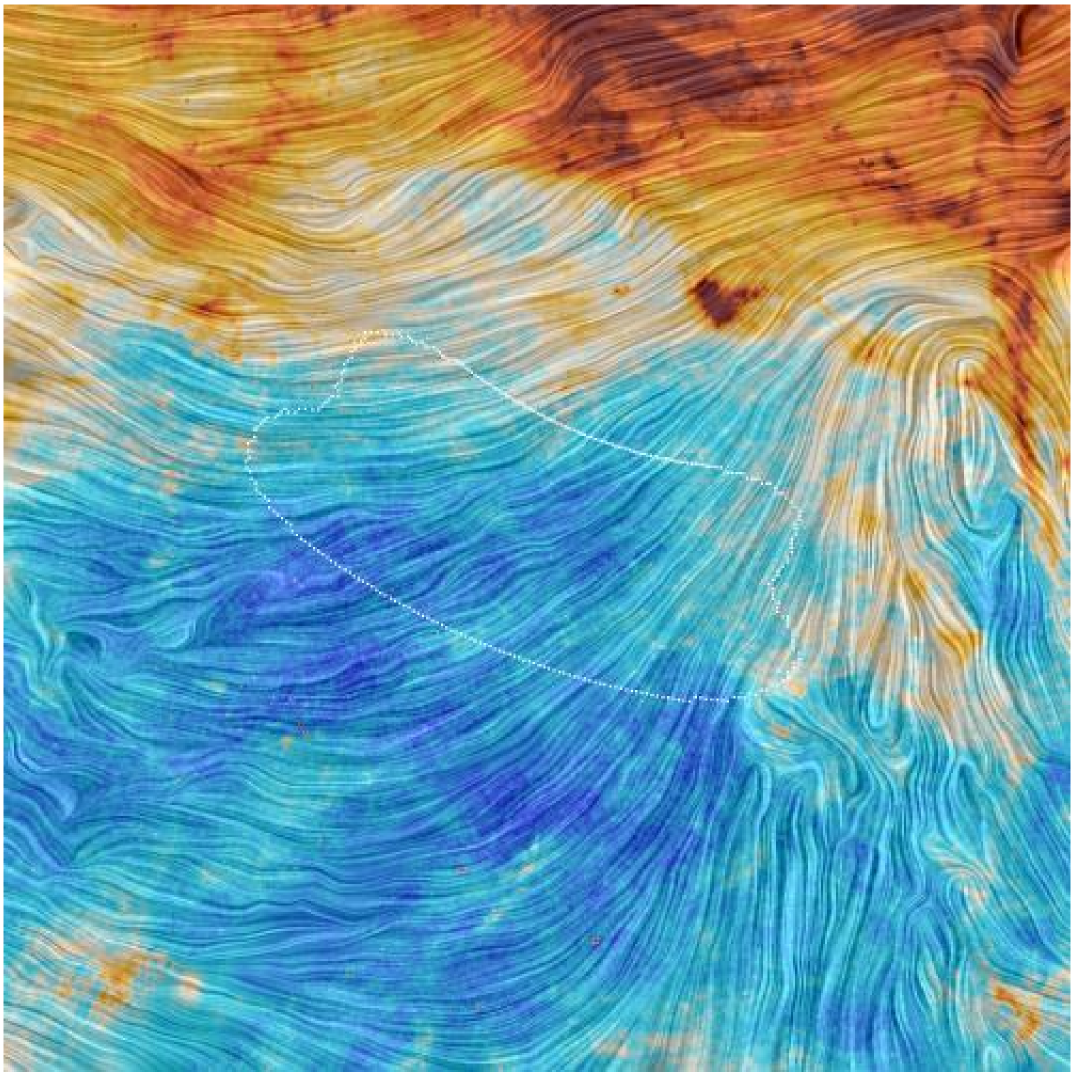
Planck: Gravitational waves remain elusive

