Several APC members are also active members of the Interim Governance Board, co-leading the international systematic Joint Study Group as well as the performance team.

More information about LiteBIRD can be found on the *LiteBIRD* mission page.[15]

[15] http://litebird.jp/eng/.

Supporting grants

2018 - 2022 ANR B3DCMB - PI : R. Stompor – http://b3dcmb.in2p3.fr/

2018 - 2022 ANR BxB - PI: F. Boulanger (ENS) – https://anr.fr/Project-ANR-17-CE31-0022

Team

M. Bucher, J. Errard, K. Ganga, L. Grandsire, J.-Ch. Hamilton, M. Le Jeune, C. Leloup, G. Patanchon, M. Piat, D. Prêle, A. Rizierri, R. Stompor, J.-P. Thermeau, M. Tristram, F. Voisin, W. Wang

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Other activities

Millimetric wavelength laboratory

The millimeter laboratory is contributing to the development of detection chains and instrumentation required for precise polarisation measurement for astrophysical observations in the millimeter and sub-millimeter wavelength range.

The current projects are three-fold:

1. The QUBIC experiment: the millimeter lab is a major contributor to the QUBIC experiment. The design of the instrument and especially of the detection chain has been made in the millimeter lab. The detectors and readout electronics are tested in the dilution fridge, before integration in the instrument.
2. The *B-mode Superconducting Detectors* project is developing Kinetic Inductance Detectors (KIDs) for astrophysical observations in two wavelength ranges:

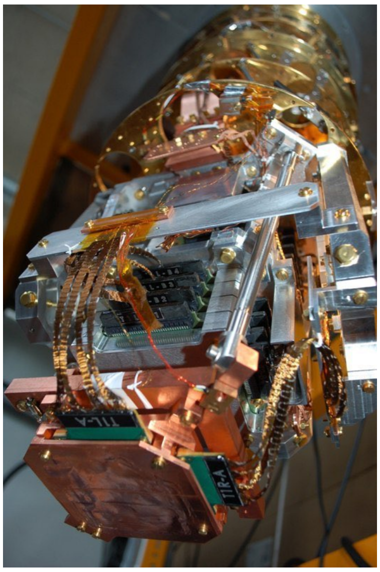

Figure 12: The dilution fridge in the millimetric wavelength laboratory

- In relation with the SPIAKID project at the Observatoire de Paris, the team tests visible and near infrared KIDs produced at GEPI. SPIAKIDs is an ERC-funded instrument aimed to detect ultra-faint galaxy in the near-infrared and optical bands (400 nm-1600 nm) using MKIDs. SPIAKIDs is planning to be deployed at NTT in 2025. The MKIDs will consist of 4 times 20000-pixel arrays. The detector characterization for the project is carried out in the test bench based on an adiabatic demagnetization cryostat (ADR) at APC. The instrument will also be integrated and tested at APC. This part of the project is supported by the LabEx UnivEarthS.
- In the millimeter wavelength range, the optimization of an instrument's optical performance would be greatly simplified if the physical dimensions of the focal plane could be reduced without decreasing the number of detectors. An elegant way to reach such architecture would be to realize multi-frequency cryogenic detectors, i.e. integrating new functionalities approaching spectroscopy. In practice, such a detection architecture is based on the use of a broadband antenna connected to a planar circuit and then to detectors (bolometers or KIDs), all at cryogenic temperatures (T<0.3K). Several options are considered for the planar circuit, the simplest being a set of filters feeding several detectors. This is the main subject of a PhD that started in October 2021 (Pham Viet Dung). CNES is supporting these developments through a R&D funding.

3. APC is leading a R&T program started early 2020, the *Next Generation Cryogenics system* project (NGCryo) funded by IN2P3 through a R&D project. NGCryo is dedicated to the development of new cryogenic technologies for detectors operating in the subKelvin temperature range. Three others IN2P3 laboratories (IJCLab, GANIL, LPNHE) are involved in this program which is composed of four work packages: continuous refrigeration, cryogenic micro-electronics, thermometers calibration and thermal properties measurements. The team is mainly involved in the following developments:

- The first concerns the design of an ASIC able to measure 16 thermometers in a time domain multiplexing scheme and operating at cryogenic temperatures. A first ASIC version was designed in 2020, manufactured during the first half of 2021 and is planned for testing for the end of 2021.
- The second contribution concerns the design of a thermometer calibration facility which will use the ASIC circuit and adsorption refrigerators. The facility will allow the calibration of 10 thermometers in the temperature range from 4K to 0.3K. These developments are done in collaboration with IJCLab. The cryostat for the calibration facility is currently in manufacturing and the assembly of its main components is planned for the end of 2021.
- The last contribution is the development of subKelvin continuous refrigeration using the adsorption process. A single shot adsorption refrigerator operating at 1K was designed and is being manufactured,

while a 0.3K version is being studied. To compensate for the need for regeneration, it is possible to combine two sets of adsorption refrigerators with alternating operating and regeneration cycles, which makes it possible to obtain quasi-continuous cooling of the detectors. The NGCryo project proposes to go further by combining the use of a dilution refrigerator system with adsorption pumps, replacing the usual 4He and 3He circulation pumps. This will be the main subject of a PhD thesis that will start in 2022 in the framework of a research collaboration with the MyCryoFirm company.

These projects are carried out with the low temperature modeling and characterization means available at APC (cryostats with 3He/4He adsorption refrigerators, dilution cryostat, cryostat with adiabatic demagnetization system, 70-250 GHz millimeter wave network analyzer, low noise characterization equipment).

The millimeter laboratory has collaborations with the University of Manchester, INFN teams (Roma, Milano, Pisa), IJCLab (Orsay), C2N (Palaiseau), GANIL (Caen), LPNHE (Paris), Paris Observatory, the Néel Institute and LPSC (Grenoble) as well as the Centro Atómico in Bariloche and the CNEA in Buenos Aires (Argentina).

Team

D. Cammilleri, C. Chapron, S. Dheilly, J. Hu, M. Karakac, B. Y. Ky, J. Lesrel, G. Monier, D. Pham Viet, M. Piat, J.P. Thermeau, S. Torchinsky, F. Voisin

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

HIRAX, Spider and SKA Members of the group are also involved in other projects that do not belong to the lab's priorities. In addition to CMB experiments such as Spider there is interest in 21 cm cosmology – Three researchers in the group are involved in the Hydrogen Intensity Real-time Analysis eXperiment (HIRAX) intensity mapping experiment, which is presently under construction. Although it was primarily designed for intensity mapping of the 21 cm line from galaxies in the redshift range between z =0.8 and 2.5, HIRAX will also discover a host of FRBs and new pulsars when it comes online.

Figure 13: The beginnings of the HIRAX array

HIRAX is a radio interferometer of closely packed 6 m dishes observing between 400 and 800 MHz. The array is currently funded for up to 256 dishes with a possible future expansion to 1024 dishes. The array will be co-located with the Square Kilometer Array at the MeerKAT radio telescope site, which is operated by the South African Radio Astronomy Observatory in the Karoo, South Africa. The experiment will conduct ground-breaking science in a number of areas, including the cutting-edge fields of Dark Energy and Fast Radio Bursts. The collaboration is led out of the University of KwaZulu-Natal with seven additional South African consortium members and 17 international partners. The project is currently funded by the South African Department for Science and Innovation and National Research

Foundation, the HIRAX South African Consortium, McGill University in Canada, and a partnership of Swiss universities with funding from the SNF.

The thesis of Zheng Zhang will study the impact of polarized emission from the galaxy on the extraction of the cosmological signal in intensity mapping studies. This work is being carried in collaboration with François Boulanger from ENS, who is a co-supervisor together with Martin Bucher.

Team

M. Bucher, K. Ganga, Z. Zhang

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Selected publications

Ade, Peter et al. "The Simons Observatory: science goals and forecasts". In: *JCAP* 2019.2, 056 (2019), p. 056. arXiv: 1808.07445 [astro-ph.CO].

Arcelin, Bastien et al. "Deblending galaxies with variational autoencoders: A joint multiband, multi-instrument approach". In: *MNRAS* 500.1 (2020), pp. 531–547. arXiv: 2005.12039 [astro-ph.IM].

Chardin, Gabriel et al. "MOND-like behavior in the Dirac-Milne universe - Flat rotation curves and mass versus velocity relations in galaxies and clusters". In: *A&A* 652 (2021), A91. URL: https://doi.org/10.1051/0004-6361/202140575.

Delabrouille, J., P. de Bernardis, F. R. Bouchet, et al. "Exploring cosmic origins with CORE: Survey requirements and mission design". In: *JCAP* 2018.4, 014 (2018), p. 014. arXiv: 1706.04516 [astro-ph.IM].

Delabrouille, Jacques et al. "Microwave spectro-polarimetry of matter and radiation across space and time". In: *Experimental Astronomy* 51.3 (2021), pp. 1471–1514.

Euclid Collaboration et al. "Euclid preparation. III. Galaxy cluster detection in the wide photometric survey, performance and algorithm selection". In: *A&A* 627, A23 (2019), A23. arXiv: 1906.04707 [astro-ph.CO].

Hamilton, J. -Ch. et al. "QUBIC I: Overview and ScienceProgram". In: *JCAP* (2020). arXiv: 2011.02213 [astro-ph.IM].

Mousset, L. et al. "QUBIC II: Spectro-Polarimetry with Bolometric Interferometry". In: *JCAP* (2020). arXiv: 2010.15119 [astro-ph.IM].

Rhodes, Jason et al. "Scientific Synergy between LSST and Euclid". In: *ApJS* 233.2, 21 (2017), p. 21. arXiv: 1710.08489 [astro-ph.IM].

Vergès, Clara, Josquin Errard, and Radek Stompor. "Framework for analysis of next generation, polarized CMB data sets in the presence of Galactic foregrounds and systematic effects". In: *Phys. Rev. D* 103.6, 063507 (2021), p. 063507. arXiv: 2009.07814 [astro-ph.CO].

Gravitation

Resp: E. Chassande-Mottin (-2018) and S. Babak (2018-)

The Gravitation team was created in January 2016 to gather in a single team all researchers involved in gravitational wave science, formerly distributed in various groups. The team is composed of 6 permanent researchers (2 University/MCF, 3 CNRS and 1 emeritus), 5 PhD students and two postdoctoral fellows. Four other PhD students are co-advised in the context of a collaboration with colleagues from other groups at APC or with other institutes (in particular, IPGP).

The team core scientific interest is gravitational-wave astronomy. The team is involved in the development and exploitation of both ground-based observatories with advanced Virgo, and the space-based observatory LISA. All team members are involved in the international collaborations that develop and exploit those instruments.

The team develops a wide range of activities going from instrument science (R&D, instrument design and simulation, commissioning), data analysis (methods, software implementation) and astrophysics (source physics, models, multi-messenger astronomy in connection to high-energy or neutrino astronomy).

The team is also involved in activities connected to the above core priorities that are possible seeds for future main projects. The team participates to the development of future detector generation (Einstein Telescope), and contributes to the gravitational-wave science using other windows, specifically pulsar timing array with the EPTA and IPTA.

In parallel to the research on gravitational waves, the team pursues activities in connection to ("Newtonian") gravity measurements and their application to geosciences in collaboration with Institut de Physique du Globe de Paris (IPGP), with the support of the LabEx UnivEarthS.

Ground-based detectors

Advanced Virgo

Advanced Virgo[16] is a second generation gravitational-wave detector aiming at a ten-fold improvement in sensitivity over the first generation that was operated during the period 2007-2010. Advanced Virgo started operation on August 1st 2017 when it joined Advanced LIGO during the science run O2 thus forming a global, world-wide detector network. About two years after O2, this network resumed operation during the 1-year long science run O3 with an enhanced sensitivity (by about a factor of 2).

[16] Acernese, F. *et al.* (Virgo Collaboration). "Advanced Virgo: a second-generation interferometric gravitational wave detector". In: *Class. Quantum Grav.* 32.2 (2015), p. 024001.

During the two science runs, LIGO and Virgo have observed 50 GW signals in total gathered in the GWTC catalog(s).[17] The catalog is largely dominated by signals from binary black hole mergers with total mass ranging from 15 to 150 solar masses, thus evidencing the existence of a population of heavy stellar-mass black holes, that had eluded conventional astronomical observations. The GWTC catalog also comprises two signals associated with the merger of binary systems of neutron stars,

[17] R. Abbott et al. "GWTC-2: Compact Binary Coalescences Observed by LIGO and Virgo During the First Half of the Third Observing Run". In: *Phys. Rev. X* 11 (2021), p. 021053. arXiv: 2010.14527 [gr-qc].

including GW170817, and two other signals possibly associated to mixed systems formed by a neutron star and a black hole.

On August 17 2017, LIGO and Virgo detected GW170817[18] associated to the merger of two neutron stars, located in NGC4993, at a distance of 40 Mpc. This detection was accompanied, in the seconds, hours and months that followed, by the cascade observation of electromagnetic waves emitted by this same source in a wide range of wavelengths, from radio waves to gamma rays.[19] This makes it the first astrophysical phenomenon observed by both its gravitational and electromagnetic radiation. This event is rich in implications, first of all for the phenomenology of gamma-ray bursts, but also for cosmology and fundamental physics.

[18] B. P. Abbott et al. "GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral". In: *Phys. Rev. Lett.* 119.16 (2017), p. 161101. arXiv: 1710.05832 [gr-qc].

[19] B. P. Abbott et al. "Multi-messenger Observations of a Binary Neutron Star Merger". In: *Astrophys. J. Lett.* 848.2 (2017), p. L12. arXiv: 1710.05833 [astro-ph.HE].

Currently, the detector undergoes the first phase of the so-called Advanced Virgo + upgrade which is expected to lead to a factor of 2 improvement in sensitivity during the up-coming science run O4 (2022-2023) jointly with Advanced LIGO. The second phase of the upgrade aims at another factor of 2 sensitivity enhancement leading to a binary neutron star range of 200-250 Mpc for the future science run O5 (2025). Looking further ahead, the observational strategy after O5 is being debated and defined in the framework of an on-going study of the possible scenarios of upgrades for the Virgo and LIGO detectors. This will constitute a major step towards the advent of the third generation detectors (Einstein Telescope and Cosmic Explorer).

The Virgo team includes 20 members (10 permanent staff, 10 doctoral and postdoctoral fellows). The team's activities range from the design and development of the Advanced Virgo detector to its scientific exploitation.

Data analysis and scientific exploitation The team is involved in the analysis of LIGO and Virgo data through many projects. Over the period from Jul 2017 to Oct 2021, the team made direct contributions to *23 articles* of the LIGO and Virgo Collaborations (4 as chair of the paper writing team, 13 as members of the paper writing team, 10 as members of the internal review committee). Those articles include major discovery papers and catalog papers such as,[20] interpretation papers (constraints on the astrophysical distribution of compact binaries, test of general relativity), various searches (signals from cosmic strings, persistent gravitation waves from isolated compact stars, stochastic backgrounds) and the main reference paper for the open data release.

[20] B. P. Abbott et al. "GW170814: A Three-Detector Observation of Gravitational Waves from a Binary Black Hole Coalescence". In: *Phys. Rev. Lett.* 119.14 (2017), p. 141101. arXiv: 1709.09660 [gr-qc]; Abbott et al., "GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral".

A member of the group had leading role in the data analysis organization, with the co-responsibility of compact binary search group (Edward Porter, 2016-2020).

The team develops a range of R&D data analysis projects that are inline with the core activities of the LIGO-Virgo Collaboration. Those include work and developments for: fast Bayesian methods for binary parameter estimation, advanced search methods for transient sources (ANR Wavegraph), contribution to waveform models (EOBNR), new tests of General Relativity (e.g., spacetime symmetry breaking), new ways to constrain the so-called "galactic field" binary formation scenario based on numerical simulations with the MESA software, algorithms for the reconstruction and characterization of the gravitational wave polarizations (ANR Ricochet) and machine-learning based methods for the detection of compact binaries from single-detector data and for the rapid computation of waveform approximants.

The group is particularly active in areas connected to cosmology and tests of general relativity. The group developments in this sector include alternative measurements of the Hubble constant or other cosmological parameters from gravitational wave observables, with or without electromagnetic counterparts. See, e.g., Fig. 14 from[21] which provides prospects for the latter possibility, often referred to as dark sirens.

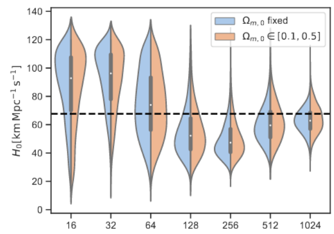

Figure 14: Posterior distributions on H_0 vs the number of detected gravitational wave events obtained by fixing Ω_m or not. The horizontal black dashed line indicates the true value.

[21] S. Mastrogiovanni et al. "Cosmology in the dark: On the importance of source population models for gravitational-wave cosmology". In: *Phys. Rev. D* 104.6 (2021), p. 062009. arXiv: 2103.14663 [gr-qc].

Operations The team made significant contributions to the detector operations. Member of the group had leading role in the release of LIGO/Virgo data through the GWOSC [22] (Eric Chassande-Mottin, since 2017, and Agata Trovato, 2017-2021) – see Fig. 15 – and in the preparation of the alert production from the data (Sarah Antier, liaison for Virgo during the preparation of O3). Nine members of the group have performed shifts for detector characterization, electromagnetic follow-up, or parameter estimation during the science run O3.

[22] http://gw-openscience.org

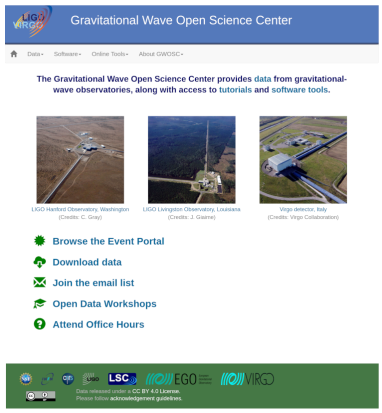

Figure 15: Home page of the Gravitational-Wave Open Science Center

R&D on quantum noise reduction through squeezing techniques The team is involved in two R&D techniques to improve the sensitivity of gravitational-wave detectors through squeeezing techniques.

R&D on frequency-dependent squeezing with filter cavity — One of the main upgrades of Advanced Virgo + is the integration of a 285m filter cavity for the realization of frequency dependent squeezing: a technology which allows to reduce quantum noise over the whole detector bandwidth. Since 2015, the team has participated to the construction of a full-scale filter cavity prototype at the National Astronomical Observatory of Japan (NAOJ). The team realized the analog electronics for several control loops of the experiment and contributed to the installation and commissioning of the experiment during multiple visiting periods in Japan. The demonstration of frequency dependent squeezing with this filter cavity has been achieved in 2020.[23] The experience acquired with this project will be crucial for the implementation of the AdVirgo + filter cavity, currently under commissioning.

[23] Yuhang Zhao et al. "Frequency-Dependent Squeezed Vacuum Source for Broadband Quantum Noise Reduction in Advanced Gravitational-Wave Detectors". In: *Phys. Rev. Lett.* 124 (17 2020), p. 171101.

R&D on frequency-dependent squeezing generation with EPR entanglement An R&D is on-going about a new technique to achieve a broadband reduction of quantum noise by using a pair of Einstein-Podolsky-Rosen (EPR) entangled photons to produce frequency-dependent squeezed light.

The development at APC has concerned the design and test of a solid Fabry-Perot etalon, shown in Fig. 16 behaving as an optical resonator whose length is tuned via thermal expansion driven by a fine and stable temperature control (0.01°C). The purpose of this optical component is to separate the two entangled fields, by transmitting the "signal" field and reflecting the "idler" beam. The finesse was chosen in order to achieve the best beam separation and to get the simplest possible control of the cavity.

The system's optical properties and thermal stabilization was tested in an ad-hoc characterization setup. The system meets the requirements for the signal/idler transmission and reflection and for the short-term and long-term thermal stability.

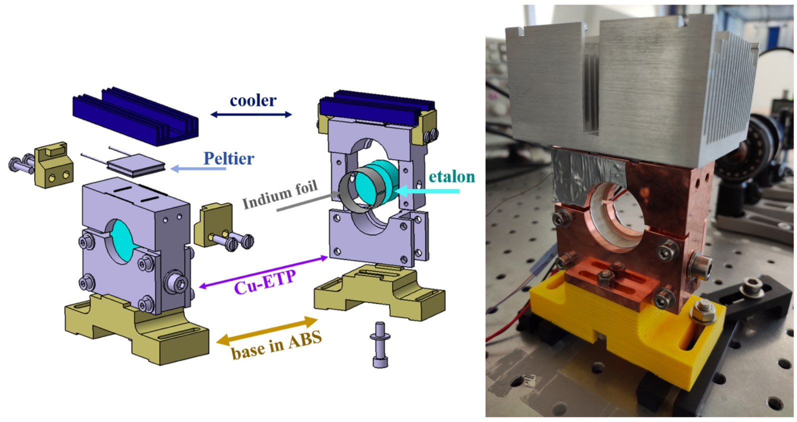

Figure 16: Solid Fabry-Perot etalon realized to separate the two entangled beams used in new technique to achieve a broadband reduction of quantum noise in GW detector by using a pair of Einstein-Podolsky-Rosen (EPR) entangled photons to produce frequency-dependent squeezed vacuum.

Contributions to Advanced Virgo+ (design, construction and commissioning)

Optimisation of the optical design of Advanced Virgo + The 2nd phase of the Advanced Virgo + focuses on the thermal noise reduction. This is achieved by enlarging by 60 % the laser beam dimension and the mirrors themselves at the extremities of the arm cavities. The team has estimated the optimal transmissivity of the main optics in this new configuration. This optimisation of sensitivity allows to an improvement of the range to binary neutron stars.[24]

[24] Jonathon Baird and Matteo Barsuglia. "Fine-Tuning the Optical Design of the Advanced Virgo+ Gravitational-Wave Detector Using Binary-Neutron Star Signals". In: *Galaxies* 8.4 (2020).

Mode-matching telescopes The team is responsible for the realization of the "mode-matching" telescopes for Advanced Virgo, which are used to magnify and adapt the main laser source to the interferometer and to collect the out-coming beam (which contains the GW information) as well as the beam transmitted by the arm cavities and a pick off of the power recycling cavity, used for the interferometer control. These five telescopes were designed, constructed, tested and integrated in the detector by the group. For the 1st phase of Advanced Virgo+ (2022), two baffles have been developed and integrated to the optical set-up of the telescope at the output port of the interferometer (detection bench), as shown in Fig. 17. The goal of these baffles is to mitigate stray light impinging on the optical components of this telescope, as it can degrade the interferometer sensitivity. The baffle design has been optimised to fulfill constraints on their mass and resonance frequency.

For the second phase of Advanced Virgo+ leading to the science run O5 (2025) the team is in charge of the re-design and realisation of the new mode-matching telescopes that are compliant with the larger beam size. The re-design activity mainly concerns the telescopes for the beams transmitted by the arm cavities end mirrors.

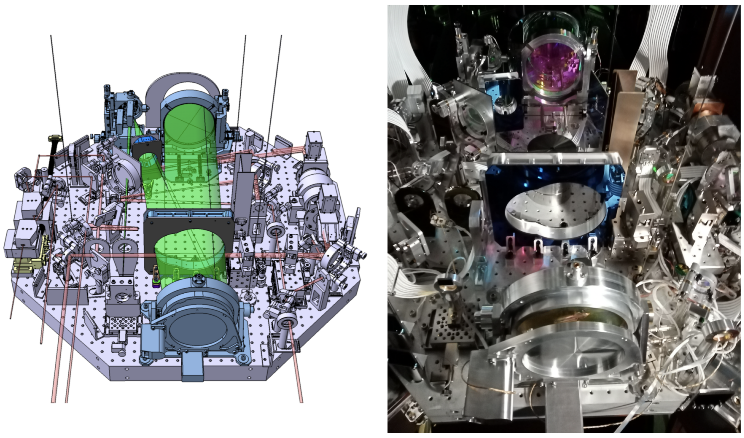

Figure 17: Global view of the optical bench at the detection port of Advanced Virgo (CAD design on the left and a picture on the right). The absorbing baffles designed by the team to mitigate stray light impinging on the optical components of the beam-reducing telescope are evidenced.

Wide-band photodiods for the new locking scheme The first phase of the AdVirgo + upgrades includes the installation of an additional mirror (known as signal recycling mirror) at the output port of the interferometer. This modification allows to shape the sensitivity of the detector and improve its astrophysical reach. This change requires a new scheme based on an auxiliary green laser for the control of the interferometer. The team is responsible of the development of fibered high-frequency photodiodes needed for this new scheme. These photodiodes and the associated electronics shown in Fig. 18 were succesfully produced within the specifications and were integrated in the detector, thus contributing to the global control of the interferometer.

Figure 18: Fibered high frequency photodiodes needed for the new Advanced Virgo control scheme, which uses auxiliary green laser beams

Frequency dependent squeezing The team contributes to the commissioning of the 285-meter filter cavity used to generate frequency-dependent squeezed light used to reduce quantum noise at all frequencies. Thanks to the experience acquired during the R&D project at NAOJ (see above) the team made important contributions to the commissioning of the cavity mirror suspensions, to the control and optical characterization of the cavity. The team will participate to the measurement of the frequency dependent squeezing.

Contribution to the "post-O5" study and Einstein Telescope technical design The O5 science run is expected to finish around 2027-2028. The strategy for the transition between the end of O5 and the advent of the third generation detectors (~ 2035-2040) is still to be defined. The team is involved in the definition of this strategy and the possible scenario of instrument upgrades through participation to the Virgo post-O5 committee. Moreover, the team is involved in the ET instrument science board (ISB), in charge of the ET technical design report, in particular in the squeezing working group.

Supporting grants

2015-2019	ANR Wavegraph - PI: E. Chassande-Mottin
2016-2021	H2020 Asterics
2016-2021	CEPIFRA project with IIT Mumbai Co-PI: Eric Chassande-Mottin
2017-2022	H2020 NEWS
2019-2024	H2020 AHEAD2020

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Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Einstein Telescope

The goal of Einstein Telescope is to gain an order of magnitude in sensitivity with respect to Advanced Virgo and Advanced LIGO and to enlarge the bandwidth of the detector down to 1-2 Hz (compared to 10 Hz for Virgo). The current design is to have 10 km arms placed in an underground site. Moreover, the detector is conceived as a xylophone, composed by two different sub-detectors working at different frequency bands, and merged together (similar to two electromagnetic telescopes sensitive to slightly different wavelengths). To fully resolve the two GW polarisations predicted by GR with a single detector, ET has a triangular shape leading to 3 independent Michelson interferometers. An alternative design (currently under discussion) could be to have 2 L-shaped detectors. The ET infrastructure is conceived to be able to accommodate future detector upgrades for the next few decades. The project has been recently inserted in the ESFRI roadmap for research infrastructures. If funded, the plan is to start the construction in 2027 and data taking in 2036. The APC is currently strongly involved in the project through two leading positions: the coordination of the french ET community (Matteo Barsuglia) and the co-chair of the Observational science board (Ed Porter). Moreover, the APC team is contributing to the instrument technical design, on the squeezing group.

The data analysis for ET will be extremely challenging. Unlike the current analysis for 2G ground-based detectors, it is expected that when operational, each year ET will observe 10^6 BBH mergers out to a redshift of $z \sim 50$ and 10^5 BNS mergers with almost 100 EM counterparts. Furthermore, given the planned low frequency cutoff for ET, not only will these signals be observable for hours to days in the detector, but many of them will be overlapping not only with each other, but also with multiple instrumental glitches and artefacts.

To tackle these issues and guarantee the maximum science extraction, the ET has formed the ET Observational Science Board (OSB). The current mandate of the OSB is to complete the ET Blue Book on a 4 year timescale. During this period, one member of the group (Ed Porter) is co-chair of the OSB. As ET is still in its formulation phase, the main activities of the OSB have been the creation of different scientific divisions, the assignment of division chairs, and the creation of a practical infrastructure for the board (i.e. wikis, mailing lists, communication channels etc.). At the end of September 2021, the OSB chairs organised an online kick-off workshop to announce the existence of the OSB to the wider scientific community. This was an extremely successful event with over 400 participants.

Team

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Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Space-based detector

LISA

In 2016, the spectacular success of the European Space Agency (ESA)'s LISA Pathfinder mission has paved the way for the Laser Interferometer Space Antenna (LISA), the much anticipated flagship mission of low-frequency Gravitational Waves astronomy. LISA will target mHz frequencies and thus, in particular, systems involving BHs in the $10^4 - 10^7\,M_\odot$ mass range. The LISA mission has completed Phase A (industrial study) and is currently going through the mission formulation review at ESA with no technical or operational problems identified so far. LISA will enter Phase B (industrial production) in 2022 and proceed to launch around 2034 (nominally), or even earlier if technical readiness is deemed satisfactory. LISA consists of 3 satellites, forming a giant interferometer - with 2.5 million km arm length - orbiting the Sun about 20° behind the Earth (see Fig. 20 and 19).

APC is involved in the exploration of scientific abilities of LISA to con-

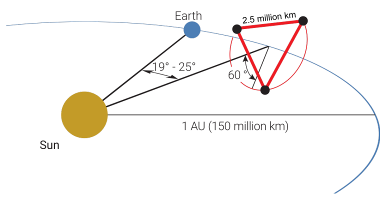

Figure 19: Schematic view of the LISA constellation

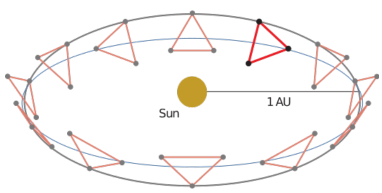

Figure 20: Schematic view of the LISA orbits around the Sun

tribute to the fundamental physics (testing General Relativity theory, inferring cosmological parameters, probing the early universe) and to identification of formation and evolution channels of GW sources. Our research is summarized in the growing number of LISA publications (20 papers published over the last year). On the project side we have two major responsibilities: on data processing and instrumentation which we now describe in details.

Contributions to the data processing One major contribution of the team to the LISA mission is prototyping of the LISA's Distributed Data Processing Center (DDPC). DDPC is the platform from which the daily LISA data analysis will be performed during (and after) the mission operation. The team brings its expertise on both the infrastructure design and development of the data analysis.

Ground segment infrastructure The team is one of the main contributors to the design of the Science Ground Segment and of the infrastructure of the DDPC led by CNES. Research and development activities have been on-going over the past 8 years. The common development environment and the prototype of the DDPC built at APC are currently used by LISA consortium for data/instrument simulation and data analysis. The team is also responsible for setting a number of collaborative services (based on CCIN2P3 infrastructure) for the LISA Consortium: Git repositories with continuous integration hosting all softwares, document management system, wiki, database with web interface and websites.

Data analysis The LISA data analysis is a challenging task that requires the integration of different methods for the signal extraction and noise reduction (e.g., laser frequency noise suppression). LISA data are expected to be dominated by the gravitational-wave signals. Thousands sources simultaneously present in the data have to be disentangled.

The main platform for developing and testing data analysis methods is the LISA Data Challenge (LDC) [25]. This project was initially built from scratch at APC (2017-2020) and is now developed by a working group with more than 100 members. The LDC working group is in charge of producing the simulated LISA data and developing a set of state-of-the-art data analysis methods, addressing detection and characterization of all known sources (Galactic binaries, massive or stellar-mass black-hole binaries, extreme mass ratio inspirals, stochastic GW signals, etc.). Tests include robustness against the presence of gaps in the data (due to antenna repointing) and noise artifacts (glitches, long-term non-stationary noise components).

[25] `https://lisa-ldc.lal.in2p3.fr/`

In the past four years three challenges have been released and one more is under way. The team played a major role in the coordination, the development of the software platform for simulating and publishing data sets, and in the development of the data analysis algorithms for detecting binary sources and stochastic GW signal. The software LISANode used for simulating the instrument was originally developed at APC.

This project benefited from the wide range of expertise present in the group, in particular GW signal modelling from merging black holes (see below) and from astrophysical knowledge of population of GW sources. This helped with the production of accurate but also fast GW signal generation algorithms, whose implementation and optimization is in progress. Finally, the team maintains a series of data analysis tutorials in order to ease and speed-up the development of new techniques especially for the groups new to the LISA project.

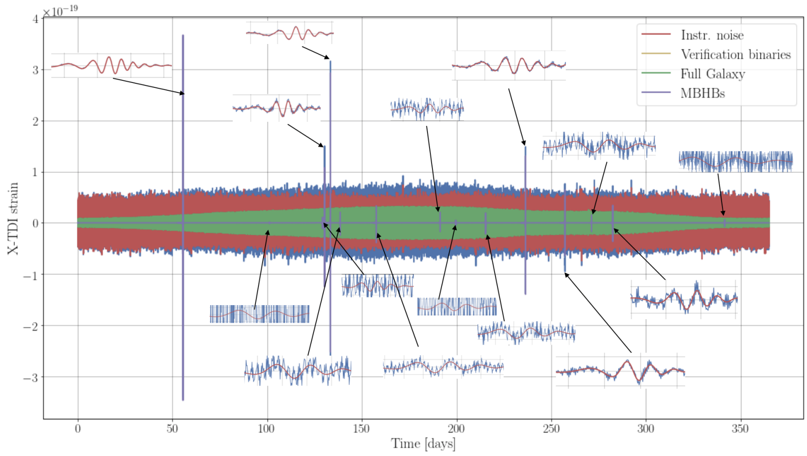

Figure 21: Simulated LISA data (training data set for the challenge "Sangria"). Data contains 30 mln Galactic white dwarf binaries and 15 merging massive black hole binaries

Instrument performance and noise budget The team is in charge of the LISA Performance working group. The main task of this group is to develop a bottom-up physical model of the instrument performance from low level instrument technical specifications up to the science requirements.

The modelling encompasses the optical metrology noises, like shot noise and stray light noises as well as the test mass acceleration noise models directly inherited from LISA Pathfinder. The team is in charge of developing the analytical modelling of the ground segment noise contributions through the Time-Delay Interferometry algorithm. These models are part of the baseline performance model.

The performance activity is at the cross-road of a wide range of expertise as the requirements specifications developed and delivered by the consortium for the phase A review are compliant with the performance model. The group supports ESA in its requirements engineering process and trade off studies. Moreover the models has also been shared with both industrial primes acting as a reference budget with supporting parametric model. Our key role in the performance Working Group directly benefit from the APC leading role in the DDPC and the French instrument activities.

Figures of merit The team has developed a set of figures of merit to quantify the scientific performance of a specific mission design. The objective is to propagate the noise budget all the way to the science investigations and assess abilities of the current mission configuration to fulfill the science objectives outlined in the science requirement document. Figures of merit are formulated as a set of numbers computed for each scientific investigation with associated metrics that allow to judge "goodness" of a given mission design. This collaboration-wide project implies a significant coordination effort between the LISA science group and the APC team. Documents presenting the rational and justification for the selected figures-of-merit, as well as the results of the phase A noise budget have been delivered for the Mission Formulation Review.

Contributions to the experiment The APC is involved in the LISA project since its creation in 2005 and participation to LISA Pathfinder. The experimental contribution to the LISA Pathfinder mission was centered on the optical tests of the Laser Modulation Unit. The first R&D activity directly related to the LISA mission was then dedicated to the application of molecular laser frequency stabilization to space-based experiment.

Over the last few years, the LISA team at the APC worked on different topics linked to the preparation and the French contribution to the mission.

LISA on Table LISA performance relies on high-precision metrological measurements, and on complex digital noise reduction techniques, such as TDI (Time Delay Interferometry). It is necessary to validate both the 'basic' technological bricks, but also the ability to correctly extract information from the entire measurement chain (involving optical benches, electronic measurements and processing of the collected data).

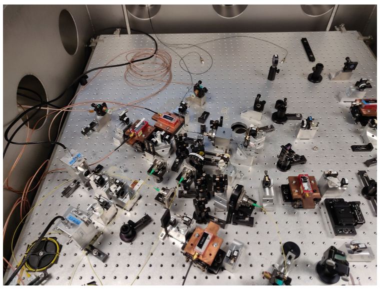

Figure 22: The interferometric bench of the LISA on Table experiment

With an optical frequency stabilised to a few tens of $\mathrm{Hz}/\sqrt{\mathrm{Hz}}$, the laser frequency noise is 7 to 8 orders of magnitude larger than the sensitivity targeted for LISA. This reduction can be achieved with the TDI techniques as demonstrated by simulations with current noise models. However, instrumental effects are only partially included in those simulations because of numerical limitations and lack of satisfactory physical models.

It is therefore important to experimentally simulate signals representative of LISA, that are as realistic as possible and acquired by devices similar to those envisaged. Once acquired, these signals are processed - digitally - by the same algorithms as those planned for LISA, in particular TDI, and their performance with 'real' signals is tested.

The LISA on Table (LOT) experiment was developed with this goal in mind, with the main objective of testing TDI with interferometric, heterodyne signals acquired by a prototype phasemeter and representative of the LISA signals, in particular, representative of the propagation delays and Doppler fluctuations between the satellites in the constellation (see 23).[26]

[26] M Laporte et al. "Status of the LISA On Table experiment: a electro-optical simulator for LISA". in: *Journal of Physics: Conference Series* 840.2017JPhCS.840a2014L (2017), p. 012014. URL: http://adsabs.harvard.edu/cgi-bin/nph-data_query?bibcode=2017JPhCS.840a2014L&link_type=ABSTRACT.

Prototyping optical benches for testing the LISA instruments In the organisation of the LISA space mission, the development of the main elements of the instrument is the responsibility of a consortium of European countries, including France, with a strong contribution from NASA. The French contribution to the LISA instrument covers 3 main activities: the establishment of a scientific data processing centre, the establish-

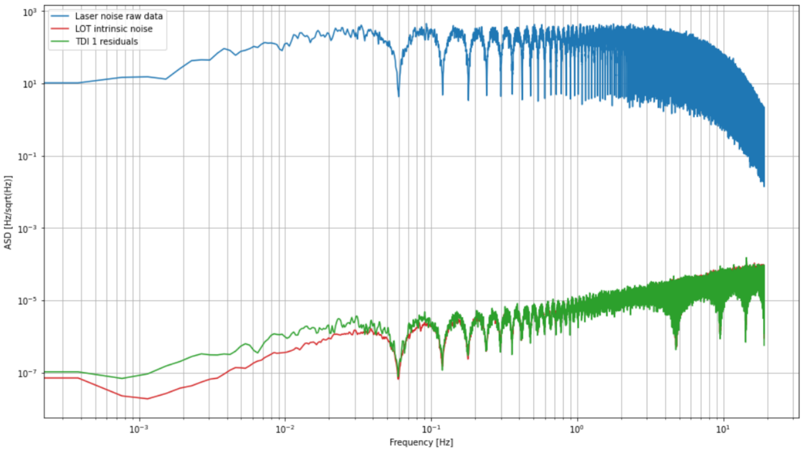

Figure 23: Performance of the LISA On Table experiment. The reduction factor of the injected noise (top curve) is 7 to 8 orders of magnitude

ment and monitoring of a scientific performance model and a strong participation in the testing and validation of partially or fully integrated instruments.

The contribution proposed by France in the framework of the LISA AIVT (Assembly, Integration, Validation and Testing) focuses on two crucial steps:

- The full responsibility for the functional and performance tests of the metrological core of the instrument, named IDS (Interferometric Detection System) and including the optical bench (with its different mounted elements), the signal acquisition system (phasemeter) and the laser source. The IDS is an early development stage to validate the Engineering (EM) and then the Qualification (QM) models of the instrument components. This step is crucial to globally validate the instrument concept and to reach a level of validation that cannot be achieved with a fully integrated instrument.

- The provision of benches and support for metrological (optical) performance tests of the fully integrated instrument (called MOSA: Movable Sub-Assembly). These tests, extensive on the qualification model and more limited on the 6 flight models (and 2 'spares'), aim to reproduce some of the IDS level measurements (in order to validate the 'correct' integration of the instrument) as well as to carry out a set of calibrations and alignment corrections.

This positioning puts French laboratories at the core of the realisation and fine understanding of the instrument, which is essential for the scientific exploitation of the data.

The role of the French laboratories, under the technical and financial guidance of CNES, is to set up the techniques and procedures that will enable the metrological performance of the LISA instrument to be validated on the ground at the IDS and MOSA levels.

This work has taken on much greater importance since the mission entered phase A (mid 2018). It is indeed necessary to define and demonstrate precisely (through the realisation of prototypes) the different integration

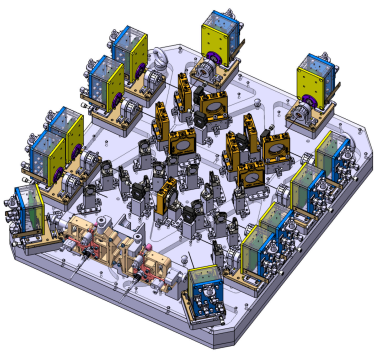

Figure 24: 3D view of the demonstration interferometric optical benches for LISA integration

and test benches before 2024 and the adoption of the mission (which signs the firm commitment of the different national agencies).

This process involves the development of two interferometric bench demonstrators, aiming at demonstrating the feasibility of testing the LISA instrument at the required performance level.

The work on these benches started at the end of 2019 at the APC and with partner laboratories. The first bench is based on traditional manufacturing (Invar metal plate and commercial optics). This 'engineering model' is entirely developed by laboratories. The second bench uses the expertise of an external company to design a Zerodur bench with optically contacted components (offering greater dimensional stability). Figure 24 shows the two versions of these benches. Their development has been delayed due to the health situation, but all procurement and technical implementation has now been completed.

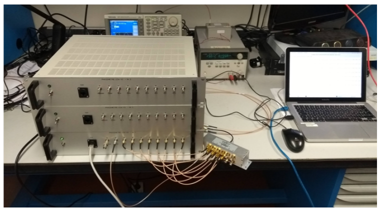

Figure 25: Digital phasemeter for MIFO and ZIFO optical benches

The assembly of the metallic bench has been fully completed in the laboratory workshops and the optical fine tuning has begun. In partnership with CEA/Irfu the team has also developed high stability phasemeters based on an original design from the Albert Einstein Institute (Hannover), see Fig. 25. Current activities now focus on the integration of the various peripheral subsystems to the bench itself including the laser source developed at SYRTE, the control/command software from CPPM, the thermal shielding from LAM, harnesses, etc. The installation in the vacuum tank (environment necessary to obtain the desired thermal stability) and then the tests will take place until Feb 2022. Some elements of the bench (injectors and photoreceptors) will then be unmounted and sent to the Winlight company for installation on the Zerodur bench.

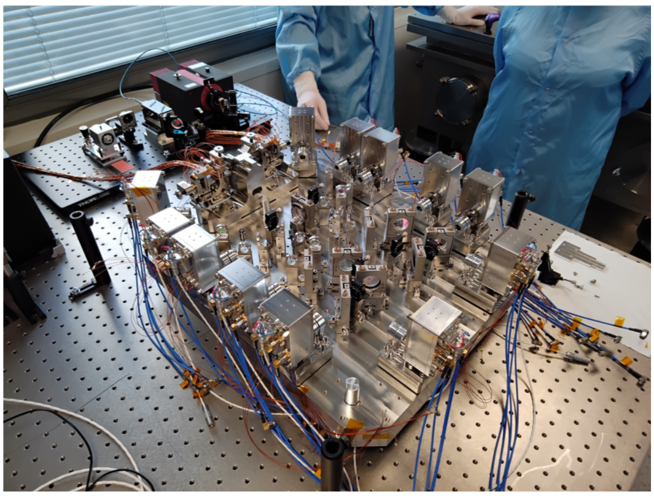

Figure 26: Integrated MIFO optical bench

Figure 26 shows the MIFO bench in the final stages of optical integration (using an optical centering bench and a three-dimensional measuring machine).

Team

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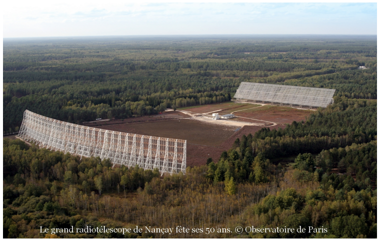

Figure 27: Nançay radio telescope

Pulsar timing array

Pulsar timing array (PTA) experiments, which monitor and measure arrival times pulses from millisecond pulsars, have been established to search for GW signals in the nanohertz band. There are several physical processes which cause deviations from the expected arrival times of radio pulses among which (the most relevant to us) are GWs. The most promising sources in the nHz part of the GWs spectrum are super-massive black hole binaries (SMBHBs) that form via the mergers of massive galaxies. Orbiting SMBHBs produce a stochastic GW background (GWB), individual periodic continuous signals and transient GW bursts. The GWB manifests as a temporally and spatially correlated noise process in the arrival times of pulses. The strain spectrum of such a background is predicted to have the power-law form $h(f) = A(f/1\mathrm{yr}^{-1})^{-2/3}$ where A is the strain amplitude. There are other potential sources of GWB in the PTA band those are: network of cosmic strings, quantum fluctuations of the gravitational field amplified by inflation and various other energetic process in the early Universe such as phase transition, turbulence. Three major world-wide PTA collaborations, NanoGrav (North America), European Pulsar Timing Array (EPTA) and PPTA (Australia) form an International PTA that is consortium of consortia. Recently Indian collaboration InPTA has joined IPTA and the Chinese PTA in the process of its formation.

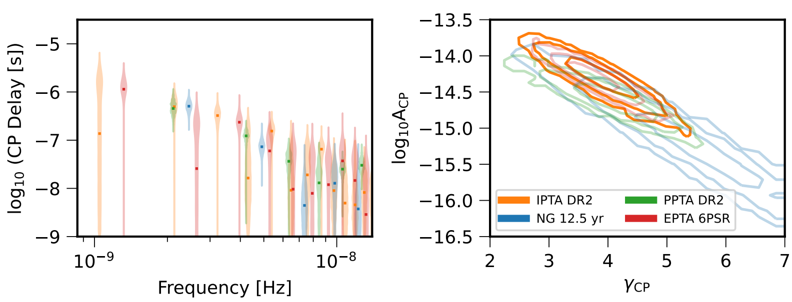

Figure 28: Common red noise observed by all three PTA collaborations. Left: estimated spectrum in each dataset. Right: Estimation of the amplitude and the spectral index of common red noise signal reported by each PTA. The slope is consistent with what we expect from the population of SMBHBs.

A small subgroup (2 part-time permanent members and 2 PhD students) are members of European Pulsar Timing Array collaboration and are involved in the data analysis searching for GW signals. This work takes place in the context of a close collaboration with the CNRS group at Orleans (LPC2E) and scientists working on Nancay radio telescope supported by an ANR grant.

The most important recent result is the independent discovery of the common red noise process. First it was reported by NANOGrav collaboration using Green Bank and Arecibo telescopes (2020) then this result was confirmed by PPTA using data from the Parkes radio telescope, and recently similar confirmation came from EPTA (using 5 largest European telescopes).[27] This is a red-noise like signal which has common spectral properties (PSD is $S(f) = A^2(f/1\mathrm{yr}^{-1})^{-\gamma}$) for all pulsars in the array, moreover the spectral index γ is consistent with what is expected from the GWB produced by a population of SMBHBs. Having a common red-noise signal is *necessary* but not sufficient for claiming GWB detection. An isotropic stochastic GW signal (within GR) induced very special correlations across pulsar data described by Hellings-Downs curve. This curve predicts correlation coefficient for each pair of pulsars which is the function of only angular separation of pulsars in the sky. The data analysised by each PTA is not sensitive enough to claim detection of those spatial correlations, in fact the data provides no significant evidence for, or against, Hellings-Downs correlations.

[27] S. Chen et al. "Common-red-signal analysis with 24-yr high-precision timing of the European Pulsar Timing Array: Inferences in the stochastic gravitational-wave background search". In: *Mon. Not. Roy. Astron. Soc.* 508.4 (2021), pp. 4970–4993. arXiv: 2110.13184 [astro-ph.HE].

The group has analyzed 6 most sensitive EPTA pulsars spanning almost 24 years of radio observations. Our particular contribution was in modelling noise in each pulsar's data.[28] Given complexity of radio emission by pulsars, its interaction with interstellar medium and with solar system environment, we might have quite a few different noise sources contributing to a total budget. We have performed Bayesian analysis customising the noise model for each pulsar and confirmed presence of the common red noise signal. We have also analysed IPTA data for presence of continuous GW signals from individual SMBHBs, we have found no strong evidence for presence of such GWs.

[28] A. Chalumeau et al. "Noise analysis in the European Pulsar Timing Array data release 2 and its implications on the gravitational-wave background search". In: (2021). arXiv: 2111.05186 [astro-ph.HE].

Team

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Scientific leader and/or Technical project manager

Gravitational-wave modelling

The gravitational-wave science based on compact binary signals is the theater of a unique interplay between theory and data analysis. Detecting and extracting signals from compact binaries, such as binary black holes or binary neutron star systems, requires to compare the data to a model of the waveforms. The two-body problem in general relativity and the problem of gravitational-wave generation is a difficult nonlinear problem with no known general solution that is the object of a very active field of theoretical physics. To tackle this challenge, different approaches are combined: analytical methods provide perturbative in the inspiral phase, far from coalescence, while the very non-linear merger of the two bodies is covered by heavy numerical simulations of the full spacetime.

After many years of continuous progress, we now have at our disposal waveform templates combining analytical and numerical information, that played an instrumental role in enabling the scientific results of LIGO and Virgo. Among these families of models, we could cite phenomenological models (Phenom), effective-one-body models (EOB), and numerical relativity surrogates.

It is important to note that we have an uneven coverage of the parameter space, and that the requirements on the accuracy of waveform models are more stringent for loud signals. Thus, the progress in waveform modelling needs to accompany the improvement in the detector sensitivity. Already, we arrive at a point where differences between waveform models are noticeable for sources at the margins of the parameter space covered by our models. This will be an outstanding challenge for future detectors including third generation detectors on the ground and LISA in space, where high signal-to-noise ratios are expected.

Team members have been actively involved in both the Waveform group of the LIGO/Virgo collaboration, which includes implementing waveform-generating codes, as well as particpating in code reviews for the crucial codes that are at the basis of LIGO/Virgo analysis in production. Group members have also been involved in the Waveform working group of the LISA consortium, coordinating a work package for the waveforms of stellar mass black holes. Additionally, group members have contributed to advances in a number of directions.

Towards post-Newtonian waveforms at the 4th PN order Post-Newtonian results form the bedrock of all waveform models, as they give perturbative analytical predictions for the inspiral. The current frontier lies at the already high 4PN order (the 4th order in the $(v/c)^2$ series), where the dynamics is known but the waveform remains to be computed. Team members have taken part in an effort to compute the main piece of this waveform computation, the mass quadrupole moment of the system.[29]

[29] Tanguy Marchand et al. “The mass quadrupole moment of compact binary systems at the fourth post-Newtonian order”. In: *Class. Quant. Grav.* 37.21 (2020), p. 215006. arXiv: 2003.13672 [gr-qc].

Machine learning approach to the properties of merger remnants The waveforms can only be computed with expensive numerical relativity simulations. It is crucial to interpolate in-between those scarce data; this knowledge then re-enters waveform models, as well as tests of general relativity. Members of the group have developed a novel approach based on machine learning techniques to train a network on the available numerical results, improving on previously existing fits.[30]

[30] Leïla Haegel and Sascha Husa. “Predicting the properties of black-hole merger remnants with deep neural networks”. In: *Class. Quant. Grav.* 37.13 (2020), p. 135005. arXiv: 1911.01496 [gr-qc].

A Phenomenological waveform model in the time-domain Phenomenological waveforms are the baseline model used by data analysis. They are easy to use, being built as an analytical ansatz with parameters fitted to numerical relativity results. Team members have contributed to a new high-accuracy model that has been built in the time domain, including precession effects, giving waveform modellers a new handle to work with.[31]

[31] Héctor Estellés et al. “Phenomenological time domain model for dominant quadrupole gravitational wave signal of coalescing binary black holes”. In: *Phys. Rev. D* 103.12 (2021), p. 124060. arXiv: 2004.08302 [gr-qc].

A new generation of EOB model with higher harmonics Effective-one-body waveforms are one of the three main families of models used in data analysis. They are built as a refactoring of post-Newtonian analytical results, with a merger phase informed by numerical relativity data. Members of the group took part in building the new generation of this model, including precession as well as higher harmonics in the signal for the first time. This model is one of the three main models that has been used in the analysis of the O3 run of LIGO/Virgo, providing an important comparison point to other results.[32]

[32] Serguei Ossokine et al. "Multipolar Effective-One-Body Waveforms for Precessing Binary Black Holes: Construction and Validation". In: *Phys. Rev. D* 102.4 (2020), p. 044055. arXiv: 2004.09442 [gr-qc].

Accelerating the evaluation of EOB waveforms with higher harmonics Effective-one-body are slow to evaluate in general, since they integrate numerically a trajectory, but waveform computational performance is a bottleneck for data analysis, and in particular parameter estimation codes. This has sparked efforts to algorithmically accelerate them, with Reduced Order Models (ROMs) trained on a set of precomputed waveforms. Team members have contributed to the construction of such a ROM for an effective-one-body model with aligned spins and higher harmonics.[33]

[33] Roberto Cotesta, Sylvain Marsat, and Michael Pürrer. "Frequency domain reduced order model of aligned-spin effective-one-body waveforms with higher-order modes". In: *Phys. Rev. D* 101.12 (2020), p. 124040. arXiv: 2003.12079 [gr-qc].

Modelling environmental effects for stellar-mass black holes in orbit around AGNs In the LISA context, stellar-mass black holes such as observed by ground-based observatories might be detectable at low frequencies, when the system is still far away from coalescence. Such systems could be affected by their environment due to accretion or dynamical friction. In particular, the possible association of GW190521 with a ZTF counterpart has raised a lot of interest by the possibility of having such a system emitting from an orbit within the accretion disk of an AGN. On top of matter effects, gravitational lensing could also play a role. Team members have been part of an ongoing effort to model these effects, implement them in data analysis tools and explore what such systems could tell us.[34]

[34] Alexandre Toubiana et al. "Detectable environmental effects in GW190521-like black-hole binaries with LISA". in: *Phys. Rev. Lett.* 126.10 (2021), p. 101105. arXiv: 2010.06056 [astro-ph.HE].

Team

S. Babak, C. Caprini, L. Haegel, A. Mangiagli, S. Marsat, A. Toubiana

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Connection to geophysics

The team contributed to an interdisciplinary activity in collaboration with IPGP to detect prompt gravity signals from earthquakes. The goal would be to produce faster early-warning alerts for earthquakes and also a new way to study seismic phenomena, alternative to the seismic waves. The team developed a conceptual design of a earthquake gravity signal detector (PEGASEWS), based on a double torsion bar and with an interferometric readout.

Team

M. Barsuglia, E. Capocasa

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

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Selected publications

Abbott, B. P. et al. "GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral". In: *Phys. Rev. Lett.* 119.16 (2017), p. 161101. arXiv: 1710.05832 [gr-qc].

– "Multi-messenger Observations of a Binary Neutron Star Merger". In: *Astrophys. J. Lett.* 848.2 (2017), p. L12. arXiv: 1710.05833 [astro-ph.HE].

Abbott, R. et al. "GWTC-2: Compact Binary Coalescences Observed by LIGO and Virgo During the First Half of the Third Observing Run". In: *Phys. Rev. X* 11 (2021), p. 021053. arXiv: 2010.14527 [gr-qc].

Chen, S. et al. "Common-red-signal analysis with 24-yr high-precision timing of the European Pulsar Timing Array: Inferences in the stochastic gravitational-wave background search". In: *Mon. Not. Roy. Astron. Soc.* 508.4 (2021), pp. 4970–4993. arXiv: 2110.13184 [astro-ph.HE].

García, Federico et al. "Progenitors of low-mass binary black-hole mergers in the isolated binary evolution scenario". In: *Astron. Astrophys.* 649 (2021), A114. arXiv: 2103.03161 [astro-ph.HE].

Mastrogiovanni, S., D. Steer, and M. Barsuglia. "Probing modified gravity theories and cosmology using gravitational-waves and associated electromagnetic counterparts". In: *Phys. Rev. D* 102.4 (2020), p. 044009. arXiv: 2004.01632 [gr-qc].

Mastrogiovanni, S. et al. "Cosmology in the dark: On the importance of source population models for gravitational-wave cosmology". In: *Phys. Rev. D* 104.6 (2021), p. 062009. arXiv: 2103.14663 [gr-qc].

Toubiana, Alexandre et al. "Detectable environmental effects in GW190521-like black-hole binaries with LISA". In: *Phys. Rev. Lett.* 126.10 (2021), p. 101105. arXiv: 2010.06056 [astro-ph.HE].

Vallisneri, Michele et al. "Time-delay interferometry without delays". In: *Phys. Rev. D* 103.8 (2021), p. 082001. arXiv: 2008.12343 [gr-qc].

Zhao, Yuhang et al. "Frequency-Dependent Squeezed Vacuum Source for Broadband Quantum Noise Reduction in Advanced Gravitational-Wave Detectors". In: *Phys. Rev. Lett.* 124 (17 2020), p. 171101.

High-Energy Astrophysics

Resp: A. Lemière (-2020) and S. Gabici (2021-)

Since the creation of APC, the High-Energy Astrophysics (HEA) team has been a mainstay of the laboratory and it is today its largest thematic group. The HEA team is currently composed of 23 permanent researchers (9 University staff, 3 CEA staff and 11 CNRS researchers), 3 postdoctoral fellows, and 7 PhD students.

The team members study the physical processes accelerating particles to relativistic energies in the Universe. The main lines of research are the origin of cosmic rays, the acceleration and propagation of particles, accretion/ejection processes, and all associated radiations: photons, neutrinos, cosmic rays themselves and the connection with gravitational waves. These phenomena take place within a wide variety of astrophysical objects, such as supermassive black holes, gamma-ray bursts, supernova remnants, pulsars. Information about these objects is also obtained indirectly through the study of their interaction with their environment (the interstellar medium).

The team also participates actively to many experiments observing the Universe at several wavelengths and using several messengers, in particular in the field of high energy photons (X-rays, MeV and TeV gamma-rays), high-energy neutrinos and cosmic-rays hadrons notably at ultra-high energy, in close collaboration with gravitational waves experiments also present at APC. The team is strongly involved in many international collaborations through instruments developments, observation campaigns and data analysis and interpretation, but we also perform high performance computing, phenomenological and theoretical modelling. In parallel, the team pursues activities in connection with geosciences in collaboration with Institut de Physique du Globe de Paris (IPGP) with the support of the LabEx UnivEarthS.

A particular effort has also been initiated within the group to work on the standardization of data formats between the different messengers (in particular neutrinos and gamma-rays) in order to be able to carry out more efficient joint analyses in the coming years. At the same time, the group is actively engaged in the implementation of accessible physical models in new generations of open analysis softwares. More generally, the group is very active in improving joint analyses between messengers and more efficient comparisons with models and numerical simulations.

One of the assets of the group lies in the interrelations between all these activities and the creation of an effective synergy between the different energy domains and messengers, and the phenomenology and simulation. Some progresses has been made these last years towards this goal, mainly through the establishment of a regular scientific meeting. Indeed, the team meets every week for a group meeting that includes general information, discussions of scientific news and presentations by group members or visitors, but also dedicated seminars or journal clubs. This appointment has become essential for the cohesion of the team, the scientific exchanges and the interactions with PhD students and postdoctoral fellows. It is also an important tool for setting up our strategy for multi-messenger astronomy. Joint meetings with the Gravitation team are regularly organized and benefit a lot to the scientific exchanges. In the following we describe the group activities and recent results.

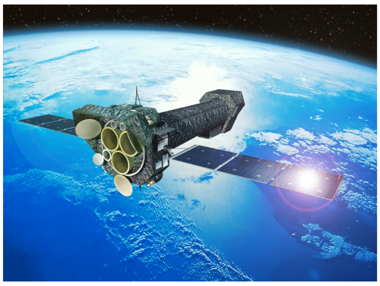

Figure 29: Artistic view of the XMM-Newton observatory

Astronomical observations through X-rays

The HEA group has a long-standing expertise in X-ray astronomy, observing astrophysical sources through high-energy photons, from X-rays to tens of MeV gamma-rays, collected from space observatories. Subsequent sections of this chapter describe integrated and holistic efforts with contributions at all levels of the science production, ranging from instrumentation, observation, data analysis to the astrophysical interpretation.

The group also conducts focused investigations of certain astrophysical sources based on targeted observations made through time allocation obtained from major observatories such as XMM-Newton (see Fig. 29). The following section provides an overview of one such investigation aiming at understanding the high-energy emission from region around the Galactic Center.

Study of the Galactic center

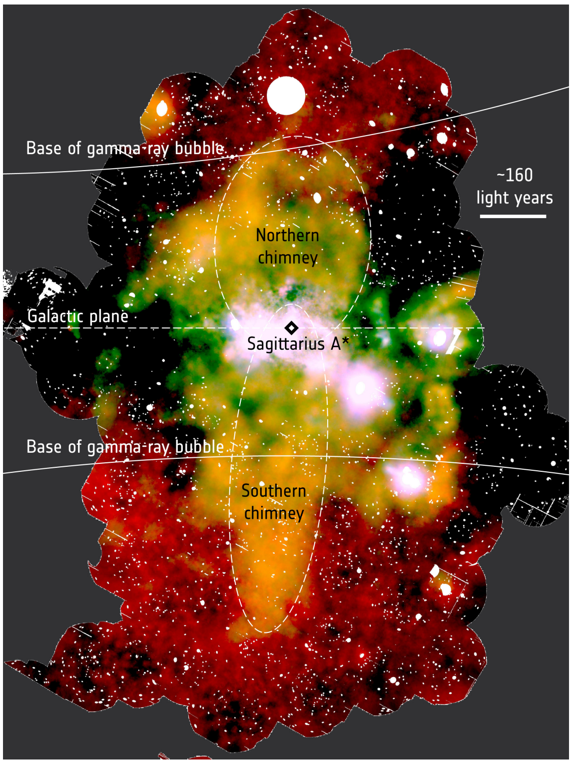

Figure 30: Image of the low energy (1.5-3.0 keV) X-ray emission from the central 300 × 500 parsecs of the Milky Way (red for low, yellow for middle and blue for high energy photons) which shows the shell-like features extending both north and south of the galactic plane, the so-called "gas chimneys", connecting the inner region around the SMBH Sgr A* with the Fermi Bubbles much further out.

One of the most dynamic and prolific research activity of the team concerns the study of the high-energy activity of the Galactic Centre (GC) Supermassive black hole (SMBH), Sgr A*, through the observation of the X–ray emission from the central regions of the Galaxy. Supported by a CNES project of XMM–Newton scientific exploitation, members of the group have continued to carry out several large projects of observations of the Central Molecular Zone (CMZ) with XMM, Chandra and Nu-Star, extending the surveys also at higher latitudes, for a total of more than 1.5 Ms exposure between 2017 and 2021. This large set of data has allowed to continue the investigations on the propagation in the GC clouds of the X-ray echoes of Sgr A* outbursts that occurred more than hundreds years ago and that shed light on the past activity of the, today very dim, SMBH of the Galaxy. In particular the thesis work of D. Chuard on the modelling of this reflected emission and the comparison to data of the variable 6.4 keV iron line and the associated continuum of the region[35] (Fig. 31 top) have allowed for the first time to position in space and time the two separate propagating events originated by Sgr A* in the past, the short event of few years originated about 80 years back while the longer one (20 years) started 240 yrs ago (Fig. 31 bottom).[36] The team also continued to monitor the present Sgr A* flaring activity with multi-wavelength campaigns involving XMM, Chandra, Nu-STAR, VLT, VLA, the most recent results[37] have provided crucial constraints on the flare radiation mechanism. But certainly the most outstanding result has been the discovery, from detail mapping of the low–energy component of the GC X-ray emission, of polar chimneys of hot gas extending from the GC to the base of the Fermi bubbles (see Fig. 30) indicating that they may be the channels through which the GC powerful activity due to the SMBH or star formation bursts injects energy in the bubbles.[38]

These results have been publicized in international conferences, in particular at the COSPAR 2019 (Pasadena) and 2021 (Sydney) general assemblies where we organized a Galactic Center session, and also to the large public through various communications[39] and the courses on the Galactic Center SMBH at the Université Ouverte of Université de Paris.

[35] R. Terrier et al. “An X-ray survey of the central molecular zone: Variability of the Fe Kssion line”. In: *A&A* 612 (2018), A102.

[36] Chuard, D. et al. “Glimpses of the past activity of Sgr Aferred from X-ray echoes in Sgr C”. in: *A&A* 610 (2018), A34.

[37] G. Ponti et al. “A powerful flare from Sgr A* confirms the synchrotron nature of the X-ray emission”. In: *MNRAS* 468.2 (2017), pp. 2447–2468. arXiv: 1703.03410.

[38] G. Ponti et al. “An X-ray chimney extending hundreds of parsecs above and below the Galactic Centre”. In: *Nature* 567.7748 (2019), pp. 347–350.

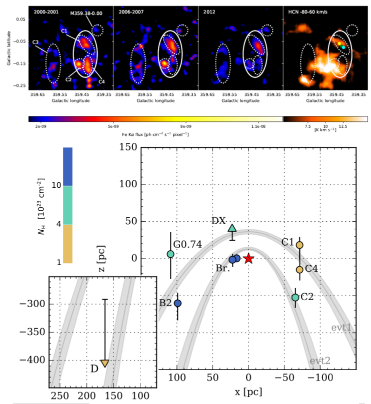

Figure 31: Top: Images of the 6.4 keV Fe line emission evolution in the GC Sgr C molecular cloud. Bottom: 3D reconstruction of the CMZ seen from the galactic pole. Line-of-sight positions (z) and column densities are derived from the X-ray spectral analysis of 9 molecular clouds with a reflection model of the emission from 2 past outbursts of Sgr A* (red star) whose echoes are represented by the grey line parabolas

[39] https://in2p3.cnrs.fr/fr/cnrsinfo/des-cheminees-rayons-x-geantes-au-centre-la-voie-lactee.

Supporting grants

2017-21	CNES project GALCENX (Study of the Galactic Center with XMM and other X and gamma-ray observatories), funded each year, PI: A. Goldwurm.
2018-22	ANR PEv COsmic RAys (PECORA) - PI : S. Gabici.

Team

D. Chuard, S. Gabici, A. Goldwurm, L. Jouvin, A. Lemière, R. Terrier

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Space borne instruments

Hitomi

The ASTRO-H JAXA project, renamed Hitomi after its launch, was the sixth Japanese satellite to observe the sky in an energy band ranging from 0.3 to 600 keV. The satellite was placed in a low orbit at 550 km altitude on February 17th, 2016. Unfortunately, Hitomi went into survival mode on

March 26, after an attitude error. Unable to communicate with the satellite to recover its normal course, JAXA declared the mission lost on April 28th, 2016.

APC participates in Hitomi through the ESA contribution, both for the technical aspect of the mission and its scientific follow-up. APC researchers were involved in the HXI (Hard X-ray Imager) and SGD (Soft-Gamma- ray Detector) instruments. With the support of ESA, they tested at APC BGO crystals for the anticoincidence systems of HXI and SGD. Thanks to this expertise, CEA and APC have also designed and built a calibration source to control the HXI detectors gain in-flight. The very low radioactive activity of the source (a few Bq, required not to pollute the weak signal from celestial objects) and the implementation of a system meeting the space environment constraints have required special developments in both laboratories.

APC researchers were involved with the support of CNES in two key areas of research: the study of the polarization of light in black hole candidates and pulsars and the central regions of the Galaxy. These two scientific topics were foreseen to be investigated with the instruments HXI and SGD in complement to previous studies conducted by the researchers with Integral and XMM-Newton. After the loss of the mission, APC researchers have been involved in many Hitomi papers dedicated to three of the six sources observed: the Perseus cluster, the Crab pulsar and the X-ray binary IGR J16318-4848. From the Perseus observations, they have contributed to give an upper limit to the 3.5 keV emission, hypothetically resulting from the sterile neutrinos annihilation. they have also looked at the polarization properties of the Crab pulsar and will participate to the interpretation of the 6.4 keV fluorescence iron line observations from IGR J16318-4848.

Team

P. Laurent, A. Goldwurm, G. Prévôt, D. Maier

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Athena

One of the major X-ray Astronomy projects in which the HEA group is involved is the Advanced Telescope for High Energy Astronomy (ATHENA), the second large space mission of the Cosmic Vision program of the European Space Agency (ESA), to be launched in 2034 (Fig. 32).

Figure 32: Artistic view of the ATHENA observatory

The mission will put in orbit a large X-ray observatory equipped with a 12 m long X-ray silicon pore optics telescope that will focus 0.1-15 keV X-rays, with a sensitive area of $\approx$1.4 m^2 and an angular resolution of $\approx 5''$-8", into 2 focal plane instruments: the Wide Field Imager (WFI) and the X-ray Integral Field Unit (X-IFU). The WFI will provide detailed images over a large field of view (FoV) of $40'$ with moderate spectral resolution, while the spectral imager X-IFU will feature an exceptional spectral resolution of 2.5 eV over its $5'$-$7'$ FoV. These unprecedented performances will lead to breakthrough explorations in the core science of the mission which include the growth and evolution of Supermassive black hole (SMBH) and the properties and formation of galaxy clusters and of the large structures in the universe. Many other science topics to be investigated by ATHENA overlap significantly with the scientific research areas of HEA, in particular for the Galactic Center astrophysics, the active galactic nuclei (AGN) spectroscopy and variability, the X-ray binaries and transient stellar size black holes, particle acceleration and cosmic ray interactions, transient events and multi-messenger astronomy. This newly emerging domain of astro-particle physics will be boosted by the strong synergies expected in the coming years between gravitational wave (GW), neutrino and X/gamma-ray observatories. APC, which is also involved in CTA (TeV gamma-rays), KM3NeT (neutrinos), advanced Virgo and LISA intends to play a major role in this field.

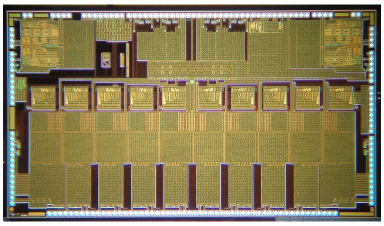

Figure 33: ATHENA Warm ASIC for the X-IFU Electronics, version 3

Since 2014 APC is in charge of one of the key elements of the read-out detection chain of the X-IFU, the Warm Front-End Equipment (WFEE) subsystem which integrates 96 readout channels including high performance low noise amplifiers and ultra-stable current sources ASIC that will carry out several electronic functions at the direct interface with the focal plane system. The project, which involves about 15 APC engineers and several members of the HEA group, has passed through several crucial steps of the mission program, completing the phase A study, end of 2019, with the X-IFU IPRR and the MFR reviews that led to the start of the phase B1, and it is now entering the phase B2. The team is now fully integrated in the X-IFU/Athena consortium, led by CNES and IRAP, and it is recognized as key element of the French contribution to the mission.[40] It counts two formal X-IFU co-Is, A. Goldwurm who was also member of the X-IFU science Advisory Team for 6 years, and D. Prêle who is also member of the X-IFU detection chain working group. APC successfully hosted in October 2018 one of the X-IFU international consortium 1-week meetings, with more than 200 participants from more than 10 countries.

[40] D. Barret et al. "The ATHENA X-ray Integral Field Unit (X-IFU)". in: *Space Telescopes and Instrumentation 2018: Ultraviolet to Gamma Ray*. Vol. 10699. Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series. July 2018, 106991G.

