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LMC-N66: A potential SN Ia progenitor?

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Abstract. The planetary nebula N66 in the Large Magellanic Cloud is an exceptional object, as its central star has a Wolf-Rayet type spectrum of the nitrogen sequence ([WN]). Moreover, the star showed a dramatic brightness outburst in 1993–1994. We analyzed the changing stellar spectra and found evidence that the central star is most likely a binary system where a white dwarf accretes matter from a non-degenerate companion at a high rate. We also studied the morphology and kinematic of the nebula. Its complex multipolar structure can be explained as result of episodic bipolar ejections from a precessing source, giving further evidence for the binary nature of the central object. Due to the high rate of mass transfer, the object is a candidate for a future type Ia supernova in our cosmic neighborhood.

1. The dramatic spectral evolution of N66

N 66 in the Large Magellanic cloud is an exceptional object. While there are many central stars of planetary nebulae with a Wolf-Rayet type spectrum of the carbon-rich type ([WC]), N 66 shows a Wolf-Rayet type spectrum of the *nitrogen* sequence ([WN]). Only one further probable central star of [WN] type has been found recently in our Galaxy (Morgan et al. 2003). Even more peculiar, N 66 increased its brightness dramatically in the beginning of the 1990s, reached a maximum in 1994 and since then returned to its quiet state. We followed its spectral variation with IUE, HST (see Fig. 1) and ground-based spectroscopy.

All available spectra from the different epochs were analyzed by means of non-LTE models for expanding atmospheres using the *Potsdam Wolf-Rayet* (PoWR) code. As the result, we obtained the stellar and atmospheric parameters. Summarizing, we found (cf. Hamann et al. 2003):

- The luminosity at quiet state, before and after the outburst, is $\log L/L_\odot = 4.6$
- The luminosity climbed up to $\log L/L_\odot = 5.4$ at outburst
- The mass-loss rate varied together with L : $\dot{M} \propto L^{0.9}$
- The stellar temperature remained roughly constant: $T_* \approx 112\,\mathrm{kK}$
- The flux variation was mainly caused by a change of the stellar radius

The chemical composition of the atmosphere and wind of N 66 is that of incompletely CNO-processed matter: it is dominated by helium, but some hydrogen (20% by mass) is also present. The mass fraction of nitrogen is slightly enhanced, while carbon is strongly depleted.

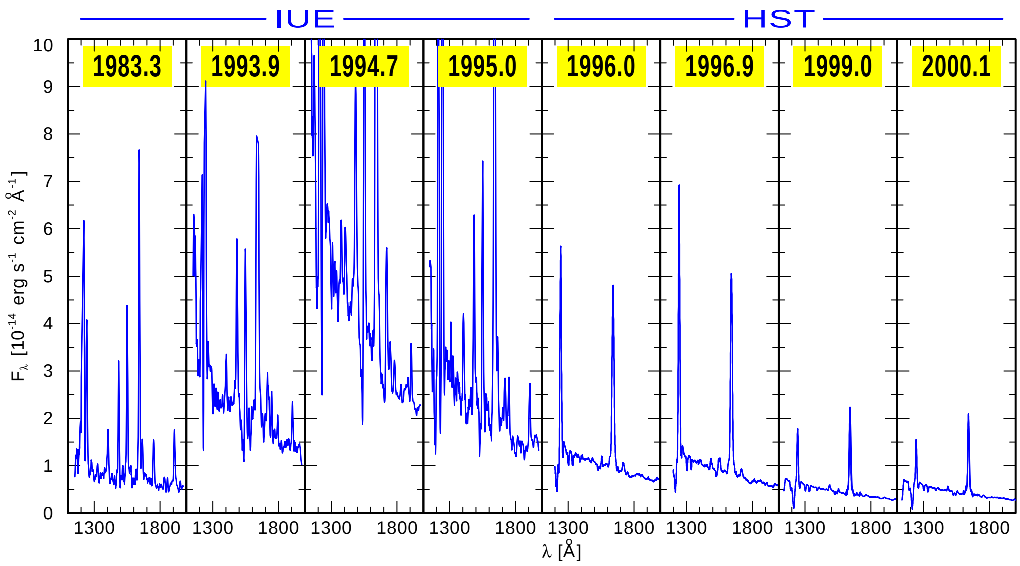

Figure 1. Series of UV spectra from different epochs. In 1994.7 the flux was 10 times higher than in the quiet state. Note the stronger contamination by nebular emission lines in the IUE spectra, than in the HST observations.

