The effect of stellar activity in planetary transits: the case of CoRot-7b.

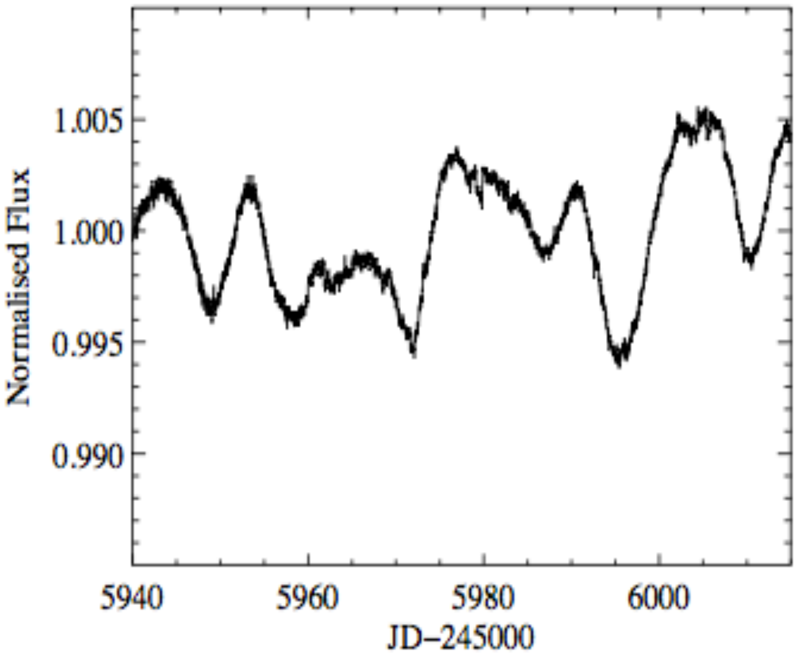
- New observations with of CoRoT-7b with CoRoT (LRa06)
- Difference from previous CoRoT observations (LRa01)
- Our tests suggest it could be due to stellar activity.

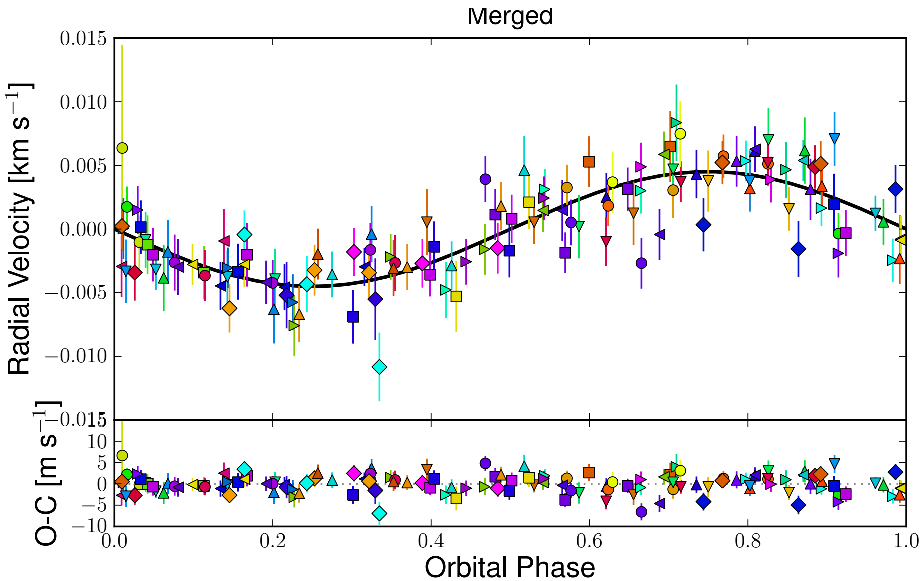
Susana Cristina Cabral de Barros

CoRoT-7 System

- CoRoT-7b was discovered during LRa01 run, October 2007 to March 2008 (Leger et al 2009).
- Period of 0.85 days and depth 0.03%, r ~ 1.6XR_{Earth}. First transiting superEarth.
- Host star is young G9 showing high stellar activity - 2% variation in the flux and 40m/s RVs.
- Planet signal ~5m/s → Mass estimation are challenging (Queloz 2009, Pont 2011, Hatzes 2010, 2011, Boisse 2011, Ferraz-Mello 2011).
- Values planetary mass ranging from 2.3-8 Mearth.
- Possible 2nd or 3rd planet in the system from RV analysis (Queloz et al. 2009, Hatzes et al. 2010).

New observations





Method Hatzes et al 2010, 2011

- New simultaneous HARPS and CoRoT observations during 26 consecutive nights in a lower activity level.
- RV analysis uses the out-of-transit light curve to correct for activity (ff' method Aigrain et al. 2012).
- The second planet was confirmed but not the third. Mb=4.88+/-0.94Me and Mc=14.20+/-1.09Me. (Haywood, R. et al.)

Lower activity level

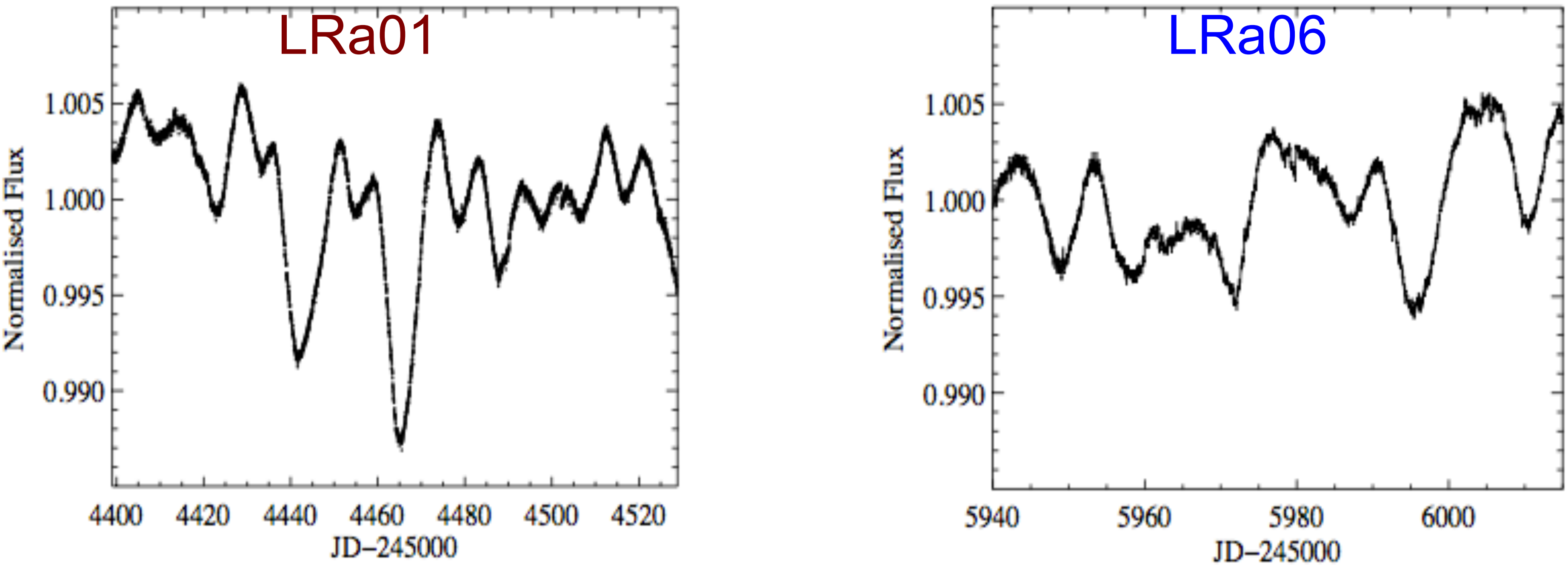
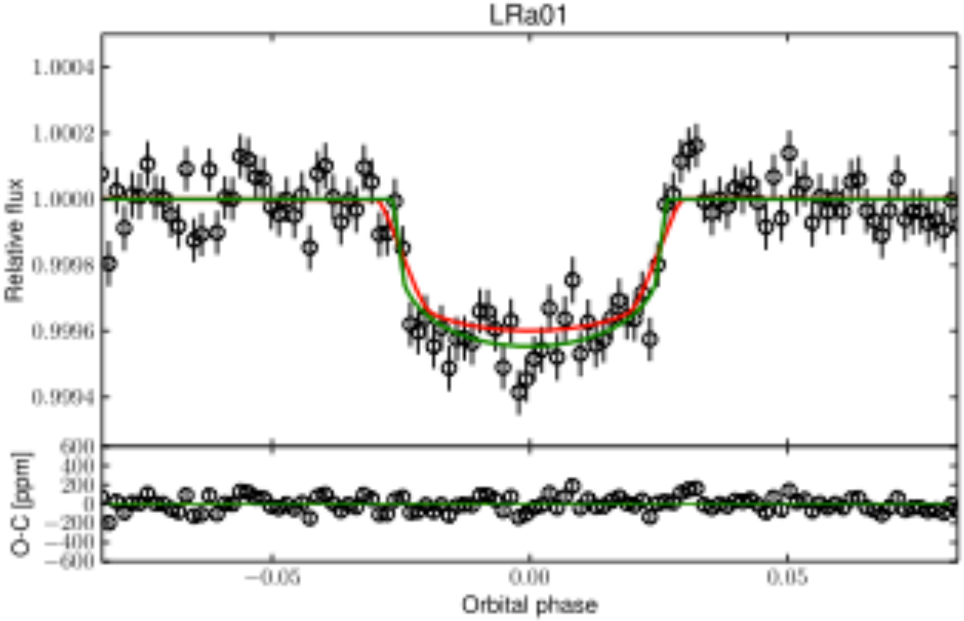


