Radiation Ripples From Big Bang Illuminate Geometry of Universe

By JAMES GLANZ

Like the great navigators who first sailed around the world, establishing its size and the curvature of its surface, astronomers have made new observations that show with startling directness the large-scale geometry of the universe and the total amount of matter and energy that it contains.

The results of those observations have provided powerful support for an audacious theory, first proposed 20 years ago, that may help answer the ultimate existential question: what ignited the Big Bang explosion in which scientists believe the universe was born?

The delicate measurements relied on telescopes placed high on mountains or borne by balloons to observe slight irregularities, or ripples, in a faint glow that permeates space and is thought to have been emitted from the fading fireball of the Big Bang explosion itself.

That glow is called the cosmic microwave background radiation, and the ripples imprinted on it can be used like ticks on a ruler to measure the cosmos.

The new data also provides fresh evidence to support a finding two years ago that the expansion of the universe is accelerating under the influence of a strange form of energy that fills empty space and apparently acts against gravity.

Many researchers had assumed that the bizarre finding would eventually be disproved, but the new observations support the existence of this energy, as well as the theory of what set off the Big Bang, called inflation, which was first proposed in 1980 by Dr. Alan Guth, a physicist at the Massachusetts Institute of Technology.

"It has such tremendous implications for the universe," Dr. Rocky Kolb, a cosmologist at the University of Chicago, said of the new work. Dr. Kolb described the range of its implications as as staggering.

One set of results, released yesterday, was obtained by a team led by

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scientists at the California Institute of Technology and La Sapienza, the main campus of the University of Rome, using a balloon-borne telescope for observing microwaves. A report describing the results of this so-called Boomerang experiment was posted on a Web site maintained at the Los Alamos National Laboratory; it has not yet been subjected to peer review. The Web site is:

http://xxx.lanl.gov

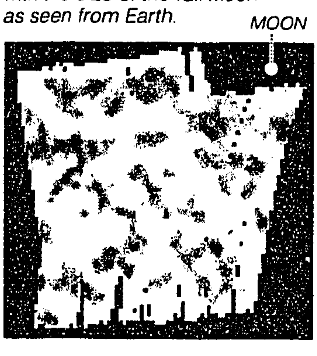
Last month, scientists at Princeton University and the University of Pennsylvania, who placed a telescope on a high plateau in Chile, published similar results in Astrophysical Journal Letters. Dr. Mark Devlin, from the University of Pennsylvania and a member of the team that worked in Chile, said, "These are completely different experiments with completely different calibrations and they fall right on top of each other."

A third team, centered at the University of California at Berkeley, has also released its preliminary map of the microwave background, made with another balloon-borne telescope.

A New Yardstick For the Universe

New observations of temperature variations, or ripples, in radiation left over from the Big Bang may enable astronomers to measure the total amount of mass and energy in the universe and its geometric structure.

Image of ripples in microwave background radiation compared with the size of the full Moon as seen from Earth.



Source: U.C. Berkeley/Maxima team

The New York Times

The teams' conclusions rest on measurements of the precise size of the ripples in the microwave background radiation. That size turns out to be about one degree on the sky, or about twice the apparent size of the full Moon as seen from Earth.

The size of the ripples is a direct indicator of the large-scale geometry of the universe, which, according to Einstein's general theory of relativity, is in turn determined by the total amount of matter and energy that the universe contains. Ripples of one degree indicate a "flat" universe, in which parallel lines never cross. Inflation, the theory of what provided the fuel for the Big Bang, predicts a universe that is almost exactly flat.

"We're seeing that the universe is flat to amazing precision," said Dr. Craig Hogan, a cosmologist at the University of Washington. "It's what inflation predicted."

Dr. Scott Dodelson, a cosmologist at the University of Chicago, said, "Basically it gets a flat universe dead-on."

And that leads astronomers to their next conclusion: because the amount of matter found by astronomers cannot produce a flat universe, Dr. Dodelson said, "the inescapable conclusion is that there is some unknown form of energy contributing to the total density." (This unknown energy is distinct from so-called dark matter, once described as the missing mass of the universe.)

