Planets and stellar activity: Hide and Seek in the CoRoT-7 system

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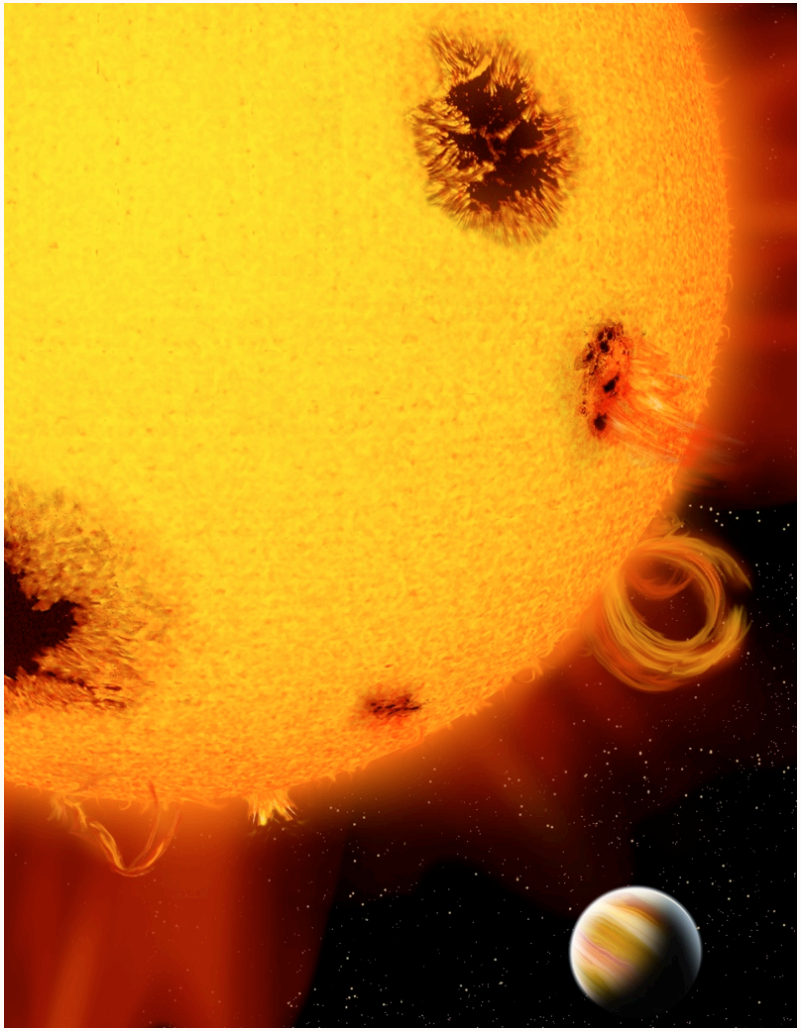
Scotland's first university

600 YEARS
1413 – 2013

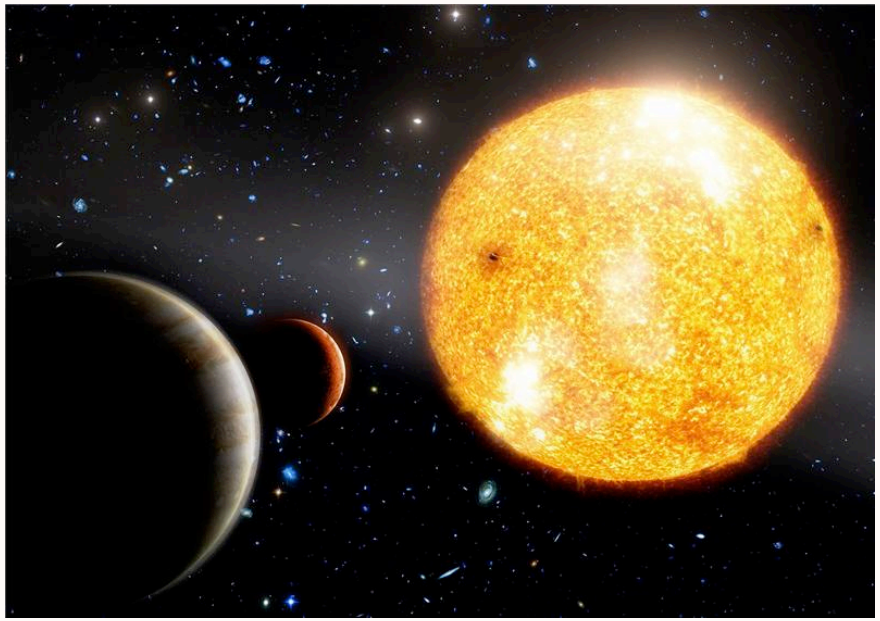
Outline

For low mass planets: planet radial velocity (RV) signal hidden in stellar activity RV "noise"

- Physical sources of activity-induced RV
- *FF'* method (Aigrain *et al.* 2011)
- Application to CoRoT-7 planetary system
- Results

