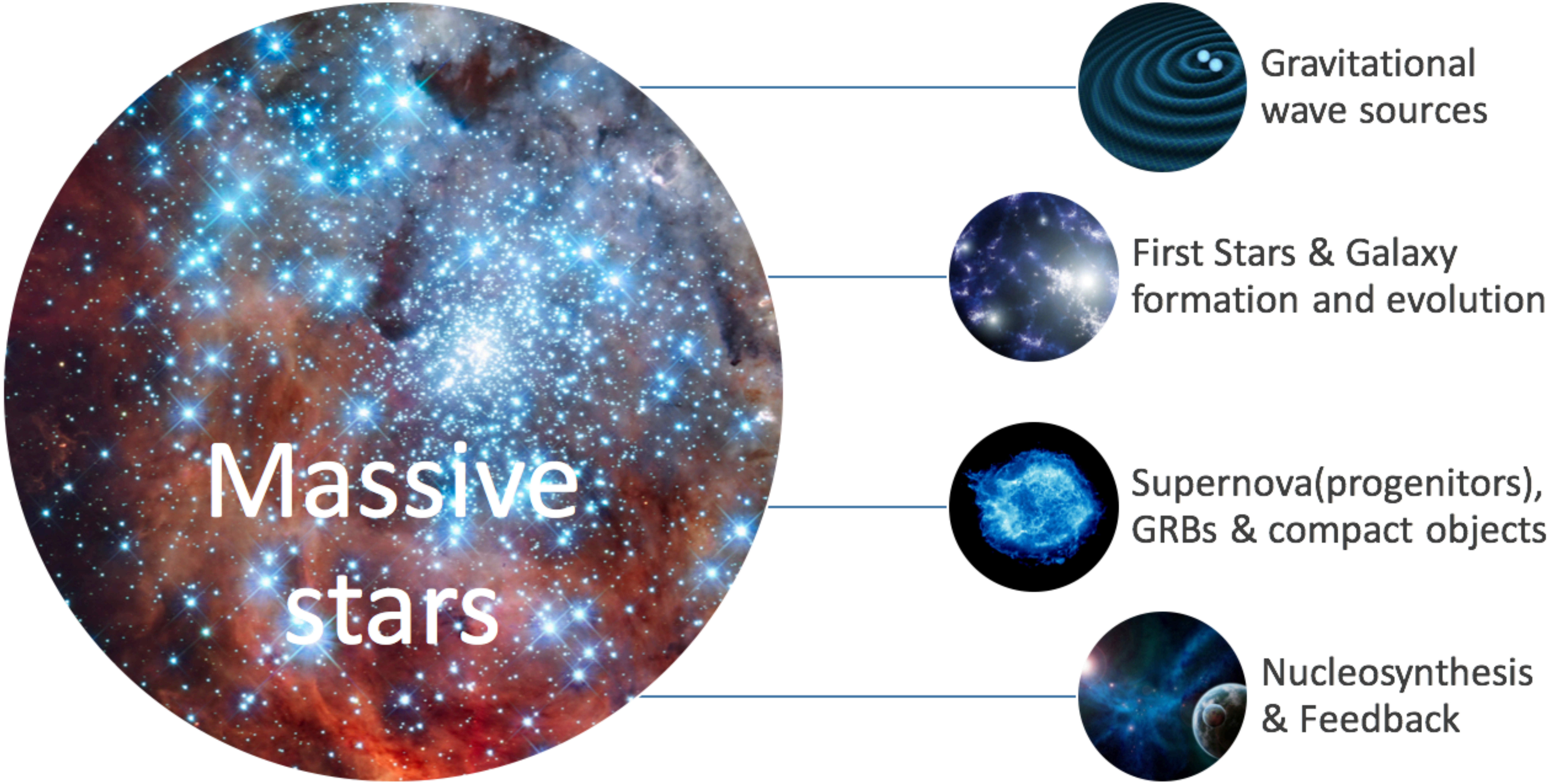
Massive binaries in the Gaia era

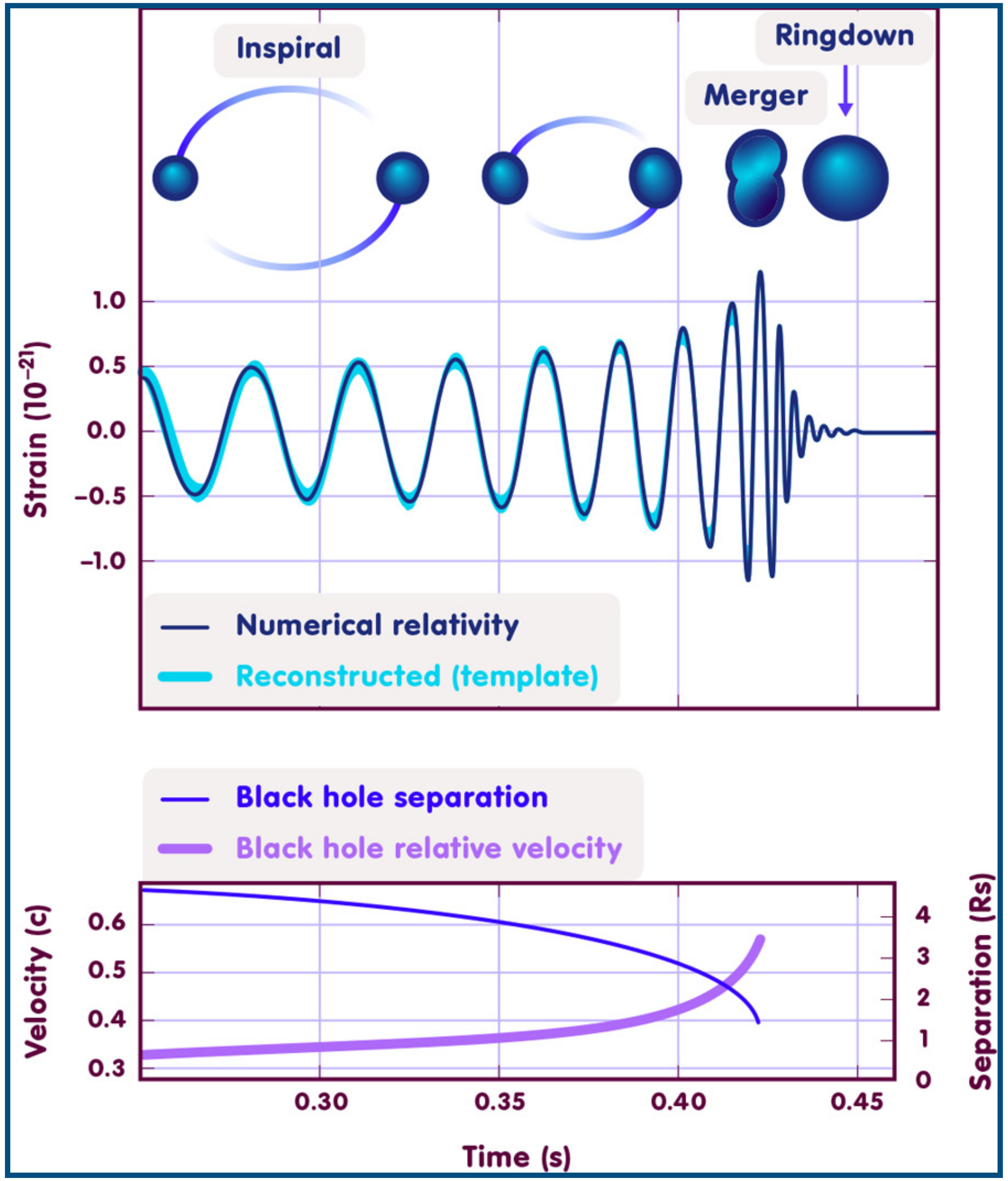
Laurent Mahy
Royal Observatory of Belgium

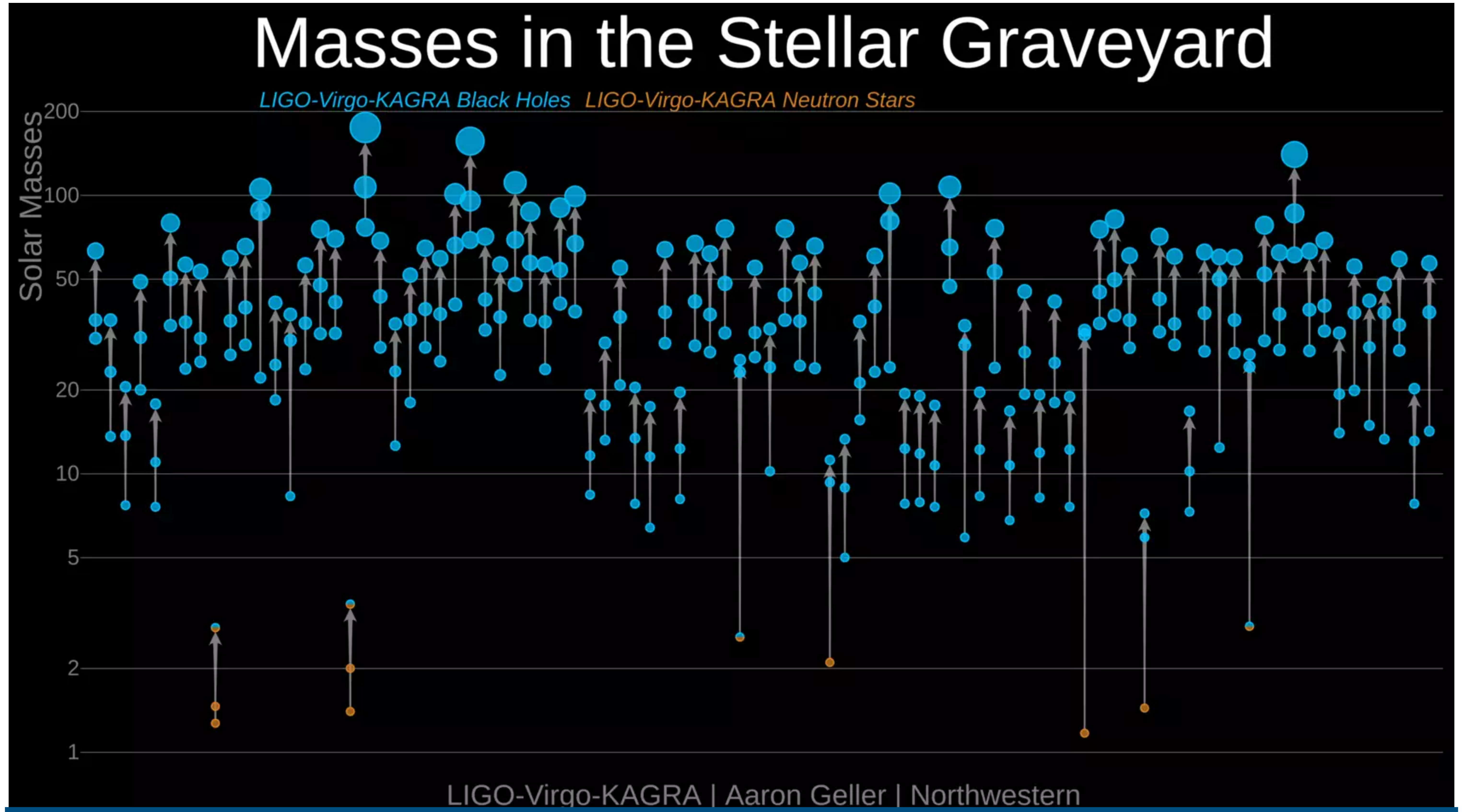
Stellar variability, stellar multiplicity: periodicity in time & motion - June 6-8th, Sofia, Bulgaria

Massive stars



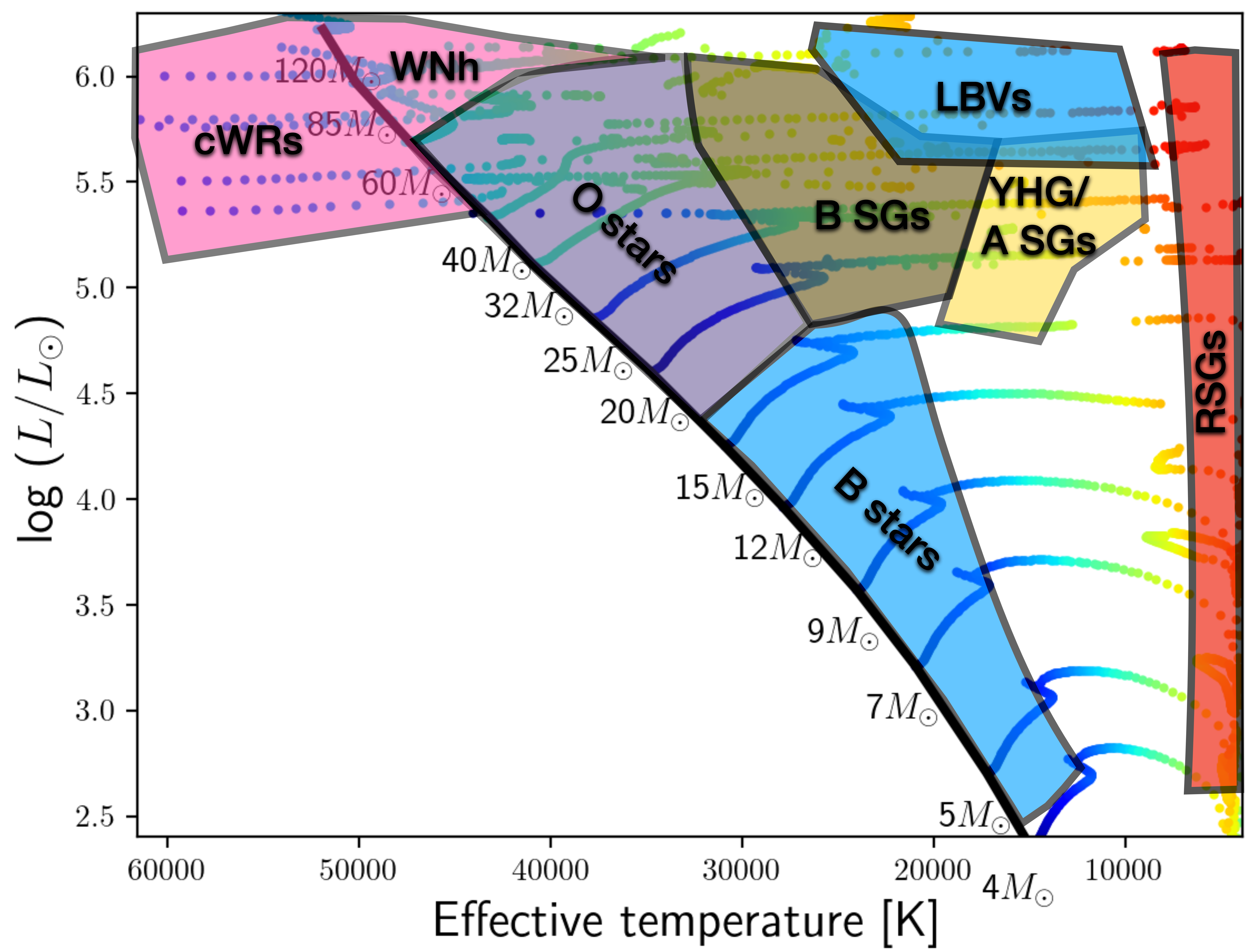
Massive stars





Multiplicity through the HRD

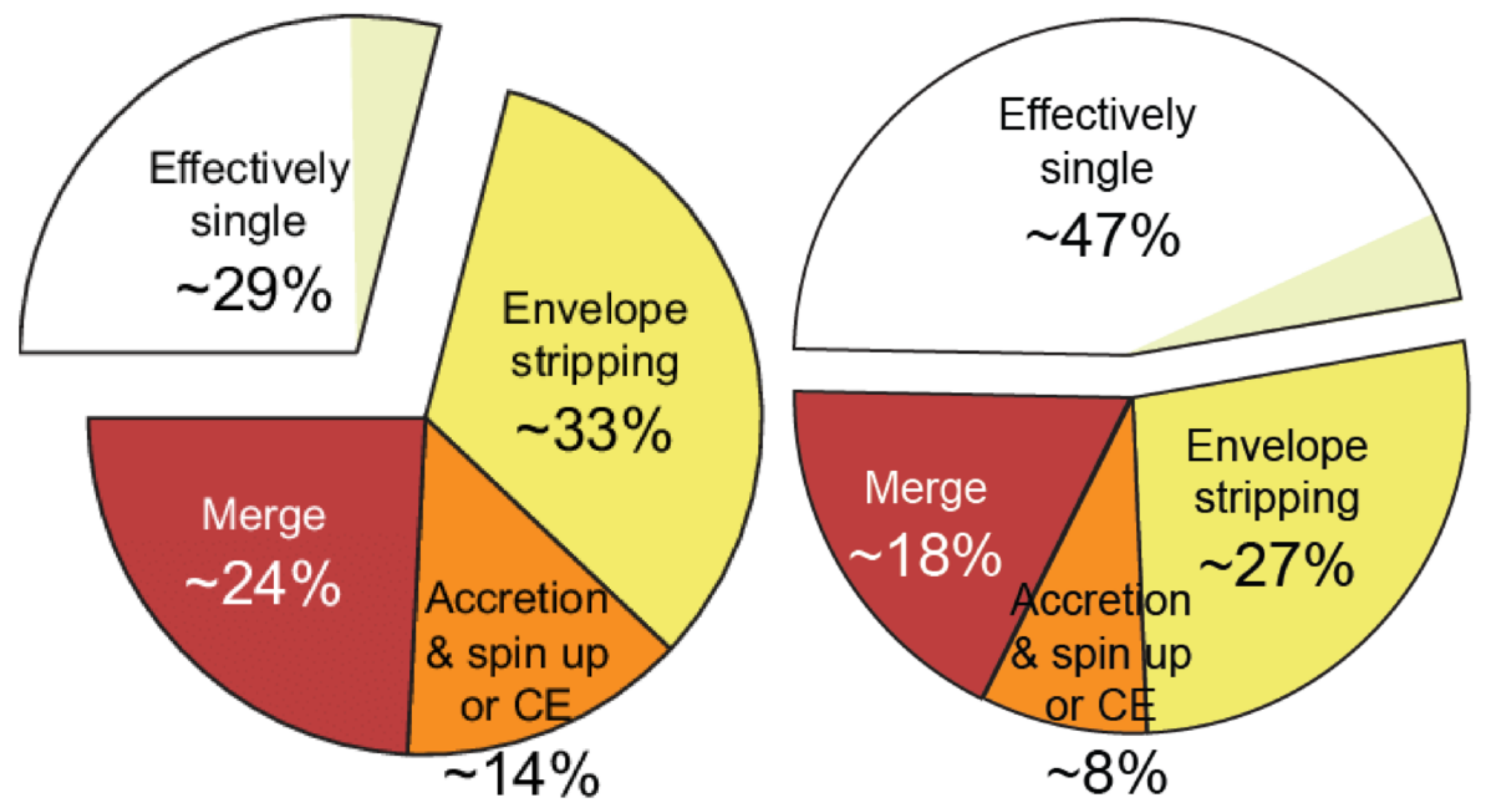
- Massive stars: M_{ini} > 8 $M_{\odot}$
- Spectral types O and early B → Teff > 20,000K
- Very luminous → L > $10^3 L_{\odot}$



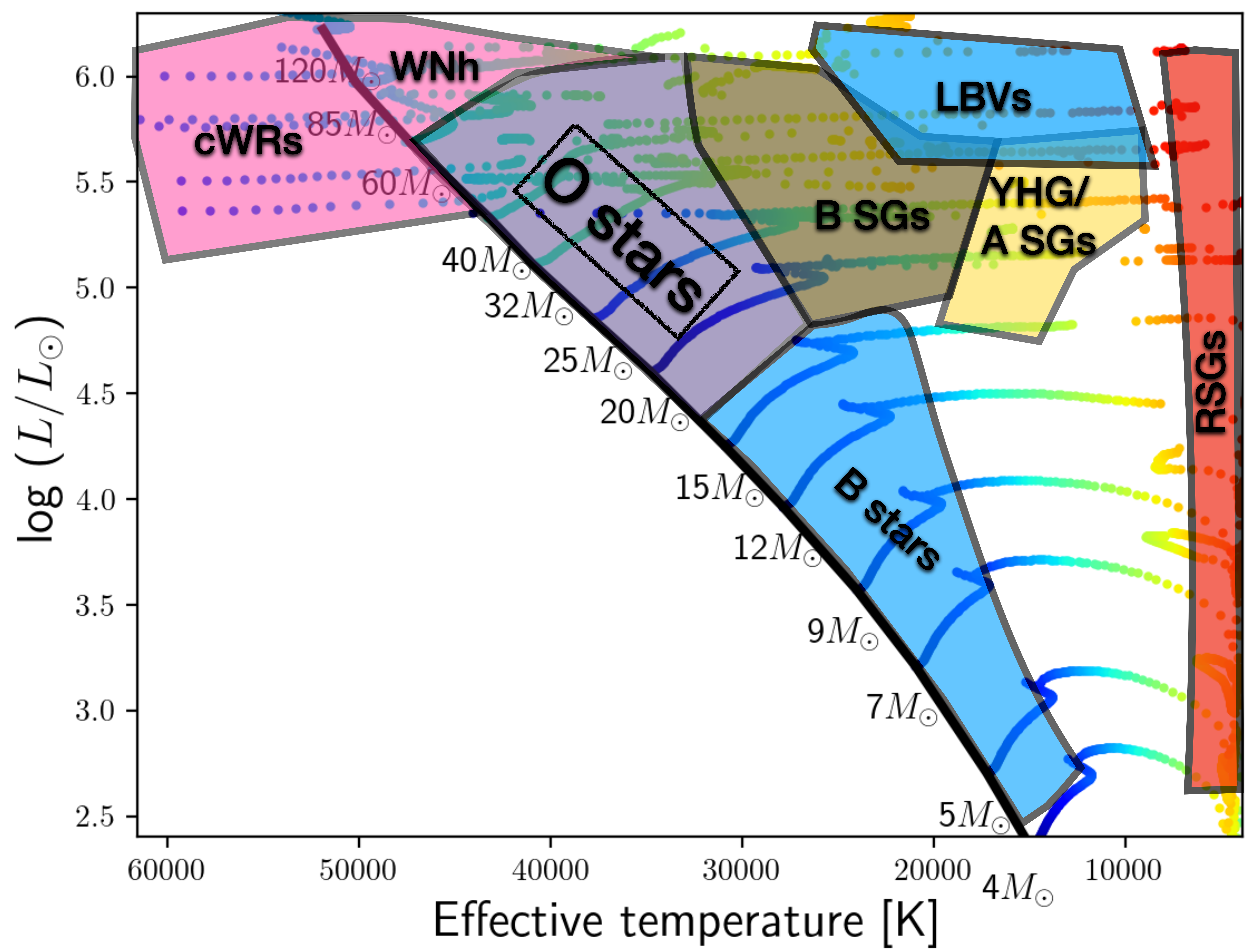
Multiplicity through the HRD

O Stars:

- **70-90%** of O-type stars are in binary or multiple systems in the MW (e.g., Sana et al. 2012; 2014; Vanbeveren et al. 1998, Barba et al 2017)
- **~50 %** in the LMC (Sana et al. 2013)



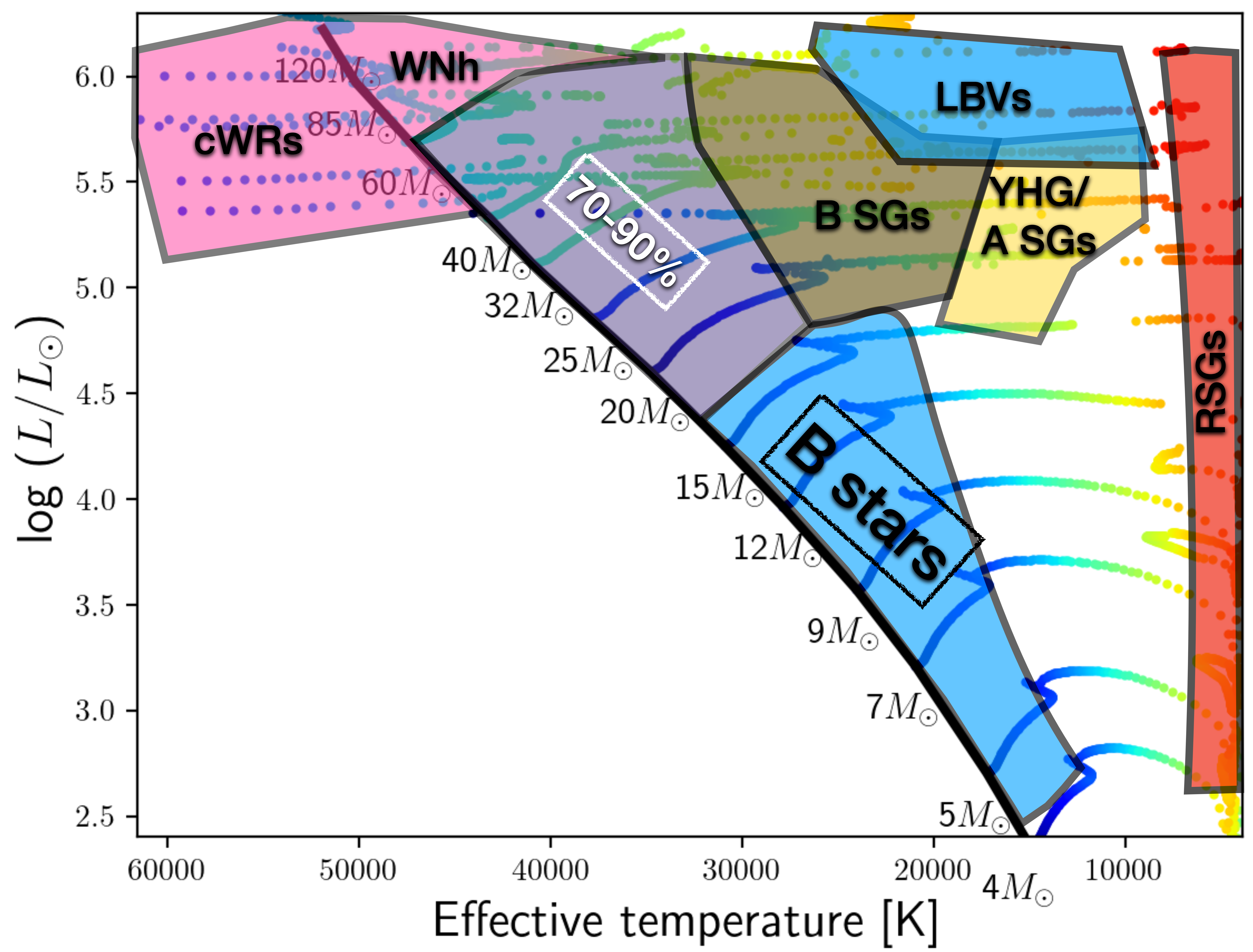
Crowther et al. (2019) adapted from Sana et al. (2012, 2013)



Multiplicity through the HRD

B Stars:

- **~55%** of B-type stars in young clusters are in binary or multiple systems (e.g., Dunstall et al. 2015, Banyard et al. 2022)



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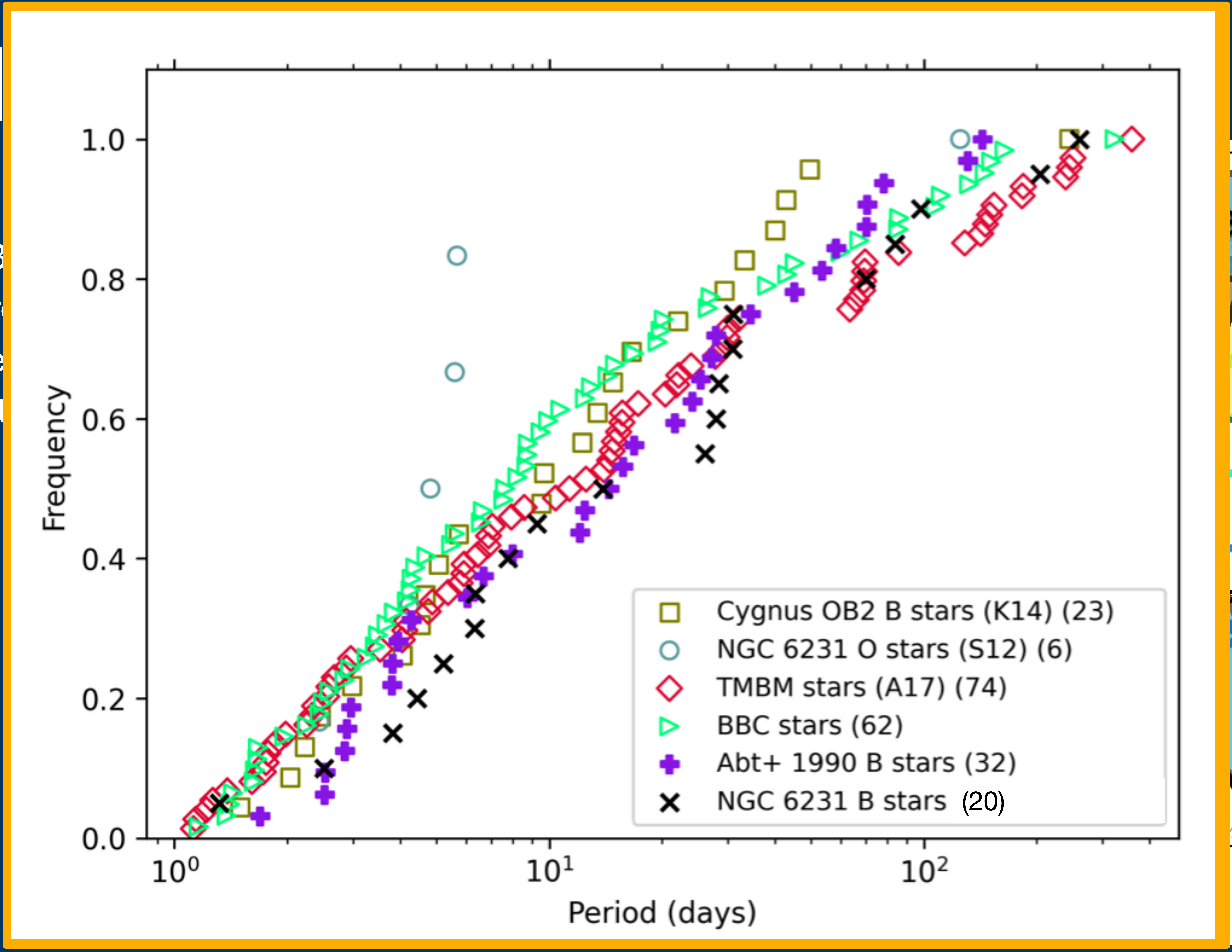
B Stars:

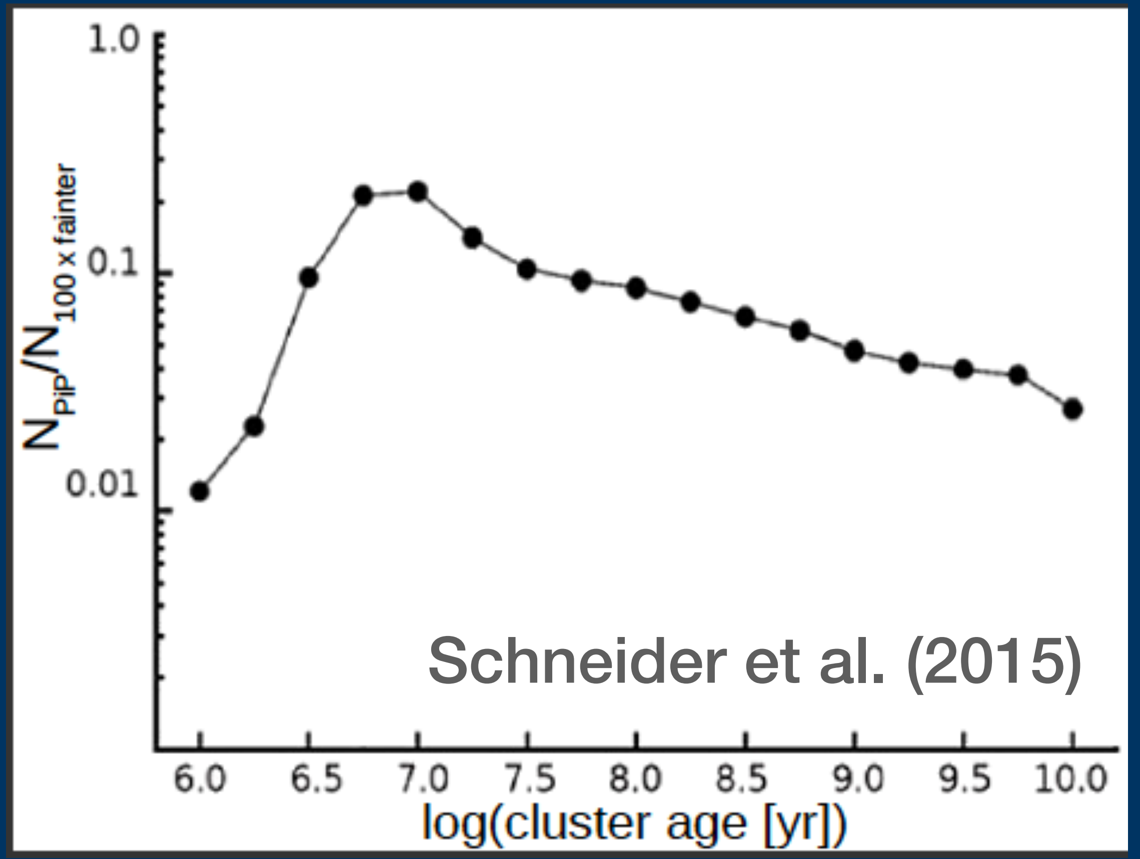
- **~55%** of B
  clusters ar
  systems (e
  Banyard et

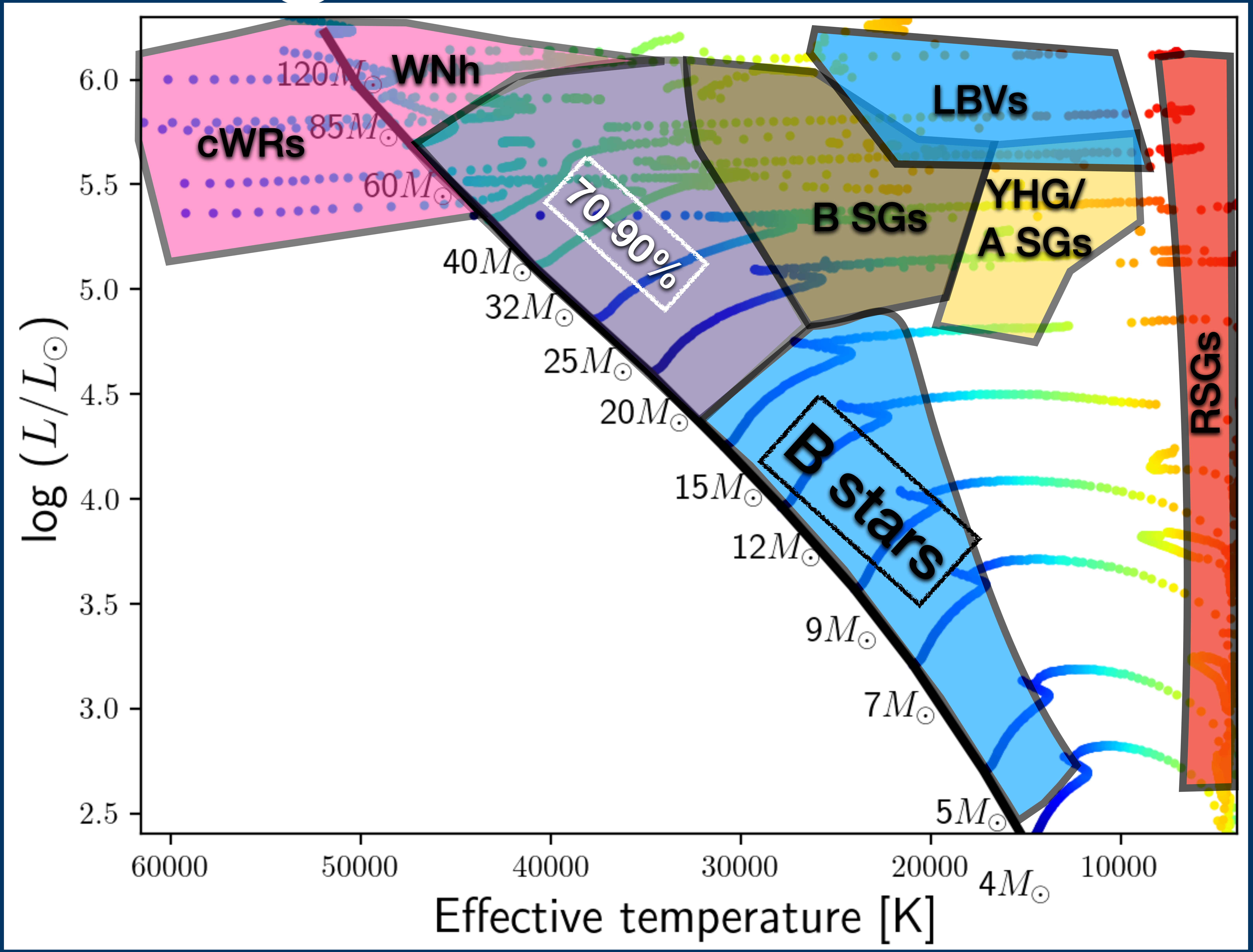


Multiplicity through the HRD

B Stars:

- **~55%** of B-type stars in young clusters are in binary or multiple systems (e.g., Dunstall et al. 2015, Banyard et al. 2022)
- **~35%** of B-type stars in older clusters are found in binary systems (Bodensteiner et al. 2021, Wang et al. 2022)

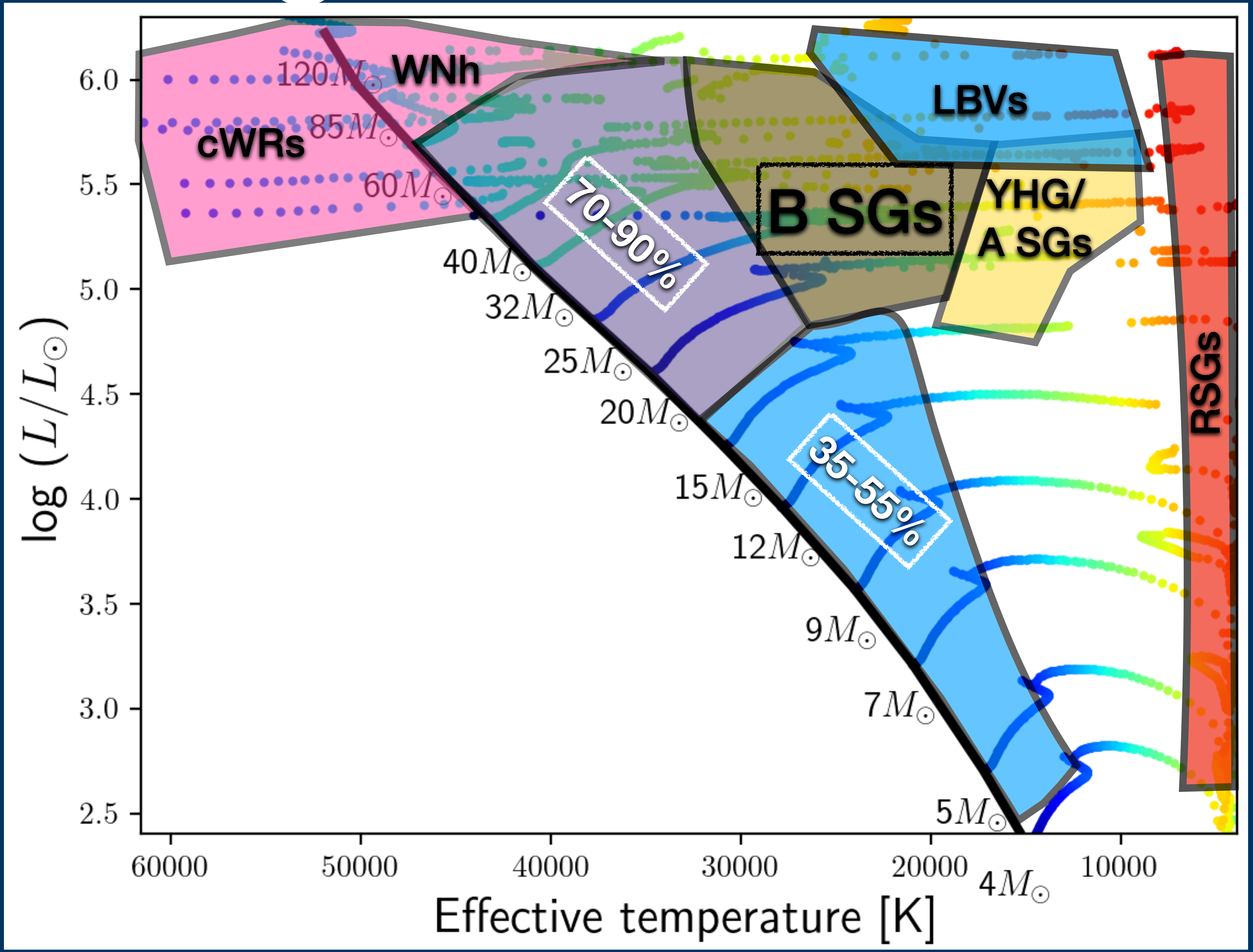




Multiplicity through the HRD

B Supergiants:

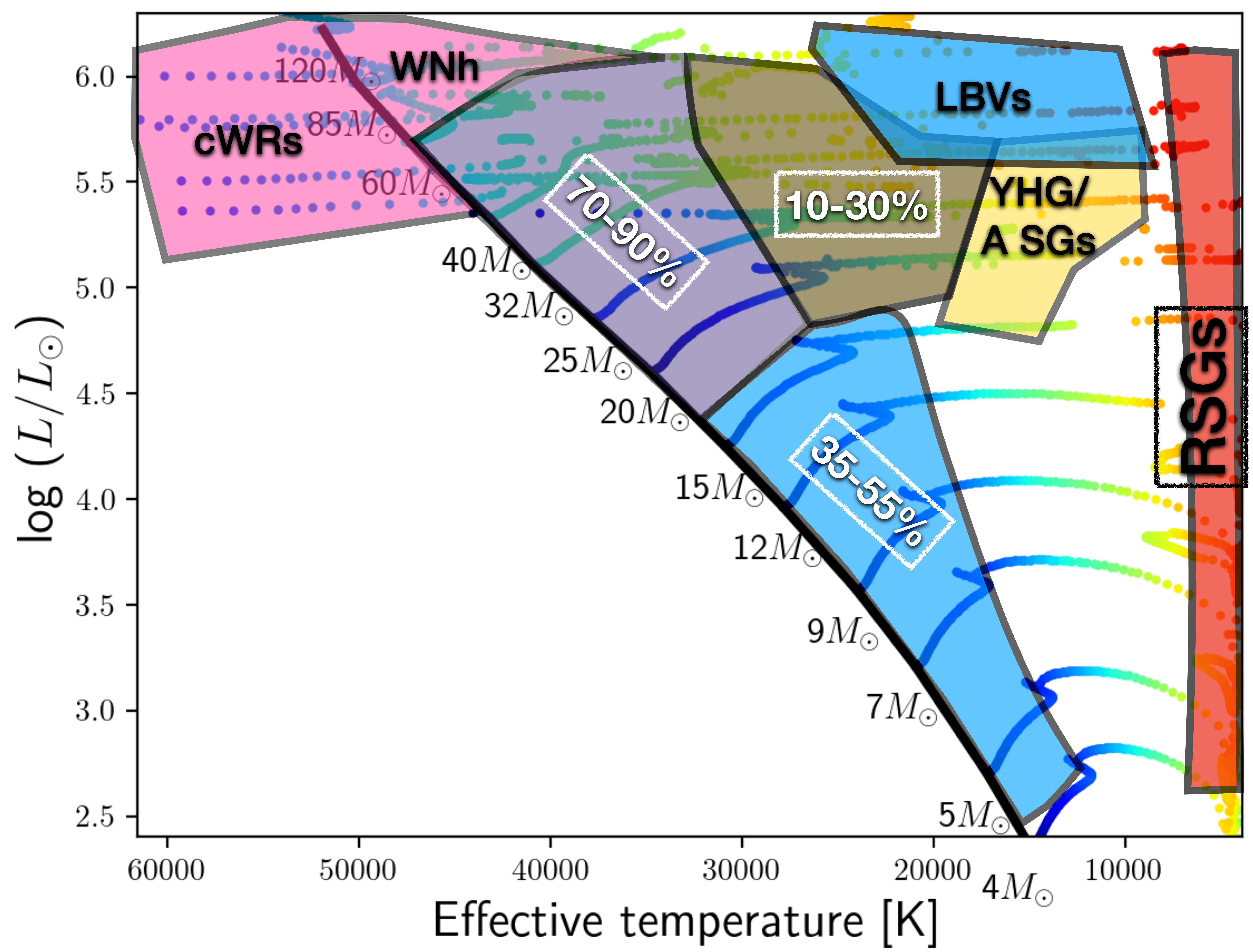
- **10-30%** of B-supergiants are in binary systems (Simon-Diaz, priv. communication; Dunstall et al. 2015)



Multiplicity through the HRD

Red Supergiants:

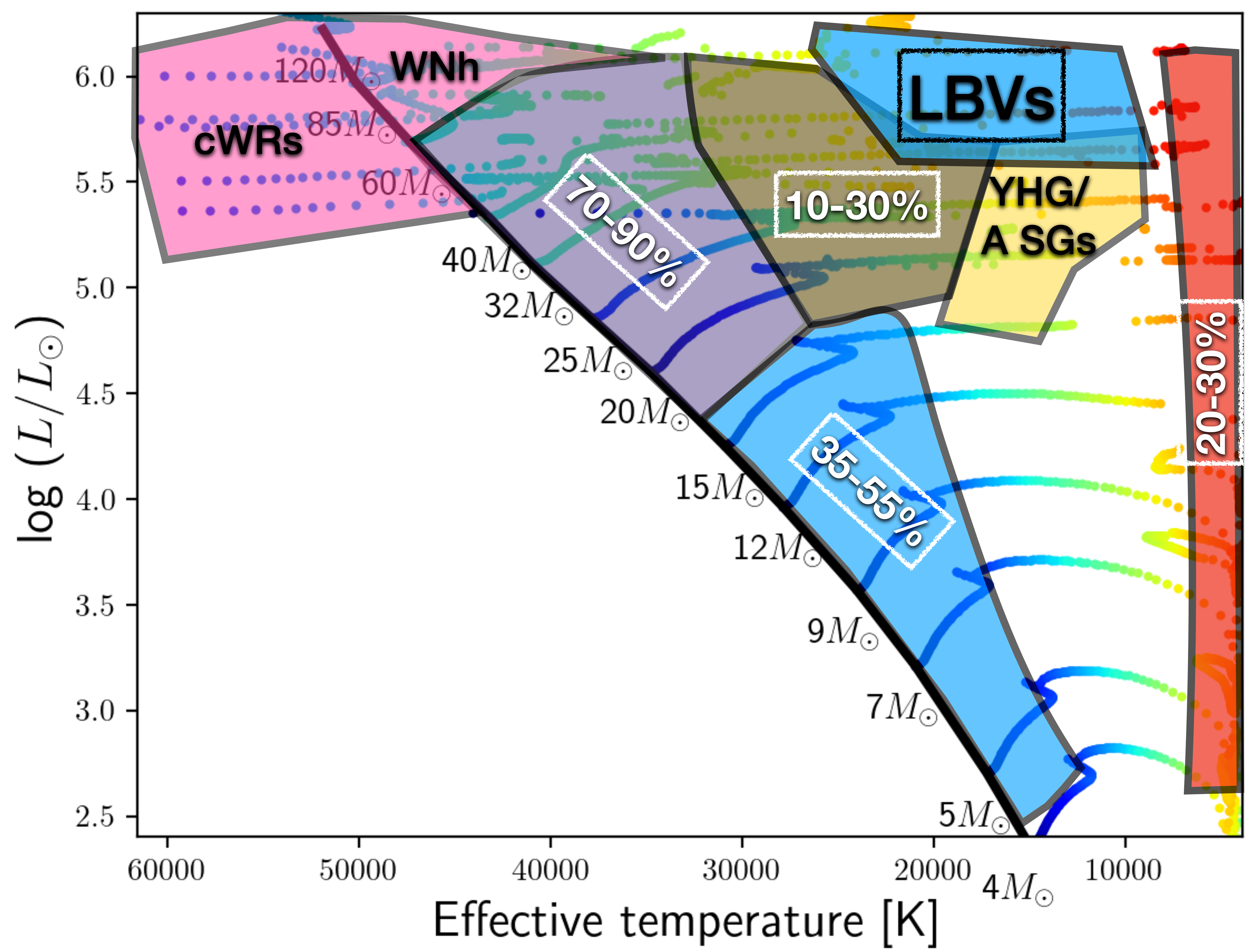
- Only a dozen known in the Milky Way
- In the SMC, Patrick et al. (2020) obtained a binary fraction of **30±10 %**
- In the LMC, Neugent et al. (2021a) derived a binary fraction of **20±7%**
- In M31, Neugent et al. (2021b) also obtained a binary fraction of **~33%**



Multiplicity through the HRD

Luminous Blue Variables:

- Extremely complicated to detect the binarity from spectroscopy
- Other techniques used:
  1. X-rays: **26-69%** (Nazé et al. 2012)
  2. Imaging: **30%** (Martayan et al. 2016)
  3. Interferometry: **60-80%** (Mahy et al 2022)

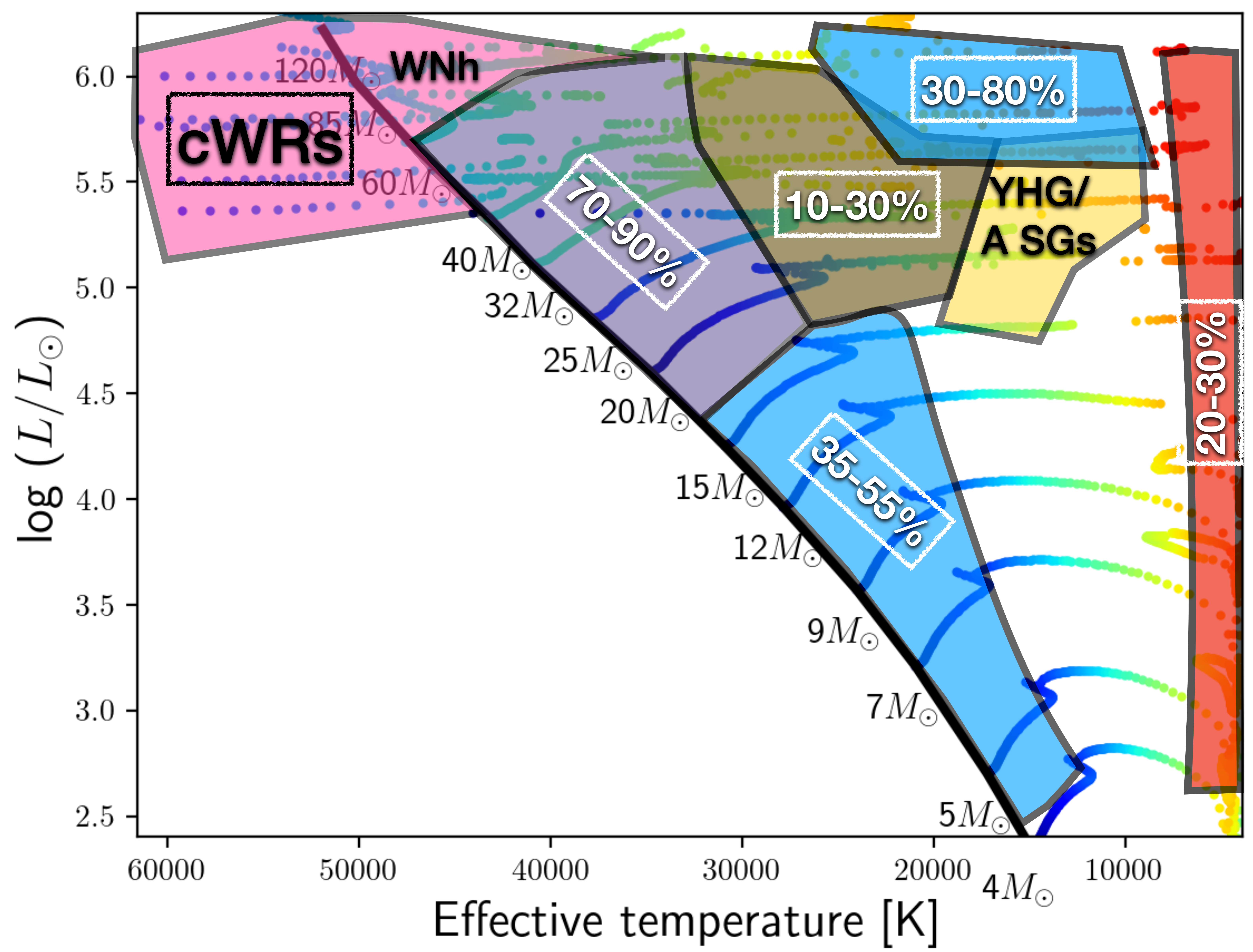


That shows the complexity to study the binarity for those objects

Multiplicity through the HRD

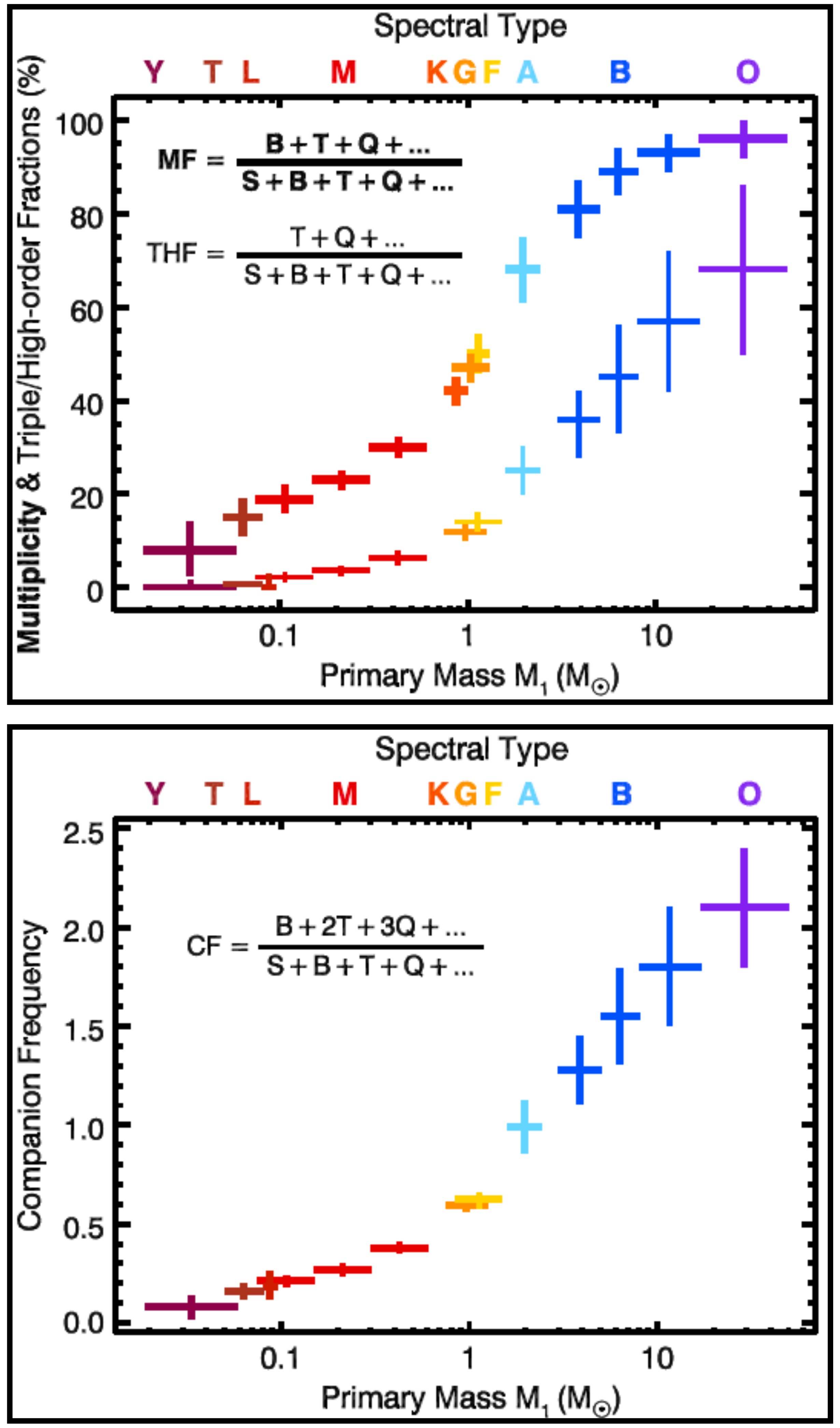
Wolf-Rayet stars:

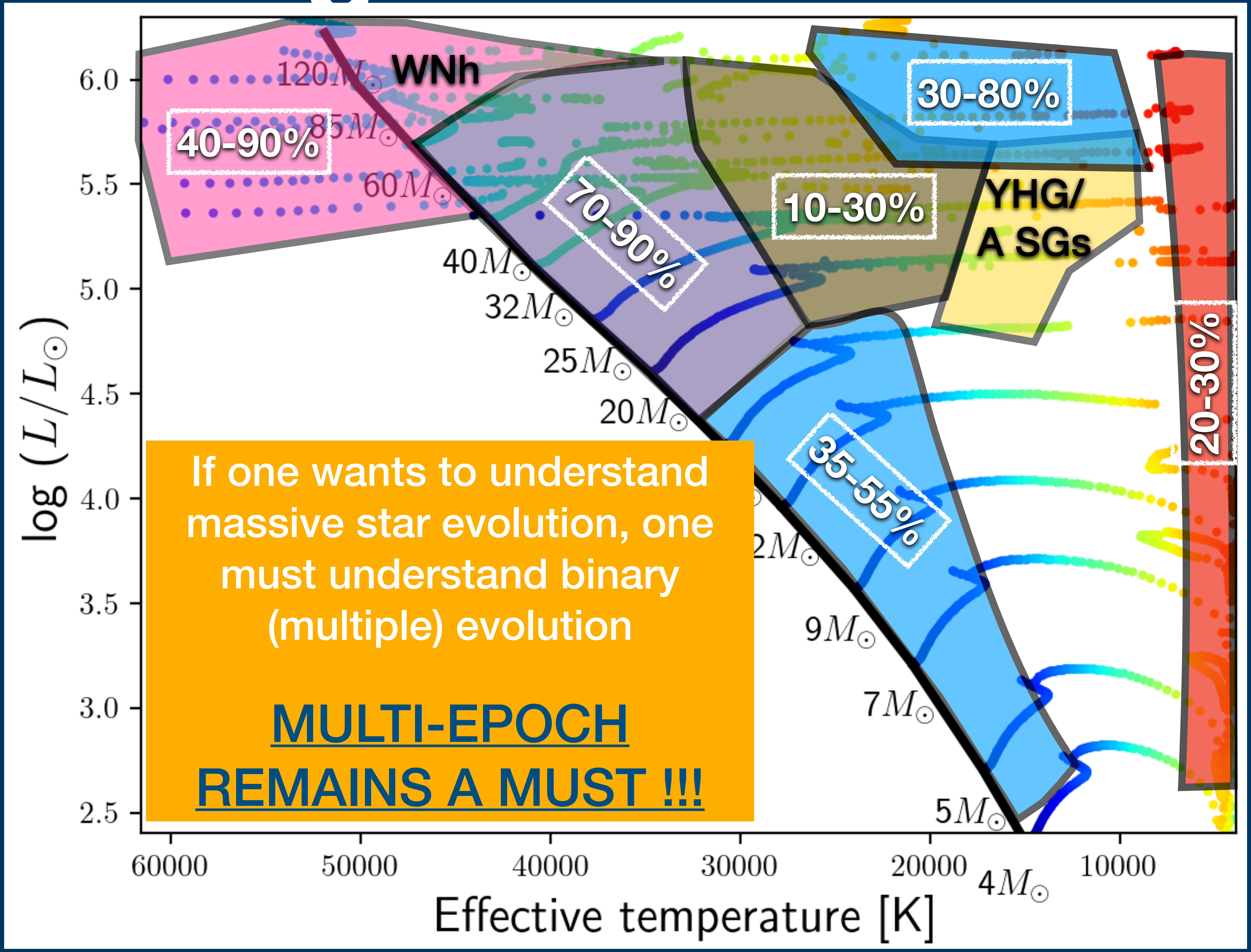
- Classical WRs:
  - **Type N:**
    - For WNE, 56 ± 20% (DSilva et al. 2022a)
    - For WNL: 42 ± 16% (DSilva et al. 2022b)
  - **Type C:** from 12 northern cWR, DSilva et al. (2020) found **72 ± 20%** of binary systems



