Anticipating future discoveries: Scientists explore nontrivial cosmic topology

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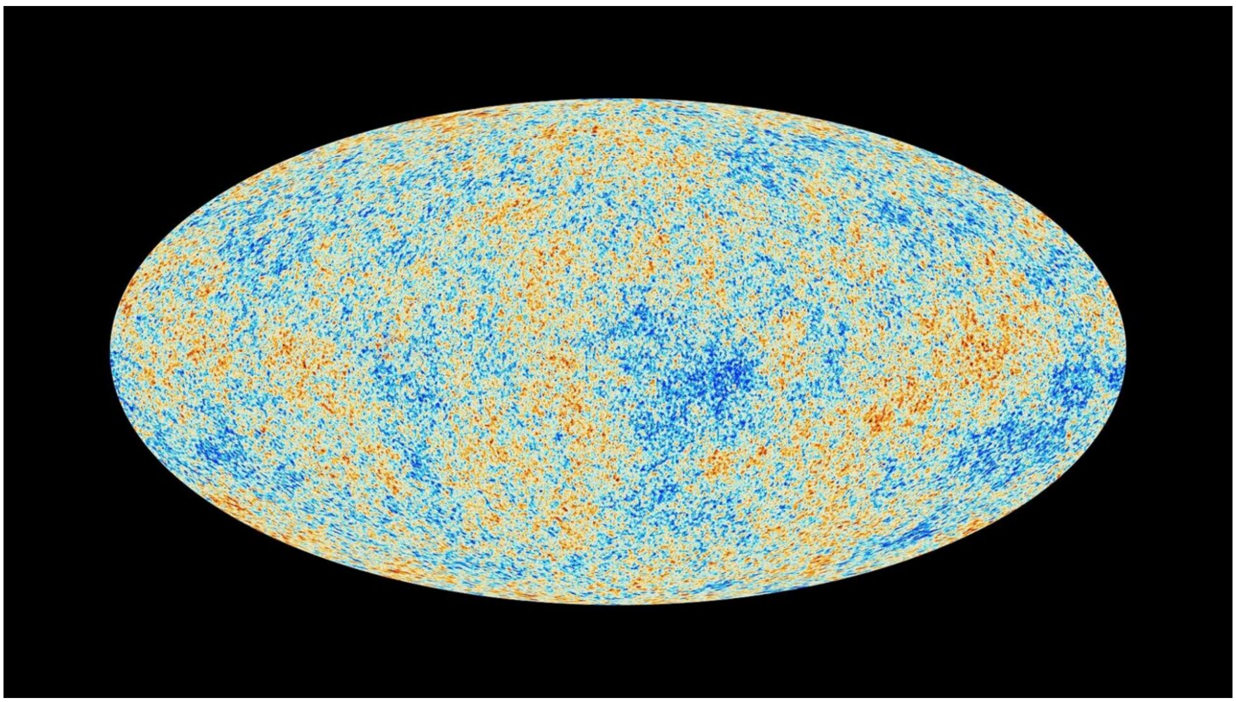

A map of the Cosmic Microwave Background radiation. Credit: ESA and the Planck Collaboration. noirlab.edu/public/images/CMB.

In a new *Physical Review Letters* (*PRL*) study, scientists explore the possibility of nontrivial or exotic topologies in the universe for explaining some of the anomalies seen in Cosmic Microwave Background (CMB).

Our cosmological model of the universe, based on quantum mechanics and general relativity, deals with the geometry of the universe as influenced by matter and energy, which for most purposes is considered to be flat.

However, it says nothing about the topology of the universe itself: Is it infinite, does it have loops, etc. The *PRL* study focuses on this aspect of the universe and whether current models and data permit the presence of these exotic or nontrivial topologies.

The research is done as a part of the COMPACT collaboration consisting of an international team of scientists. One of the co-authors of the study, Prof. Glenn D. Starkman from Case Western Reserve University in Ohio, U.S. spoke to Phys.org about the team's work.

Discussing his motivation to pursue this work, he said, "The possibility that the universe has 'interesting' topology is entirely within our Standard Model of physics but is nevertheless typically regarded as exotic."

