High mass star binary fraction

Hugues Sana

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Holy Grail :

search for observational constraints on the massive star formation

O-type stars

$15\ M_{sol} < M_*$

→ Hot : $30\ kK < T_{eff} < 45\ kK$

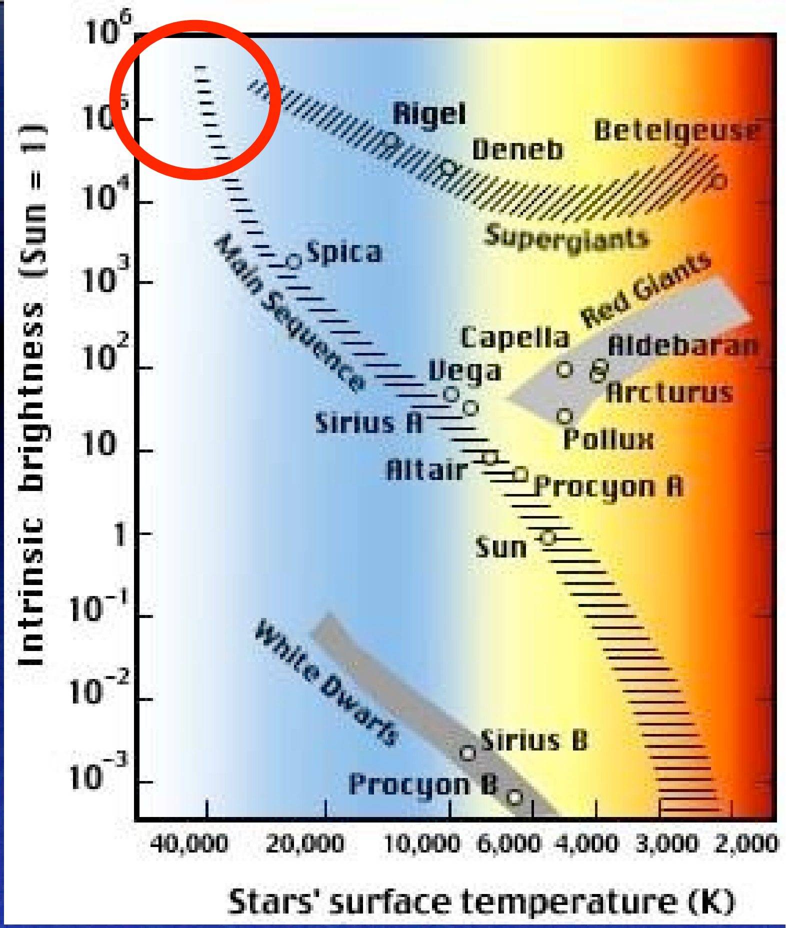
→ Luminous: $5{\times}10^4\ L_{sol} < L_* < 5{\times}10^5\ L_{sol}$

→ short life-time (a few 10^6 yr)

→ few in number

→ Binary frequency is high

→ Mass ratio is low (M_1/M_2~1-3)



- Powerful stellar winds
  - $10^{-7}\ M_{sol}\ yr^{-1} <\ _* < 10^{-4}\ M_{sol}\ yr^{-1}$ → affect the star's evolution
  - $v_\infty \sim 2000\text{-}3000\ km\ s^{-1}$ ($v = v_\infty\,(1 - R_*/r)^\beta$; $\beta = 0.8\text{–}1.0$)
- Main source of ionizing radiations
- Strong influence (radiative & kinetic energy, chemical input)

