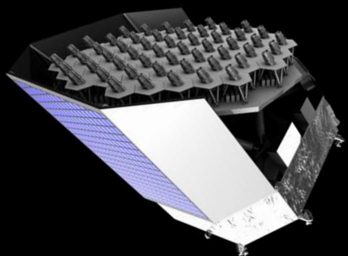
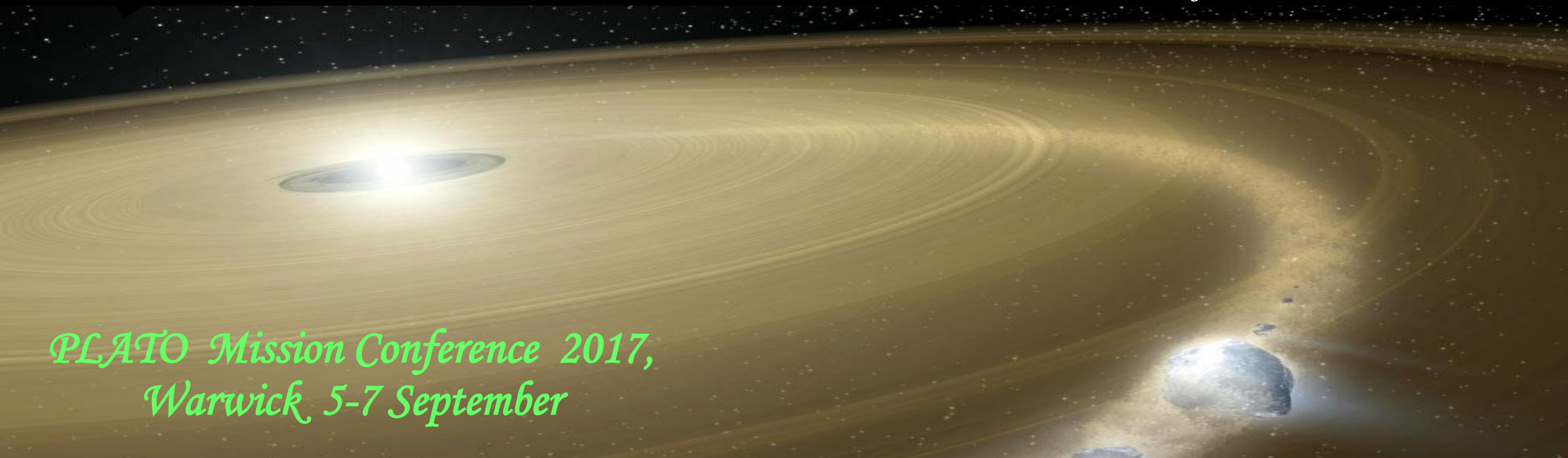
Planets transiting hot subdwarfs (HSDs) and white dwarfs (WDs): from Kepler/K2 to TESS to PLATO



Roberto Silvotti

INAF - Osservatorio Astrofisico di Torino



PLATO Mission Conference 2017, Warwick 5-7 September

Outline

- (1) **Introduction, the period gap, detection methods**
- (2) **Substellar companions to hot subdwarfs (HSDs)**
- (3) **WD remnants of ancient planetary systems**
- (4) **HSD/WD transits: from Kepler/K2 to TESS to PLATO (and LSST)**

1. HSD/WD planets: why ?

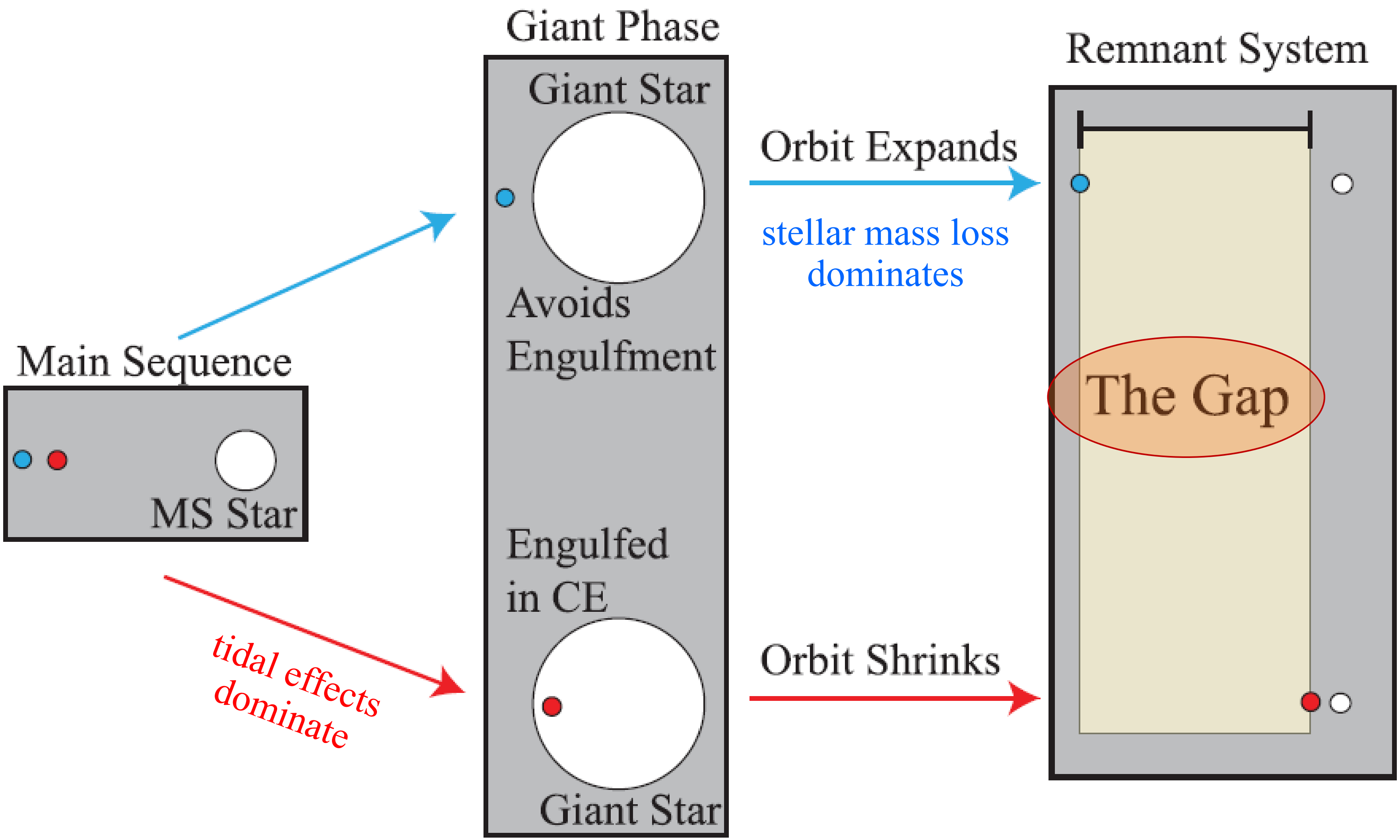
- because >95% of stars become WDs at the end of their evolution and the final configuration of these >95% planetary systems is poorly known.

- Even though only 1-2% of stars experience a hot subdwarf phase, planets around these stars allow to disentangle the effects of the RGB expansion alone (while WD planets are affected also by AGB expansion, thermal pulses and PN ejection).

1. HSD/WD planets: open questions

- Are there planets in close orbits around HSDs/WDs ?
- Which is the minimum distance to escape engulfment ?
- Which is the minimum mass to survive engulfment ?
- Which is the minimum mass for a companion to eject the envelope of a hot subdwarf precursor ?
- Does the period gap actually exist and which are its boundaries ?

1. The Period Gap

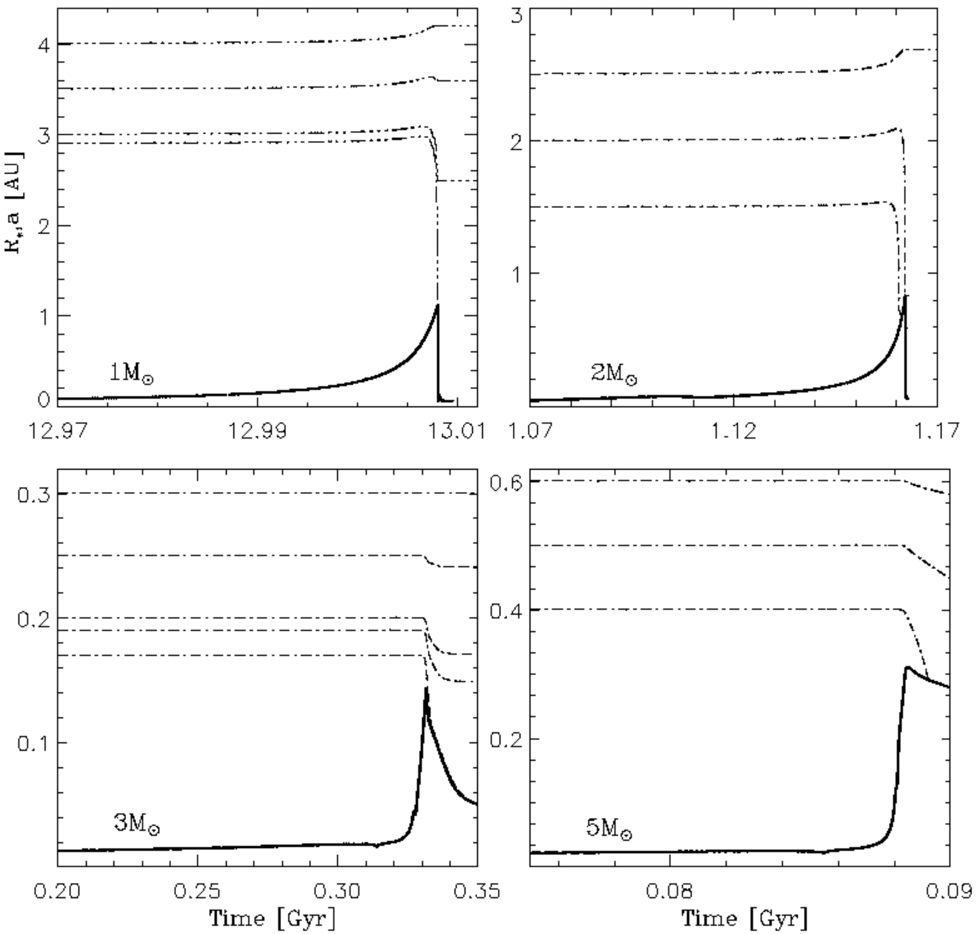


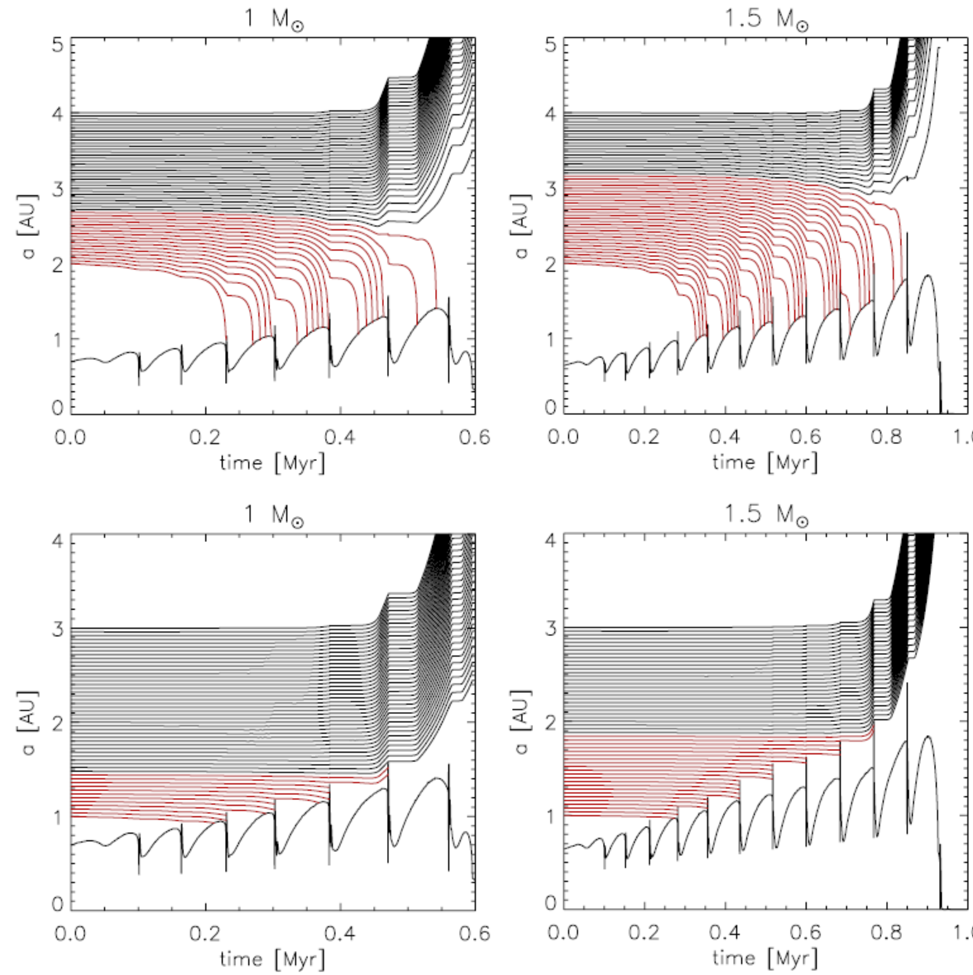
(from Nordhaus & Spiegel 2013)