"I have long been concerned that we would miss an extraordinary discovery about our universe by just looking the other way. In the meantime, there is growing evidence that the universe is not 'statistically isotropic,' i.e. that physics is the same in all directions. Topology is a very natural way for anisotropy to creep into our universe."

Cosmic microwave background

CMB is a type of radiation belonging to the microwave spectrum. Predicted in the 1940s as a remnant of the Big Bang, it was detected in 1965 by accident.

After the Big Bang, which is how the present universe came into existence, there was nothing but a soup of fundamental particles and gases at extremely high temperatures and pressures, often referred to as a primordial soup.

As the universe expanded, it also cooled down. This led to the fundamental particles combining to form atoms. Up until this point, photons were interacting with these fundamental particles and scattering, not allowing them to travel freely. But once atoms started to form, photons traveled more freely, around 380,000 years after the Big Bang.

This marked the propagation of CMB, which is considered an 'afterglow' of the Big Bang. It holds important information about the early universe and the subsequent processes that led to the formation of large-scale structures like stars and galaxies.

CMB is present everywhere and, for the most part, is uniform in temperature. However, there are small fluctuations and anomalies in CMB data that haven't been explained.

The researchers in the *PRL* study propose that these fluctuations and anomalies in CMB measurements can be explained by considering nontrivial topologies of the universe, which means we don't have to look at it as 'flat.'

Cosmic topology

Topology is a branch of mathematics that deals with the shape and structure of objects. The rules of topology are quite different from the rules of geometry. While geometry and topology are distinct concepts, geometry influences topology.

Geometry defines how space is curved (spacetime is considered flat at small scales), and topology defines the overall connectivity of space.

If we were to have flat space, we can't have topologies where space curves inwards or have loops. This means to travel between two points, we would have to take a straight line path without any detours or loops.

Prof. Starkman explained, "The universe may be like an old-time video game, where leaving the right side of the screen would see you popping in from the left, so you can get back where you started by a straight-line path. This is called being multiply connected."

Essentially, the straight-line path suggests that despite the appearance of continuous motion, the underlying topology of space allows for unexpected connectivity, where what seems like a linear trajectory may actually loop back on itself.

Matched temperature circles

If the universe were to be 'multiply connected' (i.e., have nontrivial topology), we would observe matched temperature circles. This is because light traveling from a source (like a star) could travel along two different paths and arrive at the observer (Earth) from two directions.

This leaves behind similar temperature fluctuations on a CMB map (or heat map), resulting in matched temperature circles. However, there has been no evidence suggesting the presence of these matched temperature circles.

"The lack of matched temperature circles is what tells us about the length of the shortest closed loop through us, but it does not tell us about the length of loops through other places," said Prof. Starkman.

The absence of matched temperature circles in the CMB data suggests that if nontrivial topology exists, the loops passing through our location (Earth) must be relatively small.

This places a limit on the length of these loops. Prof. Starkman explained, "If the CMB anomalies are due to cosmic topology, then the length of the shortest loops through us should not be more than about 20–30% longer than the diameter of the last scattering surface—a sphere with a radius equal to the distance that light has traveled in the history of the universe."

Future constraints and searches

In light of the above constraint and the search for nontrivial topology, the researchers propose additional ways for detecting such topology in the future.

In particular, they mention alterations in the statistical patterns of temperature fluctuations in CMB data as well as in the large-scale structure of the universe. These fluctuations or alternations would come to light if nontrivial topology were present.

But, these detections require enormous computational power and the researchers suggest the use of machine learning algorithms to speed up calculations and mining CMB data to detect nontrivial topology.

"The search for topology will be renewed after about a decade-long hiatus. Hopefully, we will detect cosmic topology and thereby understand the origin of the anisotropy of our universe and get a glimpse into the processes responsible for the original emergence of our universe," concluded Prof. Starkman.

The study also highlights that even in the absence of explicitly matched circles, the presence of statistical anisotropy (or anomalies) in the CMB indicates the potential existence of detectable information about the universe's structure and topology.

More information: Yashar Akrami et al, Promise of Future Searches for Cosmic Topology, *Physical Review Letters* (2024). DOI: 10.1103/PhysRevLett.132.171501