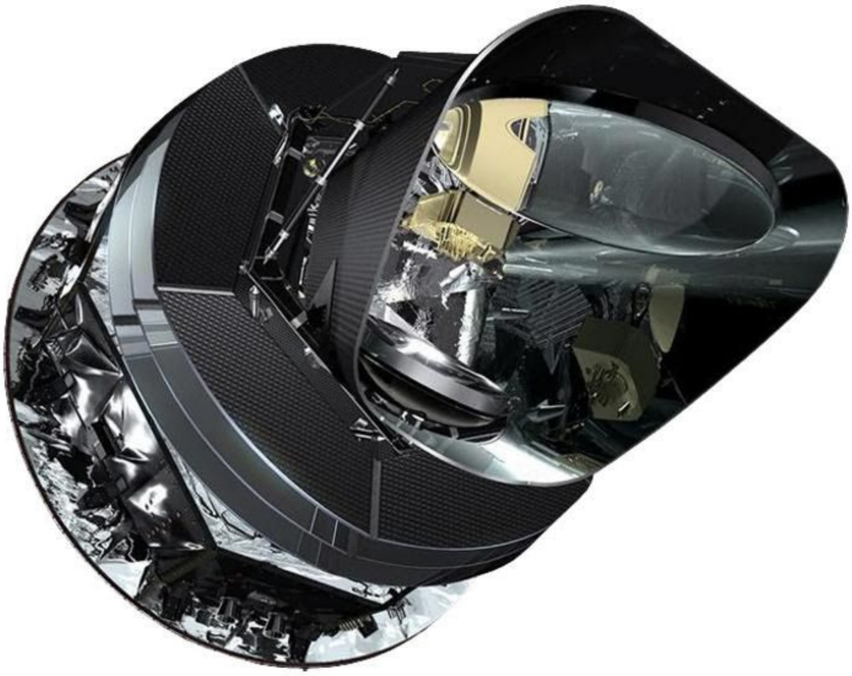
PLANCK

(retour d’expérience pour le CS IN2P3)



July 2020

1. Résumé (une page)

Planck was an ESA mission to observe the first light in the Universe. Planck was selected in 1995 as the third Medium-Sized Mission (M3) of ESA's Horizon 2000 Scientific Programme, and later became part of its Cosmic Vision Programme. It was designed to image the temperature and polarization anisotropies of the Cosmic Background Radiation Field over the whole sky, with an unprecedented combination of sensitivity and angular resolution. Planck was testing theories of the early universe and the origin of cosmic structure and providing a major source of information relevant to many cosmological and astrophysical issues.

Planck was formerly called COBRAS/SAMBA. After the mission was selected and approved (in late 1996), it was renamed in honor of the German scientist Max Planck (1858-1947), Nobel Prize for Physics in 1918.

Planck was launched on 14 May 2009, and the minimum requirement for success was for the spacecraft to complete two whole surveys of the sky. In the end, Planck worked perfectly for 30 months, about twice the span originally required, and completed five full-sky surveys with both instruments. Able to work at higher temperatures than the High Frequency Instrument (HFI), the Low Frequency Instrument (LFI) continued to survey the sky for a large part of 2013, providing even more data to improve the Planck final results. Planck was turned off on 23 October 2013.

The high-quality data the mission has produced was released in three major sets of papers:

- **2013 data release (PR1)**
  On 21 March 2013, the European-led research team behind the Planck cosmology probe released the mission's all-sky map of the cosmic microwave background together with a set of 32 scientific papers. This release included the data from the nominal mission (2 surveys, 15 months) in temperature only.
- **2015 data release (PR2)**
  A full set of 28 papers detailing the mission results were released in February 2015. This release covers the full-mission data (5 surveys, 30 months) with polarised maps.
- **2018 data release (PR3)**
  In July 2018, the Planck collaboration released a last series of 12 papers together with the version of the data used to produce the results.

In addition to the Public Releases, the Planck collaboration published a bunch of 13 “pre-launch” papers in 2010, 26 papers in the “early release” (2011), and more than 56 “intermediate papers all along the Planck mission (2012-2020).

