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978-1-107-18089-5 — Compact Star Physics
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COMPACT STAR PHYSICS

This self-contained introduction to compact star physics explains key concepts from areas such as general relativity, thermodynamics, statistical mechanics, and nuclear physics. Containing many tested exercises, and written by an international expert in the research field, the book provides important insights on the basic concepts of compact stars and discusses white dwarfs, neutron stars, quark stars, and exotic compact stars. The topics covered also include a discussion of astrophysical observations of compact stars, and present and future terrestrial experiments with strong relations to the study of compact stars, as experiments on exotic nuclei and relativistic heavy-ion collisions probing the equation of state of dense matter. Major developments in the field such as the discovery of massive neutron stars and a discussion of the recent gravitational-wave measurement of a neutron star merger are also presented. This book is ideal for graduate students and researchers working on the physics of compact stars, general relativity, and nuclear physics.

JÜRGEN SCHAFFNER-BIELICH is a professor in theoretical astrophysics at Goethe University, Frankfurt. Since completing his PhD, he has worked at the Niels Bohr Institute; the Lawrence Berkeley National Laboratory as Feodor-Lynen fellow of the Humboldt Foundation; the RIKEN BNL Research Center at the Brookhaven National Laboratory, Columbia University; and as a professor at the University of Heidelberg.

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To
Joran, Laurin, and Annkatrin

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Preface

Compact stars are stars in which effects from general relativity become important. Commonly, they are associated with white dwarfs and neutron stars. Compact stars in general are more than that and encompass quark stars and hybrid stars, as well as hypothetical boson and fermion stars made of exotic particles. This textbook is about those types of compact stars.

The research area of compact stars experiences exciting new developments. Massive neutron stars with a mass of more than two solar masses have been detected. There is the first direct detection of gravitational waves produced by the merger of two neutron stars by the gravitational wave detectors LIGO and VIRGO. Numerical simulation codes have reached a new status of maturity to compute the birth of neutron stars in core-collapse supernova and to compute the merger of neutron stars. There has been tremendous progress in the microphysical modeling of compact stars in recent years, bringing to light new insights for the behavior of matter under extreme conditions. New space-based missions are planned to explore compact stars in much more detail, as well as new ground-based facilities in the near future, such as the X-ray satellite eROSITA, the James Webb Space Telescope (JWST), the Square Kilometer Array (SKA), and the Extremely Large Telescope (ELT).

There is a rapidly growing scientific community consisting of astrophysicists, numerical relativists, and nuclear physicists who perform research related to compact stars worldwide. There are the excellent classic textbooks by Shapiro and Teukolsky (1983) with an emphasis on relativistic astrophysics and by Glendenning (2000) with a focus on the field theoretical description of compact stars. In view of the rapid development in the research field, this textbook is intended to give an updated introduction to the physics of compact stars, covering many new facets and developments in the field since Shapiro and Teukolsky, and Glendenning. It is based on courses given at Goethe University Frankfurt, at the Ruprecht Karl University of Heidelberg, and several lectures given at summer and winter schools.

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The intended readership is advanced undergraduate students and graduate students with a basic knowledge in mechanics, electrodynamics, quantum mechanics, and statistical mechanics. The key concepts of general relativity necessary for compact stars and the basis of dense matter and quantum statistics will be worked out in the textbook. Unfortunately, in view of the large amount of material and the limits of space and time, many topics had to be omitted, such as rotation, cooling of neutron stars, proto-neutron stars, and core-collapse supernovae.

I thank my colleagues, coauthors, students, and friends Mark Alford, Almudena Arcones, Krešo Baotic, Andreas Bauswein, Gordon Baym, David Blaschke, Ignazio Bombaci, Michael Buballa, Fiorella Burgio, Debarati Chatterjee, Jan-Erik Christian, Alessandro Drago, Tobias Fischer, Avraham Gal, Norman Glendenning, Carsten Greiner, Pawel Haensel, Matthias Hanauske, Kai Hebeler, Matthias Hempel, Oliver Lawrence Hoffmann, Thomas Janka, Burkhardt Kämpfer, Aleksi Kurkela, Jim Lattimer, Stefan Leupold, Matthias Liebendörfer, Gabriel Martínez-Pinedo, Bruno Mintz, Igor Mishustin, Guiseppe Pagliara, Chris Pethick, Rob Pisarski, Jose Pons, Madappa Prakash, Sanjay Reddy, René Reifarth, Luciano Rezzolla, Dirk Rischke, Stephan Rosswog, Stefan Rüster, Irina Sagert, Klaus Schertler, the late Stefan Schramm, Achim Schwenk, Hans-Josef Schulze, Armen Sedrakian, Igor Shovkovy, Andrew Steiner, Rainer Stiele, Horst Stöcker, Christian Sturm, Friedel Thielemann, Markus Thoma, Laura Tolos, Stefan Typel, Isaac Vidaña, Aleksi Vuorinen, Fridolin Weber, Simon Weissenborn, and Andreas Zacchi for the numerous discussions on compact star physics and related topics. I apologize to those whom I forgot to mention.

I am indebted to Eduardo Fraga for bringing up my name for a textbook on compact stars to Simon Capelin from Cambridge University Press, and to Simon for following up on it. I thank him, Sarah Lambert, Henry Cockburn, Roisin Munnelly, and the staff at Cambridge University Press for their help and assistance in the production process. I am grateful to Joe Kapusta for helpful advice on how to write a textbook. I thank Jan-Erik Christian, Eduardo Fraga, Matthias Hanauske, Irina Sagert, Laura Tolos, Fridolin Weber, and Andreas Zacchi for a critical reading of selected chapters. Finally, I thank my family, my wife Annkatrin and my two sons Laurin and Joran, for their love. This book is dedicated to them.

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