Constraints on Impulsive Mass Loss in η Carinae

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Impulsive Mass Loss

Supermassive binary stars lose mass during their evolution in the form of a (sometimes very strong) stellar wind. Impulsive mass loss, on a time scale shorter than the orbital period, may also occur. This changes the configuration of the system and, in extreme cases, may destroy it.

If the system remains bound, its present state may give some clues about the history of the binary. This is the point we address here. We consider an instantaneous removal of mass of one star, no shell impact on the companion, no random kick velocity. Classical mechanics prescribes the connection between past and present (Hills, Ref.1).
The generic behaviour is shown in box 1.

Equations

$$\frac{a}{a_0} = \left(1 - \frac{\Delta M}{M_0}\right)\left(1 - \frac{2a_0}{r}\frac{\Delta M}{M_0}\right)^{-1}$$

$$e^2 = 1 - (1 - e_0^2)\frac{M_0^2}{(M_0 - \Delta M)^2}\left(1 - \frac{2a_0}{r}\frac{\Delta M}{M_0}\right)$$

$$a_0(1 - e_0) \le r \le a_0(1 + e_0)$$

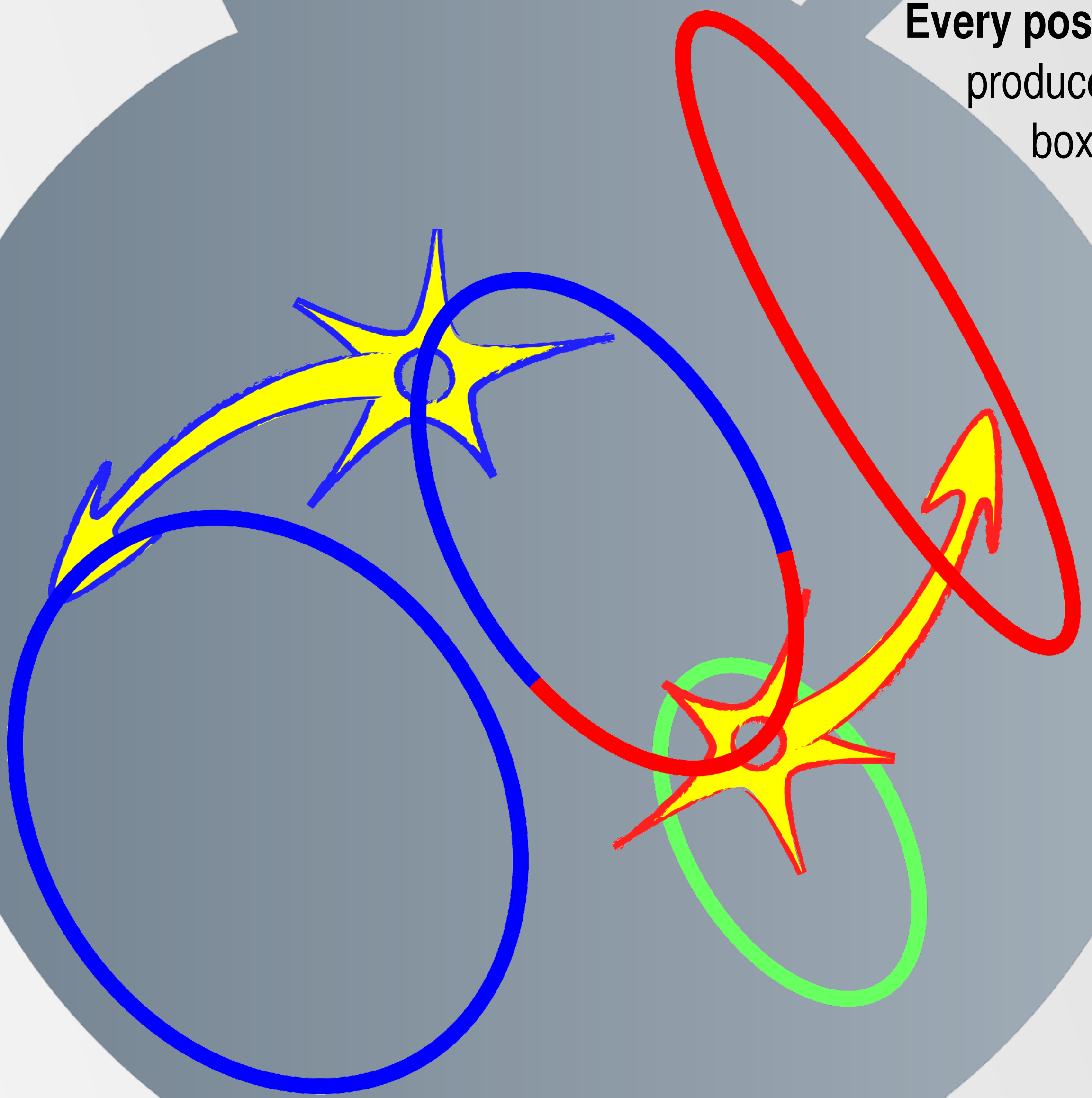
η Carinae

The subject of this investigation came up during our ongoing study of the hydrodynamics of Eta Carinae. Comparison of our computations and existing observations indicates that the remarkable properties of this very massive dual-wind binary (90 and 30 $M_\odot$, period 5.52 *yr*, eccentricity 0.8-0.9) may contain information about its state before the "Great Eruption" in 1843, which produced the bipolar nebula called "Homunculus".