O-type stars

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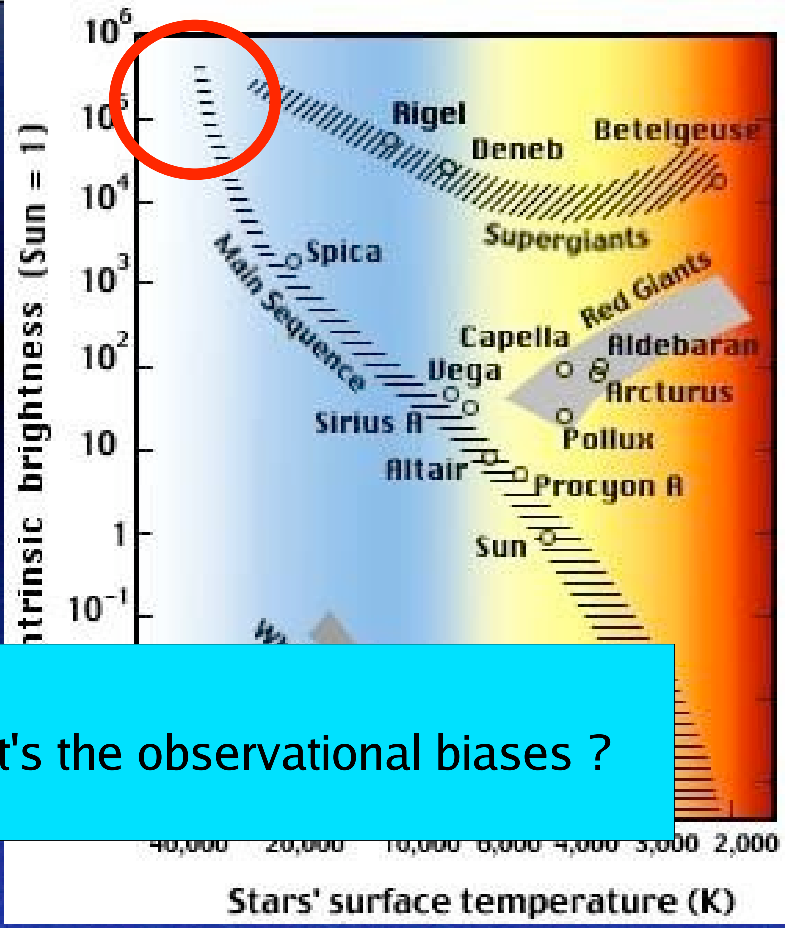

→ Hot : 30 kK < T_{eff} < 45 kK

→ Luminous: $5\times10^4\ L_{sol} < L_* < 5\times10^5\ L_{sol}$

→ short life-time (a few 10^6 yr)

- Binary frequency is high
- Mass ratio is low (M_1/M_2~1-3)

→ What's the observational biases ?

→ Mass ratio is low (M_1/M_2~1-3)

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O-type stars are rare

"Tonight, looking at the sky, I came to the conclusion that they were many more stars that what we need."

Mafalda (Quino)

- 1 O star — 15-100: M_{sol}
- 9 B stars — 4-15 M_{sol}
- 13 A stars — 2-4 M_{sol}
- 19 F stars — 1.2-2 M_{sol}
- 22 G stars — 0.8-1.2 M_{sol}
- 141 K stars — 0.5-0.8 M_{sol}
- 295 M stars — 0.1-0.5 M_{sol}

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- 1 O star 15-100: M_{sol}
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Open clusters naturally provide homogeneous unbiased sample of massive stars

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Nearby clusters rich in O stars

Table 4. Binary frequency of clusters $N_{\mathrm{O\,star}} > 5$

Cluster	Number of O-stars	Number of SBs	Frequency
IC 1805	10	8	0.80
NGC 6231	14	11	0.79
NGC 2244	6	3	0.50
IC 2944	16	7	0.44
NGC 6611	12	5	0.42
Tr 16	20	7	0.35
Cr 228	21	5	0.24
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Garcia & Mermilliod 2001, A&A 368, 122

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Loose (IC 1805, NGC 6231)

Dense (Tr 14)

Suggestion : anticorrelation between cluster density and binary fraction

Garcia & Mermilliod 2001, A&A 368, 122

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Loose

Dense

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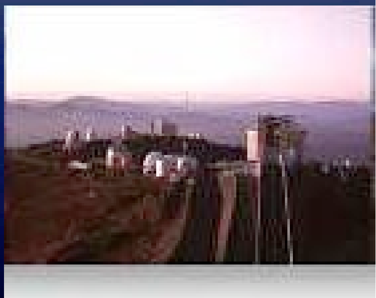
Observational sample



IC 2944

- 13 O stars
- ~ 100 spectra (+70 coming)
- 2 epochs (a 3rd coming)

NGC 6231

- 15 O stars + 1 WR
- > 500 spectra
- Large number of epochs

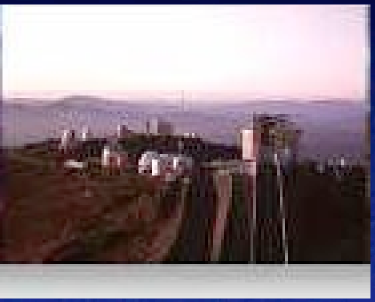
HiRes high SNR:

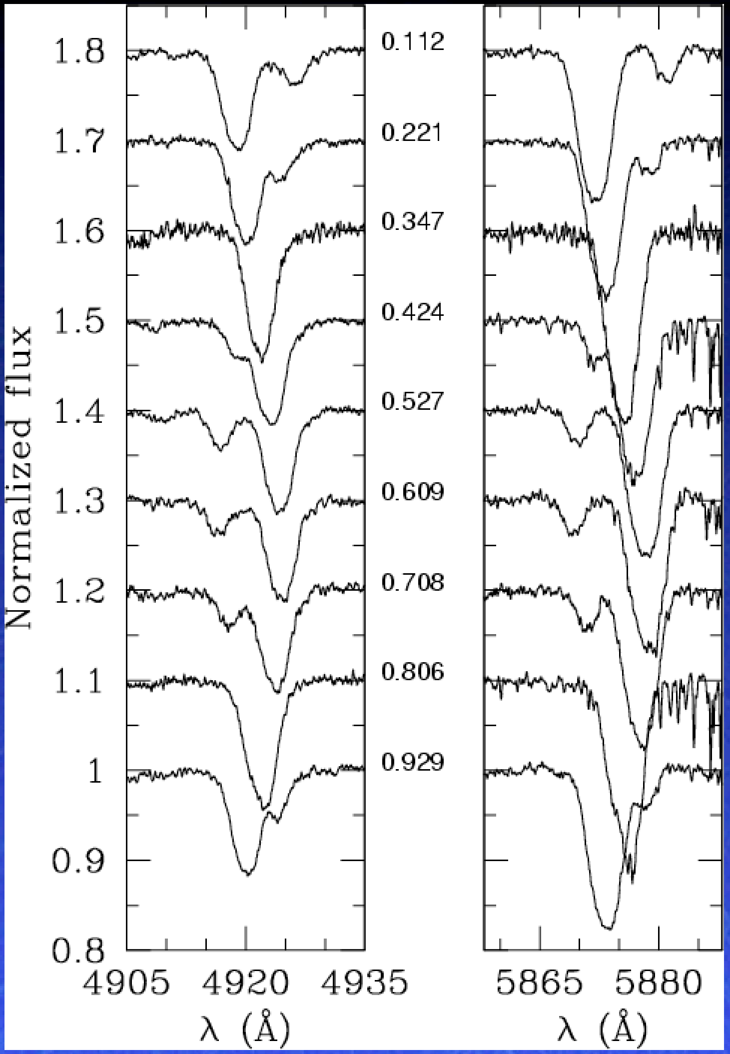
- R > 30000
- SNR > 150

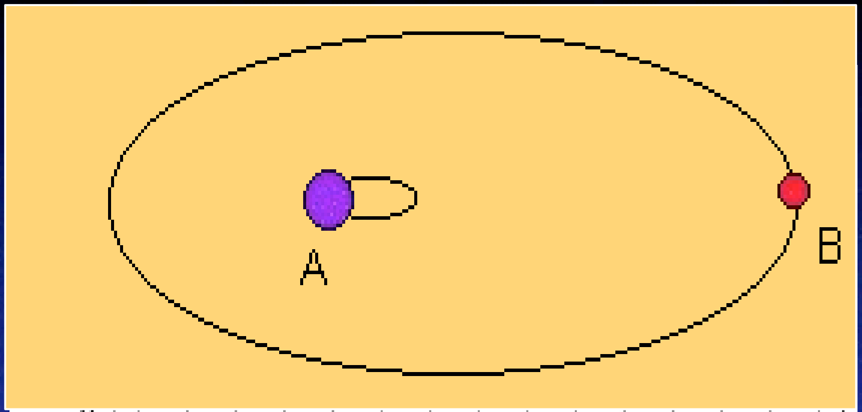
NGC 6611

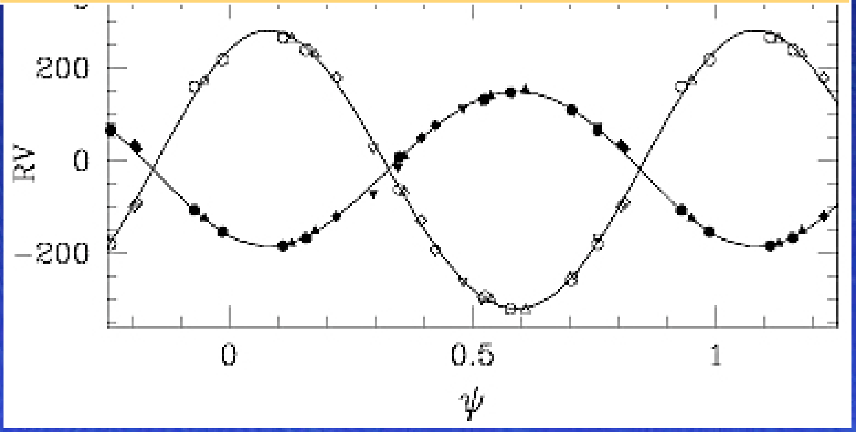
- 12 O stars
- ~ 40 spectra
- 2 epochs (3rd submitted)

