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Simulating the Outer Nebula of SN 1987A

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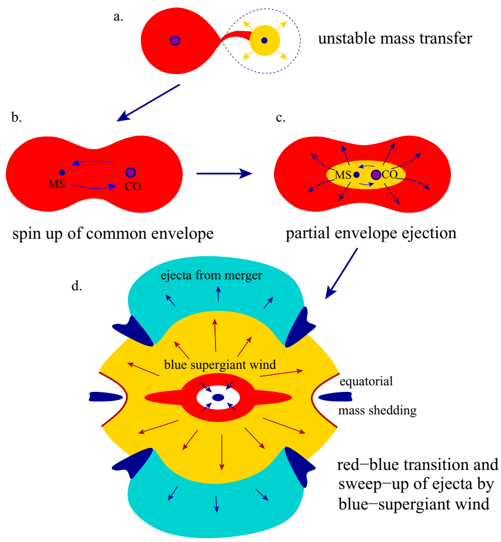
Abstract. As has been shown previously, the triple-ring nebula around SN 1987A can be understood as a direct consequence of the merger of two stars, some 20,000 yr before the explosion. Here we present new SPH simulations that also include the pre-merger mass loss and show that this may be able to explain other structures observed around SN 1987A, such as Napoleon's hat and various light echoes.

Keywords. binaries (including multiple): close, stars: mass loss, supernovae: SN 1987A, supernova remnants

1. The Binary Merger Model for SN 1987A

SN 1987A was an unusual supernova. Its various anomalies, in particular, the blue-supergiant progenitor, the chemical anomalies in the ejecta and the complex triple-ring nebula surrounding it, are best explained by the merger of two massive stars, 20,000 yr before the explosion (Podsiadlowski *et al.* 2007). In this model (see diagram), the material that was ejected in the merger process was then swept up by the blue-supergiant wind to form the outer two rings, while the inner ring is the result of equatorial mass loss when the merged object shrank to become a blue supergiant. Morris & Podsiadlowski (2007) showed that this naturally reproduces all the features of the triple-ring nebula.



2. Modeling the Circumstellar Medium

Beyond the triple-ring nebula, there are other complex structures as seen with the NTT ('Napoleon's hat'; Wampler *et al.* 1990) and deduced from detailed light-echo studies (Sugerman *et al.* 2005). In order to understand their origin, we have performed detailed SPH simulations, using the GADGET-2 code (Springel 2005), that include the mass loss before the actual merger. Specifically, these include a slow red-supergiant wind (with $\dot{M}_{\rm RSG} = 2.0 \times 10^{-5} M_{\odot}{\rm yr}^{-1}$ and $v_{RSG} = 20\,{\rm km\,s}^{-1}$) and a bipolar outflow emitted from the accreting component in the early dynamically unstable mass-transfer phase (the first stage in the diagram above) with $\dot{M}_{\rm bi} = 6 \times 10^{-5}\,M_{\odot}{\rm yr}^{-1}$ and $v_{\rm bi} = 350\,{\rm km\,s}^{-1}$, lasting for 1000 yr.

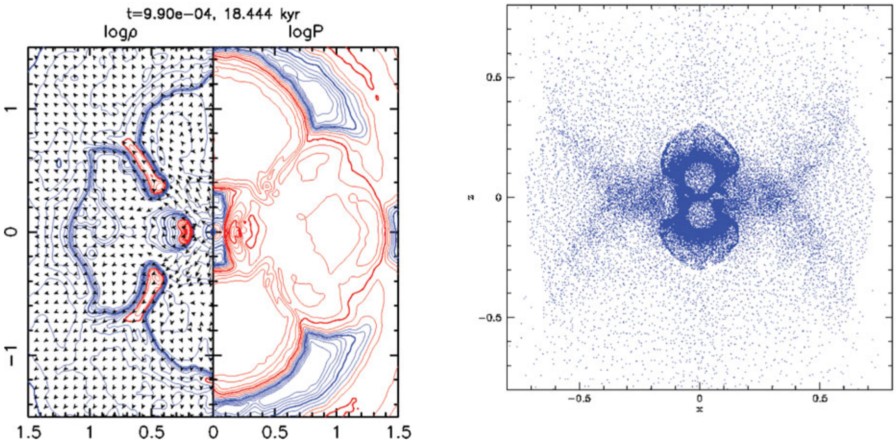


Figure 1. *Left:* Density/pressure distribution of the inner SN87A nebula from a supernova triple-ring simulation with a previous RSG wind (without bipolar jet). *Right:* Large-scale structure of the SN 87A nebula, including a RSG wind and a bipolar jet. The CE ejecta in the inner nebula are not properly resolved in this simulation. Structures similar to the 'spurs' in the Sugerman *et al.* (2005) reconstruction are found at the equatorial edges of the wind-compressed region. Axes are in units of 8 parsecs.

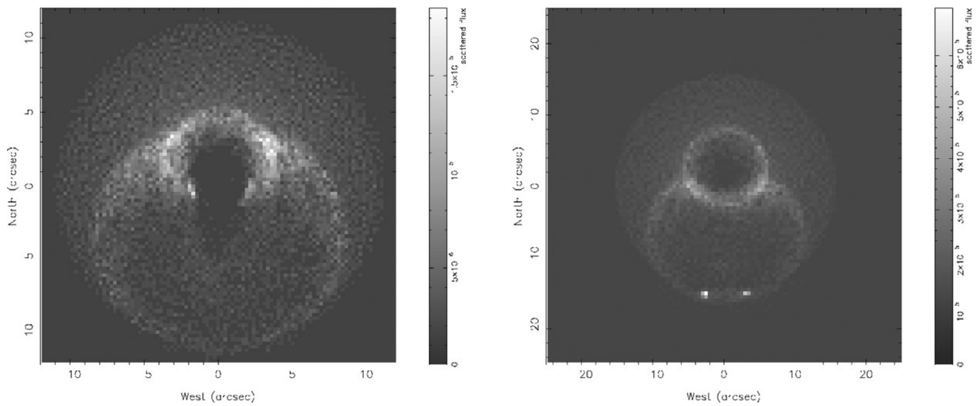


Figure 2. Simulated light echoes 1.8 years (left) and 4 years (right) after the supernova, assuming a constant-luminosity light curve of 0.3 years duration in a 24" by 24" field of view for the following parameters: jet velocity: $350\,\mathrm{kms}^{-1}$, jet opening angle: 15°, and RSG wind velocity: $20\,\mathrm{kms}^{-1}$.

Figure 1 present some the results of the SPH simulations, showing the large-scale structure and Figure 2 shows simulated light echos for our best-fit simulation.

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