ASTROPHYSICS AND SPACE SCIENCE LIBRARY

PHYSICAL PROCESSES IN RED GIANTS

Edited by Icko Iben Jr. and Alvio Renzini

VOLUME 88

PROCEEDINGS

D. REIDEL PUBLISHING COMPANY
DORDRECHT, HOLLAND / BOSTON, U.S.A. / LONDON, ENGLAND

PHYSICAL PROCESSES IN RED GIANTS

PROCEEDINGS OF THE SECOND WORKSHOP, HELD AT THE ETTORE MAJORANA CENTRE FOR SCIENTIFIC CULTURE, ADVANCED SCHOOL OF ASTRONOMY, IN ERICE, SICILY, ITALY, SEPTEMBER 3–13, 1980

Edited by

ICKO IBEN, Jr.
Department of Astronomy, University of Illinois at Urbana-Champaign, U.S.A.

and

ALVIO RENZINI
Osservatorio Astronomico, Università di Bologna, Italy

D. REIDEL PUBLISHING COMPANY
DORDRECHT, HOLLAND / BOSTON : U.S.A.
LONDON : ENGLAND

Library of Congress Cataloging in Publication Data
Main entry under title:

Physical processes in red giants.

(Astrophysics and space science library. Proceedings ; v. 88)
Organized by the Advanced School of Astronomy.
Includes indexes.
1. Red giants–Congresses. I. Iben, Icko, 1931–
II. Renzini, Alvio. III. Ettore Majorana International Centre for Scientific Culture. Advanced School of Astronomy. IV. Series.
QB843.R42P49 523.8'2 81-5882
ISBN 90-277-1284-0 AACR2

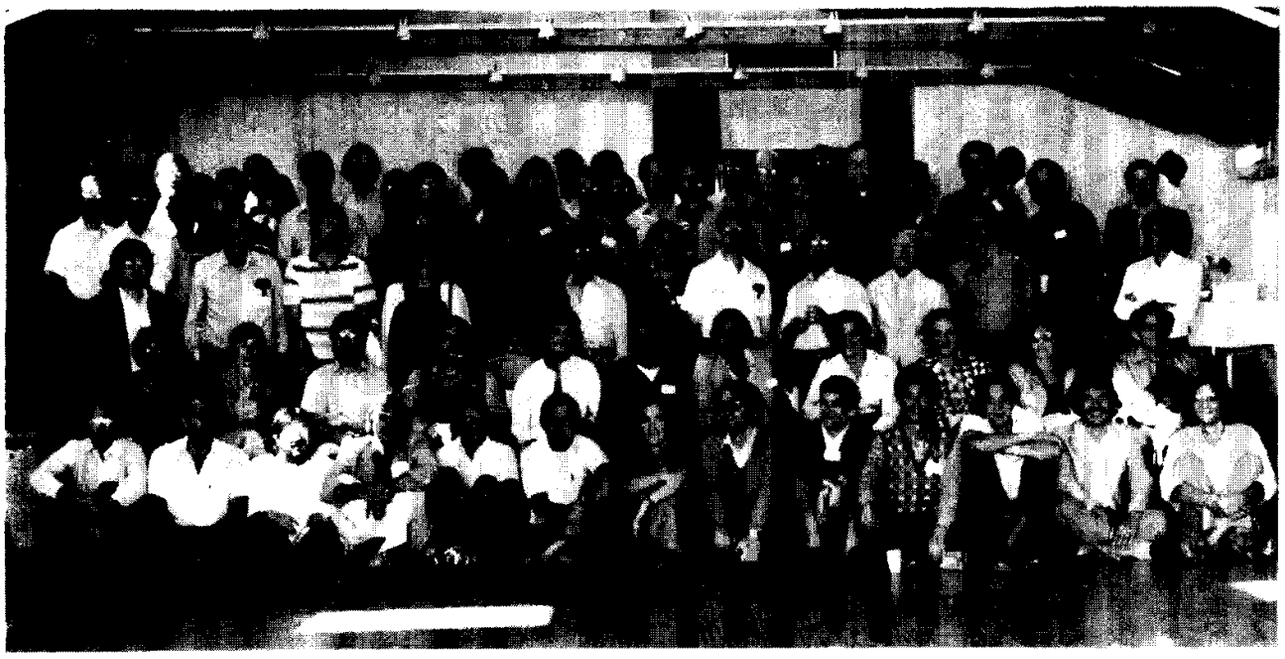
Published by D. Reidel Publishing Company,
P.O. Box 17, 3300 AA Dordrecht, Holland.

