InVestagating the Sun's radial velocity jitter

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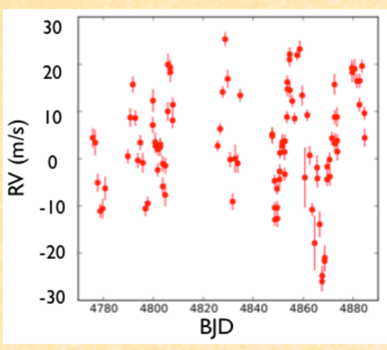
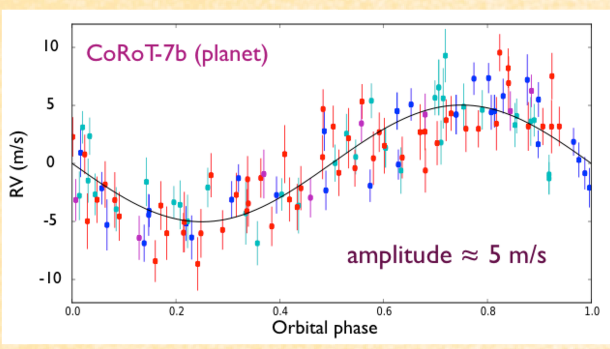
One of the most common methods used to discover extra-solar planets is to monitor a star's radial velocity (RV) in order to detect the reflex orbital motion caused by one or more planets orbiting the star. In the case of low-mass planets (Neptune or Earth mass), the RV variations induced by these planets are of the same amplitude as the "rumble" arising from the star's activity. Identifying reliable proxies to disentangle both signals would therefore greatly improve the rate of detection of low-mass planets.

Exoplanet radial-velocity amplitudes *vs* stellar jitter

Example: CoRoT-7



≈ 20 - 30 ms^{-1} amplitude, mostly due to stellar activity



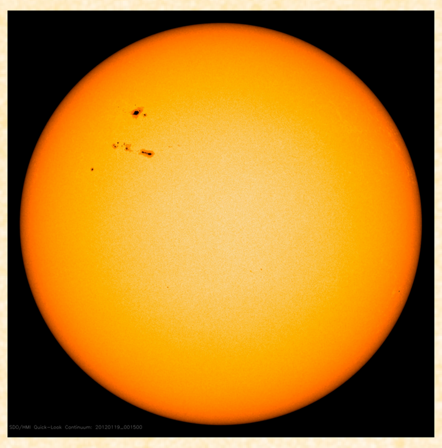
Activity markers on the surface of the Sun

Sunspots and surface granulation (present on the continuum image) also give rise to irregularities in the Sun's dopplergram, *i.e.* they have an effect on its radial velocity.

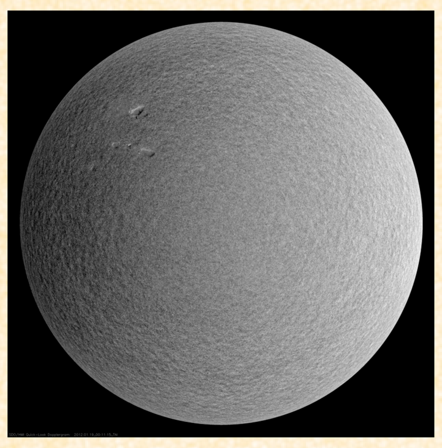
For an Earth-like planet orbiting a typical dwarf star at 10 pc:

- planet RV amplitude ≈ 0.1 ms^{-1}
- activity-induced RV variations ≈ 0.5 ms^{-1}

(Makarov et al. 2009)

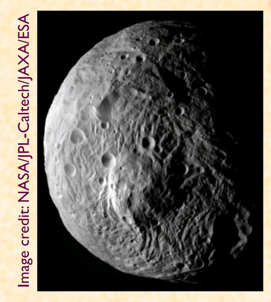


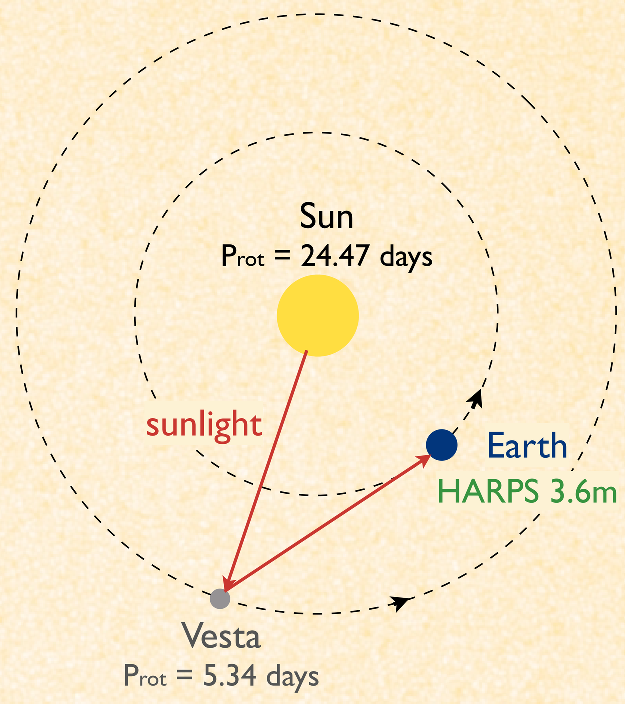
HMI Intensitygram (SDO online database)



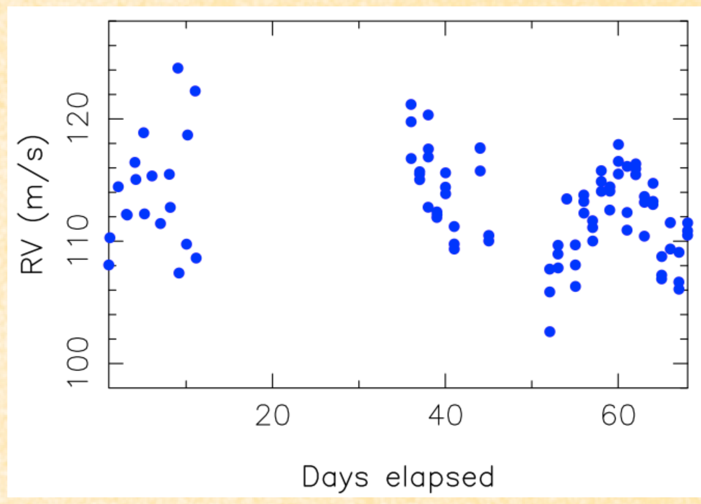
HMI Dopplergram (SDO online database)

Using the asteroid Vesta to obtain the Sun's radial velocity variations





Solar RV variations *before* removing effects of Vesta's axial rotation

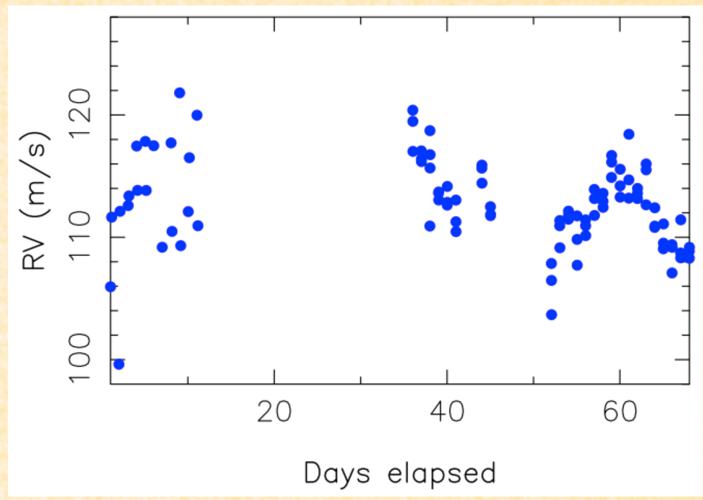


HARPS observations: 29 Sept. - 7 Dec. 2011

Steps undertaken to obtain Sun-as-a-star RVs:

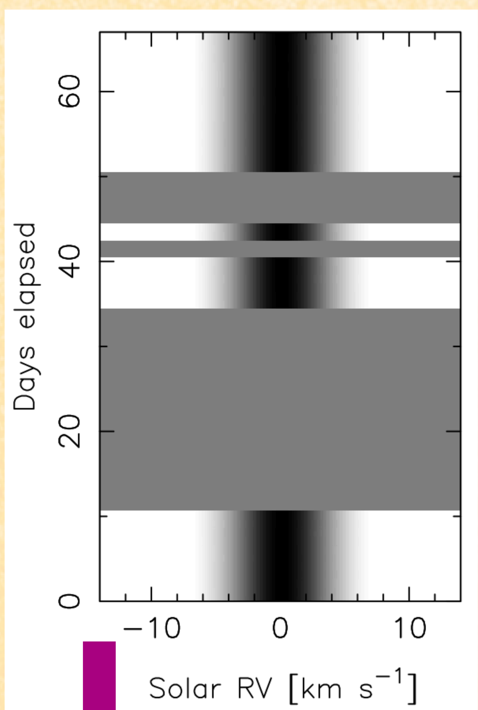
- Removed Doppler shifts induced by (a)Vesta relative to the Sun and (b) observer relative to Vesta using JPL HORIZONS ephemeris
- Modelled and removed effect of Vesta's axial rotation and uneven surface brightness using a linear model (*cf.* Hatzes *et al.* 2011). The amplitude was found to be 2.3 ms^{-1}.

Solar RV variations *after* removing effects of Vesta's axial rotation

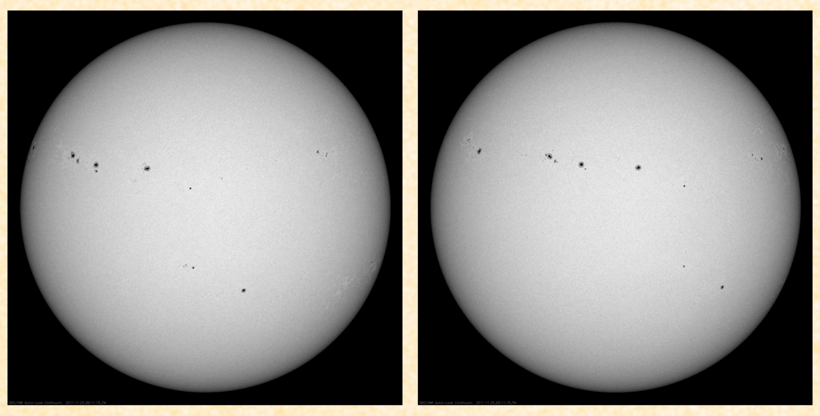


The Sun's line-profile distortions

Time-series of cross-correlation functions (CCFs)