1. The Period Gap

Orbital evolution of gas giant planets during RGB (left) and AGB (right)

(from Villaver & Livio 2009 and Mustill & Villaver 2012)

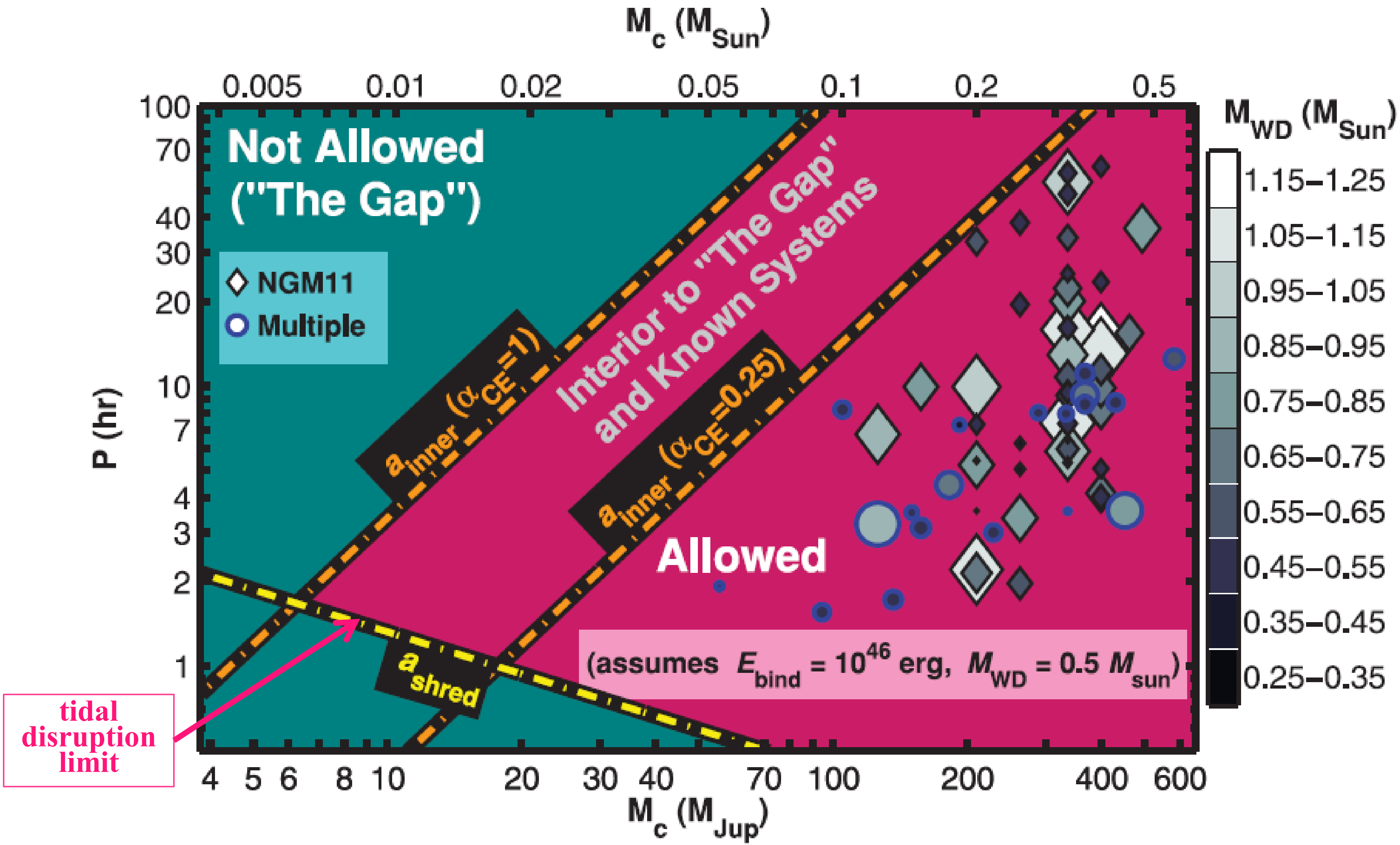




$M_p = 1\ M_J$

$M_p = 1\ M_J$ (2 upper panels)
$M_p = 1\ M_E$ (2 lower panels)

1. The Period Gap vs WD companion masses



Nordhaus & Spiegel 2013

1. Detection methods

method	pros	cons	detectable	detected
RVs	• low mass stars → higher RVs	• rel. small # of lines (H/He too broad) • only bright stars	close orbits, down to ≈10 M_J	≥5 sdB+BD (Schaff.+2014) ≥5 WD+BD (Casewell+2015, 2017; Farihi+2017)
Transits	• small star radii → deep transits	• small star radii → low transit prob.	close orbits, down to ≈ R_E or less	1 WD with disintegrating asteroids (Vanderb.+2015)
Illumination (reflection/re-emission)	• rel. ind. from dist.	• need space phot (Kepler) • R,M not dir. measured • many unknown param. (albedo, dark/heated . hemisph. temp. ratio)	close orbits, down to ≈ R_E or less, mainly hot subdwarfs or hot WDs	many sdB+BDs, 2 sdB+planet cand. (Charpinet+2011; Silvotti+2014)
The gap				
Timing (eclipse/pulsation)	• rel. ind. from dist.	• false detections !	large orbits, mass ≳ 1 M_J	many ET PCEB circ. planet cand. (1 robust NN Ser) + a few PT planet cand.
IR (AO) imaging	• any inclination	• only young (2° gen) planets	large orbital distances	1 WD BD comp., M~7 M_J (Luhman+2011)
Astrometry (GAIA)	• any inclination	• d ≲ 100 pc	large orbital distances WD planets with M>10 M_J	–

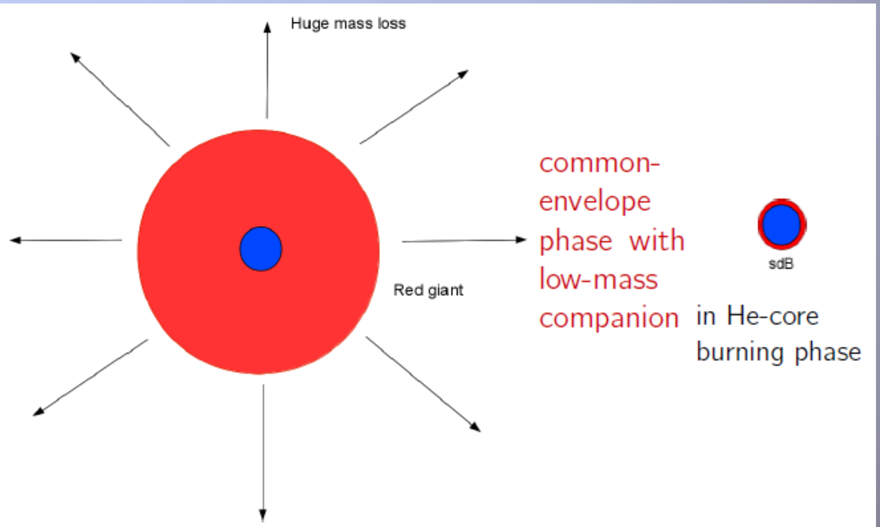
2. Substellar companions to hot subdwarfs (HSDs)

$$R_{HSD} \approx 0.2\ R_{SUN} \approx 20\ R_{EARTH}$$

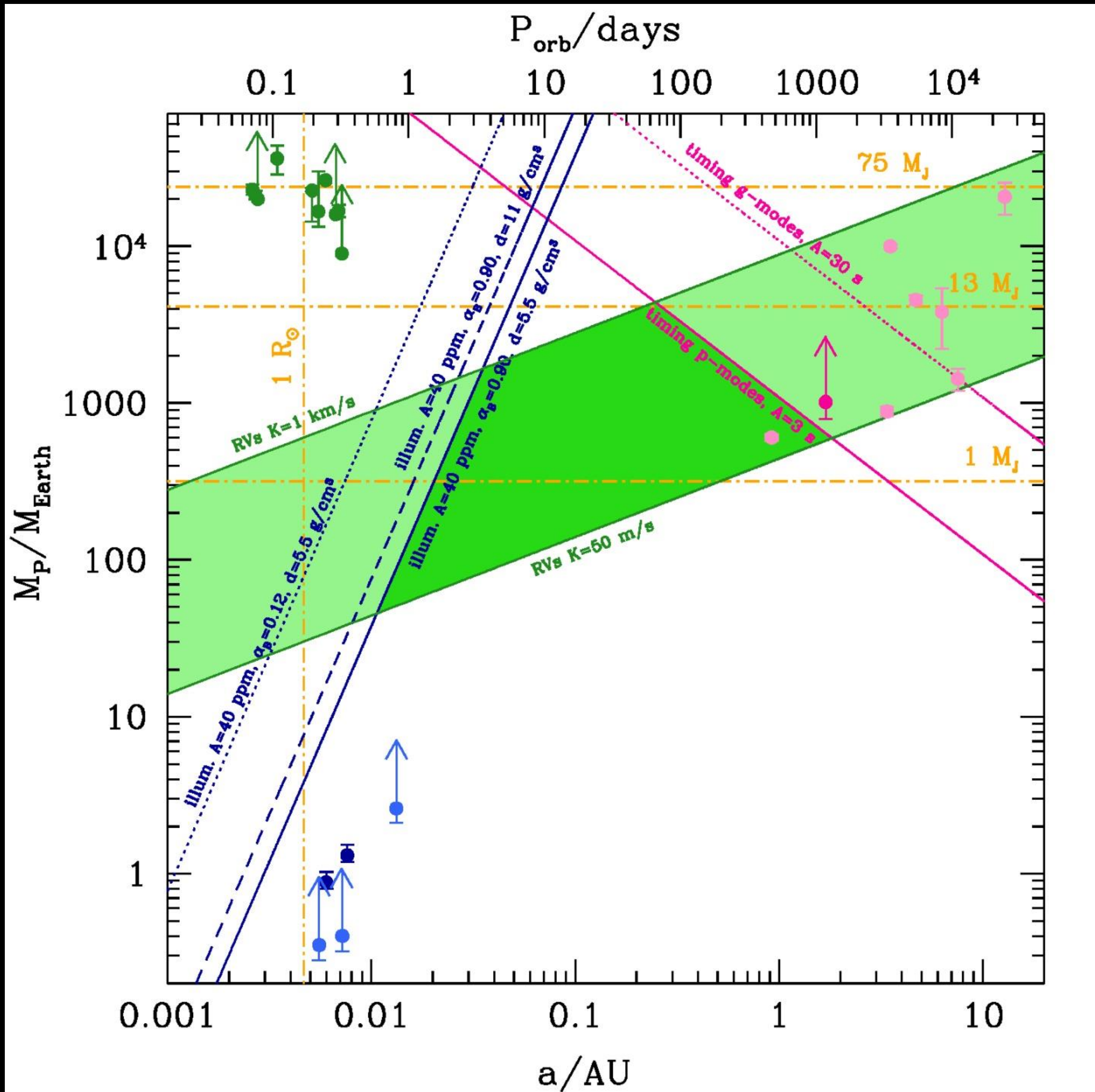
$$M_{HSD} \approx 0.5\ R_{SUN} \approx 1.7\text{x}10^5\ M_{EARTH}$$

$$g \sim 10^3\text{-}10^4\ \text{ms}^{-2}$$

(Sun is at 274 ms^{-2})



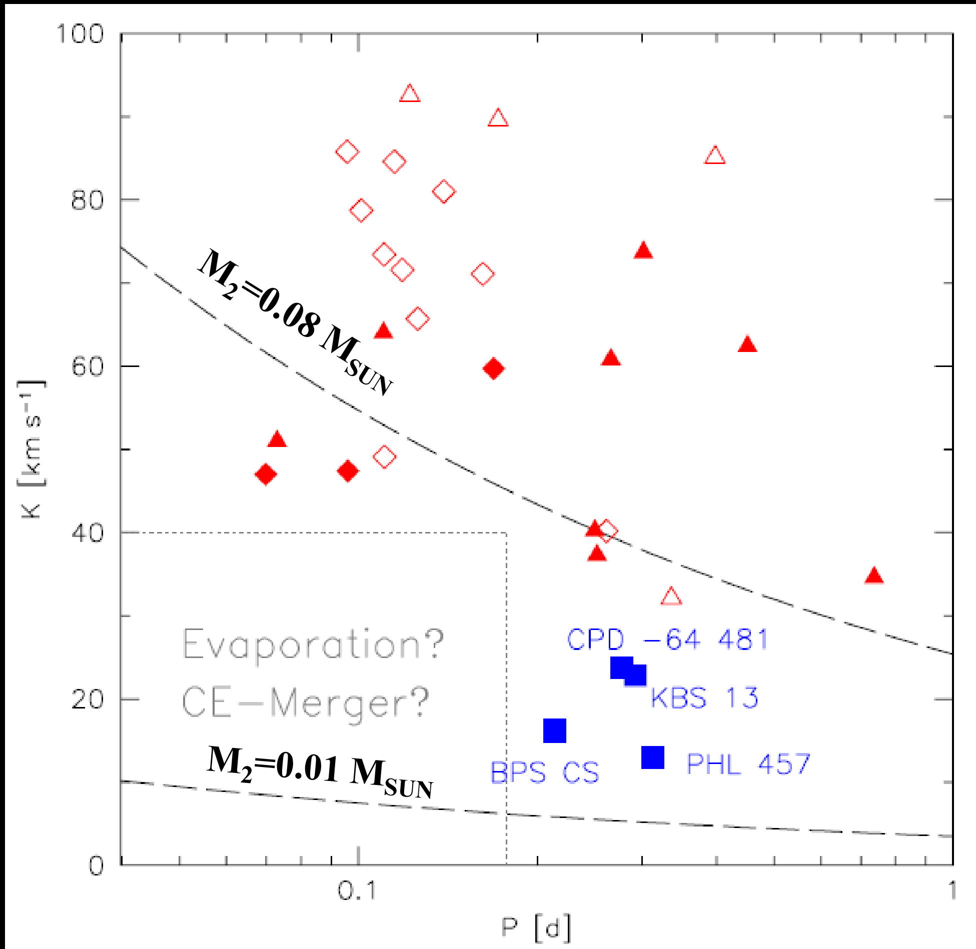
2. Substellar companions to hot subdwarfs (HSDs)



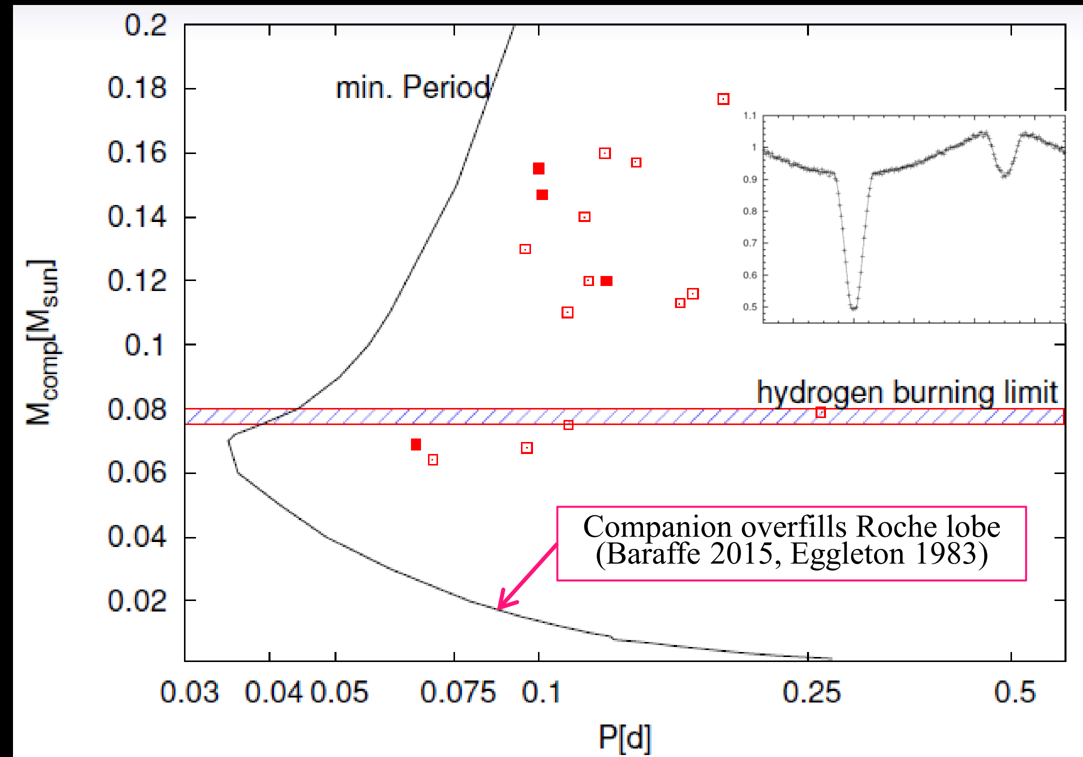
With high resolution instruments like FEROS, HERMES, HARPS, HARPS-N we start to access the green region, but only for very bright stars !

On the other hand, because of the opposite effects of tidal interaction and stellar mass loss, it’s also possible that this region is NOT populated at all !

2. Substellar companions to hot subdwarfs (HSDs)



SdB binaries with spectroscopic solutions.
Diamonds = true mass (eclipsing systems).
Other symbols = min mass (reflection effects).



Only sdB eclipsing binaries (updated 2017). Following Soker (1998) or Han (2012), BD or even massive planet companions might be able to eject the RG envelope of the sdB progenitor.

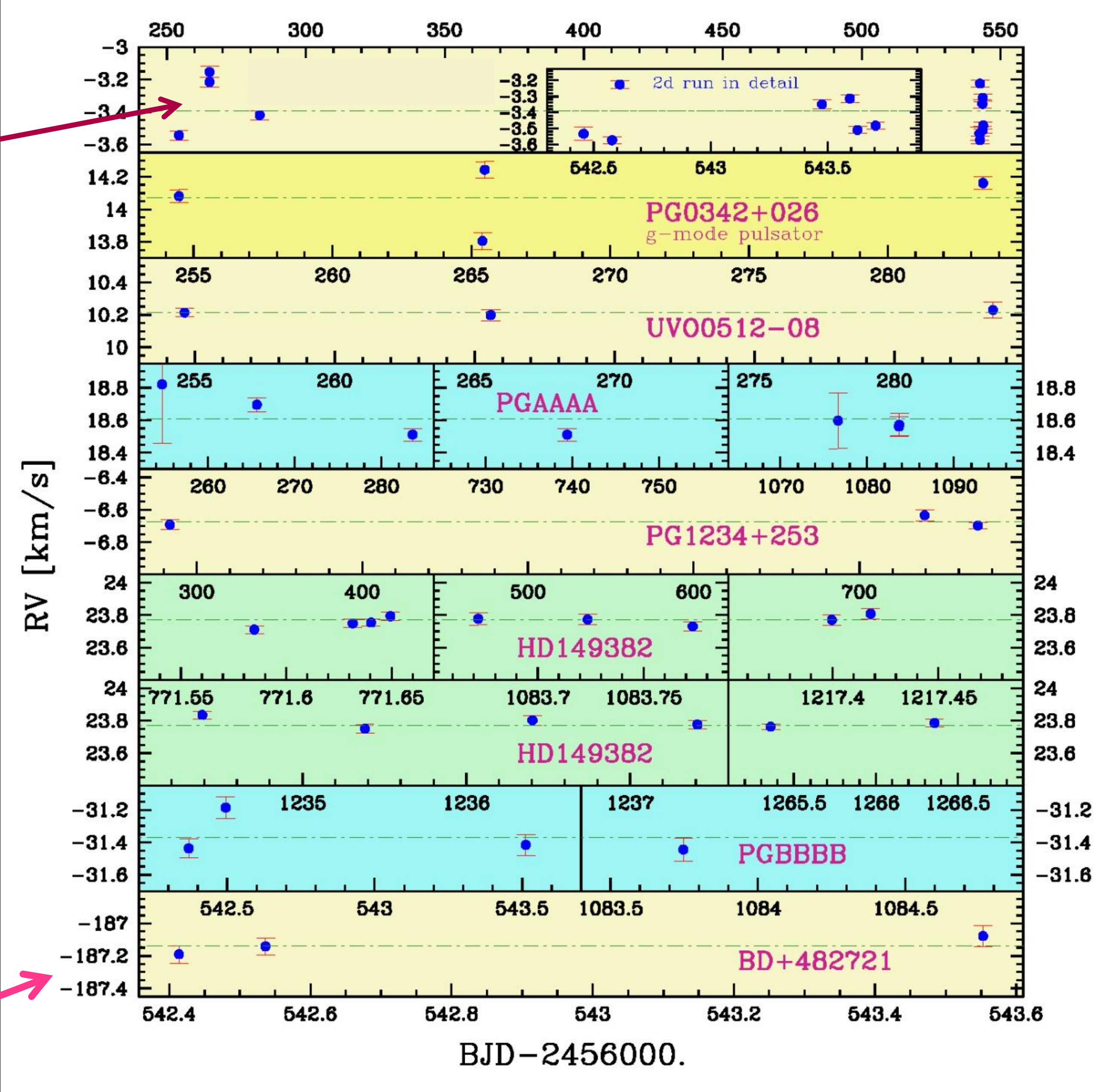
Figures from Schaffenroth 2014 (left) and 2017 (right, Haifa meeting on «Planetary Systems beyond the MS II»)

2. Substellar companions to hot subdwarfs (HSDs)

it is indeed a pulsator !!
(puls. detected by K2)
Silvotti et al. in prep.

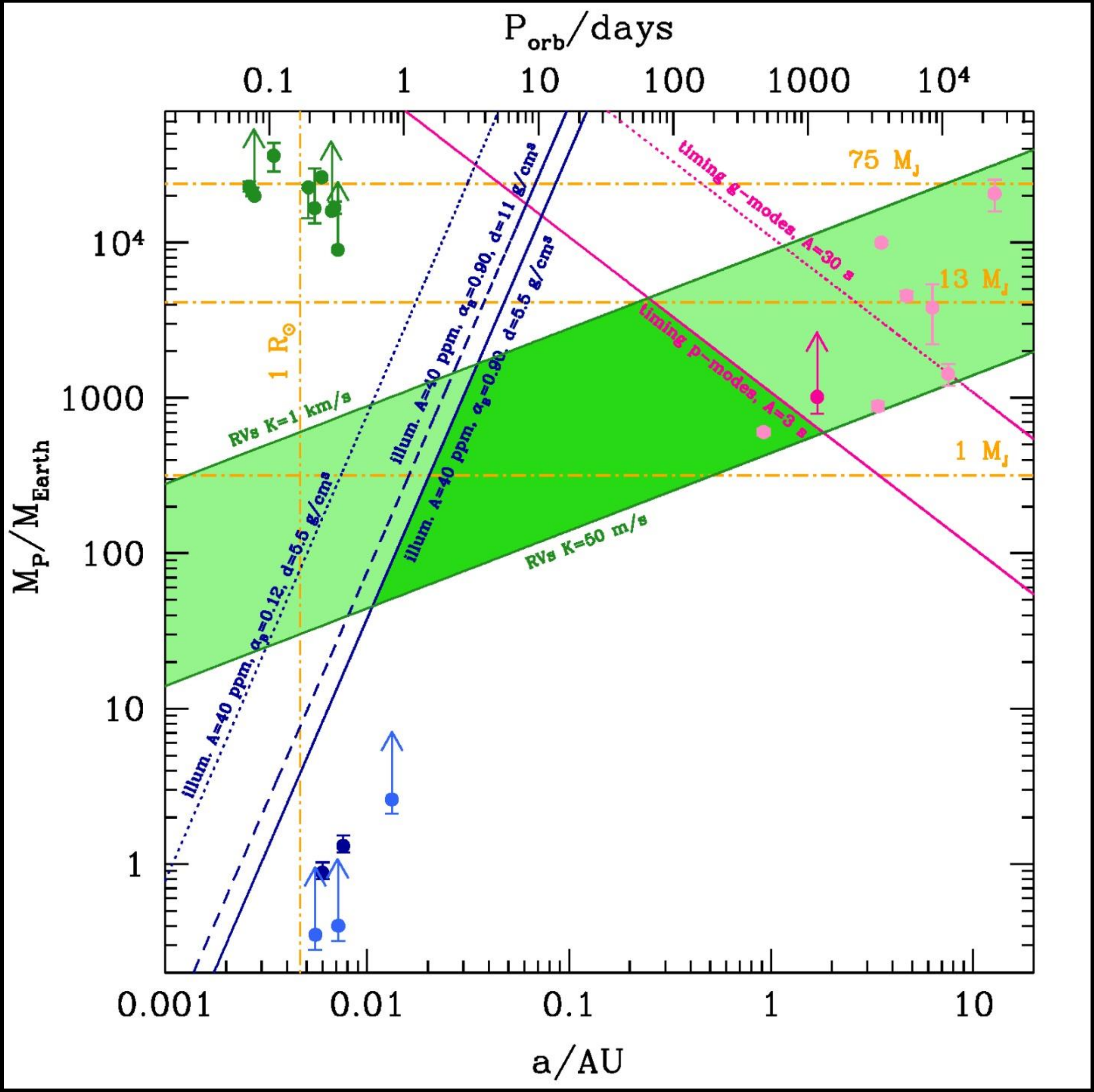
the search for substellar companions to hot subdwarfs through RVs is limited by the RV accuracy achievable in these stars

