Plasma Cosmology

Part II. The Universe Is a Sea of Electrically charged Particles

Anthony L. Peratt

A challenger to the Big Bang model is gaining support from supercomputer simulations, laboratory experiments, and astronomical observations.

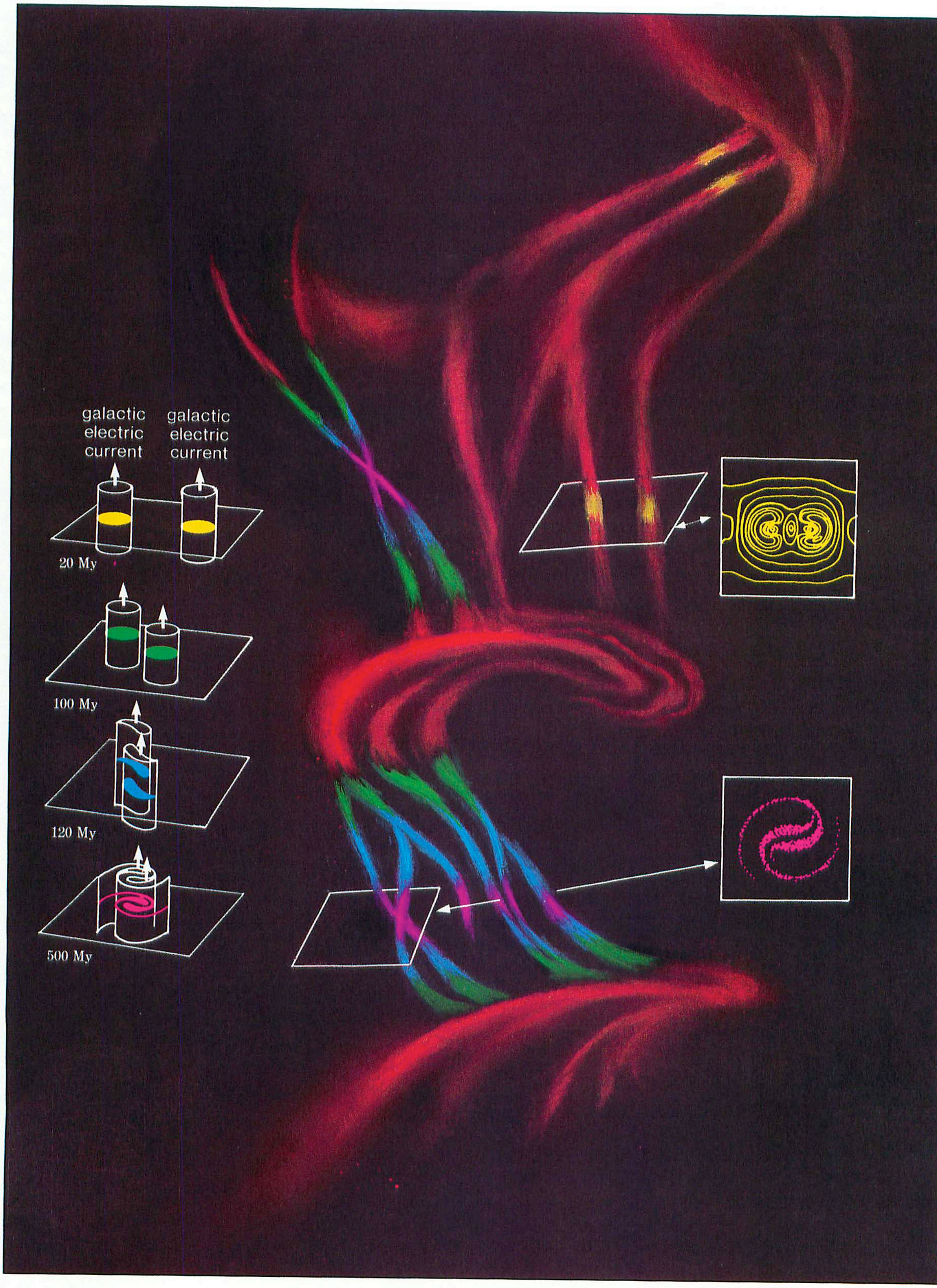
The presently dominant cosmology postulates gravitational forces and charge-neutral matter as the dominant components of the universe. Part I (August 1989) reviewed the origin, rise to ascendancy, and present observational challenges to this Big Bang model of the universe. Part II introduces the Plasma Universe model, which postulates electromagnetic forces and electrically charged matter as being the dominant factors in most of the universe.

The clear night sky with its myriad of observable stars, which may range up to thousands of light years distant, and its fuzzy "nebulae," such as the Andromeda galaxy some two million light years away, has inspired poets and scientists alike. Many are the scientists who have pursued the dream of comprehending the physics of the universe based on what they could observe in the clear night sky. Yet our experience in understanding the energetic events in our own Solar System suggests that the dream can never be realized.

Although we are now able to monitor deep space using the full electromagnetic spectrum from the very short wavelength gamma rays to the tens of meters long radiowaves, we are unable to send observing instruments out to cosmic distances. This constraint severely limits our ability to understand the universe. As previously outlined [see "Space Plasmas" March 1988, p. 166], only after satellites monitored our near-earth environment and spacecraft directly observed the environment of the nearest planets could we begin to get a true picture of the highly energetic processes occurring everywhere in the Solar System.

