O. La Marle, Astrophysics Program Manager
CNES, 2 place Maurice Quentin, 75039 Paris, France.

Astrophysics

The end of PLANCK and HERSCHEL operations in 2013 led to a considerable amount of data to exploit. An annual average of 300 peer-reviewed publications is released about each of HERSCHEL, PLANCK and XMM-Newton space missions. They are currently the world's most scientifically productive missions after the Hubble Space Telescope.

PLANCK

PLANCK French teams, backed by CNES, have been a key player in processing the HFI instrument's data. They have provided ESA and the scientific community with high added value products such as intensity and polarization maps, the last of which will be provided in 2016. The expertise of HFI teams gave them a key role in the combined analysis of data in collaboration with the BICEP American team, producing the most accurate cosmologic parameters ever.
Beyond cosmology, PLANCK's map of the sky in nine frequencies is the subject of much interest in astrophysics, from the study of our own galaxy to the evolution of the large structures in our Universe.
We still have a lot to learn about CMB. The next objective is the research of B-mode polarization, the characteristic mark left by the brief episode of inflation during the first fraction of a second of the Universe. CNES and its partners have implemented scientific and technological activities in preparation of a mission dedicated to these goals.

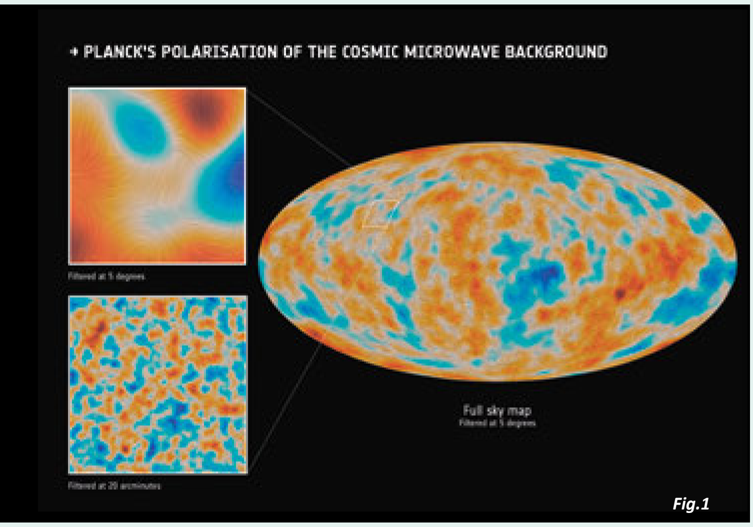


Fig.1

COROT

The exploitation of the data from the CNES COROT satellite, deactivated on June 17, 2014, is ongoing. The French laboratories have implemented the necessary corrections to transmit data on thousands of star light curves of the utmost accuracy to the scientific community, in 2016. A reference book gathering useful information about COROT's data and main results (including the characterization of 35 exoplanets) is currently being written. Thanks to this pioneering mission, the French laboratories acquired new skills granting them a key role in data interpreting for NASA's Kepler mission and in the preparation of ESA's PLATO, CHEOPS and ARIEL missions.

XMM-NEWTON

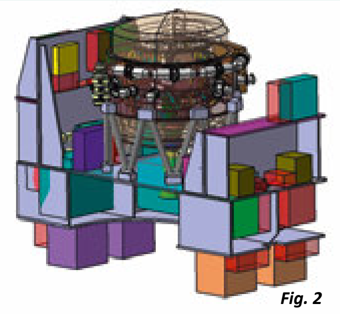
Since 2014, IRAP (Research Institute in Astrophysics and Planetology, Toulouse) backed by CNES, has coordinated the work of the XMM-Newton Survey Science Center (SSC), the European consortium in charge of the mission's data processing and of picture, spectrum and catalog delivery. The source catalog published in 2015 by the SCC comprises 396 910 sources, making it the largest and most comprehensive reference material in this field [1]. Thanks to XMM-Newton, the French laboratories acquired new skills which strengthen their leading position for the future ATHENA mission.

