Evidence for past Roche-lobe overflow in two O-type binaries

Gregor Rauw[1], Françoise Raucq[1], Laurent Mahy[1,2], Yaël Nazé[1], & Eric Gosset[1]

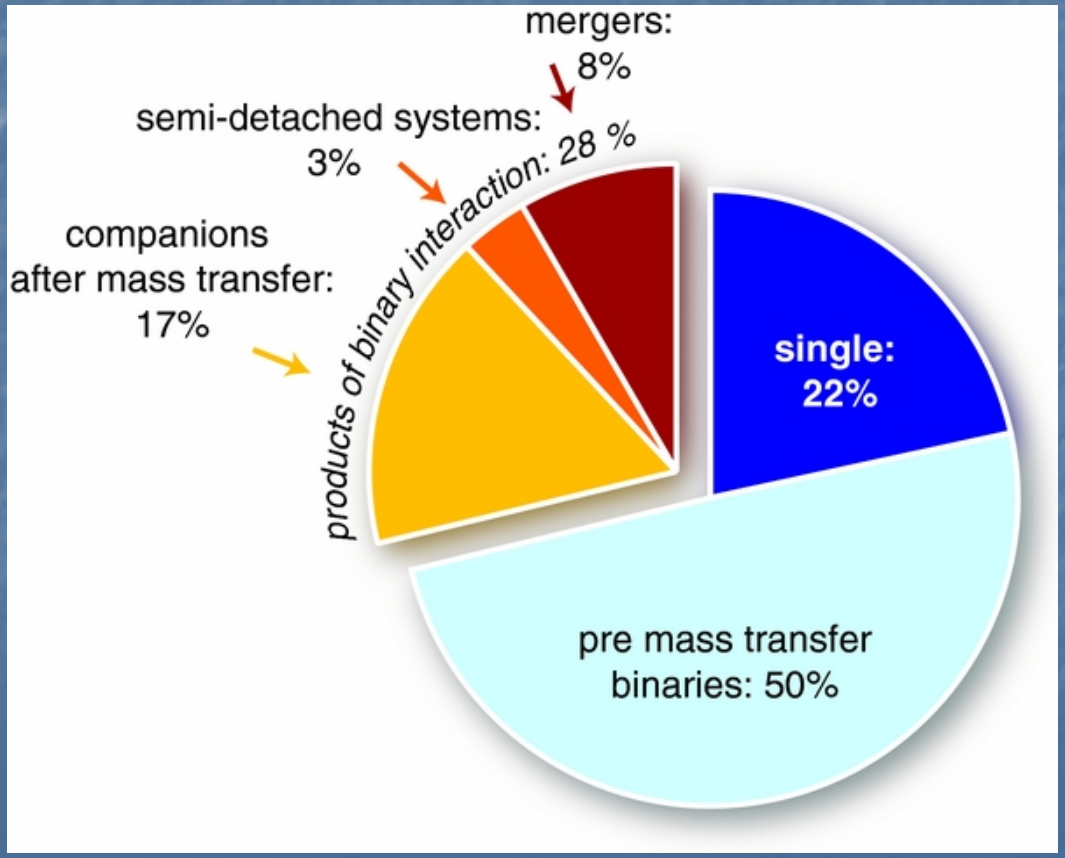
[1] Liège University, Belgium
[2] KU-Leuven, Belgium

Outline

- Mass and angular momentum transfer in massive binaries.
- Methods.
- HD149404: a detached post RLOF binary
- LSS3074: a contact binary with odd properties
- Conclusions and open issues.

Mass and angular momentum transfer in massive binaries

- A large fraction (~ 80%) of massive stars are found in binary systems (Sana et al. 2012, Science 337, 444, Duchêne & Kraus, 2013 ARA&A 51, 269) and many of them will interact at some point of their evolution (de Mink et al. 2014, ApJ 782, 7).



- Several aspects of the binary interaction in massive stars are not yet well constrained:

1. What fraction of the transferred mass is accreted, and what fraction is lost (e.g. Petrovic et al. 2005, A&A 435, 1013)?
2. Does the common envelope phase lead to merger events or does it produce double degenerate systems (e.g. Kruckow et al. 2016, A&A 596, A58)?
3. What fraction of the angular momentum is removed by material that is lost from the system (e.g. De Donder & Vanbeveren 2004, New AR 48, 861)?
4. …

- Theoretical work needed, but observational studies of massive post-RLOF systems are also scarce: only about a dozen good candidates of post-RLOF O-star binaries are known (Nazé et al. 2017, MNRAS 467, 501) and only a handful have been studied in detail.

