Presentation of the Einstein Telescope project

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Summary

Einstein Telescope is the European underground research infrastructure project to host a third-generation gravitational wave observatory by the end of the 2030s. It builds on the success of the second-generation laser interferometric detectors, Advanced Virgo and Advanced LIGO, whose discoveries of black hole and neutron star mergers have revolutionized our knowledge of the Universe and our way of studying the Universe. Einstein Telescope will improve sensitivity by increasing the size of the interferometer with 10 km long arms, compared to 3 km for Virgo, and by implementing a whole series of new technologies currently in development. This document has been prepared by the members of ET-France who have officially joined the Einstein Telescope international collaboration which has recently been created. It describes the on-going developments of the Einstein Telescope project, the French contributions to date and those envisaged in the years to come. Particular attention is given to the articulation between second- and third-generation projects.

1. Scientific context

The Einstein Telescope (ET) is a planned European third-generation Gravitational Wave (GW) Observatory, a new research infrastructure designed to observe the entire Universe using GWs. The ET conceptual design is aiming for a multi-interferometer observatory allowing the detection from Earth of GW in the frequency range from 3 Hz to several kHz.

In 2015, a new observational window was opened on the Universe with the detection of GWs from the binary black hole (BBH) merger GW150914. Since then, three very successful observational campaigns have been concluded by the Advanced Virgo - Advanced LIGO interferometers. After the 03 run, the total number of GW detections now stands at 90. And at the end of May 2023, the O4 began, and will run until the end of 2024, with the expectation of multiple events per week.

While a number of very interesting and theoretically challenging events have been observed, the crown jewel is still the binary neutron star (BNS) merger GW170817. The detection of GW170817 provided the possibility of a full multi-band analysis which had an immense effect on the scientific community: the two second delay between the arrival of the GWs and gamma rays detected by Fermi ruled out a large number of alternative theories of gravity and confirmed that GWs travel at the speed of light; the combined redshift - luminosity distance measurements permitted a new way of estimating Hubble's constant; observation of the associated kilonova suggests that the dominant source of heavy element production may actually be BNS mergers and not supernova as previously thought; finally, combining GW and electromagnetic (EM) data allowed us to put constraints on the nuclear equation of state (EOS) for neutron stars.

By 2030, the current 2G ground-based detectors LIGO and Virgo will have reached optimal design configuration and will have a redshift detection range of almost $z = 2$. This is an important point in the evolution of the universe as it is expected that this is where the peak of the star formation rate lies. While reaching this distance is the optimum goal of the 2G detectors, it also represents the limit of their infrastructure and ability to explore the GW Universe. In contrast, the expected reach of ET is approximately $z = 100$. This corresponds to a few tens of millions of years after the Big Bang and right at the point of structure formation in the Universe. The ability to probe this deep into the Universe would allow us to test the existence of primordial black holes and cosmic strings in the early Universe, track stellar evolution across cosmic time, resolve the population of compact objects in the Universe and potentially discover unknown/unpredicted sources of GWs.

In Europe, the innovative concept ET was initially developed within the framework of the FP6 and FP7 programs, which made it possible to carry out a "conceptual design study" published in 2011 [1]. In 2020, a consortium of five European countries (Belgium, Italy, Netherlands, Poland and Spain) led by INFN and Nikhef, and supported by a larger group of funding agencies and laboratories, including CNRS-IN2P3, have presented the application of ET to enter as a project in the ESFRI roadmap. A design report update [2] has been produced to support this application, which was finally successful (c.f. the ESFRI 2021 roadmap [3]). This success has generated great enthusiasm in Europe, and a significant number of teams of scientists and engineers have joined the ET project to officially form the "ET Collaboration" during a founding workshop which took place in June 2022 in Budapest. The ET collaboration now has just over 1400 collaborators, mainly Europeans, from 207 laboratories in 22 countries. In parallel, the Project Directorate lead by INFN and Nikhef has been setup to define and prepare the future Research Infrastructure, now called the "ET Organization" (ETO).

While ET on its own will be capable to making incredible discoveries, it's true potential lies as part of a network with other facilities that will exist in the 2030s+. As well as a potential second GW interferometer in the US (Cosmic Explorer), there will be a number of tier 1 neutrino (DUNE, Hyper-Kamiokande, KM3NeT, IceCube) and EM facilities on Earth and in space (CTA, SKA, Vera Rubin

Observatory, ELT, Athena). The current prediction is that ET will observe between 10-100 BNS mergers per year with EM counterparts. This will result in the most precise multi-messenger studies in the history of science.

The detection of GWs to study the Universe is and will remain in the coming decades a major and strategic element of the scientific program led by IN2P3 in the field of astroparticles. Participating in the development of a third-generation GW detector based on the French expertise and facilities acquired on Virgo has been clearly identified as a priority project in the Strategic Plan for French Nuclear, Particle and Astroparticle Physics recently published [4].

