

The Effects of Stellar Variability on the Detection and Characterization of Exoplanets

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Astrophysical noise sources: p-modes, granulation, meridional flows

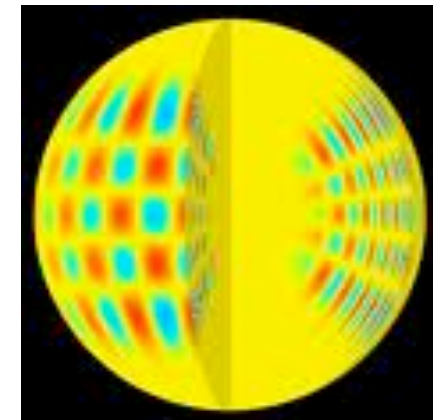
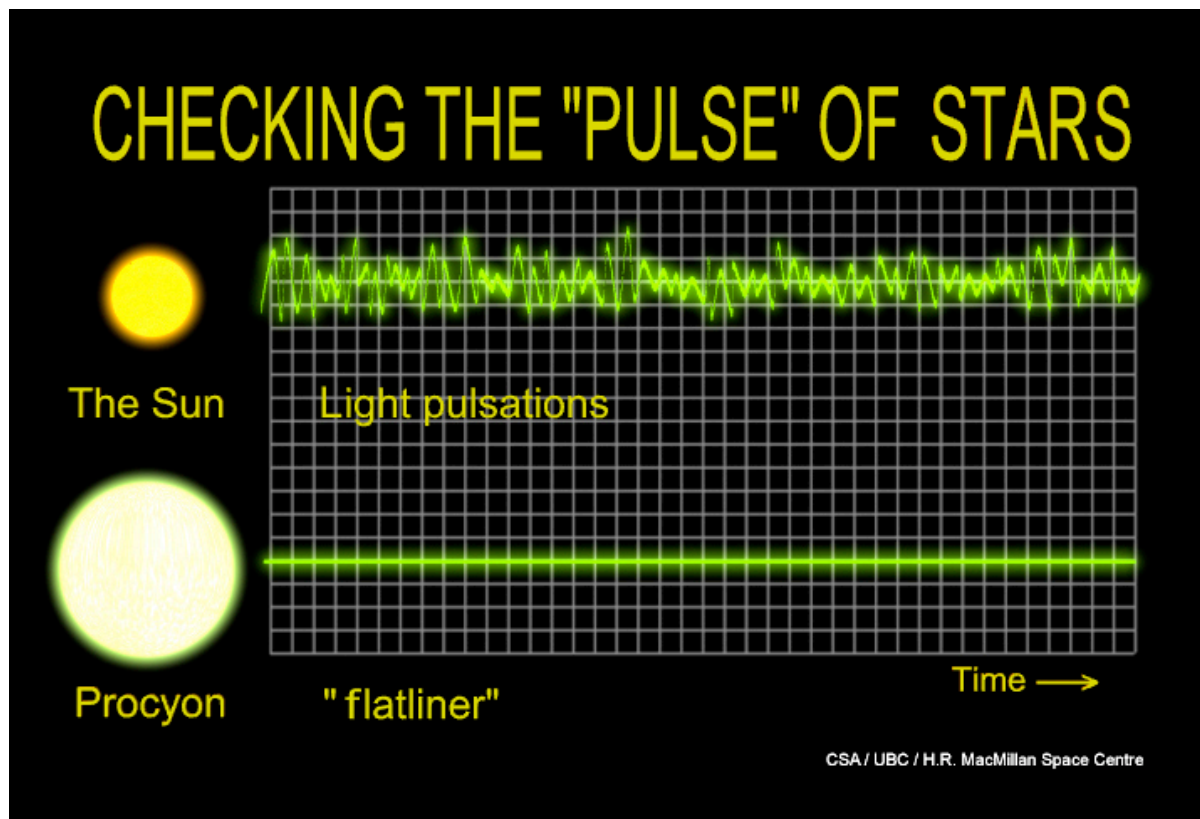
Diagnostics: S-values, log R'HK, photometry, bisector analysis

Impact on RV technique

Measuring line shifts of $1/3000$ of a pixel already. As we reduce this further (e.g., with laser frequency combs) what will we measure: dynamical motions or astrophysical flows? The latter might be less interesting.

Impact on photometry and astrometric observations

Noise sources: P-mode oscillations



Noise sources: p-modes

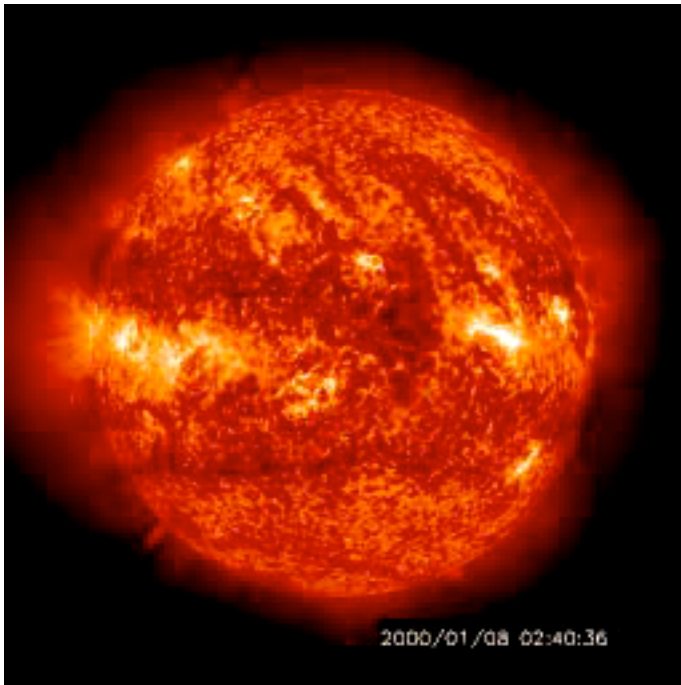
Millions of seismic eigenmodes driven by non-adiabatic granular pressure fluctuations are excited to low amplitudes with a frequency spectrum that grows as f^4 until it reaches a narrow maximum at 3 mHz, then drops off again toward higher frequencies.



5 minute oscillations in the Sun.

Pressure modes move in and out of resonance - probably no way to correct for them. However, we can average over them by taking longer or multiple exposures.

Noise sources: Spots and flares

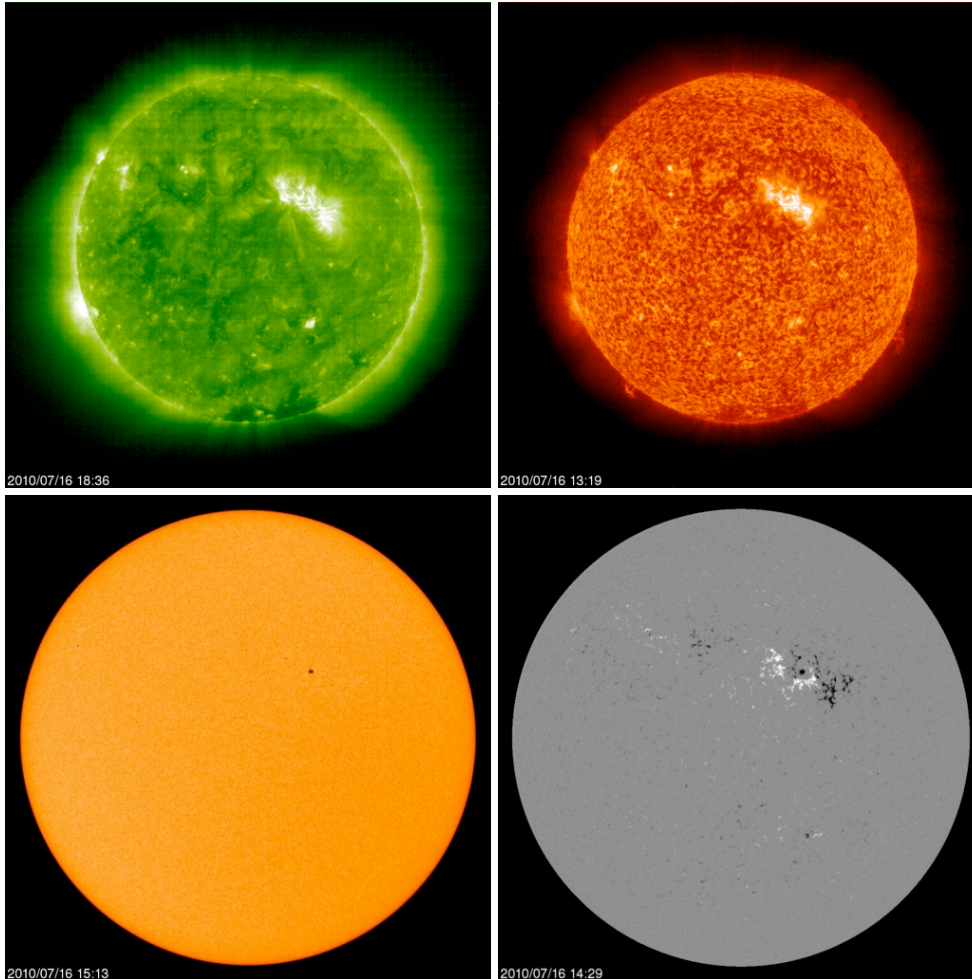


This is the quiet, steady old Sun!

