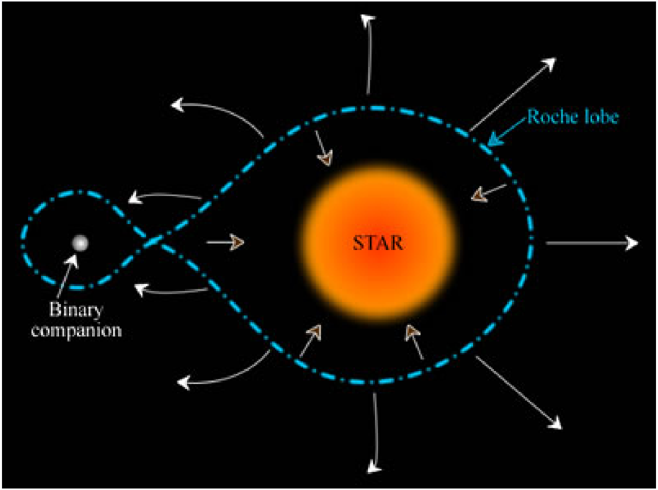
Constraining the stability of mass transfer

Veronika Schaffenroth

Binary and Multiple Stars in the Era of Big Sky Surveys,
Litomyšl, 10.9.24

Thüringer Landessternwarte Tautenburg

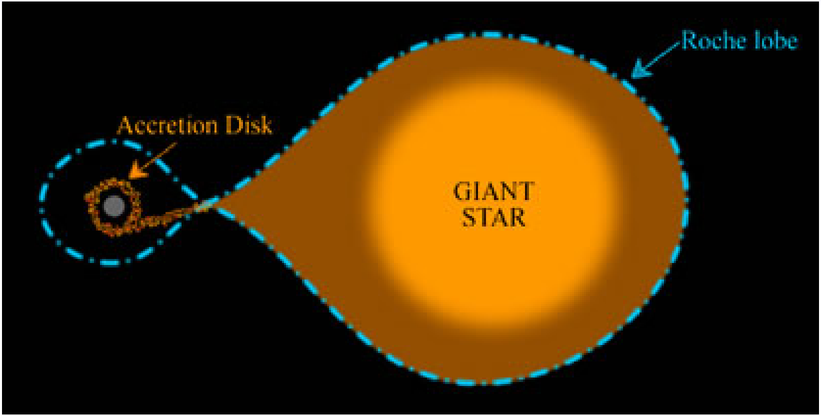
Mass transfer – Roche lobe



https://astronomy.swin.edu.au/cosmos/R/Roche-lobe

$$\frac{r_{\mathrm{L},1}}{a} = \frac{0.49q^{2/3}}{0.6q^{2/3} + \ln(1 + q^{1/3})}, \qquad q = \frac{M_1}{M_2} \tag{1}$$

Stable Mass transfer – Roche lobe overflow



https://astronomy.swin.edu.au/cosmos/R/Roche-lobe

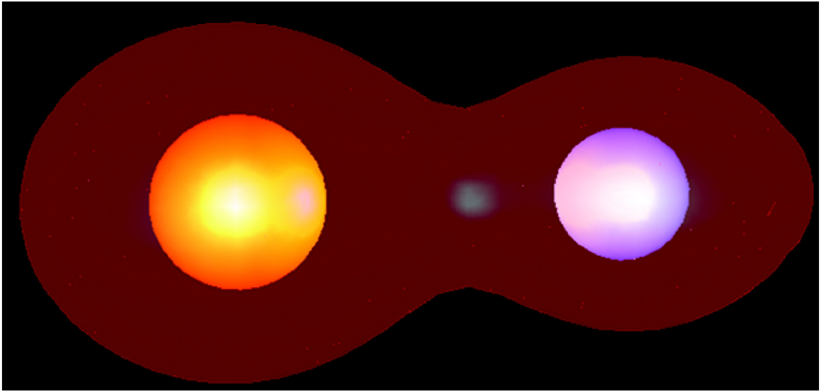
- stable mass transfer: Roche lobe overflow in close binaries with critical mass ratio:

$$q = M_{\text{donor}}/M_{\text{gainer}} < 1.2 - 1.5 \qquad \text{for low-mass stars} \qquad (2)$$

→ orbit widens

Unstable Mass transfer – Common Envelope Evolution (CEE)

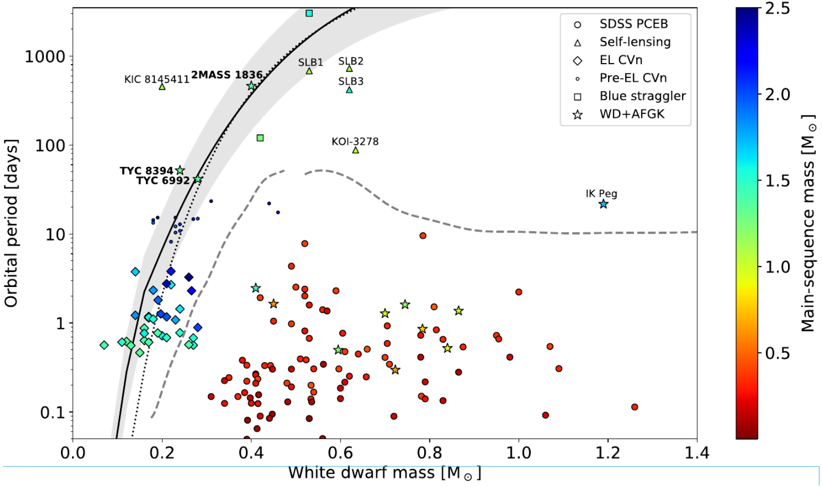
- for larger mass difference: unstable mass transfer
  $\Rightarrow$ common envelope phase



