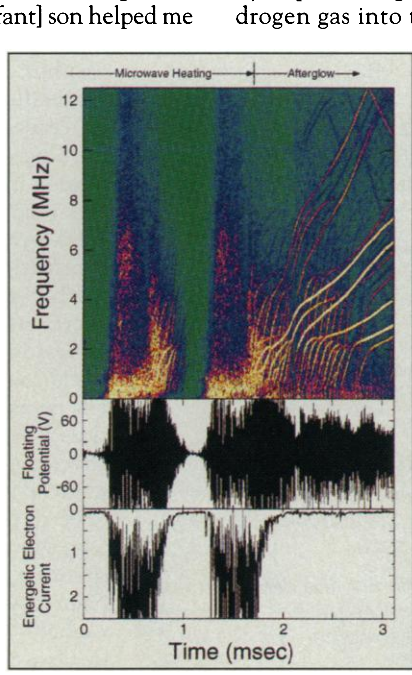
MEETING BRIEFS

Physicists Find Windows of Opportunity in Plasmas

The 1500 physicists from Europe, the United States, the Pacific Rim, and the former Soviet Union who gathered in Minneapolis from 7 to 11 November had many messages but one medium: plasmas. As the presentations at the meeting of the American Physical Society's division of plasma physics showed, the windows that laboratory plasmas can provide into space, turbulent liquids, and matter-antimatter interactions are opening wider than ever.

Magnetospheric Mayhem

Columbia University physicist Michael Mauel hastens to say that the disheveled appearance of his poster has nothing to do with its content. "My [infant] son helped me put up my poster," said Mauel ruefully. Yet his son's handiwork may be fitting. Mauel and his colleague Harry Warren, also at Columbia, are trying to understand an unruly phenomenon in space physics: the bursts of energetic electrons that sometimes pelt satellites in Earth orbit, destroying sensitive electronics. And he and Warren think, based on a laboratory model, that the bursts are unleashed by chaos.



Storm in a bottle. Microwave heating excites high-frequency waves in a laboratory plasma *(top)*, which periodically unleashes bursts of electrons *(bottom)*. A similar process may take place during storms in Earth's magnetosphere.

Space physicists know that electron bursts are a danger during magnetospheric substorms: episodes of turbulence in the magnetosphere, where vast envelopes of charged particles are trapped by Earth's magnetic field. But just as weather forecasters can't tell for sure whether a thunderstorm will breed a tornado, space physicists have had no way of knowing whether a substorm will unleash the damaging electrons—or whether they will remain safely trapped along the lines of magnetic force in the magnetosphere. Now Mauel and Warren have evidence suggesting that the bursts are triggered when the storm-driven waves in the magnetosphere satisfy the mathematical conditions for chaos. The result, say other researchers, could help space weather forecasters predict which substorms will lead to the dangerous bursts and which aren't a threat.

Mauel and Warren set about trying to capture the essence of these stormy processes in an aluminum vacuum chamber with a dipole magnet at the center, representing Earth, and an electron-energy-sensitive probe nearby, representing a satellite. By puffing hydrogen gas into the chamber, then irradiating it with microwaves, the team created an analog of the magnetosphere: a shell of hot electrons trapped by the magnetic field. Some of the free energy of the electrons went into generating large-amplitude waves, much like those of magnetic substorms. By monitoring the waves with current-collecting probes while keeping track of the electron bursts to the "satellite," Mauel and Warren hoped to learn what kinds of waves tend to trigger the electron bursts.

In this microcosm, at least, the researchers found that even powerful plasma waves aren't always enough to dislodge the electrons from their paths along the magnetic field lines. But for certain combinations of waves, the "satellite" probe measured bursts of current. By plotting the orbits of the electrons swirling in the waves, the researchers found that the current bursts were triggered only when the waves' amplitudes and wavelengths threw the electron orbits into something resembling chaos: what Warren calls "a stochastic sea," in which the orbits wandered wildly.

Anthony Chan, a plasma physicist at Rice University in Houston who is also studying chaos in the magnetosphere, says the setup may not be a perfect model of the magnetosphere, but he calls it "one of the best experiments I've seen for studying this type of [electron] transport." And he thinks there's a good chance that Mauel and Warren have zeroed in on "fundamental processes" that will help forecasters who monitor the magnetosphere with satellites send out warnings as soon as the far reaches of space turn threatening.