Convective dynamos spawn magnetic fields and result in spots and flares with km s^{-1} outflows producing convective blue shifts in spectral line profiles.

These arise from the photosphere and are not dynamical Doppler shifts, but how to tell the difference?

Example: The Sun: July 16, 2010

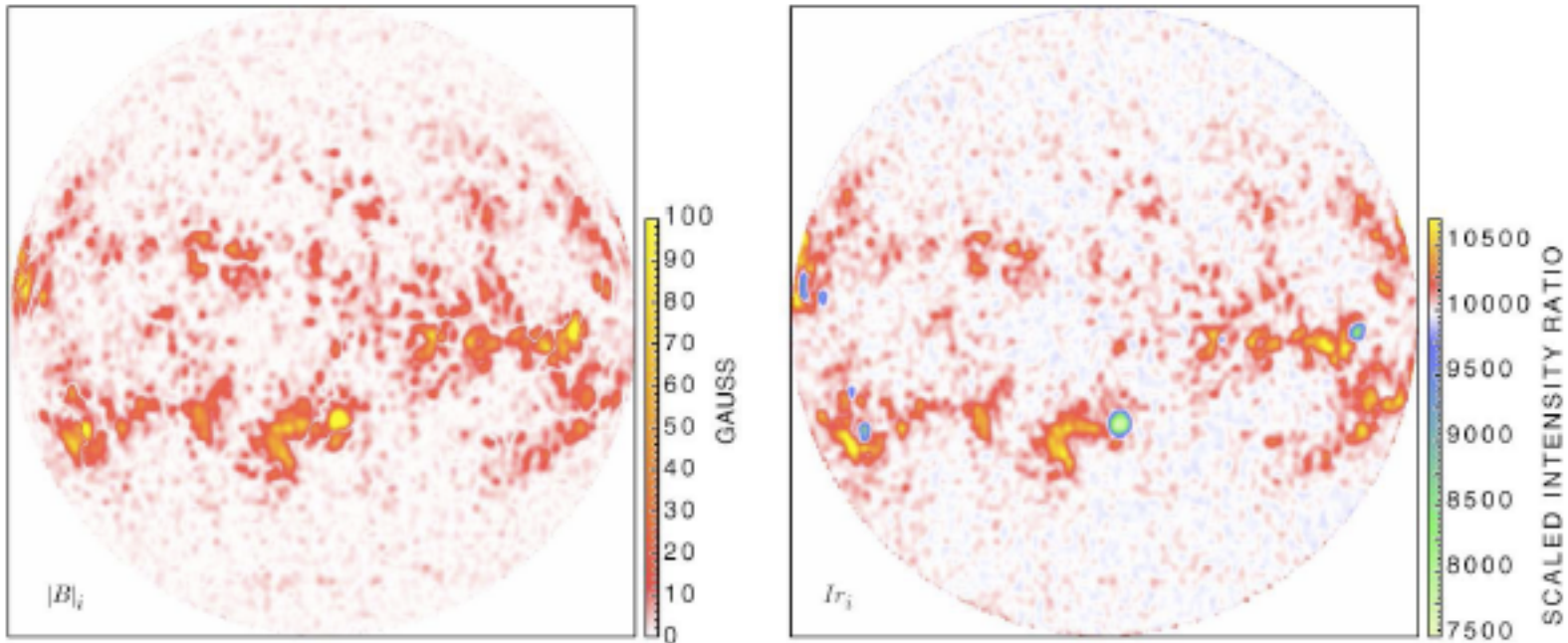


EIT images: 195A 1.5M K
304A 70,000K

(Which of these images higher layers in the solar atmosphere?)

MDI images: 6768A (continuum)
Magnetogram
(black and white show opposite polarity)

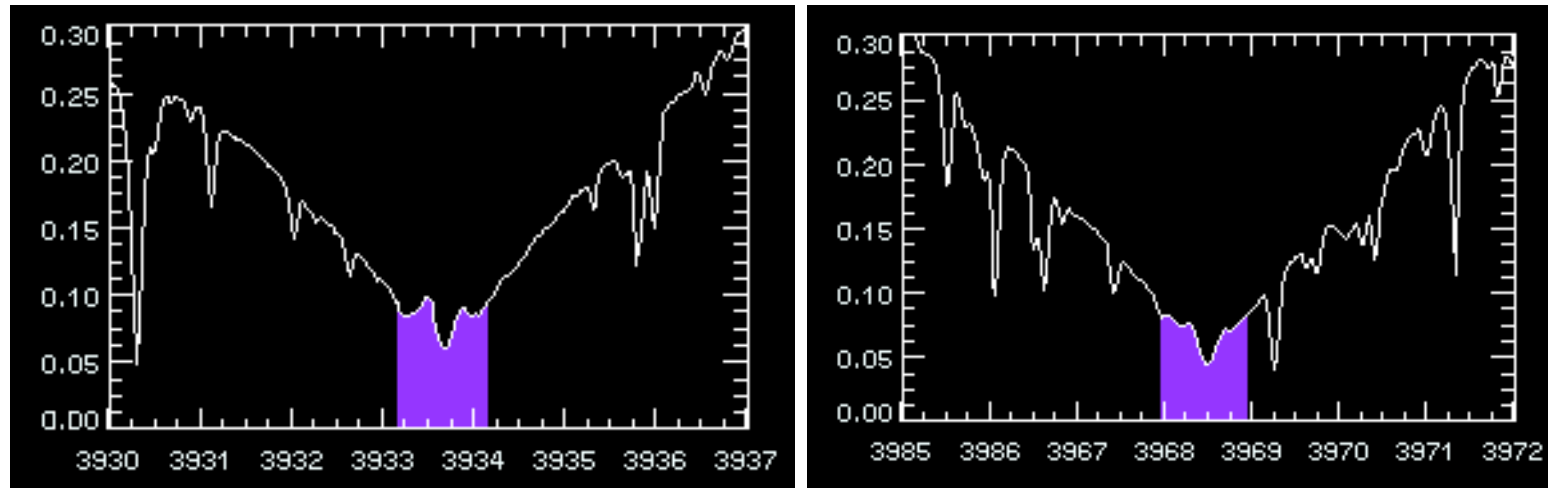
Diagnostic tool: Ca II H&K



Ulrich *et al.* (2010) map magnetic field intensity (using the λ 5250 flux strength_ from MWO (1997 – 2007) to the total solar irradiance (using line ratio 5250A/ 5237A (upper photosphere / lower chromosphere).

Evidence that magnetic fields in the photosphere are casually related to chromospheric emission.

Diagnostic tool: Ca II H&K

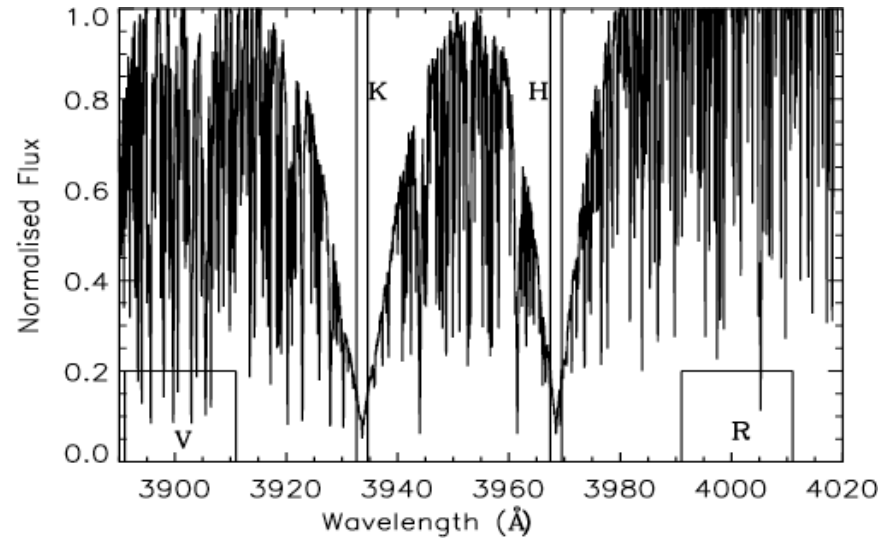


Singly ionized calcium produces broad absorption features in the solar spectrum, the Ca II H&K lines, formed in the lower chromosphere.

