Stellar activity in transit and RV planet searches: synergies and challenges

Suzanne Aigrain

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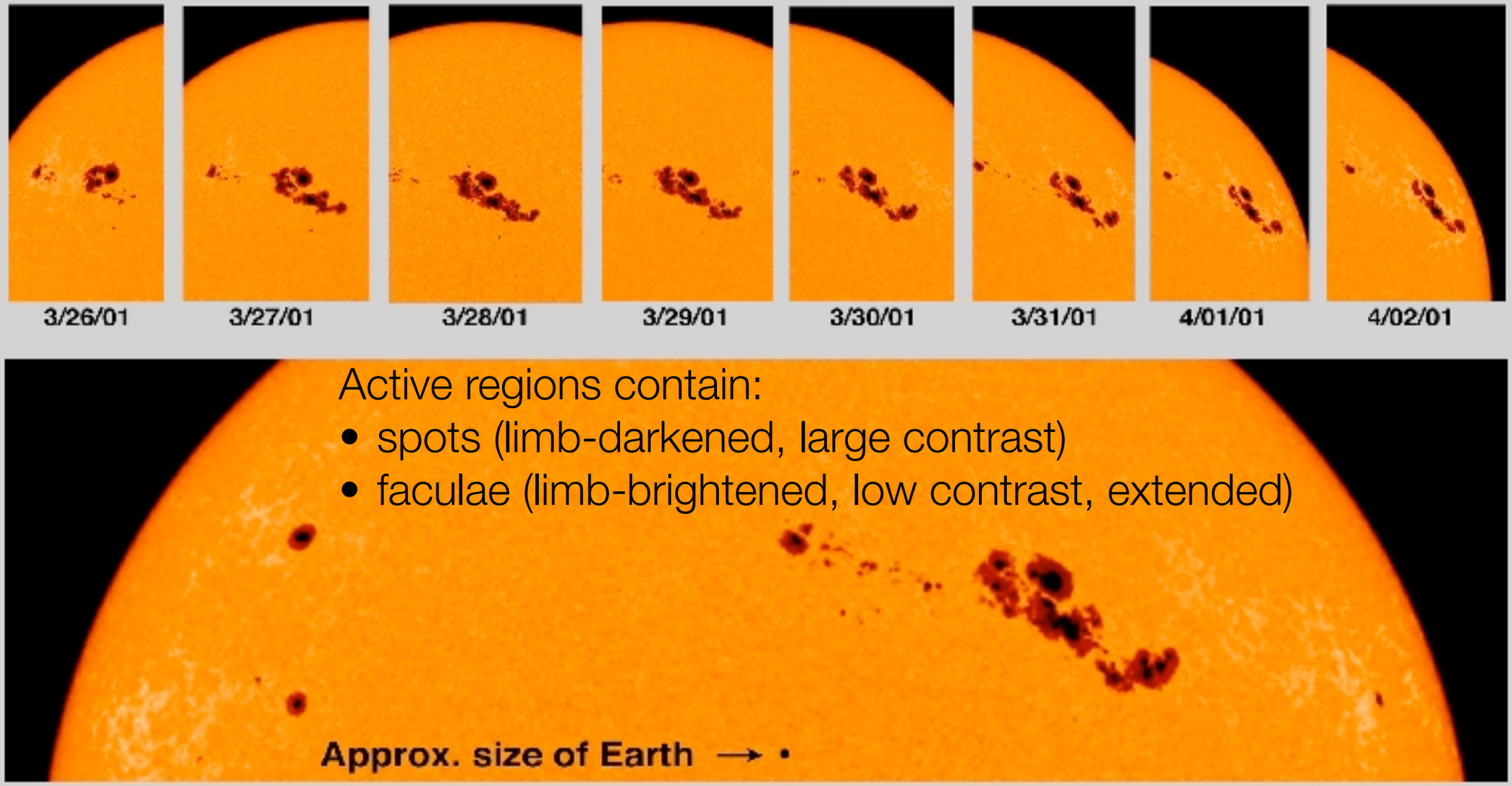
UNIVERSITY OF OXFORD

Active regions on the Sun

SoHO/MDI continuum intensity

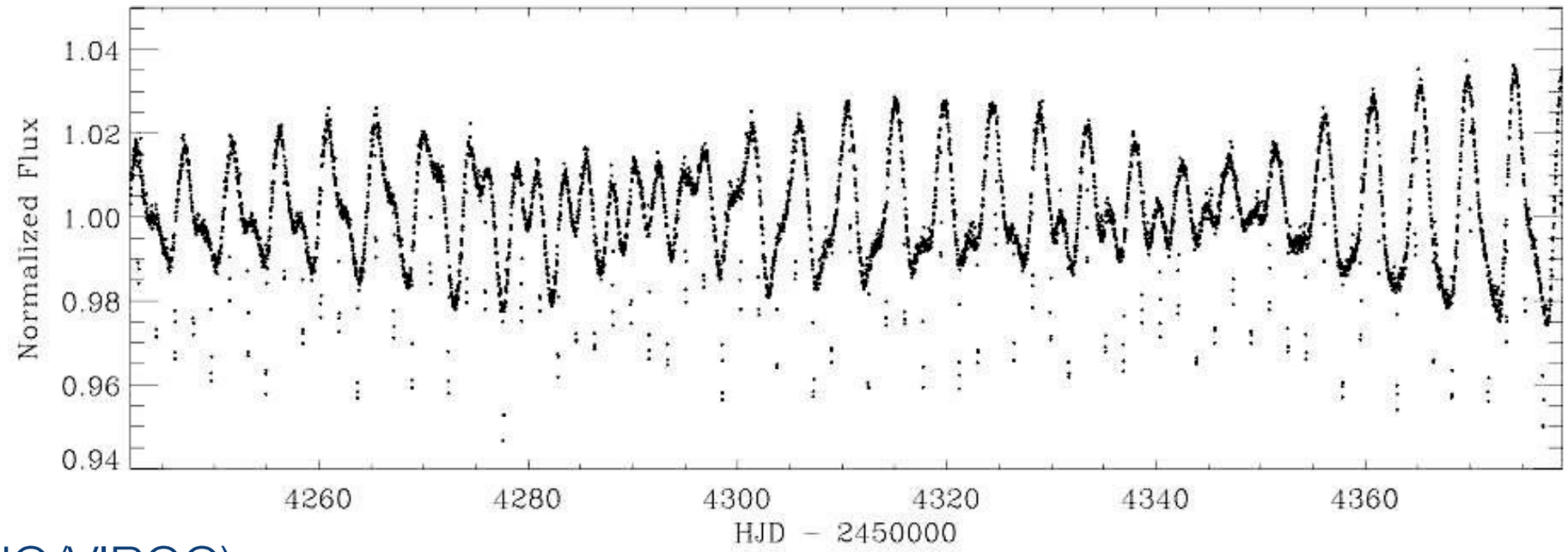


Note also: granules, bright points, … (much smaller)

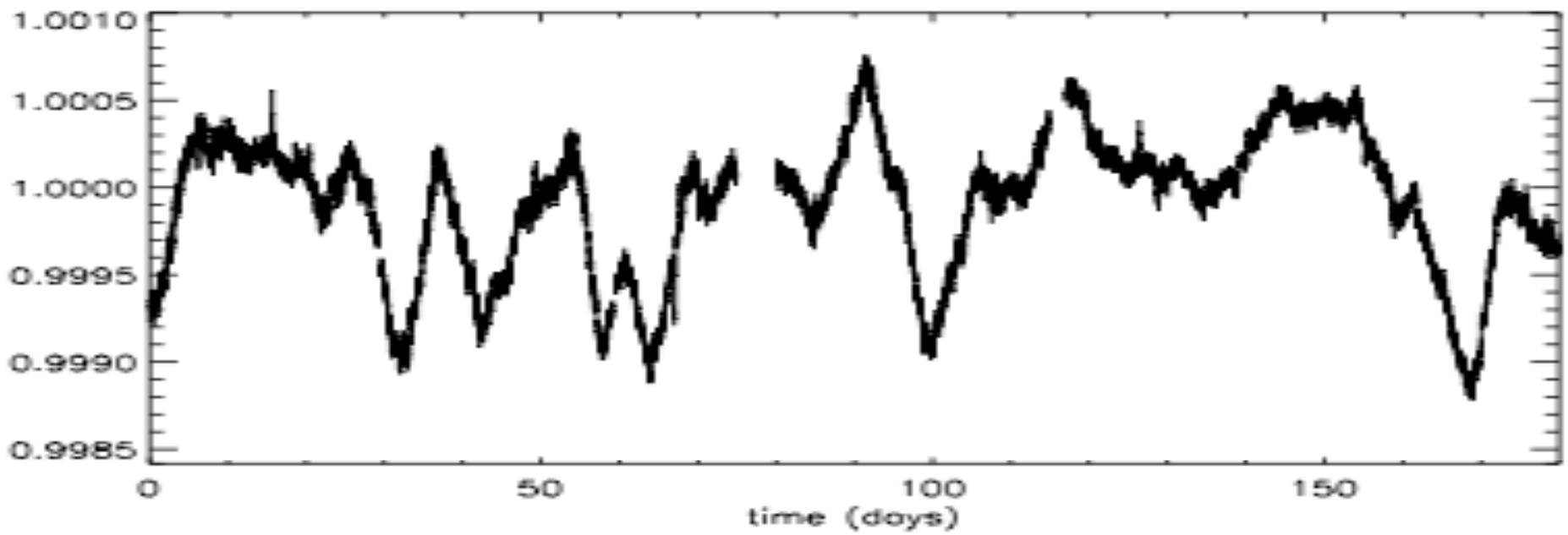
Activity and transits

Photometric effects of spots and faculae

Active star (CoRoT-2)

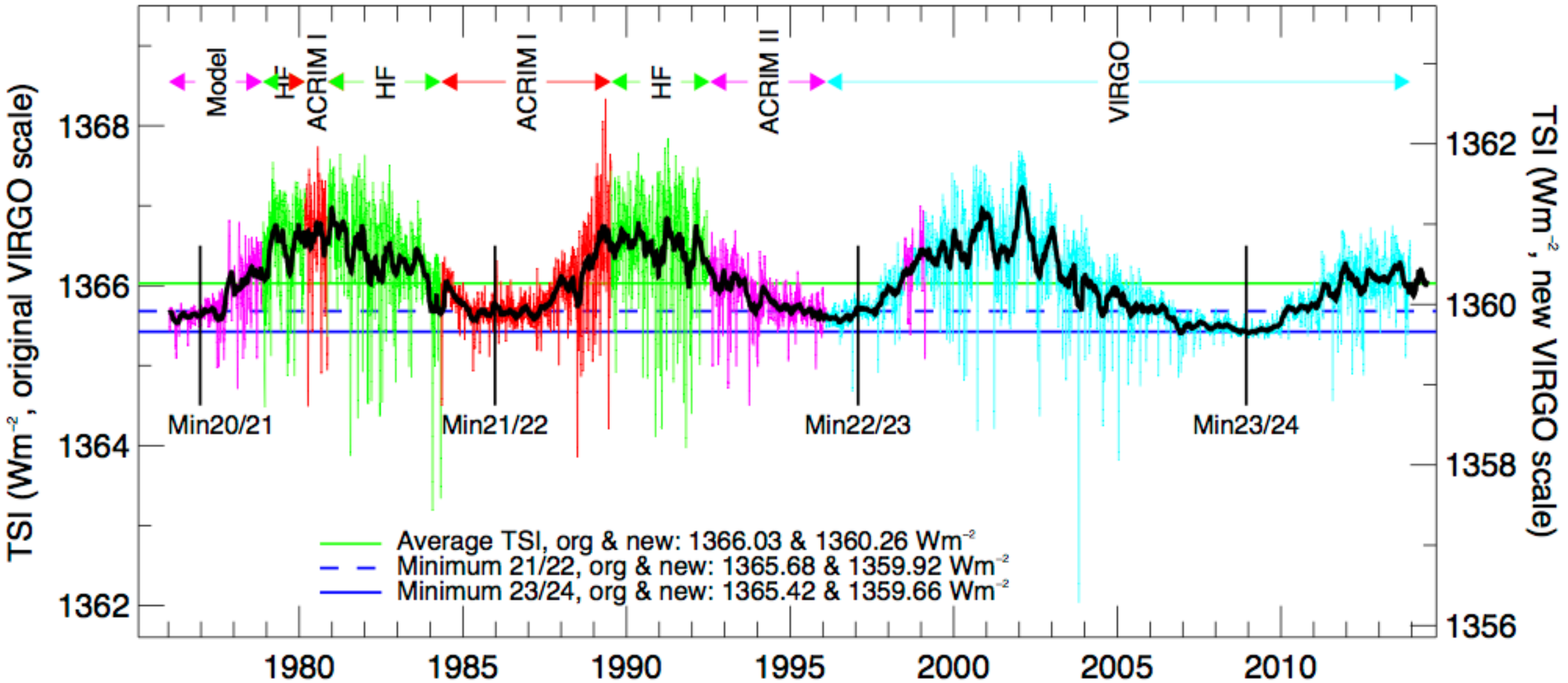


Sun (SoHO/VIRGO)



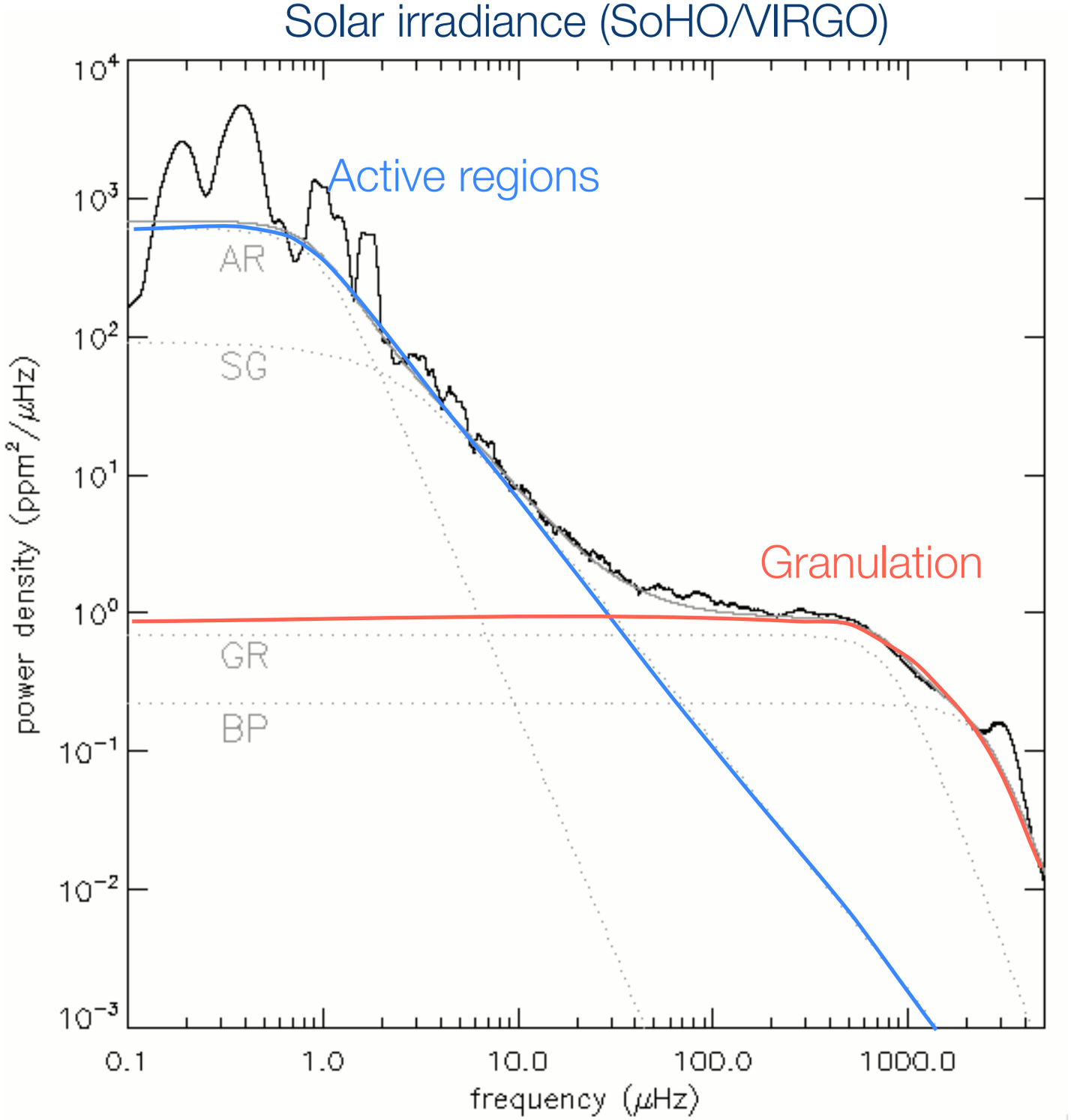
Photometric effects of spots and faculae

Composite total solar irradiance (TSI) from PMOD/WRC (C. Froehlich)



On the Sun, faculae have large filling factor and dominate the net photometric effect.
On active stars, the ratio of faculae to spot filling factor is thought to be lower.

Timescales



(Aigrain, Favata & Gilmore 2004)

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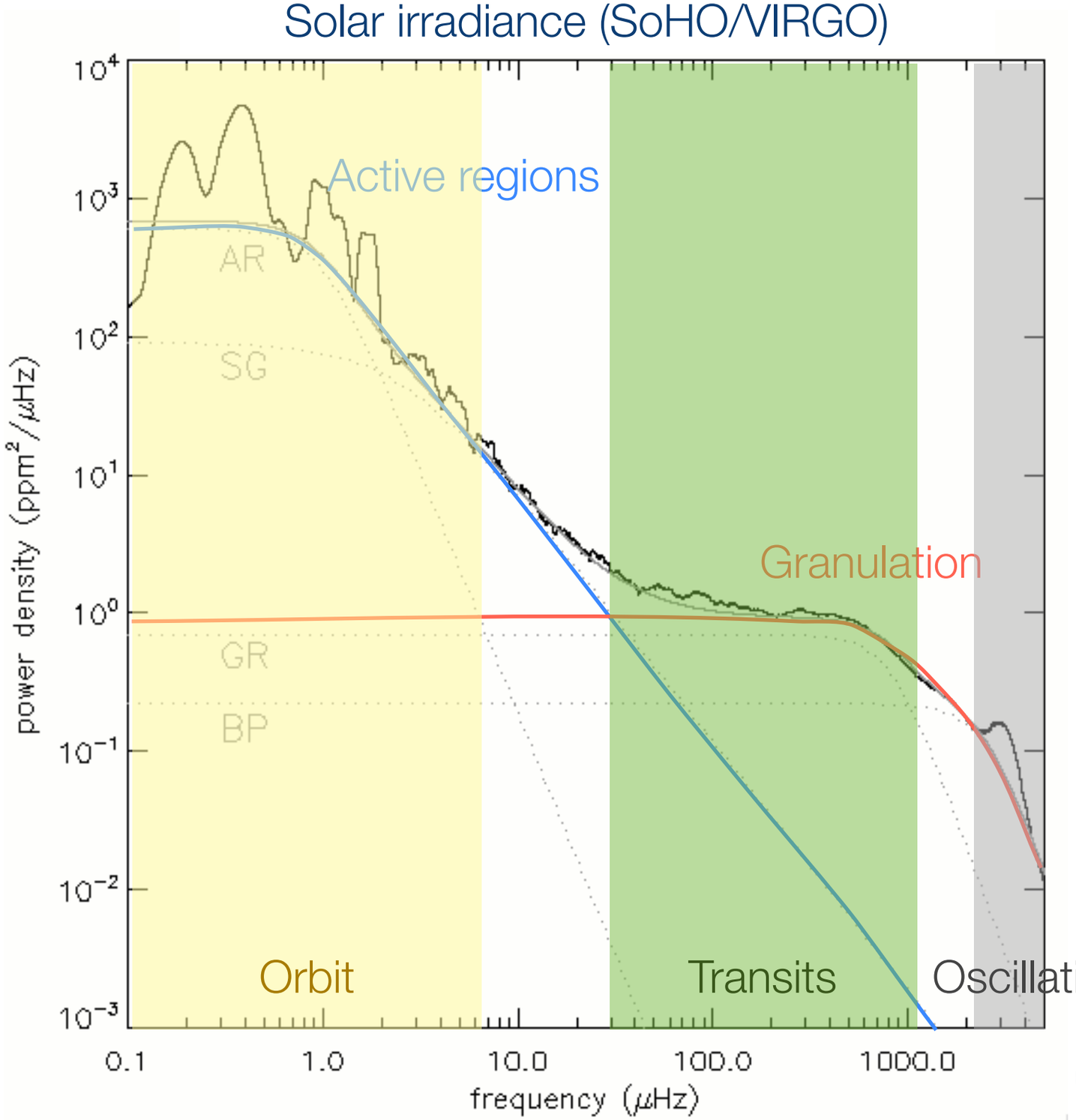

Transits can be separated from photometric variations due to active regions in the Fourier domain … so long as the star doesn't rotate to fast!

Granulation, on the other hand, gives rise to photometric variability on similar timescales to transits (hours).

(Aigrain, Favata & Gilmore 2004)

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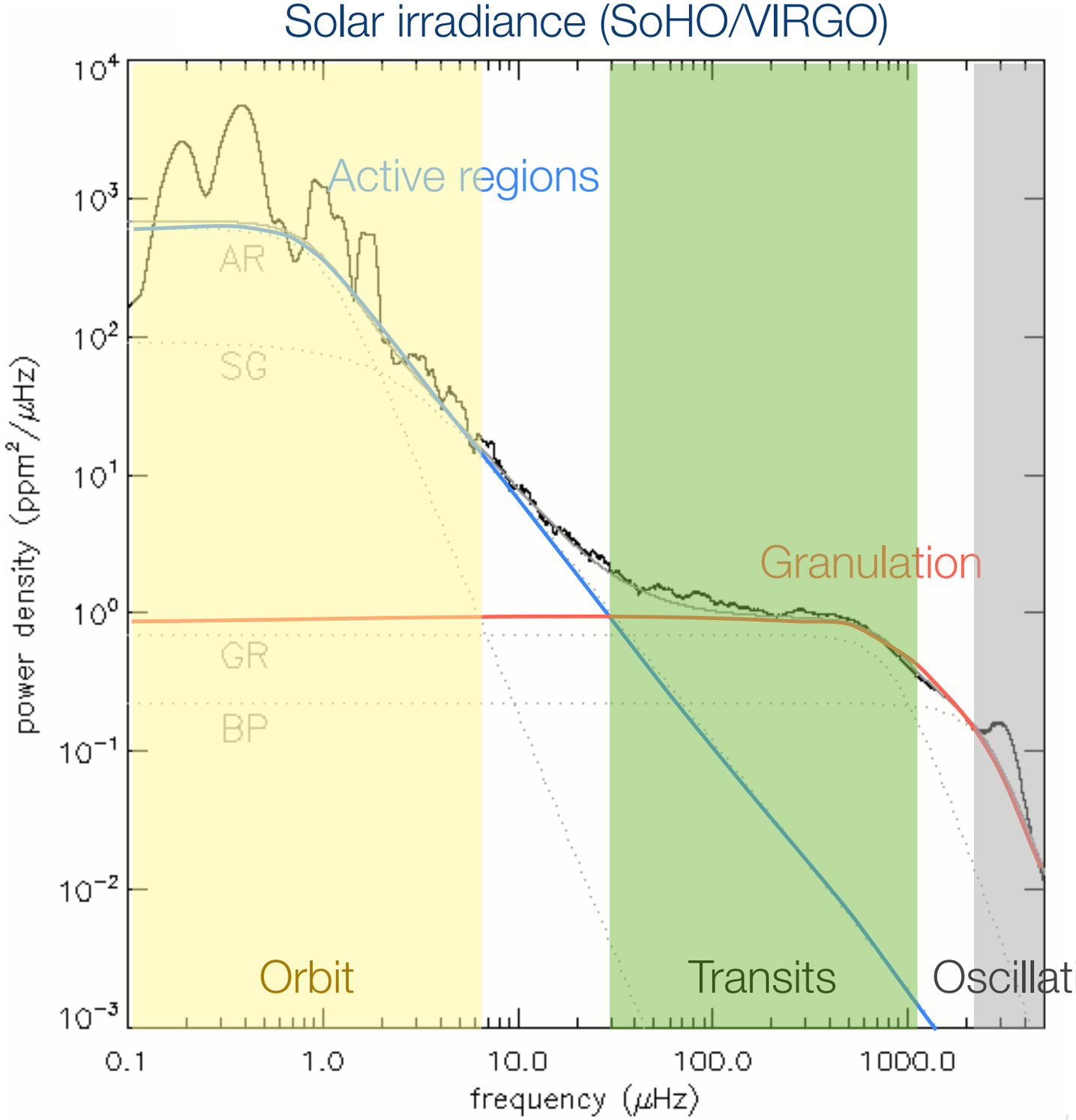

