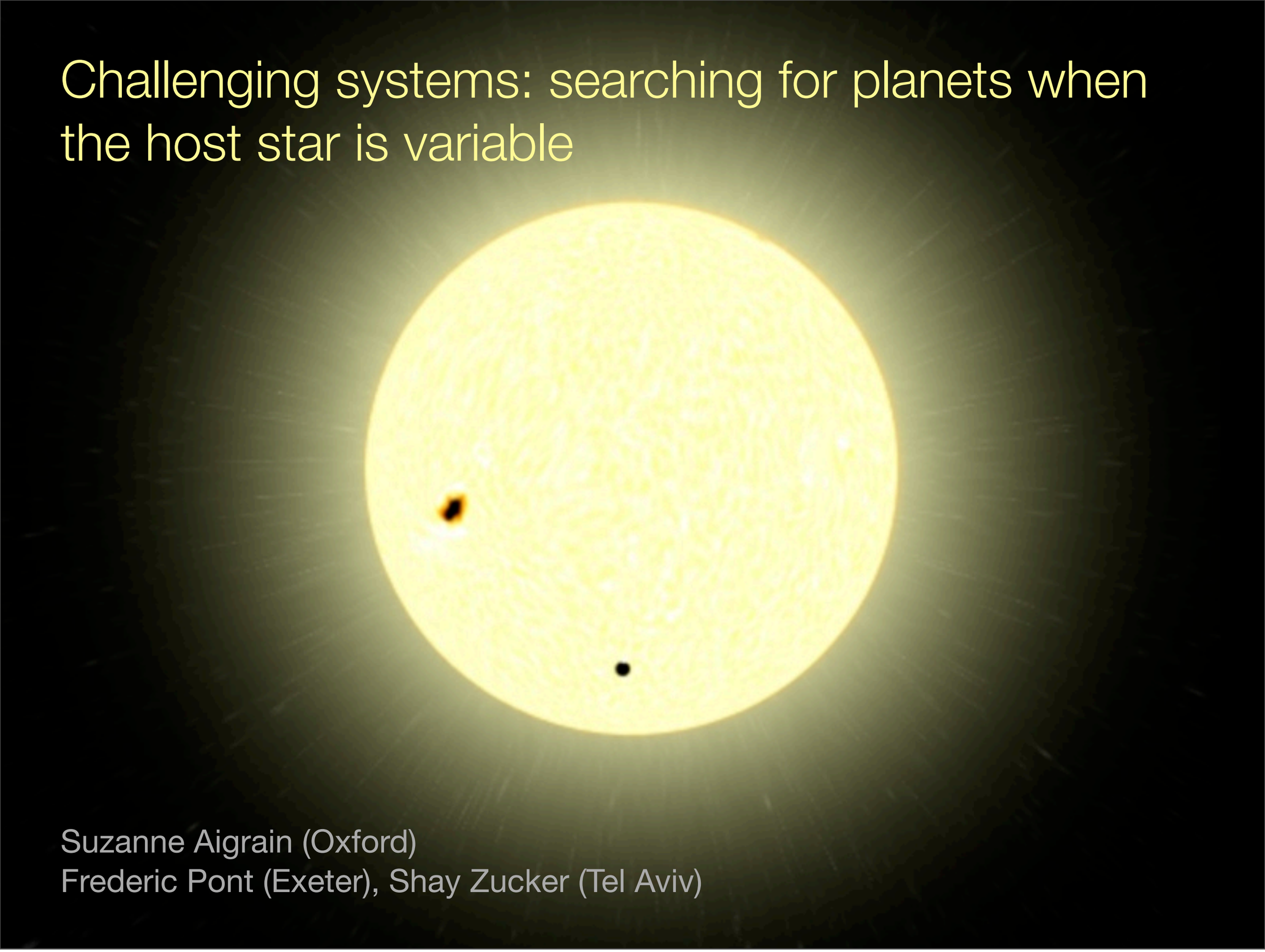
Challenging systems: searching for planets when the host star is variable



Suzanne Aigrain (Oxford)
Frederic Pont (Exeter), Shay Zucker (Tel Aviv)

Planet

Star

Radial Velocities

- period = orbital period
- amplitude = 1–100's m/s

- period ~ rotation period (+ harmonics)
- amplitude = 1–100's m/s

Photometry

- duration = 2–12h
- depth = 0.01–few %

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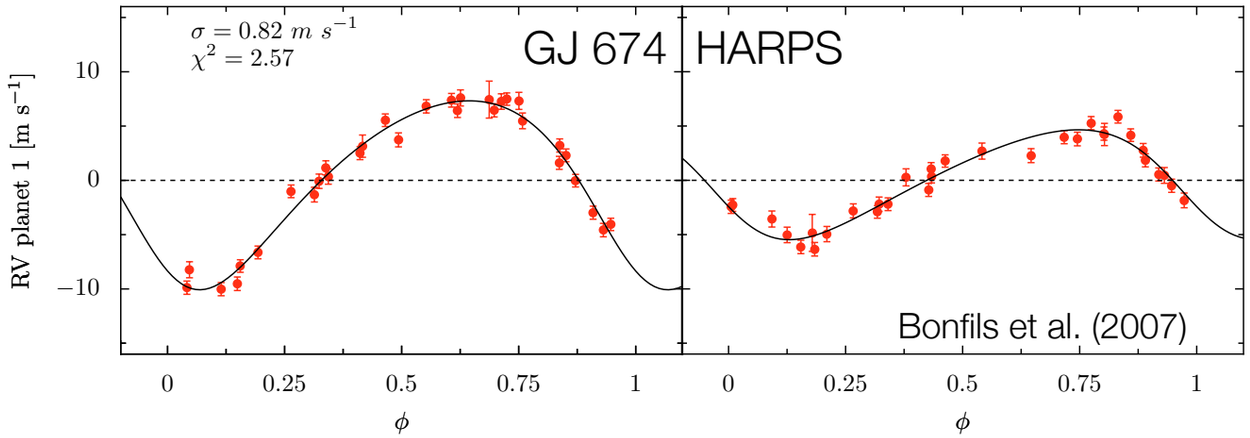

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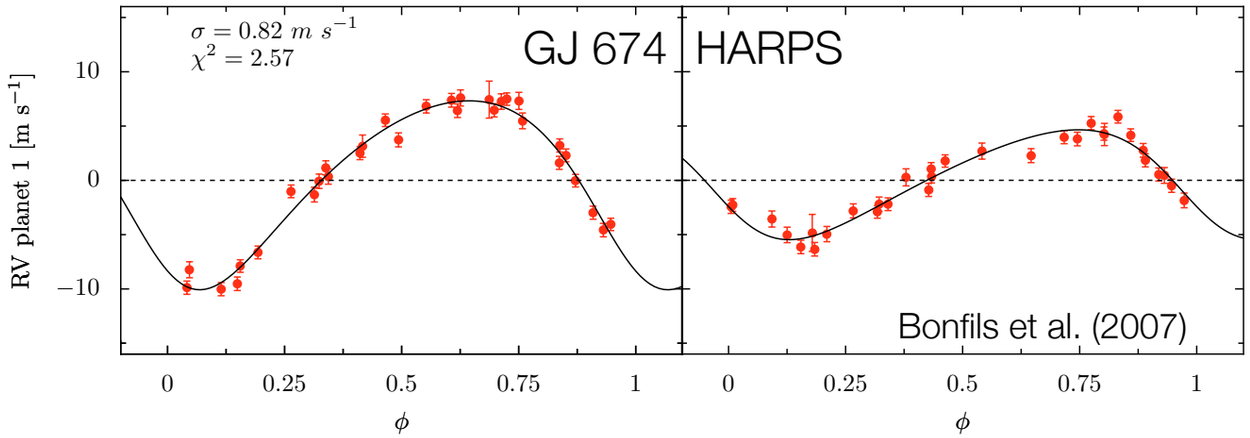

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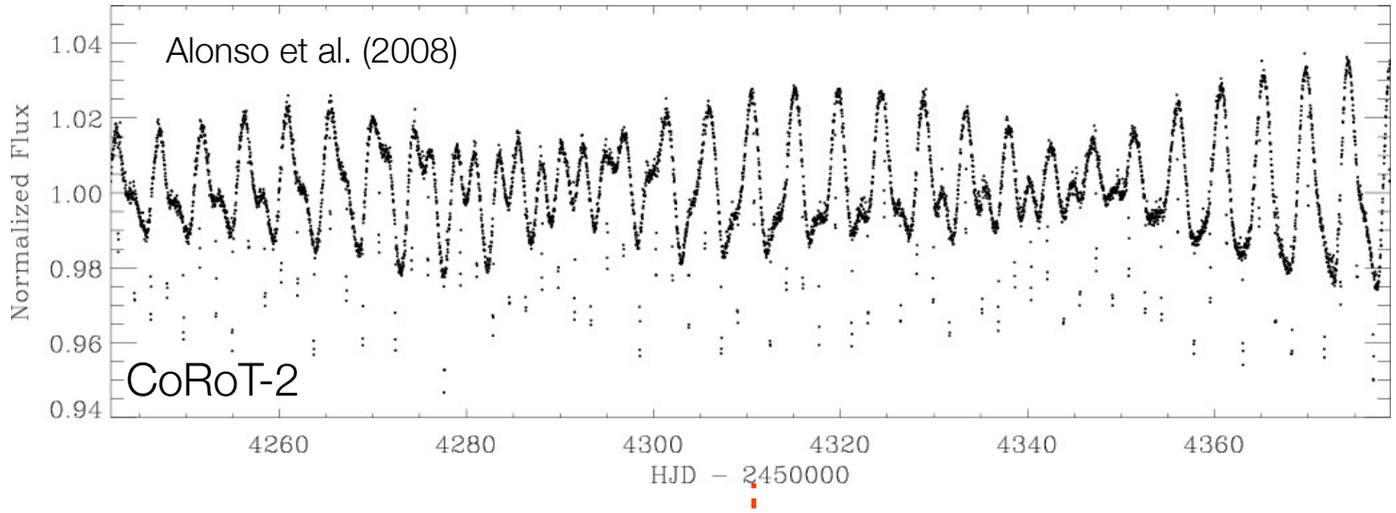

The challenging case of CoRoT-7

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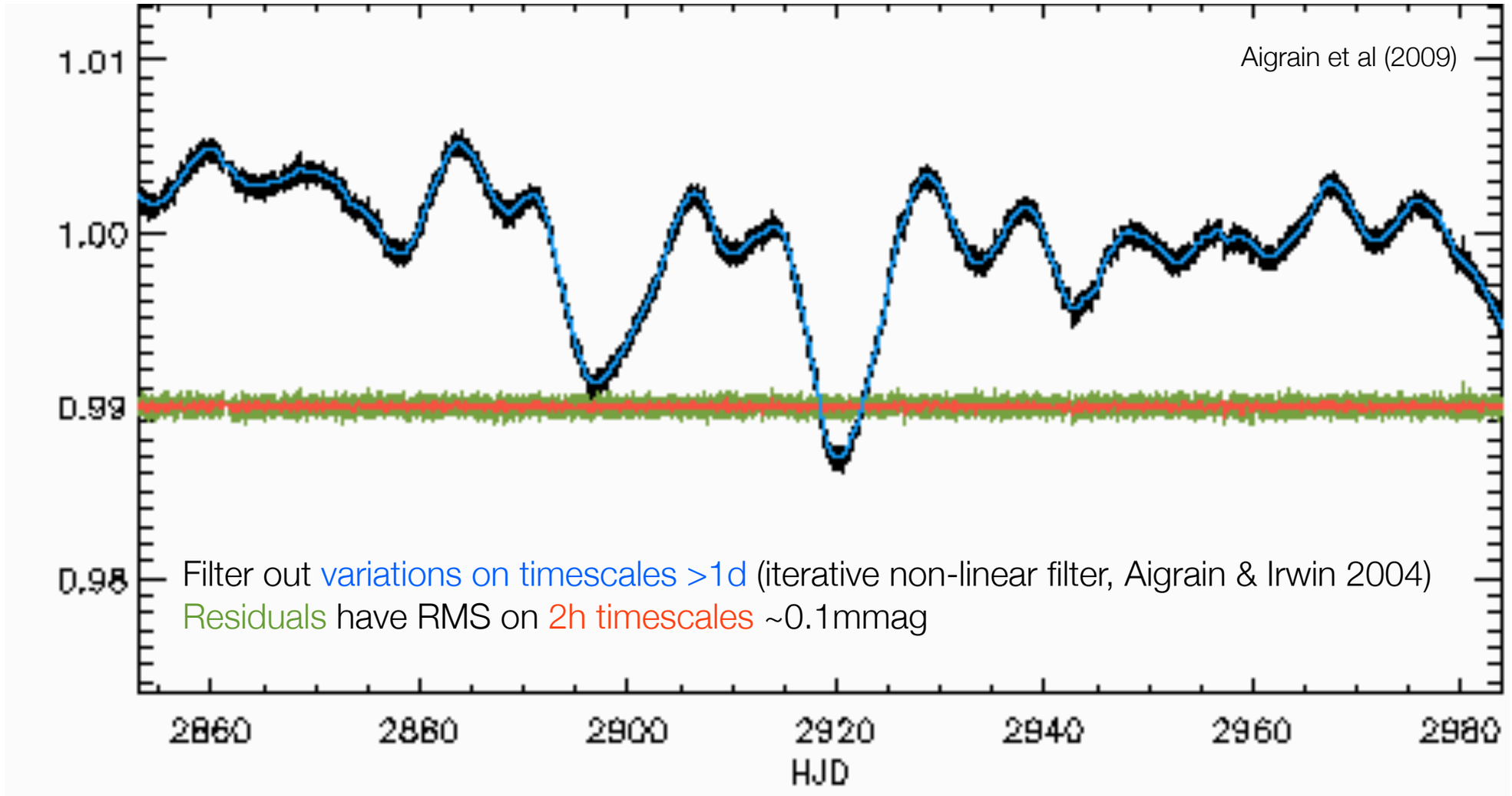

