Introduction to the Interstellar Medium

The gas and dust between the stars emit across the electromagnetic spectrum and are found in a range of physical conditions from diffuse plasmas to cold, dense, and molecular. Through their study we see how quantum processes shape the structure of our Galaxy and fluid mechanics sets the stellar mass scale. The interstellar medium is a very broad subject with layers of complexity, a long history, and a steady flow of new results. This comprehensive yet accessible textbook provides a self-contained one-semester course for advanced undergraduate or beginning graduate students. It is written in a style that students can follow by themselves and allows instructors to use class time to go deeper into the details or show applications to current research. It makes extensive use of publicly accessible data to illustrate specific points and to encourage students to learn by performing their own analyses.

Jonathan P. Williams is an astronomer at the University of Hawaii at Manoa. His research in the interstellar medium has ranged from the formation of the giant molecular clouds that form stars to the evolution of disks around young stars that give birth to planets. He has written pedagogical reviews on these topics and taught a wide variety of courses at the undergraduate and graduate level. This textbook builds on his course notes that have been widely used and class-tested over almost two decades.

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Preface

A basic understanding of the Interstellar Medium (ISM) should be a core part of an astrophysics curriculum. The gas and dust between the stars emit across the electromagnetic spectrum and the ISM is found in a range of physical conditions from diffuse plasma to cold, dense, and molecular. Through its study we see how quantum processes shape the structure of our Galaxy and fluid mechanics sets the stellar mass scale. There is a tremendous richness here and plenty to keep theorists, observers, and instrumentalists busy. Although most astronomers will spend their careers in different areas, every telescope looks through the ISM and many analyses must account for its effect on the data or use it as a diagnostic tool.

The study of the ISM is a relatively mature field with a wide variety of phenomena that are generally well understood. Of course, there remains much to be discovered and a continual flow of interesting papers. However, it is easy for a new student to get lost in the details of recent work before fully grasping the fundamentals. This pedagogical book is intended to introduce general concepts for an undergraduate senior, beginning graduate student, or anyone with a solid physics background that is interested. It does not describe the latest findings in a fast-paced research world though I hope that its broader perspective might help more seasoned researchers make new connections.

The philosophy of this book is that doing is the best way of learning. The internet has become the great leveler and everyone can now access all sorts of wonderful data. This is a boon to our abstract field. As an encouragement for students to explore these goldmines for themselves, almost all the figures in this book were created from scratch using publicly available datasets acquired through open archives, and python notebooks to recreate them are available at interstellarmedium.github.io. The figures are black and white to keep costs down but beautiful color images of all these phenomena are available at your fingertips. In the same spirit, questions at the end of each chapter walk through additional steps of derivations in the text or recreate plots. The length is appropriate

for a one semester course and I have tried to write at a level that a physics major can follow by themselves so that an instructor can use lectures to augment the material with additional details or recent findings. To limit distractions, I have not given references in the main text but include the most pertinent at the end of each chapter, and make suggestions for other books and review articles there. At a more advanced level, there is at least one paper per day, and often many more, on arXiv (arxiv.org/archive/astro-ph) that apply concepts from this book in current research.

This book grew out of lecture notes that I wrote over almost two decades of graduate teaching at the University of Hawaii, with their genesis in the notes I took as a student myself in an ISM class co-taught by the "dream team" of Chris McKee and Carl Heiles at the University of California at Berkeley 30 years ago. I am grateful to them for nurturing my interest in this field and also to influential teachers further back in my academic journey including John Green and Doug Gough at the University of Cambridge and beginning with Jeff Aspinall at Aylesbury Grammar School. This is my way to pay it forward.

Getting to this point has been a long, but enjoyable, journey and would not have been possible without a lot of help. First and foremost, the Institute for Astronomy provided the environment to get me started and the freedom to finish this project. I have been fortunate to have worked with and learned from many talented faculty, postdocs, and students on many aspects of the ISM. Their names are on our papers but I would like to single out Leo Blitz who introduced me to the Rosette molecular cloud which features prominently throughout these pages. Cathie Clarke and Chris DuPree bravely read the first draft and gave invaluable comments. The aforementioned Chris McKee continued to educate me through his detailed suggestions.

Last and definitely not least, I would like to thank my family, Laura, Nicholas, and Julian, for their love and support throughout.