astrophysics. However rigorous our mathematics, we cannot be sure that we have done justice to the actual complexities of the systems we are discussing. The crisis created by the missing solar neutrinos is alone ample evidence of this. Moreover, when we do grapple with the complexities, the mathematics rapidly becomes intractable, as is the case, for example with turbulent convection in stars (touched on by Martin Schwarzschild), the electrodynamics of pulsars (discussed by Leon Mestel), and the singularities of space-time (discussed by Roger Penrose).

Faced with these problems we all have our own ways of trying to cope. Chandrasekhar's way is to concentrate on systematizing the mathematical treatment even at the risk of oversimplifying the physical models underlying the mathematics. This approach has the advantage that any discrepancies with observation cannot be attributed to inadequate mathematics but must stem from the failure of the models themselves. It has the disadvantage that few of us have Chandrasekhar's mathematical virtuosity or stamina. His latest papers on perturbations of rotating Kerr black holes, for example, are marvels of algebraic wizardry designed to arrive in the end at the most succinct and effective representation. In this case, owing to the Carter uniqueness theorem for Kerr black holes, it can be said that the physical model is probably correct, and these papers must be among Chandrasekhar's most valuable contributions to astrophysics.

The article in the book that lies closest to his present interests is also the longest, namely, Kip Thorne's discussion of general-relativistic astrophysics. This subject has now become so broad that only an extensive treatise could do justice to it. Nevertheless, by concentrating on three topics, Thorne succeeds in conveying much of our present understanding, especially in those parts of the subject that relate most closely to potential observations. The topics are: the flux of gravitational waves emitted by realistic astronomical sources, attempts to improve the sensitivity of gravitational wave detectors, and the theory of small perturbations of relativistic stars and black holes and the gravitational waves that they emit.

I must confess to a feeling of optimism about the future of this work. It is my belief, as it is Thorne's, that gravitational waves from astronomical sources *will* be detected in the future, perhaps within the next 10 or 15 years. To prepare for that day, much more theoretical work needs to be done, and with Chandrasekhar as one of our leaders we can be confident that an adequate framework will be constructed for the analysis of the data to come.

However, in my enthusiasm for relativity I must not neglect the other valuable articles in the book. In addition to those already mentioned, I would draw the reader's attention particularly to the remaining longer articles, by Paul Ledoux on stellar stability, George Contopoulos on stellar dynamics, and T. W. Mullikin on radiative transfer. The short articles also are strong on insight, and the book as a whole should be a gift from every research supervisor to every new graduate student in theoretical astronomy.

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The Interstellar Medium

Physical Processes in the Interstellar Medium. LYMAN SPITZER, JR. Wiley-Interscience, New York, 1978. xviii, 318 pp., illus. $15.95.

Several percent of the matter in the Milky Way lies between the stars. Containing atoms, ions, molecules, and dust particles, the interstellar medium both supplies the matter for forming new stars and receives the mass and energy flowing out of active stars. It thus plays an important role in the evolution of the galaxy.

As is the case with other branches of astronomy, study of the interstellar medium has expanded rapidly as new techniques have been brought to bear since World War II. Before then, our knowledge was almost entirely confined to that garnered by optical telescopes. When Lyman Spitzer published his first book on the interstellar medium, *Diffuse Matter in Space*, in 1968, he had available the surveys of neutral hydrogen atoms made by radio telescopes utilizing the 21-centimeter hyperfine emission line, as well as the radio continuum surveys of synchrotron emission by interstellar relativistic electrons.

Since then, rapid progress on millimeter-wave astronomy has shown that much of the interstellar medium is in the form of molecular clouds, consisting largely of H_2 molecules but most easily studied by means of the radio spectral lines of CO, H_2CO, HCN, and other polar molecules. Infrared telescopes have found both continuum and line emission from the interstellar medium. The discovery of sharp bursts of radio emission from pulsars has permitted the study of the intervening medium by its dispersion and by its rotation of the plane of polarization of these bursts. X-ray detectors have observed the hard radiation from very hot gas behind supernova-induced shock waves. And satellite-borne ultraviolet telescopes have vastly extended the number of absorption lines in stellar spectra formed in the intervening interstellar medium, yielding a rich store of information on H_2 molecules as well as other atoms, ions, and molecules. The result has been a flood of observational information, now occupying a substantial fraction of the total astronomical literature.

