Formation of the Long-Period, Eccentric Binary IP Eri

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Introduction

IP Eri is a long-period ($P \approx 1100$ d), eccentric ($e \approx 0.25$) binary consisting of a Helium white dwarf (He-WD) with a K0IV companion situated at the base of the red giant branch (RGB, Merle et al., 2014, A&A, submitted). The He-WD is likely formed by the ejection of the progenitor's envelope as it ascends the RGB, induced by the presence of the companion. However, the high eccentricity cannot be accounted for by the canonical formation channels:

- Roche lobe overflow (RLOF),
- Common envelope evolution.

The merging of the inner stellar components of a hierarchical triple binary (where the outer component consists of a main sequence star), can produce an eccentric compact binary (Clausen & Wade, 2011, ApJ, 733, L42), but it requires the merging of two He WDs, which cannot produce a He WD close to the minimum WD mass!

We present a consistent evolutionary scenario to explain the observed properties of IP Eri – invoking a tidally enhanced wind loss mechanism – using our state-of-the-art binary evolution code BINSTAR (Siess et al. 2013,A&A,550,100). Its key features are

- Treatment of mass loss/ accretion via winds and RLOF,
- Orbital angular momentum evolution arising from mass exchange and tides,
- A Henyey scheme to solve the orbital separation, eccentricity and stellar equations simultaneously.

Using BINSTAR, we aim to

- Investigate the impact of wind losses on the eccentricity,
- Obtain a best-fit model for IP Eri.

This work is based on the article Siess, Davis & Jorissen, 2014, A&A (in press).

Key Binary Input Physics

Enhanced Wind Loss Mechanism

In the RLOF scenario, tides always circularise the orbit before mass transfer starts, since the giant possesses a deep convective envelope. To preserve the eccentricity, mass must be removed from the giant while it is well within its Roche lobe, keeping tidal interactions weak. To achieve this, we apply the scheme of Tout & Eggleton (1988,MNRAS,231,823), whereby wind losses are enhanced by tidal forces (Fig. 1):

$$\dot{M}^{wind} = \dot{M}^{Reimers}\left\{1 + B_{wind}\times min\left[\left(\frac{R}{R_L}\right), \frac{1}{2^6}\right]\right\} \quad \textbf{Eq. 1}$$

where $\dot{M}^{Reimers}$ is the Reimers mass loss rate, $B_{wind} \approx 10^4$ is a constant, and R and is R_L the radius of the giant and its Roche lobe, respectively.

