

What is known of the many, maybe most, stars that pulsate

Theory of Stellar Pulsation

J. P. Cox

380 pp. Princeton U. P., Princeton, N. J., 1980. \$40.00 cloth, \$13.50 paper

Reviewed by J. Christensen-Dalsgaard

The study of pulsating stars is currently undergoing a profound change. Until fairly recently only stars in rather well-defined, restricted regions in the Hertzsprung-Russell diagram were thought to pulsate. Now, largely due to improvements in observing techniques, pulsations have been found in a number of different types of stars, including the Sun, and it seems reasonable to predict that most stars are pulsating, although most likely with amplitudes so small in many cases that observational verification is difficult.

There is clearly considerable intrinsic interest in understanding the reasons some stars are pulsating and in describing theoretically the properties of such oscillations. In addition, stellar oscillations—in particular their periods—may yield information about the structure of pulsating stars and in this way help test the theory of stellar evolution. This is especially the case for some of the stars whose pulsations have been recently discovered, notably the Sun, where several periods of oscillation are present. On the basis of observed periods it may eventually become possible to determine empirically the variation of, say, density throughout the Sun, in a manner analogous to the way seismological studies investigate the interior of the Earth.

Thus the time is ripe for a book that summarizes our current understanding of stellar pulsation and provides a basis for future developments, the more so as the last major treatise on stellar oscillation theory, written by P. Ledoux and T. Walraven (*Handbuch der Physik*, Volume 51, Chapter IV) more than 20 years ago, predates much of our detailed knowledge about the causes and properties of stellar pulsation. Although the book under review cannot quite replace the work of Ledoux and Walraven, it is certainly going to be very useful for anybody working in this field.

Cox has played an important role in the development of the theory of stellar



Henrietta Leavitt (1868-1921), who discovered the period-luminosity law for Cepheid variables. (Photo courtesy of Margaret Harwood; Shapley Collection of the AIP Niels Bohr Library).

pulsation. In the fifties he, and independently S. A. Zhevakin, suggested that the instability of the Cepheid variables is caused predominantly by changes in the thermodynamic state and the absorption coefficient in the region where the second ionization of helium takes place; this mechanism accounts for the position of these variables in the H-R diagram. Since then his work has helped provide a detailed theoretical understanding of many aspects of these and related variables. Given his background, it is not surprising that the book goes into greatest detail and is most successful in dealing with radial oscillations of such "classical" pulsating stars.

The book is divided into three parts. Part I contains a brief description of the observational background and a very good introduction to the equations of fluid dynamics. Part II deals in detail with radial oscillations, and Part III treats the theory of nonradial oscillations. Throughout, the emphasis is on basic theory rather than its application to specific types of pulsating stars. Great stress is placed on explaining the results in physical terms, often very successfully. On the other hand, some demands are made on readers who wish

to follow through derivation of the equations, which is generally omitted or merely sketched. While this abbreviation was clearly motivated by the need to keep the book down to a reasonable size, the inclusion of slightly more detail would occasionally have led to a disproportionate improvement in clarity. For example, the discussion on page 89 of the conditions for the existence of oscillatory modes would have been considerably easier to follow with the integral expression for the eigenfrequency explicitly displayed.

The treatment of radial oscillations is thorough and generally excellent. Cox presents the physical mechanisms responsible for the oscillations very clearly, extensively using the energy integral, which determines both the period and the stability of the oscillation. Particularly instructive is the discussion of the conditions for instability, which Cox originally put forward in 1963, namely, that the transition from almost adiabatic to strongly nonadiabatic oscillation must take place in the region of the second helium ionization. This understanding permits prediction of the position of the instability strip corresponding to the Cepheids to be made with surprising accuracy. There

is also a highly interesting discussion of the phrase lag between minimum radius and maximum luminosity, based on the work of John Castor.

Relatively little is said about the nonlinear theory of radial oscillations. In fact much of the basic physics can be understood in terms of the much simpler linear theory. Furthermore, the detailed nonlinear calculations that have been made involve numerical complications that are probably beyond the scope of a book of this nature. Nevertheless a discussion of some of the results of such calculations, or indeed of the results of the linear calculations, would have been valuable as illustrations of the theory presented. These could perhaps have been included at the expense of the treatment of one of the simplified models for nonlinear oscillation. Still, Cox gives ample references to such detailed calculations.

A major problem in the theory of stellar stability involves the treatment of convection. It is normally assumed that the increase in the efficiency of convection causes the return to stability at the low-temperature edge of the Cepheid instability strip. This conjecture receives some support from the—so far few—calculations that have attempted to take convection into account. These problems perhaps merit a somewhat more extensive treatment than given here. Cox barely mentions that Wasaburo Unno and Douglas Gough have generalized the commonly employed mixing length theory to oscillating stars; yet in my opinion such an approach offers greater promise for an understanding of this difficult subject than the severely truncated nonlinear calculations by Robert Deupree that Cox apparently prefers.