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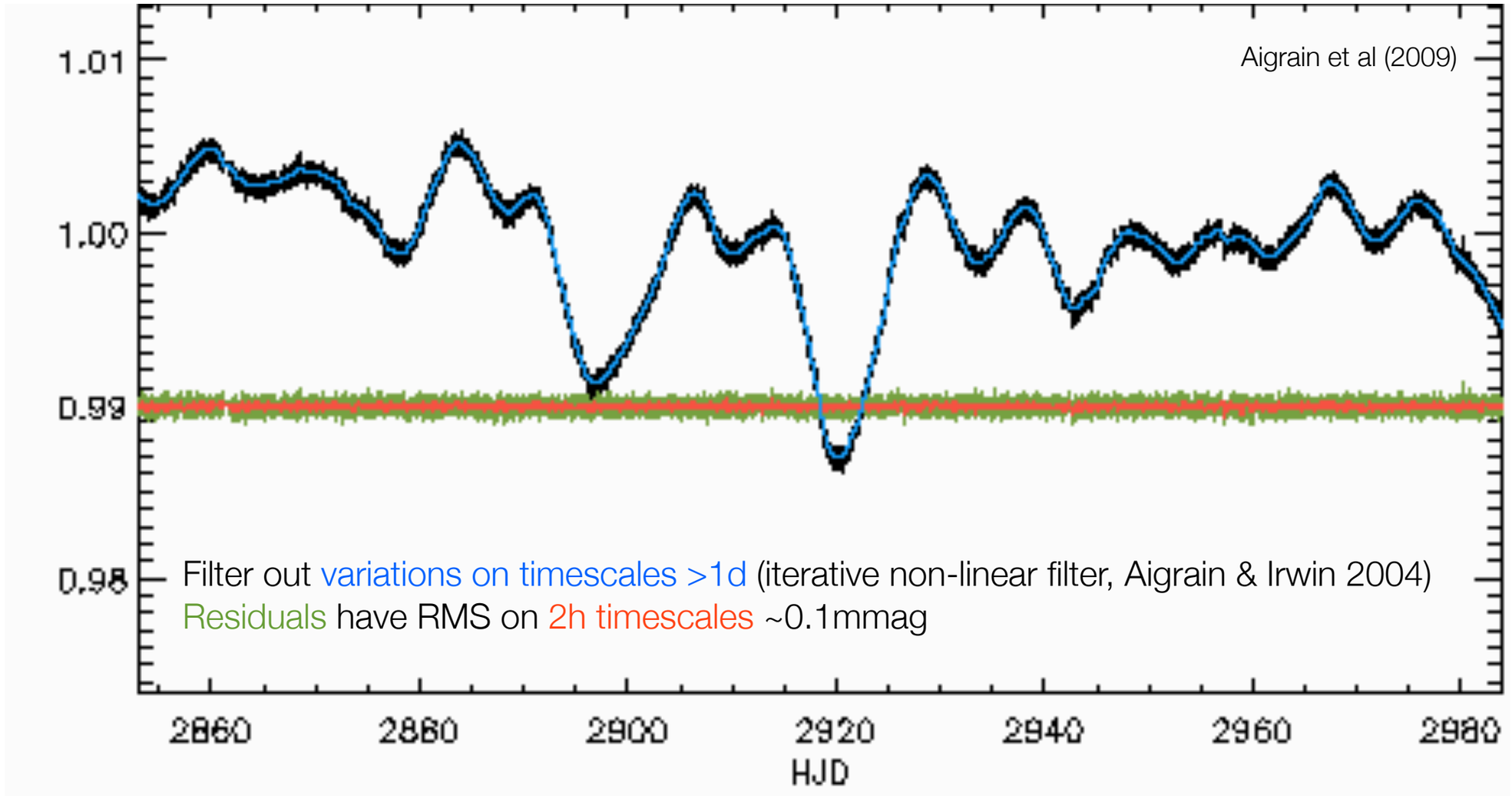
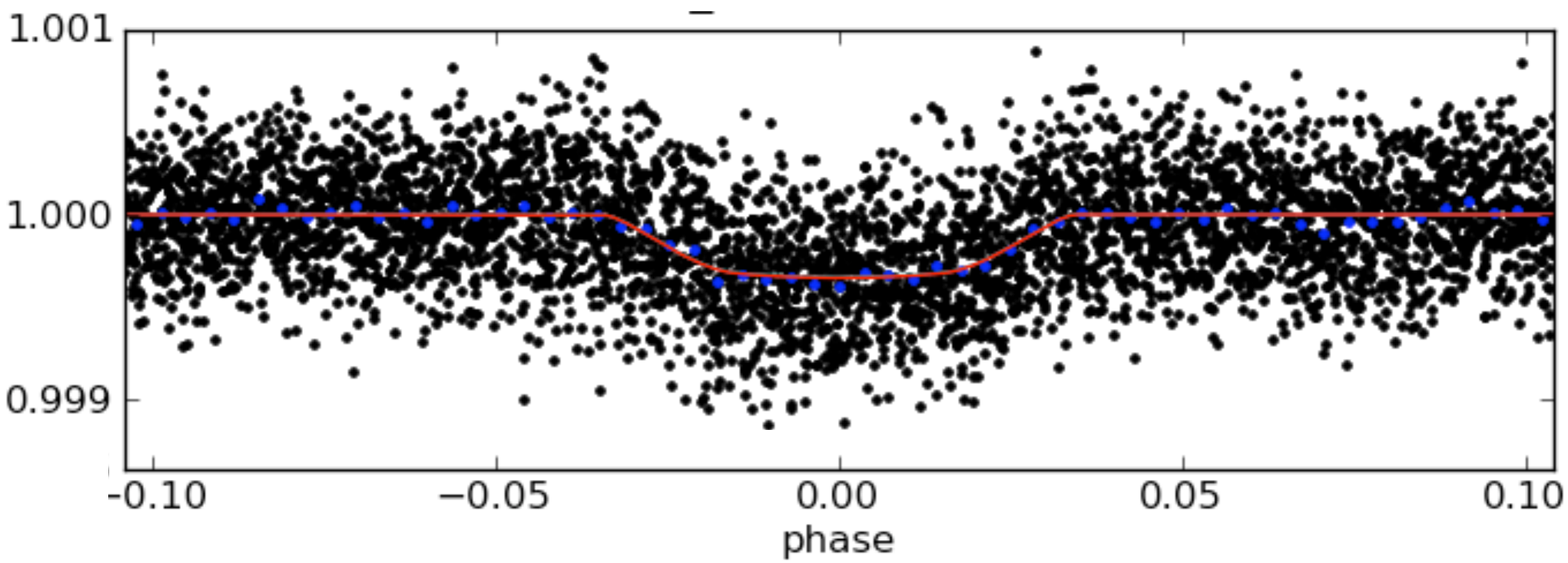


The impact of activity on short-period transit detection is significant only in extreme cases. Is the same true for longer period (hence duration) transits?

The challenging case of CoRoT-7

Search for transits in residuals (least squares box-search or equivalent)
0.3mmag transit at P=0.85d (Leger et al 2009)



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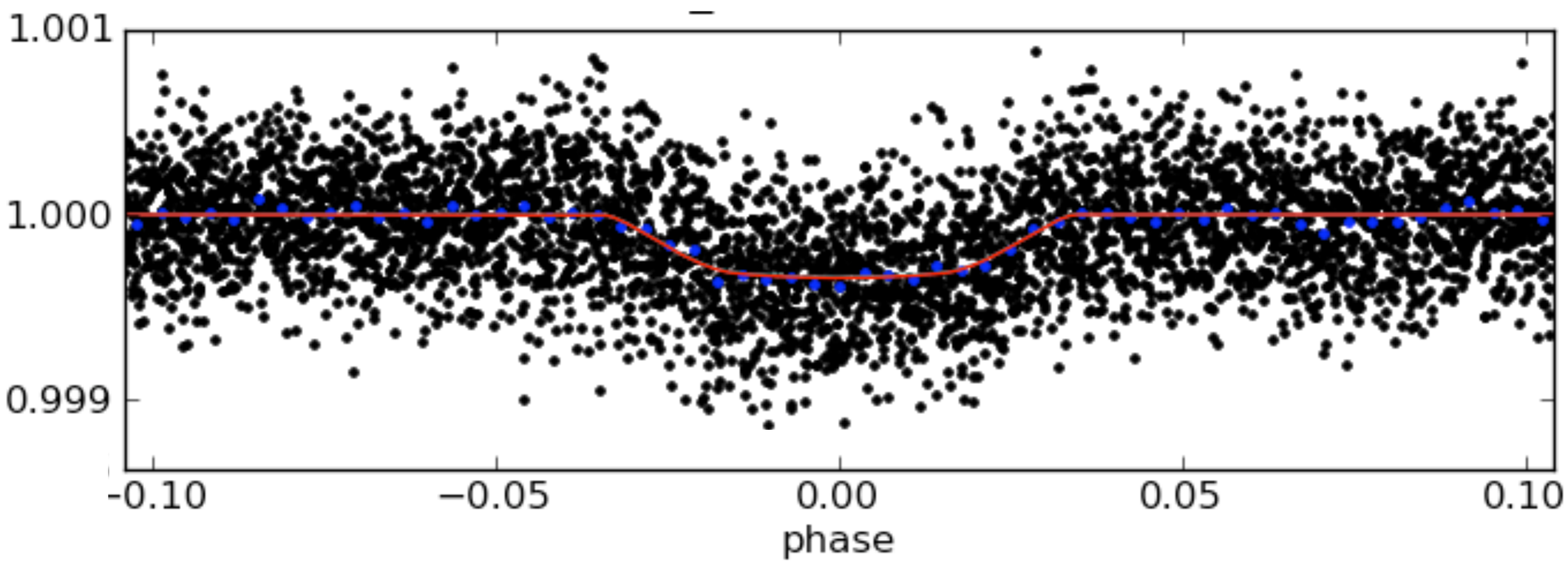

If planetary, companion has R ~ 2 R_{Earth}.
Slightly long ingress/egress for expected stellar radius...
... but small transit timing variations could also cause this.

Tricky RV follow-up

RV detection of a few Earth-mass planet around 11^{th} mag, $0.8M_{Sun}$ star is challenging even without activity.

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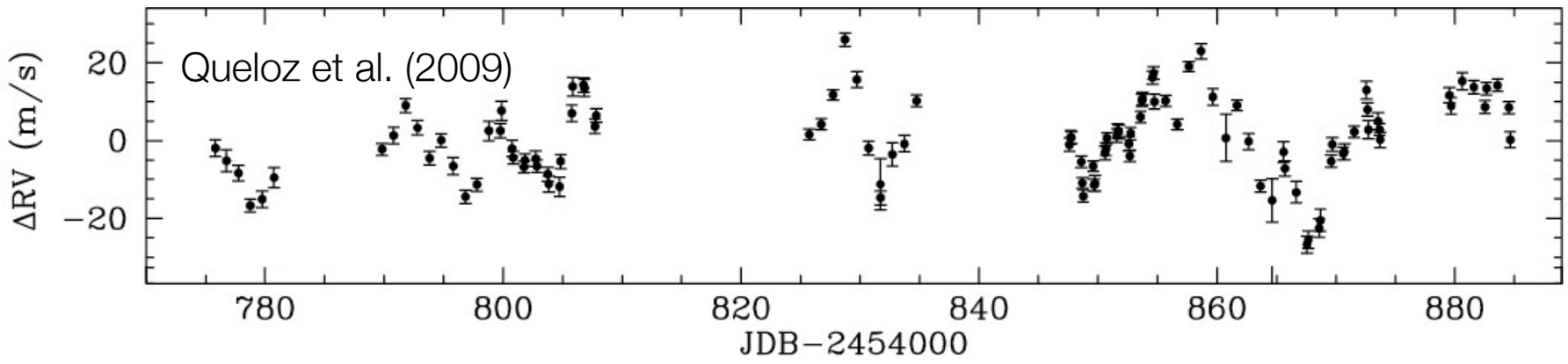

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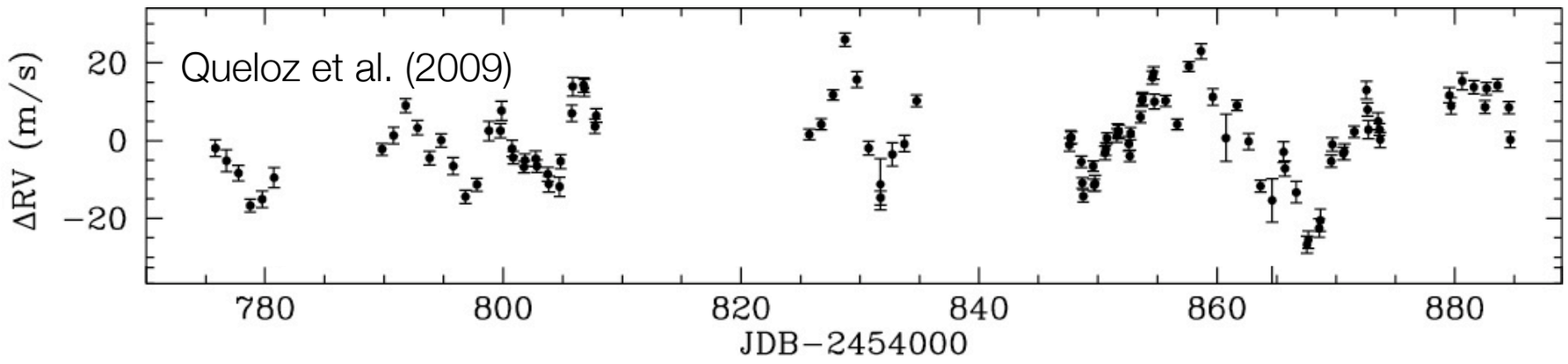

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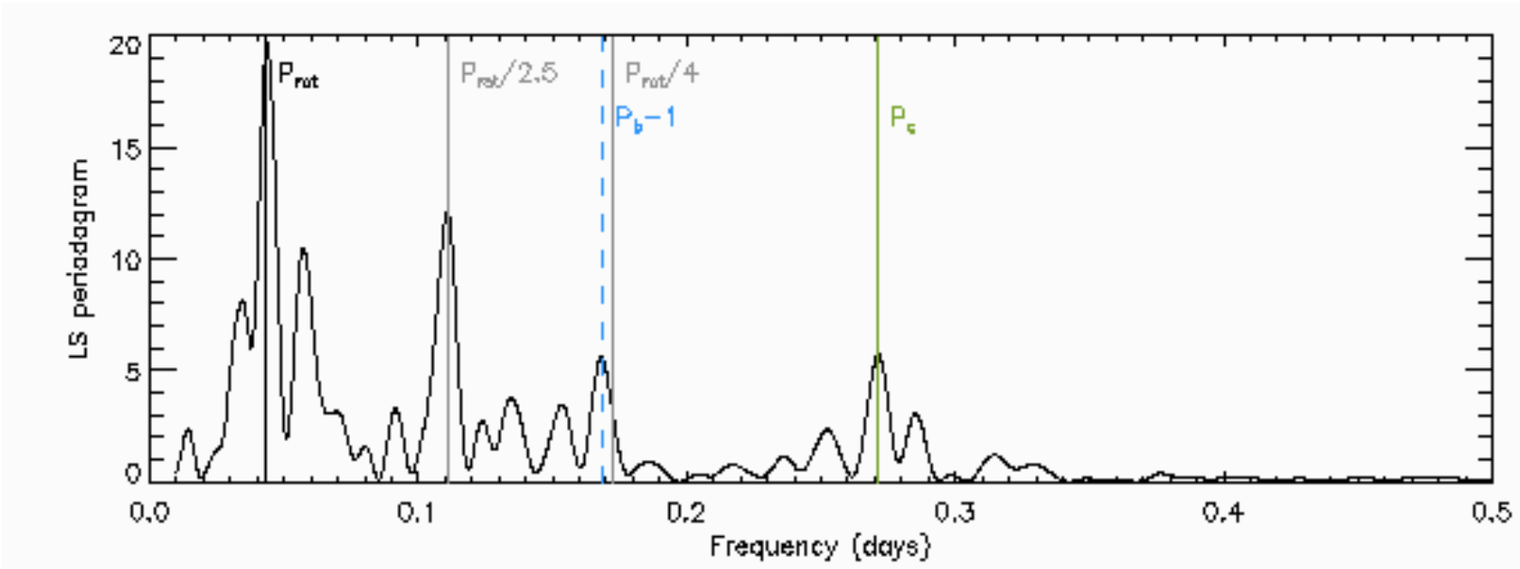

HARPS RV time series contains signal at ~0.85d (or its 1day alias), but how much of that comes from activity?
There is also an un-explained peak at ~3.7d.

