



The effects of stellar activity on detecting and characterising exoplanets

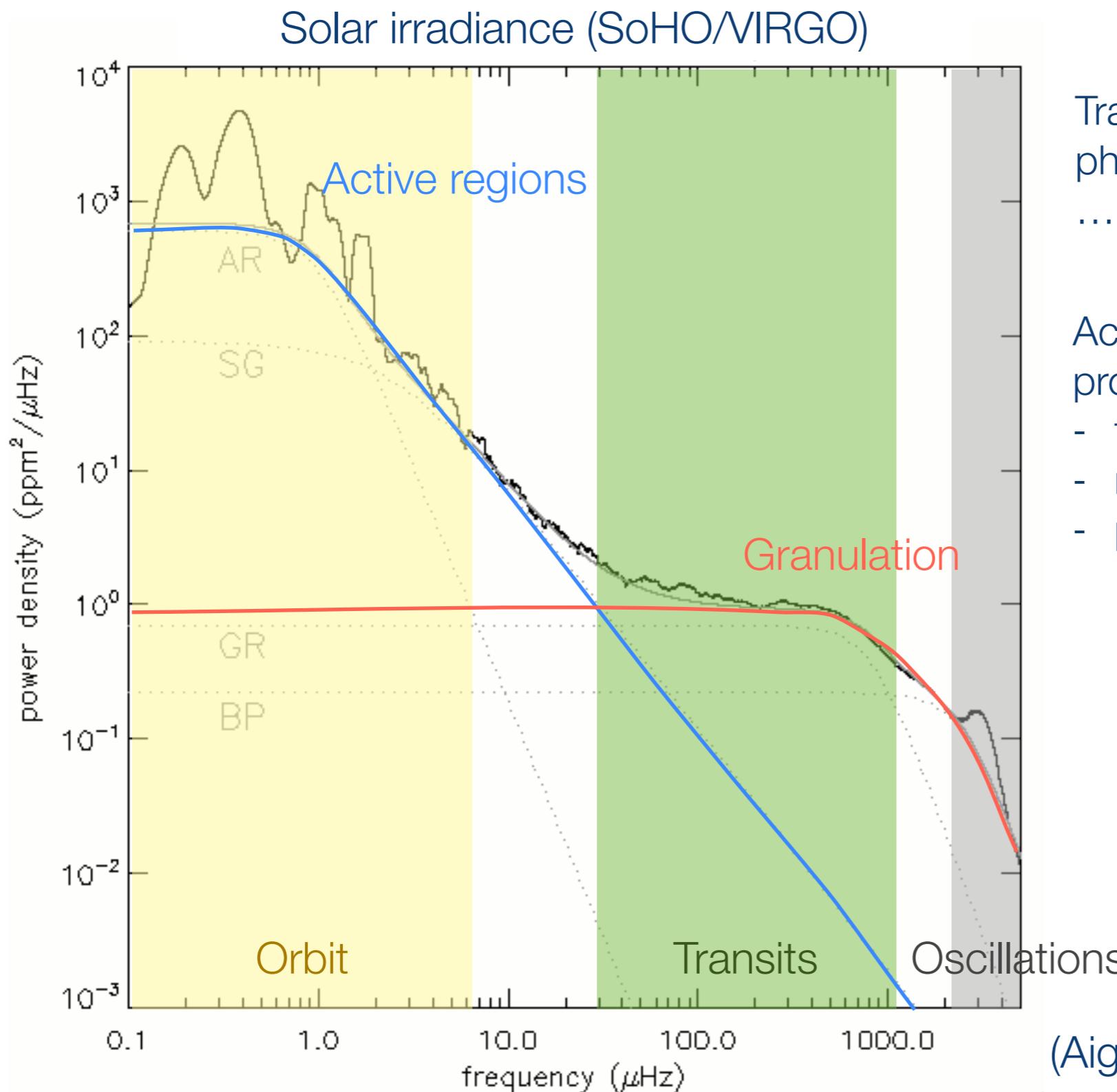
Suzanne Aigrain

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S. Roberts, A. McQuillan, N. Gibson, T. Mazeh, F. Pont, S. Zucker



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Timescales



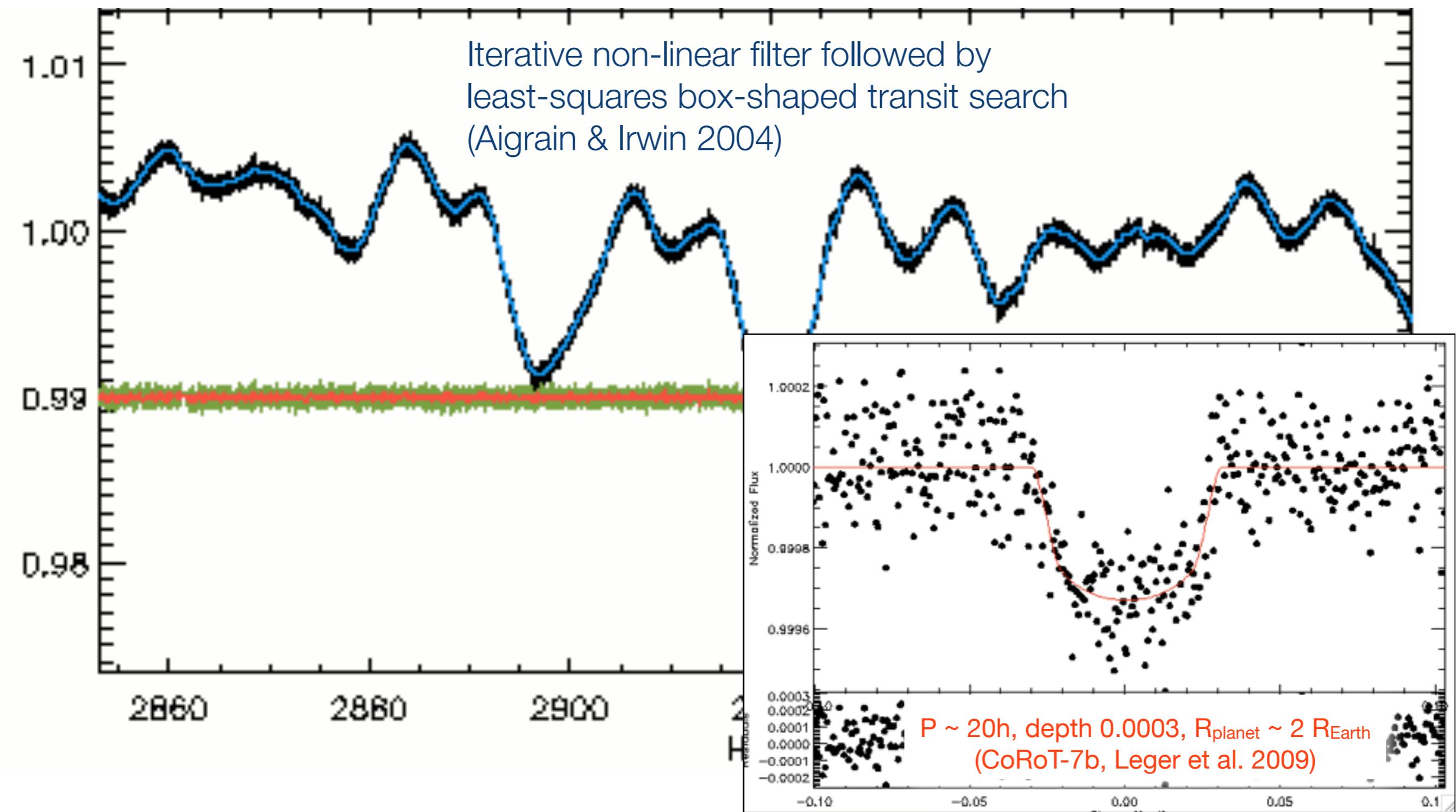
Transits are easy to separate from photometric variations due to star spots ... up to a point!