During the 2017-2021 period the team has been confronted to two major challenges, the change from frequency to time domain multiplexing system and the change of the ASIC technology employed for the WFEE due to the expected end of the industrial production of the chip normally used in the circuits. Thanks to the team dedicated work, the recent recruitment of a microelectronic engineer at APC and the arrival of senior engineer to support the project management, the team has managed to cope with these challenges and is progressing well in order to provide the first versions of circuits to be used in the demonstrator model, Fig. 33. This WFEE DM is currently assembled at APC, which also provides the EGSE of the communication bus required for the full X-IFU demonstration in Toulouse (see Fig. 34).

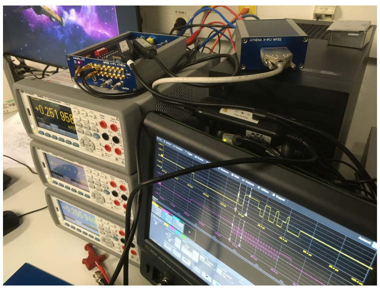

Figure 34: Integration of the AwaXev2.5 ASIC and ATHENA PIC EGSE bus in operation

The microelectronic studies for the WFEE[41] have generated an important scientific production. The PhD on the ASIC circuits for the WFEE has been successfully completed by Si Chen under the direction of D. Prêle. Several associated studies have been performed, published in refereed reviews, and advertised in international conferences in particular at SPIE Conference on Space Telescopes and Instrumentation, and at the

[41] Si Chen et al. "Development of the WFEE subsystem for the X-IFU instrument of the ATHENA Space Observatory". In: *Space Telescopes and Instrumentation 2018: Ultraviolet to Gamma Ray*. Vol. 10699. Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series. 2018, 106994P, 106994P.

International Workshop on Low Temperature Detectors.[42]

The nearly contemporary launch of LISA and ATHENA will revolutionize the study of SMBH. Detecting the gravitational-wave signal from SMBH mergers (see LISA) simultaneously with its electromagnetic counterpart would be a real breakthrough opening up new scientific opportunities to probe AGN physics, accretion/ejection processes and cosmology as well as fundamental physics. In this context, since 2019, the project MIMOSA (MultI-Messenger Observation of Supermassive Accreting systems), led by A. Coleiro and funded by the LabEx UnivEarthS takes advantage of the unique involvement of APC in both ATHENA and LISA, as well as in high-performance numerical simulation, to improve our understanding of compact objects and their mergers, in particular focusing on SMBH mergers in the era of ATHENA and LISA synergies. The project has allowed to fund one thesis and two postdocs who work on these topics both within the ATHENA and the high-performance simulation HEA teams.

A number of outreach activities have also been carried out to advertise Athena to the large public, including a contribution to X-IFU video and the France Culture broadcast[43] of October 2021 where D. Prêle presented the lab activities on microelectronics in cryogenic conditions for ATHENA.

[42] Damien Prêle et al. "Warm front end electronic modelization for the X-IFU ATHENA readout chain simulation". In: *Space Telescopes and Instrumentation 2020: Ultraviolet to Gamma Ray*. Vol. 11444. International Society for Optics and Photonics. SPIE, 2020, pp. 618–628.

[43] `https://www.franceculture.fr/emissions/la-methode-scientifique/athena-l-observatoire-du-x`.

Supporting grants

2020-23 MIMOSA LabEx UnivEarthS project - PI : A. Coleiro.

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WFEE project team: F. Ardellier, C. Beillimaz, S. Blin, S. Chen, S. Colonges, B. Courty, S. Dheilly, A. Givaudan, M. Gonzalez, C. Hugon, M. Karakak, J. Lesrel, D. Menia , J. Mesquida, G. Monier, R. Oger, D. Pailot, L. Pavili-Baladine, D. Prêle, E. Rangayen, F. Voisin.

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Integral

The HEA team is involved in the analysis and understanding of the Integral mission observations. APC hosts the IBIS Co-Principal Investigator (P. Laurent). Concerning calibration, the team has strongly contributed to the improvement of ISGRI imaging and spectral analysis. In the recent years, the team has developed software and calibration files, which now enable astronomers to recover the absolute flux of the observed source over the whole energy range. Moreover, since 2017, APC has also contributed to the development of tools for real-time follow-up of transient sources as well as for the optimization of tiling strategies necessary for a accurate follow-up of gravitational-wave sources.

Concerning science, one of the major results from INTEGRAL is the detection of GRB 170817A associated to the binary neutron star merger

GW170817 detected by the LIGO and Virgo interferometers on August 17, 2017. The significance of association between the gamma-ray burst observed by INTEGRAL and GW170817 was estimated to 3.2 σ. GRB 170817A was detected by the SPI-ACS instrument about 2 s after the end of the GW event (see Fig. 35).

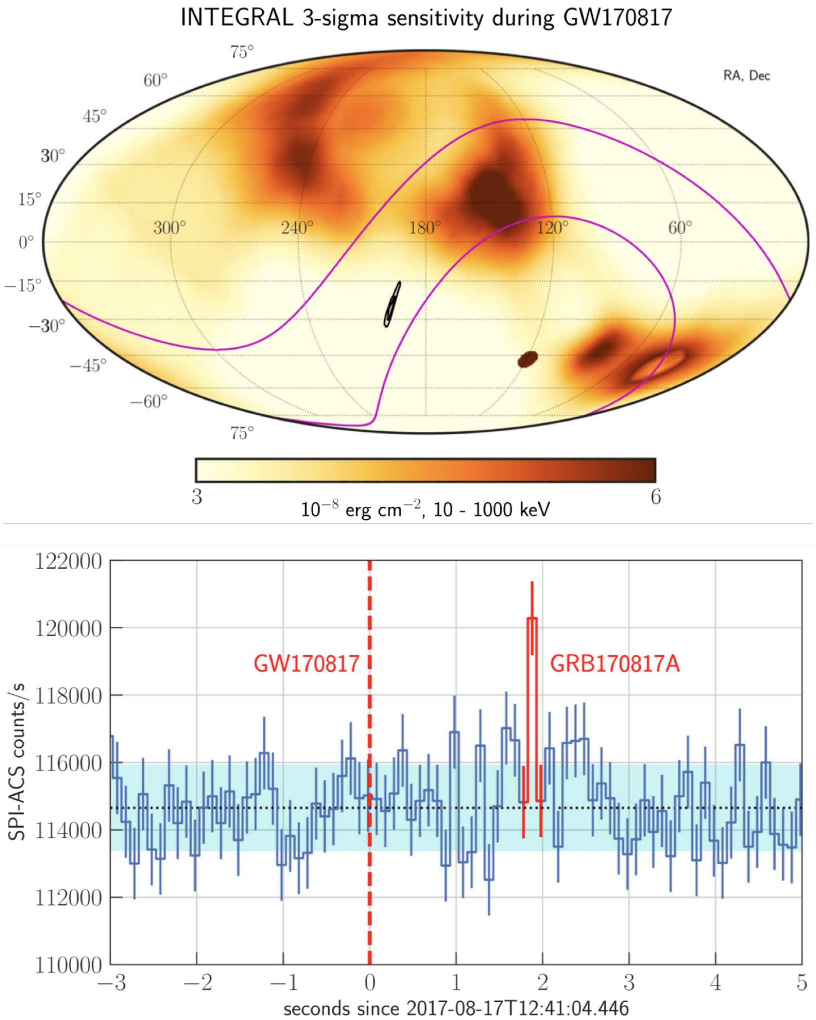

Figure 35: Top: INTEGRAL 3σ sensitivity to a 100 ms burst characterized by Comptonized emission with the best fit spectral model for GRB 170817A. Black contours correspond to the confidence regions (90% and 50%) of the LIGO/Virgo localization. The magenta annulus corresponds to the constraint on the GRB 170817A location derived from the difference in arrival time of the event to Fermi and INTEGRAL. Bottom: INTEGRAL/SPI-ACS light curve of GRB 170817A (100 ms time resolution), detected 2 seconds after GW170817. The red line highlights the 100 ms pulse, which has an S/N of 4.6 in SPI-ACS. The blue shaded region corresponds to a range of one standard deviation of the background

A pointed follow-up observations carried out by INTEGRAL started 19.5 hr after the event, and lasting for 5.4 days. This provided a stringent upper limit on any electromagnetic signal in a very broad energy range, from 3 keV to 8 MeV, constraining the soft gamma-ray afterglow flux. Exploiting the unique capabilities of INTEGRAL also helped to constrain the gamma-ray line emission from radioactive decays that are expected to be the principal source of the energy behind a kilonova event following a binary neutron-star coalescence. Finally, the INTEGRAL data put a stringent upper limit on any delayed bursting activity, for example, from a newly formed magnetar.

In addition to this important result, INTEGRAL plays a significant role in the multi-wavelength follow-up of high-energy neutrino events. Regardless of the nature of the electromagnetic counterpart, multi-wavelength data are crucial to firmly identify the sources of high-energy neutrinos. In this context, INTEGRAL systematically follows ANTARES alerts, under an MoU agreement signed with the ANTARES collaboration and the IceCube triggers sent publicly through GCN notices [44]. The team is at the forefront of this work with the implementation of ANTARES alerts monitoring with INTEGRAL and the monitoring of IceCube alerts, in collaboration with ISDC.

Recently, the team has also participated in the discovery with IBIS of a transient hard X-ray flare of the Galactic source SGR 1935+2154 simultaneously to a fast radio burst detected by the radiotelescopes CHIME and Stare2, see Fig. 36 from.[45]

This result first seems to indicate that part of the so-called fast radio bursts, whose origin was unknown until now, would be emitted by compact stars with very strong magnetic fields: the magnetars. The IBIS imager on INTEGRAL played a crucial role in this discovery since it was the first instrument to issue an alert following the detection of the X-ray flare and it allowed to precisely pinpoint the origin of the burst, confirming its association with the magnetar SGR 1935+2154.

Capitalizing on the expertise developed in the group, in close collaboration with the Astrophysics Department of CEA/Saclay, the team has also continued its work on the polarization of high-energy sources (gamma-ray bursts and microquasars) in the hard X-ray domain which brings strong constraints on our understanding of accretion and ejection processes. In particular, polarization measurements help to distinguish between the different possible emitting media (Comptonization corona versus synchrotron jets) in microquasars and provide important clues about the composition, energetics and magnetic field of the jet. Following the detection of the hard X-ray polarization of the microquasar Cygnus X-1 with IBIS in 2011, state resolved analysis of Cygnus X–1 polarization showed that the high-energy tail observed above 400 keV is detected by INTEGRAL during the low hard state (LHS) as well as during its high soft state (HSS). While the high-energy tail of Cygnus X-1 during both LHS and HSS is still under investigation with INTEGRAL data, Cangemi et al., 2021 showed that it could originate from the compact jet in the hard state and from hybrid Comptonization in either a magnetized or non-magnetized corona in the soft state. The same approach was used by the team to study the microquasar Cygnus X-3. Stacked INTEGRAL spectra for each spectral state allowed to investigate the properties of the non-thermal hard-X-ray emission (>100 keV) with the highest sensitivity. In this context, Cangemi et al., 2021 showed that a nonthermal power-law-like component is present in all the states of Cygnus X-3.

[44] https://gcn.gsfc.nasa.gov

[45] Mereghetti S. et al. "INTEGRAL Discovery of a Burst with Associated Radio Emission from the Magnetar SGR 1935+2154". In: *ApJ* 898.2 (2020), p. L29.

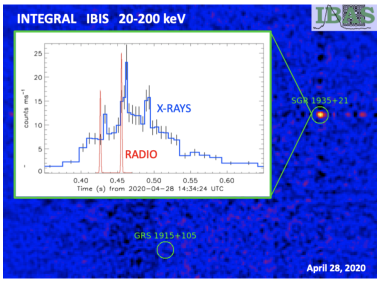

Figure 36: Image obtained by the ISGRI camera of the IBIS telescope between 20 and 200 keV. The magnetar SGR 1935+2154 is clearly seen on the right. Its light curve (in the insert) shows the X-ray burst (blue) and the two radio pulses (in red) which precede the signal recorded by INTEGRAL by a few milliseconds

Team

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Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Taranis and XGRE-NG

In 2009, the APC Laboratory took the responsibility for the development of the fast X-Gamma-Ray and Relativistic Electrons (XGRE) of the CNES mission TARANIS, a satellite dedicated to the observation of TGF. The instrument consisting of three detectors provides a high detection surface of 900 cm^2 and can detect gamma-ray photons in the 20 keV to 10 MeV energy range with a high count rate (3 MHz), good resolution at 511 keV (12 %) and high timing accuracy (1 μs).

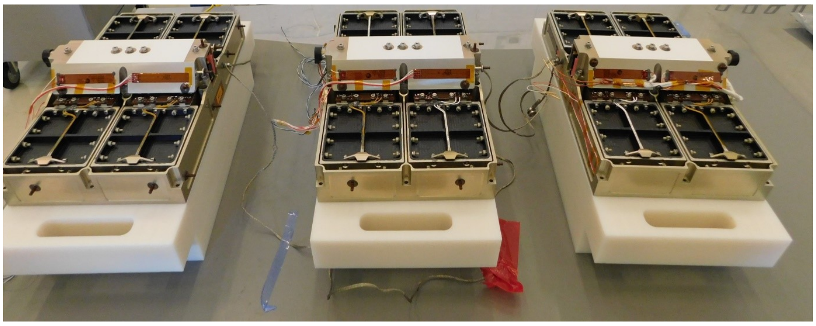

Figure 37: View of the three XGRE sensors flight models delivered to CNES in 2020

Until 2017 the team designed, verified and developed the complete instrument, involving all technical departments of the laboratory (mechanics, electronics, quality and instrumentation). During the 2017 to 2020 period, the team assembled, integrated, validated, qualified, calibrated on the satellite and delivered the flight model of the instrument to CNES. The team then performed the ground commissioning and defined the flight commissioning plan. Unfortunately, in November 2020, the launch of the satellite failed due to what was later discovered to be a human error in the integration of the last stage of the rocket.

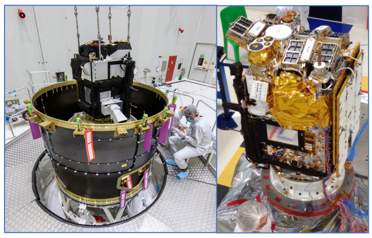

Figure 38: View of the TARANIS satellite. The three XGRE sensors appear on top of the satellite (Right). View of the TARANIS satellite inserted in the rocket cover before launch at Kourou (Left)

Despite this appalling event, this experience, that spanned across all phases of a space project, was a great opportunity for APC to develop strong technical skills and specific management know-hows related to space instrument development. Furthermore, the laboratory gained strong expertise in innovative gamma spectrometer development, analogic and digital embedded electronics, space qualification and acceptance processes along with the rigorous quality insurance work frame dictated by the European Cooperation for Space Standardization . This development allowed APC to become a recognized space laboratory by CNES and IN2P3, opening up new prospects for future space missions.

Soon after the mission failure, the CNES created a taskforce to evaluate the feasibility of a new TARANIS-2 mission that unfortunately did not come to fruition due to budget unavailability. In this study, the XGRE team worked on two scenarios : a “conservative” solution consisting of the same technology of the previous XGRE instrument and an “innovative” solution incorporating cutting-edge technologies (new scintillator and new photodetector).

Despite the above mentioned decision not to develop a TARANIS-2 mission, CNES showed high interest in this “innovative” solution and funded a collaboration involving APC and LESIA in order to further develop an instrument prototype and demonstrate its feasibility. This prototype is based on new Gadolinium Aluminium Gallium Garnet (GaGG) scintillators and Silicon PhotoMultiplier (SiPM), and is composed of 16 detection units (16 couples of GaGG scintillator and SiPM) read by the APOCAT fast ASIC developed by the IDEAS company. The GaGG scintillators have the advantage to be very fast, luminous and not hydroscopic.

The use of these technologies will ensure an instrument observing the sky in the 20 keV – 20 MeV energy range, with very good timing (hundred of nanoseconds) and energy (10% at 511 keV) resolution. This instrument is versatile and can be operated for many different gamma-ray space missions (such as TGF studies, solar physics, gamma-ray astrophysics, …).

Team

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Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Compton R&D

The group has also constantly looked at the future of the discipline by getting involved in the high-energy space projects proposed by the European community and in associated R&D.

MeV gamma-ray astronomy, in the 1–100 MeV energy range, is one of the last windows on our Universe still very little explored. The latest observations in this field date back to 1990s, with the Comptel telescope on board the CGRO American satellite, with a sensitivity one hundred times less than that of current X-ray telescopes. On the other hand, the SPI telescope on board the European INTEGRAL satellite is observing since 2002 the sky up to a few MeV, but with a sensitivity comparable to Comptel.

This R&D long-term goal was to create a much more sensitive telescope than Comptel in order to carry out a detailed mapping of the sky between 100 keV and 100 MeV. This study, started in 2012, led to the design of the eASTROGAM mission, proposed in 2016 for the M5 ESA call but not selected. The eASTROGAM telescope was designed with two main components, a “scatterer” where the Compton scatters occurred, and a “calorimeter” that absorbs the scattered photons.

Since the beginning, it was recognized by the eASTROGAM collaboration that Silicon detectors were the best suited for the scatterer. It was the reason why, in 2012, a CNES R&D program started at APC in the aim to build a prototype for this silicon detector, based upon 1.5 mm thick, 10 × 10 cm Double Sided Stripped Detectors (DSSD). The project has been funded by CNES, LabEx UnivEarthS, the Université de Paris Space Campus and CNRS/MITI.

The first step of this program (2012 – 2016) was to design and optimize the DSSD in order to ensure the best performances (low capacitance, dark current, bias voltage, …) using a dedicated software (SILVACO) and close relationship with the manufacturer (Micron SemiConductor Ltd, England). This first step was successfully completed with the delivery in 2016 of two fully implemented detectors (see Fig. 39). The electrical characterisation have proven the DSSD to be close to the specifications (strip capacitance of 20 pF on cathode side and 31 pF on anode side ; leakage current of 35 nA/strip at 20°C and of 2.9 nA/strip at -12°C with a 270 V depletion voltage).

The second step of the program (2017 – 2021) aimed to readout this detector using the IdefX ASIC developed at CEA Saclay. The first light was achieved in 2017 where the spectra of a ^{241}Am and ^{57}Co sources with one strip of the DSSD (see Fig. 40. However, due to the too high-leakage current of the detector, it was not possible to readout more strips in DC mode. Thus, we switched to AC mode, and at the end of 2018, we managed to readout a ^{57}Co source with 27 out of the 32 ASIC channels.

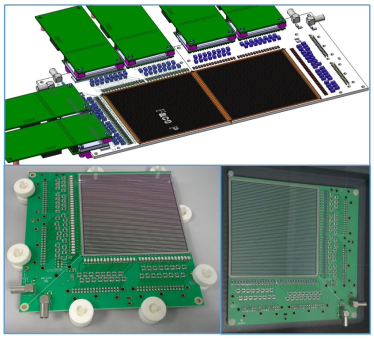

Figure 39: Bottom right: Photo of the Double Sided Stripped Detector, delivered in 2016. Left: its symmetric delivered in 2019. Top: Those two detectors are assembled to compose a half quadrant as shown in the sketch

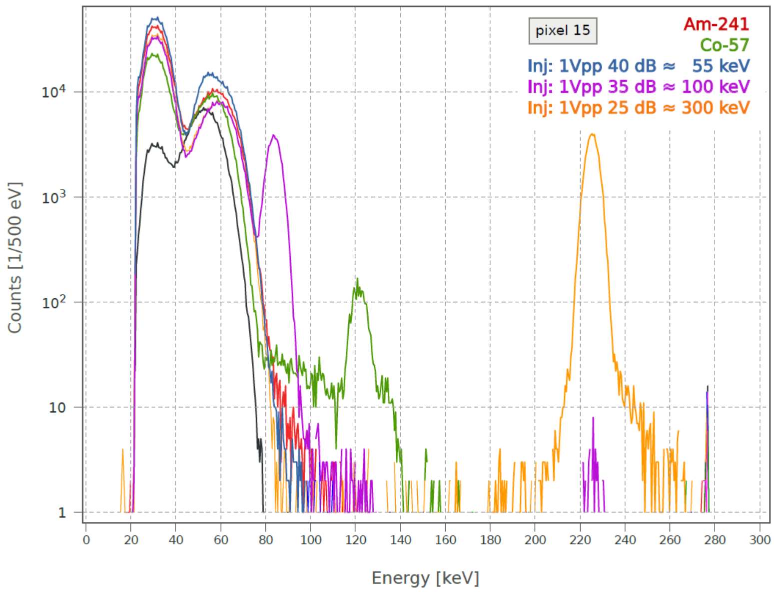

Figure 40: 241Am and 57Co spectra obtained in 2017 with one DSSD

Team

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Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

SVOM

The HEA group is strongly involved in the next large high-energy space mission of France, the bilateral Chinese-French SVOM mission to be launched in mid-2023. The involvement is both in technical developments related to the ECLAIRs telescope and in the scientific activities.

ECLAIRs' coded mask ECLAIRs is the main wide field of view instrument onboard Space-based multi-band astronomical Variable Objects Monitor (SVOM). ECLAIRs is a coded mask telescope in the domain of hard X-rays (4 – 150 keV). The instrument will observe GRBs and other transients alerts and contribute to follow-up observations within the network of multi-messenger observatories thanks to its very wide field of view (FOV) that covers $\simeq 1/6^{th}$ of the total celestial sphere.

Since 2008, the SVOM team is in charge of the realisation of the coded mask. The lower threshold of 4 keV implied the development of a self-supporting mask. Its elaboration was a real challenge since it is the first self supporting mask to be sent on a space mission. The vibration resistance at launch implied the development of a very innovative design, see Fig. 41. APC was in charge of the scientific pattern, mechanical design and machining of the coded mask. It is made of tantalum for the X-ray absorbing part and titanium to improve its mechanical resistance. To give an idea of the complexity of this mask, more than 82 kg of materials are required to build the final 7.6 kg mask. The flight model of the coded mask has been delivered to CNES in February 2021 after a long period of tests. Currently, the full ECLAIRs telescope is undergoing intense tests and will be delivered to China at the end of the year for its final installation on the scientific platform.

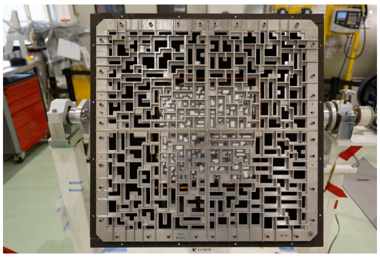

Figure 41: Picture of the flight model of the coded mask mounted on the ECLAIRs telescope. The shadow of the mask is reflected at the bottom of the camera by the detection plane

ECLAIRs GP pipeline The SVOM team is also involved in the design, the development, the test and the delivery of the software pipeline for the ECLAIRs instrument. On the ground, the development and processing phases are done in coordination with other French laboratories involved in the *French Science Center*.

The ECLAIRs GP pipeline is responsible for the processing of data received from the ECLAIRs instrument. The processing involves well identified steps including real time data calibration, binning of photons and subtraction of cosmic X-ray background on the detector, imaging of the sky and an estimation of the physical properties of sources (flux, sky position, spectra, etc).

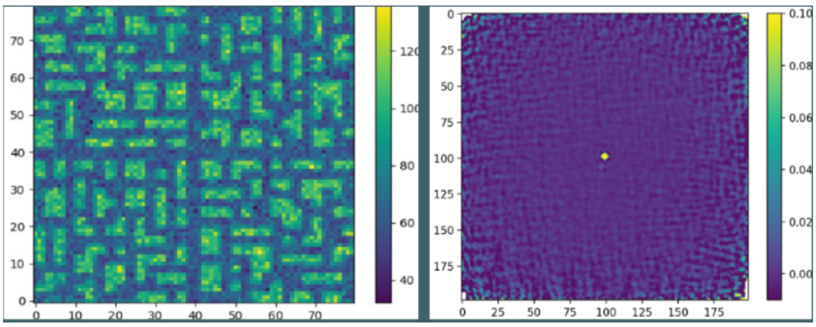

Figure 42: Left: Pattern projected onto the detector by the X-ray light coming from a distant cosmic source and going though the mask. Right: By processing the data associated with this pattern, the sky image can be reconstructed. The location of the source appears clearly at the center of the field of view.

An original recent development compared to previous X-ray missions is the inclusion of effects that involve the Earth passing in ECLAIRs' FOV. Indeed, when the Earth is present in the FOV it modulates the expected background shape and intensity on the detector. This novel functionality has been developed in 2020.

The team has been involved in multiple Data Challenges (DCs) organized by FSC and CNES. At those occasions, the technical and scientific functioning of the software pipeline is tested. Between 2018 and 2021, four DCs have been successfully completed with increasingly realistic situations and functionalities.

In addition to these technical contributions, APC hosts the leading scientists for the General Program (A. Goldwurm) and for the Target of Opportunity program (C. Lachaud). The definition of the target of the General Program for the first year of the mission is currently under intense discussions. The ToO program currently undergoes preparatory system tests to check the programming loops involving different mission centers.

Supporting grants

2016-20	GRBs: A unique laboratory for modern astrophysics - LabEx UnivEarthS project - co-PI: C. Lachaud
2020-22	Multi-messenger astrophysics with Gamma-Ray bursts - LabEx UnivEarthS project - co-PI: C. Lachaud

Team

Coded mask project team: W. Bertoli, C. Chapron, S. Dheilly, A. Givaudan, C. Juffroy, M. Karakac, L. Pavili-Baladine, B. Silva
Pipeline project team: P. Bacon, N. Bellemont, C. Catalano, J-M. Colley, F. Dodu, H. Jiménez-Pérez, D. Thibaut
Science: S. Antier, A. Coleiro, N. Dagoneau, A. Goldwurm, C. Lachaud, J-B. Vielfaure

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

IGOSat

The Ionospheric and Gamma-ray Observations SATellite (IGOSat) project is a nanosatellite project using the standard CubeSat 3U format (10 × 10 × 30 cm). It consists of a 3-axes attitude stabilized platform hosting two scientific observation instruments. This CubeSat is entirely developed by students, supervised by 2 engineers in charge of software and hardware system aspects as well as 3 experts' teams from APC and IPGP and CNES. This satellite is largely funded by the Labex UnivEarthS as well as by CNES via the NanoLab Academy project. IGOSat is an exceptional opportunity for APC and IPGP to develop an innovative space mission and to gain valuable experience on this new satellite standard, intended to facilitate access to space for new scientific experiments.

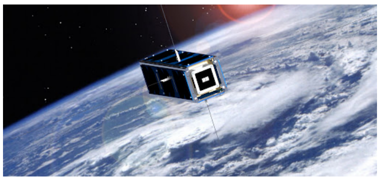

Figure 43: Artist's view of IGOSat

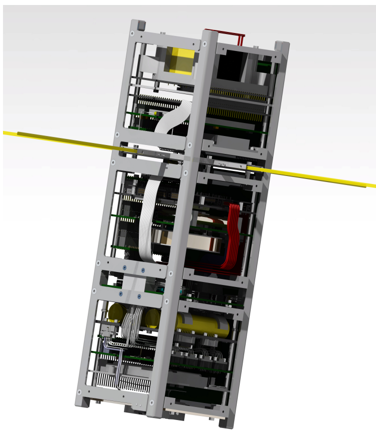

Figure 44: 3D view of the integrated satellite (without its solar panels)

The project has two main objectives. The first objective is scientific and is carried by two complementary payloads, the scintillator and the GPS receiver. The objective of the IGOSat scintillator is both to study radiation belts (also called Van Allen belts, these are regions of the Earth's magnetosphere where solar wind particles are trapped), and to verify the performance of three innovative components in space conditions:

the Cerium bromide scintillator (CeBr3), the SiPM photo-detector matrix detecting the light coming from this scintillator and the EASIROC ASIC, which allows data acquisition and digitization.

The scientific mission of the GPS receiver is the observation of the Earth's ionosphere, by measuring the effects of propagation of radio signals through the ionized environment. Using the radio occultation technique, it will be possible to probe the ionosphere between 100 and 500 km altitude, below the satellite's orbital altitude, and to obtain a full Earth coverage of the vertical distribution of electrons[46] .

[46] Hubert Halloin, Pierdavide Coïsson, and Philippe Laurent. "Traquer les aléas de l'ionosphère". fr. In: *La Recherche* 549 (2019), pp. 68–70.

The second objective of IGOSat is to train a new generation of engineers through projects and internships in order to carry out the different stages of a space mission. Indeed, since 2012, students design the entire CubeSat. They have defined the profile of the scientific mission and carried out various associated simulations, for instance modeling the thermal response of the satellite in orbit. They have conceived the mechanical structure design, carried out the satellite subsystems integration, developed the on-board software, etc. IGOSat should be launched in 2023 on a low-Earth quasi-polar orbit, depending on available launch opportunities, for a nominal mission duration of at least one year. Scientific and housekeeping data will be downloaded on ground through the collaboration of the worldwide radio-amateur network; Indeed, IGOSat transmits its data in UHF/VFH in the frequency bands allocated to radio-amateur space communication.

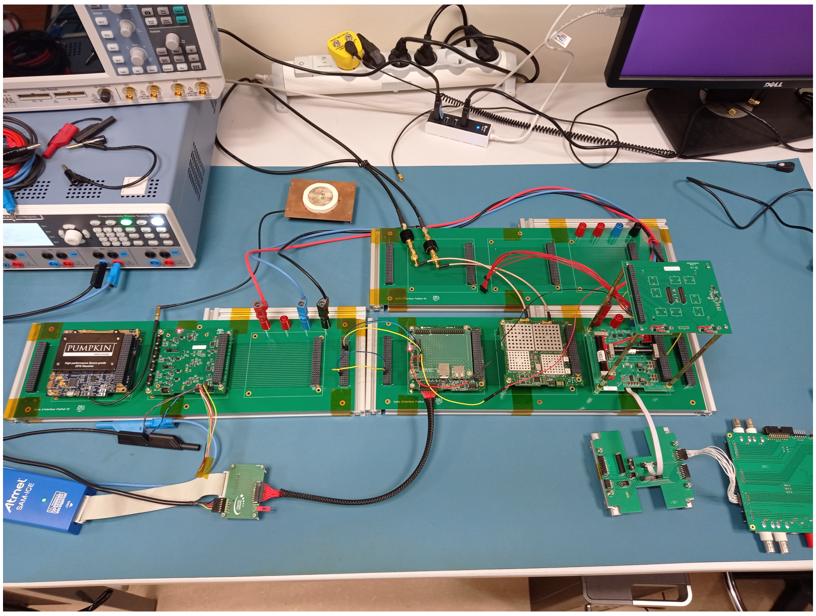

Figure 45: Flatsat of the IGOSat EQM

The IGOSAT team is currently testing the satellite qualification model in the lab (see fig.45) and preparing future environmental tests and production of the flight model in 2022. At the same time, at the software level, the integration of the PUS library (Packet Utilisation Standard) supplied by CNES offers a reliable command-control solution, while respecting ECSS (European Cooperation for Space Standardization). Similarly different flight software (on-board computer, GPS payload software, scintillator

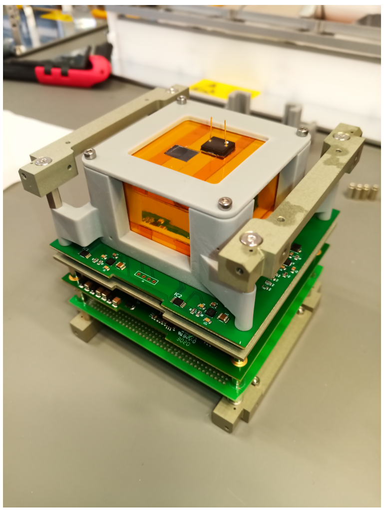

Figure 46: Prototype of the scintillation payload onboard IGOSat

acquisition and attitude control boards) are at the end of their development phase and will soon be ready for integration and functional testing in 2022. The team is also developing the entire ground segment as well as the radio communication station in order to operate the satellite, retrieve the data and archive them in collaboration with CNES and AMSAT (the radio AMateur SATellite corporation).

Team

É. Bréelle, P. Coïsson, B. Courty, S. Durand, A. Givaudan, H. Halloin, A. Ilioni, P. Laurent, A. Malecot, R. Oger, D. Paillot, P. Prat, O. Robert,and 90+ interns and 300+ students since 2012

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

JEM-EUSO

Since its creation, the HEA team has been heavily involved in the study of Ultra High-Energy Cosmic Ray (UHECR). The dedicated group develops activities in all aspects of UHECR research: instrumental, experimental, phenomenological and theoretical. Over the last five years it has involved 9 permanent researchers and 2 PhD students.

In this period, the main experimental activities have taken place in the framework of the international JEM-EUSO collaboration. The group members play a crucial role in this collaboration, and are recognised for their contributions to the development of the pathfinder missions as well as for their important participation in the management. They are responsible for two central workpackages for all EUSO missions: i) the conception, development and production of the detection units (so-called "elementary cells", or EC), and ii) the calibration of the focal surface. Both activities are supported by CNES. In particular, in the last four years, the JEM-EUSO group developed and implemented the ECs of second generation for the space mission MINI-EUSO (a joint ASI/ROSCOSMOS mission), which was launched in August 2019 to the International Space Station and operates nominally since then. Then, they developed a third generation of ECs, which are more compact and integrate the high-voltage power supplies in the shadow of the photodetectors (64 channel MAPMTs). They have been used for the prototype of the ROSCOSMOS space mission K-EUSO (2019) as well as for the NASA missions EUSO-SPB2 (selected and funded for a long-duration balloon flight in 2023), and have been chosen for the NASA mission POEMMA (selected as a Probe study in 2018 and under study within the decadal survey).

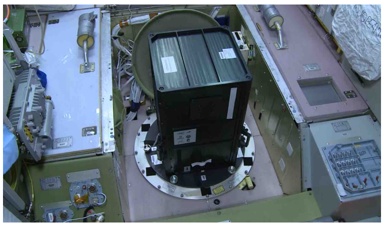

Figure 47: The MINI-EUSO instrument installed in the Russian module Zvezda onboard the ISS

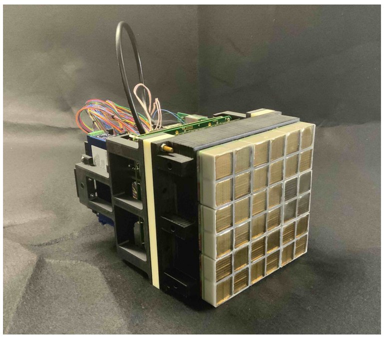

Figure 48: Assembled photodetection module for the EUSO-SPB2 mission

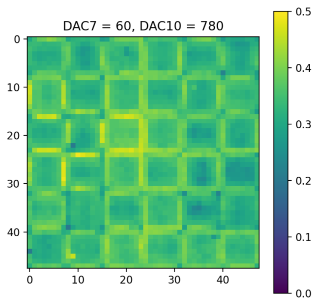

Figure 49: Efficiency map of one photodetection module of the EUSO-SPB2 mission, developed, integrated and calibrated in the photodetection laboratory

In addition to its traditional work packages the team has proceeded in 2021 with the integration of the focal surface for EUSO-SPB2 mission, in the Photodetection laboratory. This includes electronics integration, mechanical integration and calibration. Three photodetection modules will be delivered to the US at the end of 2021, for integration with the optics and field tests during 2022, before the flight in spring 2023.

Regarding the management of the collaboration, the team has two members in the Executive Committee and one member in the Publication and Conference Committee. Finally, the group leader and national PI has been appointed in June 2021 as the international PI/spokesperson of the JEM-EUSO Collaboration.

HEA group members are also recognized leaders in the domain of UHECR theory, with key contributions to the study of the propagation of UHECRs from their extragalactic sources to the Earth, as well as original works on particle acceleration. In particular, the HEA members were the first to recognize and demonstrate the importance of considering composed nuclei, in addition to protons, to understand the phenomenology of UHECRs.

The inclusion of nuclei was later made unavoidable by the experimental results of the Pierre Auger Observatory. In the previous period, state of the art computations of UHECR and secondary photons and neutrinos production during the propagation or the acceleration where proposed. In the past two years the efforts of the team were mostly dedicated to the modeling of UHECR anisotropies : a detailed study of particle propagation including energy losses, composition changes through photodissociation and angular deflections by Galactic and extragalactic magnetic fields, with skymap predictions and the statistical analysis of their intrinsic anisotropies for a wide range of astrophysical models has been conducted. The predictions are confronted to current data and discussed in the context of future instruments with a higher sensitivity to composition or with larger exposures. This contribution, which will be summarized in a series of papers currently in preparation (the first of which has been submitted in Oct 2021), is an important element for the science case of the various instruments of the JEM-EUSO1 program (see Sec Interpretation of the anisotropic arrival directions of UHECRs for more details).

Team

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Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Ground based instruments

The HEA team is one of the pioneering groups in the field of very high energy gamma-ray. It has with significant technical and scientific contributions to the H.E.S.S. array of Imaging Atmospheric Cherenkov Telescopes (IACT), as well as to the CTA project.

H.E.S.S.

H.E.S.S. is an array of five IACT located in Namibia that image the Cherenkov light produced by atmospheric air showers. In its first phase (H.E.S.S. I), the array consisted of four identical 12m Cherenkov telescopes placed at the corners of a square of 120m side length. The fifth Cherenkov tele-

Figure 50: The H.E.S.S. array

scope with a diameter of 28 m was added in the center of the array in July 2012, initiating the second phase of the experiment. In this configuration, H.E.S.S. is sensitive in the energy range 30 GeV - 100 TeV.

The year 2018 has seen the completion of the H.E.S.S. I legacy program. It consisted in numerous scientific analyses covering most of the Galactic science covered by H.E.S.S. using the data taken during phase I (until 2012) that were finally published in a special issue of Astronomy and Astrophysics.[47]

[47] Forveille, Thierry, Campana, Sergio, and Shore, Steve. "H.E.S.S. phase-I observations of the plane of the Milky Way". In: *A&A* 612 (2018), E1.

The team has been involved in analyses and writing of six of these papers. The main one is a detailed catalog built using the deep survey of more than 2000 hours of observation of the Galaxy that H.E.S.S. conducted over the years. A uniform analysis of the full dataset was performed resulting in a catalog of 78 objects with 10 new discoveries among which two previously unknown shell type supernova remnants (SNR). Systematic studies of the Galactic population of SNR and pulsar wind nebulae (PWN) were based on the catalog to understand the general physical processes at play. The PWN catalog paper[48] has demonstrated that PWN evolve with time and confirmed the picture of ancient nebulae populating the TeV sky.

[48] H. E. S. S. Collaboration. "The population of TeV pulsar wind nebulae in the H.E.S.S. Galactic Plane Survey". In: *A&A* 612 (2018), A2. arXiv: 1702.08280.

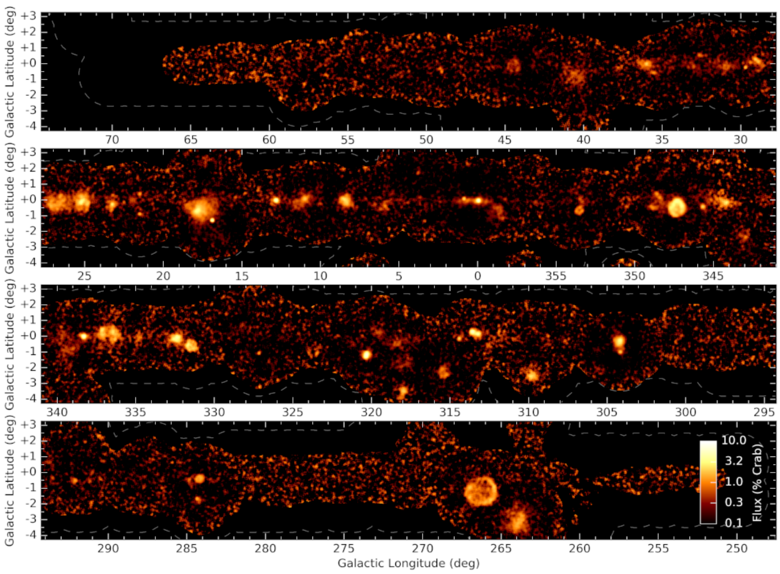

Figure 51: Flux map of the H.E.S.S. Galactic Plane Survey. It reveals 78 objects emitting in the TeV range, among which 10 were previously unknown. A half of the sources can be firmly identified, and most of the remainder has a tentative association. About 10 sources completely lack plausible associations. The majority of the identified sources are pulsar wind nebulae objects and supernova remnants

A major issue in the puzzle of Galactic cosmic-rays is the origin of PeV particles. The advent of ground-based wide field-of-view instruments such as HAWC and LHAASO is shedding new light on the Galaxy at very high energies. An essential question is now to bring together the two approaches. A first step in this direction is the comparison on the H.E.S.S. and HAWC surveys of the Galaxy which was recently performed.[49] To go further, our team has been working on improved selection criteria to enhance the sensitivity of H.E.S.S. in the multi-TeV range. This has lead to the first survey of the Galaxy beyond 20 TeV in the southern hemisphere. This high-energy survey has revealed several candidate PeVatron sources. Among them, H.E.S.S. J1702-420 presents a very hard spectrum detected

[49] H. Abdalla et al. "TeV Emission of Galactic Plane Sources with HAWC and H.E.S.S.". In: *ApJ* 917.1, 6 (2021), p. 6. arXiv: 2107.01425 [astro-ph.IM].

up to 100 TeV.[50]

The team is also actively studying the center of the Galaxy at very high energies. The two key questions are the origin of the gamma-ray source at the Galactic centre and its connection with the Supermassive black hole (SMBH) as well as the sites of cosmic-ray production in the inner 200 pc and their impact on the larger scales. A detailed analysis of the diffuse emission in the central 200 pc lead by the team confirmed that the cosmic ray density is maximal in the inner ten parsec of the Galaxy and decreases with the distance to the centre, consistent with the presence of a steady accelerator in the vicinity of the supermassive black hole. A new VHE source in the vicinity of the radio arc was also discovered.[51] The development of 3D analysis methods within the Gammapy effort now allows us to obtain more detailed characterizations of the cosmic-ray distribution over a broad energy range thanks to the joint analysis of Fermi-LAT data. This will allow us to precisely test injection and propagation models. Finally, we are also characterizing the emission of the Galactic Centre source, in particular, looking for time variability to explore its connections to the SMBH.

The detection of pulsed emission from the Vela pulsar, under one of team member's leadership, has opened the field of pulsar physics to H.E.S.S.. The measurement of the Vela pulsar spectrum down to energies of 20 GeV, in full agreement with the signal obtained with the Fermi-LAT instrument, has validated the design of the fifth telescope. This is a major breakthrough in gamma-ray astrophysics from the ground.[52]

The pulsed signal from a second pulsar, PSR B1706-44, was later found by members of the team.[53] An important discovery has been made recently with the detection of pulsed emission in the multi-TeV domain from the Vela pulsar. Such a hard emission is unexpected with current models. A significant revision in our knowledge of pulsar emission mechanisms is required after this discovery (article in preparation).

The team has been involved in the study of gamma-ray emitting blazars with H.E.S.S.. In particular, one of the team members led the publication[54] on the discovery of very-high energy gamma-ray emission of the blazar 1ES 2322-409.

The team contributes to the development of open data formats and open software in very high-energy gamma-ray astronomy. The team worked on the design of an open format for VHE data and on the production of compliant H.E.S.S. data. A first dataset was released publicly in order to support the development of open-source tools with "real" science data.[55]

In this respect, the team at APC is a leading actor in the development of the library Gammapy.[56] This library is an open-source Python package for gamma-ray astronomy built on Numpy, Scipy and Astropy (see Science Tools & Gammapy). It is the reference software library recommended by the H.E.S.S. collaboration for science publications. As a demonstration, the team worked on the joint analysis of the Crab nebula using most instruments above 10 GeV, such as MAGIC, VERITAS and HAWC[57]

[50] H. Abdalla et al. "Evidence of 100 TeV γ-ray emission from HESS J1702-420: A new PeVatron candidate". In: *A&A* 653, A152 (Sept. 2021), A152. arXiv: 2106.06405 [astro-ph.HE].

[51] H. Abdalla et al. "Characterising the VHE diffuse emission in the central 200 parsecs of our Galaxy with H.E.S.S.". In: *A&A* 612, A9 (2018), A9. arXiv: 1706.04535 [astro-ph.HE].

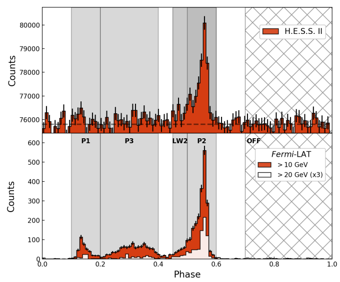

Figure 52: γ-ray phasogram of the Vela pulsar obtained using the 28 m equivalent diameter H.E.S.S. telescope (CT5) (top panel), and Fermi-LAT data above 10 and 20 GeV (bottom panel).

[52] H. Abdalla et al. "First ground-based measurement of sub-20 GeV to 100 GeV γ-Rays from the Vela pulsar with H.E.S.S. II". in: *A&A* 620, A66 (Dec. 2018), A66. arXiv: 1807.01302 [astro-ph.HE].

[53] Marion Spir-Jacob et al. "Detection of sub-100 GeV gamma-ray pulsations from PSR B1706-44 with H.E.S.S". in: *ICRC proceedings*, arXiv:1908.06464 (2019), arXiv:1908.06464. arXiv: 1908.06464 [astro-ph.HE].

[54] H. Abdalla et al. "VHE γ-ray discovery and multiwavelength study of the blazar 1ES 2322–409". In: *Mon. Not. Roy. Astron. Soc.* 482.3 (2019), pp. 3011–3022. arXiv: 1810.04641 [astro-ph.HE].

[55] H. E. S. S. Collaboration. *H.E.S.S. first public test data release*. 2018. arXiv: 1810.04516 [astro-ph.HE].

[56] http://gammapy.org/, https://doi.org/10.5281/zenodo.4701500.

[57] C. Nigro et al. "Towards open and reproducible multi-instrument analysis in gamma-ray astronomy". In: *A&A* 625, A10 (2019), A10. arXiv: 1903.06621 [astro-ph.HE].

Supporting grants

2019-21 Projet: Labex Multi-messenger Analysis Package to Model Extreme Cosmic Accelerators (MAPMECA) - PI : B. Khelifi
2019-22 Projet: Labex At the heart of our galaxy with multi-messenger astronomy: turning back the cosmic clock on SgrA* activity - PI : A. Lemière
2018-22 ANR PEv COsmic RAys (PECORA) - PI : S. Gabici.
2021-24 ANR Modélisation, Observation, Recherche de Pulsars de la Haute Energie à la Radio (MORPHER) - PI : J. Pétri (Université de Strasbourg), pour l'APC : A. Djannati-Ataï
2018-19 Post-doc In2p3

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Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Figure 53: Science with the Cherenkov Telescope Array (CTA) (Credits: CTA Consortium)

CTA

APC is strongly involved in the Cherenkov Telescope Array (CTA) project. Following on from the current generation of gamma-ray telescopes in operation, such as H.E.S.S. network in Namibia, CTA is an international project led by more than 30 countries aiming to build the largest and most sensitive gamma-ray observatory in the VHE range (above around 30 GeV) with dozens of telescopes planned at two sites, one in each hemisphere (Island of La Palma, Spain, and near Paranal, Chile).

The team members are actively committed to the preparation of the science with CTA since more than a decade: one of the members (S. Gabici) was the former lead of the Galactic Science working group, another (P. Goldoni) is the current lead of the Blazar spectroscopy working group,[58] and other members are either leading or involved strongly in tasks, e.g. search for pulsars (A. Djannati-Ataï),[59] AGN and gamma-ray "cosmology" (S. Pita)[60] . Thanks to their recognised know-how, team members contributed significantly to the the preparation of the CTA science book (see Fig. 53) including coordination of 2 chapters. Among other subjects, team members are active in the search for PeVatrons (L. Giunti, B. Khelifi),[61] SNRs, propagation and diffuse emission (S. Gabici, A. Neronov, D. Semikoz), Galactic Center (A. Lemière and J. Devin).

Timing and Clock Stamping The search for coincident events between telescopes within a site depends on accurate time-stamping of the Cherenkov flashes detected by each telescope, which even allows real-time coincidence search in a central Software Array Trigger, to eliminate lone events. A system called UCTS (Unified Clock distribution and Trigger time Stamp-

[58] P. Goldoni et al. "Optical spectroscopy of blazars for the Cherenkov Telescope Array". In: *A&A* 650, A106 (2021), A106. arXiv: 2012.05176 [astro-ph.HE].

[59] CTA Consortium. "Survey of the Galactic Plane with the Cherenkov Telescope Array". In preparation. 2022.

[60] H. Abdalla et al. "Sensitivity of the Cherenkov Telescope Array for probing cosmology and fundamental physics with gamma-ray propagation". In: *JCAP* 2021.2, 048 (2021), p. 048. arXiv: 2010.01349 [astro-ph.HE].

[61] CTA Consortium. "Search for PeVatrons with CTA". In preparation. 2022.

ing) was proposed for CTA to allow the synchronisation of the telescopes in the array and provide these accurate timestamps. To implement the UCTS concept, the team has developed the TiCkS (Timing and Clock Stamping) board, based on the White Rabbit system from CERN.

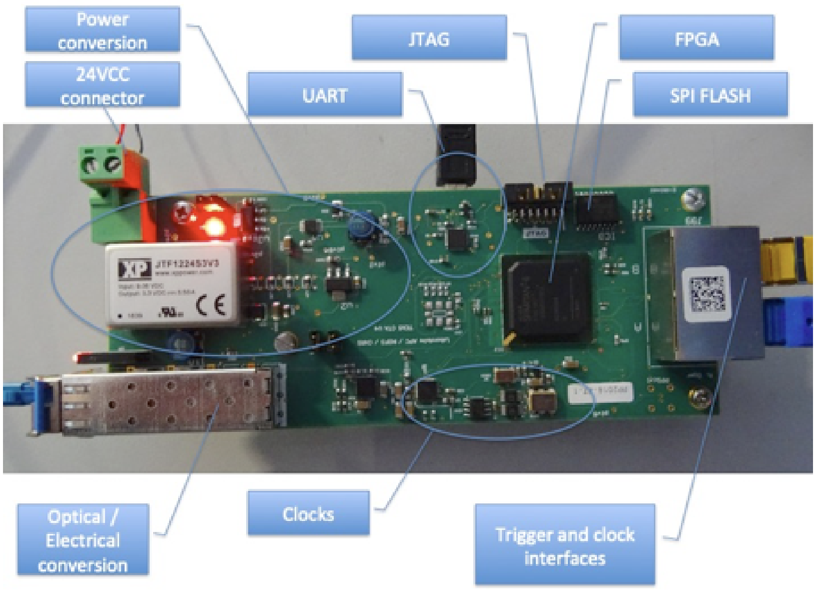

Figure 54: TiCkS time-stamping board and its main functions

The development of these boards has allowed APC to gain recognised expertise in the increasingly-used White Rabbit clock distribution technology, and provides the opportunity to gain experience in the implementation and interfacing of Raspberry-Pi compute modules. Furthermore, the expertise of the laboratory in the QA/QC field was deployed in the context of the validation of the boards (e.g. electrical interference tests with industry, HASS screening tests).

Telescope Array Trigger S(t)imulator In parallel, the same team has developed an Telescope Array Trigger S(t)imulator (TATS) test-bench. Based on the commercial Genesys 2 Kintex-7 FPGA Development Board, with APC-designed fan-out boards, the FPGA firmware developed at APC allows the TATS to send trigger signals as if there were N telescopes providing these, with user-programmable delays between the "telescopes". CTA Monte Carlo simulations provide, for each Cherenkov event, a list of telescopes triggered and their trigger delays, which can be re-run in real-time by the TATS. Then, by time-stamping these trigger signals and searching for coincidences within the time-stamp streams with a SoftWare Array Trigger (SWAT), the real-time performance of the time-stamping, transmission, and SWAT operation can be tested validated well-before N telescopes are actually installed on-site. This test-bench has been validated with the CTA SWAT prototype for 8 telescopes in 2018, and the current test-bench has been extended to 16 telescopes.

Science Tools & Gammapy CTA will be mainly operated as a proposal-based open observatory, with public access to the observational data for scientific users, together with openly accessible analysis software. From 2015, the open source Python package, gammapy, was developed as a prototype of a future analysis software for CTA, but also with a view to sharing with other research groups in gamma astronomy. With common analysis software and in open development, the path has been opened to use data from multiple instruments and to obtain combined measurements with much better accuracy. The project was structured in 2017 around an international steering committee with strong APC leadership (R. Terrier, B. Khelifi). It has since seen contributions from more than 70 scientists (researchers and students) from ten different countries, mainly around the Franco-German tandem with APC and MPIK. Gammapy was selected on June 2021 as the core library for the CTA Science Analysis tools and should be distributed for the *Early Science* phase of CTA.

Software Proposal Handling Platform As an open observatory, CTA offers several services through the centralized web Science Gateway which provides an access with a single identification to all CTA applications. In this context, the APC IT Department is committed to implement the Proposal Handling Platform for scientific observations to the CTA consortium. After validation of a demonstrator relying on the Django framework, several prototypes have been developed since 2017, implementing various functionalities (modularity, preparation, submission) with the release of Version 2.0 of the software in 2020. The project was recently referenced in the CTAO cost-matrix, should also be distributed for the *Early Science* phase of CTA.

Redshift determination group database In support to the Redshift Determination Group of the CTA consortium, a database with a web interface is developed in the laboratory relying on the Django framework. It contains useful information for the redshift determination of more than 100 blazars selected as CTA candidates.

Supporting grants

2015-2021	Action Fédératrice CTA, Observatoire de Paris - Key Science Program, Gammapy, PHP, Pulsars, Blazar Redshifts, Extragalactic Science
2018-2022	ANR PECORA
2020-2022	LabEx UnivEarthS, Gammapy & PHP Projects

Team

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Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Underwater instruments

The HEA team is also involved in the design, construction and exploitation of the large-scale neutrino Cherenkov detectors in the Mediterranean Sea: ANTARES and KM3NeT.

The team has acquired a strong visibility in both ANTARES and KM3NeT collaborations, with contributions at the scientific, technical and institutional levels. A. Kouchner is the elected Spokesperson of the ANTARES Collaboration since June 2014, and M. Lindsey Clark is the elected Technical Project Manager of KM3NeT since 2019. Other group members serve in the Steering, Publication and Conference Committees of ANTARES or KM3NeT.

Figure 55: Artist's view of the ANTARES detector

ANTARES

The ANTARES detector has been operating continuously since 2007 in the Mediterranean Sea, demonstrating the feasibility of an undersea neutrino telescope. The APC group is responsible for the charge calibration and data quality monitoring of the detector, which are crucial to achieve and maintain the best possible detector performance over the years.

The period 2017-2021 has been particularly fruitful for the scientific exploitation of ANTARES data, with several key contributions from the APC group to constrain the origin of the cosmic neutrino flux discovered by the IceCube detector. A first analysis exploited 10 years of ANTARES to probe the presence of a Galactic diffuse neutrino flux, based on the popular KRA$_\gamma$ model of cosmic ray propagation in the Galaxy[62] (see Fig.56). A subsequent combination of data from ANTARES and IceCube allowed to reject the version of the model with a 50 PeV cutoff in the primary cosmic ray spectrum, and to constrain the contribution of diffuse Galactic neutrino emission to the IceCube astrophysical signal to less than 10%.[63] A similar study of the Galactic Plane region is being performed with an extended dataset, together with a new analysis focusing on the Galactic Ridge. Recently,[64] the group has also produced the first ANTARES measurement of the atmospheric electron neutrino spectrum, and the first two-flavour atmospheric neutrino spectrum in the energy range from 100 GeV till 100 TeV, based on new event selection and unfolding procedures.

[62] A. Albert et al. "New constraints on all flavor Galactic diffuse neutrino emission with the ANTARES telescope". In: *Phys. Rev. D* 96.6 (2017), p. 062001. arXiv: 1705.00497 [astro-ph.HE].

[63] A. Albert et al. "Joint Constraints on Galactic Diffuse Neutrino Emission from the ANTARES and IceCube Neutrino Telescopes". In: *Astrophys. J. Lett.* 868.2 (2018), p. L20. arXiv: 1808.03531 [astro-ph.HE].

[64] A. Albert et al. "Measurement of the atmospheric ν_e and ν_μ energy spectra with the ANTARES neutrino telescope". In: *Phys. Lett. B* 816 (2021), p. 136228. arXiv: 2101.12170 [hep-ex].

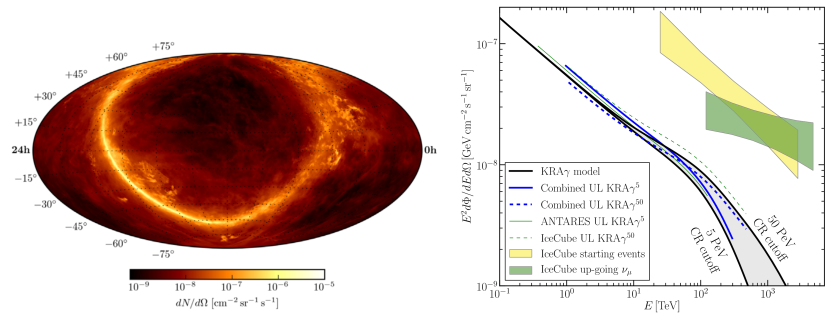

Figure 56: **Left:** Neutrino flux per unit of solid angle (in equatorial coordinates) expected in the KRA$_\gamma$ model of cosmic ray propagation in the Galaxy, assuming a cutoff at 5 PeV per nucleon. **Right:** Constraints on the neutrino flux from the KRA$_\gamma$ model obtained with the combined analysis of ANTARES and IceCube data, and compared with the IceCube signal

Despite its small size, the superior angular resolution of ANTARES in the reconstruction of neutrino events of all flavors has yielded unprecedented sensitivity for neutrino point source searches in the southern sky at TeV energies. Such a search has been performed using 11 years of ANTARES data, in correlation with several astrophysical catalogs of potential sources, such as Fermi blazars, X-ray selected radio galaxies, and IceCube very-high-energy events.[65] The analysis uses a stacking maximum likelihood method, in order to be sensitive to a potential collective excess of individual faint sources. While no significant excess has been found, the special case of the blazar MG3 J225517+2409 has been investigated in detail, because of the presence of five ANTARES track events lying at less than 1° from the source position, together with a high-energy track from IceCube occuring during a flaring period of the blazar observed in γ-rays, an association whose p-value was estimated to $p \sim 2.6\sigma$.

[65] A. Albert et al. "ANTARES Search for Point Sources of Neutrinos Using Astrophysical Catalogs: A Likelihood Analysis". In: *Astrophys. J.* 911.1 (2021), p. 48. arXiv: 2012.15082 [astro-ph.HE].

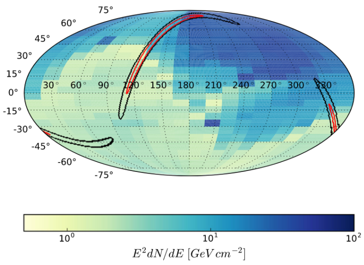

Figure 57: All-sky upper limits on the $\nu_\mu + \bar{\nu}_\mu$ spectral fluence from the GW170104 event (black and red contours), as a function of source direction, assuming an E^{-2} neutrino spectrum and flavour equipartition (map in equatorial coordinates)

Capitalizing on the broad expertise available at APC, the group has also provided important contributions to the ANTARES multi-messenger program, in particular by pioneering since 2008, together with the APC Virgo group, the development of joint searches for High-Energy Neutrino (HEN) and Gravitational Wave (GW), in the framework of an international working group "GWHEN" with collaborators from IceCube and LIGO. Neutrinos are a potentially powerful tool for the follow-up of GW events thanks to their better angular resolution (0.1 to a few degrees), allowing a faster repointing by narrow-field optical telescopes, which would enable an earlier localisation and characterization of the sources before they fade out. The team developed analysis tools and search strategies for the rapid follow-up of GW events which are applied on ANTARES data since 2015 and were used for fast follow-up searches and flux limits for all published GW events and some exceptional gamma-ray bursts (see e.g. Fig. 57). Those studies include in particular the neutron star merger GW170817 for which electromagnetic emission from the associated Gamma-ray burst and kilonovae was also observed.[66] These tools have since then been adapted within the ANTARES collaboration for other transients events searches like FRBs. The group is currently performing the search for neutrino counterparts from the O3 LIGO-Virgo last public catalog. They are also responsible for ANTARES sub-threshold searches of joint GW and HEN sources on all GW interferometers data-sets since 2007. The search performed on LIGO O1 data yielded constraints on the population density of joint sources reaching for the first time the order of magnitude of observed phenomena like core-collapse supernovae or binary neutron star merger.[67] The work is on-going to update the search with the LIGO-Virgo O2 and O3 observing runs.

[66] A. Albert et al. "Search for High-energy Neutrinos from Binary Neutron Star Merger GW170817 with ANTARES, IceCube, and the Pierre Auger Observatory". In: *Astrophys. J. Lett.* 850.2 (2017), p. L35. arXiv: 1710.05839 [astro-ph.HE].

[67] A. Albert et al. "Search for Multimessenger Sources of Gravitational Waves and High-energy Neutrinos with Advanced LIGO during Its First Observing Run, ANTARES, and IceCube". In: *Astrophys. J.* 870.2 (2019), p. 134. arXiv: 1810.10693 [astro-ph.HE].

The ANTARES detector will soon be decommissioned, and the activity of the team members is progressively shifting to KM3NeT, although analysis activities on the final dataset will continue for a couple of years. The preservation of ANTARES data through the MMO platform is in progress at APC (see François Arago Centre – FACe).

Supporting grants

2015-2020 IUF Junior grant - A. Kouchner
2019-2022 LabEx Project: *At the heart of our galaxy with multi-messenger astronomy: turning back the cosmic clock on SgrA* activity* - PI : A. Lemière

Team

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Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

KM3NeT

Cubic Kilometre Neutrino Telescope (KM3NeT) is the next-generation neutrino telescope currently under construction on two abyssal sites in the Mediterranean Sea: ORCA near Toulon, France, and ARCA near Capo Passero, Sicily. The KM3NeT design builds upon the experience gained with ANTARES, while introducing significant technological improvements such as the use of digital optical modules (DOMs) comprising 31 small (3-inch) photomultipliers, providing increased photon counting and directionality performances (see Fig. 58). While ORCA is primarily dedicated to fundamental neutrino physics studies at energies > 1 GeV, ARCA's main goal is high-energy (TeV-PeV) neutrino astronomy. The completion of the full ARCA (resp. ORCA) arrays are planned for 2026 (resp. 2024) and both detectors are expected to run for at least 10 years. Ten detection units are already installed (see Fig. 59) and taking data on the ORCA site (since June 2019) and eight on the ARCA site (since September 2021). Both detectors are expected to provide physics results already during the construction phase.

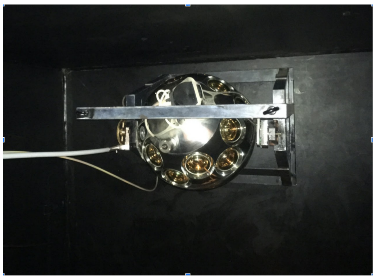

Figure 58: Digital optical module in the testing tank before water filling

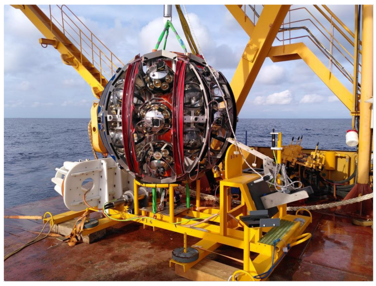

Figure 59: A KM3NeT detection unit with 18 DOMs furled on the launcher structure, ready to be deployed

The scientific activities of the group are currently focused on neutrino physics studies with ORCA (see KM3NeT – ORCA) and on evaluating the potential of both ORCA and ARCA for low-energy (< GeV) neutrino astronomy, with a particular interest in the possibility to detect MeV neutrinos from core-collapse supernovae (in the framework of the Low Energy Astrophysics with KM3NeT (LEAK) project).

On the technical side, the group operates in the lab assembly hall an 8 m^3 water tank surrounded by scintillators for the characterization of the DOM acceptance and response to atmospheric muons. The team, in collaboration with CPPM, is also in charge of the design and construction of the first KM3NeT Calibration Unit (see Fig. 60) to be deployed in the upcoming months on the ORCA site. The Calibration Unit comprises a Laser Beacon (for time calibration of DOMs in different lines), a hydrophone and an acoustic long-baseline emitter (to perform the acoustic positioning of the DOMs). It is connected to an Instrumental Unit featuring a recoverable inductive line that will support clusters of sensors (temperature, pressure, salinity, sea current, . . .) different depths, to monitor the environmental conditions that can affect the detector performance.

A novel design was proposed for the emission rod of the laser beacon, and the electronics control and optical characterization of the instrument were performed on dedicated test benches developed at APC. Tests in hyperbaric chamber have recently validated the instruments and electronics containers for deep-sea deployment, and the mechanical frame of the CB has been delivered in view of its upcoming installation.

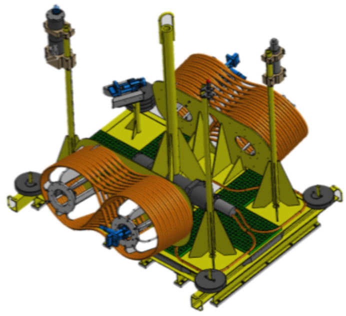

Figure 60: Sketch of the KM3NeT Calibration Base

Supporting grants

2016-2020 ANR Project DAEMONS - PI: A. Kouchner
2016-2021 IUF Junior Grant - PI: V. Van Elewyck

Team

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Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Interdisciplinary projects with ANTARES and KM3NeT: Earth and Sea Sciences Beyond its neutrino (astro-)physics program, KM3NeT also constitutes a deep-sea instrumented platform with permanent, high-power and high-bandwidth connection to shore, offering opportunities for synergies with Earth and Sea Sciences. In the framework of the ARGOS (Astrophysics Research, Geology and Oceanography Studies) project of LabEx UnivEarthS, the group explores new paths for the interdisciplinary exploitation of the KM3NeT detectors together with marine scientists from IPGP. The project instrumental activity aims at the development and characterization of a novel “North Finder” using a gyrocompass sensitive to the Coriolis force (and insensitive to electromagnetic perturbations) to determine the absolute orientation of marine devices, with potential applications e.g., for the positioning of oceanography instruments or elements of the KM3NeT detector. The network of optical and acoustic sensors available in the KM3NeT infrastructure will also provide large samples of environmental and acoustic data that can be used in collaboration with sea scientists for oceanography, bioacoustics and bioluminescence studies.

The team also participates in the EU Citizen Science project REINFORCE (REsearch INfrastructure FOR Citizens in Europe[68] that aims at engaging citizens into frontier science projects involving the major European research infrastructures – one of which being KM3NeT. APC contributes to REINFORCE through the development, in collaboration with

[68] https://www.reinforceeu.eu.

CPPM (Marseille), of an open platform of optical and acoustic data where citizens are invited to participate in the data classification and noise identification.

Through this project, new collaborations are developing with S. Martini and C. Tamburini at the Mediterranean Institute of Oceanography in Marseille, to study the bioluminescence signals recorded by the KM3NeT photosensors; and with H. Glotin and its team at the Computer Science & Systems Laboratory in Toulon, to use the KM3NeT hydrophones to trace bioacoustic signals of sea mammals present in the environment of the KM3NeT detector.

Supporting grants

2016-2021 LabEx Project ARGOS: *Astroparticle Research, Geology and Oceanography Studies with KM3NeT* - PI: V. Van Elewyck

2019-2022 EU H2020 Project REINFORCE: *Research Infrastructures FOR Citizens in Europe* - PI: S. Katsanevas

Team

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Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Transverse activities

Modeling Galactic cosmic rays

The study of galactic cosmic rays is amongst the main lines of research carried out by the High Energy Astrophysics group at APC. These theoretical/phenomenological investigations are focused on the acceleration of cosmic rays at supernova remnant shocks, on their propagation in the turbulent interstellar magnetic field, and on the study of the radiative signatures (especially in the gamma ray domain) resulting from the interactions of cosmic rays with ambient matter and background radiation fields. A particular attention has been devoted to the study of the interactions of cosmic rays in dense molecular clouds. The interactions of high-energy (GeV and TeV) cosmic rays in molecular clouds produce an intense flux of gamma ray photons, observable by both ground and space borne instruments. On the other hand, low energy (MeV) cosmic rays ionise the gas and influence the dynamical evolution of clouds and thus the process of star formation.

Finally, the interactions of galactic cosmic rays with the interstellar gas also result in the production of neutrinos. The group has been active in predicting neutrino fluxes expected from bright and hard Galactic gamma-ray sources. Moreover, it has been suggested that a halo of cosmic rays surrounding our galaxy could contribute significantly to the production of the isotropic flux of multi-TeV neutrinos recently detected by Icecube. If such cosmic ray halos are a common feature of galaxies, interactions in the circumgalactic gas might also explain the halo of gamma-rays observed around Andromeda.

Supporting grants

2018-2022 ANR PRC: *PECORA: PEv COsmic RAys* - PI: S. Gabici

Team

S. Gabici, P. Vo Hong Minh, V. Niro, S. Ravikularaman, S. Recchia, T. Vieu

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Interpretation of the anisotropic arrival directions of UHECRs

The most important experimental results concerning the origin of UHECRs, collected in the past five years, are related to the discovery of anisotropies in the arrival directions of cosmic-rays at the highest energies. Auger revealed a dipole modulation of the right ascension distribution of UHECRs above 8 EeV with a significance larger than 5σ while hints of associations of excesses in the UHECR number count with star forming galaxies or the active galaxy CenA were also claimed at higher energies.

With the development of future UHECR observatories in mind, it is important to investigate to what extent these observations allow to contrain the nature of the UHECR sources, their spatial density and distribution, their composition, or the intervening magnetic fields and whether there are currently some limitations, either experimental (statistics, sensitivity to composition) or theoretical (*e.g*, structure and strength of cosmic magnetic fields) preventing us from understanding the origin of these particles. To that purpose, we used the numerical tools we developed over the years to simulate to extragalactic and galactic propagation of UHECR taking into account the relevant energy loss processes. The team implemented some updates on the giant dipole resonance cross sections with respect to our previous works. An important work on astrophysical catalogs has also been undertaken for this study.

The team has simulated various source models fulfilling the current observational constraints for a distribution of (discrete) UHECR sources following the distribution of the ordinary matter in the universe, taking into account the (current and future) statistics of UHECR observatories and the so-called cosmic variance. The team attempted to reproduce the recently published anisotropy observations of Auger and TA at large and intermediate angular scales and to discuss their implications for the above-mentioned astrophysical parameter relevant to the UHECR puzzle. The results and their implications are summarized in a series of 2 papers (one submitted to A&A, arXiv:2110.10761, the second in preparation).