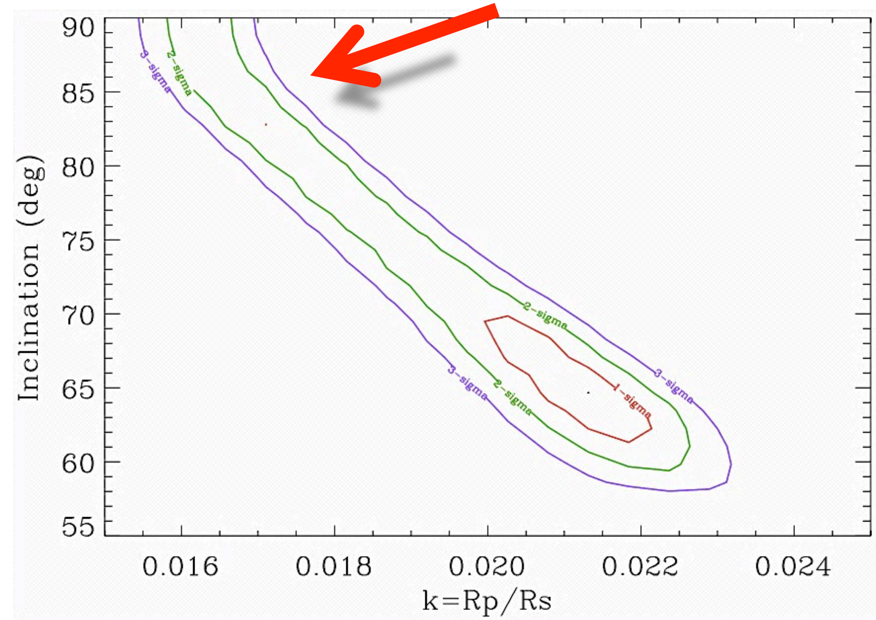
Fig. 1 CoRoT-7 observations taken during LRa01(left) and LRa06 (right).

- In LRa06 the light curve show half of the amplitude variability than LRa01.
- Spectroscopic activity index log R'_{HK}= -4.60+/-0.03 decreased to -4.73+/-0.03.
- Activity signature in RVs decreased from 40m/s to 15m/s.

Stellar density problem

Prior in stellar radius





Phase folded 152 transits of CoRoT-7b for LRa01

Transit derived stellar density = $0.2\rho_\odot$

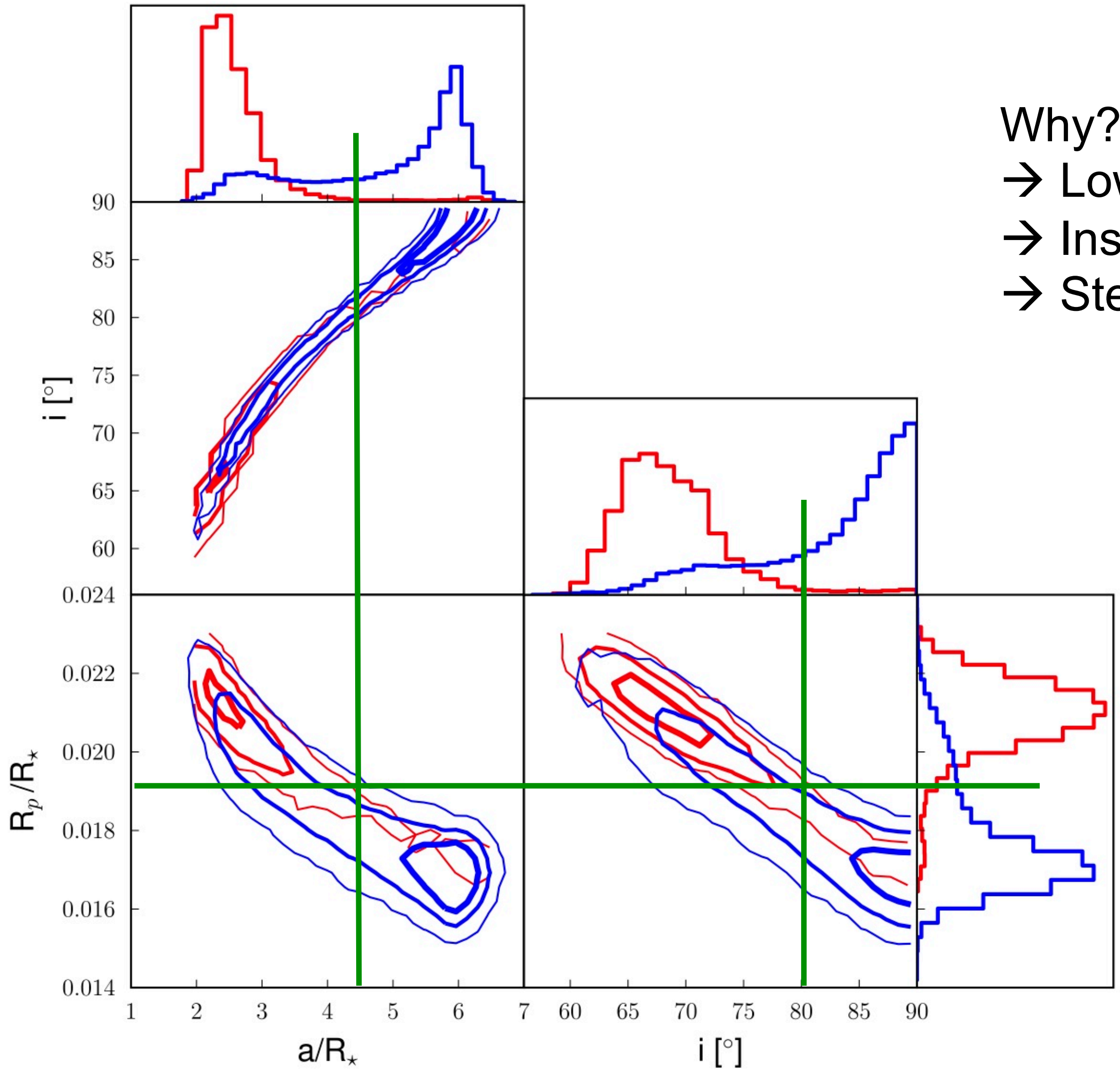
Spectroscopic derived = $1.6\rho_\odot$

Suggested stellar activity or TTVs

In transit surveys the two density comparison is used to test consistency and false positive detection.