Activity-induced variability is more problematic for:

- transmission spectroscopy
- radial velocity planet searches
- phase curve studies

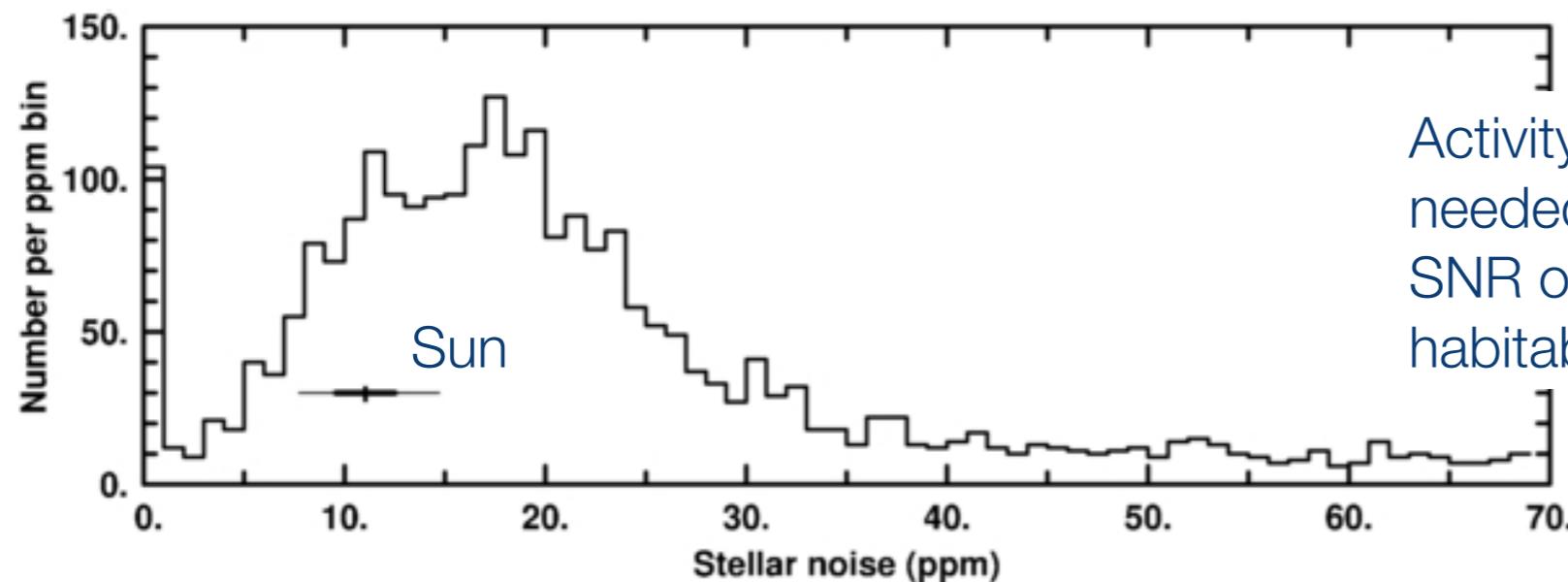
(Aigrain, Favata & Gilmore 2004)

Filtering activity to detect transits



When does activity matter for transit searches?

Intrinsic stellar variability on 6 hour time-scales from Kepler (Gilliland et al. 2011)



Transit SNR =
 $\text{sqrt}(N_{\text{transits}}) \times \text{depth} / \text{sigma}(T_{\text{transit}})$

where:

- N_{transits} is number of transits
- T_{transit} is duration of transit

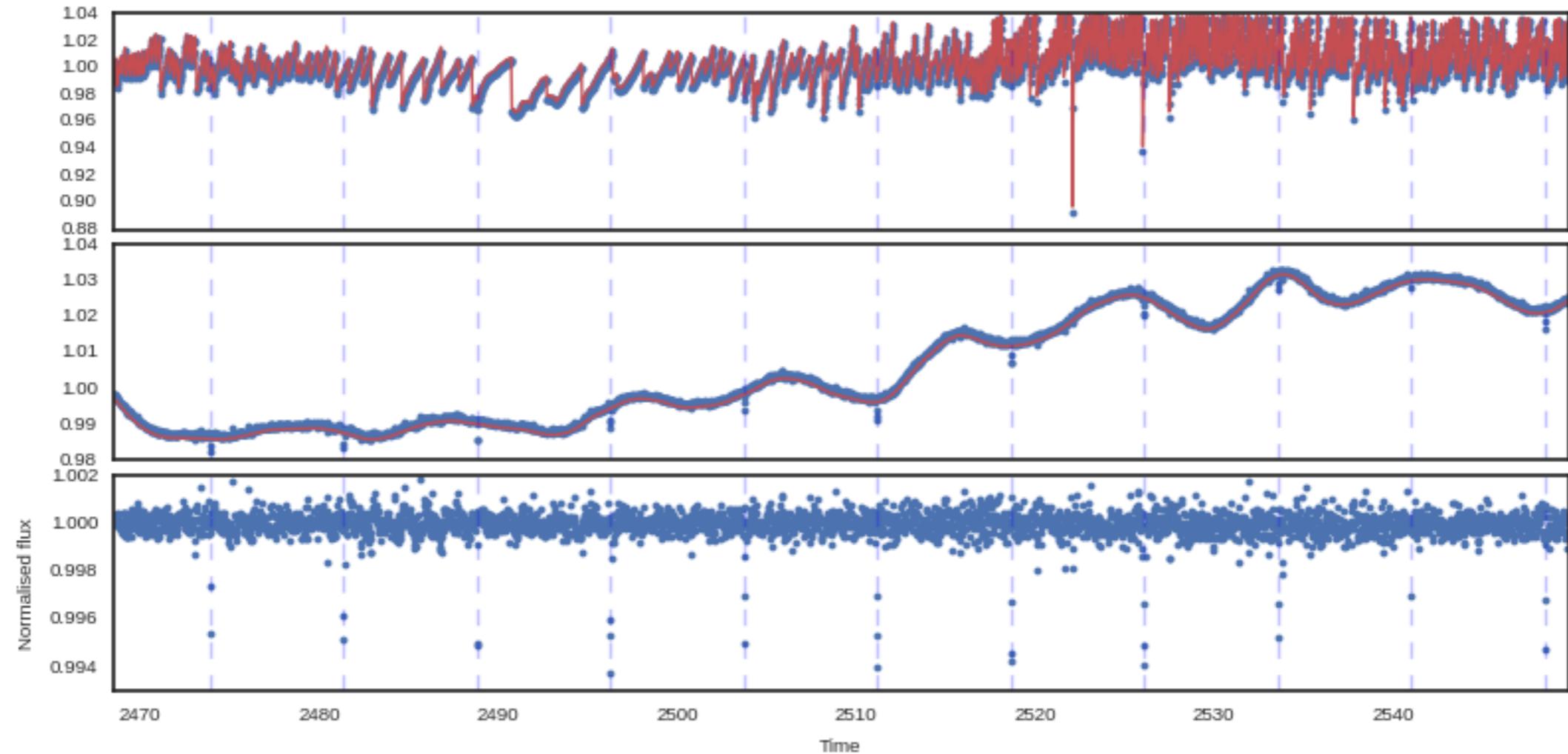
Activity means Kepler would have needed 7 rather than 4 years to reach SNR of 10 for Earth-like planets in the habitable zone of Sun-like stars

This can be addressed, at least partially, by *modelling* the activity-induced variations *simultaneously* with the transits

Modelling stellar signals and instrumental systematics jointly using Gaussian Processes (GPs)

Example from K2 Campaign 7

Model activity as a quasi-periodic a Gaussian process.
Simultaneously model pointing-related systematics



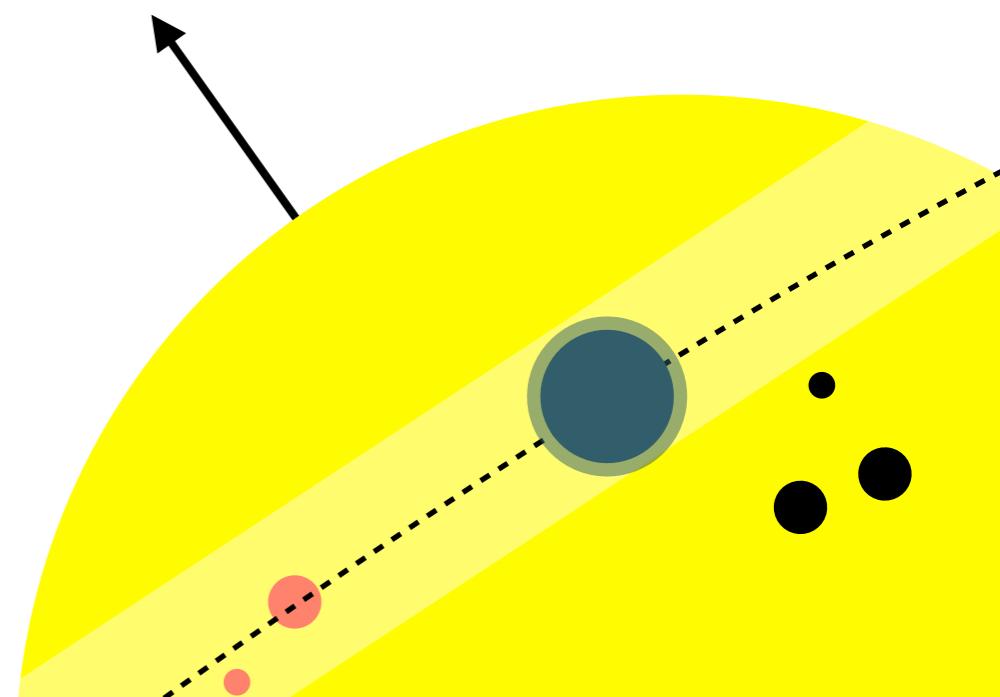
K2SC pipeline - Aigrain et al. 2016.

