Planck finds no new evidence for cosmic anomalies

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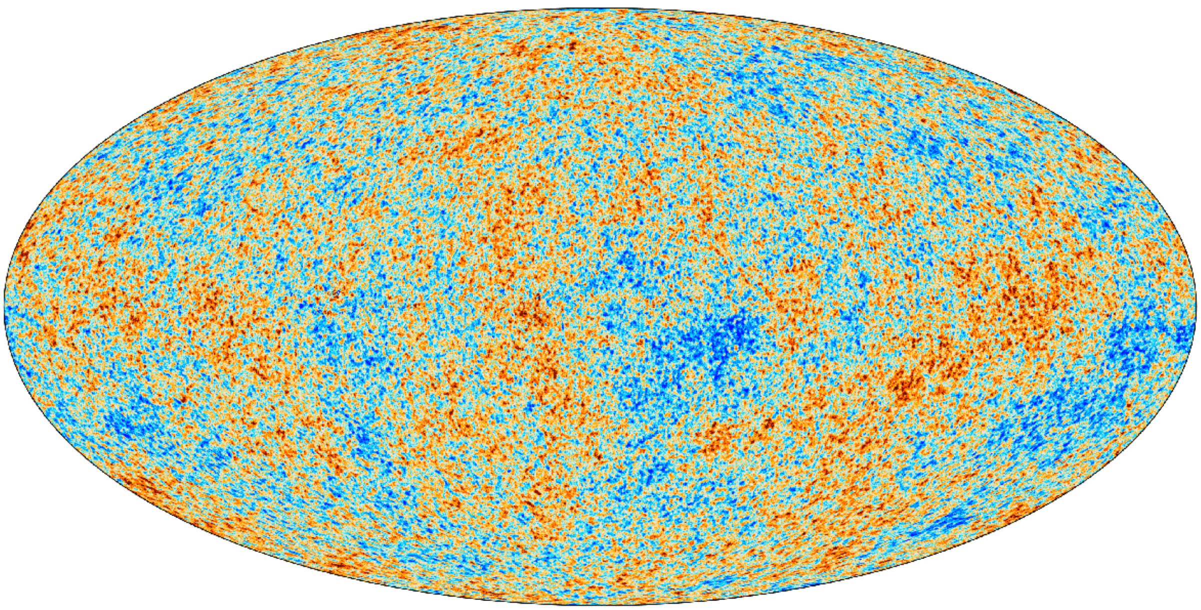


The anisotropies of the cosmic microwave background, or CMB, as observed by ESA's Planck mission. The CMB is a snapshot of the oldest light in our cosmos, imprinted on the sky when the Universe was just 380 000 years old. It shows tiny temperature fluctuations that correspond to regions of slightly different densities, representing the seeds of all future structure: the stars and galaxies of today. The first view in this sequence shows anisotropies in the temperature of the CMB at the full resolution obtained by Planck. In the second view, the temperature anisotropies have been filtered to show mostly the signal detected on scales around 5º on the sky. The third view shows the filtered temperature anisotropies with an added indication of the direction of the polarised fraction of the CMB. A small fraction of the CMB is polarised – it vibrates in a preferred direction. This is a result of the last encounter of this light with electrons, just before starting its cosmic journey. For this reason, the polarisation of the CMB retains information about the distribution of matter in the early Universe, and its pattern on the sky follows that of the tiny fluctuations observed in the temperature of the CMB. These images are based on data from the Planck Legacy release, the mission's final data release, published in July 2018. Credit: ESA/Planck Collaboration

ESA's Planck satellite has found no new evidence for the puzzling cosmic anomalies that appeared in its temperature map of the Universe. The latest study does not rule out the potential relevance of the anomalies but they do mean astronomers must work even harder to understand the origin of these puzzling features.

