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

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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

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

Star rotates

- no spots
- new distorted shape

Δλ ⇒ ΔRV
How does stellar activity affect RV?

II. Suppression of convective blueshift

Hot & bright outgoing flow $\rightarrow$ blueshift

Cool & dark sinking flow $\rightarrow$ redshift

$\Rightarrow$ Net blueshift

Active regions suppress granulation blueshift

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

$\Delta RV_{\text{super-Earth}} \sim$ 0.5-5 m/s
CoRoT-7 2012 data

**Lightcurve (transits of CoRoT-7b removed)**

**RV data**

\[
\text{RV}_{\text{total}} = \text{RV}_{\text{activity}} + \text{RV}_{\text{planets}}
\]
Modelling stellar RV variations

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

\[
\Delta \text{RV}_{\text{activity}} = A \Delta \text{RV}_{\text{rot}} (t, \psi_0) + B \Delta \text{RV}_{\text{conv}} (t, \psi_0)
\]

\[
\Delta \text{RV}_{\text{rot}} \propto F . \frac{dF}{dt}
\]

\[
\Delta \text{RV}_{\text{conv}} \propto F^2
\]

A, B constants
\(\psi_0 = \) unspotted flux level
Total RV model

\[ RV_{total} = A \Delta RV_{rot} (t, \psi_0) + B \Delta RV_{conv} (t, \psi_0) + \text{planet } b (K_b, e_b, \Omega_b) + \text{planet } c (K_c, e_c, \Omega_c, P_c, T_{peri_c}) + \text{planet } d (K_d, e_d, \Omega_d, P_d, T_{peri_d}) + RV_0 \]

⇒ 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 suppression 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”

\[ \sigma_{\text{total}} = \sigma_{\text{data}} + \sigma_{\text{rumble}} \]  
(additively, not in quadrature)
RV models out of MCMC

Data

Suppression of convective blueshift
Stellar rotation

CoRoT-7 b
CoRoT-7 c
CoRoT-7 d

Data
Total model

Residuals

RV [m/s]

Time [days]
3 planets

**CoRoT-7 b (transiting)**

- $P = 0.85359165 \pm 5.6 \times 10^{-7}$ days
- $m = 3.38 \pm 0.86 \, M_{\oplus}$
- $e = 0$ (fixed)

**CoRoT-7 c**

- $P = 3.68 \pm 0.02$ days
- $m = 13.31 \pm 1.27 \, M_{\oplus}$
- $e = 0$ (fixed)

**CoRoT-7 d**

- $P = 8.54 \pm 0.24$ days
- $m = 11.92 \pm 2.11 \, M_{\oplus}$
- $e = 0$ (fixed)
CoRoT-7 b

Models from Fortney et al. (2007)

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

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

When \( e \) is fitted:
\[ e = 0.22 \pm 0.07 \]
• 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