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PROPERTIES OF SIX MASSIVE BINARIES

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Abstract. We present the analysis of six massive binaries observed with the SOPHIE spectrograph mounted on the T-193 telescope of the Observatoire de Haute Provence. The spectra are collected over the orbital period of the systems and are separated with a disentangling method. The resulting spectra are analyzed by means of atmosphere models. The stellar parameters of the components of each system are determined together with the CNO surface abundances. The degree of nitrogen enrichment and carbon and oxygen depletion is compared to theoretical predictions and to results for single stars and other binary systems. We conclude that surface abundances are not modified by binarity unless mass transfer and envelope removal takes place.

Keywords: Stars: binaries: spectroscopic – Stars: binaries: eclipsing – Stars: massive – Stars: abundances

1 Introduction

Massive stars evolve under the main influence of mass loss and rotation (Chiosi & Maeder 1986; Maeder & Meynet 2000). But a non negligible, perhaps a majority, of massive stars are also members of multiple systems (Kobulnicky et al. 2014; Sana et al. 2014). Tides induced by the presence of a companion trigger energy exchange that affects both the orbital/rotational properties but also the internal structure. When mass transfer occurs as a result of the evolution of one component and Roche lobe filling, angular momentum and material is lost/accreted. This also affects the general appearance and future evolution of stars. Of particular concern is to which level the surface abundances of massive stars are affected by binarity. High or low values of the N/C ratio sometimes escape predictions of single star evolution including rotation (Grin et al. 2017). The effect of a companion is usually quoted as a possible reason for such a discrepancy. However no quantification of such an effect has ever been performed.

In this study we present a first step towards an investigation of the effect of binarity on surface abundances of OB stars.

2 Spectral disentangling and spectroscopic analysis

We have selected massive binaries from the compilation of Gies (2003). We focussed on short-period systems in which the components are more likely to interact. We selected eclipsing binaries when possible in order to determine accurately masses and rotational velocities. We ended up with a sample of six systems: AH Cep (B0.2V+B2V), XZ Cep (O9.5V+B1III), V478 Cyg (O9.5V+O9.5V), Y Cyg (O9V+O9.5V), V382 Cyg (O6.5V((f))+O6V((f))) and DH Cep (O5.5V-III+O6V-III). The periods range from 1.77 to 5.10 d.

We used the SOPHIE spectrograph (Bouchy et al. 2013) mounted on the T-193 telescope of the Observatoire de Haute Provence. SOPHIE provides échelle spectra covering the 3900-6900Å wavelength range at a resolution of 39000. We observed each systems between 6 and 15 times depending on their period, in order to sample the orbital phase and especially the phases of maximum separation. The spectra were reduced automatically by the SOPHIE pipeline (Bouchy et al. 2009).

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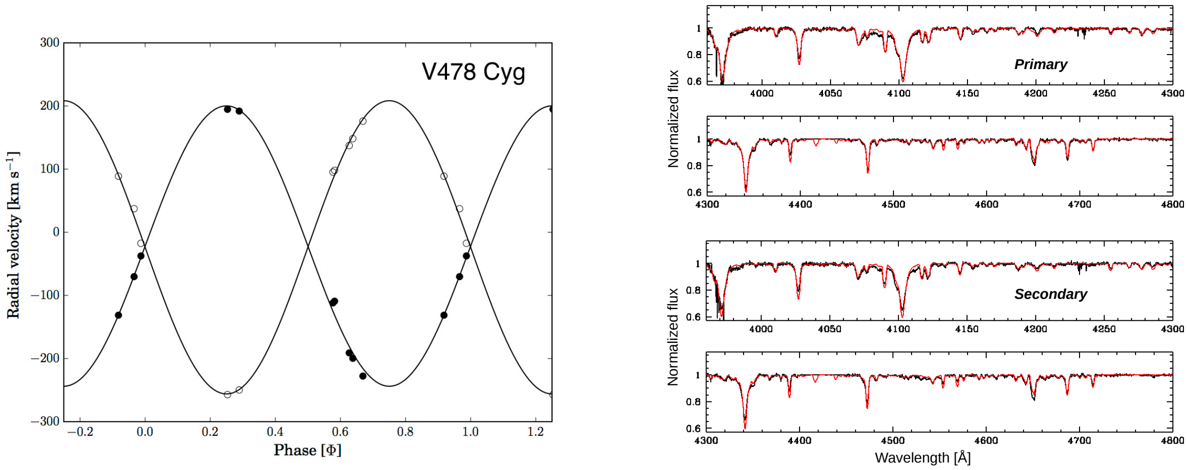

