Modeling the optical spectrum of Romano's star

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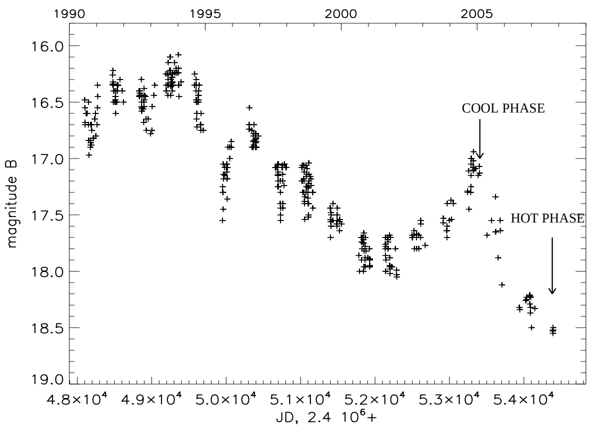
Using the radiative transfer code CMFGEN (J.D.Hillier), we determine the physical parameters of Romano‘s star (GR290 or V532) – Luminous Blue Variable in M33 galaxy. We consider Romano‘s star in two different spectral states: in the optical minimum of 2007/2008 and during a local brightening in 2005. All the observed properties of the object in the minimum are well described by a late WN star model, while the spectrum during the outburst corresponds to the spectral class WN11 and is similar to the spectrum of P Cyg. Bolometric luminosity is shown to vary between the two states by a factor of $\sim$1.5. This makes GR290 another example of an LBV that shows variations in its bolometric luminosity during an outburst. V532 in maximum of brightness (V=17mag, Feb. 2005) lies on the LBV minimum instability strip in the Hertzsprung-Russell (HR) diagram. And it moves to the left of the LBV minimum instability strip in the minimum of brightness. Probably, we observe final transition from LBV to WN.

V532, known as Romano‘s star, is an interesting variable star located in the M33 galaxy. The first light curve for V532 was presented by Romano (1978). As it demonstrates pronounced photometrical and spectral variability (Kurtev et al., 2001; Polcaro et al., 2003), V532 is classified as an LBV. The object changes from a B emission line supergiant in the optical maximum (Szeifert, 1996), through Ofpe/WN (WN10,WN11) and WN9 toward a WN8-like spectrum in deep minima (Maryeva & Abolmasov, 2010). Figure 1 shows a B-band light curve of V532 from 1990 to 2008.

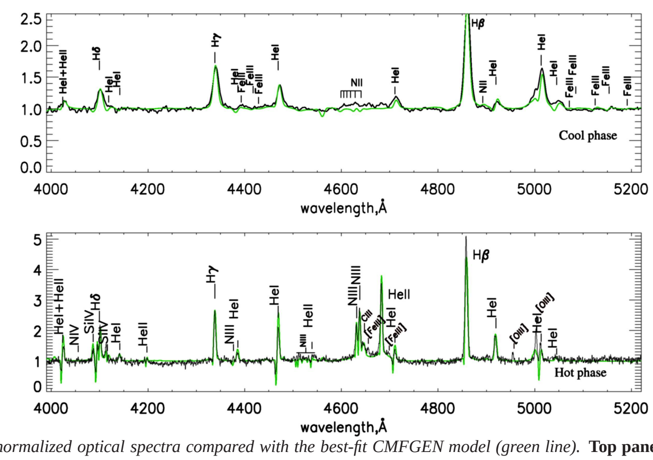
Fig. 1



The B-band light curve of V532. Arrows indicate the dates of spectral observations.

During 2004 and 2005, V532 becomes brighter by about $1^{\rm m}$ in B and reaches $17^{\rm m}$ in this band. Starting from the middle 2005, Romano's star weakens in all bands. Its visible magnitude reaches $18^{\rm m}.68$ in the V band in February 2008. We investigate the optical spectra of V532 in two different states, the brightness minimum of 2008 (*hot phase*) and a moderate brightening in 2005 (*cool phase*), using the non-LTE radiative transfer code CMFGEN (Hillier & Miller, 1998). In Figure 2 we show the observed spectra of V532 at different phases and the best-fit model spectra. Stellar parameters derived for both hot- and cool-phase models are given in Table . For comparison, the values of these parameters for some other stars taken from the literature are given in the table.

Fig. 2



The normalized optical spectra compared with the best-fit CMFGEN model (green line). **Top panel:** *the spectrum obtained in February 2006 where V532 is $17^{\rm m}.27$ in V band.* **Bottom panel:** *the spectrum obtained in October 2007 — $V = 18^{\rm m}.68$*

Table shows that V532 in the minimum of brightness is similar to a classical WN8 star, but the wind velocity is lower, characteristic rather for a WN9 star. We see that relative hydrogen abundance (H/He) for V532 is similar to that of WN8h stars. V532 as well as other LBVs AG Car and P Cyg shows significant enhancement of helium (more than a factor of 2 relative to solar), impying the end of the hydrogen shell-burning phase. High nitrogen content and depletion of carbon and oxygen are indicative of material which has undergone the CNO cycle.
In February 2005, during the outburst, parameters of the star correspond to the spectral class WN11. The model spectrum is similar to the spectrum of P Cyg in 1998. V532 shows a WN11 spectrum in the maximum, while the classical LBVs like AG Car and P Cyg become WN11 only in the deep minima and in the long-lasting quiet state, respectively. Note however that V532 had a strong maximum in 1993 ($0^{\rm m}.9$ brighter than in February 2005) and exhibited a B-supergiant spectrum.

