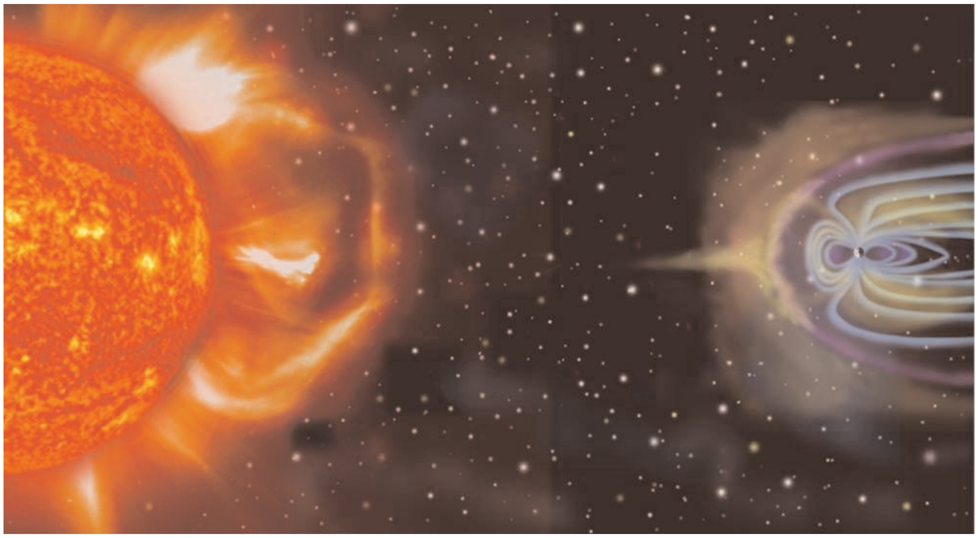
about Plasmas

from the Coalition for Plasma Science

Space Plasmas

Experience lightning (ka-boom!), aurora (wow!), and a bright Sun (whew, it's hot!) – all plasmas. Add to that stars, most interstellar and galactic materials, and the insides of fluorescent lamps – all plasmas.



Twin solar prominences (left) arcing away from the Sun add new energetic plasma to the solar wind, which may create magnetic storms surrounding the Earth. This figure, not drawn to scale, dramatically understates the distance to the sun and the size of the sun.

The metaphor "Plasma Universe," coined by Tony Peratt and popularized by Nobel-prize winner Hannes Alfvén, aptly describes how plasmas comprise more than 99% of the visible universe. Plasmas represent a fourth state of matter and are an electrically conducting, interactive mix of uncharged particles, positively charged particles, negative electrons, electric fields and magnetic fields. The fraction of uncharged particles in a plasma varies dramatically, from more than 95% in the lower ionosphere to less than 1% in the solar wind, the continuous stream of plasma from the Sun. Plasmas conduct electricity and have other unique properties that make them more than simply a type of electrical 'gas.'

This auroral curtain is created by particles from Earth's space plasma environment.

Plasmas in the everyday world of human activity are generally confined to fluorescent lamps, arc lamps, and laboratory experiments in sealed chambers. One major exception is lightning: brief, long-range electrical discharges through the atmosphere. Lightning is part of a global electrical circuit that links the Earth's surface to the conducting ionosphere. This linkage has been dramatically recorded in the recent discovery of high-altitude lightning. Such lightning has been directly observed, with its blue jets and red sprites, from less than 30km above very large storm systems to an altitude of almost 90km near the base of the ionosphere.

Beautiful auroral displays result from solar wind plasmas that filter through the magnetic field surrounding the Earth, eventually striking and exciting ionospheric atoms or molecules and causing them to radiate different colors. Particle ejections from the solar corona and solar flares can result in space weather affecting technological systems, such as communications spacecraft,

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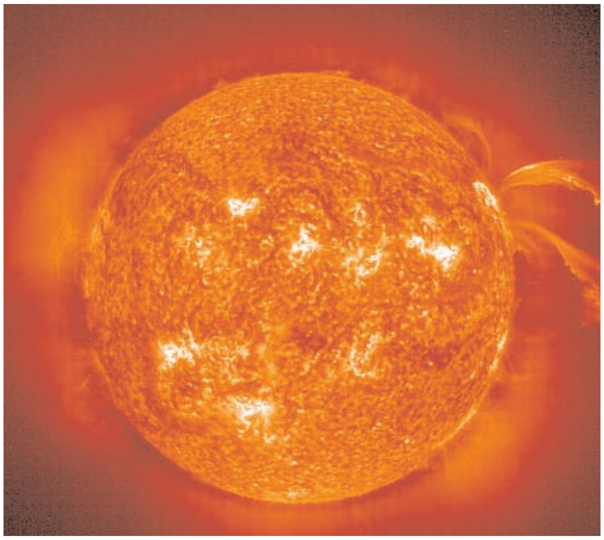
all around the globe. During such magnetic storms, the auroras brighten and move to lower latitudes, providing more of the world's population an opportunity to witness the natural beauty of the plasma universe. Between such storms and during daylight hours, the auroras are generally not visible, but are nevertheless always present as a continuous halo over the northern and southern polar caps of the Earth, centered on the magnetic poles.

The Tarantula Nebula is a diffuse cloud of plasma and dust with multiple shock waves.

Being able to image plasmas at high altitudes allows a direct view of space plasmas surrounding the Earth. They comprise a large space weather region more than 50,000 times the volume of the solid Earth! The immense plasma environment surrounding Earth and ordered by the geomagnetic field is comet-like, as is the case with any other obstacle (comet, planet, satellite) in the solar wind flow, and includes a compressed plasma region on the sunward side and a long tail downstream. This space weather domain, which is called the "magnetosphere," extends from the ionosphere out to more than 10 times the Earth's radius on the sunward side and out to several hundred Earth radii on the tailward side. As with most other plasma systems, magnetospheres have processes and organized regions at widely varying spatial scales. Furthermore, these space plasmas are highly interconnected due to interactions between charged particles and magnetic fields, electric fields and currents.



The Sun, viewed here in ultraviolet light, hurls its plasma out in all directions to form the solar wind.

With the emergence of radio wave, UV- and X-ray images of distant astrophysical systems, we are now beginning to recognize the importance of plasma processes not just for the solar system but for all astrophysical systems. New images of stellar nebulae like that of the supernova remnant shown above dramatically reveal a broad range of plasma processes. Plasma studies have advanced our understanding of stellar shock waves, cosmic rays, neutron stars, radio jets, and galactic magnetic fields. Astronomical work until recently has focused on only one of the two long-range force fields in physics – the gravitational field. Now the second long-range force field – electromagnetism – is receiving more attention in astrophysics, first in relation to stars and galaxies, and perhaps eventually with regard to the entire cosmos. Wherever these research frontiers lead, we now know that our cosmos is more than just gravity plus gas; instead it is gravity, some neutral gas, and lots of plasma!

Suggested Reading:
Michael J. Carlowicz, *The Emerging Science of Space Weather*, National Academy Press, 2002.
John W. Freeman, *Storms in Space*, Cambridge University Press, 2001.
Tamas I. Gombosi, *Physics of the Space Environment*, Cambridge University Press, 1998.
Kenneth R. Lang, *The Sun from Space*, Springer, New York, 2000.
Sten Odenwald, *The 23rd Cycle: Learning to Live with a Stormy Star,* Columbia University Press, 2000.
Anthony L. Peratt, *Physics of the Plasma Universe*, Springer-Verlag, 1992.

Text: Tim Eastman, Plasmas International; Tony Peratt, Los Alamos National Laboratory
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