2. The Einstein Telescope project

2.1. Presentation

ET will be based on the same basic concept demonstrated in the framework of LIGO and Virgo: a modified Michelson interferometer, with Fabry-Perot cavities in the arms and the techniques of power recycling and signal recycling. However, ET's ambitious sensitivity target, in particular at low frequencies (sensitivity down to about 3 Hz compared to 10 Hz for Virgo), is based on several technology innovations. – In its initial design, the specificities of the ET concept are:

- *Triangle* – ET is composed of three nested detectors in a configuration of an equilateral triangle, pair-wise sharing a 10 km long tunnel. With a minimum of tunnelling, this configuration was defined to enable ET to resolve the GW polarization, provide a null stream and allow for continuous operation during maintenance.
- *10 km* – The ET detectors will have 10 km long arms, to increase the signal produced by the GWs. This change will provide a factor of about three improvements compared to Virgo (with 3 km long arms) with respect to virtually all of the sensitivity-limiting noises.
- *Xylophone* – Each of the three ET detectors will be composed of a pair of complementary interferometers, one with a peak sensitivity at low frequencies and the other with a sensitivity optimized for higher frequencies. The reason is to separate the challenges related to the use of high power stored in the arms (needed to reduce the photon shot noise) such as thermal and radiation pressure effects, from those related to achieving the targeted low-frequency sensitivity (limited by Brownian noise, quantum back-action noise and radiation pressure driven control noise). The low-power detector (ET-LF), operating at a temperature of 10-20 K, will be optimized for low frequency gravitational wave sources and the high-power detector (ET-HF), operating at room temperature, will work at high frequencies.
- *Underground operation* – In order to reduce the impact of seismic noise and gravity gradient noise induced by seismic waves and compression waves of the surrounding air, ET will be built underground. The underground operation will allow to extend the frequency band of the observatory down to a few Hz. The three 10 km long tunnels, each having an inner diameter of 6.5 m and containing 4 vacuum pipes, and the caverns containing the large vacuum tanks, will be excavated using well-established tunneling and underground excavation techniques. Besides the main caverns at the vertices of the triangle, several auxiliary caverns will host further interferometer components.

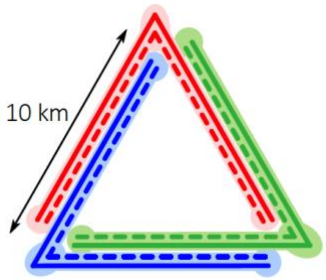

Figure 1: Initial design of ET: a triangular geometry with three nested detectors, each consisting of two interferometers.

Since 2022, a process called "Cost Benefit Analysis" is in progress to study in more details scientific, technological and logistical aspects of the design of ET and examine the impact on changing the reference design in triangle. A detailed evaluation of the science case for a single triangular geometry observatory is especially compared with a network of two L-shaped detectors (either parallel or misaligned) located in Europe, considering different choices of arm-length for both the triangle and the 2L geometries. This process is currently in progress.

2.2. Site candidates

One of the consequences of the extension of the observation band towards lower frequencies is that environmental disturbances and therefore the quality of the observatory location play an increasingly important role. A strong reduction of environmental noise is achieved by placing the detectors in an underground location, provided that a suitable site is chosen. The key evaluation criteria for the site selection for the Einstein Telescope include: impact on infrastructure lifetime, observatory sensitivity, observatory operation and duty cycle, site-quality preservation, construction cost, and socio-economic impact of the observatory.

Two candidate sites have been identified for a detailed site-characterization: one in the north of Lula in Sardinia, and one in the Meuse-Rhine Euroregion. Characterization of these two sites is in progress with dedicated budget obtained in Italy and in the Netherlands. In 2022, Germany decided the creation of a new laboratory, the DZA Centre for Astrophysics, which will feature facilities to develop and test ET technologies. With a staggered schedule compared to the others, this could eventually lead to a German proposal for hosting ET on this site.

2.3. Organization

Since 2022, the structuring of the ET project is progressing on two fronts: within the newly created international collaboration Einstein Telescope and around the Project Directorate in charge of defining and preparing the creation of the Research Infrastructure, the Einstein Telescope Organization.

ET Collaboration – officialized in June 2022, the Collaboration Board with representatives from the 81 Research Units has elected the first ET spokesperson, M. Punturo, in March 2023. The collaboration is organized in four Boards, the Instrument Science Board (ISB), the Observational Science Board (OSB), the e-Infrastructure Board (EIB), and the Site Preparation Board (SPB), which are further divided into working groups called "Divisions". With one co-chair of the OSB and one co-chair of the EIB, 2 scientists from ET-France are therefore ex-officio members of the Executive Board. French scientists are also co-chairing Divisions, two in the ISB (Optics and Interferometer and six in the OSB (Multimessenger observations, Synergies with other GW observatories, Nuclear Physics, Stellar collapse and isolated neutron stars, Waveforms, Data analysis platform). France is not contributing so far to the SPB.

ET Observatory (or Organization) – The organization of ETO is coordinated by funding agencies of the two countries having a site candidate for ET, INFN in Italy and Nikhef in the Netherlands. the governance model (c.f. Figure 1 left) envisaged is quite common for a research infrastructure, with a project directorate, the "Board of Governing Representatives" (to prepare a future "Council") with representatives from the ministries of the participating countries, a "Board of Scientific

Representatives" with representatives from the funding agencies. IN2P3 management is representing France in the BSR. CNRS contribution to ETO is described in Section 3.3.

