

THE HALF-CENTURY HISTORY OF STUDIES OF ROMANO'S STAR

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Abstract. A short review of observations and simulations of one of the most interesting high-mass stars, Romano's star in the M33 galaxy (M33 V532), is presented.

Key words: stars: individual: Romano's star (M33) – galaxies: individual: M33 – stars: supergiants – stars: Wolf-Rayet

1. INTRODUCTION

Luminous blue variables (LBVs) are rare objects of very high luminosities ($\sim 10^6 L_\odot$) and mass-loss rates ($10^{-5} \div 10^{-4} M_\odot \text{ yr}^{-1}$), low wind velocities, exhibiting strong irregular photometric and spectral variability (Conti 1984; Humphreys & Davidson 1994; Humphreys et al. 2014). They are generally believed to be a relatively short evolutionary stage in the life of a massive star, marking the transition from the Main Sequence toward Wolf-Rayet (WR) stars. However, recent studies indicate that progenitors of several supernovae underwent LBV-like eruptions. These studies support the view that at least some LBV stars are the end point of evolution but not a transition phase. LBVs are rare objects, whose observations in the Galaxy inevitably encounter difficulties in determination of their distance and interstellar extinction. Hence, studying these rare objects in nearby galaxies is potentially more prospective. Therefore, investigation of the extragalactic star M33 V532, hereafter V532¹, which is now classified as LBV/post-LBV star and shows a late-WN spectrum, is very important for our understanding of evolution of high-mass stars in general.

2. PHOTOMETRIC OBSERVATIONS

Photometric observations of V532 had been started by Giuliano Romano in Asiago observatory (Italy) in the early 1960s. Romano (1978) demonstrated a light curve showing that the magnitude of V532 irregularly varied between 16.7 and 18.1. He classified V532 as a variable of the Hubble-Sandage type by the shape of the light curve and its color index.

Photometric investigations were continued by Kurtev et al. (2001). They com-

¹ Romano's star (M33 V532, or GR290) with $\alpha=01:35:09.712$, $\delta=+30:41:56.55$ (J2000.0) according to SIMBAD data base.

binned data by G. Romano with their series of photometric observations, carried out during 8 years. Kurtev et al. found that, during the whole studied interval, Romano's star had displayed two brightness maxima. The first of them was near 1970 and the second one, in early 1990s. Moreover, Kurtev et al. (2001) discovered short-timescale variability with an amplitude of ~ 0.5 mag, typical of an LBV star.

Zharova et al. (2011) investigated photometric variability of V532 using the Moscow collection of photographic plates. They combined these data with new data obtained using the 60 cm Zeiss telescope of the Sternberg Astronomical Institute and 1 m Zeiss telescope of the Special Astrophysical Observatory (SAO) and with photometric data published earlier by Romano (1978), Humphreys (1980), Viotti et al. (2006). Thus, Zharova et al. (2011) constructed the most comprehensive light curve covering 50 years of observations. The light curve shows that V532 exhibits irregular light variations with different amplitudes and time scales. Generally, the star shows large and complex wave-like variations, with duration of the waves amounting to several years. Four maxima of the waves were observed (Zharova et al. 2011). In general, the variability is irregular, with the power spectrum fairly approximated by a red power-law spectrum (Abolmasov 2011).

In late 2010, a small brightening of Romano's star was detected; the star again reached 17.8 mag in the V passband (Calabresi et al. 2014). Calabresi et al. (2014) reported that, after a moderate luminosity maximum at the beginning of 2011, Romano's star had reached a new deep minimum at $V = 18.7$ mag and $R = 18.4$ mag in December 2013, which appears to be the deepest one so far recorded in its known light curve history.

Additional photometric observations of V532 were carried out in the infrared range. Its magnitudes are $J = 16.8$ mag, $H = 16.87$ mag and $K_s = 16.8$ mag according to the 2MASS survey (Cutri et al. 2003), 16.3 mag and 15.9 mag in $3.6 \mu\text{m}$ and $4.5 \mu\text{m}$ passbands, respectively, according to the data of Spitzer space telescope (McQuinn et al. 2007).

3. SPECTROSCOPIC OBSERVATIONS

Spectroscopic observations of Romano's star began only in 1992. Szeifert (1996) obtained the first optical spectrum of Romano's star with the 3.5 m Calar Alto telescope; the red range of the spectrum is shown in Fig. 5 of the cited paper. The description of the spectrum by T. Szeifert was: "Few metal lines are visible, although a late B spectral type is most likely".

