

# Lecture Notes in Physics

Edited by H. Araki, Kyoto, J. Ehlers, München, K. Hepp, Zürich  
R. Kippenhahn, München, H. A. Weidenmüller, Heidelberg  
and J. Zittartz, Köln

255

## Radiation Hydrodynamics in Stars and Compact Objects

Proceedings, Copenhagen 1985

Edited by D. Mihalas and K.-H.A. Winkler



Springer-Verlag

# Lecture Notes in Physics

Edited by H. Araki, Kyoto, J. Ehlers, München, K. Hepp, Zürich  
R. Kippenhahn, München, H. A. Weidenmüller, Heidelberg  
and J. Zittartz, Köln

Managing Editor: W. Beiglböck

255

---

## Radiation Hydrodynamics in Stars and Compact Objects

Proceedings of Colloquium No. 89 of the  
International Astronomical Union  
Held at Copenhagen University  
June 11–20, 1985

Edited by D. Mihalas and K.-H.A. Winkler

---



Springer-Verlag

Berlin Heidelberg New York London Paris Tokyo

**Editors**

Dimitri Mihalas

Department of Astronomy, University of Illinois  
1011 W. Springfield Ave., Urbana, IL 61801, USA

Karl-Heinz A. Winkler

Los Alamos National Laboratory  
Los Alamos, New Mexico 87545, USA

ISBN 3-540-16764-1 Springer-Verlag Berlin Heidelberg New York  
ISBN 0-387-16764-1 Springer-Verlag New York Berlin Heidelberg

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically those of translation, reprinting, re-use of illustrations, broadcasting, reproduction by photocopying machine or similar means, and storage in data banks. Under § 54 of the German Copyright Law where copies are made for other than private use, a fee is payable to "Verwertungsgesellschaft Wort", Munich.

© Springer-Verlag Berlin Heidelberg 1986  
Printed in Germany

Printing and binding: Beltz Offsetdruck, Hemsbach/Bergstr.  
2153/3140-543210

## Preface

One of the most exciting developments in astrophysics over the past few years has been the discovery, usually through observations that were technically impossible a decade ago, of the ubiquity of energetic (often violent) flows in an astonishingly wide variety of objects. As theoreticians have struggled to keep pace with these discoveries and to provide even a rough descriptive framework for the observed phenomena, there has been a growing realization of the decisive role that radiation frequently plays in determining the nature of the flow. But too often important developments in this area have occurred in relative isolation in various subdisciplines of astrophysics, with the undesirable consequence that their full implications have not been widely understood or appreciated.

Thus it seemed to be an opportune time to hold a broad interdisciplinary conference, having as a major goal the exposure of a wide cross-section of astronomers to the fundamental importance of radiation hydrodynamics in extremely diverse astrophysical contexts. It was the hope of the organizers that the meeting would promote communication and exchanges of ideas among active workers in several fields.

The meeting was cosponsored by IAU Commissions 35 and 36, and approved by the IAU Executive Committee as IAU Colloquium No. 89. The program was developed by a Scientific Organizing Committee composed of G. T. Bath, A. N. Cox, J. M. Marlborough, R. McCray, D. Mihalas (chairman), A. Nordlund, Y. Osaki, A. Peraiah, M. J. Rees, E. A. Spiegel, and K.-H. Winkler. Although he insisted that he not be listed as a member of the SOC, Bengt Gustafsson was de facto an important participant in all of its deliberations, and consistently contributed wise advice and fruitful suggestions and ideas. As plans for the conference began to take definite form, we were extremely fortunate to receive generous financial support from the Danish National Science Research Council, the Swedish Natural Science Research Council, the Max Planck Institut für Astrophysik (Garching), and NORDITA. In addition, the home institutions of many of the invited speakers contributed partial or complete support for travel. Without this support it would have been impossible to assemble such a large group of experts from all over the world.

The practical arrangements for this rather large meeting were handled very efficiently by the Local Organizing Committee consisting of A. Nordlund (chairman), H. Klingerich, D. Dravins, B. Gustafsson, and H. Schnopper. We wish particularly to acknowledge the truly heroic efforts made by Åke Nordlund on behalf of the Colloquium. In addition to the very large amount of work he did in securing financial support from the Scandinavian organizations mentioned above, he patiently and effectively dealt with the innumerable last-minute crises that inevitably bedevil any international meeting.

