The Sun as an exoplanet-host star: testbed for radial-velocity variations

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Motivation: why should we care about the Sun?

- Accounting for stellar activity is **necessary** if we are to detect and characterise small, rocky exoplanets.
- Statistics will only tell us so much. *as discussed yesterday*
- We currently do not have reliable proxies for activity RV variations. *today*
- Can we leverage on our existing knowledge/observations of our best-known star, the Sun? In parallel, can we observe the Sun as an exoplanet-host star? *today*

SDO

Two experiments:

1. HARPS observations of sunlight reflected from asteroid Vesta

2. HARPS-N observations of disc-integrated sunlight through the solar telescope

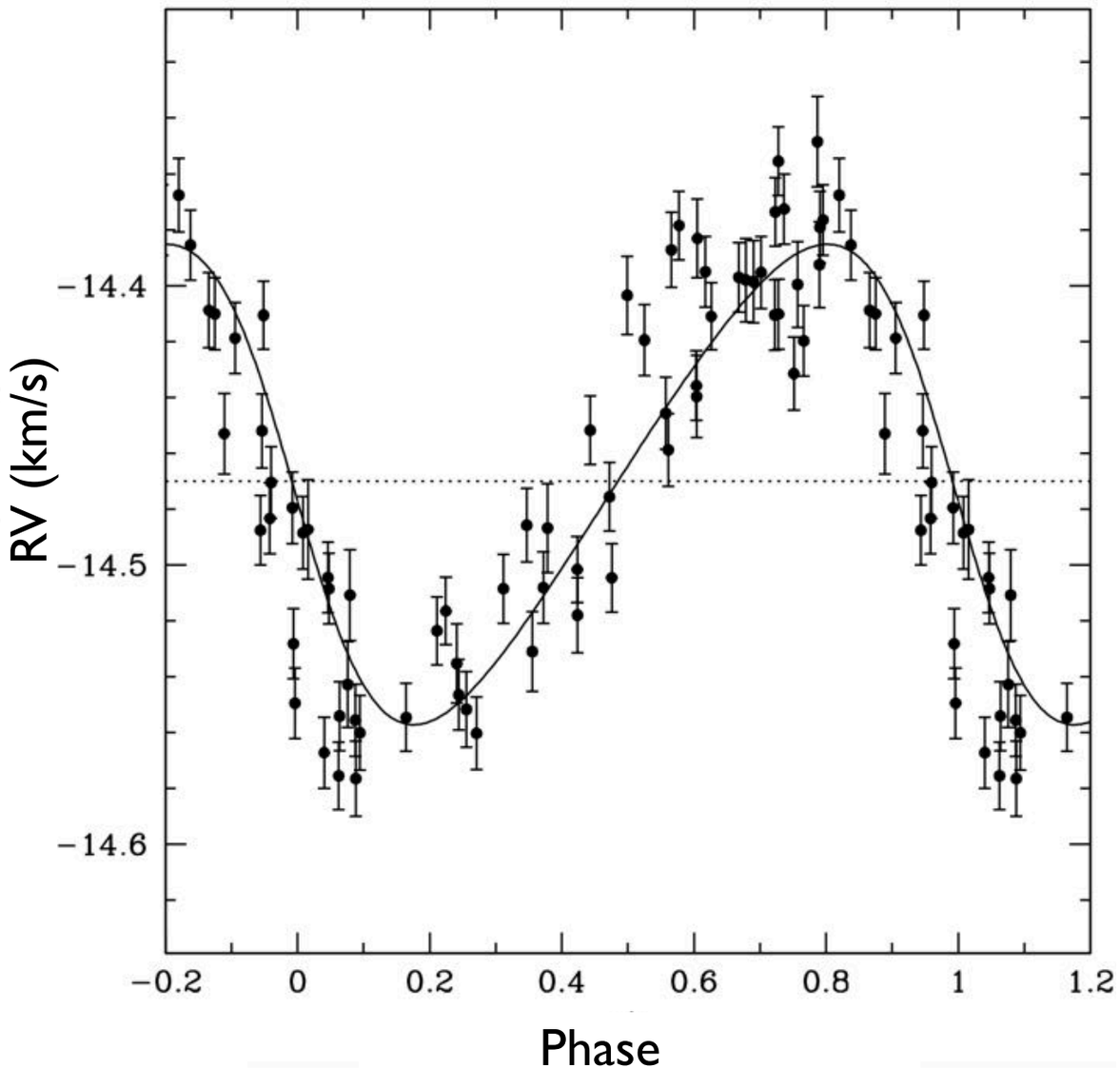
3.6m/HARPS

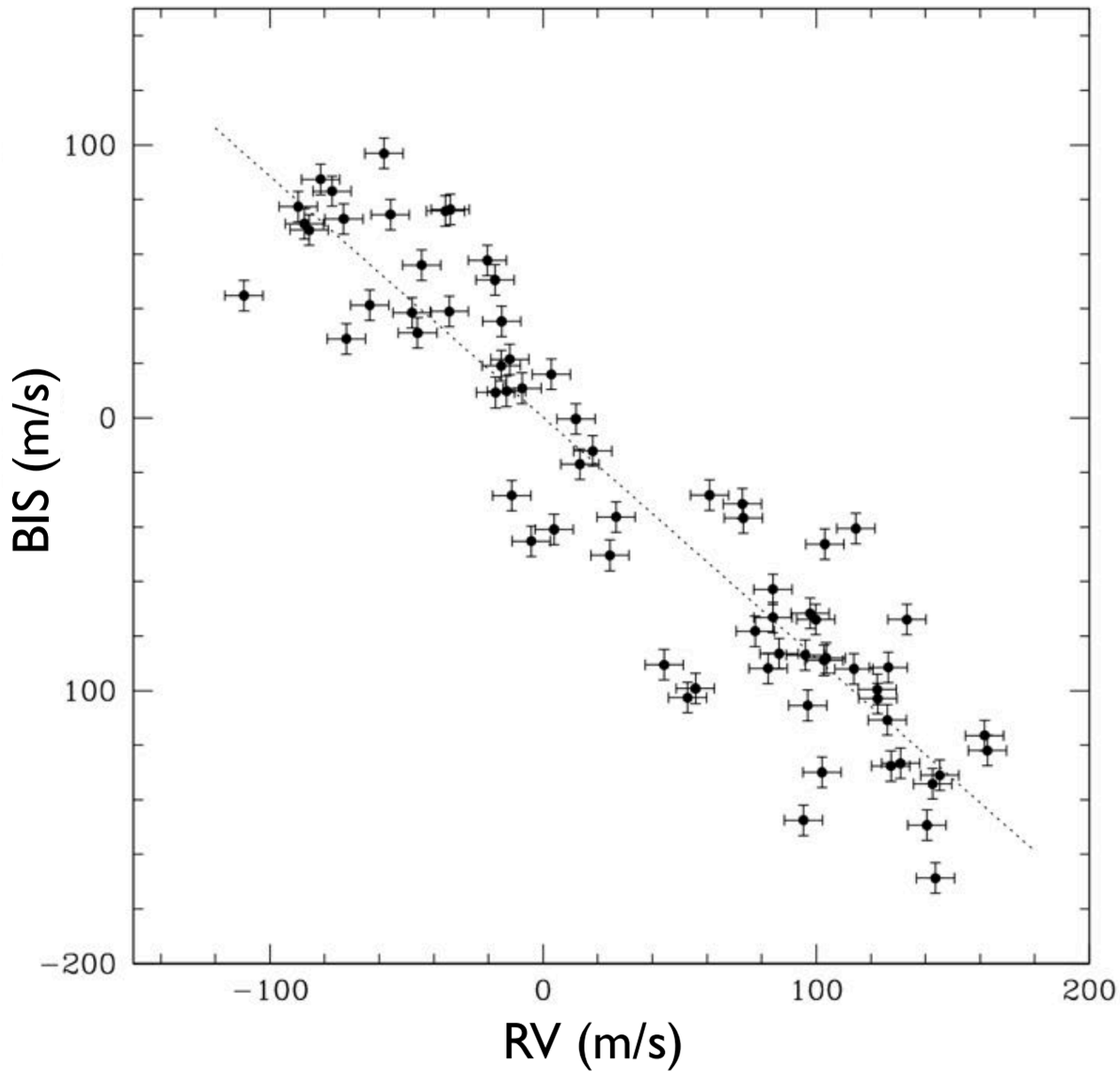
solar/HARPS-N

“Traditional” activity indicators: when they work

HD 166435: a young, fast rotating (3 days) G0V star

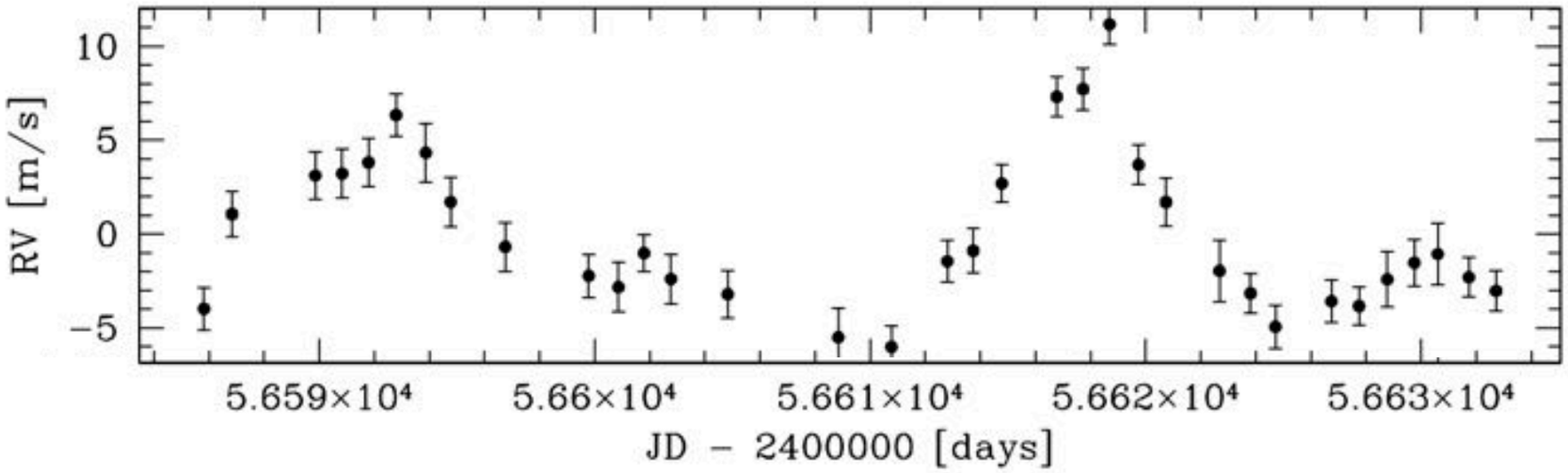
Its surface is dominated by spots





Queloz et al. 2001

“Traditional” activity indicators

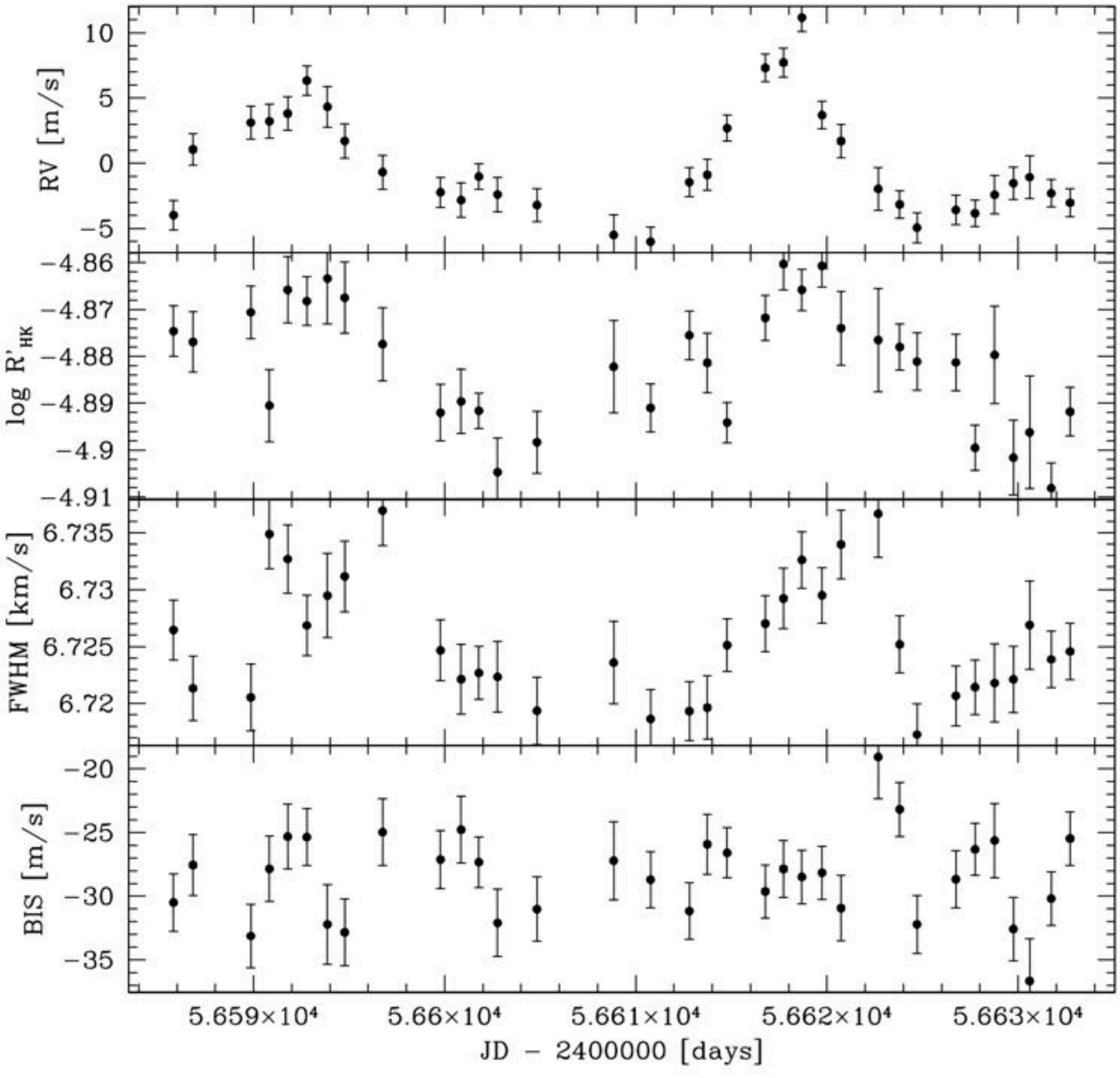


HD 41248: slowly-rotating (20±3 days), G2 star

Planet at 25 days?

Santos, Mortier et al. 2014

“Traditional” activity indicators



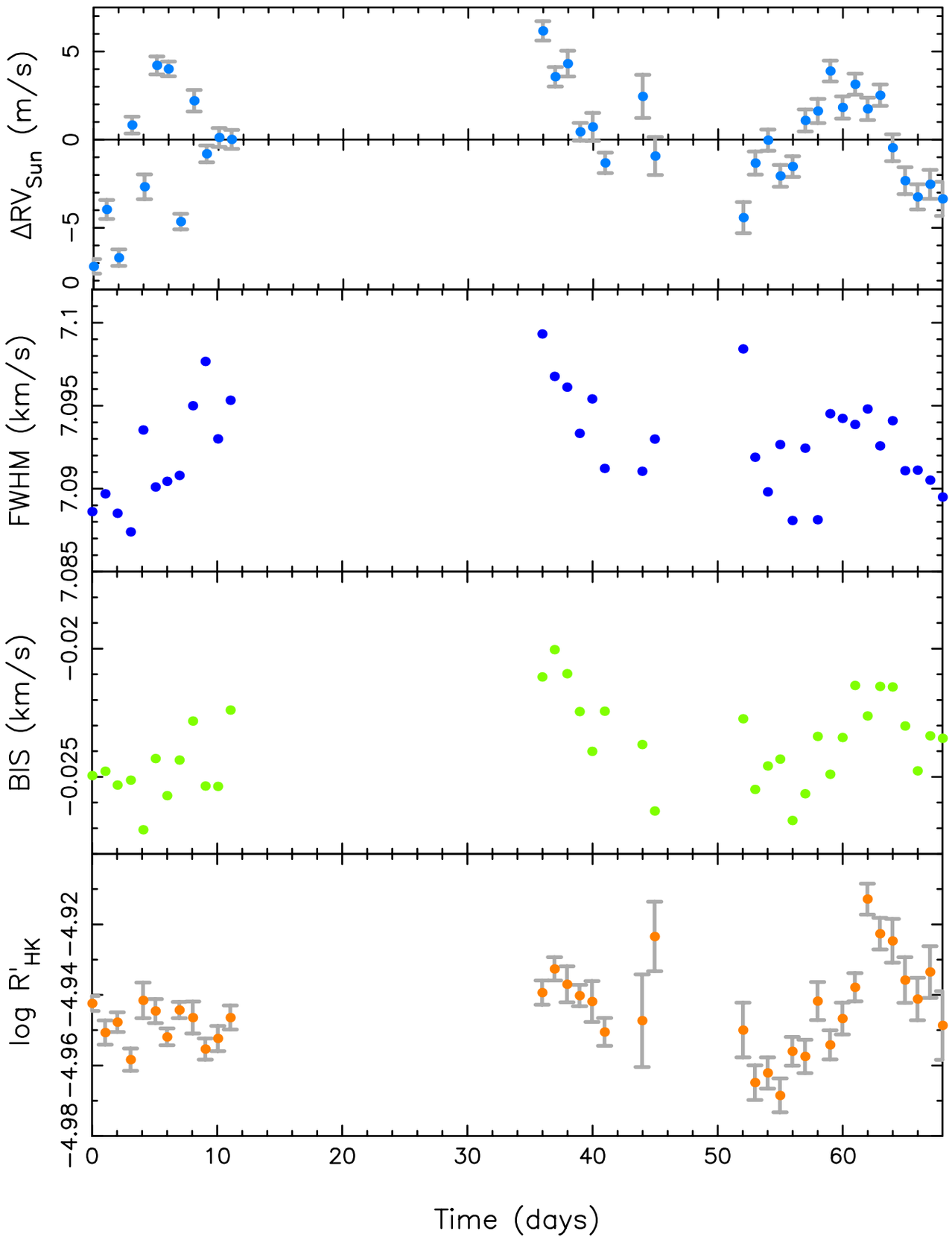
HD 41248: slowly-rotating (20±3 days), G2 star

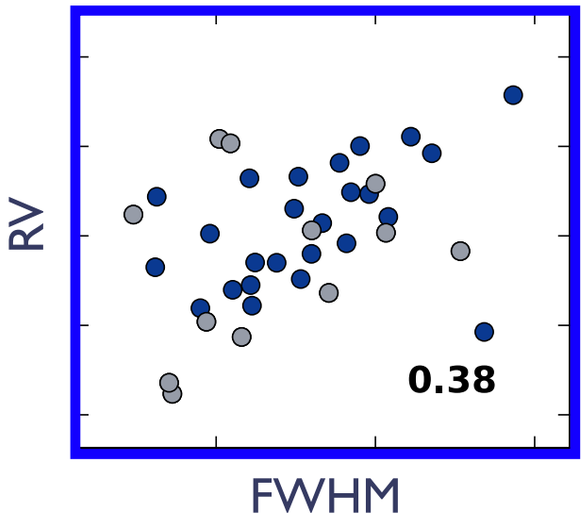
Planet at 25 days?