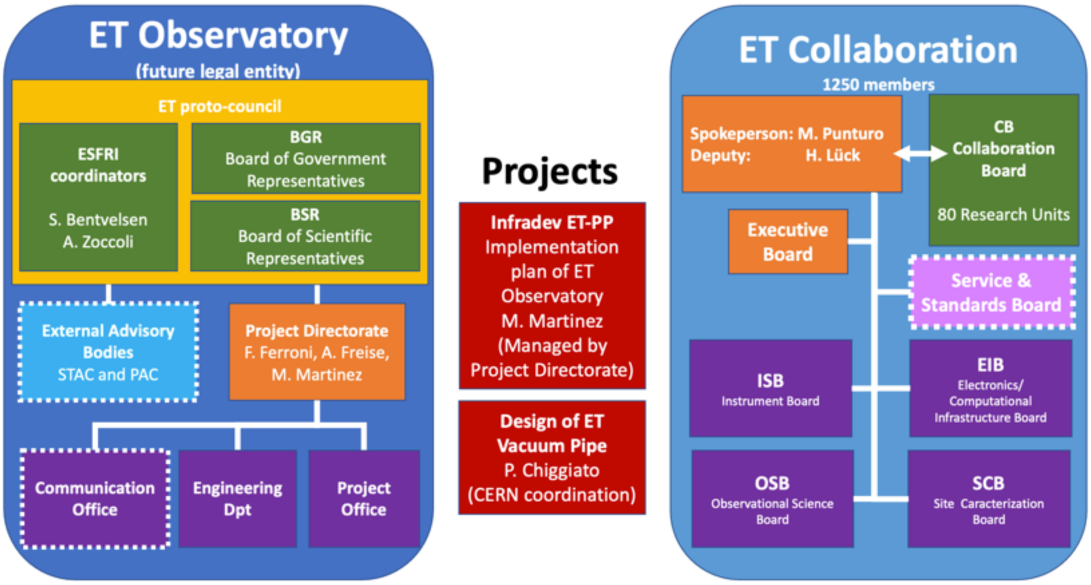

Figure 2 : Overview of the organization of the ET Observatory and ET Collaboration.

2.4. Schedule

The schedule of ET (c.f. Figure [3]) as presented, after the ESFRI proposal was accepted, indicates a preparatory phase of four years (2022-2026) in order to deliver all documentation materials needed for the implementation of the ET RI. The site decision would be taken at the end of this period in 2025-2026. The construction of the ET RI, which includes the excavation of long tunnels and large caverns, the construction of new buildings, and the construction of the first interferometer elements would start in 2026 and will last for about 10 years. In this very optimistic scenario, data taking would start in 2035. The Einstein Telescope RI will be in operation for a period of 50 years. It is designed to accommodate in the future several technology upgrades.

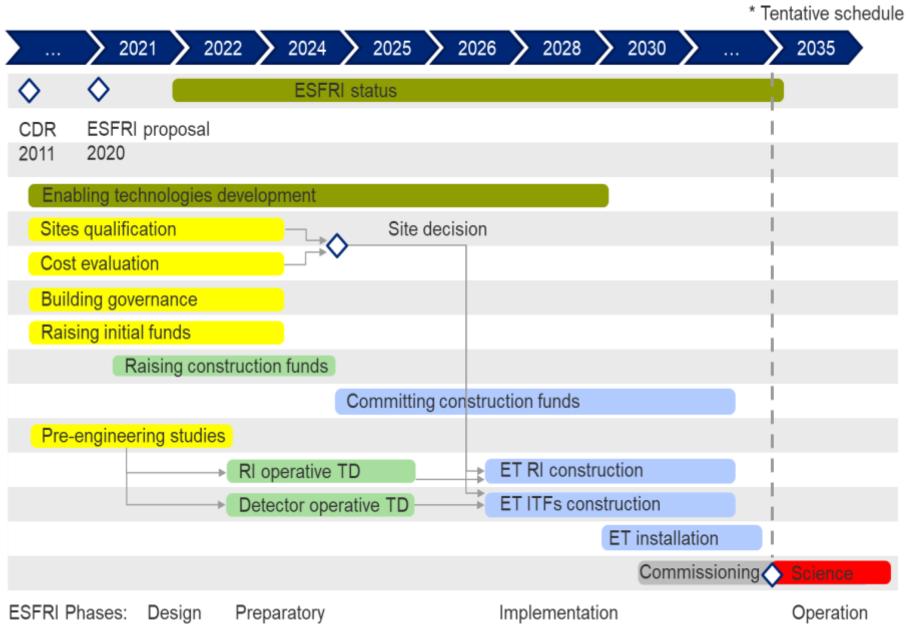

Figure 3 : Schedule of the ET Project (in date of July 3rd, 2023).

2.5. International context

LIGO, Virgo and Kagra are currently in operation and the O4 data-taking run just started in May 2023. Between O4 and O5, the Virgo and LIGO upgrades (AdV+ phase 2 for Virgo) will be completed enabling these experiments to run for 2 years (until 2029) at their nominal performance. In order to push these infrastructures to their ultimate limit in sensitivity, the collaborations are planning a final upgrade in 2029-2032, called LIGO A# and Virgo_nEXT, which would allow to start a 06 run in 2032. In parallel, it is very likely that Japan will launch an upgrade program for Kagra during this period. Finally, it is planned that LIGO India would become operational around 2030. This international program for ground-based GW detection is aiming to optimized science return until 3rd generation GW interferometers become fully operational in the second half of the 2030's.

