How Cosmology Became a Science

The discovery of the cosmic microwave background in the 1960s established the big bang theory and made cosmology into an empirical science

by Stephen G. Brush

Did the universe begin, or has it always existed? Scientists long regarded this question as lying outside their concern, in the metaphysical realm of philosophers and theologians. Not until the middle of this century did physicists and astronomers begin to equip themselves with theories powerful enough and experimental techniques sensitive enough to address the issue.

Two competing cosmologies then emerged. One, popularly called the big bang, assumes that the universe evolved from initial conditions so hot and dense that only radiation and elementary particles could exist; the universe then expanded and cooled, precipitating the stars and galaxies. The opposing model offers a universe that has always existed; the dispersal of matter resulting from the observed expansion of the universe is compensated by the continuous creation of matter.

The big bang theory has prevailed, largely because of the prediction, observation and interpretation of a phenomenon known as the cosmic background radiation. This radiation, widely regarded as the afterglow of the big bang, suffuses the sky in all directions at microwave frequencies. Arno A. Penzias and Robert W. Wilson of Bell Laboratories discovered the cosmic background in 1964–65 while trying to rid their radio antenna of microwave noise. The steady state model of the universe predicted no such radiation and could not plausibly account for it. Thus, for the first time, hypotheses about the origin of the cosmos had faced an empirical test that left a winner and a loser.

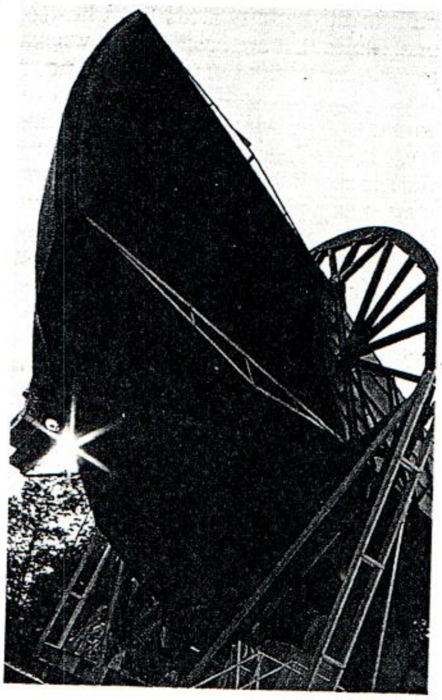
Rarely do theories stand or fall on the outcome of a single test. This time, however, opinion shifted almost overnight. Within a few years, most cosmologists had either adopted the big bang theory or ceased publishing in the field. Penzias and Wilson won the Nobel Prize in Physics in 1978 for their achievement. Just this past April, measurements of minuscule variations in the background radiation vindicated another prediction of the big bang theory.

Yet no one could have appreciated the significance of the cosmic microwave background without the legacy of knowledge that many other scientists had been building throughout the century. The history of the discovery yields another kind of insight. By following the story past 1965 to see how the discovery affected the standing of rival cosmological theories, we can test competing ideas about the nature of scientific progress.

Big bang cosmology began to come into focus in the 1930s, after Edwin P. Hubble, the eminent American astronomer, showed that galaxies appear to recede from one another and that the most distant ones recede at the greatest rate. Hubble's finding implies that the universe is expanding. It was also interpreted to imply that the cosmos had once been concentrated in a very small space at a definite time. Alexander A. Friedman, a Russian physicist, and Georges Lemaître, a Belgian priest, each used Albert Einstein's general theory of relativity to describe how such an expanding universe might evolve.

Nuclear physics played a role by providing the tools with which to model the synthesis of the elements from fundamental particles. Those tools served not only George Gamow, champion of the big bang, and his colleagues Ralph A. Alpher and Robert Herman but also Fred Hoyle—then at the University of Cambridge—who favored the rival steady state theory.

Vital to the theoretical work was the



COSMIC AUDITORS Arno A. Penzias (*left*) and Robert W. Wilson (*right*) of Bell Laboratories pose on the microwave horn antenna (*shown on this page*) that first cupped an ear to the big bang.

