MN112: a new Galactic candidate luminous blue variable

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ABSTRACT

We report the discovery of a new Galactic candidate luminous blue variable (cLBV) via detection of an infrared circular nebula and follow-up spectroscopy of its central star. The nebula, MN112, is one of many dozens of circular nebulae detected at 24 μm in the Spitzer Space Telescope archival data, whose morphology is similar to that of nebulae associated with known (c)LBVs and related evolved massive stars. Specifically, the core-halo morphology of MN112 bears a striking resemblance to the circumstellar nebula associated with the Galactic cLBV GAL 079.29+00.46, which suggests that both nebulae might have a similar origin and that the central star of MN112 is an LBV. The spectroscopy of the central star showed that its spectrum is almost identical to that of the bona fide LBV P Cygni, which also supports the LBV classification of the object. To further constrain the nature of MN112, we searched for signatures of possible high-amplitude (≳1 mag) photometric variability of the central star using archival and newly obtained photometric data covering a 45-yr period. We found that the B magnitude of the star was constant within error margins, while in the I band the star brightened by ≃0.4 mag during the last 17 yr. Although the non-detection of large photometric variability leads us to use the prefix ‘candidate’ in the classification of MN112, we remind the readers that the long-term photometric stability is not unusual for genuine LBVs and that the brightness of P Cygni remained relatively stable during the last three centuries.

Key words: line: identification – circumstellar matter – stars: emission-line, Be.

1 INTRODUCTION

Luminous blue variables (LBVs) are rare evolved massive stars in the upper left of the HR diagram (Conti 1984). Besides the very high luminosity, most LBVs are characterized by irregular large spectrophotometric variability (Humphreys & Davidson 1994; van Genderen 2001), which manifests itself in drastic changes in spectral type and visual brightness (by 1–2 mag) of these objects. The origin of the variability and its characteristic time-scale are not yet well understood. Although the majority of confirmed LBVs show variations over decades or even years, some of them (e.g. PCygni) are photometrically stable during the much longer periods of time (e.g. de Groot, Sterken & van Genderen 2001).

It is believed that LBVs represent an intermediate phase in the evolution of the most massive stars from the core-hydrogen burning O stars to the hydrogen-poor Wolf–Rayet stars, during which a massive star loses a significant fraction of its initial mass through the copious stellar wind or in the form of instant outbursts. As a result of this mass loss, most, if not all, of established and candidate LBVs (cLBVs) are surrounded by compact (≲1 pc) circumstellar nebulae (e.g. Weis 2001; Clark, Larionov & Arkharov 2005), detected either though direct imaging (in the optical, infrared or radio wavebands) or inferred via the presence of forbidden emission lines in their spectra. These nebulae show a wide range of morphologies, ranging from simple round to bipolar and triple-ring forms (e.g. Nota et al. 1995; Weis 2001; Smith 2007; Gvaramadze, Kniazev & Fabrika 2010a).

Detection of LBV-like nebulae around stars with P Cygni-type or η Car-type spectra could serve as circumstantial evidence that

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these stars are genuine LBVs even if their photometric variability has not yet been detected (Bohannan 1997; Massey et al. 2007). On the other hand, search for LBV-like nebulae accompanied by spectroscopic follow-up of their central stars could be a powerful tool for detection of new (c)LBs and related evolved stars (Clark et al. 2003; Gvaramadze et al. 2009, 2010a,b).

In this paper, we report the discovery of a new Galactic cLBV via detection of a ring-like nebula (reminiscent of the circumstellar nebula of the cLBV GAL 079.29+00.46) and follow-up spectroscopy of its central star, revealing a striking similarity between the spectrum of the star and that of the bona fide LBV P Cygni.

### 2 Infrared Nebula MN112 and Its Central Star

The new Galactic cLBV was identified via detection of its circumstellar nebula (Gvaramadze et al. 2010a) in the *Spitzer Space Telescope* archival data obtained with the Multiband Imaging Photometer for Spitzer (MIPS; Rieke et al. 2004) within the framework of the 24 and 70 Micron Survey of the Inner Galactic Disk with MIPS (MIPSGAL; Carey et al. 2009). This nebula is one of many dozens of circular nebulae discovered at MIPS 24 μm images, whose appearance is very similar to that of nebulae associated with known (c)LBs and related evolved massive stars (Gvaramadze et al. 2010a).