Spectroscopic activity diagnostics

Chromospheric activity indicators and bissector span can be used to diagnose and in some cases correct RV time-series for activity (Boisse et al. 2008) ... but correction not demonstrated at better than few m/s level.

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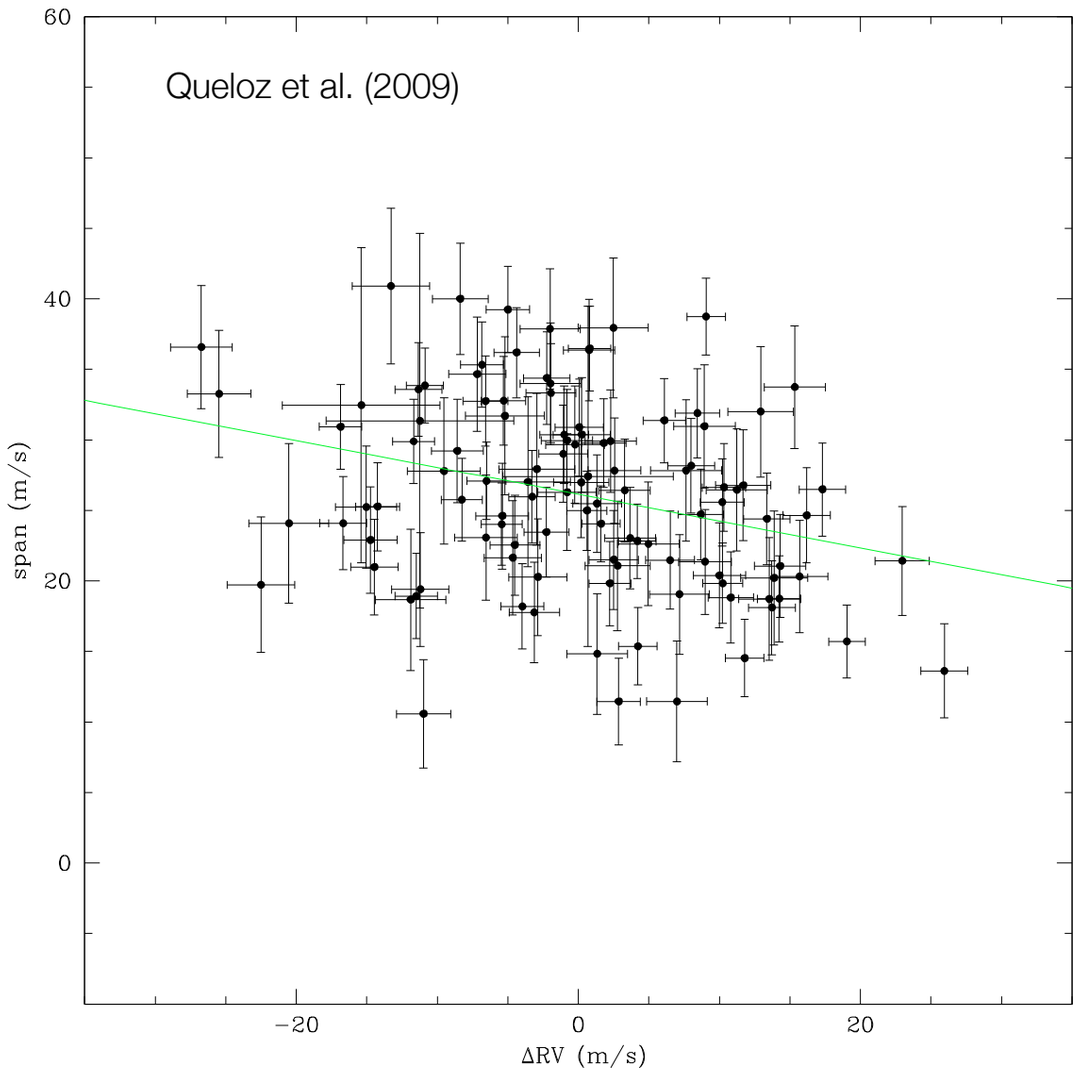

Correlation is too messy to be used in CoRoT-7 dataset.

Harmonic filtering

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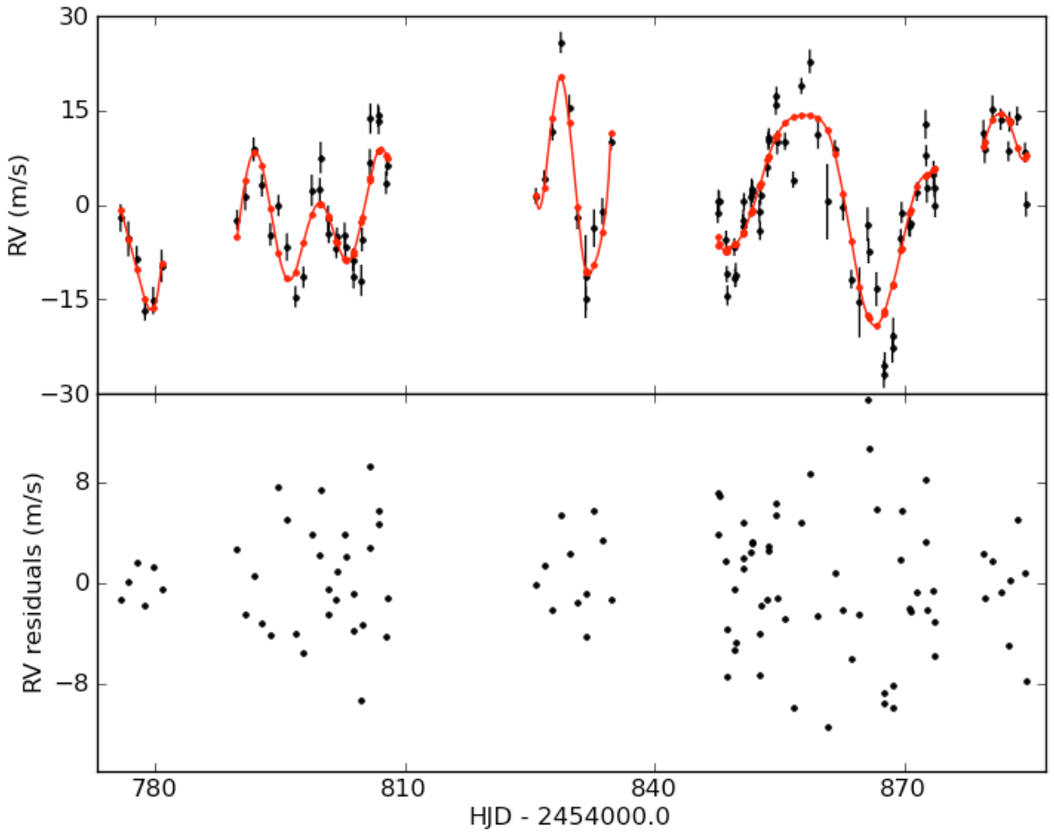

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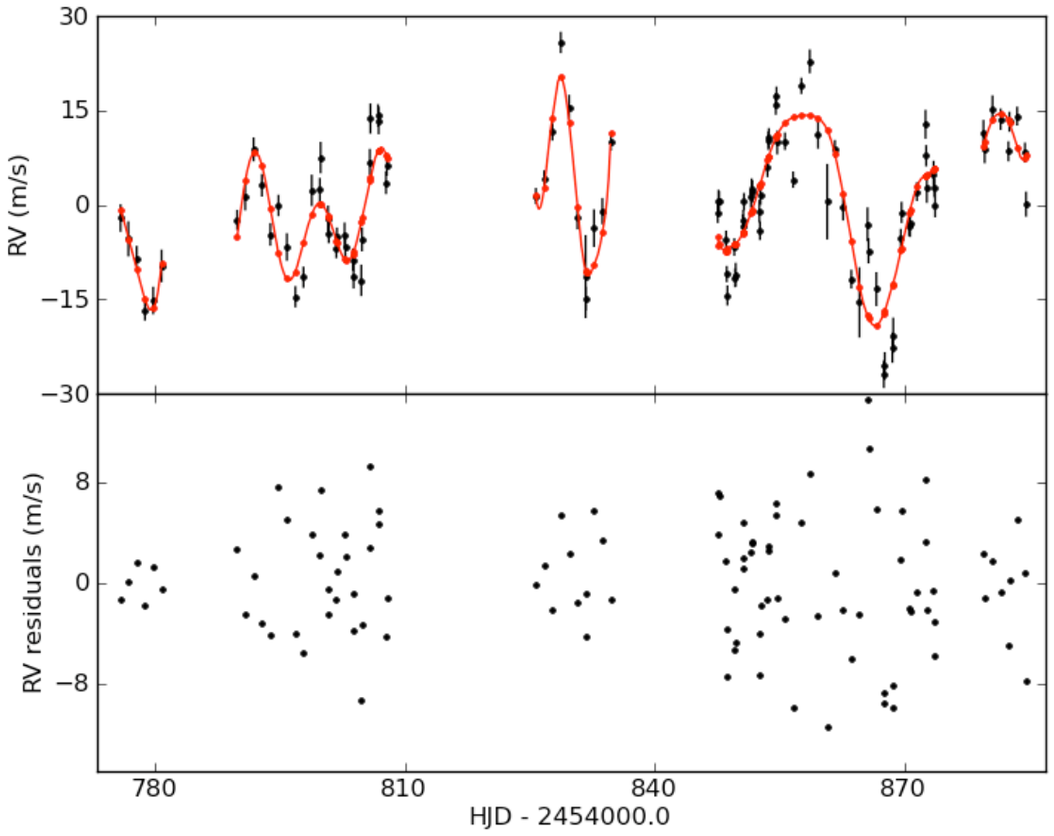

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Hatzes et al. (2010) even find a 3rd planet at P~9d using a CLEAN approach (successive fitting and subtraction of sinusoids at most significant periods).

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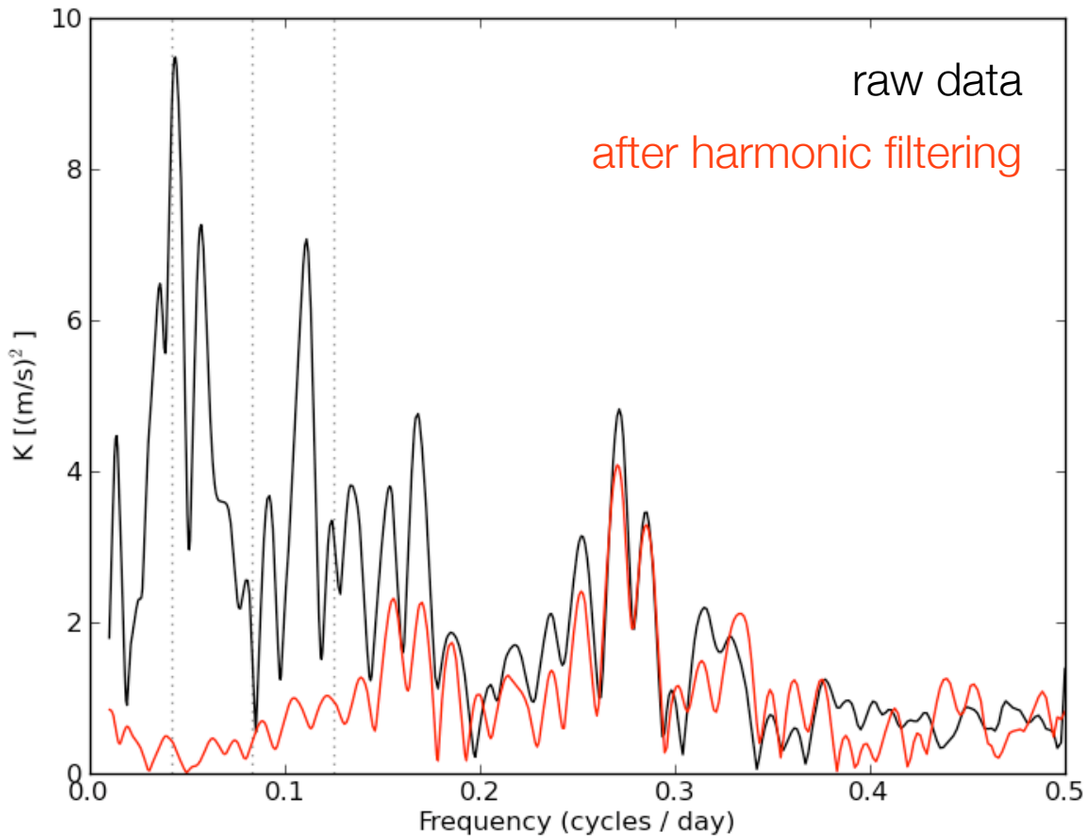