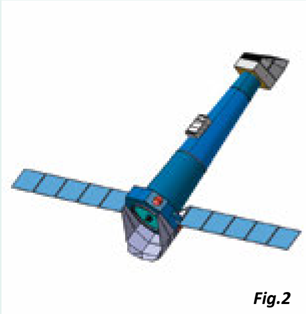
ATHENA

In 2014, ESA chose the ATHENA mission to address the theme "the Hot and Energetic Universe" selected the previous year and planned for launch in 2028. Feasibility studies have begun. There will be a Wide Field Imager (WFI) and an X-ray Integral Field Unit (X-IFU) on board. The latter will analyze physical and chemical properties of the warm-hot intergalactic medium, such as gas trapped in galaxy groups and clusters as well as supernovae remnants. CNES and IRAP are managing the work of a large scientific X-IFU consortium encompassing the US and Japan.

GAIA

After an in-orbit checkout in 2014, GAIA started its astrometry survey. Exceptional results are expected





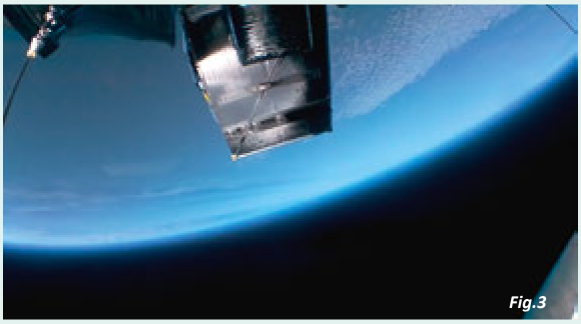


Fig. 1: The colors in the map represent temperature differences in CMB radiations compared with their average value. Cool blue regions and hotter red regions illustrate the variations of matter density in the early Universe. Direction and intensity are imprinted on the polarization of the CMB, showing on the temperature map that matter moves from low-density regions to higher-density regions. These structures can be observed at various scales in the sky. *© ESA – PLANCK Collaboration*

Fig. 2: Athena and the X-Ifu instrument. In the center, the cryostat cools the detectors down to 50 mK. *© CNES and the Athena X-IFU collaboration*

Fig. 3: Pilot flying in the stratosphere. The baffle in the foreground protects the telescope (1 m diameter). *© CNES*

from this ESA Cornerstone mission. The sensitivity of its two telescopes is so high that the mission will probe our galaxy deeper than expected. The European scientists of the Data Processing and Analysis Consortium (DPAC) have started to work on the considerable amount of data. CNES data processing center (DPCC) is gathering momentum with the gradual implementation of the processing software programs provided by the DPAC laboratories. The first GAIA catalog will be published in 2016.

JAMES WEBB TELESCOPE

The James Webb Space Telescope is undergoing integration and test efforts in the US. The Mid-Infrared Instrument (MIRI), to which CNES, the CEA and the CNRS contribute, ran several key tests, such as in a thermal vacuum chamber, inside the Integrated Science Instrument Module (ISIM), that holds Webb's four scientific instruments. The MIRI testing results show that the instrument is performing extremely well. The focus is now on data processing preparation and observation planning. The JWST is scheduled for launch in October 2018 on an Ariane 5 rocket on a trajectory toward the second Lagrange point (L2).

SVOM

In August 2014, CNES and the Chinese National Space Agency made a cooperation agreement for the SVOM mission. SVOM will be launched at the end of 2021 to detect gamma-ray bursts (GRB), especially the distant ones, coming from the Universe's first billion years. These mysterious high-energy phenomena constitute powerful beacons for their progenitor's local environment. The most distant of them are key to literally observe the early Universe, a period of time that is still out of the reach of our most powerful telescopes. We believe that GRBs are the result of neutron star coalescence or of the collapse of massive stars, which also produce gravitational waves. While gravitational waves have recently been directly detected for the first time ever, the complementarity between SVOM and ground-based gravitational wave detectors is extremely promising.

In the past two years, two balloons-borne astronomical experiments have performed maiden flights.

EUSO-BALLOON

In August 2014, after a launch by CNES from the Stratospheric Balloon Base in Timmins, Ontario, the EUSO-BALLOON telescope has performed a ten-hour flight to test the concept for detection of high-energy cosmic-ray-induced air showers and to measure the ultraviolet radiations from the Earth. EUSO-BALLOON is a demonstrator for a potentially forthcoming large-scale space mission. A second flight will be carried out possibly in 2017 in cooperation with NASA.