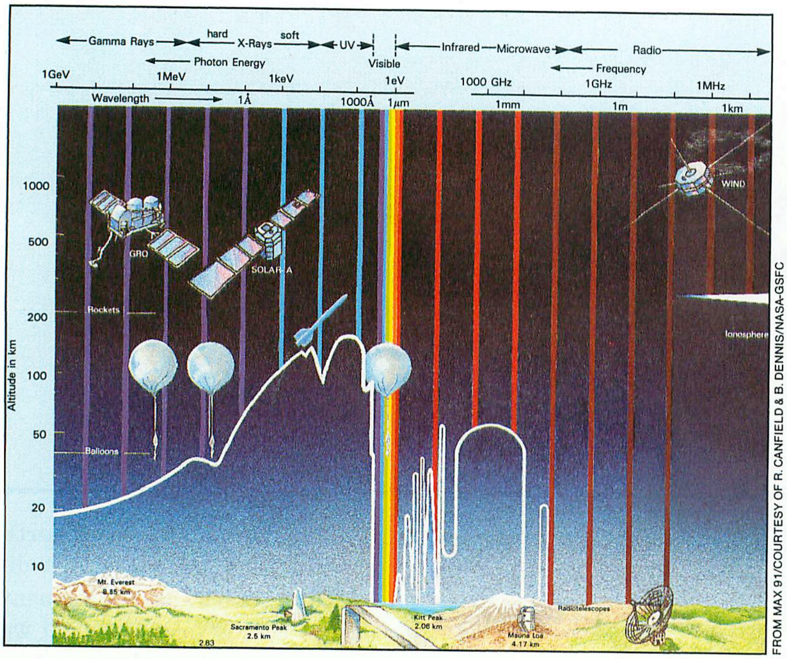
Our satellites and spacecraft have discovered that what we once thought of as empty space is rather a dynamic sea of

The Plasma Universe model directly contradicts the Big Bang model of the universe and is consistent with a universe that is eternal and infinite. In the Plasma Universe swirling streams of electrons and protons form filaments spanning vast reaches of space, as shown in this artist's conception. Where pairs of filaments interact over hundreds of millions of years, the particles gain velocity (indicated by the colors) and at narrow "pinch" regions produce the full range of galaxy types, as well as the full spectrum of cosmic electromagnetic radiation. The filamentary structure is invisible from a distance, just as is the solar wind of charged particles streaming past Earth.



ART BY E. OZAKI/WORLD & I/CONCEPT BY A. PERATT/LANL

PLASMA COSMOLOGY



FROM MAX 91/COURTESY OF R. CANFIELD & B. DENNIS/NASA-GSFC

The full electromagnetic spectrum, from gamma rays to radio waves, carries vast quantities of information about the universe. However, Earth's atmosphere serves as an absorption shield, limiting penetration of the various frequences to the altitudes shown by the curved white line. Only in the last two decades has the full spectrum been accessed by sending balloons, rockets, and satellites beyond the shield.

low-density charged particles, called plasma. Completely invisible in the visual portion of the electromagnetic spectrum, this sea is traversed by electric and magnetic fields and is filled with complex flow patterns and electric currents transporting and depositing energy over large distances.

Moving through this plasma sea, the planets are surrounded by teardrop-shaped plasma sheaths, called magnetospheres. Yet viewed from the Earth's surface, the only clues to this rich space environment are the auroras found near the poles of the Earth and suggestions, carried by low-frequency radio waves, of charged-particle acceleration in magnetic fields around the planets.

If plasmas are found throughout the Solar System, then what of the rest of the cosmos? For those oriented to seeing plasmas, the cosmos is filled with demonstrations of plasma behavior, and astronomical observation substantiates that more than 99 percent of the matter in the universe exists in the plasma state. Having verified the continuity of plasma behavior from the laboratory to the sun to the far reaches of our Solar System, plasma scientists then naturally extrapolate out to our galaxy and beyond to the depths of extragalactic space.

We expect to find plasma sources of energy, long distance electric and magnetic fields, and the transport of energy via electric currents throughout the vast reaches of the cosmos. With the advent in the early 1980s of techniques for simulating cosmic plasmas on large computer systems, a new era of cosmological investigation has been ushered in. The computer models provide in situ observation of distant or inaccessible plasma regions. While the first simulations were simple, with the physics issues limited by constraints in computer speed and memory, supercomputers have made it possible to study the full three-dimensional, fully electromagnetic and gravitational evolution of magnetized plasma over a very large range of sizes. Since a simulation involves the motion of particles carrying mass and/or charge and subjected to electromagnetic and/or gravitational forces, in situ information is available.

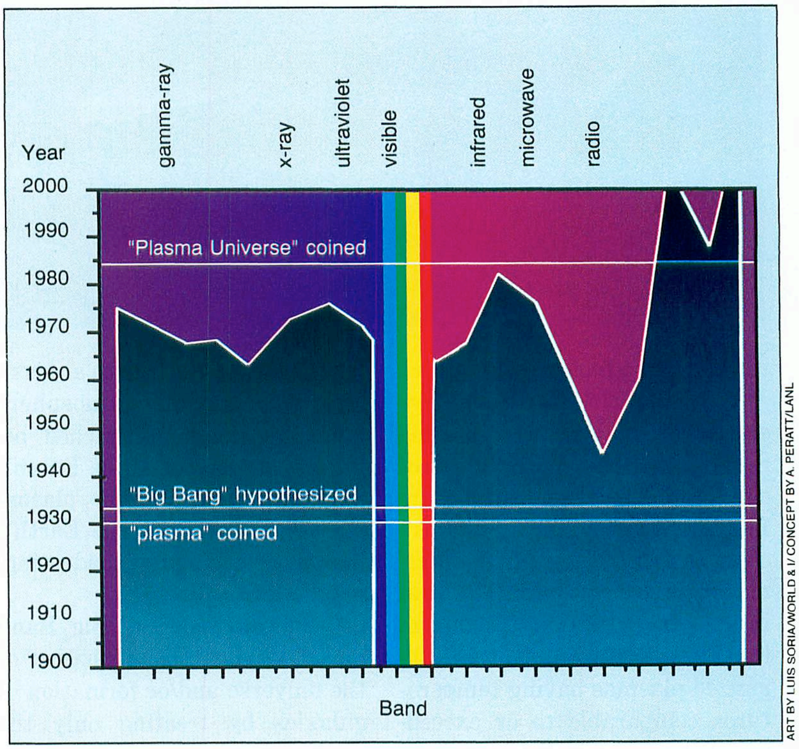
If the simulation correctly models the cosmic plasma object under study, the simulation should reproduce the electromagnetic radiation observed from the object over the entire electromagnetic spectrum, pro-

