Modeling Close Stellar Interactions Using Numerical and Analytical Techniques

by

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B.Sc., University of Orsay, 2005
Diplôme d'ingénieur, Ecole Nationale de Techniques Avancées, 2008
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Berichte aus der Astronomie

Jean-Claude Passy

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ABSTRACT

The common envelope (CE) interaction is a still poorly understood, yet critical phase of evolution in binary systems that is responsible for several astrophysical classes and phenomena. In this thesis, we use various approaches and techniques to investigate different aspects of this interaction, and compare our models to observations.

We start with a semi-empirical analysis of post-CE systems to predict the outcome of a CE interaction. Using detailed stellar evolutionary models, we revise the α equation and calculate the ejection efficiency, α, both from observations and simulations consistently. We find a possible anti-correlation between α and the secondary-to-primary mass ratio, suggesting that the response of the donor star might be important for the envelope ejection.

Secondly, we present a survey of three-dimensional hydrodynamical simulations of the CE evolution using two different numerical techniques, and find very good agreement overall. However, most of the envelope of the donor is still bound at the

end of the simulations and the final orbital separations are larger than the ones of young observed post-CE systems.

Despite these two investigations, questions remain about the nature of the extra mechanism required to eject the envelope. In order to study the dynamical response of the donor, we perform one-dimensional stellar evolution simulations of stars evolving with mass loss rates from 10^{-3} up to a few $M_{\odot}$/yr. For mass-losing giant stars, the evolution is dynamical and not adiabatic, and we find no significant radius increase in any case.

Finally, we investigate whether the substellar companions recently observed in close orbits around evolved stars could have survived the CE interaction, and whether they might have been more massive prior to their engulfment. Using an analytical prescription for the disruption of gravitationally bound objects by ram pressure stripping, we find that the Earth-mass planets around KIC 05807616 could be the remnants of a Jovian-mass planet, and that the other substellar objects are unlikely to have lost significant mass during the CE interaction.

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CO-AUTHORSHIP

The published work in this thesis is contained in Chapter 2 through Chapter 5, and Appendices A and B. At the start of each of these chapters and appendices, I have indicated whether the work presented within is a reprint or a draft based on a paper already published.

The project and articles were developed in collaboration with my supervisors Orsola De Marco and Falk Herwig, and Mordecai-Mark Mac Low.

In addition to writing parts of Chapter 2, I performed the analytical calculations and fits presented in Section 2.2, as well as the stellar evolution calculations for the determination of α. Orsola De Marco, Falk Herwig and I developed the reconstruction technique described in Section 2.3.

Chapter 3 was written entirely by me. I carried out the *Enzo* simulations, and analyzed the *Enzo* and the *SNSPH* simulations. The *SNSPH* simulations were performed by Chris L. Fryer and Steven Diehl.

I carried out and analyzed all the simulations presented in Chapter 4, and wrote the entire paper.

In addition to writing most of Chapter 5, I developed the different formalisms and performed the simulations presented in Section 5.1. The work presented in Section 5.2 is the result of an ongoing collaboration with Greg L. Bryan (Columbia University).

The observations used in Appendix A were acquired in November 2008 by Orsola De Marco and Maxwell Moe. I reduced and analyzed the data obtained during these 8 nights. I determined the photometric magnitudes and uncertainties of the targets, standard and reference stars (Section A.4).

I performed the Enzo simulations presented in Appendix B, and wrote a small part of the paper.

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DEDICATION

To my parents, with love.