Methods

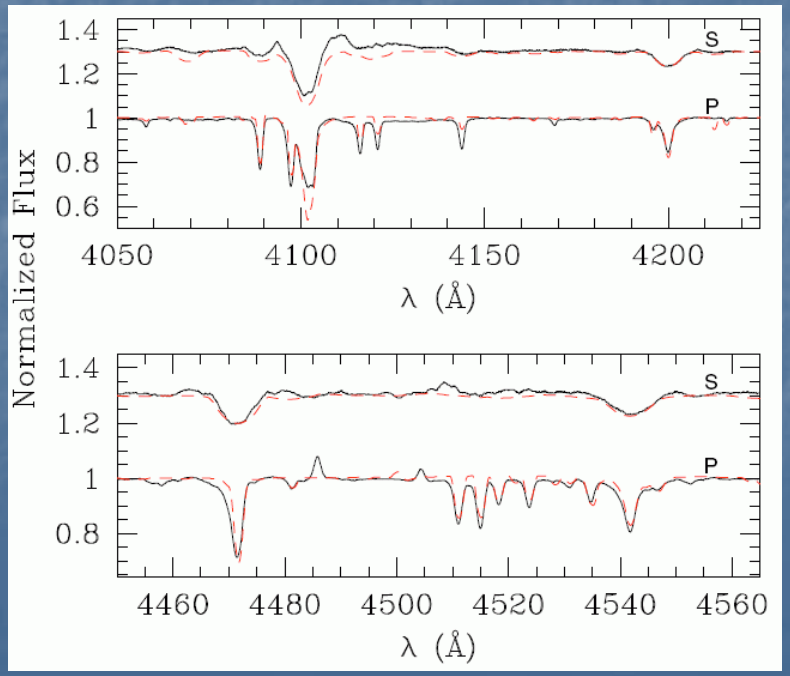
- Determination of properties of the binary components requires access to the individual spectra of both stars in addition to orbital parameters.
- Spectral disentangling based on the method of González & Levato (2006, A&A 448, 283) + model atmosphere fitting using CMFGEN (Hillier & Miller 1998, ApJ 496, 407) to derive fundamental properties such as T_{eff}, log g, v sin(*i*) and chemical abundances (C, N, O, He).

- Method previously applied to HD47129 (Linder et al. 2008, A&A 489, 713) and LZ Cep (Mahy et al. 2011, A&A 533, A9).
- Evidence for a past RLOF episode was found in these systems:

1. Strong abundance anomalies due to removal of the mass donor's outer layers.
2. Asynchronous rotation due to transfer of angular momentum.
3. Over- or under-luminosities compared to single star evolutionary tracks of same mass.

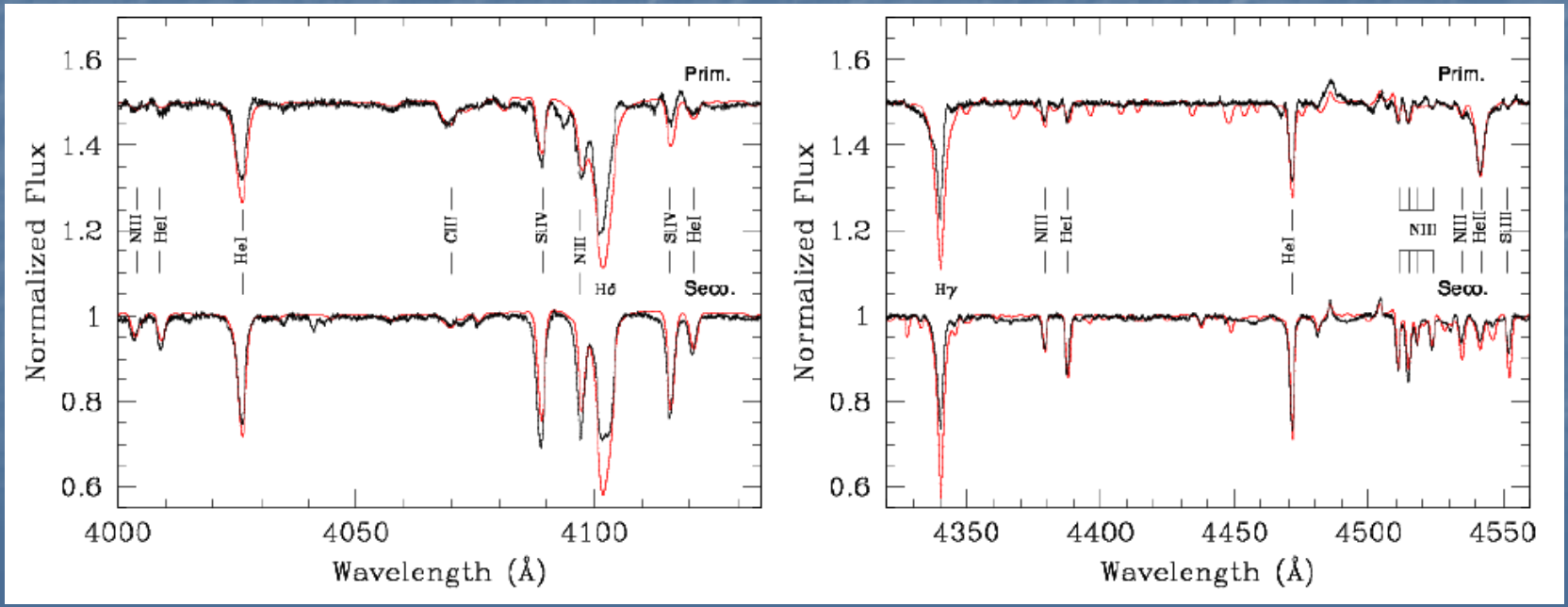
- E.g. HD47129 = Plaskett's Star (O8III/I + O7.5III, P_{orb} = 14.4 days, e = 0) :