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contribution that Einstein and Max Planck made around the turn of the century while formulating the physics of blackbody radiation. The blackbody gets its name from its idealized property of absorbing all incoming radiation and then reradiating it. This reradiated energy is distributed across the spectrum in a highly characteristic pattern, predicted by Planck. Because the primordial fireball, in its early phases, would have put energy and matter into perfect thermal equilibrium, the first radiation liberated from the cooling explosion would have to have displayed the blackbody pattern.

Still to be supplied was a precise calculation of how energetic that spectral pattern would appear today, many billions of years after the fireball began to expand and cool. What was the temperature of the radiation in space? An answer to that question could come only after scientists developed a quantitative theory of the evolution of the fireball after the big bang.

The development of this quantitative theory began with Gamow, a Russian-born physicist who had made his reputation by explaining radioactive decay. In the 1930s he came to the U.S., teaching first at George Washington University and then at the University of Colorado. At George Washington, he concentrated on the astrophysical and cosmological aspects of nuclear reactions—above all, the mechanisms by which the first elements had been synthesized.

Gamow looked for his answer at both ends of the cosmic scale. In the early 1930s astronomers showed that most stars were composed predominantly of hydrogen and helium. It was reasonable to assume that hydrogen was the first element to form because its nucleus contains but a single proton and that helium—the next heaviest element, whose nucleus contains two protons and two neutrons—was the first "higher" element formed by the fusion of hydrogen. But protons will fuse only if some force overcomes the immense electrostatic repulsion between them. This process seemed to require so much heat and pressure that only a primordial event or the interior of a star could have provided the right conditions.

STUFF AND NONSENSE: In a montage he made to amuse friends, George Gamow emerges, genielike, from a bottle of the primeval matter created in the big bang. He is conjured up by Robert Herman (*at left*) and Ralph A. Alpher (*at right*), who showed how such matter—which they called "ylem"—could have combined to form the light elements.

The reigning theory of the nuclear physics of stars, which remains for the most part valid today, had been developed in 1938 by the German-born physicist Hans Bethe of Cornell University. Bethe wanted to explain how the sun shines. He did so by assuming that nuclear fusion in stellar interiors converts mass into energy. Specifically, Bethe proposed that two fusion reactions could take place in stars like the sun: one fuses protons into helium nuclei, and another adds protons to carbon nuclei to form heavier elements.

But where did the carbon originate? That question was not answered until the 1950s, when Hoyle proposed a reaction that could produce carbon from three helium nuclei under the special conditions found at the core of a star. That reaction and others needed to create heavier elements were confirmed experimentally, in a high-energy particle accelerator, by William A. Fowler and his group at the California Institute of Technology. Hoyle and E. E. Salpeter provided important theoretical help. By 1957 a scheme explaining how stars might have synthesized most of the elements from hydrogen and helium had been worked out by Fowler, Hoyle and Margaret Burbidge of Caltech, together with Geoffrey Burbidge, then at the Mount Wilson and Palomar observatories. The work was done independently by A.G.W. Cameron, then at Atomic Energy of Canada. Yet the cosmic abundance of helium remained a mystery.

Gamow had already formulated a daring hypothesis that ultimately led to the solution of the helium puzzle. In his version of the big bang, Gamow suggested that the elements might have formed even before the stars came into being, in a stupendously hot and dense gas of neutrons. Some of the neutrons would then have decayed into protons and electrons—the building blocks of hydrogen. In 1948 Gamow, known for his impatience with detail as well as for his brilliance, assigned the task of developing the theory to Ralph Alpher, a graduate student at George Washington. Alpher later joined forces with Robert Herman of the Johns Hopkins University Applied Physics Laboratory. Alpher gave Gamow's initial substance the name "ylem" from a Greek word meaning "primordial matter."

According to Gamow's theory as worked out by Alpher and Herman, larger nuclei formed in the primeval inferno when smaller ones, beginning with hydrogen, grew through the successive capture of neutrons. The process continued until the supply of free neutrons ran out, the temperature fell and the particles dispersed.

Hoyle attempted to belittle this new rival to his own steady state scenario by calling it the big bang theory. The attempt at ridicule backfired: the phrase was so vivid that the theory's advocates adopted it as their own.