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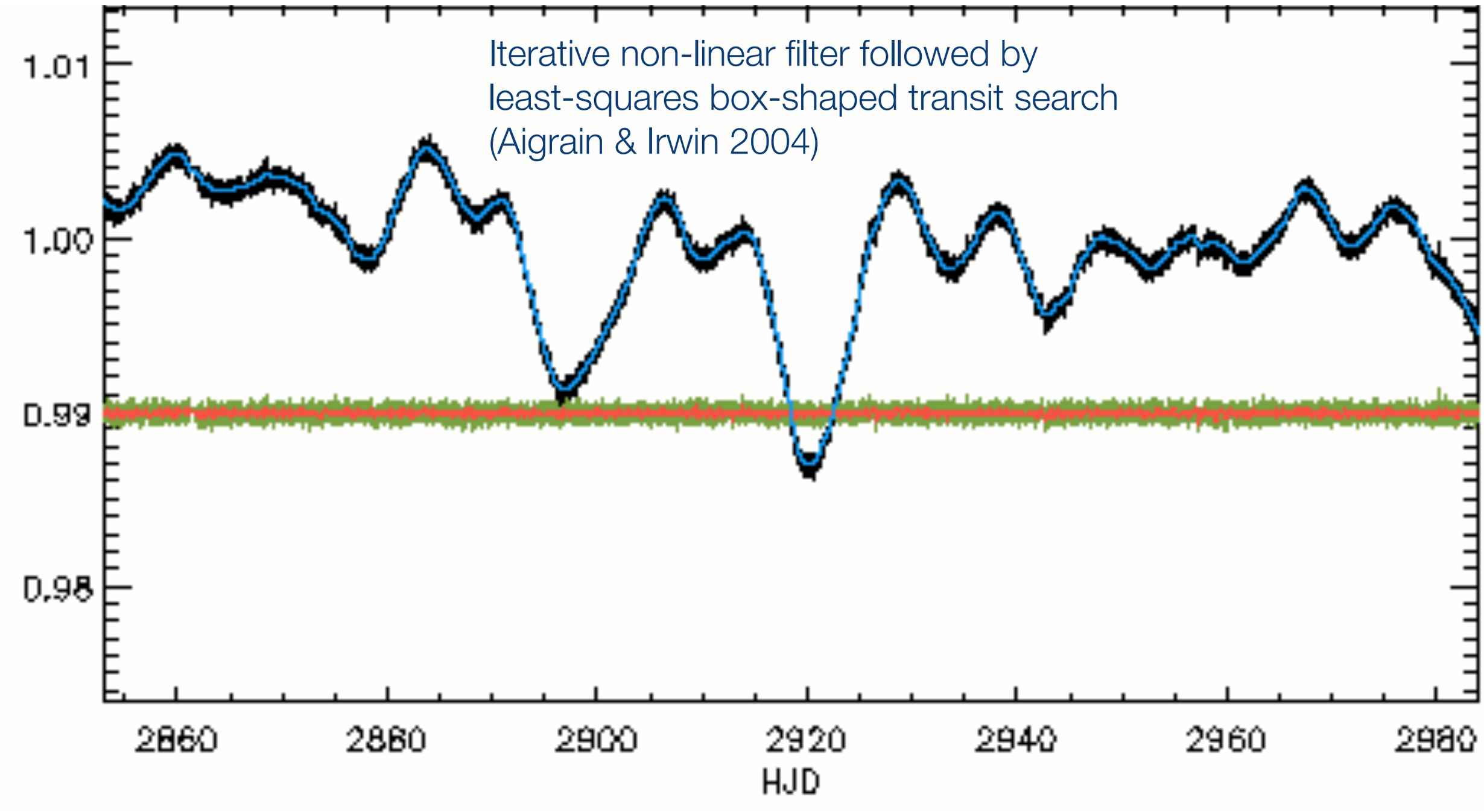
Activity-induced variability is even more problematic for radial velocity planet searches (also important but not shown here: activity cycles)

(Aigrain, Favata & Gilmore 2004)

Filtering activity to detect transits



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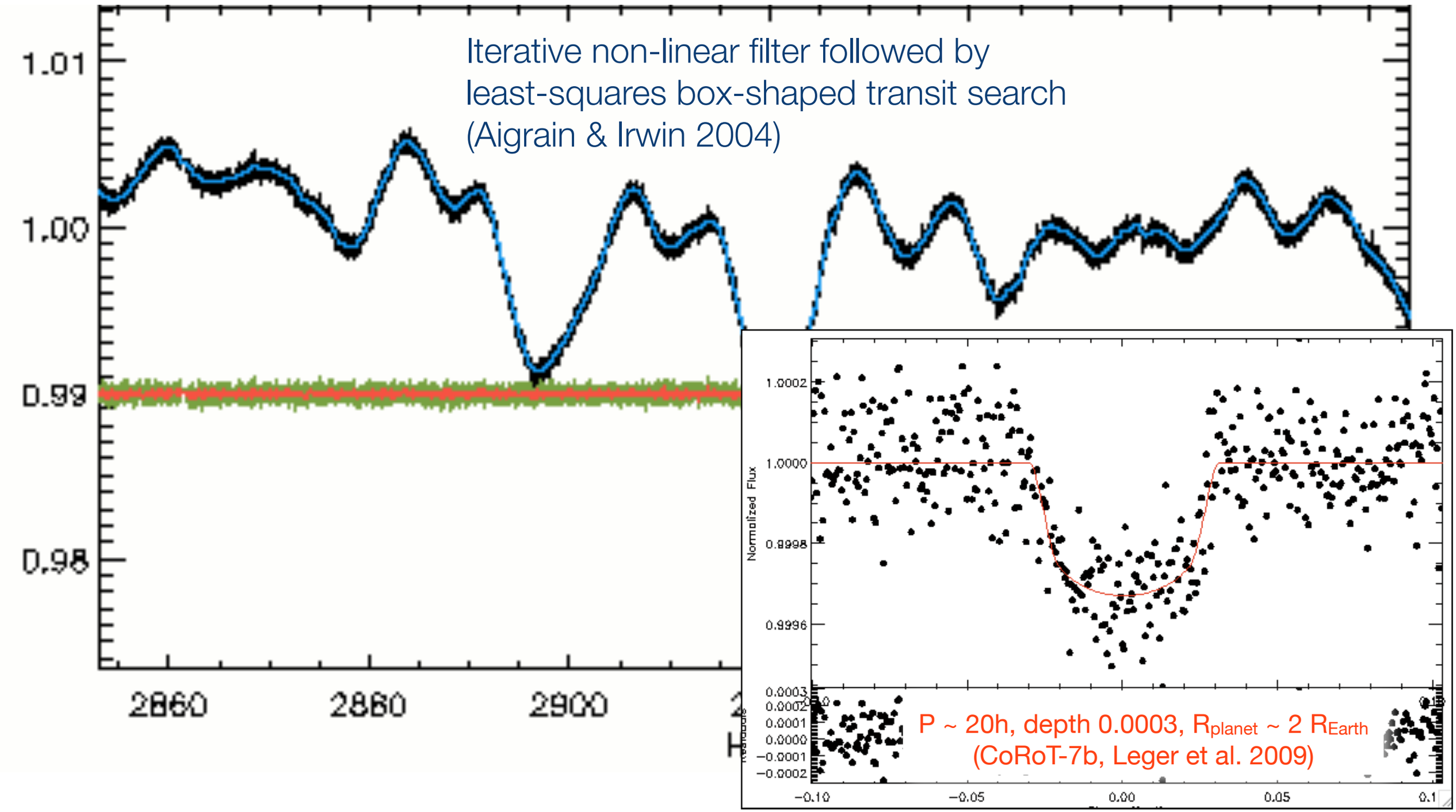

When does activity matter for transit searches?

Transit SNR =
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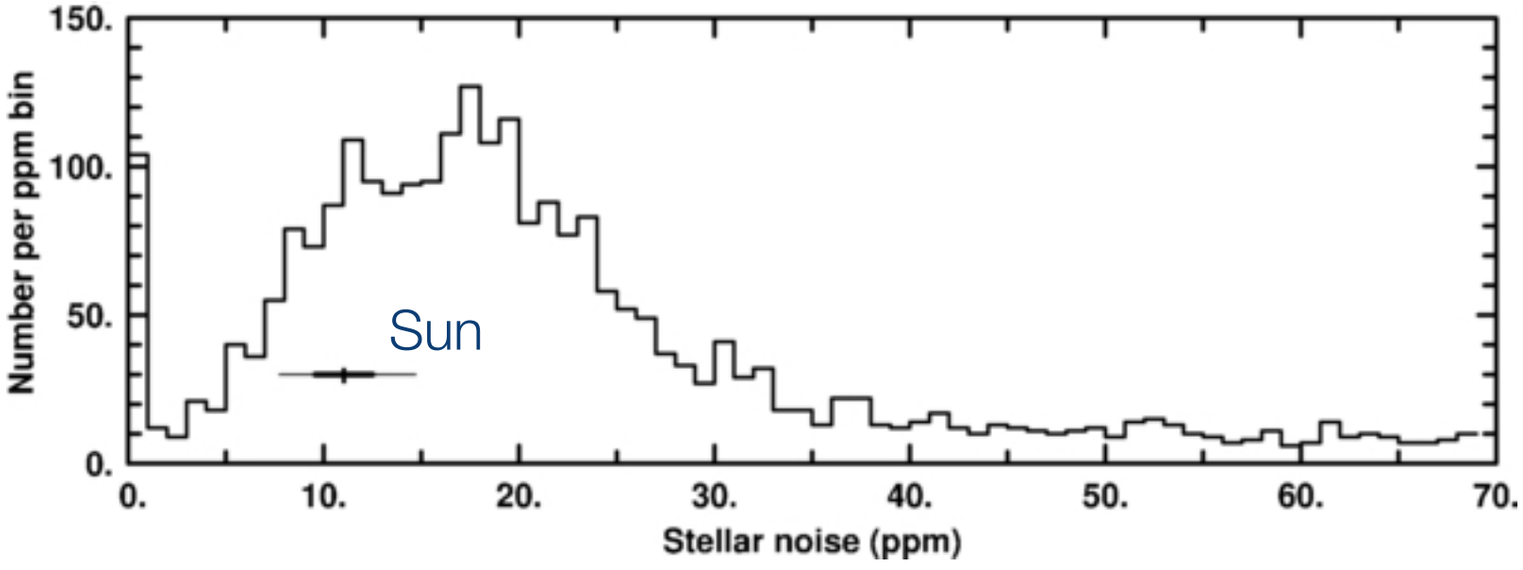

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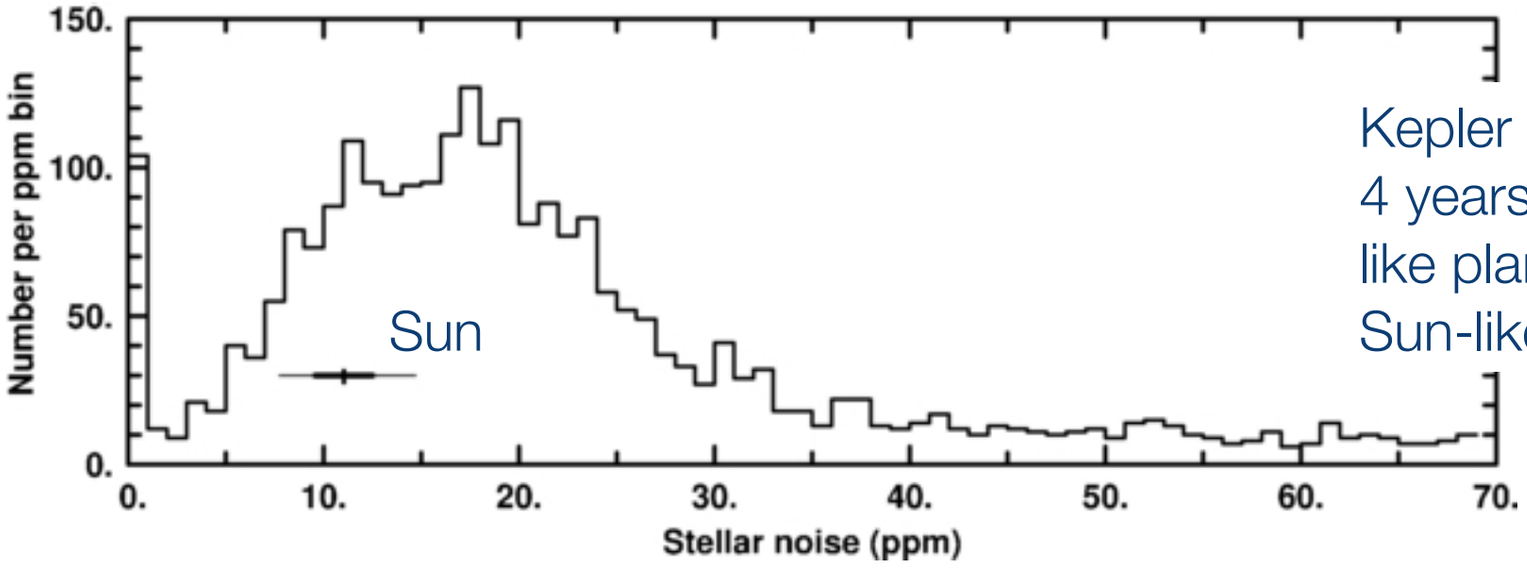

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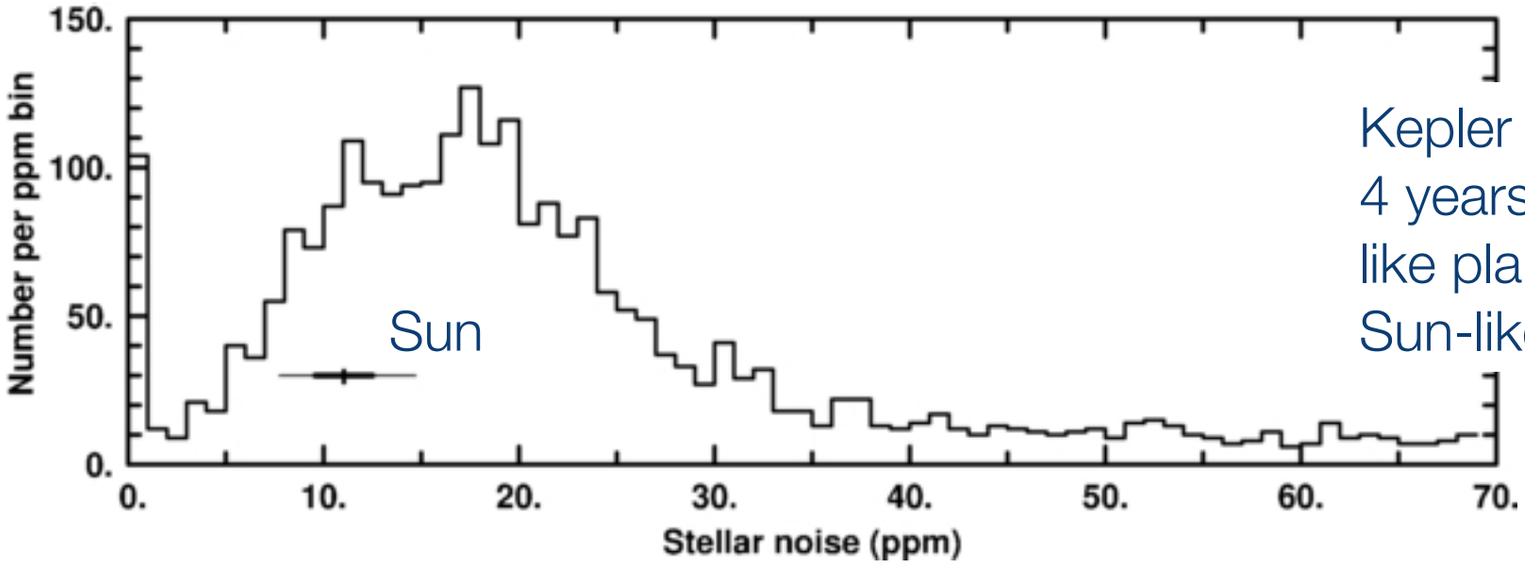

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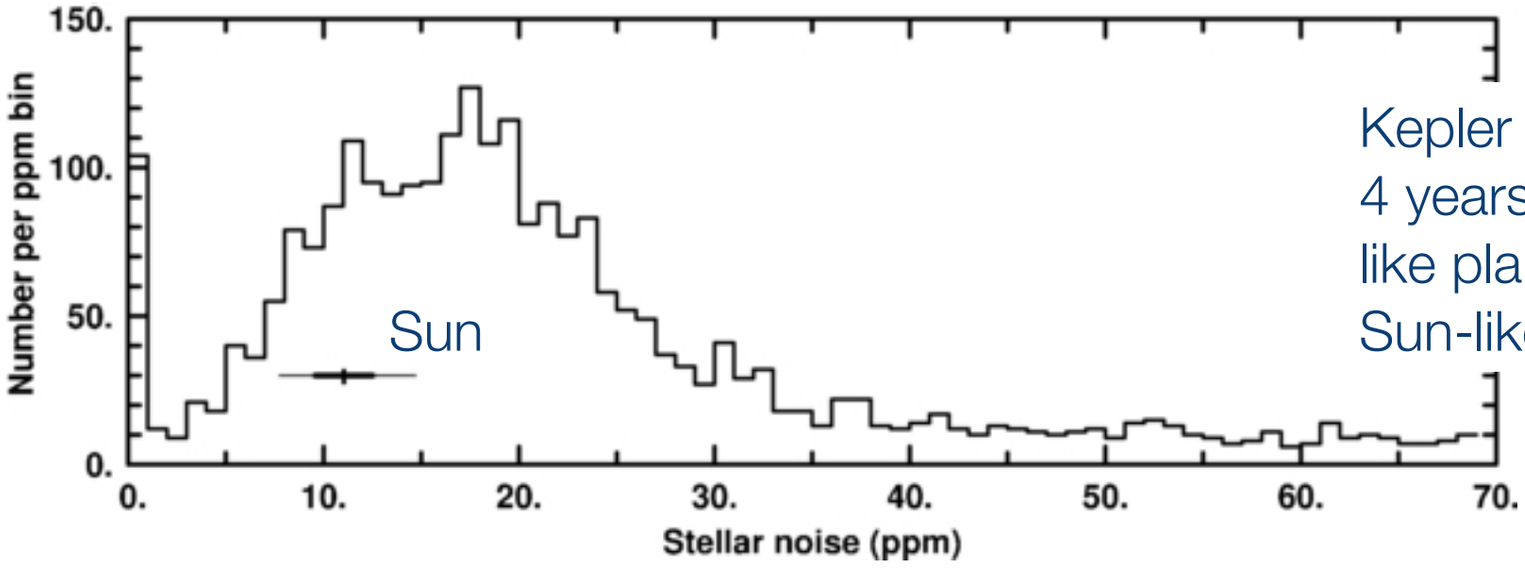

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This can be addressed, at least partially, by *modelling* the activity-induced variations *simultaneously* with the transits

Modelling stellar and planetary signals jointly using Gaussian Processes (GPs)

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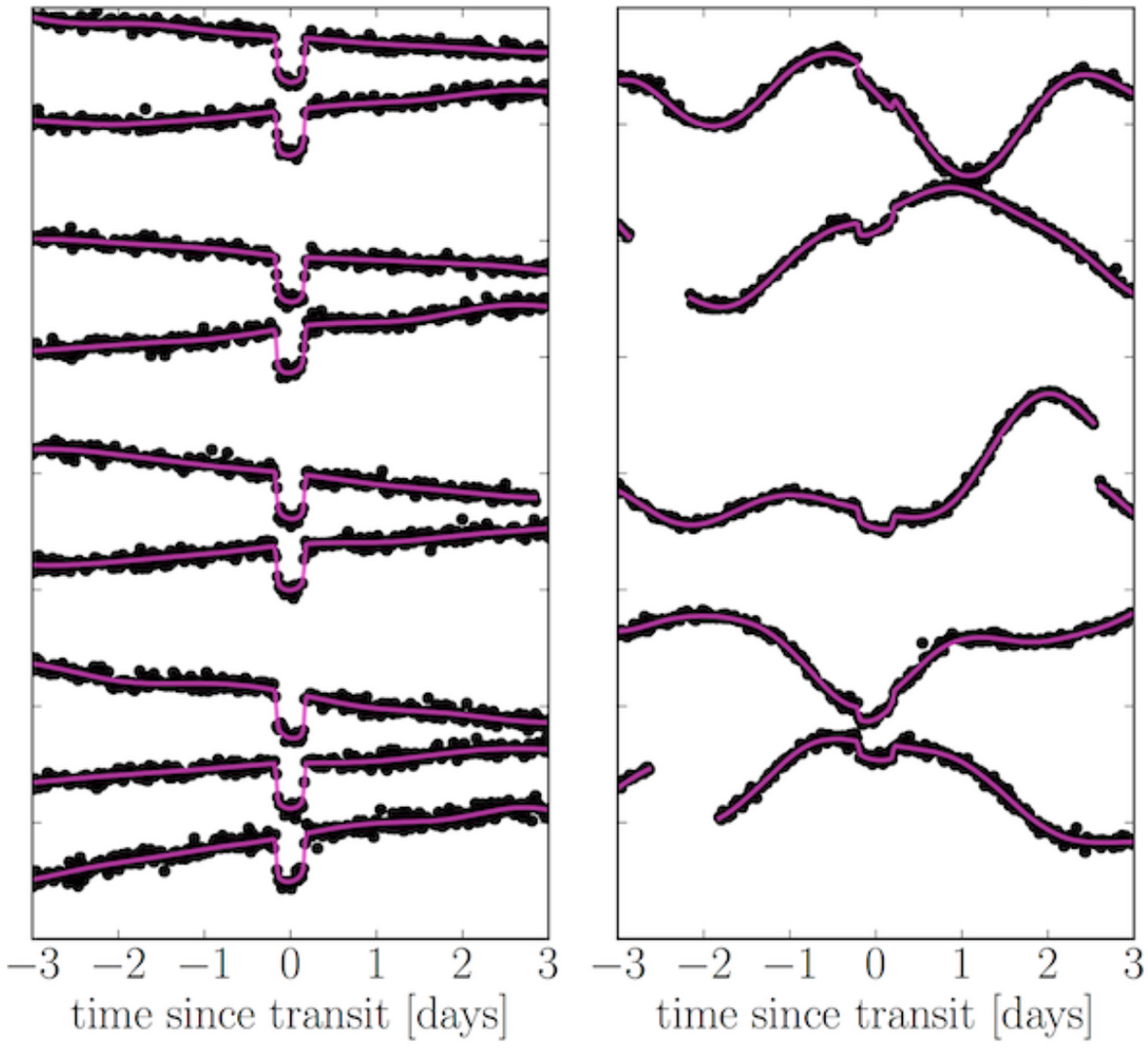

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HD189733 out of transit variability
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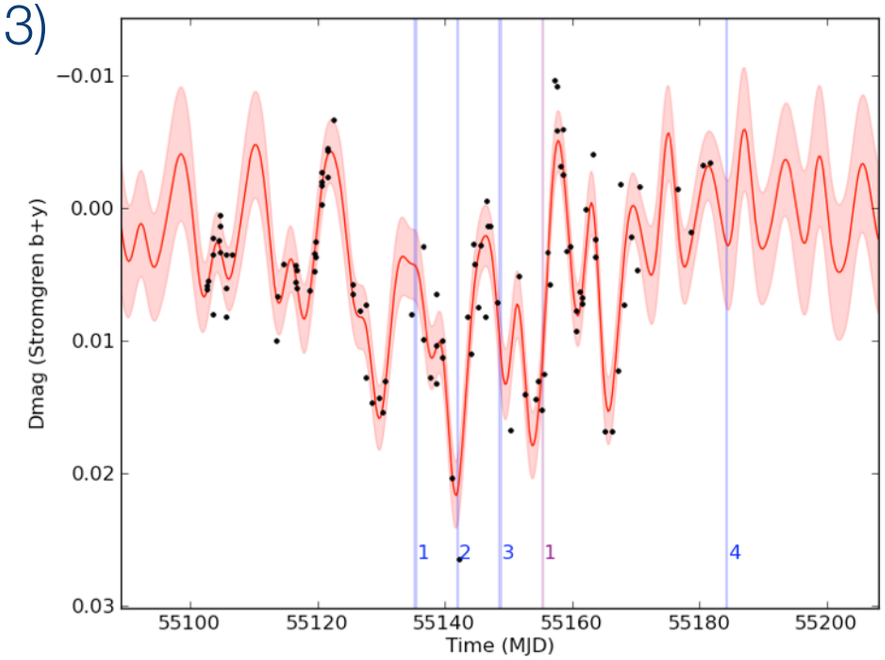

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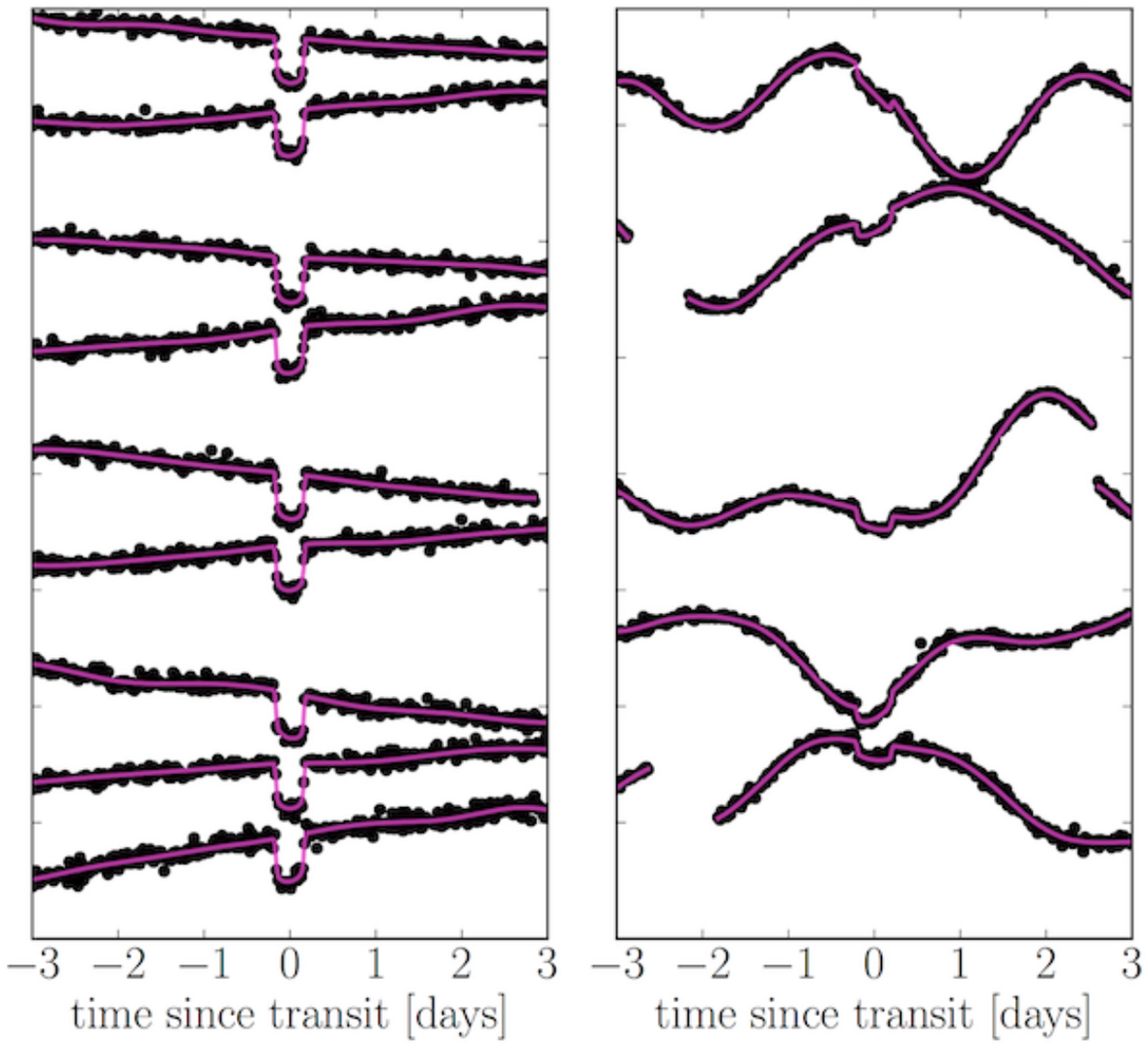