January 30 2015



This image shows a patch of the southern sky and is based on observations performed by ESA's Planck satellite at microwave and sub-millimetre wavelengths. The colour scale represents the emission from dust, a minor but crucial component of the interstellar medium that pervades our Milky Way galaxy. The texture, instead, indicates the orientation of the Galactic magnetic field. It is based on measurements of the direction of the polarised light emitted by the dust. The highlighted region shows the position of a small patch of the sky that was observed with two ground-based experiments at the South Pole, BICEP2 and the Keck Array, and yielding a possible detection of curly B-modes in the polarisation of the Cosmic Microwave Background (CMB), the most ancient light in the history of the Universe. However, a joint analysis of data from BICEP2, the Keck Array, and Planck has later shown that this signal is likely not cosmological in nature, but caused by dust in our Galaxy. The image shows that dust emission is strongest along the plane of the Galaxy, in the upper part of the image, but that it cannot be neglected even in other regions of the sky. The small cloud visible in red, to the upper right of the BICEP2 field, shows dust emission from the Small Magellanic Cloud, a satellite galaxy of the Milky Way. The image spans 60° on each side. Credit: ESA/Planck Collaboration. Acknowledgment: M.-A. Miville-Deschênes, CNRS - Institut d'Astrophysique Spatiale, Université Paris-XI, Orsay, France

Despite earlier reports of a possible detection, a joint analysis of data from ESA's Planck satellite and the ground-based BICEP2 and Keck Array experiments has found no conclusive evidence of primordial gravitational waves.

The Universe began about 13.8 billion years ago and evolved from an extremely hot, dense and uniform state to the rich and complex cosmos of galaxies, stars and planets we see today.

An extraordinary source of information about the Universe's history is the Cosmic Microwave Background, or CMB, the legacy of light emitted only 380 000 years after the Big Bang.

ESA's Planck satellite observed this background across the whole sky with unprecedented accuracy, and a broad variety of new findings about the early Universe has already been revealed over the past two years.

But astronomers are still digging ever deeper in the hope of exploring even further back in time: they are searching for a particular signature of cosmic 'inflation' – a very brief accelerated expansion that, according to current theory, the Universe experienced when it was only the tiniest fraction of a second old.

This signature would be seeded by gravitational waves, tiny perturbations in the fabric of space-time, that astronomers believe would have been generated during the inflationary phase.

Interestingly, these perturbations should leave an imprint on another feature of the cosmic background: its polarisation.

When light waves vibrate preferentially in a certain direction, we say the light is polarised.

The CMB is polarised, exhibiting a complex arrangement across the sky. This arises from the combination of two basic patterns: circular and radial (known as E-modes), and curly (B-modes).

Different phenomena in the Universe produce either E- or B-modes on different angular scales and identifying the various contributions requires extremely precise measurements. It is the B-modes that could hold the prize of probing the Universe's early inflation.

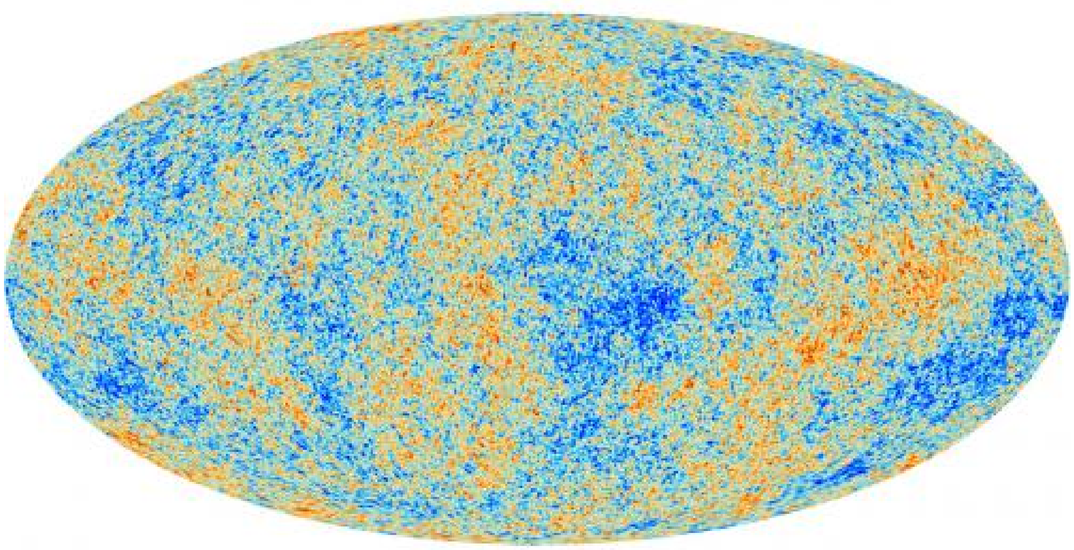
"Searching for this unique record of the very early Universe is as difficult as it is exciting, since this subtle signal is hidden in the polarisation of the CMB, which itself only represents only a feeble few percent of the total light," says Jan Tauber, ESA's project scientist for Planck.