Multiplicity through the HRD

Multiplicity through the HRD



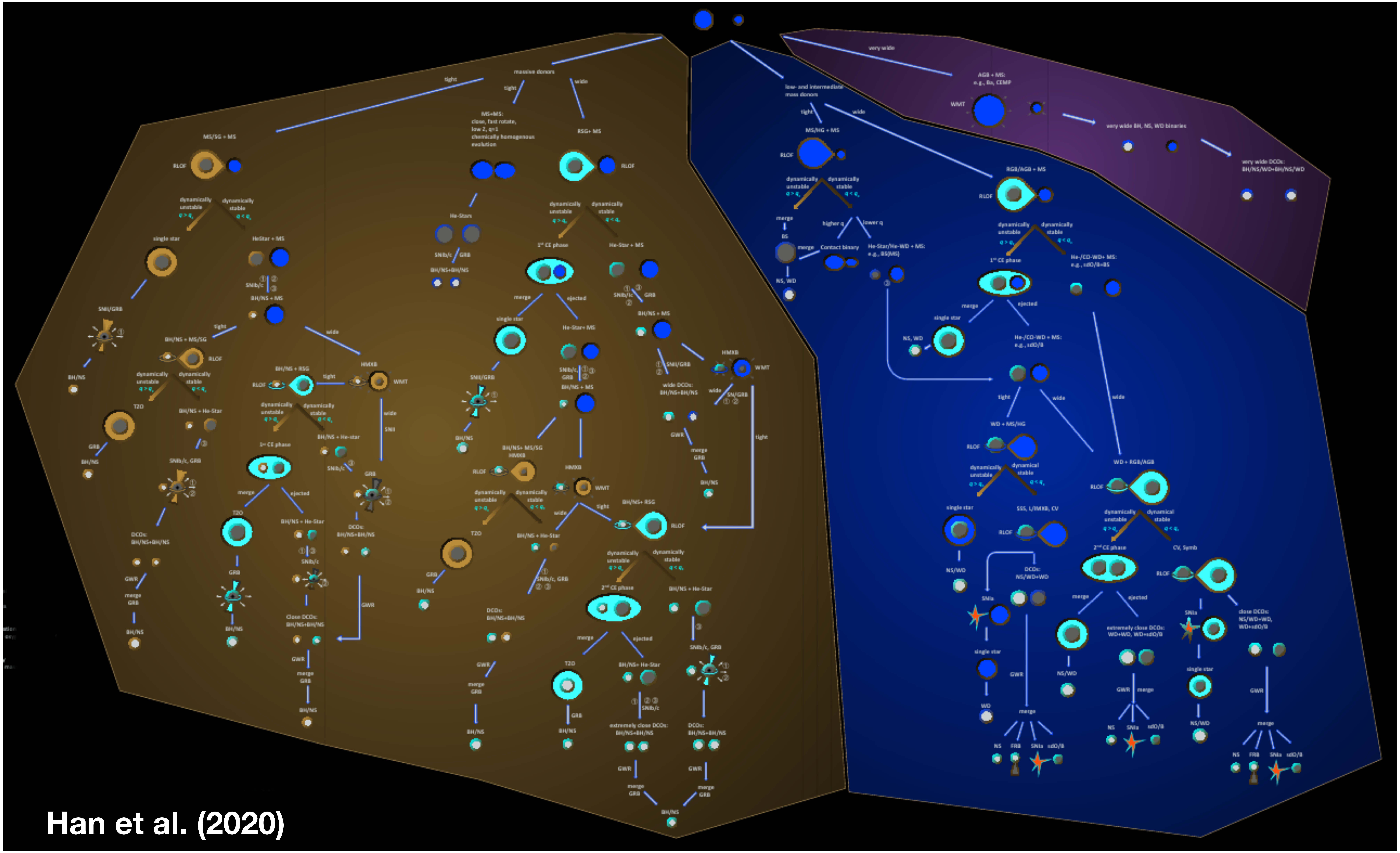


If one wants to understand massive star evolution, one must understand binary (multiple) evolution

MULTI-EPOCH REMAINS A MUST !!!

Offner et al. (2022)
Moe & di Stefano (2017)

Massive star evolution



Han et al. (2020)

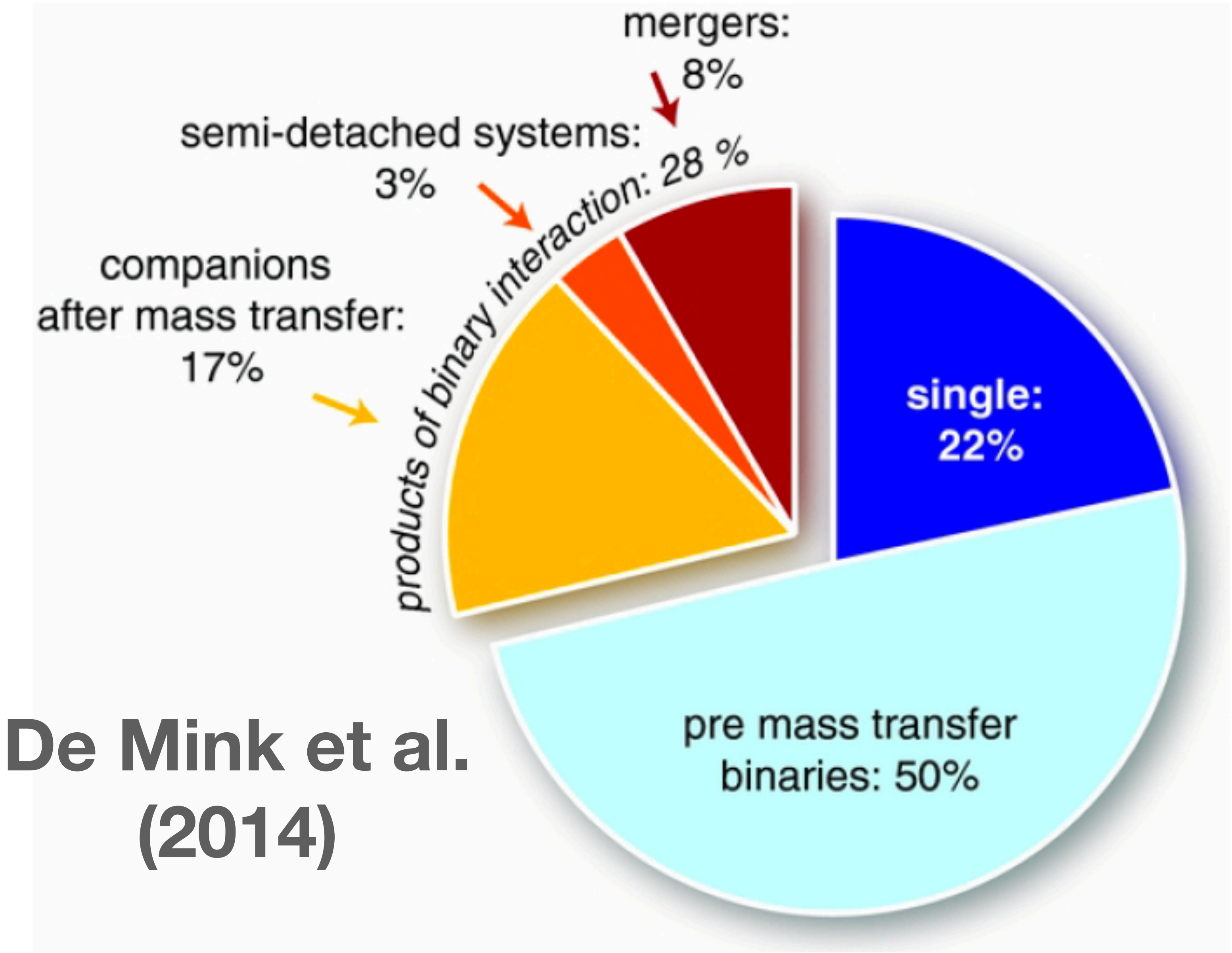
Massive star evolution

Characterisation of OB+OB binaries

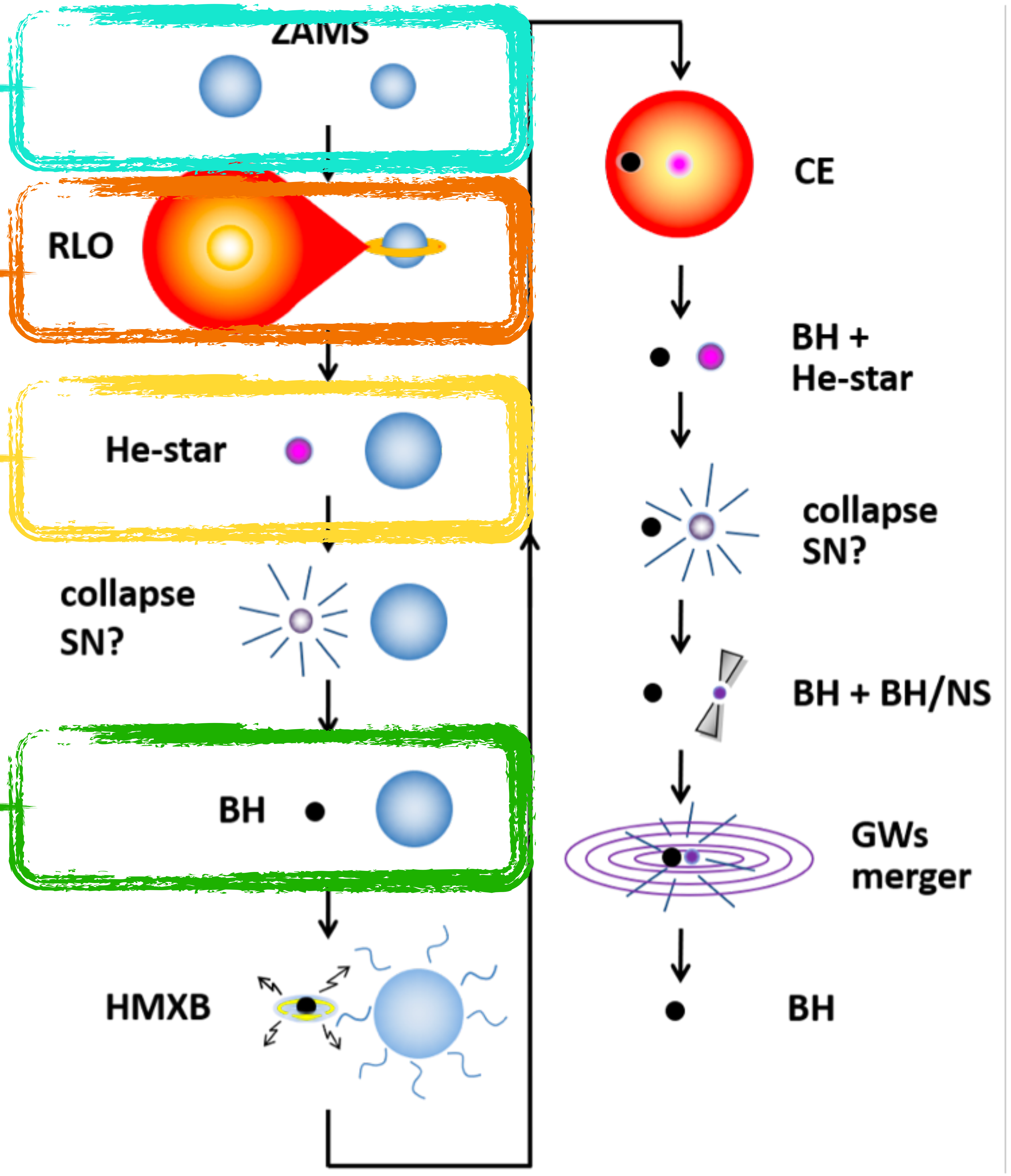
Interacting binaries

Binary evolution products / stripped stars

OB + BH systems



De Mink et al. (2014)



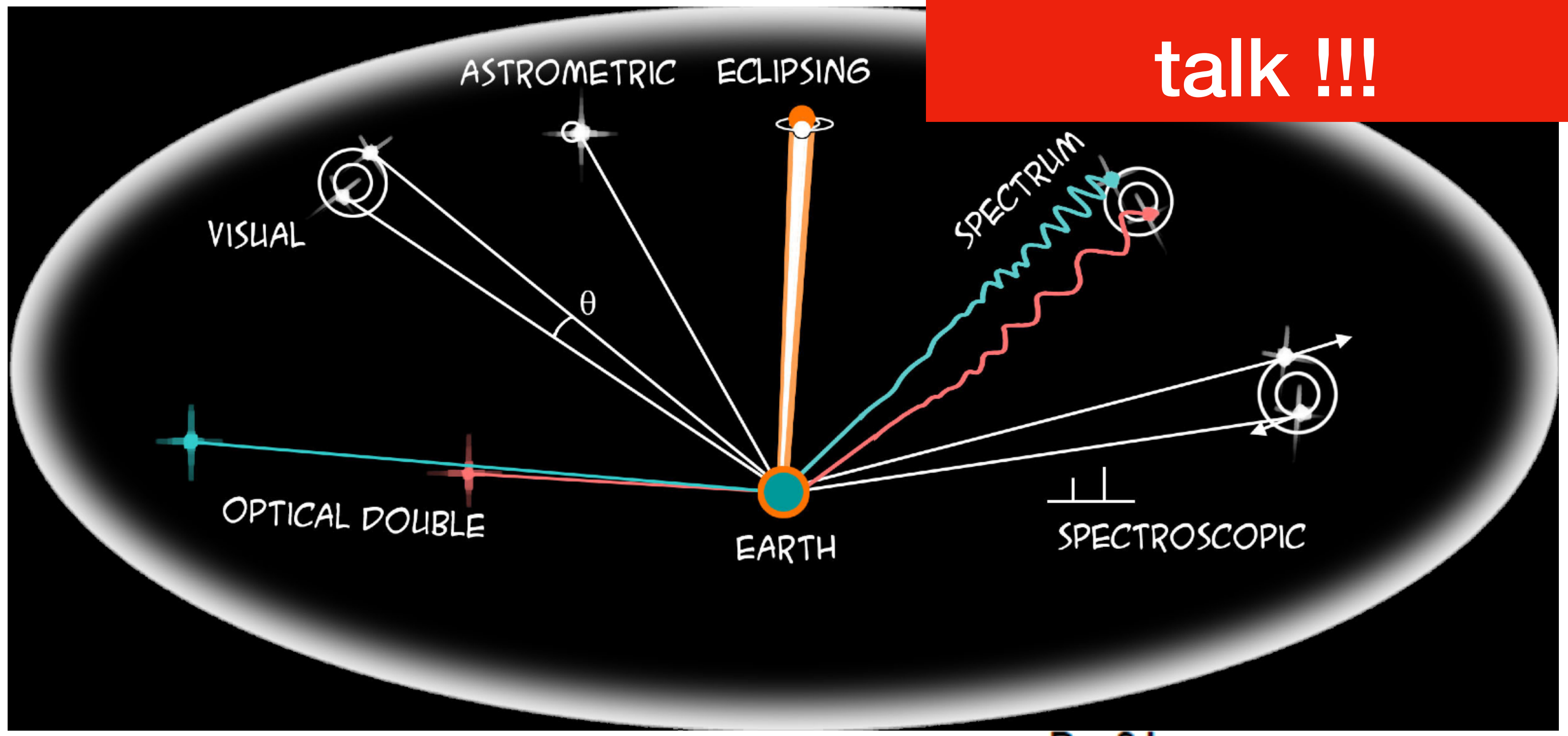
Langer et al. (2020)

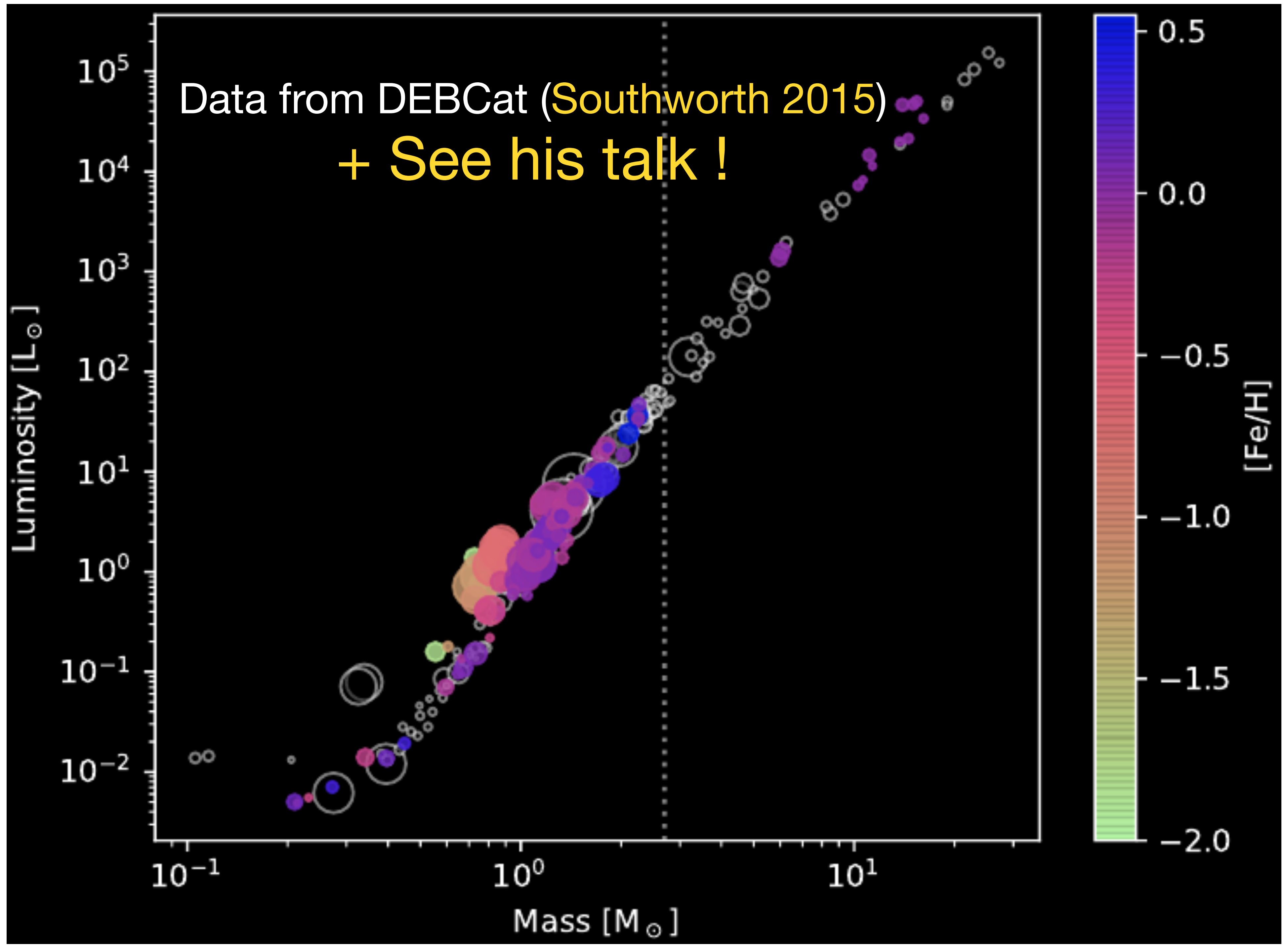
OB + OB binaries

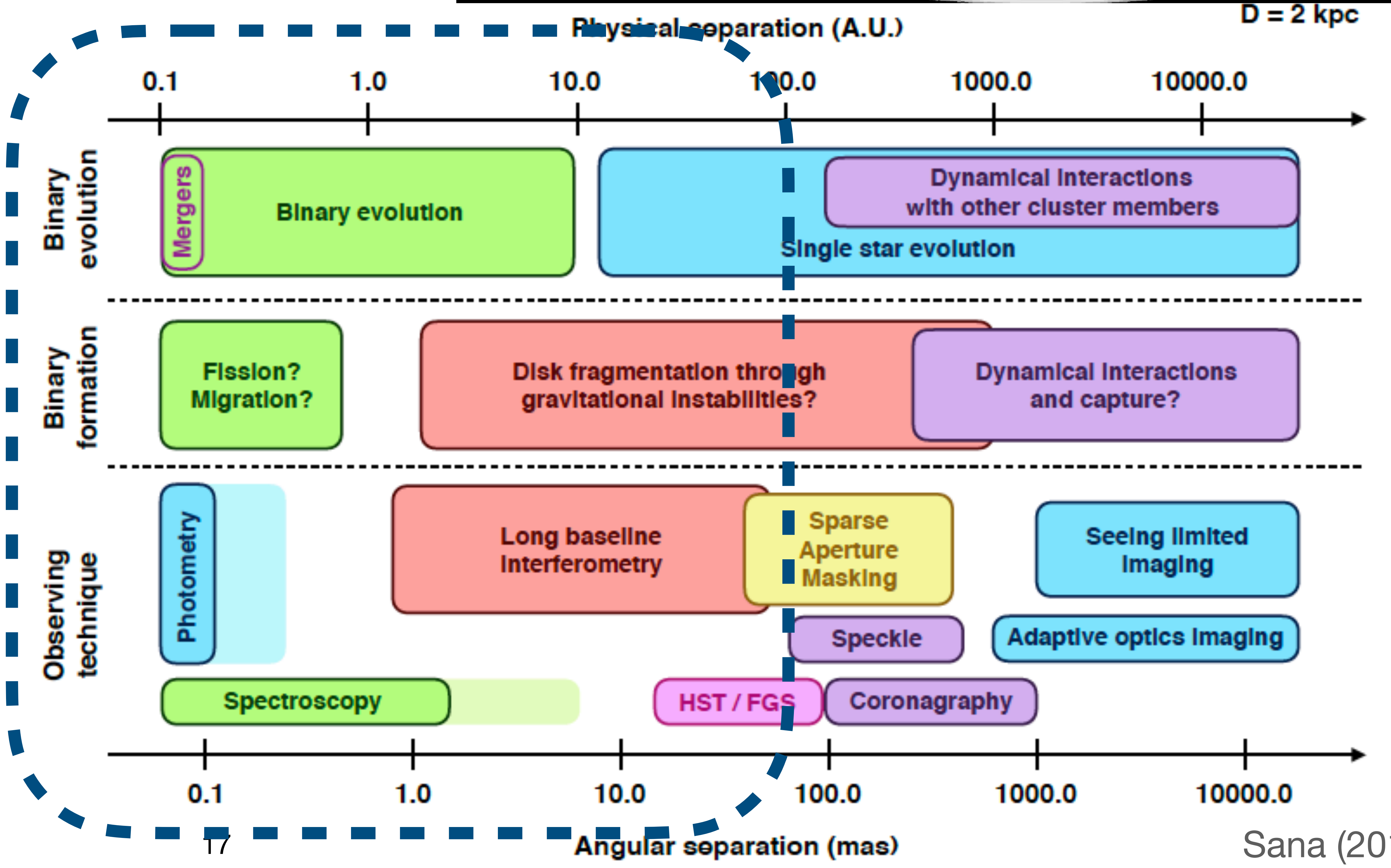
For interferometry, see A. Gallenne's talk !!!

Detached binary systems evolve (almost) as single stars:

- Cornerstones on which single-star evolutionary models are anchored (e.g., Paczyński 1970, Iben 1984, Kippenhahn 2013, etc.)
- Provide precise mass-radius and mass-luminosity calibration scales (e.g., Eker et al. 2018, Mova et al. 2018)







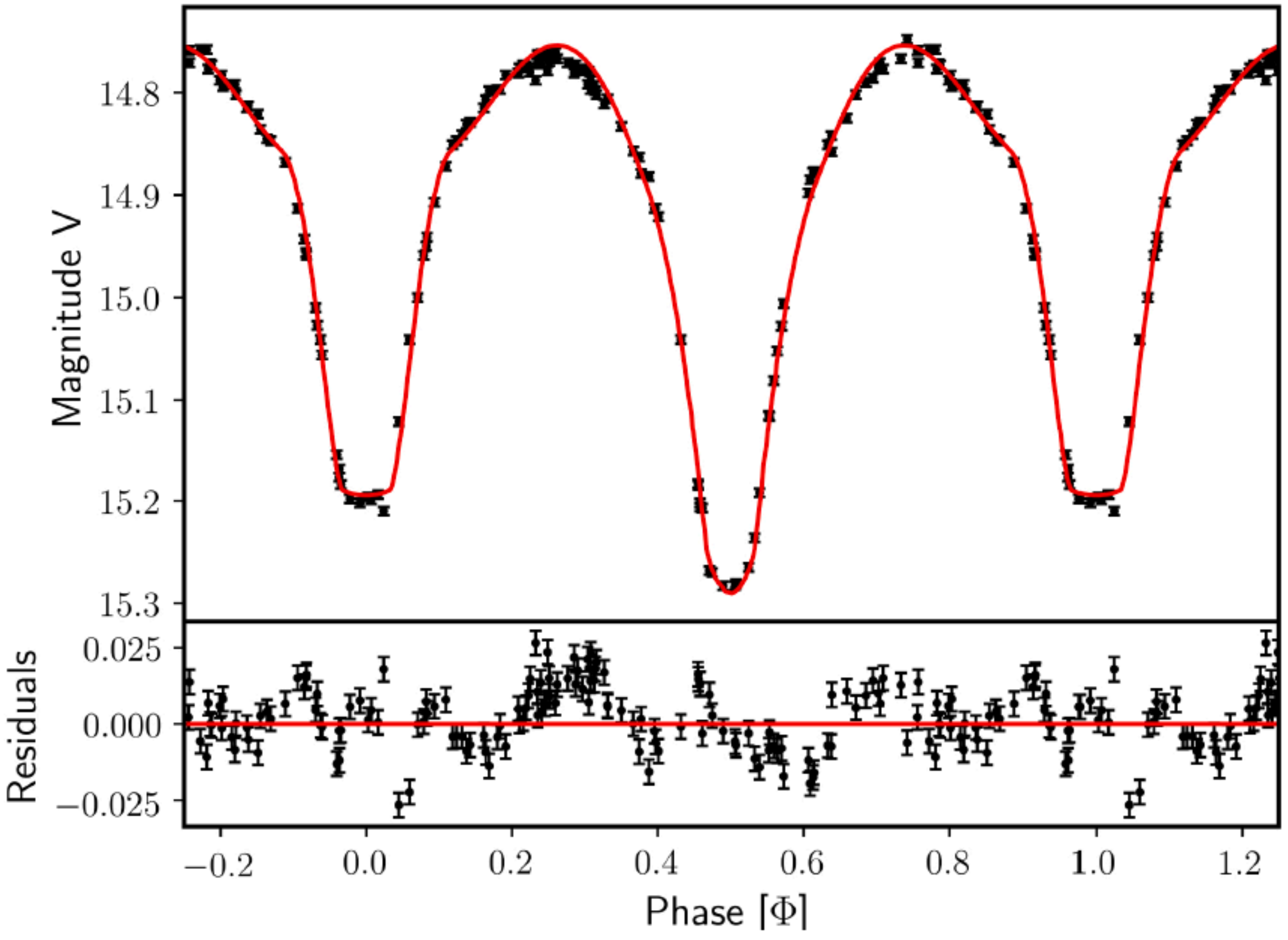
Sana (2017)

