Cambridge astrophysics series

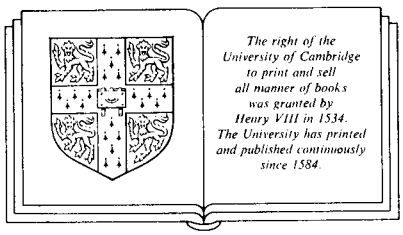
X-ray emission from clusters of galaxies

FOR JANE

X-ray emission from clusters of galaxies

CRAIG L. SARAZIN

Department of Astronomy, University of Virginia



CAMBRIDGE UNIVERSITY PRESS

Cambridge

New York New Rochelle

Melbourne Sydney

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo, Delhi

Cambridge University Press
The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521113137

First published 1988
This digitally printed version 2009

A catalogue record for this publication is available from the British Library

Library of Congress Cataloguing in Publication data

Sarazin, Craig L.

X-ray emission from clusters of galaxies.

(Cambridge astrophysics series)
Bibliography
1. Galaxies – Clusters. 2. X-ray astronomy.
I. Title. II. Series.
QB858.7.S27 1988 523.1'12 86-23322

ISBN 978-0-521-32957-6 hardback
ISBN 978-0-521-11313-7 paperback

CONTENTS

PREFACE

As this book was being completed, observational X-ray astronomy was in a relatively quiet period between the demise of the *Einstein* X-ray observatory, and the launch of the next generation X-ray observatory, AXAF. This seemed like a good time to summarize what we have learned about the X-ray emission of clusters of galaxies. This book is mainly devoted to a review of the observational properties of X-ray clusters of galaxies and of the theoretical understanding we currently have of the physical state, dynamics, and origin of the hot intracluster gas. The book also contains less complete reviews of the optical and radio properties of clusters of galaxies, and of their dynamics.

Much of the material in this book first appeared in a review article in *Reviews of Modern Physics* (Sarazin, 1986a). I should like to thank Ed Salpeter for suggesting this review, and for many helpful suggestions.

Andy Fabian, Richard Mushotzky, Paul Nulsen, Simon White and an anonymous referee very kindly provided detailed comments on an early draft of the manuscript and caught many significant errors. I really would like to thank them for all their help. I am also indebted to John Bahcall, James Binney, Pat Henry, Hernan Quintana, Yoel Rephaeli, Herb Rood, Hy Spinrad, Mel Ulmer, and Ray White for helpful comments, suggestions, and unpublished results. I should particularly like to thank John Bahcall for his encouragement. Figures for the original review paper and for this book were very kindly provided by Neta Bahcall, Jack Burns, Claude Canizares, Christine Jones, Andy Fabian, Bill Forman, Paul Gorenstein, Mark Henriksen, Roger Lynds, George Miley, Richard Mushotzky, Chris O'Dea, Herb Rood, Steve Strom, and Simon White. I should like particularly to thank Christine Jones and Bill Forman for producing special figures from the *Einstein* X-ray data.

Much of the original review article was written while I was a visitor at the Institute for Advanced Study in Princeton, N.J., and I would like to thank the

Institute and particularly John Bahcall for their hospitality. Karen Jobes at the Institute for Advanced Study helped considerably with the word processing. Part of the review was written during visits to the Aspen Center for Physics and the National Radio Astronomy Observatory, and I would also like to thank them.

The manuscript for the book was completed while I was a Visiting Fellow at the Joint Institute for Laboratory Astrophysics of the University of Colorado and the National Bureau of Standards. I should like to thank the JILA Fellows for their hospitality. During this sabbatical leave I was also supported in part by a Sesquicentennial Fellowship from the University of Virginia.

This research was supported in part by NSF Grant AST 81-20260 and NASA Astrophysics Theory Center Grant NAGW-764.

This work would have been impossible without the support and patient understanding of my wife Jane.