Observational signatures of past mass-exchange episodes in massive binaries :
The cases of HD 149404 and HD 17505

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Definitions

- **Massive star** :
  - $M > 10\, M_{Sun},\ T_{eff} > 20\ 000$ K, $L > 10^6 L_{Sun}$
  - $v_\infty \sim 2000 - 3000\, km/s$ and $\dot{M} \sim 10^{-6} - 10^{-5} M_{Sun}/year$

- Large fraction of massive stars in **binary or higher multiplicity** systems

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But multiplicity can also lead to **complications** :

- **Interactions** between the stellar **winds**

- **Transfer** of matter and kinetic momentum through a **Roche Lobe overflow** interaction (Podsiadlowski et al. 1992 ; Wellstein et al. 2001 ; Hurley et al. 2002)

⇒ Binarity significantly affects the spectra and the subsequent evolution of the components

HD 149404

- Detached, non-eclipsing O-star binary, member of the Ara OB1 association
- Circular orbit with an orbital period of 9.81 days
- Orbital inclination of 21° **(Rauw et al. 2001)**
- Variability of emission lines (He II λ 4686, Hα) likely indicative of a wind-wind interaction **(Rauw et al. 2001, Thaller et al. 2001, Nazé et al. 2002)**
- One ON component due to significant nitrogen enrichment of the atmosphere
  $\Rightarrow$ This could hint at a past binary interaction

HD 17505

- Multiple system composed of 7 visual companions, member of the Cas OB6 association
- Central object composed of three O-stars
- Low excentricity orbit of the inner binary, $e = 0.095$, with an orbital period of 8.57 days
- Orbital period of the tertiary < 61 years

Spectral disentangling

Previous determination of the orbital solution by Rauw et al. (2001)

$\rightarrow$ Recover the individual spectra of both components via **disentangling** (González & Levato 2006)

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This technique also has its **limitations** (González & Levato 2006)

- Broad spectral features are not recovered with the same accuracy as narrow ones
- Spectral disentangling does not yield the brightness ratio of the stars
- Small errors in the normalization of the input spectra lead to oscillations of the continuum in disentangled spectra
- Quality of the results depends on the RV ranges covered

In the specific case of HD149404 : emission lines partly formed in the wind-wind interaction zone (Rauw et al. 2001, Thaller et al. 2001, Nazé et al. 2002)

Spectral types and brightness ratio

Based on the reconstructed individual line spectra :

- Conti's quantitative classication criteria for O-type stars **(Conti & Alschuler 1971, Conti & Frost 1977, Mathys 1988, see also van der Hucht 1996)**

  $\Rightarrow$ Primary star is an **O7.5 If** and secondary is an **ON9.7 I**

- $\frac{I_1}{I_2} = (\frac{EW_1}{EW_2})_{obs}(\frac{EW_{O9.5}}{EW_{O7.5}})_{mean}$

  $\Rightarrow$ Mean brightness ratio : $\mathbf{0.72 \pm 0.17}$

Good agreement with the ones derived by Rauw et al. **(2001)** :

$$\text{O7.5I(f)} + \text{ON9.7I and } \frac{I_1}{I_2} = 0.90 \pm 0.16$$

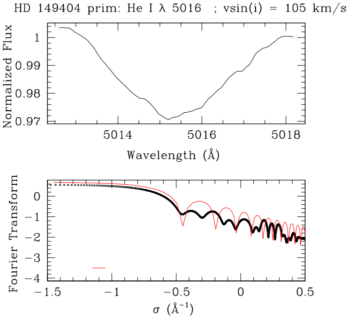
Rotational velocities and macroturbulence

HD 149404

- **Rotational velocities**

  ⇒Determination of the **v sin(i)** of the stars of the system using a **Fourier transform method** **(Gray 2008, Simón-Díaz & Herrero 2007)**

  ⟹Mean vsin(i) = **93 and 63 kms^{-1}** for the P and S stars respectively



- **Macroturbulence**

  ⇒MACTURB **(Gray, R.O. 2010, http://www.appstate.edu/~grayro/spectrum/spectrum276/node38.html)**

  ⟹**70 and 80 kms^{-1}** for the P and S stars respectively

The CMFGEN code and method

Non-LTE model atmosphere code CMFGEN (Hillier & Miller 1998) :

Equations of radiative transfer and statistical equilibrium in the co-moving frame for plane-parallel or spherical geometries

First approximation of gravity, stellar mass, radius and luminosity **from literature** (Martins et al. (2005), Rauw et al. (2001) and Muijres et al. (2012))

