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# Planck: new revelations on dark matter and relic neutrinos

**The Planck collaboration, which notably includes the CNRS, CEA, CNES and several French universities, has disclosed, at a conference in Ferrara, Italy, the results of four years of observations from the ESA's Planck satellite. The satellite aims to study relic radiation (the most ancient light in the Universe). This light has been measured precisely across the entire sky for the first time, in both intensity and polarisation[1], thereby producing the oldest image of the Universe. This primordial light lets us "see" some of the most elusive particles in the Universe: dark matter and relic neutrinos.**

Between 2009 and 2013, the *Planck* satellite observed relic radiation, sometimes called cosmic microwave background (CMB) radiation. Today, with a full analysis of the data, the quality of the map is now such that the imprints left by dark matter and relic neutrinos are clearly visible.

Already in 2013, the map for variations in light intensity was released, showing where matter was in the sky 380,000 years after the Big Bang. Thanks to the measurement of the polarisation of this light (in four of seven frequencies[2], for the moment), *Planck* can now see how this material used to move. Our vision of the primordial Universe has thus become dynamic. This new dimension, and the quality of the data, allows us to test numerous aspects of the standard model of cosmology. In particular, they illuminate the most elusive of particles: dark matter and neutrinos.

**New constraints on dark matter**

The Planck collaboration results now make it possible to rule out an entire class of models of dark matter, in which dark matter-antimatter annihilation[3] is important. Annihilation is the process whereby a particle and its antiparticle jointly disappear, followed by a release in energy.

The basic existence of dark matter is becoming firmly established, but the nature of dark matter particles remains unknown. There are numerous hypotheses concerning the physical nature of this matter, and one of today's goals is to whittle down the possibilities, for instance by searching for the effects of this mysterious matter on ordinary matter and light. Observations made by *Planck* show that it is not necessary to appeal to the existence of strong dark matter-antimatter annihilation to explain the dynamics of the early universe. Such events would have produced enough energy to exert an influence on the evolution of the light-matter fluid in the early universe, especially around the time relic radiation was emitted. However, the most recent observations show no hints that this actually took place.

These new results are even more interesting when compared with measurements made by other instruments. The satellites *Fermi* and *Pamela*, as well as the AMS-02 experiment aboard the International Space Station, have all observed an excess of cosmic rays, which might be interpreted as a consequence of dark matter annihilation. Given the *Planck* observations, however, an alternative explanation for these AMS-02 or *Fermi* measurements—such as radiation from undetected pulsars—has to be considered, if one is to make the reasonable hypothesis that the properties of dark matter particles are stable over time.

Additionally, the Planck collaboration has confirmed that dark matter comprises a bit more than 26% of the Universe today (figure deriving from its 2013 analysis), and has made more accurate maps of the density of matter a few billion years after the Big Bang, thanks to measurements of temperature and B-mode polarisation.

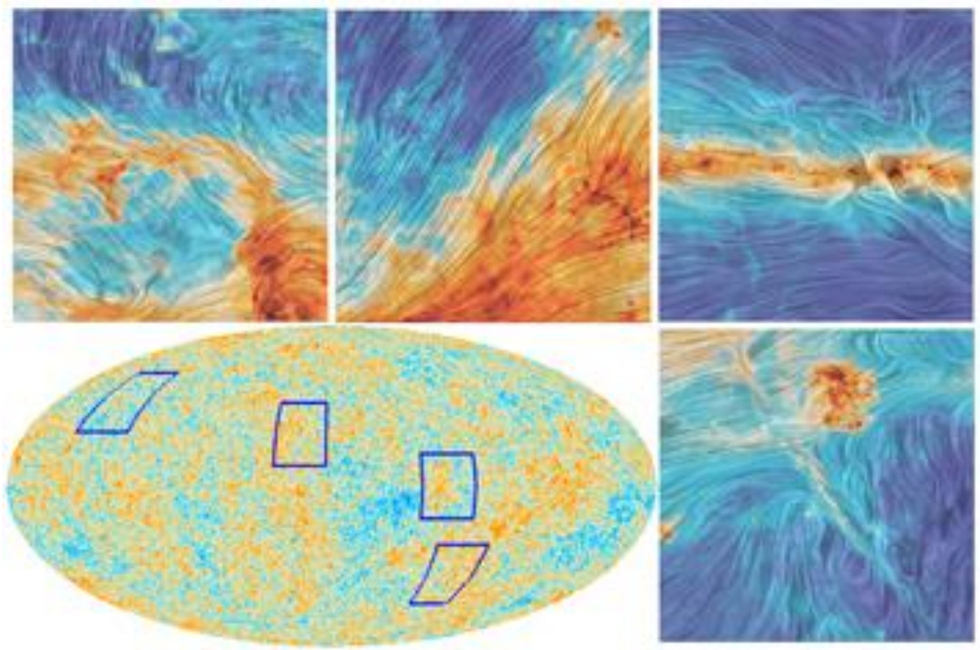
**Neutrinos from the earliest instants detected**

The new results from the Planck collaboration also inform us about another type of very elusive particle, the neutrino. These "ghost" particles, abundantly produced in our Sun for example, can pass through our planet with almost no interaction, which makes them very difficult to detect. It is therefore not realistic to directly detect the first neutrinos, which were created within the first second after the Big Bang, and which have very little energy. However, for the first time, *Planck* has unambiguously detected the effect these relic neutrinos have on relic radiation maps.