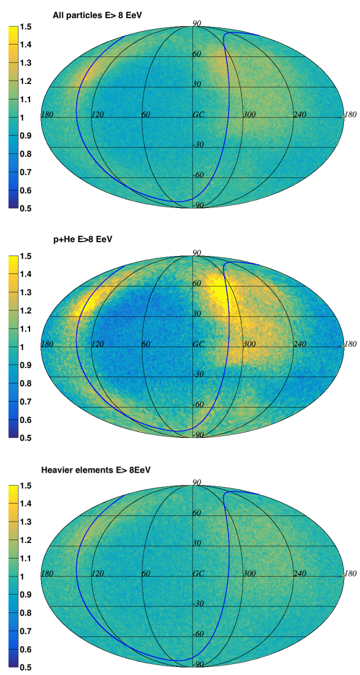

Figure 61: Density skymap above 8 EeV, assuming a uniform full-sky exposure, for an astrophysical scenario reproducing the Auger spectrum and composition, assuming the sources are distributed as the galaxies, taking into account deflexions in the extragalactic and Galactic magnetic fields. Top: skymap for all particles. Middle: lighter (H+He) elements. Bottom: heavier elements. (The color scale is linear)

Team

D. Allard, J. Aublin, B. Baret, E. Parizot

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Numerical observatory of violent accreting systems

The high performance computing team's main interest lies in the study of astrophysical plasmas in the vicinity of compact objects, such as in Fig 62, as well as in the particle acceleration processes at work in astrophysical shocks. Over the last five years our team has focused on the development and usage of two complementary and innovative numerical tools for both the astrophysical high-energy and astroparticle physics communities.

Regarding the study of plasmas in the vicinity of compact objects, the group has developed `NOVAs` the Numerical Observatory of Violent Accreting systems which is composed of `GRAMRVAC`, the first General Relativistic MHD French code developed at APC, and of `GYOTO` the general relativistic ray-tracing code developed by the Paris Observatory and in particular F. Vincent former ATER in our group. This gives us the unique opportunity to produce synthetic observations of the compact system we are studying. The team has published several papers devoted the study of accretion disk instabilities in the close vicinity of Kerr black holes[69,70] and their impact on observables[71,72] but we have also started from the observation side and explore different observed behaviors to see how it could be used to constrain models.[73]

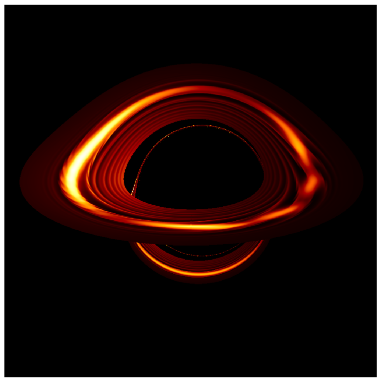

Figure 62: X-ray image of an fluctuating accretion disk orbiting very close to a spinning black hole

[69] F. Casse, P. Varniere, and Z. Meliani. In: *MNRAS* 464.3 (Jan. 2017), pp. 3704–3712.

[70] F. Casse and P. Varniere. In: *MNRAS* 481.2 (2018), pp. 2736–2744.

[71] P. Varniere, F. Casse, and F. H. Vincent. In: *A&A* 625, A116 (2019), A116.

[72] P. Varniere, F. H. Vincent, and F. Casse. "Living on the edge: Rossby wave instability and HFQPOs in black hole binaries". In: *A&A* 638, A33 (2020), A33.

[73] P. Varniere and J. Rodriguez. In: *ApJ* 865.2, 113 (Oct. 2018), p. 113.

In particular it is worth mentioning two results from the first GRMHD simulations of the Rossby Wave Instability (RWI, Fig 62) with direct application to fast variability in black hole systems. First of all, by studying how the spin impacts the RWI we were able to predict how the rms amplitude of the resulting variability should behave as function of the spin of the black hole and, as shown in Fig. 63, *tentatively* compare it with the limited observations we have. Another aspect of our numerical observatory is that we can process our 'numerical observations' similarly to direct observations.

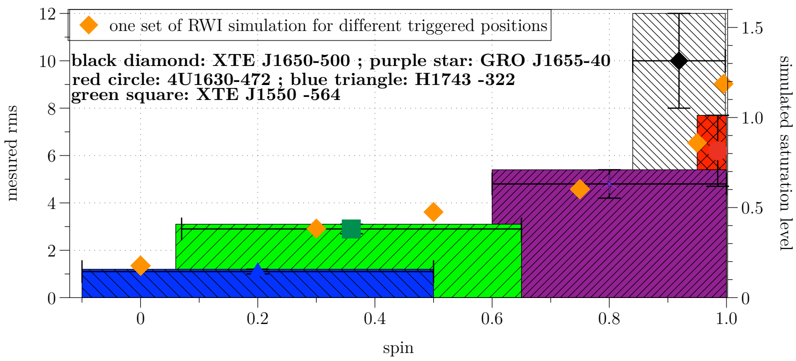

Figure 63: NOVAs simulations versus observations of the amplitude of disk oscillations as a function of the spin of the black hole

This leads to the production of the Power Density Spectra of the X-ray thermal of disks compatible with what is actually observed. This was the first time that a model could produce PDS exhibiting the same variety as is observed in X-ray binaries.

The second part of our activity is devoted to non-thermal particle acceleration in relativistic plasmas in the vicinity of astrophysical shocks. To that end, the high performance computing team has developed an numerical hybrid approach to the particle acceleration phenomenon. The inclusion[74,75] of a Particle-In-Cell (PIC) module dedicated to non-thermal particle within the MHD framework of our code `mPIC-AMRVAC` has enable us to self-consistently describe the Fermi acceleration occurring near astrophysical shocks over unprecedented temporal and spatial scales. The team was also able to depict the particle acceleration in a full 3D context for the first time in the literature (see Fig.64) as well as in the context of ultra-relativistic shocks.[76] The group is now on the verve of producing an unique numerical observatory where astroparticle yields (photons, cosmic rays and neutrinos) will be considered within general relativistic simulations of the very close vicinity of black holes, paving the way toward a multi-messenger numerical observatory of compact objects.

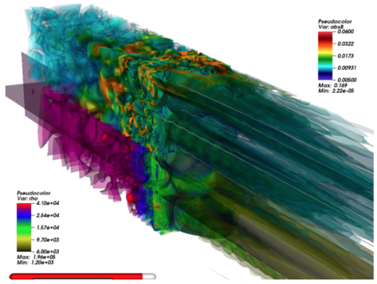

Figure 64: 3D PIC-MHD of magnetic turbulence induced by accelerated cosmic ray in the vicinity of a shock

[74] A.J. van Marle, F. Casse, and A. Marcowith. In: *MNRAS* 473.3 (2018), pp. 3394–3409.

[75] A.J. van Marle, F. Casse, and A. Marcowith. In: *MNRAS* 490.1 (Nov. 2019), pp. 1156–1165.

[76] C. Demidem, M. Lemoine, and F. Casse. In: *Phys. Rev. D* 102.2, 023003 (2020), p. 023003.

Supporting grants

2014-2018	: ANR *MACH: MicroAstroCHoc*, Co-I: F. Casse
2014-2019	: LabeX UnivEarthS Exploratory project "NOVAs", PI: F. Casse
2020-	: LabeX UnivEarthS Young team project "MIMOSA", PI: A. Coleiro

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Selected publications

Albert, A. et al. “ANTARES Search for Point Sources of Neutrinos Using Astrophysical Catalogs: A Likelihood Analysis”. In: *astrophysical-journal* 911.1, 48 (Apr. 2021), p. 48. arXiv: 2012.15082 [astro-ph.HE].

Bacholle, S. et al. “Mini-EUSO Mission to Study Earth UV Emissions on board the ISS”. In: *astrophysical-journal-supplement* 253.2, 36 (2021), p. 36. arXiv: 2010.01937 [astro-ph.IM].

Barret, Didier et al. “The ATHENA X-ray Integral Field Unit (X-IFU)”. In: *Space Telescopes and Instrumentation 2018: Ultraviolet to Gamma Ray*. Vol. 10699. Society of Photo-Optical Instrum. Engineers (SPIE) Conf. Series. 2018, 106991G, 106991G. arXiv: 1807.06092 [astro-ph.IM].

Cherenkov Telescope Array Consortium, B. S. Acharya, et al. *Science with the Cherenkov Telescope Array*. 2019.

de Angelis, A. et al. “Science with e-ASTROGAM. A space mission for MeV-GeV gamma-ray astrophysics”. In: *Journal of High Energy Astrophysics* 19 (Aug. 2018), pp. 1–106. arXiv: 1711.01265 [astro-ph.HE].

H. E. S. S. Collaboration, H. Abdalla, et al. “The H.E.S.S. Galactic plane survey”. In: *astronomy-and-astrophysics* 612, A1 (2018), A1. arXiv: 1804.02432 [astro-ph.HE].

Hitomi Collaboration, Felix Aharonian, et al. “Solar abundance ratios of the iron-peak elements in the Perseus cluster”. In: *Nature* 551.7681 (2017), pp. 478–480. arXiv: 1711.10035 [astro-ph.HE].

Ponti, G. et al. “An X-ray chimney extending hundreds of parsecs above and below the Galactic Centre”. In: *nature* 567.7748 (2019), pp. 347–350. arXiv: 1904.05969 [astro-ph.HE].

Savchenko, V. et al. “INTEGRAL Detection of the First Prompt Gamma-Ray Signal Coincident with the Gravitational-wave Event GW170817”. In: *astrophysical-journal-letters* 848.2, L15 (2017), p. L15. arXiv: 1710.05449 [astro-ph.HE].

Varniere, P., F. H. Vincent, and F. Casse. “Living on the edge: Rossby wave instability and HFQPOs in black hole binaries”. In: *A&A* 638, A33 (2020), A33.

Neutrinos and dark matter

Resp: D. Franco

The Neutrino group has developed its center of gravity over the past decade around neutrinos, exploring their role in the evolution of the universe, in astrophysical phenomena and in particle physics phenomenology. The group is involved in a number of experiments aiming at precision measurements of oscillation parameters and tests of the three-neutrino paradigm (Double Chooz, DUNE, ORCA, Borexino), determining the neutrino mass ordering (ORCA, DUNE), and measuring the CP-violating phase (DUNE). The advantage of this manifold approach is also to have access to several neutrino sources like the Earth and the Sun (Borexino), reactors (Double Chooz), the atmosphere (ORCA, DUNE), and accelerators (DUNE). Since a few years, the group has extended its field of interest to direct dark matter search with participation in the DarkSide project. Indeed, low energy neutrino physics and dark matter physics share many experimental techniques and challenges such as those related to very low radioactive contamination. Very recently, the group has completed its scientific portfolio by integrating an activity mainly focused on the study of the Higgs boson in collider experiments, such as the ATLAS detector at the LHC and the Future Circular Collider (FCC), becoming one of the largest groups in France with 8 CNRS researchers, 5 academic staff of Université de Paris, 2 emeritus, 2 postdoctoral researchers and 7 PhD students.

The research action of the group can therefore be divided into three main axes: precision tests to verify the Standard Model of particle physics (Higgs boson), the search for effects beyond the Standard Model (neutrino mixing, dark matter), and astroparticle physics (Supernova, Earth and solar neutrino detection). The group changed its name to Particles group in September 2021 to be consistent with this extension of the research field.

The interests of the group have a large complementarity and overlap. The group contributes to three experiments sensitive to the neutrino mass ordering which use two different types of detector technology (water Cherenkov and a liquid argon TPC), four different sources of neutrinos (atmospheric, reactor, solar and beam) and exploit two different underlying physical mechanisms: the matter-effect (ORCA and DUNE) and vacuum oscillations (Borexino). This later complementarity will open interesting avenues for future combined analyses and the wider goal of confirming the three-neutrino paradigm. Despite the difference in technology, we are developing synergies, in particular related to the detection of photons and associated electronics and acquisition (DUNE and DarkSide).

The group also has a cross-cutting project (Low Energy Astrophysics with KM3NeT (LEAK)) to exploit the synergies and complementarity of neutrino detection from core-collapse supernovae by exploiting the different interaction channels of DUNE, DarkSide and KM3NeT/ORCA. The APC DarkSide team was also involved in the MVM project at the beginning of the COVID-19 pandemic, aimed at compensating for the dramatic shortage of pulmonary ventilators in many countries.

Neutrinos

DUNE

The Deep Underground Neutrino Experiment (DUNE) will study long-baseline neutrino oscillations with the main goal of determining the neutrino mass ordering and searching for CP violation in the lepton sector, as well as measuring precisely the oscillation parameters and testing the 3-flavour paradigm. It will also offer interesting opportunities to search for physics beyond the Standard Model, such as baryon number violation and new particles. In addition, DUNE will be able to detect solar and atmospheric neutrinos and will be prepared, should one occur, to detect neutrinos from a galactic supernova.

DUNE (Figure 65) consists of a far detector located deep underground, at the Sanford Underground Research Facility (SURF) in South Dakota, USA, and a near detector at Fermilab in Illinois. It will study neutrino oscillations over a 1300 km baseline, using a wide-band neutrino beam produced at the Fermilab accelerator complex.

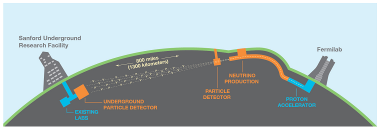

Figure 65: Layout of the DUNE experiment

The far detector will be a modular liquid argon Time Projection Chamber (LArTPC) with a total fiducial mass of about 40 kton. The LArTPC technology provides excellent tracking and calorimetric performance. The scintillation light provides the trigger for non-beam interactions and the event depth in the detector, while the ionization charge is drifted to one end to measure the two other coordinates with high granularity. The full imaging of events in the DUNE detector will allow the study of neutrino interactions and other rare events with unprecedented detail.

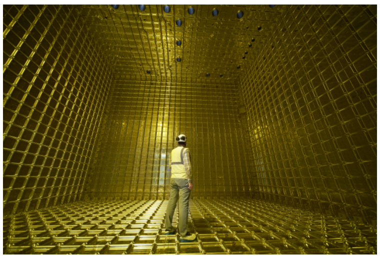
Figure 66: ProtoDUNE's cryostat from inside the detector

APC members have covered coordination roles in the physics working groups and other instances of the Collaboration (Institution Board, Speakers' Committee). They have been critical in the conception and design of DUNE, and the formation of the collaboration, which includes, as of today, nearly 1300 scientists from 205 institutes in 32 countries. The TDR of the project was published in January 2020.[77]

The team hosted Joao Torres de Mello Neto from Univ. Federal Rio de Janeiro as a visiting professor in 2018.

A dedicated prototyping effort is necessary to validate the technical solutions of the DUNE far detectors and to prove their performance for physics. The WA105 demonstrator,[78] with a fiducial volume of 4 tonnes, was operated at CERN in 2017. The thesis of A. Scarpelli (2016-2019) was largely devoted to the analysis of its data, whose results were recently published.[79]

Two detector prototypes were built at the CERN North Area for a full-scale test of the two proposed detector technologies for charge collection, single and dual-phase. ProtoDUNE-DualPhase (Fig. 66) took data with cosmic rays in 2018. The team was heavily involved in the operation and data analysis. J. Dawson was nominated co-convener of the ProtoDUNE Data Reconstruction and Analysis working group. The thesis of E. Chardonnet (2018-2021) covered dedicated developments of the reconstruction algorithms.

[77] Babak Abi et al. "Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume I Introduction to DUNE". in: *JINST* 15.08 (2020), T08008. arXiv: `2002.02967 [physics.ins-det]`; Babak Abi et al. "Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume II: DUNE Physics". In: (2020). arXiv: `2002.03005 [hep-ex]`.

[78] B. Aimard et al. "A 4 tonne demonstrator for large-scale dual-phase liquid argon time projection chambers". In: *JINST* 13.11 (2018), P11003. arXiv: `1806.03317 [physics.ins-det]`.

[79] B. Aimard et al. "Performance study of a 3×1×1 m3 dual phase liquid Argon Time Projection Chamber exposed to cosmic rays". In: *JINST* 16.08 (2021), P08063. arXiv: `2104.08227 [physics.ins-det]`.

The so-called "Vertical Drift" technology has been recently proposed for the second module of the DUNE far detector, implementing collection of the ionisation charge on Printed Circuit Board (PCB) after their drift over a large volume. The team is actively contributing to this new design and is in charge of the development of an analog readout system for the scintillation light signal, led by S. Sacerdoti and J. Dawson. They are participating to the construction of a test setup and of a detector prototype at CERN. Studies on the reconstruction and physics performance are also ongoing.

The second DUNE far detector module is recognised as Très Grande Infrastructure de Recherche (TGIR) in the 2022-2026 French National Roadmap, as a joint project of CNRS/IN2P3 and CEA/IRFU.

DUNE's Light Read Out Detecting scintillation light from liquid argon is fundamental to the work of DUNE's Far Detectors which will be liquid argon TPC. This light provides the time stamp of the event, allowing the determination of the depth of the interaction in the liquid argon volume, and will provide the trigger for DUNE's off-beam physics program which includes the search for proton decay and the detection of neutrinos from a galactic supernova explosion (should one occur).

Digital electronics have been developed to digitise signals from Photo-Multiplier Tubes, for the Dual-Phase TPC, based on an industrial telecoms standard micro-TCA. A 16-channel card was designed and produced, containing a 65MHz 14-bit ADC and the OMEGA produced ASIC, catiROC.

The team has recently extended its role to tackling the problem of detecting light in the Vertical Drift TPC. For good optical coverage, the photodetectors will be Silicon PhotoMultiplier (SiPM) embedded in the cathode plane of the TPC – at a potential of -300 kV and immersed in liquid argon (87 K). At such a high potential, signals can not be transmitted via copper cables. Instead, the team has developed an analog transmitter (see Fig. 67) which converts electrical signals from SiPMs to optical signals which can then be carried on optical fiber to the exterior of the cryostat. The optical signal will then be converted back to an electrical signal and digitised.

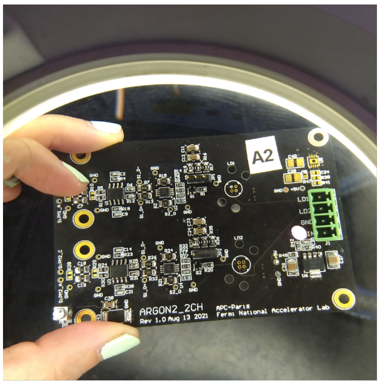

Figure 67: DUNE's SiPM analog transmitter

Team

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Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

KM3NeT – ORCA

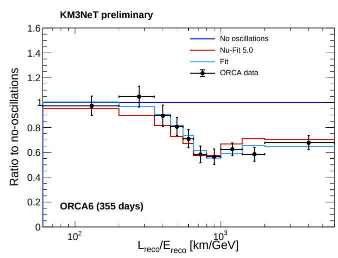

Figure 68: Event count in KM3NeT/ORCA vs ratio of distance travelled by the neutrino (L) by the neutrino energy (E). The decay is characteristic of neutrino oscillations. No-oscillation is excluded at 5.9 σ (light-blue: simulation, red: prediction using a fit of other experiments).

The KM3NeT team is heavily involved in the study of atmospheric neutrinos with the ORCA detector. The team developed one of the main analysis frameworks used in KM3NeT for performing general measurements of neutrino physics in the standard oscillation paradigm as well as searches for physics beyond the standard model. The team hosts one of the co-coordinators (J. Coelho) of the neutrino oscillations working group in

KM3NeT, who has led the first measurement of oscillation parameters by KM3NeT/ORCA announced at ICRC 2021[80] (see Fig. 68). In the current global context, ORCA is one of the key players in the race to measure the neutrino mass ordering (NMO).[81] If the normal ordering of neutrino masses is realised in Nature, a 5 σ measurement could be achieved with 28 Mton-years exposure. The inverted order scenario would require 80 Mton-years. However, a strong synergy has been demonstrated[82] in collaboration with the JUNO experiment, and in particular colleagues at IPHC, which shows that a 5 σ determination of the NMO is possible with less than 42 Mton-years of KM3NeT/ORCA data and 6 years of JUNO reactor neutrino data independent of any combination of neutrino mixing parameters.

[80] L. Nauta et al. "First neutrino oscillation measurement in KM3NeT/ORCA". in: *PoS* ICRC2021 (2021), p. 1123.

[81] S. Aiello et al. "Determining the Neutrino Mass Ordering and Oscillation Parameters with KM3NeT/ORCA". 2021. arXiv: `2103.09885 [hep-ex]`.

[82] S. Aiello et al. "Combined sensitivity of JUNO and KM3NeT/ORCA to the neutrino mass ordering". 2021. arXiv: `2108.06293 [hep-ex]`.

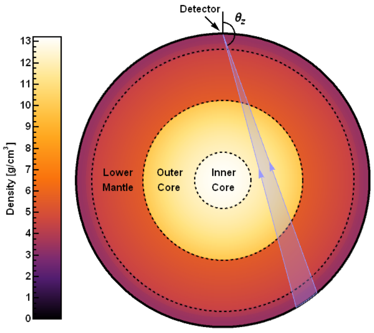

Figure 69: Schematic of the neutrino tomography concept. Neutrinos produced in the atmosphere cross the Earth and reach the detector on the other side. By focusing on particular directions, neutrino detectors can extract tomographic information about the material that the neutrino has crossed, both in terms of matter density and composition.

Beyond the measurement of the NMO, the team has played a leading role in the development of searches for physics beyond the standard model, including sterile neutrinos[83] and non-standard interactions. The team is also spearheading an interdisciplinary project to explore the potential of neutrino detectors to measure properties of the Earth's interior[84] (see Fig. 69). In collaboration with IPGP, the team has established the potential of upcoming neutrino detectors to search for traces of hydrogen in the outer core via neutrino tomography, shedding light on the long-standing problem of the core composition. Moreover, the requirements have been identified for a neutrino detector technology that may test the main hypotheses of core composition within the geophysics community. This detector would have to combine a Mton size characteristic of neutrino telescopes with a density of photo-sensors large enough to achieve 10 % energy resolution and 5 degree pointing resolution.

[83] S. Aiello et al. "Sensitivity to light sterile neutrino mixing parameters with KM3NeT/ORCA". 2021. arXiv: `2107.00344 [hep-ex]`.

[84] Van Elewyck, V. et al. "Probing the earth´s interior with neutrinos". In: *Europhysics News* 52.1 (2021), pp. 19–21.

Supporting grants

2015-2017	IdEx Sorbonne Paris Cit'e Project ONSET: *Oscillations Neutrino Studies and Earth Tomography* - PI: V. Van Elewyck
2016-2020	ANR Project DAEMONS - PI: A. Kouchner
2016-2021	LabEx Project ARGOS: *Astroparticle Research, Geology and Oceanography Studies with KM3NeT* - PI: V. Van Elewyck
2019-2021	CNRS MITI 80|PRIME Project NuSET: *Neutrino Studies and Earth Tomography* - PI: V. Van Elewyck

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Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Double Chooz

The Double Chooz experiment (Figure 70) was designed to measure the mixing angle θ_{13} using antineutrinos from the Chooz nuclear power station (Ardennes, France). The experiment relied on two identical detectors in shallow underground laboratories, one located 400m (Near Detector) and the other at 1050 m (Far Detector) from the reactor cores. The Near Detector monitored the reactor flux and spectrum, cancelling major systematics on the measurement.

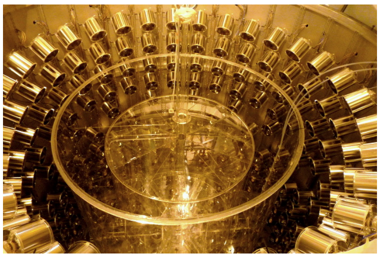

Figure 70: Internal view of the Double Chooz detector (Credits: Double Chooz)

The APC team had a leading role in the conception construction and operation of the experiment, with members in key positions. A. Cabrera has been the IN2P3 national co-ordinator, director of the LNCA laboratory and analysis/detector coordinator.

Double Chooz took data from 2011 to 2017. Since then, the APC technical services are actively contributing to dismantling activities.

After the first evidence for a non-zero value of θ_{13} in 2011, in combination with the T2K and MINOS experiments, a recent highlight[85] from Double Chooz is an improved measurement of θ_{13} via total neutron capture detection. Other physics results include a measurement[86] of cosmogenic isotope yields, the reactor rate modulation oscillation analysis[87] with two detectors and a search for signatures of sterile neutrinos.[88]

[85] H. de Kerret et al. "Double Chooz θ_{13} measurement via total neutron capture detection". In: *Nature Phys.* 16.5 (2020), p. 558.

[86] H. de Kerret et al. "Yields and production rates of cosmogenic ^{9}Li and ^{8}He measured with the Double Chooz near and far detectors". In: *JHEP* 11 (2018), p. 053. arXiv: 1802.08048 [hep-ex].

[87] T. Abrahão et al. "Reactor rate modulation oscillation analysis with two detectors in Double Chooz". In: *JHEP* 01 (2021), p. 190. arXiv: 2007.13431 [hep-ex].

[88] T. Abrahão et al. "Search for signatures of sterile neutrinos with Double Chooz". In: *Eur. Phys. J. C* 81.8 (2021), p. 775. arXiv: 2009.05515 [hep-ex].

Team

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Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Borexino

The solar neutrino detector Borexino (see Fig. 71) has been conceived in the 1990's to solve the solar neutrino problem (deficit of observed neutrinos compared to predictions of solar models) by measuring the so-called ^{7}Be-neutrinos. It has been installed in the Gran Sasso Underground Laboratory (Italy) from 2000, when the APC laboratory joined the collaboration, and has taken data from May 2007 to October 2021. Borexino strongly contributed to our understanding of the fusion processes in the core of the Sun, powered by cycles of nuclear reactions based on the fusion of four atoms of hydrogen into an atom of helium, releasing an energy of 26.7 MeV. Two cycles have been suggested by Hans Bethe and Carl von Weizsäcker at the end of the 1930's, the proton-proton (pp) chain, initiated by the primary reaction $p + p \rightarrow d + e^{+} + \nu_e$, and the CNO cycle, where C, N and O play the role of catalyzers. Many of these reactions produce electron-neutrinos with different energy spectrum and their detection informs us directly about the core of the Sun.

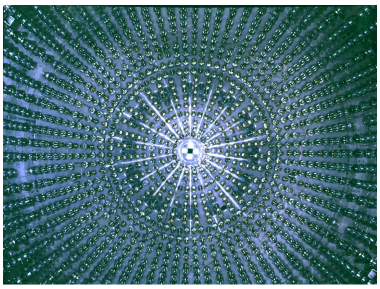

Figure 71: View of the internal of the Borexino Stainless Steel Sphere with PMTs (Credits: Borexino)

The Borexino detector consists in a metallic sphere containing 270 tons of liquid scintillator (pseudocumene) surrounded by non-scintillating liquid. Solar electron-neutrinos interact with electrons from the liquid target and the recoiled electrons excites the scintillator, which emits light observed by about 2200 photomultipliers all around the metallic sphere. The success of Borexino strongly depended on the unprecedented levels of radio-purity and extensive thermal stabilisation, which opened the long-awaited door to neutrino spectroscopy of the Sun.

The major achievements in the previous reports have been the first real-time measurement of the ^{7}Be-neutrinos, pep-neutrinos and pp-neutrinos, all induced by pp-chain reactions, in addition to the measurement of the ^{8}B-neutrino spectral shape with the lowest energy threshold.[89] Thanks to these results, Borexino was able to test neutrino oscillations in both matter-enhanced and vacuum-dominated regimes, as shown in Figure 72. Borexino also measured geoneutrinos coming from the natural radioactivity of the Earth.

[89] M. Agostini et al. "Comprehensive measurement of *pp*-chain solar neutrinos". In: *Nature* 562.7728 (2018), pp. 505–510.

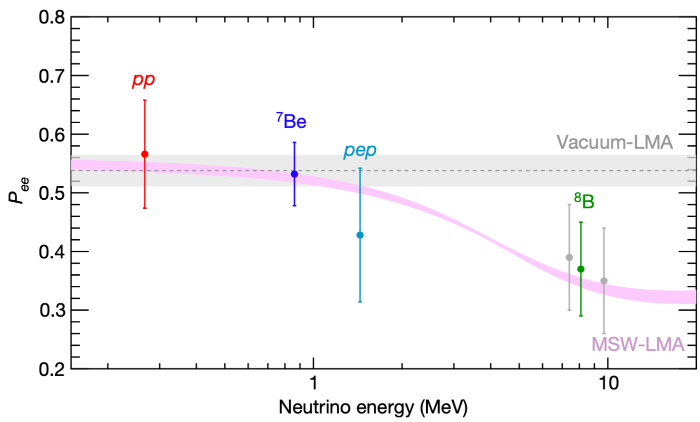

Figure 72: Survival probability of electron neutrinos, from pp, pep, ^{7}Be, and ^{8}B solar reactions. The pink band represents the prediction from the Large Mixing Angle (LMA) Mikheyev-Smirnov-Wolfenstein solution to the solar neutrino problem. The grey band represents the expected probability assuming LMA vacuum oscillation only

In the past three years, Borexino has refined the spectroscopy of the neutrinos from the pp-cycle and provided the first ever direct measurement of CNO neutrinos.[90] The CNO cycle is responsible of about 1% of the energy produced in the core of the Sun, but is dominant in the stars more massive than the Sun; this is why its observation is a breakthrough in the understanding of "how the stars shine". Moreover, CNO neutrinos are the only way to obtain the chemical composition of the Sun at the time of its formation. Their flux depends directly from the composition of the solar core, which is decoupled from the surface by the existence of a radiative zone. The so-called metallicity (chemical elements heavier that hydrogen and helium) is today an enigma: the metallicity measured in the photosphere does not agree with the helioseismological data and the CNO neutrinos may help in solving the problem.

[90] M. Agostini et al. "Experimental evidence of neutrinos produced in the CNO fusion cycle in the Sun". In: *Nature* 587 (2020), pp. 577–582. arXiv: 2006.15115 [hep-ex].

Team

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Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Dark Matter

DarkSide

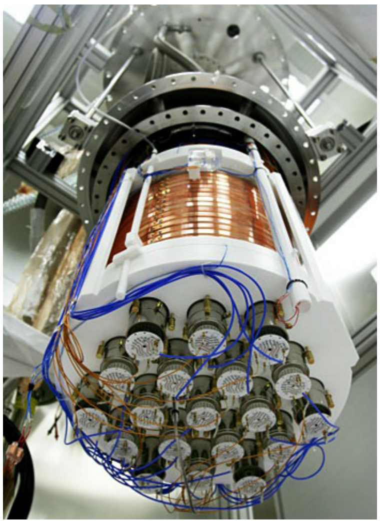

Figure 73: Picture of DS-50

Dual-phase noble liquid Time Projection Chamber (TPC) are the present leading technology in the field of direct dark matter search. The "dual phase" technique has the main advantage to provide simultaneous access to the scintillation (S1) and to the ionization (S2) signals, allowing for the event topology reconstruction and for the discrimination between electron and WIMP-like (or nuclear) recoils. A number of TPC's, such as Xenon1T, PandaX, and LUX, successfully profit from liquid xenon (LXe) target masses, which guarantee an excellent radio-purity and a high stopping power for penetrating radiation. Liquid argon (LAr) has similar properties but suffers of the intrinsic contamination of cosmogenic ^{39}Ar, though recently mitigated by the DarkSide collaboration.

DarkSide is a multi-stage program, begun in 2010 with the construction of DS-10, a 10-kg liquid argon (LAr) prototype detector. In 2012 APC joined the DarkSide collaboration, one year before DS-50 (Figure 73), with 50 kg target mass, was installed underground at LNGS, inside an active neutron veto based on a boron-loaded organic scintillator, in turn inside a 1000 ton water Cherenkov muon veto. The acquisition started in November 2013, with the detector filled with argon extracted from atmosphere (AAr), naturally exposed to cosmic rays, which produce ^{39}Ar by spallation on ^{40}Ar. The DarkSide collaboration solved the problem of such contamination by extracting underground argon (UAr) from a CO_2 well, ~2 km deep, and thus shielded against cosmogenic ^{39}Ar production. The residual contamination was measured by DS-50, with an analysis led by the APC team, to be about a factor 1400 lower than in AAr. In addition, LAr is intrinsically characterized by an extraordinary discrimination power ($>10^8$) between nuclear and electron recoils, exploiting the scintillation pulse shape. DS-50 probed the potential of LAr, operating with UAr: the outcome of the dark matter search is a null result with a ~20 ton-days exposure.[91] The discrimination (see Figure 74) between events induced by natural radioactivity and nuclear recoils – the potential candidate dark matter events – confirms once more that a future generation of multi-ton liquid argon detectors will also be able to operate completely free of background and in a real discovery mode. In addition, the analysis of very-low energy events in DS-50, to which APC has strongly contributed, has led to the world-best limits for masses below 6 GeV/c^2.[92]

Building on the successful experience of DS-50, the four world-leading argon dark matter projects (ArDM at LSC, DS-50 at LNGS, DEAP-3600 and MiniCLEAN at SNOLab) agreed on joining forces to carry out a unified program forming the Global Argon Dark Matter Collaboration (GADMC),

[91] P. Agnes et al. "DarkSide-50 532-day Dark Matter Search with Low-Radioactivity Argon". In: *Phys. Rev. D* 98.10 (2018), p. 102006. arXiv: 1802.07198 [astro-ph.CO].

[92] P. Agnes et al. "Low-Mass Dark Matter Search with the DarkSide-50 Experiment". In: *Phys. Rev. Lett.* 121.8 (2018), p. 081307. arXiv: 1802.06994.

for the next DarkSide phase, DS-20k, a dual-phase LAr TPC with an active (fiducial) mass of 23 ton (20 ton).[93] DS-20k has a highly innovative design: the TPC will be immersed in a 600 ton LAr bath, a solution that allows hosting the entire TPC in an ultra-pure acrylic vessel, and it will be equipped with ~15 m^2 of Silicon PhotoMultiplier (SiPM), characterized by higher radiopurity and lower material mass than PMT, very high quantum efficiency and fill factor (40% photodetection efficiency), low noise (0.1-1 Hz/mm^2), and high single-electron resolution.

[93] C. E. Aalseth et al. "DarkSide-20k: A 20 tonne two-phase LAr TPC for direct dark matter detection at LNGS". in: *Eur. Phys. J. Plus* 133 (2018), p. 131. arXiv: `1707.08145 [physics.ins-det]`.

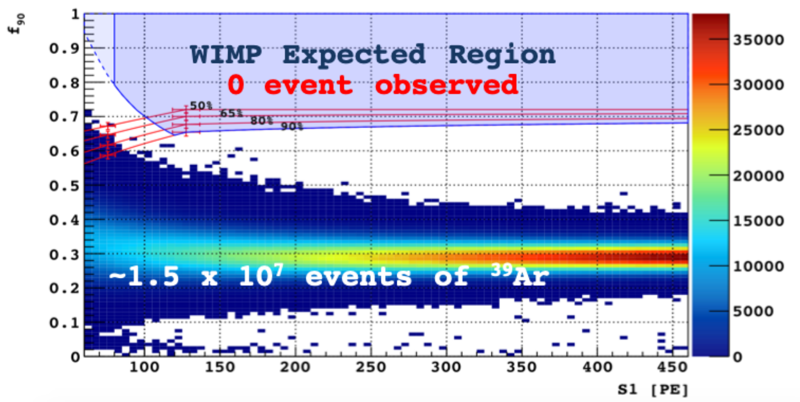

Figure 74: Discrimination of electronic background from ^{39}Ar β-decays with DS-50, filled with AAr. The scintillation pulse shape discrimination estimator (f_{90}), defined as the fraction of light detected in the first 90 ns, is shown as a function of the number of photoelectrons (S1). None of the approximately 1.5×10^7 events from ^{39}Ar leak into the region where WIMP-signals are expected.

Within DS-20k, the team is in charge of coordinating simulations, data reconstruction development, and sensitivity studies for dark matter search and for neutrino physics too, like the evaluation of the DS-20k potential in solar and core-collapse supernova neutrino detection. In addition, the team conceived ARIS (Argon Response Ionization and Scintillation), a small scale dual-phase LAr TPC which was exposed to interaction of neutrons produced by the ^{7}Li(p,^{7}Be)n reaction at the ALTO facility in Orsay. ARIS provided in 2018, among other results, the most accurate measurement of the nuclear recoil quenching factor in LAr.[94]

[94] P. Agnes et al. "Measurement of the liquid argon energy response to nuclear and electronic recoils". In: *Phys. Rev. D* 97.11 (2018), p. 112005.

Supporting grants

2020-23	Twinning European Project DarkWave
2018-21	Labex UnivEarth - PI : D. Franco
2020-22	IN2P3–COPIN - PI: D. Franco

Team

D. Franco, T. Hugues, M. Lai, J. Rode, A. Tonazzo

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Higgs

ATLAS and FCC

Since March 2021 a "Higgs" team, working on the measurement of the properties of the Higgs boson (H) with data from the ATLAS experiment at the Large Hadron Collider (LHC) at CERN and on the preparation of the Future Circular Collider (FCC), has joined the Neutrino (now Particles) group.

The Higgs boson plays a prominent role in the Standard Model (SM) of particle physics, explaining the spontaneous breaking of electroweak symmetry and the origin of the masses of elementary particles. Its role in theory and its atypical properties (notably its spin 0) make it a fundamental subject of study, that might also have potential cosmological implications.

The ATLAS experiment (Figure 75) is a multipurpose detector, 46 m long, 25 m high, weighing 7000 tonnes, located 100 m below ground around one of the collision points of the LHC's counter-rotating beams. It consists of six different detecting subsystems arranged concentrically, to record the momenta and directions of the particles produced in the collisions. The measured quantities are used to investigate a wide range of physics processes, such as strong interactions, electroweak production of W and Z bosons, top quark and Higgs boson properties, and to search for hypothetical phenomena beyond the Standard Model such as extra dimensions or dark matter particles. Since the beginning of the LHC data taking, our team has focused on the physics of the Higgs boson. It contributed to its discovery at LHC Run 1 (2010-2012) using its decays into two photons, and to the demonstration of its Yukawa couplings to the fermions of the SM through the observation of its decays into bottom quark pairs with data from Run 2 (2015-2018).

Since joining APC, our team has worked on the following analyses of the proton-proton (pp) collisions collected by ATLAS during Run2:

- The measurement of the Higgs boson production cross sections using the $H \to b\bar{b}$ and $H \to \gamma\gamma$ decays. The $H \to b\bar{b}$ decay has a large branching ratio (58%) but suffers from large background from QCD multihadron production, while the $H \to \gamma\gamma$ decay has small branching ratio (0.22%) but much lower backgrounds. The cross sections are measured as a function of several kinematic quantities which can be used to probe different Higgs production mechanisms and to look for deviations from the predictions of the SM. The $H \to b\bar{b}$ analysis is still ongoing and a publication is expected in late 2022, while the $H \to \gamma\gamma$ analysis was recently completed and the corresponding publication will appear in arXiv soon.

- The search for the production of pairs of Higgs bosons (HH). This process is the portal to measuring the Higgs boson self-coupling parameter λ and thus the potential of the Higgs boson. We focused on the search for di-Higgs production in the final state $b\bar{b}\gamma\gamma$, one of the two most sensitive ones, which combines the large branching ratio to $b\bar{b}$ for one Higgs boson with the good S/B of the $\gamma\gamma$ decay for the other.

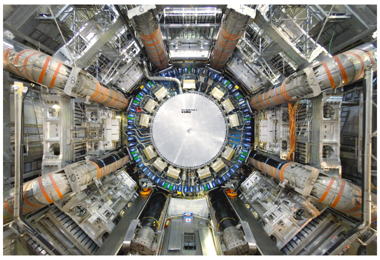

Figure 75: The ATLAS detector

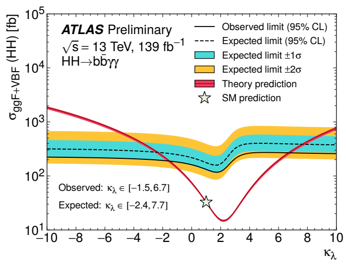

Figure 76: Observed and expected limits at 95% confidence level on the production cross section of non-resonant Higgs boson pairs as a function of the Higgs boson self-coupling modifier κ_λ. The theoretical prediction curve represents the scenario in which all the parameters and couplings are set to their SM values except for κ_λ

A preliminary analysis of the full ATLAS data from Run 2 released in spring 2021[95] found no excess compared to the background, and set an upper limit, with a confidence level (CL) of 95%, of 130 fb on the production cross section of $pp \to HH$ corresponding to 4.1 times the SM prediction. The result implies the following constraint on the Higgs boson self-coupling modifier $\kappa_\lambda = \lambda_{HHH}/\lambda_{HHH}^{SM}$: $-1.5 < \kappa_\lambda < 6.7$ at a 95% CL (see Fig. 76).

[95] ATLAS Collaboration. *Search for Higgs boson pair production in the two bottom quarks plus two photons final state in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector.* Tech. rep. ATLAS-CONF-2021-016. 2021. URL: http://cds.cern.ch/record/2759683.

The quality of the results of the ATLAS experiment requires proper functioning of the detector as well as a detailed understanding of the objects used in the analyses. During the period March-October 2021 our team focused on:

- The improvement of the performance of identification of prompt photons and of rejections of candidate photons coming either from the decay of a neutral meson in a hadronic shower, or from the electromagnetic shower initiated by an electron, for the future LHC data taking (Run 3, 2022-2025).
- The characterization of the reconstruction and tagging performance of jets of particles resulting from the hadronization of a b quark, with two *in situ* measurements of (i) the calibration of the energy scale of the b quark jets using $t\bar{t}$ events followed by a $t \to Wb \to qqb$ decay and the known top quark mass, and (ii) the efficiency of identifying a b-quark jet, using a fit to the momentum distribution of a muon in a jet relative to the axis of the jet+muon system.
- The measurement of radiation damage to the ATLAS tracker pixel sensors[96] and its implementation in the ATLAS detector simulation. With increasing luminosity radiation damage effects are not negligible, and it will be important to account for them in the simulations for the future LHC data taking phases.
- The construction and software development of the future silicon vertex detector ("ITk") of the ATLAS experiment for the high-luminosity phase of the LHC (HL-LHC). We have started to work on the development of the digitization code of the ITk ixel sensors, and we continue our collaboration with the other teams of the Paris region (IJCLab, CEA/Irfu, LPNHE) on the construction of the ITk pixel detector, having contributed to the market survey process of the various vendors of sensors and to the preparation of the next phase of pre-production and testing of modules (sensor + front-end chip + bonded flexible circuit glued and wire-bonded).

[96] I Dawson. *Radiation effects in the LHC experiments: Impact on detector performance and operation.* CERN Yellow Reports: Monographs. Geneva: CERN, 2021; ATLAS Collaboration. "Measurements of sensor radiation damage in the ATLAS inner detector using leakage currents". In: *JINST* 16 (2021), P08025. arXiv: 2106.09287 [hep-ex].

Finally, our team is also contributing to the development of the physics case of the electron-positron phase of the future circular collider (FCC-ee), a next-generation collider of about 100 km in length proposed to take over from the LHC (Fig. 77).

The FCC-ee offers unprecedented opportunities to determine Higgs boson parameters, with over 10^6 $e^+e^- \to ZH$ events and nearly 10^5 $WW \to H$ events produced at center-of-mass energies around 240 and 365 GeV and with a much lower background than at the LHC, and without pileup effects.

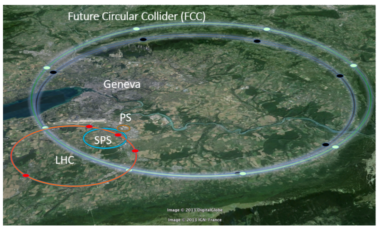

Figure 77: Illustration of the potential location of the Future Circular Collider at CERN, near Geneva. Also shown are the CERN PS, SPS and LHC rings, which would be part of the FCC injection and acceleration chain

Another advantage over the LHC is related to the complete knowledge of the kinematics of the colliding e^+e^- particles, which makes it possible to identify the ZH events with the "recoil mass" technique, reconstructing the products of the decays of the Z boson and therefore - thanks to the conservation of energy and total momentum - the mass of the system recoiling against the Z boson (Figure 78).

In spring 2021 we carried out first studies of the precision that FCC-ee could expect on the cross section of the ZH process and on the mass of the Higgs boson[97] and on its hadronic couplings (to b and c quarks and gluons), using signal and background noise events generated and interfaced to a parametric simulation of the detector response. These initial studies will be updated according to the different technologies and projects proposed for the FCC-ee detectors, optimizing the selection criteria and the fit strategies to further improve the sensitivity of the analysis, in view of a “Conceptual Design Report” by 2025 for the update of the European strategy for particle physics. This will mark the completion of the FCC-ee feasibility study, and allow CERN Council to decide whether the project can proceed with the start of the excavation of the FCC tunnel.

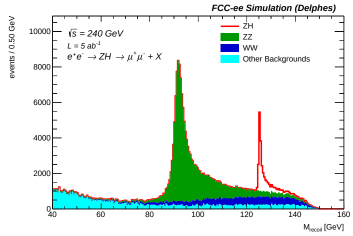

Figure 78: Inclusive m_{recoil} distribution for events with a Z boson decaying to $\mu^+\mu^-$, between 40 and 160 GeV. The peak near m_Z from the ZZ background and the peak near m_H from the ZH signal are well visible

[97] Paolo Azzurri et al. “A special Higgs challenge: Measuring the mass and production cross section with ultimate precision at FCC-ee”. In: *EPJ+ (in preparation)* (2021). arXiv: `2106.15438 [hep-ex]`.

Supporting grants

2021 Chaire Université de Paris “Installation Nouvelles Equipes” - G. Marchiori

Team

G. Bernardi, M. Bomben, R. Bouquet, A. Li, G. Marchiori, K. Nakkalil

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Other Activities

Low Energy Astrophysics with KM3NeT (LEAK)

The observation of astrophysical low energy (sub-GeV) neutrinos is crucial in order to characterize a wide range of transient phenomena, such as core-collapse supernovae (CCSN) or solar flares. The KM3NeT experiment, presented earlier, could play an essential role in studying these neutrinos; however its observational potential at low energy and its areas of complementarity with other telescopes is still underexplored. The LEAK project (funded by the LabEx UnivEarthS) aims at enhancing KM3NeT low-energy neutrino detection capabilities, and perform combined studies with other experiments APC is involved in, such as DUNE and DarkSide. Last year, this project involved 20 researchers from APC (12 people), AIM (CEA Saclay), LESIA, and LUTH. The team explored three main directions: noise modeling for the analysis of sub-GeV neutrinos in KM3NeT, synergies between KM3NeT and other experiments for core-collapse supernova studies, and detection of solar flares with KM3NeT.

The team carried out a study to characterize the main background sources for sub-GeV neutrino signals in KM3NeT, and proposed a prelimi-

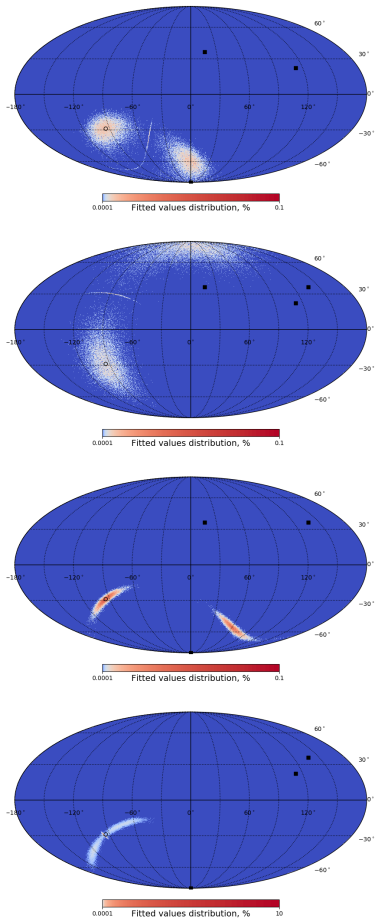

Figure 79: Mollweide projections of the 90% confidence areas obtained using triangulation for a CCSN located at the Galactic Center. From top to down: IceCube, KM3NeT/ARCA and JUNO; Hyper-Kamiokande, KM3NeT/ARCA and JUNO; IceCube, Hyper- Kamiokande and KM3NeT/ARCA; IceCube, Hyper-Kamiokande and JUNO

nary set of cuts to identify sub-GeV neutrinos and optimize the sensitivity to CCSN bursts. Since CCSN neutrinos carry unique information about the supernova mechanisms and neutrino properties, we also investigated how neutrino observations from KM3NeT could be combined with other experimental results, in collaboration with the DUNE and DarkSide teams at APC. As shown in Figure 79, we notably evaluated the potential of combining KM3NeT/ARCA with IceCube, JUNO, and Hyper-Kamiokande to locate CCSNs by triangulation. The combination of these four experiments provides a 90% confidence area of 140±20 deg^2. This study is currently continued in collaboration with the SNEWS and GRANDMA telescope networks, in order to maximize the probability to detect an electromagnetic counterpart following a supernova neutrino alert. Moreover, we showed that a combined analysis involving KM3NeT, DUNE, and DarkSide would allow to determine the neutrino mass hierarchy at more than 5σ for a supernova within 10 kpc. Finally, parallel to supernova analyses, we have performed a multi-wavelength analysis to identify solar flares most likely to have produced neutrinos, and hence most relevant for KM3NeT studies. This study allowed us to identify multiple groups of solar flares that are likely to involve similar processes.[98]

[98] A. Coleiro et al. "Combining neutrino experimental light-curves for pointing to the next galactic core-collapse supernova". In: *Eur. Phys. J. C* 80.9 (2020), p. 856. arXiv: 2003.04864 [astro-ph.HE].

Team

M. Bendahman, A. Coleiro, M. Colomer-Molla, J. Dawson, G. de Wasseige, D. Franco, A. Kouchner, T. Patzak, S. Sacerdoti, A. Tonazzo, V. van Elewyck, C. Volpe

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Mechanical Ventilator Milano

The COVID-19 pandemic is causing a rapidly increasing number of SARS-CoV-2 pathologies across the world, with severe pneumonia as a common and often deadly outcome. Effective medical intervention in this pathology requires the use of mechanical ventilation to pump oxygen into the lungs and then to remove carbon dioxide as the patient breathes out. To compensate for the dramatic shortage of such ventilators in many countries, a group of physicists and engineers, whose core originated from the DarkSide collaboration, designed and developed the Mechanical Ventilator Milano (MVM), inspired by the Manley ventilator, based on "*the possibility of using the pressure of the gases from the anaesthetic machine as the motive power for a simple apparatus to ventilate the lungs of the patients in the operating theatre*". MVM integrates advanced features designed by anesthesiologists participating in the project who work in the medical wards in Lombardy, one of the regions most severely hit by the COVID-19 epidemics. The design was optimized to permit large scale production in a short time and at a limited cost, relying on off-the-shelf components, and readily available worldwide from hardware suppliers.

Figure 80: The MVM apparatus. (Credits MVM)

The APC DarkSide team was involved in the project since its conception (end of March 2020), developing the framework for analyzing pressure and flow data from MVM, tested on the ALS-5000 mechanical breathing simulator. The team coordinated the analysis first for the optimization and then for the certification of the device. In just over six weeks, US FDA declared (May 1st) that the MVM falls within the scope of the Emergency Use Authorization for ventilators. This was followed a few months later by the Health Canada Approval for use under Interim Order.

Team

F. Ardellier, D. Franco, J. Rode

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Selected publications

Abi, Babak et al. “Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume I Introduction to DUNE”. In: *JINST* 15.08 (2020), T08008. arXiv: 2002.02967 [physics.ins-det].

Agnes, P. et al. “Low-Mass Dark Matter Search with the DarkSide-50 Experiment”. In: *Phys. Rev. Lett.* 121.8 (2018), p. 081307. arXiv: 1802.06994.

– “Measurement of the liquid argon energy response to nuclear and electronic recoils”. In: *Phys. Rev. D* 97.11 (2018), p. 112005.

– “Sensitivity of future liquid argon dark matter search experiments to core-collapse supernova neutrinos”. In: *JCAP* 03 (2021), p. 043. arXiv: 2011.07819 [astro-ph.HE].

Agostini, M. et al. “Comprehensive measurement of pp-chain solar neutrinos”. In: *Nature* 562.7728 (2018), pp. 505–510.

– “Experimental evidence of neutrinos produced in the CNO fusion cycle in the Sun”. In: *Nature* 587 (2020), pp. 577–582. arXiv: 2006.15115 [hep-ex].

Aiello, S. et al. “Combined sensitivity of JUNO and KM3NeT/ORCA to the neutrino mass ordering”. 2021. arXiv: 2108.06293 [hep-ex].

– “Determining the Neutrino Mass Ordering and Oscillation Parameters with KM3NeT/ORCA”. 2021. arXiv: 2103.09885 [hep-ex].

Aimard, B. et al. “Performance study of a 3×1×1 m3 dual phase liquid Argon Time Projection Chamber exposed to cosmic rays”. In: *JINST* 16.08 (2021), P08063. arXiv: 2104.08227 [physics.ins-det].

Kerret, H. de et al. “Double Chooz θ_{13} measurement via total neutron capture detection”. In: *Nature Phys.* 16.5 (2020), p. 558.

Theory

Resp: C. Volpe (2017) and D. Semikoz (2018-)

The theory group is composed by 15 permanent researchers of which 6 University researchers, 5 CNRS researchers and 4 Emeritus. The group has 5 associate researchers from other institutions, including H. Bergeron (ISMO Orsay), K. Noui (Tours U. now at IJCLab), U. Reinosa (Polytechnique), B. Van Tent (LPT Orsay), F. Vernizzi (IPhT Saclay). Before November 2017, C. Volpe was head of the group with D. Steer as deputy, and are now replaced by D.Semikoz and E. Huguet.

During 2017-2021 the group has supervised 16 PhD theses , 8 postdocs and 15 internships at different University levels (L3, M1, M2).

The research activities of the Theory group are centered on key open questions at the forefront of research in astroparticle physics, cosmology, gravitation, quantum field theories and its applications. The work focuses both on theoretical and on phenomenological aspects of fundamental interactions, some being closely related to international experimental projects and more generally to observations. The latter puts the theory group in close symbiosis with the experimental groups of the laboratory. Some group members are involved, or develop research, in close connection with experiments including LSST, Euclid, LISA, Virgo, CTA, KM3NeT, JEM-EUSO, JUNO.

String theory and holography

The holographic correspondence (or gauge/gravity duality) is today one of the most studied topics in the context of string theory and string-inspired phenomenology. It states that certain strongly coupled QFTs can be rephrased in terms of a weakly coupled gravitational theory defined on a curved, higher dimensional space-time.

In the past four years, E. Kiritsis, F. Nitti and collaborators have researched several aspects of the gauge/gravity duality, from formal developements to phenomenological applications, which are discussed below.

Self-tuning of the cosmological constant

The cosmological constant problem is the (theoretical) clash between the observed small value of the cosmological constant today (bounded by the observed large scale acceleration) and the very large value of the vacuum energy one would expect from effective field theory arguments. Ref.[99] proposed a framework, based on holography, that may solve this contradiction. Following this framework, our observed 4D universe is a dynamical defect (*brane*) embedded in a five-dimensional curved spacetime (*bulk*), as schematically represented in Fig. 81.

[99] C. Charmousis, E. Kiritsis, and F. Nitti. "Holographic self-tuning of the cosmological constant". In: *JHEP* 09 (2017), p. 031. arXiv: 1704.05075 [hep-th].

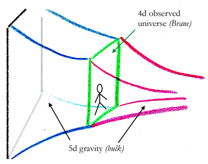

Figure 81: A schematic view of the holographic "braneworld" setup

The dynamics of the model leads, generically, to stabilization of the brane having *flat spacetime geometry* at a certain radial position in the bulk. The brane-localized vacuum energy curves the bulk geometry, but leaves the brane flat, thereby decoupling vacuum energy from 4d spacetime curvature.

Ref.[100] extends analysis to the possibility of brane-universes with a four-dimensional curved geometry (specifically, de Sitter or Anti-de Sitter). Ref.[101] includes the dynamics of the Higgs on the four-dimensional brane as well as an additional bulk pseudoscalar (*bulk axion*). In this work it was studied the interplay between brane-stabilisation, electroweak symmetry breaking and axion dynamics, and proposed a holographic version of the *relaxion* mechanism, which addresses the electroweak hierarchy problem.

[100] J. K. Ghosh et al. "De Sitter and Anti-de Sitter branes in self-tuning models". In: *JHEP* 11 (2018), p. 128. arXiv: 1807.09794 [hep-th].

[101] Y. Hamada et al. "The Self-Tuning of the Cosmological Constant and the Holographic Relaxion". In: *Fortsch. Phys.* 69.2 (2021), p. 2000098. arXiv: 2001.05510 [hep-th].

Holographic Renormalization Group of QFTs on curved manifolds

In gauge/gravity duality, the Quantum Field Theory (QFT) renormalization group (which describes how couplings evolve with scale) is given a geometric representation as evolution along a radial dimension of the higher-dimensional dual spacetime. In the past four years the nature of *holographic RG flows*, i.e. solutions of the bulk gravitational theory which are dual to field theory RG flows was systematically investigated by our team.

In this context, the paper[102] was the starting point of a systematic exploration of holographic RG flows of QFTs which themselves are defined on a curved (constant curvature) spacetime. This gave rise to a very general framework for analysing holographic field theories on curved spacetimes. Ref.[103] uses our result to construct possible F-functions (monotonic functions which are conjectured to interpolate between the *central charges* of a UV and an IR CFT) from the partition function on the sphere of a holographic QFT in 3D. Ref.,[104] uses the sphere RG flows to revisit vacuum decay between spacetimes with negative curvature (a question which is very important for the landscape of string vacua) and to study the existence and the holographic interpretation of the corresponding decay-mediating instanton solutions. In[105] our analysis was extended to QFTs defined on products of spheres.

Other works focused on flat-spacetime QFTs. In[106] and[107] RG flows for the QFT θ-parameter which, in four-dimensional gauge-theories, is the coupling constant associated to the instanton density operator $TrF\tilde{F}$ were considered. In[108] holographic RG flows with multiple bulk scalar fields (corresponding to multi-coupling flows in the QFT) was analysed and classified. In[109] finite-temperature effects and phase transitions in theories with "exotic" RG flows (which were found in previous work by the same authors in 2016) was considered.

[102] J. K. Ghosh et al. "Holographic RG flows on curved manifolds and quantum phase transitions". In: *JHEP* 05 (2018), p. 034. arXiv: 1711.08462 [hep-th].

[103] J. K. Ghosh et al. "Holographic RG flows on curved manifolds and the F-theorem". In: *JHEP* 02 (2019), p. 055. arXiv: 1810.12318 [hep-th].

[104] J. K. Ghosh et al. "Revisiting Coleman-de Luccia transitions in the AdS regime using holography". In: *JHEP* 09 (2021), p. 065. arXiv: 2102.11881 [hep-th].

[105] E. Kiritsis, F. Nitti, and E. Préau. "Holographic QFTs on $S^2 \times S^2$, spontaneous symmetry breaking and Efimov saddle points". In: *JHEP* 08 (2020), p. 138. arXiv: 2005.09054 [hep-th].

[106] Y. Hamada et al. "Axion RG flows and the holographic dynamics of instanton densities". In: *J. Phys. A* 52.45 (2019), p. 454003.

[107] Y. Hamada et al. "Holographic Theories at Finite θ-Angle, CP-Violation, Glueball Spectra and Strong-Coupling Instabilities". In: *Fortsch. Phys.* 69.2 (2021), p. 2000111.

[108] F. Nitti et al. "On multi-field flows in gravity and holography". In: *JHEP* 07 (2018), p. 022.

[109] Umut Gürsoy et al. "Exotic holographic RG flows at finite temperature". In: *JHEP* 10 (2018), p. 173.

Holography and cosmology

Applications of the aforementioned works in the cosmological setting have been particularly interesting. In[110] the cosmological evolution of the brane was explored when displaced out of equilibrium. In[111] holography and the results of[112] were used to investigate the (non-perturbative) fate of de Sitter spacetime when the latter is generated by a strongly-coupled conformal field theory coupled to four-dimensional gravity.

[110] A. Amariti et al. "Brane cosmology and the self-tuning of the cosmological constant". In: *JCAP* 10 (2019), p. 007. arXiv: 1904.02727 [hep-th].

[111] J. K. Ghosh et al. "Back-reaction in massless de Sitter QFTs: holography, gravitational DBI action and $f(R)$ gravity". In: *JCAP* 07 (2020), p. 040. arXiv: 2003.09435 [hep-th].

[112] Ghosh et al., "Holographic RG flows on curved manifolds and quantum phase transitions".

Emergent gravity

The AdS/CFT correspondence has revived and justified old ideas in which gravity is an effective low-energy theory of a different high-energy ordinary QFT, and the graviton is a composite of the high-energy degrees of freedom. This has been studied in general by E. Kiritsis and external collaborators, and several properties of emergent gravity were established.[113]

In particular, the generalized gravitational interaction although it generically contains 6 degrees of freedom instead of the standard two for a massless graviton, is positive definite and healthy. The graviton is either part of a continuum or is massive, but in holographic theories, its mass can be made arbitrarily small. It is always accompagnied by a dilaton that poses a threat to the equivalence principle as in string theory.

Emergent gravity is a bimetric theory, as apart from the fluctuating metric, it depends on the fiducial metric in which the generating QFT is defined. This has the remarkable consequence, that if this metric is flat, then a flat metric is always a solution of the emergent gravity theory, independent of quantum corrections, a first step towards solving the cosmological constant problem. The dual description of this setup is the holographic bulk/brane models, that were investigated earlier by the team, and it agrees with the self-tuning mechanism found there.

[113] P. Anastasopoulos et al. “Emergent/Composite axions”. In: *JHEP* 10 (2019), p. 113. arXiv: 1811.05940 [hep-ph]; P. Betzios et al. “Global symmetries, hidden sectors and emergent (dark) vector interactions”. In: *JHEP* 12 (2020), p. 053. arXiv: 2006.01840 [hep-ph]; P. Betzios, E. Kiritsis, and V. Niarchos. “Emergent gravity from hidden sectors and TT deformations”. In: *JHEP* 02 (2021), p. 202. arXiv: 2010.04729 [hep-th].

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Quantum Field theory

QFT in curved spacetime

In the past four years, works about classical and quantum fields in curved spacetimes was continued. It was obtained from what is sometimes called "conformal space", that is the $d+2$ dimensional space of reals endowed with the metric invariant under the conformal group $\mathrm{SO}(d,2)$, denoted $\mathbb{R}^{d+2}$. The main idea is that the field equations are somehow simpler in $\mathbb{R}^{d+2}$. A formalism in which the spacetime is realized as the intersection of the null cone of $\mathbb{R}^{d+2}$ and a hyper-surface was developed.

The restriction from the conformal to the Robertson-Walker spacetime of the Laplace-Beltrami operator for scalar field was obtained in work with J. P. Arias Zappata, A. Belokogne (respectively intern and post-doc in 2017) and J. Quéva (Université de Corse).[114] We also showed, with J. Quéva, how field equations for scalar fields (massive or not) on (Anti)-de Sitter

[114] J. P. Arias Zapata et al. “Friedmann-Lemaitre-Robertson-Walker spaces as submanifolds of $\mathbb{R}^6$: Restriction to the Klein-Gordon operator”. In: *J. Math. Phys.* 58.11 (2017), p. 113503. arXiv: 1711.10771 [math-ph].

space can obtained from "massless" conformal scalar in $\mathbb{R}^{d+2}$ and the constraints defining the space.[115]

In parallel, our team has developed specific Wilsonian renormalisation group tools to address the question of nonperturbative infrared fluctuations of quantum fields in de Sitter space, of direct relevance to inflationary cosmology.[116] In[117] and,[118] we have applied these tools to compute the backreaction of scalar fields on the geometry through self-consistent semi-classical Einstein equations. We have shown that the apparent instability of de Sitter space predicted by perturbation theory, proposed as a possible explanation of the cosmological constant problem in earlier literature, is in fact screened by nonperturbative effects in the case of scalar fields. The de Sitter space is stable against quantum fluctuations of such fields.

Team

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Dynamics of strong interactions and confinement

Since 2010, our group develops, together with collaborators at Sorbonne Universités (M. Tissier), Ecole Polytechnique (U. Reinosa) and University of Montevideo (M. Pelaez and N. Wschebor), a novel approach to describe the infrared regime of non-Abelian Yang-Mills theories and of QCD, based on a modified perturbation theory in the Landau gauge, the perturbative Curci-Ferrari model. The approach allows to successfully reproduce various results from numerical lattice simulations, both in vacuum[119] and at nonzero temperature and chemical potential.[120] For instance, a simple one-loop calculation in our approach gives an accurate description of the confinement-deconfinement transition in Yang-Mills theories and of the temperature dependence of the order parameter of the transition (the Polyakov loop).[121] In the period 2017-2021, we have applied our approach to treat the quark sector of QCD. We have computed the phase diagram of QCD-like theories with heavy quarks at one[122] and two-loop[123] orders, in very good agreement with lattice results.

In Ref.[124] and,[125] we have further developed the approach to deal with (realistic) light quark dynamics, which requires a proper description of the dynamical breaking of chiral symmetry. Combining our perturbative approach in the pure gauge sector and the t'hooft expansion in the inverse number of colors, we have proposed a novel systematic, controlled approximation scheme to describe the infrared regime of QCD. Our results for the quark propagator at leading order in this expansion compares very well with lattice simulations, down to the deep infrared, where the spontaneous breaking of chiral symmetry results in the dynamical generation of the constituent quark mass. The perturbative Curci-Ferrari approach to QCD has been and its many results have been described in detail in a recent review.[126]

[115] E. Huguet, J. Queva, and J. Renaud. "Massive scalar field on (A)dS space from a massless conformal field in $\mathbb{R}^6$". In: *J. Math. Phys.* 61.5 (2020), p. 053506. arXiv: 1606.07611 [gr-qc].

[116] Maxime Guilleux and Julien Serreau. "Nonperturbative renormalization group for scalar fields in de Sitter space: beyond the local potential approximation". In: *Phys. Rev. D* 95.4 (2017), p. 045003. arXiv: 1611.08106 [gr-qc].

[117] G. Moreau and J. Serreau. "Stability of de Sitter spacetime against infrared quantum scalar field fluctuations". In: *Phys. Rev. Lett.* 122.1 (2019), p. 011302. arXiv: 1808.00338 [hep-th].

[118] G. Moreau and J. Serreau. "Backreaction of superhorizon scalar field fluctuations on a de Sitter geometry: A renormalization group perspective". In: *Phys. Rev. D* 99.2 (2019), p. 025011. arXiv: 1809.03969 [hep-th].

[119] U. Reinosa et al. "How nonperturbative is the infrared regime of Landau gauge Yang-Mills correlators?" In: *Phys. Rev. D* 96.1 (2017), p. 014005. arXiv: 1703.04041 [hep-th].

[120] U. Reinosa et al. "Yang-Mills correlators across the deconfinement phase transition". In: *Phys. Rev. D* 95.4 (2017), p. 045014. arXiv: 1606.08012 [hep-th].

[121] D. M. van Egmond et al. *A novel background field approach to the confinement-deconfinement transition.* 2021. arXiv: 2104.08974 [hep-ph].

[122] J. Maelger et al. "Universal aspects of the phase diagram of QCD with heavy quarks". In: *Phys. Rev. D* 98.9 (2018), p. 094020. arXiv: 1805.10015 [hep-th].

[123] J. Maelger et al. "Perturbative study of the QCD phase diagram for heavy quarks at nonzero chemical potential: Two-loop corrections". In: *Phys. Rev. D* 97.7 (2018), p. 074027. arXiv: 1710.01930 [hep-ph].

[124] M. Peláez et al. "Small parameters in infrared quantum chromodynamics". In: *Phys. Rev. D* 96.11 (2017), p. 114011. arXiv: 1703.10288 [hep-th].

[125] M. Peláez et al. "Spontaneous chiral symmetry breaking in the massive Landau gauge: realistic running coupling". In: *Phys. Rev. D* 103.9 (2021), p. 094035. arXiv: 2010.13689 [hep-ph].

[126] M. Peláez et al. "A window on infrared QCD with small expansion parameters". In: (June 2021). arXiv: 2106.04526 [hep-th].

Finally, we have investigated the possible origin of the dynamically generated gluon mass observed in lattice simulations in the Landau gauge in relation with the issue of Gribov ambiguities when fixing the gauge in non-Abelian theories. We have proposed a gauge fixing that properly accounts for the Gribov copies (unlike the standard Faddeev-Popov approach) and where a gluon mass is dynamically generated through a mecanism of symmetry restauration similar to what happens in the nonlinear sigma model.[127]

[127] U. Reinosa et al. "Symmetry restoration and the gluon mass in the Landau gauge". In: *SciPost Phys.* 10.2 (2021), p. 035. arXiv: 2004.12413 [hep-th].

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Quantum: formalism, mechanics and field

Over the last five years J.-P. Gazeau developed his research along five directions. The term "Quantum" is a common leitmotiv:

1. Covariant integral quantization of various classical systems and applications to models of early cosmology (FRW, Bianchi I, Bianchi 9 and Mixmaster model) with regularisation of models presenting singularities in their classical versions.

   Covariant integral quantizations linearly transform functions ("classical observables") on phase spaces (in a wider sense) into operators "quantum observables") on some Hilbert spaces of "quantum states". They are based on the resolution of the identity by continuous or discrete families of normalised positive operator valued measures (POVM) which transform in a covariant way under some symmetry group actions. In the simplest cases these symmetries are described by the Weyl-Heisenberg group (projective representations of translations in 2d dimensions), or by the affine groups (translations of a subset of variables combined with dilations of the remnant subset of bounded below variables). Starting from (quasi-) probability distribution(s) on the phase spaces on which the Weyl-Heisenberg or affine groups are acting (classical Hamiltonian models) these quantizations yield their corresponding quantum models and associated probabilities (e.g. Husimi) or quasi-probabilities (e.g. Wigner) distributions. In return the tracing of the involved POVM with the operators provides semi-classical portraits of the quantum models which a regularization of the original classical model. These quantization methods whose the origin can be traced back to Klauder, Berezin, Toepiltz, are relatively easy to manipulate when compared with geometric or deformation or other quantizations. As a matter of fact they allow to circumvent the problems of ordering (canonical quantization), or those due to the presence of singularities in the classical models. Three pedagogical presentations of the method were given in.[128]

   There are multiple developments and applications of the method:

[128] Hervé Bergeron et al. "Orientations in the Plane as Quantum States". In: *Brazilian Journal of Physics* 49 (2019), pp. 391–401.

(a) Motions on the half line and on the punctured plane and the fundamental role of the affine symmetries in their quantum regularisation[129]

(b) Quantum motion on the circle , on hyperbolic geometry , on other constrained geometries with variable mass[130]

(c) Regularised quantum FRW and Mixmaster models for early cosmology and gravitational waves[131]

2. Quantum field theory in de Sitter space-time, and cosmological implications. These works lie in the continuation of a long-lasting program, initiated more that 25 years ago, for establishing a rigorous covariant quantum field theory in de Sitter space-time[132]

3. A new interpretation of the Cold Dark Matter viewed as a gluonic Bose-Einstein condensate emerging from the transition QGP-Hadrons, based on QCD and Anti-de-Sitter symmetry due to the positive curvature provided by the QGP conformal anomaly[133]

4. Works on generalised coherent states, POVM and Helstrom bound for quantum communication[134]

5. Quantum formalism and information, and other works[135]

[129] Jean Pierre Gazeau, Tomoi Koide, and Romain Murenzi. "2-D Covariant Affine Integral Quantization(s)". In: (Nov. 2019). arXiv: 1911.00578 [math-ph].