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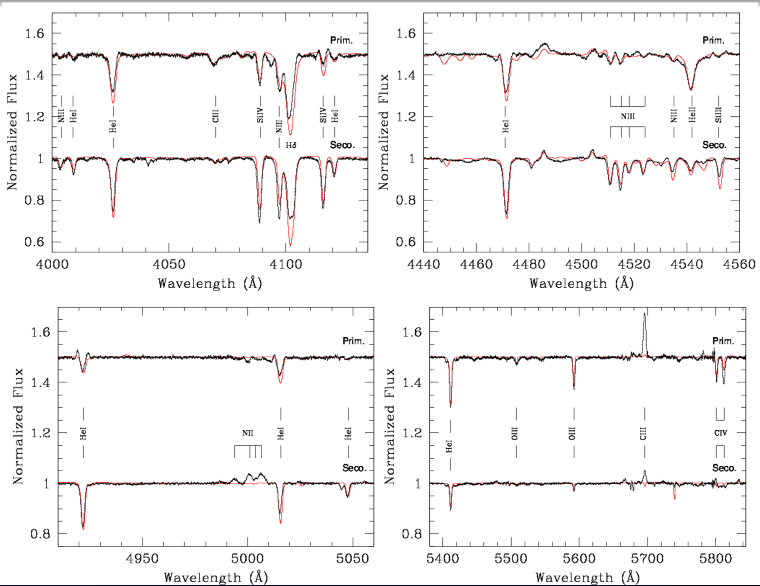
Iterative process that permits us to adjust these parameters :

1. The temperatures : relative strength of the He I λ 4471 and He II λ 4542 lines (Martins 2011)
2. Surface gravities : ~~through wings of Balmer lines~~
   Together with luminosities : iterative process through BC and $\frac{M_1}{M_2}$
3. Mass-loss rate and the clumping factor $\rightarrow$ Approximations
4. CNO abundances through the strengths of the associated lines

Results (1)

HD 149404



Results (2)

HD 149404

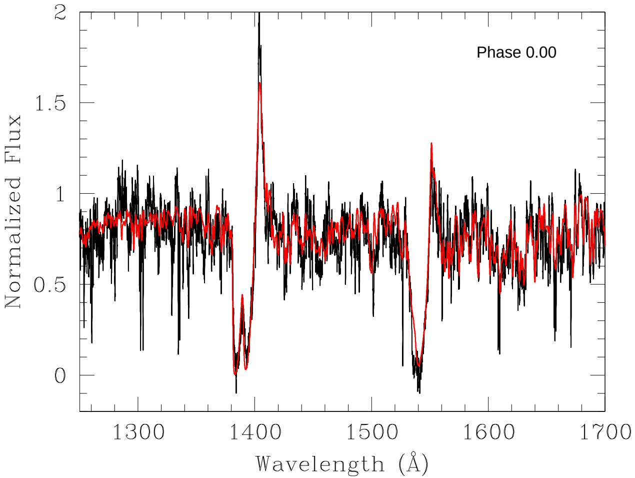


Figure 2 : IUE spectrum (black) and binary modelised spectra through re-combination of CMFGEN primary and secondary spectra (red).

Results (3)

Two very interesting results :

- **Overabundance in N** confirmed in the S star

  $$[N/C] = 100\,[N/C]_0$$
  $$[O/C] \geq 5\,[O/C]_0$$
  for the S star and
  $$[N/C] \simeq 2-3\,[N/C]_0$$
  for the P star

	Primary	Secondary	Sun [1]
He/H	0.1	0.1	0.089
C/H	$1.02^{+0.10}_{-0.11} \times 10^{-4}$	$1.89^{+0.47}_{-0.47} \times 10^{-5}$	2.69×10^{-4}
N/H	$1.32^{+0.20}_{-0.15} \times 10^{-4}$	$7.15^{+2.5}_{-1.8} \times 10^{-4}$	6.76×10^{-5}
O/H	$7.33^{+1.1}_{-1.1} \times 10^{-4}$	$7.85^{+1.8}_{-1.1} \times 10^{-5}$	4.90×10^{-4}

1. (Asplund et al. 2009)

Results (3)