Leger et al. 2009

Parameter posterior distributions



Why?
→ Low signal to noise of the transit
→ Instrumental noise
→ Stellar activity

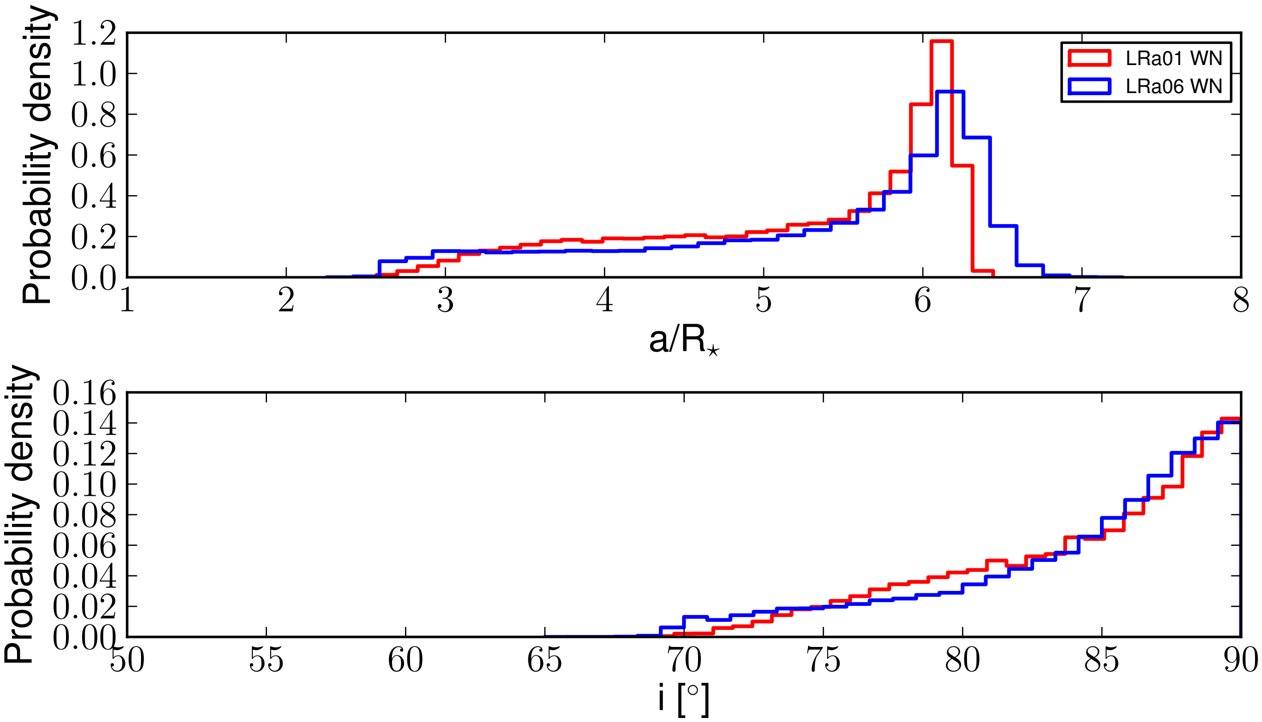
LRa01

LRa06

Fig. 1 Parameter correlation plots for the transit parameters of CoRoT-7b for the runs analyzed separately.

White noise test

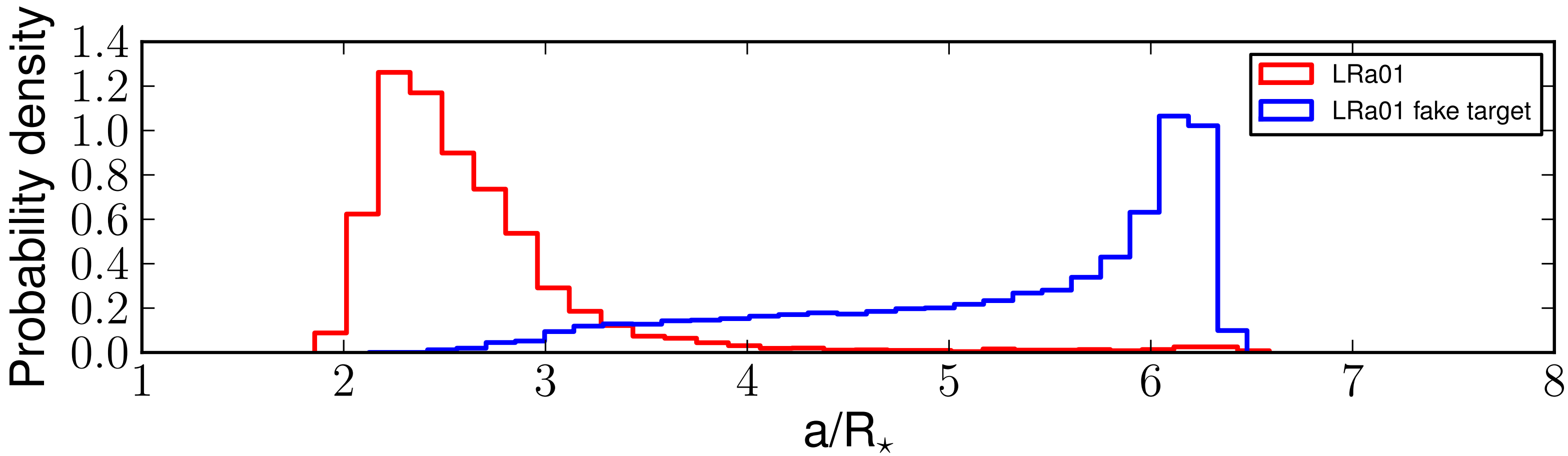
- Using time stamps of CoRoT observations we simulated transits with the final transit shape and included white noise corresponding to each run.



- Conclude that the parameter posterior distributions observed for LRa06 are characteristic of low signal-to-noise transit where the ingress/egress time are not resolved and we cannot constraint the inclination.
- Conclude that white noise cannot explain the shape of the distribution of LRa01.

Test LRa01 instrumental noise

- Injected transits in a close by star in LRa01 to test instrumental noise.
- Obtained a posterior distribution shape similar to the one of white noise tests.



- Could the higher stellar activity of LRa01 be the cause of the difference in the distributions?

