The interaction of core-collapse supernova ejecta with a stellar companion

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1. Introduction

- ▷ The progenitors of many core-collapse supernovae (CCSNe) are expected to be in binary systems[1,8]. After the SN explosion in a binary, the companion star may suffer from mass stripping and be shock heated as a result of the impact of the SN ejecta[6,10]. If the binary system is disrupted by the SN explosion, the companion star is ejected as a runaway star, in some cases as a hypervelocity star[9].
- ▷ The nature of the SN explosion determines whether any given binary system remains bound or is disrupted[2]. An additional consequence of the SN explosion is that the companion star is affected by the impact of the shell debris ejected from the exploding star. Besides chemical enrichment, such an impact has kinematic effects and may induce significant mass loss and heating of the companion star.

2. Aims and Methods

- ▷ **Aims:** By performing a series of three-dimensional (3D) hydrodynamical simulations of the collision of SN ejecta with the companion star, we investigate how CCSN explosions affect their binary companion.
- ▷ **Methods:** We use the `BEC` stellar evolution code[5] to construct the detailed companion structure at the moment of SN explosion. The impact of the SN blast wave on the companion star is followed by means of 3D smoothed particle hydrodynamics (SPH) simulations using the STELLAR GADGET code[7].

3.2. Post-explosion companion star

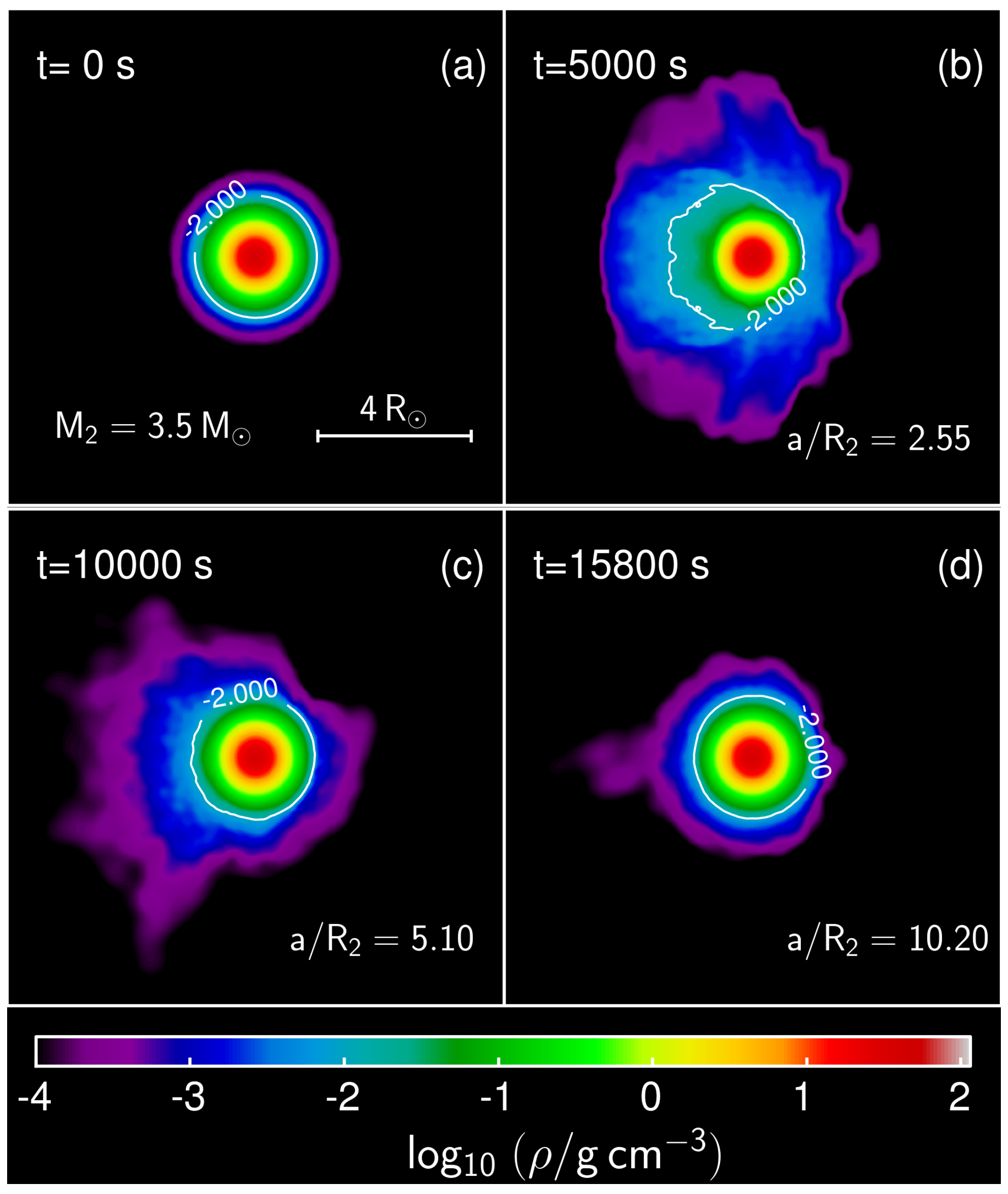