If plasmas are found throughout the Solar System, then what of the rest of the cosmos?

vided only that the model contains enough physics and is zoned finely enough to resolve the phenomena under question spatially and temporally.

In science, the viability of a theory is measured based on two requirements: its ability to describe the currently available data and its ability to predict the behavior of the system under consideration.

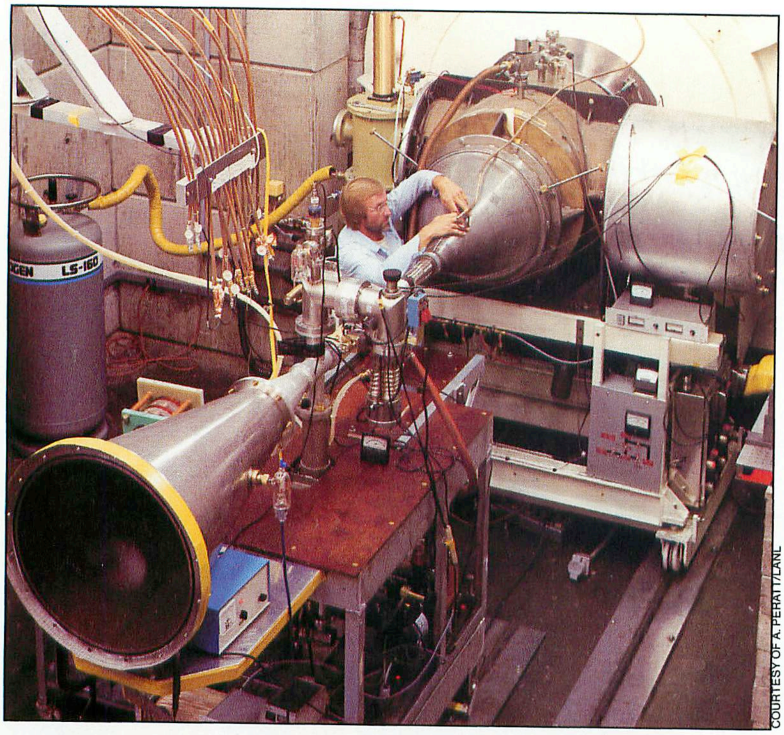
The description of the currently available data should have a minimum of qualifiers. For example, the credibility of a theory is weakened if it requires the addition of "epicycles" to match the model to the recorded data. Even the Ptolemaic theory was in excellent agreement with the observed positions of the planets when a sufficient number of epicycles were fitted to the model. Based on its predictive capability, a theory should serve as a guide for future observations or measurements. When a theory in a given area lacks predictive capability, experimenters often forage off on their own, and in the process may make major discoveries which further (temporarily) confound theorists. For example, most of the advancements of radio astronomy were serendipitous.



The approximate year when new technology made possible observation in the different regions of the electromagnetic spectrum. As shown, most of the spectrum was not accessible until the mid-1970s.

Comparing the Two Models

In addition to hypothesizing that electromagnetic forces are more primary than gravitation in most of the universe, the Plasma Universe model also differs from the Big Bang model in two other fundamental ways. These differences concern which alternative states of matter are considered in the model and how much of the information carried by electromagnetic radiation has been


COURTESY OF A. PERATT/LANL

The Plasma Universe model has emerged on the foundation of three powerful, complementary technologies—terawatt generators, space probes, and supercomputers. This terawatt (trillion watt) generator has produced plasmas in the laboratory with properties similar to those found to exist throughout the Solar System.

referenced in building the model.

Considering alternative states of matter, the plasma model focuses not on the states of solid, liquid, and gas, which are familiar on the Earth, but are cosmically rare, but on the plasma state with its vast natural range—from plasmas flowing in the Earth's auroras to the fully ionized plasmas having temperatures comparable to or exceeding those found in the stars [see "Space Plasmas"]. This range greatly exceeds that of the matter found in the Earth's crust, hydrosphere, and atmosphere which is itself sandwiched between the plasma of the Earth's magnetosphere and the plasma that must comprise the Earth's molten, electrically conducting, magnetized core.

In contrast, the Big Bang model studies the structure of the universe and/or formation of galaxies by treating only the gravitational interactions between cold solid bodies having properties similar to those found in the Earth's crust, or with "missing mass" (having properties completely unknown). While the Big Bang fireball must also have been a plasma, very little plasma physics is employed by Big Bang theorists. In fact, the foundations of Big Bang cosmology were laid even before the plasma state of matter gained general recognition in the scientific community.[1]

Moreover, the Big Bang and all its theoretical predecessors are based primarily upon observations in the very narrow visual portion of the electromagnetic spectrum. These data are supplemented only by nonoptical data for the cosmic microwave background discovered at 4.08 gigahertz (7.35 cm wavelength) followed by observations up to about 150 gigahertz (2 mm wavelength) [see Part I]. The discovery of background radiation in the X-ray, gamma-ray, and infrared regions was unpredicted by the Big Bang model and was the first in a long list of "surprises" which theorists then sought to incorporate into that cosmology. Unfortunately, the ad hoc explanation of observations not predicted by a theory rings of Ptolemy's epicycles.

