

# Observational signatures of past mass-exchange episodes in massive binaries : The case of HD 149404

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# Definitions

- **Massive star :**

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

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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  $21^\circ$  (Rauw et al. 2001)
- Variability of emission lines (He II  $\lambda$  4686, H $\alpha$ ) 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  
⇒ This could hint at a past binary interaction

# Spectral disentangling

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

→ Recover the individual spectra of both components via **disentangling**  
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→ Recover the individual spectra of both components via **disentangling**  
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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 classification criteria for O-type stars (Conti & Alschuler 1971, Conti & Frost 1977, Mathys 1988, see also van der Hucht 1996)

⇒ Primary star is an **O7.5 If** and secondary is an **ON9.7 I**

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

⇒ Mean brightness ratio : **0.72 ± 0.17**

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

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

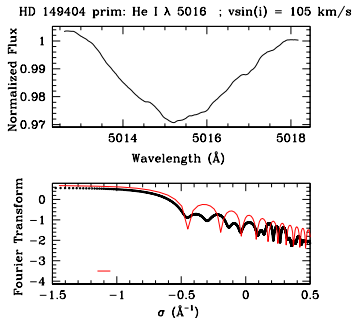


# Rotational velocities and macroturbulence

## ● 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  $v \sin(i) = 93$  and  $63 \text{ km s}^{-1}$   
for the P and S stars respectively



## ● Macroturbulence

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

⇒  $70$  and  $80 \text{ km s}^{-1}$  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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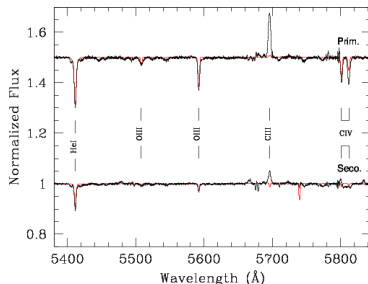
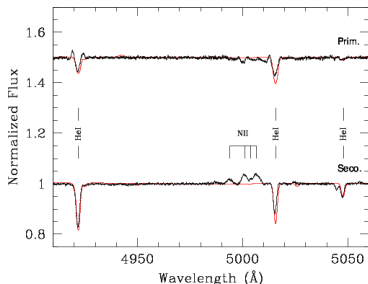
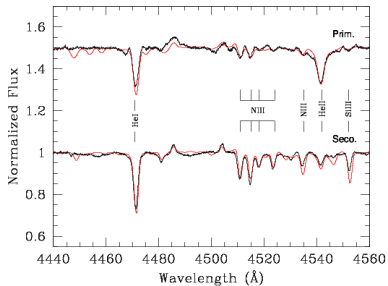
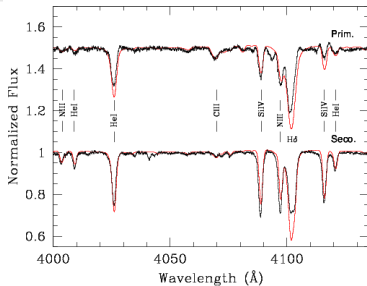
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**Iterative process** that permits us to adjust these parameters :

- 1 The temperatures : relative strength of the He I  $\lambda$  4471 and He II  $\lambda$  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)



## Results (2)

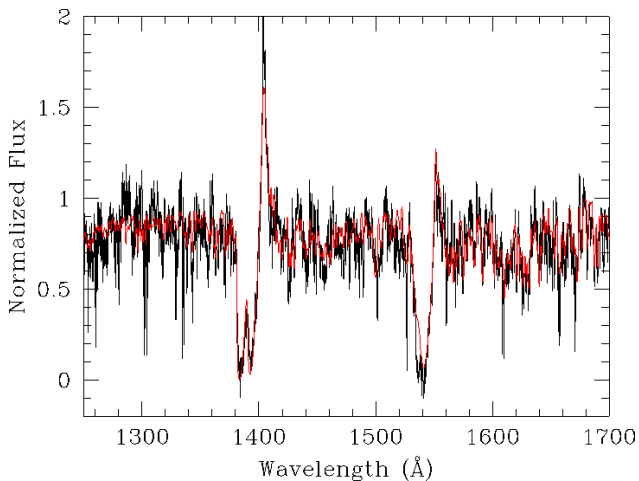


Figure 2 : IUE spectrum (black) and binary modelised spectra through re-combination of CMFGEN primary and secondary spectra (red).