Tracing Eta's past is important because it is not known what instability caused this eruption. Current stellar models do not predict such a phase. We hope to understand not only the creation of bipolar nebulae like η Car, but also the evolution of massive binaries in general.

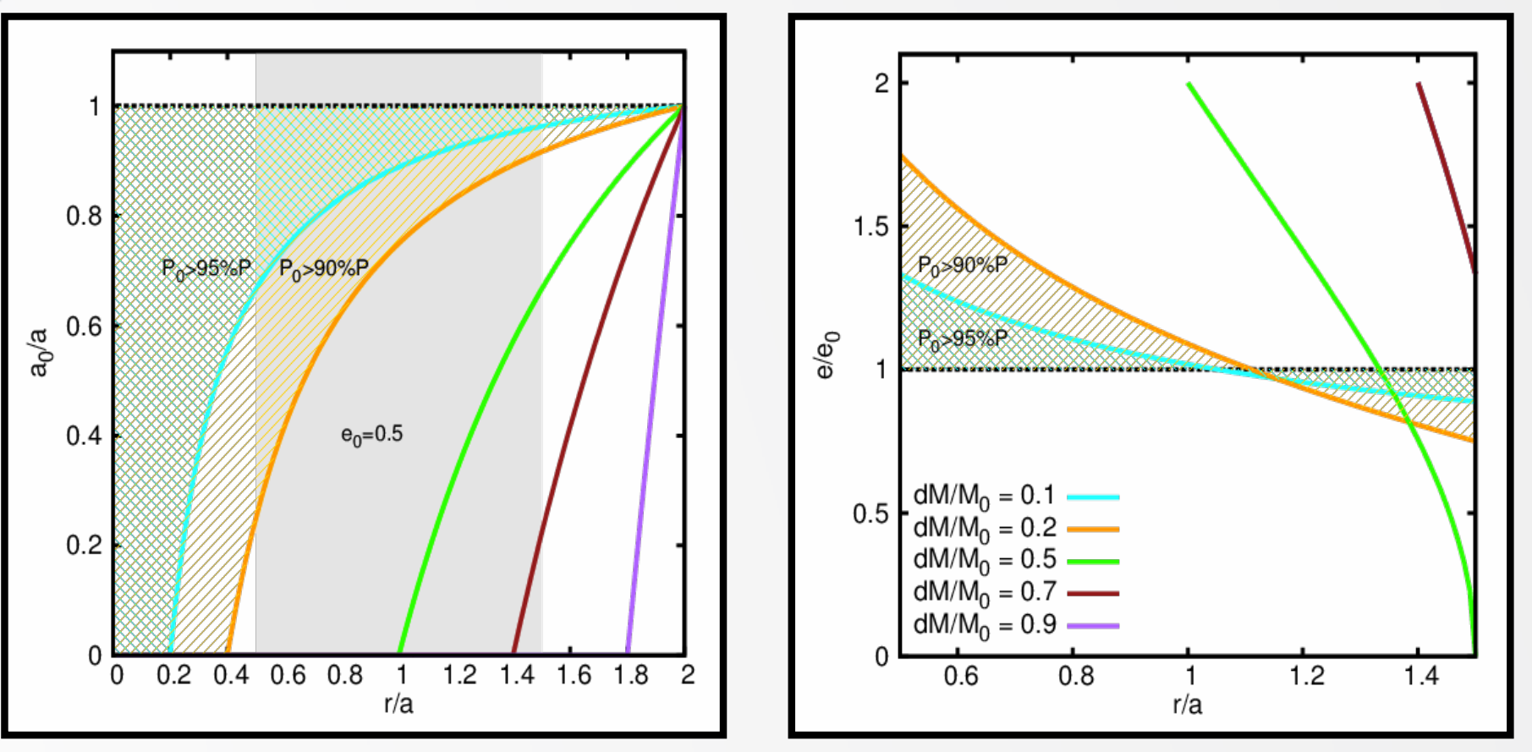
Smith & Frew (2) proposed that Eta's period was 5% shorter before the Great Eruption. Using this clue, we performed an analytical study of the orbital parameters, investigating the consequences of a "failed supernova" impulsive mass loss by way of approximation. Slower mass loss must be computed numerically, but the analytic results provide clear constraints on what could have happened in η Car, and can be applied to similar systems. This may well include objects like SN1987A, with its dual-ring nebula.