Direct relation b/t magnetic field strength and emission in the Ca II lines (Skumanich et al . 1975). Energy from stellar magnetic fields is transferred into the upper chromosphere where it fills in the line cores with emission. ***Ca II H&K core emission lines are a signature of magnetic activity (chromospheric activity) in stars.***

The Mt Wilson H&K project obtains time series measurements of H&K line core emission for hundreds of stars: S_{HK} metric.

Diagnostic tool: S_{HK} and $\log R'_{HK}$

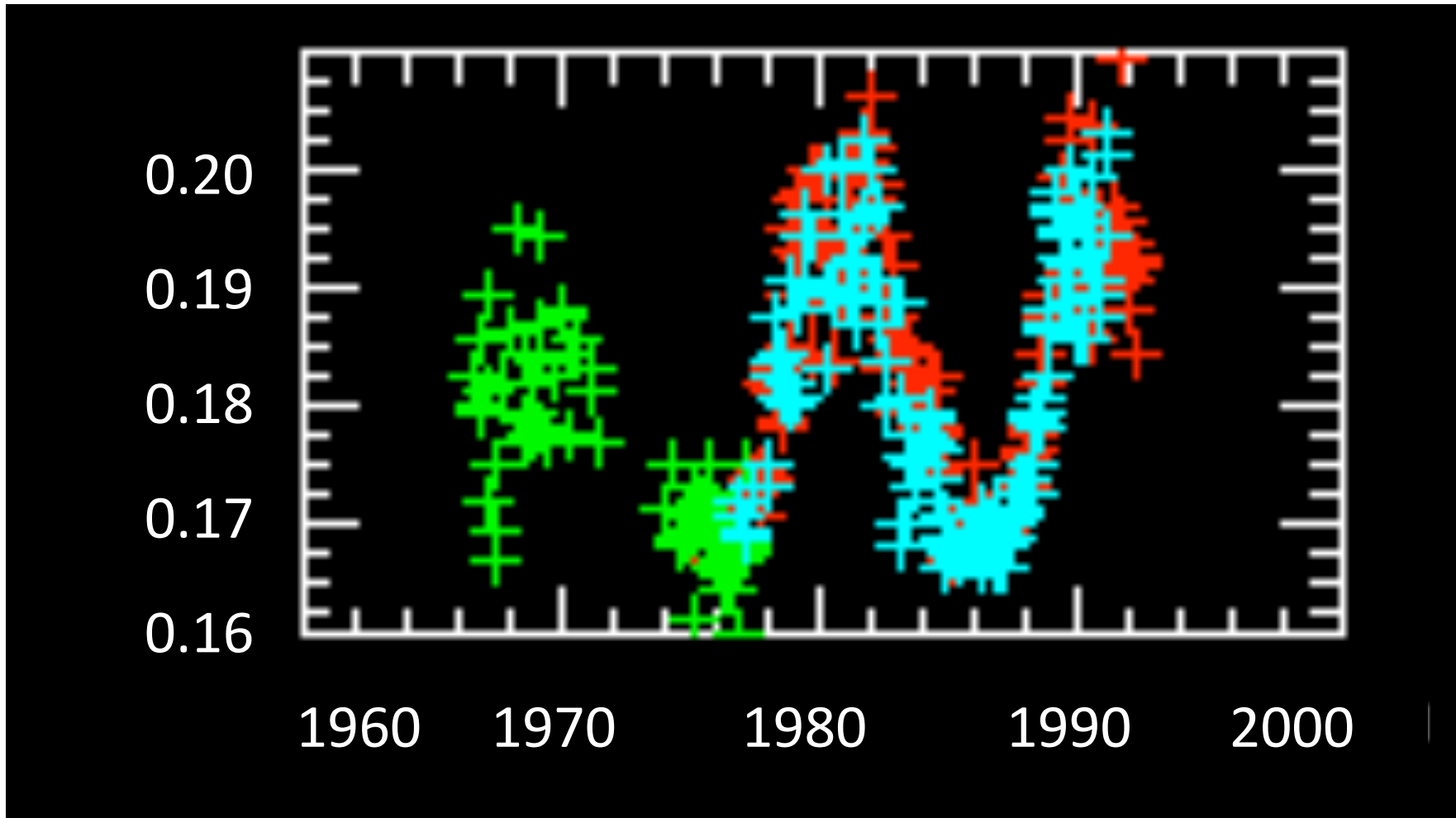


S_{HK} is the ratio of emission in the Ca II line cores (relative to continuum windows).

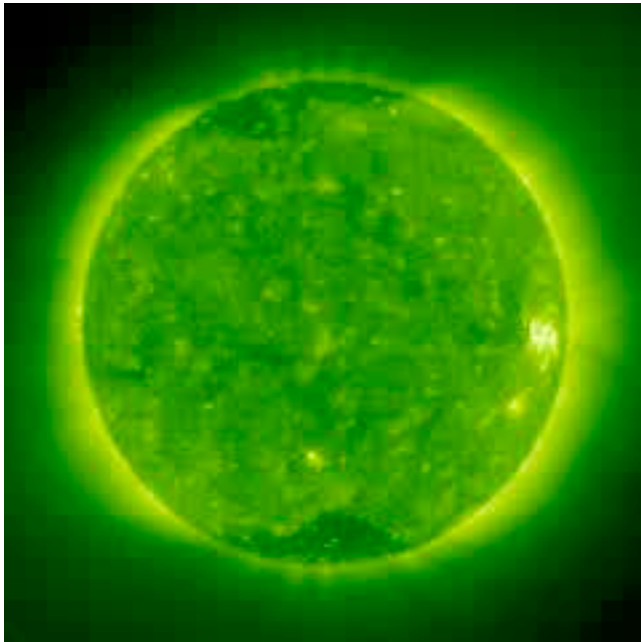
The continuum at 3900Å is extremely low in red stars; S_{HK} can increase either because more energy is being dumped into the upper chromosphere or because continuum flux is decreasing.

$\log R'_{HK}$ was defined, essentially as a ratio of S_{HK} to photospheric flux. Puts all stars on a common “activity” scale.

Example: Time series solar Ca H&K cycle



Noise sources: Meridional Flows

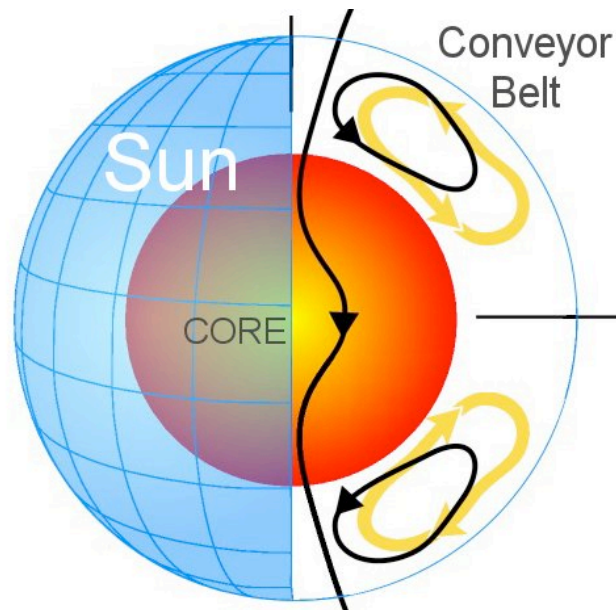


Long term cycles in the magnetic fields may also be associated with cycles in photospheric velocities - a non-dynamical source of RV variation.

Modeling Ca H&K line emission can at least serve to warn you - but we don't have a good correction yet.

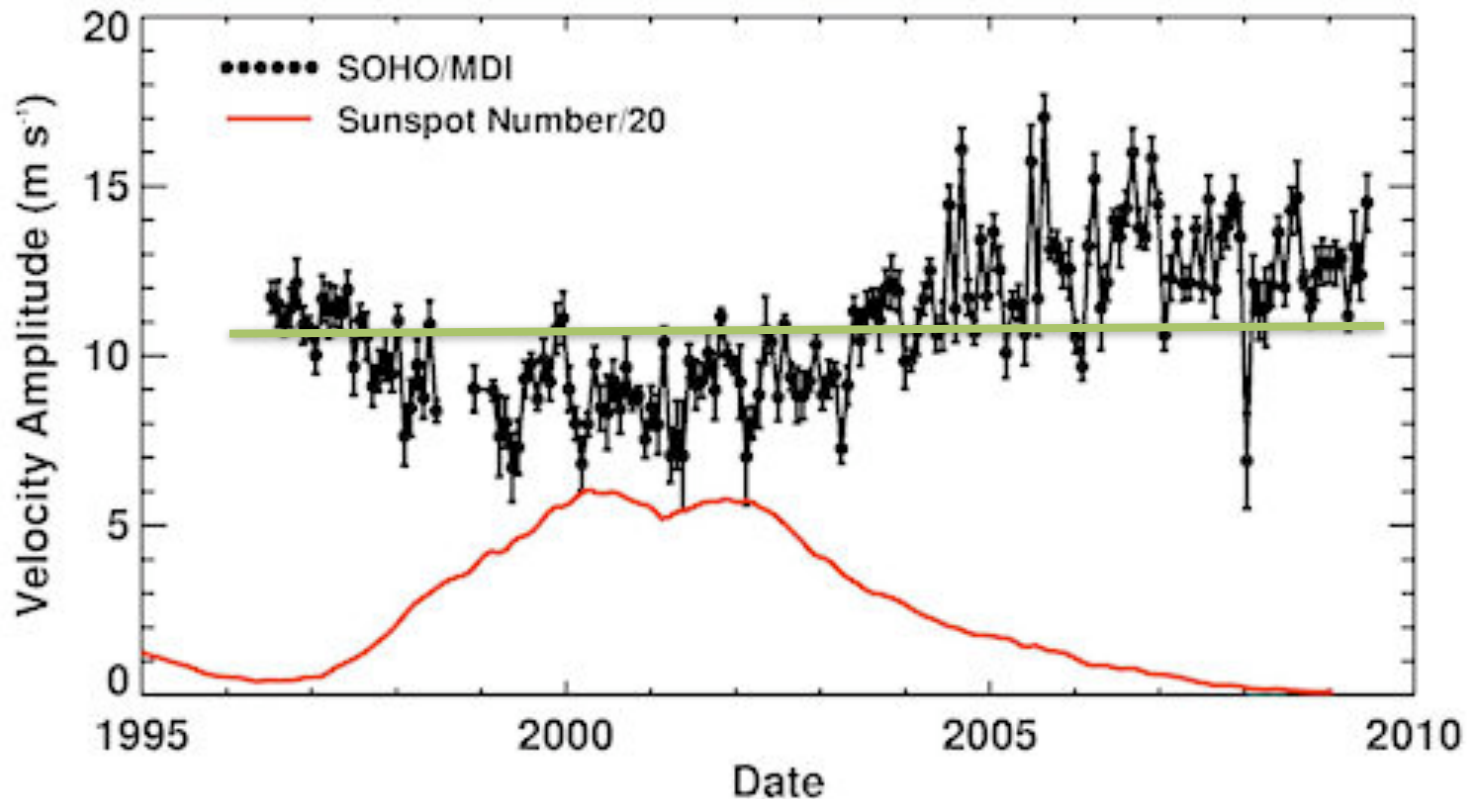
This is the quiet, steady old Sun!

Example: Solar meridional flow



Meridional Circulation: massive flow pattern that transports hot plasma to the poles and deeper CZ layers. Flows are thought to be $\sim 10 \text{ m s}^{-1}$ (slow, relative to the outflows from plages or spot rotation). Meridional flow may govern the strength of the polar magnetic field and strength of sunspots.

Example: solar meridional flow



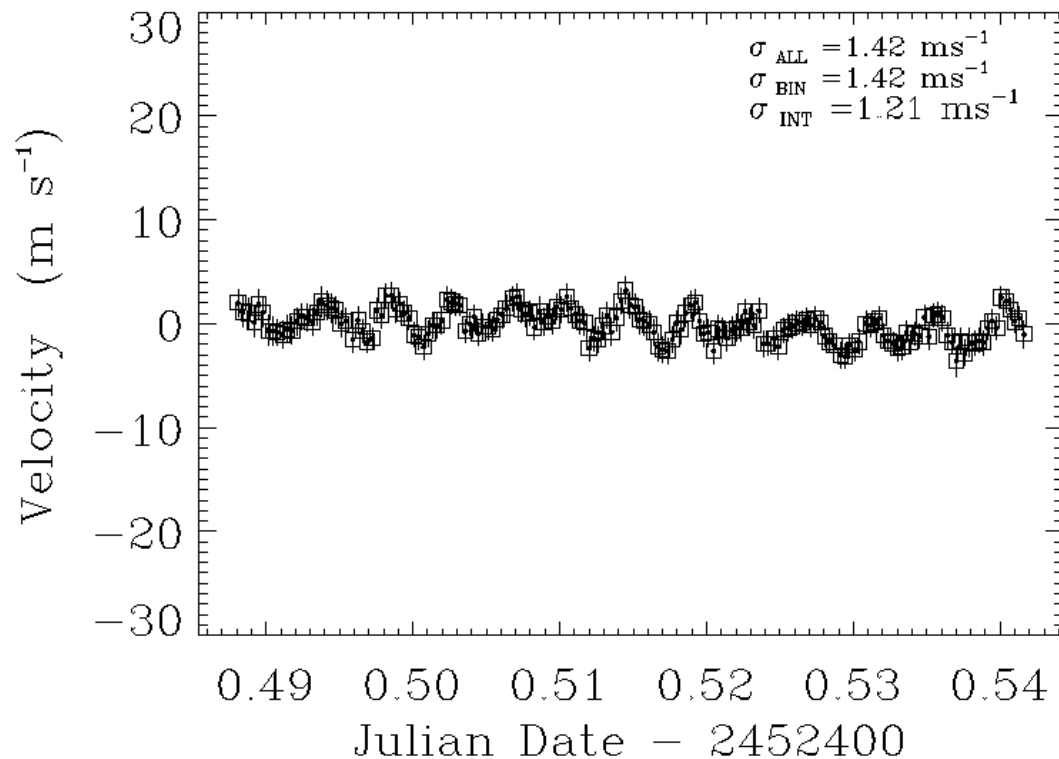
Meridional Flow variation 1996 – 2009 measured by SOHO/MDI. The scaled sunspot number in red indicates the phase of the solar activity cycle (Hathaway & Rightmire: 2010, *Science* 327, 1350).

One take-away message: RV variations may be out of phase with activity cycles.

