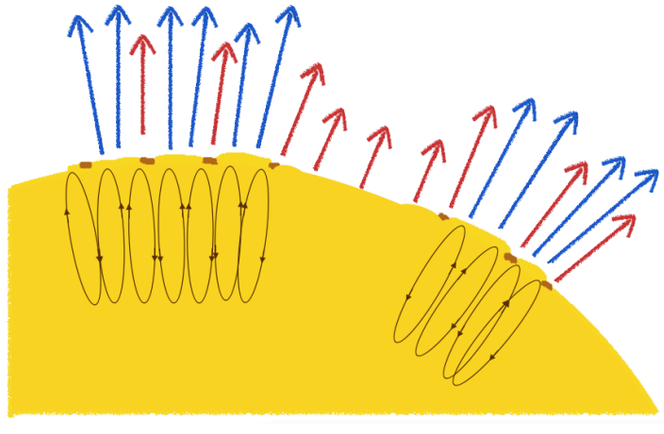
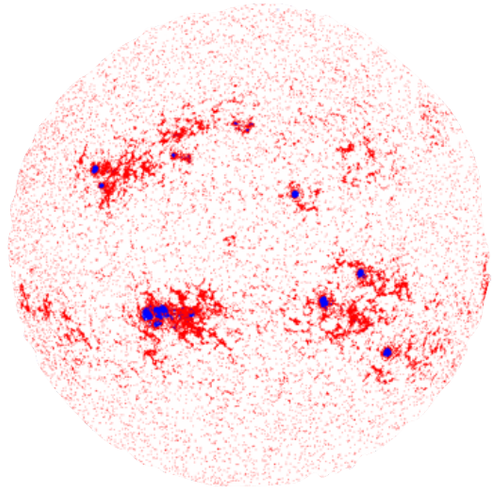
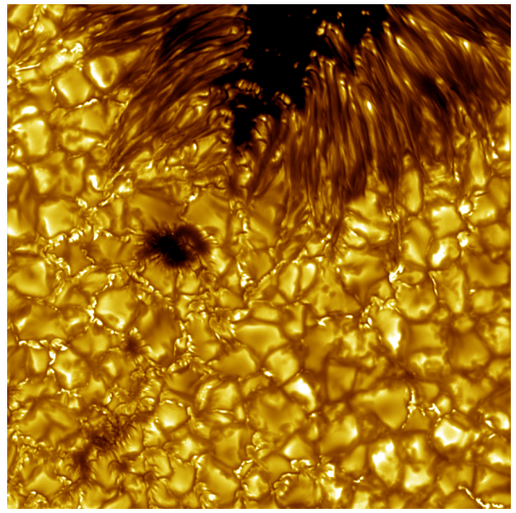
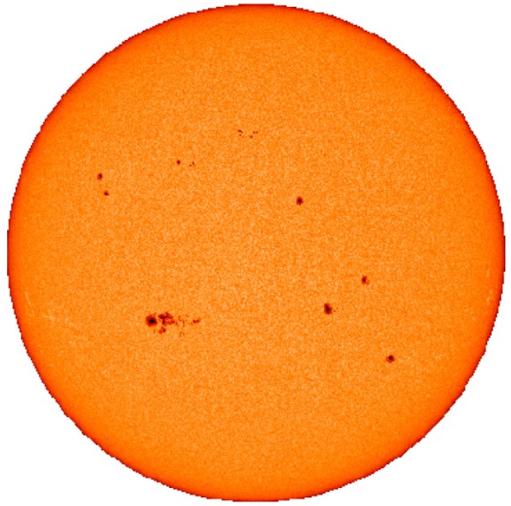
What can we learn from the Sun?









Raphaëlle D. Haywood

NASA Sagan Fellow, Harvard College Observatory

Images: Solar Telescope at HARPS-N (D. Phillips), suppression of convective blueshift (R. Haywood), solar faculae and spots (R. Haywood), solar granulation (Swedish 1-m Telescope, V. Henriques), Sun (HMI/SDO), Solar Dynamics Observatory (NASA).

Outline

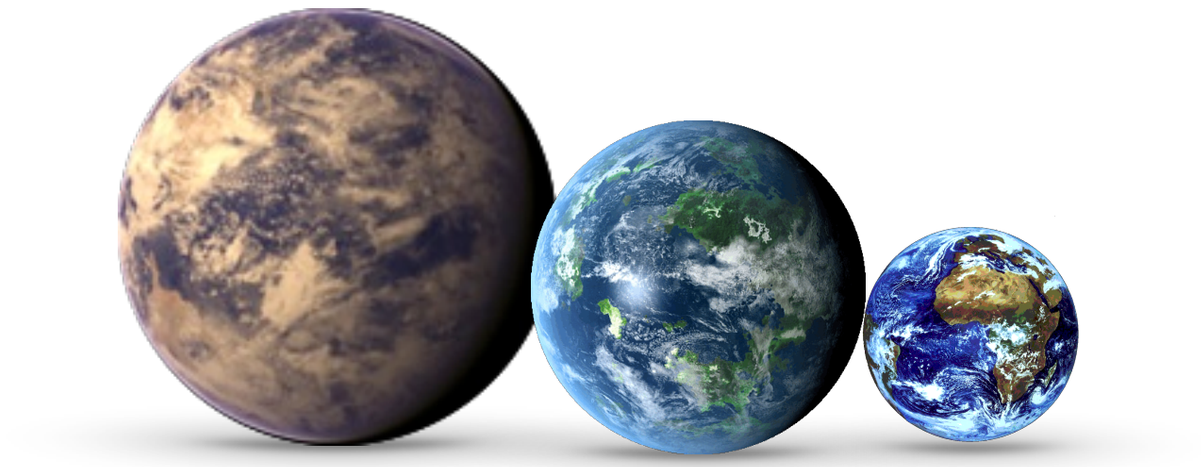
- What is the current obstacle to determining reliable masses of small planets through radial-velocity (RV) observations?

- What are the physical processes and surfaces features driving intrinsic RV variations on the Sun?

- Can we identify a good proxy to correct for activity-induced RV variations in other stars?

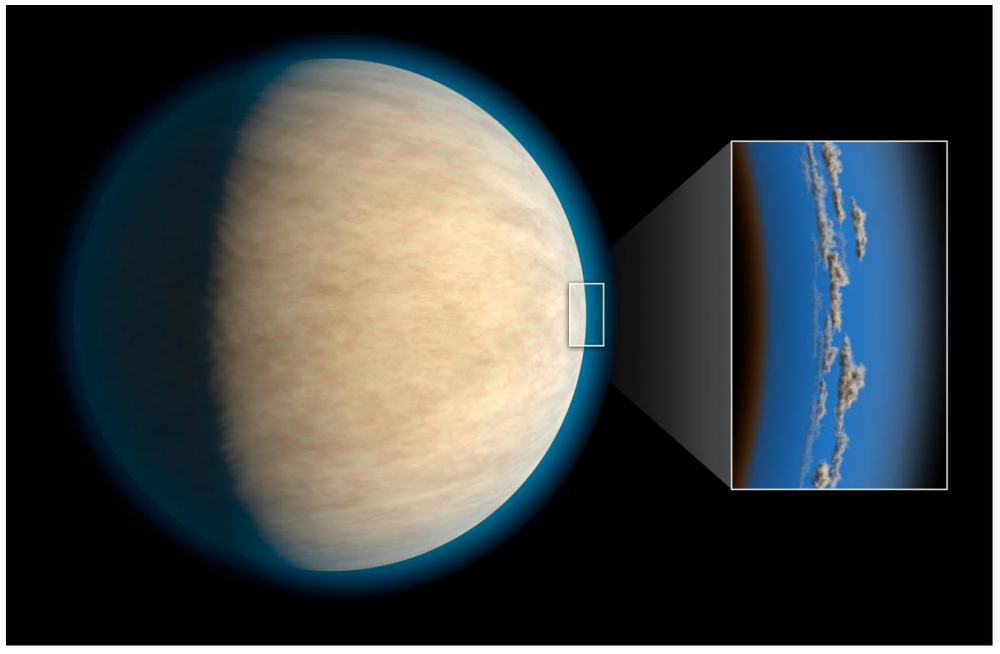
Mass and radius are the most fundamental parameters of a planet

Main inputs for models of interior composition/structure



Zeng & Sasselov (2013)

Mass is essential to interpreting observations of atmospheres



Morley et al. (2017)
Winn (2010)

Image credits: NASA

Radii are well constrained (5-10% precision).