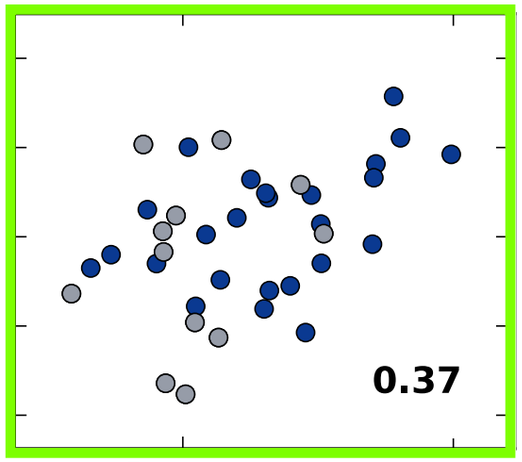
Probably not.

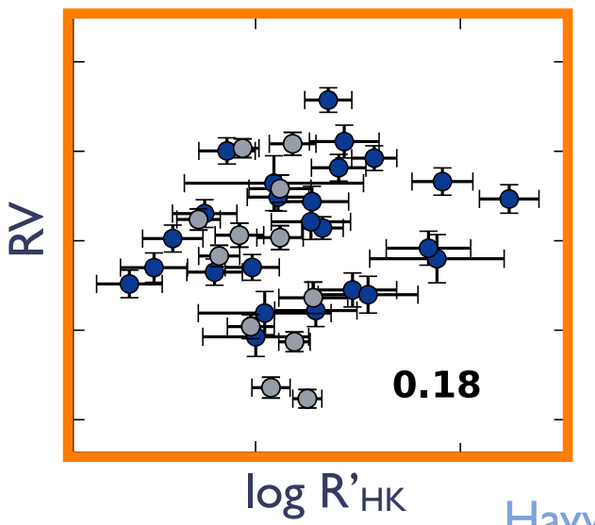
Santos, Mortier et al. 2014

“Traditional” activity indicators: the Sun









Haywood et al. (2016)

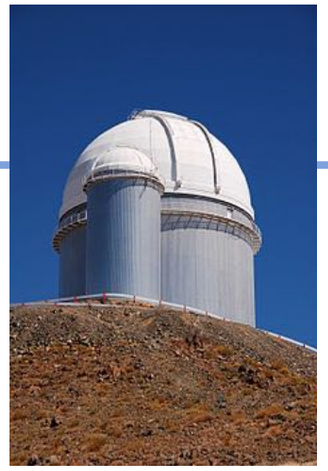
"Traditional" activity indicators do not always correlate with activity signals

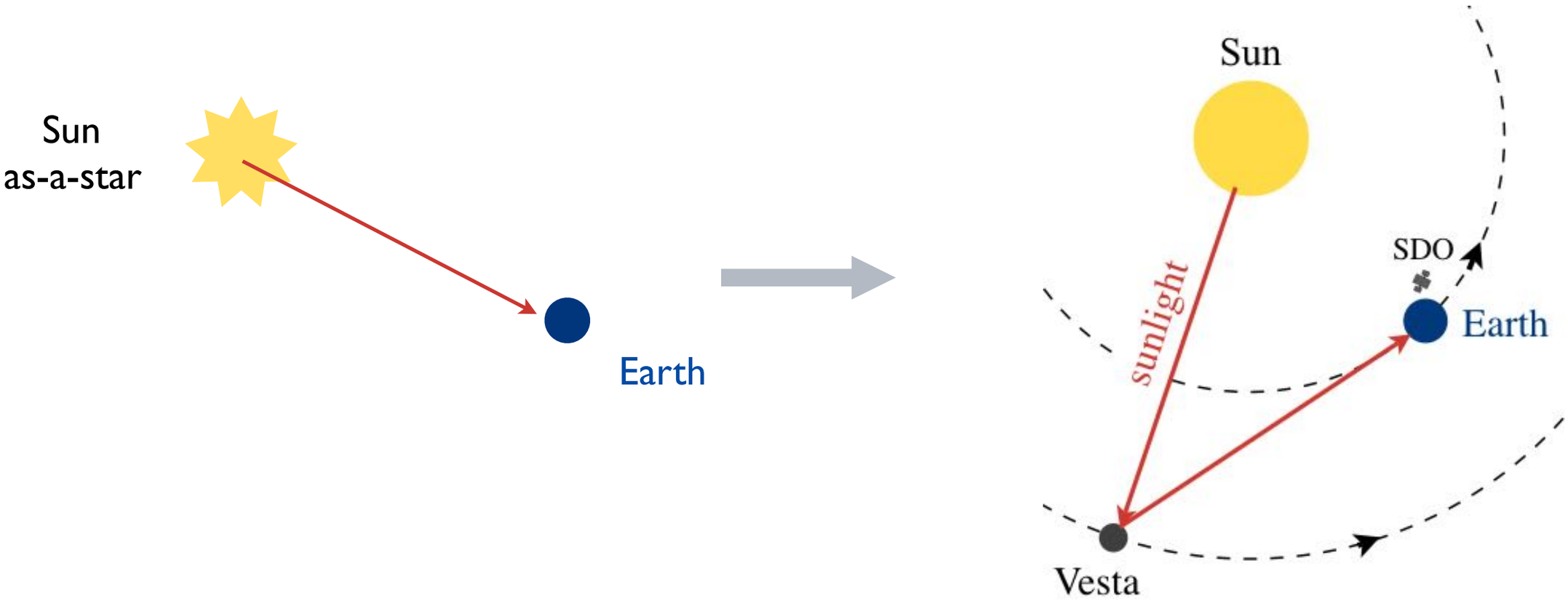
Corollary:

A lack of correlation does not mean it is a planet!

The Sun as an exoplanet-host star

Experiment 1: sunlight scattered off Vesta



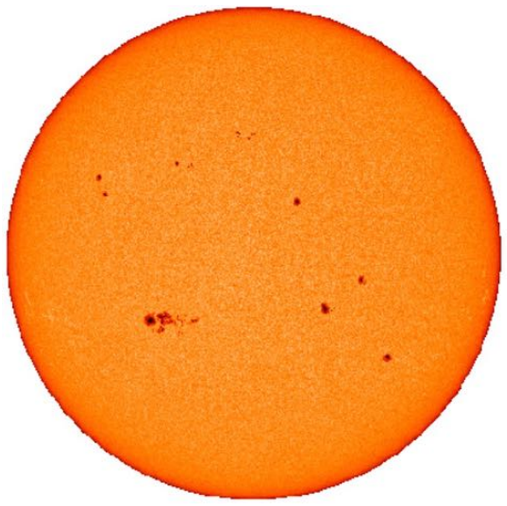


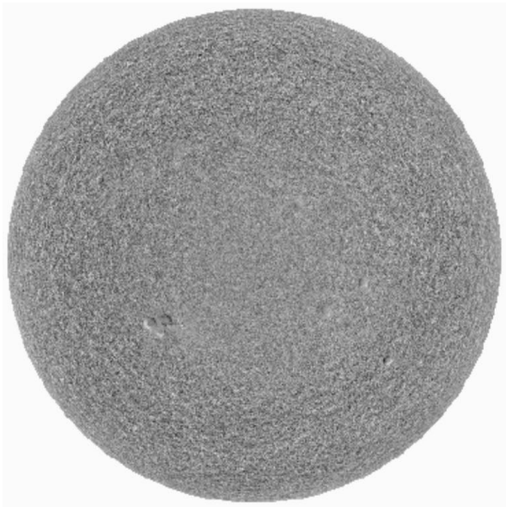
Observations span ~2 solar rotations taken during Sept. — Dec. 2011

Haywood et al. (2016)

Reconstruct solar activity RV with SDO images

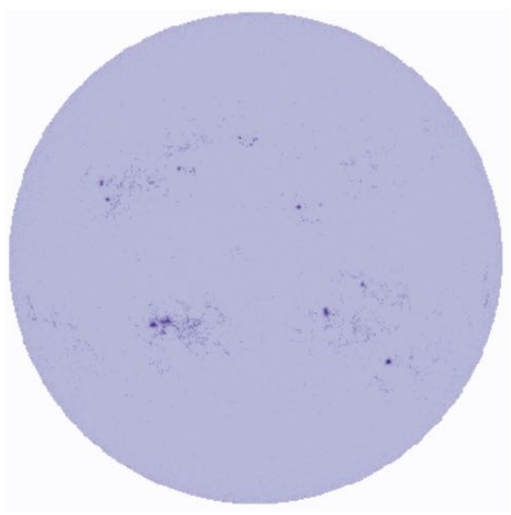
Continuum intensity

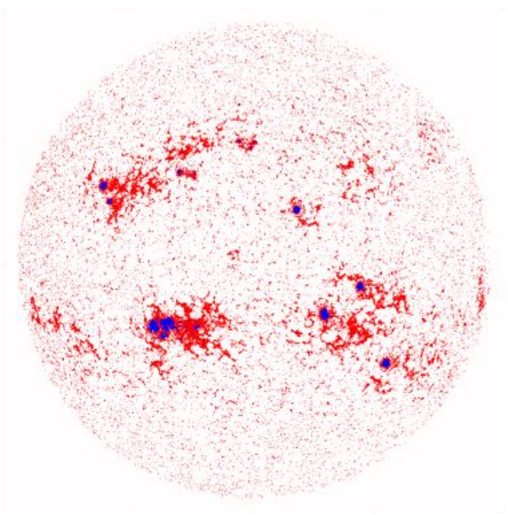




Doppler image

Magnetic flux

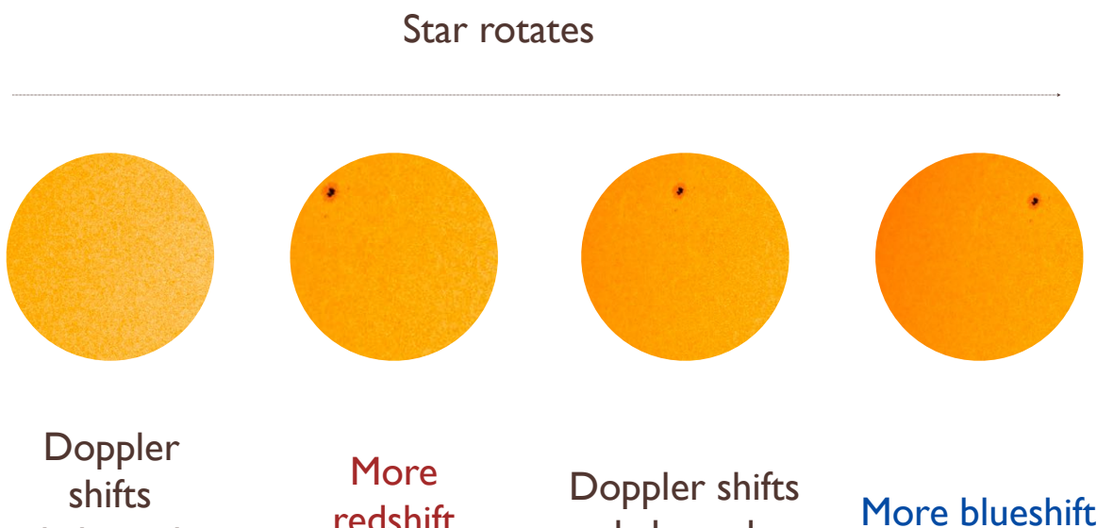




Thresholded image

Technique developed by Meunier et al. (2010b)

How do active regions induce RV variations?



Rotational imbalance due to brightness inhomogeneities
(~0.1 m/s)

Lagrange et al. (2010), Haywood et al. (2016)

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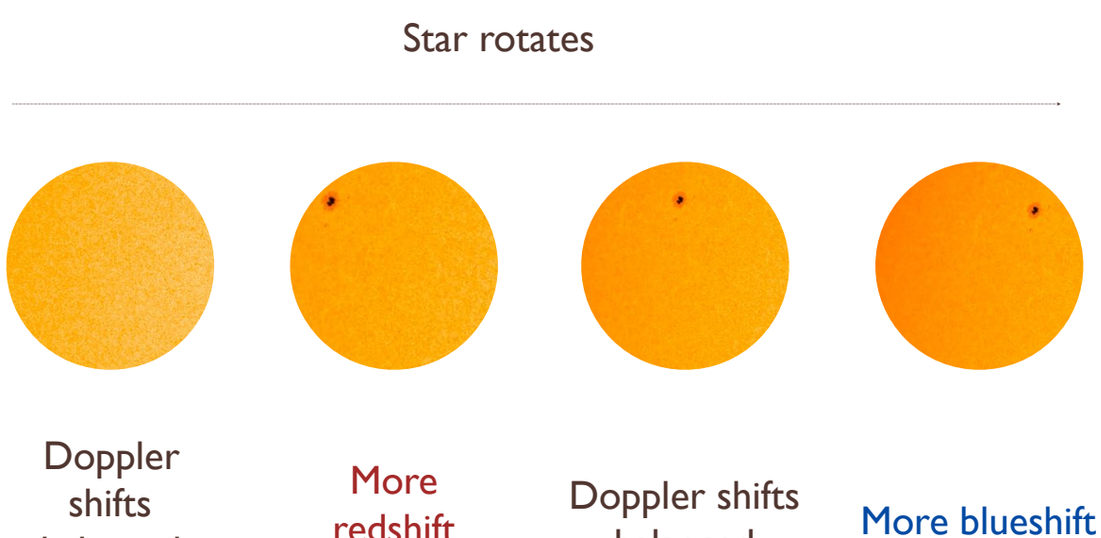

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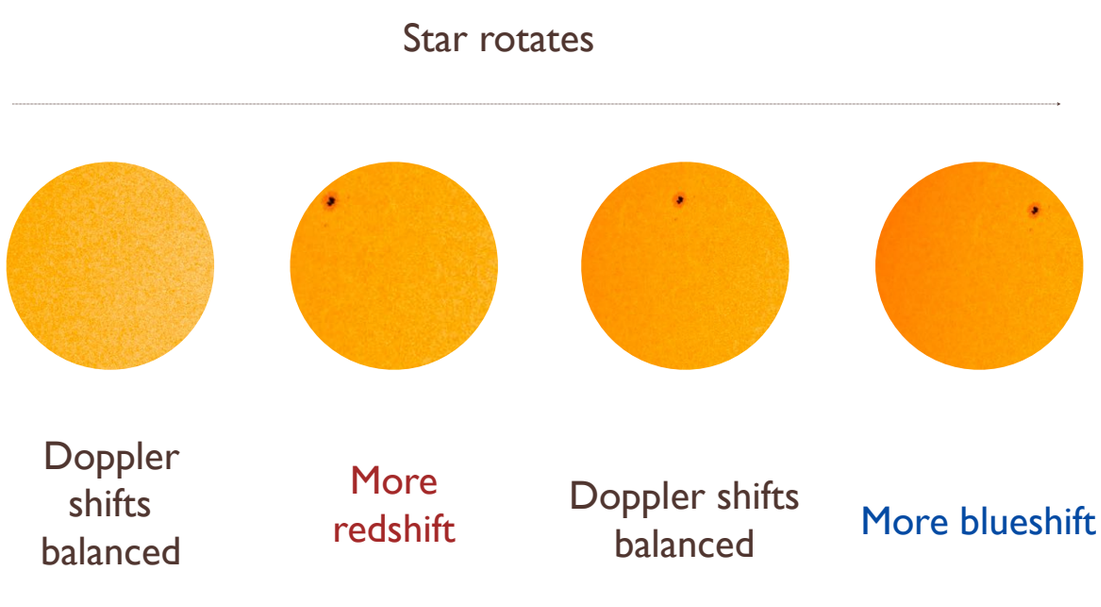
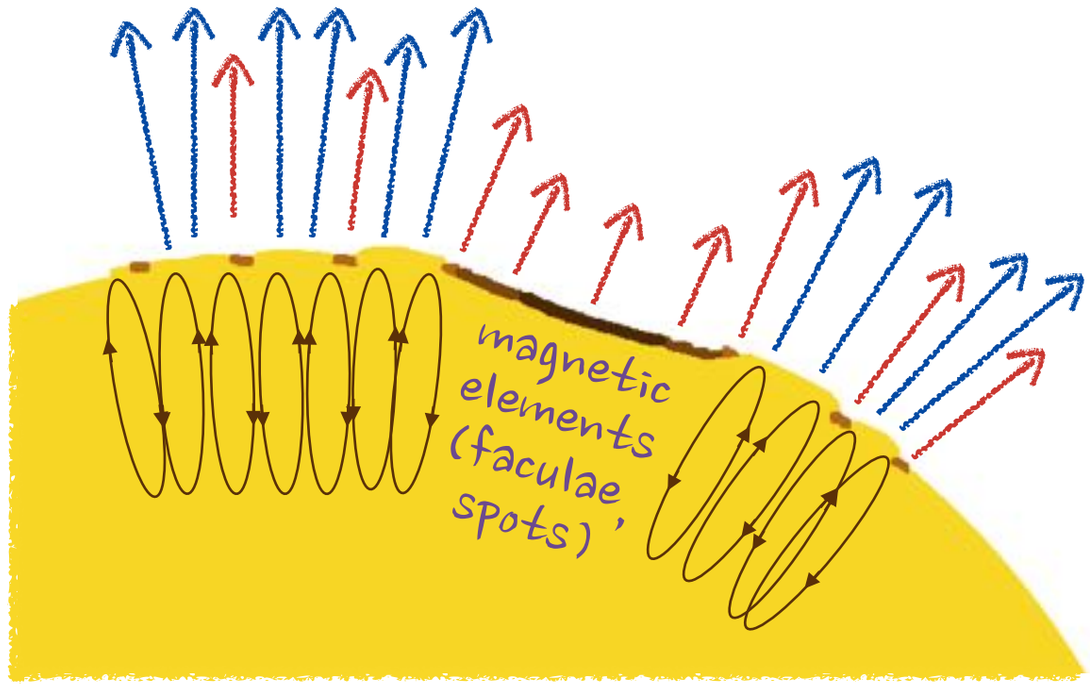




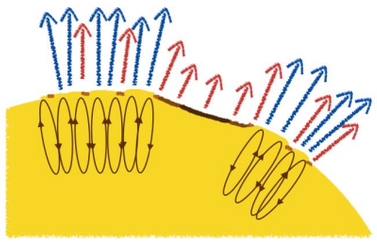
Rotational imbalance due to brightness inhomogeneities
(~0.1 m/s)

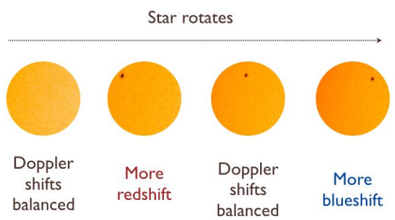
Lagrange et al. (2010), Haywood et al. (2016)

Suppression of convective blueshift by magnetic regions
(~few m/s)

Meunier et al. (2010a,b), Haywood et al. (2016)

Can we reconstruct the RV of the Sun as a star with SDO?





