Exoplanets around (very) evolved stars

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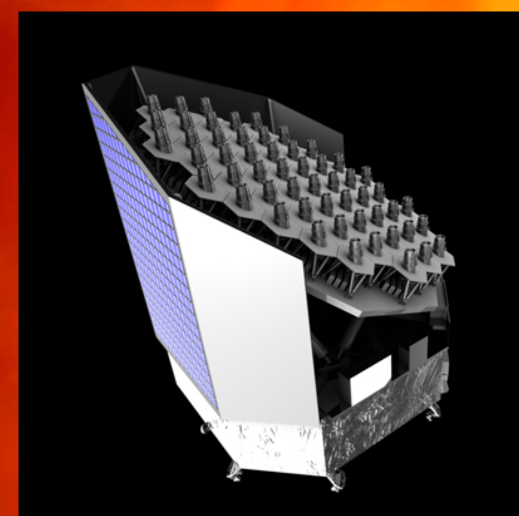


PLATO 2.0 Science Workshop, ESA-ESTEC, 29-31/07/2013

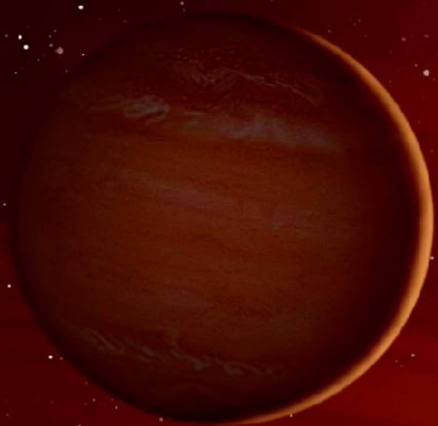
Outline

- post-RGB sub-stellar companions: model predictions
- detection methods and current observational results
- (WD) and sdB planets: from Kepler to PLATO

one of the PLATO goals is

"How do planets and systems evolve"

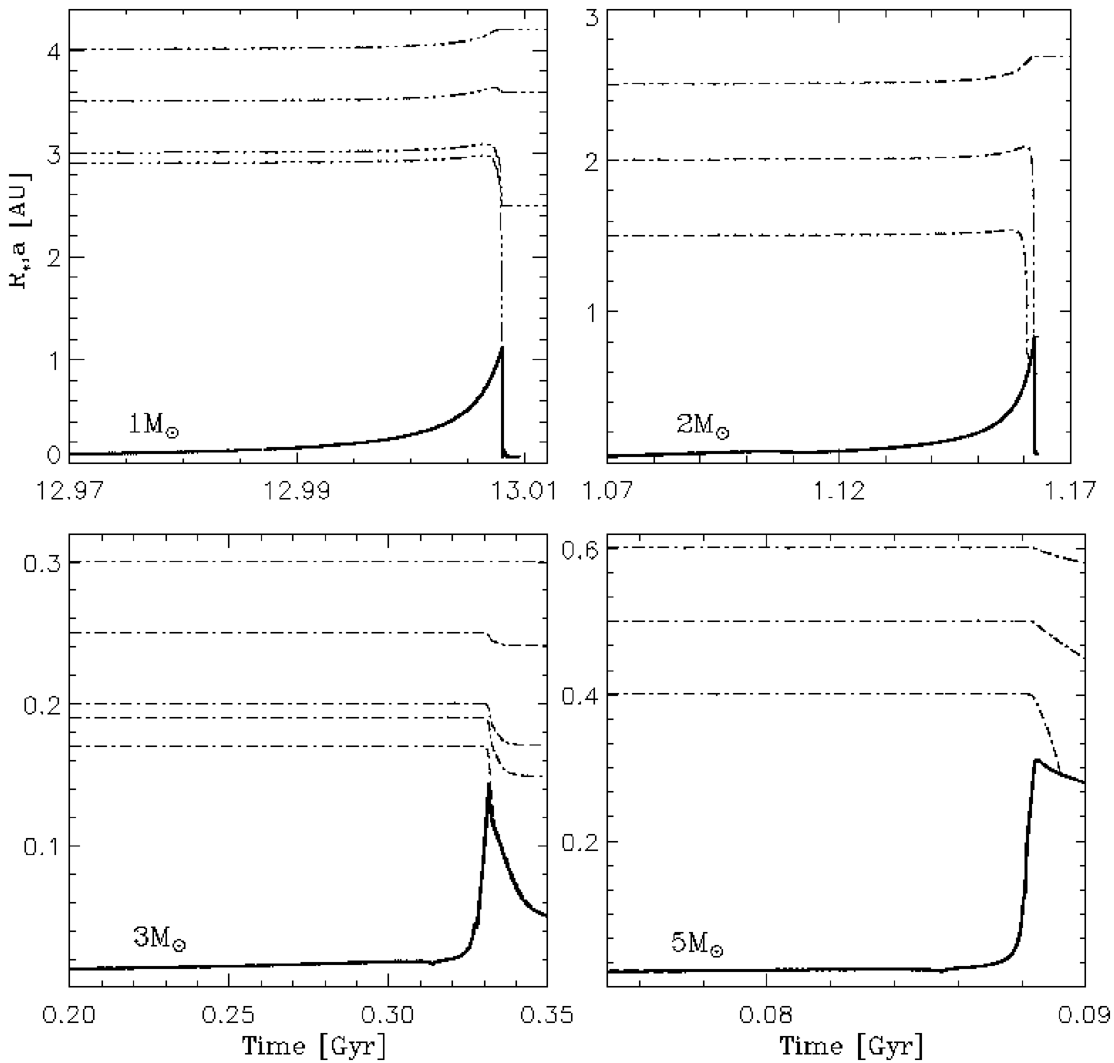
1) What happens to the planets during and after the red-giant-branch ?



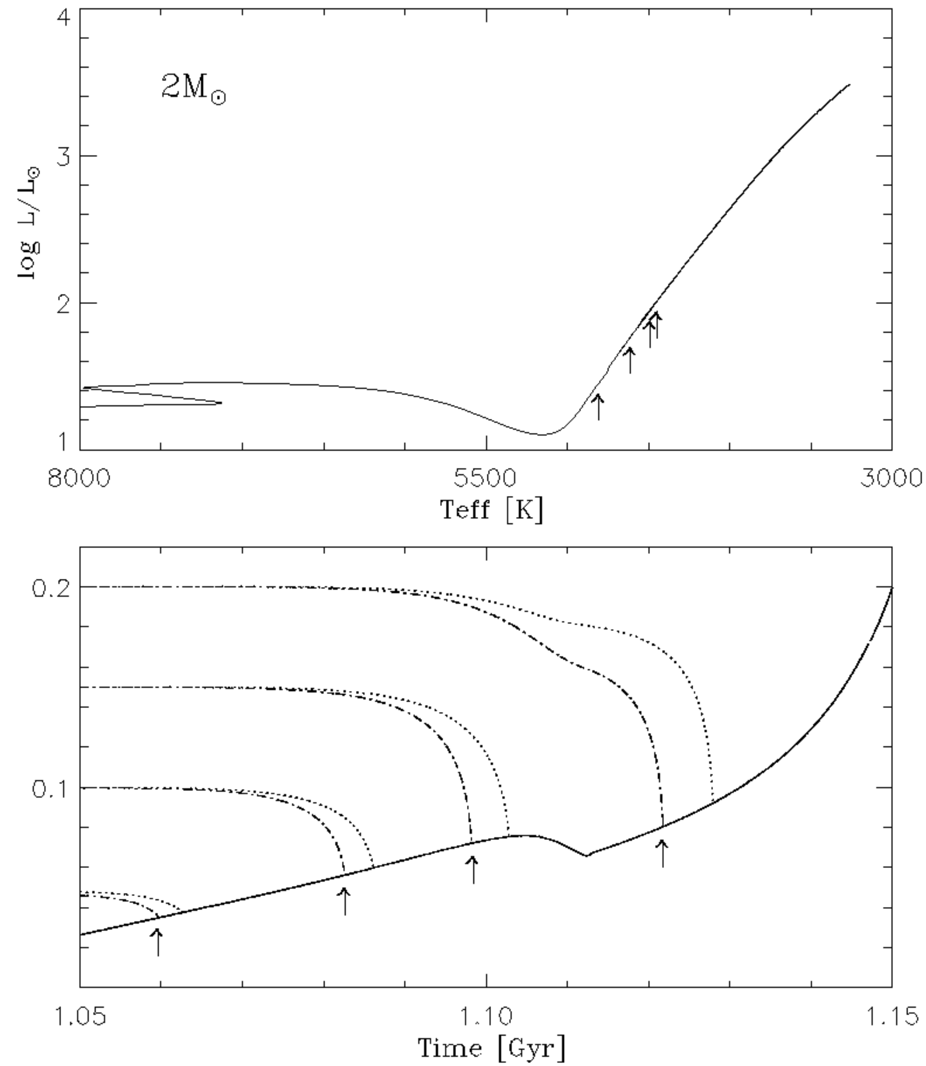
let's see some model predictions …

Orbital evolution of gas giant planets around giant stars

(Villaver & Livio 2009, ApJ 705, L81)

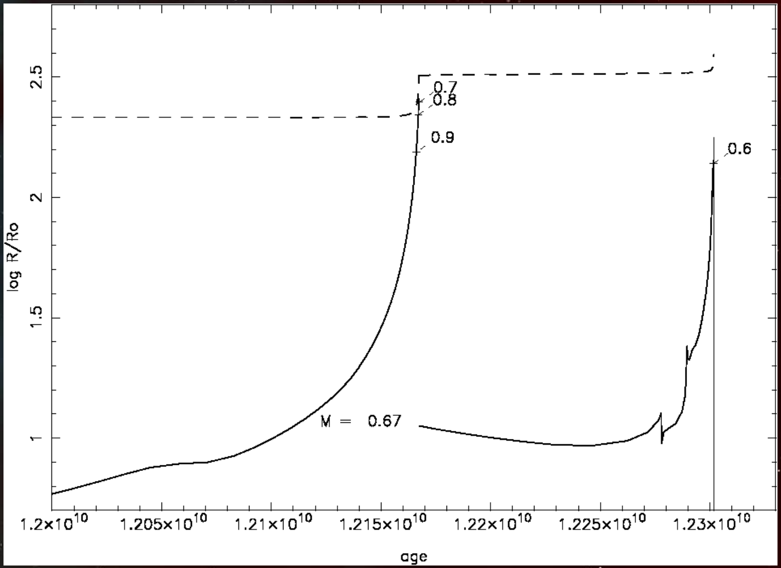


M_p=1 M_J

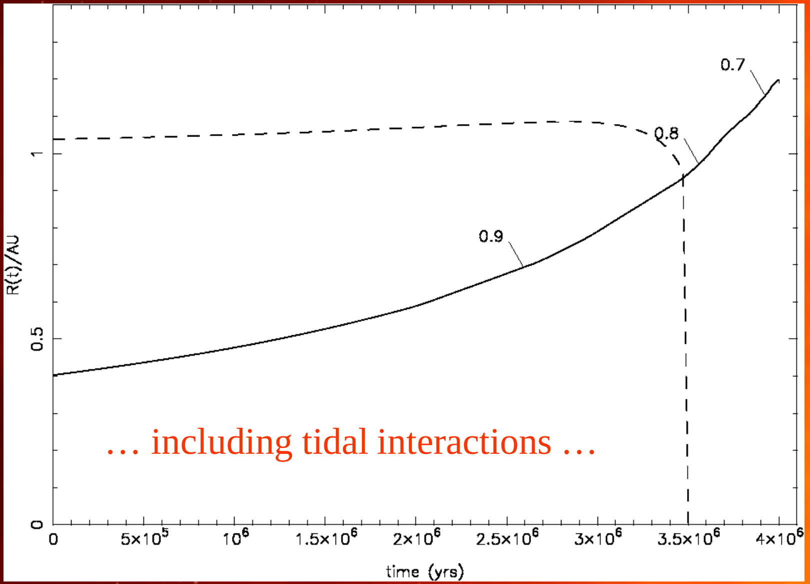


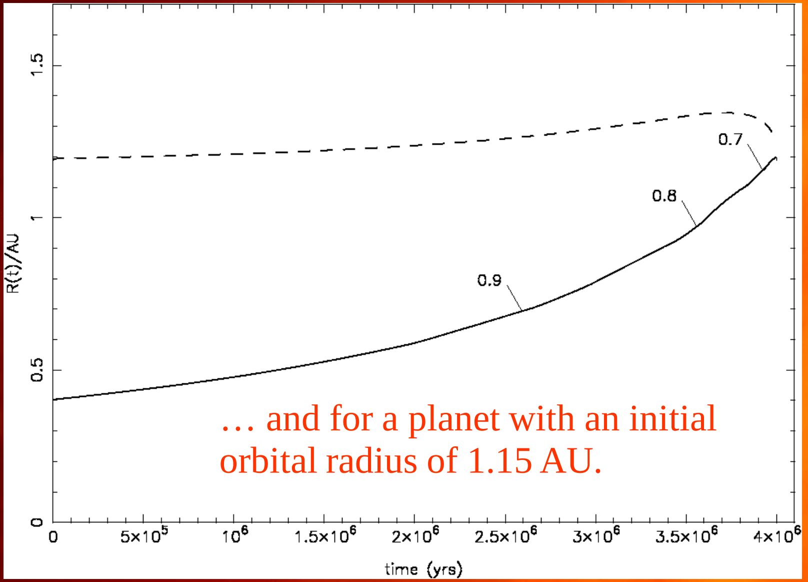
M_p= 3 M_J (dotted line)

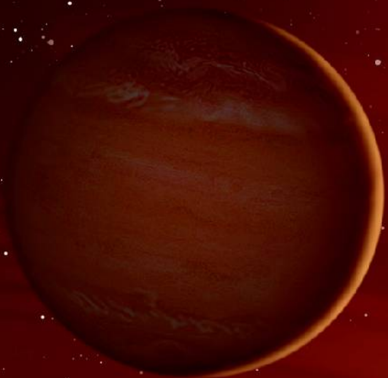
M_p= 5 M_J (dash-dotted line)



Solar radius evolution during RGB and AGB. Dashed curve: Earth orbital radius taking into account solar mass loss only. The labels show the mass of the Sun in units of its present-day mass.





