X-Ray and Radio Bright Type Ic SN2002ap –
A Hypernova Without an Associated GRB

F.K. Sutaria[1], A. Ray[2], and P. Chandra[2,3]

[1] The Open University, Milton Keynes, MK7 6AA, U.K.
[2] Tata Institute of Fundamental Research, Bombay 400 005, India
[3] Joint Astronomy Programme, Indian Institute of Science, Bangalore 560 012, India

Abstract. Combined X-ray (0.3 – 10 keV) and Radio (0.61 and 1.42 GHz) observations of the type Ic SN 2002ap are used here, to determine the origins of the prompt X-ray and radio emission from this source. Our analysis of the XMM-Newton observations suggests that the prompt X-ray emission originates from inverse Compton scattering of photospheric thermal emission by energetic electrons. In addition, we use the reported multifrequency VLA observations of this supernova. We compare the early radiospheric properties of SN 2002ap with those of SN 1998bw (type Ic) and SN 1993J (type IIb), to contrast the prompt emission from a GRB associated SN and other supernovae without such counterparts.

1   Introduction

The nature and origins of X-ray and radio emission from supernovae is a subject of much interest. This is mainly because early (few days to years) emission in these bands occurs from a shocked, dense CSM around the progenitor, and this can be used to infer the mass loss rate and the nature of the progenitor. Further, early synchrotron radio emission can also occur from relativistic electrons in amplified magnetic fields within the ejecta itself and its detection constrains theoretical models on emission and reabsorption mechanisms in shocked matter.

SN2002ap is an energetic ($E_{\text{explosion}} \sim 4 - 10 \times 10^{51}$ ergs [8]), one of the closest (in M 74, distance $d = 7.3$ Mpc [12]), type Ic SN which exploded on Jan. 28 ± 0.5, 2002 [8]. It was also one of the earliest detections in multiple bands, as in SN1987A and SN1993J. Interest in highly energetic ("hypernova") type Ib/Ic SNe has been intense after the temporal and positional near-coincidence of GRB 980425 with the type Ic SN1998bw implied a possible GRB-SN connection for the long duration GRBs.

We report our findings from the combined, near-simultaneous observations of SN2002ap with XMM-Newton, GMRT [14] and VLA [1]. For a detailed analysis of the X-ray data and early 610 and 1420 MHz observations of SN2002ap with GMRT (Giant Meterwave Radio Telescope), we refer the reader to [14].

2   XMM-Newton and GMRT Observations and Analysis

SN2002ap was detected by XMM-Newton EPIC CCDs between 5.025 to 5.42 days after explosion [10] (See also [13], [14]), with an effective exposure time

of $\sim$ 25.5 ks. After subtracting the contribution from the nearby "contaminating" X-ray source CXU J013623.4+154459 in the 50'' spectral extraction region on the EPIC-PN CCD, we estimate the 0.3-10 keV flux from SN2002ap as $1.07^{+0.63}_{-0.31} \times 10^{-14}$ ergs cm^{-2} s^{-1}. Because the source is very faint, both thermal bremsstrahlung model ($N_H = 0.49 \times 10^{22}$ cm^{-2}, $kT = 0.8$ eV) and a simple powerlaw ($N_H = 0.42 \times 10^{22}$ cm^{-2}, spectral index $\alpha = 2.5$) fit the sparse spectra well, with $\chi^2/d.o.f. = 1.2/20$. Simultaneous XMM-Newton Optical Monitor (OM) observations of M74 in the UVW1 band yield a flux of $(7.667 \pm 0.002) \times 10^{-15}$ erg cm^{-2} s^{-1} Å^{-1}.

SN 2002ap was observed with the Giant Meterwave Radio Telescope (GMRT) at 0.61 GHz 8.56 days after explosion, and at 1.42 GHz 42 days after explosion. The exposure time for each observation was 4 hours. We did not detect the SN in either observation and the upper limits on the flux have been tabulated in Table 1.