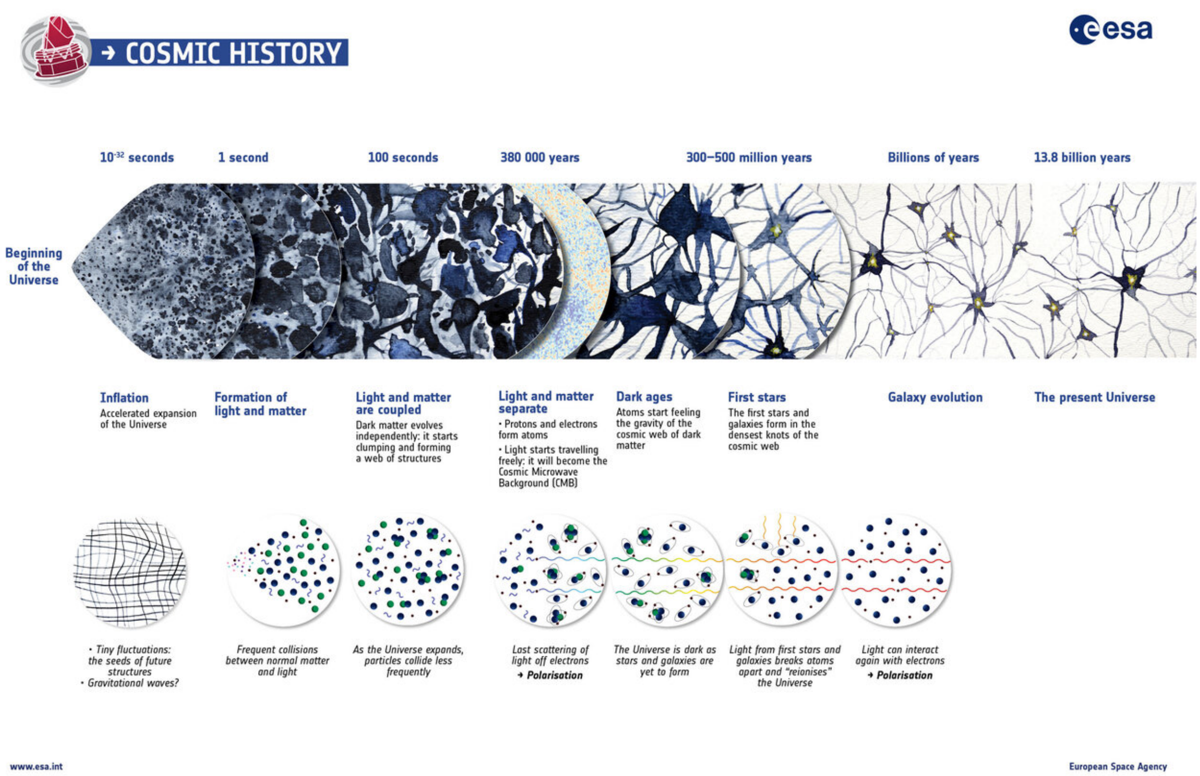
Planck's latest results come from an analysis of the polarisation of the Cosmic Microwave Background (CMB) radiation—the most ancient light in cosmic history, released when the Universe was just 380 000 years old.

The satellite's initial analysis, which was made public in 2013, concentrated on the temperature of this radiation across the sky. This allows astronomers to investigate the origin and evolution of the cosmos. While it mostly confirmed the standard picture of how our Universe evolves, Planck's first map also revealed a number of anomalies that are difficult to explain within the standard model of cosmology.

The anomalies are faint features on the sky that appear at large angular scales. They are definitely not artefacts produced by the behaviour of the satellite or the data processing, but they are faint enough that they could be statistical flukes—fluctuations which are extremely rare but not entirely ruled out by the standard model.

Alternatively, the anomalies might be a sign of 'new physics', the term used for as-yet unrecognised natural processes that would extend the known laws of physics.

To further probe the nature of the anomalies, the Planck team looked at the polarisation of the CMB, which was revealed after a painstaking analysis of the multi-frequency data designed to eliminate foreground sources of microwave emission, including gas and dust in our own Milky Way galaxy.