Planck is not alone in this search. In early 2014, another team of astronomers presented results based on observations of the polarised

CMB on a small patch of the sky performed 2010–12 with BICEP2, an experiment located at the South Pole. The team also used preliminary data from another South Pole experiment, the Keck Array.

They found something new: curly B-modes in the polarisation observed over stretches of the sky a few times larger than the size of the full Moon.

The BICEP2 team presented evidence favouring the interpretation that this signal originated in primordial gravitational waves, sparking an enormous response in the academic community and general public.



The anisotropies of the Cosmic Microwave Background (CMB) as observed by Planck. The CMB is a snapshot of the oldest light in our Universe, imprinted on the sky when the Universe was just 380 000 years old. It shows tiny temperature fluctuations that correspond to regions of slightly different densities, representing the seeds of all future structure: the stars and galaxies of today. The highest resolution version of this image [12 572 px × 6286 px] is available upon request. Please make inquiries using the "Contact Us" link in the left-hand menu. Credit: ESA, Planck Collaboration

However, there is another contender in this game that can produce a similar effect: interstellar dust in our Galaxy, the Milky Way.

The Milky Way is pervaded by a mixture of gas and dust shining at similar frequencies to those of the CMB, and this foreground emission affects the observation of the most ancient cosmic light. Very careful analysis is needed to separate the foreground emission from the cosmic background.

Critically, interstellar dust also emits polarised light, thus affecting the CMB polarisation as well.

"When we first detected this signal in our data, we relied on models for Galactic dust emission that were available at the time," says John Kovac, a principal investigator of BICEP2 at Harvard University, in the USA.

"These seemed to indicate that the region of the sky chosen for our observations had dust polarisation much lower than the detected signal."

The two ground-based experiments collected data at a single microwave frequency, making it difficult to separate the emissions coming from the Milky Way and the background.

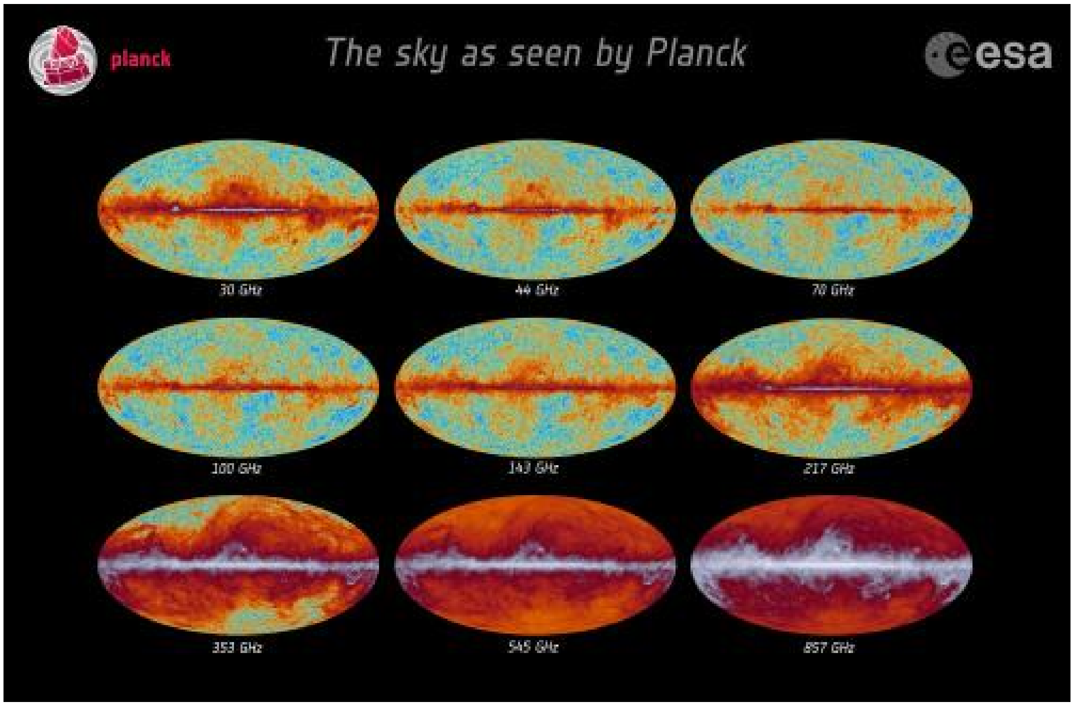
On the other hand, Planck observed the sky in nine microwave and sub-millimetre frequency channels, seven of which were also equipped with polarisation-sensitive detectors. By careful analysis, these multi-frequency data can be used to separate the various contributions.