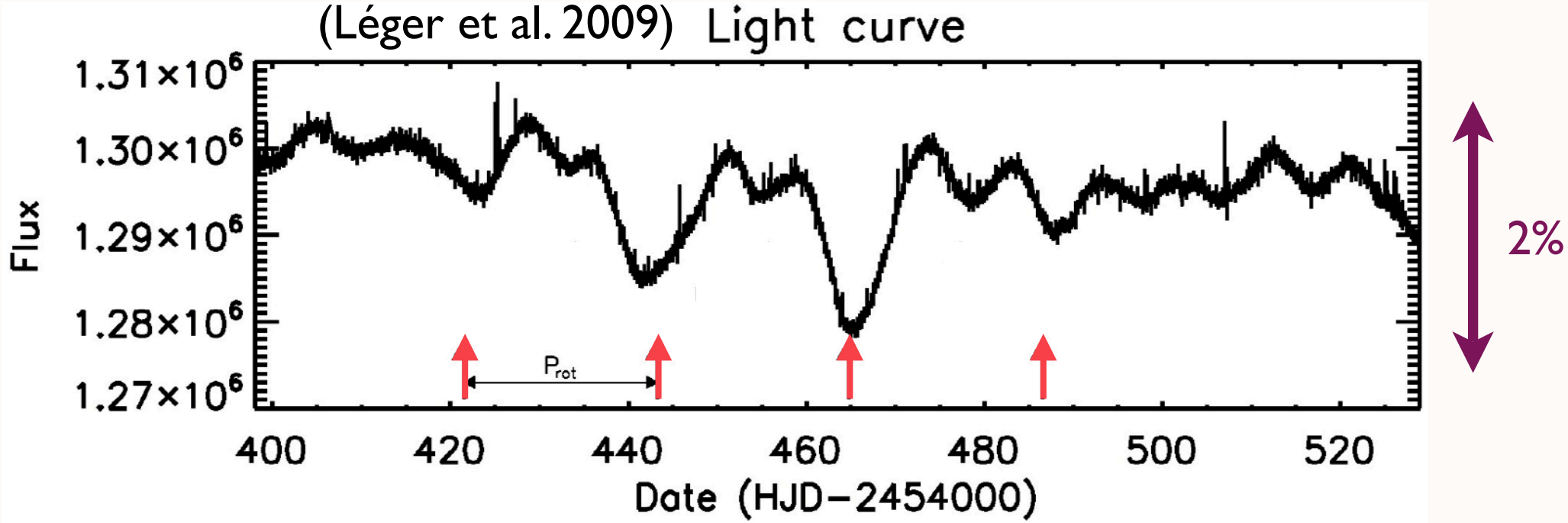


CoRoT-7



- G9, V=11.7
- CoRoT transit observations in 2009
  - ➡ super-Earth CoRoT-7b *(Léger et al. 2009)*
- HARPS radial-velocity campaign (2009)
  - ➡ another super-Earth CoRoT-7c *(Queloz et al. 2009)*
  - ➡ sub-Neptune mass planet CoRoT-7d *(Hatzes et al. 2010)*
- Many analyses, no agreement
  Bruntt et al. 2010, Lanza et al. 2010, Pont et al. 2010, Boisse et al. 2010, Ferraz-Mello et al. 2011, Hatzes et al. 2011
- Jan. 2012: New observations: simultaneous CoRoT photometry & HARPS RV

CoRoT-7 in 2009

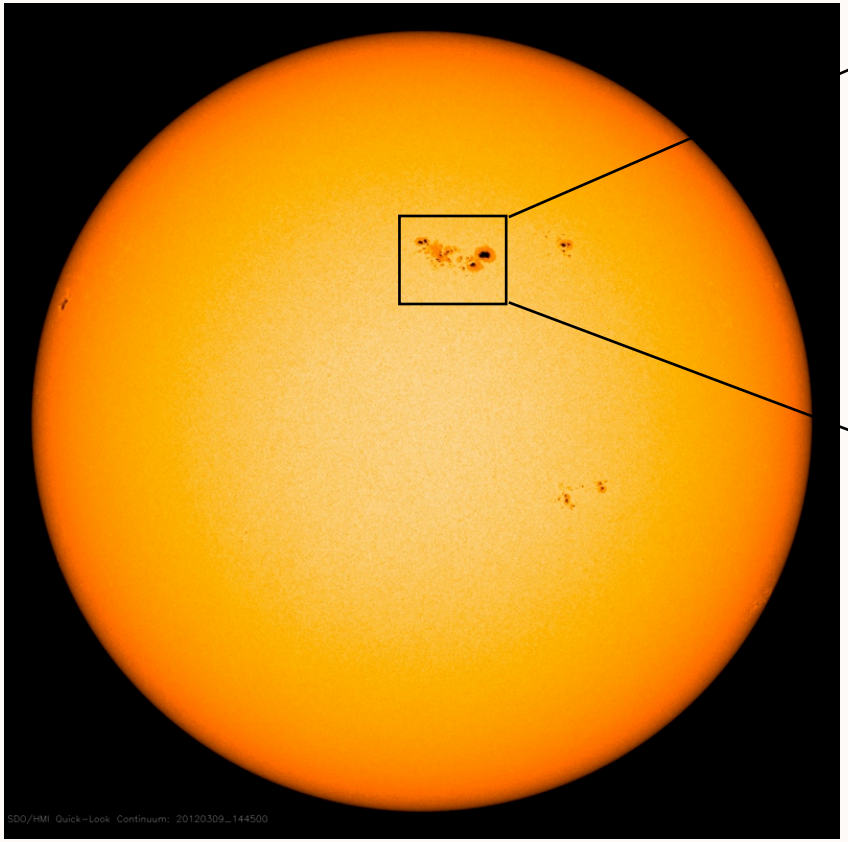


A very active star!

