The long-period massive binary HD 54662 revisited

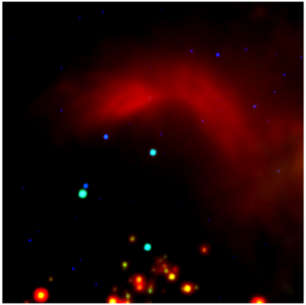
Enmanuelle Mossoux, Laurent Mahy & Gregor Rauw 2018, A&A, in press
(arXiv: 1802.06535)

Outline

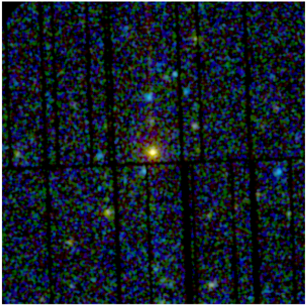
1. HD 54662
2. Optical analysis
3. X-ray analysis
4. Conclusion

HD 54662

- Brightest and earliest member of the CMa OB1 association (Gies 1987)
- O7 Vz var? (Sota et al. 2014)
- Runaway (Noriega-Crespo et al. 1997; Peri et al. 2012)
- Orbital period still debated: 92 days (Stickland & Lloyd 2001), 558 days (Boyajian et al. 2007), 2103 days (Le Bouquin et al. 2017)
- $i = 74.87^\circ$ (Le Bouquin et al. 2017)



WISE image (red=22.2 μm, green=12.1 μm, blue=3.4 μm)



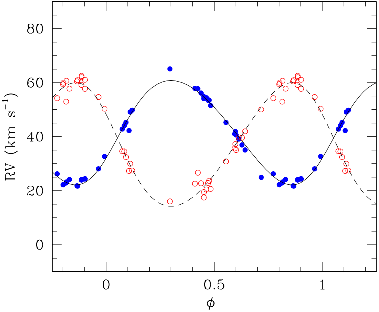
XMM-Newton image (red=0.2-0.7 keV, green=0.7-6.6 keV, blue=6.6-10 keV)

Orbital solution

Spectra: 15 TIGRE + HEROS, 13 UT2 + UVES, 9 MPI2.2 + FEROS, 1 NOT + FIES, 1 CFHT + ESPaDOnS

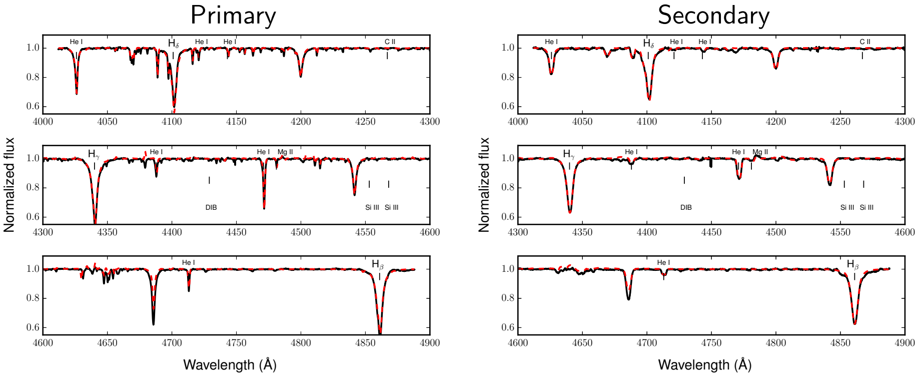
- Spectral disentangling (González & Levato 2006)$\rightarrow$ new RVs
- Fourier method on new and archival RVs $\rightarrow P = (2104 \pm 13)$ days
- SB1 solution with LOSP (Sana et al. 2006)$\rightarrow P = (2103.4 \pm 3.3)$ days
- SB2 solution (only new RVs) with LOSP and $P = 2103.4$ days

	Primary	Secondary
m_2/m_1	0.843 ± 0.032	
v_0 (km s^{-1})	42.5 ± 1.2	35.9 ± 1.2
e	0.11 ± 0.02	
K (km s^{-1})	19.3 ± 0.6	22.9 ± 0.7
ω (°)	240.9 ± 10.9	
T_0 (HJD-2450000)	6084 ± 62	
$a \sin i$ ($R_\odot$)	797 ± 24	945 ± 28
$m \sin^3 i$ ($M_\odot$)	8.72 ± 0.64	7.35 ± 0.53
rms (km s^{-1})	1.72	2.52