[130] Jean-Pierre Gazeau et al. "Quantum and semi-classical aspects of confined systems with variable mass". In: *J. Phys. A* 53.50 (2020), p. 505306. arXiv: 2005.14231 [quant-ph].

[131] Hervé Bergeron et al. "Integrable Toda system as a quantum approximation to the anisotropy of the mixmaster universe". In: *Phys. Rev. D* 98.8 (2018), p. 083512. arXiv: 1802.04662 [gr-qc].

[132] Hamed Pejhan et al. "Massive Rarita-Schwinger field in de Sitter space". In: *Phys. Rev. D* 100.12 (2019), p. 125022. arXiv: 1909.13450 [gr-qc].

[133] Gilles Cohen-Tannoudji and Jean-Pierre Gazeau. "Cold Dark Matter: A Gluonic Bose–Einstein Condensate in Anti-de Sitter Space Time". In: *Universe* 7.11 (2021), p. 402. arXiv: 2111.01130 [gr-qc].

[134] Jean-Pierre Gazeau et al. "Generalized Susskind–Glogower coherent states". In: *Journal of Mathematical Physics* 62.7 (2021), p. 072104. arXiv: 2011.10303v1 [quant-ph].

[135] Roberto Beneduci et al. "Real POVMS on the plane: integral quantization, Naimark theorem and linear polarization of the light". In: (2021). arXiv: 2108.04086v2 [quant-ph].

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Cosmology

Early-universe cosmology

In the past four years, different aspects of primordial cosmology have been investigated.

Recent observations of the gravitational waves emitted by black-hole mergers, together with the apparent persistence of unsolved questions in Cosmology (ranging from the origin of dark matter to the seeding of supermassive black holes in galactic nuclei) have made Primordial Black Holes (PBHs) the subject of increasing attention. If they arise from large quantum fluctuations produced in the early universe, they provide an unprecedented opportunity to constrain the physics at play during the early epoch of cosmic inflation, where the universe underwent a period of accelerated expansion. Since they require large cosmological perturbations to form, they also require to understand physical regimes where quantum backreaction plays an important role in shaping the dynamics of the early universe.

This is why V. Vennin and collaborators have developed the so-called "stochastic-δN formalism",[136] in which the backreaction of quantum fluctuations onto the expanding background is accounted for in a stochastic

[136] Vincent Vennin and Alexei A. Starobinsky. "Correlation Functions in Stochastic Inflation". In: *Eur. Phys. J. C* 75 (2015), p. 413. arXiv: 1506.04732 [hep-th].

effective theory, and the statistics of the resulting cosmological fluctuations can be obtained by solving a first-passage time problem. This has led to the discovery that the distribution function of these perturbations have heavy exponential tails,[137] that deviate from Gaussian statistics in a non-perturbative way, and which drastically change the expected abundance of PBHs in inflationary models.

[137] Chris Pattison et al. "Quantum diffusion during inflation and primordial black holes". In: *JCAP* 10 (2017), p. 046. arXiv: 1707.00537 [hep-th].

Fundamental aspects of the stochastic formalism have also been studied by J. Grain (associate to APC) and V. Vennin, who developed the required tools to extend the formalism to contracting phases, and by J. Serreau and G. Moreau (PhD), who used specific QFT techniques to compute various nontrivial observables.

The amplification mechanism that gave rise to PBHs can also take place after inflation, for instance during the phase where the inflaton oscillates at the bottom of its potential. These oscillations trigger a parametric resonant instability in the dynamics of the density contrast (a mechanism known as "metric preheating"), which may eventually collapse into PBHs. This mechanism has been studied by T. Papanikolaou (PhD student at APC between 2018 and 2021) and V. Vennin,[138] and a detailed calculation of the mass fraction of PBHs in this scenario has been obtained by P. Auclair (PhD student at APC over the same period) and V. Vennin. These studies have shown that metric preheating is very efficient at producing ultra-light PBHs, such that the universe could have undergone a period dominated by ultra-light PBHs, before they Hawking evaporate, thereby reheating the Universe. D. Langlois, T. Papanikolaou and V. Vennin have investigated the background of gravitational waves that would be induced by such a PBHs-dominated phase.[139]

[138] Jérôme Martin, Theodoros Papanikolaou, and Vincent Vennin. "Primordial black holes from the preheating instability in single-field inflation". In: *JCAP* 01 (2020), p. 024. arXiv: 1907 . 04236 [astro-ph.CO].

[139] Theodoros Papanikolaou, Vincent Vennin, and David Langlois. "Gravitational waves from a universe filled with primordial black holes". In: *JCAP* 03 (2021), p. 053. arXiv: 2010.11573 [astro-ph.CO].

According to the standard cosmological paradigm, cosmological fluctuations originate from the gravitational amplification of quantum fluctuations in the early universe. Although this framework provides predictions in excellent agreement with the data, it raises a number of fundamental issues, such as the validity of the prescription for quantising metric fluctuations, or the emergence of a classical, single configuration for the universe out of a quantum superposition of different states (this is the so-called "meassurement problem" of quantum mechanics, which becomes more severe in the cosmological context since no exterior observer can be identified). This has led V. Vennin and collaborators to work on possible experimental signatures of the quantum origin of cosmological structures.[140] Extending tools developed in quantum information theory (such as quantum discord, generalised Bell inequalities, etc) to the realm of quantum cosmological fields, new approaches have thus been proposed to better describe (and hopefully reveal) genuine quantum properties of the primordial fluids. In the same vein, Cosmology can be used to further constrain quantum mechanics and some of its alternative formulations. In particular, V. Vennin and collaborators have shown that models for the dynamical collapse of the wavefunction, which incorporate non-linear extension to the Schrödinger equation, lead to predictions that are ruled out by current measurements of the cosmic microwave background, at least in their current formulation.[141]

[140] Jerome Martin and Vincent Vennin. "Quantum Discord of Cosmic Inflation: Can we Show that CMB Anisotropies are of Quantum-Mechanical Origin?" In: *Phys. Rev. D* 93.2 (2016), p. 023505. arXiv: 1510.04038 [astro-ph.CO].

[141] Jérôme Martin and Vincent Vennin. "Cosmic Microwave Background Constraints Cast a Shadow On Continuous Spontaneous Localization Models". In: *Phys. Rev. Lett.* 124.8 (2020), p. 080402. arXiv: 1906.04405 [quant-ph].

Although inflation is often described by a single scalar field, given that it is enough to account for cosmological observations, more degrees of freedom are expected to play a role at the high energies at which inflation proceeds. Those may result into environmental effects such as quantum decoherence, which V. Vennin and collaborators have studied through effective techniques (Lindblad and master equations, etc). In particular, they have identified relevant regimes where decoherence proceeds without substantially affecting the observables of the system.[142]

[142] Jerome Martin and Vincent Vennin. "Observational constraints on quantum decoherence during inflation". In: *JCAP* 05 (2018), p. 063. arXiv: 1801.09949 [astro-ph.CO].

Finally, our group has developed QFT techniques to analytically compute the spectrum of the Fokker-Planck operator in the stochastic formalism that describes the effective infrared dynamics of long wavelength fluctuations of quantum scalar fields. The work[143] uses a supersymmetric formulation of the stochastic dynamics and computes the lowest eigenvalues, of relevance to various observables of cosmological interest (power spectrum, autocorrelation length/time, decoherence, etc.) both in perturbation theory and in a nonperturbative $1/N$ expansion, where N is the number of scalar fields. In,[144] we develop specifically the $1/N$ expansion for the stochastic theory in terms of the Fokker-Planck equation and we obtain the complete spectrum in closed analytical form both at leading and next-to-leading orders.

[143] G. Moreau and J. Serreau. "Unequal Time Correlators of Stochastic Scalar Fields in de Sitter Space". In: *Phys. Rev. D* 101.4 (2020), p. 045015. arXiv: 1912.05358 [hep-th].

[144] G. Moreau and J. Serreau. "The $1/N$ expansion for stochastic fields in de Sitter spacetime". In: *Phys. Rev. D* 102 (2020), p. 125015. arXiv: 2004.09157 [hep-th].

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Dark energy and modified gravity

Most of the dark energy models are based on scalar-tensor theories. It is thus natural to consider dark energy in the most general framework of scalar-tensor theories with a single scalar degree of freedom, known as Degenerate Higher-Order Scalar-Tensor (DHOST) theories, discovered by D. Langlois and K. Noui.[145]

[145] D. Langlois. "Dark energy and modified gravity in degenerate higher-order scalar–tensor (DHOST) theories: A review". In: *Int. J. Mod. Phys. D* 28.05 (2019), p. 1942006. arXiv: 1811.06271 [gr-qc].

If one takes into account the constraint on the speed of gravitational waves from the binary neutron star merger GW170817, observed via both gravitational and electromagnetic waves, one obtains severe restrictions on DHOST theories.[146] Cosmological models within this restricted subclass of theories have been explored.[147]

[146] David Langlois et al. "Scalar-tensor theories and modified gravity in the wake of GW170817". In: *Phys. Rev. D* 97.6 (2018), p. 061501. arXiv: 1711.07403 [gr-qc].

[147] M. Crisostomi et al. "Cosmological evolution in DHOST theories". In: *JCAP* 01 (2019), p. 030. arXiv: 1810.12070 [hep-th].

One can also adopt the viewpoint that gravitational waves from GW170817 correspond to a scale of order 1000 km, much smaller than cosmological scales, and therefore does not necessarily apply to dark energy models. Relaxing the constraints on the speed of gravitational waves, the phenomenology of dark energy models is much richer. Ref.[148] provides an example where the transition between a matter-dominated era and a phase of accelerated expansion can be studied.

[148] Hamza Boumaza, David Langlois, and Karim Noui. "Late-time cosmological evolution in degenerate higher-order scalar-tensor models". In: *Phys. Rev. D* 102.2 (2020), p. 024018. arXiv: 2004.10260 [astro-ph.CO].

An important ingredient for the viability of dark energy models is the linear stability of the background solution. In order to examine this aspect, we have extended the framework of the Effective Theory of Dark Energy to

DHOST theories,[149] thus providing a powerful tool to study cosmological perturbations within a vast class of dark energy models.

[149] David Langlois et al. "Effective Description of Higher-Order Scalar-Tensor Theories". In: *JCAP* 05 (2017), p. 033. arXiv: 1703.03797 [hep-th].

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Gravity and cosmology

2015 saw the first observation of gravitational waves from a binary black hole merger event by the LIGO/Virgo Collaborations. Since then, the LIGO-Virgo-Kagra collaboration has finished its third observing run, and has detected about 50 gravitational-wave events. These include binary neutron stars — of which one, GW170817, was also observed in electromagnetic radiation — neutron-star black-hole binaries, and finally numerous black-hole binaries. This has enabled many tests of the gravitational interaction and of cosmology, such as tests of General Relativity, the measurement of the Hubble factor today, and constraints on different early universe phenomena.

The science case of the Laser Interferometer Space Antenna (LISA), which will fly in ~ 2034, is very rich, spanning from astrophysics, to fundamental physics, to cosmology. We work on several aspects of the science that can be done with LISA. In particular, LISA has a great potential to provide cosmological tests. It can detect a stochastic gravitational wave background (SGWB) from the primordial Universe (which can be sourced e.g. by inflation, phase transitions, topological defects, primordial black holes), which would furnish unique information about the status of the primordial Universe and help discriminating among model. The gravitational-wave signal from compact binaries measured by LISA (e.g. massive black hole binaries) can also be used to probe the redshift-distance relationship and determine cosmological parameters, either in combination with the coincident detection of an electromagnetic counterpart, or through statistical identification of the binary host galaxy.

Gravitational waves

The research of our group mainly focuses on probing cosmology with gravitational waves, both with the present data from the LIGO/Virgo collaboration, and providing forecasts for future gravitational-wave observatories, in particular LISA (see also[150,151]).

C. Caprini wrote an important and timely review on the stochastic background of gravitational waves (SGWB) of cosmological origin,[152] which is already a reference for this area of physics. She also worked extensively on the science case of LISA, for instance on the ability of LISA to detect a SGWB from a first order electroweak phase transition in the early universe.[153] The electroweak energy scale corresponds indeed to the mHz frequency range, detectable by LISA, and the measurement of a SGWB signal generated at electroweak phase transition epoch in the

[150] Manuel Arca Sedda et al. "The missing link in gravitational-wave astronomy: discoveries waiting in the decihertz range". In: *Class. Quant. Grav.* 37.21 (2020), p. 215011. arXiv: 1908.11375 [gr-qc].

[151] Alberto Sesana et al. "Unveiling the gravitational universe at μ-Hz frequencies". In: *Exper. Astron.* 51.3 (2021), pp. 1333–1383. arXiv: 1908.11391 [astro-ph.IM].

[152] Chiara Caprini and Daniel G. Figueroa. "Cosmological Backgrounds of Gravitational Waves". In: *Class. Quant. Grav.* 35.16 (2018), p. 163001. arXiv: 1801.04268 [astro-ph.CO].

[153] Chiara Caprini et al. "Detecting gravitational waves from cosmological phase transitions with LISA: an update". In: *JCAP* 03 (2020), p. 024. arXiv: 1910.13125 [astro-ph.CO].

early universe would bring invaluable information on the fundamental theory describing the universe at this scale, opening up interesting connections with beyond the Standard Model physics, baryogenesis, and dark matter candidates. Exploiting this amazing discovery potential for LISA resides however on the possibility to disentangle the SGWB from other astrophysical foregrounds and from the detector noise.[154]

[154] Chiara Caprini et al. "Reconstructing the spectral shape of a stochastic gravitational wave background with LISA". in: *JCAP* 11 (2019), p. 017. arXiv: 1906.09244 [astro-ph.CO].

LISA can also be used to probe late-universe cosmology, and in particular its background acceleration. Together with A. Mangiagli, we work on forecasting the ability of LISA to constrain cosmological parameters via coincident observation of the gravitational-wave emission from massive black hole binaries coalescence and of the EM emission associated to the merger and/or to the host galaxy. This entails performing accurate parameter estimation of the binary waveform (to get the luminosity distance and sky-position of the binary) and constructing models for the electromagnetic counterpart at several frequencies (optical, radio, X-ray) as well as building counterparts detection strategies adapted to the different telescopes (LSST, ELT, SKA, ATHENA).

D.A. Steer has worked extensively on the signatures of cosmic strings (a type of topological defect) in gravitational wave, both at LISA and LIGO/Virgo frequencies. In particular, together with PhD student Pierre Auclair, and using latest data from LIGO/Virgo, the most up-to-date constraints on cosmic strings are found in.[155] Constraints at LISA frequencies were studied in.[156]

[155] R. Abbott et al. "Constraints on Cosmic Strings Using Data from the Third Advanced LIGO–Virgo Observing Run". In: *Phys. Rev. Lett.* 126.24 (2021), p. 241102. arXiv: 2101.12248 [gr-qc].

[156] Pierre Auclair et al. "Probing the gravitational wave background from cosmic strings with LISA". in: *JCAP* 04 (2020), p. 034. arXiv: 1909.00819 [astro-ph.CO].

D.A. Steer has also contributed a number of theoretical developments on the subject of cosmic strings. Of particular note is the joint constraint on cosmic strings from both gravitational wave and γ-ray observations.[157]

[157] Pierre Auclair, Danièle A. Steer, and Tanmay Vachaspati. "Particle emission and gravitational radiation from cosmic strings: observational constraints". In: *Phys. Rev. D* 101.8 (2020), p. 083511. arXiv: 1911.12066 [hep-ph].

D.A. Steer has also been involved in the work of the LIGO/Virgo collaboration centered on measuring cosmological parameters with gravitational wave. In particular, together with members of the gravitation group, she contributed to the first measurement of the Hubble constant H_0 using GW170817.[158] Finally, amongst our main results are constraints on modified theories of gravity using gravitational-wave observations.[159]

[158] B. P. Abbott et al. "A gravitational-wave standard siren measurement of the Hubble constant". In: *Nature* 551.7678 (2017), pp. 85–88. arXiv: 1710.05835 [astro-ph.CO].

[159] S. Mastrogiovanni, D. Steer, and M. Barsuglia. "Probing modified gravity theories and cosmology using gravitational-waves and associated electromagnetic counterparts". In: *Phys. Rev. D* 102.4 (2020), p. 044009. arXiv: 2004.01632 [gr-qc].

Modified gravity

We have studied modified gravity in the context of Degenerate Higher-Order Scalar-Tensor (DHOST) theories. These theories can be considered for dark energy, as discussed earlier, but they can also describe, with a different set of parameters, modified gravity in astrophysical bodies.

We have investigated some DHOST models in neutron stars in,[160] showing in particular that one can obtain a higher maximal mass than in general relativity, with the same equation of state for nuclear matter. We have also analysed linear perturbations of stealth Kerr black holes.[161]

[160] Jeremy Sakstein et al. "Towards Strong Field Tests of Beyond Horndeski Gravity Theories". In: *Phys. Rev. D* 95.6 (2017), p. 064013. arXiv: 1612.04263 [gr-qc].

[161] C. Charmousis et al. "Perturbations of a rotating black hole in DHOST theories". In: *Class. Quant. Grav.* 36.23 (2019), p. 235008. arXiv: 1907.02924 [gr-qc].

More recently we have studied the linear perturbations of black holes in DHOST theories, by introducing a new analytical approach to obtain the asymptotic behaviour of metric and scalar perturbations at spatial infinity and near the horizon. This enables us to identify the boundary conditions that define quasi-normal modes and, in principle, to compute numerically their (complex) frequencies.[162]

[162] D. Langlois, K. Noui, and H. Roussille. *Black hole perturbations in modified gravity*. 2021. arXiv: 2103.14750 [gr-qc]; D. Langlois, K. Noui, and H. Roussille. *Asymptotics of linear differential systems and application to quasi-normal modes of nonrotating black holes*. 2021. arXiv: 2103.14744 [gr-qc].

We have shown that so-called mimetic theories, introduced by Chamseddine and Mukhanov, can be seen as a particular subset of DHOST theories.[163] In a similar vein, DHOST theories can be useful to effectively recover some results of loop quantum cosmology.[164]

Beyond DHOST theories, we have investigated theories at the "boundary" of DHOST theories: these theories, which we named U-DHOST theories, are degenerate only in the unitary gauge (where the scalar field is uniform) and contain a second scalar degree of freedom, which however does not propagate and can be described as instantaneous.[165]

Ref.[166] explores metric theories described by Lagrangians that contain up to second-order derivatives of the metric, as well as scalar-tensor theories involving couplings between the Riemann tensor and first or second-order derivatives of a scalar field. We used the criterium of degeneracy to select viable theories.

More recently,[167] we have presented quadratic DHOST theories in a novel and remarkably simple formulation, using disformal transformations to rewrite the Lagrangian as the sum of an Einstein-Hilbert term and a few simple geometrical quantities characterising the uniform scalar field hypersurfaces.

[163] D. Langlois et al. "Mimetic gravity as DHOST theories". In: *JCAP* 02 (2019), p. 036. arXiv: 1802.03394 [gr-qc].

[164] David Langlois et al. "Effective loop quantum cosmology as a higher-derivative scalar-tensor theory". In: *Class. Quant. Grav.* 34.22 (2017), p. 225004. arXiv: 1703.10812 [gr-qc].

[165] Antonio De Felice et al. "Generalized instantaneous modes in higher-order scalar-tensor theories". In: *Phys. Rev. D* 98.8 (2018), p. 084024. arXiv: 1803.06241 [hep-th].

[166] M. Crisostomi et al. "Beyond Lovelock gravity: Higher derivative metric theories". In: *Phys. Rev. D* 97.4 (2018), p. 044034. arXiv: 1710.04531 [hep-th].

[167] David Langlois, Karim Noui, and Hugo Roussille. "Quadratic degenerate higher-order scalar-tensor theories revisited". In: *Phys. Rev. D* 103.8 (2021), p. 084022. arXiv: 2012.10218 [gr-qc].

Gauge Gravity

The Teleparallel Equivalent to General Relativity (TEGR) theory is a theory of gravity, leading to the same observable predictions as General relativity (GR). Contrary to GR in which the gravity is encoded in the curvature only, that of the Levi-Civita connection, the TEGR encodes gravity in torsion only, through the Weitzenböck connection, the curvature being equal to zero. The TEGR is often described as the gauge theory for the translations group.

With M. Fontanini, M. Le Delliou an Z.-C. Lin (University of Lanzhou, China) we pointed out that the gauge potential in gauge-translation TEGR does not correspond to a connection as required in a gauge theory. We proposed a formulation of TEGR using a Cartan connection - different from the Ehresmann one used in gauge theory of particle physics. This allowed us to describe TEGR, including the coupling to matter, in a coherent mathematical framework and to show how the usual gauge theory formalism has to be modified if one insist to interpret it as a gauge theory for the translation group (see[168]).

[168] E. Huguet, M. Le Delliou, and M. Fontanini. "Cartan approach to Teleparallel Equivalent to General Relativity: A review". In: *Int. J. Geom. Meth. Mod. Phys.* 18.supp01 (2021), p. 2140004. arXiv: 2101.07064 [gr-qc].

Team

P. Auclair, C. Caprini, E. Huguet, D. Langlois, A. Mangiagli, K. Noui, H. Roussille, D. Steer

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Astroparticle physics

Neutrino physics

In the last two decades milestones have been made in our knowledge of neutrinos as well as in our understanding of neutrino flavor evolution in astrophysical and cosmological environments. Crucial open questions remain on neutrino properties and on our understanding of how neutrinos change flavor in dense astrophysical environments, i.e. core-collapse supernovae (CC SNe) and binary neutron star mergers (BNS).

M.C. Volpe has published 10 articles, focussed on key open questions at the forefront of neutrino physics and astrophysics.

With A. Chatelain, she has been working on neutrino flavor evolution in BNS remnants and performed the first investigation of non-standard interactions and show that a complex pattern of flavor mechanisms arise, even for very small values of non-standard couplings, which can influence r-process nucleosynthesis in such sites.[169] Moreover the role of wrong helicity contributions due to the neutrino mass have also been studied based on detailed BNS simulations. Based on a perturbative argument valid both for BNS and CC SNe, these contributions are shown not to impact flavor evolution due non linear feedback.[170] These investigations are important in connection with kilonova observations.

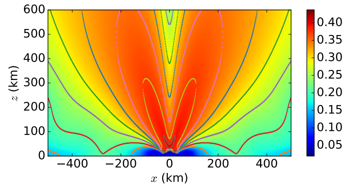


Figure 82: I-resonance location, triggered by non-standard interactions, in a binary neutron star merger remnants. Flavor conversion mechanisms produce neutrino spectral swappings and influence the neutron/proton ratio, a key parameter for r-process nucleosynthesis in kilonovae (and core-collapse supernovae)

[169] Amélie Chatelain and Maria Cristina Volpe. “Neutrino propagation in binary neutron star mergers in presence of non-standard interactions”. In: *Phys. Rev. D* 97.2 (2018), p. 023014. arXiv: 1710.11518 [hep-ph].

[170] Amélie Chatelain and Cristina Volpe. “Helicity coherence in binary neutron star mergers and non-linear feedback”. In: *Phys. Rev. D* 95.4 (2017), p. 043005. arXiv: 1611.01862 [hep-ph].

Effects of gravitational fields nearby compact objects on neutrino propagation and flavor evolution are still little explored. With A. Chatelain, M.C. Volpe has perfomed the first study of decoherence effects due to gravitational fields on neutrino wavepackets. Extending the density matrix formalism to curved spacetime, she has shown that gravity can impact significantly the decoherence proper time.[171]

[171] Amélie Chatelain and Maria Cristina Volpe. “Neutrino decoherence in presence of strong gravitational fields”. In: *Phys. Lett. B* 801 (2020), p. 135150. arXiv: 1906.12152 [hep-ph].

Fast conversion modes have triggered an intense activity since they can occur on short time scales and potentially influence CC SNe explosion dynamics. It was speculated in the literature that such modes could introduce flavor equilibration, which would simplify the complexity of predicting supernova neutrino signals of a future (extra)galactic supernova. With S. Abbar, she has investigated on a schematic two beam model that has clearly shown that fast modes do not produce flavor equilibration, contrarily to what is believed.[172] Moreover, analysis of neutrino angular distributions has shown the occurrence of fast modes for the first time in two- and three-dimensional supernova simulations and the conditions for their occurrence have been identified.[173]

[172] Sajad Abbar and Maria Cristina Volpe. “On Fast Neutrino Flavor Conversion Modes in the Nonlinear Regime”. In: *Phys. Lett. B* 790 (2019), pp. 545–550. arXiv: 1811.04215 [astro-ph.HE].

[173] Sajad Abbar et al. “On the occurrence of fast neutrino flavor conversions in multidimensional supernova models”. In: *Phys. Rev. D* 100.4 (2019), p. 043004. arXiv: 1812.06883 [astro-ph.HE]; Sajad Abbar et al. “Fast Neutrino Flavor Conversion Modes in Multidimensional Core-collapse Supernova Models: the Role of the Asymmetric Neutrino Distributions”. In: *Phys. Rev. D* 101.4 (2020), p. 043016. arXiv: 1911.01983 [astro-ph.HE].

With A. Gallo Rosso and A. Vissani, M.C. Volpe has studied the ability to reconstruct supernova neutrino spectra in Cherenkov detectors, if a galactic supernova explodes. A ten-dimensional likelihood analysis of the neutrino spectra has shown that we will be able to reconstruct the gravitational binding energy of the newly formed neutron star with 11% precision in Super-Kamiokande and 3% precision in Hyper-Kamiokande, by combining neutrino electron scattering and inverse beta-decay.[174] This measurement and knowledge of neutron star equation of state allows to determine the neutron star compactness and mass-radius relation. With S. Abbar as well, she has been investigating the possibility to pin down information on extended theories of gravity (f(R) theories) through

[174] Andrea Gallo Rosso, F. Vissani, and Maria Cristina Volpe. “Measuring the neutron star compactness and binding energy with supernova neutrinos”. In: *JCAP* 11 (2017), p. 036. arXiv: 1708.00760 [hep-ph]; Andrea Gallo Rosso, F. Vissani, and Maria Cristina Volpe. “What can we learn on supernova neutrino spectra with water Cherenkov detectors?” In: *JCAP* 04 (2018), p. 040. arXiv: 1712.05584 [hep-ph].

a precise determination of the neutron star radius.[175]

As for cosmological neutrinos at the epoch of Big Bang Nucleosynthesis, with J. Froustey and C. Pitrou, M.C. Volpe rederived the neutrino quantum kinetic equations, based on the BBGKY hierarchy that she had already been using to extend mean-field equations for astrophysical applications. Numerical calculations including for the first time the full collision term, as well as QED corrections, have given a precise determination[176] of the effective number of degrees of freedom $N_{\text{eff}} = 3.0440$.

[175] Andrea Gallo Rosso et al. "Late time supernova neutrino signal and proto-neutron star radius". In: *JCAP* 12 (2018), p. 006. arXiv: 1809.09074 [hep-ph].

[176] Julien Froustey, Cyril Pitrou, and Maria Cristina Volpe. "Neutrino decoupling including flavour oscillations and primordial nucleosynthesis". In: *JCAP* 12 (2020), p. 015. arXiv: 2008.01074 [hep-ph].

Team

M.C. Volpe, S. Abbar, A. Chatelain, J. Froustey, A. Gallo Rosso

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Cosmic rays

Despite cosmic rays was discovered more then 100 years ago, their origin is still unknown. Significant progress in experimental measurements over last 20 years provided large observational data for their theoretical study. In period 2017-2021 we developed theory of galactic and extragalactic cosmic rays in 11 works.

The most significant result was the development of anisotropic diffusion model in a series of works. In Ref.[177] it was shown that consistency of existing data excluded isotropic diffusion model and cosmic rays should propagate anisotropically. In Fig. 83 green band show the value of diffusion coefficient required by boron to carbon ratio. Black line show value of diffusion coefficient as function of energy in isotropic case, which is well below data at low energies. Color lines show the diffusion coefficients parallel and perpendicular to regular magnetic field. Since parallel diffusion is much faster, cosmic rays diffuse anisotropically along this field. As a result, at every local point of the Galaxy the number of the contributing sources significantly decreases.

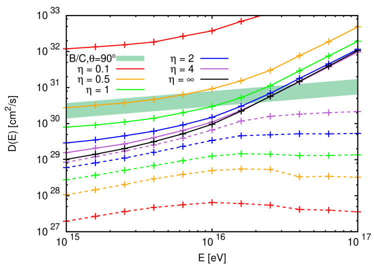


Figure 83: Diffusion of cosmic rays in isotropic and anisotropic magnetic field

[177] G. Giacinti, M. Kachelriess, and D. V. Semikoz. "Reconciling cosmic ray diffusion with Galactic magnetic field models". In: *JCAP* 07 (2018), p. 051. arXiv: 1710.08205 [astro-ph.HE].

This allowed us to study the contribution of individual sources to the cosmic ray flux at PeV energies. We modeled the contribution of the nearest young supernova remnant Vela to the local cosmic ray flux taking into account both the influence of the Local Superbubble and the effect of anisotropic diffusion in ref..[178] The magnetic field in the bubble wall prevents low-energy particles to penetrate into the bubble, leading to an energy-dependent suppression of CRs from Vela inside the bubble. The resulting CR flux at Earth in the energy region around the cosmic ray knee can naturally explain the observed fluxes of individual groups of nuclei and their total flux.

[178] M. Bouyahiaoui, M. Kachelriess, and D. V. Semikoz. "Vela as the source of Galactic cosmic rays above 100 TeV". in: *JCAP* 01 (2019), p. 046. arXiv: 1812.03522 [astro-ph.HE].

In work[179] we studied cosmic ray flux in the outer Galaxy. For this study we constructed the pion decay model of the combined Fermi LAT + Tibet gamma-ray spectrum in the outer Galaxy. We found that the cosmic ray spectrum in outer the Galaxy is close to the local He spectrum with slope 2.5 and differs from the local proton spectrum, which has a slope index of 2.7. This important result shows that the 2.7 slope of cosmic ray proton

[179] Sergey Koldobskiy, Andrii Neronov, and Dmitri Semikoz. "Pion decay model of the Tibet-ASγ PeV gamma-ray signal". In: *Phys. Rev. D* 104.4 (2021), p. 043010. arXiv: 2105.00959 [astro-ph.HE].

spectrum measured at Earth is a local effect.

Team

M. Bouyahiaoui, A. Neronov, D. Semikoz

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Intergalactic magnetic fields

The Intergalactic Magnetic Field (IMF) in the voids of large scale structure is dominated by the contribution of primordial magnetic fields, possibly created during inflation or at phase transitions in the Early Universe. Primordial magnetic fields can be probed via measurements of secondary gamma-ray emission from gamma-ray interactions with extragalactic background light. Lower bounds on the magnetic field in the voids were derived from the non-detection of this emission.

In the work[180] we studied the sensitivity reach of the gamma-ray method for measurement of relatively strong cosmological magnetic field with strength in the 1-10 pG range using deep exposure of the nearest hard spectrum blazar Mrk 501 with CTA telescopes. We shown that the gamma-ray measurement technique can sense the primordial magnetic field with a strength of up to 10^{-11} G.

[180] Alexander Korochkin et al. "Sensitivity reach of gamma-ray measurements for strong cosmological magnetic fields". In: *Astrophys. J.* 906.2 (2021), p. 116. arXiv: 2007.14331 [astro-ph.CO].

It is not clear a-priori what kind of magnetic field is responsible for the suppression of the secondary gamma-ray flux: a cosmological magnetic field that might be filling the voids or the field spread by galactic winds driven by star formation and active galactic nuclei. In Ref.[181] we used IllustrisTNG cosmological simulations to study the influence of magnetized galactic wind bubbles on the secondary gamma-ray flux. We shown that within the IllustrisTNG model of baryonic feedback, the galactic wind bubbles typically provide energy-independent secondary flux suppression at the level of about 10%. This might not be the case for a special case when the primary gamma-ray source has a hard intrinsic gamma-ray spectrum peaking in the energy range above 50 TeV. In this case, the observational data may be strongly affected by the magnetized bubble blown by the source host galaxy.

[181] Kyrylo Bondarenko et al. "Account of baryonic feedback effect in the γ-ray measurements of intergalactic magnetic fields". In: (June 2021). arXiv: 2106 . 02690 [accepted to Astronomy and Astrophysics].

In Ref.[182] we studied the gravitational-wave signal produced by a primordial magnetic field generated during the QCD phase transition in the early universe. Magneto-hydrodynamics processes related to the presence of the primordial magnetic field during phase transitions can generate gravitational waves in the frequency band probed by Pulsar Timing Arrays. The noise excess recently discovered by several Pulsar Timing Arrays experiments (see Pulsar timing array) can be explained in terms of a stochastic gravitational-wave background due to a primordial magnetic field at the QCD scale. Furthermore, this magnetic field would evolve in the early universe until the recombination era, and could leave a visible trace in the CMB. It has therefore the potential to be probed by both gravitational wave and CMB observables.

[182] Andrii Neronov et al. "NANOGrav signal from magnetohydrodynamic turbulence at the QCD phase transition in the early Universe". In: *Phys. Rev. D* 103.4 (2021), p. 041302. arXiv: 2009 . 14174 [astro-ph.CO].

In Fig. 84 taken from[183] the lower light blue shading shows the sensitiv-

[183] Neronov et al., "NANOGrav signal from magnetohydrodynamic turbulence at the QCD phase transition in the early Universe".

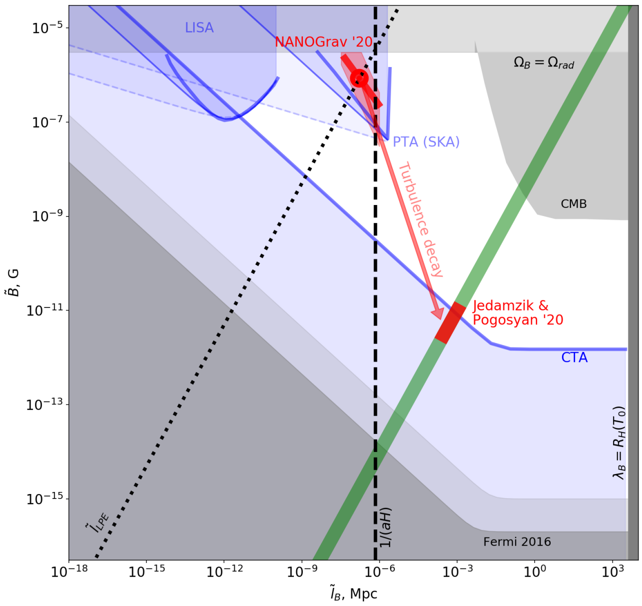


Figure 84: Constraints on cosmological magnetic fields, compared to the PTA result interpreted as evidence for the detection of a primordial magnetic field.

ity of CTA to intergalactic magnetic fields. The lower bounds with different degrees of grey shading show the existing Fermi/LAT lower bound on the intergalactic magnetic field. The red dot shows the amplitude and correlation scale of the primordial magnetic field, which would produce the gravitational-wave signal compatible with the PTA noise excess. The green line shows the endpoints, at the recombination epoch, of the cosmological evolution of primordial magnetic fields. The rose arrow shows the evolutionary path via compressible turbulent decay of the gravitational-wave sourcing magnetic field. The red interval on the green line evidences the amplitude and correlation scale it would have at recombination.

Supporting grants

2020-2023 ANR PRCI 'Multimessenger Universe', PI: D. Semikoz, C. Caprini, A. Neronov

Team

Ch. Caprini, A. Korochkin, A. Neronov, M. Ramsoy, A. Roper Pol, D. Semikoz

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Multimessenger astrophysics

Despite their discovery about 10 years ago, sources of astrophysical neutrinos are still unknown. We worked on multimessenger astrophysics which neutrinos and gamma-rays at energies above TeV. In particular we constructed models of galactic and extralactic neutrino sources and compared their predictions with gamma-ray and neutrino observations.

In work[184] we reported the discovery of a γ-ray excess at high galactic

[184] A. Neronov, M. Kachelrieß, and D. V. Semikoz. "Multimessenger gamma-ray counterpart of the IceCube neutrino signal". In: *Phys. Rev. D* 98.2 (2018), p. 023004. arXiv: 1802.09983 [astro-ph.HE].

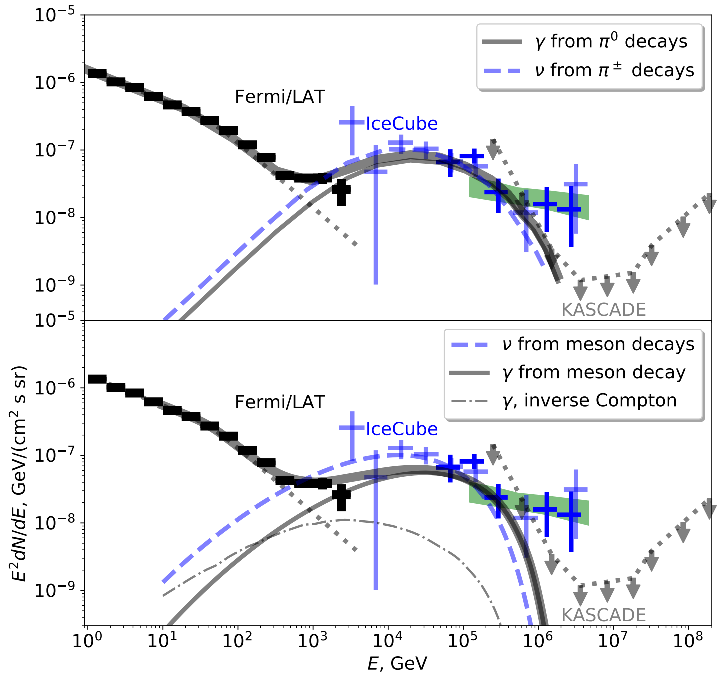


Figure 85: Contribution of local source (top) or Dark Matter with PeV mass (bottom) to neutrino and gamma-ray fluxes at high galactic latitudes. Model predictions for gamma-ray flux are shown with black lines, model predictions for neutrino fluxes with blue lines. Arrows show limits on gamma-ray flux from KASCADE Grande. Green band is extragalactic neutrino flux contribution from IceCube

latitudes starting at energies 300 GeV in the data of the Fermi telescope, see Fig. 85 . We show that the multi-TeV γ-ray diffuse emission has spectral characteristics at both low and high galactic latitudes compatible with those of the IceCube high neutrino signal in the same sky regions. This suggests that these γ-rays are the counterpart of the IceCube neutrino signal, implying that a sizable part of the IceCube neutrino flux originates from the Milky Way. We argue that the diffuse neutrino and γray signal at high galactic latitudes originates either from previously unknown nearby cosmic ray "PeVatron" source(s), an extended galactic cosmic ray halo or from decays of heavy dark matter particles.

In the work[185] we explained in a unified way the experimental data on ultrahigh energy cosmic rays (UHECR) and neutrinos, using a single source class and obeying limits on the extragalactic diffuse gamma-ray background (EGRB). we find a good description of experimental data on the total CR flux, the mean shower maximum depth X max and its width RMS(X max) in the whole energy range above $E = 100$ PeV. The predicted high-energy neutrino flux matches IceCube measurements above 100 TeV, while the contribution to the EGRB is of order 30 %.

[185] M. Kachelrieß et al. "Minimal model for extragalactic cosmic rays and neutrinos". In: *Phys. Rev. D* 96.8 (2017), p. 083006. arXiv: 1704.06893 [astro-ph.HE].

In the work.[186] we for the first time found diffuse gamma-ray Galactic emission at all latitudes at TeV energies from Fermi LAT data and make predictions for neutrino data.

[186] A. Neronov and D. Semikoz. "Galactic diffuse gamma-ray emission at TeV energy". In: *Astron. Astrophys.* 633 (2020), A94. arXiv: 1907.06061 [astro-ph.HE].

We showed that, in spite of the lack of correlation between the neutrino arrival directions and the nearby gamma-ray emitting blazars, the cumulative blazar flux from FSRQ and bright BL Lac blazars could explain most of the astrophysical neutrino flux measured in the muon neutrino channel. This occurs when the gamma-ray flux from neutrino-emitting sources is higher than the neutrino flux due to the dominating leptonic channel.

Team

A. Neronov, D. Semikoz

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Selected publications

Abbar, Sajad and Maria Cristina Volpe. "On Fast Neutrino Flavor Conversion Modes in the Nonlinear Regime". In: *Phys. Lett. B* 790 (2019), pp. 545–550. arXiv: 1811.04215 [astro-ph.HE].

Abbott, B. P. et al. "A gravitational-wave standard siren measurement of the Hubble constant". In: *Nature* 551.7678 (2017), pp. 85–88. arXiv: 1710.05835 [astro-ph.CO].

Basile, I., J. Mourad, and A. Sagnotti. "On Classical Stability with Broken Supersymmetry". In: *JHEP* 01 (2019), p. 174. arXiv: 1811.11448 [hep-th].

Charmousis, C., E. Kiritsis, and F. Nitti. "Holographic self-tuning of the cosmological constant". In: *JHEP* 09 (2017), p. 031. arXiv: 1704.05075 [hep-th].

Giacinti, G., M. Kachelriess, and D. V. Semikoz. "Reconciling cosmic ray diffusion with Galactic magnetic field models". In: *JCAP* 07 (2018), p. 051. arXiv: 1710.08205 [astro-ph.HE].

Huguet, E., M. Le Delliou, and M. Fontanini. "Cartan approach to Teleparallel Equivalent to General Relativity: A review". In: *Int. J. Geom. Meth. Mod. Phys.* 18.supp01 (2021), p. 2140004. arXiv: 2101.07064 [gr-qc].

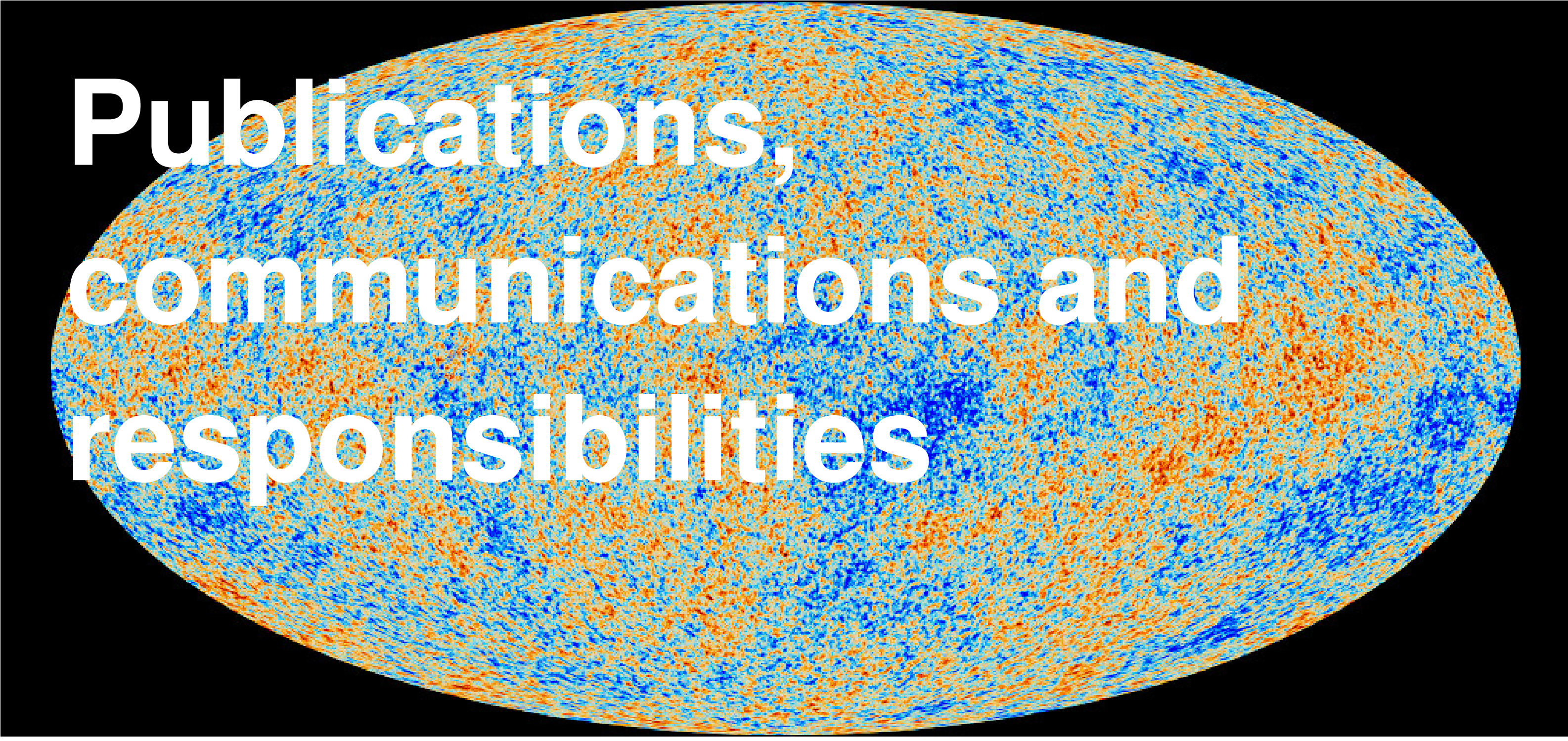
Langlois, David et al. "Effective Description of Higher-Order Scalar-Tensor Theories". In: *JCAP* 05 (2017), p. 033. arXiv: 1703.03797 [hep-th].

Neronov, A., M. Kachelrieß, and D. V. Semikoz. "Multimessenger gamma-ray counterpart of the IceCube neutrino signal". In: *Phys. Rev. D* 98.2 (2018), p. 023004. arXiv: 1802.09983 [astro-ph.HE].

Neronov, Andrii et al. "NANOGrav signal from magnetohydrodynamic turbulence at the QCD phase transition in the early Universe". In: *Phys. Rev. D* 103.4 (2021), p. 041302. arXiv: 2009.14174 [astro-ph.CO].

Pattison, Chris et al. "Quantum diffusion during inflation and primordial black holes". In: *JCAP* 10 (2017), p. 046. arXiv: 1707.00537 [hep-th].

Publications, communications and responsibilities



This chapter provides the list of individual contributions from the lab's members in terms of science dissemination and communication, role and responsibility at various levels and distinctions and awards.

The list is divided into the following categories:

- **Communication and conferences**
- **Lectures at summer schools**
- **Organization of conferences and summer schools**
- **Responsibilities in university, scientific and technical bodies**
- **Participation in scientific and technical evaluation committees**
- **Outreach and communication to the general public**
- **Distinctions**

Communication and conferences

D Allard :

Probing the Extragalactic Cosmic Rays origin with gamma-ray and neutrino backgrounds. Invited seminar at the Astrophysical Big Bang Laboratory, Riken (Japan), Dec 2017
Probing the Extragalactic Cosmic Rays origin with gamma-ray and neutrino backgrounds. Invited talk at the PACIFIC2018 conference, Akaigawa (Japan), Feb 2018
Very-high and ultra-high-energy cosmic-rays: recent observations and perspectives. invited talk at CFRCos, Paris, Mar 2018
Probing the Extragalactic Cosmic Rays origin with gamma-ray and neutrino backgrounds. Invited seminar at the LUPM, Montpellier, 2019
Review of the mixed composition model and its multi messenger implications. invited talk at VHEPU, Quy Nhon, Aug 2018
Probing the Extragalactic Cosmic Rays origin with gamma-ray and neutrino backgrounds. Invited seminar at the DAP (CEA), Saclay, Jan 2019
Probing the Extragalactic Cosmic Rays origin with gamma-ray and neutrino backgrounds. Invited seminar at the LUTh (Paris Observatory), Meudon, Feb 2019
What can be learnt from UHECR anisotropy observations?, Invited seminar at the Astrophysical Big Bang Laboratory, Riken (Japan), Dec 2019
What can be learnt from UHECR anisotropy observations? Invited seminar at the PCC New York University, New York (USA), Feb 2020

J Aublin :

Point source stacking with 11 years of ANTARES data. Talk at ICRC, Madison (USA), Jul 2019
Search for an association between neutrinos and radio-selected blazars with ANTARES. Talk at VLVnT, Valencia (Spain), May 2020
Search for an association between neutrinos and radio-selected blazars with ANTARES. Talk at ICRC, Berlin (Germany), Jul 2021

S Babak :

Introduction to Data Analysis of Gravitational Wave Signals. Invited talk at Caltech/KISS, Jan 2018
Sources of gravitational waves from kHz to nHz, Colloquium, MITP, Moscow, Apr 2018
Detecting EMRIs with LISA. Invited Talk at 21st Capra meeting, Potsdam Germany, Jun 2018
Searching for supermassive black holes through low frequency gravitational wave emission. Invited talk SF2A, Bordeaux, Jul 2018
Detecting gravitational waves from kHz to nHz, Colloquium IPhT, Oct 2018
Detecting low frequency gravitational waves. Colloquium, Rome, Jan 2019
Status of Research on Gravitational Waves. Plenary talk. 31st Rencontres de Blois on "Particle Physics and Cosmology", Jun 2019
Challenges in LISA data analysis. Invited talk (remote). LISA symposium, Sep 2020
GW190521 and alike: what can we learn from multi-band observations. Colloquium (remote), Nov 2020
Gravitational wave transient catalogue from O3a. Plenary talk (remote). 7th Kagra International workshop, Dec 2020
Gravitational waves, Seminar Izran (remote), Jun 2021

B Baret :

Fundamental Physics and Astrophysics with Neutrino Telescopes. Invited talk at Multimessenger@Prazgue Winter Workshop, Prague, Tchech Republic, Dec 2019
High Energy Neutrino Telescopes and the Search for Quantum Gravity, COST Action CA18108 Quantum gravity phenomenology in the multi-messenger approach - Kick-off meeting, Barcelona, Spain, Oct 2019
Gravitational waves and neutrinos joint searches in the Mediterranean Sea , on behalf of the ANTARES and KM3NeT collaborations, VLVnT – 2018 Very Large Volume Neutrino Telescopes, Dubna, Russia, Oct 2018
Neutrino Multi-messenger searches in the Mediterranean, on behalf of the ANTARES and KM3NeT collaborations, VLVnT – 2018 Very Large Volume Neutrino Telescopes, Dubna, Russia, Oct 2018
High Energy Neutrinos. Invited review, European Cosmic Ray Symposium and Russian Cosmic Ray Conference, Barnaul, Russia, Jul 2018
Sources Astrophysiques de Neutrinos, Atelier Transient Sky 2020, Montpellier, France, Jun 2018

JG Bartlett :

SZ (and other "CMB" observations) as a Probe of Cosmic Structure and Baryonic Physics. Invited talk at "Towards the European Coordination of the CMB Programme" meeting in Florence, Italy, 2017

R Bouquet :

b-jet energy scale using $t\bar{t}$ lepton+jets events in ATLAS Run 2 data, JRJC, 2021

M Bucher :

CMB From Space, CosmoAndes 2018 Conference and School, Pontifica Universidad Catolica de Santiago, Santiago, Chile, Jan 2018
Probing the Big Bang Using the CMB, Cosmology Seminar, Universidad de Chile, Santiago, Chile, Jan 2018
Probing Fundamental Physics with the Cosmic Microwave Background, Present Status and Future Prospects, Physics Colloquium, Tata Institute for Fundamental Research, Mumbai, India, Feb 2018
Mapping the Remnants of the Big Bang: A Survey of the Microwave Sky, Nehru Planetarium, Mumbai, India, Feb 2018
Theory of the Microwave Background: Defending the Orthodoxy, The Physical Universe Conference, Nagpur, India, Feb 2018
Present and Future Observations of the Cosmic Microwave Background, Mondello Workshop 2018, Frontier Research in Astrophysics III, Palermo, Italy, May 2018
Status of Cosmic Microwave Background Observations, Division of Radio Astronomy Meeting, IAU General Assembly, Vienna, Austria, Aug 2018
Observations du fond diffus cosmologique, Department of Physics and Mathematics Colloquium, University of Tours, Sep 2028

Exploring the Primordial Universe with the Cosmic Microwave Background and Beyond, Physics Colloquium, University of North Carolina at Chapel Hill, US, Nov 2018
Neil Turok and Observational Cosmology, Quantum Universe: An Intimate Celebration of Neil's 60th, Valdivia, Chile, Nov 2018
Observations of the Cosmic Microwave Background: Early History and Future Prospects, Physics Colloquium, University of Okayama, Okayama, Japan, Feb 2019
Probing Dark Energy With HIRAX, Accelerating Universe in the Dark, Yukawa Institute, University of Kyoto, Japan, Mar 2018
Probing the Big Bang Using the CMB," Chinese Academy of Sciences, Wuhan, China, Mar 2019
Probing Dark Energy With HIRAX, Korean Institute for Advanced Study, Seoul, Korea, Apr 2019
CMB Probes for Cosmology and Particle Physics. Invited Lecture, Russian National Research Nuclear University (MEPHI), Moscow, Russian Federation, May 2019
What is the Symmetry of the Primordial Universe: Searching for Parity Violation, Beyond the Power Spectrum, Alli CPT Symposium, Beijing, China, Sep 2019
New directions in non-Gaussianity, Remnants of the Big Bang Conference, Mesa, Arizona, Jan 2020
The Mathematics of Covid-19 and Other Diseases: Current Questions and A Historical Perspective, UKZN Data Breakfast Seminar Series, Durban, South Africa, Jun 2020
Foundations of Theoretical and Computational Epidemiology, (five lectures) CHPC-NITheP Summer School, Feb 2021
Bell's Rocket Problem, Dark Energy, and Solids in General Relativity, Gravitex 2021 (Gravitation: Theory and Experiment), Aug 2021
Mini-School Lecture Series Mapping the Initial Conditions of the Universe: Exploring the Cosmic Microwave Background, NITheCS (National Institute of Theoretical and Computational Sciences, South Africa, Sep 2021

C Caprini :

Invited talk at 14th Edoardo Amaldi Conference on Gravitational Waves, online, Jul 2021
Invited talk at Gravitational Wave Probes of Physics Beyond Standard Model, online, Jul 2021
Invited talk at Workshop on Gravitational Wave Astrophysics for Early Career Scientists, online, May 2021
Invited talk at Gravitational-Wave Primordial Cosmology, online, May 2021
Invited talk at From Inflation to the Hot Big Bang, KITP Santa Barbara, Feb 2020
Invited talk at Third annual symposium of the innovative area "Gravitational Wave Physics and Astronomy: Genesis", Kobe, 2020
Invited talk at Quantum gases, fundamental interactions and cosmology, Pisa, 2019
Invited talk at String Phenomenology, CERN, 2019
Invited talk at CosmoGold, Colloque de l'IAP, Paris, 2019
Invited talk at The mysterious universe: dark matter, dark energy and cosmic magnetic fields, MITP Mainz, 2019
Enabling LISA Science Exploitation Workshop, Lorentz Centre, Leiden, 2019
Invited talk at LISA Fundamental Physics Working Group Workshop, GGI Florence, 2018
Invited talk at DESY Theory meeting, DESY Hamburg, Germany, 2017
Invited talk at COSMO17, Paris, 2017

F Casse :

"Processus d'accélération de particules dans les plasmas astrophysiques relativistes", Conférence "MHD : Classical physics for the 21st century", Revue invitée, Leiden (Pays-Bas), Oct 2021
"Numerical simulations of cosmic ray acceleration near astrophysical shocks", 2nd Conférence de la communauté française sur le rayonnement cosmique CFRCOS2, Montpellier, Nov 2019
"Simulations of cosmic ray acceleration near astrophysical shocks : the Particle in MHD Cells approach", Workshop "Simulating the evolution and emission of relativistic outflows", Observatoire de Meudon, Nov 2019
"A Numerical Observatory of Violent Accreting systems : NOVAs", Journées nationales du Programme National des Hautes Energies, IAP, Oct 2018
Approche PI[MHD]C, 12th High Energy Density Laboratory Astrophysics (HEDLA), Présentation invitée, Kurashiki, Okayama, Japon, Jun 2018
"Numerical simulations of particle acceleration in astrophysical plasmas", Atelier de la communauté française de recherche sur le rayonnement cosmique (CRFCOS), Mar 2018
"On magnetic field amplification and particle acceleration near astrophysical shocks : Particle in MHD Cells simulations", 44th EPS conference on Plasma Physics, Belfast, Irlande du Nord, Jun- Jul 2017

M Cerruti :

Photons and neutrinos from AGNs: a review on hadronic radiative models. Invited talk at 16th Marcel Grossmann meeting, online, Jul 2021
The blazar hadronic code comparison project. Talk at the 37th International Cosmic Ray Conference, Berlin (online), Jul 2021

E Chardonnet :

Reconstructing 3D trajectories in DUNE. Talk at the La Thuile Conference, Mar 2021

E Chassande-Mottin :

Détection des ondes gravitationnelles et traitement du signal associé. Invited plenary talk at XXVIème Colloque Gretsi, Juan-les-Pins, Sep 2017
Temps-fréquence et ondes gravitationnelles. Journée Yves Meyer - Prix Abel 2017, Cachan, Jun 2017
Joseph rencontre Albert. Fourier aujourd'hui, Institut H Poincaré, Apr 2018
L'avènement de l'astrophysique multi-messager avec les ondes gravitationnelles. Invited talk at Colloque de la Société Française de Physique, Nantes, Jun 2019
Sicut in caelo et in terra: Data representations for seismic and gravitational waves. Invited talk at Celebration for Alexandre Grossmann and Yves Meyer, Orsay, Jun 2019

Observations gravitationnelles et incertitudes dans la mesure de distance. General Assembly GdR Ondes Gravitationnelles, Lyon, Sep 2019
GW astronomy in 2030. Journée THESEUS France, Paris, Sep 2019
Sur les fusions d'étoiles à neutrons – L'avènement de l'astrophysique multimessager. JOGLy, Lyon, Oct 2019
Overview of LIGO and Virgo observations during the science run O3a. Triangular meeting, Paris, May 2021

S Chaty (from Sep 2019) :

Exploring the Gaia view of High-Mass X-ray Binaries, Yukawa Institute for Theoretical Physics at Kyoto University, YKIS2019 "Black Holes and Neutron Stars with Gravitational Waves", Nov 2019

S Chen :

Design and Development of Radiation Hardened Application- Specific Integrated Circuit for the ATHENA Mission. Conference Elbereth, Paris, Nov 2017
Development of WFEE for X-IFU of ATHENA Space Observatory. SPIE Astronomical Telescopes & Instrumentation, Austin, US, Jun 2018
RHBD for WFEE of X-IFU/ATHENA Space Observatory. 14th SERESSA International School on the Effects of Radiation on Embedded Systems for Space Applications, Noordwijk, The Netherlands, Nov 2018
Radiation Hardened Integrated Circuits For Space Observatory. Congrès des Doctorants, Paris, Mar 2019
Analysis and Improvement of Linearity Performance of Low Noise Amplifier with Diode Loads. 2nd International Conference on Microelectronic Devices and Technologies (MicDAT' 2019), Amsterdam, The Netherlands, May 2019
Radiation Tolerance of RHBD techniques on a SiGe BiCMOS 350 nm ASIC technology. Radiation and its Effects on Components and Systems (RADECS) 2019, Montpellier, Sep 2019
ATHENA Warm ASIC for the X-IFU Electronics. SPIE Astronomical Telescopes & Instrumentation, Online, Dec 2020
Warm ASIC for the SQUID/TES Readout of ATHENA's X-IFU Instrument. 19th International Workshop on Low Temperature Detectors (LTD19), Online, Jul 2021

A Coleiro :

"Multi-messenger astronomy with ATHENA and THESEUS", Séminaire au laboratoire Subatech, Nantes, Jun 2020
"Observational strategies Athena/CTA/neutrino telescopes", Athena Multi-messenger workshop, May 2020
"Access to large-scale telescopes for neutrino event follow-up", Town Hall KM3NeT workshop, Marseille, Dec 2019
"Multi-messenger synergies with SKA", Journée SKA France, Paris, Sep 2019
"What can we gain by exchanging time series instead of only alarms ?", SNEWS 2.0 workshop, Sudbury Canada, Jun 2019
«L'astronomie multi-messagers" (atelier "Faire de l'astrophysique avec les ondes gravitationnelles"). Semaine de l'Astrophysique Française (Contribution invitée), May 2019, Nice
"Multimessenger astronomy with neutrinos : what have we learned ?", Séminaire à l'Institut de Planétologie et d'Astrophysique de Grenoble, Jan 2019
"Multi-messenger synergies between Athena and KM3NeT", The Athena Multi-messenger and High-energy Astrophysics synergy workshop, Alicante, Espagne, Nov 2018
"ANTARES neutrinos followup of gravitational-wave signals". Invited talk at GEMMA Lecce, Italy, Jun 2018

S Colonges :

Electronics Reliability methods for Neutrino Telescopes : The KM3NeT case - VLVnT, Valencia, May 2021
Reliability studies for the White Rabbit Switch in KM3NeT: FIDES and Highly Accelerated Life Tests - IPRD - Siena, Italy, Oct 2019
KM3NeT Acquisition Electronics: New Developments and Advances in Reliability, Proceedings of science, ICRC 2021
TICKS: A flexible WHITE-RABBIT based Time-Stamping board - ICALEPS 2017, Aug 2021

A Creusot :

Latest results of Antares Observatory and recent news of KM3NeT-ARCA Observatory - ICHEP, Seoul, Korea, Jul 2018
Simulation of photomultiplier tubes - Hamamatsu, Tokyo, Japan, 2019

J Delabrouille :

Future CMB Projects. Invited talk at EPS Conference on High Energy PhysicsVenice, Italy, Jul 2017
The Cosmic Origins Explorer. Invited talk at Post-Planck Cosmology: Enigma, Challenges and Visions, Pune, India, Oct 2017
Probing Inflation and Cosmic Origins: The foregrounds problem. Invited talk at CMB Foregrounds Workshop, University of San Diego - La Jolla, USA, Dec 2017
Peering at the CMB through the polarized Galaxy. Invited talk at Designing future CMB experiments workshop, Keck Institute for Space Studies, Pasadena, USA, Mar 2018
Spectro-imaging of the polarized CMB. Invited talk at Probing fundamental physics with CMB spectral distortions, CERN, Geneva, Switzerland, Mar 2018
Present and future of CMB observations. Invited talk at PACTS 2018: Particle, Astroparticle and Cosmology Tallinn Symposium, Tallinn, Estonia, Jun 2018
Component separation for future CMB observations. Invited talk at the International Symposium on Cosmology and Ali CMB Polarization Telescope, Shanghai, China, Sep 2018
The Planck Sky Model and simulations for future CMB experiments. Invited talk at CMB Foregrounds for B-mode studies, Tenerife, Spain, Oct 2018
The Cosmic Origins Explorer and the CMB-Bharat proposal. Invited talk at CMB Foregrounds for B-mode studies, Tenerife, Spain, Oct 2018
PICO: The probe of Inflation and Cosmic Origins. Talk at the PNCG workshop, Lyon, France, Nov 2018
The Planck Sky Model and simulations for Future CMB experiments.

