On the Mass of CoRoT-7b

And what to do about it

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And the CEST team

Just what is the mass of CoRoT 7b?

Is it $3.5 \pm 0.6\ M_{Earth}$ (Queloz et al. 2009) ?

Is it $6.9 \pm 1.43\ M_{Earth}$ (Hatzes et al. 2010) ?

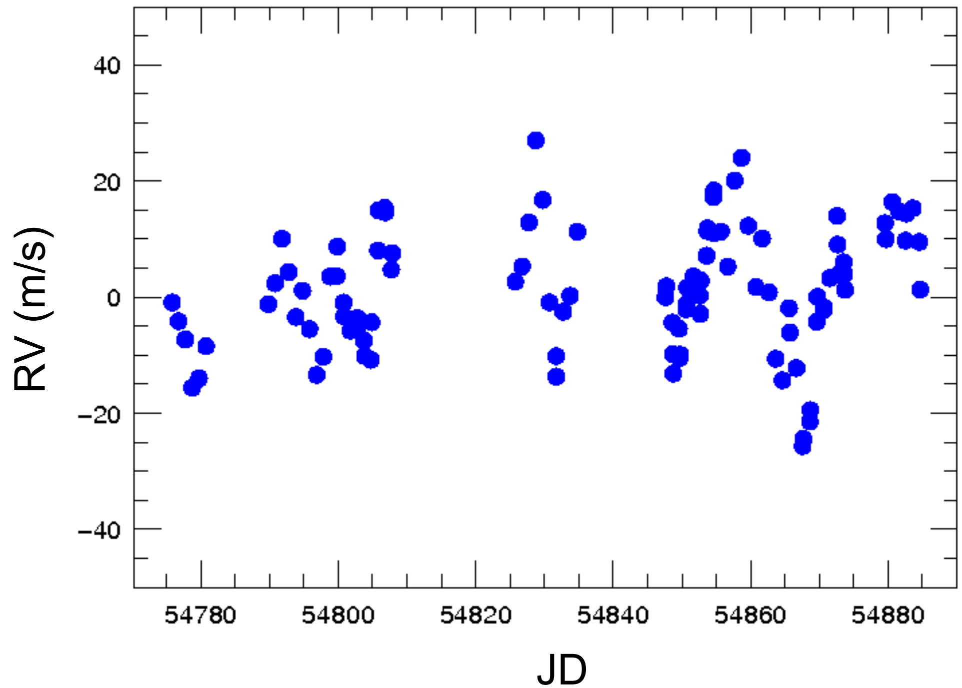
Is it $8.0 \pm 1.2\ M_{Earth}$ (Ferraz-Melo al. 2010) ?

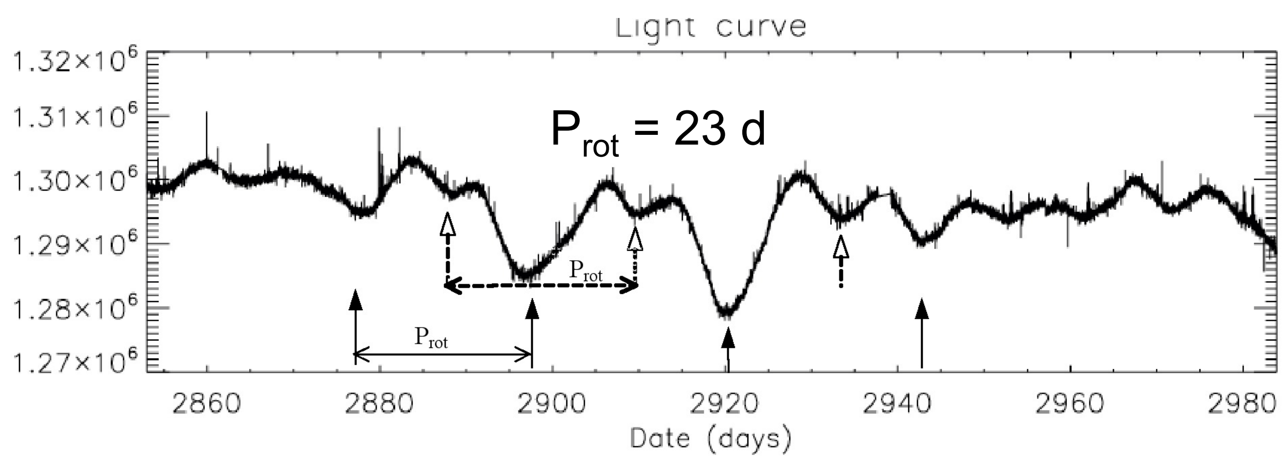
Is it $5.65 \pm 1.6\ M_{Earth}$ (Boisse al. 2010) ?

Is it $2.26 \pm 1.83\ M_{Earth}$ (Pont al. 2010) ?

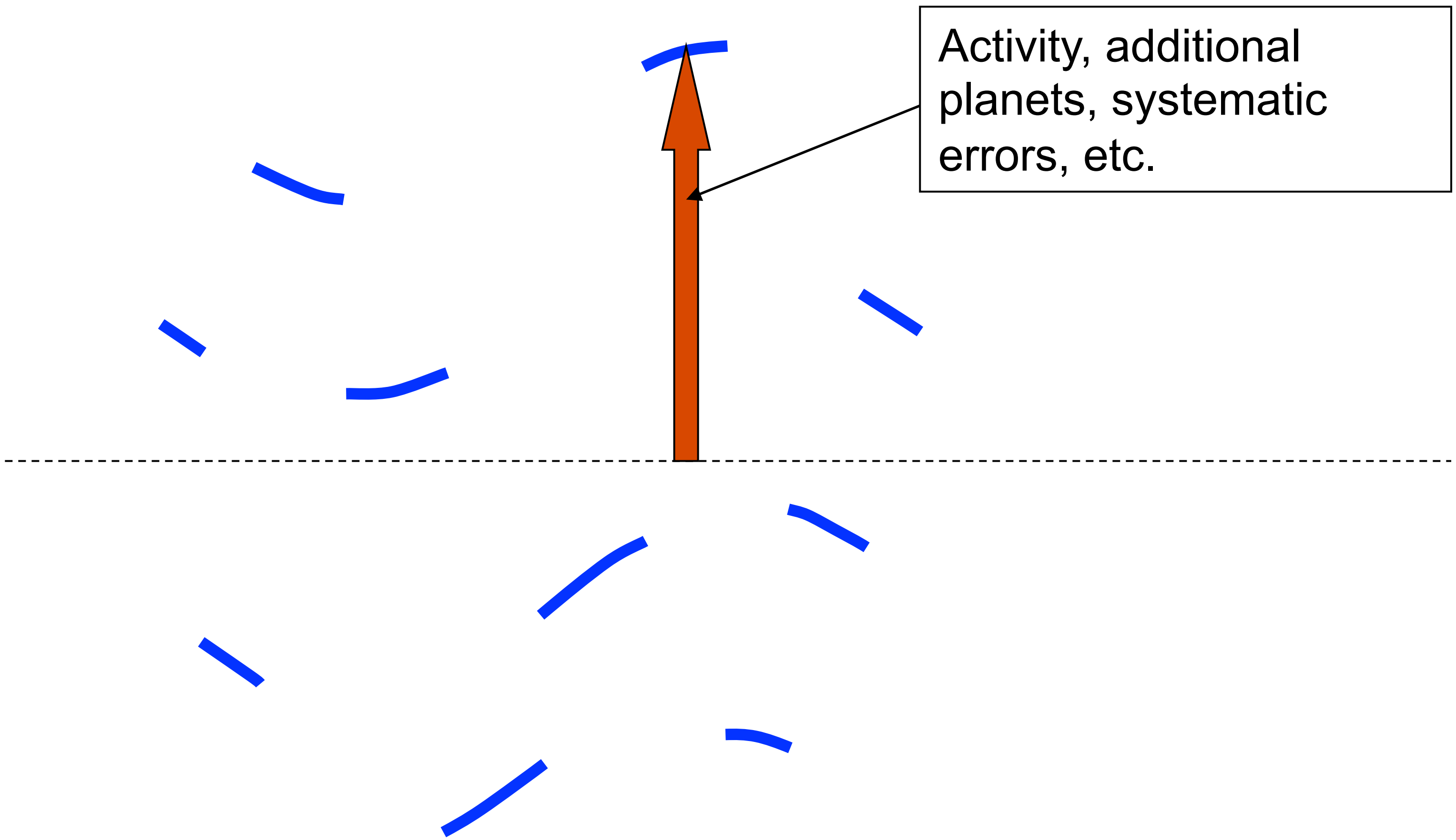
Why the large range?