Fig. 1 shows the MIPS 24 μm image of the nebula (hereafter MN112, in accordance with the nomenclature adopted in Gvaramadze et al. 2010a) and its central star. MN112 consists of a bright circular shell (with a radius of ±33 arcsec) surrounded by a halo (with a radius of ±54 arcsec). The core-halo morphology of MN112 strikingly resembles that of the circumstellar nebula of the Galactic cLBV GAL 079.29+00.46 (Gvaramadze et al. 2010a). This similarity suggests that both nebulae might have a similar nature and that the central star of MN112 is a (c)LBV as well.

MN112, like the majority of other LBV-like nebulae detected with *Spitzer*, is visible only at 24 μm (cf. Carey et al. 2009). Unlike the nebula, the central star (in what follows, we will use for the star the same name as for the nebula) is visible not only at 24 μm but also at all four (3.6, 4.5, 5.8 and 8.0 μm) images obtained with the *Spitzer* Infrared Array Camera (IRAC; Fazio et al. 2004) within the Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE; Benjamin et al. 2003). According to the GLIMPSE I Spring ‘07 Archive,1 the star is located at α2000 = 19 h 44 m 37 s, δ2000 = 24° 19′ 05″ 9 and has the following IRAC magnitudes: [3.6] = 6.73 ± 0.03, [4.5] = 6.42 ± 0.04, [5.8] = 6.18 ± 0.02, [8.0] = 5.84 ± 0.02. Using the IRAC photometry, 2MASS magnitudes (J, H, Ks) = (8.86 ± 0.02, 8.02 ± 0.02, 7.42 ± 0.02) of the star (Skrtaskie et al. 2006) and the colour–colour diagrams by Hadfield et al. (2007), one finds that MN112 falls in the region populated by Wolf–Rayet and other hot, evolved massive stars.

The optical counterpart to MN112 was identified by Dolidze (1975) as an emission-line star, named [D75b] Em* 19-008 in the SIMBAD data base.2 This star was included in the Catalogue of H-alpha emission stars in the northern Milky Way (Kohoutek & Wehmeyer 1999). Two other SIMBAD names of the star are [KW97] 44-47 and HBHA 4202-22.

We determined the photometric B, V, and I magnitudes of MN112 on CCD frames obtained with the SBIG CCD ST-10XME attached to the 40-cm Meade telescope of the Cerro Armazones Astronomical Observatory of the Northern Catholic University (Antofagasta, Chile) during our observations in 2009 April 22. The results are given in Table 1, where we also present photometry obtained from different sources and calibrated using the secondary photometric standards established from the Meade data (see Section 4 for more details).

### 3 Spectroscopic Follow-Up

To determine the nature of MN112, we obtained spectra of the central star with the Cassegrain Twin Spectrograph (TWIN) of the 3.5-m telescope in the Observatory of Calar Alto (Spain) during director’s discretionary time on 2009 May 5 (exposure time of 1800 s). The set-up used for TWIN was the grating T08 in the first order for the blue arm (spectral range 3500–5600 Å) and T04 in the first order for the red arm (spectral range 5300–7600 Å) which provides an inverse dispersion of 72 Å mm⁻¹ for both arms. A slit of 240 arcsec × 2.1 arcsec was used for these spectral observations. The resulting FWHM spectral resolution measured on strong lines of night sky and reference spectra was 3–3.5 Å. The seeing during the observations was stable, ±1.3–1.4 arcsec.

Additional spectra were obtained with the Russian 6-m telescope using the SCORPIO3 focal reducer (Afanasiev & Moiseev 2005) in

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1Available at http://irsa.ipac.caltech.edu/index.html
2Note that the SIMBAD data base provides erroneous coordinates for the star.
3Spectral Camera with Optical Reducer for Photometrical and Interferometrical Observations; http://www.sao.ru/hq/lfsvo/devices/scorpio/scorpio.html

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**Table 1. Photometry of MN112.**

| Date       | B     | V     | I     |
|------------|-------|-------|-------|
| 1990 July 25<sup>a</sup> | 17.06±0.21 | –     | –     |
| 1992 July 23<sup>a</sup> | –     | –     | 11.56±0.12 |
| 1996 July 12<sup>b</sup> | 16.90±0.18 | –     | –     |
| 2009 April 22<sup>c</sup> | 17.13±0.12 | 14.53±0.03 | 11.15±0.03 |
| 2009 June 21<sup>d</sup> | 16.94±0.05 | 14.46±0.04 | –     |

<sup>a</sup>Poss-II; <sup>b</sup>GSC 2.2; <sup>c</sup>40-cm Meade telescope; <sup>d</sup>6-m/SCORPIO.
a long-slit mode with a slit width of 1 arcsec, providing a spectral resolution of 5 Å. The spectra were taken on 2009 June 21 in spectral ranges $\lambda \lambda$4030–5830 Å (exposure time of 2400 s) and $\lambda \lambda$5730–7500 Å (exposure time of 1800 s). The seeing during observations was $\simeq$1.5 arcsec.