Talk at Future work with Planck data, ESAC, Madrid, Dec 2018
The Cosmic Origins Explorer. Invited talk at Cosmology – The next decade, Bangalore, India, Jan 2019
Future Cosmic Microwave observations from Space: A European perspective. Invited talk at the 2nd International Symposium on Cosmology and Ali CMB Polarization Telescope, Beijing, China, Sep 2019
Voyage 2050 CMB science white papers: an overview. Invited talk at the European CMB coordination meeting, Paris, France, Sep 2019
Constraining Gravitation with CMB Observations. Invited talk at the 6th conference of the Polish Society on Relativity, Szczecin, Poland, Sep 2019
Microwave Spectro-Polarimetry of Matter and Radiation across Space and Time. Invited talk at the Voyage 2050 ESA Workshop: Shaping the European Space Agency's Space Science Plan for 2035-2050, Madrid, Spain, Oct 2019
The Voyage 2050 process and perspectives. Invited talk at the National Dark Energy Prospective Colloquium, Paris, France, Nov 2019
Microwave Spectro-Polarimetry of Matter and Radiation across Space and Time. Talk at the B-mode from Space workshop, Garching, Germany, Dec 2019
Microwave Spectro-Polarimetry of Matter and Radiation across Space and Time. Invited talk at the 16th Marcel Grossmann meeting, session on New Horizons in Cosmology with CMB Spectral Distortions, online conference, Jul 2021
Options for an L-class Microwave Spectroscopy Space Mission. Talk at the Second CMB-France Colloquium, Paris, France, Nov 2021

A Djannati-Ataï :

H.E.S.S. array stereoscopic observations of the Vela pulsar above 100 GeV – Discovery of pulsations in the 3 to beyond 7 TeV range. Talk at the 29th Texas Symposium, Cape Town, SA, Dec 2017
The Quest of TeV Emission from Pulsars: Towards a New Era. Invited talk at Neutron stars: towards a general view, PHAROS workshop, Rome, Mar 2018
Detection of sub-100 GeV gamma-ray pulsations from PSR B1706-44 with H.E.S.S, ICRC, Madison USA, Jul 2019
H.E.S.S. Observations of Pulsars at Very High Energies, ICRC, Madison USA, Jul 2019
Gamma-ray Pulsars in the CTA Era. Invited talk at CTA Linkages workshop, Adelaide, Nov 2019
H.E.S.S. observations of pulsars at very high energies, TeV Particle Astrophysics (TeVPA), Sydney, Dec 2019

J Errard :

Detecting B-modes in Firenze, European CMB conference, Sep 2017
Foregrounds cleaning for LiteBIRD with xForecast-multipatch and SMICA, B-modes from space conference in Berkeley, US, Dec 2017
The Simons Observatory. Invited talk at the Rencontres de Moriond, La Thuile, Italy, Mar 2018
Characterizing bias from foregrounds residuals. Invited talk at the conference CMB foregrounds for B-modes studies, Tenerife, Spain, Oct 2018
Galactic foregrounds for the next generation CMB projects. Invited talk at the CosmoGold conference, IAP, Paris, Jun 2019
Future observations of the primordial, polarized Cosmic Microwave Background: expected science and challenges. Invited colloquium at SISSA, Trieste, Italy, Jan 2021

D Franco :

Improved measurement of the 8B solar neutrino rate with 1.5 kton year of Borexino exposure. Invited talk at Recent developments in neutrino phsysics and astrophysics, L'Aquila, Italy, Sep 2017
DarkSide: the quest for dark matter with liquid argon. Instrumentation days on gaseous detectors, Bordeaux, Oct 2018
New physics results from DarkSide-50. Rencontres de Moriond-Electroweak, La Thuile, Italy, Mar 2018

S Gabici :

Low energy cosmic rays, CFRCOS2, Montpellier, France, Nov 2019
Cosmic rays in the CTA era, COSPAR, Pasadena, US, Jul 2018
Cosmic ray transoprt in (and around) molecular clouds, CRATER Workshop, L'Aquila, Italy, Jun 2018
Cosmic ray penetration in diffuse clouds, Cosmic rays: the salt of star formation recipe, Arcetri, Italy, May 2018
Gamma rays and the sources of Galactic cosmic rays, Solvay Workshop, SUGAR 2018, Brussels, Belgium, Jan 2018
Cosmic ray propagation of cosmic rays in turbulent magnetic fields. Invited talk at Amsterdam-Paris-Stockholm 7th Meeting, Woerden, The Netherlands, Oct 2017

K Ganga :

Presentations at "Towards the European Coordination of the CMB Programme" meetings in Florence, Italy 2017 and 2018 and Paris 2019
Presentation at the "Fundamental Cosmology Meeting", Teruel, Spain, Sep 2017
CMB Foregrounds for B-mode studies, Tenerife, Spain, Oct 2018
HIRSAP Workshop, Karlsruhe, Germany, Sep 2019

JP Gazeau :

Covariant Weyl-Heisenberg integral quantisations: From classical to quantum models: the regularising rôle of integrals, symmetry and probabilities. Invited Talk at Conference on Quantum Harmonic Analysis and Symplectic Geometry, Strobl, Austria, Apr 2018
Un formalisme quantique "jouet", and Etats cohérents en optique quantique, 2 Invited Talks at 2nd International Workshop on Quantum Information Quantum Electronics, Al-Hoceima, Morocco, Sep 2018
From classical to quantum models: the regularising rôle of integrals, symmetry and probabilities. Talk at the XXXIIth International Colloquium on Group Theoretical Methods in Physics, GROUP 32, Session SYMQP, Jul 2018
Signal analysis and quantum formalism, A quantization with no Planck constant. Invited Talk at the Conference on "Estate Quantistica 2018" (*dedicated to Júlio Fabris, Richard Kerner, and Winfried Zimdahl*), Scalea, Italy, Jun 2018
Various generalizations of Glauber-Sudarshan coherent states for

Quantum Optics. Invited Talk at The International Conference on Mathematical Methods in Physics, Marrakech, Marocco, Apr 2019

Geometric aspects of coherent states. Invited Talk at GIRAGA 17, Conference on Analysis, Geometry and Applications, Bujumbura, Burundi, Dec 2019

Pavel Winternitz et Symétries: Une belle histoire d'amour & Quelques intéressantes implications des symétries comparées de de Sitter, d'Anti-de-Sitter et de Poincaré. Invited Talk at Group Theoretical Methods in Physics: In memory of Pavel Winterntiz, Montréal, Jul 2021

Illustration of Lie Group Theory with real 2 × 2 matrices: SL(2,R) Group, sl(2,R) algebra, notations, definitions, properties, actions, isomorphisms, representations. Invited lecture at the CIMPA School "Groups and Lie Algebras, Representation Theory, and their Applications", Bujumbura, Burundi, Jul 2021

Real POVMs on the plane: integral quantization, Naimark theorem and linear polarisation of the light. Invited Talk at "Analytic and algebraic methods in physics XVIII", Prague, Sep 2021

Les espace-temps à symétrie maximale: Minkowski, de Sitter et anti-de-Sitter. Invited Talk at GIRAGA 18, Conference on Analysis, Geometry and Applications, Yaoundé, Cameroun, Dec 2021

P Goldoni :

Looking for infrared counterparts of Fermi/LAT blazar candidates, ICRC2017, Busan Korea Jul 2017

Southern African Large Telescope Spectroscopy of BL Lacs for the CTA project, ICRC2021, Proceeding of Science, online, 2021

Talk: Redshift Determination of gamma-ray Blazars for the Cherenkov Telescope array, European Astronomical Society (EAS) meeting, online, 2021

A Goldwurm :

Present and past high-energy activity of the Massive Black Hole at the Center of the Galaxy. Invited talk at the Ginzburg Conference on Physics, Moscow, Russia, May 2017

SVOM General Program and ToO Quick Look Analysis. Talk at 3rd SVOM Science Workshop, Les Houches, May 2018

Multi-wavelength coverage of a powerful flare from Sgr A* confirms the synchrotron origin of the X-ray emission. Talk at COSPAR General Assembly 2018, Pasadena, US, Jul 2018

X-Ray Surveys reveal the past activity of the Galactic Center supermassive black hole and of the nuclear region. Invited talk at 25th Congress of SFP, Nantes, Jul 2019

Sgr A* recent past activity from the X-ray echoes propagating in the Central Molecular Zone. Talk at the conference X-Ray Astronomy 2019, Bologna, Italy, Sep 2019

Reconstructing the past light curve of Sgr A* with X-ray echoes, poster at Galactic Center Workshop 2019, Yokohama, Japan, Oct 2019

M Gonzalez :

Fully differential broadband LNA with active impedance matching for SQUID readout. 19th International Workshop on Low Temperature Detectors (LTD19), Online, Jul 2021

L Haegel :

Searching for new physics during gravitational waves propagation. Rencontres de Blois, Oct 2021

Search for spacetime symmetry breaking during gravitational waves propagation. GdR Gravitational Waves: General Assembly, Oct 2021

Probing spacetime birefringence with gravitational waves. Edoardo Amaldi Conference on Gravitational Waves (14th edition), Jul 2021

How machine learning can enhance gravitational-waves physics? Invited talk at the Multiband Gravitational-Wave Science Workshop, May 2021

Searching for new physics during gravitational waves propagation. Invited WIPAC Seminar, University of Wisconsin-Madison (USA), Apr 2021

Enhancing Gravitational-Wave Science with Machine Learning. Invited EPAP Seminar, King's College London (UK), Mar 2021

Searching for new physics during gravitational waves propagation. Rencontres de Moriond in Gravitation (55th edition), Mar 2021

Entering the era of gravitational waves precision physics: signal modelling and tests of new physics. Invited Seminar, IPHC Strasbourg, 2021

Enhancing Gravitational-Wave Science with Machine Learning. Invited LUTH Seminar, Paris Observatory, Jan 2021

Enhancing Gravitational-Wave Science with Machine Learning. Invited LASTRO Seminar, EPFL (Switzerland), Jan 2021

Enhancing Gravitational-Wave Science with Machine Learning. Invited seminar at the Institute for Computational Science, University of Zürich (Switzerland), Nov 2020

Enhancing Gravitational-Wave Science with Machine Learning. Accelerated AI for Big Data Experiments, Oct 2020

Testing spacetime birefringence with gravitational waves. GdR Gravitational Waves: General Assembly, Oct 2020

Prediction black holes remnant parameters with neural networks. Swiss National Science Foundation Fellows Conference, Jul 2020

Machine learning applications to gravitational waves modelling. Paris Center for Cosmological Physics Workshop: Bayesian Deep Learning for Cosmology and Gravitational Waves, Mar 2020

A new phenomenological time-domain model of gravitational waveforms for tests of general relativity in LIGO/Virgo. GdR Gravitational Waves: Waveforms and Tests of Relativity, Feb 2020

H Halloin :

LISA at APC, LISA France Meeting, Paris, Oct 2017

LISA: Hearing the Heavens, Seminar at LAM, Marseille, Apr 2018

MOSA AIVT Plan, LISA AIVT Workshop, Nice, May 2017

LISA: Hearing the Heavens, Journées GRAM, Besancon, Jun 2018

Cours LISA, Paris, 24-25 Jul 2018

System level Straylight studies, LISA Consortium Meeting, Marseille, Nov 2018

LISA: Hearing the Heavens, Seminar at CPPM, Marseille, May 2019
LISA On Table: un simulateur de table pour LISA, Rencontre de Technologies Spatiales du CNES, Paris, Jun 2019
LISA Status and LISA France Activities, GdR Ondes Gravitationnelles, Jun 2019
High precision metrology in the milliHz to Hz regime, Séminaire de prospective IN2P3 Détecteurs et Instrumentation Associée, Jan 2020
LISA: Hearing the Heavens, MEMO Student Chapter Webinar 'Optics for Space', online, May 2020
Development of Optical Demonstrators for the Integration of the LISA Instrument, LISA Symposium XIII, online, Aug 2020
Cours LISA, online, Jan 2021
Optical demonstrators and performance tests of the LISA instruments, GdR 'Ondes Gravitationnelles - Workshop Instrumentation, online, Apr 2021
LISA: Un détecteur spatial à l'écoute de l'Univers, Les 50 ans de l'IN2P3 à l'APC, Paris, Jul 2021
LISA: The Instrument, IPhU Gravitational Waves mini-conference, online, Jul 2021
IGOSat : un nanosatellite pour l'étude de l'environnement radiatif terrestre, Webinaire Nanosatellite CurieSat/CENSUS, online, Oct 2021

JC Hamilton :

QUBIC. CPPM Seminar, Marseille, France, Sep 2021
QUBIC. CosmoGlobe Workshop, Oslo, Norway, Jun 2021
QUBIC. B-Modes from Space, Munich, Germany, Dec 2019
CMB Polarization. Biennal du LLR, Toulouse, France, Sep 2019
QUBIC. CNEA Seminar, Buenos Aires, Argentina, Nov 2021
QUBIC. WIN2019, Bari, Italy, Jun 2019
QUBIC. Tenerife, Spain, Oct 2018
QUBIC. LLR Seminar, Palaiseau, Feb 2018
QUBIC. Prospectives CMB France, Paris, Jan 2018
QUBIC. École Chalonge-De Vega, Paris, Nov 2017
QUBIC. Observatorio Nacional de La Plata, Argentina, Aug 2017
QUBIC. Ministry of Science and Technology, Argentina, Aug 2017

E Huguet :

TEGR as a gauge theory: Translations and Cartan connection. Teleparallel Gravity Workshop COSMOGRAV 2020 Tartu, Estonia, Jun 2020

H Inchauspé :

LISA Symposium XIII, Contributed Talk: LISA dynamics in LISANode: A first implementation of the closed-loop dynamics of the constellation, Sep 2020
Cinquième assemblée GdR ondes gravitationnelles, Contributed Talk: LISA Dynamics & Control: DFACS Simulation and Optimization, Noise assessment and Data processing, Annecy, Oct 2021
Organisation d'un cycle de séminaires de Philosophie des Sciences (avec L. Haegel), The Möbius Seminars, ayant vocation de rapprocher les communautés de philosophes et de physiciens, et plus largement d'ouvrir nos thématiques communes au grand public

B Khélifi :

The 2nd Thai-CTA workshop on Astroparticle Physics: hands-on session with Gammapy, the CTAO Science Tools, remote, 2021
Gammapy: a python package for gamma-ray astronomy, International Cosmic-Ray Conference, Berlin, 2021
Discovery of 100 TeV gamma-rays from HESS J1702-420: a new PeVatron candidate, International Cosmic-Ray Conference, Berlin, 2021
Revisiting the PeVatron candidate MGRO J1908+063 with an updated H.E.S.S. analysis, International Cosmic-Ray Conference, Berlin, 2021
Searching for PeVatrons with CTA, COSPAR Scientific Assembly, Sydney, 2020
Detection of sub-100 GeV gamma-ray pulsations from PSR B1706-44 with H.E.S.S., International Cosmic-Ray Conference, Madison, 2019
CTA observations: from proposal to high-level data analysis, Texas Symposium, Cape Town, 2017
H.E.S.S. array stereoscopic observations of the Vela pulsar above 100 GeV, Texas Symposium, Cape Town, 2017

M Khlopov :

Search for double charged particles as direct test for Dark Atom Constituents. Invited talk at 20th Anniversary Workshop "What comes beyond the standard models", Bled, Slovenia, Jul 2017
Problems of dark matter physics. Invited talk at 21st Workshop "What comes beyond the standard models", Bled, Slovenia, Jun 2018
Time dependent dark energy. 18th Colloque national Dark Energy, 2ème édition IAP, Paris, Oct 2018
Dark atom solution for puzzles of direct dark matter searches. Invited Talk at 9th Symposium on Large TPCs for Low-Energy Rare Events, APC, Paris, Dec 2018
The nature of dark matter in the context of Zeldovich's legacy in cosmoparticle physics. Seminar dedicated to 105 Anniversary of Ya. B. Zeldovich .SAI, Moscow, Russia Mar 2019
Primordial nonlinear structures as cosmological reflection of particle symmetry. Invited VIA talk at Bahamas Advanced Studies Institute and Conferences (BASIC), The 2 BASIC Workshop on Solitons, Instantons, and Other Nonlinear Phenomena, Bahamas, Apr-May 2019
Conspiracy of BSM physics and cosmology. Invited talk at 22 Workshop "What comes beyond the standard models", Bled, Slovenia, Jul 2019
Cosmoparticle physics of dark matter. Invited talk at Third Symposium of the BRICS Association on Gravity, Astrophysics and Cosmology. Kazan, Russia, Aug-Sep 2019
Cosmoparticle physics of dark matter. Invited talk at XXIV International Workshop High Energy Physics and Quantum Field Theory, Sochi,Russia, Sep 2019
Unveiling conspiracy of nonstandard cosmology. Atelier Théories of III National action "Dark Energy", Paris, Nov 2019
New trends in BSM physics and cosmology. Invited talk at the Online 23d Workshop "What comes

beyond the standard models", Cosmovia, Jul 2020
Multi-messenger cosmological probes for new physics in the light of Ya.B.Zeldovich's Legacy. Invited talk at The Fourth Zeldovich virtual meeting. An international conference in honor of Ya. B. Zeldovich, ICRA-Net, Sep 2020
Multi-messenger cosmology of new physics. Invited talk at 5 International Conference on Particle physics and Astrophysics, dedicated to 90th anniversary of B.A.Dolgoshein (ICPPA2020), Moscow, Russia, Oct 2020
Primordial Black holes as probes for physics of the modern cosmology. Invited Talk at the International webinar "Adventures with Black holes: Unfolding the Nobel prize winning discoveries in Physics 2020" Organized by University of Lucknow, India, Oct 2020
Multimessenger probes for physics of the modern cosmology. Invited talk at International Webinar on Recent Advances in Science and Technology (RAST-2020) organized by Indira Gandhi Institute of Technology, Sarang, India, Nov 2020
Multimessenger probes for new physics in the light of A.Sakharov's legacy in cosmoparticle physics. Satellite Workshop "Developing A.D.Sakharov Legacy in cosmoparticle physics" of 1 Electronic Conference on Universe (ECU2021), Feb 2021
Fundamental relationship of BSM Physics and BSM Cosmology. Invited talk at Beyond Standard Model: From Theory to Experiment (BSM-2021), online, Mar 2021
Developing A.D.Sakharov Legacy in cosmoparticle physics. Invited talk at the Memorial meeting, dedicated to 100th Anniversary of Andrei Dmitrievich Sakharov, May 2021
BSM Cosmology from BSM Physics. Invited talk at the Online 24th Workshop "What comes beyond the standard models", Cosmovia, Jul 2021
Cosmoparticle physics - towards a fundamental physical basis for cosmology. Invited talk at Physics and astrophysics - from fundamental constants to cosmology. In memory of D.A. Varshalovich". St.Petersburg, Russia, Sep 2021

E Kiritsis :

"Non-relativistic scale invariant theories and their hydrodynamics". Invited talk at the Workshop "Holography and Quantum Matter", IFT, Madrid, Spain, Sep 2017
" Finite density and CP-odd physics in V-QCD". Invited talk presented at the workshop "Holographic dense QCD and neutron stars", ENS, Paris, France, Nov 2017
"Non-relativistic scale invariant theories and their hydrodynamics". Invited talk given at the workshop "Aspects of Time-dependent Holography", Amsterdam, The Netherlands, Dec 2017
"Holography and the Quantum Renormalization Group". Invited talk given at the workshop, "Athens Xmass meeting in Theoretical Physics", Athens, Greece, Dec 2017
"Holographic self-tuning of the cosmological constant". Invited talk given at "Gravity and Cosmology 2018", Kyoto, Japan, Feb 2018
"Holographic RG flows at finite curvature". Invited talk given at the conference "Recent Developments in High Energy Physics and Cosmology", Athens, Greece, Mar 2018
"Exotic Holographic RG Flows at zero and finite curvature". Invited talk given at the "Eurostrings Conference", London, UK, Apr 2018
"Thermalization in a confining gauge theory". Invited talk given at the "15th Workshop on Non-Perturbative Quantum Chromodynamics", Paris, France, Jun 2018
"Holographic RG flows on curved manifolds and F-functions". Invited talk given at the "Conference Gauge/Gravity Duality 2018", Würtzburg, Germany, Jul 2018
Chair of the panel discussion on Holography applications to condensed matter physics. Workshop: "Bringing Holography to the Lab: Explaining Strange Metals with Virtual Black Holes", Leiden, The Netherlands, Jan 2019
"Scale Invariance and its breaking in Cosmology". Invited talk given at the Workshop: Scale Invariance in particle Physics and Cosmology CERN, Geneva, Jan 2019
"C-functions and C-theorems: from the master equation to entaglement entropy". Talk given at the Conference: "From mesons to orbifolds via affine Lie algebras", Berkeley, CA, Mar 2019
"Renormalization group flows beyond perturbation theory". Invited talsk given at the "Annual Conference of Greek High Energy Physics", Athens, Greece, Apr 2019
"On de Sitter realizations in gravity and string theory". Talk given at the Workshop: "String Geometry and String Phenomenology Institute", CERN, Geneva, Jun 2019
"Emergent gravity from hidden sectors". Invited talk given at the Conference: "What lies ahead of the Standard Model", Bled, Slovenia, Jul 2019
Panel Chair: "Where in the cosmos should we look for new physics?" at the Workshop: Cosmological Frontiers of Fundamental Physics, Perimeter Institute, Canada, Sep 2019
"Two novel Roads to de Sitter in string theory". Invited talk given at the Xmass Theoretical Physics Workshop, Athens, Greece, Dec 2019
"Composite and holographic axions". Invited talk given at "Iberian Strings 2020", Santiago de Compostella, Spain, Jan 2020
"Holographic RG Flows on curved manifolds and F-theorems". Invited talk given at "Frontiers of Holography", Moscow, Russia, Apr 2020
"Emergent gravity and the self-tunning of the cosmological constant". Invited talk given at "What comes beyond the Standard Model", Bled, Slovenia, Jul 2020
"Emergent gravity from hidden sectors and TT deformations". Invited talk given at "The dual mysteries of gauge theories and gravity", Chennai, India, Oct 2020
Panel chair "On the nature of Quantum Gravity" at the Workshop: Quantum Gravity, Holography and quantum information, Munich, Germany, Mar 2021
"Emergent gravitons and dark photons from strongly coupled sectors". Invited talk given at "Beyond the Standard Model: from theory to experiment", Zewail City, Egypt, Mar 2021

"Emergent gravity and cosmology". Talk at the Workshop: The theoretical Physics of two infinities, Paris, France, Jun 2021
"QFTs on de Sitter, holography and Coleman-de Luccia transitions". Invited talk at the Conference: "What comes beyond the Standard Model", Bled, Slovenia, Jul 2021
"Emergent Gravity from Hidden Sectors". Invited talk given at the Workshop on "New Developments in Quantum Gravity and String Theory", Corfu, Greece, Sep 2021
"Euclidean Wormholes". Invited talk given at the Workshop: " Physics Sessions Initiative", Heraklion, Greece, Sep 2021
"Holographic Self-tuning of the cosmological constant". Invited Seminar given at the Theory division, CERN, Geneva, Jul 2017
"Holographic Self-Tuning of the Cosmological Constant". Invited Seminar given at DAMPT, Cambridge, UK, Oct 2017
"Holographic Self-Tuning of the Cosmological Constant". Invited Seminar given at Peierls Institute, Oxford, UK, Nov 2017
"Holographic RG Flows at zero and finite curvature". Invited Seminar given at the Yukawa Institute, Kyoto, Japan, Feb 2018
"Holographic RG flows on curved manifolds and F-functions". Invited Seminar given at the Theory Division, CERN, Geneva, Aug 2018
"Emergent Gravity from Hidden Sectors". Invited Seminar given at LMU, Munich, Germany, Oct 2018
"RG flows beyond perturbation theory". Invited Colloquium given at Trinity College, Dublin, Ireland, Jan 2019
"Emergent Gravity from Hidden sectors". Invited Seminar Given at UC Berkeley, USA, Mar 2019
"Holographic RG flows on flat and curved manifolds and F-functions". Invited Seminar given at Stanford University, Palo Alto, USA, Mar 2019
"Emergent gravity and axions from hidden sectors". Invited Seminar given at Democritus Institute, Athens, Greece, Apr 2019
"Holographic RG flows on flat and curved manifolds and F-functions. Invited Seminar given at the University of Torino, Italy, Jun 2019
"Emergent Gravity from Hidden sectors". Invited Seminar Given at the Theory Division of CERN, Geneva, Aug 2019
"Emergent Gravity from Hidden sectors". Invited Seminar Given at the Central European Institute for Cosmology and Fundamental Physics, Prague, Feb 2020
"Composite and Holographic axions, and the dynamics of instanton densities". Invited Seminar Given at the University of Wien, Vienna, Austria, Apr 2020
"The self-tuning of the cosmological constant and the holographic relaxion". Invited Seminar given at the City College of New York, USA, May 2020
"Holographic RG Flows on curved manifolds and F-theorems". Invited Seminar given at the Israel Triangular seminar, Neve Shalom, Israel, Jun 2020
"Emergent Gravity from Hidden sectors and TT deformations". Invited Invited Seminar given at EPFL, Switzerland, Nov 2020
"Emergent Gravity from Hidden sectors and TT deformations". Invited Seminar given at Imperial College London, Feb 2021
"Emergent Gravity from Hidden sectors and TT deformations". Invited Seminar given at the University of Wien, Vienna, Austria, Jul 2021
"QFTs on de Sitter, Holography and Coleman-de Luccia transitions". Invited Seminar given at the Theory Division of CERN, Geneva, Nov 2021

A Kouchner :

High-Energy Neutrino Searches in the Mediterranean Sea: probing the Universe with ANTARES and KM3NeT/ARCA. On behalf of ANTARES, 3eme Rencontres du Vietnam, Quy Nhon, Vietnam, Jul 2017
High-Energy Neutrino Searches in the Mediterranean Sea. Invited talk at 18th Lomonosov Conference, Moscow, Russia, Aug 2017
Review on High-Energy Neutrino Astronomy. Integral Symposium, Venice, Italy, Oct 2017
ANTARES et KM3NeT : détecteurs sous-marins de neutrinos. Seminaire à la faculté des sciences de l'university Cadi Ayyad, Marrakech, Maroc, 10 Octobre 2017
Highlights from ANTARES and KM3NeT/ARCA. On behalf of the ANTARES & KM3NeT Collaboration. 29th Texas Symposium on Relativistic Astrophysics. Cape Town, South Africa, Dec 2017
Atmospheric mass ordering measurements. Invited talk at NuPhys2017: Prospects in Neutrino Physics, Dec 2017, London
Measuring the neutrino mass ordering and more with KM3NeT-ORCA. Talk on behalf of KM3NeT, 35th International Cosmic Ray Conference 2017, Busan, South Korea, Dec 2017
Atmospheric mass ordering measurements. NuPhys2017: Prospects in Neutrino Physics, London, Dec 2017
Deep Sea Neutrino Telescopes. Invited Seminar at the Mathematics and Physics Department of Roma Tre University, Mar 21st 2018
Tiny but Mighty: Neutrinos and the New Frontiers of Science. Invited talk at European Science Open Forum, Toulouse, Jul 2018
Advances in Neutrino Astrophysics. Invited talk at High Energy Astrophysics in Southern Africa (HEASA 2018), Parys, South Africa, Aug 2018
Highlights from ANTARES. Very Large Volume Neutrino Telescope, Dubna, Russia, Oct 2018
Neutrino Astronomy. Invited talk at HE physics Conference, Constantine, Algeria, Oct 2019
Neutrino Studies in the Mediterranean Sea: from ANTARES to KM3NeT. 12th workshop of France China Particle Physics Laboratory, Shanghai, China Apr 2019
Neutrino Astronomy. Invited talk HE physics Conference, Constantine, Algeria, Oct 2019
Detecting Neutrinos Underwater and Under Ice. Invited Seminar at the physics department of the University of Sharjah (UAE) Nov 2019
What will the neutrino landscape look like in the next decade? Invited talk at Cosmic Rays and Neutrinos in the Multi-Messenger Era, Paris (remote), France, Dec 2020
Recent Results from ANTARES. Invited talk at The XIX International Workshop on Neutrino Telescopes, Venice (remote), Italy, Feb 2021

Underwater Neutrino Astronomy. Invited Seminar at DESY-Zeuthen (Germany) Jun 2021

C Lachaud :

The SVOM contribution to multi-messenger astrophysics. Talk given at 16eme rencontres du Vietnam, Theory Meeting Experiment : Particle astrophysics and cosmology, Quy Nhon, Vietnam, Jan 2020
The SVOM mission. Conseil Scientifique de l'IN2P3, Jul 2020

M Lamoureux :

ANTARES & KM3NeT/ARCA: present and future of neutrino telescopes in the Mediterranean Sea. Rencontres de Blois, Oct 2021

D Langlois :

Invited talk at Colloque “Energie noire et gravitation modifiée”, 24e congrès général de la SFP, Jul 2017
Invited lectures, Workshop DARKMOD 2017, Saclay & Orsay, Sep 2017
Invited talk at The 4th Conference of the Polish Society on Relativity Kazimierz Dolny, Poland, Sep 2017
Invited review talk at Colloque National “Dark Energy”, Orsay, Oct 2017
Invited lectures, Workshop “Gravity in the Early Universe”, Princeton, Jan 2018
Invited plenary talk at Yukawa International Seminar (YKIS) "General Relativity - The Next Generation -",Yukawa Institute for Theoretical Physics (YITP), Kyoto, Japan, Feb 2018
Invited talk at Workshop “Gravitational waves in modified gravity”, ETH Zurich, May 2018
Invited talk at GdR Ondes Gravitationnelles: Atelier aux Journées de la SF2A Bordeaux, Jul 2018
Invited talk at Assemblée Générale du GdR Ondes Gravitationnelles, Univ Diderot, Paris, Oct 2018
Invited talk at Workshop "Black Holes and Neutron Stars in Modified Gravity", Meudon, Nov 2019
Invited talk at Conference "New Trends in Physics", Académie polonaise des sciences, Paris, Nov 2019
Invited talk at 7th Korea-Japan Workshop on Dark Energy (on line), Dec 2020
Invited talk at Workshop "Current challenges in gravitational physics", SISSA (on line), Apr 2021
Invited talk at Quarks Workshop " Quantum Gravity and Cosmology", Russia (on line), Jun 2021
Invited talk at Quarks Workshop “Modification of Gravity: Theories and Observations”, Russia (on line), Jun 2021

A Li :

Perspectives for Higgs measurements at Future Colliders. Talk at the 22nd edition of Particles and Nuclei International Conference (PANIC2021), online, Sep 2021
ZH and mH studies at FCC-ee. Talk at Higgs2021 conference, online, Oct 2021

A Lemiere :

The neutron star binary merger GW170817 observation with HESS. Talk at Workshop on GW170817, Paris (FRANCE), Oct 2017
The excess of Cosmic-rays at the Center of our Galaxy with HESS. Talk at TEXAS Symposium, Cap Town (South Africa), Dec 2017
The Galactic Center observed in gamma-rays. Invited Seminar, Berlin (Germany), Jun 2017
The Galactic Center observed with HESS. Talk at COSPAR, Los Angeles (USA), Jul 2018
Origin of the VHE cosmic-ray excess at the Galactic Center. Talk at Workshop Searching for sources of Galactic CRs, Paris (FRANCE), Dec 2018

A Mangiagli :

Parameter estimation for inspiralling MBH binaries in LISA. Talk at Meeting of the National Research Group on Gravitational Waves, Institut Henri Poincaré, Apr 2021
Unveiling early black hole growth with multi-frequency gravitational wave observations. Talk at 3rd LISA Astrophysics Working Group Meeting, University of Zurich, Jun 2021

G Marchiori :

Higgs boson measurements in decays to boson final states in ATLAS. Invited talk at the Higgs Hunting 2021 conference, online, Sep 2021

S Marsat :

Sky localization and parameter estimation of massive black hole mergers with LISA, GdR Gravitational Waves General Assembly, Paris, France, 2021
Localizing massive binary black holes with LISA, GWMess conference at IHP, Paris, France, 2021
Simulating the parameter recovery of massive binary black holes with LISA, GdR Gravitational Waves Data Analysis Workshop, Paris, France, 2020
Parameter estimation and sky localization of massive binary black holes with LISA, GdR Gravitational Wave General Assembly, Paris, France, 2020
Analyzing massive binary black holes with LISA: the role of high frequencies and higher harmonics, LISA symposium main session, en ligne, 2020
Characterizing binary black hole signals with LISA, GdR Gravitational Waves assembly, Lyon, France, 2019
Parameter estimation for binary black holes in LISA, Moriond conference on gravitation, La Thuile, Italie, 2019
Frequency-domain waveforms and instrument response for LISA, Workshop on Reduced Order GW modeling, Potsdam, Allemagne, 2018

J Martino :

Performance des micro-propulseurs dans LISA. Workshop joint Microscope-LISA. CNES Toulouse, Sep 2017
Résultats de LISA Pathfinder et la mission LISA. Journées de la gravitation de la SFP, Nov 2017
Résultats de LISA Pathfinder. Journée détecteurs du GDR Ondes gravitationnelles, Jun 2018

Searching for GW echoes with GWTC-1 using a morphology-independent template bank. Invited talk at GWverse, COST action meeting, Portugal, Lisbon, Sep 2021
Data analysis with $3rd$ generation detectors. Invited talk at Physics and Astrophysics at the Extreme VII, Remote, Aug 2021
Studying the Universe with Gravitational waves. Invited talk at Subat-

ech Laboratory, Nantes, France, Jul 2021

On the importance of populations for gravitational-waves cosmology. Talk at European Physical Societe conference, Remote, Jul 2021

On the importance of populations for gravitational-waves cosmology. Talk at 14th International Amaldi Conference, Remote, Jul 2021

Estimating the Hubble constant with GWcosmo and GW170817. Talk at Groupement de recherche ondes gravitationelles - data analysis workshop, Remote, Nov 2020

Population properties of compact objects from the second LIGO–Virgo Gravitational-Wave Transient Catalog. Invited talk at Online LIGO Virgo webinar, Nov 2020

Tests of general relativity and cosmology with gravitational from binary neutron stars. Talk at 3ème Assemblée générale du GdR Ondes Gravitationnelles, Remote, Oct 2020

The road to precision cosmology with gravitational waves and ground based detectors. Invited talk at Réunion du Groupe de Travail Cosmologie, Paris, France Nov 2019

How-to: testing alternatives theories of gravity with gravitational waves. Talk at Assemblée générale du Groupement de recherche ondes gravitationelles, Lyon, France, Oct 2019

Measuring The Impact Of The Gravitational Wave Intrinsic Geometry On The Hubble Constant Measure. Talk at Amaldi13/GR22, Valencia, Spain, Jul 2019

Full Coherent Searches For Continuous Gravitational Waves With The Ligo Second Observing Run at Amaldi13/GR22, Valencia, Spain, Jul 2019

S Mei :

From the CARLA survey experience : Why do we need multi-object spectroscopy for the study of cluster and protoclusters at $z > 1.5$. Talk at Massively Parallel Large Area Spectroscopy from Space, Jun 2021

Quenching and star-forming in CARLA clusters and proto-clusters at $z > 1.5$. Talk atAmerican Astronomical Society, Jun 2021

Clusters and proto-clusters at $z > 1.5$: the CARLA survey and lessons learned for Euclid. Invited talk at Cluster France 2020, Paris, Nov 2020

Summary talk and future of the field. Invited talk at the virtual conference 2020 Proto-clusters: galaxies in confinement, Sep 2020

Galaxy evolution and IGM in clusters and proto-clusters at $z > 1.5$. Invited talk at workshop First galaxies, First structures, Oct 2019

Compactification, mergers and quenching in CARLA clusters and proto-clusters at $z > 1.5$. Talk at Birth, life and fate of massive galaxies and their central beating heart, Favignana, Sep 2018

Quenching of galaxies in cluster/proto-clusters at $z \sim 2-3$. Talk at Galaxy formation and evolution, Santa Cruz, Aug 2017

L Mousset :

Status of QUBIC, Rencontres de Blois, Oct 2021

Latest calibration results from QUBIC, RadioNet Workshop, Sep 2020

Latest calibration results from QUBIC, Conférence Elbereth, Feb 2020

Exploring the primordial Universe with QUBIC, Rencontres des Jeunes Physicien.ne.s, Nov 2019

V Niro :

Neutrinos from galactic sources and the perspective for the coming years. Invited talk at Town Hall KM3NeT Meeting, Marseille, Dec 2019

Neutrinos from galactic sources. Talk at ICHEP 2020, virtual conference, Jul 2020

Galactic neutrino sources. Talk at Cosmic Rays and Neutrinos in the Multi-Messanger Era, virtual conference, Dec 2020

Neutrinos from galactic sources. Invited talk at CEICO seminars, Prague (online), May 2021

Neutrinos from galactic sources. Talk at VLVnT 2021, virtual conference, May 2021

Neutrinos from galactic sources. Talk at WIN 2021, virtual conference, Jun 2021

Neutrinos from galactic sources. Talk at ICRC 2021, virtual conference, Jul 2021

Neutrinos from galactic sources. Talk at TAUP 2021, virtual conference, Aug 2021

F Nitti :

Holographic self-tuning of the cosmological constant. Invited talk at the workshop Modern aspects of Gravity and Cosmology, LPT Orsay, Nov 2017

Holographic self-tuning of the cosmological constant. Invited talk at the 9th Crete Regional Meeting in String Theory, Kolymbari, Greece, Jul 2017

Holographic self-tuning of the cosmological constant. Invited talk at Gravity and Cosmology Workshop, Kyoto, Japan, Jan 2018

Axion holographic RG flows and the dynamics of topological densities. Invited talk at the Workshop Holographic QCD, Stockholm, Sweden, Jul 2019

Self-tuning and cosmology in a holographic braneworld. Invited talk at the conference Cosmological Frontiers in Fundamental Physics,Waterloo, Canada, Sep 2019

Self-tuning and cosmology in a holographic braneworld. Invited talk at the 10th Crete Regional Meeting in String Theory", Kolymbari, Greece, Sep 2019

Two routes to de Sitter in holography. Invited talk at the workshop De Sitter Constructions in String Theory, IPhT Saclay, Dec 2019

Axion holographic RG flows and the dynamics of topological densities. Invited talk at the Simons Center workshop Application of gauge topology, holography and strings models to QCD, online, Jul 2020

Holographic routes to de Sitter. Invited talk at the online conference Cosmological Frontiers in Fundamental Physics, May 2021

Holographic theories at finite θ-angle, glueball spectra and instanton condensation. Invited talk at the Simons Center workshop Application of gauge topology, holography and strings models to QCD, online, Aug 2021

T Papanikolaou :

Primordial Black Holes from the Preheating Instability. Poster at

the COSMO19 Conference, Aachen, Germany, Sep 2019
Constraining Reheating with Primordial Black Holes. Elbereth Conference, Paris, Feb 2019

E Parizot :

Trust and doubt: a subtle balance between two essential driving forces of Science Invited talk at the WEXD Conference on “Trust, Expert Opinion and Policy”, Dublin, Ireland, Sep 2017
The space road to UHECR observations: challenges and expected rewards. Invited talk at the ISVHECRI 2018 conference, Nagoya, Japan, May 2018
The space road to UHECR observations: challenges and expected rewards. Invited talk at the UHECR 2018 conference, Paris, France, Oct 2018
Ultra High Energy Cosmic Rays and Neutrinos. Invited talk at IGC@25: The Multi-Messenger Universe (25 years Jubilee of Institute for Gravitation and the Cosmos), Penn State University, USA, Jun 2019

G Patanchon :

Planck results. Invited plenary talk at the conference "International Pulsar Timing Array", Sèvres, Jul 2017
Systematic effects in Planck: Evaluation, Processing and lesson learned. "B-mode from space" conference, at the University of Berkeley, USA, Dec 2017
Results from the Planck High Frequency Instrument, lesson learned, LiteBIRD Kick-off Symposium, Tokyo, Japan, Jul 2019
Planck-HFI lessons learned on systematics and calibration. Online plenary session talk at the Workshop "CMB systematics and calibration", IPMU, Tokyo, Dec 2020

T Patzak :

“Status of the DUNE Experiment”. Invited talk at the 15th International Workshop on non-perturbative QCD, IAP, Paris, Jun 2018

A Petiteau :

The LISA mission: status and perspectives for PNHE, Journées PNHE, Remote, Sep 21
LISA Observing GW Universe from space, Workshop GW Probes of Physics Beyond Standard Model, Remote, Jul 21
LISA Science and Ground Segment, IPHU conference on Gravitational Waves, Remote, Jul 21
The LISA mission Instrument, GWAECS Workshop, Remote, Jun 21
LISA Data Processing Group, LISA Canada workshop, Remote, Apr 21
LISA: Observing Universe with Gravitational Wave from space, ISCO 2020, Remote, Apr 21
Observing Universe With Low Frequency Gravitational Wave, Séminaire Les Mines, Remote, Dec 20
Challenges of LISA data analysis, LISA Finland, Helsinki, Feb 20
LISA: from onboard measurements to Gravitational Wave Data Analysis, Seminar at Astrophysics department, Birmingham, Birmingham, Oct 19
Observing the Gravitational Universe with LISA, NORDITA GW from the Early Universe, Stockholm, Sep 19
LISA: Observing Gravitational Wave From Space, IPTA, Pune, Jun 19
Scientific Challenges with LISA, GRASS, Padova, Nov 18
LISA: Observing Gravitational Wave From Space, Séminaire CENBG, Remote, Nov 18
Laser Interferometer Space Antenna, Assemblé générale GdR OG, Paris, Oct 18
LISA Data Processing Group, LISA Symposium 12, Chicago, Jul 18
LISA: exploring the Universe using low frequency gravitational waves, Journée de prospectives pour le futur des OGs, Orsay, Jun 18
Pulsar Timing Array, Journée de prospectives pour le futur des OGs, Orsay, Jun 18
LISA: exploring the Universe using low frequency gravitational waves, Colloquium Bielefeld, Bielefeld, Apr 18
LISA: des précisions métrologiques extrêmes pour l’observation de l’Univers gravitationnel depuis l’espace , Journée de l’innovation CNES, Toulouse, Jan 18
LISA (distributed) Data Processing Center, KISS workshop "The Architecture of LISA Science Analysis", Pasadena, Jan 18
LISA: observing gravitational waves from space, Séminaire CPPM, Marseille, Nov 17
LISA Ground Segment, SciOps 2017, Villafranca del Castillo, Oct 17
Gravitational waves and space experiments, Ecole de Gif, Orsay, Sep 17
LISA data analysis: observing gravitational waves sources from space, ETH Seminar, Zurich, Sep 17
From LISAPathfinder to LISA: space-based observatory for gravitational waves, IPTA 2017, Sèvres, Jul 17
From LISAPathfinder to LISA: space-based observatory for gravitational waves, SF2A, Paris, Jul 17
Data Analysis and GW Observatory, School on Gravitational Waves for Cosmology and Astrophysics, Benasque, Jun 17
Data Analysis for PTA, IPTA student week, Sèvres, May 17

M Piat :

Millimeter/sub-millimeter detection: Transition Edge Sensors. Rencontre de Technologies Spatiales CNES, Paris, Jun 2018
Planar detection architecture for CMB polarisation observations. Atelier COMET CNES "Les charges utiles et les technologies du futur de la bande W à l’infrarouge lointain", session "détection directe", Toulouse, Oct 2018
TES Bolometer Arrays for the QUBIC B-Mode CMB Experiment. Invited. 18th International Workshop on Low Temperature Detectors (LTD-18), Milan, Jul 2019

S Pita :

Looking for infrared counterparts of Fermi/LAT blazar candidates. ICRC 2017, Busan Korea, Jul 2017
Studying cosmological γ-ray propagation with the Cherenkov Telescope Array. ICRC 2017, Busan Korea, Jul 2017
Extragalactic source population studies at very high energies in the Cherenkov Telescope Array era. ICRC 2017, Busan Korea, Jul 2017
Testing cosmology and fundamental physics with the Cherenkov Telescope Array. ICRC 2019, Madison

USA, Jul 2019
Southern African Large Telescope Spectroscopy of BL Lacs for the CTA project. ICRC 2021, Berlin, Germany, Jul 2021
CTA sensitivity for probing cosmology and fundamental physics with gamma rays. ICRC 2021, Berlin, Germany, Jul 2021

E Porter :

LIGO/Virgo: current status and future plans. Invited talk International Pulsar Timing Array symposium, Sevres, France, Jul 2017
Characterising IMBHs/IMRIs for 2G/3G detectors. Invited talk Physics and Astrophysics and the eXtreme (PAX) workshop, Amsterdam, The Netherlands, Aug 2017
GW170817 and implications for fundamental physics. Invited talk Workshop on holographic dense QCD and Neutron Stars, ENS Paris, Nov 2017
Astrophyics, cosmology and fundamental physics in the age of GW astronomy. Invited talk Modern aspects of Gravity and Cosmology, LPT, Orsay, France, Nov 2017
Astrophyics, cosmology and fundamental physics in the age of GW astronomy. Invited talk Journée 'La Gravitation', Division champs et particules de la SFP, Nov 2017
Implications of the LIGO/Virgo GW detections for fundamental physics and cosmology. Invited plenary talk 30th Rencontres de Blois, Blois, France, Jun 2018
The LIGO/Virgo GW detections: implications for fundamental physics and cosmology. Invited talk Gravity, cosmology and physics beyond the standard model, UPMC, Paris, France, Jun 2018
Computing requirements in the 3G era. Invited talk DAWN IV workshop, Amsterdam, The Netherlands, Aug 2018
What have we learned about the nuclear equation of state from GW170817? Invited talk GdR Resanet et Ondes Gravitationnelles, Observatoire de Paris, Paris, France, Sep 2018
Investigating fundamental physics and cosmology with Advanced LIGO / Advanced Virgo. Invited talk Colloque Nationale Dark Energy, IAP, Paris, France, Oct 2018
A Hamiltonian Monte Carlo algorithm for Bayesian inference of compact binary coalescences. Invited talk Computing challenges in GW astronomy, IPAM - UCLA, Los Angeles, USA, Jan 2019
Detecting gravitational waves, Journées thématiques Ondes Gravitationnelles, Lyon, France, Feb 2019
Measuring the neutron star equation of state using binary neutron star sources, Nuclear equation of state meeting, Observatoire de Paris, Paris, France, Mar 2019
The basics of compact binary searches, LVK Open Data Workshop, APC, Paris, France, Apr 2019
The detection of compact binary mergers using the Advanced LIGO and Advanced Virgo detectors. Invited plenary talk GR22/Amaldi 13 conferece, Valencia, Spain, Jul 2019
Compact binary mergers during the Advanced LIGO/VIRGO O3a observation run. Invited talk GdR Ondes Gravitationnelles, Lyon, France, Oct 2019
Gravitational Waves: a new window on the universe. Invited talk Conseil Scientifique Observatoire de Paris, Paris, France, Sep 2020
GWTC-2: the O3a catalog of GW sources, TS-2020 Meeting, Remote, Dec 2020
The Einstein Telescope, GWMess 2021, Remote, Mar 2021
Fundamental physics and cosmology after the second LIGO/Virgo GW catalog. Invited plenary talk Quarks 2021, Remote, Jun 2021
DeepHMC: a deep neural network based Hamiltonian Monte Carlo algorithm for BNS parameter estimation. GWMull 2021, Remote, Jul 2021
Future plans for the LVK network and for the Einstein Telescope. Journée PNHE, Remote, Sep 2021
The gravitational wave universe. Physics in Collision 2021, Aachen, Germany, Sep 2021
The Einstein Telescope: Data Analysis, Virgo France meeting, Lyon, France, Sep 2021

D Prêle :

Warm front end electronic modelization for the X-IFU ATHENA readout chain simulation, Conference on Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy X, part of SPIE Astronomical Telescopes + Instrumentation, 2020
SiGe Integrated Circuit Developments for SQUID/TES Readout, LTD17, Japan Jul 2017

M Punch :

ALTO concept and design choices, Workshop on a wide field-of-view Southern Hemisphere TeV gamma ray observatory, Puebla, Mexico, Nov 2016
Results from the simulations of the ALTO observatory. Invited talk at SGSO, for a Wide Field-of-View Gamma Ray Observatory in the Southern Hemisphere, Heidelberg, Germany, Oct 2018

S Recchia :

Cosmic Rays in the turbulent interstellar medium. TTK, AAchen, Apr 2019

A Roper Pol :

Gravitational wave radiation from early universe turbulence. Talk at the Spanish-Portuguese Relativity Meeting, online, Sep 2021

H Roussille :

Black hole perturbations in modified gravity. Talk at GWverse meeting, Lisbon, 2021
Black hole perturbations in modified gravity. Talk at Rencontres du GdR Ondes Gravitationnelles, Paris, 2021
Black hole perturbations in modified gravity. Talk at TUG workshop, Paris, 2021

S Sacerdoti :

*El experimento DUNE: la próxima generación de detectores de neutrinos.*Invited Talk at the RAFA, anual physics meeting in Argentina, virtual-Argentina, Oct 2021
Development of analog signal transmission in LAr for DUNE. Talk at LIDINE 2021, virtual-USA, Sep 2021
A LArTPC with Vertical Drift for the DUNE Far Detector. Talk at NuFact 2021, Cagliari, Italy, Sep 2021
A Vertical Drift LArTPC for the DUNE experiment. Poster at WIN 2021, virtual-USA, Jun 2021

D Semikoz :

Looking for the galactic sources of astrophysical neutrinos. Talk at "Perspectives in Astroparticle physics from High Energy Neutrinos (PAHEN)" workshop, Naples, Sep 2017
Measurement of intergalactic magnetic fields with gamma-ray telescopes. talk at CTA France meeting Paris Observatory, Paris, Oct 2017
Signatures if nearby supernova in cosmic ray data. Talk at seminar of CERN theory department, CERN, Geneva, Switzerland, Dec 2017
Signatures if nearby supernova in cosmic rays. Talk at EPFL seminar, Lausanne, Switzerland, Feb 2018
Looking for the origin of astrophysical neutrinos. Talk at INR RAS theory department seminar, Moscow, Russia, Mar 2018
Signatures if nearby supernova in cosmic ray data. talk at LAPP department seminar, JINR, Dubna, Russia, May 2018
Looking for the origin of the IceCube astrophysical neutrinos. Talk at GVD neutrino telescope meeting, Moscow, Russia, May 2018
Astroparticle physics perspectives and future. Summary lecture at International Baikal Summer School on Physics of Elementary Particles and Astrophysics, Lake Baikal, Russia, Jul 2018
Minimal model for UHECR and astrophysical neutrinos. Talk at UHECR-2018 conference, Paris, France, Oct 2018
Multimessenger astrophysics: science of 21 century. Public lecture at Russian School of Economy, Moscow, Russia, Feb 2019
Multi-messenger excess at TeV-PeV energy and Super-Heavy Dark Matter. Talk at INR Theory department seminar, Moscow, Russia, Feb 2019
First source of astrophysical neutrinos . Talk at IAP seminar, Paris, France, Apr 2019
Modelling IceCube neutrino flux and flux from point sources: what we can expect for GVD. Talk at GVD neutrino telescope meeting, Dubna, Russia, May 2019
Multi-messenger signatures of high energy neutrino sources. Talk at LAPP department seminar, JINR, Dubna, Russia, May 2019
Diffuse gamma-ray background by Fermi LAT. Talk at INR RAS theory department seminar, Moscow, Russia, Jul 2019
Gamma-rays and cosmology, intergalactic magnetic fields. Talk at Prospectives IN2P3 2020 - GT-04, Annecy, France, Nov 2019
Opening new windows on Early Universe with multi-messenger astronomy. Talk on ANR CES 31 meeting, Dec 2019
Diffuse gamma-ray background above 1 TeV. Talk on 10th LHAAS0 workshop, Nanjing, China, Jan 2020
Diffuse gamma-ray background. Talk on MPIK gamma-ray department seminar, Heidelberg, Germany, Feb 2020
Multi-messenger signatures of high energy neutrino sources. Talk on MPIK neutrino department seminar, Heidelberg, Germany, Feb 2020
LHAASO science case. Talk on SWGO seminar, Heidelberg, Germany, Feb 2020
Diffuse gamma-ray background above 1 TeV. Talk on SWGO collaboration meeting, online zoom, May 2020
Multi-messenger signal from Super-Heavy Dark Matter in neutrino and gamma-ray data. Bled workshop, online zoom, Jul 2020
Diffuse gamma-ray background above 1 TeV. Talk at LHAASO science workshop, Roma, online zoom, Jul 2020
Inter-Galactic Magnetic Fields . Talk at AGUILA meeting, online zoom, Oct 2020
Sources of astrophysical neutrinos . Talk at GVD neutrino telescope meeting, online zoom, Feb 2021
New gamma-ray measurements at $E > 100$ TeV and expectations for neutrino signal in Baikal. Talk at GVD neutrino telescope meeting, Moscow, Russia, Jun 2021
Multimessenger diffuse emission. IN2P3 theory meeting, online zoom, Jun 2021

J Serreau :

A perturbative window on the infrared regime of QCD. Invited seminar (zoom), Universidad de la República Montevideo, Uruguay, Jul 2021
The massive gluon and the massless pion. Invited talk at the 4th International Workshop on *Non-Perturbative Aspects of QCD WONPAQCD 2019*, Universidad de la República Montevideo, Uruguay, Dec 2019
The massive gluon and the massless pion. Talk at the international conf. LC2019 - QCD on the light cone: from hadrons to heavy ions, Ecole Polytechnique, Palaiseau, France, Sep 2019
Une histoire quantique de l'Univers : de l'univers primordial à nos jours. Conférence invitée pour la journée "Physique Quantique" organisée par l'association *Fête le Savoir*, Apr 2019
A mass for a mess. Invited talk at the 61ème anniversaire du Centre de Physique Théorique (CPHT) de l'École Polytechnique de Palaiseau, Paris, Mar 2019
Stability of de Sitter spacetime against infrared quantum scalar field fluctuations. Talk at the international workshop on The Universe as a Quantum Lab, Paris, Sep 2018
Backreaction of quantum scalar fields fluctuations on de Sitter geometry. Talk at the 9th International conference on the Exact Renormalization Group ERG, Paris, Jul 2018
Perturbative dynamics of massive gluons and chiral symmetry breaking. Talk at the 13th international conference on Strong and Electroweak Matter, SEWM2018, Barcelona, Jun 2018
Perturbative dynamics of massive gluons. Invited talk at the international workshop *From correlation functions to QCD phenomenology*, Physikzentrum Bad Honnef (Germany), Apr 2018

E Savalle :

The DAMNED experiment, Journées des jeunes chercheurs CNES, Toulouse, Oct 2021

GF Smoot :

“Introduction to Cosmology”, Enseigner l'Univers programme. Training workshop for high-school teachers, APC, 2018 and 2019
“An Introduction to Kinetic Inductance Detector (KIDs)”, PCCP Lecture Course, APC, May 2019

C Stahl :

Colloque national Action Dark Energy 3, Paris, Oct 2019
Mini-workshop : Cosmology and high energy physics. Invited talk "Primordial non-gaussianities or relativistic effects in LSS?", Montpellier, Feb 2020
News from the dark 5, Observatoire astronomique de Strasbourg, Jun 2020
GR simulations in cosmology, Queen Mary University of London, Sep 2020
Colloque national Action Dark Energy 4 (à distance), Oct 2020
Relativistic Aspects of Large-Scale Structure - Theory and Simulation (à distance). Contribution: "Relativistic effects: A contamination of primordial non-Gaussianities", May 2021
Ecole de Gif 2021 - Au delà du Modèle Standard de la Cosmologie, Marseille, Sep 2021
Ramses user meeting 2021, "`Bi-Poisson`: a `RAMSES` implementation of two coupled Poisson equations", remote meeting, Sep 2021
ICRANet-ISFAHAN Astronomy Meeting. Invited Talk: "Probing the first instants of the universe with large scale structure", remote meeting, Nov 2021

D Steer :

Latest gravitational wave constraints on cosmic strings, Cargèse workshop "Hot topics in modern cosmology", Cargèse, May 2017
General Relativiy and theories beyond. Invited lectures at the National Encounter of Physics Students, Lisbon, Portugal, Feb 2019
Gravitational waves and cosmology. Invited seminar Plymouth University, Apr 2021
Probing particle physics and cosmology with cosmic strings and gravitational waves. Invited seminar in "Copernicus International Webinar Seminar Series", Jun 2021
Cosmology with ET. Invited talk at "ET-France" workshop, Feb 2021
Le GDR Ondes gravitationnelles. Invited talk at "Virgo-France" workshop, Sep 2021
Probing particle physics and cosmology with cosmic strings and gravitational waves. Invited talk at the international conference "Gravitational Waves Probes of Physics Beyond Standard Model", Jul 2021
Cosmology with GWs. Invited talk at the international conference "DESY theory workshop 2021", Sep 2021
Strings of different kinds. Invited talk at the international conference "Remnants of the Big Bang", Arizona State University, 2020
Cosmology and tests of General Relativity with gravitational waves. Invited Seminar for cosmology group at Arizona State University, 2020
Cosmic strings and GW constraints. Invited seminar "6th LISA Cosmology working group workshop", Madrid, 2019
"Loops: from the Vinen equation to LIGO-Virgo constraints". Invited talk at international conference "Cosmic string workshop", Leiden, Oct 2018
Invited Seminar of the cosmology group, Arizona State University, 2018

R Stompor :

From few to kilo- and more detectors - a DA perspective. Invited talk, Workshop on European Coordination of the CMB effort, Florence, Sep 2017
Quest for CMB B-modes: from Polarbear to Simons Array and Observatory, and to LiteBIRD. Invited seminar at Laboratoire d'Accélérateur Linéaire, Orsay, Sep 2017
Computational challenges in CMB data analysis. Invited talk, Workshop on Analytics, Inference, and Computation in Cosmology, Paris, Oct 2018
Computational challenges in CMB data analysis. Invited talk, workshop on Fundamental physics with new CMB probes, Trieste, Oct 2019
Searching for CMB B-modes from ground and space. Invited seminar at Warsaw University Astronomical Observatory, Warsaw, Nov 2019

R Terrier :

Gammapy: a Python package for gamma-ray astronomy, Iternational Cosmic-Ray Conference, Berlin, 2021
Gammapy: An open tool for gamma-ray and multi-messenger astronomy, École thématique du LabEx UnivEarthS 2020, Dec 2020
Very high energy emission from the Galactic centre. Invited talk at the 42nd COSPAR Scientific Assembly. Pasadena, Jul 2018
An X-ray survey of the Central Molecular Zone: variability of the Fe K emission line, The X-ray Universe 2017, Rome, Jun 2017

A. Tonazzo :

Status of DUNE. Talk at the 15th International Workshop on Tau Lepton Physics, Amsterdam, Sep 2018

A Trovato :

LIGO/Virgo open science, ASTERICS DADI ESFRI Forum & Training Event, Trieste Italy, Dec 2017
Accessing data through LOSC. Open Data Workshop #1, Pasadena, US, Mar 2018
LIGO/Virgo open science, European Data Provider Forum & Training Event, Heidelberg, Germany, Jun 2018
Overview about machine learning in gravitational wave astronomy, Rencontre GdR ISIS-OG, Paris, Oct 2018
Gravitational Wave Open Science Center: how to access LIGO/Virgo open data. 1st Conference on Machine Learning for Gravitational Waves, Geophysics, Robotics, Control Systems, Pisa, Italy, Jan 2019
GWOSC: Gravitational Wave Open Science Center. The New Era of Multi-Messenger Astrophysics, Groningen, The Netherlands, Mar 2019
Gravitational Wave Open Science, Journées PhyFOG Paris, May 2019
Accessing and using GW open data, Gravitational Wave Open Data Workshop #2, Paris, May 2019
Machine-learning to exploit LIGO/Virgo single-detector data taking periods. GR22-Amaldi13, Valencia, Spain, Jul 2019
GWOSC: Gravitational Wave Open Science Center. 2nd Conference on Machine Learning for Gravitational Waves, Geophysics and Control Systems, Rijeka, Croatia, Sep 2019
GWOSC: Gravitational Wave Open Science Center. 2nd General Assembly of GdR Ondes Gravitationnelles, Lyon, Oct 2019

V Van Elewyck :

Multi-messenger astronomy with neutrinos, an experimental review. Invited talk at 26th workshop on Weak Interactions and Neutrinos (WIN 2017), UC Irvine USA, Jun 2017

KM3NeT/ORCA: status and perspectives for measuring the neutrino mass hierarchy and other oscillation parameters. Invited talk at Conference on Nuclear and Neutrino Physics (CNNP 2017), Catania Italy, Oct 2017

The Antares and Km3Net Neutrino Telescopes: Status And Outlook For Acoustic Studies. Invited talk at Conference on Acoustic and Radio EeV Neutrino Detection Activities (ARENA 2018), Catania, Italy, Jun 2018

Earth tomography with neutrinos in KM3NeT-ORCA. Talk at 8th Very Large Volume Neutrino Telescopes Workshop (VLVnT 2018), Dubna, Russian Federation, Oct 2018

Neutrino tomography III: High-energy neutrinos to probe the Earth's core and mantle. Talk at Workshop on Observatory Synergies for Astroparticle physics and Geoscience (APPEC/GEO-8/Academia Europaea), Paris, Feb 2019

Recent results from ANTARES. Invited talk at Workshop on Perspectives in Astroparticle physics from High Energy Neutrinos (PAHEN 2019), Berlin (Germany), Sep 2019

KM3NeT/ORCA: Status, first data and perspectives for neutrino oscillation and mass ordering measurements. Talk at 27th Workshop on Weak Interactions and Neutrinos (WIN 2021), online, Jul 2021

P Varnière :

GR simulations of the RWI: What impacts HFQPOS observables. Talk at the Fifteenth Marcel Grossmann Meeting on General Relativity, Rome, Jul 2018

NOVAs: a Numerical Observatory of Violent Accreting systems, poster at the Fifteenth Marcel Grossmann Meeting on General Relativity, Rome, Jul 2018

Disk spectrum evolution as function of spin, impact on model fitting, poster at the Fifteenth Marcel Grossmann Meeting on General Relativity, Rome, Jul 2018

Living on the edge: the RWI in accretion disk around Kerr Black hole, poster at Journées de l'Astrophysique Française, Bordeaux, Jul 2018

NOVAs: a Numerical Observatory of Violent Accreting systems, poster at Journees de l'Astrophysique Francaise. Bordeaux, Jul 2018

Living on the edge: the RWI in accretion disk around Kerr Black hole, poster at the XMM-Newton 2018 Science Workshop, Madrid, Jun 2018

NOVAs: a Numerical Observatory of Violent Accreting systems, poster at the XMM-Newton 2018 Science Workshop, Madrid, Jun 2018

RWI in disk around high spin black hole: how does it impact the observables, poster at Journées de l'Astrophysique Française, Nice, May 2019

On the road to apply QPO models made for X-ray binaries toward higher mass systems, poster at EAS Conference, online, Jun 2021

V Vennin :

Can we show that cosmological perturbations are of quantum-mechanical origin?, COSMO conference, Paris, France, Aug 2017

Stochastic inflation and primordial black holes, Astroparticule and Cosmology Laboratory (APC), Paris, Sep 2017

Cosmological inflation in the early Universe, Aarhus Institute of Advanced Studies (AIAS), Aarhus (Denmark), Nov 2017

Stochastic Inflation and Primordial Black Holes, Dutch Cosmology Meeting, Nikhef and the University of Amsterdam, The Netherlands, Nov 2017

Cosmic Inflation and Quantum Mechanics, Workshop Quantum Foundations: New frontiers in testing quantum mechanics from underground to the space, Laboratori Nazionali di Frascati (INFN), Italy, Nov 2017

Stochastic Inflation and Primordial Black Holes, CP3 (Center for Cosmology, Particle Physics and Phenomenology), Louvain University, Belgium, Nov 2017

Observing quantum decoherence during inflation, ICG (Institute of Cosmology and Gravitation), Portsmouth, UK, Feb 2018

New supergravity solutions for inflation, University of Montpellier, France, S.low.SUGRA meeting, Apr 2018

Observing quantum decoherence during inflation, Rencontre de Physique des Particules (RPP 2018), Laboratoire de Physique Nucléaire et de Hautes Energies (LPNHE), France, Apr 2018

Cosmic Inflation in the early Universe, Laboratori Nazionali di Frascati (INFN), Italy, May 2018

Stochastic Inflation and Primordial Black Holes, Institut d'Astrophysique de Paris (IAP), France, May 2018

Observing quantum decoherence during inflation, Laboratoire Astroparticules et Cosmologie (APC), France, May 2018

Inflationary magnetogenesis, Cosmic Puzzles: From the LSS to LSS, Institut d'Astrophysique Spatiale (IAS), France, Jul 2018

Observing quantum decoherence during inflation, 7th International Conference on New Frontiers in Physics (ICNFP 2018) Kolymbari, Crete, Greece, Jul 2018

Primordial black holes from quantum diffusion during inflation, 7th International Conference on New Frontiers in Physics (ICNFP 2018) Kolymbari, Crete, Greece, Jul 2018

Primordial black holes from quantum diffusion during inflation, IHP trimester: "Analytics, Inference, and Computation in Cosmology", Institut Henri Poincaré (IHP), France, Sep 2018

Observing quantum decoherence in the early Universe, Conference "The Universe as a Quantum Lab", Laboratoire Astroparticules et Cosmologie (APC), France Sep 2018

Higgs and Starobinsky inflation, Institut Pluridisciplinaire Hubert Curien (IPHC), Strasbourg, France, Nov 2018

Primordial black holes from quantum diffusion during inflation, 28th Workshop on General Relativity and Gravitation in Japan - JGRG28, Rikkyo University, Japan, Nov 2018

Can we prove that cosmological perturbations are of quantum origin?, ICAP meeting at Institut d'Astrophysique de Paris (IAP), France, Jan 2019

Observational constraints on spring inspired inflationary models, Geometrical Tools for String Cosmology, Casa Matematica, Oaxaca, Mexico, May 2019

Primordial black holes from quantum diffusion during inflation, Spring workshop on gravity and cosmology, Warsaw University, Poland, May 2019

Can we prove that cosmological structures are of quantum-mechanical origin?, Workshop on Inflation and the dark sector, Jyvaskyla University, Finland, Jun 2019

Primordial Black Holes from Inflation, Institut d'Astrophysique de Paris (IAP), France, Sep 2019

Primordial black holes from quantum diffusion during inflation, Workshop on Theoretical Aspects of Modern Cosmology Tours University, France, Oct 2019

Primordial Black Holes from Inflation, Laboratoire de l'accélérateur linéaire (LAL), France, Oct 2019

Cosmic inflation: where do we stand?, ICG (Institute of Cosmology and Gravitation), Portsmouth, UK, Oct 2019

Primordial black holes from quantum diffusion during cosmic inflation, International Conference on Gravitation & Cosmology IISER Mohali, India, Dec 2019

Primordial Black Holes and quantum diffusion, Laboratoire de physique nucléaire et de hautes énergies (LPNHE), Paris, France, Feb 2020

Quantum aspects of primordial cosmological perturbations, Quantum Aspects of Space-Time and Matter (QASTM) Seminar series, Aug 2020

Stochastic approach to primordial cosmology, International Workshop on "Physics of the Early Universe", International Centre for Theoretical Sciences (ICTS), Bengaluru, India, Sep 2020

Inflation in the NMSSM, Institut Pluridisciplinaire Hubert Curien (IPHC), Strasbourg, France S.low.SUGRA meeting, Oct 2020

Can we prove that cosmic structures are of quantum mechanical origin?, Van Swinderen Institute, University of Groningen, Netherlands, Oct 2020

Primordial black holes from the early Universe, 4th colloquium of the Dark Energy national action, Oct 2020

Primordial black holes from the early Universe, IRN TERASCALE meeting (International research network on the experimental and theoretical search for new physics at the TeV scale), Nov 2020

Can we prove that cosmic structures are of quantum mechanical origin?, Universidad de Chile, Santiago, Chile, Dec 2020

Quantum diffusion and cosmic inflation, HIP (Helsinki Institute of Physics), Finland, Feb 2021

Quantum diffusion during cosmic inflation, Nuclear theory physics group, University of Minnesota, USA, Mar 2021

Quantum diffusion and primordial black holes, Kavli Institute for Cosmological Physics, Chicago, USA, Mar 2021

Primordial black holes and gravitational waves from metric preheating, Brain-storming workshop on Primordial Black Holes and Gravitational Waves online (Yukawa Institute for Theoretical Physics, Kyoto University), Jun 2021

Can we prove that cosmic structures are of quantum mechanical origin?, McGill Centre for High Energy Physics, Montreal, Canada, Jul 2021

Can we prove that cosmic structures are of quantum mechanical origin?, University of Oldenburg, Germany, Jul 2021

Primordial black holes from metric preheating, Birla Institute of Technology and Science, Pilani, Goa Campus, India, Aug 2021

MC Volpe :

Neutrino astrophysics and connections to nuclear physics. Invited Talk at CNNP 2017, Catane, Oct 2017

Extendend evolution equations and helicity coherence, Reconstructing the gravitational binding energy of a newly formed neutron star. Invited Talk at SNOBS 2017, Mainz, Oct 2017

Supernova neutrinos: both observational and theoretical aspects. Invited Talk at Physics of core-collapse supernovae and compact star formations, Waseda University, Japan, Mar 2018

Neutrinos from neutron star mergers and core-collapses : similarities and differences. Invited Talk at Core-collapse supernovae in the multi-messenger era, l'Aquita and GSSI, Jul 2018

Neutrinos from supernovae and in binary neutron star mergers. Invited Talk at Gamma-ray bursts and supernovae : from central engines to the observer, Paris-Saclay, Jul 2018

Neutrinos from core-collapse supernovae and binary neutron star mergers. Invited Talk at Physics of supernova neutrinos, Brighton, Sep 2018

Recent advances on neutrino flavor evolution in dense media and kilonova observation. Invited Talk at Particle Theorists Meeting, LPNHE Paris, Apr 2018

SN neutrino kinetic equations. Invited Talk at SN neutrino physics at the crossroads : astrophysics, oscillation and detection, Workshop, ECT* Trento, Italy, May 2019

Neutrino flavor evolution in dense media. Invited Talk at the PhyFOG Meeting, IAP Paris, Jun 2019

Theoretical aspects of neutrino propagation in dense environments. Invited Talk at the LANL-NBIA Workshop, Copenhagen, Denmark, Aug 2019

Key open questions in theoretical neutrino (astro)physics. Invited Talk at LLR Perspectives, Toulouse, Sep 2019

Neutrinos from core-collapse supernovae : flavor mechanisms and future observations. Talk at Weak Interactions and neutrinos (WIN) 2021, Minnesota University, Jun 2021

Neutrino flavor evolution in dense environments and the r-process. Talk at Particles and Nuclei International Conference (PANIC), Sep 2021

Neutrinos : from the r-process to the diffuse supernova neutrino background. Talk at Topics in Astroparticle and Underground Physics (TAUP) 2021, Valencia, Spain, Aug-Sep 2021

Neutrinos in binary neutron star mergers. Invited Talk at New Directions in Neutrino Flavor Evolution in Astrophysical Systems, INT Seattle, Sep 2021

Lectures at summer schools

D Allard :

"Transition from Galactic to extragalactic cosmic-rays", Physics and Astrophysics of cosmic-rays (PARC School), Observatoire de Haute-Provence, Nov 2019

S Babak :

"Gravitational Waves", Summer School on Cosmology 2018, ICTP, Trieste, Jun 2018
"Detecting gravitational waves with LISA" Max Planck Lecture week, Urbino, May 2019
"Modelling gravitational waves, PTA, LISA" summer school ISAPP (remote), Jun 2021

A Boucaud :

3rd ASTERICS-OBELICS International School : Getting started with deep learning, Apr 2019
Deep learning tutorials at ADA IX Summer School, Valencia, Spain, May 2019
Organisation et cours de machine learning à l'ANF *Machine Learning pour les informaticiens de l'IN2P3 et de l'IRFU*, Sep 2020
Ateliers sur l'intelligence artificielle, JDEV, Jul 2021
Enseignant à l'école thématique d'hiver CNRS *AstroInfo2021*, Barcelonette, Dec 2021

C Caprini :

"Cosmology from Gravitational waves", IV Joint ICTP Trieste/SAIFR School on Cosmology, online, Jan 2021
"Gravitational waves", lectures for the Annual Retreat of the University of Mainz, Mainz, Sep 2017

F Casse :

Ecole d'hiver MECMATPLA, Cours invité sur l'approche PIC/MHD, Montgenèvre, Mar 2019

E Chassande-Mottin :

Traitement des données pour l'astronomie gravitationnelle, lecture at the BasMaTi summer school, Jun 2018
GW data analysis – A primer, lecture at the ISAPP summer school on gravitational waves, May 2021

A Coleiro :

Ecole d'automne du LabEx UnivEarthS : cours sur l'astrophysique des hautes énergies et l'astronomie multi-messager, Toulouse, Oct 2021
Ecole d'été School on gravitational waves for Cosmology and Astrophysics: "Multi-messenger astronomy", Benasque, Espagne, Jun 2017

CMB experiments. Lecture at the Varenna Fermi School, Varenna, Italy, Jul 2017
The Cosmic Microwave Background. Three lectures at USTC, Hefei, China, Nov 2018
Astroparticle Cosmology. Six lectures at USTC, Hefei, China, May-Jun 2021

A. Djannati-Ataï :

Entretiens sur l'observation et la modélisation des pulsars, National Workshop (PNHE) , Two sessions per year, 2017-2019

J Errard :

Journées Rencontres Jeunes Chercheurs 2016, Angers, France, Dec 2016
Observer l'infiniment grand, Rencontres d'été de l'infiniment grand à l'infiniment petit 2019 : promotion Vera Rubin, Paris, Jul 2019
Teaching the Universe, APC, Paris, May 2019 and 2021

S Gabici :

Cosmic ray acceleration and transport, School on Cosmic Explosions, Cargese, May 2019

K Ganga :

CMB Experimental Landscape, Cargèse School of Cosmology, Nov 2017

JC Hamilton :

CMB Polarization - Theory and Experiments, HIRSAPP Doctoral School, Karlsruhe, Germany, Dec 2020
CMB Polarization Experiments, LAPIS2018, La Plata, Argentina, Apr 2018
The Cosmic Microwave Background, Instituto Sabato, Buenos Aires, Aug 2017
CMB Data Analysis, Instituto Sabato, Buenos Aires, Aug 2017

M Khlopov :

Neutron stars and Black holes: Indirect probes for new physics. Invited lecture at DIAS Summer School in High-Energy Astrophysics 2018, Dublin, Ireland, Jun 2018

E Kiritsis :

"The holographic Renormalization Group": Lectures given at the summer school JOINT FAR/ANSEF-ICTP and RDP-VW summer school in theoretical physics, Yerevan, Armenia, 2018

A Kouchner :

High-energy Neutrino Astronomy. International Max Planck Research School (IMPRS), Gößweinstein, Germany, Sep 2017
Astronomie Neutrino a l'ère multi-messagers. CentraleSupelec "Black Swan" (statistique et machine learning pour la cosmologie et la physique des particules), Apr 2019
Les neutrinos : nouvelle fenêtre sur l'univers. Séminaire du Magistère de Physique de l'Université de Paris, Mar 2020

J Martino :

Retour d'expérience: l'ingénierie système dans le Projet LISA. ANF ingénierie système, Observatoire de Haute Provence. Oct 2021

S Mastrogiovanni :

The compact binaries coalescence from LIGO and Virgo, lecture at International School in Astroparticle Physics on gravitational waves, Online meeting, Jun 2021

F Nitti :

Holographic Self-tuning of the Cosmological Constant, 9th Aegean Summer School, Apollonia, Greece, Sep 2017

E Parizot :

Extragalactic cosmic-rays and transition, ISAPP School 2018 "LHC Meets Cosmic Rays", CERN, Switzerland, Oct 2018

G Patanchon :

Thermal history of the Universe, Quy Nhon summer school, Vietnam, Aug 2018

M Piat :

Instrumentation cryogénique, école thématique AFF commission Cryoénie et Supraconductivité, Détecteurs millimétriques : TESs, KIDs, FIAP Paris, Nov 2017
CMB instruments, XIIIème école de Cosmologie, «The CMB from A to Z: Promises and challenges of the CMB as cosmological probe», Cargèse, Nov 2017
Astronomie mm – CMB, école Thématique CNRS "Détection du Rayonnement à Très Basse Température", Aussois, Dec 2018

E Porter :

Gravitational waves from compact binary coalescences, Cosmic Explosions 19 Summer School, Cargese, Corsica, France, May-Jun 2019

D Prêle :

Détecteurs Cryogéniques, 8ième école Détection de Rayonnement à Très Basse Température – Introduction talk - DRTBT 2018, Aussois, France, Dec 2018
Multiplexages Cryogéniques, 8ième école Détection de Rayonnement à Très Basse Température – DRTBT 2018, Aussois, France, Dec 2018
SQUIDs et amplificateurs bas bruit, Ecole AFF-CCS Instrumentation Cryogénique 2017, FIAP, Paris, Nov 2017

J Serreau :

Lectures on quantum field theory in curved spacetime: invited lecture at the International summer school on high energy physics TAE2017 Centro de Ciencias de Benasque Pedro Pascual (Spain), Sep 2017

D Steer :

Ondes gravitationnelles et cosmologie, Ecole de GIF, Orsay, Sep 2017
Gravitational wave and cosmology. Invited series of lectures at "Gravitational waves: a new messenger to explore the universe", Institut Henri Poincaré, Mar 2021
Gravitational-wave theory, lecture at the ISAPP summer school on gravitational waves, May 2021

V Van Elewyck :

High-energy neutrino astronomy: motivations, techniques and obervations, lecture at the International Cargese School "Cosmic Explosions", Cargese, May 2019

V Vennin :

Physical Cosmology, Euclid Summer School, Roscoff, Aug 2018
Physical Cosmology, Euclid Summer School, Banyuls, Aug 2019
Physical Cosmology, Euclid Summer School, Hyeres, Aug 2020
Physical Cosmology, Euclid Summer School, Anglet, Aug 2021

Organization of conferences and summer schools

D Allard :

Co-organizer of the PARC School "Physics and Astrophysics of cosmic-rays", Observatoire de Haute-Provence, Nov 2019

E Aubourg :

Co-organizer of the Dark Energy Science Collaboration summer meeting, Paris, Jul 2019
Member of the scientific organization committee, Bayesian Deep Learning for cosmology and gravitational waves workshop, Paris, Mar 2020

JG Bartlett :

French National Euclid School, since 2016

A Boucaud :

Member of the Local Organizing Committee of the Rubin/LSST-DESC Collaboration Meeting, APC, Paris, Jul 2019
Member of the Scientific and Local Organizing Committee of the *Bayesian Deep Learning for Cosmology and Gravitational waves* workshop, APC, Paris, Mar 2020
Member of the Local Organizing Committee of the *Golden Cosmological Surveys Decade (GOLD)* workshop, Orsay, Apr 2020
Membre du comité de pilotage de l'ANF *Machine Learning pour les informaticiens de l'IN2P3 et de l'IRFU*, 2020
Member of the Local Organizing Committee of the Rubin/LSST-DESC Sprint Week, APC, Paris, Oct 2021
Membre du comité de programme de l'école thématique d'hiver CNRS *AstroInfo2021*, Barcelonette, 2021

C Caprini :