Radial Velocity Measurements of CoRoT-7b with HARPS





A simple way to remove the acvitity signal



If the RV variations due to activity, additional planets, or systematic noise are constant on a given night, then these can be simply subtracted and the segments of the CoRoT-7b sine wave „stiched together“

Two simple and reasonable assumptions:

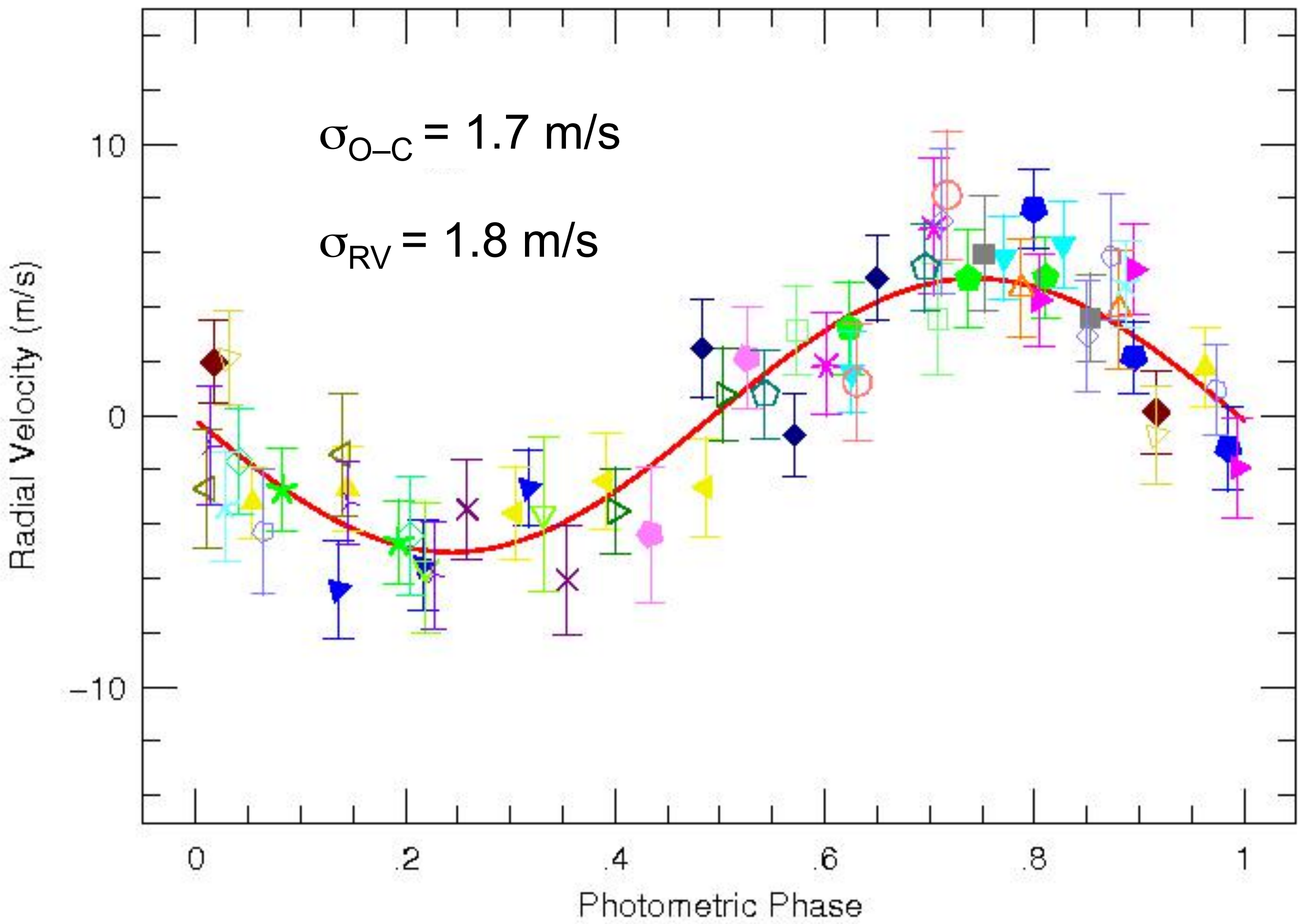
1) A 0.85 d period is present in the RV data

   - Reasonable given Leger, Rouan, Schneider, et al (2009), Hatzes et al. (2010)

2) RV Variations from other phenomena (activity, other planets, systematic errors) over $\Delta T < 4$ hours is small.