The most likely candidate for that exotic energy, Dr. Hogan and Dr. Dodelson said, is what has come to be known as the cosmological constant, an energy with repulsive gravity that may fill apparently empty space. Einstein first proposed the concept, thinking that he needed it to keep the universe from collapsing, but he later renounced the idea when it was discovered that the universe was expanding.

The geometry of the universe is determined solely by the amount of matter and energy contained in it, according to Einstein's general theory of relativity, which explains gravity as the "curvature" of spacetime. In a geometrically "closed" universe, photons of light, initially traveling parallel to each other, would eventually converge, just as lines of longitude on Earth's curved surface meet at the poles.

Cosmologists agree that the universe could have three possible geometries. Besides the closed geometry, the universe might be open or flat. In an open geometry, parallel lines would diverge, and in a flat universe they would simply remain parallel.

Relativity predicts that a closed universe contains more matter and energy than a certain fixed amount. An open universe contains less, and a flat universe holds precisely that amount: the one predicted by Dr. Guth's theory.

According to the theory of inflation, a small piece of space became catastrophically stretched by the energy of fields that are predicted by advanced theories of physics. Those theories unify all known interactions between particles. No matter how curved that part of space might have been to begin with, this "inflation" would have stretched it out, like the surface of a balloon as it is blown up, in a tiny fraction of a second and created a flat universe. The tremendous well of energy in the inflated piece of space would have served as the fuel for the subsequent fireball of the Big Bang.

In the present universe, gravity does warp the relatively small regions of space close to massive objects like the Sun, neutron stars or black holes. Still, some cosmologists had suggested, on purely aesthetic grounds, that the universe in the large would be free of curvature. Inflation, with its cosmic stretching, was the first theory to explain why those suspicions might be true.

But despite that stretching, inflation would also leave telltale ripples on this exploding, Big Bang universe. The ripples occur because of principles of quantum mechanics, which impose a kind of small-scale fuzziness on all particles. The ripples in the microwave background are thought to be the legacy of that early quantum fuzziness.

The background radiation, cosmologists believe, was emitted from the fireball of the Big Bang after the inflationary expansion a few hundred thousand years after the creation event. The radiation then traveled through space for roughly 15 billion years, the present estimated age of the universe, and arrives at Earth as a sort of cosmic fossil.

"The ripples themselves were produced during inflation," Dr. Kolb said.

Because cosmologists can calculate the actual size of the ripples in the young universe, their apparent size on the sky is a measure of whether radiation from them traveled to Earth on straight or curved paths. The paths turned out to be straight, providing the main piece of evidence for the flat universe.

The Boomerang experiment measured the ripples using a telescope based on reflecting, aluminum optics and a cooled, semiconducting detector that looks like a tiny spider web, said Dr. Paolo de Bernardis, an astrophysicist at La Sapienza, who is a principal investigator of the Boomerang experiment. The microwaves heat the detector very slightly, and that change is converted into an electronic signal.

"The system is so cool and so clean that you can detect these changes in the system," he said.

The Maxima experiment, based at Berkeley, used a related balloon-borne system. The Microwave Anistropy Telescope, which made its own measurements from a high plateau in Chile, used an entirely different detector based on powerful electronic amplifiers.

All the data are consistent with a flat universe, said scientists on the projects and others who have read the teams' reports.

"These really favor a flat universe," said Dr. Alessandro Melchiorri, an astrophysicist at La Sapienza.

Dr. Kolb of the University of Chicago said that the new results easily represented the biggest step in the field since NASA's Cosmic Microwave Background Explorer first saw the barest outlines of the ripples in 1992. Even that satellite could not detect the much tinier ripples that have been measured by the new telescopes. Dr. Kolb described the reaction of inflationary cosmologists to the new data as one of "guarded euphoria."

Scientists on all the experiments said that even more precise data would soon be made public, offering the promise of even tighter tests of inflation, and of the geometry and contents of the universe.

"You haven't seen anything yet," said Dr. Adrian T. Lee, a Maxima collaborator at Berkeley. "We are entering the era of precision cosmology."