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ζ Ophiuchi as a test bed for modeling accretors

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ABSTRACT

■ [write abstract] ■

Keywords: stars: individual: ζ Ophiuchi – stars: massive – stars: binaries

1. INTRODUCTION

■ [**In the intro:**

- **runaway nature**
- **association with pulsar and SNe polluting Earth**
- **debate on parent association**
- **weak wind problem**

Methods:

- **self-consistent modeling of the evolution (see also ?)**
- **depends on many free parameters governing the intricate and coupled physics of mass transfer, mixing, rotation**

Aim:

- **since observations are not always agreeing with each other, we aim at finding a model in the right ballpark and explore how physical variations move such model around**
- **in this way we find a set of recommended parameters for the evolution of massive binary system going through stable mass transfer**

] ■

The nearest O-type star to Earth is ζ Ophiuchi, classified as O9.5IVnn type star (e.g., ?) and with a parallax of 5-8 milliarcsec (e.g., ?, and references therein). This star has been the target of many observations and underpins many open puzzles.

Software: `mesaPlot` (?), `mesaSDK` (?), `ipython/jupyter` (?), `matplotlib` (?), `NumPy` (?), `MESA`(?????)

2. MODELING MASS TRANSFER WITH `MESA`

3. INITIAL GRID OF MODELS

3.1. *Favorite model*

4. PHYSICAL VARIATIONS

5. DISCUSSION

6. CONCLUSIONS

ACKNOWLEDGEMENTS

APPENDIX

A. `MESA` SETUP

■ [possibly move to methods] ■ We use `MESA` version 15140 to compute our models. The `MESA` equation of state (EOS) is a blend of the OPAL ?, SCVH ?, PTEH ?, HELM ?, and PC ? EOSes. ■ [update EOS] ■

Radiative opacities are primarily from OPAL (??), with low-temperature data from ? and the high-temperature, Compton-scattering dominated regime by ?. Electron conduction opacities are from ?.

Nuclear reaction rates are a combination of rates from NACRE (?), JINA REACLIB (?), plus additional tabulated weak reaction rates **???**. Screening is included via the prescription of **?**. Thermal neutrino loss rates are from **?**. We compute the pre-merger evolution using an 8-isotope α-chain nuclear reaction network and switch to a 22-isotope nuclear network for the post-merger evolution.

We evolve our models from the pre-main sequence to the terminal age main sequence of the most massive $58\,M_{\odot}$ star, defined as the time when the central hydrogen abundance $X(^1\mathrm{H}) \leq 10^{-4}$. We treat convection using the Ledoux criterion, and include thermohaline mixing (until the central temperature $\log_{10}(T_c/[\mathrm{K}]) > 9.45$, **?**) and semiconvection, both with an efficiency factor of 1. We assume $\alpha_{\mathrm{MLT}} = 2.0$ and use **?** overshooting for the convective core burning. We have tested that varying core overshooting does not impact significantly the post-merger evolution, however, when including shell overshooting and/or undershooting we were unable to find solutions to the stellar structure equations. Moreover, we employ the MLT++ artificial enhancement of the convective flux (e.g., **??**). Stellar winds are included using the algorithms from **?** with an efficiency factor of 1.

To compute through the very late phases, we reduce the core resolution and increase the numerical solver tolerance when the central temperature increases above $\log_{10}(T_c/[\mathrm{K}]) > 9.45$. We define the onset of core-collapse when the iron-core infall velocity exceeds $1000\,\mathrm{km\ s^{-1}}$ (e.g., **?**).

The inlists, processing scripts, and model output will be made available at link.