Charged-Up Plasmas

To all but the cognoscenti, ordinary plasmas seem exotic enough. These collections of positively and negatively charged particles are the most common form of matter in the universe, found in stars and interstellar space, but they can only be created on Earth under special conditions and confined with the greatest difficulty. At the plasma physics meeting, however, an even more esoteric form of matter—rare even in the universe as a whole—came in for close scrutiny: plasmas that contain just a single kind of charge.

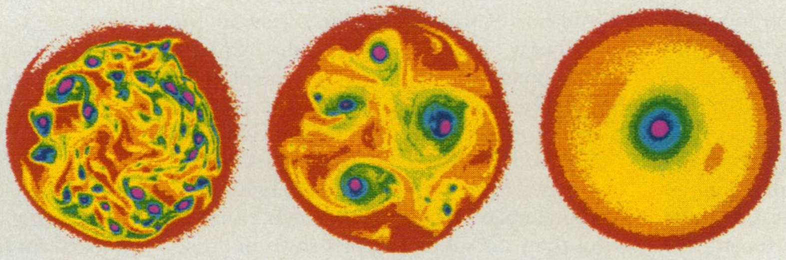
These nonneutral plasmas, made up of electrons, positively charged ions, or antimatter particles called positrons, aren't new to physics. But ordinary, neutral plasmas have had the upper hand in the past, says plasma theorist Dan Dubin of the University of California, San Diego (UCSD), because their study "has been pushed by applications" in fields like fusion and astrophysics. Now nonneutral plasmas may be on the verge of entering the mainstream. In a series of presentations, researchers showed that nonneutral plasmas can serve as powerful laboratories for studying fluid turbulence and the behavior of the clouds of antimatter that are believed to form in exotic corners of the universe.

One way to make a nonneutral plasma is simply to bottle a neutral plasma inside a Penning trap, which cages particles within a region of strong magnetic field lines and keeps them from leaking away along the field lines with charged electrodes, or end caps. The end caps can confine particles with only one sign of charge, however—if the caps are positively charged, negatively charged particles will leak through, and vice versa. What remains is a football or spheroid containing as many as a billion particles of the same charge, which can be held for hours or even days.

That's a much longer shelf life than that of ordinary plasmas, whose oppositely charged particles can do a kind of electromagnetic tango across the field lines of any magnetic trap and escape. It gives researchers ample time to monitor the plasma's temperature and density by measuring its natural oscillation frequencies, as Dubin showed, and map its structure by inserting probes or dumping it along the field lines onto a phosphor screen. Among the structures that interest physicists most are those formed by turbulence.

Nonneutral plasmas are largely free of

the wall-friction and viscosity of ordinary liquids, so they can display turbulence in its purest form. And although they are three-dimensional objects, these plasmas can sustain a simplified two-dimensional form of turbulence. When a cloud of electrons is confined in a Penning trap, for example, the electrons often bounce back and forth along the field lines in the trap fast enough to smooth out any variations along the axis of the trap. The result is a plasma spheroid that behaves as a nearly ideal, 2D "fluid" when viewed end-on—a good match for the work of theorists, who often try to cut through the almost impenetrable mathematics of turbulent fluids by considering them in two dimensions only.



DRISCOLL, ET AL.

Spinning down. A plasma containing only electrons, at first highly turbulent *(left)*, relaxes into a single large vortex in these images of electron density.

Already this testing ground is yielding surprises, as UCSD's Fred Driscoll reported. Theory predicts that complex, turbulent initial states—which Driscoll generates by injecting electrons into the trap from spiral-shaped filaments that emit charges when heated—should quickly relax to a calmer final state in which the entire spheroid spins about its long axis. Driscoll and his colleagues found that for initial conditions of 20 to 50 small vortices, this kind of relaxation does indeed occur. But for other, seemingly indistinguishable starting points, as many as 10 long-lived vortices emerge from the confusion and remain frozen in a spinning "crystalline" pattern. Gradually, over the course of 1000 to 10,000 rotations, the vortices diffuse away one by one. The result is so surprising, says Driscoll, that "we do not yet even know how to phrase the proper questions" about what is responsible for the phenomenon.