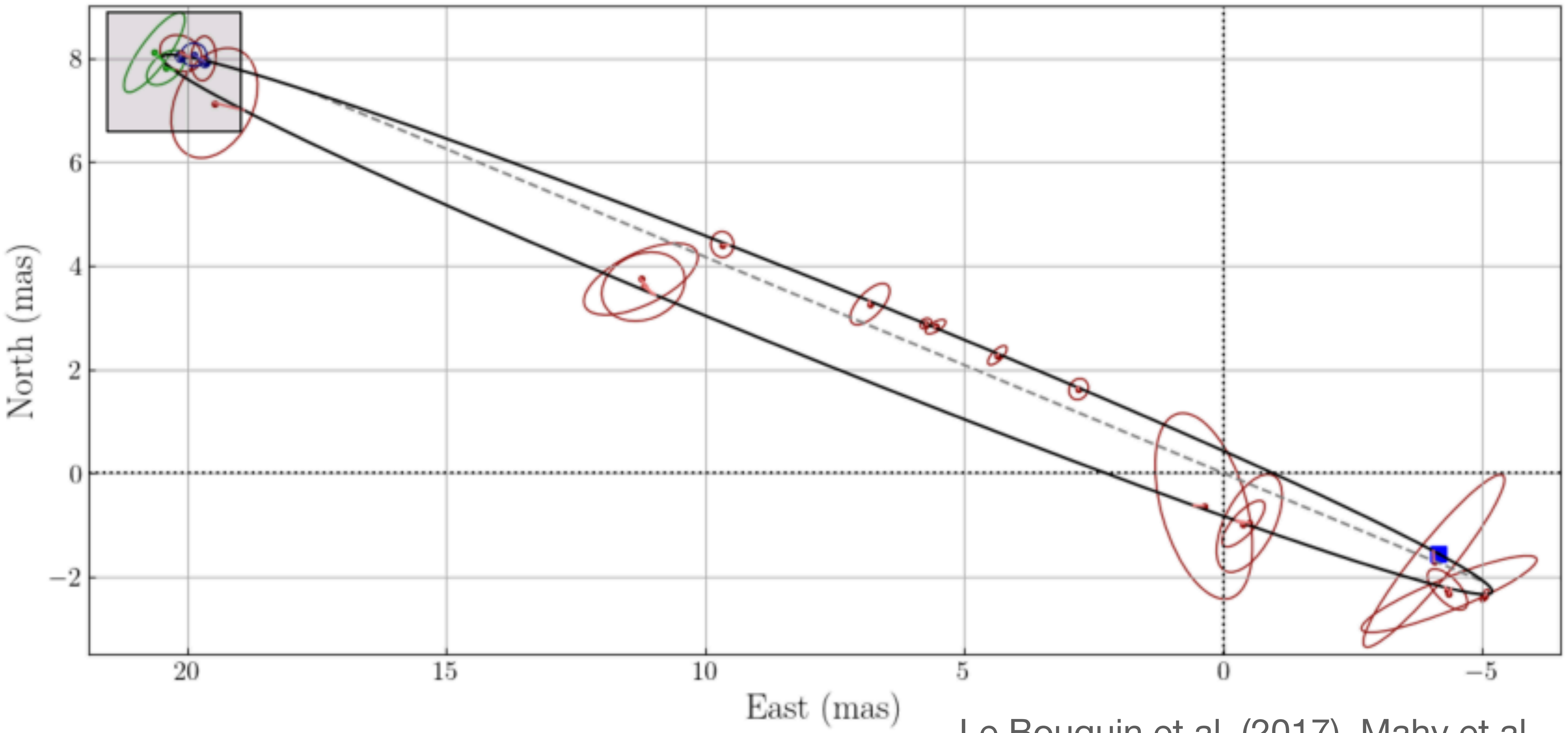
OB + OB binaries

Spectroscopy only provides measurements of the orbital parameters and minimum masses of the components

BUT

When combined with Photometry or Interferometry





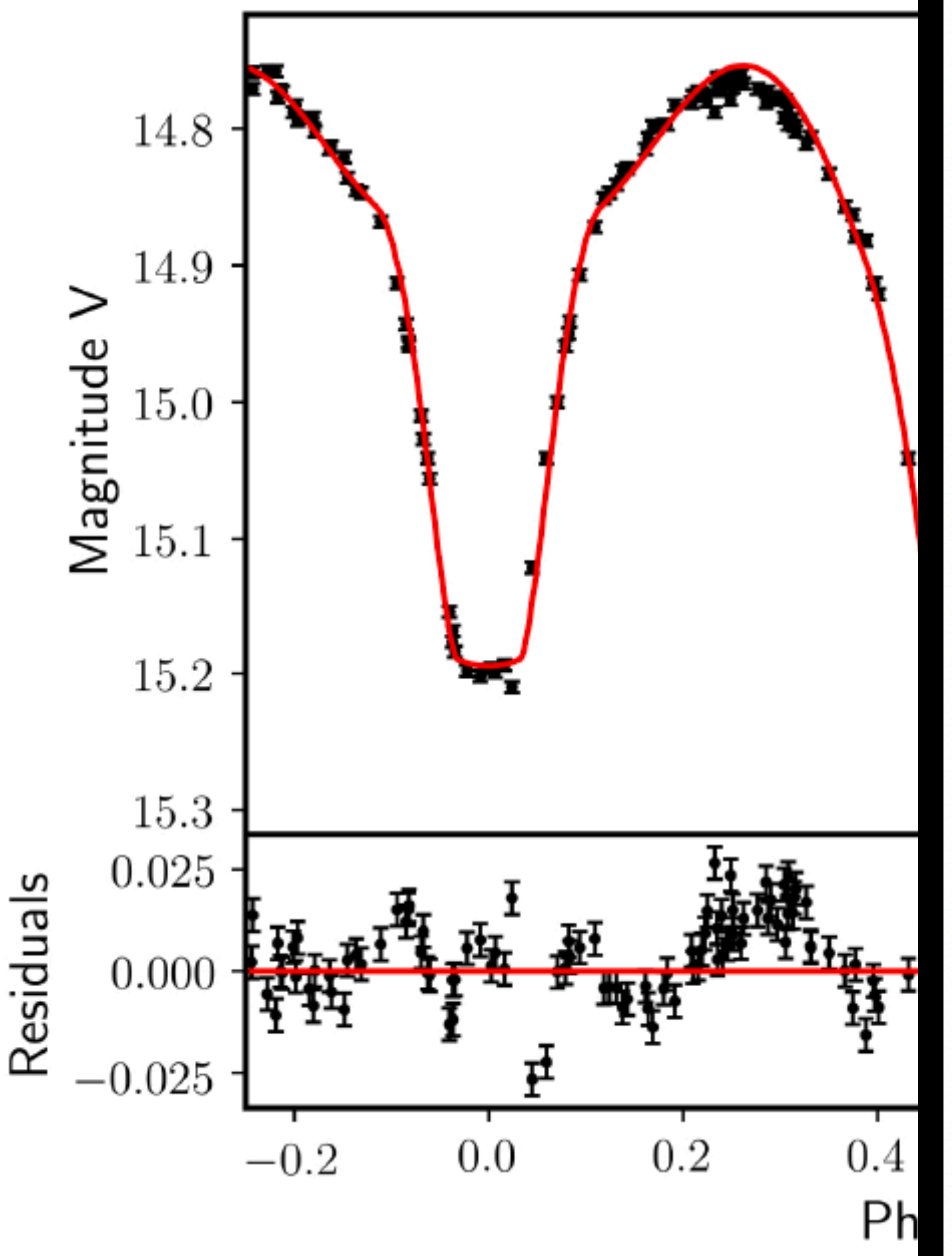
Le Bouquin et al. (2017), Mahy et al. (2018), Fabry et al. (2021)

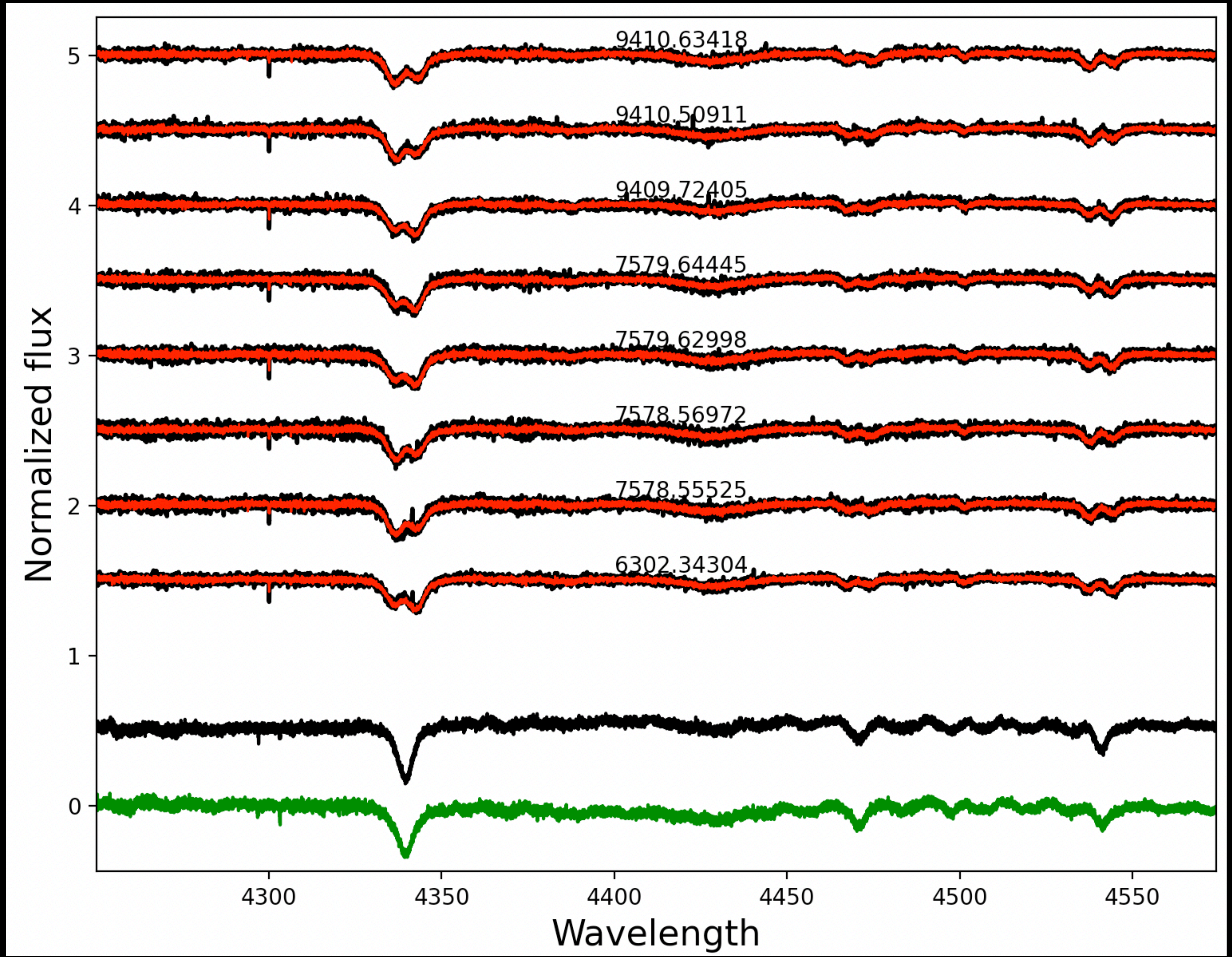
OB + OB binaries

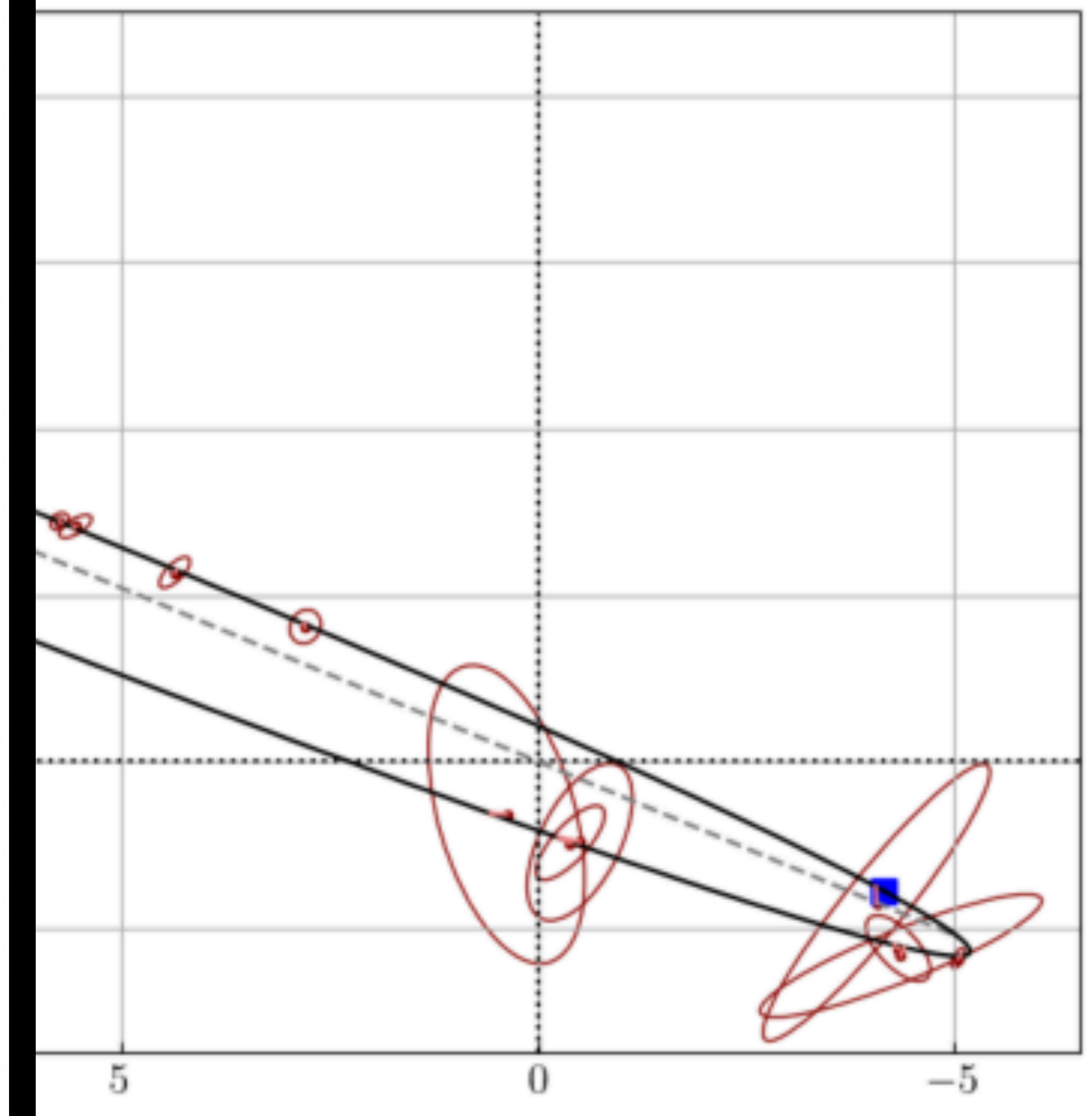
Spectroscopy ... parameters and

Wh... metry

Spectral disentangling + Atmosphere modelling



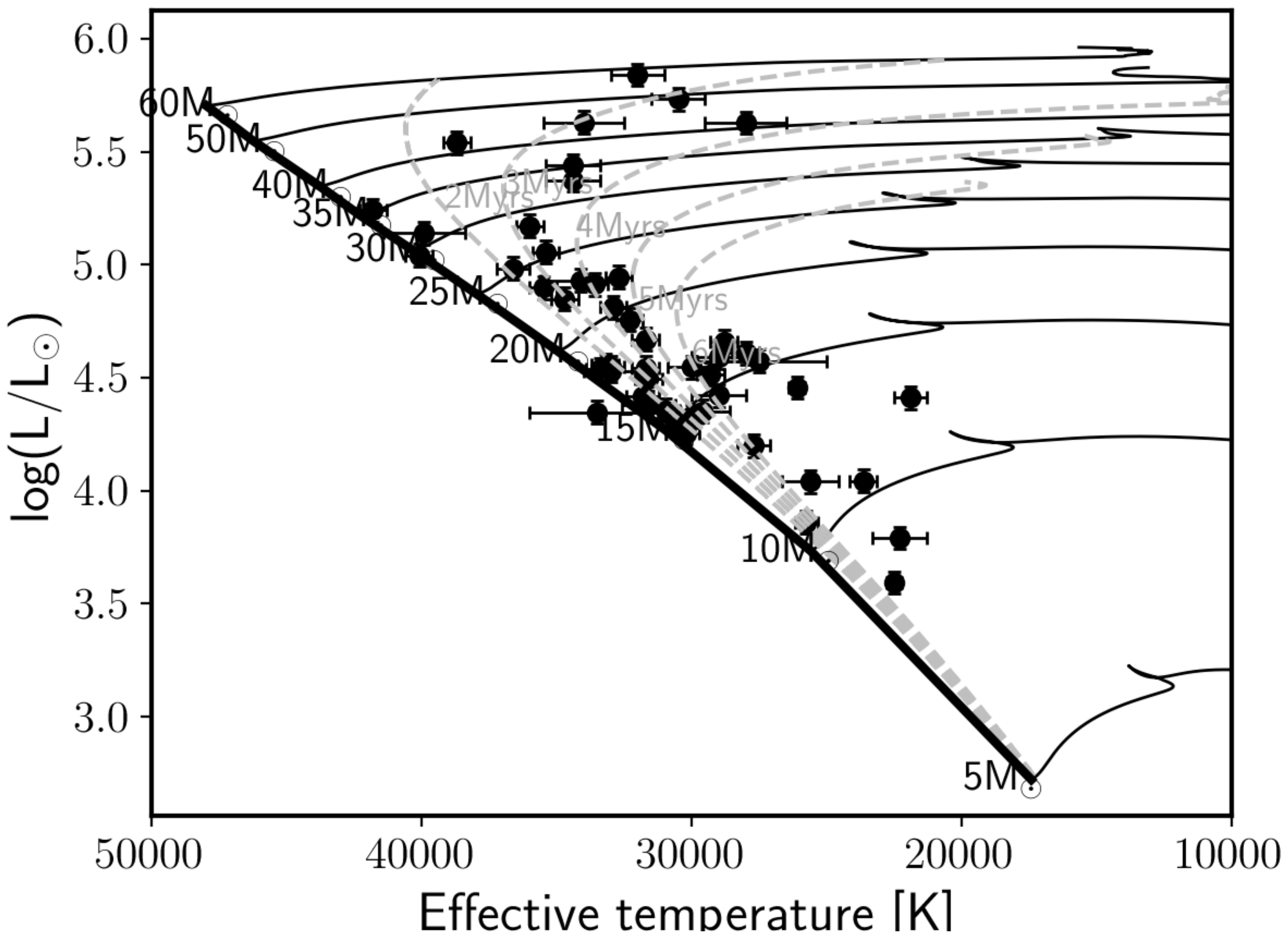




Le Bouquin et al. (2017), Mahy et al. (2018), Fabry et al. (2021)

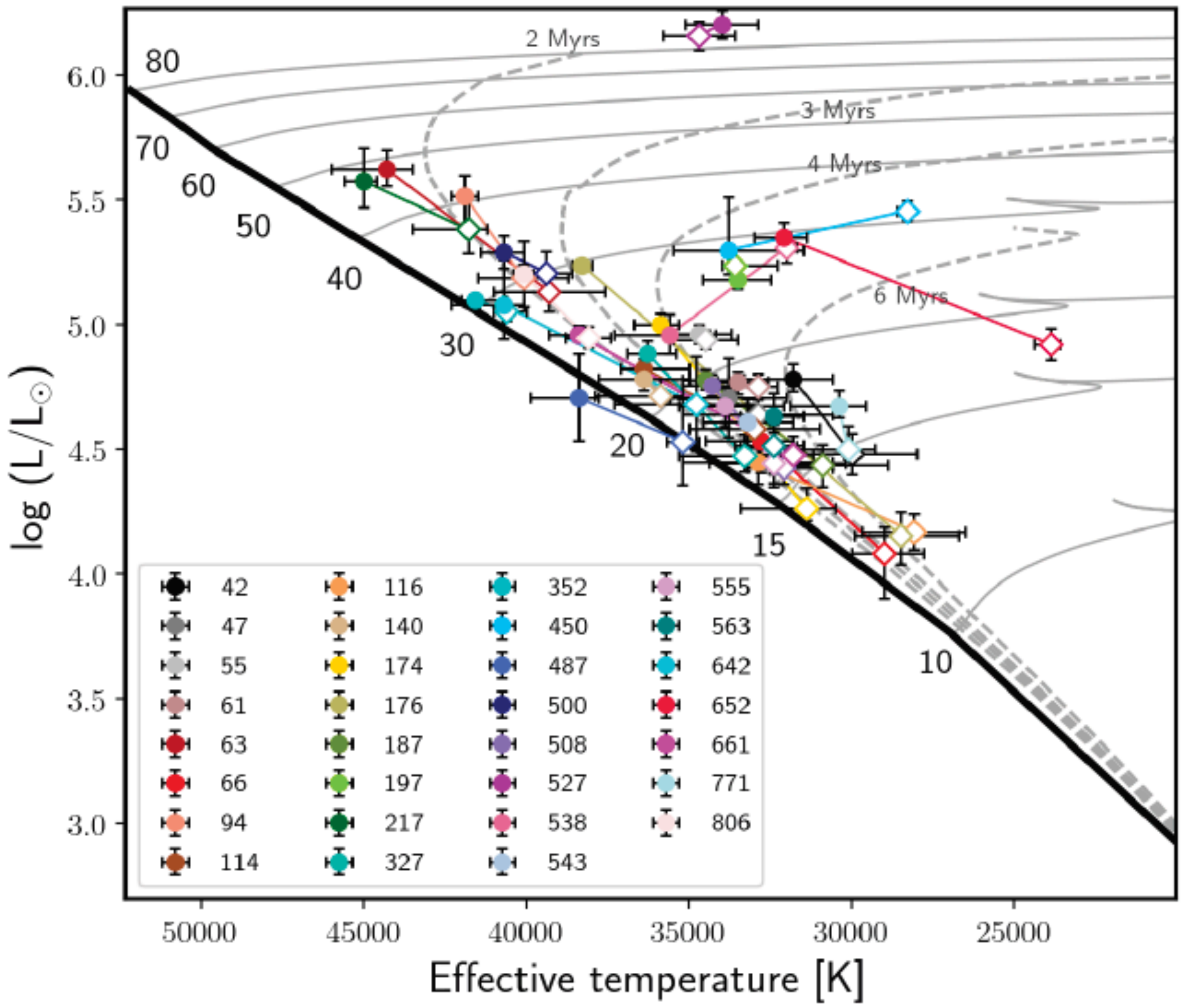
OB + OB binaries

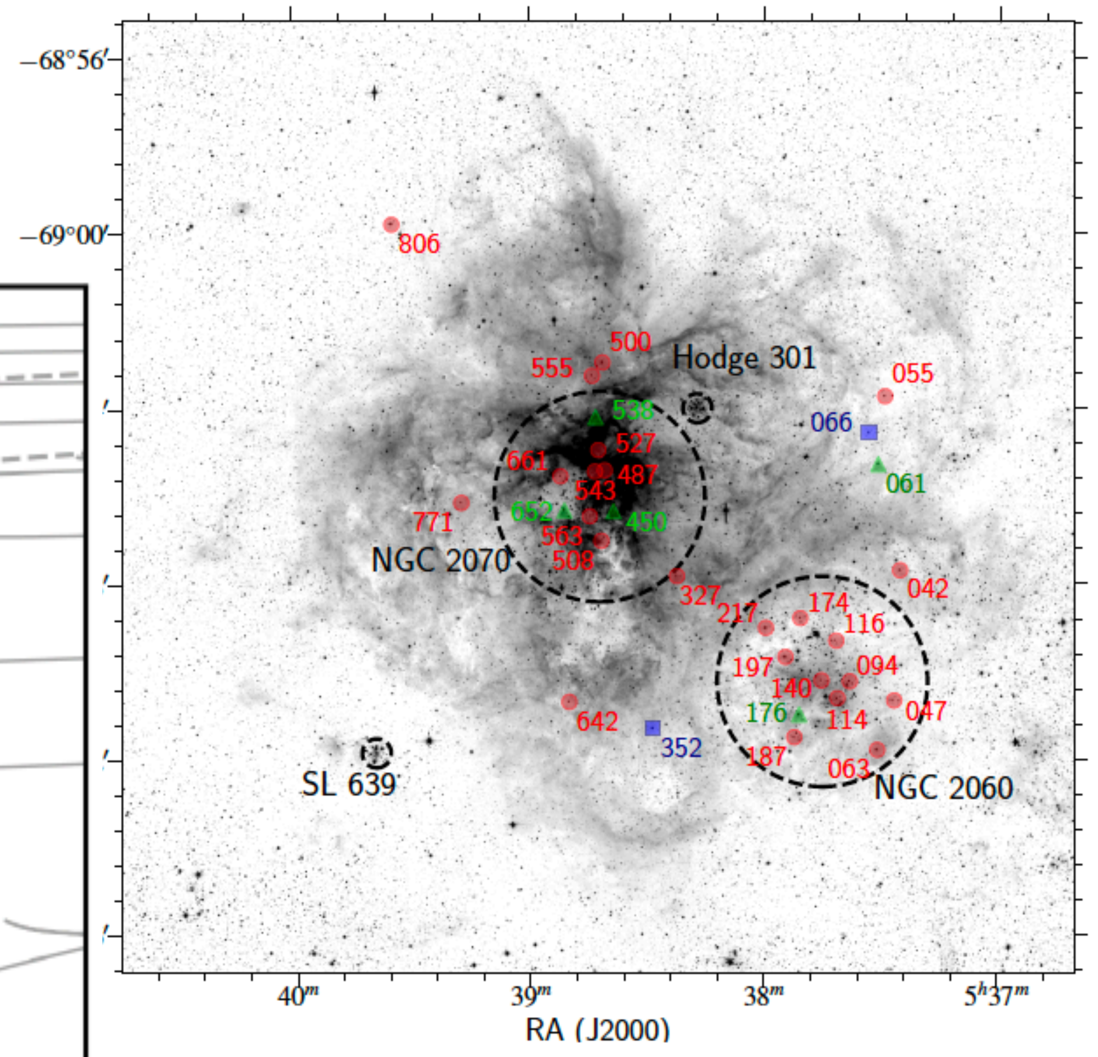
In the Milky Way



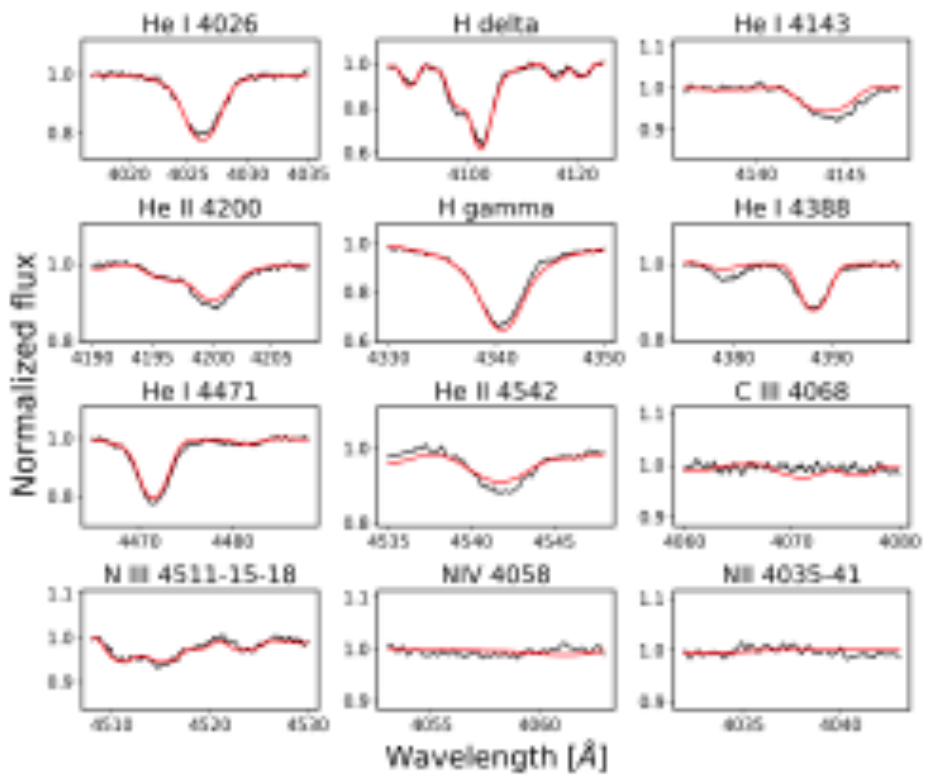
Mahy et al. (2017, in prep.)
Martins et al. (2017)
Pavlovski et al. (2018, 2013)
Raucq et al. (2016, 2017)
Rauw et al. (2018)
Rosu et al (2021, 2022)

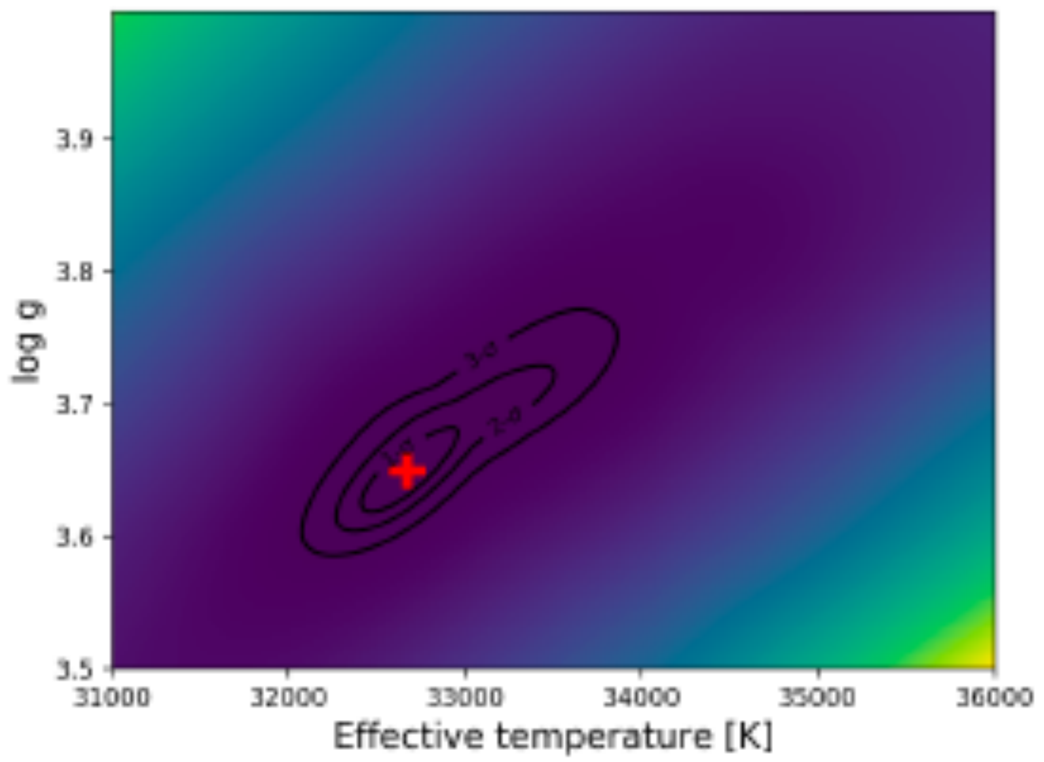
In the LMC (30 Dor)