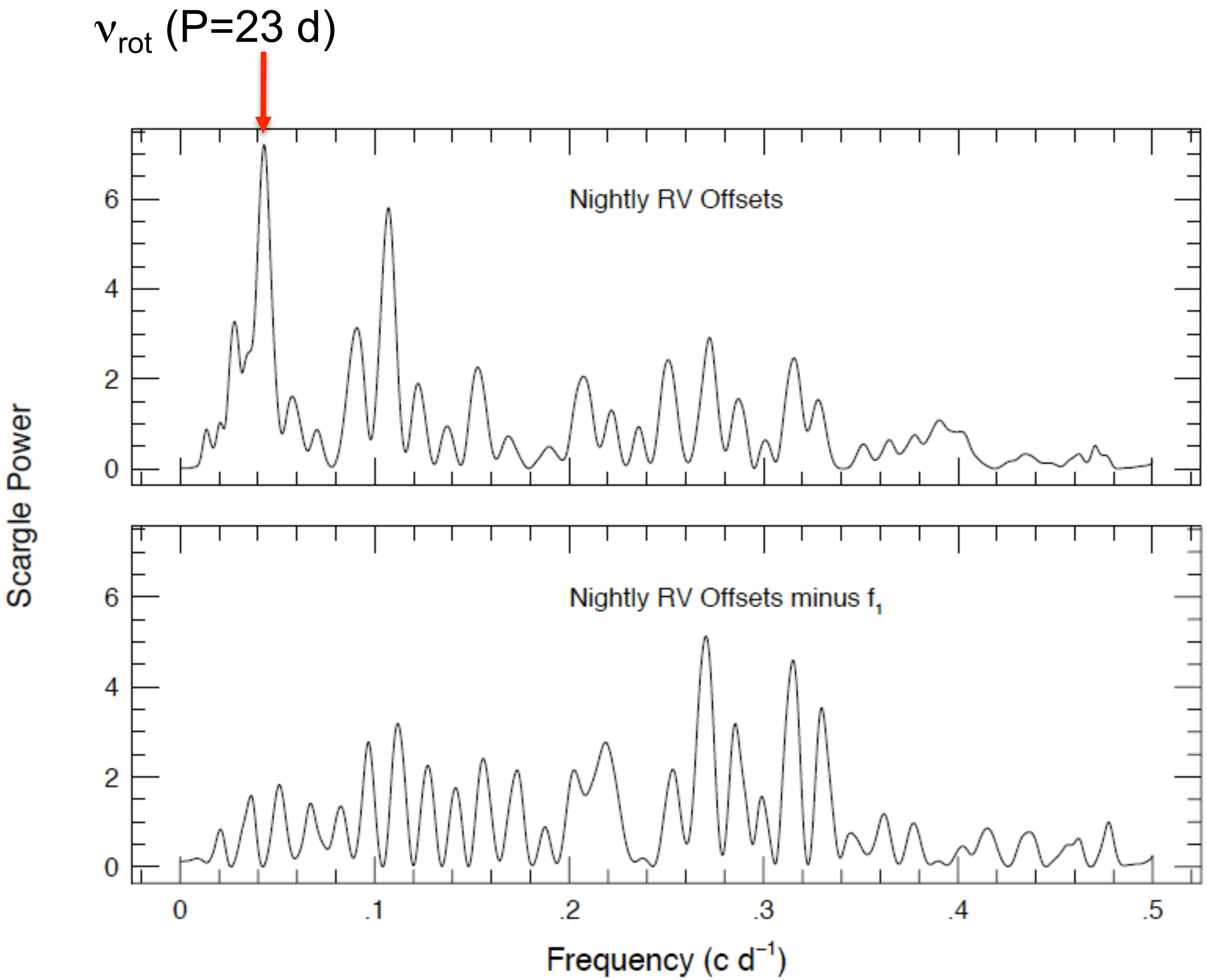
   - $\Delta\phi_{rot} = 0.01$, $\Delta RV < 0.5$ m/s
   - $\Delta RV_{planets} = 0 \pm 0.9$ m/s

Throw out half the HARPS measurements and only use those where multiple measurements are taken each night with a $\Delta T < 4$ hrs



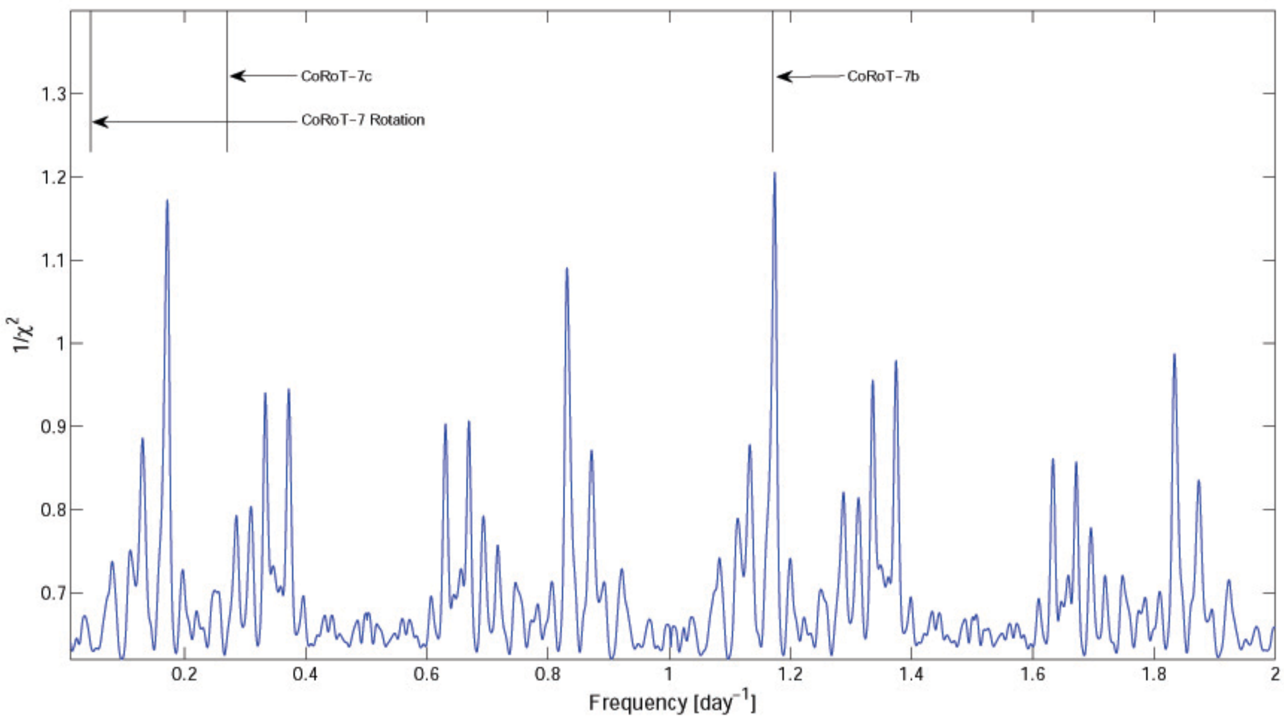
Zero point offsets and phase are the only free parameters. The RV phase agrees with transit phase to within 0.1 phase

Sanity Check: Periodogram of the nightly offsets



Amplitude of variations ≈ 10 m/s

The best fit to the data is provided with a 0.85-d period



Note: We can remove assumption 1), we have found an 0.85-d period in the RV, we do not have to assume it.

