ACCRETION PROCESSES IN STAR FORMATION

Second Edition

Our understanding of the formation of stars and planetary systems has changed greatly since the first edition of this book was published. This new edition has been thoroughly updated, and now includes material on molecular clouds, binaries, star clusters and the stellar initial mass function (IMF), disk evolution and planet formation.

This book provides a comprehensive picture of the formation of stars and planetary systems, from their beginnings in cold clouds of molecular gas to their emergence as new suns with planet-forming disks. At each stage gravity induces an inward accretion of mass, and this is a central theme for the book. The author brings together current observations, rigorous treatments of the relevant astrophysics, and 150 illustrations, to clarify the sequence of events in star and planet formation. It is a comprehensive account of the underlying physical processes of accretion for graduate students and researchers.

LEE HARTMANN is Professor of Astronomy at the University of Michigan and a Vice-President of the American Astronomical Society. He is an expert in the field of star formation and protoplanetary disk evolution.

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SECOND EDITION

LEE HARTMANN

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In memory of Alice Lewis Hartmann

Contents

Preface to the first edition

The topic of star and protoplanetary disk formation touches almost every area of astrophysics, from galaxy formation to the origin of the solar system. Our understanding of the early evolution of stars has advanced substantially in the last few years as a result of improved observational techniques, particularly in the infrared and radio spectral regions. Although many fundamental problems of star formation remain to be solved, so much has been learned in the last decade about pre-main-sequence accretion processes that an attempt to outline the emerging picture of low-mass star formation seems justified.

In this book I have tried to provide a discussion of accretion in early stellar evolution which can be used at a variety of levels: as an introduction to the subject for advanced graduate students; as a reference for researchers in star formation; and as an overview for scientists in other, related fields. The text assumes a basic familiarity with astronomical concepts and graduate-level physics, though I have made some effort to include some astronomical definitions and references to fundamental physical equations needed for my development. I have adopted a point of view close to that of my own research, which is generally near the interface between theory and observation, and so have tried to discuss basic physical concepts in relation to observational results. Many plausible and even aesthetically pleasing theories have been constructed which have failed to meet observational tests. Conversely, observations by themselves are not very meaningful unless (or until) they are placed into a physical context. I have also tried to include a substantial number of references, but I warn the reader that my selection is necessarily incomplete and probably biased in such a rapidly evolving subject; my intent is mainly to provide entry points into the literature for further research.

I especially hope to stir the interest of specialists in other fields where accretion disks are important. There are of course direct applications of pre-main-sequence disk physics and evolution to the study of planet formation, which has taken on added importance with the discovery of extrasolar planets. Beyond this, much of what we currently know about astrophysical disks is based on studies of accreting binary systems, and the accretion disks probably present in active galactic nuclei may have points of similarity to protostellar disks, in that they both exhibit powerful jets and dusty infalling envelopes. One hopes that the similarities among and differences between astrophysical accretion disks will yield further insight into accretion processes.

In writing this book I found myself continually revising material to take current important developments into account. Although this can be problematic, since very recent ideas or results may not have been fully tested, it is difficult to avoid incorporating new material in

such a rapidly developing field. Specialists will recognize that many new results have not been included, and I can only ask for their understanding in view of the rate at which the literature is expanding.

I have tried to express a point of view which is not always that of the "standard models" if the observations do not support these models. In discussing these matters I have tried to be evenhanded and to provide enough information for the reader to make his or her own judgements, although this can be difficult in addressing current areas of contention. Although some of the issues of today may be of transient importance, the conflict between opposing views seems to me to be part of the excitement of science, and the means by which we sharpen our understanding of astrophysical objects. I have also indulged in a little historical discussion to provide a faint hint of how science is actually done. In an area of rapidly evolving research such as star formation, texts such as the present one serve not simply to define the current state of knowledge, but to challenge readers to do better.

Cambridge, Massachusetts L.H.
October 6, 1997

Preface to the second edition

Initially it seemed like a good idea to revise this book, because so much has been learned about star and planet formation over the last ten years. It eventually became clear that it was a bad idea to revise this book, because so much has been learned about star and planet formation over the last ten years. By then I was halfway through and it was too late to back out.

I therefore beg the reader's indulgence for things I have left out or treated schematically. At some point in a project like this "the best is the enemy of the good", as Voltaire apparently said; just give up and send it off. Perhaps there is some value in having a treatment that does not try to cover everything in an enormous tome, but instead provides accessible points of departure. As was the case for the first version, I hope that this will be a useful reference for non-specialists as well as a starting point for researchers entering the field.

Ann Arbor, Michigan L.H.
February 27, 2008

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Many friends and colleagues helped me by reading and commenting upon the manuscript. Nuria Calvet, Neal Evans, Charles Gammie, Erik Gullbring, Phil Myers, Cesar Briceño, and James Muzerolle were especially helpful in reviewing the first edition, and Javier Ballesteros-Paredes, Nuria Calvet, Catherine Espaillat, Fabian Heitsch, John Tobin, and Zhaohuan Zhu provided important comments and corrections on this edition. Special thanks go to Catherine Espaillat, John Tobin, and Zhaohuan Zhu for building the index.

I also wish to thank Doug Lin for suggesting that I write this book, and the people at Cambridge University Press for their patience. As a practical matter, I also wish to cite the Astrophysics Data System's abstract service, without which I could not have finished this effort in my remaining lifetime.

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