Code and LCs available - talk to Hannu Parviainen

First planet candidate catalog: Pope et al. (2016, on arXiv this week)

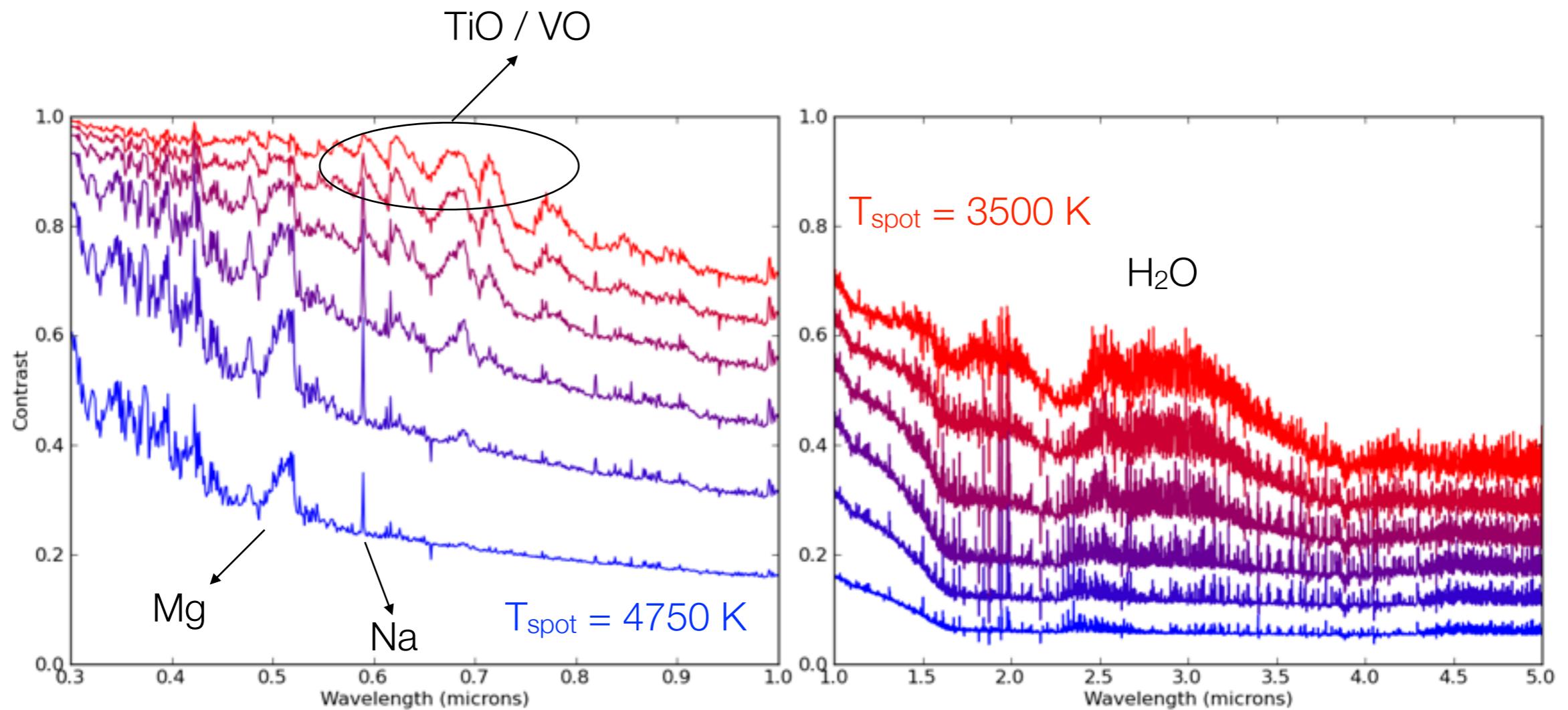
Activity in transit spectra

- In any kind of high precision transit studies, need to worry about spots (see e.g. Pont et al. 2013):
 - occulted: distort transit, or make it seem shallower
 - un-occulted: make transit appear deeper
- Both effects are very important and hard to correct for transmission spectroscopy
 - even in the IR (see e.g. Barstow et al. 2015 - JWST)
- Plages may also be important (low contrast but large area) - Oshagh et al. (2014)

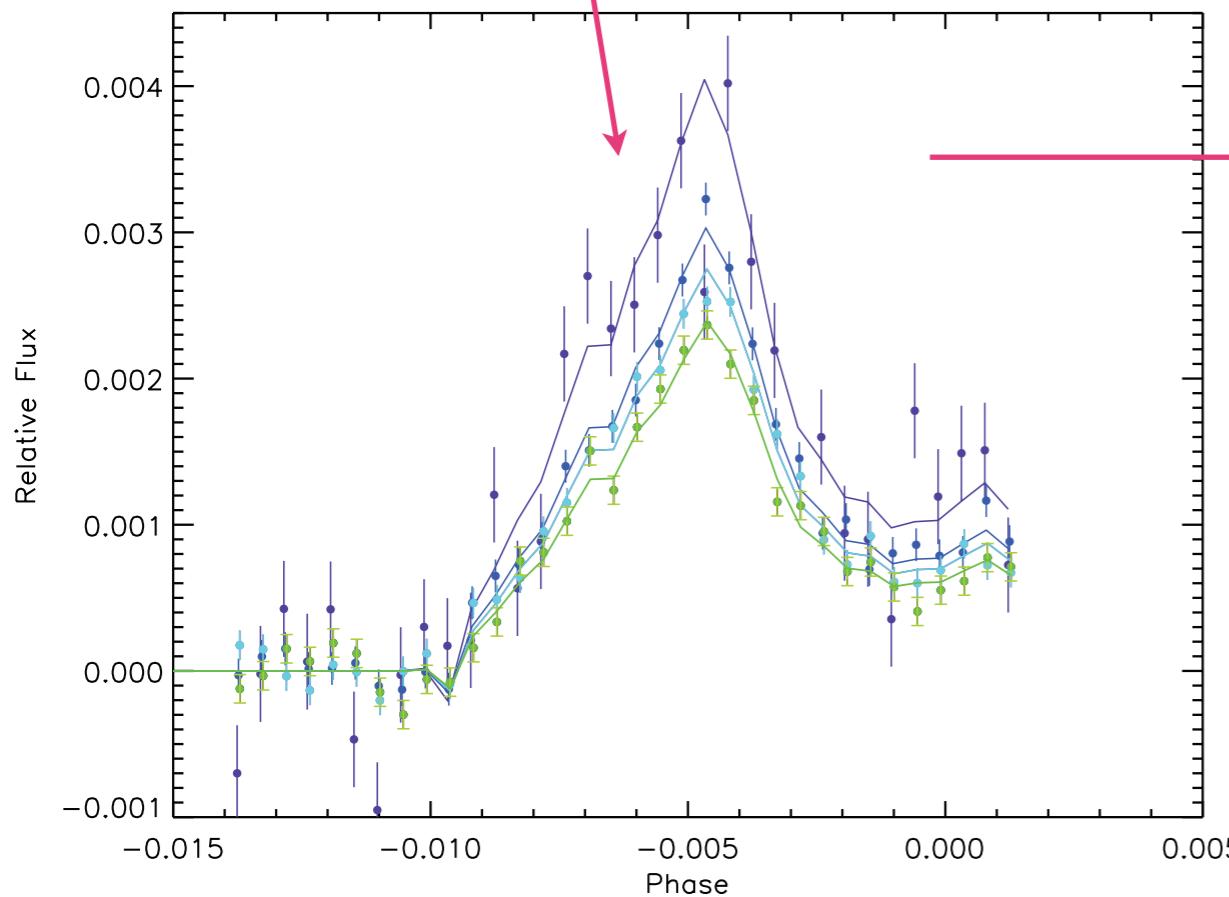
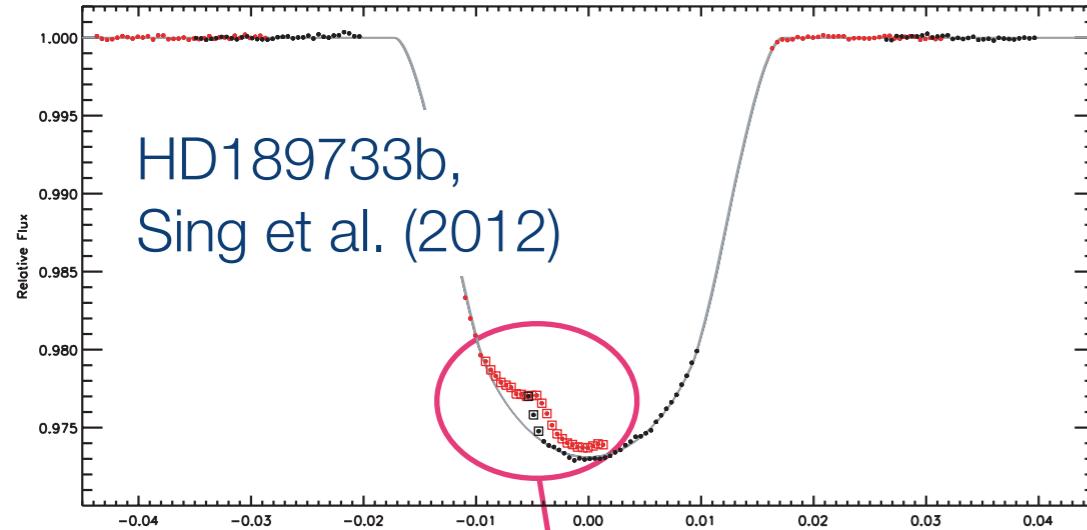


Spectroscopic effects of star spots

Contrast between 5000 K photosphere and cool spots with different temperatures
(MARCS models, Gustafsson et al. 2008, $\log g = 4.5$, $[Fe/H] = 0$)

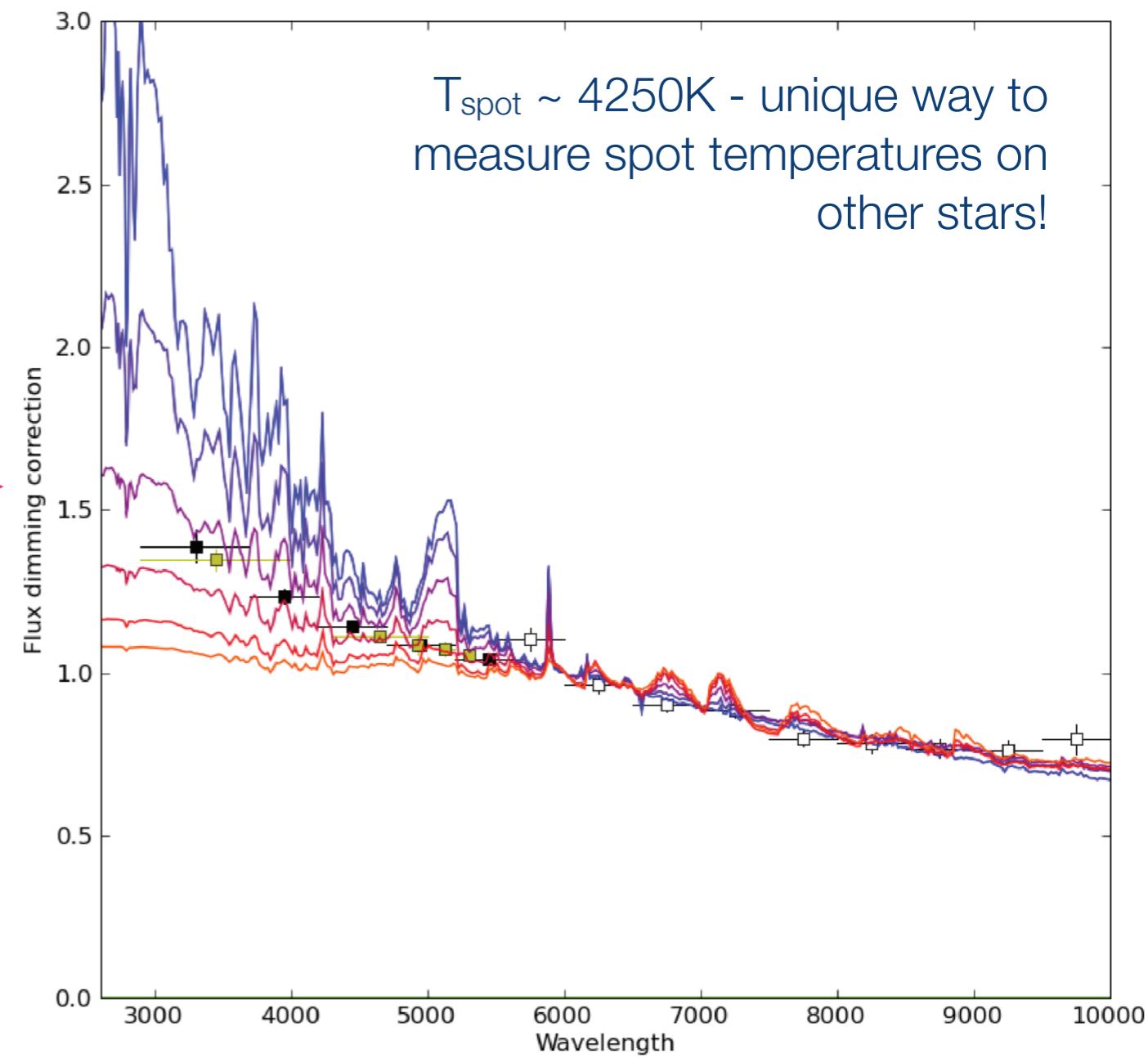


Accounting for spots in transmission spectra



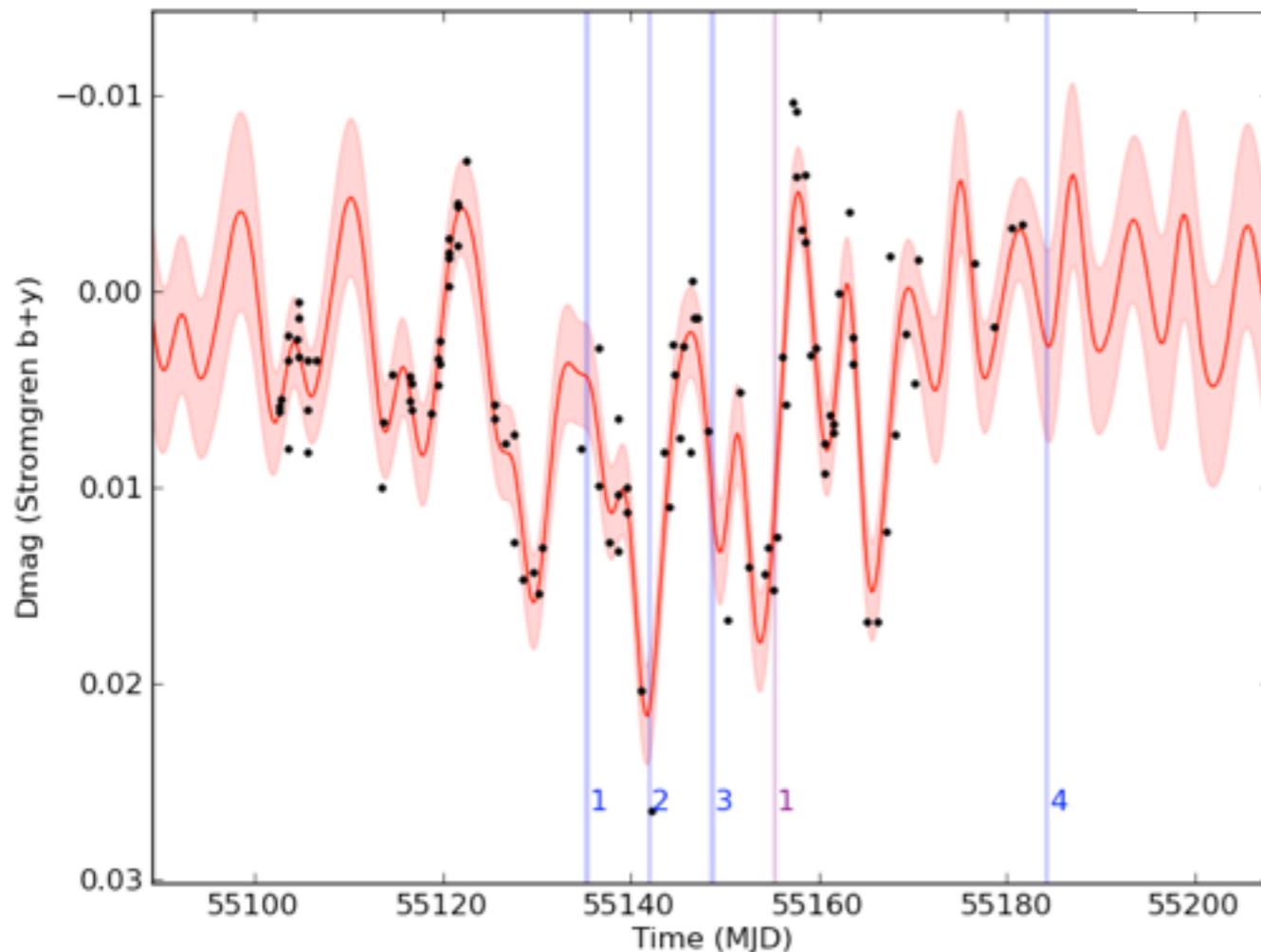
Estimate spectrum/temperature of spots from
occulted spots

$T_{\text{spot}} \sim 4250\text{K}$ - unique way to
measure spot temperatures on
other stars!



Accounting for spots in transmission spectra

HD189733 (Pont et al. 2013)



Estimate spectrum/temperature of spots from occulted spots - only possible in visible

Estimate overall spot coverage from out-of-transit variability - only lower limit

Estimate spot coverage of transit chord from rate of occulted spots - only catch the big ones

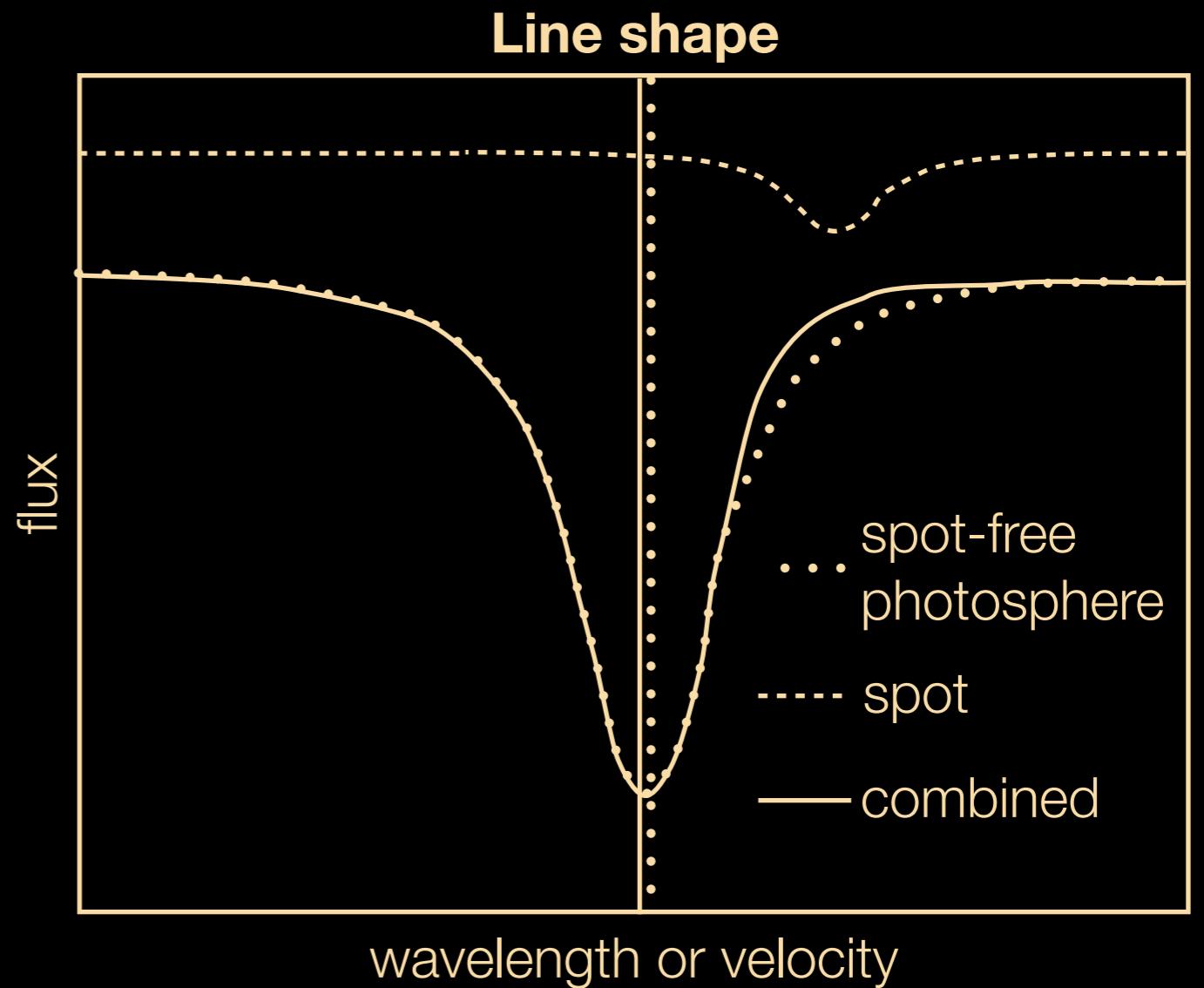
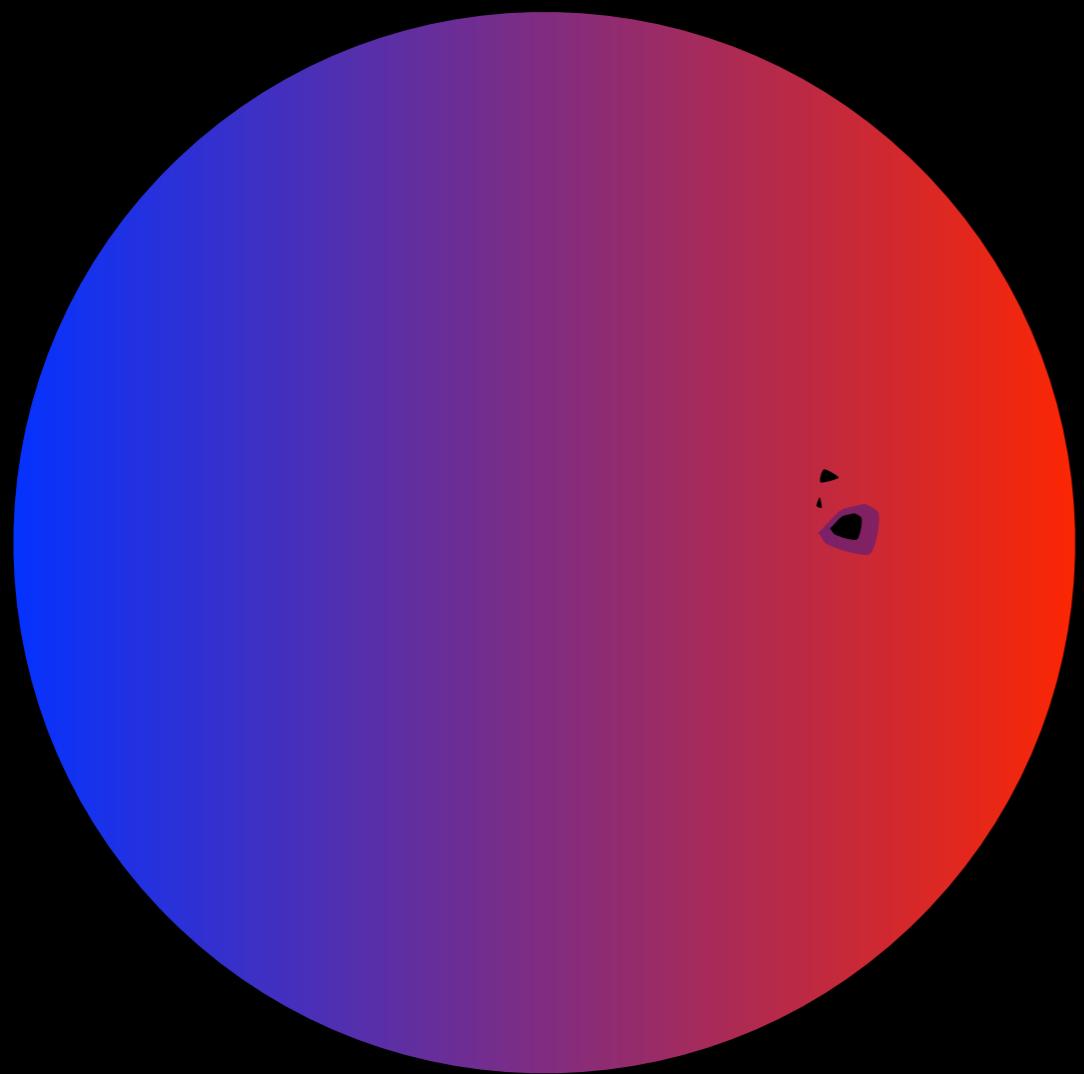
In best cases, can estimate uncertainties due to spots, but not really correct for them