HARPS
Sun as-a-star
RVs

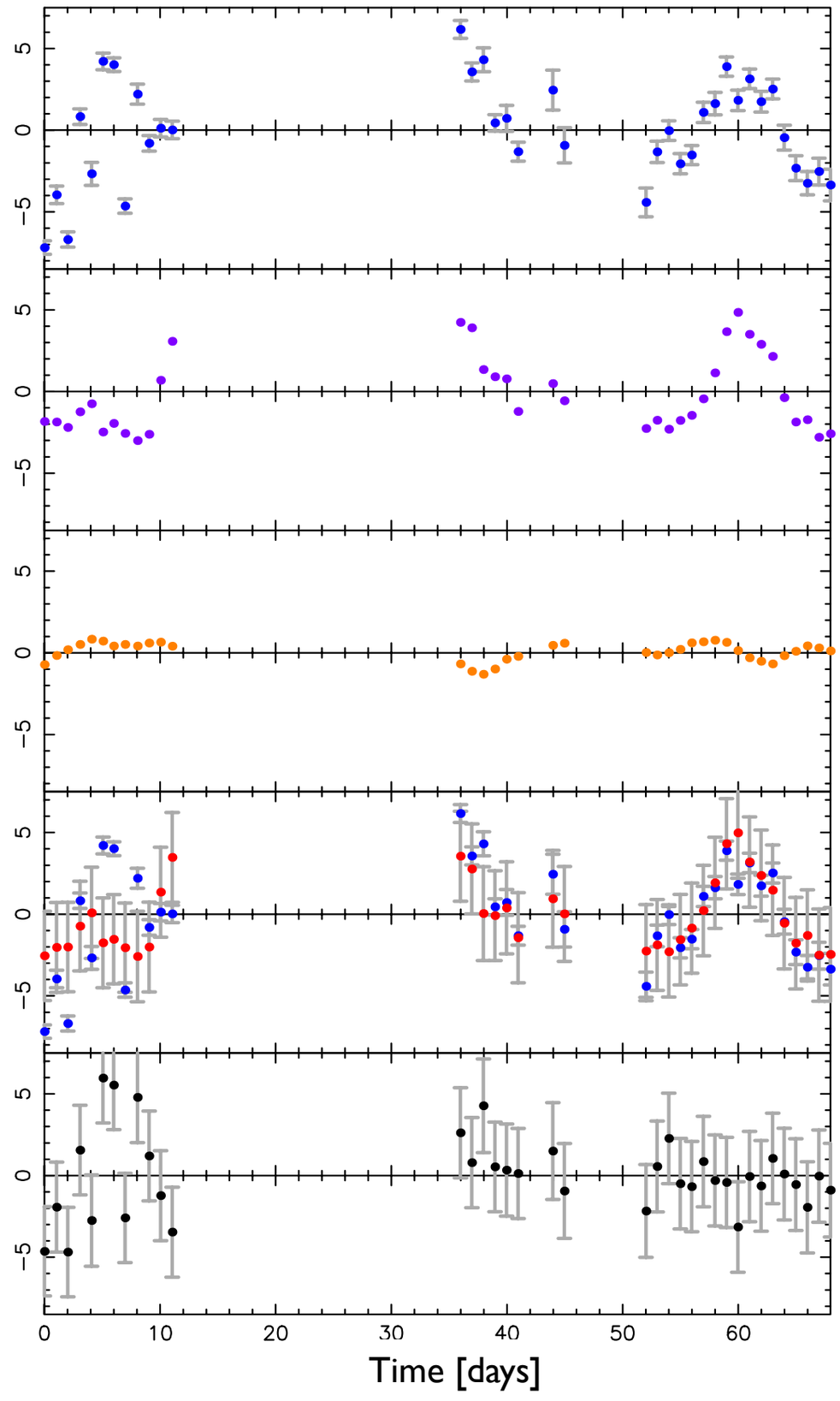
ΔRV_{conv}

ΔRV_{phot}

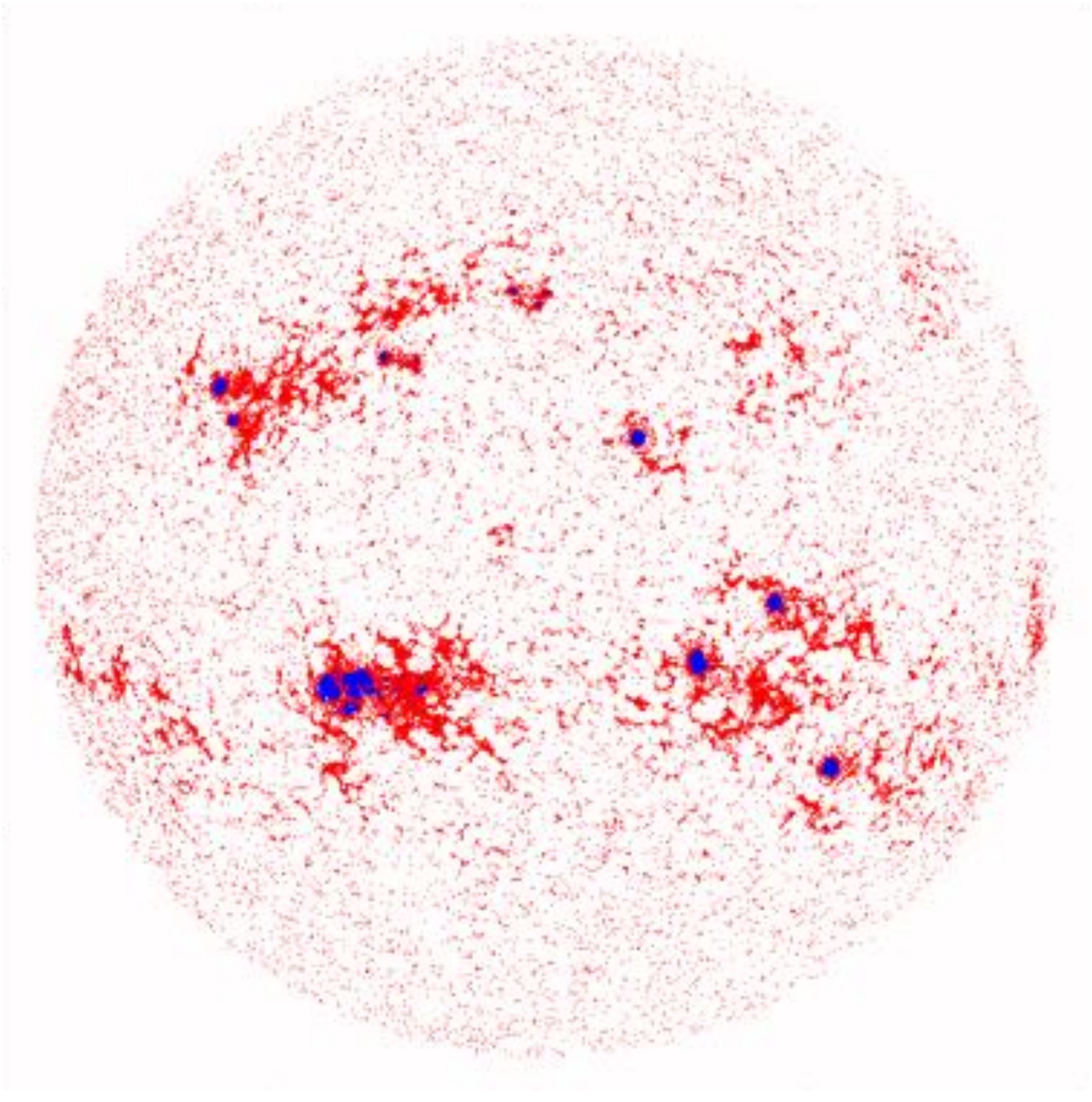
Model

Residuals

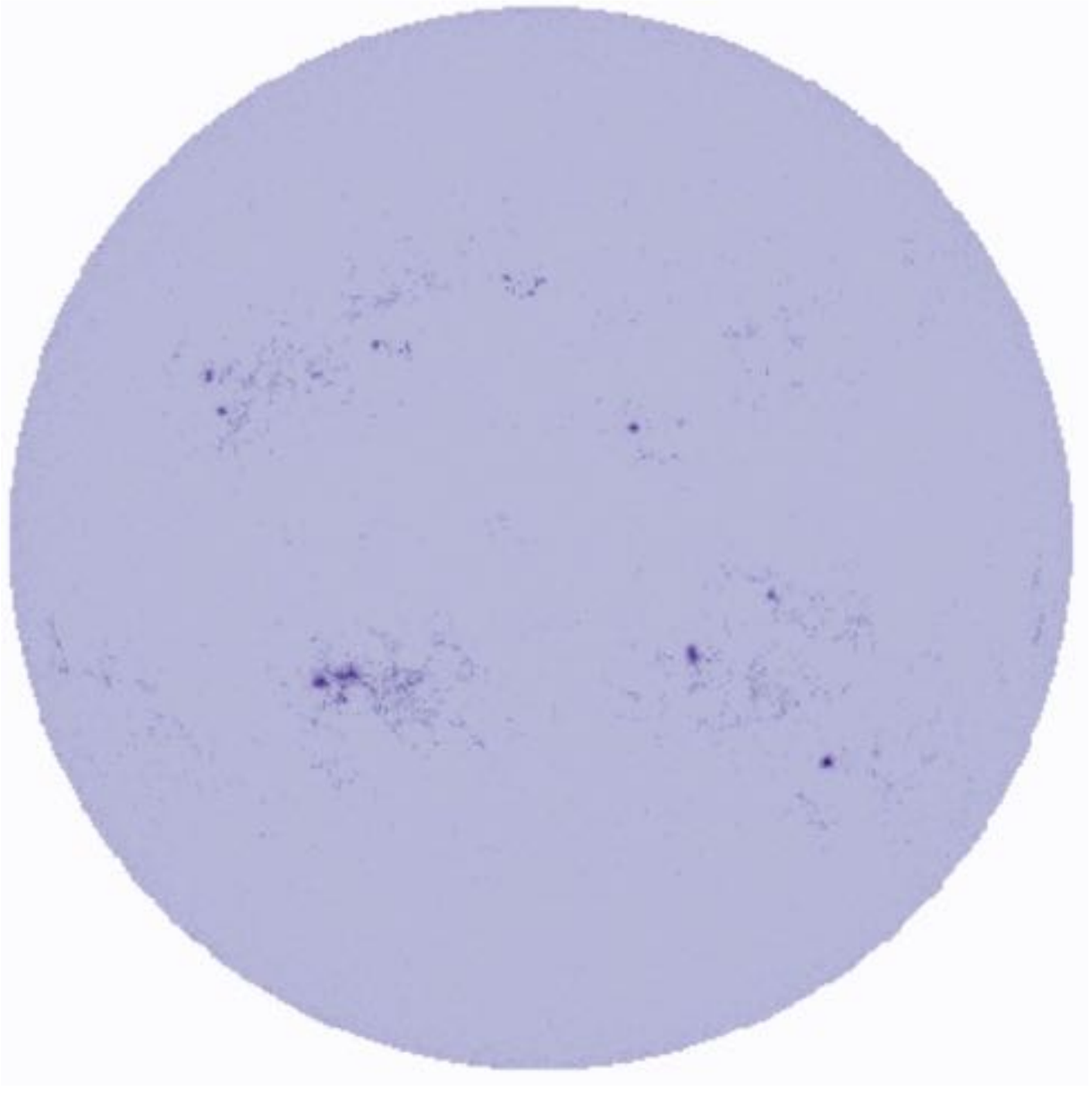
[m/s]



Haywood et al. (2016)

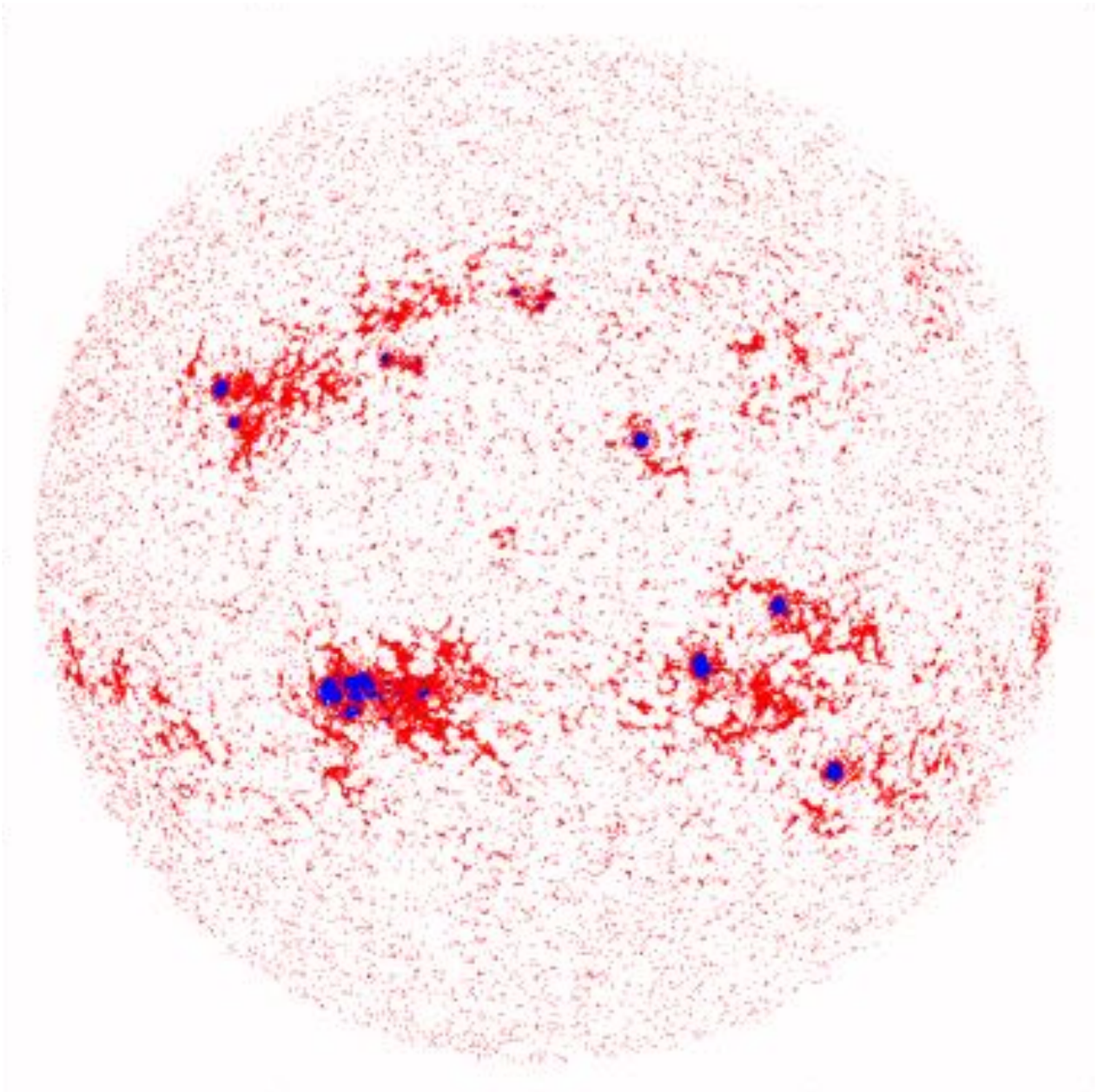


Faculae pixels
Sunspot pixels



SDO/HMI magnetogram

Meunier et al. (2010), Haywood et al. (2016)

