Fluctuations discovered in cosmic background radiation

The findings from the Cosmic Background Explorer raise many questions, above and beyond whether it proves the validity of a hypothetical Big Bang cosmology. David Cherry reports.

The discovery of temperature fluctuations in the cosmic microwave background radiation (CBR) was announced April 23 by a team of scientists at the Washington meeting of the American Physical Society.[1] The finding, which results from analyzing the first year of data from NASA's Cosmic Background Explorer satellite (COBE), is being hailed as a big boost for "Big Bang" cosmology.

Without the eventual discovery of *some* fluctuations, the Big Bang theory would be in big trouble, even in the eyes of its staunchest defenders. For years, cosmologists have been revising their theories to predict fluctuations of lesser and lesser amplitude, as better and better searches failed to find the previously predicted ones—until now.

According to the Big Bang hypothesis, the universe began as a point without dimensions; has expanded to its present size; and will either expand until there are no energy differentials for living things to exploit ("heat death"), or will eventually cease expanding and collapse upon itself in a gravitational catastrophe. For the most part, this fashionable hypothesis—obligatory for professional astronomers—has been turned by our institutions into a certitude and a substitute for religion, but with the opposite conclusion: It is used to show that human existence is pointless. Big Bang cosmologists themselves—with exceptions—converge toward agreement on this point. Some Christians have endorsed the theory for its seeming coherence with the account of Creation in Genesis, as well as its prediction of a programmed "apocalyptic" death of the universe. Of course, this latter point has made the theory attractive to malthusians who see it as substantiating their anti-human assumptions.

It is necessary to distinguish between this philosophical misuse of a scientific hypothesis and the scientific value of the hypothesis itself. But the Big Bang does not do well by the latter standard, since, like much of scientific thought in the 19th and 20th centuries, it is premised on the dominance of no more than gravitation and random collisional processes. The theory cannot account for the existence of the human mind. Nor is there room in it for the possibility of a future in which the human mind might play an ever-larger role in ordering the universe, as it has built civilizations on Earth.[2]

Fluctuations in Big Bang theory

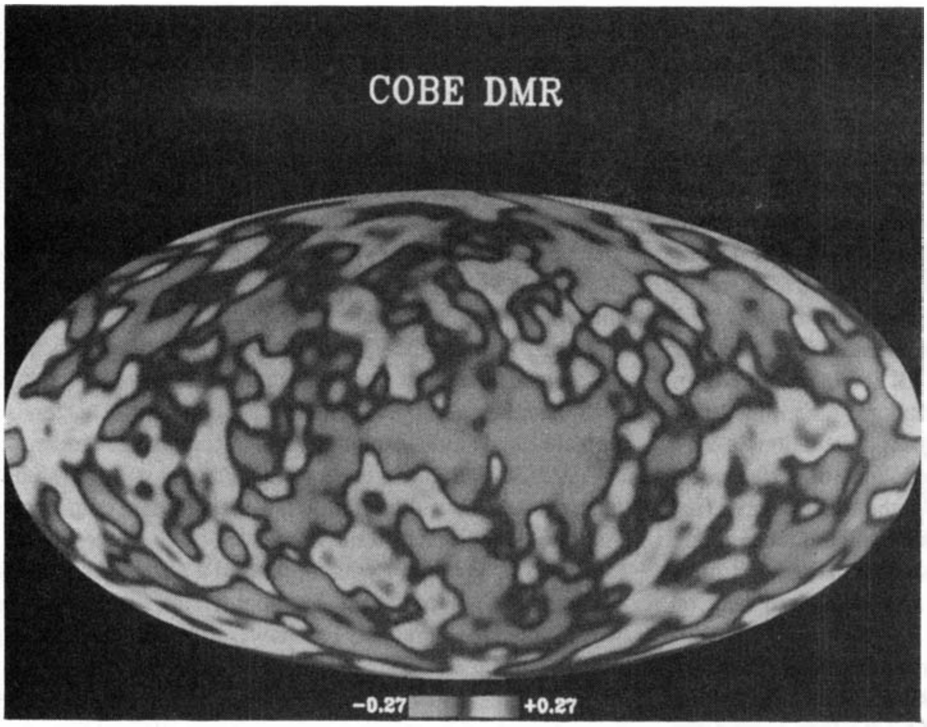
The existence of the cosmic microwave background radiation is a cornerstone of Big Bang theory, and the theory goes on to say that there must be fluctuations (signs of gravitational clumping) if the eventual formation of galaxies and clusters of galaxies is to be explained.

The reported fluctuations are much too large in spatial extent (too large in "angular scale," strictly speaking) to represent the precursors of galaxies or galaxy clusters. Such precursors are still being sought.

If the reported fluctuations are confirmed, however, they are important, Big Bang or no Big Bang, as they disclose an important feature of the cosmos.

