

# Lecture Notes in Physics

Edited by H. Araki, Kyoto, J. Ehlers, München, K. Hepp, Zürich  
R. Kippenhahn, München, D. Ruelle, Bures-sur-Yvette  
H.A. Weidenmüller, Heidelberg, J. Wess, Karlsruhe and J. Zittartz, Köln  
Managing Editor: W. Beiglböck

333

---

I. Appenzeller H.J. Habing  
P. Léna (Eds.)

## Evolution of Galaxies Astronomical Observations



Proceedings of the Astrophysics School I,  
Organized by the European Astrophysics  
Doctoral Network  
at Les Houches, France, 5–16 September 1988

---



Springer-Verlag

Berlin Heidelberg New York London Paris Tokyo Hong Kong

## **Editors**

I. Appenzeller  
Universität Heidelberg and Landessternwarte  
Königstuhl, D-6900 Heidelberg, FRG

H. J. Habing  
Sterrewacht Leiden, Huyghens Lab.  
Wassenaarseweg 78, NL-2300 RA Leiden, The Netherlands

P. Léna  
Université de Paris VII and Observatoire de Meudon  
F-92195 Meudon Cédex, France

ISBN 3-540-51315-9 Springer-Verlag Berlin Heidelberg New York  
ISBN 0-387-51315-9 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 the rights of translation, reprinting, re-use of illustrations, recitation, broadcasting, reproduction on microfilms or in other ways, and storage in data banks. Duplication of this publication or parts thereof is only permitted under the provisions of the German Copyright Law of September 9, 1965, in its version of June 24, 1985, and a copyright fee must always be paid. Violations fall under the prosecution act of the German Copyright Law.

© Springer-Verlag Berlin Heidelberg 1989  
Printed in Germany

Printing: Druckhaus Beltz, Hemsbach/Bergstr.  
Binding: J. Schäffer GmbH & Co. KG., Grünstadt  
2158/3140-543210 – Printed on acid-free paper

# Preface

Scientific progress in astronomy is heavily dependent upon increased scientific collaboration, a stronger mobility of scientists and an adequate use of large research facilities, available within Europe through multinational or bilateral cooperation.

These objectives led to the foundation in 1986 of the European Astrophysics Doctoral Network, which today federates 11 Departments of Astronomy in European Universities, all these Departments having a graduate program in Astrophysics.

The Network decided to organize each year a Summer School at a predoctoral level, gathering European PhD students at the beginning of their research period, placing them in interaction with the international community of scientists and among themselves, offering them a broad exposure to major fields of astronomy at an early stage of their own research in order to deepen their scientific education and enable them to gain maximum advantage from the possibilities offered by international and European collaboration, especially from the large observing capabilities provided by space- and ground-based European telescopes.

In 1988, this objective converged with the intention of the Fédération Française des Magistères de Physique of organizing each year, in the famous Les Houches School of Physics, a new set-up: Ecoles Pré-doctorales de Physique, aimed at PhD students in various fields of Physics, and somehow returning to the early "Les Houches" style. The merging of this objective with those of the Network led to a joint organization of the 1988 School, held in Les Houches.

The 1988 school dealt with two parallel topics : "The Origin, Structure and Evolution of Galaxies" and "Astronomical Observations: Methods and Tools".

These subjects, particularly active in Europe, were chosen to cover areas where considerable theoretical progress and fundamental discoveries are expected in the coming years, given the new observational tools Europe will have at its disposal: the Space Telescope, the Infrared Space Observatory, the Very Large Telescope, the IRAM radio-interferometer, the Hipparcos satellite, the southern millimetric telescope (SEST), the James Clerk Maxwell millimetric telescope in Hawaii, and many other instruments built either in bilateral cooperation or within the European Southern Observatory (ESO) or the European Space Agency (ESA).

This volume contains all lectures presented at the Astrophysics School I, with the exception of the course on "Instrumentation of Large Telescopes" by Sandro D'Odorico. Although an important part of the school programme, this lecture had to be omitted, as Professor D'Odorico's responsibilities in connection with initiating the ESO-VLT instrumentation programme unfortunately made it impossible for him to prepare a manuscript at the present time.

It became clear during the School that graduate studies in Europe are arranged with great diversity: some countries have, or can afford to have, many graduate courses, while others have none or, in some cases, lack the minimum geographic concentration of students needed for their organization. The opportunity of having specially prepared courses, understandable by students fulfilling the minimum requirement of a solid education in Physics, was therefore greatly appreciated. A careful planning of topics and their order made sure that these lectures were accessible to research students exposed to one year or less of research in Astrophysics.

