IMPACT OF BINARIES ON STELLAR EVOLUTION

Alain Jorissen

Institut d'Astronomie et d'Astrophysique
Université libre de Bruxelles (Belgium)

Collaborators: H. Boffin, A. Escorza, T. Merle, D. Pourbaix, L. Siess, S. Van Eck, H. Van Winckel

HERMES / Mercator radial-velocity data

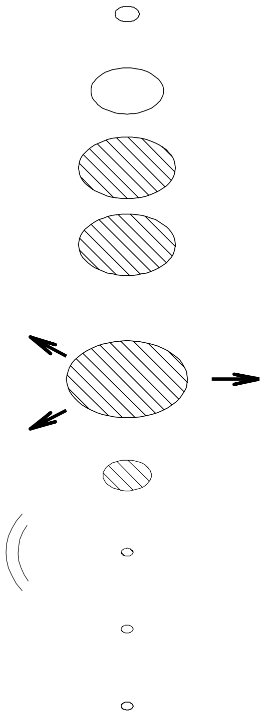
IMPACT OF BINARIES ON STELLAR EVOLUTION

Classes of stars for which duplicity (or non-duplicity!) is essential:

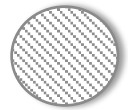
- ❑ Algols & blue stragglers
- ❑ Barium (dwarfs, sgCH & giants)
- ❑ Post-RGB, He WDs & sdB
- ❑ R stars (no binaries)
- ❑ (Asymmetric) Planetary Nebulae
- ❑ Type Ia SN, gravitational-wave emitters...

Evolution of low- and intermediate-mass stars

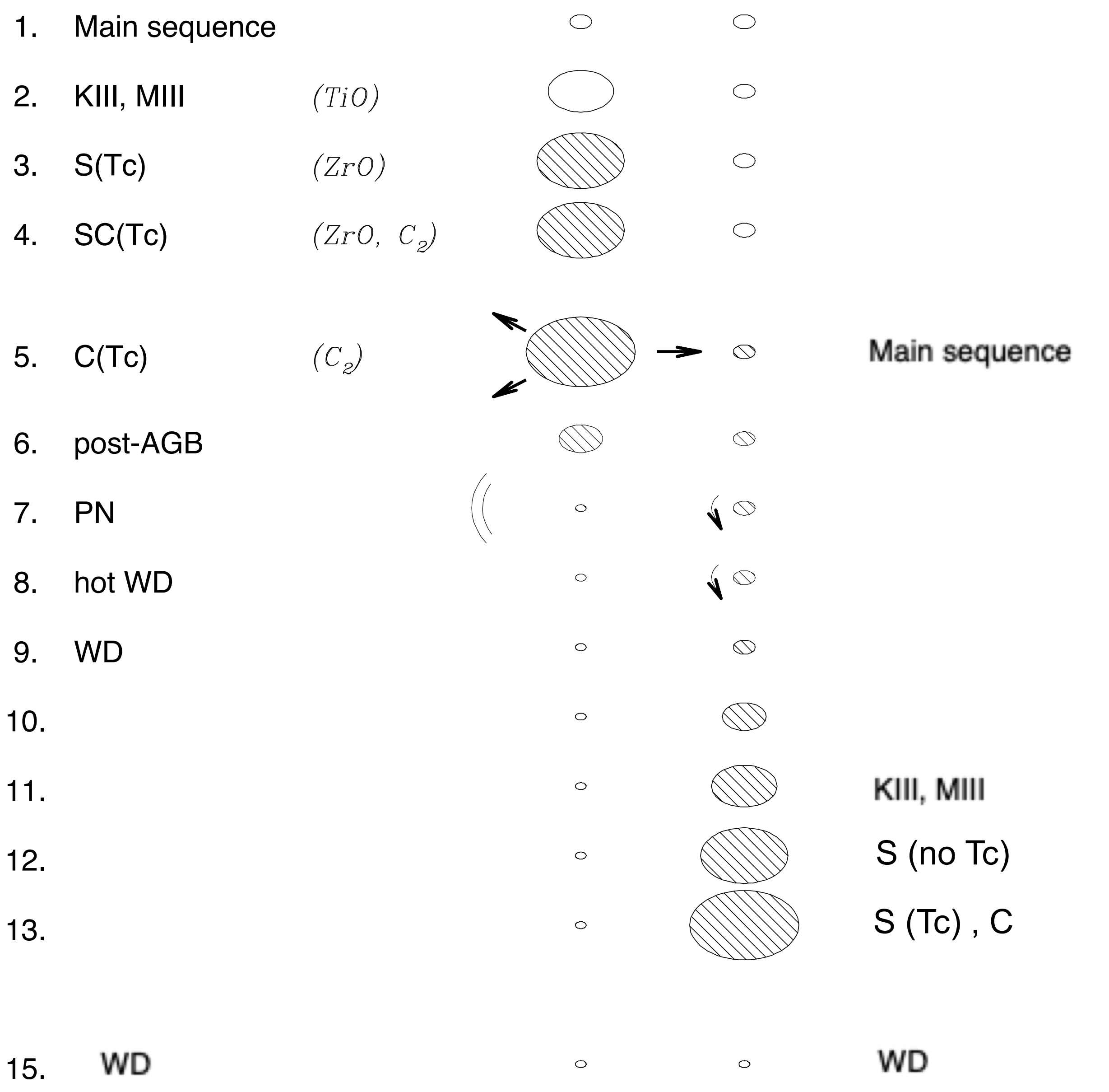
1. Main sequence
2. KIII, MIII *(TiO)*
3. S(Tc) *(ZrO)*
4. SC(Tc) *(ZrO, C_2)*
5. C(Tc) *(C_2)*
6. post-AGB
7. PN
8. hot WD
9. WD



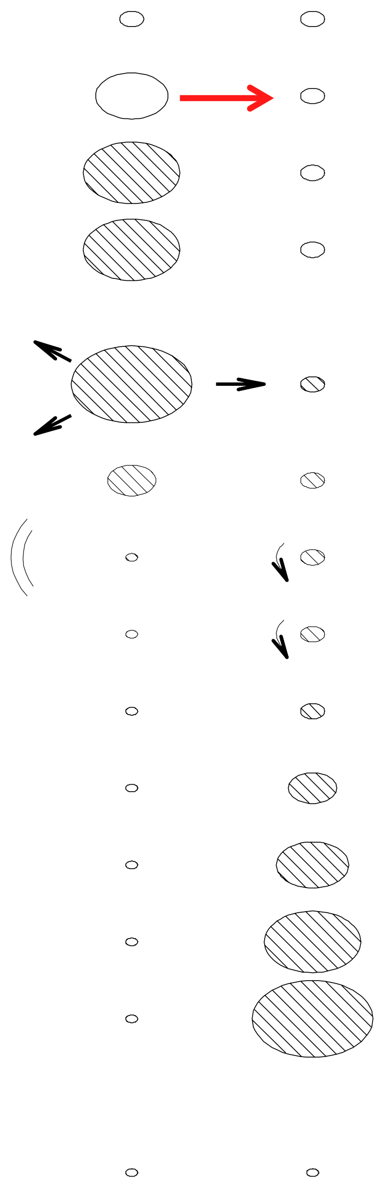
with carbon and heavy-element enhancements =



Evolution of binary low- and intermediate-mass stars



Evolution of binary low- and intermediate-mass stars



1.	Main sequence		
2.	KIII, MIII	(TiO)	
3.	S(Tc)	(ZrO)	
4.	SC(Tc)	$(ZrO,\ C_2)$	
5.	C(Tc)	(C_2)	Main sequence
6.	post-AGB		
7.	PN		
8.	hot WD		
9.	WD		
10.			
11.			KIII, MIII
12.			S (no Tc)
13.			S (Tc) , C
15.	WD		WD

(case B) Algols & blue stragglers

= One of the first historical cases of impact of binarity on stellar evolution !

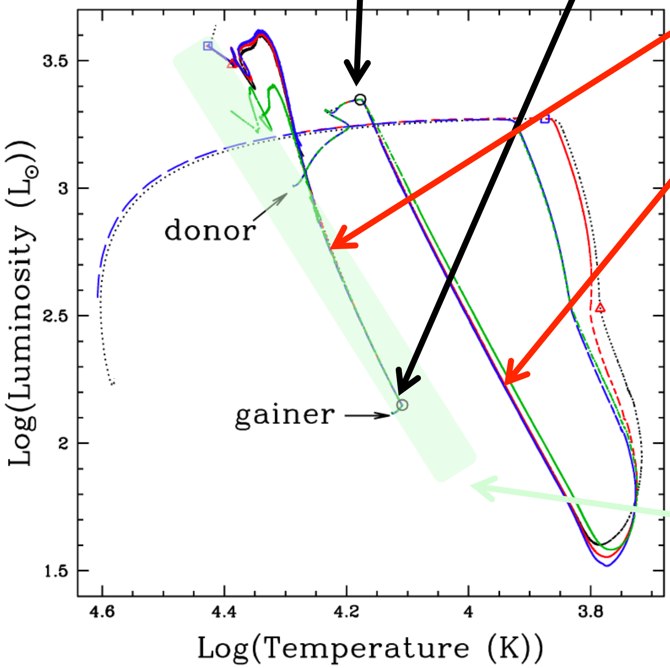
Evolution of Algols (BINSTAR code Siess et al. 2014, A&A 565, A57)

Case B mass transfer : 6 M_{o} + 3.6 M_{o} , P = 2.5 d

Mass transfer starts here (case B) ...

... and here starts the mass dump on the companion

Phase of rapid mass-transfer (RLOF)



Main sequence

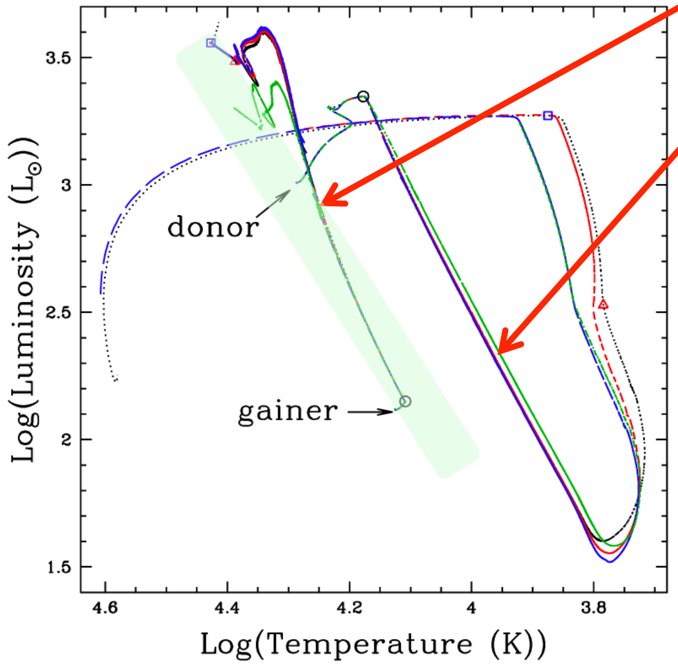
Siess et al., 2013, A&A 550, A100

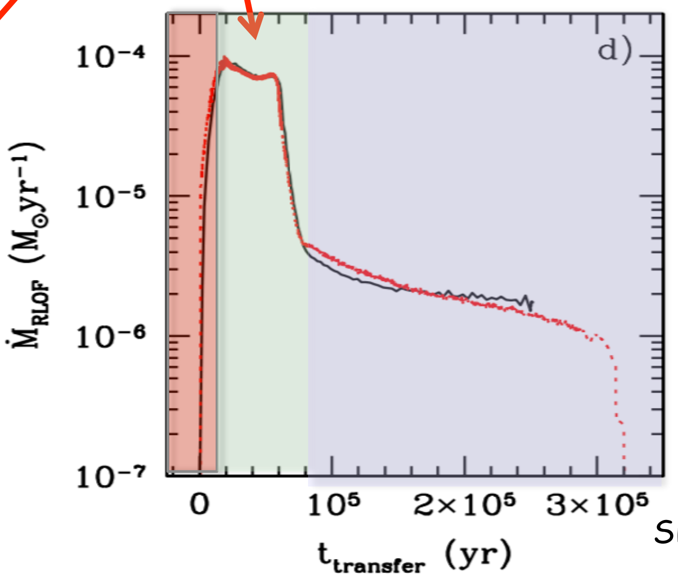
Evolution of Algols (BINSTAR code Siess et al. 2014, A&A 565, A57)