2. Enjeux scientifiques

The existence of the cosmic microwave background (CMB) was postulated on theoretical grounds in the late 1940s by George Gamow, Ralph Alpher, and Robert Herman, who were studying the consequences of the nucleosynthesis of light elements, such as hydrogen, helium and lithium, at very early times in the Universe. They realised that, in order to synthesise the nuclei of these elements, the early Universe needed to be extremely hot and that the leftover radiation from this 'hot Big Bang' would permeate the Universe and be detectable even today as the CMB. Due to the expansion of the Universe, the temperature of this radiation has become lower and lower – they estimated at most 5 degrees above absolute zero (5 K), which corresponds to microwave wavelengths. It wasn't until 1964 that it was first detected (accidentally) by Arno Penzias and Robert Wilson, using a large radio antenna in New Jersey, a discovery for which they were awarded the Nobel Prize in Physics in 1978.

The first space mission specifically designed to study the cosmic microwave background (CMB) was the Cosmic Background Explorer (COBE), launched by NASA in 1989. Among its key discoveries were that averaged across the whole sky, the CMB shows a spectrum that conforms extremely precisely to a so-called 'black body' (i.e. pure thermal radiation) at a temperature of 2.73 Kelvin, but that it also shows very small temperature fluctuations on the order of 1 part in 100,000 across the sky. These findings were rewarded with the award of the 2006 Nobel Prize in Physics to John Mather and George Smoot.

The second generation space mission, the Wilkinson Microwave Anisotropy Probe (WMAP) was launched by NASA in 2001 to study these very small fluctuations in much more detail. The fluctuations were imprinted on the CMB at the moment where the photons and matter decoupled 380,000 years after the Big Bang, and reflect slightly higher and lower densities in the primordial Universe. These fluctuations originated at an earlier epoch (immediately after the Big Bang) and would later grow, under the effect of gravity, giving rise to the large-scale structure (i.e. clusters and superclusters of galaxies) that we see around us today. WMAP's results have helped to determine the proportions of the fundamental constituents of the Universe and to establish the standard model of cosmology prevalent today, and its scientists, headed by Charles Bennett, have garnered many prizes in physics in the intervening years.

Planck was the third generation CMB space mission. While it was originally designed to measure the sky in intensity with the ultimate sensitivity up to 5arcmin resolution, it was also capable of polarized measurements on a large part of its frequency range. As the whole sky had never been observed in the far infrared to mm domains with such an angular resolution (5' for Planck instead of 7 deg for COBE), the science targeted by the Planck mission is very broad. Planck is so sensitive that the limits to what it can see aren't set by instruments, which can measure down to 5arcmin or so, but by the fundamental astrophysics of the Universe itself.

The primary science goals of Planck includes:

- Mapping the Cosmic Microwave Background anisotropies with improved sensitivity and angular resolution in temperature and polarization
- Measuring the amplitude of structures in the Cosmic Microwave Background (angular power spectrum)
- Determining of ΛCDM parameters at percent level
- Testing inflationary models of the early Universe

- Probing Fundamental Physics with Planck (Neutrino, Dark-Energy, string Cosmology)
- Performing measurements of Sunyaev-Zel'dovich effect
- Constraining reionization history
- Measuring the large-scale matter distribution with lensing effects

Extra science were derived from the full-sky measurements, including:

- Galactic emissions and interstellar medium (Synchrotron, Dust, Free-free, molecular lines) in temperature and polarisation
- Extra-galactic objects (clusters, diffuse emission from galaxies with the Cosmic Infrared Background, radio sources, dusty galaxies)
- studies of the Solar System, including planets, asteroids, comets and the zodiacal light

It is important to note that Galactic science becomes more and more important with time given that it is now the major source of systematics that affect the CMB measurement (both in temperature and in polarisation).

3. État de l’art

Planck was the third generation of CMB space missions after COBE (1989-1993) and WMAP (2001-2010).

The WMAP mission (NASA), was selected at the same time as Planck but launched before (2001). Its sensitivity and resolution were lower than Planck, it covered the full-sky from 30GHz to 100GHz and provided a detailed measurement of the CMB power spectrum in temperature. Planck improved the temperature map by adding the small scales (thanks to a better resolution) and large frequency range (especially at high frequency up to 857 GHz) allowing to measure accurately the Galactic foreground emissions. Planck also significantly improved the measurements of polarisation.