	Primary	Secondary
v sin i (km/s)	66 ± 9	310 ± 20
$He/He_{\odot}$	1.17 ± 0.35	1.76 ± 0.53
$C/C_{\odot}$	0.2 ± 0.1	1.0 (fixed)
$N/N_{\odot}$	16.6 ± 5.0	0.2 ± 0.1



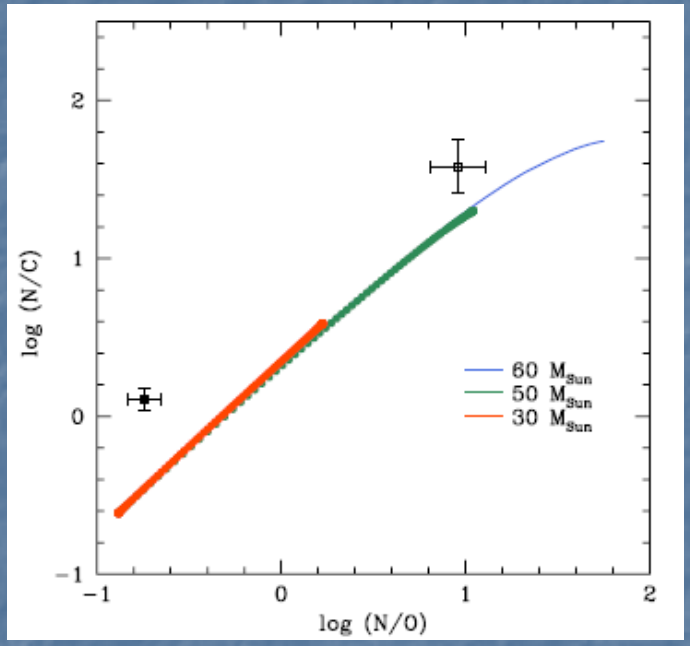
HD149404: a detached post RLOF binary

- HD149404: O7.5 If + ON9.7 I, P = 9.81 days, e = 0.0 (Rauw et al. 2001, A&A 368, 212)
- ON spectral-type → good candidate for chemical enrichment due to case-A RLOF.
- Spectral disentangling based on FEROS and Coralie echelle data previously used for orbital solution (Raucq et al. 2016, A&A 588, A10):



- Inferred abundances incompatible with single star evolution.
- No detectable enhancement of He abundance.
- $[N/C]_{secondary} \sim 150\ [N/C]_{\odot}$ consistent with predictions for post case B mass exchange, but HD149404 should be a post case A system.

