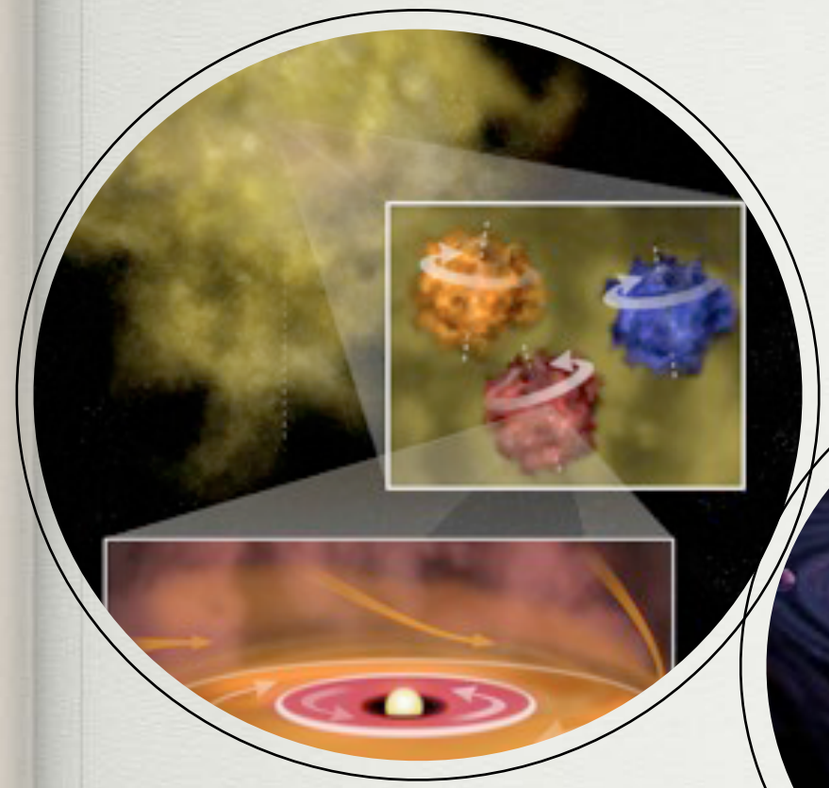
CENTRO DE ASTROBIOLOGÍA · CAB
ASOCIADO AL NASA ASTROBIOLOGY PROGRAM
CSIC

Planets and WDs

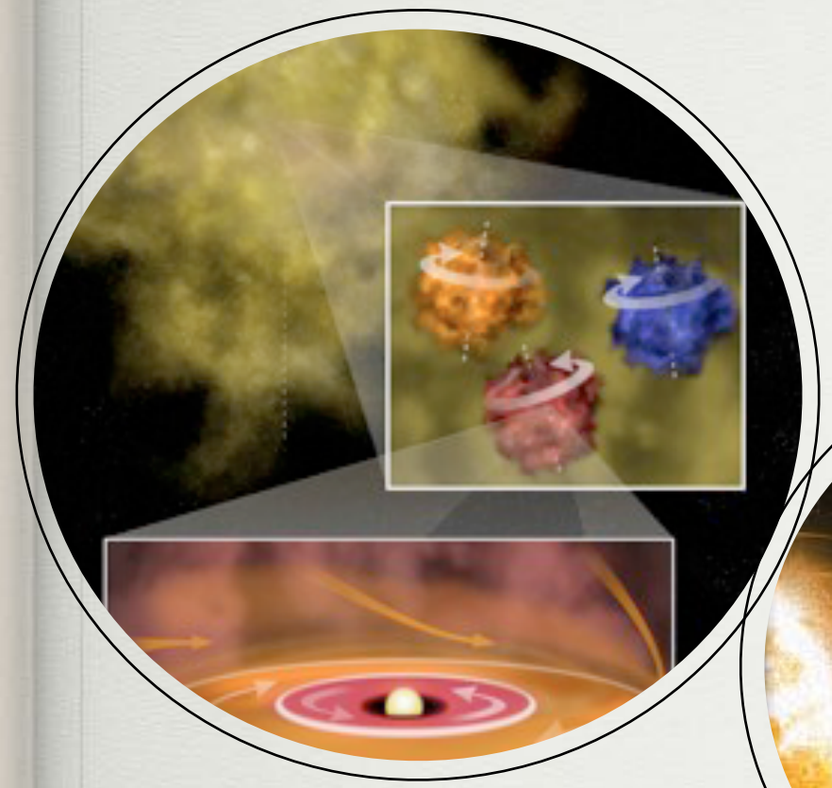
Eva Villaver (CAB)

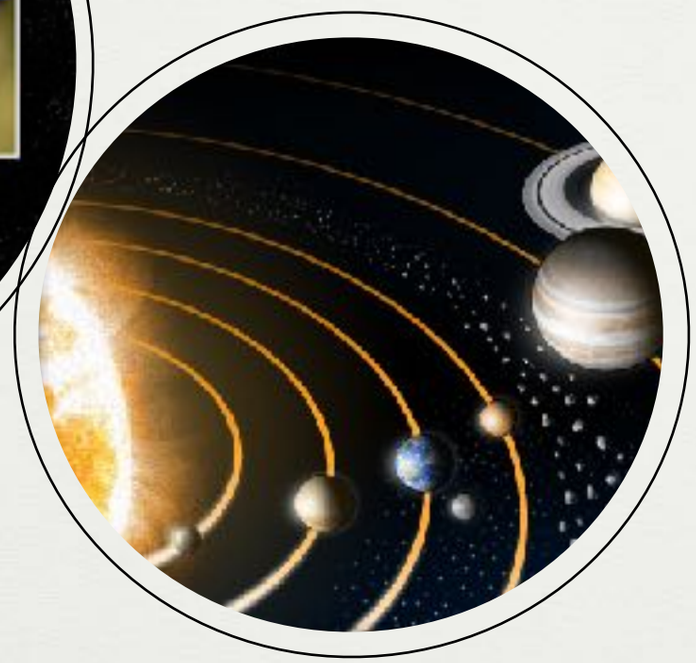
KITP White Dwarfs from Physics to Astrophysics. March 29

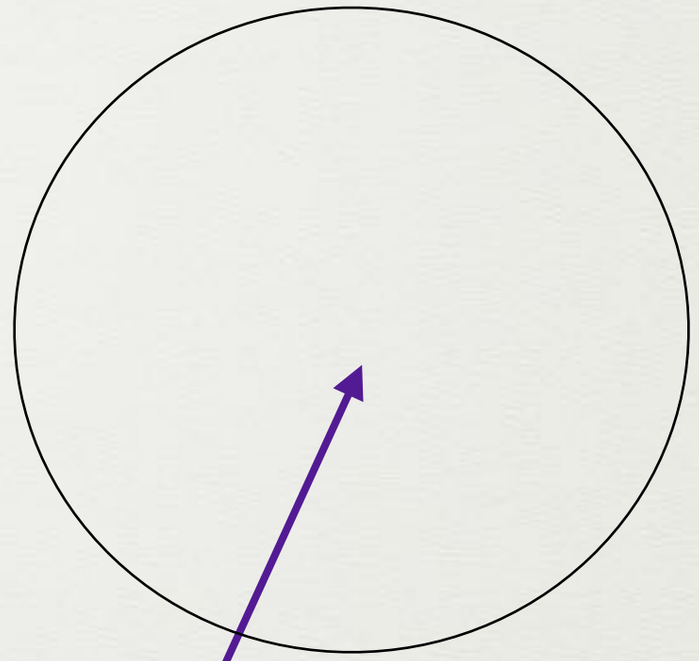


WD

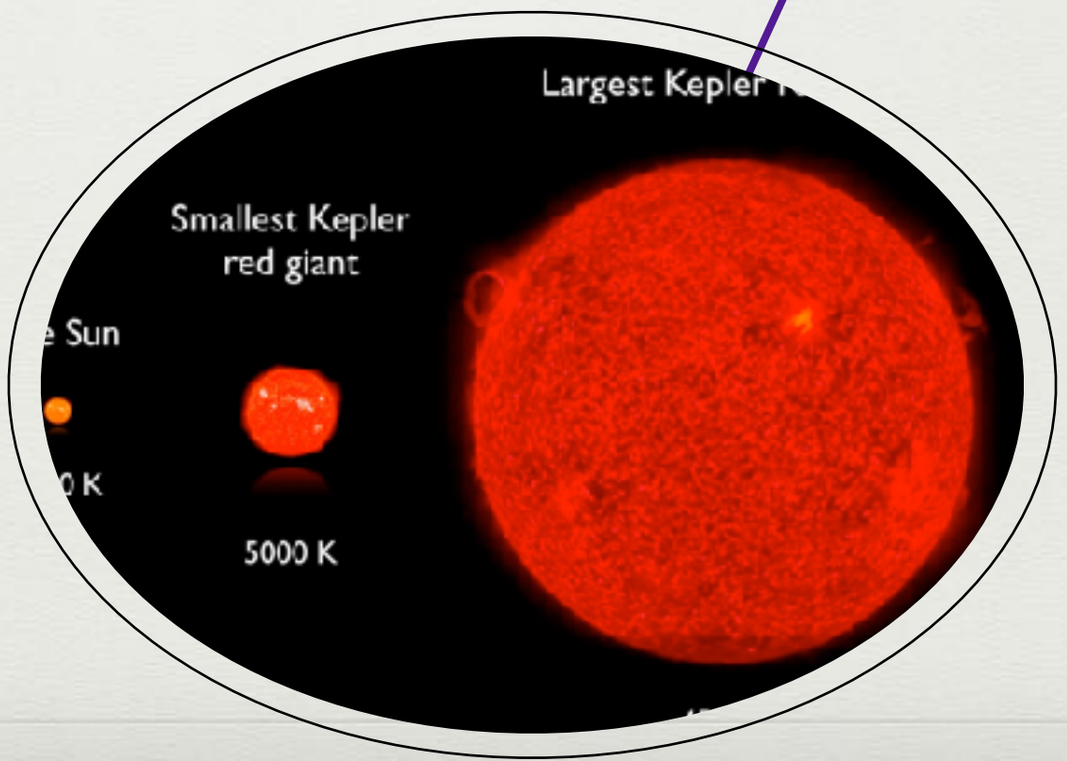
What is the problem with planets around WDs?

