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DDO68-V1: an extremely metal-poor LBV in a void galaxy

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Abstract. The lowest metallicity massive stars in the Local Universe with $Z \sim (Z_\odot/50\text{-}Z_\odot/30)$ are the crucial objects to test the validity of assumptions in the modern models of very low-metallicity massive star evolution. These models, in turn, have major implications for our understanding of galaxy and massive star formation in the early epochs. DDO68-V1 in a void galaxy DDO68 is a unique extremely metal-poor massive star. Discovered by us in 2008 in the HII region Knot3 with $Z = Z_\odot/35$ [12+log(O/H)$\sim$7.14], DDO68-V1 was identified as an LBV star. We present here the LBV lightcurve in V band, combining own new data and the last archive and/or literature data on the light of Knot3 over the 30 years. We find that during the years 2008-2011 the LBV have experienced a very rare event of 'giant eruption' with V-band amplitude of 4.5 mag ($V \sim 24.5^m - 20^m$).

Keywords. stars: individual (DDO68-V1), stars: supergiants, stars: abundances, stars: mass loss, stars: variables: LBV, galaxies: individual (DDO68, UGC5340)

1. Introduction

Luminous Blue Variable (LBV) stars represent a short (about or less than 0.1 Myr) transient phase of massive star evolution from the main sequence hydrogen burning O stars to the core-helium burning Wolf-Raye (WR) stars.

Evolution of massive stars with the lowest known metallicities is crucial for understanding the early galaxy formation and evolution at high redshifts due to their great energy release/feedback (e.g., Barkana & Loeb (2001)).

The most metal-poor **massive** stars are currently identified in several extremely metal-poor ($Z \sim Z_\odot/45\text{–}\ Z_\odot/35$) dwarf galaxies. Most of these extreme galaxies are found in nearby voids.

Stellar evolution models (including those with the fast rotation) have substantially advanced during the last decade. However, the direct comparison of the model predictions with the properties of real extremely metal-poor massive stars is still absent. Such studies should await for the next generation extremely large telescopes.

2. Overview

DDO68, at the distance D=12.75 Mpc, is one of the most metal-poor galaxies ($Z \sim Z_\odot/35$) residing in the nearby Lynx-Cancer void. DDO68 is a merger of low-mass gas-rich components (Ekta, Chengalur, Pustilnik (2008), Makarov *et al.* (2017)). Its very low-Z gas was identified with BTA spectra in 2005. Most of SF regions are found at the periphery, mainly in the 'Northern ring' and the 'Southern tail' (Pustilnik, Kniazev, & Pramskij (2005), Izotov, & Thuan (2007)).