Case B mass transfer : 6 M_o + 3.6 M_o , P = 2.5 d

BINSTAR

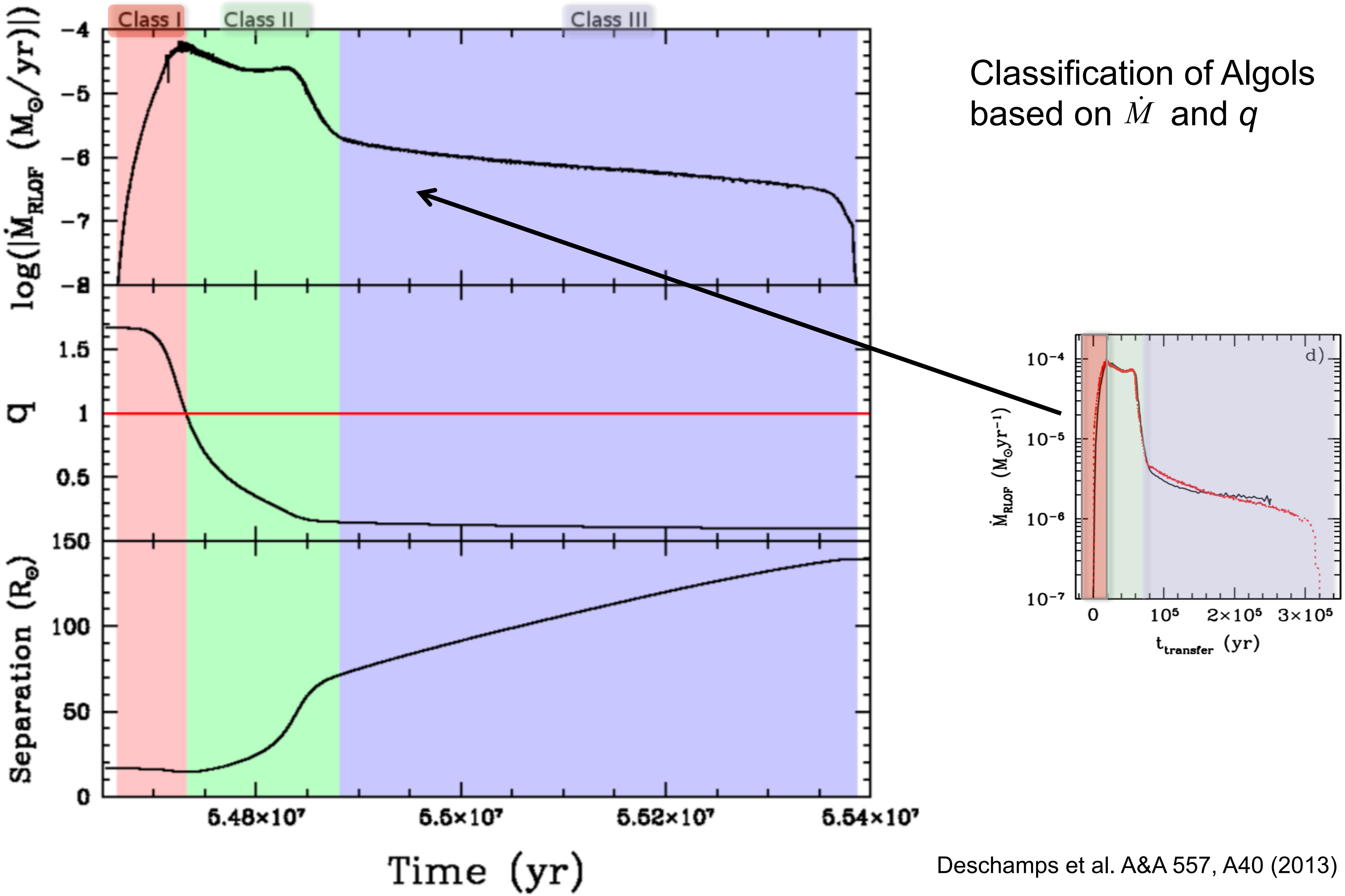
Phase of rapid mass transfer (RLOF)





Siess et al., 2013, A&A 550, A100

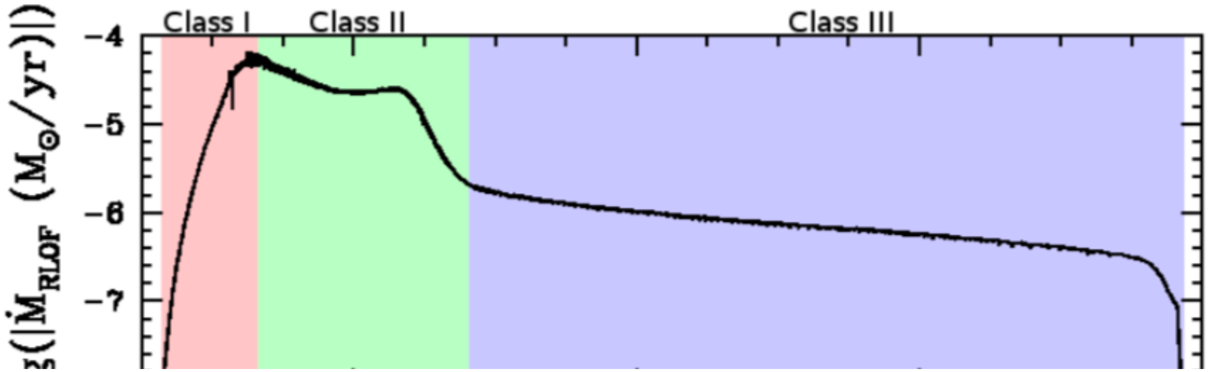
Evolution of Algols (BINSTAR code Siess et al. 2014, A&A 565, A57)



Classification of Algols based on $\dot{M}$ and q

Deschamps et al. A&A 557, A40 (2013)

Evolution of Algols (BINSTAR code Siess et al. 2014, A&A 565, A57)



Deschamps et al. A&A 557, A40 (2013)

Table 2. Observational prototypes for the different classes introduced in Sect. 4.2.1 and Fig. 8. Sp_d (Sp_g) is the spectral type of the donor (gainer). The gainer of W Ser is embedded in an accretion disc and its spectral type is unknown but believed to be B-A.

Theoretical class	Prototype	$M_d + M_g$ ($M_\odot$)	$q = M_d / M_g$	$\dot{M}_{RLOF}$ ($M_\odot$ yr^{-1})	Period (d)	$Sp_d + Sp_g$	Ref.
Class I	SV Cen	8.56 + 6.05	1.41	1.626×10^{-4}	1.6585	B1 + B4.5	1,2,4
	UX Mon	3.90 + 3.38	1.15	5.46×10^{-6}	5.904	A7p + G2p	3
Class II	β Lyr	4.25 + 14.1	0.30	3.440×10^{-5}	12.9138	B6-B8 II, + B0.5 V	1,2,5
	W Ser	0.970 + 1.510	0.64	$\sim1\times10^{-7}$	14.154	F5III + B-A (emb.)	6,8
Class III	β Per	0.81 + 3.7	0.21	$\sim1\times10^{-11}$	2.8673	K4 + B8	1,7

References. (1) van Rensbergen et al. (2011) and references herein; (2) van Rensbergen et al. (2010a); (3) Sudar et al. (2011); (4) Wilson & Starr (1976); (5) Lomax et al. (2012); (6) Budding et al. (2004); (7) Giuricin et al. (1983); (8) Piirola et al. (2005): mass-transfer rate derived from period-change rate ($\dot{P}/P$ = 14 s yr^{-1}) assuming a conservative mass transfer.

Evolution of Algols (BINSTAR code Siess et al. 2014, A&A 565, A57)

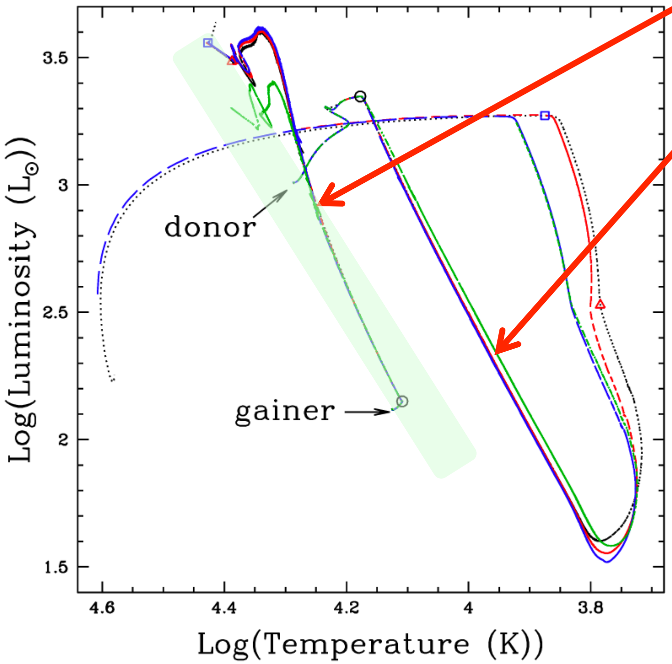
Case B mass transfer : 6 M_o + 3.6 M_o = 9.6 M_o P = 2.5 d INITIAL

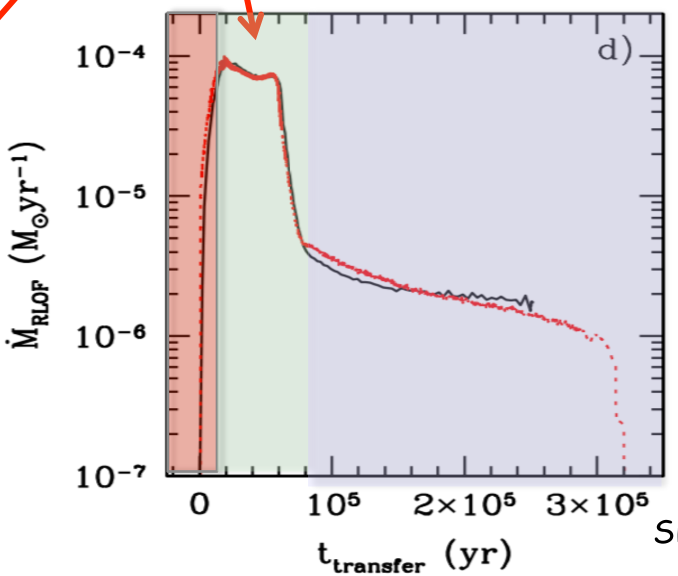
non-conservative 1.7 M_o + 6.5 M_o = 8.2 M_o, P = 8.3 d FINAL

Is mass-transfer really fully conservative ? Definitely NOT !

Does it leave signatures on circumstellar environment? Definitely YES !