This RV curve can be due to 3 possibilities:

1) It is due entirely to a planet

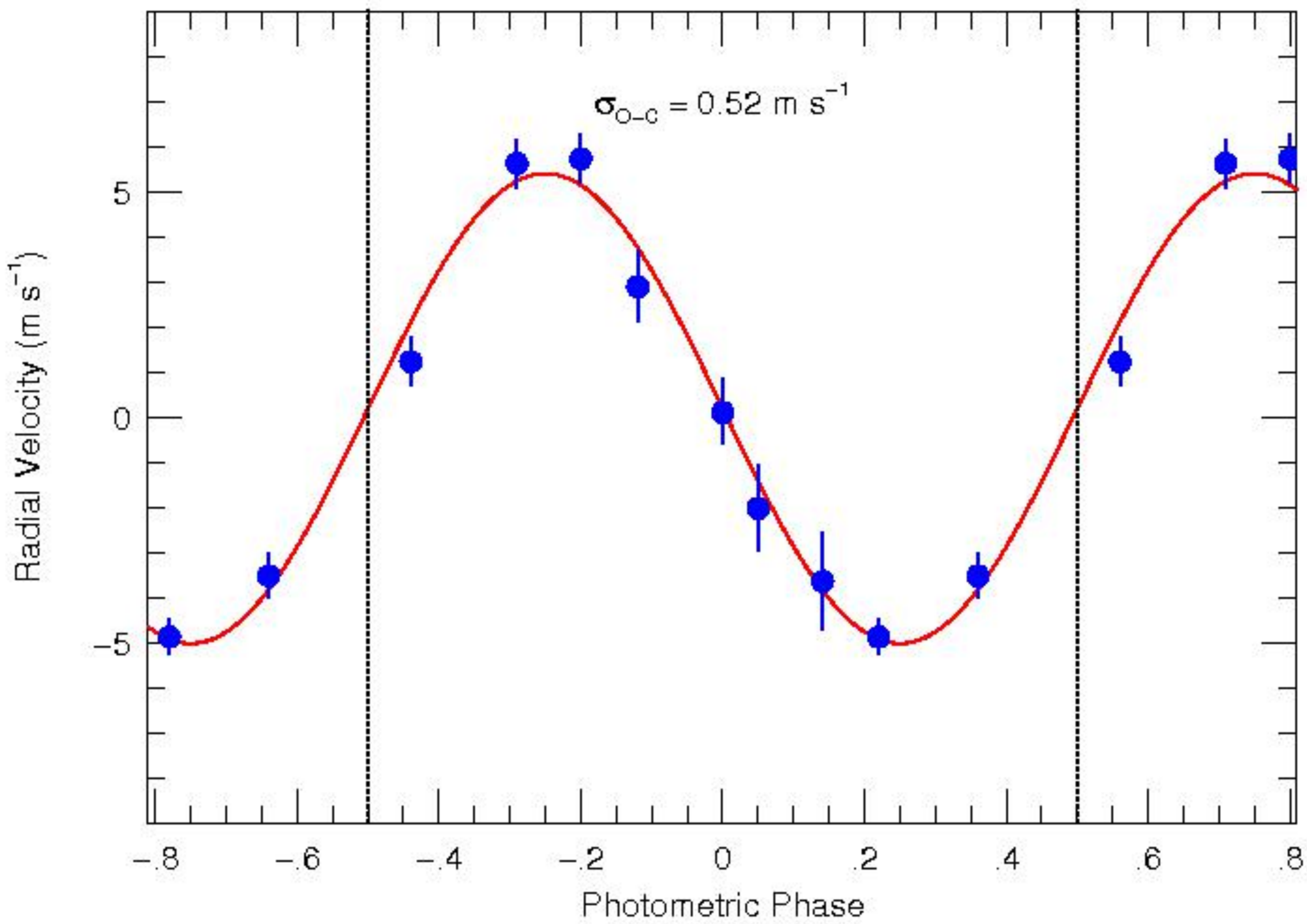
2) It is due entirely to activity

3) It is due to activity plus a planet

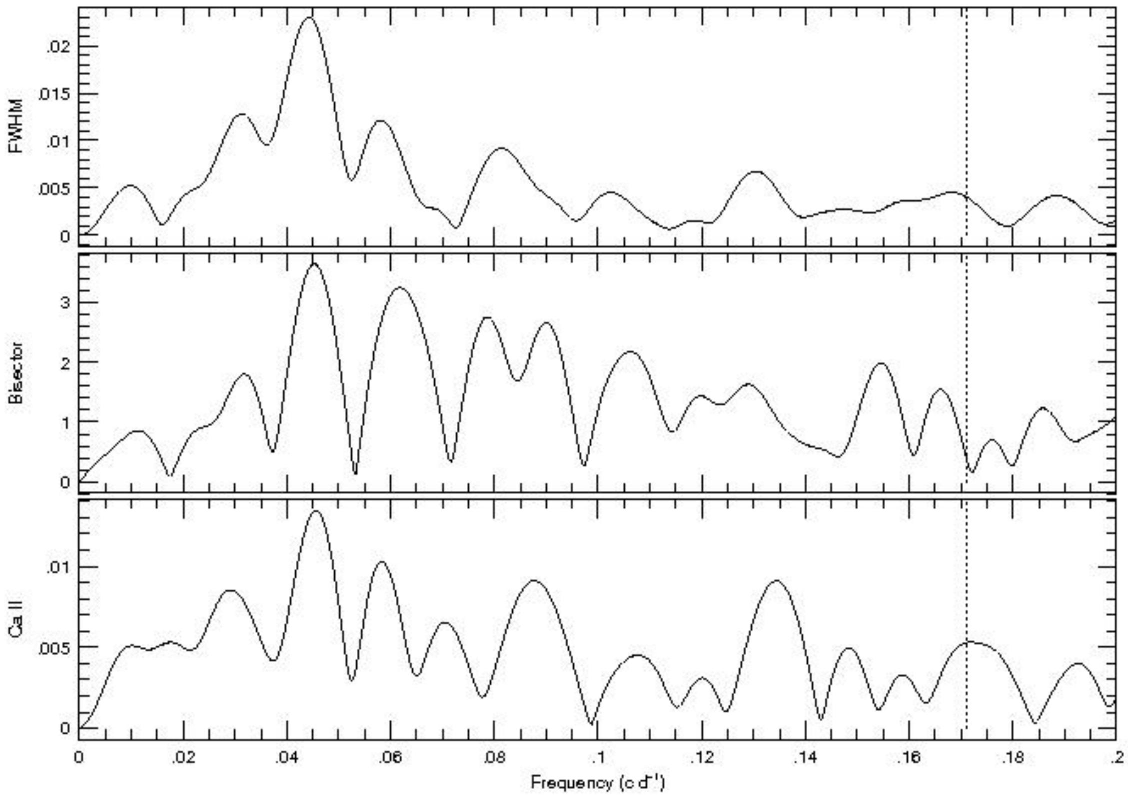
For 2) and 3) to hold the observed 0.85-d variations must be due to an alias of the third rotational harmonic:

$$4\nu_{rot} + 1 = 1.17 \text{ c/d} \approx \nu_{\text{CoRoT-7b}}$$

If Pont et al. K-amplitude of 1.6 m/s is correct, then 3.5 m/s is the activity contribution

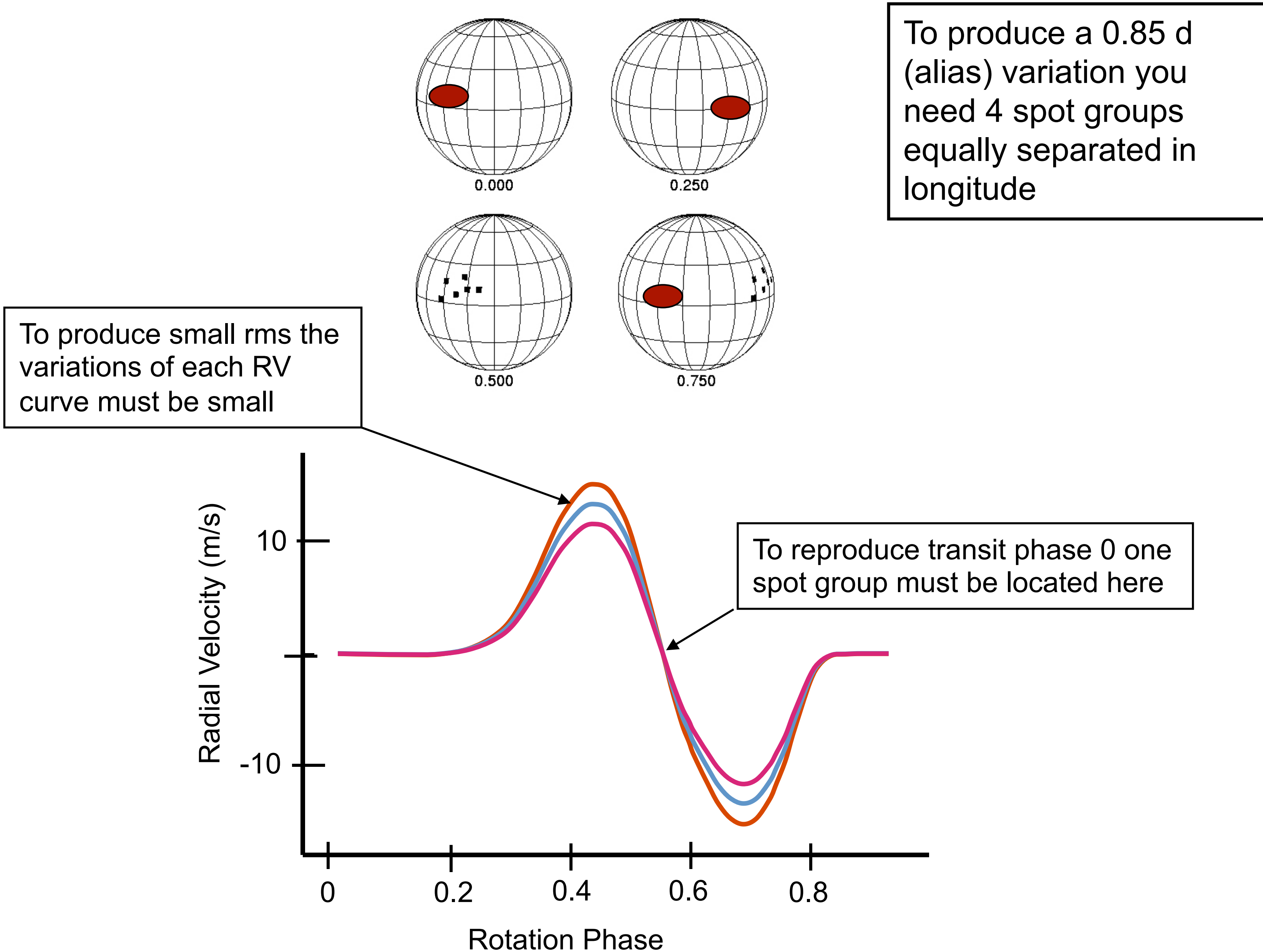


Amplitude spectra of activity indicators



No evidence for significant power at $4\nu_{rot}$

Amplitude of FWHM @ $4\nu_{rot}$ is 0.2 of main peak. This implies an RV amplitude < 1.7 m/s



To produce a 0.85 d (alias) variation you need 4 spot groups equally separated in longitude
0.000
0.250
0.500
0.750
To produce small rms the variations of each RV curve must be small
To reproduce transit phase 0 one spot group must be located here
Radial Velocity (m/s)
10
-10
0
0.2
0.4
0.6
0.8
Rotation Phase

Estimating the RV amplitude due to Spots:

- Saar & Donahue (1997) : $A_{RV} \approx 6.5\ f^{0.9}\ v\sin i$ (m/s)
- Hatzes (2002): $A_{RV} = (8.6\ v\sin i - 1.6) f^{0.9}$

