Better characterizing **white dwarfs** to illuminate **planet occurrence** around **intermediate-mass stars**

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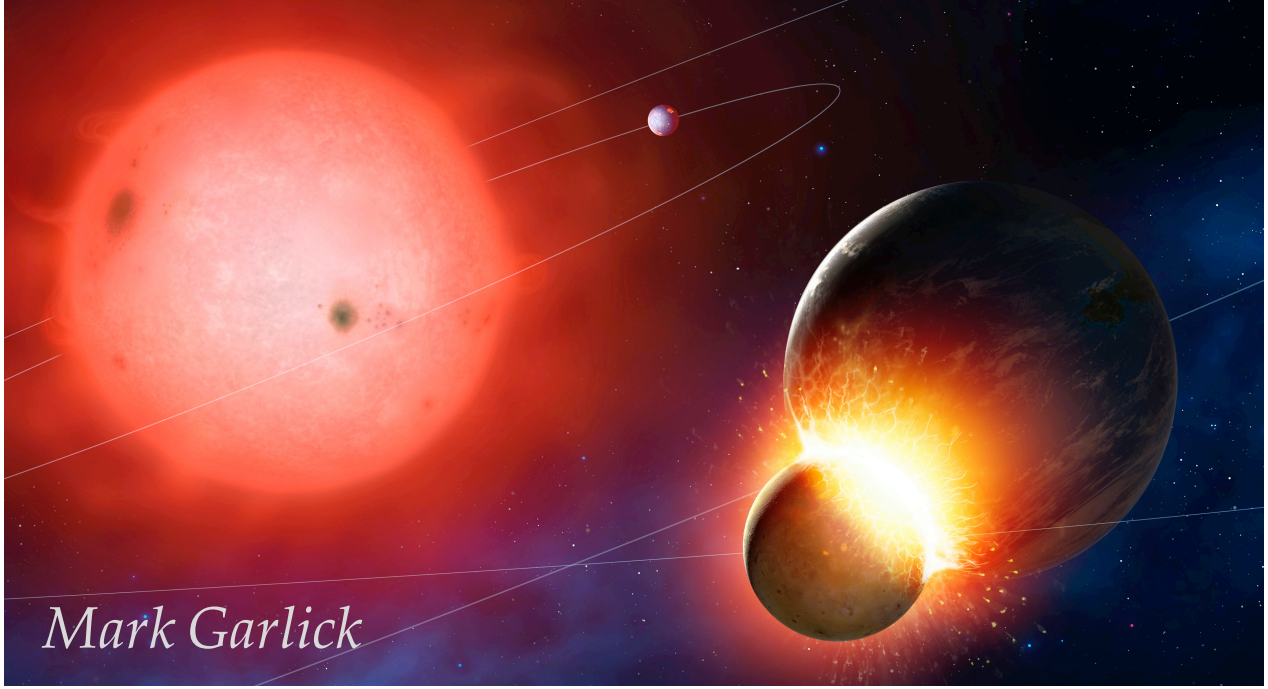
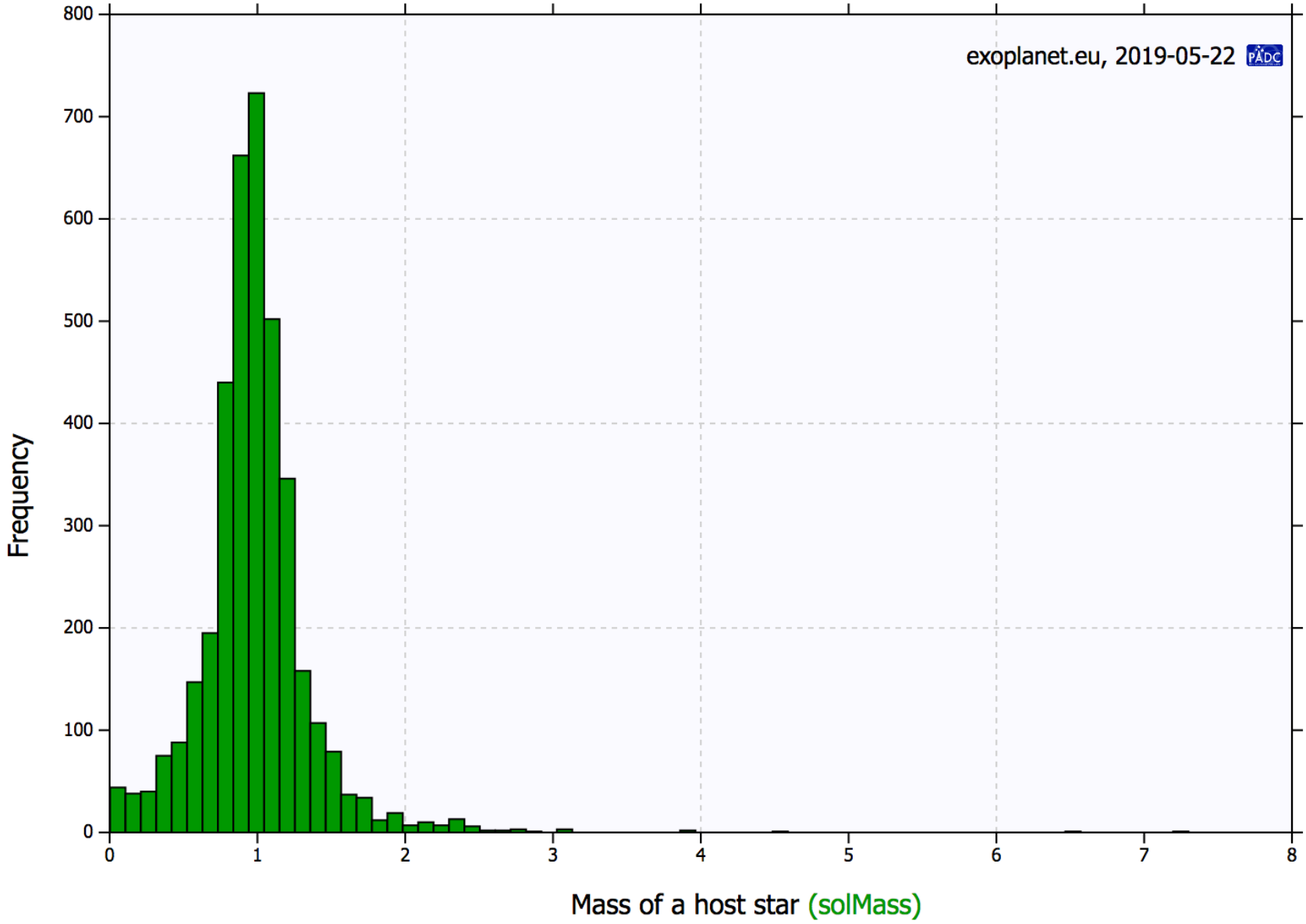
h/t Boris Gänsicke, Bart Dunlap, Dimitri Veras, EESS team



- **>30-50%** of WDs descending from **1.5-3.5 solar-mass** ZAMS progenitors reveal evidence for **remnant planetary systems**
- But **<10%** of WDs coming from **4-6 solar-mass** ZAMS progenitors show the same evidence

- **The question:** Can we connect **WD pollution fractions** to **planetary occurrence rates?**



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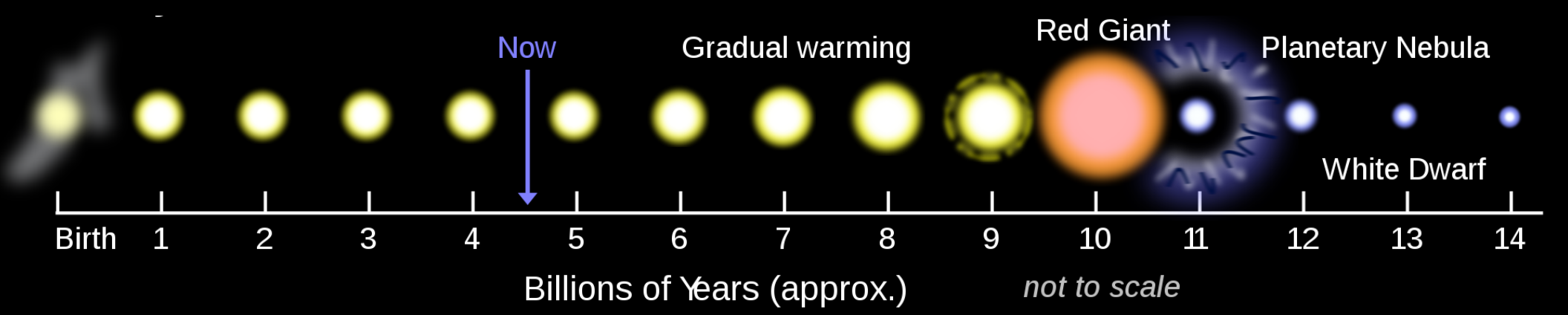
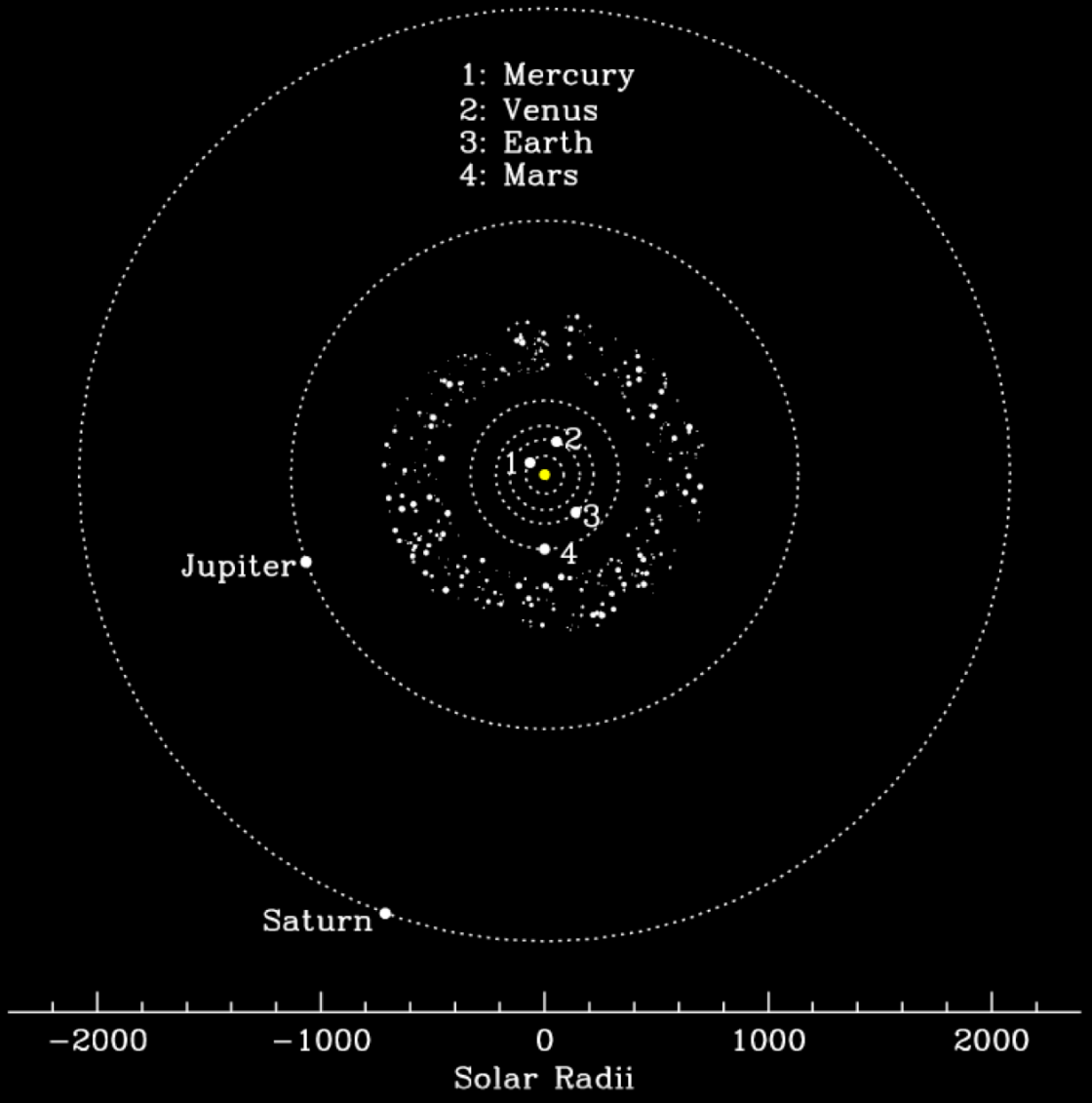
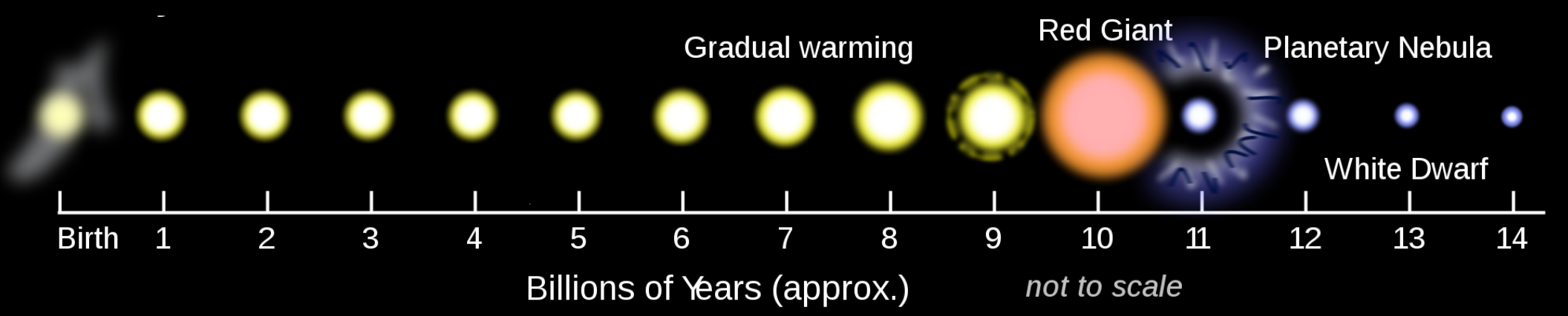