Masses: *best* determinations have 15-30% precision.

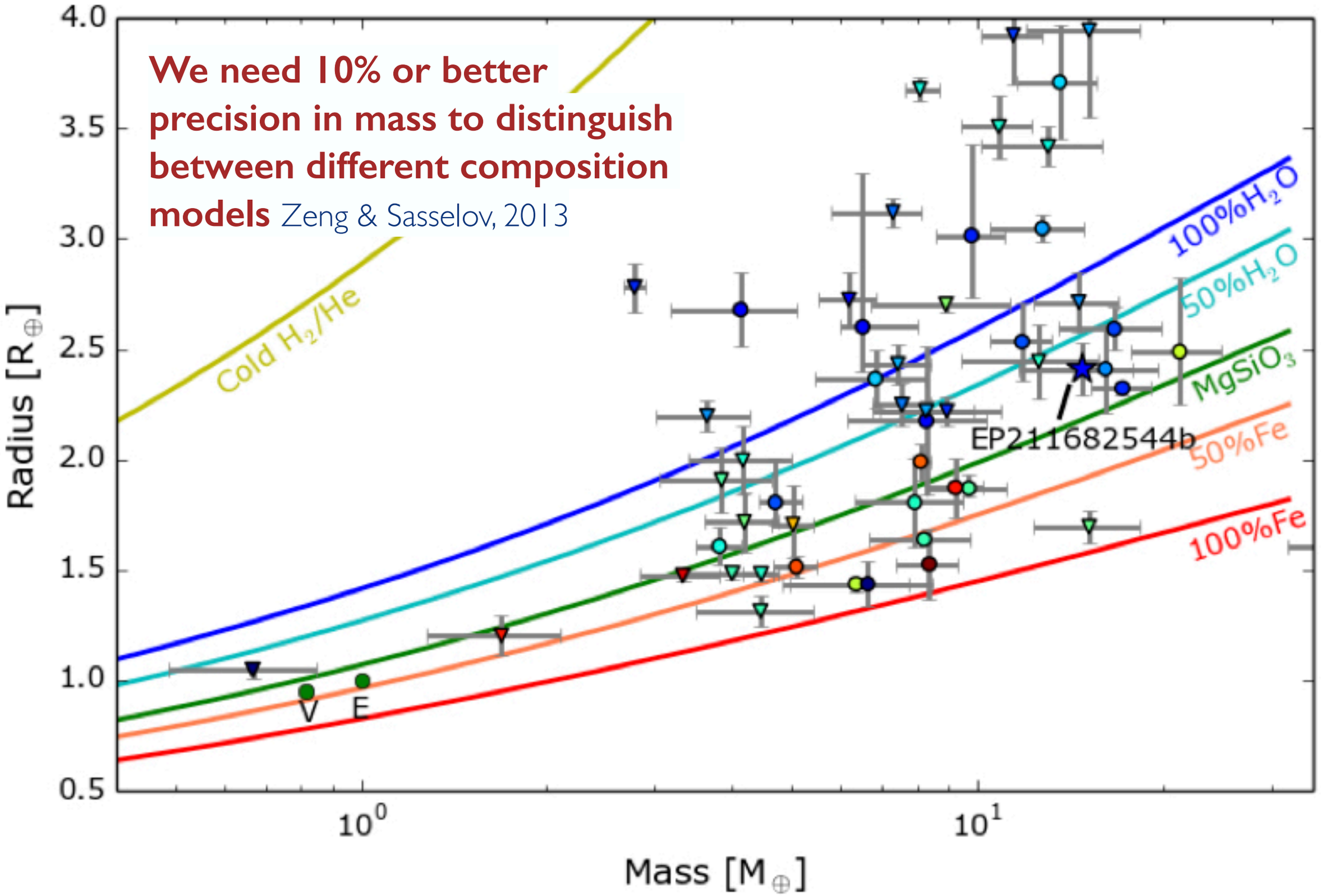
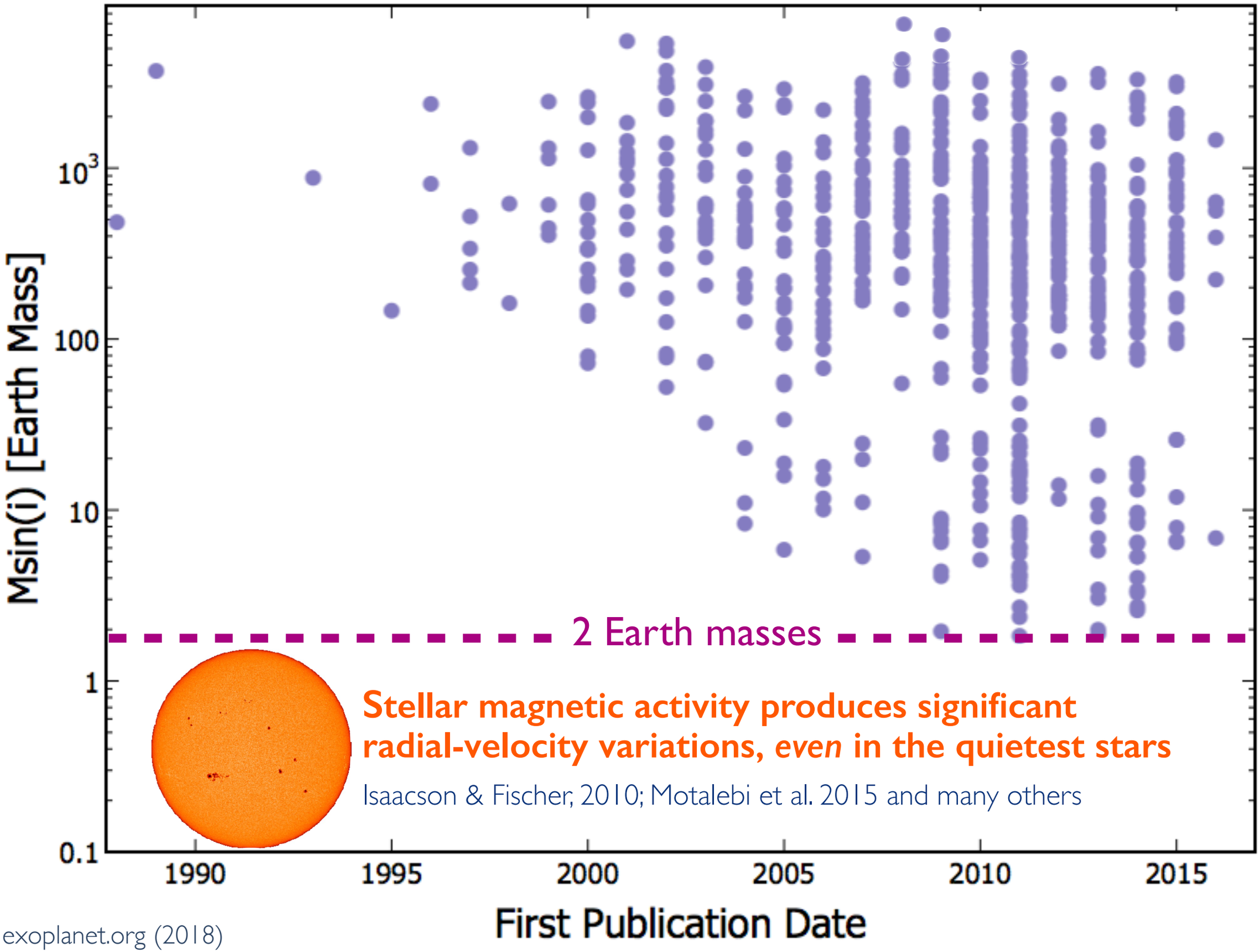


