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XMM-Newton and VLT observations of SN 1995N

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Abstract. We present the results of the first *XMM-Newton* observation of the interacting type IIn 1995N. The X-ray flux has dropped at a value about an order of magnitude lower than that of a previous *ASCA* observation of January 1998. The X-ray spectrum shows statistically significant evidence for the presence of two distinct thermal components at different temperatures. From these temperatures we derive that the exponent of the ejecta density distribution is $n = 6.4$. Coordinated optical and infrared observations allow us to reconstruct the simultaneous infrared to X-ray flux distribution of SN 1995N. We find that, at ~8 years after explosion, the direct X-ray thermal emission due to the wind/ejecta interaction is ~ 5 times larger than the total reprocessed IR/optical flux.

Key words. Supernovae: general – Supernovae: individual: SN 1995N – X-rays: stars – X-rays: individual: SN 1995N

1. Introduction

Among all core-collapse supernovae (SNe), the subclass of Type IIn SNe shows prominent narrow H emission lines that are thought to originate from the reprocessing of radiation generated by a violent collision of the ejecta with a dense surrounding gas released by the progenitor star in a previous evolutionary stage. The pressure and temperature behind the shock, generated as a consequence of the collision bewteen the ejecta and the surrounding medium, are sufficiently high that the post-shock ejecta and circumstellar material (CSM) may become powerful X-ray emitters. In the standard model of X-ray emission from circumstellar interaction (Chevalier & Fransson 1994) the observed radiation arises mainly from the shell behind the reverse shock. The forward shock produces a hotter shell ($\sim 10^9$K), while the reverse shock produces a denser, cooler ($\sim 10^7$ K) shell, from which the observable X-ray emission arises. If the progenitor stellar wind is clumpy, the interaction of the forward shock with clumps of gas can give rise to cooler X-ray emission (Chugai 1993).

Only ~20 SNe have been detected at X-ray energies. Of special interest is the case of SN 1995N, discovered in May 1995, several

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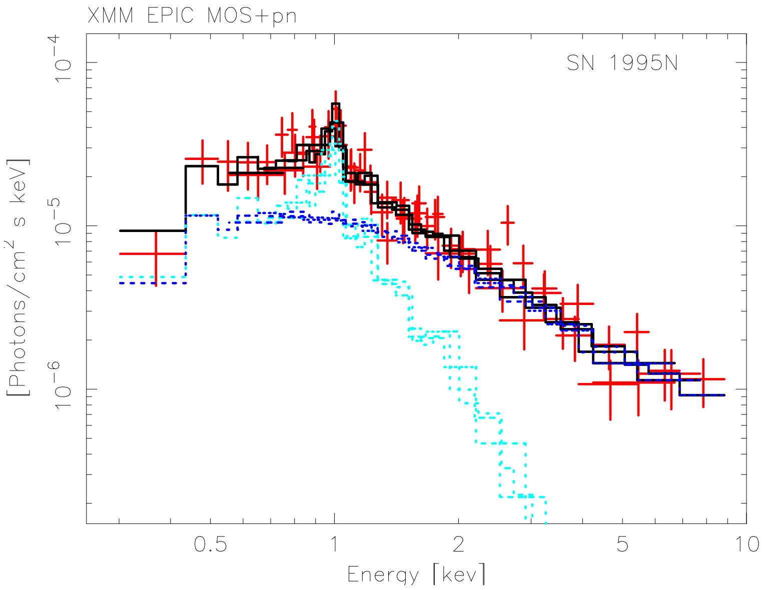

Fig. 1. *XMM* EPIC MOS and pn spectra of SN 1995N in the [0.2–10.0] keV interval, along with the best fitting continuum model (solid line) and the two MEKAL components (dotted lines).

months after the explosion (Pollas et al. 1995; Benetti et al. 1995). Fransson et al. (2002) assumed an explosion date of 1994 July 4, about 2 years before the first X-ray observation. X-ray emission has been detected with ROSAT and ASCA at different epochs. The X-ray light curve from 2 to 3.5 years after explosion suggests that the CSM is distributed inhomogeneously and that the average X-ray luminosity does not decline significantly (Fox et al. 2000; Chugai 1993). Here we present the results of a *XMM-Newton* observation of SN 1995N, performed on July 2003, along with those from a simultaneous optical/infrared observation performed at ESO VLT.