PILOT

On September 20, 2015, the one-ton PILOT telescope was sent aloft from Timmins for a twenty hour maiden flight, 40 km into the sky. The data collected will provide an accurate map of polarized emission from dust clouds in our galaxy.

EUCLID

The EUCLID astronomy mission passed the Preliminary Design Review. It approved the satellite design and the ground segment which comply with highly ambitious requirements. EUCLID can now start building the test and flight models. CNES and its CNRS and CEA partners coordinate a 1 300-member scientific consortium - a historic high for an astronomical mission - which is in charge of instrument development and data processing.

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O. La Marle, Astrophysics Program Manager
CNES, 2 place Maurice Quentin, 75039 Paris, France.

Astrophysics

PLANCK and HERSCHEL on the track of proto-clusters

Galaxies such as ours are usually not randomly scattered in the modern Universe: they make up clusters of hundreds and even thousands of galaxies. Studies based on satellite data from PLANCK and HERSCHEL have partially lifted the veil on how these huge and diverse structures originated from a highly homogeneous infant Universe.

According to current models, the tiny density fluctuations found in dark matter distribution shortly after the Big Bang were amplified and led to dark matter halos of young star-forming galaxies. This theory argues that when the Universe was only two to three billion years old (13.8 today), young galaxies started to group into clusters, hence the term “proto-cluster”.

The theory also suggests that many of these galaxies, made up of gas and dust, were then at the peak of their star-forming activity – hundreds of times more intense than the Milky Way today. They emitted bright visible and ultraviolet radiations which their interstellar dust would absorb and re-emit in the far-infrared domain.

This infrared radiation, stretched to millimeter wavelength ranges during its travel through the expanding Universe, should reach us today in a frequency band of several hundred GHz, which is exactly the frequency range covered by PLANCK’s High Frequency Instrument.

234 BRIGHT SOURCES

Researchers identified among PLANCK’s data 234 especially luminous sources which may be distant proto-clusters. However, neither PLANCK’s spectral range nor its image resolution is enough to draw conclusions: sources may have other origins, such as a remote starburst galaxy amplified by a closer massive object (another galaxy or a cluster) because of gravitational lensing.

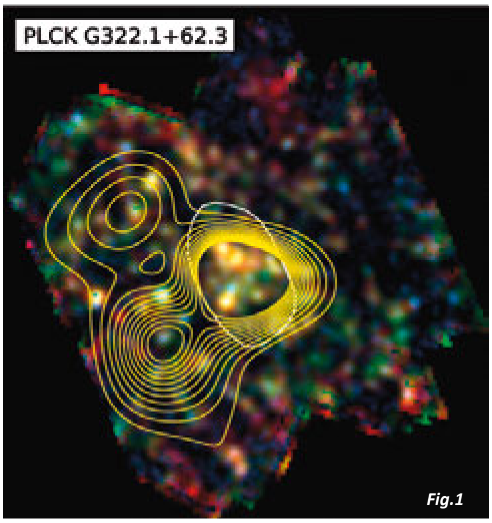
Although ESA’s HERSCHEL satellite was not built to survey the entire sky as its cousin PLANCK, its image resolution is higher. Before the end of its mission in 2013, it scanned each of the 234 sources. In most cases, its SPIRE instrument revealed a high number of infra-red emission galaxies in dense clusters.

“We were immediately shocked by the large fluxes or angular concentrations of these galaxies. Finding so many intensively star forming galaxies in such small groups was a huge surprise. We think this is a missing piece of cosmological structure formation: intensely star-forming groups of galaxies at high redshift, which are the precursors of today’s largest galaxy clusters” said Pr. Hervé Dole (IAS, Orsay) who led the analysis conducted as part of the PLANCK collaboration which involves CNES-backed laboratories in France, Europe and the US.

Ludovic Montier (IRAP, Toulouse), in charge of PLANCK’s high-redshift (*i.e.*, remote) source catalog, explained: *“we are preparing a comprehensive catalog on proto-cluster candidates, for which we may identify additional objects.”*

And more is yet to come. Not only did HERSCHEL confirm that most of the bright sources detected by PLANCK were proto-clusters, it also detected high-redshift “lensed” galaxies, meaning that they are amplified by massive objects in the foreground. They are usually extremely hard to analyze because of their apparent lack of luminosity, but gravitational lensing is such a powerful tool that we will be able to study these remote galaxies detected by PLANCK and HERSCHEL as if they were close to us!