Einstein Telescope in Europe and Cosmic Explorer (CE) [6] in the US are these 3rd generation projects for ground-based GW detection. The design concept of CE features two surface facilities, one with arms 40 km long and one with arms 20 km long, each housing a single L-shaped detector. CE would start taking data at the end of the 2030's.

3. French contribution to Einstein Telescope

3.1. Science with Einstein Telescope

Given the broad-band frequency range of ET, the number of science objectives are broad and varied [7]. Below, a short description of the primary science goals are presented.

Compact Binary Coalescences (CBC) – The ET data set will be dominated by the inspiral and merger of compact binary systems composed of black holes, neutron stars and mixed black hole - neutron stars (NSBH). Given the latest population models and rate estimates from the third LIGO-Virgo-KAGRA (LVK) observing campaign (O3), it is expected that ET will observe approximately 10^6 BBHs, 10^5 BNSs and 10^4 NSBHs per year at design sensitivity. Assuming the event rates are correct, this would allow us to resolve almost the entire population of binary black holes and around 80% of the population of binary neutron star in the universe. These observations would place the strictest constraints possible on stellar evolution and population models across cosmic time.
As well as stellar mass black holes, the low frequency performance should also allow us to search for intermediate mass black holes. These will either be composed of comparable mass binaries in dense stellar clusters, or in some cases, the so-called intermediate mass ratio inspirals where a stellar mass object coalesces with an intermediate mass black hole. Given the long duration of the inspiral, these latter sources will allow us to map the space-time around the black hole, testing GR and the "Kerr-ness" of the black hole.
While BBHs will account for the majority of detections, ET expects to observe around 10^5 BNSs per year, of which it is predicted that between 10-100 will have EM counterparts. With a much higher number of events, and the opportunity of resolving the post-merger remnant, it is possible that ET will break the Hubble constant tension, constrain nuclear physics in a way not possible in a terrestrial laboratory and further constrain alternative theories of gravity. Given the expected low frequency performance of ET, tracking the BNS inspiral over many hours will not only provide potential pre-merger alerts to the EM community, but will also allow us to test deviations from GR, while the high frequency ET sensitivity should allow us to resolve the post-merger remnant of BNS and NSBH events

Stochastic Background — The goal of research into the GW stochastic background is to estimate the energy density of GWs in the universe, Ω_{GW}, and can be divided into two potential sources. The background from cosmological sources will be a superposition of GWs from cosmic strings, primordial black hole mergers and first-order phase transitions in the early Universe. These tensor modes will be represented as a continuous emission of GWs.

On the other hand, the astrophysical background will be more of a “pop-corn” noise from unresolvable Population I and II stars in the local universe and Population III stars in the distant universe. While the Pop-I and -II stars will most likely still be in a phase of inspiral, it is expected that the Pop-III stars will be undergoing late inspiral and merger in the ET band. At different parts of the ET frequency band, the astrophysical background can be further decomposed into contributions from the Pop-III stars, BBH formation channels combined with star formation history and the residual BNS background.

Fundamental Physics — The main GW analysis technique is based on the method of matched filtering, where one phase matches a theoretical waveform model with the data. At present, all of our waveform models are based on the assumption that General Relativity (GR) is correct, and that the BHs observed in the Universe are described by the Kerr metric. Given the predicted sensitivity of ET, and given the expected long duration of GW signals, it will be possible to track the phase evolution of the signals over an incredibly large number of GW cycles. This will allow us to look for deviations from GR, test the no-hair theorem, and look for echoes and other near-horizon structures with unprecedented precision.

Cosmology – One of the most exciting results from the observation of GW170817 was the ability to make a third independent estimate of Hubble’s constant, without an observation of the CMB, a cosmic distance ladder or an assumption on the cosmology of the universe. This can be done in one of two ways: the first, and easiest, would be a joint GW-EM detection where the luminosity distance to the source is estimated from the GWs and the redshift is obtained from the EM observations. The second, and less precise, is to use the GW observations and information from EM catalogs. Also, by using joint GW-EM observations, it is possible to set constraints on dark energy for some models by estimating the present matter fraction Ω_M.

Nuclear Physics – One of the primary targets for ET is to use both binary and isolated NSs as an astrophysical laboratory and explore nuclear physics in a way not possible in terrestrial labs. Due to the long duration of BNS signals, the goal is to use the low frequency inspiral to estimate the tidal deformation of the two NSs, while observation of the post-merger remnant will provide further information on the nuclear EOS. This is possible as the post-merger signal will allow us to determine if the two NSs immediately collapsed to form a BH, if they formed a hypermassive or supramassive NS that eventually collapses to a BH, or even a stable NS. All of these scenarios have different GW signatures, and provide valuable information on the EOS. Furthermore, with precise EOS measurements, it will be possible to constrain the mass-radius relation for NSs.

