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Two New LBV Candidates in the M 33 Galaxy

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Abstract: We present two new luminous blue variable (LBV) candidate stars discovered in M 33. We identified these stars (Valeev et al. 2010a, b) as massive star candidates at the final stages of evolution. The candidates were selected from the Massey et al. (2006) catalog based on the following criteria: emission in Hα, $V < 18\overset{\mathrm{m}}{.}5$ and $0\overset{\mathrm{m}}{.}35 < (B-V) < 1\overset{\mathrm{m}}{.}2$ (presumably reddened early stars). Based on our spectroscopy of the stars, we estimated their main parameters. Object N 45901 has a bolometric luminosity $\log(L/L_\odot)$ = 6.0 – 6.2 with the value of interstellar extinction $A_V = 2.3 \pm 0.1$. The temperature of the star's photosphere is $T_\star \sim 13000 - 15000$ K, its probable mass is M $\sim$ 60–80 $M_\odot$. The infrared excess in N 45901 corresponds to the emission of warm dust with a temperature $T_{warm} \sim 1000$ K. the bolometric luminosity of the second object, N 125093, is $\log(L/L_\odot)$ = 6.3 – 6.6, the value of interstellar extinction is $A_V = 2.75 \pm 0.15$. Its photosphere's temperature is $T_\star \sim 13000 - 16000$ K, the initial mass is M$\sim$ 90-120 $M_\odot$. The infrared excess in N 125093 amounts to 5–6 % of the bolometric luminosity. Its spectral energy distribution reveals two thermal components with temperatures $T_{warm} \sim 1000$ K and $T_{cold} \sim 480$ K. The [Ca II] $\lambda\lambda 7291, 7323$ lines, observed in LBV-like stars Var A and N 93351 in M 33, are also present in the spectrum of N 125093. The high bolometric luminosities of these stars and broad Hα emissions allow classifying the studied objects as LBV candidates.

1 Introduction

Apparently, most of the LBV stars without notable interstellar extinction in our Galaxy are already discovered. However, it is probably still possible to discover a few dozen more such objects in the Galaxy using modern infrared surveys (Gvaramadze et al. 2010a, 2010b). In M 33 almost all the LBV-like objects may be detected, as its fortunate orientation and a relatively close distance (950 kpc, Bonanos et al. 2006) allow detailed spectroscopy of its bright stars.

According to the catalog (Massey et al. 2006), M 33 contains 2304 stellar objects with $V < 18\overset{\mathrm{m}}{.}5$. If we assume that the mean interstellar extinction of the brightest stars in the galaxy is $A_V \approx 1\overset{\mathrm{m}}{.}0$ (see, e.g., Fabrika et al. (1999), where this value is estimated as $A_V \approx 0\overset{\mathrm{m}}{.}95 \pm 0\overset{\mathrm{m}}{.}05$), then with the distance modulus to M 33 of $(m-M)_0 = 24\overset{\mathrm{m}}{.}9$ (Bonanos et al. 2006), the stars with $V < 18\overset{\mathrm{m}}{.}5$ and $(B-V) < 0\overset{\mathrm{m}}{.}35$ will have the luminosity $M_V < -7\overset{\mathrm{m}}{.}4$ and color $(B-V)_0 \leq 0\overset{\mathrm{m}}{.}0$. In our paper (Valeev et al. 2010a) we obtained photometry in the Hα images of all the stars from the catalog of Massey et al. (2006) with the above restrictions on color and magnitude, and made a list of stars with an excess in Hα. These are bright supergiants of the Iab luminosity class and brighter, and the hottest Ib supergiants (with B0 spectra and earlier). We expected that all the potential LBV candidates will make it into our list. We hence isolated in Valeev et al. (2010a) 185 blue emission objects ($V < 18\overset{\mathrm{m}}{.}5$ and $(B-V) < 0\overset{\mathrm{m}}{.}35$), candidates for massive stars at the final stages of evolution.

