Massive Stars Near and Far
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Intrinsic polarization of Wolf-Rayet stars due to the rotational modulation of the stellar wind

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Abstract. Wolf-Rayet stars are regarded as candidates for progenitors of core-collapse supernovae, and they are expected to be progenitors of long gamma-ray bursts. These types of stars are considered to be fast rotators. Their high rotation speed breaks the sphericity of the star and leads to an axisymmetric wind density structure. In such a case, the electron scattering takes place in a nonspherical environment, and as a result, we might expect an intrinsic polarization. We present a 2.5D radiation hydrodynamic stellar wind model of these stars. The model simulations account for the deformation of the stellar surface due to rotation, gravity darkening, and nonradial forces. We computed the polarization from the density variable of the hydrodynamic model, derived the upper limit of rotational velocities, and found no conflict with the previous studies of Wolf-Rayet stars.

Keywords. stars: rotation, stars: Wolf-Rayet, stars: mass loss, techniques: polarimetric

1. Introduction

Collapse of WR stars to a black hole could lead to a long gamma-ray burst (Woosley 1993). From spectropolarimetry observations, Stevance et al. (2018) derived the upper limit of rotational velocities of two WR stars. We used 2.5D hydrodynamic simulation (Owocki et al. 1994) to obtain the wind density structure of these stars (Fig. 1), from which we computed the polarization (Fig. 2).

2. Intrinsic polarization

We intend to compute the polarization due to electron scattering in continuum (Thomson scattering). The analytic expression of the polarization was developed by (Brown & McLean 1977), which depends on the inclination angle, optical depth, and geometry factor, as follows:

$$P_R \approx \bar{\tau}\,(1-3\gamma)\sin^2 i, \tag{2.1}$$

where $\bar{\tau}$ is the averaged Thomson scattering optical depth defined as the integral of the number density over the radius and the colatitudinal angle θ and γ is determined by the density distribution. To take the depolarization effect of finite stellar geometry into account, Cassinelli et al. (1987) introduced the correction factor $D(r) = \sqrt{1 - R_\star^2/r^2}$.

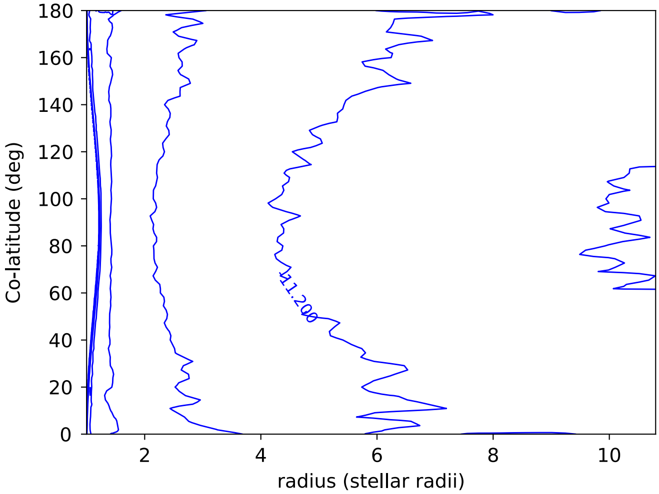

Figure 1. Density (in $\mathrm{g\,cm^{-3}}$) contours of stellar wind of the star WR93b versus radius and colatitude θ, in log scale spaced by 0.8 dex; denoted contours correspond to $\log\rho = -11.2$, for rotation $V_{\rm rot} = 1100\,\mathrm{km\,s^{-1}}$, with nonradial forces and gravity darkening.

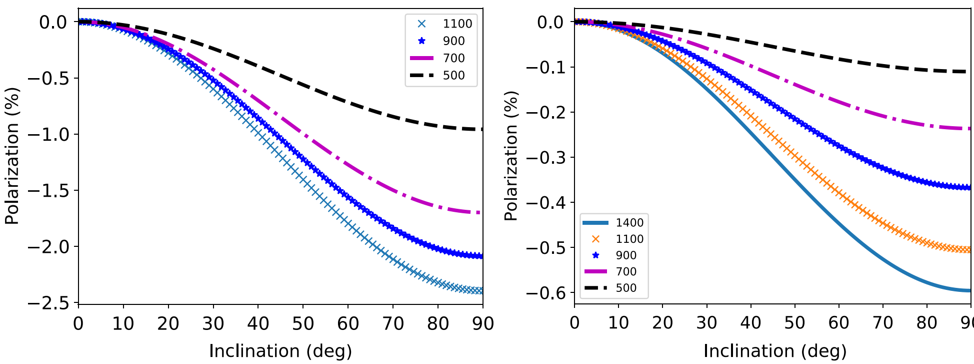

Figure 2. Polarization of WR93b (left), and WR102 (right), as a function of the inclination for different rotational velocities (denoted in the graph in units of $\mathrm{km\,s^{-1}}$) determined from the models, including nonradial forces and gravity darkening.

3. Results

The obtained limits of angular momentum (Abdellaoui et al. 2022) exceed the threshold of MacFadyen & Woosley (1999); as a result, the two stars could be progenitors of a long gamma-ray burst.

4. Conclusions

Fast rotation of WR stars leads to prolate density distribution, which produces a weak polarization signature that is smaller than the derived upper limit of polarization from observation (Stevance et al. 2018). The derived limit of rotational velocities is not in conflict with the model of a long gamma-ray burst.

Acknowledgements

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