The French community (CNES, INSU, CEA, IN2P3) was involved in the Planck High Frequency Instrument (HFI) with a French PI lead. Three labs from IN2P3 joined the project (APC, LAL, LPSC).
France provided approximately 50% of the hardware from HFI. The IN2P3 contribution was 50% of the French contribution.
Before Planck, in 1995, IN2P3 was not involved in any space mission project and the community working on cosmology was centered on Supernovae and micro-lensing. The IN2P3 joined the project after the redaction of the redbook for the COBRAS/SAMBA project submitted to ESA. The project in France was led by our colleagues from INSU. IN2P3 was welcomed to join the effort in 1996. Researchers from IN2P3 (APC, LAL, ISN) then worked in close connection with our colleagues from IAS, IAP, IRAP, IPAG together with CEA-IRFU and INP.
The first IN2P3/CNES convention, signed in 2000, raised from the GLAST and PLANCK space mission collaboration needs.

4. Projet

a. Archeops

Archeops was a balloon-borne experiment dedicated to measuring the Cosmic microwave background (CMB) temperature anisotropies.

The instrument was designed by adapting concepts put forward for the High Frequency Instrument of Planck surveyor (Planck-HFI) and using balloon-borne constraints. Namely, it consists of an open ^{3}He-^{4}He dilution cryostat cooling spiderweb-type bolometers at 100 mK; cold individual optics with horns at different temperature stages (0.1, 1.6, 10 K) and an off-axis Gregorian telescope.

Archeops allowed for an increase of the TRL of the hardware (e.g. cryogenic dilution) and a validation of instrumental concepts but it was also very important for acquiring experience on the instrument as well as in the data processing and analysis.

After one test-flight from Trapani (1999), Archeops made two successful campaigns at Kiruna for scientific measurements (Kiruna 2001 and 2002). The science achievements includes:

- Measurement of CMB TT power spectrum (first link with COBE data)
- First measurement of dust emission in polarisation
- Point sources and SZ stacking analysis

The IN2P3 had a large implication in the hardware (essentially provided by the LPSC working closely with Institut Néel and IPAG at Grenoble). Our labs were involved in the ground calibrations, and in the launch campaigns and provided leaders in the data analysis and the pointing reconstruction.

b. Planck

Planck is the ESA M3 mission to observe the first light in the Universe with all-sky measurements in 9 frequencies in the mm domain. It was launched on 14 May 2009 from Kourou with an Ariane 5. The orbit was around the L2 Lagrangian point of the Earth-Sun system (1 500 000 kilometres from the Earth). The mission was extended from the nominal 15 months up to 30 months.

The payload carried two instruments at the focal plane of a 1.5m Gregorian telescope. Both instruments can detect both the total intensity and polarization of photons, and together cover a frequency range from 30 to 857 GHz. The Low Frequency Instrument (LFI) included 22 radio receivers, 27 - 77 GHz, operated at 20K. The High Frequency Instrument (HFI) included 52 bolometric detectors, 83 GHz - 1 THz, operated at 0.1K.

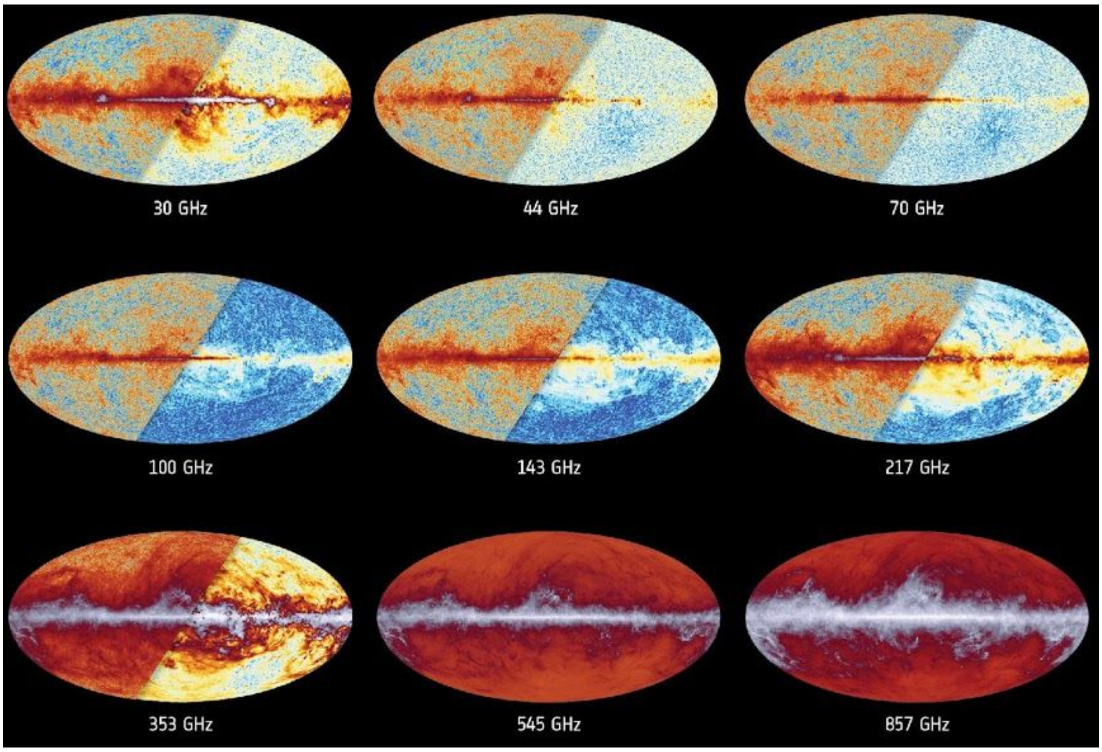
Each individual was a member of one or more among four Consortia of scientists:

