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# Astrophysical Plasmas

Stars, galaxies, and fusion reactors all contain a substance that simultaneously obeys the laws of electromagnetism and fluid dynamics. In 1928, Irving Langmuir named it "plasma" and the recipe is simple: take matter and heat until ionized. The result is a collection of charged particles possessing all of the qualities of a fluid but with added twists and turns caused by electric and magnetic fields. Although the use of plasmas for controlled thermonuclear fusion has received the most scientific attention, plasma physics is an essential part of many astrophysical phenomena. The five articles in this issue of *Science* examine plasmas in astrophysical settings, from the densest stars to the most rarified planetary magnetospheres.

Van Horn describes the state of plasma under extremely high pressure, as might be found in white dwarf stars, neutron stars, the giant planets, or the still hypothetical "brown dwarfs." The electrons are packed so tightly that the exclusion principle of quantum mechanics, rather than electrical repulsion, keeps them apart. Stars in this condition exhibit unusual properties: the stellar structure, for instance, is almost completely independent of temperature. On the other hand, the cores of white dwarfs and the surfaces of neutron stars can freeze solid if the temperature is low enough. Calculations of heat transfer, nuclear reaction rates, and equations of state of dense plasmas allow the evolution of such bodies to be understood.

Jets of plasma associated with stars and galaxies are among the largest and most energetic objects in the universe. De Young surveys the observational evidence and theoretical understanding of these jets. Instead of the spherical outward flows of ionized gas that all stars emit, stellar jets are highly directional. Extragalactic jets are more vigorous, and they take many shapes and sizes. Although much has been learned, the specific energy sources and mechanisms for stellar and extragalactic jets are still puzzles.

McKee and Draine consider another energetic phenomenon: interstellar shock waves. Stellar winds push the surrounding interstellar medium outward at velocities of ten to hundreds of kilometers per second; supernovae generate shock waves that travel up to about 10,000 kilometers per second. The way these shocks collide with the ambient interstellar medium tells much about the nature of that tenuous plasma. Such shock waves are believed to accelerate the cosmic rays that are observed on Earth. Shock waves have also been observed in molecular clouds, the large clumps of neutral gas in the interstellar medium. In this case, the coupling of even small amounts of ionized gas to the neutral matter by magnetic fields can completely alter the structure of the shock wave.

The sun emits a plasma too, the solar wind, and although of low density, it is highly ionized and hot. Neugebauer describes the properties and acceleration mechanisms of the solar wind plasma. It exists in two states: the quasi-stationary solar wind, which fluctuates over time scales of months, and the transient wind, caused by explosive ejection of plasma from the solar atmosphere. Differences in the properties of these two states have been elucidated by interplanetary space probes, but questions still remain about the processes involved. A picture has emerged over the last decade in which the acceleration of the solar wind is tied closely with the heating of the solar atmosphere.

What happens when the solar wind interacts with the magnetic fields of planets to form magnetospheres? Before direct exploration of the solar system by spacecraft, the concept of a magnetosphere—the region where a planet's magnetic field dominates the solar wind—was unknown. Hill and Dessler discusss the six planets in the solar system that have well-developed magnetospheres: Mercury, Earth, Jupiter, Saturn, Uranus, and Neptune. A comparative approach to studying the motions of plasma within these magnetospheres may lead to a basic understanding of more remote astrophysical systems.

Because they follow two sets of rules, electromagnetic and hydrodynamic, plasmas display a rich array of phenomena. The degrees of freedom are many and the intricacies can be a source of astonishment. Wherever plasmas are located in the cosmos, their complexity continues to challenge observers and theorists alike.—DAVID VOSS

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