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Henri M. J. Boffin · David Jones

The Importance of Binaries in the Formation and Evolution of Planetary Nebulae

Springer
To our families, without whom none of this would have been possible.

Cathy, Yuki and Niall
Flori and Idris
Foreword

The evolution of stars in gravitationally bound binary systems is an extraordinarily rich field of study. Not only can the evolution of each star be dramatically altered with respect to the evolution of single stars, but a number of physical phenomena also occur that are highly relevant to other fields of astrophysics. The very long list includes, but is most certainly not limited to: tidal interactions, surface irradiation, mass transfer and accretion, the production of stellar jets and other outflow phenomena, gravitational wave emission and other relativistic effects. As many of these effects are the stellar analogues of similar phenomena occurring at much larger scales, such as in the cores of galaxies, modern astrophysics cannot be conceived without a thorough understanding of binary stars. Their relevance is further enhanced by the fact that it is believed that more than 50% of stars are found in binary or higher-order systems, which makes binarity a necessary ingredient even for the interpretation of the most basic relationships such as the classical Hertzsprung–Russell diagram.

Binary interactions occur among all types of stars and span a large range of orbital separations, from the shortest binary systems known nowadays, pairs of compact white dwarfs with orbital periods as short as five minutes (HM Cancri), through to giant stars that can be affected by the presence of companions even at orbital periods of many hundreds of years (o Ceti [Mira]).

This book by Astrophysicists Henri M. J. Boffin and David Jones focusses on the effects of binarity in the final evolutionary stages of low- and intermediate-mass stars. The relevance of binary interactions to explain the properties of planetary nebulae has been an active subject of debate since the first high-quality catalogues of narrowband images of planetary nebulae were obtained at the beginning of the 1990s both from the ground and with the Hubble Space Telescope. Today, far fewer astronomers doubt that the key to understanding the wide variety of planetary nebulae shapes, or indeed some of their peculiar chemical properties, is binary evolution. However, much work has still to be done in order to constrain the overall statistical relevance of binarity in the formation and evolution of planetary nebulae as well as the specific physical processes involved and how they are related to observed nebular properties. The topic also has important implications for our
understanding of cataclysmic variables and novae, Type Ia supernovae, symbiotic stars and other phenomena such as the production of astrophysical jets.

This book comprehensively outlines current understanding in sufficient detail as to make it a valuable reference text, providing not only a global view of the subject but also guidance for planning the future research in a field that has shown tremendous, albeit still insufficient, progress over the last three decades. I have no doubt that this book will occupy a permanent place on my desk for years to come.

La Palma, Spain

Romano L. M. Corradi
It is now clear that a binary evolutionary pathway is responsible for a significant fraction of all planetary nebulae (PNe), with some authors even going as far as claiming that the Sun will not become a PN. At the very least, it is now clear that binary interactions play a critical role in the shaping of many PNe—including some of the most well studied. Furthermore, PNe offer a unique window into many key aspects of binary evolution, providing multiple avenues to explore the various physical processes involved. Beyond the central stars themselves, the surrounding nebulae offer an additional route to trace the mass loss and mass transfer histories of these systems, meaning that one can, in principle, derive a complete picture of the impact of binary evolution on these systems. Furthermore, binary central stars of PNe represent progenitor systems for a wide range of astrophysical phenomena, including cosmologically important Type Ia supernovae and the stellar-mass gravitational wave sources that will be revealed by next-generation detectors. This combined with the fact that the majority of stars are found to reside in binary systems, many of which will interact at some point during their lives, only serves to further highlight the importance of understanding the impact of binarity on stellar evolution including the late stages which in intermediate-mass stars are characterised by the formation of a PN. Collectively, the weight of recent advances has led to the requirement that textbooks need to be rewritten. This SpringerBriefs is the very first step in this direction.

We have tried, and by no means claim to have succeeded, to present in a succinct way all the theoretical and observational support for the importance of binarity in the formation of PNe. In the process, we outline some of the key principles and techniques, as well as their flaws and advantages, used in the study of binary PNe (many of which have wider applications). As such, we hope that this book will be useful for all specialists, from graduate students to senior astronomers, working in (binary) stellar physics, but also to anyone that is interested in this very important and aesthetically beautiful phase of stellar evolution.

It is a pleasure to thank our many long-suffering collaborators who have contributed significantly to much of the work detailed within this book, including Romano Corradi, Jorge García-Rojas, Alain Jorissen, Dimitri Pourbaix, Pablo
Rodríguez-Gil, Miguel Santander-García, Roger Wesson, Brent Miszalski, Paulina Sowicka, Todd Hillwig, Hans Van Winckel, Alex Brown, Ana Escorza, Alba Aller, Myfanwy Lloyd, Lionel Siess, Sophie Van Eck, the Phoebe development team and many, many more. We also owe a debt of gratitude to the excellent scientists who over the years have contributed enormously to our understanding of planetary nebulae and binary evolution, and whose work serves as the bedrock for this book. HMJB reserves special thanks for Prof. A. Acker for introducing him to this very exciting research field.

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Acronyms

\(M_\odot\)    Solar mass
\(R_\odot\)    Solar radius
ADF            Abundance discrepancy factor
AGB            Asymptotic giant branch
bCSPNe         Binary central stars of planetary nebulae
BRET           Bipolar, rotating, episodic jet
CE             Common envelope
CS             Central star
CSPNe          Central stars of planetary nebulae
CV             Cataclysmic variable
DD             Double degenerate
ESO            European Southern Observatory
FDU            First dredge-up
GE             Grazing envelope
GISW           Generalised interacting stellar wind
HBB            Hot bottom burning
IFMR           Initial–final mass relation
ISW            Interacting stellar wind
LMXB           Low-mass X-ray binary
LSST           Large Synoptic Survey Telescope
MACHO          Massive Compact Halo Object project
MS             Main sequence
NTT            New Technology Telescope
OGLE           Optical Gravitational Lensing Experiment
PN(e)          Planetary nebula(e)
PNLF           Planetary nebula luminosity function
RGB            Red-giant branch
RLOF           Roche lobe overflow
SDU            Second dredge-up
SNe            Supernovae
| Acronym | Definition |
|---------|------------|
| TDU     | Third dredge-up |
| TP-AGB  | Thermally pulsing asymptotic giant branch |
| VLT     | Very Large Telescope |
| WD      | White dwarf |
| WRLOF   | Wind Roche lobe overflow |