

about Plasmas

from the Coalition for Plasma Science

Solar Plasmas

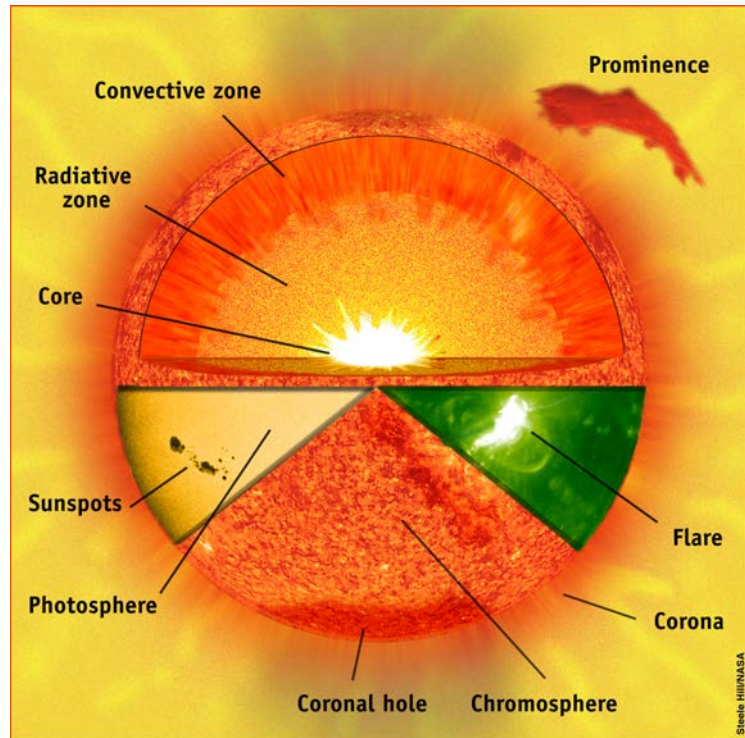
Did you know that you live inside the atmosphere of a star? We all do because our entire solar system sits inside the atmosphere of our star, the sun. Like earth's atmosphere, the sun's atmosphere is complex and dynamic, producing phenomena analogous to hurricanes, tornadoes, torrential rains and powerful winds. But there is one radical difference. The sun's atmosphere is composed not of normal gases, but rather of plasma, the fourth state of matter. This plasma atmosphere, consisting of particles and magnetic fields, interacts with the interplanetary environment and produces "space weather," creating effects on earth both beautiful (auroras) and destructive (power and communication blackouts).

While in many respects the sun is an average star, it is 260 thousand times closer than any other star, the center of our universe and the engine of our existence. It is the creator and dynamo for the heliosphere (the sun's extended "atmosphere", or space environment), a cauldron of dynamic activity, reliably constant in overall energy output, yet changing all the time.

How big is it? The sun is about one million miles (1.6 million km) across. It's so big one million earths could fit inside it, like gum balls in a bubble gum machine. Yet, because earth is 93 million miles (150 million km) away, the sun appears to be only the size of the moon, which is a mere 250,000 miles (400,000 km) from earth.

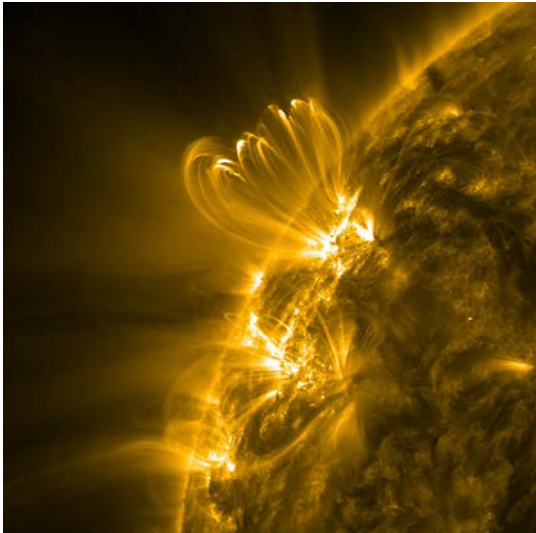
The study of helioseismology provides insight into the sun's interior. In the same way that seismologists learn about earth's interior by monitoring waves caused by earthquakes, helioseismology researchers learn about the sun's interior by studying waves within the sun. Temperature, density and motions deep in the sun influence these waves; studying them yields insights into interior conditions.