In contrast, the Plasma Universe model welcomes and seeks ever more data from the entire electromagnetic spectrum, from extremely low frequency radiowaves with wavelengths of kilometers or longer to gamma rays with wavelengths of 10^{-13} meters. This requirement arises because plasmas are prodigious producers of electromagnetic radiation. Investigations of plasmas in labs and in space have led to the discovery of the continuity of plasma physics from the labo-

1. The Big Bang manages to avoid having much to do with plasma physics since in its eyes the plasma state persisted only for a few hundreds of thousands of years before entering a "matter-dominated" era.

In Situ Space Probes

Until the early 1970s, almost everything we knew about the universe had been obtained through the medium of electromagnetic radiation. Only a very small part of our total knowledge stemmed from material information carriers. These had included meteorites hitting the surface of the earth, cosmic ray particles, and material collected both by spacecraft (manned and unmanned) and by landings (lunar and planetary).

With the advent of earth-orbiting and interplanetary space probes, our knowledge has been augmented by in situ measurements in our own Solar System. These measurements have often resulted in discoveries that were unsuspected or that had been misinterpreted based only on information carried in the electromagnetic spectrum alone. For example, prior to space probe measurements, it was universally assumed that the earth's outer magnetosphere was composed of hydrogen plasma from the solar wind and, hence, was ultimately from the sun. We now know, however, that the magnetosphere is sometimes dominated by oxygen plasma originating in the earth's own atmosphere. Electric fields within the near-earth plasma were generally not thought possible until space probes measured them directly. Their existence was either uninferrable by means of electromagnetic radiation or their radiation signatures were at frequencies far below that currently measurable on earth.

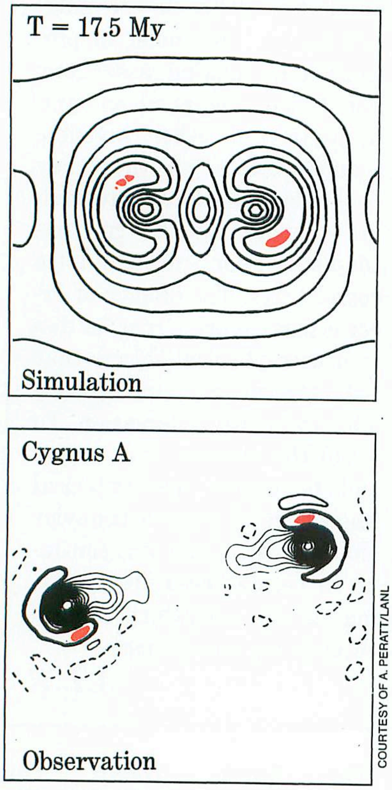
It is a sobering fact that even after hundreds of satellites had circled the earth, the generally accepted picture of our space environment was fundamentally wrong in aspects as basic as the origin and chemical composition of matter in the earth's own neighborhood and the existence and role of electric fields in the magnetosphere. This must inspire caution in making assertions about the composition and properties of other invisible cosmic objects, whether they be stellar interiors, interstellar plasma, pulsar magnetospheres, or intergalactic cosmic rays. The danger of error is particularly great for distant astrophysical objects that will forever remain inaccessible to in situ observation. To avoid this danger, it is essential to utilize the empirical knowledge of plasma behavior that has been, and will continue to be, gathered from plasmas in the laboratory and accessible regions of space.

A.L.P.

ratory to the Solar System: Identical types of electromagnetic waves are produced in both media regardless of a size differential of some 9 orders of magnitude.

The study of the Plasma Universe follows a three-pronged method—lab experimentation, observation, and simulation—first followed by the Norwegian scientist Kristian Birkeland (1867–1917), as he sought to unravel the mysteries of the aurora. Birkeland built laboratory models to examine the Earth-solar wind interaction in aurora generation. He then organized expeditions to polar regions to observe the aurora firsthand with scientific instruments. Thirdly, Birkeland, an accomplished mathematician, and his colleagues developed algorithms that enabled them to calculate the trajectories of charged particles along the magnetic field lines produced by the Earth. Today, this laboratory-observation-simulation methodology is used by plasma physicists to study plasmas ranging from those within the Solar System out to those in the far reaches of the cosmos.

The differences in content of the Big Bang model and the Plasma Universe model reflect a deeper, more fundamental methodological difference. Following the traditional theoretical mode of modern general relativity and particle physics, the Big Bang model attempts to deduce and *explain* observations of the universe beginning from original principles. This contrasts with the attempt by the Plasma Universe model to *replicate* much of the measured extragalactic data in astrophysics based on experimental and simulational investigations.



COURTESY OF A. PERATT/LANL

Simulations of interacting plasma filaments replicate the properties of double radio galaxies in some detail. Cygnus A, the strongest synchrotron radiation source in the sky, produces a low-resolution synchrotron radiation map (below) that corresponds closely with a low-resolution magnetic field energy density map produced by the simulation for 17.5 million years after the filaments began interacting (above). The simulation even replicates the distinctive hot spots which appear in opposing arms of the two galaxies.