The BICEP2 team had chosen a field where they believed dust emission would be low, and thus interpreted the signal as likely to be cosmological.

However, as soon as Planck's maps of the polarised emission from Galactic dust were released, it was clear that this foreground contribution could be much higher than previously expected.

In fact, in September 2014, Planck revealed for the first time that the polarised emission from dust is significant over the entire sky, and comparable to the signal detected by BICEP2 even in the cleanest regions.

So, the Planck and BICEP2 teams joined forces, combining the satellite's ability to deal with foregrounds using observations at several frequencies – including those where dust emission is strongest – with the greater sensitivity of the ground-based experiments over limited areas of the sky, thanks to their more recent, improved technology. By then, the full Keck Array data from 2012 and 2013 had also become available.



This image shows the all-sky maps recorded by Planck at nine frequencies during its first 15.5 months of observations. These were collected using the two instruments on board Planck: the Low Frequency Instrument (LFI), which probes the frequency bands between 30 and 70 GHz, and the High Frequency Instrument (HFI), which probes the frequency bands between 100 and 857 GHz. The Cosmic Microwave Background is most evident in the frequency bands between 70 and 217 GHz. Observations at the lowest frequencies are affected by foreground radio emission from the interstellar material in the Milky Way, which is mostly due to synchrotron radiation emitted by electrons that spiral along the lines of the Galactic magnetic field, but also comprises bremsstrahlung radiation, emitted by electrons that are slowed down in the presence of protons, as well as emission from spinning dust grains. Observations at the highest frequencies are affected by foreground emission from interstellar dust in the Milky Way. The combination of data collected at all of Planck's nine frequencies is crucial to achieve an optimal reconstruction of the foreground signals, in order to subtract them and reveal the underlying Cosmic Microwave Background. Credit: ESA and the Planck Collaboration

"This joint work has shown that the detection of primordial B-modes is no longer robust once the emission from Galactic dust is removed," says Jean-Loup Puget, principal investigator of the HFI instrument on Planck at the Institut d'Astrophysique Spatiale in Orsay, France.

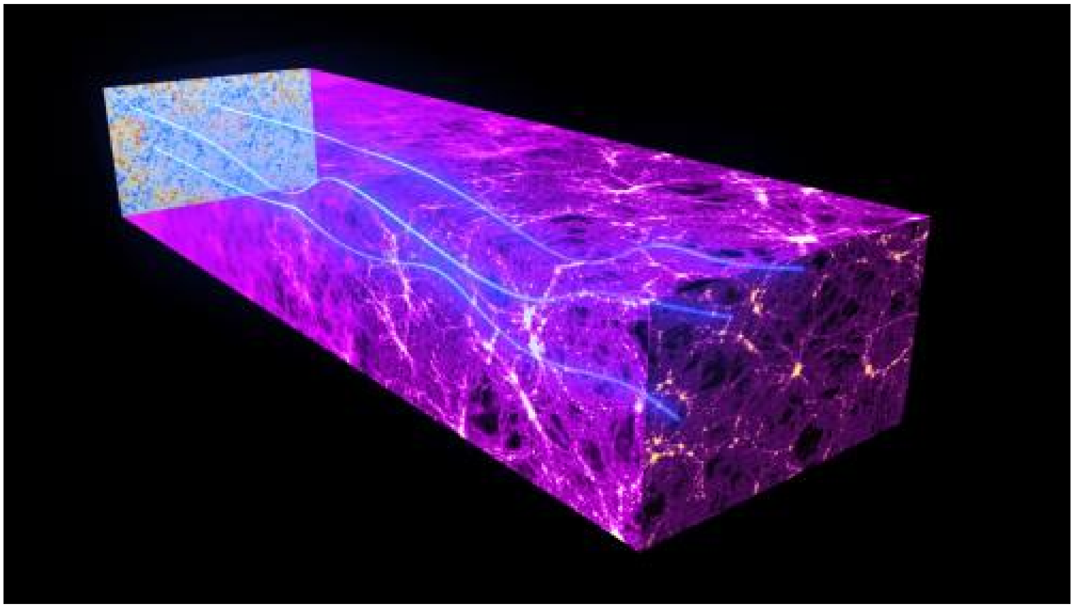
"So, unfortunately, we have not been able to confirm that the signal is an imprint of cosmic inflation."