Alpher and Herman soon realized that the radiation pervading their model universe would maintain the spectrum of a blackbody source as it cooled. Moreover, they could calculate how the expansion of the universe would have attenuated this radiation and reduced its temperature. The two scientists used estimates of the present density of matter in the universe to predict the temperature of the cosmic background radiation today and derived a value of about five kelvins (degrees Celsius above absolute zero).

Astronomers did not rush to confirm the prediction, perhaps because they did not know how to pick out the cosmic background from other radiative sources or perhaps because they did not take seriously the cosmology on which the prediction was based. The original version of the big bang theory had two major drawbacks. First, it failed to explain the formation of the elements beyond helium, which has a mass number of four. Because there are no stable isotopes having mass numbers of five and eight, one cannot make heavier elements out of helium by adding neutrons one at a time. This problem could be solved only by invoking the stellar nucleosynthesis of Hoyle, Fowler and their collaborators, a concept associated with the steady state theory. Indeed, the modern version of the big bang theory assumes that elements beyond helium arose only after the formation of the first generation of stars.

A second objection to a big bang universe involved the question of age. Astronomical measurements of the distances and recessional speeds of galaxies, in conjunction with Hubble's law of expansion, implied that the universe was two billion years old. Yet the rocks of the earth's surface prove that the planet is significantly older than that.

The steady state theory was conceived to resolve this apparent contradiction. One night in 1946, three young scientists in Cambridge, England—Hoyle, Hermann Bondi and Thomas Gold—went to see a ghost story film, *Dead of Night*. As Hoyle later recalled the movie, it "had four separate parts linked ingeniously together in such a way that the film became circular, its end the same as its beginning." Gold asked his friends whether the universe might be similarly constructed. In the ensuing discussion the workers sketched out a dynamic but noncyclic model of the universe that would always look the same even though it is always changing.

According to Hoyle, Bondi and Gold, the universe had no beginning.They argued that the galaxies' rushing away from us does not imply a continuous attenuation of matter: our own galaxy will never be left all alone, they said, because matter is being created continuously, at a rate just sufficient to compensate for the matter that is disappearing from the visible universe. This new matter will eventually form stars and galaxies, so that the universe will always look about the same to any observer at any time.

One might object that the creation of matter out of nothing violates the law of conservation of mass and energy. The riposte is obvious: the big bang also violates this law and does so by creating matter all at once, at the beginning of time, when the act is beyond the reach of scientific study. (In a later version of the steady state theory, Hoyle proposed that gravitational energy creates matter, a refinement that restores the overall conservation of mass-energy but introduces other problems.)

Proponents of the steady state asserted that their theory was more scientific than the big bang because it postulated a process—continuous creation—that might in principle be observed. Moreover, they argued, their theory made definite predictions of a kind that astronomers could test in the near future.

In staking their model on the outcome of a small number of observations, Bondi, Gold and other proponents of the steady state model explicitly invoked the doctrine of Karl Popper, an Austrian-born philosopher now living in England. Popper defines science as a discipline founded on the creation of hypotheses that predict phenomena—preferably new ones—that can be tested. If a prediction fails, the scientist abandons the hypothesis; if the hypothesis survives, the scientist does not claim to have proved it but merely to have established the hypothesis as a basis for further research.

Popper's principle holds that testability rather than truth should be the criterion for judging scientific theories. For instance, Popper dismisses Marxism and psychoanalysis as "pseudoscience" because he believes those theories are so flexible that they can explain any fact and thus elude any test.

Bondi proposed to challenge the steady state theory by comparing the universe as it is with the universe as it once was. Because the steady state theory says the universe always looks the same, it predicts that galaxies formed recently will resemble those formed long ago. If you look out into space—and thus back in time, because the speed of light is finite—and see that distant galaxies are different from nearby ones, Bondi concluded, "then the steady-state theory is stone dead." Like others writing before 1965, however, Bondi failed to mention another test of the steady state model: it does not predict a cosmic microwave background.