2. From X-rays to Infrared

We observed SN 1995N with *XMM-Newton* on July 27–28, 2003 (72 ks, ID 0149620201; see Zampieri et al. 2005, for details on data reduction and analysis). *XMM* EPIC MOS and pn spectra are shown in Figure 1. The best fit is obtained with a dual MEKAL[1] model, convolved with interstellar absorption (column density of the interstellar medium $N_H = 1.3 \times 10^{21}$ cm^{-2}, temperatures of the two MEKAL components $kT \simeq 0.8$ and 9.5 keV, respectively). The improvement over a single componet model is significant at the 4.1 σ level. Taking the best-fitting spectral model, the unabsorbed flux in the 0.2-10.0 keV band is $F = 1.8 \times 10^{-13}$ erg cm^{-2} s^{-1} (L = 9.4×10^{39} erg s^{-1}, at the distance of the host galaxy d=24 Mpc), about an order of magnitude lower than that of the *ASCA* observation of January 1998.

After ~8 years SN 1995N is still well detected in all optical/IR bands (BVRIJHK) of our coordinated ESO VLT observation of July 30, 2003. These data confirm that this object is one of the brightest Type IIn SNe ever detected also in the optical domain and that the magnitude decline is rather slow (~ 0.1 – 0.2 mag/100 days), as expected if the optical/IR light curve is powered by the interaction of the ejecta with the CSM. The significant excess in the *K* band is attributed to reprocessing of the optical and X-ray radiation by dust formed in the ejecta.

During the *XMM-Newton* observation of SN 1995N a series of exposures with the OM was

[1] The MEKAL model is the spectrum emitted by an optically thin, thermal plasma.

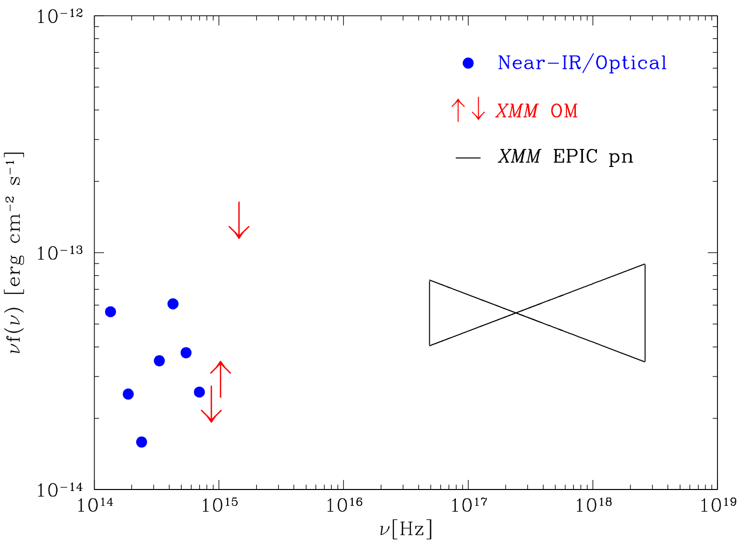

Fig. 2. Infrared through X-ray flux distribution of SN 1995N from our coordinated ESO-*XMM* observations. The points represent the VLT BVRIJHK photometry, while the arrows are the OM limits for the *u*, UVW1 and UVW2 bands, from left to right respectively.

also taken. Nothing is visible at the position of SN 1995N except for a faint object detected inside the X-ray error box in the $UVW1$ image ($F_{UVW1} \gtrsim 6 \times 10^{-15}$ erg cm^{-2} s^{-1}).

The simultaneous broadband flux distribution of SN 1995N from the IR to the X-ray bands is reported in Figure 2.

3. Conclusions

We observed SN 1995N with *XMM* at ~8 years after the explosion. The decline of an order of magnitude in the X-ray flux is signalling that SN 1995N has probably started to evolve towards the remnant stage. The EPIC spectrum shows evidence for the presence of two distinct thermal components at different temperatures. If they are interpreted as the temperatures of the gas below the reverse/forward shock, we derive that the exponent of the ejecta density distribution is $n = 6.4$. From the fluxes of these two spectral components we estimate that the mass loss rate of the progenitor is $\dot{M} \sim 2 \times 10^{-4} M_\odot$ yr^{-1}, at the upper end of the interval exhibited by red super-giants. The X-ray data were obtained within the framework of a multiwavelength (IR/optical/UV/X-ray) observational campaign. The simultaneous infrared to X-ray flux distribution of SN 1995N shows that the direct X-ray thermal emission due to the wind/ejecta interaction is ~ 5 times larger than the total reprocessed IR/optical flux. At the epoch of our multi-wavelength observation, the IR emission has greatly diminished.

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