Keplerian Doppler shifts

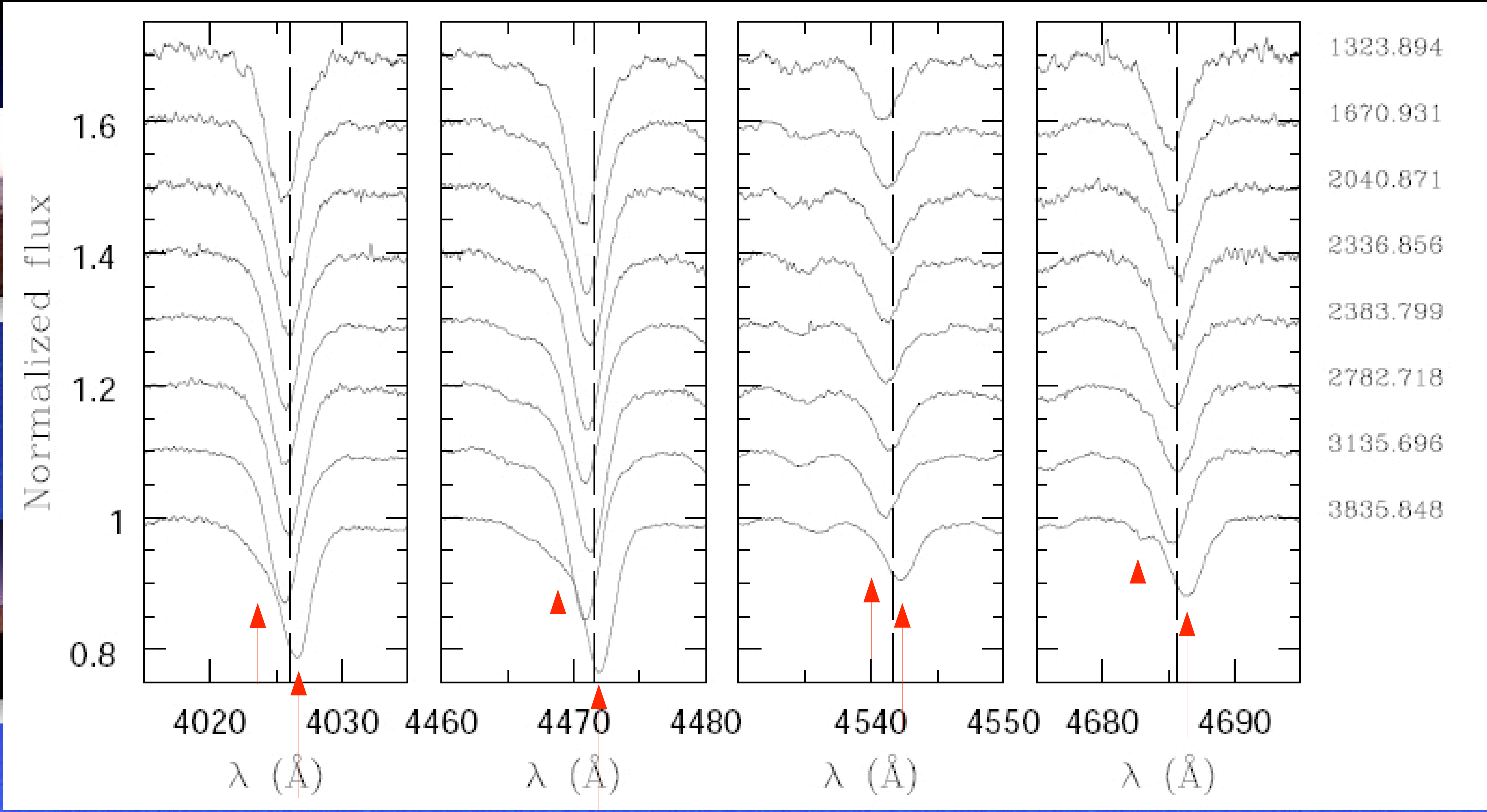








Multiple signatures & opposite RV shifts



Criteria for spectroscopic binaries

Keplerian Doppler shifts

or

Multiple spectral signature + opposite RV variations

⇓

Definite proof of binarity

Complete O star population ==> ⇓

Minimal binary fraction = N_{binary}/N_{stars} (firm limit)