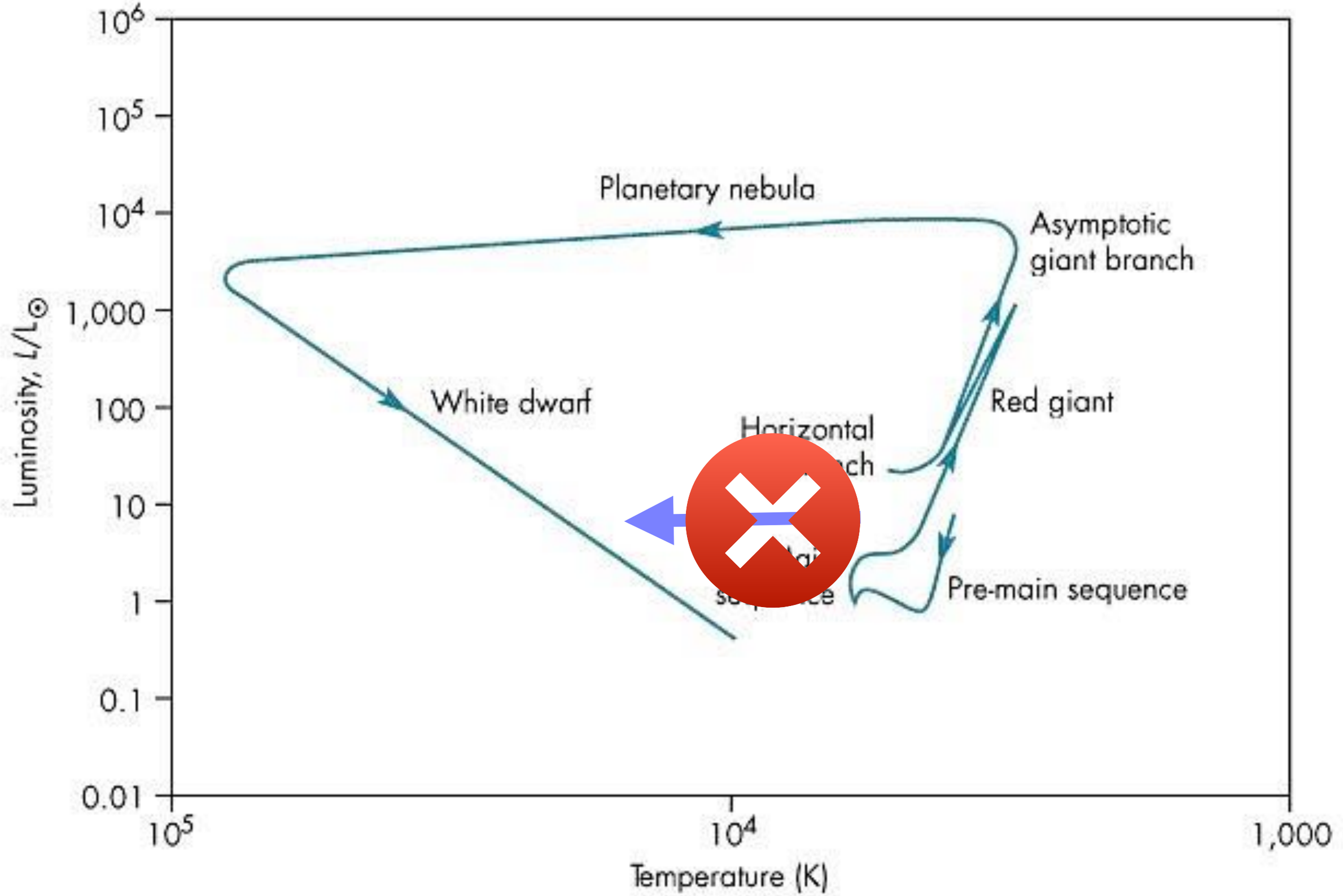




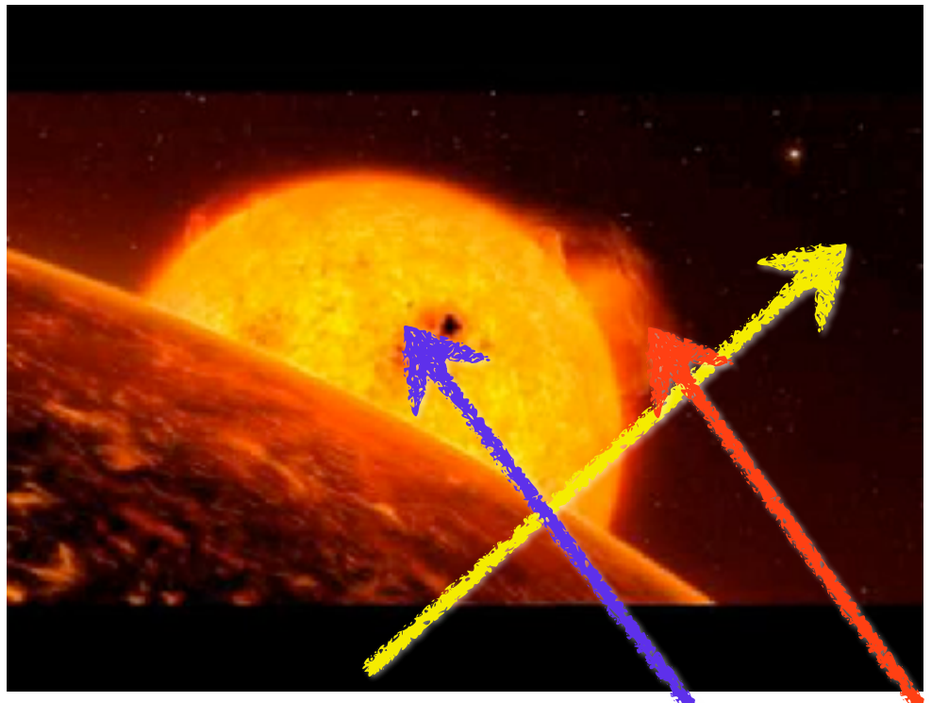


WD



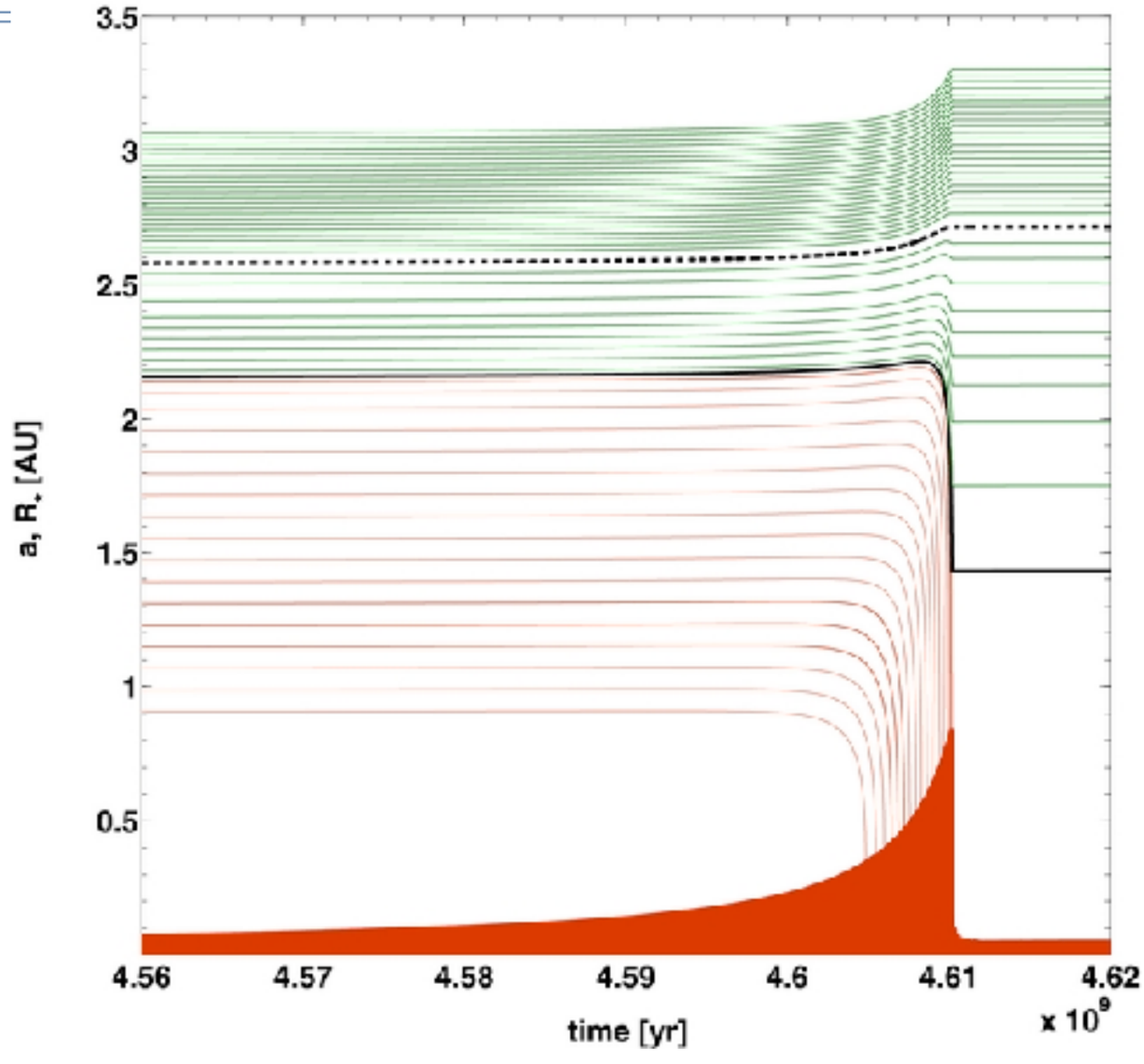

10^6
10^5
10^4
1,000
100
10
1
0.1
0.01
Luminosity, $L/L_\odot$
Planetary nebula
Asymptotic giant branch
White dwarf
Red giant
Horizontal
Pre-main sequence
10^5
10^4
1,000
Temperature (K)

Orbital evolution



$$\left(\frac{\dot{a}}{a}\right) = -\frac{\dot{M}_* + \dot{M}_p}{M_* + M_p} - \frac{2}{M_p v}\left[F_f + F_g\right] - \left(\frac{\dot{a}}{a}\right)_t \quad ,$$

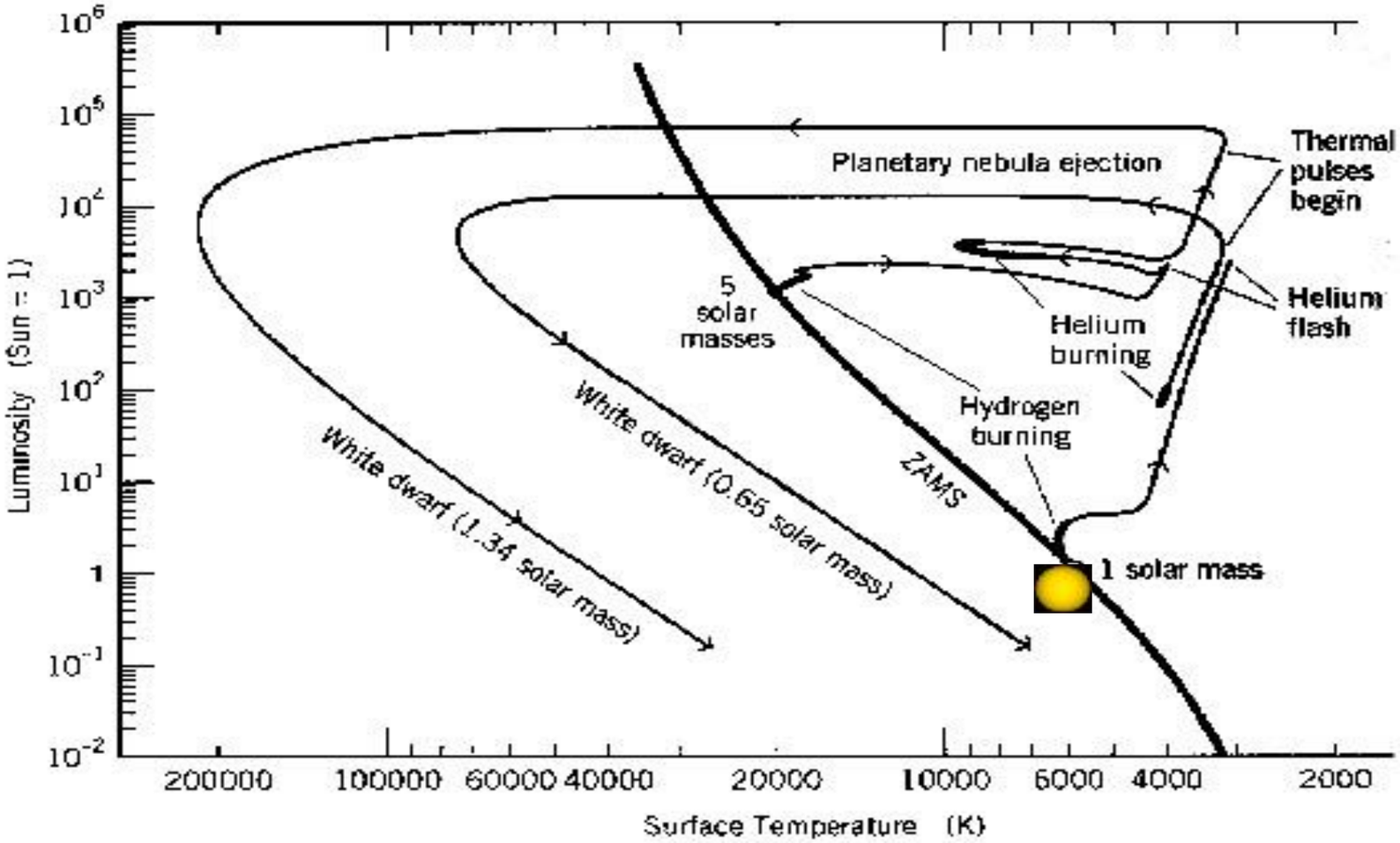
$$\left(\frac{\dot{a}}{a}\right)_t = \frac{f}{\tau_d}\frac{M_{\rm env}}{M_*} q(1+q)\left(\frac{R_*}{a}\right)^8$$



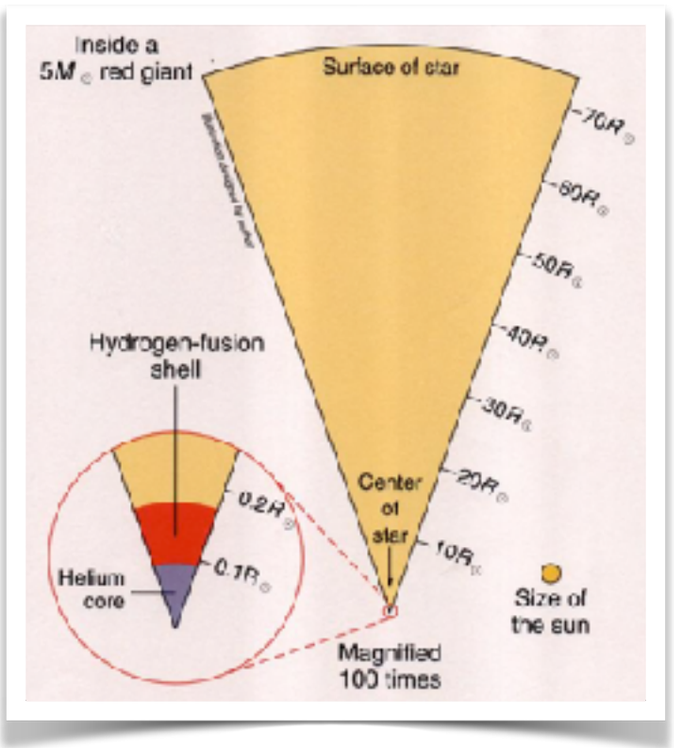
Villaver et al. (2014)

Villaver & Livio (2009); Gallet et al. (2017); Sun et al. (2018); Rao et al. (2018)

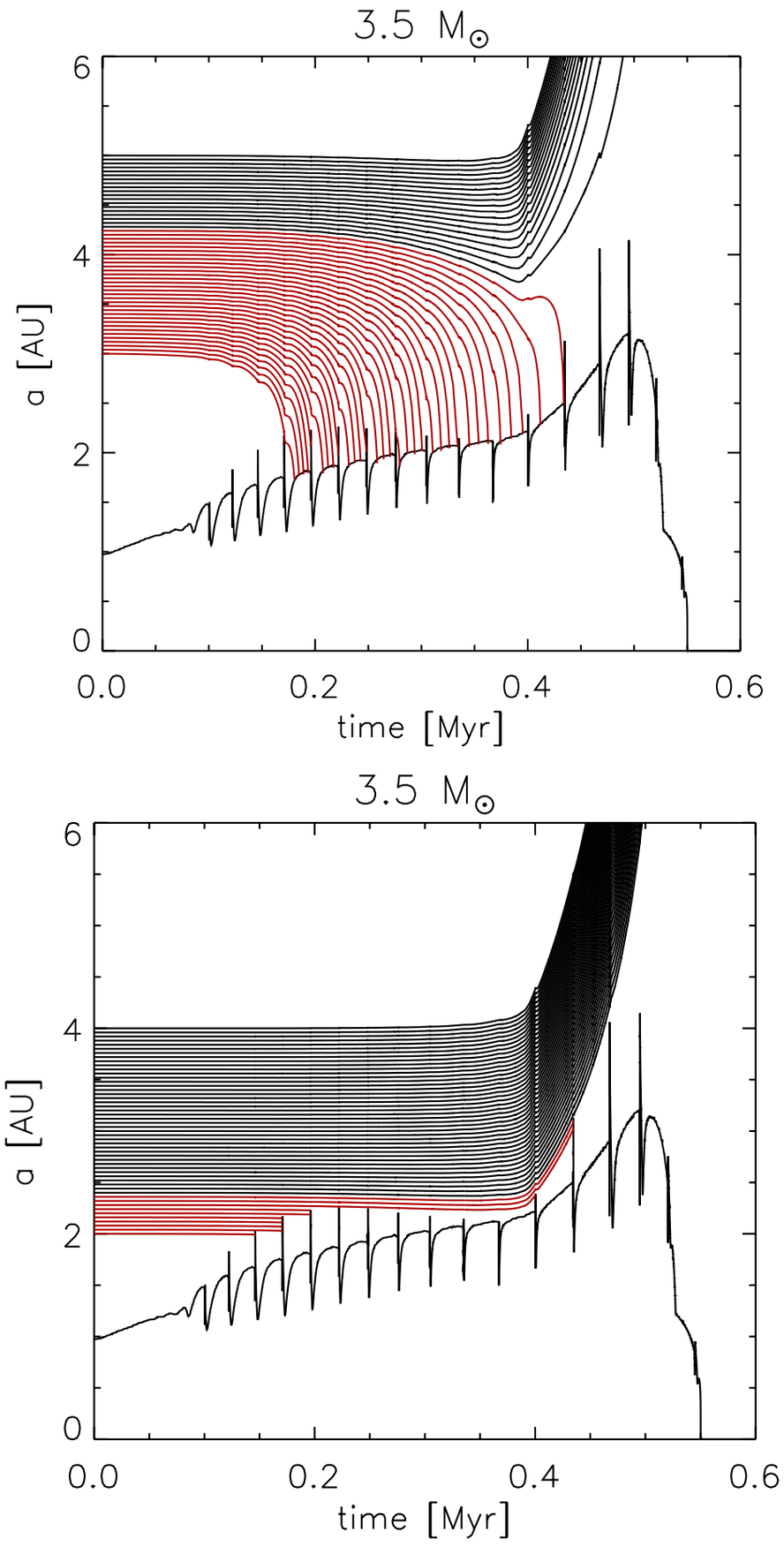
AGB evolution



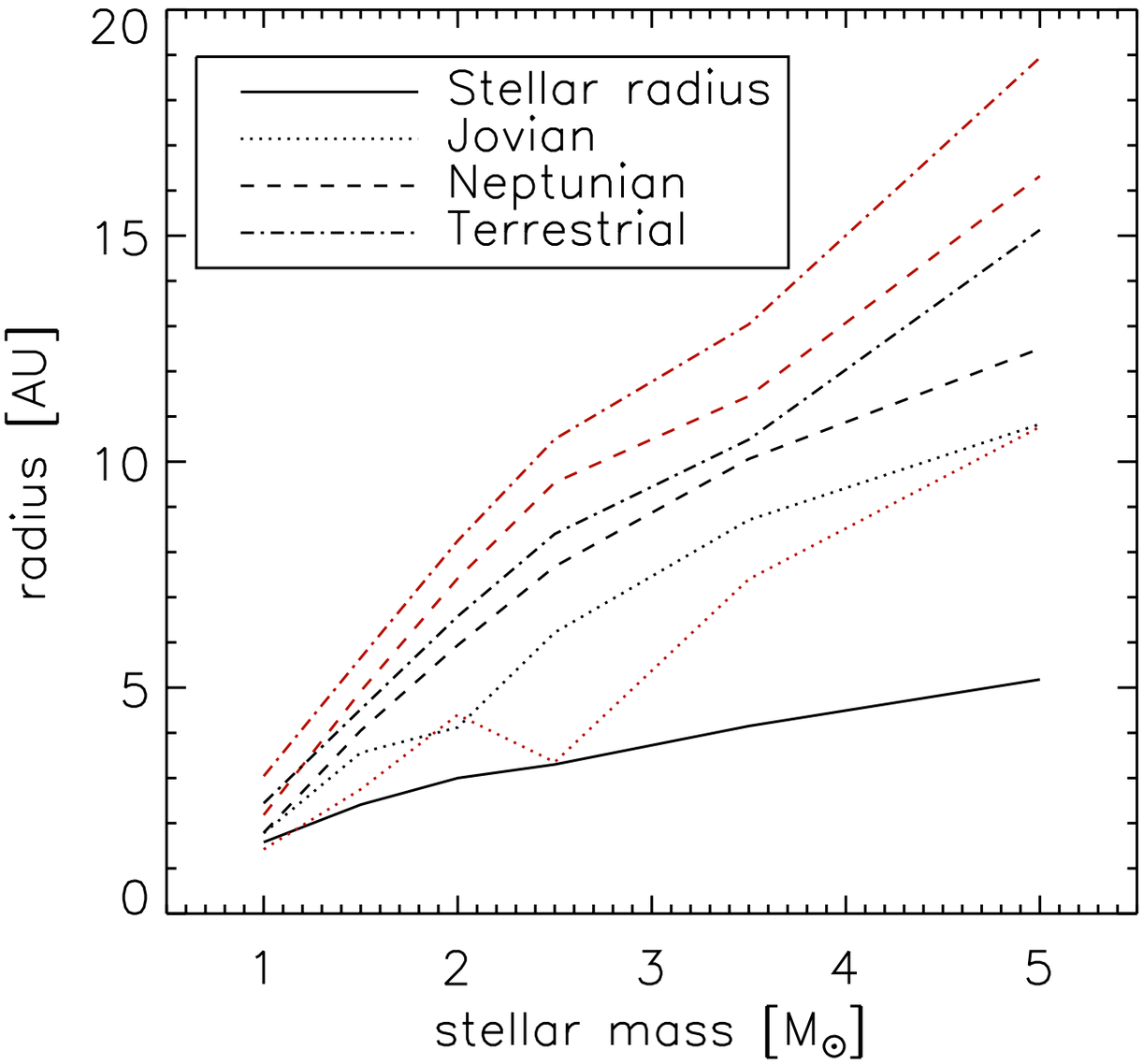
Hydrogen Shell Burning on the Red Giant Branch



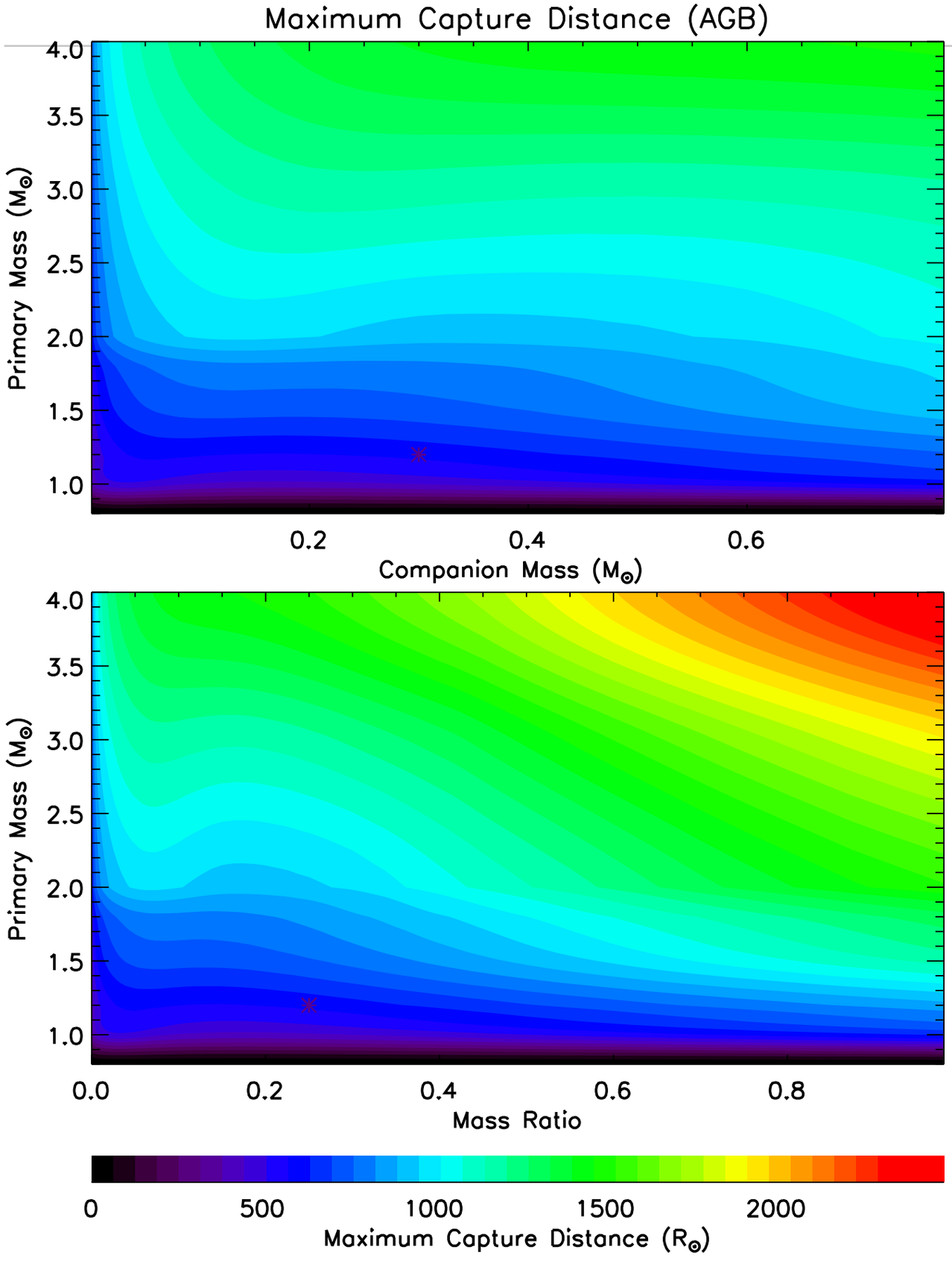
Orbital Evolution cont…



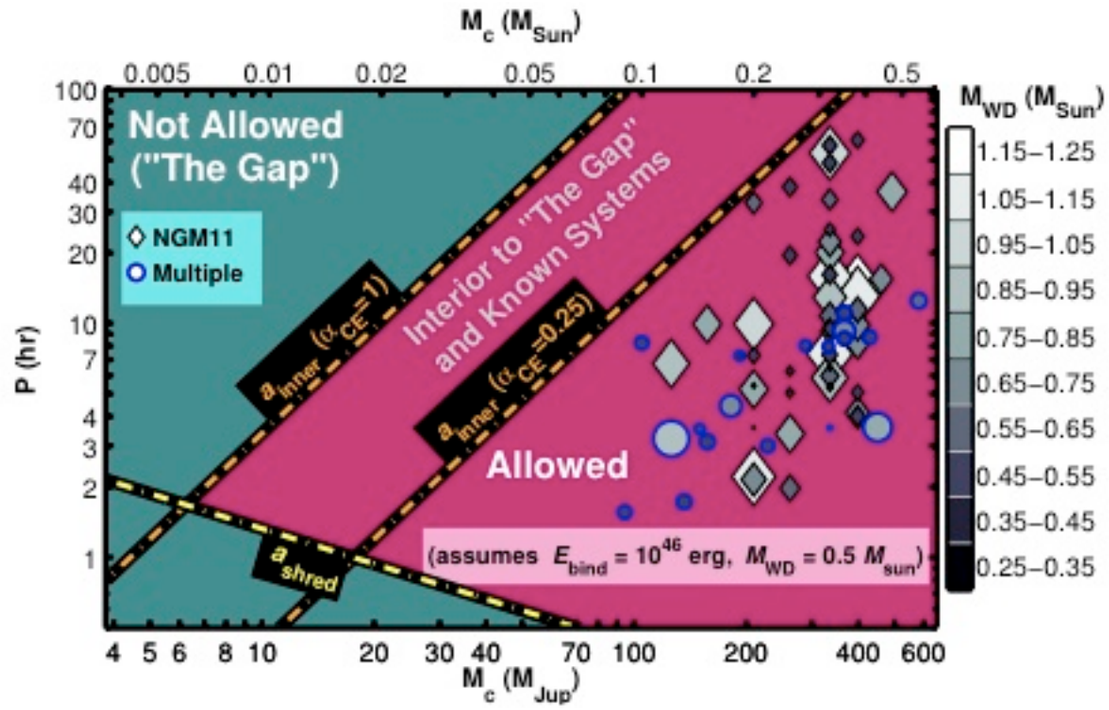
Final location of the innermost surviving planets



Mustill & Villaver (2012)



Madappatt, de Marco and Villaver (2016)



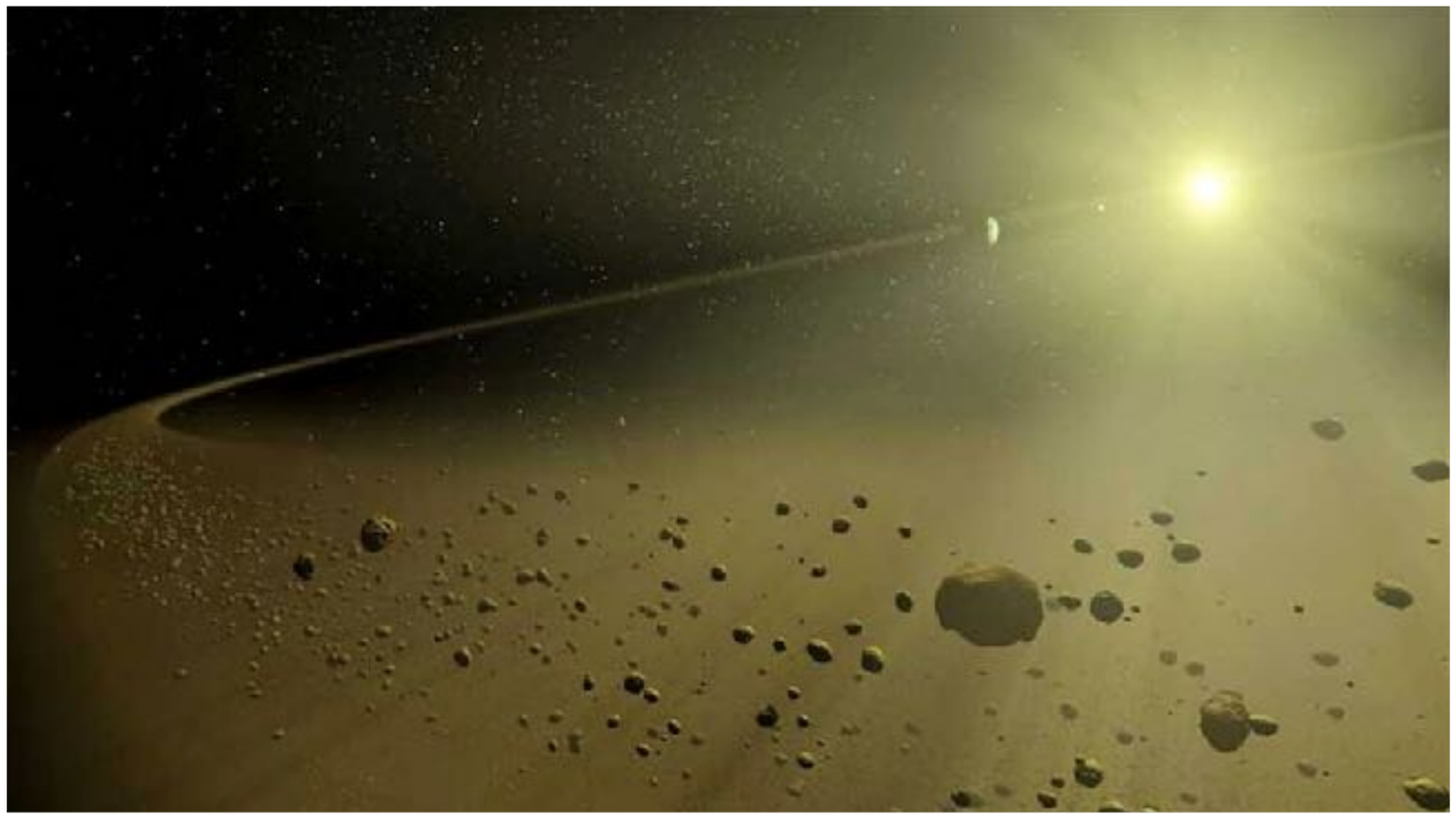
Nordhaus et al. (2010)
Nordhaus & Spiegel (2013)

How can we bring material close to the WD to explain WD pollution?

Gravitational assistance:

Keeping material (asteroids/moons/fragments of planets) far from the star at several au + major planet to perturb the orbit

Single planet far away interacting gravitationally with a disk



- Planet on circular orbit + kuiper belt: Bonsor et al. (2011, 2012)
- Planet MMR + asteriod belt: Debes, Walsh & Stark (2012)
- Single planet with varying e and mass: Frewen & Hansen (2014)
- Circular orbits do not work: Antoniadou & Veras (2016) see as well Veras et al. (2014, 2018a)

Giant Planet in Transit: Vanderburg et al. (2020)
Giant planet as acretor: Gänsicke et al. (2019)

How can we bring planets close to the WD?

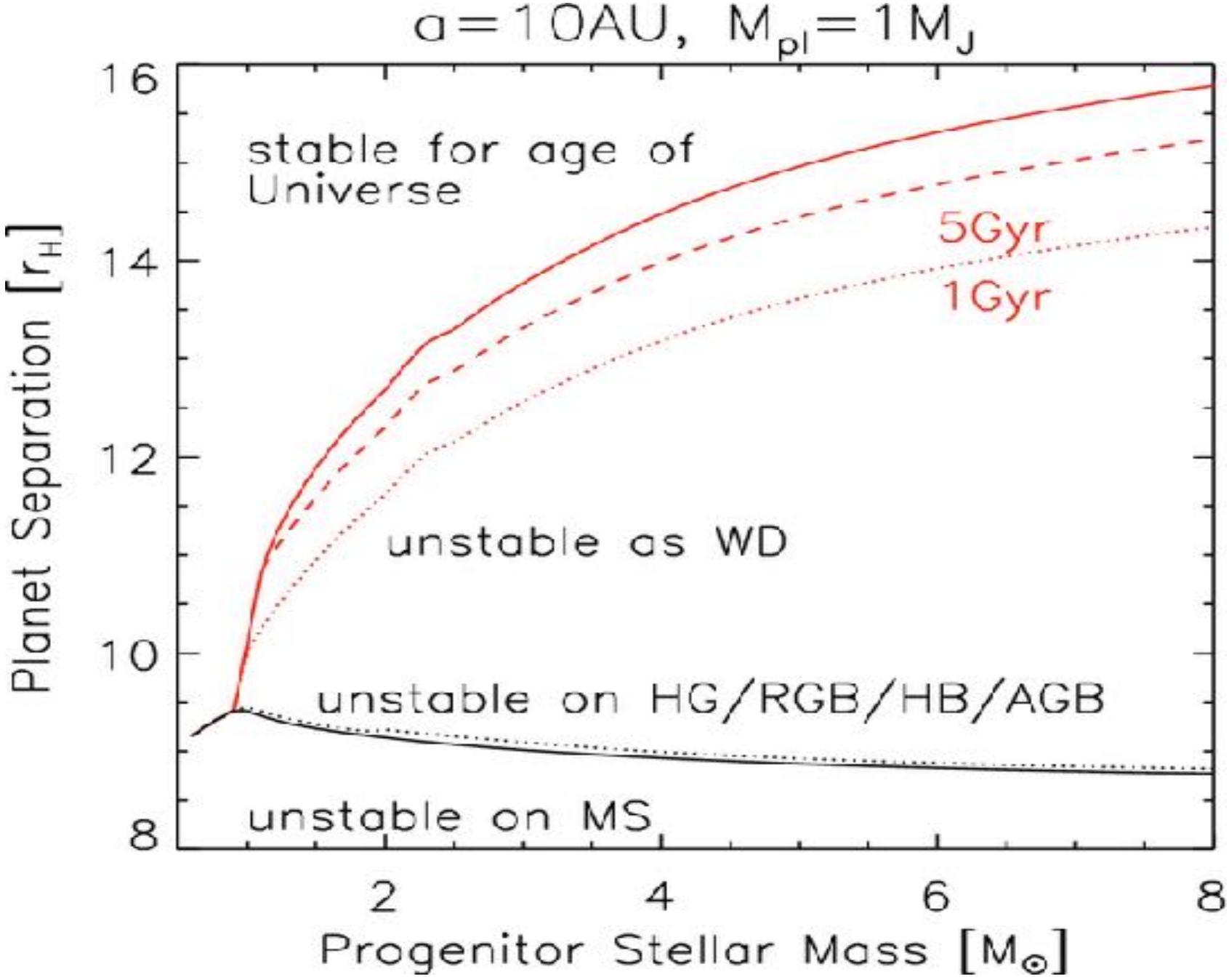
-múltiple planets
-múltiple stars

or…

-common envelope evolution

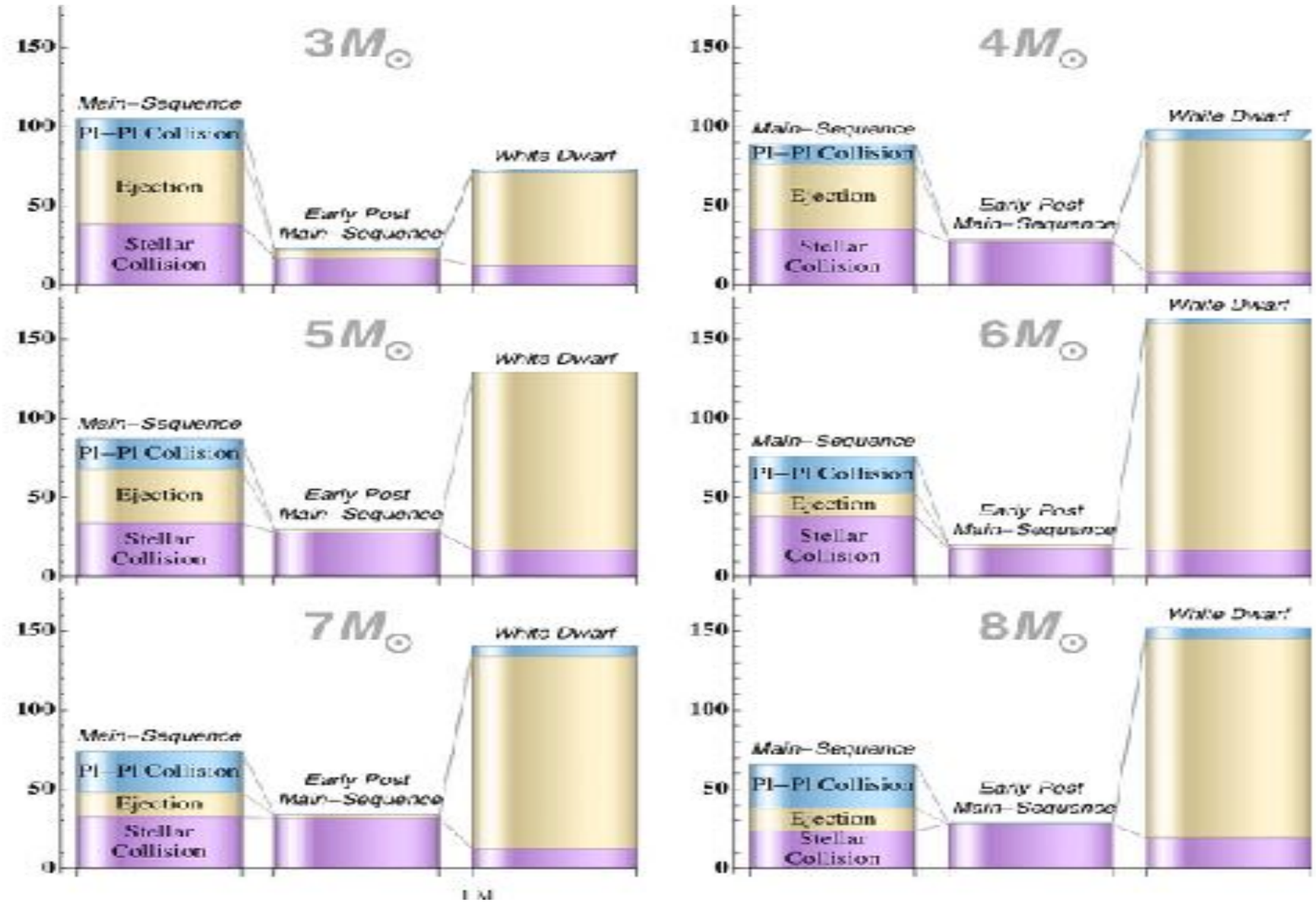
Multiple planetary systems

Stability of multiple planetary systems



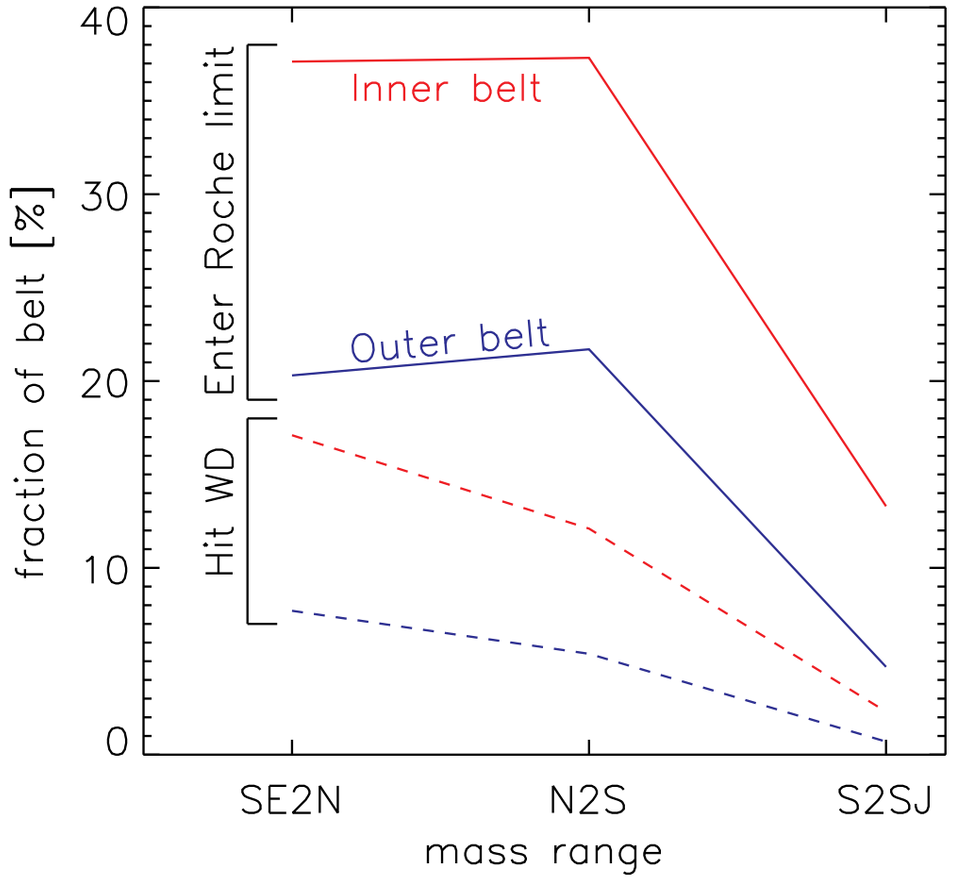
Debes & Sigurdsson (2002)
Veras et al. (2013, 2016a); Smallwood et al. (2018)

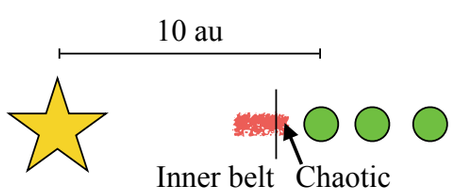
3-planet system instability

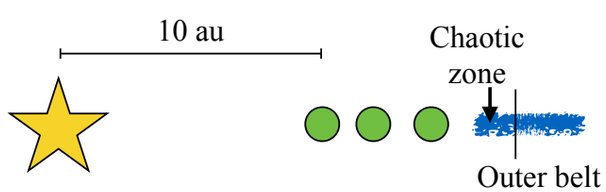


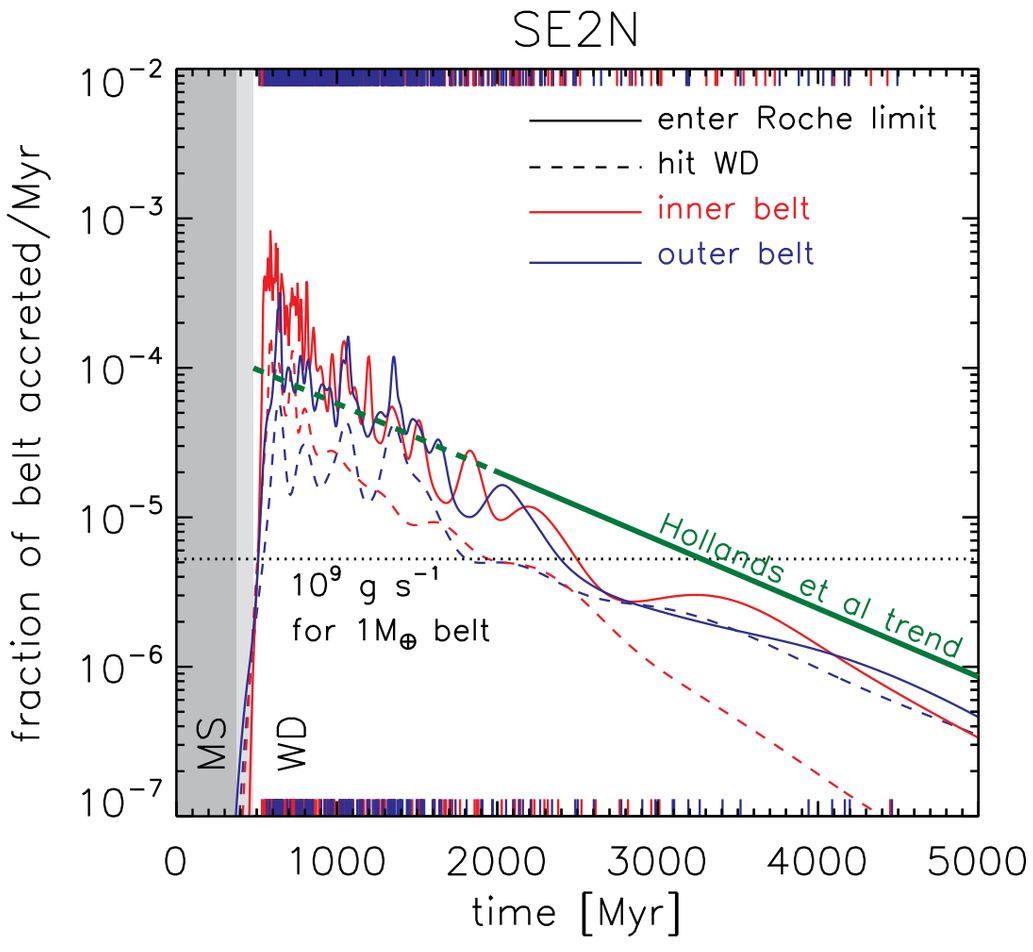
Mustill, Veras & Villaver (2014)