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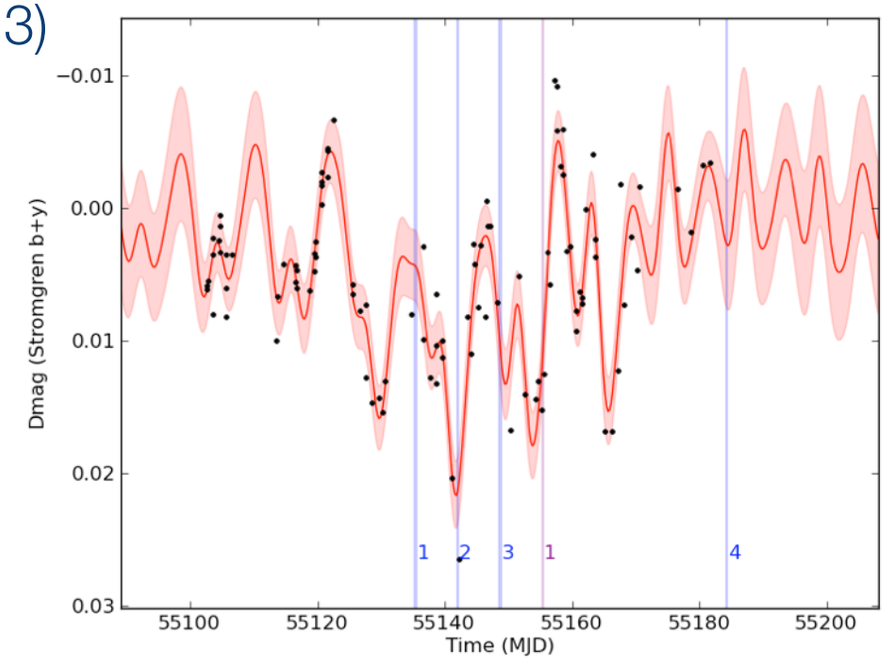

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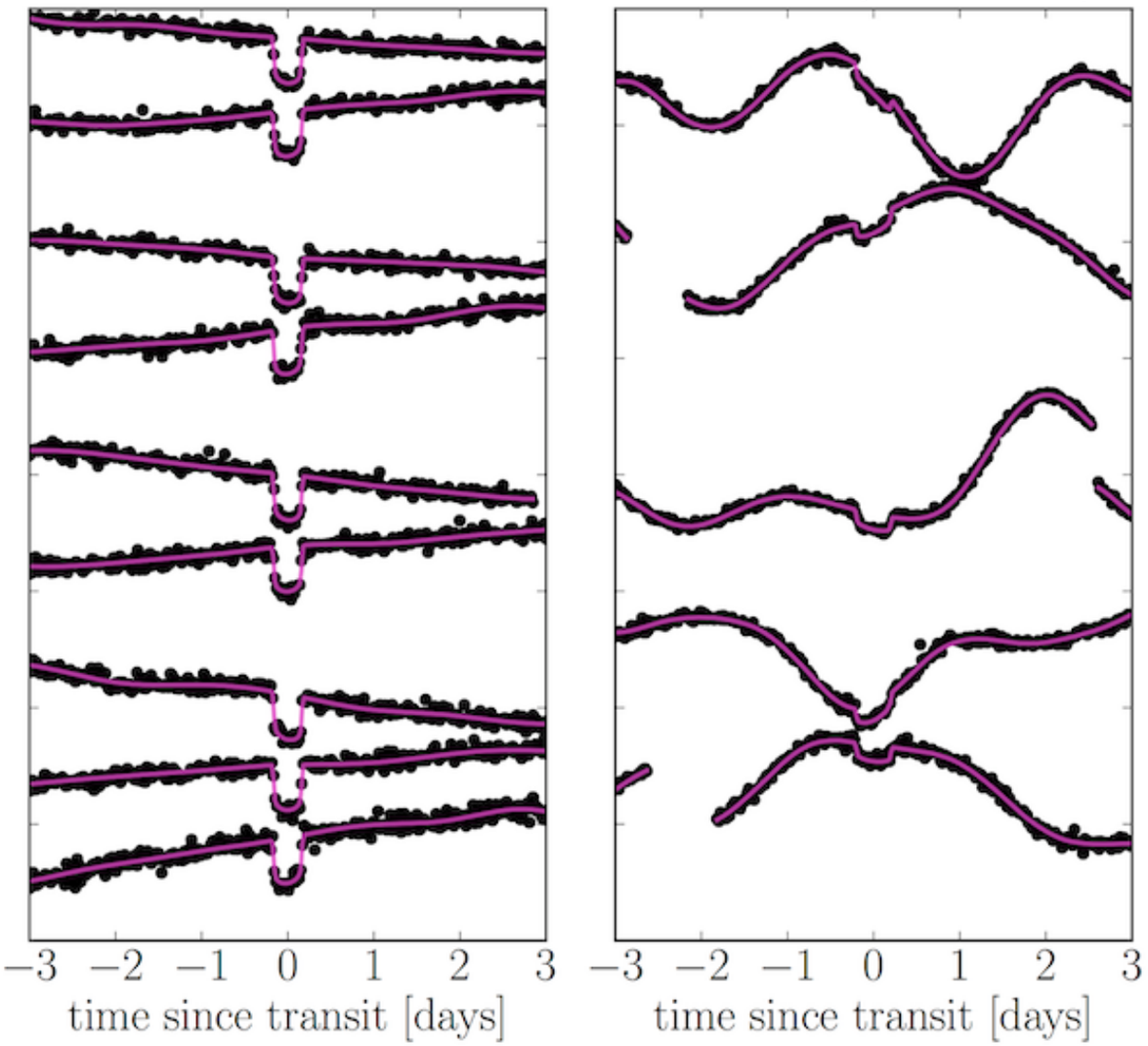


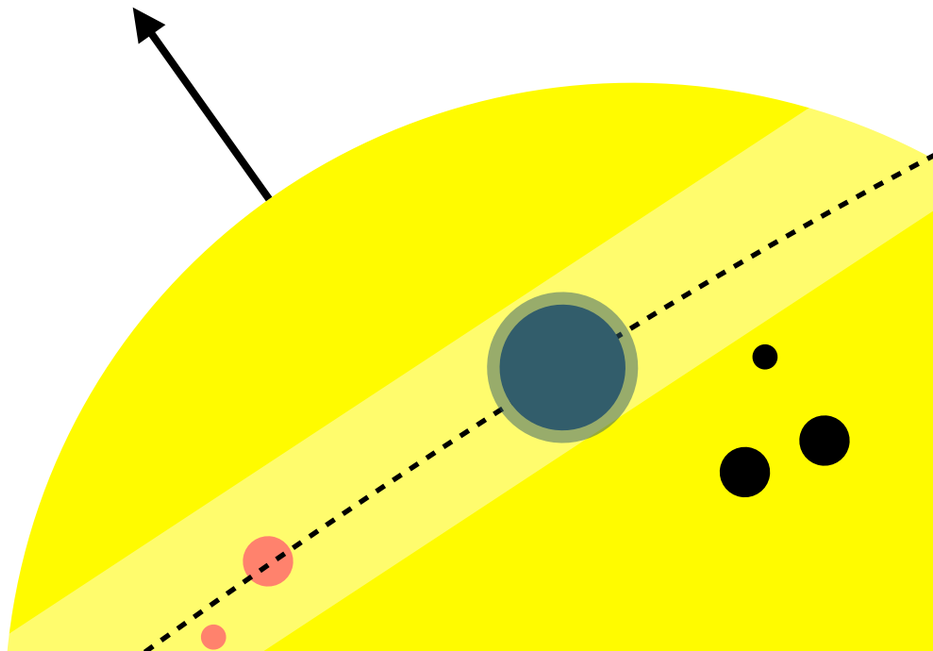
More on GPs in J. Christiansen, R. Haywood's talks!

Simple Python GP regression for beginners: https://github.com/saigrain/SuzPyUtils/GP_simple.py

Fast GP regression using rapid matrix inversion: http://dan.iel.fm/george

Activity in transmission spectra

- In transmission spectroscopy, need to worry about
  - occulted spots: distort transit, or make it seem shallower
  - un-occulted spots: make transit appear deeper
- Both effects are very important and hard to correct for transmission spectroscopy
  - not just in the optical / UV! cf. Pont et al. (2013)



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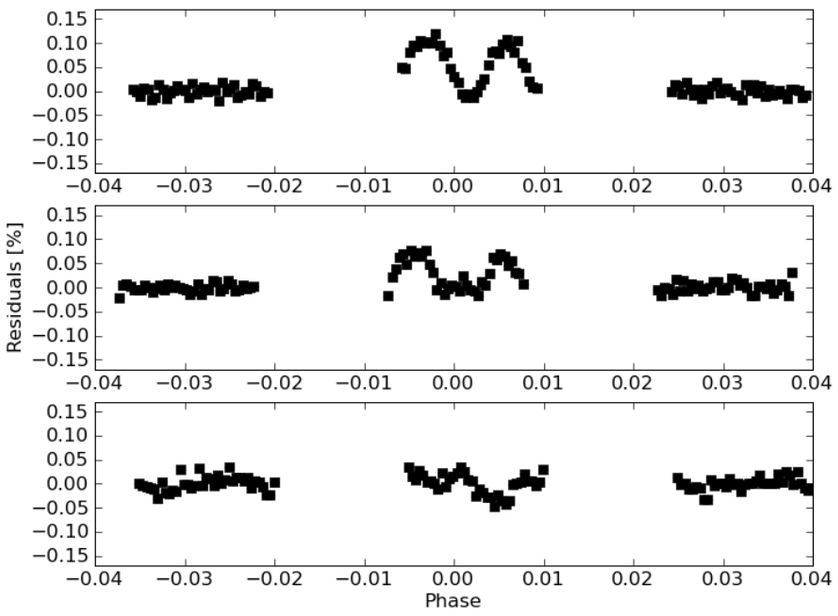

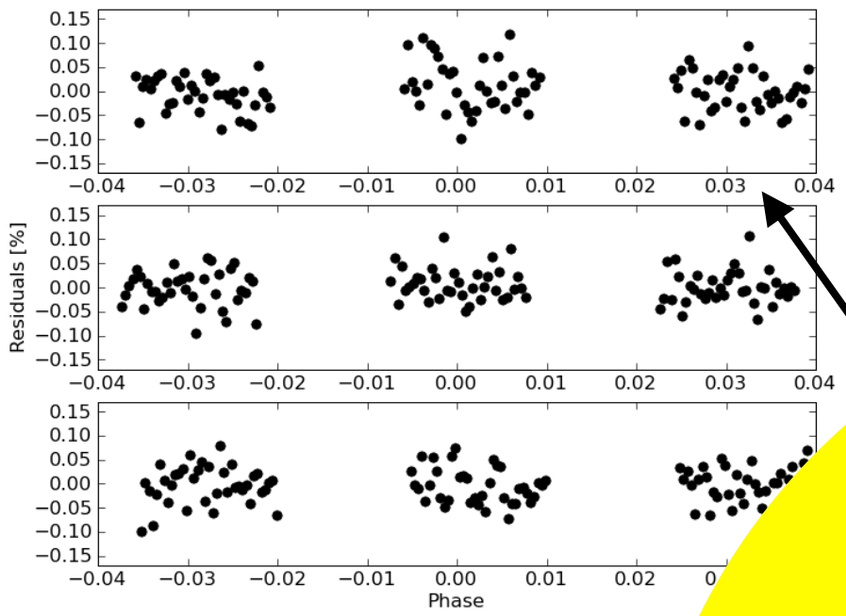

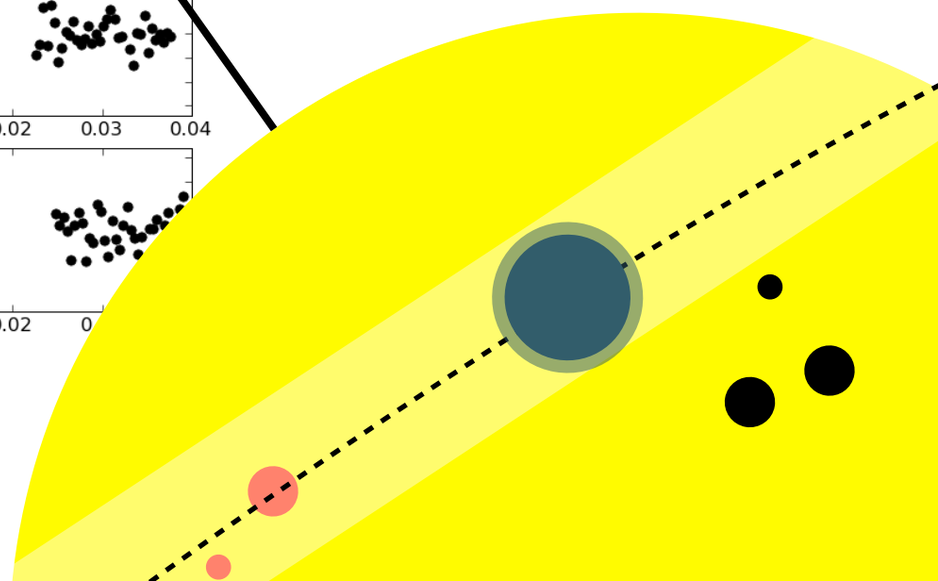

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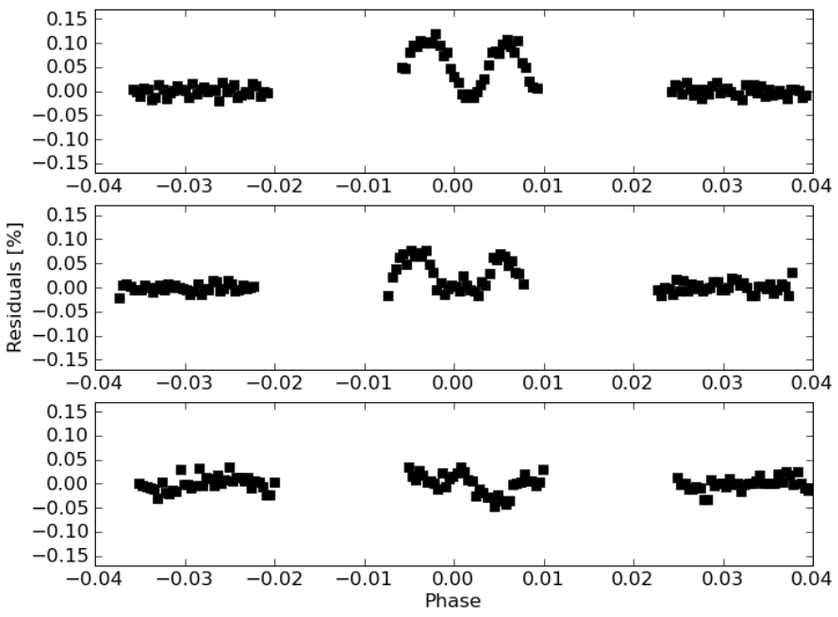
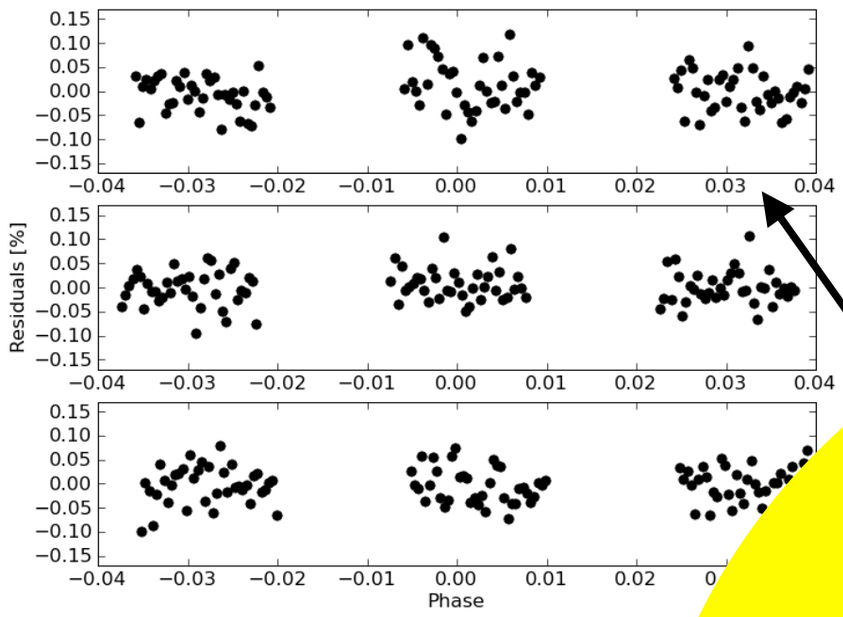
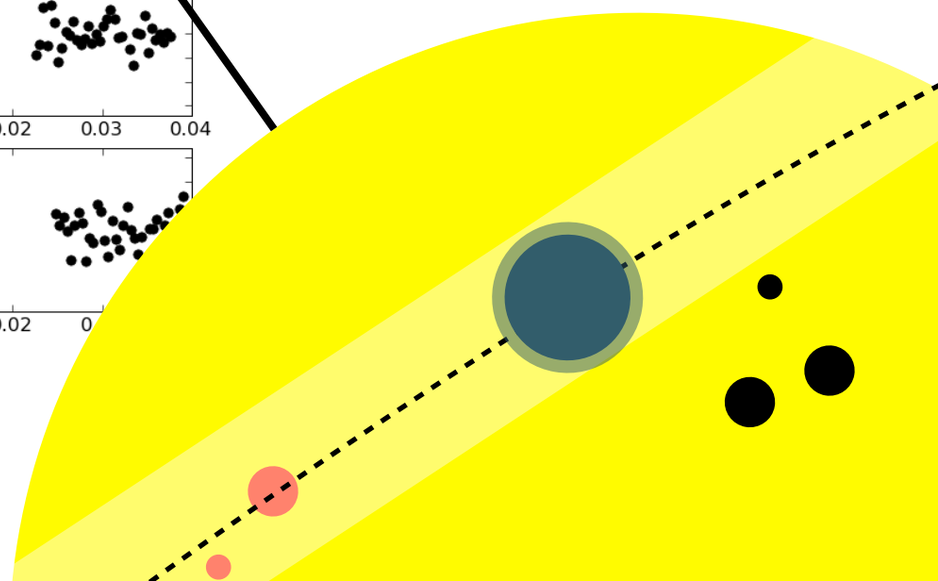


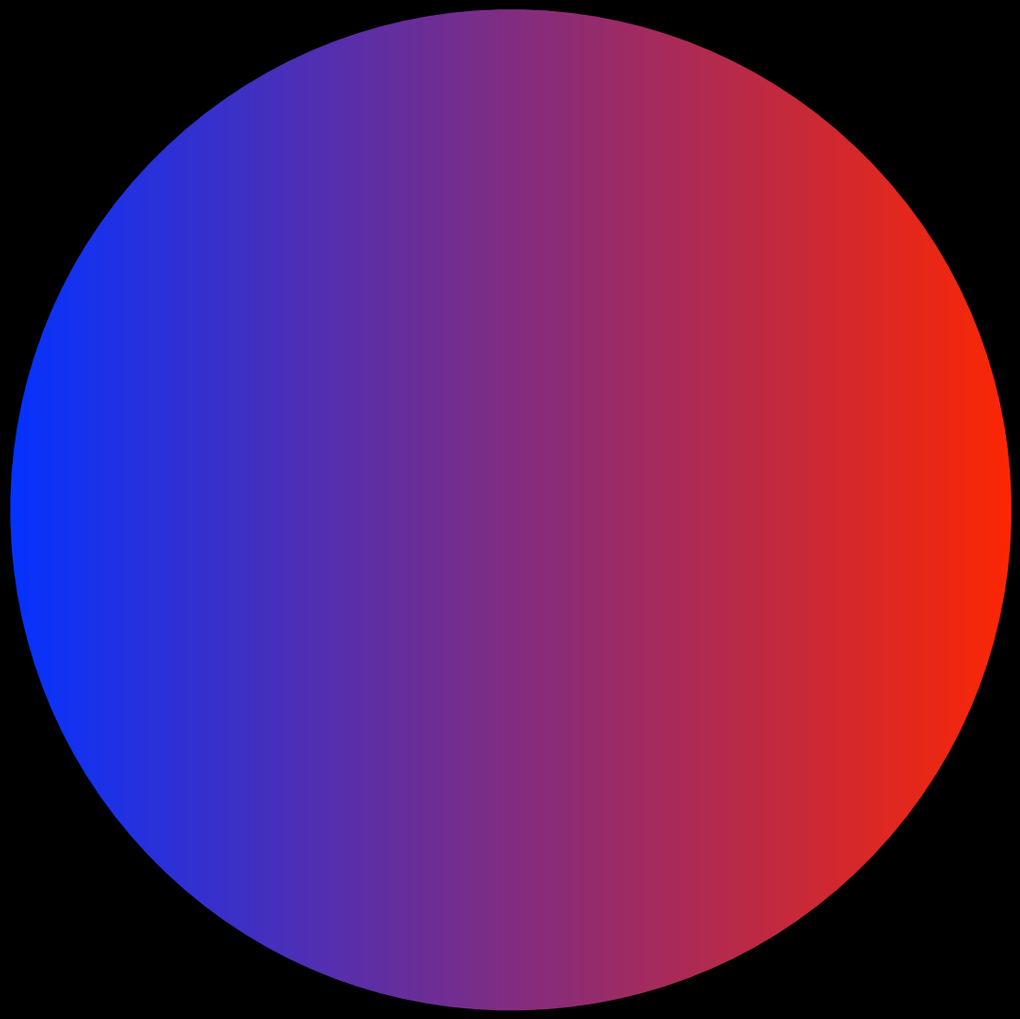


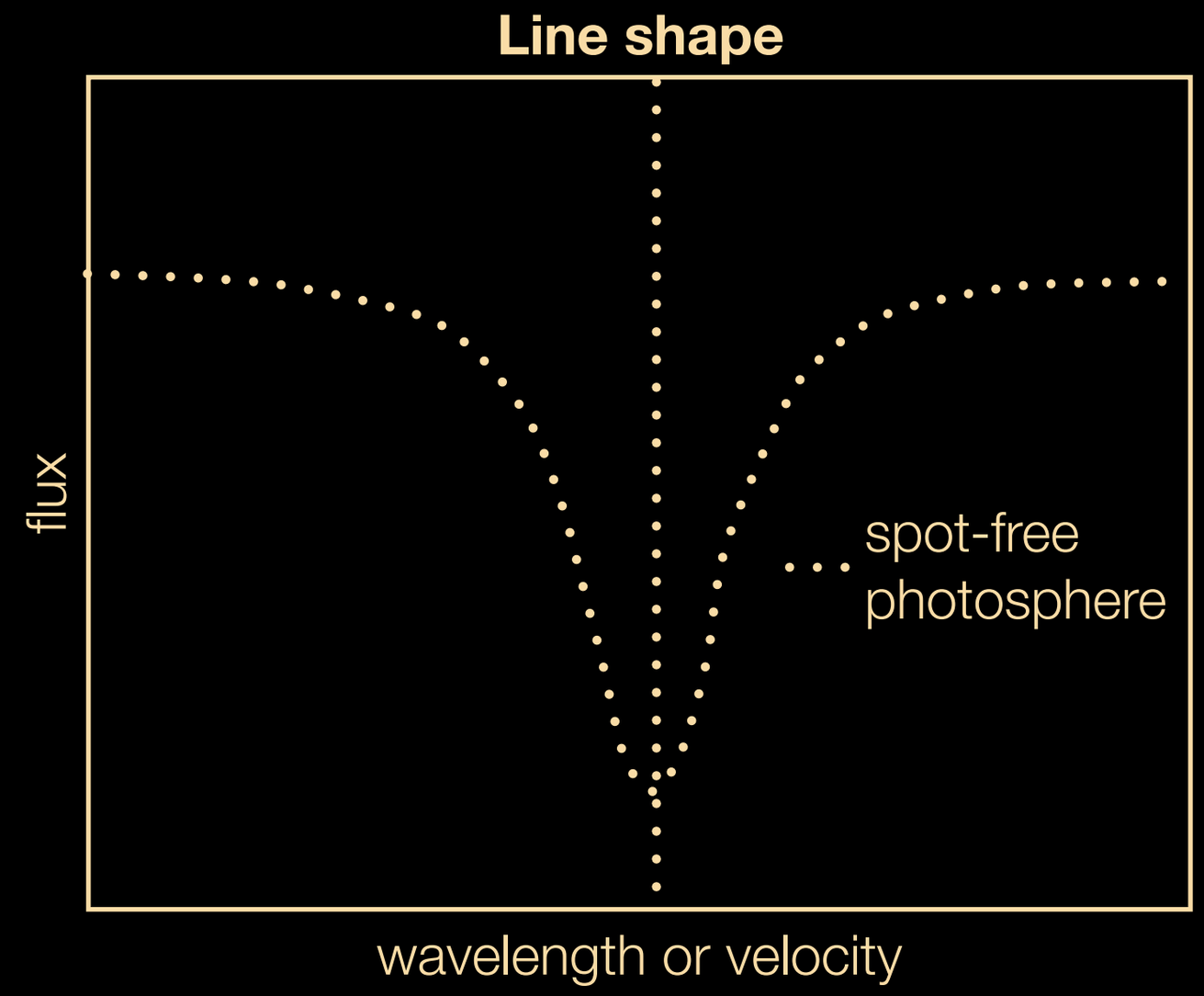


Plages also matter - see talk by M. Oshagh

Activity and RVs

RV effects of activity - 1:
distortion of rotation profile (a.k.a. photometric effect)





