Springer Theses

Recognizing Outstanding Ph.D. Research

For further volumes:
http://www.springer.com/series/8790

Aims and Scope

The series “Springer Theses” brings together a selection of the very best Ph.D. theses from around the world and across the physical sciences. Nominated and endorsed by two recognized specialists, each published volume has been selected for its scientific excellence and the high impact of its contents for the pertinent field of research. For greater accessibility to non-specialists, the published versions include an extended introduction, as well as a foreword by the student’s supervisor explaining the special relevance of the work for the field. As a whole, the series will provide a valuable resource both for newcomers to the research fields described, and for other scientists seeking detailed background information on special questions. Finally, it provides an accredited documentation of the valuable contributions made by today’s younger generation of scientists.

Theses are accepted into the series by invited nomination only and must fulfill all of the following criteria

- They must be written in good English.
- The topic should fall within the confines of Chemistry, Physics, Earth Sciences, Engineering and related interdisciplinary fields such as Materials, Nanoscience, Chemical Engineering, Complex Systems and Biophysics.
- The work reported in the thesis must represent a significant scientific advance.
- If the thesis includes previously published material, permission to reproduce this must be gained from the respective copyright holder.
- They must have been examined and passed during the 12 months prior to nomination.
- Each thesis should include a foreword by the supervisor outlining the significance of its content.
- The theses should have a clearly defined structure including an introduction accessible to scientists not expert in that particular field.

Robert Allan Mesler III

Searching for the Long-Duration Gamma-Ray Burst Progenitor

Doctoral Thesis accepted by
the University of New Mexico, USA

Springer

Robert Allan Mesler III
Department of Physics and Astronomy
University of New Mexico
Albuquerque, NM, USA

ISSN 2190-5053 ISSN 2190-5061 (electronic)
ISBN 978-3-319-06625-7 ISBN 978-3-319-06626-4 (eBook)
DOI 10.1007/978-3-319-06626-4
Springer Cham Heidelberg New York Dordrecht London

Library of Congress Control Number: 2014939008

© Springer International Publishing Switzerland 2014
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

To my parents, Bob and Kathy, without whom this dissertation would never have been possible.

Foreword

The mystery of the most brilliant explosions known in the Universe is continued to be unveiled. On average, once a day the sky as observed in gamma-rays is lit up by a spectacular explosion, named a gamma-ray burst (GRB). These extremely energetic events are associated with exploding, massive stars, and are thought to be the signatures of black holes being born. At this time, space missions are providing a wealth of data on the prompt emission of these bursts, and follow up observations of bright bursts and their accompanying afterglow emission are standard procedures using ground-based telescopes. These observations have made it clear that GRBs come in two types, those for which the prompt emission lasts shorter than a few seconds, and the long-duration bursts lasting up to a few minutes. The prompt gamma-ray emission period is hence very brief, but related afterglow emission at lower frequencies can be observed on timescales of months to years after the initial burst.

The most fundamental GRB physical parameters include the total energy of the explosion, the circumburst medium distribution and density profile, and the afterglow geometry. These parameters are usually estimated using the early GRB X-ray and optical light curves. The drawback is the large Lorentz factor during this early phase, implying large uncertainties in the total amount of energy since the GRBs are strongly beamed. An improvement to this method was made using radio light curves during which the fireball expansion transition into the non-relativistic regime can be observed. At this point a spherical Sedov-Taylor expansion can be assumed for which the dynamics is better understood.

Closely related to the fundamental explosion parameters is the question of the GRB progenitors. The two main candidate models for GRB progenitors are the collapsing star and the merging binary compact object models. Typically, GRB astronomers differentiate the two progenitors by assuming massive star models have surrounding environments characterized by a wind profile while merger models have constant density interstellar medium densities. For the collapsar GRB progenitor model proposed for the long-duration GRBs, the explosion of the progenitor star occurs in the pre-burst stellar wind expected to have a density declining with distance from the central object. However, modeling using optical, X-ray and infrared light curves of long-duration GRB afterglows most often are consistent with a constant ambient density instead suggesting an interstellar medium model. The fine details of the surroundings of these cosmic explosions depend upon the specifics of the progenitor, and there are a wide variety of stellar evolution scenarios currently studied as massive star collapsar engines. Although all models invoke strong winds, the surroundings can be affected by binary mass ejection and luminous blue variable outbursts.

In general the modeling of afterglow light curves is prone to the theoretical uncertainties in the time evolution of the shock microphysics parameters (especially near the non-relativistic transition), and in the dynamics during the relativistic phase (jet structure and dynamics, possible energy injection). A more robust method would be to use direct imaging of the afterglow, and very long baseline interferometry (VLBI) observations provide the means for direct measurements of the source size and the evolution thereof. Unfortunately, only extremely bright afterglows can be observed by this technique. One of the few bright bursts studied by VLBI is the GRB030329, providing unique input for models as discussed in this thesis. Most GRB afterglows are much weaker, and the development of more detailed modeling of the possible physical processes is essential to progress our understanding of GRBs and their origin. The doctoral work of Robert Mesler implements improved GRB shock physics models and calculates resulting emission, predicting possible observational signatures in light curves and spectra that can be used to discriminate between progenitor models. Dr. Mesler's work of studying specific emission from detailed hydrodynamic models of the progenitors lays the foundation for applying those models to GRB light curves.

Albuquerque, USA
November 2013

Ylva Pihlström

Acknowledgments

Many thanks are in order…

To my advisor, Ylva Pihlström, for her support and advice at every step of the long road that ended with this dissertation. Thank you for making graduate school such a challenging and yet richly rewarding experience.

To my collaborators Dan Whalen, Nicole Lloyd-Ronning, and Chris Fryer for their guidance and assistance.

To Greg Taylor for generously offering to support me when other funding sources dried up, and to the LWA staff for bearing with me while I learned to operate the LWA.

To Sarah, for her patience and understanding and for helping to keep me just a little sane.

To Janelle Whalen and Kirsten White for challenging me in high school physics and computer science. You motivated me to learn and kindled my life-long love of science. This is all your fault!

Contents