https://astrobites.org/2013/02/12/are-we-seeing-common-envelopes-after-all/cee/

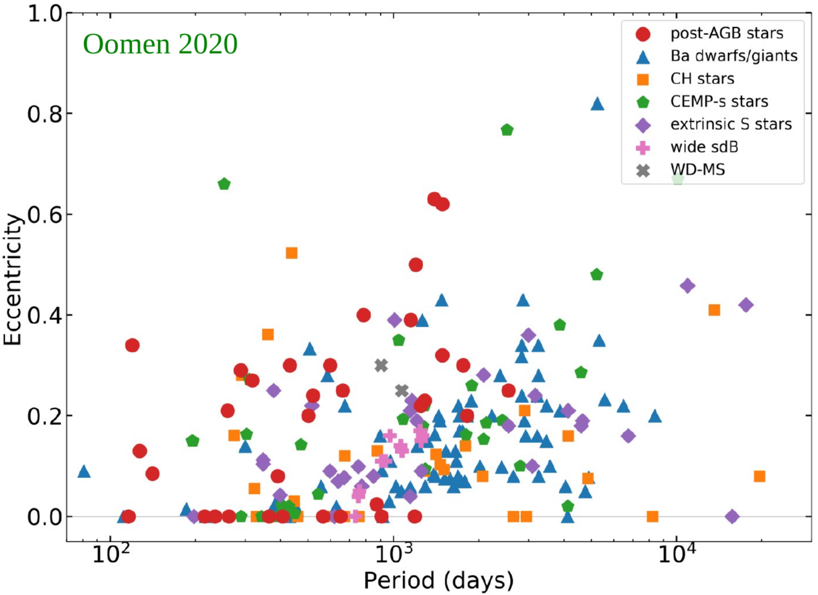
$\rightarrow$ difficult to observe directly $\rightarrow$ orbit shrinks significantly

Periods and WD masses of WD+MS binaries

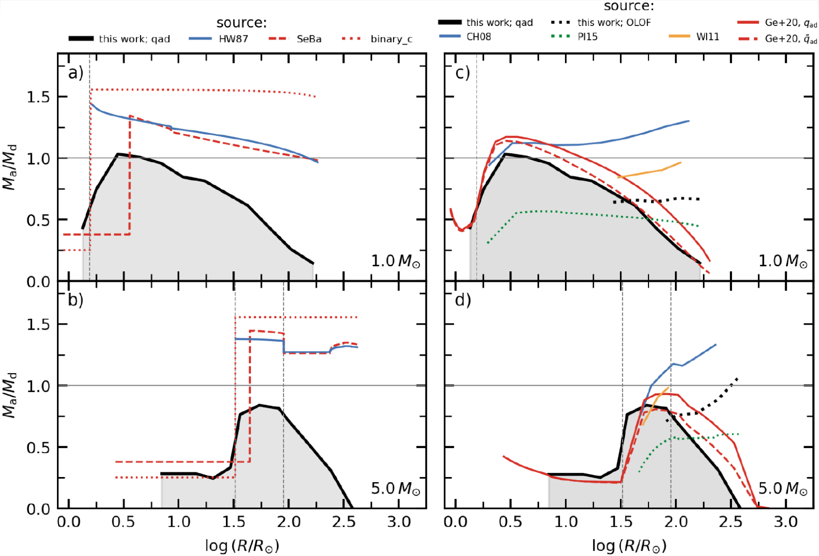


Parsons et al. 2023

Periods and eccentricity of post-AGB systems



Critical mass ratio for stable mass transfer

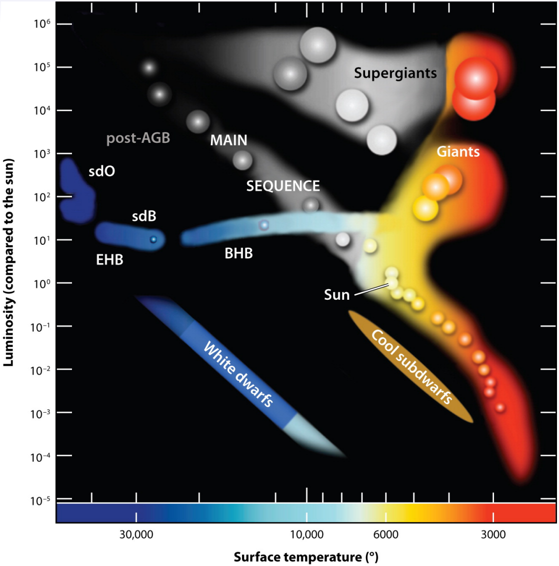


Temmink et al. 2022

→ depends on how stellar and Roche lobe radius react to mass transfer

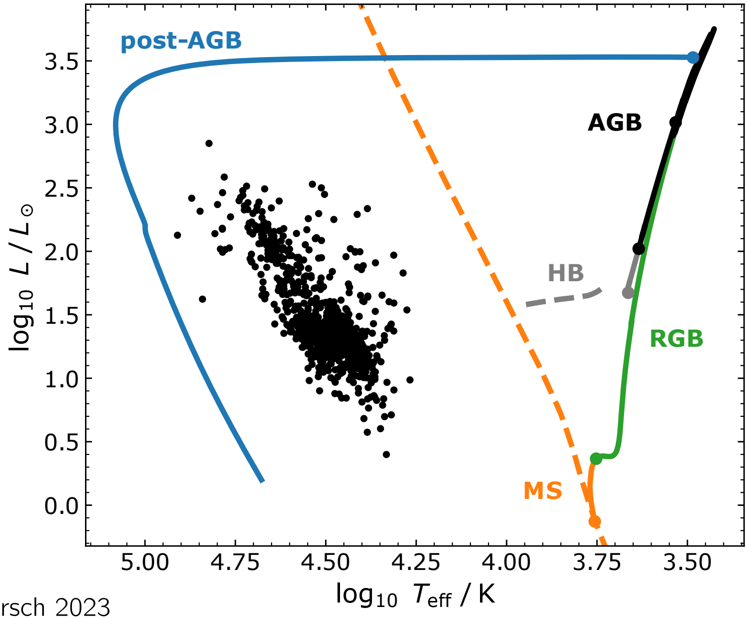
→ significant impact on binary evolution and its outcome

Hot subdwarf stars of spectral type B (sdB)



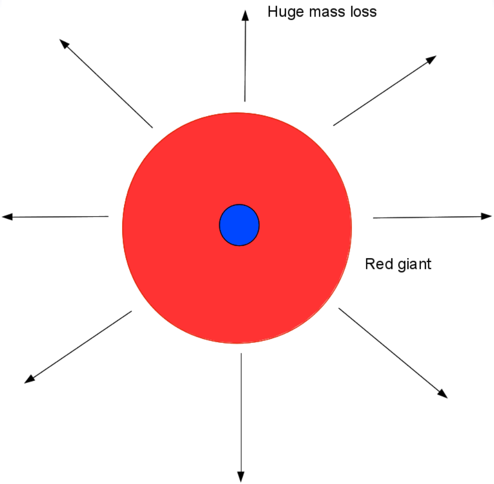
Heber U. 2009.
Annu. Rev. Astron. Astrophys. 47:211–51

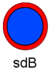
Hot subdwarf stars of spectral type B (sdB)



