Spectroscopic and Photometric Observations of SN IIn 1995N and Energy Estimates

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Abstract. We present the results of a long–term program of monitoring of the famous SN 1995N, observed both in photometry (*UBVRIJHK* bands) and optical spectroscopy. The observations span a period of about 9 years. These new data, together with others available in literature, extend from the X–ray wavelengths to the radio, and allow to estimate the total energy radiated by the supernova over a decade after its explosion.

1. Introduction

Type IIn Supernovae (SNe IIn) form an interesting group of objects whose observed properties (high luminosity, slow light curve decline, spectra with multi-component lines, with very narrow emission features and without broad P–Cygni absorptions) are interpreted in terms of quick reprocessing of the mechanical energy of the SN explosion via interaction between the SN ejecta and a pre–existent circumstellar medium (CSM). Most IIn events are thought to be core–collapse explosions. However, recently, some authors proposed that also thermonuclear SNe may explode within a H–rich CS environment, producing IIn–like spectra (see SN 2002ic, e.g. Hamuy et al. 2002; Wang et al. 2004).

SN 1995N, discovered when it was about 10 months old (Fox et al. 2000), is one of the best observed SNe IIn so far. Due to its vicinity, the peripheral location in the host galaxy and the exceptional duration of the interaction ejecta–CSM, it is an ideal target for a long–term monitoring at all wavelengths. SN 1995N has been studied from X–ray to radio wavelengths. Briefly, X–ray band observations are reported by Fox et al. (2000), Mucciarelli et al. (these proceedings) and Zampieri et al. (in preparation). UV–optical spectroscopy is presented by Fransson et al. (2002), late time optical photometry by Li et al. (2002), and near IR photometry by Gerardy et al. (2002). Moreover, a few sparse radio observations are available in Van Dyk et al. (1996) and in the web site of K. W. Weiler and the radio–SN collaboration[1].

We have increased the available data set of SN 1995N with new optical and IR observations, obtained over a period of ∼9 years (1995–2004). These new data will be discussed in detail in a forthcoming paper (Pastorello et al., in preparation).

2. *UBVRIJHK* PHOTOMETRY AND OPTICAL SPECTRA

2.1. Optical and infrared photometry

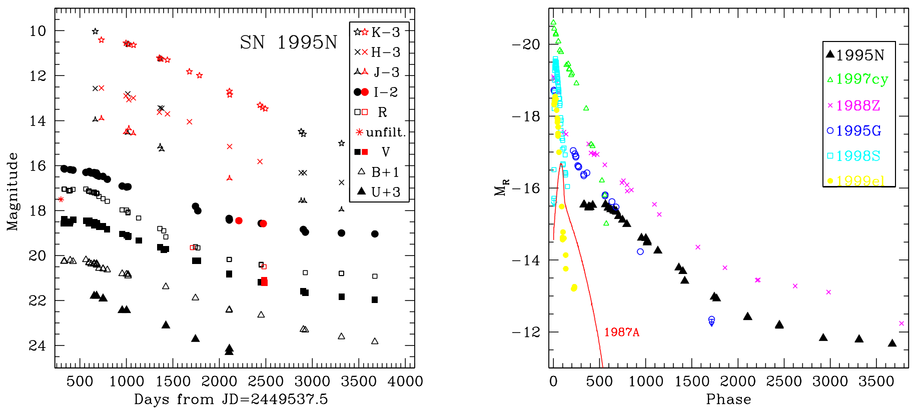

Figure 1. *UBVRIJHK* light curves (left) and absolute R band light curve (right) of SN 1995N, compared with those of other SNe IIn (see text).

In Fig. 1 (left), *UBVRIJHK* light curves of SN 1995N are reported. Together with our unpublished data, also data from other sources (Gerardy et al. 2002; Li et al. 2002) are shown. The very slow magnitude decrease in all bands is remarkable: the observations provide an average decline rate of about 0.10 mag/100 days (over a period of 9 years) in V band, and ∼ 0.19 mag/100 days (over more than 7 years) in K band. Another interesting property of SN 1995N and other SNe IIn, discussed also by Gerardy et al. (2002), is the huge K band excess, attributed to dust emission.

Fig. 1 (right) shows the absolute R band light curve of SN 1995N compared with those of other interacting SNe: 1988Z (Aretxaga et al. 1999, and references therein), 1997cy (Germany et al. 2000; Turatto et al. 2000), 1995N (Pastorello et al. 2002), 1998S (Liu et al. 2000; Fassia et al. 2000; Li et al. 2002) and 1999el (Di Carlo et al. 2002). The light curve of the non–interacting SN 1987A (Whitelock et al. 1989, and references therein) is also shown. Adopting the explosion epoch of SN 1995N reported by Fox et al. (2000), this object is about 1 magnitude fainter than SN 1988Z, even if their light curves are very similar in shape.

[1] *http://rsd-www.nrl.navy.mil/7213/weiler/kwdata/rsnhead.html*

We remark that a recent observation of SN 1995N (on July 2004, i.e. ∼10 years after explosion), shows the object clearly visible in all optical bands.