We take here the opportunity to express our gratitude to Jean Heyvaerts, (the Network coordinator), the Conseil d'Administration de l'Ecole des Houches, the European bodies in Brussels (Erasmus Program) and Strasbourg (the European Council), the Fritz Thyssen Stiftung, the Ministries of Foreign Affairs (MAE) and of Research and Technology (MRT) of

France, the UK Science and Engineering Research Council, the Academie Suisse des Sciences Naturelles, the NWO of the Netherlands, and the JNICT of Portugal, which all supported this new venture both financially and morally.

The most important prerequisite for the success of the school was clearly the great enthusiasm of the 57 students (representing 15 different countries) who interacted continuously among themselves and with the lecturers. The spirit, as well as the languages, in the School were truly European, with, unfortunately, as yet no participants from Eastern Europe.

This publication was made possible thanks to the interest of Springer-Verlag, through Prof. W. Beiglböck.

Agnés Fave, Annie Glomot and Nicole Leblanc devoted a great deal of energy and smiling enthusiasm to the success of the School and the production of this volume.

## Contents

---

### Part I      The Origin, Structure, and Evolution of Galaxies

---

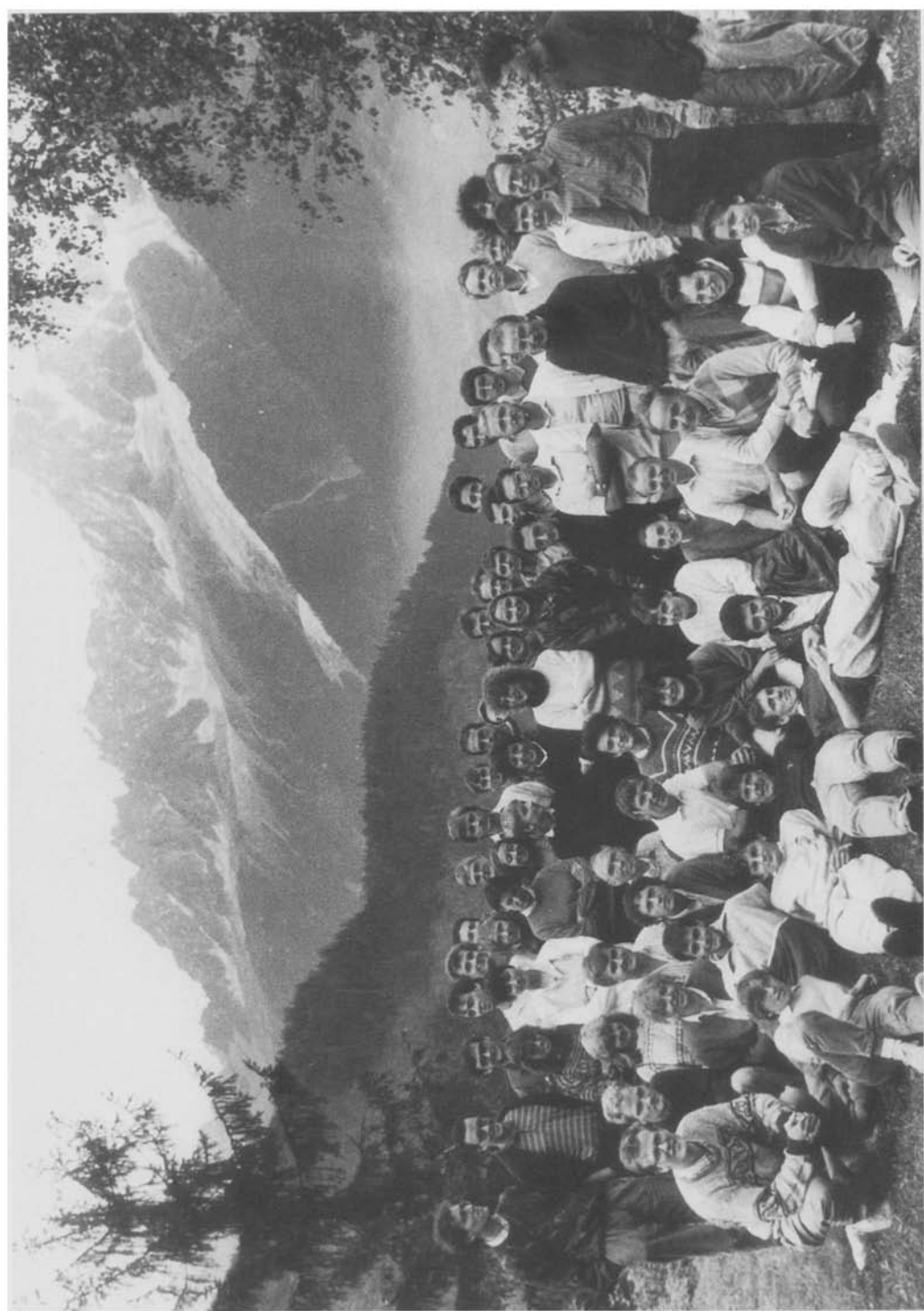
Galaxy Formation By Malcolm S. Longair .....	1
Stellar Dynamics By James Binney .....	95
Stellar Populations in Galaxies: Structure and Evolution By James Lequeux .....	147
The Interstellar Medium By Harm J. Habing .....	181

