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What Lies Beneath a Sunspot

Using techniques similar to medical ultrasound diagnostics, scientists have peered inside the Sun and discovered what lies beneath sunspots, planet-sized dark areas on the surface of our star. Sunspots are surprisingly shallow, say researchers, and they lie on top of swirling hurricanes of electrified gas (plasma) big enough to swallow the planet Earth.

The new research, gathered from the Michelson Doppler Imager (MDI) onboard the Solar and Heliospheric Observatory (SOHO), will deepen our understanding of stormy areas on the Sun – called "active regions" — where sunspots appear. Powerful explosions from magnetic active regions can trigger beautiful auroras on Earth and affect high-technology systems such as satellites, power grids, and radio communications.

Sunspots have fascinated people since the early 1600's when Galileo's observations of them contradicted the common belief that heavenly objects like the Sun were flawless. Sunspots have remained a mystery for nearly 400 years. At first glance, it seems they should rapidly disappear. Instead, they persist for weeks or more.

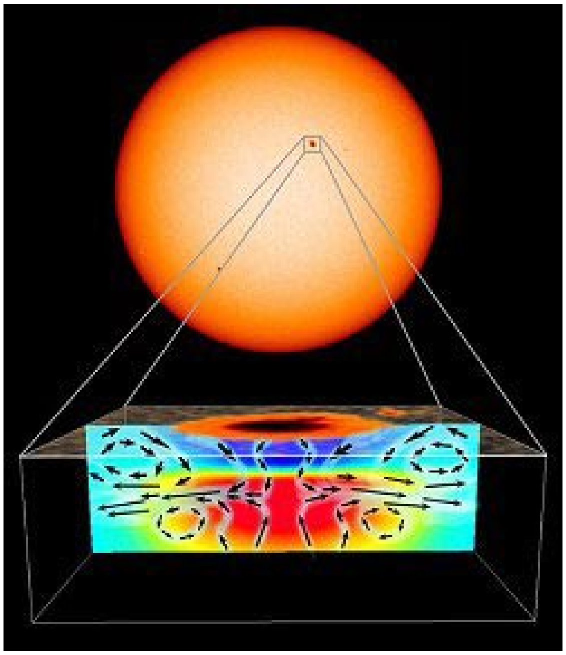
Astronomers have long known that sunspots are regions where magnetic fields become concentrated. Yet anyone who played with magnets as a child has felt how magnetic fields of like polarities repel each other. Likewise, the strong magnetic fields of sunspots should naturally repel each other, causing the sunspot to quickly dissipate. Indeed, observations show that surface material clearly flows out of the spots.

What then makes sunspots so long-lasting? How do they remain intact for weeks and months? A team of scientists had to look beneath the surface of the Sun to find the answer.

Alexander Kosovichev and Junwei Zhao of Stanford University, along with Thomas Duvall of NASA's Goddard Space Flight Center, used MDI's unique ability to probe the happenings just below a sunspot's surface — and for the first time they have clearly observed inward-flowing material.

"We discovered that the outflowing material was just a surface feature," said Zhao. "If you can look a bit deeper, you find material rushing inward, like a planet-sized whirlpool or hurricane. This inflow pulls the magnetic fields together."

The Sun is a humming ball of sound waves launched by turbulent convective motions in our star's outer layers. "The waves we monitor [using MDI] have a period of about 5 minutes," says Phil Scherrer of Stanford University, principal investigator for the MDI instrument. "That's roughly the turn-over time of the California-sized bubbles that appear as granulation of the photosphere." Solar granulation is what excites the Sun's internal sound waves.



An artist's concept of hidden gases swirling beneath a sunspot.

The material above the plug cools and becomes denser, causing it to plunge downward as fast as 3,000 miles per hour, according to the new observations. That draws the surrounding plasma and magnetic field inward toward the sunspot's center. The concentrated field promotes further cooling, and as that cooling plasma sinks it draws in still more plasma, thereby setting up a self-perpetuating cycle. As long as the magnetic field remains strong, the cooling effect will maintain an inflow that makes the structure stable. Outflows seen right at the surface are confined to a very narrow layer.

Since the magnetic plug prevents heat from reaching the solar surface, the regions beneath the plug should become hotter. A June 1998 observation provided evidence for this. "We were surprised at how shallow sunspots are," said Kosovichev. Below 3,000 miles the observed sound speed was higher, suggesting that the roots of the sunspots were hotter than their surroundings, just the opposite of conditions at the surface.

"The cool downward flows dissipate at the same depth where the hot upward flows diverge," said Duvall. "With these data one cannot get a sharp enough picture to really explain the details. Until now we've looked down at the top of sunspots like we might look down at the leaves in treetops. For the first time we're able to observe the branches and trunk of the tree that give it structure. The roots of the tree are still a mystery."

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For further images go to: http://science.nasa.gov/headlines/y2001/ast07nov_1.htm

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“Spinning” Fusion Energy Source Improves Prospects for Power Applications

San Diego, CA – July 2, 2001 — Researchers at the U. S. Department of Energy funded DIII–D National Fusion Facility at General Atomics, the largest fusion energy experiment in the United States, have nearly doubled the usual limits on pressure in a fusion energy device by spinning the hot, fusion fuel (plasma) very rapidly. A significant scientific advance in understanding the pressure limit in fusion energy devices made these higher limits possible. These results are an important step towards controlled fusion power production that is feasible, economical, and attractive.