At its core, a huge thermonuclear reactor fuses hydrogen atoms into helium, producing 15 million degree temperatures. Near its visible layer, the "photosphere," the sun is like a pot of boiling water, with bubbles of hot, electrified gas (actually a roughly neutral mix of electrons and protons in plasmas circulating up from the interior) rising to the photosphere, and heading out into space. Compared to the core, the temperature of the photosphere is a much milder 6,000°C. But, curiously, as we move farther above the photosphere, the sun's plasma atmosphere gets continually hotter even as it becomes thinner and thinner. The temperature goes from 10,000s of degrees just above the photosphere, in a region we call the "chromosphere," to many millions of degrees in the outermost solar region, the "solar corona." How the corona achieves such high temperatures is not completely understood — one of the great mysteries of solar physics.



Plasma processes impose ever more structure as one moves outward from the sun's inner, nuclear furnace to source regions for the solar wind.

Coronal action does not stop there. The transport of energy and plasma away from the sun continues as a steady stream of plasma called the “solar wind.” Blustering at 800,000 to 5 million miles per hour (350 km/s to 2000 km/s), the solar wind carries a million tons of matter into space every second – equal to the mass of Utah’s Great Salt Lake. It’s not the mass or speed that makes the solar wind so potent. In fact, the solar wind would not even ruffle the hair on your head because it is billions of times less dense than the air we breathe. Instead, it is the overall coupled plasma and magnetic fields that enable this plasma wind to effectively buffet earth’s protective magnetic shield (the “magnetosphere”). Though less than about 1% of the solar wind penetrates the magnetosphere, this large-scale plasma interaction generates millions of amps of electric current and causes occasional magnetic storms in the space around earth.



Plasma structures abound near the solar surface. These loop structures are made of superheated plasma supported by magnetic fields.

What makes the sun so dynamic? The three basic necessary elements are plasma, differential rotation and magnetic fields. The sun is not a solid body but, like the gaseous planets Saturn and Jupiter, it rotates at different speeds depending on latitude, spinning faster at the equator (rotating about once every 25 days) and slower towards the poles (rotating about once every 36 days). In addition, the sun has strong magnetic fields running through it from pole to pole. The faster moving plasma at the equator drags the sun's magnetic fields, causing them to become twisted and to build up energy, much like twisting up a rubber band. These twisted magnetic fields rise up to the solar surface, poke through and create areas of concentrated magnetic field known as “sunspots.” The most notable features on the visible sun, these dark splotches - about the size of earth - are caused by the appearance of cooler (4000° C) areas amid the roiling surface plasmas (6000°C). These areas are cooler because intense magnetic fields, 1000 times stronger than the magnetic field of earth, prevent hot plasma from rising through the photosphere. Groups of sunspots are often the source region of solar storms, like solar flares and coronal mass ejections (CMEs).

Solar flares are fast, intense bursts of mostly electromagnetic radiation (from X-rays through radio waves) into space. CMEs are rapid expulsions of solar plasma and magnetic field. Though powerful, flares usually do not affect us here on the earth’s surface; however, they can impact communications and technology in space. When CMEs are expelled, the resulting solar storm propagates rapidly outward, carrying some of the sun’s magnetic field with it. A CME plasma cloud races through space and can reach earth in one to four days, traveling over a million miles per hour. A typical CME can carry more than 10 billion tons of particles into the solar system, a mass equal to that of 100,000 battleships. The energy in such a bubble of particles is comparable to a hundred hurricanes. However, it is especially the magnetic energy of such plasma clouds that can upset technology here at earth.

The sun goes through an 11-year cycle of activity, usually measured by the number of sunspots. At its peak, the sun often has numerous spots, many of them quite large, producing many solar storms each day; near its minimum period there are often no sunspots. The sun’s dynamic plasma atmosphere, via the solar wind, effectively creates the heliosphere, which is the source for the plasma environments encompassing each and every object in the solar system (planets, moons, spacecraft), and dominates our local astrophysical environment. High-resolution observations from NASA’s Solar Dynamics Observatory and other spacecraft are a revolution in solar physics research, enabling scientists to study plasmas in ways that are directly relevant to plasma processes for all other stars and stellar systems, and for understanding plasma throughout the universe.

Suggested Reading:

Coalition for Plasma Science, essays on “Space Plasmas” and “Space Weather”
Kenneth J. H. Phillips, Guide to the Sun, Cambridge University Press, 1995.
Leon Golub and Jay M. Pasachoff, Nearest Star, Harvard University Press, 2002.
A. Severny, Solar Physics, University Press of the Pacific, 2004.
Markus J. Aschwanden, Physics of the Solar Corona, Springer, 2006.

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