A summary of the almost 14 billion year history of the Universe, showing in particular the events that contributed to the Cosmic Microwave Background, or CMB. The timeline in the upper part of the illustration shows an artistic view of the evolution of the cosmos on large scales. The processes depicted range from inflation, the brief era of accelerated expansion that the Universe underwent when it was a tiny fraction of a second old, to the release of the CMB, the oldest light in our Universe, imprinted on the sky when the cosmos was just 380 000 years old; and from the 'Dark Ages' to the birth of the first stars and galaxies, which reionised the Universe when it was a few hundred million years old, all the way to the present time. Tiny quantum fluctuations generated during the inflationary epoch are the seeds of future structure: the stars and galaxies of today. After the end of inflation, dark matter particles started to clump around these cosmic seeds, slowly building a cosmic web of structures. Later, after the release of the CMB, normal matter started to fall into these structures, eventually giving rise to stars and galaxies. The inserts below show a zoomed-in view on some of the microscopic processes taking place during cosmic history: from the tiny fluctuations generated during inflation, to the dense soup of light and particles that filled the early Universe; from the last scattering of light off electrons, which gave rise to the CMB and its polarisation, to the reionisation of the Universe, caused by the first stars and galaxies, which induced additional polarisation on the CMB. Credit: ESA

This signal is the best measurement to date of the so-called CMB polarisation E-modes, and dates back to the time when the first atoms formed in the Universe and the CMB was released. It is produced by the way light scattered off electron particles just before the electrons were gathered into hydrogen atoms.

Polarisation provides an almost independent view of the CMB, so if the anomalies were also to show up there, this would increase astronomers' confidence that they could be caused by new physics rather than being statistical flukes.

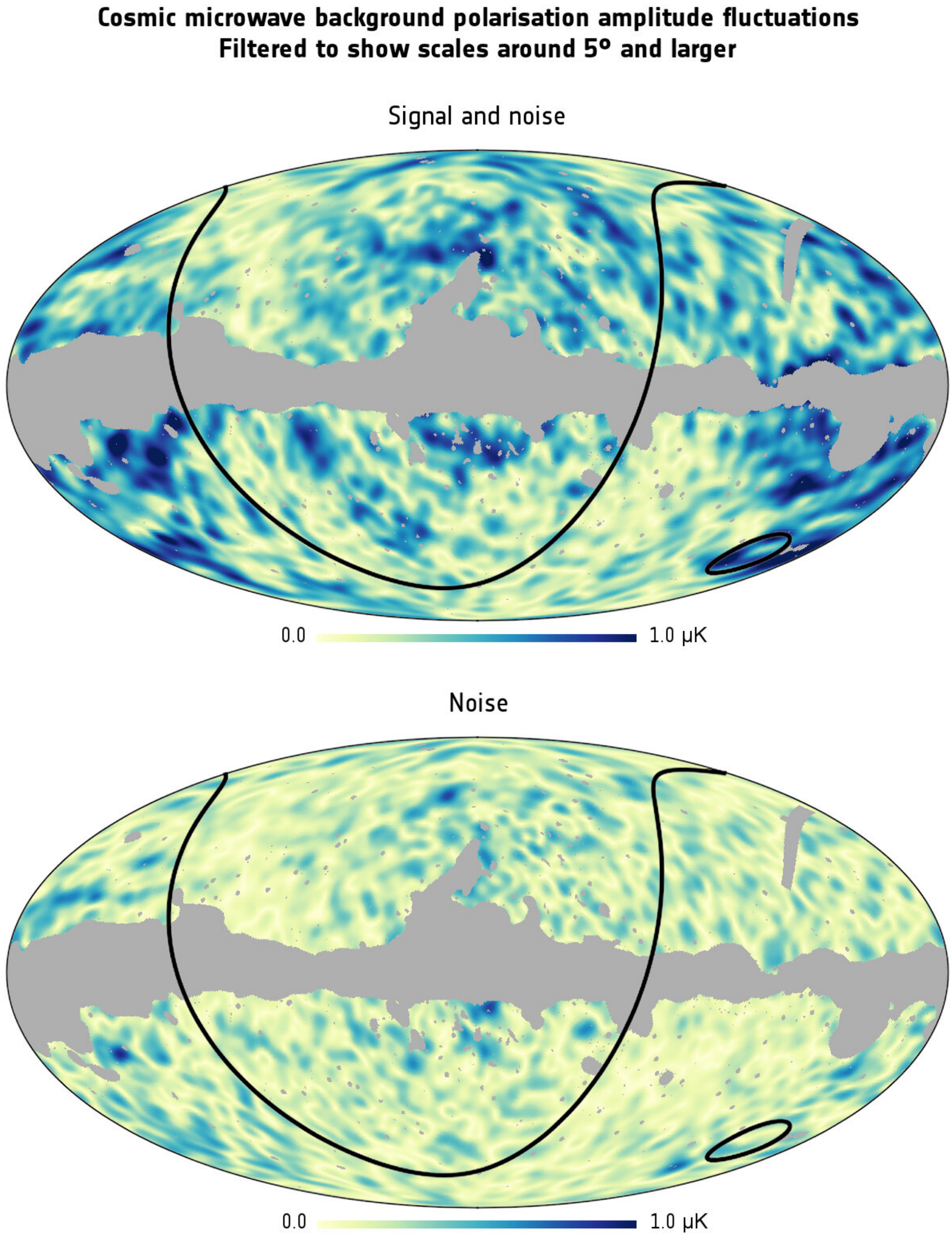
While Planck was not originally designed to focus on polarisation, its observations have been used to create the most accurate all-sky maps of the CMB polarisation to date. These were published in 2018, greatly improving the quality of Planck's first polarisation maps, released in