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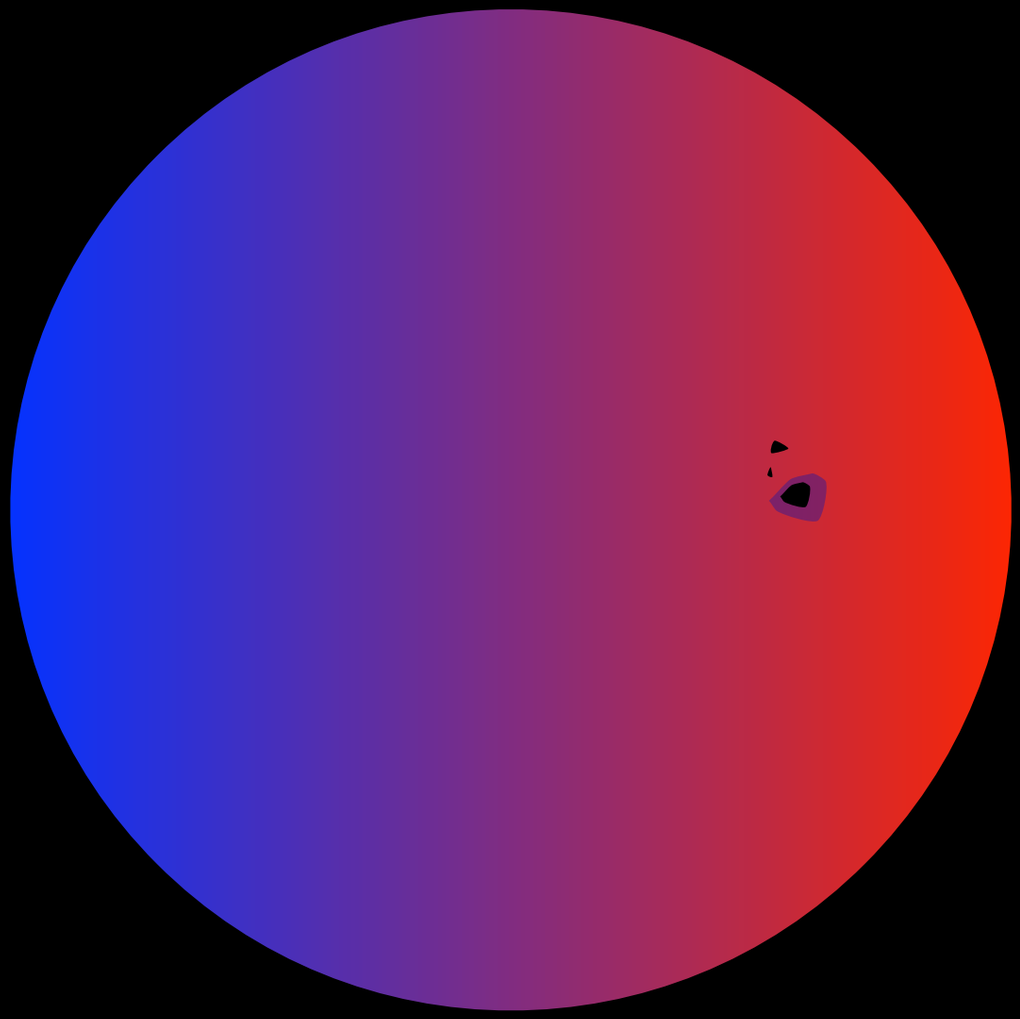

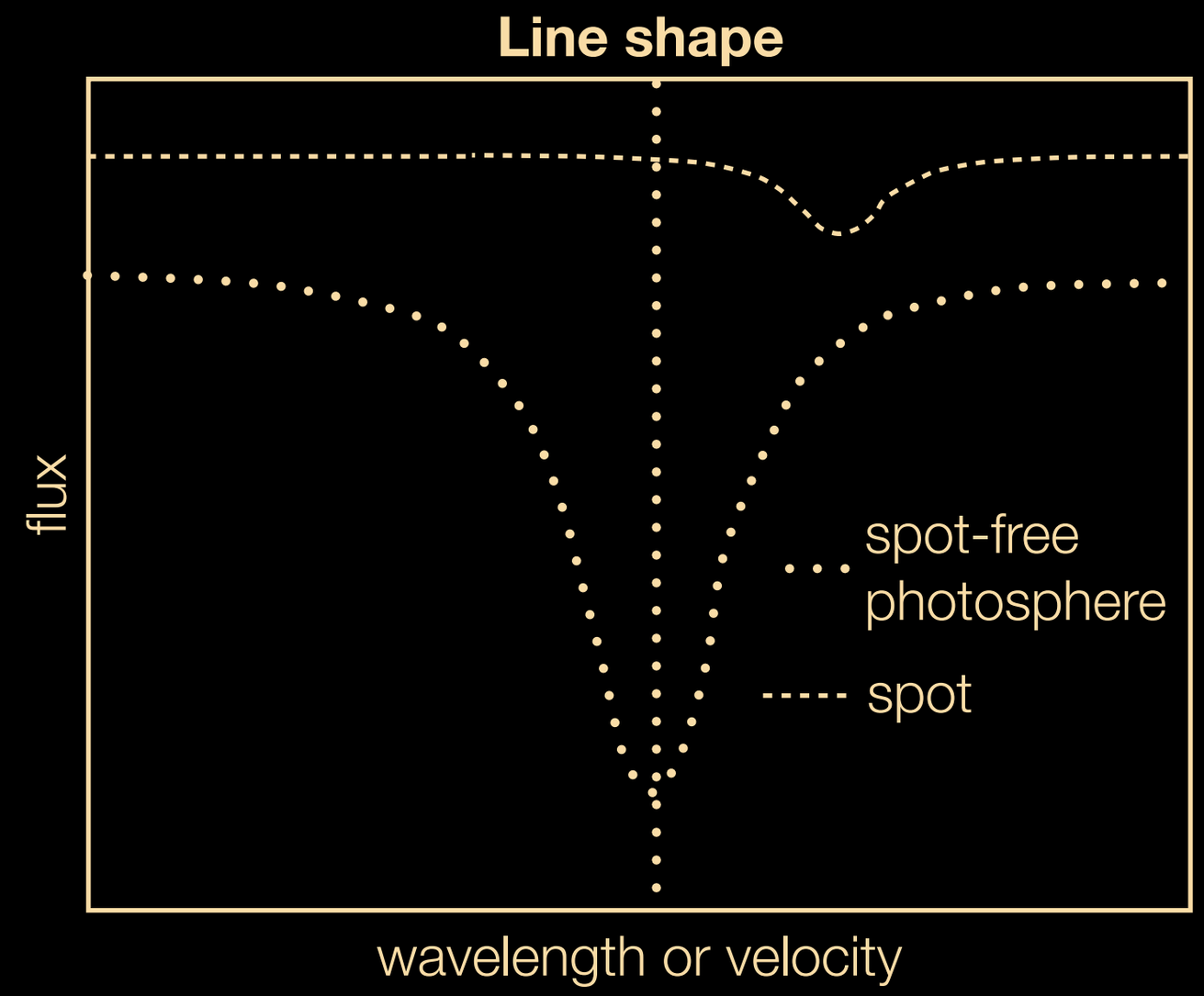

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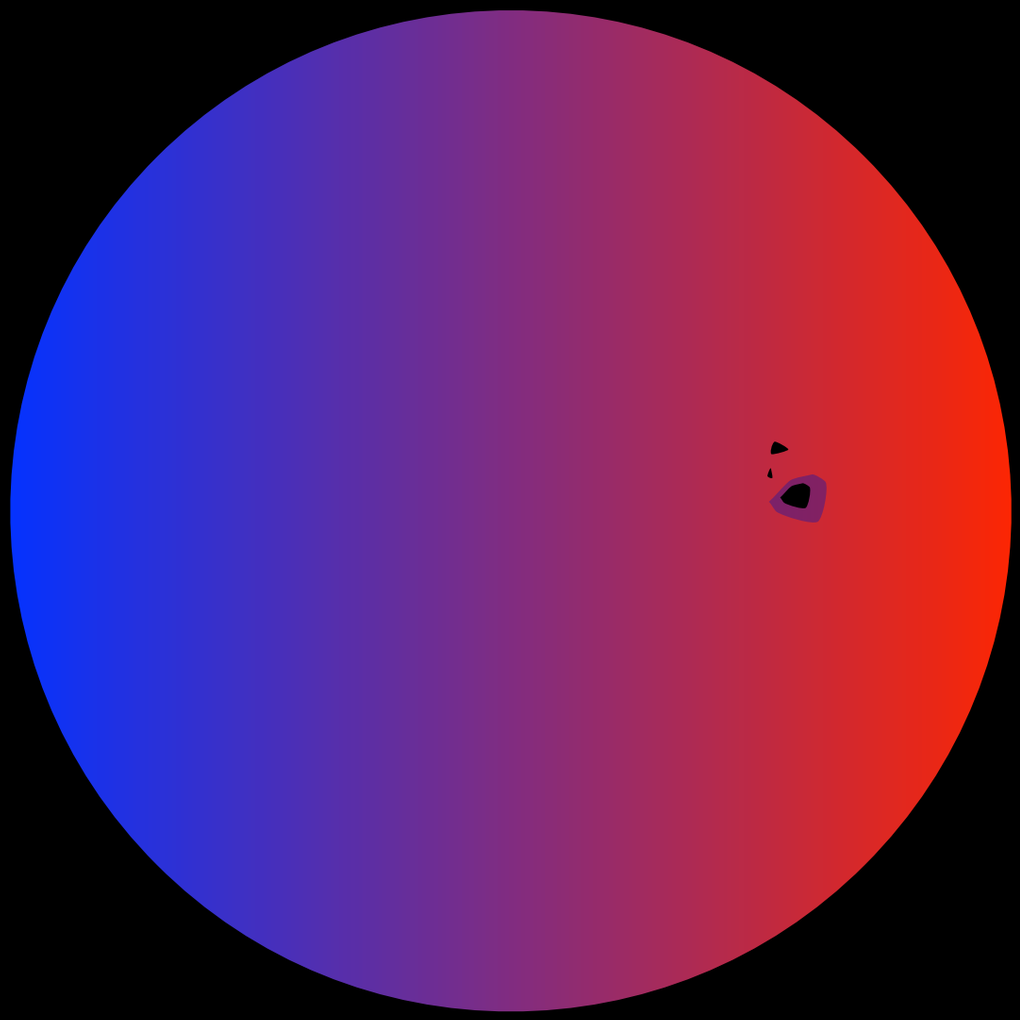
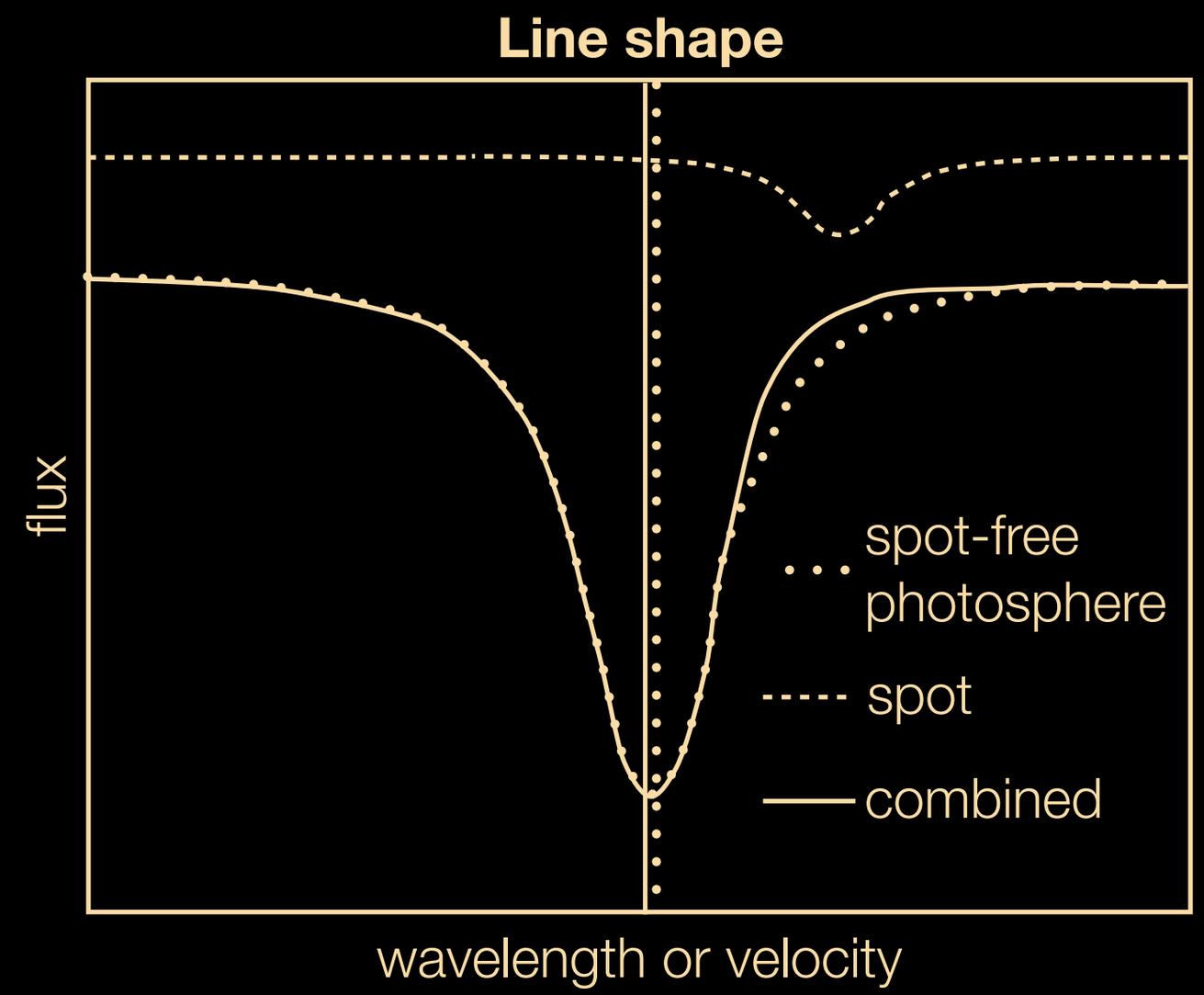
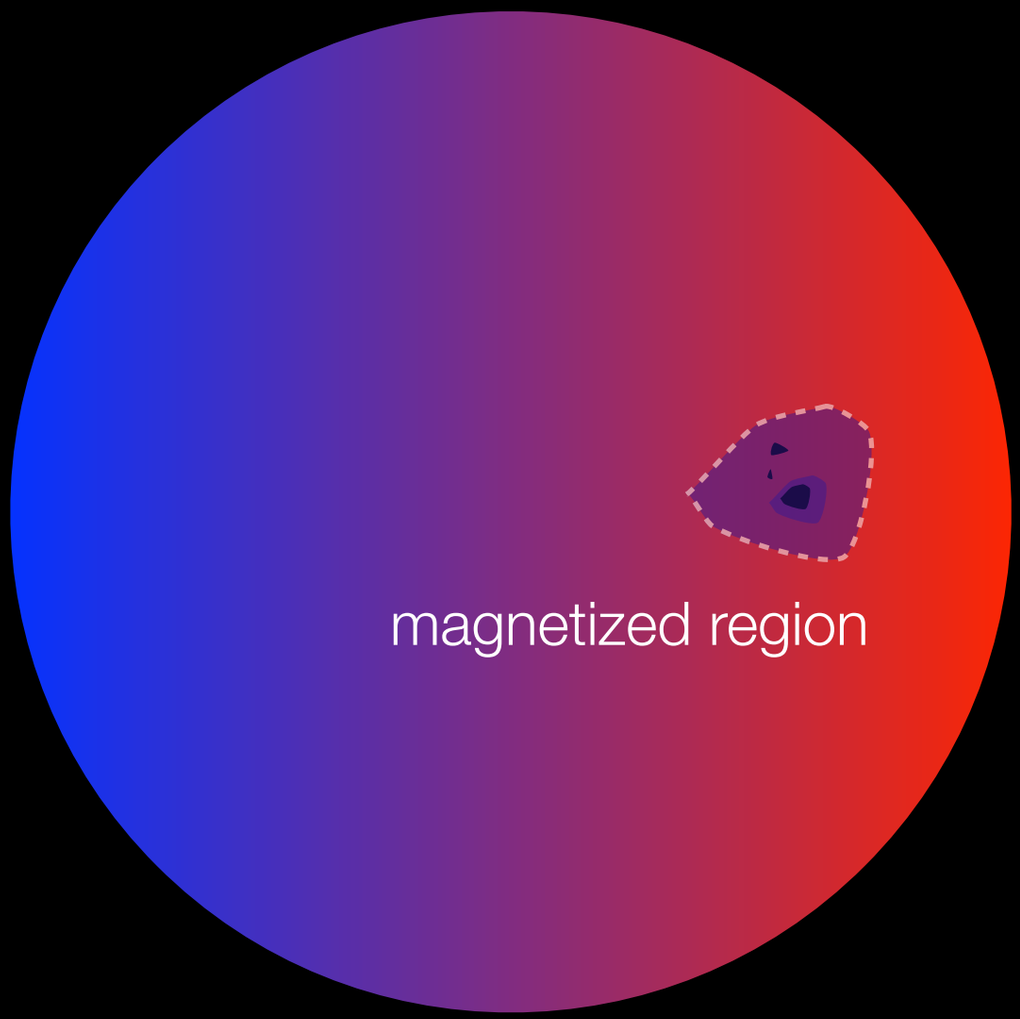




RV effects of activity - 2:
convective blueshift suppression



Convection is partially suppressed in regions where surface magnetic field is large

Why does this affect RVs?

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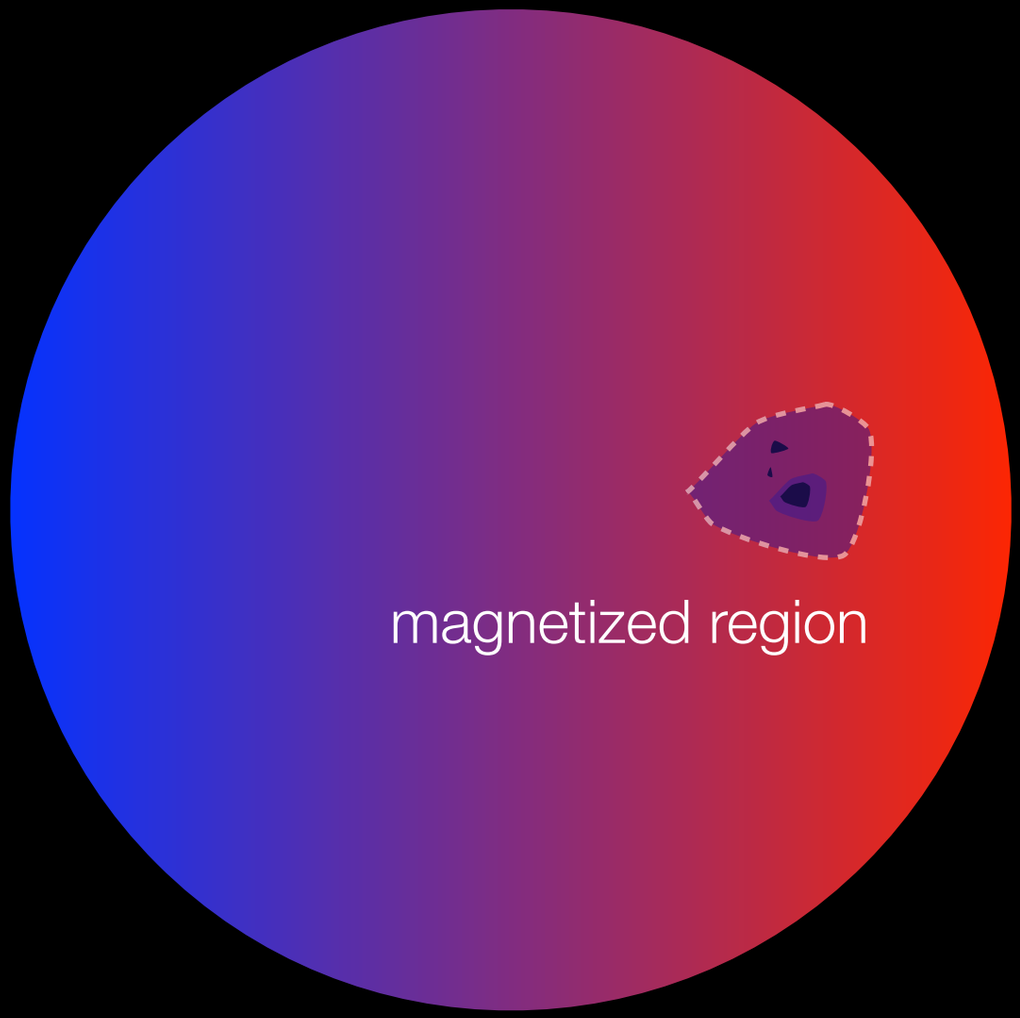

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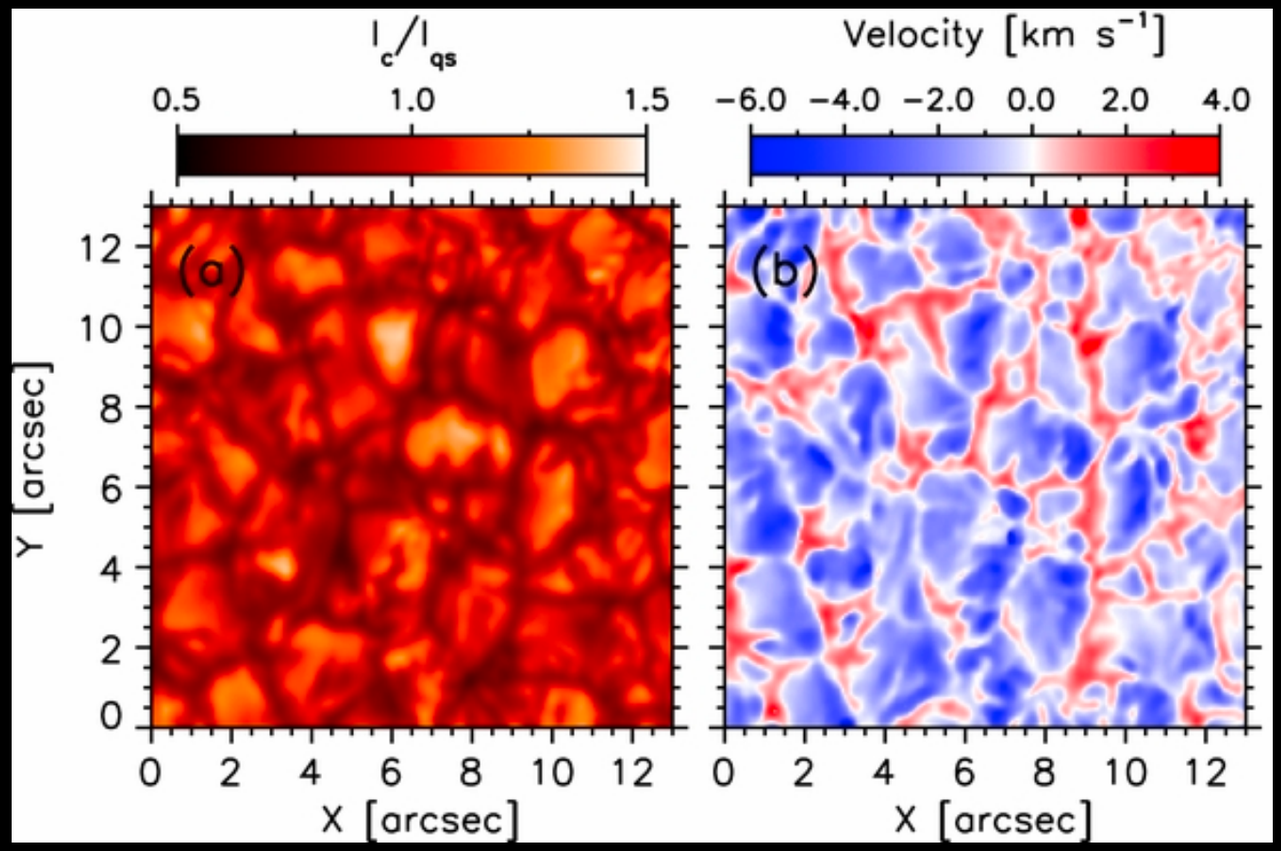
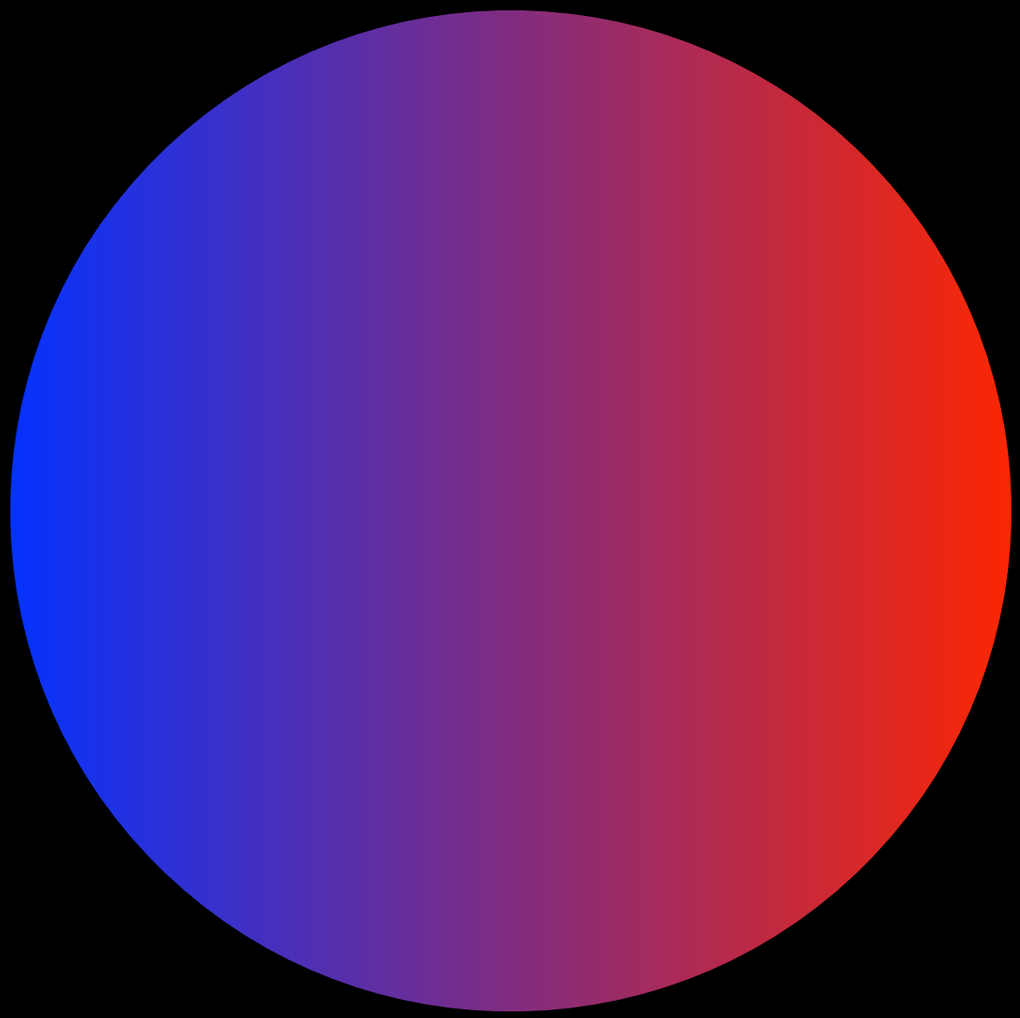


Joshi et al. (2011)

Spectral line in “normal” photosphere



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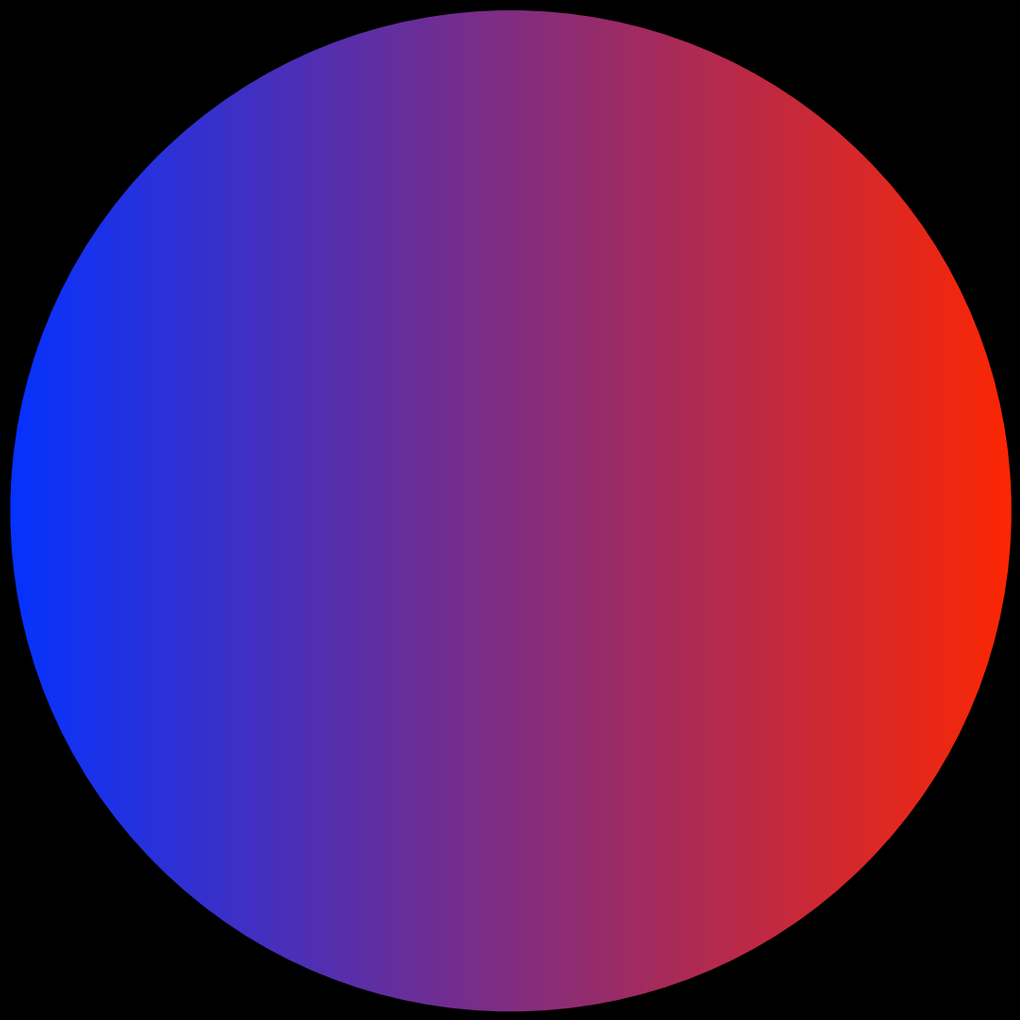

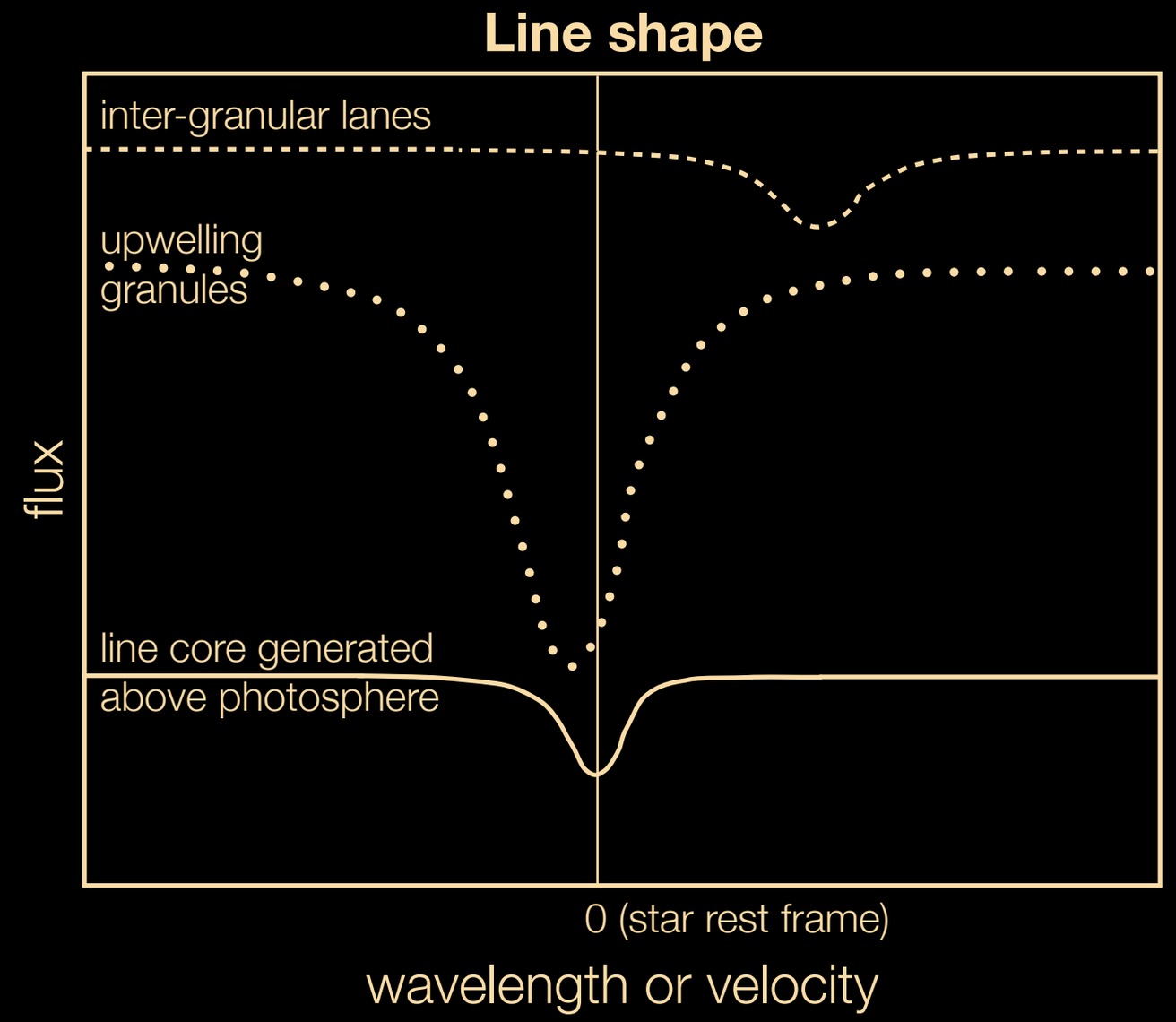

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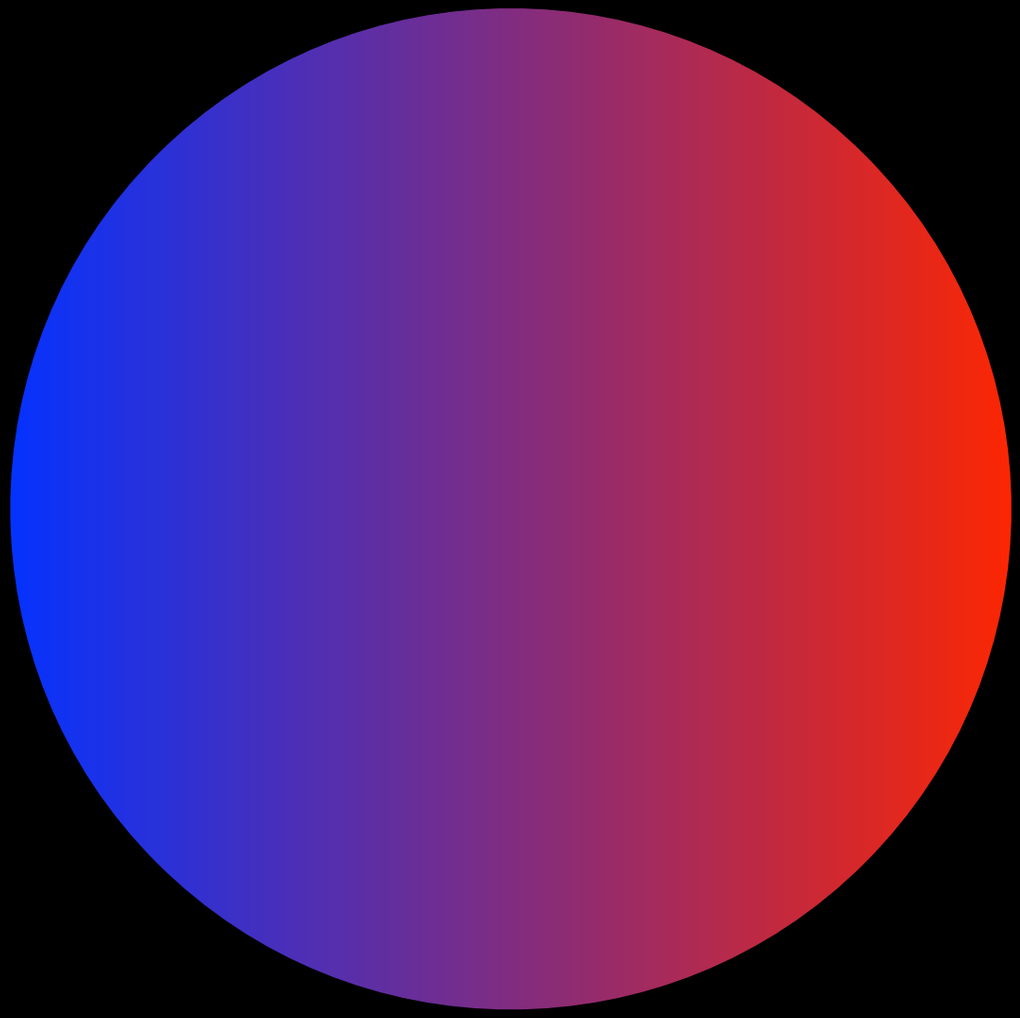

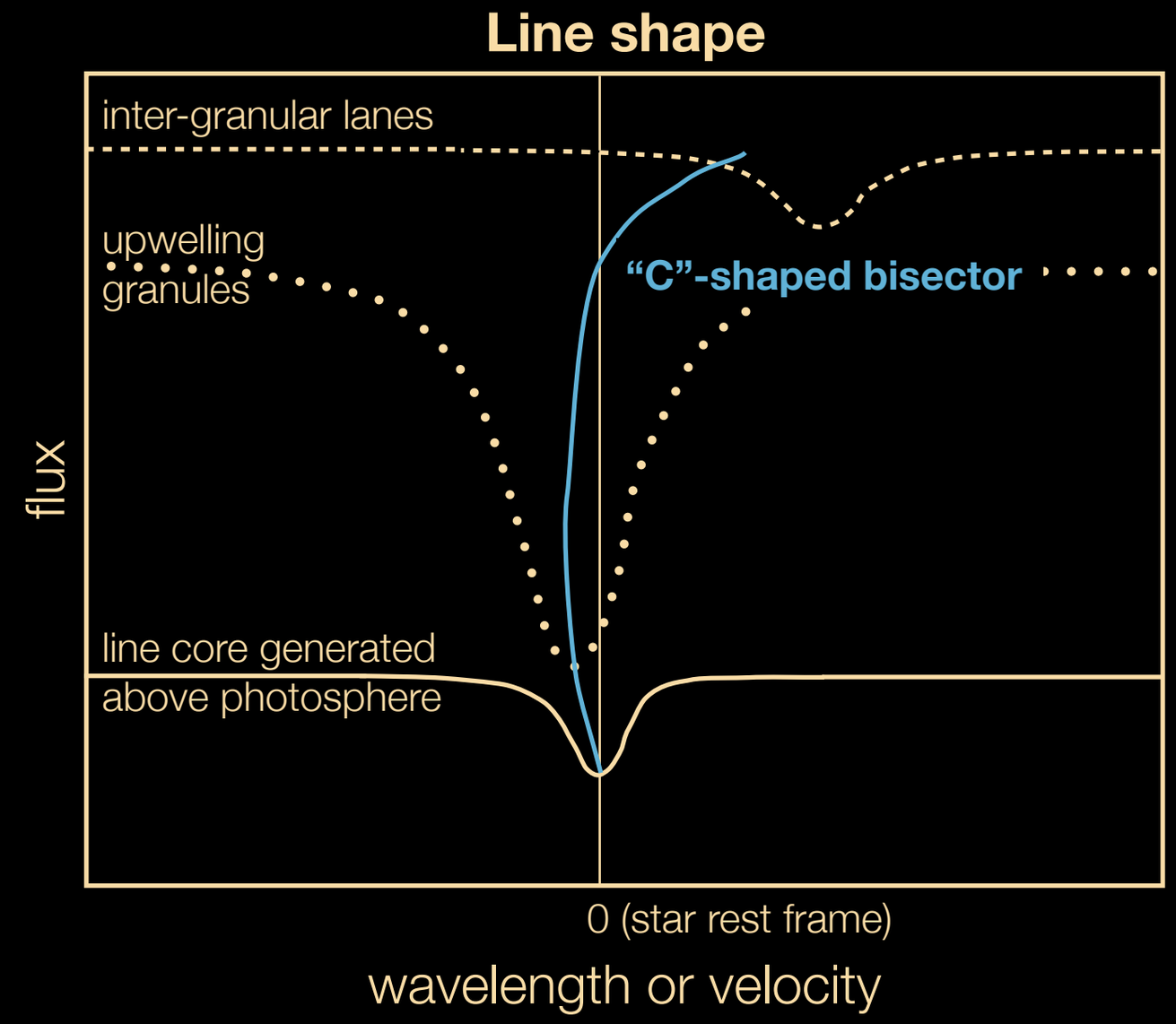

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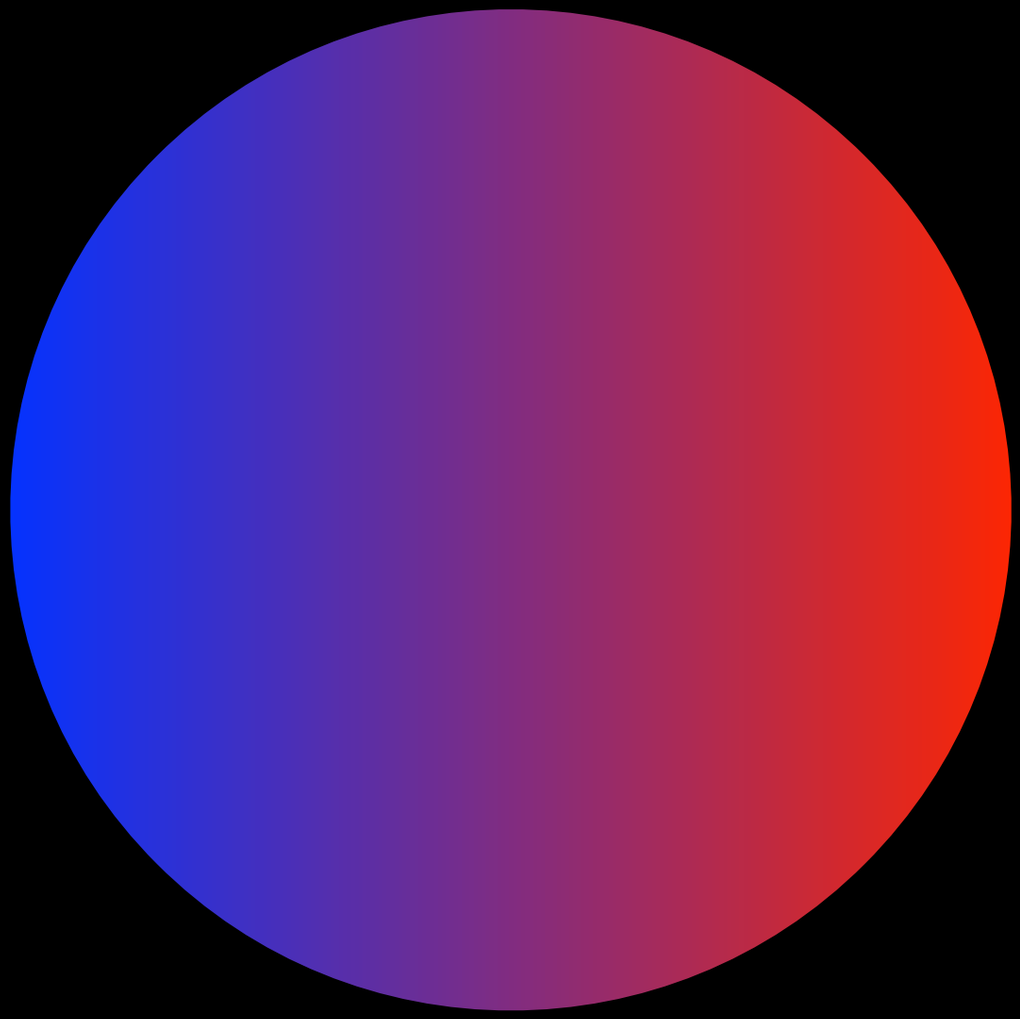

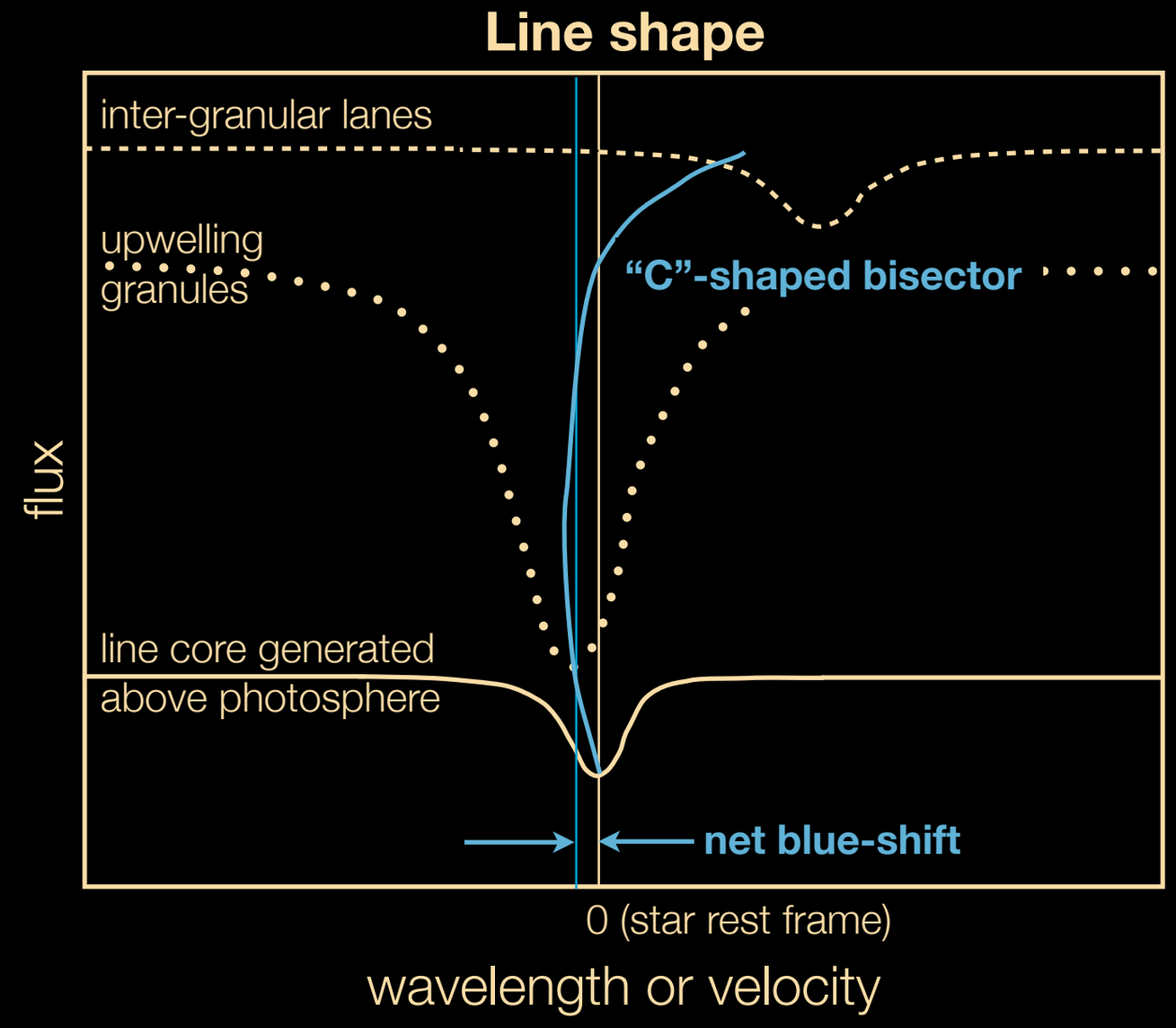

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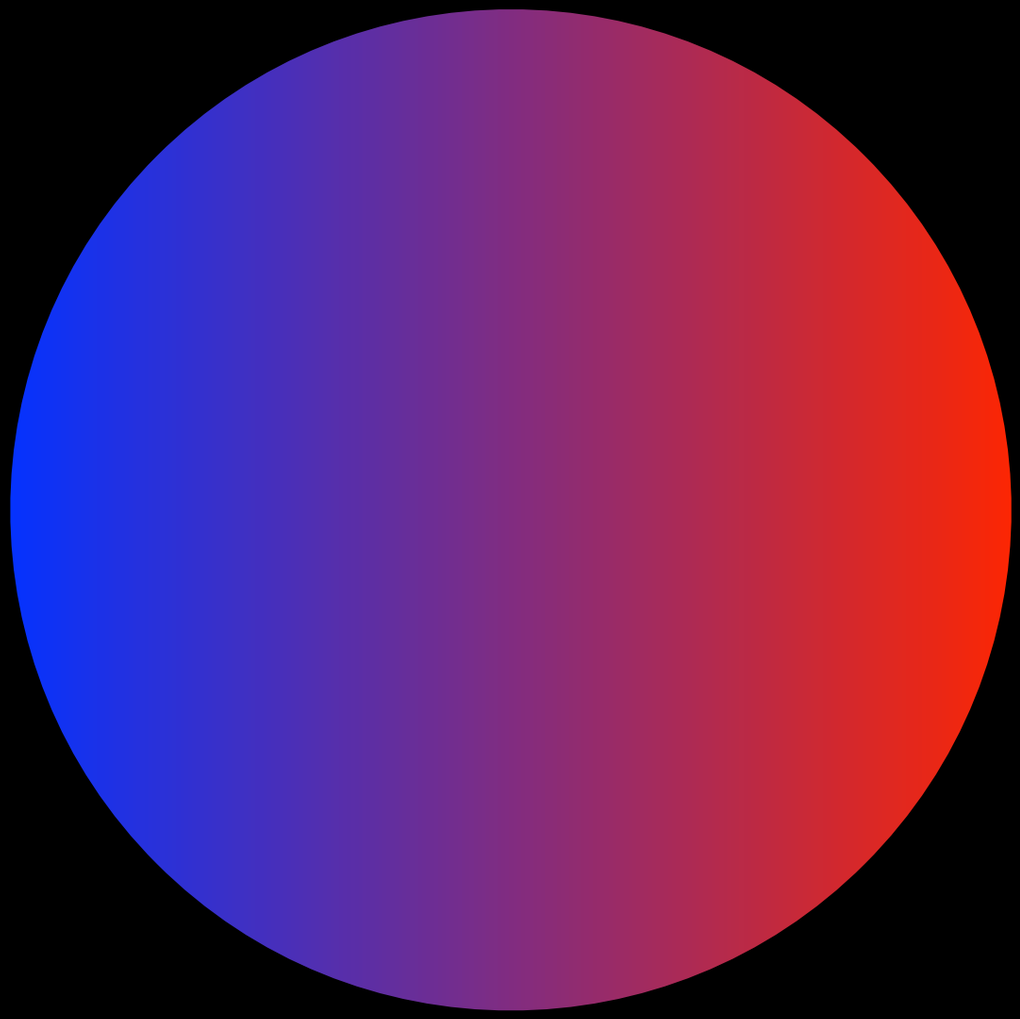
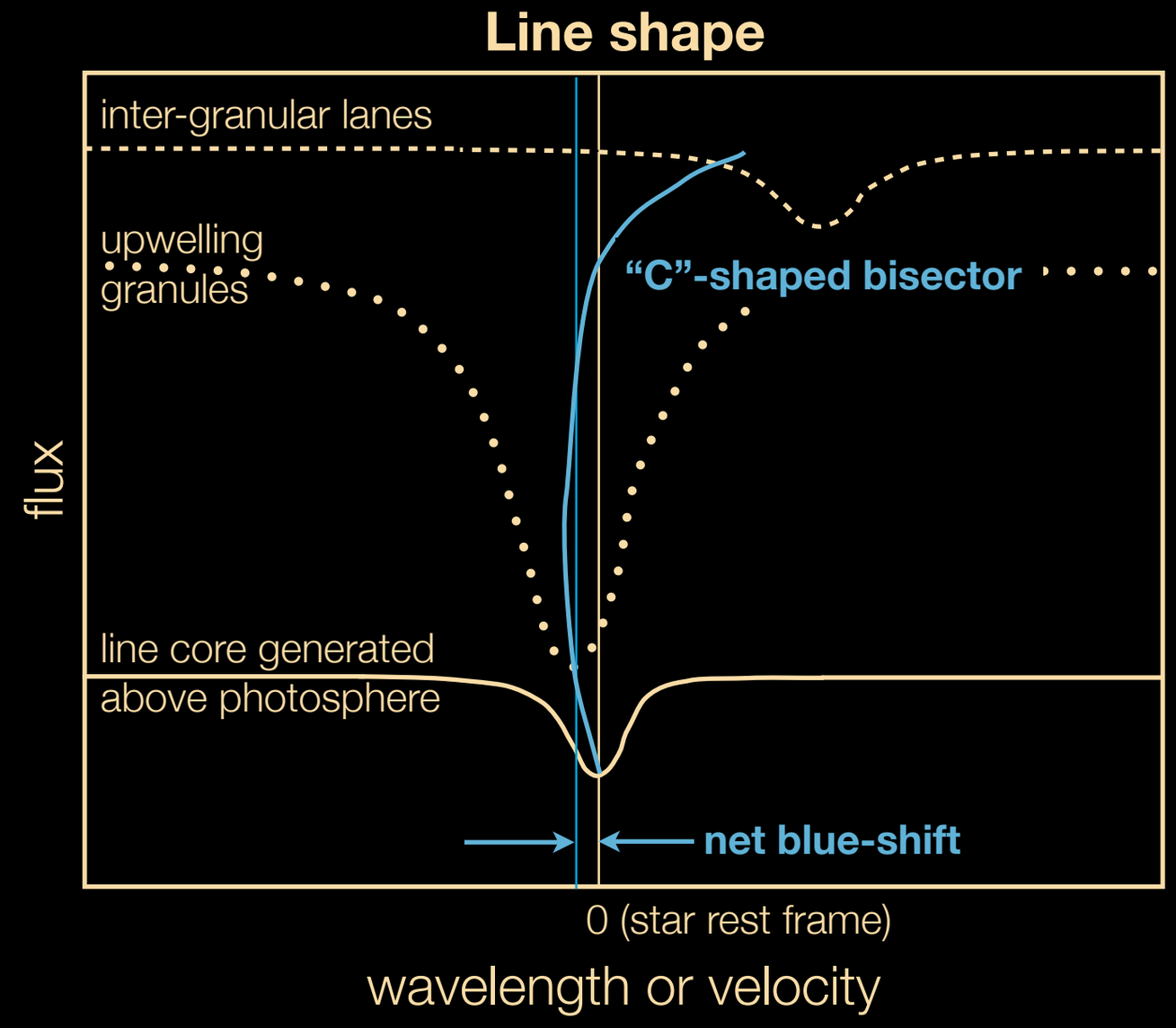
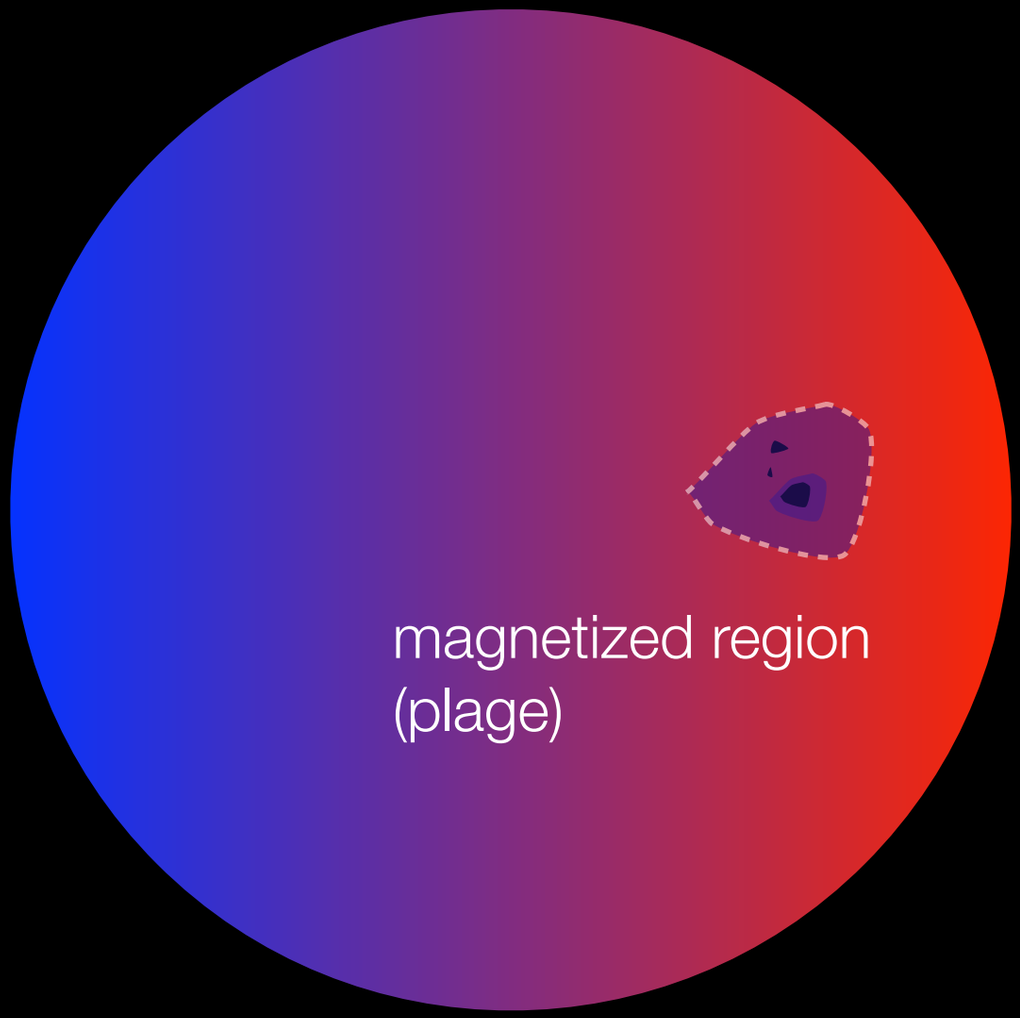
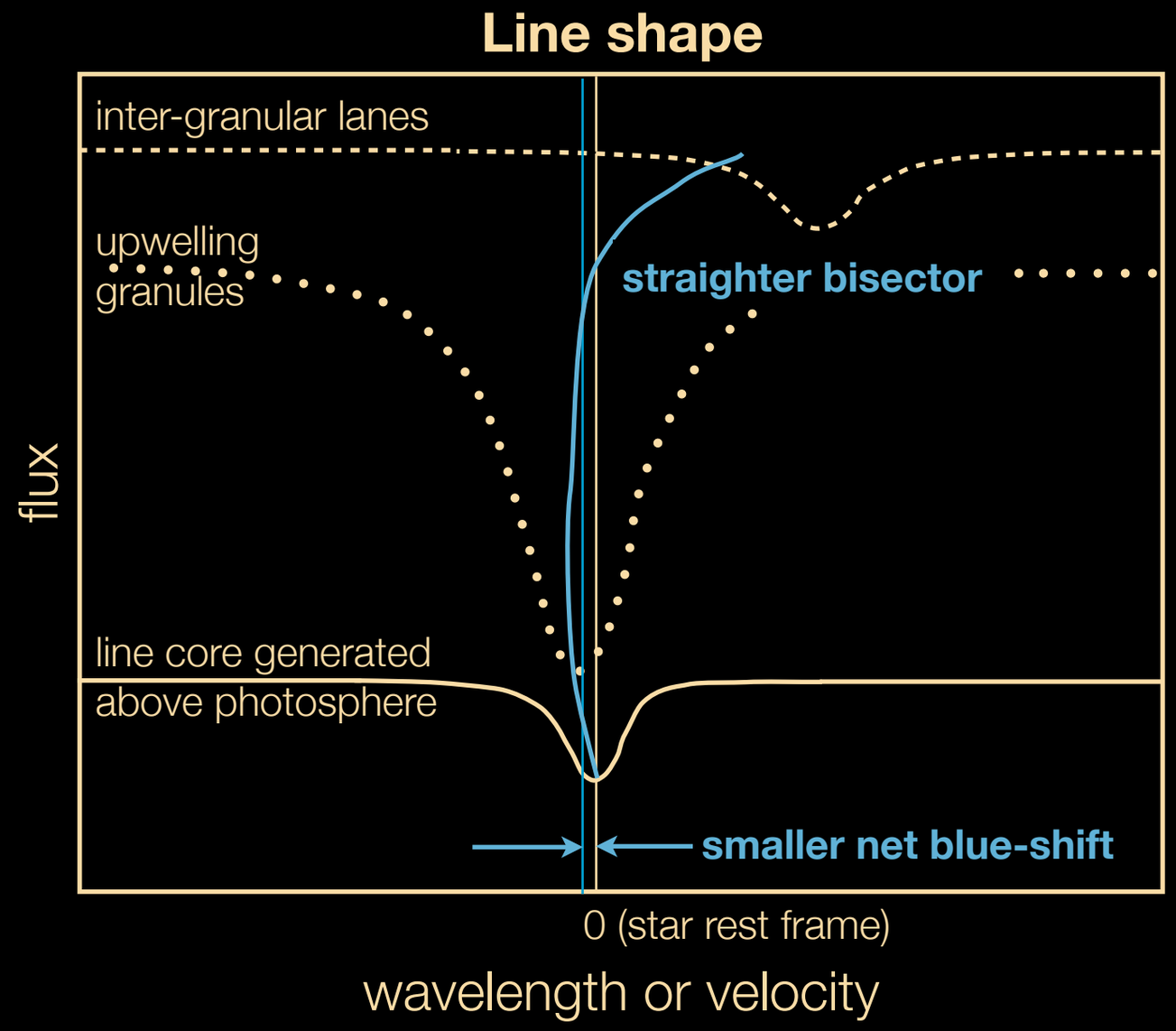




Line shape and absolute convective blue-shift depend on line strength (Gray 2009)

Effect of convective blueshift suppression on RV and spectral line shape





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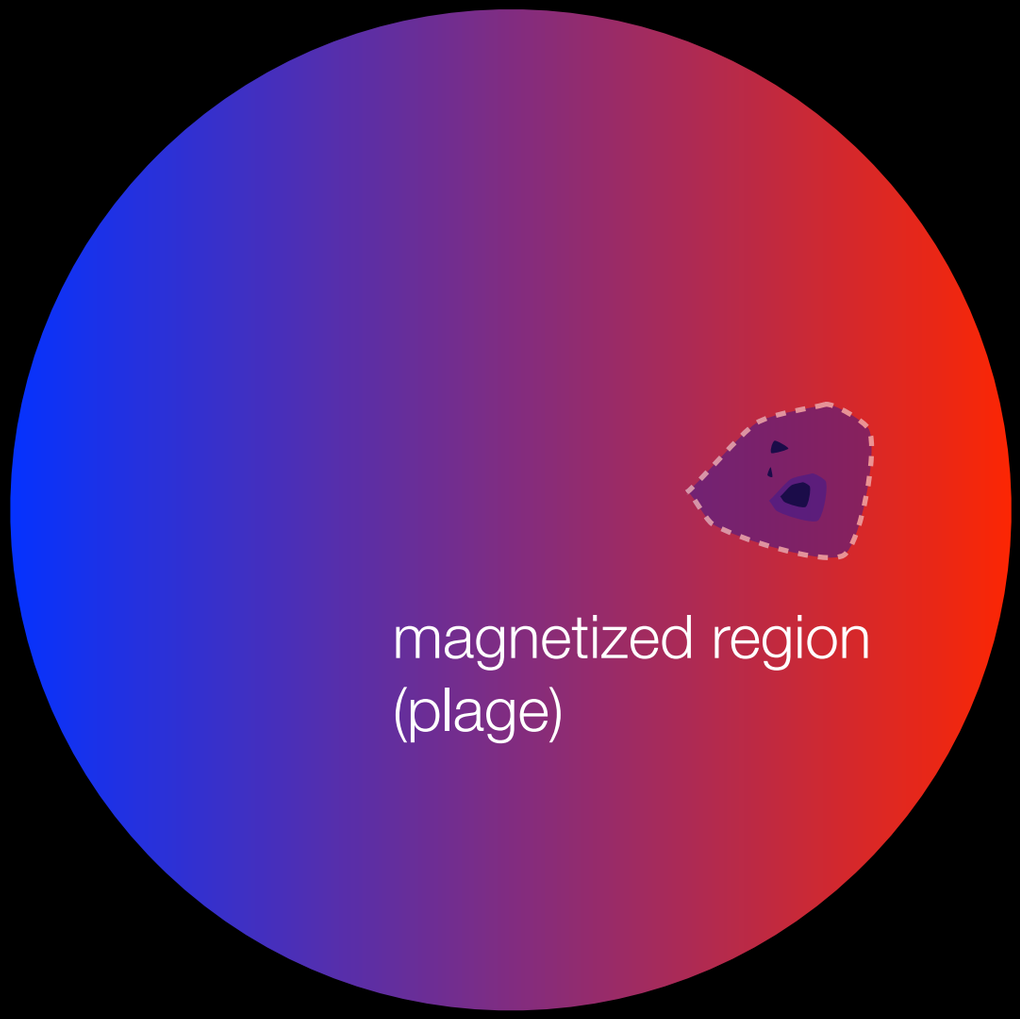
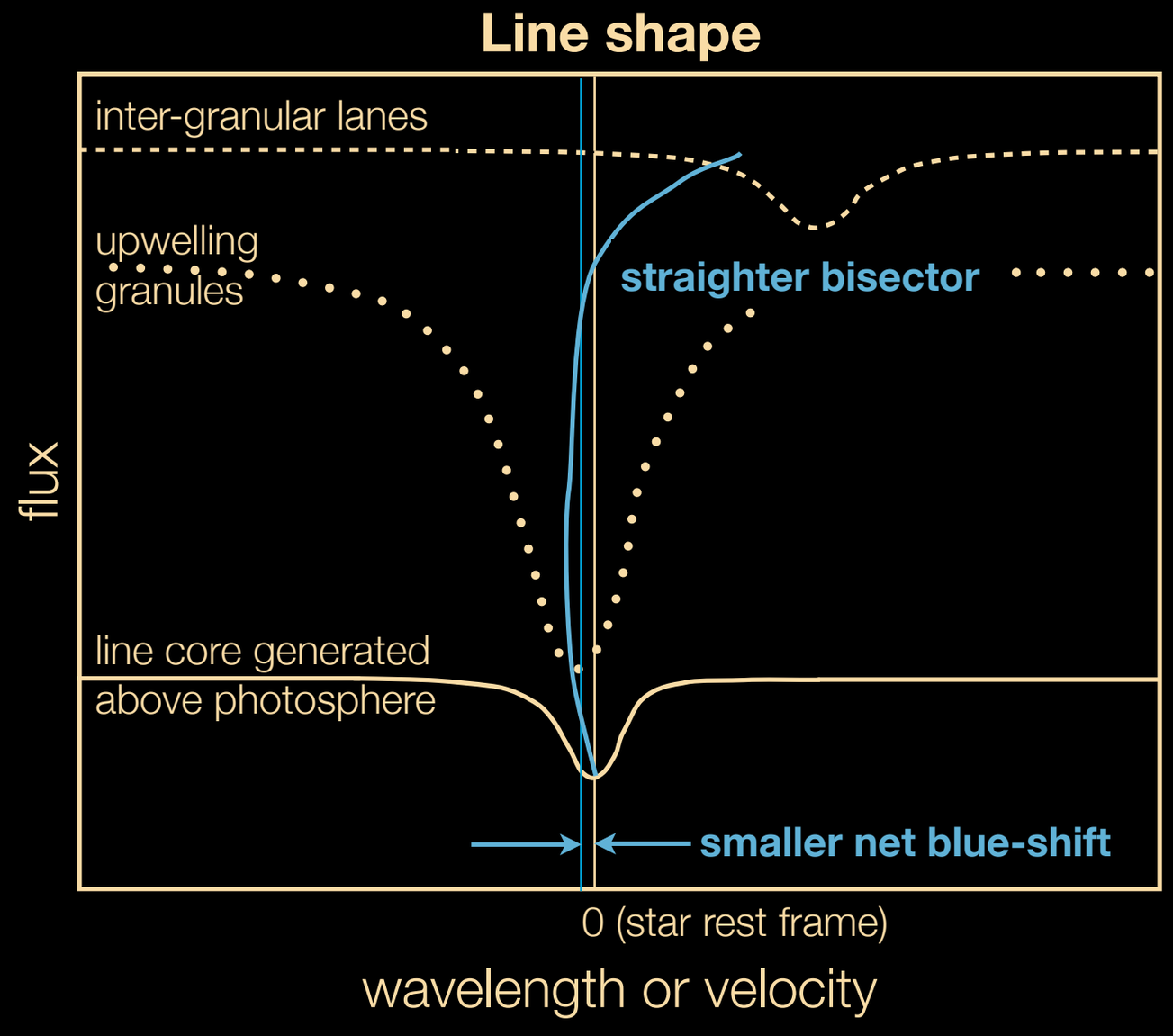




This dominates over the effect of spots for the Sun (Meunier et al. 2010)

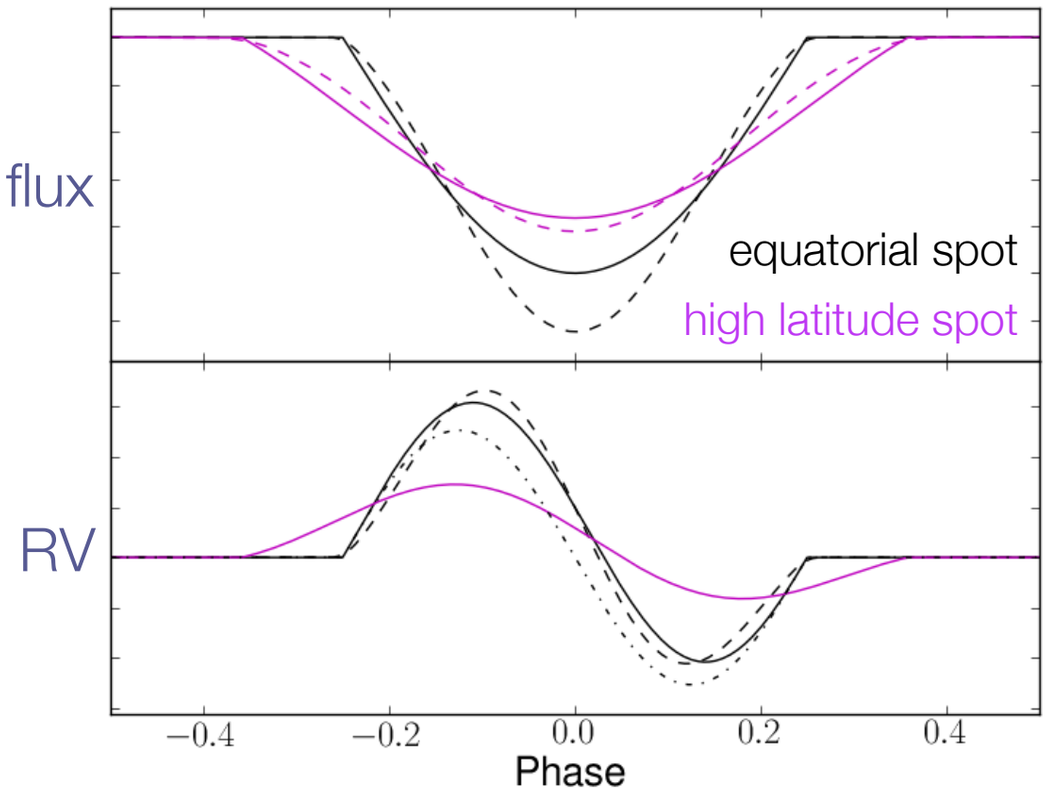
Methods to identify / filter / model activity signals in RV

- Correlation with CCF bisector span (Bonfils et al. 2007, Boisse et al. 2009).
- Correlation with Ca H & K index (Boisse et al. 2011, Dumusque et al. 2011, Meunier et al. 2013) or UV variability (Cegla et al. 2014).
    - Long-term component of Ca index for “activity cycle” (Dumusque et al. 2012)
- Sine-fitting of RVs at harmonics of the rotation period (e.g. Dumusque et al. 2012)
- Spot modelling (Lanza et al. 2007, 2010, Boisse et al. 2011 - SOAP)
- *FF’ method* (Aigrain et al. 2012) - simplified relationship between photometric and RV effects of active regions
- Hydrodynamical simulations of convection (Cegla et al. 2013)

The *FF'* method

(Aigrain, Pont & Mazeh 2012)

Perturbation to full disk measurement due to one spot



Can show that:

$$\Delta V_{rot} \propto F \times dF/dt$$

The *FF'* method

(Aigrain, Pont & Mazeh 2012)

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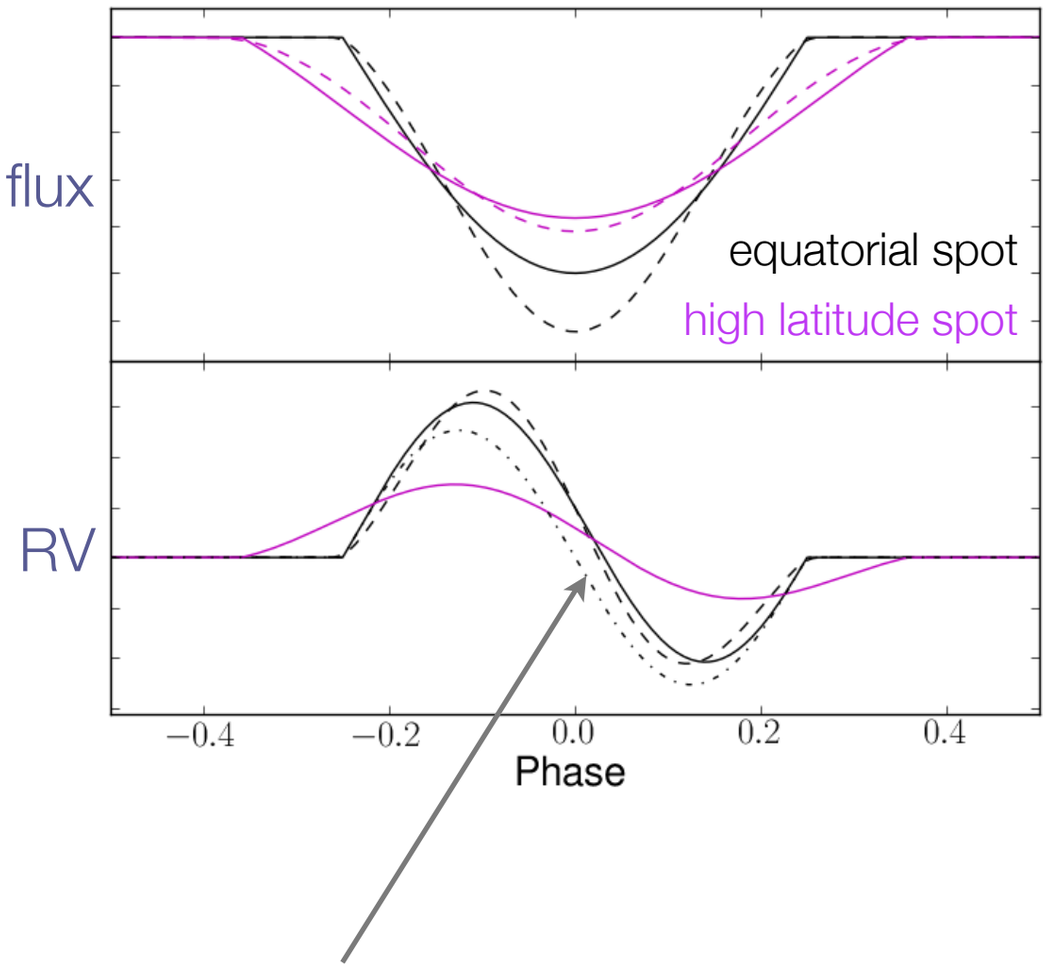

including convective blue-shift suppression

Can show that:

$\Delta V_{rot} \propto F \times dF/dt$

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

The *FF'* method

(Aigrain, Pont & Mazeh 2012)

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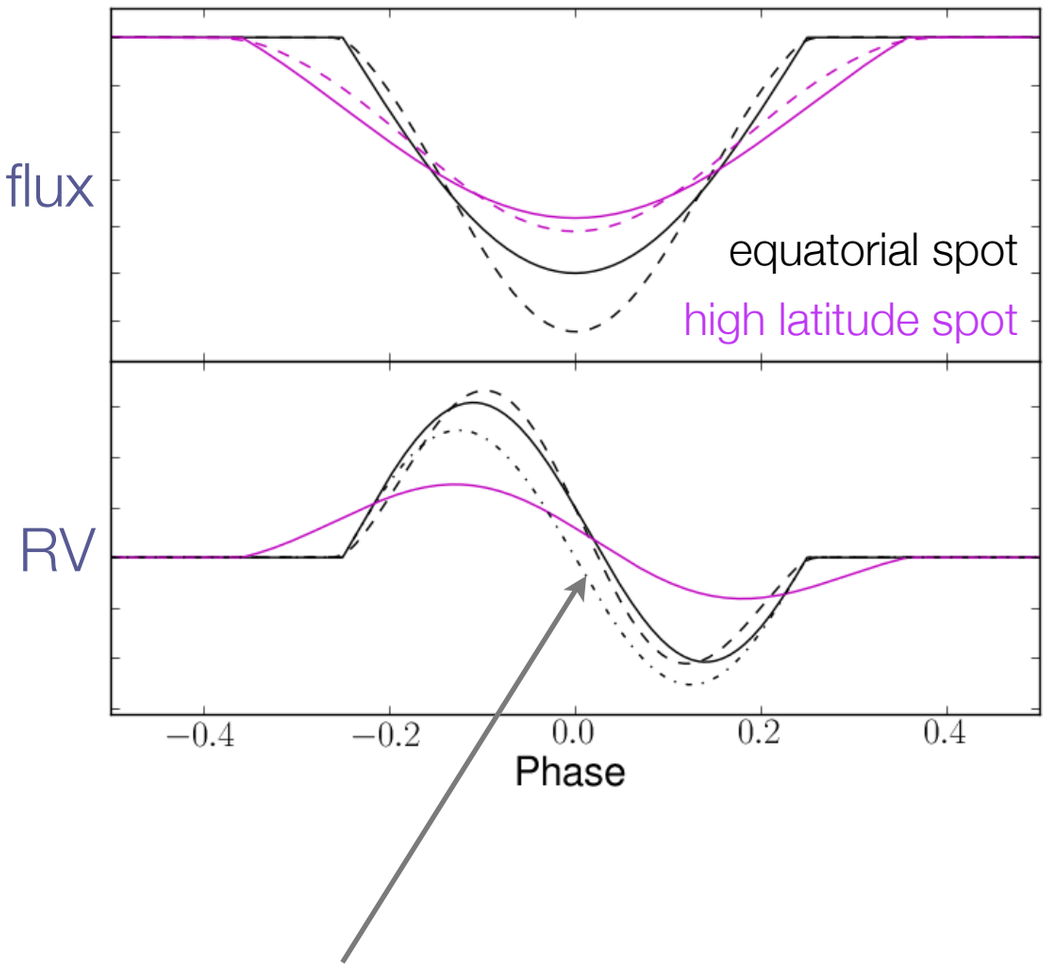