Phase of rapid mass transfer

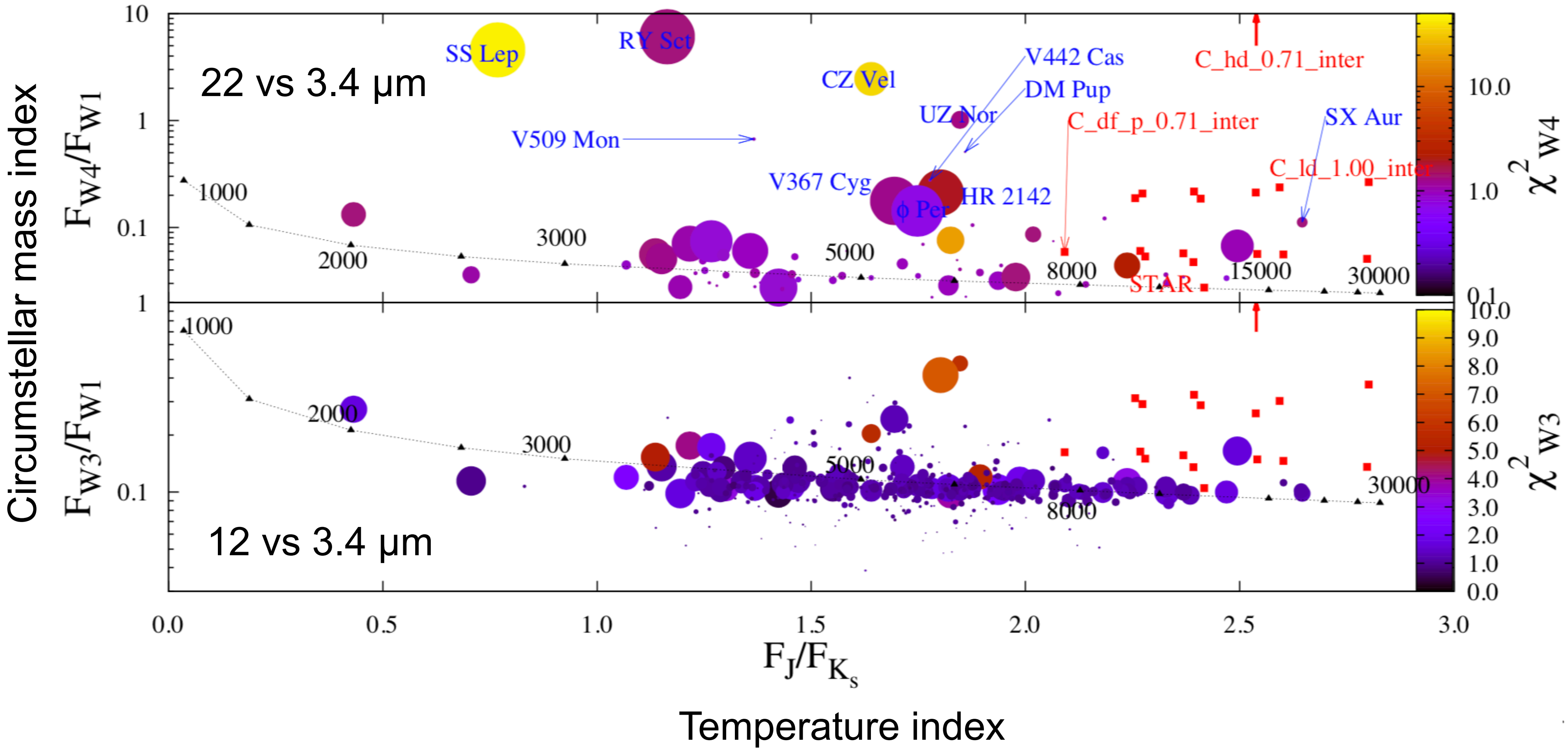




Siess et al., 2013, A&A 550, A100

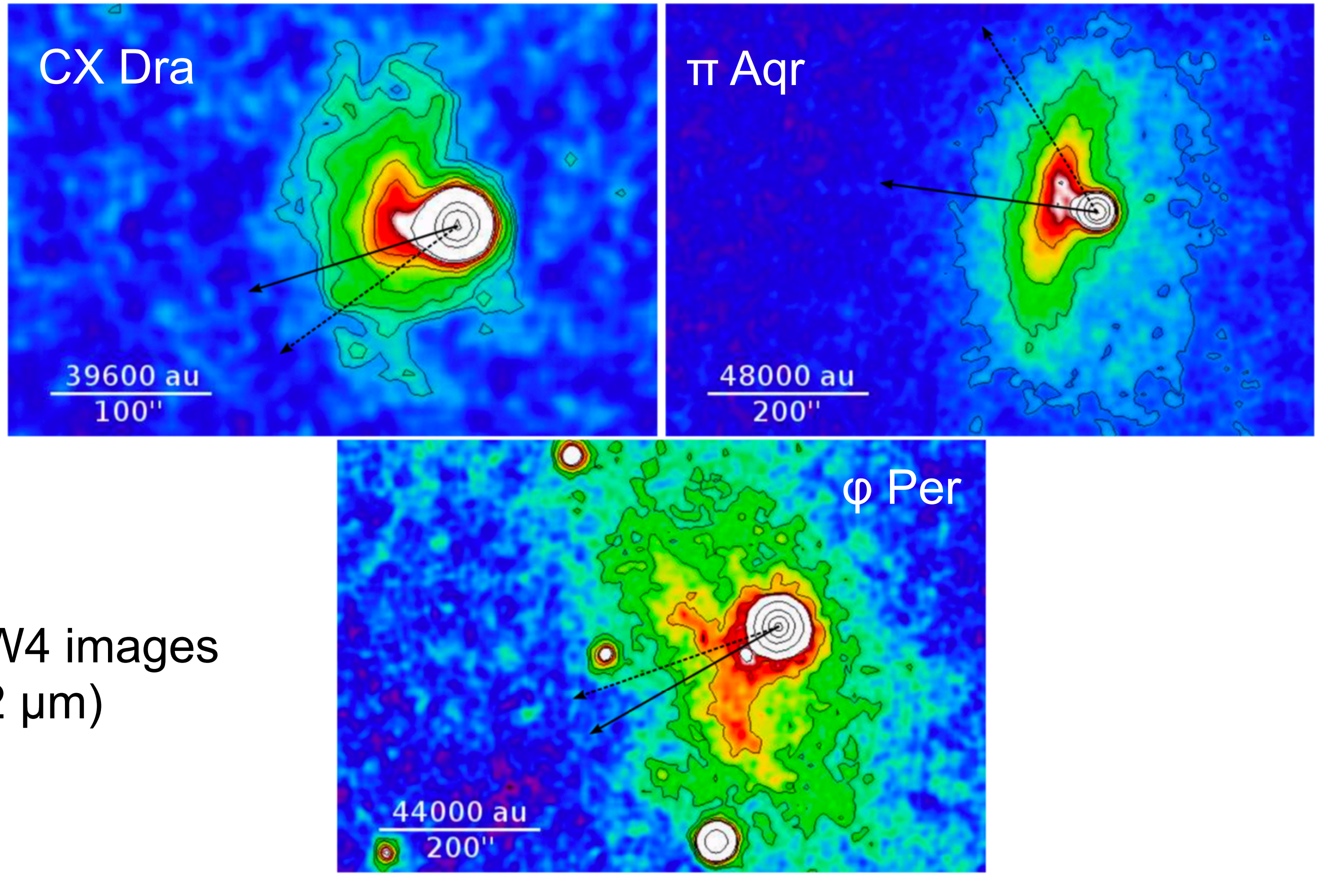
Evolution of Algols: Detection of circumstellar matter

using WISE and 2MASS photometry



Deschamps et al. 2015, A&A 577, A55

Evolution of Algols: Detection of circumstellar matter



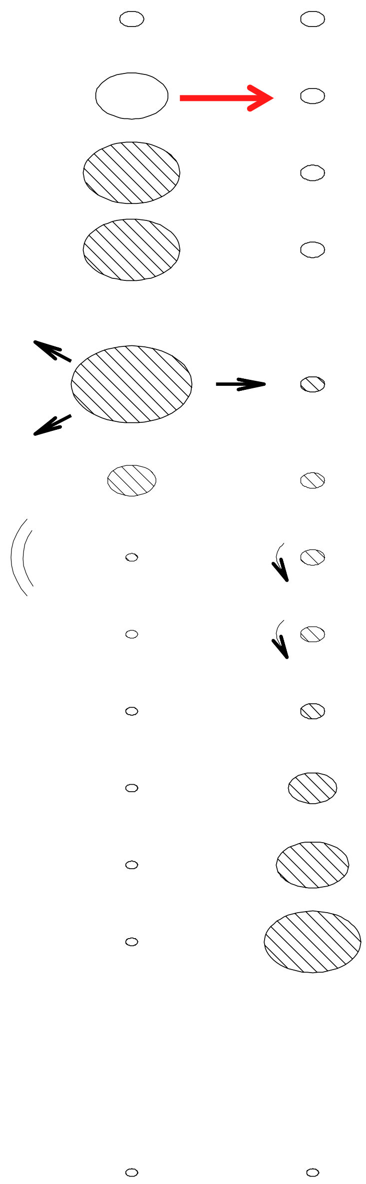
WISE W4 images
(22 μm)

Mayer et al., 2016, A&A 587, A30

Evolution of binary low- and intermediate-mass stars

1. Main sequence
2. KIII, MIII (TiO)
3. S(Tc) (ZrO)
4. SC(Tc) (ZrO, C_2)
5. C(Tc) (C_2)
6. post-AGB
7. PN
8. hot WD
9. WD
10.
11.
12.

15. WD



(case B) Algols & blue stragglers

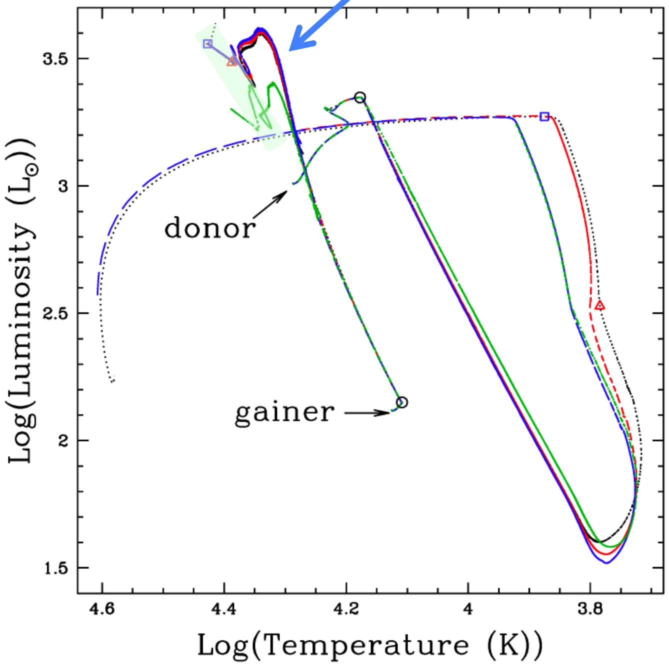
= One of the first historical cases of impact of binarity on stellar evolution !