Fig. 3: Density distribution simulations of the companion star using a 3.5 $M_\odot$ B-star MS model with different initial binary separations. Only the bound material that originally belonged to the companion star and final accreted ejecta are shown. The top-left panel shows the initial configuration for all three cases. The motion of the incoming SN ejecta is from right to left. The following three panels are for initial orbital separations of $a/R_2 = 2.55$, 5.10 and 10.20, respectively. In the widest system (lower-left panel), the impacted star is not significantly inflated compared to its initial state before the SN impact. The white curves show constant density contours ($\log_{10}\rho = -2.0$).

Conclusions:

At small orbital separations, the companion star is strongly impacted and heated by the passing shock wave and hence it is bloated after the SN impact (top-right panel of Fig. 3). As the orbital separation increases to $\approx 5.0\,R_2$, the SN impact and heating of the companion star are reduced. Only a small amount of companion mass is removed and the SN heating is too inefficient to make the surviving companion star inflate by much (bottom row of Fig. 3).

5. References

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3. Results (Liu et al., 2015, A&A, 584, A11)

Fig. 1 demonstrates the interaction of SN ejeca on its companion star. At the beginning of the simulation, the MS companion star is in equilibrium. The SN explodes on the right side of the star, the SN ejecta expands freely for a while and hits the tar, removing H-rich material from its surface through stripping and ablation. After the interaction, the envelope of the companion star may be enriched by heavy elements from the SN ejecta while part of its H-rich material is stripped off by the SN impact.