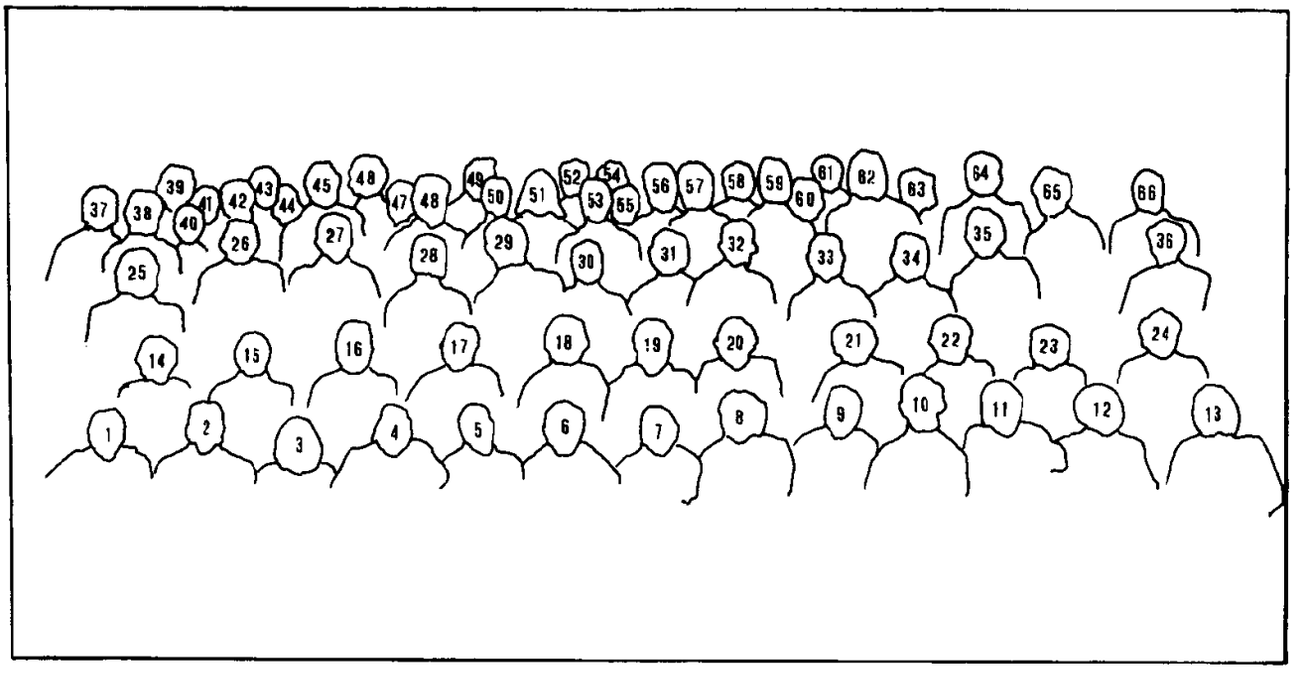
Sold and distributed in the U.S.A. and Canada
by Kluwer Boston Inc.,
190 Old Derby Street, Hingham, MA 02043, U.S.A.

In all other countries, sold and distributed
by Kluwer Academic Publishers Group,
P.O. Box 322, 3300 AH Dordrecht, Holland.

D. Reidel Publishing Company is a member of the Kluwer Group.

Printed in The Netherlands





1. Clegg, 2. Wing, 3. Serrano, 4. Littleton, 5. Preite-Martinez, 6. Iben, 7. Schönberner, 8. Peimbert, 9. Voli, 10. Iijima, 11. Olnon, 12. Renzini, 13. Bienaymé, 14. Natta, 15. Woodrow, 16. Despain, 17. Richer, 18. Cacciari, 19. Altamore, 20. de la Reza, 21. Malagnini, 22. Magalhães, 23. Bianco, B. M., 24. Blanco, V. M., 25. Fujimoto, 26. Becker, 27. Rood, 28. Caloi, 29. Tornambè, 30. Marilli, 31. Chieffi, 32. Linsky, 33. Pottasch, 34. Weidemann, 35. McCabe, 36. Capuzzo-Dolcetta, 37. Castor, 38. Kwok, 39. Draine, 40. Rieu, 41. Wood, 42. Rocca-Volmerange, 43. Olofsson, 44. Willson, 45. Elitzur, 46. Toelle, 47. Erikson, 48. Unidentified, 49. Feast, 50. Morossi, 51. Engels, 52. Ridgway, 53. Strazzulla, 54. Gallino, 55. Castellani, 56. Lub, 57. Herman, 58. Goldberg, 59. Kinman, 60. Unidentified, 61. Frogel, 62. McCarthy, 63. Unidentified, 64. Reimers, 65. Gustafsson, 66. Eggleton.