Continuous and transient GW sources – A major missing component from current GW astronomy is a detection from an isolated source, such as a single pulsar or a supernova. Both of these sources are additional, and potentially cleaner, methods of estimating the EOS for NSs. The GW signal from a supernova would also constrain a lot of the physics of the stellar collapse and the nature of the post-collapse remnant. In theory, it is also possible to put some constraints on dark matter using exotic signals such as clouds of boson stars around BHs.

Multimessenger astronomy – The multiband, multispectrum analysis of GW170817 demonstrated the capabilities of multimessenger astronomy. Given the potential number of events with EM counterparts in the ET era, the opportunity exists to solve some of the most outstanding issues in stellar evolution, formation structure and nucleosynthesis.

Future Challenges for ET Science – While the science potential of ET is enormous, so too are the challenges to be faced. As with any new interferometer, there will be new unseen families of instrumental glitches and other artefacts that will contaminate the data set. This will require precise and advanced detector characterization and calibration methods.

Once the data is cleaned, the data set will be dominated by a very large number of long-duration and overlapping signals (this will be different from the LISA data problem where the data will be dominated by white dwarf binaries in our galaxy which are quasi-monochromatic in frequency, with the occasional broad-band transient passing through the data). At present, the techniques needed to disentangle the sources and ensure the proper science extraction do not exist, and will potentially require advanced algorithms based on machine learning, AI, etc.

A final challenge is the precision of current gravitational waveforms and numerical relativity simulations. Models are based on GR and have systematic errors that are smaller than current parameter estimation abilities. However, the state-of-the-art waveforms and numerical simulations are not precise enough for ET data analysis and will require considerable improvement in the future.

Position and Capability of the French Scientific Community – The French community is currently very strongly represented in the governance of ET science. As well as co-chair of the ET Observation Science Board (OSB), of the ten internal OSB science divisions, six have French researchers as co-chairs. This already puts the French community in a crucial position regarding the direction and prioritization of ET science.

Due to the diversity of the French community, French scientists are in a strong position to tackle all of the potential challenges and aspects of ET science. While many other international groups are making their first foray into the world of GWs, most of the current French ET community are also active members of the LVK. This ensures both a parallel development of methods and algorithms for the LVK and ET, and more importantly, the ability of overcome potential hurdles in real time analysis of LVK data. French ET members are actively participating in the "GDR Ondes Gravitationnelles", which provides scientific interaction between all scientists interested in this scientific domain, strengthens the collaboration between experiences and theory, and provides a great national forum especially for young scientists.

3.2. Design of Einstein Telescope

The Einstein Telescope will be a new gravitational wave observatory with a unique design. It will combine the proven concepts from current detectors LIGO and Virgo with new technologies such as cryogenic mirrors. Detailed description of current ET's design can be found in [3] while the following paragraphs highlight current and foreseen involvements from CNRS teams.

Interferometer design and simulation – The xylophone strategy of ET, i.e., splitting each detector into a low-frequency and a high-frequency interferometer, allows the pursuit of different strategies in optimizing the noise for each frequency range. French teams are deeply involved in the design of the layout of the interferometers, which require developments and continuous updating of noise budgets, including both, the ET-LF and ET-HF detectors with theoretical noise curves. This is a major deliverable at the interface between the instrument and the science case definition. French teams also have key expertise in the development of optical simulation codes and they are involved in the design of the optical systems of the interferometer such as the core optics (substrates and coatings for the large optics) and the input and output optics (optical systems taking care of the injection of of the detection of the laser beams).

Optics and Mirrors – The ET-HF interferometer will use fused silica mirrors and suspensions, as used in Virgo and LIGO. And the ET-LF interferometer will use ultra-pure crystalline substrate, silicon or sapphire. The KAGRA detector is currently using sapphire, providing a valuable in-situ test of the use of this material in a GW cryogenic detector. These substrates must have exceptional size properties (450 mm in diameter for a weight of 200 kg) as well as extremely low optical losses (absorption, diffusion or birefringence). Currently, neither silicon nor sapphire have been able to demonstrate the required properties.

Research on sapphire for GW began in Lyon (iLM and LMA) about four years ago with the first joint funding where iLM takes care of the crystal growth and the LMA of the optical characterization and checks the adequacy with the requirements of the project. The goal of this R&D, which is just starting, is to design and produce a prototype with integrated suspensions, also in sapphire. An activity on optical polishing is also starting in order to be able to master the entire production chain of a high-performance and large mirror in the long term.

Readout electronics, data acquisition, timing and control system – IN2P3 Labs LAPP and IPHC have strong responsibilities and commitments in the electronics and real time software developed for Virgo. In the continuity of the upgrade proposal for Virgo_nEXT, these developments and expertise will also benefit to ET. R&D for ET to further improve the entire readout chain will require improved analog and digital electronics with lower noise. Dedicated electronic boards and software for the data acquisition and control systems will have to be developed, including ADCs, DACs and real-time data treatment.

