ASTRONOMY

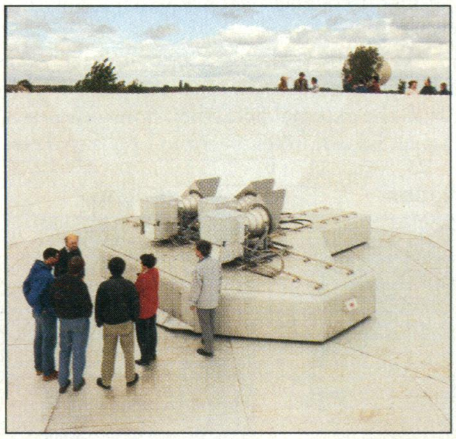
Interferometer Maps Cosmic Microwaves on the Cheap

CAMBRIDGE, U.K.—Four years ago, the National Aeronautics and Space Administration's Cosmic Background Explorer (COBE) satellite stunned the world with the first direct image ever of the cosmic microwave background (CMB)—the faint afterglow of the big bang. Because the details of the radiation show how matter was distributed through the newborn universe some 15 billion years ago, such images hold "the promise of explaining the origin of galaxies, clusters of galaxies, and voids that are observed today," says Ed Cheng of NASA's Goddard Space Flight Center. But while COBE was a first, its resolution was poor.

Now a team here has demonstrated the ability of a relatively cheap prototype ground-based telescope system to create an image of the CMB that is 60 times as sharp. The new Cosmic Anisotropy Telescope (CAT) is an "interferometer" that combines signals from three small microwave receivers placed a few meters apart. Its first image, which was presented at last week's Moriond Astrophysics Meeting in Les Arcs, France, and will appear next month in *The Astrophysical Journal*, is largely a proof of principle, but other astronomers think the technology will soon be yielding insights into cosmic origins. "I think that the CAT-like technology—interferometers—is the best way to obtain the smaller angular scale data," says George Smoot of Lawrence Berkeley National Laboratory, a member of the COBE team.

The CMB is a feeble microwave noise that permeates all space and represents a snapshot of the fledgling universe at an age of 300,000 years, when the initial fireball had cooled enough to become transparent. Originally emitted at optical wavelengths, the radiation shifted to longer wavelengths as the universe expanded, ultimately reaching an energy equal to that given off by a body at 2.7 kelvin. But, as COBE was the first to show, the temperature of the signal fluctuates slightly from point to point in the sky. Hot spots in the pattern mark density peaks in the primordial fireball, which would one day condense into galaxies and clusters of galaxies.

The COBE results, however, had an angular resolution of only about 10 degrees. "Ten degrees, if you ask what does that correspond to in terms of scale sizes of objects around today, is absolutely huge," says CAT scientist Anthony Lasenby of Cambridge University's Cavendish Laboratory. "It's much bigger than any actual object we know about in the universe." COBE's angular resolution was limited because it built up a map by comparing the signals arriving at each of two microwave horns set in a V configuration, each horn gathering signals from a large patch of sky. Balloon experiments, surveying the CMB with an antenna that rocks back and forth to compare signals from different points in the sky, have managed resolutions as fine as 1 or 2 degrees, but they did not gather enough information to create images.



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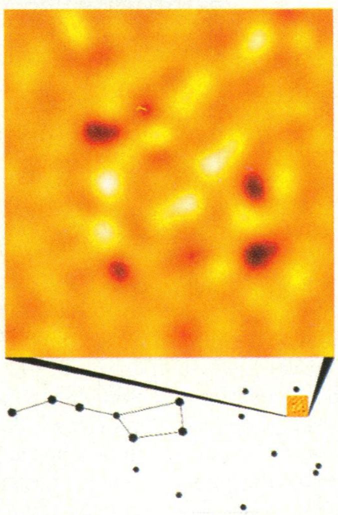

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CAT's eye. The three horns of the CAT interferometer *(above)* and the fine structure they reveal in the microwave background near the Big Dipper.

CAT achieves a finer resolution by using three separate microwave receiving horns, each 70 centimeters in diameter, linked to low-noise electronics cooled with liquid helium. The separation between the receivers increases their resolution by allowing them to simulate a single, larger antenna. At less than 2 meters, the spacing is surprisingly small, but it tunes the apparatus to an angular scale that is of great interest to cosmologists, around a third of a degree.

Besides yielding higher resolution, this setup also enabled the Cambridge group to beat some of the interference problems that have forced other groups to fly their instruments on balloons or satellites. "Nature has made these measurements relatively difficult, impressing roughly 30 microkelvin variations on a 3-kelvin CMB signal that we have to measure living in a 300-kelvin environment," explains Cheng. The main enemy is water vapor. At 300 K it gives off microwave signals a million times stronger than those of the CMB fluctuations, so these experiments are like trying to read a faint illuminated sign through the beam of a search light.

"We thought we could make these observations successfully from the ground," says CAT group leader Paul Scott, "and the reason ... was that we use interferometers." By combining the signals from all three horns, the group could cancel out the bulk of the atmospheric emission. They also switched between frequencies and averaged data over a period of several months to remove other atmospheric effects. At the same time, careful horn design and an aluminum shield half enclosing the apparatus largely eliminated emissions from the ground, which are also strong enough to swamp the CMB.

The final image, built up from the three receivers by a technique called aperture synthesis, shows primordial structures on scales small enough to be compared with the distribution of existing galaxies. It also yields a point on what cosmologists call the "power spectrum" of the CMB. This is a measure of the relative contributions of regions of different sizes to the overall brightness distribution of the CMB. Competing cosmological models predict different forms for the spectrum, and the position of a peak in the power spectrum yields clues to the overall mass density of the universe. Results from COBE and other experiments fall on one side of the region that must contain this peak. The single point from CAT falls on the other side, so it should help astrophysicists set tentative limits to the overall density of the universe.

The Cambridge team now plans to build a 10-horn version of CAT, nicknamed the Very Small Array, in Tenerife in the Canary Islands. This instrument, together with new satellite experiments, will soon fill in the rest of the power spectrum. "We've done simulations which show that with the [Very Small Array] you can actually read off each of the wiggles separately in the power spectrum," says Richard Saunders of the CAT team. As a result, says Lasenby, "an amazing era is just dawning now when we can start discriminating between the different theories [of cosmic origins] in a way that proponents of the theories, I shouldn't think, would ever have thought we'd be able to do."

–Andrew Watson

Andrew Watson is a writer in Norwich, U.K.