Monitoring X−Ray Emission from Circumstellar Interaction in SN 1986J

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Abstract

SN1986J ranks as one of the most luminous, X-ray bright supernovae ever observed. The X-ray emission is attributed to circumstellar interaction with the dense wind from its red supergiant progenitor star. Because X-ray bright supernovae are rare and relatively faint, only a small number have been observed in X-rays at an age of more than a year or two. We present preliminary results from a recent Chandra observation of SN1986J which, combined with earlier ASCA and Rosat/PSPC data, suggest that spectral evolution has occurred. In particular, the X-ray absorbing column appears to have increased significantly during the intervening ~ 5 years. Recent radio spectrum observations by Bietenholz, Bartel & Rupen (2002) appear consistent with a corresponding increase in radio frequency absorption.

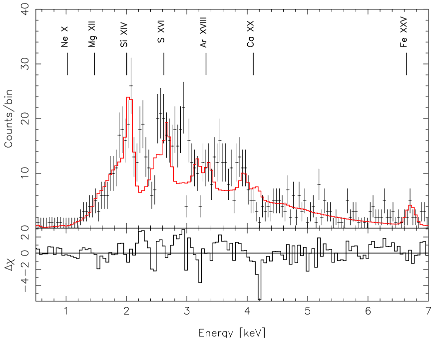

Fig. 2.– Nov 2000 Chandra ACIS-S X-ray spectrum of SN1986J. For comparison, the solid curve is a heavily absorbed **`vmekal`** thermal spectrum, with $N_H = 3.5 \times 10^{22}$ cm^{-2}, $kT = 3.3$ keV, and with 5 times solar abundances of Si, S, Ar and Ca. Note that several spectral features are not described by the model. The precise origin of these spectral features is unclear.

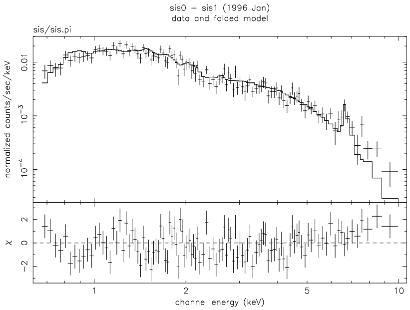

Fig. 5.– January 1996 ASCA SIS spectrum of SN1986J. The fitted model is a thermal **`mekal`** spectrum with kT = 5.5 keV, abundance 0.6 solar and absorbing column $N_H = 0.5 \times 10^{22}$ cm^{-2}; a soft component with kT=0.62 keV to account for diffuse thermal emission from the host galaxy. Note that the X-ray line flux appears significantly stronger in the Nov 2000 Chandra observation (Figure 2). This difference may be due in part to source contamination – because of its broad point-spread function, the ASCA spectrum contains significant contamination from an ultraluminous X-ray source 27 arcsec north of the supernova and from diffuse emission in the host galaxy.

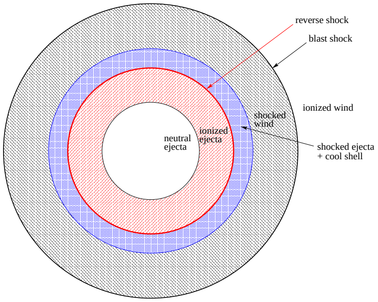

Fig. 1.– Interaction of cool, freely expanding supernova ejecta with a circumstellar wind (Chevalier & Fransson 1994). The red-supergiant progenitor star of SN 1986J probably had a massive stellar wind with $\dot{M} \approx 2.4 \times 10^{-4} M_{\odot}$yr^{-1} (Weiler, Panagia & Sramek 1990) and a wind velocity of about 10 km s^{-1}. The interaction between the ejecta and the wind generates forward and reverse shock waves which bound the shocked wind and ejecta. Radiative cooling downstream from the reverse shock front can lead to a cool shell which absorbs X-rays and emits low-ionization optical lines. X-rays from the reverse shock create a highly ionized region in the ejecta just inward of the reverse shock. Free-free absorption in the interaction shell may cause the radio spectrum inversion seen above 10 GHz by Bietenholz et al. (2002).

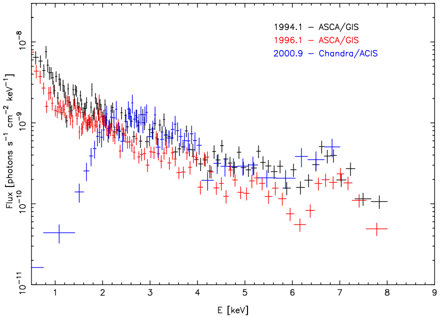

Fig. 3.– Evolution of the 0.5-8 keV X-ray spectrum. ASCA/GIS spectra from 1994 Jan (black) and 1996 Jan (red) are shown (Houck & Bregman 1998). The Chandra/ACIS spectrum from 2000 Nov (Bregman & Irwin 2002) is shown in blue. Note that, while there was little change in the overall flux level above 2 keV, the absorbing column increased significantly between 1996 and 2000 from $N_H \approx 0.5 \times 10^{22}$ cm^{-2} to $N_H \approx 3.5 \times 10^{22}$ cm^{-2}. For comparison, earlier Rosat/PSPC observations yielded an absorbing column of $N_H \approx (0.3 - 0.7) \times 10^{22}$ cm^{-2} (Houck & Bregman 1998).

