Listening to the Music of the Spheres

Astronomers are tuning in to the deep-seated vibrations of distant stars, hoping to catch their message about the structure and composition of stellar interiors

AROUND 500 B.C. PYTHAGORAS PROPOSED that the revolutions of the heavenly bodies create musical tones that blend to fill the universe with a grand, harmonious song. The idea of heavenly harmonics is now making a comeback among astronomers. But instead of listening to the revolutions of the spheres, modern astronomers are tuning in to vibrations within stars.

"The stars are humming to themselves in the dark," says University of Texas astronomer Edward Nather. And that humming is music to the ears of a small band of astronomers such as Nather and his colleagues, who call themselves asteroseismologists. The vibrations, which manifest themselves as periodic variations in brightness, penetrate deep into the interiors of stars—a realm long considered inaccessible to observation. In theory, measuring these fluctuations in brightness offers a way to explore stellar interiors.

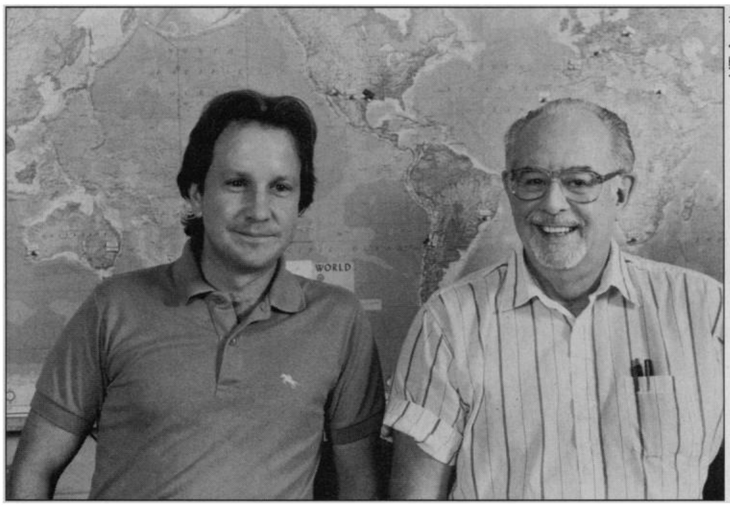
That theory is rapidly becoming reality thanks to a stunning set of observations reported by Nather and his colleague Donald Winget in the 1 September *Astrophysical Journal*. Astronomers have long realized that most stars vibrate at resonant frequencies, much as musical instruments do, but no one had been able to observe enough different frequencies for any star except the sun to learn much about its internal structure—until now. By patiently recording the surface flickers of the white dwarf star known as PG-1159-035 with a global telescope network, Nather and Winget identified an astonishing array of frequencies—101 in all, with periods ranging from around 400 to 1000 seconds. This little star turned out to sing a much more detailed song than they expected, and already the Texas researchers have started to catch the words. They used the pattern of vibrations to get a fix on their star's mass, rotation rate, and magnetic field. And they expect shortly to use them to build the first-ever picture of a distant star's internal structure based on direct observations.

What Winget and Nather are doing for their white dwarf is common practice for the sun. A group of solar astronomers called helioseismologists has been mapping the sun's interior by watching its surface rise and fall under the influence of myriad internal resonances. The resonances are excited when small fluctuations in the opacity of the sun's outer layers cause the material to absorb heat and swell, then shrink again, generating sound waves. Some of the resonant waves are long enough to cause an entire hemisphere to heave and settle back; others have much shorter wavelengths and create a fine pattern of ripples across the solar surface.

Those fine-scale vibrations would blur to nothing at the distances of other stars. What astronomers observing stellar oscillations detect are the very largest waves, which cause the entire visible side of the star to brighten and dim. Those oscillations have been seen in many kinds of stars: small hydrogen-burning stars like our sun, exotic variable stars, and white dwarfs—ancient, burned-out stellar cinders. It is the white dwarfs, with some of the strongest pulsations, that have attracted the most attention from asteroseismologists.

