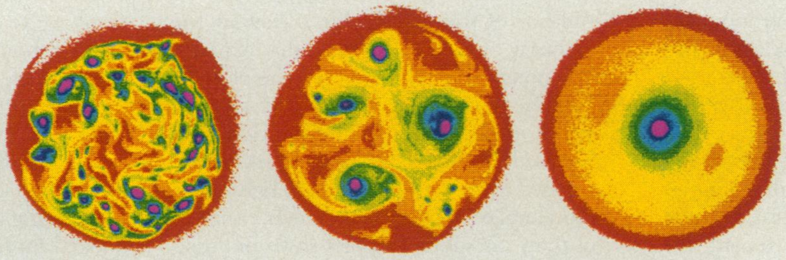
the wall-friction and viscosity of ordinary liquids, so they can display turbulence in its purest form. And although they are three-dimensional objects, these plasmas can sustain a simplified two-dimensional form of turbulence. When a cloud of electrons is confined in a Penning trap, for example, the 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

James Glanz is a science writer in Chicago.

ASTRONOMY

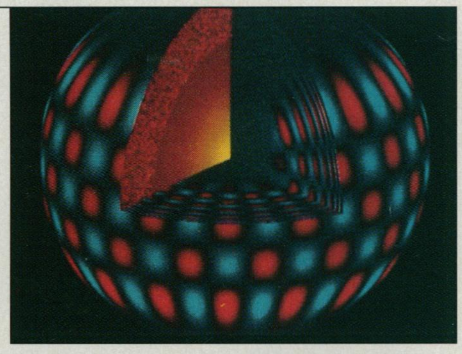
Taking Soundings From a Distant Star

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.

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.



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 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 white dwarfs, which have more pronounced surface oscillations, that asteroseismologists have had any definite success at all; they've documented subtle brightness changes (*Science*, 13 September, p. 1207).

The new technique, developed by Danish astronomer Hans Kjeldsen, may change that frustrating record by providing astronomers with an easier way to record the millikelvin temperature variations produced by a star's sound waves. The key is the effect temperature changes have on hydrogen. Hydrogen atoms absorb specific wavelengths of light, which astronomers can easily see as thick absorption lines in the spectra of stars. The hotter the star, the more light gets absorbed by these atoms. Timothy Bedding, a co-author of the paper who is now at the University of Sydney in Australia, explains that temperature variations can therefore be determined by changes in the relative strength of these hydrogen absorption lines (indicated by their width in a spectrum) compared to the rest of the star's light. And these changes appear to be much easier to spot than the subtle Doppler shifts or variations in brightness.

In April, Kjeldsen, Bedding, and their colleagues put the new approach to the test and, over six nights, used a 2.5-meter telescope in the Canary Islands to study Eta Bootis, 38 light-years away and one of the brighter sunlike stars in the sky. They teased 13 apparently distinct frequencies out of the data. "We think we've detected oscillations," says Bedding, although he notes that others, using the older methods, have made similar claims that have not been confirmed. But their confidence in the new technique is boosted, he adds, because the frequencies agree with theoretical predictions for oscillations in this star.

Bedding and his colleagues already have booked more observing time next April to look for oscillations in Alpha Centauri, the nearest sunlike star. Other asteroseismologists like Brown are considering their own plans to test the new approach. With the new technique, astronomers hope they now have the tool to put the asteroseismology of distant stars on a sound footing.

–John Travis

MATHEMATICS

Getting Comfortable in Four Dimensions

Physicists often borrow their tools for describing the laws of nature from mathematicians. But sometimes they invent their own mathematical tools—and then they get to return the favor. That was the case last month when two physicists trying to describe the behavior of subatomic particles ended up giving mathematicians a new technique that may have revolutionized an even more abstract pursuit: the study of geometry in dimensions higher than our familiar three.

The implications of the physics advance—a step toward understanding the baffling behavior of fundamental particles called quarks—are just starting to sink in. But mathematicians needed little prodding to recognize that along the way, Edward Witten of the Institute for Advanced Study in Princeton, New Jersey, and Nathan Seiberg of Rutgers University had streamlined some important basic math needed for working with higher dimensional spaces. "It's great," says mathematician Clifford Taubes of Harvard University. "I haven't had so much fun since—I can't remember when."

Witten and Seiberg were working on one of the most intractable problems in theoretical physics: the description of the force holding together the particles called quarks and gluons, which make up the protons and neutrons in the atomic nucleus. Experiments in accelerators show that this "strong" force is very strange indeed: Unlike gravity or magnetism, the attraction between two quarks gets stronger as they are pulled farther apart. And the force also seems to forbid quarks from existing alone—they are only observed "confined" in groups of other quarks.

The problem for physicists is that the theory they rely on to describe quarks can predict very little of this behavior, at least in practice. As Witten puts it, "The equations governing quarks and gluons are too hard." So unwieldy is the math that even the world's most powerful computers can only calculate a tiny fraction of the observed behavior.

Witten and Seiberg simplified the physics problem by choosing a special case—one that assumes among other things that a still-unproven theory of fundamental particles and forces, called supersymmetry, holds true. In this "practice version," as Seiberg calls it, they were for the first time able to calculate the strange inverse attraction of quarks. Because of the assumptions, Witten says, he and Seiberg can't claim that they have solved the problem once and for all, but they have discovered "new life in this area that has been too difficult in the past."

"I haven't had so much fun since—I can't remember when."

—Clifford Taubes

The excitement spread to the mathematics community in mid-November, when Taubes went to hear Witten talk about his work. During his lecture the physicist suggested that the reformulated math might apply to Taubes' field of higher dimensional geometry. Taubes took Witten at his word and spread the news to others in his field, including Peter Kronheimer of Oxford University and Tom Mrowka of Caltech. Within days they found that the new technique solves some of the toughest problems that crop up when mathematicians describe the shapes made by folding "surfaces" of many dimensions into spaces of even higher dimensions.

The process is analogous to folding two-dimensional surfaces into three-dimensional shapes, such as spheres or doughnuts, says Taubes. These shapes, or "manifolds," are classified by the number of holes they have—a pancake is essentially the same as a sphere and a washer is the same as a doughnut. Similarly, mathematicians want to classify the ways a four-dimensional surface can fold into five-dimensional space, or 27-dimensional surfaces can fold into 28-dimensional space.

Oddly, says John Morgan of Columbia University, the toughest manifolds to describe exist not in 15 dimensions, or 28, but in a mere four. Yet four-dimensional manifolds have a special importance because general relativity, Einstein's theory of gravity, operates in four dimensions. Mathematicians' best strategy for coping with them has been a classification scheme known as Donaldson theory, devised 10 years ago by Simon Donaldson of Oxford. But applying Donaldson theory to four-dimensional shapes was no picnic, says Taubes. "We worked like dogs to get information out of Donaldson theory," he says. Witten and Seiberg's new technique makes the theory much more user-friendly, says Taubes.

When Taubes shared this reformulation of Donaldson theory with his colleagues, the computer networks started buzzing. "It turned out this new equation had all of the information of the old one, but it's probably 1000 times easier to get all the information out," he says. Several mathematicians have already used the technique to reclassify their vast collection of four-dimensional shapes.

But whether mathematicians will be able to repay their debt to physics by coming up with new insights into the four-dimensional space-time postulated by Einstein isn't clear yet, says Morgan. "We don't know if one of the [manifolds] we describe corresponds to reality." The tools of mathematics and physics may be the same, but their aims are somewhat different, explains Taubes. "Physics is the study of the world, while mathematics is the study of all possible worlds."

–Faye Flam