

## The ISM near SN 1987A: Kinematics and 3-D Structure

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**Abstract.** We present two views of the region around SN 1987A: a three-dimensional map of structure revealed by light echoes, and a multicomponent velocity map at  $10 \text{ km s}^{-1}$  resolution in [N II], correlating the various superbubble structures found in both, with implications for their age and dynamics, as well as the history of the SN progenitor

The Large Magellanic Cloud (LMC) exhibits gas shells from  $\sim 100$  pc to 1000 pc across. A new tool for unfolding the three-dimensional (3D) configuration of these structures seen to overlap in projection is the light echo from SN 1987A. We (Xu, Crofts, & Kunkel 1995) discuss the large scale interstellar medium (ISM) distribution in the SN foreground, and construct a map of these complicated structures from the light echoes, identifying dust sheets from 310 to 3240 pc in front of the SN. Additionally, we report results from a map of the velocity structure in the same field, revealed by long-slit echelle spectroscopy in [N II] (Xu & Crofts 1999). This information is tied to the same features seen in the echoes, revealing the kinematics and dynamics of the bubbles.

Significantly, N157C is not just the small shell of  $H\alpha$  filaments north-east of SN1987A. Instead, echoes from  $H\alpha$  structure extending south-west of the SN form a sphere with center of curvature on OB association LH90, at N157C's center, so N157C extends to  $\sim 220$  pc in diameter. X-ray maps (Wang & Helfand 1991a) reveal a bubble  $\sim 120$  pc across, while N157C seen in 21-cm emission extends over  $\gtrsim 200$  pc (Kim et al. 1998), nearly coextensive with the echo. The dust coincides with the H I, but sits outside the X-ray-emitting region.

Two additional bubbles are indicated along the sightline to the SN. Two echoes sit  $\sim 1$  kpc in front of SN 1987A. These and N157C may form opposite sides of a giant bubble 600 pc across. Dense clouds about 100 pc in front of SN1987A bound a large region evacuated around SN 1987A, and therefore may contain the bubble blown by the SN and its companions. We also notice components at 269 and  $301 \text{ km s}^{-1}$  within  $\sim 20''$  of SN1987A. These structures are probably due to the red supergiant wind, and are treated in a separate paper.

High resolution ( $10 \text{ km s}^{-1}$ ) [N II] spectra, sampled every 13 arcsec in a  $6'$  square around SN1987A were obtained on the CTIO 4m/Echelle (Xu & Crofts 1999). Three components,  $V_{hel} = 265, 277$  and  $285 \text{ km s}^{-1}$ , were identified as N157C, having the same morphology as the echoes corresponding to the shell centered on LH90. Wang and Helfand (1991b) reported X-ray emission in N157C, corresponding to very hot gas; therefore, N157C may be in the energy-conservation stage. The radius of this superbubble is found to expand at  $10 \text{ km s}^{-1}$ , with a lifetime of  $6 \times 10^6$  years and a total energy of  $3 \times 10^{51}$  ergs, determined according to superbubble theory (McCray & Kafatos 1987):  $R_S =$

97 pc  $(N_*E_{51}/n_0)^{1/5}t_7^{3/5}$  (Eqn. 1), and  $V_S = 5.7 \text{ km s}^{-1} (N_*E_{51}/n_0)^{1/5}t_7^{-2/5}$  (Eqn. 2). Dividing one equation by the other,  $t_7 = (R_S V_S) / [(5.7 \text{ km s}^{-1})(97 \text{ pc})]$  (Eqn. 3), where  $n_0$  is the gas atomic density, the age  $t_7 = t/10^7$  yr,  $R_S = 100$  pc, and  $V_S = 10 \text{ km s}^{-1}$ . We estimate N157C to have  $t = 6$  Myr, still very young.

The morphology of  $V_{hel} = 235 \text{ km s}^{-1}$  component corresponds to the echo 1 kpc in front of the SN, the near side of the 600 pc cavity. With nothing between this structure and N157C, this indicates a bubble expanding at  $\sim 40 \text{ km s}^{-1}$  relative to the centroid of N157C. We suspect that this 600 pc bubble has blown out of the LMC disk: not only is its wall fragmented, but Wang and Helfand (1991b) report that this region has soft X-ray emission much higher than the background but much lower than other young superbubbles in 30 Doradus. Also, 600 pc is one of the largest superbubbles ever observed in the LMC, and approaches the limit on the superbubble size imposed by LMC disk thickness. McCray and Kafatos (1987) suggest that superbubbles breaking out of the galaxy, distort by gravitational instability, collapse to form giant clouds, and ignite propagating star formation. LH90 may have formed in the collapse of the 600 pc bubble.

If this superbubble blew out in its snow-plow stage, prior to this it was described in terms of the time ( $t_c$ ) and expansion radius ( $R_c$ ) beyond which cooling becomes important in the interior e.g. post-adiabatically, according to McCray and Kafatos:  $R(t) \approx R_c(t/t_c)^{1/4}$ , for  $R_c = 50 \text{ pc } \zeta^{-0.9}(N_*E_{51})^{0.4} n_0^{-0.6}$ , and  $t_c = 4 \times 10^6 \zeta^{-1.5}(N_*E_{51})^{0.3} n_0^{-0.7}$ , where  $\zeta \approx 0.3$  is metallicity,  $N_*$  is number of stars  $\geq 7M_\odot$ ,  $E_{51} = E/10^{51} \text{ ergs}$ , and  $n_0 \approx 0.35$  is gas atomic density. Let's guess  $N_* = 50$  (like N157C) and  $E_{51} = 1$ , hence  $t_c = 160$  Myr, and  $R_c \approx 1.3$  kpc, much bigger than 300 pc. Therefore, this bubble was probably hot when it blew out, implying an age at blowout of  $\sim 10$  Myr from eq. 3, or 15 Myr using eq. 1. This appears older than N157C, and may have created LH90.

Two components,  $V_{hel} = 255$  and  $245 \text{ km s}^{-1}$  are identified as the inner major echo  $\sim 130$  pc in front of SN1987A. Two components,  $300$  and  $313 \text{ km s}^{-1}$ , may be the far side of a bubble in which SN1987A exploded. They do not correspond to any known absorption lines or echoes (which show up mainly in front), hence probably lie behind the SN. If these components form the far side of a bubble surrounding SN1987A, its radius expands at  $30 \text{ km s}^{-1}$ . If we adopt a 90 pc radius, the bubble's age is  $\sim 2$  Myr (from eq. 1).

We find that the time it took the SN1987A progenitor to move to the current location 300 pc behind N157C (at  $\gtrsim 20 \text{ km s}^{-1}$ ) is comparable to the age of N157C as well as that of the progenitor itself ( $\sim 10^7$  y). This suggests that perhaps LH90 and the progenitor were created in the same previous superbubble collapse. Suggestively, the age the 600 pc giant bubble is consistent with this.

## References

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## Discussion

*David Graff:* What is the density of the different clumps?

*Crofts:* Most of the extinction is in N157C. There is greater extinction in patches of the cloud 1 kpc in front of the SN, but this feature is very non-homogeneous. The wall 100 pc in front of the SN is a few times thinner than N175C. The total amount of material corresponds to about  $2 \times 10^{21} \text{ cm}^{-2}$  in H I.