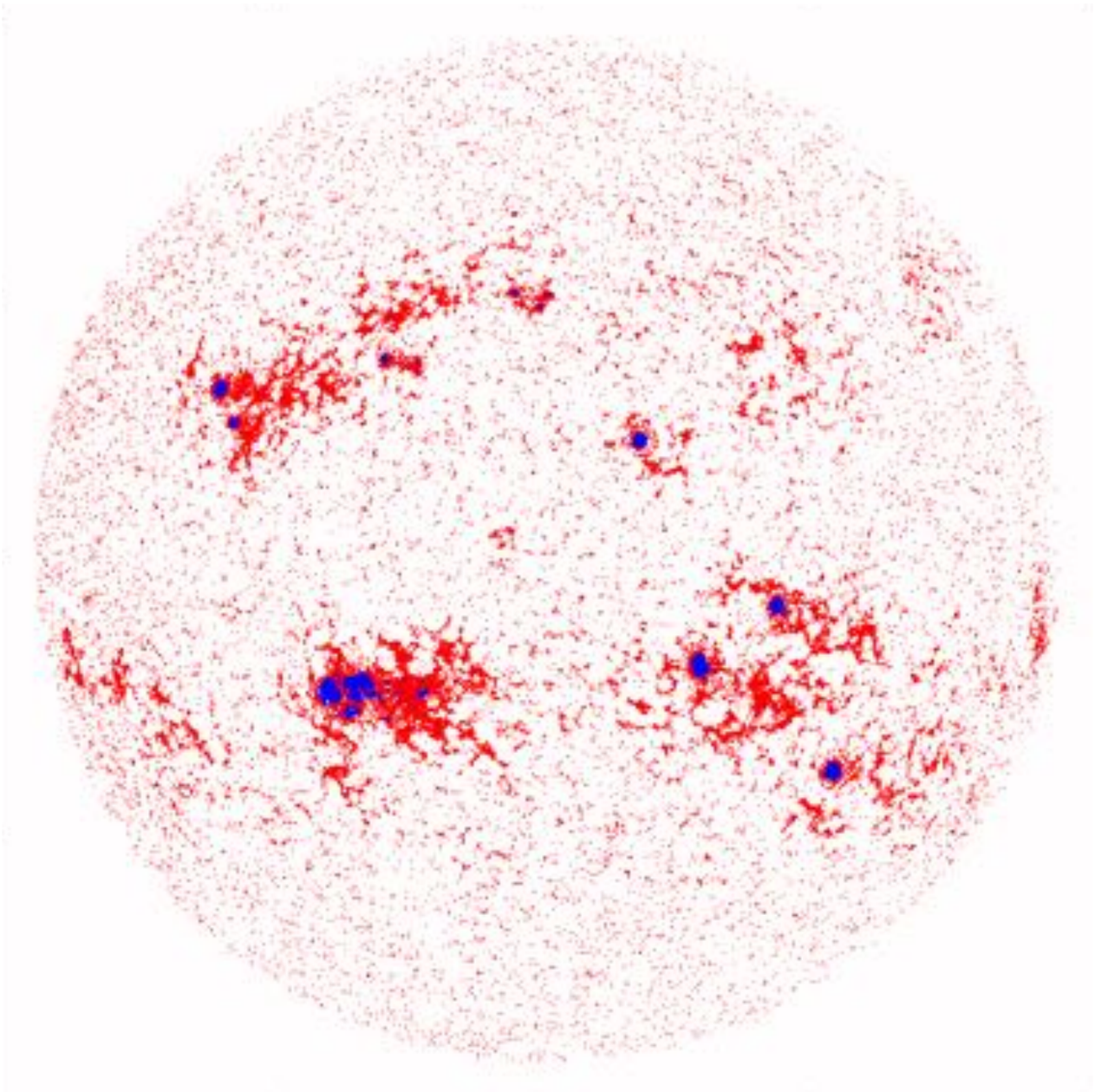


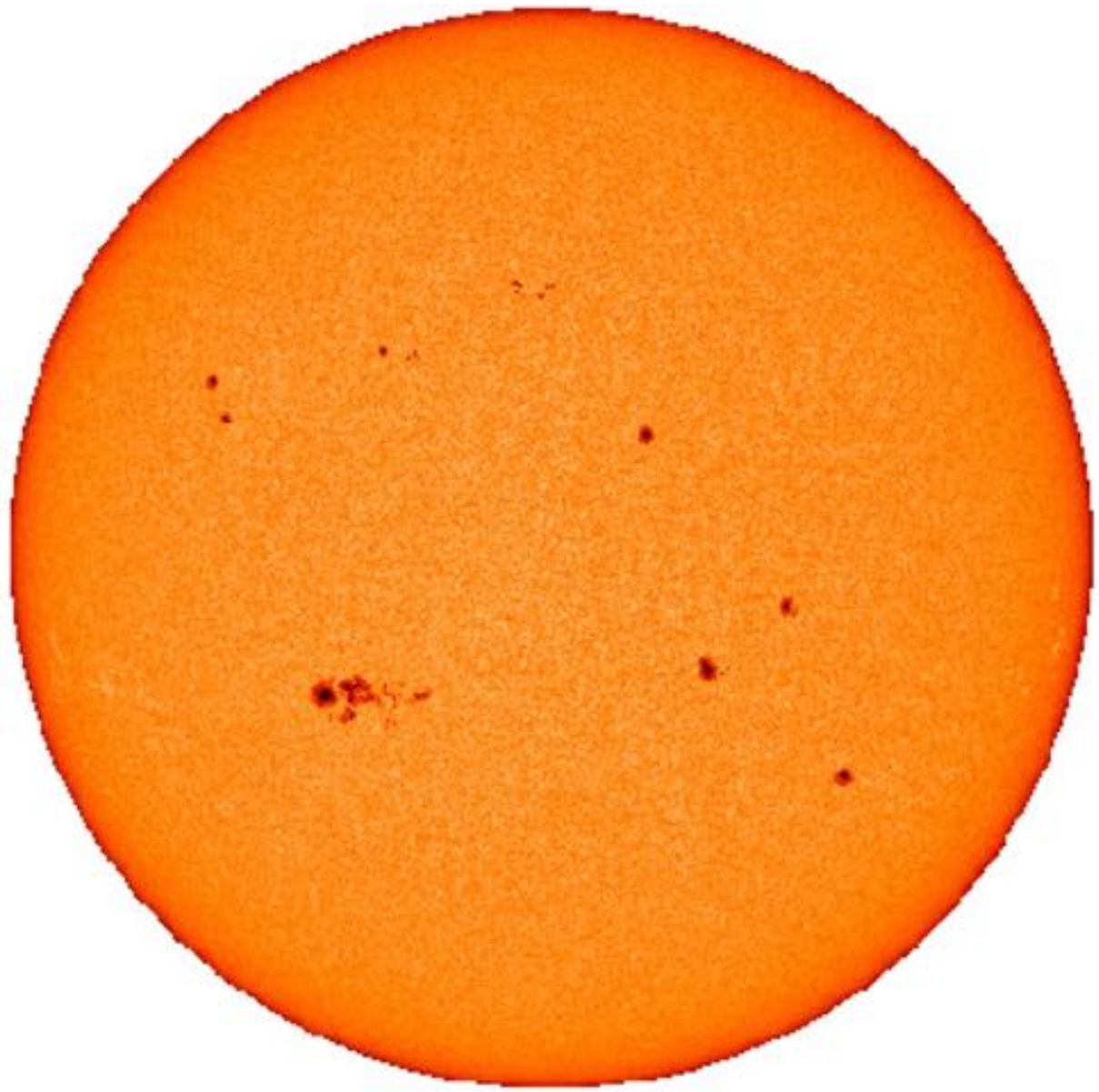
Faculae pixels
Sunspot pixels

Faculae
are the main source of
suppression of
convective blueshift

Meunier et al. (2010), Haywood et al. (2016)

Optical lightcurves can only give incomplete prediction of RV variations



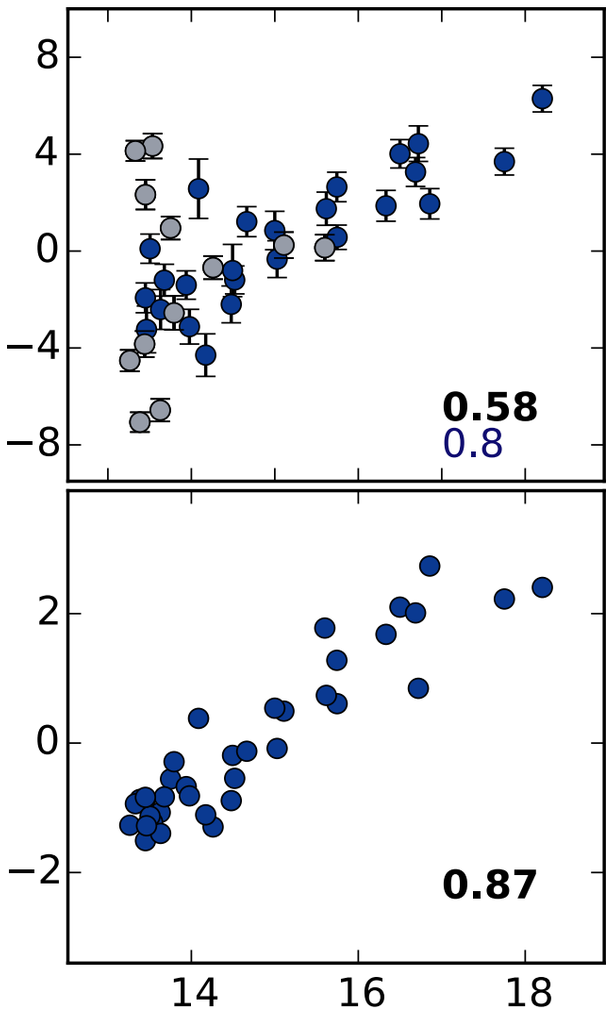


Faculae pixels

Sunspot pixels

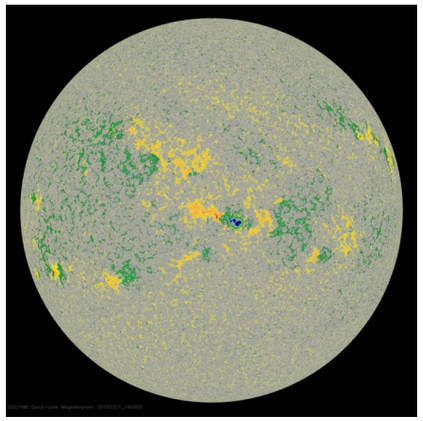
Full-disc magnetic flux as an activity indicator

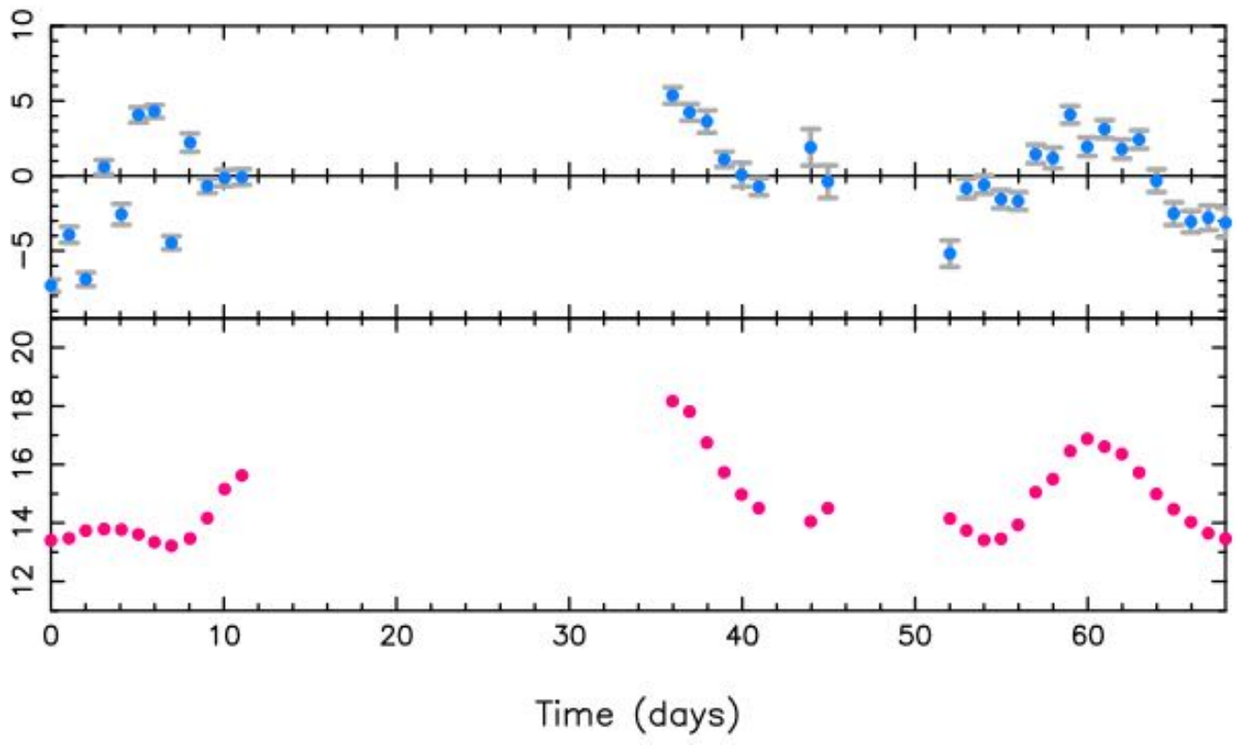
HARPS
Sun as-a-star
RVs (m/s)



ΔRV_{conv}
(m/s)

Disc-averaged
magnetic flux
(G)





- Cannot yet measure in distant Sun-like stars
- But could become useful in the future!

Haywood et al. (2016)

We need to identify proxies that track faculae directly

We need a well-sampled, continuous dataset!

Experiment 2: solar telescope at HARPS-N

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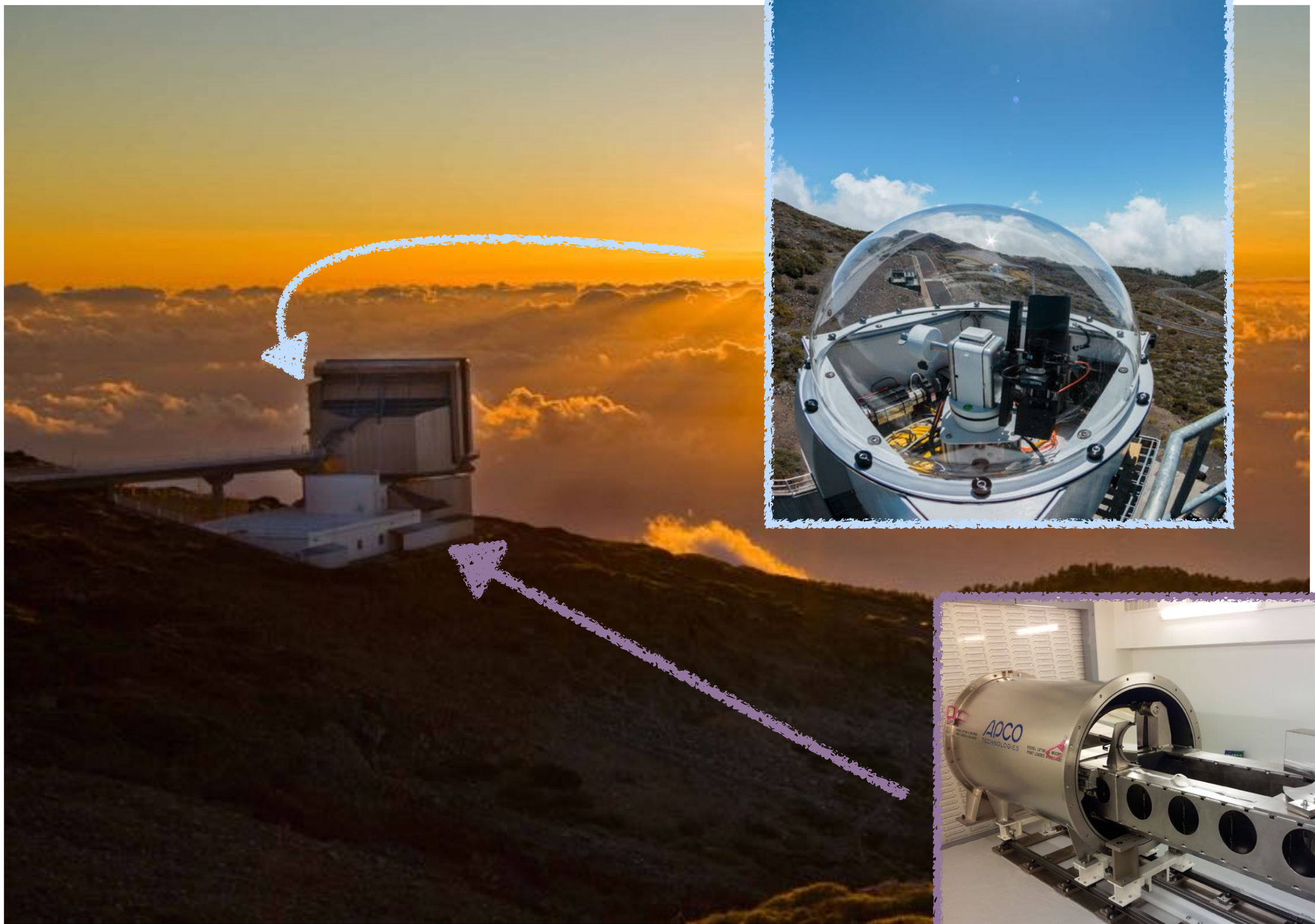


Experiment 2: solar telescope at HARPS-N

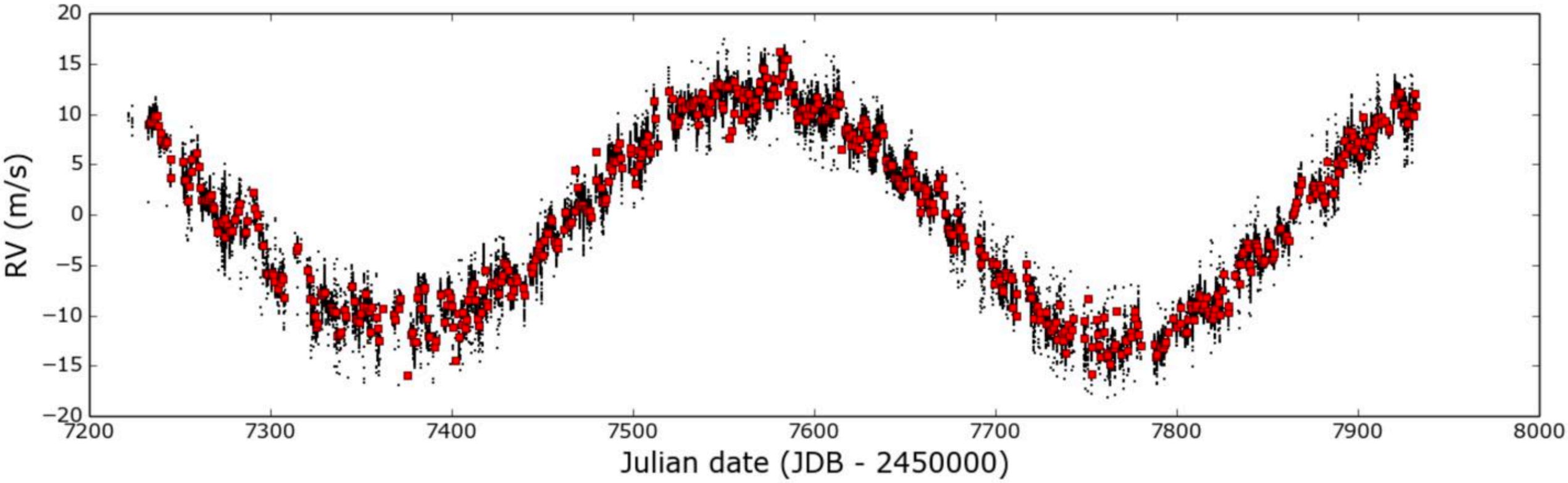
- 3-inch automated telescope feeding an integrating sphere
- Integrated sunlight then fed into HARPS-N spectrograph
- Operational since July 2015
- 5 min cadence from ~ 10am — 4pm each day

See:
Glenday et al. (2015)
Dumusque et al. (2016)
Phillips et al. (2016)

Image credit: David Phillips

Experiment 2: solar telescope at HARPS-N

Full dataset since July 2015, 5-min cadence



Plots: Annelies Mortier

Experiment 2: solar telescope at HARPS-N

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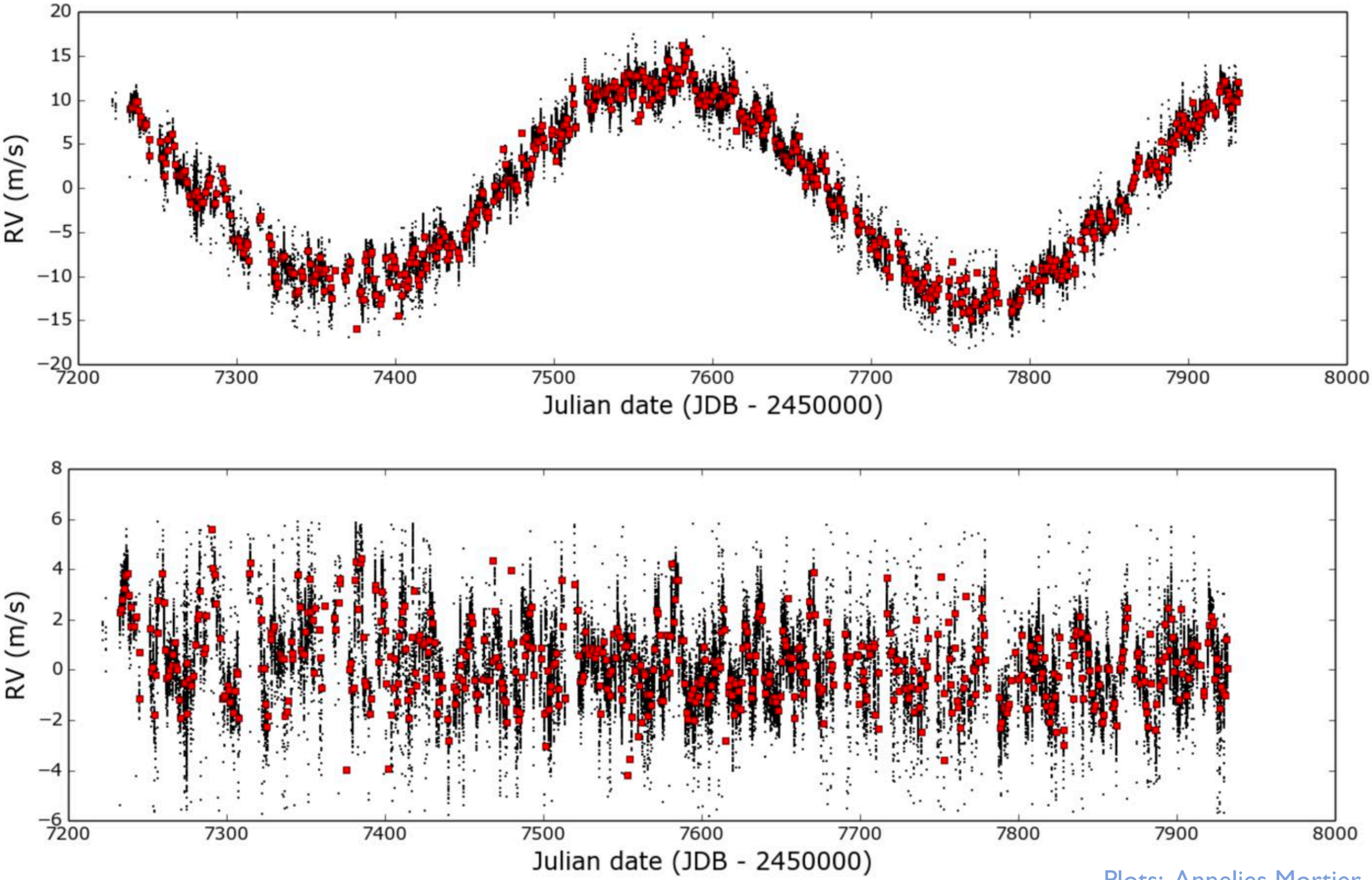
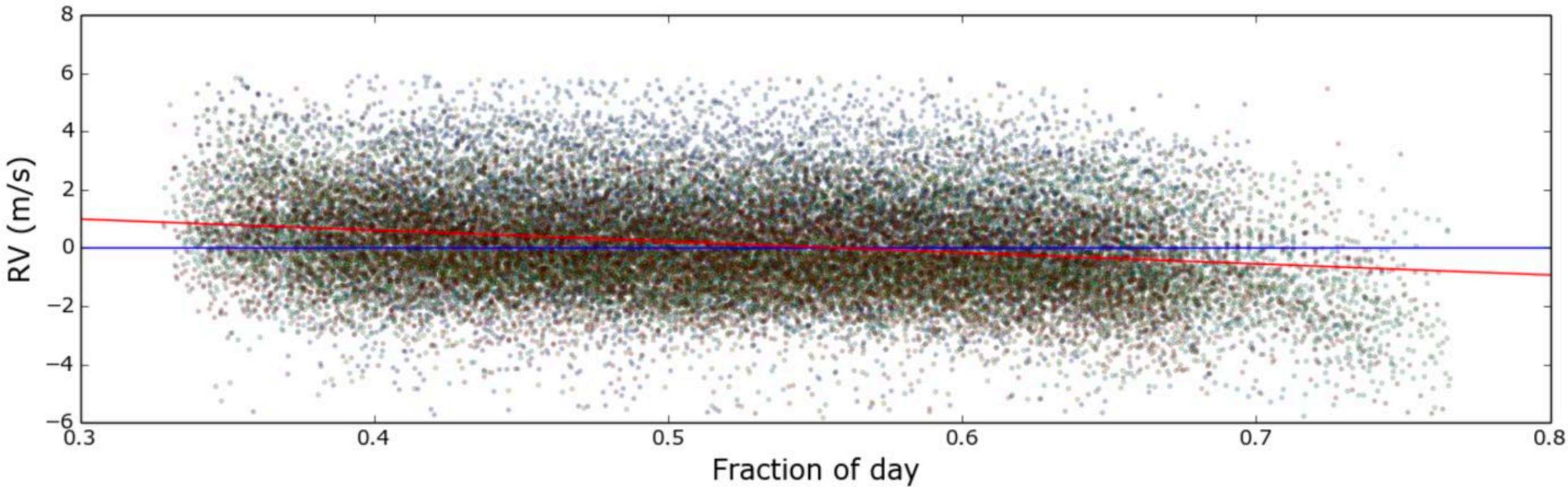


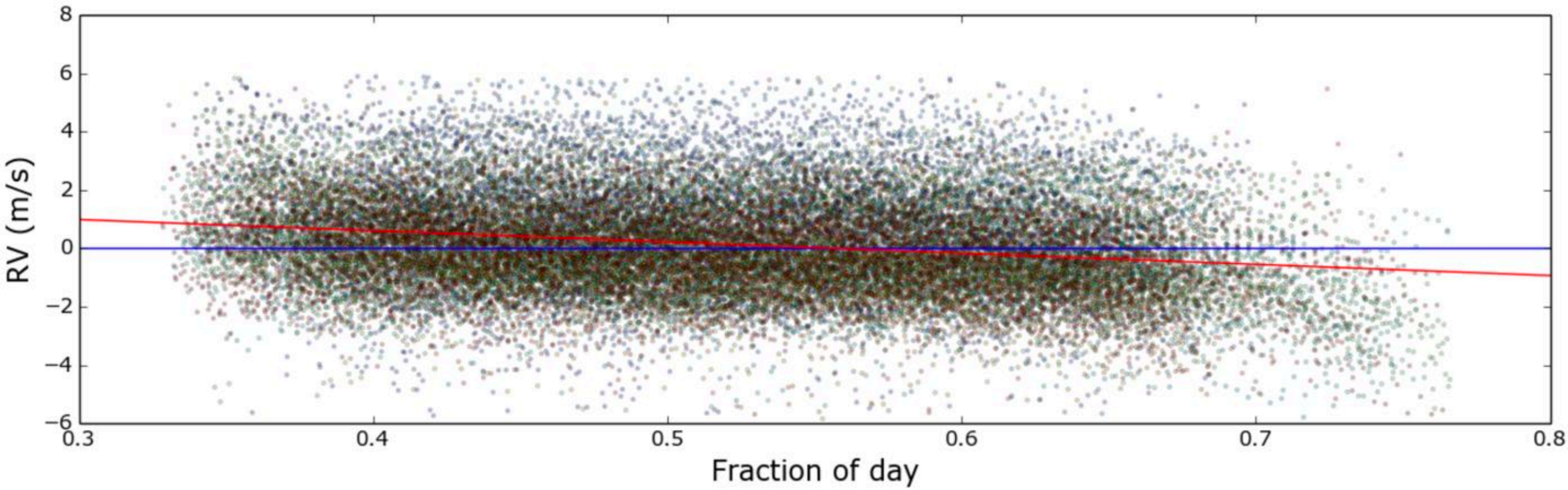
Plots: Annelies Mortier

Daily downwards trend



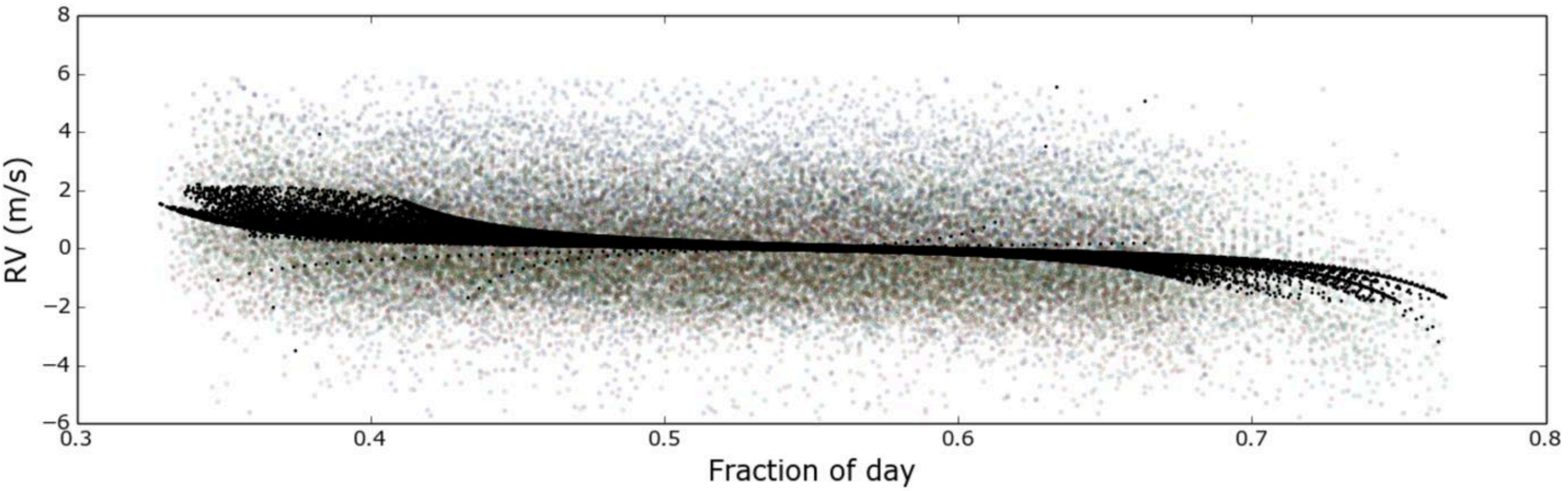
Plots: Annelies Mortier

Daily downwards trend: differential exctinction across the solar disc?



Plots: Annelies Mortier

Correct for differential extinction



Plots: Annelies Mortier

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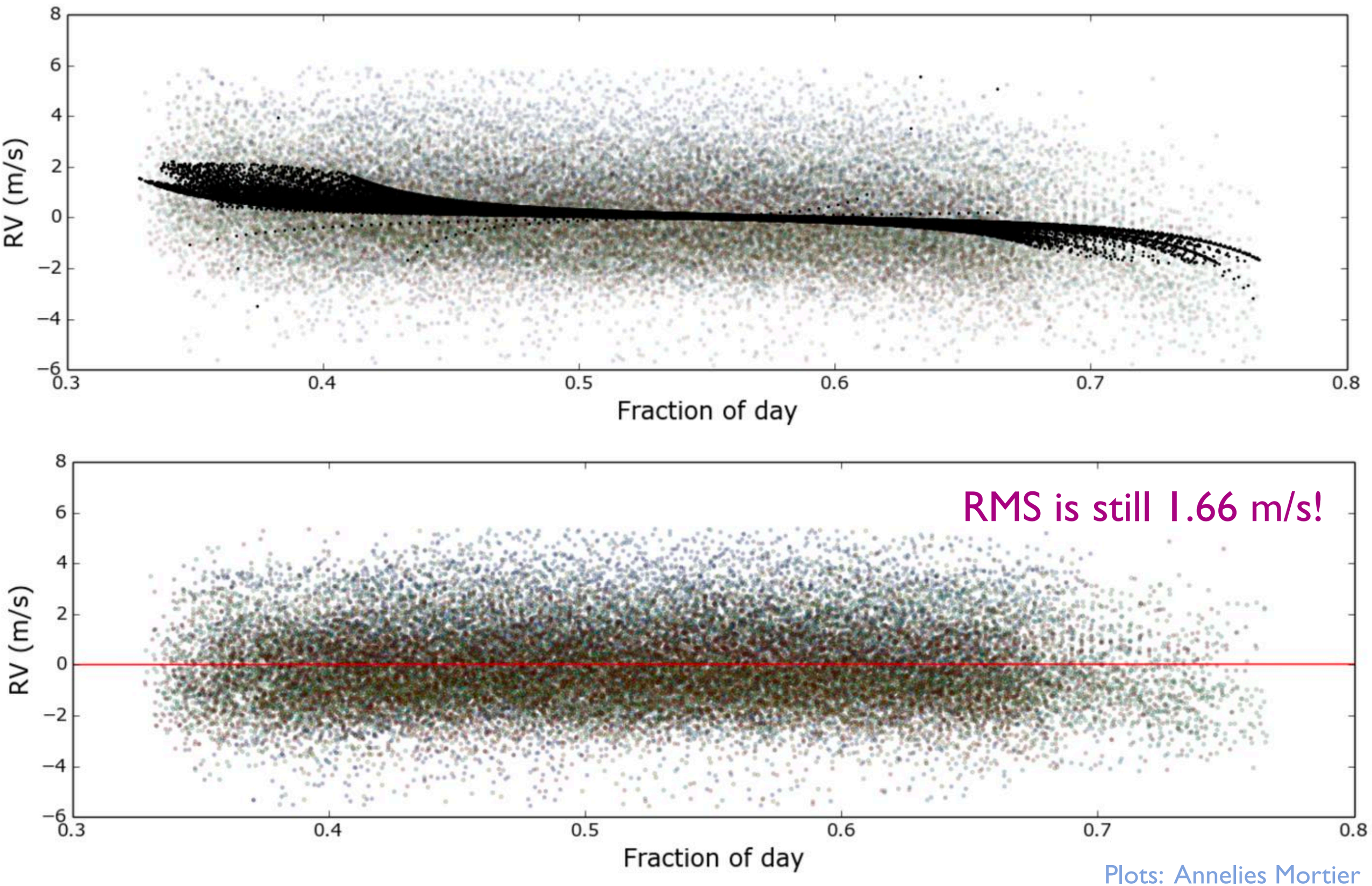
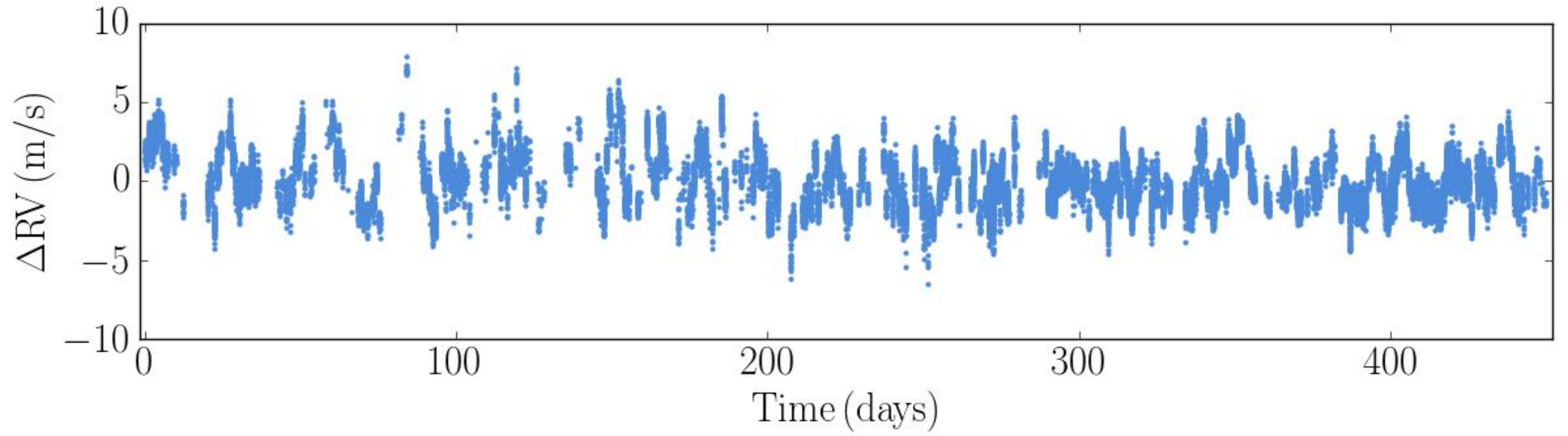