- LFI: PI Mandolesi (Bologna), deputy Bersanelli (Milan)
- HFI: PI Puget (IAS), deputy Bouchet (IAP)
- The DK-Planck Consortium (telescope): PI H.U. Norgaard-Nielsen (Denmark)
- ESA's Planck Science Office: Project Scientist J. Tauber (ESA)

The Planck HFI instrument and associated Data Processing Centre were designed, built, and are operated by an international consortium of laboratories, universities and institutes, with important contributions from industry, under the leadership of the PI institute, the Institut d'Astrophysique Spatiale at Orsay, France.

Planck's passive and active cooling systems allow the HFI focal plane to maintain a temperature of 100mK. The cryogenic chain was made of three levels: a 20-K cryocooler for both the low- and high-frequency instruments (JPL, NASA), a 4-K stage using a mechanical pump performing the Helium Joule-Thomson refrigeration (UK), 0.1-K through a dilution of ^{3}He in ^{4}He with an intermediate 1.6K stage performed through Joule-Thomson refrigeration of the mix ^{3}He/^{4}He (developed by Institut Néel, Grenoble). From August 2009, Planck was the coldest known object in space, until its active coolant supply was exhausted in January 2012.

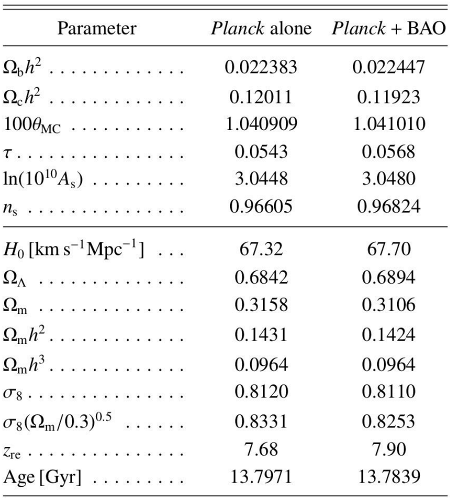
The HFI was sensitive between 100 and 857 GHz, using 48 bolometric detectors, manufactured by JPL/Caltech (NASA), optically coupled to the telescope through cold optics, manufactured by Cardiff University's School of Physics and Astronomy, consisting of a triple horn configuration and optical filters, a similar concept to that used in the Archeops balloon-borne experiment. These detection assemblies are divided into 6 frequency bands (centred at 100, 143, 217, 353, 545 and 857 GHz), each with a bandwidth of 33%. Of these six bands, only the lower four have the capability to measure the polarisation of incoming radiation.



Planck maps at 9 frequencies (from 30GHz to 857 GHz) including temperature and polarization

Planck covered a wider frequency range in more bands and at higher sensitivity than WMAP, making it possible to make a much more accurate separation of all of the components of the submillimetre and microwave wavelength sky, including many foreground sources such as the emission from our own Milky Way Galaxy. This thorough picture thus reveals the CMB and its tiny fluctuations in much greater detail and precision than previously achieved. Planck used this greater sensitivity to prove the standard model of cosmology beyond doubt and digged into deviations from the model which might reflect new physics beyond it.