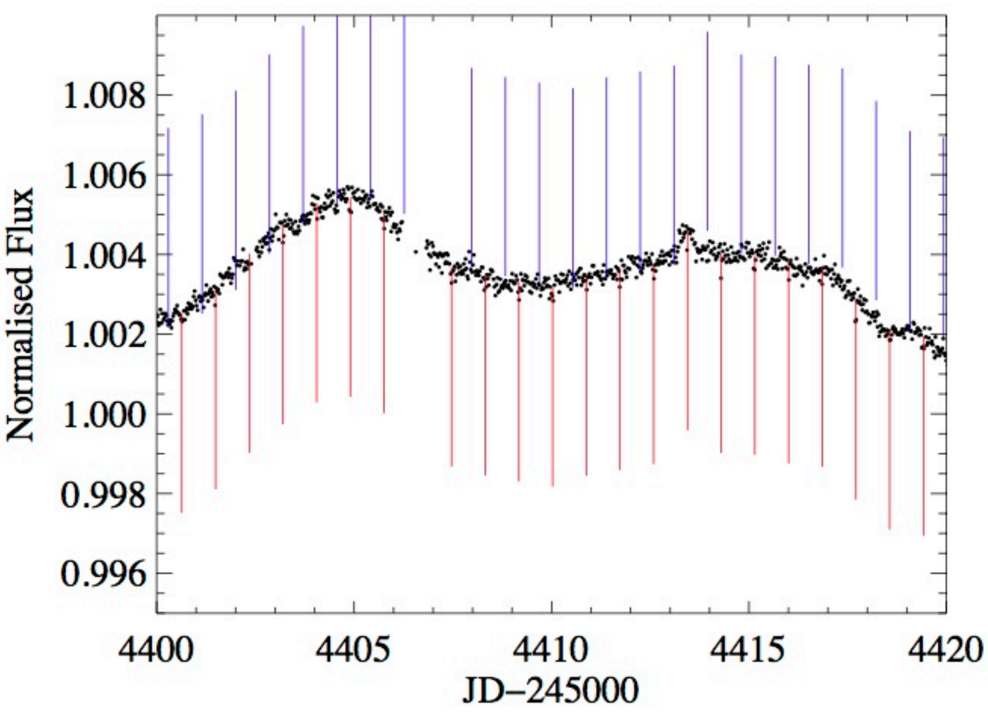
Out-of-transit stellar variability

The 2% out of transit variability of CoRoT-7 affects transit depth:

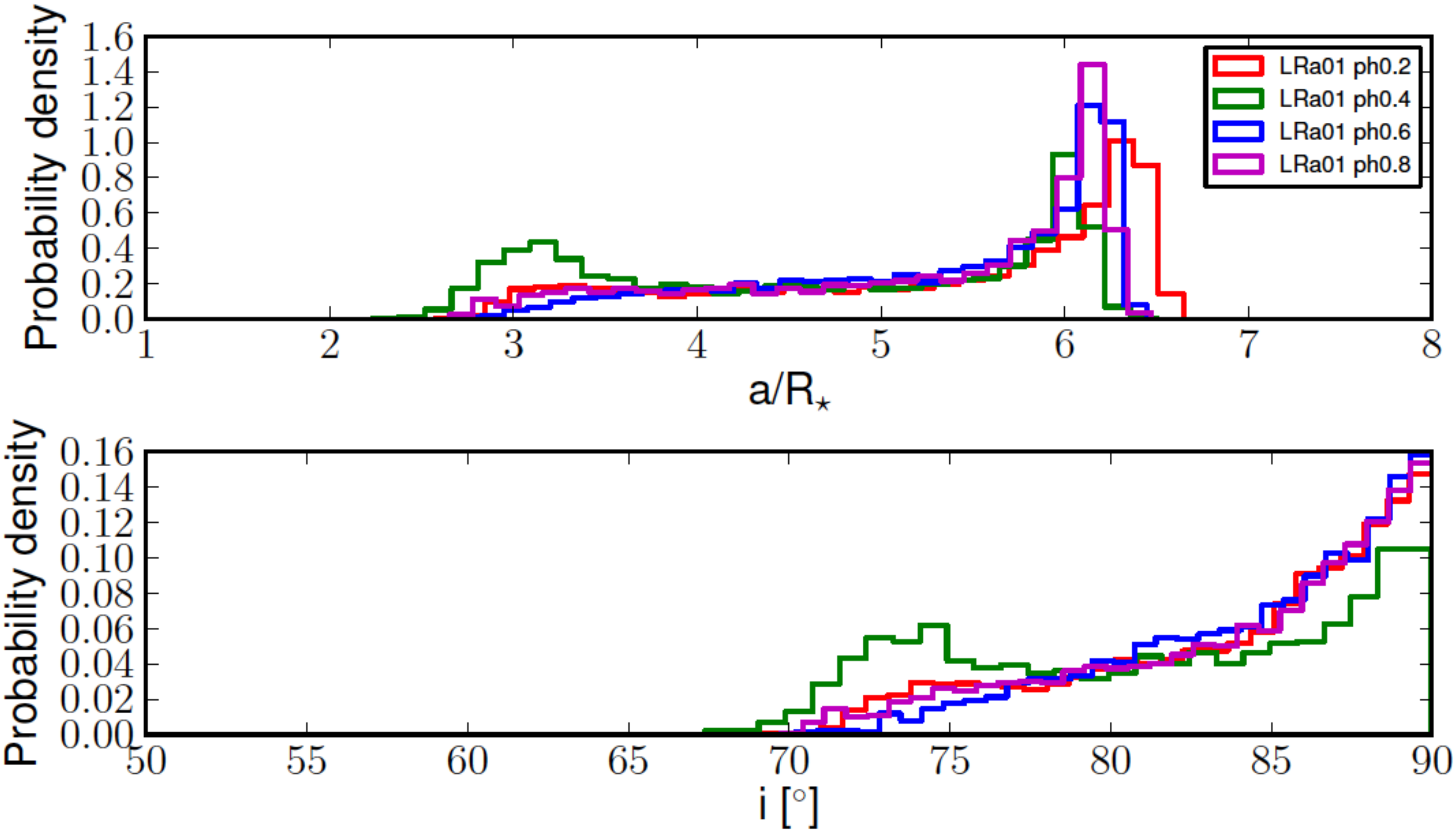
- 0.6% affect of the derived stellar density
- 1% affect the derived planetary radius if not accounted for.

Affects shape of the light curve.

- Injected transit at different phases in the LRa01 light curve.

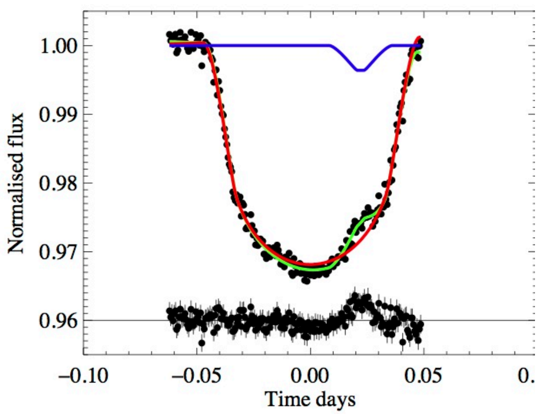


Red noise/out-of-transit variability

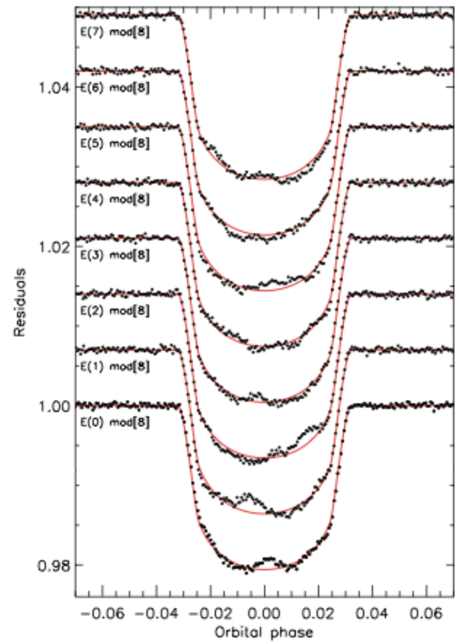


- Simulations cannot reproduce LRa01.
- In transit variability? Spot crossing events?

