Physics Honours Project Plan

The Lifes and Deaths of the Wolf Rayet Binaries
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1 Introduction

A significant proportion of star systems are composed of two or more stars which often have interesting interactions dynamically and which affect their stellar evolution. One hierarchical triple system, Apep (aptly named after the Egyptian god of chaos), hosts 3 massive stars; the inner binary of this system is believed to be of Wolf-Rayet (WR) classification [Callingham et al., 2020] and the only known WR-WR binary in the Galaxy. The WR stage of massive end-of-life stellar evolution is a short-lived and violent phase, which makes it surprising that two stars so close are at this stage at the same time. Further, the inner binary *may* prove to be a Long Gamma Ray Burst (LGRB) progenitor - a class of Type Ic supernova that should be exceedingly rare in the current cosmic epoch of the Milky Way [Callingham et al., 2019].

As a result of WR-WR proximity, the two WR stars are what's called a colliding-wind-binary (CWB) which produces a spiral dust nebula [Callingham et al., 2019]. CWB dust is an important contributor to enriching the interstellar medium (ISM) with metals, particularly in the early universe, seeding the chemistry for early generations of stars.

2 Method

Previous work has been successful in fitting a geometric model to the dust plume of Apep [Han et al., 2020], but without uncertainty quantification with modern statistical methods. The main goal of my Honours project is to create a similar model in Python/JAX that will allow us to perform a Markov Chain Monte Carlo (MCMC) fit to the data. At the outset, we already have a wealth of data from the Very Large Telescope (VLT) and the Very Large Telescope Interferometer (VLTI). We are also scheduled to observe again for 6 hours with the VLTI in March, giving us high resolution measurements to resolve the inner WR-WR binary in imaging for the first time.

The dust plume geometry encodes the WR binary's orbital properties, and MCMC will determine the binary orbit *with uncertainties*. Investigating this is essential in determining how a WR-WR binary originated in the first place.

We aim to support this investigation with the population synthesis code COMPAS, which uses current state-of-the-art stellar evolution models to synthesise a stellar population [Riley et al., 2022], to answer the question: can stellar evolution models produce a WR-WR binary?
As a stretch-goal of the project, we aim to fit the geometric model with MCMC to other WR CWBs. While Apep is the only known WR-WR binary, unique dust plumes are also observed with WR-O/B binaries [Lau et al., 2017], which have never been previously studied with uncertainty quantification and where there is potential to infer dust formation and acceleration physics from JWST and other data.

The timeline of the project and expected duration of each component is outlined below (Table 1).

Task	Project Week														
	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28
Project Plan	x														
Literature Review (readings)															
Translating Model to Python/JAX															
VLTI Observing and Data Processing															
MCMC on Model															
Population Synthesis															
Fit other WR Binaries (time permitting)															
Progress Talk							x								
Progress Report / Literature Review								x							
Thesis Preparation															x
Final Talk (incl. Preparation)														x	
Oral Examination															x

Table 1: Estimated Project Timeline and Milestones. Crosses indicate a rough due date (±1 week) of that assessment piece.

References

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