Main sequence

KIII, MIII

WD

Evolution of Algols producing Blue stragglers

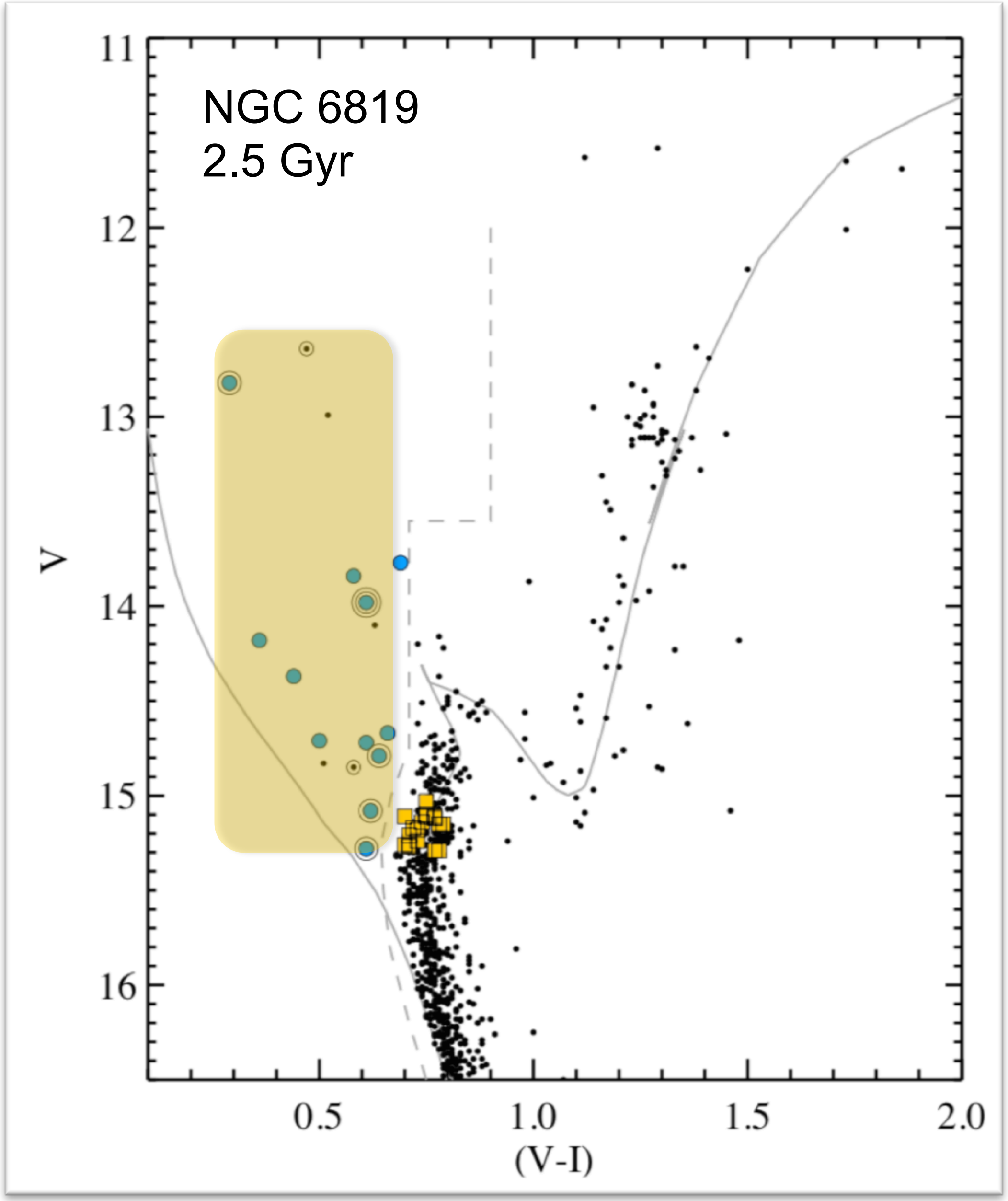


Case B mass transfer : 6 M_o + 3.6 M_o

➔ 1.7 M_o + 6.5 M_o

Siess et al., 2013, A&A 550, A100

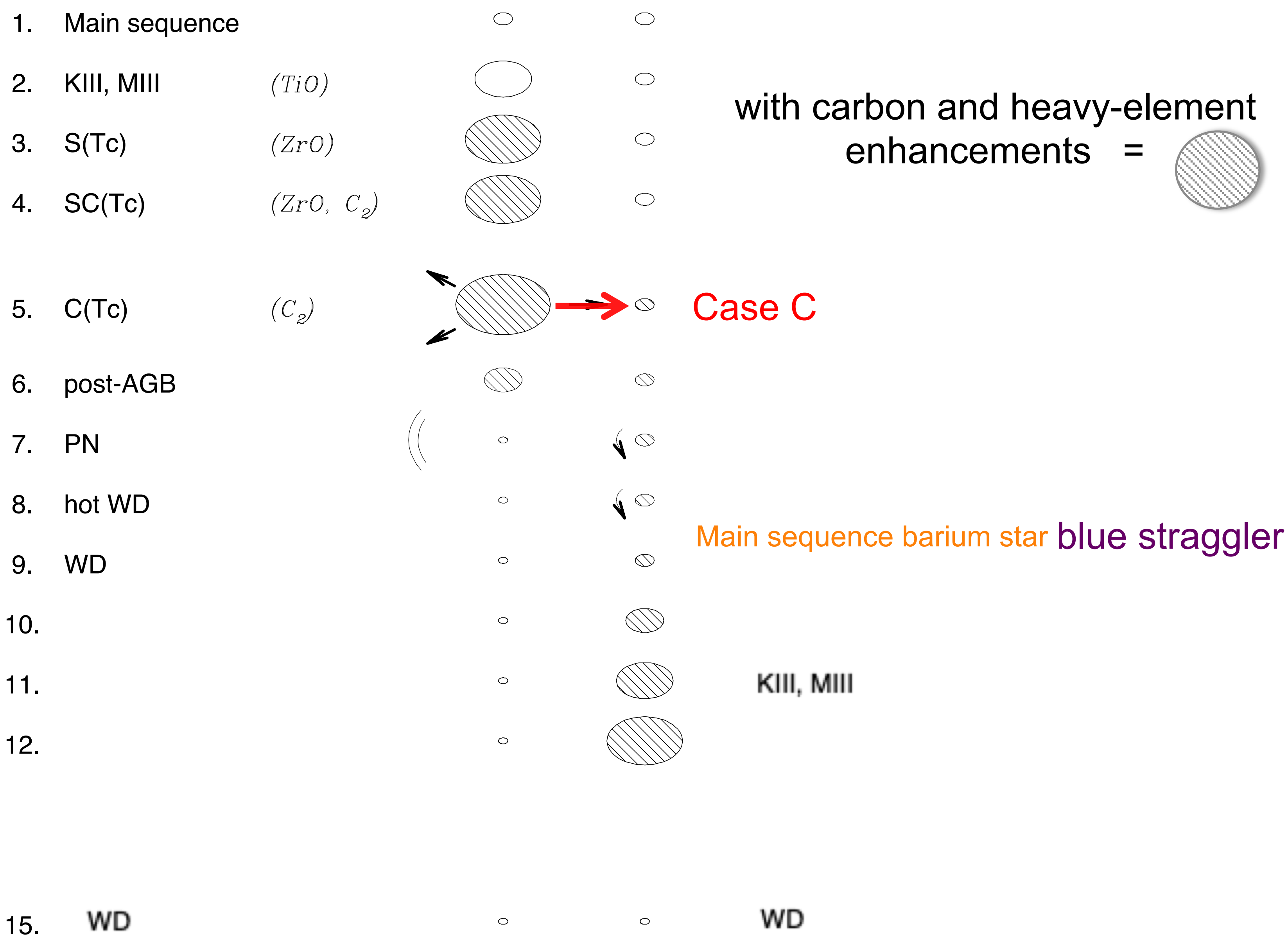
Detecting Blue stragglers



If case C mass transfer from AGB, then barium enhancement predicted

Milliman, Mathieu & Schuler, 2015, AJ 150, 84

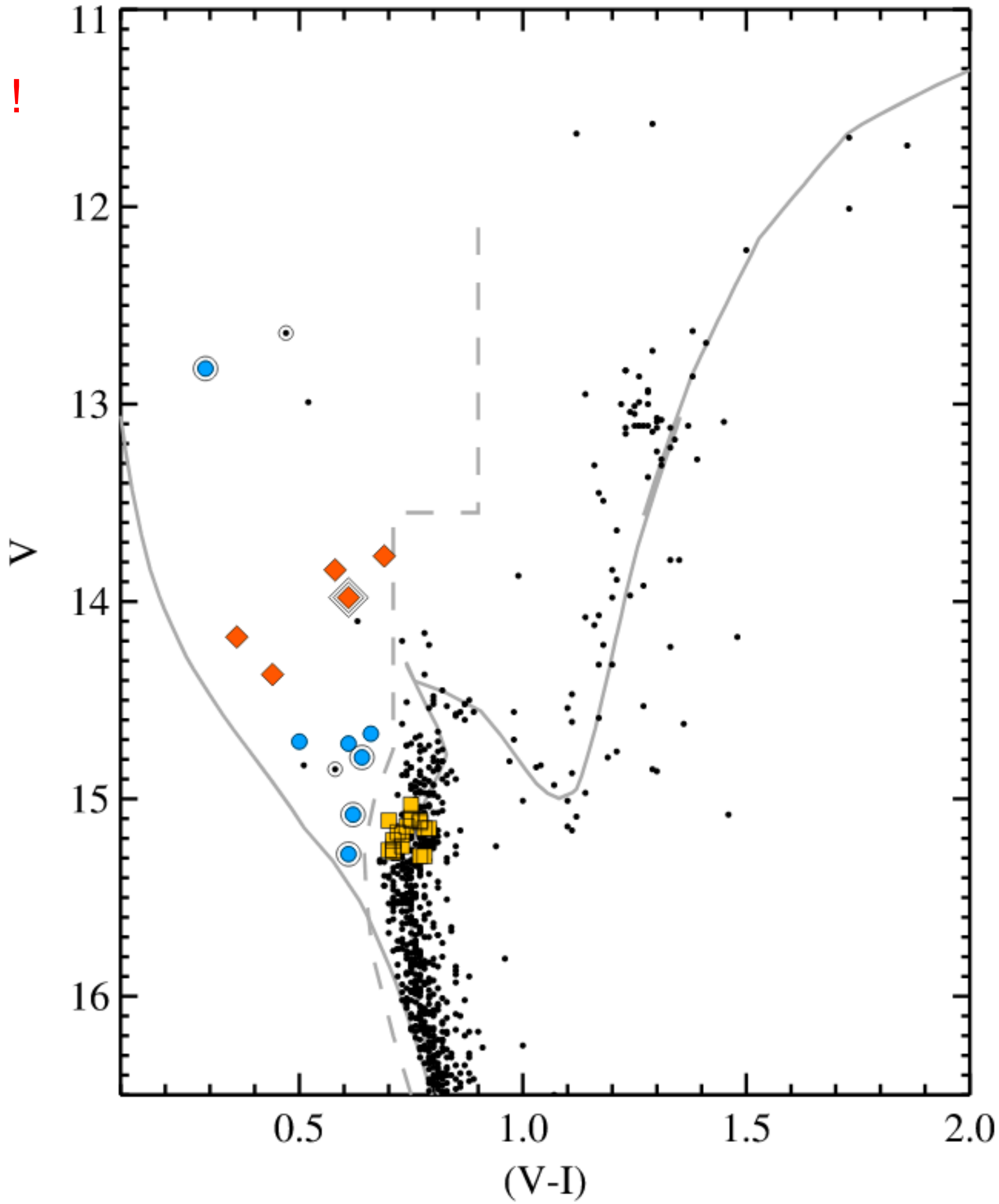
Evolution of binary low- and intermediate-mass stars



Detecting blue stragglers barium stars

Just a problem:
Only 1/5 shows signature of duplicity !

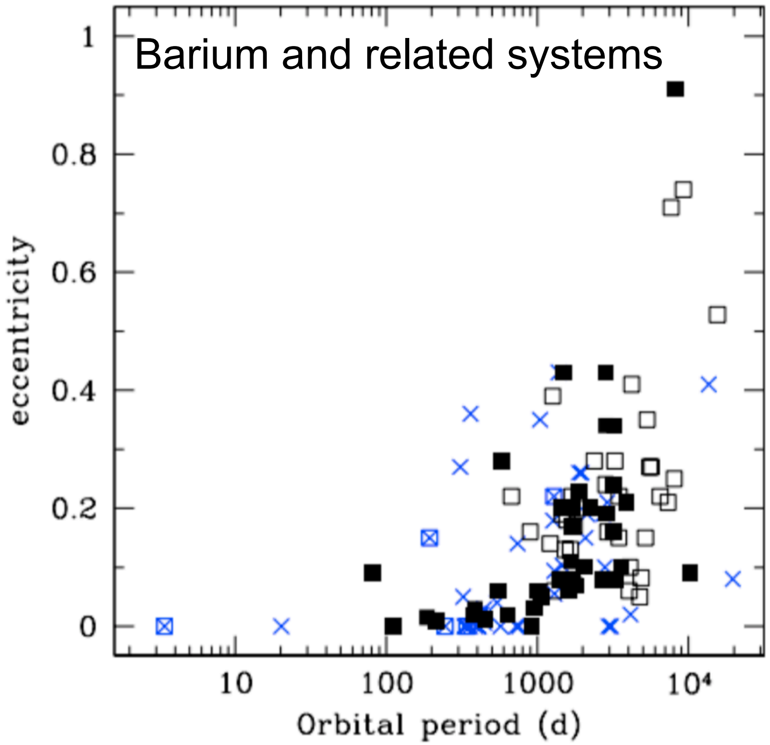
Blue straggler barium stars



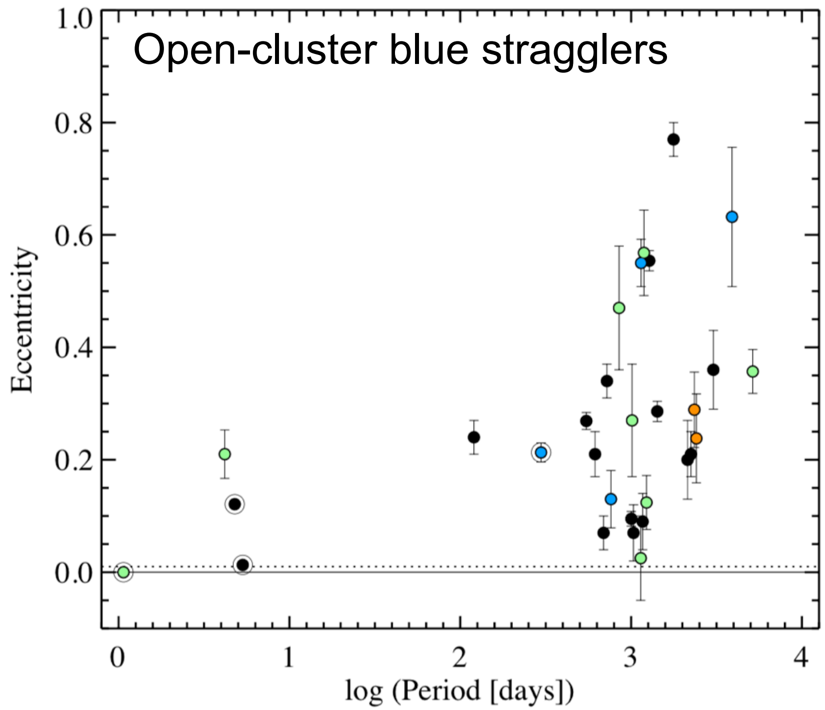
Milliman, Mathieu & Schuler, 2015, AJ 150, 84

Detecting blue stragglers barium stars

Just a second problem:
Same e – P diagram but not all are barium stars



Jorissen et al. 2015



Four Open Cluster BSS:
NGC 7789, NGC 6819, M67, NGC 188

Milliman, Cambridge conference on binary stars, 2015

Detecting blue stragglers (barium stars)

Especially promising in the Gaia era

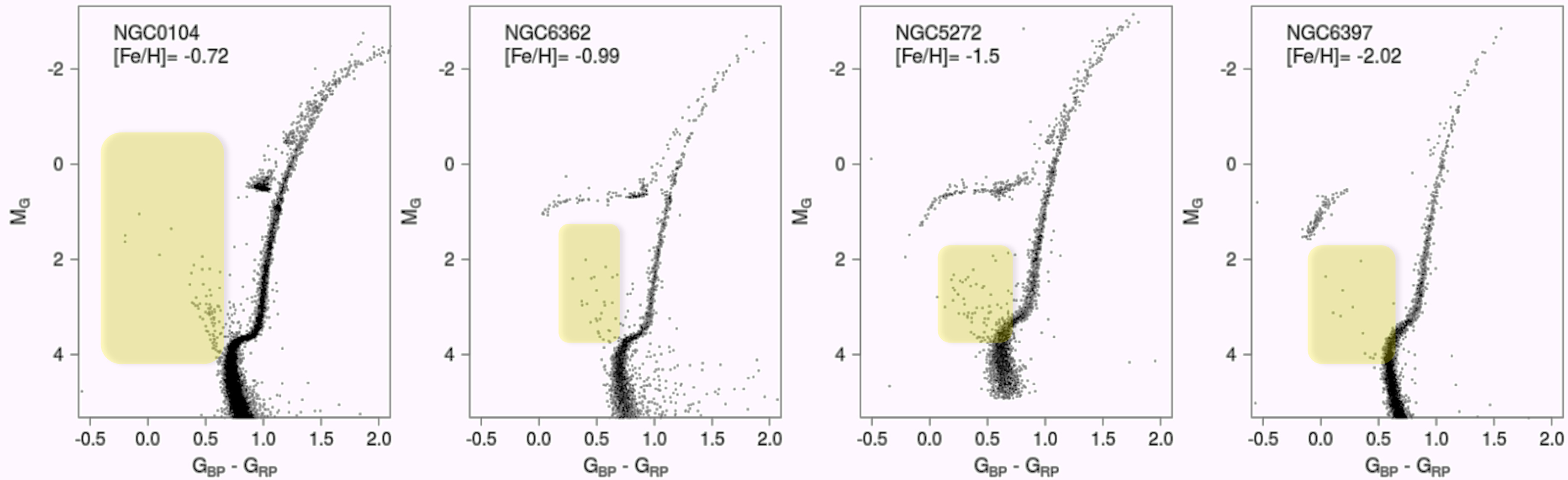
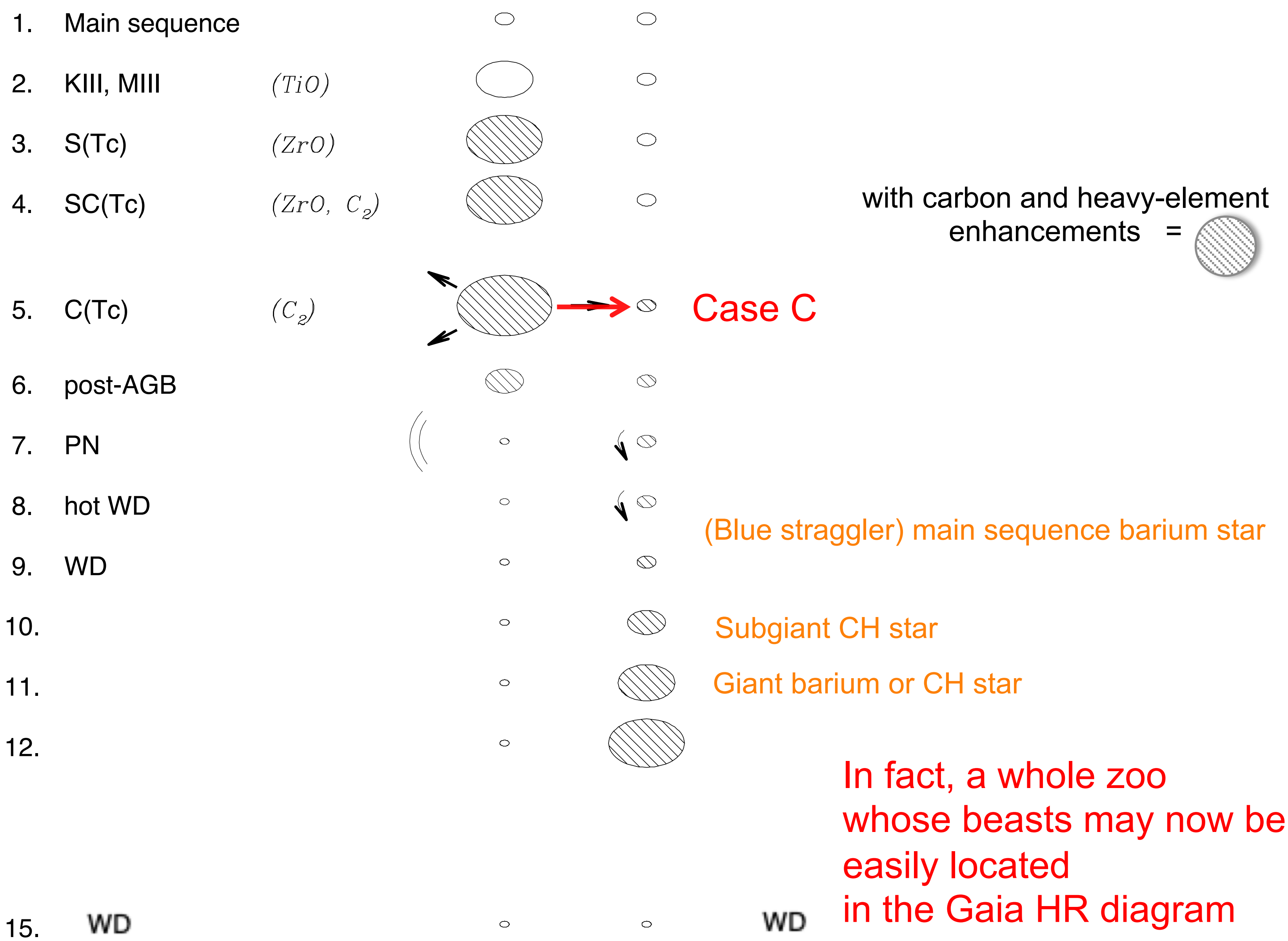