Plots: Annelies Mortier

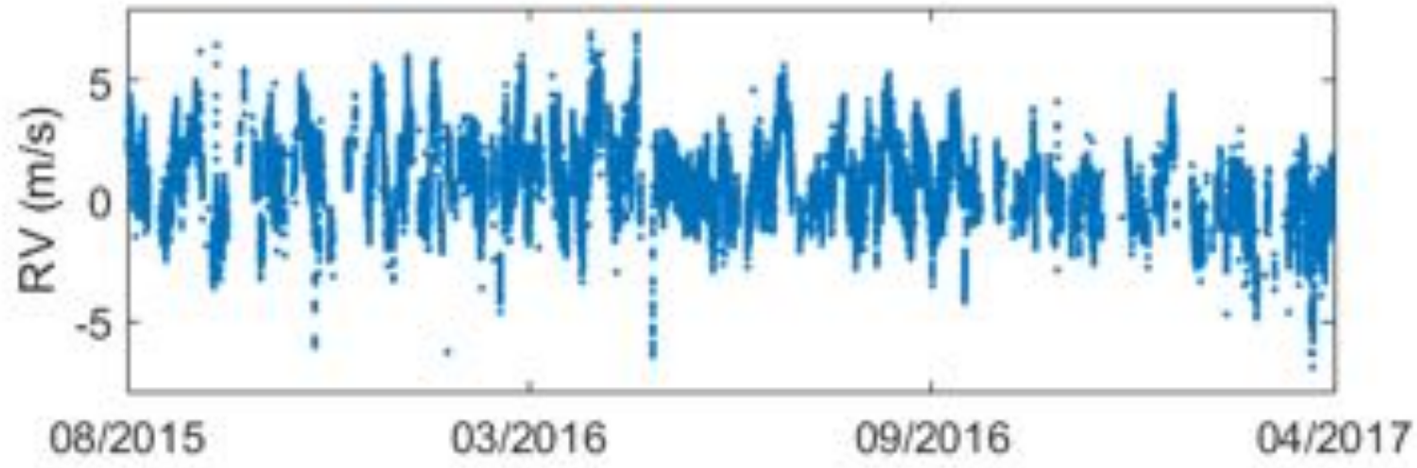
Sun as a star radial-velocity variations

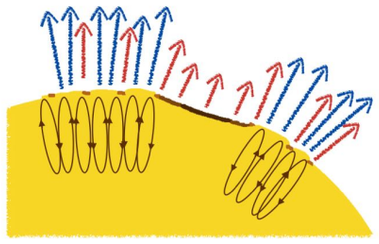
Photon noise rms scatter:
40-50 cm/s in 5-min exposures



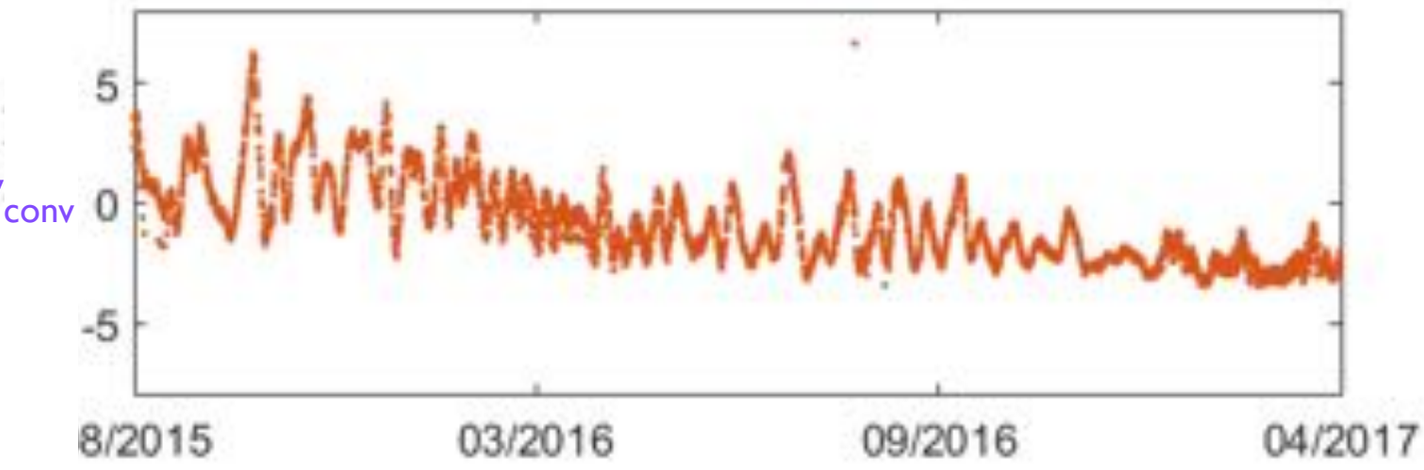
Reconstructing the RV of the Sun using SDO/HMI images

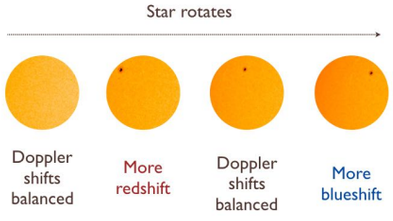
Milbourne et al. (in prep.)



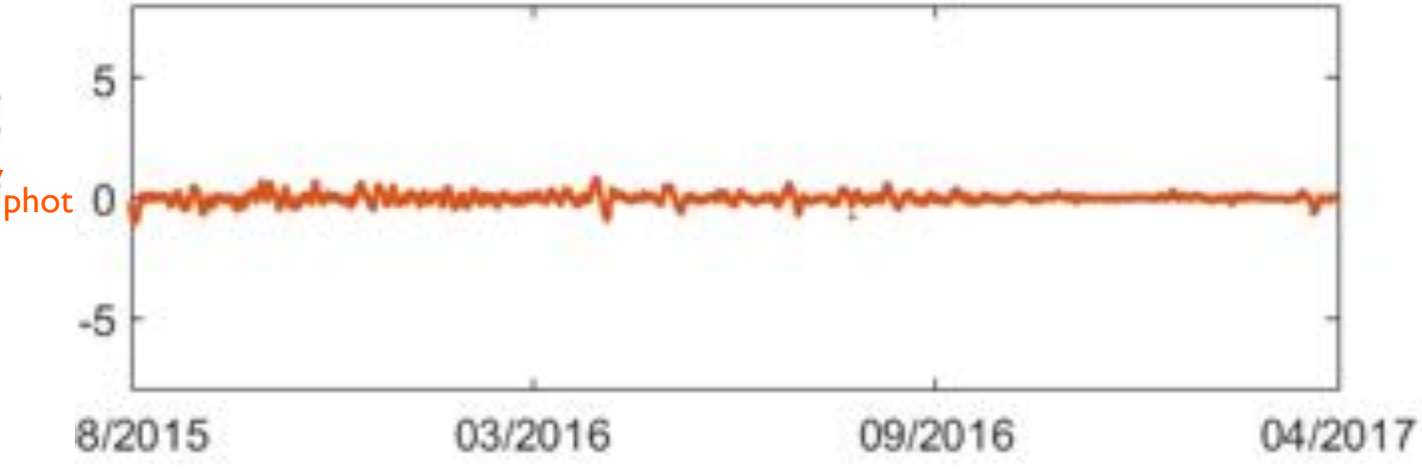


ΔRV_{conv}





ΔRV_{phot}



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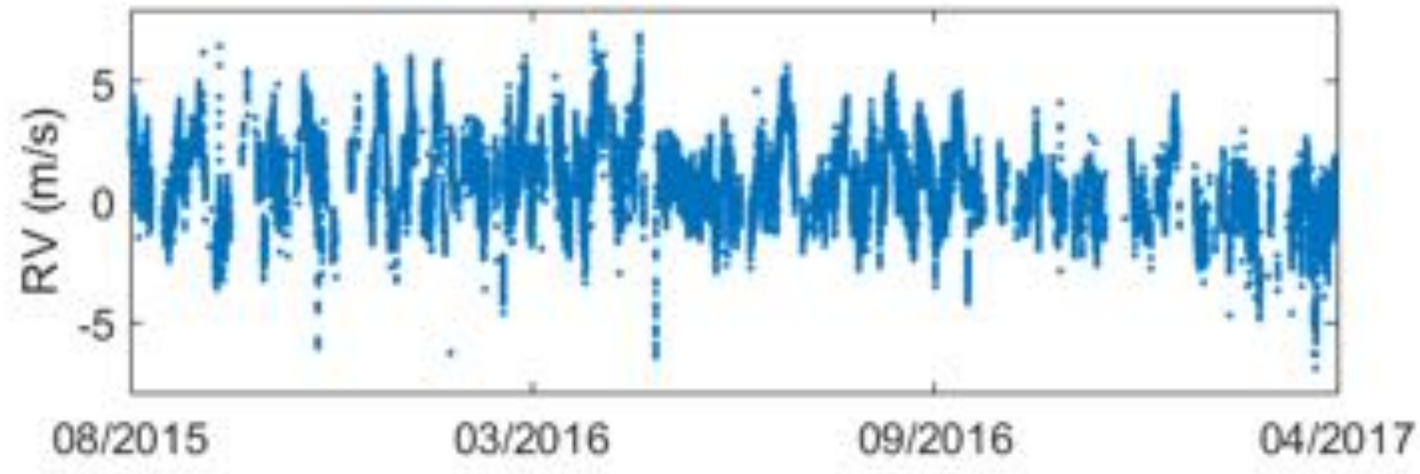
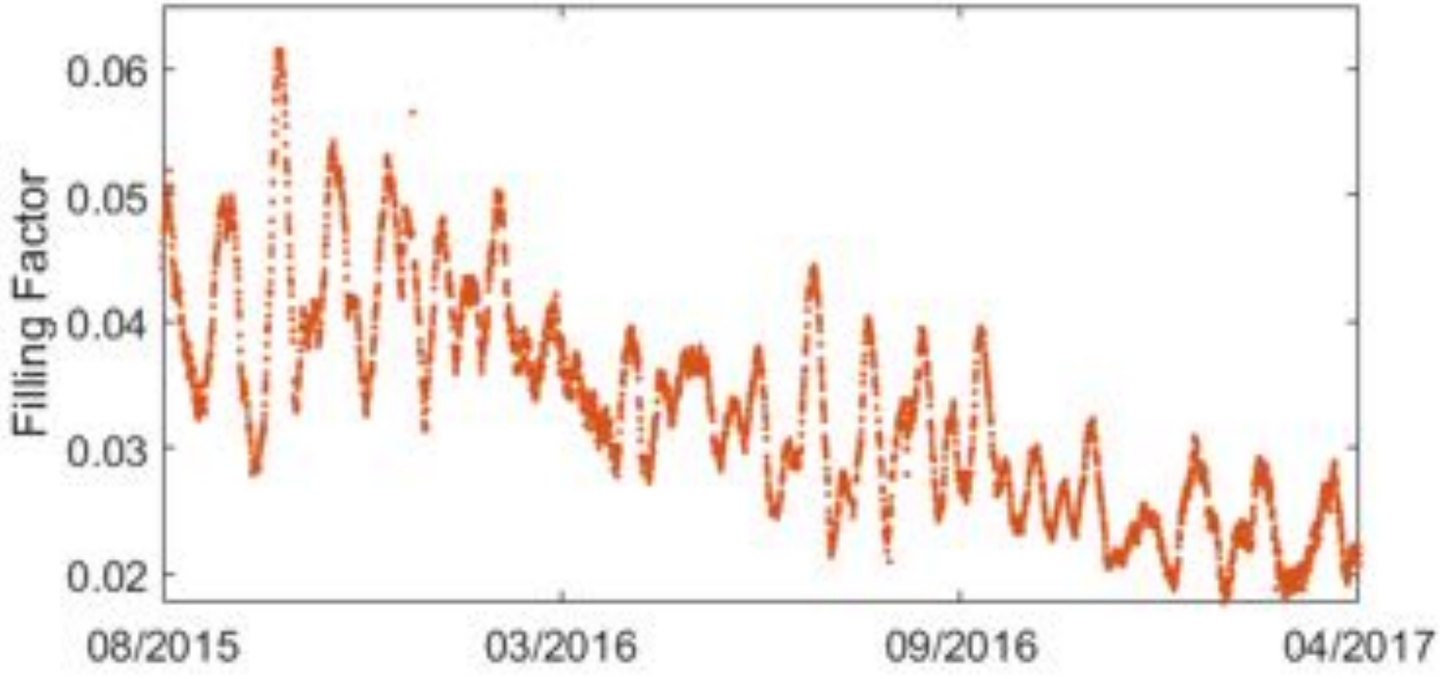
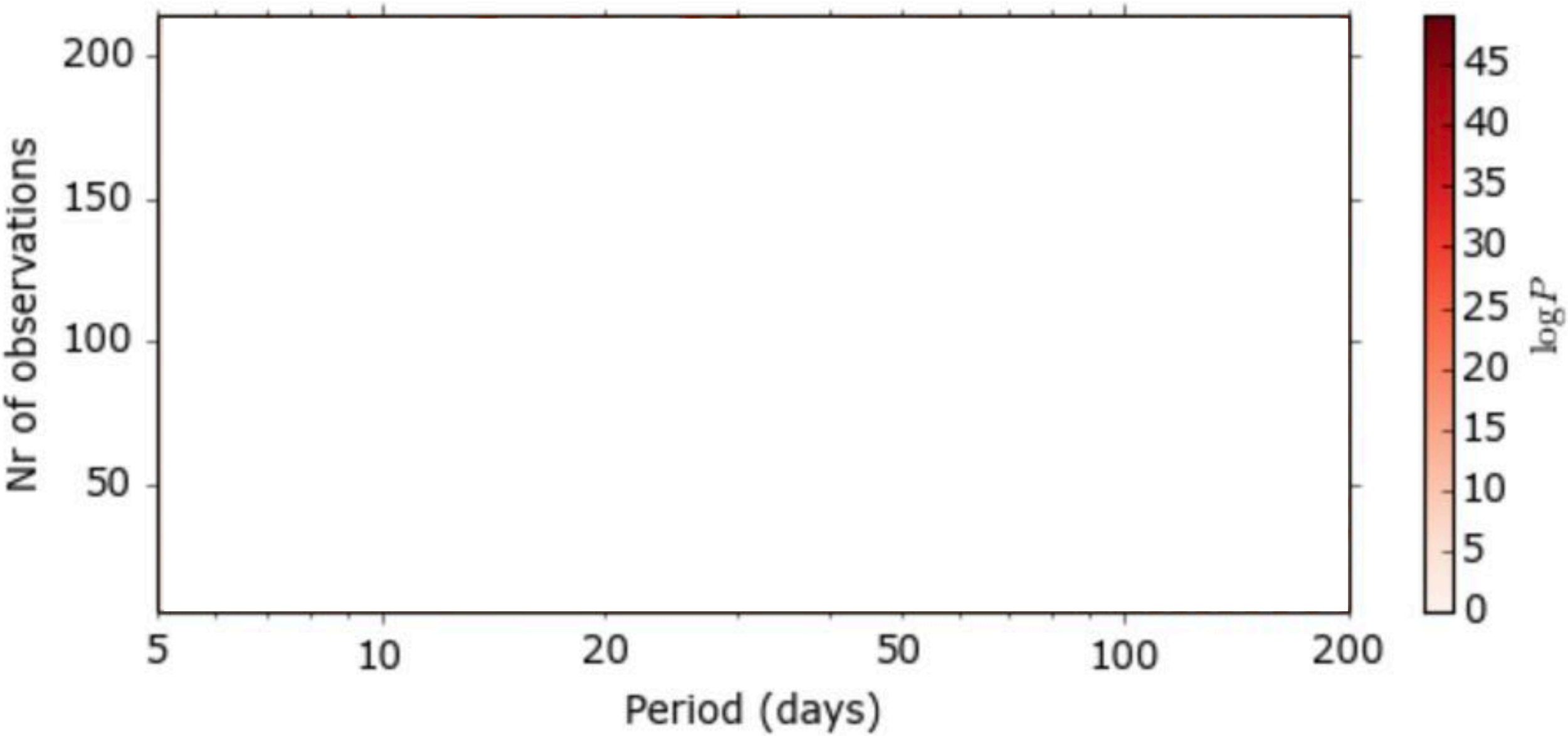




Stacked periodograms

Mortier et al. (2015); Mortier & Collier Cameron (2017)