3   Results and Discussion

The earliest radio detection of SN2002ap was $\sim$ 4.5 days after the explosion, in the 8.46 MHz band, and the frequency of the peak radio flux declined gradually from 8.46 GHz to 1.43 GHz over a period of 10 days from the explosion epoch (VLA observation, [1]) – a clear indication of the presence of relativistic electrons. This wavelength dependence of the radio turn-on can be due to either free-free absorption (FFA) in the thermally excited, homologously expanding matter overlying the interaction region, or synchrotron self-absorption (SSA) by the relativistic e^- responsible for radio emission, accelerated in regions close to the expanding interaction region [3]. In the case of SN 2002ap, the combined GMRT upper limits [14] and VLA observations [1] are best fit by the SSA model (Fig. 1) in the optically thin, spherically symmetric limit, consistent with the early optical observations. The corresponding values of spectral index α, magnetic field B, and the radius of the radiosphere R_r are tabulated in Table 2.

Table 1. GMRT observations of SN2002ap

Date of Obs.	ν (MHz)	Resolution (arcsec)	2σ Flux mJy	RMS mJy/ beam
5 Feb'02	610	9.5 x 6	< 0.34	0.17
8 Apr'02	1420	8 x 3	< 0.18	0.09

Table 2. Best Fit parameters of the SSA Model for SN2002ap on day 8.96. F_p is the peak flux emitted at frequency ν_p, B is the ambient magnetic field in the radiosphere at radius R_r.

α	ν_p GHz	F_p μJy	R_r cm.	B G
0.8	2.45	397	3.5×10^{15}	0.29

The early radio and X-ray turn-ons imply that the mass-loss rate of the progenitor was relatively low, at $\dot{M} \leq 6 \times 10^{-5}$ $M_\odot$ yr^{-1} ([14], using VLA detection by [1], and the SSA models for X-ray absorption by [2]).
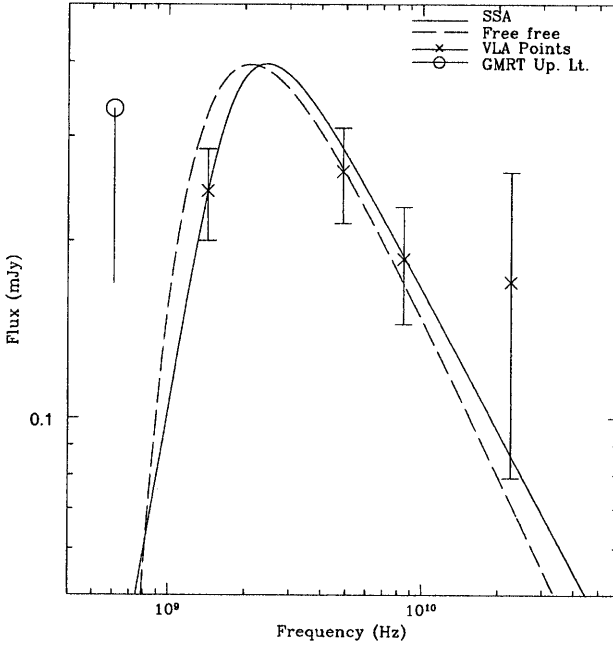
Fig. 1. Best fit synchrotron self-absorption spectrum (solid line) for SN2002ap radio emission on day 8.96 with energy spectral index = -0.8. Also shown is the free-free absorption model (dashed line) with parameters used taken from [1]. The VLA data is marked with a "×", while the GMRT upper limit at 610 MHz is marked by a "○"

Table 3. Comptonising Plasma Properties at t = 5d with x-ray energy index $\gamma = 3$ and $R_{opt} = 3.4 \times 10^{14}$ cm

Scenario	$\dot{M}_{-5}$	u_{w1}	τ_e	T_e
	$\times 10^{-5}\ M_\odot\ yr^{-1}$	10 km/s	$\times 10^{-4}$	$10^9\,K$
Wolf-Rayet	1.5	58	4	2
Case-BB Binary	10	58	25	1.5

3.1 Origins of X-Ray Emission

Using the optical observations of SN 2002ap [9] at the same epoch as the XMM-Newton observation, we find that the radius of the optical photosphere $R_{opt.} = 3.4 \times 10^{14}$ cm. We note that the radiosphere in the SN (Table 2) was well outside this optical photosphere at a similar epoch. However, Compton optical depth considerations ([14], [4]) suggest that the X-ray production region is closer to the optical photosphere.