From the past orbital period and increasing the total mass of the system, we computed the initial semi-major axis a_0 (box 2). For all possible combinations of mass loss and a_0 we derived the distance *r*, between the stars at the time of the eruption, that produced the current *a* = 15.4 *AU* (box 3). Finally, we used these data to calculate the initial eccentricity e_0, if we assume *e* = 0.9 (box 4).



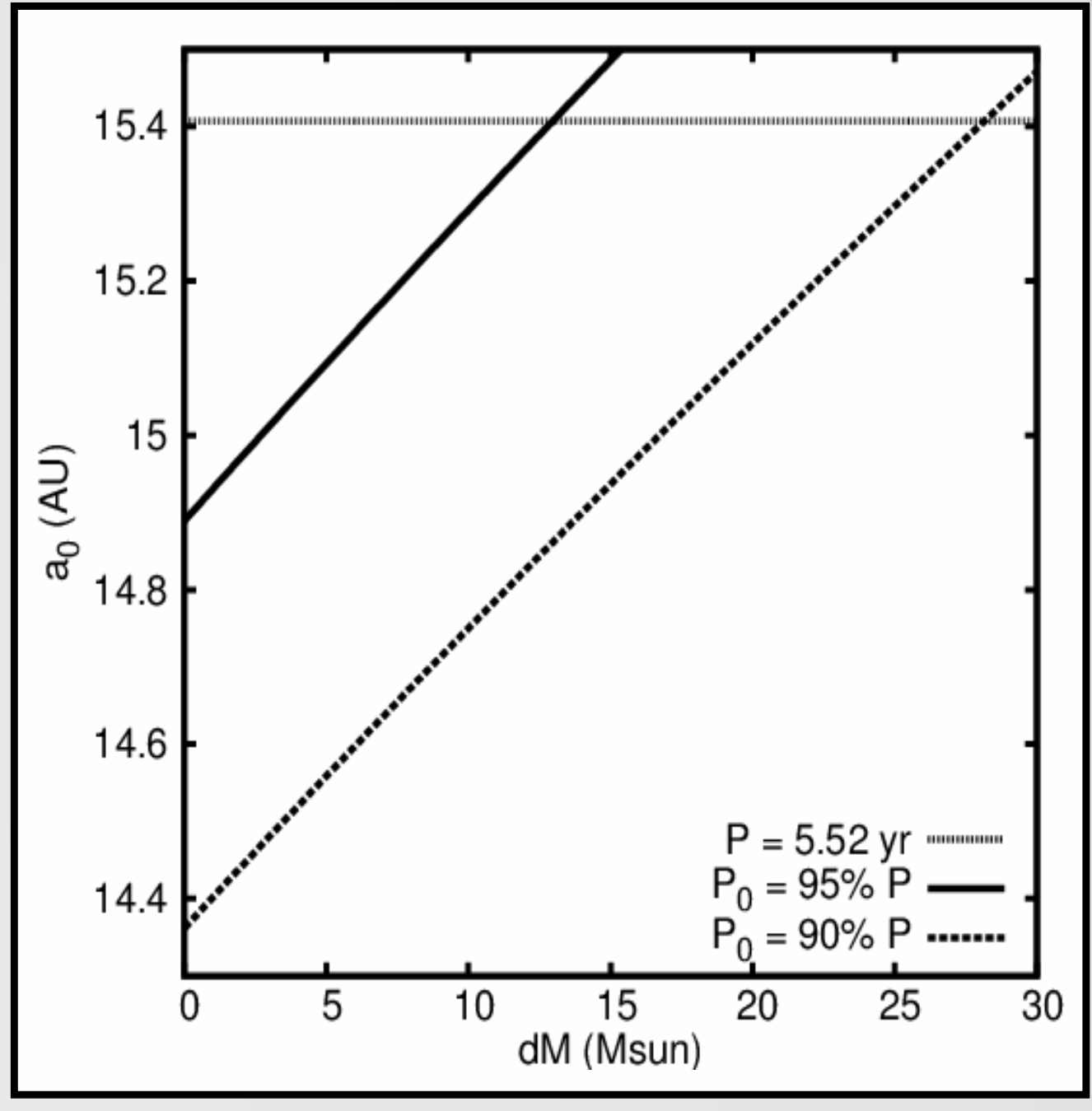
1

Changes in semi-major axis *a* and eccentricity *e* (for e_0 = 0.5), as a function of the distance *r* between the stars at the time of ejection, for different mass loss.
***a* always increases**, and some orbital positions are excluded if the system is to remain bound.