PREFACE

In recent years, it has become clear that the red-giant phase is one of the most dramatic periods in a star's life, when all of its parts become involved in ways that have both direct and indirect observational consequences. This is most particularly true of low- and intermediate-mass stars during the second ascent of the giant branch. Such stars bring to their surfaces products of nucleosynthesis currently taking place in their deep interiors, they pulsate as Mira variables, develop extended outward-flowing atmospheres that may exhibit maser properties, and shed great quantities of matter, sometimes highly processed, into the interstellar medium.

The manner in which processed matter is brought to the surface is far from being completely explained, and the precise mechanism or mechanisms whereby matter is ejected from the stellar surface (whether by deposition of Alfven waves, radiation pressure on grains, or as a consequence of some large scale envelope instability) has yet to be elucidated to everyone's satisfaction.

The purpose of the second workshop in Astrophysics, organized by the "Advanced School of Astronomy", was to bring together experts on all the physical processes occurring in red giants in an effort to emphasize the interrelatedness of these individual processes, and to encourage a dialogue among experts that might serve to initiate a synthesis, or at least sharpen our understanding of the most important problems to address in the future.

The workshop was held in Erice, Sicily, at the "Ettore Majorana Centre for Scientific Culture", during the period September 3 through 13, 1980, and was organized about a sequence of review lectures, each followed by contributed talks related to the preceding review. Discussion during and after talks was spirited, and all participants were urged to incorporate, in the written versions of their contributions, insights they may have gained as a consequence of their participation.

It is hoped that this volume will reflect some of the excitement in learning new things that many of us experienced during the workshop, and that many of the articles, though written ostensibly by one person, exhibit those positive characteristics of multiple authorship that the organizers hoped to promote. This volume also includes the review lecture

I. Iben Jr. and A. Renzini (eds.), Physical Processes in Red Giants, xi–xii.

that Dr. J.M. Scalo would have given if he had not been impeded from coming at the last minute to attend the meeting.

Icko Iben Jr.
Editor,
Director of the Workshop

Alvio Renzini
Editor,
Director of the
"Advanced School of Astronomy"

PARTICIPANTS

Altamore, A.	Roma, Italy
Andriesse, C.D.	Groningen, Netherlands
Becker, S.A.	Pasadena, CA, U.S.A.
Bedijn, P.J.	München, W. Germany
Bienaymé, O.	Nice, France
Blanco, B.M.	La Serena, Chile
Blanco, V.M.	La Serena, Chile
Cacciari, C.	Villafranca, Spain
Caloi, V.	Frascati, Italy
Castellani, V.	Frascati, Italy
Castor, J.I.	Boulder, CO, U.S.A.
Capuzzo-Dolcetta, R.	Roma, Italy
Catalano, S.	Catania, Italy
Chieffi, A.	Frascati, Italy
Chiosi, C.	Padova, Italy
Clegg, R.E.S.	Leiden, Netherlands
D'Antona, F.	Roma, Italy
de la Reza, R.	Rio de Janeiro, Brazil
Despain, K.H.	Haverford, PA, U.S.A.
Draine, B.T.	Princeton, NJ, U.S.A.
Eggleton, P.P.	Cambridge, England
Elitzur, M.	Lexington, KY, U.S.A.
Engels, D.	Bonn, W. Germany
Erikson, K.	Uppsala, Sweden
Feast, M.W.	Cape, South Africa
Frogel, J.A.	La Serena, Chile
Fujimoto, M.Y.	Urbana, IL, U.S.A.
Gallino, R.	Torino, Italy
Goldberg, L.	Tucson, AZ, U.S.A.
Greggio, L.	Padova, Italy
Gustafsson, B.	Uppsala, Sweden
Herman, J.	Leiden, Netherlands
Iben, I.Jr.	Urbana, IL, U.S.A.
Iijima, T.	Asiago, Italy
Kafatos, M.	Fairfax, VA, U.S.A.

