Guest Editorial
Special Issue on Space and Cosmic Plasma

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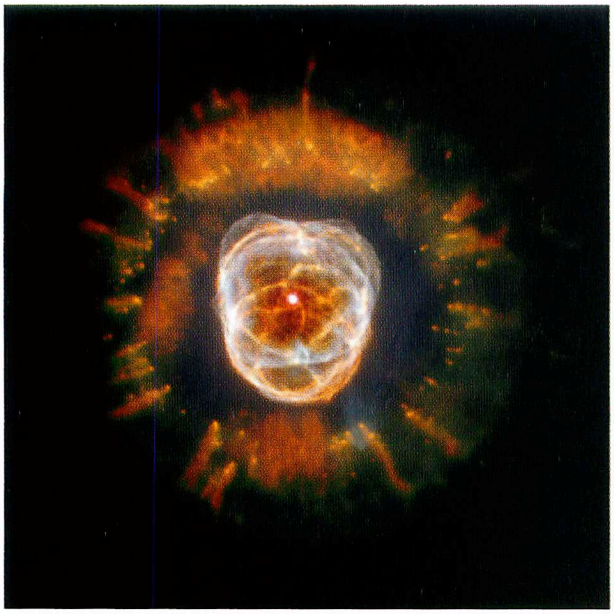
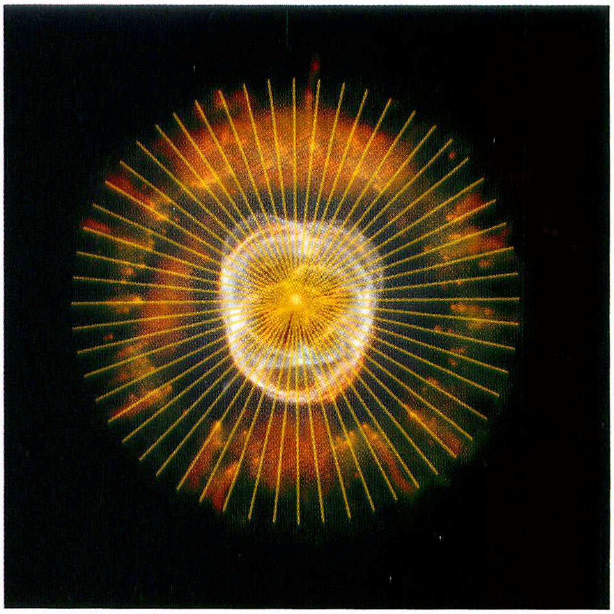

Eskimo Nebula, NGC 2392, Hubble Space Telescope Image (credit: NASA). Space plasma researchers and pulse power engineers have long speculated that the progenitor of intense auroras, protoplanetary and planetary nebula, and supernovae is the *Z*-pinch, as both display the temporal, morphological, and radiation properties that are found in high-energy-density plasmas produced in the laboratory and in extreme high-current explosive test experiments. On the right is an overlay of 56 radial lines representing 56 twisted pairs of current filaments, as recorded in pinches and the penumbra of the dense plasma focus [1]–[3]. The template lines are centered on the intensely radiating pinch at the center of the nebula. The Eskimo Nebula has a distance of 2.9 kly and a radius of approximately 3.4 ly. (A. L. Peratt, Los Alamos National Laboratory).

GRAVITY was the focus of twentieth-century astrophysics; for the twenty-first century, it will be electromagnetism and plasmas in addition. This emerging paradigm shift is presaged by the rapid pace of discoveries about our own star—the Sun—and its total plasma environment. These discoveries are particularly well marked by the discovery in 1958, at the beginning of the Space Age, of Earth's radiation belt, or Van Allen belts, by Dr. J. A. Van Allen (1914–2006) for whom this Special Issue on Space and Cosmic Plasma is dedicated. Van Allen's discovery and many other discoveries over the past four decades have profoundly changed our view of space environments—from "empty" space to the fullness of space plasmas at all scale lengths. Some examples of these discoveries are the following:

1) *in-situ* measurements of the properties of plasmas in the magnetospheres, leading to the confirmation of Birkeland field-aligned currents, double-layer acceleration of charged particles, magnetic flux ropes in the ionospheres of planets, and a system of currents in the magnetospheres of the outer planets;
2) discovery of an immense filamentary magnetic field-aligned plasma structure at the center of our galaxy and the continuing discovery of related multiscale filamentary plasma structures in most astrophysical environments;
3) laboratory experiments duplicating the power laws of electromagnetic radiation from extragalactic sources and confirming that plasma processes are often responsible for the acceleration of charged particles to high energies;
4) the advent and application of multidimensional, relativistic, and fully electromagnetic particle-in-cell simulations to space and cosmic plasma.

The goals of this Special Issue of the IEEE TRANSACTIONS ON PLASMA SCIENCE are to provide an update on progress in topical areas of the plasma universe and to report on the exchange of knowledge between plasmas of all dimensions in the size hierarchy from new observational, theoretical, experimental, and computational results.

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Van Allen not only discovered the radiation belts, or "Van Allen" belts, but also, in 1979, demonstrated the existence of radiation belts around Saturn as well. Indeed, we now recognize that space plasma environments surround every solar system body, all of which are embedded in the pervasive solar wind plasma flow. All earlier inferences of space plasma were dependent on interpretations of remote sensing theory or models—Van Allen's work added the power of *in-situ* measurement for revealing our plasma universe [4].

This Space and Cosmic Plasma issue begins with a very special summary of Van Allen's life and accomplishments by two of his long-time colleagues, D. Gurnett and S. Krimigis. They point out how "the totally unexpected discovery [in 1958] of very intense and highly energetic belts of radiation encircling the Earth immediately attracted worldwide attention, both in the scientific world and by the general public."

Both Van Allen's discoveries and "modest" suggestions will indefinitely impact space physics and astrophysics research. One of his many fruitful hypotheses is featured by I. Alexeff, who describes a simple plasma model, which was inspired by Faraday, to explain how the magnetic moments of planets and stars are proportional to their angular momenta over some 12 orders of magnitude.

One of the great pioneers of auroral science, S.-I. Akasofu, discusses some outstanding issues in solar-terrestrial physics by examining relatively simple cases for key space plasma phenomena: sunspots, solar flares and CMEs, and magnetospheric substorms. He concludes that certain core concepts, such as magnetic flux ropes and reconnection, have limitations that may be forgotten when we focus on the recent success of powerful magnetohydrodynamic (MHD) simulations.

Another pioneer of twentieth-century space plasma studies was H. Alfven (1908–1995), who won the Nobel Prize for his work in MHD and created theories concerning the Van Allen radiation belts, magnetic storms, and aurora. One of his theories was about the critical ionization velocity (CIV) effect, which could have wide astrophysical significance. G. Verschuur analyzes interstellar neutral hydrogen (HI) emission spectra and finds several families of linewidths whose numerical values coincide with the CIVs of the most common interstellar atomic species. Evidence is given for how CIV leads to enhanced electron densities where rapidly moving neutral gas masses interact with ambient plasma, with the latter one being an interactive mix of electrons, ions, neutrals, and fields. Verschuur's mappings show that galactic foreground HI structure is not random but part of very long twisted filaments of cosmic scale. These form a "plasma forest" through which any observation of the microwave background must be capable of penetrating. For example, an all-sky survey of high-frequency radio continuum emission from observations of the Wilkinson Microwave Anisotropy Probe (WMAP) spacecraft should have no relationship to galactic HI filaments. However, Verschuur finds just such a relationship that, if validated, has far-reaching implications for the interpretation of WMAP data.