Planck demonstrated that the 6-parameter ΛCDM model provides an excellent fit to the cosmic microwave background data at high and low redshift, describing the cosmological information in over 150 million map-pixels with just six parameters. With 18 peaks in the temperature and polarization angular power spectra constrained well, Planck measures five of the six parameters to better than 1% (simultaneously), with the best-determined parameter ($\theta *$) now known to 0.03 %.
The CMB anisotropies in temperature and polarisation (TT, TE, EE), CMB lensing $\Phi\Phi$, as well as BAO, BBN, and SNIa measurements are all consistent, among themselves and across experiments, within ΛCDM. The Planck data, alone and in combination with other probes, provide stringent constraints on our models of the early Universe and the large-scale structures within which all astrophysical objects form and evolve. These probes allow many different checks of the robustness for the ΛCDM model and some of its extensions, including flatness at 5.10^{-3} level, sum of neutrinos masses and effective number, dark matter annihilation limits, dark energy equation of state w(z), details of the recombination history (A2s□1, T0, and also fundamental constants variation, or any energy input...).



Parameter	*Planck* alone	*Planck* + BAO
$\Omega_b h^2$	0.022383	0.022447
$\Omega_c h^2$	0.12011	0.11923
$100\theta_{MC}$	1.040909	1.041010
τ	0.0543	0.0568
$\ln(10^{10}A_s)$	3.0448	3.0480
n_s	0.96605	0.96824
H_0 [km s^{-1}Mpc^{-1}]	67.32	67.70
Ω_Λ	0.6842	0.6894
Ω_m	0.3158	0.3106
$\Omega_m h^2$	0.1431	0.1424
$\Omega_m h^3$	0.0964	0.0964
σ_8	0.8120	0.8110
$\sigma_8(\Omega_m/0.3)^{0.5}$	0.8331	0.8253
z_{re}	7.68	7.90
Age [Gyr]	13.7971	13.7839

5. Genèse et calendrier

Planck's major dates are:

- 1992: First studies of the HFI-Samba concept
- 1995: M3 selection (COBRAS-SAMBA)
- 1996: End phaseA / ESA selection (name: Planck)
- 1997: project accepted at IN2P3
- 1999 : first CNES budget for IN2P3 labs
- 2004 & 2006 & 2008: calibrations
- 14 may 2009: launch
- 13 January 2012: end of mission HFI
- mid-2013: end of mission LFI
- 23 oct. 2013: spacecraft turned off

Planck published a large number of papers during the different steps of the project:

- 2010: “pre-launch results” (13 papers)
- 2011: “early results” (26 papers) - 7 articles with 100 to 300 citations each
- 2014: “2013 results” (32 papers) - almost 7000 citations for the “Cosmological parameters” paper, 18 other articles with 120 to 1700 citations each
- 2016: “2015 results” (28 papers) - more than 8700 citations for the “Cosmological parameters” paper, 17 other articles with 100 to 2100 citations each
- 2020: “2018 results” (12 papers) - close to 3000 citations for the “Cosmological parameters” paper, 5 other articles with 100 to 800 citations each
- 2011-2019: “intermediate results” (57 papers) - 7 articles with 100 to 400 citations each

Papers lead by IN2P3 researchers: 13
PhD at IN2P3: more than 30 (including Archeops)
HDR at IN2P3: 6
(cf. Annexe)

6. Ressources et moyens

Three labs from IN2P3 joined the project:

- LPSC (ex ISN)
    - date: 1999
    - up to 11 researchers / 25 IT
- IJClab (ex LAL)
    - date: 1996 (MOU LAL/IAS signed in april 2004)
    - up to 8 researchers / 14 IT
- APC (ex PCC Collège de France)
    - date: 1996
    - up to 16 researchers / 28 IT

CNES provided the resources for money and CDD both for the technical support and the scientific exploitation.
The CNRS provided manpower. The IN2P3 had a large involvement in terms of IT and researchers (around 200 FTE).

CC-IN2P3 was involved in the computing for Planck-HFI as well as support from IN2P3 with engineers for software computing.
The CMB data analysis is highly HPC, with the need for large memory and CPU requiring a high level of parallelism. Planck-HFI makes use of a specific machine Magique (in several versions across the years) at IAP. Big simulations and heavy runs were also performed at NERSC (Berkeley) taking advantage of the HPC system there. CC-IN2P3 was not fully adapted for CMB data analysis but was used for specific studies and as an archive solution.

