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MAXIMA, a balloon borne experiment directed by UC Berkeley, finds evidence for a flat universe, inflation and a cosmological constant Berkeley -- Astrophysicists have taken another major step in depicting the universe in its infancy. The first results from a balloon borne experiment peering back to a time shortly after the big bang provide confirmation of a mysterious "dark matter" and "dark energy" that make up most of the cosmos.

Results of the experiment, an international collaboration called the Millimetre Anisotropy eXperiment IMaging Array (MAXIMA), directed by the University of California, Berkeley, are contained in two papers submitted Monday, May 8, to Astrophysical Journal Letters and scheduled for posting Tuesday on the internet at http://xxx.lanl.gov/list/astro-ph/new

The MAXIMA results confirm results announced last month by another group after analysis of data from a balloon borne experiment called Balloon Observations Of Millimetric Extragalactic Radiation and Geophysics (BOOMERANG), and extend these results to smaller angular scales on the sky. The MAXIMA map is the highest resolution map of the cosmic microwave background yet published.

These results provide strong evidence that the universe is flat, with a large scale geometry just like the Euclidean geometry everyone learns in high school. However, only about 5 percent of its mass and energy is comprised of ordinary matter -- the stuff of which the Earth, the stars and humans are made. The remainder is either cold dark matter -- the unseen mass that holds galaxies together -- or dark energy, a mystifying pressure or repulsive force that seems to be accelerating the expansion of the universe. The dark energy often is referred to as the cosmological constant.

"A subset of cosmological theories, those involving inflation, dark matter and a cosmological constant, fit our data extremely well," said team leader Paul Richards, UC Berkeley professor of physics. Inflation is the most popular cosmological theory describing the early history of the universe.

"This is a good confirmation of the standard cosmology, and a large triumph for science, because we are talking about predictions made well before the experiment, about something as hard to know as the very early universe."

The MAXIMA team, consisting of 22 collaborators from 13 institutions and five countries, is funded by the National Science Foundation and the National Aeronautics and Space Administration, with the Department of Energy supporting the data analysis.
http://cfpa.berkeley.edu/group/cmb/sanders/

"Although some members are common both to the MAXIMA and to the BOOMERANG teams, the two analyses were done completely independently," noted Shaul Hanany, professor of physics at the University of Minnesota, Minneapolis, and first author of one of the papers. "The fact that these independent experiments give such similar results is the best indication that we are both getting the science right." "These are extremely difficult experiments, and yet the data from MAXIMA and BOOMERANG show spectacular agreement," added cosmologist Adrian Lee, a leader of the MAXIMA project from the NSF Centre for Particle Astrophysics and the Space Sciences Laboratory, both at UC Berkeley.

Inflationary theories refer to an event that happened an infinitesimally small fraction of a second after the big bang, an explosive event that most astronomers believe kicked off our universe some 10-20 billion years ago. At that moment, the expanding universe underwent a rapid inflation that smoothed out the matter and energy. Only afterwards did pressure waves or sound waves imprint detailed information about the nascent universe on the clumps of hot, dense matter created during inflation.

This early history is invisible to us, but clues come from a time about 300,000 years later, when the universe cooled to approximately 3,000 Kelvin, allowing atoms of hydrogen to form. Light suddenly was freed from constant collision with charged particles, and flashed us a snapshot of the hot and cold clumps at that instant.

The radiant heat from that event cooled as the universe continued to expand, until today the microwave background is a mere 2.7 Kelvin, or 454 degrees Fahrenheit below zero. The hot and cold spots vary by a few parts per 100,000. MAXIMA and BOOMERANG both measured the temperature variations of the cosmic microwave background, producing thermal maps of the universe 300,000 years after the big bang.

The size of the spots in the thermal map told the cosmologists immediately one important parameter of the universe, its geometry or curvature. Both experiments saw spots clustered in a size range of about one degree across, indicating a flat universe like the ancient Greek geometer Euclid described more than 2,300 years ago. That type of geometry, the most familiar to us, is characterized by parallel lines that always remain the same distance apart.

A closed universe, akin to the two dimensional surface of a sphere where parallel lines eventually cross, would produce larger spots; an open universe, in which parallel lines always diverge, would produce smaller spots.

When combined with recent data on the universe obtained from studies of distant supernovas, the data also support the inflationary theory of the universe. Specifically, the experiments peg the amount of normal matter in the universe at about 5 percent; the amount of dark matter at about 30 percent; and the amount of dark energy -- cosmological constant -- at about 65 percent.

