On the nature of anomalous reddening of Cygnus OB2 #12 hypergiant

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Abstract. To explain the nature of the anomalously high reddening ($A_V \approx 10$ mag) towards one of the most luminous stars in the Galaxy – Cyg OB2 #12 (B5 Ia-0), also known as MT304, we carried out spectro-photometric observations of 24 stars located in its vicinity. We included five new B-stars to the members of Cygnus OB2, and for five more photometrically selected stars we spectroscopically confirmed their membership. We constructed the map of interstellar extinction within 2.5 arcmin radius and found that interstellar extinction increases towards MT304. The increase of reddening suggests that the reddening excess may be caused by the circumstellar shell ejected by the star during its evolution. We also report the detection of a second component of MT304, and discovery of an even fainter third component, based on data of speckle interferometric observations taken with the Russian 6-m telescope.

Introduction

Stellar association Cyg OB2 (VI Cyg) is one of the closest star formation regions to the Sun (distance is 1.4 ± 0.1 kpc (Rygl et al. 2012)) and it is a zoo of unique objects among which there is an enigmatic star Cyg OB2 #12 (Schulte 12, MT304). MT304¹ is enigmatic not only due to its high luminosity (its bolometric luminosity is $1.9 \cdot 10^6 L_\odot$ (Clark et al. 2012) and according to various estimates, the star is one of the brightest stars in the Galaxy (Clark et al. 2012)), but also because of its strong reddening, which is higher than average reddening of the massive stars in the association (see Chentsov et al. (2013) and references therein, and Wright et al. (2015)).

MT304 is classified as B5 Ia-0 (Chentsov et al. 2013) or B3-4 Ia (Clark et al. 2012) hypergiant. Compared to other bright massive stars in the association MT304 is significantly more reddened. Interstellar extinction towards it is $A_V \approx 10.1$ mag (Kiminki et al. 2007; Wright et al. 2015). According to Wright et al. (2015) the difference between MT304 and MT488, second most reddened OB-star, is $\Delta A_V = 1.9$ mag. Nature of this excessive absorption remains unclear. Does it originate in a small dense dust

¹MT is the catalogue of Cyg OB2 members by Massey & Thompson (1991)
cloud which is accidentally caught in the line of sight (see Whittet (2015) and discussion therein)? Or does it arise in a circumstellar shell (see for example Chentsov et al. (2013))?

In order to investigate the extinction near MT304 we carried out long-slit spectroscopy and photometry of stars within 2.5 arcmin from it. Moreover we refined parameters of the second companion of MT304 using speckle-interferometer observations with the Russian 6-meter telescope. In this article we will report the results of these observations.

Multiplicity of MT304

Caballero-Nieves et al. (2014) discovered a second component of MT304, with the separation between the components of 63.6 mas and the magnitude difference of $\Delta m = 2.3 \pm 0.2$ mag in F583W filter. To confirm it, and to measure the brightness difference in other spectral bands, as well as to better study the immediate neighbourhood of MT304 in general, we performed speckle-interferometric observations with the Russian 6-m telescope on February 12 and December 5 2014. Observations were carried out in the visual and near-infrared spectral ranges (Table 1).

Table 1. Resolved companions of MT304. $\theta$ is the measured position angle, $\rho$ is the measured angular separation, $\Delta m$ is the observed magnitude difference, $\lambda$ is the central wavelength of the filter used for the observation, $\Delta \lambda$ – the full width at half-maximum (FWHM) of the filter passband. * Data taken from Caballero-Nieves et al. (2014)

| Pair | Epoch      | $\theta$, [$^\circ$] | $\rho$, [mas] | $\Delta m$, [mag] | $\lambda$, [nm] | $\Delta \lambda$, [nm] |
|------|------------|----------------------|---------------|-------------------|-------------------|-------------------------|
| AB   | 2014.1198  | 293.0 ± 0.3          | 65 ± 1        | 1.79 ± 0.02       | 700               | 40                      |
|      | 2014.1199  | 293.0 ± 0.3          | 64 ± 2        | 1.75 ± 0.03       | 800               | 100                     |
|      | 2014.9290  | 291.7 ± 0.3          | 64 ± 2        | 2.0 ± 0.1         | 800               | 100                     |
|      | 2014.9290  | 291.7 ± 0.3          | 69 ± 2        | 1.8 ± 0.1         | 900               | 80                      |
| AC   | 2014.1198  | 271.3 ± 0.2          | 1246 ± 2      | 4.8 ± 0.2         | 700               | 40                      |
| AB*  | 2006.2346  | $^{305.9}_{283.5}$ ± 3.3 | 63.5 ± 3.5    | 2.3 ± 0.2         | 583               | 234                     |

The autocorrelation function (see left panels of Figure 1) clearly displays the second component of MT304, discovered by Caballero-Nieves et al. (2014). Moreover, the fainter third companion is also seen with the significance better than at least 7 sigmas. The measured parameters are given in Table 1; for the second component they are well consistent with the estimates by Caballero-Nieves et al. (2014).