Basic Model of the Plasma Universe

The basic model of the Plasma Universe has been inspired by two recent technological advances: supercomputers and thousand billion-watt generators. Each of these technologies offers an independent means of investigating conditions similar to those in space. Used in complement, these two powerful tools raise plasma science to a new level of mastery that finds its natural application in the study of extragalactic plasmas. Plasma modelers work with plasma filaments, which are distributions of charged particles along magnetic field lines. The basic model is a pair of adjacent current-conducting plasma filaments which mimics plasma filaments observed in a variety of space environments, the most familiar being the aurora. Although many filaments are usually observed, the two closest interact the most strongly and are the minimal number required to produce astrophysical data. In both experiments and simulations, the interactions of fields and filaments produce synchrotron radiation remarkably similar to electromagnetic radiation emanating from a multitude of natural cosmic sources, the strongest source being double radio galaxies. These sources are thought to be many hundreds of millions of light years away and may give us a picture of the universe at a much earlier time in its evolution.

In the radio wavelengths, a double radio galaxy is "seen" as a pair of lobes, each measuring about 100,000 light years across (about the diameter of our galaxy) and separated from each other by about 250,000 light years. These dimensions make double radio galaxies the largest objects known in the universe.

The double radio galaxy Cygnus A, one of the brightest synchrotron sources in the sky, has been used as a reference for comparing simulational and observational results. The simulation data was recorded from the plasma model during peak synchrotron power output. Both sets of data show two regions of intense synchrotron radiation, with intensities of 1.16 x 10^{37} watts (simulation) and 1.6-4.4 x 10^{37} watts (observation). The lobes are "C-shaped" and each contains a single hot spot of intense radiation near the end of one arm.

The double structure and precise alignment of the enigmatic hot spots was long a mystery in astrophysics. Standard astrophysical models have sought to explain double radio galaxies as being due to a "black hole" emitting relativistic electron beams that in turn produce the synchrotron radiation. However, plasma studies of single intense relativistic electron beams in the laboratory do not show this behavior unless they are part of an interacting current system, which is, of course, the basic model of the Plasma Universe. In the simulations, the long narrow filaments themselves produce relativistic electron beams periodically along each filament. Where the electron beams in adjacent filaments interact, they produce synchrotron radiation whose pattern in the plane of interaction is similar to that observed from double radio galaxies, even including the distinctive hot spots. The simulation thus suggests that no black hole is needed to account for double radio galaxies.

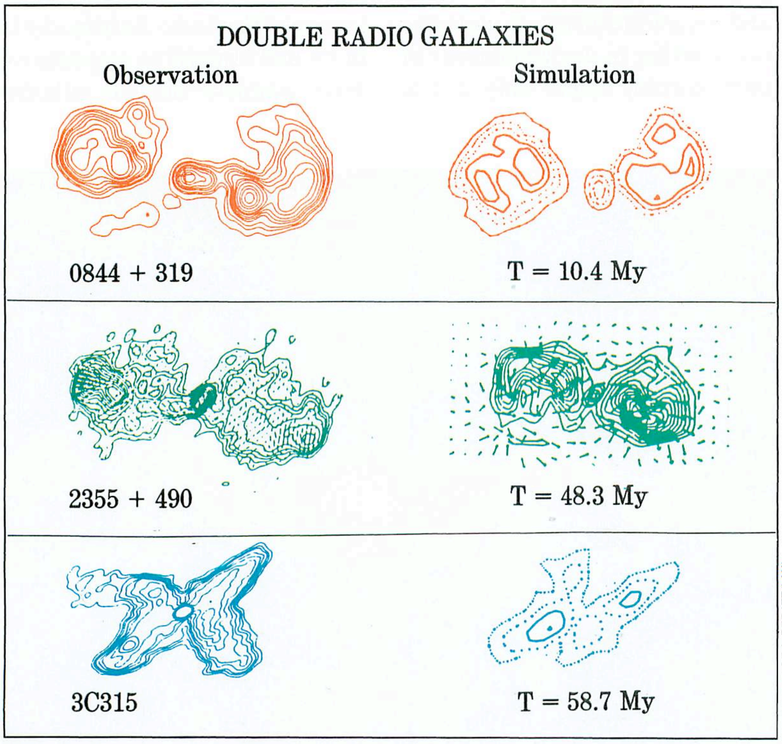
Verification of the model is achieved by comparing frame-by-frame the lobe structure generated in the computer simulation with the lobe structure of many double radio galaxies plotted by radio telescopes. Fine detail comparisons show that the variety of patterns found in double radio galaxies corresponds quite closely with the changing lobe structure generated by the simulation. Thus double radio galaxies of quite different appearance may be following similar paths of development, and be merely separated in age by a few million years.

A study of the evolution of double radio galaxies on supercomputers has led to a remarkable discovery: Nearly all cosmological objects from quasars to spiral galaxies appear to belong to a single species and to differ only in their age. The simulations show how a 250,000-light-year-wide double radio galaxy can, over 500 million years, progressively evolve through recognizable stages into a 100,000-light-year-wide barred-spiral galaxy out of which stars will eventually condense.

Predictions of the Plasma Model

Large-scale structure—The interacting currents model solves another problem. In the laboratory, the width of a synchrotron-emitting filament is about 1/10,000th of its length. If a double radio galaxy is in effect the cross section of the interacting filaments that produce it, then double radio galaxies (and ultimately all galaxies) should be in filamental structures a billion light years long, similar to those discovered in 1987 [See Part 1].