Although other data from HERSCHEL or other laboratories had led to believe that similar candidates existed, they were only few of them, and they were too far off to be analyzed. PLANCK’s discovery is a goldmine. Astrophysicists will compare their model of galaxy and cluster formation and evolution to this catalog. Cosmologists had waited for this type of data to test their hypotheses on dark matter distribution in the Universe, and its evolution since distant times to this day in our expanding Universe. Lastly, French scientists and CNES play a key role in EUCLID, ESA’s upcoming mission dedicated to dark energy.



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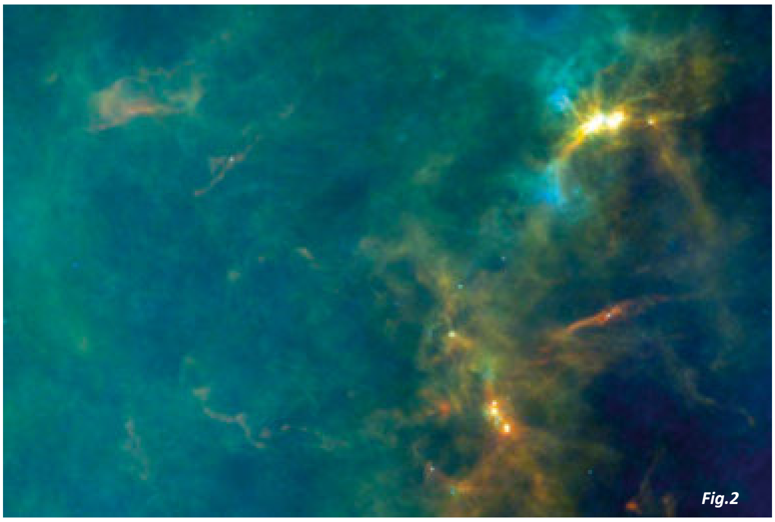

Fig.2

Fig.3

Fig. 1: A picture of a proto-cluster candidate. The white contours show the emitting area detected by Planck. In the background is a false-color image of this region captured by Herschel. The galaxy concentration scanned by Planck is visible to the naked eye. Galaxy density, outlined in yellow, confirms this observation. *© Dole, Guéry, Planck Collab., IAS, CNES, Univ. Paris sud, CNRS*

Fig. 2: The interstellar medium fills the "empty" space between the stars in our galaxy. It is a mix of molecular clouds, cold and warm gases, regions of electrically charged hydrogen, and more. Molecular clouds are the densest part of the interstellar medium, holding most of its mass in the form of hydrogen gas. ESA's Herschel space observatory has revealed that many are built around filaments, with dense threads snaking throughout each cloud. These filaments potentially transport material, and, when massive enough, are known to form new stars. This Herschel image shows the Serpens Core, the heart of a giant molecular cloud. The Core is the bright clump towards the upper right, with a more diffuse secondary cluster, named Ser G3-G6, shown at the bottom right. Also visible as a faint yellow glow towards the upper left of the frame is a region known as LDN 583 that shines brightly in the far infrared. *© ESA/Herschel/PACS/SPIRE/V. Roccatagliata (U. München, Germany)*

Fig. 3: Fierce flashes of light ripple through delicate tendrils of gas in this new image, from ESA's Herschel space observatory, which shows the dramatic heart of a large and dense cosmic cloud known as Mon R2. This cloud lies some 2700 light-years away and is studded with hot, newly-formed stars. Packed into the bright center of this region are several hot "bubbles" of ionized hydrogen, associated with newborn stars situated nearby. Here, gas heated to a temperature of 10 000 °C quickly expands outwards, inflating and enlarging over time. Herschel has explored the bubbles in Mon R2, finding them to have grown over the course of 100 000 to 350 000 years. This process forms bubble-like cavities that lie within the larger Mon R2 cloud. These are known as HII regions and Mon R2 hosts four of them, clustered together in the central blue-white haze of bright light – one at the very center, two stretching out like butterfly wings to the top left and bottom right, and another sitting just above the center. Each is associated with a different hot and luminous B-type star. These stars can be many times the mass of the Sun and usually appear with a blue hue due to their high temperature. *© ESA/Herschel/PACS/SPIRE/HOBYS Key Programme consortium*

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O. La Marle, Astrophysics Program Manager
CNES, 2 place Maurice Quentin, 75039 Paris, France.

