RevMexAA (Serie de Conferencias), **20**, 41–43 (2004)

THE CENTRAL STAR OF THE PLANETARY NEBULA LMC-N66: A MASSIVE ACCRETING WHITE DWARF?

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RESUMEN

La estrella central del sistema PN LMC - N66 presentó una impresionante transferencia de masa en 1993 - 1994 y regresó a su condición inicial alrededor de 8 años más tarde. Su espectro se parece al de una estrella WN4.5 y es la única estrella central confirmada de nebulosas planetarias que posee este tipo de espectro. Presentamos el análisis reciente de los parámetros para la estrella central llevado a cabo por Hamann et al. (2003) que encontraron que durante la transferencia de masa la luminosidad bolométrica se incrementó en un factor mayor que 6. Discutimos los posibles escenarios que fueron propuestos para explicar los excepcionales parámetros estelares y el mecanismo de transferencia de masa. Las características estelares, la morfología y la cinemática de la nebulosa planetaria sugieren la presencia de un sistema binario (una estrella masiva con una compañera menos masiva o una enana blanca que acreta la materia en un sistema de binarias cercanas), siendo éstos los casos que contradicen de manera menos severa las restricciones observacionales.

ABSTRACT

The central star of the PN LMC-N66 showed an impressive outburst in 1993 – 1994, returning to its initial conditions about 8 years later. Its spectrum resembles that of a WN4.5 star, being the only confirmed central star of planetary nebulae showing such a spectral type. Recent analysis for the central star parameters, performed by Hamann et al. (2003) is presented. They have found that the bolometric luminosity increased by a factor larger than 6, during the outburst. We discuss the possible scenarios which have been proposed to explain the exceptional stellar parameters and the outburst mechanism. The stellar characteristics and the morphology and kinematics of the planetary nebula suggest the presence of binary system (massive star with a less massive companion or, a white dwarf accreting matter in a close-binary system). These cases pose the least severe contradictions with observational constraints.

Key Words: **ISM: KINEMATICS AND DYNAMICS — ISM: JETS AND OUTFLOWS — PLANETARY NEBULAE: INDIVIDUAL (LMC-N66) — STARS: EVOLUTION — STARS: WOLF-RAYET**

1. INTRODUCTION

LMC-N66 is a well known planetary nebula whose central star developed huge WN features and its brightness increased by several magnitudes at the end of 1993. The outburst lasted almost 10 years. We have followed closely the evolution of the event (e.g.. Peña et al. 1997; Hamann et al. 2003 and references therein). Recent spectra show that the star has returned to the pre-outburst state.

The evolution of the central star during the outburst has been analized in detail by Hamann et al. (2003), by means of most advanced non-LTE expanding atmosphere models. The models reproduce the stellar continuum and emission lines at different epochs. The most important changes of the central star parameters are presented in Table 1. According to these results, the sudden huge brightness enhancement was due mainly to large increases in the mass loss rate and in the stellar radius. The change in bolometric luminosity from $10^{4.6}$ $L_\odot$ (pre-outburst) to $10^{5.4}$ $L_\odot$ at maximum, shows that the energy source changed, increasing its efficiency, due to an additional energetic process. Interestingly, Hamann et al. found that the chemical composition of the stellar wind corresponds to "incomplete" CNO-processed matter, that is, it is dominated by helium ($\sim$ 80%) with a rest of hydrogen ($\leq$ 20%). Carbon and oxygen appear strongly depleted, while nitrogen is slightly enhanced.

The analysis for different epochs allows us to follow the evolution of the star during the outburst in the HR diagram (see Fig. 8 by Hamann et al.). It is worth to notice that, even at quiet state, the central star is unusually bright ($10^{4.6}$ $L_\odot$) for a planetary nebula progenitor. The evolutionary path allows to

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TABLE 1

EVOLUTION OF STELLAR PARAMETERS DURING THE OUTBURST[(1)]

epoch	$\log L/L_\odot$	$\log \dot{M}$	R ($R_\odot$)
1990.6	4.60	-5.74	0.52
1993.9	5.13	-5.25	0.98
1994.7	5.43	-5.02	1.38
1995.0	5.13	-5.25	0.98
1995.7	4.88	-5.51	0.73
1996.0	4.98	-5.44	0.82
1999.0	4.88	-5.51	0.73
2000.1	4.60	-5.67	0.52

[(1)] Adapted from Hamann et al. (2003). The effective temperature of 112kK, and the terminal velocity of the wind remained roughly constant during the outburst.

discard the "final He-flash" and the "LBV-type atmospheric instability" as probable outburst's mechanisms. Hamann et al. analysed different scenarios trying to understand the nature and evolutionary origin of N66. A low-mass single star scenario is in conflict with surface abundances, and a high-mass single star is not predicted to reach such zone of the HR diagram and there is no explanation for the outburst. Therefore they suggest a binary scenario as the one posing the least severe contradictions with observational constraints. The binary scenarios discussed are: a massive star which has lost its hydrogen in a recent common envelope phase with a less massive companion, or a massive white dwarf accreting matter at high rate from a close unevolved companion. In the latter possibility, the massive white dwarf is smoothly burning the H-rich accreted material in its outer layers producing the high luminosity observed for this object. The outburst could have been due a He shell flash in the white dwarf. The present high accretion rate would bring the WD to the Chandrasekhar limit within some thousand years, thus N66 would be a candidate for a future type Ia supernova explosion in the LMC.

