Type Ia Supernovae: Explosions and Progenitors

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A thesis submitted for the degree of

Doctor of Philosophy

of The Australian National University

Research School of Astronomy & Astrophysics

August 2011

Disclaimer

I hereby declare that the work in this thesis is that of the candidate alone, except where indicated below or in the text of the thesis.

Chapter 2:
The candidate was not involved in the acquisition of Subaru data for Tycho-G. The theoretical calculations for the expected rotation were carried out by Philipp Podsiadlowski The surface gravity was measured by Anna Frebel.

Chapter 3:
The candidate was not involved in the acquisition of Keck data for the donor star candidates. The effective temperature, surface gravity and metallicity measurements were conducted by David Yong (except Tycho-B). The analysis of the Tycho-B HIRES spectrum was partly performed by Simon Jeffery. All other parameters and the LRIS spectrum were analyzed by the candidate.

Chapter 4:
All work (including data acquisition) was performed by the candidate, except rotation which was measured by John Laird (but confirmed by the candidate).

Chapter 5:
The spectrum synthesis code was written by Paolo Mazzali and his group. All other work was performed by the candidate.

Wolfgang E. Kerzendorf
15th November 2011

Acknowledgments

First and foremost I'd like to thank my supervisor Brian Schmidt. He struck a balance between academic independence and supervision that allowed me to explore a lot of different fields of astronomy, but also focused me on the thesis when necessary. Brian did not only guide me professionally but also personally making him a true 'Doktor Vater' (literally 'doctor father' german name for a PhD supervisor). Thank you for five exciting, interesting and wonderful years here at Mt. Stromlo and to many more years of fruitful collaboration and friendship in astronomy or otherwise.

I have to thank Rainer Wehrse (who unfortunatley passed away) without whom I would have never been able to start my PhD at Mt. Stromlo.

My supervisory panel consisted of Mike Bessell, Frank Briggs, Bruno Leibundgut and Reynald Payne. I thank Mike Bessell for many hours of chats about photometry and stellar spectroscopy. He has been a very patient teacher even in times when my questions were not posed all to well. I thank Frank Briggs for encouraging me to fearlessly ask questions about any subject in the many cosmlogy lunches that I was ignorant about. I thank both Bruno Leibundgut and Reynald Payne for being my external advisors.

At Mt. Stromlo there have been many people who made my stay fun, engaging and exciting. I will unfortunately only be able to name a few of them. In the academic ranks, Harvey Butcher has certainly contributed to my pleasant stay at Mt. Stromlo and I'd like to thank him for that. Not only through his financial support, but also through his advice on the Dalek project. He suggested that nonlinear optimisation is a very active field and that my problem is not unique (which I had assumed). I have to thank Ken Freeman for his help in particular with the use of Fourier transforms to analyse spectra. Peter Wood has always been very helpful when concerning questions of stellar evolution and I thank him for his patience. In the same spirit I thank Amanda Karakas who has taught me a lot stellar evolution and has tolerated the music and language next doors. Stuart Sim has been of invaluable help in the the recent months, educating me about supernova radiative transfer and supernova theory as well as many chats over tea or coffee - thank you. I have to thank Chris Onken for his unbreakable cheerful spirit throughout many projects that we have done together. David Yong has been very patiently teaching me stellar abundance analysis - thank you. I thank all the students at Mt. Stromlo for their friendship and support over the last few years. Especially I'd like to thank Brad Tucker for his catering services for many Mt. Stromlo events. Out of the Mt. Stromlo crowd I have to thank, last but not least, my office mate Simon Murphy for his four years of a fun-filled and enjoyable PhD experience as well as his zealous love for Python that we both share.

Finally I have to thank the Computer Section. All of them have been very helpful, but I have to thank especially Kim and Bill for their computer support as well as witty remarks.

I have to thank all of my collaborators for their help and comments and especially Philipp Podsiadlowski for his valuable insights in binary star evolution and his patience in teaching me. In addition I have to thank my collaborator James Montgomery for helping me with all things about Genetic algorithms. I have to thank the MPA Supernova group for their hospitality and companionship during my stays with them. Specifically I'd like to thank Stephan Hachinger my collaborator, who has helped me master the spectrum synthesis code and patient in teaching me about the theory underlying that code.

I'd like to thank Thomas Magill for designing such a wonderful cover. His artistic skill also made the film 'Starcatchers' a success.

Outside the astronomy community I have to thank all the people that contributed to the wonderful Numpy, Scipy and Matplotlib computing environment. I have to especially thank the support I have received from mailinglists of these products and the IRC Python chat room.

I have to thank all of my friends and family that have accompanied on this journey and helped when things seemed dire.

Last but not least I have to thank my parents Gertraud and Werner. Their unwaivering support, love and companionship have made it possible for me to reach this goal in life.

Abstract

Supernovae are the brightest explosions in the universe. Supernovae in our Galaxy, rare and happening only every few centuries, have probably been observed since the beginnings of mankind. At first they were interpreted as religious omens but in the last half millennium they have increasingly been used to study the cosmos and our place in it. Tycho Brahe deduced from his observations of the famous supernova in 1572, that the stars, in contrast to the widely believe Aristotelian doctrine, were not immutable. More than 400 years after Tycho made his paradigm changing discovery using SN 1572, and some 60 years after supernovae had been identified as distant dying stars, two teams changed the view of the world again using supernovae. The found that the Universe was accelerating in its expansion, a conclusion that could most easily be explained if more than 70% of the Universe was some previously un-identified form of matter now often referred to as 'Dark Energy'.

Beyond their prominent role as tools to gauge our place in the Universe, supernovae themselves have been studied well over the past 75 years. We now know that there are two main physical causes of these cataclysmic events. One of these channels is the collapse of the core of a massive star. The observationally motivated classes Type II, Type Ib and Type Ic have been attributed to these events. This thesis, however is dedicated to the second group of supernovae, the thermonuclear explosions of degenerate carbon and oxygen rich material and lacking hydrogen - called Type Ia supernovae (SNe Ia).

White dwarf stars are formed at the end of a typical star's life when nuclear burning ceases in the core, the outer envelope is ejected, with the degenerate core typically cooling for eternity. Theory predicts that such stars will self ignite when close to 1.38 $M_\odot$ (called the Chandrasekhar Mass). Most stars however leave white dwarfs with 0.6 $M_\odot$ and no star leaves a remnant as heavy as 1.38 $M_\odot$, which suggests that they somehow need to acquire mass if they are to explode as SN Ia. Currently there are two major scenarios for this mass acquisition. In the favoured single degenerate scenario the white dwarf accretes matter from a companion star which is much younger in its evolutionary state. The less favoured double degenerate scenario sees the merger of two white dwarfs (with a total combined mass of more than 1.38 $M_\odot$).

This thesis has tried to answer the question about the mass acquisition in two ways. First the single degenerate scenario predicts a surviving companion post-explosion. We undertook an observational campaign to find this companion in two ancient supernovae (SN 1572 and SN 1006). Secondly, we have extended an existing code to extract the elemental and energy yields of SNe Ia spectra by automating spectra fitting to specific SNe Ia. This type of analysis, in turn, help diagnose to which of the two major progenitor scenarios is right.

Understanding the progenitors of SN Ia has wide ranging applications. Not only would we better be able to calibrate SNe Ia for use as distance probes, but we could also dramatically improve our understanding of the chemical history of the universe, which SNe Ia play a seminal role in.

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