Dorsch 2023

Stripped red giant at the tip of the RGB



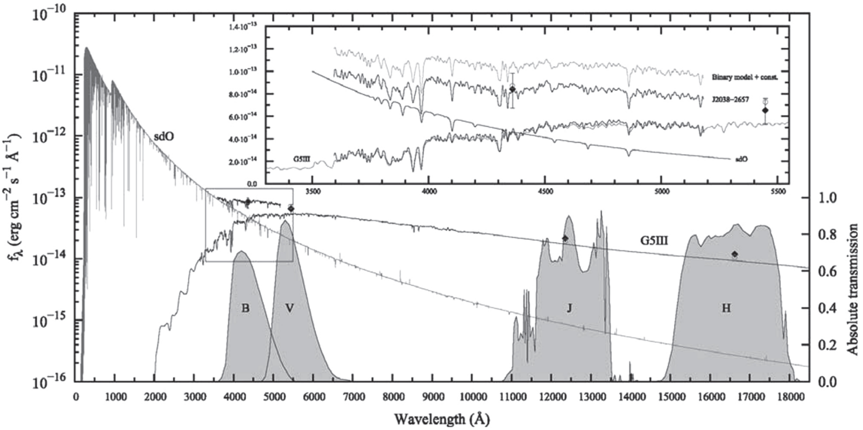


in He-core burning phase

direct observation,
e.g., Maxted, .., Schaffenroth 2013, Nature

→ binary interaction required

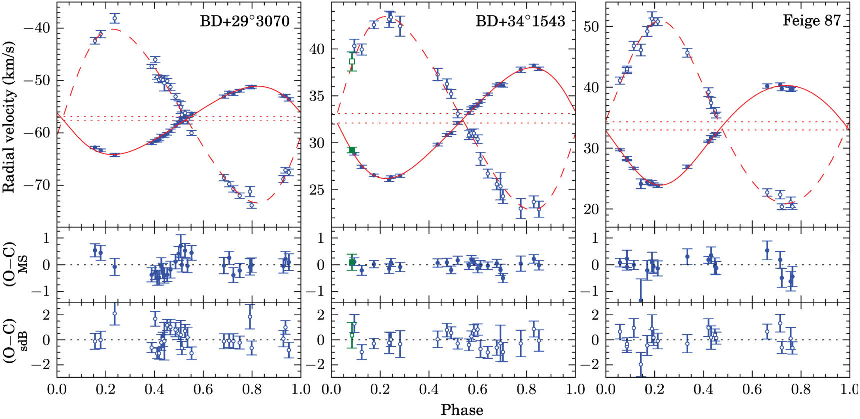
Hot subdwarfs in wide binaries (sdO/B+F/G/K)



Nemeth et al. (2012)

→ 1/3 of all sdB show an infrared excess in the spectral energy distribution, many of them are composites

RV variation of composite sdBs

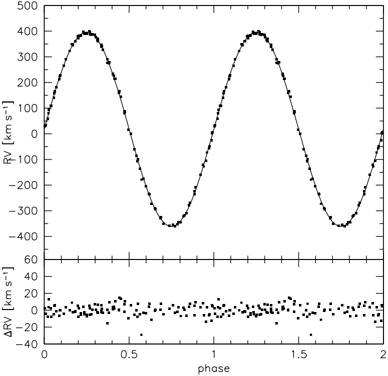


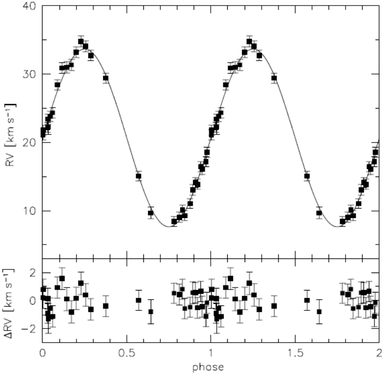
Vos et al. (2013)

→ currently 23 sdB+F/G/K binaries with solved orbits + two sdO+F/G binaries (P = 500 to 1800 days), post-RLOF systems

Hot subdwarfs in close binaries

unseen companion discovered by radial velocity method





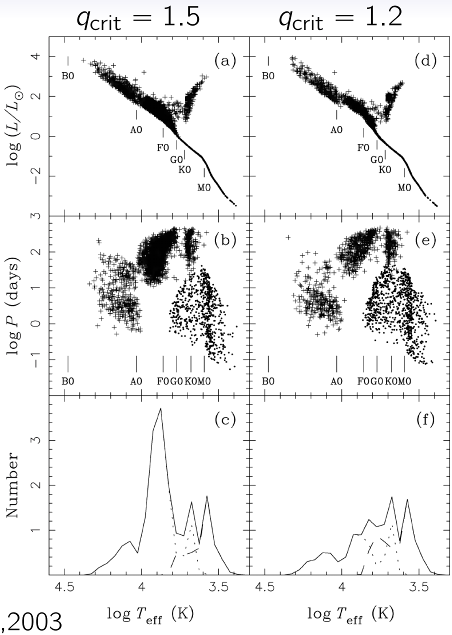
CD-30°1122, $P = 0.0498$ d
(Geier,.., Schaffenroth et al. 2013)

PHL 457, $P = 0.3131$ d
(Schaffenroth et al. 2014)

about 1/3 of sdBs in close binaries ($P < 30$ d)

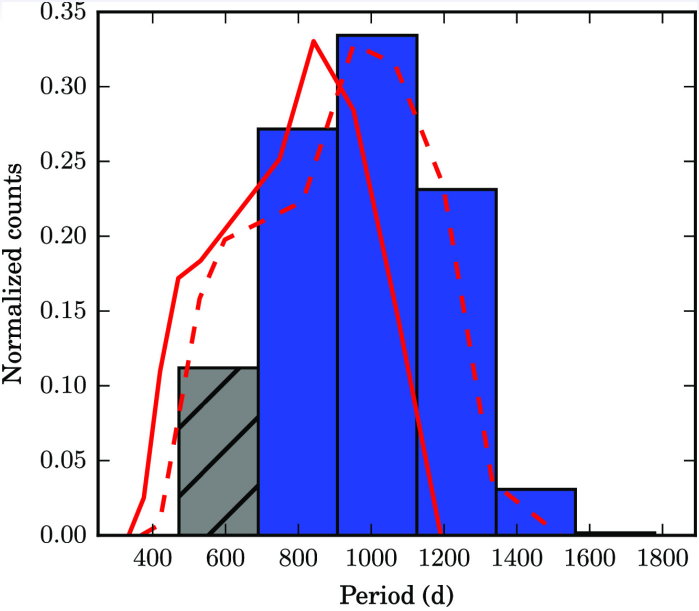
→ post-common envelope systems
(eclipses, reflection or ellipsoidal/beaming)

