Preface

In its simplest terms, star formation is the combination of processes that, in the context of very low-density interstellar gas, brings a certain amount of material to the point where the force of gravity exceeds all other opposing forces, resulting in collapse. On the theoretical side, one of the early significant accomplishments in the development of this concept was the determination, by Sir James Jeans in 1928, of what is now called the "Jeans length", one of the important conditions needed for the collapse in the interstellar medium to begin. Observationally, an early convincing piece of evidence in favor of the above hypothesis was the discovery, for example, by Walter Baade, that hot massive stars, that must be young, were associated with dust clouds and relatively dense interstellar gas in the spiral arms of galaxies outside the Milky Way, such as M31. In the last few decades, progress in understanding the details of this basic picture has been extraordinarily rapid. Observationally, the development of large ground-based telescopes and space observatories, and especially the opening up of the infrared and millimeter regions of the spectrum, have revealed the intricate structures of star-forming regions. Theoretical advances, based in part on the availability of high-powered computers, have begun to link together the various important physical and chemical processes that must be involved in star formation. Nevertheless, many basic questions, such as why the stars have the range in mass that is observed, and what decides whether a star is going to end up as a single object or a binary, are just beginning to be understood.

An impressive range of time scales and length scales are involved in the star formation process. Star formation began in the early Universe, only a few hundred million years after the Big Bang. Considerable research effort has been devoted to the chronicling of the history of the star formation rate throughout the entire history of the Universe. Star formation can occur at a relatively modest rate, such as in isolated regions of molecular clouds in our Galaxy, or at a moderate rate, such as in local regions of star cluster formation, or at quite a rapid rate, as in starburst galaxies. The length scales involved in star formation are measured in parsecs, the typical size of molecular clouds, while the sizes of the end products are measured in the range 0.1–10 solar radii, up to 9 orders of magnitude smaller. As a result a wide variety of physical processes must be considered. Clearly radiative transfer is of paramount importance, as the radiation from the star-forming regions forms the main link between the actual physical events and the observer. Hydrodynamical flows, including turbulent flows, and orbital mechanics are also key elements of the physical picture, but they must be supplemented by additional effects, including chemistry, atomic physics, nuclear physics, magnetic fields, and the properties of matter, for example, the equation of state of a gas. Thus the study of star formation brings together a rich diversity of physical processes, with the result that a rather complex theoretical model must be generated to interpret the observational data, which themselves are continuously increasing in resolution and detail.

The main theoretical methods applied in astrophysics range from the very approximate "back of the envelope" calculations, used to derive order-of-magnitude estimates from the fundamental laws of physics, to rigorous analytic theory, based in part on linear perturbation theory, to large-scale numerical simulations, based on approximate representation of the differential equations involved in the rigorous theory. There is usually an interplay between all three of these theoretical methods, and in this book the reader will find examples of each. However, the more recent theoretical results rely heavily on the numerical approach, as the complexity of the processes involved makes the purely analytical approach intractable. Analytical results play an important role as test cases against which to check the numerical codes, and the order-of-magnitude estimates serve as a "reality check" as to the physical reasonableness of the results. Even so, the reader is advised to maintain a critical attitude toward the details of particular numerical simulations, no matter how flashingly displayed. Many simulations involve magnetohydrodynamics in three space dimensions coupled with radiation transfer, a system of equations that can tax the computing power of even the most sophisticated modern machines. Is the numerical resolution sufficient to represent the important physical effects? Are the approximations, needed to weed out insignificant effects, justifiable? Has the simulation been run for a long enough time to provide a significant comparison with observations? Are there hidden numerical effects that significantly degrade the solution? Only by continual detailed testing of the numerical results can progress be assured.

As an introduction to the science of star formation, this book concentrates on the interpretation of observations in star-forming regions relatively nearby, in our own Galaxy, at the present time, where the most detailed and accurate results can be obtained. An excursion is made into the realm of the early Universe and the formation of the first stars, although no observations are as yet available to validate the theory. The range of observed phenomena includes turbulent clouds, magnetic fields, star-forming cores in molecular clouds, infrared protostellar sources, outflows and jets, Hertzsprung–Russell diagrams of young stellar clusters, disks around young stars, and multiple stellar systems. Observations over wavelengths ranging from the X-rays, at 1 nanometer or less, to the radio, at 1 centimeter or greater, are relevant. While the details of the observational and theoretical results are likely to change in the future as this developing subject evolves, many of the basic concepts should still remain appropriate. The on-going nature of research in this area is emphasized in the final chapter, which makes clear that there are numerous fundamental questions still to be resolved.

As an introductory text, this book does not, for the most part, go into "first-principles" derivations of the physical equations. Many other reliable sources are available to provide this information. The treatment may be regarded as somewhat simplified, in order to provide a general view of the subject rather than a rigorous discussion of the many important details. As such, the text should be useful for beginning-level graduate courses in astrophysics, as well as for the more advanced undergraduate courses for students who have had a few years of physics courses as well as an introduction to the basic concepts of astronomy. The student wishing to go into more depth on a specific topic is advised to first consult the *Annual Review of Astronomy and Astrophysics*, whose articles are written by experts in the field. And finally, the author acknowledges the many contributions to the substance of this book that were made by the graduate students in Astronomy and Astrophysics at the University of California, Santa Cruz, who took the course in Star Formation, the lecture notes for which formed the basis for this text.

Santa Cruz *Peter Bodenheimer*
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Bodenheimer, P.
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