7. Réalisations techniques

- Data Processing Unit (DPU)
    - development and construction of the Planck-HFI DPU (both Hardware and qualified On Board Software)
- Electronics for cryogenic devices
    - sorption cooler electronics (SCE-20K)
    - 100 mK dilution control electronics (DCE)
    - control command (SCE-20K) (software & validation tests)
    - cryo-harness (SCE-50K)

- Participation to the ground pre-flight HFI calibration
    - construction of the polarisation wheel and source
    - calibration sources
    - control command of the calibration setup cryogenics
    - measurement of time constants, non-linearity, cross-talk
    - Bandpass FTS measurements
    - impact of cosmic rays on detector (using particle beam)
    - Thermal regulation of HFI
- Data taking
    - participation to calibration phases (2004 & 2006 & 2008)
    - participation to the Daily Tele-Communication Period
    - participation to the cryogenic regulation and setup configuration of HFI

New expertise has been developed at IN2P3. IN2P3 labs provided both onboard hardware and onboard software up to the flight model. The technical teams acquired experience in integrating and validating techniques for space missions and TRL improvement.

Support has been provided by CNES but interaction was in both ways: IN2P3 shared competences in quality (HFI quality engineer came from IN2P3). The methodology has then been applied to other IN2P3 projects.

Participation in Planck allowed for interactions with new partners such as CNES, ESA, NASA.

IN2P3 teams fulfilled initial commitments (and even more !). Their expertise has been recognised by all the Planck partners.

8. Contributions à la science

Researchers at IN2P3 participated actively in all major steps of the Planck project: design, forecasting, hardware construction, calibration (data taking and analysis), simulations, raw data processing, development of new analysis methods, cosmological interpretation, product delivery, and public outreach.

The contributions from IN2P3 researchers include:

- Simulations
    - pipeline construction and support
    - development of simulation modules for instrumental effects
- Data processing and systematics studies
    - study of glitch impact on data and method for removal
    - model for non-linearity of the detector response (from ADC)
    - studies of systematics for polarisation (including impact of NL ADC)
    - Time constant models
- Responsible for Timeline processing
    - development of time processing pipeline and algorithms (demodulation, detector non-linearity, temperature variation deconvolution)
    - Cleaned timeline production
    - Data validation
- Responsible for Map-Making and calibration
    - development of map-making algorithm
    - upgrades to include identified systematics (as templates)
    - inflight calibration in temperature and polarization
    - map production (for public releases 2013 & 2015, plus internal releases ~2 per year)
- Component separation
    - software development (SMICA, NILC, GNILC, MILCA) and participation to the challenges
    - full-sky CMB, Compton parameter and CO maps provided to the collaboration
- Sky modeling
    - development of Planck Sky Model (PSM) used for all simulations
- CMB Lensing
    - lensing reconstruction (first analysis using patches, full sky reconstruction)
    - production of the lensing-induced B-mode map
- Cosmological likelihood analysis
    - likelihood for CMB anisotropies temperature and polarisation
    - new likelihood dedicated to large-scale polarisation
    - profile likelihoods and adaptive sampling (CAMEL)
- SZ science
    - cluster catalog production
    - y-map, tSZ power-spectra
- Cosmology with galaxy-clusters
    - CMB-lensing cluster-mass measurements

9. REX Auto-analyse

Researchers at IN2P3 participated actively in all major steps of the Planck project: design, forecasting, hardware construction, calibration (data taking and analysis), simulations, raw data processing, development of new analysis methods, astrophysical and cosmological interpretation, product delivery, outreach activities.
The integrated engineer-scientist IN2P3 teams have been very visible all through the project history. This was particularly important to solve specific systematic issues including: the design of the polarisation focal plane; on board data compression (unsolved problem before IN2P3 involvement); calibration sources using pulsed IR Carbon fiber (developed for Planck and tested on Archeops), mapmaking code with destriping technics, in-flight ADC nonlinearity correction...

With its participation in the Planck mission (and in particular in the Planck-HFI), technical and scientific expertises at IN2P3 have been recognised by the community. Interactions with new partners have been developed (including space agencies CNES, ESA, NASA).