Data reduction was performed using the standard procedures. The resulting spectra are shown in Fig. 2. The top panel presents blue spectra taken with both telescopes, as the TWIN spectrum has better resolution, while the SCORPIO one has better signal-to-noise ratio. The bottom panel shows the TWIN spectrum in the red region, where the TWIN spectrograph provides better resolution. Detailed comparison of the spectra from both telescopes does not show any evidence of significant change.

Equivalent widths (EWs) and radial heliocentric velocities (RVs) of main emission lines [measured applying the MIDAS programs; see Kniazev et al. (2004) for details] are summarized in Table 2. For EWs we give their mean values derived from both spectra, while for measurements of RVs we used the TWIN spectrum alone (owing to its better resolution).

### Table 2. EW and RV of main emission lines in the spectrum of MN112.

| $\lambda_0$ (Å) | Ion          | EW(Å)  | RV (km s$^{-1}$) |
|----------------|--------------|--------|-----------------|
| 3889           | He + H$\beta$| 3.8±0.4|                 |
| 4101           | H$\beta$     | 1.5±0.1|                 |
| 4340           | H$\gamma$    | 4.8±0.1| 35±8            |
| 4471           | He I         | 2.3±0.3| 24±15           |
| 4713           | He I         | 1.6±0.2| 22±13           |
| 4861           | H$\beta$     | 16.2±0.3| 23±7         |
| 4922           | He I         | 1.2±0.2| 40±20           |
| 5016           | He I         | 4.6±0.3|                 |
| 5127           | Fe III       | 0.5±0.2|                 |
| 5156           | Fe III       | 0.5±0.2|                 |
| 5755           | [N II]       | 1.1±0.2| 65±9            |
| 5834           | Fe III       | 0.6±0.2| 65±8            |
| 5876           | He I         | 14.7±0.4|               |
| 5979           | Fe III       | 1.1±0.2| 56±6            |
| 6000           | Fe III       | 0.4±0.1| 68±9            |
| 6033           | Fe III       | 0.8±0.2| 66±7            |
| 6347           | Si II        | 1.6±0.2| 75±15           |
| 6371           | Si II        | 0.7±0.2| 28±14           |
| 6482           | N ii         | 0.7±0.2| 21±12           |
| 6563           | H$\delta$    | 64.1±0.8| 16±5          |
| 6678           | He I         | 7.5±0.3|                 |
| 7065           | He I         | 12.2±0.3| 20±5         |
| 7281           | He I         | 4.5±0.3|                 |

### 4 MN112 – A NEW CANDIDATE LBV

A first look at Fig. 2 reveals that the spectrum of MN112 is extremely similar to that of the bona fide LBV P Cygni (see Fig. 3). We therefore used the spectral atlas of P Cygni by Stahl et al. (1993) to identify the lines indicated in Fig. 2. The spectrum of MN112, like P Cygni, is dominated by strong emission lines of hydrogen and He I. The Balmer lines have prominent wings and weak P Cygni
absorption material might be caused by variability of the wind density, which in turn is due to variability of the stellar mass-loss rate and/or the wind velocity.

We now turn to estimates of the reddening towards MN112. Proceeding from the close similarity between the spectra of MN112 and P Cygni, it is tempting to assume that both stars have the same temperatures and therefore the same intrinsic colours. For $B = 17.13$ mag and $V = 14.53$ mag (see Table 1) and adopting from Najarro et al. (1997), the intrinsic colour of $(B - V)_0 = -0.26$ mag, one finds $E(B - V) \simeq 2.86$ mag. An indirect support to this estimate comes from comparison of dereddened spectral slopes of MN112 and P Cygni, which should coincide with each other if the temperatures of both stars are similar. For this comparison we obtained a spectrum of P Cygni with SCORPIO on 2009 September 19. We found that the SCORPIO spectra of both stars nicely match each other if one dereddens the spectrum of MN112 by $\pm 2.2$ mag in $E(B - V)$. Adopting $E(B - V) = 0.51$ mag for P Cygni (Najarro et al. 1997), one finds $E(B - V) = 2.71$ mag for MN112, which is in a good agreement with the above estimate.