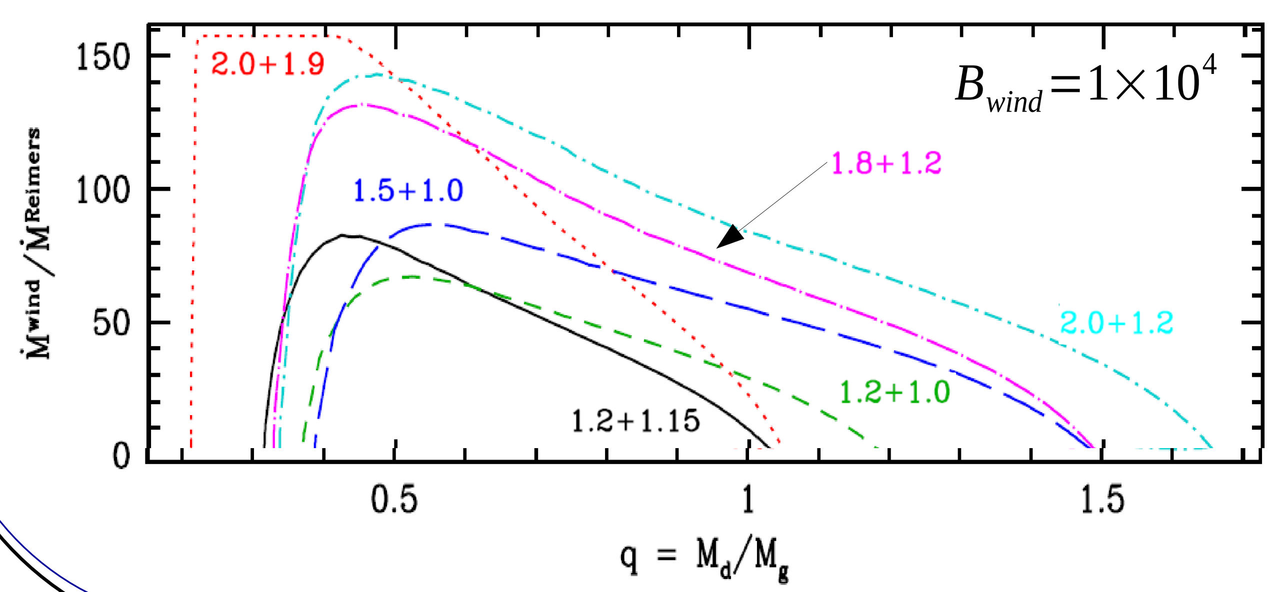
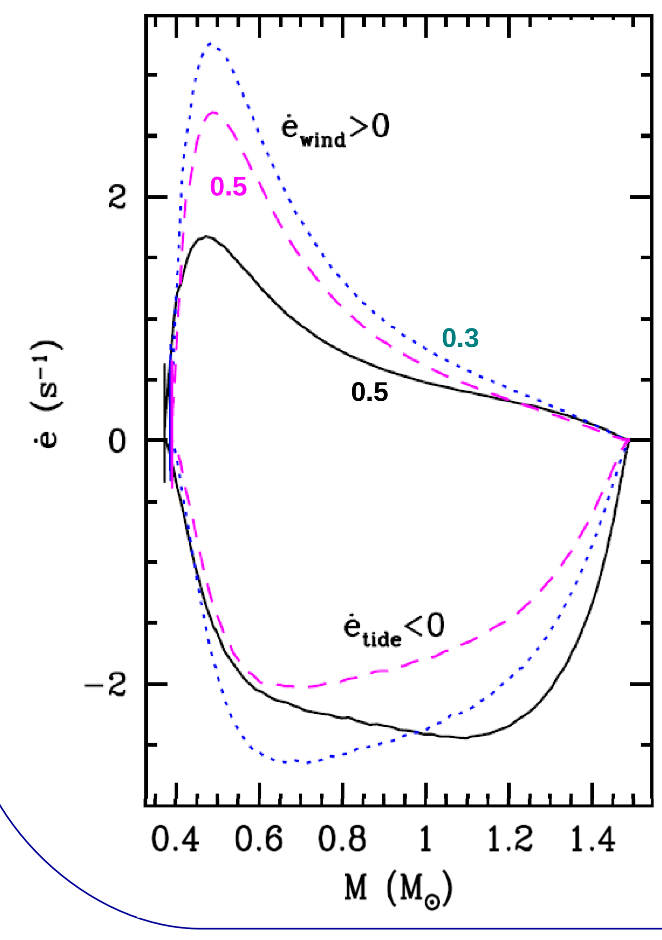


Fig 1: Wind enhancement factor as a function of the mass ratio (mass of loser M_d divided by mass of gainer M_g) for different initial configurations as indicated in the plot.

Calculating the Orbital Evolution

We assume that mass loss occurs via the Jean's mode i.e. the ejected mass carries the specific orbital angular momentum of the mass-losing star.

Additionally, the rate of change of the eccentricity, $\dot e$, is calculated from the sum of the tidal contribution ($\dot e_{tide,d}$ and $\dot e_{tide,g}$), which circularises the orbit ($\dot e_{tide} < 0$ Fig. 2), and that due to wind losses $\dot e_{wind}$:



$$\dot e = \dot e_{winds} + \dot e_{tide,d} + \dot e_{tide,g} \quad \textbf{Eq. 2}$$

The $\dot e_{wind}$ term is (Soker 2000,A&A,357,557)

$$\dot e_{wind}(\nu) = \frac{|\dot M_d^{wind} + \dot M_g^{wind}|}{M_d + M_g}(e + \cos\nu) \quad \textbf{Eq. 3}$$

Here $\dot e_{wind} > 0$ (Fig. 2) and ν is the true anomaly.

