Accretion Power in Astrophysics

Accretion Power in Astrophysics examines accretion as a source of energy in both binary star systems containing compact objects, and active galactic nuclei. Assuming a basic knowledge of physics, the authors describe the physical processes at work in accretion discs and other accretion flows. The first three chapters explain why accretion is a source of energy, and then present the gas dynamics and plasma concepts necessary for astrophysical applications. The next three chapters then develop accretion in stellar systems, including accretion onto compact objects. Further chapters give extensive treatment of accretion in active galactic nuclei, and describe thick accretion discs. A new chapter discusses recently discovered accretion flow solutions.

The third edition is greatly expanded and thoroughly updated. New material includes a detailed treatment of disc instabilities, irradiated discs, disc warping, and general accretion flows. The treatment is suitable for advanced undergraduates, graduate students and researchers.

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Third Edition

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Preface to the first edition

The subject of this book is astrophysical accretion, especially in those circumstances where accretion is believed to make an important contribution to the total light of an astrophysical system. Our discussion therefore centres mainly on close binary systems containing compact objects and on active nuclei. The reader is assumed to possess a basic knowledge of physics at first degree level, but only a rudimentary experience of astronomy is required. We have tried to concentrate on those features, particularly the basic physics, that are probably more firmly established; but the treatment is necessarily somewhat heterogeneous. For example, there is by now a tolerably coherent line of argument showing that the formation of an accretion disc is very likely in many close binaries, and giving a plausible picture of what such a disc is like, at least in some simple cases. In other areas, such as accretion on to the surface of a compact object, or in active nuclei, we are not so fortunate, and we must work back and forth between theory and observation. Our aim is that the book should provide a systematic introduction to the subject for graduate students. We hope it may also serve as a reference for interested astronomers in other fields, and that selected material will be suitable for undergraduate options in astronomy.

In Chapters 2 and 3 we present introductory material on fluid dynamics and plasma physics. Many excellent texts exist in these areas, but they tend to be too detailed for our needs; we have tried to extract just those basic ideas necessary for the subsequent discussion, and to set them in an astrophysical context. We also need basic concepts of radiation mechanisms and radiative transfer theory. These we have not attempted to expound systematically since there are many books written for astrophysics students which are suitable. For convenience we have collected some of the necessary results in an appendix. The astrophysics of stellar accretion is dealt with in Chapters 4 to 6. Chapters 7 and 8 set the observational scene for two models of active nuclei (or possibly for two aspects of a single model) considered in Chapters 9 and 10. In the main we have not given references to sources, since this would yield an enormous list out of keeping with the spirit of the book. Detailed references can be found in the reviews cited in the bibliography.

A final note on units and notation. For the most part astrophysicists use units based on the cm, g, s (cgs system) when they are not indulging themselves in archaic astronomical conventions. The system one rarely sees in astrophysics is the otherwise standard mks (SI) system. For ease of comparison with the astrophysical literature we have quoted numerical values in cgs units. A special problem arises in electromagnetism; here the formulae are different in the two systems. We have adopted the compromise of giving the formulae in cgs units with a multiplicative conversion factor to mks units in square brackets. These factors always involve the quantities ε_0, μ_0 or c, and no confusion should arise with the use of square brackets in algebraic formulae. Also, we have followed the normal astrophysical usage of the symbols '$\sim$' and '$\cong$' in algebraic formulae; the former standing for 'is of the order of' of the latter for 'is approximately equal to'.

The idea for this book grew out of discussions with Dr Simon Mitton, whom we should like to thank for his encouragement and advice. We have benefited from the comments of our students, on whom some of the early versions of much of this material were tested. We also thank our scientific colleagues for much useful advice. We are grateful to Diane Fabian for her help in seeing our final efforts through the Press.

Preface to the second edition

In the years since the first edition of this book appeared the study of astrophysical accretion has developed rapidly. Perhaps the most fundamental change has been the shift in attitude over active galaxies and quasars: the view that accretion is the energy source is now effectively standard, and the emphasis is much more on close comparison of observation and theory. This change, and the less spectacular but still profound one which has occurred in the study of close binary accretion, have been largely brought about by the wealth of new data accumulated in the interval. In X-rays, the ability of EXOSAT to observe continuously for as much as 3 to 4 days was a dramatic advance. In the optical, new instrumentation has produced far tighter observational constraints on theory. Despite these challenges, the basic outlines of the theory are still recognizably the same.

Of course our understanding is very incomplete. As the most glaring example, we still have essentially no idea what drives disc accretion; and there are new problems such as the dynamical stability of thick discs, or the nature of fieldline threading in magnetic binaries. But it is now difficult to deny that some close binaries possess discs approximately conforming to theoretical ideas; or that some kind of anisotropic accretion occurs in active galactic nuclei. Encouragingly, accretion theory is increasingly integrated into wider pictures of the relevant systems. The process is well advanced for close binaries, particularly for the secular evolution of cataclysmic variables, and is in its early stages for active galaxies.