MN112 is located in the direction towards the OB association Vul OB1 at $\approx 1$ degree from the open cluster NGC 6823 (which is part of Vul OB1). The distance estimates to NGC 6823 range from $\pm 2$ to 3.5 kpc (e.g. Sagar & Joshi 1981; Kharchenko et al. 2005), which puts the cluster (and association) in the local (Orion) spiral arm. Assuming that MN112 is a member of Vul OB1 association, one finds its absolute visual magnitude $M_V \simeq -(5.8 - 7.1)$ mag and luminosity of $\log(L/L_\odot) \simeq 4.8 - 5.3$ [here we assumed that the bolometric correction of MN112 is equal to that of P Cygni, $-1.54$ mag (Najarro, personal communication)]. These estimates imply that, in principle, MN112 might belong to a group of low-luminosity (c)LBVs with $\log(L/L_\odot) \simeq 5.2 - 5.6$ (Humphreys & Davidson 1994; see also Clark et al. 2009), provided that it is located at the distance of $\approx 3.5$ kpc. Another possibility is that MN112 is located in the next arm out, the Perseus Arm. An indirect support of this possibility comes from our estimate of the visual extinction towards MN112, $A_V = 3.1 E(B - V) \simeq 8.4 - 8.9$ mag, which is several times larger than that towards Vul OB1 and its central cluster NGC 6823 [2.3–3.3 mag (Thé & van Paradijs 1971) and 2.6 mag (Kharchenko et al. 2009), respectively]. In this case, the distance to MN112 is $\geq 7$ kpc, which corresponds to $M_V \lesssim -8.6$ mag and $\log(L/L_\odot) \gtrsim 6.0$ [$M_V$ and $\log(L/L_\odot)$ of P Cygni are equal to $-8.0$ mag and 5.8, respectively; Najarro et al. 1997].

To further constrain the nature of MN112, we searched for its possible large-scale ($\gtrsim 1$ mag) photometric variability, using the secondary photometric standards established with the 40-cm Meade telescope. We used CCD $B$ and $V$ frames taken with the Russian 6-m telescope and recalibrated photometry from POSS-II $B$ and $I$ plates and the Guide Star Catalog 2.2 (McLean et al. 2000). These measurements (summarized in Table 1) show that the $B$ magnitude of MN112 remains constant within error margins over the last 19 years, while in the $I$ band the star brightened by 0.41 ± 0.12 mag. Also, we used the collection of photographic plates of the Sternberg Astronomical Institute (Moscow, Russia). The star was detected on 19 $B$-band plates covering a 30-year period from 1965 to 1994. We found that over this period the $B$ magnitude of MN112 was $\approx 17.2 \pm 0.2$.

Although disappointing, the non-detection of large variability of MN112 is not completely unexpected in view of the similarity between this star and the bona fide LBV P Cygni, whose brightness remained relatively stable during the last three centuries and which shows irregular variability of $\sim 0.2$ mag superimposed on the gradual brightening by $\sim 0.1$ mag per century (de Groot et al. 2001).
Moreover, it is quite possible that a significant fraction of LBVs (if not all of them) goes through the long quiescent periods (lasting centuries or more; e.g. Lamers 1986) so that the fast variability (on time-scales from years to decades) observed in the vast majority of classical LBVs could be merely due to the selection effect (e.g. Massey et al. 2007).

5 CONCLUSION AND FURTHER WORK

We identified a new Galactic cLBV via detection of a ring nebula (reminiscent of the circumstellar nebula associated with the cLBV GAL 079.29+00.46) and follow-up spectroscopy of its central star showing that the spectrum of the star is almost identical to that of the bona fide LBV PCygni. Taken together, these findings strongly suggest that the detected object, MN112, is an LBV. To unambiguously prove the LBV nature of MN112, it is necessary to detect the major changes in its brightness and spectrum. Although we realize that MN112, like PCygni, could be in the long-term quiescent phase, we have launched a spectrophotometric monitoring of this star in the hope that the ‘duck’ will ‘quack’ in the foreseeable future (cf. Bohannan 1997). Confirmation of the LBV nature of MN112 will add another object to the rare class of transitional massive stars and will have profound consequences for understanding their evolution and interaction with the ambient medium.

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