Chair of the scientific organizing committee, "Gravitational waves: a new messenger to explore the Universe", long-term workshop at the Institut Henri Poincaré, Paris, Mar 2021
Chair of the LISA Cosmology Working Group Workshop - MITP Mainz, Oct 2017, University of Helsinki, Jun 2018, Universidad Autonónoma de Madrid, Jan 2019, Università di Padova, Sep 2019, APC Paris, Jul 2020
Chair of the organizing committee for the "Assemblée Générale du GdR Ondes Gravitationnelles" - Paris, Oct 2018, IPNL Lyon, Oct 2019, IAP Paris (online), Oct 2020, IHP Paris (online), Mar 2021, LAPP Annecy, Oct 2021
Member of the scientific organizing committee for "PONT d'Avignon – Progress on Old and New Themes in cosmology", Annecy, Apr 2017 and Dec 2020
Member of the scientific organizing committee, "School on Gravitational Waves for Cosmology and Astrophysics", Benasque, Spain, May 2017
Member of the scientific organizing committee, "Journées LISA France", APC (Paris), Oct 2017

E Chassande-Mottin :

Member of the scientific organizing committee, 1st OBELICS International School on "Advanced software programming for astrophysics and astroparticle physics", Annecy, Jun 2017
Member of the scientific organization committee, Bayesian Deep Learning for cosmology and gravitational waves workshop, Paris, Mar 2020
Member of the scientific organizing committee, Gravitational wave open data workshop #1-#4, 2018–2021
Co-organizer of a Workshop on Gravitational wave data analysis for the GdR Ondes Gravitationnelles, Paris, Oct 2018 and online, Nov 2020
Member of the scientific organizing committee, "Gravitational waves : a new messenger to explore the Universe", Institut Henri Poincaré, Paris, Mar 2021

S Chaty (from 09/2019) :

Member of the scientific organizing committee, Hands-on JWST workshop (IAP, 02/2020)

A Coleiro :

Membre du LOC de l'atelier "Low-latency alerts & Data analysis for Multi-messenger Astrophysics", 2022
Convener de la session "Astroparticle physics and cosmology" de la conférence "Weak Interactions and Neutrinos 2021" organisée par l'Université du Minnesota, 2021
Membre du SOC de la conférence "Cosmic Rays and neutrinos in the multi-messenger era", Université de Paris, 2021
Membre du SOC des ateliers PNHE TS2020 (Transient Sky for 2020+), 2020
Membre du SOC du Town Hall Meeting KM3NeT, Marseille, 2019
Member of the Scientific Advisory Committee of the 8th Very Large Volume Neutrino Telescopes (VLVnT) Workshop, Dubna Russia, Oct 2018

J Delabrouille :

Member of the SOC of the First International Symposium on Cosmology and Ali CMB polarization telescope, Shanghai, China, 2018
Member of the SOC of the Second International Symposium on Cosmology and Ali CMB polarization telescope, Beijing, China, Sep 2019
Member of the SOC of the B-modes from Space conference, Garching, Germany, Dec 2019

D Franco :

Member of the Scientific Committee of the European Nuclear Physics Conference, Bologna, Italy, Sep 2018
Member of the Scientific Committee of "Light Detection In Noble Elements (LIDINE)", Manchester, UK, 2019

S Gabici :

Member of the Organising Committee, Cosmic Rays and Neutrinos in the Multi-Messenger Era, APC, Dec 2020
International Cosmic Ray Conference 2019, member of the International Science Program Committee, Madison, USA, 2019
Searching for the Sources of Galactic cosmic rays, member of the organizing committee, APC, Dec 2018
Co-director of the MIAPP Programme on "The High Energy Universe: Gamma Ray, Neutrino, and Cosmic Ray Astronomy", Munich, Germany, Feb 2018

K Ganga :

Organizer of the "Towards the European Coordination of the CMB Programme" meetings, Florence, 2017 and 2018, and Paris, 2019
Member of the Organizing Committee for the Rencontres de Moriond and Rencontres de Vietnam Cosmology Meetings, 2017-2021

A Goldwurm :

Main Scientific Organizer of the session E1.11 on the Galactic Center at the COSPAR Scientific Assembly 2018, Pasadena (US), Jul 2018
Main Scientific Organizer of the session E1.13 on the Galactic Center at the COSPAR Scientific Assembly 2020, Sydney (Australia), Jan 2021

H Halloin :

Member of the Organizing Commitee for the LISA France Meeting, Paris, Oct 2017
Organizer of the 'Cours LISA' for LISA France, Paris, Jul 2018 and Online, Jan 2021

M Khlopov :

Member of the Scientific Organizing Committee of 20-24th Workshop "What comes beyond the Standard Model", Bled, Slovenia, Jul 2017, Jun 2018, Jul 2019 and Cosmovia, Jul 2020, Jul 2021
Member of Scientific Organizing Committee of 5th International Conference on Particle physics and Astrophysics (ICPPA2020), Moscow, Russia, Oct 2020
Organizer of Satellite Workshop "Developing A.D.Sakharov Legacy in cosmoparticle physics" of Electronic Conference on Universe (ECU2021), Feb 2021

E Kiritsis :

Member of the organizing committee of the 2017 European Physical Society Conference on High Energy Physics "EPSHEP 2017", Venice, Italy, Jun 2017
Chairman of the organizing committee of the conference "9th Crete Regional Meeting on String Theory", Kolymbari, Crete, Jul 2017
Co-organizer of the Perimeter-Brussels-APC conference "Cosmological Frontiers in Fundamental Physics", Brussels, May 2018
Co-organizer the conference "Gravity, cosmology & physics beyond the Standard Model", Paris, France, Jun 2018
Co-organizer of the Nordita conference "Holographic QCD", Stockholm, Jul 2019
Co-organizer of the Perimeter-Brussels-APC conference "Cosmological Frontiers in Fundamental Physics", Perimeter, Sep 2019
Co-organizer of the conference "10th Crete Regional Meeting on String Theory", Kolymbari, Crete, Sep 2019
Co-organizer of the conference "Frontiers of Holographic Duality", Steklov Mathematical Institute, online, Moscow, Apr 2020
Co-organizer of the summer web-seminar series "Applications of gauge topology, holography and string models to QCD", Simons Center for Geometry and Physics, Aug 2020
Co-organizer of the conference "11th Crete Regional Meeting on String Theory", May 2021
Chair of the organisation committee of the triangular workshop (APC-Perimeter-Solvay) "Cosmological Frontiers of Fundamental Physics", May 2021
Co-organizer of the summer web-seminar series "Applications of gauge topology, holography and string models to QCD", Simons Center for Geometry and Physics, Aug 2021

A Kouchner :

Member of the Neutrino scientific advisory committee Rencontres du Vietnam ICISE Quy Nhon, Vietnam, Jul 2017
Chair of a parallel session at ICRC 2017 Conference International Conference of Astroparticle physics Busan, Korea, Jul 2017
Member of the scientific advisory committee of "Gravitational-waves, ElectroMagnetic and dark-MAtter Physics Workshop" (GEMMA)

Lecce, Italy, Jun 2018
Member of the scientific advisory committee of "Perspectives in Astroparticle physics from high energy neutrinos" (PAHEN) DESY, Zeuthen, Sep 2019
Cosmic Rays and Neutrinos in the Multi-Messenger Era APC, Dec 2020
Member of the International Advisory Committee (IAC) of TAUP 2021 Valencia (remote), Spain, Sep 2021
Member of the International Advisory Committee of "Large TPCs for low-energy rare event detection", Online meeting, Dec 2021

C Lachaud :

Member of the scientific organizing committee, “Transient sky in 2020” Workshop, Orsay, Jun 2017
Member of the scientific organizing committee, "Disentangling the merging universe with SVOM" at Les Houches School, May 2018
Member of the scientific organizing committee, "SVOM Burst Advocate Winter School" at Les Houches School, Mar 2020

D Langlois :

Member of the scientific organizing committee, COSMO17, APC, Aug 2017

A Lemiere :

Member of the scientific organizing committee, Paris-Saclay Astroparticle Symposium, Saclay, Oct 2021
Chair of the scientific organizing committee, Labex UnivEarths thematic school 2020 on Open Science, Paris, Nov 2020
Member of the scientific organizing committee, Labex UnivEarths thematic school 2021 on Spatial Astrophysics, Paris, Oct 2021
Co-organizer of the Physics department day, Université de Paris, Paris, Nov 2018

G Marchiori :

Co-chair of the Large Hadron Collider Physics (LHCP) 2021 conference, online, Jun 2021
Co-convener of the Higgs parallel sessions of the EPS-HEP 2021 conference, online, Jul 2021

J Martino :

Organisation du workshop détecteurs pour le GDR Ondes Gravitationnelles. Remote, Apr 2021

S Mastrogiovanni :

Gravitational wave open data workshop #2-#4, 2019–2021

S Mei :

Member of Scientific Organising Committee, Extragalactic Spectroscopic Surveys: Past, Present and Future of Galaxy Evolution (GALSPEC2021), Online meeting, Apr 2021
Chair of "First Galaxies, First Structures" meeting, Paris, Oct 2019
Member of Scientific Organizing Committee for "Birth, life and fate of massive galaxies and their central beating heart" meeting, Favignana, Sep 2019
Galaxy evolution across time (Chair), Paris, Jun 2017

V Niro :

Co-chair of Cosmic Rays and Neutrinos in the Multi-Messenger Era, Paris, virtual conference, Dec 2020

E Parizot :

Member of the IAC (International Advisory Committee) of the 26th European Cosmic Rays Symposium (ECRS), Barnaul, Russian Federation, Jul 2018
Member of the IAC (International Advisory Committee) of the 27th European Cosmic Rays Symposium (ECRS), Nijmegen, Jul 2020
Organiser of the 30th International JEM-EUSO Collaboration meeting, Paris, France (and remote), Dec 2021

T Patzak :

Member of the Organizing Committee of NDIP 2017 (International Conference on New Developments in Photodetection), Tours, Jul 2017
Member of the Program Advisory and Organizing Committee of TPC 2018 (International symposium on Large TPCs for low-energy rare event detection), Université Paris Diderot, Dec 2018
Member of the Program Advisory and Organizing committee of NDIP 2020 (International Conference on New Developments in Photodetection), Troyes, Jun 2020
Member of the Program Advisory and Organizing committee of TPC 2021 (International symposium on Large TPCs for low-energy rare event detection), Université de Paris, Dec 2021

M Piat :

Organiser of direct detection session of CNES COMET workshop: Les charges utiles et les technologies du futur de la bande W à l’infrarouge lointain, Toulouse, Oct 2018

D Prêle :

Member of the scientific organizing committee, 8th Ecole de Détection Rayonnement à Très Basse Températures, Aussois, Dec 2018
Chair of the 7th X-IFU ATHENA Consortium Meeting, Paris, Mar 2018

C Roucelle :

Co-organizer of the Dark Energy Science Collaboration summer meeting, Paris, Jul 2019
Member of the scientific organization committee, Bayesian Deep Learning for cosmology and gravitational waves workshop, Paris, Mar 2020
Co-organizer of the Dark Energy Science Collaboration hybrid sprint week, Paris, Oct 2021

S Sacerdoti :

Coordination of the instrumentation session at the Journées de Rencontre des Jeunes Chercheurs, Nov 2019 and Oct 2021

D Semikoz :

Head of organizing committee Workshop "Searching for the sources of Galactic cosmic rays", Paris Dec 2018
Member of advisory committee conference "QUARKS 2020", Russia, Jul 2020
Head of organizing committee Workshop "Cosmic Rays and Neutrinos in the Multi-Messenger Era", Paris Dec 2020

J Serreau :

Organizer of the international workshop Infrared QCD, Nov 2017

D Steer :

Scientific Organising Committee de “Cosmology with gravitational waves” GdR OG meeting, Paris, 2019 & 2021
Member of the scientific organizing committee of “Remnants of the Big Bang” workshop at Arizona State University, Tempe, Jan 2020
Member of the scientific organizing committee of workshop “Gravity Falls: Implication of gravitational waves observations on modified gravity theories”, Paris, Dec 2018

A Tonazzo :

Chair of the “Gender in Physics Day”, Paris, Jan 2018

V Van Elewyck :

Member of the Scientific Advisory Committee of the 8th and 9th Very Large Volume Neutrino Telescopes (VLVnT) Workshop, Dubna Russia, Oct 2018 and Valencia, Spain, Sep 2021
Member of the International Advisory Committee of the 34th and 35th International Cosmic Ray Conferences, Madison US, Jul 2019 and Berlin, Germany, Jul 2021
Member of the Organizing Committee of the International Workshop on Cosmic Rays and Neutrinos in the Multi-Messenger Era, APC & online, Dec 2020

P Varniere :

Member of the scientific organizing committee of the XMM workshop "Time-domain astronomy: a high energy view", Madrid, Spain, Jun 2018

V Vennin :

Organiser of the international conference “The Universe as a Quantum Lab”, Paris, 2018
Organising Committee of the triangular conference “Cosmological frontiers in fundamental physics”, Paris, 2021
Organiser of the “Paris primordial cosmology meetings”, since 2019

MC Volpe :

Member of the International Advisory Committee of the 45th Erice workshop, Erice, 2019
Member of the International Advisory Committee of the SNEWS2 workshop, SNOLAB, 2019
Member of the International Advisory Committee of the TPC workshop, Paris, 2021

Responsibilities in university, scientific and technical bodies

D Allard :

Member of the Scientific Council of the PNHE (national program), until 2019
Member of the JEM-EUSO speakers bureau, since 2015
Member of the Subatech Scientific Council, 2019
Member (elected) of the APC Laboratory Council, until 2019

E Aubourg :

Chair of the Collaboration Council of the Rubin/LSST Dark Energy Science Collaboration (DESC), 2020
Member of the Operartions Committee of the Rubin/LSST Dark Energy Science Collaboration (DESC), since 2021
Membre du comité national de la recherche scientifique, section 01, since 2021

S Babak :

Head of Gravitation group since 2019
Member of GWIC dissertation committee 2020-2021
PhD examiner: Hannover University 2018; Gran Sasso Science Institute 2019
Member of 3P+ committee (International Pulsar Timing Array), since 2021

M Barsuglia :

National responsible for Virgo, since 2020
National responsible for Einstein Telescope, since 2020
Member of the scientific council of the GdR ondes gravitationnelles, since 2017
Invited member of the Virgo steering committee, since 2020
Member of the Einstein Telescope steering committee, since 2019
Member of the Projet Supervising Board of the Advanced Virgo+ project, since 2020
Member of the Virgo Organization Committee, since 2020
Member of the Virgo Core Program committee, since 2020
Member of the Virgo post-O5 committee, since 2020
Chair of the ISAPP summer school on gravitational-waves, 2021
Director of the Paris Center for Cosmological Physics, since 2018

JG Bartlett :

Co-lead of the Galaxy Cluster Analysis Working Group for the CMB-S4 Collaboration, since 2021
Lead for *Euclid* science at IN2P3, since 2020
Co-coordinator of the *Euclid* Key Project *Evaluating the* Euclid *Galaxy Cluster Selection Function*, since 2021
Co-coordinator of Euclid Consortium *Cluster Science Working Group*, since 2011
Elected member of Simons Observatory Collaboration Council Oversight Committee since 2020
Member of Euclid Consortium Speakers Bureau, since 2019
Invited member for expertise on cosmic structure science to the Conceptual Design Task Force chartered by DOE and NSF for the CMB Stage 4 program, 2017
Member of the Physics Department Scientific Council, *Université Paris Diderot*, 2016 - 2021
Member of the French national *Euclid* Coordination Committee, since 2015

W Bertoli :

Member of the mechanical review for the Calibration Units of KM3NeT, 2019
President of selection board for the entrance examination at CNRS for a position of robotics research engineer at the ICube laboratory (exam n°34), 2019
President of selection board for the promotion at CNRS to the grade of research engineer for BAP C (exams n° 2104 and n°2105), 2021

A Boucaud :

Member of the Membership Committee of the Rubin/LSST Dark Energy Science Collaboration (DESC), since Jan 2021
Chair of the Collaboration Council Nominating Committee of the Rubin/LSST Dark Energy Science Collaboration (DESC), Sep-Dec 2021

Membre du comité d'experts pour le renouvellement du marché de formations en informatique auprès de la Délégation Régionale de Villejuif, 2021

R Bouquet :

Framework responsible and developper of the code of the $VH(\to b\overline{b})$ and $VH(c\overline{c})$ analyses (ATLAS)

JN Capdevielle :

Membre de l'Académie des Sciences d'Outre Mer since 2011

C Caprini :

Coordinator of the “Interpretation and Key Science Projects” Work-Package of the LISA Science Group, since 2019
Coordinator of the Cosmology Working Group of the LISA Consortium, 2014-2020
Director of the “Groupement de Recherche Ondes Gravitationnelles”, IN2P3 (CNRS), since 2017
Member of the Astronomy Working Group of ESA, since 2020
Member of the Groupe thématique “Astroparticle physics” for the “Prospective 2020-2030” of IN2P3, 2020
Member of the Groupe de Travail Physique Fondamentale of the French Space Agency CNES, 2017-2019
Member of the conseil scientifique of the Programme National GRAM (INSU, INP, CNES), 2010-2017

F Casse :

Directeur de l'école doctorale 560 STEP'UP depuis Jul 2020
Directeur-adjoint du laboratoire APC, Jul 2018-Sep 2020
Vice-président de la section CNU 34 "Astronomie - Astrophysique", 2015-2019
Membre du conseil scientifique de l'UFR de Physique de l'université de Paris, 2015-2021
Membre du comité thématique no4 (Astrophysique et Géophysique) d'attribution du temps de calcul sur supercalculateurs nationaux (DARI), 2006-2018

G Chardin :

Membre du Haut Conseil des Infrastructures de Recherche (MESRI), depuis 2020
Membre du Comité scientifique de Sciences et Citoyens (CNRS), 2017-2021
Président du Comité des Infrastructures de Recherche (CNRS), 2014-2019

E Chassande-Mottin :

Member of the scientific council of the GdR Ondes Gravitationnelles since 2016
Member of Scientific Committee of the UFR Physique, since 2018
Adjunct lab director since 2019
Member of the Virgo steering committee since 2020
Adjunct director of the data intelligence institute of Paris (diiP), since 2019

S Chaty (from Sep 2019) :

Elected member of the Conseil de Faculté des Sciences, Univ. de Paris, since 2019
Member of Scientific committee Physics Department, 2015-2021
Member of executive bureau of LabEx UnivEarthS, since 2019
Member of the scientific council of the GdR Ondes Gravitationnelles, since 2016
Chargé de mission vice-présidence «Evénementiel» Université de Paris, since 2021
Chargé de mission Programme de physique de Sciences Ouvertes, 2019-2020
Co-organizer of general seminars of Physics Department, since 2015
PI of Astronomical Observatory on UP campus in use since 2018
Organiser of Formation Continue Astrophysique (Rectorats Paris/Créteil/Versailles)
Member of Société Française d'Exobiologie, since 2017
Member of SF2A (Société Française d'Astronomie et Astrophysique)

A Coleiro :

Membre du conseil scientifique de l'UFR de Physique de l'Université de Paris, depuis 2021
Membre du conseil de l'école doctorale 560 STEP'UP, depuis 2019
Membre élu du conseil de laboratoire, depuis 2018

A Creusot :

Membre du conseil des enseignements de l'UFR de Physique de l'Université de Paris, depuis 2021
Co-responsable du master NPAC, depuis 2021
Responsable de la liaison lycée-université (LLU), depuis 2019
Responsable local du comite d'oganisation des Olympiades de physique, 2019
Responsable de l'étalonnage des détecteurs de l'Observatoire KM3NeT, depuis 2017
Responsable du système d'acquisition du banc d'étalonnage des unités de détection de la caméra JEM-EUSO, depuis 2018
Responsable R&D du wavelength shifter pour l'Observatoire KM3NeT, depuis 2020

J Delabrouille :

Principal Investigator of the Cosmic Origins Explorer (CORE), submitted to ESA as a candidate medium-size space mission. Coordinator of a series of 10 papers reviewing the mission and instrument design, the science case, and the data analysis pipeline, published in a special issue of JCAP, 2017-2018
Member of the Executive Committee of the "Probe of Inflation and Cosmic Origins" (PICO) mission concept study in preparation for the US decadal review, 2018
Coordinator and contact scientist for the "Microwave Spectro-Polarimetry of Matter and radiation across Space and Time" white paper submitted in answer to the "Voyage 2050" call by the European Space Agency, 2019

A Djannati-Ataï :

Coordination of Pulsar Observations with HESS, since 2014
Member of the HESS Collaboration Board, 2005-2021
Member of the CTA Consortium Board, since 2015
Member of the Physics Department Council, 2015-2020

J Errard :

Elected member of the Simons Observatory Theory and Analysis Committee, 2019-2021
Member of the Scientific Council of ILANCE (IRL University of Tokyo), since 2020
Member of the POLARBEAR/Simons Array Collaboration boards

Member of the “Conseil de laboratoire” (laboratory board), since 2019

S Gabici :

Member of the Scientific Council of APC, since 2021
Member of the Scientific Council of the Physics Department, Univ. of Paris, since 2021
Member of the Scientific Council of Programme National Hautes Energies, CNRS, since 2021

K Ganga :

Member of APPEC SAC, since 2017
Member of the Collège des personnes qualifiées du conseil d’administration of the CFM Foundation
Member of HCERES review Committees for IAS, 2018 and LPC, 2020
Member CNRS/INSU Section 17, 2016-2021
Member of IN2P3 Prospectives Groupe de Pilotage for Inflation and Dark Energy, 2019-2021

A Goldwurm :

Co-I for the X-IFU/Athena
IN2P3 National contact point for Athena project
Chair of the Compact Object panel of the Integral Time Allocation Committee, 2017-2018
Member of the ANR scientific committee, 2019-2020
Member of the INSU committee on Gravity+ project, 2021

D Franco :

Co-coordinator of the division “Neutrinos dans l’Univers” of GdR CNRS Neutrino, since 2017

L Haegel :

Member of the Virgo Organisation Committee since 2021
Co-chair of the Virgo Early Career Scientists group since 2020

H Halloin :

Member of the PN GRAM Scientific Committee, since 2016
Member of the CNES Groupe Thématique ’Astronomie et Astrophysique’, since 2020
Member of the LISA System Engineering Office at ESA, since 2018
Project Scientist of the LISA Master Project at IN2P3, since 2016
PI of the IGOSat nanosatellite project at Universté de Paris, since 2012

JC Hamilton :

Member of the LIA-ALFA (France-Argentina) Scientific Committee, since 2016

E Huguet :

Deputy head of the APC Theory group, since 2017

M Khlopov :

Member of Scientific Council of Research Institute of Physics, Southern Federal University, Rostov on Don, Russia, since 2021
President of Center for Cosmoparticle physics Cosmion, Moscow, Russia
Director of Virtual Institute of Astroparticle physics
Organizer of Scientific-Creative discussion seminar online on the platform of CosmoVIA

E Kiritsis :

Elected deputy chair of the High-Energy Particle Physics Division Board of the European Physical Society, 2017-2018

A Kouchner :

Membre du conseil scientifique du DIM ACAV de la région IdF, 2017-2019
Lab director, since 2018
Co-director of LabEx UnivEarthS, since 2018
Spokesperson of the ANTARES Collaboration, since 2019
Co-Chair of the General Assembly of APPEC (AstroParticle Physics European Consortium), since 2020

D Langlois :

Membre de la Commission de recrutement du département de Physique de l’Ecole polytechnique, depuis 2015
Member of the ERC panel “Universe sciences” for the selection of ERC Consolidator Grants, 2012-1018
Président du comité d’évaluation HCERES du Centre de Physique Théorique (CPHT), Ecole polytechnique, 2018
Member of the Steering Committee of EuCAPT (European Consortium for Astroparticle Theory), since 2019

A Lemiere :

Membre du Conseil scientifique de l’UFR de Physique de l’Université de Paris, 2016-2021
Membre de Commission de recrutement du département de Physique de l’Université Paris Sorbone, 2019
Membre de Commission de recrutement du département de Physique de l’Université de Paris, 2020
Présidente de Commission de recrutement du département de Physique de l’Université de Paris, 2021
Membre du TAC Chandra review panel SNR, PWN, GRBs and GW events, Boston,(USA), 2018

G Marchiori :

Member of the ATLAS Publication committee, since 2021

J Martino :

Membre du comité de pilotage du réseau IN2P3-INSU ingénierie système
Responsable du groupe performance dans la collaboration LISA
Co-responsable du groupe Simulation dans la collaboration LISA
Co-responsable du groupe de travail détecteurs au sein du GDR Ondes Gravitationnelles, depuis 2020

S Mei :

Vice-President of the National Commission of French Universities for Astronomy and Astrophysics (CNU 34), since 2015
Member of the Ethics working group of the National Commission of French Universities (CP-CNU), since 2020
Deputy director of the PhD program Astronomy and Astrophysics, Université de Paris, 2012-2021
Member of the selection committee for a professor position at the University of Naples Federico II, 2018
Reviewer for the NESSF-18 "NASA Earth and Space Science Fellowship Program" , 2017-2018

Member (elected) of the Scientific Council, Observatory of Paris, 2017-2018
Member of the HST TAC
Member of the Euclid France steering committee, since 2015
Elected Member of the Physics Department council, University of Paris D. Diderot, 2015-2020
Coordinator of the Action de synergie Structure of the Universe, Observatory of Paris, 2012-2021
Member of the HCERES review committee for LAM, 2017

E Parizot :

National PI and member of the Executive Committee of the JEM-EUSO Collaboration, since 2009
European Coordinator of the JEM-EUSO Collaboration, since 2018
PI/Spokesman of the international JEM-EUSO Collaboration, since 2021
National coordinator of the French-Polish COPIN research agreement on UHECRs and atmospheric showers, since 2012
Coordinator of the international Topical Team of the European Space Agency (ESA) on ultra-high-energy cosmic rays, since 2018
Coordinator of the CNES-funded R&T program on "Développement d'une unité de détection UV et visible ultra-sensible et versatile", since 2020
Responsible of the development and calibration of the photo-detection units for the MINI-EUSO space mission (ROSCOSMOS and ASI, onboard the ISS since 2019) and for the EUSO-SPB2 mission (NASA), since 2017
Member of the Physics Department Board (Conseil d'UFR) of Université de Paris, since 2016
Member of the "Conseil des enseignements" of the Physics Department (UFR) of Université de Paris, since 2021

G Patanchon :

Coordinator of the European H2020-RISE project CMB-INFLATE, since Oct 2021
Co-coordinator of the systematics joint study group of the LiteBIRD experiment, since 2018
LiteBIRD: member of Interim Governance Board, since 2019
Director of the SPACE department of the University of Science and Technology of Hanoi, since 2020
Director of the SPACE master of the University of Science and Technology of Hanoi, since 2020
Alternate member of the *Conseil National des Universités*, section 34, since 2020
Co-director of the Master 2 "NPAC"
Member of the *Conseil des Enseignements*, UFR de Physique, Université de Paris, since 2020

T Patzak :

PI DUNE APC, since 2015
Member of the Scientific Council of the Laboratoire Leprince-Ringuet, École Polytechnique, 2016-2019
Chairperson of the DUNE Speakers Board, 2017-2019
Member of the DUNE Publication Board, since 2019
Chairperson of the DUNE Membership Rules and Responsibilities Board, since 2020
President of the organizing committee of the "Ecole de GIF", 2013-2020
Vice-Dean of Recherche of the Faculty of Sciences, Université de Paris, since 2019
President of the Commission Recherche of the Faculty of Sciences, Université de Paris, since 2019
President of the Restricted Academic Council of the Faculty of Sciences, Université de Paris, since 2019

A Petiteau :

Member of LISA Formulation Management Team, since 2021
Member of scientific board of Paris Observatory, since 2020
Member of topical group fundamental physics at CNES, since 2019
Member of the evaluation committee Voyage2050 Topical teams of ESA, in 2019
Member of GWIC-Braccini Thesis Prize committee, 2019
Member of two committees of prospectives INSU 2019 on "Prospective of ressources / ground-space complementarity" and R&D, 2018-2019
Co-Lead of LISA mission, member of Executive Committee of LISA Consortium, since 2017
PI LISA France, member of LISA Consortium board, since 2017
Member of the LISA Science Study Team at ESA, since 2017
Lead of the LISA Data Processing Group and of the Ground Segment for the LISA Consortium, since 2017
Member of the LISA Publication and Presentation Committee, since 2017
Member of the LISA Coordination Team and the LISA Application Review Board, from 2017 to 2021
Member of the ATER committee at the Physics department (Univ. Paris), 2017-xs2021
Member of the scientific board of SKA-LOFAR group in France, 2017-2021
Member of the laboratory council at APC, 2015-2019
French PI of the LISAPathfinder mission, since 2014
French scientific lead of the LISA Data Processing Center, since 2014
Member of the scientific working group Square Kilometer Array France, since 2014
Member of scientific board of "Action spécifique" GPhys on Gravitation and Fundamental Physics and PhyFOG on Fundamental Physics and Gravitational Waves, Paris Observatory, 2014-2021

M Piat :

Member of the Astronomy-Astrophysics CNES advisory group, 2010-2019
Member of the inter organism group on the development of sub-mm and mm-wave detection chains (CNES, IN2P3, INSU, CEA, INSIS, INP), 2016-2019
Co-responsible of the Centre region coordination team for micro-electronics at IN2P3, 2017-2020
Responsible of the IN2P3 network on cryogenic detectors, 2013-2020
Responsible of the Physics cursus at Denis Diderot Engineering School (EIDD), since 2014

D Prêle :

CoI for the ATHENA X-IFU Instrument, since 2016
Member of the X-IFU detection chain working group, since 2020
Coordinator of the work package *Technologies alternatives*, MI2I

(μElec. IN2P3) Executive committee, 2021
Member of the IN2P3 μElectronique working group - Roadmap techno., 2019-2020
Coordinator of the working group *G5 : Développement de détecteurs et moyens d'essai - plateformes technologiques - développements de détecteurs/instruments spatiaux* for the *Pole Spatial*, 2019
Responsible for the M1 Space & applications USTH, 2021
Member of the APC Scientific Council, since 2017

C Roucelle :

Member of the speakers' bureau policy committee Dark Energy Science collaboration (DESC), 2019-2021
Member of the DESC member review policy committee, 2019-2020
Membre élue de la commission de recherche de la faculté des sciences de l'Université de Paris, since 2019
Membre du conseil académique de la faculté des sciences de l'université de Paris, since 2019
Responsable de la mention de Licence de Physique de l'Université de Paris, since 2017
Membre du conseil des enseignements de l'UFR de Physique de l'Université de Paris, since 2012
Membre élue du conseil d'UFR de Physique de l'Université de Paris, 2015-2021
Vice-Présidente du conseil des enseignements de l'UFR de physique de l'Université de Paris, 2014-2016
Membre de la commission de suivi des étudiants de licence de physique de l'Université de Paris, since 2019

S Sacerdoti :

Elected member of the Comité National de la Recherche Scientifique, Section 01, since 2021

D Semikoz :

Head of APC theory group, since 2017

J Serreau :

Member of the HCERES review committee for IPhT, 2019 and LAPTH, 2020
Member of the Conseil National des Universités, Section 29 (suppléant), 2015-2019
Jury member of the selection committee of École Doctorale STEP'UP of Université de Paris, 2014-2020

GF Smoot :

President of Paris Center for Cosmological Physics, since 2011
Chair of scientific committee of LabEx UnivEarthS, since 2011

D Steer :

Member of the scientific council of the GdR Ondes Gravitationnelles, since 2016
Co-coordinator of the division "Cosmology" of GdR CNRS Ondes gravitationnelles, since 2017
LISA: member of the "cosmic string" working group
Member of Physics Dpt council, since 2021
Member of the *Conseil National des Universités*, section 34, 2015-2020
Member of the conseil de laboratoire du LUTH (Meudon)
Co-director of the Master 2 "NPAC"
Responsible for the student international exchange programme, Physics department

R Stompor :

Member of the Polarbear/Simons Array Management Committee, since 2009
Member of the Simons Observatory Theory and Analysis Committee, 2016-2019
Member of the European Steering Committee of the LiteBIRD mission, 2017-2021
Member of the Interim Governance Board of the LiteBIRD mission, 2017-2021
Co-spokesperson of the LiteBIRD-France collaboration, 2017-2019
Member of the Coordination Team of the LiteBIRD-France collaboration, 2019-2021
Director of the International Research Laboratory, IRL2007, Centre Pierre Binétruy, since 2019

R Terrier :

President of the scientific board of the Programme National des Hautes Energies, since 2016
Member of steering committee of astroparticle working group (GT04) for In2p3 prospective, 2020
Member of group A (thematiques) for INSU-AA prospective INSU, 2019
Open Source Tools working group leader, HESS I/T department, since 2019
Member of the H.E.S.S. Observation Committee, 2016-2020
Member of time allocation committee for XMM, 2019

A Tonazzo :

Deputy Director of the STEP'UP doctoral school, since 2018
Elected member of the Administration Council of Paris-Diderot University, 2018-2019
Member of the Council of Doctoral School AAIF, since 2019
Member of the Steering Committee of Initiative Physique des Infinis (IPI), Sorbonne Université, 2020-2021
Co-coordinator of the division "Common tools for neutrino physics" of GDR CNRS Neutrino, until 2019
Member of the HCERES review committee for LLR, 2018

V Van Elewyck :

Elected member of the Physics department Board at Université de Paris, 2016-2021
Member of the Scientific Board of the Physics Department at Université de Paris, 2016-2021
Chair of the ANTARES & KM3NeT Publication Committees, 2016-2021
Member of the C4 commission (Astroparticles) of the International Union for Pure and Applied Physics, since 2018
Member of the steering committee of the IN2P3 decadal survey 2020-2030: Geosciences section, 2020-2021
Member of the Steering Committee of Initiative Physique des Infinis (IPI), Sorbonne Université, since 2021

V Vennin :

Member of the "Conseil de laboratoire" (laboratory board) of APC, since 2019
Convener of the cosmology working group of the "Gravitational Wave" groupement de recherche (GdR), since 2019
Member of the "primordial black holes" working group in the LISA collaboration (gravitational waves interferometer), since 2020

PI of the International Emerging Action "Primordial black holes from cosmological inflation" (CNRS), since 2020
Elected member of the CNRS national committee in section 02, since 2021

MC Volpe :

Member of the APC Scientific Council, 2017
Member of the Editorial Board of Journal of Physics G, 2017
Member of the Scientific Council of the Fédération de Recherche sur les Interactions Fondamentales (FRIF), 2017-2021

Participation in scientific and technical evaluation committees

F Ardellier :

Membre du comité international de revue AGATA - Phase 2 (Physique Nucléaire), 2020
Membre du comité d'évaluation HCERES de SUBATECH - Campagne d'évaluation du groupe B, 2020-21
Membre du groupe de revue IN2P3 du projet PALLAS (Prototype Accélérateur Laser Plasma), 2021

S Babak : NASA grant review panel Sep 2018; Grant review for Russian national funding agency, 2019

C Caprini : Member of the Science Assessment Review Panel for the M5 mission selection, ESA, 2021; Member of the Advisory Board of the Mainz Institute for Theoretical Physics, 2018 to 2020

J Delabrouille : Member of several International Review Panels for the evaluation of grant proposals submitted to the Polish "Narodowe Centrum Nauki" (NCN), 2018-2021

D Franco : Referee for SNF (Swiss National Foundation), 2018

S Gabici : Referee for DFG (Germany), ANR (France), IRC (Ireland), NSF (US), Ministry of Education and Science of the Russian Federation, Institut Polaire Francais

A Goldwurm : Referee for ERC and ANR

JC Hamilton : Referee for SNF (Swiss National Fund) and for ANR, 2017-2021

M Khlopov : Referee for FNRS (Belgium), FCT (Portugal), RSCF (Russia), SFRS (Serbia)

E Kiritsis : Referee for the ERC 2017-2021; for the American-Israeli binational foundation, 2017-2019; for the FWO (Flemish Council for Research), Belgium 2017-2021; for F.N.R.S, Belgium, 2017-2021; for the Swiss Science Foundation, 2017; for STFC (Individual projects), 2019, and rolling grants, 2017; for the Royal Society, UK, 2017-2018; for the Einstein Foundation, Berlin, Germany, 2017; the German-Israeli binational foundation, 2017-2018, for the Austrian Research Foundation, 2018-2019; for the Indo-French Centre for the Promotion of Advanced Research (CEFIPRA), New Delhi, India, 2018; for the Physics Evaluation Panel for the European Science Foundation, 2018-202; for CONICYT, Chile, 2019; for N.W.O, Netherlands, 2020; Member for the Physics Evaluation Panel for the Shota Rustavelli Foundation, Georgia, 2021

A Kouchner : Referee for FNRS (Belgium); Member of the NSF review panel of the IceCube Neutrino Observatory; Evaluateur pour le MESRI

E Parizot : Referee for ERC, ANR, and SNSF (Switzerland)

M Piat : Referee for ANVUR (Agenzia Nazionale di Valutazione del Sistema Universitario e della Ricerca)

D Prêle : Referee for ANR *Micro et nanotechnologies pour le traitement de l'information et la communication*, 2017

M Punch : Referee for the Irish Research Council and for the Natural Sciences and Engineering Research Council of Canada, 2019

D Steer : Referee for ANR, CNRS/JSPS Japan, Royal Society, Research Council (Belgium), Univ. Louvain la Neuve, SNF (Swiss National Fund)

R Stompor : Referee for H2020 MSCA Programs, Italian Ministry for University and Research, and US Dept. of Energy Early Career Awards

V Van Elewyck : Referee for the European Research Executive Agency (MSCA Program)

V Vennin : Referee for the National Science Center of Poland

MC Volpe Referee for Deutsche Forschungsgemeinschaft (DFG), Polish National Science Centre, Swiss National Science Foundation (SNSF), Natural Sciences and Engineering Research Council of Canada (NSERC), Canada Foundation for Innovation, Tata Institute for Fundamental Research

Outreach and communication to the general public

D Allard :

"Les rayons cosmiques ultra-énergétiques, une énigme pour l'astrophysique". Conférence débat pour le club d'astronomie de l'université du Maine CAUM, Le Mans, May 2018
"Les rayons cosmiques ultra-énergétiques, une énigme pour l'astrophysique". Series of Astronomy courses for the general public, Cycle histoire du cosmos (POET), Université de Paris, Feb 2020 and Mar 2021
"Le métier de chercheur en astrophysique", Conférence débat at the Henri Poincaré high-school, Palaiseau, Nov 2017 and Nov 2021

M Barsuglia :

Les vagues de l'espace-temps, general public book, Dunod, 2019. Ciel & Espace prize for the best general public astronomy book 2020

M Bucher :

Essential facts about Covid-19: the disease, the responses, and an uncertain futures (for South African learners, teachers, and the general public), co-edited with A. Mall, Academy of Science of South Africa, Aug 2021
Editorial Advisory Board, Quest Magazine, since 2020

C Caprini :

"La cosmologie et les ondes gravitationnelles", seminar for school students in the context of the initiative "Elle & l'infini: mathématiques, nom féminin?", Cité de la Science, Paris 2020; collège "Albert Camus" de Brunoy (Essonne), 2021
"Ondes gravitationnelles", seminar for high-school students, Lycée de La Plaine de Neauphle, Trappes en Yvelines, 2016; Lycée Albert Schweitzer, Le Raincy, 2017
Intervention "Gravitation, Virgo et trous noirs", Bar de Sciences, Paris, 2017

G Chardin :

Retour sur le paradoxe de Fermi, *in* Agelou et al. *Où sont-ils ? Les extraterrestres et le paradoxe de Fermi*, CNRS Editions, Sep 2017
L'insoutenable gravité de l'univers, Editions Le Pommier, Mar 2018
Président du jury du Concours CGenial, Fondation CGenial et Sciences à l'Ecole, 2017-2021
Le voyage dans le temps est-il possible?, BTLV, Emission télévisée, Mar 2019
Espace-temps: vous êtes ici, La Méthode Scientifique, France Culture, Oct 2019
Extraterrestres: il est Fermi d'en douter, La Méthode Scientifique, France Culture, Jan 2020
Le temps en (astro)physique, Conférence Opera Mundi, Salle Alcazar, Marseille, Oct 2020
Matière Noire: la fin du MOND?, La Méthode Scientifique, France Culture, Jan 2021
Comité d'organisation de la Nuit des Temps, Mar 2021
Sommes-nous seuls dans l'Univers?, Les Chemins de la Philosophie, France Culture, May 2021
Gravitation : tombée pour elle?, Eureka!, France Culture, Aug 2021
Multivers, multidimensions, une réalité?, BTLV, Emission télévisée, Oct 2021
Le temps de l'Univers, Conférence Fête de la Science, L'Isle-sur-la-Sorgue, Oct 2021

E Chassande-Mottin :

Intervention "Gravitation, Virgo et trous noirs", Bar de Sciences, Paris 2017
Intervention dans le programme Arts et Science Univers 2.0, Nov 2017
Aux frontières de la physique: les ondes gravitationnelles. Festival des nouvelles explorations, Royan, Oct 2018
Bonnes vibrations de l'Univers obscur. Treize Minutes, Marseille, Apr 2018
L'or des fiançailles cosmiques. Treize Minutes, Univ. de Paris Diderot, Feb 2019
Un chercheur, une manip, Palais de la découverte, May 2019
Cours sur l'astronomie gravitationnelle à l'Université ouverte de l'Université de Paris, 2020 et 2021
Interview in "Images des mathématiques", Apr 2021

S Chaty :

«La colonisation de l'espace», CNRS Editions, Collection A l'oeil nu, Mar 2020
«Le Ciel et les Etoiles», Gallimard Jeunesse, Collection Le Petit Monde Animé, Apr 2018
Various conferences and classes at Festival d'Astronomie de Fleurance, Aug 2019, 2020, 2021
Conference "La colonisation de l'espace", festival d'astronomie au Liban, Apr 2021
Conference "La colonisation de l'espace", fête de la science Univ. de Toulouse, Oct 2021
Conference "La colonisation de l'espace", fête de la science Univ. de Paris, Oct 2021
Public lectures in Université Ouverte/Sciences Ouvertes of Université de Paris : series of conferences "A Cosmos History" Jan 2020 & 2021
"A la recherche de la vie extraterrestre". Round table at the "Festival des Idées", Nov 2019
"Voir l'univers autrement". Round table at the "Festival des Idées", Nov 2020

S Chen :

Conception d'ASICs mixtes durcis aux radiations pour observatoires spatiaux, 5 minutes pour ma thèse, Festival des 2 infinis, Paris, Oct 2018

A Coleiro :

Cours sur l'astronomie multi-messager, Université ouverte (enseignement non diplômant) du pôle "formation tout au long de la vie" de l'Université de Paris, 2020 et 2021
Interview pour le journal de vulgarisation "Ciel et Espace" sur les résultats multi-messager de la mission INTEGRAL
Membre du groupe de travail "Outreach" de la collaboration SNEWS
Cours à l'école d'été du CLEA sur "l'Univers chaud et énergétique" , Gap, France, 2019
Cours dans le cadre du stage "Enseigner l'Univers" du plan académique de formation (Académies de Paris, Versailles et Créteil) organisé par le PCCP (laboratoire APC) sur l'observation multi-messager, 2019

A Creusot :

Détection des rayons cosmiques, des abysses à l'espace - Séminaire Phisis, UFR de physique, Paris, Nov 2021

J Delabrouille :

Member of the organizing committee and lecturer at the Fleurance Astronomy Festival, 2017-2021
Interview at the Radio Emission "La Méthode Scientifique", France Culture, May 2021

A Djannati-Ataï :

Co-founder and main animator of the amateur Astronomy Association, "De l'eau aux Etoiles", since 2011

J Errard :

Teacher and coordinator of a yearly series of lectures called "Cosmos History", for the Université Ouverte of the Université de Paris, since 2018
Collaborating with APC artists-in-residence, graduated from the ESAD Art School (through PCCP), 2019-2020 and 2021-2022
Writing and designing a book for children about observational cosmology, in collaboration with Ève Barlier, master student at the École Estienne (Paris), 2017-2018

D Franco :

Interviews at "La Méthode scientifique" on France Culture and Ciel & Espace, 2018
Participation to the debate at "Bar des sciences", Paris, 2018
Organization of a general public conference with the Nobel Prize laureate Art McDonald, 2018

K Ganga :

Journée Orient'Action de la Fondation Eureka, Goussainville, France, Apr 2018
Contribution at PCCP's Enseigner l'Univers, Paris, France, Jul 2018

P Goldoni :

"Redshift: Why does distance Matter to CTA ?", CTA Newsletter, 2021

A Goldwurm :

Teacher and coordinator of lectures on "Sgr A*, le Trou Noir Supermassif de la Galaxie", for the Université Ouverte of the Université de Paris, 2018–2021

L Haegel :

Organisation of the philosophy of science "Möbius Seminars" (with H. Inchauspé), since 2020
"La nouvelle ère de l'astrophysique gravitationnelle". Interviewed for an article in Sciences & Avenir, 2020
"Voir l'univers autrement". Round table at the "Festival des Idées", 2020
Q&A with the Planetarium of Vaulx-en-Velin, Lyon, 2020
Mentoring of female science students with "The Supernova Foundation" and "Femmes et Sciences" association

H Halloin :

IGOSat et les nanosats : Des projets spatiaux à l'Université, Journée 'Un Château dans les étoiles', Vincennes, May 2028
Les Ondes Gravitationnelles - Comment les détecter ?, Fête de la Science, Oct 2018
Cours de l'Université Ouverte sur les Ondes Gravitationnelles, 2018 et 2019

JC Hamilton :

Article sur QUBIC sans Sciences et Avenir, Sep 2021
La cosmologie: une histoire de distanciation sociale cosmique (video), La Nuit de Idées, Buenos Aires, Sep 2021
Articlee sur QUBIC dans "Le Monde", Apr 2021
Explorer l'Univers primordial avec QUBIC, Société Astronomique Nantaise, Nantes, Jan 2020
Que sait-on de la matière noire ?, Quai des savoirs, Toulouse, 2019
Explorer l'Univers primordial avec QUBIC, Société Française d'Astronomie, Paris, Jun 2020
Interview at "La Méthode Scientifique" on France-Culture, May 2019
L'Univers : du Big-Bang à nos jours: Uranoscope, Gretz-Armainvilliers, 2018
L'Univers : du Big-Bang à nos jours, Fête de la science, 2017
El Universo : desde el Big Bang hasta nuestros dias, Salta, Argentine, 2017-2018
L'Univers : du Big-Bang à nos jours, Lycée Lavoisier, Paris, 2017

M Khlopov :

Interview to all-andorra.com on cosmoparticle physics, Sep 2019 (Russian version), Oct 2019 (English version), Nov 2019 (French version), Dec 2019 (Catalan)
Cosmoparticle physics: the enlightening voyage to the Dark Universe. Scientific Voyage, Apr-Jun 2020
Opening of space for Art and Science activity in St. Petersburg, Russia, Oct 2021

E Kiritsis :

"Destinations in Physics". Lecture at the Tedx Heraklion, Mar 2018
"Gravity and the primordial Universe". Lecture at event "Teaching the Universe", destined to high school teachers at Eugenideion Idryma, Athens, Greece, Jul 2018
"Quantum Gravity, String Theory and the Structure of Space-time", Public lecture given at the Cambridge University Physics Society, Dec 2020
"Elementary Particles: from experiment to theory". Lecture given at the event destined for high school teachers: "Teaching particle Physics", Athens, Greece, Feb 2021
"String Theory in a nutshell", Princeton University Press, 2019

A Kouchner :

Les nouveaux messagers de l'Univers. General public conference at Semaine des ateliers expérimentaux Arts & Science, Clans, Jul 2017
Les neutrinos, nouveaux messagers de l'Univers. General public conference at Palais de L'Univers et des Sciences, Grande Synthe, Oct 2017
Looking at the sky from under the sea. Article co-écrit avec V. Van Elewyck, Special issue of Physics World - Nov 2017
Looking at the sky from under the sea. Special issue of Physics World, Nov 2017
Why Scientists Sank a Telescope Into the Deepest Parts of the Ocean? Interview pour "Atlas Obscura", Dec 2017
Interview au journal télévisé de la 2e chaîne marocaine, Feb 2018
Interview pour Le Reporter (Maroc), Feb 2018
A la Recherche des neutrinos with Stéphane Lavignac, Quai des Sciences, Dunod, Sep 2018
A la recherche des neutrinos. Interview pour "Ciel & Espace radio", Sep 2018
Neutrino, la plus mystérieuse des particules, Interview pour "Sciences et Avenir" , Nov 2018
Les neutrinos. Invité de "La Tête au Carré" France Inter, Nov 2018
Les neutrinos ou l'art de défier les conventions. Invité de "La conversation scientifique" France Culture, Dec 2018
Les neutrinos, nouveaux messagers de l'Univers. Conférence grand public Cap Sciences, Bordeaux, Jan 2019
Les neutrinos, nouveaux messagers de l'Univers. Conférence grand public en marge du spectacle Aganta Kairos, Arcachon, Jan 2019
Le laboratoire APC et les nouveaux messagers de l'univers. General public conference at Lycée Charles de Gaulle, London, UK, Mar 2019
L'astronomie des neutrinos de haute énergie. General public conference at Ecole Nationale Supérieure d'Informatique, Alger, Algeria, Oct 2019
D'inexplicables particules détectées en Antarctique. Interview pour "La méthode scientifique, le journal des sciences», France Culture, Jan 2020
Particules en Antarctique : l'univers de l'autre côté du Big-Bang, Invité de "La méthode scientifique" France Culture, May 2020
Reis van een verscheurde ster naar de Zuidpool, Interview pour le journal néerlandais NRC Lien , Feb 2021
Traquer des particules fantômes sous les glaces du lac Baïkal, Interview pour Science et Vie, Apr 2021

A Lemiere :

Séminaires et tables rondes pour les journées "Women in science", Paris, 2018, 2019, 2020
Seminaires et débats, Fête de la Science, Paris, Oct 2018, 2019, 2020
Présentation "la mort des étoiles" à la "Nuit des étoiles" GRANDREX, organisé par l'Observatoire de Paris, GRANDREX, Paris, oct 2019
Presentation "l'Astrophysique à haute énergie" au Festival

STAR'sUP, organisé par l' Observatoire de Paris, Meudon, Oct 2020
Participation au projet "residence jeunes artistes" organized by PCCP, APC ,Paris, 2019-2020, 2020-2021
Presentation sur le Centre Galactic à la "Journée de l'UFR", Paris, 2020
Table rond "Voir l'univers autrement" - Festival des idées Université de Paris, remote, 2020
Présentation sur l'Astronomie mulit-messagers ,"Teaching the Universe" organisé par le PCCP, en ligne, 2021

G Marchiori :

L'origine de la masse et la découverte du boson de Higgs, séminaire pour les professeurs de collège et des lycées, dans le cadre de l'initiative "Enseigner l'Univers", online, May 2021

J Martino :

Conférence fête de la Science: Le satellite LISA Pathfinder. Oct 2019

S Mastrogiovanni :

Teaching about gravitational waves in high schools, Frontiers e-summer/winter schools, Remote meeting, Jan and Jul 2021
Teaching about gravitational waves in high schools, Frontiers e-summer school, Remote, Jul 2020
Teaching about gravitational waves in high schools, Atelier de formation, Paris, France, Mar 2020

L Mousset :

Observer la toute première lumière de l'Univers avec le télescope QUBIC, Journée des enfants de l'AFA, Sep 2021
Explorer l'univers primordial avec l'instrument QUBIC, Journée des enfants de l'AFA, Sep 2020

E Parizot :

Scientific outreach through the YouTube channel "E.T. d'Orion: dans le champ des étoiles" (http://tinyurl.com/etdorion): ~ 9000 subscribers, ~ 500000 views
Scientific knowledge communication through YouTube channel "Etienne Parizot" (http://tinyurl.com/playlists-ep): > 13000 subscribers, and > 1.5 million views

G Patanchon :

Lecture on Cosmology at the CLEA (Comité de Liaison Enseignants et Astronomes) summer school for high school teachers in physics/-math/Bio, Gap Col Bayard, Aug 2018

A Petiteau :

Les sources d'ondes gravitationnelles, Fête de la science 2018, Paris, Oct 18
Cours sur les ondes gravitationnelles à l'Université Ouverte de l'Université Paris-Diderot, Mar 2018 & Feb 2019
G. Theureau, S. Chen et A. Petiteau. Des pulsars pour traquer les ondes gravitationnelles. "Pour la science", Aug 2021
Débat sur les "Ondes gravitationnelles" au cercle universitaire d'Enghien-les-bains, Sep 2018
Mardi de l'espace sur les ondes gravitationnelles, Dec 2019
Conseiller scientifique et animation "Pourquoi observer l'Univers et les trous noirs en écoutant les vibrations de l'espace-temps ?" au Festival Image Sonore, 2020
Animation "Pourquoi écouter l'Univers ?" au Festival Image Sonore, 2021

M Piat :

Détection du rayonnement fossile, démonstration aux rencontres d'été de physique de l'infiniment grand à l'infiniment petit, Jul 2017
Radioastronomie amateur : comment cartographier notre Galaxie avec une clé USB TNT, cours et travaux pratiques, 27ème festival d'Astronomie de Fleurance (Gers), Aug 2017
Le Soleil, la Terre et la Lune, exposé dans une classe de CP, Ecole Boulard Paris, Dec 2017
Entretien avec des élèves de 1ère S du lycée Amyot à Melun (77) sur le thème Poussières d'étoiles, TPE (professeur : Catherine Royer), Dec 2017
Petite introduction à la Cosmologie, exposé à l'ensemble des classes de 3ème, collège Stanislas, Jun 2018
Le système solaire, exposé dans une classe de CP, École Boulard Paris, Jun 2018
Détection du rayonnement fossile depuis le toit de l'APC. Vidéo pour l'action grand public de la SFP La Nuit des temps, Mar 2021
Interview pour une vidéo leblob.fr sur le thème de QUBIC et le C2N, 2021

D Prêle :

Interview at "La Méthode Scientifique" Athena : l'observatoire X, France-Culture, Sep 2021
Warm front-end for X-ray cryogenic detectors, CMP Europractice Report 2020-2021
Editorial board of a promotional film on the ATHENA X-IFU detection chaine, X-IFU | Mesure de haute précision des rayons X dans l'espace, 2020
Specific Integrated Circuit for the X-IFU Warm Front-End Electronic, AthenaNugets 37, May 2019
Know more about the APC contribution, The X-IFU Gazette N°7, Apr 2018
Space and Ground-Based Telescopes ATHENA & QUBIC - The Need for New Instruments, USTH seminar, USTH, Hanoi, Vietnam, Nov 2017

D Steer :

Translation into English & expertise of the book by P.Binétruy: "À la poursuite des ondes gravitationnelles"
Presentation on cosmology to 17-18 year olds from a school in Oxfordshire, Jan 2018
Interview & contribution to the CNRS article "Les premiers pas de l'astronomie gravitationnelle", Jun 2020

R. Terrier :

Le trou noir au centre de la Galaxie à tous les temps, Université Paris Diderot, Fête de la science, Sep 2017

V Van Elewyck :

Participant to the theatre performance & outreach event "Aganta Kairos – Particule Fantôme" (Laurent Mulot & Thierry Poquet), various venues in Compiègne & Lille, 2017
Looking at the sky from under the sea (with A. Kouchner), article in Special issue of Physics World, Nov 2017

Probing the earth's interior with neutrinos (with J. Coelho, E. Kaminski and L. Maderer), article in Europhysics News 52/1, 2021

Participation to the organization of the first KM3NeT drawing contest 'Draw me a neutrino' & chair of the French jury, 2019

P Varniere :

Participation to a book on numerical simulation targeting the general public. *Numerical Simulation, An Art of Prediction*, Vol. 2, 2020

V Vennin :

Popularisation articles: in Science & Avenir, 2021, Ciel & espace, La recherche, Science & Vie, 2020

Public lectures: in the Paris Open University series of conferences "A Cosmos History", 2020 & 2021

Radio shows: La méthode scientifique, France Culture, 2018 and 2019

High school conference at Lycée Louis le Grand, 2020; High school conference "Demain la Terre" organised by Paris Diderot University, 2019; School workshop (age 13-14) at collège Evariste Galois, 2018

Online video for the Causa Mundi think tank, 2019

MC Volpe :

School : Interactive Lectures for children in primary school (CM2), «Comment meurent les étoiles ?», 2017

Popularisation talk at the "Forum des Métiers", in middle School, "Le métier de chercheuse/chercheur", 2021

G de Wasseige :

Organization of the contest 'Draw me a neutrino', 2019

Distinctions

As part of Planck team – JG Bartlett, M Bucher, C Cressiot, J Delabrouille, S Fromenteau, K Ganga, Y Giraud-Héraud, M Le Jeune, G Patanchon, C Rosset, R Stompor : Gruber Prize in Cosmology, 2018; Royal Astronomical Society Group Award, 2018, Marcel Grossman Institutional Award, 2018

M Bucher : Election to Academy of Science of South Africa, 2019

F Casse : PEDR, 2018

S Chaty : PEDR 2018, Promotion de l'Ecole des Cadres de l'Université de Paris, 2021-22

J Delabrouille : International talent distinguished scientist, Chinese Academy of Sciences, 2020

D Langlois : PEDR, 2018

M Le Jeune : CNRS crystal medal, 2020

S Mastrogiovanni : Amaldi Research Center prize, 2021

S Mei : PEDR, 2018; Senior member de l'Institut Universitaire de France, 2012-2017

E Parizot : PEDR, 2018

T Patzak : Senior member de l'Institut Universitaire de France, 2013-2018, PEDR 2013-2018, 2019-2023

A Petiteau : Prix Jean Thibaud de l'Académie des sciences, belles-lettres et arts de Lyon, 2018

E Savalle : IAU PhD Prize to Recognise Excellence in Astrophysics : Division A Fundamental Astronomy, 2021

V Van Elewyck : Junior member of Institut Universitaire de France, 2016-2021

V Vennin : PEDR, 2018

F Virieux : Cristal collectif du CNRS, 2021

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Education and research training

Education, training and dissemination of knowledge constitute one of the main missions of APC. In fact, the laboratory has a strong contribution to the education program of Université de Paris at both the undergraduate and graduate levels.

The laboratory hosts 29 professors. At the undergraduate level, our professors teach a wide variety of classes, from the first year general classes in Physics, Engineering and Mathematics to advanced classes at the Master and Doctoral levels. Some of our CNRS researchers and our engineers also have a regular teaching activity, mostly at the graduate level. The majority of the faculty and researchers supervise internships at all levels, and doctoral theses.

Our teaching and training activities thus allows us to educate students and give them first-hand experience with research projects from the very first years of their University studies up to their Ph.D. This creates a strong and long-standing connection between the students and our laboratory environment, and gives them multiple opportunities to learn in class and to deepen their knowledge with research projects within the laboratory.

Our professors also have responsibilities in the direction of teaching programs and are members of the Physics Department council, and its Scientific and Teaching council.

Undergraduate studies

The APC members teach lectures at the undergraduate level (from calculus and mechanics in the first year to quantum mechanics and relativity in the third year), both in general topics, but also in classes more focused on the laboratory's research topics (astrophysics, etc.).

In 2017-2021, Cécile Roucelle has been responsible of the Physics Bachelor program, which includes several specializations: *Physique Générale* (Physics, ~120 new students each year), *Double licence physique chimie* (Double diploma in Physics and Chemistry; ~30 new students each year), *Enseignement physique-chimie* (Diploma in Physics and Chemistry; 10 new students each year), *Cycle universitaire de préparation aux grandes écoles (CUPGE)* (Preparatory studies for the grandes ecoles; ~70 new students each year), *L2 Maths-Physique Santé* (Diploma in Mathematics, Physics and Health Studies; ~30 new students each year) and *L2 techniques et méthodes physiques* (Applied Physics; ~10 new students each year). Danièle Steer is responsible for the Erasmus and international exchanges for the physics undergraduate students. APC professors have been very active for the creation of several new programs (*L2 techniques et méthodes physiques, L2 Maths-Physique Santé*. They also lead programs to help students that are behind, and to monitor and give orientation to undergradiate students (Cécile Roucelle). We are responsible of the orientation program for freshmen and second year students (Alexis Coleiro).

Graduate school Earth, Planets, Universe

APC leads the graduate school Earth, Planets, Universe (EPU) [187] in a parternship with Institut de Physique du Globe de Paris (IPGP). EPU includes several master programs in astroparticule, astrophysics, theoretical physics and cosmology, and its goal is to train leading scientists and engineers in geosciences, astrophysical and space sciences.

[187] https://u-paris.fr/en/graduateschools/

The vision is that training through research is essential. Our students are offered a growing share of "curriculae without frontiers", in partnership with renowned foreign universities and laboratories. EPU includes a wide range of 26 Master specializations in Fundamental and Applied Physics, Earth, Planet and Environmental Sciences, and Environmental Hazards and Risks, and the doctoral school STEP'UP. This corresponds to ~ 100 researchers and ~ 400 students. The EPU coordinator is a APC professor, Simona Mei, who works with a direction team of five people among which the APC director, also a professor, Antoine Kouchner.

Master programs

EPU includes the following Master programs:

- the first year Master program of the Physics Department at Université de Paris[188], with two branches: Fundamental physics[189], and Applied Physics[190]
- the international Master *Paris Physics Master*[191] in parternship with Sorbonne Université. An APC professor, Sylvain Chaty, is the coordinator of this Master program for the University of Paris.
- the two year Master program of the International Centre for Fundamental Physics[192], in parternship with Sorbonne University, Université de Paris, Paris-Saclay University and Institut Polytechnique de Paris (M2).
- the two year Master program SPACE, in parternship with the University of Science and Technology of Hanoi
- the second year of Master NPAC
- the second year of Master AAIS and Space Science and Technology

The first years of these Masters provide broad programs that include statistical physics, high energy physics, atomic physics, condensed matter physics, astrophysics and physics for biology. Two are thought in English, the International Centre for Fundamental Physics and the Paris Physics Master.

In the second year of Master, the students specialize in different domains in astroparticule, astrophysics, cosmology, particle physics and theoretical physics. We outline below our main responsibilities within the Master NPAC and SPACE, where the APC has the stronger contribution, both in the coordination and in teaching.

Master NPAC The specialities of the NPAC master are particle physics, nuclear physics, astro-particles and cosmology. NPAC is a reference Master in France for these fields of research, and has strong links with top laboratories in the Ile de France region. NPAC students choose internships and often apply for Ph.D. studies in experimental physics (often within large astroparticle experiments), in instrumentation developement, and also in theory and phenomenology. NPAC provides a strong background in theory with lectures such as quantum field theory and general relativity, and in experimental physics and instrumentation, with lectures on detector physics and laboratory practice.

The Master is supported by three universities: Université de Paris, Paris-Saclay University and Sorbonne University. The two coordinators for the University of Paris are from APC: Guillaume Patanchon from 2017 and Alexandre Creusot from 2020. Antoine Kouchner was coordinator up to 2019 and Danièle Steer from 2019 to 2020. APC researchers lead several classes in the master: Stefano Gabici is teaching Astroparticles, Danièle Steer General Relativity, Alessandra Tonazzo detector physics as well as Thomas Patzak up to 2019, Davide Franco Neutrino physics, and Guillaume Patanchon Advanced Cosmology.

[188] https://physique.u-paris.fr/masters-en-physique

[189] https://www.master-physique-universite-paris.fr/m1/

[190] https://www.master-physique-universite-paris.fr/m1/

[191] http://www.parisphysicsmaster.com/

[192] https://www.phys.ens.fr/spip.php?rubrique284&lang=en

Master SPACE The University of Science and Technology of Hanoi was created in 2009 by an international agreement between France and Vietnam. The SPACE department[193] was founded in 2011, and the Master programs were created in the two following years (M1 in 2012 and M2 in 2013), renewed in 2020 for 4 years. The objective is to train scientists and engineers in Vietnam to support the development of Vietnamese space activities. This involves both the establishment of a space agency capable of building and managing satellite projects and the processing and exploitation of scientific data obtained from satellites dedicated to the Earth observation and astrophysics. The Master is a partnership with Université de Paris, Observatoire de Paris, Université de Montpellier, Université Paris Est Créteil, and the CNES.

193 `https://www.usth.edu.vn/en/programusth/master-in-space-and-aeronautics-sa/`

Our Master SPACE students found a job in the industry or pursued Ph.D. studies in the fields: Earth observation, astrophysics and satellite technology (five students were at APC and worked on Euclid, LiteBIRD, IGOSAT, and with millimeter laboratory). They obtained scientist positions in various research institutes (academic or industry) worldwide.

Yannick Giraud-Héraud was the director of the department and of the master program from their creation up to 2020, and Guillaume Patanchon became director in 2020. Damien Prêle is responsible for the first year of Master and Cyrille Rosset for the second year. Hubert Halloin, Guillaume Patanchon, Damien Prêle, Cyrille Rosset and Etienne Savalle lead classes in both years.

Doctoral School STEP'UP

Most Ph.D. candidates at APC are affiliated to the Sciences de la Terre, de l'Environnement et Physique de l'Univers (Doctoral school # 560) (STEP'UP) [194]. The doctoral school has the task to monitor the progress of each thesis while providing dedicated training to the PhD candidates. It is the role of the school to also authorize the PhD defence and to check that all the requirements are met in order to deliver the PhD diploma. APC is one out of six laboratories affiliated to STEP'UP whose scientific themes range from the study of the Earth's interior and climate to the study of the structure of our Universe and its fundamental components. APC constitutes the majority of the doctoral school's Physics of the Universe department. On average, approximately 12 PhD candidates from APC successfully defend their thesis every year.

194 `https://ed560.ed.univ-paris-diderot.fr/en/the-doctoral-school/`

APC has always played an important role in the management of the doctoral school since its creation. Yannick Giraud-Héraud has been the director of the school from 2015 to 2020. Fabien Casse became the director in 2020, and Alessandra Tonazzo is the director of the Physics of the Universe department of the doctoral school since 2018.

Teaching Responsibilities

- Responsibility in undergraduated studies: Cécile Roucelle (responsible Licence de Physique, since 2017)
- Responsible of the Physical Engineering cursus (L3, M1 and M2) at the

Denis Diderot Engineering School (EIDD): Michel Piat (since 2014)

- Co-Direction of the international Master *Paris Physics Master* : Sylvain Chaty, in parternship with Sorbonne Université;
- Direction of Master NPAC: Guillaume Patanchon (since 2017), Alexandre Creusot (since 2021), Danièle Steer (2015-2021)
- Direction of the Doctoral school STEP'UP: Yannick Giraud-Héraud (director in 2015-2020); Fabien Casse (director since 2020), Alessandra Tonazzo (vice-director since 2018), Alexis Coleiro (member of the Council), Julien Serreau (member of the selection committee, 2014-2019)
- Graduate School (EUR) Earth, Planets, Universe (EPU) direction: Simona Mei (coordinator), Antoine Kouchner (direction team)

Responsibilities in University committees

At the Faculty level:

- Faculty of Sciences management team: Thomas Patzak (Vice-dean for Research and President of the "Commission Recherche", since 2020)
- Commission Recherche of the Faculty of Sciences: Cécile Roucelle (since 2019)
- Administrative Council of (former) Paris Diderot University and Bureau of the University's Vice-President: Alessandra Tonazzo (2018-2019)
- Council of the Faculty of Sciences: Sylvain Chaty (since 2019)

At the Physics Department level:

- Direction of the Physics Department: Francesco Nitti (vice-director since 2015)
- Council of the Physics Department: Arache Djannati-Atai (2015-2021), Cécile Roucelle (2015-2021), Eleonora Capocasa (2021-present), Etienne Parizot (since 2015): Simona Mei (2015-2021), Veronique Van Elewyck (2015-2021), Danièle Steer (since 2021), Béatrice Silva (since 2015), Martin Souchal (since 2015), Léon Vidal (since 2015), Léna Arthur (since 2015)
- Scientific Council of the Physics Department: James Bartlett (2015-2021), Fabien Casse (2015-2021), Anne Lemière (2015-2021), Eric Chassande-Mottin (since 2017), Alexis Coleiro (since 2021), Veronique Van Elewyck (2015-2021), Louise Mousset (2017-2020), Bastien Arcelin (2017-2020), Sylvain Chaty (2015-2021), Stefano Gabici (since 2021), Julien Serreau (2012-2016)
- Teaching Council of the Physics Department: Simona Mei (since 2021), Etienne Parizot (since 2021), Cécile Roucelle (vice-president, 2014-2016), Alexandre Creusot (since 2021), Guillaume Patanchon (since 2021), Danièle Steer (until 2021), Alessandra Tonazzo (2015-2020).

Responsibilities in national committees

- Section 29 (Particle Physics) of the Conseil National des Universités (CNU): Julien Serreau (2015-2019)

- Section 34 (Astronomy, astrophysics) of the CNU: Simona Mei (vice-president, 2015–present), Guillaume Patanchon (substitute, 2015-present), Fabien Casse (vice-president, 2015-2019), Danièle Steer (2015-2020)

Internships

At both the undergraduate and graduate levels, we train students through internships, lasting typically from few weeks to few months. The research projects usually lead to a written report and an oral defence.

Figure 86: A group of secondary school students during a lab visit

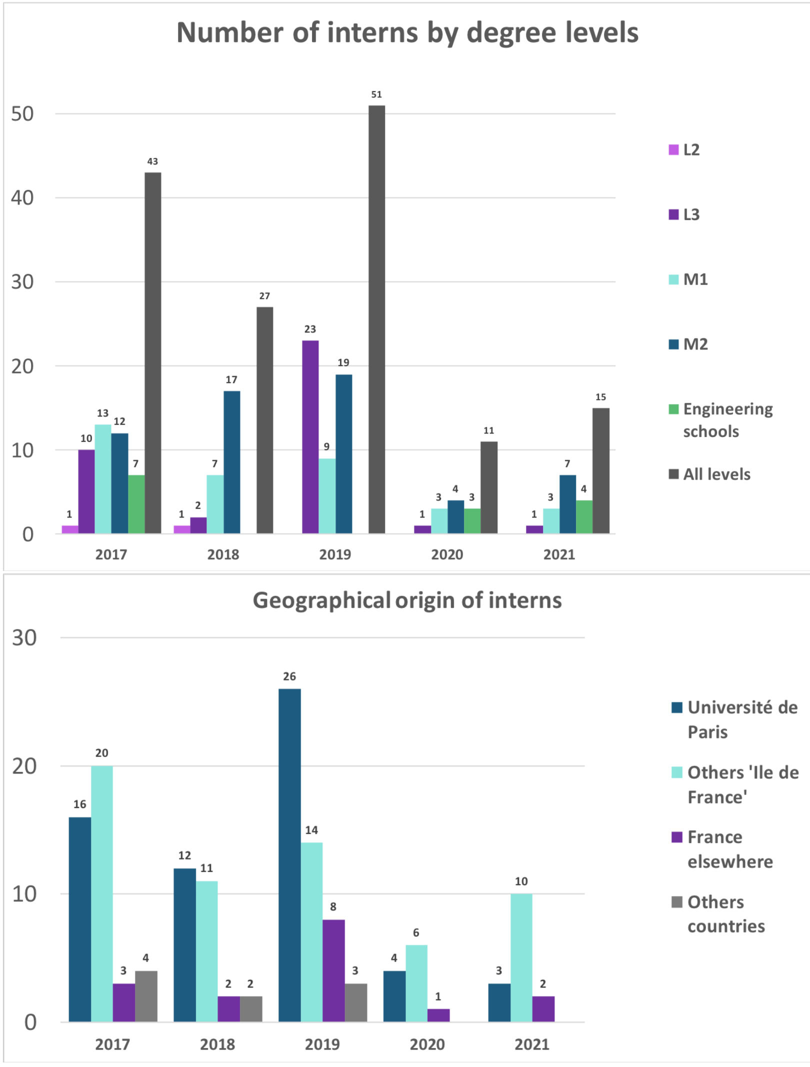


Figure 87: (Top) Distribution of trainees by level of education. (Bottom) Provenance of lab's trainees.