The next spectrum was obtained by Sholukhova et al. (1997) with the Russian 6 m telescope. They classified V532 as a WN star candidate based on the similarity of its spectrum to that of MCA 1B. The latter star is also located in the M33 galaxy and was classified as Ofp/WN9 (Willis et al. 1992; Smith et al. 1995). Since 1998, regular observations of V532 are being carried out in the SAO (Fabrika et al. 2005; Sholukhova et al. 2011). Sholukhova et al. (2011) have published details of a series of spectroscopic observations.

Since 2003, spectroscopic observations are being performed by Italian astronomers using telescopes of the Cima Ekar (Asiago) and Loiano (Bologna) observatories (Polcaro et al. 2003; Viotti et al. 2006; Polcaro et al. 2011). Spectra of V532 at two important extrema: at the brightness minimum in 2008 and at the moderate luminosity maximum of 2010, were described by Polcaro et al. (2011), Maryeva & Abolmasov (2010) and Clark et al. (2012).

Table 1. Derived properties of V532. H/He denotes hydrogen number fraction relative to helium, f is the filling factor.

	Sp. type	T_{eff} [kK]	$R_{2/3}$ [$R_{\odot}$]	$\log L_*$ [$L_{\odot}$]	$\dot{M}_{cl}, 10^{-5}$ [$M_{\odot} \text{ yr}^{-1}$]	f	v_{∞} [km/s]	H/He
2005 ^a	WN11h	20.4	69.1	5.89	4.5	0.5	200	1.4
2008 ^a	WN8h	31.7	23.9	5.72	2	0.1	360	1.9
2010 ^b	WN10h	26	41.5	5.85	2.18	0.25	265	1.5
2014	WN8h	32.7	22	5.72	1.7	0.1	400	1.9

a: data taken from Maryeva & Abolmasov (2012a); b: data from Clark et al. (2012).

4. THE CIRCUMSTELLAR NEBULA

The nebular lines of [O III] at 4959 and 5007 Å, [N II] at 6548–83 Å, [Ar III] at 7135 Å and [Fe III] at 4658 and 4701 Å are clearly seen in the spectrum of V532 (Maryeva & Abolmasov 2010). Maryeva and Abolmasov estimated the size and mass of the V532 nebula and concluded that parameters of the nebula are by the order of magnitude consistent with those typical for ejecta of LBV stars. The emitting gas was probably ejected during one or several outburst events at wind velocities of about 100 km s^{-1} . A dust circumstellar envelope has not been detected (Humphreys et al. 2014).

5. STUDIES OF SPECTRAL VARIABILITY AND SPECTRAL CLASSIFICATION

The first investigations of spectral variability were started by Viotti et al. (2006 2007) using five spectra acquired in 2003–2006. Viotti et al. (2006 2007) found an anti-correlation between equivalent widths of the Wolf-Rayet blue bump at 4630–4686 Å and the visual luminosity. Maryeva & Abolmasov (2010) classified archive spectra of V532 and demonstrated evidence for a correlation between the spectral type and visible magnitude. It was also demonstrated that, in the deep minimum (2008), the spectrum of Romano’s star became similar to that of a WN8 star (Maryeva & Abolmasov 2010).

It is easy enough to classify every single spectrum obtained at various times, but there is no consensus among the researchers on the type of the star. As stated above, G. Romano classified the star as a Hubble-Sandage variable. Humphreys & Davidson (1994) classified the star as an LBV candidate based on its variability. Polcaro et al. (2003) estimated the bolometric absolute magnitude of the object as $M_{\text{bol}} \approx -10.4 \text{ mag}$, using the bolometric correction “of at least -3 mag ” and distance modulus $m - M = 24.8 \text{ mag}$. They classify V532 as an LBV because the object fulfills all the criteria of Humphreys & Davidson (1994).

An additional argument for the LBV/post-LBV status of V532 is its location in the galaxy. V532 does not belong to any OB association of M33. Smith & Tombleson (2014) remarked that LBVs systematically avoid clusters of O-type stars and are almost never closely associated with O-type stars of similar (presumed) initial mass.

However, Polcaro et al. (2011) concluded that bolometric luminosity had significantly changed during the minimum phase in 2008 and suggested that Romano’s

star is now about at the end of its LBV phase and to become a late WN-type star.

In a recent article, Humphreys et al. (2014) picked out an additional feature of an LBV star: its slow stellar wind. LBVs have low wind speeds in their hot, quiescent or visual minimum states, compared to the B-type supergiants and Of/WN stars which they spectroscopically resemble. Humphreys et al. (2014) concluded that in spite of Romano's star having slow wind, it was not an LBV star by all its characteristics. Most probably, Romano's star has already passed its LBV phase and is a post-LBV star now.

6. NUMERICAL SIMULATION

At present, the numerical modeling provides the most complete information about the parameters of stellar atmospheres. The first modeling of the V532 atmosphere was performed by Maryeva & Abolmasov (2012a). A non-LTE radiative transfer code CMFGEN (Hillier & Miller 1998) was used for the analysis. To accurately determine the luminosity, the model flux of each model was recalculated for the distance of M33. The distance to M33 was adopted as $D = 847 \pm 60$ kpc, which gives a distance modulus of $m-M = 24.64 \pm 0.15$ mag (Galleti et al. 2004). Then, the simulated spectra were convolved with the B and V passband sensitivity curves. The resulting fluxes were converted to magnitudes (Lang 1974) and compared to the photometric data.

Maryeva & Abolmasov (2012a) investigated the optical spectra of Romano's star in two different states, the brightness minimum of 2008 ($B = 18.5 \pm 0.05$ mag) and a moderate brightening in 2005 ($B = 17.1 \pm 0.03$ mag). Figure 1 shows the observed spectra of V532 at different phases and the best-fit model spectra. Stellar parameters derived for both models are given in Table 1.

The main result of the study by Maryeva & Abolmasov (2012a) is that the bolometric luminosities of V532 were different in 2005 and 2008. The bolometric luminosity of V532 in 2005 ($L_* = 7.5 \cdot 10^5 L_\odot$) is 1.5 times higher. This result confirms the conclusion of Polcaro et al. (2011).

Clark et al. (2012) modeled the spectrum of Romano's star obtained in September 2010 when the V -band magnitude of the object was between 17.75 mag and 17.85 mag. They also used CMFGEN code (Hillier & Miller 1998). For comparison, the results by Clark et al. (2012) are also listed in Table 1. They inferred (see Table 1) that the physical properties (T_{eff} , v_∞ , filling factor f) of Romano's star in 2010 were a smooth progression between photometric minima and maxima. We find that the values of H/He agree within errors. It may be seen from the table that luminosities in 2008 and 2010 were different. However, it must be noted that Clark et al. (2012) assumed the distance to M33 to be 964 kpc, while Maryeva & Abolmasov (2012a) adopted the distance of 847 kpc. Recalculating the luminosity found by Clark et al., $L_* = 7 \cdot 10^5 L_\odot$, to the distance 847 kpc, we find that the luminosity of V532 is $L_* = 5.4 \cdot 10^5 L_\odot$ and it did not change after 2008 within the error limits ($L_* = 5.2 \pm 0.2 \cdot 10^5 L_\odot$, Maryeva & Abolmasov (2012a)).

7. NEW OBSERVATIONS

In August 2014, we obtained a new spectrum of V532 using the Russian 6 m telescope with the SCORPIO multi-mode focal reducer in the long-slit mode (Afanasiev & Moiseev 2005). The spectrum was reduced using the **ScoRe** package written in the IDL language. The package includes all the standard stages of

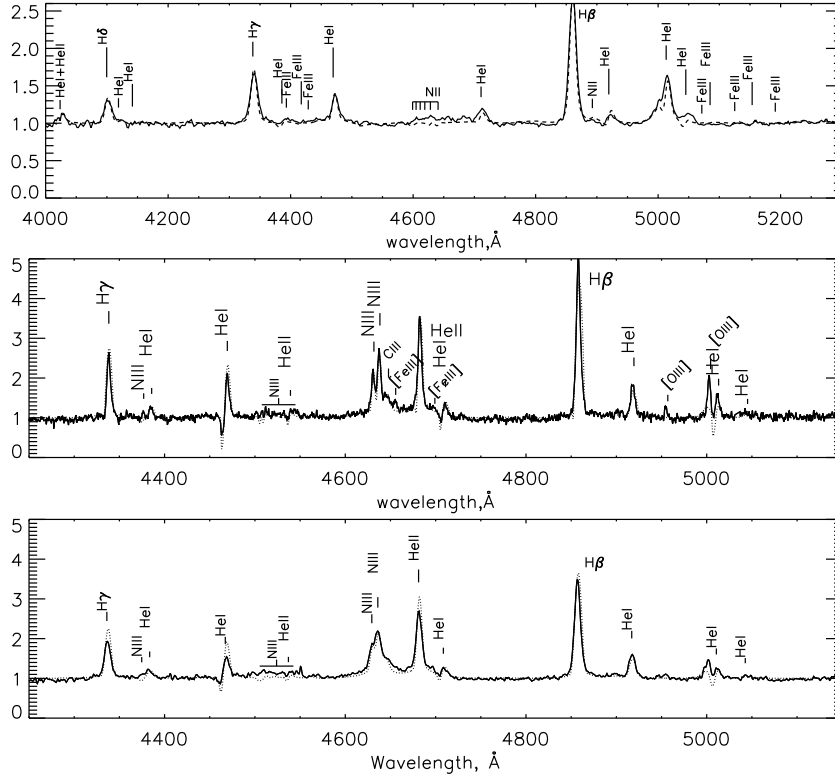


Fig. 1. The normalized optical spectrum (solid curve) compared to the best-fit CMFGEN models (dashed curve). Top panel: the spectrum obtained in February 2005 when V532 was at 17.27 mag in the V passband. Middle panel: the spectrum obtained in October 2007 ($V = 18.68$ mag). Bottom panel: the spectrum obtained in August 2014 ($V = 18.7$ mag).

long-slit data reduction process.

V532 is now at the brightness minimum, its visual magnitude is $V = 18.7$ mag. The photometric data were kindly provided by Roberto Haver and Massimo Calabresi, scientists of Associazione Romana Astrofili (ARA). The bottom panel of Figure 1 shows the spectrum obtained in August 2014 and its best-fit model. Figure shows that the new August spectrum is very similar to that obtained in October 2007. This is a verification of the hypothesis that the change of magnitude occurs simultaneously with spectral type changes. The dependence of the magnitude on spectral type does not vary with time. Therefore, we can use this property for studies of the time intervals for which we have only photometric data.

8. CONCLUDING REMARKS

Figure 2 presents the positions of V532 in different phases in the Hertzsprung-Russell (HR) diagram according to modeling by Maryeva & Abolmasov (2012a). V532 in the brightness maximum ($V = 17$ mag, February 2005) lies at the LBV minimum instability strip. It moves to the “forbidden region” in its minimum

brightness. V532 is the first star which demonstrated the transition from the instability strip to the WR region (Maryeva 2013). The main argument that V532 is now not an LBV is that it does not exhibit S Dor-like transitions to the cool, dense wind state. Instead, it oscillates in the HR diagram between two hot states, characterized by WN spectroscopic features (Humphreys et al. 2014). However, there is a spectrum obtained in 1992 which is classified as a late-B spectral type (Szeifert 1996). Maybe this spectrum is a confirmation that V532 in early 1990s was actually in a cool state?

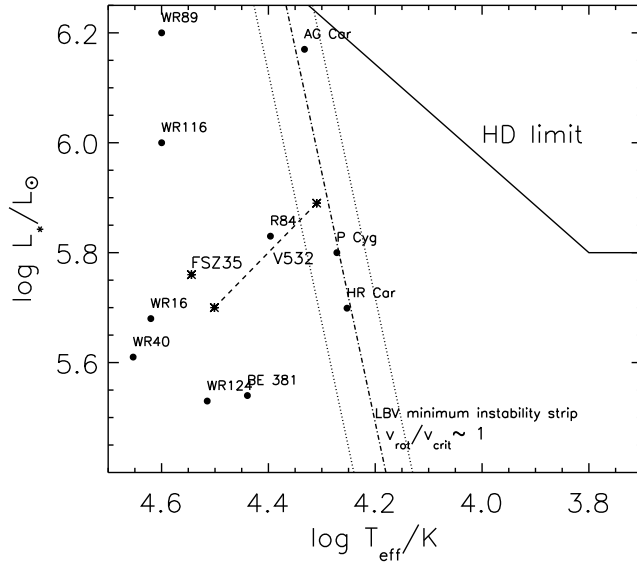


Fig. 2. A schematic presentation of the upper part of the HR Diagram. The position of the LBV minimum instability strip is plotted as a dashed-dotted line. The location of the Humphreys-Davidson limit (Humphreys & Davidson 1994) is shown as the solid line. The dashed line shows the transit of V532 across the instability strip. WN9 (BE381, R84), WN8 (WR124, WR16, WR40, FSZ35) and LBV (AG Car, HR Car, P Cyg) stars are shown for comparison. Data on these objects were taken from Crowther & Smith (1997), Crowther & Smith (1997), Crowther et al. (1999), Herald et al. (2001), Herald et al. (2001), Maryeva & Abolmasov (2012b), Groh et al. (2009b), Groh et al. (2009a), Najarro (2001).