2015.

When the Planck team looked at this data, they saw no obvious sign of the anomalies. At best, the analysis, published today in *Astronomy and Astrophysics*, revealed some weak hints that some of the anomalies may be present.

"Planck's polarisation measurements are fantastic," says Jan Tauber, ESA Planck project scientist.

"Yet in spite of the great data we have, we don't see any significant traces of anomalies."


Cosmic microwave background polarisation amplitude fluctuations
Filtered to show scales around 5° and larger
Signal and noise
0.0
1.0 μK
Noise
0.0
1.0 μK

Map of the cosmic microwave background (CMB) polarization amplitude as observed by ESA's Planck satellite. While fluctuations in the CMB are present and were observed by Planck down to very small angular scales, these images have been filtered to show mostly the signal detected on fairly large scales in the sky, around 5 degrees – as a comparison, the full Moon spans about half a degree. On these large scales, a number of anomalies are observed in the CMB temperature – these are features that are difficult to explain within the standard model of cosmology, which relies on the assumption that the Universe, on large scales, has the same properties when observed in all directions. The most serious anomaly is a deficit in the signal observed on scales around 5 degrees, which is about ten per cent weaker than predicted. Other anomalous traits are a significant discrepancy of the signal as observed in the two opposite hemispheres of the sky (the two hemispheres are outlined by the large, roughly u-shaped curve in the image, the northern one being at the centre) and a so-called 'cold spot' – a large, low-temperature spot with an unusually steep temperature profile (the location of this spot is also outlined in the lower right). Such anomalies were not detected, at least not at any significant level, in Planck's observations of the CMB polarisation. A comparison between the top map, showing the total Planck measurement – comprising both signal and noise – with the bottom map, showing only the noise, indicates that some anomalous features may be present, such as for example a power asymmetry between the two hemispheres, but they are statistically unconvincing. The lack of statistically significant anomalies in the polarisation maps does not rule out the potential relevance of those seen in the temperature, but makes it even more challenging to understand the origin of these puzzling features. Regions shown in grey in the maps were masked out in the analysis to avoid residual foreground emission from our Milky Way or extragalactic sources affecting the cosmological results. Credit: ESA/Planck Collaboration

On the face of it, this would seem to make the anomalies more likely to be statistical flukes, but actually it does not rule out new physics because nature might be trickier than we imagine.