Given this situation, Spitzer had to make some tough choices in writing *Physical Processes in the Interstellar Medium*, a revision of his earlier book. Rather than try to summarize all the new observational information, he has chosen to emphasize even more than in the first book the physical principles—atomic collisions, radiation processes, magnetohydrodynamics—that are involved, which still apply.

The first book was widely used as a graduate textbook and played a major role in training a generation of astrophysicists who are now working on theoretical studies of the interstellar medium. There is still plenty of opportunity for such studies, in view of the rapid developments on the observational side and the need for careful modeling to understand the dynamical processes being observed. Thus, there is certainly a strong need for a book like the present one.

Physical Processes is about 50 percent longer than *Diffuse Matter*. It is written in the same condensed but lucid style and is largely concerned with the same topics; however, there are significant additions, including discussions of plasma dispersion, photon pumping, the physics of interstellar masers, infrared emission by interstellar dust, hydrodynamic instability, accretion flow, spiral density waves, the interaction of H_2 molecules with radiation, the effect of dust on the photoionization of hydrogen, charge-exchange processes, circular polarization by interstellar grains, and gravitational equilibrium in the presence of a magnetic field.

On the other hand, one topic covered briefly in the earlier book, relativistic particles in the interstellar medium, has been omitted because the author claims inadequate knowledge of it. Its omission is not a serious problem, for there exist adequate treatments in other books. There is not much discussion of the role played by molecules other than H_2 in interstellar studies. In my view, this is unfortunate, because much of the current observational effort is in this direction and often seems to be poorly connected to theoretical issues. Among the topics I would have liked to see discussed at greater length are: formation of molecules via charge-exchange process versus catalysis on the surface of dust particles, chemical fractionation, ionization equilibrium in molecular clouds, trapping of CO line emission in interstellar dust clouds, and interpretation of the large Doppler widths of interstellar molecular lines. Of course these topics are discussed in the literature, but inclusion of them here would have given the reader a better background for interpreting data.

The format of the book is attractive. The chapters and sections are well organized, and the figures are helpful (although relatively few in number). The index is well done, and there is a helpful list of symbols. Cross-references, which are plentiful, consist of citations of chapter, section, and subsection (not page). Unfortunately, none of these numbers appear serially at the top or bottom of the pages, so the reader must thumb through until his or her eye happens to light on the proper section.

In summary, *Physical Processes* will become the standard textbook in the field of theoretical studies of the interstellar medium, just as its predecessor was. Another generation of astrophysicists will be strongly influenced by Spitzer's approach to the field. And that is all to the good, for his mastery of the field is unparalleled.

