State of the Universe

If not with a Big Bang, then what?

By IVARS PETERSON

For untold generations, people throughout the world have felt a deep-seated urge to define their place in the universe. Confronted with a mysterious, velvety black hemisphere studded with thousands of twinkling lights, they have fashioned fanciful cosmologies to explain the heavens and the relationship of the universe to human existence.

The same tantalizing questions asked centuries ago still reverberate throughout modern cosmology. When and how did the universe begin? How long will it last? Does it have an edge? Why is there something rather than nothing? The answers to these and other fundamental questions concerning the origin and history of the universe remain the subjects of wide-ranging speculation and acrimonious debate.

But one cosmology—one set of answers—now clearly dominates the debate and research about the universe's beginnings and evolution. "Nearly all serious cosmologists operate in the framework of the Big Bang," says David N. Schramm of the University of Chicago. In other words, cosmologists generally suppose that we live in an expanding universe that grew out of an unimaginably dense, hot beginning.

"In my opinion, there is no viable alternative to the Big Bang," adds Edward W. Kolb of the Fermi National Accelerator Laboratory in Batavia, Ill. "I think the evidence [favoring the Big Bang] has never been stronger."

A few researchers challenge this assessment, offering intriguing though little-heeded alternative models. "Practically everybody now goes around talking about the Big Bang as if it were the one and only cosmology, and very little is said about alternatives," says Geoffrey R. Burbidge of the University of California, San Diego, who describes himself as an elderly radical. "I find this total lack of balance very bad."

Proponents of the Big Bang model counter such criticism by noting that this unbalanced situation merely reflects the strength of the evidence in the model's favor. "I don't think any alternative model has the kind of coherence that Big Bang cosmology has in terms of explaining so many observations in one formal framework," says Lawrence M. Krauss of Yale University in New Haven, Conn.

But the standard Big Bang model doesn't yet supply all the answers that researchers would like to have. What happened in the first moments of the Big Bang? When and how did galaxies start forming? Postulated answers to these questions remain wrapped in controversy and uncertainty.

The universe itself offers few clues about its most distant times and parts, but modern astronomical observations have furnished three hooks on which to hang a cosmology. These form the basis for present-day belief in the Big Bang.

About 60 years ago, astronomer Edwin P. Hubble, when examining the light spectra arriving from distant galaxies, noticed that key spectral features appear at longer wavelengths than those produced by comparable sources on Earth. Moreover, more distant galaxies show a greater shift toward the longer-wavelength, or, red end of the spectrum than nearby galaxies.

Indeed, this redshift is roughly proportional to the galaxy's apparent distance from Earth. A galaxy twice as far away as another galaxy has twice the redshift.

The discovery of this remarkable linear relationship, now known as Hubble's law, supplied evidence for the notion of an expanding universe. A few years earlier, on the basis of Einstein's general theory of relativity, theorist Alexander Friedmann had proposed a model universe in which the distance between galaxies increases as the *space* between them expands. This scenario produced just the kind of distance-redshift relationship that Hubble later found.

This type of uniform expansion looks much the same from our own or any other galaxy. Although other galaxies are moving away from the Milky Way, they are also moving away from each other. That makes it practically impossible to define a center from which all motion emanates or to establish an edge beyond which the universe doesn't exist.

By taking Friedmann's model backward in time, it's also possible to imagine a period when the universe was significantly hotter and more dense than it is now. In 1948, Ralph A. Alpher, now at Union College in Schenectady, N.Y., took this idea and calculated that thermonuclear reactions taking place in this primordial furnace would forge a characteristic mixture of light elements such as hydrogen, deuterium and helium.

Refined versions of Alpher's theory predicted that if the Big Bang hypothesis were true, hydrogen would account for about 75 percent of the mass in the universe, and helium would represent close to 24 percent, with the remaining light elements present in significantly smaller quantities. In the last few years, measurements of light-element abundances in old stars and gas clouds have closely matched these proportions.

"The nucleosynthesis result has proved to be extremely robust," says George B. Field of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass. "People are constantly working to see if there are other ways to explain [the light-element abundances], but you have to go to great lengths to fit everything in."

