terms of a variability factor. Indeed, in 1968 Arnold Court and his co-workers found that the optimum length of record useful in predicting the next year's weather was no greater than ten years.

If climatic variability exists, then why speak of climatic change? To answer that question a great deal more has to be examined than events of the last ten years. Acceptance of the fact that the earth has experienced climatic patterns significantly different from the current pattern was gained with the determination in the last century that massive ice sheets had covered much of northwestern Europe, and especially the northern half of North America, in the relatively recent past. It is now accepted that at least seven ice ages occurred still earlier and that at present we are living in a world far from completely free of ice, at a time that probably represents an interstadial period past its peak of warmth.

Where, then, do we stand with respect to the processes and stages that account for the sequence of events that we term climatic change? It is to that question, directly or indirectly, that most of the pages of these books are devoted. A précis would go something like this.

Glaciation of the polar regions has occurred when large landmasses drifted into high latitudes. At such times, the glacial cycle can be initiated when the orbital elements of the earth combine in such a way as to provide least solar energy to the summer hemisphere. A periodicity of the order of 2×10^4 years is involved, which was first adequately described by Milankovitch in 1938. The pulse provided by orbital (and axial) changes is rapid compared to the pace of continental drift, thus allowing a series of advances and retreats of ice to occur over the same terrains. In the case of Antarctica, ice apparently first reached sea level in middle Oligocene times, 37 million years ago, according to Frakes (in Pittock *et al.*). The Northern Hemisphere ice domes were formed much more recently, perhaps a little more than a million years ago, although Alaskan alpine glaciers were formed earlier than that.

The most recent events of the Pleistocene are dated more accurately than earlier stages, for a variety of reasons. For the past 150,000 years, Mason (in Pittock *et al.*) reports astonishingly good agreement between ice advance and retreat in the Northern Hemisphere and the heat excesses and deficits calculated by the methods of Milankovitch, which Mason has revised on the basis of improved astronomical data. Nevertheless, Flohn (in Gribbin) notes intermediate ice advances that do not fit the periodicities supplied by Milankovitch and attributes them to surges of Antarctic ice sufficient to affect global climate.

Budyko (in Gribbin), as well as Sellers and others, believes that variations in the solar constant are also a causal agent in controlling the ice margin of northern polar ice. Small changes in solar output—differences little larger than those provided by Milankovitch—may be sufficient to shift the ice margin from its present position (72° north latitude) to its average Pleistocene limit (50° north latitude). Lorenz, by very different reasoning, also concludes that the present climate is unstable.

Against this background of historical evidence and theoretical reasoning, we are led to contemplate our present climatic pattern with new appreciation of its geniality and to hope that this amiable state of affairs will last longer. It is known, of course, that humans have altered the climatic system for millennia by changing water tables and vegetation in establishing agriculture and, more recently, by adding to the carbon dioxide content of the atmosphere through combustion of fossil fuels and by increasing the dust veil already provided by volcanic activity. Interesting and possibly significant extrapolations of climatic changes have been made on the basis of inadvertent changes in atmospheric composition caused by humans.

It is the hope of some investigators that computer simulations of atmospheric activity will allow us to predict the effects of both natural and anthropogenic variables on the climatic system. The books under review consider that possibility as promising, but not attainable with present computing capacities. Above all, improved linkage between the atmosphere and the hydrosphere is needed to provide realistic climatic models. It is hardly accidental that two of the great meteorologists of this century, C.-G. Rossby and J. Bjerknes, turned toward the oceans in their later years.

The question of solar effects has always loomed large in studies of climatic change, for however much heat may be stored in the oceans it originated with the sun, and over long spans of time variability in solar activity has the potential of explaining most of the facts of climatic history. Unfortunately, we still do not have a record of insolation accurate to within 1 percent and so cannot verify through observation that the sun is effectively variable.

Both books are signficant collections of information. A useful blend of fact and theory is found in each, though differences in balance exist: climatic change as a problem is cleanly presented in the Gribbin collection, whereas Pittock and his co-workers include more data, and some writing that borders on the didactic. With books of this quality, comparisons are essentially invidious. So ramified is the subject of climactic change that both books can be read with profit.

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Honoring Chandrasekhar

Theoretical Principles in Astrophysics and Relativity. Papers from a symposium, Chicago, May 1975. NORMAN R. LEBOVITZ, WILLIAM H. REID, and PETER O. VANDERVOORT, Eds. University of Chicago Press, Chicago, 1978. viii, 258 pp., illus. $23.

This book contains the papers presented at a symposium held in honor of the 65th birthday of Subrahmanyan Chandrasekhar. The topics of these papers touch on many, but by no means all, of his interests, which are so diverse that it would take another Chandrasekhar to write an adequate review of the book. There being no one like him, I agreed to review the book for the opportunity it gives me to join in honoring him.

Since his first published paper in 1928, entitled "Thermodynamics of the Compton effect with reference to the interior of stars," Chandrasekhar has made a massive and unique contribution to mathematical astronomy. As remarkable as his contribution is his style of work. He takes up a subject for a few years, imposes on it his own mathematical authority, organizes the material in a definitive treatise, and then leaves the subject, rarely to return to it. I can still remember the excitement I felt when he told me in the early '60's that he intended to take up the study of general relativity. His first important paper on this subject was published in 1964 and contained a result typical of him—the instability of a massive sphere in general relativity. Fortunately for relativists he has not yet written his definitive treatise on the subject. Long may it be delayed!

The papers in this book are organized around two main themes, stars (and stellar systems) and relativistic astrophysics. They vary from brief and predominantly verbal accounts to extensive, systematic, mathematically detailed reviews. They all bring out very clearly the great difficulties of modern 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