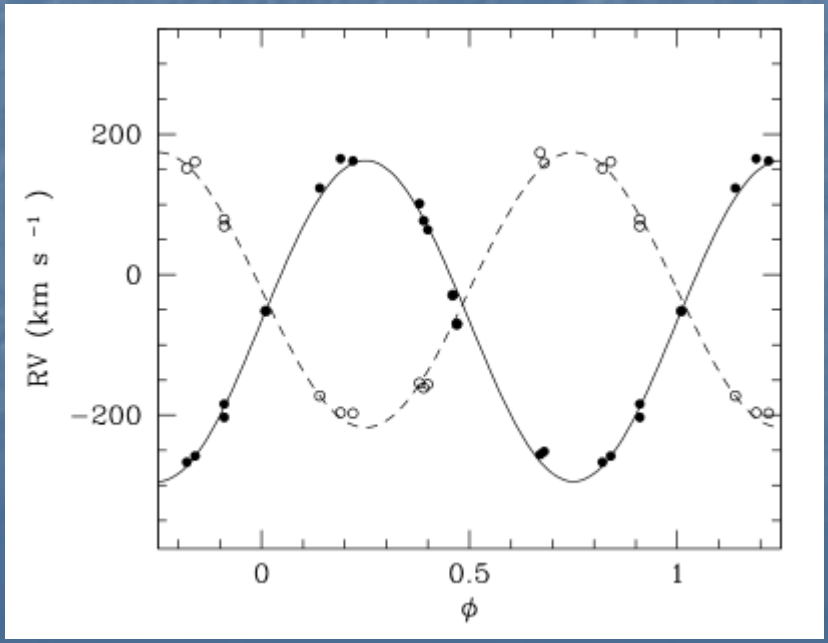
	Primary	Secondary
M ($M_{\odot}$)	50.5 ± 20.1	31.9 ± 9.5
He/He$_{\odot}$	1.12 (fixed)	1.12 (fixed)
C/C$_{\odot}$	0.38 ± 0.04	0.07 ± 0.02
N/N$_{\odot}$	1.95 ± 0.30	10.6 ± 3.2
O/O$_{\odot}$	1.50 ± 0.22	0.16 ± 0.03



- Primary star rotation period ~ ½ secondary star rotation period (≈ orbital period).
- HD149404 has undergone case A RLOF where the present-day secondary was the initially more massive star (Raucq et al. 2016, A&A 588, A10).

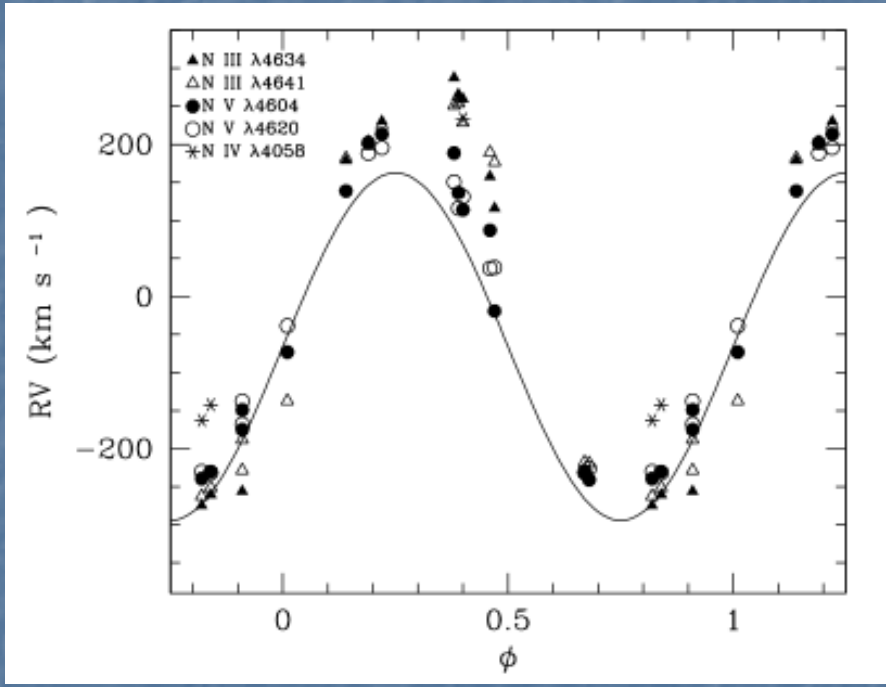
LSS3074: a contact binary with odd properties