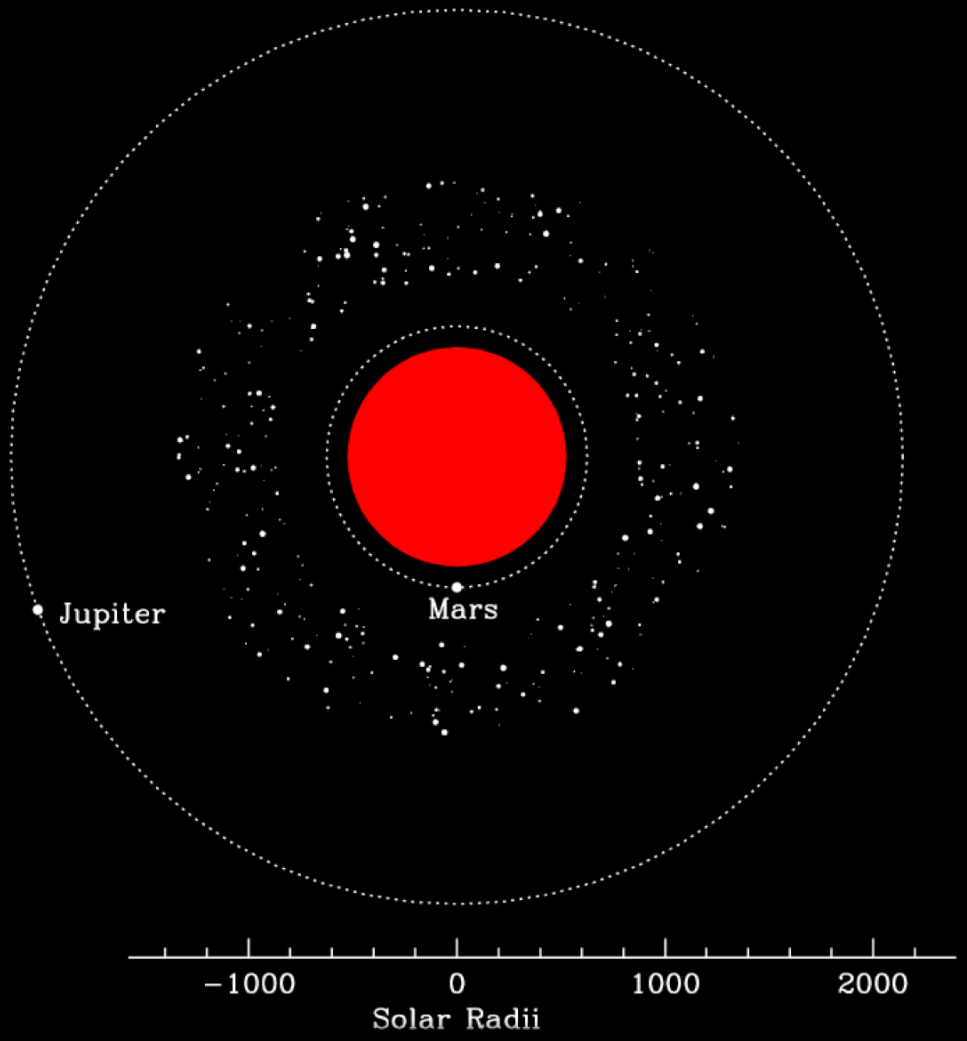
Today



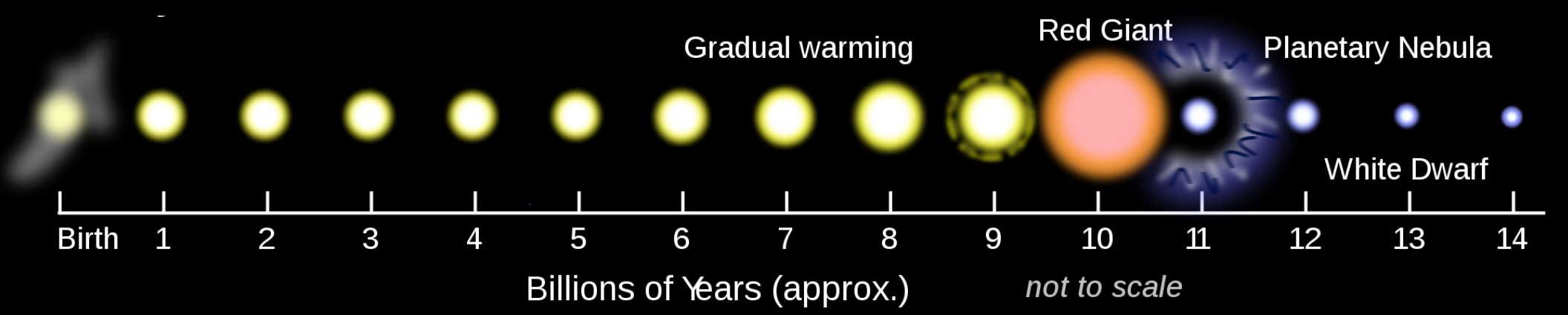
Boris Gänsicke



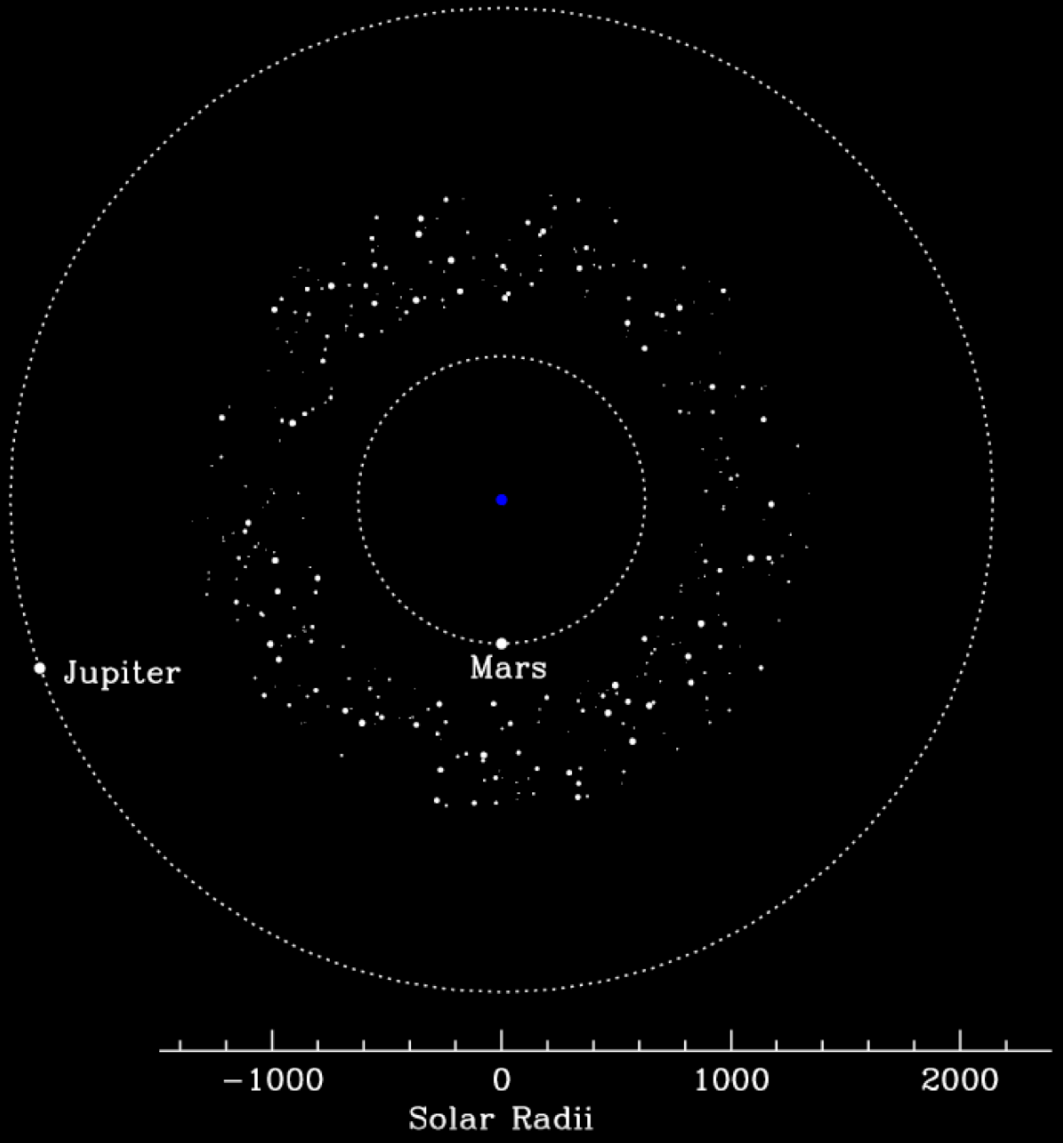
5 billion years from now



Boris Gänsicke



7 billion years from now



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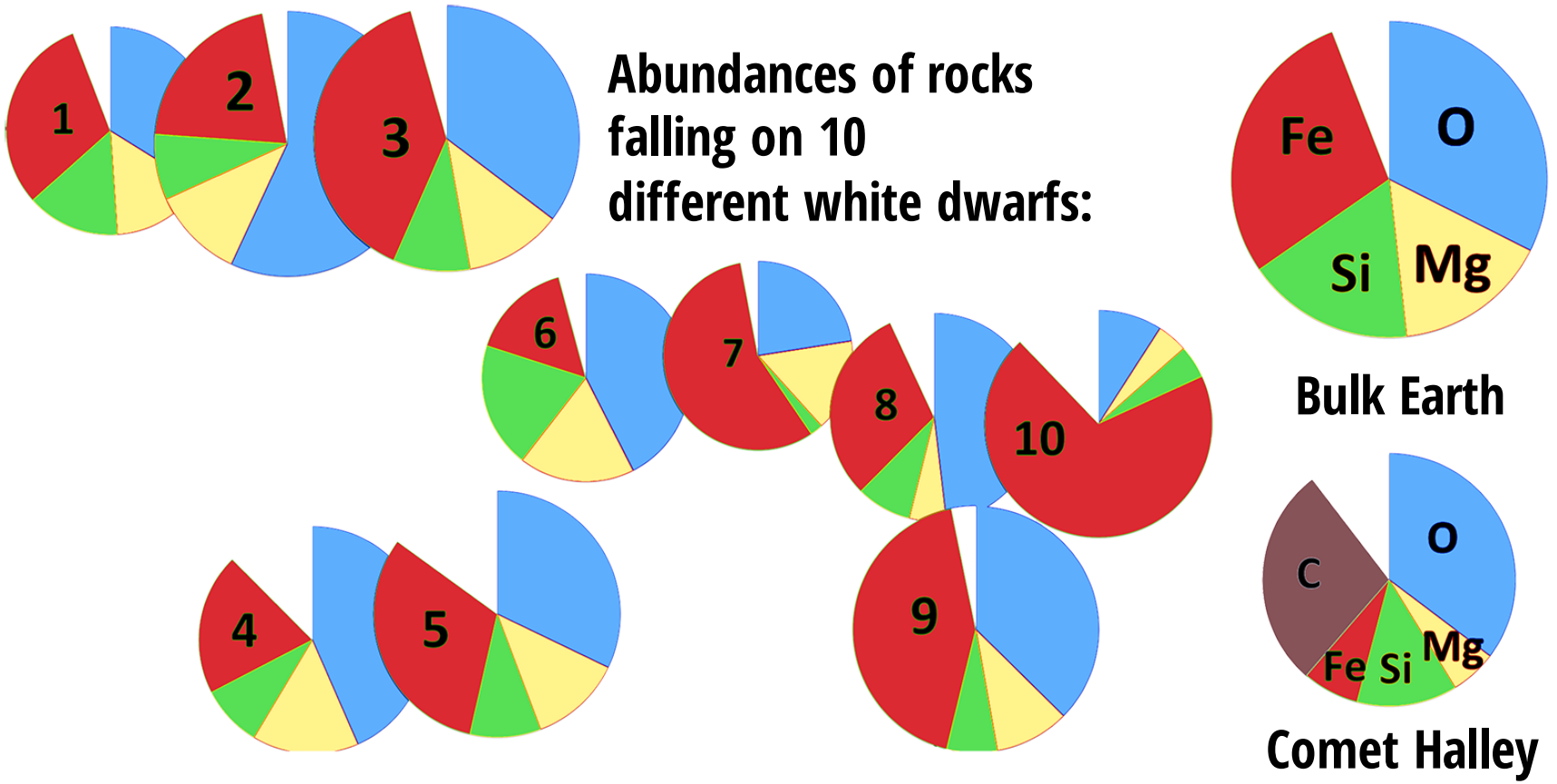
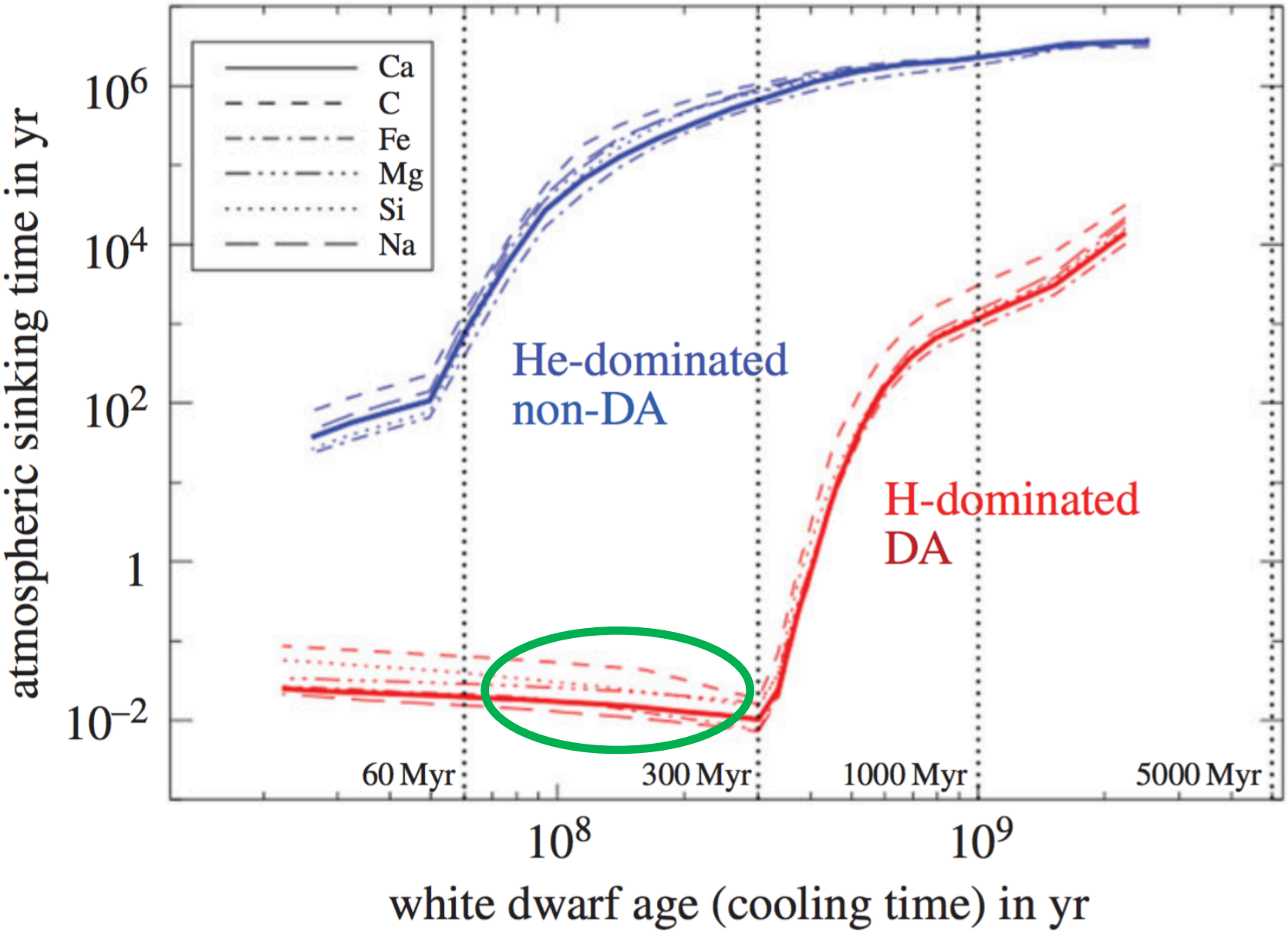