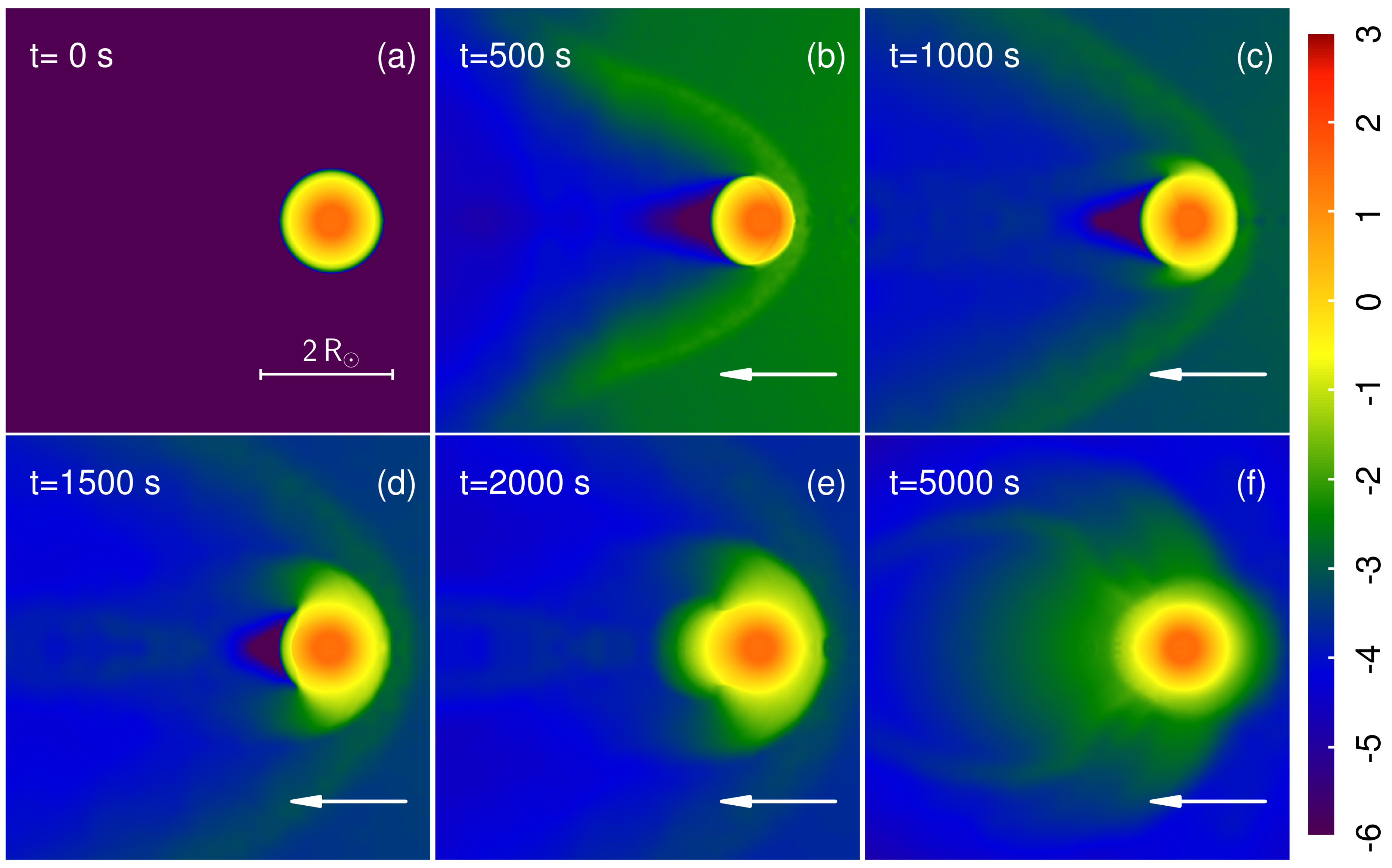

Fig. 1: Density distributions of all gas material as a function of the explosion time in the impact simulations for a G/K-dwarf companion model ($M_2 = 0.9\,M_\odot$) with a binary separation of 5.48 $R_\odot$ ($= 7.1\,R_2$). The direction of motion of the incoming SN shell front is from right to left (see arrow symbols). The impact is initiated at $t \approx 100\,\mathrm{s}$ after the explosion. The color scale shows the logarithm of the mass density in $\mathrm{g\,cm^{-3}}$.