⇨ Each group has a filling factor of ≈0.25%

σ = 0.5 m/s (binned) ⇨ Each group has a same area with 10%

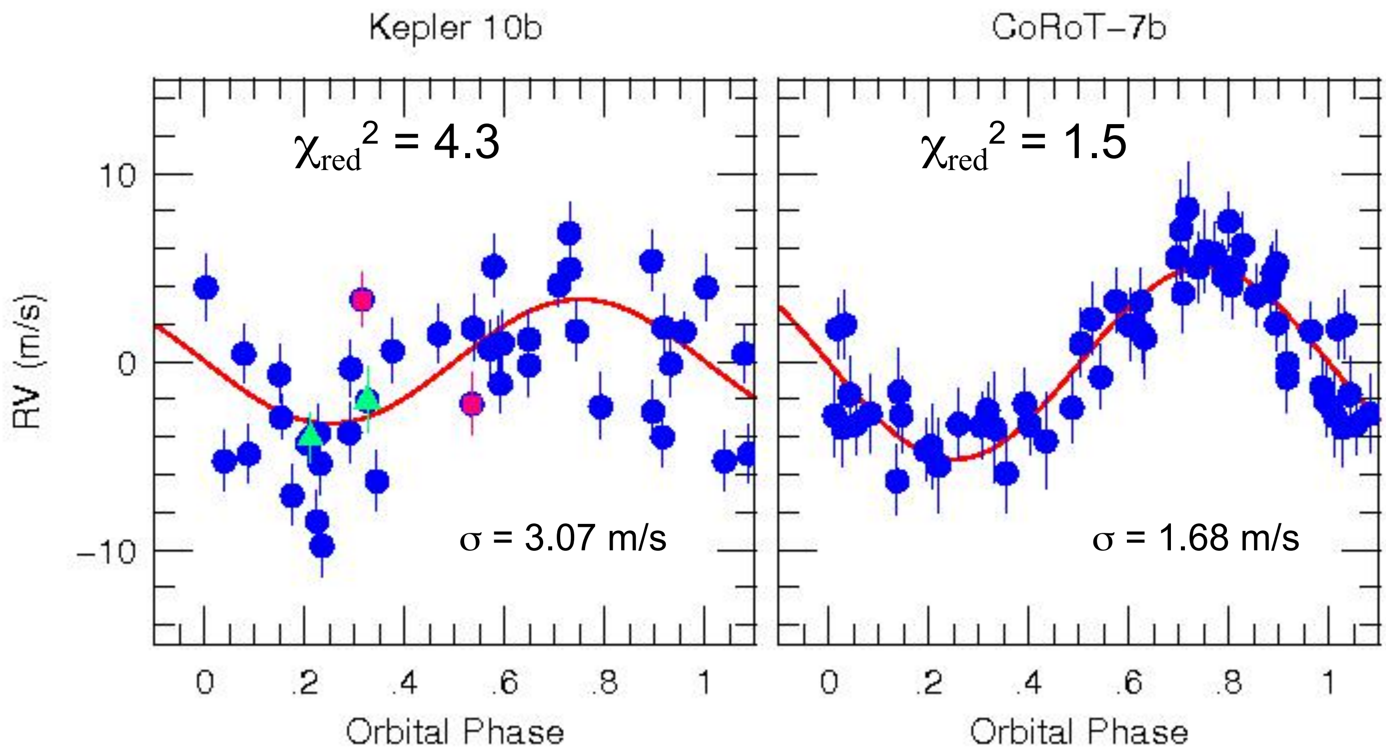
⇨ This spot coverage is constant over 80 days

The RV curve leaves little room for activity „jitter“

For activity to contribute significantly to the RV curve the spot distribution must have a very special configuration:

1. Have 4 spot groups *must* be equally spaced in longitude, otherwise these would not add in phase to the 0.85-d period.
2. One spot group *must* be located at transit phase 0, otherwise there will be large distortions to a sine wave in the RV curve.
3. The area (filling factor) of the 3 spot groups *must* be the same within about 17% otherwise this would introduce scatter in the RV curve.
4. The spot evolution in these groups *must* be small over the time span of the observations (≈ 80 days) otherwise this would introduce scatter above the measurement error.

