Magnetic features on the Sun can be either dark (sunspots) or bright (faculae and a more scattered network). Faculae are more important for the excess oblateness because of their much greater area. This implies that the solar core is not rapidly rotating, although the boundary between the core and the convection zone is still a poorly understood region. Without a geometrical oblateness from a rapidly rotating core, the scalar-tensor theory fails this observational test. It has already failed tests of the so-called Shapiro time delay (*13*) and the deflection of starlight (*14*) (applied to radio sources). Part of the mission of the European spacecraft PICARD (*15*), due to be launched in 2009, is to measure the shape of the Sun at different wavelengths. It will be good to have an independent space-based determination of the Sun's shape as a comparison.

A major solar physics question has to do with the internal rotation of the Sun. Does the core rotate slightly faster than the surface? (This would have a negligible effect on the solar oblateness.) If the core rotates faster than the outer parts of the Sun, does this affect the operation of the solar dynamo? The Sun is currently in its magnetic activity minimum. This quiet period should improve the search for solar shapes more complex than a simple oblateness. There are still more things to learn in the solar interior.

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ASTRONOMY

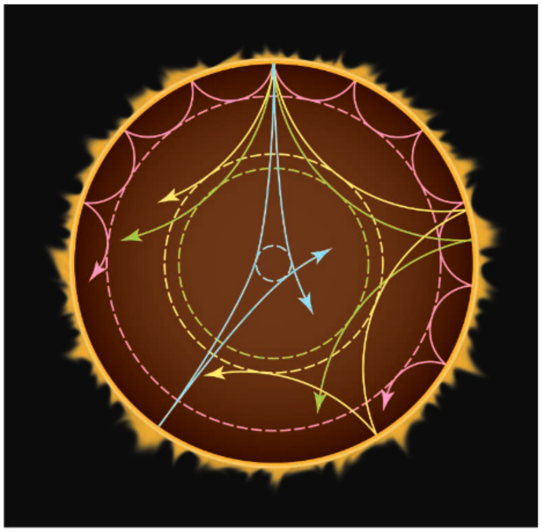
# The Pulse of Distant Stars

**M. H. Montgomery**

Space-based observations can now be used to "see" the pulsations and surface granulations of distant stars similar to those of the Sun.

Far from being a constant light source, the Sun oscillates at thousands of different frequencies simultaneously and has granulations at its surface associated with rising and falling fluid elements. Despite the amplitudes of the induced light variations being at a level of about one part per million, the Sun's brightness has allowed its "pulse," in terms of luminosity variations, to be measured using Earth-based telescopes. On page 558 of this issue, Michel *et al.* (*1*) present data from the space satellite CoRoT (Convection Rotation and Planetary Transits), demonstrating the ability to characterize the oscillation amplitudes and the signature of stellar granulation in three other stars. In addition to the technical success that this represents, the measurements show that solar-like oscillations do occur in these stars, although with somewhat smaller amplitudes than predicted. This bodes well for the future of space-based seismology programs while simultaneously challenging us to refine our models of these stars.

Stellar pulsations allow us to probe a star's structure beneath its surface. This is analogous to seismology on Earth, in which earthquakes produce waves that travel through Earth's interior. By measuring the properties of these waves as they return to the surface, geologists have been able to constrain models of Earth's interior structure. The pulsations of a star can be thought of as a superposition of traveling waves that propagate through its interior, return to the surface, and are reflected back into the interior (see the figure). The study of a star's interior through its pulsation modes is called asteroseismology and, when applied to the Sun, helioseismology.



**Star oscillation modes.** Ray paths of low- (blue), medium- (yellow, green), and high-degree (pink) modes. Each mode samples the star's interior in a different way.

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Because each pulsation mode samples a star's interior differently, the more pulsation modes that are present in a star, the tighter the constraints on its internal structure. Some stars, such as the well known Cepheids, pulsate in only one mode, so we learn little about their internal structure. On the other hand, these stars have proven to be extremely useful as distance indicators because their period-luminosity relationship allows the observed period to be converted into an absolute luminosity, and hence a distance, for the star (*2*). Other stars pulsate in many modes simultaneously, such as the white dwarf variables, which have amplitude variations on the order of a few percent and can have from a dozen to more than 100 observed modes. This larger number of modes allows deductions to be made concerning their inner chemical profiles and composition and their mass, temperature, and rotation rate (*3*, *4*).