Reconstructed spectra

- He I λ 4471 + He II λ 4542 lines (Conti & Alschuler 1971; Conti & Frost 1977) $\rightarrow$ O6.5 stars
- $L_1/L_2 \sim 2$
- $v_1 \sin i = 43\,\mathrm{km\,s^{-1}}$ using He I λ 4713 line
- $v_2 \sin i = 158\,\mathrm{km\,s^{-1}}$ using He I $\lambda\lambda$ 4144, 4388, 4471, 4713, He II $\lambda\lambda$ 4200, 4542 and Mg II λ 4481 lines



Model atmosphere fitting

Effective temperatures and surface gravities:

- Non-LTE atmosphere code CMFGEN (Hillier & Miller 1998)
- Chemical species: H, He, C, N, O, Si, S, Ne, Mg, Al, Ar, Fe, and Ni

	Primary	Secondary
T_{eff} (K)	37700 ± 1000	37500 ± 1000
$\log g$	3.96 ± 0.1	3.81 ± 0.1

Abundances (Martins et al. 2015; Mahy et al. 2017):

- Carbon: C III $\lambda\lambda$4068-70 lines
- Nitrogen: triplet around 4515 Å

	Primary	Secondary	Sun
He/H	0.1	0.1	0.089
C/H	$(2.6 \pm 0.3) \times 10^{-4}$	$(2.3 \pm 0.2) \times 10^{-4}$	2.69×10^{-4}
N/H	$(2.3 \pm 0.3) \times 10^{-4}$	$(9.5 \pm 1.5) \times 10^{-5}$	6.76×10^{-5}

Surprisingly low masses

- $m_1 = 9.7 \pm 0.7 M_\odot$ and $m_2 = 8.2 \pm 0.6 M_\odot$ using $i = 74.87^\circ$ $\rightarrow$ very low for O-type stars (Martins et al. 2005; Weidner & Vink 2010)
- $i = 38^\circ$ leads consistent masses

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- Our $a/\sin(38^\circ) = a$ from Le Bouquin et al. (2017) $\rightarrow$ $d = 1.27$ kpc (close to 1.2 kpc Kaltcheva & Hilditch 2000)
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- $m_1 = 28 M_\odot$ in SB1 solution with $i = 74.87°$ & $m_2/m_1 = 0.53 < 0.84 \pm 0.03$
- $m_1 = 28 M_\odot$ and $m_2/m_1 = 0.53 \rightarrow m_2 = 14.8 M_\odot \rightarrow$ for B0-type star
- BUT sharp-lined primary star $\rightarrow$ robust determination of its orbital solution

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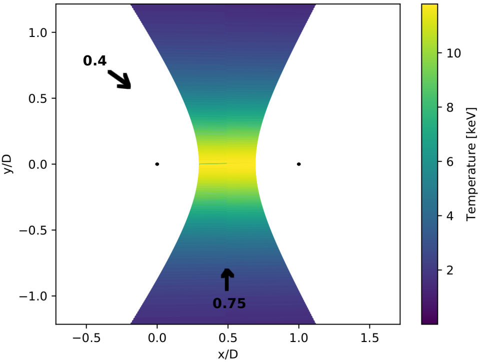
Pair of sub-dwarf O stars?

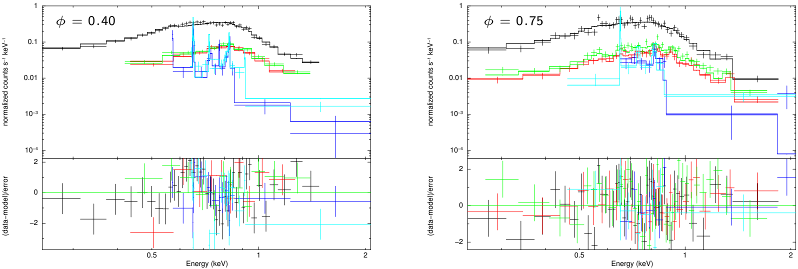
- sdO masses < HD 54662 minimum masses
- sdO $\log g$ > HD 54662 $\log g$
- sdO luminosities < HD 54662 luminosity

X-ray observations

- 2 XMM-Newton observations
- Phases: 0.40 & 0.75
- Distance between the stars: $d/a = 1.094$ & 1.012
- Presence of a shock between the two winds ?