Population synthesis of sdB+MS



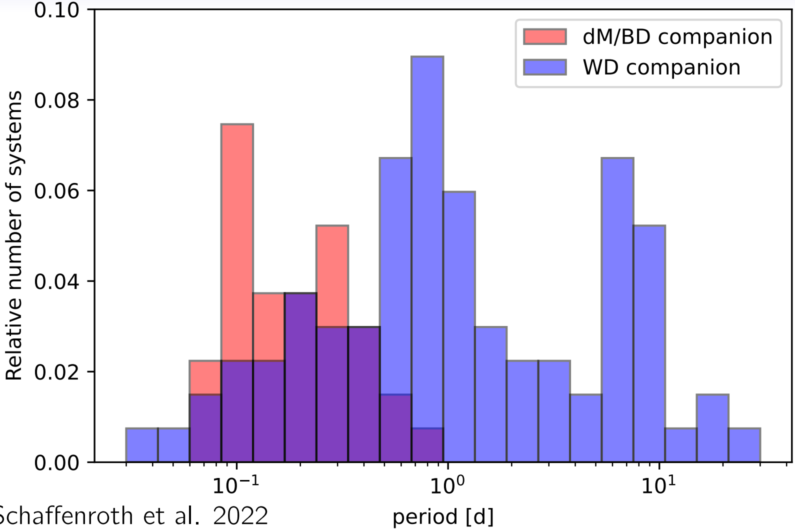
Han et al. 2002,2003

Orbital periods of composite sdBs



Vos et al. (2019)

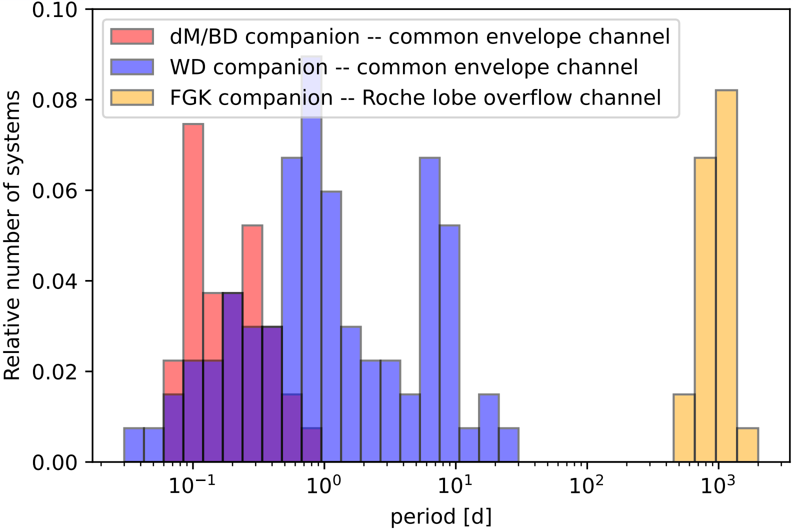
Orbital periods of close sdB binaries



Schaffenroth et al. 2022

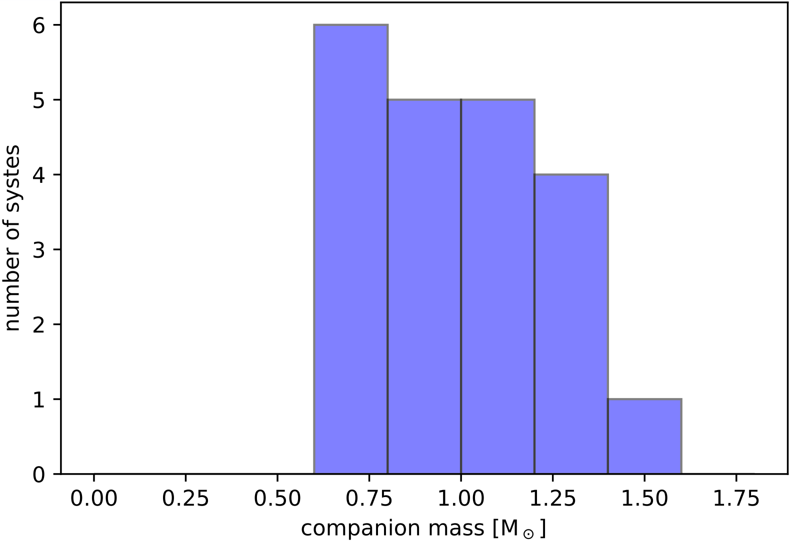
→ study of known sdB binaries and new reflection effect systems using TESS light curves

Orbital periods of sdB binaries



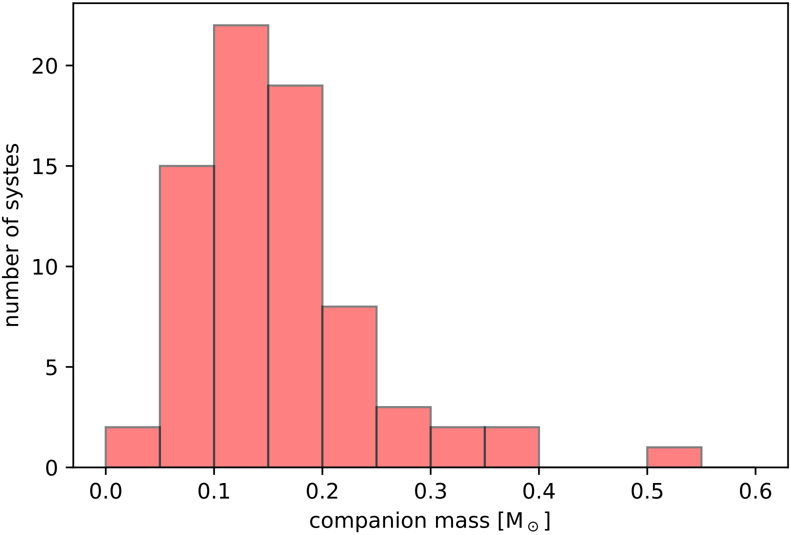
adopted from Schaffenroth et al. 2022 and Vos et al. 2019