Alpher and Robert Herman of the University of Texas in Austin also predicted that the Big Bang would produce a faint, uniform sea of radiation. This cosmic glow would represent the fossil remains of an epoch when the universe had expanded and cooled enough for atomic nuclei to combine with electrons to form atoms, allowing matter and radiation to evolve independently from that time on.

In 1965, Arno A. Penzias and Robert W. Wilson detected just such a sky-filling microwave bath, confirming this prediction. Data collected during the past year by the Cosmic Background Explorer (COBE) spacecraft confirm the uniformity of this cosmic microwave background and the fact that the radiation spectrum resembles that of an ideal heat source, called a blackbody, at a temperature of about 2.7 kelvins (SN: 1/20/90, p.36).

"An expanding universe, the microwave background and nucleosynthesis—these are the three key elements of the Big Bang model that seem to be very well verified observationally," says Paul J. Steinhardt of the University of Pennsylvania in Philadelphia. "They set a standard for any competing model."

"What makes the Big Bang cosmology so appealing is that it's not just one observation but a whole bunch of observations that hang together," Krauss says. "You predict a beautifully thermal microwave background with the same theory that predicts the right abundance of light elements produced in the Big Bang."

Other new findings further strengthen the evidence in favor of a Big Bang. For instance, recent measurements confirm that the redshifts observed for distant galaxies are independent of wavelength to an extraordinarily high degree, as required by general relativity. In other words, the amount of redshift observed doesn't depend at all on the spectrum of light emitted by a galaxy and accurately reflects the rate at which the universe is expanding, a rate modified slightly by whatever random motion galaxies may have individually.

Particle physics provides another important piece of evidence. The calculations that go into predicting the light-element abundances resulting from an epoch when the universe was sufficiently hot and dense to drive thermonuclear reactions also yield limits on the number of different types of neutrinos that may exist. In 1989, researchers studying the decay of Z particles produced in particle accelerators generated data consistent with the existence of three – and only three – neutrino types, confirming the astrophysical prediction (SN: 10/21/89, p.260).

"We made that prediction 15 years ago, and at the time it seemed totally absurd that you could use arguments from the Big Bang to tell you how many elementary particles there are," Schramm says. "It gives us a lot of confidence that the basic Big Bang works very well."

"That's a remarkable convergence of two completely different approaches to things," Alpher says. "It could have been completely otherwise, but it wasn't."

On another front, COBE data continue to support the notion that the universe at one time was an incredibly smooth and homogeneous mix of matter and energy. "The COBE measurements show that the spectrum of this background radiation is thermal [blackbody] to dazzling precision," says P.J.E. Peebles of Princeton (N.J.) University. "It's exceedingly difficult to think of another way to produce that other than in an expanding universe."

Because the Big Bang model allows one to extrapolate backwards in time to some kind of explosive beginning, the apparent age of the universe and objects within it becomes an important issue. Separate logical arguments produce strikingly consistent ages for the Earth and solar system, various types of stars, galaxies, galactic clusters, and the universe as a whole, says Kenneth Brecher of Boston University.

"The evidence, taken together, strongly suggests that something occurred between 10 and 20 billion years ago," he says.

Studies of distant, hence old, objects, such as quasars, also reveal signs of evolution. The universe in times past did not look like the universe of today, many researchers now conclude.

"I'm happy with the generic Big Bang," Brecher says. "It hangs together beautifully."

The "standard" hot Big Bang model, however, does not directly address two important issues: What happened during, say, the first minute of the Big Bang expansion? And what led to the formation of galaxies, especially galaxies arranged in huge clusters and great walls (SN: 11/25/89, p.340)?

"The most difficult problem in the Big Bang is understanding how galaxies originate – how we end up with an extremely smooth background of radiation and an extremely lumpy distribution of matter," Burbidge says. "To the zeroth order [at the simplest level], the Big Bang is fine, but it doesn't account for the existence of us and stars, planets and galaxies."

To solve this puzzle, Big Bang proponents have sought answers within the framework of an expanding universe. Indeed, attempts to address these concerns have led to a number of variations on the Big Bang theme, which feature the addition of such exotic components as cold dark matter, inflation, cosmic strings and global texture (SN: 3/24/90, p.184). Much of this research remains highly speculative and controversial.