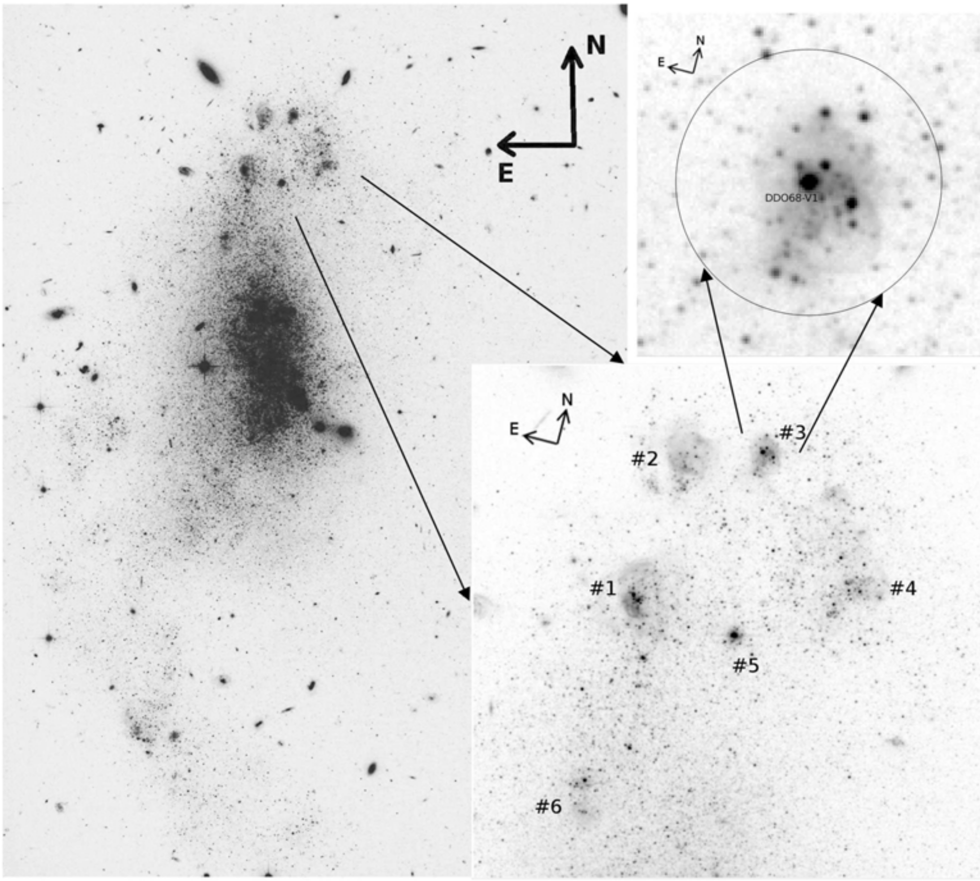

Figure 1. The part of the HST image of DDO68 in $W606$ (V) band centered on the region Knot 3 with the used aperture superimposed ($D_{\rm aper} = 5''$). DDO68-V1 is in the center of the aperture.

In 2008 we discovered in its SF Knot 3 (Fig. 1) a transient which was identified with an LBV (Pustilnik *et al.* (2008), see also Izotov, & Thuan (2009)). Hubble Space Telescope (HST) images of DDO68 were obtained in May 2010 with *ACS* for Proposal GO 11578 (PI A.Aloisi) and presented in papers by Sacchi E. *et al.* (2016) and by Makarov *et al.* (2017).

The lightcurve of Knot 3 (Fig. 2) in DDO68 in V and B bands since 1988 is based on the new and archive data and the data from Pustilnik *et al.* (2017). All magnitudes are for the aperture with r=2.5$''$. The dotted lines at $V = 20.20$ and $B = 20.25$ correspond to the minimal observed light of the entire Knot 3. These minimal levels were slightly reduced due to a more advanced background determination with respect of that adopted in paper by Perepelitsyna & Pustilnik (2017). These magnitudes are consistent, in particular, with Knot 3 light on the night 2005.01.12, when the LBV was too faint and did not show up in the spectrum of Knot 3.

With except of one direct photometry (the HST image), all other magnitudes are derived as the 'residual light' via subtraction of the constant luminosity of the underlying HII region ($V = 20.20$) from the lightcurve on the Fig. 3. We observe a very rare case of LBV 'giant eruption' (Smith & Owocki (2006)) during the years 2008-2011, with the total amplitude of the LBV optical variability δV$\sim$4.5^m, reaching $M_{\rm V}$ = -10.5. Series

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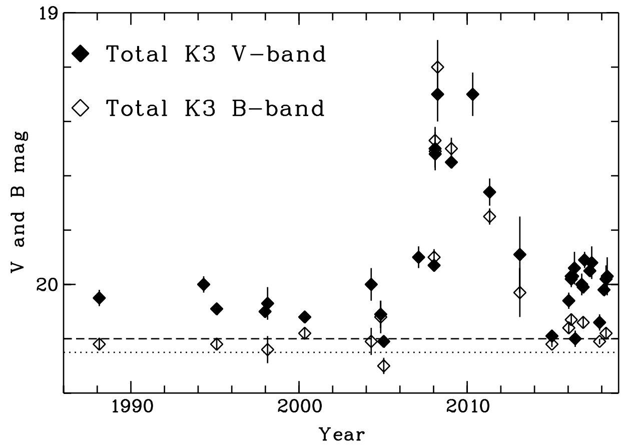

Figure 2. The lightcurve of Knot 3 in DDO68 in V and B bands since 1988 based on new and archive data and the data from Pustilnik *et al.* 2017. All magnitudes are for the aperture with r = 2.5″.