The theory failed the test Bondi had set it. In the 1950s and early 1960s a variety of astronomical observations showed that the universe had changed significantly over time. Martin Ryle of Cambridge counted both distant and nearby radio sources, knowing that the more distant signals had taken longer to arrive and thus reflected an earlier stage in cosmic history. Ryle concluded that there had been fewer sources in the past. Although some astronomers argued that he had not proved his case, additional supporting evidence emerged when astronomers discovered what seemed to be the oldest radiative sources—quasistellar objects, or qua-

Two Cosmological Theories and Their Predictions

	TEMPERATURE OF SPACE	AGE OF UNIVERSE	CREATION OF MATTER	FORMATION OF ELEMENTS
BIG BANG	Initially very high; now a few degrees above absolute zero	Two billion years (1950 version); 10 to 20 billion years (current estimate)	All at once	Occurred just after big bang
STEADY STATE	Zero (no radiation)	Infinite	All the time	Occurs in stars all the time

FRED HOYLE, champion of the steady state universe, conceived of the theory with Hermann Bondi and Thomas Gold in 1946, after the three had seen a ghost story film whose plot ended in a return to the opening scene.

sars. These objects had no contemporary parallel whatsoever.

Meanwhile the awkward issue of the disparity between the age of the universe and the age of the earth was resolved in a way that favored the big bang. In 1952, following the lead of Walter Baade of the Mount Wilson Observatory, astronomers revised their scale of galactic distances upward by a factor of two. The estimated age of the universe therefore doubled. Later work raised it to a minimum of 10 billion years, whereas the age of the earth remained fixed at 4.5 billion years.

Yet many scientists, particularly in Britain, liked the simplicity of the steady state theory and so continued to cling to the concept. They pointed out that one did not have to make arbitrary assumptions about a big bang or worry about what happened before the big bang. Advocates of the steady state model also took heart from the failure of earlier attempted refutations, a record that made them suspicious of any new attacks.

As the steady staters spent ever more time explaining away the evidence accumulating against their theory, their adherence to Popper's methodology steadily became less credible. Instead they seemed to be illustrating Planck's more cynical view of science. Writing in his *Scientific Autobiography and Other Papers* (1949), the great physicist argued, "A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it."

Planck's principle, as historians of science now call it, contradicts Popper's principle by emphasizing the human element in science to the detriment of abstract logic. Just as astronomers can weigh the big bang against the steady state as a description of the universe, so may historians of science try to decide between Planck's and Popper's descriptions of science. Let us see which seems more accurate in this particular case, without undertaking to judge whether science always works in this way.

In 1959 a survey showed that a majority of astronomers rejected continuous creation, although only a third of those voting actually favored the big bang. Even Hoyle abandoned his original model and replaced it with a more complicated hypothesis. In 1964 he concluded that the high abundance of helium in the universe implied it had been "cooked" at temperatures exceeding 10^{10} kelvins. Yet Hoyle refused to abandon the idea of the continuous creation of matter. A new shock was needed.

The discovery of the cosmic microwave background provided that shock. Penzias and Wilson made the discovery by measuring the temperature of space or, as a physicist would say, by detecting the Planck blackbody spectral distribution that corresponds to a particular temperature. Electromagnetic radiation pervades the regions between the planets and the stars, and it can be detected by instruments on the earth. Much of this radiation comes in specific frequencies determined by the physical and chemical properties of astronomical sources. It thus cannot be accurately characterized by a single temperature. Instead investigators look for radiation that is in thermal equilibrium at a particular temperature. That is to say, the radiation is continuously distributed over different frequencies according to the law discovered by Planck in 1900.

The Planckian distribution has a characteristic shape for every temperature [*see illustration on opposite page*]. For the universe in which we live, the background radiation corresponds to a temperature slightly less than three kelvins. The distribution peaks at a wavelength of about 0.18 centimeter, which is in the microwave region of the spectrum.

One can infer a temperature of space indirectly. As Arthur Stanley Eddington pointed out in 1926, the amount of light coming from all the stars—that is, the total energy density—would be equivalent to 3.2 kelvins if converted to thermal equilibrium. But Eddington did not propose a specific procedure for testing his prediction.

At that time, even a scientist of Eddington's caliber would have found the task daunting. Obviously, ordinary thermometers would be swamped by energy coming from the sun, other celestial objects and the earth's atmosphere. Only exceedingly sensitive instruments, tuned to wavelengths between a millimeter and a centimeter and insulated from local sources, can hope to detect the cosmic microwaves.