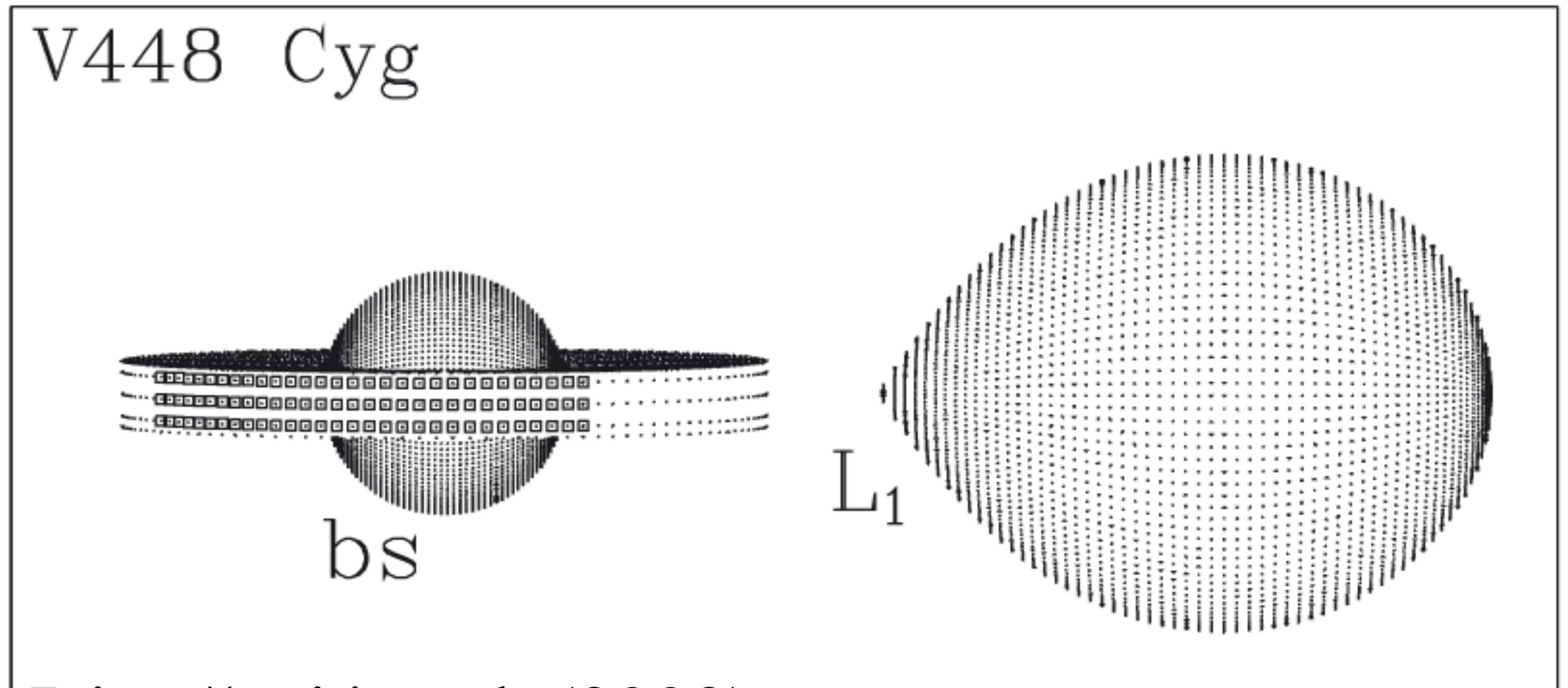


Mahy et al. (2020a,b)



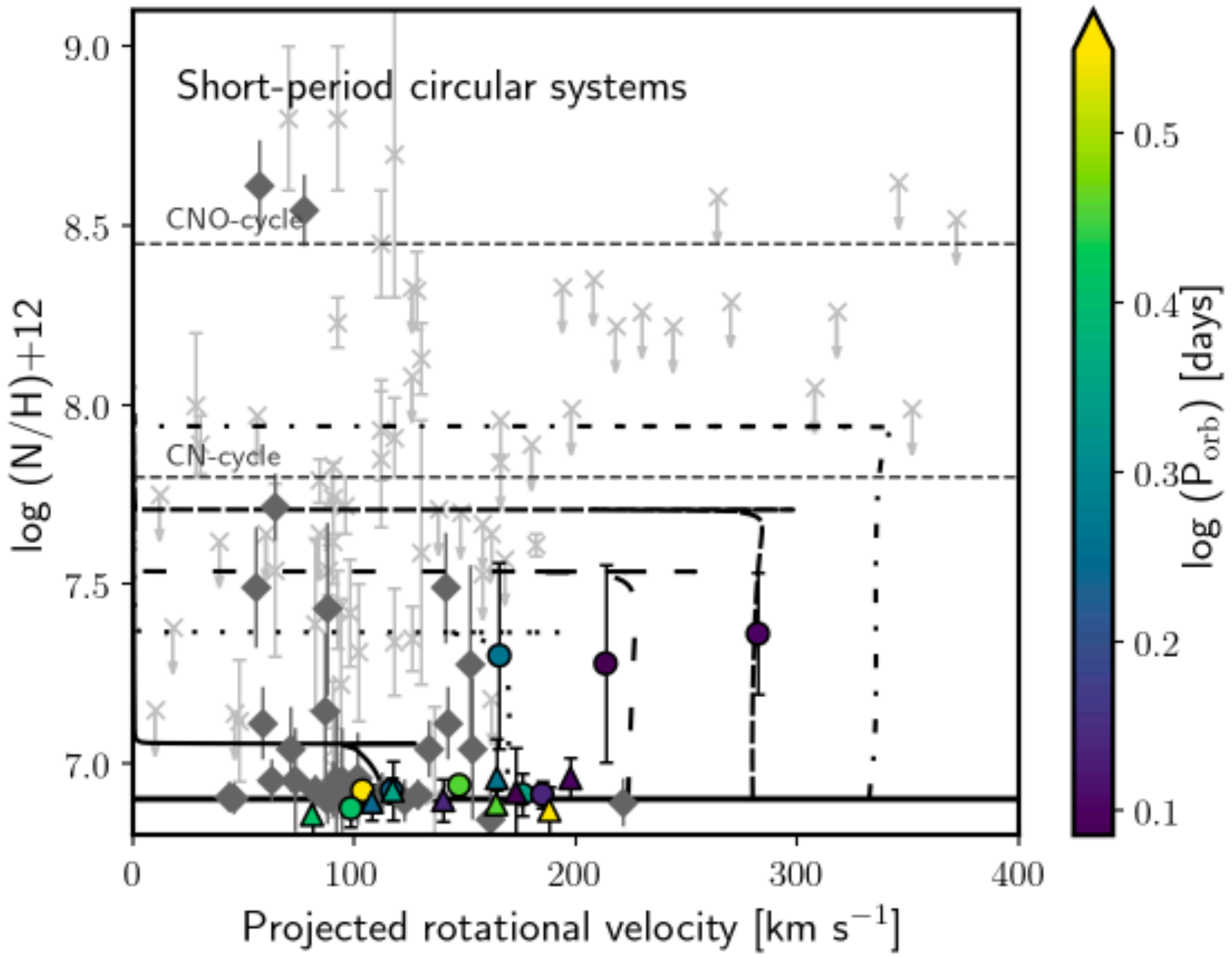


Interacting binaries - semi-detached phase

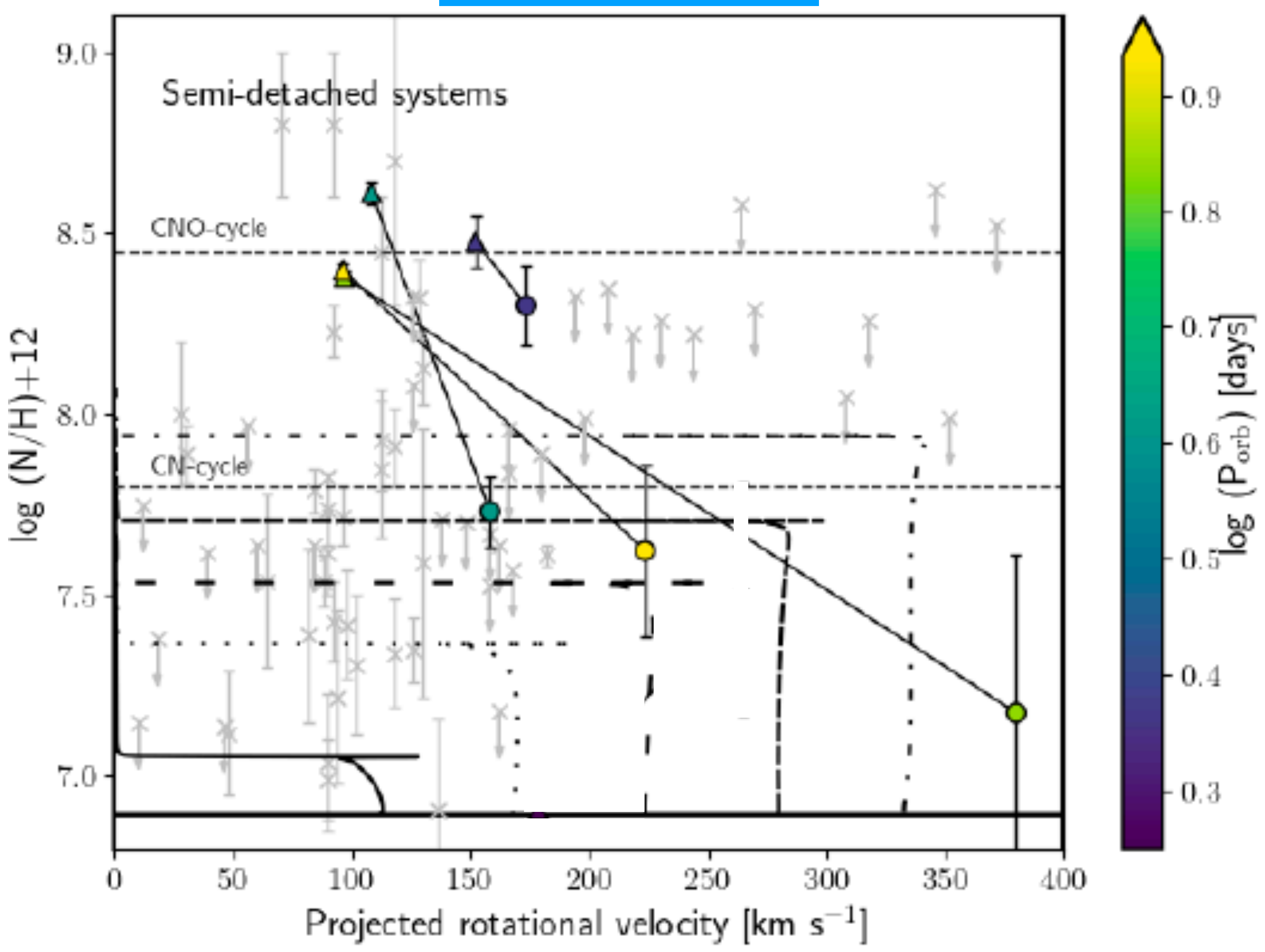


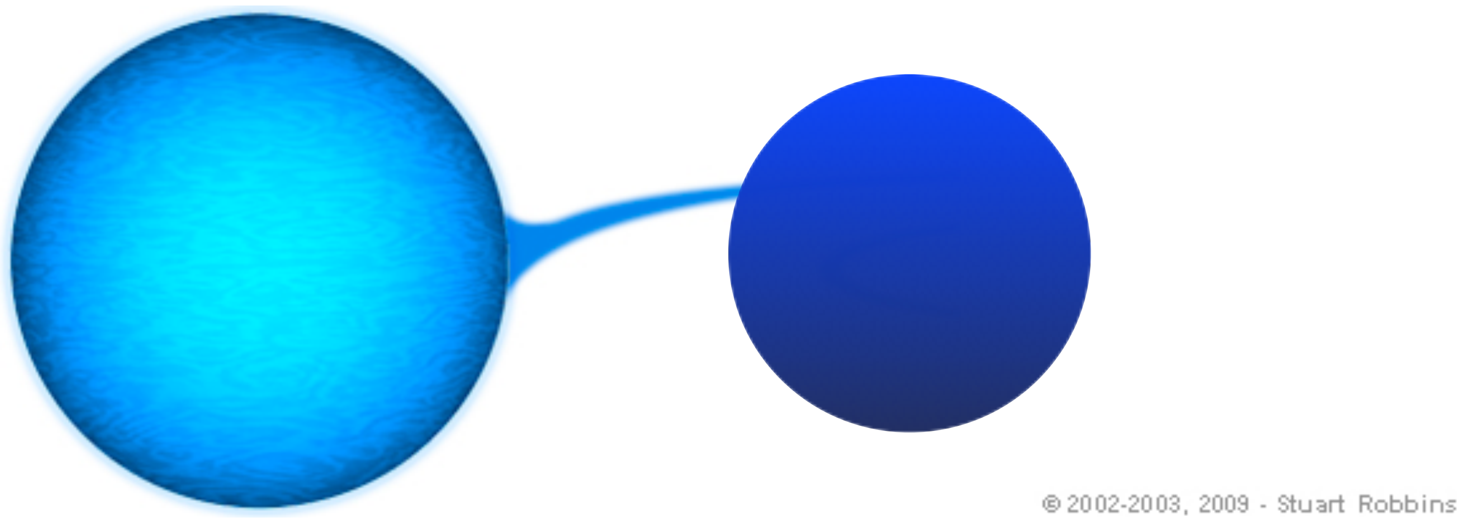
Djurašević et al. (2009)

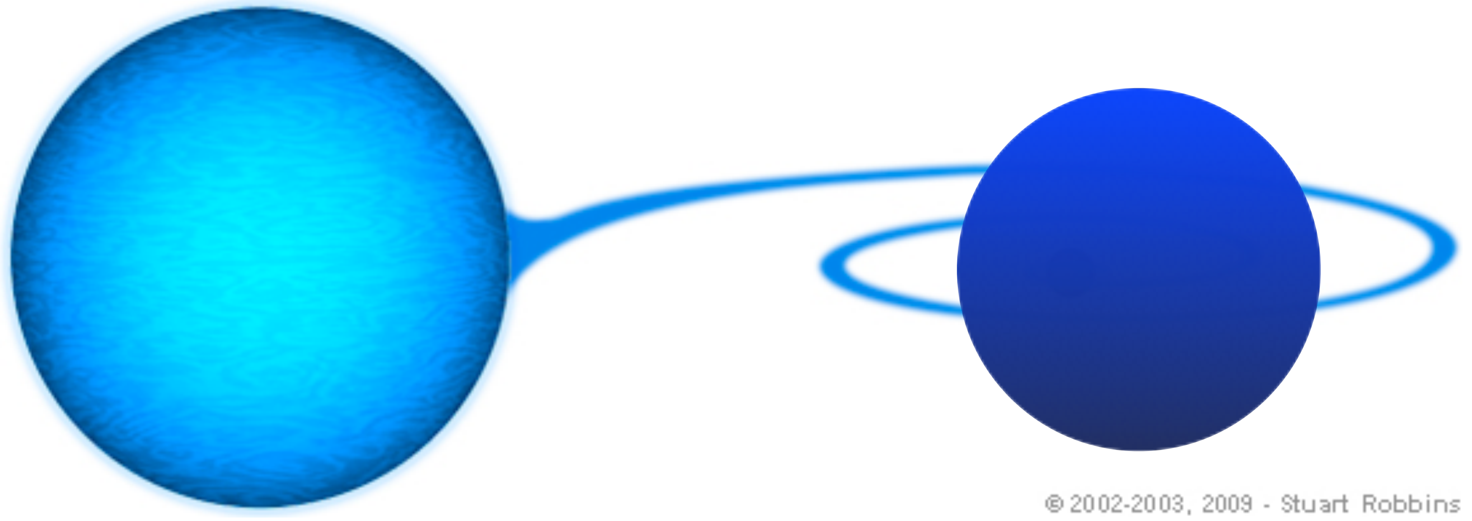
Detached

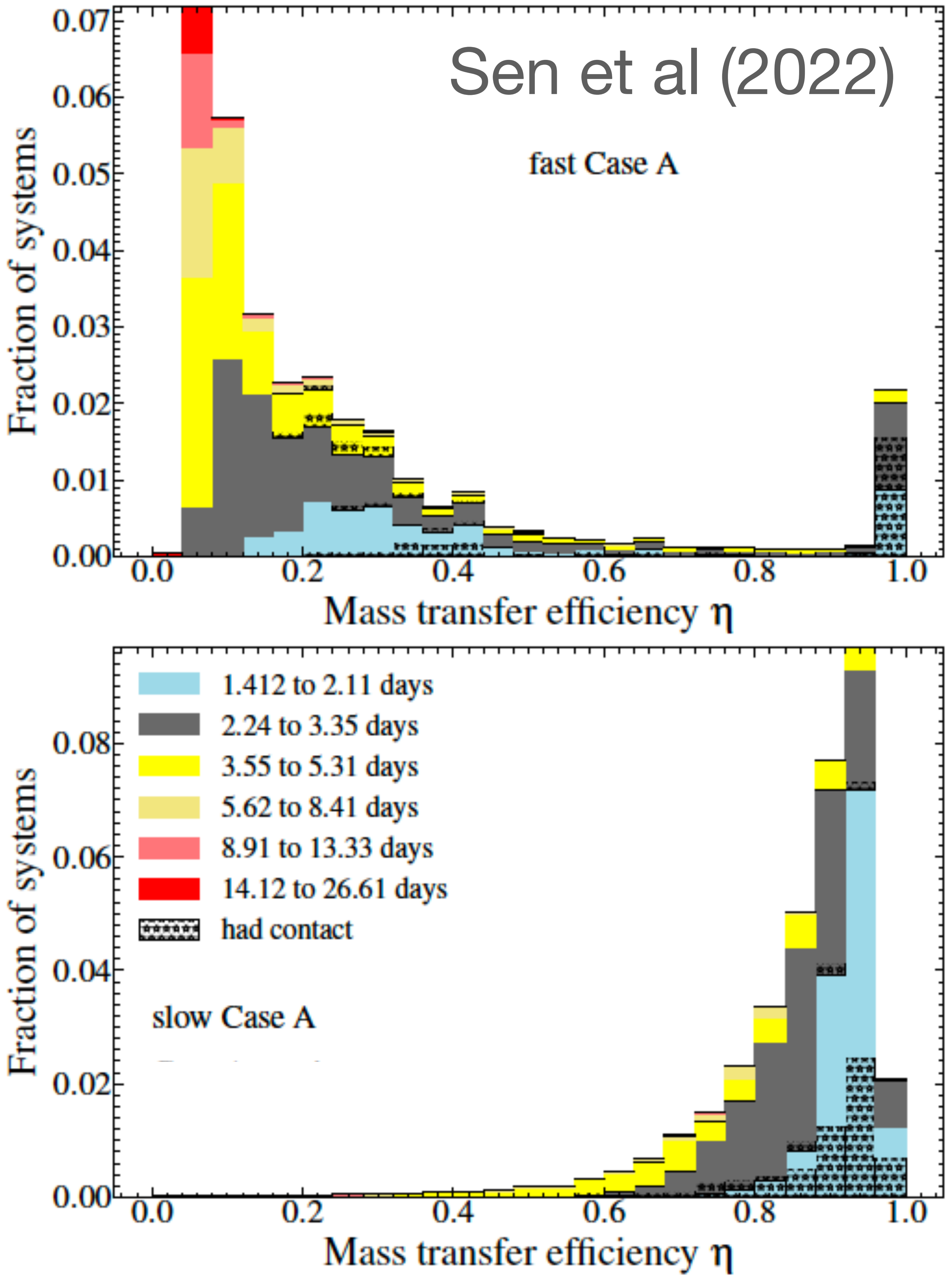


Interacting





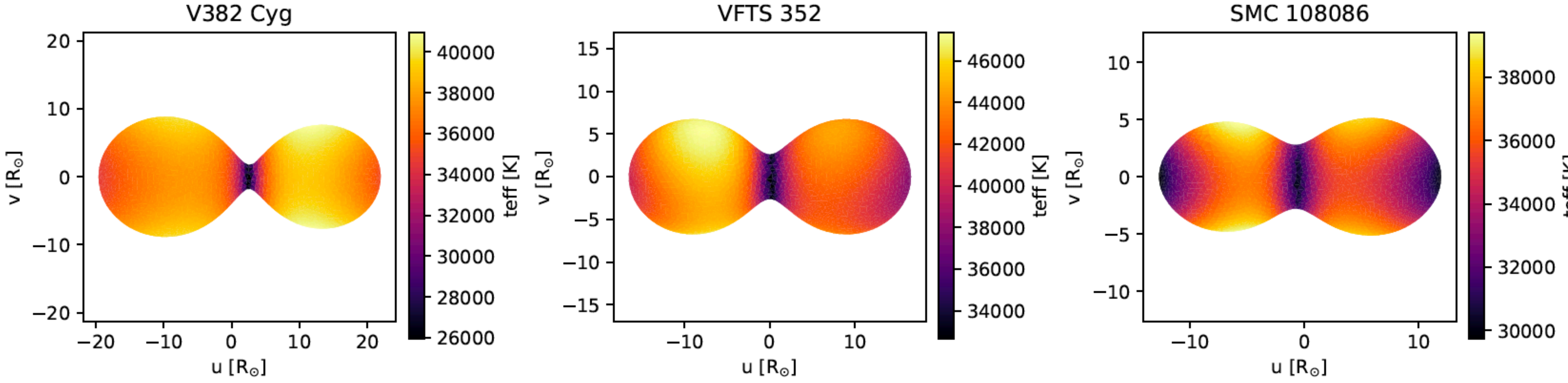


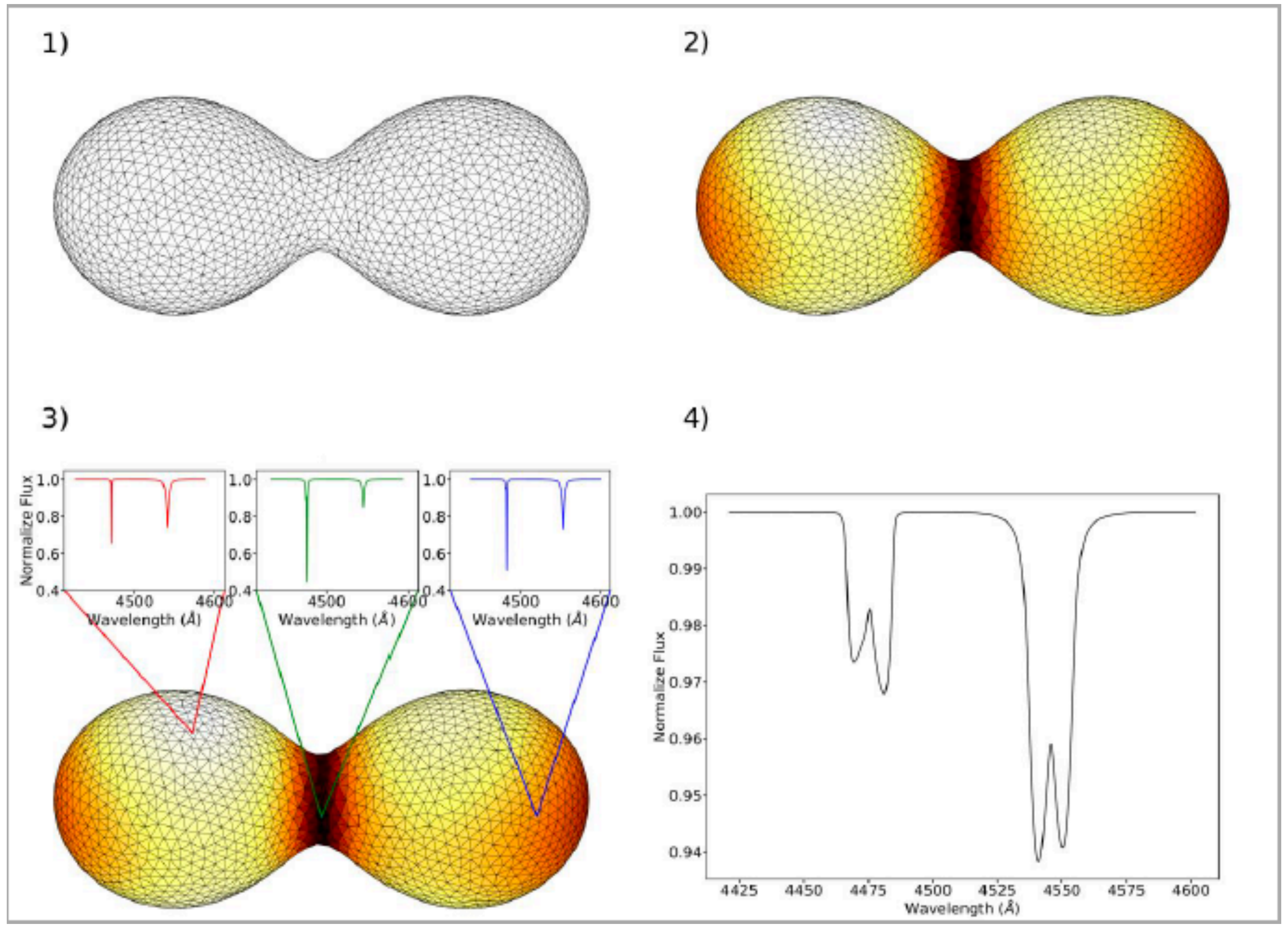


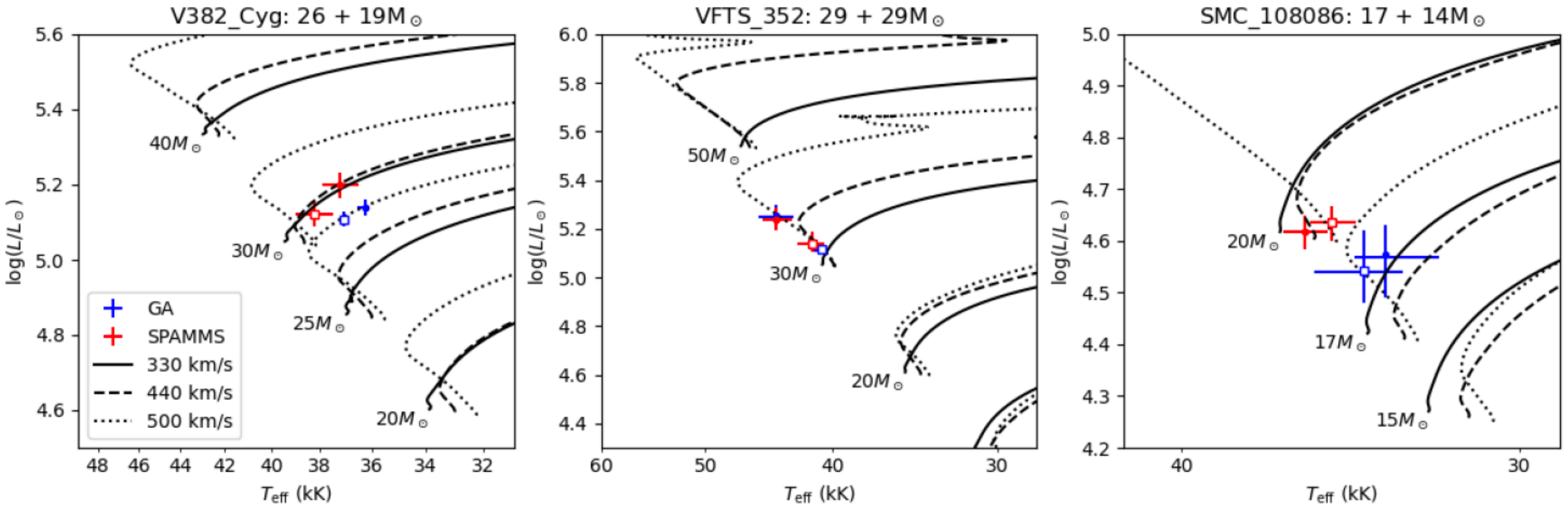
Mahy et al (2020a,b)