We conducted speckle interferometric observations of MT304 in February and December 2014. As can be seen in Table 1 during these 10 months the position angle of the secondary component has changed by 1.7 °, greatly exceeding the measurement errors. It strongly favours the physical connection between A and B components. Our measurements together with the results of Caballero-Nieves et al. (2014) suggest a rotation period of the secondary component of about 100-200 years. The motion of the secondary component is large enough to build the orbit of the system in ten years of observations and therefore to derive the mass ratio of these stars.

The observed spectrum of MT304 does not display any lines of the secondary component (see e.g. Chentsov et al. (2013)) and is perfectly fit by a single star model (Clark et al. 2012), and therefore we may suggest that the secondary component is a B dwarf with spectrum similar to the one of the brighter star. Dedicated observations
with high signal to noise ratio are definitely necessary to classify it better. We can not presently say anything about the third component, but its spatial proximity suggests that it may belong to the Cyg OB2 association and be physically connected to MT304 too. We will perform further observations of this system.

**Reddening around MT304**

Longslit spectroscopy of stars close to MT304 was carried out with the Russian 6-m telescope with the focal reducer SCORPIO (Afanasiev & Moiseev 2005), using the grism VPHG 1200G (spectral resolution $\Delta \lambda \approx 6.5$, spectral range 4000–5700 Å). All the SCORPIO spectra were reduced using the ScoRe package$^2$.

Images of the region around MT304 in $B$ and $V$ filters have been acquired using the direct imaging mode of SCORPIO focal reducer and the CCD photometer of Zeiss-1000 telescope of SAO RAS.

We performed the spectral classification of the stars in our sample. By combining estimates of spectral types with the photometric data we measured the individual interstellar extinction $A_V$. We analyzed the stars with $V=13-20$ mag and we increased the number of highly reddened massive stars, reducing the difference in reddening between MT304 and other members of the association. Before our study MT488 was the second reddened massive star ($\Delta A_V = 1.8$ mag) after MT304. Now J203240.35+411420.1 and J203239.90+411436.2 are the most reddened massive stars and the difference is reduced down to $0.9 \pm 0.1$ mag. However MT304 remains the most reddened among massive stars in Cyg OB2.

Figure 1 shows the map of interstellar extinction based on the obtained data. Extinction clearly increases with approaching to MT304, as it is shown in left panel of

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$^2$ScoRe package http://www.sao.ru/hq/ssl/maryeva/score.html
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Figure 2. Dependency of the interstellar extinction $A_V$ on the distance to MT304 (left part) and on the distance to core A of the clump (right part).

Figure 2. For the stars located within 30 arcsec from MT304 the extinction is higher than 8.5 mag.

Conclusions

To study the high reddening affecting the hypergiant Cyg OB2 #12 (MT304) we conducted longslit spectroscopy and photometry of 24 stars with $V$=13-20 mag laying within 2.5 arcmin from this hypergiant. For 22 of these stars the spectroscopy was performed for the first time. Spectral analysis shows that 13 of the studied stars, along with MT304, belong to Cyg OB2. Thus, the extended the list of Cyg OB2 massive stars by ten more B stars.

Interstellar extinction increases while approaching to MT304. J203240.35+411420.1 and J203239.90+411436.2 are the most reddened massive stars after MT304. They are located within 13 and 15 arcsec away from MT304 and their $A_V$ are 9.1 $\pm$ 0.1 mag and 9.02 $\pm$ 0.02 mag respectively.

Our speckle-interferometer observations confirmed that MT304 has a second companion, which was discovered by Caballero-Nieves et al. (2014). We detected its orbital motion which suggests that the orbital period of the system ranges from 100 to 200 years. We also observed for the first time a third component which is weaker than main component by 4.8 mag.

More details are published in the article by Maryeva et al. (2016b) and Maryeva et al. (2016a).

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