Fig. 11. Several globular clusters selected to show a clearly defined and very different horizontal branch, sorted by decreasing metallicity. *Panel a*: NGC 104 (47 Tuc), *panel b*: NGC 6362, *panel c*: NGC 5272, and *panel d*: NGC 6397.

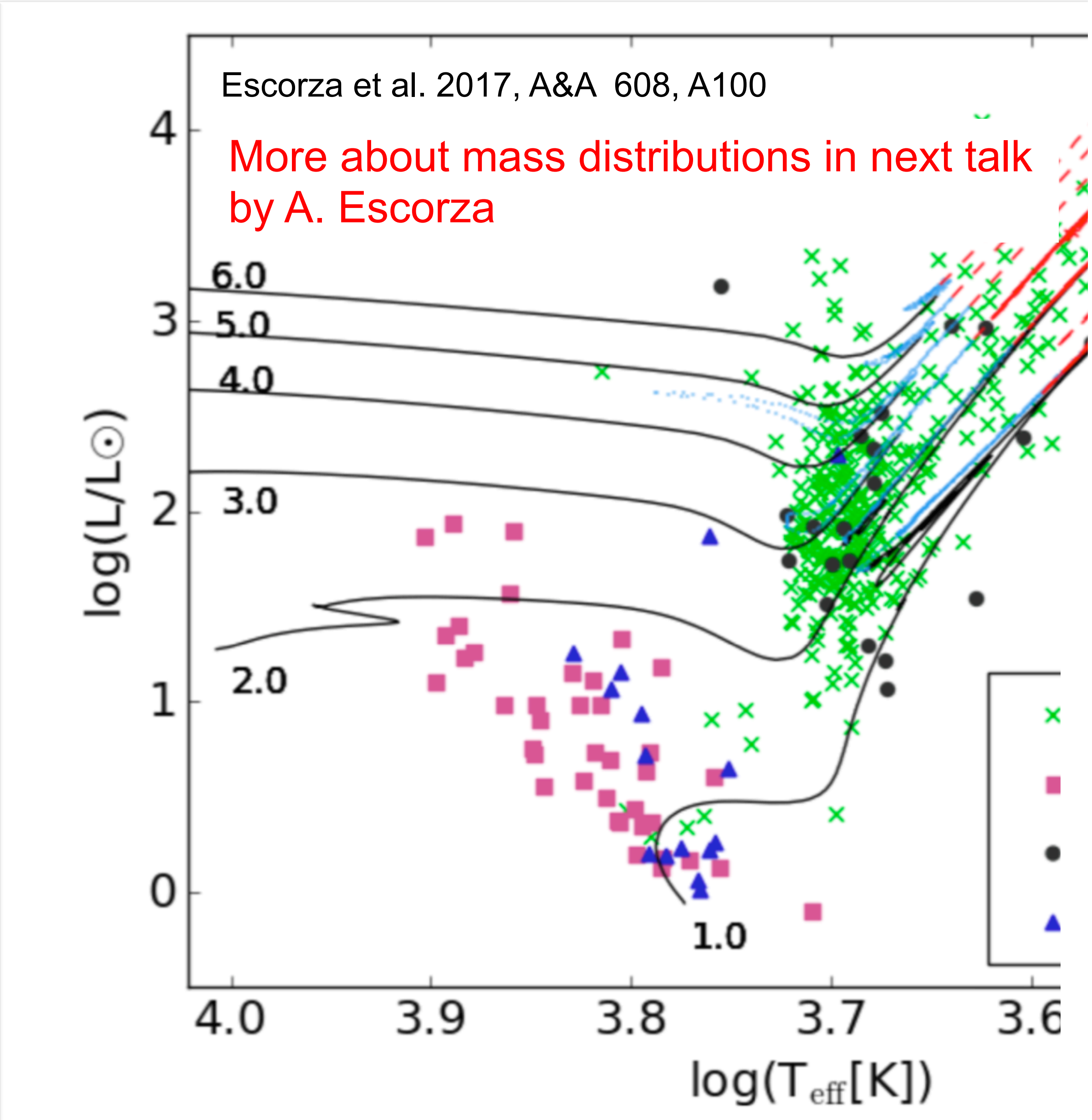
Gaia collaboration, Babusiaux et al. 2018, A&A 616, A10

Evolution of binary low- and intermediate-mass stars



In fact, a whole zoo whose beasts may now be easily located in the Gaia HR diagram

Locating the "barium-enhanced" zoo in the HR diagram



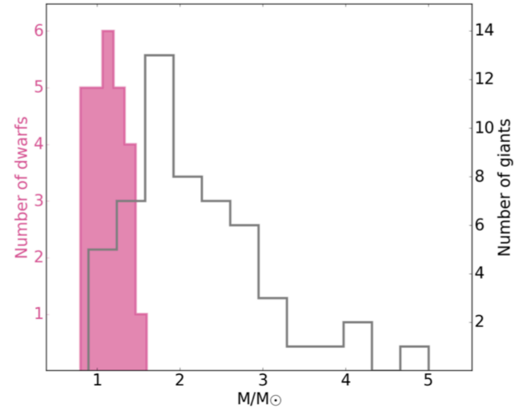
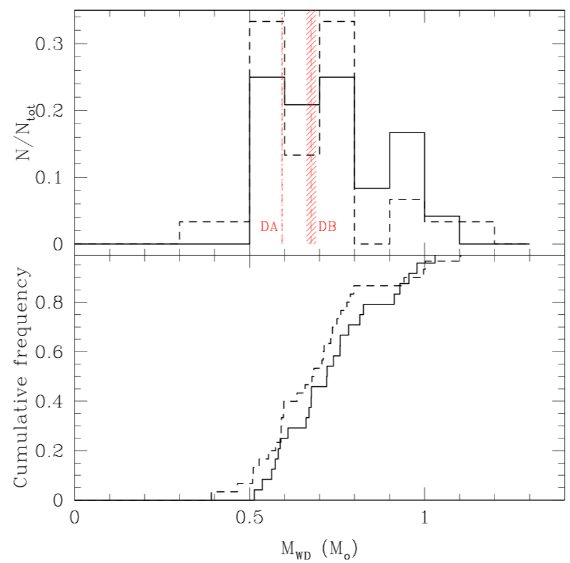


Fig. 10. Mass distribution of dwarf and subgiant Ba and CH stars (solid pink) and of Ba giants (grey) from Jorissen et al. (2019).

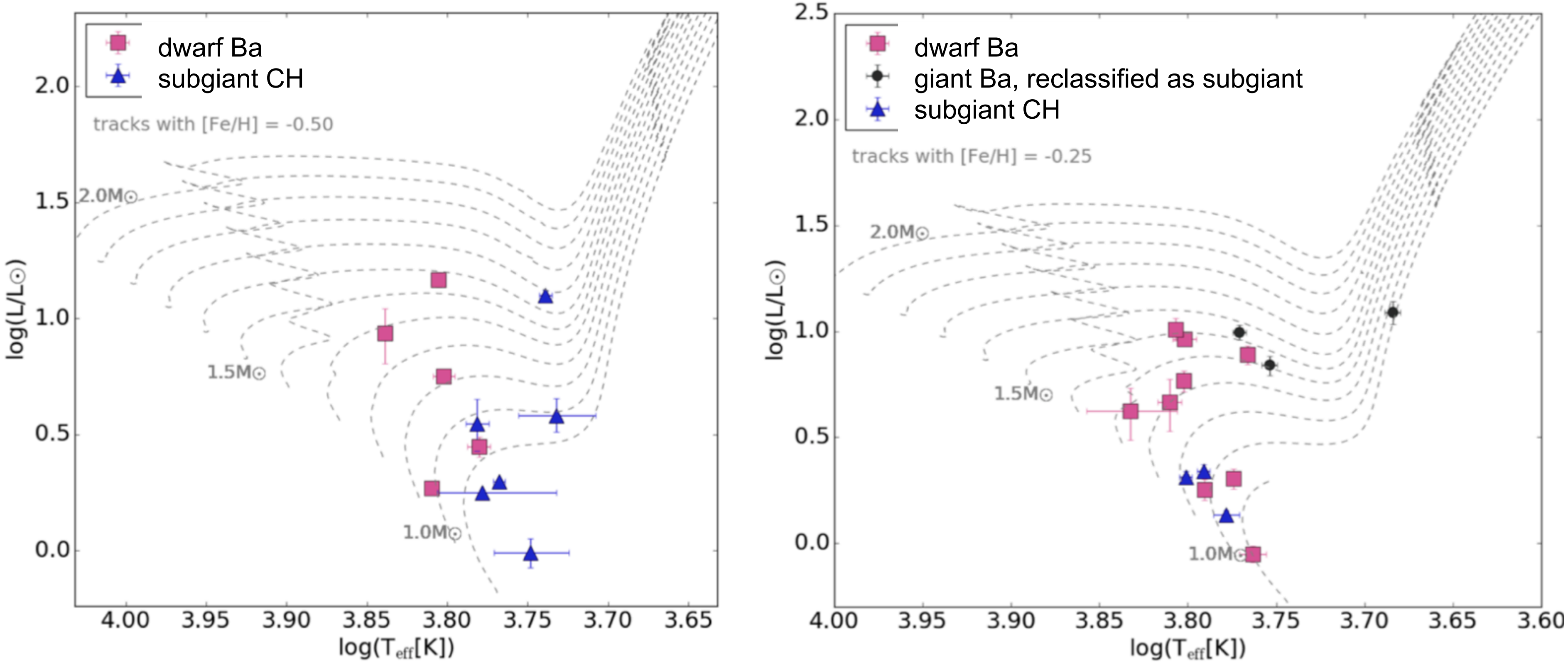
including WD masses !



