Guest Editorial
Electrical Engineering, Plasma Science, and the Plasma Universe

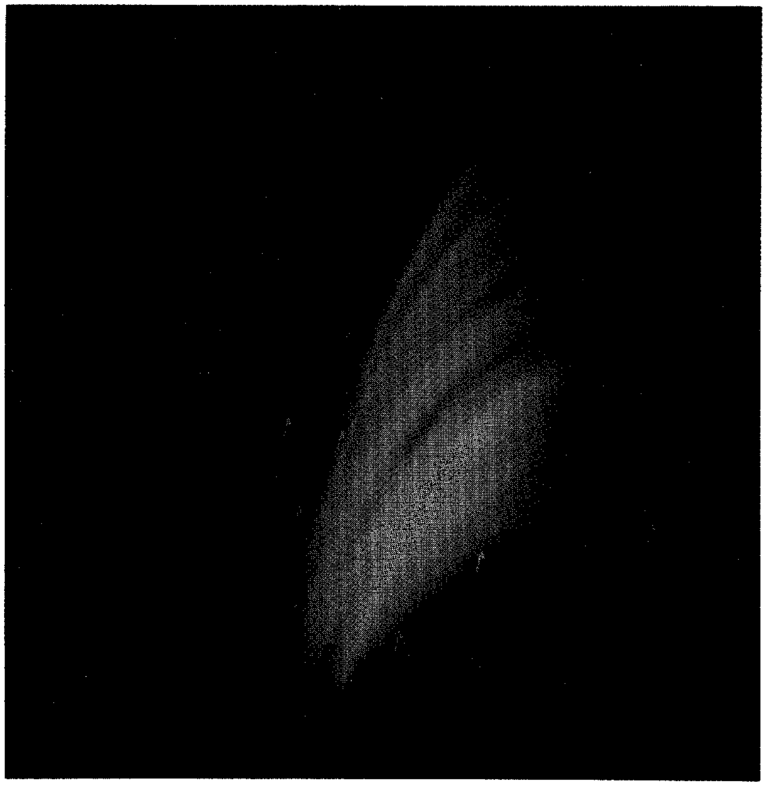

Fig. 1. Starfish event. Artificial aurora produced by plasma particles streaming along the earth's magnetic field lines. Picture taken from a Los Alamos KC-135 aircraft 3 min after the July 9, 1962, 1.4-megaton 400-km-altitude nuclear detonation above Johnston Island. This event produced a degradation of radio communications over large areas of the Pacific and an intense equatorial tube of synchrotron emitting electrons having a decay constant of 100 days. The brightest background object (mark) at the top, left-hand corner is the star Antares, while the right-hand-most object is θ-Centarui. The burst point is two-thirds of the way up the lower plasma striation.

ELECTRICAL and electronics engineering originally comprised electrical power, illumination, and the telephone and telegraph but have now expanded into other areas including radio communication, digital computation, automatic control of machines and systems, navigational systems as for radar, sonar, loran, and shoran equipment, laser research and measurements, and the science of information as a basic understanding of the communications process. Frequently included in this field is the analysis of large interacting systems ranging from transportation to biological, ecological, and economic systems. These are logically related to electrical engineering because the mathematical process employed in the solution of interconnected electrical systems can be applied to other complex interrelated systems.

With the coming of the space age and the subsequent discovery of magnetospheric–ionospheric electrical circuits [1], Kirchoff's laws and therefore electrical engineering were suddenly catapulted to dimensions eight orders of magnitude larger than that previously investigated in the laboratory and nearly four orders of magnitude greater than that associated with the longest power distribution systems on earth. Since that time, space probe measurements of the planetary magnetospheres have

0093-3813/86/1200-0613$01.00

pushed electrical engineering as related to plasma science several orders of magnitude deeper into space, i.e., the dimension of the solar system.

The solar system is the primary laboratory in which plasma processes of great generality can be studied. By the early 1960's, with the discovery of extremely high electrical powers generated in the plasmas of nuclear devices exploded in the atmosphere (and their effect on the earth's natural plasmas and magnetic field, Fig. 1), the Van Allen radiation belts, and the solar wind, it was already clear that future understanding of the earth and sun would be expressed in terms of plasma science. Plasma science is recognized as the key to understanding the generation of magnetic fields in planets, stars, and galaxies; phenomena occurring in stellar atmospheres, in the interstellar and intergalactic media, in neutron-star magnetospheres, in active radio galaxies, and in quasars; and the acceleration and transport of cosmic rays. There are convincing arguments for the view that the clouds out of which galaxies form and stars condense are ionized. The problem of the formation of astronomical bodies therefore naturally belongs to the field of cosmic plasma science [2]. The study of each of these subjects depends on and contributes to laboratory plasma science. Each has traditionally been pursued independently. Only recently has there been a tendency to view them as a unified discipline.