with Harps-N we can reach 1σ errors of ≈30 m/s at S/N=100



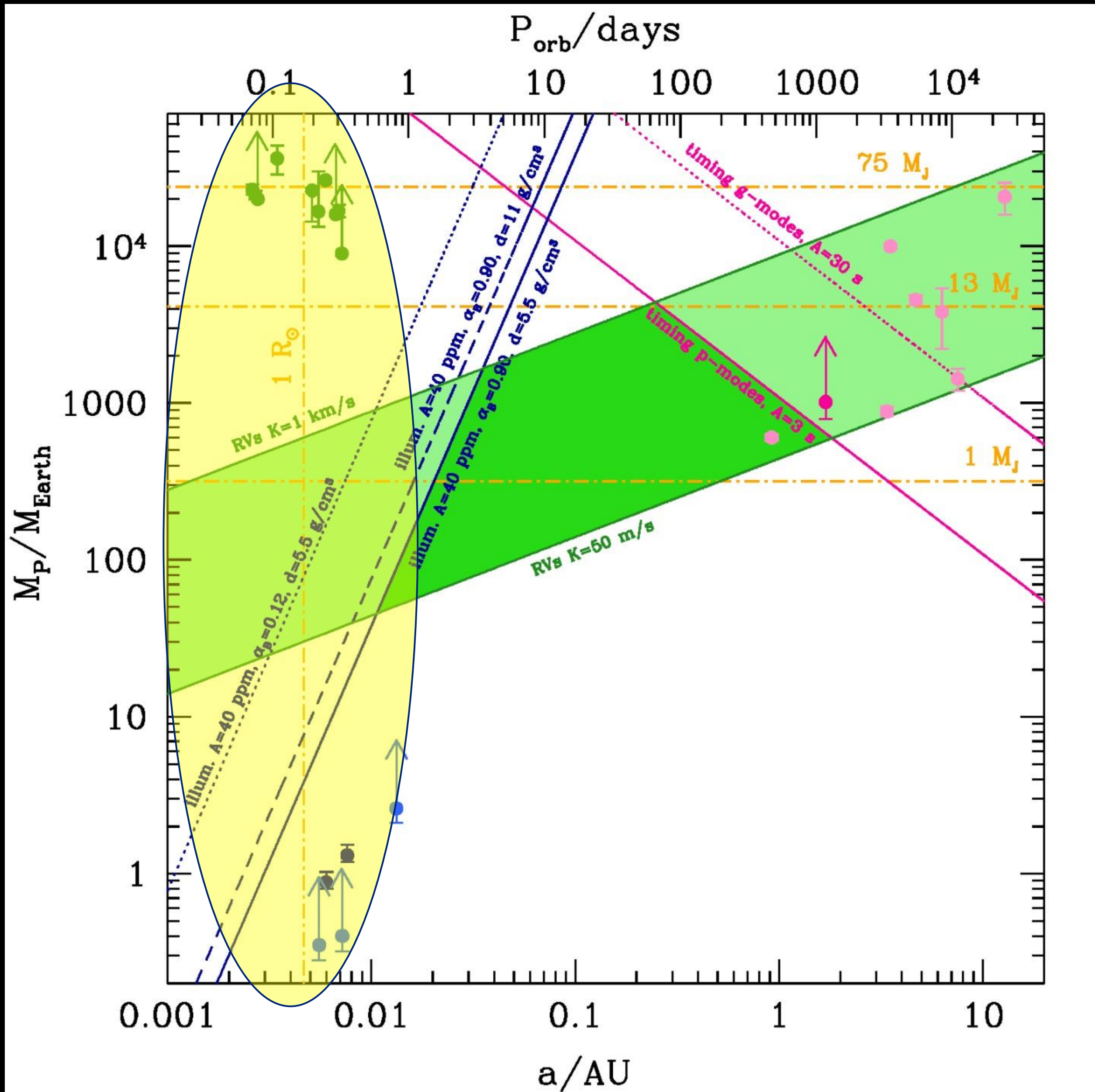
Updated from Silvotti+2014

2. Substellar companions to hot subdwarfs (HSDs)



How to explore the tight-orbit-region at low masses/radii ?

2. Substellar companions to hot subdwarfs (HSDs)

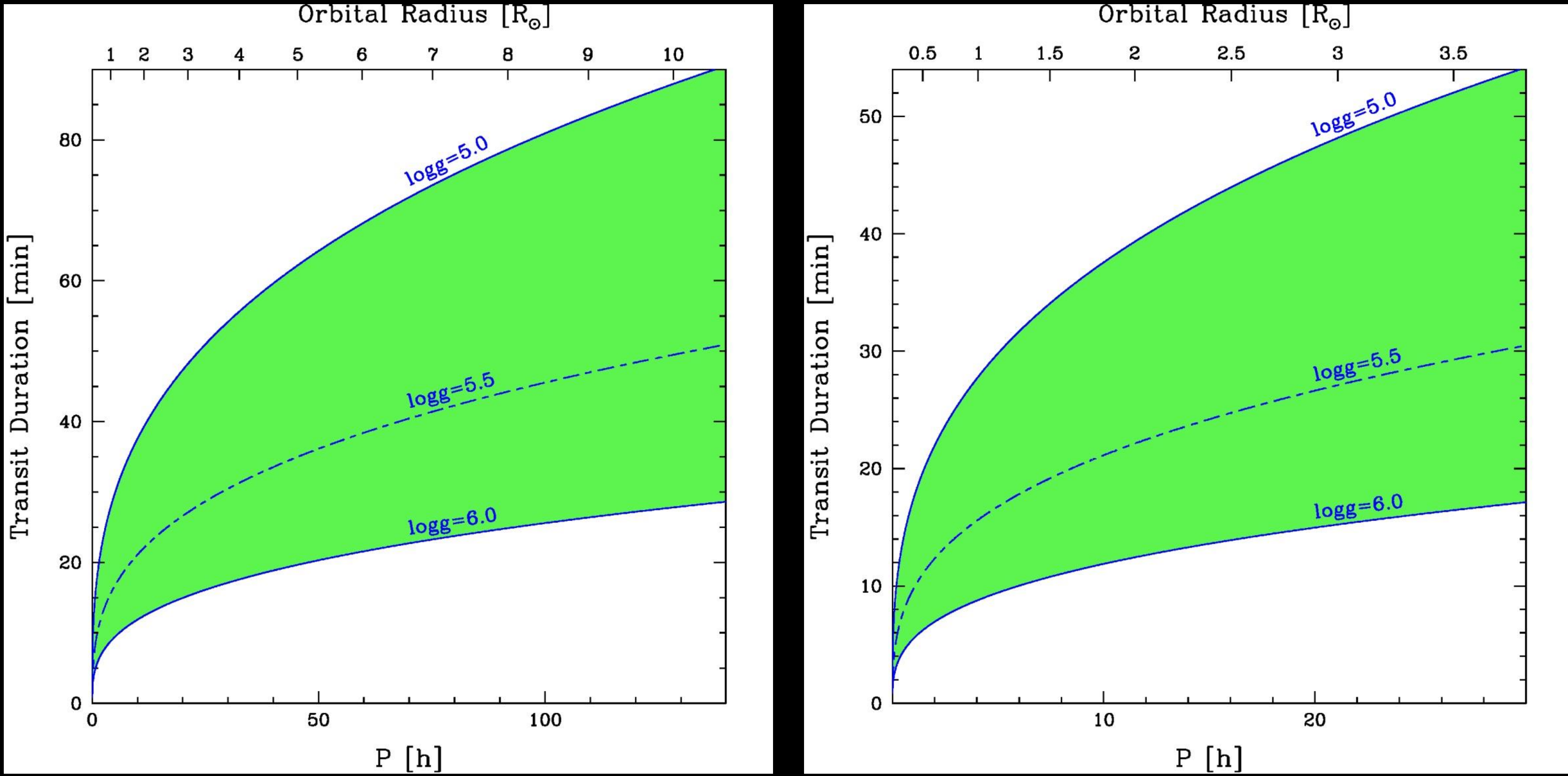


How to explore the tight-orbit-region at low masses/radii ?

By searching for transits !

2. Substellar companions to hot subdwarfs (HSDs)

Transit duration for a hot subdwarf
(transit depth is ~25% for 1 R_J and ~0.2% for 1 R_E)

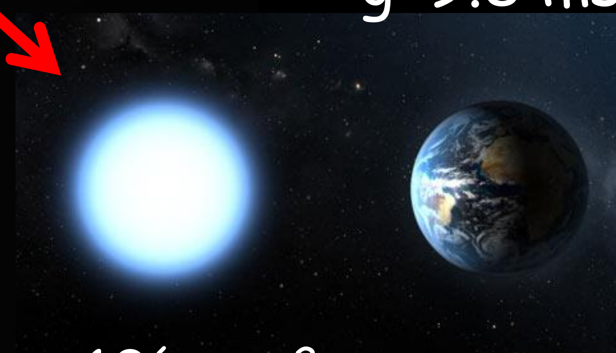


3. WD remnants of ancient planetary systems

$R_{WD} \approx 0.01\ R_{SUN} \approx R_{EARTH}$

$M_{WD} \approx 0.6\ R_{SUN} \approx 2\text{x}10^{5}\ M_{EARTH}$

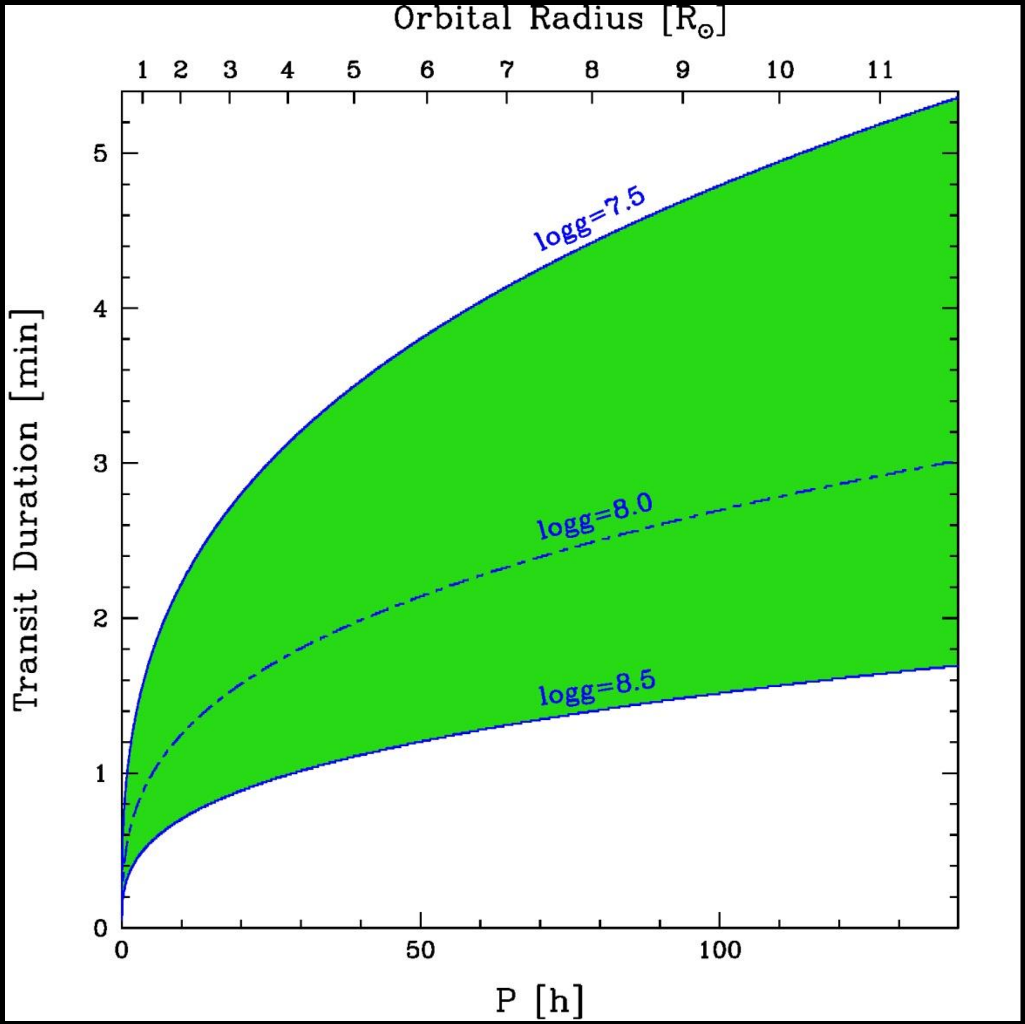
$g=9.8\ ms^{-2}$

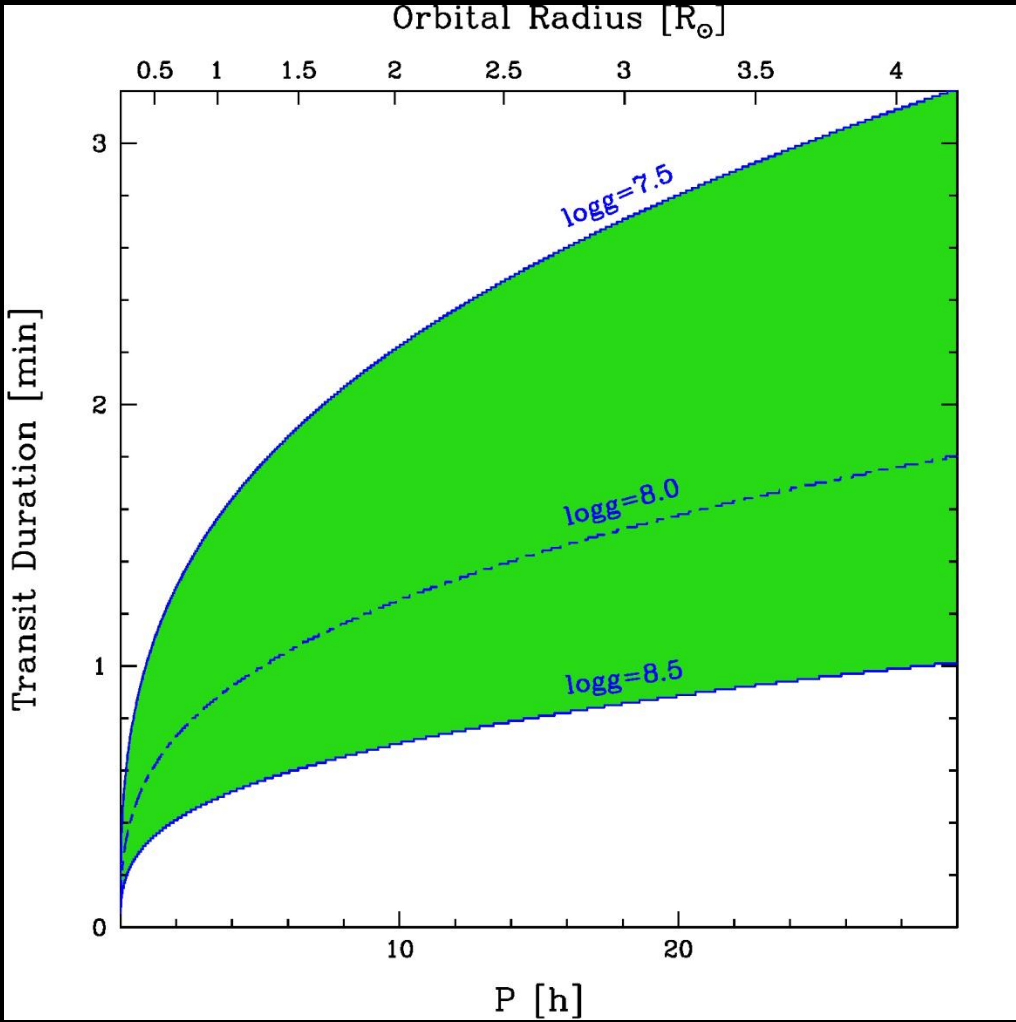


$g\sim10^{6}\ ms^{-2}$

3. WD remnants of ancient planetary systems

Transit duration for a white dwarf (transit depth for a canonical WD is ≈50% for 1 R_E)