R&D on mirror coatings – The thermal noise of thin layers of mirrors limits the sensitivity of current (LIGO, Virgo, KAGRA) and future (ET, CE) GW interferometric detectors and will soon be the most limiting factor for the field of gravitational astronomy. The development of thin films with low thermal noise would increase the distance and the event observation rate of the detectors. Since 2002, an intense research activity on the thermal noise of thin films has been underway, and the worldwide competition is very strong in this field of research. Within the Virgo Collaboration, this activity is led by a collaboration of French, Italian, Japanese and Dutch laboratories co-managed by the LMA. The LMA has produced and characterized the very high-reflection thin films of all current GW detectors and is currently the only platform capable of manufacturing this type of device. A challenging R&D program is conducted at LMA on amorphous materials (current coatings are SiO_2 with titania and tantala). In the preparation of Virgo_nEXT and ET, new materials aiming at a thermal noise reduction factor of 3 to 4 are being and will be tested (nitrides, amorphous semi-conductors, oxide mixtures such as Geo2-TiO2, SiO2-TiO2 and HfO2-Ta2O5). This strategy is supported by the project to extend the LMA which includes a new coater able to handle very large mirror substrates. In parallel, crystalline coatings have shown promising performances to reduce the thermal noise. A full R&D program has to be put in place at IN2P3 to develop this technology for GW physics, with the labs who master the development of crystalline coatings (and which are currently not involved in GW physics) and with the industrial sector.

High power and stabilized laser – While the cryogenic ET-LF will require new materials for the mirror substrates and therefore to move to a longer laser wavelength of 1550nm, ET-HF will be operated at room temperature, use fused silica optics, and have a laser at a wavelength of 1064 nm able to deliver 700W. At high frequency, GW detectors are limited by the shot noise resulting from the coupling of the carrier of the injected beam and the sidebands of the vacuum field. Hence, the shot noise level scales like the square root of the injected power. Therefore, improving the detector sensitivity at high frequency, among other possibilities, goes through the increase of the injected power. However, increasing the intracavity power shall enhance thermal effects and parametric instabilities related issues within the cavity. ARTEMIS is conducting R&D on high-power and stabilized lasers based on fiber technology for Virgo_nEXT and ET. This development is done in collaboration with LP2N and an industrial partner, Azur Light Systems.

Light Squeezing – Virgo and LIGO detectors have recently been upgraded with *squeezed light* which generates correlations between the phase and the amplitude quadrature. In the shot noise dominated frequency range, squeezed light is used which shows lower phase fluctuations (at the cost of the amplitude fluctuations) in comparison to classical laser light in the interferometer arms. In the low-frequency, radiation pressure dominated range the fluctuations need to be lowered in the amplitude quadrature, providing the right spectral dependence of the so-called *squeezing angle* can be achieved by reflecting squeezed light off a filter cavity. For ET, 15 dB initial squeezing level at the squeezing source

and an effective squeezing level of 10 dB to be available are assumed (equivalent to a shot noise reduction from a laser power increase by a factor of 10).
The squeezing level, and with it the sensitivity improvement that can be reached, depends on the optical losses in the squeezer, the filtering optics, the interferometer, and all optical devices on the way to the photodetector, including the photodetector efficiency itself. It will therefore be essential to keep the optical losses as low as possible. These levels of squeezing, and maintaining the low losses to preserve the squeezing, require technology developments in which French labs are key deeply involved (APC, IJCLab, LKB).

Vacuum system – The vacuum system for ET's arms will be one of the most challenging ever built. The cost of the vacuum system would be about 500 M€ if the same technology as for Virgo were to be used, and it represents a significant fraction of the total cost of the RI. Therefore, robust development is required to find the best compromise between cost and performance; for that purpose, material selection, manufacturing techniques and pumping technologies are being investigated in close collaboration with the European industry and the collaborating institutes. An agreement has been signed between INFN, Nikhef and CERN (for 3 years) such that the CERN vacuum department manages the design of the vacuum tube (aiming at reducing drastically the cost) and in order to produce the corresponding TDR. French laboratories who designed and built the Virgo vacuum system, IJCLab and LAPP, are involved and providing critical elements and expertise in this project. Contact with French industries is currently in progress.

e-Infrastructure – Within EIB and WP8 of ET-PP (c.f. section 3.3), CNRS labs are involved in the definition of the computing model and of the data access of ET, including: the definition of the workflow, the estimation of the required resources, the design of the online Tier-0 data center, and the clarification of the policy for the storage and the access to the ET data on all relevant time scales, respecting the EU policies on open data. Globally, the work relies on existing efforts in the ET Collaboration and other astroparticle and HEP experiments. These efforts rely also on the presence of experts from large computing centers with long experience on massive computing demanding challenges, and CC-IN2P3 is involved in these developments.

3.3. Toward the Einstein Telescope Organization

The entry of ET on the ESFRI roadmap has allowed to submit a proposal to an EU call supporting definition for future implementation of a new research infrastructure. This project, called “Einstein Telescope Preparatory Phase” (ET-PP) [8] was selected and funded for four years (2022-2026). The main objective of ET-PP is to support crucial items in the preparatory phase of the experiment, including: the enlargement of the ET consortium, the legal framework, governance schemes, and financial regulations under which the ET Research Infrastructure, now called “ET Organization (ETO)”, will be constructed and operated; the technical design and costing of the ET observatory; the preparation of the site selection, where ET will be deployed, detailing and cost-estimation of the required site infrastructure, and its socio-economic and environmental impacts; the schemes for technology transfer, procurement and industry involvement in the technical design and construction of ET; and the required linking with relevant science communities regarding the detailed definition of the science program, and the user services and data access model.