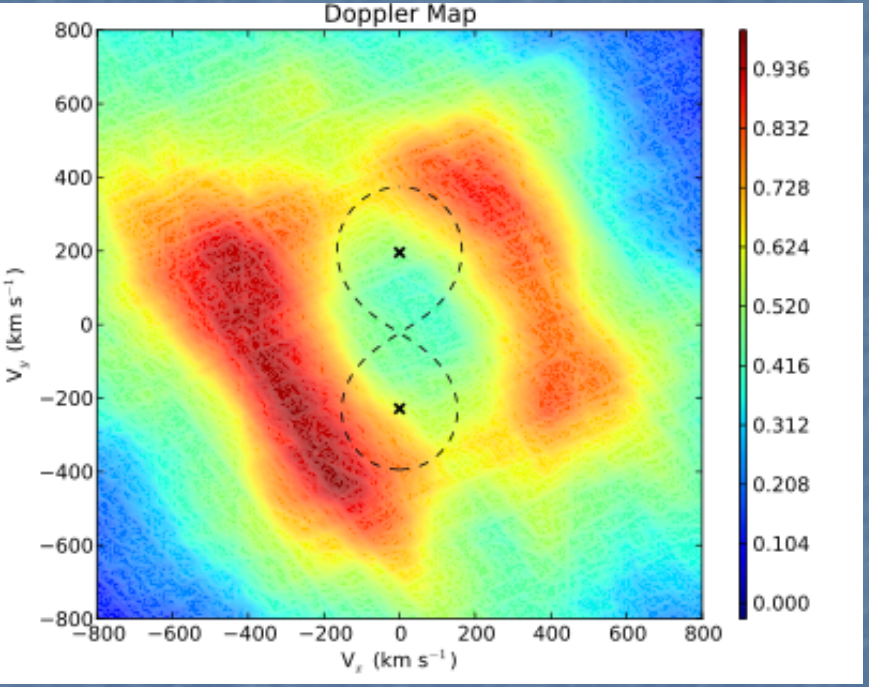
- LSS3074: O5.5 If^{+} + O6.5-7If, P = 2.185 days, e = 0.0 (Raucq et al. 2017, A&A 601, A133)
- Of^{+} star = transition object between O and WN star
- Previous studies reported surprisingly low dynamical masses (Morrell & Niemela 1990, ASPC 7, 57).
- Analysis based on high-resolution FEROS and EMMI spectra + ANDICAM (B, V, R, I) photometry.



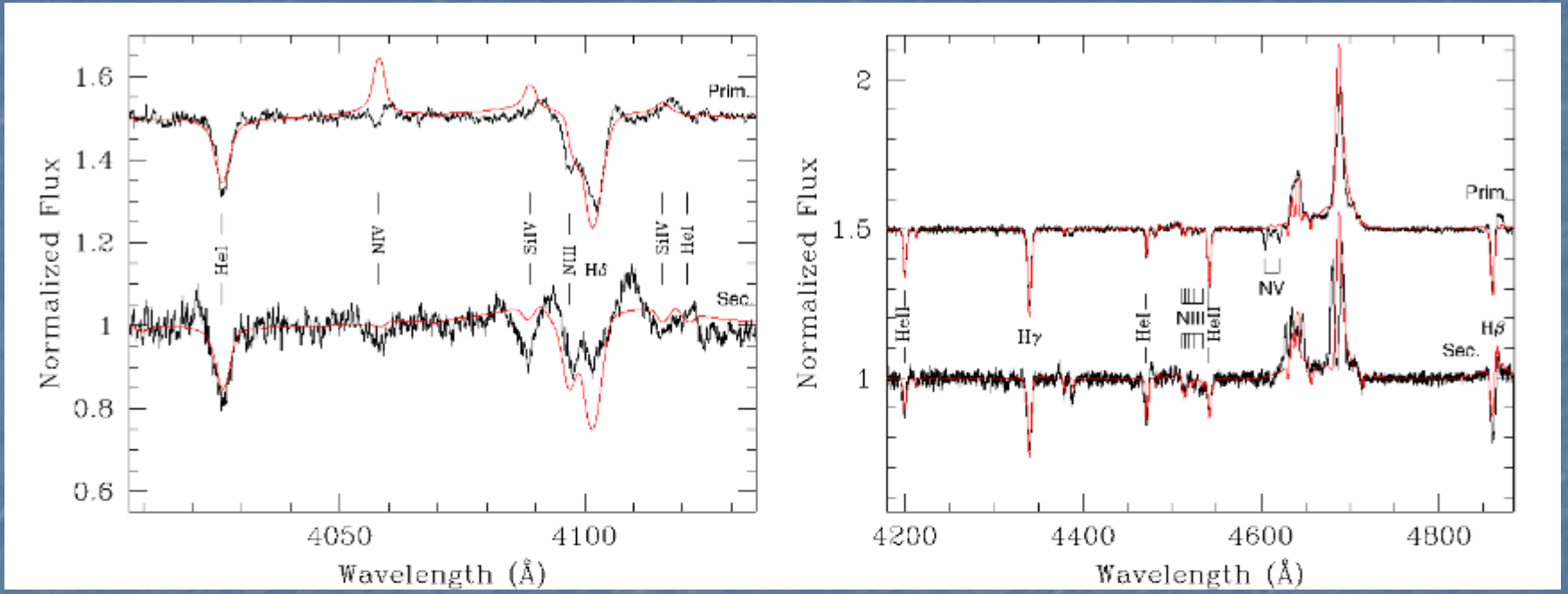
	Primary	Secondary
T_0 (HJD - 2 450 000)	2000.851 ± 0.008	
γ (km s^{-1})	–66.0 ± 5.0	–21.7 ± 4.7
K (km s^{-1})	228.5 ± 7.1	196.0 ± 6.1
$a \sin i$ ($R_\odot$)	9.9 ± 0.3	8.5 ± 0.3
$q = m_1/m_2$	0.86 ± 0.04	
$m \sin^3 i$ ($M_\odot$)	8.0 ± 0.5	9.3 ± 0.7
$R_{RL}/(a_1 + a_2)$	0.37 ± 0.01	0.39 ± 0.01
$R_{RL} \sin i$ ($R_\odot$)	6.7 ± 0.2	7.2 ± 0.2
σ_{fit}	3.11	