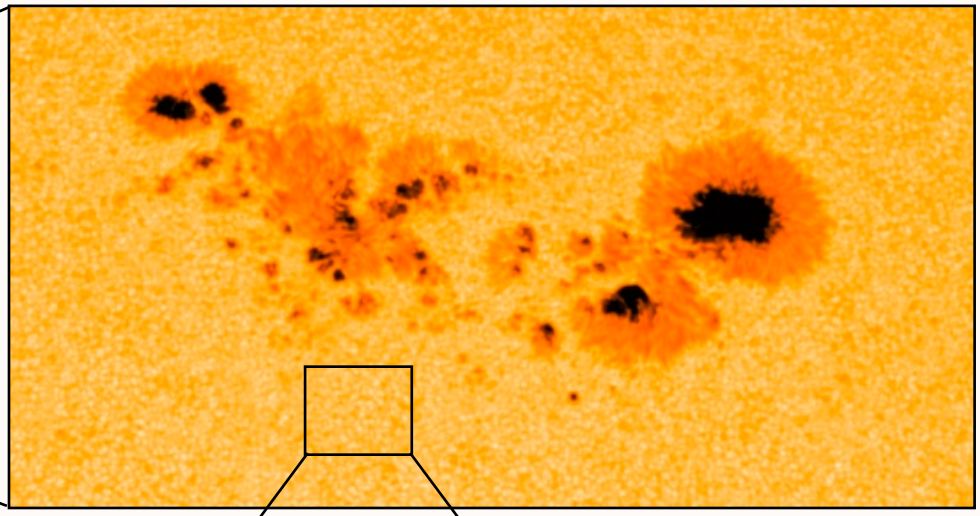
This affects the star's radial velocity variations