The CNRS is one of the main partners of ET-PP, with in-kind contributions in manpower from IN2P3 Labs, APC, IJCLab, IP2I and LAPP (273 persons.months, i.e., 1.9 M€) complemented by 0.9 M€ obtained from EU to hire three engineers with temporary positions during the time of the project. This contribution was setup to optimize the impact of French teams, and it was decided to focus the effort on the creation of ET Project Office (see below). The total budget from EU is 3.45M€ with in-kind contribution from participants and third parties of about 10.55M€, for a total estimated cost of the ET-PP project of 14 M€. ET-PP is organized in ten work-packages (WP), which are: WP1 - Management and

Coordination, WP2 - ET Organization, Governance and Legal Aspects, WP3 - Financial Architecture, WP4 - Site Preparation, WP5 - Project Office and Engineering Department, WP6 - Technical Design, WP7 – Innovation and Industrial engagement, WP8 – Computing and Data Access, WP9 - Sustainable Development Strategy, WP10 - Education, Outreach and Citizen Engagement. Among those ten work-packages, those in which CNRS is particularly involved are shortly described:

- *WP5 (Led by CNRS): Project Office and Engineering Department*

One of the main missions of ET-PP is the creation and consolidation of the ET Project Office and the corresponding Engineering Department. A significant fraction of the ET-PP funds (about 43%) are devoted to this mission. Holding to the primary constraints which are the scope, the schedule, and the budget, the role of the Project Office is to guarantee, that the as built RI - comprising infrastructure, technical systems and the interferometer itself - fully complies with the requirements, the parameters, the layout detailed in the TDR without having undergone changes which were not endorsed by the stakeholders. While the requirements, the parameters, the layout of the interferometer are set by the collaboration in charge of the GW observatory, the infrastructure and technical systems associated with the interferometer are designed, procured, installed, commissioned, maintained and eventually dismantled by an Engineering Department yet to be created.

- *WP6 (Led by INFN): Technical Design*

ET-PP will provide a refined TDR of ET including both the infrastructure and the experiment together with updated cost estimates. This work is developed to a large extent within the ET Collaboration, and is counting with the assistance of experts on civil engineering, vacuum, cryogenics and infrastructure services in the ET Project Office. This WP includes in particular the design of the vacuum system for ET's arms which will be one of the most challenging ever built for research facilities. This developments currently led by CERN with major IN2P3 contributions, includes detailed information on the proposed technologies, planning and tunnel integration, and budget, and is being investigated in close collaboration with European industries and the collaborating institutes.

- *WP8 (Led by BSC): Computing and Data Access*

The development of a valid computing and data access model is an objective of ET-PP. It requires close cooperation with ISB, OSB and EIB of the ET Collaboration to define the workflow from the instrument to the publication. A geographically distributed model of resources is foreseen as the only way to match the computing needs of the experiment over its lifetime. A powerful T0 on-site computing center will receive the data taken by the experiment. The model will define the services provided by the center, and the delimitation against services realized with distributed computing. The development of the model is intimately linked to a proper estimate of the computing resources (computing power and data storage), the personnel, and the operational cost required for all aspects of ET computing, where the potential for mitigation must be addressed. Similarly, the ET computing solutions must include those aspects related to the sustainability and energy efficiency of the model. Moreover, ET-PP will develop a policy on the storage, curation, preservation of the data and the access to the data, following all the EU open data standards.

- *WP9 (Led by EGO): Sustainable Development Strategy*

Sustainable Development Strategy focuses on those crucial aspects necessary for the design of a sustainable RI, minimizing the landscape and environmental impacts. This includes, for example, strategies for low carbon footprint, low energy consumption, sustainable reuse of excavation materials and a smart model for transportation.

3.4. Organization in France

When setting up the ET collaboration in 2022, the laboratories were invited to group together in "Research Units" in order to exceed a threshold in FTE allowing them to have one voting-voice within the Collaboration Board. The eight research Units in France are listed in Table 1. On the institutional aspects, IN2P3 is representing CNRS in the Board of Scientific Representatives (BSR) of ETO. And France has one representative in the "Board of National Representatives" of the ET collaboration.

In term of project organization at IN2P3, ET is kept as a subproject (since 2023) of the Virgo Master-Project in order to maximize synergies between Virgo and ET.

Research Unit (RU)	**Laboratories**
Artemis	ARTEMIS
Astroparticule et Cosmologie (APC)	APC
	IAS
IF-ILM	IF
	ILM
	MSME
IJCLab	IJCLab
	LKB Paris
IP2I - LMA	IP2I Lyon - IN2P3
	LMA - IN2P3
IPHC-L2IT	IPHC
	L2IT
LAPP	LAPP
Paris - Caen	Observatoire de Paris (GEPI, LUTH, SYRTE)
	GANIL / LPC Caen
	IAP

Table 1: List of the French Research Units and laboratories, which are members of the ET Collaboration (in date of July 3rd, 2023).