Evidently, LBVs and similar objects may well have an extinction $A_V > 1\overset{m}{.}0$, for which reason an additional list of stars with $V < 18\overset{m}{.}5$ and $0\overset{m}{.}35 < (B-V) < 1\overset{m}{.}2$ with emission in Hα was made in Valeev et al. (2010a) containing 25 candidates. We have recently obtained spectra of 15 candidate stars from the supplementary list, among them we discovered two new LBV candidates (Fig. 1). In this paper we present the results of our study of these two objects.

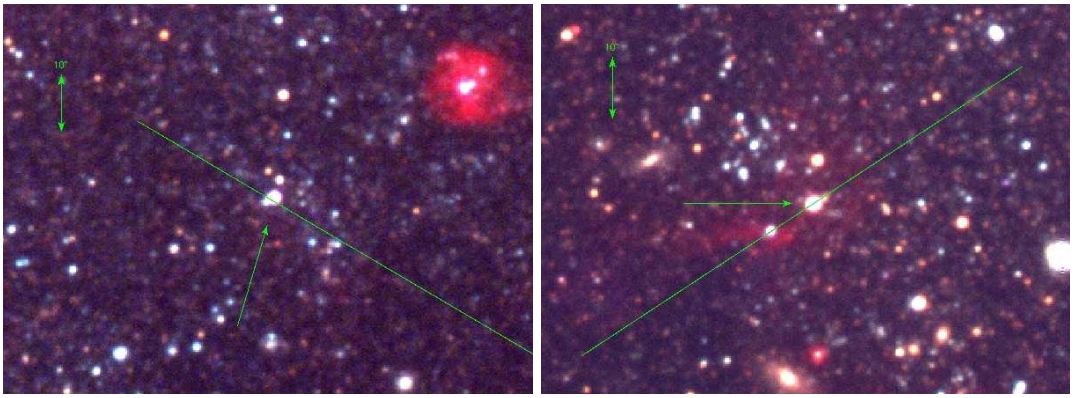

Figure 1: Finding charts in the B, V, Hα rgb image for the objects N 45901 (left) and N 125093 (right), the arrows mark their positions. The star numbers are according to nomenclature by Massey et al. (2006). The slit orientation during the observations is shown. North is at the top, west on the left.

2 Spectra and stellar parameters

The spectrum of **N 125093** is shown in Fig. 2 compared to the spectra of the known LBV stars in M 33, Var A, Var B, V 532 and a new quite firm LBV candidate in this galaxy, N 93351[1].

In the spectrum of N 125093 we see a broad Hα line with a width FWHM = 1000 km/s and equivalent width 36Å. The He I emissions in the spectrum of this star are very weak, but noticeable, the brightest line He I $\lambda\lambda 5876$ has a low intensity. The red region of the spectrum reveals weak Fe II emission lines, and several forbidden [Fe II] lines. There are nebular lines, [O I] $\lambda\lambda 6300, 6364$ as well as weak [N II] $\lambda\lambda 6548, 6384$ lines in the wings of the broad Hα emission. The [Ca II] $\lambda\lambda 7291, 7323$ lines are quite interesting, they indicate a recent gas eruption and linked dust activity (Valeev et al. 2009).

Absorption Fe II lines are visible in the blue region of the spectrum, some Ti II lines (like those in the spectrum of N 93351) and two Si II $\lambda\lambda 6347, 6371$ lines. However, the strongest metal line Fe II $\lambda 5169$ possesses emission components in the wings. In the spectrum of N 125093 diffuse interstellar bands (DIBs) are clearly visible, the Na I $\lambda\lambda 5890, 5896$ doublet is also strong. The Hβ emission of N 125093 is relatively weak and does not have broad wings at the given spectrum quality in the region.

We conducted the Gaussian analysis of the Hα emission, and found that a narrow component of this line has FWHM= 5.9 Å, which is not much different from our spectral resolution (5 Å), but its broad component has FWHM= 22.5 Å, which corresponds to the velocity dispersion in the outflowing wind of approximately 1000 km/s (after correcting for the spectral resolution). The narrow component of the Hβ line has FWHM= 4.4 Å.