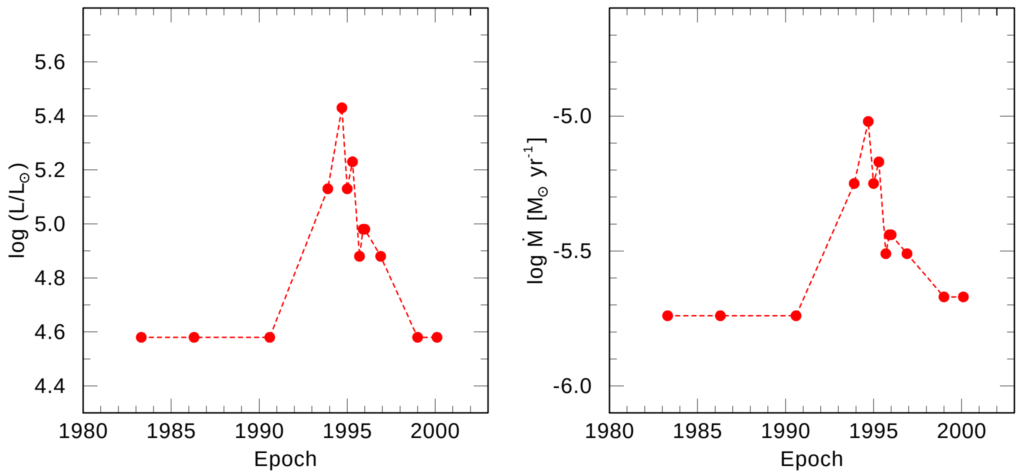

Figure 2. Variation of luminosity and mass-loss rate with time

2. The nebula

Although the N 66 nebula has only a few arcseconds in diameter, its morphology and kinematic have been analyzed in detail, using images and high-resolution spectra obtained with the HST and the ESO-VLT (Peña et al. 2004). The object presents a complex multipolar structure (Fig. 3). It can be explained as result of episodic bipolar ejections with changing axis, probably from a precessing source. The nebula contains about $0.6\,M_\odot$ of matter with roughly solar composition. The kinematical age of the youngest knot is only 500 years.

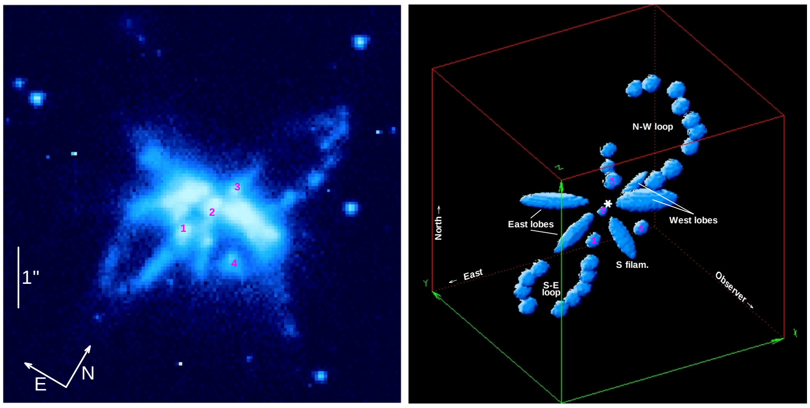

Figure 3. Direct image of N 66 with HST STIS (left). From a slitless spectrum in the [O III] 5007 emission line we derived the radial velocities of the different knots and filaments. This information has been employed to deduce a three-dimensional model of the nebula (right). The bipolar structures of different orientation might have been produced by collimated streams from a precessing source, thus supporting binary scenarios.