The measurements on which the announced finding rests—hundreds of millions of them—were made by the Differential Microwave Radiometer (DMR), one of the instruments aboard the Cosmic Background Explorer that was launched in 1989.

The DMR is a set of three radio receivers, each with a pair of horn antennas. The members of each pair of antennas are set at a 60-degree angle with respect to each other and the radio receiver into which they both feed is sensitive to the difference in the amount of power coming down the horns. This means it is measuring differences in brightness or temperature across the sky. The antenna pairs are tuned to



This computer-generated map of the sky, using COBE data, shows the reported temperature fluctuations in the cosmic background radiation. The discovery, if confirmed, discloses an important feature of the universe.

The original computer image is in color, with light blue for relative cold, dark blue for cool, pink for warm, and red for relative hot—the entire range, of course, is minute. In this black and white print, the lightest regions correspond to pink; the darker patches in their centers are red. The lightest (pink) regions are bounded by dark blue; the large, medium-dark regions are light blue.

Most of the apparent temperature differential shown on the map is actually instrument noise. Computer statistical analysis is used to show that some of it is not.

wavelengths of 3.3, 5.7, and 9.6 millimeters, respectively.

Credit for the identification of the fluctuations belongs to the team responsible for COBE science, known as the COBE Science Working Group, chaired by Rainer Weiss of the Massachusetts Institute of Technology (MIT), with John Mather of NASA's Goddard Space Flight Center as project scientist. Mather, whose interests include cosmology and infrared optical astronomy, has been the leader of the team on a day-to-day basis for 15 years. George Smoot of the Lawrence Berkeley Laboratory in California is principal investigator for the DMR instrument aboard COBE. Charles Bennett of Goddard is deputy principal investigator, and others have had major roles.

The team had had indications that fluctuations were present in the data as early as last August, but made no announcements, while they subjected the data to extensive computer analysis and searching criticism.

The evidence for the existence of fluctuations is "not strong," according to the team's press release issued by the Lawrence Berkeley Laboratory April 23. The release goes on to say, however, that the scientists "believe their measurements and maps are correct, and will attempt to corroborate their findings with additional data" from other experiments and from COBE.

The view that the evidence is "not strong" is not the majority view in the Science Working Group, however. In an interview with this author, Harvey Moseley of Goddard, a member of the group, said, "We are as sure as we can be that the results are correct, and would not have come forward with them without such confidence." George Smoot is reported to have said that there is a "10 to 20%" chance the finding is wrong. But Moseley commented, "That's like trying to quantify the perversity of the world. That's not the result of any statistical measure of confidence. Any remaining doubts have less to do with this finding, and more to do with the nature of life itself."

Smoot predicts a "gold rush" of physicists trying to confirm or disconfirm the finding. Stephan Meyer of MIT, another member of the Science Working Group, who has also participated in MIT balloon-borne experiments to search for the fluctuations, says the MIT results overlap those just reported from COBE. The MIT group found an upper limit for the possible amplitude of temperature fluctuations—it is in the middle of the range found from COBE data—but the MIT group found no lower limit, leaving open the possibility that fluctuations are smaller, or even absent. The comparison is not direct, and depends upon some assumptions, since the MIT instrument is looking for fluctuations of smaller spatial extent. Meyer hopes a lower limit may yet be found from the MIT data, much of which have not yet been analyzed.

What is the cosmic background?

If you tune your FM radio to the quietest position between stations and turn the volume up, you will hear a quiet ocean of background noise. Most of it comes from warm objects around you, and small parts of this radio transmission come from the Sun and our galaxy. But one-half percent comes from the cosmic background, which gets its name from the fact that its intensity is the same in all directions (except for the minuscule variations just reported), and hence is not arriving from any isolated source.

Just as Karl Jansky in 1930 discovered by accident the existence of radio waves arriving from space, so Arno Penzias and Robert Wilson discovered by accident the cosmic background component of these radio waves in 1964—thinking at first that they had a bug in their equipment. The cosmic background is in the microwave or short radiowave range (its intensity peaks at a wavelength of 1 mm), and is vastly less intense than the beams in microwave ovens. It is so faint that its temperature is 2.73° Kelvin, or 2.73° above absolute zero.

In January 1990, a COBE instrument determined that the spectrum of the cosmic background radiation is very precisely that of the hypothetical black body or perfect equilibrium radiator; its spectrum follows the Planck curve (see **Figure 1**). And now it is reported that there are temperature fluctuations in the cosmic background radiation, but none larger than 6 parts per million in amplitude (see map on preceding page).