[1]The spectrum of V 532 was kindly provided by Szeifert et al. (1994) and obtained with a resolution of 1.2 Å. All the remaining spectra were obtained with SCORPIO: the spectra of Var A, Var B with a spectral resolution of 12 Å, while the spectrum of N 93351 with a resolution of 5 Å. (Valeev et al. 2009)

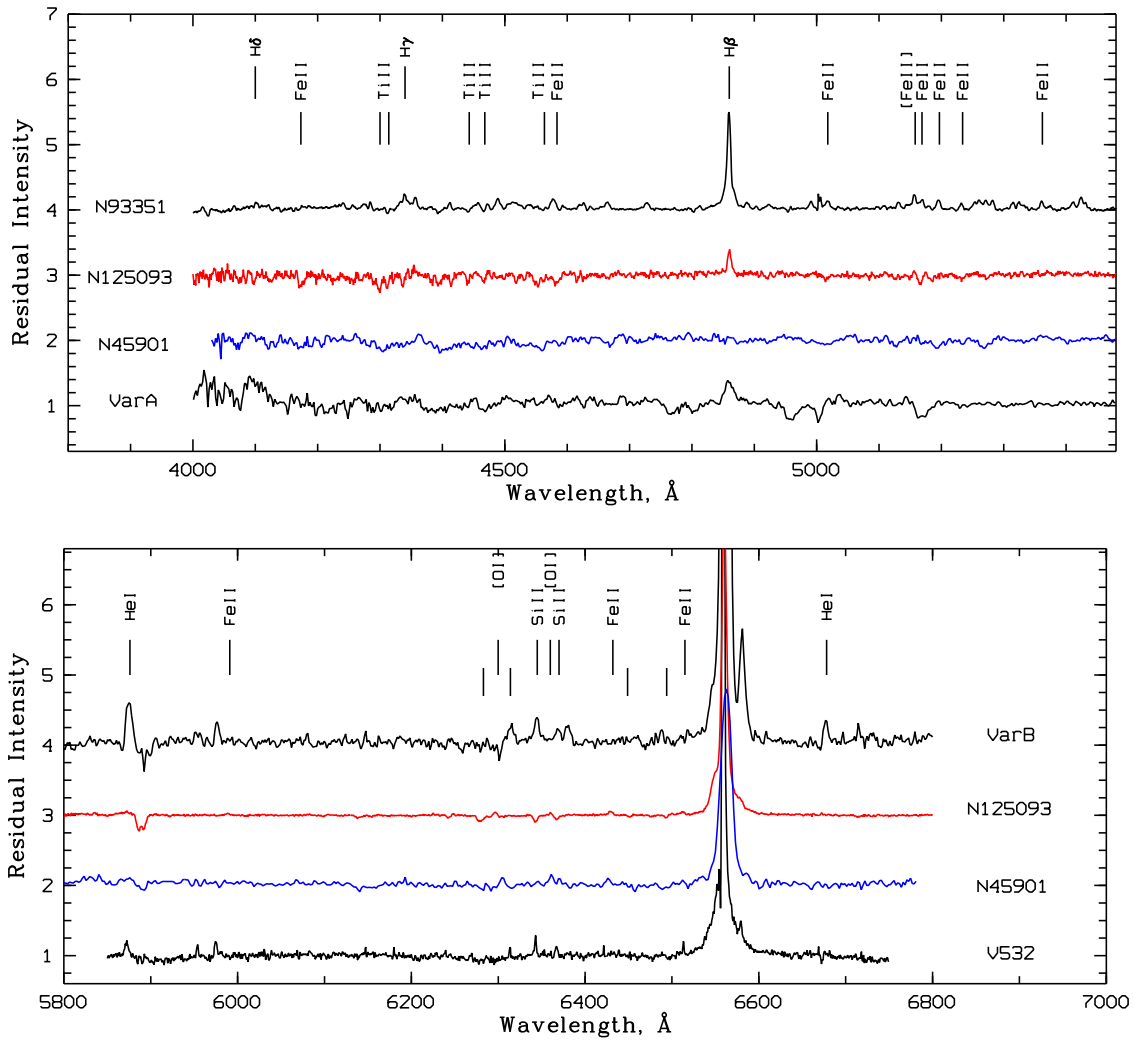

Figure 2: The normalized spectra of LBV candidates N 45901 and N 125093 in red and blue regions. The spectra of the two new LBV candidates were taken with the Russian 6-m telescope BTA with the SCORPIO focal reducer. For comparison we plot spectra of a known LBV in M 33, Var A (an LBV or a red hypergiant) and N 93351 (a firm LBV candidate) (top), Var B and V 532 (bottom). The main spectral lines detected in the spectra of our candidates are marked.

Faint and extended H II regions were captured by the slit. However around N 125093 the H II emission is very weak. To estimate the interstellar extinction, we used the Hα/Hβ line flux ratio for the emision extracted near the star. For the gaseous nebulae this ratio amounts to approximately 2.87 in a wide range of temperatures and densities (Osterbrock & Ferland 2006). We used the law of interstellar reddening from the work of O'Donnell (1994) at R_V=3.07. We obtained the value $A_V \leq 2.5$. A comparison of the spectrum of N 125093 with the spectra of relatively hot stars Var B and V 532 allows us to conclude that the temperature of the photosphere of N 125093 is certainly lower than 20000 K. On the other hand, based on the presence of deep Si II absorptions we can deduce that the temperature is definitely above 10000 K.