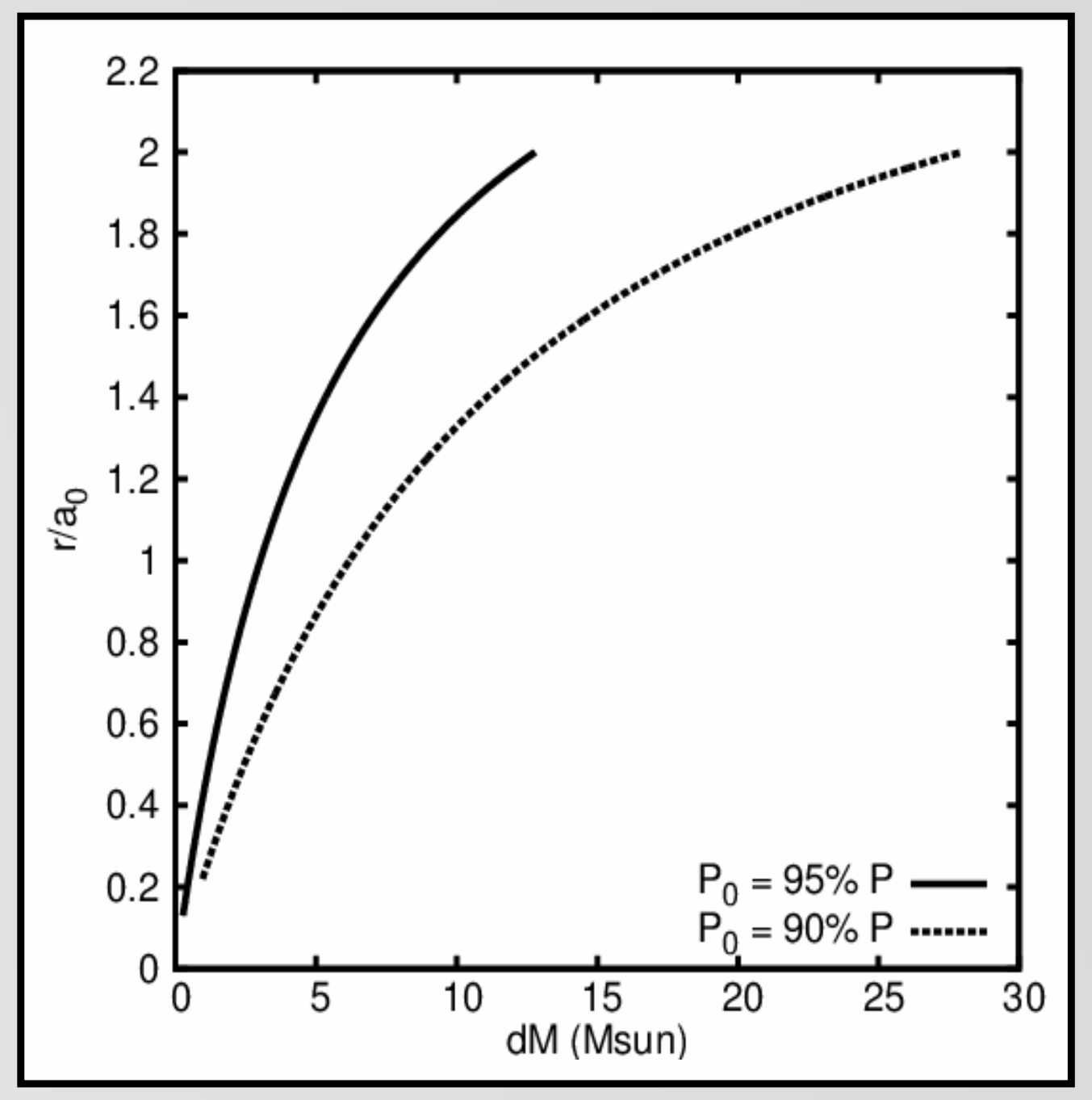
2

Possible values for the initial semi-major axis a_0, as a function of mass loss, for 5% and 10% difference in period before and after the eruption.
Since *a* must be bigger after the ejection, there is a **maximum mass loss** for every different past period.



3

Distance *r* between the stars at the time of ejection, as a function of mass loss, for 5% and 10% difference in period before and after the eruption.
Every possible mass loss requires a specific *r*, in order to produce the observed final semi-major axis *a*. As shown in box 1 not all *r* values are possible for every e_0.