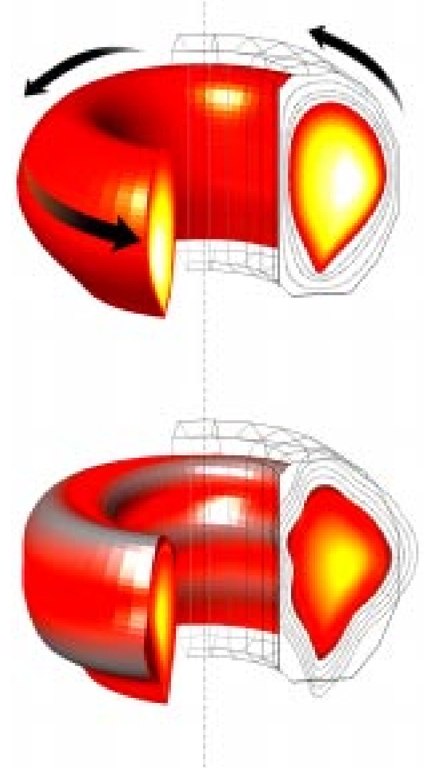
Fusion, the combining of two small atomic nuclei to form a heavier nucleus, is the vast energy source that powers the sun and the stars. Scientists worldwide are striving to harness the fusion process. As stated in the recently released U. S. National Energy Policy: “Fusion — the energy source of the sun — has the long-range potential to serve as an abundant and clean source of energy. The basic fuels, deuterium (a heavy form of hydrogen) and lithium, are abundantly available to all nations for thousands of years.” Fusion power will have no smog or greenhouse gas emissions to pollute air, ground, or water.

The fusion process requires extraordinarily high temperatures in the fusion fuel to produce useful amounts of energy. The DIII–D fusion energy device uses strong magnetic fields to contain the very hot (200 million degrees) fusion fuel (called a “plasma”) inside a 15-foot diameter donut-shaped metal reaction chamber. This tokamak magnetic field configuration is presently the most successful fusion system being investigated by scientists worldwide. At these very high temperatures, all atoms are separated into their constituent nuclei and electrons forming an electrically conducting, high pressure plasma similar to that found inside a fluorescent light bulb or neon sign, but thousands of times hotter.

High pressure in the fusion fuel is critical because the power released from fusion reactions increases very rapidly with increasing pressure. However, previous experiments and theory have identified an upper limit to the allowable pressure, called the free-boundary pressure limit. Beyond this pressure limit the hot fusion fuel becomes unstable, bulges outward, contacts the metal chamber wall, and cools rapidly.

In the early 1990’s, theoretical and experimental work had suggested that the plasma pressure might be increased beyond the usual free-boundary pressure limit by rapidly spinning the fusion fuel. Current experimental plasmas are easily spun at extremely high rates (10 to 100 miles/second) like a spinning top. In the initial experiments on DIII–D that sought to raise the plasma pressure while spinning the fusion fuel, the spin rate would always slow down and the hot plasma would become unstable and be lost. “Scientists felt that the free-boundary pressure limit was unavoidable — we could not get beyond it. Sustaining the pressure beyond this limit is a significant scientific breakthrough,” said Dr. Ronald D. Stambaugh, Program Director at the DIII–D National Fusion Facility at General Atomics.

Efforts to study the predicted effects of plasma rotation have not been possible before because the plasma was very resistant to spin. “The observed slow-down of the spinning plasma was a big mystery to us initially, and we were concerned that more aggressive stabilization methods would be needed to raise the plasma pressure,” said Prof. Gerald A. Navratil of Columbia University, one of the leaders of the multi institutional team from Columbia University, Princeton Plasma Physics Laboratory, and General Atomics studying stabilization of high pressure plasmas on the DIII–D National Fusion Facility. However, the recent experiments on DIII–D clearly demonstrated that the slow-down of the spinning plasma was due to a tendency of the plasma to amplify very small imperfections in the magnetic field (at the level of the Earth’s magnetic field). By applying new controls that automatically correct these small magnetic field imperfections the team was able to maintain the necessary high rate of spin needed for stability at high plasma pressure. These techniques have been used to sustain the pressure above the free-boundary limit in a variety of conditions, reaching levels nearly double the free-boundary limit in some cases.



SPINNING PLASMA stabilizes the plasma surface allowing improved performance. When stable, the plasma in the DIII–D tokamak is a tear-drop shaped donut inside a metal chamber, as in the upper cutaway figure. When unstable, the plasma surface distorts as shown in the lower figure (exaggerated about 10 times). Control magnet coils (not shown) push back on these distortions, keeping the surface smooth, allowing the plasma to continue spinning rapidly (in the direction of the arrow) and to remain stable to higher pressure.

The capability to double the pressure limits in fusion devices by spinning the fuel will have broad application to a range of approaches to fusion energy. These results will increase the emphasis on developing methods to spin the fusion fuel in a fusion power source. The DIII–D research team expects this advance could ultimately allow the design of more economical fusion power sources and reduce the time required to develop and deploy reliable sources of fusion energy.

For further information contact Dan Fouquet, Public Relations Coordinator, General Atomics, 858-455-2173; http://www.gat.com/news/fusion.html

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These brief summaries are drawn from several sources and are issued throughout the year. For more information please contact the source given at the end of each article or the editor: rivenberg@psfc.mit.edu; 617/253-8101