In the case of the Sun, millions of pulsation modes are observed, which is the reason helioseismology has proved to be so successful over the past 30 years (*5*). We have learned that the Sun's convection zone extends over

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the outer 29% of its radius. Inside this point, it rotates like a solid body, whereas throughout the convection zone it shows appreciable differential rotation. In addition, helioseismology has allowed us to make a very accurate model of the Sun, and this showed that the solar neutrino problem, the deficit of detected versus predicted neutrinos from the Sun, could not be explained by an incomplete understanding of the Sun's interior. As we now know, the resolution of this problem came from new particle physics in the form of neutrino oscillations (*6*). Helioseismology has also allowed us to measure the evolutionary state of the Sun, including constraints on its age and chemical composition.

If the Sun were as distant as other stars, we would no longer be able to see the millions of pulsation modes; we would be limited to around 100 or less. Having refined our techniques and experience based on the Sun, however, this number of pulsation modes is more than sufficient for providing accurate constraints on the parameters and structure of other stars (*7*). This is fortunate, because stellar models that are calibrated to the Sun are unlikely to be as accurate for stars of different mass and temperature. The work of Michel *et al.* represents a substantial first step in understanding stars somewhat more massive than the Sun (the masses of their targets were between 1.17 and 1.4 solar masses). Their data show that the oscillation amplitudes are 1.5 times as large as those of the Sun, which is still about 25% lower than theoretical estimates. This is noteworthy because these amplitudes depend on the nature of convection in the outer layers of these stars. In addition, they were able to measure properties of the granules seen at the surface of these stars, a further manifestation of convection within them. This provides us with the opportunity to test and refine our theories of convection, which is one of the largest sources of uncertainty in the modeling of stars. And, perhaps most important, their results showed that the expected oscillations were present with measurable amplitudes, thereby demonstrating the viability of space-based investigations.

Further observations by CoRoT and the upcoming NASA mission Kepler should yield a wealth of information on other solar-like stars. It will then be possible to place tighter constraints on quantities such as the total mass, luminosity, radius, age, and rotation rate of a very large number of stars. These space-based observations will test our understanding of physical processes, such as convection in the envelopes and cores of stars, but will also enhance our understanding of the ages and evolutionary states of objects throughout our Galaxy and the local universe.

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GENETICS

# GenBank—Natural History in the 21st Century?

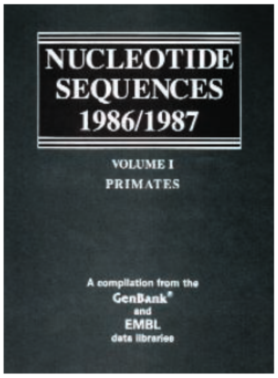
Since its foundation, the nucleic acid sequence database GenBank has merged the values of natural history with those of the experimental sciences.

**Bruno J. Strasser**

The American nucleic acid sequence database GenBank, as well as its European (European Molecular Biology Laboratory, EMBL) and Japanese (DNA Databank of Japan, DDBJ) mirror organizations, each contain far more nucleotides than "the number of stars in the Milky Way," as the U.S. National Institutes of Health (NIH) once put it in a press release (*1*). The early history of this database illustrates the transformation of biology into a new science that links the methods of natural history with those of experimentation.

GenBank represents the cutting edge of biology, but it also belongs to the centuries-old tradition of natural history—a tradition best characterized as the practice of collecting, describing, naming, comparing, and organizing natural objects. The method applies equally to plants, bones, or molecular sequences. This view challenges the received historical picture, in which the experimental sciences overtook natural history in the late 19th century and triumphed in the mid-20th century with the rise of molecular biology. As GenBank and other databases attest, the practices of natural history have been imported into the experimental sciences.

In March 1979, 30 molecular biologists and computer scientists meeting at the Rockefeller University in New York agreed on the necessity to create a national, computerized database (*2*). The impetus was the same as that behind most natural history collections, which were often created in reaction to a perceived overabundance of information—for example, when the expansion of European travel to the New World led to the accumulation of previously unknown specimens. This time, it was the explosive growth in the number of known DNA sequences and the promise of producing biological knowledge by analyzing and comparing them that made a database seem indispensable. Several scientists were maintaining individual sequences collections, but none was comprehensive.



It took almost 3 years for the NIH to come up with a funding scheme, and by that time, the EMBL had already made its own sequence database publicly available. This delay—somewhat embarrassing for the NIH—resulted not only from bureaucratic inertia, as some have argued, but also from uncertain scientific prospects for a natural history collection at a time when experimentation triumphed in revealing the secrets of nature. Frederick Sanger would later put it bluntly: "'Doing' for a scientist implies doing experiments" (*3*). Pressed by a few vocal experimental scientists the NIH eventually issued a Request for Proposals. Two

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