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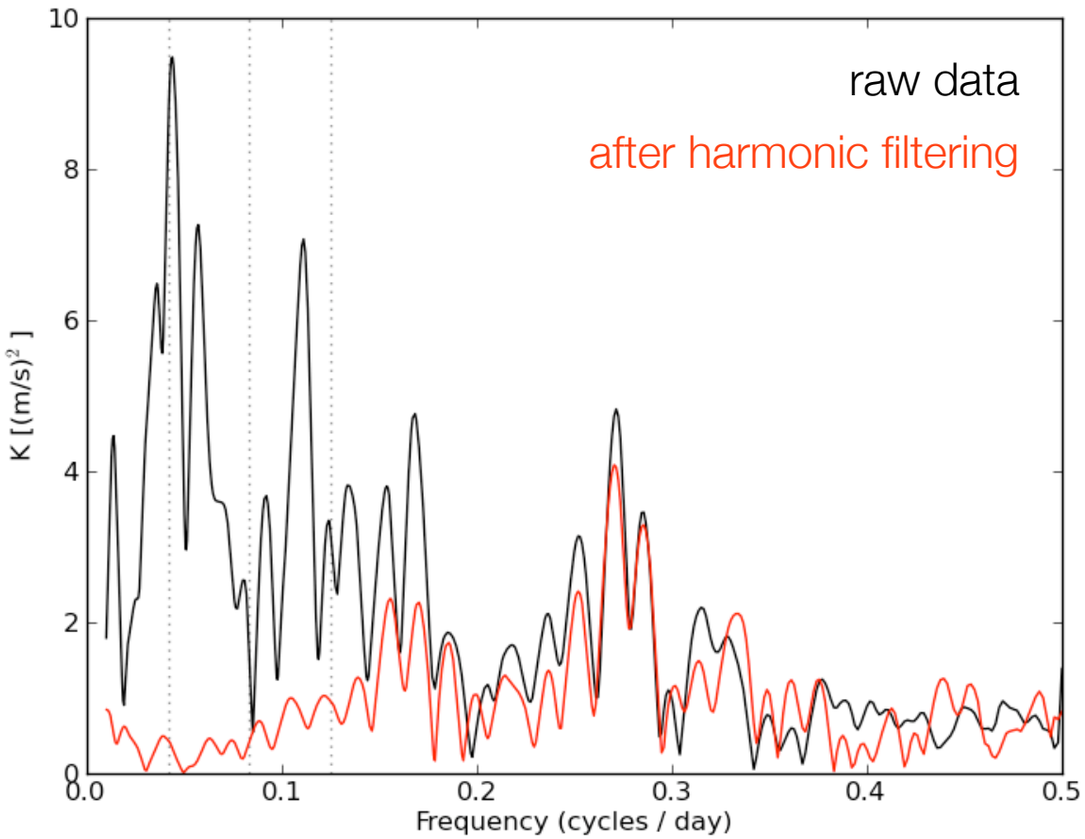

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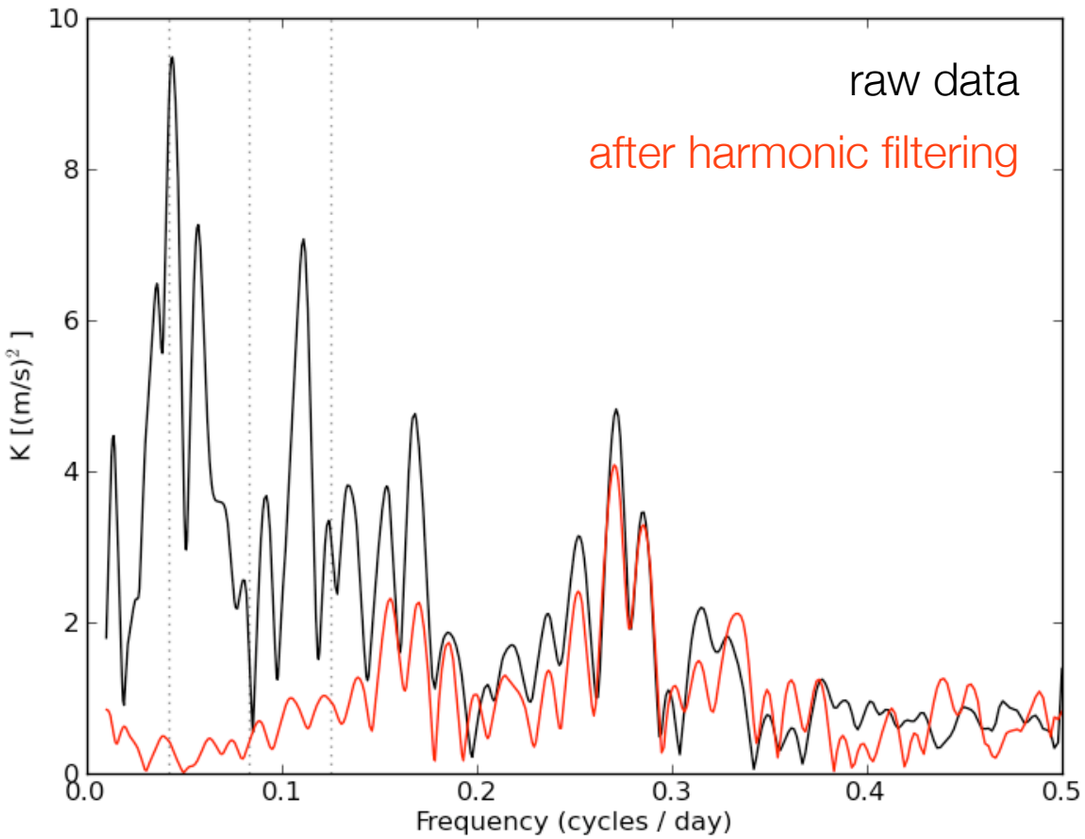

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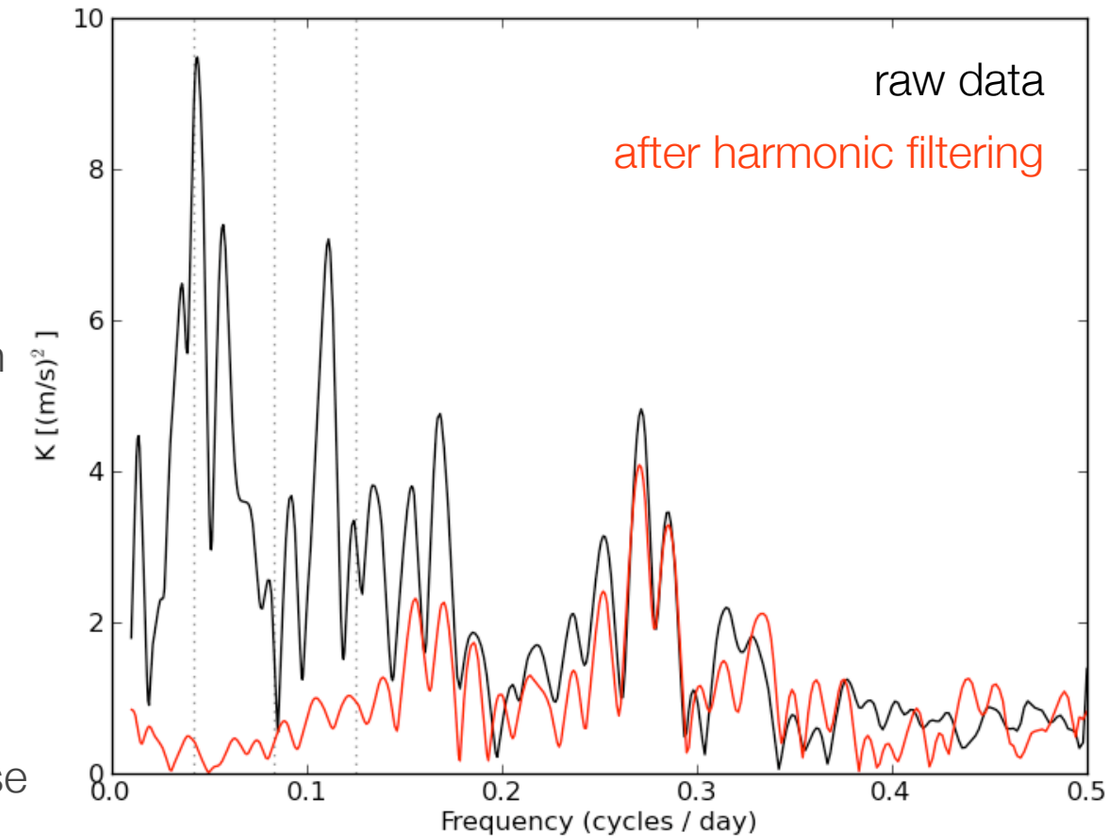

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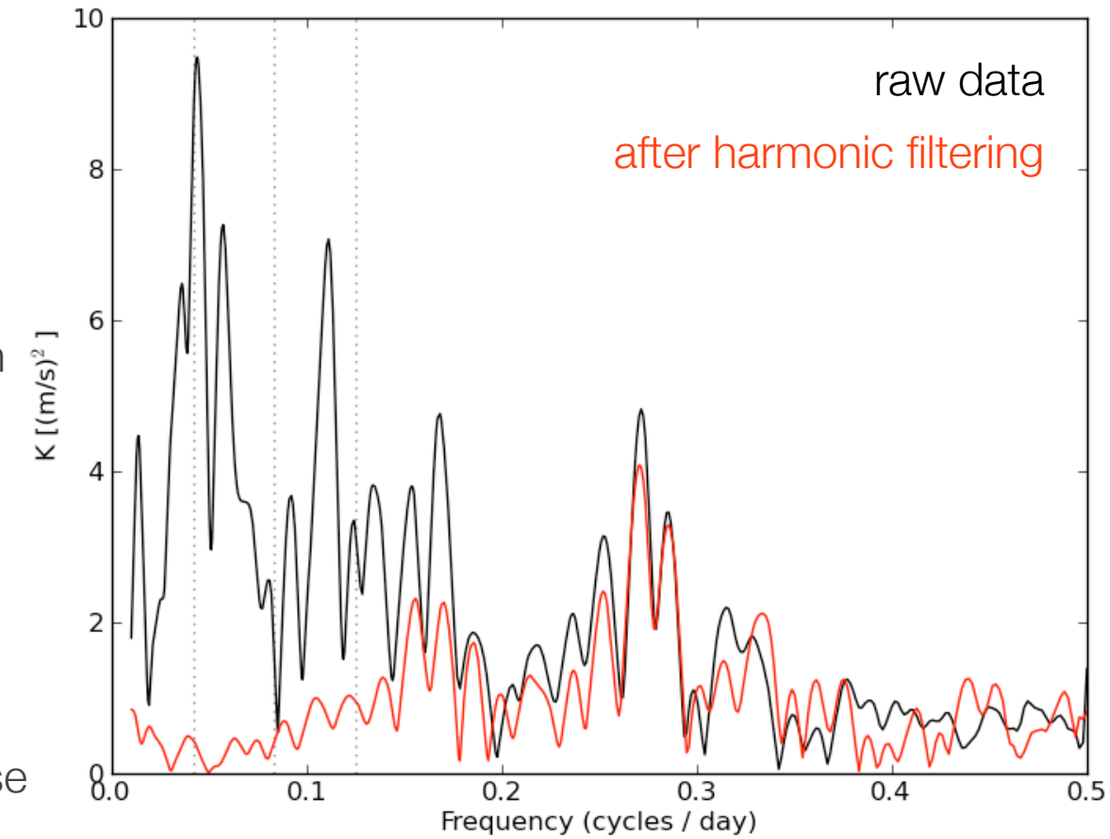

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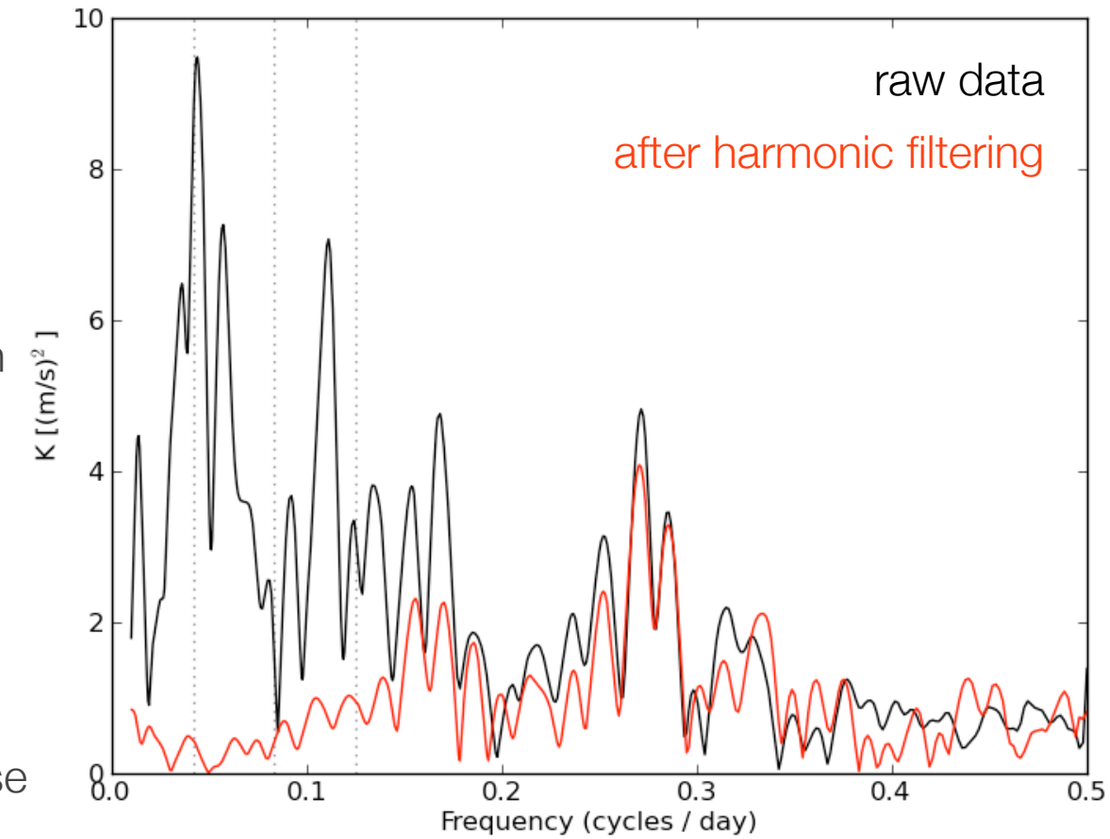

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- There is no good way to estimate how much of the signal removed or added the period of CoRoT-7b is of planetary origin. Queloz et al. (2009) apply a correction by a factor ~2, without justification.

Can we use photometry to predict RVs?

Lanza et al. (2010) modelled the expected activity signal by fitting a model with a few active regions to the CoRoT LC. This kind of approach works well to reproduce the Sun's LC (Lanza et al. 2004, 2005) and RV (Meunier et al. 2010). Problem: degeneracy, some parameters must be fixed (e.g. number of active regions).

