

been key features of the revival of interest in the study of gravitation. That anyone could even contemplate, never mind achieve, the measurement of changes in length of a macroscopic body of the order of 10^{-20} meters I still find astonishing. But feats of similar difficulty are being accomplished in many areas in order to see the effects particular to general relativity. The papers by Clifford Will, Alan H. Cook and Kip Thorne make clear the ingenuity and skill of the experimenters taking part in the explosive development of this field.

I have only touched on some of the rich contents of this book. Even in the most mathematically detailed of the articles, such as that on the equations of motion of bodies in general relativity by Thibault Damour, there is still more than enough meat on the technical bones for the uninitiated reader. For the expert, the articles are a rich storehouse of reference material. For both, the articles all raise questions about and provide insights into not only the details of the fields, but also into the nature of physical reality and the enterprise of physics. Gravitation invites wonder and speculation and draws forth insights into areas once reserved for philosophy, as Steven Weinberg demonstrates in his musings on the nature of physical theory.

Do I have any criticisms of this book? Only a few quibbles. Although the table of contents is quite detailed, the lack of an index is still a shame. The technical tidbit provided for this volume by Cedomir Crnković and Edward Witten is disappointing in the context of the other articles. At times some of the reviews become uncritical catalogs of work done rather than critical guides.

I recommend this book to anyone who has an interest in the state of the study of gravitation today. As at the time of Newton, it is gravitation that is drawing us toward a new vision of the world. That vision may still be but dimly seen, but the papers in this collection show us that it is exciting, provocative and stimulating nonetheless.

Dynamical Evolution of Globular Clusters

Lyman Spitzer Jr

Princeton U. P., Princeton,
N. J., 1987. 180 pp.

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\$14.50 pb ISBN 0-691-08460-2

Globular clusters are roughly spherical systems of typically a few million gravitationally interacting stars. On

a time scale of about 10^8 years, these clusters are in quasi-equilibrium. However, on a longer time scale, two-body stellar interactions cause the clusters to evolve. The outer parts expand and the inner cores collapse toward an infinite central density. Over the last two decades, our understanding of the dynamical evolution of globular clusters has progressed greatly. The dynamics of core collapse is now more or less understood, although what happens after core collapse is not so certain. Lyman Spitzer is one of the principal contributors to the theory of the dynamical evolution of globular clusters, and *Dynamical Evolution of Globular Clusters* is an elegant and succinct account of the subject. (Previous reviews of the subject include Alan Lightman and Stuart Shapiro's in *Rev. Mod. Phys.* **50**, 437, 1978, and Rebecca Elson, Piet Hut and Shogo Inagaki's in *Annu. Rev. Astron. Astrophys.* **25**, 565, 1987.)

The book begins with a brief overview of the observed properties of globular clusters, the stationary equilibrium models of these systems, and the perturbations that drive their dynamical evolution. The granularity of the clusters causes them to diffuse in velocity space toward a Maxwellian state, which is unattainable because the stars in the high-energy tail evaporate from the cluster. External perturbations from the galactic tidal field enhance this evaporation. As the high-energy stars are lost, the core contracts and becomes dynamically hotter. This inherent instability drives the core to collapse.

The relative motions of the stars in a cluster produce fluctuations in the gravitational field. These fluctuations slowly change the energy and angular momentum of each star, and in this way cause the cluster to evolve. In the second chapter Spitzer discusses the velocity changes produced by stellar encounters in terms of diffusion coefficients in velocity space. The basic theory is used to estimate the rate of equipartition of energy between stars of different masses, and the characteristic relaxation time for approaching a Maxwellian distribution. The Fokker-Planck equation, which gives a quantitative description of the cluster's diffusion in velocity space due to small successive velocity changes, is then derived. The presentation of this material is very clear and to the point.

Several simultaneous physical processes contribute to the evolution of a real cluster (or a realistic model). To gain some understanding of these processes, Spitzer considers the evolu-

tion of idealized models, which make it possible to isolate individual processes. These processes include evaporation from an isolated uniform cluster and from a tidally limited cluster, the collapse of an isothermal sphere (illustrating the negative specific heat of gravitationally bound systems), and the mass stratification instability, in which the tendency toward equalization of kinetic energy can lead to a steady collapse of the subsystem of heavier stars.

The next chapter is on the evolution of the "standard" model—an isolated cluster with no perturbing external fields, no binary stars and no physical changes in the stars themselves. The methods for computing changes in the velocity distribution function as a result of stellar encounters include two Monte Carlo techniques and direct numerical integration of the Fokker-Planck equation. The evolving cluster develops two distinct regions, an inner isothermal sphere and an outer halo in which the stars move in predominantly radial orbits. As the evolution proceeds, the core collapses and the outer regions expand. Spitzer's discussion illustrates very nicely the relative importance of the individual physical processes that affect the evolution of the cluster.

But a real cluster is not isolated. It moves in a galactic gravitational field, and the tidal force associated with this field allows stars to escape from the cluster if their orbits are energetic enough to extend beyond a critical distance from the cluster center. Furthermore, this tidal field is time dependent, as seen by the cluster. This time dependence can lead to heating effects in the halo of the cluster, particularly through the tidal shocks the cluster suffers as it passes through the galactic disk or near the galactic center. These effects of external fields on the evolution of clusters are discussed in chapter 5.