Locating the "barium-enhanced" zoo in the HR diagram:

A zoom on dwarf and subgiants

Escorza et al. 2019, arXiv:1904.04095



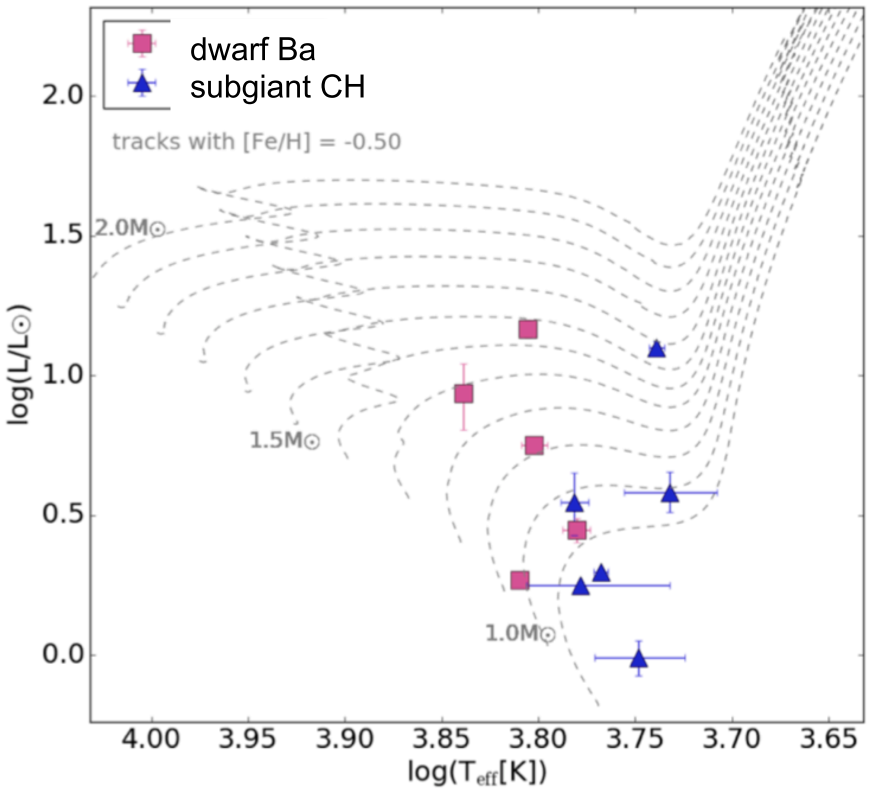
Different class names but same location in the HRD !

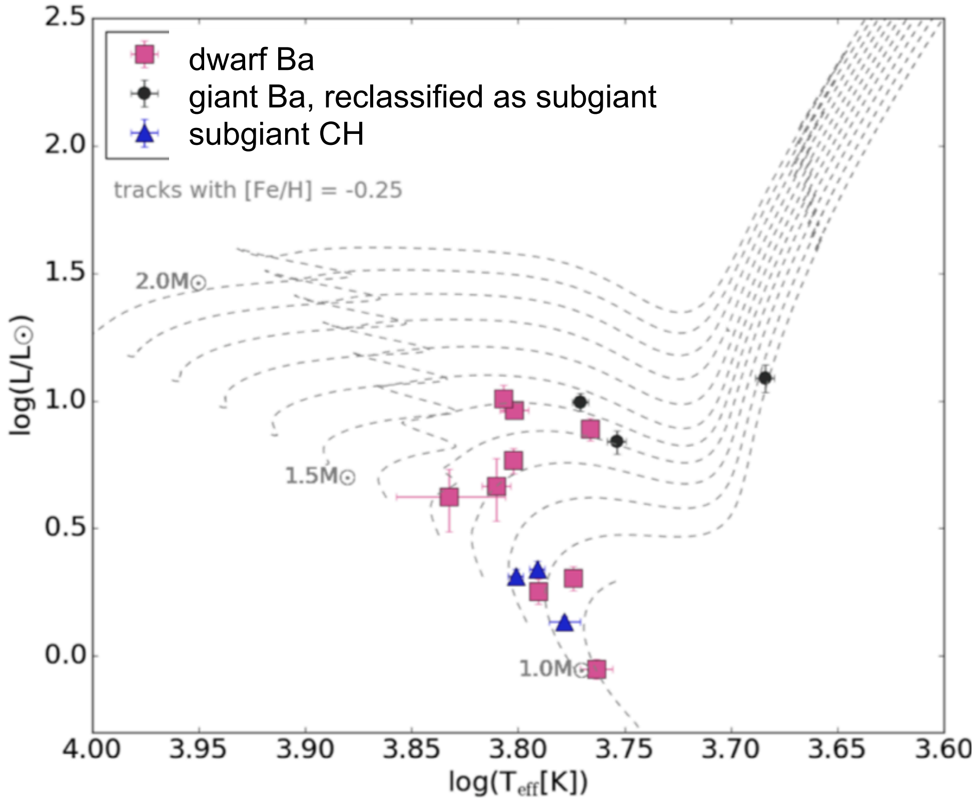
→ Necessity to re-classify the peculiar stars in a homogeneous manner, especially in view of the forthcoming/existing large surveys

Locating the "barium-enhanced" zoo in the HR diagram:

A zoom on dwarf and subgiants

Escorza et al. 2019, arXiv:1904.04095

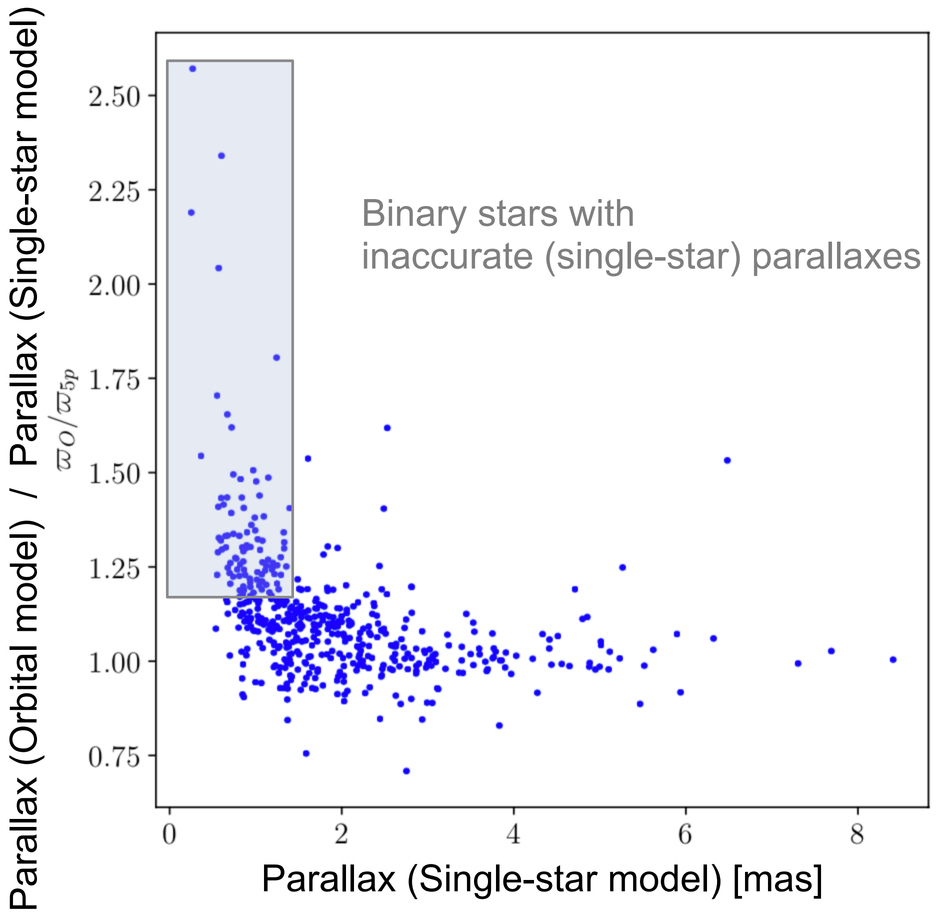




CAVEAT : Are the DR2 parallaxes of binary stars reliable ?

Comparing single-star parallaxes with binary-star parallaxes (pre-DR3)

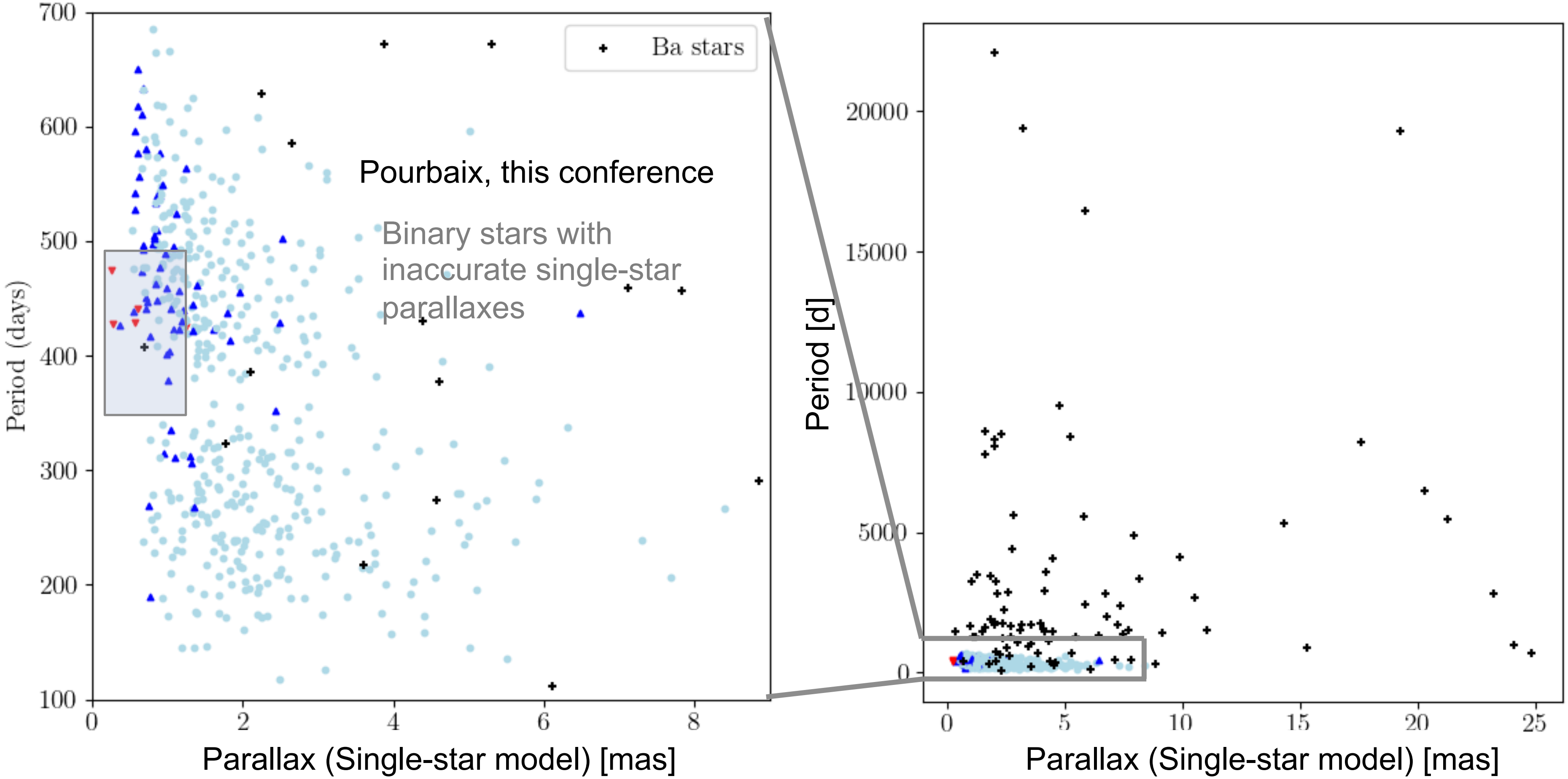
Pourbaix, this conference



CAVEAT : Some DR2 (single-star-model) parallaxes of binary stars may be unreliable!

Locating the "barium-enhanced" zoo in the HR diagram:

CAVEAT : where are the inaccurate parallaxes located ?