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Aigrain, Pont & Zucker (in prep)

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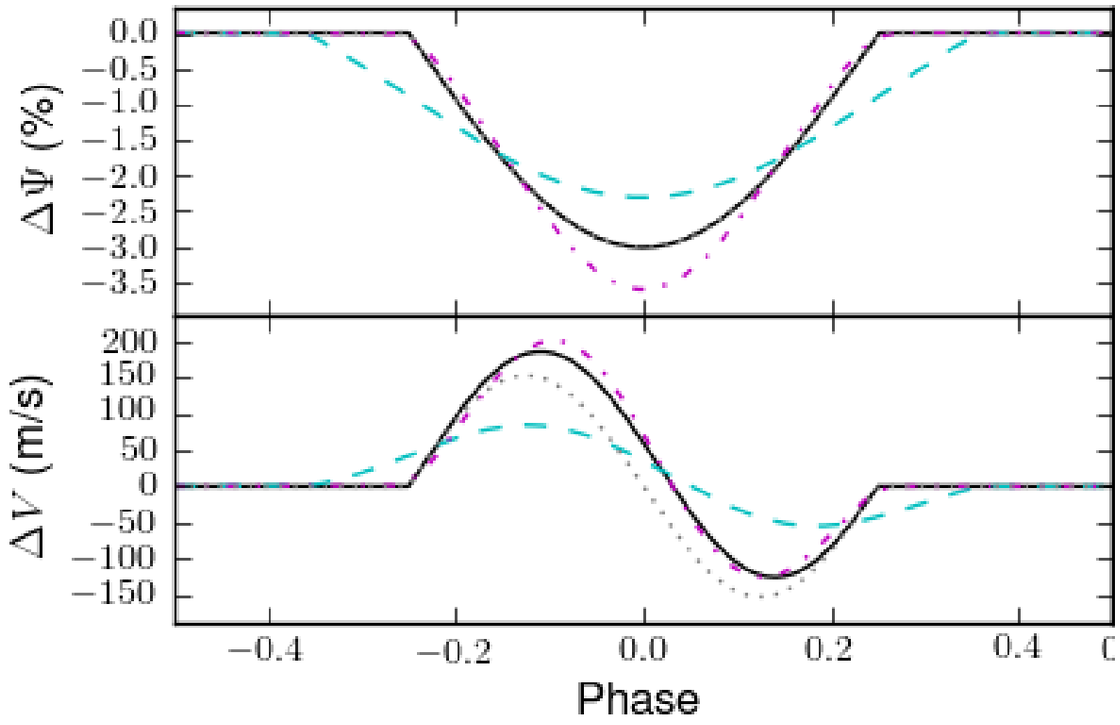

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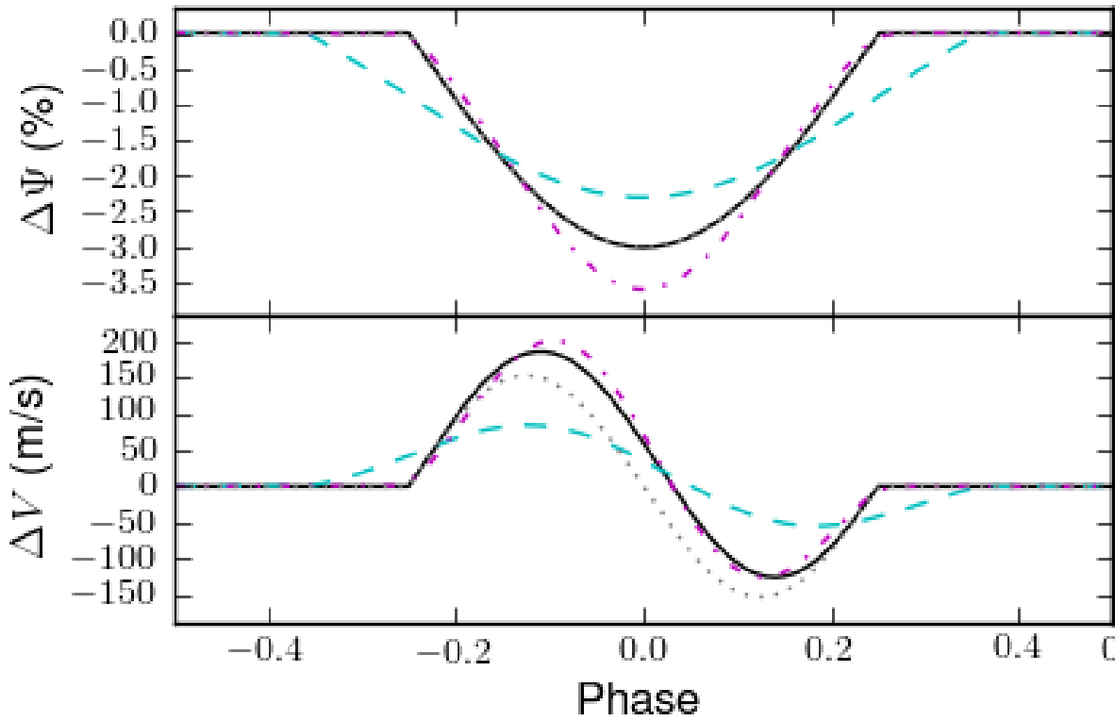

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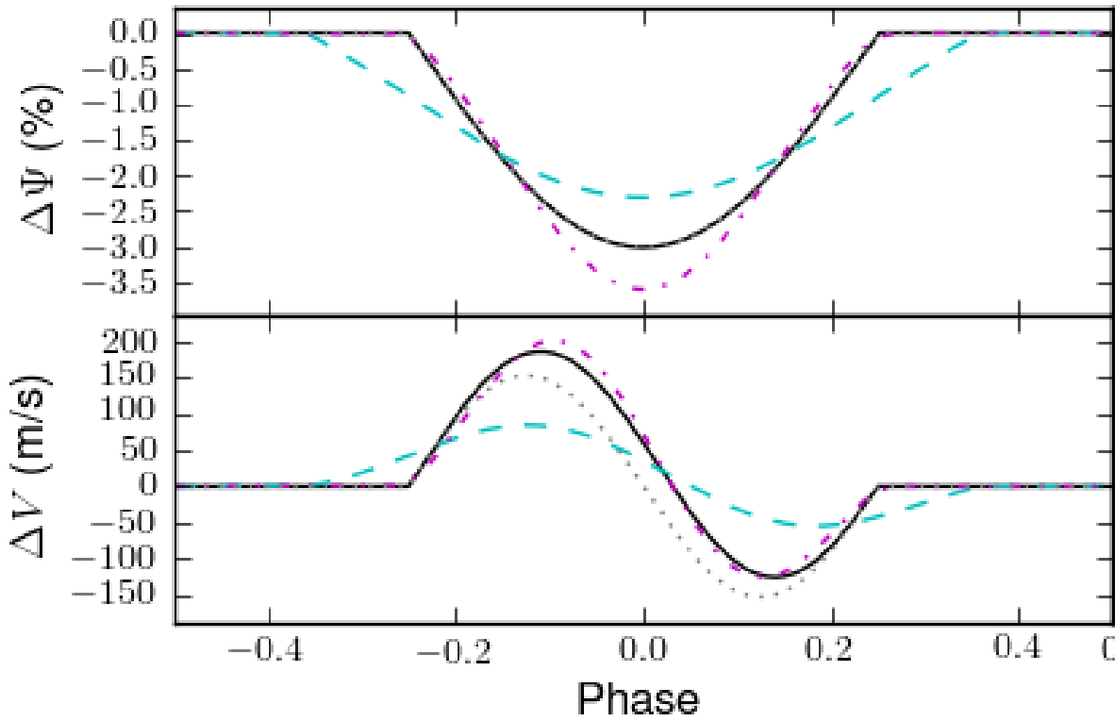

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Then $\Delta V(\mathrm{i}) \propto F(t)\, V_{orb}$. In general:

$$\Delta V(t) \propto F(t)\,\dot{F}(t)$$

FF’ method example: HD 189733

Black points: MOST photometry

Grey line: smoothed version used to estimate F(t) and F’(t).

Grey points: SOPHIE RVs

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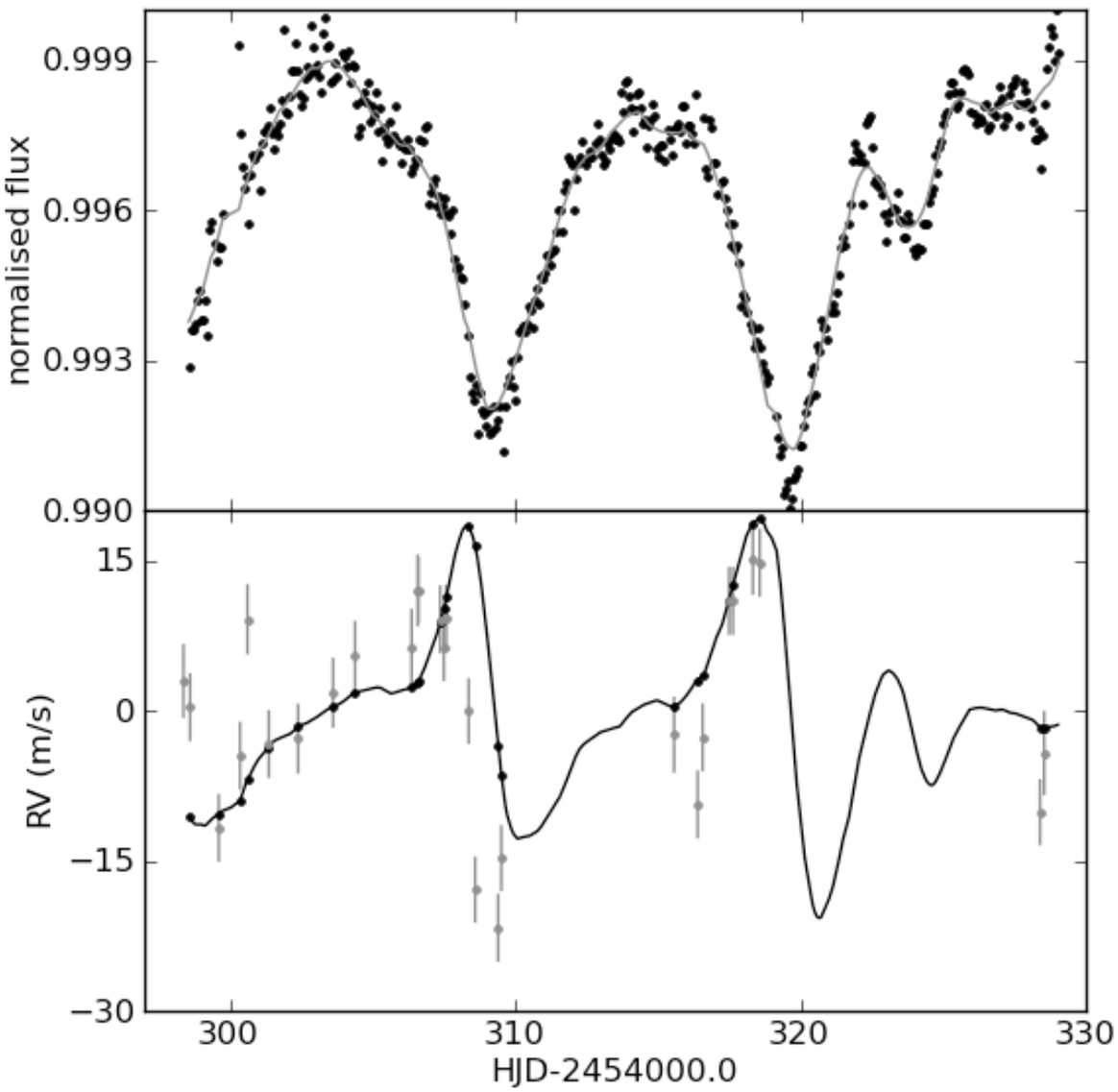
Data from Boisse et al. (2008)



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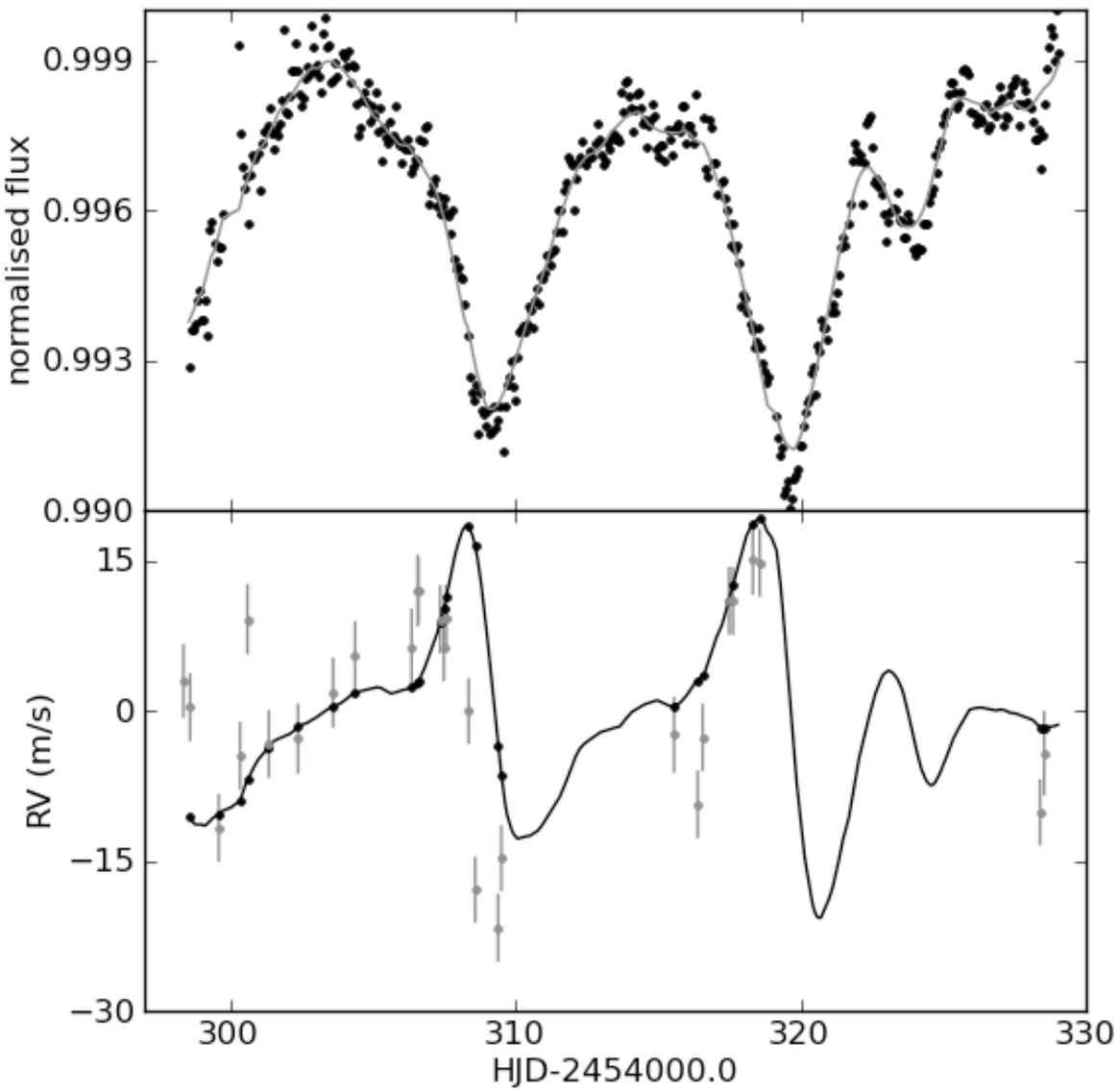