Interacting binaries - contact phase

SPAMMS

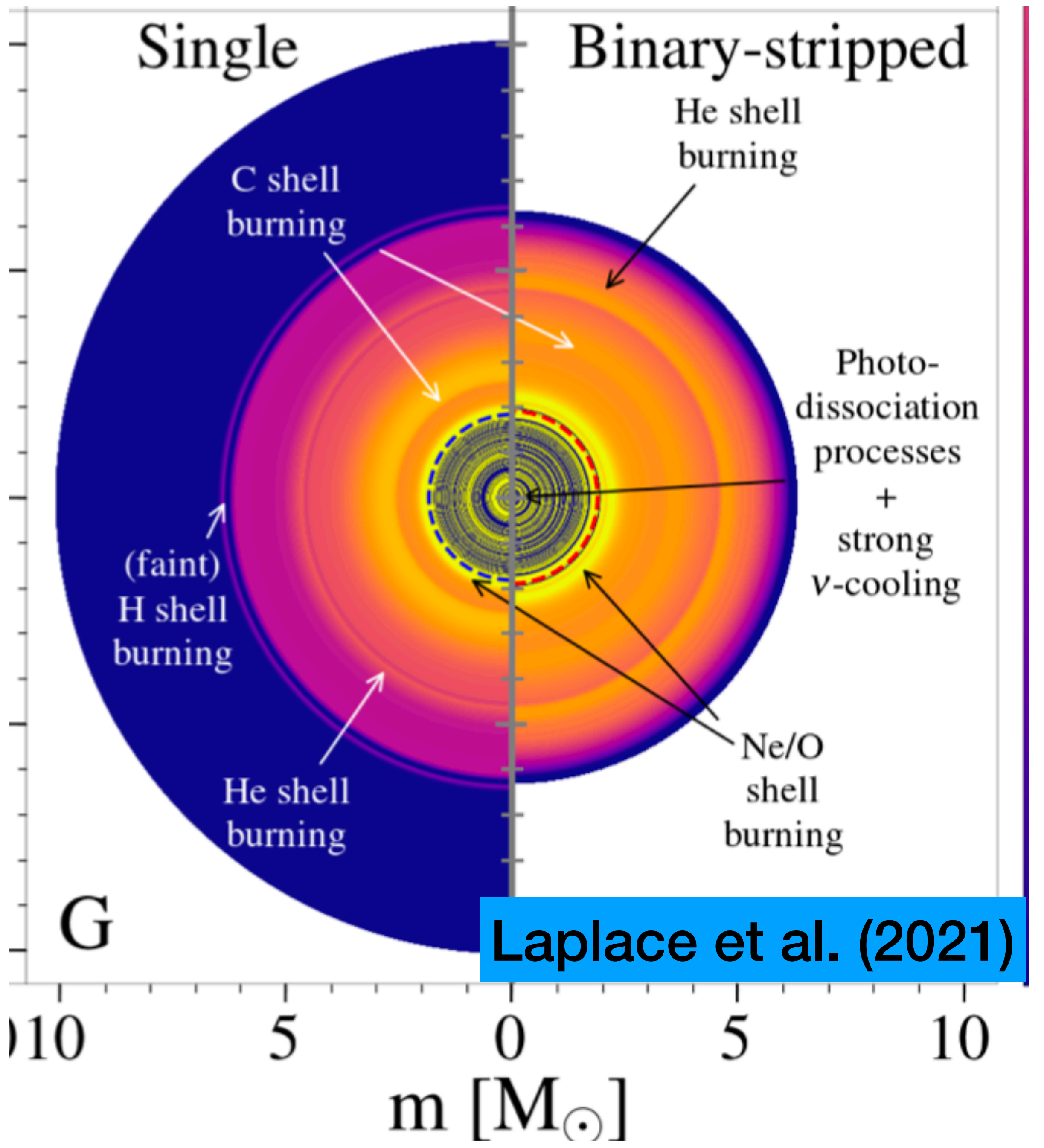


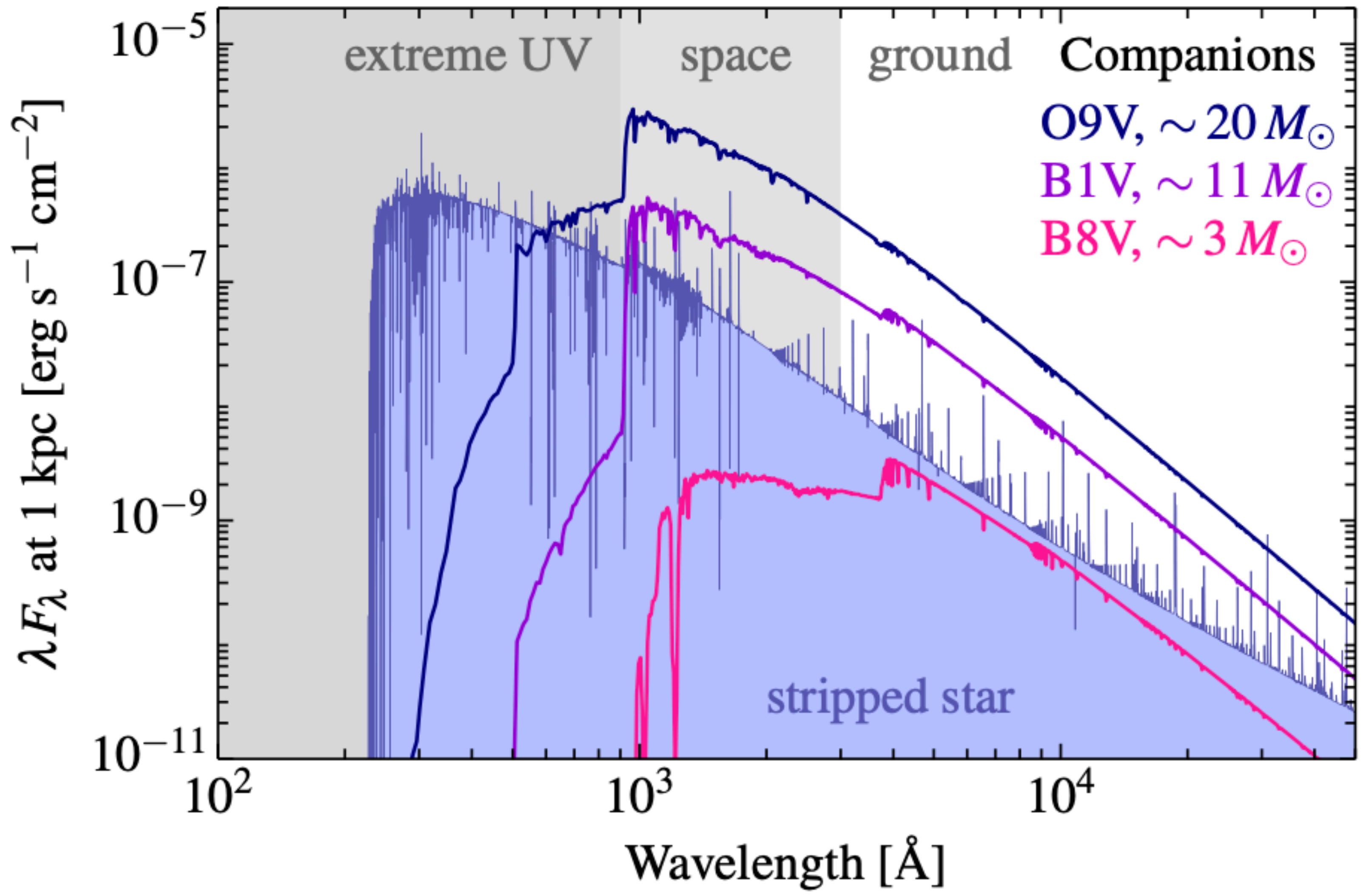




Abdul-Masih et al (2019, 2021, 2023)

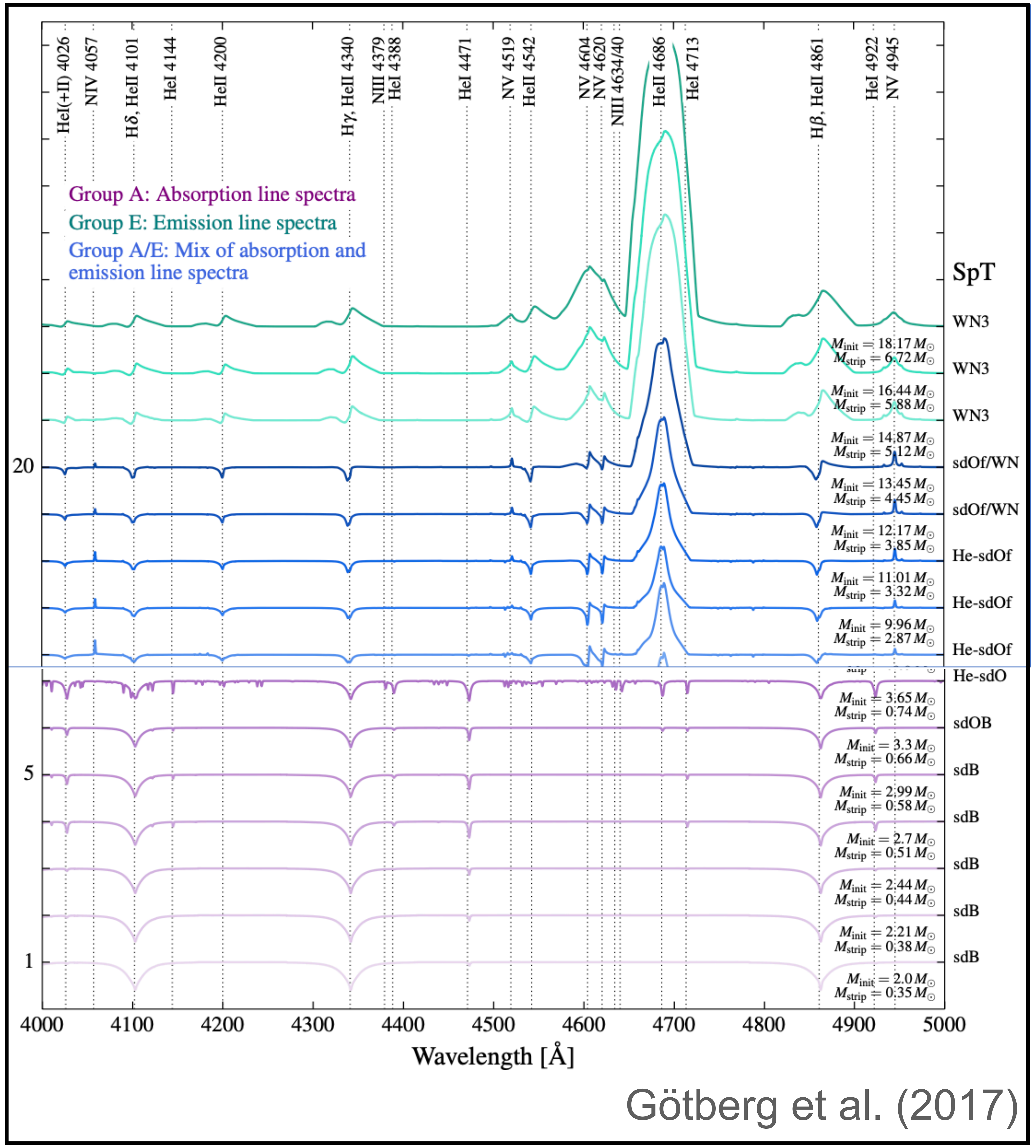
Stripped stars



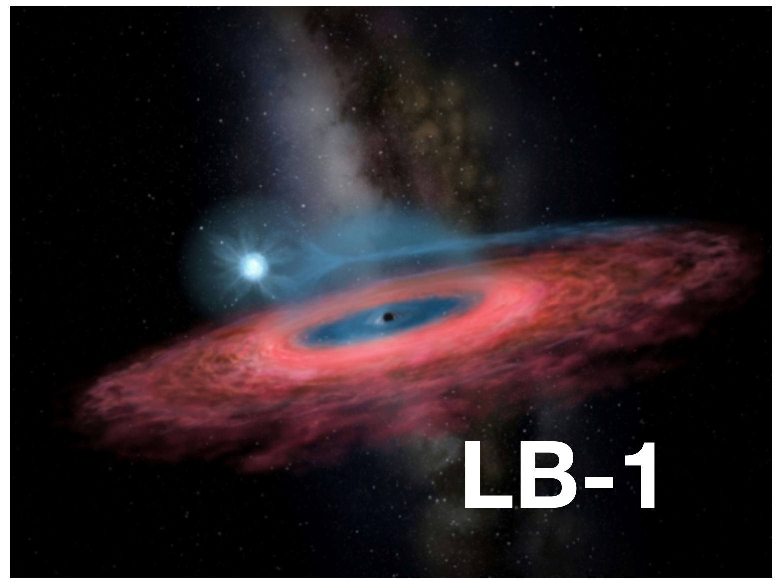


Spectral characteristics ranging from sdB- to Wolf-Rayet-like depending on the stripped star mass

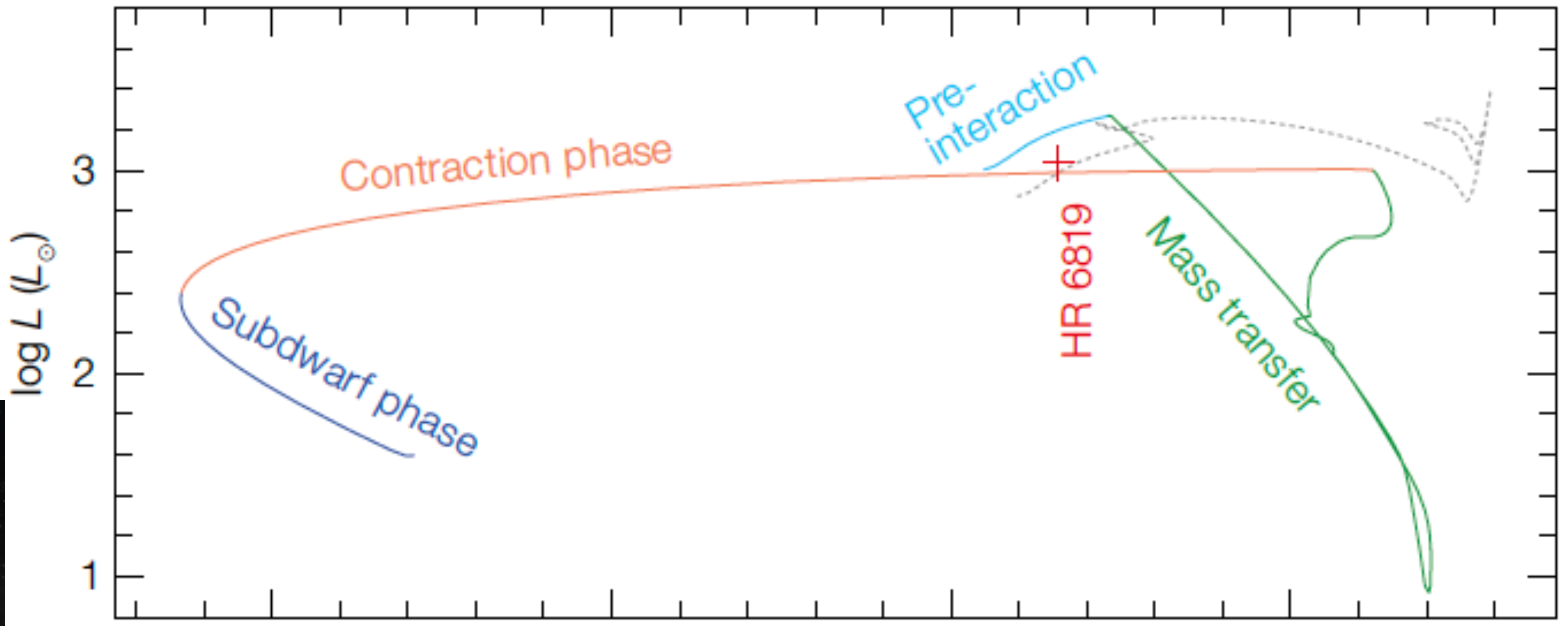
- Hot (40+kK) and compact (~1Rsun or less)
- Different (pre-supernova) stellar core structure
  - Different yields
  - Different explodability
- Strong ionising flux
- Relatively frequency (several 10^3-10^5 in Milky-Way like SF rate)
- Dominate EUV of young starbursts

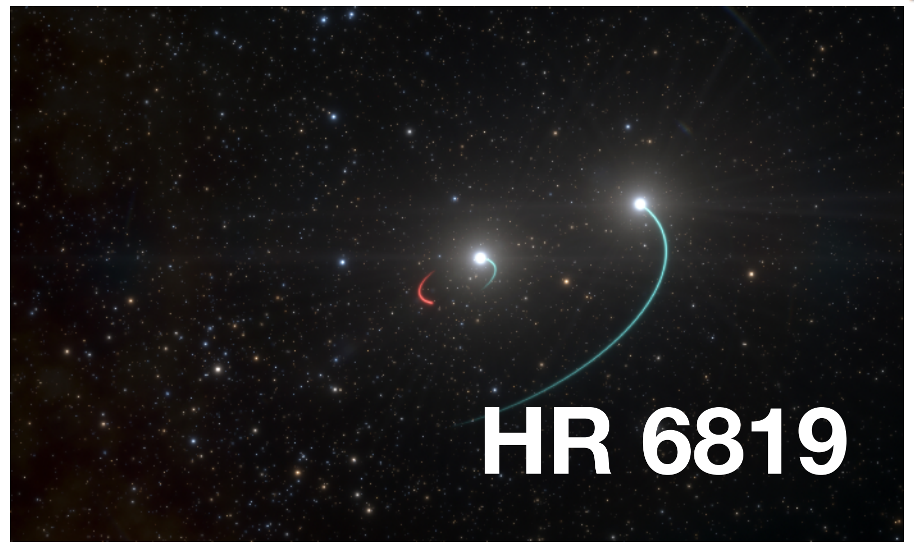


Stripped stars



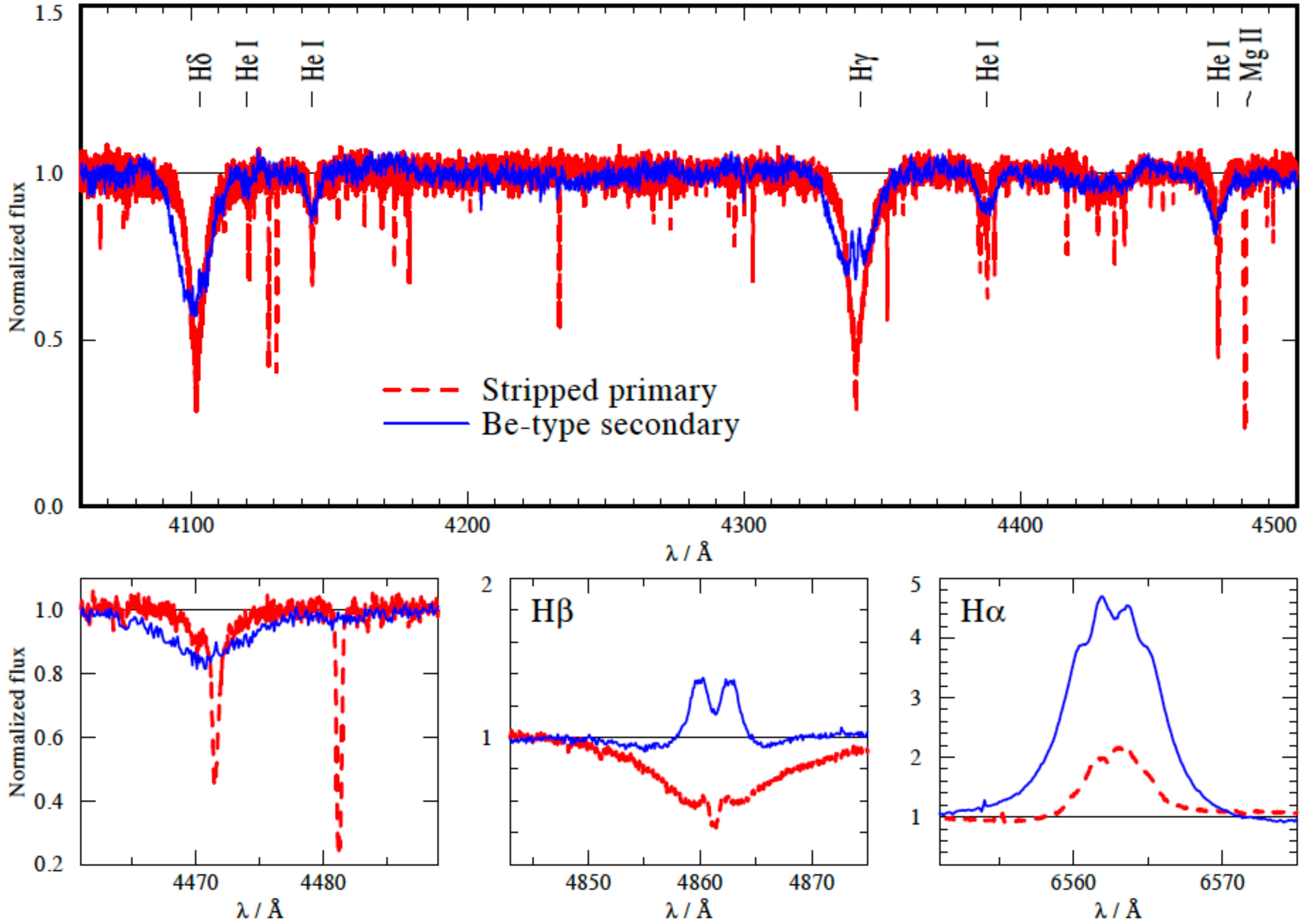
"70 Msun stellar-mass Black hole"

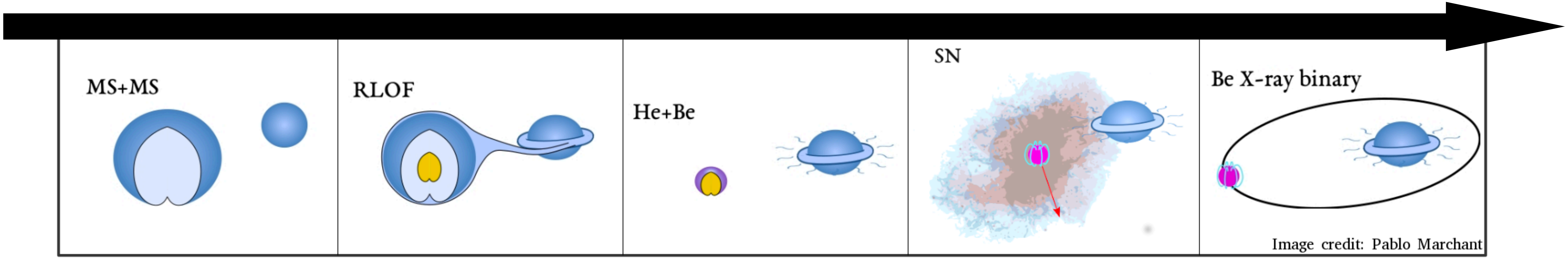




"A naked-eye triple system with a non-accreting black hole in the inner binary"

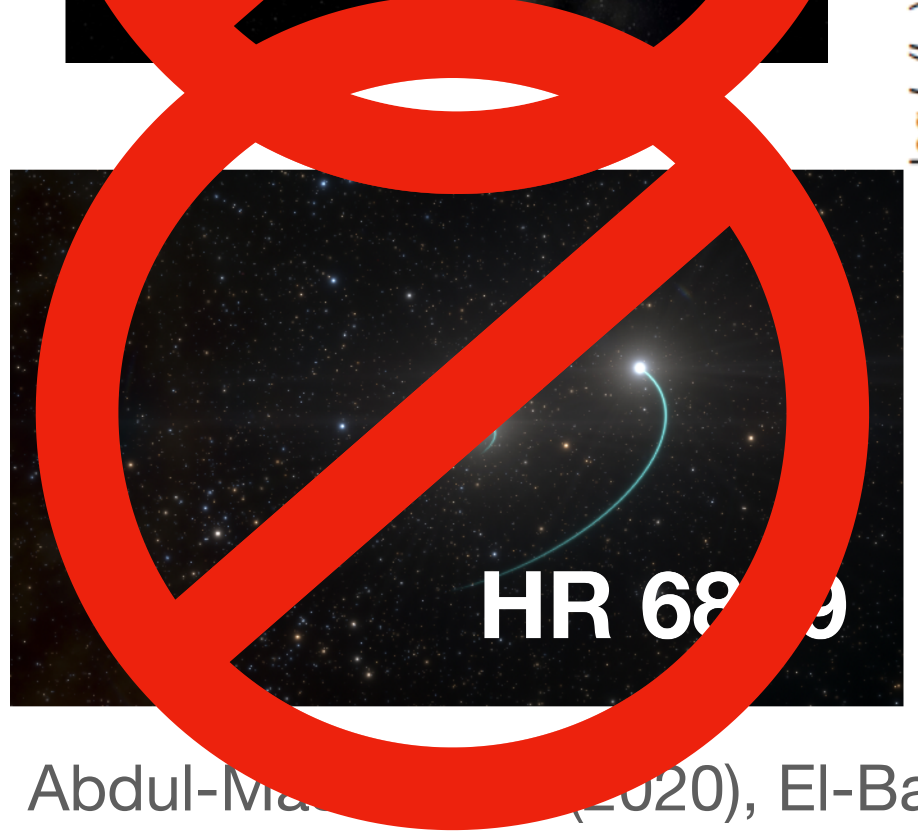
Abdul-Masih et al. (2020), El-Badry et al. (2020), Shenar et al. (2020), Bodensteiner et al. (2021), Frost et al. (2022), Simon-Diaz et al. (2020), among others

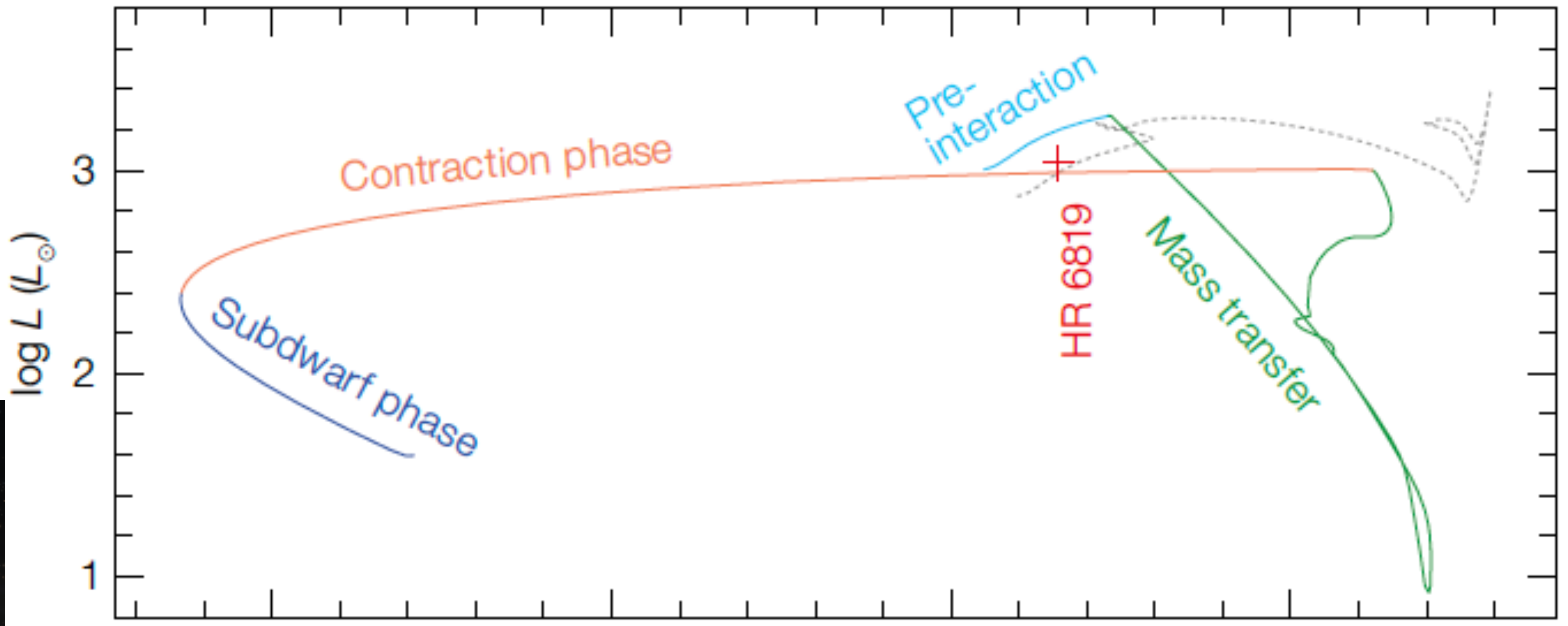




Stripped stars

“70 Msun stellar-mass Black hole”





