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MOLECULAR ASTROPHYSICS

Focusing on the organic inventory of regions of star and planet formation in the interstellar medium of galaxies, this comprehensive overview of the molecular Universe is an invaluable reference source for advanced undergraduates through to entry-level researchers. It includes an extensive discussion of microscopic physical and chemical processes in the Universe; these play a role in the excitation, spectral characteristics, formation, and evolution of molecules in the gas phase and on grain surfaces. In addition, the latest developments in this area of molecular astrophysics provide a firm foundation for an in-depth understanding of the molecular phases of the interstellar medium. The physical and chemical properties of gaseous molecules, mixed molecular ices, and large polycyclic aromatic hydrocarbon molecules and fullerenes and their role in the interstellar medium are highlighted. For those with an interest in the molecular Universe, this advanced textbook bridges the gap between molecular physics, astronomy, and physical chemistry.

A. G. G. M. TIELENS is a professor of Astronomy at both Leiden University and the University of Maryland. He has held appointments at the University of California in Berkeley, NASA Ames Research Center, the University of Groningen, and the Dutch Space Agency; was the project scientist of the HIFI instrument on board the Herschel Space Observatory; and was the NASA project scientist of the Stratospheric Observatory for Infrared Astronomy (SOFIA). He is a member of the Royal Netherlands Academy of Arts and Sciences and was awarded the Spinoza Prize in 2012.

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Preface

While interstellar molecules were first discovered some hundred years ago, over most of the intervening years, the molecular Universe lay dormant; the realm of a few brave pioneers that were undaunted by the prospect of the deep dive into molecular physics required to make sense of it all. Indeed, over much of this period, the Eddington quote in the Introduction sums up the attitude of the astronomical community, paraphrased to: *Molecules are not for astrophysicists*. However, over the last two decades, the opening up of the infrared and submillimeter spectral windows – driven by the rapid increase in detector technologies and ever-increasing telescope sizes – has provided us with a view of the richness of the molecular Universe. We are living in a molecular Universe where molecules are abundant and widespread and play an important role in the evolution of galaxies. We have also realized that regions of planet formation contain a rich organic inventory that may have provided the prebiotic roots of life. Finally, molecules provide an excellent tool to determine the physical conditions and probe the dynamics of many astronomically interesting objects and phenomena. Hence, molecular astrophysics has come into its own right as a key subdiscipline within astronomy. Conversely, future generations of astromomers will have to become familiar with all things molecular.

This book has grown out of lectures presented at a number of different summerschools on molecular astrophysics organized over the years. While preparing these lectures and discussing with students the molecular physics involved, I realized that a comprehensive introduction into molecular physics and its application to molecules in the interstellar medium of galaxies at the level of graduate students was sorely lacking. My earlier textbook on the physics and chemistry of the interstellar medium covers some of these aspects, and relevant chapters have been incorporated but updated with the latest developments and, in addition, their scope has been greatly expanded. The introduction to each chapter provides a short guide on what aspects would be particularly relevant for a course and which sections are, instead, provided for in-depth study by graduate students entering the field. Each chapter also provides a further reading and resource guide that will provide entry points for students into the rich literature of the field. Here, I have to appologize as, due to lack of space, it is impossible to do justice to all the relevant literature. The resource guide will typically provide references to some of the earliest studies and to some of the

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more recent developments. Together, this should enable students to trace back all relevant ideas and concepts. Finally, each chapter also contains a set of exercises that will allow students to test their comprehension of the material.

This book was largely written over a period of three years during extensive stays at the Astronomy Department of the University of California in Berkeley, the Astronomy Department of the University of Maryland in College Park, and the Astronomy Department of the University of Colorado in Boulder. I owe a deep debt of gratitude to these institutions for their hospitality and for providing a great atmosphere for science that was conducive to creative writing. Much of this book reflects a lifelong interest in the molecular Universe. I am deeply grateful to Harm Habing who, during the early stages of my career, taught me that graduate students are to be treated humanly. I wouldn't be where I am now if Harm hadn't stepped in at the right moment. I am also much in debt to Lou Allamandola and David Hollenbach who have been my guides through the molecular Universe over much of my career. Last, but not least, I greatfully acknowledge the many great students, postdocs, and collaborators who never tired of showing me the parts of the molecular Universe that inspired them.

Book Description

This work provides a comprehensive overview of our understanding of the molecular Universe, in particular the organic inventory of regions of star and planet formation in the interstellar medium of galaxies. It contains an extensive discussion of the microscopic physical and chemical processes that play a role in the excitation, spectral characteristics, formation, and evolution of molecules in the gas phase and on grain surfaces. Based on our current experimental, theoretical, and observational understanding of the molecular physics relevant for the interstellar medium of galaxies, this book includes the latest developments in this area of molecular astrophysics and provides a firm foundation for an in-depth understanding of the molecular phases of the interstellar medium. The physical and chemical properties of gaseous molecules, mixed molecular ices, and large polycyclic aromatic hydrocarbon molecules and fullerenes and their role in the interstellar medium are highlighted. This is an invaluable reference source for advanced undergraduate and graduate students and research scientists. Related resources for this book can be found at TBD.

Author

A. G. G. M. Tielens is a professor of Astrophysics at Leiden Observatory, the Netherlands, and at the Astronomy Department of the University of Maryland, College Park. Prior to this, he worked as an assistant researcher in the Astronomy Department of the University of California, Berkeley, a senior scientist at NASA Ames Research Center, California, professor of Astrophysics at the Kapteyn Institute in the Netherlands, and a senior scientist with the Dutch space agency, SRON. He was the project scientist of the HIFI instrument

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that flew on the Herschel Space Observatory, launched by the European Space Agency in 2009, and he was the NASA project scientist of the Stratospheric Observatory for Infrared Astronomy, SOFIA, from 2005 to 2007. He has published extensively on various aspects of the physics and chemistry of the interstellar medium of galaxies.

Cover Illustration

The tip of Orion's sword, where bright stars set their environment aglow in the light of large polycyclic aromatic hydrocarbon molecules. Figure courtesy of NASA/JPL-Caltech & T. Megeath (University of Toledo, Ohio).

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