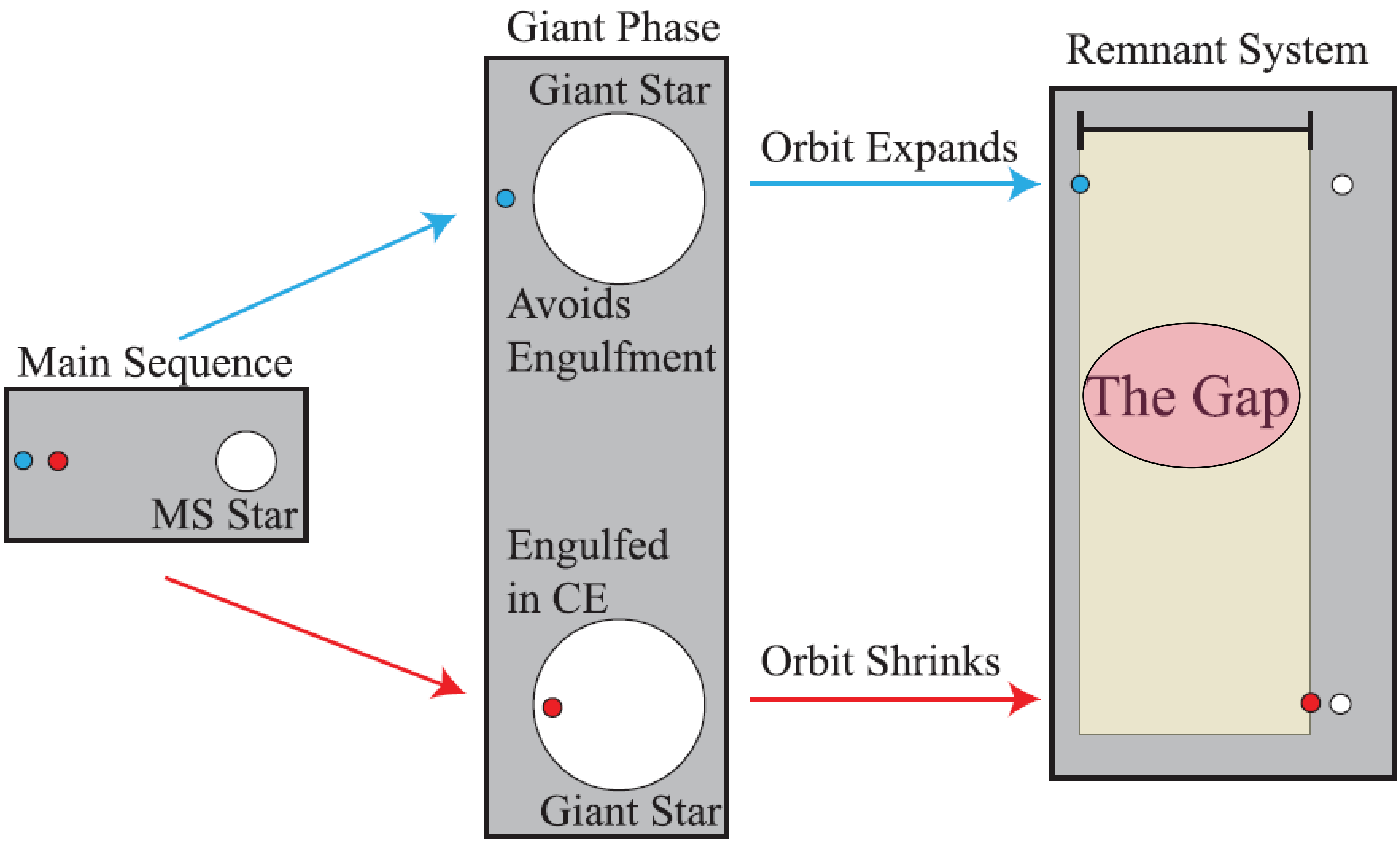


Schröder & Connon Smith (2008, MNRAS 386, 155) :

1) The closest Earth-Sun encounter will occur during the tip-RGB expansion, 7.6 Gyr from now, and not during the lower-size tip-AGB phase, as previously believed.

2) The Earth will not be able to escape engulfement.

3) In order to survive the solar RGB phase, any hypothetical planet would require a present-day orbital radius >~1.15 AU.

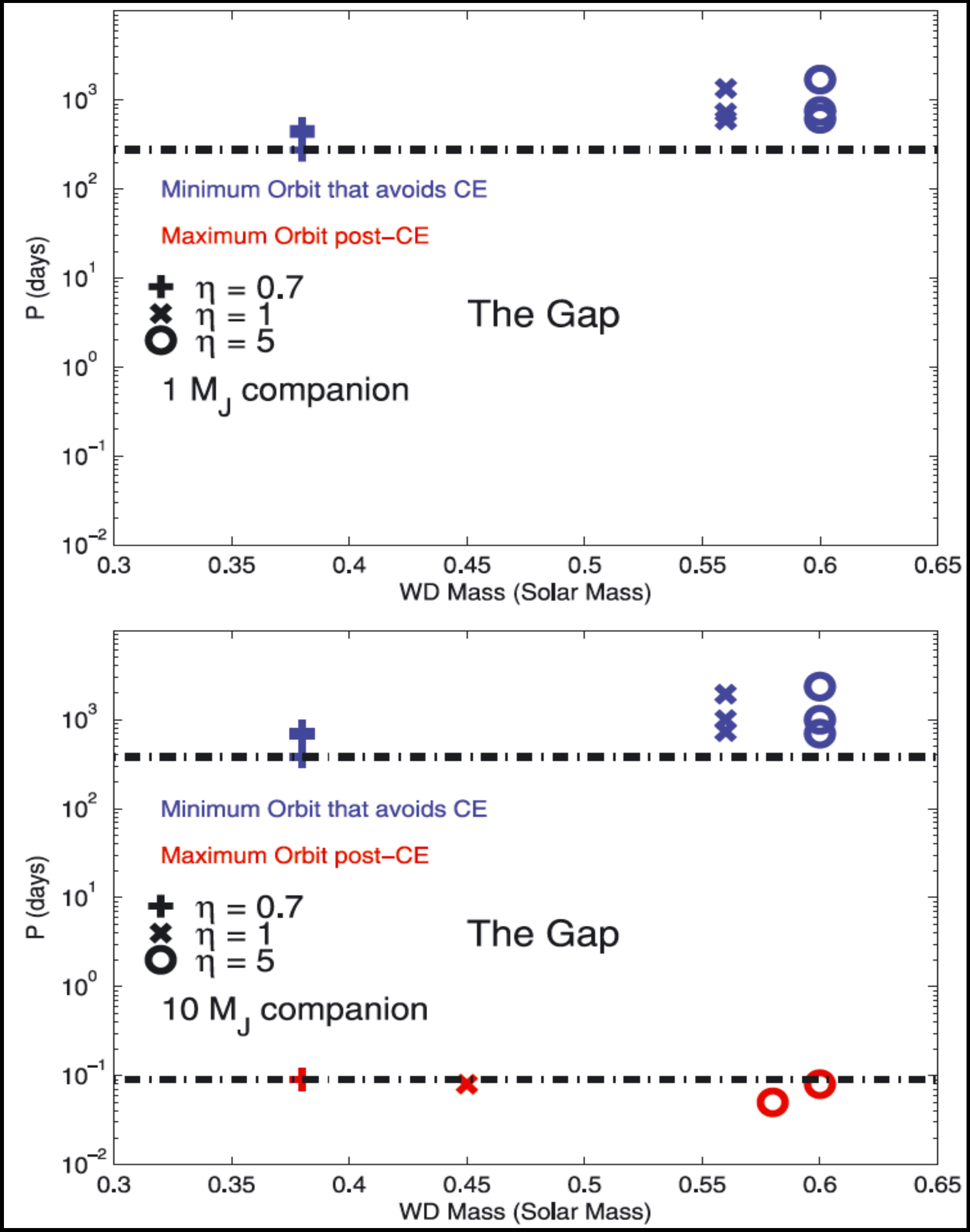


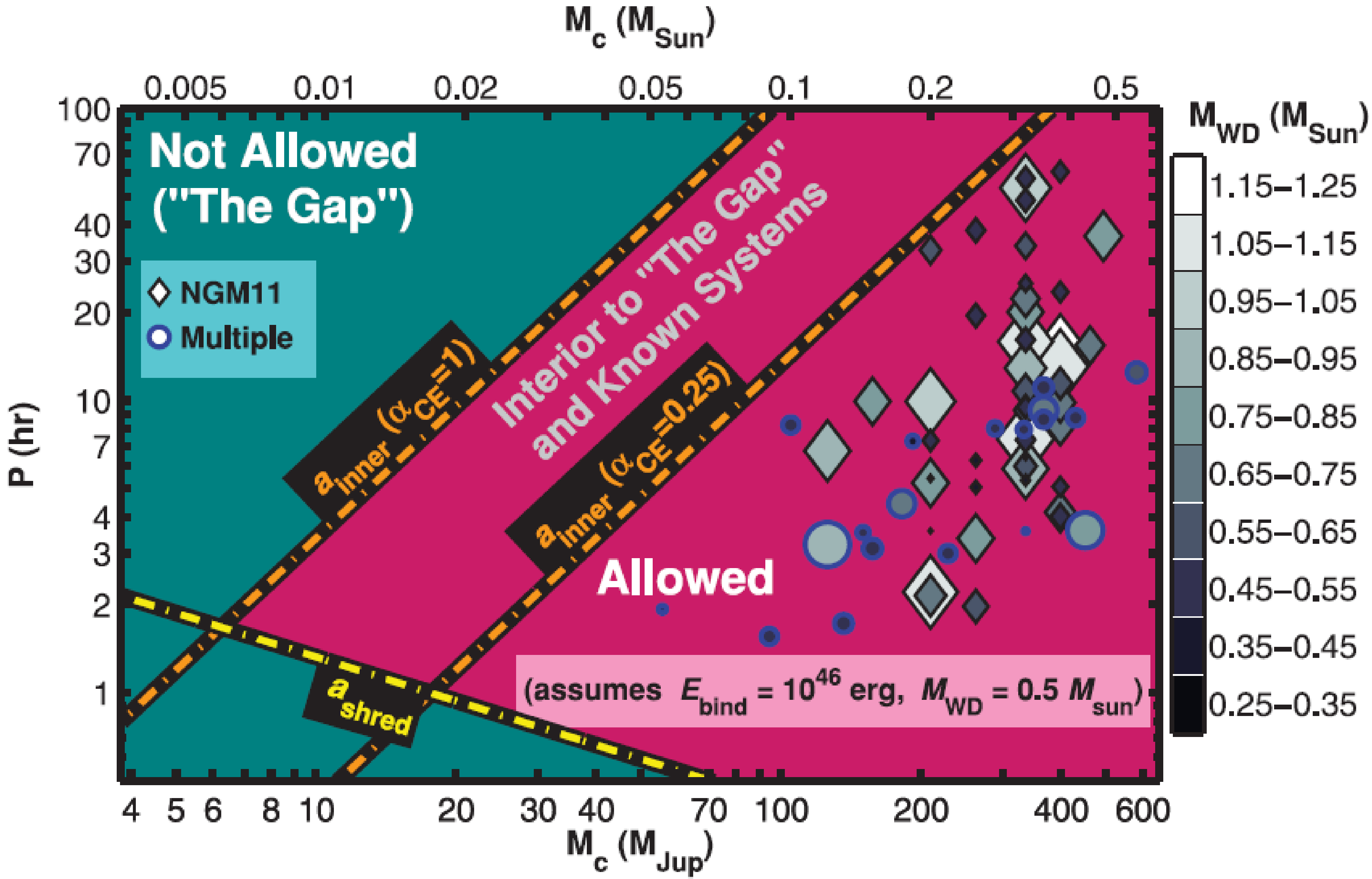
Nordhaus & Spiegel 2013

Period gaps for Planets and Brown Dwarfs around White Dwarfs

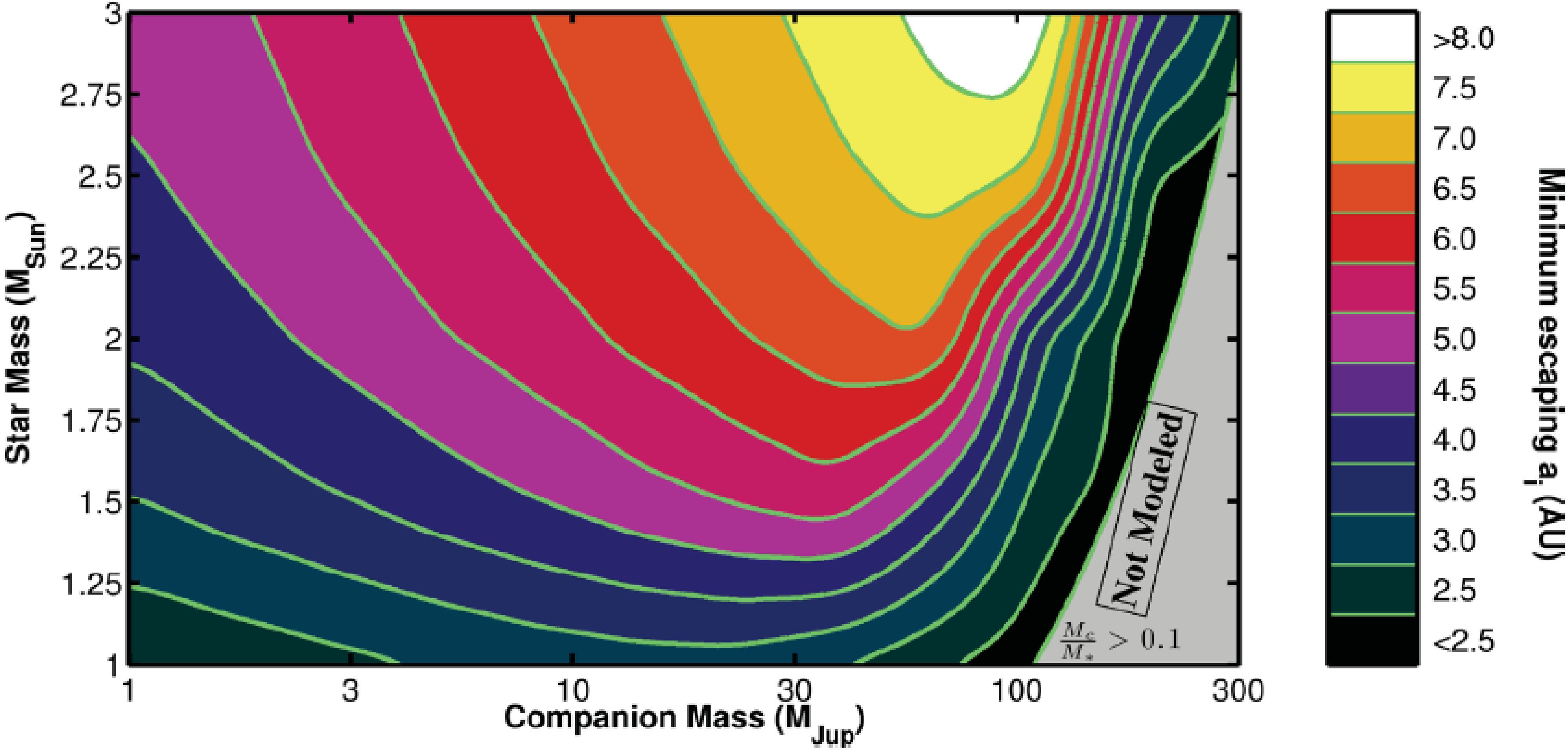
Nordhaus et al. 2010 →

Figure 8. The predicted period gaps for a 1 $M_\odot$ progenitor with $1 M_J$ (top) and $10 M_J$ (bottom) companions. The symbols represent different Remiers η values for the various tidal prescriptions listed in Table 2. For the $1 M_J$ system, no companion survives CE evolution. Thus, we predict a paucity of $1 M_J$ companions with periods $\lesssim$270 d. For the 10 $M_\odot$ system, several companions survive CE evolution and are located in short-period orbits. The predicted period gap occurs between ~0.1 and 380 d.