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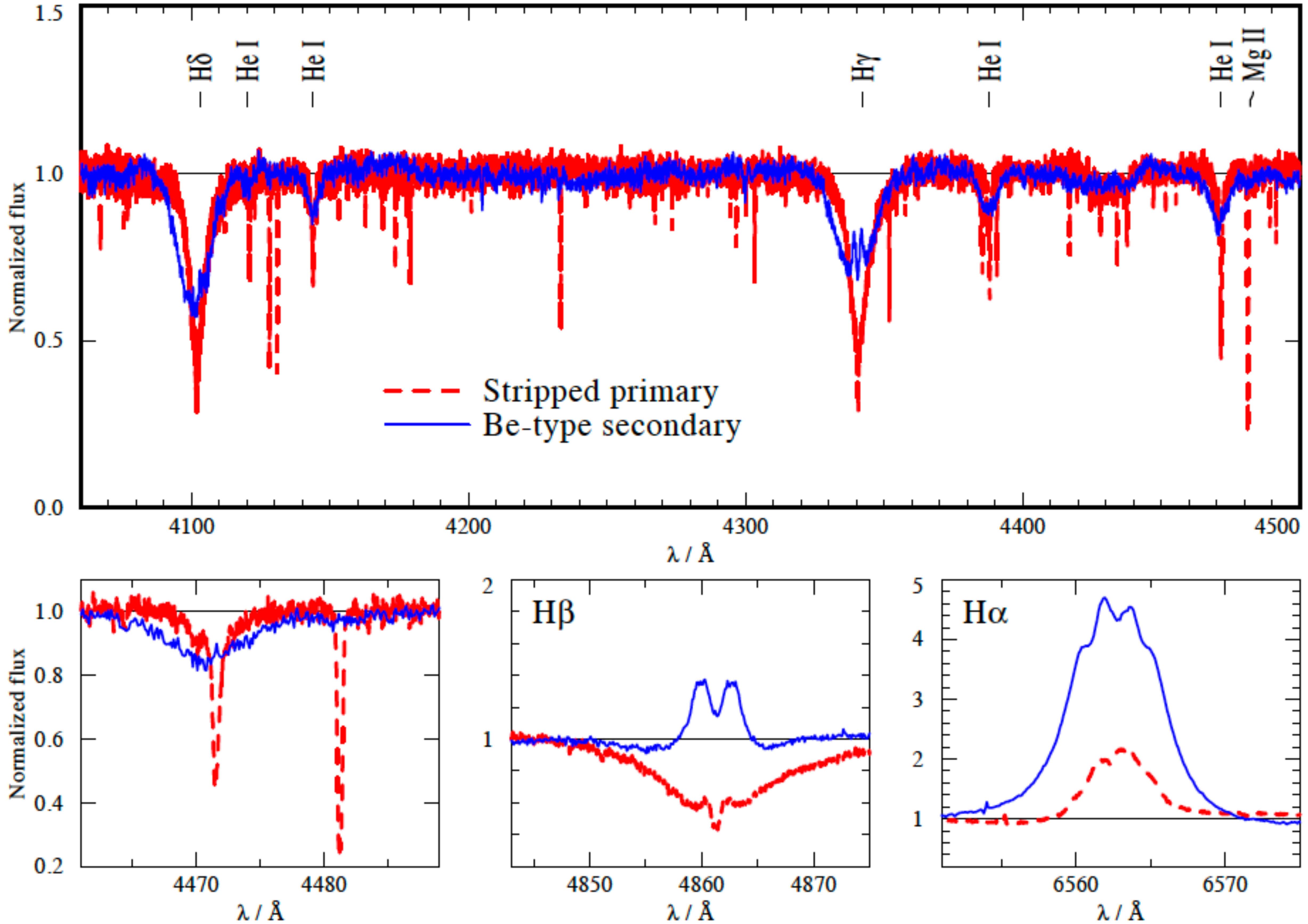
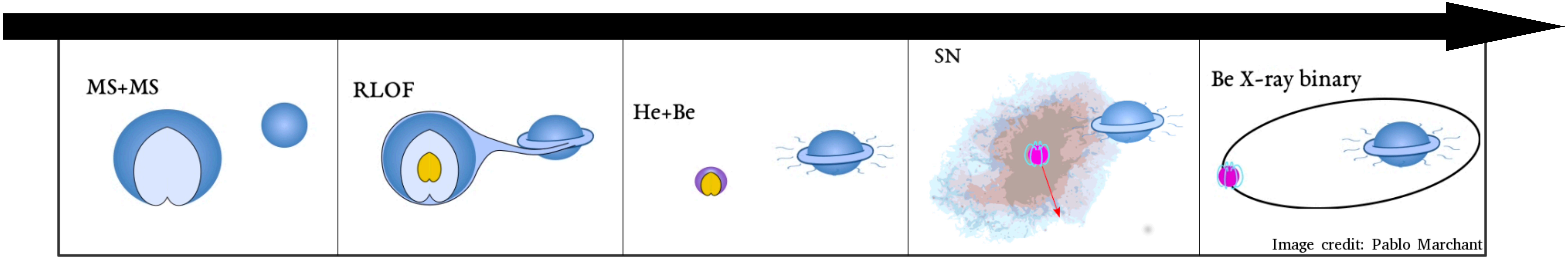
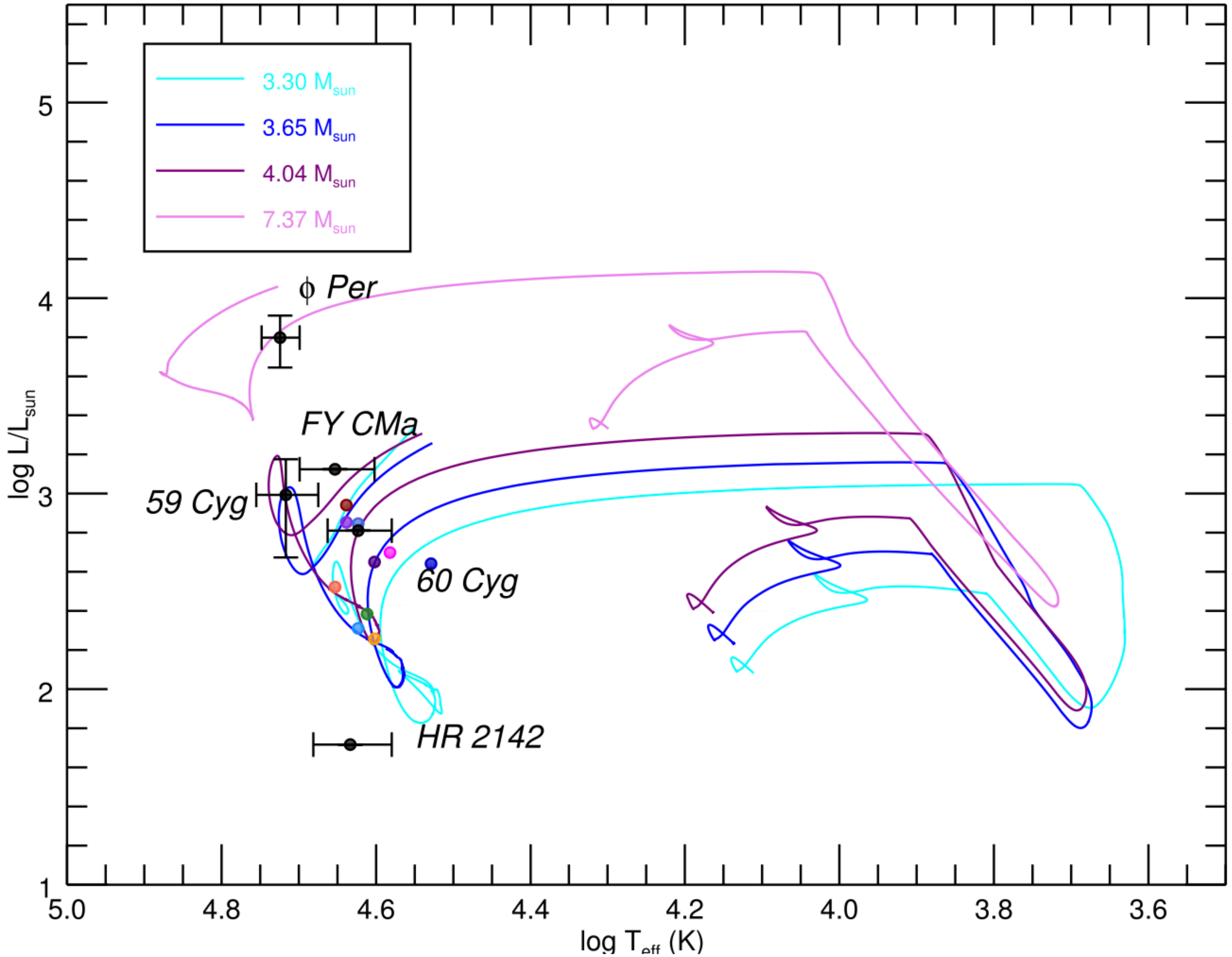


Shenar et al. (2020)



Stripped stars



So far ~15 detection

out of ~140 massive Be stars (B0-B3) → 12%

What about the rest?

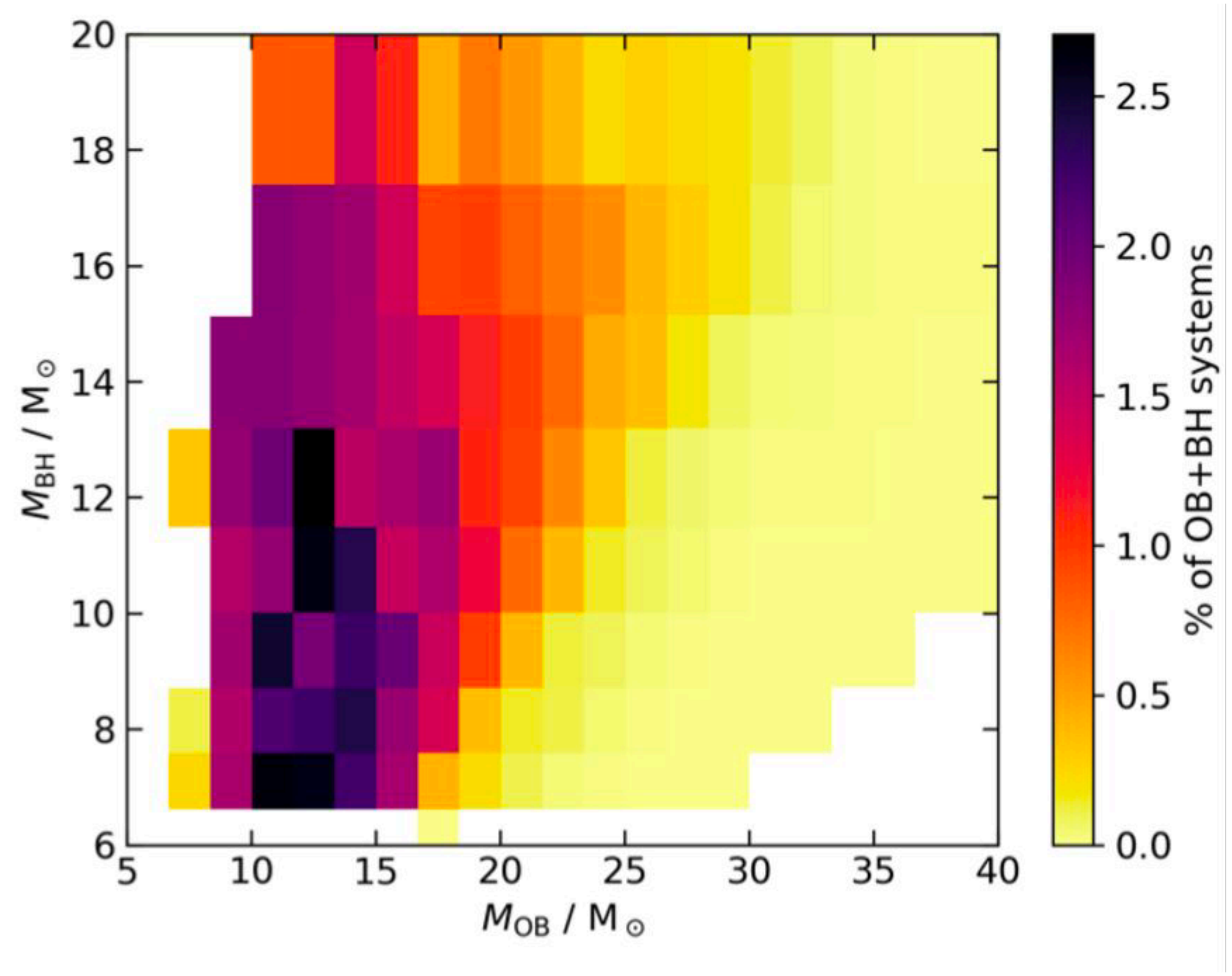
- Binary disruption (RW)
- He star has exploded
- Too faint

Wang et al. (2021)

Quest of quiescent BHs

Direct collapse (no mass loss) and no kick:
Predicted 2% of OB binaries with BH

Langer et al. (2020)



- ~1200 OB+BH in the Milky Way, handful within 3kpc
- ~ 15 OB+BH in 30 Doradus, Large Magellanic Cloud (LMC)

Quest of quiescent BHs

Milky way sample

32 SB1 systems Mahy et al. 2022

- Archive + new Mercator & SALT data (Mercator, ESO, SALT, …)
- High-Res, S/N > 100

17 identified stellar companions (news SB2s)

Tarantula sample (LMC)

51 SB1 systems Shenar et al. 2022a,b

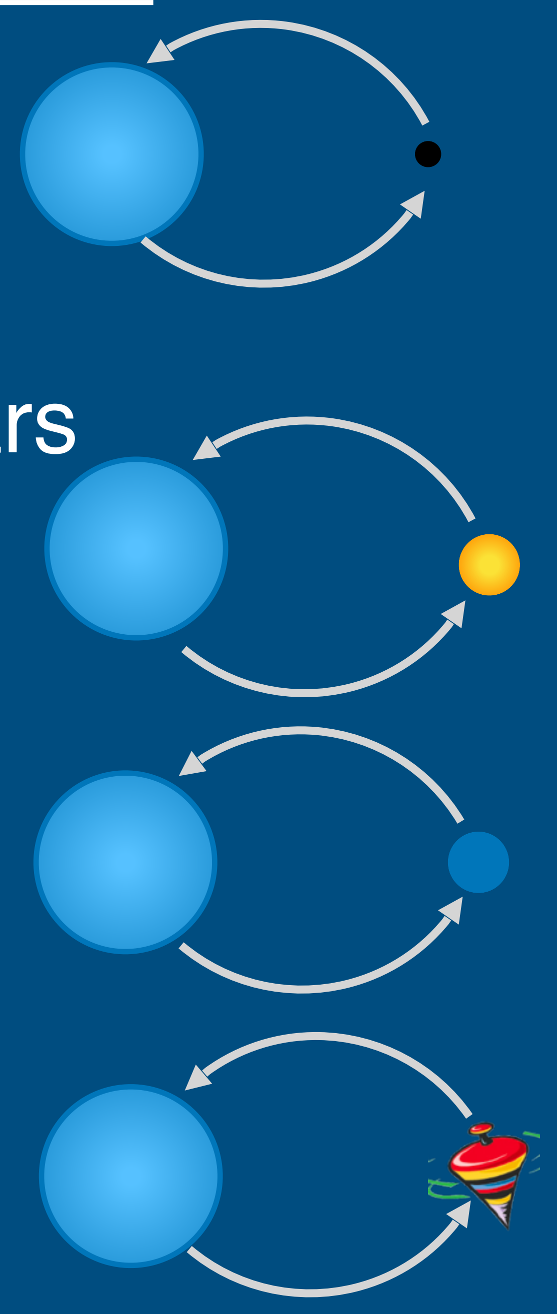
- Tarantula Massive Binary Monitoring (32 epochs VLT/FLAMES)
- Mid-Res, S/N ~ 70

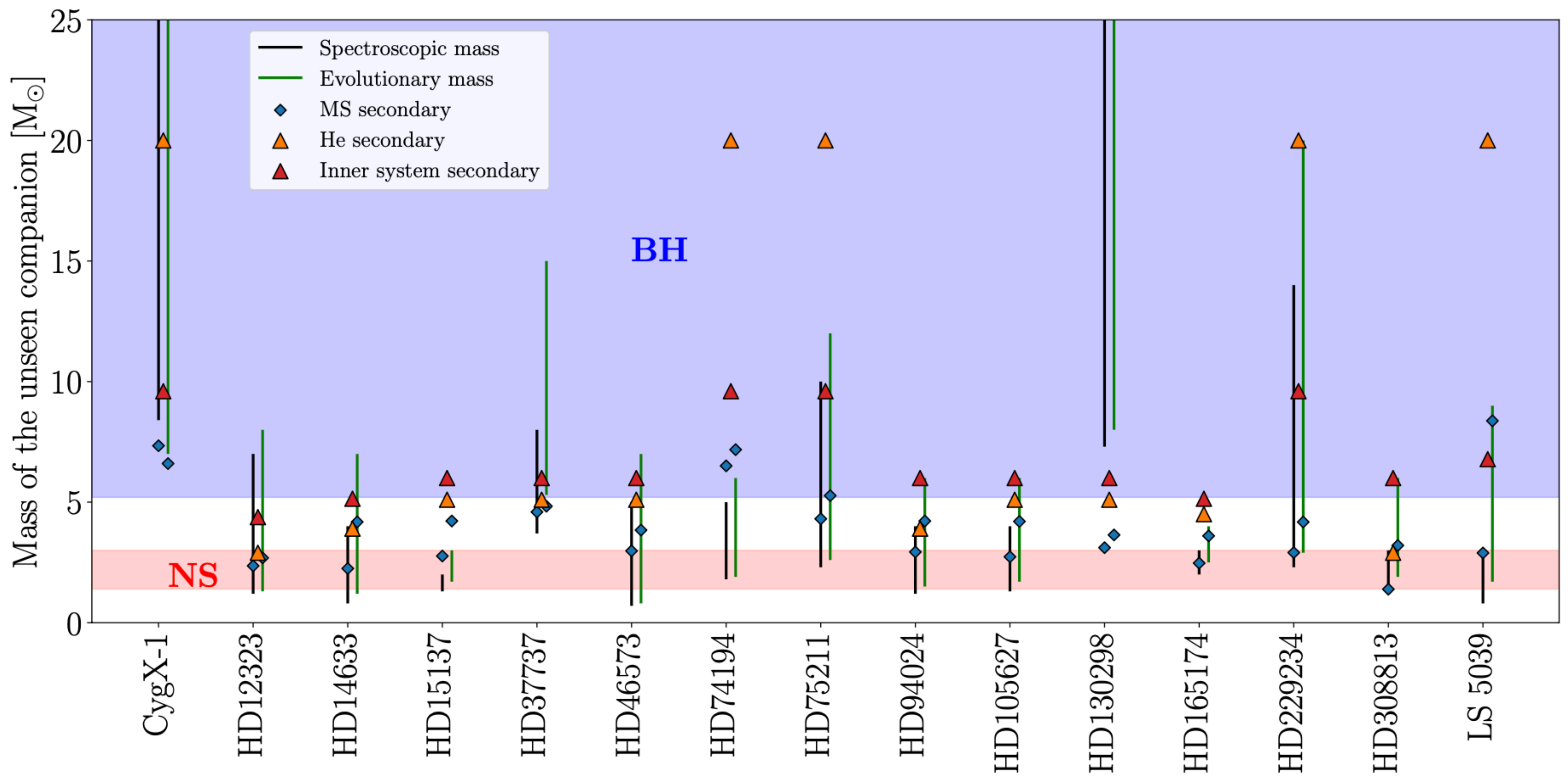
33 identified stellar companions

10 doubtful cases

Companion might be:

- Compact object
- (very) Low mass stars
- Stripped He-star
- Rapid rotator





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https://doi.org/10.1038/s41550-022-01730-y
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An X-ray-quiet black hole born with a negligible kick in a massive binary within the Large Magellanic Cloud

Tomer Shenar[1,2], Hugues Sana[1], Laurent Mahy[1,3], Kareem El-Badry[4,5,6], Pablo Marchant[1], Norbert Langer[7,8], Calum Hawcroft[1], Matthias Fabry[1], Koushik Sen[7,8], Leonardo A. Almeida[9,10], Michael Abdul-Masih[11], Julia Bodensteiner[12], Paul A. Crowther[13], Mark Gieles[14,15], Mariusz Gromadzki[16], Vincent Hénault-Brunet[17], Artemio Herrero[18,19], Alex de Koter[1,2], Patryk Iwanek[16], Szymon Kozłowski[16], Daniel J. Lennon[18,19], Jesús Maíz Apellániz[20], Przemysław Mróz[16], Anthony F. J. Moffat[21], Annachiara Picco[1], Paweł Pietrukowicz[16], Radosław Poleski[16], Krzysztof Rybicki[16,22], Fabian R. N. Schneider[23,24], Dorota M. Skowron[16], Jan Skowron[16], Igor Soszyński[16], Michał K. Szymański[16], Silvia Toonen[2], Andrzej Udalski[16], Krzysztof Ulaczyk[25], Jorick S. Vink[26] and Marcin Wrona[16]

Quest of quiescent BHs

HD130298:

O+BH: 25 + (>) 7M☉ with P = 14.6 days and e = 0.46

Large kick + large mass ejecta (< 8 M☉)

BH formation through fallback/with kick

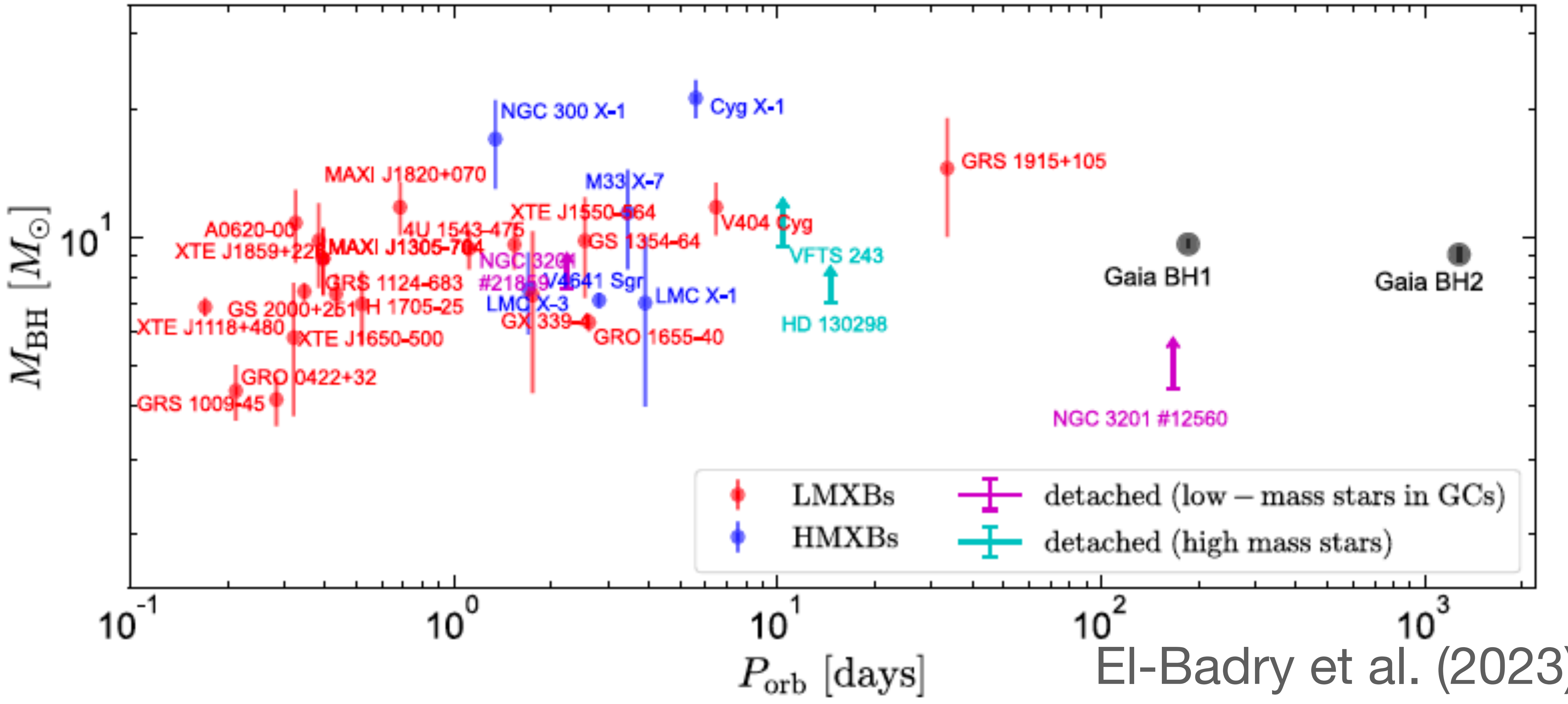
VFTS 243:

O+BH: 25 + 10 M☉ with P = 10.4 days and e < 0.03

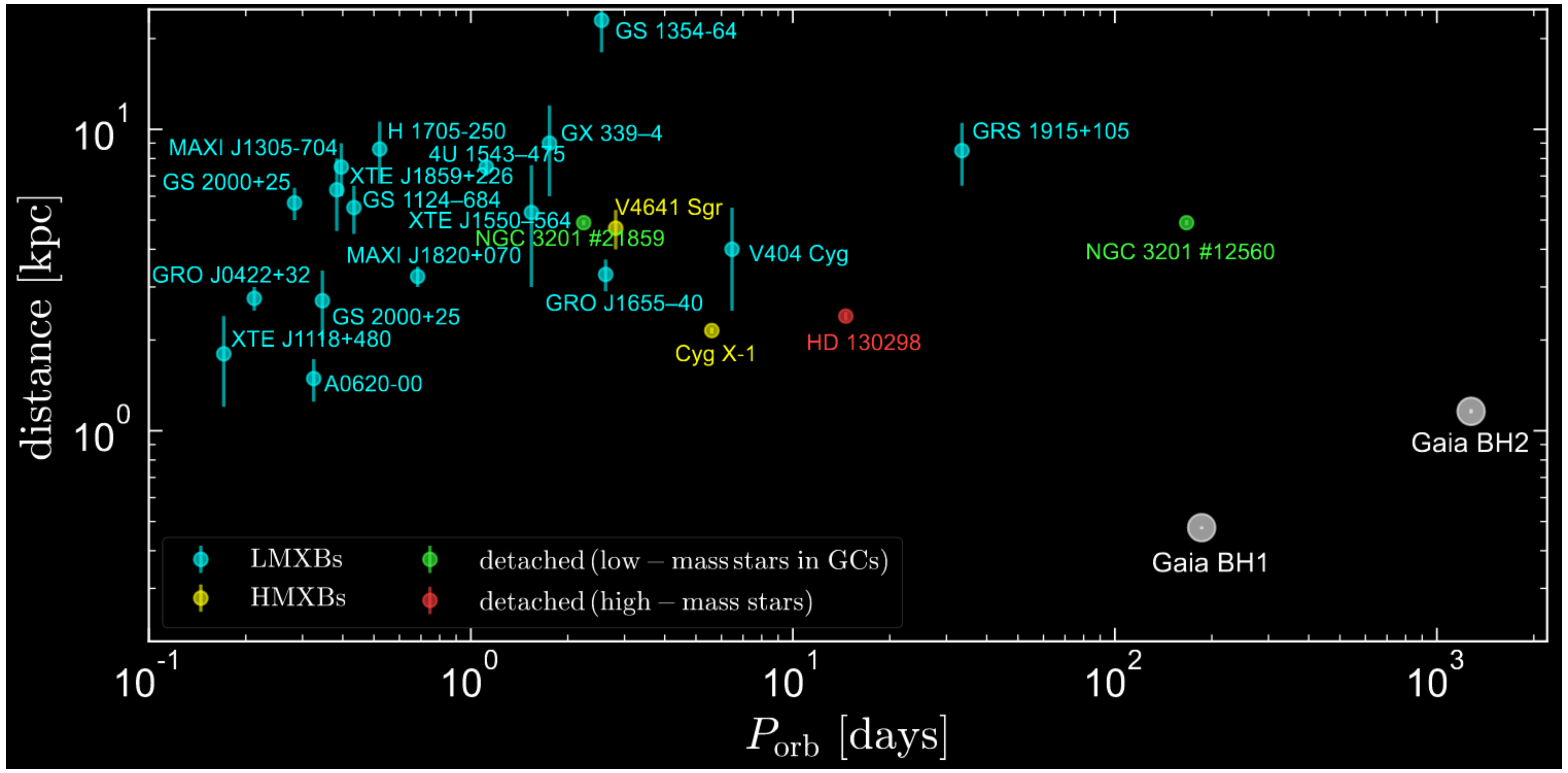
No kick + Mass ejecta (< 1.1 M☉)

BH formation through direct collapse

Marchant et al. (in prep.)



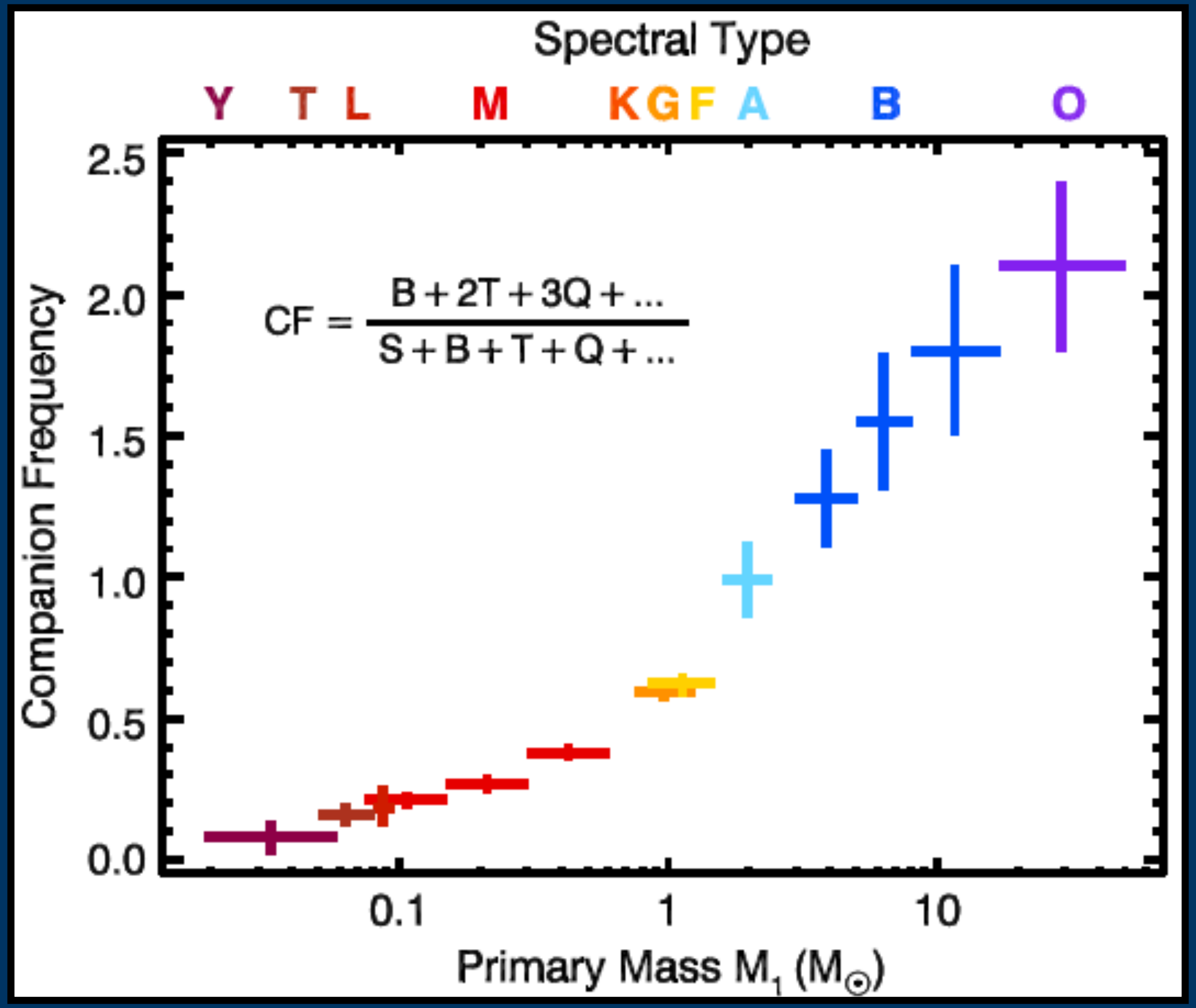
El-Badry et al. (2023)



The Gaia revolution

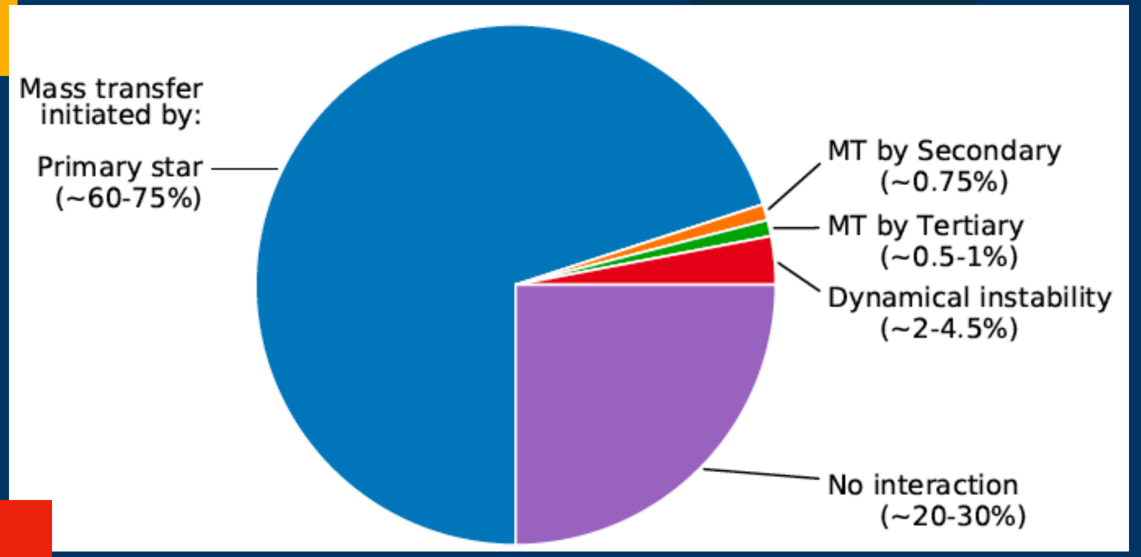
Gaia, up to DR4, was not well suited for massive stars !