White Dwarfs Directly Probe Rocky Exoplanetary Material

- WD debris is comparable to bulk Earth (mostly **Fe, O, Si, Mg**)
- Some of this debris is **water-rich**! *(Farihi et al. 2013; Raddi et al. 2015)*
- Rocks are **volatile-depleted** (low C/O ratio) *(Wilson et al. 2016)*



Xu et al. 2014

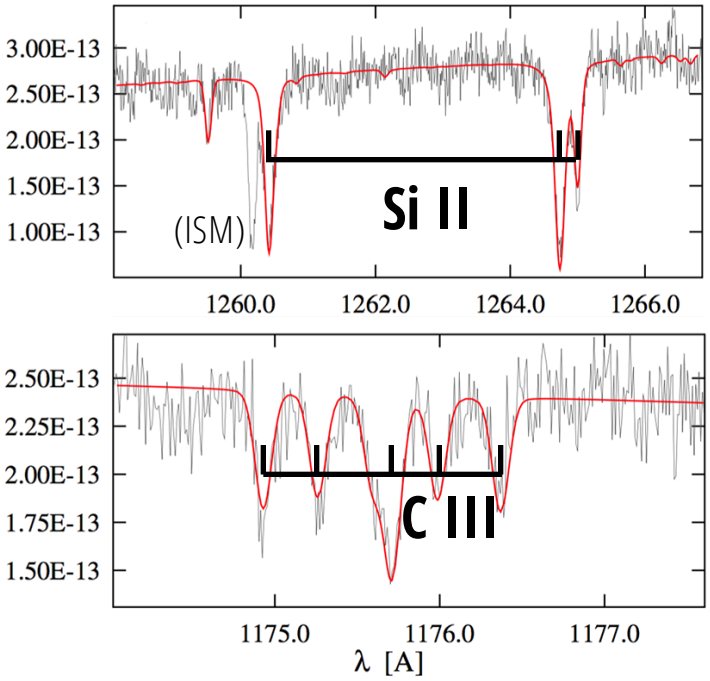
WD Metal Pollution Reflects Active Accretion of Rocks

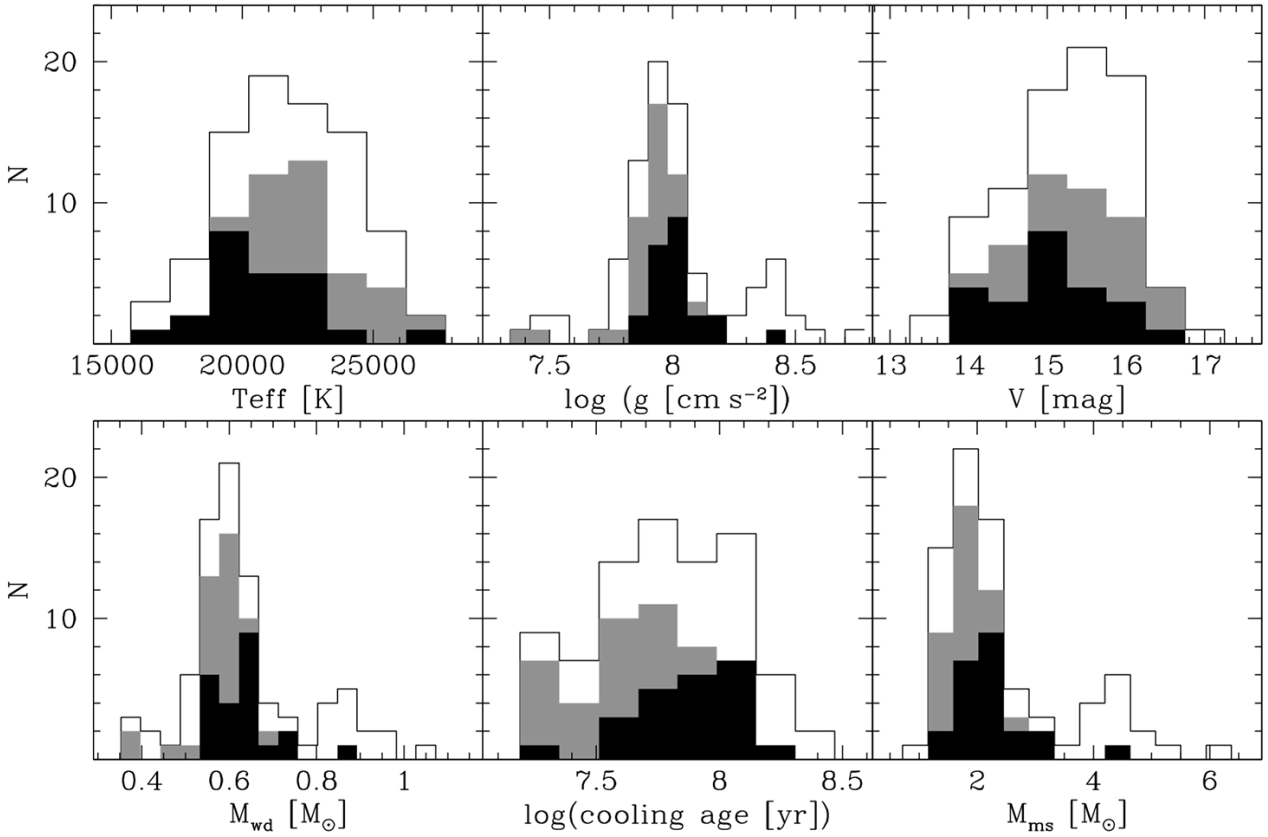


Wyatt et al. 2014, from Veras 2016

HST Snapshot Programs: Pollution Fraction Around WDs

- **30%-50% of WDs** are metal polluted *(Koester, Gänsicke & Farihi 2014)*





Si detected, must be accreted

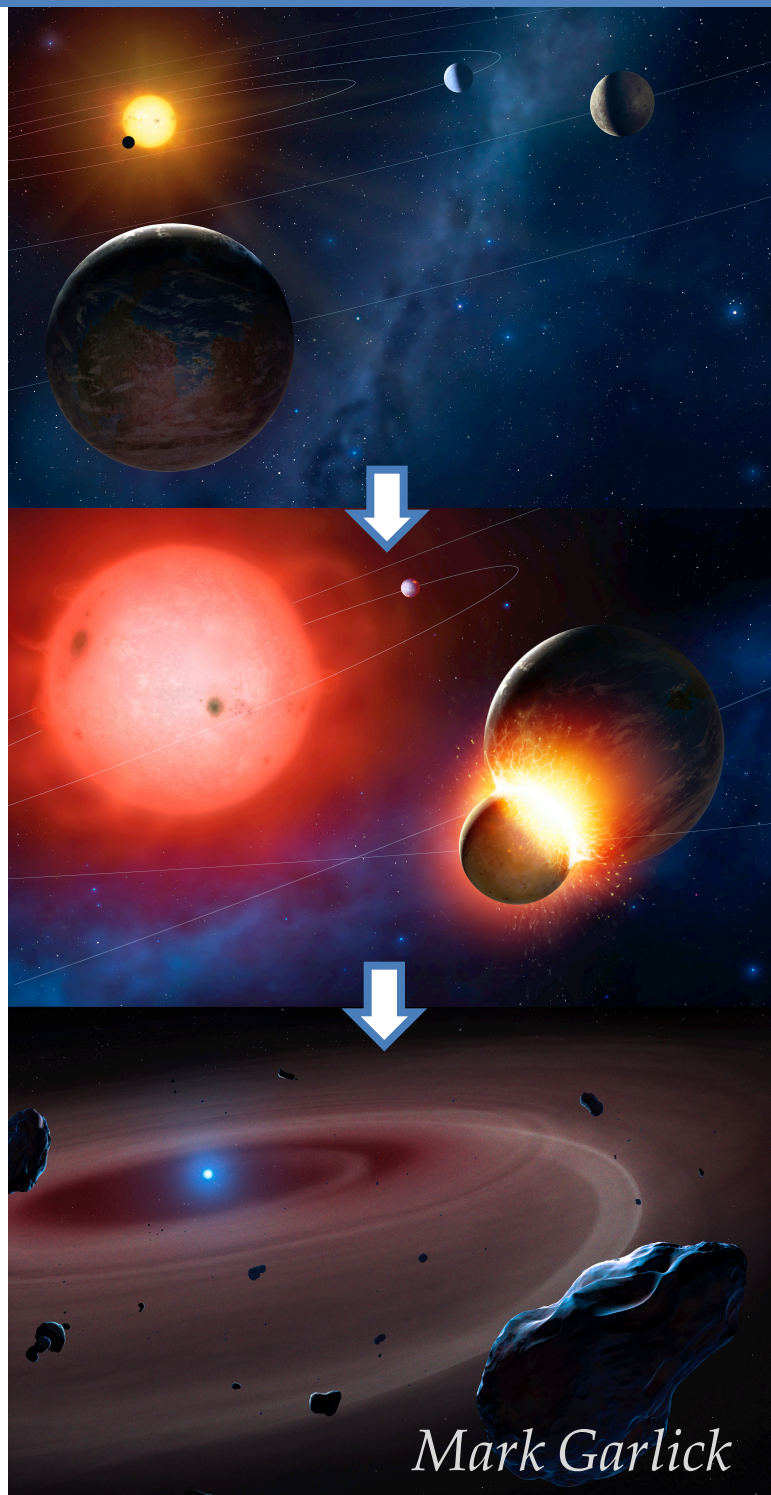
Si detected, most likely from recent accretion

No Si detected

Does Metal Pollution Necessarily Reflect Remnant Planets?

- **Metal pollution** always seen with IR excess (warm, dusty debris disks) as well as Ca II emission (co-located gaseous debris disks)
- **Rocks** are scattered in at high-*e* and tidally disrupted (typical mass accretion rates suggest ~10^{8} g/s, so ~10^{21} g or ~40-200 km asteroids)
- If thermohaline mixing occurs, rates may be as high as 10^{13} g/s, corresponding to ~10^{26} g (~1 Moon mass)

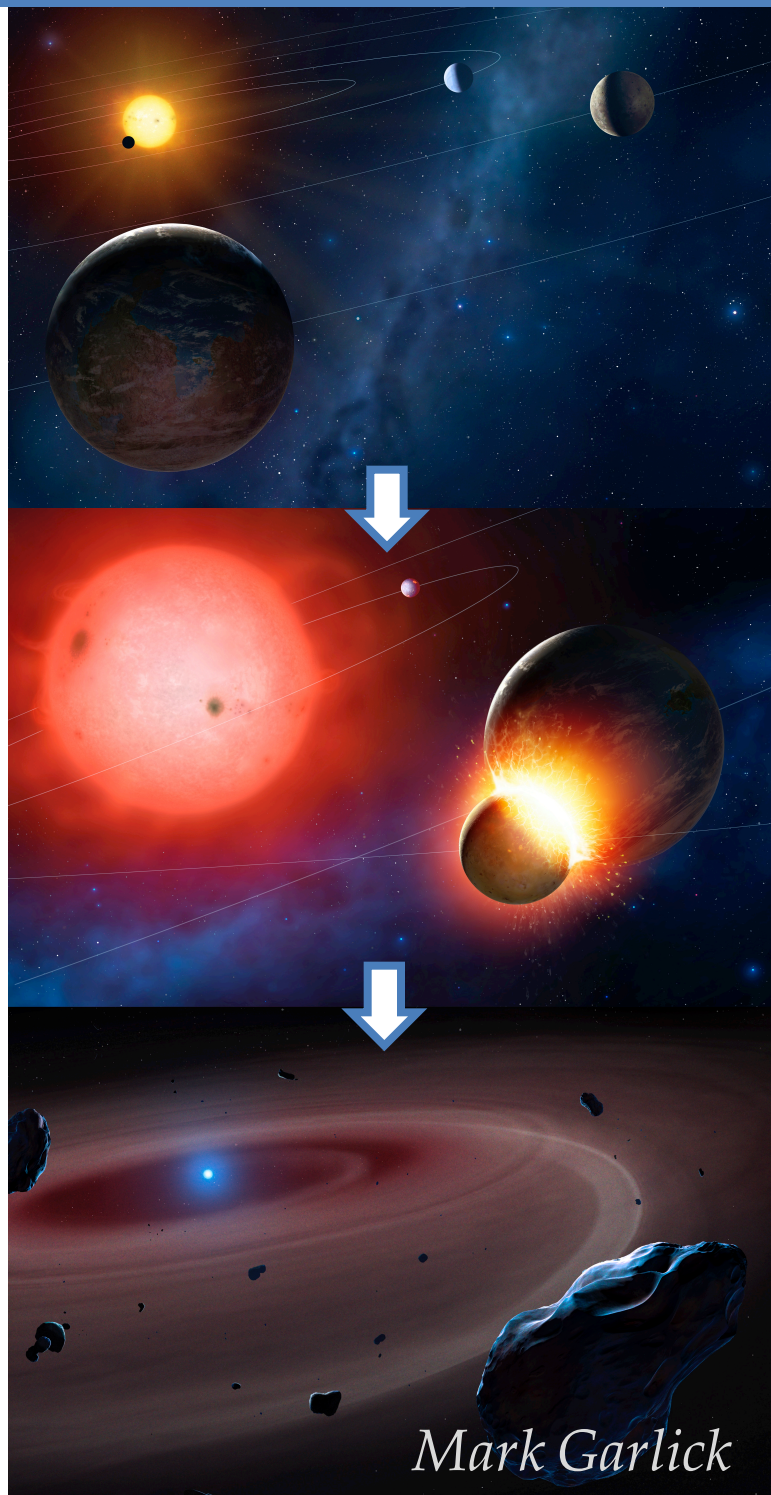
(Bauer & Bildsten 2019)



See the reviews by Veras 2016 and Farihi 2016

Does Metal Pollution Necessarily Reflect Remnant Planets?

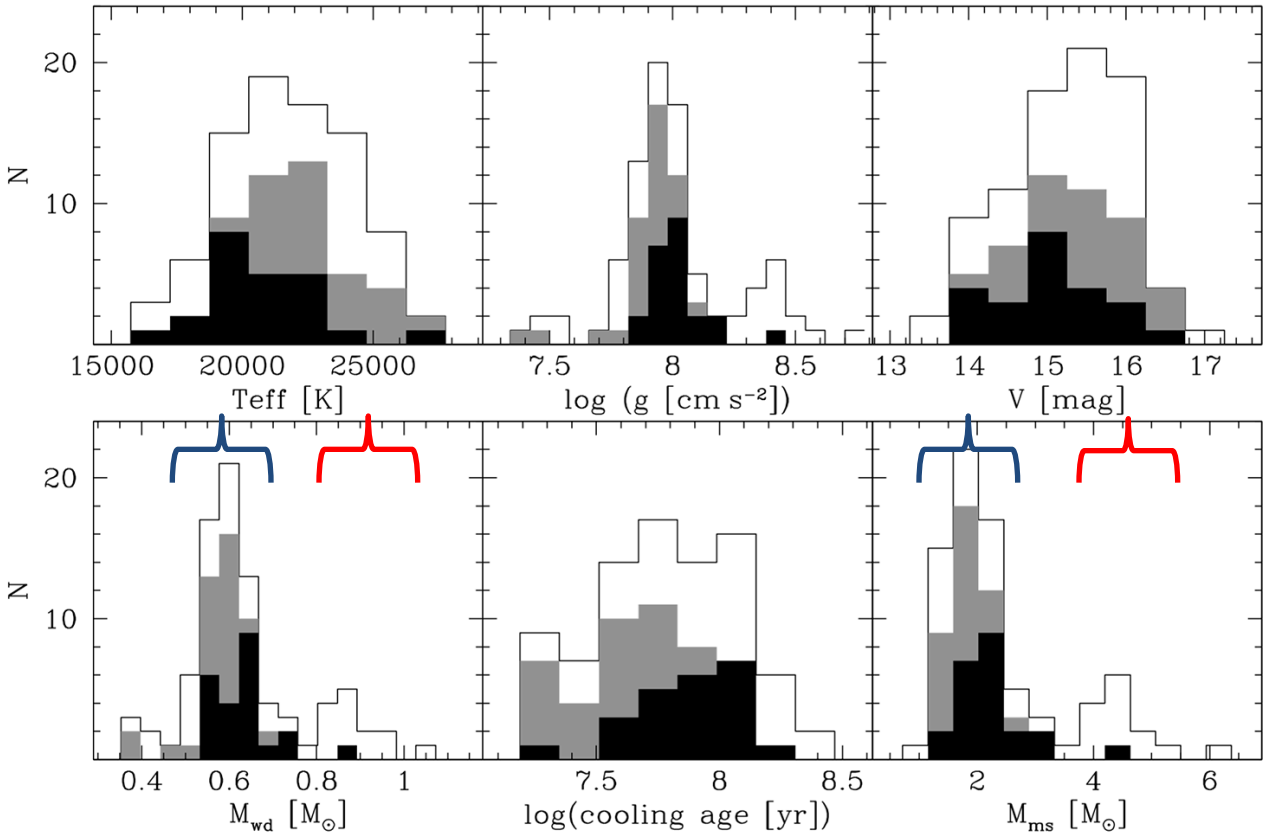
- **WD pollution** is likely a signature of:
  - A modest **reservoir** of asteroids, comets, moons and/or planetesimals
  - At least 1 surviving **major planet**
    - Unless you are in a binary *(e.g., Veras et al. 2018)*



See the reviews by Veras 2016 and Farihi 2016

Drastic Difference in Metal Pollution for More Massive WDs

- **30%-50% of 1.5-3.5** solar-mass ZAMS progenitors show evidence of remnant planetary systems (48/85 WDs)
- **<10%** of **4-6** solar-mass ZAMS progenitors show the same evidence (1/12 WDs)



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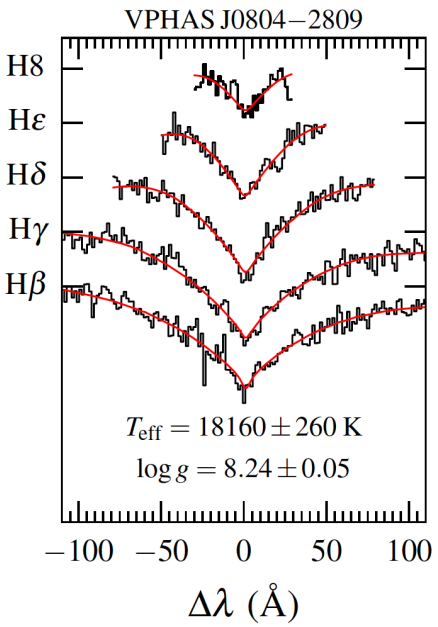
Si detected, likely from recent accretion

No Si detected

Koester, Gänsicke & Farihi 2014

So How Do We Get a Progenitor Mass for a WD?



Raddi et al. 2015

An example:

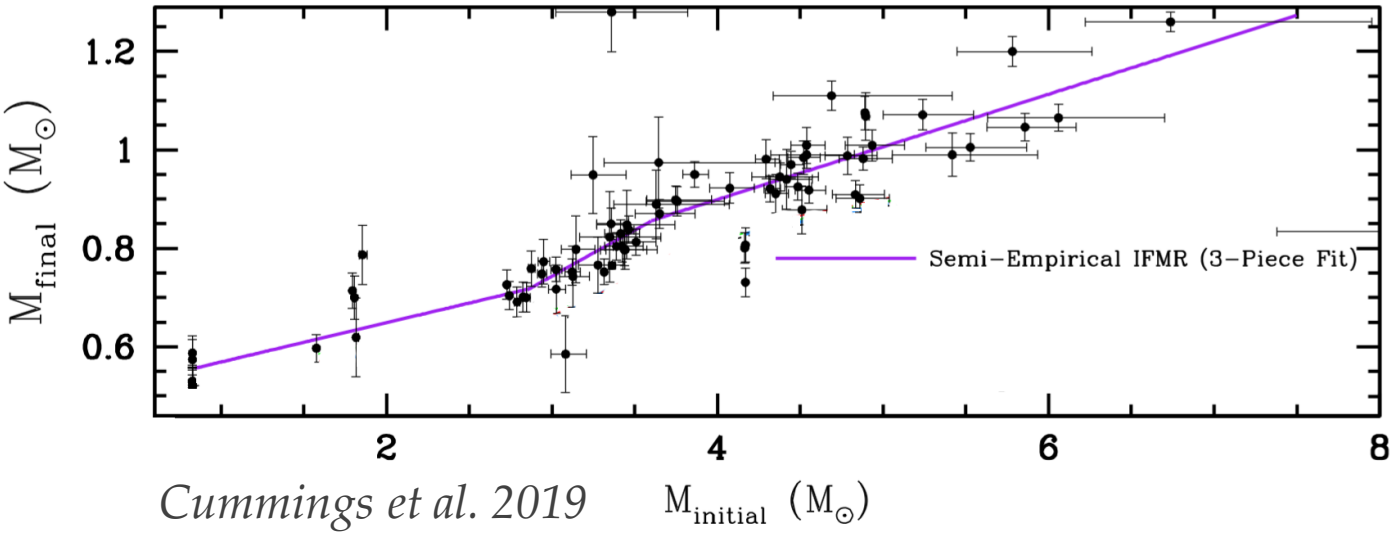
→ **0.77(0.03) $M_\odot$** WD in NGC 2527 (630 Myr)

185 Myr WD cooling age

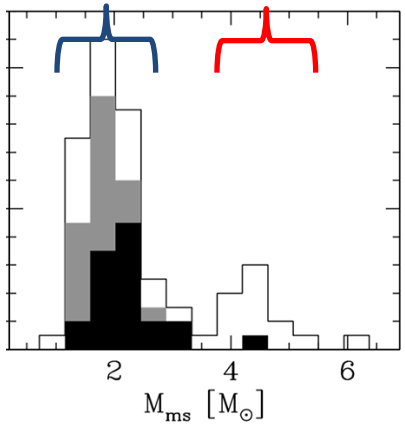
t_{prog} = 445 Myr

→ M_{prog} = 3.1 $M_\odot$

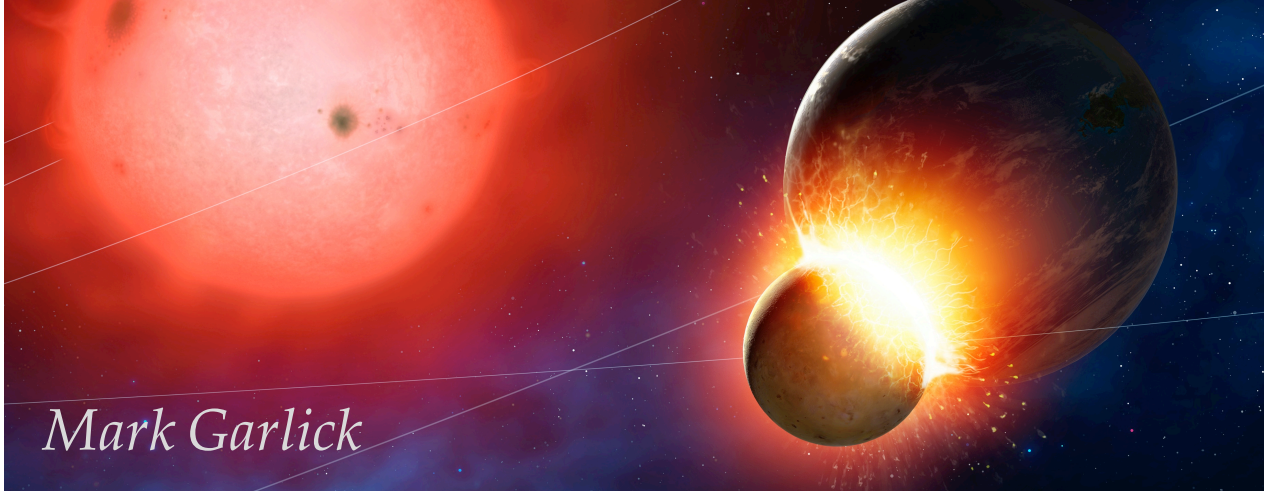
"IFMR" *(initial-to-final-mass relation)*



Cummings et al. 2019



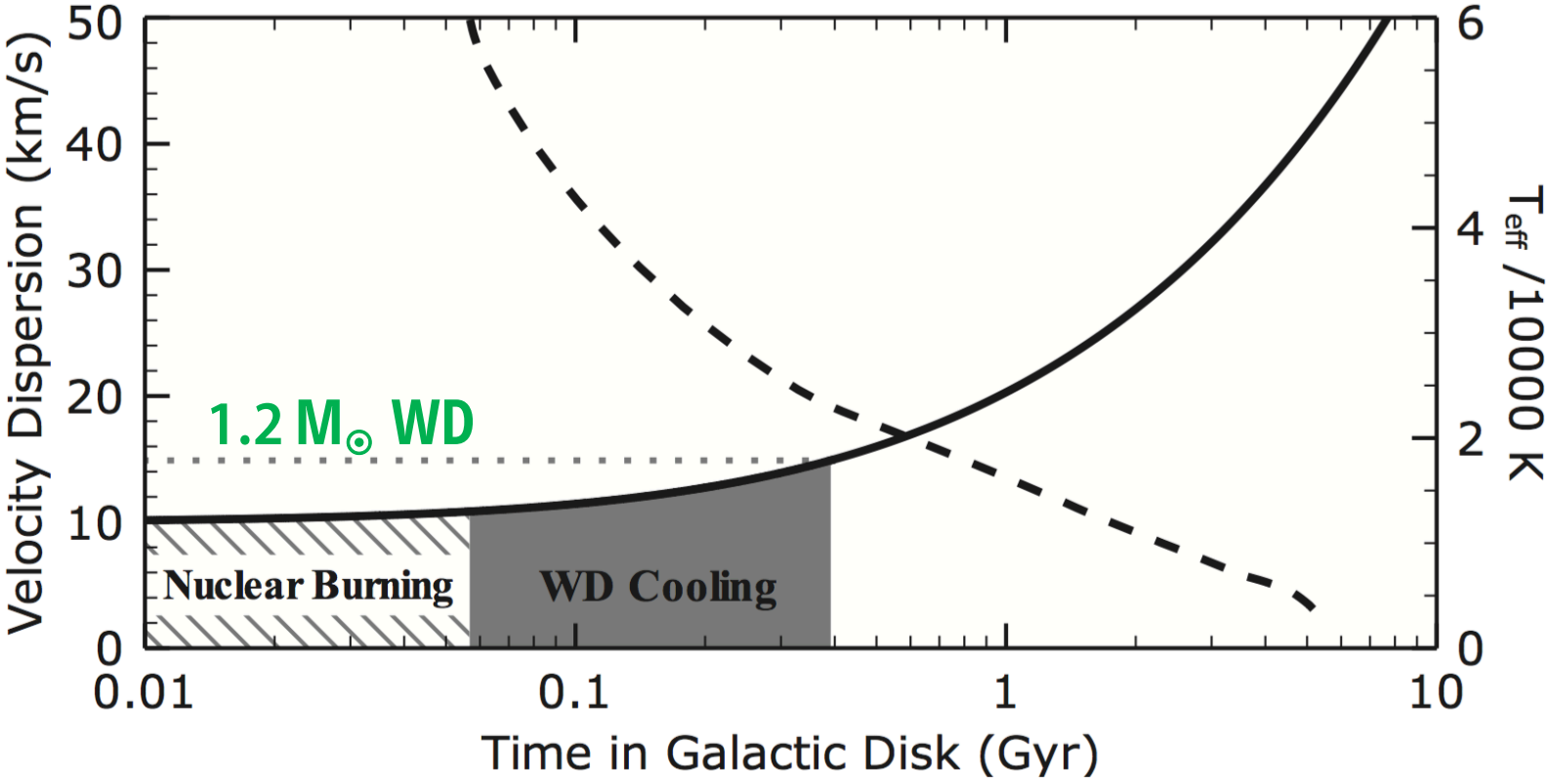
Koester, Gänsicke & Farihi 2014

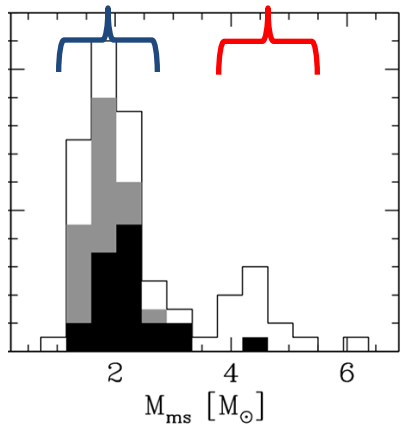


- **>30-50%** of WDs from **1.5-3.5 solar-mass** ZAMS progenitors show **remnant planetary systems**
- **<10%** of WDs from **4-6 solar-mass** progenitors show the same evidence
- Is this caused by: **mergers or binarity?**
  late-stage stellar violence?
  differences in planetary architectures?
  differences in planetary occurrence?

Are Massive WDs Mostly Merger Byproducts?

- Hot (>15 kK) **massive** WDs descending from single stars were **born <1 Gyr ago**
- They should thus have **low** velocity dispersions





Koester, Gänsicke & Farihi 2014

Dunlap & Clemens 2015

Massive WDs Generally Evolved from Single Stars

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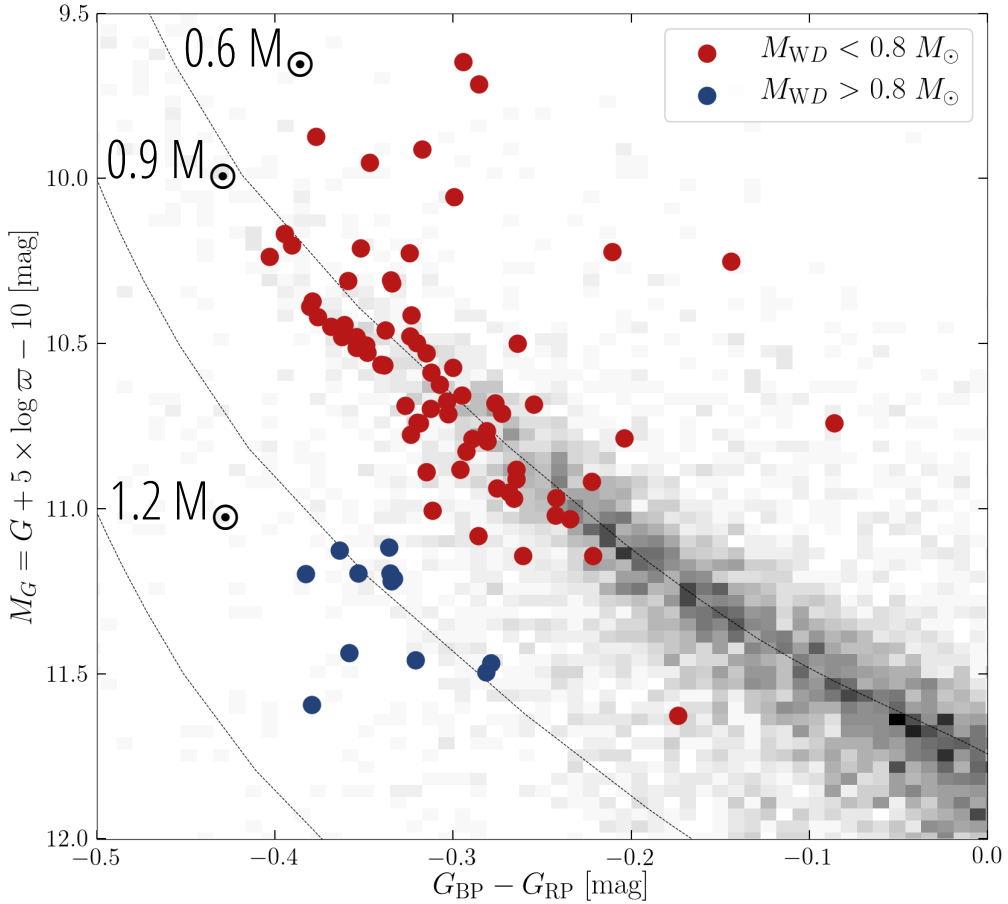
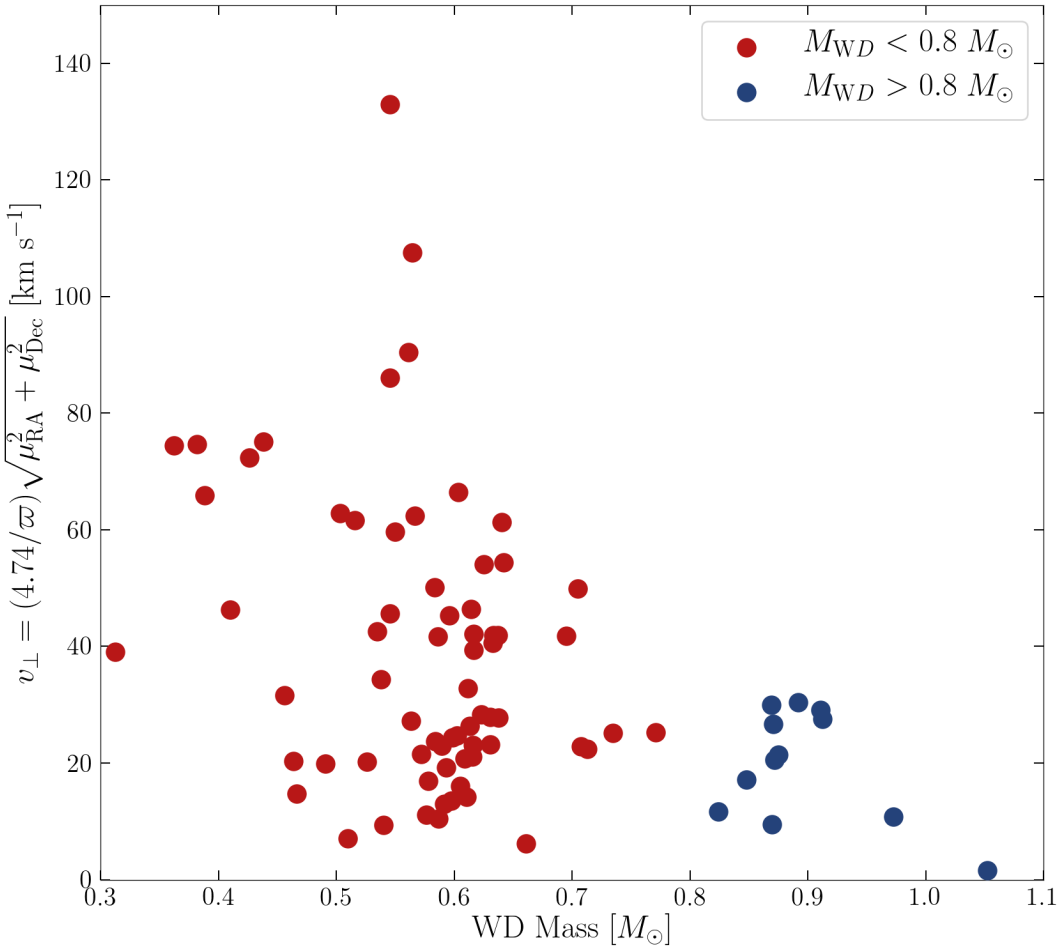
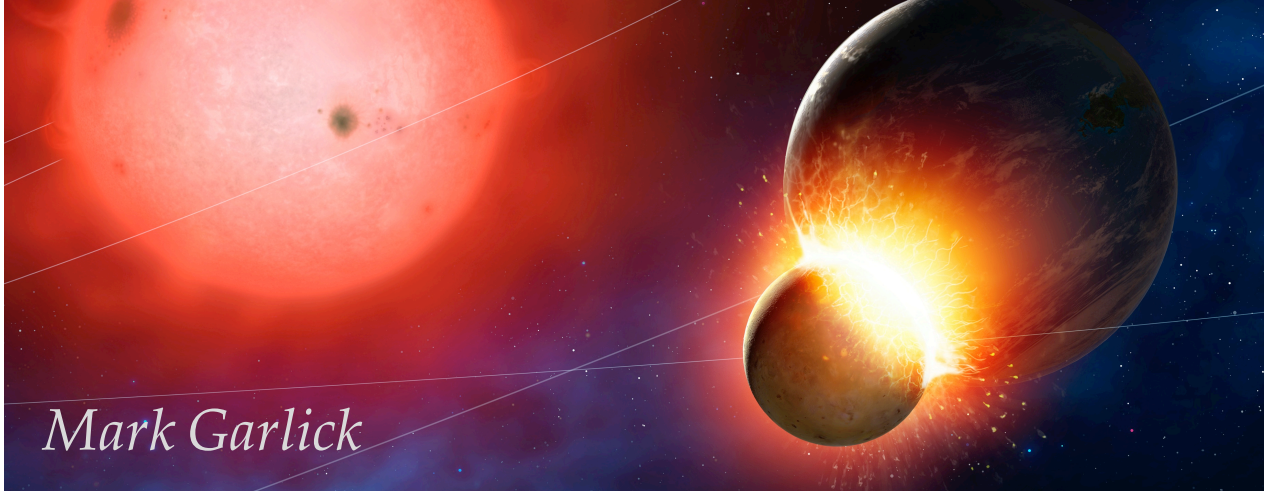