Figure from Mortier et al. (2018)

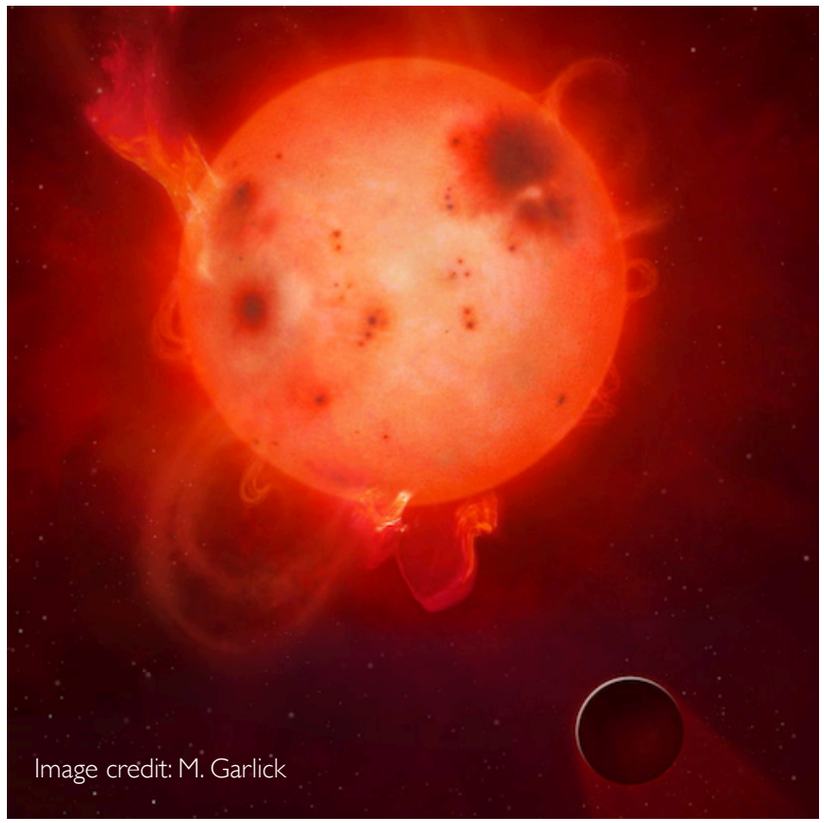
We cannot yet measure reliable masses of small, rocky planets



Plotted at exoplanet.org (2018)

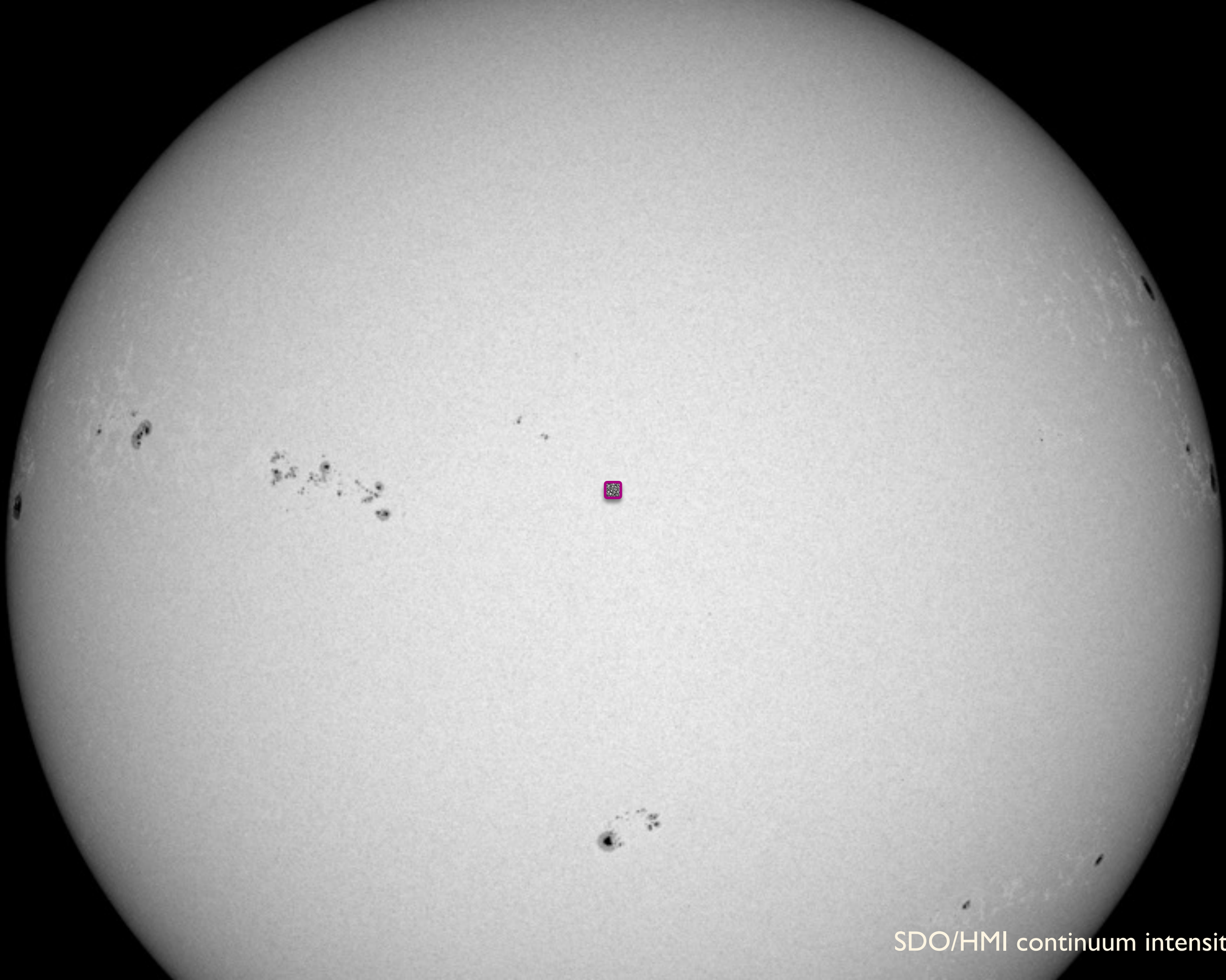
To determine precise masses of small, rocky planets, we need to understand the physical processes at play on the surfaces of the host stars

See Fischer et al. (2016), Dumusque et al. (2017) and others

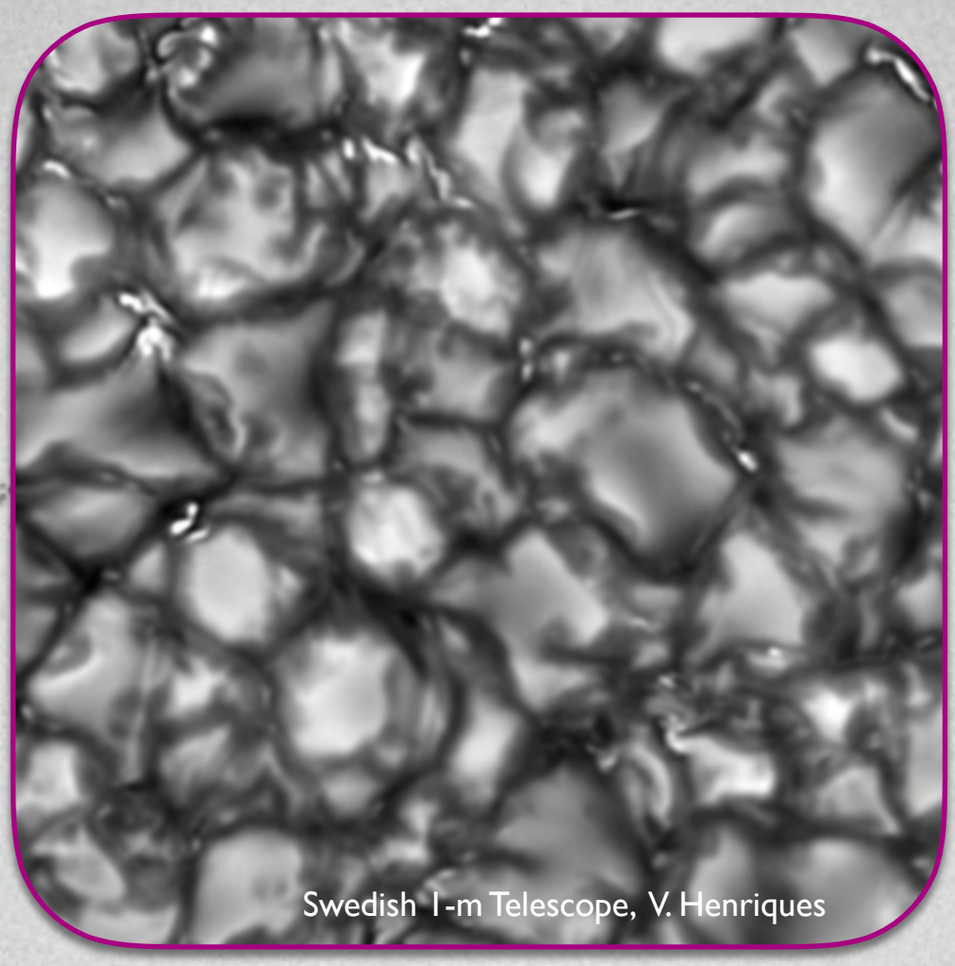


We can do this by studying the Sun!