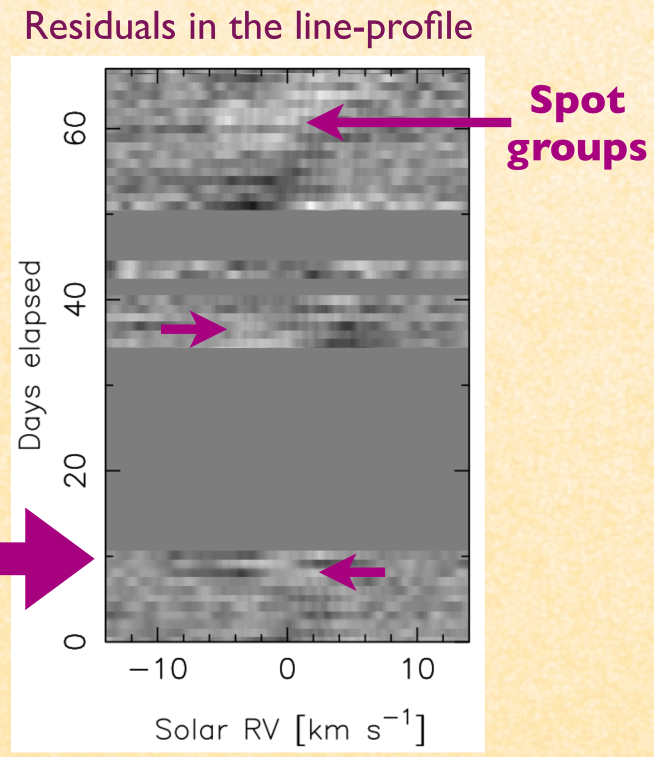


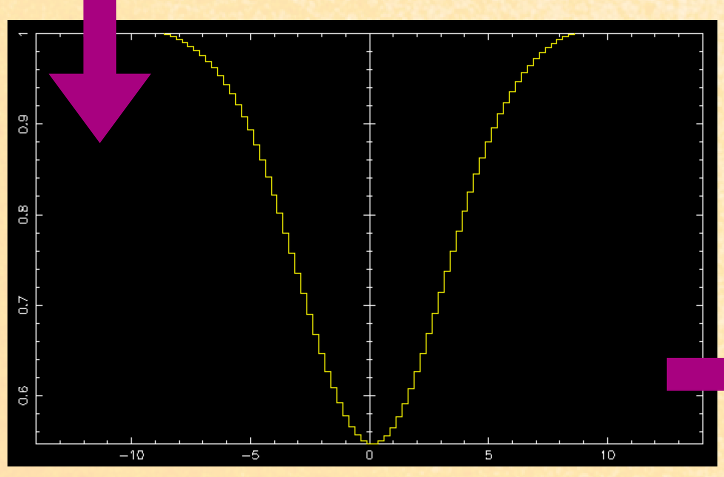
23 Nov. 2011 | 25 Nov. 2011



These HMI continuum images of the Sun taken two days apart show groups of sunspots drifting across the solar surface.

Residuals in the line-profile



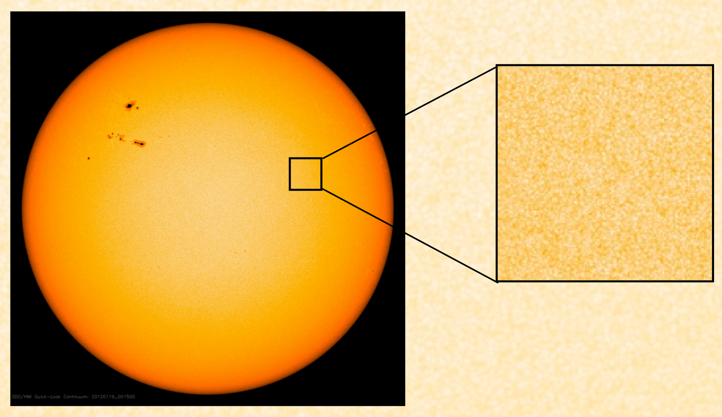


Average of all CCFs: subtract this from each individual CCF to obtain residuals.

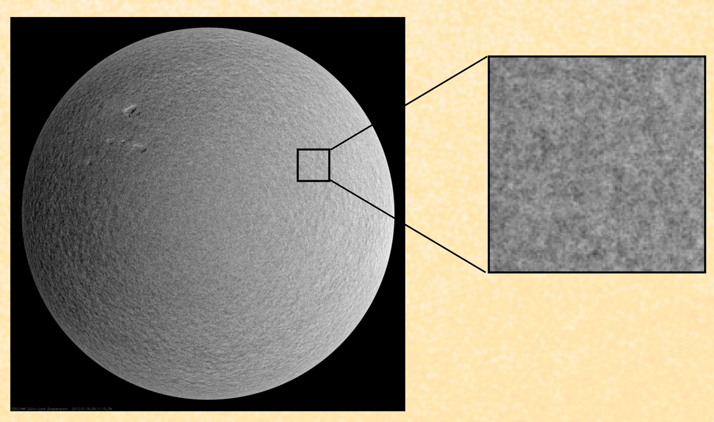
The residuals in the line-profile show how the shape of the spectral lines evolve with time. The white trails cutting across the solar rotation profile are caused by sunspots drifting across the face of the Sun.

Next step: model line-profile distortions caused by stellar activity

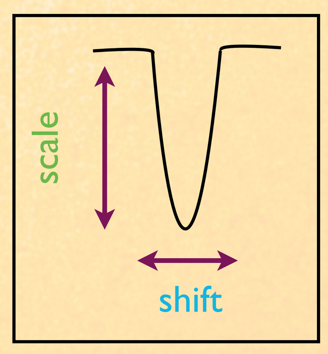
Continuum image (scale)



Doppler image (shift)



We are using high resolution data from the HMI instrument aboard the Solar Dynamics Observatory to synthesize Sun-as-a-star CCFs from full-disk continuum images and dopplergrams.



Our goal is to determine the relative importance of sunspots, p-mode oscillations and granulation as contributors to the "rumble" that masks signals caused by the orbit of low-mass planets around solar-type stars.

Image credit: HMI/SDO online database

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