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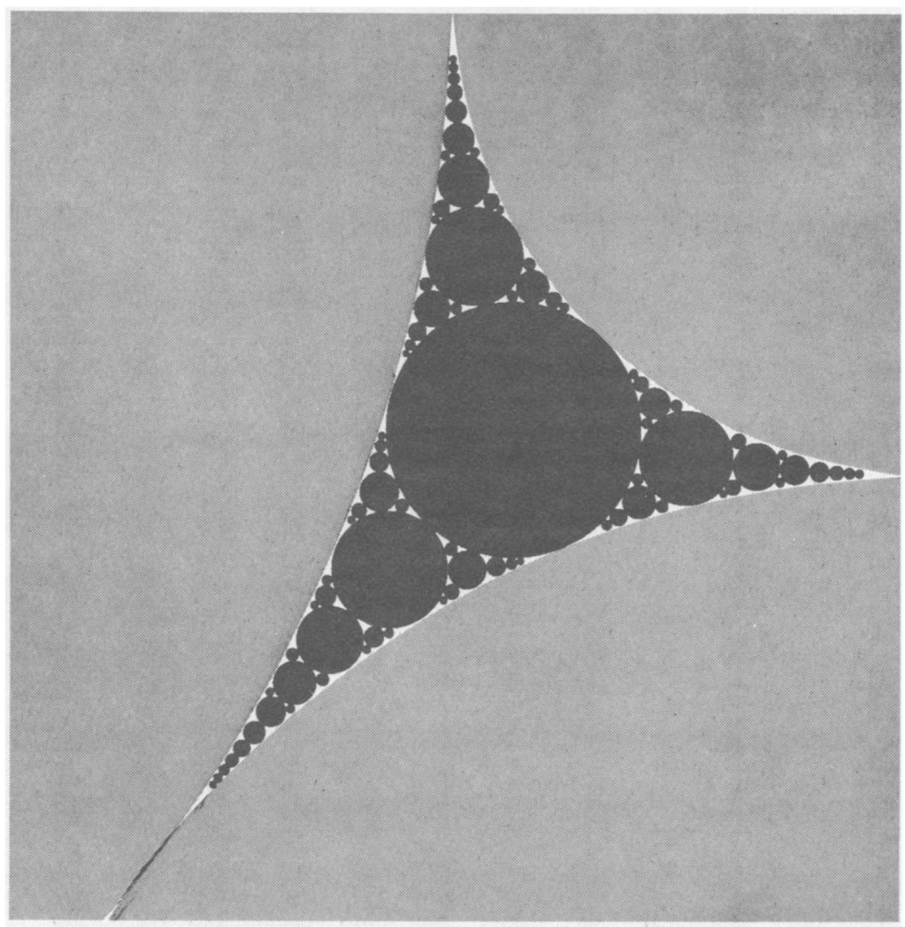
Characterizing Irregularity

Fractals. Form, Chance, and Dimension. BENOIT B. MANDELBROT. Translation and revision of French edition (Paris, 1975). Freeman, San Francisco, 1977. xviii, 366 pp., illus. $14.95.

"Fractal" is a word invented by Mandelbrot to bring together under one heading a large class of objects that have certain structural features in common although they appear in diverse contexts in astronomy, geography, biology, fluid dynamics, probability theory, and pure mathematics. The essential feature of a fractal is a fine-grained lumpiness or wiggliness that remains inherent in its texture no matter how thin you slice it. In an article in *Science* 11 years ago, "How long is the coast of Britain?," Mandelbrot pointed out that the concept of length is inappropriate to the description of a natural coastline. If you measure the length by following all the wiggles around the boundary of a map of Britain, the answer will depend on the scale of the map. The finer the scale, the more wiggly the boundary and the greater the measured length. To characterize the texture of the coastline in a manner independent of scale, you can say that it has a geometric dimension $D = 1.25$, intermediate between the dimension of a smooth curve ($D = 1$) and the dimension of a smooth surface ($D = 2$). The coastline is here showing the typical behavior of a fractal. In his book, Mandelbrot collects a great variety of examples from various domains of science and shows that they can all be described in the same way as the coastline of Britain by being assigned suitable "fractal dimensions." Important examples from human anatomy are our vascular system (veins and arteries) and the bronchiole structure of our lungs. In the vegetable world we have trees, in the world of geography we have river networks and archipelagoes, in astronomy we have the hierarchical clustering of stars and galaxies.

The cataloging of natural objects with fractal structure is only half of Mandelbrot's theme. The other half is the historical role that fractals played in the development of pure mathematics. A great revolution of ideas separates the classical mathematics of the 19th century from the modern mathematics of the 20th. Classical mathematics had its roots in the regular geometric structures of Euclid and the continuously evolving dy-



Apollonian gasket, dimension about 1.306951. "To construct a circle tangent to three given circles constitutes one of the geometric problems that tradition attributes to Apollonius of Perga. Begin with three gray circles tangent two by two, forming a circular triangle, and let the above construction be iterated to infinity. The black Apollonian circles (less their circumferences) will 'pack' our triangle, in the sense that almost every point of it will eventually be covered. The remainder will be called [an] *Apollonian gasket*. Its surface measure vanishes, while its linear measure, defined as the sum of the circumferences of the packing circles, is infinite. Thus the shape of the Apollonian gasket lies somewhere between a line and a surface. It enters in the theory of Smectic A liquid crystals." [From *Fractals*]