X-RAY OBSERVATION OF RADIO SUPERNOVA SN1979C BY ASCA

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Abstract. We report on the X-ray observation of the radio selected supernova SN1979C carried out with ASCA in December 1997. The supernova of type II\textsubscript{L} was first observed in the optical and occurred in the weakly barred, almost face on spiral galaxy NGC 4321 (M100) which is at a distance of 17.1 Mpc, and contains at least three other supernovae discovered in this century. No point source was detected at the radio position of SN1979C in a 3' diameter half power response circle in a 27.3 ks SIS exposure. The background and galaxy subtracted SN signal had a 3\sigma upper limit to the count rate of 1.2\times10^{-3} cps in the full ASCA SIS band (0.4-10.0 keV). These measurements give the first ever x-ray flux limit of a Type II\textsubscript{L} SN in the higher energy band (≥ 2 keV) which is an important diagnostic of the outgoing shock wave ploughing through the circumstellar medium.

I X-RAY AND RADIO EMISSION FROM SUPERNOVAE

The observation of X-rays provides the most direct view of the region of interaction between the ejecta from a core-collapse supernova (SN) and the circumstellar medium of the progenitor star (see e.g. Chevalier & Fransson 1994). This circumstellar interaction gives rise to copious X-ray emission within days to months of the supernova explosion, in contrast to X-ray emission that occurs in the later supernova remnant (SNR) during the free expansion, adiabatic or radiative phases. The circumstellar matter is heated by the outgoing SN shock wave while the SN ejecta are heated by a reverse shock wave. At the same time, this interaction is expected to produce nonthermal radio radiation; in recent years several young SNe have been found to be emitting in the radio bands (see Weiler et al. 1998). Relativistic electrons and magnetic fields in the region, which give rise to the radio emission, may be built up by acceleration in the shock wave and field amplification through Rayleigh-Taylor instabilities. The detection of strong radio emission from a SN provides good empirical evidence of circumstellar interaction of ejecta, and
such a SN is a probable emitter at X-ray wavelengths as well. The temperature behind the outgoing shock is typically 10 keV and therefore the bulk of this radiation detected by ASCA would appear in its higher energy bands. In the circumstellar interaction model, the shocked supernova ejecta is the dominant source of X-rays because of its higher density and lower temperature.

II OBSERVED PROPERTIES OF SN1979C BY ASCA AND PREVIOUS MISSIONS

The supernova is thought to have originated from a red supergiant progenitor with $M_{ZAMS} = 17 - 18 \pm 3 M_\odot$ (Van Dyk et al. 1999). An observation by the Einstein HRI in December 1979 established only a 3σ upper limit of $L_x \leq 8.8 \times 10^{39}$ erg s$^{-1}$ (Palumbo et al. 1981). An analysis of the combined Einstein data (of total duration 41.3 ks) between days 64 and 454 after explosion gave an upper limit of $5.9 \times 10^{39}$ erg s$^{-1}$ (Immler et al. 1998, assuming a 5 keV coronal plasma spectrum). The foreground column density of neutral hydrogen is $N_H = 2.3 \times 10^{20}$ cm$^{-2}$ (Immler et al. 1998). An X-ray observation by the ROSAT HRI detected a source coincident with the position of SN1979C for the first time, more than 16 years after the explosion (source H25, Immler et al. 1998). The corrected ROSAT HRI position is at $\alpha = 12^h 22^m 58.5^s, \delta = +15° 47' 53.5''$ (J2000), within about 2.7'' with the position determined by radio interferometry (Penhallow 1980). The measured count rate is $6.9 \times 10^{-4}$ cps. The corresponding 0.2 - 2.4 keV flux and luminosity are $F_x = 2.9 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$ and $L_x = 1.0 \times 10^{39}$ erg s$^{-1}$ respectively, assuming a 5 keV thermal spectrum.

In this paper, we report on an X-ray observation of SN1979C using ASCA. These observations provide the first constraint on the X-ray flux in the energy band higher than 2 keV for a Type II$L$ SN. NGC 4321 was observed by ASCA on December 18-19, 1997. The Solid State Imaging Spectrometers (SIS) had useful exposure times of 24.3 ks (SIS0) and 25.2 ks (SIS1); the Gas Scintillation Imaging Spectrometers (GIS) had exposure times of 27.5 ks (GIS2) and 28.1 ks (GIS3). A combined SIS0+SIS1 image is shown in Figure 1. A 3' diameter half power response circle is shown superposed at the location of SN1979C. Emission associated with the known agglomeration of sources in the central region of NGC 4321 is clearly seen. On the other hand, no source is evident in the circle. A point source detection task failed to detect SN1979C in either the SIS or GIS image.