Kinman, T.	Tucson, AZ, U.S.A.
Kwok, S.	Ottawa, Canada
Lambert, D.L.	Austin, TX, U.S.A.
Linsky, J.L.	Boulder, CO, U.S.A.
Littleton, J.E.	Morgantown, WV, U.S.A.
Lub, J.	La Silla, Chile
Magalhaes, A.M.	Sao Paulo, Brazil
Malagnini, M.L.	Trieste, Italy
Marilli, E.	Catania, Italy
Matteucci, F.	Padova, Italy
Mazzitelli, I.	Frascati, Italy
McCabe, E.M.	Brighton, England
McCarthy, M.F.	Castelgandolfo, Italy
Morossi, C.	Trieste, Italy
Mullan, D.J.	Newark, DE, U.S.A.
Natta, A.	Frascati, Italy
Olnon, F.M.	Leiden, Netherlands
Olofsson, H.	Onsala, Sweden
Paternò, L.	Catania, Italy
Peimbert, M.	Mexico, Mexico
Pottasch, S.R.	Groningen, Netherlands
Preite-Martinez, A.	Frascati, Italy
Reimers, D.	Hamburg, W. Germany
Renzini, A.	Bologna, Italy
Richer, H.B.	Vancouver, BC, Canada
Ridgway, S.T.	Tucson, AZ, U.S.A.
Rieu, N.-Q.	Paris, France
Rocca-Volmerange, B.	Paris, France
Rodonò, M.	Catania, Italy
Rood, R.T.	Charlottesville, VA, U.S.A.
Rumpl, W.M.	Greenbelt, MA, U.S.A.
Schmid-Burgk, J.	Bonn, W. Germany
Schönberner, D.	Kiel, W. Germany
Serrano, P.A.	Mexico, Mexico
Strazzulla, G.	Catania, Italy

Toelle, F.	Heidelberg, W. Germany
Tornambè, A.	Frascati, Italy
Voli, M.	Bologna, Italy
Weidemann, V.	Kiel, W. Germany
Willson, L.A.	Ames, IA, U.S.A.
Wing, R.F.	Columbus, OH, U.S.A.
Wood, P.R.	Canberra, Australia
Woodrow, J.	Vancouver, BC, Canada

TABLE OF CONTENTS

EVOLUTION AND COMPOSITION PECULIARITIES OF RED GIANTS

ON THE INTERIOR PROPERTIES OF RED GIANTS[1]

Icko Iben, Jr.
University of Illinois at Champaign-Urbana

I. INTRODUCTION

If one focuses solely on the excursions which they make in the Hertzsprung-Russell diagram on an evolutionary, nuclear-burning, time scale, red giants are perhaps among the least interesting objects in the sky. They do practically nothing! Low luminosity red giants simply grow uneventfully brighter at nearly constant surface temperature (when viewed in a diagram that contains main-sequence stars and white dwarfs) for a period of perhaps 10^8 yr. They then transform into brighter red giants, which also grow steadily brighter at nearly constant surface temperature over a period of perhaps 10^6 yr.

If, however, one examines their behavior on ever shorter time scales and takes a careful look at phenomena occurring in their interiors and at their surfaces, one finds that red giants are incredibly complex and fascinating objects. They pulsate acoustically, on occasion they blow up in their central cores, and some of them are veritable factories for the synthesis of dozens of new elements that are subsequently convected to the surface, where they enrich the spectral distributions which we view through our telescopes. In the "surface" regions of the red giant which we can "see," matter is being expelled permanently from the star, perhaps as a consequence of shock heating, the action of Alfvén waves, the pressure of radiation on grains forming in the cool atmosphere, or perhaps by some combination of all of these processes.

All stars whose initial mass on the main sequence M_{MS} is less than $M_{C5} \cong 8 - 10\ M_\odot$ effectively end their lives as consumers of nuclear fuel while on the red giant branch. In a last burst of rapid mass loss on the red giant branch, a low mass star in this range expels most of its hydrogen-rich envelope. The expelled envelope becomes a planetary nebula and the remnant core evolves rapidly to the white dwarf stage. A more massive star in this range may explode totally as a supernova, provided that the mass in its hydrogen- and helium-exhausted core reaches a value of about $1.4\ M_\odot$ before its outer

I. Iben Jr. and A. Renzini (eds.), Physical Processes in Red Giants, 3–24.