The prediction that the uni-



COURTESY OF A. PERATT/LANL

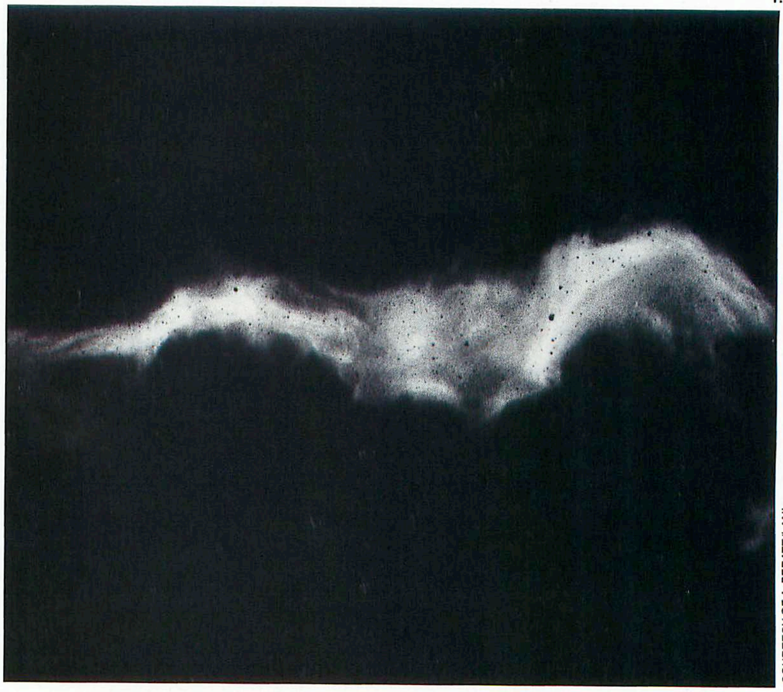
High-resolution synchrotron radiation maps of radio galaxies show great variety (left column) with no apparent order. Simulations of interacting plasma filaments (right column) replicate these diverse shapes in the form of electric field energy density maps, showing that the apparently unrelated radio galaxies are all part of the same family, but are merely at different stages of development.

verse should have a cellular and filamentary structure at the large scale is a major difference between the Big Bang and Plasma Universe models.

Filamentary, magnetized structures in our galaxy—Since the plasma model assumes that the properties of plasmas are the same throughout the ranges of sizes from the laboratory to the cosmos, a model has been developed based on processes verified in the lab and observed on the Sun which predicts that plasma filaments should be found at the center of our galaxy. In 1984, researchers using the Very Large Array radio telescope in New Mexico found a 500-light-year-long magnetized plasma filament at the center of our galaxy. The structure was a textbook example of the simulation model: plasmas following helical magnetic fields with sharp bends. The strength of the field was 1 milligauss, 100 times what astrophysicists had thought possible on such a large scale, but nearly identical to values published a month earlier based on the plasma model. For comparison, at the surface of the Earth the magnetic field strength is about 500 milligauss.

The discovery of such a large-scale magnetized plasma within our own galaxy has spurred research in a once highly controversial and nearly neglected field: magnetic fields in galaxies. Although a significant fraction of astrophysicists still believe magnetic fields play no role in galaxy formation, astrophysical conferences on plasmas and magnetic fields in galaxies are starting to draw hundreds of participants, where only a few dozen would have been expected a decade ago.

Magnetic fields in galaxies—In early 1984, plasma simulations of galaxies suggested that highly ordered magnetic fields stretching for tens of thousands of light years should exist in galaxies. The strengths of the magnetic fields appearing in the simulations suggested that appreciable amounts of weakly ionized hydrogen should collect around the field lines. Simulation plots of the magnetic fields compared nicely with maps of observed regions of weakly ionized hydrogen, both showing a "horseshoe-shaped" distribution of gas with a bipolar characteristic. At about the same time, radio astronomers at the Max Planck Institute for Radio Astronomy in Bonn had started to measure ordered magnetic fields in galaxies



The continuity of plasma behavior over vastly different scales is demonstrated by plasmas ranging from the laboratory to the sun to the center of the galaxy.
1. At Los Alamos National Laboratory, 1 trillion watts of power were used to produce this 1-inch-long plasma with characteristic filamentary structure. Radiation in the X-ray region was used to capture this image.
2. On the Sun. An ultraviolet image of a solar flare taken by Skylab in 1973 shows plasma filaments that are 500,000 miles long.
3. In 1984 a radio wave image of the center of our own Milky Way galaxy recorded plasma filaments that are 800 trillion miles long.

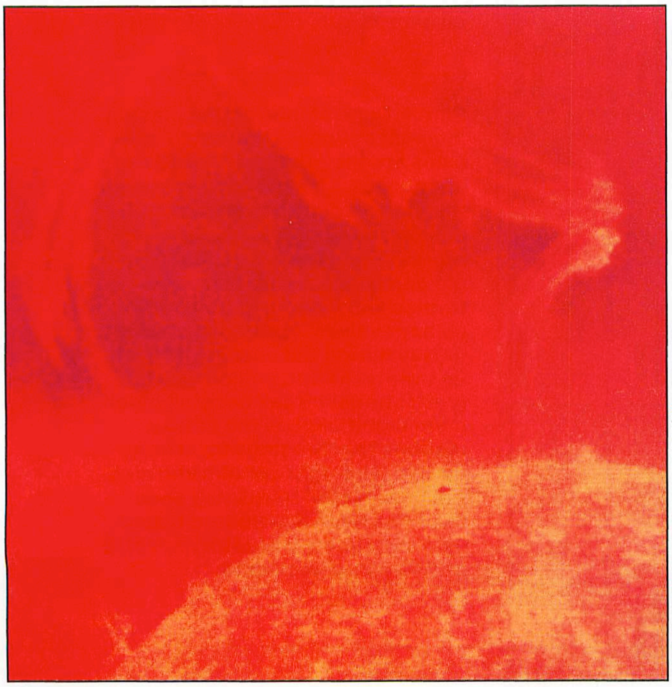
Plasma simulations suggest that highly ordered magnetic fields should exist in galaxies.

by analyzing the polarization of radiation received from galaxies. This work, which was initially suspect in the astronomical community, had, by 1988, shown unequivocally that large-scale magnetic fields do exist in galaxies and that the distribution of weakly ionized hydrogen follows these fields.