Part III, on nonradial oscillations, is not quite on the same high level as the preceding parts, partly because of the rapid development of this field in recent years and probably also because Cox has participated only little in the study of nonradial oscillations. Nevertheless he gives a good introduction to the subject. A Japanese group that made a major contribution to the development of this field recently published a monograph dealing only with nonradial oscillations (W. Unno, Y. Osaki, H. Ando and H. Shibahashi: *Non-radial Oscillations of Stars*, University of Tokyo Press, 1979) that gives a more up-to-date and much more detailed treatment of the subject than the present book. However, Cox is often more successful in describing the basic physics in simple terms.

A few minor criticisms may be made. On page 222 it could have been pointed out that toroidal modes, here introduced as a mathematical concept, in fact just correspond to infinitely slow

rotations of spherical shells; such motion is clearly possible in a spherically symmetric star with no rigidity. Similarly it would have been instructive to note on page 237 that the solenoidal mode with $l=1$ is a uniform displacement of the entire star. It should perhaps have been made clearer that the properties presented as characteristic for g modes only strictly apply to high-order modes; in particular the quotation on page 236 from T. G. Cowling's important paper is presented as referring to g modes in general, rather than to modes "of very long period."

The book would have profited from stricter editing. The discussion of the energy integral, somewhat repetitive, could probably have been presented more concisely. Furthermore the notation is at times slightly confusing. Although in a work as wide-ranging as this it is probably impossible to keep a completely consistent and unified notation, a little more care would have yielded more clarity.

The book requires a knowledge about basic mathematical techniques in differential equations and vector analysis, but is otherwise largely self-contained. However the reader would profit from having some background in the theory of stellar structure. It would be very useful as a text for a graduate course on stellar pulsations, provided the instructor ensures that the students go through the details of the derivations (in fact this might partly make up for the lack of exercises) and supplements it by including a few well-chosen research papers giving more detail about results of numerical work, or perhaps sections of the book by Unno *et al.*

The critical remarks presented above must not overshadow the book's obvious merits. It represents a very valuable addition to the astrophysical literature and is warmly recommended to anyone interested in stellar oscillations or stellar structure. By reading it one should acquire a thorough basic understanding of the processes responsible for stellar pulsations.

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Knowledge and Wonder. The Natural World as Man Knows It. Second Edition

V. F. Weisskopf

290 pp., MIT P., Cambridge, Mass., 1979.
\$5.95

This book began as a series of lectures that Victor F. Weisskopf, then head of the world's largest physics department

(at MIT), gave to the students at the Buckingham School in Cambridge, Massachusetts. Its first edition, in 1963, was a tremendous success—and justly so. Sixteen years later, he has revised the original edition, devoting special attention to the sections on particle physics, on chemistry and on the biochemistry of life.

The title comes from Francis Bacon's remark that, "all knowledge and wonder (which is the seed of knowledge) is an impression of pleasure in itself..." Weisskopf obviously derived enormous pleasure from writing this book; so also will any reader—with or without any background in physical science. Originally written for those with no special grounding in science, the book is also a treasure chest for professional scientists, who time after time will be brought up short by a gem of simplicity or explanation.

Weisskopf undertakes to understand, in an essentially qualitative way, why Nature is the way she is: Why are mountains the height they are? Why are bacteria the size they are? How did our universe evolve and how did life originate? He is remarkably successful.

Perhaps his greatest success is instilling in his readers some of that sense of wonder that shines within all great scientists. At each step along the way—from the infinitely small to the infinitely large—he catches the reader's attention with a commonplace example or analogy that leaves the nonscientist thinking, "I understand that, so maybe I really can understand the rest," and the scientist thinking, "Why didn't I think of that?"

Weisskopf begins with a remarkably complete overview of the basic concepts of science, the natural forces, the structure of matter and the fundamental unity of science, passes on to the wondrous structures of life, the giant biological molecules and the evolution of life and of human beings.

At a time when this nation desperately needs better secondary-level education in science—both to give rise to a better-informed public and to encourage a larger fraction of our most talented youth to undertake careers in science and to prepare them for those careers—this little book should be required reading for every US secondary-school student, and, I should add, for every US secondary-school science teacher. I know of no other book that is as successful in making accessible, to a general audience, the truly astonishing breadth and scope of modern science.

None of his many friends will be in the least surprised by the lucidity of Weisskopf's book. From his days at Los Alamos, the University of Rochester, MIT, and CERN, Weisskopf has always been able to make the most abstruse