Fig 2: Rate of change of the eccentricity due to the tides ($\dot e_{tide}$) and wind losses ($\dot e_{wind}$) for stars with initial masses 1.5 + 1.4 M_{sun}, and a range of initial eccentricities, as indicated.

Results

Impact of Wind Loss on the Orbital Evolution

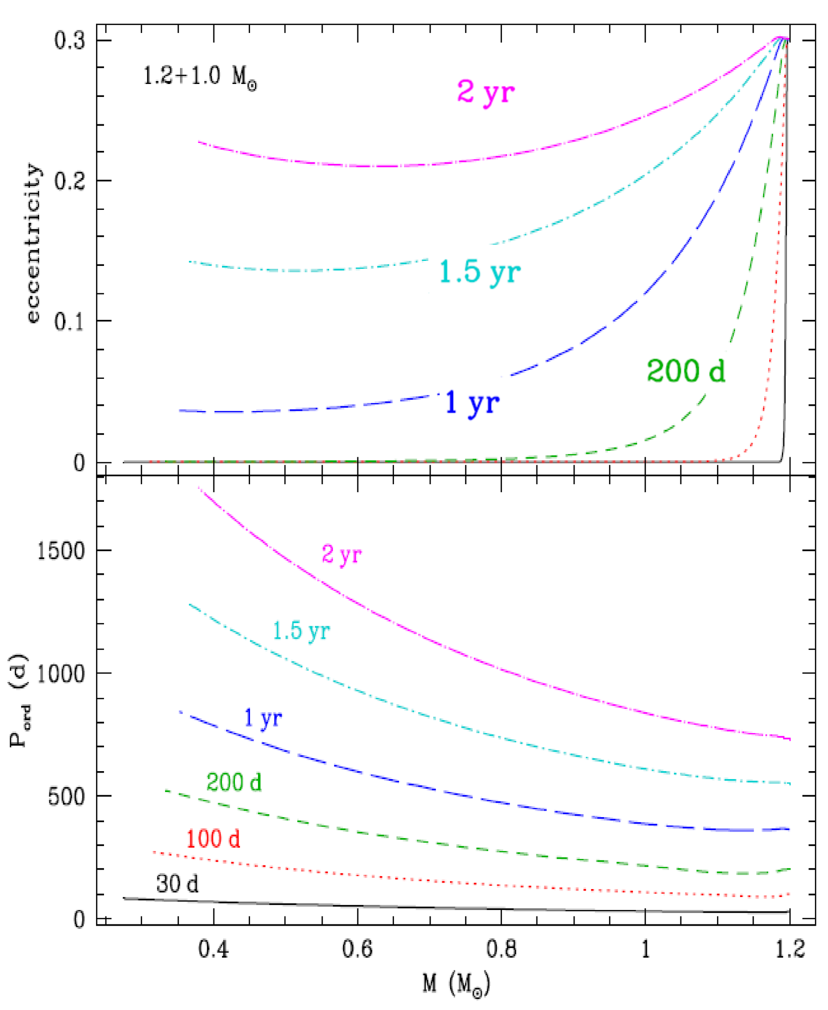


Fig. 3: Evolution of the eccentricity (top panel) and period (bottom panel) for a 1.2+1.0 M_{Sun} binary, with different initial periods.

- If the initial period is too small ($P \lesssim 200$ d, in Fig. 3) the wind enhancement mechanism starts too early, when $\dot M^{Reimers}$ is too low.

  The $\dot e_{tide}$ term dominates over $\dot e_{wind}$ and the eccentricity globally shrinks (green curve, top panel, Fig. 3).

- If P is large enough then the eccentricity can be preserved or even increased (e.g. magenta curve).
- **Hence, the wind loss enhancement scenario can explain the eccentricity of IP Eri, and for related systems.**
- Wind ejection causes the orbital period to rise (bottom panel).