Companion mass distribution of composite sdB binaries



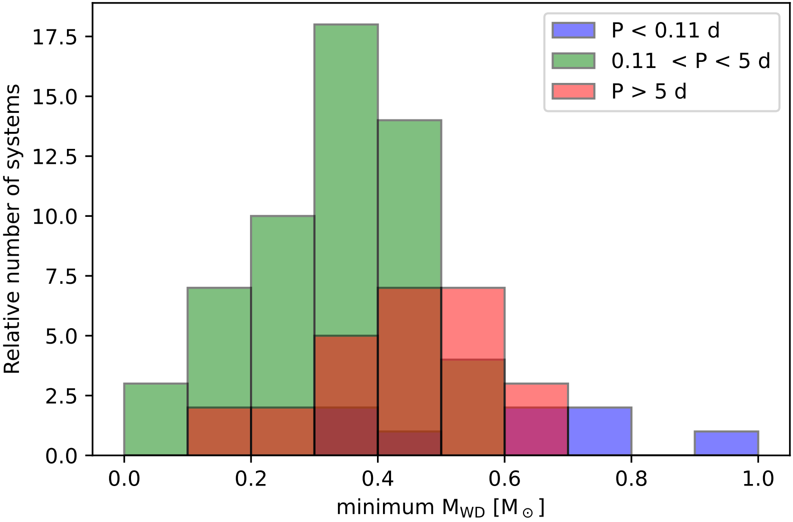
using Vos et al. 2019

Preliminary mass distribution of the sdB+dM/BD systems



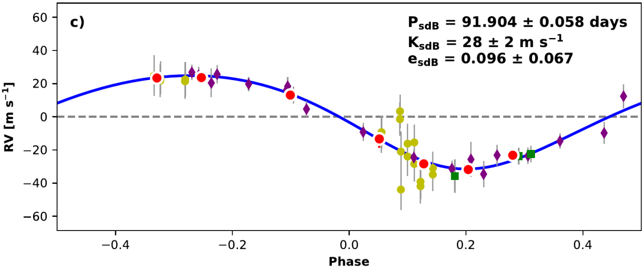
EREBOS project: Schaffenroth et al. in prep

Minimum companion mass sdB+WD



Schaffenroth et al. in prep

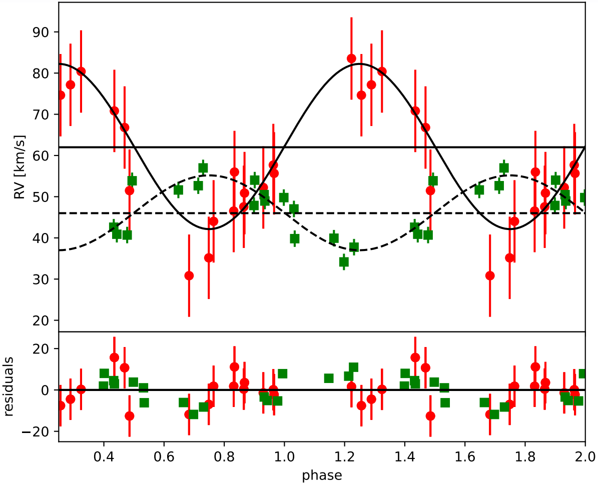
PB5333 - an intermediate period sdB binary



Schaffenroth et al. in prep

sdB+K8V with an intermediate period of $P = 92$ d
→ period in between post-CE and post-RLOF systems
→ minimum mass of the companion $M_{2,\mathrm{min}} = 0.70\,\mathrm{M}_{\odot}$
→ interesting for binary formation scenarios

EC20358-2708 - sdO+K0III

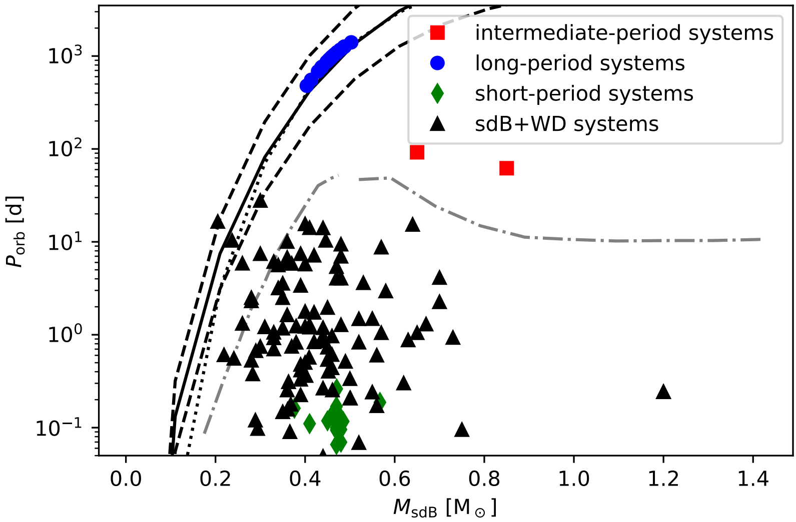


Vennes et al. 2018, Schaffenroth et al. in prep

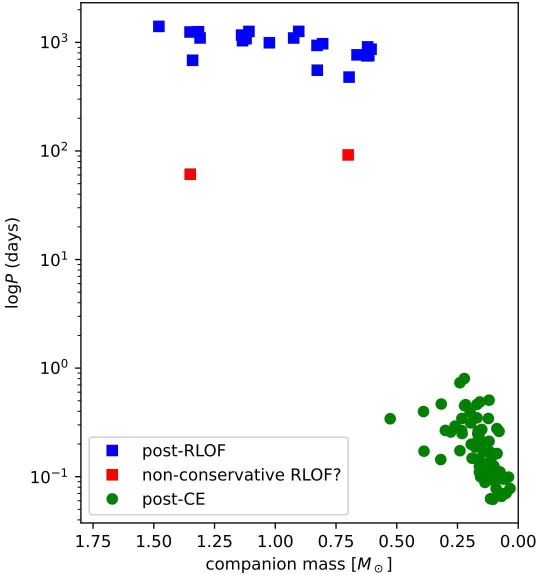
- $P = 61 \pm 2$ d, $K_{\rm sdO} = 20 \pm 1$ km/s, $K_{\rm RG} = 9.0 \pm 0.7$ km/s

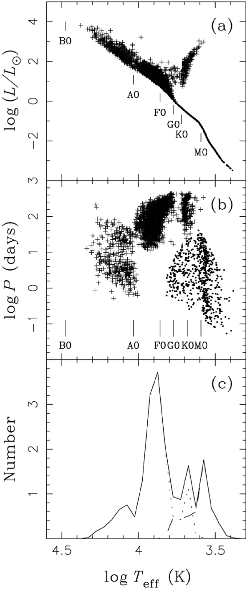
$\rightarrow$ $M_{\rm RG} = 1.45 \pm 0.45\,{\rm M}_\odot$

