Massive Stars Near and Far
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Spins of stripped B stars support magnetic internal angular momentum transport

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Abstract. The galactic binary star LB-1 contains a recently stripped B-type star. Comparing its properties to detailed binary star models shows that tidal braking and magnetic torques lead to low surface rotational velocities in the stripped donors after Roche-lobe overow. Models without magnetic torques cannot reproduce the observed low surface rotation.

Keywords. stars: rotation, stars: interiors, stars: binaries, stars: magnetic fields

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1. Motivation

In order to predict the spins of stellar remnants, we need to understand the evolution of the internal rotation of stars, and to identify at which stage the rotation of the contracting cores of evolved stars decouples from their expanding envelopes. The donor stars of mass transferring binaries lose almost their entire envelope and may thus offer a straight view on their core rotation. While after the mass transfer event they contract and fade rapidly, they are well observable when caught in the short-lived B-star phase. The B-type primary of the galactic binary star LB-1, which was originally suggested to contain a massive black hole (Liu et al. 2019), is well explained as a stripped star (He- and N-rich) accompanied by a fainter Be star (Shenar et al. 2020). The narrow absorption lines in the primary's spectrum signify extremely slow rotation ($v_{\rm rot} \sin i = 7\,$km/s), atypical for B-type main-sequence stars (Lennon et al. 2021; Shenar et al. 2020).

2. Methods

We identify a LB-1 progenitor model using a grid of generic MESA (Paxton et al. 2013) binary models (Wang et al. 2022) with initial rotation rates of 60% and 20% critical. We search for post-Roche-lobe-overflow model with $T_{\rm eff}$, $L/M \sim T_{\rm eff}^4/g$ and $Y_{\rm surf}$ similar to the observations (Shenar et al. 2020; Lennon et al. 2021). We find an initial donor mass of about $4\,{\rm M}_\odot$ and an initial period of $16\,$d.

Three processes can alter the rotation rate of a mass shell in a stellar model. Contraction (expansion) leads to acceleration (deceleration). If a model fills its Roche-lobe, tidal torques force the outer layers in corotation with the orbit (Zahn 1977). At last, angular momentum is transported within the stellar model by torques, which can be induced by convection, hydrodynamic instabilities (Heger et al. 2000), and magnetic fields e.g. due to the Spruit-Tayler dynamo (STD), which grows with the Brunt-Väisälä frequency to the $-4^{\rm th}$ power, wherefore gradients of entropy and mean molecular weight weaken the magnetic torque (Spruit 2002; Heger et al. 2005)

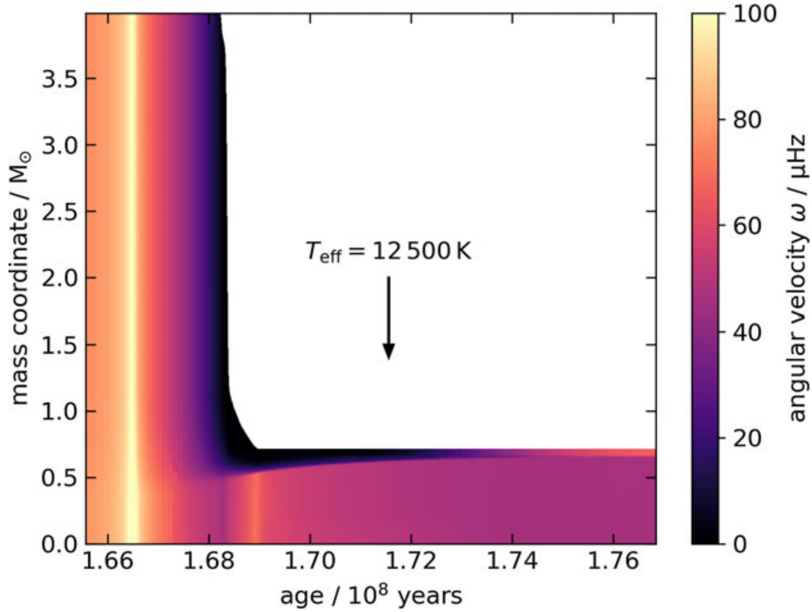

Figure 1. Kippenhahn-type diagram of the mass donor of our fiducial binary model, showing the internal evolution of its rotational frequency (colorbar on the right) after TAMS. The arrow marks the time corresponding to LB-1.

3. Rotational evolution with and without magnetic fields

During hydrogen core burning (until $1.665 \cdot 10^8$ years, Fig. 1) the magnetic torques of the STD keep the model in nearly rigid rotation. After central hydrogen depletion the envelope expands and tides become important, so the surface rotation rate drops. The magnetic torques drain so much angular momentum out of the core that it decelerates in spite of its contraction.

When the star fills its Roche-lobe ($1.68 \cdot 10^8$ years) the surface rotates at the same rate as the orbit. Hydrogen shell burning has increased the gradients of entropy and mean molecular weight so much that the STD becomes ineffective. No angular momentum is drained out of the core anymore and it accelerates due to contraction. Soon after that, helium core burning ignites. The envelope contracts increasing its rotation rate. At an age of $1.75 \cdot 10^8$ years it becomes faster than the core, which could not be archived by the STD. The model will evolve to a subdwarf with a rotational velocity in broad agreement with observations (Wang et al. 2021).

In an alternative model without STD the rotation rate of core and envelope decouple already during hydrogen burning. The core is barely braked during Roche-lobe filling leading to a fast rotating stripped star in contradiction with observation. The results are independent of initial rotation.

4. Conclusions

Tidal braking and magnetic torques lead to low surface rotational velocities in the stripped donor after Roche-lobe overflow. Models without magnetic torques cannot reproduce the low surface rotation of LB-1. The removal of angular momentum from core is supported by earlier works.

Supplementary material

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/S1743921322002113.

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