- N III, N IV and NV lines mostly follow orbital motion of primary star
- Hα emission line displays complex variations with Doppler map suggesting circumstellar material (colliding winds?) but nothing alike an accretion disk or jet of material between the stars.



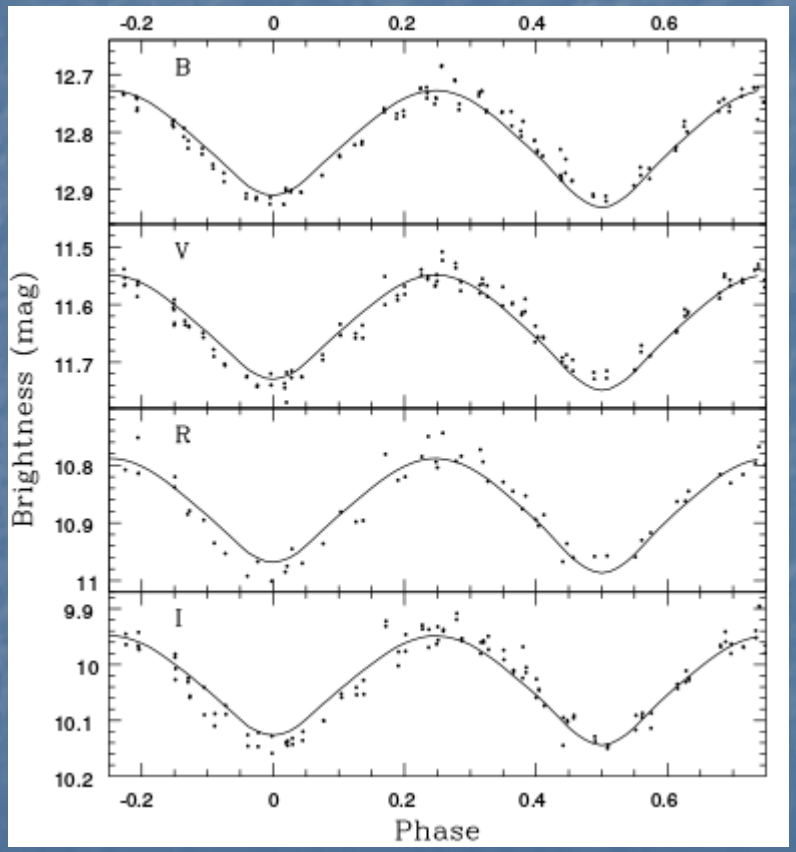


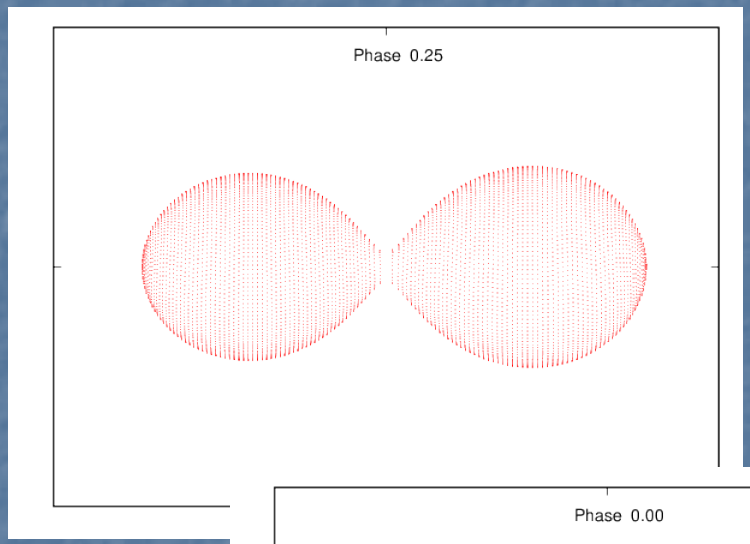
- CMFGEN analysis of disentangled spectra (Raucq et al. 2017, A&A 601, A133) fails to simultaneously reproduce the strength of the N III, N IV and N V lines.