see also Wegg & Phinney 2012



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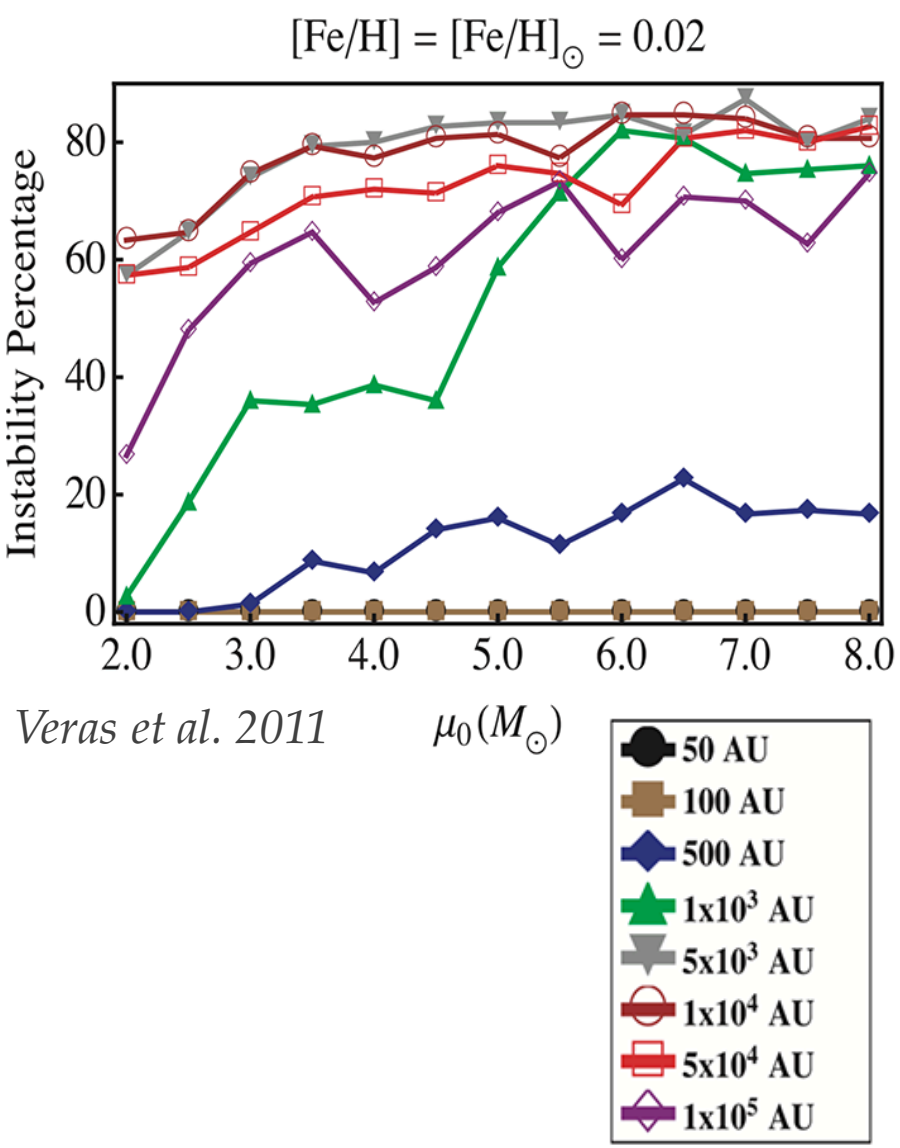
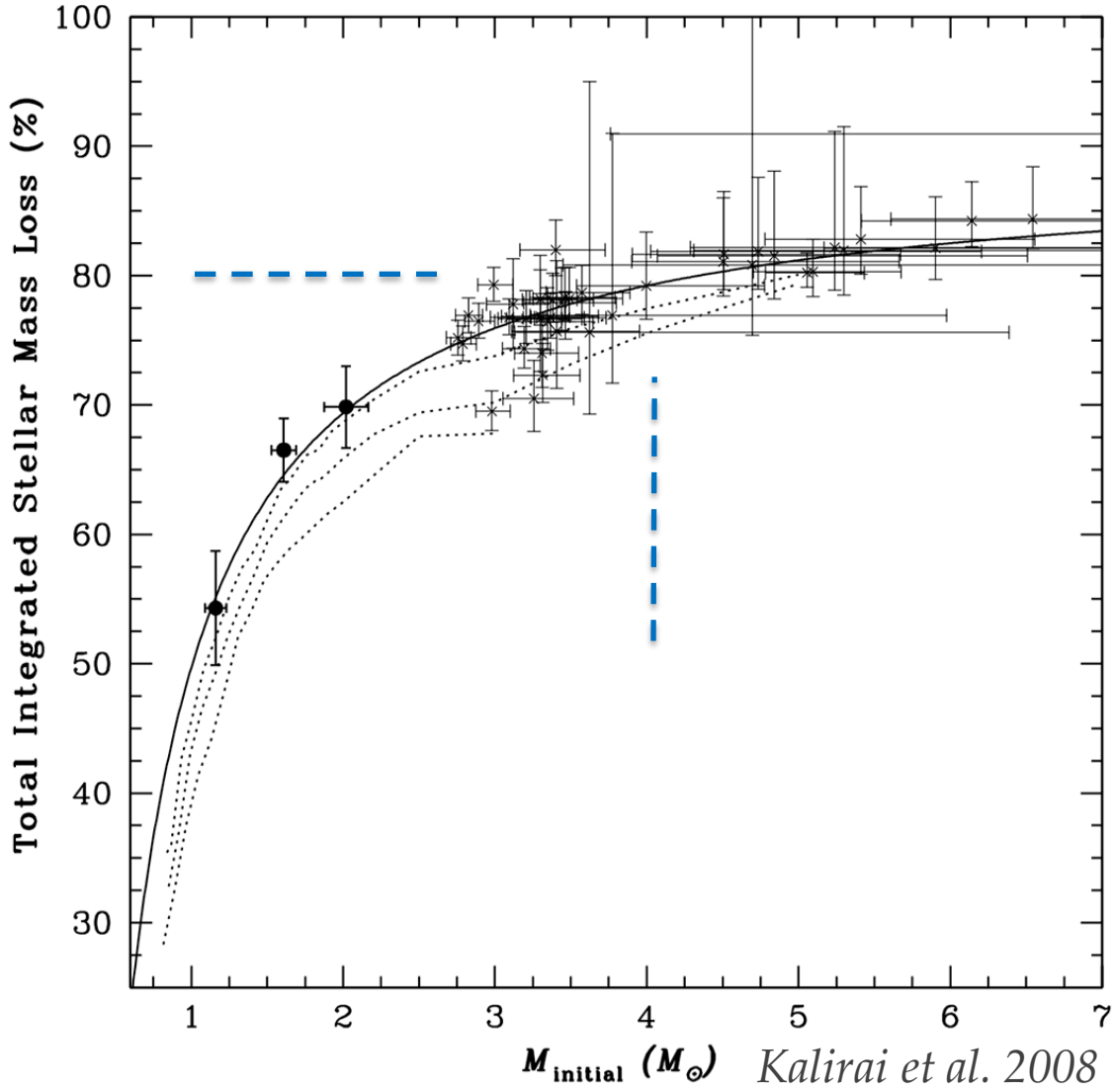
Could Mass-Loss Destabilize Planets For Massive AGB Stars?

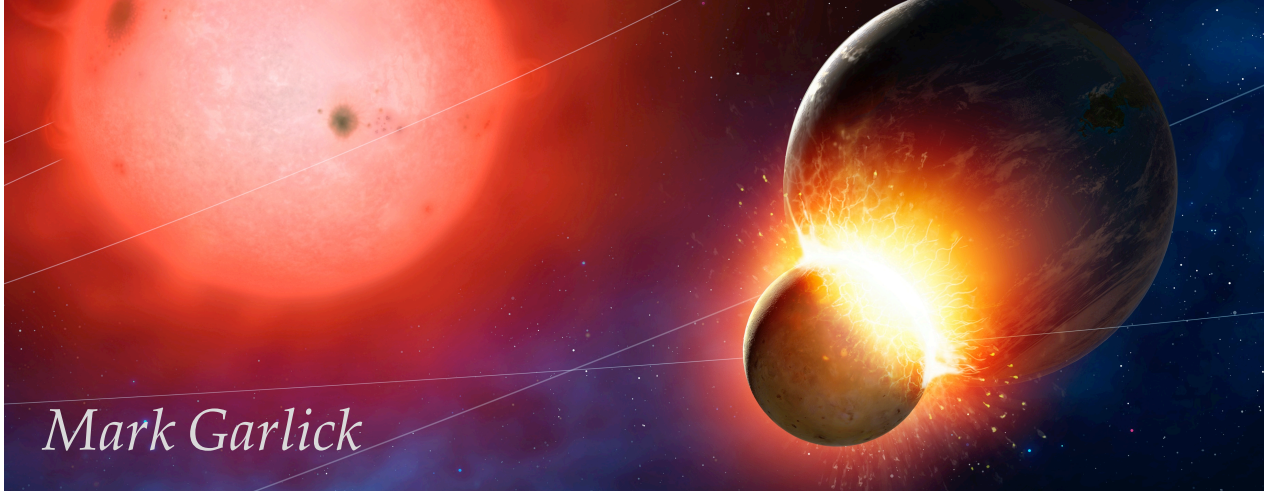
- **Most major planets inside 100 au survive** mass loss