Rotational velocities of galaxies—In the Big Bang model, the strongest evidence cited for "missing mass" in the universe is the rotational velocities of spiral galaxies. In a gravitationally bound system, such as the Solar System, the rotational velocities of the planets follow the Keplerian $1/r^2$ law: The inner planets rotate more rapidly around the sun than do the outer planets. If galaxies were gravitationally bound systems, their outer matter should also follow Kepler's laws of motion, and the outer matter should be slower than the inner matter. In fact, observations of galaxies showed that the in/outer matter flowed just as rapidly as the in/inner matter, giving a "flat" velocity curve. The only way to explain this characteristic in a gravitational system is to postulate large amounts of unseen matter in the form of a massive halo about galaxies.

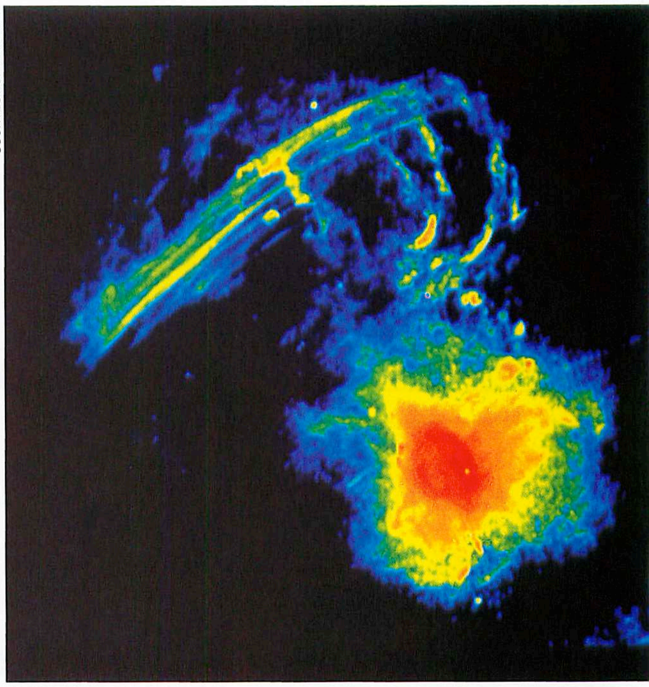
Plasma simulations show that electromagnetic forces, which are 39 orders of magnitude stronger than the gravitational force, are central to the dynamics of galaxy formation. Using the observable mass of a typical galaxy, about 100 billion suns, the plasma simulations replicate the rotational curves of spiral gal-

2.