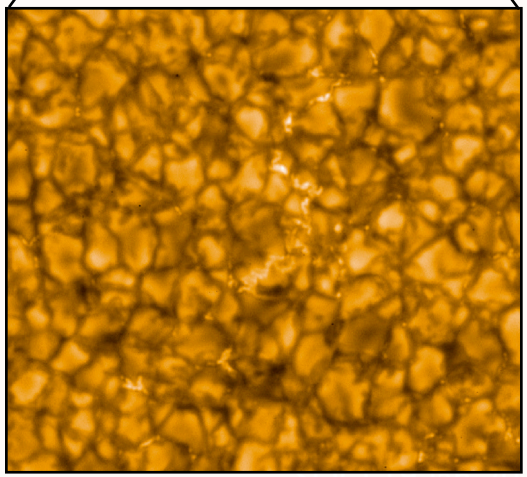
Markers of stellar activity

The Sun



Sunspots

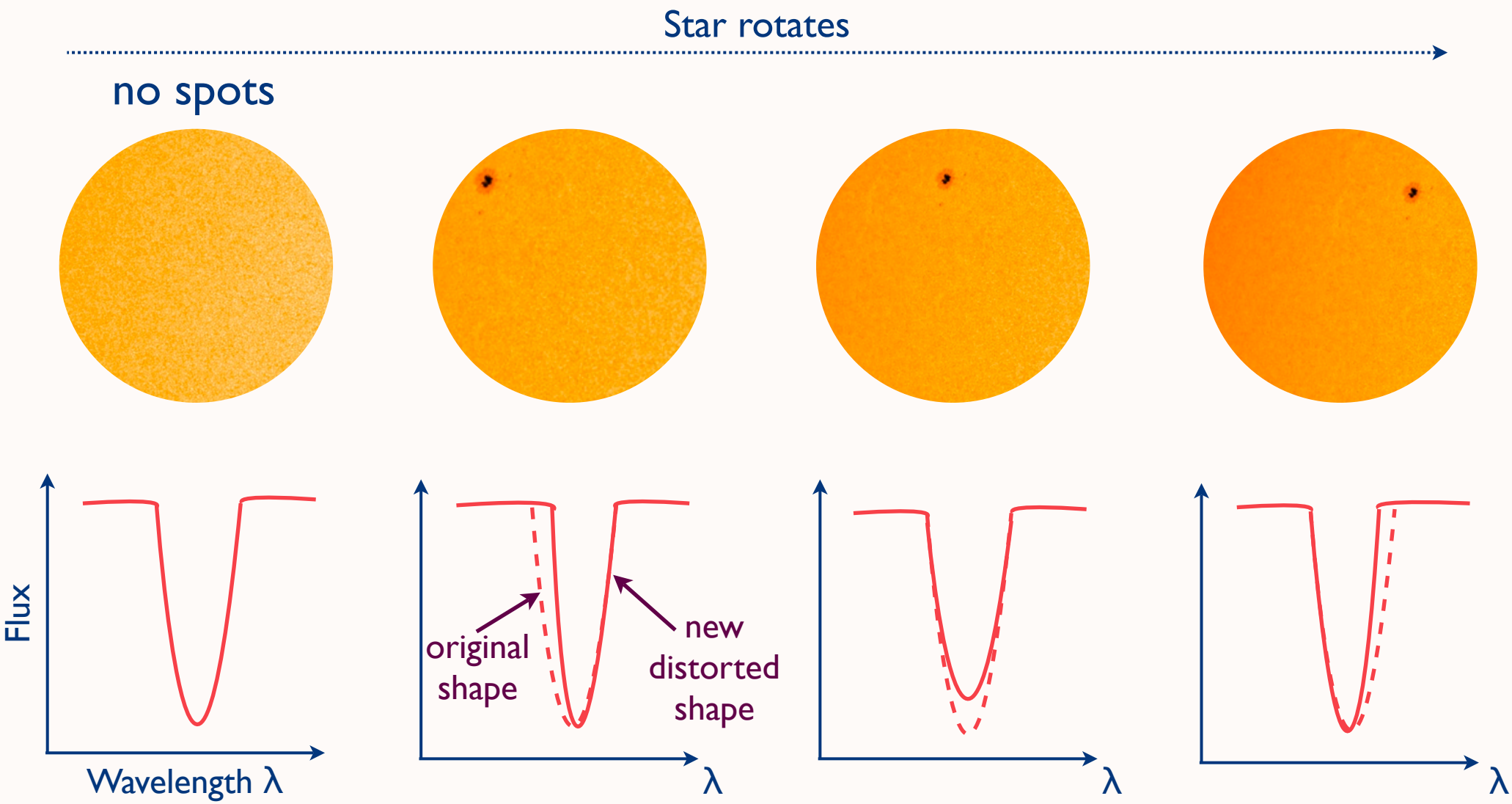




Granulation

How does stellar activity affect RV?

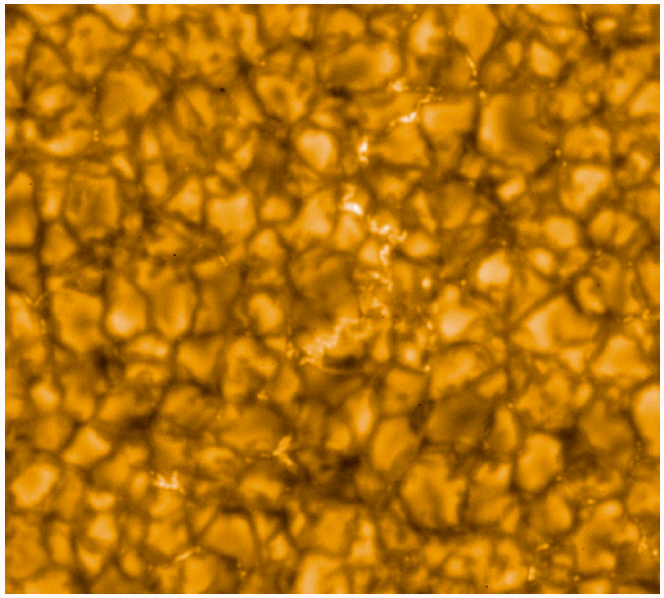
I. Stellar rotation

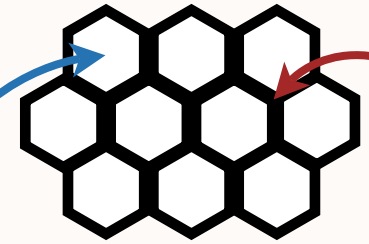


$\Delta\lambda \Rightarrow \Delta RV$

How does stellar activity affect RV?

II. Suppression of convective blueshift

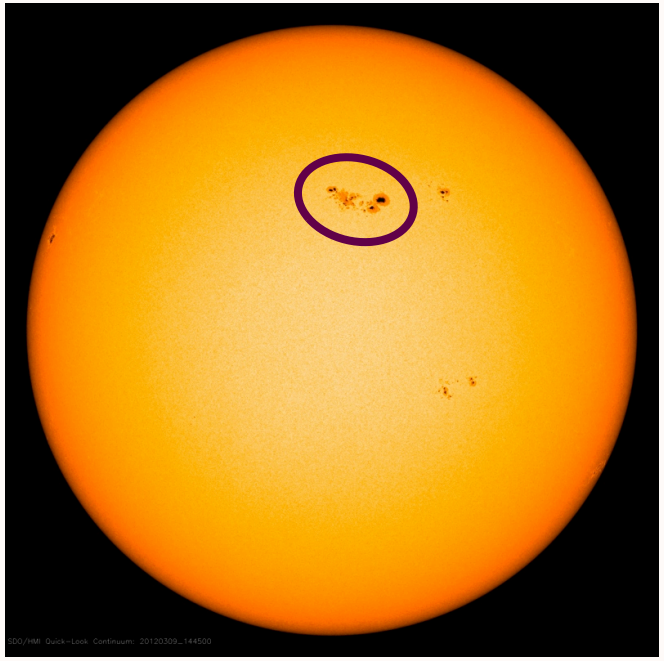




Hot & bright outgoing flow → blueshift

Cool & dark sinking flow → redshift

⇒ Net blueshift



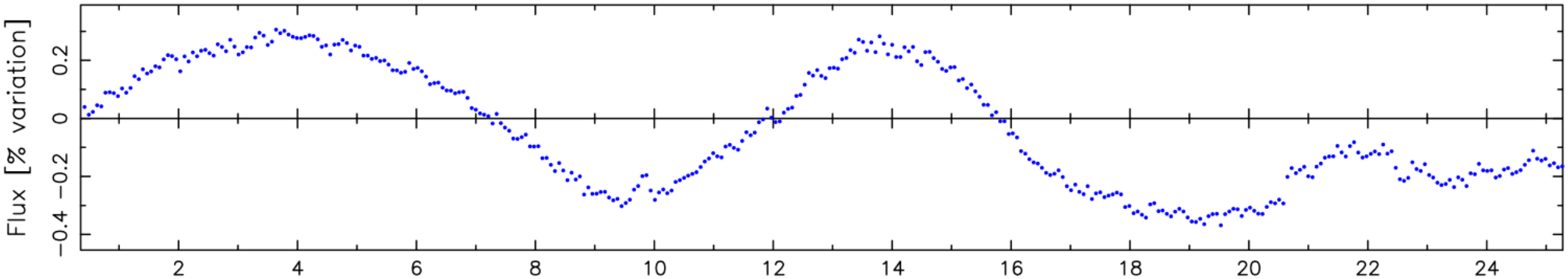
Active regions suppress granulation blueshift

$\Delta RV_{activity}$ ~ a few m/s

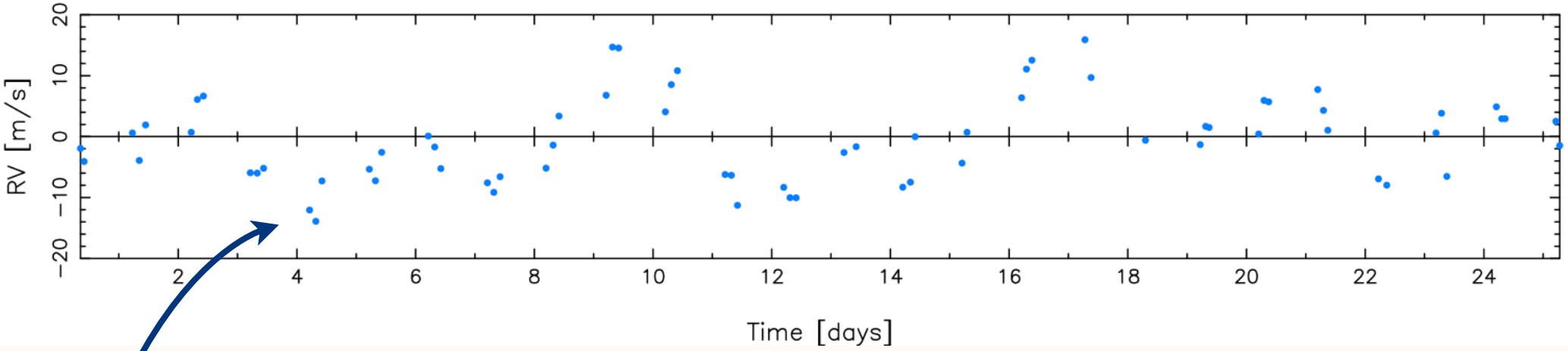
$\Delta RV_{super\text{-}Earth}$ ~ 0.5-5 m/s

CoRoT-7 2012 data

Lightcurve (transits of CoRoT-7b removed)



RV data

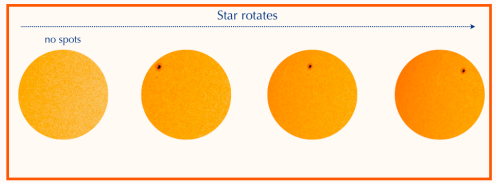


$RV_{total} = RV_{activity} + RV_{planets}$

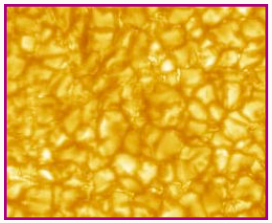
Modelling stellar RV variations

Model RV variations based on variations in the lightcurve:
(Aigrain et al. 2011)

rotation of stellar disk



suppression of convective blueshift

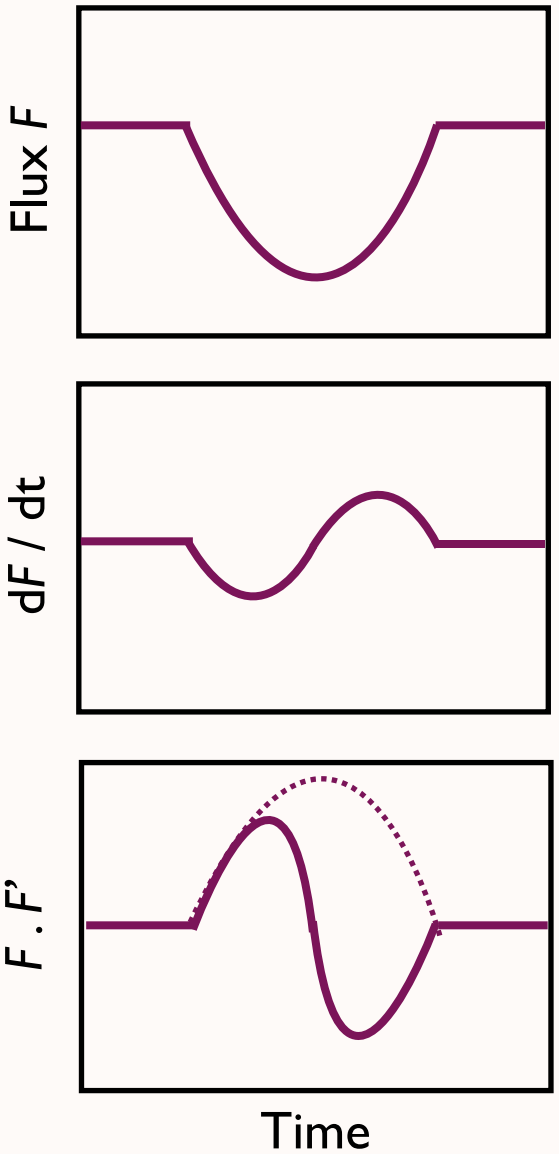


$$\Delta RV_{activity} = A\ \Delta RV_{rot}\ (t,\psi_0) + B\ \Delta RV_{conv}\ (t,\psi_0)$$