About 15 years after Eddington made his prescient prediction, Andrew McKellar of the Dominion Astrophysical Observatory in Canada suggested a practical way to measure what he called the effective temperature of space. McKellar, one of the first astronomers to propose that molecules as well as atoms could exist in interstellar space, suggested that the cyanogen (CN) molecule be employed as a thermometer. He noted that cyanogen emits spectral lines whose relative intensity corresponds to the number of electrons in higher-energy states—itself a function of the temperature of space; McKellar estimated that temperature to be 2.3 kelvins.

These indirect approaches could not rule out interference from local sources. To do that, one must detect the radiation itself and map it across the sky. Radar equipment developed at the Massachusetts Institute of Technology during World War II was just barely capable of sensing the cosmic background directly—for anyone who wanted to look for it.

In 1946 a group at M.I.T., led by Robert H. Dicke, reported atmospheric radiation measurements taken by a microwave radiometer. The team noted that the "radiation from cosmic matter at the radiometer wavelengths" was quite sparse—less than the equivalent of 20 kelvins—but did not follow up this observation. Dicke, who subsequently moved to Princeton University, later recalled that "at the time of this measurement we were not thinking of the 'big bang' radiation but only of a possible glow emitted by the most distant galaxies in the universe."

Steven Weinberg, in his book *The First Three Minutes,* suggests two reasons why no one made a systematic search for the background radiation before 1965. First, the big bang had lost some credibility when it failed to explain the formation of elements heavier than helium, so that it did not seem important to test the theory's other predictions. In contrast, nucleosynthesis in stars—a theory linked to steady state cosmology—seemed to explain how heavy elements could have been made from hydrogen and helium, even though it did not explain how the helium had formed in the first place.

Second, Weinberg points to a breakdown of communication between theorists and experimentalists. The theorists did not realize one could observe the radiation with existing equipment, and the experimentalists did not realize the significance of their observations. From this perspective it is noteworthy that Dicke, who is both a theorist and an experimentalist, played a major role: together with P. James E. Peebles, he helped to relate a peculiar microwave noise to cosmological theory.

The most remarkable missed opportunity resulted from a misunderstanding between Gamow and Hoyle. Although each criticized the other's theory, they could still have friendly discussions. In the summer of 1956 Gamow told Hoyle that the universe must be filled with microwave radiation at a temperature of about 50 kelvins. (He arrived at this estimate on his own, after Alpher and Herman had published their prediction.)

As it happened, Hoyle was familiar with McKellar's proposal that the temperature of space is about three kelvins. So Hoyle argued that the temperature could not be as high as Gamow claimed. But neither of them realized that if a direct measurement could confirm the three-kelvin value and also establish the Planckian spectrum, it would refute the steady state theory, which—as Hoyle recognized—predicts a zero temperature for space.