Another source of B-mode polarisation, dating back to the early Universe, was detected in this study, but on much smaller scales on the sky.

This signal, first discovered in 2013, is not a direct probe of the inflationary phase but is induced by the cosmic web of massive structures that populate the Universe and change the path of the CMB photons on their way to us.

This effect is called 'gravitational lensing', since it is caused by massive objects bending the surrounding space and thus deflecting the trajectory of light much like a magnifying glass does. The detection of this signal using Planck, BICEP2 and the Keck Array together is the strongest yet.

As for signs of the inflationary period, the question remains open.



This illustration shows how photons in the Cosmic Microwave Background (CMB) are deflected by the gravitational lensing effect of massive cosmic structures as they travel across the Universe. Using data from ESA's Planck satellite, cosmologists have been able to measure this gravitational lensing of the CMB over the whole sky for the first time. The CMB consists of the most ancient photons in the history of the Universe, which were emitted only 380,000 years after the Big Bang. Since then, CMB photons have travelled for over 13 billion years across the Universe, witnessing the dramatic changes that took place during the various cosmic epochs such as the formation of stars, galaxies and galaxy clusters. Several observable effects arise from the interaction between CMB photons and the large-scale structure they crossed during their journey. One of the most intriguing is gravitational lensing, the deflection of light as it travels in the vicinity of massive objects such as galaxies and galaxy clusters. Gravitational lensing creates tiny, additional distortions to the mottled pattern of the CMB temperature fluctuations. On their way to the Solar System, where they are eventually detected by the sensors on board Planck, photons from the CMB may cross many different massive systems as well as empty spaces. The photons encounter structures in different evolutionary stages, since the massive structures grow denser and the cosmic voids become less dense as time goes by. All of the structures from the different cosmic epochs contribute to bending the path of CMB photons. The total effect of these multiple deflections is a modification to the pattern of CMB temperature fluctuations, thus changing the typical 'shapes' of hot and cold spots in the CMB. As a result of the detection of gravitational lensing experienced by CMB photons, cosmologists can use Planck to explore 13 billion years of the formation of structure in the Universe. Credit: ESA and the Planck Collaboration

"While we haven't found strong evidence of a signal from primordial gravitational waves in the best observations of CMB polarisation that are currently available, this by no means rules out inflation," says Reno Mandolesi, principal investigator of the LFI instrument on Planck at University of Ferrara, Italy.

In fact, the joint study sets an upper limit on the amount of gravitational waves from inflation, which might have been generated at the time but at a level too low to be confirmed by the present analysis.

"This analysis shows that the amount of gravitational waves can probably be no more than about half the observed signal", says Clem Pryke, a principal investigator of BICEP2 at University of Minnesota, in the USA.

"The new upper limit on the signal due to gravitational waves agrees well with the upper limit that we obtained earlier with Planck using the temperature fluctuations of the CMB," says Brendan Crill, a leading member of both the Planck and BICEP2 teams from NASA's Jet Propulsion Laboratory in the USA.

"The gravitational wave signal could still be there, and the search is definitely on."

More information: Notes:

"A Joint Analysis of BICEP2/Keck Array and Planck Data" by the

BICEP2/Keck and Planck collaboration has been submitted to the journal *Physical Review Letters*.

The study combines data from ESA's Planck satellite and from the US National Science Foundation ground-based experiments BICEP2 and the Keck Array, at the South Pole.

The analysis is based on observations of the CMB polarisation on a 400 square degree patch of the sky. The Planck data cover frequencies between 30 GHz and 353 GHz, while the BICEP2 and Keck Array data were taken at a frequency of 150 GHz.

A public release of Planck data products will follow later next week.

Provided by European Space Agency