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# Cosmic Background Imager Uncovers Fine Details of Early Universe

WASHINGTON, D.C.- Cosmologists from the California Institute of Technology using a special instrument high in the Chilean Andes have uncovered the finest detail seen so far in the cosmic microwave background radiation (CMB), which originates from the era just 300,000 years after the Big Bang. The new images, in essence, are photographs of the cosmos before stars and galaxies existed, and they reveal, for the first time, the seeds from which clusters of galaxies grew.

The observations were made with the Cosmic Background Imager (CBI), which was designed especially to make fine-detailed high-precision pictures in order to measure the geometry of space-time and other fundamental cosmological quantities.

The cosmic microwave background (CMB) originated about 300,000 years after the Big Bang and it provides a crucial experimental laboratory for cosmologists to understand the origin and eventual fate of the universe because at that remote epoch matter had not yet formed galaxies and stars. Tiny density fluctuations at that time grew under the influence of gravity to produce all the structures we see in the universe today, from clusters of galaxies down to galaxies, stars and planets. These density fluctuations give rise to temperature fluctuations that are seen in the microwave background.

First predicted soon after World War II and first detected in 1965, the CMB arose when matter got cool enough for the electrons and protons to combine to form atoms, at which point the universe became transparent. Before this time the universe was an opaque fog because light couldn't travel very far before hitting an electron.

The CBI results released today provide independent confirmation that the universe is "flat." Also, the data yield a good measurement of the amount of the mysterious non-baryonic "dark matter" —which differs from the stuff everyday objects are made of—in the universe. The results also confirm that "dark energy" plays an important role in the evolution of the universe.

According to Anthony Readhead, the Rawn Professor of Astronomy at Caltech and principal investigator on the CBI project, "These unique high-resolution observations give a powerful confirmation of the standard cosmological model. Moreover this is the first direct detection of the seeds of clusters of galaxies in the early universe."

The flat universe and the existence of "dark energy" lend additional empirical credence to the theory of "inflation," which states that the universe grew from a tiny subatomic region during a period of violent expansion a split second after the Big Bang —a popular theory to account for troubling details about the Big Bang and its aftermath.

Because it sees finer details in the CMB sky, the CBI goes beyond the recent successes of the BOOMERANG and MAXIMA balloon-borne experiments and the DASI experiment at the South Pole.

The previous findings relied on a simple model that the higher resolution CBI observations have verified. If the interpretation were incorrect, it would require nature to be doubly mischievous to be giving the same wrong answers from observations on both large and small angular scales.

"We have been fortunate at CITA to work closely with Caltech as members of both the CBI and BOOMERANG teams to help analyze the cosmological implications of these exquisite high precision experiments," says Richard Bond, director of the Canadian Institute for Theoretical Astrophysics, " It is hard to imagine a more satisfying marriage of theory and experiment."

Given the radical nature of the results coming from cosmological observations, it is crucial that all aspects of cosmological theory be thoroughly tested. The fact that the CBI observations compared with others are at very different resolution, and that the various observations are made with widely differing techniques, at different frequencies, and cover different parts of the sky, and yet agree so well, gives great confidence to the findings.

The CBI hardware was designed primarily by Steven Padin, chief scientist on the project, while the software was designed and implemented by senior research associate Timothy Pearson and staff scientist Martin Shepherd. Postdoctoral scholar Brian Mason and three graduate students, John Cartwright, Jonathan Sievers, and Patricia Udomprasert all played critical roles in the project.

The photons we see today with instruments like the CBI, the earlier COBE satellite, and the BOOMERANG, MAXIMA, and DASI experiments, have been traveling through the universe since first emitted from matter about 14 billion years ago.

The temperature differences observed in the CMB are so slight, only about one part in 100,000, that it has taken 37 years to get images with details as fine as these presented today. Though first detected with a ground-based antenna in 1965, the cosmic microwave background appeared to be quite smooth to earlier experimentalists due to the limitation of the instruments available to them. It was the COBE satellite in the early 1990s that first demonstrated slight variations in the cosmic microwave background. The celebrated COBE images were of the entire sky, but the details were many times larger than any known structures in the present universe.

The CBI and the DASI instrument of the University of Chicago, which is operating at the South Pole, are sister projects that share much commonality of design, both making interferometry measurements of extremely high precision.

The BOOMERANG experiment, led by Caltech's Goldberger Professor of Physics Andrew Lange, demonstrated the flatness of the universe two years ago. The BOOMERANG observations, together with observations from the MAXIMA and DASI experiments, not only indicated the geometry of the universe, but also bolstered the inflation theory via accurate measurements of many of the fundamental cosmological parameters. The combination of these previous results with those announced today covers a range of angular scales from about one-tenth of a moon diameter to about one hundred moon diameters, and this gives great confidence in the combined results.

The CBI is a microwave telescope array comprising 13 separate antennas, each about three feet in diameter, set up in concert so that the entire machine acts as an interferometer. The detector is located at Llano de Chajnantor, a high plateau in Chile at 16,700 feet, making it by far the most sophisticated scientific instrument ever used at such high altitudes. The telescope is so high, in fact, that members of the scientific team must each carry bottled oxygen to do the work.

In five separate papers submitted today to the Astrophysical Journal, Readhead and his colleagues at Caltech, together with collaborators from the Canadian Institute for Theoretical Astrophysics, the National Radio Astronomy Observatory, the University of Chicago, the Universidad de Chile, the University of Alberta, the University of California at Berkeley, and the Marshall Space Flight Center, report on observations of the cosmic microwave background they have obtained since the CBI began operation in January 2000. The images obtained cover three patches of sky, each about 70 times the size of the moon, but showing fine details down to only one percent the size of the moon.

The next step for Readhead and his CBI team is to look for polarization in the photons of the cosmic microwave background. This will be a two-pronged attack involving both the CBI and DASI instruments and teams in complementary observations, which will enable them to tie down the value of these fundamental parameters with significantly higher precision. Funds for the upgrade of the CBI to polarization capability have been generously provided by the Kavli Institute.

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