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With 112 Figures and 35 Tables



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To my teacher, Yakov Borisovich Zeldovich

Preface to the English Edition

The development of the theory of stellar evolution has been relatively rapid since 1989, which is when the Russian edition of this book was published. Progress in the field concerned mainly a better understanding of the physical background of stellar processes, in particular the improvements made in calculating new opacity tables. The latter led to a better description of some observational phenomena, such as Cepheid oscillation models, but otherwise led mainly to quantitative corrections of previously known results. The field that may be strongly influenced by the increase of opacity according to the new tables is the mass loss from massive evolved stars. This latter phenomenon has not yet been investigated, however. Many new results have been obtained in helioseismology, the theory of supernova explosions, accretion theory, and 2-D calculations of different phenomena, such as star formation, explosions of rotating magnetized stars and numerical simulations of stellar convection.

This book has been updated and now includes over 150 new references. New material has also been added to otherwise well established sections. This includes the CAK theory of mass loss from hot luminous stars, the description of the Eggleton method of stellar evolution, and a more detailed consideration of the accretion disk structure around black holes.

The revisions and additions of new material substantially increased the number of pages, making it desirable to produce two essentially self-contained volumes. The first volume, "Fundamental concepts and stellar equilibrium", contains the material related to the first six chapters of the Russian edition. The second volume, "Stellar evolution and stability", includes the material of the other chapters of the Russian edition. While both volumes retain the structure of the Russian edition, each of these two volumes now has a self-contained character and could be interesting for different kinds of readers. The first one contains a detailed description of physical processes in stars and the mathematical methods of evolutionary calculations. Thus this volume will be of interest for physicists and specialists in numerical mathematics regardless of the level of their actual involvement in the work on stellar evolution. The second volume contains both the qualitative and the quantitative descriptions of stellar evolution, explosions, stability and oscillations. This will be of interest for the wider astronomical community, observers and theoreticians alike, working or interested in astrophysical phenomena related to

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stellar formation and evolution. Finally, those who directly work in the theory of stellar evolution, or want to study this field in depth, will find that both volumes provide them with a comprehensive introduction to and survey of the present state of the art in this field.

I am very grateful to my colleagues from the Cambridge Institute of Astronomy, D.O. Gough, P. Eggleton, and C. Tout, and from Queen Mary and Westfield College, I.W. Roxburgh, A.G. Polnarev, and S.V. Vorontsov, for their hospitality during my stay in these places, many discussions and help with the work on different parts of the book, as well as improvements to the English. I am also grateful to M.M. Romanova, A. Blinov, and S.V. Repin, who translated the Russian edition of the book into English and prepared the T_EX file of this translation.

Moscow, August 2000

G.S. Bisnovatyi-Kogan

Preface to the Russian Edition

The desire of astrophysicists to gain insights into the mysteries of the birth and death of stars has required the application of almost all branches of modern physics. The results of atomic physics are necessary for studies of stellar birth out of the interstellar medium; and knowledge of the structure of white dwarfs and neutron stars requires the use of liquid- and solid-state theory, and the theory of phase transitions, superconductivity, and superfluidity. Between these extremes, in the area where stars mostly exist, the laws of nuclear physics and weak interactions, and the theories of matter and radiative transfer, are at work.

The equilibrium of a star is described by the equations of hydrodynamics supplemented by general relativity and electromagnetic field theory. The problem of turbulence and convection, not yet completely resolved in terrestrial applications, is even more important and difficult in problems of stellar evolution. This book deals with many of these problems, trying to develop the theory of stellar evolution from a physical standpoint. In this regard, I have followed D.S. Frank-Kamenetski's excellent *Physical Processes in Stellar Interiors* [215]; however, spectacular achievements in the field during the last 25 years have considerably reduced the overlap with this book. An essential part of the items treated here has been considered more qualitatively in Ya.B. Zel'dovich's lectures published in *Physical Grounds of Stellar Structure and Evolution* [107].

The astrophysical results given in Part II have much of the descriptive character typical of astronomy. The reason for this is that the major results are obtained here through numerical experiments which, just as in a real astronomical situation, can only be described rather than reproduced in a book. I have also tried to clarify, whenever possible, the physical sense of the results.

The material in this book is to some extent presented according to my personal preference, as particular attention is often paid to items connected to my scientific interests. Nonetheless, I have tried to preserve a general understanding of the problems discussed and to give results which are basic, as I see them, to the theory of stellar evolution.

I have tried to select from a large variety of papers those reviews and monographs either representing an important advance in solving some as-

trophysical problem, or dealing with interesting physical problems which are not necessarily important (or are not regarded as such) for the development of the theory of stellar evolution. I have considerably softened the selection rules for my own results. Some problems in the book remain unanswered; I have included them in the hope that some reader will succeed in finding their solution.

The book is concerned only with the evolutionary paths of single stars. The theory of stellar evolution for close binaries, in which there is a considerable increase in the evolutionary paths, is treated in the recently published monograph by A.G. Masevich and A.V. Tutukov *Stellar Evolution: Theory and Observations* [156]. The relationship between theory and observations is also considered in this book.

I gratefully acknowledge the assistance of and useful discussions with S.I. Blinnikov, S.A. Lamzin and A.F. Illarionov, and express my particular thanks to E.V. Bugaev and D.G. Yakovlev, who have read several chapters of the book and made many helpful remarks.

Moscow, September 1989

G.S. Bisnovatyi-Kogan

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List of Symbols and Abbreviations

Some Important Constants

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