Escorza et al. 2019, arXiv:1904.04095

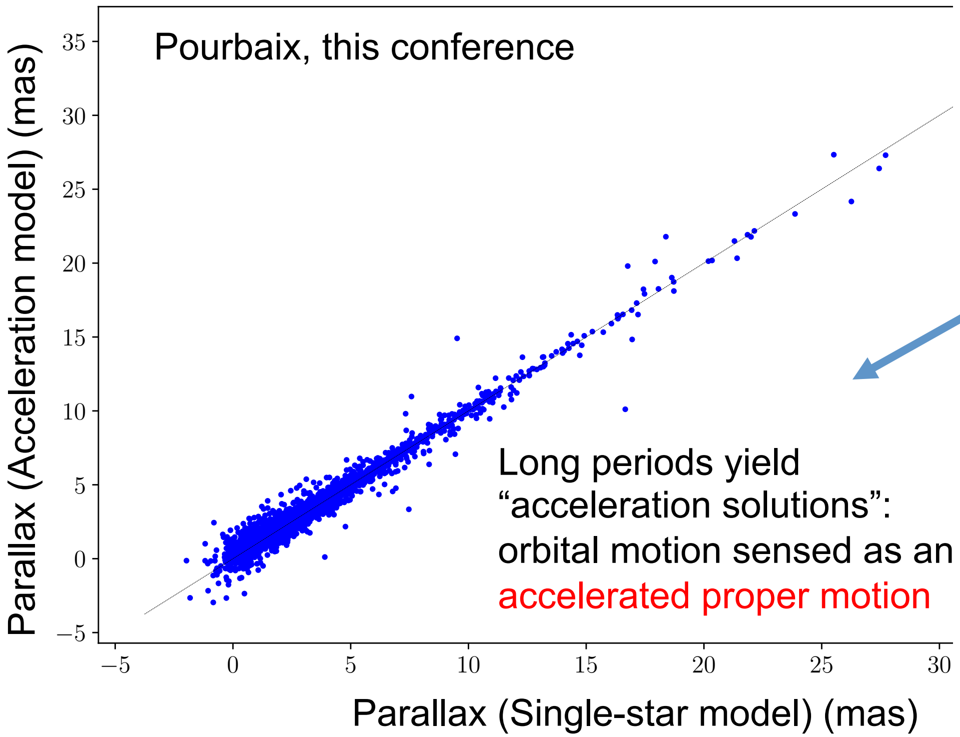
Parallax (Orbital model) / Parallax (Single-star model) < 1.25
1.25 <= Parallax (Orbital model) / Parallax (Single-star model) < 1.75
1.75 <= Parallax (Orbital model) / Parallax (Single-star model)

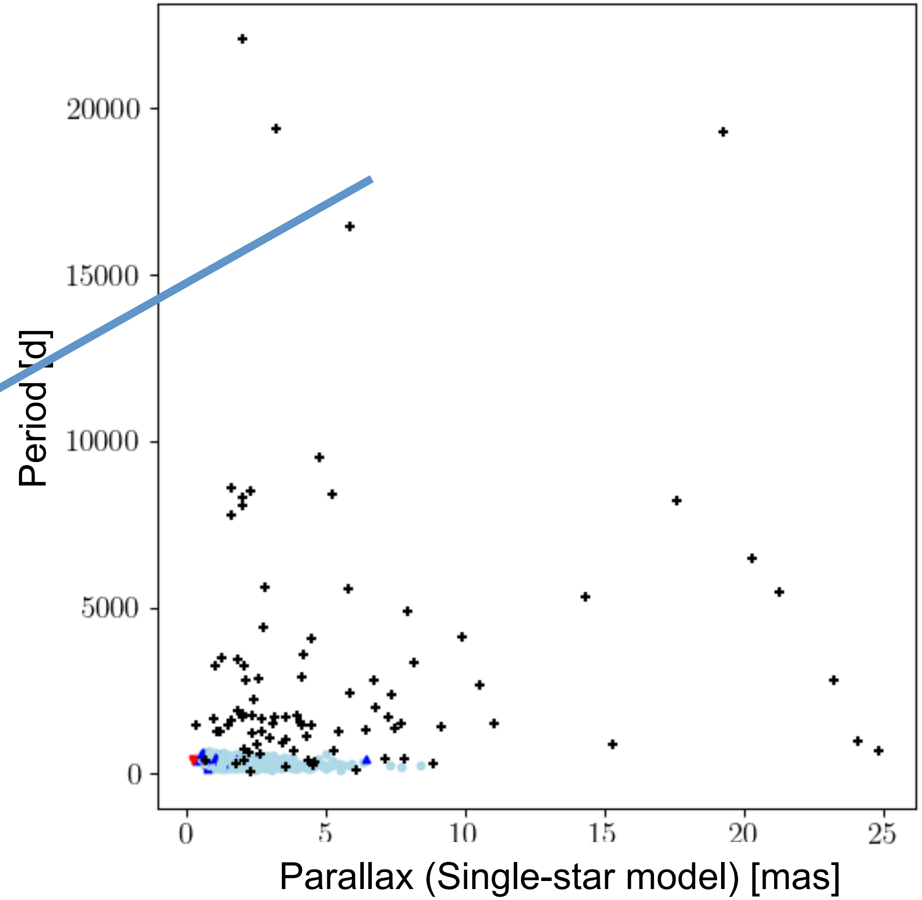
Black dots = Barium stars

NO THREAT !

Locating the "barium-enhanced" zoo in the HR diagram:

CAVEAT : Are the DR2 parallaxes of binary stars reliable ?

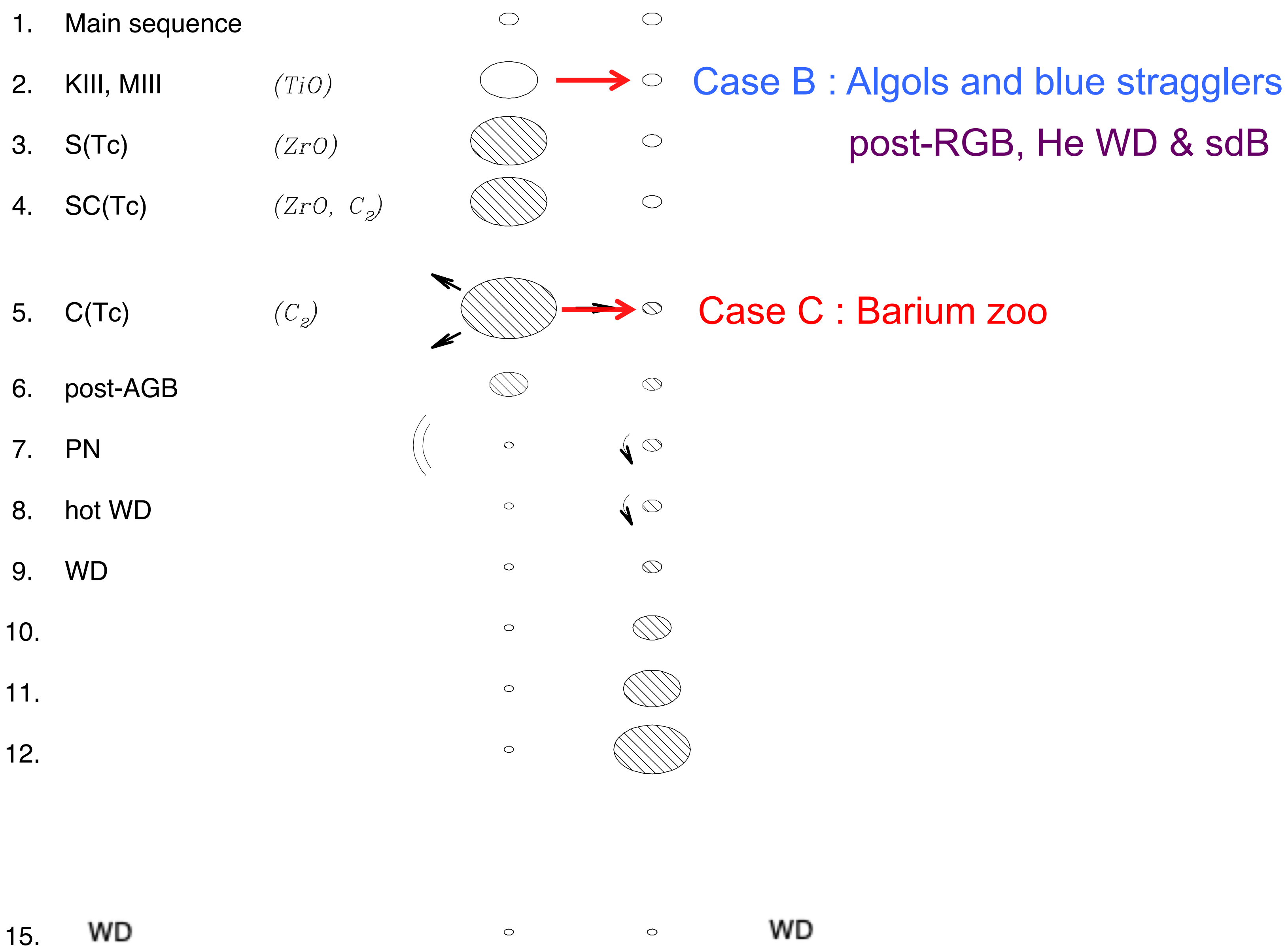




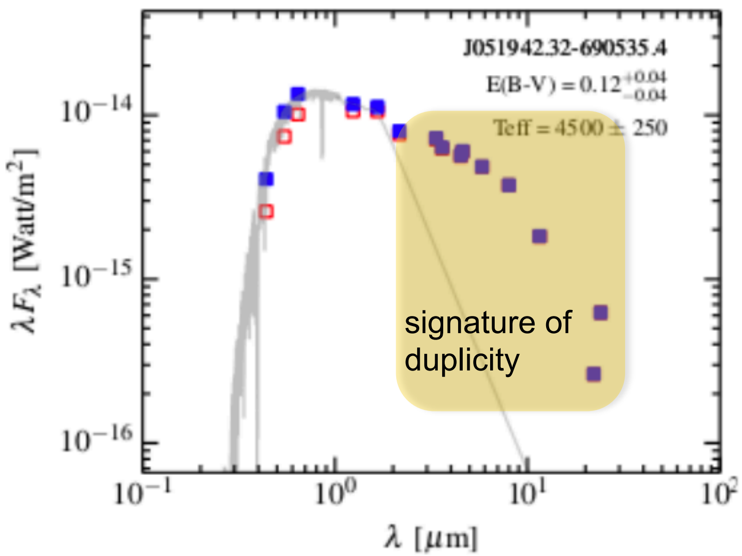
Escorza et al. 2019, arXiv:1904.04095

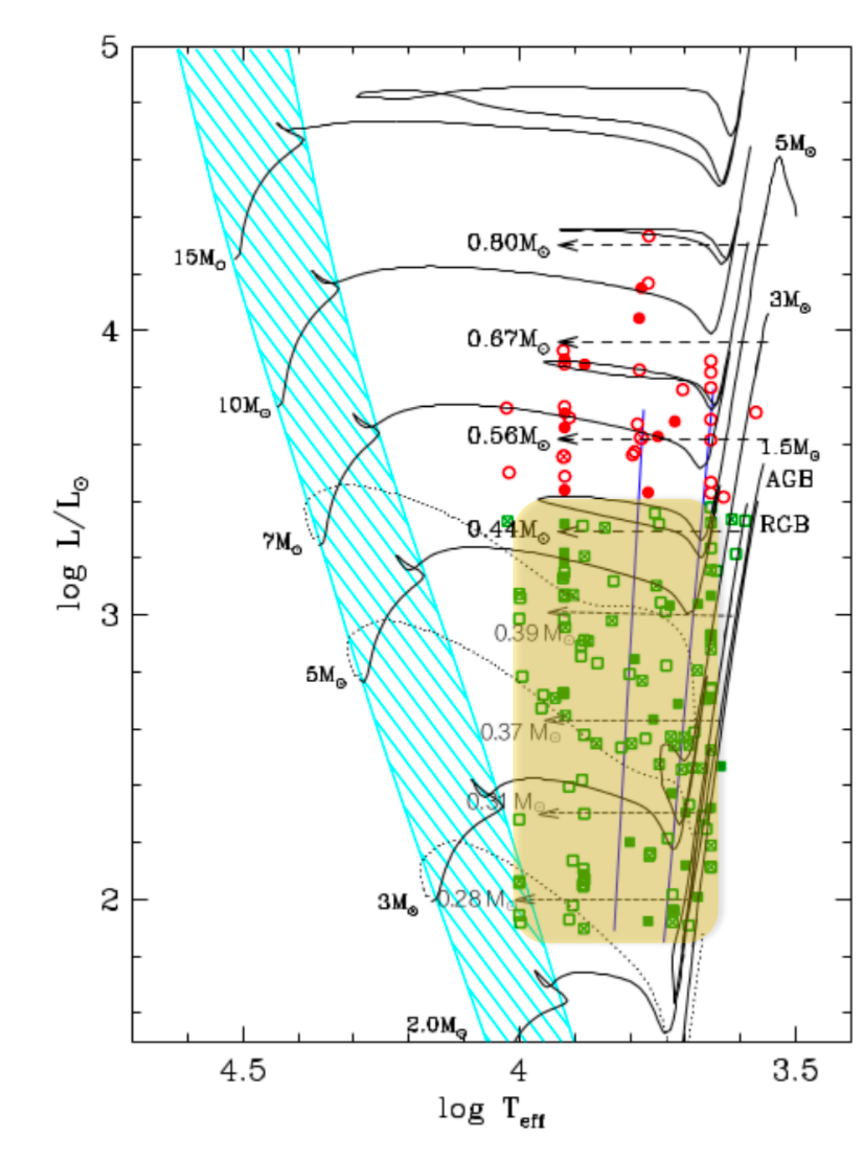
Black dots = Barium stars

Evolution of binary low- and intermediate-mass stars



Evolution of binary low- and intermediate-mass stars: Post-RGB stars in the LMC





Kamath et al., 2015, MNRAS 454, 1468

Evolution of binary low- and intermediate-mass stars:

He WDs

One prototypical case: IP Eri (see Merle et al. 2014 A&A 567, A30)

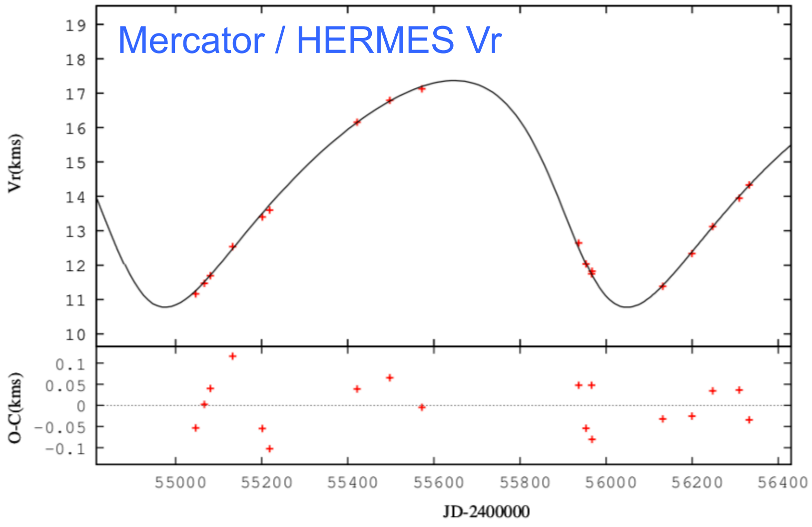
EUV source by ROSAT and EUVE satellites

T_{eff} = 29 290 K , log g = 7.5 ⟶ M = 0.43 $M_{\odot}$ ⟶ He WD

subgiant K0 companion in a long-period, eccentric orbit P = 1071 d , e = 0.25

Very difficult to produce from standard binary evolution models

because RLOF forbidden
(predicts short P and e = 0 !)



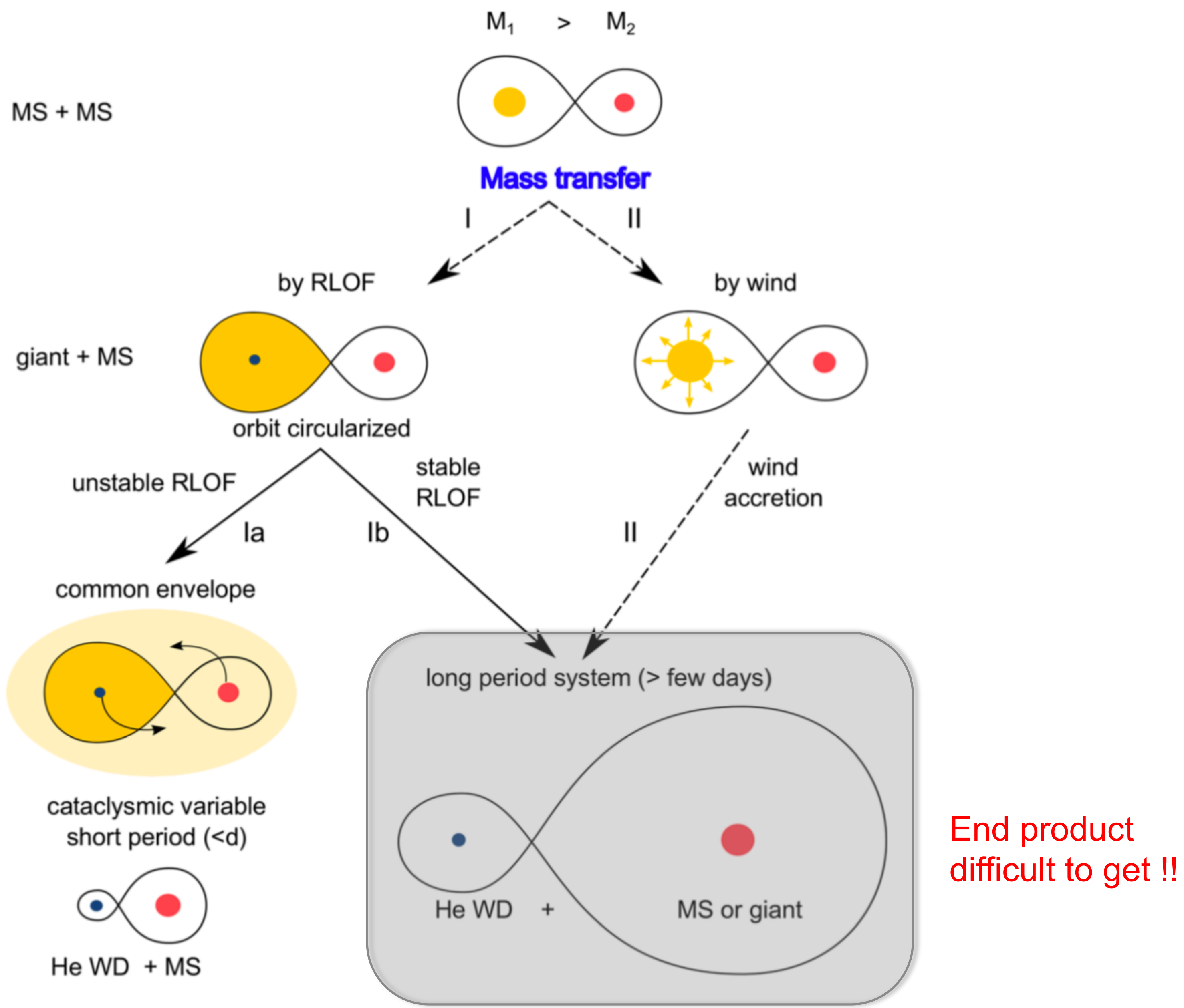


Fig. 9. Evolutionary channels for the formation of a He WD. The dashed lines refer to channels where the eccentricity can be preserved (see text for details).

Siess et al. 2014, A&A 565, A57

Evolution of binary low- and intermediate-mass stars:

He WDs and their sdB analogs

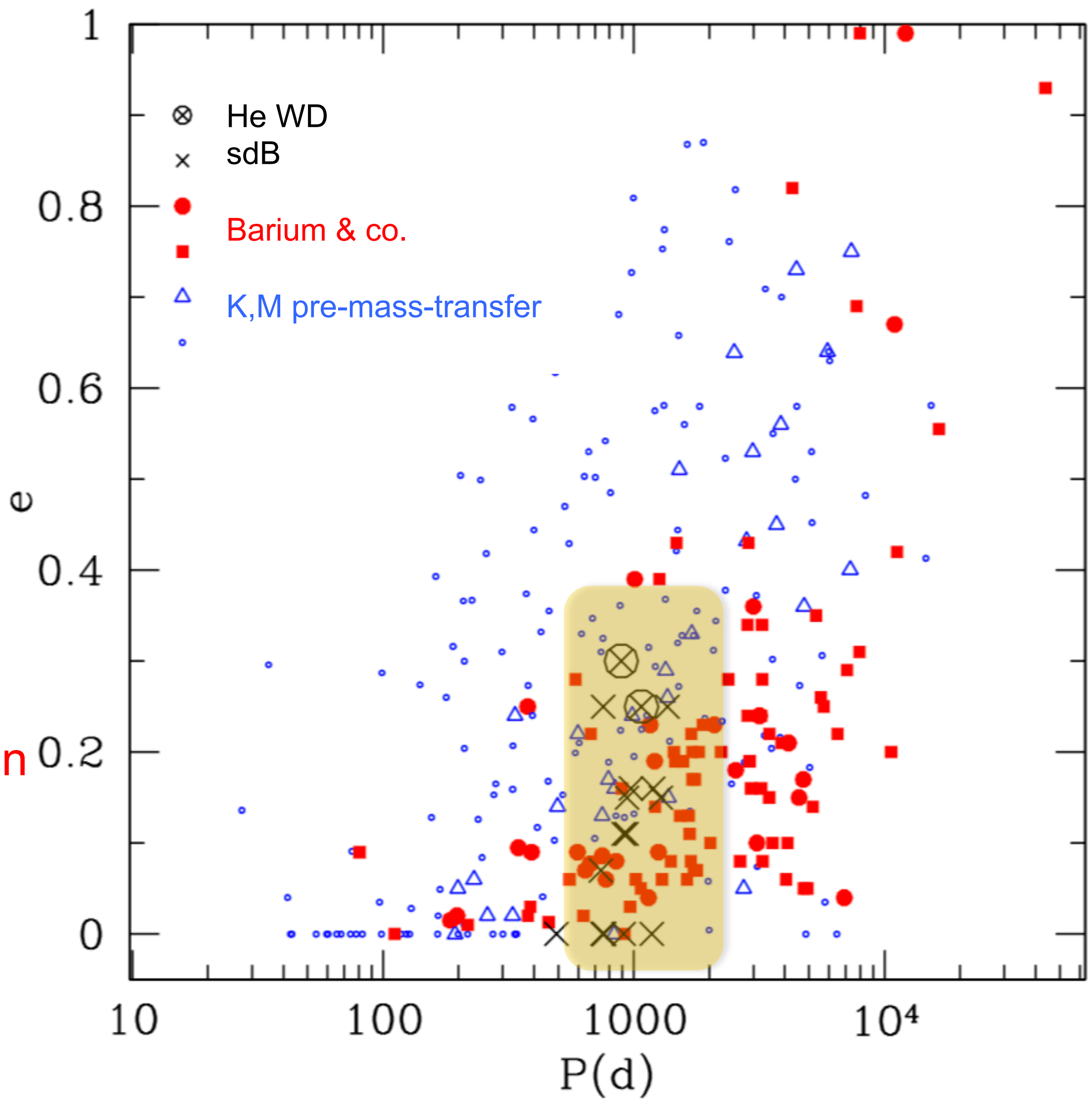
IP Eri is representative of
sdB e – P values

Hence similar binary evolution channels ?

except

sdB = core He-burning with
thin H envelope

He WD = never reached He ignition



Vos et al., 2017, A&A 605, A109
Merle et al. 2014 A&A 567, A30

Evolution of binary low- and intermediate-mass stars:

The case of IP Eri (sg K0 + He WD)

THE SOLUTION :

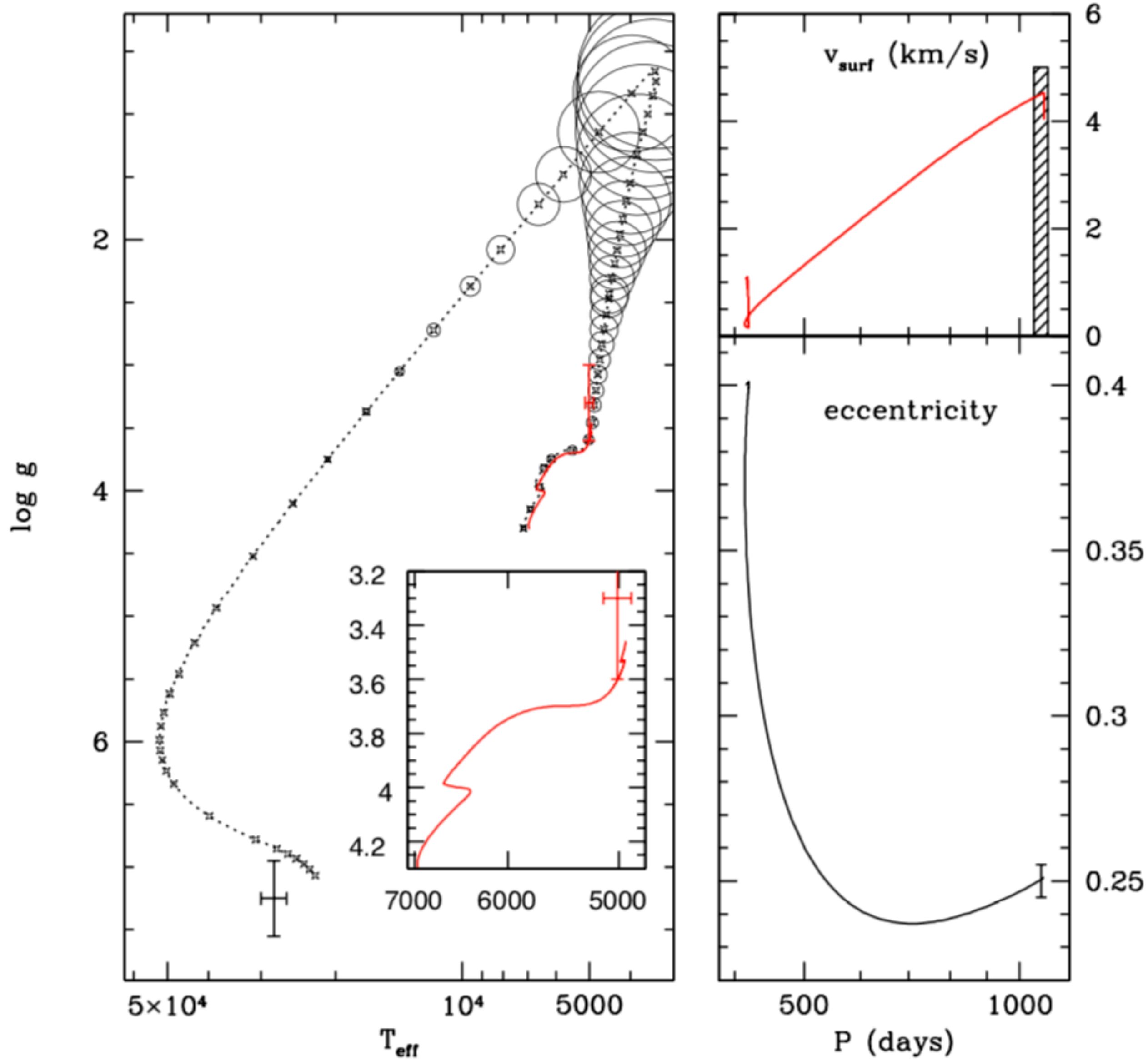
Initial conditions:

1.5 + 1.45 M_o !

P = 415 d
e = 0.4

+

tidally-enhanced wind



Siess et al. 2014, A&A 565, A57

UNIVERSITÉ LIBRE DE BRUXELLES

IMPACT OF BINARIES ON STELLAR EVOLUTION :

SUBSTANTIAL PROGRESS IN OUR UNDERSTANDING!

- **Algols & blue stragglers :**
  - non conservative mass transfer
- **Barium (g, d & sgCH) :**
  - clarification needed in classification
- **Post-RGB, He WDs & sdB :**
  - found possible evolutionary channel even for long P, large e systems