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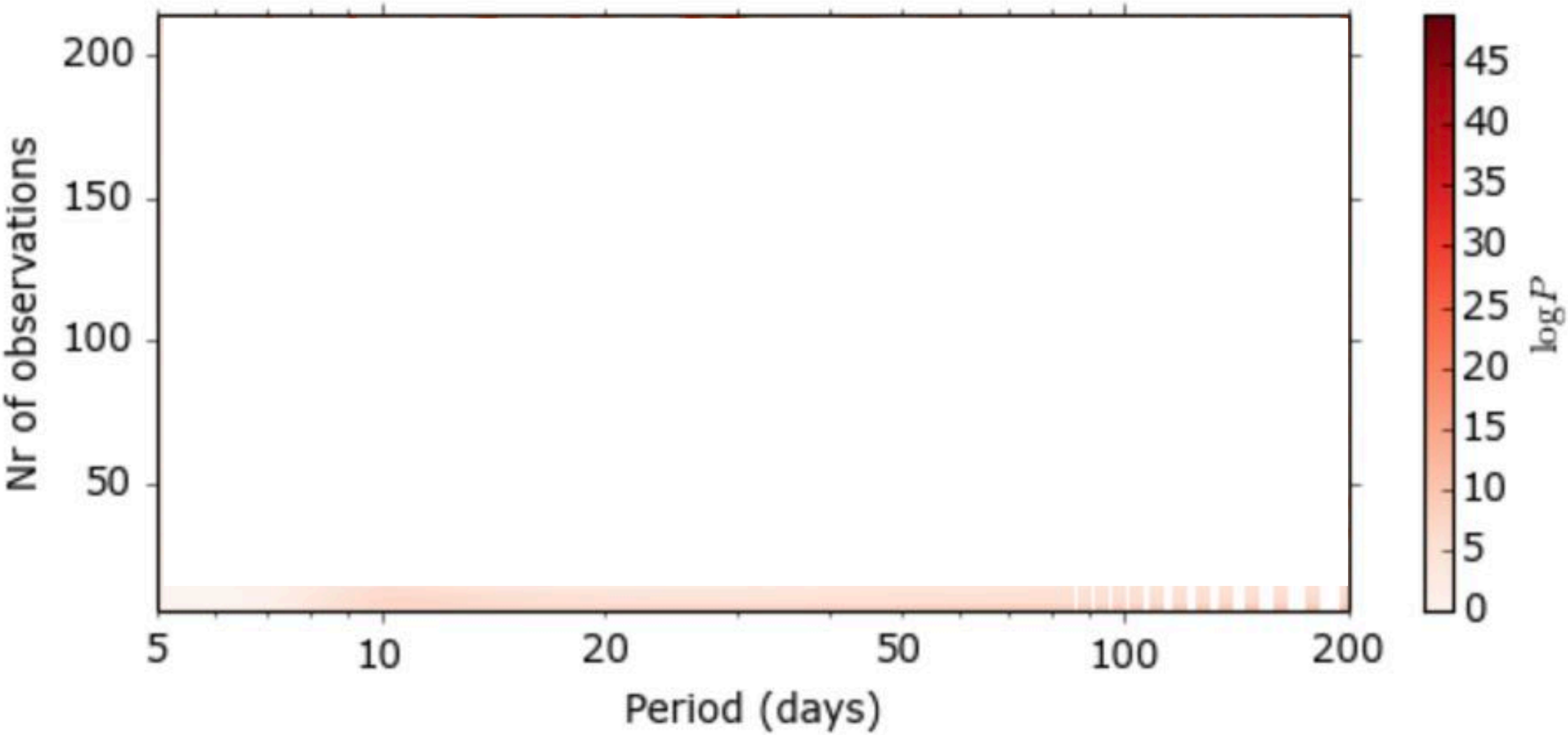

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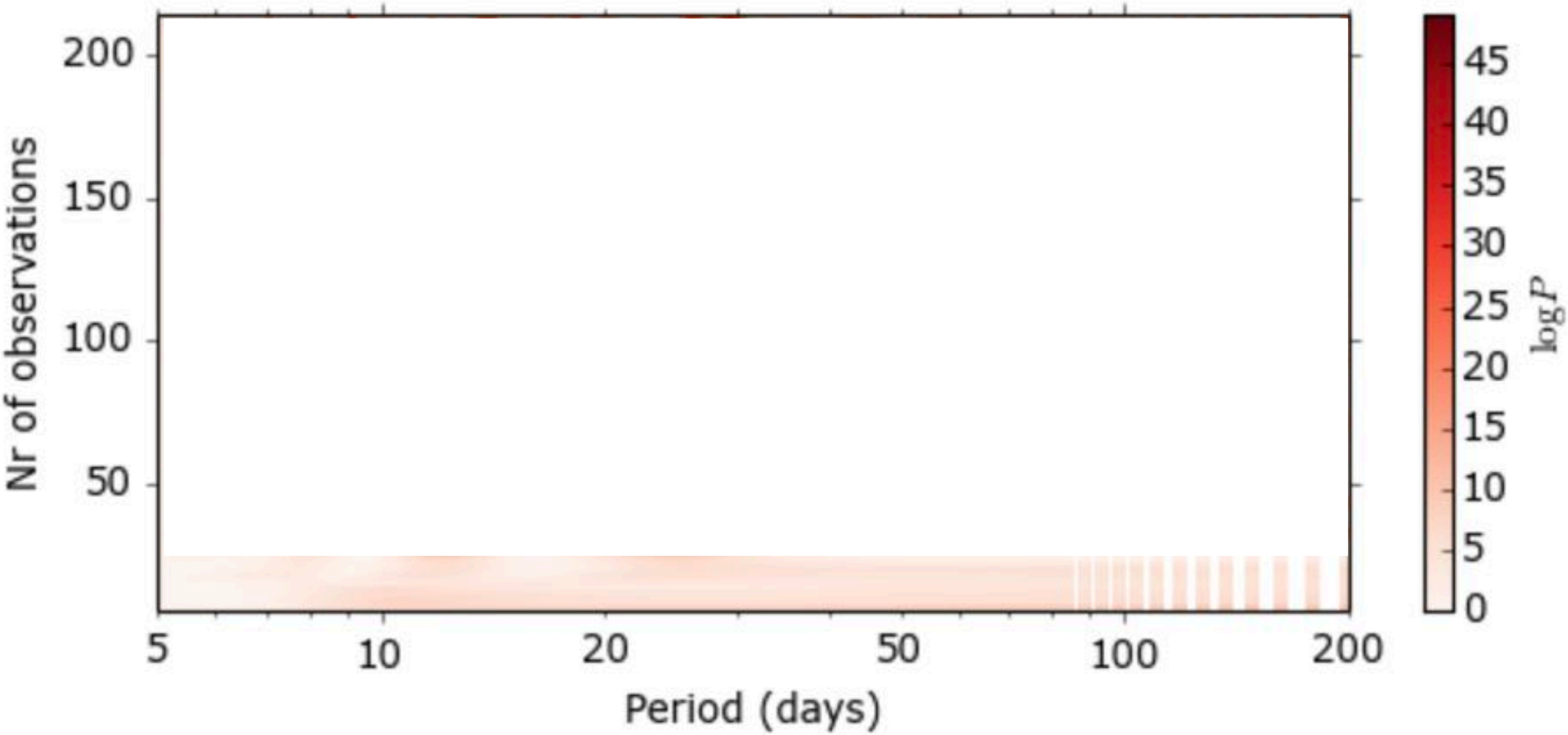

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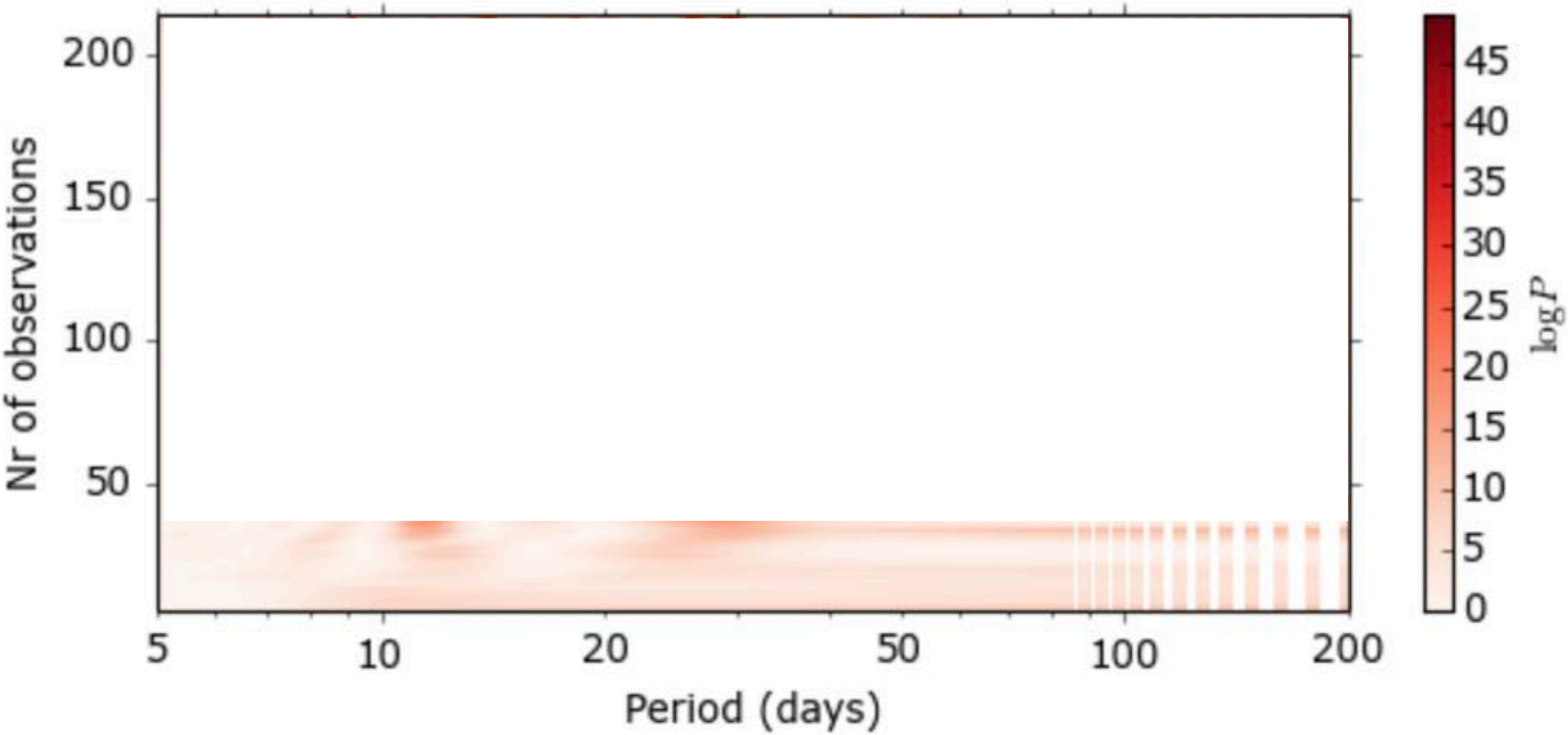

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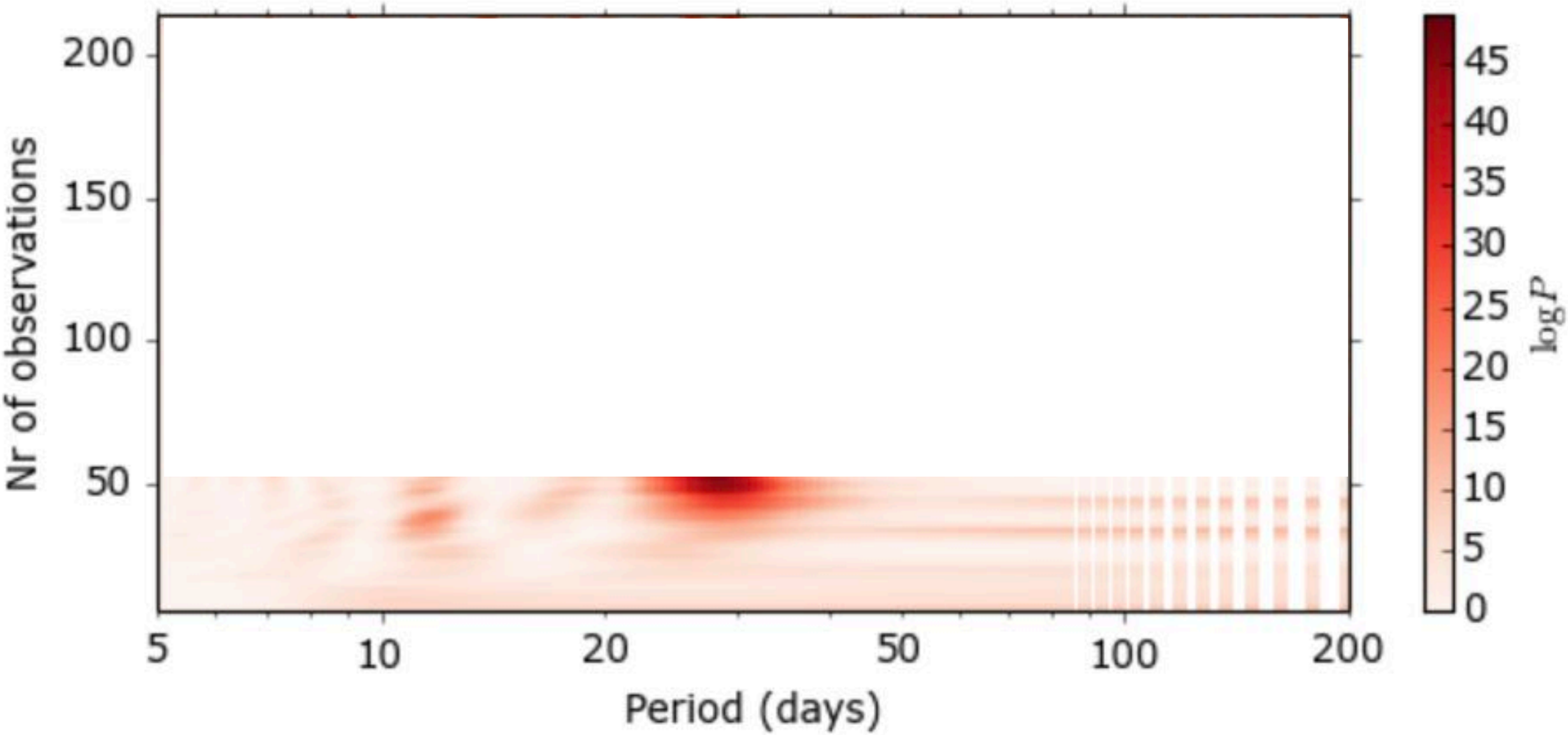

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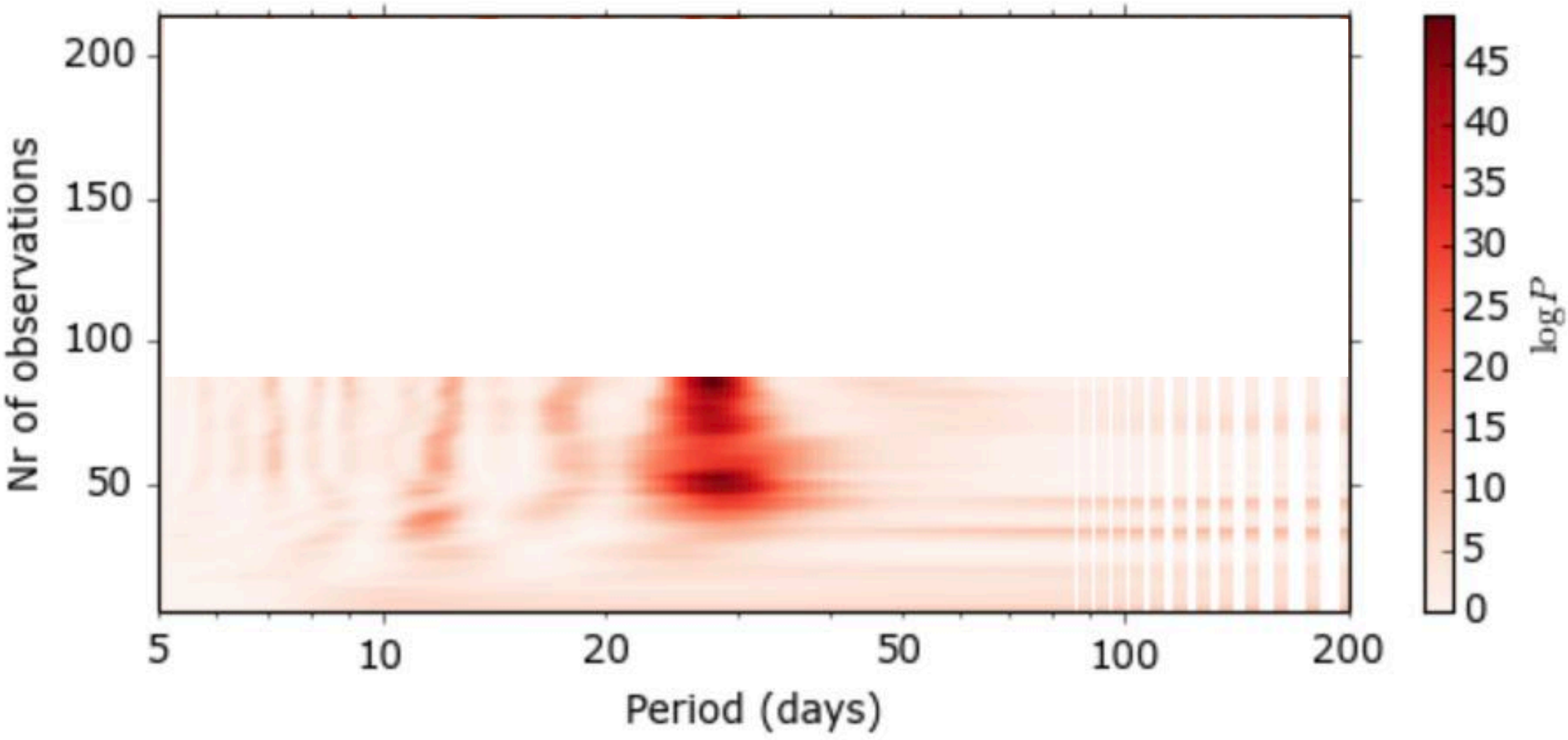