Getting entire spectrum in one go helps!
cf. EChO/Ariel/Twinkle projects

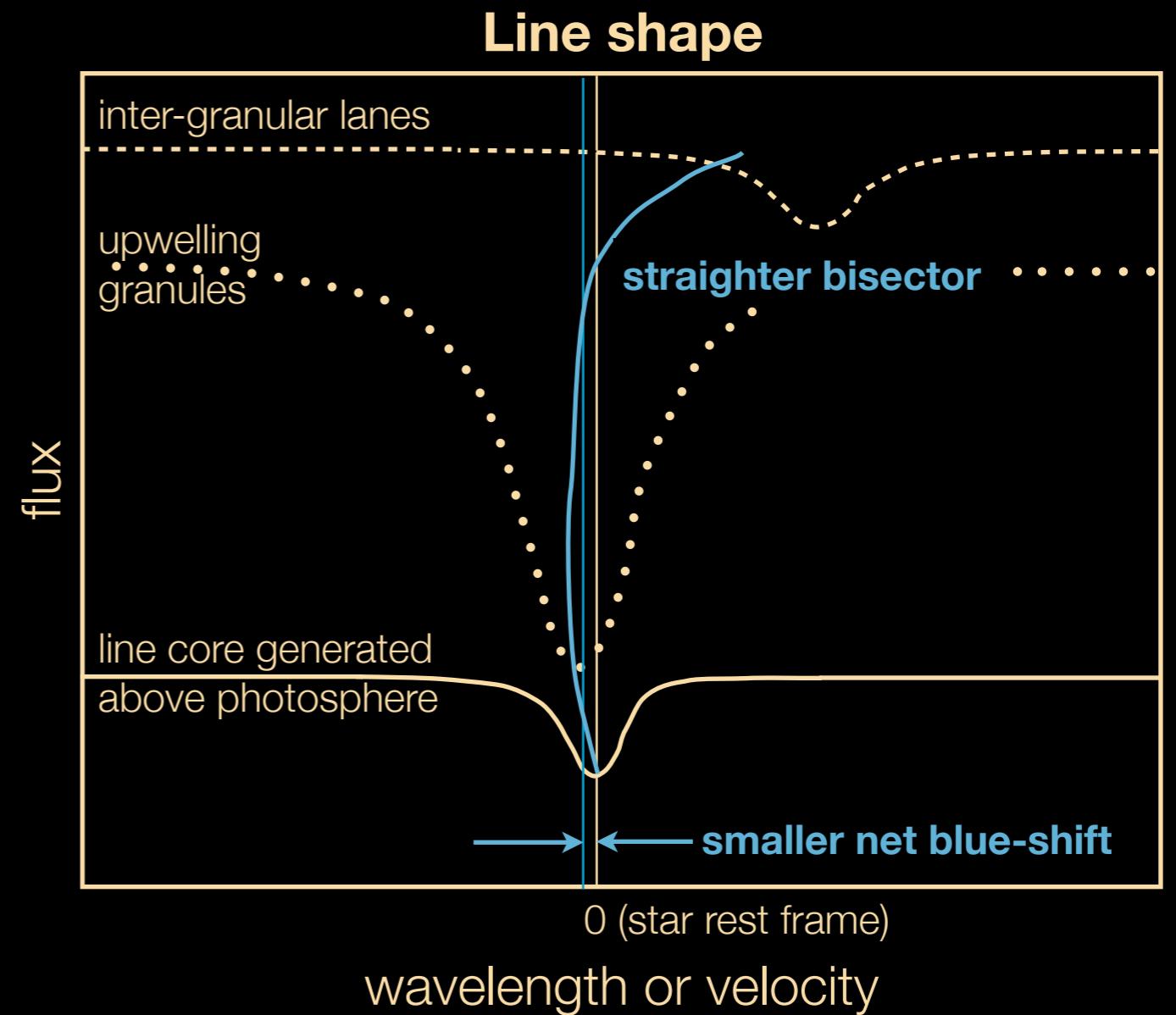
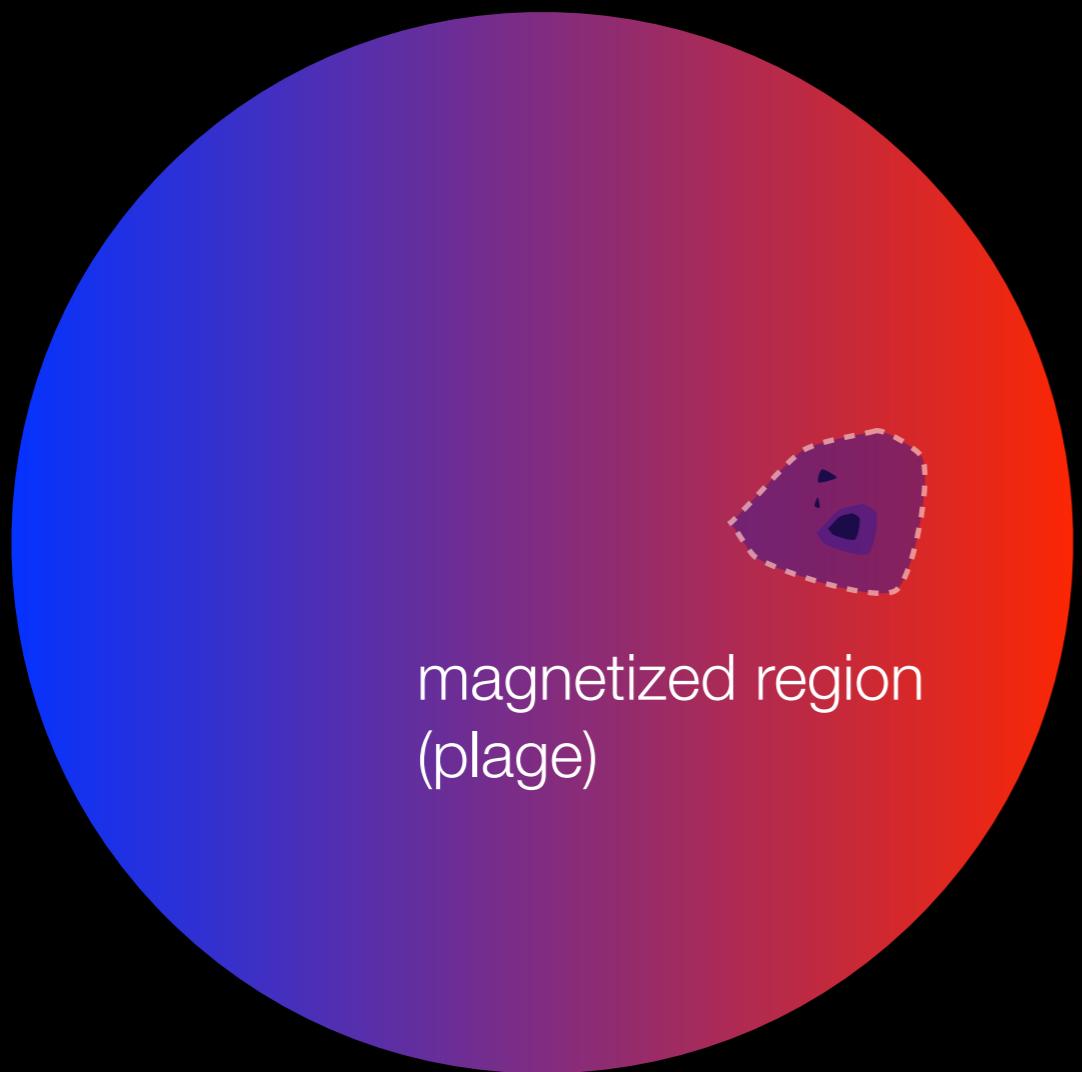
See Barstow et al. (2015) for study of impact on JWST transmission spectroscopy

RV effects of activity - 1:

distortion of rotation profile



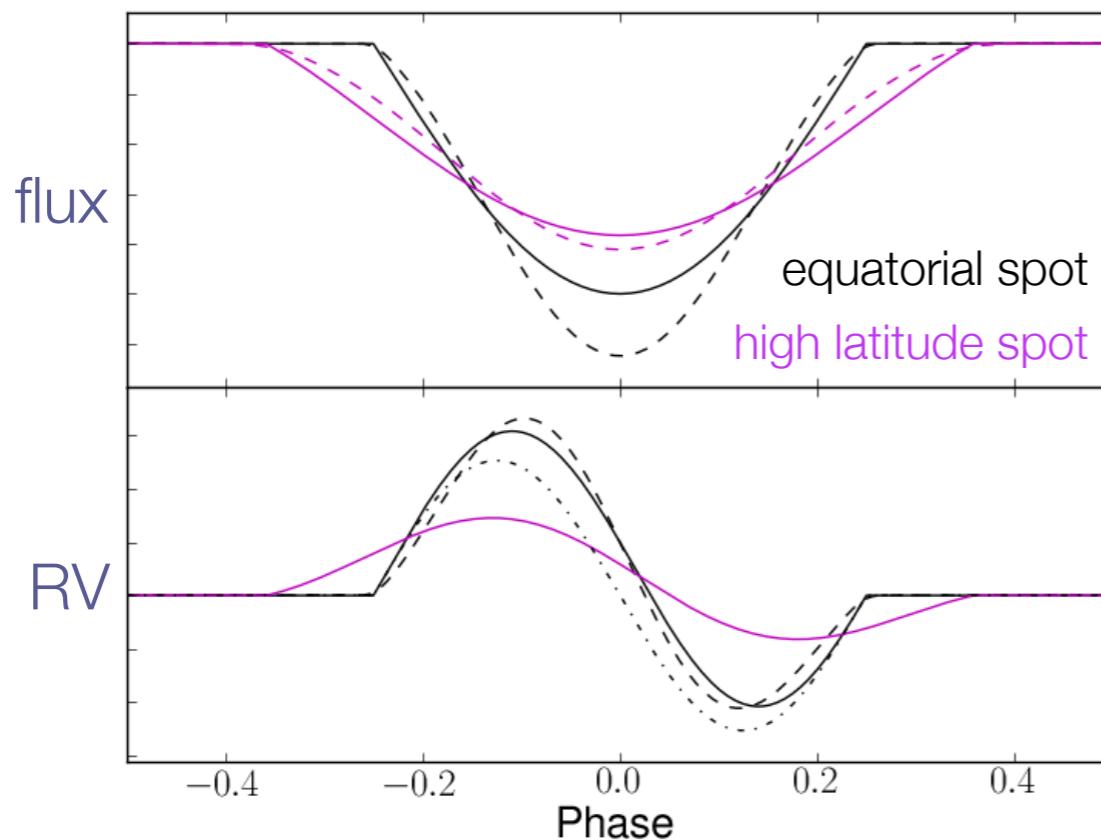
RV effects of activity - 2: convective blueshift suppression



This dominates over the effect of spots for the Sun (Meunier et al. 2010)

