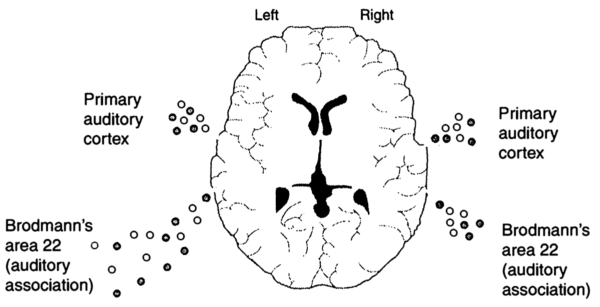

Cable connections. An axial section through the human brain showing Brodmann's area 22 and the primary auditory cortex in both the left and right hemisphere. In area 22 of the left hemisphere (which is preferentially activated during language processing) clusters of neurons are spaced further apart and are cabled together with longer axons than the neuronal clusters in area 22 of the right hemisphere. This asymmetry is not apparent in the primary auditory cortex where the neuronal clusters in both hemispheres have the same spacing. (The neuronal clusters in area 22 and in the primary auditory cortex are the same size in both hemispheres.)

of the cortical areas proves irrefutably their specific functional differentiation—for it rests as we have seen on the division of labor—the large number of specially built structural regions points to a spatial separation of many functions and from the sharp delineation of some fields there follows finally the sharply delimited localization of the physiological processes which correspond to it" (*5*).

In studying the human brain, basic researchers have the advantage of calling upon a vast neuropsychological literature to help them interpret their results. For example, Galuske and co-workers speculate that because the right brain hemisphere is capable of taking over crucial language and speech activities if the left hemisphere is injured (*6*), the differences in cellular architecture that they observed between the two hemispheres of their normal adult brain samples may be the result of differential activation during development (*7*). They predict that the essential framework for a particular cortical zone to develop language and speech capabilities is laid down in both hemispheres, but it is only through use and practice that the structural arrangement of neurons becomes different. It will be fascinating to see whether these asymmetries in cellular microstructure between the two hemispheres are absent in the brains of newborns. One possible way such subtle microstructural differences might be detected is through analysis of gene expression in various cortical regions of both hemispheres with cDNA microchip arrays. Such work is now under way in mice (*8*).

Despite the Galuske work, we remain ignorant of what additional crucial differences might exist in the cellular organization of the two hemispheres. As there seem to be more clusters of neurons interconnected in language areas of the left hemisphere, it could be argued that these better connected clusters permit greater information exchange with a putative cortical processing center that is shared by both hemispheres. Alternatively, the particular way the clusters are arranged and interconnected may provide a unique architecture that is capable of specifically processing incoming language signals.

Recently, it has been proposed that because the brain evolved from a very simple structure into a very complex one, there cannot be a universal learning system, but rather, there are different areas of the brain that oversee the learning of separate activities (*9*). For example, the area of the human brain involved in learning to recognize faces is completely different from that involved in learning to navigate a tricky maze. These areas or signal processing centers probably have different local connections both within and between the myriad neuronal clusters that compose the cortex. Seeking subtle differences in the local connections between neuronal clusters should help us to understand how a unique cellular architecture can direct human behavior.

The elegant work of Galuske *et al.* demonstrates that the melding of neuropsychology, brain anatomy, and the cellular and molecular biology of neurons is under way. It is no longer a dream—the exciting reality is here.

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PERSPECTIVES: ASTRONOMY

Don't We Already Know Everything About Polaris?

Nancy Remage Evans

Recent developments in ground-based and satellite instruments are providing unprecedented levels of quantitative precision in stellar studies. Measurements of Cepheids, a group of variable stars used as an astronomical yardstick, illustrate this new precision with which stellar parameters can now be measured and show that even groups of stars that we thought we understood well are good for surprises.

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Classical Cepheids are stars that are several time as massive as the sun and have exhausted the hydrogen fuel in their cores. They generate their luminosity by a more complicated mix of nuclear burning and are therefore considered evolved stars. For certain combinations of mass, luminosity, and temperature, Cepheids pulsate (expand and contract) with a very regular period. During pulsation, basic properties such as mass and luminosity of the stars are unchanged; it is only the envelope of the star that pulsates. The period of pulsation is tightly correlated with their intrinsic luminosity. The resulting period-luminosity relation can be used to determine the intrinsic luminosity of the star. Comparison with the apparent brightness of the star then gives an accurate distance from Earth. This is why Cepheids are important "primary extragalactic distance indicators" for galaxies that are relatively close but external to our own Milky Way.

Polaris is a Cepheid with a very low amplitude of pulsation. Recently, its diameter was measured (*1*, *2*) with a new ground-based interferometer. The diameter confirms a recent result (*3*) from the Hipparcos satellite (the first of several satellites that measure stellar distances with increasingly high precision) that Polaris is pulsating not in the fundamental mode, but in the first