We were therefore very glad to have the chance to revise our book, and extremely grateful to many colleagues who made suggestions for improvements. Inevitably the vast expansion of the subject has obliged us to be selective, and we have had to omit or curtail discussion of some topics. This is particularly true of fairly specialized areas such as quasi-periodic oscillations in low-mass X-ray binaries, or the jets in SS 433 (incidentally the subjects of two of EXOSAT's more spectacular discoveries). We have completely rewritten Section 4.4, adding a discussion of secular binary evolution. In Chapter 5 on accretion discs we have rewritten Section 5.7 on the confrontation with observations, particularly of low-mass X-ray binaries, and added three new sections. Section 5.9 deals with tides and resonances and the phenomenon of superhumps. Much of accretion disc theory is relevant to star formation, and Section 5.10 gives a brief introduction. In Section 5.11 we discuss accretion via spiral shocks. In Chapter 6, Sections 6.3 (accretion on to magnetized neutron stars and white dwarfs) and 6.4 (white dwarf column accretion) have been extensively revised.

The material on active galaxies has been subject to substantial rearrangement, reflecting the changing emphasis in the subject. In Chapter 7 we have added a new section on the gas supply to the central engine. Chapter 8 includes an extended discussion of the broad line region. New material on X-ray emission has been added in Chapters 8 and 9, which now include a brief discussion of two-temperature discs (or ion tori) and slim discs.

Finally, Chapter 10 now includes a discussion of the instability of thick discs to global non-axisymmetric modes. This is treated in a new Section 10.6, and Section 10.7 on astrophysical applications has been rewritten.

We have also added a selection of problems, of varying degrees of difficulty, which we hope will make the book more useful for teaching purposes.

We would particularly like to thank Mitch Begelman, Jean-Pierre Lasota, Takuya Matsuda, Robert Connon Smith and Henk Spruit for pointing out errors in the first edition and suggesting new material.

Preface to the third edition

In the decade since the second edition of this book, accretion has become a still more central theme of modern astrophysics. We now know for example that a γ-ray burst briefly emits a gravitationally powered luminosity rivalling the output of the rest of the Universe. This and other startling discoveries are a result of observational progress, driven as ever by technological advances. But these advances are also having a powerful effect on theory; modern supercomputers allow one to perform as a matter of routine calculations which were unthinkable a decade ago. This increasing capability will significantly alter the way theory is done, and indeed thought about.

The impact on accretion theory has already been profound. Most obviously, supercomputer simulations have been central in verifying that angular momentum transport in accretion discs is probably mediated by the magnetorotational instability. This opens the prospect of at last understanding how accretion is driven in the discs we see.

These changes and others make a new edition of this book timely. We are grateful for the opportunity of revising and extending the treatments of the earlier editions. As always, we have been obliged to be selective, but have tried to convey the essence of recent developments. In addition to discussing the new work on disc viscosity referred to above, we give a more thorough treatment of the thermal–viscous disc instability model now generally thought to be the basic cause of the outbursts of dwarf novae and soft X-ray transients. The importance of irradiation of an accretion disc has been recognized in at least three ways, in affecting global stability properties, in drastically modifying outbursts when they occur, and in tending to make the disc warp. Accordingly we have added an extensive treatment of it. Since the second edition, the presence of black holes in a significant number of low-mass X-ray binaries has become widely accepted, and we comment on this changed situation.

The advance in our understanding of active galactic nuclei (AGN) has also been significant. There is now compelling observational evidence that most galaxies, even those outwardly normal, harbour a black hole whose mass correlates with the mass of the spheroidal component of the galaxy, and that all galaxies are active at some level. The Hubble Space Telescope has given clear evidence of discs, dusty tori and jets in active galactic nuclei, and Chandra has detected the jet in Cen A. There is evidence from VLBI observations of Keplerian rotation in the central disc of the active galaxy NGC 4258. On the theory side, the main change is one of focus. Most AGN researchers now seek to use the knowledge gained from the study of galactic sources. In particular the majority of workers interpret observations in terms of the kinds of accretion discs familiar from those objects, unless there are good reasons to do otherwise. Progress has been relatively slow in optical spectroscopy and the understanding of strong radio sources, but these are still important for a unified picture, so the basic theory remains relevant. The increasing wealth of detailed X-ray observations are likely to provide the most important information on the structure of both galactic and extragalactic black hole accretion.

Despite recent progress, we still do not know the functional form of the viscosity in an accretion disc. This freedom allows the possibility of several alternative types of accretion flow, often referred to by acronyms such as ADAF, CDAF, etc. We have added a new chapter dealing with these. Finally, we have updated and extended the range of problems at the end of the book.

In line with the remarks above, we have tried to make use of supercomputer simulations to illustrate much of what we say. Interested readers can view animations of many of these flows on the websites of the UK Astrophysical Fluids Facility (http://www.ukaff.ac.uk/movies.shtml) and of the LSU Astrophysics Theory Group (http://www.phys.lsu.edu/astro/home.html).

We thank the many colleagues who offered valuable advice and encouragement as we prepared this edition. We thank CUP for their forebearance during this process. In particular we are grateful to our copy-editor, Margaret Patterson, for her very professional work on the text.