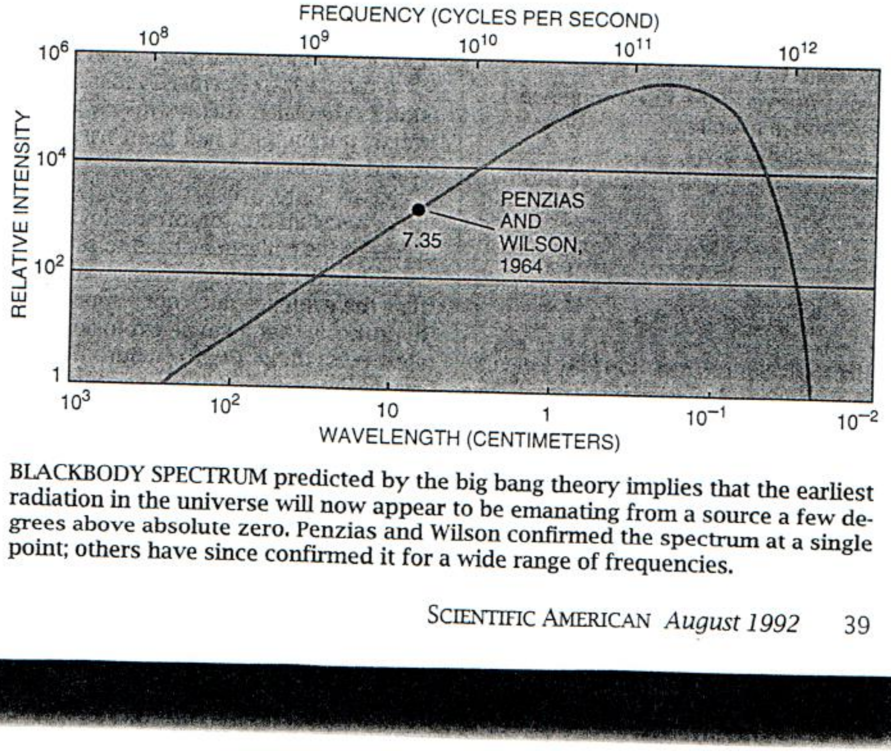
A different kind of communication problem—satellite relays—did lead to the discovery of the cosmic microwave background. Bell Labs wanted its satellites to convey as much information as possible at microwave frequencies, a task that required its workers to find and eliminate noise from all sources. The relay hardware, deriving from the firm's war-related work on radar, consisted of a horn-shaped receiver that Bell Labs engineers Harald T. Friis and A. C. Beck had built in 1942. Another Bell Labs engineer, Arthur B. Crawford, carried the idea much further. In 1960 he built a 20-foot horn receiver at the Crawford Hill facility near Holmdel, N.J. That reflector, originally used to receive signals bounced from a plastic balloon high in the atmosphere, became available for other purposes just in time for Penzias and Wilson.

The two investigators wanted to start a research program in radio astronomy. To prepare the highly sensitive instrument for their work, Penzias and Wilson first had to rid it of microwave noise. They failed in their first few attempts. Finally, in January 1965, Penzias heard that Peebles had a theory that might explain the origin of the stubbornly persistent signal.

Peebles was working with Dicke at Princeton, about 25 miles from the Holmdel laboratory. Dicke rejected the assumption that the universe necessarily began with the big bang. He thought it more likely that the universe went through phases of expansion and contraction. At the end of each contraction, he conjectured, all matter would pass through temperatures and densities intense enough to break down the heavier nuclei into protons and neutrons.

Thus, although Dicke's universe did not start with a big bang, each of its cycles must begin in a similar cataclysm. Moreover, Dicke's cosmology implied an initial fireball of high-temperature radiation that retains its Planckian blackbody character as it cools down, and he estimated that the present temperature of the radiation would be 45 kelvins. He evidently had forgotten his own 1946 measurement that suggested the existence of background radiation at a temperature less than 20 kelvins. Peebles made further calculations from Dicke's theory and obtained an estimate of about 10 kelvins.

Dicke and Peebles, together with two graduate students, P. G. Roll and D. T. Wilkinson, then started to construct an antenna at Princeton to measure the cosmic background radiation. Before they had a chance to get any results, Dicke received a call from Penzias, suggesting they get together to discuss the noise in the Crawford antenna, corresponding to a temperature of about 3.5 kelvins. It was soon apparent that Penzias and Wilson had already detected the radiation predicted by Dicke and Peebles and earlier by Alpher and Herman. But until the two astronomers talked to Dicke and Peebles, they did not know what they had found. The



BLACKBODY SPECTRUM predicted by the big bang theory implies that the earliest radiation in the universe will now appear to be emanating from a source a few degrees above absolute zero. Penzias and Wilson confirmed the spectrum at a single point; others have since confirmed it for a wide range of frequencies.

theoretical interpretation was essential to turn mere detection into true discovery. That discovery came more than a decade late because the scientific world had simply overlooked the earlier work by Gamow, Alpher and Herman.

The reports of the groups from Bell Labs and Princeton were sent to the *Astrophysical Journal* in May 1965 and appeared together in the July 1 issue. Publication unleashed a flood of articles in both the mass media and the scientific journals. Even Hoyle admitted that the steady state theory, at least in its original form, "will now have to be discarded," although he later tried to hang on to a modified version that could explain the microwave radiation. But Bondi's emphasis on the testability of the steady state theory had come back to haunt its proponents. Any attempt to twist the theory to explain the new discoveries risked being labeled as pseudoscience.