An independent verification of Verschuur's filaments comes from a totally independent study of the structure of the plasma universe. A. B. Kukushkin and V. A. Rantsev-Kartinov of the Kurchatov Institute, Moscow, report on very long filamentary plasma cylinders with unexpected longevity, which was observed in laboratory electrical discharges and in space. Kukushkin and Rantsev-Kartinov have given the name "heteromacs" to these heterogeneous magnetoplasma "cables" that twist, forming helical structures along the filament. Heteromacs likely formed the "figures drawn with fire on a black background" that were reported in the 1859 intense aurora and likely constitute the "backbone in the sky" that was reported by all cultures in antiquity. This skeletal morphology is common in high-current-density Z-pinch framing photographs. Pictures of these filamentary cylinders are, for all practical purposes, identical to the filamentary galactic HI filaments that were recorded by Verschuur. Indeed, in the work reported here, Kukushkin and Rantsev-Kartinov have extended their 100-μm observations to 21-cm observations.

In 1962, only five years after Van Allen's discovery of the radiation belts, T. Gold raised a startling question about the impact of very rare but extremely large solar outbursts. Bringing together interests in southwestern artifacts and theoretical expertise in high-current Z-pinches, Peratt *et al.* have previously reported the striking qualitative similarity of petroglyphs to plasma experiments. This work is substantially extended here with both qualitative and quantitative analyses involving several tens of thousands of ancient recordings from around the world, with specific examples documented here region by region. Their results and modeling lead to a reconstruction of the auroral forms that are presumably associated with such rare and extreme solar outbursts and have been directly observed over the centuries and captured most often in the ancient's medium of choice—rock!

The dense plasma focus is perhaps the most "physics rich" of all experimental plasma devices. It is a prodigious producer of neutrons and, depending on the polarity of the inner and outer cylindrical electrodes, can be made to produce intense charged particle beams or, at the end of the cylinders, a penumbra, which is often called a "chalice" because of its fine lacework of radial electrical currents. In a meticulous set of ongoing experiments, M. M. Milanese *et al.* have applied their work to the study of intense aurorae, time sequentially photographing the evolution of "about sixty" radial filaments.

Ponomarenko *et al.* of the Russian Academy of Sciences (RAS), Novosibirsk, Russia, report here on the "first attempts to simulate in a laboratory both initial (at the Sun) and final (near the Earth) stages of relevant interaction processes between the plasma flows and magnetic fields" for large solar flares or Coronal Mass Ejections. Beginning with K. Birkeland more than a century ago, there have been strong linkages between laboratory experiments, theory, and observations in space plasma studies, and this RAS group effectively carries this tradition into the twenty-first century.

D. Scott reiterates the fundamentals of electrical engineering as applied to many fields of human endeavor, illustrating when experimental knowledge has been correctly or incorrectly applied and where pitfalls may be expected (Maxwell's equations derive from Faraday's experiments twenty equations with twenty unknowns, which were reduced to four by H. Hertz and O. Heaviside four decades later). As Scott points out, in engineering, the correctness of the application is obvious; the device either works as designed or does not. However, in less accessible environments such as space and cosmic plasma, the information gathered is often not obvious, insufficiently located (Earth or satellite), or incomplete. In addition, of course, controlled laboratory experiments—the final adjudicator in science—are typically absent in space research. As the backdrop for this elucidation, Scott uses the multidisciplinary origins of the plasma universe [5].

A document that is worth more than a cursory glance is that of C. J. Ransom and W. Thornhill, who recognized many planetary features as suggestive of marks from electrical discharges. They report experimental results that will give those of us who study such phenomena, and likely our planetary geologist colleagues, good reason to ponder.

Plasma cosmology, or cosmology in the plasma universe [6], as derived by K. Birkeland, H. Alfvén, C.-G. Fälthammar, N. Herlofson, B. Lehnert, L. P. Block, P. Carlqvist, and a host of others since Anders Celsius first identified the aurora as an electromagnetic phenomena nearly 300 years ago, has long associated the plasma pinch as the progenitor of many objects in the cosmos [7]–[9]. In the paper "The Z-pinch morphology of supernova 1987A and electric stars," W. Thornhill revisits plasma cosmology adding new insights that link together plasma phenomena ranging from auroras to supernovae.