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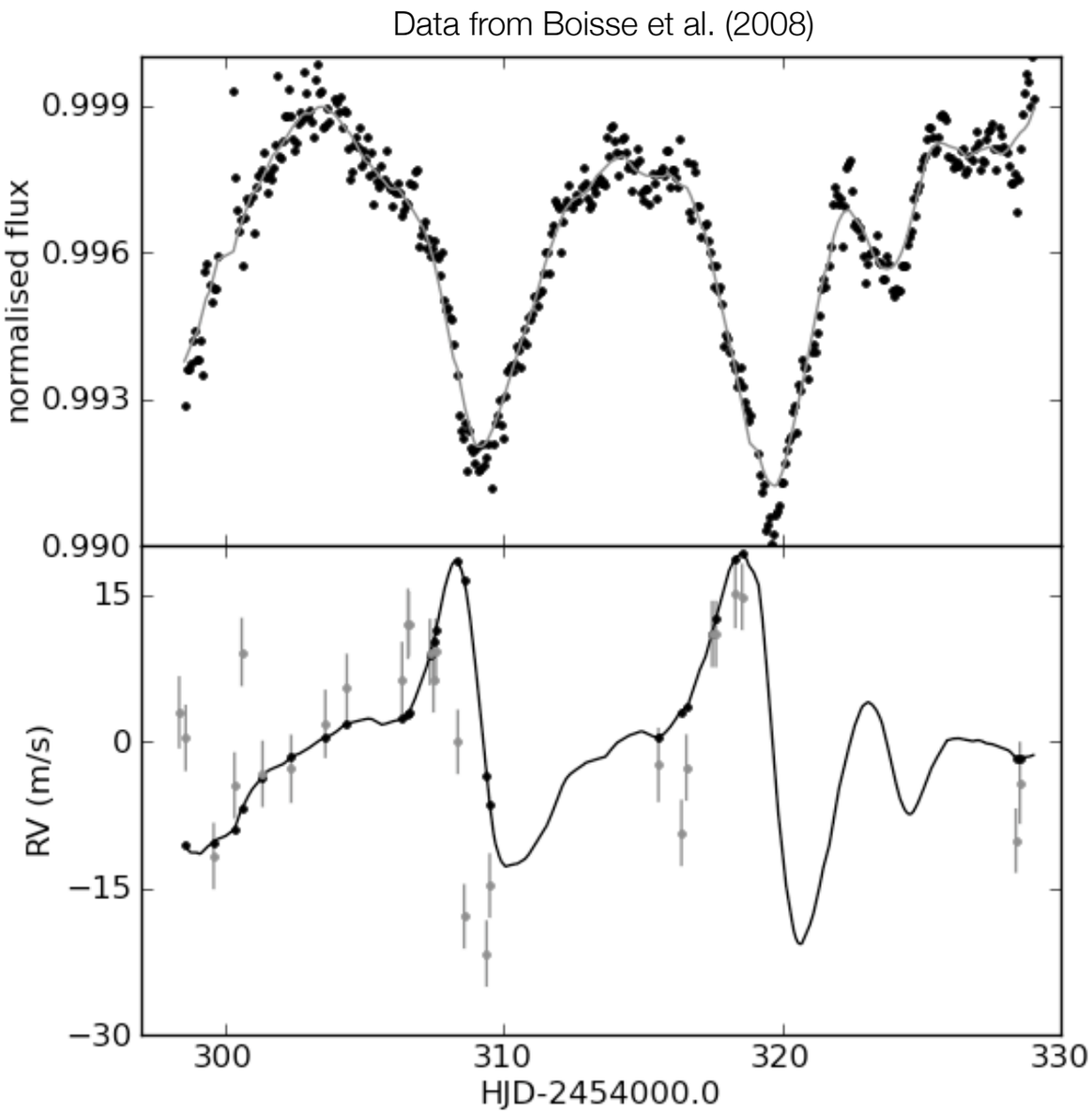

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FF’ be applied to any well sampled LC, but ... the RV and LC data are not simultaneous for CoRoT-7b

A “minimum assumption” many-spot model

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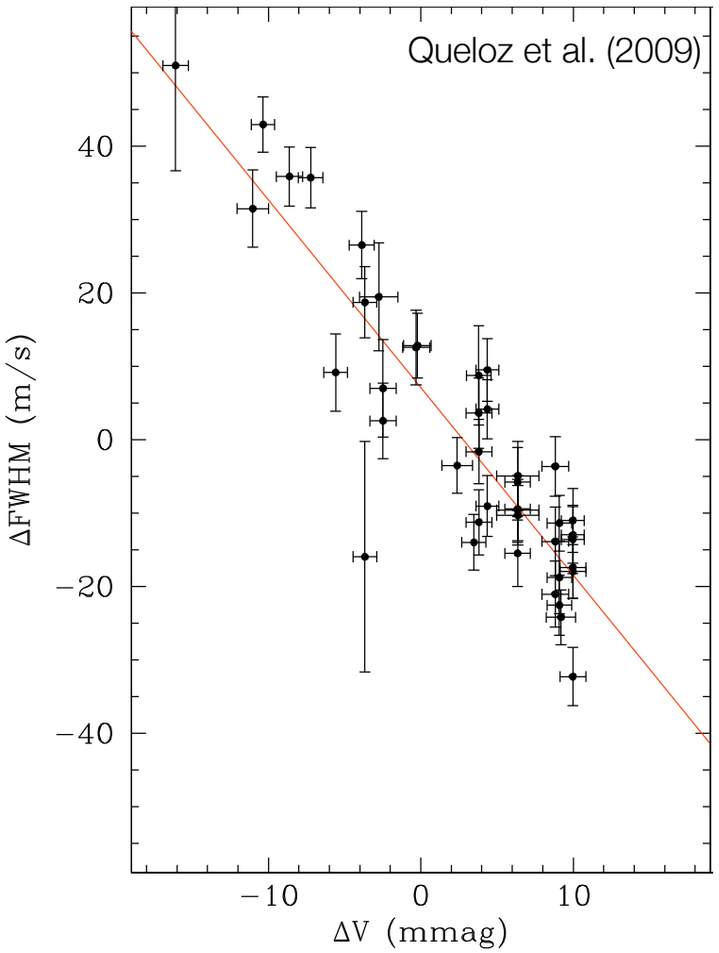
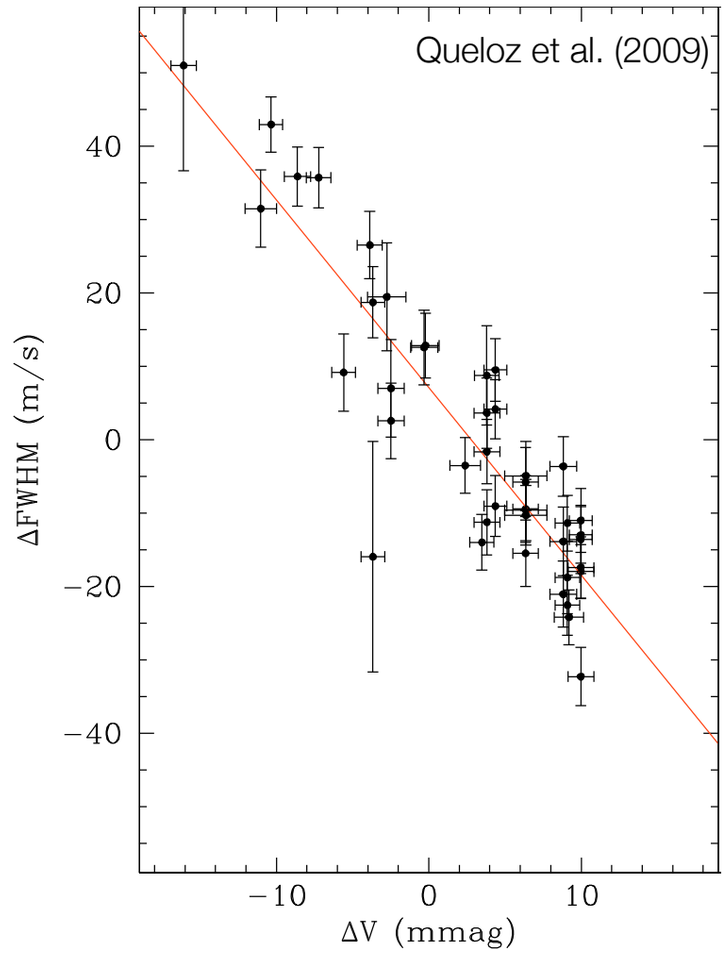
FWHM of CCF is good proxy for photometry



A “minimum assumption” many-spot model

FWHM of CCF is good proxy for photometry

Fit “ proxy LC” with between 3 and 200 spots each hiding a fraction *df* of the stellar flux, which evolves according to a Gaussian. Spot longitude and peak time are drawn from uniform distribution, *df* and lifetime from logarithmic distribution. Predict RV and bissector span.



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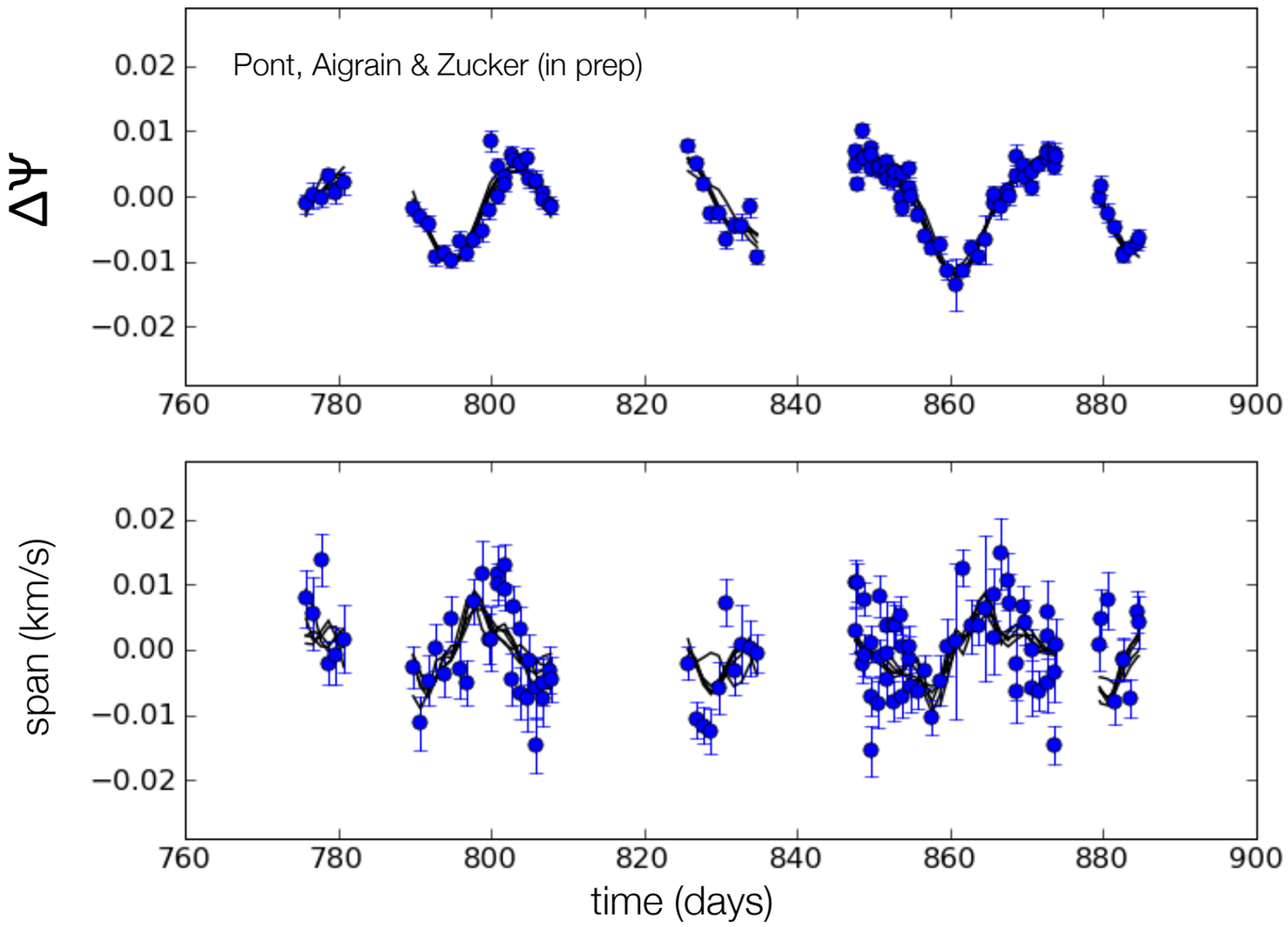

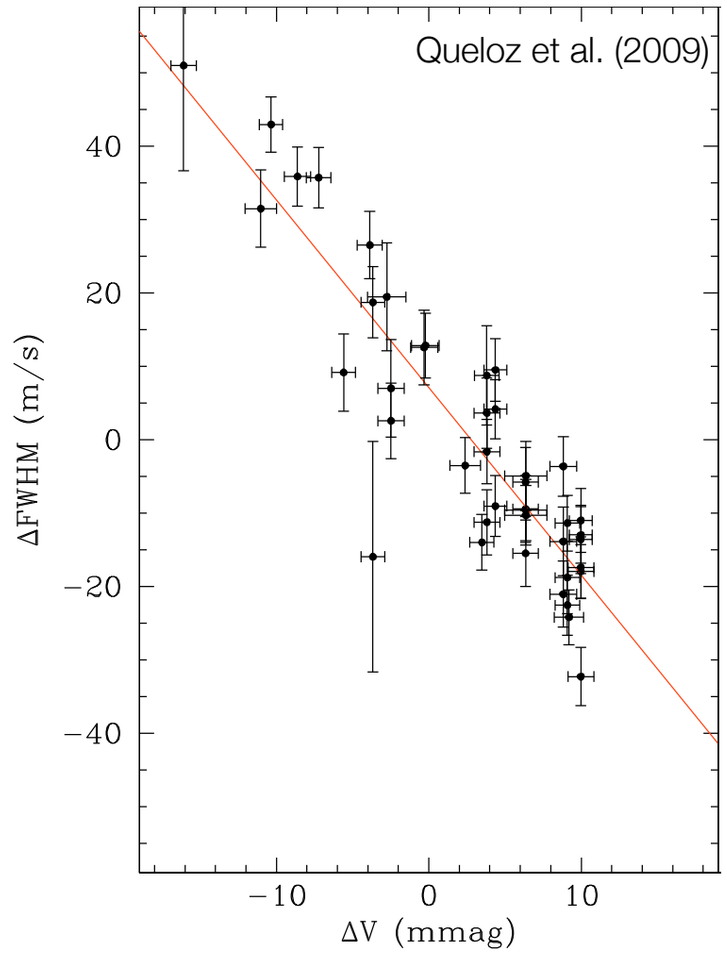

Many possible realisations fit data (6 shown here). Vary number of spots and initial parameter set to identify representative set of solutions (in the spirit of MaxEnt image reconstruction).

Bissector span predicted very well whatever spot distribution.

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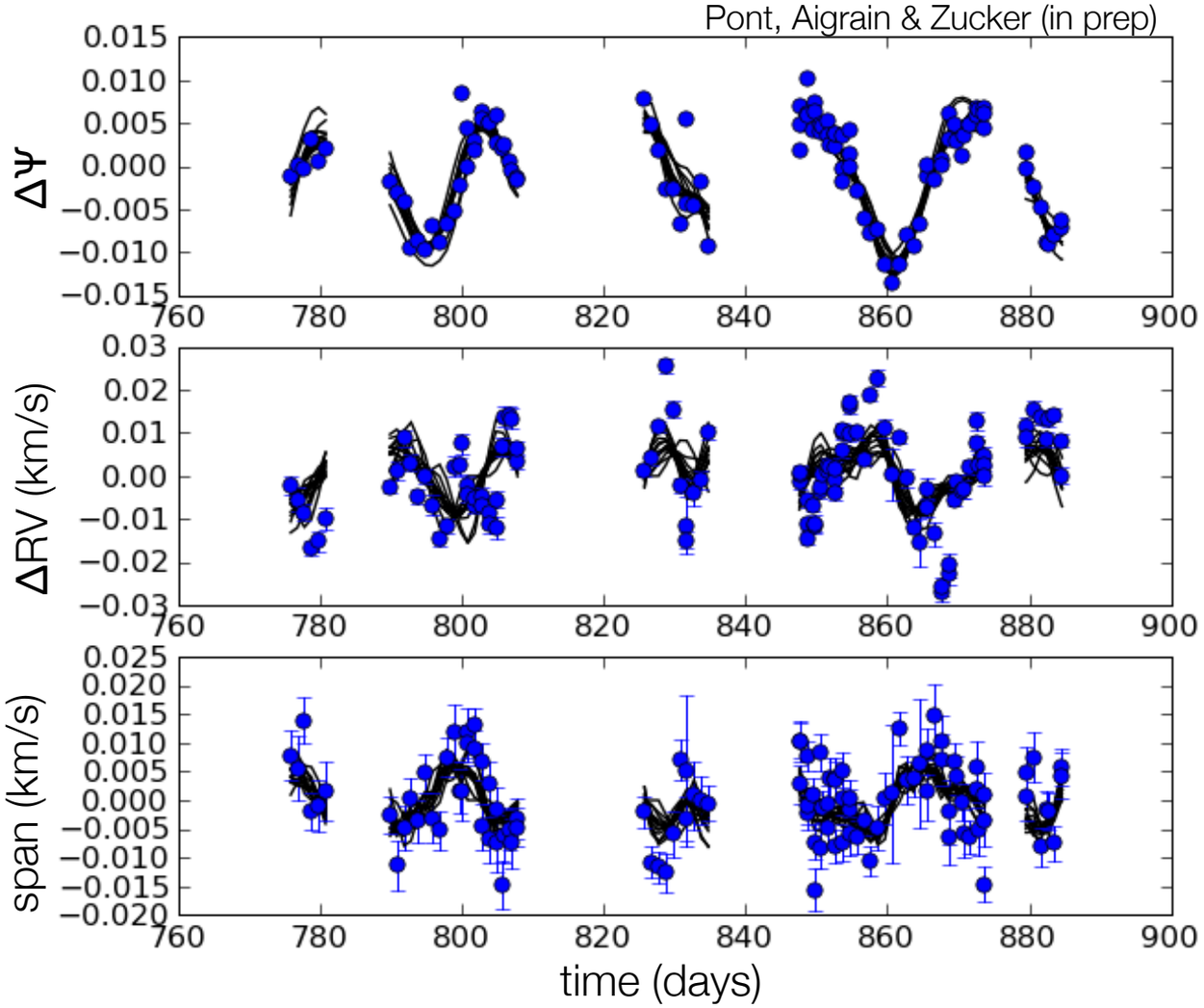
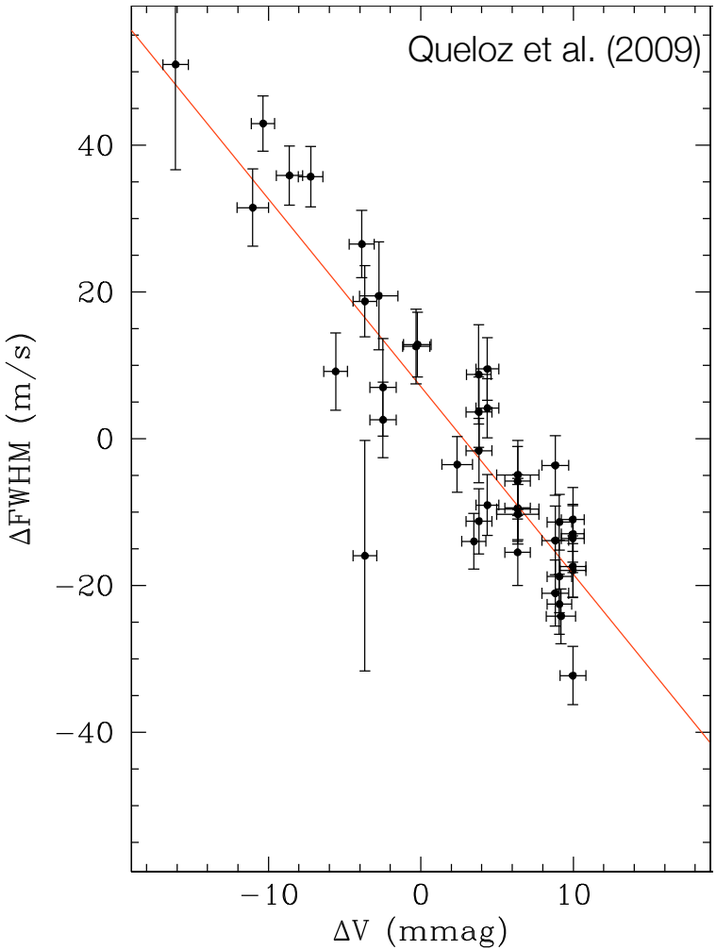
Pont, Aigrain & Zucker (in prep)



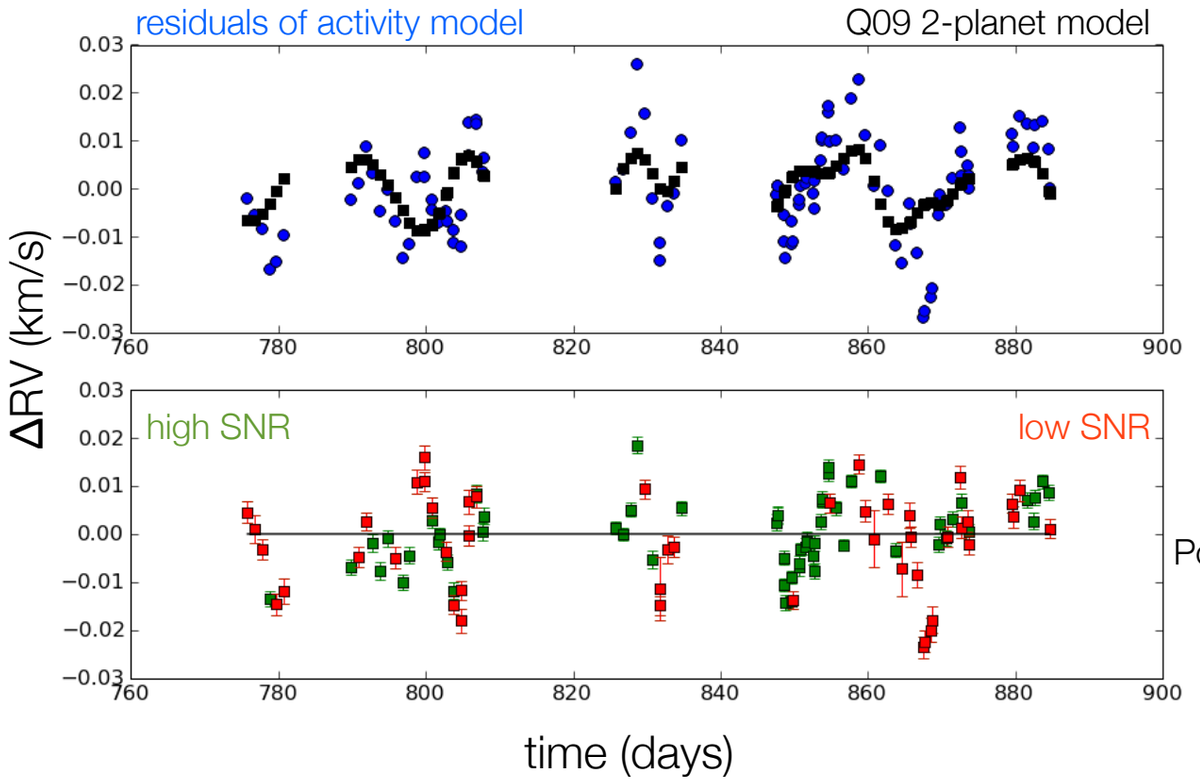


Can also fit both “LC” and bissector span to derive RV. 14 realisations shown here.

Large discrepancies with observed RV.

A “minimum assumption” many spot model

Construct median model and compare residuals to 2-planet model of Queloz et al. (2009)



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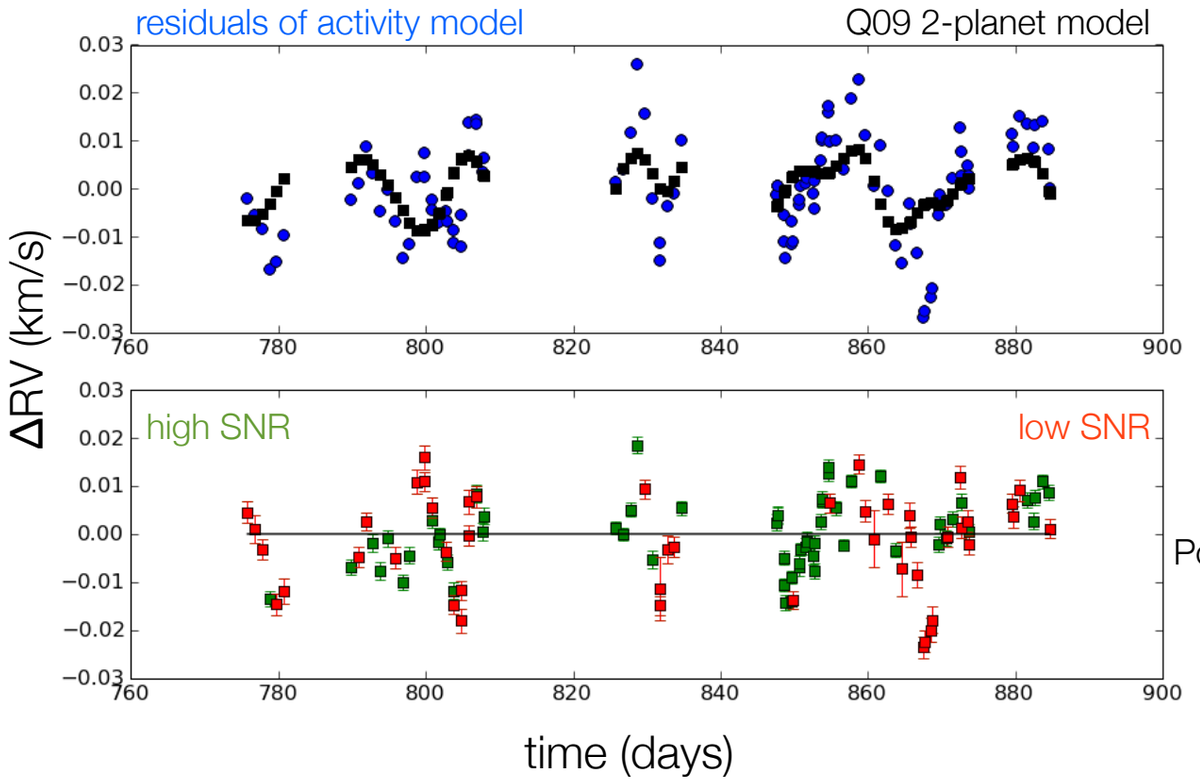

There are residual variations at the 510 m/s level which are explained neither by activity nor by the 2-planet model.

These are particularly noticeable in the half of the data with lower SNR - suggests systematics.