3.1. Binary Separation Dependency (Liu et al., 2015, A&A, 584, A11)

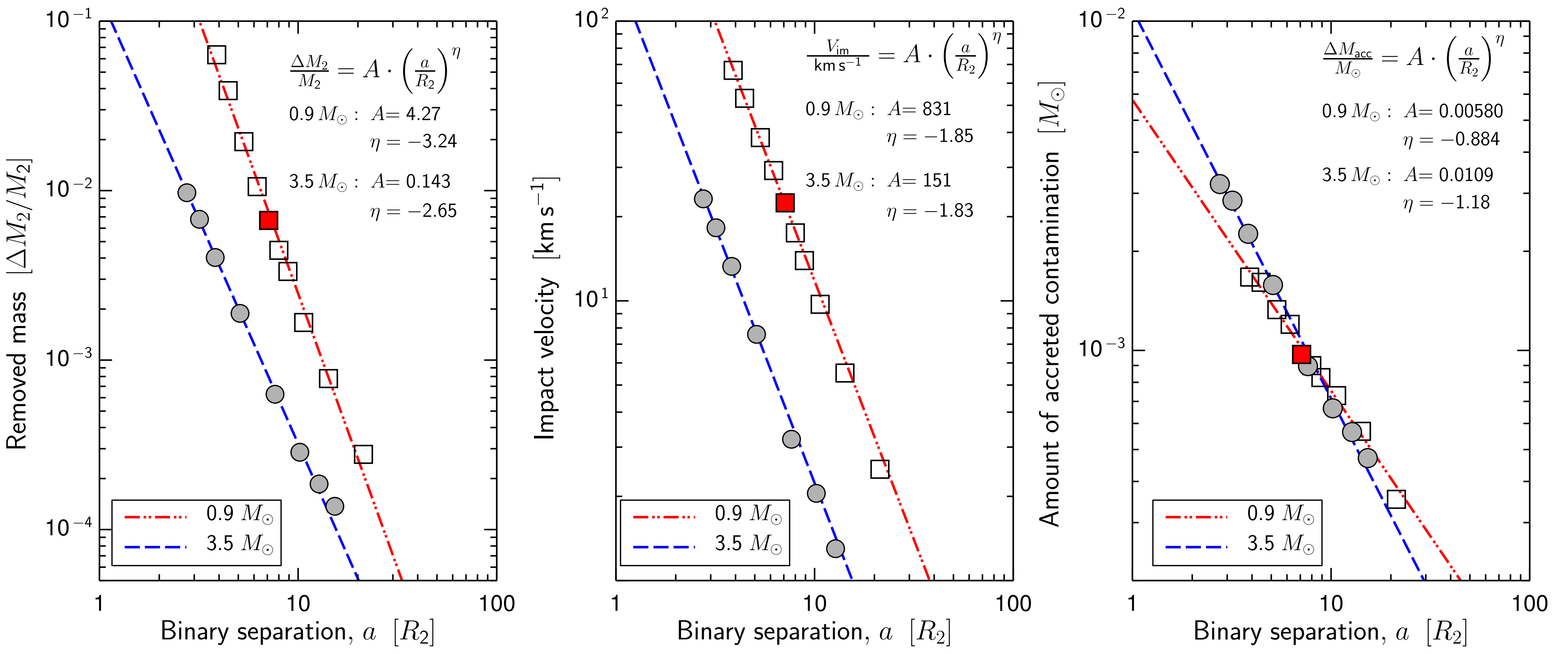

Fig. 2: Total removed companion mass (left panel), resulting impact velocity of the companion (middle panel) and the amount of accreted contamination from the SN ejecta (right panel), as a function of initial binary separations for a G/K-dwarf (square symbols, $M_2 = 0.9\,M_\odot$ and $R_2 \approx 0.77\,R_\odot$) and a late-type B-star (filled circle symbols, $M_2 = 3.5\,M_\odot$ and $R_2 \approx 2.18\,R_\odot$) companion model. Power-law fits are presented in each panel.