3. The enigmatic nature of N 66

Scenarios for N 66 are discussed with respect to the observed facts (see Table 1):
(1) For a single, low-mass star ($M < 1.4\,M_\odot$), the luminosity at outburst exceeds the Eddington limit by far. The observed abundances cannot be explained from a post-AGB evolution.
(2) For a single, massive WN-type star, the luminosity of N 66 in quiet state is too low (cf. Fig. 4). While a massive WN star could produce the observed abundances, it does not explain the outburst and its short (≈1 yr) timescale.
(3) The central star of N 66 could have been produced by the merging of two White Dwarfs with He+He or He+CO cores. While such *double-degenerate* (DD)

Table 1. *Pros* (+) and *Contras* (−) for the different scenarios

Scenario	single low-mass	single high-mass	DD merger	binary high-mass	binary low-mass
HRD position	−	−	+	+	+
Surface: helium	−	+	+	+	+
Surface: rest H	−	+	+	+	+
Surface: low C	−	+	+	+	+
Wind: v_∞	+	−	+	−	+
Outburst instability	+	−	+	−	+
H-K timescale	+	−	+	−	+
Eddington limit	+−	+	+−	+	+−
Nebula: H-rich	+	+	−	+	
Nebula: bipolar	−	−	+	+	+
Nebula: young	+	−	+		+

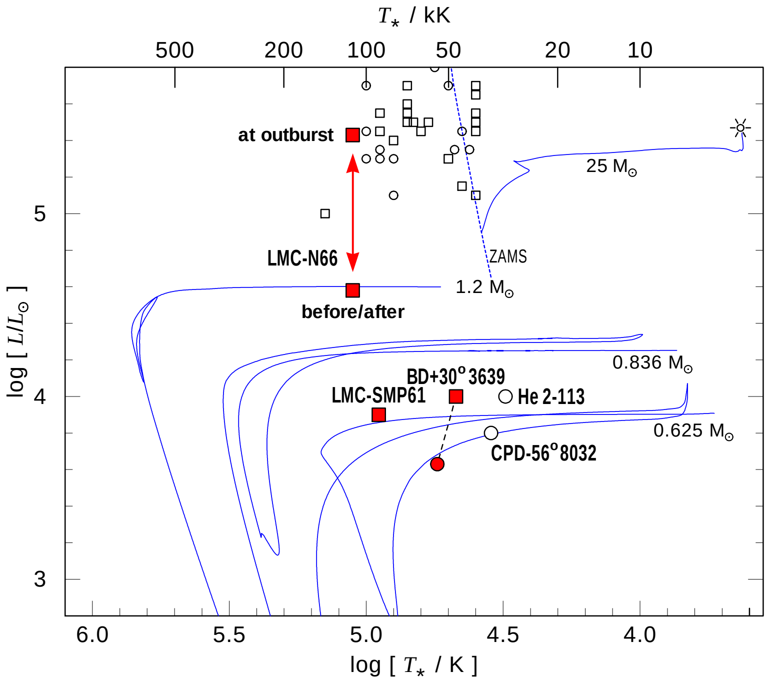

Figure 4. HRD with the position of N 66 at outburst and at quiet state. Other hydrogen-deficient (but [WC]-type) CSPN (labeled symbols) are less luminous, while massive WN stars (unlabeled symbols) are more luminous than N 66 at quiet state. Some post-AGB tracks and one track for a 25 $M_\odot$ star are shown for rough orientation.

scenarios could explain the properties of the central star, they cannot provide the amount of H-rich material in the nebula.

(4) A massive star with a low-mass close companion goes through a common-envelope phase, loosing the hydrogen-rich envelope which then forms a nebula. A helium star with the observed (quiet-state) luminosity might remain. The unevolved low-mass secondary also survives but is undetectable. This scenario provides no explanation for the outburst, and predicts a too high escape velocity in relation to the observed terminal wind speed.

(5) A white dwarf accretes and burns matter from a non-degenerate companion. In contrast to usual cataclysmic variables, the transfer rate (and hence the luminosity) is very high because the donor star is more massive than the gainer.

The latter scenario (5) has least contradictions to the observational constraints. If accretion on the WD continues with the present rate, the CO core of N 66 will reach Chandrasekhar's limit in a few times 10^5 yr. Hence LMC-N66 is a potential future type Ia supernova in our cosmic neighborhood.

References

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