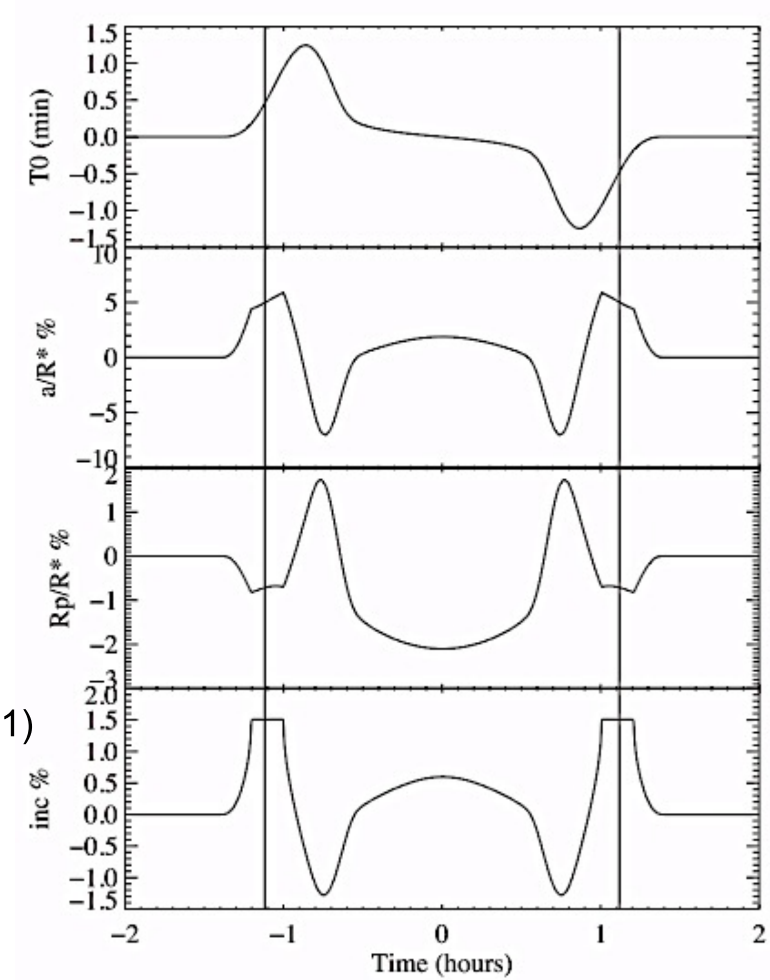
Effects of spot occultation events

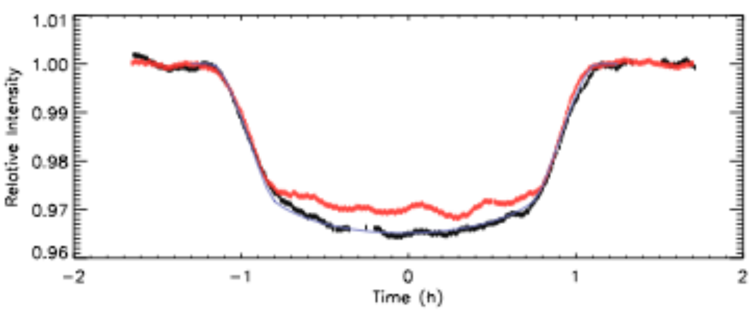


WASP-10b
(Barros et al, MNRAS 2013)



Kepler-17b
(Desert et al ApJ 2011)



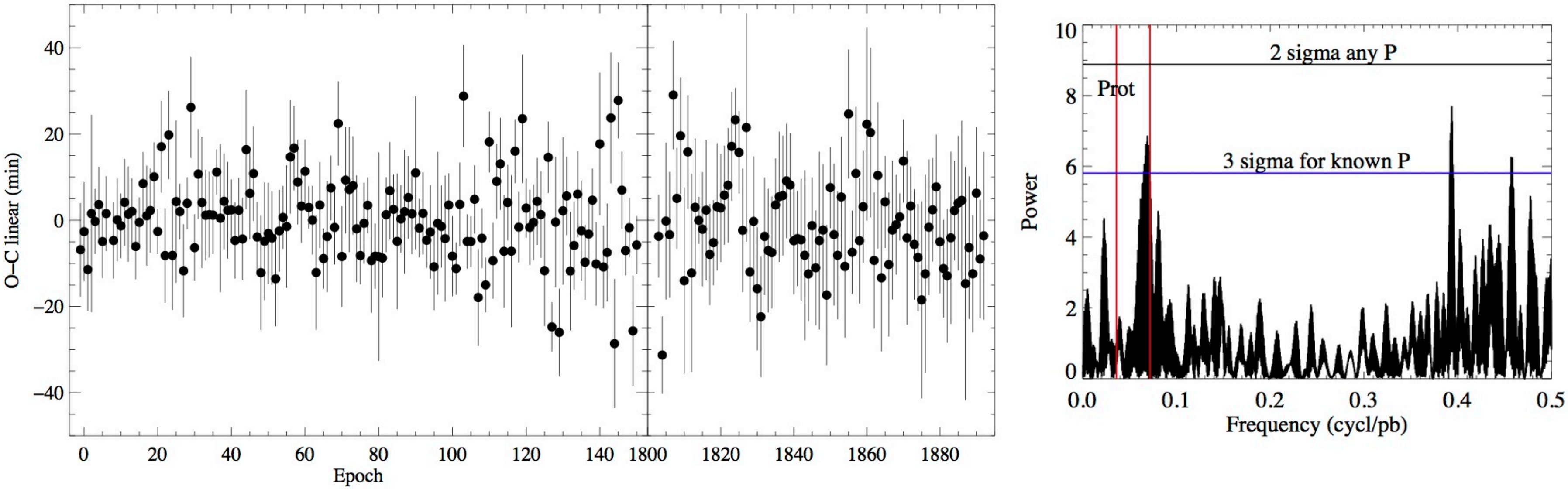


CoRoT-2 (Silva-Valio et al 2010 A&A)

Effect of spot occultation events in the derived transit parameters as a function of spot phase.

TTVs

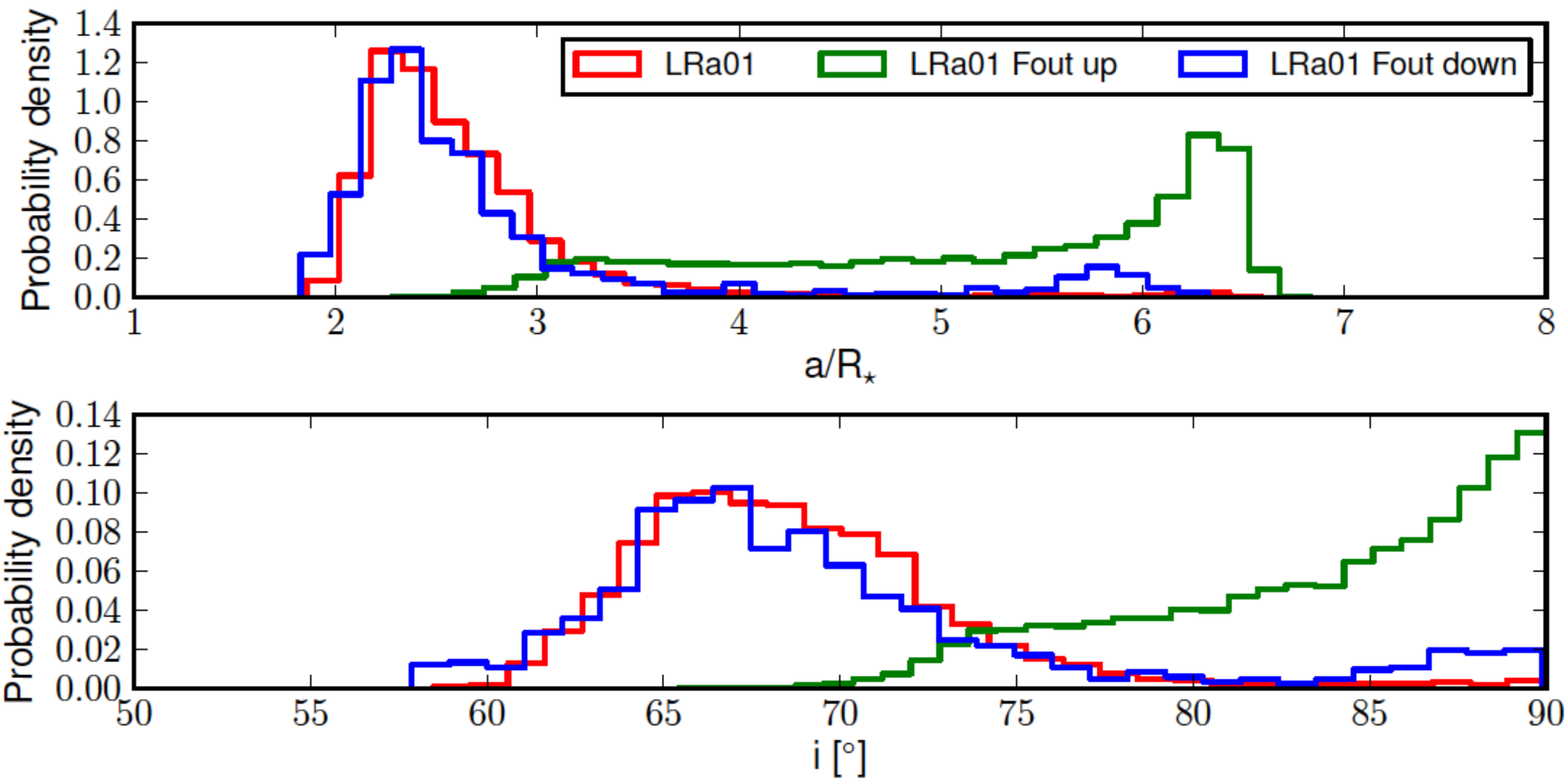
- When spot crossing events affect the shape of the light curves a periodicity related to the rotation period of the star has been seen (CoRoT-8, Borde et al 2010, Kepler-17b Desert et al 2011, WASP-10, Barros et al 2013).



- Periodicity of TTVs suggested that some transit affected by spot occultation events that would produce a steeper ingress/egress of the mean transit shape.

- TTVs due to the other planets (CoRoT-7c and CoRoT-7d are less then 5 seconds below our sensitivity.

Selection on out-of-transit flux



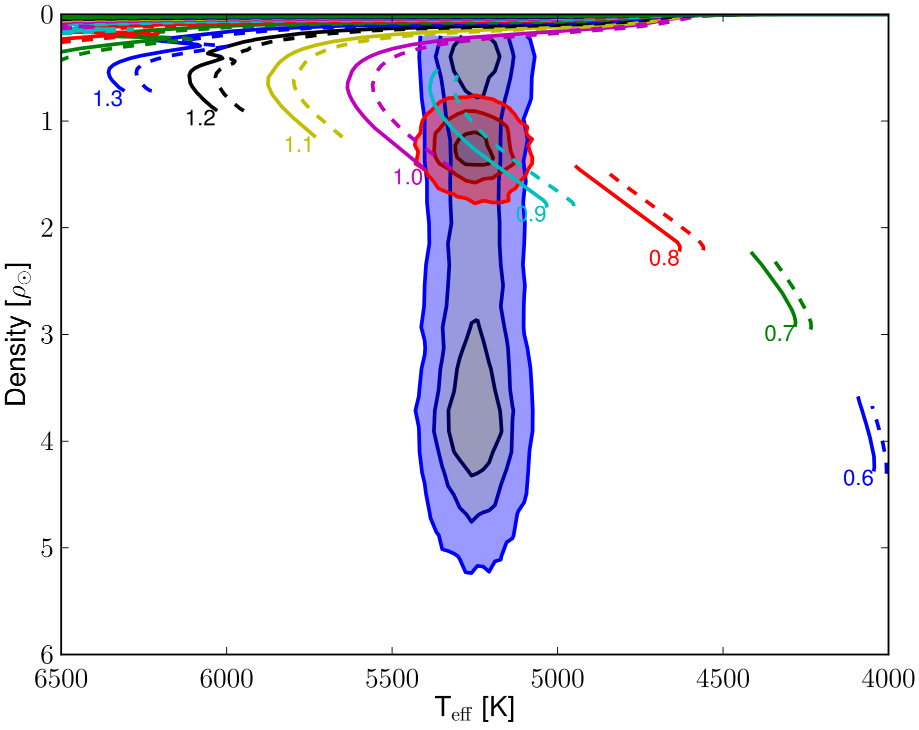
- The posterior probability distribution is different for the out-of-transit selection of higher flux and lower flux. This supports the difference between LRa01 and LRa06 being due to activity.
- We use this selection to obtain final results that will include RVs and stellar models.

PASTIS transit modelling
Jose Manuel Almenara/ Rodrigo Diaz

- Transits LRa01sel + LRa06
- RVs
- Stellar evolution tracks
- Self-Consistent model

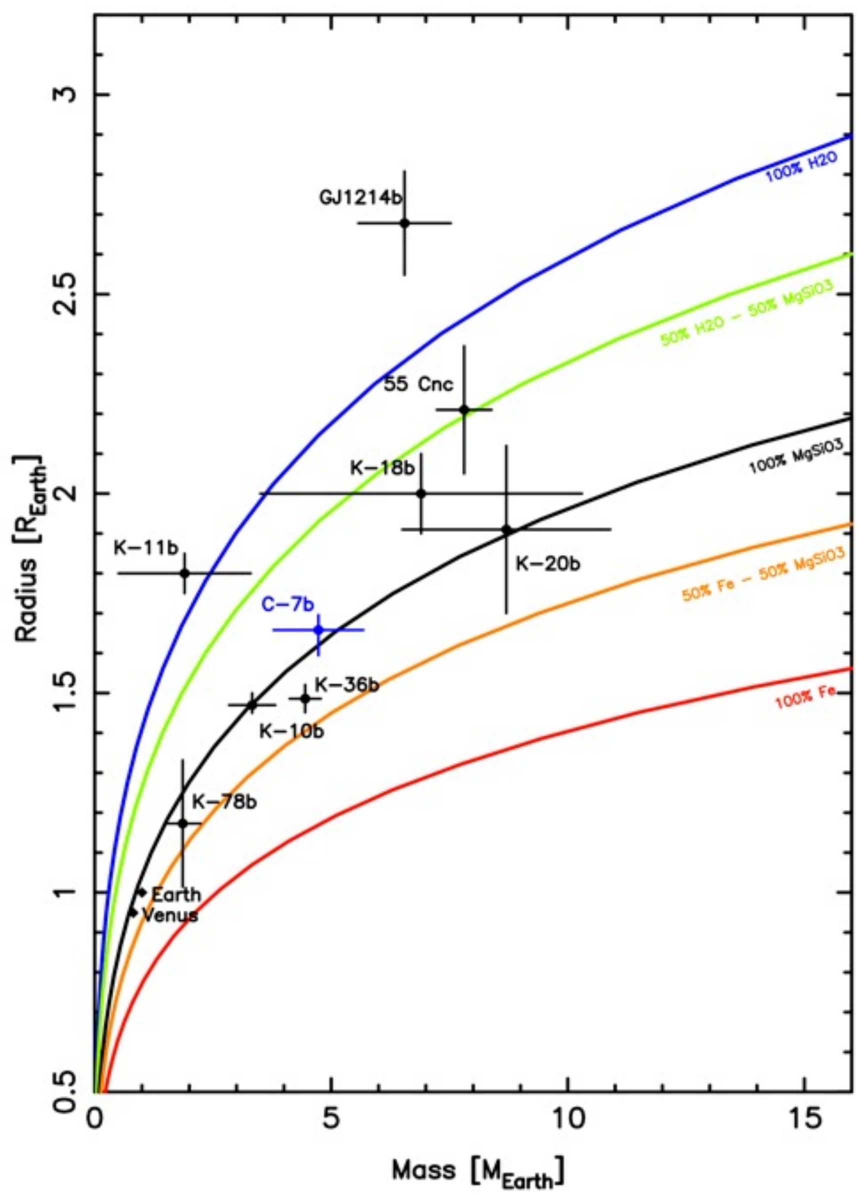
Spectroscopy (Bruntt 2010)

