Observational signatures of past mass-exchange episodes in massive binaries:
The cases of HD 17505 and HD 206267

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5th TIGRE Workshop
1 Introduction
   - Definitions
   - HD 17505
   - HD 206267

2 HD 17505
   - Preparatory analysis
     - Disentangling
     - Spectral types and brightness ratio
   - Spectral analysis
     - Rotational velocities and macroturbulence
     - The CMFGEN code and method
     - Results

3 HD 206267

4 Conclusion
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

$\Rightarrow$ Orbital motion allows to observationally determine the masses of the stars
Definitions

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

  ⇒ Orbital motion allows to observationally determine the masses of the stars

  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 17505

- Multiple system composed of 7 visual companions, member of the Cas OB6 association
- Central object composed of three O-stars
- Low eccentricity orbit of the inner binary, $e = 0.095$, with an orbital period of 8.57 days
- Orbital period of the tertiary $< 61$ years
HD 206267

- Triple system O6.5 V((f )) + O9.5: V + OB of the Cep OB2 association
- Orbital period of the inner massive binary of 3.71 days
- Slightly eccentric orbit: $e = 0.119$
- Third component with constant radial velocity
Previous determination of the orbital solution by Hillwig et al. (2006) for the inner binary + measures of the RVs of the third component

→ 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
Spectral disentangling

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In the specific case of HD17505: third component “pollutes” the observed spectra
Figure 1: 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.
**Figure 2**: Parts of a normalized spectrum of the triple system HD 17505 (black), along with the best-fit CMFGEN model spectra (red).
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)

  \[ \frac{l_1}{l_2} = \left( \frac{EW_1}{EW_2} \right)_{obs} \left( \frac{EW_{O7}}{EW_{O7}} \right)_{mean} = \left( \frac{EW_1}{EW_2} \right)_{obs} \]

  \[ \Rightarrow \text{Mean brightness ratio: } 0.88 \pm 0.09 \]

Good agreement with previous studies (Hillwig et al. 2006):

- O7.5V + O7.5V and \( \frac{l_1}{l_2} \sim 1.00 \)
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 $v \sin(i) = 62$ and $68 \text{ km s}^{-1}$ for the P and S stars respectively

- **Macroturbulence**
  

  ⟩⟩ $60$ and $65 \text{ km s}^{-1}$ 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), Hillwig et al. (2006) 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 $\lambda$ 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)

Figure 3: Part of the normalized spectra of the primary (top, shifted upwards by 0.5 continuum units) and secondary star (bottom), along with the best-fit CMFGEN model spectra (red).
Results (2)

No significant overabundances:

\[
\frac{\text{[N/C]}}{\text{[N/C]}} \sim 3 \quad \text{for the P star}
\]
\[
\frac{\text{[N/C]}}{\text{[N/C]}} \sim 2 \quad \text{for the S star}
\]

\[
\frac{\text{[N/O]}}{\text{[N/O]}} \sim 1 - 2 \quad \text{for the donor star in the case of a post-RLOF system}
\]

\begin{tabular}{|c|c|c|c|}
\hline
 & Primary & Secondary & Sun$^1$ \\
\hline
He/H & 0.1 & 0.1 & 0.089 \\
C/H & $1.91^{+0.37}_{-0.40} \times 10^{-4}$ & $1.97^{+0.40}_{-0.41} \times 10^{-4}$ & $2.69 \times 10^{-4}$ \\
N/H & $1.37^{+0.25}_{-0.21} \times 10^{-4}$ & $9.70^{+1.06}_{-0.84} \times 10^{-5}$ & $6.76 \times 10^{-5}$ \\
O/H & $3.87^{+1.15}_{-0.93} \times 10^{-4}$ & $4.73^{+2.19}_{-1.45} \times 10^{-4}$ & $4.90 \times 10^{-4}$ \\
\hline
\end{tabular}

\(^1\text{(Asplund et al. 2009)}\)
No significant overabundances:

\[
\frac{[N/C]}{[N/C]} \approx 3 \frac{[N/C]}{[N/C]} \oplus \\
& \frac{[N/O]}{[N/O]} \approx 3 \frac{[N/O]}{[N/O]} \oplus \\
\frac{[N/C]}{[N/C]} \approx 2 \frac{[N/C]}{[N/C]} \oplus \\
& \frac{[N/O]}{[N/O]} \approx 1 - 2 \frac{[N/O]}{[N/O]} \oplus
\]

for the P star

for the S star

No asynchronous rotation:

\[
\frac{P_P}{\sin i} = 10.91 \quad \text{and} \quad \frac{P_S}{\sin i} = 10.12 \text{ days}
\]
No significant overabundances:

\[
\begin{align*}
[N/C] &\approx 3 \left[ \frac{N}{C} \right]_\odot \\
&\& \& [N/O] \approx 3 \left[ \frac{N}{O} \right]_\odot \text{ for the P star} \\
[N/C] &\approx 2 \left[ \frac{N}{C} \right]_\odot \\
&\& \& [N/O] \approx 1 - 2 \left[ \frac{N}{O} \right]_\odot \text{ for the S star}
\end{align*}
\]

No asynchronous rotation: 

\[
\frac{P_P}{\sin i} = 10.91 \text{ and } \frac{P_S}{\sin i} = 10.12 \text{ days}
\]

\[\Rightarrow\] No observational evidence of a past RLOF episode
Figure 4: Parts of a normalized spectrum of the triple system HD 206267 (black), along with a first fit with CMFGEN model spectra (red).
Other targets that have been studied: HD 149404 & LSS 3074
(Raucq et al. 2016, Raucq et al. 2017 (submitted))

→ First systems in a sample of binary systems with past mass-exchange episode

→ First step to better understand the interactions in massive binaries

HD 17505 does not seem to be a good candidate

Cases of HD 17505 and HD 206267: Difficulties inherent to the techniques to be further studied and overcome
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Thank you
Table 1: The best-fit CMFGEN model parameters. The quoted errors correspond to 1σ uncertainties.