"It's because the Big Bang is doing so well that people can start to ask these next-order questions about how to make galaxies," Schramm says. "That's where the debate is right now."

Despite the apparent failure of several proposed theories of structure formation in the universe, Schramm and many others feel no need to abandon the basic elements of the Big Bang model (SN: 1/26/91, p.52). "We have trouble predicting tornadoes, but that doesn't mean that we in any way doubt that the Earth is round," Schramm says. "Similarly, we have trouble making galaxies, but we don't doubt that there was a Big Bang."

"There's no crisis," Peebles insists. "There are alternative theories floating around – all within the context of the Big Bang. They'll receive more attention now that people are at last convinced that one promising-looking idea [cold dark matter] is in deep trouble."

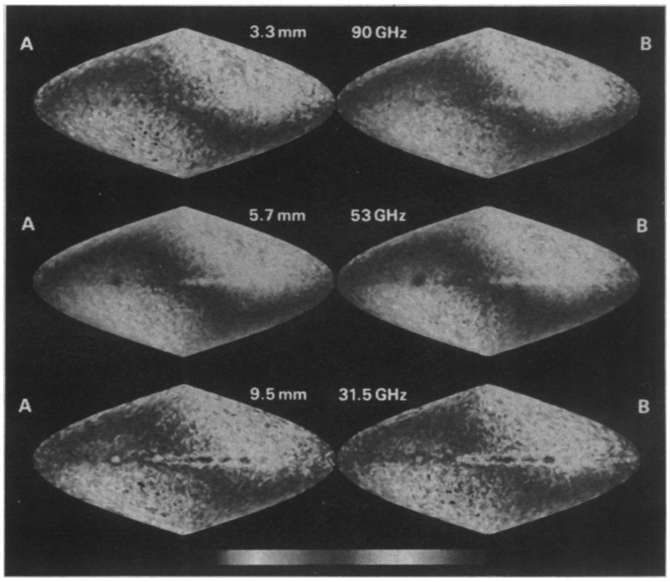
"My own feeling is that the game is just beginning," Field says. "I think the broad outlines are correct, but we need to work out the details."

But simply tinkering with parameters within the Big Bang model itself fails to satisfy a few researchers, who call for a thorough reconsideration, if not a complete overthrow, of the Big Bang model.

To that end, Burbidge, along with Halton C. Arp of the Max Planck Institute for Astrophysics in Garching, Germany, Jayant Narlikar of the Inter-University Centre for Astronomy and Astrophysics in Pune, India, and Fred Hoyle and N.C. Wickramasinghe of the University of Wales College of Cardiff, issued a manifesto. Published in the Aug. 30, 1990 NATURE, it declared in effect that the emperor Big Bang has no clothes.

The dissidents revive an alternative "steady-state" model of the universe, which they contend better satisfies astronomical observations. In this model of an infinite universe with no beginning or end, matter is continually created – via a succession of "little bangs" – and new galaxies form at a rate determined by the pace at which the universe expands.

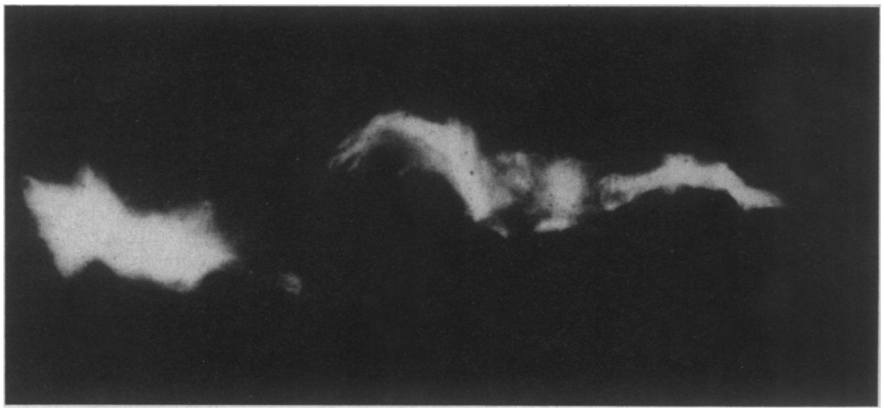
Much of their paper hinges on Arp's



The microwave sky at three different wavelenths, as measured by an instrument aboard the Cosmic Background Explorer spacecraft. The maps show a smooth variation between the cold and hot spots on opposite sides of the sky – an effect attributed to the motion of the solar system relative to more distant matter.