Astrophysics

PLANCK takes a look at our Galaxy's magnetism

The images released by the PLANCK Collaboration give us access to the structure of our Galaxy's magnetic field, a key actor in the life cycle of interstellar matter. In our Galaxy, interstellar space is not empty. It contains gas and tiny dust grains – the material from which new stars and their planets are formed throughout the Galaxy. Interstellar dust emits radiation at the wavelengths probed by PLANCK. Interstellar space, just like the earth or the sun, is pervaded by a magnetic field. The latter tends to align the grains, which polarizes their radiation. For the first time, PLANCK measured this polarization over the whole sky to provide the 353 GHz polarization map.

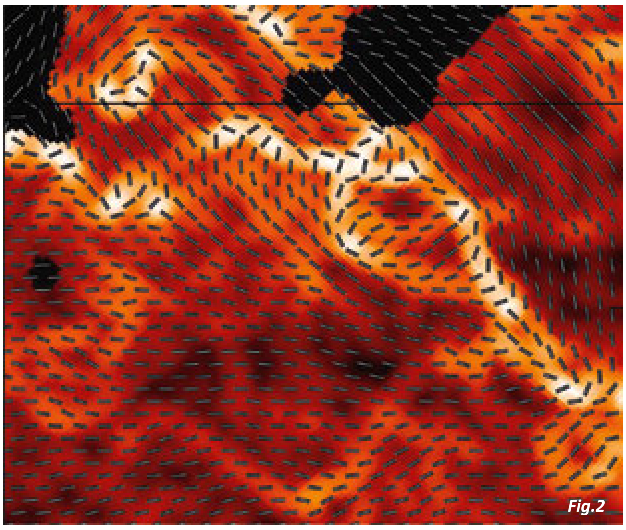
The discovery of our Galaxy's magnetism is linked to cosmic rays. They are accelerated by supernovae and, without the magnetic field, would escape from the Galaxy almost at the speed of light. These particles are retained by the magnetic field, which is in turn controlled by interstellar matter. Matter, magnetic field and cosmic rays interact with one another, constituting a dynamic system. Although the key role of the magnetic field in this trio has long been known, there is little data available to study it. Astrophysicists have long sought to understand how gravity overcomes the magnetic field to trigger star formation.

PLANCK released two new sky polarization maps: one of the synchrotron radiation of cosmic rays electrons and the other of dust emission (Fig. 1 next page). The data reveal the structure of the Galactic magnetic field in unprecedented detail. The polarization of both the synchrotron emission and dust emission indicates the direction of the magnetic field.

The small-scale analysis of this map provides a rich harvest of data. To characterize the structure of the magnetic field more accurately, maps of the dispersion in the magnetic field orientation have been built: at each point, the standard deviation of the field directions around this point is calculated in a 0.5-degree radius approximately. The dispersion reflects local magnetic field homogeneity: it is close to 0 in homogeneous regions and increases in inhomogeneous regions.

Figure 2 shows the superposition of the dispersion map and of the apparent magnetic field orientation map in the Polaris Flare region. In most studied areas, one can observe that the dispersion map is very structured in a complex network of filaments that mostly separate areas where the direction of the apparent magnetic field is, on the contrary, very homogeneous.

In addition, the fraction of dust radiation polarization drops in these filaments, while it can reach high values where the magnetic field is regular.
The analysis of these maps has only just begun. Magnetohydrodynamic simulations as well as observations with a better angular resolution by the PILOT balloon are expected to provide new insights into the origin of this peculiar structure of the magnetic field.