- Teff = 5250 +/-60 K
- Fe/H = 0.12 +/-0.06
- Log g = 4.47+/-0.05
- Age limit 3 Gyr as Bruntt 2010



Density

- Using our new estimation of radius and the mass estimation from Haywood et al.2014 we derive a planetary density of 1.04 +/-0.20, so CoRoT-7b compatible with an earth composition.
- According to the composition models of Zeng et al 2013, CoRoT-7b can be composed of silicates, compatible with a Rocky composition.
- Atmosphere would introduce degeneracy.
- Age of the system is close to the lifetime of water vapour (Valencia 2011 and Selsis 2007).



Barros et al 2014, A&A submitted.

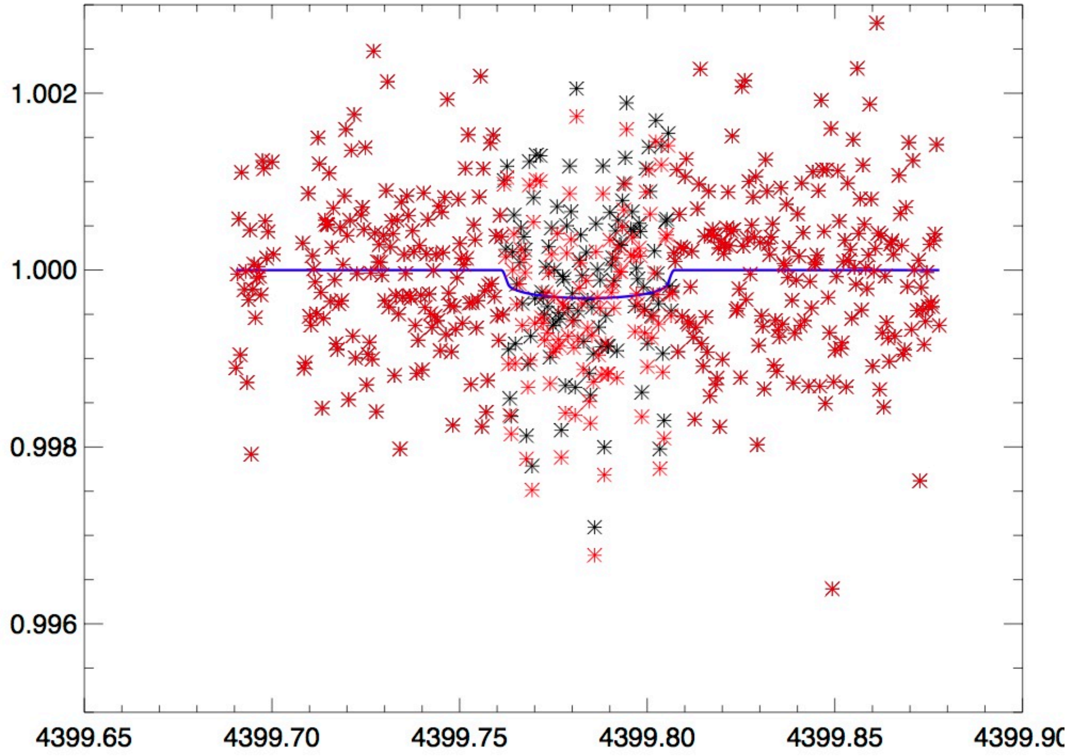
Summary

- We find different posterior parameter distributions for transit parameters in the two CoRoT observations of CoRoT-7b.
- In low signal-to-noise transits where the transit shape is not well constrained, the stellar density from spectroscopy or asteroseismology can help constrain the transit parameters.
- LRa01 appears to have an extra noise component that could be due to out-of-transit stellar variability or spot-occultation events which we favour.
- A selection using the out-of-transit flux allowed to remove transits that are more affected by the noise.
- In this case the activity does not significantly bias the transit radius which could be due to the strong external constrain on the density.

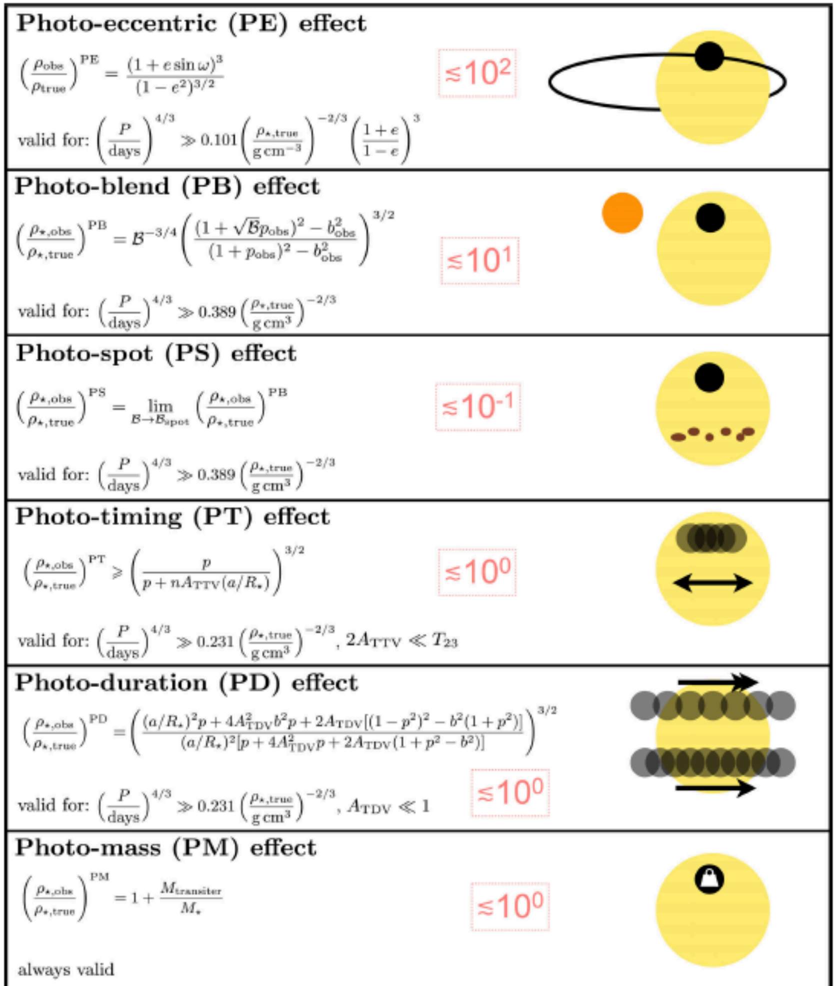
THANK YOU

White noise test

- Using time stamps of CoRoT observations we simulated transits with the final transit shape and included white noise with rms of 970 ppm per point.