The relic neutrinos detected by *Planck* were released about one second after the Big Bang, when the Universe was still opaque to light but already transparent to these particles, which can freely escape from environments that are opaque to photons, such as the Sun's core. 380,000 years later, when relic radiation was released, it bore the imprint of neutrinos because photons had gravitational[4] interaction with these particles. Observing the oldest photons thus made it possible to confirm the properties of neutrinos.

*Planck* observations are consistent with the standard model of particle physics. They essentially exclude the existence of a fourth species of neutrinos[5], previously considered a possibility based on the final data from the *WMAP* satellite, the US predecessor of *Planck*. Finally, *Planck* makes it possible to set an upper limit to the sum of the mass of neutrinos, currently established at 0.23 eV (electron-volt)[6].

The full data set for the mission, along with associated articles that will be submitted to the journal *Astronomy & Astrophysics* (A&A), will be available December 22 on the ESA web site. These results are notably derived from measurements made with the High Frequency Instrument (HFI), which was conceived and assembled under the direction of the Institut d'astrophysique spatiale (CNRS/Université Paris-Sud), and utilized, under the direction of the Institut d'astrophysique de Paris (CNRS/UPMC), by different laboratories including those from the CEA, the CNRS and French universities, with funding from CNES and the CNRS.



*Temperature map of the relic radiation (bottom left), and close-ups showing, in relief, the polarisation of light in the 353 GHz channel (the colors correspond to the intensity of the thermal emission from galactic dust.*



[1] ***Polarisation is a property of light on the same level as color or direction of travel. This property is invisible to the human eye, but remains familiar (sunglasses with polarised lenses and cinema 3D glasses, for instance). A travelling photon is associated with an electrical field (E) and a magnetic field (B), at right angles to each other and to their direction of travel. If the electrical field remains in the same plane, the photon is said to be linearly polarised, as is the case for relic radiation.***

[2] ***In all three frequencies of the Low Frequency Instrument (LFI) and in the 353 GHz channel of the High Frequency Instrument (HFI).***

[3] ***In some models, dark matter particles are their own anti-particles.***

[4] ***According to general relativity, even if photons have no mass, they are sensitive to the gravitational force that bends space-time.***

[5] ***According to the standard model of particle physics, there are three species of neutrinos.***

[6] ***The electron volt (symbol: eV) is a unit of energy used in particle physics to express mass, since mass‑energy equivalence links energy and mass ($E=mc^2$, where c represents the speed of light). The lightest known particle after photons and neutrinos weighs 511 keV, more than 2 million times the sum of the mass of all three neutrinos.***

**The primary French laboratories involved in the *Planck* mission**

The following French laboratories were involved in building and analyzing the data from the HFI instrument (from raw measurements to frequency maps), and also in the astrophysical and cosmological interpretation of the whole dataset of the *Planck* mission:

- APC, AstroParticule et cosmologie (Université Paris Diderot/CNRS/CEA/Observatoire de Paris), Paris.
- IAP, Institut d'astrophysique de Paris (CNRS/UPMC), Paris.
- IAS, Institut d'astrophysique spatiale (Université Paris-Sud/CNRS), Orsay.
- Institut Néel (CNRS), Grenoble.
- IPAG, Institut de planétologie et d'astrophysique at Observatoire des sciences de l'Univers de Grenoble (CNRS/Université Joseph Fourier), Grenoble.
- IRAP, Institut de recherche en astrophysique et planétologie of the Observatoire Midi-Pyrénées (Université Paul Sabatier/CNRS), Toulouse.
- CEA-IRFU, Institut de recherche sur les lois fondamentales de l'Univers of the CEA, Saclay.
- LAL, Laboratoire de l'accélérateur linéaire (CNRS/Université Paris-Sud), Orsay.
- LERMA, Laboratoire d'étude du rayonnement et de la matière en astrophysique et atmosphères (Observatoire de Paris/CNRS/ENS/Université Cergy-Pontoise/UPMC), Paris.
- LPSC, Laboratoire de physique subatomique et de cosmologie (Université Joseph-Fourier/CNRS/Grenoble INP), Grenoble.
- CC-IN2P3, Centre de calcul de l'Institut national de physique nucléaire et de physique des particules (IN2P3) of the CNRS.

## **For more information** (in French)

- The *Planck* mission web site for the general public: www.planck.fr
- "Mission Planck" films: 2013, Images of the Universe in Formation, 2014, New Results, and Planck 2014, Seeing the Invisible, directed by Véronique Kleiner, produced by CNRS Images. *The videos are available from the CNRS video library, videotheque-diffusion@cnrs.fr*
- FAQs on the results of the *Planck* mission for download.

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