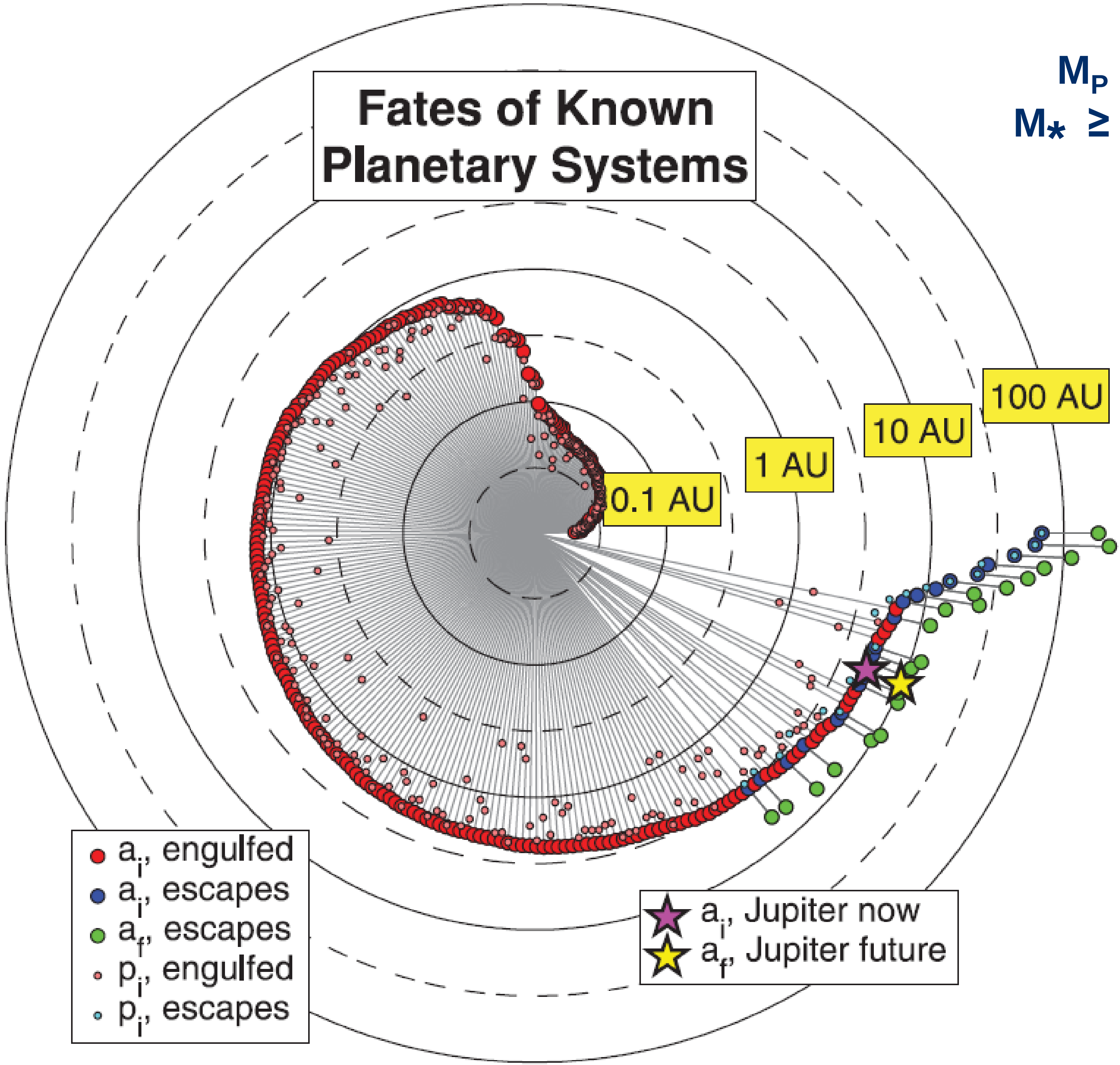
Nordhaus & Spiegel 2013



Nordhaus & Spiegel 2013

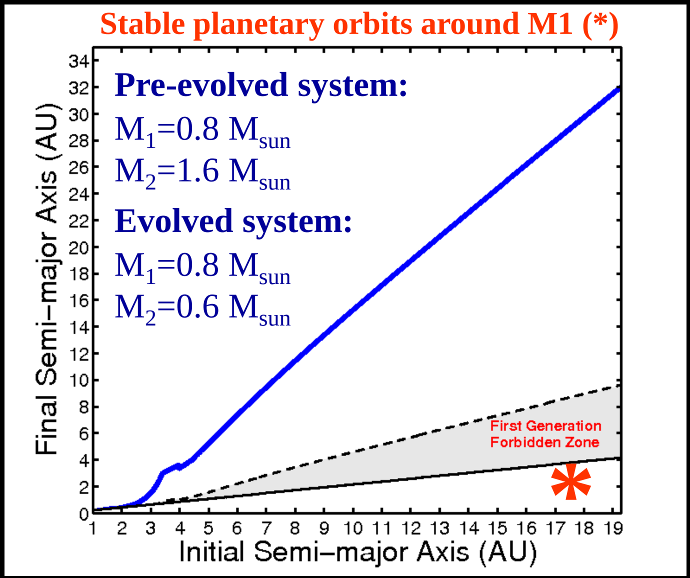
$M_P \geq M_J$

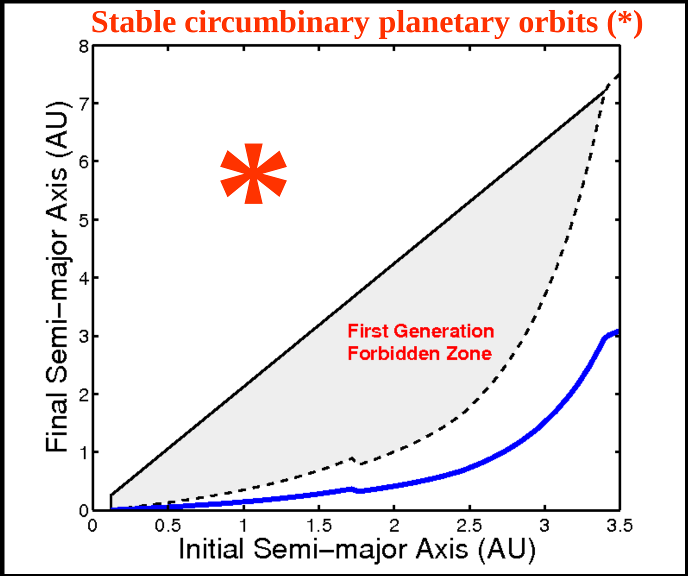
$M_* \geq 1\ M_{SUN}$

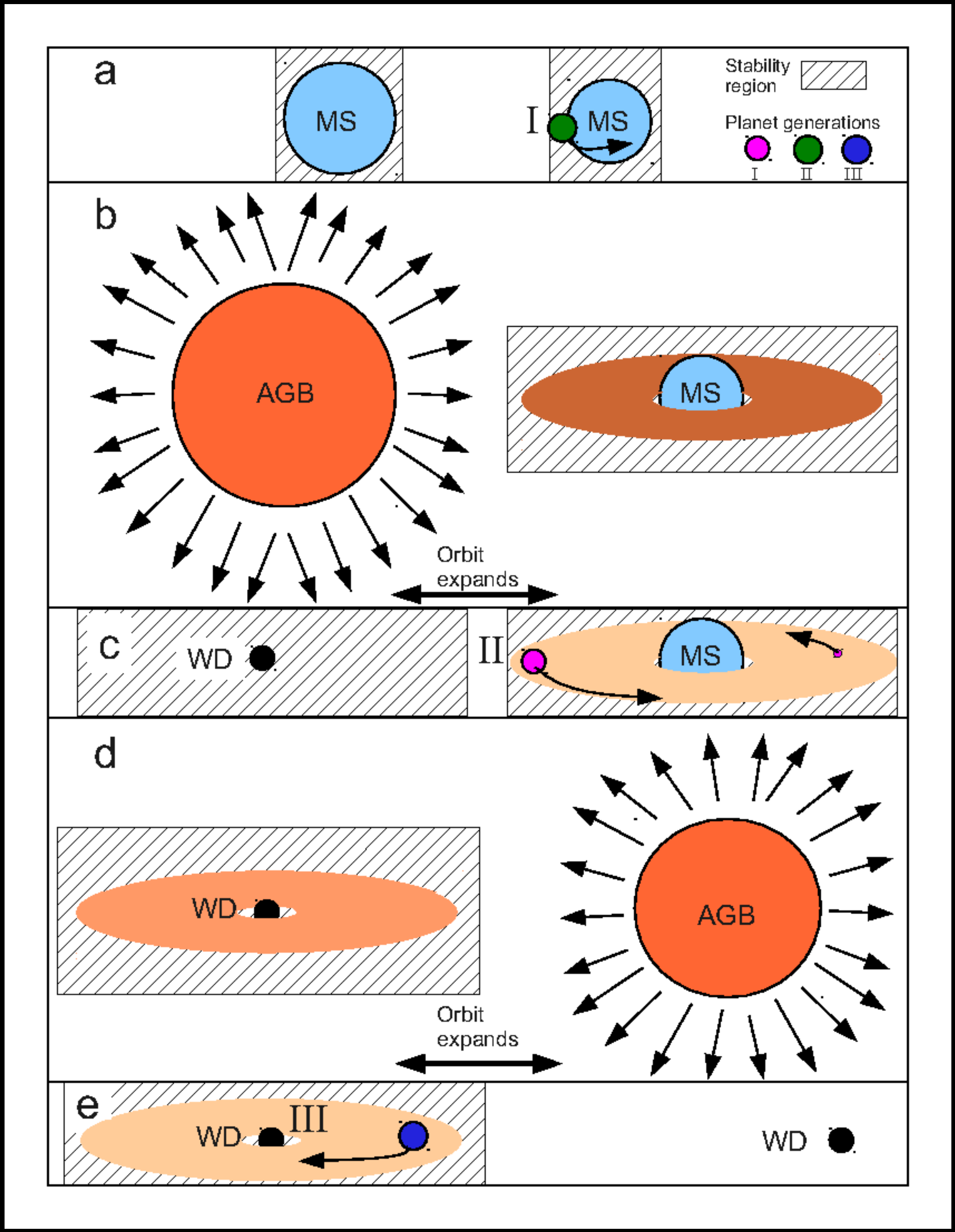


Nordhaus & Spiegel 2013

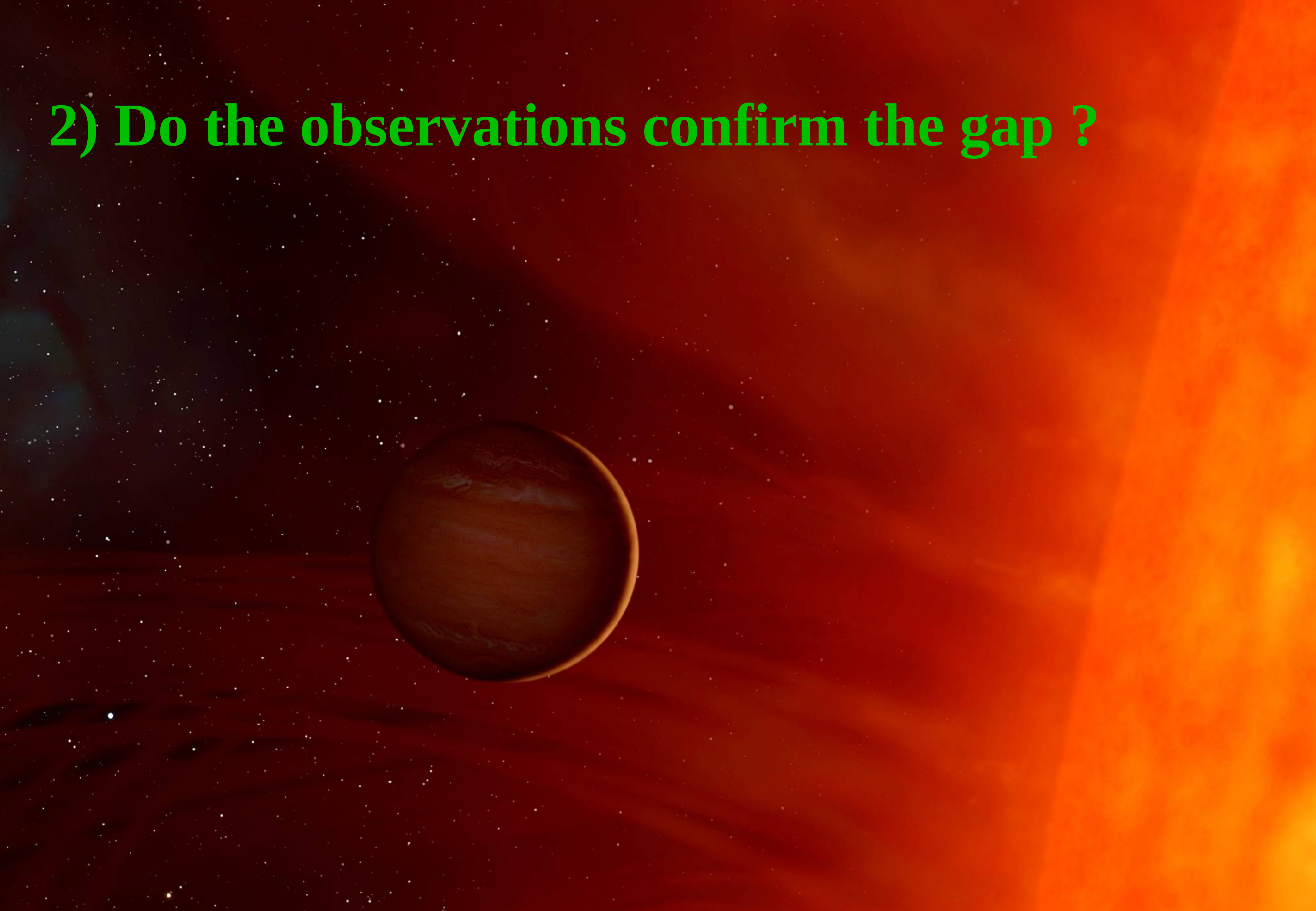
2^d generation planets
(Perets 2011, AIPC 1331, 56)







2) Do the observations confirm the gap ?