Placing an upper limit on the ASCA band flux from SN1979C is complicated by contamination from the integrated flux from the sources in the nuclear region of NGC 4321. The center of NGC 4321 is only 100 arc seconds from SN1979C, resulting in a non-negligible overlap of point responses. Furthermore, the emission from the galaxy is clearly broader than that produced by a single unresolved source. Thus determining a count rate from SN1979C requires subtraction both of diffuse background and the contribution of the integrated flux from the other sources in the galaxy.
An analysis of SIS1 data of 25 ks exposure, combined with the above 24 ks exposure for SIS0, gives a combined upper limit to the count rate of $1.2 \times 10^{-3}$ cps. The corresponding upper limit to the combined data from GIS2 and GIS3 (28 ks each) gives $8 \times 10^{-4}$ cps. The net exposures, total galaxy- and background-subtracted net source counts and their $\sigma$ errors together with the $3\sigma$ upper limits on the SN count rates for SIS (S0 and S1) and GIS (G2 and G3) are given in Table 1. The above SIS combined upper limit corresponds to a flux limit of $3.5 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$ in the 0.4-10.0 keV band for a Thermal Bremsstrahlung spectrum with $T = 3$ keV ($N_H = 3 \times 10^{20}$ cm$^{-2}$). In Table 2 we give the detected x-ray source fluxes (or the upper limits) for three separate missions Einstein, ROSAT and ASCA along with their respective band-passes and luminosities at different epochs.

### III DISCUSSION

Until now almost all SNe detected in the X-ray were measured in the lower energy band (0.1 - 2.0 keV) of ROSAT. Our reported measurement of SN1979C here gives the flux limit in the higher energy band ($> 2$ keV) for the first time for a Type II$_L$ SN (the only other X-ray detected Type II$_L$ SN is SN1980K). Because the outgoing shock wave expanding through circumstellar material generally creates a higher temperature emission spectrum compared to the reverse shock wave, the measurement of SN X-ray fluxes in the higher energy bands constitutes as important goal.

Both the ROSAT detection of the x-ray emission as well as our ASCA upper limit referred to above are well below its expected value if we scale its X-ray emission with respect to another type II-L SN active in the radio and X-ray, e.g. SN1980K. This lower than expected $L_x/L_R$ may mean that the X-ray and radio emission properties of SNe could be quite variable from one environment to another, i.e. the emission in the two bands are not directly scalable in a universal way or that the X-ray emission could be more strongly time variable than the radio emission. The shock may be interacting with local cloudlets to give enhanced thermal X-ray emission at certain epochs whereas the radio radiation may be coming from a more global arrangement of amplified magnetic fields and synchrotron radiating accelerated electrons with long lifetimes.

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TABLE 1. ASCA observation of SN 1979C in NGC4321 in December 1997

| Instrument | Exposure (ks) | Band (keV) | Net source counts | Counts/sec (3σ lim) | Flux |
|------------|---------------|------------|-------------------|---------------------|------|
| SIS: S0 + S1 | 24 + 25 | 0.4-10.0 | 29.6 ± 20 | ≤ 1.2 × 10⁻³ | ≤ 6.3 × 10⁻¹⁴ |
|             |               | 2.0-10.0   | 13.3 ± 11      | ≤ 6.7 × 10⁻⁴ | ≤ 3.5 × 10⁻¹⁴ |
| GIS: G2 + G3 | 28 + 28 | 1.0-10.0 | −3.5 ± 16     | ≤ 8.4 × 10⁻⁴ | ≤ 4.4 × 10⁻¹⁴ |
|             |               | 2.0-10.0   | −12.0 ± 11    | ≤ 6.2 × 10⁻⁴ | ≤ 3.2 × 10⁻¹⁴ |

TABLE 2. SN 1979C X-ray flux and upper limits from different missions

| Mission   | Date    | Exp (ks) | Band (keV) | Flux (erg cm⁻² s⁻¹) |
|-----------|---------|----------|------------|---------------------|
| Einstein HRI | Dec 1980 | 41       | 0.1 - 4.5  | ≤ 1.7 × 10⁻¹³       |
| ROSAT HRI  | Jun 1995 | 42.8     | 0.1 - 2.4  | 2.0 × 10⁻¹⁴ (TB 3keV) |
| ASCA SIS   | Dec 1997 | 49       | 2.0 - 10.0 | ≤ 3.5 × 10⁻¹⁴ (TB 3keV) |

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FIGURE 1. ASCA SIS image of the galaxy NGC4321 (M100) containing the SN1979C