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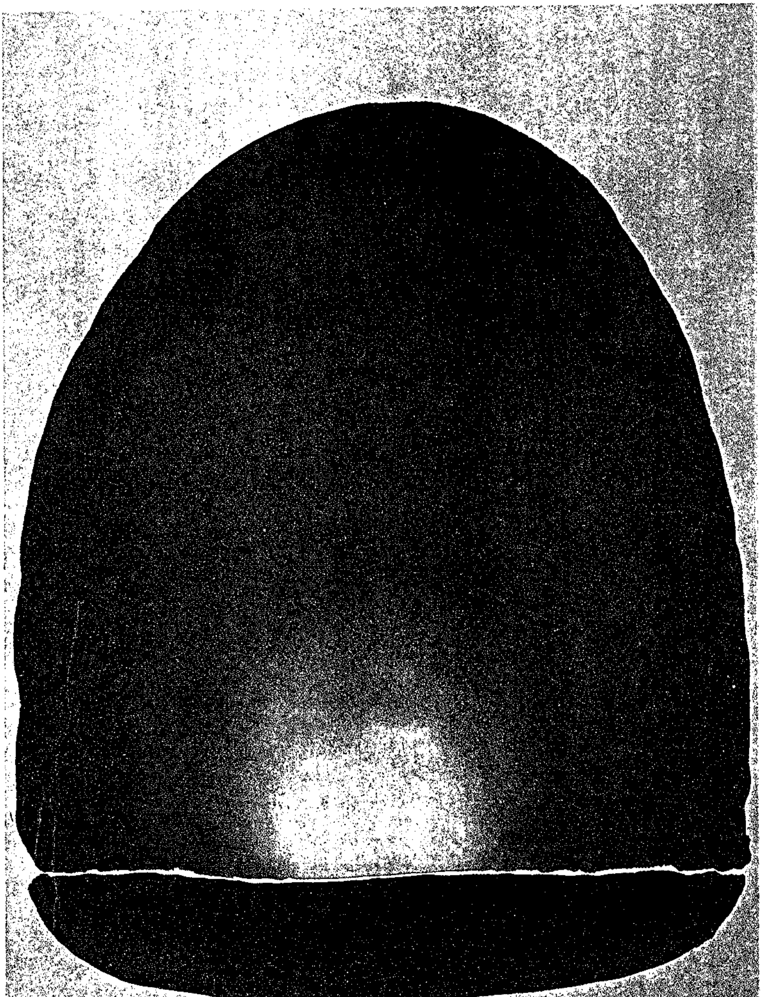


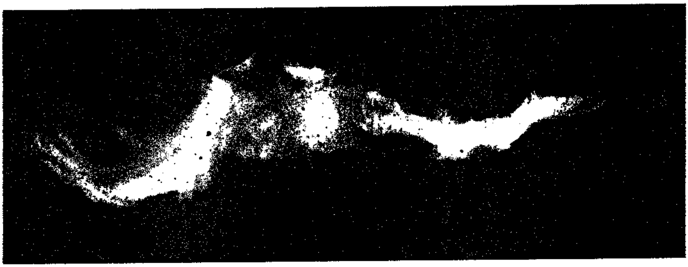
NEW BEGINNINGS

Creating the Universe Without the Big Bang

NOT WITH A BANG

The Universe May Have Evolved from a Vast Sea of Plasma

by ANTHONY L. PERATT



Anthony L. Peratt, Laboratory Plasma, *1989*

MR. PALOMAR, the title character of Italo Calvino's 1983 novel, enjoys constructing mental models to explain the world around himself: a model that geometrically describes all human hope and despair, perhaps, or more practically, a model that will help him select the perfect cheese from the many kinds displayed in the cases at the corner shop. He draws on the deductive methods cosmologists use to investigate the structure of the universe, and he has come to appreciate the coherence required of a well-made model. Unfortunately Palomar is not so adroit at fitting his model to the real world. Each time the model carries him to the brink of revelation, he is swamped by a flood of intangibles: in his rush to fill his elaborate order for cheese, for example, he stammers, then blurts out the most mundane and best advertised choice. But he perseveres in spite of these setbacks, for a model, he realizes, "is by definition that in which nothing has to be changed, that which works perfectly; whereas reality, as we see clearly, does not work and constantly falls to pieces." The solution, Palomar concludes, is to force reality to take the shape of his model.