SDO/HMI continuum intensity

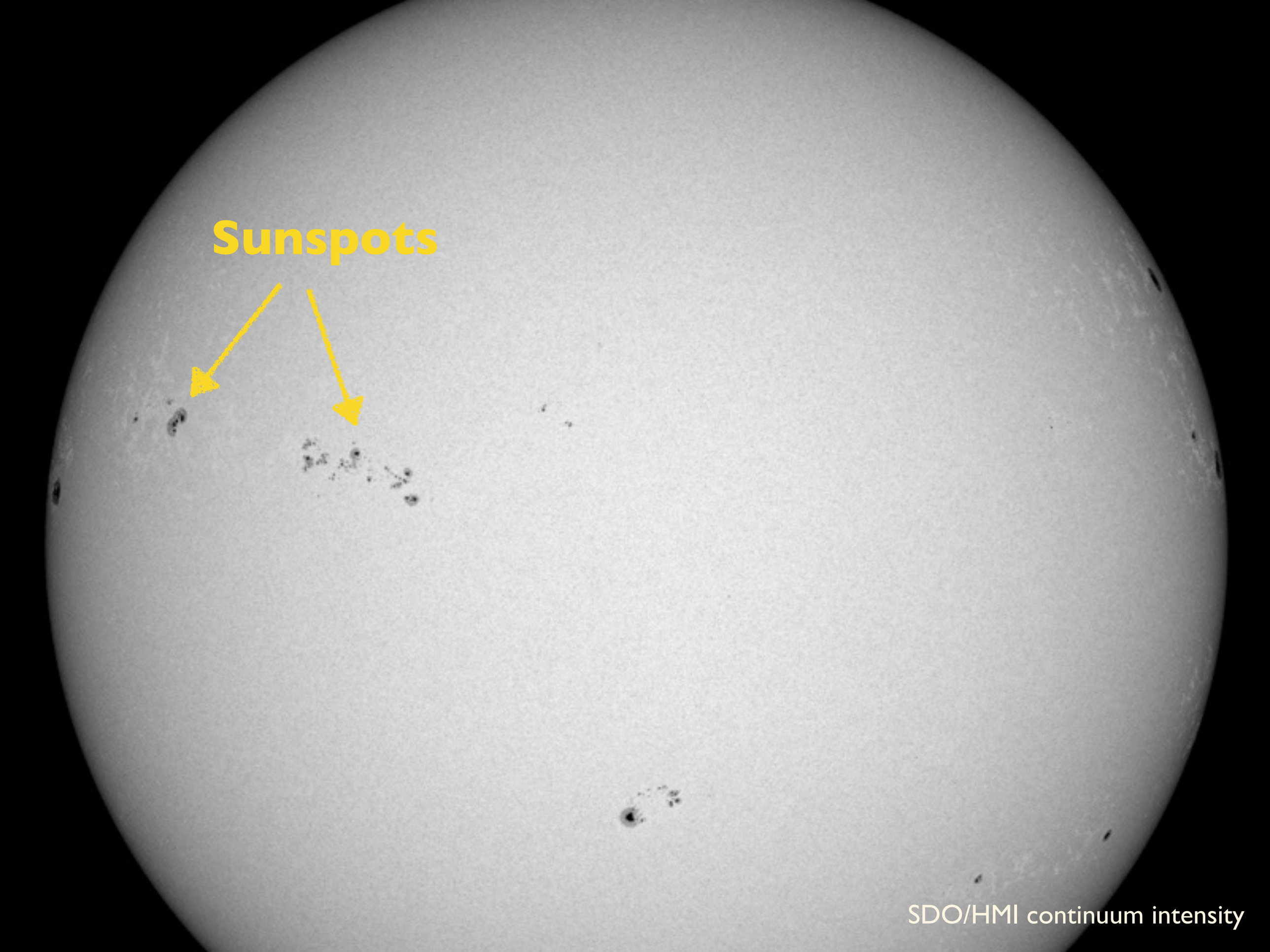


SDO/HMI continuum intensity

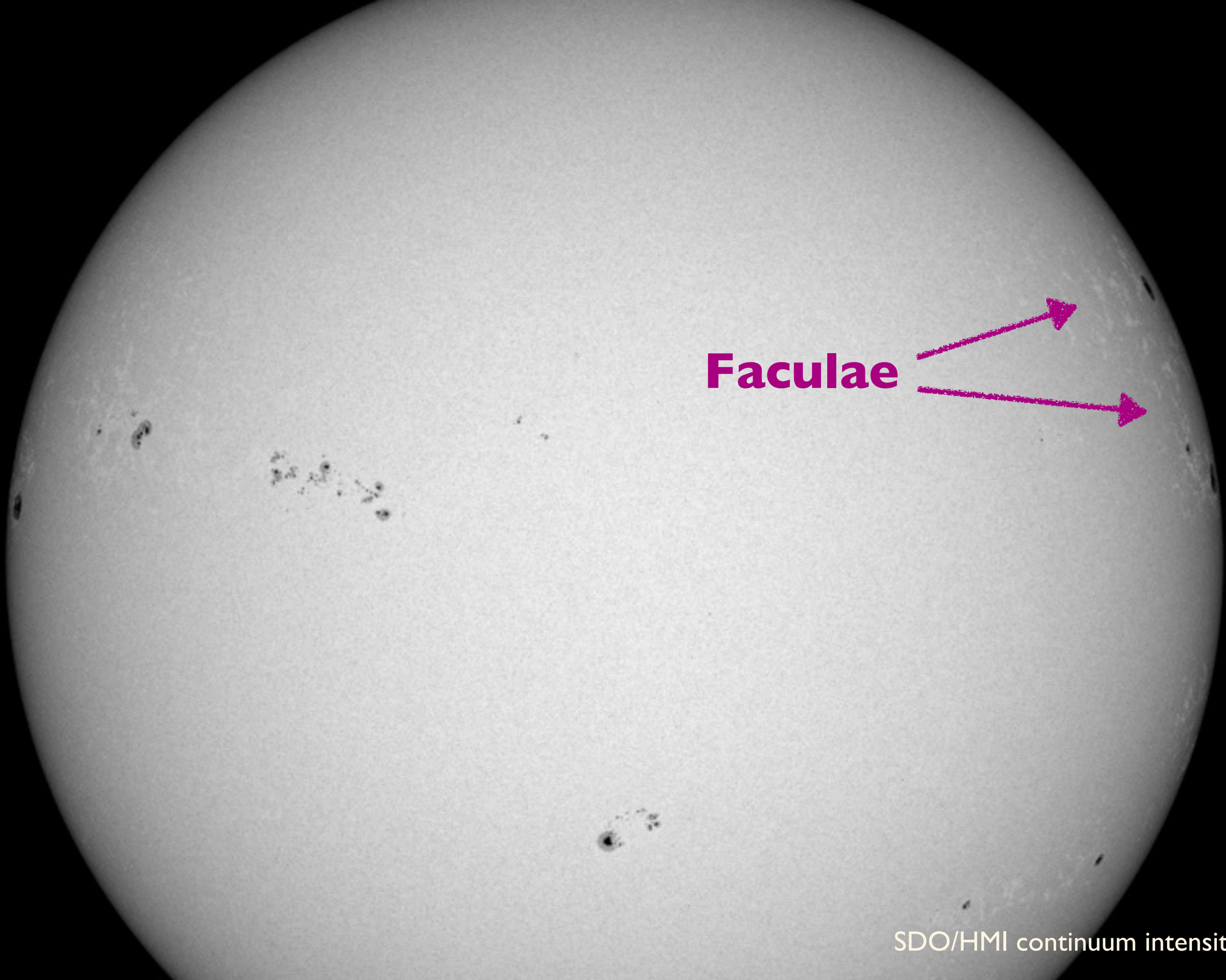


Swedish 1-m Telescope, V. Henriques

SDO/HMI continuum intensity



SDO/HMI continuum intensity



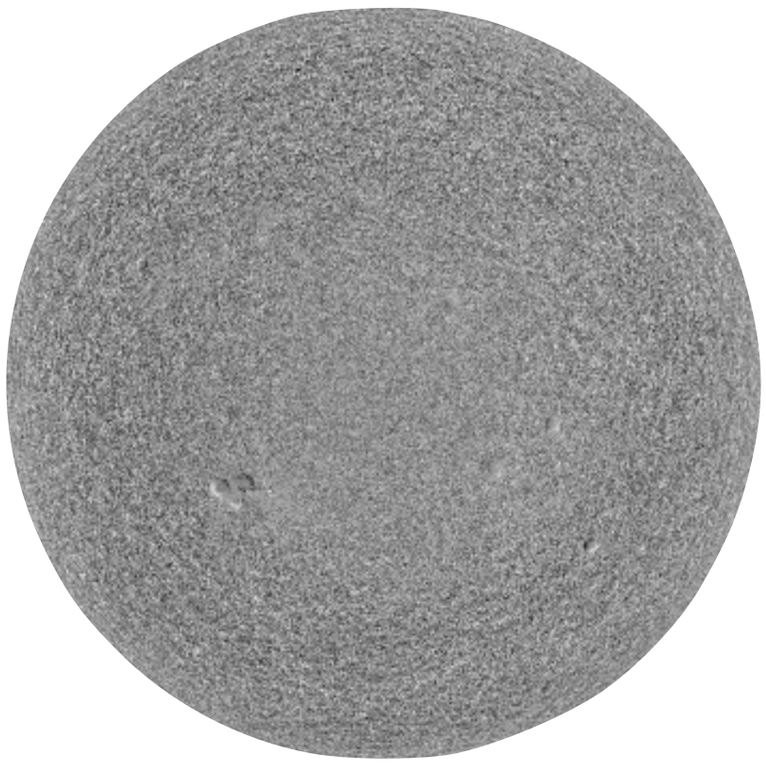
SDO/HMI continuum intensity

Faculae

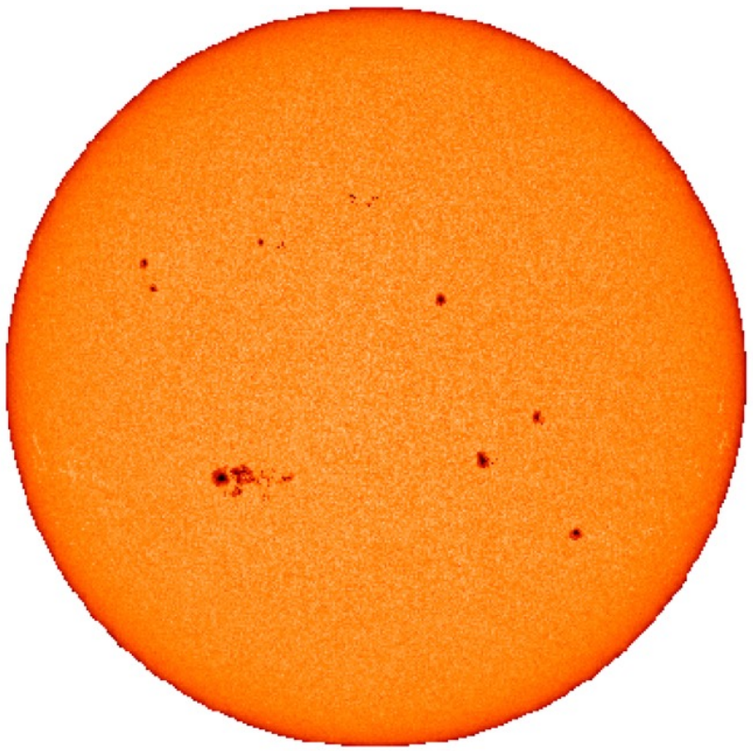
HMI continuum intensity

Estimating the radial-velocity variations of the Sun

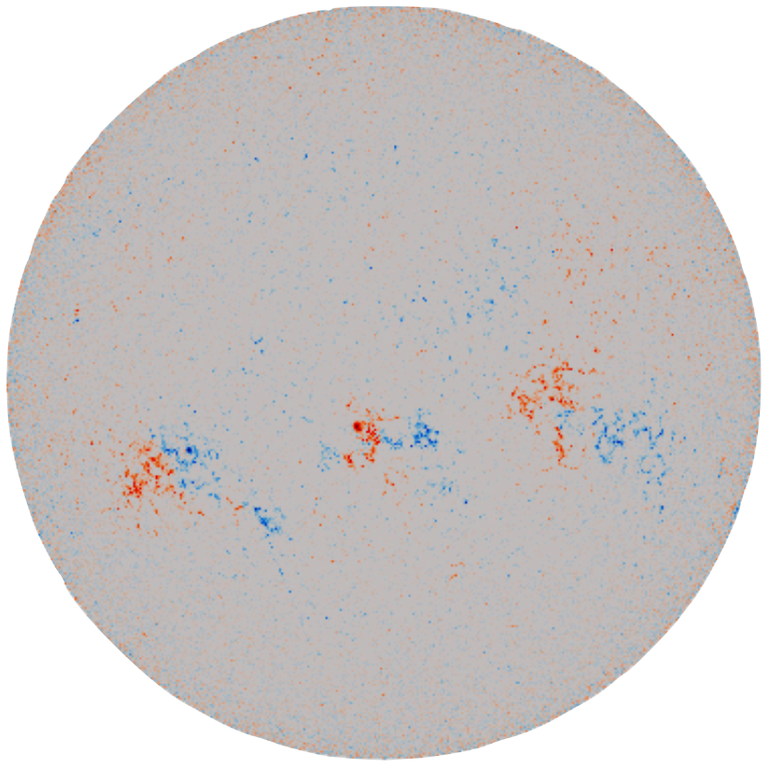
Using spatially resolved images
from the Helioseismic & Magnetic Imager (HMI)
onboard the Solar Dynamics Observatory (SDO)



Doppler image



Continuum intensity