Impact on RV technique

Example: *p*-modes

R. P. Butler: observations of α Cen, a chromospherically inactive, old, slowly rotating, sunlike star

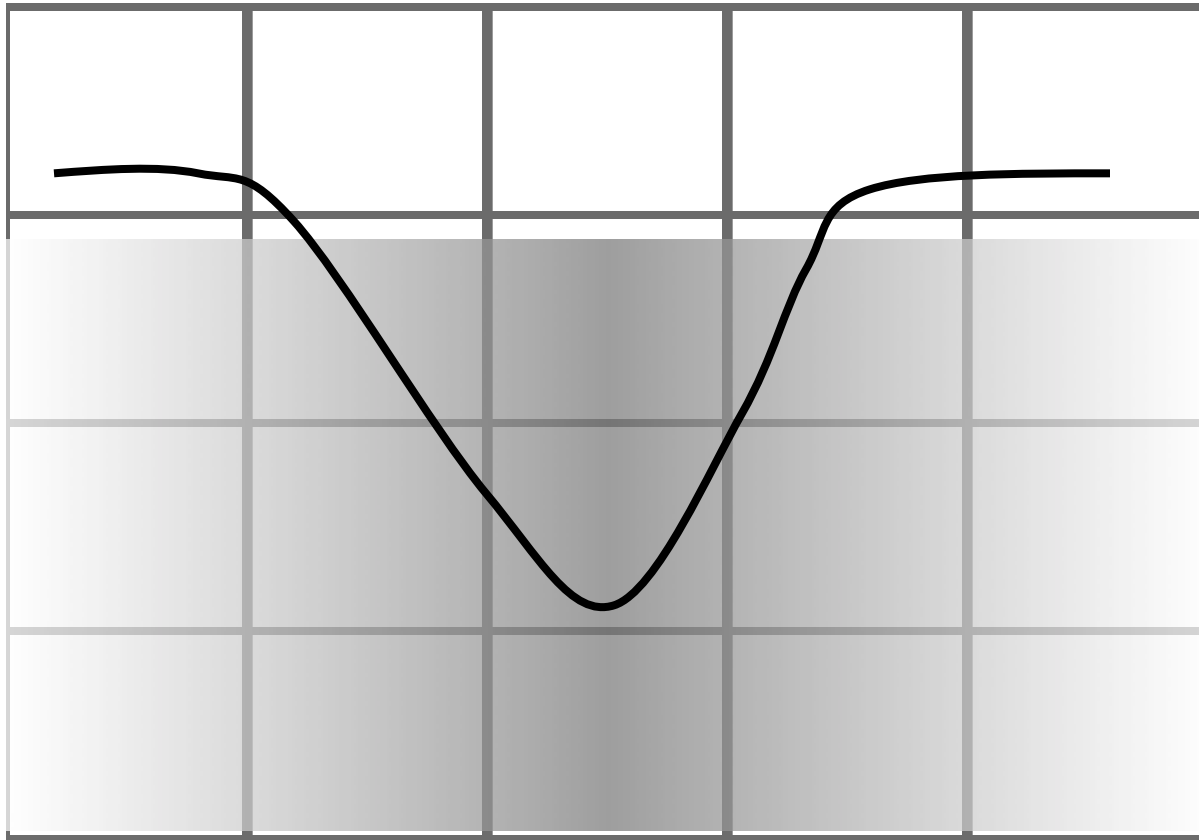


P-mode oscillations

5 minute periodicity,
amplitude of about 3 m/s

Short exposure times would
register snapshots of this
RV variability

Impact on RV technique



One pixel

Physical dimension: 15 μ

Dispersion λ : 0.05 \AA

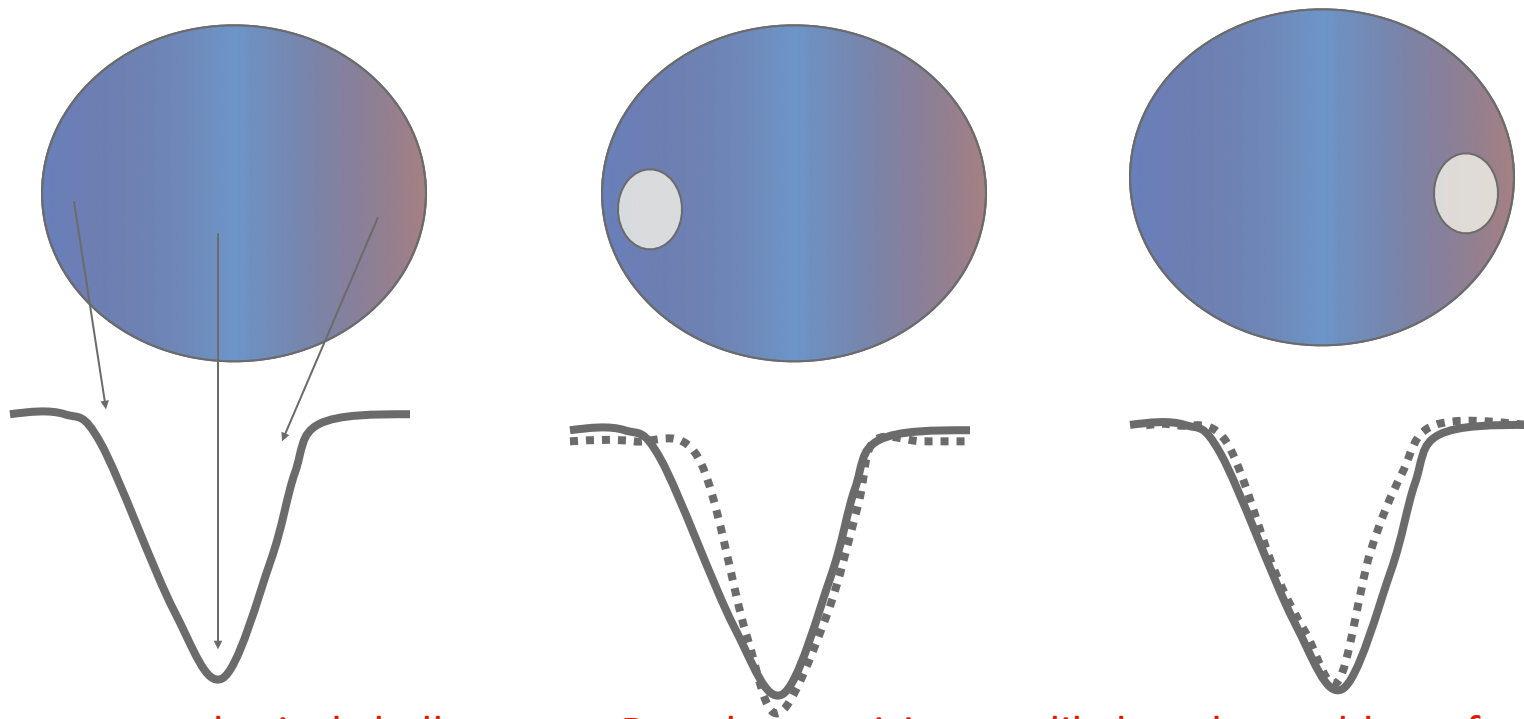
Velocity: 3000 m/s

For typical high resolution spectrographs with 15 μ micron pixel CCD detectors (e.g. HDS on Subaru or HIRES on Keck), $\delta\lambda = 0.0002 \text{\AA}$ corresponds to 0.004 pixel shift. To measure this signal, you need a precision that is many times better.

Note: typical spectral lines are a few CCD pixels (or more) in width, so we need to detect shifts better than 1/1000 the width of the lines we model.

Impact on RV technique

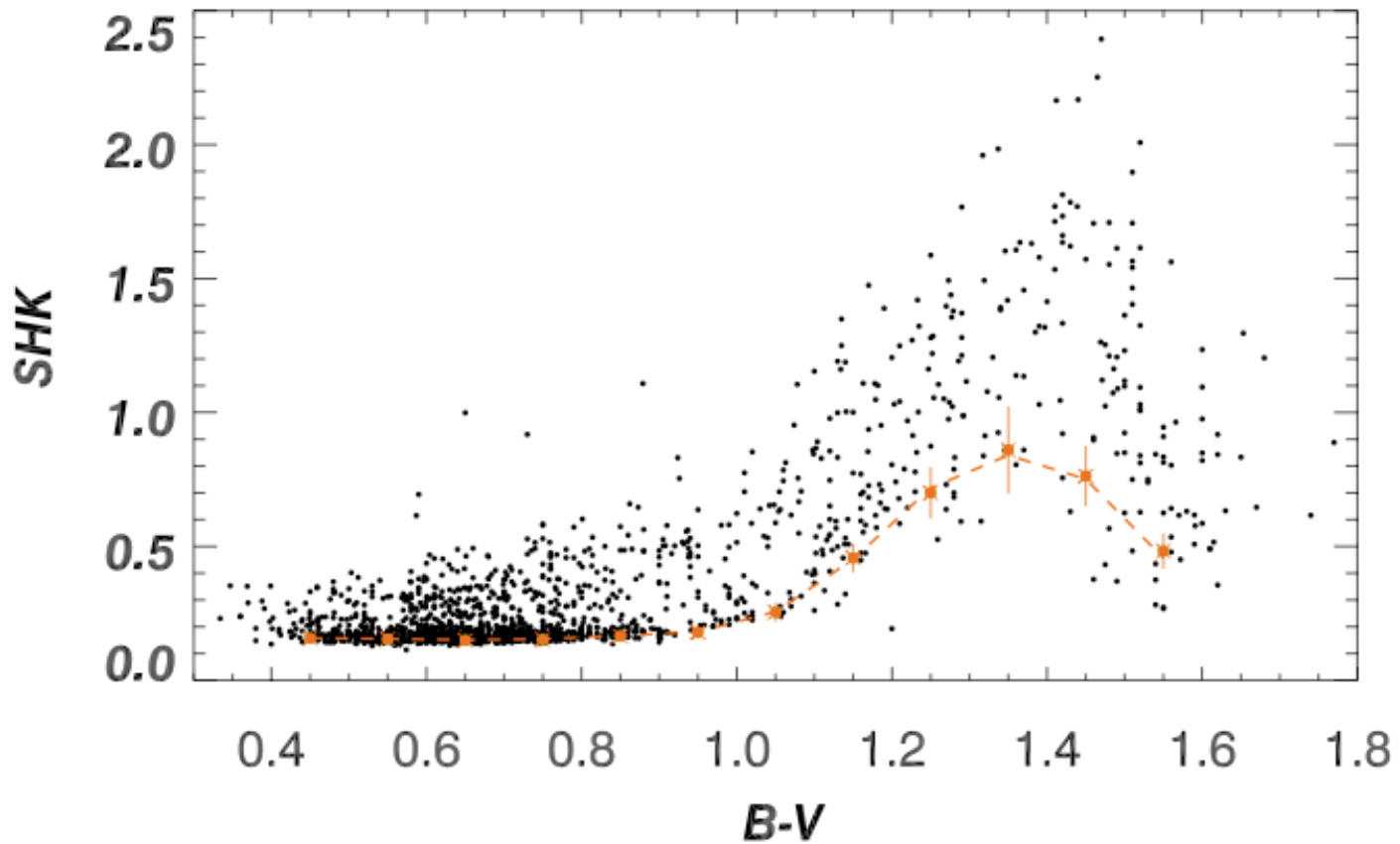
High rotational velocities are associated with chromospheric activity and starspots. As starspots rotate across the star, the line centroid shifts.



These astrophysical challenges to Doppler precision are likely to be problems for other detection techniques, too.