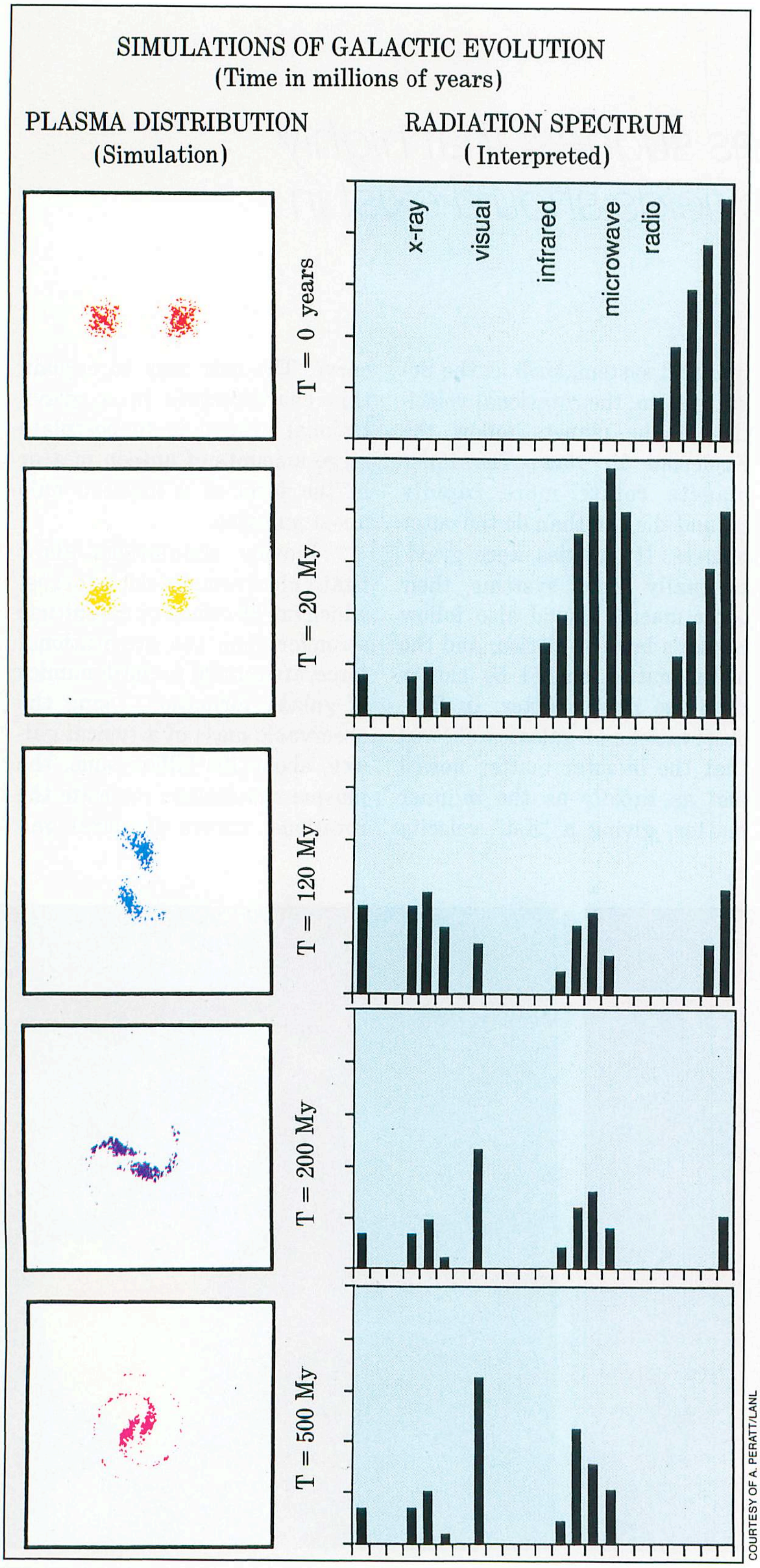


COURTESY OF NAVAL RESEARCH LABORATORY

COURTESY OF NRAO/AUI



3



COURTESY OF A. PERATT/LANL

axies. (The large order of magnitude difference between the forces of electromagnetism and of gravity is determined by comparing for two electrons the gravitational force of attraction and the electromagnetic force of repulsion.)

Cosmic Microwave Background—One of the serendipitous but extremely significant discoveries of the Plasma Universe simulation model was a background of microwaves with an energy density very nearly equal to that observed from the cosmic microwave background. This important feature of the Plasma Universe model was discovered through laboratory efforts to design high-power microwave generators.

In the laboratory, a filamentary plasma or electron beam that does not produce microwaves is unknown. In fact, the high-power microwaves (with power levels measured in billions of watts)

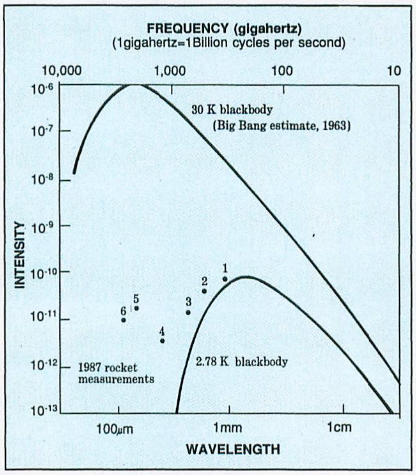
Simulations of interacting plasma filaments suggest that radio galaxies are the precursors of all other galaxies. The left column shows the plasma distribution over 500 million years, with frame 2 representing the era of double radio galaxies. The next three frames show how a double radio galaxy evolves into a normal spiral galaxy during the ensuing 400 million years. At 500 million years, gravitational forces become much more significant as the galaxy reaches the threshold for star formation. The right column showing the interpreted frequency spectrum has been assembled based on simulations, laboratory spectra, and observational data.

generated by plasmas in the laboratory are potentially so harmful that it has been necessary to develop a means of absorbing the radiation. This is now achieved by surrounding the experiment with a substance called eccosorb, whose thousands of filaments absorb and thermalize the microwaves and in the process produce a blackbody spectrum. Coincidentally, the lab investigations for developing and using eccosorb have required the acquisition of considerable knowledge about the distribution of radiation energy, which is readily transferable to studies of the cosmic microwave background.

The distribution of radiation energy of the Plasma Universe was not calculated until six years after the simulations began. When this was calculated the result was startlingly close to the distribution of energy of the cosmic microwave background. The closeness of this result to the observed value is emphasized by the fact that prior to the discovery of the background radiation by Penzias and Wilson in 1965 cosmologists had estimated the radiation energy density to be about 10,000 times higher than that actually discovered.

It is interesting to note that discussions of the Big Bang often describe the cosmic microwave background in terms of temperature, such as 3 degrees Kelvin. In fact, temperature is a very imprecise and insensitive parameter for describing the energy radiated from a blackbody source.

Anomalous Microwave Background



ART BY E. OZAKI/WORLD & I/ CONCEPT BY A. PERATT/LANL

In "Plasma Cosmology, Part I." (Aug. 1989, p. 298), the key data points were left off one diagram. This diagram is reproduced correctly here.
Measurements made in 1987 by a Japanese-American experiment are clearly inconsistent with the Big Bang model but consistent with the Plasma Universe model. Data points 1,2, and 3, which show an appreciable excess of microwaves beyond those predicted by the Big Bang model, present a major challenge to orthodox cosmology. The excess in points 4,5, and 6 is attributed to interstellar dust at a temperature of 20 K.

The distribution of radiation energy is much more sensitive.[2]

In an infinite universe of filamentary plasma (large-scale structure) the microwave background from synchrotron sources would necessarily be very smooth. This natural association of large-scale structure and smooth microwave background in the Plasma Universe model provides a significant contrast to the Big Bang model, which cannot presently explain how there could be a smooth microwave background if there is large-scale structure as has recently been discovered.

The Plasma Universe model further predicts that the cosmic microwave background from synchrotron sources will be found to have a distribution of radiation energy at high frequencies that differs from that predicted by the Big Bang model. This prediction is yet to be tested. It will await the launching in November 1989 of the Cosmic Background Explorer satellite to ascertain the true nature of the sea of microwaves that pervade our universe and perhaps give us further insights about the plasma universe in which we live.

The interactive web of supercomputer simulations, full electromagnetic spectrum astrophysical observations, and laboratory experiments with plasmas is a richly productive field today. The upstart Plasma Universe model is growing stronger year by year and promises to be a major contender in the arena of cosmological discourse for the coming decade.■

2. Since the discovery, cosmologists have been able to present claims for previously mentioned temperatures ranging between 5 and 50 degrees Kelvin.

Anthony L. Peratt studies plasmas at Los Alamos National Laboratory. His book, The Plasma Universe, *will be published by Springer-Verlag in mid-1990.*