Fig. 1. Left: Radial velocity curve (circles) and orbital solution (solid line). **Right:** Best fit (red) of the disentangled spectra (black) of the primary (upper two panels) and secondary (lower two panels).

The Liège Orbital Solution Package (LOSP*) was subsequently used to perform an orbital solution. The left panel of Fig. 1 shows an example in result in the case of the system V478 Cyg. In order to separate the spectra of the two components we used a spectral disentangling method based on the method of Hadrava (1995). The orbital solution is used as an input. The resulting spectra of V478 Cyg are shown in the right panel of Fig. 1. The main difficulty is the reconstruction of the Balmer lines which are the broadest and are never totally separated from each other in the combined observed spectra.

The separated spectra were then analyzed with atmosphere models and synthetic spectra computed with the code CMFGEN (Hillier & Miller 1998). We relied on classical methods to determine the main fundamental parameters (see a summary in Martins 2011). In short, the projected rotational velocity (V sin$i$) was determined from the Fourier transform of the OIII 5592 or HeI 4713 lines. The effective temperature was obtained from the fit of the HeI and HeII lines. The surface gravity $\log g$ was determined from the width of the Balmer lines. To constrain the surface abundances of carbon, nitrogen and oxygen we computed synthetic spectra with fixed $T_{\rm eff}$ and $\log g$ but different CNO abundances. We used a χ^2 analysis to estimate the best fit of a selection of C, N and O lines (for a description of the method see Martins et al. 2015). The right panel of Fig. 1 shows our best fit models for the primary and secondary of the V478 Cyg system.

3 Effect of binarity on surface abundances

The main results of our study are gathered in Fig. 2. First of all, we see that almost all components of our six systems have N/C ratios consistent with little enrichment. The only exception is the secondary star of XZ Cep that has log(N/C)=1.0. According to single-star evolutionary tracks, this degree of enrichment is achieved in stars with masses in the range 30-50 $M_{\odot}$(assuming an initial rotational velocity of 300 km s^{-1}). However the dynamical mass of this star is close to 7 $M_{\odot}$. This argues for a peculiar evolution of the secondary of XZ Cep (see below). For the other stars there is no obvious deviation from what is expected from single-star evolution.

Another way, rather model-independent, to reach the same conclusion is to compare the sample systems with single stars. The small symbols in Fig. 2 are such objects analyzed by Martins et al. (2015). We do not see any difference in the N/C ratios of stars in binary systems and single stars. If binarity affects surface abundances, this is with a magnitude smaller than the dispersion among single stars (dispersion that is due to different initial masses and rotational velocities).

In Fig. 2 we have added four systems known to have experienced mass transfer (Linder et al. 2008; Mahy et al. 2011; Raucq et al. 2016, 2017). Interestingly in all of them at least one component has a large N/C ratio. For LZ Cep and HD 149404 the enrichment is much larger than predicted by single-star evolutionary tracks of mass corresponding to the dynamical mass of the components. These results, combined with the

*LOSP is available at `http://www.stsci.edu/~hsana/losp.html`.