2. MORPHOLOGY AND KINEMATICS OF THE PLANETARY NEBULA: CONFIRMING THE BINARY NATURE

In highly resolved images LMC-N66 appears as an extended nebula with a very complex morphology (Blades et al. 1992). Fig. 1 presents a recent image retrieved from HST archives. It corresponds to the STIS ID o6el5y010 observation, obtained through the MIRVIS grating. Evidently N66 is a multipolar nebula. Two lobes oriented approximately E-W and

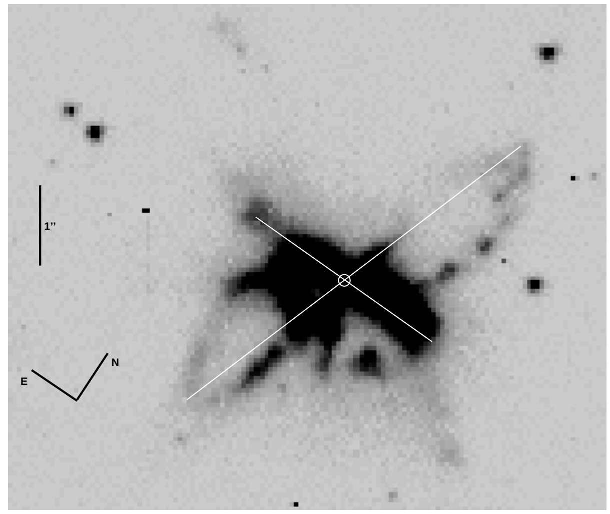

Fig. 1. HST STIS image of LMC-N66 through MIRVIS grating. The orientations of the two main bipolar structures are marked. The central circle indicates the position of the central star.

a couple of faint twisted loops, opposite one to the other, are the most conspicuous features. The orientations of these bipolar structures have been marked in the figure. We see that they differ by about 130°. The structures are separated by a narrow waist. In addition there are some filaments and knots mainly in the southern zone.

Peña et al. (2004) show that the kinematics of the nebula presents also a bipolar morphology. The gas is mainly approaching or receding at ± 40 km s^{-1}, relative to the system velocity (the system velocity was measured to be about 300 km s^{-1}). In particular we have found that the E-W lobes and the loops present well defined approaching and a receding sides. Therefore these structures correspond to bipolar ejections, which have emerged from the central source in different epochs, with different orientations and different collimation degree. The possibility that the collimation mechanisms could be a dusty toroid around the central star is discarded and we suggest that magnetic collimation of the fast post-AGB wind, where the magnetic field is misaligned with the rotation axis of the central star (as proposed by García-Segura 1997) has caused the bipolar structures, in particular, the opposite twisted loops.

In order to have multiple bipolar ejections with different orientations, it seems to be necessary that the central source precesses. Such a precession should be due to a torque on the rotation axis of the star. García-Segura (1997) has discarded the possibility of an internal torque and suggest that a binary companion could produce an external torque.

In such a case, only a wide companion is required. Following this, we propose that the multipolar morphology and kinematics of the extended planetary nebula have been produced by multiple bipolar ejections with different orientations, from a precessing central star due to the presence of a binary companion.

We have estimated that the oldest structures (loops) were ejected a few thousand years ago, while the knots near the central star could be only some hundred years old.

3. DISCUSSION

The binary nature of the central star in N66 is suggested by two independent analyses. A close binary system where an unevolved star would be transfering H-rich material to a massive white dwarf (in a possibly second mass exchange) would explain the H-deficient surface abundances, the high stellar luminosity and the 1993 outburst of this object (as due to a He shell flash in the massive white dwarf), The multipolar morphology and kinematics of the extended H-rich nebula (formed a few thousand to a few hundred years ago), would indicate the presence of a companion inducing a precession of the rotation axis of the central source.

There are some indications that outbursts in N66 could be periodic. Nail & Shapley (1955) identified this object with a LMC irregular variable with Δm$\sim$0.9 mag in photographic brightness. No other variation was reported until 1993. For the latter outburst, the total brightness variations (star plus nebula) was about 0.3-0.4 mag.

In the scenario of a high-rate accreting white dwarf, thermal pulses (He flashes) repeat on time scales of 10^3 years (Langer et al. 2000), depending on model parameters. The time scale for variations in N66 seems to be much shorter. This could be due to unusual parameters of the central source.

Very probably, we will be witnessing some important variations in the near future, that will help to better understand the nature and origin of this, up to now, unique object.

This work received financial support from DGAPA/UNAM (IN 114601) and CONACYT.

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