Although the press was quick to conclude that Penzias and Wilson had confirmed the big bang definitively, scientists realized that their results were limited to only a few wavelengths clustered at one end of the Planck curve. Other explanations of the background radiation, such as a combination of radio sources, could explain those data points. It was not until the mid-1970s that enough measurements at different frequencies had been made to convince the skeptics that the background radiation actually follows Planck's law. The spectrum of the CN molecule played an important part here, as astronomers resurrected and built on the earlier work of McKellar.

By the late 1970s nearly all the original supporters of the steady state model had explicitly abandoned it or simply stopped publishing on the subject. A survey of American astronomers conducted at that time by Carol M. Copp of California State University at Fullerton found that a large majority supported the big bang over the steady state.

The rapid demise of the steady state theory after 1965 shows that Popper's principle, rather than Planck's, applies in this case. The discovery of the cosmic microwave background, combined with arguments about helium abundance and observations of distant radio sources and quasars, convinced most steady staters that their theory was no longer worth pursuing. It had been tried and found wanting.

Yet in 1990, when the steady state theory was all but forgotten, Hoyle and a few of his colleagues tried to revive it as a "mini-big bang" theory, arguing that the evidence does not support the hypothesis that a single explosion created everything. Geoffrey Burbidge recently summarized this view in an essay in these pages [see "Why Only One Big Bang?"; February].

Although proponents of the big bang could dismiss most such criticisms, some puzzles still remained unsolved. For example, the microwave background seemed too smooth. It lacked the slight variations in temperature and, by implication, in density that seemed necessary to seed later gravitational clumping. Without such seeding, there would not have been sufficient time to produce the galaxies and supergalactic structures now observed.

Then, in April of this year, George P. Smoot and his colleagues at the University of California at Berkeley and at the Lawrence Berkeley Laboratory released evidence that may fill this gap in the big bang theory. They announced an analysis of measurements of the cosmic background radiation gathered by an orbiting observatory called the *Cosmic Background Explorer* (*COBE*). The data showed slight temperature variations in the cosmic background, just as had been expected by big bang theorists. The researchers interpret these "ripples" as fluctuations in the density of matter and energy in a very early phase of cosmic history. Such ripples may help explain how matter clumped under the force of its own gravity in time to form the stars, galaxies and larger structures of the contemporary universe.

Did the universe really begin at the big bang, or was there a previous contraction phase—a "big crunch"—that led to the high temperature and density? Will the universe continue to expand forever, or will it eventually collapse into a black hole? Does the creation of the universe involve quantum theory in a fundamental way? These ideas now dominate physical thought [see "Quantum Cosmology and the Creation of the Universe," by Jonathan J. Halliwell; SCIENTIFIC AMERICAN, December 1991]. That scientists consider such questions worthy of serious investigation is itself largely a consequence of the discovery of the cosmic microwave background, which transformed cosmology into an empirical science.

Selection from George Gamow's *Mr Tompkins in Paperback*

"Your years of toil,"
Said Ryle to Hoyle,
"Are wasted years, believe me.
The steady state
Is out of date
Unless my eyes deceive me,

My telescope
Has dashed your hope;
Your tenets are refuted.
Let me be terse:
Our universe
Grows daily more diluted!"

Said Hoyle, "You quote
Lemaître, I note,
And Gamow. Well, forget them!
That errant gang
And their Big Bang—
Why aid them and abet them?

You see, my friend,
It has no end
And there was no beginning,
As Bondi, Gold,
And I will hold
Until our hair is thinning!"

"Not so!" cried Ryle
With rising bile
And straining at the tether;
"*Far galaxies,*
Are, as one sees,
More tightly packed together!"

"You make me boil!"
Exploded Hoyle,
His statement rearranging;
"*New matter's born*
Each night and morn
The picture is unchanging!"

"Come off it, Hoyle!"
I aim to foil
You yet" (The fun commences)
"And in a while,"
Continued Ryle,
"I'll bring you to your senses!"

Verses by Barbara Gamow

FURTHER READING

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