NASA/GSFC

In an experiment at the Los Alamos National Laboratory, 1 trillion watts of power generated an inch-long plasma with a characteristic filamentary structure.



Peratt/LANL

argument that the powerful but mysterious radiation sources known as quasars, or quasistellar objects, are in fact much nearer than their redshifts indicate. Independent astronomical determinations of the distances to nearby galaxies demonstrate that the Hubble relationship between redshift and distance works reasonably well for these populations. However, because astronomers have no reliable way of independently estimating the distances to quasars, no one is completely sure that the same relationship holds for quasars, which can exhibit very large redshifts.

In 1971, Arp found a remarkable "optical bridge" – a filament of matter – apparently connecting a nearby, bright galaxy to a quasar with a redshift much larger than the galaxy's. That discovery signaled the possibility that the galaxy and quasar were actually at roughly the same location, and that the quasar's redshift was not a true measure of its distance from Earth. Since then, Burbidge and others have compiled a list of nearly 500 such bridged quasar-galaxy pairs (SN: 3/24/90, p.181).

"There are too many for this to be due to an accident," Burbidge says. "The evidence is overwhelming that this effect is real."

The possibility that quasars are not distant objects casts doubt on studies based on counting quasars at different redshifts to demonstrate how the universe has evolved over billions of years. And if quasars aren't really distant objects and the universe hasn't evolved, a steady-state picture, in which every part of the universe resembles every other part, becomes feasible.

But the evidence isn't compelling enough to convince most astronomers and astrophysicists that it can explain away all or even most large quasar redshifts. Indeed, strong observational evidence supports the notion that quasars really are distant objects. The gravitational force exerted by foreground galaxies seems to act as a lens to produce images of background quasars.

Burbidge and his colleagues tackle the dilemma of creating galaxies against a smooth microwave background by suggesting that galaxies came first and the microwaves second, contrary to the Big Bang order of events.

"The commonsense inference from the ... nature of the spectrum of the microwave background and from the smoothness of the background is that, so far as microwaves are concerned, we are living in a fog and that the fog is relatively local," the researchers write in their NATURE paper. "A man who falls asleep on the top of a mountain and who wakes in a fog does not think he is looking at the origin of the Universe. He thinks he is in a fog."

The researchers propose that this "local fog" may result from the scattering effects of some sort of pervasive, extragalactic medium – perhaps clouds of fine iron needles – that strongly absorbs microwaves but is nearly transparent to visible light and long-wavelength radio waves.

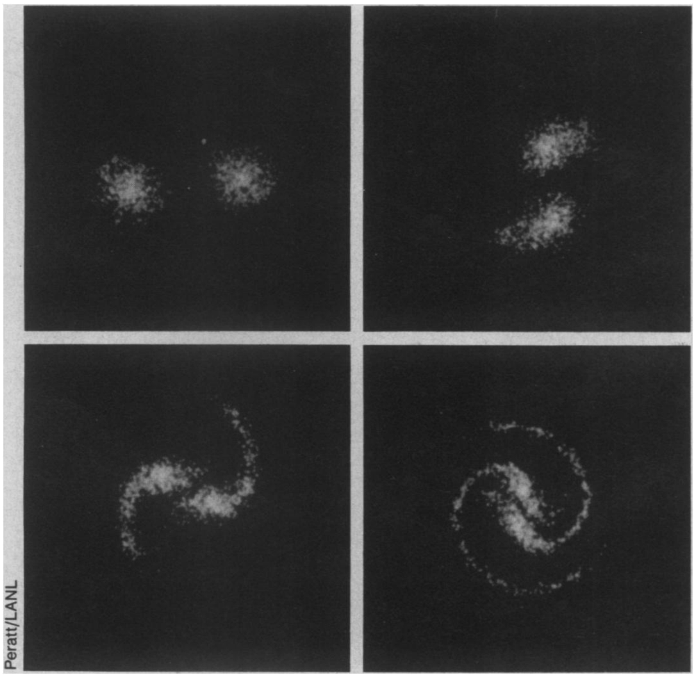
"It's normal radiation from stars, which has been scattered, absorbed and reradiated from these iron needles," Burbidge suggests. Such metallic whiskers could form in the material ejected from supernovas, the researchers say.