Discovery of more binary/triple/quadruple systems with photometry and astrometry

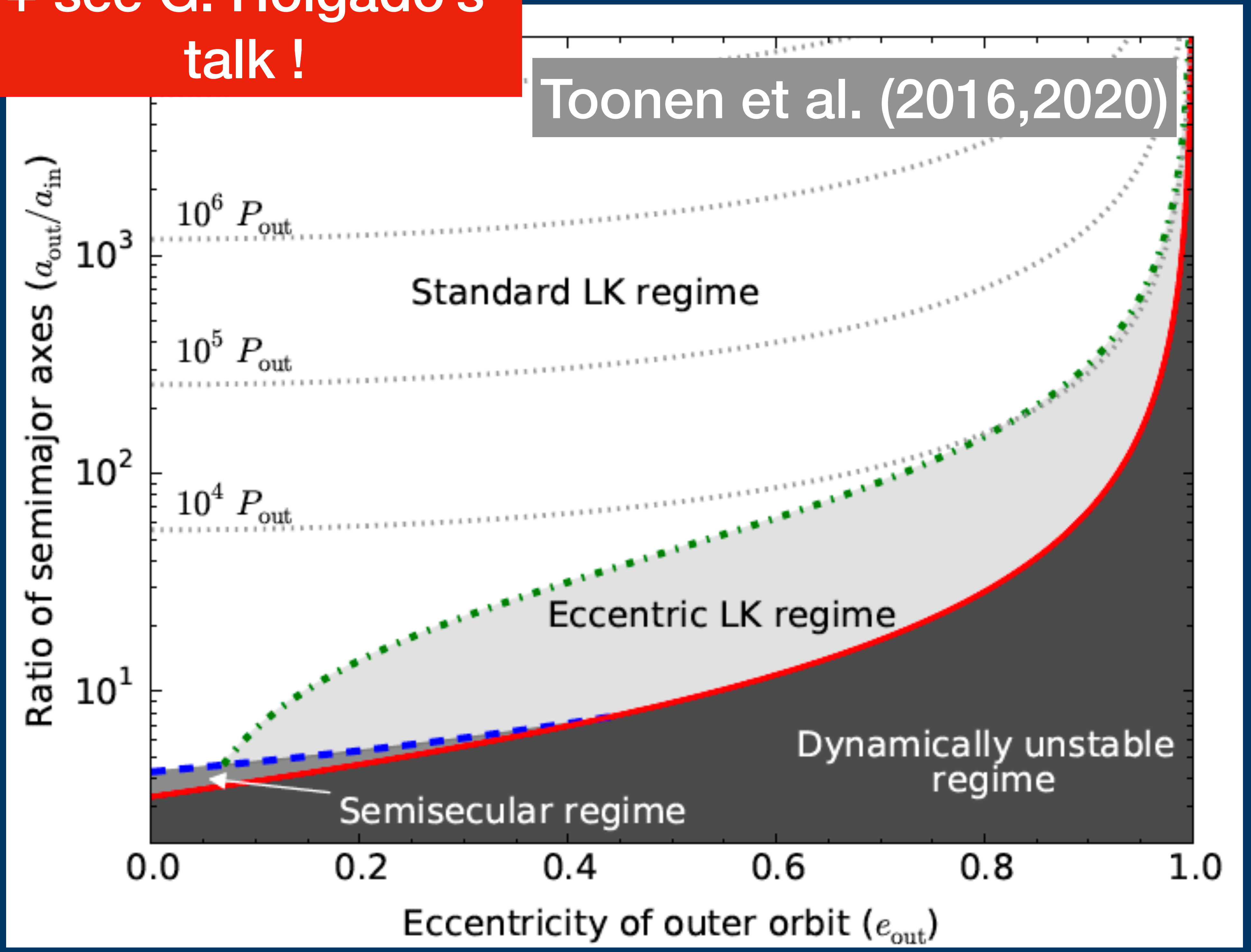


Better characterisation of the Kozai-Lidov mechanism

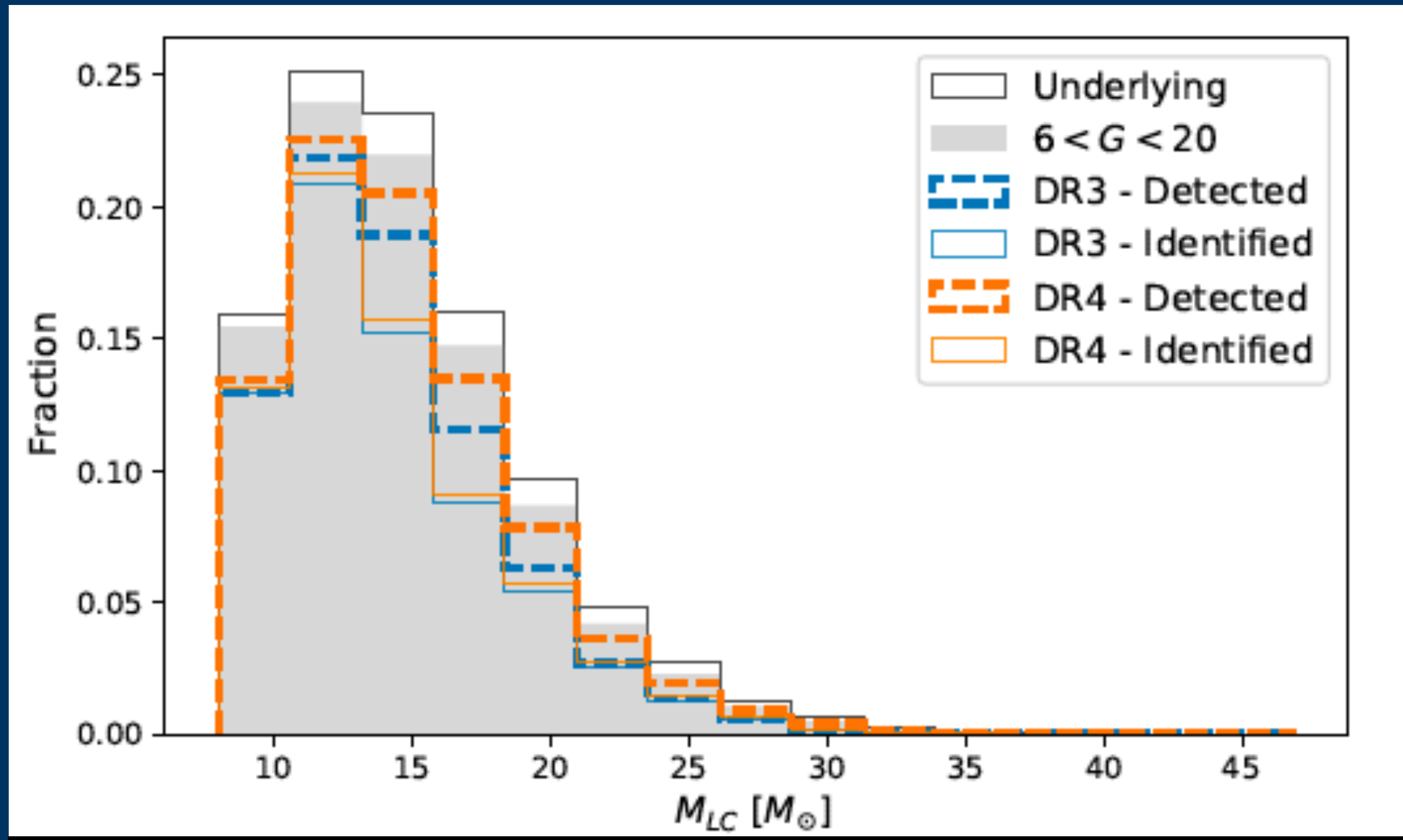
Understand the way triples evolve

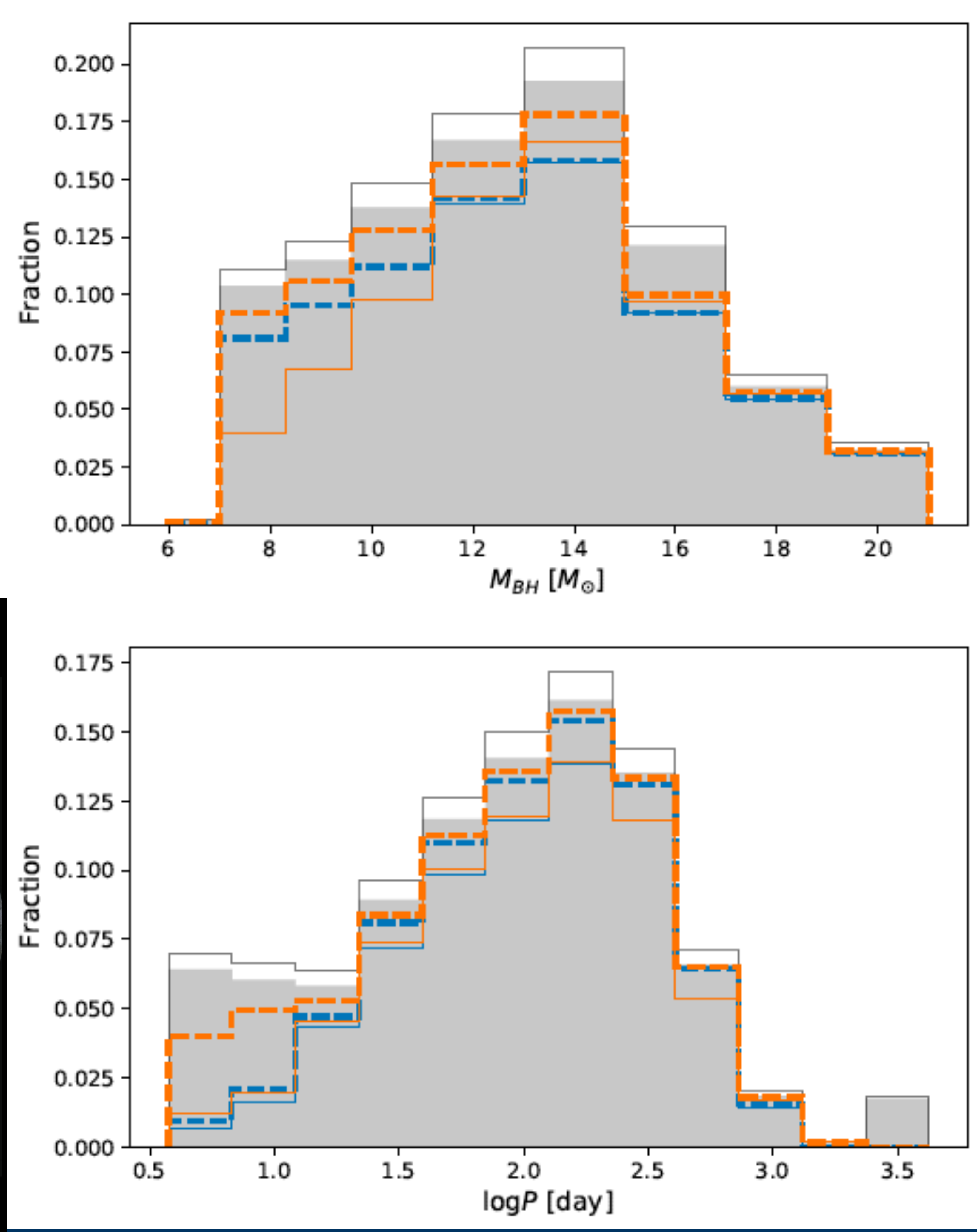


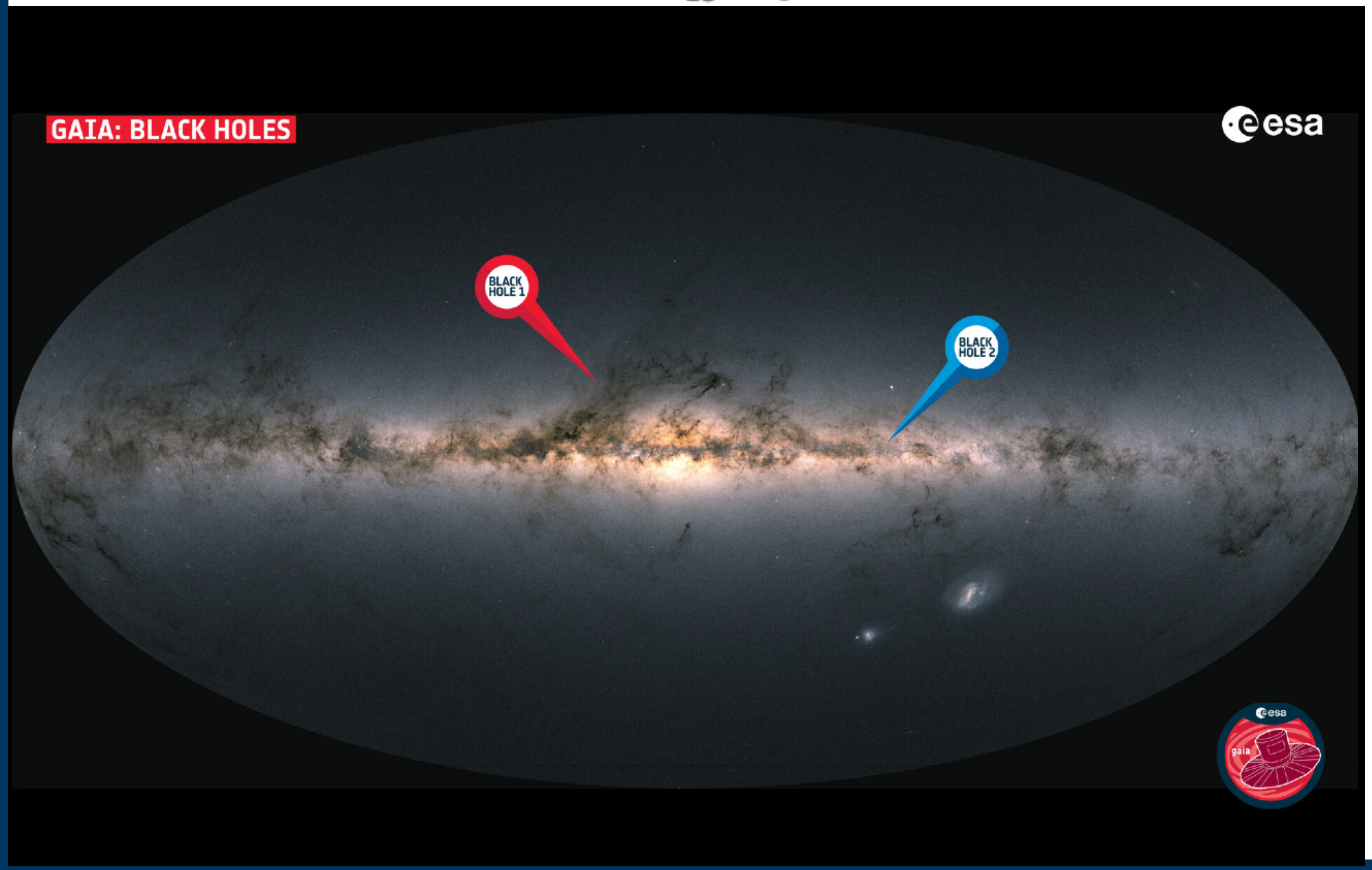
+ see G. Holgado's talk !



The Gaia revolution



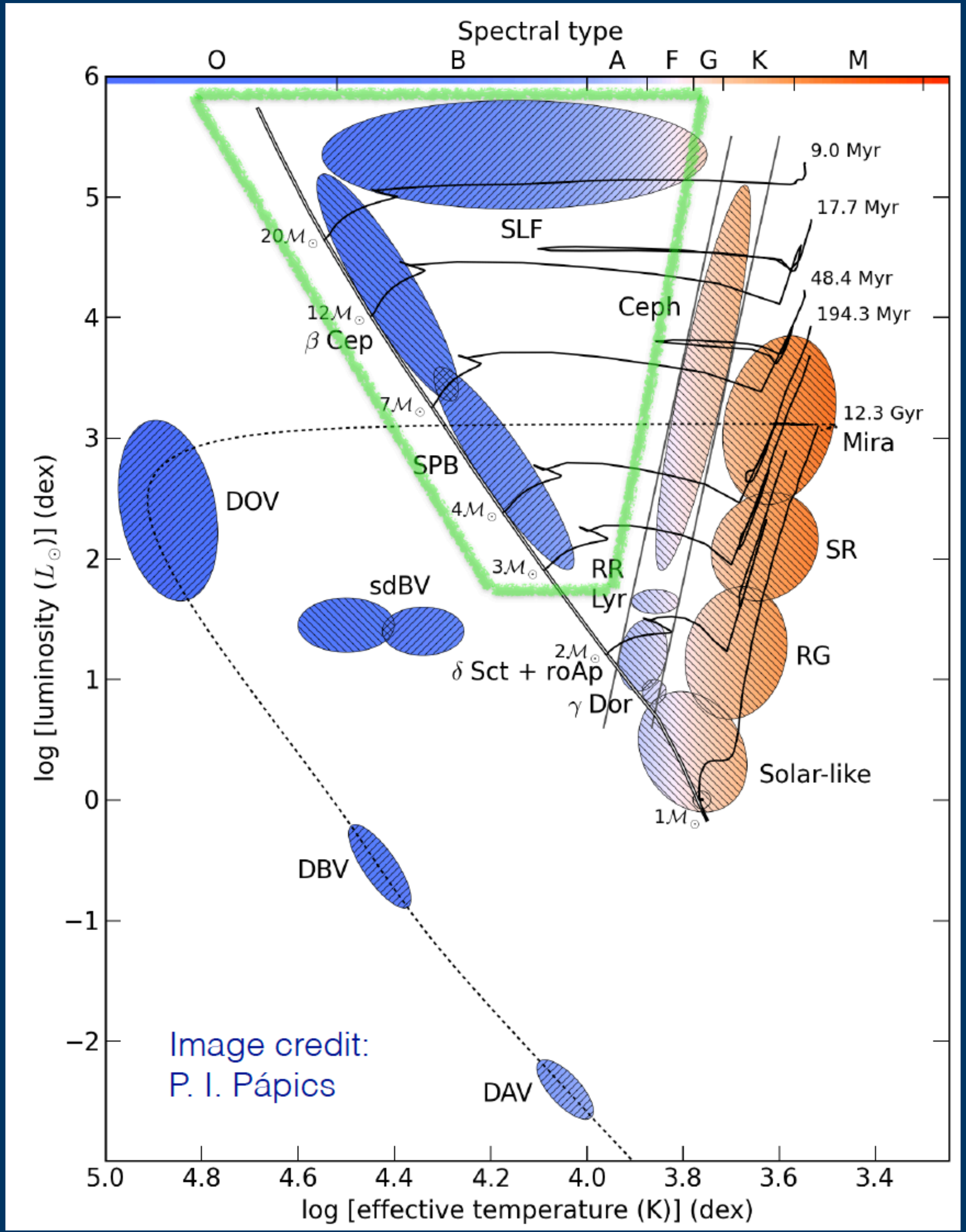




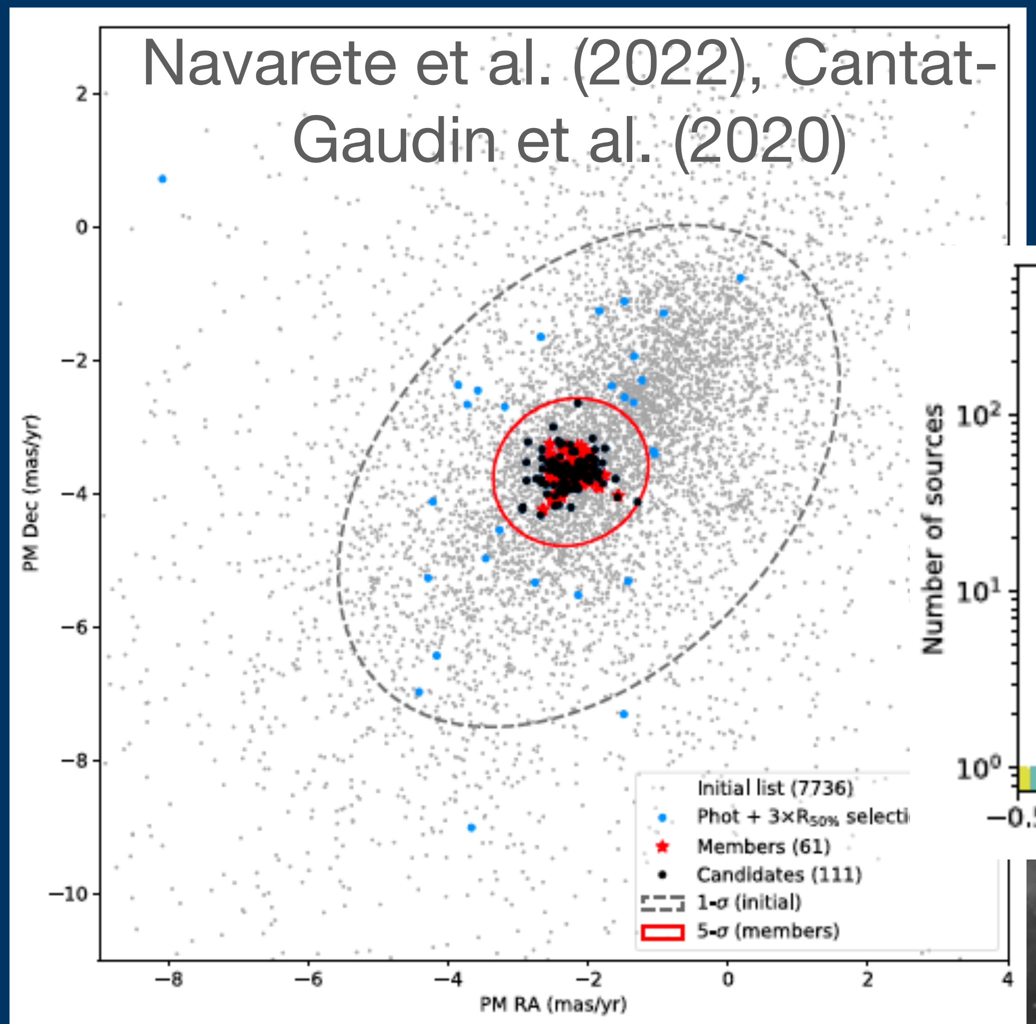
Found more nearby dark companions

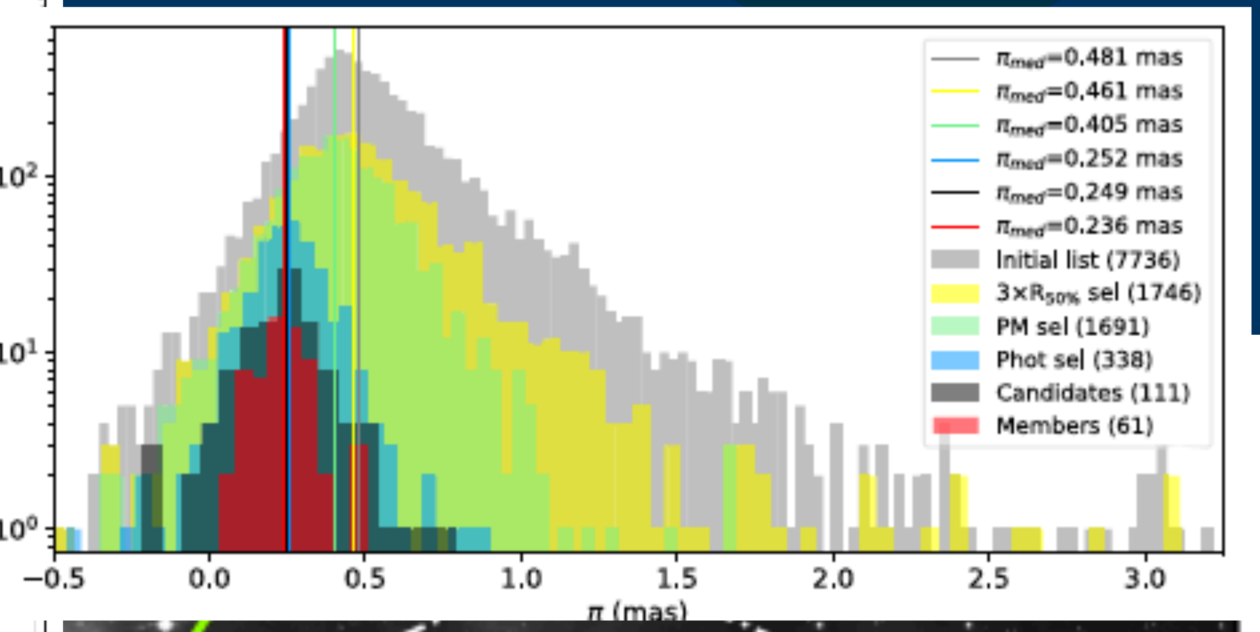
Janssens et al. (2022), Gomel et al. (2021), Mazeh et al. (2022), El-Badry et al. (2022, 2023)

The Gaia revolution



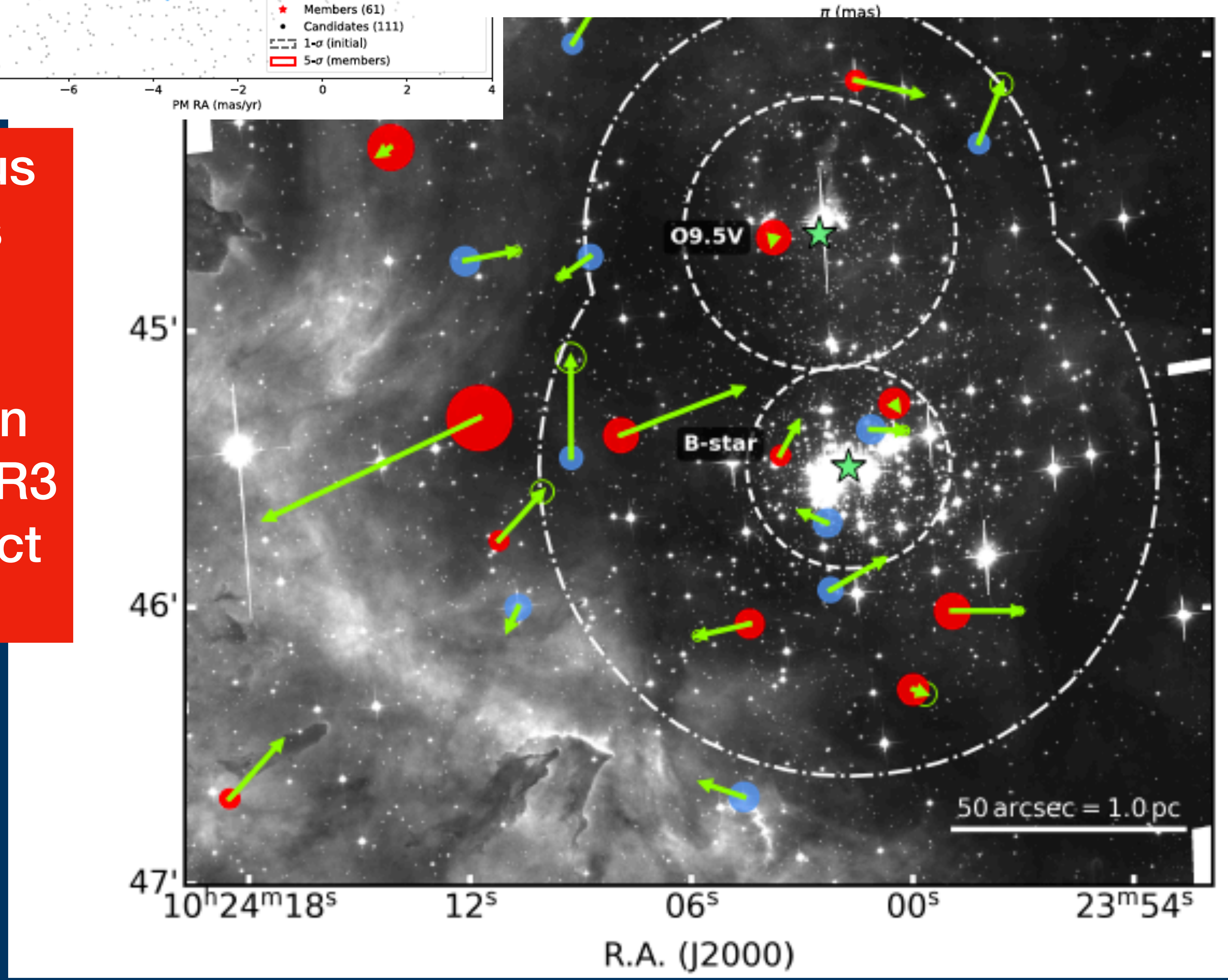
Kinematics in clusters





+Also check Jesus Maiz Apellaniz's paper (2022):

"The Gaia view on massive stars: EDR3 and what to expect from DR3"



Asteroseismology

Massive binaries in the Gaia era

Laurent Mahy
Royal Observatory of Belgium

Stellar variability, stellar multiplicity: periodicity in time & motion - June 6-8th, Sofia, Bulgaria