Best-Fit Model

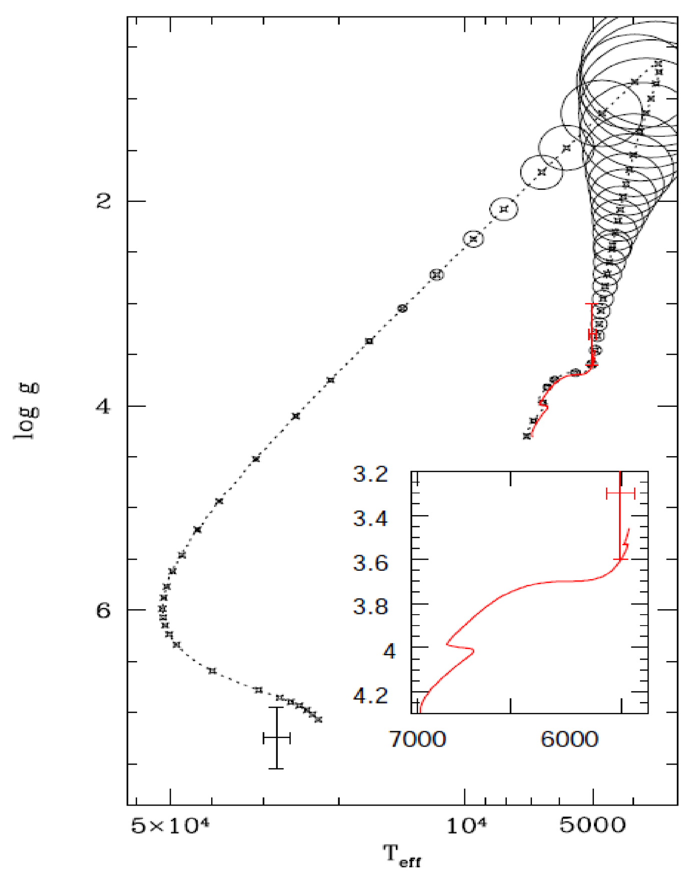


Fig. 4: Evolution of a 1.5 M_{Sun} (black curve) + 1.45 M_{Sun}, (red, see also inset) binary with an initial period of 415 d, e = 0.4 on the surface gravity – effective temperature plane. The locations of the WD and the K0 star are indicated by the black and red crosses, and the circle sizes are proportional to the WD progenitor radius. We use $B_{wind} = 3.6\times 10^4$.

Best-fit models are summarised in Figs. 4 and 5, where we reproduce remarkably well the observed parameters of IP Eri.

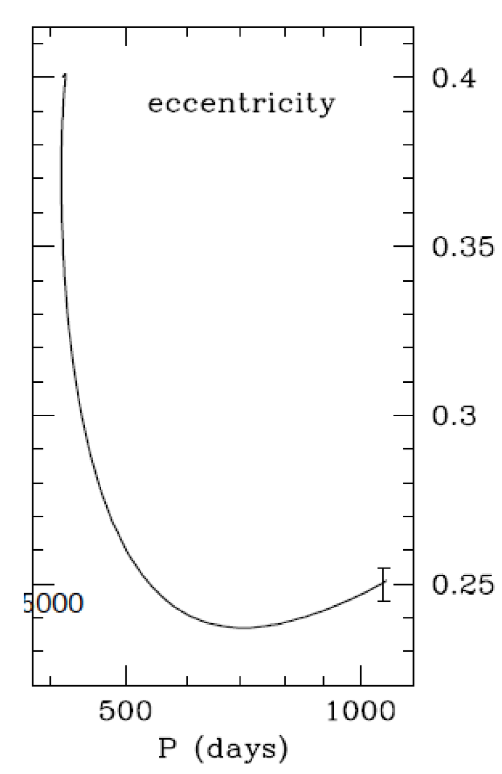


Fig 5: Evolution of the 1.5 + 1.45 M_{Sun} binary on the orbital period – eccentricity plane. The vertical error bar indicates the observed location of IP Eri.

Summary

- Currently available formation channels of compact binaries cannot account for the significant eccentricities observed in systems like IP Eri,
- Enhanced wind losses from the giant star via tidal forces presents a promising mechanism that can preserve or even increase an initial "seed" eccentricity,
- Using this scenario, we can reproduce the observed properties of IP Eri remarkably well.

For further information see: