Old Planetary Systems

Eva Villaver
Universidad Autónoma de Madrid

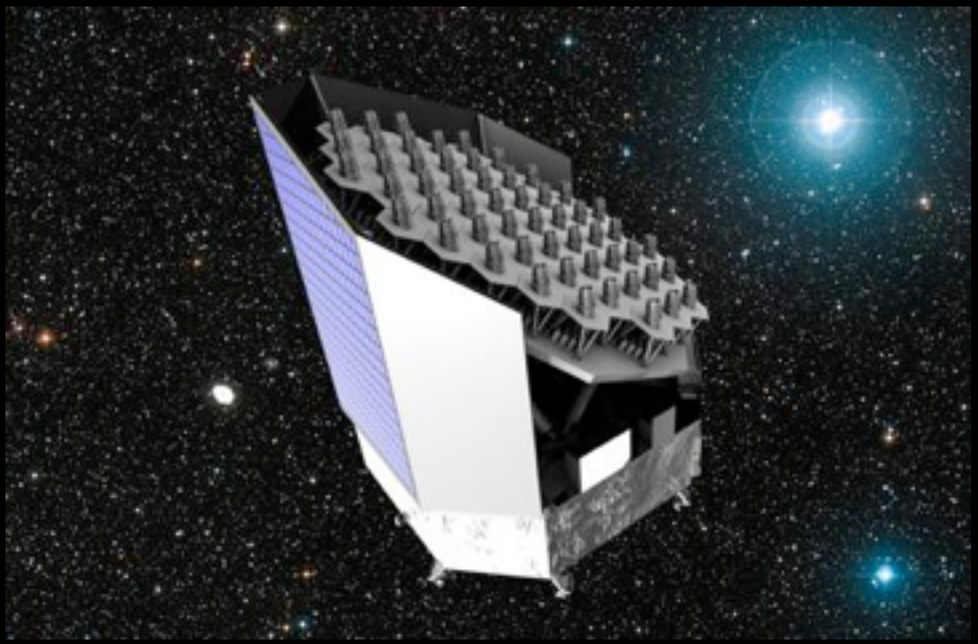
What is the unique capabilities that THEIA can provide to EXOPLANET detection?

TARGETS for Earth detection and Characterisation??

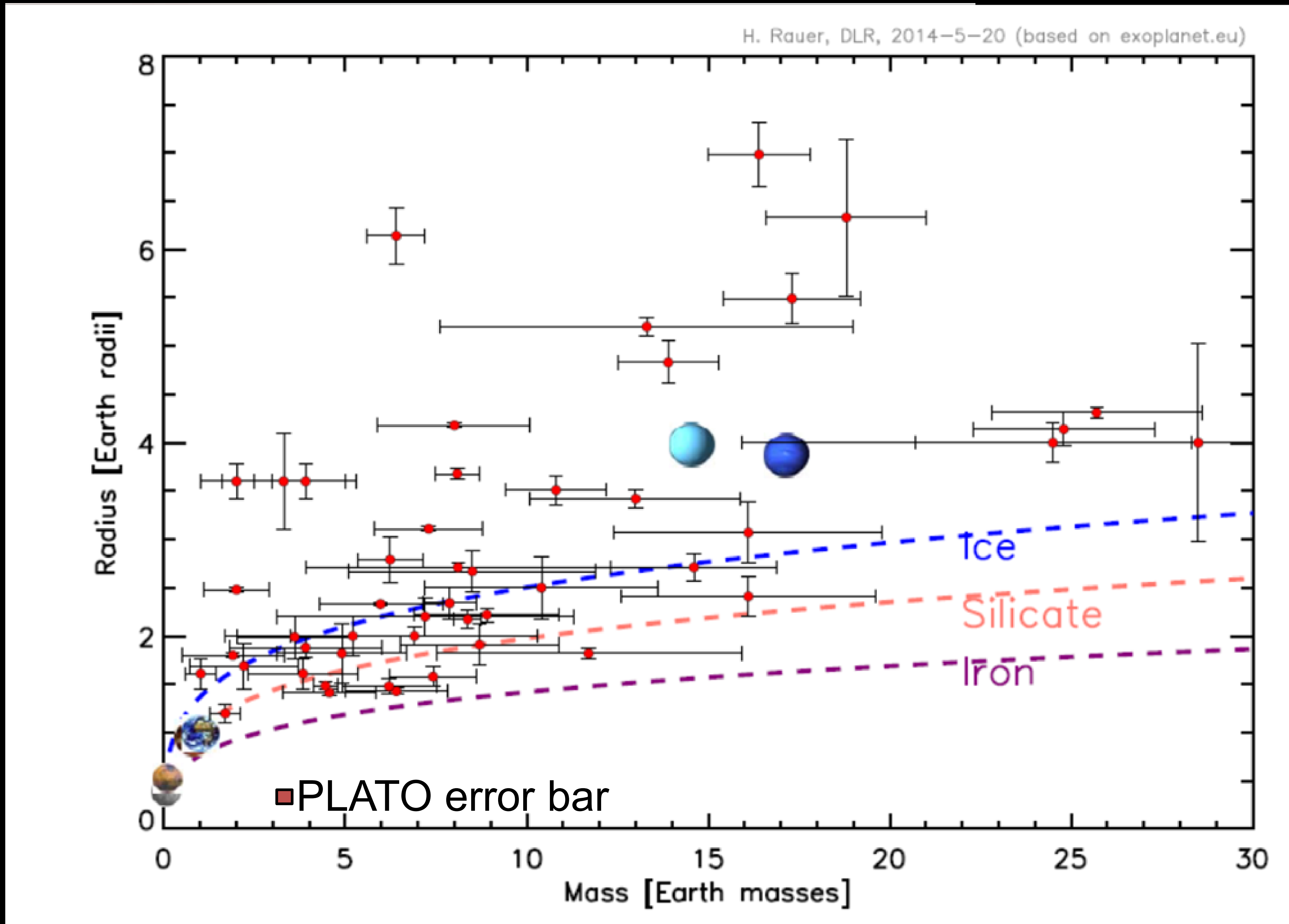
Clear science objective. Focus on what is the new science that THEIA will allow in the current context of the approved missions.

- **DARK MATTER**: ESA has approved EUCLID (M-class galaxy clustering and weak lensing) for DE, context needed.
- **EXOPLANETS**: PLATO, CHEOPS, TESS, GAIA + lots of science that can be done from the ground.

PLATO



- Planet masses (better than 10% precision 4-11mag stars) from ground-based radial velocity follow-up
- Determination of accurate stellar masses, radii, and ages (10% precision) from asteroseismology
- 42% of the sky.



To break model degeneracy important to reduce error bars

- What is the fraction of Earth-like planets around Solar-type stars? Still not known…

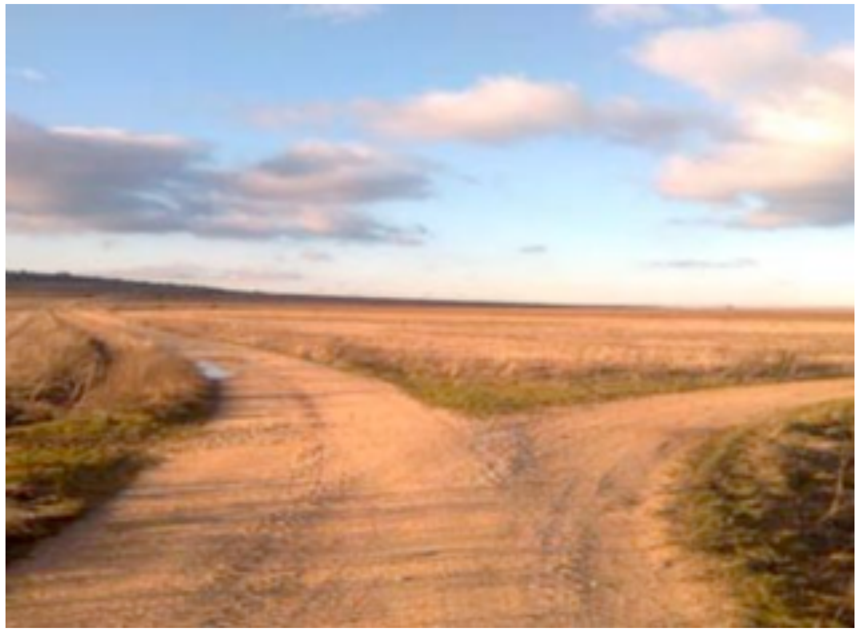
- How many targets are available for an astrometric mission with the goal of detecting Earth-mass planets approx. 50 targets….

- What are other options that can be address: **complementary science…**

Post-MS habitability

1. Survival:

what (life) planet
would need to endure
after the MS.

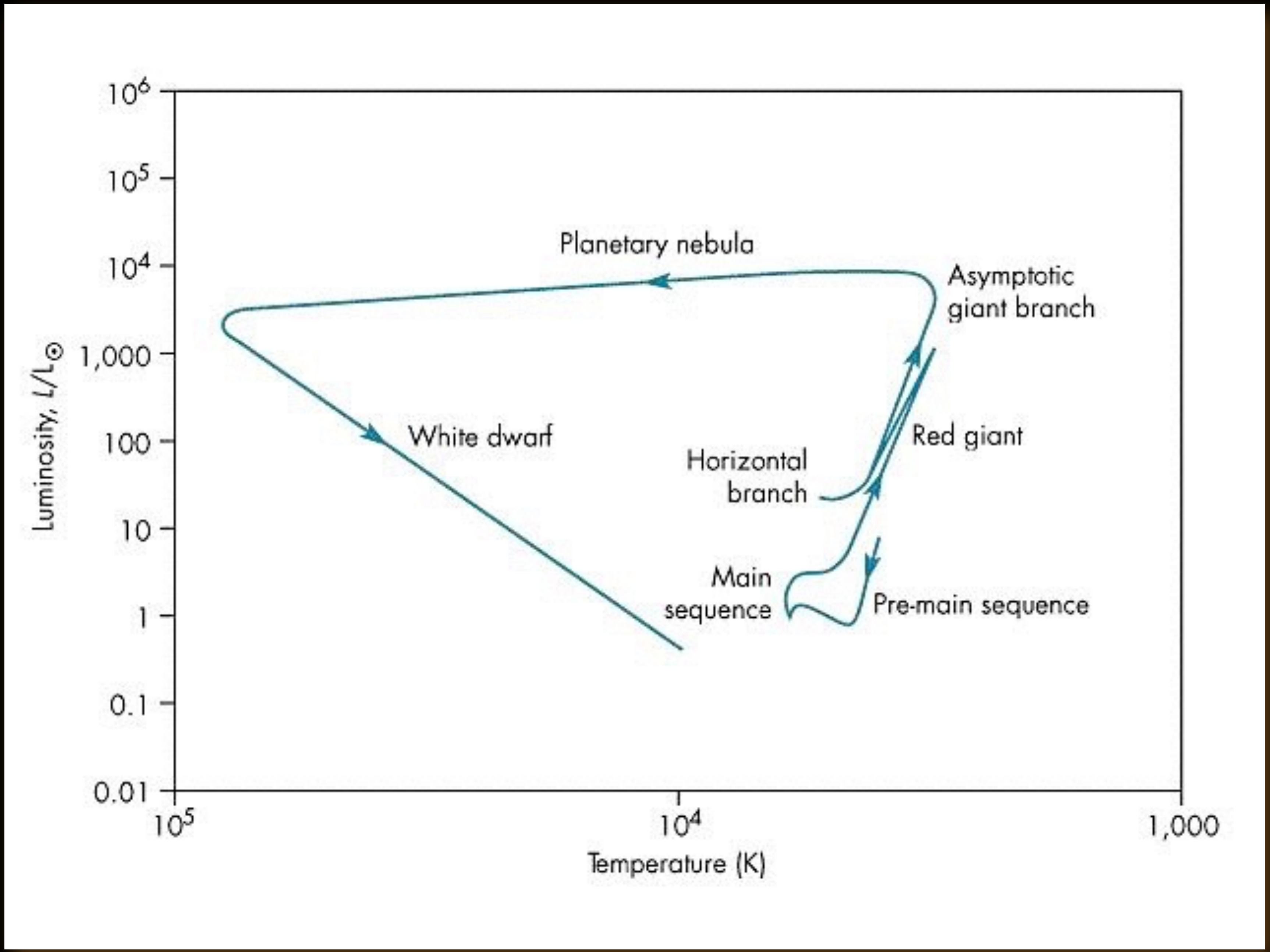


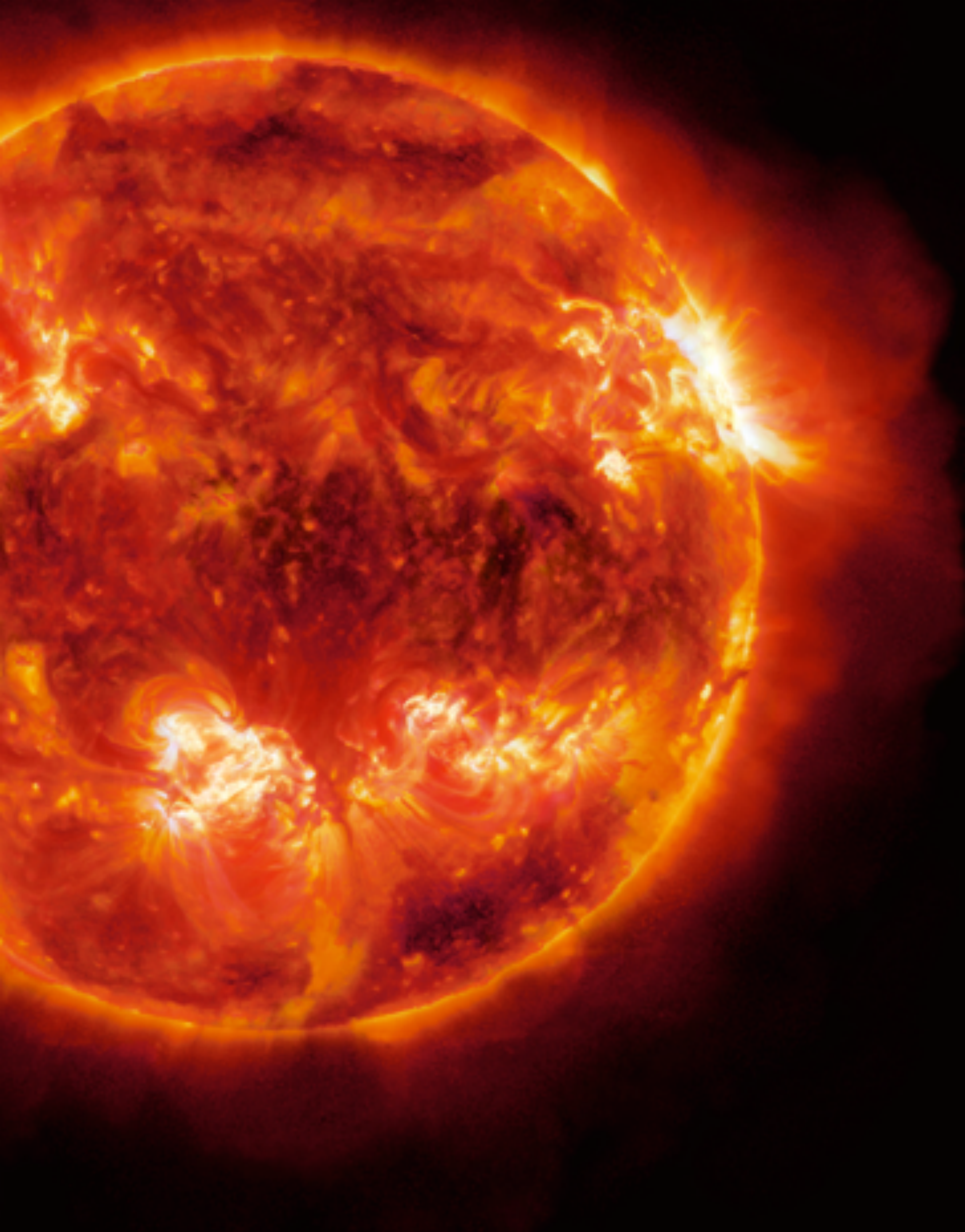
2. Second chance:

are there suitable
condition after the MS
for life to develop?

1. Survival

Where planets can be found at late stages of stellar evolution?

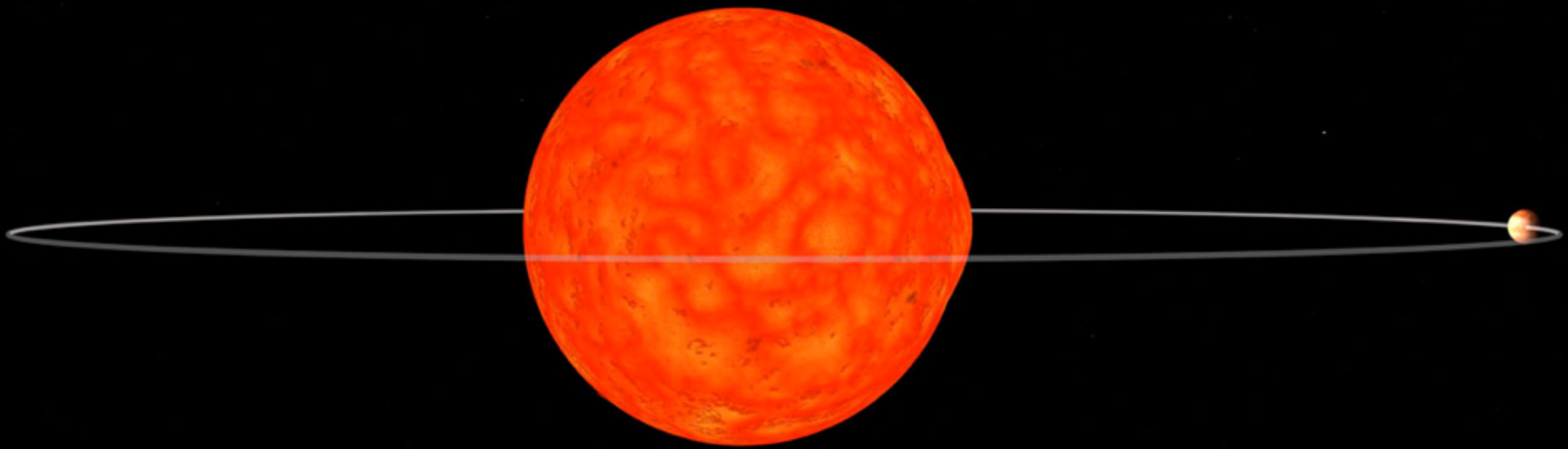




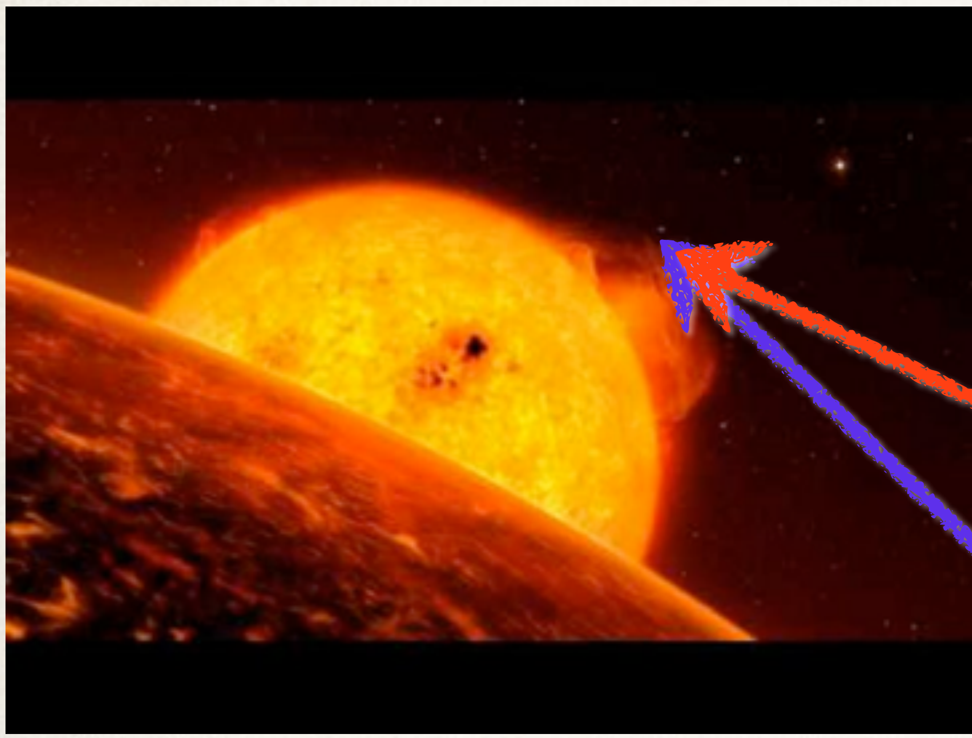
survive?

Schröder & Smith´08	NO	Schröder & Cuntz´05
Rybicki & Denis´01	Yes prob.	6 different mass-loss
Rasio et al. ´96	NO $f > 1$ Yes if $f = 1$	$\eta = 0.6$
Sackmann et al. ´93	YES	varies η but no tides

Single stellar evolution, single planet



Orbital evolution

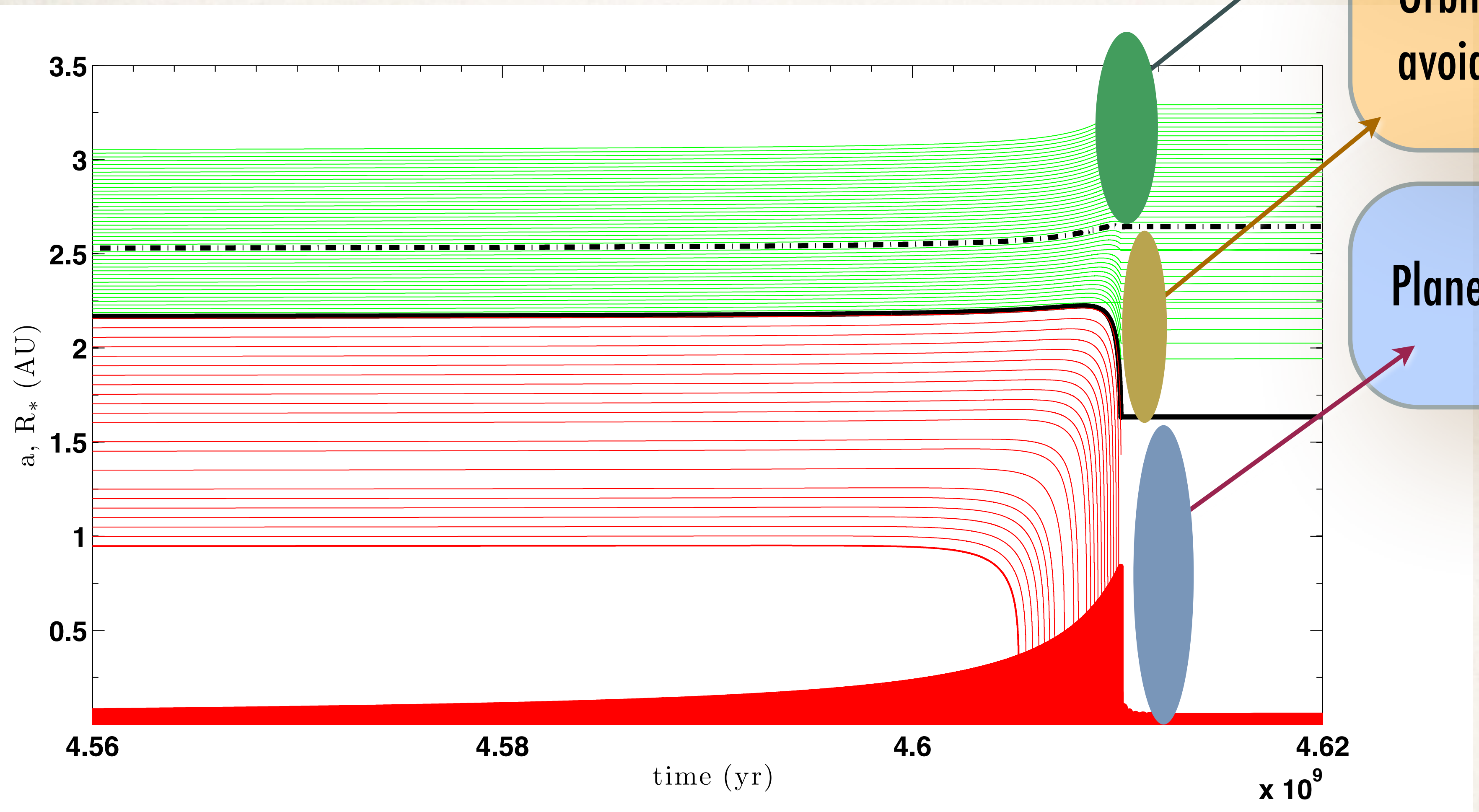


$$\left(\frac{\dot{a}}{a}\right) = -\frac{\dot{M}_* + \dot{M}_p}{M_* + M_p} - \frac{2}{M_p v}\left[F_f + F_g\right] - \left(\frac{\dot{a}}{a}\right)_t \quad ,$$

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

Villaver & Livio (2009); Nordhaus et al. (2010); Nordhaus & Spiegel (2012); Mustill & Villaver (2012); Adams & Bloch (2013); Villaver et al. (2014)

Orbital evolution on the RGB



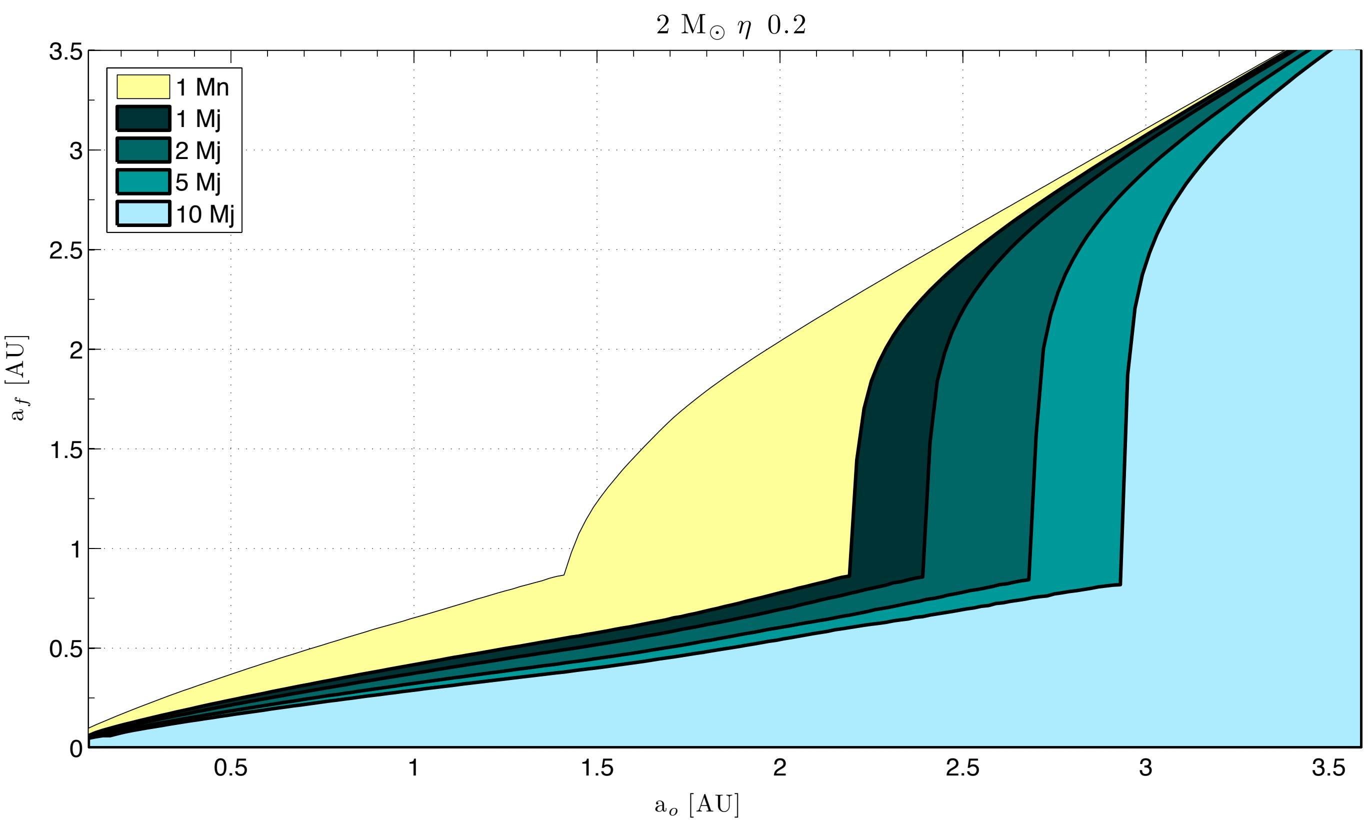
Mass-loss dominates orbital evolution

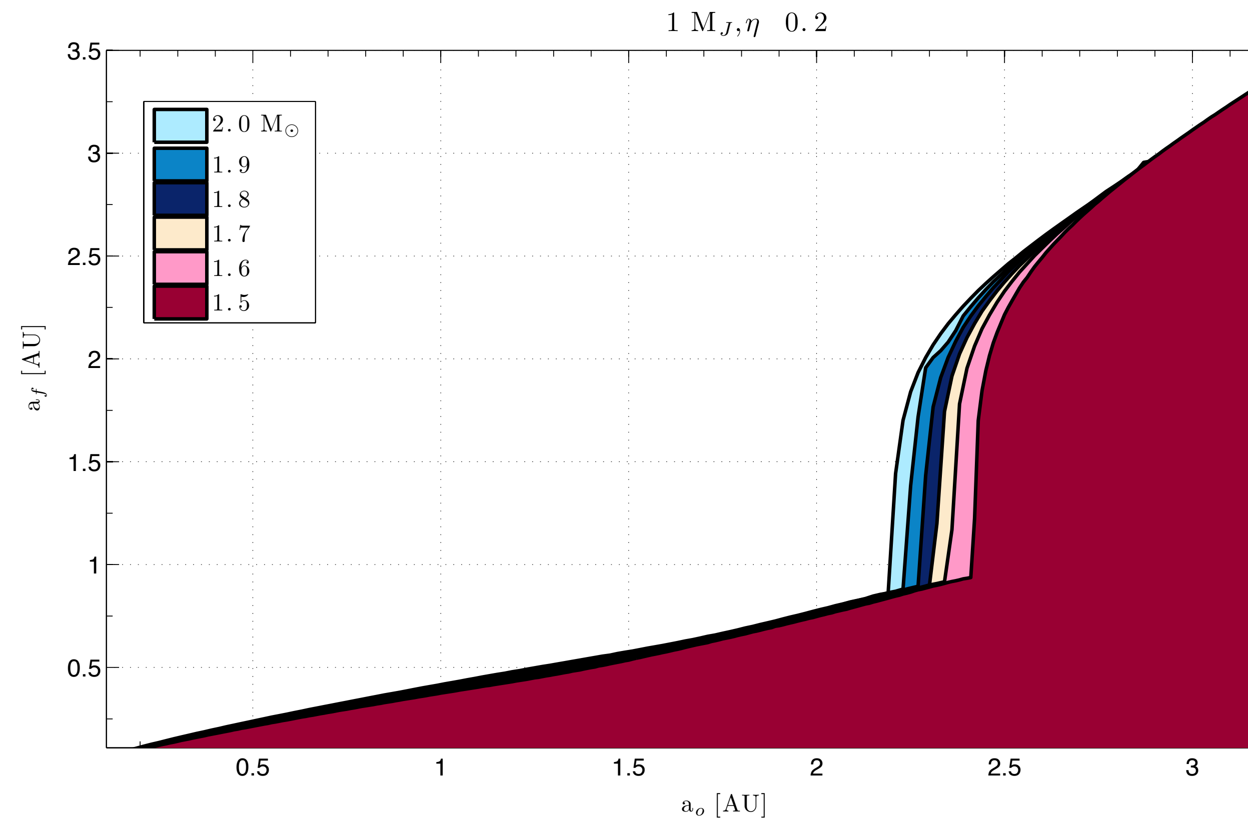
Orbit decays but planet avoids engulfment

Planet enters the stellar envelope

Villaver & Livio (2009) Villaver et al. (2014)

Dependencies





Planet mass

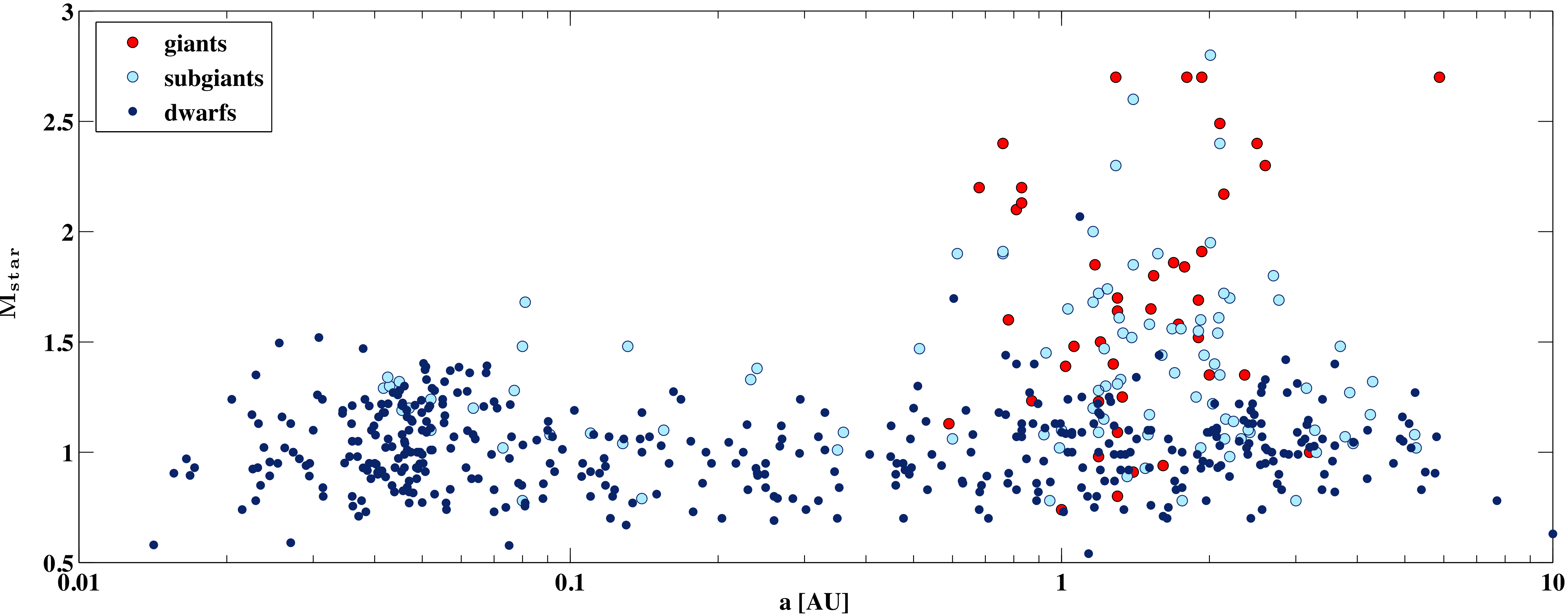
Stellar mass

Minimum Orbital Radius to Avoid Tidal Capture

M_*	$R_*^{\max}$ (AU)	$a_{\min}$ (AU)		
		$M_p = M_J$	$M_p = 3\,M_J$	$M_p = 5\,M_J$
$1\,M_\odot$	1.10	3.00	3.40	3.70
$2\,M_\odot$	0.84	2.10	2.40	2.50
$3\,M_\odot$	0.14	0.18	0.23	0.25
$5\,M_\odot$	0.31	0.45	0.55	0.60

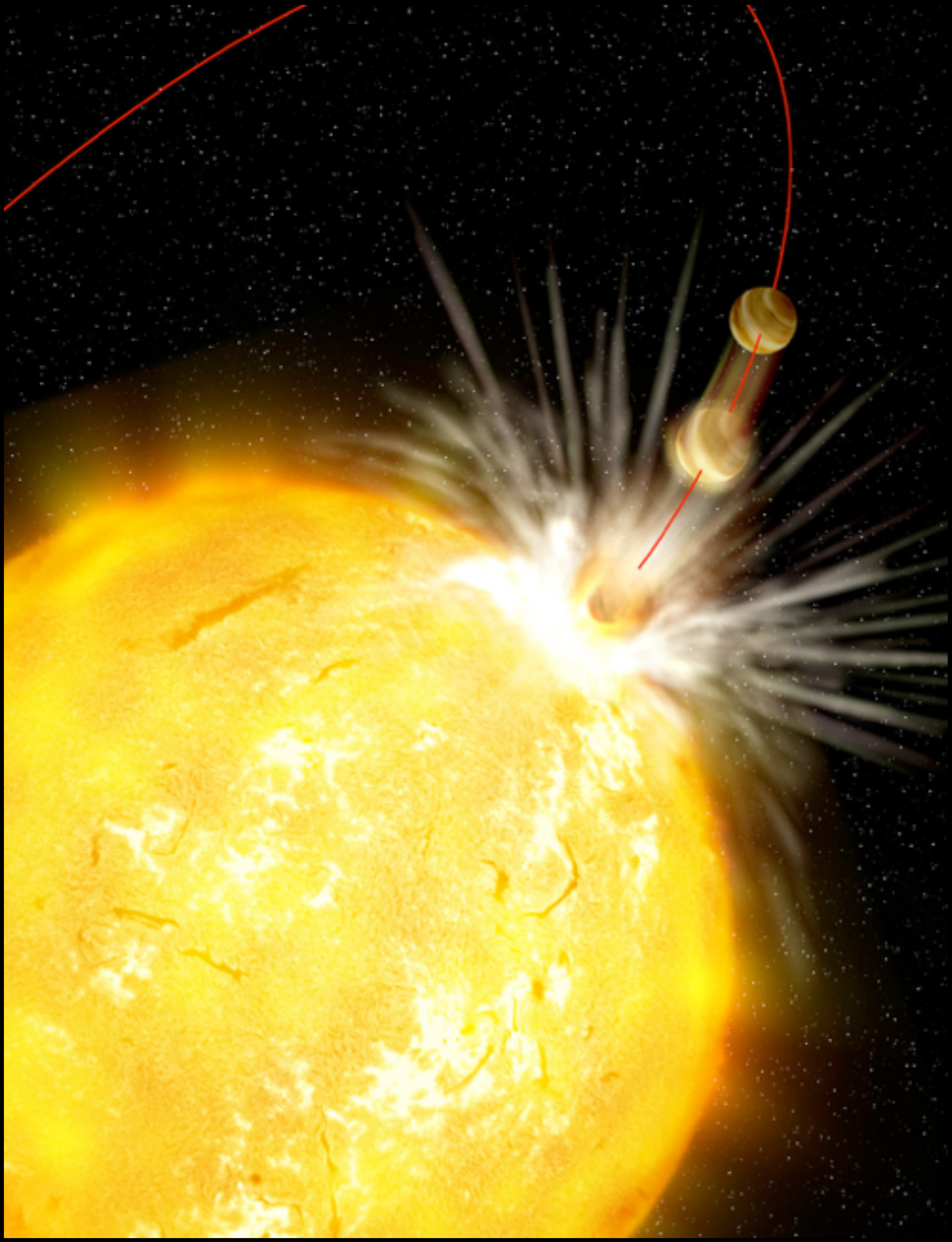
Villaver & Livio (2009); Villaver et al. (2014)

Confirmed planets, RV method



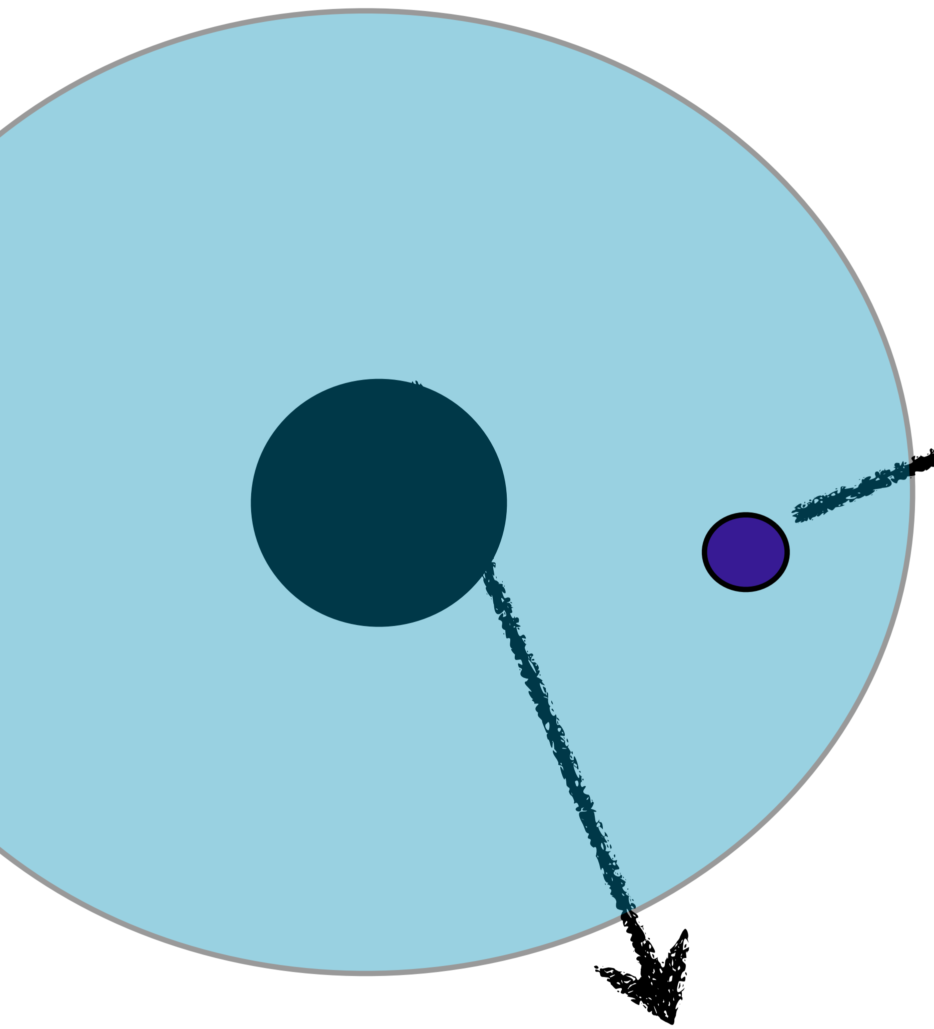
Villaver et al. (2014)

Engulfment



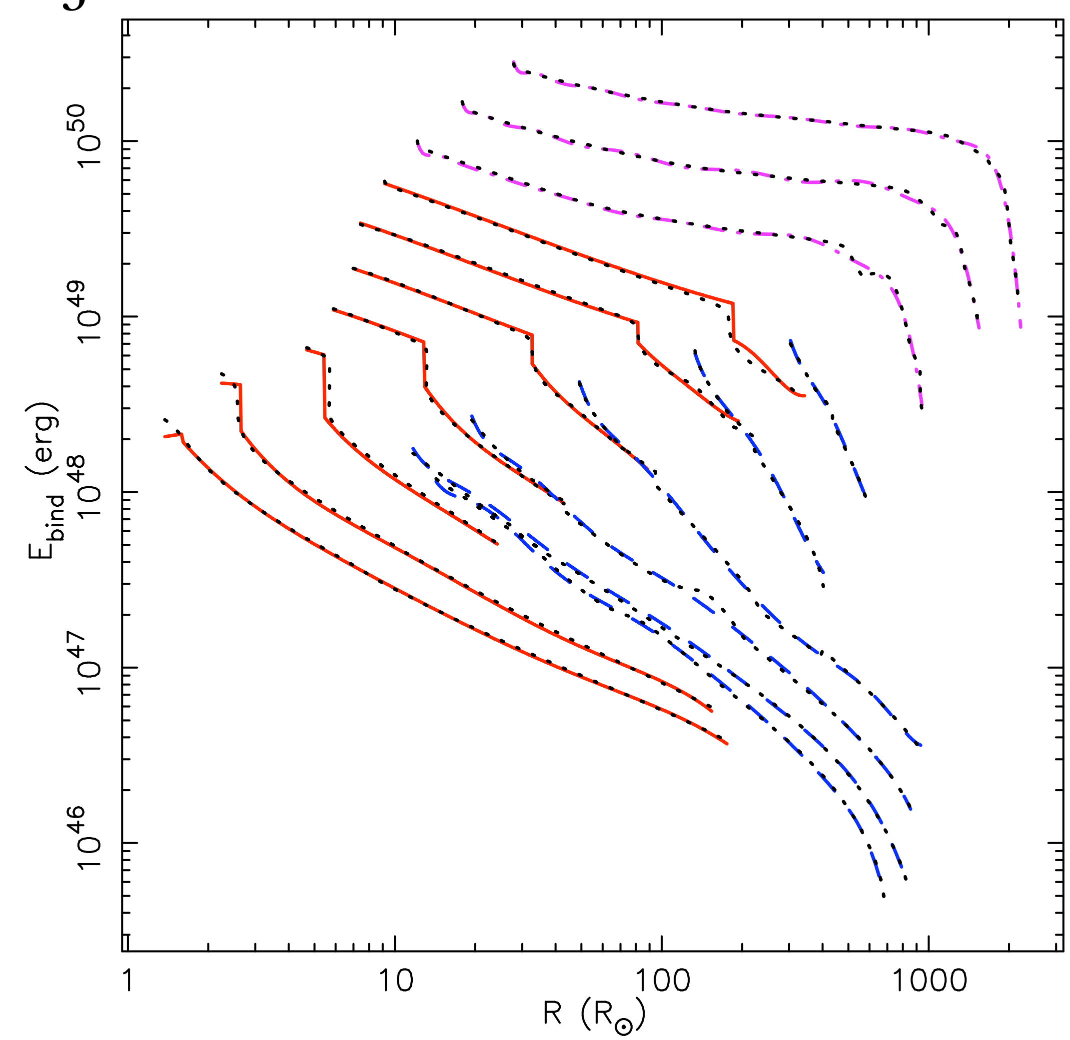
Gabi Perez /IAC

Common Envelope Evolution



Stable binary system

If orbital energy leads to envelope ejection.



Loveridge et al. (2010)

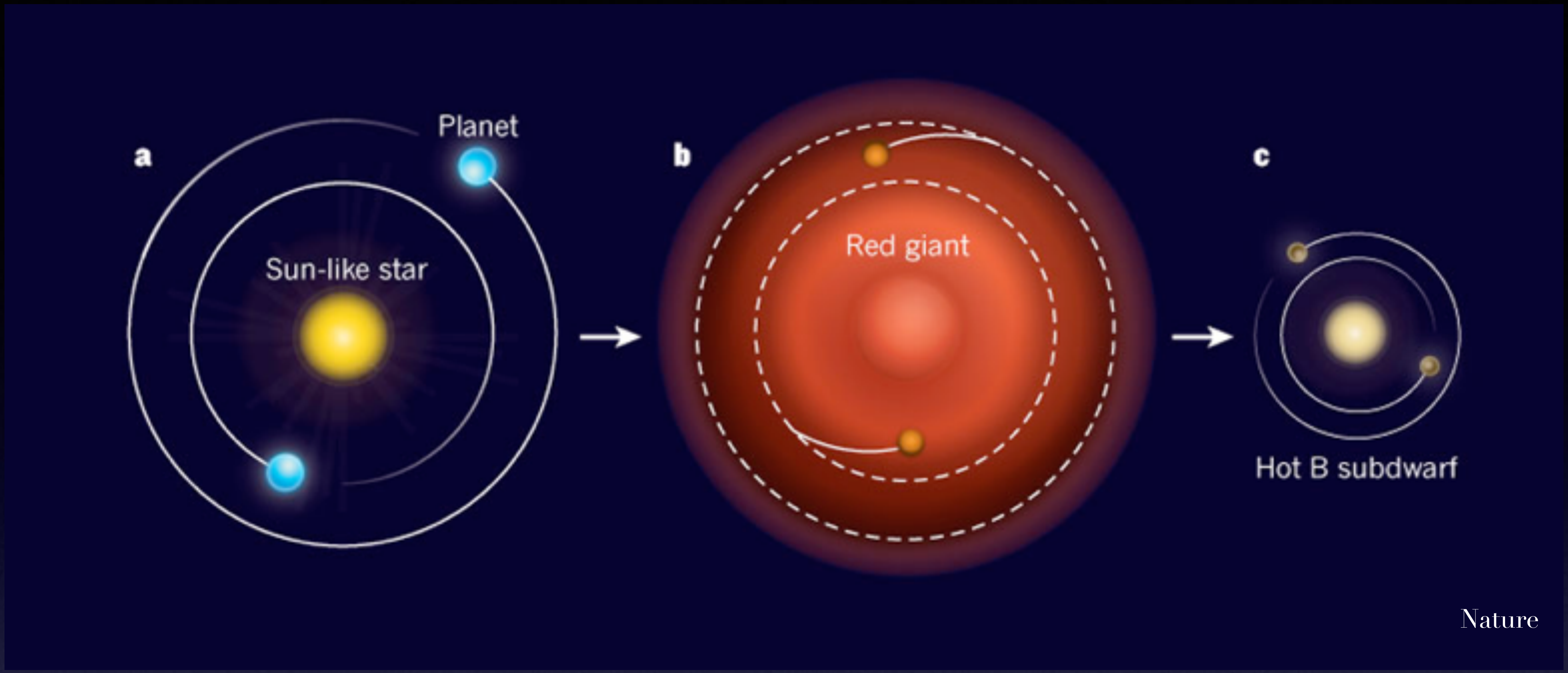
Merger

Planet mass destroyed:

15 Mj for a 1Msun AGB

Villaver & Livio (2007)

Nordhaus et al. (2010)

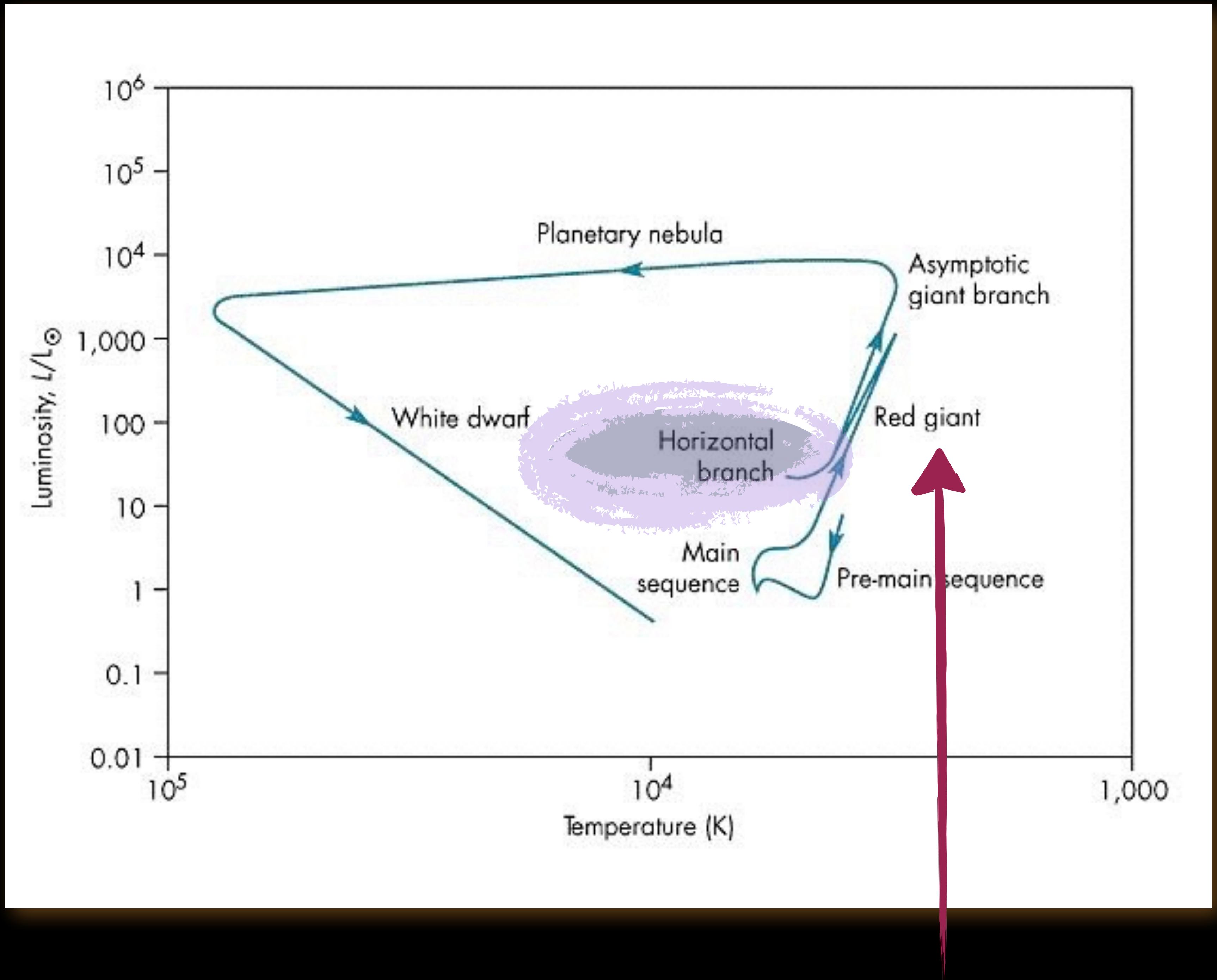


KIC 05807616 two Earth-like planets at 0.0060 & 0.0076AU

Charpinet et al. (2011)

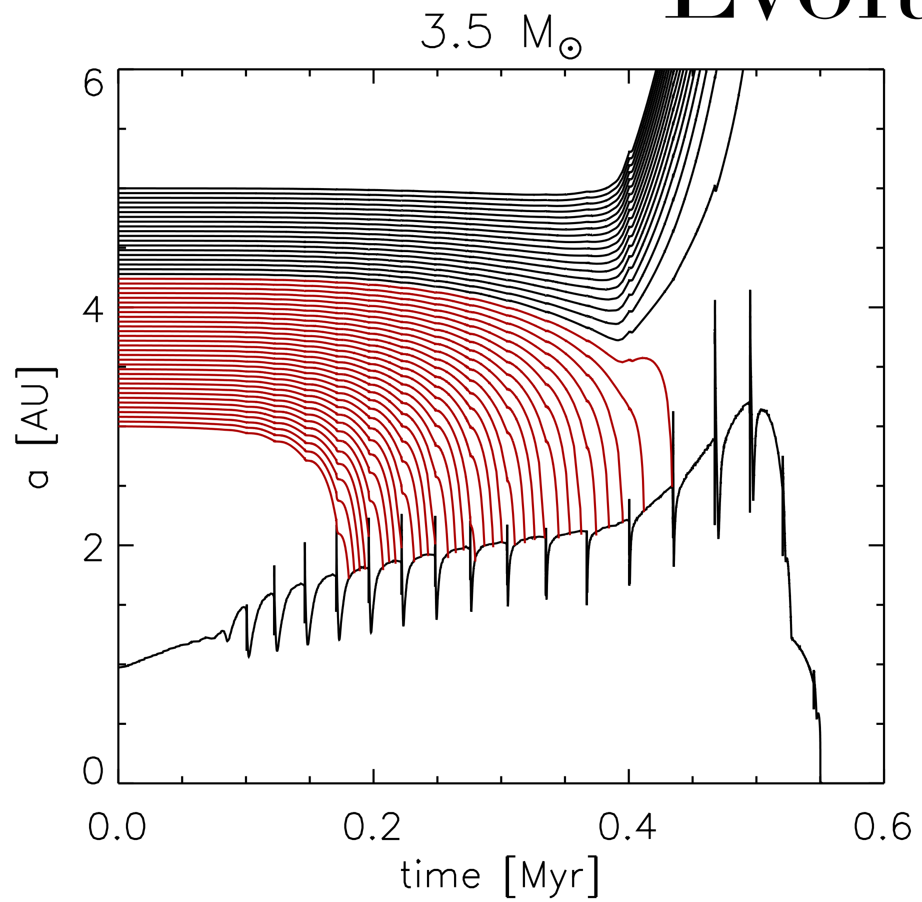
Bear & Soker (2012)
Passy et al. (2012)
remnants of one or two Jovian-mass planets that lost extensive mass during CE phase.

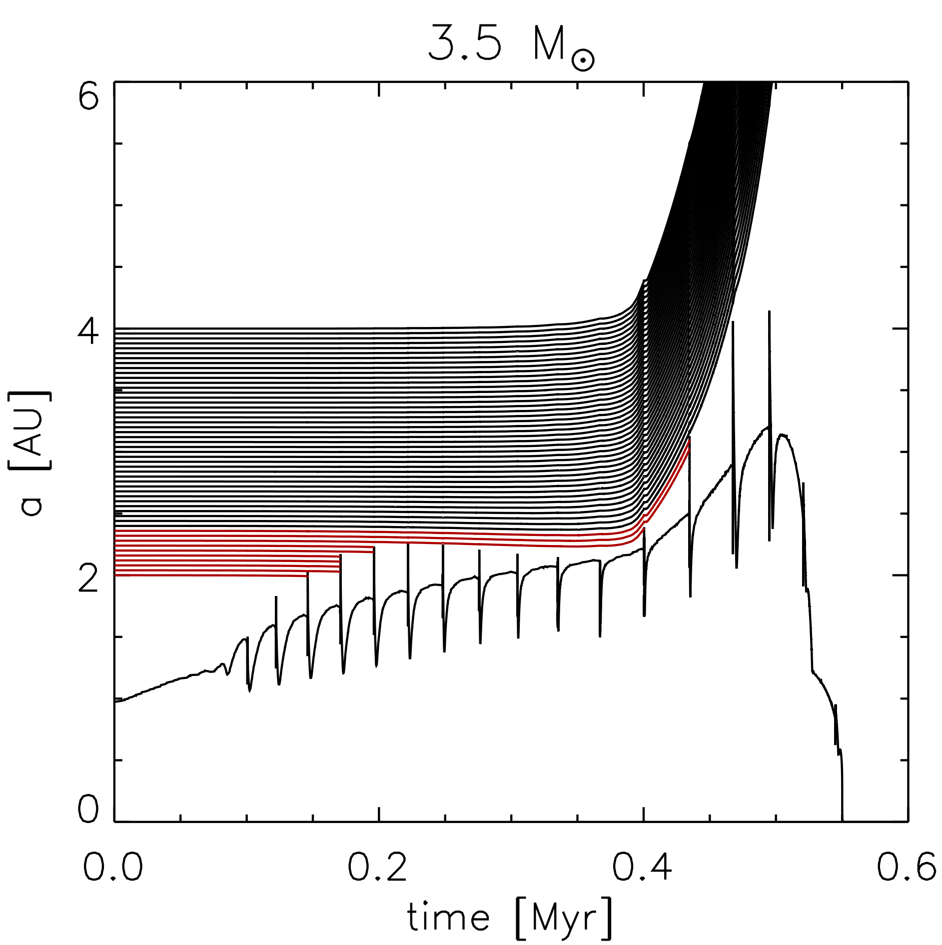
Han et al. (2002)
Form single sdB stars via merger of two He WDs, planet formation following this event may be possible.



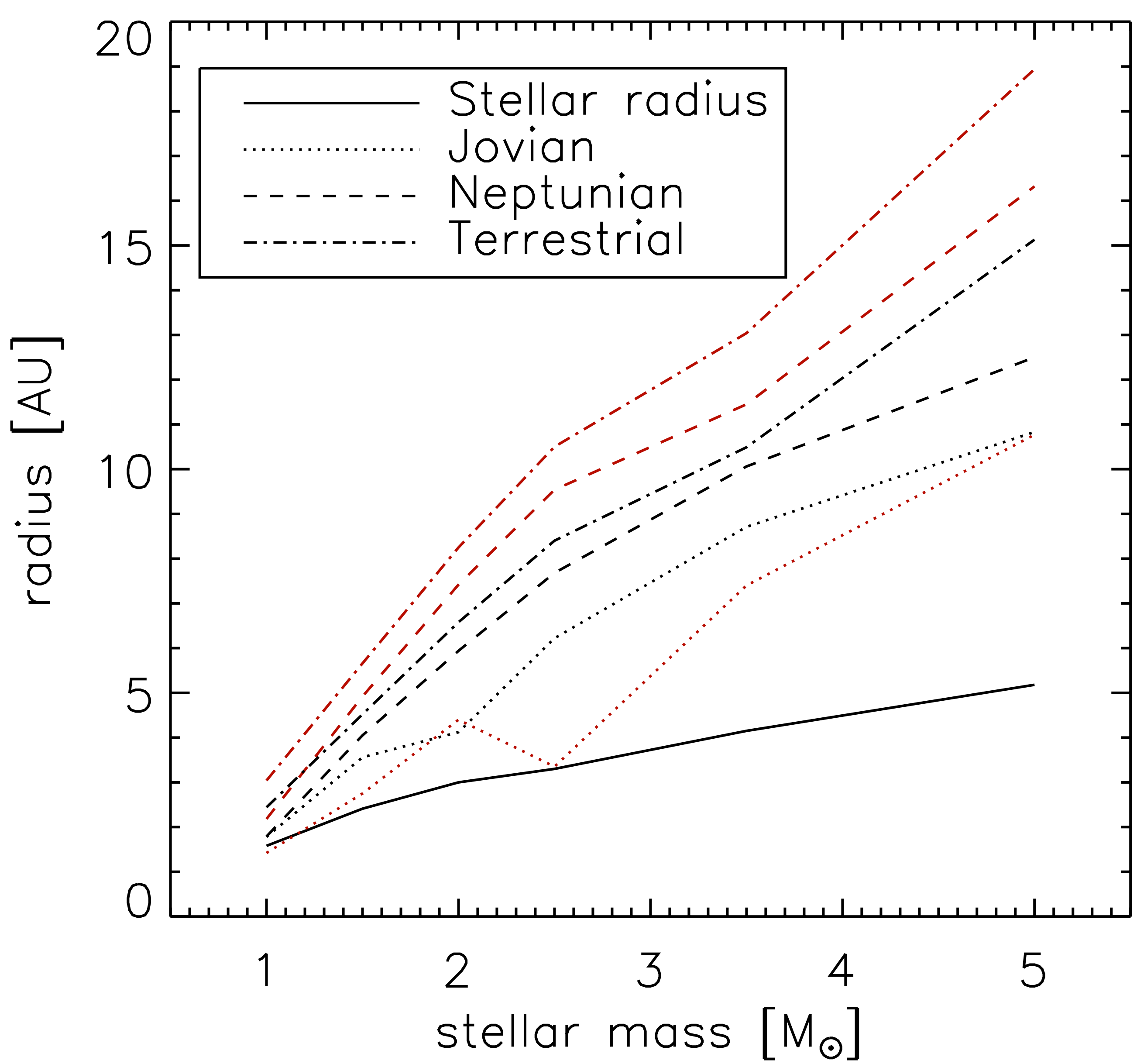
We have only made it here!!

Evolution along the AGB

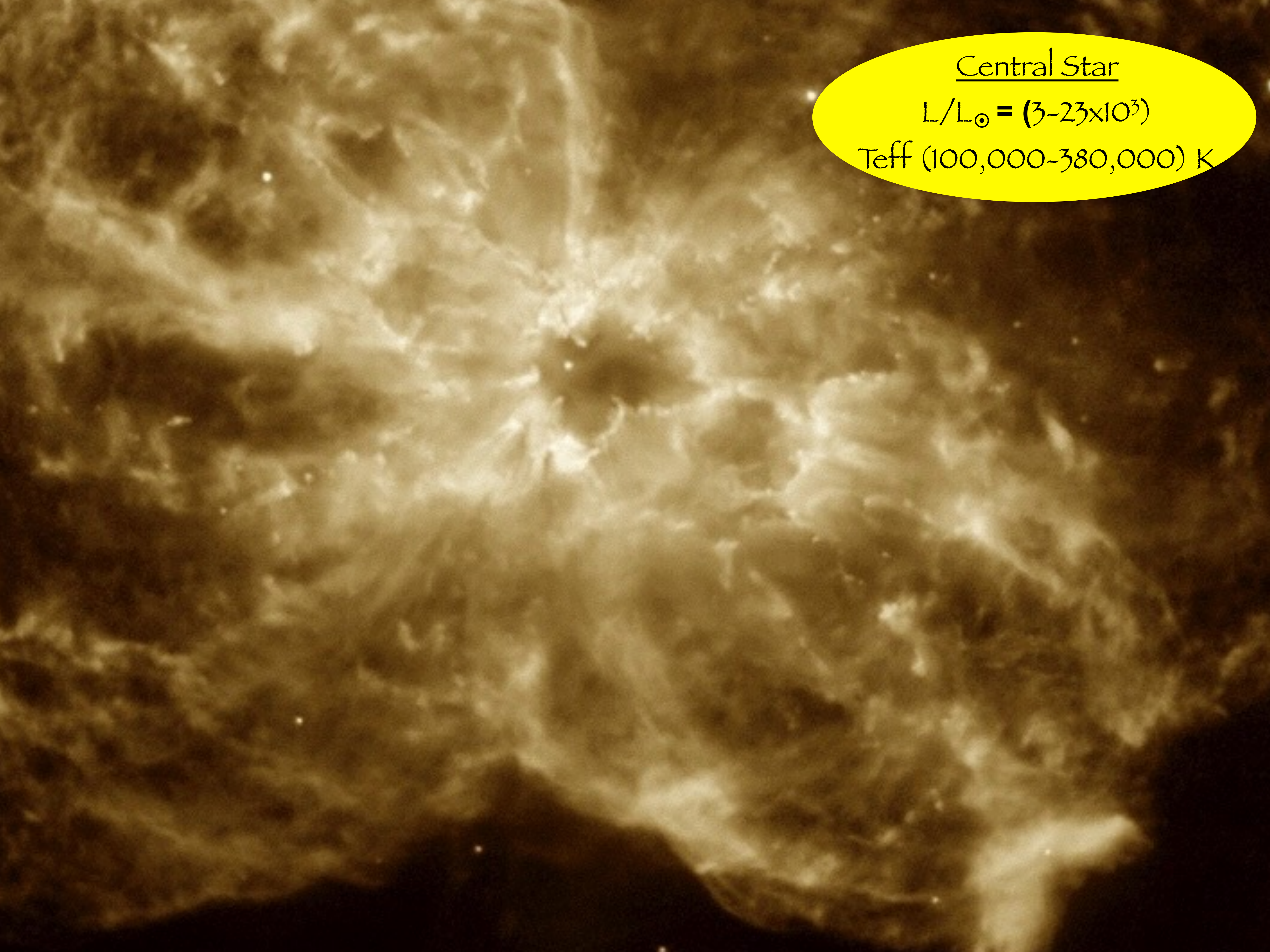




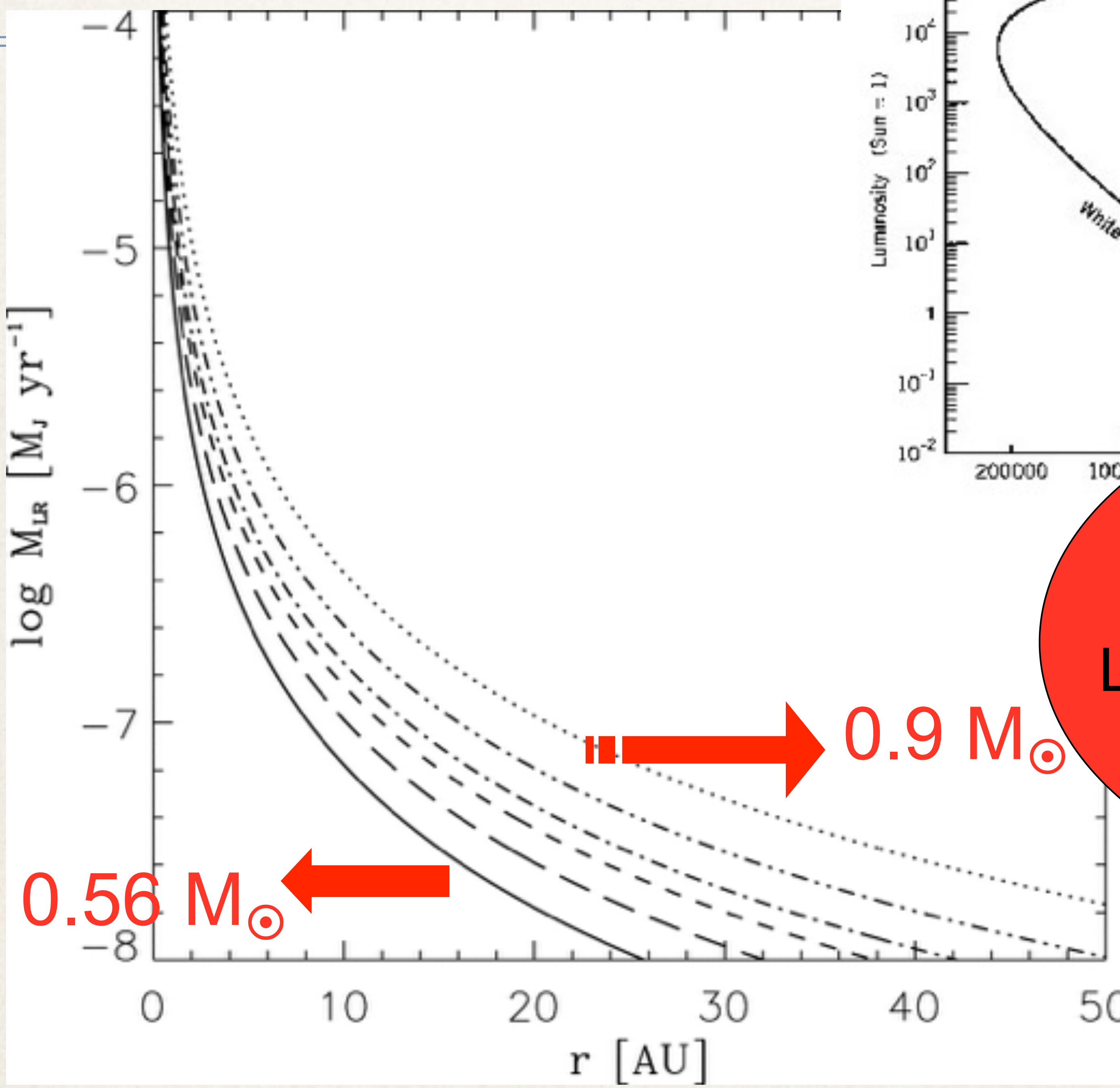
Final location of the innermost surviving planets

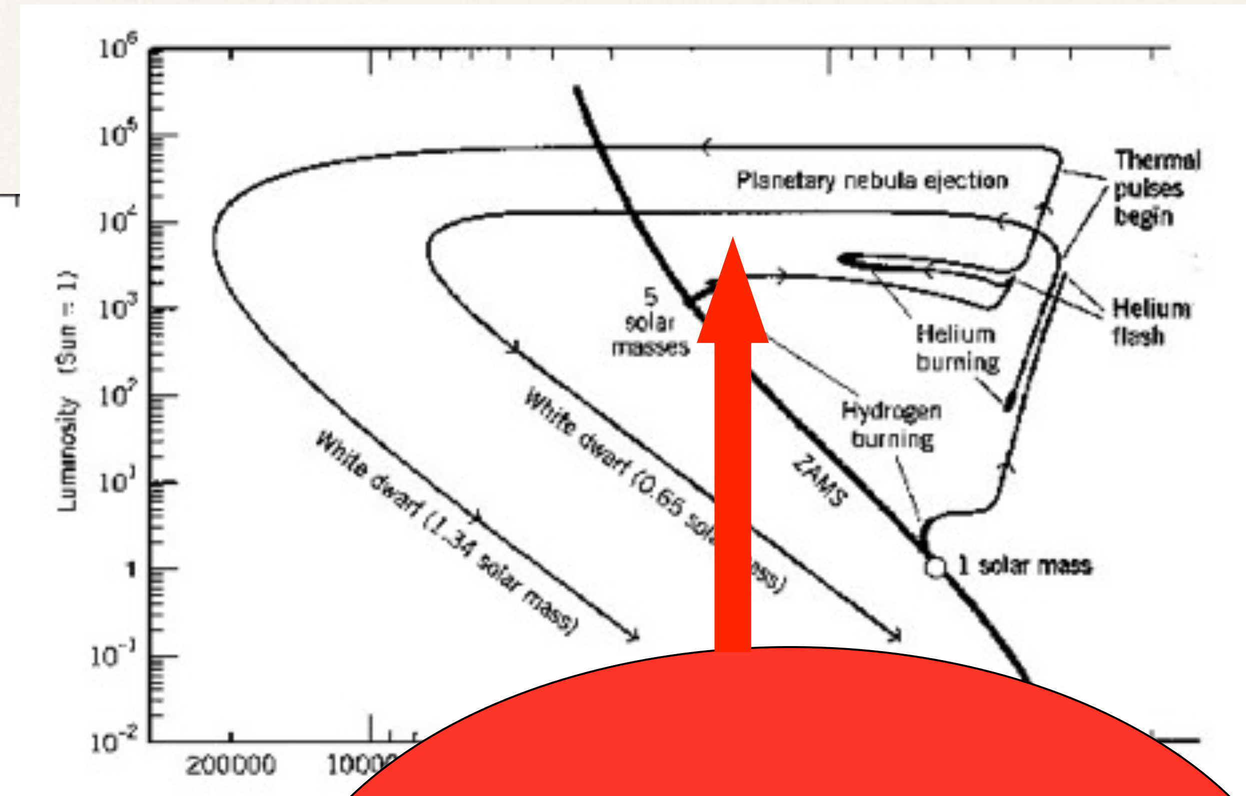


Mustill & Villaver (2012)


Central Star
$L/L_{\odot}$ = (3-23x10^3)
Teff (100,000-380,000) K

Planet evaporation rates





Teff=40,000 K
$L_* = 3600\ L_\odot$ for $0.56\ M_\odot$
$23000\ L_\odot$ for $0.9 M_\odot$

Villaver & Livio (2007)

Post-MS evolution for a single planet-single star system

- A clearance zone due to evolution through the giant phases of the star
- Survival only massive planets/BDs
- Strong UV flux at the PNe stage

Alternatives:

1. Where are the HZ around post-MS stars?
2. Can we have planets there?
3. Long enough?

What are the other options?

Life to develop a second time.

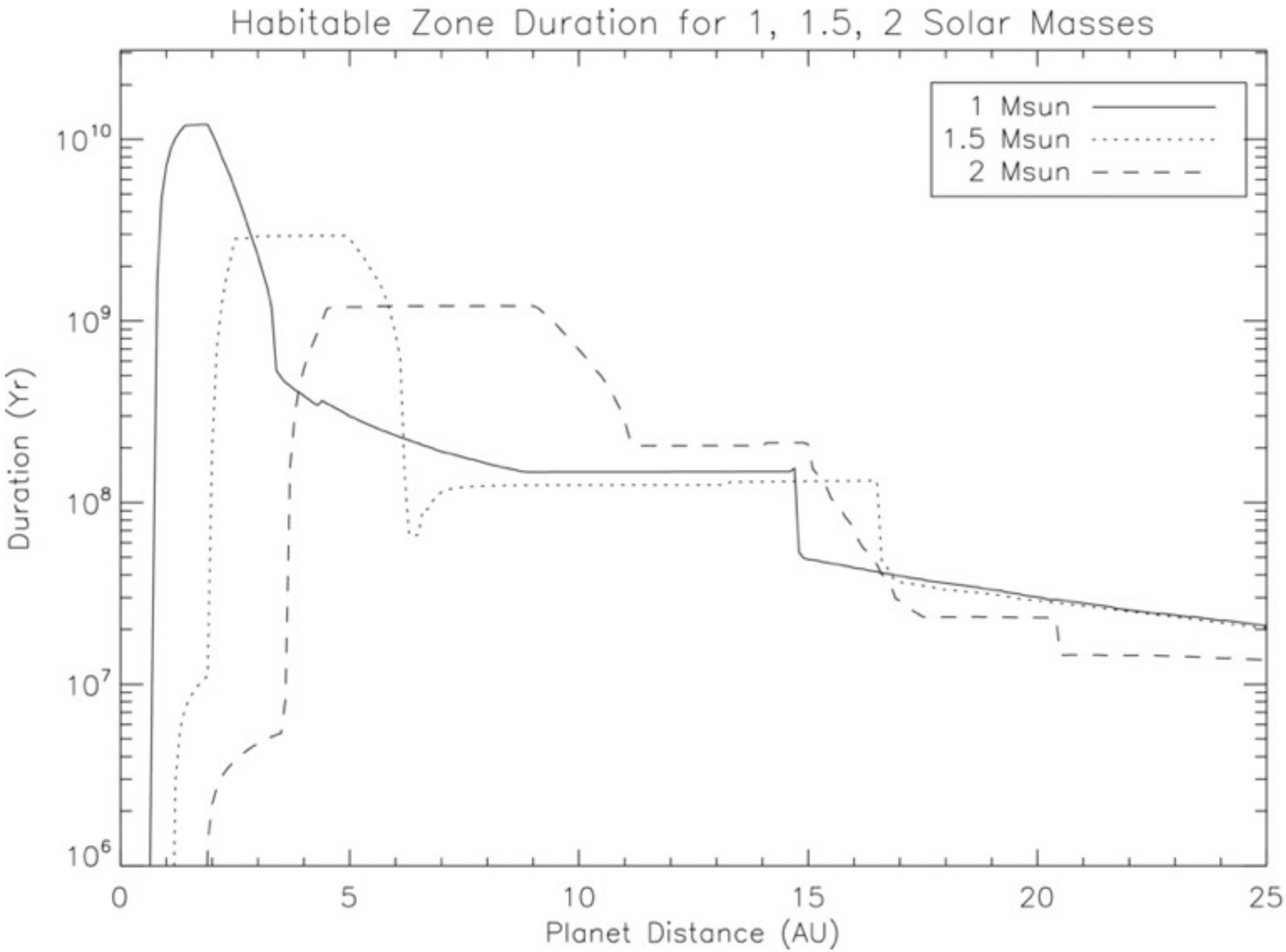
Timescales of evolution + planets at suitable distances

- Multiple-planetary systems
- Binary stars
- WD polution as indirect evidence of possible planet scattering of material to the star

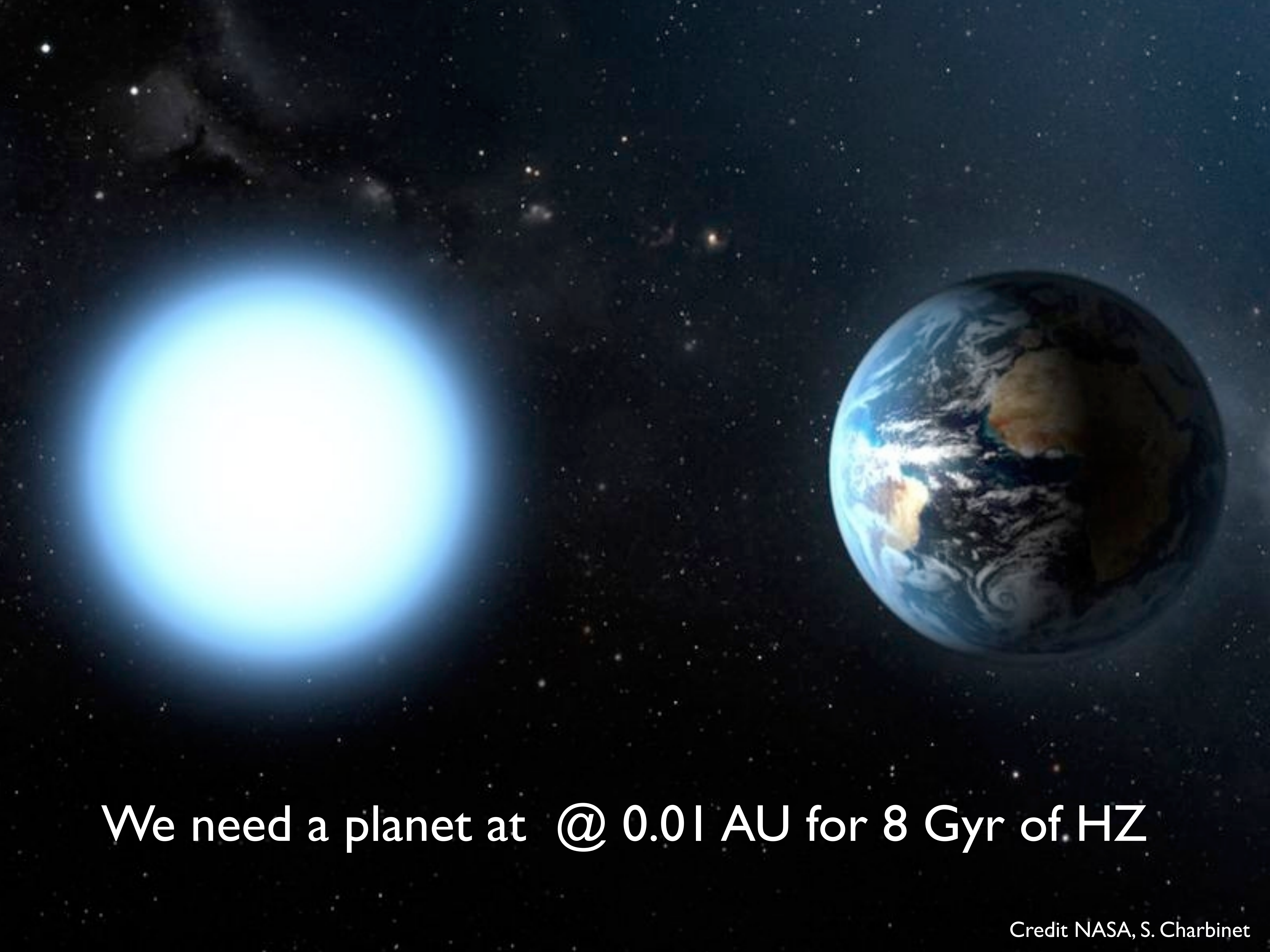
Timescales

- Several stages of evolution with very different timescales:
  RGB, HB, AGB, PN, and WD.

Post-MS Habitability



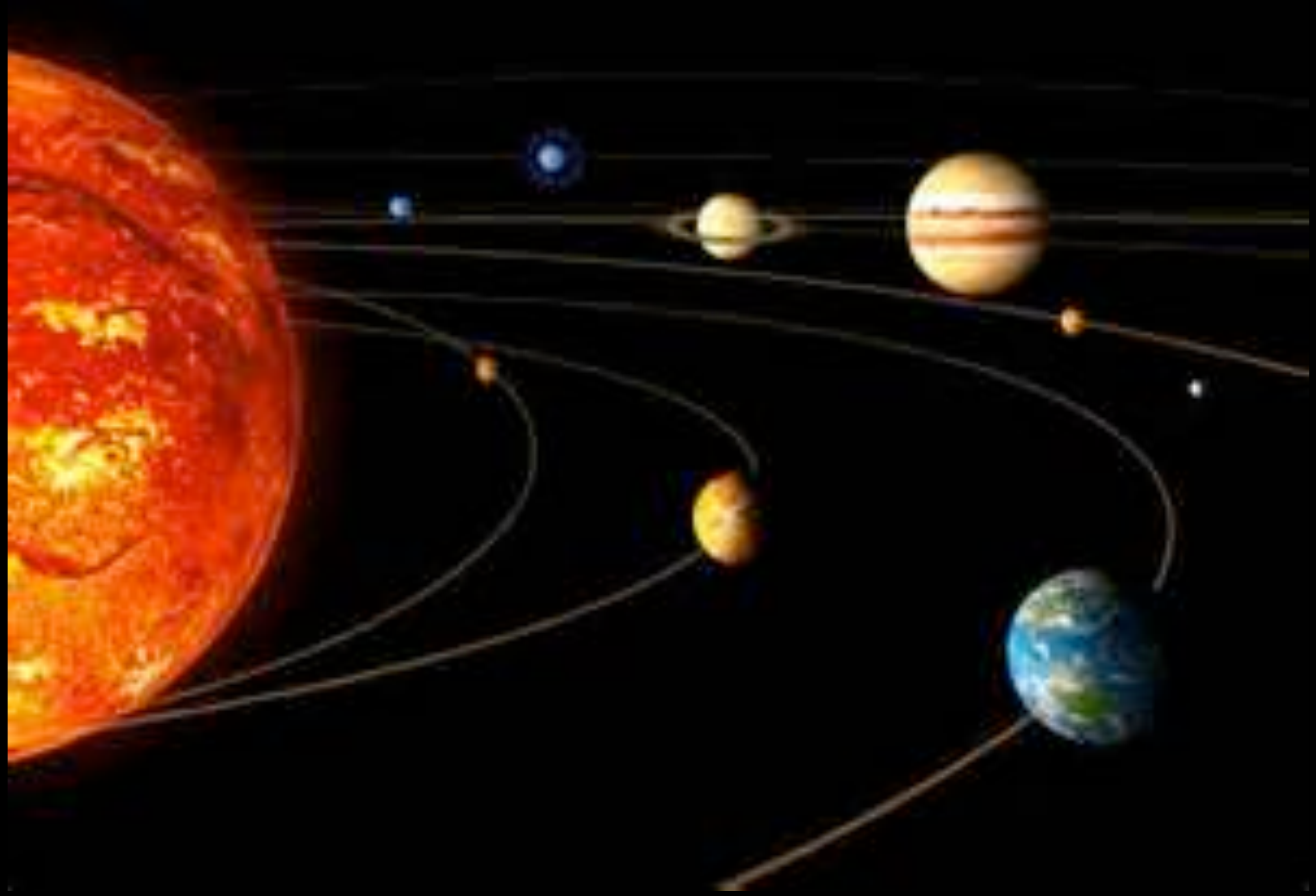
Danchi & Lopez (2013)