Post-RGB compact star's planet candidates

Planet name	M sin$i$/M$_J$	a/AU	P/yr	e	Stellar evolut. phase	Detect. method	References
PSR 1257+12 b PSR 1257+12 c PSR 1257+12 d	M≅6 e-5 M≅0.014 M≅0.012	0.19 0.36 0.46	25.262 d 66.5419 d 98.2114 d	0 0.0186 0.0252	pulsar	radio timing radio timing radio timing	Wolszczan & Frail 1992 Konacki & Wolszczan 2003
PSR B1620-26 b	2.5	23	100		pulsar+WD in GC	radio timing	Thorsett et al. 1994 Sigurdsson et al. 2003
PSR 1719-14	~1	0.0004	0.0907 d	<0.06	pulsar	radio timing	Bailes et al. 2011
WD0137-349 b	M≅55	0.375 R_{sun}	1.927 h		WD	RVs	Maxted et al. 2006
GD356 ?	M<12		>2.7 h		magnetic WD	inferred from Zeeman splitting	Wickramasinghe et al. 2010
V391 Peg b	3.2	1.7	3.2	0	EHB (puls. sdB)	pulsation timing	Silvotti et al. 2007
HS0444+0458 ?	31	0.27	72 d		EHB (puls. sdB)	pulsation timing	Lutz 2011
HS0702+6043 ?	5.6	1.15	1.8		EHB (puls. sdB)	pulsation timing	Lutz 2011
HW Vir b HW Vir c	14.3 65	4.7 12.8	12.7 55	0.40 0.05	EHB (ecl. sdB+dM)	eclipse timing eclipse timing	Lee et al. 2009, 2010 Camurdan et al. 2012 Beuermann et al. 2012b
HS0705+6700 b	31.5	3.5	8.4	0.38	EHB (ecl. sdB+dM)	eclipse timing	Qian et al. 2009a Beuermann et al. 2012a
NY Vir	2.3	3.3	7.9	0	EHB (ecl. sdBV+dM)	eclipse timing	Qian et al. 2012a
NSVS14256825 ?	12	6.3	20	0.5	EHB (ecl. sdB+dM)	eclipse timing	Beuermann et al. 2012a
KIC 05807616 b KIC 05807616 c	M≅0.4 M_E ? M≅0.7 M_E ?	1.29 R_{sun} 1.64 R_{sun}	5.76 h 8.23 h	0 0	EHB (puls. sdB)	illumination	Charpinet et al. 2011
KIC######## b KIC######## c KIC######## d	M< 30 M_E M< 30 M_E M< 1 M_J	1.19 R_{sun} 1.55 R_{sun} 2.84 R_{sun}	5.3 h 7.8 h 19.5 h	0 0 0	EHB (puls. sdB)	illumination	Silvotti et al. 2013 (to be submitted soon)
HIP 13044 b	1.25	0.116	16.2 d	0.25	RHB (extragal. orig.?)	RVs	Setiawan et al. 2010
NN Ser b NN Ser c	6.9 2.3	5.4 3.4	15.5 7.7	0 0.2	pre-CV (ecl.WD+dM)	eclipse timing eclipse timing	Qian et al. 2009b Beuermann et al. 2010 Hessman et al. 2010
RR Cae	4.2	5.3	11.9	0	ecl. WD +dM	eclipse timing	Qian et al. 2012b
DP Leo b	6.05	8.2	28.0	0.39	CV (eclips. polar)	eclipse timing	Qian et al. 2010a Beuermann et al. 2011
QS Vir b	M≅6.65	4.2	7.86	0.37	CV (hybernat. ecl.)	eclipse timing	Qian et al. 2010b
HU Aqr b HU Aqr c	5.9 4.5	3.6 5.4	6.5 12.0	0 0.51	CV (eclips. polar)	eclipse timing eclipse timing	Qian et al. 2011

Planets orbiting wide WD+MS binaries are not included (at least 3 such systems exist, Desidera e Barbieri 2007).
A few post-RGB BDs of particular interest are included (but the list of post-RGB BDs is not complete).

Post-RGB planets: detection methods (1)

RVs

pros: low-mass stars ▶ higher RVs

cons: high gravity means broad H/He lines, few metal lines, needs bright stars!

detectable planets: close orbits and massive, down to ≈10 M_J (?)

detected planets: ~5 sdB BDs close to the BD upper mass limit

➡ (Geier et al. 2012), 1 RHB planet (Setiawan+2011), 1 WD BD

Transits

pros: small star radii ▶ strong transit depth

cons: small star radii ▶ small transit probability

detectable planets: close orbits, down to Earth size and less

detected planets: no planets found around 194 WDs from WASP (Faedi+2011)

➡ **less than 10% of WDs have R_{Jup} companions with P_{ORB}<0.1-0.2 d**

Post-RGB planets: detection methods (2)

Timing (pulsation or eclipse timing)

pros: sensitive to large orbital distances

cons: false detections are a concern (e.g. Applgate's mechanism)

detectable planets: large orbits, mass $\gtrsim 1\ M_J$

detected planets: 7 sdB planets through pulsation (3, Silvotti+2007, Lutz 2011) or eclipse timing (4, Lee+2009; Qian+2009a, 2011a); 7 CV/pre-CV planets through eclipse timing (Qian+2009b, 2010a, 2010b, 2011b, 2012; Beuermann 2010a, 2010b)

Illumination

pros: can detect Earth-size planets in close orbits even at relatively low inclinations

cons: need high-quality space phot. (Kepler), many unknown parameters, (albedo, dark/heated hemisphere. temp. ratio), radii or masses are not directly measured

detectable planets: very close orbits, down to Earth size, **only** around very hot stars

detected planets: 5 sdB planets (Charpinet+2011, Silvotti+2013)

Post-RGB planets: detection methods (3)

IR AO imaging (from 8m class to JWST and EELT)

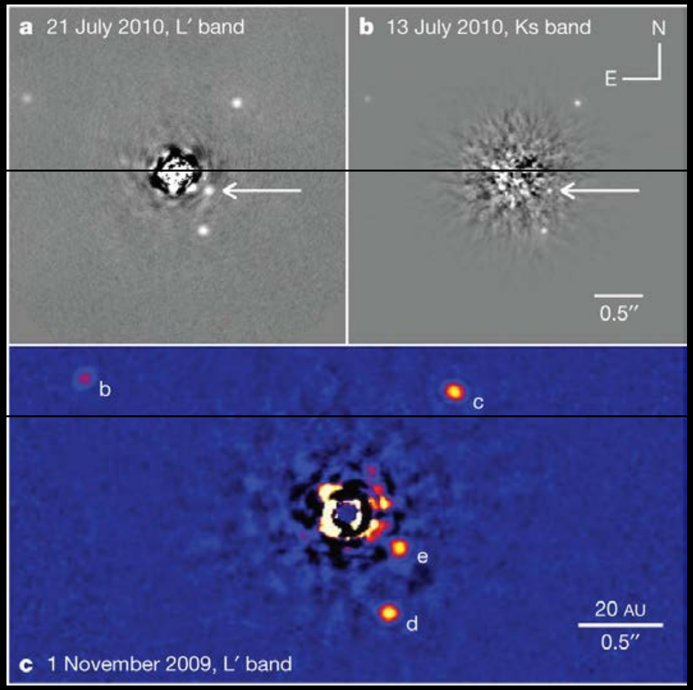
pros: sensitive to large orbital distances

cons: efficient only for young (2° generation) planets

Astrometry:

see slides on GAIA later on this talk

The 4 planets of the young MS γ Dor star HR8799 (t<100 Myr d=39 pc, Marois+2009)



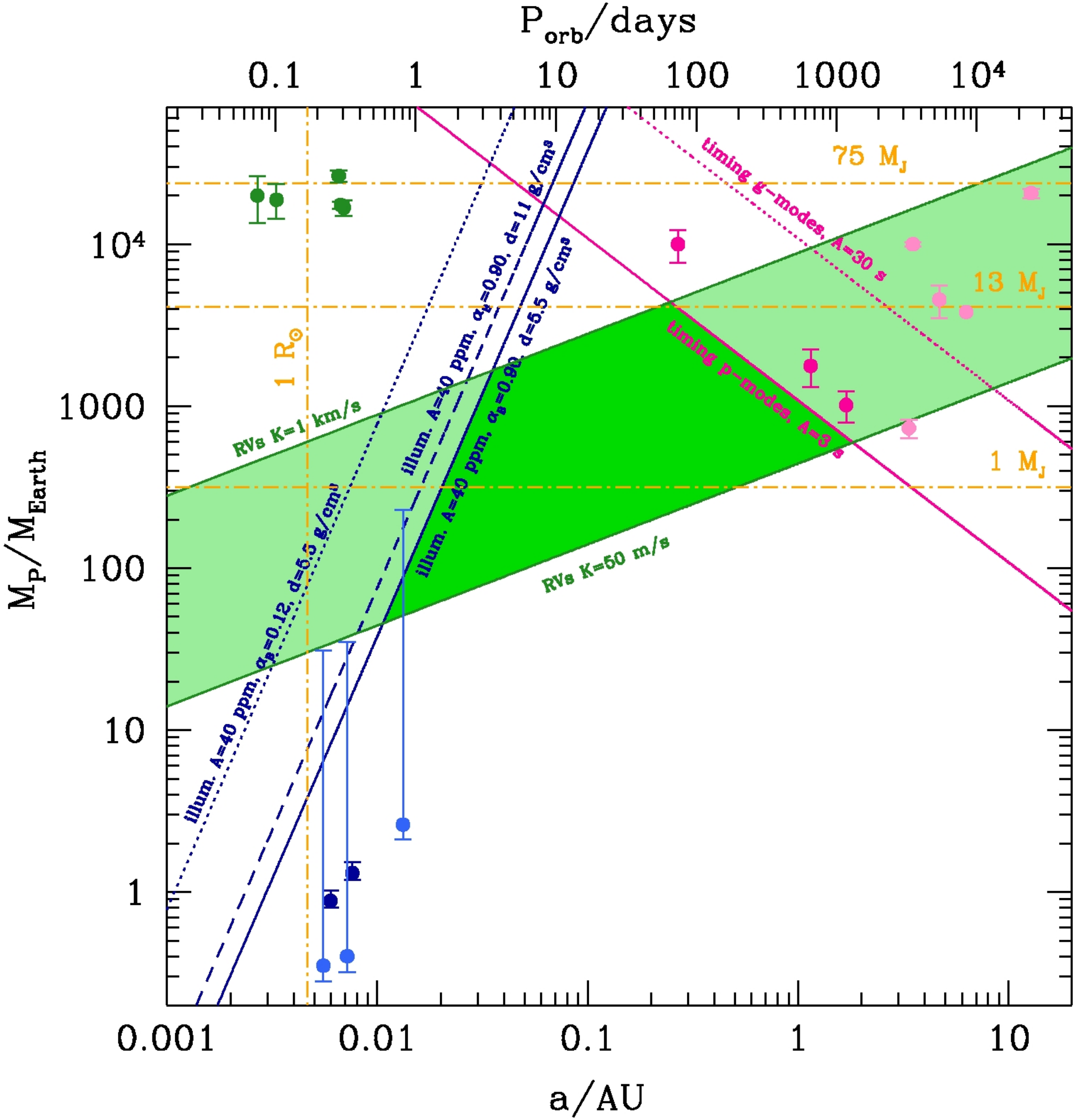
sdB Planets

Why to study them ?

After all only ≈1% of stars become sdBs !

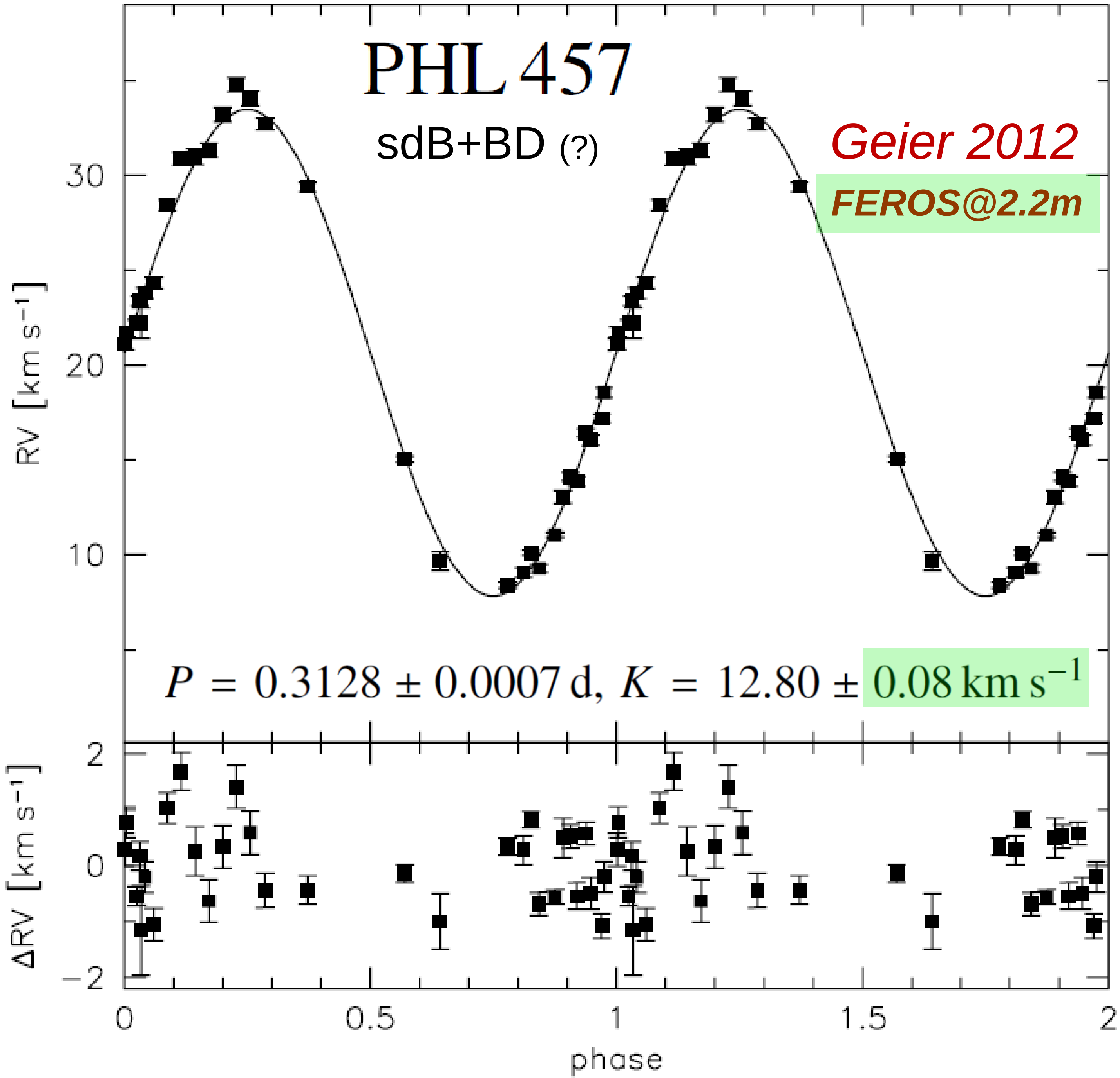
1) because sdB planets allow to isolate the effects of RGB expansion: no AGB, no PN for these stars !