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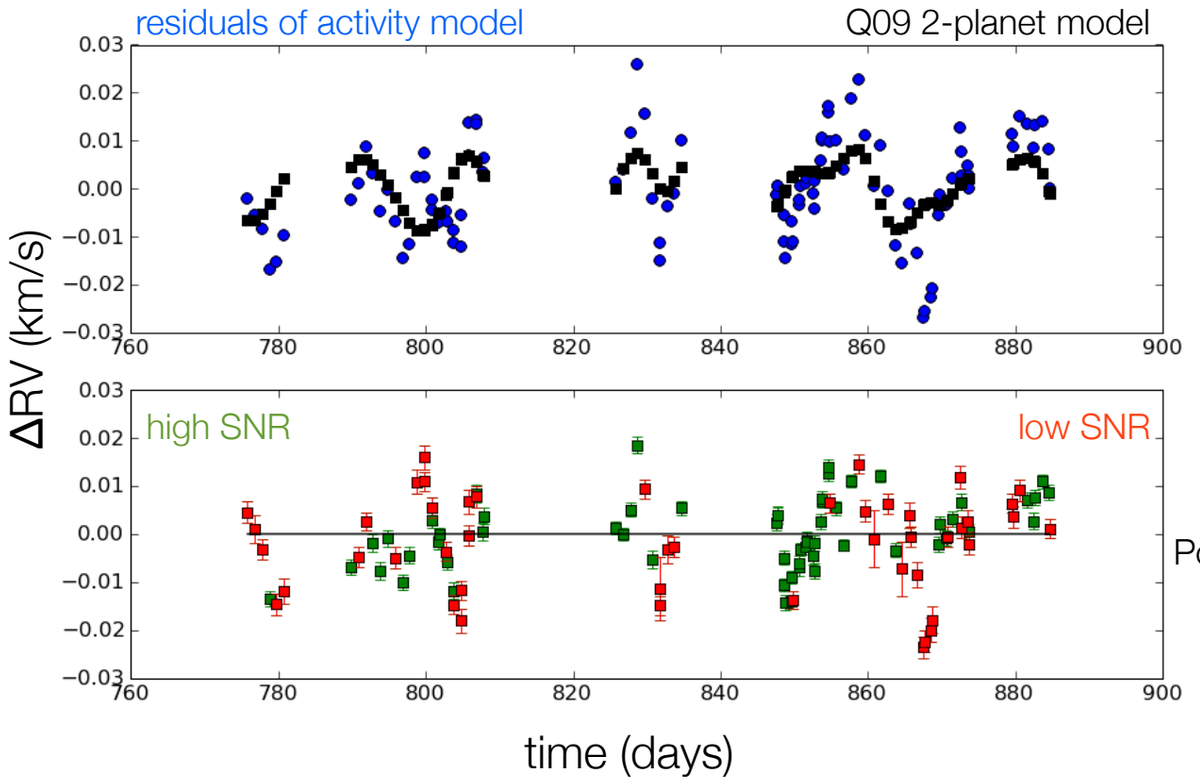
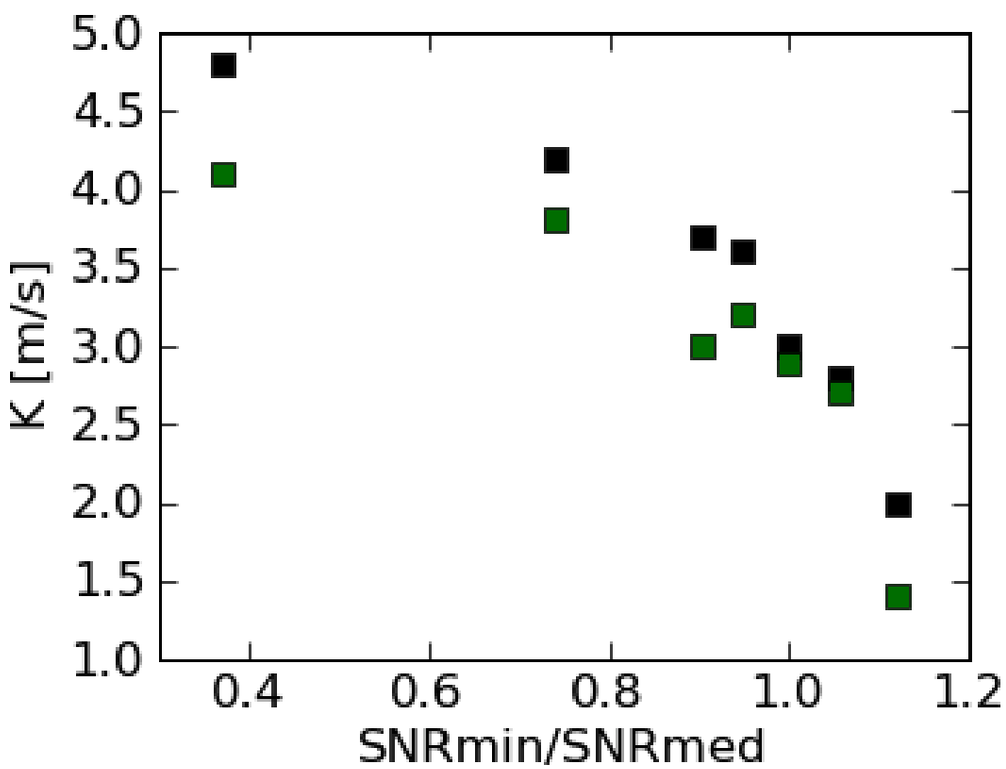


There are residual variations at the 510 m/s level which are explained neither by activity nor by the 2-planet model.

These are particularly noticeable in the half of the data with lower SNR - suggests systematics.

Estimate of CoRoT-7b’s semi-amplitude depends strongly on SNR threshold - including lower SNR leads to larger K.
Note result is similar whether fitting raw data (black) or residuals of activity model (green).

Pont, Aigrain & Zucker (in prep)



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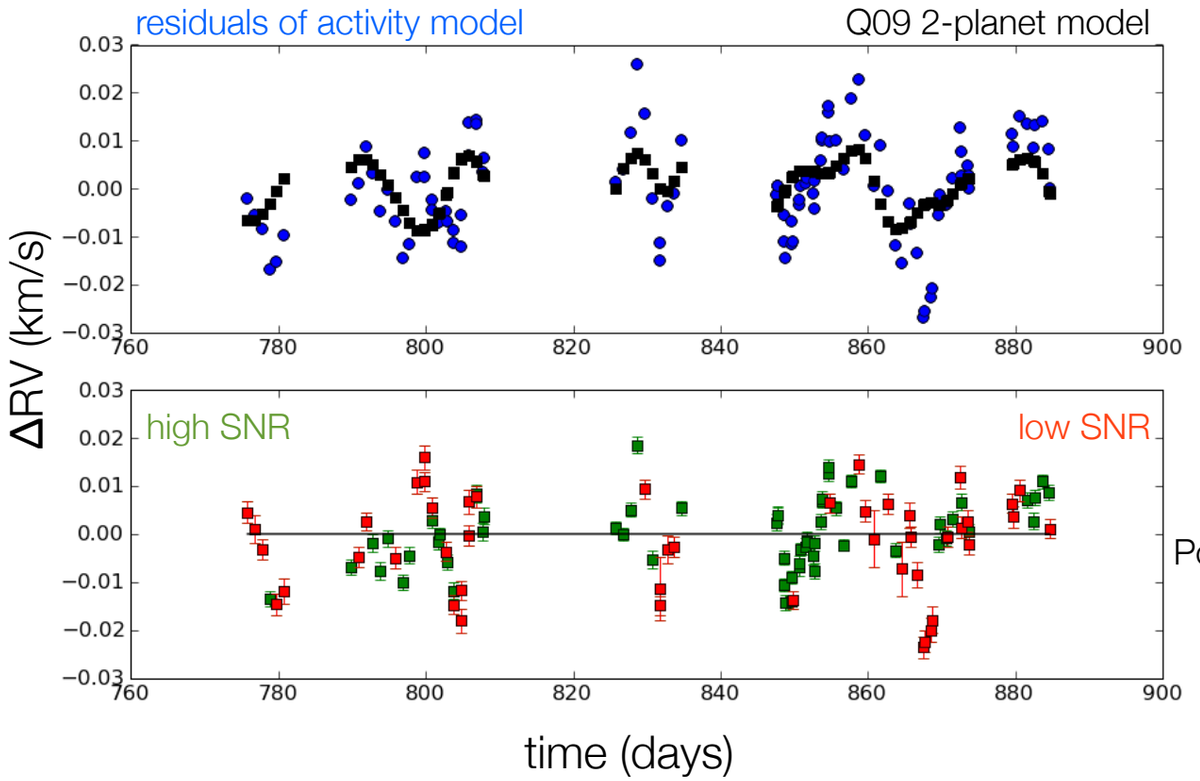

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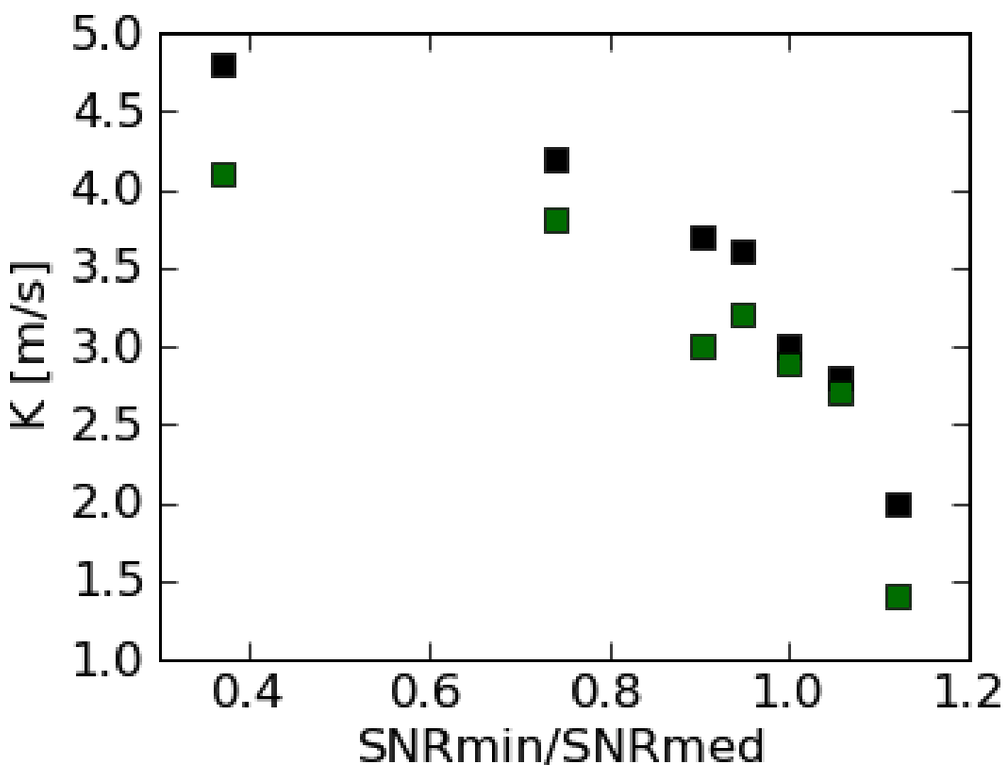

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Our “best guess” estimate (using most stringent SNR threshold) is K=1.7m/s. Error from bootstrap 1.3m/s (accounts for white noise only): safer to adopt K=2±2m/s.
C.f. Q09’s estimate: K=3.5±0.6m/s

Implications

Using a flat prior in log for planet masses, we derive a lower mass for CoRoT-7b and a significantly larger error:

1–3 M_{Earth} (1σ)

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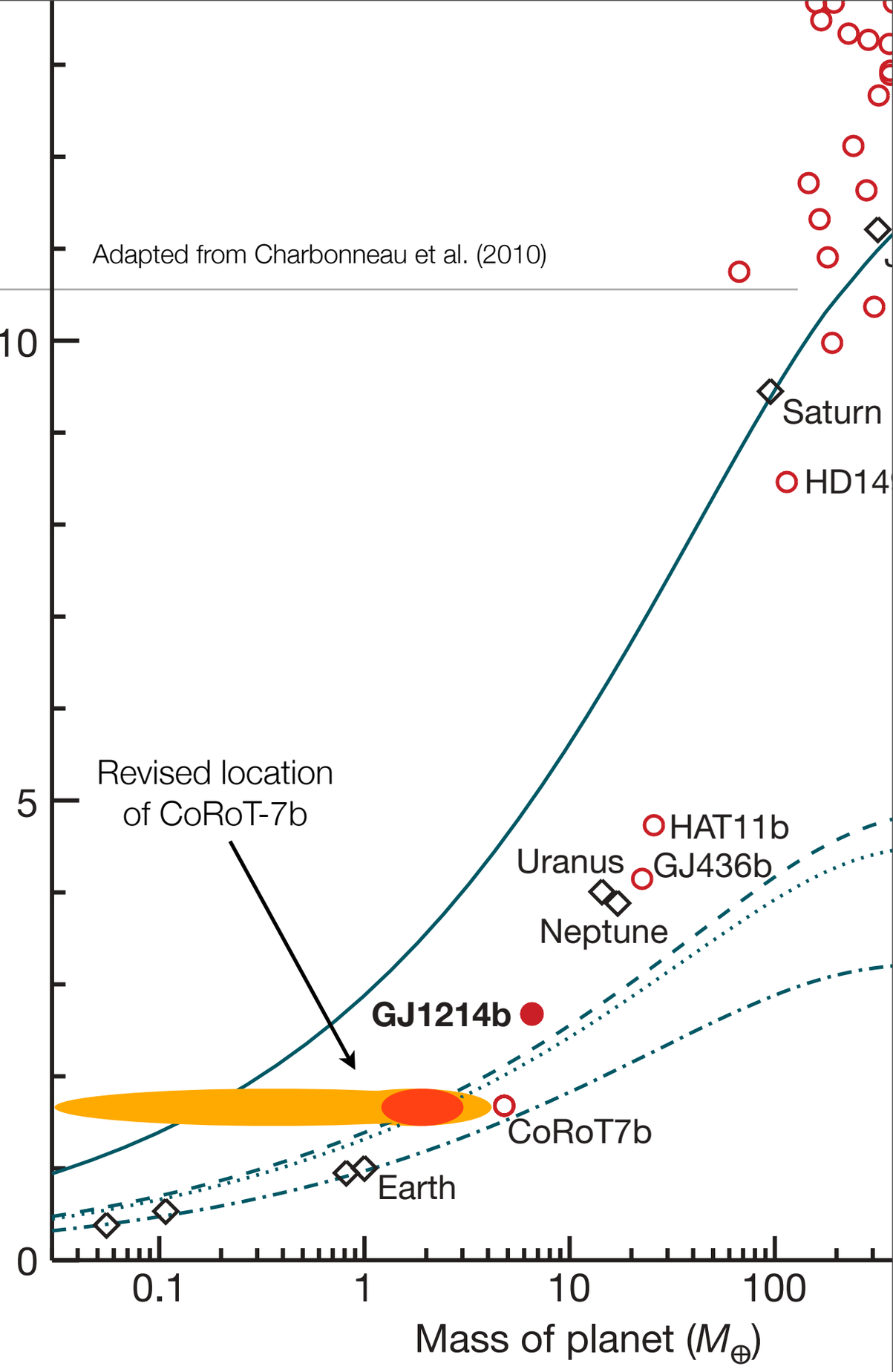
This makes the most likely composition of CoRoT-7b more similar to that of GJ1214b. It now fits better with the “sequence” of hot Neptunes and hot Super-Earths.



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- Challenging systems will be the rule, not the exception, in the “Earth-like” regime (c.f. solar RV variability, Meunier et al. 2010).
- Robust methods for assessing (multiple) planet system hypotheses in the presence of activity and other correlated signal and noise are urgently needed.