Period-sdB mass diagram of sdB binaries



Preliminary companion mass-period diagram of sdB binaries with main sequence companions





Conclusions

2/3 of all sdBs are in binaries either post-RLOF or post-CE

$\rightarrow$ perfect objects to study mass transfer and its stability

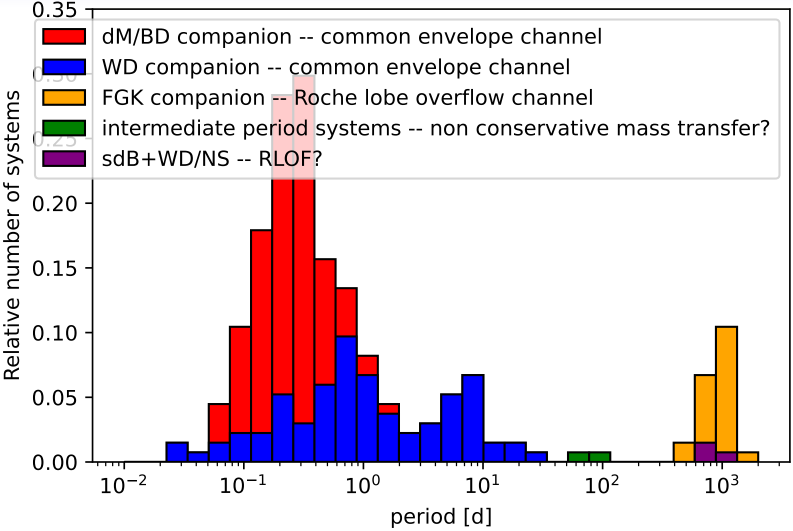
- P and m_{comp} distributions show: sdB+dM/BD or WD are post-CE and sdB+FGK are post-RLOF $\rightarrow$ mass transfer more stable than expected $q_{\text{crit}} \simeq 2 - 3$ for low mass stars

$\rightarrow$ follow-up and analysis of more short, intermediate, and long-period sdB+BD/MS systems in the EREBOS project to get a statistical significant sample over the parameter range

$\rightarrow$ new population synthesis study taking new observational constraints into account

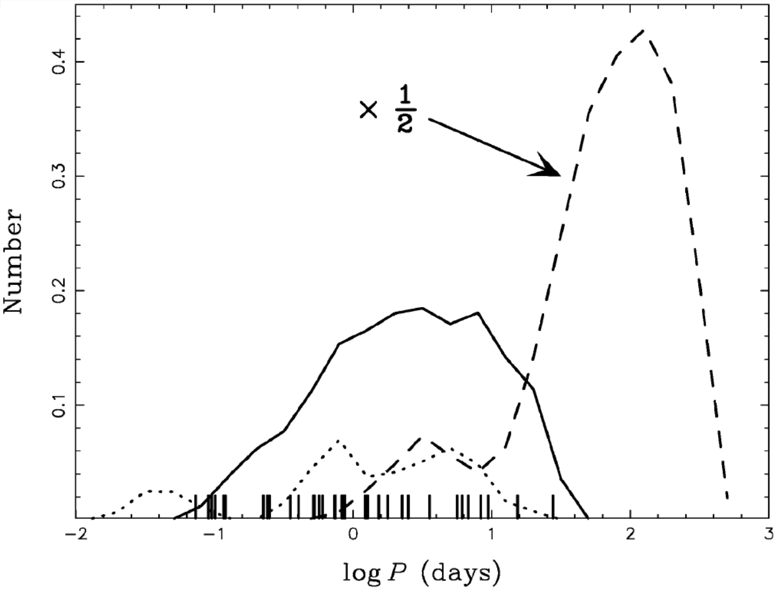
Questions!?

Period distribution of all sdB binaries



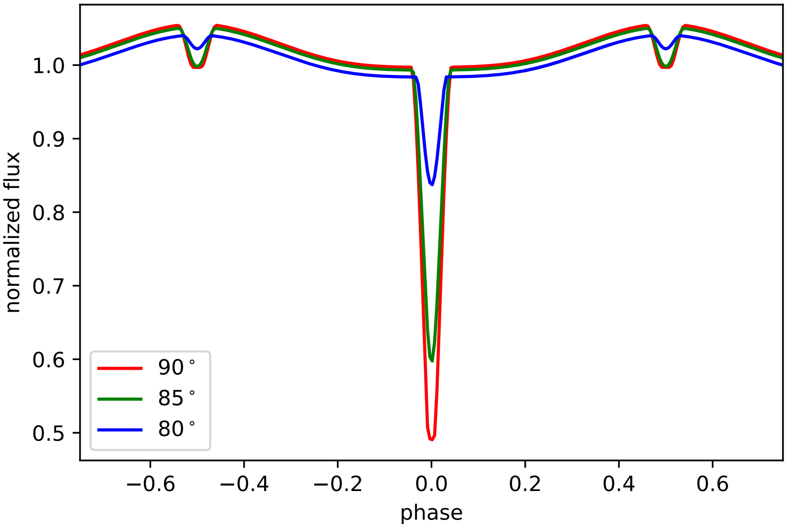
adopted from Schaffenroth et al. 2022, Schaffenroth et al. in prep, Vos et al. 2019, Geier et al. 2024

Period distribution of sdBs from BPS



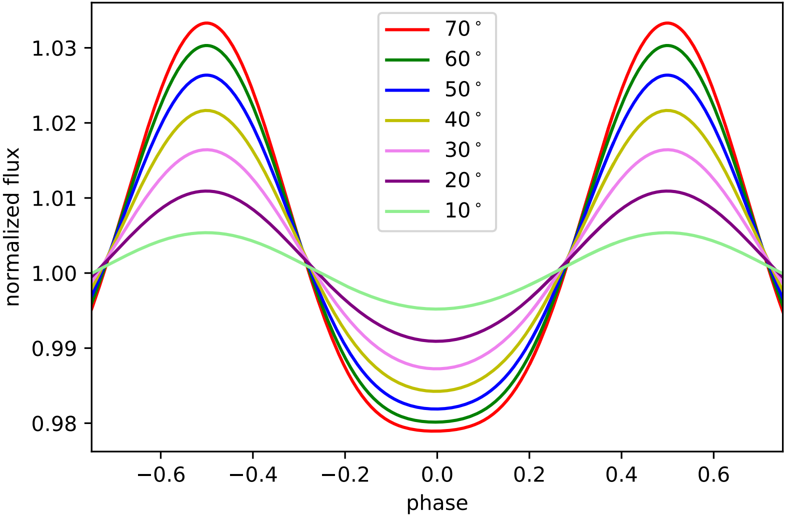
Han et al. 2003

Eclipsing Reflection effect (HW Vir systems)