Moreover, it is interesting to observe variability in different ranges. We consider the investigation of V532 in a wide range of wavelengths as a top priority task.

Another interesting question is: how did the luminosity of Romano's star change before and after the moderate brightening in 2005? How did other parameters of the atmosphere behave? To answer these questions, numerical modeling of archive spectra is needed. The mass-loss rate depends on luminosity, hence it is necessary to make calculations for different phases in a consistent way.

It is clearly seen from this review that V532 has been primarily studied in the optical range. While its optical monitoring was more or less regular, it has not been studied well in other wavebands. Estimates of the X-ray, ultraviolet and radio luminosities of V532 are necessary for precise construction of its spectral energy distribution (SED).

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REFERENCES

- Abolmasov P. 2011, *New Astronomy*, 16, 421
- Afanasiev V. L., Moiseev A. V. 2005, *Astronomy Letters*, 31, 194
- Calabresi M., Rossi C., Gualandi R. et al. 2014, *Astronomer's Telegram*, 5846, 1
- Clark J. S., Castro N., Garcia M. et al. 2012, *A&A*, 541, A146
- Conti P. S. 1984, in *Observational Tests of the Stellar Evolution Theory* (IAU Symp. 105), p. 233
- Crowther P. A., Pasquali A., De Marco O. et al. 1999, *A&A*, 350, 1007
- Crowther P. A., Smith L. J. 1997, *A&A*, 320, 500
- Cutri R. M. et al. 2003, *VizieR Online Data Catalog* II/246
- Fabrika S., Sholukhova O., Becker T. et al. 2005, *A&A*, 437, 217
- Galletti S., Bellazzini M., Ferraro F. R. 2004, *A&A*, 423, 925
- Groh J. H., Damineli A., Hillier D. J. et al. 2009a, *ApJ*, 705, L25
- Groh J. H., Hillier D. J., Damineli A. et al. 2009b, *ApJ*, 698, 1698
- Herald J. E., Hillier D. J., Schulte-Ladbeck R. E. 2001, *ApJ*, 548, 932
- Hillier D. J., Miller D. L. 1998, *ApJ*, 496, 407
- Humphreys R. M. 1980, *ApJ*, 241, 587
- Humphreys R. M., Davidson K. 1994, *PASP*, 106, 1025
- Humphreys R. M., Weis K., Davidson K. et al. 2014, *ApJ*, 790, 48
- Kurtev R., Sholukhova O., Borissova J., Georgiev L. 2001, *Rev. Mex. AA*, 37, 57
- Lang K. R. 1974, *Astrophysical Formulae: a Compendium for the Physicist and Astrophysicist*, Springer
- Maryeva O. 2013, *Astron. Astrophys. Trans.*, 28, 35
- Maryeva O., Abolmasov P. 2010, *Rev. Mex. AA*, 46, 279
- Maryeva O., Abolmasov P. 2012a, *MNRAS*, 419, 1455
- Maryeva O., Abolmasov P. 2012b, *MNRAS*, 421, 1189
- McQuinn K. B. W., Woodward Ch. E., Willner S. P. et al. 2007, *ApJ*, 664, 850
- Najarro F., 2001, in *P Cygni 2000: 400 Years of Progress*, ASPC, 233, 133
- Polcaro V. F., Gualandi R., Norci L. et al. 2003, *A&A*, 411, 193
- Polcaro V. F., Rossi C., Viotti R. F. et al. 2011, *AJ*, 141, 18
- Romano G. 1978, *A&A*, 67, 291
- Sholukhova O. N., Fabrika S. N., Vlasjuk V. V., Burenkov A. N. 1997, *Astronomy Let.*, 23, 458
- Sholukhova O. N., Fabrika S. N., Zharova A. V. et al. 2011, *Astrophys. Bull.*, 66, 123
- Smith N., Tombleson R. 2014, *ArXiv e-prints*
- Smith L. J., Crowther P. A., Willis A. J. 1995, *A&A*, 302, 830
- Szeifert T. 1996, in *LBVs and a late WN-star in M 31 and M 33*, *Liege Internat. Astrophys. Coll.*, 33, 459
- Viotti R. F., Galletti S., Gualandi R. et al. 2007, *A&A*, 464, L53
- Viotti R. F., Rossi C., Polcaro V. F. et al. 2006, *A&A*, 458, 225
- Willis A. J., Schild H., Smith L. J. 1992, *A&A*, 261, 419
- Zharova A., Goranskij V., Sholukhova O. N., Fabrika S. N. 2011, *Variable Stars Suppl.*, 11, 11