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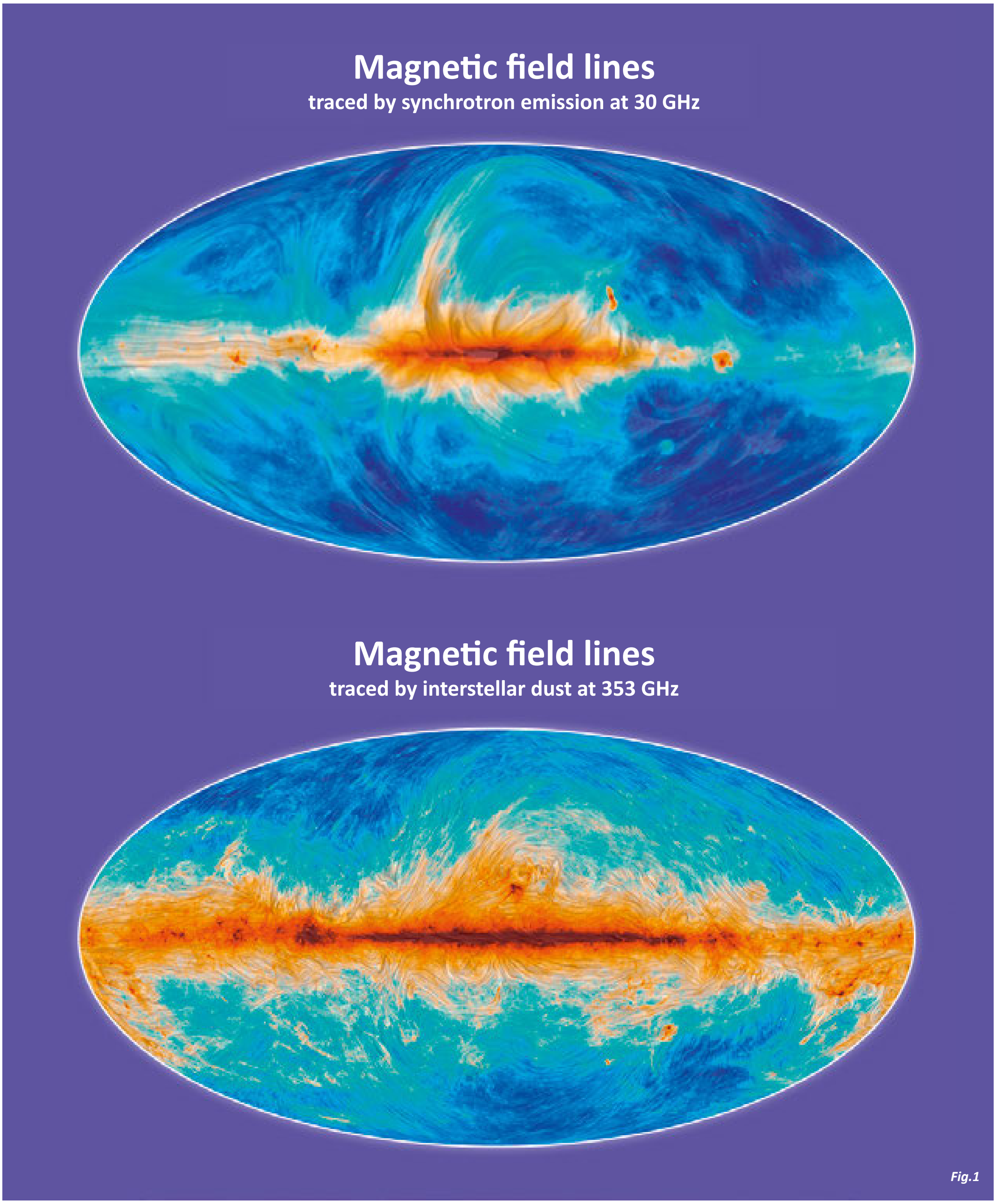

Fig. 1: Two-dimensional map of the sky. Colors represent the intensity of the emission while embossed texture reflects its polarization. The orientation of the global magnetic field is shown in regions where the texture is smooth. Data are more difficult to interpret in regions where it is irregular, associated with changes in the direction of the magnetic field. *© ESA/Planck Collaboration/M.-A. Miville-Deschênes, CNRS – Institut d'Astrophysique Spatiale, Université Paris-Sud, Orsay, France*

Fig. 2: Superposition of the apparent magnetic field orientation (dashes) to its localized dispersion, which constitutes a network of filaments in which radical changes in the orientation of the magnetic field occur. *(Planck collaboration (2015), A&A, 576, A104)*

O. La Marle, Astrophysics Program Manager
CNES, 2 place Maurice Quentin, 75039 Paris, France.

Astrophysics

PLANCK & BICEP2/KECK collaboration: an upper limit on the intensity of primordial gravitational waves

By pooling their data, the PLANCK and BICEP2/KECK collaborations have shown that the detection of primordial gravitational waves through the observation of the cosmic microwave background (CMB) polarization has not yet occurred. They have also set a robust upper limit on their amplitude and confirmed PLANCK's previous cosmological model.