Many electrical engineers have gained acclaim beyond the field of electrical engineering in their discoveries relating to space and cosmic plasma. The first systematic approach to understanding the flow of plasma or currents in space was undertaken by the Norwegian electro-technologist Kristian Birkeland (1867–1917). Birkeland advocated a plasma-filled universe populated with *systems* of galaxies, and he studied a wide range of astrophysical phenomena with his terrella experiments. Even as the Vega, Suisei, and Giotto spacecraft encountered comet Halley [3], the Guest Editor read of Birkeland's hypothesis that "comets consist of an accumulation of cosmic dust, with various carbonaceous substances, concentrated about one or more nuclei, which are surrounded by a highly rarefied vaporous envelope in which possible carbonaceous gases are comparatively strongly represented" [4]. Birkeland based his comet hypotheses on observed luminous pencils of rays from his coal-coated-cathode comet simulations. It is perhaps one of the great losses to science of the 20th century that Birkeland's work was so long neglected. Birkeland died as a working committee was in the process of nominating him for the Nobel prize in physics.

Irving Langmuir (Nobel prize in chemistry, 1932), an electronics engineer with General Electric, Schnectady, New York, was truly an interdisciplinarian; his interests ranged from electrical discharges and plasmas to biological and geophysical phenomena. Langmuir coined the name *plasma*, borrowing the term from medical science, probably to describe the, at times, almost lifelike behavior of the balanced regions of electrons and ions with which he experimented; he was also the first to make detailed analyses of double layers.

P. A. M. Dirac (Nobel prize in physics, 1933; Medal of the Royal Society, 1939) attributed his problem-solving abilities and concepts (e.g., the Dirac symmetric matter–antimatter universe) to the methodology he learned while studying electrical engineering as an undergraduate.

The science of radio astronomy had its beginnings in the experiments of Karl G. Jansky (Fellow, IRE) in 1931. Jansky (brother to C. Moreau Jansky, Jr., President, IRE, 1934) was a radio engineer at the Holmdel, New Jersey, field site of the Bell Telephone Laboratories. Assigned to study the direction of arrival of thunderstorm static, he discovered "· · · a steady hiss type of static of unknown origin" (*Proceedings of the IRE*, December 1932). In a series of *Proceedings* papers, Jansky had, by 1935, identified the source of static as the Milky Way. Thus was opened a new window on the cosmos, revealing a sky very different from the optical one we had known.

In 1937, Grote Reber, a radio engineer living in Wheaton, Illinois, became interested in Jansky's work and constructed a 9.5-m diameter parabolic-reflector antenna in the backyard of his home. Reber was the first to recognize that the antenna-receiver combination (a radio telescope) acts as a bolometer to measure the equivalent temperature of distant parts of space, which is projected by the antenna response pattern. He undertook a systematic survey of the sky and published his findings in a series of papers on cosmic static in the *Proceedings of the IRE* and the *Astrophysical Journal* (he purposely reported his work in terms of decibels re 1 mW as the actual temperatures they represented would have been unacceptable at that time [5]). Reber's 1940 paper turned out to be one of the classic papers of radio astronomy, inspiring the discovery of the van de Hulst 21.1-cm (1.420-GHz) radiation from neutral hydrogen and the formation of a new field of research dealing with the hydrogen line [6].

Edward V. Appleton (Nobel prize in physics, 1947; IEEE Medal of Honor, 1962) characterized the radio properties of the earth's ionosphere with his electromagnetic wave propagation studies.

In 1965, Arno Penzias and Robert Wilson (Nobel prize in physics, 1978), two radio engineers at the Bell Telephone Crawford Hill Laboratory discovered the 3°K isotropic microwave background radiation using a converted TD-2 transcontinental telephone system microwave horn. Their measurements of the background radiation at microwave wavelengths, as well as the subsequent discovery of X-ray and gamma-ray backgrounds provide fundamental tests to all cosmological theories.