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Can show that:

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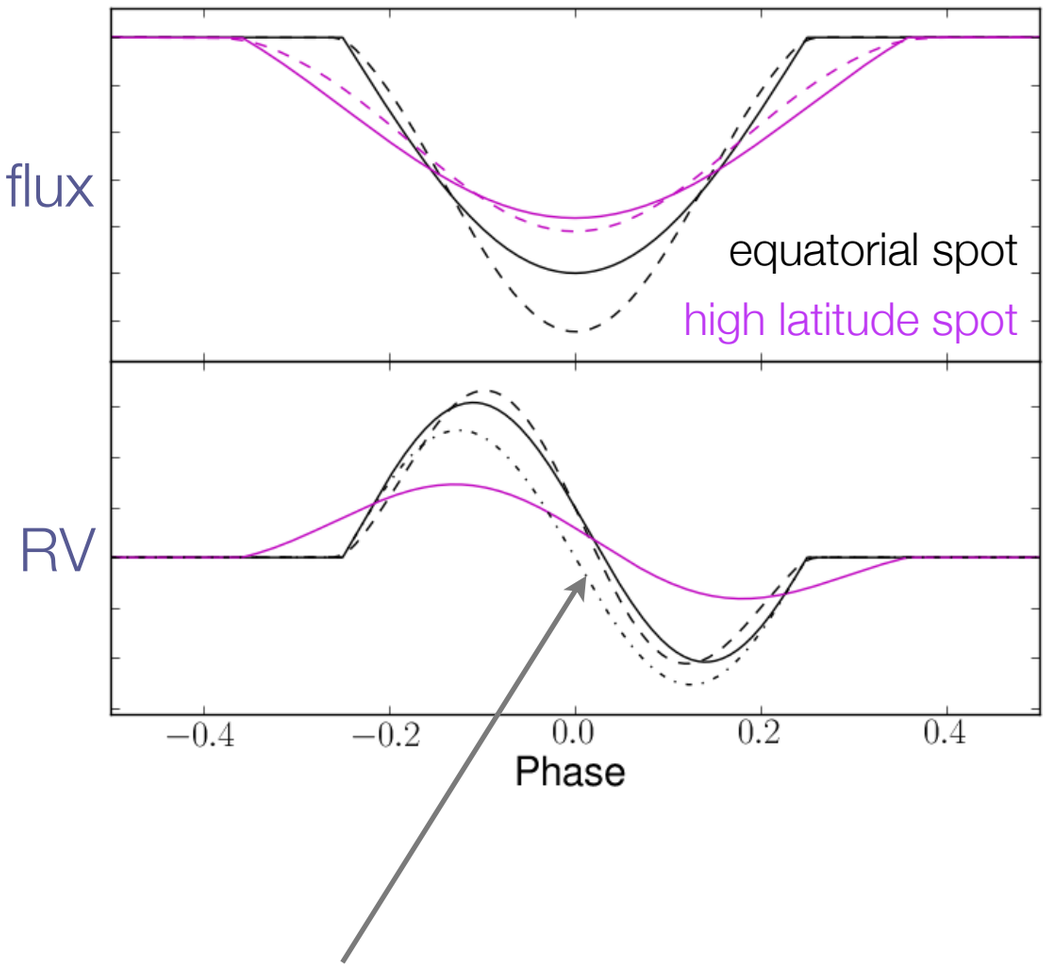

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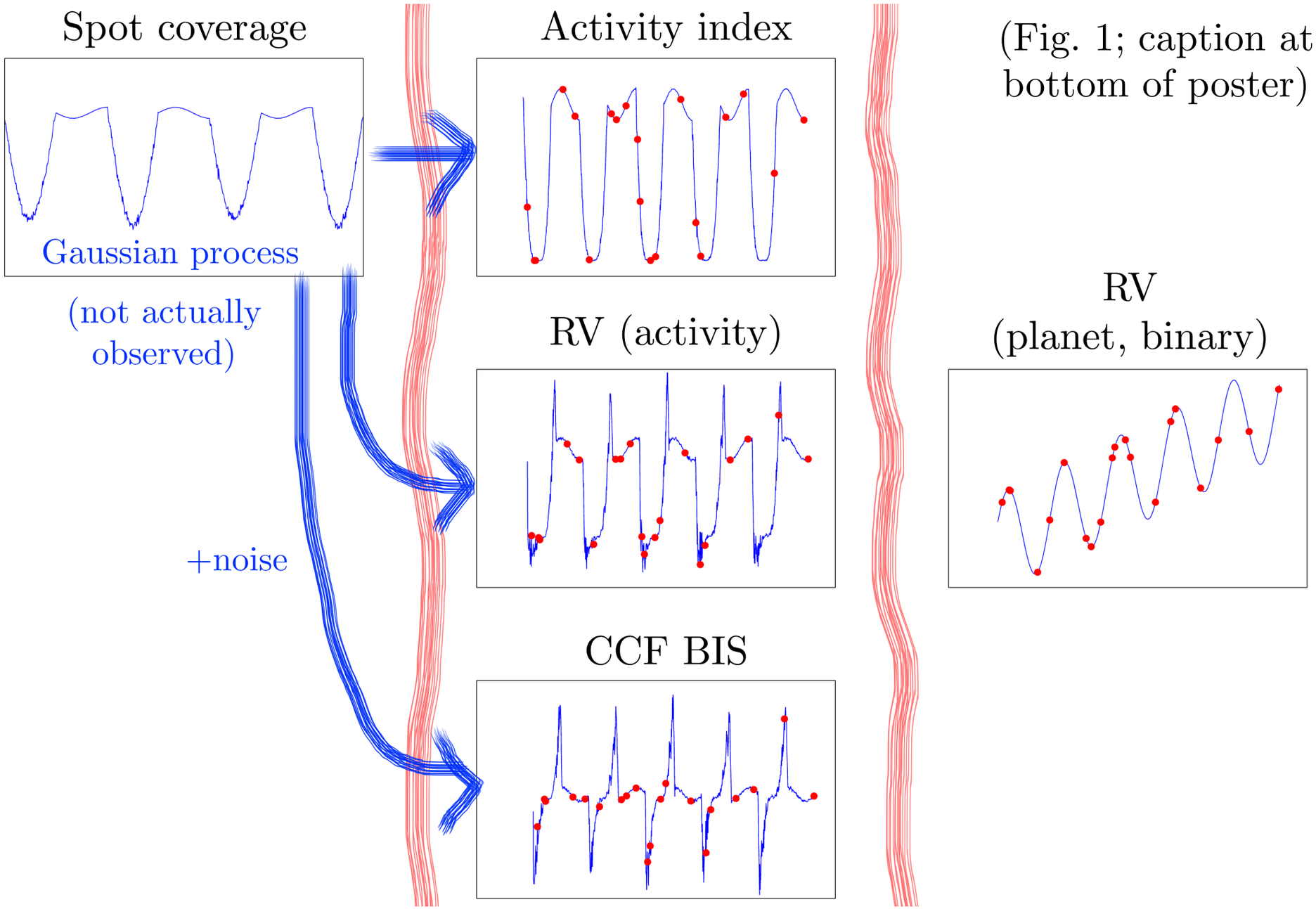
See Raphaelle Haywood's talk for a real-life test!

Beyond *FF'*: joint modelling of activity signals in RV and spectral activity indicators using GPs

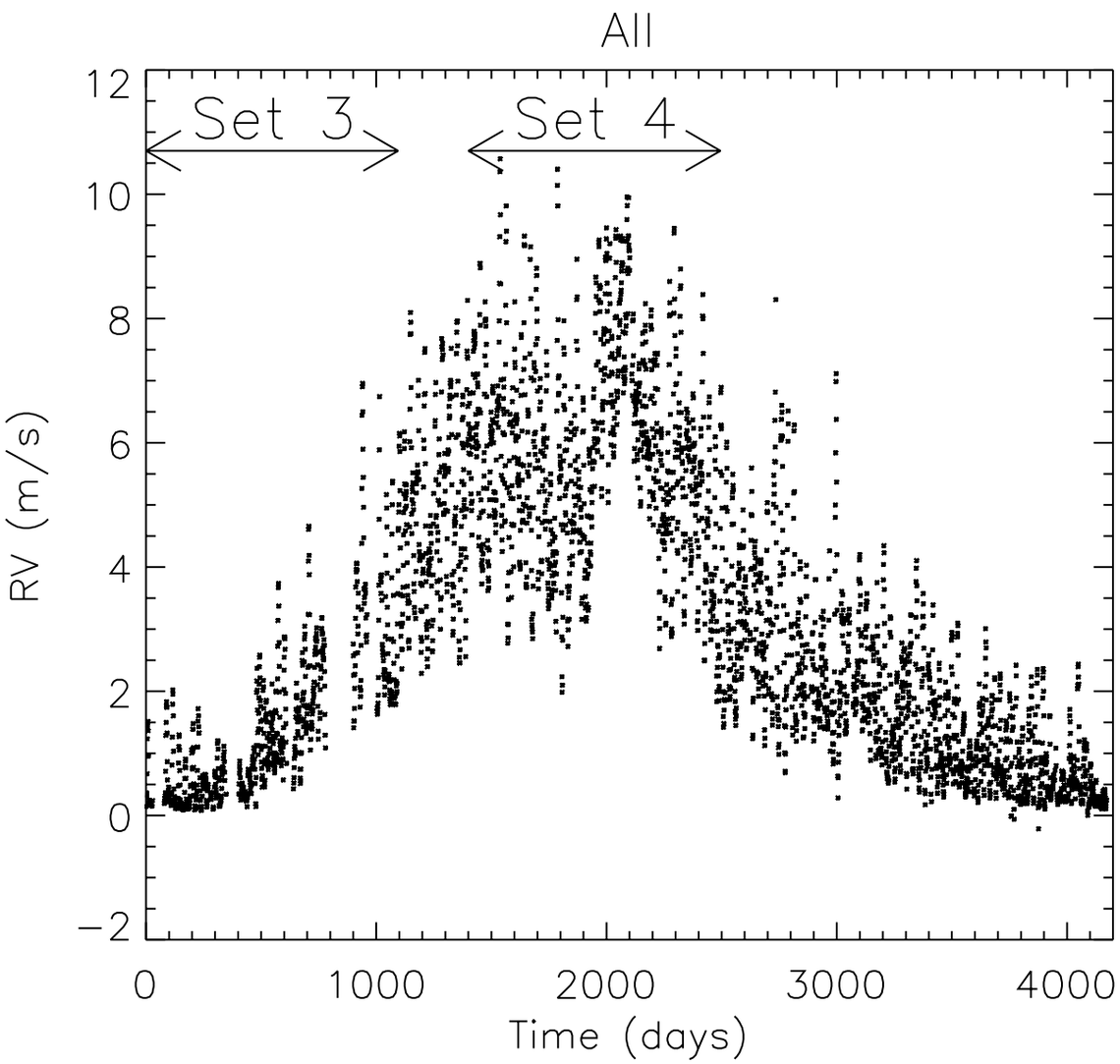
See poster P5.5 by Vinesh Rajpaul

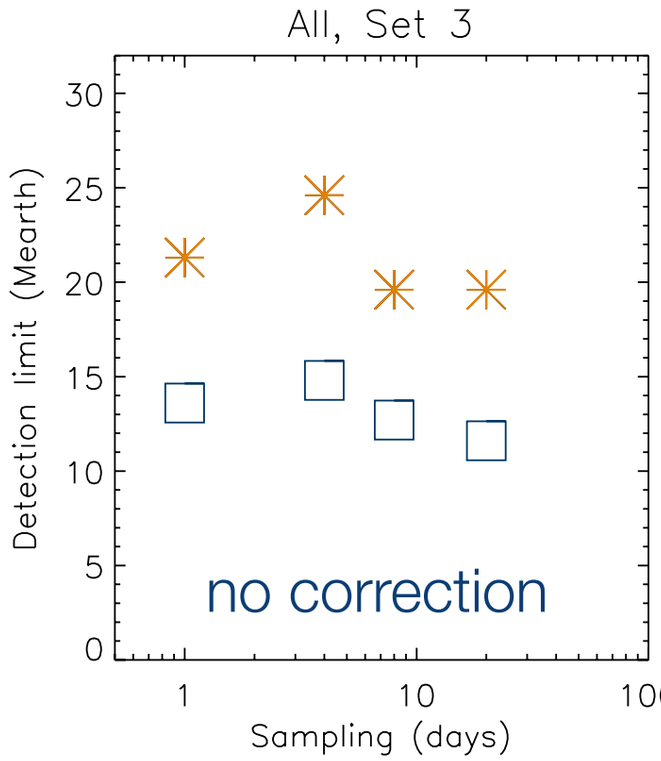


(Fig. 1; caption at bottom of poster)

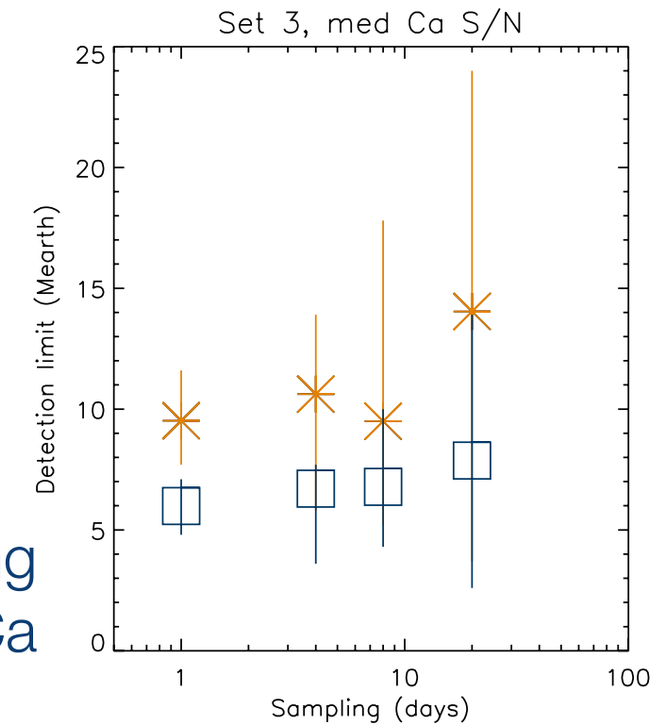
Planet detectability estimates for Sun

Meunier & Lagrange (2013)





simulated planet in 480 day orbit



correction using observed Ca

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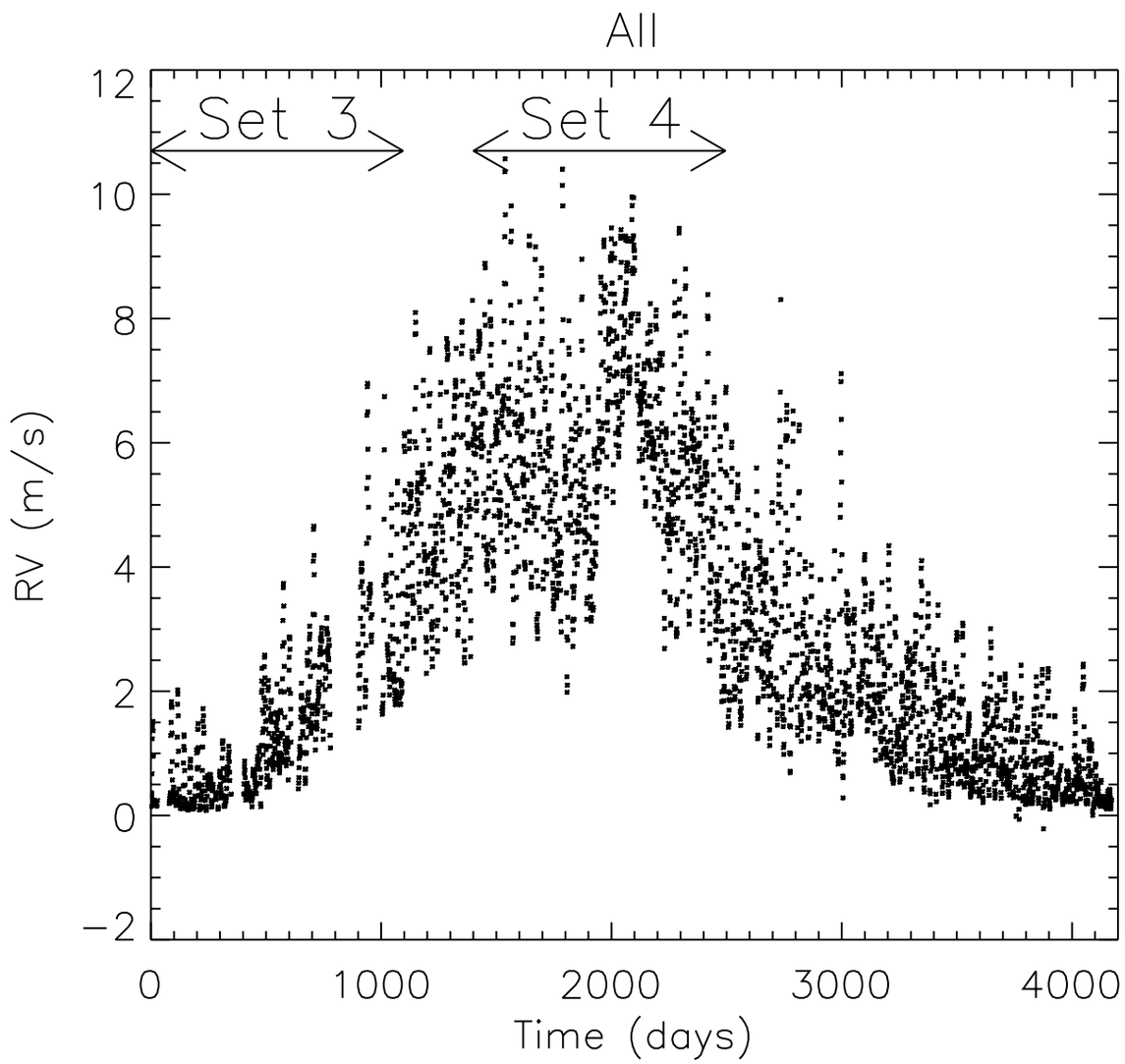
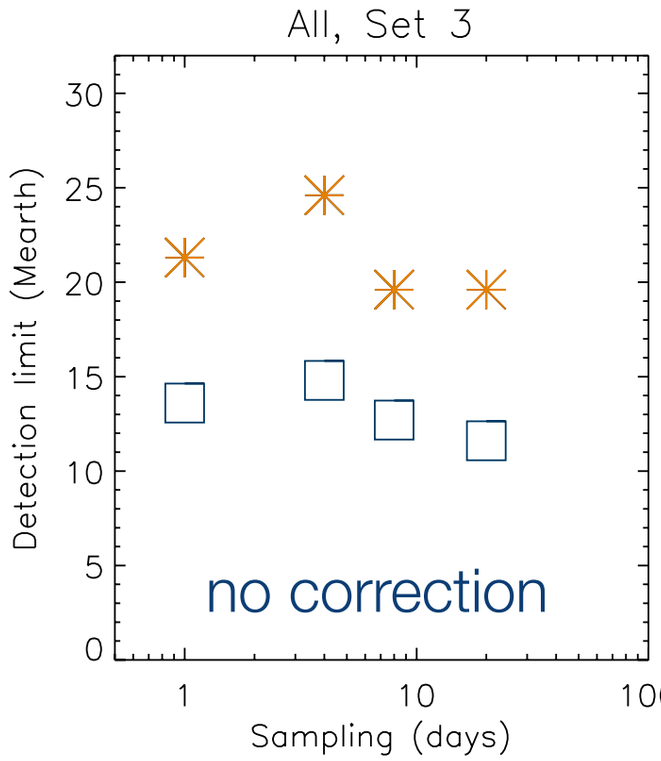
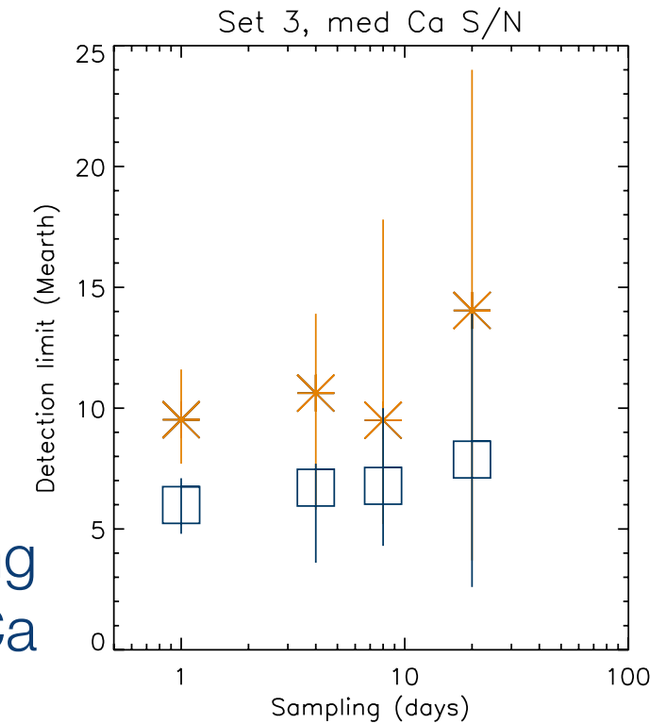




simulated planet in 480 day orbit

"...we estimate that a probability larger than 50% to detect a 1 M_{Earth} at 1.2 AU requires more than 1000 well-sampled observations and a Ca S/N larger than 130."

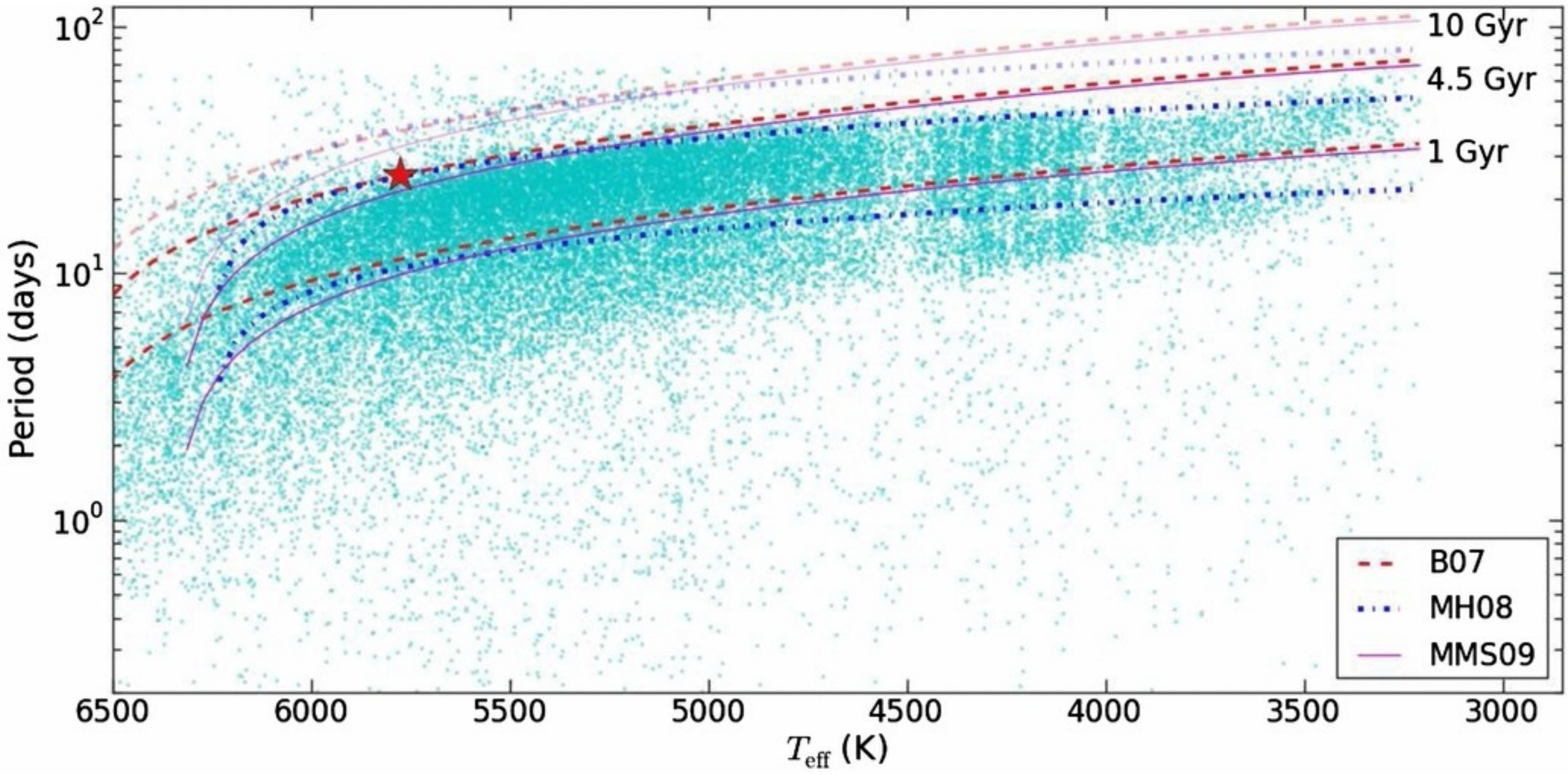


correction using observed Ca

It’s not just noise!