Anticipating his critics, Burbidge adds, "I think anybody who says that iron needles are unreasonable would have to concede that nonbaryonic [dark] matter is even more unreasonable."

Although their paper goes into several other cosmological issues, Arp and his collaborators admit they don't have all the answers. But they maintain that on balance, a steady-state model affords a more reasonable, testable cosmology than the Big Bang.

"People have to look at both of these theories on their merits," Burbidge says. "I think they are both very incomplete, and they have to be worked on."

In a concluding salvo pitched at the Big Bang, Arp and his coterie of elderly radicals write, "As a general scientific principle, it is undesirable to depend crucially on what is unobservable to explain what is observable, as happens frequently in Big Bang cosmology."



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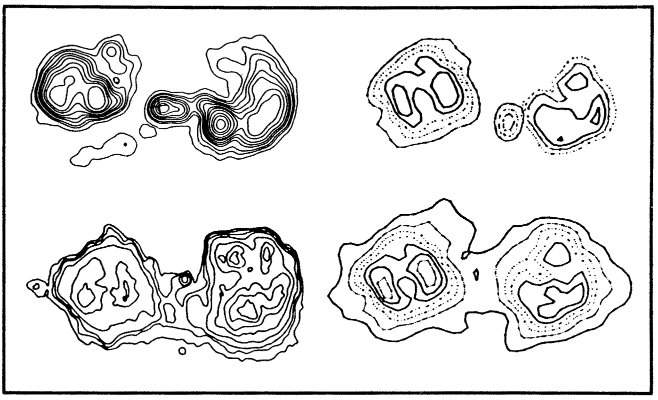
Computer simulations of interacting plasma filaments suggest that a spiral galaxy (bottom right) represents the result of an evolutionary process that spans 1 billion years and begins with a double radio galaxy (top left).

It seems somewhat surprising to find lengthy discussions of cosmology in electrical engineering journals. But this unexpected digression represents an outgrowth of a cosmological model first proposed about a decade ago by plasma physicist Hannes O.G. Alfvén of the Royal



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Computer simulations of plasma interactions (right) mimic the observed radiation patterns produced by double radio sources.

Institute of Technology in Stockholm, Sweden. His model dispenses with the Big Bang and posits that we are part of a finite cloud of material forever expanding into otherwise empty space. Electromagnetism — not gravity — acting on a vast cosmic sea of electrons and protons is the dominant shaper of matter in the universe, he contends.

Not surprisingly, this plasma cosmology has attracted the attention of researchers versed in the intricacies of plasma physics. “Especially in the last decade, with rockets, satellite probes and radiotelescope data, we've come to realize that most of space is in fact filled with plasma,” says Anthony L. Peratt of the Los Alamos (N.M.) National Laboratory. “Electromagnetic forces must play some kind of role.”

Laboratory experiments and computer simulations reveal that initially uniform plasmas tend to break up into cells and filaments that bear a striking resemblance to the large-scale patterns of galaxies now apparent in the sky. “Our experiments show that on a very large scale, the universe is going to be cellular and filamentary,” Peratt says. Furthermore, “we have been able to replicate not only the optical shapes of galaxies but also their radiation properties.”

Although few researchers now deny that the universe is steeped in plasma, most put gravitational forces ahead of electromagnetic forces in molding the large-scale structure of the universe. “Gravitation is still the dominant force in the universe, however much you want to invoke electromagnetic forces,” Burbidge says.