The laboratory regularly hosts interns from secondary schools (3rd grade) for one-week visits during which the students learn about the diversity of jobs in the research sector by interacting and discussing with researchers and engineers (see Fig. 86.

Theses

The APC laboratory hosts 68 researchers and faculty members. Among them 42 have the "Habilitation à Diriger des Recherches" (HDR) allowing them to supervise PhD theses. Younger permanent staff have the opportunity to become co-adviser of PhD candidates in collaboration with senior researcher and faculty members, enabling them to get their habilitation in the future. The number of ongoing PhD thesis within the APC laboratory is increasing each year to reach a total of 51 in 2021 leading to an average of 1.2 PhD thesis per HDR permanent staff. The vast majority of the PhD candidates are enrolled in the doctoral school STEP'UP in the "Physics of the Universe" department where the progress of each PhD thesis is monitored on a yearly basis by both members of the board of the doctoral school and a specific external committee for each PhD candidate.

The range of topics of PhD thesis performed within the APC laboratory matches the vast span of research of APC. Indeed, APC PhDs ranges from the most fundamental theoretical physics topic to the most applied physics as for instance the development of new technologies dedicated to both Earth-based and space borne instruments. The variety of subject also stems from the ability of the APC laboratory to maintain high-quality research in every aspect of the multi-messenger astronomy, making the APC laboratory one of the most sought-after places to do a PhD in the astroparticle international community. It is noteworthy that a significant fraction (nearly half of them) of our PhD candidates originates from abroad while the other part comes from various origins in France. Most of our PhD students managed to successfully obtaining Master degree in astrophysics and particle physics (Masters M2 A&A, NPAC, and othersother M2 in France) while the rest directly comes from Engineering schools or from the private sector.

The attractivity of the APC labs regarding PhD lies also in its ability to receive PhD funding from a very wide range of institutional partners. Indeed, PhD thesis within APC are funded from various grants such as French ministry of research, CNRS-IN2P3, Labex, ERC, ANR, University of Paris IdEX, private non-lucrative fundations, Région "Ile-De-France", the city of Paris and other international grants (China Science Council, Vietnam government).

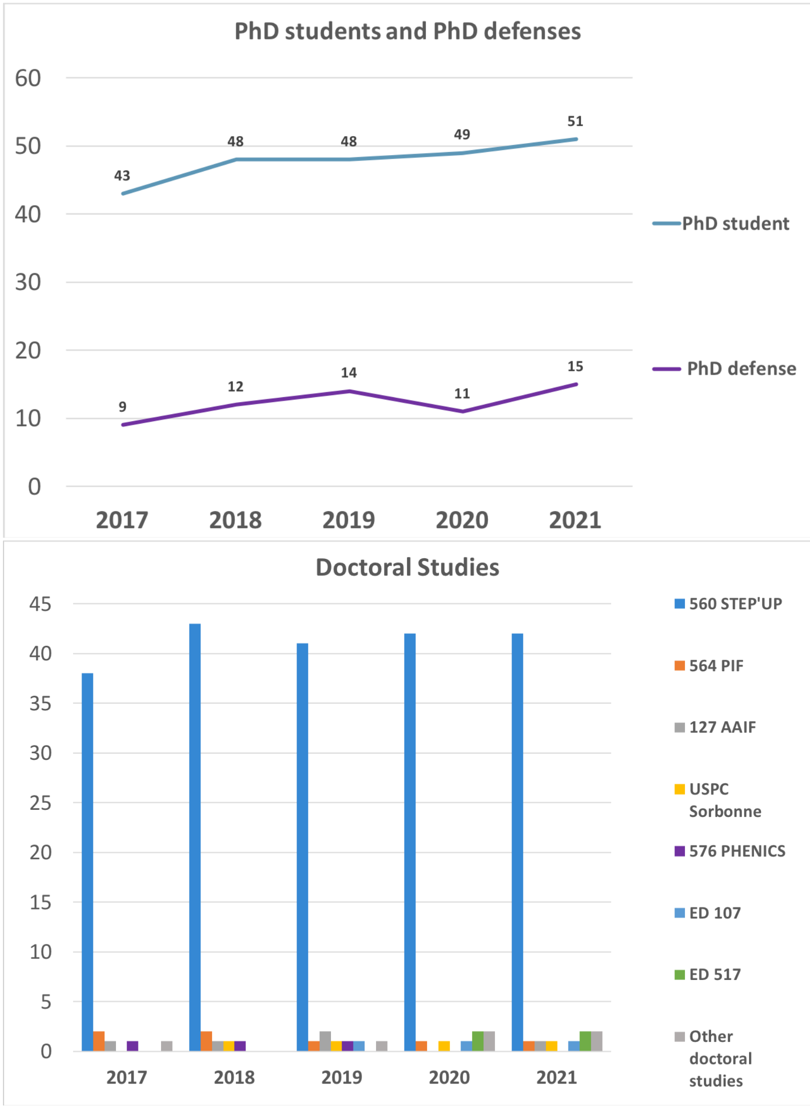


Figure 88: (Top) Recent evolution of the number of PhD students (in the three year thesis program) and of total number of PhD thesis defences per year. (Bottom) Distribution of the PhD students by their affiliation to doctoral schools

List of theses in progress or defended since 2017

This list does *not* include the theses that have started in Fall 2021.

- **Cosmology**

  Banerji, Ranajoy – *Optimisation d'une mission spatiale CMB de 4e génération* . Defense in 2017. Affiliated with Ecole doctorale 560 STEP'UP

  Doux, Cyrille – *Combinaisons de sondes cosmologiques : Etudes de cas avec les données de Planck et SDSS-III/BOSS* . Defense in 2017. Affiliated with Ecole doctorale 560 STEP'UP

  Ntelis, Pierros – *Tests de la cosmologie via l'échelle de transition vers l'homogénéité au travers des relevés des grandes structures dans l'Univers* . Defense in 2017. Affiliated with Ecole doctorale 560 STEP'UP

  Traini, Alessandro – *Antenna-Coupled LEKIDs for Multi-Band CMB Polarization Sensitive Pixel* . Defense in 2018. Affiliated with Ecole doctorale 560 STEP'UP

  Hoang, Duc Thuong – *Optimization of future projects for the measurement of Cosmic Microwave Background polarization* . Defense in 2018. Affiliated with Ecole doctorale 560 STEP'UP

  Beck, Dominic – *Zooming on B-Modes : data analysis and scientific exploitation of current and future data sets of POLARBEAR/Simons Array - next generation CMB B-mode observatory.* . Defense in 2019. Affiliated with Ecole doctorale 560 STEP'UP

  Bui, Van Tuan – *A study of the large scale structure of the universe with galaxy clusters: from Planck to Euclid* . Defense in 2019. Affiliated with Ecole doctorale 560 STEP'UP

  Murray, Calum – *Preparing The Euclid Dark Energy Survey with Clusters* . Defense in 2020. Affiliated with Ecole doctorale 560 STEP'UP

  Vergès, Clara – *Searching for cosmological B-modes in the presence of astrophysical contaminants and instrumental effects* . Defense in 2020. Affiliated with Ecole doctorale 560 STEP'UP

  Arcelin, Bastien – *Bayesian deep learning for weak lensing analyses: overlapping galaxies separation and galaxy parameters estimation from blended scenes* . Defense in 2021. Affiliated with Ecole doctorale 560 STEP'UP

  El-Bouhargani, Hamza – *Combinaisons de sondes cosmologiques : Etudes de cas avec les données de Planck et SDSS-III/BOSS* . Defense in 2021. Affiliated with Ecole doctorale 560 STEP'UP

  Montandon, Thomas – *Inflationary Non-Gaussianities* . Defense in 2021. Affiliated with Ecole doctorale 560 STEP'UP

  Mousset, Louise – *Exploring the primordial Universe, inflation and promordial Gravitational Waves with QUBIC, the QU Bolometric Interferometer for Cosmology* . Defense in 2021. Affiliated with Ecole doctorale 560 STEP'UP

  Stankowiak, Guillaume – *Caractérisation et commissioning de l'instrument QUBIC* . Defense in 2021. Affiliated with Ecole doctorale 560 STEP'UP

  Jost, Baptiste – *Analyse de l'ensemble des données actuelles et à venir du "Fond Diffus Cosmologique " CMB* . Defense in 2022. Affiliated with Ecole doctorale 560 STEP'UP

  Afanasyev, Anton – *Progenitors of massive ellipticals at $z > 2$* . Defense in 2022. Affiliated with Ecole doctorale 127 Astronomie et Astrophysique d'Ile de France

  Kou, Raphaël – *Cosmic Microwave Background Observations for Large-Scale Structure Studies* . Defense in 2023. Affiliated with Ecole doctorale 560 STEP'UP

  Wang, Wang – *Evaluation of the impact of systematic effect on the future LiteBIRD satellite mission for the measurement of the Cosmic Microwave Background B-mode polarization* . Defense in 2023. Affiliated with Ecole doctorale 560 STEP'UP

  Zhang, Zheng – *The Role of Polarization in 21 cm* . Defense in 2023. Affiliated with Ecole doctorale 560 STEP'UP

  Grishin, Kirill – *Combinaisons de sondes cosmologiques : Etudes de cas avec les données de Planck et SDSS-III/BOSS* . Defense in 2024. Affiliated with Ecole doctorale 560 STEP'UP

- **Gravitation**

  Bouffanais, Yann – *Bayesian inference for compact binary sources of gravitational waves* . Defense in 2017. Affiliated with Ecole doctorale 560 STEP'UP

  Capocasa, Eleonora – *Optical and noise studies for Advanced Virgo and filter cavities for quantum noise reduction in gravitational-wave interferometric detectors* . Defense in 2017. Affiliated with Ecole doctorale 560 STEP'UP

  Fayon, Lucile – *Instrumentation sismologique spatiale : Fonction de transfert du sismomètre 6 axes InSight et développement d'un capteur de déplacement picométrique par interférométrie* . Defense in 2018. Affiliated with Ecole doctorale 560 STEP'UP

  Bacon, Philippe – *Contribution à l'analyse de données en prévision de la première détection directe à ondes gravitionnelles.* . Defense in 2018. Affiliated with Ecole doctorale 560 STEP'UP

  Laporte, Matthieu – *Amélioration et exploitation d'un simulateur électro-optique du détecteur spatial d'ondes gravitationnelles LISA* . Defense in 2019. Affiliated with Ecole doctorale 560 STEP'UP

  Bayle, Jean Baptiste – *Modélisation instrumentale et analyse associée.* . Defense in 2019. Affiliated with Ecole doctorale 560 STEP'UP

  Arène, Marc – *Estimation des paramètres des sources d'ondes gravitationnelles* . Defense in 2020. Affiliated with Ecole doctorale 560 STEP'UP

  Chalumeau, Aurélien – *Gravitational wave confu-*

sion problem across frequency band . Defense in 2021. Affiliated with Ecole doctorale 560 STEP'UP

N'Guyen, Catherine – *Development of squeezing techniques for quantum noise reduction in gravitational-wave detectors* . Defense in 2021. Affiliated with Ecole doctorale 560 STEP'UP

Toubiana, Alexandre – *Tests of general relativity and Bayesian population studies with gravitational waves from coalescing binaries* . Defense in 2021. Affiliated with Ecole doctorale 560 STEP'UP

Dam, Quang Nam – *Simulations and associated data analysis for realistic LISA configuration / Simulations et analyses de données pour une configuration réaliste de LISA* . Defense in 2022. Affiliated with Ecole doctorale 560 STEP'UP

Falxa, Mikel – *Detecting low-frequency gravitational waves* . Defense in 2022. Affiliated with Ecole doctorale 560 STEP'UP

Vidal, Léon – *Validation expérimentale des performances interférométriques de LISA* . Defense in 2022. Affiliated with Ecole doctorale 560 STEP'UP

- **High-energy astro**

Jouvin, Léa – *Le centre Galactique aux très hautes énergies : modélisation de l'émission diffuse et premiers éléments d'analyse spectro-morphologique.* . Defense in 2017. Affiliated with Ecole doctorale 560 STEP'UP

Grégoire, Timothée – *Optimisation des méthodes de reconstruction des événements de type cascade dans les téléscopes Tcherentron sous-marins.* . Defense in 2018. Affiliated with Ecole doctorale 560 STEP'UP

Phan, Thanh Hien – *Simulation and Experimental Characterization of the Scintillation Detector for IGOSat* . Defense in 2018. Affiliated with Ecole doctorale 560 STEP'UP

Chuard, Dimitri – *Impact et réatroaction du trou noir supermassif galactique sur la zone moléculaire centrale de notre galaxie.* . Defense in 2018. Affiliated with Ecole doctorale 560 STEP'UP

Spir-Jacob, Marion – *Pulsar à très hautes énergie.* . Defense in 2019. Affiliated with Ecole doctorale 560 STEP'UP

Chen, Si – *Conception d'Asicsm mixtes durcis aux radiations pour observatoires spatiaux* . Defense in 2019. Affiliated with Ecole doctorale 560 STEP'UP

Demidem, Camilia – *Simulations PIC-MDH de l'accélération de particules dans une turbulence magnétisée.* . Defense in 2019. Affiliated with Ecole doctorale 560 STEP'UP

Giunti, Luca – *La Galaxie au-delà du TeV avec H.E.S.S.-2 et CTA* . Defense in 2021. Affiliated with Ecole doctorale 560 STEP'UP

Marchioro, Julien – *L'univers gravitationnel: à la recherche des progéniteurs d'ondes gravitationnelles* . Defense in 2023. Affiliated with Ecole doctorale 560 STEP'UP

Phan, Vo Hong Minh – *CRIME: Cosmic Ray Interactions in Molecular Environments* . Defense in 2020. Affiliated with Ecole doctorale 560 STEP'UP

Vieu, Thibault – *Superbubbles and the origin of Cosmic Rays* . Defense in 2021. Affiliated with Ecole doctorale 560 STEP'UP

Zouari, Samuel – *Etude de l'origine de l'émission à très haute énergie au centre de notre galaxie et connexion possible avec SgrA* notre plus proche trou noir supermassif* . Defense in 2022. Affiliated with Ecole doctorale 560 STEP'UP

Arthur, Léna – *Prediction of X-ray counterparts to supermassive black-hole mergers* . Defense in 2023. Affiliated with Ecole doctorale 560 STEP'UP

Ravikularaman, Sruthiranjani – *Searching for the origin of the excess of cosmic rays observed in the galactic centre region. Supernovae, stellar winds or the galactic centre black hole?* . Defense in 2024. Affiliated with Ecole doctorale 560 STEP'UP

- **Neutrinos**

Houdy, Thibaut – *Testing non-standard neutrinos interactions: From 8B solar e rate measurement with Borexino to characterisation of the 144Ce source for testing the sterile hypothesis with the SOX experiment.* . Defense in 2017. Affiliated with Ecole doctorale 560 STEP'UP

Avgitas, Theodore – *Study of fundamental properties of neutrinos and earth tomography with a deep see cherenkov* . Defense in 2017. Affiliated with Ecole doctorale 560 STEP'UP

Bourret, Simon – *Etudes d'oscillations de neutrinos et tomograohie terrestre avec le détecteur protoype d'ORCA (ONSET).* . Defense in 2018. Affiliated with Ecole doctorale 560 STEP'UP

Scarpelli, Andrea – *Long Baseline neutrino oscillations in DUNE and the WA105 prototype at CERN* . Defense in 2019. Affiliated with Ecole doctorale 560 STEP'UP

Colomer Molla, Marta – *Etude du potentiel astrophysique de télescope à neutrinos sous marin KN3NET* . Defense in 2020. Affiliated with Ecole doctorale 560 STEP'UP

Han, Yang – *High Precision Neutrino Oscillation with the JUNO Experiment* . Defense in 2020. Affiliated with Ecole doctorale 560 STEP'UP

Chardonnet, Etienne – *Study of the reponse of the dual-phase liquid argon TPC* . Defense in 2021. Affiliated with Ecole doctorale 560 STEP'UP

Chau, Thien Nhan – *Etude des neutrinos astmosphériques sous-marin KM3NET/ORCA* . Defense in 2021. Affiliated with Ecole doctorale 560 STEP'UP

Lai, Michela – *Dark matter search and neutrino physics in Liquid Argon* . Defense in 2021. Affiliated with Ecole doctorale 560 STEP'UP and Cagliari U.

Maderer, Lukas – *NuSET: Neutrino Studies and Earth tomography with the KM3NeT neutrino telescope* . Defense in 2022. Affiliated with Ecole doctorale 560 STEP'UP

Bouquet, Romain – *Mesure de propriétés du boson* *de Higgs (H) et de ses couplages au quark bottom et aux bosons W/Z dans l'état final W/Z(− >leptons)+H(− − >bb)+X dans l'expérience ATLAS* . Defense in 2022. Affiliated with Ecole doctorale 560 STEP'UP

Hugues, Théo – *Search for dark matter with liquid argon detectors* . Defense in 2023. Affiliated with Ecole doctorale 560 STEP'UP

Li, Ang – *Recherche et perspectives pour la découverte de la production de di-Higgs et mesure de l'auto-couplage du boson de Higgs dans l'état final bb-γγ* . Defense in 2023. Affiliated with Ecole doctorale 560 STEP'UP

Nakkalil, Keerthi – *Mise à niveau du détecteur de traces de l'expérience ATLAS et recherche de la production de di-Higgs dans l'état final bbγγ pour la mesure de l'auto-couplage du boson de Higgs* . Defense in 2024. Affiliated with Ecole doctorale 560 STEP'UP

Hessel, Timothée – *Direct dark matter search in Liquid Argon with DarkSide-20k* . Defense in 2024. Affiliated with Ecole doctorale 560 STEP'UP

- **Theory**

Chatelain, Amélie – *Neutrino propagation in dense astrophysical environments : beyond the standard frameworks* . Defense in 2018. Affiliated with Ecole doctorale 560 STEP'UP

Silva pimenta, Leandro – *Phases Extrêmes de la Matière.* . Defense in 2018. Affiliated with Ecole doctorale 560 STEP'UP

Julié, Félix Louis – *Ondes séquentielles et tests des théories de gravité modifiée.* . Defense in 2018. Affiliated with Ecole doctorale 560 STEP'UP

Lamy, Frédéric – *Aspects théoriques et phénoménologiques des trous noirs sans singularité* . Defense in 2018. Affiliated with Ecole doctorale 560 STEP'UP

Liu, Hong Guang – *Vers une résolution des contraintes de réalité en gravitation quantique à boucles. Application aux trous noirs et à la cosmologie quantique.* . Defense in 2019. Affiliated with Ecole doctorale 352

Maelger, Jan – *Transitions de phases en Chromidynamique Quantique* . Defense in 2019. Affiliated with Ecole doctorale 576 PHENIICS

Ghosh, Jewel Kumar – *Aspects of Holographic Renormalization Group Flows on Curved Manifolds* . Defense in 2019. Affiliated with Ecole doctorale 560 STEP'UP

Moreau, Gabriel – *Théorique quantique des champs en espace-temps courbe et groupe de renormalisation non perturbatif* . Defense in 2020. Affiliated with Ecole doctorale 560 STEP'UP

Korochkin, Alexander – *New extragalactic background light model and its application to axion-like participes and extragalatic magnetic fields* . Defense in 2021. Affiliated with Ecole doctorale 560 STEP'UP

Papanikolaou, Theodoros – *Studying Aspects of the Early Universe with Primordial Black Holes* . Defense in 2021. Affiliated with Ecole doctorale 560 STEP'UP

Auclair, Pierre – *Cosmology with Gravitational Waves* . Defense in 2021. Affiliated with Ecole doctorale 560 STEP'UP

Bouyahiaoui, Makarim – *Models of multi-messenger sources of cosmic-rays, gamma-rays and neutrinos* . Defense in 2021. Affiliated with Ecole doctorale 560 STEP'UP

Roussille, Hugo – *Modèles de gravité modifiée et futures observations en astrophysique et cosmologie* . Defense in 2022. Affiliated with Ecole doctorale 560 STEP'UP

Kastikainen, Jani – *Investigations of quantum information and gravity* . Defense in 2022. Affiliated with Ecole doctorale 560 STEP'UP

Leyde, Konstantin – *Cosmology and tests og general relativity with gravitationnal waves* . Defense in 2023. Affiliated with Ecole doctorale 560 STEP'UP

Colas, Thomas – *Testing quantum mechanics in the early universe: theoretical aspects and observational contraints* . Defense in 2023. Affiliated with Ecole doctorale 564 PIF

Nourry, Valentin – *Strong coupling physics, holography and cosmology* . Defense in 2023. Affiliated with Ecole doctorale 560 STEP'UP

Préau, Edwan – *Holography and extreme phases of matter* . Defense in 2023. Affiliated with Ecole doctorale 560 STEP'UP

- **Instrumentation**

Cojocari, Ion – *Etude des performances de détecteurs polarimetriques pour de futures missions spatiales X/gamma* . Defense in 2022. Affiliated with Ecole doctorale 560 STEP'UP

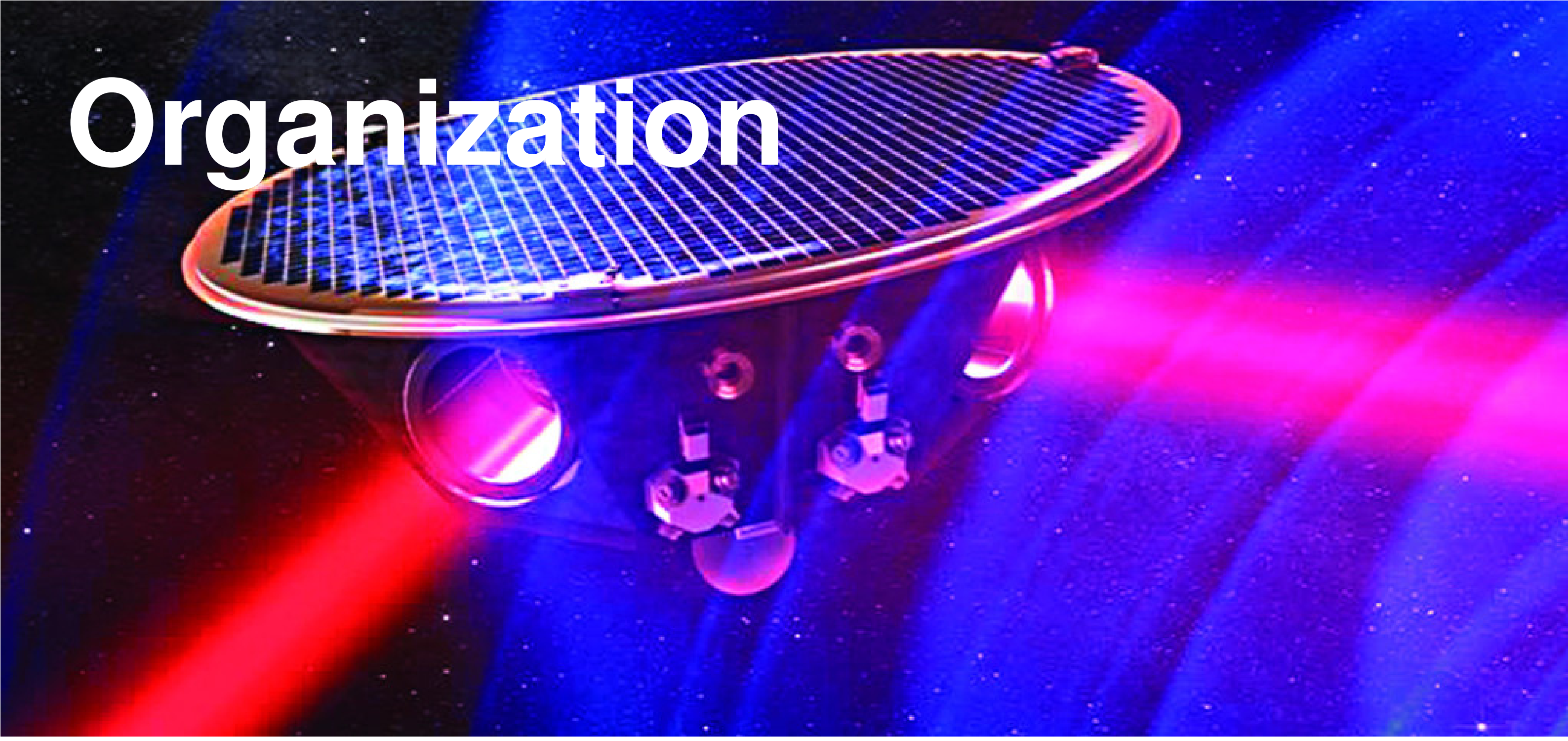
- **Others**

Vour'ch, Thomas – *Dynamique de suspensions actives de cyanobactéries (moteur moléculaire) pour les énergies renouvelables* . Defense in 2019. Affiliated with Ecole doctorale 564 PIF

Nguyen, Minh Chau – *Thermo-hydrodynamical transport phenomena in suspensions of micro-organisms : production of long carbonated chains (biofuels) and bioreactor design* . Defense in 2021. Affiliated with Ecole doctorale 564 PIF

Pashmi, Elnaz – *Effet de stress hydrodynamique sur la dispersion des micro-organismes* . Defense in 2021. Affiliated with Ecole doctorale 564 PIF

Organization



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General organization and main bodies

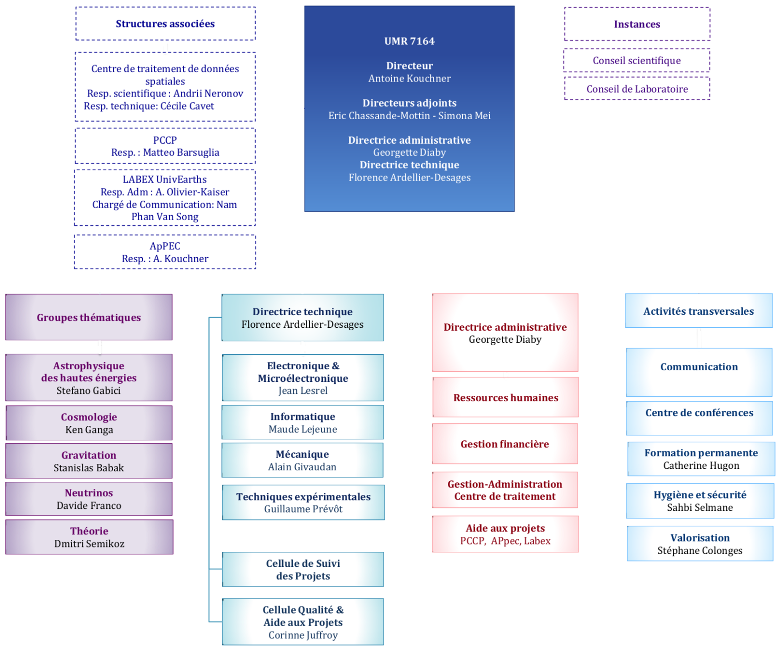

Figure 89: Laboratory's organizational chart

Direction team

The direction team is currently composed of the director Antoine Kouchner assisted by the technical director Florence Ardellier, the administrative director Georgette Diaby, and two deputy directors: Eric Chassande-Mottin and Simona Mei.

The period covered by this report overlaps with the mandates of other direction teams. Stavros Katsanevas was the director until Dec 2017, with Thomas Zerguerras as technical director, Emmanuelle Ancourt-Foissac as administrative director, and Antoine Kouchner and Sotiris Loucatos as deputy. Sotiris Loucatos became director ad-interim for a period of 6 months. Fabien Casse and him were deputy when Antoine Kouchner began his mandate as director.

The direction team is in charge of the laboratory organization and works closely with the lab trustees and the associated structures. The direction team meets regularly with the heads of the scientific teams, the technical services and the administration.

Laboratory Council

The Laboratory Council deals with all aspects of the life of the laboratory. It has an advisory function, its opinions are reflected in the conclusions and are known to all. The meetings of the laboratory council are open to all.

The Laboratory Council is composed as follows:

- Members of the direction team: Antoine Kouchner, Florence Ardellier, Georgette Diaby, Simona Mei, Eric Chassande-Mottin
- Five members elected by the researchers: Alexis Coleiro, Josquin Errard, Cyril Lachaud, Santiago Pita, Vincent Vennin
- Five members elected by the technical and administrative staff (ITA-BIATSS): Cécile Cavet, Cédric Champion, Alain Givaudan, Joseph Martino, Béatrice Silva
- One member elected by the PhD students: Louise Mousset
- One member elected by the postdoctoral fellows: Agata Trovato
- Five members nominated by the Director: Fabrice Dodu (BIATSS), Catherine Hugon (ITA), Bruno Khélifi (researcher), Elias Kiritsis (research), Damien Pailot (ITA)

Over the period 2017-2021, the Laboratory Council met four times (Dec 2019, Sep 2020, Feb 2021, Oct 2021).

Scientific Council

The Scientific Council is a consultative body. It gives its assessment on the orientations of the research policy and the scientific projects of the research unit, the required means and the thematic priorities for the recruitment of permanent or non permanent researchers.

The Scientific Council is composed as follows:

- The director and the deputy directors: Antoine Kouchner, Simona Mei, Eric Chassande-Mottin
- The thematic team leaders: Stanislav Babak (Gravitation), Stefano Gabici (High-energy astrophysics), Davide Franco (Particles), Dmitri Semikoz (Theory), Ken Ganga (Cosmology)
- Six external experts, including at least three foreigners, appointed by the supervisory bodies on the proposal of the Director: Eugenio Coccia (Gran Sasso Science Institute, INFN), Roger Blandford (Stanford University et SLAC), Natalie Roe (Berkeley Lab's Associate Director for Physical Sciences), Anthony Noble (Scientific Director, McDonald Institute), Jean-Loup Puget (IAS Orsay), Gabriele Veneziano (CERN)
- The members of the Project Monitoring Unit (see Project quality assurance): Rémi Cornat (Technical Director of LPNHE), Sandrine Couturier (Technical Director of IAS), Andrea Formica (CEA/Irfu), Frédéric Vincent (LESIA, Observatoire de Paris)
- Three elected members of the laboratory: Stefano Gabici, Jean-Christophe Hamilton, Damien Prêle

Over the period 2017-2021, the Scientific Council met three times (Nov 2017, Mar 2020, Dec 2021).

Technical services

Key figures

The lab's four research areas involve experimental and instrumental developments. Those development and realizations are carried out by technical services composed of qualified engineers and technicians. A total of 40 permanent engineers and technicians and about 10 fixed-term contractors are divided into five departments: experimental techniques, electronics and microelectronics, mechanics, IT and quality/product assurance.

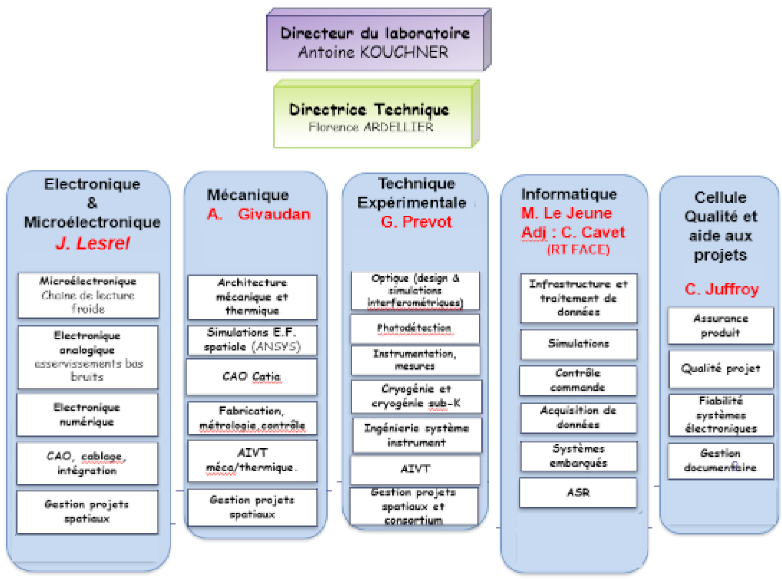

Figure 90: Organizational chart of the technical services

The technical department of the laboratory is divided into five main services under the direct supervision of the Technical Director as depicted in Fig. 90. The services are : Electronics & Microelectronics, Mechanics, Experimental techniques, Information Technologies, Quality and Project assessment. All will be described into more details in the following.

The overall organization follows a "matrix" approach which allows to capitalize on the return of experience and to carry out several projects at different phases in parallel. Each service develops a set of skills that can be deployed in different community fields such as space technologies, neutrinos, cosmology or high-energy space imaging spectrometry, …

This organization allows a better communication and cooperation between the various skills and areas of expertise. This also allows to maintain the capability to master all the steps of the activity chain related to instrument developments, from preliminary studies to data analysis.

An internal procedure formalizes the development of a new experimental project that requires the support from the technical services. The project team has to be coordinated by a Scientific Manager and a Technical Manager, who together guarantee the conformity of the development

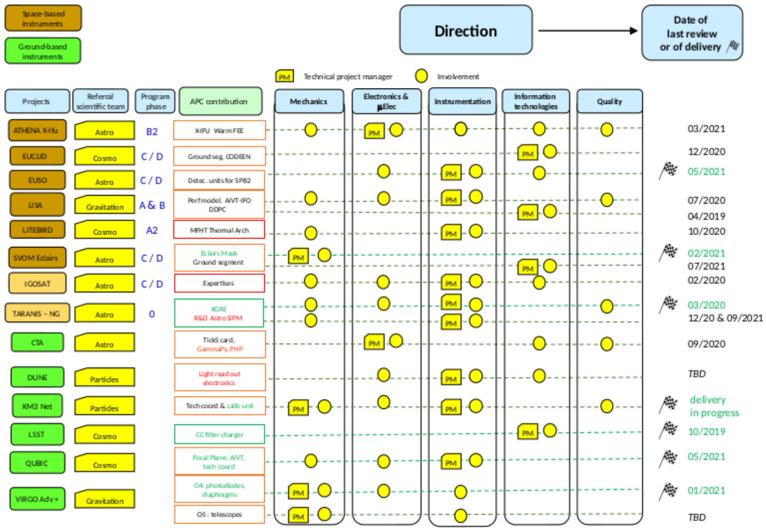

Figure 91: Project vs service involvement matrix

with the expected performances in constrained environments (undersea with high pressures, space, low noise, cryogenics, etc).

Internal procedures for project organization and monitoring A procedure formalizes the development of a new experimental project that requires the support from the technical services. The project team has to be coordinated by a Scientific Manager and a Technical Manager, who together guarantee the conformity of the development with the expected performances in constrained environments (undersea with high pressures, space, low noise, cryogenics, etc).

For project portfolio monitoring, dashboards (see Fig. 91) are set up at the technical directorate level (human resources, workload plan, monitoring of project portfolio, milestones, etc) and shared during monthly heads of department meetings in order to better anticipate the opportunity to get involved on new projects, along with resources adaptations induced by potential planning slippages. In addition, a Project Monitoring Unit known as Cellule de Suivi de Projets (CSP) led by the Technical Director and composed of members of the Scientific Council, department heads and APC management regularly analyses the progress of each project and the evolution of resource requests. Furthermore, a project seminar is set up every year to review the progresses made, and anticipate future steps and the associated resources needed.

Technical expertise and know-how The technical services have developed specific expertise in the following technological and methodological axes:

- Control of optical precision interferometer metrologies required in the field of gravitational wave detection, and high-performance low-noise electronics for phase-meters.

- Mastering sub-K reading channels that requires microelectronic realizations (ASICs).
- Sub-K Cryogenics including low temperature and low noise read-out detection chains (based on microelectronics)
- On-board ground and underwater photodetection
- Containers and continuous integration and deployment of applications
- Web frameworks
- Knowledge of space and submarine environments
- System approach inspired by space engineering
- Product insurance

R&T or R&D activities are also developed along those axes in order to anticipate and remain competitive in the context of future instrumental projects. Those include:

- KIDs for applications in Cosmology
- Optimization of very low temperature cryogenics with the R&T NG Cryo
- Low noise, low temperature microelectronics
- R&D on optical squeezing which was the subject of a thesis
- Servo control for production and transport of squeezed light
- Two photodetection R&T that study the potential of SiPM for future space projects.
- R&D on containers for High Performance Computing applications
- Machine learning techniques for astrophysics data analysis

Finally, APC is equipped with facilities that are essential to the various technical developments conducted by the laboratory. Those facilities, maintained by the technical services, include:

- ISO8 clean room for space and optical instruments
- Low noise room including a thermalized Faraday chamber
- François Arago Centre (FACe) for data analysis; Multi-Messenger Observatory (MMO), shared software and IT development platform, and training, education, outreach
- Millimetric laboratory, with 100 mK dilution-free cryostats and Vector network analyser
- Photodetection laboratory
- Mechanical workshop and a mounting hall that allows large instruments integration and calibration
- Two very precise metrology instruments; one of them being in the clean room

The first three items in this list are labelled as "Université de Paris plateform" which evidences their broader interest.

In addition, the deployment of a concurrent engineering room is currently underway within the framework of the Spatial Pôle of the Université de Paris. The goal is to improve the design methodology as inspired by system engineering.

Electronics & microelectronics

Key figures

The Electronics and Microelectonics department is able to manage the developement of large and complex electronic systems. Area of specific expertise includes: the design of analog ASICs operating at cryogenic or room temperatures, low noise ASICs and electronics compatible with the space environment, and the development of very low-noise digital and/or analog electronic systems. The department also provides an expertise in system engineering of complex detection chains.

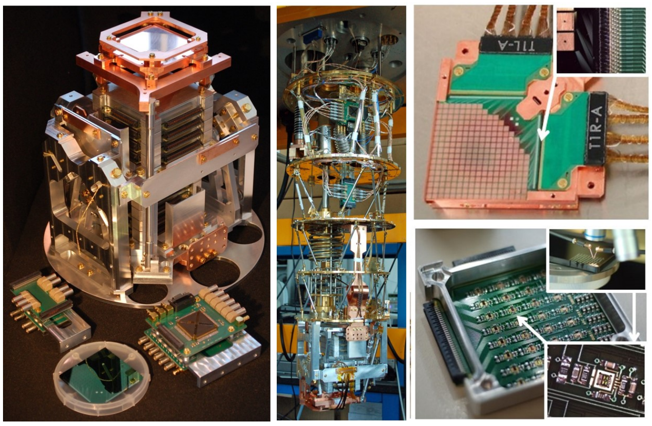

Figure 92: Left and middle: validation of a quarter of the QUBIC detection chain in a dilution cryostat. Top and bottom right: interconnections and testing of TES arrays and SQUID modules respectively

The Electronics and Microelectronics department consists of thirteen members including five research engineers, five design engineers, two assistant engineers and one technician. The departementresulted from the merger of the Electronics department and the Microelectronics department in 2019. It is involved in the laboratory projects, not only for space, but also for ground and underwater missions.

The achievements of the Electronics and Microelectronics department are presented in the previous parts of the report throughout descriptions of the projects in which it contributes. The department uses simulation tools and the whole Cadence CAD toolkit for the design of Application-Specific Integrated Circuit (ASIC) and Printed Circuit Board (PCB).

On average, the service carries out about thirty developments per year, ranging from double-sided PCB to 12-layer PCB with microvias, from class 4 to non-class 88 μm. When manufacturing is subcontracted to the industry, the designers provide the necessary files for manufacture as well as manufacturing tracking files.

A small workshop allows the production of prototypes which can be assembled either manually or with a reflow oven. This workshop also allows the replacement of defective components.

The Electronics and Microelectronics department has a dedicated erea to perform electronic measurements. In addition, it also carries the responsibility of the low-noise room facility mentioned earlier. This facility is an infrastructure dedicated for low noise tests and characterization, especially at low frequencies (down to milli-Hertz). This platform is part of the space hub of Université de Paris and is open to other institutes and external laboratories and companies. A dedicated section in this chapter describes the low noise room facility into more details.

Several engineers in the department manage national and international large projects that involve skills such as project management and quality control.

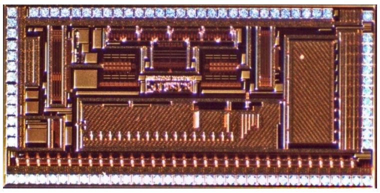

Figure 93: "SQMUX128": cryogenic (4 K) device dedicated to the readout and multiplexing of the QUBIC instrument

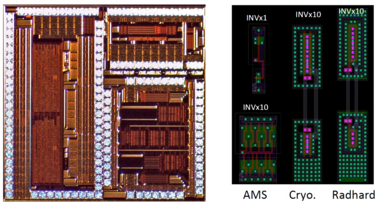

Figure 94: Left: "AwaXe_v1": first ASIC version (Phase A) integrating the test vehicles for the selection of topologies compatible with the WFEE specifications of the X-IFU instrument onboard the ATHENA satellite. Right: "full custom" layout of digital cells for validation of radiation hardening techniques.

Expertise of the department The department's engineers design, build, test and monitor systems intended to operate on experimental sites in severe environments such as the presence of ionizing radiations, extreme temperatures and pressures, vibrations, etc. The design has thus to meet very strict quality criteria to ensure the correct operation of the equipment.

The department has the expertise to build a wide range of systems involving diverse electronic topics such as fast analog, low-noise and high-dynamic range or digital. The team masters several types of technologies: discrete components, bipolar or CMOS integrated, analog, digital or mixed, programmable or specific circuits. Programmable digital circuits (FPGA programmed in VHDL or VERILOG) are commonly used in various developments.

The departement also has a know-how in microelectronics. The microelectronics activity revolves around three permanent research engineers and a permanent study engineer with the support of the laboratory's IT department for the installation and maintenance of the necessary CAD software.

This team has the ability to develop analog and mixed ASICs, produced in standard CMOS and/or BiCMOS SiGe technologies, for instruments in the field of observational cosmology or experiments in astroparticles. The circuits are drawn in full custom using standard CADENCE Virtuoso CAD tools. Most of the developments have been carried out in AMS CMOS and BiCMOS SiGe 0.35µm technologies as well as in STMicroelectronics BiCMOS SiGe 130nm technology.

For more than ten years, the department has developed an in-depth expertise in the design of low-noise ASICs below $\mathrm{nV}/\sqrt{\mathrm{Hz}}$ operating in a cryogenic environment at 4 K or at room temperature for the integration of superconducting sensors (TES, SQUID, KIDs) or radiative-hardened sensors for space applications.

This specific expertise has allowed the technical involvement of the laboratory in several flagship projects such as the cryogenic reading chain of the QUBIC ground telescope for millimeter wavelengths or the X-IFU instrument for X-rays detections.

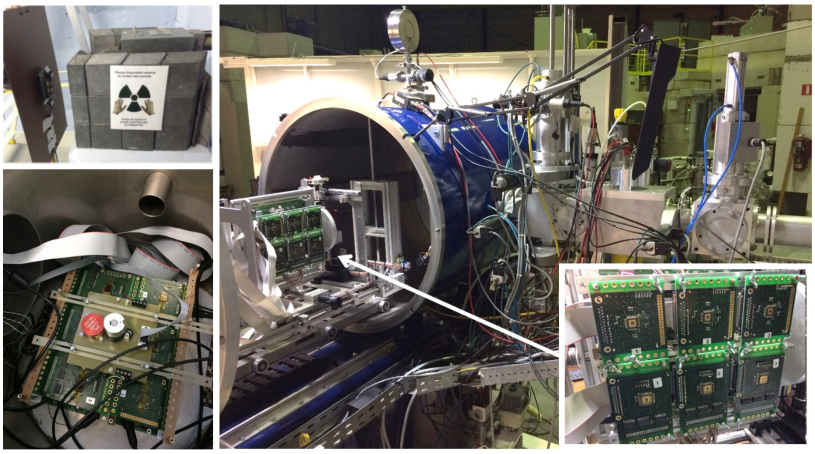

Figure 95: Top left: Dose tests with a Cobalt 60 source at COCASE (CEA Saclay). Bottom left: SEL tests with a Californium 252 source at TRAD (Toulouse). Right: SEL qualification at the cyclotron of UCL Louvain (Belgium)

Team

C. Boutonnet, C. Champion, S. Chen, B. Ky, J. Lesrel, J. Mesquida, G. Monier, D. Nita, R. Oger, P. Prat, D. Prêle, S. Selmane, F. Voisin

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Information Technology

Key figures

The IT department gathers around 20 people and is organized along 3 axes: infrastructure and services (with 8 FTE among which 4 FTE dedicated to lab facilities), software engineering, data and computing (with 9 FTE working on Euclid, LSST, SVOM and LISA data analyses) and online development (with 2 FTE).

The IT department is in charge of the administration of all personal computers of the lab (around 300 laptops or desktops), and provides the associated user support. The IT department also manages around 50 servers, including data servers (50 Tb), electronic and mecanics stations, and web services. A special care regarding all potential security issues, and quality assurance is taken for all those administrative tasks. The team also manages a computing cluster of 800 CPU and 160 Tb, named DANTE and hosted at IPGP (see The DANTE computing facility)

Figure 96: A view of APC's server room

During the past 5 years, an expertise on virtualization and continuous integration has been acquired, allowing for light and smooth maintenance of more and more services. This expertise has been developed through our involvment in international projects like Euclid or LISA and the R&D project named ComputeOps. ComputeOps aims at studying the benefit of using containers for High Permormance Computing (HPC). It gathers around 20 people in the French HPC community led by APC and is supported by IN2P3, through the DECALOG master project.

Regarding web services, a handful of new applications have been developed during the past 4 years: either lightweight applications tailored for the needs of a particular team, or more eloborated solutions for a broader audience (see LISA and CTA). Most of them have been developed using the Django framework: a rich Python environment offering numerous embedded tools (authentication, security, forms, style cheet, etc), and for which the team has now a consolidated expertise.

Thanks to our deep involvement in space projects over the past decade, the team has developped a strong know-how on software development for scientific ground segment and data processing. This covers software quality and good practices, as well as data analysis concepts and techniques (from statistical methods to machine learning), and high performance computing skills (see Euclid, LISA, SVOM, Vera C. Rubin Observatory).

The IT department works in close collaboration with Université de Paris regarding all network aspects, and with CCIN2P3 for our RENATER high throughput link, as well as the high level computing services they offer (CPU and GPU clusters). We take an active part in all groups of expertises existing at the IN2P3 level (RI3) and national level (DevLog, Resinfo, ...), through participation to training schools and workshops, especially in machine learning and containers for scientific computing.

Training school organization The team is very much involved into training activities aimed at students or other researchers and engineers. Here is a list of the team contributions over the past four years:

07/2017 JDEV: Transporter ses applications parallèles avec les containers LXD et Singularity, M. Souchal, A. Garcia

06/2018 ANF Ecole informatique IN2P3: Conteneur en production, M. Souchal, C. Cavet

09/2018 SBAC-PAD : Singularity, M. Souchal

10/2018 Journées Informatiques IN2P3 : Singularity pool, M. Souchal

04/2019 GPU workshop @ CCIN2P3 : Neural networks and deep learning, A. Boucaud

04/2019 3rd ASTERICS-OBELICS International School : Getting started with deep learning, A. Boucaud

03/2020 PCCP workshop series: Bayesian deep learning for cosmology and gravitational waves, A. Boucaud

05/2020 CNRS lectures: Fondamentaux du Machine Learning, A. Boucaud

07/2020 APC docker summer training, M. Souchal

09/2020 ANF Ecole informatique IN2P3: Machine Learning pour informaticiens, A. Boucaud

11/2020 JDEV: Ateliers intelligence artificielle, A. Boucaud

01/2021 ANF User Support Tools for HPC: TP Conteneurs, M. Souchal

06/2021 CNRS lectures: Fondamentaux du Machine Learning, A. Boucaud

07/2021 AI DevTalks INRIA : Containers for science, M. Souchal

10/2021 ANF Ecole informatique IN2P3: Qualité logicielle, A. Boizard

11/2021 Ecole AstroInfo 2021 : deep learning courses and hackathon, A. Boucaud

Team

P. Bacon, N. Bellemont, A. Boizard, A. Boucaud, C. Cavet, B. Courty, F. Dodu, R. Fahed, H. Jiménez-Pérez, M. Le Jeune, P. Malbranque, A. Malecot, S. Marsat, J. Pollack, M. Souchal, F. Virieux, P. Yu, P. Zakharov, S. Zappino,

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Mechanics

The mechanical department is in charge of the development of mechanical subsystems of instruments, usually in close connection with other subsystems (electronics, optics, sensors, cryogenics, ...). It contributes to the laboratory projects at all stages: preliminary studies and specifications, design and simulation, manufacturing, integration and assembly of components, follow-up of industrial subcontracting, tests and on-site installation. Inside the laboratory matrix organization (departments vs projects), the members of the team have also responsibilities in projects, as project managers or mechanical architects for instruments or sub-systems, both for on-board (satellites, balloons) and for ground-based experiments. In 2021, the design office includes 6 people plus 1 intern and the workshop includes 1 person. The department ensures overall control of the development process for instrument projects, from the drafting of specifications to delivery to the laboratory or installation on site, maintenance and even dismantling. The members of the team have also responsibilities in projects, as project managers or mechanical architects for instruments or sub-systems, both for on-board (Coded mask of SVOM / ECLAIRs, optical bench MIFO of LISA) and for ground-based experiments (QUBIC, end benches and detection telescopes of Virgo, calibration base anchor of KM3NeT)

The design office works on CATIA (CAD), and ANSYS (FEA) with the support of the mechanical networks.

The workshop is composed of two 3 axis numerically controlled machining and a numerical control lathe, controlled by TopSolid (CAM software), a conventional lathe and two milling machine, two 3D printers, ...

The department is also equipped of two coordinate measuring machines in cleaned room (one is numerically controlled) and an articulated arm in mutualization with two other laboratories. The last twelve months have been marked by the delivery of the coded mask of SVOM/ECLAIRs, mechanics for the QUBIC detector (except the cryostat), diaphragms for the Virgo's detection telescope, refrigerators of NG Cryo R&D.

Team

W. Bertoli, C. Chapron, S. Dheilly, A. Givaudan, A. Ilioni, M. Karakac, M. Le Cam

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Instrumentation

Key figures

The Instrumentation department develops three technology gems: heterodyne & homodyne interferometers for metrology, EUSO detection Unit, adsorption cryogenic refrigerator.

The instrumentation department gathers the simulation, engineering and technical skills, which are needed to design, setup, develop, integrate, validate and calibrate an innovative R&D experiment or a complex instrument. A total of 12 members (9 research engineers, 2 study engineers and 1 post-doc) compose the team, covering various areas of expertise: physics, optics, photodetection, cryogeny, integration & tests, system engineering and project management.

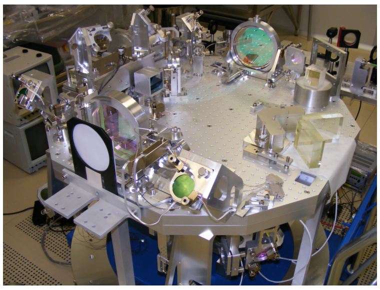

Figure 97: One of the Virgo mode-matching telescopes delivered by APC

The project-related achievements of the department are presented throughout the report, in the relevant corresponding sections.

In the 128 square meter ISO8 cleanroom of the APC laboratory, the optical engineers of the team integrate and characterize the performances of the benches they designed (with optical design & illumination simulation software tools), in preparation for the delivery of telescopes or in order to improve homodyne and heterodyne interferometric metrology techniques dedicated to gravitational waves detectors (see Advanced Virgo and LISA). They also support pioneering R&Ds dedicated to Laguerre-Gauss modes productions and to vacuum squeezing techniques aimed at contributing to the future generation of interferometers.

The team members involved in the field of photodetection handle the definition, the design, the development, the integration and the calibration of X/Gamma spectrometers (with calibrated light sources or with radioactive sources) and of neutrino & UHECR telescope focal surfaces. Additionally, dedicated R&Ds are developed by these engineers in strong collaboration with the main suppliers of the sector, notably with Hamamatsu-Japan, to increase the performances of the multi-anode photomultipliers.

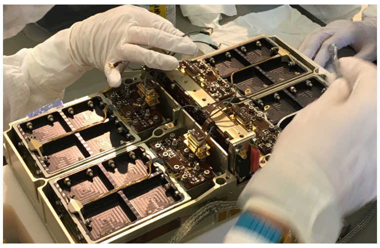

Figure 98: Picture of TARANIS's detection unit being tested

The cryogenic engineers of the team design, develop and integrate cryogenic refrigeration systems, in particular for cosmological detectors and for particle accelerators. They lead R&Ds for the development of thermoacoustic machines, cryomodules and sub-Kelvin adsorption refrigeration systems dedicated to next generations instruments.

All along the life of the projects, the system engineers and the project managers of the department, in charge of subsystems or responsible for global projects of national or international collaborations, lead and coordinate the key project meetings and reviews. Furthermore, they set work frames and produce the significant documentation used to define the processes and methodologies that the project teams follow to build and to achieve the deliverables.

Outreach represents an important activity of the instrumentation department, from trainee's supervision in our labs (from High school to Master 2 and engineering schools) to loans dedicated to high school teachers and students for participating to instrumentation, photo-detection and data analysis, possibly in relation with observations. Additionally, writing of scientific papers and conference preparations complete naturally this field.

Team

S. Blin, É. Bréelle, S. Durand, M. Gonzalez, L. Grandsire, M. Laporte, M. Lindsey Clark, J. Martino, D. Pailot, G. Prévôt, J.-P. Thermeau,T. Zerguerras

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Quality & Project Support

The Quality team and project support unit is directly linked to the technical direction of the APC laboratory. Its goal is to develop a consistent lab organization regarding project management and support activities. The staff is of 3 engineers, and it has recruited 3 one year contract apprentices since 2017.

Project quality assurance

Key figures

21 project reviews have been completed by CSP between 2018 and 2021

Quality assurance tasks consist in implementing steps in order to control the critical parameters of a system or a project. It includes the redaction and the implementation of the Quality Manual, procedures, product traceability and non-conformances system, and project processes management.

For both space projects and ground observatories, Product Assurance is mandatory to obtain high quality products compliant with their specifications. For the products to fulfill the required functions in a safe, available and reliable way, the CQAP unit runs the quality assurance, together with dependability and safety activities. Moreover, the unit selects and validates material, processes, electrical and mechanical components of products.

The project review is scheduled and conducted by the Cellule de Suivi de Projets (CSP) to follow project status, give recommendations and decisions in terms of hardware facilities, human resources and skills availability. The choice of submitted projects depends on their imperatives and their progress status.

Electronic Product Quality Assurance The CQAP unit has developed expertise in qualification and electronic product assurance which are of high interest when purchasing space application components and preparing qualification test plan documents for subcontractors. In this context, the CQAP members of staff have established ties with other radiation and reliability experts inside professional networks and by attending conferences. Another application of these skills is to assist and advise internal and external microelectronic designer teams to harden their design or mitigate radiations effects.

Product Quality Assurance in Space Projects Since 2012, CQAP has consolidated and completed its product assurance expertise for space projects in the following related fields:

- Risk, reliability analysis, technology readiness level review, electronic (EEE components qualification and selection), Firmware (VHDL), and mechanic.
- Assembly Integration Tests and instrumentation Quality Assurance skills developed with the Taranis project.

Document and Information Management and Reporting This task covers the needs of Electronics Document Management, scientific bibliography, development of database studies and various types of indicators. This activity provides crucial information for the laboratory and funding agencies together with an efficient support for decision-making at global laboratory management level (Directors Boards, Scientific Advisory Board, Working Groups on Prospectives, etc.).

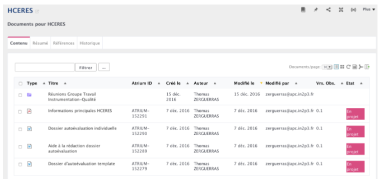

Figure 99: Document management system Atrium used for archiving important documentation

Team

S. Colonges, C. Juffroy, C. Hugon

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Technical facilities

The DANTE computing facility

To increase their computing capacity, and in line with the national digital roadmap, IPGP and APC have joined forces to set up a shared supercomputing platform with a capacity of 298 teraflops (at peak) with the financial support of the Île-de-France region.

Called DANTE (for multi Data ANalysis and compuTing Environment for science), this supercomputer is a scientific instrument that has opened in October 2021. The objective of this project is to build and eventually, to mutualize the hardware and software resources of the Service de Calcul Parallèle et d'Analyse de Données (S-CAPAD) of the IPGP and FACe within the IPGP. It is planned to improve the capacities of the resources and services according to the evolution of the needs and the research practices

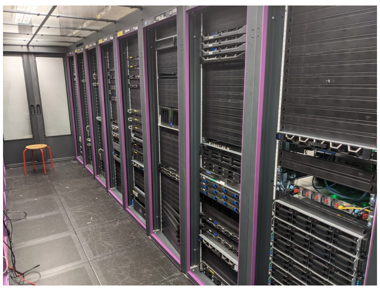

Figure 100: A view of the DANTE server room

at IPGP and APC. It is also planned to provide training actions in the framework of the joint project between APC and IPGP (LabEx UnivEarthS, EUR v2).

APC's commitment to the DANTE project amounts to €150,000: the APC platform has started operation since February 2021 and allows the laboratory's researchers and associates to benefit from a high-performance storage space of more than 130 Terabytes and a little more than 600 computing cores.

Team

P. Zakharov, M. Souchal, C. Cavet

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Low noise room

Figure 101: A view of the low noise room

The low-noise room allows to perform fine noise characterization of electronic components in a frequency range between 0.1 mHz and 1 Hz. This facility is located in the basement of the Condorcet building in order to minimize the effects induced by the vibrations of the building. The low noise room is air-conditioned and temperature-regulated at a value between 20 and 25°C with a precision better than 1°C. The floor of the room is made out of an antistatic material, that integrates copper wires in the coating. Thermal drifts can be greatly reduced (almost eliminated) by placing the components in a Peltier incubator or a cryo-thermostat.

The main equipment currently installed in the low noise room is listed below.

The low-noise room is currently used to characterize electronic components and systems for ATHENA and LISA.

Team

P. Prat, D. Prêle

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Equipment

- Faraday cage (brand: ALBATROSS Project) in galvanized steel (without dye), with dimensions 3×2.5×2.5 m^3, and an antistatic PVC floor. It is equipped with 4 SMA connectors and a waveguide (144 × 25 mm, cut-off frequency 20 GHz), ventilation, 5 EMC filters for power supplies (4 × 32 A and 2 × 10 A at 220V) and two waveguides (50 mm diameter, cut-off frequency 20 GHz) allowing for immersions in liquids and gases
- Electronic bay (brand: SCHROFF, model: Varistar VHD 1800H6X8), equipped with an LHX3 air/water heat exchanger
- RF signal and spectrum analyzer from 10 Hz to 4GHz (brand: ROHDE & SCHWARZ, model FSV3004), completed by a RF signal generator (model R&S SMB100B)
- Phase noise analyzer (brand AEROFLEX: model PN8000), with a 2MHz to 1.8 GHz frequency measurement range
- Digital oscilloscope (brand: TEKTRONIX, model DPO4104, 1 GHz)
- Second digital oscilloscope (brand AGILENT, model DSO1024A, 200 MHz)
- Signal synthesizer (brand: AEROFLEX, model 2023A, frequency range 9 kHz - 1.2 GHz)
- Arbitrary function generator (brand: TEKTRONIX, model AFG3052, frequency range 1 µHz - 240 MHz, 2 channels)
- Acquisition unit for temperature measurements (brand: AGILENT, model 34980)
- Triple precision power supply (brand AGILENT: model E3631A)

- Double precision power supply (brand AGILENT: model E3649A)
- Precision benchtop multimeter (brand AGILENT: model 34411A)
- 1,000,000-point benchtop digital multimeter, brand KEYSIGHT, model 34465A
- Refrigerated incubator with Peltier effect (brand: MEMMERT, model IPP500, 108 liters) with adjustable temperatures between +5°C and +70°C, a stability better than ± 0,1°C and a uniformity better than ± 0,4°C
- Circulating cryo-thermostat (brand: LAUDA, model Proline RP845C, 150×150×200 mm^3) with adjustable temperatures between -45°C and +200°C, a stability of ± 0,1°C, a heating capacity of 3,5 kW and a cooling capacity of 0,8kW at 20°C National Instruments acquisition system, composed of a PXI-1033 chassis and a PXI-6229 module, controlled by PC via LabVIEW software

Cleanroom

The clean room is one the key facilities to develop space instrumentation and very challenging optical benches for gravitational-wave astronomy.

The clean room complies with ISO-8 class standards, and is of a total surface of 140 m^2 divided into 3 distinct areas.

Area 1: Integration clean room This area (see Fig. 102) was used for the integration, tests and qualifications of the TARANIS XGRE space mission flight models delivered in 2019 to the CNES. Also, the Transition-Edge Sensor (TES) matrix for the QUBIC project have been prepared and checked in this area. Furthermore, the vacuum chamber has been recently adapted in order to perform ageing tests for the ATHENA's X-IFU WFEE ASICs, thermal cycles for the IGOSat Nanosatellite flight model and other prospects.

Figure 102: A view of the integration area

Figure 103: Another view of the integration area

Equipment

- 3D mechanical metrology machine with a precision of ~10 µm
- Probe station for electronic components and detector electronical precision testing
- Vacuum and thermal chamber called used for space qualification campaigns, that allows a temperature range between - 60°C and + 120°C, and a vacuum level of 10^{-7} mbar
- Ultra-Pure Water distribution system
- Extractor hood for component cleaning
- Storage cabinet with humidity and temperature monitoring

Area 2: laser room for LISA The optical test bench LISA on Table has been developed and tested in this clean room which is nowadays also dedicated to the MIFO experiment (Mechanical interFerOmeter).

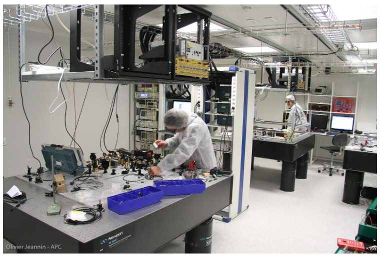

Figure 104: A view of the laser room

Equipment

- Clean room compatible crane
- Comb frequency generator: laser emission allowing a spectral band from 1 to 2µm with a frequency step of 250 MHz
- Two YAG lasers: 500 Nd-YAG laser (λ= 1064nm, P=500mW) and 1000 Nd-YAG laser (λ = 1064 nm, P= 1000 mW)
- Two optical tables
- Vacuum chamber for optical test benches

Area 3: laser room for Virgo This clean room is dedicated to optical measurements and tests for gravitational-wave detectors (see Advanced Virgo), R&D activities for new generation gravitational-wave instruments.

Equipment

- Two optical tables

- Two INNOLAG YAG lasers: model Mephisto 500 mW & He-Ne laser
- A cylindrical vacuum vessel
- An accordable Faraday insulator
- A Beamage Focus II beam profiler and associated instrumentation

Team

L. Grandsire, D. Pailot

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Photodetection laboratory

Figure 105: The photodetection laboratory includes the main room (Top) but also extra spaces with peculiar prototypes and specific authorizations (Bottom)

Photodetection is omnipresent in astroparticle physics, in the frame of cosmics rays, neutrinos and X/Gamma telescopes.

The Photodetection laboratory gathers skills in the development, the use, the characterization and the calibration of photodetectors. Its main activities concern the prototyping and AIVT of photodetectors (photomultipliers tubes, MAPMT, SiPM, ...).

The photodetection laboratory is a transverse facility created to ensure the evolution of the skills and synergies across the field, for a wide spectrum of applications: the photodetection laboratory has played a key role allowing the lab to take responsibility of workpackages in SIMBOL-X, TARANIS, KM3NeT, JEM-EUSO or DUNE with a high reactivity.

The current projects of the laboratory are DUNE, KM3NeT, JEM-EUSO and TARANIS-NG. These projects are carried out with specific equipments, including

- PMT, MAPMT, SiPM, APD, PIN photodiodes, ...
- Black Boxes, calibrated light sources (calibrated photodiode + integrating sphere + pinhole), optical fibers, motorized micro linear stages, spectrometers, ...
- CAEN modules, dedicated ASIC & FPGA, high definition scopes
- Organic and inorganic scintillators
- Radioactive sources for X/Gamma spectrometer calibrations

The photodetection laboratory has collaborations with Hamamatsu Japan, especially in the frame of characterization and the improvements of new MAPMT. The lab is also involved in two R&T programs funded by CNES for the development of high TRL instruments based on SiPM.

Numerous publications involving the photodetection laboratory have been written under the aegis of the related projects.

Team

S. Blin, C. Boutonnet, É. Bréelle, C. Champion, A. Cohen, B. Courty, A. Creusot, J. Dawson, A. Ilioni, P. Laurent, M. Lindsey-Clark, J. Lesrel, D. Nita, D. Pailot, E. Parizot, T. Patzak, G. Prévôt, S. Selmane, H. Souza, D. Trofimov

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Laboratory administration

The main mission of the Administrative Service is to accompany and assist the staff in their scientific and technical activities.

It is composed of a team of managers who are each in charge of a project portfolio in agreement with the "matrix" organization of the laboratory according to scientific groups, services, scientific projects and platforms.

This service includes about ten persons and is organized in four poles:

- Finance and Budget Poles
- Human Resources Pole
- Communication Pole

Finance and budget pôles

Key figures

40 contracts and grants with a diverse set of funding agencies
Approximately 5000 management acts per year
Typically 700 missions per year

These two poles ensure the execution of the lab's budget, which is made up of allocations from the funding entities and contributions from partners such as the Ile de France region, Europe, ANR or other foreign organizations, but also from private contractors, see Tables 1 and 2 in Sec. International partners. The share of contracts and subsidies represents on average nearly 80 % of the overall budget.

The activities of these poles relate to six main areas: verification and monitoring of credits, placing orders, processing invoices, reimbursement of mission expenses, monitoring inventories and reporting.

Over the period from January 2017 through November 2021, the Administrative Department managed an average annual budget of 6.75 million €.

Team

C. Ferreira Pires, V. Guiffo, L. Pavili-Baladine, B. Silva, S. Tesson

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Year	Acronym	Project name	Grant number
2017	B3DCMB	Big Bang à partir de Big Data	ANR-17-CE23-0002
2017	PECORA	PeV Cosmic Rays – Extreme particle accelerators in the Galaxy	ANR-17-CE31-0014
2017	BxB	Interstellar B-fields crossing inflation B-modes	ANR-17-CE31-0022
2018	PTAFrance	Gravitational wave search with a Pulsar Timing Array in France	ANR-18-CE31-0015
2019	MMUniverse	Opening new windows on Early Universe with multi-messenger astronomy	ANR-19-CE31-0020
2019	AstroDeep	Analyse de données astronomiques massives avec de l'apprentissage machine	ANR-19-CE23-0024
2020	MORPHER	Modelling, observing, searching pulsars: from high energy to radio	ANR-20-CE31-0010
2021	RICOCHET	Bivariate signal processing: a geometric approach to decipher polarization	ANR-21-CE48-0013

Table 1: List of the ANR grants led by or involving the laboratory teams over the period considered by this report. Grants from the European Union H2020 are listed separately in Table 2

Human resources

Key figures

198 recruitments of fixed-term staff members
30 interns per year on average hosted by the laboratory

Two agents make up this pole and ensure the administrative management of the permanent and contractual staff affiliated with the different governing bodies. Their activities include the reception of newcomers, the accompaniment of agents in the implementation of HR procedures, the follow-up of HR campaigns and the diffusion of information to the whole laboratory.

The pole ensure the recruitment of fixed-term staff in the framework of the research projects financed by partners such as CNES, EGO, Europe, ANR and IdEx Université de Paris.

On Nov 1st 2021, the laboratory was composed of 219 members distributed as shown in Fig. 106 which also shows the evolution during the past years. The parity within the laboratory staff has remained stable over the period considered for this report in the same figure with about 25 % women in the workspace (see Fig. 107).

Team

N. Okalla, S. Mergirie

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

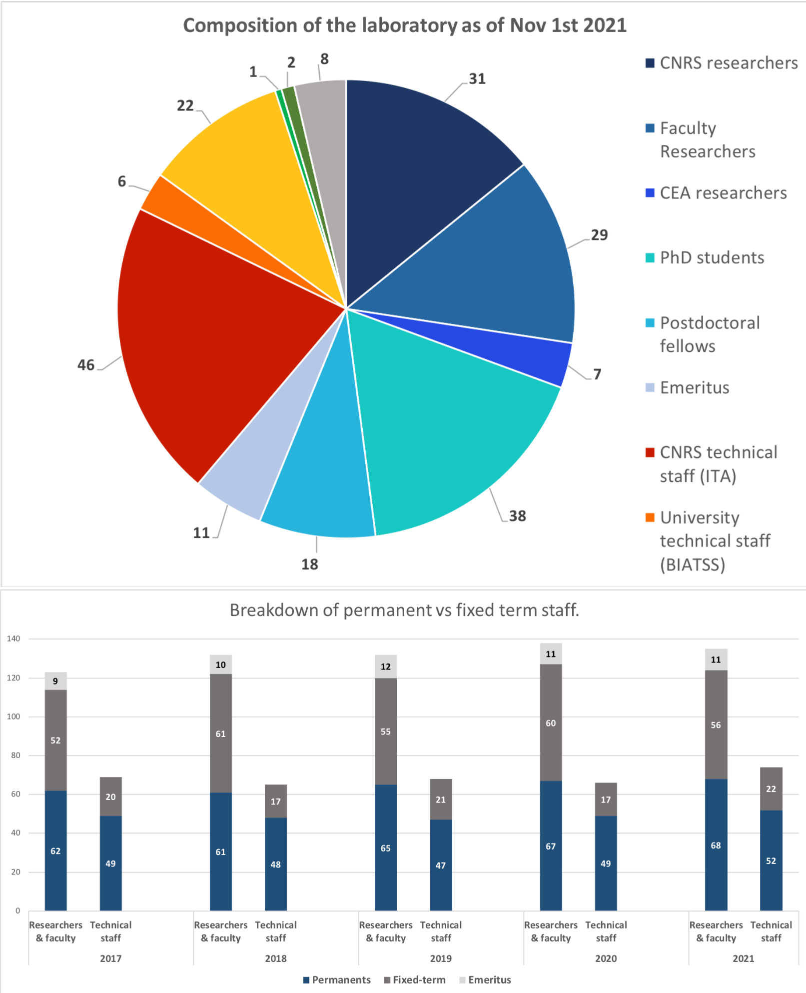

Figure 106: (Top) Composition of the laboratory as of Nov 1st 2021 – (Bottom) Evolution during the last years

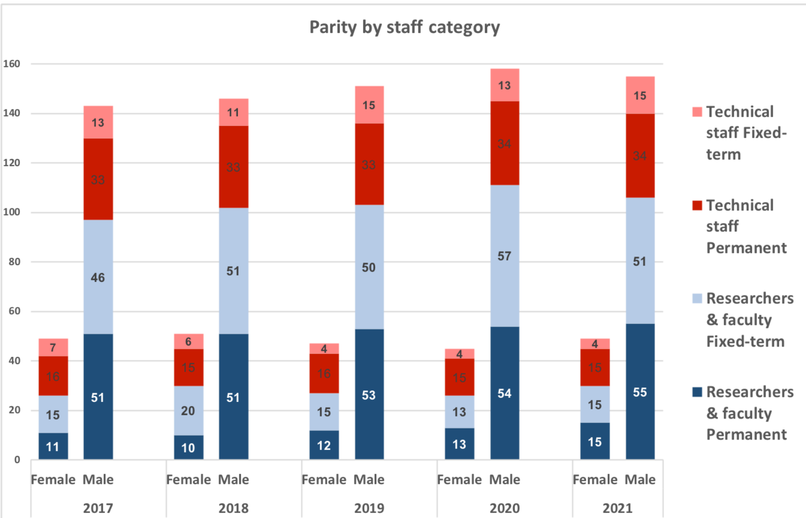

Figure 107: Evolution of the gender ratio over the past 5 years

Transverse actions

Activities related to communication are described elsewhere, in the section about Outreach and communication to the general public.