Linking stellar photometric and RV variations

Perturbation to full disk measurement
due to one spot



Can show that:

$$\Delta V_{\text{rot}} \propto \Delta F \times d(\Delta F)/dt$$

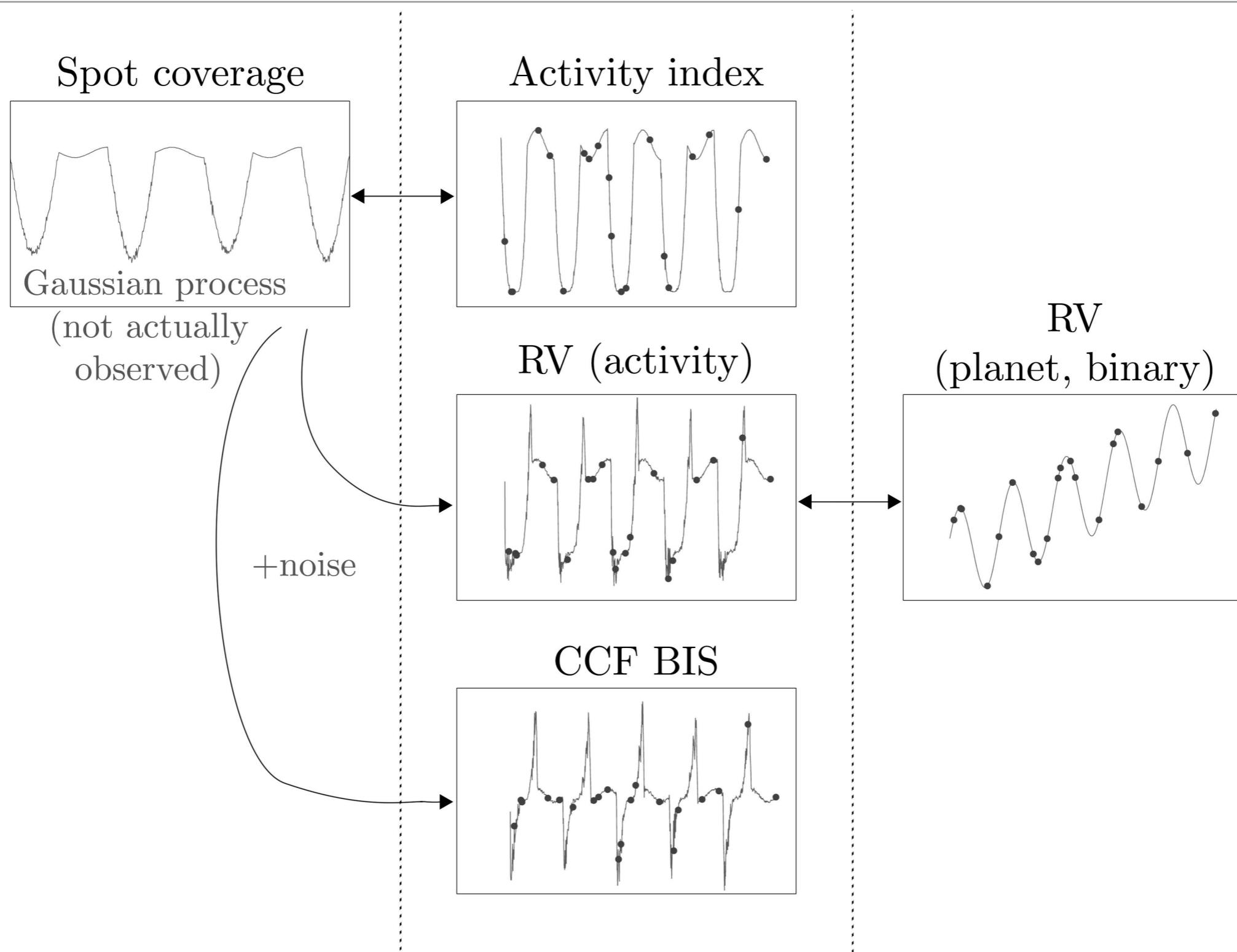
$$\Delta V_{\text{conv}} \propto \Delta F^2$$

(Aigrain, Pont & Zucker 2012)

Limitations:

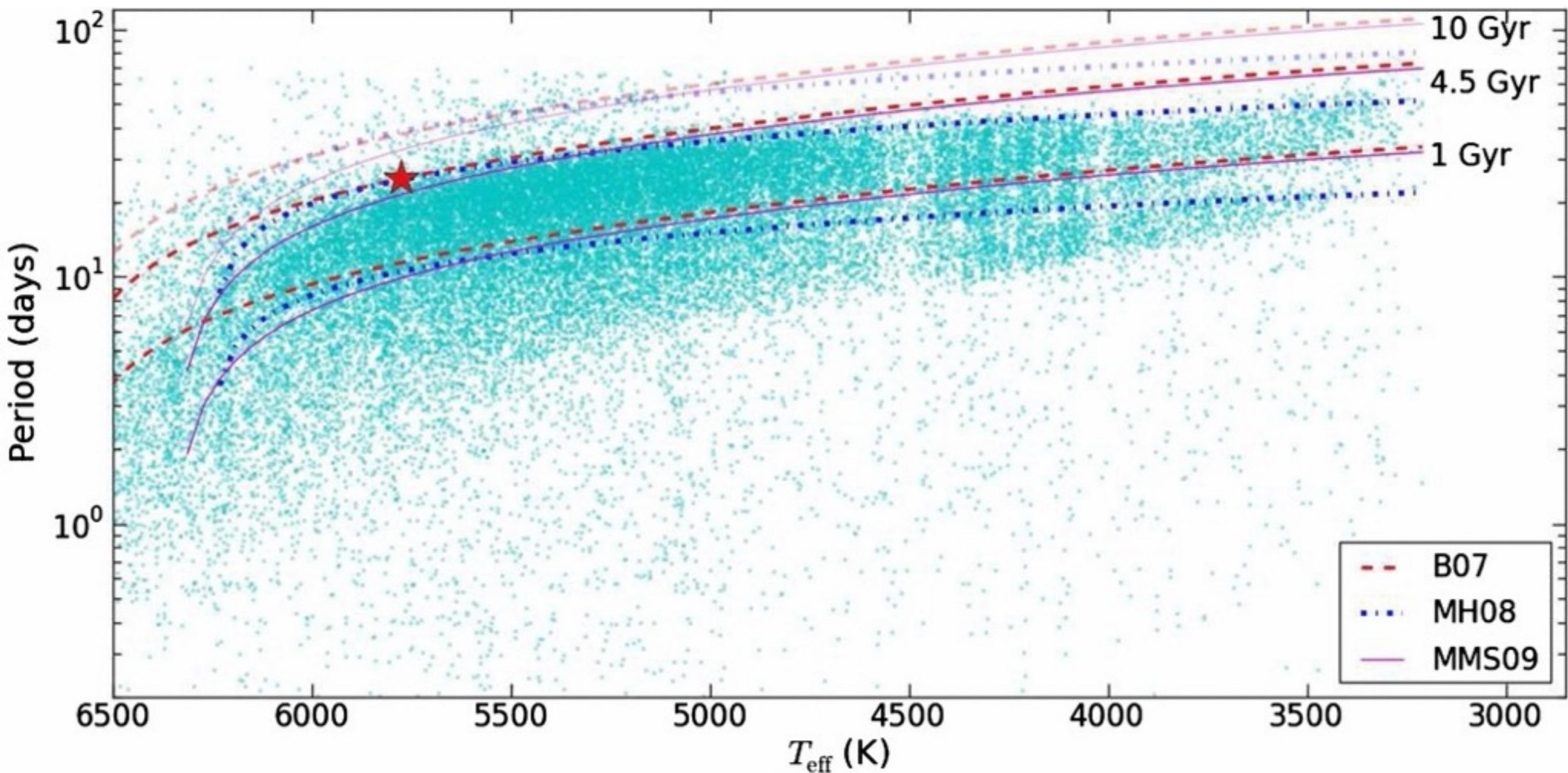
- photometry (almost) insensitive to faculae
- some active region configurations have no photometric signals, but do have RV signals
- we do not always have simultaneous photometry

Even with only spectra...



Transit survey light curves give 1000's of rotation periods

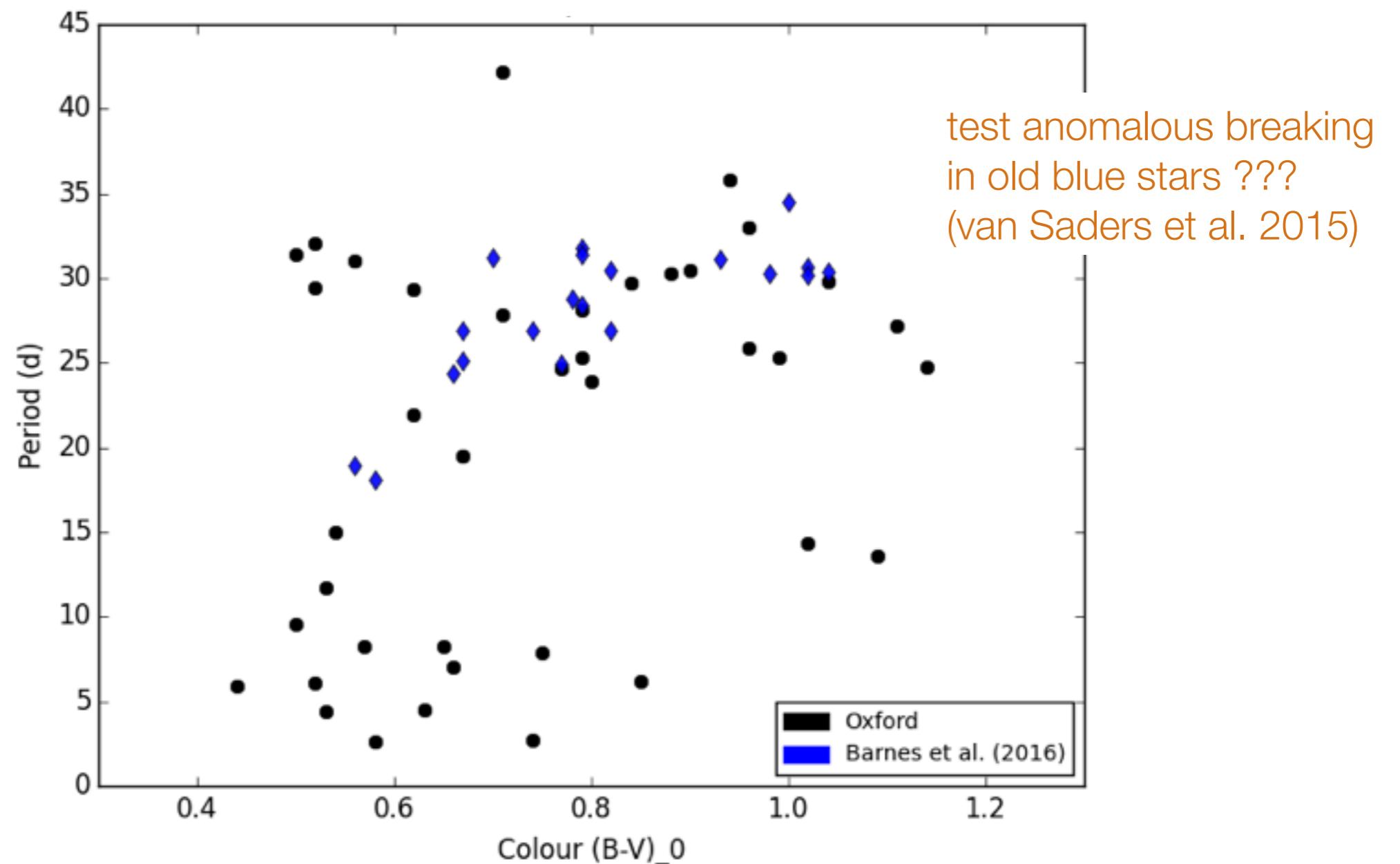
Largest ever catalog of stellar rotation periods (McQuillan, Mazeh & Aigrain 2014)