Management of space missions is different from the projects in which IN2P3 is usually involved in. The scientific development of the mission was directed by the Planck Science Team (PST) with a very centralised decision process concerning the development of the satellite, payload and ground segment. The PST also has taken the role to organise, plan, coordinate, and oversee all the common activities related to the scientific exploitation of Planck during the proprietary period (PST in charge of membership, talks in conferences, paper leaders, hardware and software decisions, ...).
The scientific activities of the Planck Collaboration within the proprietary period were organised in "Projects", which consist of teams of people who are responsible to write papers on specific scientific topics on behalf of the whole Collaboration. "Working groups" gather Projects in similar areas.
Major responsibilities (including PST positions and WG leaders) were decided at the beginning of the project (the few changes were directly agreed at the PST level), with no rotation of responsibilities over the years.
Such an organisation progressively implied a lack of controversial and fruitful scientific discussions among the collaboration and no collegial scientific decisions.

The management structure was already in place when IN2P3 engaged in the project. Despite its huge implication in both the instrument and the data-analysis, IN2P3 was not represented in Planck’s decisional instances (no member at the Planck Science Team, no WG leader).
Paper leads were decided by the PST with only a few science papers being led by IN2P3 people (14/168) despite an important participation in the data analysis and the science interpretation. Talks in conferences have not been distributed equally (essentially concentrated on PI and first deputies, plus some specific persons). Post-doctorants and PhD students had very little visibility outside the project (some PhD defences “à huit-clos", membership procedure very heavy).
Those conditions progressively pushed some Planck collaborators (from IN2P3 but also from CEA) to quit the collaboration or reduce their involvement.

The separation between the Data Processing Centers (DPC) and the Science Working groups did not allow for enough discussions between the instrumental teams and the data processing. To solve this issue, the HFI PI created the Core Team later in the project. With a large expertise in the systematic effects and their impact on the science, the IN2P3 people were naturally strongly involved in the Core Team.

Importance of simulations have been pushed by researchers (especially at IN2P3) all along the duration of the project. Planck management has under-estimated the needs and the requirements for simulations (no real Monte-Carlo available till 2020 with only less than 1000 sims) which is the only way to correctly assess the impact of systematics and properly propagate their uncertainties up to the final products.

A large technical and scientific community was involved in the various steps of the life of the Planck project, and this is the strength of such missions. The fact that the ownership of the raw data belongs to the PI, rather than shared within the collaborators, is not in phase with such a huge collaborative work. ESA imposed regular public releases during the proprietary period but, for Planck, they do not contain all the information needed to reproduce the analysis.

10. Conclusions

Planck measurements provided the reference for cosmological parameters, neutrino masses and species, dark matter, Galactic emissions, SZ clusters and even more. Full-sky maps in the mm domain will remain the reference for the next decades.
Planck papers totalized more than 40,000 citations (3-4 per day since the 2013 release).

IN2P3 participated actively in all major steps of the Planck project including hardware construction, raw data analysis, development of new analysis methods, cosmological interpretation, product delivery, and public outreach.
Our work and expertise has been recognised both inside the collaboration and by our new partners (including the space agencies CNES,ESA,NASA).
IN2P3 researchers had strong responsibilities in data analysis and led some collaboration papers. They received two international prices as part of the Planck team (Group Achievement Award 2018 of the Royal Astronomy Society, Gruber Cosmology prize 2018).
The participation in the Planck project has allowed us to gain state-of-art expertise in cosmology, which have then been used for new experiments and projects. However visibility could have been more closely related to the huge work that IN2P3 scientists have accomplished.

Planck acted as a huge stepping stone for IN2P3 in CMB cosmology. A large community has been formed, recruited and trained, expertise in cosmology has been developed (instrumentation, data-analysis and science). The support from IN2P3 in manpower was strong with recruitment of young scientists (section 01 and section 47) and IT.
IN2P3 is now an important partner in the CMB community with participation in the two CMB roadmap exercises in 2016 and 2018. Indeed, IN2P3 has the largest active CMB community (compared to other institutes) with leaders in many of the future CMB projects (Simons-Observatory, CMB-S4, LiteBIRD). The experience acquired with Planck also helped to increase IN2P3 visibility and involvement in further space missions (including EUCLID, LISA, SVOM).