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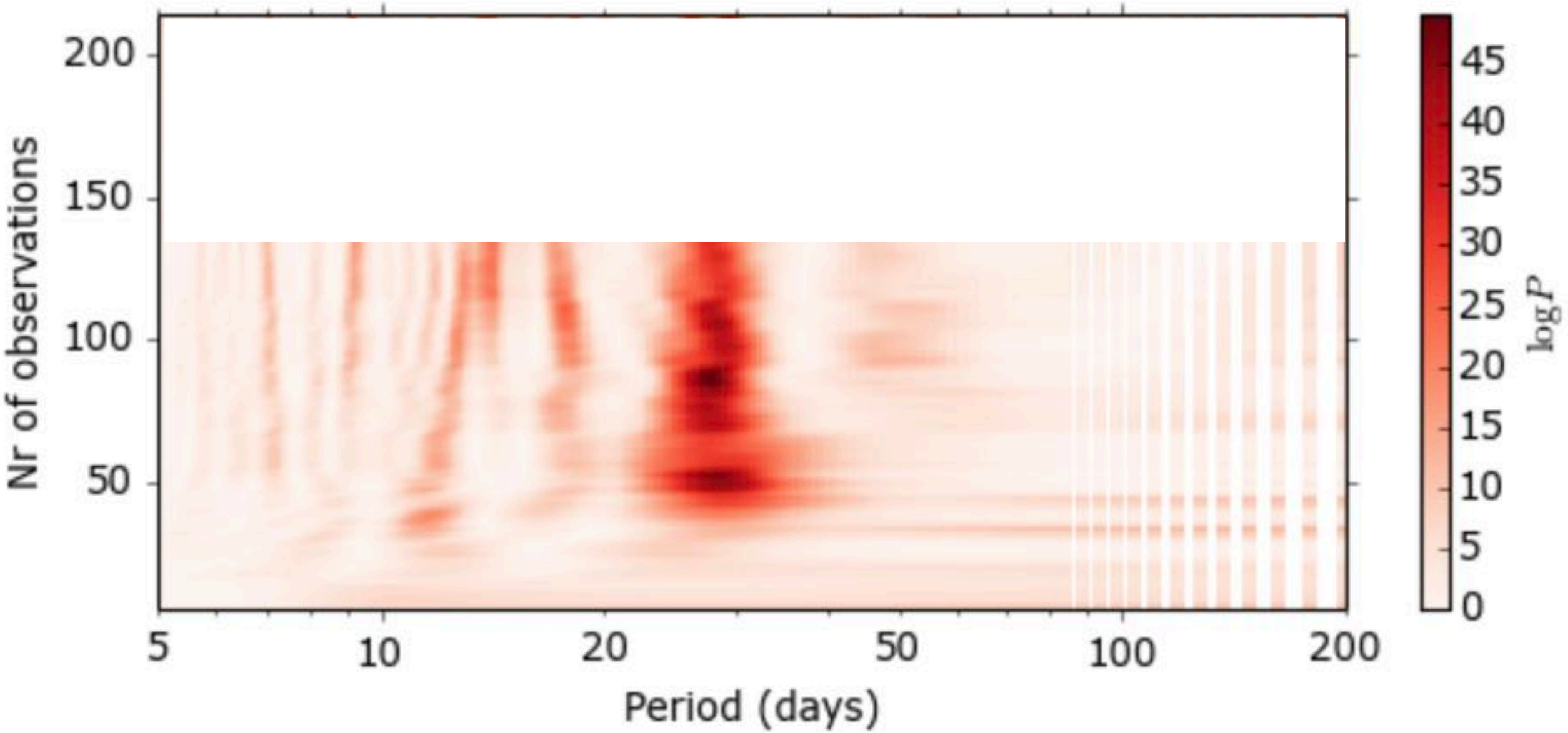
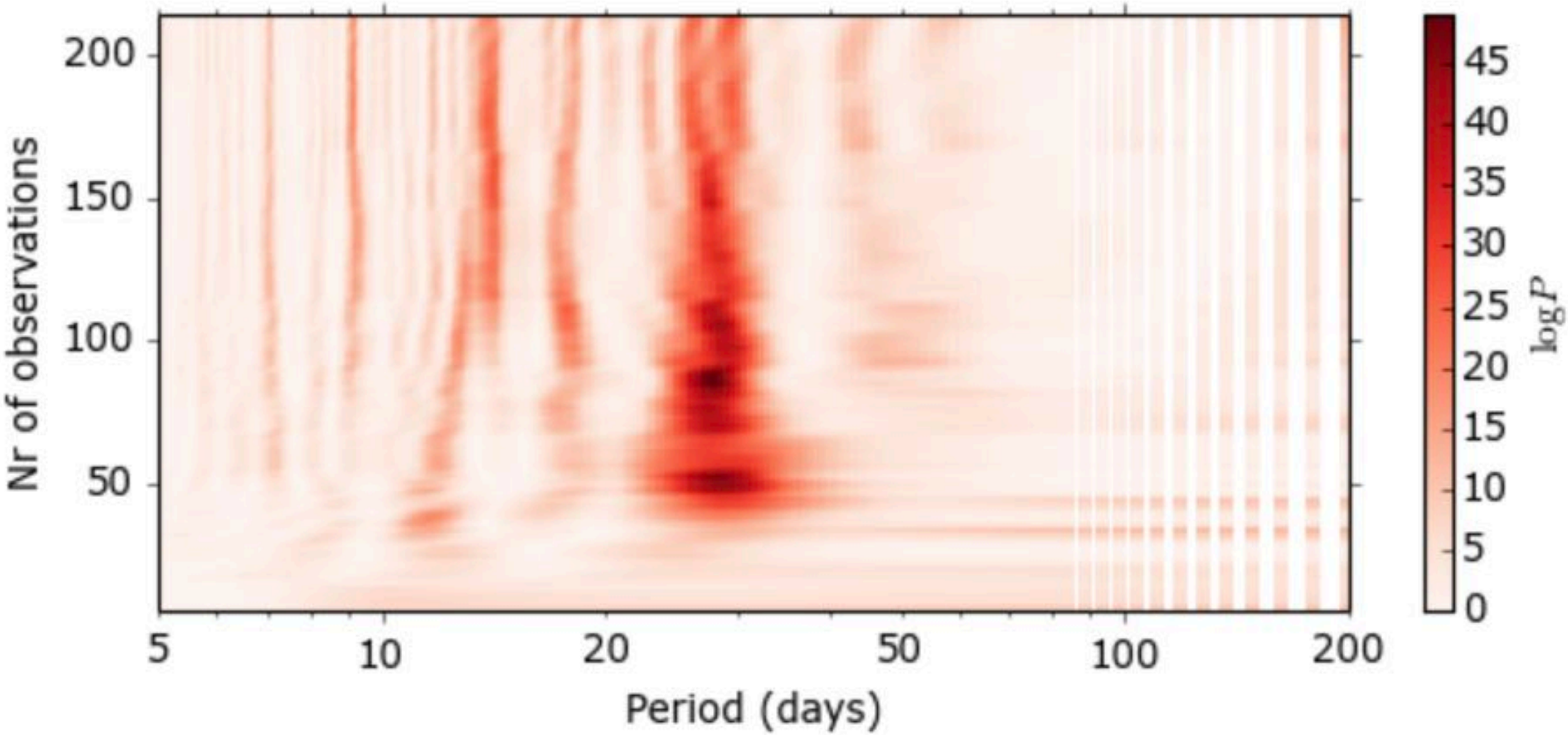


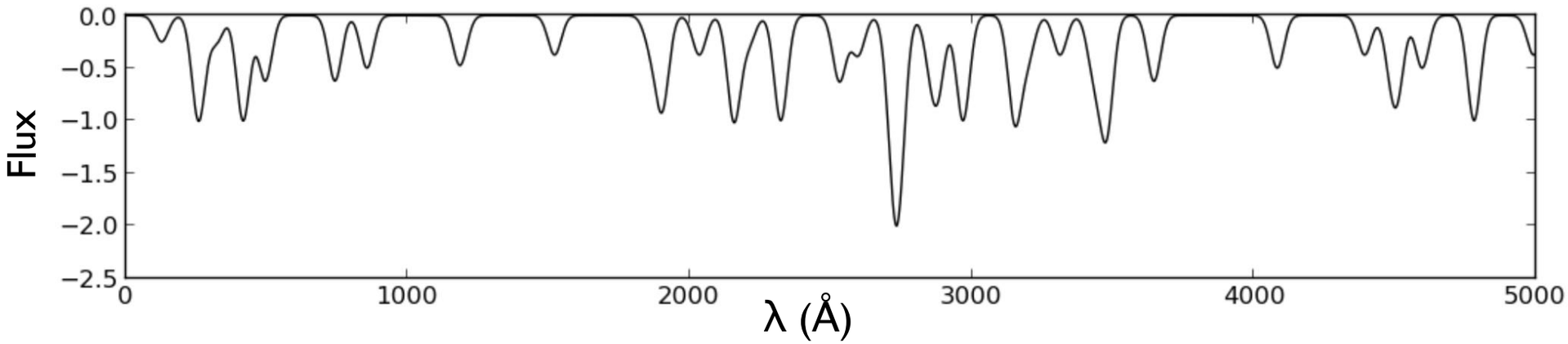
Stacked periodograms

Mortier et al. (2015); Mortier & Collier Cameron (2017)



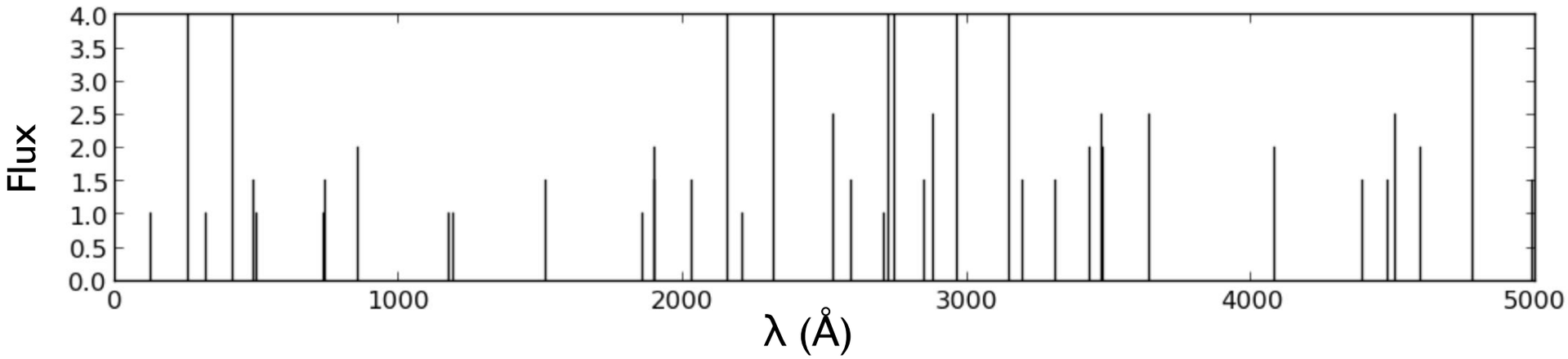
We get more than just radial-velocity measurements

Stellar spectrum



*

Line mask



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Cross-correlation function (CCF)

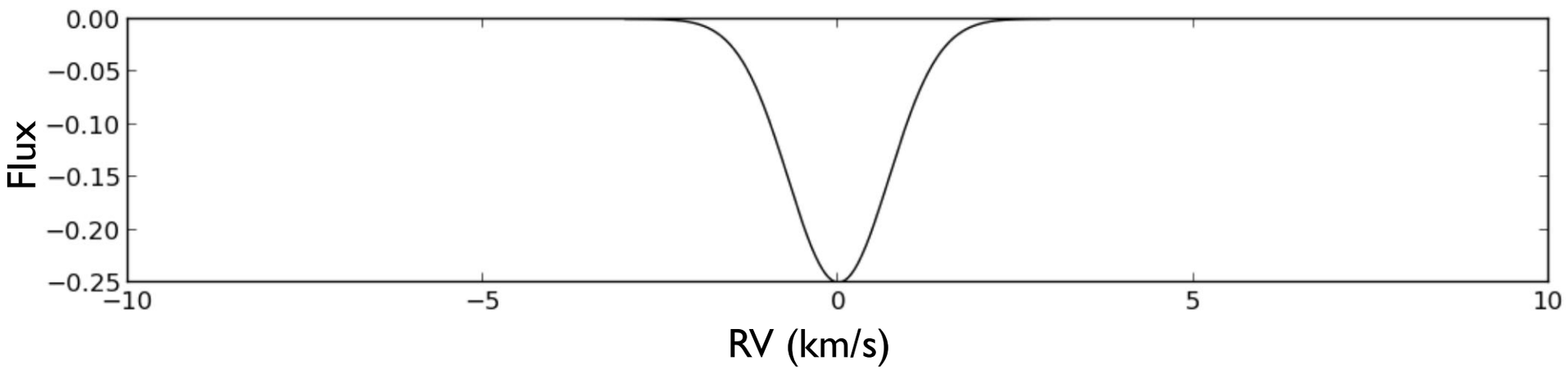
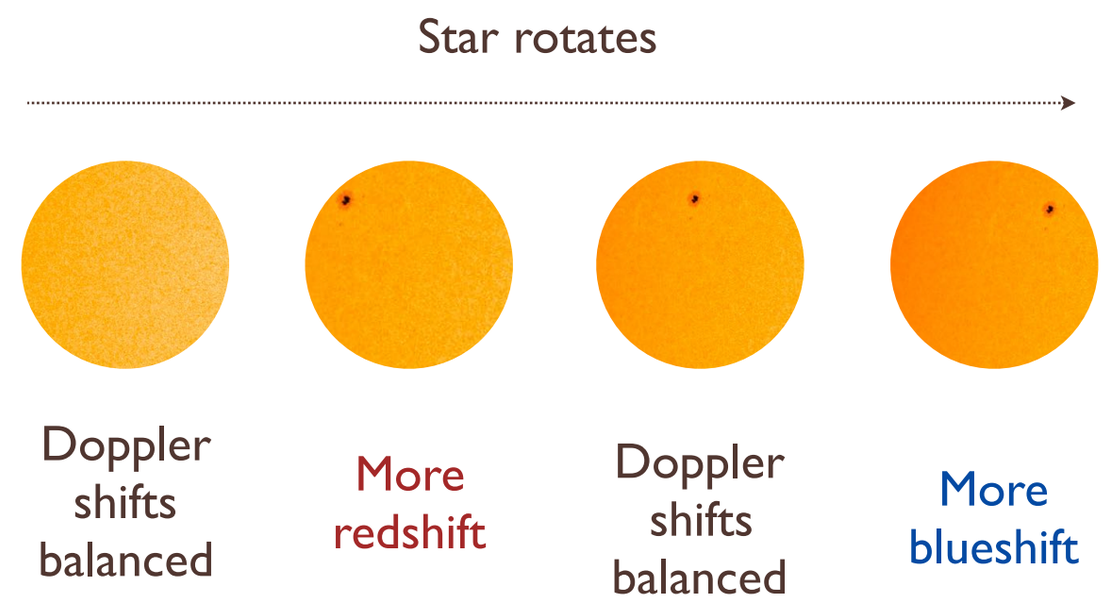
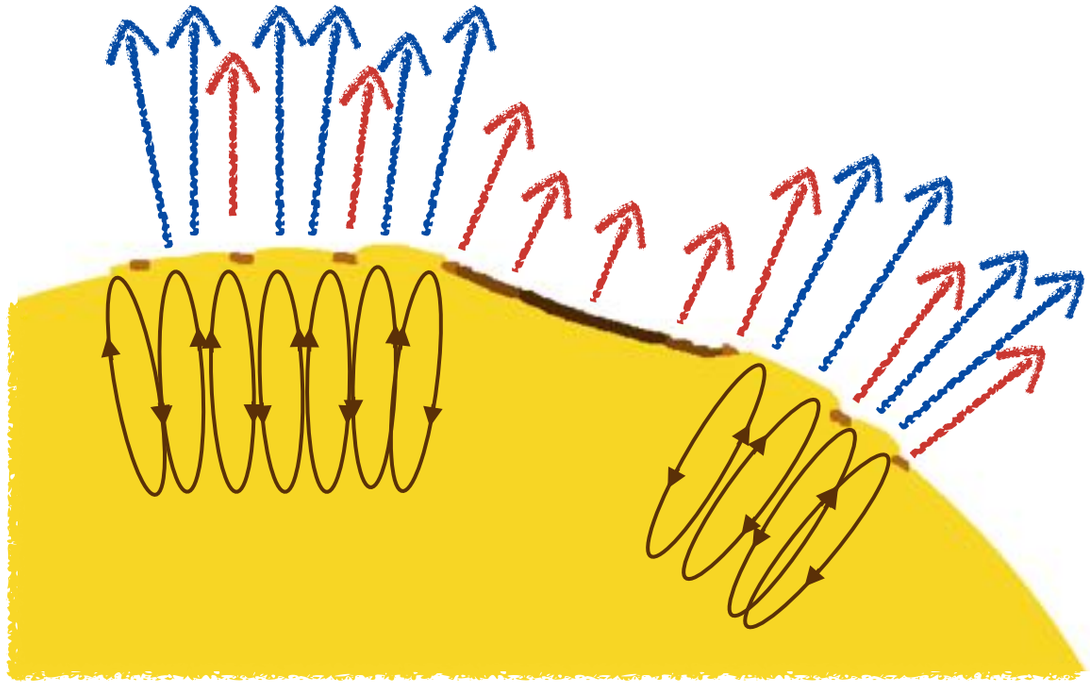
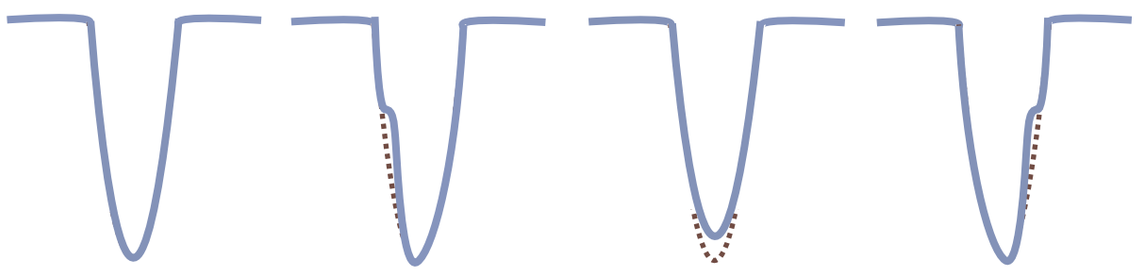


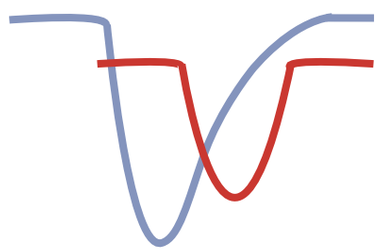
Image credit: Annelies Mortier

Spots, faculae and granulation distort the shape of spectral lines









Dravins 1981, see also Cegla et al. (2013)

Summary

- On the Sun, the dominant contribution to activity-induced radial-velocity variations is suppression of convective blueshift via faculae, not spots

- "Traditional" activity indicators (FWHM, BIS, log R'_{HK}) correlate with RV variations sometimes, but not always

- What can we do with Sun as an exoplanet-host star RV observations?
  - Identify direct proxy for faculae
  - Understand the effects of specific surface features on RV variations
  - Design and test physically-driven models for activity of other stars
  - Study the distortions in the spectral line profiles induced by activity
  - Test observing strategies

See tomorrow