An Introduction to Star Formation

Guiding the reader through all the stages that lead to the formation of a star such as our Sun, this textbook aims to provide students with a complete overview of star formation. It examines the underlying physical processes that govern the evolution from a molecular cloud core to a main-sequence star, and focuses on the formation of solar-mass stars. Each chapter combines theory and observation, helping readers to connect with, and understand, the theory behind star formation. Beginning with an explanation of the interstellar medium and molecular clouds as sites of star formation, subsequent chapters address the building of typical stars and the formation of high-mass stars, concluding with a discussion of the by-products and consequences of star formation. This is a unique, self-contained text with sufficient background information for self-study, and is ideal for students and professional researchers alike.

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This book is based on lectures given by the authors, at Cardiff University and elsewhere, on star formation.

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For Jane, Hilary and the boys

Contents

Illustrations

Preface

This book is directed at the student undertaking a course in star formation for the first time. This may be in the later years of an undergraduate degree in physics, astrophysics, or physics with astronomy. Alternatively, it may be that the student only meets this subject for the first time during the first years of a masters degree. In either case we have assumed that the student already has a grounding in physics and mathematics, including, for example, Maxwell's equations, quantum mechanics and the laws of thermodynamics. Nevertheless, we find from teaching experience that brief reminders to students of things they learnt in other courses are generally welcomed as helpful. Hence, we remind the reader of some of the important points from other branches of physics where they are relevant.

We assume only a minimal knowledge of astronomy, and we derive the necessary astrophysical equations as we go along. We assume no prior knowledge of the subject of star formation itself and begin from first principles. Throughout the book we attempt to stay on ground that is firmly established, and try to avoid that which is trendy or the latest discovery. Experience has taught us that these matters often become outdated much more quickly than the solid foundations on which the subject is based. In cases where we stray onto less sure footing, we inform the reader that we are doing so.

The book does not aim to be a comprehensive encyclopedia of star formation, but merely an introductory text, as the title suggests. The biggest problem when compiling such a work is knowing what to leave out. We have tried largely to include topics that lend themselves to mathematical demonstration, even if that leads to slight over-simplification of cases encountered in the real Universe in this very complex field. We therefore apologise in advance if we have omitted any reader's favourite topic or detail. However, we hope that the reader will nevertheless find the book useful.

The ordering of the book is that we first assemble the necessary tools, and then we cover all aspects of star formation in the order in which they occur for solar-type stars in an evolutionary sense. Then we look at some of the ways in which higher-mass stars differ from this picture. Chapter 1

sets the scene with some introductory and background material. Chapter 2 discusses the electromagnetic radiation that we receive from star-forming regions, and how we use this to discover the physical properties of those regions. Chapter 3 looks at the interstellar medium, where the raw materials exist for the formation of future generations of stars. Chapter 4 studies molecular clouds, where the majority of star formation takes place, to discover the initial conditions for star formation.

Chapter 5 describes the issues associated with collapse and fragmentation on the way to forming a star. Chapter 6 covers the growth of a star from the seed of a protostar to a main-sequence star of roughly solar mass, through its pre-main-sequence evolution. Chapter 7 examines some of the issues peculiar to higher-mass stars and the effects they have on their surroundings. Finally, Chapter 8 gives a few 'tasters' of subjects that flow from star formation, which will hopefully lead the reader into further related topics.

There is an index as well as a list of symbols, to aid the reader. Where possible we have tried to avoid the use of the same symbol for two different meanings. However, we have also tried to use the symbols that are most commonly used in the scientific literature, so that the student is not lost when moving on from this book. Occasionally this leads to clashes. So we have made it clear in each case, when defining every symbol, what meaning we are using for that symbol, and wherever possible we have used a different font or subscript to remove ambiguities.

Our aim is that a student who has read and understood this book should be ready to undertake a higher degree in this field, to read and understand more advanced research texts in the subject, and to embark upon research of their own.

There are many people we would like to thank, who helped in the fashioning of this book, including many students, both undergraduate and postgraduate, who have given helpful feedback and comments on the text. We wish to thank a number of our postdocs, who have also read the text and commented on it, including Annabel Cartwright, Jason Kirk, David Nutter and Dimitris Stamatellos. We would also like to thank Peter Brand, Shantanu Basu and Jonathan Rawlings, who each read and commented on parts of the book, although any mistakes that may remain are entirely our own. We wish to thank Cambridge University Press for their patience, especially Simon Mitton, Adam Black, Jacqueline Garget, Vince Higgs and Claire Poole. Finally, we wish to thank our wives and families for putting up with us!

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