Draft version December 22, 2020
Typeset using LaTeX **twocolumn** style in AASTeX63

# $\zeta$ Ophiuchi as a test bed for modeling accretors

M. Renzo[1,2] and ■ [ ] ■

[1]*Center for Computational Astrophysics, Flatiron Institute, New York, NY 10010, USA*
[2]*Department of Physics, Columbia University, New York, NY 10027, USA*

## ABSTRACT

■ [write abstract] ■

*Keywords:* stars: individual: $\zeta$ 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 $\zeta$ 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 $\alpha$-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.