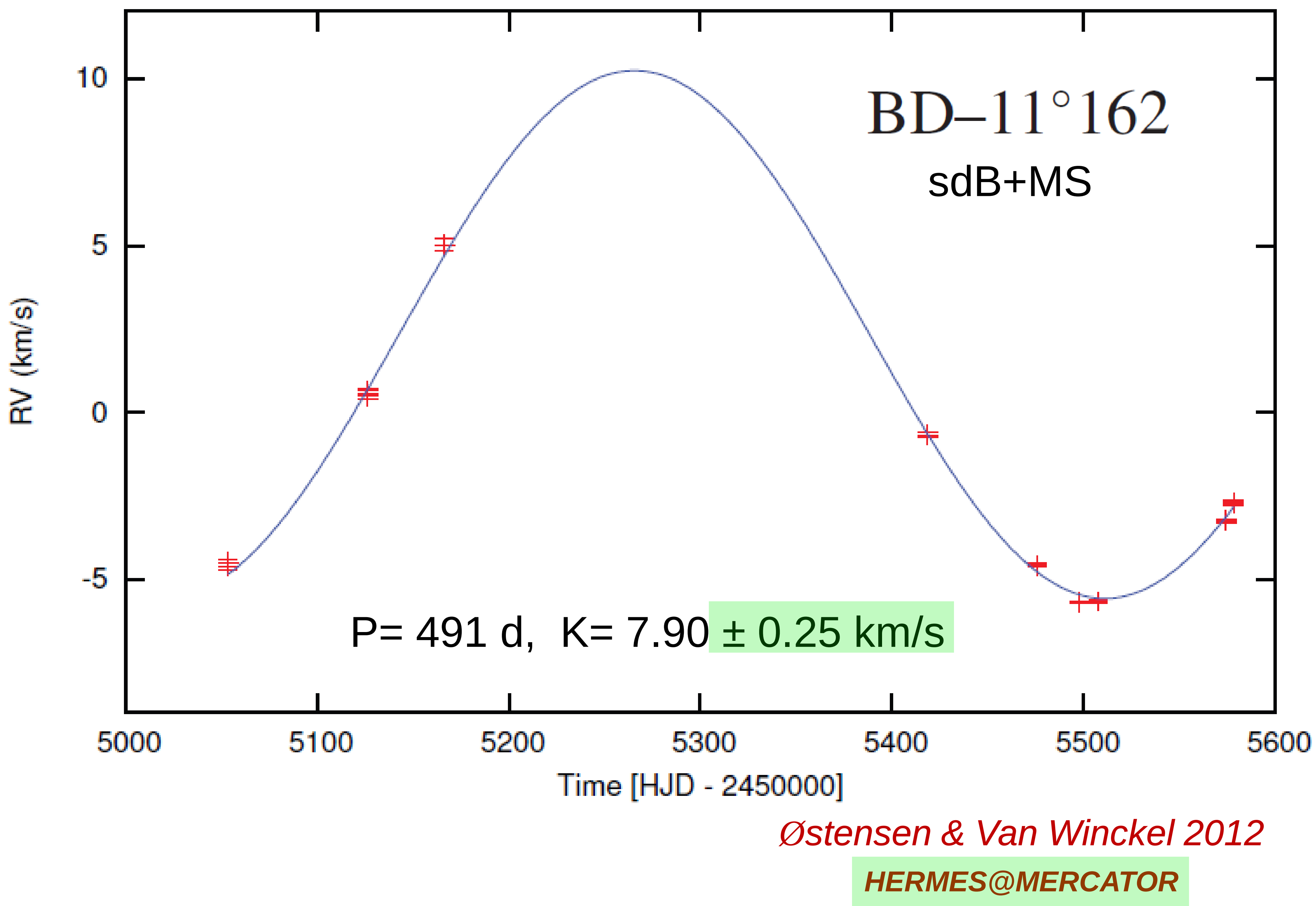
2) because single sdB stars could be particularly reach of planets !



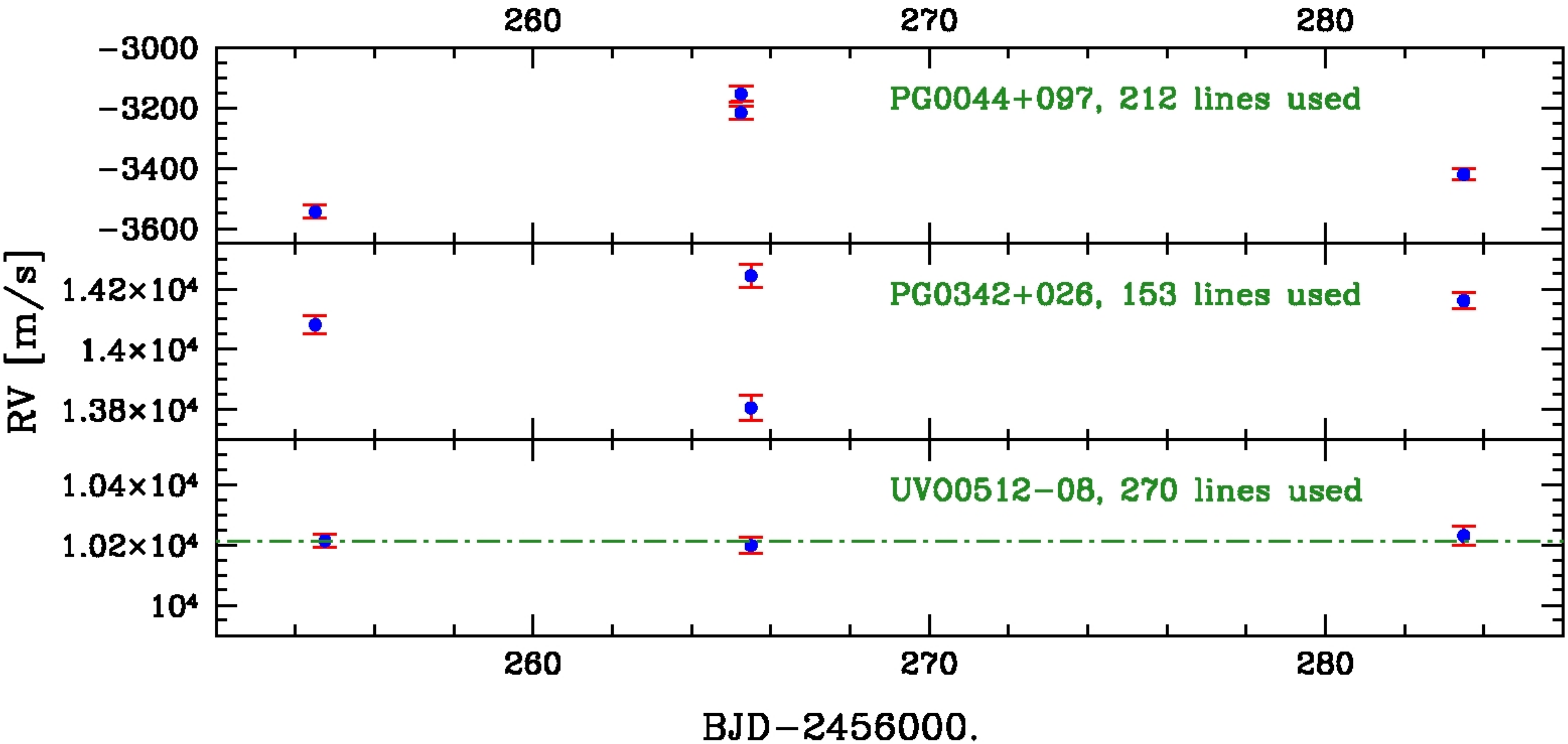
sdB planets/BDs

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


PHL 457
sdB+BD (?)
Geier 2012
FEROS@2.2m
P = 0.3128 ± 0.0007 d, K = 12.80 ± 0.08 km s^−1
RV [km s^−1]
ΔRV [km s^−1]
phase
30
20
10
2
0
−2
0
0.5
1
1.5
2

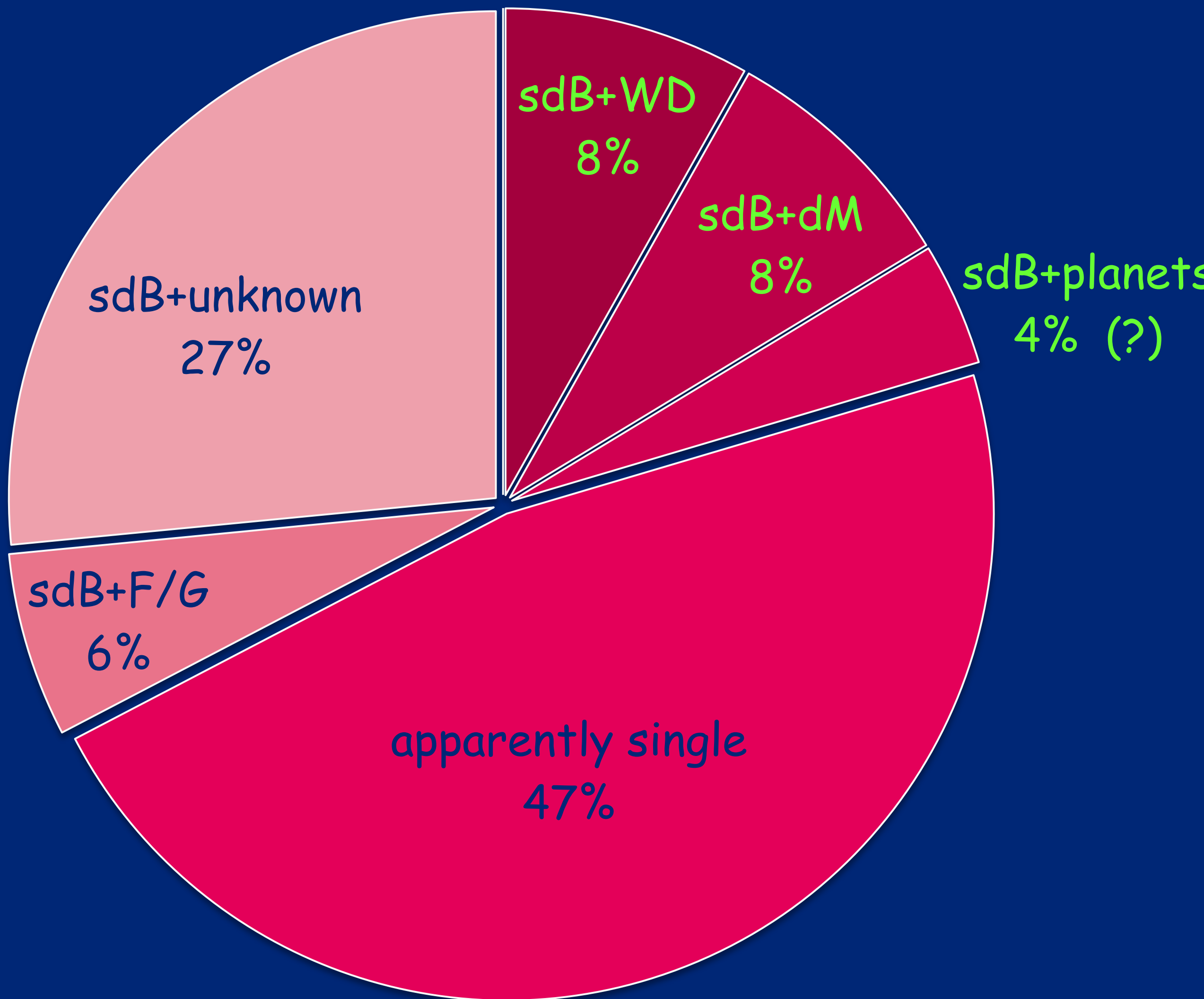

BD–11°162
sdB+MS
P= 491 d, K= 7.90 ± 0.25 km/s
RV (km/s)
10
5
0
-5
5000
5100
5200
5300
5400
5500
5600
Time [HJD - 2450000]
Østensen & Van Winckel 2012
HERMES@MERCATOR

Harps-N: errors **~ ±25 m/s**

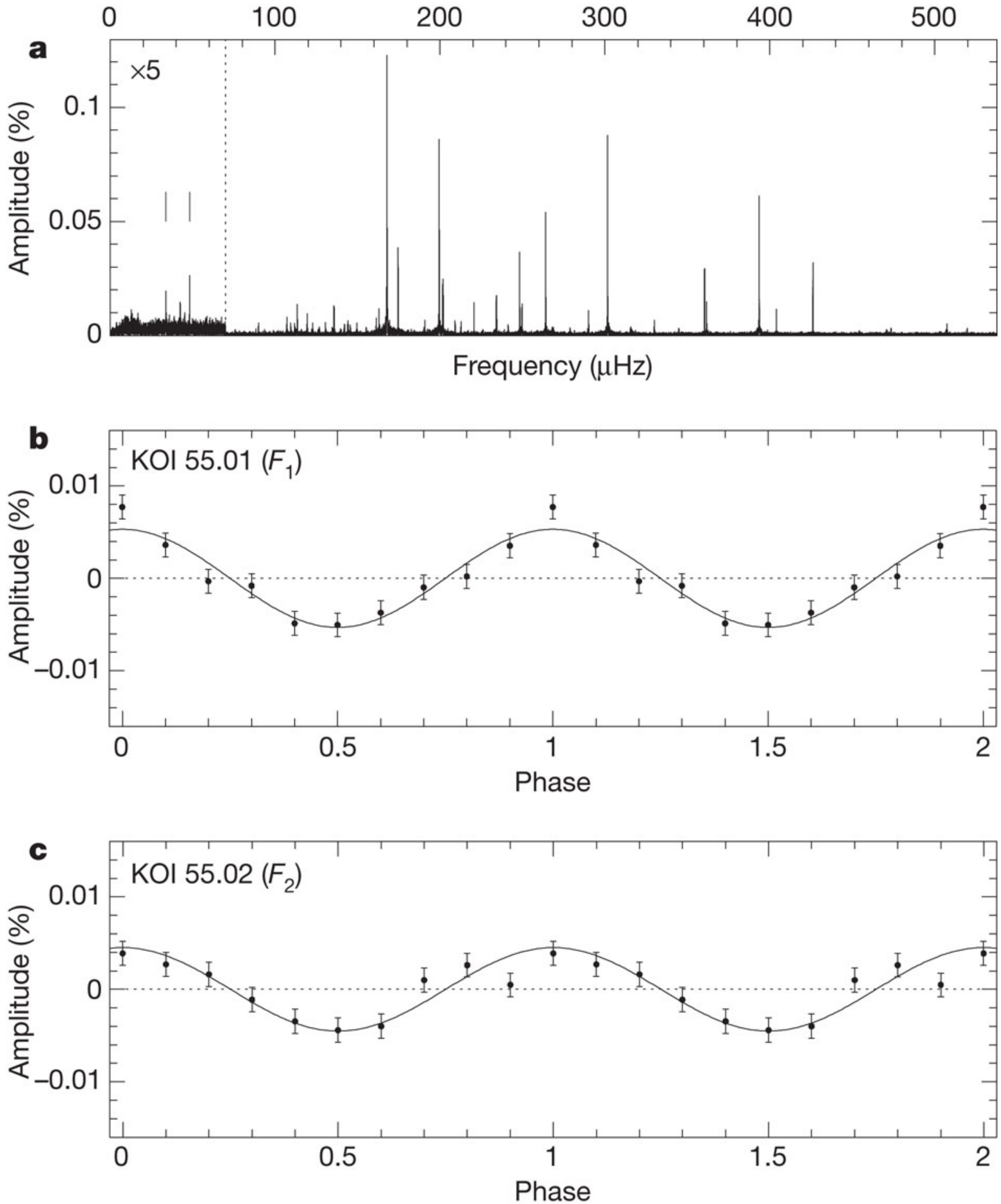


Silvotti, Østensen, Telting & Lovis, ongoing

Kepler sdBs (49 including a few sdOBs)