We need a planet at @ 0.01 AU for 8 Gyr of HZ

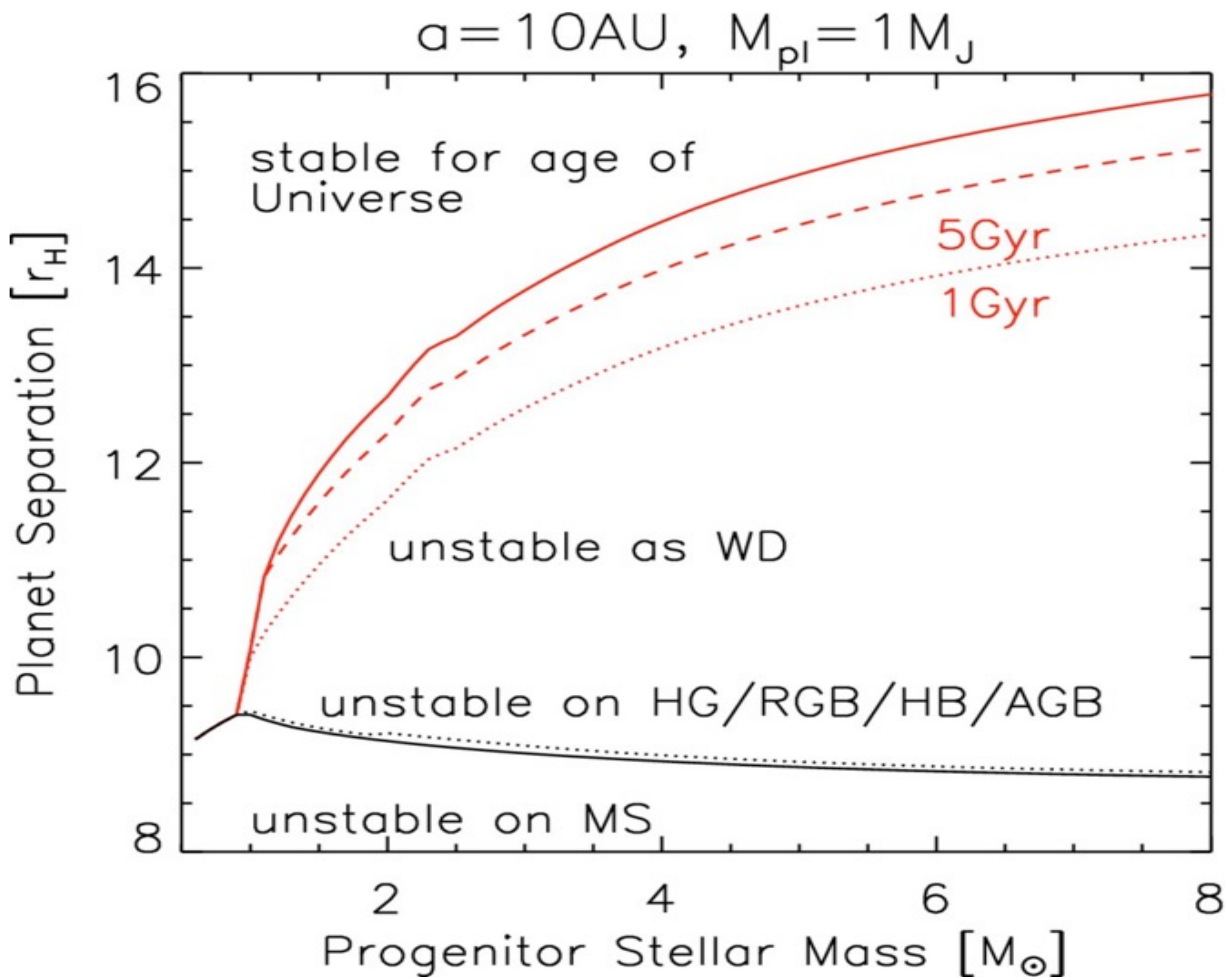
Credit NASA, S. Charbinet

1.Multiple-planetary Systems



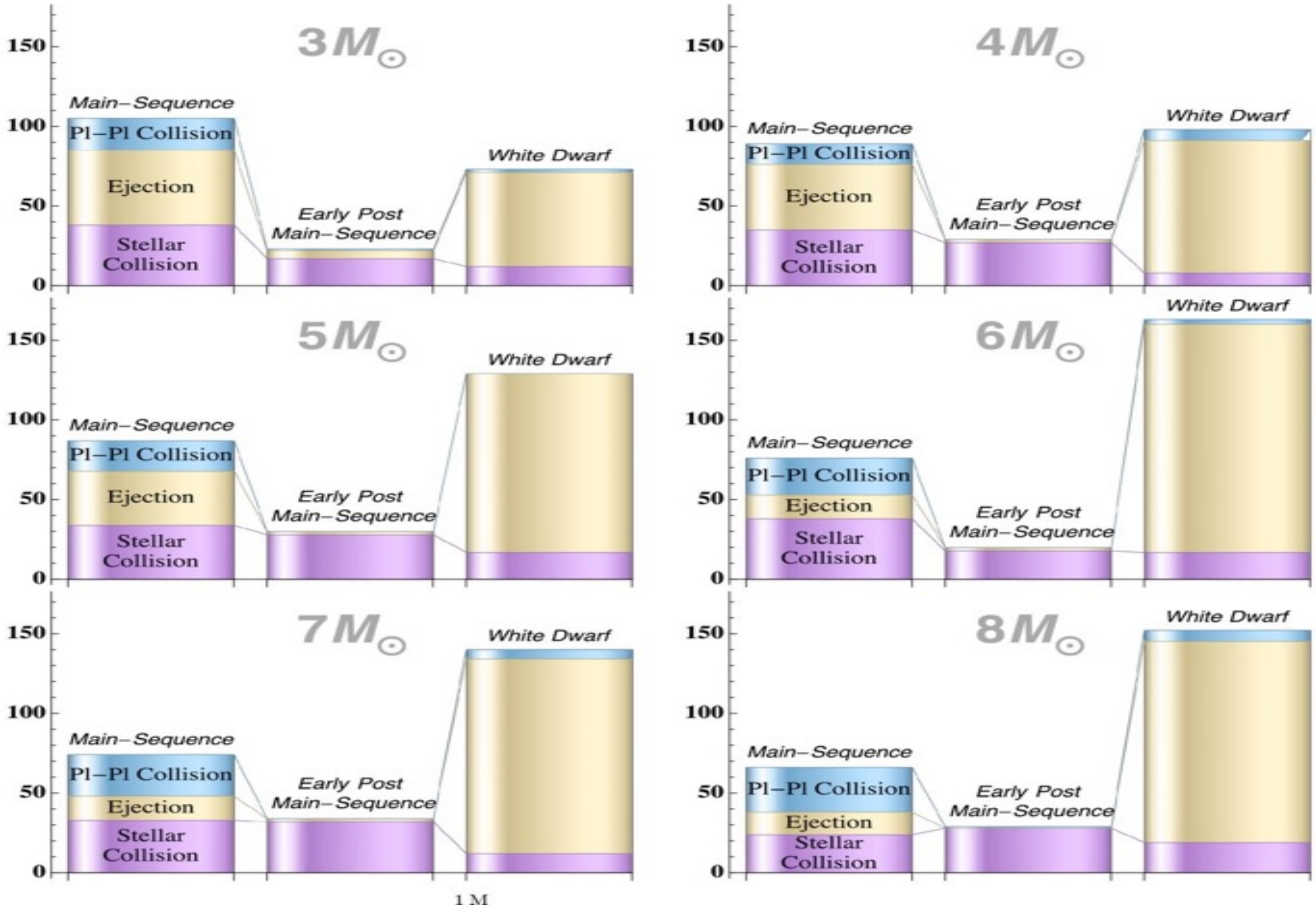
So far multiplicity: 22%...

Stability behaviour of three-planet systems



Mustill, Veras & Villaver (2014)

3-planet system instability



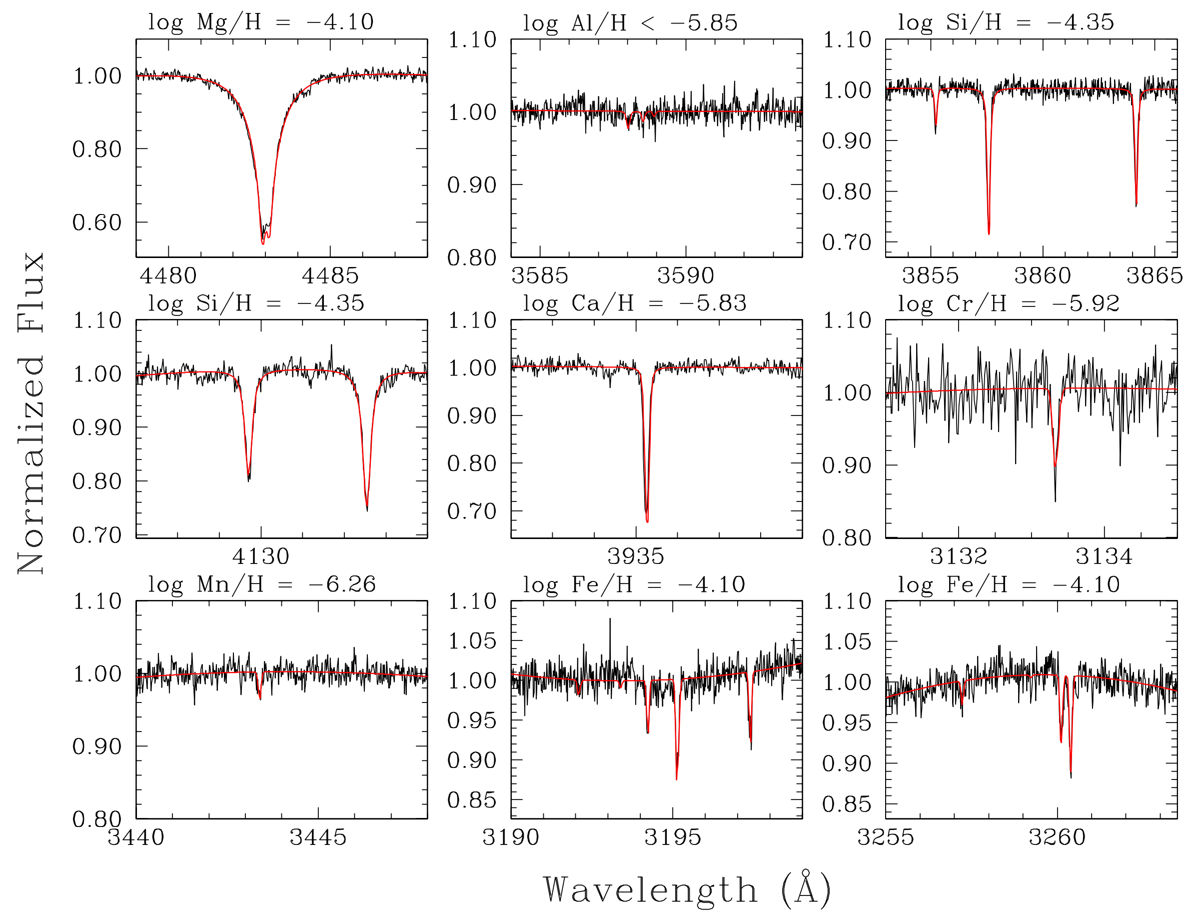
Mustill, Veras & Villaver (2014)

Number of planets lost in the three-1 MJ runs

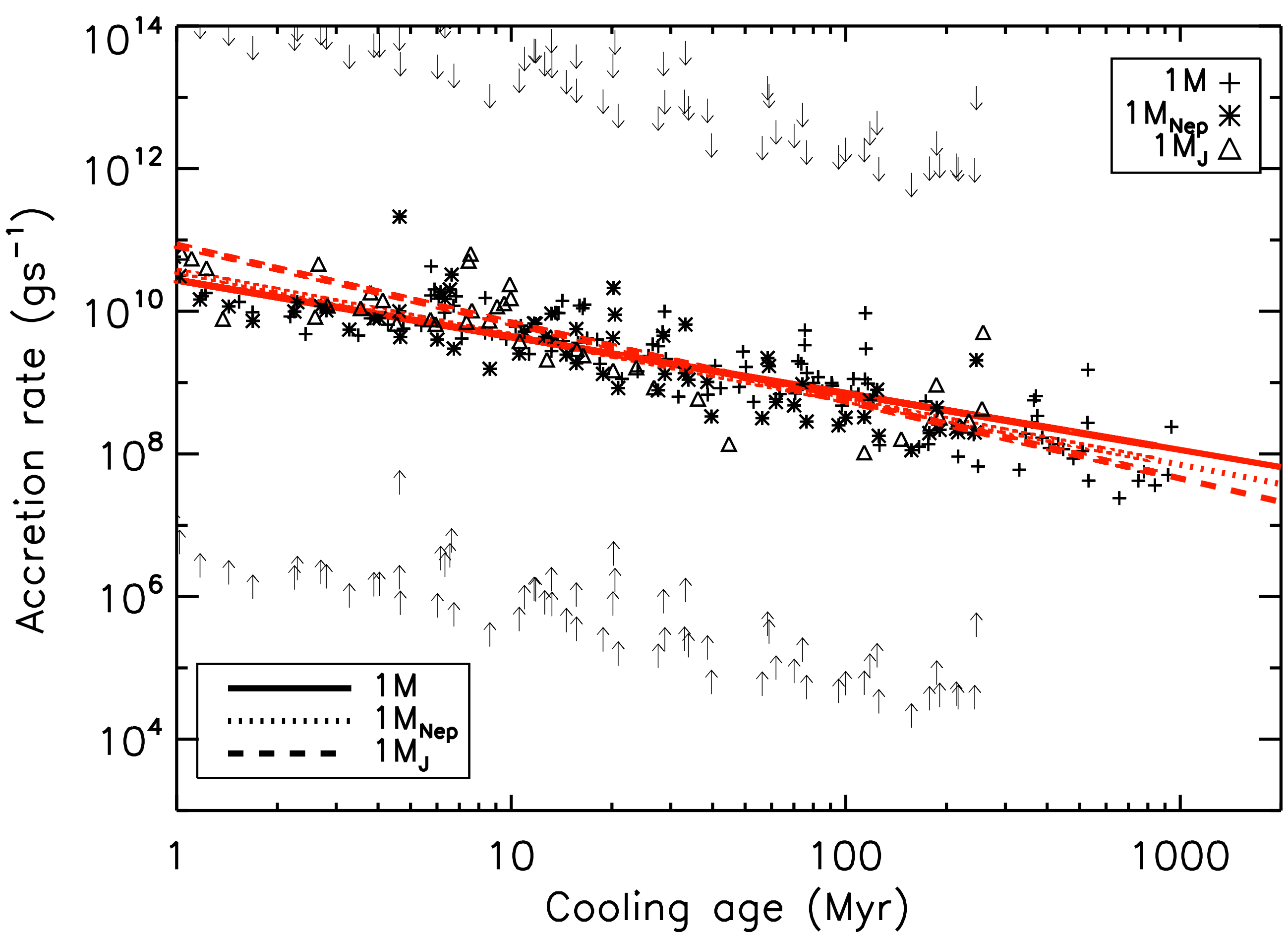
Poluted WDs

Metal Rich WDs:

DA WDs contain heavy elements (Zuckerman et al.03).
Asteroids or comets are scattered to close orbits to the star
(Jura 03; Debes & Sigurdsson 2002).



GALEX J193156.8+011745; Mellis et al. (2011)

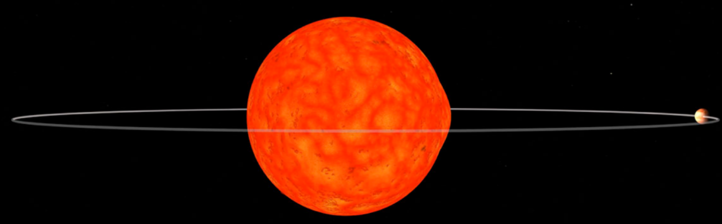


Bonsor et al. (2011)

Debris Disks:
e.g. Gänsicke et al.; Jura et al.; Kilic et al.; Zuckerman et al., Farihi et al., von Hippel et.
R< 0.01 AU

DAZ white dwarfs:
see e.g. Becklin et al. , Jura et al., Gänsicke et

- Unstable multiple planetary systems, Debes & Sigurdsson (2002)
- Planet on circular orbit + kuiper belt, Bonsor et al. (2011)
- Planet MMR + asteriod belt, Debes, Walsh & Stark (2012)
- 2 planet systems, Veras et al. (2013)
- Single planet with varying e and mass, Frewen & Hansen (2014)



SSE clear predictions

Transportation of
microorganisms:
meteorites
planet to planet
between planetary systems
?

Offer an alternative
if they can help deliver a planet at
the right distance from the star
.....or secondary planet formation?
via WD mergers

- WD as possible complimentary science cases then we could have a way of pushing planetary science case + stellar astrophysics.

- Although… I still I believe a clear science case, of astrophysical importance is the best argument for this type of mission.

- Science coming out of GAIA will probably have a lot to say on the Open Time for the telescope…

- and new survey missions could provide better targets for astronometry in the next few years.