The Ring Around SN1987A

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MOTIVATION

Stars in the 9-40 $M_\odot$ range play a prominent role in the hydrodynamical and chemical evolution of galaxies. Their stellar winds and supernova explosions are believed to create the hot component of the interstellar medium (ISM). In some galactic disks, the kiloparsec sized superbubbles formed around clusters of massive stars may blow out of the disk plane and release hot, metal enriched gas into the galaxy's halo. Additionally, the expanding shock front of a superbubble in the disk may trigger additional star formation. Furthermore, similar processes probably drive the galactic winds associated with starburst nuclei that enrich the intracluster and intergalactic mediums.

Nonetheless, the explosion of a blue supergiant in the Large Magellanic Cloud (LMC), SN1987A, illuminated the incompleteness of our understanding of massive stars. Evolutionary models of massive stars do not synthesize the observed supergiant populations in either the Milky Way or LMC. Our modeling of the formation of SN1987A's ring will improve our knowledge of both the post-main-sequence evolution of massive stars and their coupling to the ISM in galaxies.

BACKGROUND

It is now generally agreed that SN1987A's progenitor was a blue supergiant (BSG) (Arnett *et al.* 1989) of spectral type B3 Ia, and there is considerable evidence that this star passed through a red supergiant (RSG) stage earlier in its life. Theoretical tracks for low metallicity $20 M_\odot$ stars (e.g. Arnett 1991) suggest the progenitor passed through two RSG stages and one BSG stage prior to the final BSG phase. Observationally, the RSG phase is inferred from the narrow UV emission lines seen in spectra of SN1987A taken after May 24, 1987 (Fransson 1989). These line widths and strengths were shown to be consistent with an origin in a low density, $(1\text{-}4) \times 10^4$ cm^{-3}, photoionized gas having CNO abundance ratios suggestive of a nucleosynthetic origin via the CNO cycle (Lundqvist & Fransson 1991). Hence, the emerging picture suggests that ashes from the nuclear burning in the interior were mixed into the progenitor's outer layers during a RSG phase and expelled in a slow stellar wind. During the subsequent BSG stage, a faster stellar wind from the hotter, smaller star collided with this circumstellar material. The resulting strong shock front swept up a dense shell (relative to the ISM) of ambient RSG wind which was subsequently photoionized by the UV/soft x-ray burst of the supernova explosion. A shell expansion rate of 15 km/s was derived by Lundqvist and Fransson (1991) from the UV emission lines.

High resolution imaging of the supernova remnant (SNR) has further constrained the morphology of this circumstellar structure. The image taken with ESA's FOC on HST through a narrow [OIII] λ 5007 filter (Panagia *et al.* 1991) reveals a clumpy ellipse of emission with a major axis a bit more than one light year across surrounding the SNR. The radial velocity gradient along the minor axis of the emission strongly suggests that the ellipse on the plane of the sky is actually a ring tilted relative to our line of sight rather than a limb brightened shell (Crotts 1991; Meikle *et al.* 1991). Crotts and Heathcote (1991) derived a ring expansion speed of 10.3 km/s from high-resolution spectra of the nebulosity. Luo and McCray (1991) have shown that the interacting winds scenario can produce an hourglass shaped circumstellar shell with a ring at the waist if the RSG wind has an equator to pole density contrast. Although the cause of such a wind asymmetry is unclear, a low mass secondary in a common envelope phase with the RSG can cause a highly asymmetrical mass-loss profile (Soker, 1992). A binary companion to the progenitor is also one possible cause for the observed asymmetric envelope expansion (Chevalier & Soker 1989).

CALCULATION

We use the PROMETHEUS code (Fryxell *et al.* 1989) to calculate the hydrodynamical interaction of a BSG wind overtaking an asymmetric RSG wind. We calculate one quadrant of a 50 x 100 grid oriented perpendicular to the plane of the ring with an origin at the progenitor star. This calculation is a step toward a 3D calculation which will investigate the stability of the ring. Only the last BSG and RSG phases of the progenitor's wind are modeled since the termination shocks of the winds blown during any previous blue loops and on the main sequence should be at much larger distances than the observed ring. The RSG wind asymmetry is described by a latitudinal density contrast in the RSG wind. We change the inner boundary condition from a RSG wind to a BSG wind abruptly since the acceleration mechanisms for the RSG and BSG winds are believed to be quite different and the stellar models indicate the progenitor evolves from the red to the blue on a time scale that is short in comparison to the time spent at either envelope solution. By choosing a RSG wind density toward the upper end of the estimated range and a BSG wind velocity toward the lower end of the observed range, we can place an upper limit on the duration of the final BSG stage.

RESULTS

The density contours and velocity vectors in Figure 1 illustrate the ring and constricted bubble resulting from an adiabatic calculation of a weak BSG wind crashing into an asymmetric, dense RSG wind with a 10:1 equator to pole density contrast. The ring has reached a radius of 1.85 lt. yr. when the progenitor has been in the final BSG stage for $\tau_{BSG} = 20,000$ yr. This distance is a factor of three larger than the observed position of the ring, and τ_{BSG} is only 80% of the value predicted by the stellar model of Arnett (1991). Hence we have a discrepancy between the interacting winds model for the ring and the stellar model. We are presently repeating the calculation with the inclusion of additional microphysics. The addition of radiative cooling and ionization losses will work to slow the ring down and increase its density. The results of this calculation will reveal whether or not there really is any discrepancy between the ring formation model and the stellar evolutionary models.

REFERENCES
Arnett, D. 1991, Ap.J. **383**, 295.

Arnett, W. D. *et al.* 1989, Annu. Rev. Astron. Astrophys. **27**, 629.

Chevalier, R. A. and Soker, N. 1989, Ap.J. **341**, 867.

Crotts, A. P. S. and Heathcote, S. R. 1991, Nature **350**, 685.

Fransson, C. *et al.* 1989, Ap.J. **336**, 429.

Fryxell, B. A. *et al.* 1989, *in Numerical Methods in Astrophysics*, P. R. Woodward, ed., (Academic Press: New York).

Lundqvist, P. and Fransson, C. 1991, Ap.J. **380**, 575.

Luo, D. and McCray, R. 1991, Ap.J. **379**, 659.

Meikle, W. P. S. *et al.* 1991, in *in Proc. ESO/EIPC Workshop on Supernova 1987A and Other Supernovae* (Marciana Marina, Elba, Italy, 1990 September 17 - 22), ed. I. J. Danziger & K. Kjär (Garching: ESO), 595.

Panagia, N. *et al.* 1991, Ap.J. **380**, L23.

Soker, N. 1992, Ap.J. **386**, 190.

Figure 1