Like Palomar, cosmologists throughout history have played fast and loose with the structure of the universe whenever it refused to fit their models. Consider Ptolemy, the ancient Alexandrian astronomer who proposed a geocentric cosmos. Ptolemy pictured the universe enclosed in a sphere dotted with stars; at the center lay an immobile Earth, around which, in perfect circles, the sun and planets moved. But as accurate observations showed, the planetary orbits deviate significantly from strictly circular shapes. To account for the perturbations, the concept of epicycles was introduced: perhaps a planet orbits a point that itself orbits the Earth. Astronomers became adept at varying the size of the epicycles or adding epicycle on epicycle to match celestial appearances—so adept, in fact, that by the middle of the sixteenth century elaborate calculations were required to chart the tangled sky. Cosmology has become much more sophisticated since the sixteenth century, but the medieval dodge still applies: by adding enough epicycles—or their modern ad hoc counterparts—it is always possible to "force reality to take the shape of [the] model."

The reigning cosmology of our time is the big bang theory, which holds that the universe was born some fifteen billion to twenty billion years ago in a primordial explosion that dispersed matter and energy in every direction. According to this model, matter is now distributed uniformly on a large scale, although there must have been smaller fluctuations in the density of matter and energy in the initial makeup of the cosmic soup. These density fluctuations slowly gravitated together, forming scattered clouds of gases that eventually collapsed under their own weight. Clusters of matter condensed and accreted, shaped by gravity to create all the objects of the visible universe: stars, planets, galaxies and galaxy superclusters millions of light-years across.

The big bang gained wide support in the scientific community, because it successfully explained a number of early astrophysical observations. For example, in 1929 the American astronomer Edwin P. Hubble noticed that the color of several galaxies appeared to shift toward the red, or long-wavelength, end of the spectrum, much the way the sound of a car horn deepens as the car speeds into the distance. From this cosmologists surmised that the galaxies are receding—a residual effect, big bang advocates have always maintained, of the initial blast. The model also explains why more helium and other low-mass elements are found in the universe than could possibly have cooked inside existing stars: they were fused together out of hydrogen in the first, intensely hot moments of the big bang.

Best of all, big bang cosmology has displayed considerable predictive power. In 1948 Ralph A. Alpher and Robert Herman, then at Johns Hopkins University, calculated that the radiation generated by the primordial explosion must by now have cooled to between six and thirty degrees above absolute zero and spread uniformly throughout the universe. Seventeen years later Arno Penzias and Robert Wilson, two radio engineers at Bell Telephone Laboratories in New Jersey, discovered microwaves at an apparent temperature of about three degrees above absolute zero. A steady hum from every direction of the sky, picked up by an ultrasensitive long-wavelength antenna, provided seemingly incontrovertible proof of the big bang. By the end of the 1960s the big bang had become almost universally accepted, and it has now penetrated the popular consciousness so deeply that at times one forgets it is still just a theory.

In spite of their many successes, proponents of the big bang have lately been forced to acknowledge a growing

Robert Siegelman, Untitled *(right panel), 1989* number of inconvenient observations, and older but still nagging difficulties with the model have refused to go away. In the past twenty years, for instance, astronomers have noticed numerous cosmological objects whose enormous red shifts may be intrinsic properties of the objects themselves; if the red shift is no longer a reliable demonstration of an expanding universe, the big bang model is left without the phenomenon it was invented to explain. Perhaps more important, some of the most prominent aftereffects of the explosion have been difficult to reconcile with observation. For example, the motions and shapes of galaxies and clusters of galaxies cannot be explained by the action of gravity alone, as the big bang model seems to require. To save the basic gravitational mechanism of the big bang itself, astronomers have postulated a variety of exotic but invisible subatomic particles that could fill the interstellar and intergalactic voids with dark but massive amounts of matter. The additional mass, if it were present, would make galaxy-size objects act as they are observed to act, and the subtlety of the postulated particles would explain why that mass has not been seen.

Even this ad hoc dark matter, however, cannot account for the enormous superclusters of galaxies astronomers have charted in recent years. West German and American astronomers recently discovered a super supercluster nearly two and a half billion light-years long; to grow to such a scale under the force of gravity alone would have taken more than 100 billion years, five times longer than the big bang model allows. Furthermore, if the universe turns out to be clumpy on this scale, where is the large-scale uniformity presumed by the big bang? Even the smooth background of cosmic microwave radiation, whose detection was once taken as proof of the big bang, does not presuppose an explosive beginning.

