A Massive Star Odyssey, from Main Sequence to Supernova
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Progenitor models of Wolf-Rayet binaries: short-period WNE+O binaries with mass ratios $q \simeq 0.5$

Jelena Petrovic and Norbert Langer

Sterrekundig Instituut, Universiteit Utrecht,
Princetonplein 5, NL-3584 CC Utrecht, Nederland

Abstract. We identify two possible paths for the progenitor evolution of observed WNE+O binaries with WNE/O mass ratios close to 0.5 and periods between 7 and 10 d. We show, through detailed binary evolution models, that with the assumption that the O-type star expels most of the matter flowing at it during mass transfer, one possibility to obtain the observed systems is through Case A mass transfer. We find a second solution using standard common envelope evolution. We conclude that in either case the O-type star in the three investigated systems did not accrete significant amounts of mass. We discuss the intricate situation that in other cases massive close binaries may evolve conservatively.

1. Introduction

Of about 20 observed Wolf-Rayet binary systems with known masses in the catalogue of van der Hucht (2001), three contain WNE stars, have small periods and mass ratios of $q \simeq 0.5$: the binaries WR 127 (HD 186943, WN3+O9.5V), WR 21 (HD 90657, WN5+O4-6) and the WR binary in WR 153 (GP Cep, WN6/WCE +O6I). Clearly, the components in these systems must have undergone strong interaction in the past. An understanding of their progenitor evolution may be the key to constrain the mass transfer efficiency in massive binaries: which fraction of the mass leaving the primary star is accumulated by the secondary star during a mass transfer event?

2. First scenario: Case A evolution

We calculate the evolution of a binary system, using the evolutionary code generated by Braun (1997), starting with a primary of 41 $M_\odot$, a secondary of 24 $M_\odot$

Table 1. Observed WNE+O systems.

WR	HD/name	type	P(d)	$M_{\rm WNE}/M_\odot$	$M_{\rm O}/M_\odot$	q
WR 127	HD 186943	WN3+O9.5V	9.56	17	36	0.47
WR 21	HD 90657	WN5+O4-6	8.26	19	37	0.51
WR 153	GP Cep	WN6/WCE+O6I	6.69	15	27	0.56

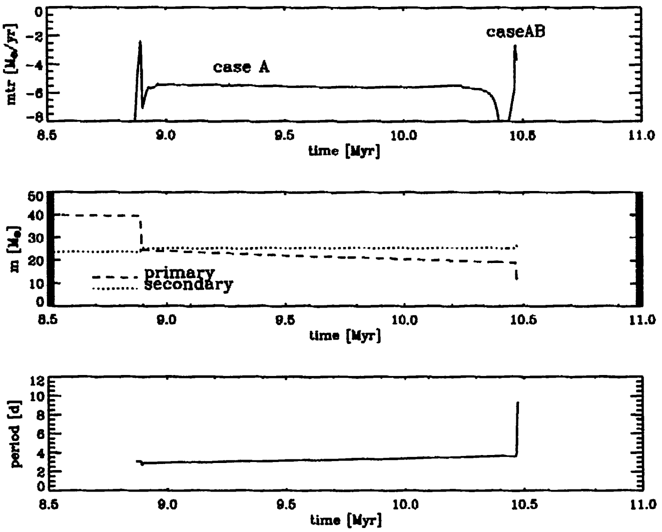

Figure 1. Mass transfer rate (*top*), masses of the primary and the secondary (*middle*) and orbital period evolution (*bottom*) of our 41 M$_\odot$+24 M$_\odot$ system with an initial period of 3 d.

and an orbital period of 3 d. During the ensuing Case A mass transfer, we assume that the secondary accretes 10 % of the mass lost by the primary and expels the rest with a specific angular momentum, corresponding to the secondary's orbital angular momentum. This assumption is motivated by binary models of Wellstein *et al.* (2001), indicating that any significant accretion might lead to contact and to a likely merger. This is confirmed by our models, which evolve into contact if the accretion efficiency is higher than 10%.