For studies of turbulence, clouds of ordinary electrons will do, but to open a different kind of experimental window, researchers are capturing electrons' antimatter counterparts, positrons. "We've gotten good enough at trapping positrons in the lab that we can do a whole new class of antimatter experiments," says Cliff Surko of the UCSD group. Surko and his colleagues reported confining 100 million positrons—10 times as many as ever before—for about half an hour. To build up this large population, Surko's group passed positrons emitted during the decay of radioactive sodium through several buffer zones of ordinary nitrogen gas. The buffers slowed the highly energetic positrons enough for them to be corralled and confined in the trap.

Surko and colleagues then used their trapped positrons to begin studying the kind of interplay between matter and antimatter that may occur in tumultuous cosmic settings like the center of our galaxy. They sent beams of ordinary electrons through the antimatter spheroids and found that instead of annihilating each other—as often happens when matter encounters antimatter—the electron beam heated the positron plasma, stirring it up like a wind over water. It's just a foretaste of the insights that nonneutral plasmas can offer, but it may help give these unusual materials a flavor that more physicists just can't do without.

–James Glanz

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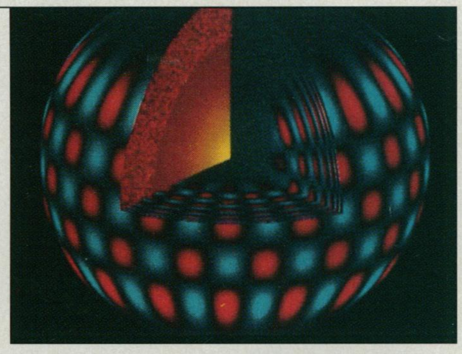
ASTRONOMY

Taking Soundings From a Distant Star

Astronomers, whose gaze has been drawn to the twinkling points of light that are stars, would dearly love a peek into their interiors. Such a vision, for example, might allow them to describe the density of the various layers of gas that exist within a star or observe how its core rotates, instead of relying on theoretical predictions. "You would be able to say things about the star you could only guess at now," says Timothy Brown, an astronomer at the High Altitude Observatory in Boulder, Colorado.

It has proven remarkably difficult, however, for astronomers to penetrate the exterior of any star other than the nearby sun. Now, in a paper to be published in the March issue of the *Astronomical Journal*, a group of astronomers from Aarhus University in Denmark and the European Southern Observatory headquarters in Germany may finally offer a way in. They describe a new technique for detecting the sound waves that bounce around the interiors of most stars and using them to reveal the inside story—much as geologists use seismic waves to probe the details of Earth's structure. "We need to see more before we can call this approach a breakthrough, but I think there's a fairly good chance it is," says Brown. "This is something people have sought for 8 years. If it's true, it would be of enormous importance," adds John Leibacher of the National Solar Observatory, who directs an effort to study the sun through its sound waves.

The practice of listening in on the sun and others stars forms a relatively new branch of astronomy called asteroseismology. Starting in the 1960s, astronomers noticed that the sun's surface pulsed up and down, and in the 1970s researchers developed a theory about the meaning of those pulses: The sun was ringing like a bell. As gas churns about within the sun, changes in pressure generate sound waves. The speeds of these sound waves are affected by the density, direction, and speed of the material they move through, and thus yield information about the sun's inner workings. Through studying these waves, for example, astronomers have been able to calculate the ratio of helium to hydrogen in the sun's core.



NSO/ASP

Internal noise. Sound waves traveling through a star like the sun,shown in this computer model, compress *(red)* and elevate *(blue)* surface areas in a pattern that reveals interior details.

These eavesdropping expeditions have generally relied on two methods. The first is to monitor closely the amount of light on the sun's surface. As sound waves reach the surface and bounce back, they compress and decompress the gases there, causing temperature changes of a few millikelvins that, in turn, elicit minute changes in the sun's brightness. The second method relies on the fact that when the sound waves bounce back and forth, the sun's surface bulges and recedes by less than a few dozen meters. This motion can be seen by astronomers in small changes, known as Doppler shifts, in the wavelength of light coming from the sun's surface.

These techniques haven't worked as well on distant stars. Earth's atmosphere distorts the light from distant stars so that it is almost impossible to see small variations in brightness. As for Doppler shift measurements, they demand high-resolution spectrographs, large telescopes, and lots of observing time—and even then very small changes in wavelength may be impossible to pick out of the data. It has only been in dense stars called