This result is the outcome of a scientific drama which held breathless cosmologists and enthusiasts alike. The signal, reported in March 2014 by the BICEP2 team, is not related to the first instants of the Big Bang. It results from the combination of the Galactic signal and of gravitational distortions of the CMB during its propagation down to us. The CMB is a remnant radiation of the Big Bang from the distant past of the Universe, 13.8 billion years ago. Since its discovery, 50 years ago, cosmologists have thoroughly studied it in order to understand the origin and contents of the cosmos. In the last years, ESA's PLANCK satellite has measured it with an unprecedented accuracy.

The CMB is a snapshot of the Universe, 380 000 years after the Big Bang. Cosmologists use it to go back further in time, from 380 000 years to the period where the tiny fluctuations originated from, less than one second after the Big Bang. It was a phase of exponential expansion during a tiny fraction of a second called inflation during which gravitational waves were created. They spread across the Universe and distort its space-time frame. Although they are reaching us every day, they are far beyond the reach of our gravitational wave detectors. But they should have left a signature in the CMB: a specific pattern in the polarization of the radiation. These so-called B-modes of polarization lie at the heart of the research conducted by the PLANCK and BICEP2 collaborations.

March 2014 - detection by BICEP2

In March 2014, after several years of observation, the BICEP2 team, whose telescope is located at the South Pole, published a widely publicized result: it announced the detection of a B-mode polarized signal in a region of the sky believed to be only weakly contaminated by the foreground radiation of our Galaxy. The signal was initially interpreted as a very likely proof of the existence of primordial gravitational waves.

September 2014 – PLANCK analyzes the galactic contribution

In September 2014, the PLANCK collaboration demonstrated that the amplitude of the polarized emission of galactic dust is at least as strong, on the entire sky, as the signal measured by BICEP2. Therefore, there are no entirely clean windows on the sky to search for primordial gravitational waves. Still, this statistical result left an uncertainty as to the nature of the signal measured by BICEP2. Was it possible to demonstrate that at least part of the signal may have been of cosmological origin?

January 2015 – the collaboration PLANCK & BICEP2/KECK bears fruits

PLANCK and BICEP2 teamed up to answer this question. At the heart of their collaboration were the map of the Galactic signal produced by PLANCK and that of the signal measured by BICEP2, complemented by new observations obtained since March 2014 thanks to the Keck Array, also at the South Pole. The comparison of the three datasets demonstrated that the galactic contribution was dominant at the angular scales where the primordial gravitational wave signal was expected.

After retrieving the galactic emission, a B-mode polarization pattern in the CMB is still detected, but it corresponds to the gravitational lens due to the distribution of matter along the path of photons down to us. This signal differs from that of primordial gravitational waves in its distribution across angular scales. Note that this direct detection, which provides information on matter distribution in the Universe, is not the first detection of this effect, but it is by far the most accurate to this day.

After eliminating the galactic signal and the contribution of the lensing effect, it appears that the data do not allow