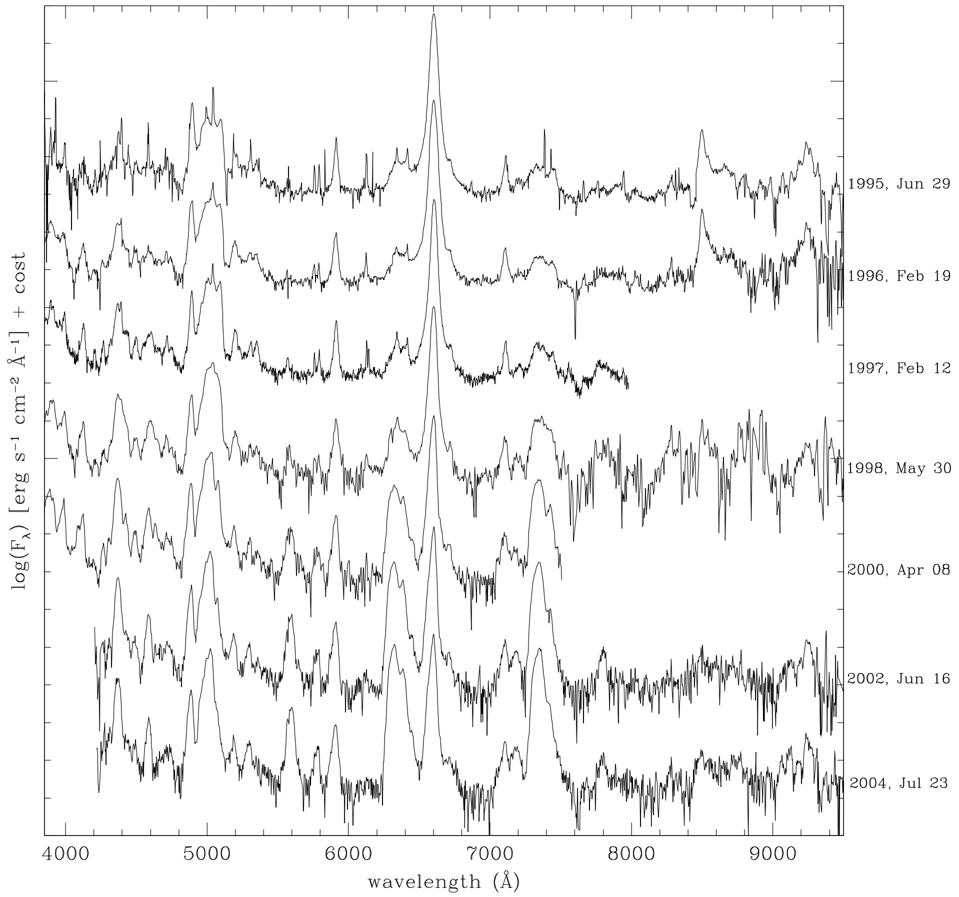

Figure 2. Spectroscopic evolution of SN 1995N: in the figure only a few, representative spectra are shown. The entire spectroscopic data set will be presented in Pastorello et al. (in preparation).

2.2. Optical Spectra

A detailed analysis of the early time spectra and the line identification is presented by Fransson et al. (2002). We have obtained a large number of spectra of this object (more than 30) during the period 1995–2004, and a small sample of our data set is shown in Fig. 2. We remark the very slow spectral evolution of this SN. The spectra are dominated by the Hα emission during the first ~ 4 years, then the forbidden O lines (especially [OIII] 4959–5007 Å, [O I] 6300–6364 Å, [O II] 7320–7330 Å) increase in strength with time and become comparable with Hα at about phase 8 years. While broader components ($\gtrsim 3000$ km s^{-1})

are still visible in the last available spectrum, the narrow unresolved, highly ionized, forbidden lines of O, Fe, Ne, Ar, are detected only at early epochs, i.e. until phase of $\sim$ 3–4 years. Hα is particularly prominent, and its luminosity evolution appears to be similar to that observed for SN 1988Z (Aretxaga et al. 1999), peaking between 1 and 2 years after the SN explosion.

3. Energy Estimates

After including all the data available in the literature, we estimate the X–ray to radio energy output of SN 1995N. We find that the major contribution to the total energy comes from the IR flux, as already noted for other SNe IIn (Gerardy et al. 2002; Pozzo et al. 2004). The K band luminosity is exceptionally high, especially until phase $\sim$ 2000 days. Later the X–ray luminosity (range 0.2–10 keV) exceeds the K band one (Zampieri et al., in preparation).

We compute the total energy emitted in each band integrating the corresponding light curves over the period of the available observations: the integrated energy in the U, V, I, J bands is about 5×10^{48} ergs, a factor 2 times larger for the B and H bands, 4 times for the R band and a 5–6 times for the K band and the 0.2–10 keV region. Note also that the radio flux contributes only marginally to the total energy, lying about 4 order of magnitudes below the optical one. Moreover we estimate the ionizing radiation absorbed by the cool material from the flux of Hβ (see Aretxaga et al. 1999).

Interpolating at missing epochs and roughly assuming that the light curve is flat during the first unobserved 10 months, we compute the X–ray, UV ionizing continuum, optical and IR energy emitted by SN 1995N over 10 years. The integration provides a value of $E_{TOT} \sim 3 \times 10^{50}$ ergs. Because other SNe IIn (e.g. 1988Z) show a luminosity peak during the period 0–300 days, such value of E_{TOT} should be considered as a lower limit for the total energy emitted by SN 1995N. A reasonable estimate is $E_{TOT} \sim 10^{51}$ ergs, not far from the classical value of non–interacting CC–SNe and about one order of magnitude smaller than estimated for SN 1988Z (Aretxaga et al. 1999).

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