Early work on a new theory to unify gravity and electromagnetism is reported here by J. Brandenburg. His Gravity Electro-Magnetism-Strong theory extends earlier theories by Kaluza-Klein, Sahkarov, and Zeldovich. Electromagnetism and gravity are unified at the planck length, which results in comparable roles for electromagnetism and plasmas as for gravity in shaping the structures of the cosmos.

A paper by G. Anagnostopoulos, Tenentes, and Vassiliadis on "The Quasi-Perpendicular Bow Shock as a Temporal Barrier and Accelerator of Magnetospheric Particles" will appear in the October issue. With a focus on Earth's bow shock regions but with implications for other space plasma shock regions, it provides a specific example of how *in-situ* plasma measurements from spacecraft, in the spirit of Van Allen's work, place strong constraints on possible models for particle acceleration.

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He was a Staff Member with Lawrence Livermore National Laboratory from 1972 to 1979; a Guest Physicist with Max Planck Institut für Plasmaphysik, Garching, Germany, from 1975 to 1977; a Guest Scientist with Alfvén Laboratory, Royal Institute of Technology, Stockholm, Sweden, in 1985; and a Scientific Advisor to the U.S. Department of Energy from 1995 to 1999. He was also with the Applied Theoretical Physics Division, Physics Division, Associate Laboratory Directorate for Experimental Programs. He has been with the Los Alamos National Laboratory, Los Alamos, NM, since 1981. He trained in aerial and satellite reconnaissance at the Defense Intelligence Agency College, Washington, DC, in 1992. He is the author of *Physics of the Plasma Universe* (Springer-Verlag, 1992) and the editor of *Plasma Astrophysics and Cosmology* (Kluwer Academic Publishers, 1995) and *Advanced Topics in Space and Astrophysical Plasmas* (Kluwer Academic

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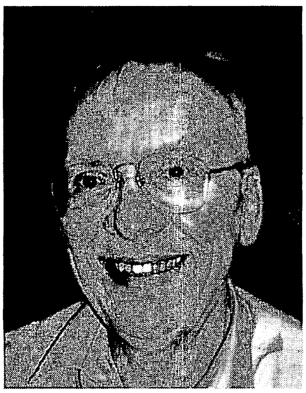
Dr. Peratt is a member of the American Physical Society, American Astronomical Society, and Eta Kappa Nu. He has served as Session Organizer for space plasmas and the IEEE International Conference on Plasma Science (1987–1989), Guest Editor of the IEEE TRANSACTIONS ON PLASMA SCIENCE and Special Issues on Space Plasmas (1986, 1989, 1990, 1992, 2000, and 2003), Organizer of the IEEE International Workshops on Space Plasmas (1989, 1991, 1993, 1995, 1996, 1997, 1998, and 2003), Associate Editor of the IEEE TRANSACTIONS ON PLASMA SCIENCE (1989), and Senior Editor (2007). He has also been an elected member of the IEEE Nuclear and Plasma Science Society (NPSS) Executive Committee (ExCom) (1987–1989, 1995–1997, and 2004–2007); General Chairman of the IEEE International Conference on Plasma Science, Santa Fe, New Mexico (1994); and IEEE NPSS ExCom Vice Chairman (1997). He was also elected to the IEEE NPSS Administrative Committee (1997 and 2004). He was the recipient of the U.S. Department of Energy Distinguished Performance Award (1987 and 1999), the IEEE Distinguished Lecturer Award (1993), and the Norsk Hydro Kristian Birkeland Lecturer Award from the Norwegian Academy of Science and Letters, Department of Physics, University of Oslo, Oslo, Norway, in 1995.



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