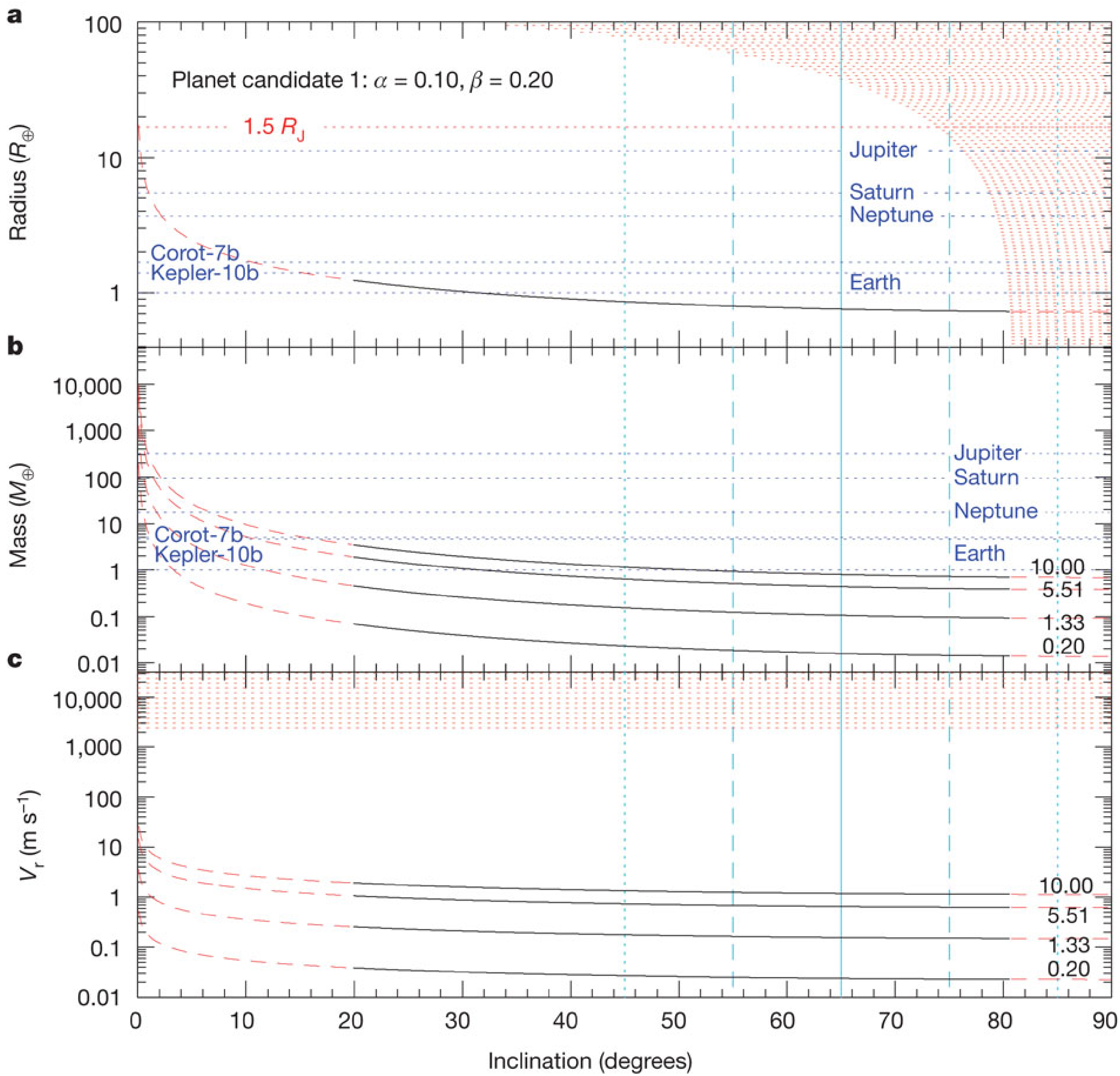
This figure considers only published RV results (Østensen+2010, 2011)



KIC05807616

Charpinet et al. 2012

$P_2/P_1=1.428$



KIC05807616

Charpinet et al. 2012

KIC05807616: how to explain the existence of the 2 planets ?

1) In order to remove the stellar envelope we need $M_P > \approx 10\ M_{jup}$

2) Planets with masses below a few M_{jup} shoud be disrupted

A possible solution is that the Earth-mass planets are the remnants of 1 or 2 giant planets that lost extensive mass during the CE phase (Passy et al. 2012) or that they are the fragments of a giant planet disrupted metallic core (Bear & Soker 2012).

If this is the right explanation, the planet densities could be very high !!

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LETTER TO THE EDITOR

Kepler detection of a new extreme planetary system orbiting the subdwarf-B pulsator KIC

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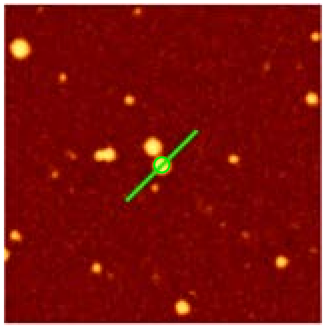
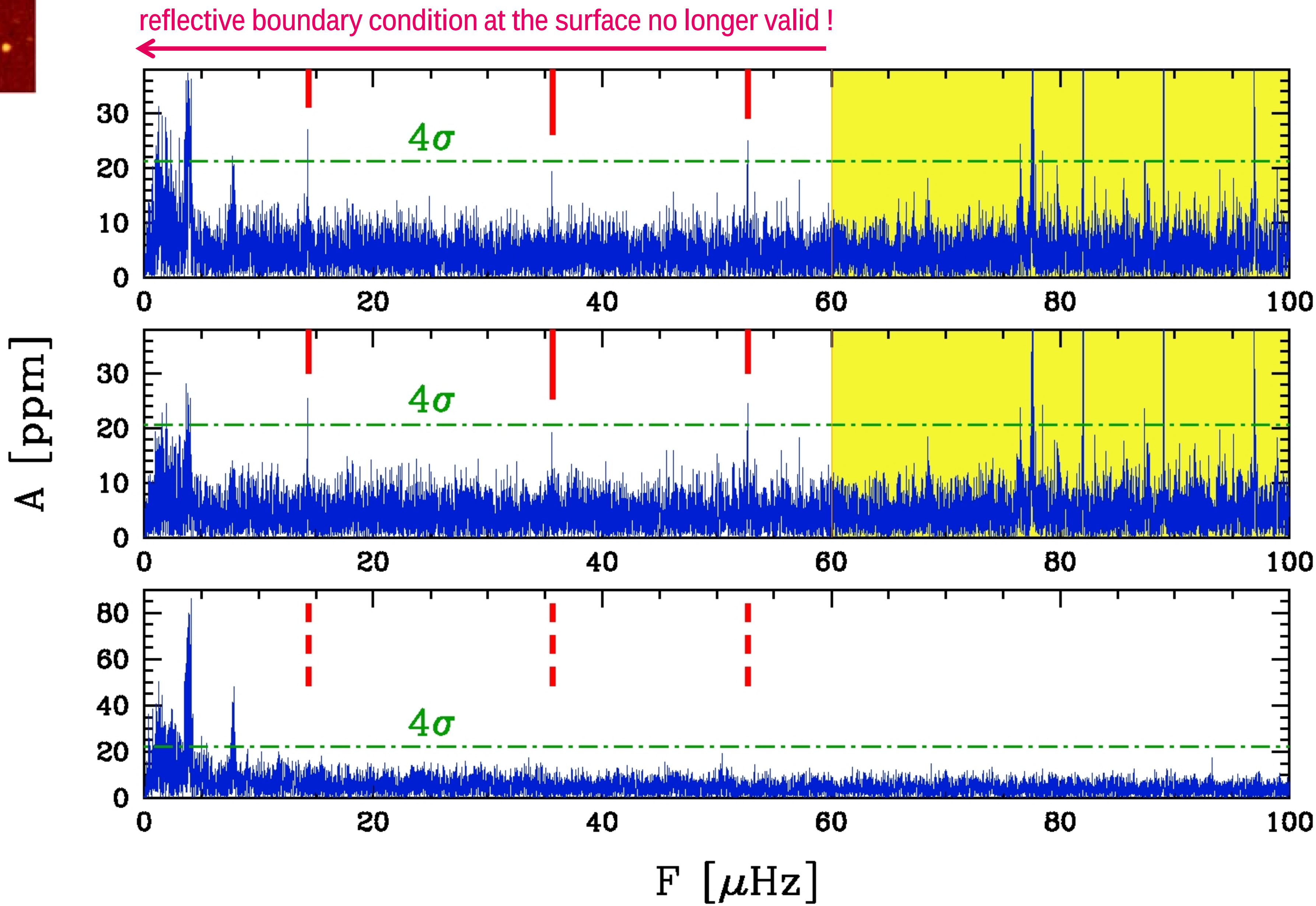
ABSTRACT

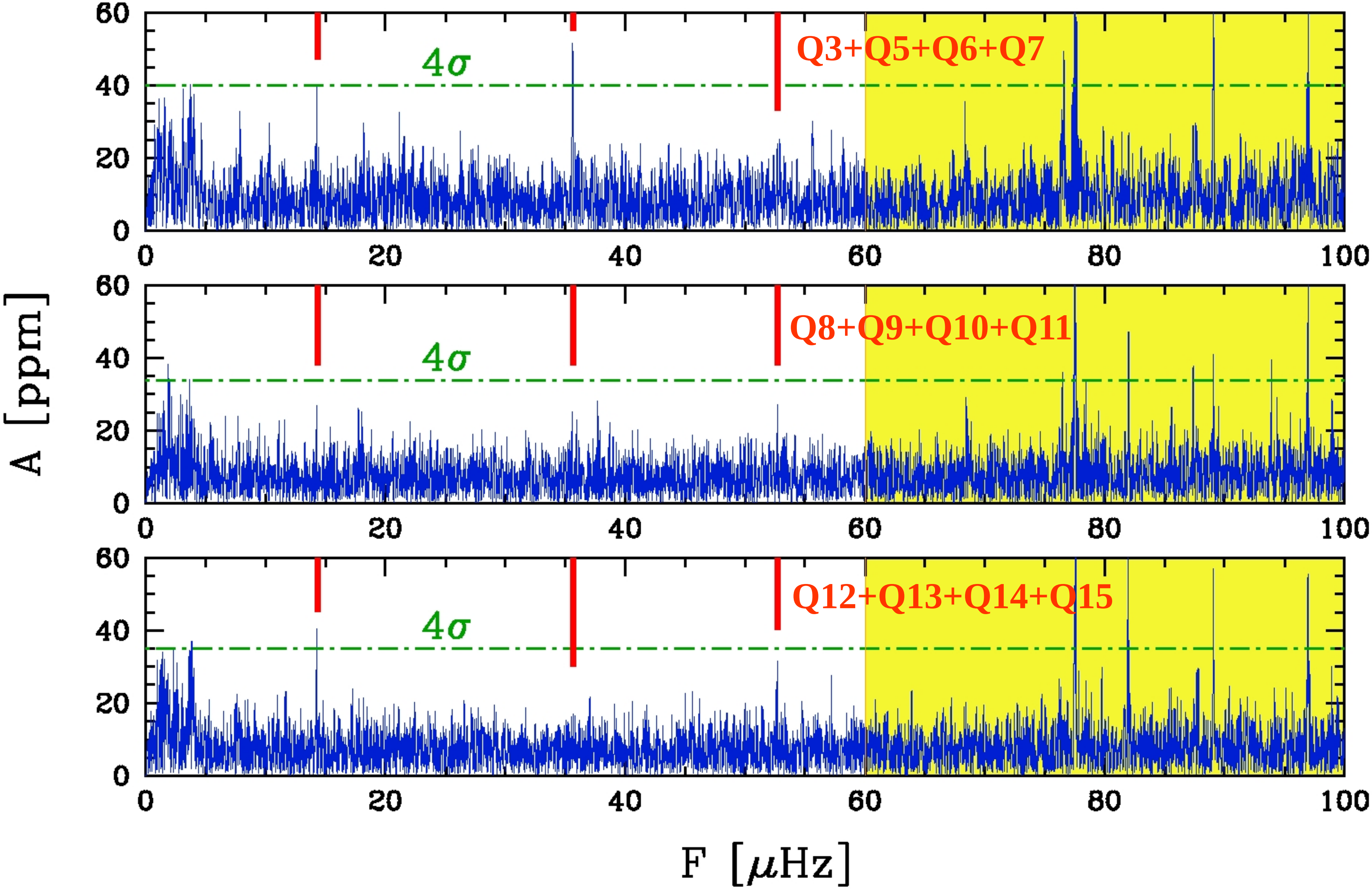
KIC ###### is one out of 19 subdwarf B (sdB) pulsators observed by the *Kepler* spacecraft. In addition to tens of pulsation frequencies in the *g*-mode domain, its Fourier spectrum shows three weak peaks at very low frequencies, too low to be explained in terms of *g*-modes. The most convincing explanation is that we are seeing the orbital modulation of three Earth-size planets very close to their parent star, that are illuminated by the strong stellar radiation. The orbital periods are P_1=5.273, P_2=7.806 and P_3=19.48 hours and the period ratios P_2/P_1=1.480 and P_3/P_2=2.495 are very close to the 3:2 and 5:2 resonance respectively. The extreme planetary system that emerge from the *Kepler* data is very similar to the recent discovery of two small planets orbiting KIC 05807616, another sdB pulsator observed by *Kepler* (Charpinet et al. 2011a).