Kepler-10b versus CoRoT-7b: Inactive versus Active



$M_{star} = 0.895 \pm 0.06\ M_{sun}$

$R_{star} = 1.056 \pm 0.02\ R_{sun}$

$M_{Pl} = 4.56 \pm 1.23\ M_{Earth}$

$R_{Pl} = 1.416 \pm 0.025\ R_{Earth}$

$\rho_{Pl} = 8.8 \pm 2.5$ cgs

$M_{star} = 0.91 \pm 0.03\ M_{sun}$

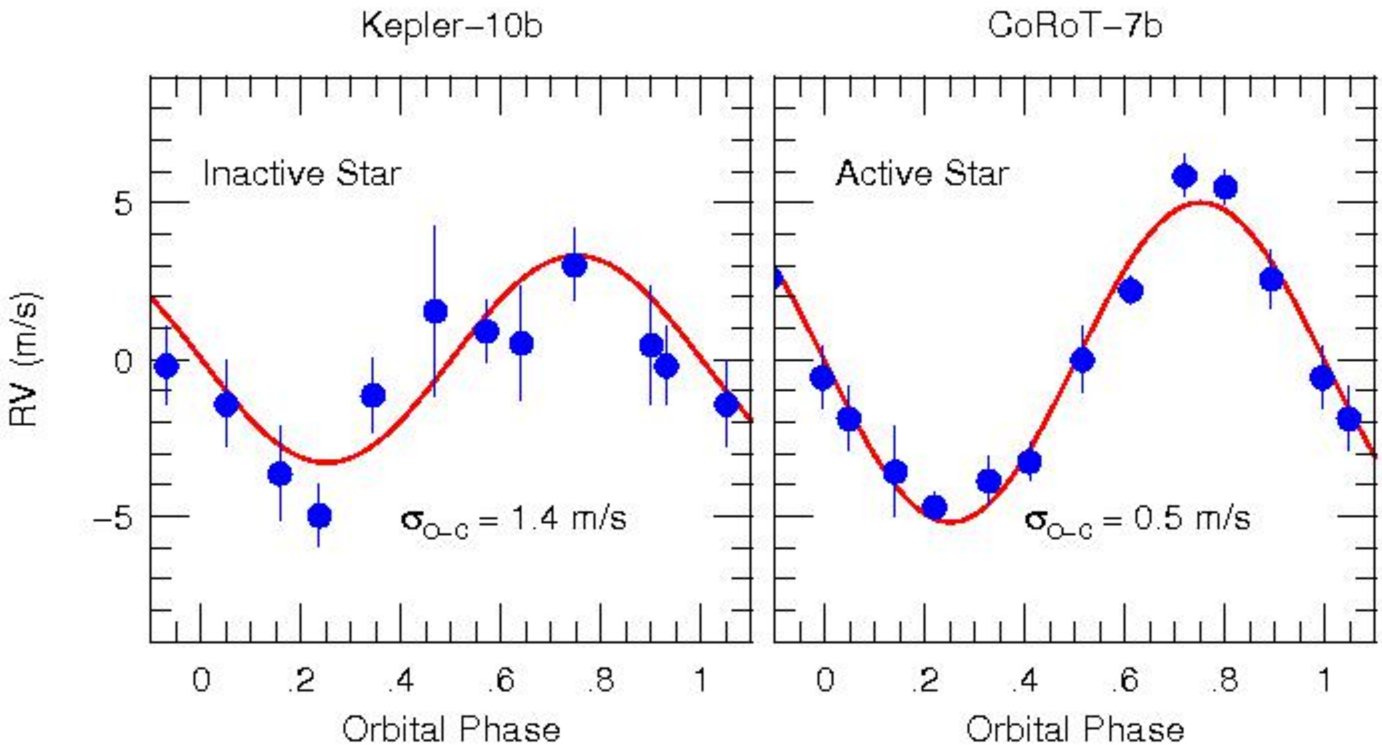
$R_{star} = 0.82 \pm 0.04\ R_{sun}$

$M_{Pl} = 7.29 \pm 1.35\ M_{Earth}$

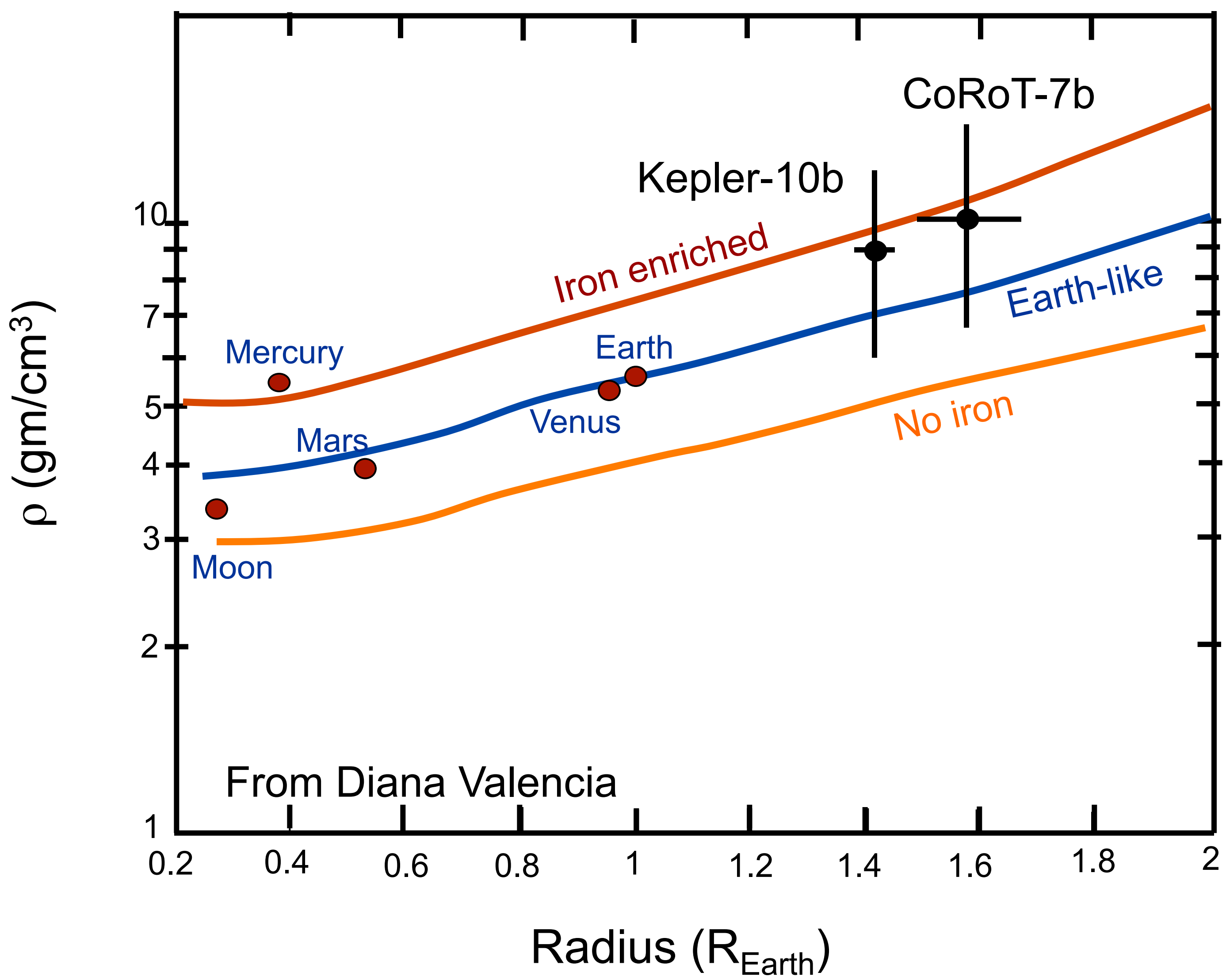
$R_{Pl} = 1.58 \pm 0.10\ R_{Earth}$

$\rho_{Pl} = 10.2 \pm 2.7$ cgs

And the binned values



Are CoRoT-7b and Kepler-10b Super Mercurys?



Summary - 1

- And another one (Winn et al, 2011):
- 55 CnC e, V = 6, G8V
- 2 weeks of MOST data
- Star: M = 0.96 M_O, R = 1.1 R_O;
- The mass of 55 CNC e is 8.57 ± 0.64 M_{Earth}
- The radius of 55 CNC e is 1.63 ± 0.16 R_{Earth}
- The density of 55 CNC e is 10.9 ± 3.1 g cm $^{-3}$.
- There are now three planets (possibly 4, Kepler 9 d) orbiting similar stars and with similar characteristics
- Another group of planets with much lower densities orbits GL 1214, Kepler 11d, e, f

Summary

- By allowing the nightly means in the RV to float one can remove the activity RV jitter with very few and very simple assumption. This method should work in any case where the planet orbital is less than the time scales of the activity
- There is little evidence for the activity contributing strongly to the CoRoT-7b RV signal. The low mass value of Pont et al. is suspect.
- Absolutely ***no*** evidence for nightly systematic errors in the HARPS data
- The mass of CoRoT-7b is 7.29 ± 1.35 M_{Earth}
- We know the mass of CoRoT-7b (18%) better than Kepler-10b (25%)
- CoRoT-7b and Kepler-10b have similar mean densities consistent with a Mercury-like planet, but large errors! In order to get a
    - Better density for CoRoT-7b → we need a better radius
    - Better density for Kepler-10b → we need a better mass

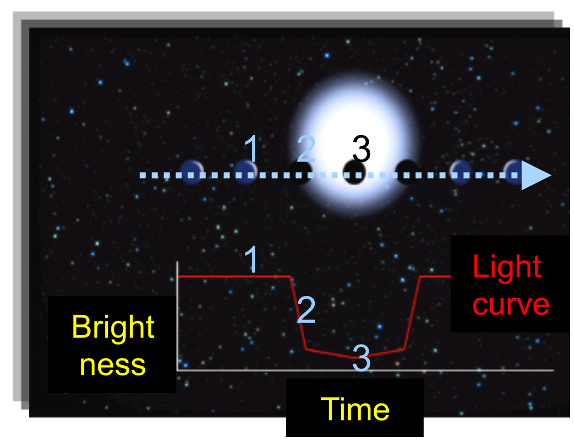
HOW?