NGC 6231

Short period

Object	P (d)	e	m_1/m_2	Sp. Type	Reference
CPD −41° 7742	2.44070	$0.027^a \pm 0.006$	1.803 ± 0.015	O9 V + B1.5 V	Sana et al. (2003)
HD 152219	4.24032	0.082 ± 0.011	2.530 ± 0.023	O9 III + B1-2 V/III	Sana et al. (2006a)
HD 152248[b]	4.81602	0.133 ± 0.005	1.012 ± 0.011	O7 III (f) + O7.5 III (f)	Sana et al. (2001)
HD 152218	5.60391	0.259 ± 0.006	1.319 ± 0.014	O9 IV + O9.7 V	Sana et al. (2007c)
CPD −41° 7733	5.681504	0.0	2.640 ± 0.012	O8.5 V + B3	Sana et al. (2007a)
WR 79(HD 152270)	8.8911	0.0	2.7	WC7 + O6V	Luehrs (1997); Hill et al. (2000)

Long period

HD152234	127d	O9.7I+O8V
HD152247	~400d	O9III+O9.7V
HD152233	~800d	O6III(f)+O8-9V:
HD152314	~3100d	O8.5V+B1-3V/III

Single stars ?

HD152076	O9.5III
HD152200	O9.7V
HD152249	O9Ib((f))
HD326329	O9.5V
HD326331	O8III((f))
CPD-41 7721	O9V

$$f_{min} = N_{binaries}/N_{stars} = 10/16 = 0.63$$

Sana et al (2007), MNRAS, submitted

Significance

In NGC6231: $f_{min} = 0.63 \le f_{true} \le 1.0$

(no error -->firm limit !!!)

Significance for a larger population :

$f_{popul} > 0.37$ @ $\alpha=0.01$

(if following the same statistical distribution than in NGC6231)

Sana et al (2007), MNRAS, submitted

Towards a larger sample

Cluster	NGC 6231	IC 2944	NGC 6611
Number of O stars	16	13	12
Min. binary fraction	0.63	0.61	0.58
Nbr of short/long period systems	6/4	4/4	3/4

No significant difference between the 3 clusters

In total : $f_{min}=N_{binaries}/N_{stars}=25/41=0.61$

$f_{popul} > 0.44$ @ $\alpha=0.01$

Binary frequency in clusters

Table 4. Binary frequency of clusters $N_{\mathrm{O\,star}} > 5$

	Number of		
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Binary frequency in clusters

Table 4. Binary frequency of clusters $N_{\mathrm{O\,star}} > 5$

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IC 2944	16	7	~~0.44~~	→ 0.61
NGC 6611	12	5	~~0.42~~	→ 0.58
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Cr 228	21	5	0.24	
Tr 14	7	1	~~0.14~~	→ 0.27

Binary frequency in clusters

Table 4. Binary frequency of clusters $N_{\mathrm{O\,star}} > 5$

Relation between cluster density and
binary fraction still need confirmation

(Can we really reject the hypothesis that
all Young Open Clusters have
a similar massive binary fraction ?)

Mass distribution of the companions

Random pairing from Salpeter IMF →

- 1 O+O star
- 9 O+B stars
- 13 O+A stars
- 19 O+F stars
- 22 O+G stars
- 141 O+K stars
- 295 O+M stars

Mass distribution of the companions

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In NGC 6231 (16 objects)

10 SB2 binaries:
- 1 WR+O
- 5 O+O
- 4 O+B (B1-B4)

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In NGC 6231 (16 objects)

10 SB2 binaries:
- 1 WR+O
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@ 5 σ

Conclusions

- f_{min} ~ 0.6 in 3 young open clusters
  - 25 binaries/41objects --> f_{popul} > 0.44 @ 0.01 level
- --> possibility to test whether all YOCs have the same binary distribution or whether there is some relation between f and the cluster properties

- Massive star campanions are not randomly drawn from a Salpeter IMF
  - --> strong bias towards O+OB systems (q~1-3)