Key words. planetary systems – stars: horizontal-branch – stars: oscillations

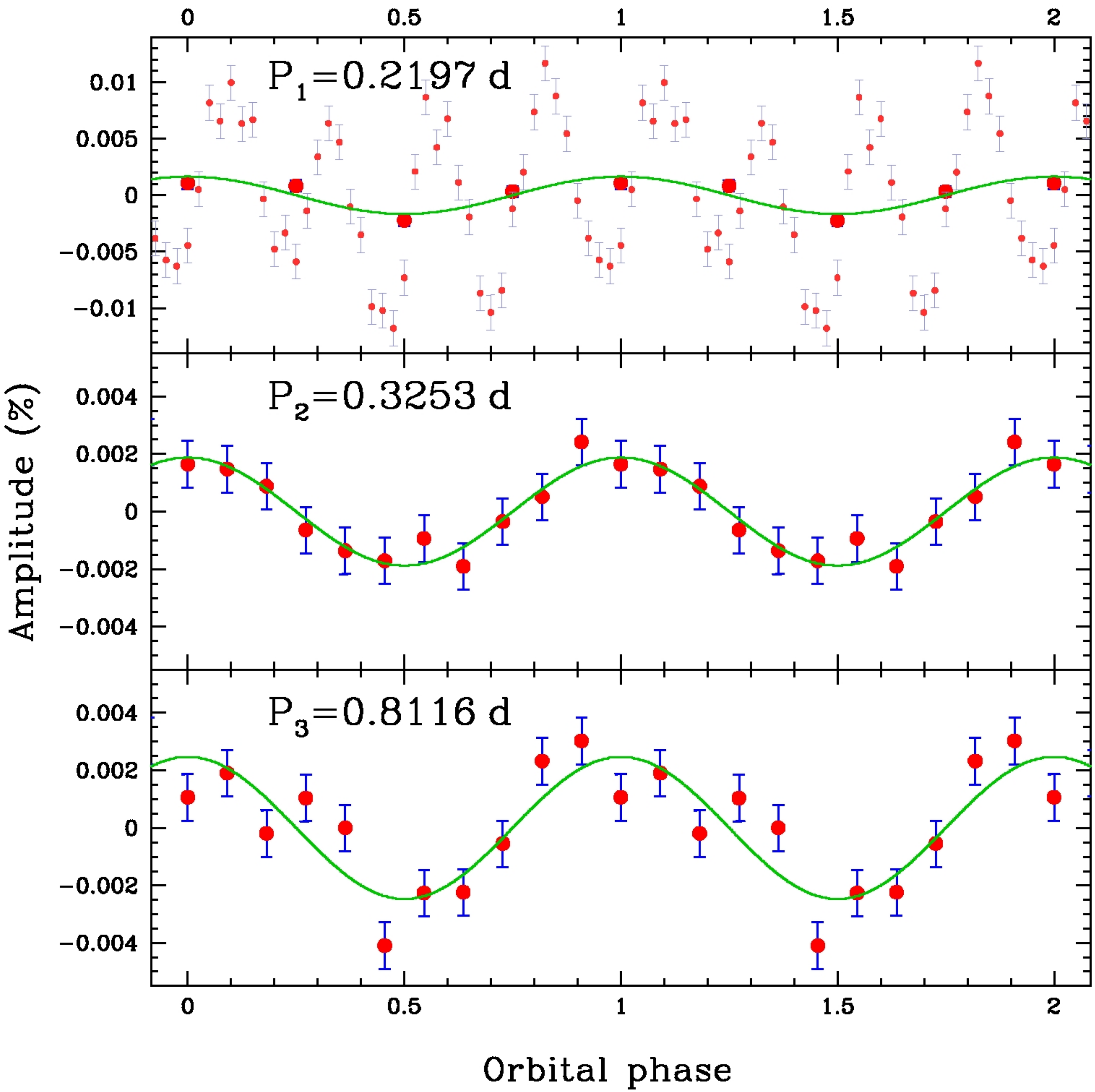
Another "extreme" planetary system from Kepler, very similar to KIC05807616 !







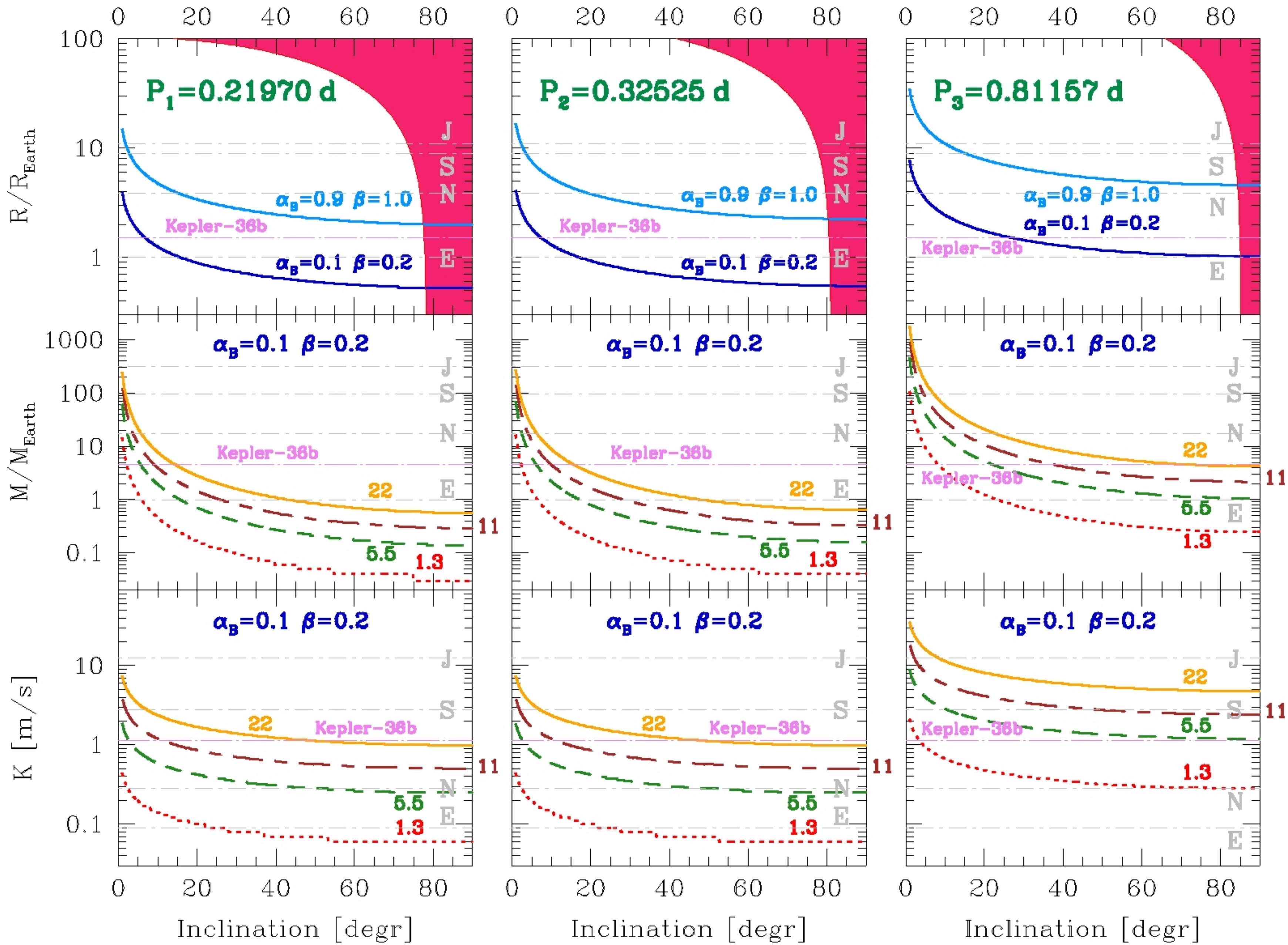
Q3+Q5+Q6+Q7
Q8+Q9+Q10+Q11
Q12+Q13+Q14+Q15
4σ
A [ppm]
F [μHz]



$P_3/P_2=2.495$

$P_2/P_1=1.480$

Moreover **the star's pulsation mode at 210.68 Hz corresponds to the 3d harmonic of the orbital frequency of the inner planet (35.58×4 = 210.72 Hz): a signature of tidal resonance.** This is the first case in which planetary tides influence g-mode pulsations in an sdB star. Previously tidal excited modes were observed in a δ Scuti + γ Dor binary (Hambleton et al. 2013)

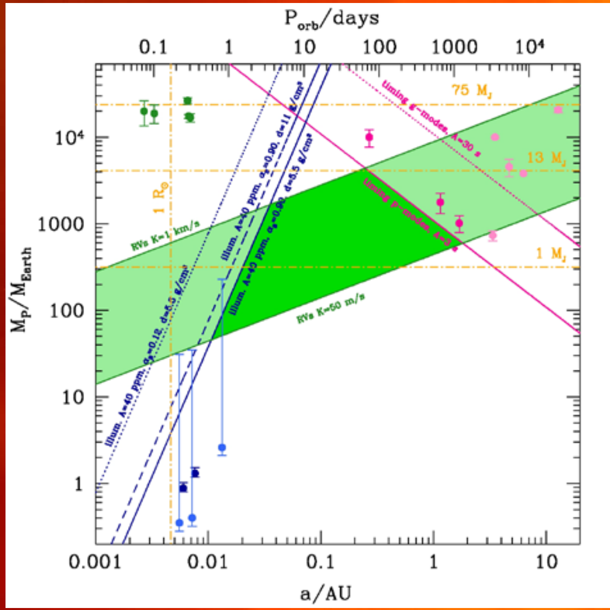


φ = 11 g/cm³ = 2 x Earth is close to the mean density of Kepler 39-b (18 M_J, 12 g/cm³) and likely close to the central density of the Earth

φ = 22 g/cm³ = 4 x Earth is close to the mean density of Corot 3-b (22 M_J, 26 g/cm³) and likely close to the central density of Jupiter

2) Do the observations confirm the gap ?

NO, even though they are compatible with the gap, we don't have enough data to confirm that the gap actually exists !



► **We need much more observations !**

WD Planets

We don't have any good WD planet candidate (yet) !

But:

1) **We know ~24 metal-rich WDs with a dusty/gaseous circumstellar disks !**

2) **GAIA will help.** Not only delivering a large catalogue of WDs, but also allowing to detect giant planets in large orbits around few thousands of WDs.

The 24 WDs with dusty/gaseous circumstellar disks (mostly from Spitzer)

dusty disks

gaseous disks

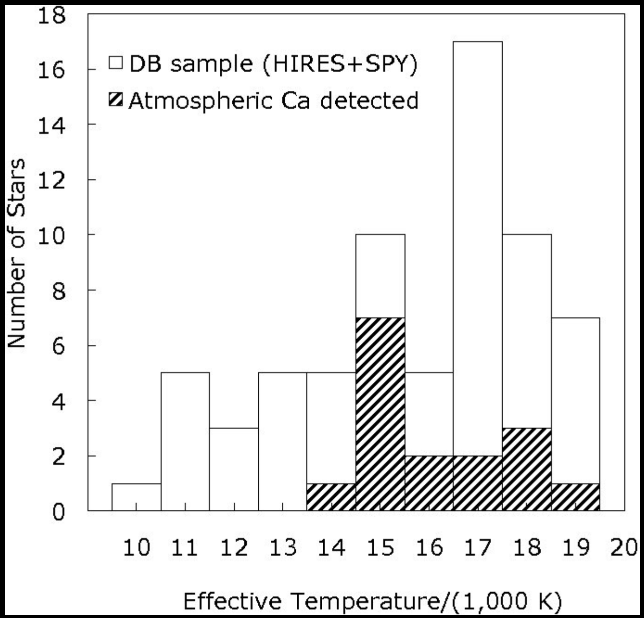
WD	Name	Type	T_{eff} [K]	Year	References
2326+049	G29-38	DAZV	11700	1987	Zuckerman & Becklin 1987
1729+371	GD362	DBZ	10500	2005	Becklin et al. 2005 Kilic et al. 2005
0408−041	GD56	DAZ	14400	2006	Kilic et al. 2006
1150−153	EC11507−1519	DAZ	12800	2007	Kilic & Redfield 2007
2115−560	LTT 8452	DAZ	9700	2007	von Hippel et al. 2007
0300−013	GD40	DBZ	15200	2007	Jura et al. 2007a
1015+161	PG	DAZ	19300	2007	Jura et al. 2007a
1116+026	GD133	DAZV	12200	2007	Jura et al. 2007a
1455+298	G166-58	DAZ	7400	2008	Farihi et al. 2008b
0146+187	GD16	DBZ	11500	2009	Farihi et al. 2009
1457−086	PG	DAZ	20400	2009	Farihi et al. 2009
0106−328	HE 0106−3253	DAZ	15700	2010	Farihi et al. 2010c
0307+077	HS 0307+0746	DAZ	10200	2010	Farihi et al. 2010c
0842+231	Ton 345	DBZ	18600	2008	Farihi et al. 2010c
1225−079	PG	DBZ	10500	2010	Farihi et al. 2010c
2221−165	HE 2221−1630	DAZ	10100	2010	Farihi et al. 2010c
TBD	SDSS 1221	DAZ	12250	2012	Farihi et al. 2012
TBD	SDSS 1557	DAZ	22800	2012	Farihi et al. 2012
1226+110	SDSS 1228	DAZ	22000	2006 2009	Gänsicke et al. 2006 Brinkworth et al. 2009
1041+091	SDSS 1043+0855	DAZ	18300	2007 2010	Gänsicke et al. 2007 Melis et al. 2010
TBD	SDSS 0959	DAZ	13300	2012	Farihi et al. 2012
0842+231	SDSS 0845+2257	DBZ	18600	2008	Gänsicke et al. 2008
TBD	SDSS 0738+1835	DBZ	13600	2010	Gänsicke et al. 2007 Dufour et al. 2010
#5 from DR7	#5 from DR7	DA	?	2011	Gänsicke et al. 2011

WD circumstellar disks:

- 21+3 WDs with close dusty/gaseous disks (within 1-2 R_{SUN}), likely due to tidal disruption of asteroids (e.g. Farihi 2011, Gänsicke 2011). Circumstellar dust is at ~1000 K.
- A few hot WDs (with or without PN) with suspected cool (~100 K) debris disks at tens of AU, which might be the final evolution of a Kuiper Belt analogue (Chu et al. 2011, Bilíková et al. 2011).

→ even if planets around (single) white dwarfs have not been detected yet, at least remnants of old planetary systems seem to be there ….