X-ray flux from the wind interaction zone



- Spectral fitting of the 2 XMM-newton observations with an absorbed APEC model
- Change of the spectral parameters by less than 20%
- No significant change of the unabsorbed flux
- $\log \frac{L_X}{L_{\rm bol}} = -6.76 \pm 0.04 \rightarrow$ consistent with both the canonical values for single and binary O-type stars (Nazé 2009)
- Adiabatic wind-shock model (Canto et al. 1996)
  - $\rightarrow$ overestimation of the X-ray flux
  - $\rightarrow$ overestimation of the mass-loss rate and terminal velocities
  - $\rightarrow$ "weak-wind problem" (Bouret et al. 2003; Marcolino et al. 2009)

Bow shock around HD 54662

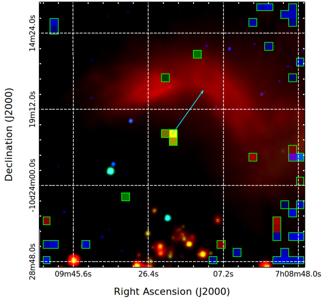
- Excess in infrared at 4′ from the binary: $I(60\mu m)/I(100\mu m) = 0.59 \pm 0.04$

  (Noriega-Crespo et al. 1997; Peri et al. 2012)
- No X-ray counterpart
- Peculiar RV $= (10.3 \pm 3.5)\,\mathrm{km\,s^{-1}} < 30\,\mathrm{km\,s^{-1}}$ threshold for runaways

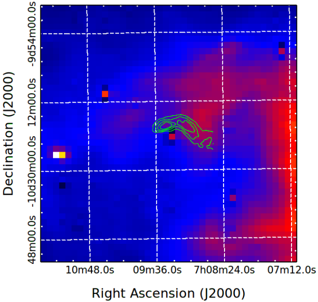
  (Cruz-González et al. 1974)
- Peculiar tangential velocity $(40.1 \pm 11.5)\,\mathrm{km\,s^{-1}} < (42 + \sigma)\,\mathrm{km\,s^{-1}}$ (Moffat et al. 1998)

$\Rightarrow$ HD 54662 is a walk-away binary

$\Rightarrow$ Bow shock created by interaction with the ionized gas of CMa OB1



WISE+XMM-Newton (2σ-clipping) image



Continuum-corrected Hα image+WISE bowshock

Conclusion

HD 54662

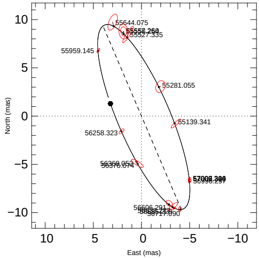
- is composed of two nitrogen-enriched O6.5 stars with faint ($L_1/L_2 \sim 2$) and rapidly rotating ($158\,\mathrm{km\,s^{-1}}$) secondary
- has a nearly circular orbit ($e = 0.11$) with $P = 2103.4$ days
- contains surprisingly low mass stars
- has very soft and non-variable X-ray emission $\rightarrow$ wind-shock emission fainter than our expectations
- is a walk-away binary
- forms an infrared bow shock via interaction with CMa OB1

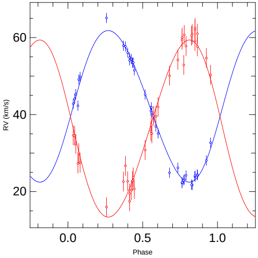
To be done:

- Constrain the masses of the stars (very low-mass O-type stars ?)
- Determination of their mass-loss rate and terminal velocities (lower than typical O-type stars ?)

Simultaneous fit of astrometric and RV data

PRELIMINARY results from a private communication with Jean-Baptiste Le Bouquin (April 24, 2018).





P (days)	2107.79
T_0 (HJD-2450000)	6164.5
d (pc)	823.1
a (mas)	10.4
i (°)	74.8
e	0.07
ω (°)	75.3
Ω (°)	23.1
v_0 (km s^{-1})	42.5
K (km s^{-1})	19.7 (P) / 23.0 (S)
m ($M_\odot$)	18.8 (P) / 10.1 (S)
L_2/L_1	1.28