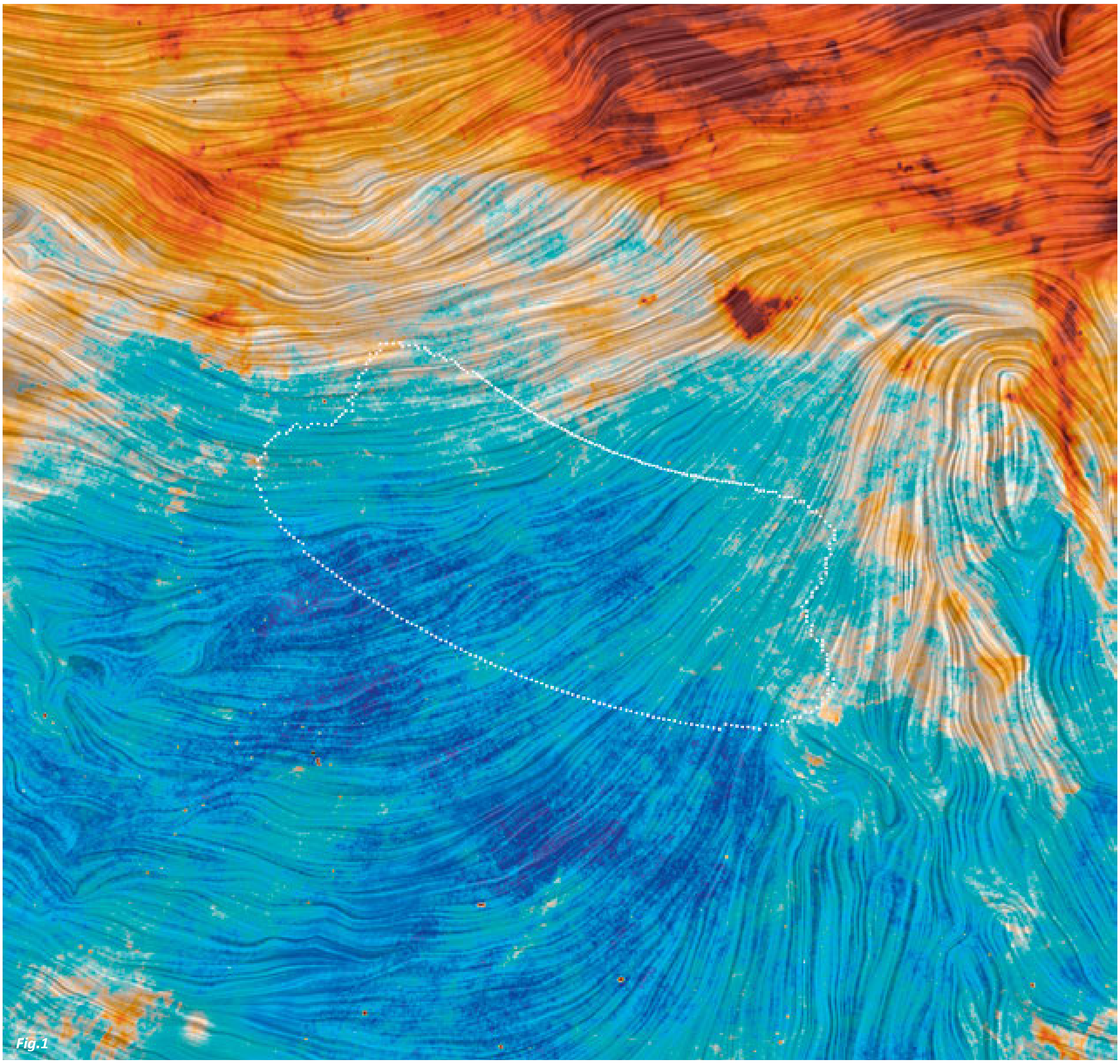

Fig. 1: This picture shows the patch of the Southern Hemisphere sky, based on Planck's data at 353 GHz. The color scale represents dust emission, a minor but crucial component of the interstellar medium that pervades the Milky Way. The texture is based on measurements of the direction of the polarized light emitted by the dust, which in turn indicates the orientation of the galactic magnetic field. The white outline is the region observed by the Keck Array and Bicep2 near the South Pole. *© ESA - Planck collaboration / Image by M.-A. Miville-Deschênes, CNRS – Institut d'Astrophysique Spatiale, Université Paris-Sud, Orsay, France*

the unambiguous detection of the footprints left by primordial gravitational waves. It does not mean that the expected signal does not exist, but that it is too weak to be detected with these datasets. However, the PLANCK/BICEP2/KECK collaboration was able to put an upper limit on the intensity of primordial gravitational waves. This limit is consistent with that obtained indirectly by PLANCK alone in 2013, based on CMB temperature fluctuations. This result was obtained before BICEP2's first publication, but it was not considered inconsistent because its interpretation depended on the cosmological model used in the data analysis. The new direct measurements show that the standard cosmological model used by PLANCK remains sufficient to describe the results.

The quest for B-modes in the CMB is not over. It will continue through ever more accurate observations made from the ground and from balloons, thanks to the fast development of detector arrays. Nevertheless, PLANCK's survey, with its frequency bands only accessible from space, will long remain an unavoidable reference to separate the signal's cosmological and galactic components.