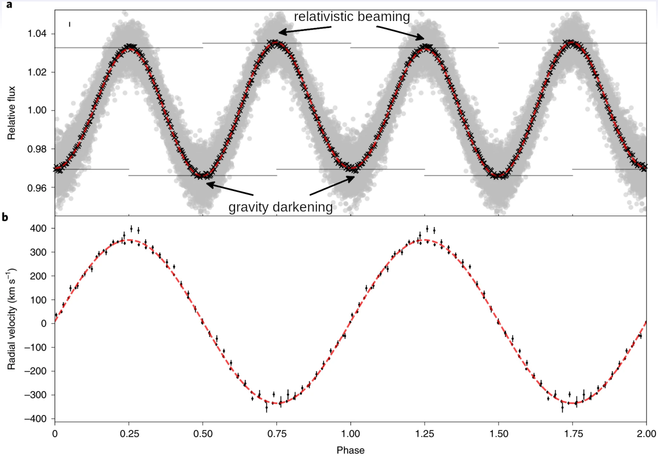
→ 20 systems with periods from 0.07 to 0.25 d analyzed

Reflection effect



amplitude depends on
flux of primary, separation (period), inclination, size of companion

Ellipsoidal modulation and Doppler beaming (sdB+WD)

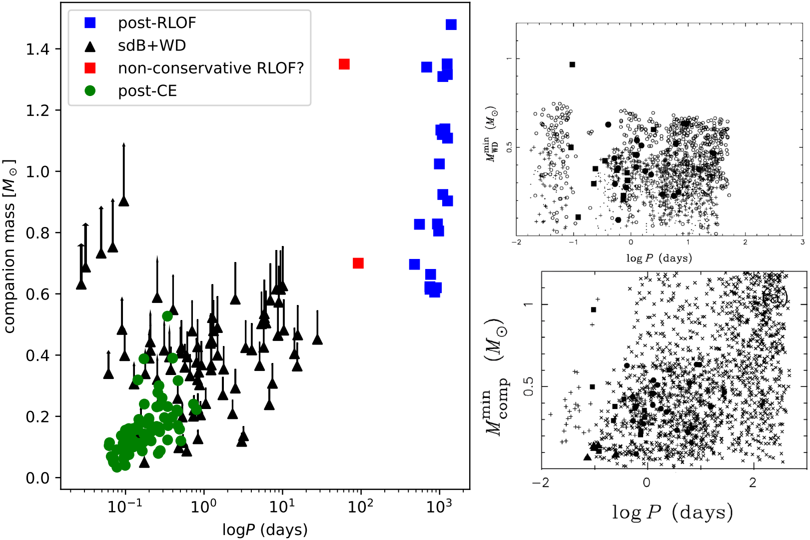


Pelisoli, ..., Schaffenroth et al. 2021, Nature Astronomy

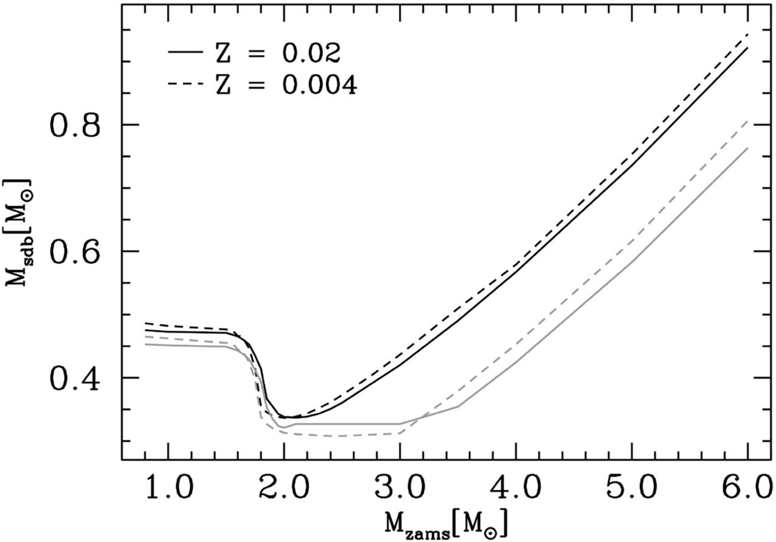
Doppler beaming at non-relativistic velocities

$$F_\lambda = F_{\lambda,0}\left(1 - B\frac{v_r}{c}\right), \qquad B = 5 + \frac{\mathrm{d}\ln F_\lambda}{\mathrm{d}\ln\lambda} \tag{3}$$