The cosmic background radiation also establishes a reference frame for all local motions: Find the vector sum of the motion of the Earth around the Sun, the Sun around the galaxy, and the galaxy in the local group and Virgo supercluster; then aim a pair of antennas, one directly into this line of motion and one in the opposite direction. The cosmic background wavelengths will be Doppler-shifted in equal and opposite amounts, relative to measurements at right angles to this line. (Doppler shifting is the lengthening or shortening of wavelengths owing to relative motion: When a locomotive approaches, the pitch of its whistle sounds higher than it does to those on board; after the train passes, the pitch drops and is lower than it sounds to those on board. The same phenomenon occurs with light waves: Light redshifts as the source recedes and blueshifts as it approaches.)

This much is the outline of what we really know about the cosmic background radiation. But what causes, or what caused, the background radiation? No one really knows.

The assumption "that the microwave background is truly primordial . . . is the foundation for all of our theories of the Big Bang expansion," wrote Yale astrophysicist Lawrence Krauss in his 1989 book, *The Fifth Essence—The Search for Dark Matter in the Universe*. The assumption is not arbitrary, but the evidence that drives it is "circumstantial," as Krauss puts it.

The Big Bang account

Let's go back a step, and review what the Big Bang theory is, and how it emerged.

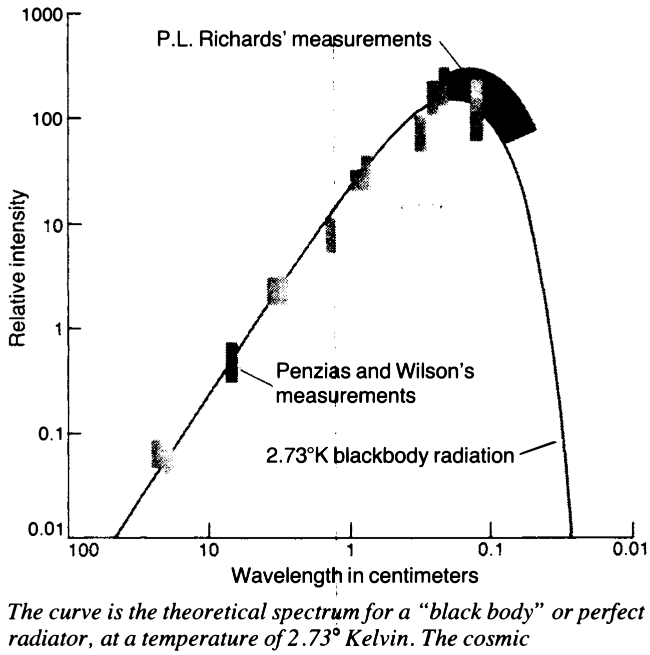
In Einstein's 1916 theory of general relativity, the equations that describe the universal gravitational field are generic—that is, capable of many solutions. Broadly, the universe could be static, expanding, or contracting. These equations were to become the foundation of the Big Bang theory.

In 1929, the American astronomer Edwin Hubble announced that the redshifts of galaxies increased on average as the galaxies got fainter—that is, as they became more distant. He interpreted the increasing redshifts as increasing velocities, and concluded that the universe was expanding. Thus he interpreted the shifts toward the red end of the spectrum as a Doppler-like effect in the realm of light. (Although he soon came to doubt this interpretation of the redshifts and never returned to it, the expanding universe became the dogma, and Hubble's views were then systematically misrepresented and certain of his papers ignored.[3])

The Big Bang theory as a history of the universe, based on general relativity and the Hubble expansion, was first formulated by Georges Lemaître, a Belgian priest-scientist. Lemaître had studied solar physics at Cambridge University in 1923-24 and there became acquainted with Einstein's champion Arthur Eddington, who was president of the Royal Astronomical Society at the time.

In his 1933 book, Lemâitre posited a primeval egg about 30 times the volume of the Sun, containing everything that was to form the universe. The universe began when the egg

FIGURE 1
Spectrum of cosmic background radiation



The curve is the theoretical spectrum for a "black body" or perfect radiator, at a temperature of 2.73° Kelvin. The cosmic background radiation was predicted to have this spectrum. The dark blocks are the actual measurements, with their error ranges, as of the mid-1970s. In 1990, data from a spectrometer aboard COBE showed that the actual spectrum follows the theoretical curve very precisely.

The intensity of the radiation peaks near a wavelength of 1 millimeter. The COBE antennas searching for fluctuations are tuned to wavelengths of 3.3, 5.7, and 9.6 millimeters, all near the peak.

exploded. The universe has been expanding ever since, according to the theory.

This original Big Bang theory was greatly refined and elaborated by the Ukrainian-American physicist, atheist, and popular writer George Gamow, beginning in 1946. Gamow wrote that the universe began with a singularity, that is, an infinitely small but infinitely dense point—as Einstein's theory strictly required. He argued that after the explosion occurred, in the first fractions of a second, the expanding egg was made of neutrons and their decay products—a mixture of neutrons, protons (hydrogen nuclei), free electrons, and electromagnetic radiation (light)—and was too hot for helium nuclei to stably form.