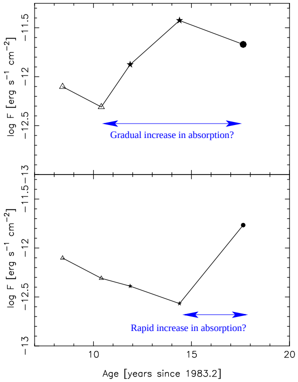

Fig. 6.– The 0.5-2.5 keV light curve, corrected for absorption. Rosat/PSPC observations from age 8.4 and 10.4 years yielded an absorbing column of log$N_H \approx 21.7$, consistent with Galactic absorption plus the contribution from NGC 891. Subsequent Rosat/HRI observations did not constrain the absorbing column. The Chandra/ACIS observation from 2000 Nov (age 17.6 years), yielded log$N_N \approx 22.65$, almost of an order of magnitude larger than the expected line of sight absorbing column, indicating a large increase in the intrinsic absorbing column.

Summary

Recent Chandra X-ray observations yield the first broad-band X-ray spectrum of SN1986J relatively uncontaminated by diffuse emission from the host galaxy and a nearby ULX source. The X-ray spectrum appears heavily absorbed, with $N_H \approx 3.5 \times 10^{22}$ cm^{-2}. Line emission from Si, S, Ar and Ca appears significantly stronger than in the 1996 ASCA observation.

Here, we interpret these data in terms of the circumstellar interaction model of Chevalier & Fransson (1994). Using parameters appropriate to SN1986J in early 1999, the self-similar solution of Chevalier & Fransson (1994) gives a column density of shocked ejecta as large as $N \approx 3 \times 10^{22}$ cm^{-2} when the power-law density profile in the outer parts of the ejecta ($\rho \propto r^{-n}$) is very steep, with $n \approx 50$.

Recent radio spectrum observations by Bietenholz, Bartel & Rupen (2002) also appear consistent with partial free-free absorption with a similar column density. Although somewhat sensitive to the temperature in the absorbing material, the radio data are consistent with a free-free absorbing column of $\sim 3 \times 10^{22}$ cm^{-2}. The model fit also requires that the emission from the back side of the supernova be about twice as bright as the front side. Although somewhat surprising, this asymmetry is not inconsistent with the complex morphology seen in VLBI observations which resolve the expanding shell (Bietenholz et al. 2002).

Because the standard circumstellar interaction model does not explain the narrow line emission ($\Delta v < 600$ km s^{-1}) from H, He, N and Fe seen in SN1986J by Leibundgut et al. (1991), an alternative model was proposed by Chugai (1993). Chugai proposed that the optical and X-ray emission is produced by shocks driven into slow-moving (10 km s^{-1}) clumps in the red-giant wind. His model predicts narrow optical and X-ray line emission, but narrow X-ray line widths have not yet been confirmed. On the other hand, Chugai's model does not explain why the [O I], [O II] and [O III] optical lines were significantly broadened ($\Delta v > 1000$ km s^{-1}).

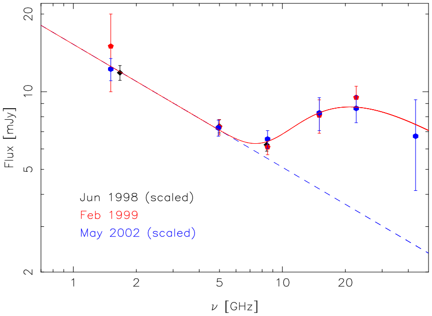

Fig. 4.– The radio spectrum of SN 1986J as measured with the VLA by Bietenholz, Bartel & Rupen (2002). The data from the three different epochs have been scaled to the 1999 epoch using the overall time dependence $t^{-2.94}$ derived by Bietenholz et al. The smooth curve (red) shows a fitted model of the form

$$S(\nu) = S_0(\nu)\left(1 + f e^{-\tau_\nu}\right) \qquad (1)$$

where $S_0(\nu) = A\nu^{-\alpha}$ is the synchrotron emission and τ_ν is the optical depth due to free-free absorption. This approximates a model in which the synchrotron emission from the back side of the supernova is absorbed in a shell with optical depth $\tau_\nu \approx 1$ at about 10 GHz. The fit yields $\alpha = 0.48 \pm 0.08$ and requires that the emission from the back side of the supernova be about twice as luminous as the front side. If the free-free absorbing material has $T \sim 10^5$ K, this is consistent with $Z^2 n_e n_i L \approx 10^{29}$ so, for an absorbing path length $L \approx 10^{16}$ cm and $Z = 1$, the implied density is $\sim 3 \times 10^6$ cm^{-3}. The free-free absorbing column is then $\sim 3 \times 10^{22}$ cm^{-2}, which is comparable to the intrinsic X-ray absorbing column derived from the recent Chandra observation. These details are somewhat sensitive to the temperature in the free-free absorbing material because the free-free optical depth, $\tau_\nu \propto T^{-3/2}$. If the free-free absorbing material is cooler, with $T \sim 10^4$ K, the required density increases by about a factor of 6.

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