4. Synergies with Virgo

Contributions from CNRS laboratories to ET design and to the development of the required technologies are mainly driven by the current involvement and the expertise acquired in Virgo. Especially, the Virgo_nEXT project will be a major asset to develop and test the technologies needed for ET-HF, thus reducing the associated risk (Ex.: mirror coatings, high power lasers, squeezing sources).

However, ET also has specificities compared to 2G detectors which require a dedicated and vibrant R&D program. It is particularly true for ET-LF which require the development of cryogenic optics, new substrates with monolithic suspensions in silicon or sapphire, lasers at 1550nm, improved vacuum and cryogenic systems.

More information about the Virgo-ET synergies is provided in the document submitted for this session of the CS-IN2P3 in the Virgo_nEXT document.

5. Resources

5.1. Human resources

Among the 1400 members of the ET collaboration, 126 are from the French laboratories listed in Table 1, and 80% of them are also members of the Virgo collaboration; 20% are therefore recent newcomers in these experimental collaborations. Furthermore, only 55% of the French Virgo members are also members of ET: today in 2023, a large fraction of the Virgo members, 45%, is fully committed to Virgo, its upgrade projects and the preparation of the O4 and O5 runs, but they expressed interest for contributing to ET in the future. Figure 3 shows the CNRS institute of French members of ET.

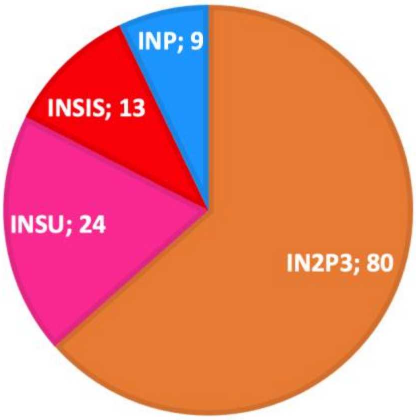

Figure 4: CNRS institute of the 126 French members of the ET Collaboration (in date of July 3^rd^, 2023).

5.2. Financial resources

The French contribution to experimental physics associated to ground detection of GWs proceeds mainly through the EGO-Virgo IR* budget, although additional budgets are punctually obtained through ANR and site initiatives (University programs, Labex). ET projects do not have dedicated budget so far, but given the synergy between the Adv Virgo+/Virgo_nEXT and ET, it is estimated that approximately €1.5 million has been spent so far for the ET project by the French teams (design studies, R&D, postdocs, with all sources of funding combined, IR*, CNRS, EU, ANR, Universities) and that currently approximately 250 k€ are devoted annually to preparing the project.

New budget sources are coming from EU, especially with ET-PP, although this project is dedicated to the RI definition and not to developing the technologies needed for ET. Some R&D funding may come in a near future from an EU INFRATECH project called M2Tech (with CTA, MAGIC, Virgo, KM3NeT and ELI partners), to be submitted in 2024, which is coordinated by an IN2P3 scientist working on Virgo and ET.

Concerning the development of R&D infrastructures in France, the funding of the extension of LMA in Lyon through a regional program (CPER) was approved in March 2023. This includes the extension of the LMA building and the funding to build a very big coater able to handle mirror substrates up to 1.6 m of diameter and 600 kg.

5.3. Industrial partnerships

The scale of the ET project, both in financial and human terms, will require significant participation from European industries. With the support of the French Ministry (MESR), which supervises aspects related to the economic impacts of research infrastructures with its service of ILOs ("Industry Liaison Officers"), the meeting “ET-France meets Industry”, was organized in March 2023 in Paris [9] in order to stimulate interest from French industries in this very ambitious project. This first meeting was successful with approximately 30 French companies present, and expressing their interests, either in the development of new technologies through common R&D program, either in the construction phase of the infrastructure and of the instrument. An organization is being put in place with the Technical Management of IN2P3 to further develop industrial partnerships within ET.

6. SWOT analysis

Strengths	***Weaknesses***
CNRS contribution to ET is based on a strong experience and expertise that its scientists and laboratories acquired during 30 years on Virgo and in the LVK collaboration. EGO, the CNRS-INFN-Nikhef European laboratory for gravitational waves physics is a major asset and the R&D base to prepare 3rd generation interferometer technologies.	A national source of budget supporting R&D programs for ET technologies has to be identified in France. Italy, Netherlands, and Germany each obtained multi-year budget of the order of €50 millions.
Opportunities	***Threats***
Increasing the sensitivity at low frequencies is generating a vibrant R&D program, especially on cryogeny, optics, sapphire substrate, mirror coatings, lasers. ET can only be successful with strong industrial partnerships in which French industry could play an essential role.	The attractiveness of GW physics is generating a strong competition among the European community with ambitious new comers (and new countries) in this field of research, both on the aspects of technology development and of physics analysis.

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Acronyms

BBH	Binary Black Hole
BNS	Binary Neutron Star
CE	Cosmic Explorer
EIB	e-Infrastructure Board
EOS	Equation of State
ET-HF	Einstein Telescope High Frequency interferometers
ET-LF	Einstein Telescope Low Frequency interferometers
ETO	Einstein Telescope Organization
ET-PP	Einstein Telescope Preparatory Phase
ISB	Instrument Science Board
LVK	Ligo Virgo Kagra Collaboration
NSBH	Neutron Star Black Hole
OSB	Observational Science Board
SPB	Site Preparation Board