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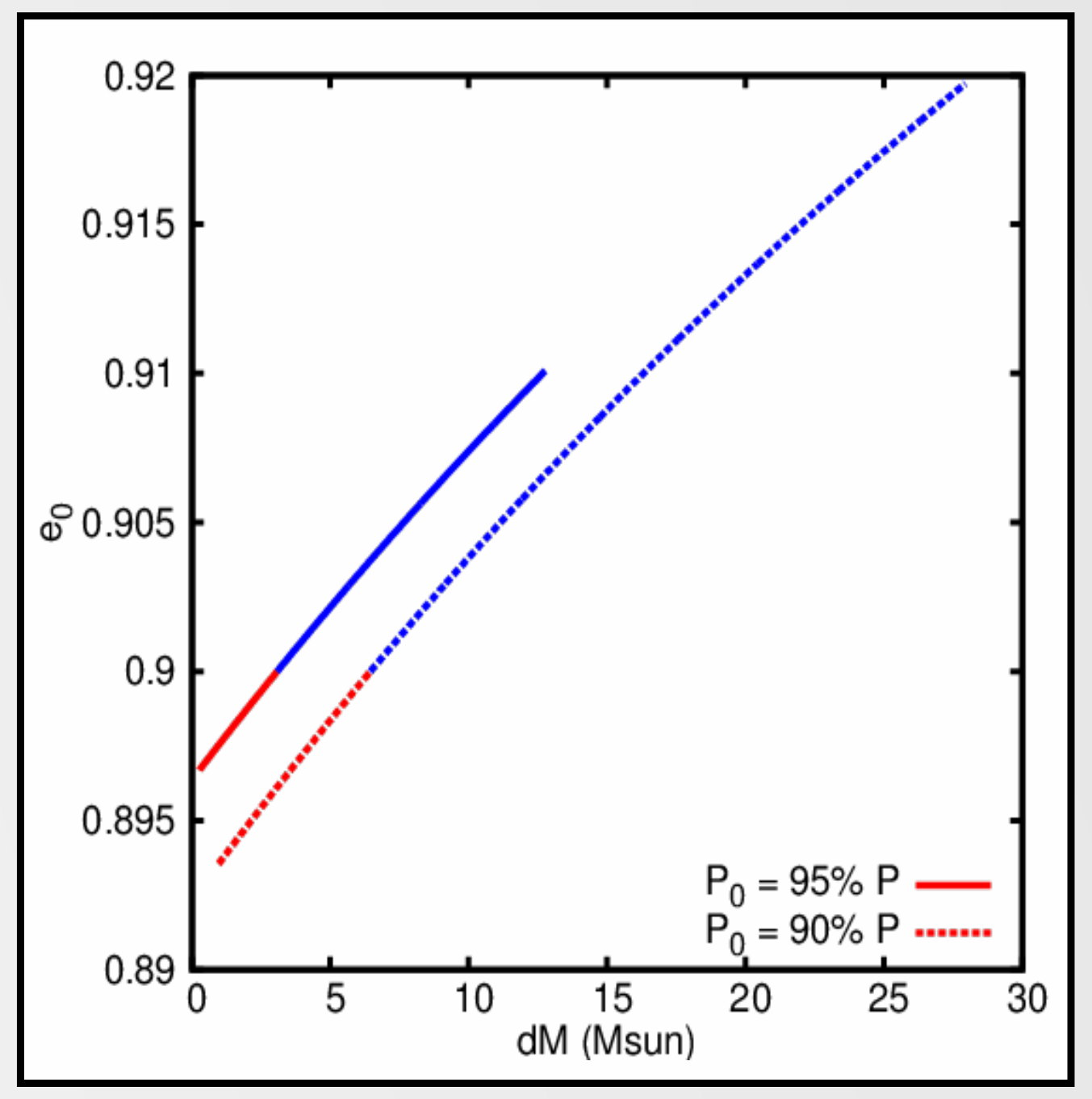
Possible values for the initial eccentricity e_0, as a function of mass loss, for 5% and 10% difference in period before and after the eruption.
Because of the small change in mass and in semi-major axis, **e_0 is close to the final eccentricity *e***.