Veras et al. 2011



Kalirai et al. 2008



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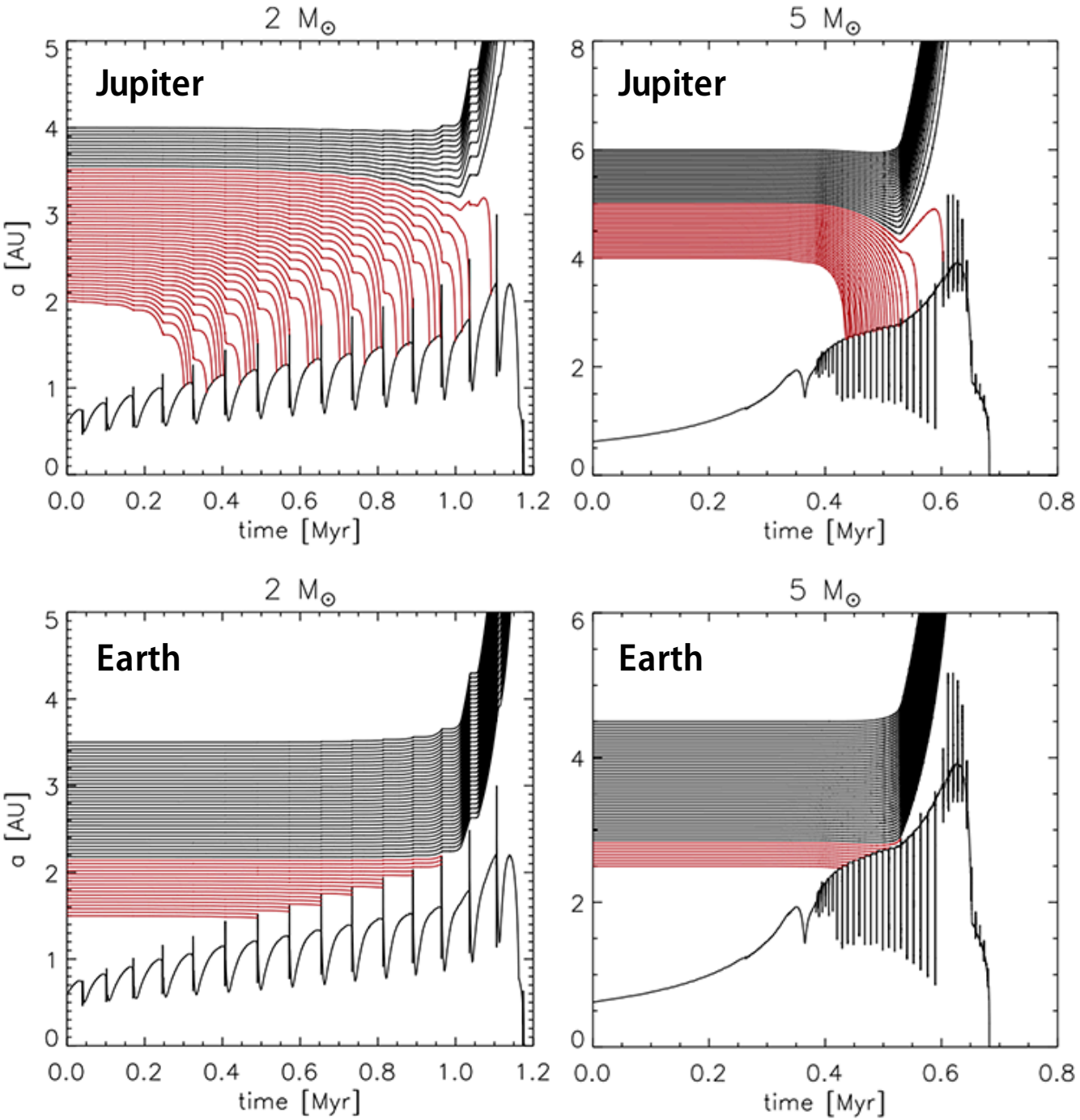
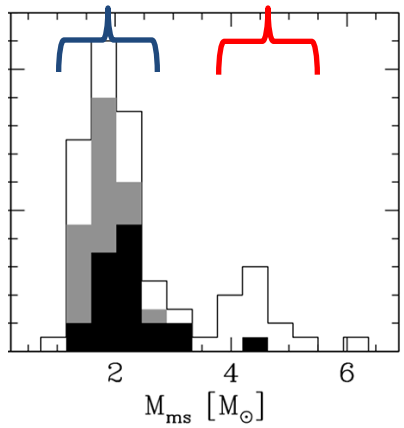
Do Planetary Architecture Shares Some Blame?



- Perhaps more massive stars have fewer **reservoirs** of asteroids, or those reservoirs more affected by RGB luminosities?

(eg, YORP: Veras et al. 2014)

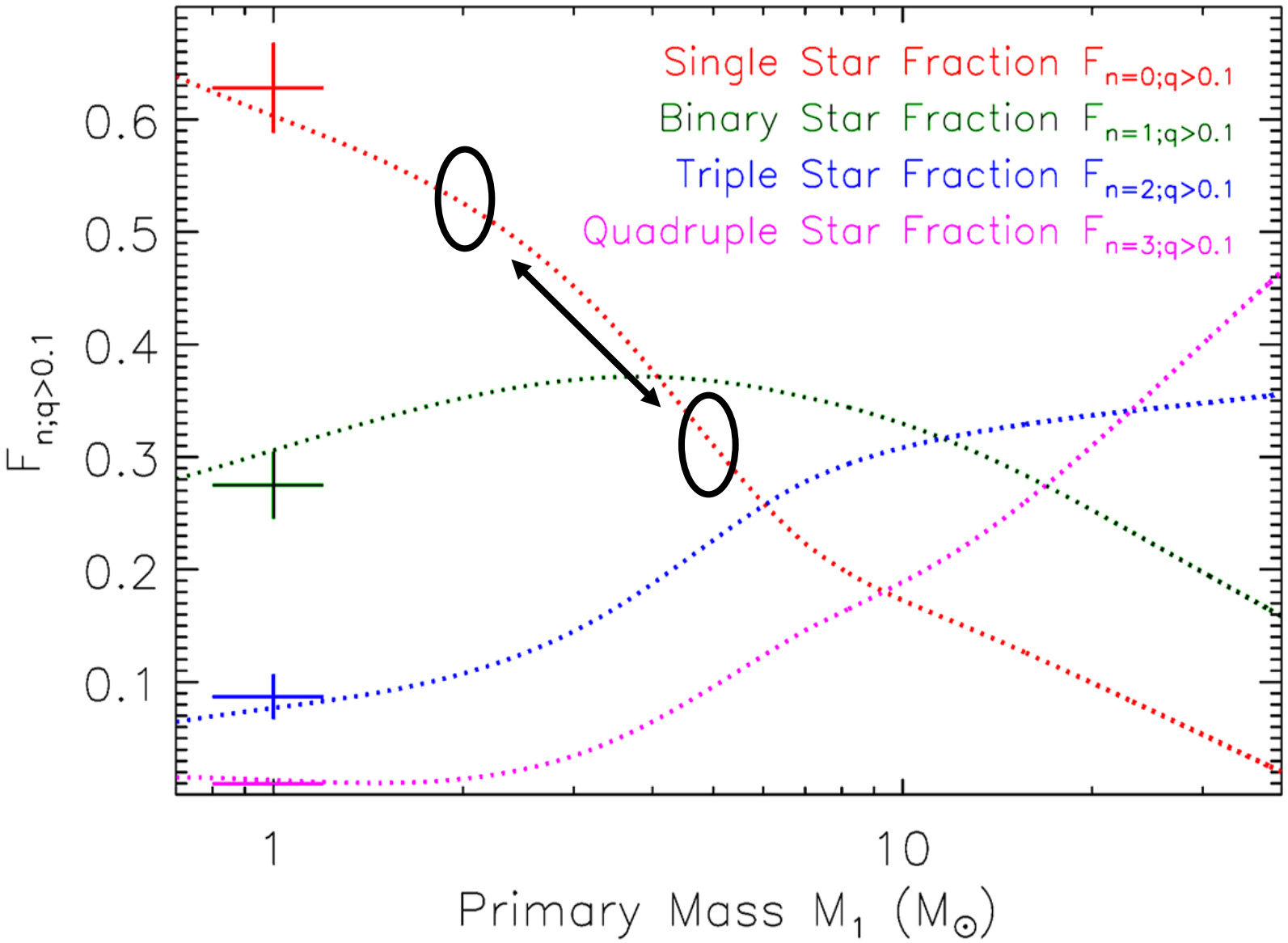


Koester, Gänsicke & Farihi 2014

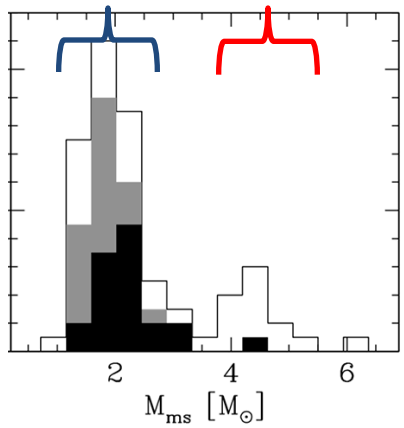
Mustill & Villaver 2012

Do Massive Stars Simply Have Lower Planetary Occurrence?

- Perhaps **disk lifetimes** too short, or are affected by **stellar companions?**



Moe & Di Stefano 2017



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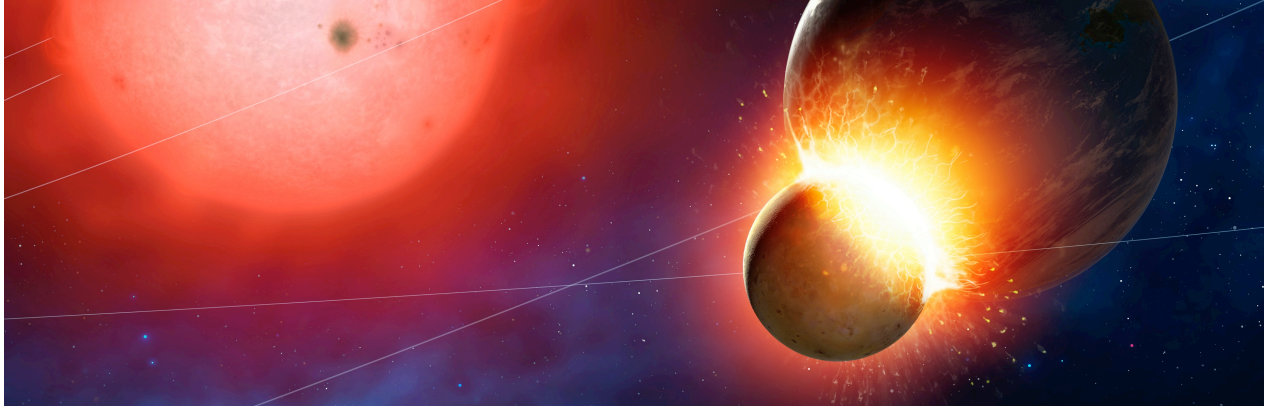

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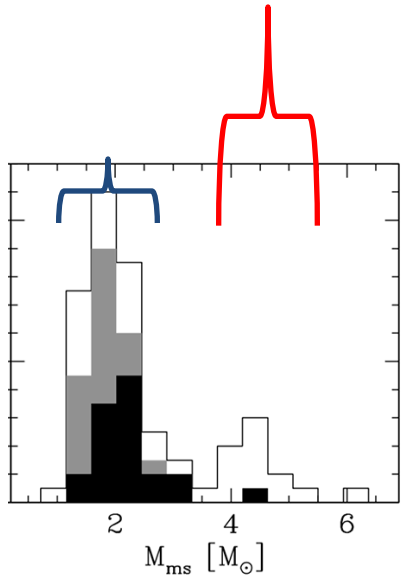

Koester, Gänsicke & Farihi 2014