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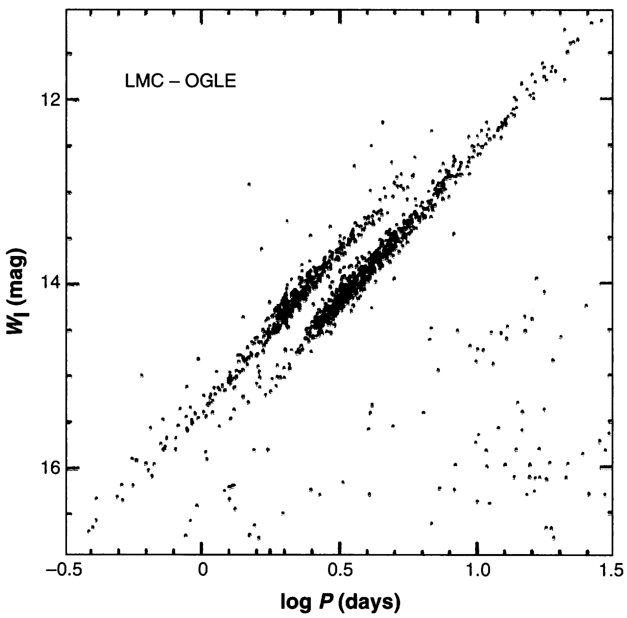
overtone mode. (The overtone mode is like having two waves in an organ pipe instead of one.) A few years ago, it was shown that Polaris not only pulsates with a very low amplitude but that the amplitude is decreasing. This is virtually unique among the very regular Cepheid class and suggests that overtone pulsators are sensitive to envelope characteristics in a different way than fundamental pulsators. This feature is also likely to be responsible for the unusually large variation in pulsation period (*4*).

High-precision velocities have recently been used by Kamper (*5*) to derive an improved orbit for Polaris, which is part of a binary star system with a less massive companion. Clever use of Hipparcos measurements has also allowed the inclination of the orbit to be determined (*6*). Ultimately, studies of this kind aim to measure the mass of a star, which can only be done for binary systems. Combined with luminosity and temperature, mass provides the most fundamental test for theoretical models. Masses of several binary Cepheids have been measured recently by measuring the velocity of their hot companions in the ultraviolet region with the Hubble Space Telescope (*7*, *8*). Dramatic improvements in resolving binary star systems using both ground-based interferometry and satellite imaging and interferometry promise to provide further mass information in the near future (*9*).



The period-luminosity relation. W_I is the measured brightness for Cepheids at the same distance (in the Large Magellanic Cloud) on a logarithmic scale, adjusted slightly for the temperature of the stars and absorption by intervening material. Brightness increases from the bottom to the top of the figure. It is plotted as a function of the logarithm of the pulsation period. Lower sequence: fundamental mode pulsators; upper sequence: first overtone pulsators.

CREDIT: FROM (14)

Theoretical modeling of Cepheids has improved or been confirmed in several ways in the last few years. Comparison of the new observations with pulsation theory and stellar evolution theory provides a test of how quantitative our understanding of Cepheids is. For example, a recent reevaluation of the opacity of Cepheid envelopes (*10*) resolved the three-decade-old "Cepheid mass problem," namely, that indirect mass estimates were not consistent within the theory. The new opacities produce pulsation masses larger than the previous ones, and are in agreement with masses inferred from evolutionary calculations. Accurate Cepheid observations are particularly important for testing the theoretical treatment of the boundary between the convective core and the radiative envelope in the previous central hydrogen burning ("main sequence") phase. Pulsation calculations have been improved recently with the addition of convective energy transport (*11*), providing for the first time models of Cepheids that pulsate in both fundamental and first overtone simultaneously (*12*).

In addition to increased precision in galactic Cepheid measurements, stunning sequences of Cepheids have been produced in external galaxies using vast numbers of light observations gathered largely as by-products of searches for microlensing events (*13*). An example of the period-luminosity relation (*14*) (see the figure) shows sequences of fundamental and first overtone pulsators, whose period is too short for the luminosity in the fundamental sequence. The data show that the pulsation mode must be identified accurately to infer the intrinsic luminosity and hence an accurate distance. These sequences confirm that the commonly used mode classification based on Fourier analysis of the light curves is accurate and that overtone pulsation is confined to short-period Cepheids. This has the fortunate consequence that the long-period stars commonly used to determine distances to external galaxies can be taken to be pulsating in the fundamental mode. The galaxies studied in these surveys vary in their metal (heavy element) abundance and thus also provide a test of theoretical predictions of intrinsic luminosity as a function of "metallicity."

The direct distance measurements by Hipparcos for Cepheids have drawn considerable attention (*13*). Polaris is the only Cepheid for which the distance has been determined accurately. Interpretation of the measurements of other Cepheids requires considerable statistical sophistication and is being vigorously debated. Using data such as the Hippacros data for Cepheids in our Galaxy (the Milky Way) is an important step in calibration of the period-luminosity relation for use in more distant galaxies. In this discussion, attention has been focused on the question, "How well do we know the distance to the nearest external galaxy, the Large Magellanic Cloud." A consistent calibration between Cepheids in the Milky Way and Large Magellanic Cloud is the first step to application to more distant galaxies (*15*).

An illustration of the motivation for understanding Cepheids as thoroughly and quantitatively as possible is provided by the Hubble Space Telescope key project, whose goal is to discover distant Cepheids, specifically in the Virgo cluster of galaxies. These Cepheids can then be used to determine an accurate distance from us to the galaxies in the Virgo cluster. This project is now coming to conclusion (*16*).

These recent advances in measuring Cepheids have been exciting because they allow us to make new observational tests of theory and in addition have presented new puzzles such as Polaris's decreasing amplitude and variable period. Improved understanding increases the precision with which we can use these standard candles at increasingly large distances.

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