The waves in white dwarfs—which brighten and dim the stars by about 5%—differ from those that roil the sun. While the sun, and presumably its kin among other stars, gently resonates with acoustic, or pressure, waves, a white dwarf beats with pulses known as gravity waves. The matter in white dwarfs is packed too tight for pressure waves to propagate through it, but it can still sustain waves in which packets of matter rise above their equilibrium position in the star, then drop back down again, with gravity acting as a restoring force. It's like jiggling jello, says Winget, only with rhythm.

Because the distance of their white dwarf subject limited the Texas researchers to watching only the simplest and largest wave patterns, they expected to be able to discern only about eight different vibration frequencies—less than a tenth of the number they actually traced. "We never expected to see that many bands," Winget says. He and his colleagues say they owe that success to the Whole Earth Telescope (WET)—actually a worldwide network of nine telescopes stretching from France to Australia. The network gave the researchers nonstop viewing, rain or shine, allowing them to gather a long enough string of data to cull even the subtlest overtones from the noise.


UT Austin

Dedicated listeners. *Donald Winget* (left), *Edward Nather, and sites of the Whole Earth Telescope, with which they eavesdropped on the rhythms of the stars.*

Winget explains that it's important to have so many vibrations because the strength of each frequency reflects characteristics of the matter at a particular depth in the star. With many different vibration frequencies to analyze, he says, "we can get an enormous number of parameters about the interior." Winget plans to use the data to map the layered interior structure of the star in detail, getting chemistry, density, and temperature in each region. But he says that the windfall of data came so unexpectedly that nobody had yet developed a complete theoretical model for translating the frequencies into the properties of each layer. That, he says, will come in the next 1 or 2 years.

The full picture of this white dwarf's internal structure will allow astronomers to test theories about how these unusual stars form and evolve. The star Winget and Nather chose should be particularly interesting in that regard because it is not yet a full-fledged white dwarf. It is still nearing the end of its birth process: the collapse of a red giant that has spent its nuclear fuel. At the same time, though, the star should be mature enough to offer astronomers a glimpse into the bizarre state of matter believed to lie within white dwarfs.

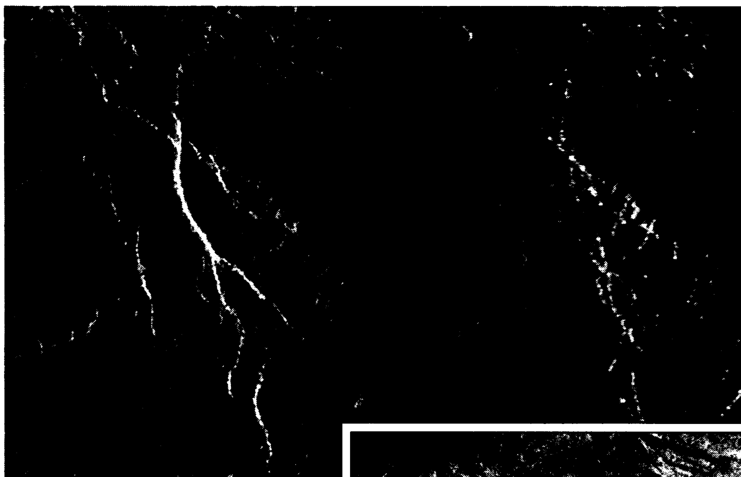
Theory has it, says Caltech astronomer Jessie Greenstein, that under the thin outer crust of a white dwarf, its intense gravity crushes its very atoms, squeezing electrons down into the nuclei—a state of matter referred to as degenerate. As a dwarf ages, he adds, it cools by pouring out light and neutrinos until the core "freezes" into something like a single crystal of degenerate matter. Astronomers and physicists are thrilled at the prospect of confirming this theoretical picture through Winget and Nather's measurements. "Asteroseismology for white dwarfs is exciting as a proof of degeneracy," says Greenstein.

In case the initial round of data doesn't satisfy the theorists, Winget says he already has two more dwarfs "in the bag"—their frequency spectra are now under analysis. And the global telescope network, he says, is now aimed at still more stars. Within three years, he expects to have frequency profiles on a sizable handful of white dwarfs.