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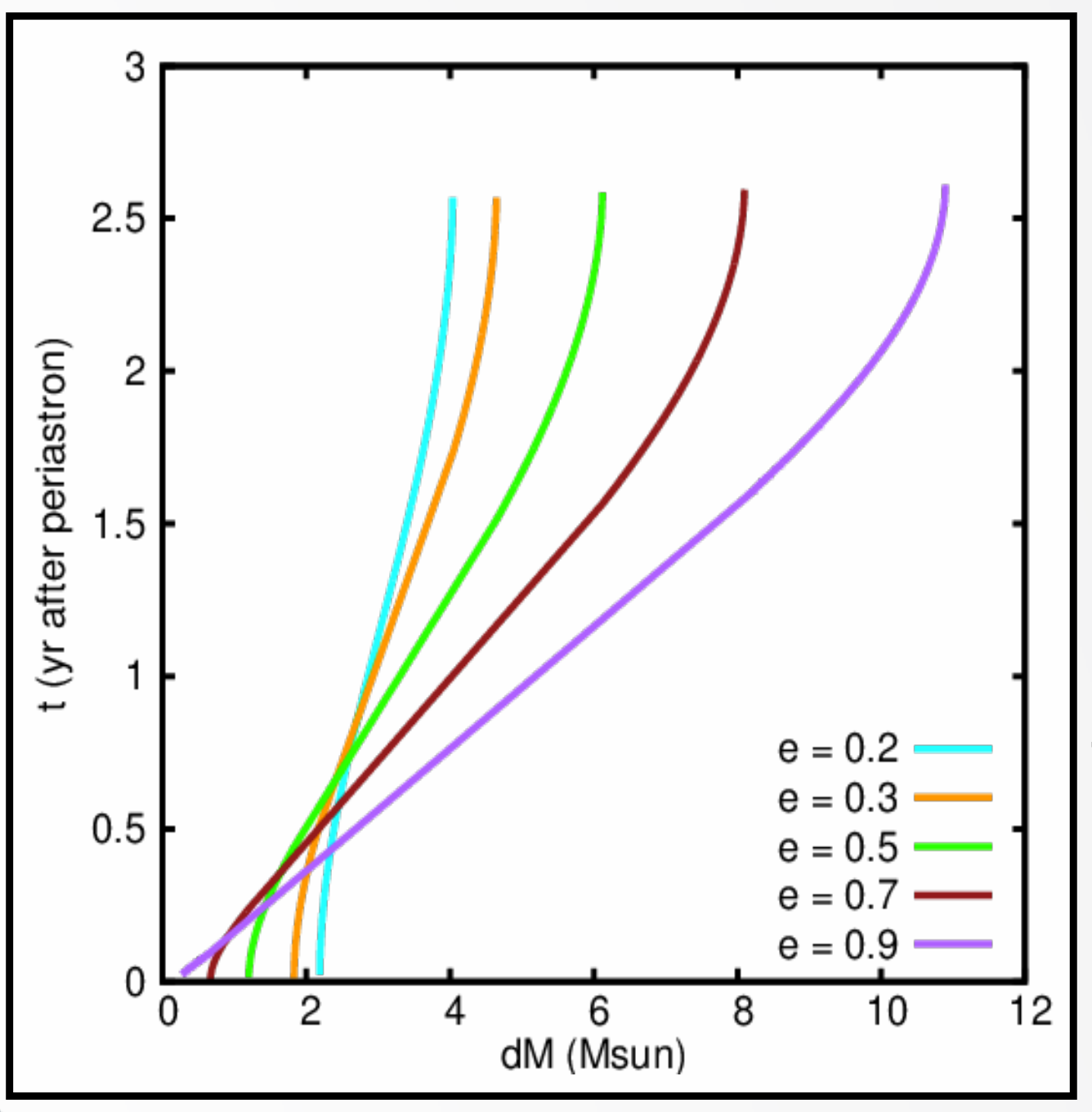

Distance *r* between the stars at the time of ejection, in years after periastron, as a function of mass loss, for 5% difference in period and various eccentricities.
Example: if the eruption occurs 1.5 years after periastron, about 8 $M_\odot$ must be ejected (with *e* = 0.9). Referring to Fig.4, we read off that this mass loss implies a somewhat **higher eccentricity before the eruption**.

Conclusions

1. The observed change in period puts constraints on the mass loss. If the eruption caused a 5% change, the Homunculus cannot contain more than 13 $M_\odot$;
2. A small change of the period always implies a small change of the orbital parameters, even if substantial mass is lost;
3. A "failed supernova" Great Eruption, that caused only a 5% difference in period, cannot drastically increase the eccentricity.
A different mechanism is required to reach *e* = 0.9 before the eruption.

References

1 Hills, J. G. 1983, Astrophys.J. **267**, 322
2 Smith, N. & Frew, D. J. 2011, Monthly Not. Roy. astron. Soc. **415**, 2009

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