High Contrast Imaging of Massive Stars

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What are massive stars?
Massive Star Formation

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Massive Star Formation Problems

Observational difficulties

- Short formation timescale
- Rareness and large distances
- Obscured environment

Direct observation of star formation
Study the properties of the outcome of star formation
Carina

close massive star region

©ESO/T. Preibisch
Carina massive project of Carina

High contrast imaging

Project of massive stars

VLT/SPHERE in IRDIFS mode

close massive star region
Carina

High contrast Imaging

Close massive star region

VLT/SPHERE in IRDIFS mode

<table>
<thead>
<tr>
<th>SPHERE</th>
<th>IFS</th>
<th>IRDIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral Range (µm)</td>
<td>0.95-1.75</td>
<td>0.95-2.32</td>
</tr>
<tr>
<td>FOV (arcsec²)</td>
<td>1.73</td>
<td>11</td>
</tr>
<tr>
<td>Pixel Scale (arcsec)</td>
<td>7.4</td>
<td>12.25</td>
</tr>
<tr>
<td>Bands</td>
<td>Y-J-H</td>
<td>K (1&amp;2)</td>
</tr>
</tbody>
</table>
Carina

High contrast imaging

Project of massive stars

close massive star region

VLT/SPHERE in IRDIFS mode

faint and low-mass companions
Carina

History

Contrast Imaging

Project of massive stars

28 stars already reduced

63 stars in P102

VLT/SPHERE in IRDIFS mode

4D data cubes

Multiplicity properties of 91 massive O and WR
SMaSH+ (Sana et al, 2014)

From Sana et al, 2014
Some example data
QZ Car (HD 93206)
FOV = 5', 2MASS

SMaSH+ Image
Sana et al, 2014
FOV = 5', 2MASS

IRDIS

11"x11"

Ab E

16"x16"

SMaSH+ Image
Sana et al, 2014
Detection method

Derotated and wavelength collapsed image

SNR map
Bright red: SNR ≥ 5
Detection method

Derotated and wavelength collapsed image

SNR map

Bright red: SNR ≥ 5
SMaSH+ (Sana et al, 2014)

Adapted from Sana et al, 2014
Spectrum Extraction
QZ Car (HD 932066)

![Diagram of QZ Car](image)

(Sanchez-Bermudez et al. 2017)

<table>
<thead>
<tr>
<th>Component</th>
<th>Spectral Type</th>
<th>$T_{\text{eff}}$ (K)</th>
<th>$R_*$ ($R_\odot$)</th>
<th>$M_*$ ($M_\odot$)</th>
<th>$L_<em>$ (log[$L_</em>/L_\odot$])</th>
<th>$\dot{M}$ ($M_\odot,\text{yr}^{-1}$)</th>
<th>log(g)</th>
<th>$v_\infty$ (km,s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aa1</td>
<td>O9.7 I</td>
<td>32000</td>
<td>22.5</td>
<td>40</td>
<td>5.7</td>
<td>$8.21 \times 10^{-6}$</td>
<td>3.19</td>
<td>1794.3</td>
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<tr>
<td>Aa2</td>
<td>b2 v</td>
<td>20000</td>
<td>6.0</td>
<td>10</td>
<td>3.7</td>
<td>$2.39 \times 10^{-14}$</td>
<td>4.3</td>
<td>1186.4</td>
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<tr>
<td>Ac1</td>
<td>O8 III</td>
<td>32573</td>
<td>26.9</td>
<td>14.1</td>
<td>5.3</td>
<td>$3.32 \times 10^{-6}$</td>
<td>3.57</td>
<td>2191.2</td>
</tr>
<tr>
<td>Ac2</td>
<td>o9 v</td>
<td>32463</td>
<td>8.9</td>
<td>28</td>
<td>4.9</td>
<td>$3.16 \times 10^{-9}$</td>
<td>3.92</td>
<td>2427.1</td>
</tr>
</tbody>
</table>

(Rainot+ in prep.)
QZ Car spectrum with FASTWIND

(Rainot+ in prep.)
Calibrated spectrum

(Rainot+ in prep.)
Early MS

(Rainot+ in prep.)
Early MS

Best fit: T10000 M2.2 R1.6?

(Rainot+ in prep.)
## Multiplicity Results - IFS

<table>
<thead>
<tr>
<th>Images</th>
<th>Visible companions (SNR &gt; 5σ)</th>
<th>Candidates (5σ &gt; SNR &gt; 3σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>6</td>
<td>12</td>
</tr>
</tbody>
</table>

- Detection ratio ≈ 0.42 companions/star
- Expected ≈ 38 companions / 91 images
GAIA distance

distance = $1167.12^{+160.72}_{-127.25}$

velocity = $43.47^{+5.92}_{-4.72}$

angle = $291.88^{+1.32}_{-1.36}$

(Rainot+ in prep.)
Conclusion

- **Discovery** of a new companion: QZ Car Ad at 1.2kpc
- Might be an **A0 star** with: $T = 10000K$, $M = 2.2M$, $R = 1.6R$
- Masses limits of IRDIS **detected sources**
- **63 stars** remain to be observed with SPHERE (P102)
- First paper to be submitted **soon**!

https://arainot.github.io  alan.rainot@kuleuven.be
Thank you!
Extra Slides

https://arainot.github.io

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IFS Contrast Curves

(Rainot+ in prep.)
IRDIS
(Rainot+ in prep.)
Analysis Techniques

Original image

Post-processed cube
PSF Fitting

Flux \[\text{log(ADU/s)}\]

Wavelength [\mu m]

H_2O

QZ Car Spectrum

Telluric Fit

Telluric Corrected