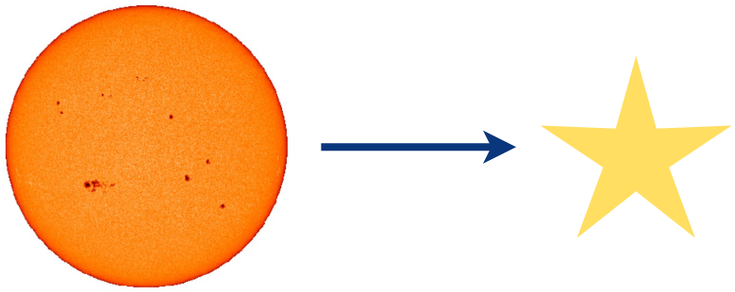


Magnetic field

Technique developed by Meunier (2010) and Fligge et al. (2000)

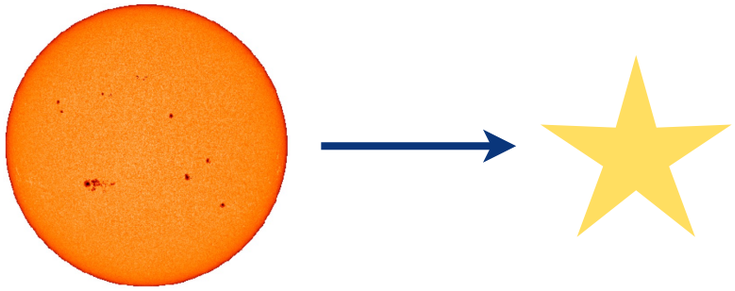
Images: SDO/HMI, NASA

In parallel, we are observing the Sun with the exoplanet hunter HARPS-N



Solar/HARPS-N Project:
Glenday, Phillips et al. (2012), Dumusque et al. (2016), Phillips et al. (2016)

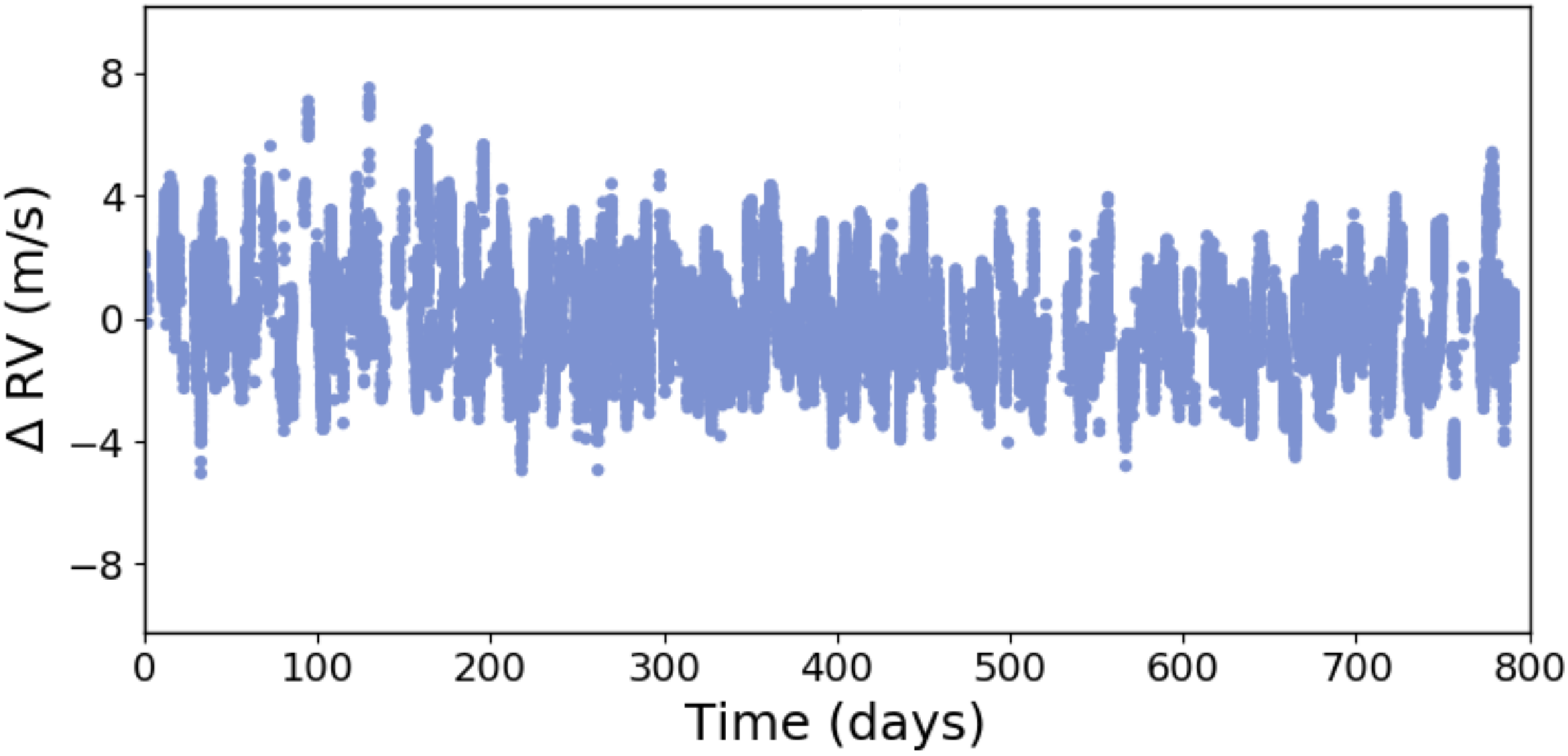
In parallel, we are observing the Sun with the exoplanet hunter HARPS-N



Solar/HARPS-N Project:
Glenday, Phillips et al. (2012), Dumusque et al. (2016), Phillips et al. (2016)

RV variations of the Sun as a distant, point-like star, with no planets orbiting it!