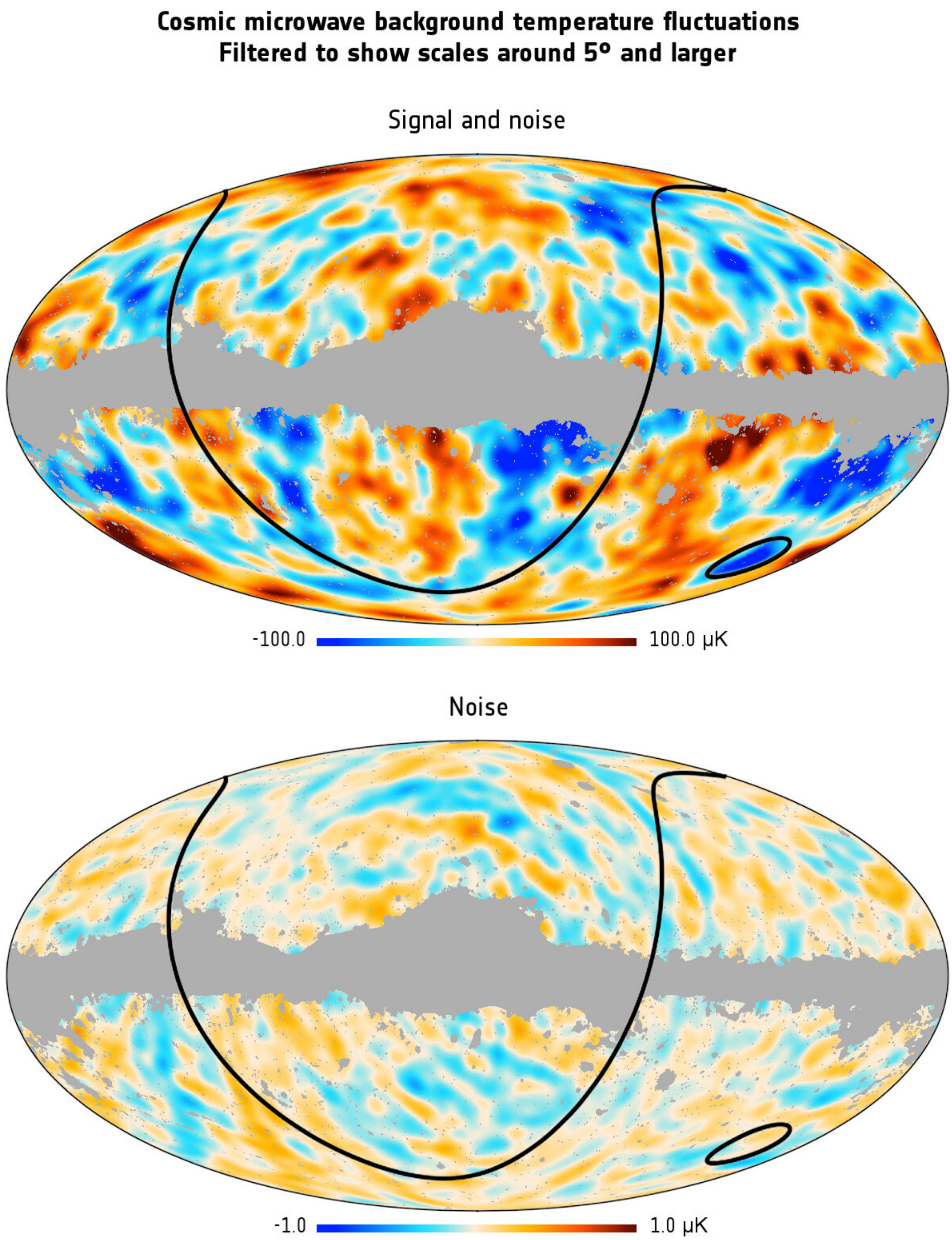
As yet, there is no convincing hypothesis for what kind of new physics could be causing the anomalies. So, it could be that the phenomenon responsible only affects the temperature of the CMB, but not the polarisation.