# 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 <sup>1</sup>
He/H	0.1	0.1	0.089
C/H	$1.02^{+0.10}_{-0.11} \times 10^{-4}$	$1.89^{+0.47}_{-0.47} \times 10^{-5}$	$2.69 \times 10^{-4}$
N/H	$1.32^{+0.20}_{-0.15} \times 10^{-4}$	$7.15^{+2.5}_{-1.8} \times 10^{-4}$	$6.76 \times 10^{-5}$
O/H	$7.33^{+1.1}_{-1.1} \times 10^{-4}$	$7.85^{+1.8}_{-1.1} \times 10^{-5}$	$4.90 \times 10^{-4}$

1. (Asplund et al. 2009)

## Results (3)

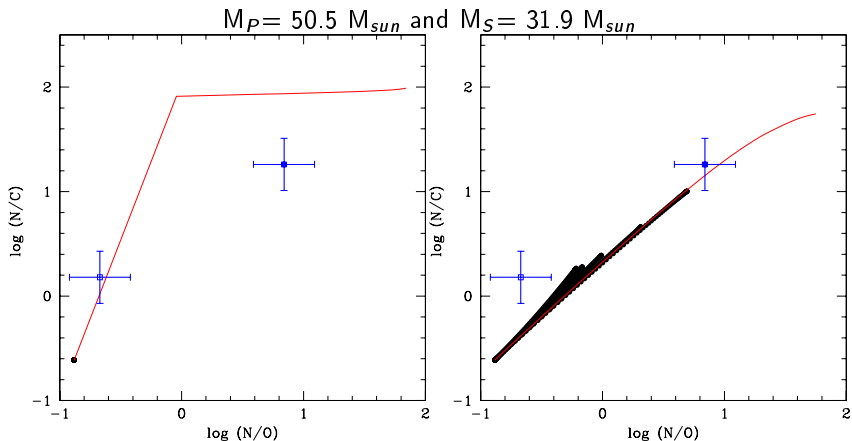


Figure 3 : Predictions of N/C vs. N/O as a function of stellar mass, on the left without any rotation of the stars and on the right including a rotation of  $0.4 \times v_{crit}$  (Ekström et al. 2012).  
Black :  $M \leq 50 M_{Sun}$ ; Red :  $60 M_{Sun}$ ; Open square : primary star; Filled square : secondary

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⇒ 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)

# Conclusion

- First system in a sample of binary systems with past mass-exchange episode (Raucq et al. 2015, submitted)

→ First step to better understand the interactions in massive binaries

- Other targets that are being studied : LSS 3074, HD 14633, HD 17505, HD 206267...

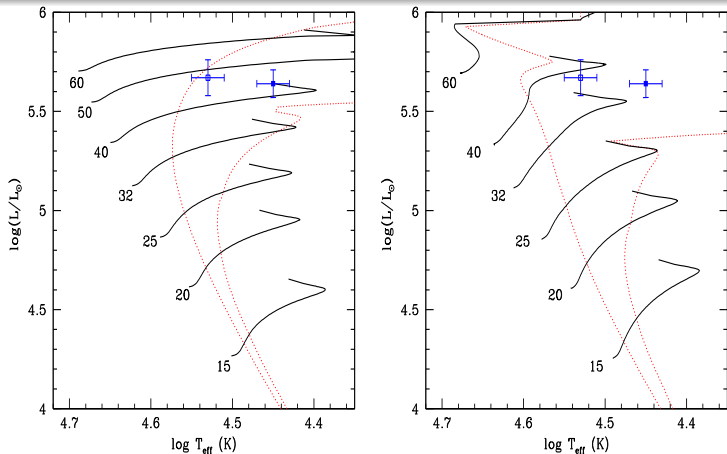
*Thank you*

## Annex (1)

	This study		Rauw et al. ([?])	
	Prim.	Sec.	Prim.	Sec.
$R (R_{\odot})$	19.3	25.9	$24.3 \pm 0.7$	$28.1 \pm 0.7$
$M (M_{\odot})$	50.5	31.9	$57.4 \pm 14.3$	$36.5 \pm 9.1$
$T_{\text{eff}} (10^4 \text{ K})$	$3.40 \pm 0.15$	$2.80 \pm 0.15$	$3.51 \pm 0.1$	$3.05 \pm 0.04$
$L (10^5 L_{\odot})$	$4.83 \pm 0.66$	$4.29 \pm 0.49$	$7.94 \pm 1.46$	$6.03 \pm 1.11$
$\log g$ (cgs)	$3.55 \pm 0.15$	$3.05 \pm 0.15$		
$\beta$	1.03 (f)	1.08 (f)		
$v_{\infty} (\text{km s}^{-1})$	2450 (f)	2450 (f)		
$\dot{M} (M_{\odot} \text{ yr}^{-1})$	$9.2 \times 10^{-7}$ (f)	$3.3 \times 10^{-7}$ (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  $21^{\circ}$ . 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  $1\sigma$  uncertainties. The symbol “(f)” in the table correspond to values fixed from the literature (Howarth et al. 1997; Muijres et al. 2012).

## Annex (2)



**Figure 4 :** 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  $0.4 \times v_{\text{crit}}$  (right). Dotted red lines : isochrones of 3.2 and 5.0 Myr for the left panel and of 4.0 and 8.0 Myr for the right panel.