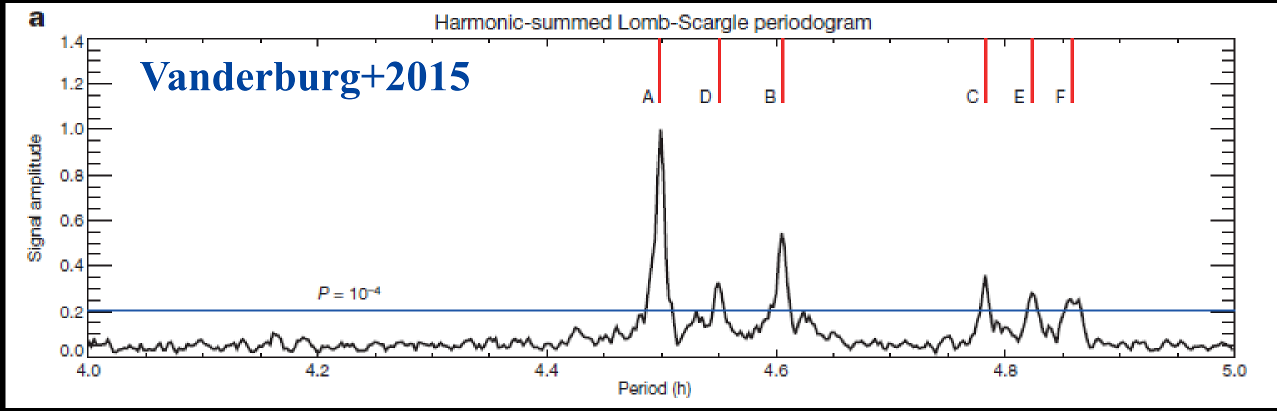


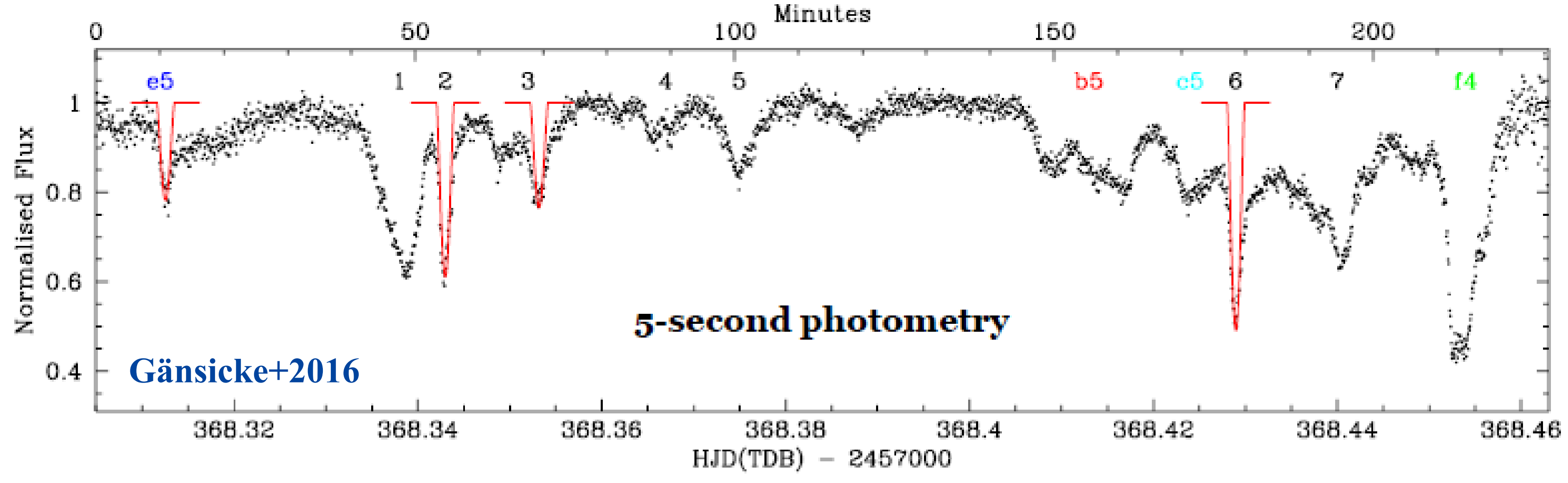


3. WD remnants of ancient planetary systems

Recent K2 discovery of many irregular transits in front of WD1145+017 (Vandenburg+2015). This is an inportant confirmation of the asteroid disruption scenario (see next slides), with the transits caused by disintegrating planetesimals.

Papers on WD1145+017:
Vanderburg+2015; Alonso+2016; Gänsicke+2016; Rappaport+2016; Xu+2016; Zhou+2016; Croll+2017; Gary+2017; Gurri+2017; Veras+2017; Hallakoun+2017; Redfield+2017; Farihi+2017; Kjurkchieva+2017.





3. WD remnants of ancient planetary systems

In the last 10 years there has been increasing evidence that many WDs have surrounding material from ancient planetary systems:

→ **25-45% of WDs show metal pollution due to asteroid tidal disruption; (Koester+2014, Wilson 2017)**

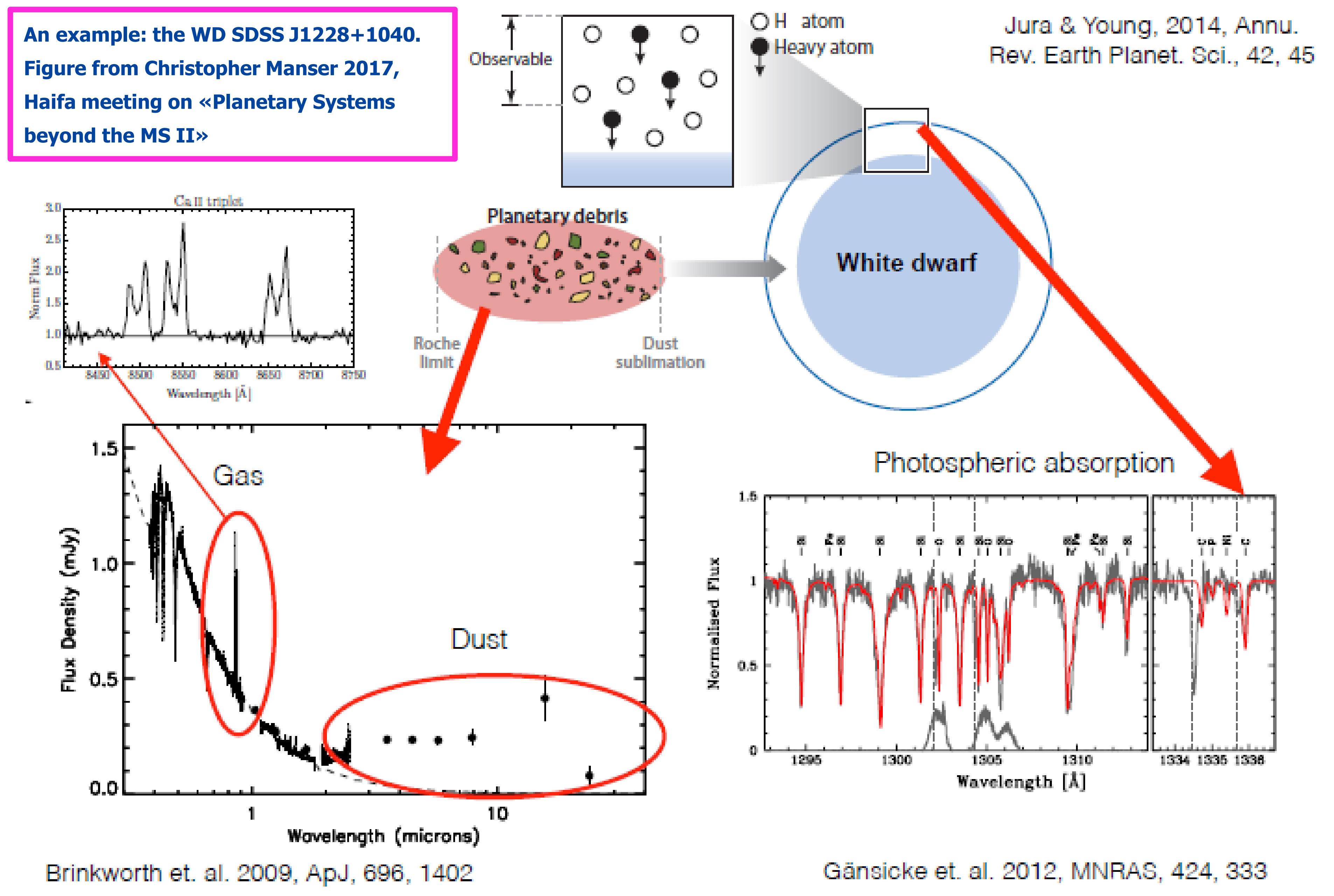
→ **1-3% of WDs show a dusty debris disk all of them show also metal pollution (Farihi+2009, Rocchetto+2015, Wilson 2017)**

→ **2-10% of debris discs have also a gaseous component (Gänsicke+2006, Manser+2017)**

Saturn to scale

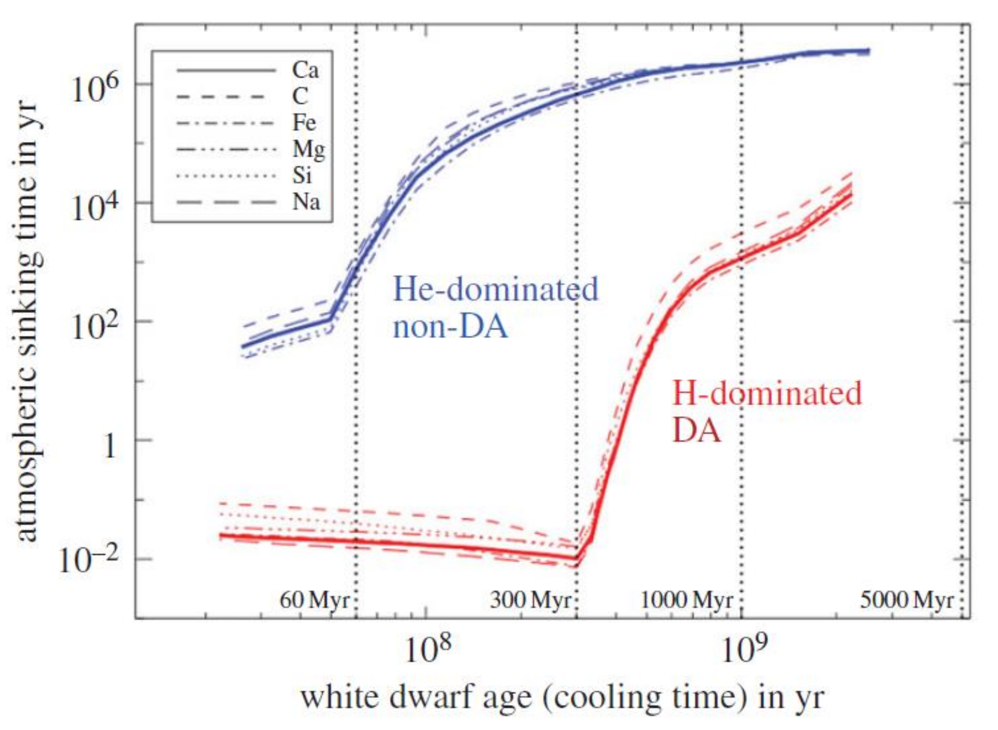
3. WD remnants of ancient planetary systems