For ESA it could be with the PLATO mission

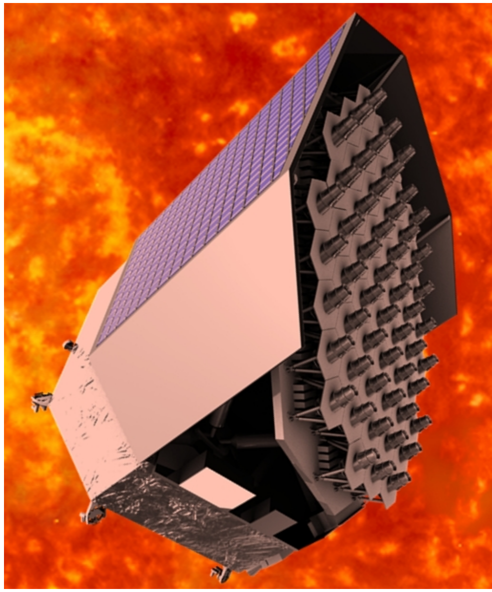
(Selection Oct 4, 2011)

Science objectives:

- Discover and characterise a large number of close-by **transiting exo-planetary systems.**
- Perform **seismic analysis** for the exo-planet host stars (stellar evolution and interior processes).
- Obtain mass, radius, age,... of stars and planets with a precision in the determination of mass and radius of 1% .
- Observation strategy
  - Cover > 50% of sky
  - Observe **many** stars (>20 000), **low noise** level (34 ppm hr^{-1})
  - For **2-3 years continuous observations**
  - Observe bright stars (m_V=4-11)
  - Additional 250000-300000 fainter stars (< 80 ppm hr^{-1})
  - Maximize number of observed **bright stars** enabling required ground based follow up observations

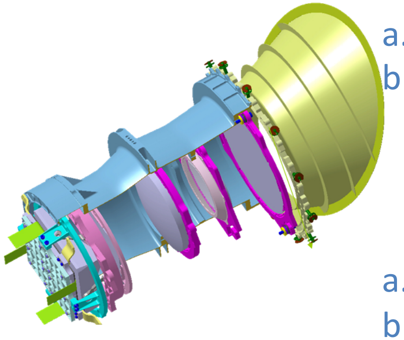


PLATO mission overview - technology



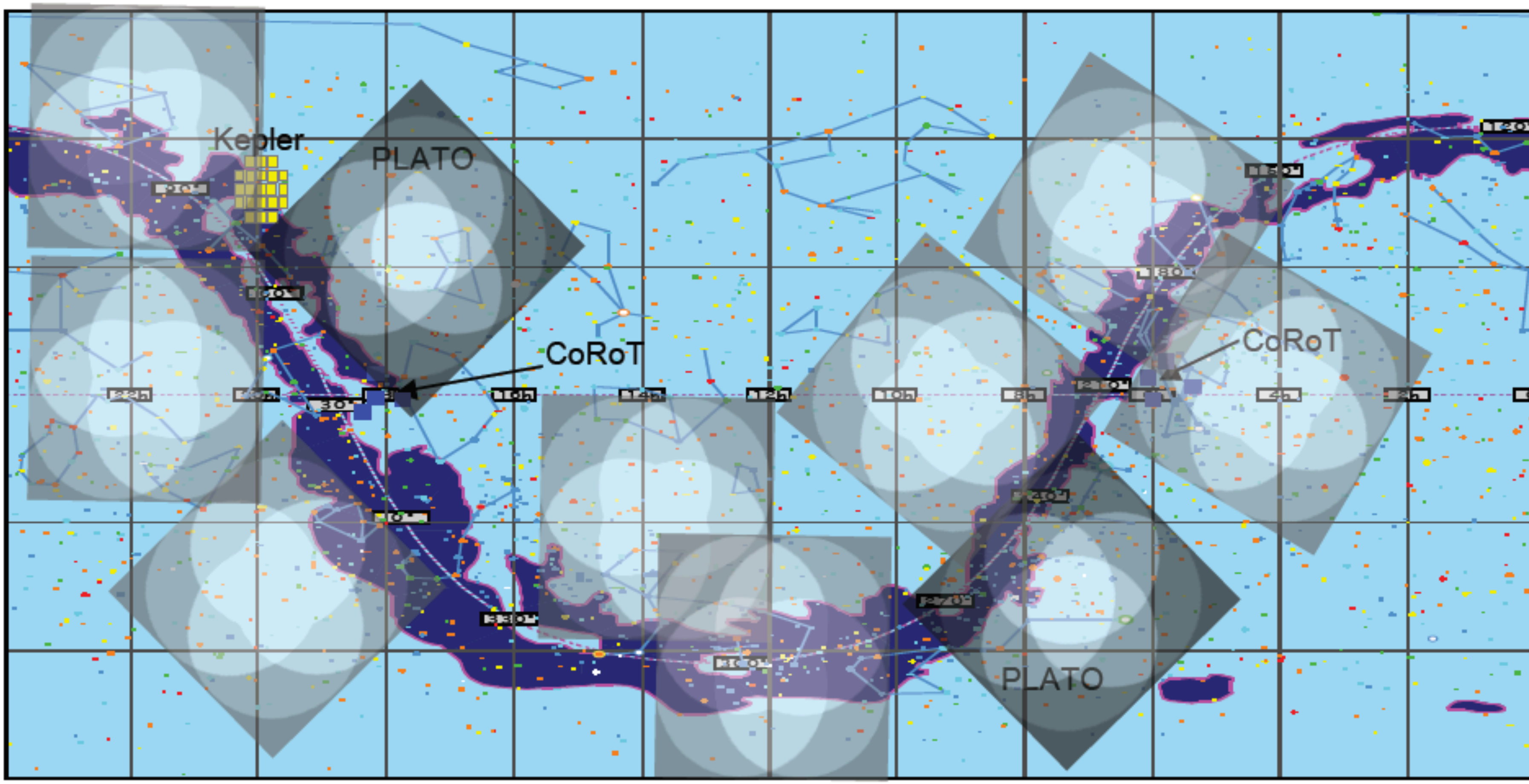
Mission description:

- Launch by end 2018 from Kourou, French Guyana
- Soyuz 2-1b with Fregat-MT upper stage
- Operational orbit: large-amplitude around L2
- Mission life time is 6 years (< 50% coverage); all subsystems sized for 8 years (< 80% coverage) in L2
- Components Technology Readiness Level ≥ 5 before July 2011
- Max launch mass: 2190 kg with adapter
- Power ~ 1.7 kW.



a. Maximise both fov (2500 deg^2) and collecting area.
b. 32+2 cameras (32 in full-frame and 2 in frame-transfer mode; 1+1 operating in loop with ACS).
   - 6 lenses/telescope (1 aspheric); radiation resistant, 120mm entrance pupil
   - mounted individually on optical bench
   - individual baffles for stray-light rejection and thermal dissipation

a. 4 CCD/camera, each CCD (4510×4510 pix, 18 µm).
b. Spectral range: 500 – 1000nm



~ 50% of the sky !

The End