>26000 observations, photon noise rms scatter: 40-50 cm/s



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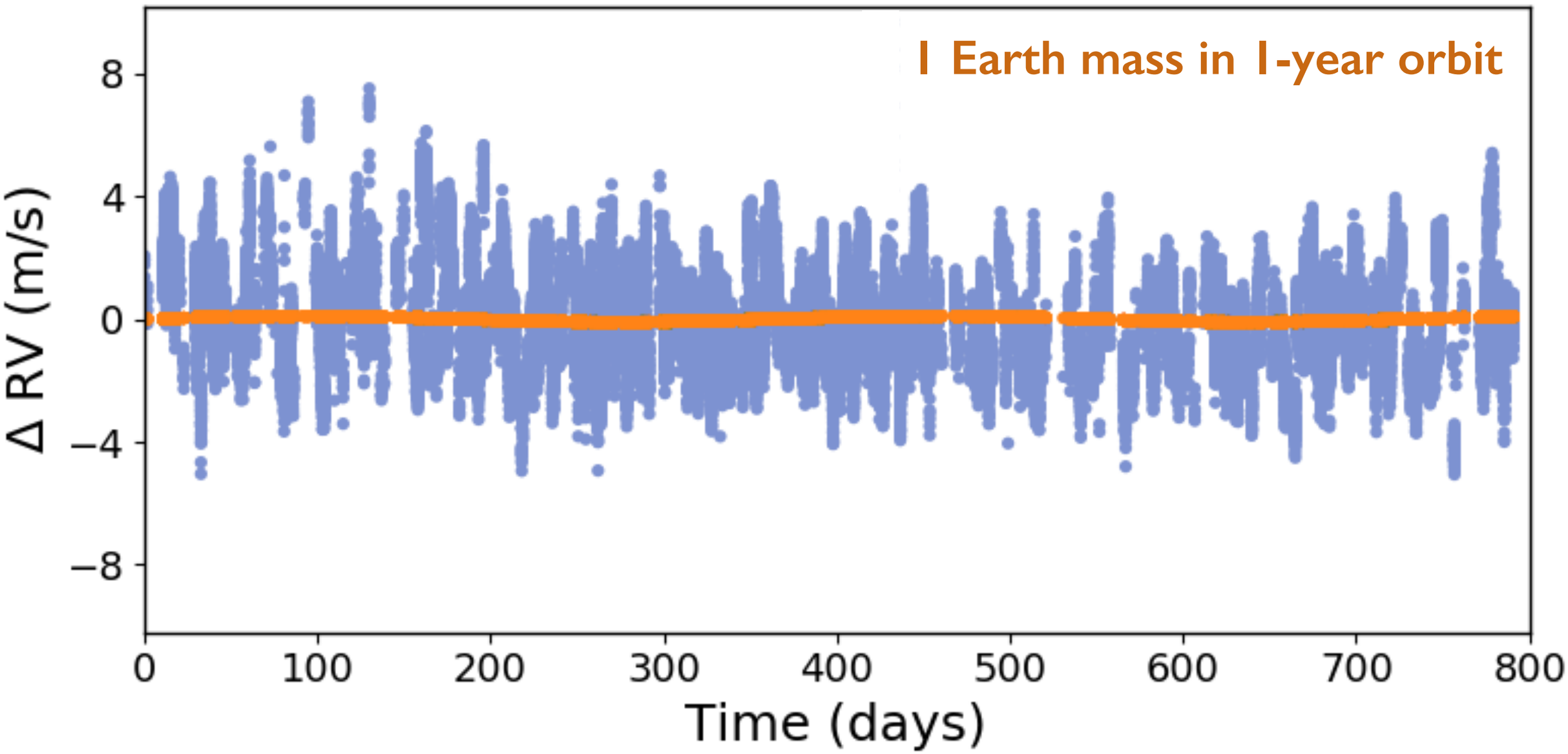

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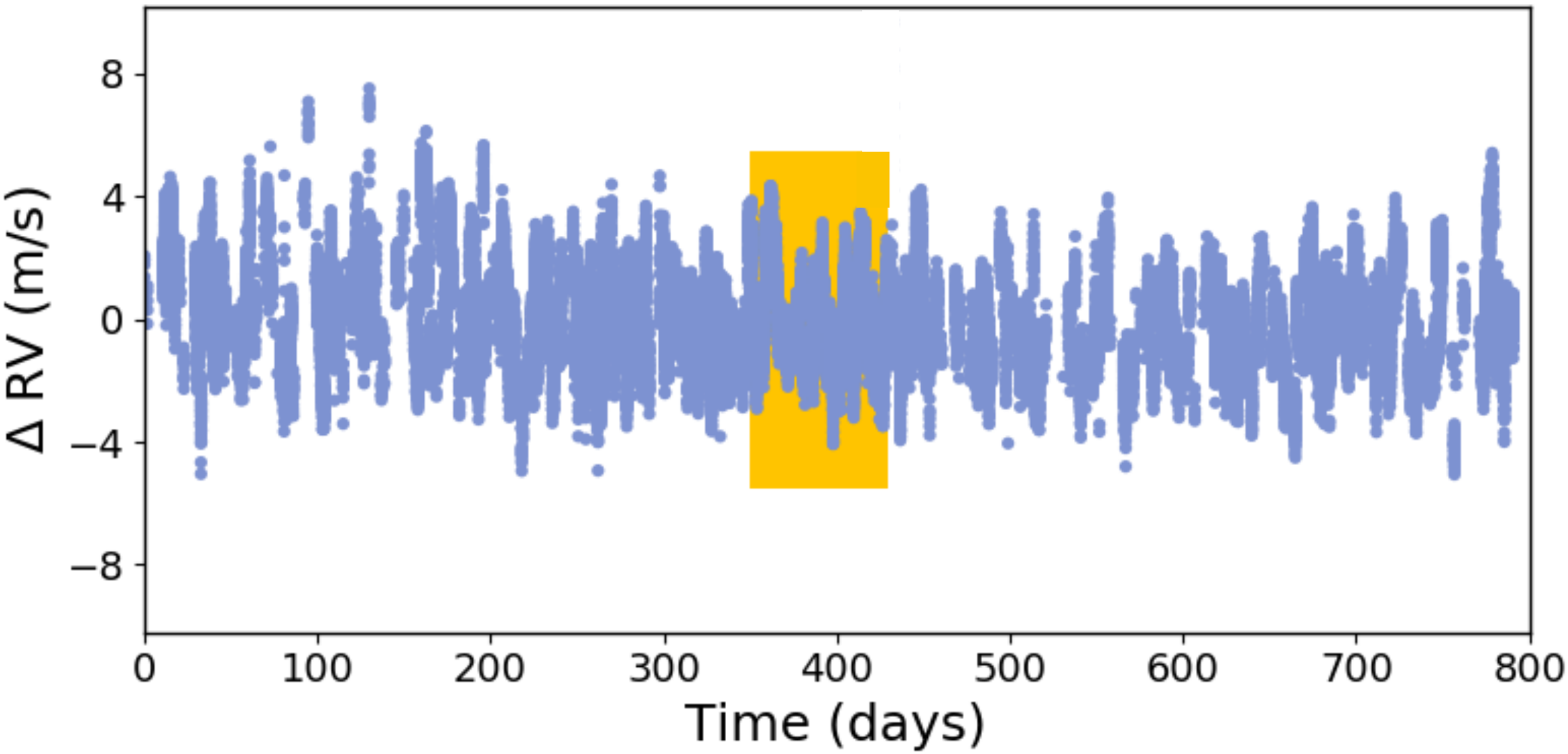
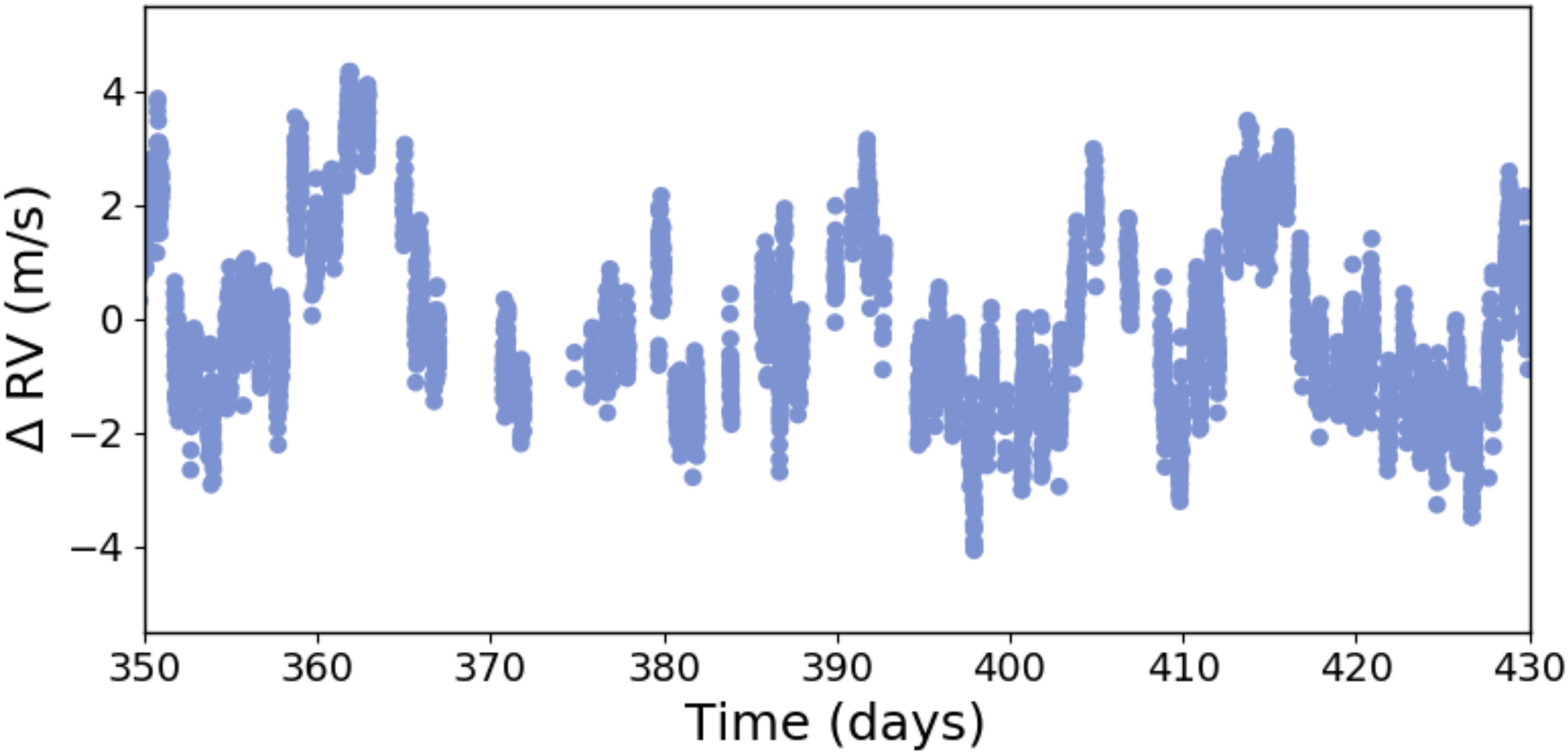