Besides answering questions about the stars themselves, he says, data on multiple white dwarfs could lead to a new estimate for the age of our galaxy. Measurements of the density and internal structure of dwarfs will reveal their cooling rate. Knowing their maximum possible temperature, astronomers can use the cooling rate to set a limit on their age—which, for the oldest white dwarfs, should correspond to the age of the galaxy itself. "The history of the universe," says Nather, "is written in these dead stars."

Meanwhile, some other astronomers are tuning in to the vibrations of other types of stars. Caltech helioseismologist Kenneth Libbrecht says he is launching a project to monitor the more subtle oscillations of ordinary sun-like stars. Hugh Van Horn at the University of Rochester says he is seeking out pulsations in brown dwarfs and neutron stars. But both Libbrecht and Van Horn agree that, for the moment, the white dwarf work is the hottest thing going in asteroseismology. ■ FAYE FLAM

Venus Caught in a Geologic Act?



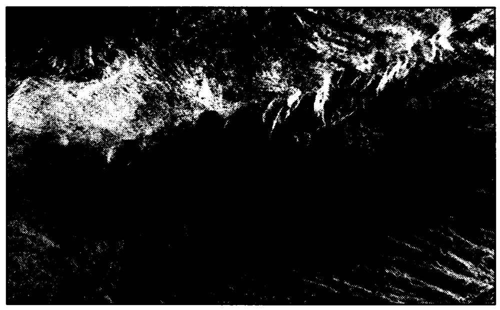
NASA/JPL

Before and after. *The bright line marking a scarp* (far left) *jumped back, leaving a debris pile* (left).

The stunning images of Venus returned by the Magellan radar mapper during the past year seemed to portray a geologically living planet: Mountainsides appeared too steep, the fracturing of impact craters too pervasive, and lava flows too pristine to be the ancient products of long-spent geologic forces. But because those images were only snapshots, they certainly didn't prove the case for a geologically active Venus; they might look like "freeze-frame" pictures of a surface in constant turmoil, but they could instead be portraits of a now dead landscape. But now comes proof of life.

Magellan scientists think they may have detected a very recent change in the surface, and a big one at that. The spacecraft recently embarked on a second mapping cycle, which is giving it a new look at some previously mapped terrain. On the rugged equatorial highlands of Aphrodite Terra, this second pass has revealed what appears to be the jumbled debris of a landslide that was not there when Magellan passed overhead just 8 months earlier. Venus, it seems, is indeed alive.

As often happens when planetary scientists are inundated with new observations, the discovery of the Venusian landslide was a bit of serendipity. Jeffrey Plaut of the Jet Propulsion Laboratory wasn't looking for surface changes at all. Instead, he was testing a method for making a stereoscopic view of Venusian terrain by combining images taken at slightly different angles. But when Plaut tried to combine two images of a steeply scarped plateau, taken on separate passes 8 months apart, they wouldn't merge. Something had changed.



NASA/JPL

All in a row. *At least three debris aprons fan out from a bright highland.*

What was different in the latest image was a 7.5-kilometer-long pile of rock at the foot of the scarp, which now is cut farther into the plateau. Apparently, a cubic kilometer or so of plateau edge had slid into the adjacent trough. That puts the slide in the same class as the avalanche of debris that tore away the north face of Mount St. Helens in 1980—the largest landslide on our own planet in historical times.

What caused the Venus slide remains unclear. No volcanism is evident, and erosional undercutting seems unlikely. That leaves some slow uplift that pushed the plateau edge toward instability, perhaps with the help of a "Venusquake." The clear implication is that Venus was geologically active this year, not just in the geologically recent past.

There is, however, one lingering doubt about this Venusian landslide, says Plaut. Some team members have suggested that the change could conceivably be an illusion. Radar images may look like photographs, but the underlying processes are quite different (*Science*, 1 March, p. 1026). For example, modest changes in radar viewing angle can drastically change the appearance of an image. The test may come when Magellan passes over the same spot in another 8 months, Plaut says—or it could come sooner, if apparent changes show up elsewhere. After all, Plaut was dealing with only a few scenes from a randomly selected strip of images that covers less than 0.5% of the planet. Either he was extremely lucky, or more changes in the Venusian landscape are waiting to be found. ■ RICHARD A. KERR