HD 149404

$M_P = 50.5\ M_{sun}$ and $M_S = 31.9\ M_{sun}$

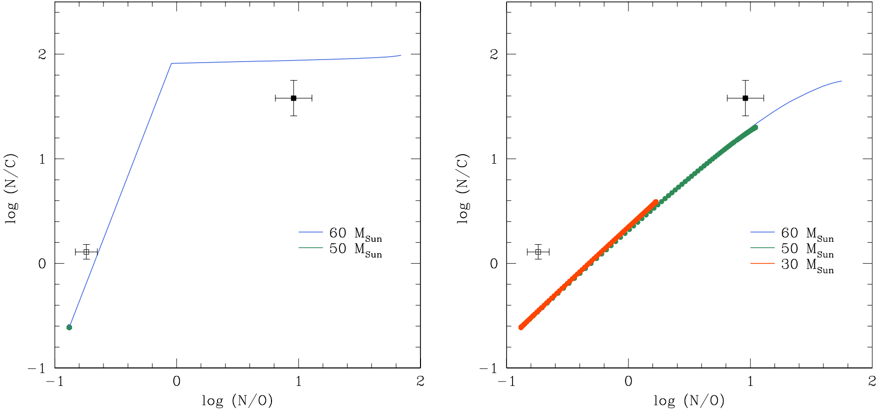


Figure 3 : Predictions of N/C vs. N/O as a function of stellar mass, on the left without any rotation of the stars and on the right including a rotation of $0.4 \times v_{crit}$ (Ekström et al. 2012). Open square : primary star; Filled square : secondary star.

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$\Rightarrow$ Tend to to confirm mass and kinetic momentum transfer from the current S to the current P (Vanbeveren 1982, 2011, Vanbeveren & de Loore 1994, Langer et al. 2003)

Disentangling

HD 17505

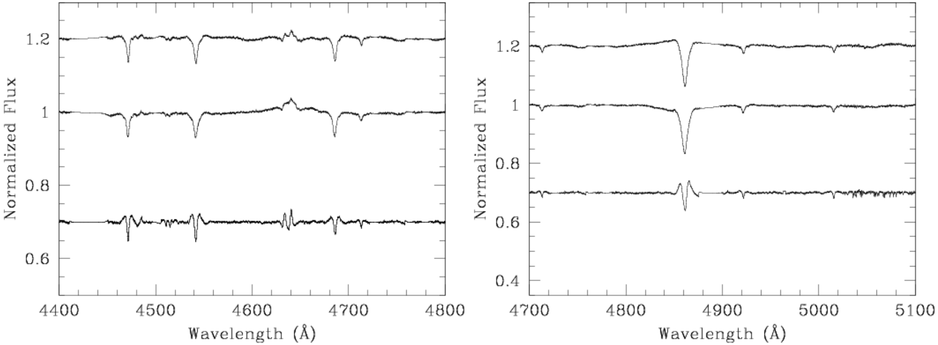

Figure 4 : Parts of a normalized disentangled spectra of the primary (top, shifted upwards by 0.2 continuum units), secondary (middle) and tertiary star (bottom, shifted downwards by 0.3 continuum units) of HD 17505.

Recombination

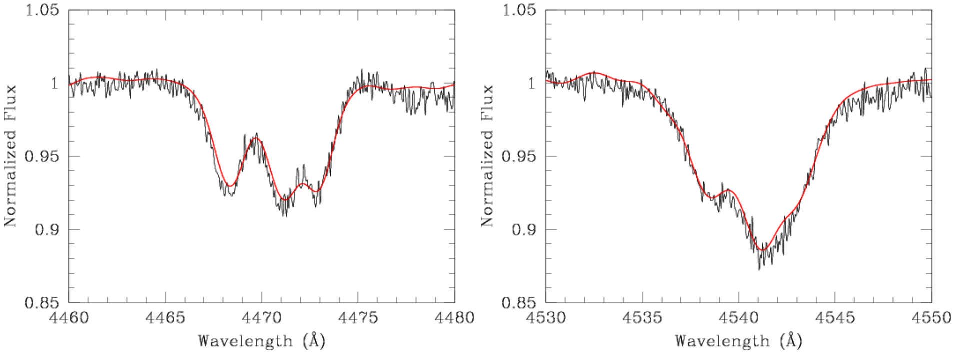

Figure 5 : Parts of a normalized spectrum of the triple system HD 17505 (black), along with the current best-fit CMFGEN model spectra (red).

Conclusion

- HD 149404 is the first system in a sample of binary systems with past mass-exchange episode (Raucq et al. 2015, accepted)

→ First step to better understand the interactions in massive binaries

- Case of HD 17505 : Difficulties inherent to the techniques to be further studied and overcome

- Other targets that are being studied : LSS 3074, HD 14633, HD 206267...