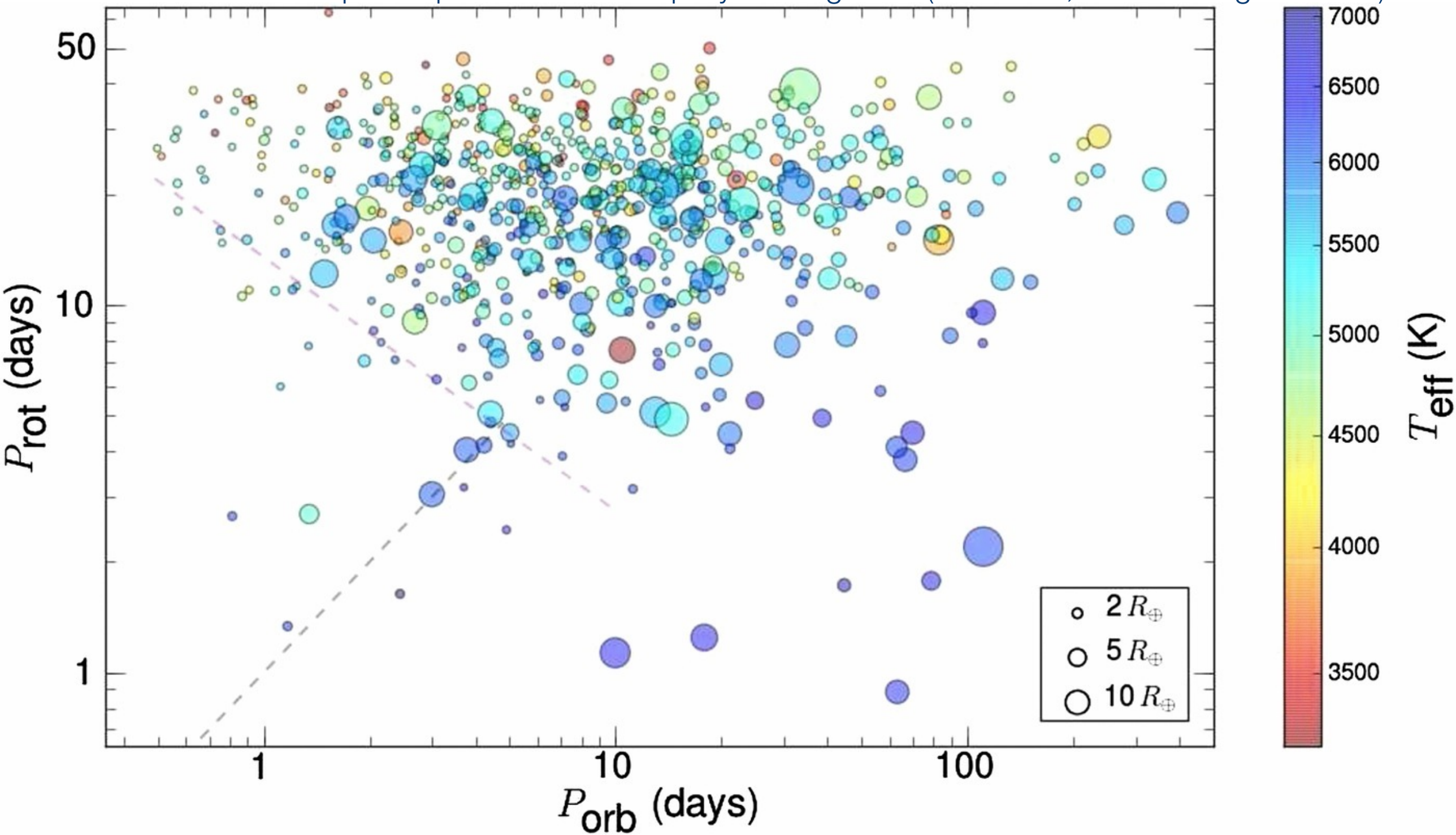
Stellar rotation periods

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



Stellar rotation periods

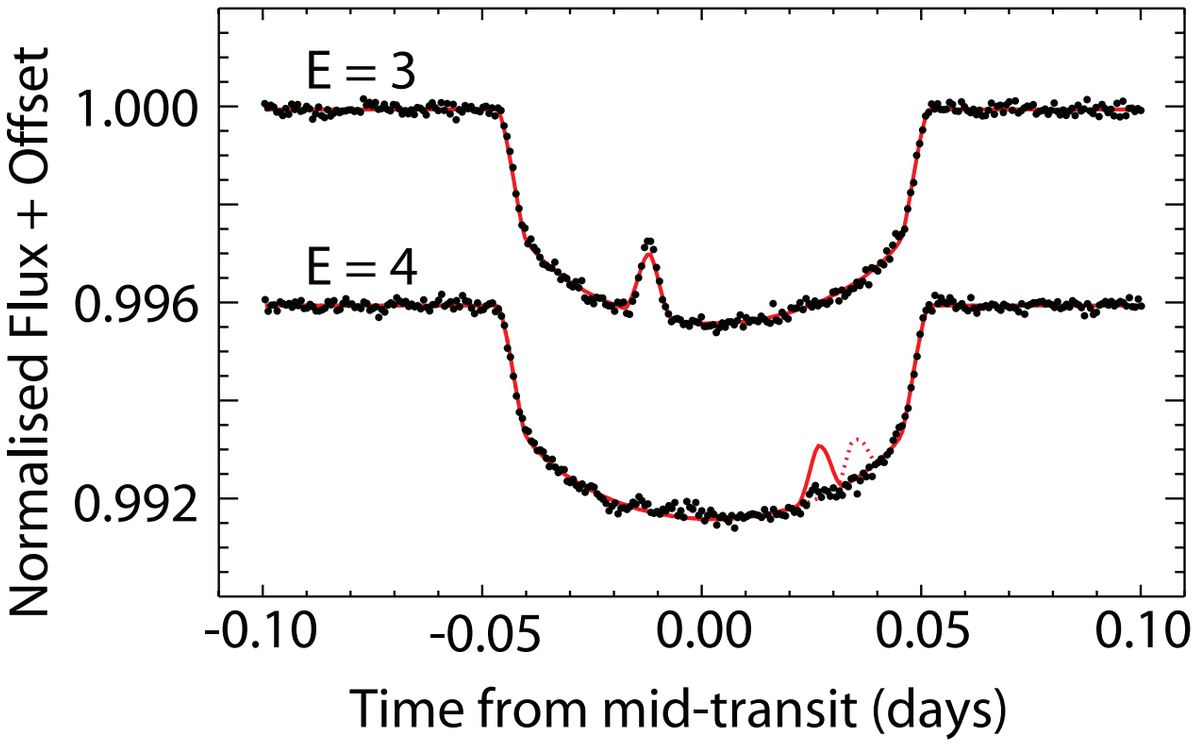
Dearth of short-period planets around rapidly rotating stars (McQuillan, Mazeh & Aigrain 2013)

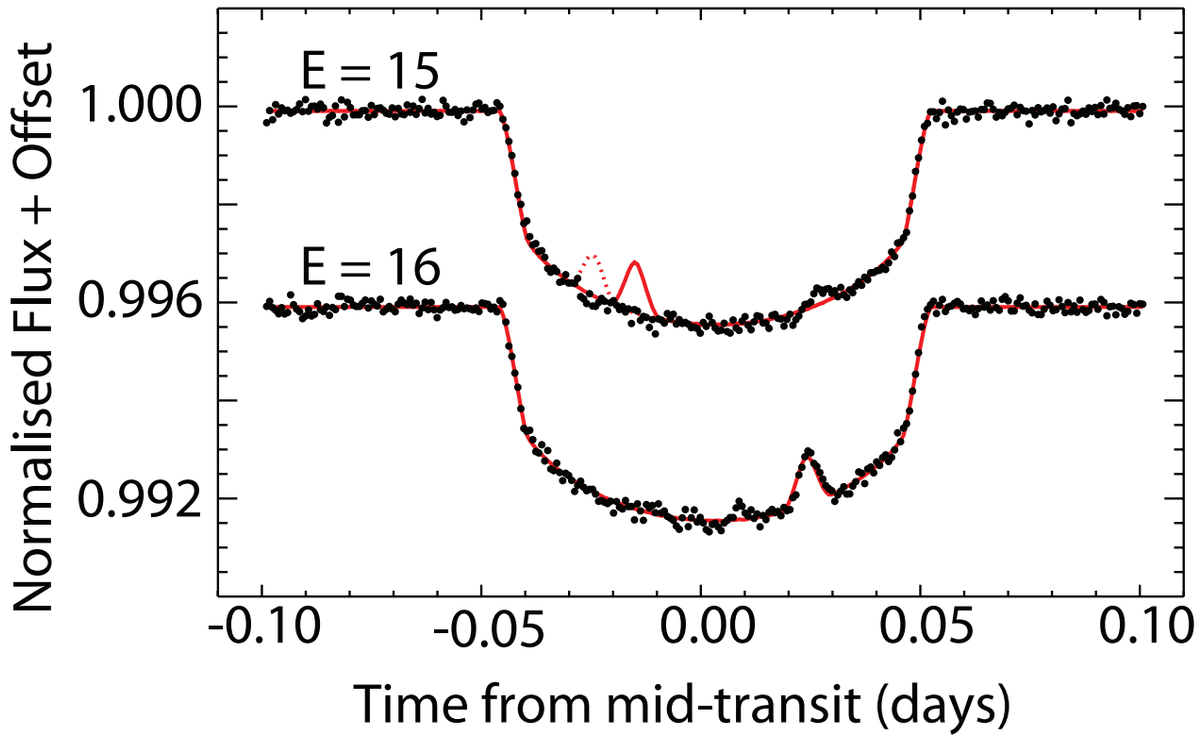


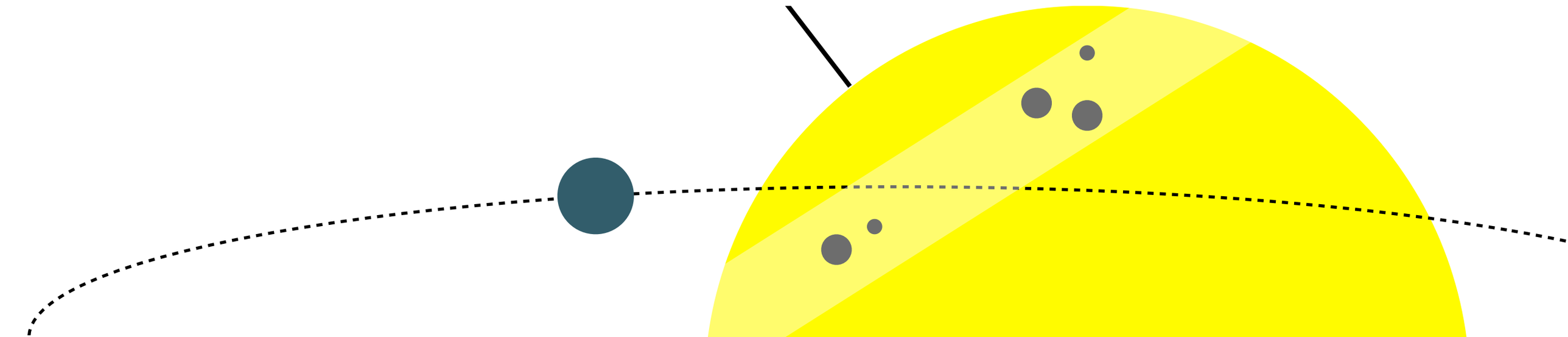
Spot mapping by transits

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

HAT-P-11

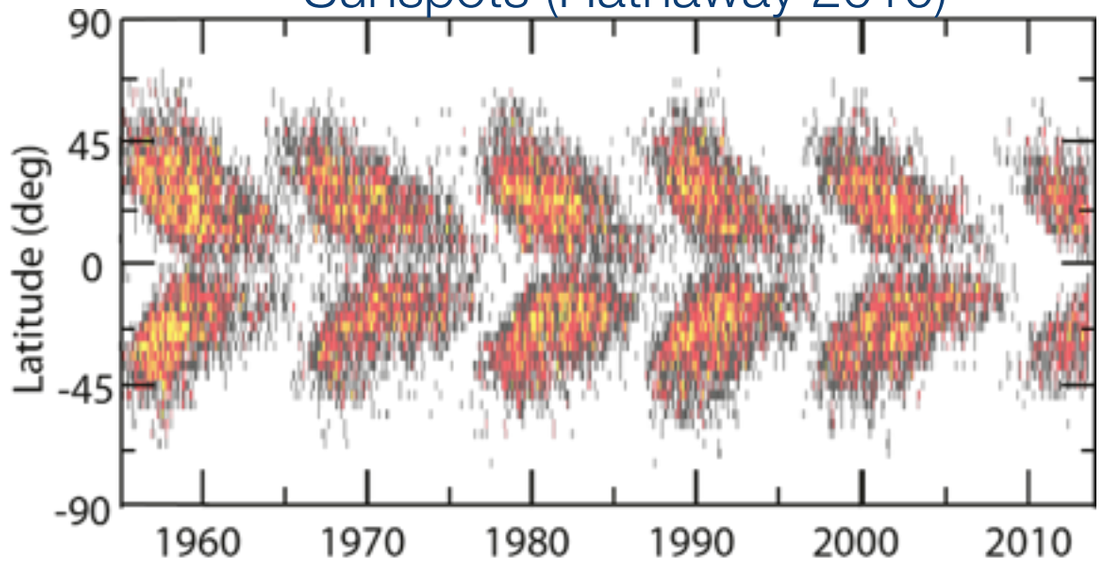




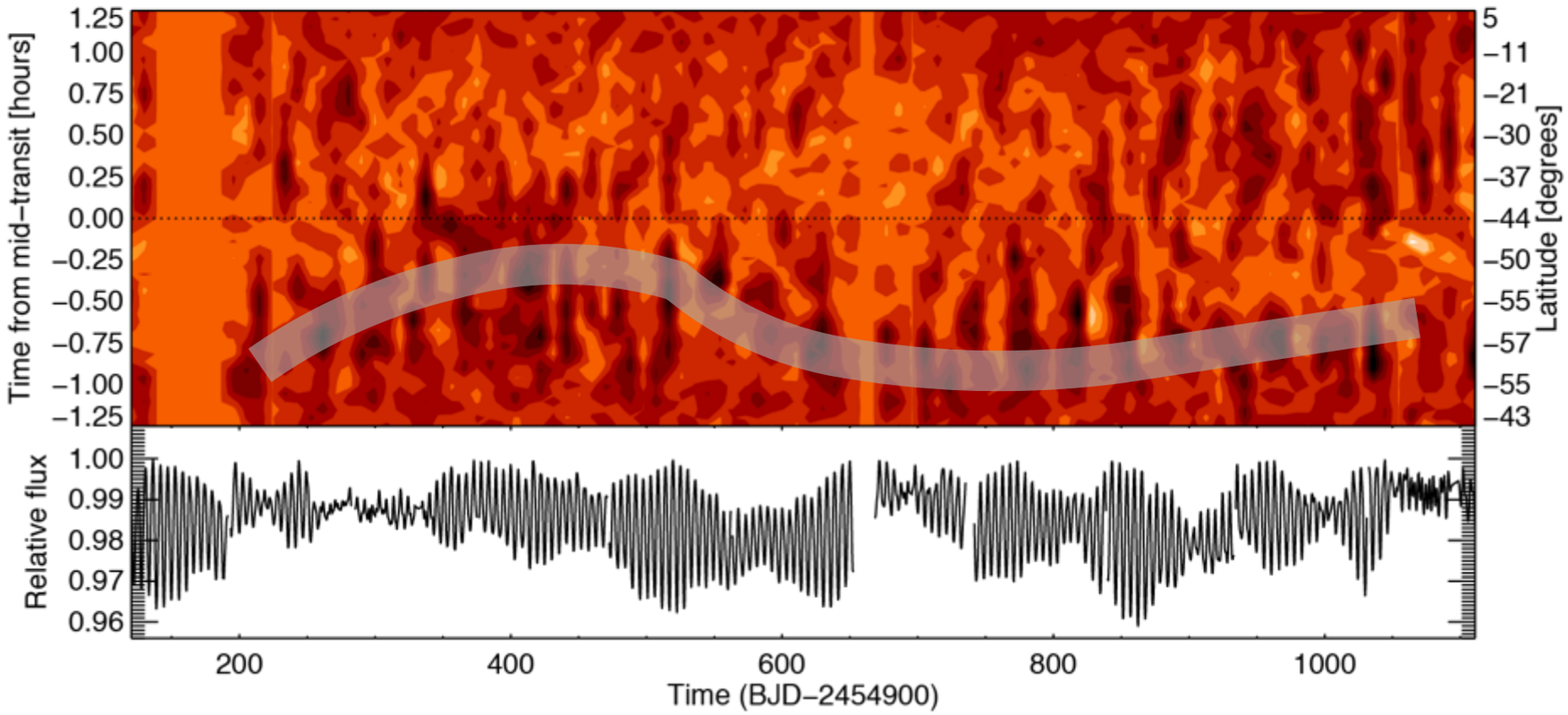


Spot mapping by transits

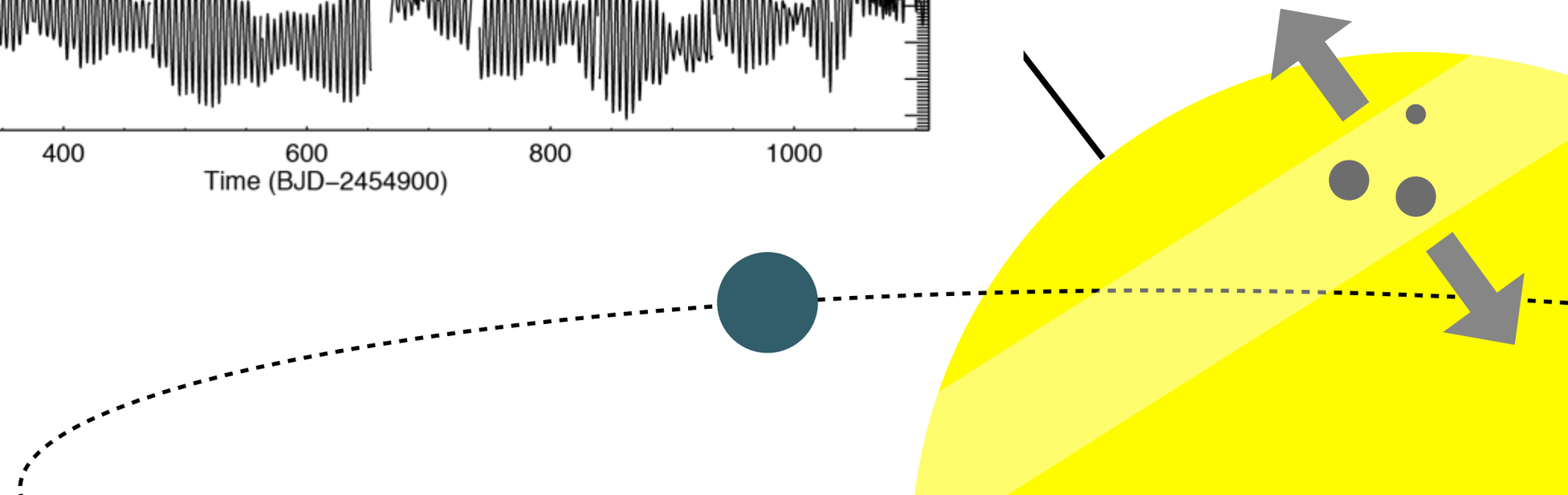
Sunspots (Hathaway 2010)



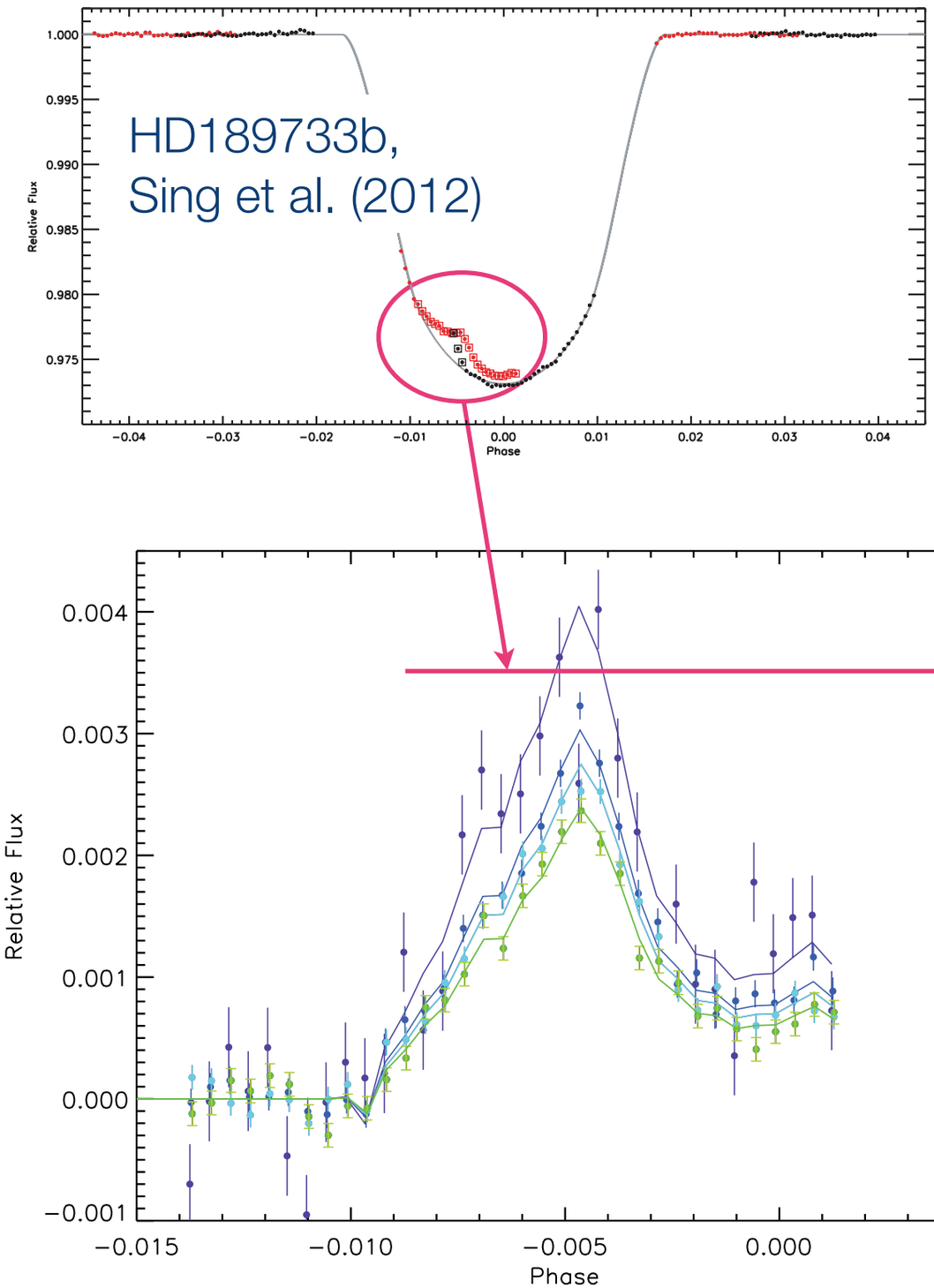
Spots occulted during many transits can reveal butterfly patterns (Sanchis-Ojeda et al. 2013)



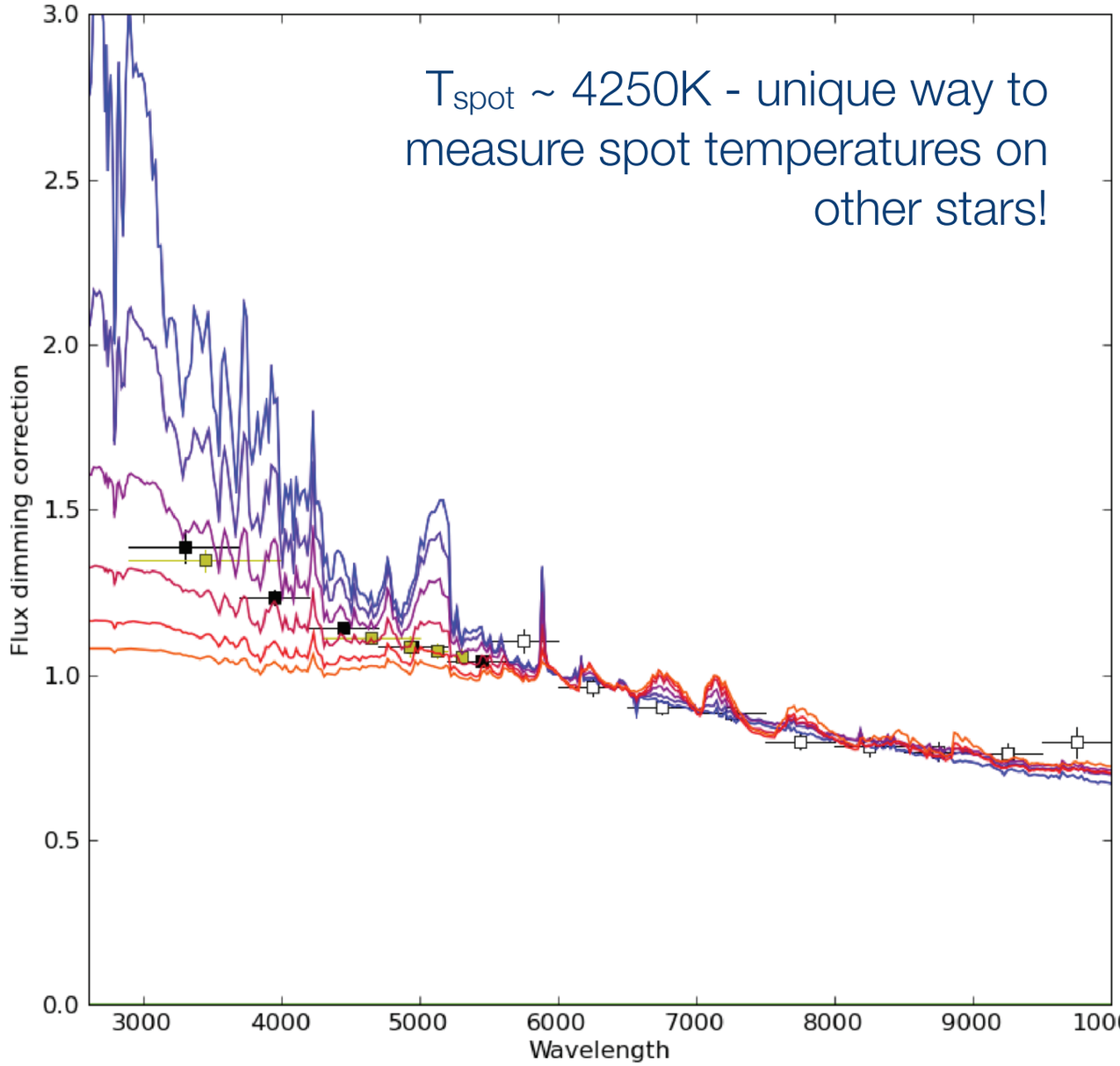
Kepler 63



Spot spectra from transits



Estimate spectrum/temperature of spots from occulted spots



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- It's not just noise! Planet datasets enable novel activity science
- Lots of really interesting posters in this session! (P5….)