Number of planets lost in the three-1 MJ runs

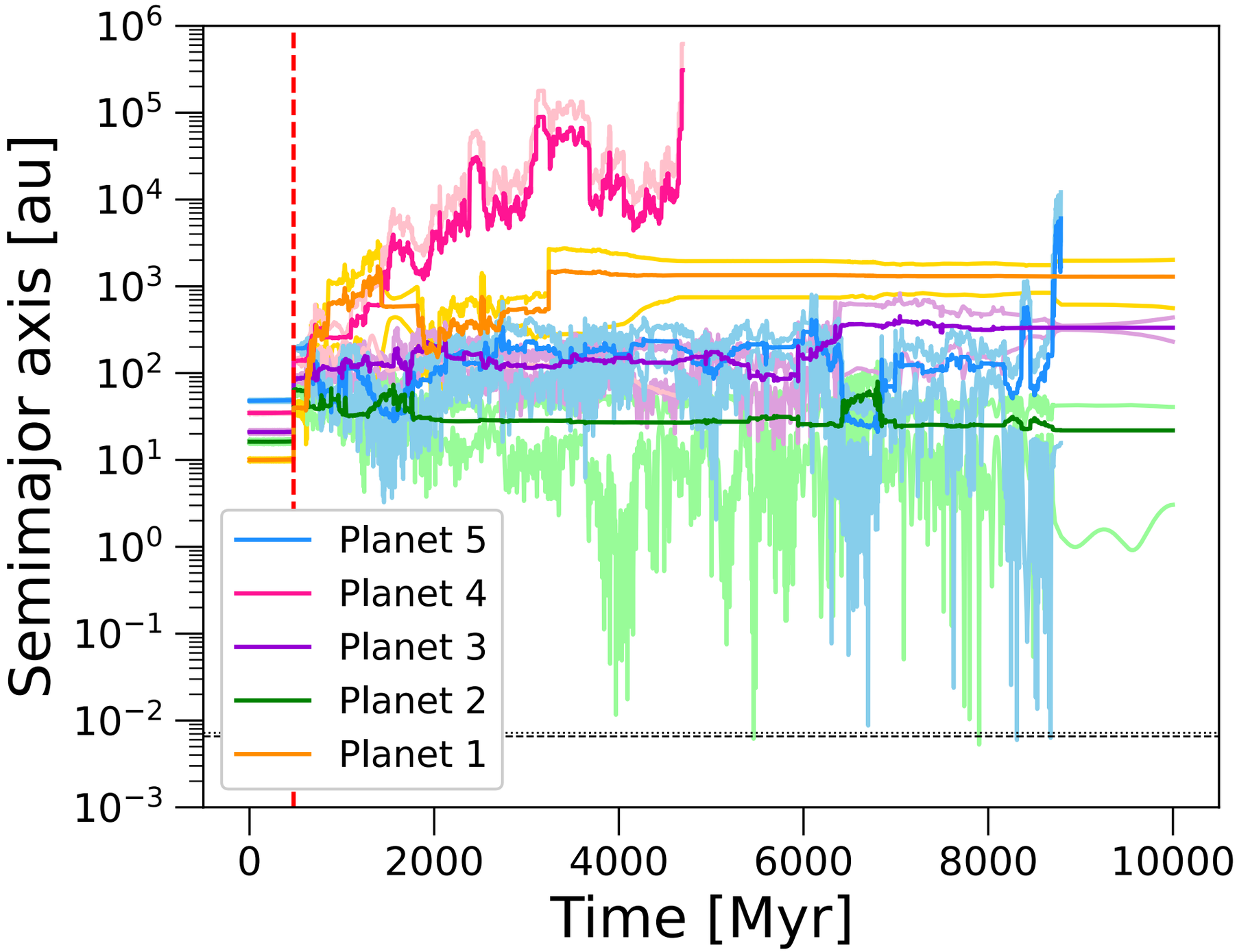




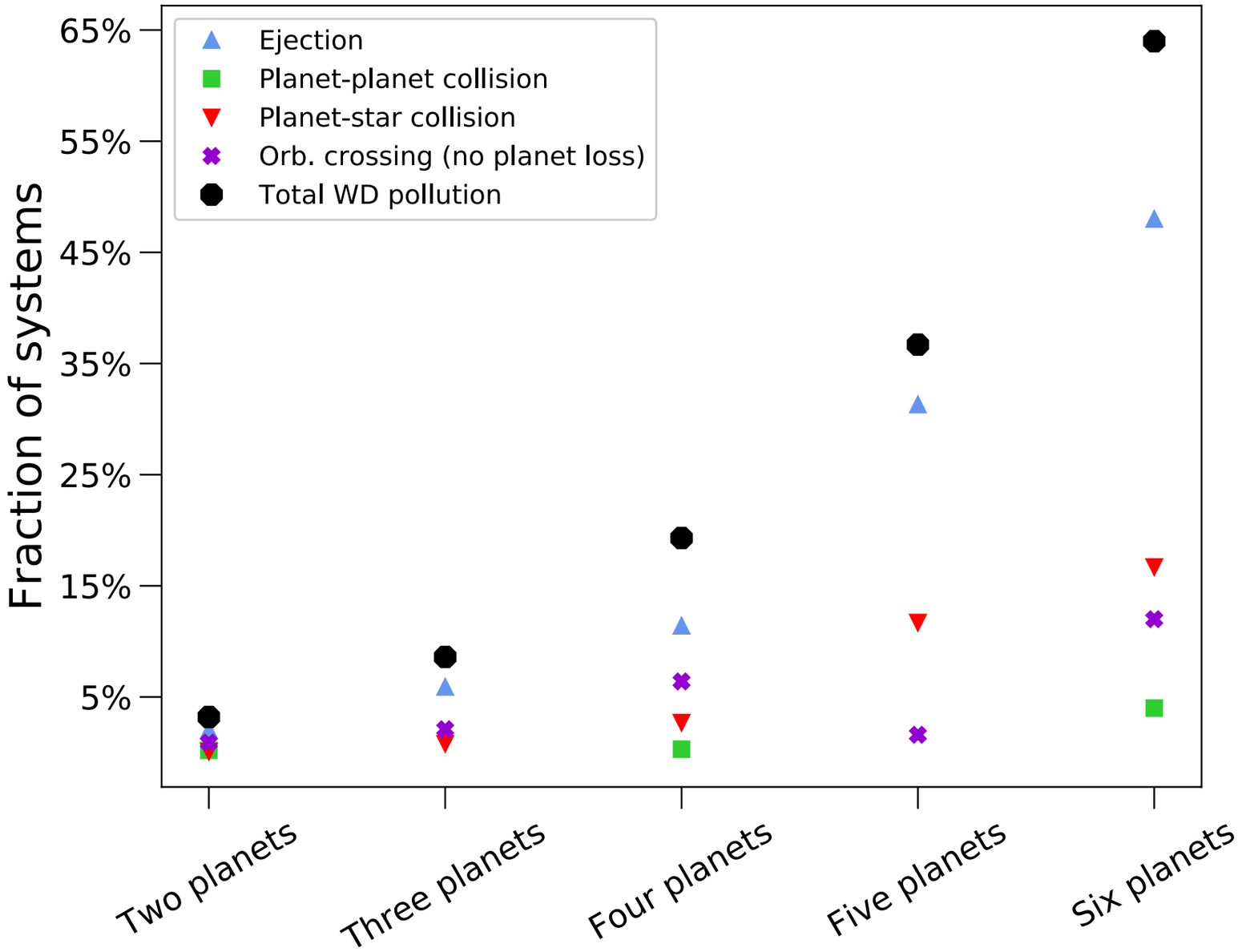




Mustill et al. (2018)
3 planets + a planetesimal belt

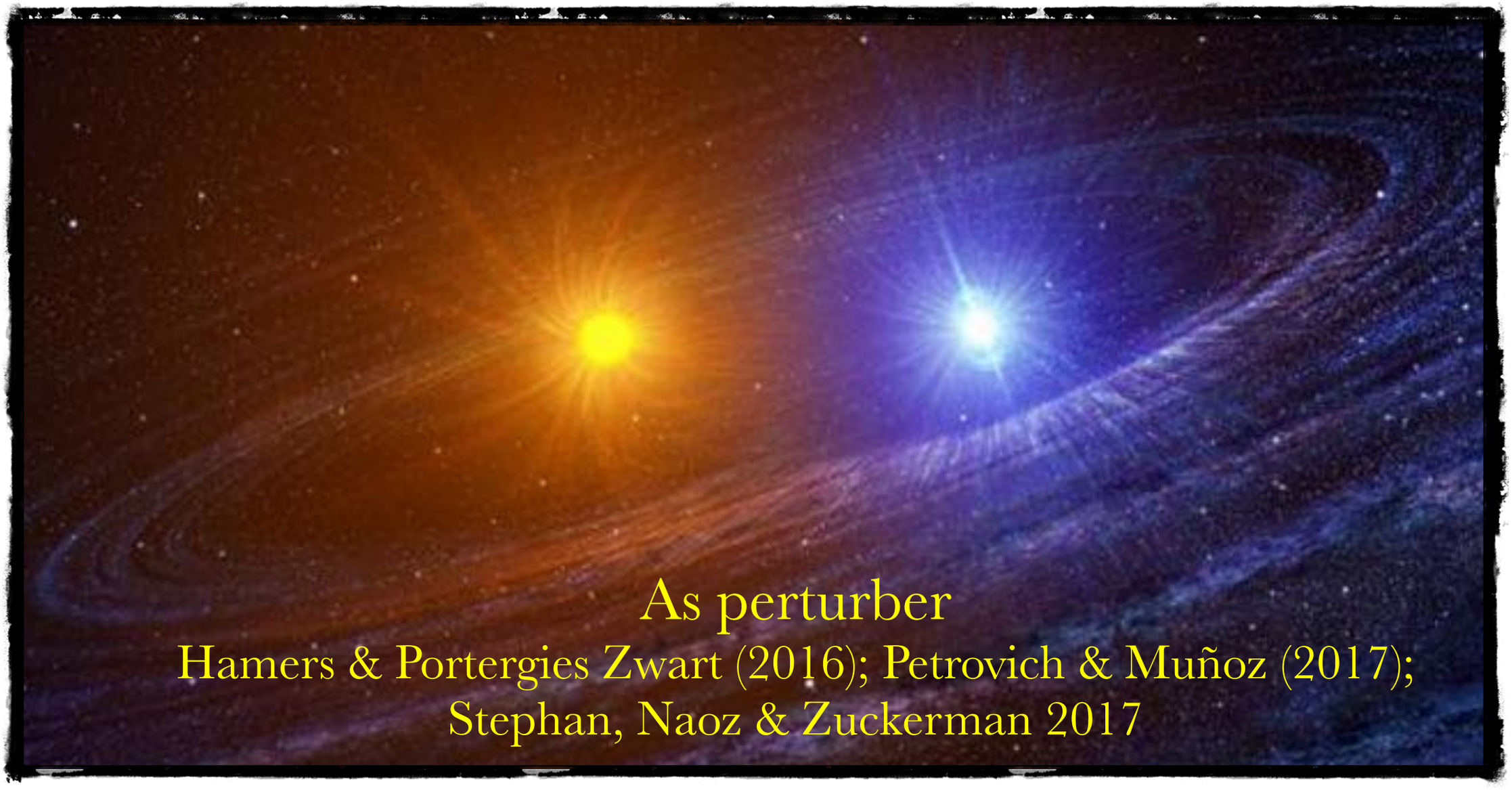


Maldonado et al. (2021)

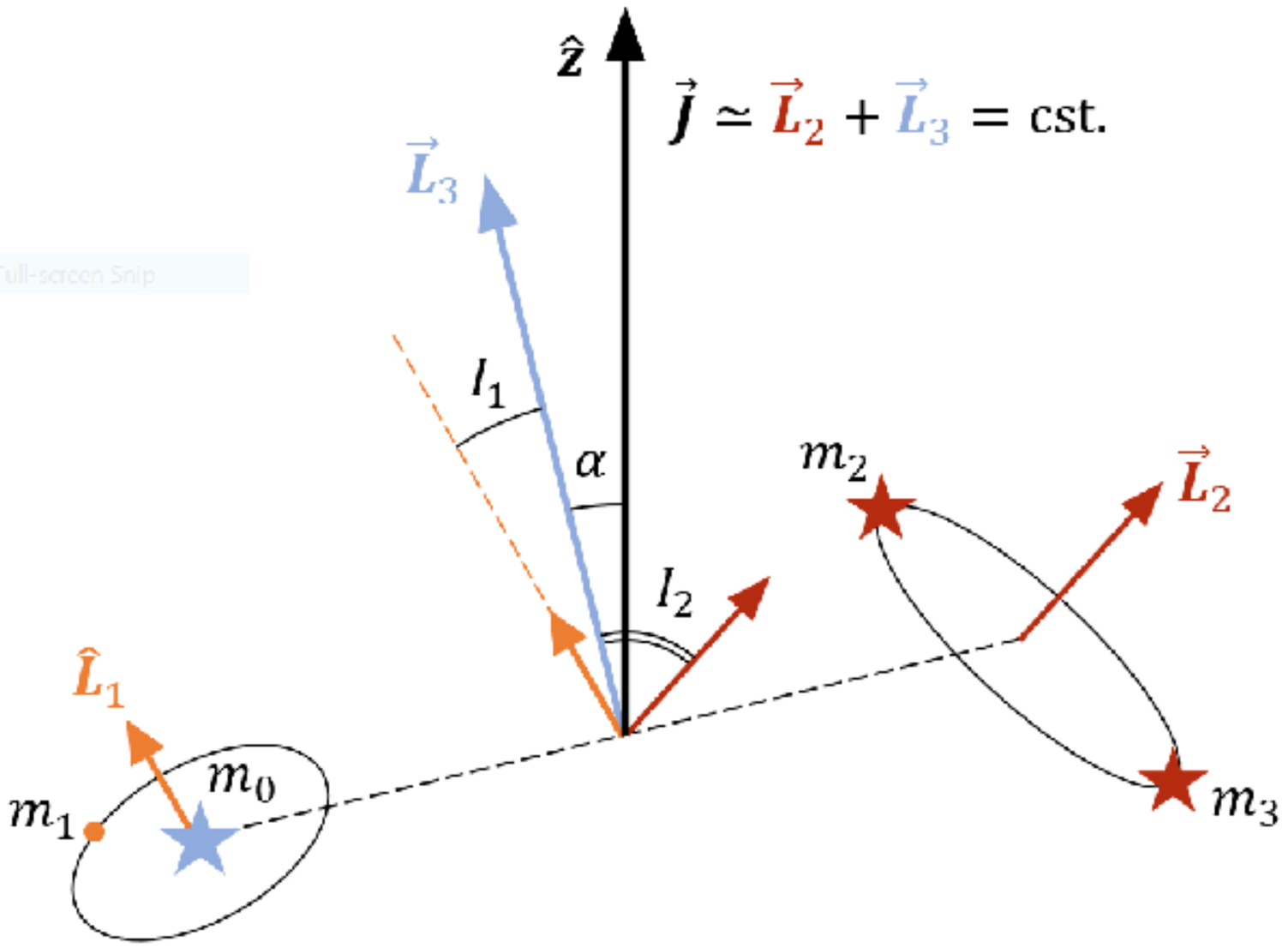


Maldonado et al. (2021)

Binaries

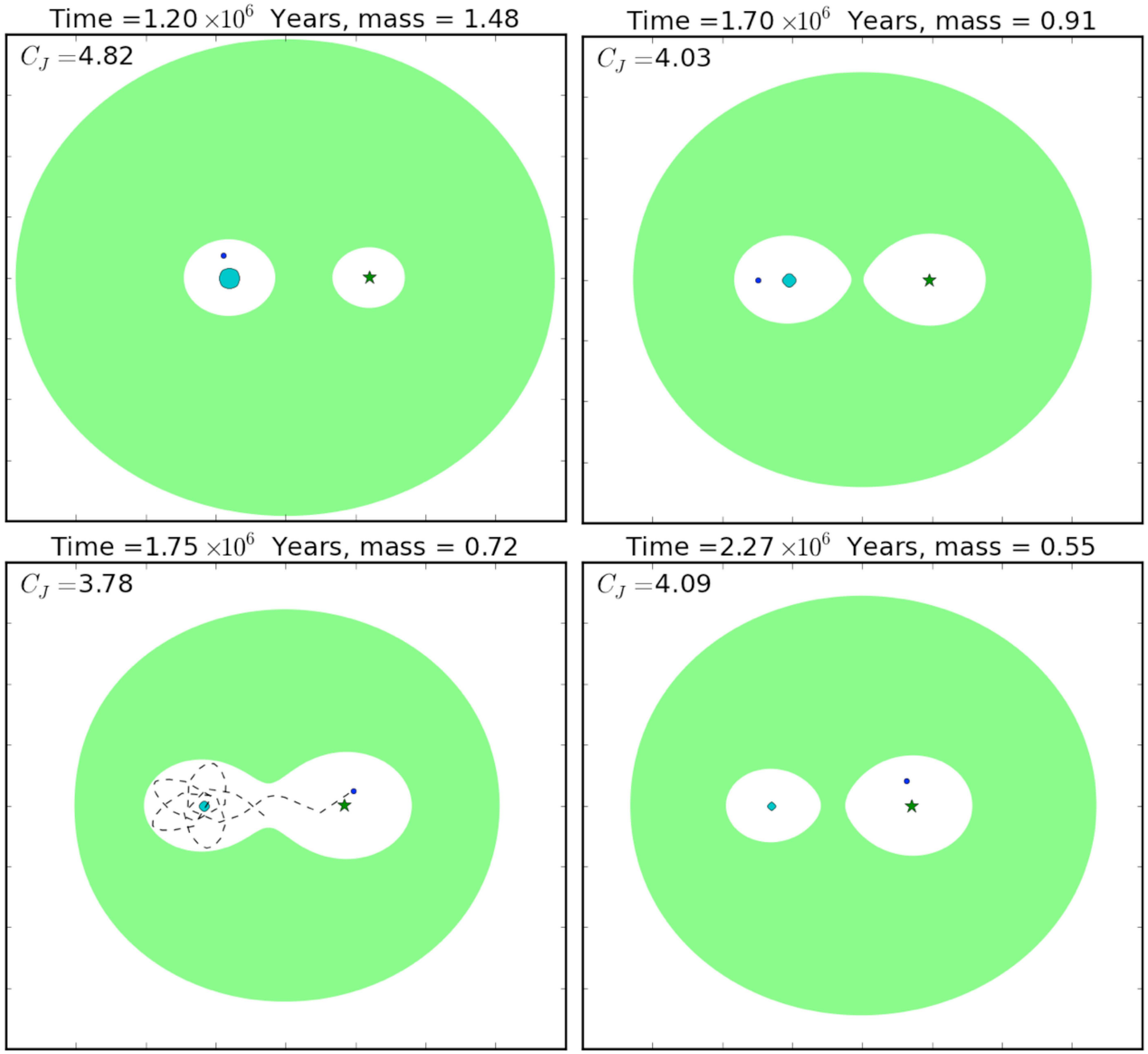


Veras, Xu & Rebassa-Mansergas (2018)
binary distance for accretion



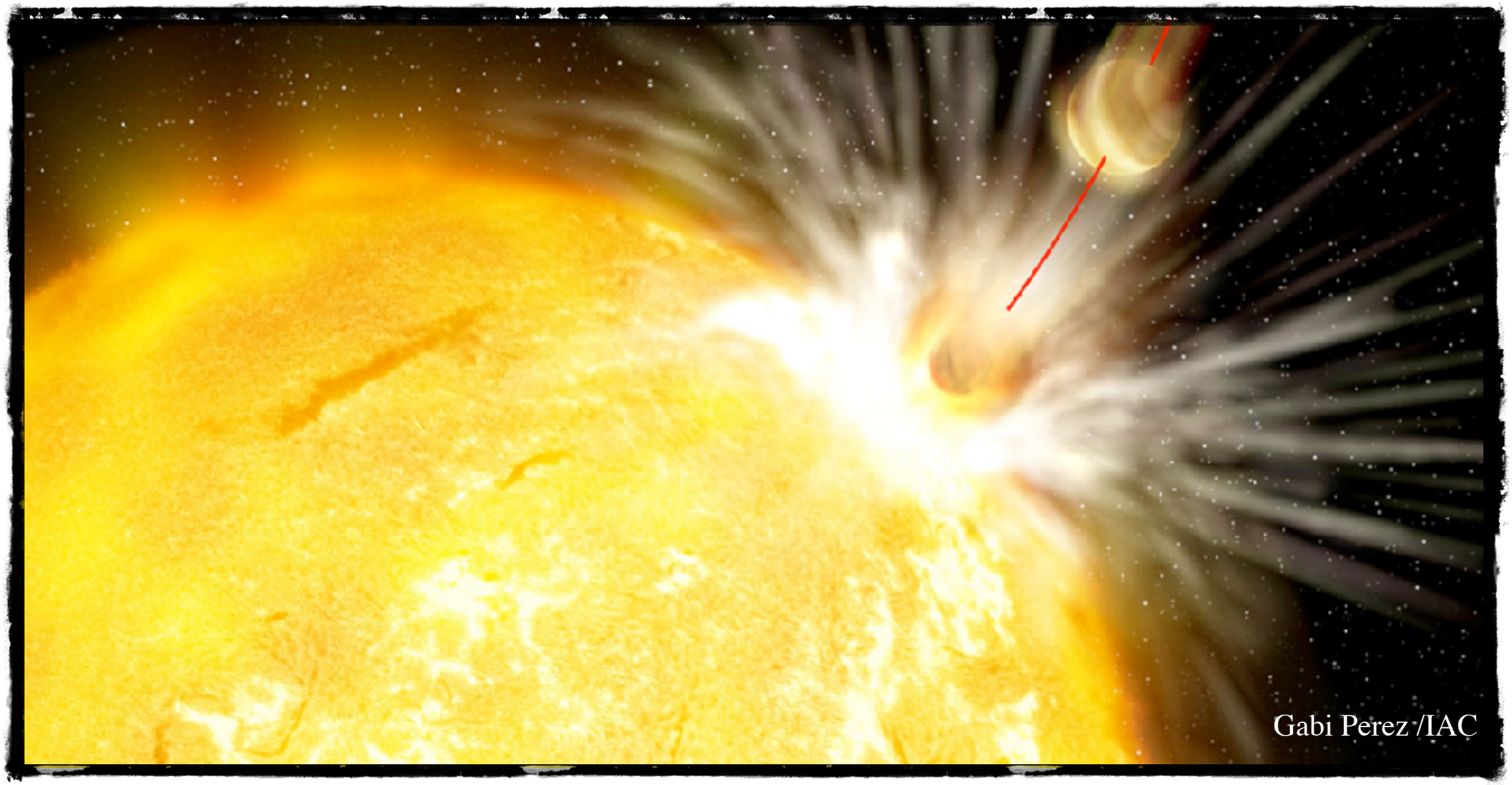
WD 1856b 1.4 days orbit
Kozai migration:

—Muñoz and Petrovich (2020)
—O´Connor, Liu and Lai (2020)
—Stephan, Daoz and Gaudi (2020)

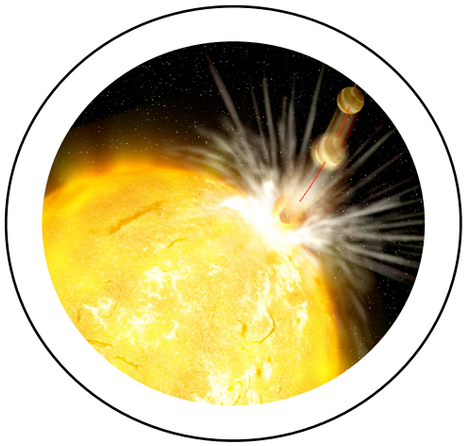


Kratter & Perets (2012)

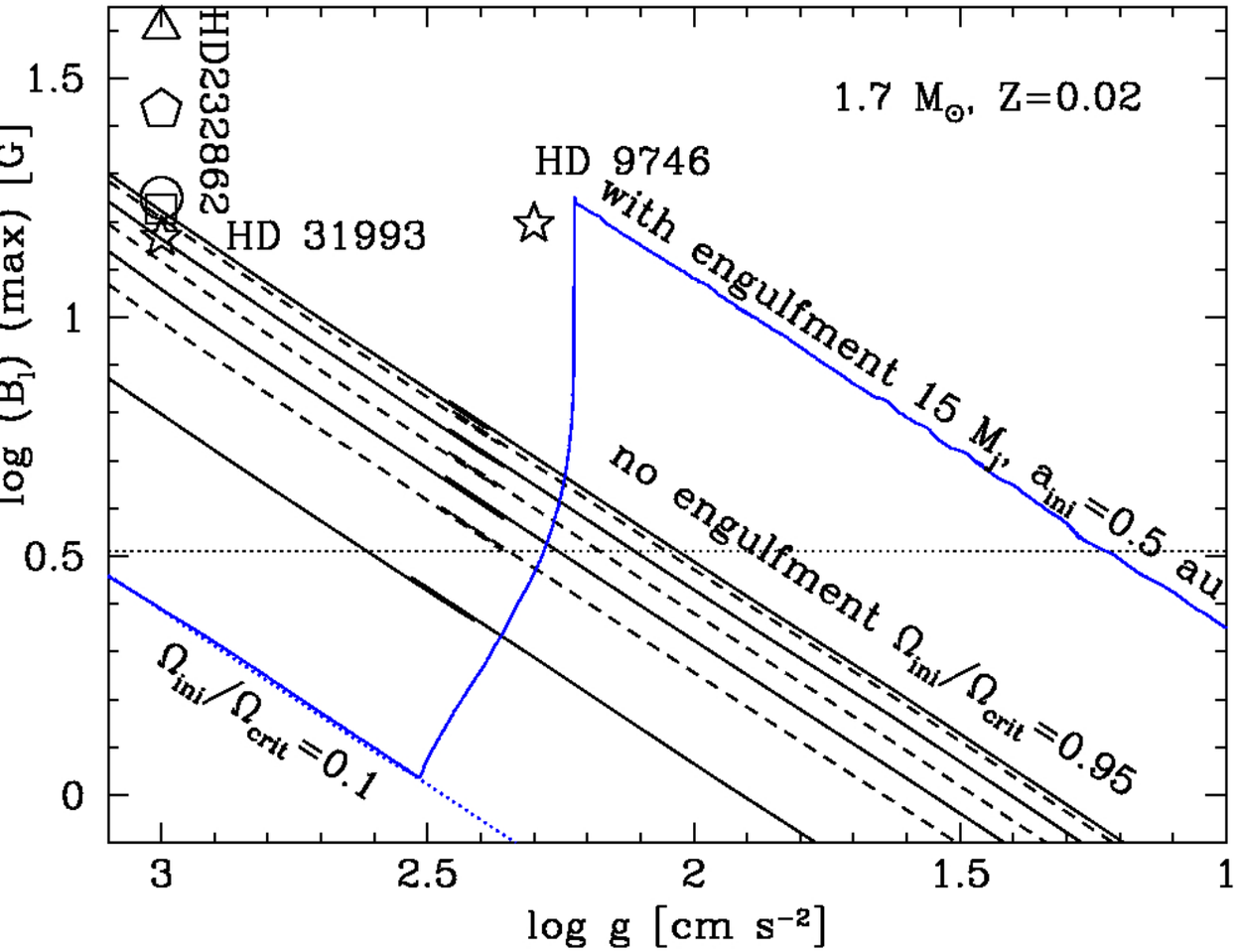
See also Perets (2010), Veras & Tout (2012), Moekel & Veras (2012)