3.3. Population synthesis predictions

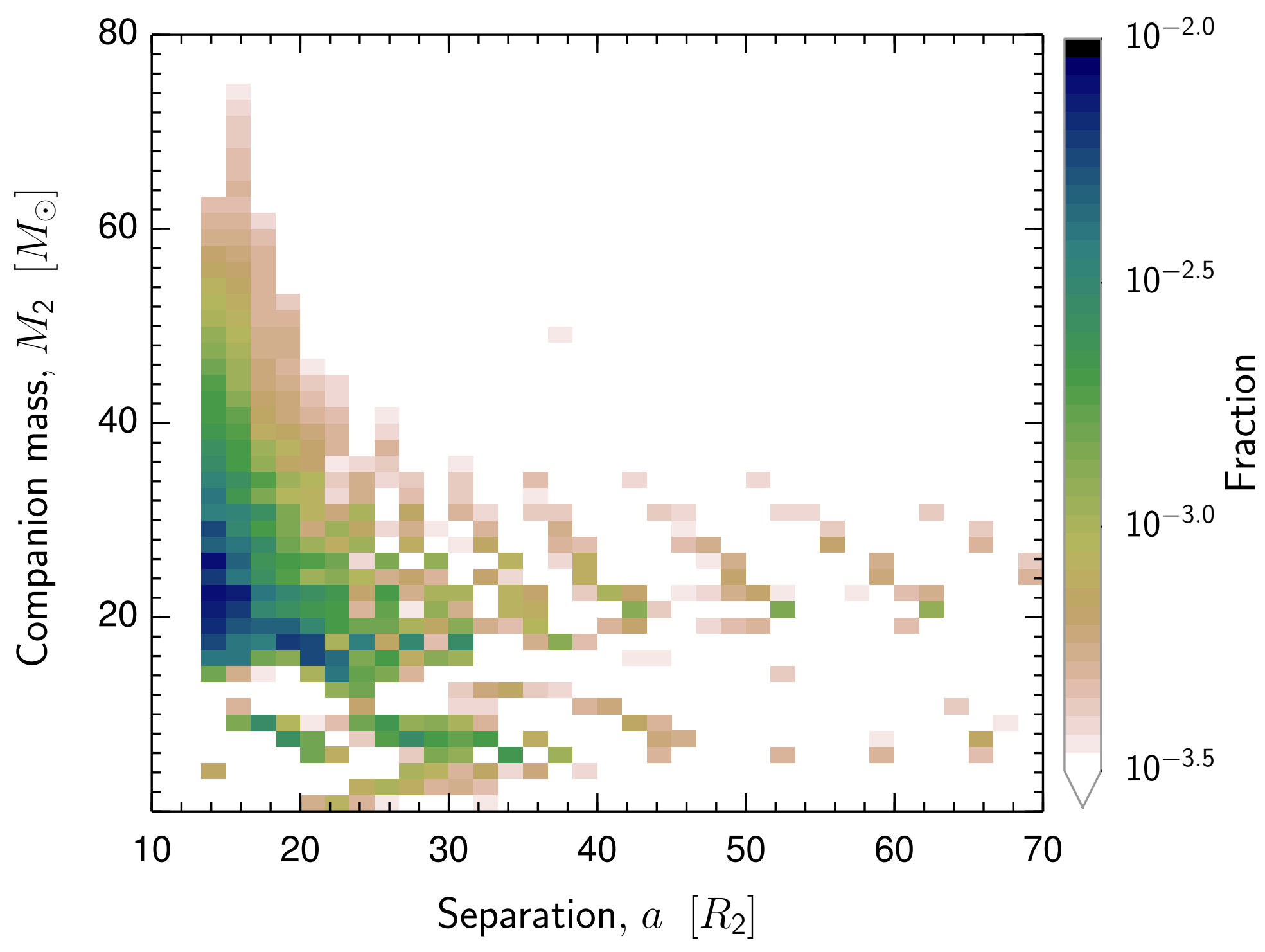

Fig. 4: Population synthesis distribution of the companion mass (M_2) as a function of the binary separation (a) when Type Ib/c supernovae explode. Here, we use the BINARY_C code.[3,4]

BPS results:

Most SNe Ib/c have an orbital separation of 5.0 R_2 , which is about a fraction of 95% in our binary population synthesis calculations. With the distributions of a/R_2 from BPS, we can simply estimate ΔM_2, v_im and ΔM_acc by applying our power-law relationships stated in Fig. 1.

4. Summary (Liu et al., 2015, A&A, 584, A11)

Our results can be summaried as follows:

i) The dependence of total removed mass (ΔM_2), resulting impact velocity (v_im) and the amount of accreted SN ejecta mass (ΔM_acc) on the pre-SN binary separation (a) can be fitted with power-law functions. All three quantities are shown to decrease significantly with increasing a, as expected.
ii) Our BPS calculations predict that in most CCSNe $< 5\%$ of the MS companion mass can be removed by the SN impact. In addition, the companion typically receives an impact velocity, v_im, of a few $10\,\mathrm{km\,s^{-1}}$, and the amount of SN ejecta captured by the companion star after the explosion, ΔM_acc, is most often less than $10^{-3}\,M_\odot$.
iii) Because a typical CCSN binary companion is relatively massive and can be located at a large pre-SN distance, we do not expect, in general, that the effects of the SN explosion on the post-impact stellar evolution will be very dramatic.
iv) It is possible that the SN-induced high velocity stars or runaway stars, may be contaminated sufficiently to be identified by their chemical peculiarity as former companion stars to an exploding star.

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