$$\Delta RV_{rot} \propto F\ .\ dF/dt$$

$$\Delta RV_{conv} \propto F^2$$

A, B constants
ψ_0 = unspotted flux level

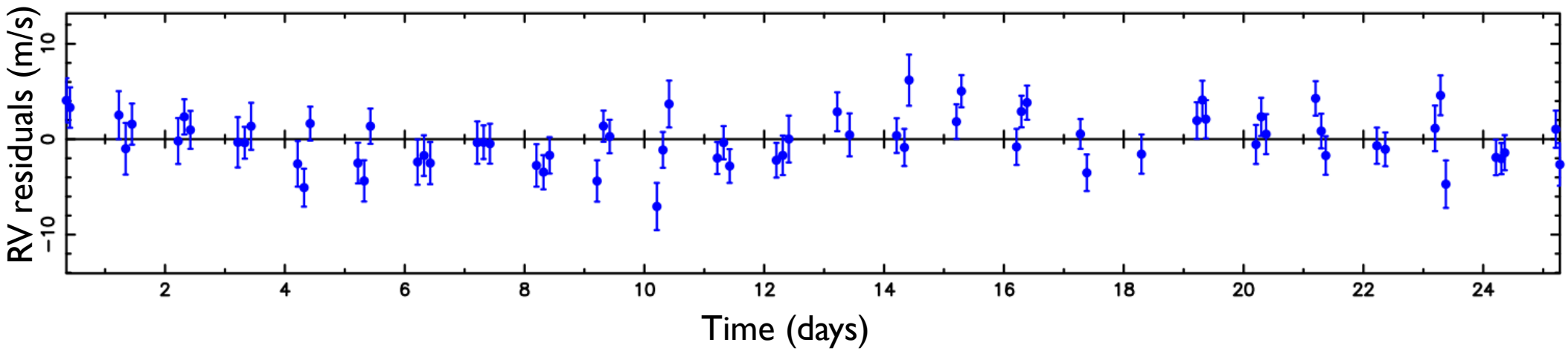


Total RV model

$$
\begin{aligned}
RV_{total} = \; & A\,\Delta RV_{rot}\,(t,\psi_0) + B\,\Delta RV_{conv}\,(t,\psi_0) \\
& + \text{planet b } (K_b, e_b, \Omega_b) \\
& + \text{planet c } (K_c, e_c, \Omega_c, P_c, T_{peri\_c}) \\
& + \text{planet d } (K_d, e_d, \Omega_d, P_d, T_{peri\_d}) \\
& + RV_0
\end{aligned}
$$

⇒ Find best solution using Monte Carlo Markov chain (MCMC)

Adding extra noise



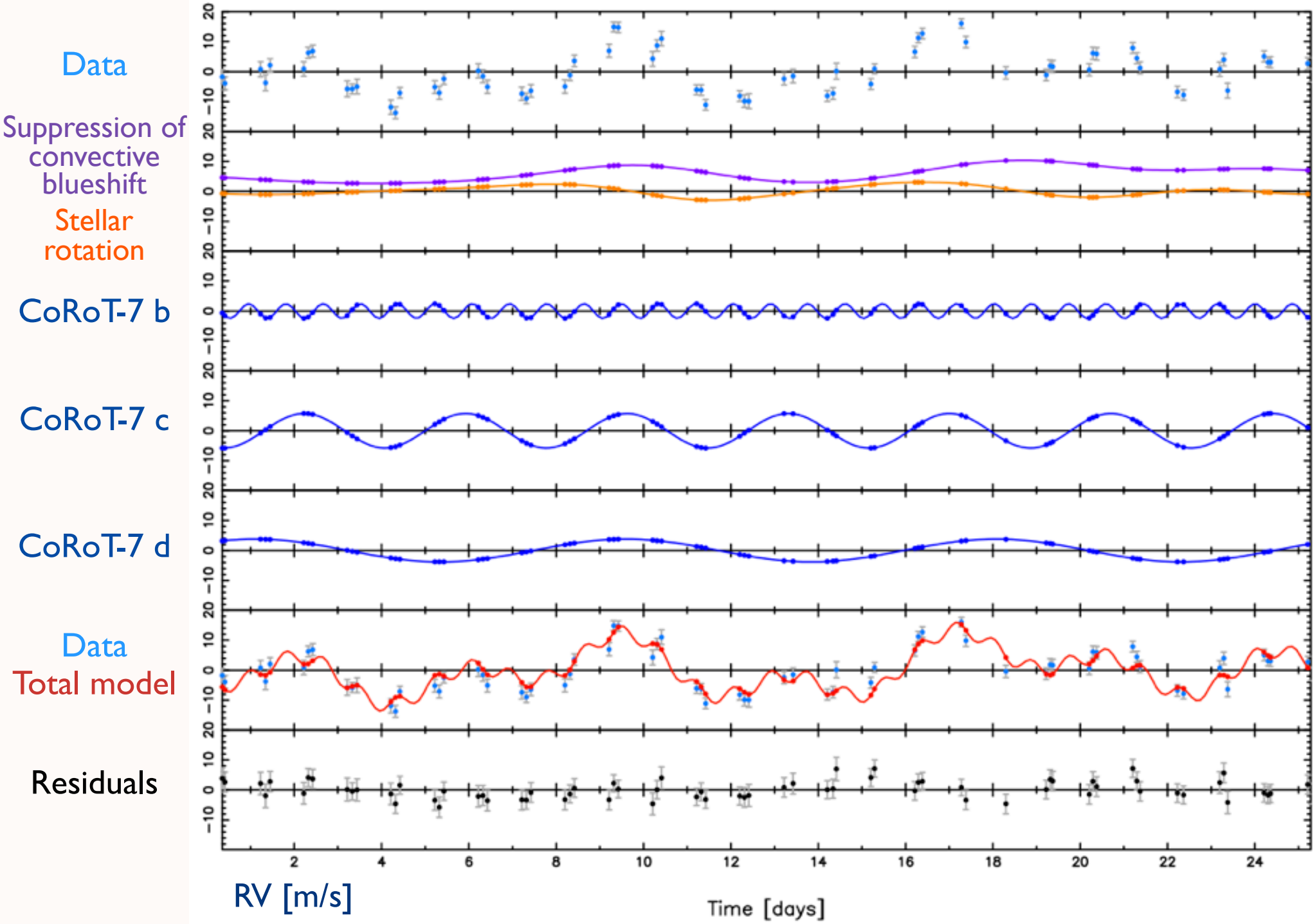
Possible reasons:

- LC model slow response to sudden appearance of active regions
- Have yet to account for:
  - Effect of faculae on suppr. of convective blueshift
  - ~ 50 m/s inflows towards active regions in the Sun (Gizon *et al.*, 2001)

⇒ Add extra noise term to account for stellar "rumble"

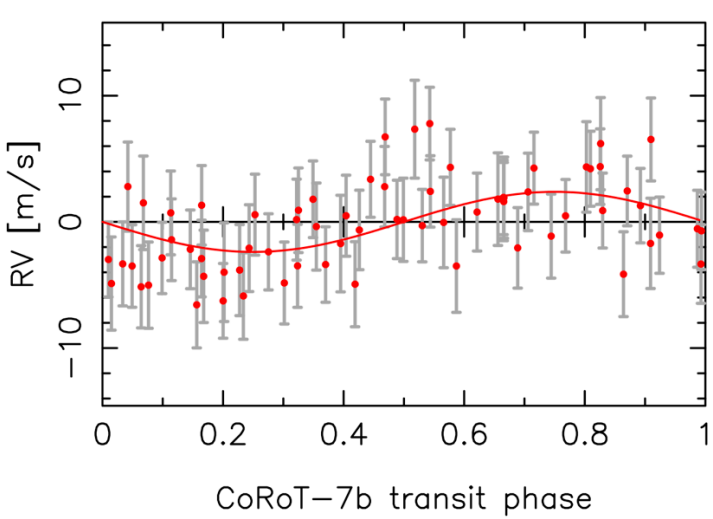
$\sigma_{total} = \sigma_{data} + \sigma_{rumble}$ (additively, not in quadrature)

RV models out of MCMC



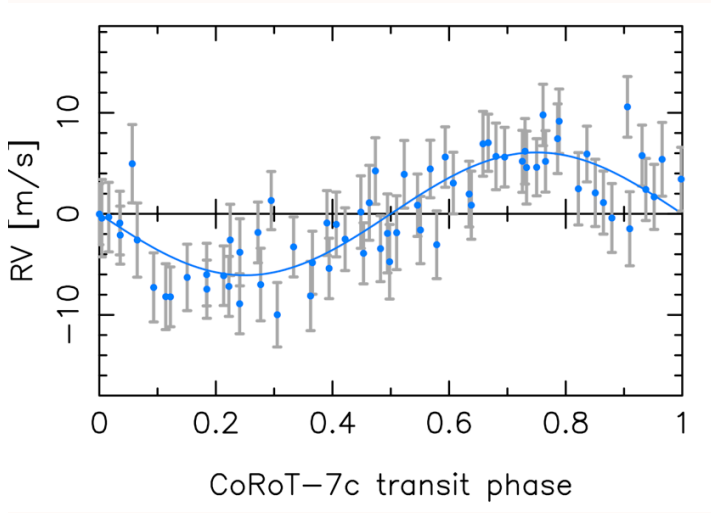
3 planets

CoRoT-7 b (transiting)



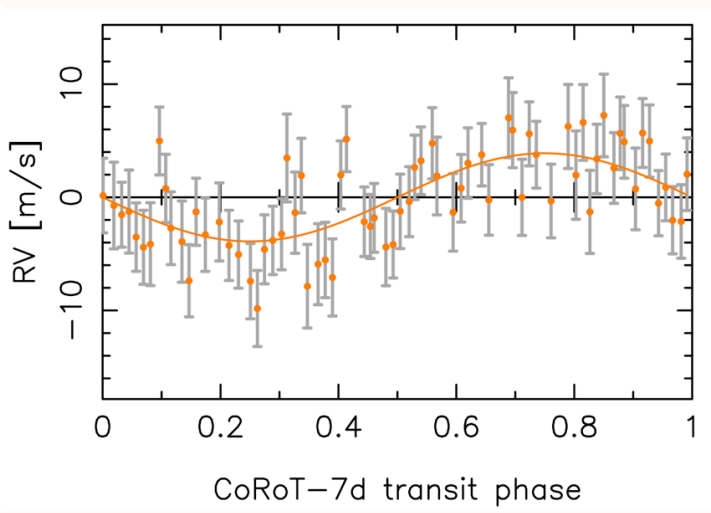
P = 0.85359165 ± 5.6.10^{-7}day
m = 3.38 ± 0.86 M⊕
e = 0 (fixed)