Hannes Alfvén, a Swedish electrical power engineer (Life Fellow, IEEE; Nobel prize in physics, 1970; Franklin Medal; Fellow, Royal Astronomical Society; Lomonosov Medal) was the leading advocate of Birkeland's ideas regarding electric currents in space at a time when space was considered to be "filled with vacuum." Translating knowledge obtained from laboratory experiments to space and cosmic plasma, Alfvén was the first to postulate the isotropy of *extragalactic* cosmic rays and the existence of a galactic magnetic field (1937); the concept of a limiting current in relativistic electron beams (1939); the notion of an equivalent magnetic moment which determines the motion of electric charges spiralling in magnetic fields (1942); identification of the synchrotron process in astronomical sources (with N. Herlofson, 1950); collective ion acceleration (1952); and the importance of double layers as astrophysical objects (1958).

The 1960's and 1970's saw a renaissance of observational astronomical research, fueled by the explosive development of electronics, space probes, and computer analyzing methods. Radio engineers and physicists set the stage for these advances in observational astronomy by opening up ten octaves of the electromagnetic spectrum to cosmic research.

In 1957, the launching of the first man-made earth satellite paved the way for sustained astronomical observations from above the earth's atmosphere, which in turn opened up the ultraviolet, X-ray, and gamma-ray bands of the electromagnetic spectrum. Satellite-based computer-controlled telescopes also are capable of higher sensitivity and better resolution at optical and infrared wavelengths.

The VLA, the Einstein X-ray satellite, and the gamma-ray satellites are now providing data on space and cosmic plasma of unprecedented quality.

The discovery of an immense filamentary magnetic-field-aligned plasma structure at the galactic center [7], whose morphology [8] and toroidal–poloidal 10^{-4}-G field were reported using large-scale particle-in-cell simulations of galactic current filaments prior to observation [9], suggests that large-scale numerical models will probably make plasma science central to the interpretation and replication of many astronomical observations and motivate new and different kinds of observations.

When launched, the Hubble Space Telescope and a gamma-ray observatory will surely revise many currently held astronomical beliefs. However, the cost of our newly gained knowledge has been, and will continue to be, high. This fact was forced upon us by Challenger's catastrophic failure last January; among whom of those on board was IEEE's Judith Resnik.

As pointed out in the contributions to this Special Issue, the universe is predominantly matter in its plasma state and electromagnetic forces are stronger than gravitation by 39 orders of magnitude. The "missing mass" problem that plagues astronomy at nearly every facet in its size hierarchy may not exist at all when electromagnetism augments gravitation. If the properties of plasma are the same everywhere from the micrometer-dimensioned structures produced in the dense plasma focus, to the Hubble distance, then not only can our knowledge of the universe be improved, but also a *backflow* of data to laboratory experiments can be expected (Fig. 2). It is with this hope that the IEEE TRANSACTIONS ON PLASMA SCIENCE presents this Special Issue on Space and Cosmic Plasma.

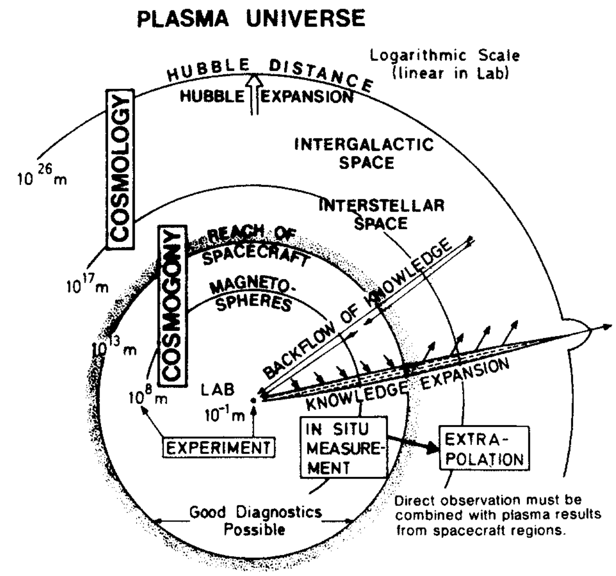

Fig. 2. The plasma universe. With the extrapolation of laboratory and magnetospheric data, the application of large-scale particle-in-cell simulations to non-*in situ* space regions, and direct observation of interstellar and intergalactic plasma phenomena, we can predict a *knowledge expansion* about the universe and a *backflow* of information to laboratory plasmas (adapted from H. Alfvén, this issue).

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Reprinted from IEEE TRANSACTIONS ON PLASMA SCIENCE, Vol. PS-14, No. 6, December 1986