Logistics

The laboratory has a logistics division which, over the last 5 years, has been marked by the retirement of its two permanent staff. The logistics division is a angular stone for the quality of life of the employees. APC laboratory made the choice to recruit for the last 2 years a “logistics and quality of life” profile on a temporary contract, under the responsibility of the technical direction.

As the APC laboratory is hosted by Université de Paris, the activities of the logistics division complement those of the University’s stewardship and security services. The logistics division relies heavily on the prevention assistant to carry out its day-to-day tasks.

Over the past two years, the logistics division had to be flexible to adapt to the health crisis while maintaining the momentum to meet the demands. The list of tasks managed by the logistics division includes:

- Office moves including furniture assembly and disassembly
- Real-time monitoring of office occupancy and key management
- Implementation of specific measures related to the CoVid crisis such as the installation of Plexiglas panels for offices occupied by several people
- Transportation of material and technical items to the laboratories or partner companies in the Ile de France area
- The maintenance of the laboratory’s car fleet
- Management of the logistics associated with seminars held at APC
- Reorganization of meeting rooms and of the conviviality space with the creation of a “Zen” garden (see Fig. 108), and the installation of models for the communication
- Redesign of the integration hall following the departure of the QUBIC experiment with the creation of an Outreach Corner.
- Monitoring of the construction site for the creation of new offices (476A)
- First-level maintenance of equipments

The reactivity and availability of the logistics department are real assets for the quality of life of the laboratory and allow researchers and engineers to save precious time.

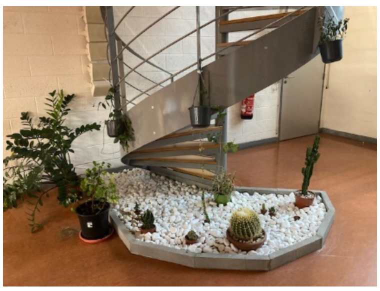

Figure 108: “Zen” garden in the lab’s conviviality space

Team

O. Lelong, S. Selmane

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Risk prevention

The prevention of professional risks, associated with the optimization of working conditions, is a major issue in the working environment. The missions of the Prevention Assistant require close collaboration with the occupational risk prevention services and prevention physicians of our two main supervisory bodies that are CNRS (represented by Paris Villejuif delegation) and Université de Paris, together with the local Fire Safety Department.

The Health and Safety structures of the laboratory are composed of

- The *prevention assistant*: Placed under the direct authority of the director of the unit, he assists and advises the latter in matters of health and safety, makes the unit's agents aware of the need to respect safety rules and to follow training courses, analyzes incidents and accidents in order to propose preventive measures, and implements or assists in the implementation of the selected proposals. This engineer has been carrying out this mission at APC since 2005. He has been assisted for several months by two new Prevention Assistants trained in 2020 and appointed in 2021, in preparation for his departure in 2022.

- The *radiation protection advisor*: Placed under the direct authority of the delegate of the authorization, he assists and advises the delegate in matters of radiation protection, raises the awareness of the unit's agents to the respect of radiation protection rules, and trains the users of radioactive sources. In addition, he supervises the implementation of workstations previously evaluated by him, takes charge of applications, renewals or modifications to the possession and use of sealed sources in the laboratory and is in contact with occupational medicine. This engineer has been carrying out this mission at APC since 2012; a second agent validated his authorization in 2021 to assist him. The first authorization obtained in 2012 was renewed in 2015 and again in 2020. Following the recommendation of Autorité de sûreté nucléaire (ASN) (the French Nuclear Safety Authority), the authorization is placed under the aegis of the University. The delegated person is the legal entity (president of the University). The laboratory holds 19 X-ray/gamma and electron calibration sources, with activities ranging from 40 kBq to 400 kBq. The authorization for possession and use concerns four rooms in the laboratory, spread over two buildings, each of which houses a storage box.

- The *laser referent*: Responsible for training in the handling of the laboratory's lasers (class 3R, class 3B and class 4) in the photodetection lab (see Photodetection laboratory) and in the clean room (see Cleanroom)

The Covid-19 pandemic and its impact on the functioning of the laboratory have been very significant and the Prevention Assistant has been involved since the first wave and the first containment of the first semester of 2020 in the continuity plan of activities, in close connection with the direction team and the Risk Prevention Department of the University for the purchase of masks, the respect of barrier gestures, the posting of information to the staff, the setting up for some agents of adaptations of their teleworking posts.

The analysis of accidents that have occurred since 2018 on the staff shows that those related to commuting are the majority, the others being accidents in the workplace, mostly due to manual handling or falls.

The main risks to which the personnel of the research unit are exposed are related to the use of machine tools, electrical equipment, and cryogenic fluid. Although the chemical risk is almost non-existent, we have a ventilated cabinet where solvents are stored. Our efforts are focused on improving safety with regard to equipment for working at heights with the purchase of a scaffolding and a stepladder with a guardrail allowing us to work safely on imposing detectors, and also on the fitting out of offices by adapting workstations with the purchase of ergonomic chairs.

Personal protective equipment is available. The overhead crane in the assembly hall is checked every year by an approved body. The fleet of lead soldering irons has been progressively replaced in accordance with the ROHS standard. A health and safety register is at the disposal of the personnel at the secretariat, where accidents and incidents of the unit are recorded.

Concerning first aid, the building is equipped with an automatic cardiac defibrillator located near the reception, and several first aid cabinets, placed in all sectors of the laboratory and particularly in the experimental rooms. Seven agents are trained as first aiders at work, The site is equipped with protection devices for isolated workers, "DATI/PTI", which are used mainly in the high-risk and isolated rooms such as the clean rooms, the workshop, and the low-noise room located in the basement. These devices, which are available from the janitor, are used to monitor the work environment.

Team

R. Oger, L. Pavili-Baladine, S. Selmane

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Carbon footprint

The laboratory monitors the carbon footprint related to its activities. Reports assessing the lab's greenhouse gas emissions has been produced for the years 2019 and 2020.

The first study (2019) was performed by a group of students (B. Friso Bellemo, H. Adberaouf, S. Couhault, C. Jacq, M. Toledo) from Master E2S [195] under the responsibility of A. Passalacqua. The assessment followed the protocol "Bilan carbone campus" established by the national agency ADEME.

[195] http://www.aied.univ-paris-diderot.fr/e2s

The study concludes that the total lab emissions correspond to 1300 tonnes of CO_2 equivalent per year. Those emissions are primarily dominated by transportation amounting to 77 % (which comprises business trips 82 % and commuting to work 17 % and visits to other laboratories in

France 1 %) followed by recurring energy consumption and maintenance (which comprises heat, electricity and refrigerants) amounting to 17 % of the total. See Fig. 109.

The second study (2020) was performed by the team using the protocol “GES 1point5” [196] concludes that the total lab emissions correspond 240 tonnes of CO_2 equivalent per year. This shows a striking decrease by a factor ~ 6 which is primarily due to the discontinuation of overseas travels due to the Covid pandemic. Indeed, the emissions due to travels have decreased by a factor of 100 (!) wrt to 2019. The emission budget is now dominated by recurring energy consumption and maintenance (71 % of the total) and computing (20 %).

[196] https://labos1point5.org

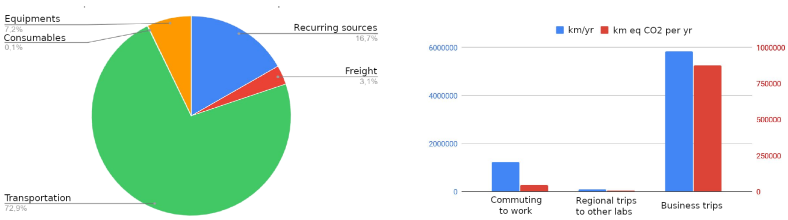

Figure 109: Breakdown of the lab’s carbon footprint estimated for the year 2019. Left: global overview (Equipments: emission due to the purchase of new equipments; Transportation: including both business trips and commuting; Recurring sources include heat, electricity and refrigerants). Right: Details about transportation impact including business trips and commuting to work.

Team

M. Le Jeune, M. Souchal

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Laboratory personnel [Jul 2017-Nov 2021]

Note: The names underlined indicates the long-term staff members that have joined the lab since 2017.

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Research Director

BABAK Stanislav [2017-]
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AUBRY Valery [-2019]
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CADI Balkis [2018-2018]
CATALANO Camille [2018-2019]
CHAN Kuo Kwan [2016-2018]
CHAU Thien Nhan [2021-2022]
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CHUARD Dimitri [2019-2020]
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FAHED Rémi [2017-2022]
GUIFFO Vincent [2019-2021]
HANKOU Nelly [2018-2019]
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LELONG Olivier [2021-2022]
LILLEY Marc [2018-2018]
MARIN-MATHOLAZ Etienne [2014-2018]
MESQUIDA Jean [2019-2021]
NGUYEN Catherine [2017-2018]
NITA Dariusz [2019-2021]
NOURY Alexis [2017-2017]
POLLACK Jennifer [2020-2023]
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University technical staff

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VERLEURE Marie [-2018]
ZAPPINO Sébastien

Technician

AHAMADA Hadji [-2020]
LEYRIT-FAILLY Delphine [-2018]

University fixed-term technical staff

BENHIZIA Hana [2018-2019]
BOUGAROUJA Mohamed [2018-2019]
CARRÉ François [2016-2017]
CHATZICHRISTOU Eleni [2017-2019]
COBAS Daniel [2016-2018]
COJOCARI Ion [2017-2019]
DURAND Sebastien [2019-2020]
EPITALON Clémence [2016-2019]
FORTIN Francis [2019-2020]
GONZALES DUBRUC Colin [2018-2019]
HAJLAOUI Jalel Eddine [2020-2021]
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KY Beng Yean [2021-2021]
MALECOT Alexandre [2019-2021]
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PHAN VAN SONG Emmanuel [2020-2022]
PIRES Cindy [2019-2020]
SAVCHENKO Denys [2021-]
SOUCHAL Martin [2016-2018]
SZYDLOWSKA Olga [2019-2021]
VANNONI Giulia [2019-2020]

Technical staff with Obs. de Paris

TORCHINSKY Stephen [2017-]

Apprentices

BATMANABANE Tamigesselvy Mylène [2016-2019]
CONFUCIUS Lina [2018-2019]
DAUGUET Julien [2017-2020]
GAUCHERY Sébastien [2017-2018]
LE CAM Maël [2021-]
MENIA Djamel Eddine [2020-2021]
NGUYEN Thanh Tam [2015-2018]

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LabEx UnivEarthS

APC is a founding member of the Laboratoire d'Excellence (LabEx) UnivEarthS, a research consortium hosted by Université de Paris and dedicated to interdisciplinary projects in the fields of Earth Sciences and Physics of the Universe. UnivEarthS brings together APC, IPGP and AIM laboratories and the French aerospace center ONERA. It aims to study the origin and evolution of the processes that have shaped and governed the history and dynamics of the Earth and the Universe.

UnivEarthS is funded by the French ANR, as part of the "Investissement d'avenir" national program. From 2011 to 2024, it will have been endowed with 1 million € per year, entirely dedicated to supporting high-potential research projects of its members, on a peer-reviewed, selective basis. UnivEarthS supports six types of projects. Frontier projects fund research activities that pursue the ambition to open new research fields, as does the HEA team who study the high-energy activity of the Galactic Centre massive black hole. Interface projects deliberately support multidisciplinary approaches, such as the ARGOS project or the application of gravitational waves detection to seismology. Third, Exploratory projects allow research teams to launch innovative, interdisciplinary, and somehow risky collaborations, like the LEAK project which explores KM3NeT low-energy neutrino detection capabilities. Fourth, Young team projects help young researchers to launch their research activity and constitute their team, like the MIMOSA project described above. Valorization projects are aimed to support scientific activities with high social impact and likely industrial applications, like the NGKIDs project dedicated in part to the development of new generation KIDs detection chain. Lastly, Education projects allow to train students, like the spatial project IGOSat and to share scientific knowledge with teachers, students and more globally with the public, like the PCCP activities.

From 2017 to 2021, APC has been involved in 3 Frontier projects (out of 9), 6 Interface projects (out of 11), 5 Exploratory projects (out of 8), 3 Young team projects (out of 5), 4 Valorization project (out of 6) and in the 3 Education projects.

UnivEarthS also offers diverse opportunities for APC research groups to welcome and train students (by affording mobility grants to international Master students), young researchers by organizing Fall schools (see Fig. 110 and 111) and even a larger audience (by supporting the diffusion of MOOCs).

The launch of UnivEarthS in 2011 by APC and its partners represented an important milestone on their common path towards increasing scientific and institutional synergies. This research consortium was like a nest for other collaborations to come: the STEP'UP doctoral school, the IGOSat project, and the new Université de Paris.

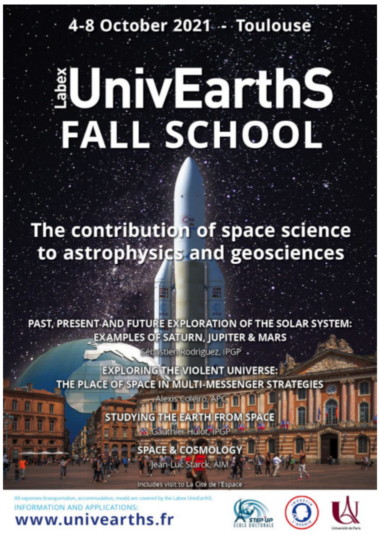


Figure 110: Poster of a recent event organized by the LabEx UnivEarthS involving members of APC

Figure 111: Participants of the LabEx UnivEarthS school in 2021

Team

S. Chaty, A. Olivier-Kaiser, A. Kouchner, S. Loucatos, N. Phan Van Song, G. F. Smoot

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Paris Center for Cosmological Physics

The Paris Center for Cosmological Physics (PCCP) [197] was created in 2010 by Pierre Binetruy thanks to the arrival of George F. Smoot (Nobel prize laureate in Physics 2006) to the APC laboratory. The PCCP has two main missions. The first one is to develop and implement outreach and education activities as well as interdisciplinary exchanges (i.e. art & science or science & philosophy) on the research topics studied at the APC laboratory. The second one is to work jointly with the RFPU Endowment Fund (Fonds de dotation pour la Recherche et la Formation dans le domaine de la Physique de l'Univers) to support the research carried out at APC.

[197] `https://www.pariscosmo.fr`

The PCCP and APC receive financial support by the associated structure of the RFPU Endowment Fund. The Fund was founded by the now-called Université de Paris in 2010 and, in the last three year, it has contributed to the funding of three PhD theses and three post-doctoral fellowships at APC, as well as several outreach projects both for schools and with artists.

In 2018/2019, the PCCP and RFPU managements were profoundly renewed with the arrival of Matteo Barsuglia as PCCP Director and of Antoine Kouchner as RFPU Director. At the same time, the two structures changed their project manager.

Figure 112: PCCP education activity in schools

Funding research From 2018 to 2021, the PCCP/RFPU have cofunded three PhD fellowships (Bastien Arcelin, Thomas Montandon, Mathias Régnier) and three postdoctoral fellowships (Jie Hu, Simone Mastrogiovanni, Clément Leloup). Moreover, the PCCP managed an external grant for the funding of an additional postdoc (Ivan Debono). Those researchers joined APC and integrated the relevant research groups while contributing part of their time to the PCCP outreach activities.

Outreach In the past three years, the PCCP has developed three major axes of action and projects: outreach and education, science and society, diversity and inclusion in physics.

Figure 113: Picture from the “Enseigner l'Univers” (Teaching the Universe) workshop for high-school teachers

Outreach and education One of the PCCP flagship activities is the workshop “Enseigner l'Univers” (Teaching the Universe). During two to three days, APC researchers give lectures to high-school teachers on the latest findings in Cosmology and Physics of the Universe. The workshop is included in the official teacher training offer of the three school districts of Paris, Versailles, and Créteil. The program started in 2011 and take place yearly, with the notable exception of 2020. In 2018, the workshop exceptionally took place in Greece. In 2021, Prof. Joseph Silk gave an introductory lecture about present status and open problems in Cosmology. In addition to the traditional courses about Astroparticle Physics and Cosmology, a new course about the Physics of the Higgs boson was proposed.

From 2018 to 2021, PCCP was a partner of the project FRONTIERS, funded by the Erasmus+ framework of the European Commission. FRONTIERS brought researchers in physics and astrophysics, including large research infrastructures such as EGO-Virgo, together with experts in pedagogy to investigate how Nobel Prize winning Physics can be integrated in school curricula in order to foster the interest of students towards science. The project was extremely successful in creating a strong teachers community and offer teaching tools and support, particularly during the COVID pandemic, well beyond European borders.

Figure 114: Screenshot of the FRONTIERS first e-Summer School in Jul 2020

At a local level, the PCCP carries out two parallel projects with schools of the Paris area. Since 2020, PCCP launched the action "Le Cosmos dans mon école" (the Cosmos in my school), a series of workshops on cosmology and astroparticle physics held by APC researchers directly in middle and high schools. Motivated by the idea that science has a crucial role to play in developing critical thinking and supporting the creation of a knowledge-based society, researchers are called to leave their usual settings to get directly involved in the field, offering learning opportunities to students directly in their schools, particularly in under-privileged areas with low access to resources.

In 2021 a new project for high-schools "F3 – Filles et Femmes aux Frontières de l'Univers" (Girls and Women at the frontiers of the Universe) was funded by the Région Ile-de-France, under the programme "La science pour tous". The project aims at addressing two key questions: fostering critical thinking and scientific literacy in high-school students, using the physics of the Universe as a tool to attract their attention and enhance their motivation towards science; address gender biases and stereotypes in science, aiming at reducing the gap between men and women access at scientific careers. Starting from a workshop series "Le Cosmos dans mon école" dedicated to the entire class, a group of girls will be offered the opportunity to work as "researchers" at APC for a few days, supervised by female mentors, to write a short scientific paper about their results and later present them to their classes in a dedicated "mock-up" scientific conference.

Figure 115: One of the F3 workshop in an high-school of the Paris area, Oct 2021

Science and society From 2017 to 2019, the PCCP/RFPU carried out a project art and science project called "Univers 2.0" funded by the Fondation Daniel et Nina Carasso. The project involved about twenty researchers, well-known artists (like Thomas Saraceno o Liliane Lyn), philosophers, and sociologist. Through a series of meetings and interactions, new art pieces were created and shown in a final exhibition "The rhythm of space" in Pisa, Italy, in December 2019. A book-catalogue presenting the dialogues between artists and researchers was released at the same time.

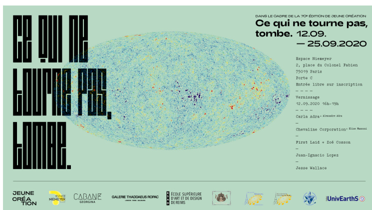


Figure 116: Poster of the exhibition Ce qui ne tourne pas tombe, Sep 2020

Since 2019, PCC/RFPU started a second programme "Art & science" dedicated to young artists. In 2019-2020, the PCCP carried out a first successful residency involving 5 groups of young artists, in collaboration with the Ecole Supérieure d'Art et de Design (ESAD) de Reims. The art residencies carried out from September to December 2019, under the tutoring of APC researchers, led to a final exhibition at the Espace Niemeyer from the 12th to the 26th of September 2020. The foreseen 250 places for the vernissage went sold out two weeks prior the event. The event was organized thanks to a fruitful connection with the art association Jeune Création and the Espace Niemeyer.

In 2019/2020, the project was financed by a private donation as well as a small contribution from the Labex project. Building on this success, a second edition of the residency was launched in September 2021. Two promising newly graduated artists from ESAD are currently exchanging with the APC researchers, visiting the lab facilities and participating to meetings and seminars in order to produce art pieces that will give rise to an exhibition in spring 2022.

Diversity and inclusion in physics In 2019, the PCCP launched a new program of actions to address some of the questions connected with diversity and inclusion in Physics. A training phase initiated with three workshops aiming at PCCP and APC staff on gender biases, gender issues in Physics, and social biases in the French education system. Following the training phase, the PCCP started a series of actions aiming at improving diversity and inclusion at the laboratory level as well as in its actions towards the general public, teachers, and school students. Simone Mastrogiovanni was invited to present the PCCP diversity actions during a meeting of the Virgo collaboration.

Early 2021, the PCCP also began the new program entitled "Women Exploring the Limits". The event "Paths around galaxies and particles" was held at the occasion of the UNESCO International Day for Women and Girls in Science. The full recording of the event is available on the PCCP Youtube channel [198] and it scored 189 views in the first three days online. A second event, "Ondes gravitationnelles : aux limites de la mesure, voyage aux confins du monde quantique" focused on the technological advancements currently being implemented on the Virgo gravitational-wave detector. Both the events featured a group of female scientific staff member from APC, spanning from PhD students to group leaders. A dedicated presentation about gender biases in Physics is planned for the entire APC staff and particularly addressed to the lab newcomers.

[198] https://www.youtube.com/channel/UCOQWzfNV3sCYiatbNjuOw6g

Team

G. F. Smoot (president), M. Barsuglia (director), A. Kouchner (RFPU director), G. Vannoni (project manager), O. Szydlowska (project officer), J.-L. Robert (communication), E. Capocasa, I. Debono, J. Hu, S. Mastrogiovanni, C. Leloup, B. Arcelin, T. Montandon, M. Régnier

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

François Arago Centre – FACe

François Arago Centre (FACe) [199] is the multi-messenger data processing centre of the APC laboratory. This centre was created in October 2010 and aims to provide the necessary infrastructure and expertise to meet the needs of space agencies for data processing (ground segment). The moving of the FACe in 2018 has breathed new life and new projects.

[199] https://si-apc.pages.in2p3.fr/face-website

As part of its renewal, the FACe 2.0 has been involved since 2019 in an innovative project, the Multi-Messenger Observatory (MMO), carried out in partnership with the Astrophysics Department of the University of Geneva. MMO aims to provide a real-time, online data analysis platform to run data processing pipelines a posteriori to the projects that developed them. This Multi-Messenger Online Data Analysis MMODA platform [200] is based on a cloud-based data management solution and virtualisation technologies. In the near future, it will address the challenges of efficient data sharing and reuse, long-term preservation, retention of data analysis systems and reproducibility of results. And from the user's point of view, the platform will provide a low-level abstraction of data analysis for different instruments, allowing interaction with scientific products, such as spectra, light curves or sky images.

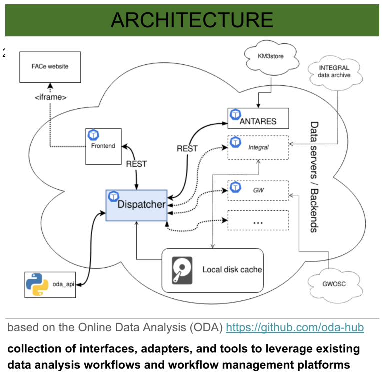


Figure 117: MMO architecture

The MMODA platform is based on a distributed computing environment between several institutions (University of Geneva, FACe in Paris, KAU in Kiev) which will be federated in a second step. Each node of the platform is based on a layer of physical or virtual machines running microservices in the form of containers. For the FACe site, the virtual machines are instantiated via the OpenStack IaaS (Infrastructure-as-a-Service) cloud of the French academic cloud federation, FG-cloud. The core infrastructures support the container orchestration solution, Kubernetes. The MMODA services (web and API interfaces, task manager, adapters corresponding to scientific analysis...) are in turn deployed in this infrastructure.

For the scientific instruments whose analysis is currently available through the interfaces, three use cases are enabled on MMODA at FACe. A simple workflow handling the analysis of ANTARES data for the period 2007-2017 is developed and deployed on the platform. This test case has already allowed to start a long-term data preservation process of the experiment and the integration of a second dataset is planned. The adapter corresponding to the analysis of the Integral space mission (developed by University of Geneva) will be deployed on MMODA at FACe and will allow the on-the-fly analysis of part of the voluminous Integral data. And a third adapter is currently developed for the analysis of LIGO/Virgo (i.e., the GWOSC data).

Team

C. Cavet, A. Neronov, D. Savchenko, M. Souchal, P. Zakharov, S. Zappino

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Other initiatives closely related to the laboratory

GdR Ondes Gravitationnelles Groupement de Recherche du CNRS (GdR) Ondes Gravitationnelles [201] is a national network aiming at federating and promoting exchanges and collaborations among the research groups working in the field of gravitational wave astronomy in France. This initiative is primarily supported by CNRS IN2P3 and APC has been its headquarters. Initially proposed by Pierre Binetruy, Chiara Caprini is the current director. Several APC staff are part of the GdR instances.

Figure 118: Logo of the GdR Ondes Gravitationnelles

[201] https://gdrgw.in2p3.fr

The GdR now assembles about 300 researchers divided in eight Working Groups on different aspects of GW science. The GdR organises annual assemblies and several more specific meetings, focussed on the research topics of the Working Groups. The GdR general assembly and other meetings are managed by APC.

The members of the APC gravitation and theory groups are among the leading active members of the GdR. The next mandate of the GdR, due to start in January 2022 (subject to official approval by IN2P3), will again be headquartered at APC under the direction of Danièle Steer.

Virtual Institute of Astroparticle physics (VIA) The Virtual Institute of Astroparticle Physics (VIA) was initially created as an ASPERA pilot project. Since 2017 VIA has broadcasted online 15 APC colloquiums (see Scientific animation), 8 seminars of the Theory groups and a number of sessions in international conferences, such as the Bahamas Advanced Studies Institute & Conferences and the Bled Workshops “What comes beyond the Standard models?”. VIA also contributes to events such as the Open Online Course on "Cosmoparticle physics" by M. Khlopov, involving lectures by D. Semikoz and M. Bucher, the Commemoration day for Patrick Fleury, held in APC and other collaborative meetings with russian institutes (SFEDU, Rostov on Don and NRNU MEPHI, Moscow). The VIA meetings hosted outstanding speakers including A. Addazi, I. Antoniadis, R. Bernabei, S. Brodsky, J. Ellis, E. Kiritsis, A. Marciano, R. Mohapatra, H.B. Nielsen, L. Randall, Q. Shafi.

Local, national and international collaborations

The identification of projects corresponding to the laboratory’s research areas and the establishment of partnership agreements are the subject of a constant and sustained activity at APC, forming one of the pillars of its scientific strategy. All of the laboratory’s research teams are involved in collaborative projects bringing together scientists and engineers, with a role as project coordinator, associated partner, member of a research group or of an international consortium. The teams are also collaborating at national level in a structured manner through Groupement de Recherche du CNRS (GdR)s and at international level viaIN2P3’s initiative such as International Research Network (IRN), International Research Project (IRP) and International Research Lab (IRL).

Local partnerships

The Observatoire de Paris, secondary supervisor of APC, maintains many links with APC through its laboratories, namely LUTH, LERMA, GEPI and USN on major research themes such as cosmology, the structuring of the Universe and the observation of pulsars and the primordial Universe.

APC is a member of the Fédération de Recherche sur les Intéractions Fondamentales (FRIF). Funded by the Université Pierre et Marie Curie (now Sorbonne Universités) and by CNRS, the federation is "a laboratory without walls" gathering several entities (the others being LPENS, LPNHE, LPTHE, as well as GReCO) whose goal is to increase exchanges between laboratories and to animate their scientific life, by organizing and subsidizing common seminars, visits of foreign researchers, (post)doctoral courses and research workshops.

As a significative part of the laboratory's projects are linked to space missions, APC plays a central role in the Pôle Spatial of the Université de Paris [202]. As an example, the CubeSat project IGOSat jointly managed by APC and IPGP with the support of JANUS – the French satellites for training programme of Centre National d'Etudes Spatiales (CNES) – has trained more than 270 students.

[202] https://u-paris.fr/en/spatial-centre-universite-de-paris/

There are similar synergies in the area of data science with the Data Intelligence Institute of Paris (DiiP). This interdisciplinary initiative fosters and supports the emergence of interdisciplinary practices around data science and data intelligence.

Figure 119: https://u-paris.fr/diip/

At the regional level

At the regional level, APC has been a member of the ACAV+ DIM project [203]. Labeled by the Île-de-France Region to support Ile-de-France research in the fields of Astrophysics and Conditions for the Emergence of Life, and coordinated by Observatoire de Paris, the network redistributed grants from the region through calls for projects.

[203] https://dimacav.obspm.fr

For the period 2022-2026, the Region continues its action in favor of structuring research projects via the DRIM, APC being a member of this new program.

Europe

At the European level, APC has established several partnerships with institutions that are internationally recognized for the quality of their research programs.

The APC laboratory is the French functional center of AstroParticle Physics European Consortium (APPEC). The APPEC consortium gathers 19 funding agencies, national policy makers and research institutes from 17 European countries, responsible for the coordination and funding of national efforts in the field of astroparticles, with a strategic roadmap established for the period 2017-2026.

A collaboration agreement was signed in 2018 with the Nicolaus Copernicus Astronomical Center (NCAC) of the Polish Academy of Sciences and AstroCeNT (Particle Astrophysics Science and Technology Center)

[204], which allowed the organization of thematic workshops, the creation of international cotutelles for doctoral programs, or the financing of R&D programs. For the latter, the LAr TPC of the DUNE and DarkSide neutrino and dark matter detectors, the technological development of SiPM, the Virgo project, big data and data analysis techniques are all topics of the program. Other projects are underway and will be realized in the coming months.

[204] https://astrocent.camk.edu.pl

APC is the leading institution of the mobility project CMB-INFLATE, coordinated by Guillaume Patanchon on advanced data analysis in view of future experiments for the measurement of B-polarization CMB modes. This H2020 RISE project funded with 1.2 M€ started on Oct 1st 2021 for four years. The program will finance visits of researchers between the institutes of an international network international network that 16 institutes/universities in the world distributed in Europe, but also in Asia and North America. The objective is to create a community of researchers for advanced and innovative analysis of polarization data focused on large angular scales for the accurate measurement of measurement of B-modes.

APC is also a strategic partner of the NCAC in the H2020 DarkWave project. The DarkWave project is looking for promising dark matter candidates WIMPS.

International partners

At the international level, the laboratory is part of an important network of collaborations.

For space missions, APC regularly collaborates with CNES, ESA and NASA. Collaboration projects are also underway with the JAXA (LiteBIRD) and with the CNSA (SVOM).

Partnerships have been signed with other major astroparticle physics laboratories or universities. These structures are the KIPAC in the framework of Laboratoire international associé (LIA), the Pierre Binetruy Center [205] in the framework of International Research Lab (IRL) in association with the University of Berkeley, the LIA ALFA in Argentina, the LIA LEPLB with the NCS Kurchatov Institute in Russia, the Kavli-IPMU in Japan. For universities, projects have been carried out with the University of Oxford, University of Hamburg and University of Chicago.

[205] https://www.cpb.in2p3.fr

These collaborations have allowed the implementation of meeting and exchange programs such as the annual cycle of conferences “Cosmological Frontiers in Fundmental Physics” with the Perimeter Institute (Waterloo, Canada) and the Solvay Institutes (Brussels), or the participation in the international PhD program IDAPP (a network including seven Italian Universities and three French University, plus three Laboratories: Italian, French, German) active on the Astroparticle area.

In a strong will of IN2P3 to develop collaborations with Japan, the IRL ILANCE has been created in April 2021. It is a new international laboratory of physics of the two infinities between IN2P3 and the University of Tokyo. The scientific program of ILANCE is very broad, ranging from neutrinos to the primordial universe, including dark matter, gravitational waves and particle physics. APC teams will be involved in many projects covering all the above mentioned research areas.

Table 2: List of EU-funded grants led by or involving the laboratory teams

Acronym	Project name	Source of funding
NEWS	NEw WindowS on the universe and technological advancements from trilateral EU-US-Japan collaboration	H2020-MSCA-RISE-2016
nuHEDGE	Neutrinos at High Energies: Disentangling Galactic and Extra-galactic components	H2020-MSCA-IF-2018
LEANOR	Detecting Low-Energy Astrophysical Neutrinos with KM3NeT ORCA: the Transient Neutrino Sky at the GeV Scale	H2020-MSCA-IF-2018
REINFORCE	REsearch INfrastructures FOR Citizens in Europe	H2020-SwafS-2019-1
DarkWave	Novel technologies for dark matter search and frontier astroparticle physics experiments	H2020-WIDESPREAD-2020-5
AHEAD2020	Integrated Activities for the High Energy Astrophysics Domain	H2020-INFRAIA-2019-1
CMB-INFLATE	Advanced Methodologies for Next Generation Large Scale CMB Polarization Analysis	H2020-MSCA-RISE-2020

Lab assembly, meetings and seminars

The internal communication and scientific animation go through different channels. Two major meeting points are particularly important:

- les 'Vendredi de l'APC' is the name for the lab general assembly
- le 'Colloquium de l'APC' designates the laboratory main seminar.

Internal communication and information dissemination

As the name indicates, Vendredis de l'APC are organized on Friday with a frequency of one per month approximately. This assembly is directed to all members. The meeting starts with general news from the direction of the laboratory, which includes the presentation of new comers. This initial part is followed by one or two presentations accessible to all covering recent scientific highlights, on topic relevant to the whole lab (for instance, the carbon footprint assessment, etc).

Every two years, the laboratory gathers off-site for a retreat called "Biennale du laboratoire". This meeting is organized and prepared by the laboratory council. The last edition of Biennale took place in May 2019 in Biarritz, France. 92 staff members participated to this three-day event. During the preparation of the meeting, working group are formed to assess the situation and collect input about a number of topics related to the lab functioning and orientation. The conclusions of the working groups are presented and discussed with the full assembly. A document summarizes the salient points agreed upon during the meeting.

The lab direction meets monthly with the heads of the scientific teams and similarly with the leaders of the technical services. Those meetings are an important link of the information transmission chain top/down and bottom/up, that from the various funding institutions to the various groups and vice-versa. This is completemented by regular email exchanges through dedicated mailing lists.

The public and private (intranet, see Fig. 120) websites also allow the regular dissemination of informations. For instance the lab internal procedures are explained on the Intranet.

Figure 120: View of the Intranet home page

Scientific animation

The Colloquium is the laboratory's main seminar. This bi-monthly seminar features a diverse selection of talks, overall covering all scientific interests of the laboratory, see Fig. 121 and the table below. The large majority of the speakers are from other institutions, and often from abroad.

During the period of this report, the Colloquium was organized by Vincent Vennin and Josquin Errard.

All scientific teams also organize their own seminar, focused on their respective field.

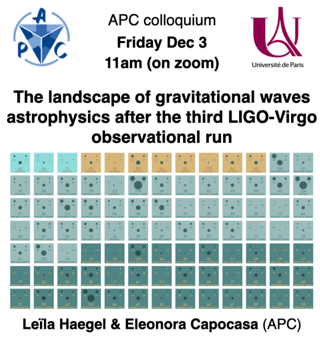


Figure 121: Example of poster for the Colloquium

List of Colloquia – 2017-2021

Year	Name	Affiliation	Title
2021	Casey, Brendan	Fermilab	First Results from the Fermilab Muon g-2 Experiment
2021	Marika, Asgari	University of Edinburgh	Seeing the dark Universe: Cosmology with the Kilo Degree Survey
2021	Vallisneri, Michele	Jet Propulsion Laboratory	The Logic of Detection: Statistics and Systematics in the Search for Gravitational Waves with Pulsar-Timing Arrays
2021	Tomasi-Gustafsson, Egle	CEA, IRFU, DPhN, Université Paris-Saclay	Exploring the internal structure of composite particles
2021	Contaldi, Carlo	Imperial College	Mapping Gravitational Wave Backgrounds
2021	Heavens, Alan	Imperial College	Bayesian Cosmology
2021	Peacock, John	The Royal Observatory Edinburgh	Tomographic lensing of the Cosmic Microwave Background
2021	Mandelbaum, Rachel	Carnegie Mellon University	Cosmology with weak lensing in ongoing and upcoming imaging surveys
2021	Lisi, Eligio	INFN Bari	Known and unknown neutrino mass-mixing properties

2021	Codis, Sandrine	AIM	The cosmic crystal clustering and connectivity of the cosmic web
2021	Gair, Jonathan	Max Planck Institute for Gravitational Physics	Gravitational-wave standard siren probes of cosmology
2021	Sesana, Alberto	Université de Milan-Bicocca	Massive black hole binaries in the era of multimessenger astronomy
2021	Shaposhnikov, Mikhail	EPFL	Higgs boson as a driver of inflation
2021	Mapelli, Michela	University of Padova	Changing paradigms for binary black hole formation
2021	Staggs, Suzanne	Princeton University	Describing the Present by Extrapolating from the Past with the Atacama Cosmology Telescope
2021	Babusiaux, Carine	IPAG - Université Grenoble Alpes; GEPI - Observatoire de Paris	The Milky Way seen by the Gaia mission
2020	Babak, Stanislav	APC	GW190521 and alike: what can we learn from multi-band observations
2020	Babusiaux, Carine	IPAG - Université Grenoble Alpes GEPI - Observatoire de Paris	The Milky Way seen by the Gaia mission
2017	Hogan, Craig	The University of Chicago	Rotational Quantum Fluctuations of Space-Time
2020	Dvorkin, Irina	IAP	Binary black holes and neutron stars: astrophysical implications of gravitational-wave observations
2020	Bern, Zvi	UCLA	From scattering amplitudes to gravitational waves
2020	Combes, Françoise	Observatoire de Paris	Active Galactic Nuclei: fueling and feedback
2020	Pettorino, Valeria	CosmoStat, CEA Paris-Saclay	Dark Energy from Planck to Euclid: degeneracies in the dark sector
2020	Babak, Stanislav	APC	Detecting gravitational waves in the nano-Hz band with Pulsar Timing Array
2020	Andrzej, M. Szelc	University of Manchester	Long- and Short-Baseline Neutrino Oscillation Experiments
2020	Perego, Albino	Trento University and TIFPA	Modeling of binary neutron star mergers: from simulations to multimessenger observations
2020	Perego, Albino	Trento University and TIFPA	Modeling of binary neutron star mergers: from simulations to multimessenger observations
2020	Palanque-Delabrouille, Nathalie	Irfu/DPhP cosmology group, CEA	DESI, unraveling dark energy
2019	Cardoso, Vitor	CENTRA, Dep. de Física, Inst. Sup. Técnico, Univ. de Lisboa	Black holes as a physics laboratory
2019	Lasserre, Thierry	CEA Irfu, APC	First neutrino mass results from KATRIN
2019	Damour, Thibault	IHES	Analytical Approaches to the General Relativistic Two-Body Problem
2019	Savchenko, Volodymyr	Geneva Observatory	Hard X-ray counterparts of multimessenger transients

2019	Altschuler, Daniel R.	Physics Department, University of Puerto Rico	Science, Pseudoscience, and the Responsibility of Scientists
2019	Vachaspati, Tanmay	Arizona State University	A Classical-Quantum Correspondence
2019	Reichardt, Christian	University of Melbourne (Australia)	Inflation and Neutrinos: Searching for New Physics with the Cosmic Microwave Background
2019	Sigl, Gunter	DESY	Radio signatures from conversion of axion–like particles to photons
2019	Vincent, Frederic	Observatoire de Paris	What can we learn from the picture of a black hole?
2019	Chardin, Gabriel	CNRS/ DGDS	Concordance of the Dirac-Milne Universe
2019	Trovato, Agata and Michał Bejger	APC	GWTC-1: First LIGO/Virgo Gravitational-Wave Transient Catalog
2019	Perrin, Guy	Observatoire de Paris	First explorations of Sgr A* at the event horizon scale and first tests of general relativity with GRAVITY
2018	McLaughlin, Gail	North Carolina University	Neutrino and nuclear physics of the r-process
2018	Kachelriess, Michael	Trondheim, Norway	A Fresh Look at Galactic Cosmic Rays
2018	Garcia-Bellido, Juan	IFT, Univ. Autonoma Madrid	Gravitational Wave signatures of Primordial Black Holes as Dark Matter
2018	Katz, David	Observatoire de Paris	The second Gaia data release: content and first scientific results
2018	Randall, Lisa	Harvard University	Darkly charged dark matter
2018	Stebbins, Albert	Fermilab	Spectroscopic Count Intensity Interferometry with Extremely Large Telescopes
2018	Billard, Julien	IPNL	Probing new physics with Coherent Elastic Neutrino- Nucleus Scattering and the future Ricochet experiment
2018	Crézé, Michel	APC	L'invention de la Voie Lactée
2018	Grant, Darren	University of Alberta	Ghosts in the ice- Searching for the Universe's most elusive particles at the South Pole
2018	Bucher, Martin	APC	The Planck Legacy and Beyond: Mapping the Initial Conditions of the Universe
2018	Smoot, George	Université de Paris, Hong Kong U. of Science and Technology, Nazarbayev U.,	Reinterpreting Low Frequency LIGO/ Virgo Events as Gravitationally-Lensed Magnified Stellar-Mass Black Hole Mergers at Cosmological Distances
2018	Armengaud, Eric	IRFU/DPhP CEA Saclay	Dark matter beyond WIMPs: light, warm, fuzzy and others
2018	Dierickx, Marion	Harvard-Smithsonian Center for Astrophysics	BICEP/Keck: Constraining primordial gravitational waves with CMB polarization observations from the South Pole

2018	Torchinsky, Steve	APC	The French community towards the Square Kilometre Array
2018	Battaglia, Nick	CCA New York, Cornell University, Princeton	Constraining fundamental physics with thermal and kinetic Sunyaev- Zel'dovich effects
2017	Levinson's, Amir	Tel Aviv University	High-Energy magnetospheric emission in stellar and super-massive black holes
2017	Barsuglia, Matteo and others	APC	GW170817: The dawn of a new era in astronomy
2017	Souradeep, Tarun	Inter-University Centre for Astronomy and Astrophysics, India	Robust but enigmatic post-Planck Cosmos
2017	Revaz, Bernard	MMOS Université de Genève	«Gaming» pour la Science : Intégration organique de tâches scientifiques dans les communautés en ligne
2017	Giannotti, Maurizio	Barry University	Astrophysical Anomalies and Axions: the physics potential of the International Axion Observatory
2017	Klimenko, Sergey	University of Florida	LIGO Observations of Binary Black Holes
2017	Janssen, Reinier	Institut d'Astrophysique Spatiale	Hybrid Kinetic Inductance Detectors: Enabling kilo-pixel arrays of high sensitivity detectors for ground-and space-based far-infrared astronomy
2017	Olinto, Angela	The University of Chicago	The Probe Of Multi-Messenger Astrophysics (POEMMA)
2017	Monfardini, Alessandro	Institut Néel CNRS	NIKA and NIKA2: from the pathfinder KID camera to the ultimate mm-wave imaging/polarimetry at the 30-meters Pico Veleta telescope
2017	Privitera, Paolo	University of Chicago	The DAMIC experiment: searching for WIMPs and beyond with CCDs
2017	Shirokoff, Erik	University of Chicago	Novel superconducting detectors for next-generation CMB and submm instruments
2017	Tao, Charling	CPPM	Baryon Acoustic Oscillations with Cosmic Voids

Outreach and communication to the general public

The main mission of the communication team is to relay informations to/from the laboratory members. The team also supports the organization of scientific conferences or other types of events.

Web and social media

The laboratory communicates through its website [206] and Twitter [207]. Some video material is also posted on the lab's Youtube channel [208].

[206] http:\apc.u-paris.fr
[207] https://twitter.com/APC_Laboratory
[208] https://www.youtube.com/user/APCLaboratoire

Contributions to the 50th anniversary of IN2P3

The team made multiple contributions to the celebration of the 50th anniversary of IN2P3 that has taken place during the year 2021 [209].

[209] https://50ans.in2p3.fr

With the active participation of E. Plagnol and D. Vignaud a chronological poster has been designed with a timeline from the lab inception to nowadays [210]. The purpose is to retrace the history of the laboratory through its milestones and a selection of experiments and flagship projects representative of the lab's activity.

[210] https://50ans.in2p3.fr/timeline-apc

In addition to this timeline, the team produced a poster that represents the "DNA" of the laboratory. This panel is one of the elements of the travelling exhibition "Les laboratoires de l'IN2P3" presented during the different events in the framework of the anniversary celebration.

On Jul 2nd 2021, APC organized its celebration day allowing to showcase the science done by the lab [211]. With the support of the CNRS media service unit "Appui à la Recherche et Diffusion des Savoirs", the portraits of four PhD students have been produced and broadcasted during this day.

[211] https://indico.in2p3.fr/event/24536/

This event was also the occasion of an exchange with our different institutional and academic partners and a moment of conviviality. About 80 people attended the event in person and about 40 followed it remotely. The recording is available here [212].

[212] https://youtu.be/KEy7zTDONqE

Participation to the "Fête de la science" and other public events

Within the framework of the high-school to University link (Liaison Lycée Université, LLU), the Physics Department opens its doors to high-school students on two occasions during the year. APC is very involved in these two events as responsible for the organization (A. Creusot) and by participating in the proposed activities.

Figure 122: KM3NeT exhibition during the Fête de la Science 2019

The first event takes place during the science festival ("Fête de la science"), at the beginning of the school year. It consists in receiving classes of high school students over several days. The teachers of the high school classes book a visit slot half a day in advance. During these few hours, small groups rotate through different workshops where speakers present a particular subject. The emphasis is usually on experimentation and manipulation, but laboratory visits, exhibitions or presentations are also organized, see Fig. 122. The most popular experiments are particle detection with a fog chamber, superconductivity with liquid nitrogen, demonstration of Michelson interferometry with reference to gravitational wave, experiments on waves and electromagnetism, properties of foams or optics with lasers. The interaction with researchers, thesis students, technicians, the participation in manipulations or the discovery of the academic world make these days a great success.

The second event is the Physics department "open doors". This event takes place at the beginning of the calendar year, before the students' orientation choices. The principle is very similar to that of the science festival. Priority is given to the senior classes.

Lab's members take part to various exhibitions and science fairs. As a (recent) example, see Fig. 123 for a photo of the citizen science program

"Kilonova-catcher" stand at the "Rencontres Ciel et Espace", one of the main astrononmy-oriented science fair in France [213]. See also the chapter Publications, communications and responsibilities for a more complete list of contributions.

[213] https://www.afastronomie.fr/rencontres-ciel-espac

Figure 123: Citizen science program "Kilonova-catcher" at the "Rencontres Ciel et Espace"

Outreach center

Thanks to funding from Labex UnivEarthS, PCCP was able acquire a few pedagogical instruments to create a new dedicated space for education and outreach for the entire laboratory. This space is referred to as the "outreach centre". During 2021, the physical space was identified and set up. The preparation was completed in September 2021. The PCCP team is in the process of mounting the instrumentation. Thanks to the F3 project, additional funding was obtained to extend the range of instruments present in the Outreach Centre. The Centre will be used during PCCP educational projects, as well as yearly laboratory outreach activities, such as Fête de la science or other open-doors days.

Team

A. Creusot, C. Hugon, O. Szydlowska, G. Vannoni

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

VALLESPIR

L'INDEPENDANT MERCREDI 2 JUIN 2021 15

CÉRET

Bélisama, un capteur de rayons gamma s'invite au lycée Déodat-de-Séverac

Philippe Laurent et Élisabeth Blanc dévoilent le détecteur Bélisama, principalement constitué d'un scintillateur BGO, d'un photodétecteur SiPM et d'une électronique de contrôle et d'acquisition.

Figure 124: BELISAMA in the press

The BELISAMA project

Atmospheric storms are one of the most important disruptive phenomena in the Earth's environment. Two thousand thunderstorms are permanently active worldwide, producing 50 to 100 lightning per second on the Earth surface. Recent observations of light emissions in the middle and upper atmosphere and atmospheric gamma-ray emissions indicate an intense coupling of the atmosphere with the Earth's ionosphere and magnetosphere above the active storm cells. This coupling can be triggered by cosmic radiation, solar wind, and meteorological and volcanic processes affecting the lower layers of the atmosphere. Current knowledge is mostly induced through observations of light emission in the visible spectrum on-ground or from optical detectors onboard satellites.

Theoretical studies show that these emissions are only part of a much more complex phenomenon (X-rays, electromagnetic wave emissions, high energy electrons). These events produce gamma-ray flashes (TGF) discovered by the NASA BATSE satellite, confirmed by the NASA RHESSI satellite, dedicated to high-energy Sun observation, and recently analyzed by the ESA ASIM mission onboard the ISS. They was one of the main objectives of the TARANIS satellite (see Taranis and XGRE-NG), unfortunately lost a few minutes after launch in 2020.

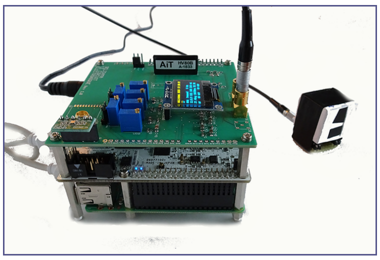


Figure 125: BELISAMA in the press

These flashes were detected from the ground by the GROWTH collaboration in Japan in 2016, but no similar studies have yet been conducted in Europe. The BELISAMA project [214], initiated by APC in collaboration with IRSN and University of Tokyo and funded by Ile-de-France region, proposes to look at this question by involving a network of French high

[214] https://ikhone.wixsite.com/belisama

schools. The project aims to make high school students discover natural gamma-ray radiation, whether it is of terrestrial origin (natural radioactivity) or atmospheric (TGF). It shows also the means and methods used to detect and analyze these gamma-ray emissions. The students measure the energy and temporal evolution of the gamma-ray light thanks to a detector, called BELISAMA (see Fig. 125), specially developed at APC for this project and installed in their high school. Students are able to share their data with those obtained in other high schools through a dedicated web site, and see if they have detected simultaneous atmospheric emissions. Up to now, six detectors are installed in Ile-de-France region, Montpellier region and in French Guyana.

Team

E. Bréelle, P. Laurent, J.-L. Robert

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

Continuing education

Continuing education answers the need to maintain and develop the level of competences of the laboratory. It allows the lab members to address new technological challenges. For this reason it is strongly correlated to the scientific orientations of the laboratory.

Every year, the training needs of the laboratory are collected through the "Plan de Formation de l'Unité (PFU)" and transmitted to the CNRS services in charge of continuing education.

A training offer is proposed in return by the following actors:

- The "service de formation permanente mutualisé d'Ile de France du CNRS" offers collective training courses. The offer is elaborated from the PFU realized by the different units located in Ile de France.

- The "service de formation permanente de l'IN2P3" implements training courses targeted to the Institute's professions and activities. They are mainly proposed in the form of thematic schools or national training actions.

- The "service de formation permanente de l'Université de Paris" offers rather general collective training courses.

Beyond this offer, the lab members have the possibility to follow specific training courses that are not offered by the above-mentioned providers. The course of "Techniques and Technologies of Space Vehicles" (TTVS) of CNES is followed every year by 1 or 2 lab member. French courses for foreign researchers or engineers are also supported.

Overall, about a hundred training sessions are followed every year, which corresponds to 80 trainees. However, a slight decrease (by about 30%) in these figures should be noted in 2020-21 due to the pandemic.

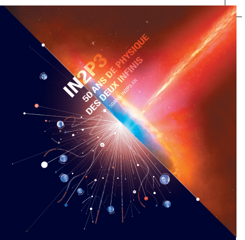
Team

C. Hugon

Permanent scientist | Fix-term scientist | Permanent technical staff | Fix-term technical staff | Associate

Scientific leader and/or Technical project manager

LABORATOIRE ASTROPARTICULE & COSMOLOGIE



Le Laboratoire Astroparticule et Cosmologie a été créé en 2002. C'est le premier laboratoire de l'IN2P3 centré sur le domaine de l'astroparticule, une physique à l'interface de l'astrophysique et de la physique des particules qui a émergé dans les années 90 en utilisant les techniques de la physique des particules pour des projets astrophysiques aussi bien au sol que dans l'espace. L'APC, hautement pluridisciplinaire, s'intéresse aussi bien à la cosmologie dite observationnelle, la physique des neutrinos, l'astronomie gamma à haute énergie, l'étude des rayons cosmiques à très haute énergie ou la recherche des ondes gravitationnelles. Il s'enrichit d'un groupe important de physique théorique sur la plupart des thématiques.

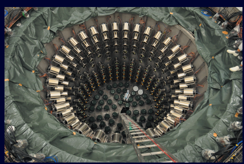
H.E.S.S.

Des physiciens de l'APC ont été pionniers dans la détection des rayons gamma à haute énergie par la technique « Tcherenkov atmosphérique ». L'expérience H.E.S.S. installée en Namibie a eu une moisson de résultats exceptionnels, que ce soit pour des sources galactiques ou extragalactiques. Sur la vignette, un physicien de l'APC intervient sur la caméra d'un des télescopes.

FrLe grand télescope central de H.E.S.S. et deux des quatre petits télescopes. Sur l'incrustation un physicien de l'APC travaillant sur la caméra. © Laboratoire APC

Double Chooz

Le projet Double Chooz a été lancé en 2003 par des physiciens de l'APC et du CEA pour mesurer l'angle d'oscillation des neutrinos θ13 auprès de la centrale nucléaire de Chooz (Ardennes). Ses premiers résultats en 2011 ont établi une valeur non nulle de ce paramètre. La photo représente la cuve du détecteur lointain, équipée de ses photomultiplicateurs.

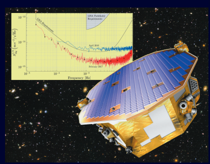


La cuve du détecteur lointain, équipée de ses photomultiplicateurs. © Laboratoire APC

Ondes gravitationnelles : Virgo et LISA

L'APC est très actif dans la recherche des ondes gravitationnelles avec deux types de détecteurs (Virgo au sol et LISA dans l'espace) permettant d'observer sur une gamme étendue de fréquences. Les physiciens ont activement contribué à la première détection des ondes gravitationnelles par la collaboration LIGO-Virgo en 2015. Dans l'expérience Virgo, en Italie, ils ont participé à l'amélioration du détecteur en construisant un télescope « adaptateur de faisceaux laser ». Pour préparer le lancement de LISA, les physiciens de l'APC ont participé à la mission spatiale LISA Pathfinder, démonstrateur technologique des méthodes de détection des ondes gravitationnelles dans l'espace. Les résultats obtenus ont très vite dépassé les objectifs, permettant une adoption de LISA par l'ESA et la NASA.

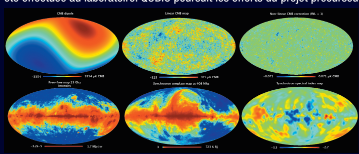
Vue aérienne des deux bras du détecteur Virgo près de Pise. Sur l'incrustation, tests des télescopes d'adaptation des faisceaux de l'interféromètre Virgo, par des physiciens de l'APC. © Laboratoire APC



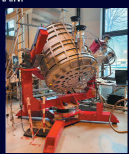
Vue d'artiste de LISA Pathfinder et de son module de propulsion. En incrustation, les résultats obtenus par LPF. © Laboratoire APC

Fond diffus cosmologique : Planck et QUBIC

L'étude du fond diffus cosmologique (CMB) a permis des avancées considérables dans notre compréhension de l'évolution de l'Univers. L'APC a fortement contribué aux résultats spectaculaires obtenus par le satellite Planck lancé en 2009. Il a joué un rôle important dans la calibration du détecteur HFI et dans la construction de la carte du ciel CMB en déterminant avec précision tous les avant-plans. L'APC est maintenant leader dans l'interféromètre bolométrique QUBIC, destiné à mesurer la polarisation du CMB, dont l'intégration a été effectuée au laboratoire. QUBIC poursuit les efforts du projet précurseur BRAIN.



Cartes du Planck Sky Model, modèle du ciel microonde du ciel synthétisant les connaissances sur les différentes composantes (avant-plans) qu'il faut soustraire pour extraire le signal du CMB. © Collaboration Planck



L'instrument QUBIC dans le hall d'intégration de l'APC. © Laboratoire APC

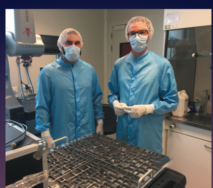
KM3NeT

Les objets les plus puissants de l'Univers émettent non seulement du rayonnement électromagnétique ou des ondes gravitationnelles, mais aussi des neutrinos. Le laboratoire APC est fortement engagé dans le projet sous-marin KM3NeT, successeur d'ANTARES et situé également en Méditerranée. Il contribue en particulier au développement d'ORCA, sous-détecteur consacré à l'étude des propriétés fondamentales des neutrinos.

Déploiement d'un module optique de KM3NeT en Méditerranée. © Collaboration KM3NeT

SVOM-ECLAIRs

Pour étudier les sursauts gamma, parmi les explosions les plus puissantes dans l'Univers, le laboratoire participe au détecteur ECLAIRs qui sera monté à bord du satellite franco-chinois SVOM (lancement prévu en 2022). Les physiciens et ingénieurs ont construit le masque codé (photo) qui a été livré au CNES en février 2021.



Dans la salle blanche de l'APC, deux mécaniciens devant le masque codé d'ECLAIRs en cours d'élaboration. © Laboratoire APC

2000

- **Réunion fondatrice de l'APC.** L'Université Paris-Diderot, présente aux tutelles, les thèmes structurants : cosmologie, astrophysique des hautes énergies, neutrinos, théorie.
- **Création de l'UMR** avec pour tutelles Université Paris-Diderot, CNRS, CEA et Observatoire de Paris. Le laboratoire PCC du Collège de France créé en 1973 rejoint l'APC.

Inauguration en 2006, de l'APC dans le grand amphithéâtre de la Bibliothèque Nationale de France © Laboratoire APC

- **Création du Groupe Théorie.** Ses activités recouvrent la cosmologie et l'astroparticule et des thèmes connexes, constituant un angle de recherche original et essentiel.
- **Inauguration de l'Observatoire Pierre Auger** destiné à détecter les rayons cosmiques à très haute énergie à Malargue en Argentine.
- **Participation de l'APC au projet TARANIS.** En 2020 livraison des trois senseurs de vol constituant le spectromètre XGRE du satellite TARANIS.

Dépose du satellite dans l'élément adaptateur de la fusée VEGA. © CNES

2010

- **Création du Paris Centre for Cosmologial Physics et du Laboratoire d'Excellence UnivEarthS.** Structures partenaires favorisant l'interdisciplinarité et les échanges scientifiques.

© UnivEarthS

- **Premiers résultats de Double Chooz** suggérant une valeur non nulle de θ13. L'APC (H. de Kerret porte-parole) et le CEA, ont joué un rôle-clé dans l'expérience.
- **Débuts du projet IGOSat.** Projet scientifique et pédagogique de nanosatellite principalement conçu par les étudiants dont le lancement est prévu en 2022.
- **Sélection par l'ESA du télescope spatial Euclid** pour étudier l'énergie noire. L'APC est impliqué dans le segment sol. Lancement en 2022.
- **Premiers résultats de Planck** sur le fond diffus cosmologique (CMB). L'APC contribue à l'analyse des données et à l'élaboration des cartes du CMB.
- **Publications de résultats scientifiques importants de INTEGRAL** observatoire spatial de rayons gamma lancé en 2002.
- **Sélection du projet d'observatoire spatial SVOM** dédié aux sursauts gamma. L'APC développe le modèle de vol du masque codé du télescope ECLAIRs (livré en 2021).
- **Première observation directe par Borexino** de neutrinos issus de la fusion primordiale entre deux protons au cœur du Soleil.
- **L'ESA sélectionne la mission ATHENA.** Projet d'observatoire à rayons X. L'APC prend en charge le développement de l'électronique de l'instrument X-IFU.

Le spectromètre X-IFU, (X-ray Integral Field Unit) instrument du futur télescope spatial Athena. © IRAP / ESA

2015

- **Première observation d'ondes gravitationnelles par les collaborations LIGO/Virgo.** Des membres de l'APC participent à l'analyse et à la rédaction de la publication .
- **Création par Pierre Binetruy du MOOC** « Gravité ! du Big Bang aux trous noirs » en collaboration avec George Smoot.
- **Lettre d'intention KM3NeT.** Observatoire de neutrinos de très haute énergie (successeur d'Antares). L'APC contribue notamment au sous détecteur ORCA.
- **Mission LISA adoptée par l'ESA** suite aux résultats de Lisa Pathfinder. L'APC est responsable du segment sol, des activités AIT/AIV."
- **Première détection multimessager d'un événement cosmique.** Une fusion d'étoiles à neutrons observée simultanément en ondes gravitationnelles, rayons gamma et neutrinos.
- **Publication des objectifs de CTA.** Successeur de H.E.S.S. pour la détection de rayons gamma d'origine cosmique. L'APC a participé à la rédaction de ce document.
- **H.E.S.S. publie le plus grand catalogue de sources gamma de très haute énergie de la Galaxie.**
- **DarkSide, meilleure limite d'exclusion** dans la recherche de matière noire de faible masse obtenue par le détecteur."

Le détecteur DarkSide-50 : la chambre à projection temporelle, remplie d'argon liquide, est entourée par un blindage actif de scintillateur liquide (dans la sphère). © Collaboration DarkSide

- **Livraison du changeur de filtres de l'Observatoire Vera-C.-Rubin** construit par des laboratoires de l'IN2P3. L'APC a développé le logiciel du changeur de filtres.

2020

- **Premiers résultats du démonstrateur technologique de l'instrument QUBIC** dont l'intégration a été effectuée à l'APC.

Institut national de physique nucléaire
et de physique des particules

Full publication record

The following record includes all publications contributed by the lab members over the period 2017-2021. This list has been produced using Inspire [215] with the query line [216].

The list contains 956 articles. We have indicated the ten most cited articles as of Dec 2021.

[215] https://inspirehep.net

[216] `jy 2017->2021 and affiliation:"APC, Paris" and (_collections:Literature or _collections:"HAL hidden") and tc p`

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Acronyms

AAIS Astronomie Astrophysique et Ingégnerie Spatiale.

ACAV+ Astrophysique et Conditions d'Apparition de la Vie.

ACS Anti Coincidence Shield of SPI.

AIM Astrophysics, Instrumentation, Modeling laboratory.

AIVT Assembly, Integration, Validation and Tests.

ANR Agence Nationale de la Recherche.

ANTARES Astronomy with a Neutrino Telescope and Abyss environmental RESearch.

APC Laboratoire Astroparticule et Cosmologie.

APD Avalanche photodiode.

APPEC AstroParticle Physics European Consortium.

ARCA Astroparticle Research with Cosmics in the Abyss.

ASIC Application-Specific Integrated Circuit.

ASN Autorité de sûreté nucléaire.

ASPERA AStroparticle Physics European Research Area network.

AstroCeNT Particle Astrophysics Science and Technology Center.

ATHENA Advanced Telescope for High Energy Astronomy.

ATLAS A Toroidal LHC Apparatus.

BIATSS Bibliothèques Ingénieurs Techniciens Administratifs Sociaux et de Santé.

C2N Centre de Nanosciences et de Nanotechnologies.

CAD Computer Aided Design.

CCIN2P3 Centre de Calcul de l'IN2P3.

CEA/Irfu Commissariat à l'Énergie Atomique et aux Énergies Alternatives, Institut de Recherche sur les Lois Fondamentales de l'Univers.

CERN Conseil européen pour la recherche nucléaire.

CFT Conformal Field Theory.

CHIME Canadian Hydrogen Intensity Mapping Experiment.

CMB Cosmic Microwave Background.

CMB-S4 Next-generation ground-based Cosmic Microwave Background experiment.

CMOS Complementary Metal-Oxide-Semiconductor.

CMZ Central Molecular Zone.

CNES Centre National d'Etudes Spatiales.

CNRS Centre National de la Recherche Scientifique.

CNSA China National Space Administration.

CNU Conseil National des Universités.

CODEEN COllaborative DEvelopment ENvironment.

CP Charge-Parity.

CPPM Centre de Physique des Particules de Marseille.

CSP Cellule de Suivi de Projets.

CTA Cherenkov Telescope Array.

DANTE Data ANalysis and compuTing Environment for science.

DDPC LISA's Distributed Data Processing Center.

DESI Dark Energy Spectroscopic Instrument.

DHOST Degenerate Higher-Order Scalar-Tensor.

DiiP Data Intelligence Institute of Paris.

DIM Domaine d'Intérêt Majeur.

DRIM Domaines de Recherche et d'Innovation Majeurs.

DUNE Deep Underground Neutrino Experiment.

EGO European Gravitational Observatory.

EPU Earth, Planets, Universe.

ERA-Net European Research Area Network.

ESA European Space Agency.

EU European Union.

EUSO Extreme Universe Space Observatory.

FACe François Arago Centre.

FCC Future Circular Collider.

FPGA Field Programmable Gate Array.

FRB Fast Radio Burst.

FRIF Fédération de Recherche sur les Intéractions Fondamentales.

FTE Full Time Equivalent.

GaGG Gadolinium Aluminium Gallium Garnet.

GANIL Grand Accélérateur National d'Ions Lourds.

GC Galactic Centre.

GCN Gamma-ray Coordination Network.

GdR Groupement de Recherche du CNRS.

GEPI Laboratoire Galaxies, Étoiles, Physique et Instrumentation.

GPS Global Positioning System.

GRB Gamma-Ray Burst.

GReCO Research team at IAP on GRavitation & COsmology.

GW Gravitational Wave.

GWOSC Gravitational-Wave Open-Science Center.

H.E.S.S. High-Energy Stereoscopic System.

HAWC High Altitude Water Cherenkov.

HEA High-Energy Astrophysics.

HEN High-Energy Neutrino.

HIRAX Hydrogen Intensity Real-time Analysis eXperiment.

IaaS Infrastructure-as-a-Service.

IACT Imaging Atmospheric Cherenkov Telescopes.

IBIS Imager on-Board the INTEGRAL Satellite.

IdEx Initiative d'Excellence.

IGOSat Ionospheric and Gamma-ray Observations SATellite.

IJCLab Irène Joliot Curie Lab.

ILANCE International Laboratory for Astrophysics, Neutrino and Cosmology Experiments.

IN2P3 Institut National de Physique Nucléaire et de Physique des Particules du CNRS.

INFN Istituto Nazionale della Fisica Nucleare.

INP Institut National de Physique (CNRS).

INSU Institut national des sciences de l'Univers (CNRS).

INTEGRAL INTErnational Gamma-Ray Astrophysics Laboratory.

IPGP Institut de Physique du Globe de Paris.

IPHC Institut Pluridisciplinaire Hubert Curien.

IRL International Research Lab.

IRN International Research Network.

IRP International Research Project.

IRSN Institut de Radioprotection et de Sûreté Nucléaire.

ISDC INTEGRAL Science Data Centre.

ISGRI Integral Soft Gamma-Ray Imager.

ISS International Space Station.

ITA At CNRS: Ingénieurs Techniciens Administratifs.

JAXA Japan aerospace exploration agency.

JUNO Jiangmen Underground Neutrino Observatory.

KIDs Kinetic Inductance Detectors.

KIPAC Kavli Institute for Particle Astrophysics and Cosmology.

KM3NeT Cubic Kilometre Neutrino Telescope.

LabEx Laboratoire d'Excellence.

LAM Laboratoire d'Astrophysique de Marseille.

LDC LISA Data Challenge.

LERMA Laboratoire d'Etudes du Rayonnement et de la Matière en Astrophysique et Atmosphères.

LESIA Laboratoire d'Etudes Spatiales et d'Instrumentation en Astrophysique.

LHAASO Large High Altitud Air Shower Observatory.

LHC Large Hadron Collider.

LIA Laboratoire international associé.

LIGO Laser Interferometer Gravitational-wave Observatory.

LISA Laser Interferometer Space Antenna.

LiteBIRD Lite (Light) satellite for the studies of B-mode polarization and Inflation from cosmic background Radiation Detection.

LPENS Laboratoire de Physique de l'Ecole Normale Supérieure.

LPNHE Laboratoire de Physique Nucléaire et de Hautes Énergies.

LPSC Laboratoire de Physique Subatomique et Cosmologie.

LPTHE Laboratoire de Physique Théorique des Hautes Energies.

LSST Legacy Survey of Space and Time.

LUTH Laboratoire Univers et THéories.

MAGIC Major Atmospheric Gamma Imaging Cherenkov Telescopes.

MAPMT Multi-anode photomultiplier tubes.

MHD Magneto-Hydro Dynamics.

MMO Multi-Messenger Observatory.

MMODA Multi-Messenger Online Data Analysis.

MOOC Massive Open Online Course.

NASA National Aeronautics and Space Administration.

NCAC Nicolaus Copernicus Astronomical Center.

NPAC Master Noyaux Particules Astroparticules Cosmologie.

ONERA Office National d'Etudes et de Recherches Aérospatiales.

ORCA Oscillation Research with Cosmics in the Abyss.

PCB Printed Circuit Board.

PCCP Paris Center for Cosmological Physics.

PMT Photo-Multiplier Tube.

QCD Quantum Chromo-Dynamics.

QFT Quantum Field Theory.

QUBIC Q & U Bolometric Interferometer for Cosmology.

RFPU Fonds de dotation pour la Recherche et la Formation dans le domaine de la Physique de l'Univers.

RG Renormalization Group.

RISE Research and Innovation Staff Exchange.

SGR Soft Gamma Repeater.

SiPM Silicon PhotoMultiplier.

SKA Square-Kilometer Array.

SMBH Supermassive black hole.

SO Simons Observatory.

SPI SPectrometer of INTEGRAL.

SQUID Superconducting Quantum Interference Device.

STEP'UP Sciences de la Terre, de l'Environnement et Physique de l'Univers (Doctoral school # 560).

SURF Sanford Underground Research Facility.

SVOM Space-based multi-band astronomical Variable Objects Monitor.

SYRTE Laboratoire Systèmes de Référence Temps-Espace.

TARANIS Observation microsatellite for the study of transient events in the Earth's atmosphere.

TES Transition-Edge Sensor.

TGF Terrestrial Gamma-ray Flashes.

TGIR Très Grande Infrastructure de Recherche.

TPC Time Projection Chamber.

TRL Technology Readiness Level.

UHECR Ultra High-Energy Cosmic Ray.

UMR Unité Mixte de Recherche.

USN Unité Scientifique de Nançay.

VERITAS Very Energetic Radiation Imaging Telescope Array System.

VHE Very High-Energy.

Virgo Gravitational-wave detector located in Italy.

WFEE Warm Front-End Equipment.

WFI Wide Field Imager.

WIMPS Weakly Interacting Massive Particles.

X-IFU X-ray Integral Field Unit.

XGRE X-Gamma-Ray and Relativistic Electrons.

YAG Yttrium Aluminum Garnet.

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