With expansion, the mess cooled, allowing the formation of helium and other light nuclei, all before the elapse of the first second.

The cosmic background radiation came much later, after about 300,000 years of expansion. Until that time, radiation within the fireball could not travel independently of the matter because the sea of electrons and protons was so dense. It was reabsorbed by matter as quickly as the matter would emit it. Then came the era of "decoupling of matter and energy" at about 300,000 years: When expanding and cooling had gone sufficiently far, electrons combined with protons to form atoms, and the radiation could travel. That initial burst of light should still be visible to us, who are "inside" the still-expanding ball ("outside" is undefined), because all subsequently generated light must be vastly less intense.

It will, however, be very weak today, having spread out over a much-expanded universe (about 5° K was originally predicted, 2.73° K is the measured value), and greatly redshifted toward longer wavelengths by the expansion of the universe (much like Doppler shifting), so that its peak intensity was predicted to occur at a wavelength of about 1 mm, as it does. Since matter and energy were in equilibrium up until decoupling, the radiation should show a black-body spectrum.

Despite the apparent triumph of these predictions, there are criticisms and questions that are more easily ignored than answered. Edward Harrison, a well-known astronomer at the University of Massachusetts at Amherst, argues that the fluctuations seen by COBE may not arise in the manner specified in the Big Bang account, but may result from the formation of galaxies. Harrison told the May 12 issue of the *New York Times* that in galaxy formation, gases are compressed by gravitation and are heated up enough for hydrogen atoms to be stripped of their electrons. This process, he said, could be responsible for the fluctuations found by COBE.

In making this point, Harrison is not bringing into question the Big Bang. There are critics of the Big Bang, however, who also attribute the cosmic background radiation to galaxy formation or even, most recently, to the cumulative effect of supernovae (Halton Arp et al., "The Extragalactic Universe: An Alternative View," *Nature*, Aug. 30, 1990).

Irving Segal, professor of mathematics emeritus at MIT, author of *Mathematical Cosmology and Extragalactic Astronomy* (1975), and a critic of the Big Bang, rejects the notion that either of the two major COBE discoveries is uniquely indicative of a Big Bang. The black-body spectrum of the cosmic background radiation, he says, is simply "the most likely disposition of remnants of light on a purely random basis, assuming the classic principle of the conservation of energy." The reported fluctuations "would be a concomitant of almost any known type of possible physical origin for this radiation," he says. Perhaps such views are not published in the *Astrophysical Journal*, but they reached a wide audience in letters columns of the *New York Times* (May 4, 1990; May 13, 1992).

The *Times*, following the lead of *Nature*, has given some encouragement to attacks on the Big Bang over the past three years, usually by advocates of some other cosmology.

The discoveries of COBE, the Gamma Ray Observatory, the Hubble Space Telescope, and kindred pioneering explorations, however, are far more valuable than the cosmological constructions within which these discoveries are usually encased.

Any deeply thoughtful person is obliged to consider the conclusion of the 88-year-old Russian astronomer Boris Vorontsov-Vel'yaminov. In the last paragraphs of his *Extragalactic Astronomy* (1987), the old astronomer wrote:

"Under our noses, spaceflight has moved humanity out of the Earth into the cosmos, having carried out, it seemed, the impossible: It revolutionized those ideas which seemed most secure about the nature of the planets—*the closest celestial bodies to us*. Taking this into account, do we really know enough about the cosmos to picture correctly the state and the processes in the universe billions of years ago?"

All the same, he believes, it is necessary to construct theories and hypotheses. He is more comfortable, however, with their transient character than are the institutions of science today.

Notes

1. The findings are reported in G.F. Smoot et al., "Structure in the COBE DMR First Year Maps," E.L. Wright et al., "Interpretation of the CMB Anisotropy Detected by the COBE DMR," C.L. Bennett et al., "Preliminary Separation of Galactic and Cosmic Microwave Emission for the COBE-DMR," all submitted to *Astrophysical Journal Letters* April 21, 1992, and A. Kogut et al., "COBE DMR: Preliminary Systematic Error Analysis," submitted to *Astrophysical Journal* April 21, 1992.

2. There are, of course, criticisms of the Big Bang on grounds that it contradicts itself: The beginning of time would seem to imply a "time" before time; the concentration of everything into a dimensionless point would make it a black hole from which nothing is supposed to escape. Perhaps these are not important. Perhaps any imaginable answer to the big questions is not free of "logical" contradiction when seen from our benighted standpoint.

3. Grote Reber, "The Big Bang is Bunk," *21st Century Science & Technology*, March/April 1989.

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