“I expect that on the very largest scales, plasmas are likely to be irrelevant,” Krauss adds. “But it wouldn't surprise me if they played some kind of role on the level of galactic structure.”

Using an argument resembling the one that favors a steady-state cosmology, plasma-cosmology proponents contend that the microwave background results from the scattering of radiation. Just as a thick fog scatters light equally in all directions, small filaments that thread the intergalactic plasma scatter microwave radiation, says Eric J. Lerner, an independent researcher in Lawrenceville, N.J. In other words, the cosmic glow detected by Earth-based observers represents microwave emissions from relatively nearby plasma.

Such plasma filaments should also scatter radio waves, implying that radio emissions from distant galaxies ought to be smeared out and considerably weaker by the time they reach Earth. To check this prediction, Lerner investigated the relationship between the infrared and radio emissions from a sample of galaxies.

“I found that, indeed, as you go further away from the Earth, the amount of radio radiation for a given amount of infrared radiation falls,” Lerner says. “Unless you can come up with a very good explanation of why radio galaxies further away from the Milky Way are such wimps, then you have to admit that there has to be a lot of absorption going on. And if you can't explain the data, then you simply can't use the microwave background as evidence for the Big Bang.”

After a lengthy peer review, Lerner's paper describing his comparison appeared in the Sept. 20, 1990 Astrophysical Journal. His data and his subsequent calculations are now mired in a debate concerning how well the samples of galaxies he chose for his analyses represent conditions in the universe.

The literature concerning diverse aspects of plasma cosmology is now quite voluminous. Various researchers have delved into what conditions are required for producing the right proportions of light elements, how to account for the large redshifts recorded for quasars, and other issues.

“The key thing is that you're looking at an evolving universe,” Lerner says. “You're going from essentially a low-energy-density state in which there are no high-density pockets to an increasingly differentiated universe with faster evolution, regions of higher energy density, and more forces coming into play.”

The standard, hot Big Bang has many rivals: plasma cosmology, a steady-state universe, a cold Big Bang, chronometric theory, a universe modeled on fractal geometry. But none of these has inspired the degree of support now accorded the Big Bang.

“I think it should be a principle that you don't consider more complicated things until you've ruled out the simplest,” Krauss says. “Certainly the simplest and most elegant model that explains all the observations is that there was a Big Bang and that gravity, which we know is the dominant force on large scales, operates.”

Kolb adds, “There's just no other viable alternative that comes anywhere close to the predictive power of Big Bang cosmology.”

But in Burbidge's view, the Big Bang theory and its chief rivals all face serious difficulties. Cosmology needs fresh, well-developed ideas, he says. The trouble is that nearly everyone works in the context of the Big Bang, and very few people get a chance to study unconventional alternatives.

“There's a tremendous bandwagon rolling, which makes anybody who says anything contrary to the Big Bang highly suspect,” Burbidge contends.

However, even strong proponents of the Big Bang concede that a great deal of work must yet be done, especially when the model becomes encumbered with such speculative appendages as inflation. “I view the Big Bang itself as a woefully incomplete theory,” Steinhardt says.

And the model itself remains assailable. “The Big Bang is a hypothesis,” Field says. “Like any scientific hypothesis, we're trying to verify whether it's true or false by experimental means.” Indeed, increasingly precise distance measurements and careful age determinations may provide clues crucial for testing the viability of the Big Bang hypothesis.

“Precisely because the Big Bang is the leading model, it should be tested in every possible way in order to find out if it's flawed,” Field says. “It may turn out to be flawed. It may turn out that you can do a crucial experiment that would disprove it, in which case you would turn to the next best model, whatever it might be.”

Meanwhile, most cosmologists and astrophysicists are content to work within the confines of the Big Bang. “There will always be alternative models and, yes, people should continue working on them,” Field says. “As far as my own research is concerned, I have adopted [the Big Bang model] as a working hypothesis because I see nothing on the horizon that compares with it for fruitfulness.”

Cosmologists face a host of slippery issues. “There are probably no deeper, more profound questions than the questions asked of cosmology,” Kolb says. “No matter what the model is, and no matter what you do, it's sure to excite strong feelings in people. No model is going to please everyone.” □