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Thank you

Apendix (1)

	This study		Rauw et al. ([?])	
	Prim.	Sec.	Prim.	Sec.
R ($R_\odot$)	19.3 ± 2.2	25.9 ± 3.4	24.3 ± 0.7	28.1 ± 0.7
M ($M_\odot$)	50.5 ± 20.1	31.9 ± 9.5	57.4 ± 14.3	36.5 ± 9.1
$T_{\rm eff}$ (10^4 K)	3.40 ± 0.15	2.80 ± 0.15	3.51 ± 0.1	3.05 ± 0.04
$\log(\frac{L}{L_\odot})$	5.68 ± 0.06	5.63 ± 0.05	5.90 ± 0.08	5.78 ± 0.08
$\log g$ (cgs)	3.55 ± 0.15	3.05 ± 0.15		
β	1.03 (f)	1.08 (f)		
v_∞ (km s^{-1})	2450 (f)	2450 (f)		
$\dot{M}$ ($M_\odot$ yr^{-1})	9.2×10^{-7} (f)	3.3×10^{-7} (f)		
BC	-3.17	-2.67		

Table 1 : The best-fit CMFGEN model parameters are compared with the parameters obtained by Rauw et al. (2001) for an orbital inclination of 21°. The effective temperatures from Rauw et al. (2001) were derived through the effective temperature calibration of Chlebowski & Garmany (1991) and permitted, along with the determined luminosities, to infer the stellar radii. The quoted errors correspond to 1 σ uncertainties. The symbol “(f)” in the table correspond to values fixed from the literature (Howarth et al. 1997; Muijres et al. 2012).

Apendix (2)

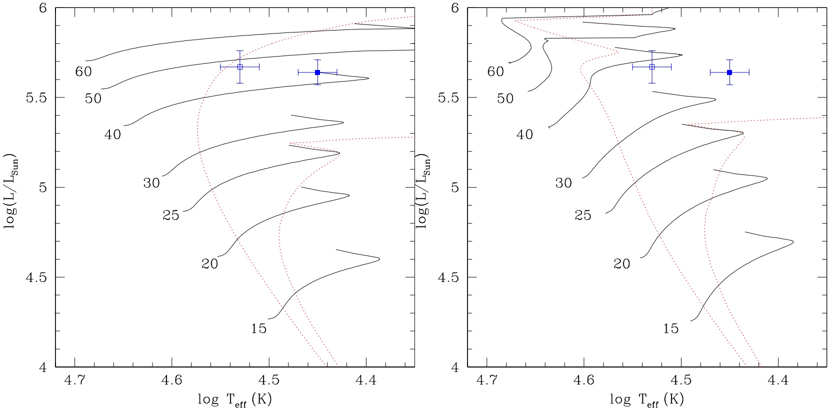

Figure 6 : **Primary (open square) and secondary (filled square) stars in the HR diagram with evolutionary tracks for single stars at solar metallicity during the core H burning phase (Ekström et al. 2012), for non-rotating stars (left), and stars rotating at 0.4 $\times$ v_{crit} (right). Dotted red lines : isochrones of 3.2 and 6.3 Myr for the left panel and of 4.0 and 8.0 Myr for the right panel.**

Apendix (3)

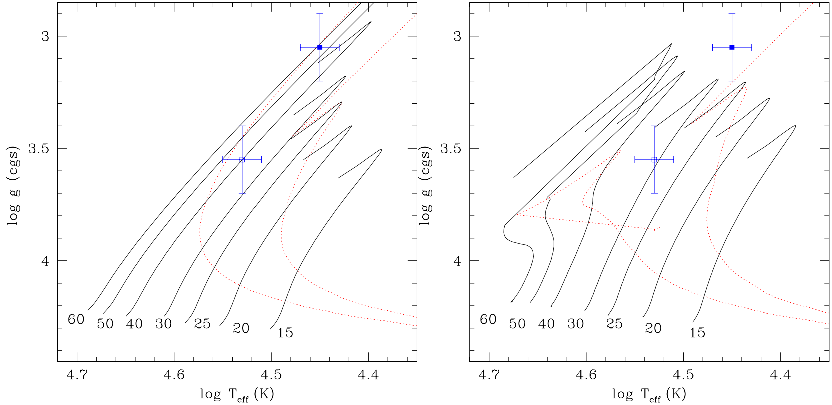

Figure 7 : **Primary (open square) and secondary (filled square) stars in the log(g)-log(T_{eff}) with evolutionary tracks for single stars at solar metallicity during the core H burning phase (Ekström et al. 2012), for non-rotating stars (left), and stars rotating at 0.4 × v_{crit} (right). Dotted red lines : isochrones of 3.2 and 6.3 Myr for the left panel and of 4.0 and 8.0 Myr for the right panel.**