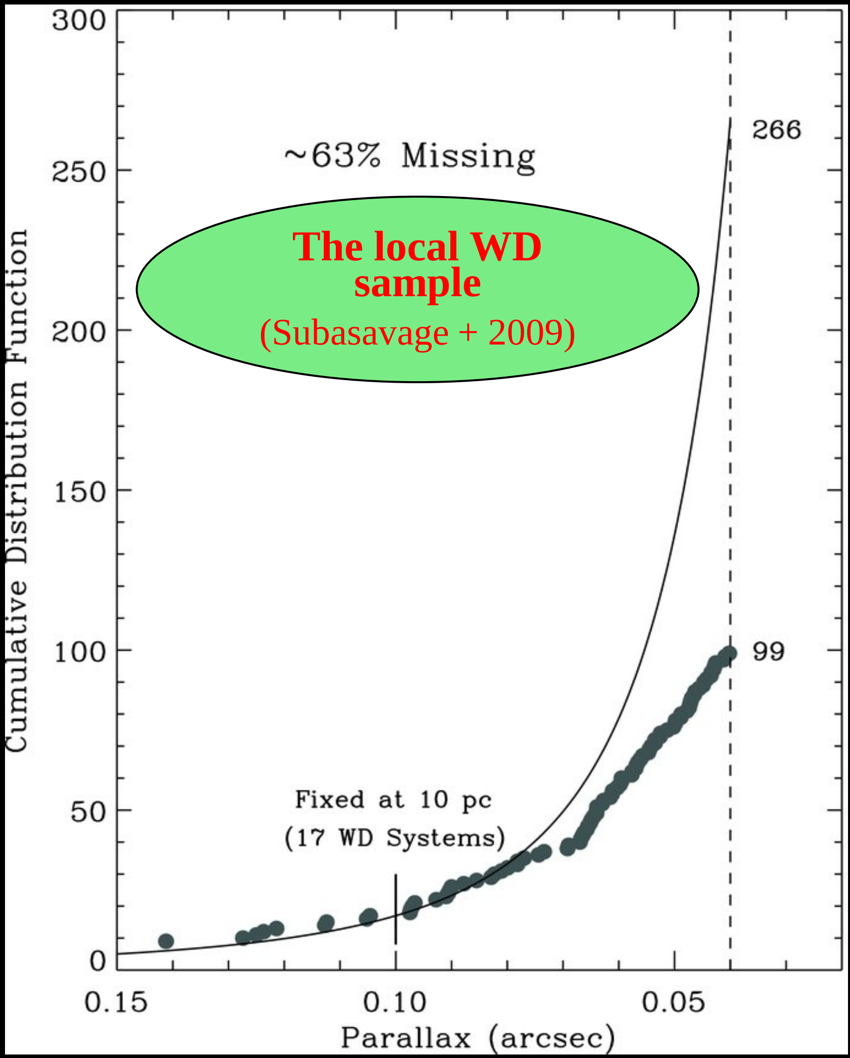
see e.g. Zuckerman et al. 2010 →



Gaia and the white dwarfs

Presently a complete WD sample extends only up to ~13 pc. Within 20 (25) pc, the local WD sample is ~50 (40)% complete. (Holberg et al. 2008, Sion et al. 2009, Subasavage et al. 2009).

GAIA will detect ≈ 400 000 white dwarfs (Jordan 2007) extending the complete WD sample up to ~50-100 pc !



GAIA WD planet discovery space

Based on double-blind tests
(Casertano et al. 2010).

The 3σ detectability curves assume σ_A=15 μas, a 0.59 M_{SUN} WD primary at 100 pc and V<15 (upper curve) or 50 pc and V<13 (lower curve).
Survey duration is set to 5 yr.

Pink dots = known exoplanets from RVs (May 2010).

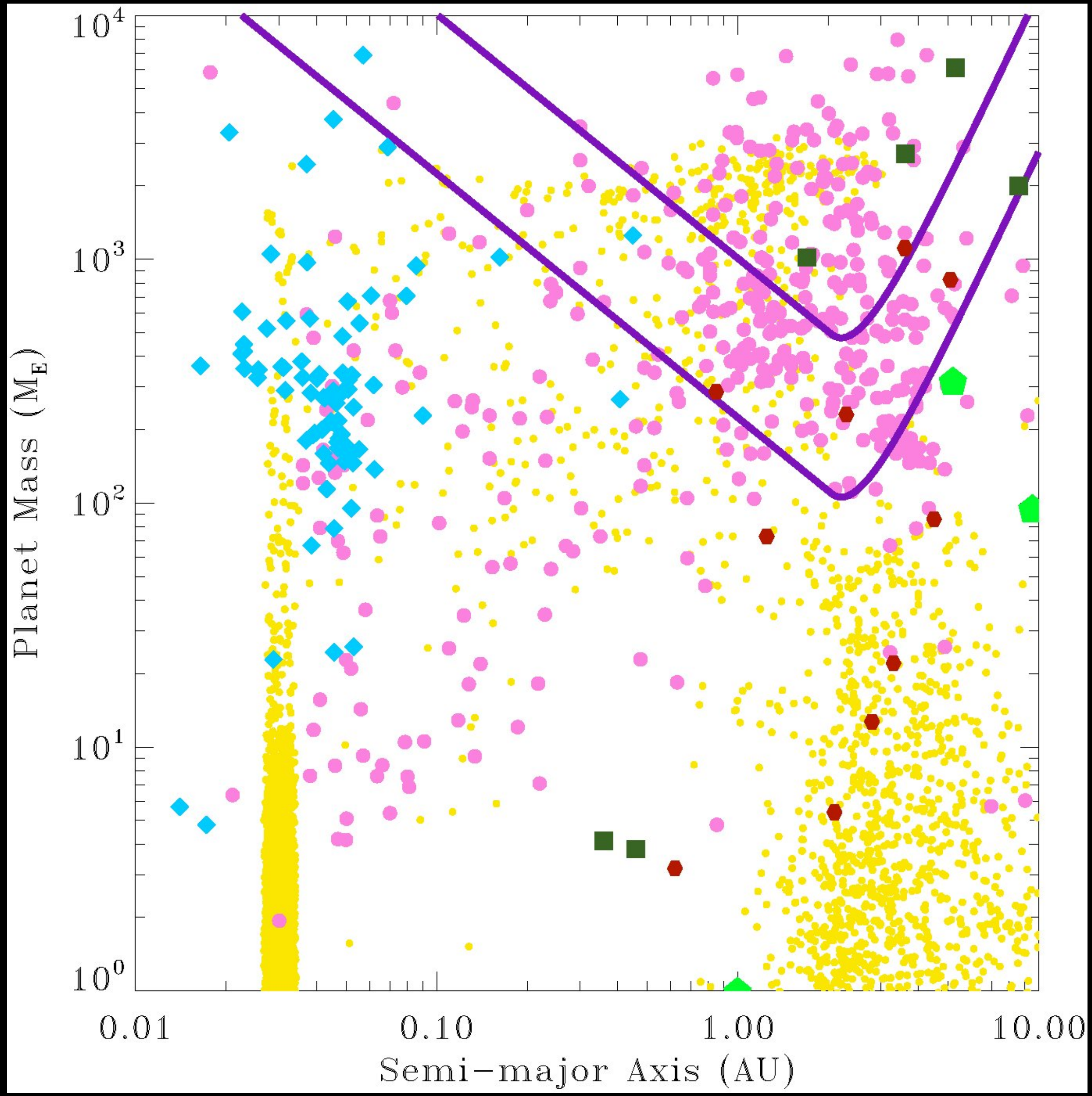
Light-blue diamonds = exoplanets detected from transits.

Red hexagons = planets detected by microlensing.

Dark-green squares = timing.

Light-green pentagons = Solar System planets.

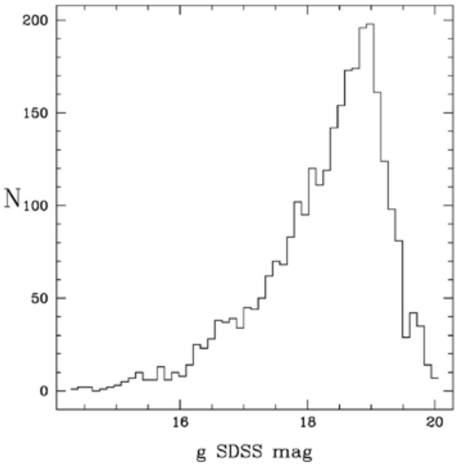
Yellow dots = theoretical distribution of masses and final orbital semi-major axes from Ida & Lin 2008.

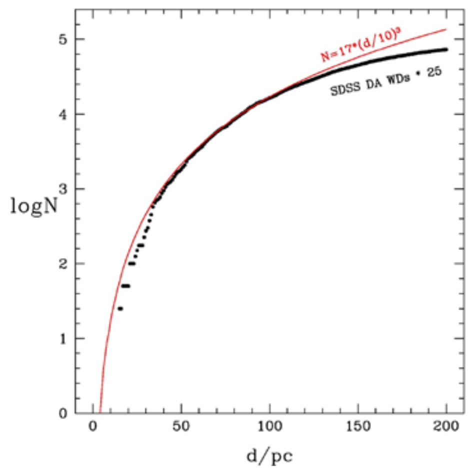


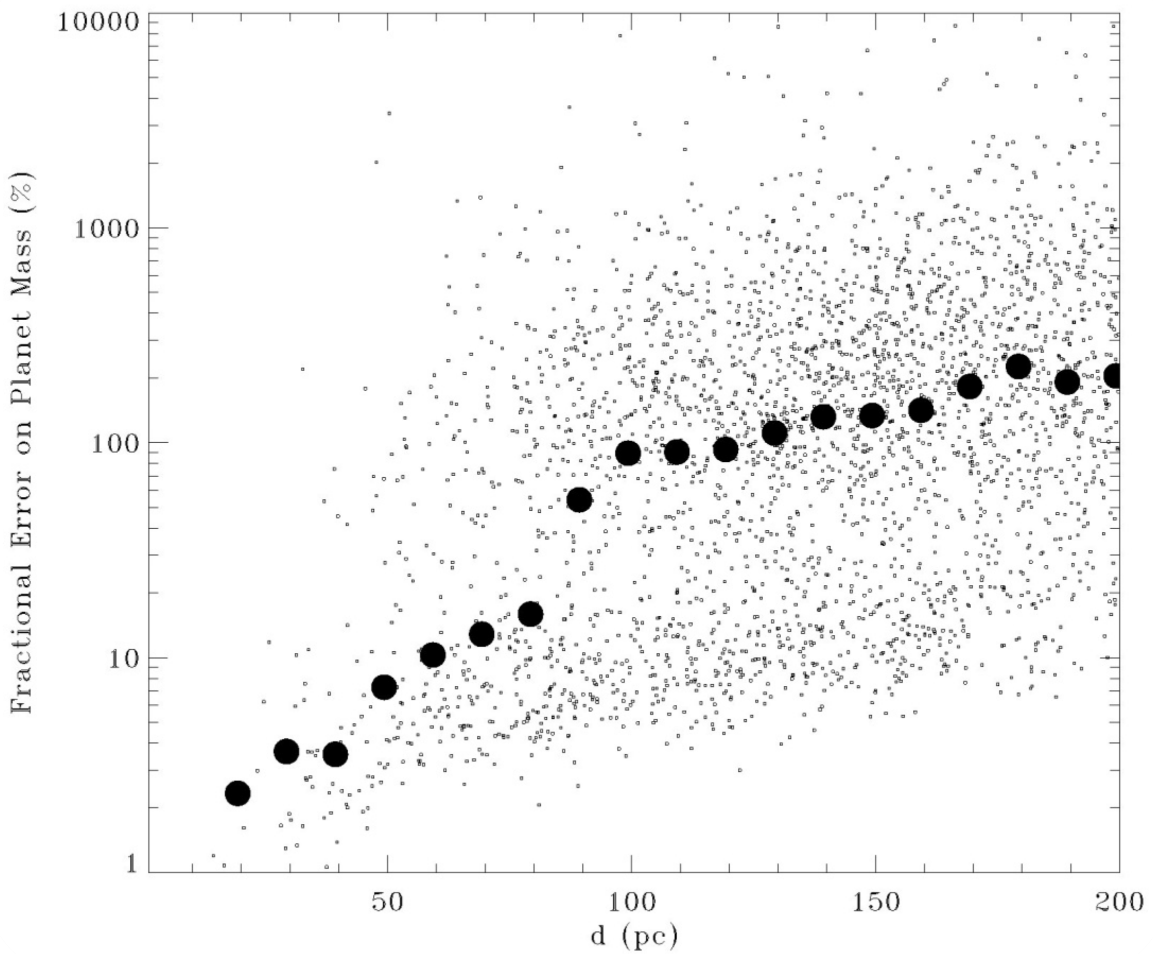
(Silvotti, Sozzetti & Lattanzi 2011)

An example of Gaia WD planets simulation on the SDSS DR7 WD sample

- Basis: Casertano et al. (2008) simulation setup
- Updated Gaia scanning law, T=5yr
- Updated error model (with gates), mean~244 μas
- Targets: all the spectroscop. confirmed WDs in the SDSS DR7 (Kleinman et al. 2012, priv. comm.) with d<200 pc, g<20
- Different orbital element distributions: random values for all orb. par. with P<15 yrs and e<0.6
- Fixed mass of the companion of 15 M_J







How many WDs/sdBs should be observed to see a transit ?

1) WDs

a) the 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" CE) is ~ **1%**

b) after CE, with orbital distances of ≈0.005 AU, the transit probability is ~ **0.1**

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

2) sdBs

a) if the KIC inner planets will be confirmed (e.g. with Pepsi@LBT or Espresso@VLT) these systems might be quite common: 2/49 Kepler sdBs means ~ **4%**

b) Because of the larger radii, at 0.005 AU the transit probability is ~ **0.3**

➡ we need to observe ≈80 sdBs to catch 1 transit

But transit is NOT the only method to detect WD/sdB planets: planets may be detected also through reflection/re-emission !

1) WDs

if 1% of WDs have inner planets, considering that:
for them reflection is dominant respect to re-emission
and considering a 120 ppm detection limit in 1 month of obs.

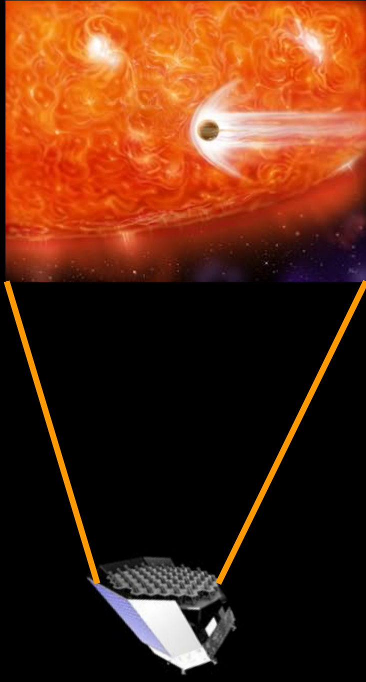
→ only planets with 6x R_{Earth} should be detectable

2) sdBs

here re-emission is ~10 times stronger than simple reflection (at T_{eff}=27000 K);
Following KIC discovery numbers the detection probability is 4%

→ 2 further planetary systems detected observing 80 sdBs !

Conclusions/suggestions: what PLATO could/should do



0) We know quite a lot on MS/subgiant planets and planetary system (PS) formation, but almost NOTHING on their final stage ! To study the final configuration of >95% of PSs should be a high priority in order to have a complete picture of PS evolution and be able to go back to the whole PS history, including the most critical phases of stellar evolution like RGB, AGB, PN ejection, where direct planetary observations are difficult or impossible.

1) Observing 5000/10000 WDs +1000 sdBs (e.g. in 1 step-and-stare field) with PLATO would open a new window on exoplanet science detecting **first** WD/sdB planet transits (+ few lluminated planets) and setting **first** robust constraints on RGB inner planets and their survival, CE and CE ejection mechanisms, single sdB evolution. This would be complementary to large-orbit WD giant planets/BDs that will be discovered by GAIA.

2) From sdB/WD asteroseismology a very good characterization of stars (and thus planets) is possible (remember Valerie's talk) , including star-planet interactions (we have had a hint from Kepler).


Thank you !
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