Preliminary companion mass-period diagram of all sdB binaries

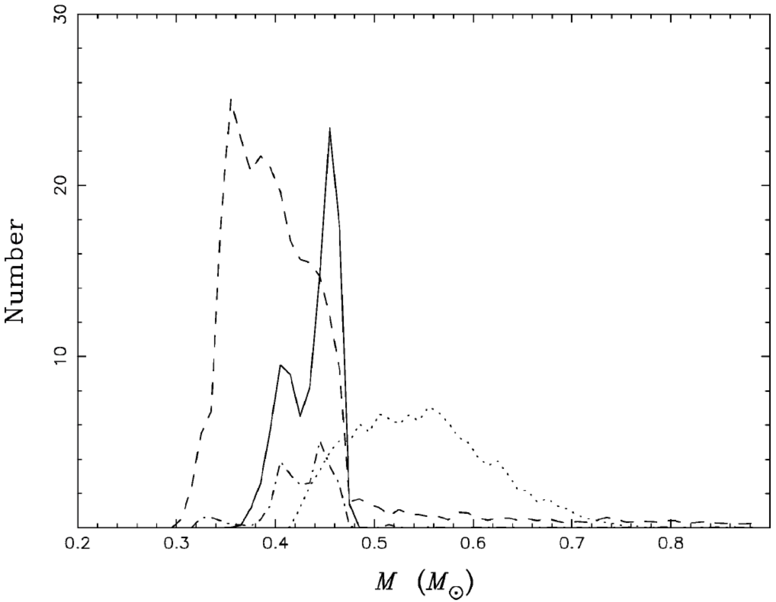


Masses of sdBs from MESA



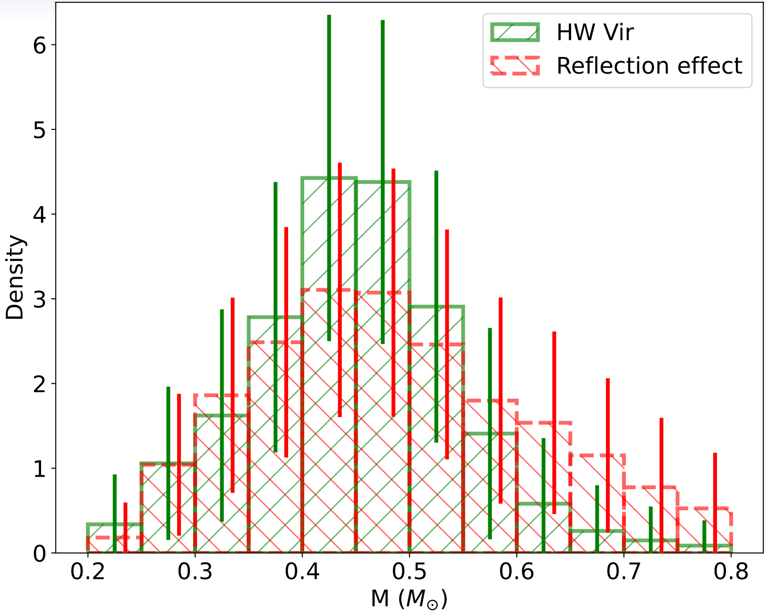
Arancibia-Rojas et al. 2023

Mass distribution of sdBs from BPS



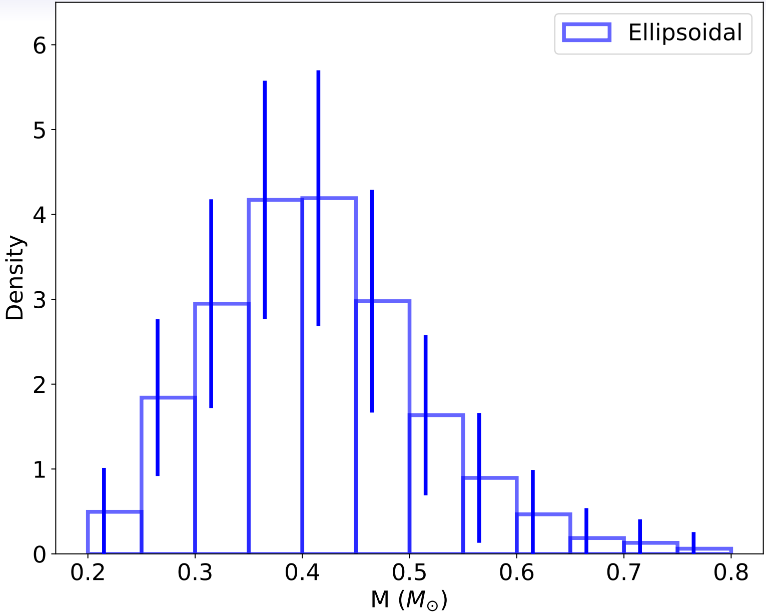
Han et al. 2003

Masses of known sdB+dM/BD



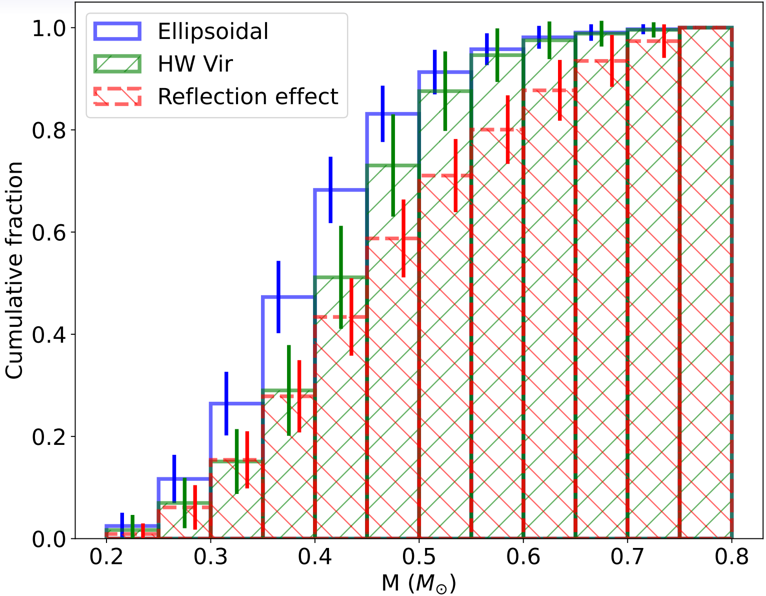
Schaffenroth et al. 2022

Masses of known sdB+WD



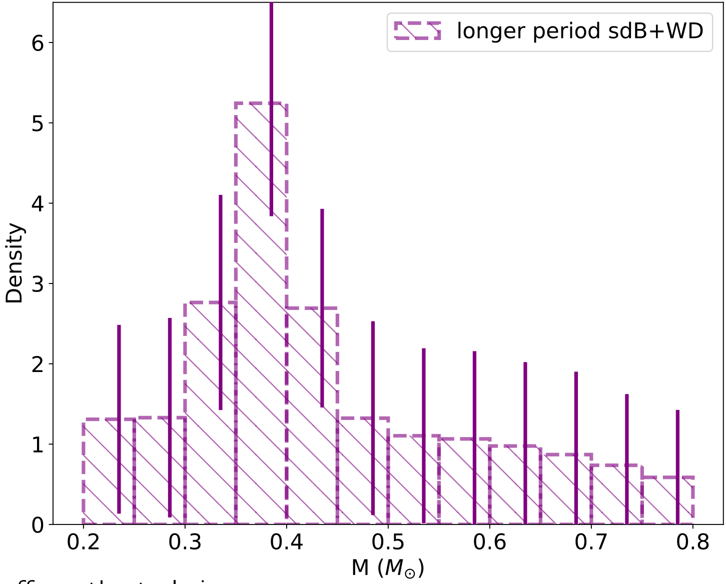
Schaffenroth et al. 2022

Masses of known hot subdwarfs in close binaries



Schaffenroth et al. 2022

Masses of known hot subdwarfs with WD companions in longer periods



Schaffenroth et al. in prep