The spectrum of the star **N 45901** is shown in Fig. 2. We see a bright and broad Hα emission with extended wings. Gaussian analysis revealed a two-component line profile: a bright narrow line and broad wings. The widths of the narrow and broad components, corrected for spectral resolution, are equal to 140 km/s and 770 km/s, respectively. There is a [N II] λ6584 line in the broad Hα wing. The second line of the [N II] doublet, which should be 3 times weaker than the first, is probably lost in the bright blue Hα wing. We also found forbidden lines [O I] $\lambda\lambda 6300, 6364$, which are formed in the

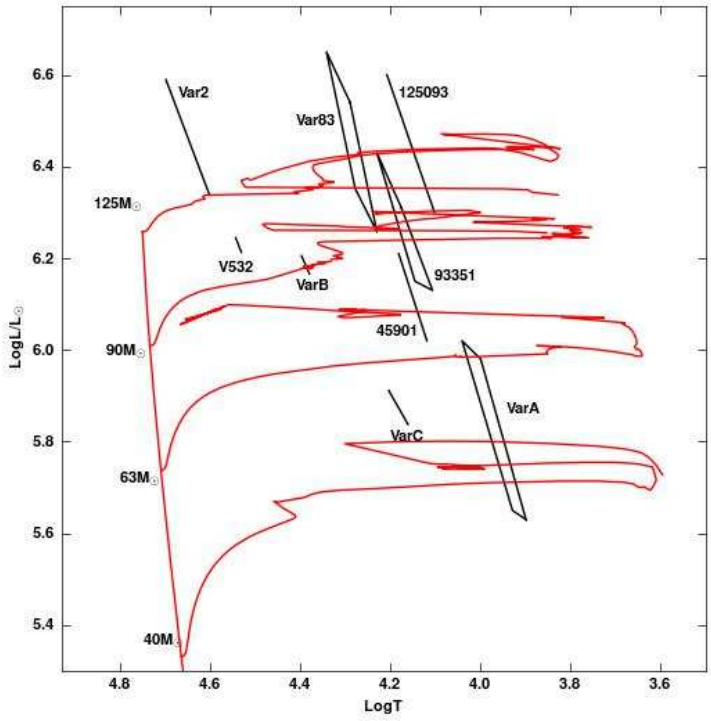

Figure 3: The temperature – luminosity diagram for all known LBV stars in M33 (Valeev et. al., 2009) with two new candidates N 45901 and N 125093 imposed. Error regions are shown. The evolution track are as calculated by Claret (2006) at metallicity Z=0.007 (M33 metallicity is 0.008).

unresolved region around the star which is smaller than 4–5 pc (at the distance of 950 kpc we adopted, the scale in M 33 is equal to 4.6 pc/arcsec). Despite the poor quality of the spectrum, especially in the blue region, the absorption lines Fe II and Ti II that are among the most intense lines of these ions, are visible in this range. In the red range, we may even suspect [Fe II] emission. The region shorter than the Hα line reveals signatures of two strongest Fe II emission lines.