Clusters!

Fantastic results in Pleiades, Upper Sco, Praesepe, Hyades
(Rebull, Douglas, Covey...)

M67 - R. Esselstein (poster 106), see also J. Weingrill (poster 28)



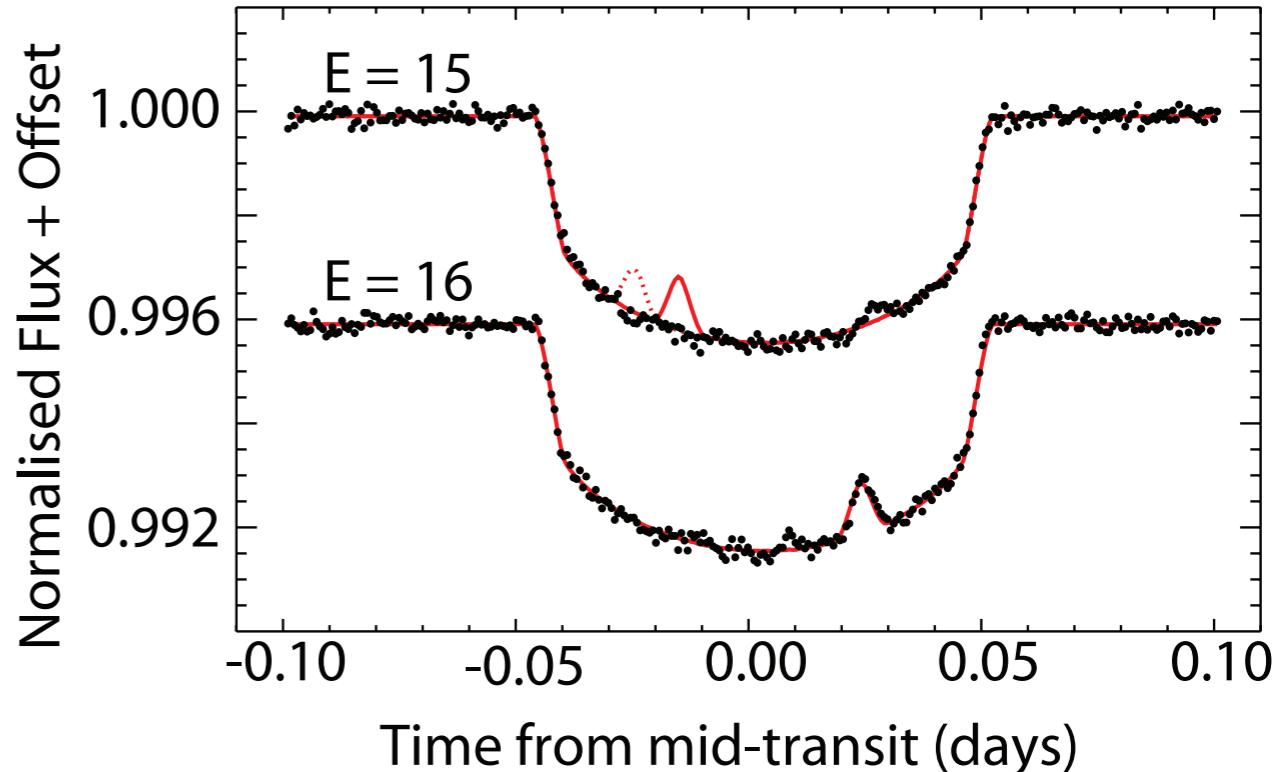
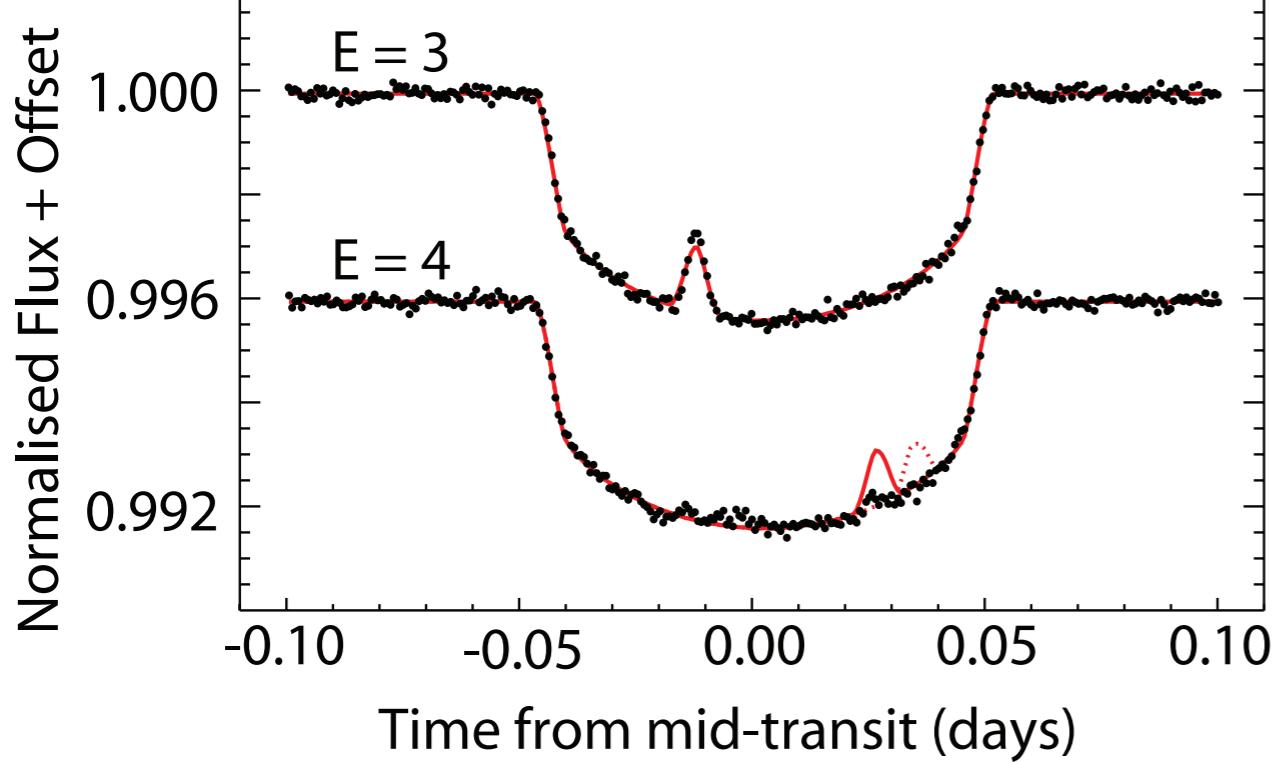
Spot mapping by transits

Spot-crossing posters @ CS19:
Hebb (330), Southworth (148)

also Gustavsson (134) - convection vs limb angle

Spots occulted during multiple transits can be used to derive projected spin-orbit angle
(Sanchis-Ojeda et al. 2011)

HAT-P-11



NB: low-SNR spot-crossings can go un-detected
but still bias measured time of transit

This can be important for transit timing variation studies

Summary

- Activity remains a major noise source for
 - detection of the shallowest, longest period planetary transits
 - detailed transit studies
 - phase curves
 - **radial velocity** detection / follow-up
- Joint modelling of activity, instrumental noise & planet signal is more robust than attempting to filter one effect to get at the other(s)
 - also more sensitive? should be, but remains to be shown in practice.
- Exoplanet datasets are goldmine for activity studies
- Want to get away from activity altogether?
 - eclipses, direct imaging & spectroscopy, astrometry, microlensing...