An example: the WD SDSS J1228+1040. Figure from Christopher Manser 2017, Haifa meeting on «Planetary Systems beyond the MS II»

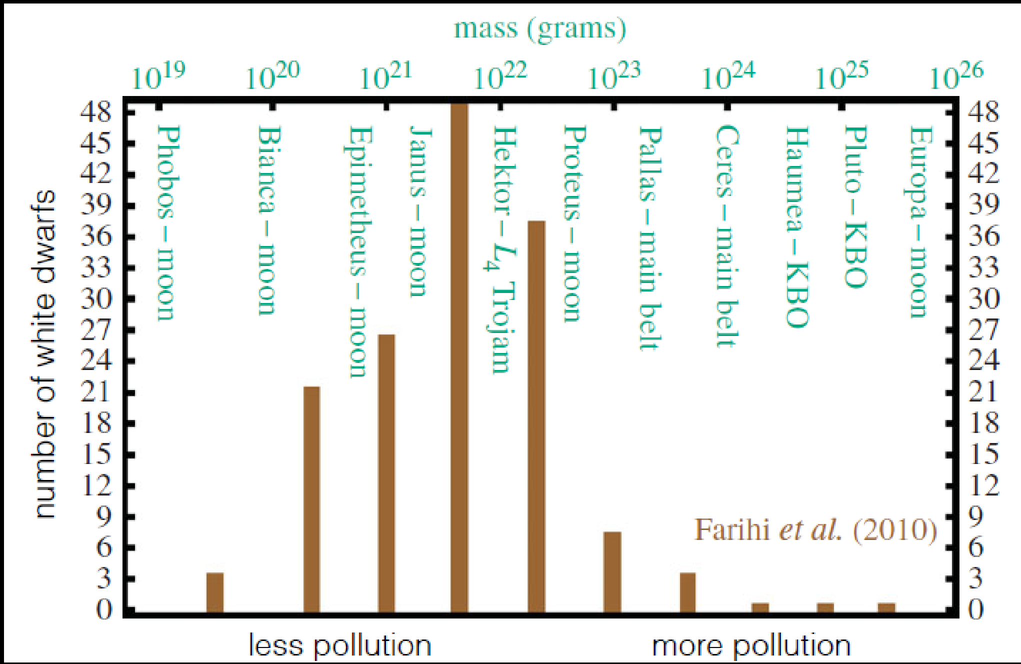


3. WD remnants of ancient planetary systems

Diffusion computations show that the sinking time is much shorter than the evolutionary time-scales, implying that the heavy elements that we see are of extra-stellar origin. Present data and theory strongly suggest that the material falling onto the WD come from a dusty disk formed after the tidal disruption of a minor planet or an asteroid (Jura 2003).



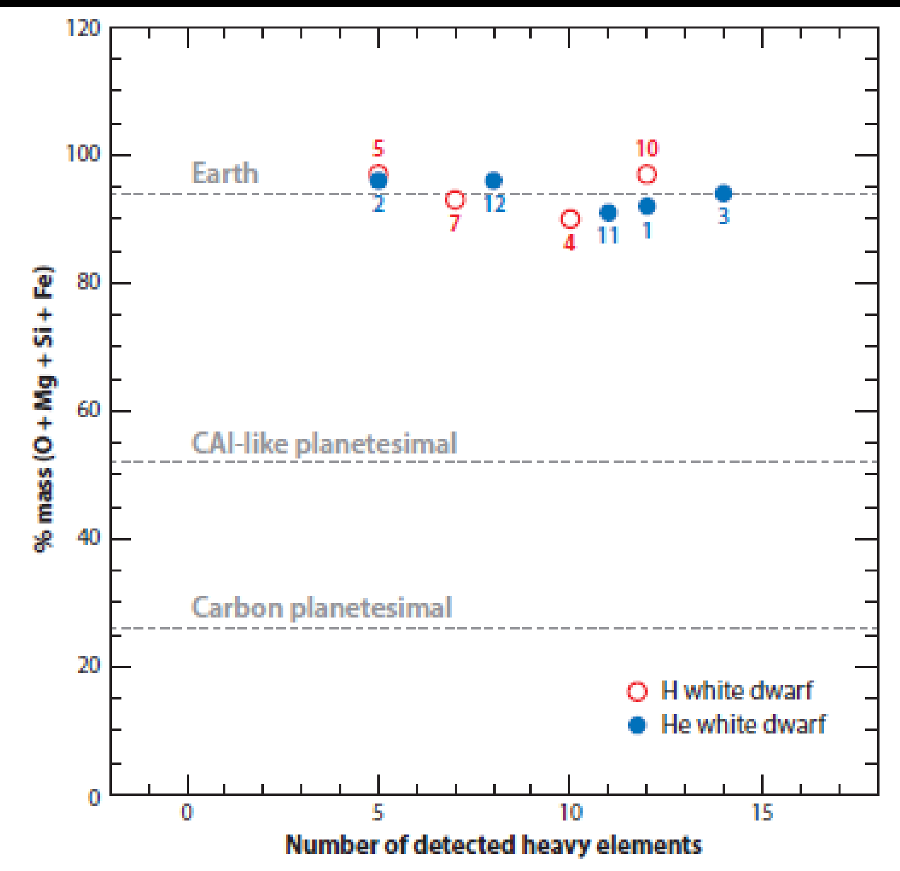
Accumulated mass of rocky substellar bodies accreted onto WDs during the last ≈1 Myr assuming that Ca represents 1.6% of the mass of the accreted bodies, like in the bulk Earth.



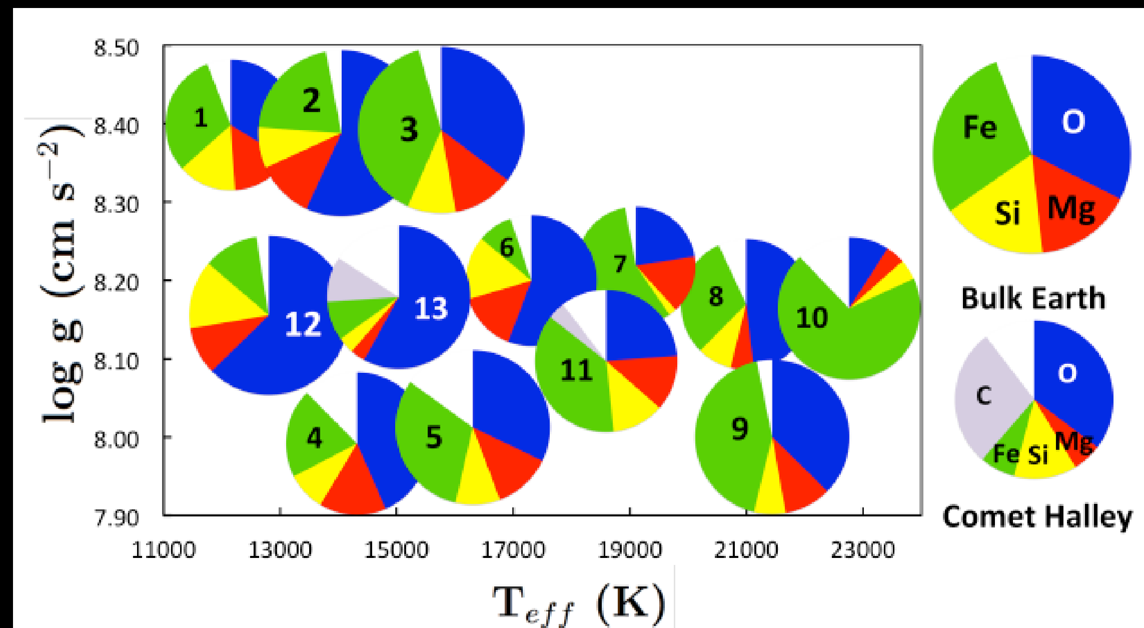
(figures from Veras 2016)

3. WD remnants of ancient planetary systems

The chemical composition of the accreted bodies is very similar to the bulk Earth and other Solar System bodies !!



(Jura & Joung 2014)



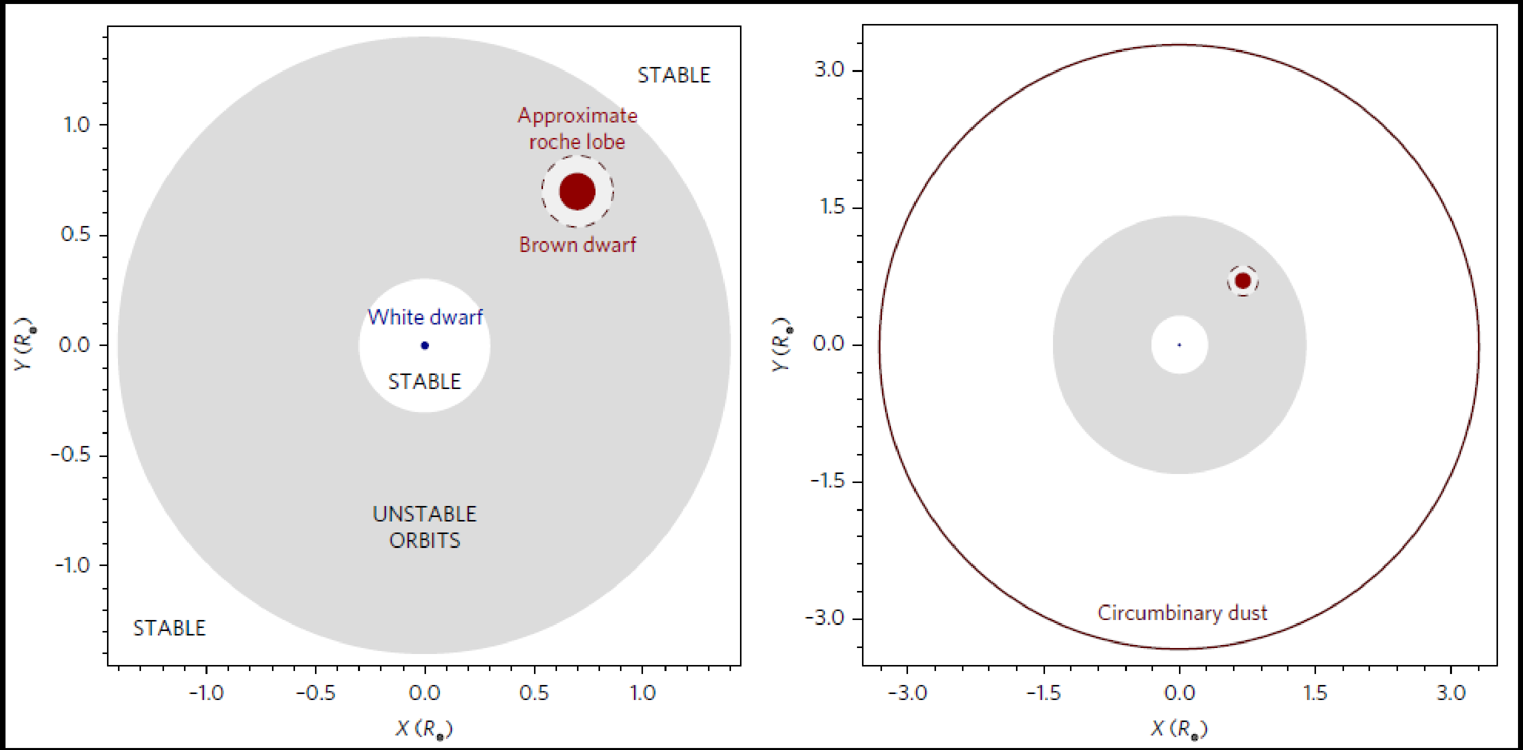
From Siyi Xu 2017, Haifa meeting on «Planetary Systems beyond the MS II»

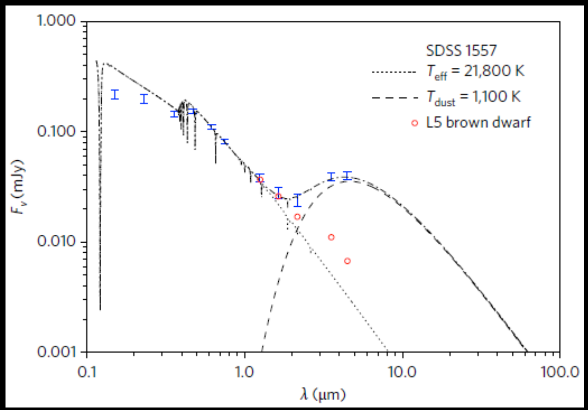
3. WD remnants of ancient planetary systems

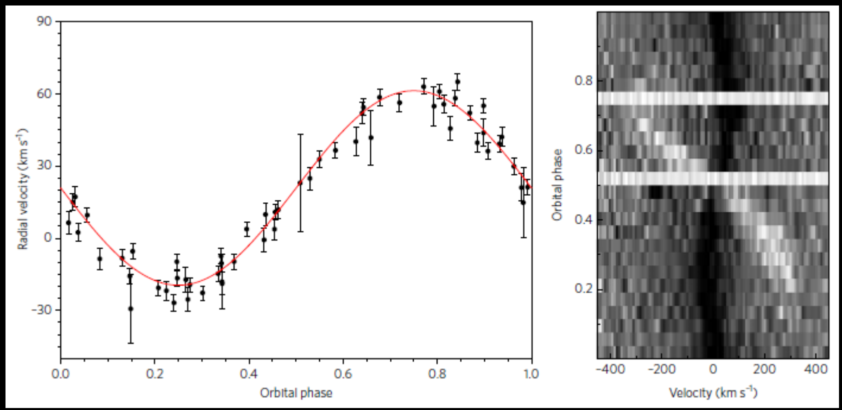
A circumbinary debris disk in a polluted WD+BD binary

WD primary:
SC: DAZ
g=18.4
T_{eff}=22000 K
logg=7.63 (cgs)
M=0.45 M_{SUN}
T_{cool}=33 Myr
d=520 pc

Binary:
P=2.27 h
K_1=40 km/s
K_2=288 km/s
M_2=0.063 M_{SUN}
i=62°
a=0.70 R_{SUN}







Farihi+2017

4. HSD/WD transits: from Kepler/K2 to TESS to PLATO (and LSST)

Results from Kepler/K2 (SC) on:

- **~80 (23+~57) apparently single hot subdwarfs**
- **and ~400 (~10+388 up to C15) mostly single white dwarfs:**

NO planetary transit detections !

but 1 K2 detection of irregular transits in front of WD1145+017 !