Table 1 *Derived properties of V532 in the maximum and the minimum of brightness and comparison with WN8h stars and LBV P Cyg. X_H is mass fraction of hydrogen*

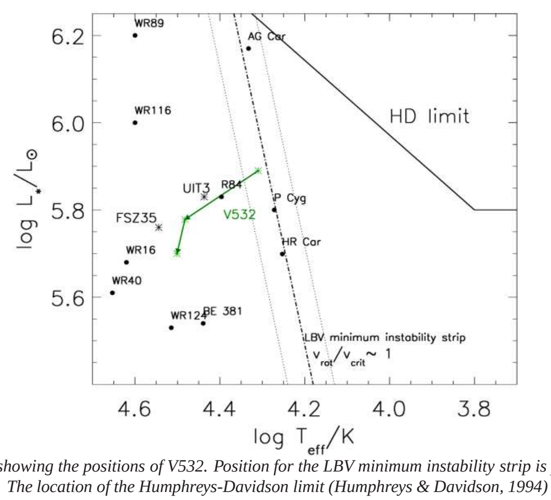
Star	Sp. type	T_* [kK]	$R_{2/3}$ [R$_\odot$]	$\log L_*$ [L$_\odot$]	$\log \dot{M}_{cl}$ [M$_\odot$ yr^{-1}]	f	v_∞ [km s^{-1}]	X_H [%]	Ref
WR40	**WN8h**	**45.0**	**10.6**	**5.61**	**-4.5**	**0.1**	**840**	**15**	**[1]**
WR16	**WN8h**	**41.7**	**12.3**	**5.68**	**-4.8**	**0.1**	**650**	**23**	**[1]**
V532 hot-phase	**WN8**	**34.0**	**20.8**	**5.7**	**-4.75**	**0.1**	**360**	**24**	**[4]**
V532 cool-phase	**WN11**	**22.0**	**59.6**	**5.89**	**-4.4**	**0.5**	**200**	**24**	**[4]**
P Cyg	**B1Ia$^+$**			**5.8**	**-4.63**	**0.5**	**185**		**[2]**

[1]- Herald et al. (2001), [2]- Najarro (2001), [3]- Maryeva & Abolmasov (2011b)

The two phases, hot and cool, are mainly distinguished by the (pseudo-)photosphere radius, that is about three times larger in the cool phase. For the two states, $\dot{M}$ differ by a factor 2.8, and the wind velocity is 1.8 times larger for the hot state. Bolometric luminosities of V532 were different in 2005 and 2008. Luminosity of V532 in 2005 ($L_* = 7.7 \cdot 10^5 L_\odot$) is 1.5 times higher. Therefore, V532 should be considered one more LBV (after the objects mentioned by Koenigsberger (2004); Drissen et al. (2001); Clark et al. (2009)) that changes its luminosity during (even moderate amplitude) eruption. In this sense, V532 behaves similarly to AG Car that has bolometric luminosity variations during its S Dor cycle (Maryeva & Abolmasov, 2011b).

Figure 3 presents the positions of V532 in different phase in the HR diagram. Groh et al. (2009) suggest that the LBV minimum instability strip is characterized by $\log(L_*/L_\odot) = 4.54 \cdot \log(T_{eff}) - 13.61$. Groh et al. (2009) suggest that the LBV minimum instability strip corresponds to the region where critical rotation is reached for LBVs with strong S-Dor-type variability. When LBVs are evolving toward maximum, the star moves far from the LBV minimum instability strip (to the right in the HR diagram), and v_{rot}/v_{crit} decreases considerably. The region in the HR diagram on the left side of the LBV minimum instability strip would be populated by unstable LBV stars with $v_{rot}/v_{crit} > 1$, which would make it a “forbidden region” for LBVs. Indeed, no confirmed strong-variable LBV is seen in this region (see (Groh et al., 2009) and references therein). V532 in maximum of brightness (V=$17^{\rm m}$, Feb. 2005) lies on the LBV minimum instability strip. And it moves to “forbidden region” in the minimum of brightness.

Fig. 3



HR diagram showing the positions of V532. Position for the LBV minimum instability strip is provided (dashed line). The location of the Humphreys-Davidson limit (Humphreys & Davidson, 1994) is shown (solid line).

Results and Conclusions

Using comoving frame numerical radiative transfer with the CMFGEN code, we estimate the physical parameters of the photosphere of Romano's star coming to the two principal conclusions. First, variability in this object is caused by correlated changes in mass-loss rate, wind velocity and hydrostatic radius. Secondly, elementary abundances do not change significantly, we find similar helium and nitrogen overabundance in both states, characteristic for hydrogen-rich WNL stars, H/He$\simeq 1.7 - 2.0$ and N/He$\simeq (3-5) \times 10^{-3}$.

We find that the bolometric luminosity of this object was higher during the eruption in 2005 by a factor of $\sim$1.5, that makes V532 one more example of an LBV that changes its luminosity. Together with the moderate intensity outburst of AFGL2298, its behaviour indicates that even moderate amplitude LBV outbursts are accompanied by changes in bolometric luminosity.

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