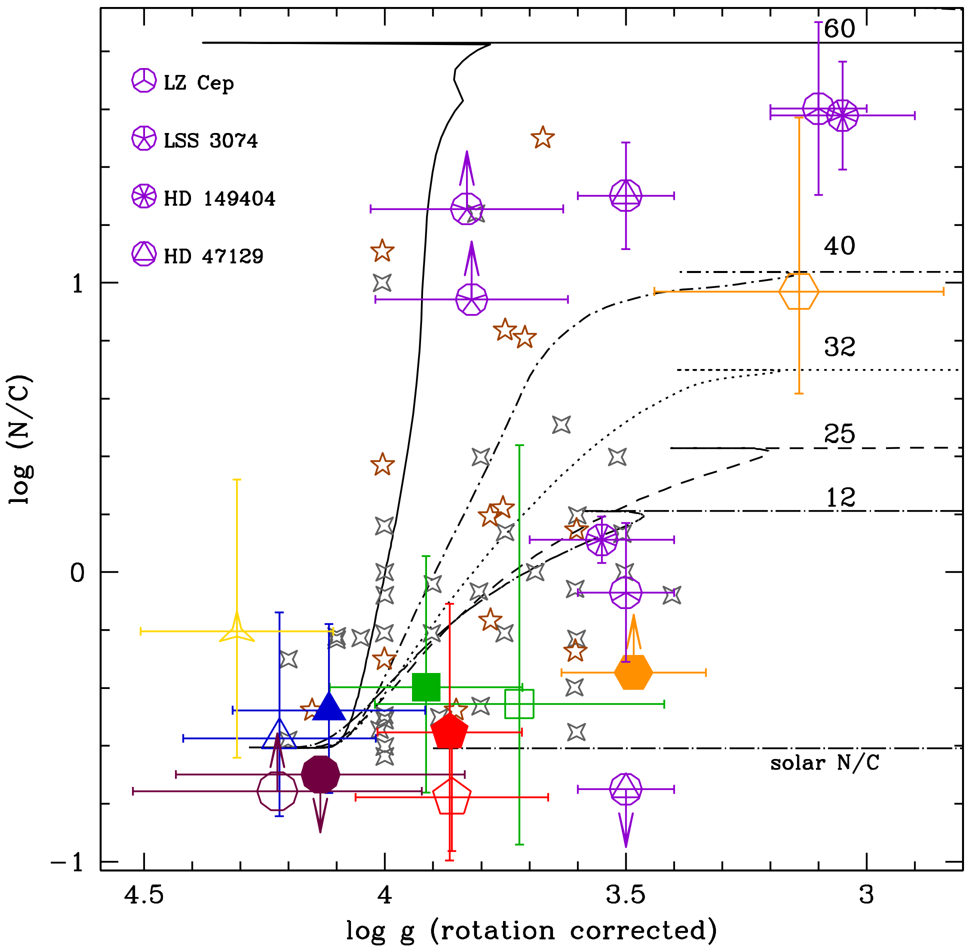

Fig. 2. log (N/C) as a function of surface gravity for the sample stars (large symbols) and other massive binaries (purple symbols). Small grey and brown symbols refer to single stars with masses below and above 28 $M_\odot$ respectively. Evolutionary tracks are from Ekström et al. (2012).

large enrichment of the secondary star of XZ Cep – which fills its Roche lobe according to our study – indicate that strong chemical enrichment is observed in stars that experienced mass transfer. More specifically, it is the component that lost part of its envelope through Roche lobe overflow that displays the largest chemical enrichment.

Our investigation thus shows that surface abundances in binary systems are not affected by tidal effects but can be modified in systems where mass transfer occurred. This conclusion obviously needs to be confirmed by analysis of additional massive binaries in different evolutionary states.

4 Conclusions

We have analyzed six massive binaries observed with SOPHIE at the Observatoire de Haute Provence. Individual spectra of each component have been retrieved by means of spectral disentangling. They have been subsequently analyzed with atmosphere models. The stellar parameters and surface abundances could be determined. We show that for most components of our systems surface abundances are not different from those of single stars with similar initial masses. The only case in which a larger N/C ratio is obtained is for a system that experienced Roche lobe overflow. Together with other such systems previously analyzed, this indicates that surface abundances are affected by binarity only if mass transfer (and envelope removal) occurred. In that case we observe deeper, more chemically mixed layers of the mass donor.

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