Diagnostic tool: S_{HK} and $\log R'_{HK}$

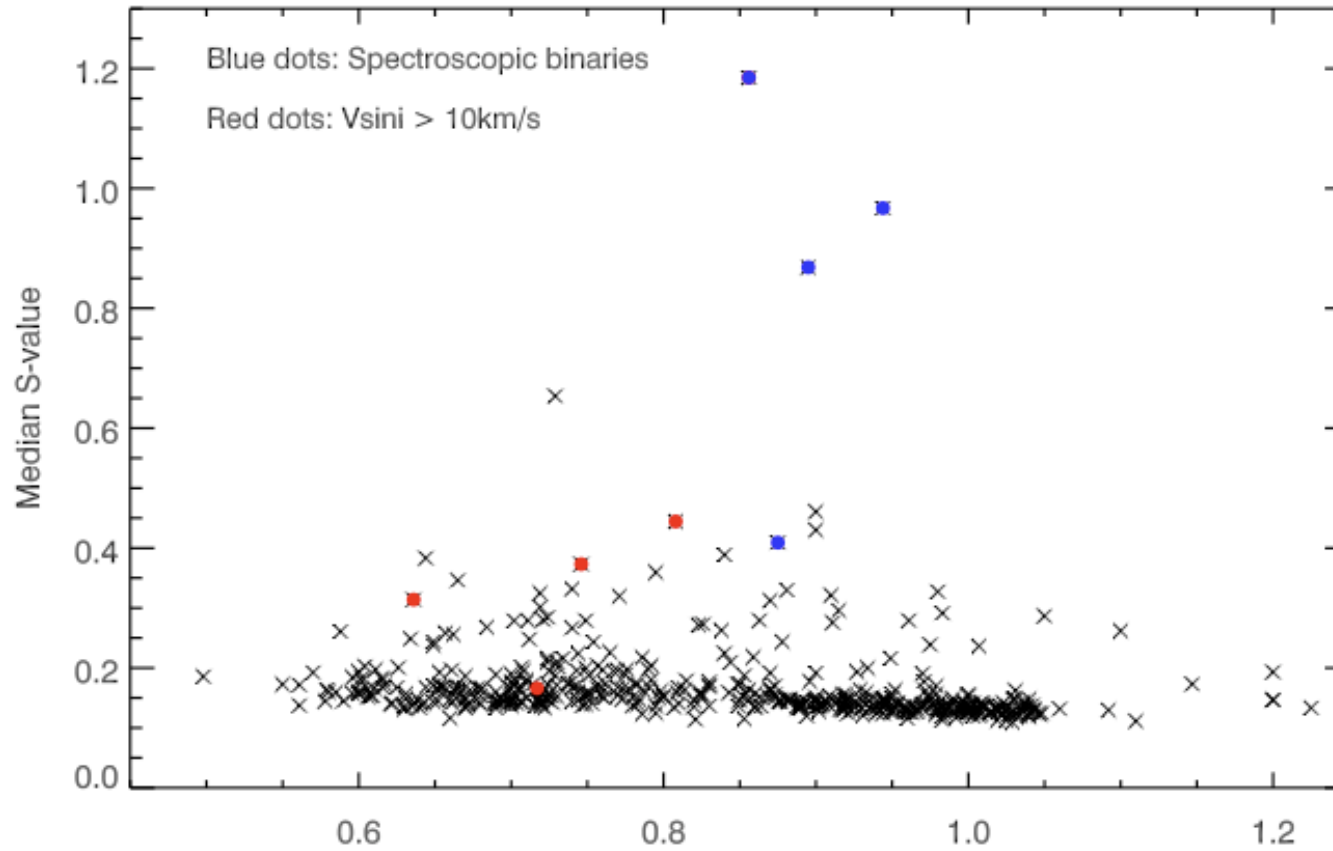
Isaacson & Fischer 2010 (ApJ in press)



Slipper diagram: lower SHK for hotter stars and smaller range. Turn-over in minimum SHK for cool stars.

Diagnostic tool: S_{HK} and $\log R'_{HK}$

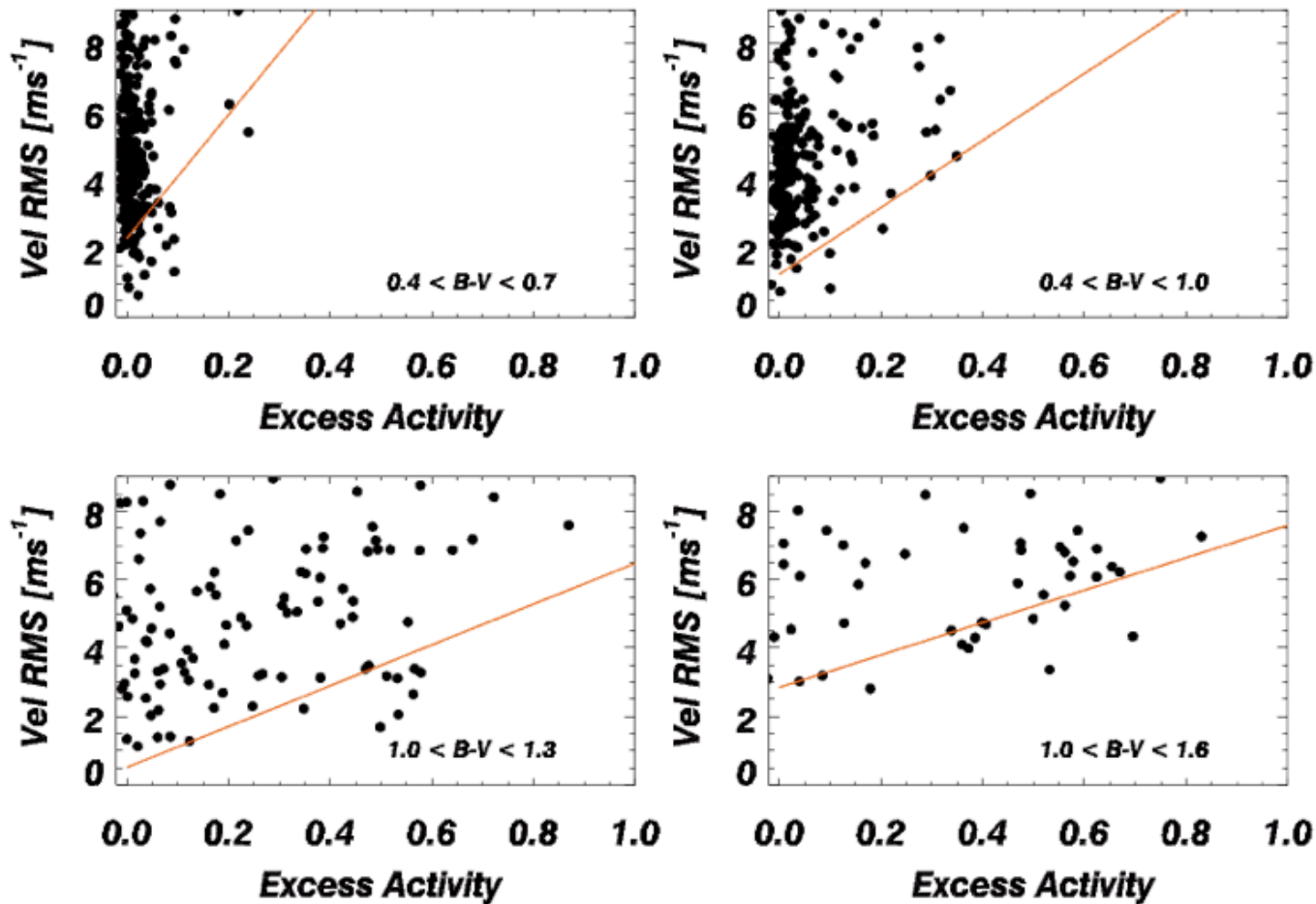
Isaacson & Fischer 2010 (ApJ in press)



Subgiants are generally low activity. Exceptions: arrival of high angular momentum stars on the MS or binary stars.