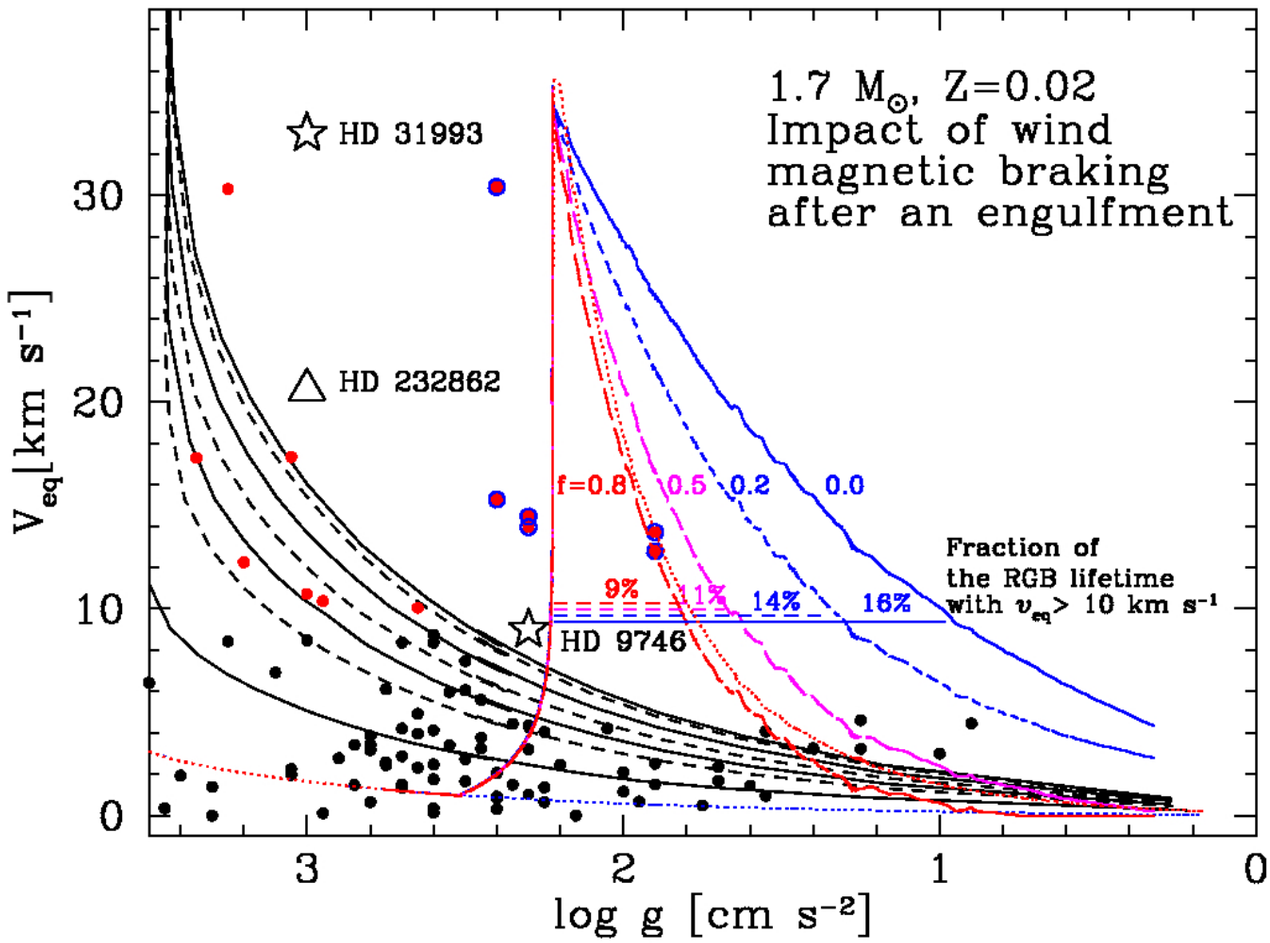


Engulfment
Common Envelope Evolution



Planet-star interactions



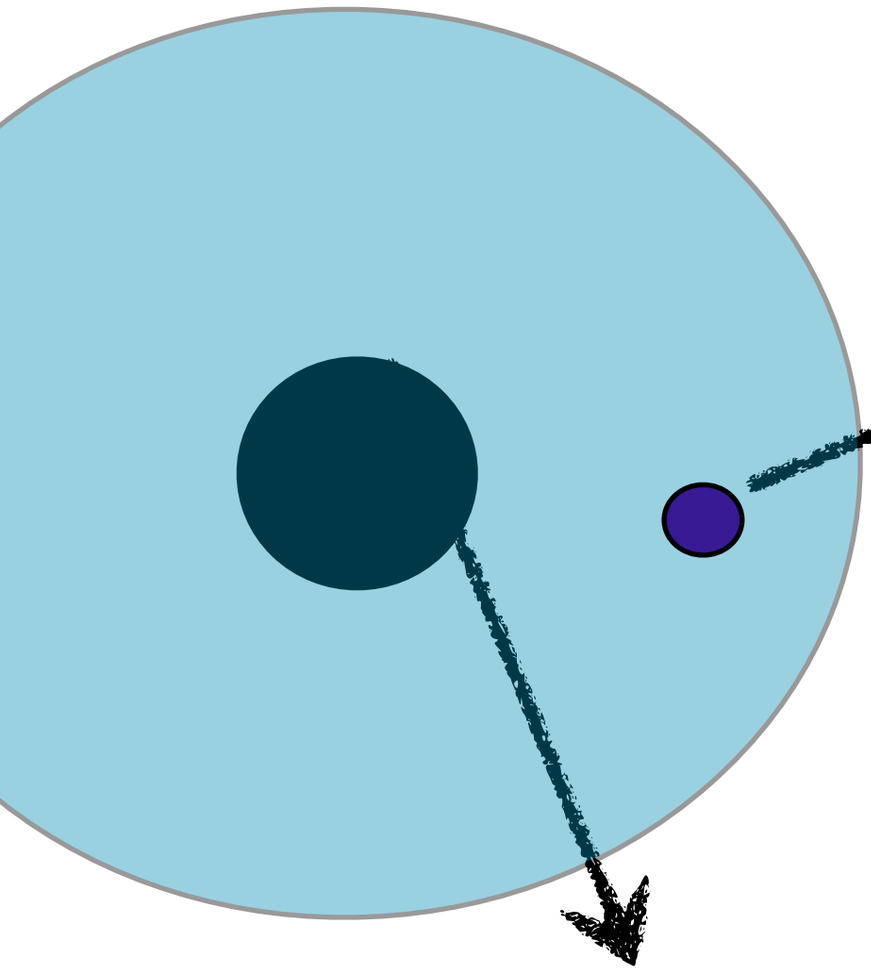


Siess & Livio (1999ab) AGB

García-Segura et al. (2014, 2016) AGB

Privitera et al. (2016abc) RGB

Common Envelope Evolution



Merger

Planet mass destroyed:

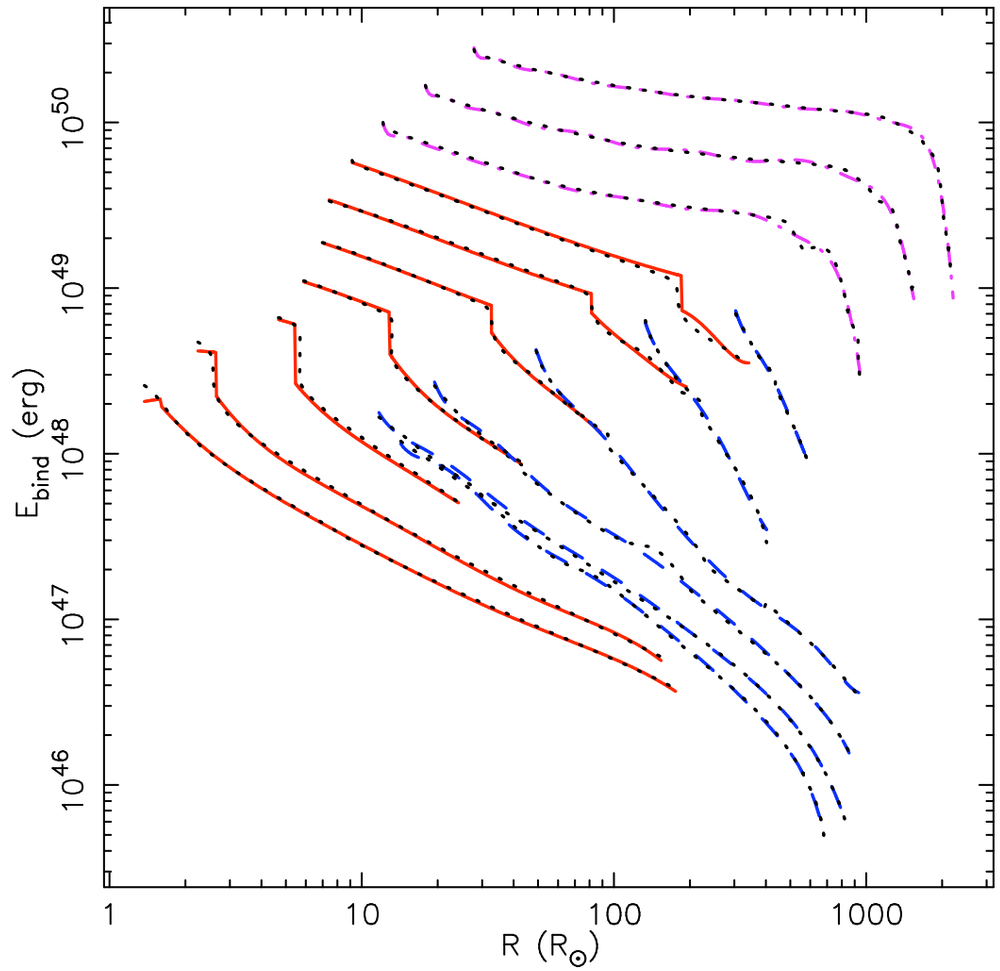
15 Mj for a 1Msun AGB

Villaver & Livio (2007) Nordhaus et al. (2006, 2010)

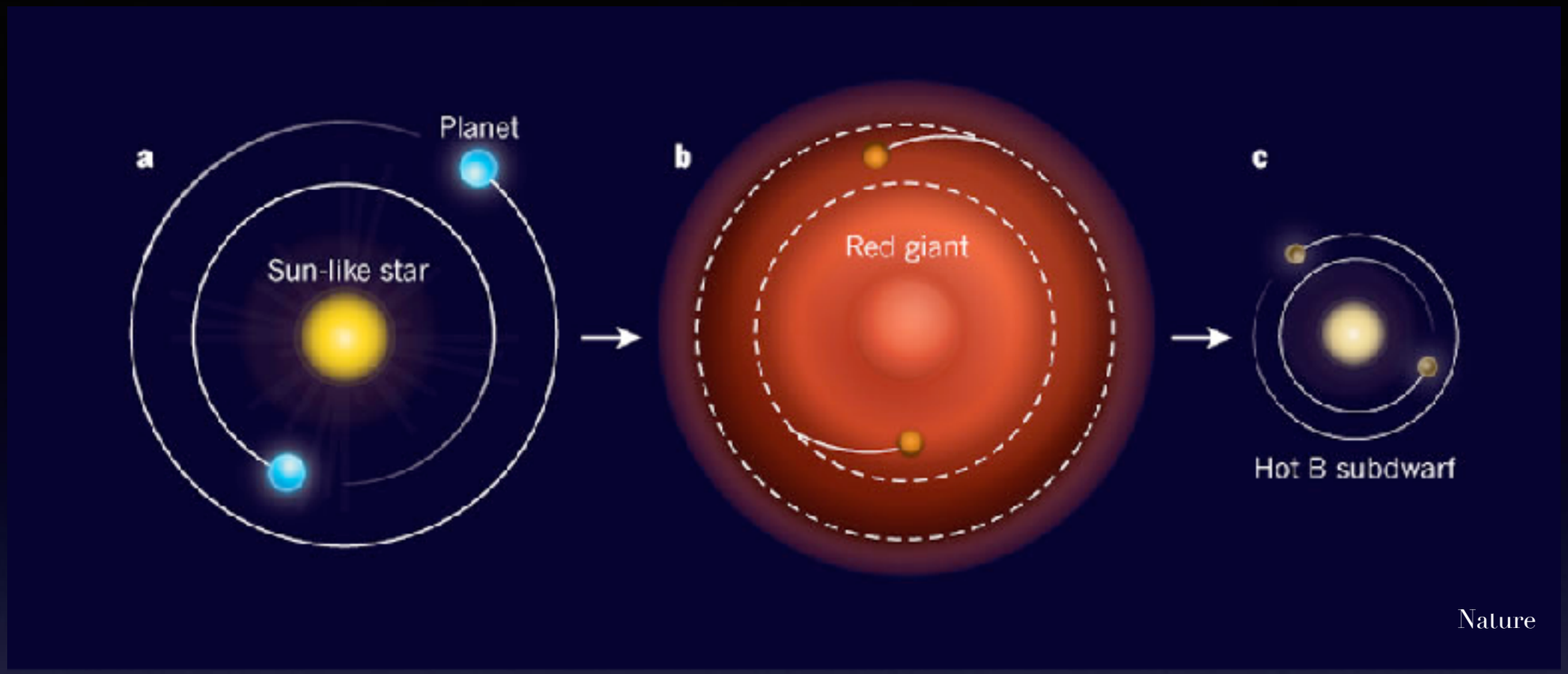
Different limits have been set recently

Stable binary system

If orbital energy leads to envelope ejection.



Loveridge et al. (2010)

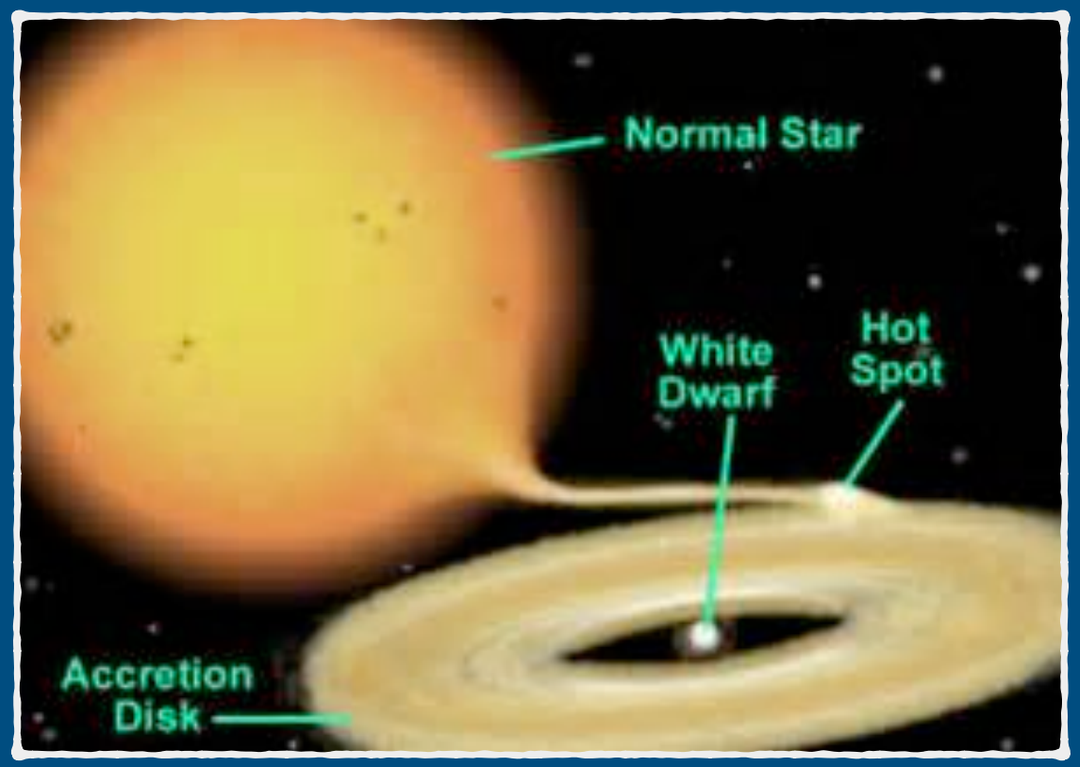


Hot Subdwarfs

Bear & Soker (2012)
Passy et al. (2012)
remnants of one or two Jovian-mass planets that lost extensive mass during CE phase.

Han et al. (2002)
Form single sdB stars via merger of two He WDs, planet formation following this event may be possible.