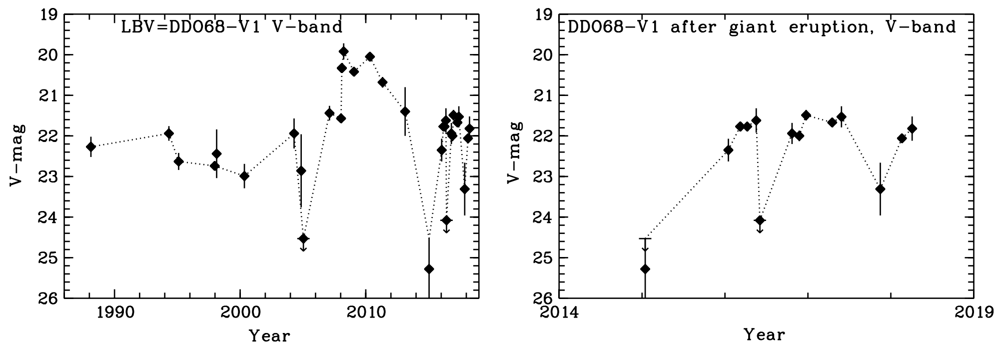

Figure 3. Left panel: Light curve of the LBV in V-band (filled lozenges). With except of one direct photometry (the *HST* W606 image in May 2010), all other magnitudes are derived as the 'residual light' via the subtraction of the constant luminosity of the underlying HII region ($V = 20.20$) from the previous lightcurve. Lozenges with arrows indicate 3σ upper limits. **Right panel:** Close-up of the LBV light curve in V-band for period of 2015 – 2018. There is an indication of the phenomenon of S Doradus type variations (Sterken 2003).

of 'giant eruptions' in LBVs which form several expanding shells, can precede their SN explosions at rather short time scale. Observations of light variations of DDO68-V1 after the 'giant eruption', since Year 2015 reveal the behaviour resembling the phenomenon of S Doradus (Sterken 2003). In the right panel of Figure 3, the photometric variability is observed up to 2.5^m over the periods of 0.5–2 years.

3. Implications and conclusions

(a) We extend the recently published lightcurve for the period of 2005 – 2015 for DDO68-V1 (Pustilnik *et al.* 2017), adding our fresh (years 2016–2018) Zeiss-1000 and BTA telescopes photometry of the HII region Knot 3 (containing the LBV = V1) and the photometry from the archive images at ten epochs with ten different telescopes over the period of 1988 – 2013.

(b) The data allow us at the first time to determine the reliable amplitude of this LBV lightcurve. All available data suggest that the LBV V-band light varied during the last

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decade in the range of $\sim$20.0^m to fainter than 24.5^m. This corresponds to the absolute magnitude $M_{\rm V}$ range of -6.0^m to -10.5^m.

(*c*) If the photometric behavior of the most metal-poor LBV is similar to that of more typical LBVs, the DDO68-V1 light variations during the last 28 years suggest that it underwent a 'giant eruption' during the years 2008 – 2011.

(*d*) We call to the community for the campaign of DDO68-V1 multiwavelength monitoring that can give the new insights in the lowest metallicity LBV properties and prove the substantial increase of its bolometric luminosity.

(*e*) Having in mind other known examples of extragalactic SN impostors, one can occasionally catch this unique object in the SN impostor phase. Moreover, in the case of the great luck, we can catch even the unique case of a nearby SNII explosion related to the extremely low-Z massive star.

The full-format paper presenting all details of observational data and their analysis as well as a wider discussion of all available data is prepared for publication in MNRAS.

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