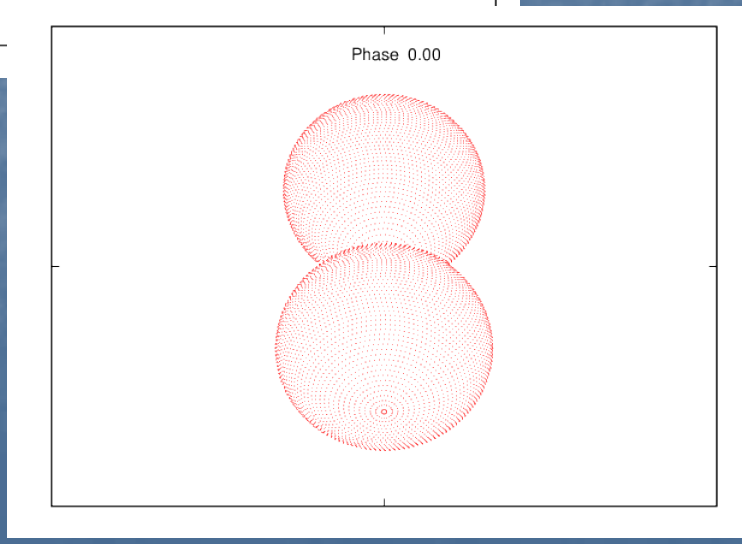


	Primary	Secondary
He/He$_\odot$	2.80	1.0
C/C$_\odot$	$\leq$ 0.24	$\leq$ 0.08
N/N$_\odot$	8.4 $\pm$ 5.2	5.5 $\pm$ 1.3
O/O$_\odot$	$\leq$ 0.05	$\leq$ 0.02

- Spectroscopy yields brightness ratio (primary/secondary) of 2.50 ± 0.43.
- But photometric data reveal ellipsoidal variations consistent with over-contact configuration and brightness ratio of 1.09!







Parameters	Primary	Secondary
i (°)	54.5 ± 1.0	
$q = m_1/m_2$	0.86 (fixed)	
Filling factor[a]	1.008 ± 0.010	1.008 ± 0.010
$T_{\rm eff}$ (K)	39 900 (fixed)	34 100 (fixed)
m ($M_\odot$)	14.8 ± 1.1	17.2 ± 1.4
$R_{\rm pole}$ ($R_\odot$)	7.8	8.4
χ^2	1820.7	
$N_{\rm d.o.f.}$	415	

- Inferred inclination yields dynamical masses of only 14.8 (O5.5 If$^+$ primary) and 17.2 $M_\odot$ (O6.5-7If secondary)!
- Overall stellar parameters do not concur with those of genuine O-star supergiants, but could be biased by strong radiation pressure making LSS3074 an **O-supergiant impostor** similar to Cyg OB2 #5 (= V729 Cygni, Linder et al. 2009, A&A 495, 231).
- Binary properties suggest that the system is currently in a slow phase of case B RLOF and is evolving into a WR + late O binary system (Raucq et al. 2017, A&A 601, A133).