Eclipsing timing variations in Post-Common Envelope Binaries



- Sub dwarf B binaries Hw Vir (Lee et al 2009)
- Pre-CVs NN Ser (Beuermann et al. 2010)
- CV HU Aqr (Quian et al 2011)

6 single planet systems
6 two-planet systems
in PCEB

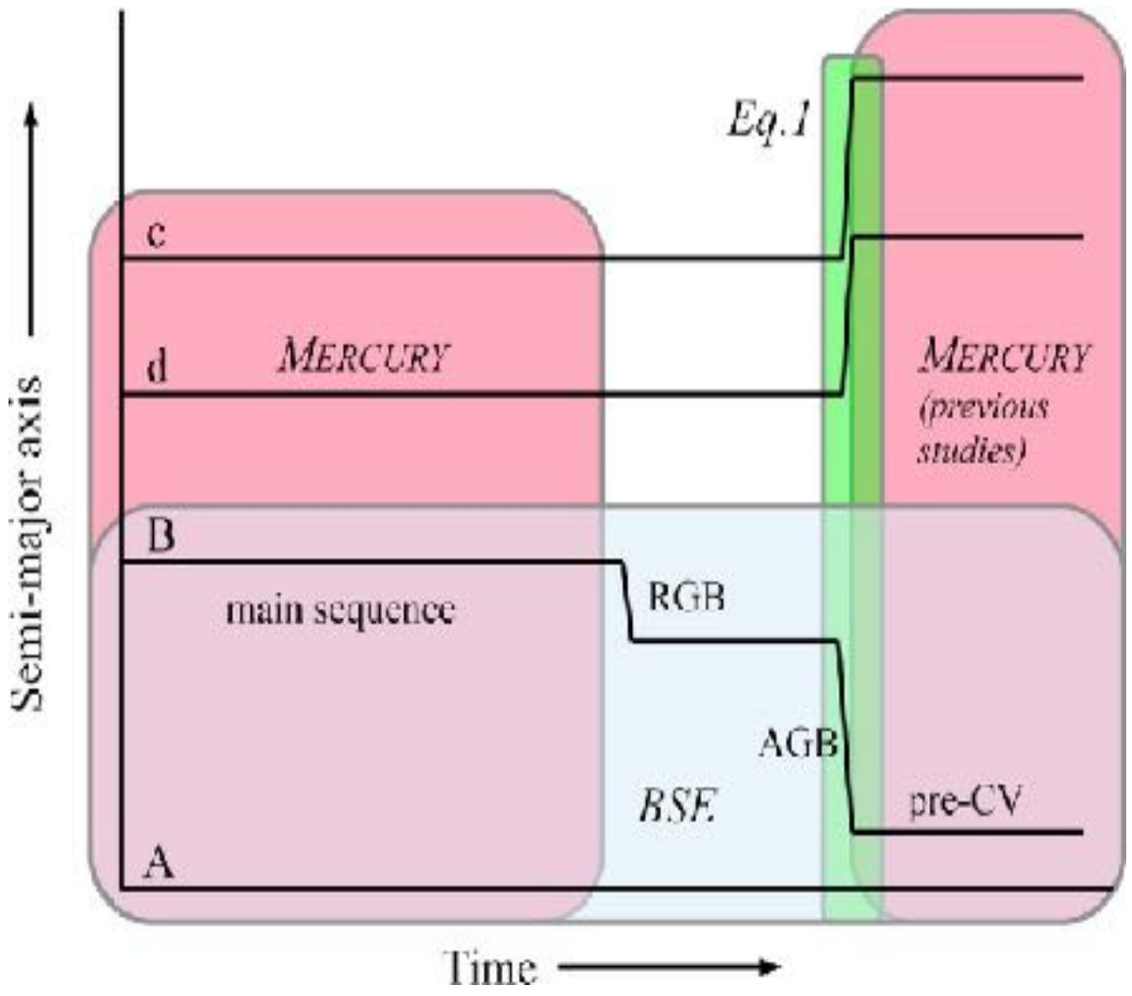
CE efficiency and timescale???

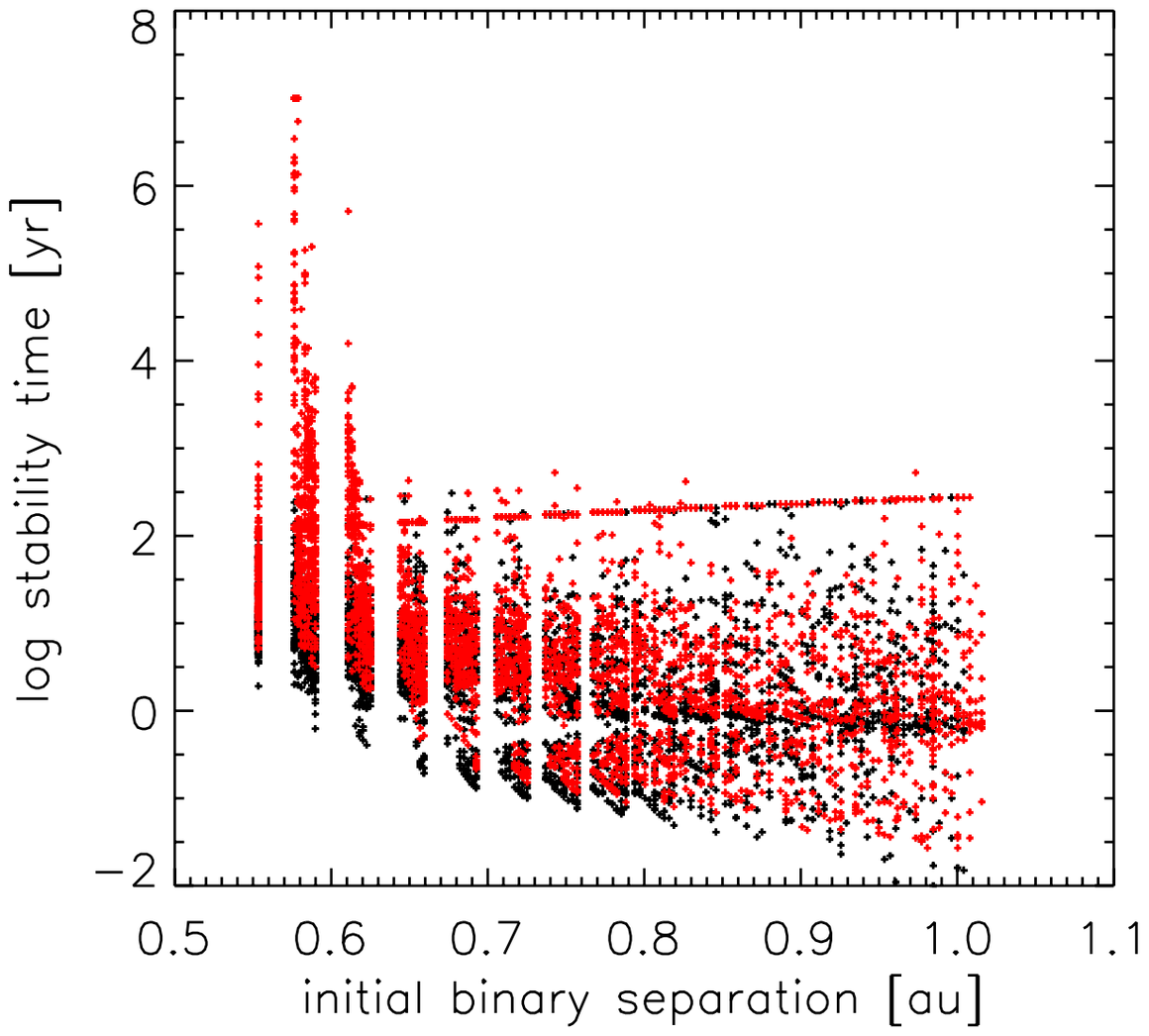
NN Ser pre-CV

We evolve 76 545 binary systems changing M1, Z, binary separation, ejection efficiency x binding energy.

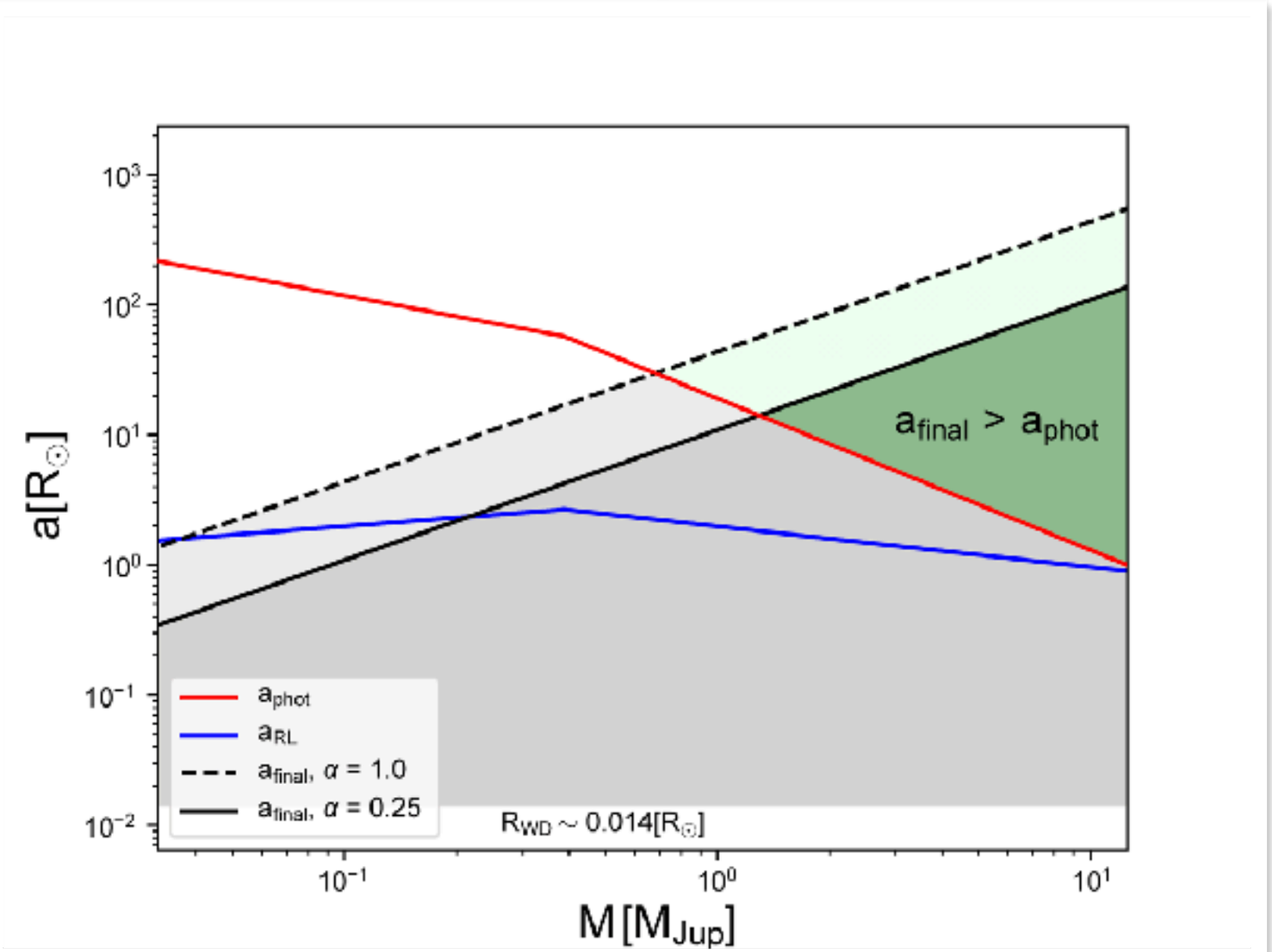
369 ok but CE par. between 0.5 to 2.0.

3690 separate integrations only 16 survive 10 Myr





Mustill et al. (2013)

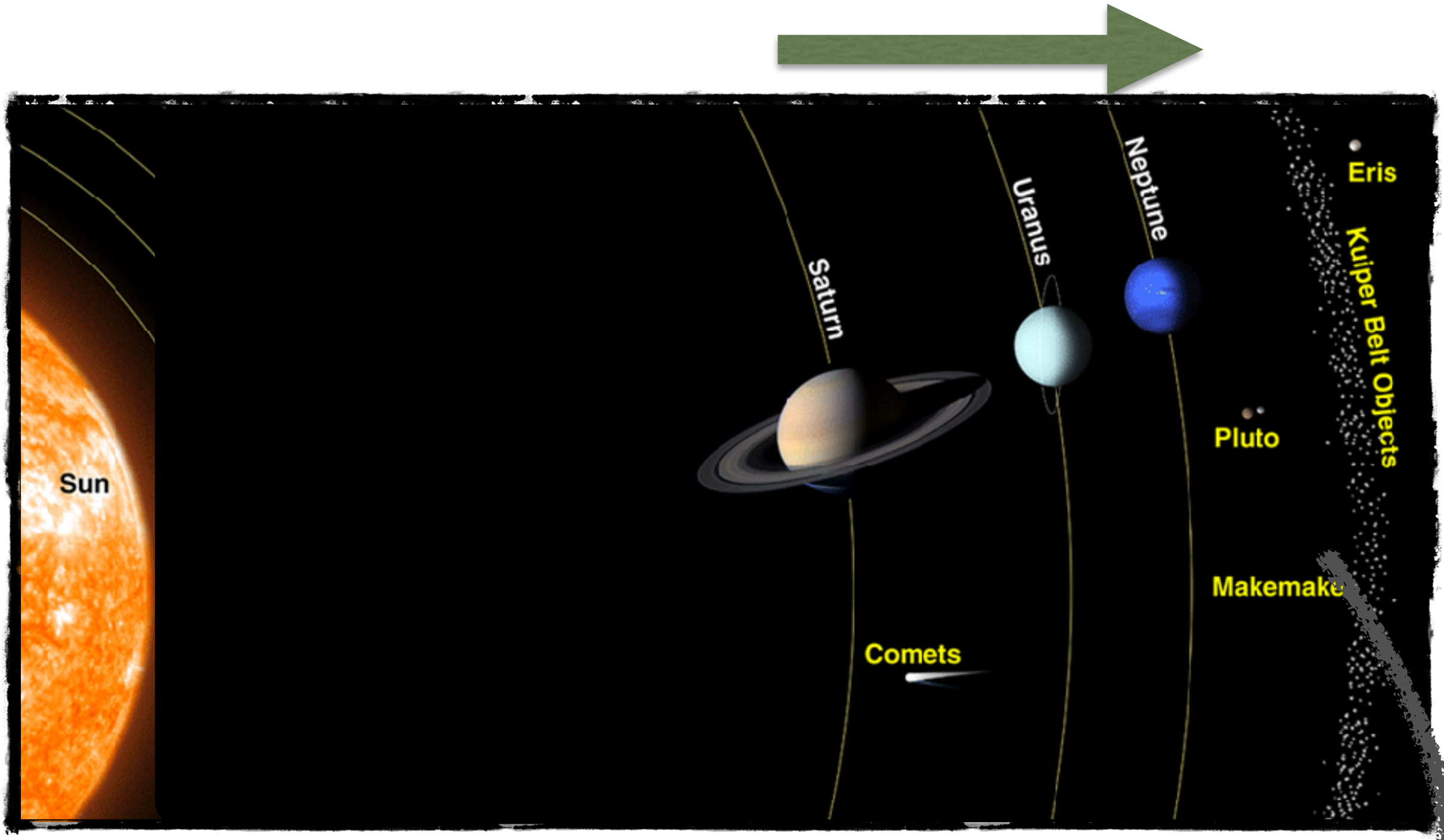


WD J0914+1914
Gänsicke et al. (2019)

WD 1856b 1.4 days orbit
Survivor of Common Envelope:

—Lagos et al. (2021)
—Chamandy et al. (2021)

Summary


Sun
Saturn
Uranus
Neptune
Eris
Kuiper Belt Objects
Pluto
Makemake
Comets