---

### Part II      Astronomical Observations: Methods and Tools

---

Images in Astronomy: An Overview By Pierre Léna .....	243
Interferometric Imaging in Optical Astronomy By Gerd Weigelt .....	283
Detectors and Receivers By Immo Appenzeller .....	299
Radio Astronomy Techniques By Dennis Downes .....	351
Index .....	385



## PARTICIPANTS:

Appl, Stephan	Landessternwarte Heidelberg, FRG
Bernard, J.Philippe	LPSP Verrieres, France
Blommaert, Joris	Sterrewacht Leiden, NL
Breitfellner, Michel	Inst. für Astronomie Wien, A
Campos Aguilar, Ana	IAC Tenerife, Spain
Charlot, Stéphane	STSI Baltimore, USA
Cuddeford, Philip	SISSA Trieste, Italy
Davies, Jeremy R.	University Coll. Cardiff, UK
Deleuil, Magali	LAS Marseille, France
Dietrich, Matthias	Univ. Göttingen, FRG
Donati, J.-Francois	Observ. Paris-Meudon, France
Dougados, Catherine	Observ. Paris-Meudon, France
Dubath, Pierre	Observatoire de Genève, CH
Dutrey, Anne	Observatoire Toulouse, France
Eckert, Josef	Physik. Inst. Erlangen, FRG
Fruscione, Antonella	IAP Paris, France
Gallais, Pascal	Observ. Paris-Meudon, France
Gama, Filomena	Engineering Faculty Porto, Portugal
Garcia Burillo, Santiago	IRAM Grenoble, France
Garcia Gomez, Carlos	IAC Tenerife, Spain
Gourgoulhon, Eric	Univ. Paris 7 Meudon, France
Hunt, Leslie	CNR Firenze, Italy
Jablonka, Pascale	Univ. Paris 7 Meudon, France
Jenniskens, Peter	Leiden University, NL
Jorgensen, Inger	Copenhagen Univ. Obsv., DK
Kamphuis, Jurgen Jan	Kapteyn Lab. Groningen, NL
Kerschbaum, Franz	Inst. für Astronomie, A
Leeuwin, Francine	Univ. Paris 7 Meudon, France
Lehoucq, Roland	IAP Paris, France
Lima, Joao Jose	Fac. Ciencias Porto, Portugal
Liu, Ronghui	Cavendish Lab. Cambridge, UK
Loup, Cécile	CERMO Grenoble, France
Madejsky, Rainer	Landessternwarte Heidelberg, FRG
Maisack, Michael	Astron. Institut Tübingen, FRG
Mannucci, Filoppo	Istituto Astronomia Firenze, Italy
Martinez, Vicent	Univ. Valencia, Spain
Mauder, Wolfgang	Physik. Institut Erlangen, FRG
Moore, Benjamin	Durham University, UK
Morin, Stéphane	Observatoire Marseille, France
Pastor Server, Josefa	Univ. Barcelona, Spain
Pello Descayre, Roser	Univ. Barcelona, Spain
Peymirat, Christophe	CRPE St-Maur, France
Pisani, Armando	SISSA Trieste, Italy
Remy, Sophie	CEN Saclay, France
Rist, Claire	IRAM Grenoble, France
Salez, Morvan	ENS Paris, France
Sauvage, Marc	Univ. Paris 7 Meudon, France
Schertl, Dieter	Physik. Institut Erlangen, FRG
Stark, Ronald	Sterrewacht Leiden, NL

Udry, Stéphane	Observatoire de Genève
Valls-Gabaud, David	IAP Paris, France
Van den Broek, Albertus	University Amsterdam, NL
Vozikis, Christos	University Thessaloniki, Greece
Wozniak, Hervé	Observatoire Marseille, France
Xiluri, Kiriaki	Univ. Crete Iraklion, Greece
Yepes Alonso, Gustavo	University Madrid, Spain
Zwitter, Tomaz	SISSA Trieste, Italy