"That's probably the most interesting result of all these experiments," Hanany said. "The combination of our data with the data from supernovas is very powerful evidence that we need something like the cosmological constant to describe our universe. New physics may be required to explain the origin of the cosmological constant."

The cosmological constant was something Albert Einstein threw into his equations of the universe and subsequently tossed out as a mistake. The surprising supernova results of the past few years resurrected the idea, since the constant can describe a universe whose expansion is accelerating.

Richards noted that while the thermal map of the sky is a "pretty picture," most of the information comes from a detailed statistical analysis of the sky data along with data at large angular scales from the COBE mission.

Using super computers at the Department of Energy's National Energy Research Scientific Computing Centre (NERSC) at Lawrence Berkeley National Laboratory, the MAXIMA team calculated the power spectrum of the sky map, which is essentially the range of sizes of the hot and cold spots in the microwave background. Just as a cluster around one degree indicates a flat universe, clusters at smaller angular sizes are a hallmark of inflationary theories.

Though the MAXIMA results cannot unambiguously identify other peaks in the power spectrum, MAXIMA was able to derive other information that strongly supports inflation. Among these is a zero "tilt," which essentially means that, immediately after inflation, the fluctuations in the energy in the universe were uniform over all size scales.

"Inflationary theories make two main predictions," Lee said. "One is a flat universe. The other is that the power spectrum has no tilt. MAXIMA supports both of these predictions."

Richards also noted that the number -- about 5 percent -- obtained for the fraction of the universe made up of ordinary matter, called baryons, fits beautifully with entirely independent estimates from the theory of nucleosynthesis in stars.

"A lot of people are sceptical of cosmology, so when your results show this type of agreement, you have more confidence in your theories," he said.

Astronomers first became aware of the cosmic background radiation in 1965, with the accidental discovery of microwave emissions from all directions of the sky. This was taken as proof of the big bang, and theorists created numerous theories over the years to explain the evolution of the universe from its explosive birth.

In 1992, the Cosmic Background Explorer (COBE) satellite provided the first evidence that the microwave glow is not uniformly 2.7 Kelvin, but varies by as much as 100 millionths of a Kelvin above or below the average -- evidence of clumps and wrinkles in the very early universe.

These clumps of matter and energy presumably evolved into the clusters and super clusters of galaxies we see today. Various small experiments since then have measured the size of these variations, hinting at a flat universe. But MAXIMA and BOOMERANG have given cosmologists far clearer evidence for this, Richards said. COBE obtained a low resolution picture of the entire sky, accurately measuring the large scale clumps, and is complementary to the MAXIMA data. MAXIMA looked with finer resolution at an area representing 0.3 percent of the sky -- a spot about 11 degrees on a side, or 22 times broader than the full moon -- in a northern region of the sky near the constellation Draco.

The data used for the analysis reported today were obtained from the first flight of MAXIMA on Aug. 2, 1998, out of the National Scientific Ballooning Facility in Palestine, Texas. The balloon, launched at sunset, flies at about 130,000 feet for one night -- 7-10 hours -- and is returned to the ground by a parachute. The 1.3 meter telescope focuses the microwave radiation on detectors cooled to one tenth of a degree Kelvin by high tech refrigerators developed by Richards' group.

The detectors can sample the sky at angular resolutions from 5 degrees to 1/6 degree. COBE could get no smaller than 7 degrees. BOOMERANG, which started as a collaboration with MAXIMA, split off to pursue a riskier approach -- launching from a ballooning facility in Antarctica in order to observe for 10 days or more, at the cost of flying less often, typically at two to three year intervals. MAXIMA, launched from the U.S., can fly once or twice a year, is more sensitive and looks at a smaller area of the sky with finer detail, while BOOMERANG gathers data over a larger area of sky. http://xxx.lanl.gov/list/astro-ph/new

MAXIMA 2 flew in June 1999 and observed roughly twice the area that MAXIMA 1 observed. MAXIMA 3 will fly in the fall of this year and will attempt to measure the polarization of the cosmic background radiation, which has never been observed.

"That the radiation is polarized is another prediction of inflationary theories," Hanany said. "Polarization measurements are the new frontier in cosmic microwave background research."

Continuing analysis of the data from MAXIMA 1 and 2, combined with the 1992 COBE data and eventually the BOOMERANG data, should provide better measurements of all the cosmological parameters, said cosmologist Adrian Lee.

"There is still a lot more we can get from the MAXIMA data. We're looking for gold in those Doppler hills," he said.