Imposing density prior



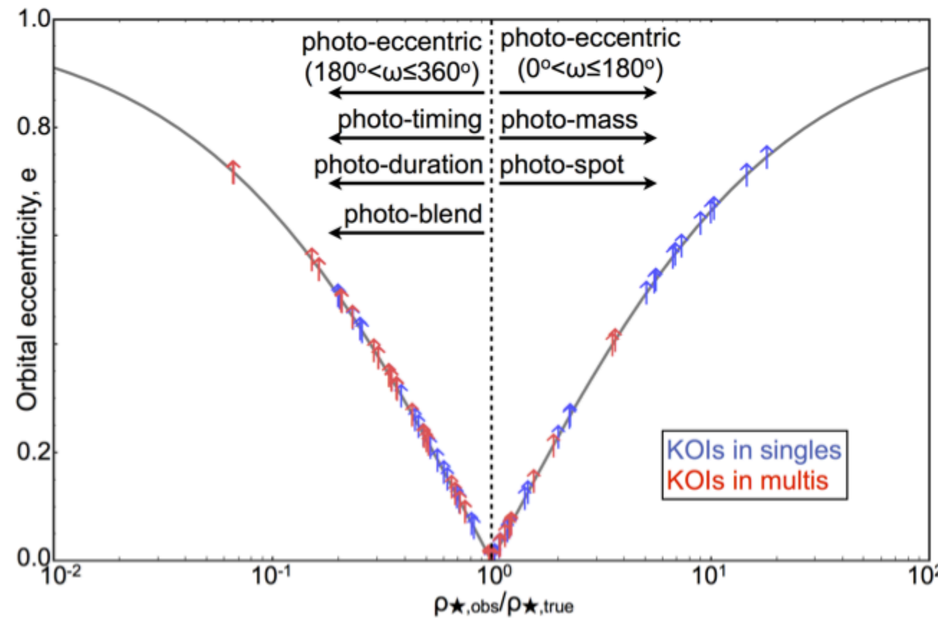


Figure 5. *The Photo-eccentric Effect: The minimum orbital eccentricity function, defined in Equation 39, plotted with respect to its only dependent variable, ($\rho_{\star,\rm obs}, \rho_{\star,\rm true}$). The arrows correspond to real KOIs with known asteroseismology measurements available, where blue are singles and red are multis. We also mark the directions in which the other asterodensity profiling effects act.*

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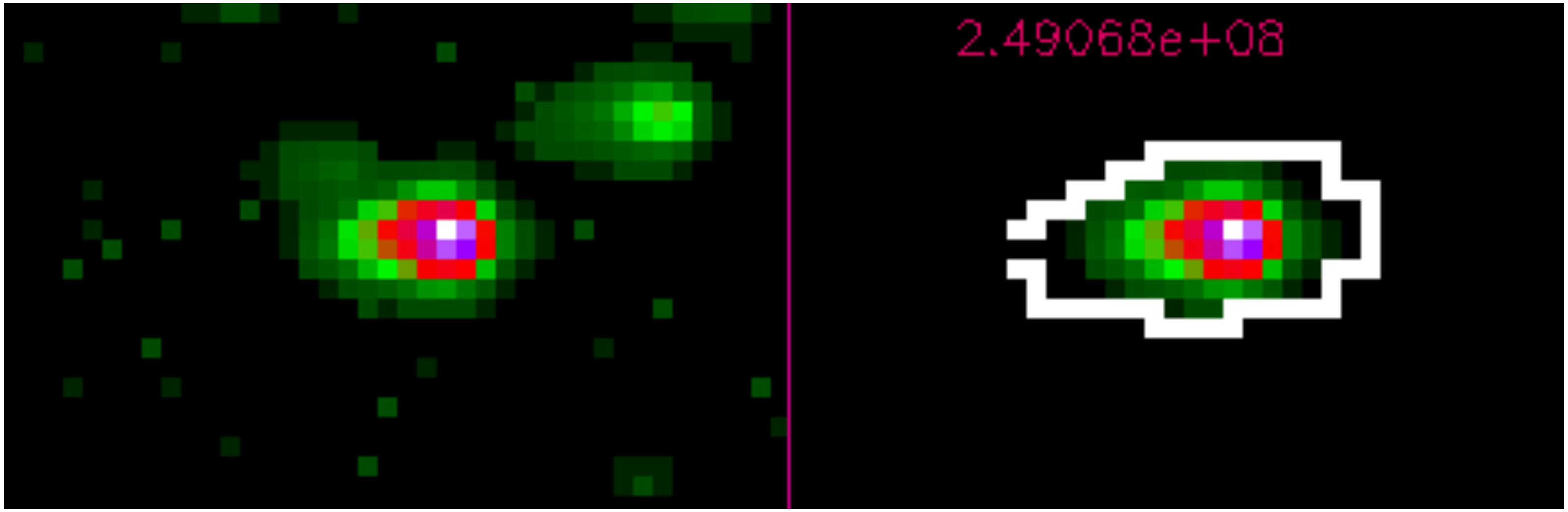
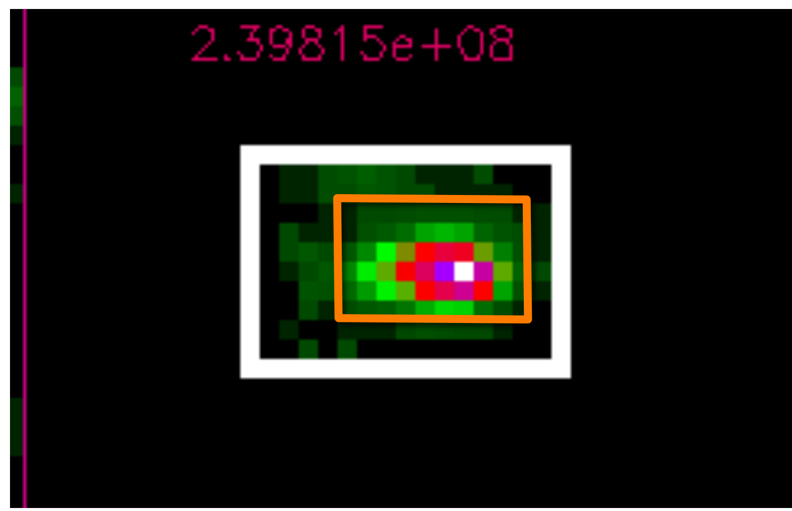
Optimisation of the mask



LRa01
>1%

LRa06
Imagette allows optimisation of mask.
Minimise the noise for timescales less than 2 hours.
The smaller mask in LRa06 means that the contaminations due to other stars is lower = 0.022 +- 0.002%



10% less flux due to ageing of the CCD.

Out-of-transit stellar variability

Photo-spot (PS) effect

$$\left(\frac{\rho_{\star,\mathrm{obs}}}{\rho_{\star,\mathrm{true}}}\right)^{\mathrm{PS}} = \lim_{B\to B_{\mathrm{spot}}} \left(\frac{\rho_{\star,\mathrm{obs}}}{\rho_{\star,\mathrm{true}}}\right)^{\mathrm{PB}}$$

valid for: $\left(\frac{P}{\mathrm{days}}\right)^{4/3} \gg 0.389 \left(\frac{\rho_{\star,\mathrm{true}}}{\mathrm{g\,cm^{3}}}\right)^{-2/3}$

$\lesssim 10^{-1}$

Kipping, D. M. 2014 MNRAS

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