Based on the presence of a broad and bright Hα emission, as well as the likely occurrence of Fe II and Ti II lines we can make a rough estimate that the temperature of the photosphere of N 45901 is above 10000–12000 K. We did not detect any He I lines, hence its temperature is below 15000 K.

2.1 Spectral energy distributions and stellar parameters

Here we present results of the spectral energy distributions (SED) of all known LBV stars in M33 and two new candidates N 45901 and N 125093 (for details see Valeev et al. 2010b). For N 125093 we find the optimal value of the interstellar extinction as $A_V = 2.75 \pm 0.15$. The temperature of the stellar photosphere is $T_\star \sim 13000 - 16000$ K, which is consistent with our estimate from the spectrum. The corresponding bolometric luminosity of N 125093 amounts to $\log(L/L_\odot)$ = 6.3 – 6.6. We find two thermal components in the spectrum, a warm component with $T_{warm} \sim 1000$ K, and a cold component with $T_{cold} \sim 480$ K. The infrared excess in N 125093 is 5–6 % of the bolometric luminosity.

In the case of N 45901 we deduced the interstellar extinction of $A_V = 2.3 \pm 0.1$. Accordingly, the temperature of the photosphere of N 45901 is estimated as $T_\star \sim$ 13000–15000 K, and its bolometric

luminosity amounts to $\log(L/L_{\odot})$ = 6.0 – 6.2. Infrared excess in N 45901 corresponds to the warm dust radiation with the temperature of $T_{warm} \sim 1000$ K and amounts to 0.1 % of the bolometric luminosity.

Figure 3 illustrates the temperature–luminosity diagram for all the LBV stars known to date (Var B, Var C, Var 2, Var 83, V 532), as well as the stars Var A and N 93351 in M 33, the parameters of which were determined in our paper (Valeev et al. 2009). We show our two new candidates N 45901 and N 125093 and the evolutional tracks Claret (2006) computed for stars with metallicity 0.007, corresponding to M 33. From this diagram, we find the mass estimates for the stars on the ZAMS. The masses of N 45901 and N 125093 are estimated as approximately $60 - 80 M_{\odot}$, and $90 - 120 M_{\odot}$, respectively.

3 Conclusion

This paper presents a preliminary study of two new LBV candidates in the M 33 galaxy. The spectra of N 45901 and N 125093 are similar to the spectra of the stars at the LBV stage. They have strong and broad Hα, emissions, forbidden [O I] and [N II] lines. The spectrum of the second star reveals [Ca II], [Fe II] and Fe II emission lines, Ti II and Fe II absorptions. The spectrum of the first star has an insufficient quality for a reliable identification, however the [O I], Fe II and Ti II lines are present in its spectrum. Comparisons of brightness estimates from different catalogs indicate a probable variability of the object N 45901. We found an infrared excess in both stars. The temperatures of warm and cold dust components in the star N 125093 (it possesses the [Ca II] emissions), amount to 1400 K and 470 K, respectively. We estimate that the star N 45901 has a bolometric luminosity of $\log(L/L_{\odot})$ = 6.0 – 6.2 and its probable mass on the initial main sequence is $M \sim 60 - 80\ M_{\odot}$. The luminosity of N 125093 amounts to $\log(L/L_{\odot})$ = 6.3 – 6.6 and its initial mass is $M \sim 90 - 120 M_{\odot}$. In Valeevet al. (2010b) the possible variability of these stars is discussed. All the above properties of N 45901 and N 12509 allow us to classify them as LBV candidates.

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