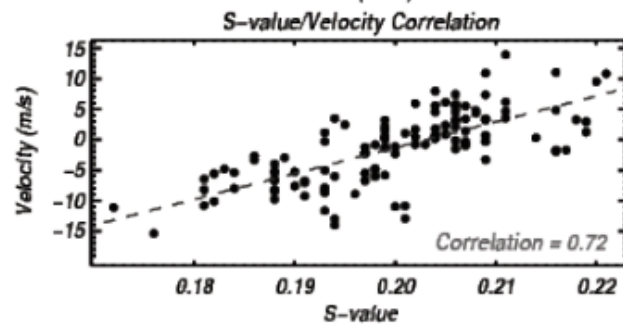
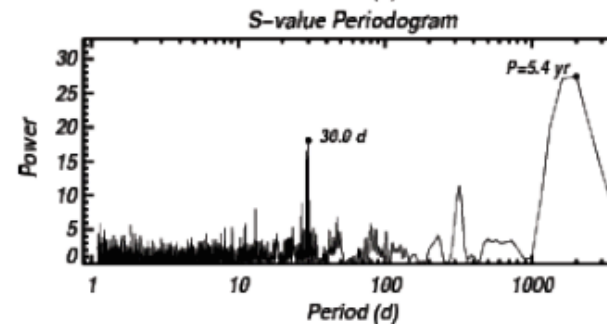
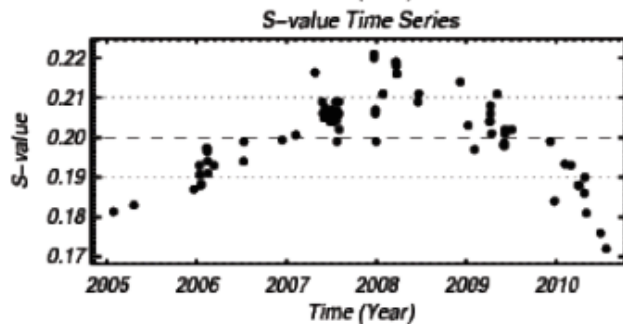
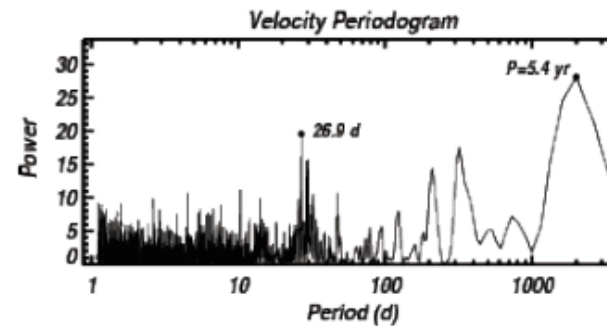
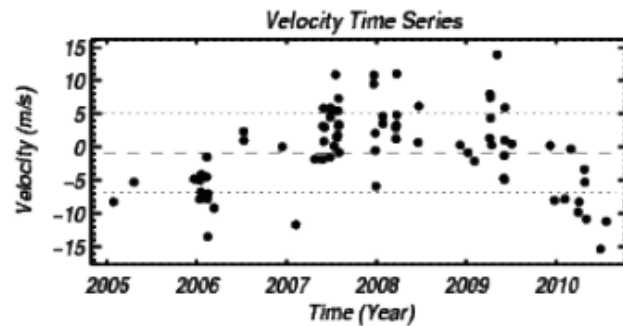
Diagnostic tool: S_{HK} and $\log R'_{HK}$

Isaacson & Fischer 2010 (ApJ in press)



The minimum RMS sets a “floor” in activity (intrinsic to star?) Includes instrumental and analysis errors. Low activity stars have less jitter.

Long term RV - activity correlations



99491

S-value = 0.200 ± 0.010

$\log(R'_{\text{rv}}) = -4.880 \pm 0.034$

$P_{\text{rv}} \sim 36$ days

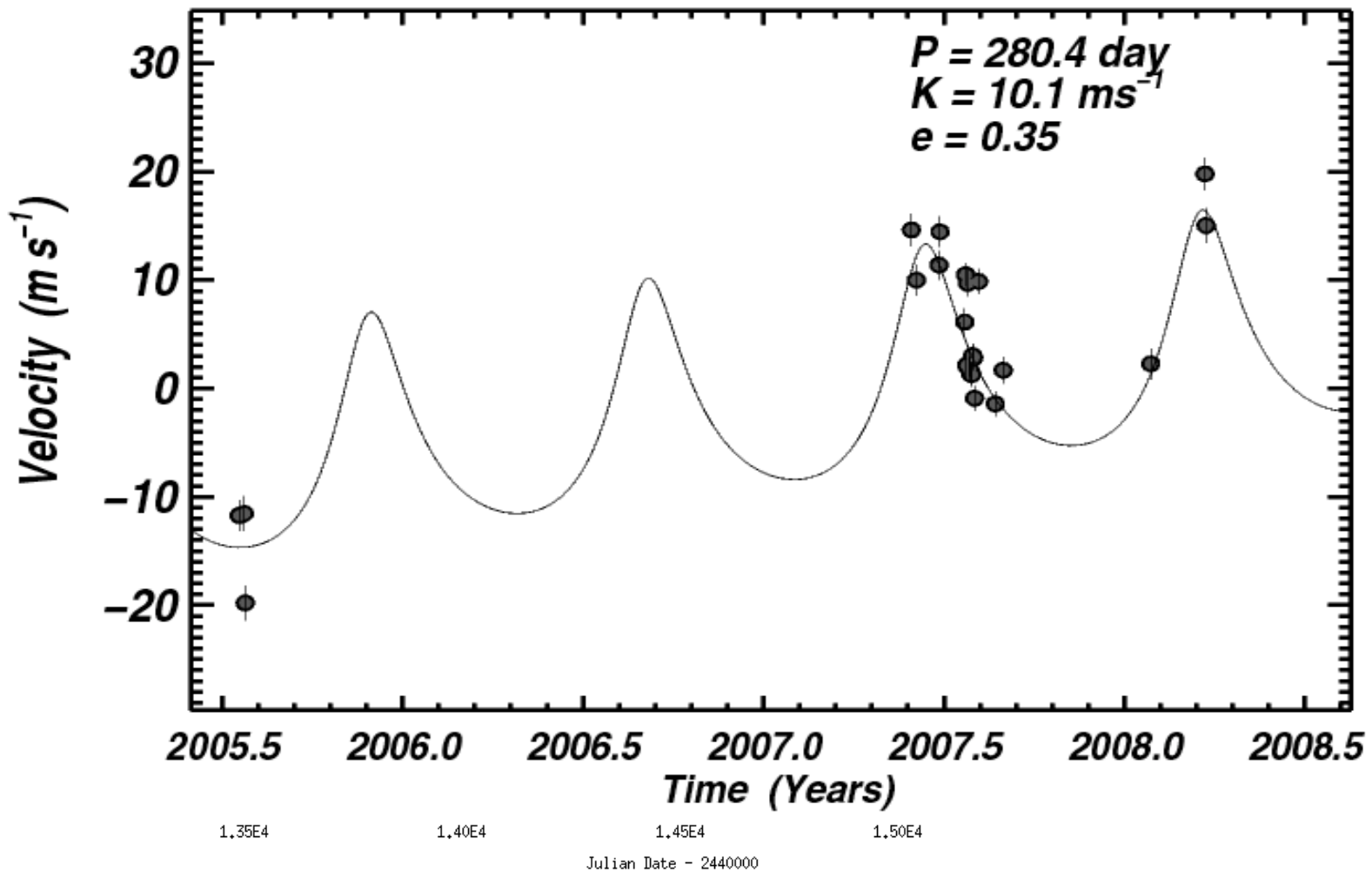
Correlation = 0.72

Fri Jul 23 19:07:16 PDT 2010

Andrew Howard, Sagan summer workshop

Impact on RV technique

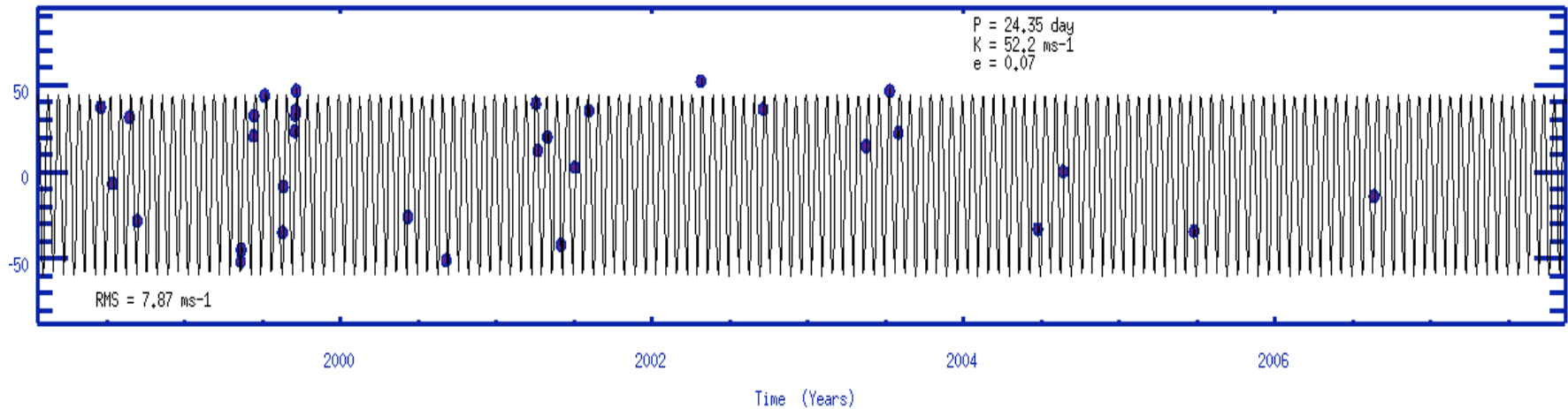
Example: HD14xxxx G0V



Impact on RV technique

Example: HD192263

(Santos et al. A&A 2000. Vogt et al. ApJ 2000)



K5V, $\log R'_{\text{HK}} = -4.37$. The Keplerian model has continued to yield a good fit for years.