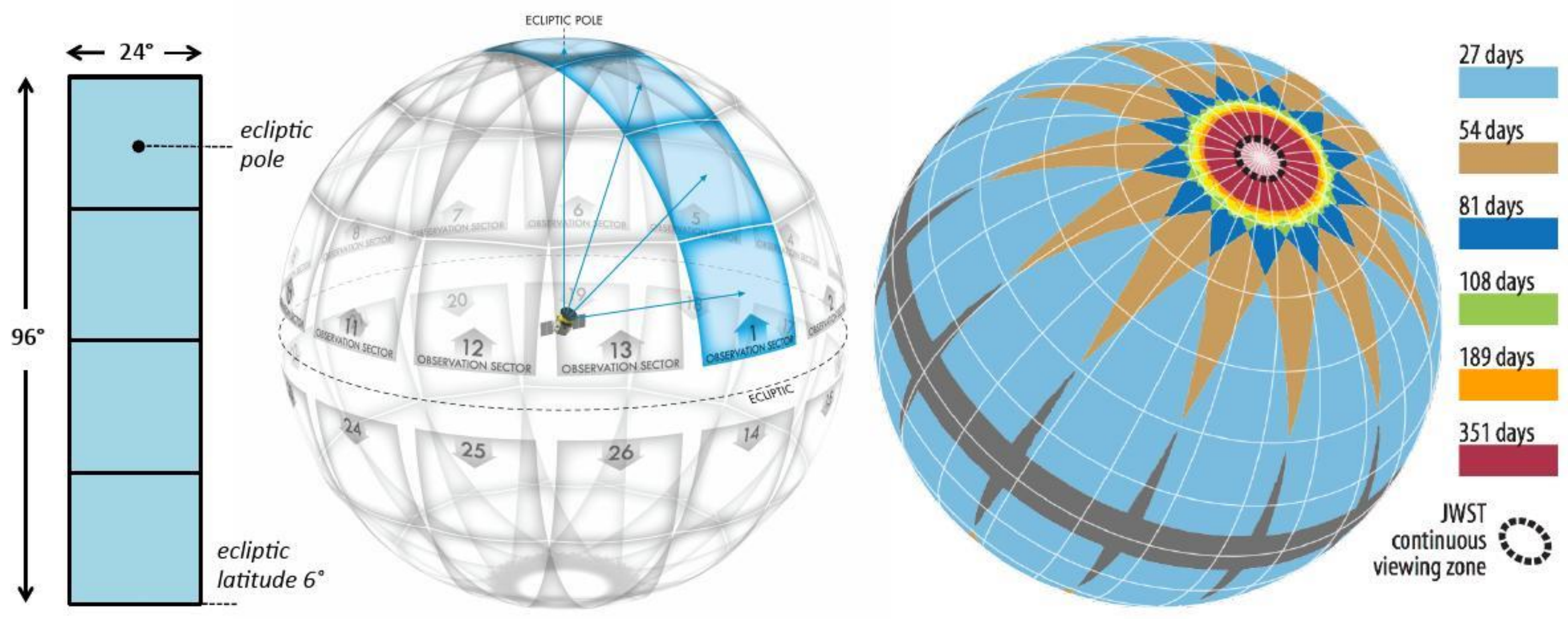
⇒ ***IF* planets in tight orbits around these compact stars exist, they are *NOT* common and we need more statistics**

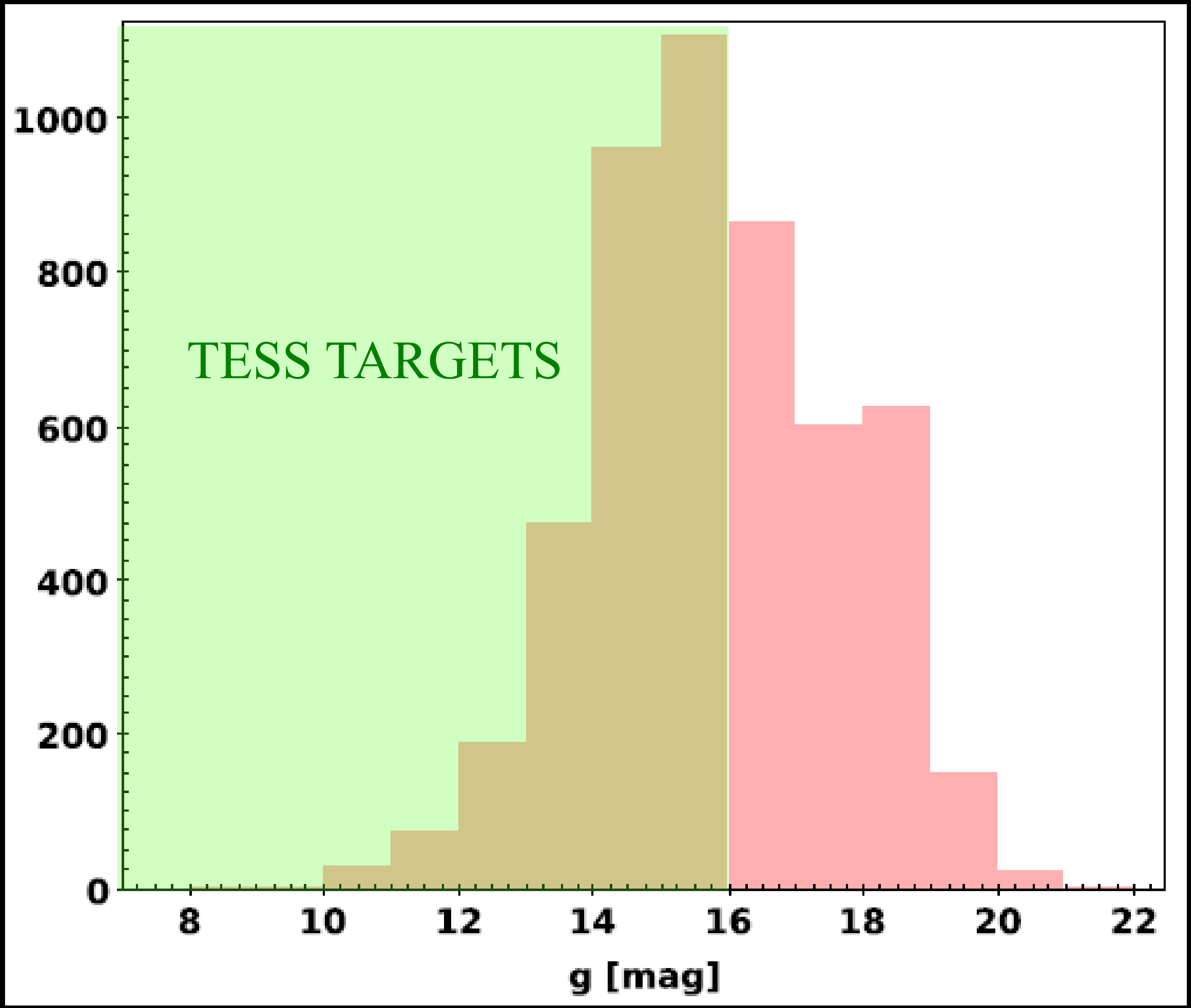
⇒ **TESS** ⇒ **PLATO**

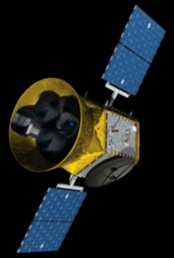
Transiting Exoplanet Survey Satellite

TESS core program: ≈~~200,000~~ 110,000-120,000 preselected stars at 2 min cadence
+ full-frame images at 30 min cadence

TASC (TESS Astero-Seismic Consort.): 1560 targets (60 x pointing) at 20s cadence
+ 19500 targets (750 x pointing) at 2 min cadence



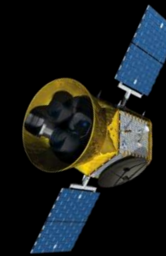




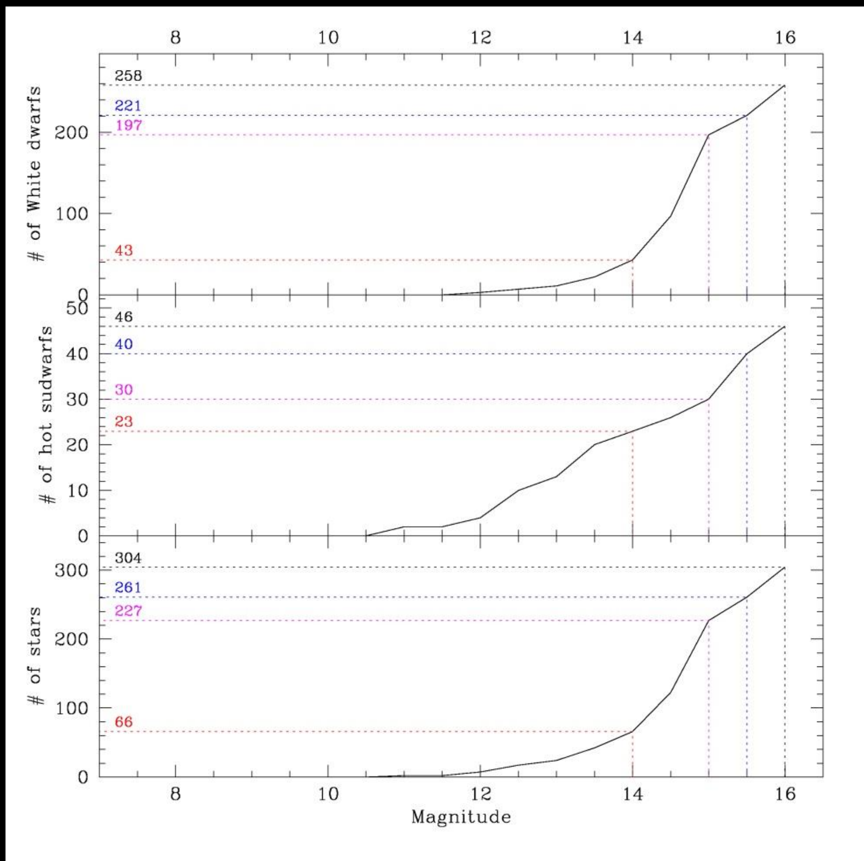
From Geier+2017: the catalogue of known hot subdwarf stars

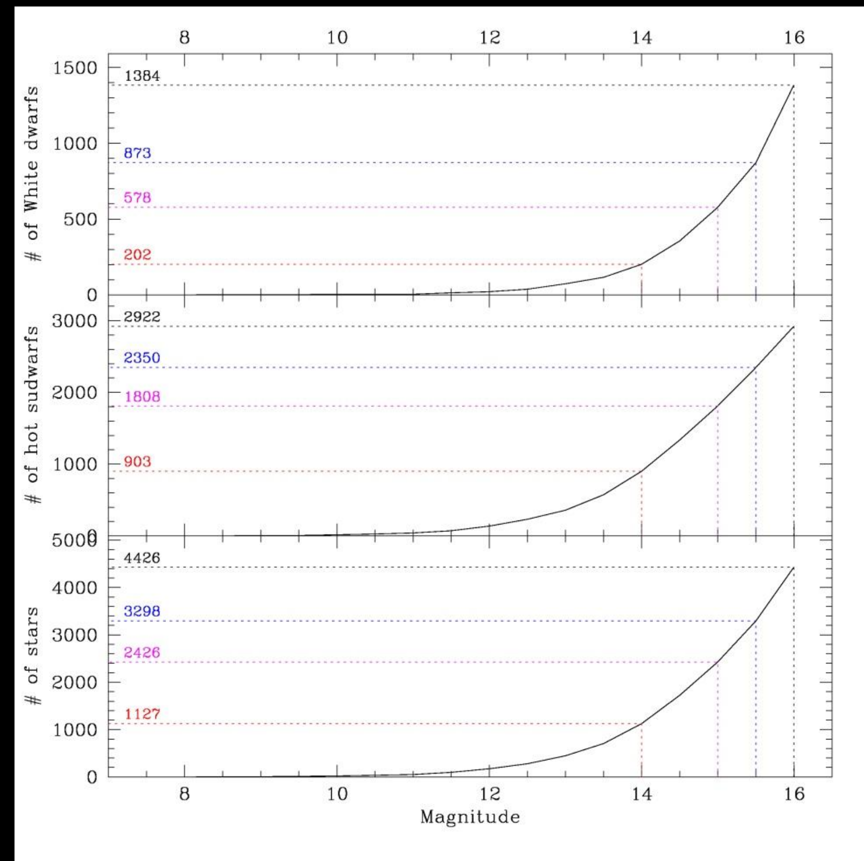
TASC: up to 46+258 SdB/WD pulsators/pulsator candidates at 20s cadence,
+ a number at 2 min cadence

