A Massive Star Odyssey, from Main Sequence to Supernova
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Discovery of narrow O VI emission from SN 1987A

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Abstract. The 1032, 1038 Å emission lines of O VI were detected from SN 1987A by the *FUSE* satellite observations in 2000 and 2001. The lines are extremely narrow (FWHM $< 35\,\mathrm{km\,s^{-1}}$), indicating that the emission is not a by-product of the various circums tellar shock phenomena. The most likely origin of the O VI emission lines is recombination of the SN progenitor's red giant wind that was photoionized by the SN shock breakout on 1987 Feb 23.

1. Observations and data analysis

SN 1987A was observed by the *Far Ultraviolet Spectroscopic Explorer* (*FUSE*) satellite (Moos *et al.* 2000) on 2000 October 7-9 (41 ksec, p.a. = 18°) and 2001 September 18-21 (81 ksec, p.a. = 1°). The narrow (1″.25 x 20″.0) HIRS aperture was used in order to minimize stray light from the nearby companion stars. The analysis used only the data from the LiF1 channel to ensure accurate aperture positioning on the SN 1987A system. The data were processed with CALFUSE-v2.0.5. The O VI 1031.93 Å and 1037.63 Å lines are narrow (FWHM $< 35\,\mathrm{km\,s^{-1}}$) and at a heliocentric radial velocity of +280 $\mathrm{km\,s^{-1}}$ (Figure 1a), which places the emitting gas at rest relative to the SN (Fransson *et al.* 1989). These are the only spectral features in the spectral range 1000 - 1187 Å that are attributed to SN 1987A. The fluxes for O VI 1032,1038 Å derived from the two observations are essentially the same at the two epochs ($F_{O\,\mathrm{VI}} = 3.3 \pm 0.6$ and $2.9 \pm 0.5 \times 10^{-15}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$ in 2000 and 2001, respectively).

Simultaneous spectra obtained in the other *FUSE* apertures, positioned about 100″ from SN 1987A, show nothing at the O VI wavelengths, eliminating diffuse emission in the LMC as a possible source of the O VI feature. The interstellar line profiles of Star 3 (1″.6 from SN) show that ISM absorption (*e.g.*, O VI, H_2 and C II) has a negligible effect on the O VI lines.

O VI is the highest ionization state yet detected in line emission from the SN 1987A circumstellar material. The narrow width of the lines indicates that

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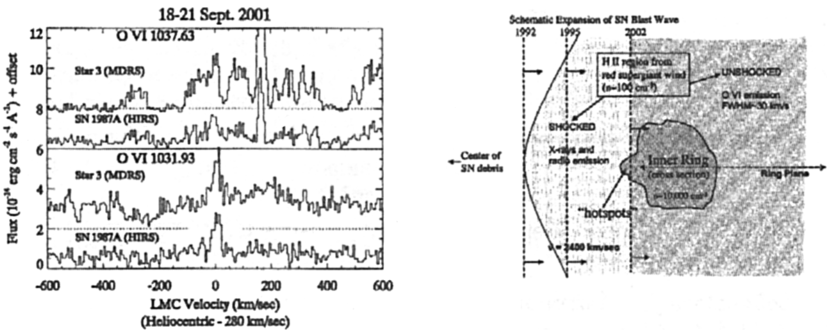

Figure 1. *FUSE* spectra of SN 1987A and Star 3 showing narrow O VI emission (*left*), and a cartoon of the CS environment (*right*).

the O VI emission does not originate in shocked gas where the SN debris collides with circumstellar material (FWHM Ly$\alpha \approx 10\,000\,\mathrm{km\,s^{-1}}$). This is the remnant of mass lost in the red giant phase of the progenitor (Sonneborn *et al.* 1998). There are also at least 16 hot spots (R. Kirshner, private communication) where the forward shock is colliding with the dense inner ring ($n_e > 20\,000\,\mathrm{cm^{-3}}$, Fransson *et al.* 1989; Sonneborn *et al.* 1997). Emission from these hot spots have FWHM $= 200 - 400\,\mathrm{km\,s^{-1}}$ (Michael *et al.* 2000).

The O VI emission probably originates from *unshocked* gas in the H II region of very low density ($n_e < 100\,\mathrm{cm^{-3}}$) material near the inner circumstellar ring that was ionized by the supernova outburst in 1987. This is the unshocked part of the same material that the SN debris is colliding with to produce the Lyα emission (see Figure 1b). It is unlikely that the narrow O VI emission is the result of recent re-ionization of circumstellar gas by X-rays produced by shock interactions. The increasing X-ray flux would be accompanied by an increase in O VI flux, which is not indicated by the present observations. The observed O VI fluxes are in agreement with recombination models (Lundqvist 1999) for the circumstellar material, after the observed O VI fluxes are corrected for interstellar extinction. Additional *FUSE* observations are planned to follow the development of the O VI emission.

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