Why no 164335 disease? The answer is almost certainly related to the spectral type (mass, magnetic fields).

Impact on RV technique

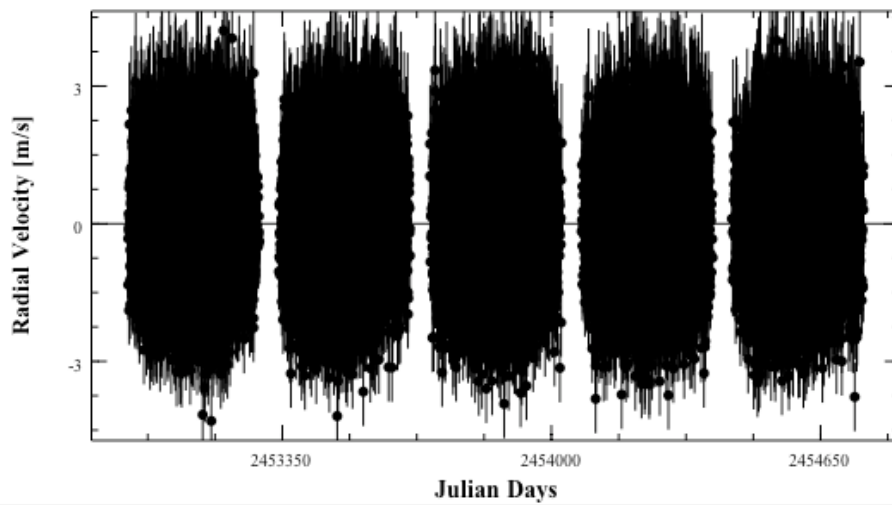
The detection of extrasolar planets requires the highest precision Doppler measurements possible.

- Jupiter: induces a reflex velocity of ~ 12 m/s in the Sun.
- Earth: induces a reflex velocity of ~ 0.1 m/s in the Sun

For $RV_{STAR} = 12$ m/s, $\delta\lambda \sim 0.0002$ Angstroms

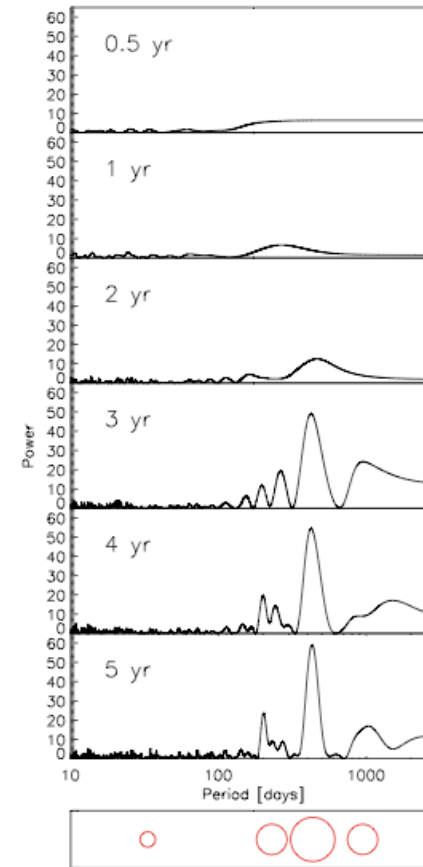
Impact on RV technique

Low amplitude systems

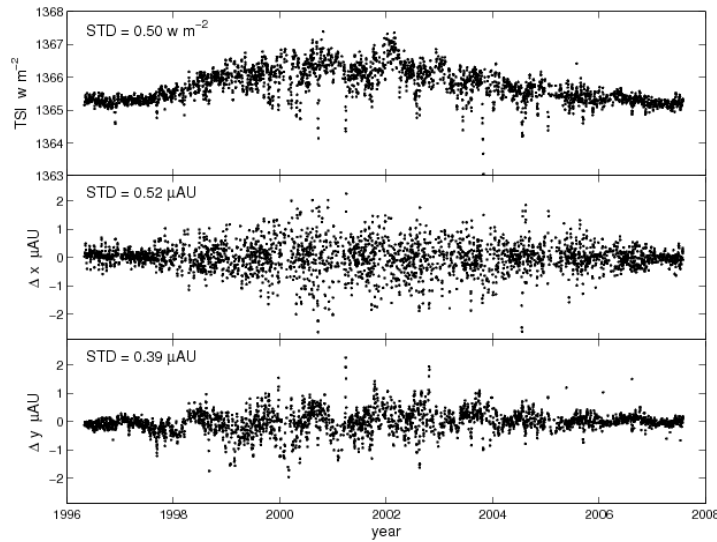


If noise sources average down on chromospherically quiet stars, then just take many observations to beat down single measurement precision.

Question for the Kepler team: what fraction of stars are at least as quiet as the Sun?



Impact on Astrometry



Using the total solar irradiance models (Ulrich et al. 2010), Makarov et al. 2010 synthesize astrometric measurements to estimate the impact of photospheric variability on astrometric (SIM) measurements.

$$\log A_s = 12.468 + 1.75 \log R'_{HK}$$

For quiet stars like the Sun: Earths are detectable. However, jitter increases with chromospheric activity:

$$\log R'_{HK} = -4.96 \rightarrow \textit{solar jitter}$$

$$\log R'_{HK} = -4.6 \rightarrow 5 \times \textit{jitter}$$

$$\log R'_{HK} = -4.2 \rightarrow 25 \times \textit{jitter}$$

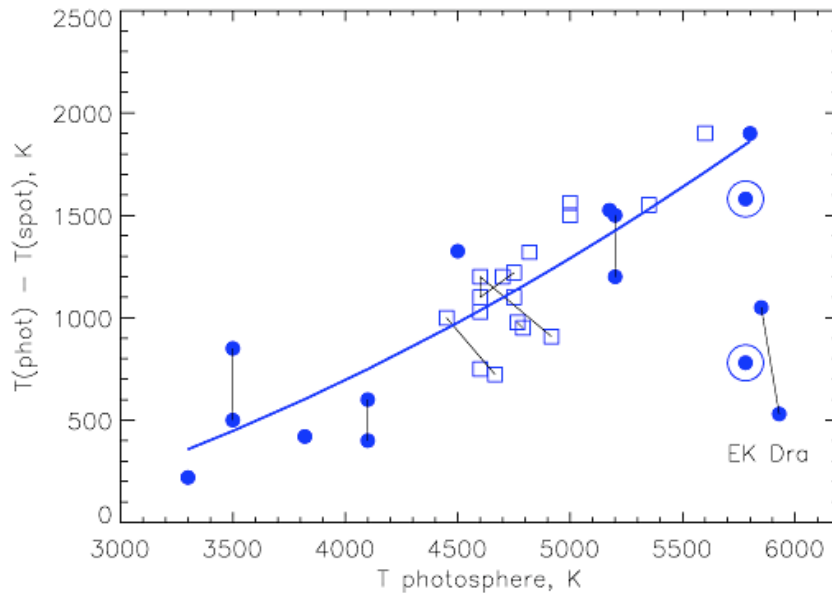
If spots are randomly distributed, the amplitude of jitter is minimized. If magnetic activity is confined to particular “active longitudes,” jitter is worse.

Comparison of Impact on RV and Astrometry

Makarov et al. 2010 compared the impact of simulated models of magnetic activity (star spots) on astrometric and RV data.

Star type	Sun	F5V	K5V
Rotation period, d	25.4	18	30
Astrometric signal, μas	0.30	0.23	0.45
RV signal, m s^{-1}	0.089	0.078	0.109
Astrometric jitter, μas	0.087	0.113	0.063
RV jitter, m s^{-1}	0.38	0.69	0.23
Astrometric SNR	3.4	2.0	7.1
RV SNR	0.23	0.11	0.47

Impact on RV and Astrometry



Contrast between magnetic features and the photosphere is less at redder wavelengths (i.e., cooler temperatures).

TW Hydra showed RV variations (similar to HD166435) at optical wavelengths, but IR observations were less impacted .

Doppler measurements at redder wavelengths? Iodine reference spectrum spans 500 – 600 nm; laser frequency combs have arbitrary wavelength ranges.

Conclude

P-mode noise is the most “treatable” noise source: many observations can average over the few-minute-long signal.

Astrophysical noise sources (magnetic origin) operate on timescales similar to planets. Spots or meridional flow can impact RV and astrometric sensitivity to “habitable” planets. Space-based astrometry should still be able to detect Earthlike planets for favorable targets.

Individual spots generally persist for one or two stellar rotation periods, however the global distribution can persist and multiple spots are the rule, forming at different latitudes with differential rotation.

Sometimes active stars have RV’s correlated with activity, sometimes they don’t. Sometimes the noise seems to phase with the RV’s, sometimes it is out of phase. There is not a reliable diagnostic that correlates astrophysical noise and RV or astrometric signatures: i.e., can’t cleanly decorrelate this noise source from RV’s.