Since the end of the Planck Collaboration, the IN2P3 CMB community has been active in or leading new space missions proposals (such as CORE, PRISM, CORE+ to ESA). It is now heavily involved in LiteBIRD which has been selected by the Japanese Space Agency (JAXA) as the strategic large mission for 2028 and is currently engaged in a phase A at CNES. LiteBIRD is targeting the detection of the primordial gravitational waves which are the smoking-gun for an inflationary phase. By measuring the amplitude of the B-modes polarisation anisotropies, it could determine the energy of the inflaton field and put strong constraints on the shape potential of such a scalar-field.
Similarly to Planck, LiteBIRD in France is a collaboration between researchers from IN2P3, INSU, INP and CEA.
The combination of LiteBIRD with ground-based measurements will allow to better constrain the B-modes amplitude and break some degeneracies in the measurements of neutrino masses.
The community is asking for a structure gathering the researchers beyond their institutes, to animate the scientific discussions, make the link with the theoreticians and discuss strategy (e.g. a GdR).

Annexe

PLANCK scientific papers
“pre-launch results” (13 papers)
“early results” (26 papers)
“2013 results” (32 papers)
“2015 results” (28 papers)
“2018 results” (12 papers)
“intermediate results” from 2011 to 2019 (57 papers)

IN2P3 lead
High Frequency Instrument polarization calibration (Rosset 2010)
Cluster SZ optical scaling relations (J. Bartlett 2012)
glitch paper (G. Patanchon 2013)
CO paper (J.F. Macias-Perez 2013)
Zodiacal light paper (K. Ganga 2013)
Impact of particles on the Planck HFI detectors (A. Catalano 2014)
profile likelihood results (S. Plaszczynski in 2014)
map-making papers (O. Perdereau in 2013, M. Tristram in 2015)
reionisation paper (M. Tristram in 2015)
Inflation paper (M. Bucher in 2013 & 2015)
tSZ map (J.F. Macías-Pérez 2013, B. Comis 2015)
Cosmology cluster count (M. Roman 2015)
lensing-induced B-modes (L. Perotto 2015)
Spectral energy distribution of dust in clusters (B. Comis 2016)

Habilitation à diriger des recherches (6)
Cécile Renault (LPSC) - Archeops - 2005
Sophie Henrot-Versillé (LAL) - Archeops et Planck - 2006
Michel Piat (APC) - Planck - 2008
Jacques Delabrouille - Planck - 2010
Juan-Francisco Macías-Pérez - Archeops et Planck - 2011
Matthieu Tristram (LAL) - Planck - 2018

Thèses (31)

Benoît Revenu (PCC-CdF) - Planck - 2000
Alexandre Amblard (PCC-CdF) - Archeops - 2002
Philippe Filliatre (LPSC) - Archeops - 2002
Nicolas Ponthieu (LPSC) - Archeops - 2003
Guillaume Patanchon (PCC-CdF) - Archeops et Planck - 2003
Cyrille Rosset (PCC-CdF) - Archeops et Planck - 2003
Alexandre Bourrachot (LAL) - Archeops et Planck - 2004
Jean-Baptiste Melin (APC) - Planck - 2004
Matthieu Tristram (LPSC) - Archeops et Planck - 2005
Laurence Perotto (APC) - Planck - 2006
Stéphane Bargot (LAL) - Archeops et Planck - 2006
Lucien Larquère (APC) - Planck - 2006
Jonathan Aumont (LPSC) - Archeops et Planck - 2007
Antoine Chamballu (APC) - Planck - 2007
Marciella Veneziani (APC) - Planck - 2009
Marc Betoule (APC) - Planck - 2009
Damien Girard (LPSC) - Planck - 2010
Laurane Fauvet (LPSC) - Archeops et Planck - 2010
Sebastien Fromenteau (APC) - Planck - 2010
Gael Roudier (APC) - Planck - 2011
Alexis Lavabre (LAL) - Planck - 2011
Guillaume Castex (APC) - Planck - 2012
Lilien Sanselme (LPSC) - Planck - 2012
Guillaume Hurier (LPSC) - Planck - 2012
Clément Filliard (LAL) - Planck - 2012
Loic Maurin (APC) - Planck 2013
Benjamin Racine (APC) - Planck - 2014
Matthieu Roman (APC) - Planck - 2014
Marta Spinelli (LAL) - Planck - 2015
Antoine Miniussi (APC) - Planck - 2015
Rémi Adam (LPSC) - Planck et NIKA - 2015