CoRoT-7 c



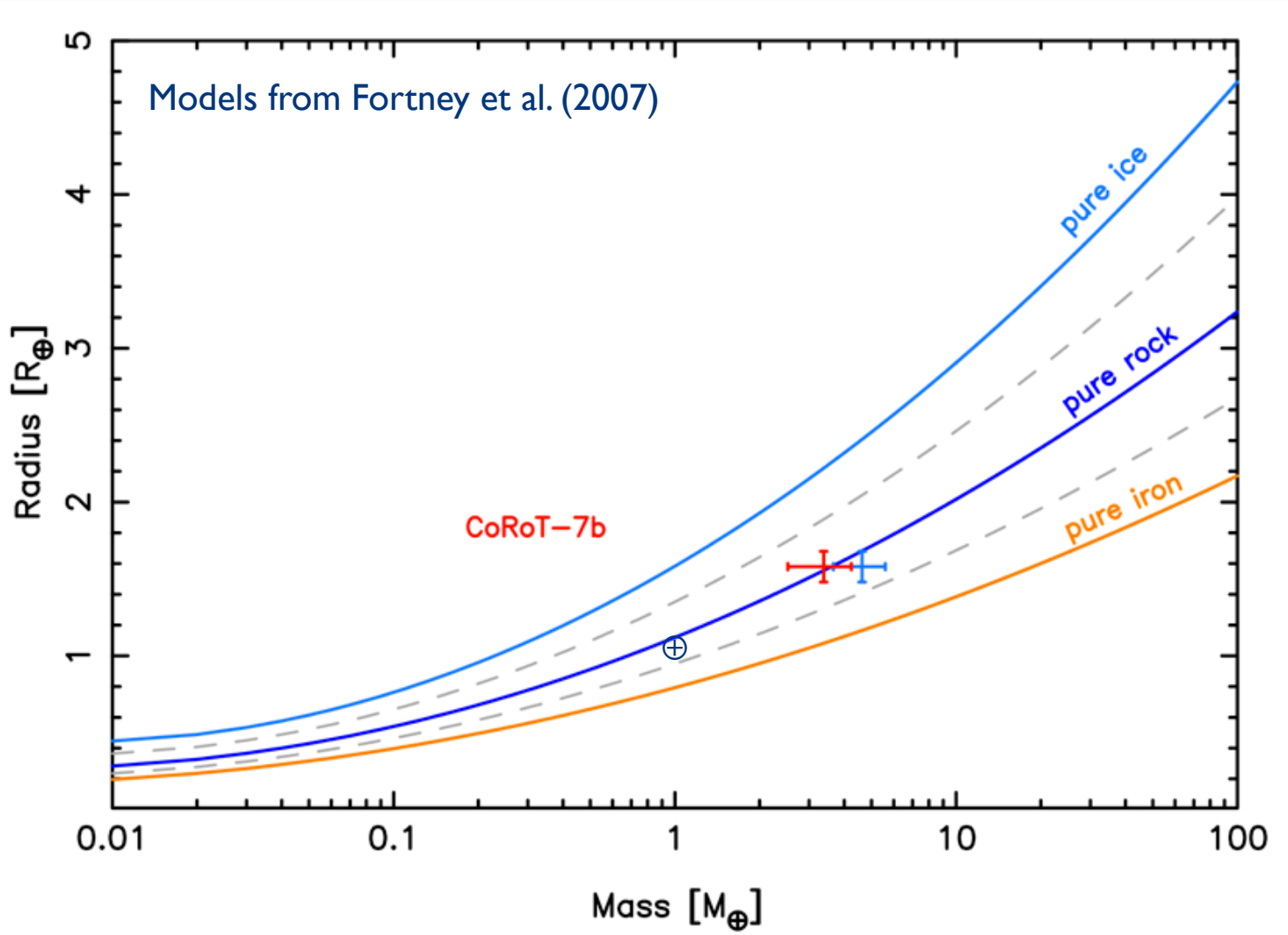
P = 3.68 ± 0.02 days
m = 13.31 ± 1.27 M⊕
e = 0 (fixed)

CoRoT-7 d



P = 8.54 ± 0.24 days
m = 11.92 ± 2.11 M⊕
e = 0 (fixed)

CoRoT-7 b



When e is fitted:
$e = 0.22 \pm 0.07$

Circular model:
$\rho = 4.73 \pm 1.21$ g.cm^{-3}

Eccentric model:
$\rho = 6.48 \pm 1.35$ g.cm^{-3}

Conclusion

- We confirm the presence of 2 sub-Neptune mass planets with $P_c = 3.68 \pm 0.02$ and $P_d = 8.54 \pm 0.24$ days
- CoRoT-7b is a rocky planet
- Activity-induced RV variations dominate total signal
- See Haywood et al. (submitted), Barros et al. (in prep.), Hatzes et al. (in prep.) & Lanza et al. (in prep.)
- Next: apply to Kepler candidates