From all remarks made to us by participants, it would appear that the meeting was a great success. To a large extent this happy outcome can be attributed to the diligent efforts of the invited speakers, who presented interesting, comprehensible, and stimulating descriptions of progress in their respective fields. As the editors of this volume, we wish to express our sincere appreciation to these individuals for preparing inclusive accounts of their contributions to the meeting in a very timely fashion. Another factor contributing to the success of the meeting was the lively interchange between the speakers and the audience in far-ranging discussion periods. We hope that the readers of this volume will get at least the flavor of these often spirited discussions from the questions and answers appended to each paper.

Another effective part of the meeting was the large number of contributed papers, all of which appeared as poster papers on display for the entire conference during a definite time period of each day. This novel (at least to us) approach eliminated the need for speakers to attempt to compress large bodies of detailed information into too-hurried (and therefore usually incomprehensible) verbal presentations, offering instead a format in which contributors and participants could interact repeatedly in a relaxed atmosphere conducive to in-depth exchange. A significant part of the long range impact of the meeting may well come from these

exchanges. We regret that it proved impossible for us to reproduce these contributions even in abstract form: the material submitted was far too inhomogeneous to deal with effectively, and moreover did not really give a fair representation of either the science actually presented or the complex interchanges it engendered.

We believe that if a conference on the subjects covered in this book is held again in, say, five years, we will all be amazed at the rapid progress that has been made. All of us who participated in this Colloquium will be gratified indeed if this volume has assisted that progress by facilitating communication among experts, and by providing inspiration to students.

April 1986

D. Mihalas  
Urbana, Illinois

K.-H. A. Winkler  
Los Alamos, New Mexico

TABLE OF CONTENTS

Introduction and Overview	
D. Mihalas .....	1
1. Protostellar Objects	
Jets from Young Stars	
R. Mundt .....	7
Theory of Protostellar Objects	
F.H. Shu .....	10
2. Normal Stars	
Radiation Hydrodynamics in Pulsating Stars	
R.F. Stellingwerf .....	37
Radiation Hydrodynamics in Solar Flares	
G.H. Fisher .....	53
Radiatively-Driven Stellar Winds	
L.B. Lucy .....	75
3. Supernovae	
The Physics of Supernovae	
S.E. Woosley and T.A. Weaver .....	91
Neutrino Transport in a Type II Supernova Environment	
P.J. Schinder and S.L. Shapiro .....	121
The Early Evolution of Supernova Remnants	
C. Fransson .....	141
The Optical Radiation of Supernovae	
R. Harkness .....	166
4. Stellar X-Ray Sources	
Compact Binary X-Ray Sources	
R. McCray .....	185
Observations of Compact X-Ray Sources	
Y. Tanaka .....	198
5. Novae and Accretion Disks	
The Classical Nova Outburst	
S.G. Starrfield .....	225
Accretion Disk Instabilities	
F. Meyer .....	249
Novae and Accretion Disc Evolution	
G.T. Bath .....	268

6.	X-Ray and Gamma-Ray Bursters	
	X-Ray Burst Sources	
	F. Melia and P.C. Joss .....	283
	Physical Constraints on Models of Gamma-Ray Bursters	
	R.I. Epstein .....	305
7.	Active Galactic Nuclei	
	Physical Processes in Active Galactic Nuclei	
	R. Svensson .....	325
	Radiation Hydrodynamics of the Broad Line Region in Seyfert Galaxies and Quasars	
	W.G. Mathews .....	346
	Hydrodynamics near the Central Engine	
	J.F. Hawley .....	369
8.	Stellar and Extragalactic Jets	
	Theory of Stellar and Extragalactic Jets	
	R.D. Blandford .....	387
	Observations of Galactic and Extragalactic Jets	
	R.A. Perley .....	403
	Interpretation of Extragalactic Jets	
	M.L. Norman .....	425
9.	Summary	
	Radiation Hydrodynamics: Conference Themes and Unsolved Problems	
	J.M. Shull .....	441
	Participants .....	451