(TASC WG8 on compact pulsators, chairs S. Charpinet & M. Montgomery)



TESS CORE/GI program: search for transits at 2 min cadence on ~3000 HSBs
(TSWG members R. Silvotti & S. Charpinet) and ~1400 WDs (TSWG members JJ Hermes, J. Farihi)

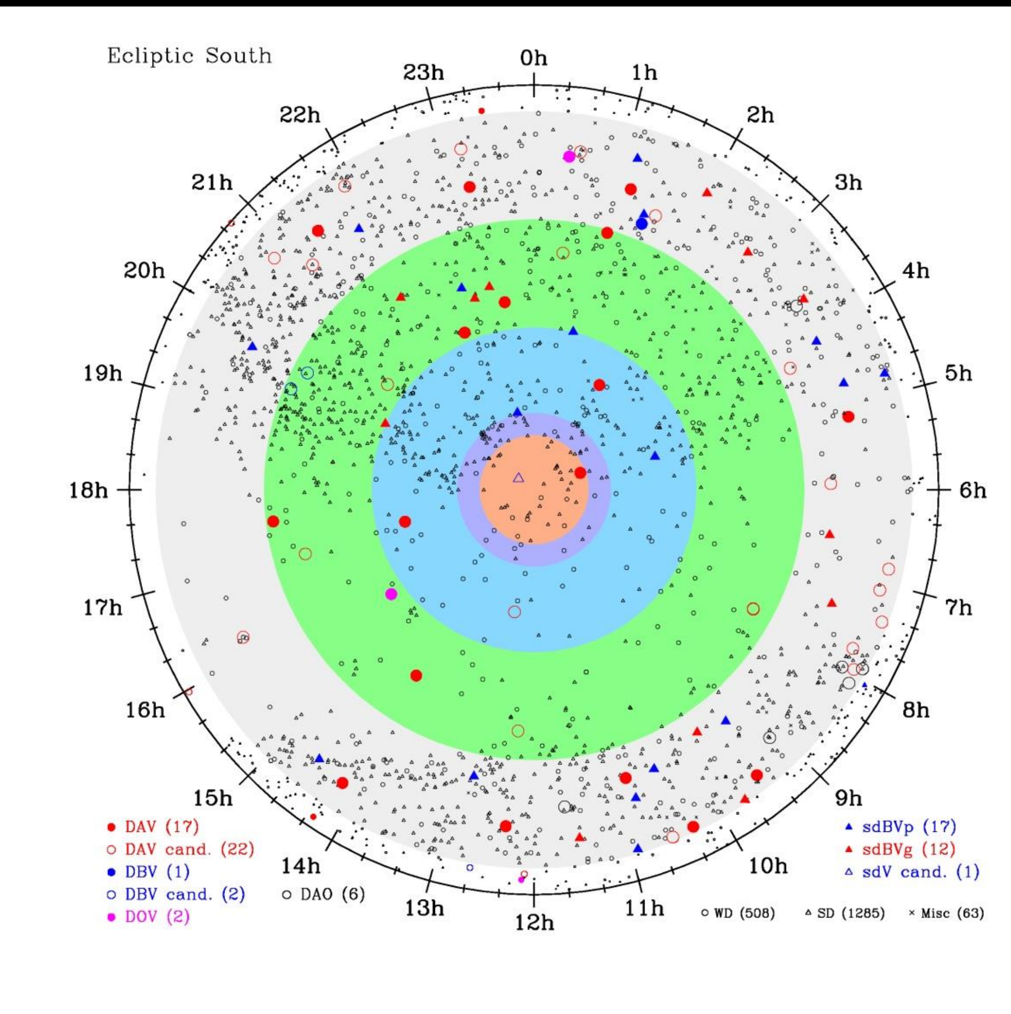


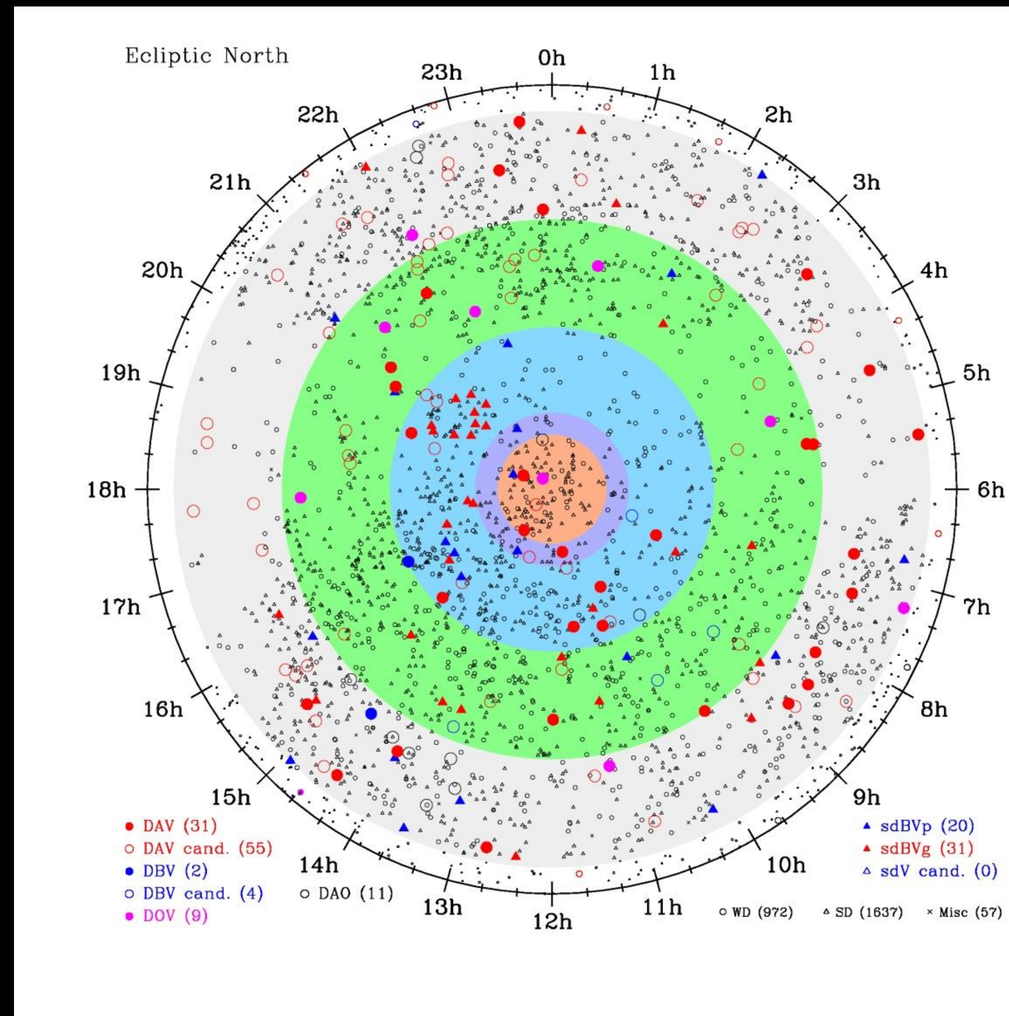


(figures from TASOC WG8 wiki pages, mainteined by S. Charpinet)

Distrbution of the HSD/WD TESS targets in the 2 emispheres

(from TASOC WG8 wiki pages, mainteined by S. Charpinet)





4. HSD/WD transits: from Kepler/K2 to TESS to PLATO (and LSST)

Why Kepler/K2 has not found any WD planetary transit yet ?

How many WDs should be observed to see one transit ?

- Assuming a 1% rate of MS planets with P_{orb}<200 d (in order to enter the RG envelope) and M>10 M_J (in order to survive the common envelope (CE) phase)
- and considering a transit probability of 0.1, corresponding to an orbital distance of 0.005 AU (or ≈1 R_{SUN}) after the CE phase

→ **we need to observe ≈1000 WDs to catch 1 transit**

This number is about 2x the total number of WDs that will be observed by Kepler/K2 at the end of the mission and is about equal to the number of WDs that can be observed by TESS.

TESS as a poorer sampling than K2 (2 min vs 1 min) but should have cleaner data.

Larger statistics can be obtained only by PLATO or LLST.

LSST can observe up to ≈170,000 WDs with G<20 that will be discovered by Gaia with ≈800 photometric measurements in 10 yrs at random times.

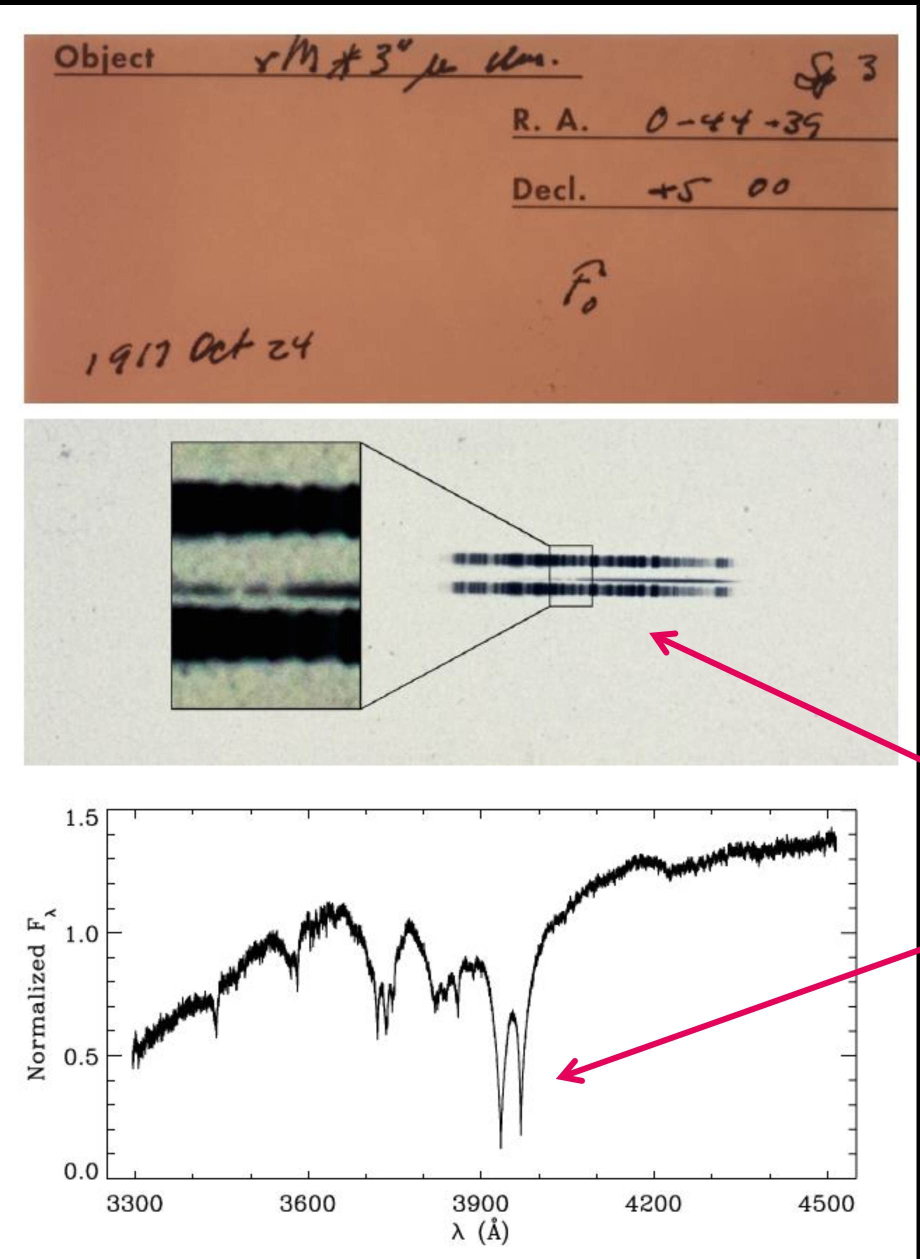
PLATO has the advantage of a regular and continuous sampling.

4. HSD/WD transits: from Kepler/K2 to TESS to PLATO (and LSST)

Concerning HSDs, if massive planets actually played a role in removing the envelope of today~apparently~single HSDs, the statistics of close massive planets/planetary remnants might be more favorable respect to the WDs .

→ ≈1000 likely single HSDs observed by TESS
(compared with ~80 these stars observed by Kepler/K2)
could make the difference !

My last slide



100 years ago: the first (indirect) evidence that exoplanetary systems exist !!

Spectrum of vMa2 (van Maanen 1917),

the nearest single WD to Earth,

showing the Ca II doublet «pollution»

(Zuckerman 2015, figure from Farihi 2016)

CaII doublet (van Maanen 1917)

CaII doublet on same star with UVES (SPY project, Napiwotzki+2003)

Grazie dell'attenzione !