metric Interferometer for Astrophysics, slated for launch in 2006 and 2009, respectively, will probably settle the matter.

–GOVERT SCHILLING

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ASTROPHYSICS

BOOMERANG Returns With Surprising News

For months, cosmologists have been rumbling with excitement, awaiting a look at the data that an antarctic balloon brought back from the edge of the universe. Now the wait is over. On 27 April, a map published in the journal *Nature* gave scientists their most detailed glimpse yet of the primordial universe, revealing the shape of the cosmos and the distribution of matter shortly after the big bang. It was worth the wait: The data support most cosmologists' view that the universe is "flat," but cast doubt on some key assumptions about the balance of matter it contains or the nature of its early expansion.

The data came from BOOMERANG, a set of sensitive microwave detectors that a truck-sized helium balloon carried on a 10-day swing around the South Pole in late 1998. During the flight, BOOMERANG (a contorted acronym of "Balloon Observations of Millimetric Extragalactic Radiation and Geophysics") probed a large swatch of sky for fluctuations in microwave radiation, a constant electromagnetic hiss that bombards Earth from all directions, accounting for about 1% of the noise on our television sets. The cosmic microwave background (CMB) is the leftover glow from the big bang.

"This is probably the farthest light that can be observed," says Phil Mauskopf, an astrophysicist at the University of Massachusetts, Amherst, and one of 36 scientists on the international team that masterminded the project. Soon after the birth of the universe, photons were tightly coupled to the hot plasma that made up most of the universe. Light and matter acted as a single fluid. But about 300,000 years after the big bang, the universe cooled enough for the plasma to condense, and the photons escaped from their cage of matter. The CMB is a snapshot of that moment. Thus, by looking at little fluctuations in the CMB, astronomers can map the ripples in the light-matter fluid just as the photons broke free. "You're looking at the surface of the early universe," Mauskopf says.

Unfortunately, the microwave background is so faint that noise from the ground and the atmosphere tend to swamp the signal from the heavens. To escape the racket, the scientists sent their microwave telescope up in a balloon, lofting it into a wind current that circles Antarctica. True to its name, BOOMERANG swung around the South Pole, returning 10 days later almost exactly to its starting point. Because the instrument was aloft for so long and had very sensitive detectors, it was able to measure the CMB over a wide area with great precision and with very low noise.

"It's really the first high-resolution map across a large part of the sky," says Wayne Hu, a cosmologist at the Institute for Advanced Study in Princeton, New Jersey. The balloon experiment has a resolution of about one-third of a degree; the famous COBE satellite, which first detected larger scale fluctuations in 1992, has a resolution of about 7 degrees.

The results are exciting—and in some cases surprising. According to relativity theory, the four-dimensional "sheet" of space and time that we live on can be curved. For years, astrophysicists have been figuring out the ways in which curved space might distort the images of distant objects, in hopes that astronomers would be able to tell by looking just which sort of space we live in—spherelike, saddle-shaped, or neither.

On ice. Five-meter-high BOOMERANG apparatus during testing at McMurdo Station, Antarctica.

CREDIT: BOOMERANG TEAM

"The best part is nobody has to know all of this any more, because the universe is flat," says Scott Dodelson of the Fermi National Accelerator Laboratory in Batavia, Illinois. BOOMERANG and other recent CMB experiments show that the fluctuations are not distorted as theory says they would be in curved space. But whereas a flat universe is what astronomers expected, another bit of BOOMERANG data took them by surprise. According to theory, the ripples in the microwave background ought to exist on many different scales, each contributing a "peak" to the data. BOOMERANG saw a peak corresponding to roughly 1-degree–sized fluctuations and theoretically should have spotted a half-degree peak as well. It didn't.

"With the simplest models, [the peak] should have been higher," Hu says. "It should have been detected." University of Pennsylvania physicist Max Tegmark is excited by the surprise. "That is extremely interesting," he says. "The mischievous side of me wanted that to happen."

The missing peak means that simple models of how the universe formed and what holds it together cannot be correct. To explain the observations, cosmologists must add some new wrinkles, but each has its own problems. "You can raise the amount of ordinary matter, baryons, in the universe, pushing up the first peak and pushing down the second," Hu says. "But you have to push it up significantly, something like 20% to 50%." You could jack up the amount of dark matter in the universe as well, or "tilt" the properties of the engine that drives inflation, or lengthen the plasma phase of the universe. But each of those models requires rethinking basic assumptions, Tegmark says. "You'd have to be violent to one of the sacred cows of cosmology." If he had to choose, Tegmark says he would rather add matter than accept the tilt or late-recombination theories. "Those are the two lesser evils of those four." Hu, on the other hand, favors a combination of extra matter and tilt.

The news is not all bad for the Standard Model, Tegmark says; the shape of the 1-degree peak eliminates some alternative theories to the inflationary model, such as the ones that assume that "topological defects" rather than inflation were responsible for the structure of the universe. "With topological defects, you only predict one peak, but a very broad one. This peak is way too narrow," says Tegmark. "This really means that most of the rivals to the standard theory just died." Thus, variants of the Standard Model are really the only game in town.

Which variants prevail will depend heavily upon future results. Much of the BOOMERANG data has yet to be processed, and soon NASA will be launching a microwave-sensing satellite, MAP, which might catch sight of the second and even a yet-to-be-discovered third peak. That would tell scientists just how much invisible dark matter and baryonic matter there is in the universe and would help nail down the values of 10 or so cosmological parameters, such as the cosmological constant. "The measurements that come out of that are going to be much more sensitive ways of weighing the universe than other cosmological tools," says Tegmark. "To me, this experiment really signifies the beginning of a new era."

–CHARLES SEIFE