In the later stages of cluster evolution, binary stars can provide an important source of energy: The binding energy of a binary system can increase during an encounter with a single star, with a corresponding increase in the kinetic energy of the single star. In chapter 6 Spitzer discusses the physical processes involving binary stars and the formation of binaries through three-body encounters and tidal capture in two-body encounters. The final chapter is on the later stages of cluster evolution. Energy liberated by recently formed binaries terminates the core collapse of the cluster, and some expansion of the core then occurs. This phase, not yet fully understood,

is interesting and important because many clusters have probably attained it already. Some models suggest that the core reaches an oscillatory state, with expansion and collapse alternating on a time scale of a few relaxation times.

This book is very good. It is well presented, with only a very few, minor errors and typos. It gives a comprehensive account of the subject, up to 1984 in some parts and 1986 in others. Spitzer emphasizes the physical processes throughout, and the reader is not overburdened with derivations of equations. This book would be excellent for a graduate course on the dynamical evolution of globular clusters.

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Principles of Ocean Physics

John R. Apel

Academic, San Diego, Calif.,

1987. 634 pp.

\$68.50 hc ISBN 0-12-058865-X;

\$35.00 pb ISBN 0-12-058866-8

General Circulation of the Ocean

Edited by Henry D. I.

Abarbanel and W. R. Young

Springer-Verlag, New York,

1987. 291 pp.

\$69.00 hc ISBN 0-387-96354-5

In oceanography we are faced with two educational problems:

- ▷ How to train oceanography graduate students amid the explosion of knowledge within the ocean sciences
- ▷ How to entice good, science-oriented students into the field, that is, how to make them aware of the excitement of the ocean sciences.

The problems are crucial, since the ocean sciences may be on the verge of a "golden age" (perhaps we are already in it—one is never sure of a golden age until it's over). Thanks largely to the expanded application of modern observational tools, including Earth-orbiting satellites, as well as high-speed computers, a true global orientation is now a reality. The educational program must reflect this evolution.

I am glad I was a physical oceanography graduate student so many years ago, in the early 1960s, when it was still possible to know a significant portion of the field by the time one got one's PhD. I am now able—but barely—to keep pace with the ever expand-

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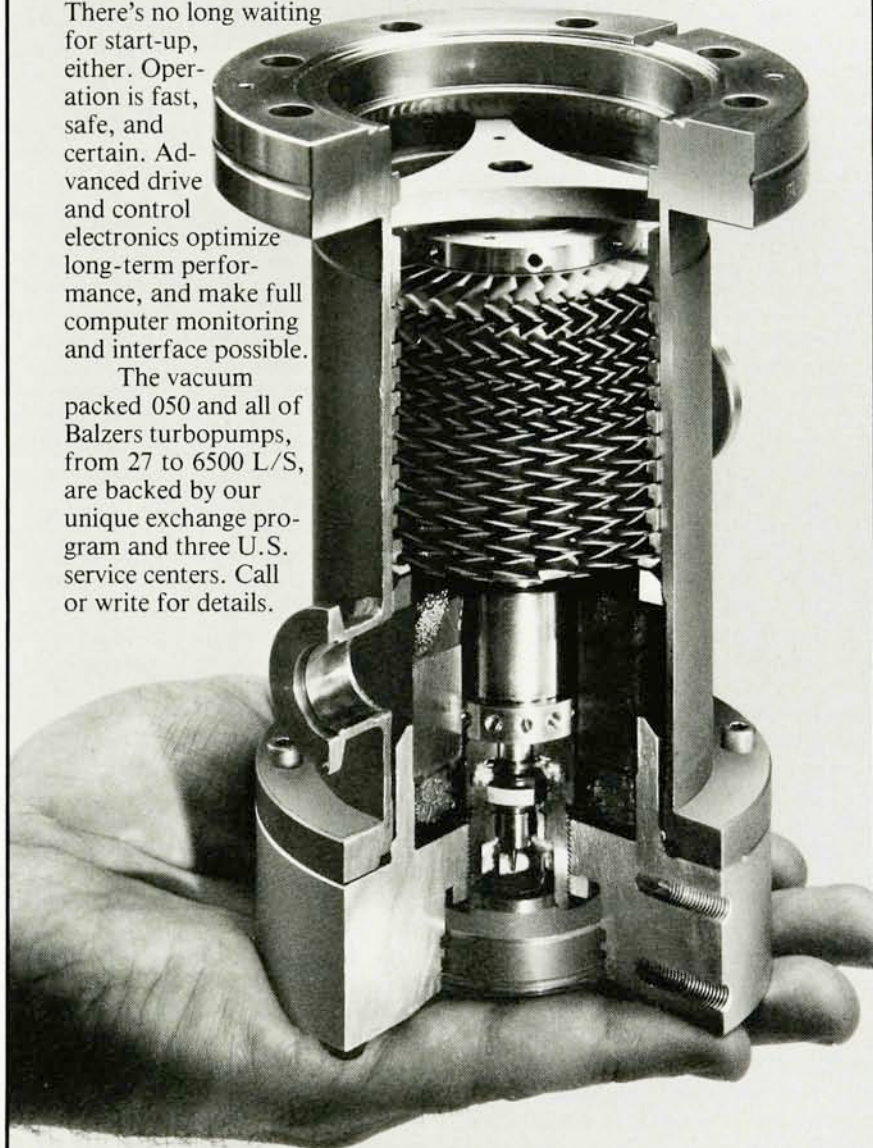
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