The unifying thread of these difficulties seems to lie in the fundamental assumption of the big bang that, on both a galactic and a cosmic scale, gravity is the only force to be reckoned with. Gravity can hold sway, though, only when forces intrinsically much stronger than gravity are canceled out; electromagnetism, for instance, which is the binding force for virtually all ordinary biological and chemical phenomena on Earth, is intrinsically 10^{39} times stronger than gravity. If the dominant form of matter were subject to the electromagnetic force as well as to the force of gravity, gravity would be swamped by the more compelling pulls and tugs of electromagnetism.

Cosmologists are loath to abandon a useful theory without a better alternative, and it must be admitted that among astrophysicists the big bang is still widely accepted. But now, among physicists who study a state of matter called plasma, many have come to believe they can offer a superior account of the structure and perhaps the origin of the universe. Plasmas are made up of electrically charged particles, and so they are subject to electromagnetism as well as to gravity; they are also the predominant form of matter in the universe. Recent sightings of intergalactic plasmas, as well as experiments that simulate galaxy formation in the laboratory and on supercomputers, offer strong evidence that the many-stranded electromagnetic currents permeating plasmas may extend throughout the universe. Such currents may be strong enough even on the largest scales to supplant gravity as the primary force for sculpting the cosmos. Cosmology, dominated for nearly a quarter of a century by a single model, has thus arrived at a critical juncture: Is the big bang model worth salvaging in spite of its apparent need for ad hoc assumptions? Or has it, like Mr. Palomar, at last gone too far in trying to dictate the shape of reality? What are the trade-offs between the big bang and the plasma cosmologies in their predictive power and their relative simplicity? Which of them finally gives a more satisfying understanding of the universe, its origins and its future? These are delicate and difficult questions whose implications reach far beyond technical cosmology, but modern cosmologists must now come to grips with them.

THE PLASMA STATE is considered a fourth state of matter: not solid, liquid or gas, a plasma most closely resembles a gas. But unlike a gas, whose components are electrically neutral, a plasma is made up of charged particles. A plasma can be formed when a gas is heated to such high temperatures that it becomes partly or fully ionized; that is, electrons are torn off the atoms in the gas, leaving a stream of negatively charged free electrons and positively charged ions (bare atomic nuclei and any electrons that remain bound to the nuclei). The term *plasma* can also refer to ionized gases at lower temperatures, even if only some of the atoms or molecules in the gas have lost electrons. Plasmas are even found inside metals at ordinary temperatures: the conducting electrons in the metal, which are free to wander through the rigid crystal lattice of metal atoms, constitute a plasma. Because of its free electrons, a plasma is a particularly good conductor of electricity. In fact, one of the most dramatic manifestations of a plasma is lightning. As a thunderstorm gathers, regions of negative electric charge form along the bases of clouds, which in turn causes positive charges to build up along the ground. The electric field between clouds and ground becomes so strong that the air is ionized. A conducting path of ions and free electrons—a plasma—is created, through which the lightning is discharged.

Another familiar plasma is found in the neon lamp, invented in 1910 by the French physicist Georges Claude. A tube of neon gas is ionized when an electric current is sent through it, and as the dislodged electrons are recaptured by the neon atoms, the atoms emit a deep red glow. Fluorescent lamps, which contain ionized mercury vapor, work in a similar way: the mercury atoms emit ultraviolet radiation, and the radiation energizes the electrons of phosphor atoms coating the inside of the tube, causing the atoms to emit white light. Not incidentally, it was a young engineer working for the General Electric Company who eventually gave plasmas their name. In 1929, fascinated with the effect of electrical discharges on gases, Irving Langmuir (who went on to win the 1932 Nobel Prize in chemistry) borrowed the term *plasma* from medical science to describe the unstable, almost lifelike behavior of the ionized material he observed.

Plasmas are dominated by electromagnetic forces and fields; for this reason the physical, and particularly the electromagnetic, properties of plasmas are far more complex than those of the other three states of matter. Whenever plasma electrons flow through a background of ions, a cylindrical magnetic field is formed around the current. In 1934 Willard H. Bennett, an American experimenter then