From this point of view, while the new analysis does not confirm that new physics is taking place, it does place important constraints on it.

The most serious anomaly that showed up in the CMB temperature map is a deficit in the signal observed at large angular scales on the sky, around five degrees—as a comparison, the full Moon spans about half a degree. At these large scales, Planck's measurements are about ten percent weaker than the standard model of cosmology would predict.

Planck also confirmed, with high statistical confidence, other anomalous traits that had been hinted at in previous observations of the CMB temperature, such as a significant discrepancy of the signal as observed in the two opposite hemispheres of the sky, and a so-called 'cold spot' – a large, low-temperature spot with an unusually steep temperature profile.

"We said at the time of the first release that Planck would be testing the anomalies using its polarisation data. The first set of polarisation maps which are clean enough for this purpose were released in 2018, now we have the results," says Krzysztof M. Górski, one of the authors of the new paper, from the Jet Propulsion Laboratory (JPL), Caltech, U.S..


Cosmic microwave background temperature fluctuations
Filtered to show scales around 5° and larger
Signal and noise
-100.0
100.0 µK
Noise
-1.0
1.0 µK

Map of the cosmic microwave background (CMB) temperature as observed by ESA's Planck satellite. While fluctuations in the CMB are present and were observed by Planck down to very small angular scales, these images have been filtered to show mostly the signal detected on fairly large scales in the sky, around 5 degrees and larger – as a comparison, the full Moon spans about half a degree. On these large scales, a number of anomalies are observed in the CMB temperature – these are features that are difficult to explain within the standard model of cosmology, which relies on the assumption that the Universe, on large scales, has the same properties when observed in all directions. The most serious anomaly is a deficit in the signal observed on scales around 5 degrees, which is about ten per cent weaker than predicted. Other anomalous traits are a significant discrepancy of the signal as observed in the two opposite hemispheres of the sky (the two hemispheres are outlined by the large, roughly u-shaped curve in the image, the northern one being at the centre) and a so-called 'cold spot' – a large, low-temperature spot with an unusually steep temperature profile (also outlined in the lower right). A comparison between the top map, showing the total Planck measurement – comprising both signal and noise – with the bottom map, showing only the noise, indicates that the anomalous features are clearly not artefacts as they are indeed present in the signal and not in the noise. Such anomalies were not detected, at least not at any significant level, in Planck's observations of the CMB polarisation. The lack of statistically significant anomalies in the polarisation maps does not rule out the potential relevance of those seen in the temperature, but makes it even more challenging to understand the origin of these puzzling features. Regions shown in grey in the maps were masked out in the analysis to avoid residual foreground emission from our Milky Way or extragalactic sources affecting the cosmological results. Credit: ESA/Planck Collaboration

Unfortunately, the new data did not take the debate any further, as the latest results neither confirm nor deny the nature of the anomalies.

"We have some hints that, in the polarisation maps, there could be a power asymmetry similar to the one that is observed in the temperature maps, although it remains statistically unconvincing," adds Enrique

Martínez González, also a co-author of the paper, from Instituto de Física de Cantabria in Santander, Spain.

While there will be further analysis of the Planck results taking place, it is unlikely that they will yield significantly new results on this subject. The obvious route to make progress is for a dedicated mission specially designed and optimised to study the CMB polarisation, but this is at least 10 to 15 years into the future.

"Planck has given us the best data we will have for at least a decade," says co-author Anthony Banday from Institut de Recherche en Astrophysique et Planétologie in Toulouse, France.

In the meantime, the mystery of the anomalies continues.

More information: undefined undefined. Planck 2018 results. VII. Isotropy and statistics of the CMB, *Astronomy & Astrophysics* (2019). DOI: 10.1051/0004-6361/201935201

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