Conclusions and open issues

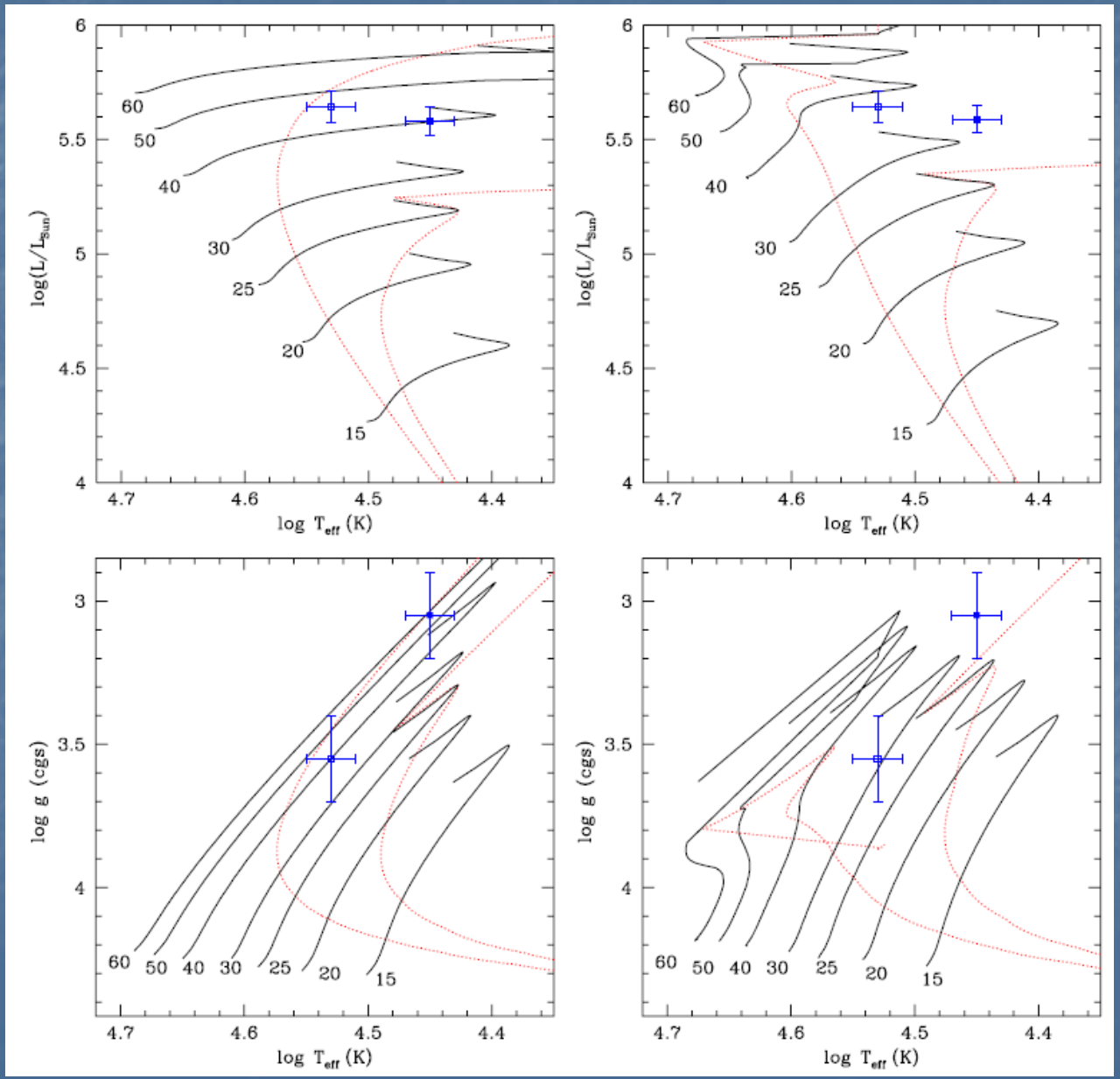
- HD149404 underwent a RLOF episode that stopped before the entire outer envelope of the mass donor was removed.
- LSS 3074 is likely in an over-contact configuration, on its way to become a CQ Cep – like WR binary.

	Spectral type	P_{orb}	Asynchronicity	[N/C] / [N/C]$_\odot$
LSS3074	O5.5 If$^+$ + O6.5-7If	2.185 days	~ 1	> 35
LZ Cep	O9 III + ON9.7 V	3.07 days	~ 1	~ 180
HD149404	O7.5 If + ON9.7 I	9.81 days	~ 2	~ 150
HD47129	O8 III/I + O7.5 III	14.4 days	~ 5	~ 80

- Spin-up of the mass gainer due to momentum transfer seems more efficient in wider systems as expected (Langer 2012, ARA&A, 50, 107), but *trend* needs further confirmation.

- Possible rejuvenation of primary star in HD149404 (Raucq et al. 2016, A&A 588, A10).

- Primary and secondary star currently fill ~52 and ~87% of their Roche lobes (Raucq et al. 2016, A&A 588, A10).



	This study	
	Prim.	Sec.
R ($R_\odot$)	19.3 ± 2.2	25.9 ± 3.4
M ($M_\odot$)	50.5 ± 20.1	31.9 ± 9.5
$T_{\rm eff}$ (10^4 K)	3.40 ± 0.15	2.80 ± 0.15
log ($\frac{L}{L_\odot}$)	5.63 ± 0.05	5.58 ± 0.04
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^{-7f}	3.3×10^{-7f}
BC	−3.17	−2.67