Table 4. Least-squares fitted SSA equipartition parameters for SN1993J, SN1998bw and SN2002ap $\sim$ 11 days after explosion.

SNe	ν_p	F_p	θ_{eq}	U_{eq}	B_0	R_0
	GHz	mJy	μ as	$\times 10^{44}$ ergs	G	$\times 10^{15}$ cm
2002ap	2.45	0.48	39.0	6.9	0.47	4.80
1998bw	5.5	50.4	112.4	35000	0.23	68.4
1993J	30.5	22.3	17.6	5.0	3.54	1.08
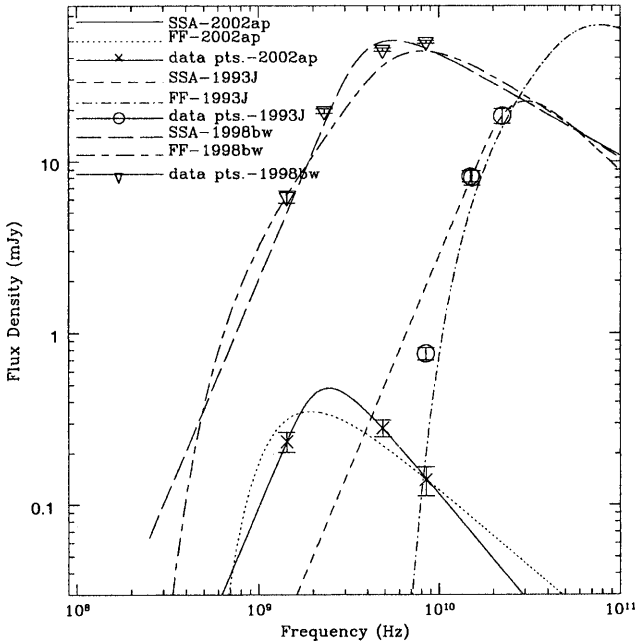
Fig. 2. Comparison of spectra of three SNe (SN1993J [15], SN1998bw [6] and SN2002ap [1]) near day 11 after explosion. Solid lines show the best fit synchrotron self absorption model and dashed lines show the corresponding free free absorption model

Free-free emission mechanisms are likely to be dominated by Compton cooling. The high ejecta velocity ($v \geq 20\,500$ km s^{-1} on day 3.5), coupled with high implied temperature of the shocked circumstellar medium ($T \sim 10^9$ K) and a limited cool absorbing shell suggests that the high energy photons would have a flat tail, up to $\sim$ 100 keV. By contrast, the X-ray spectra is quite soft with thermal bremsstrahlung $T_B = 0.8$ keV. Hence, free-free absorption is unlikely to explain the observed X-ray spectra. However, Compton cooling is the dominant radiative mechanism when the optical photospheric temperature is $T_{\text{eff}} \geq 10^4$ K.

Using the Monte Carlo simulations of Compton scattered spectra for the shocked CSM [11], we find that the observed flux by XMM can be accounted for both in terms of energetics and spectrum, if the electron plasma has $T_e \sim$ few times of 10^9 K (See [14]). Table 3 gives the properties of Comptonised plasma for two likely progenitor systems ([7,5]) for this event.

Finally, we compare the rarely observed early radio spectra of SN2002ap with that of SN1993J (type IIb) and SN1998bw (type Ic, GRB-association), 11 days after explosion. In Fig. 2, we fitted the SSA model to the data, and in Table 4 we estimate the energy U_{eq} in the radiating plasma and the magnetic field B_0, from equipartition arguments, and determine corresponding the angular radius θ_{eq} of the radio-sphere. Comparing θ_{eq} for the 3 SNe, the hydrodynamic shock in SN1998bw causes more rapid expansion leading to larger radio-sphere, while SN2002ap is similar to SN1993J across type classification irrespective of presence or absence of H- and He-envelope in the progenitor.

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