The chosen system evolves through Case A and Case AB mass transfer. Figure 1 shows that the mass transfer rate during the fast phase of Case A and during Case AB goes up to some $10^{-3}\,M_\odot\,yr^{-1}$. We cannot specify at this point which physical mechanism can actually push 90 % of the overflowing matter out of the binary system. Dessart, Petrovic & Langer (these Proceedings) show that radiation pressure by itself is unlikely to be able to do this. Wellstein (2001) investigated the additional role of the centrifugal force on the spun-up secondary star. He found that such high mass loss rates from the binary system are indeed possible, but it remained unclear if massive Case A binaries can produce them.

Figure 1 shows how the masses of the primary and secondary change during evolution of the system. The primary loses ~15 M$_\odot$ during fast Case A mass transfer (thermal time scale). After that, it decreases its mass by ~6 M$_\odot$ due to slow Case A mass transfer (nuclear time scale) and stellar wind mass loss. It becomes a hydrogen poor WNE star ($X_{\rm surface} \simeq 0.14$) at a mass of ~11.2 M$_\odot$ during Case AB mass transfer. The secondary accretes around 2 M$_\odot$ during Case A and around 1 M$_\odot$ during Case AB mass transfer. Its mass is also modified by its stellar wind and the final value is ~26.2 M$_\odot$. Thus, the mass ratio in the WNE+O stage is $q = 0.43$.

Table 2. Common envelope scenario.

	$M_1/\mathrm{M}_\odot$	$M_2/\mathrm{M}_\odot$	P (d)
initial	41	27	26
start CE	34.8	30.0	26.6
end CE	14	30.0	7.6

The period evolution of this system is also shown on the Figure 1. We can see that during the first part of Case A mass transfer, until the maximum mass transfer rate ($4.5 \times 10^{-3}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$) is achieved, the period decreases to a minimum value of ~2.7 d. Thereafter, during slow Case A mass transfer ($\dot{M} \simeq 10^{-6}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$), the period increases slowly to about 4 d at the beginning of Case AB mass transfer. During Case AB mass transfer (maximum value $\dot{M} \simeq 2.25 \times 10^{-3}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$), the period grows to ~9.4 d.

3. Second scenario: common envelope evolution

The observed systems (Table 1) can also be modeled from an initial configuration with a $41\,\mathrm{M}_\odot$ primary, a $27\,\mathrm{M}_\odot$ secondary and a period of 26 d, which evolves into a Case B mass transfer. However, after about $3\,\mathrm{M}_\odot$ of matter have been transfered, the secondary expands very rapidly, which results in a common envelope situation. Using standard common envelope estimates (de Kool 1990), the stellar properties at the moment of contact — a He core mass of the primary of $\sim 14\,\mathrm{M}_\odot$, an orbital separation of $\sim 150\,\mathrm{R}_\odot$ and a Roche radius of the primary of $\sim 60\,\mathrm{R}_\odot$ — lead to a post common envelope system with a mass ratio $q = 0.47$ and a period of 7.9 d.

4. Conclusion

We find two possible ways to produce the short periods of the WNE+O binaries listed in Table 1: (*i*) 'normal' mass transfer evolution, which requires a short initial period (*i.e.*, mass transfer through Case A) *and* a very low accretion efficiency to avoid a strong widening of the orbit; and (*ii*) common envelope evolution. For either path, no significant accretion of matter onto the O-type component occurs. This is remarkable, as other massive Case A binaries are known to evolve almost conservatively — *e.g.*, the massive X-ray binary Wray 977 (*cf.* Wellstein & Langer 1999). This means that either Case A evolution did not occur in the three WNE+O binaries of Table 1, or the accretion efficiency of massive Case A systems is a sensitive function of the initial mass ratio of the system.

References

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