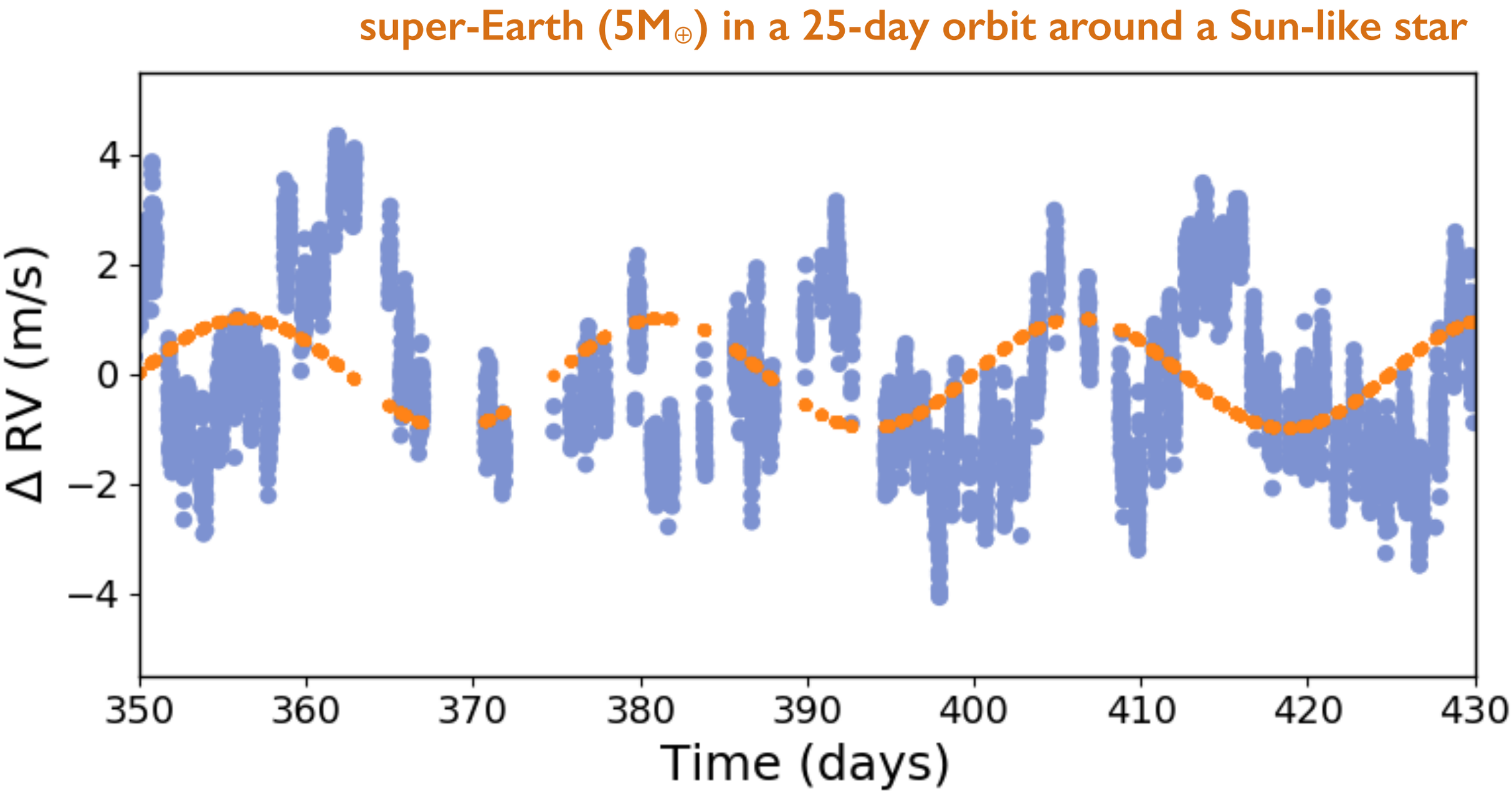
Solar/HARPS-N Project:
Glenday, Phillips et al. (2012), Dumusque et al. (2016), Phillips et al. (2016)

RV variations of the Sun over a few solar rotations



Solar/HARPS-N Project:
Glenday, Phillips et al. (2012), Dumusque et al. (2016), Phillips et al. (2016)

RV variations of the Sun over a few solar rotations



Solar/HARPS-N Project:
Glenday, Phillips et al. (2012), Dumusque et al. (2016), Phillips et al. (2016)

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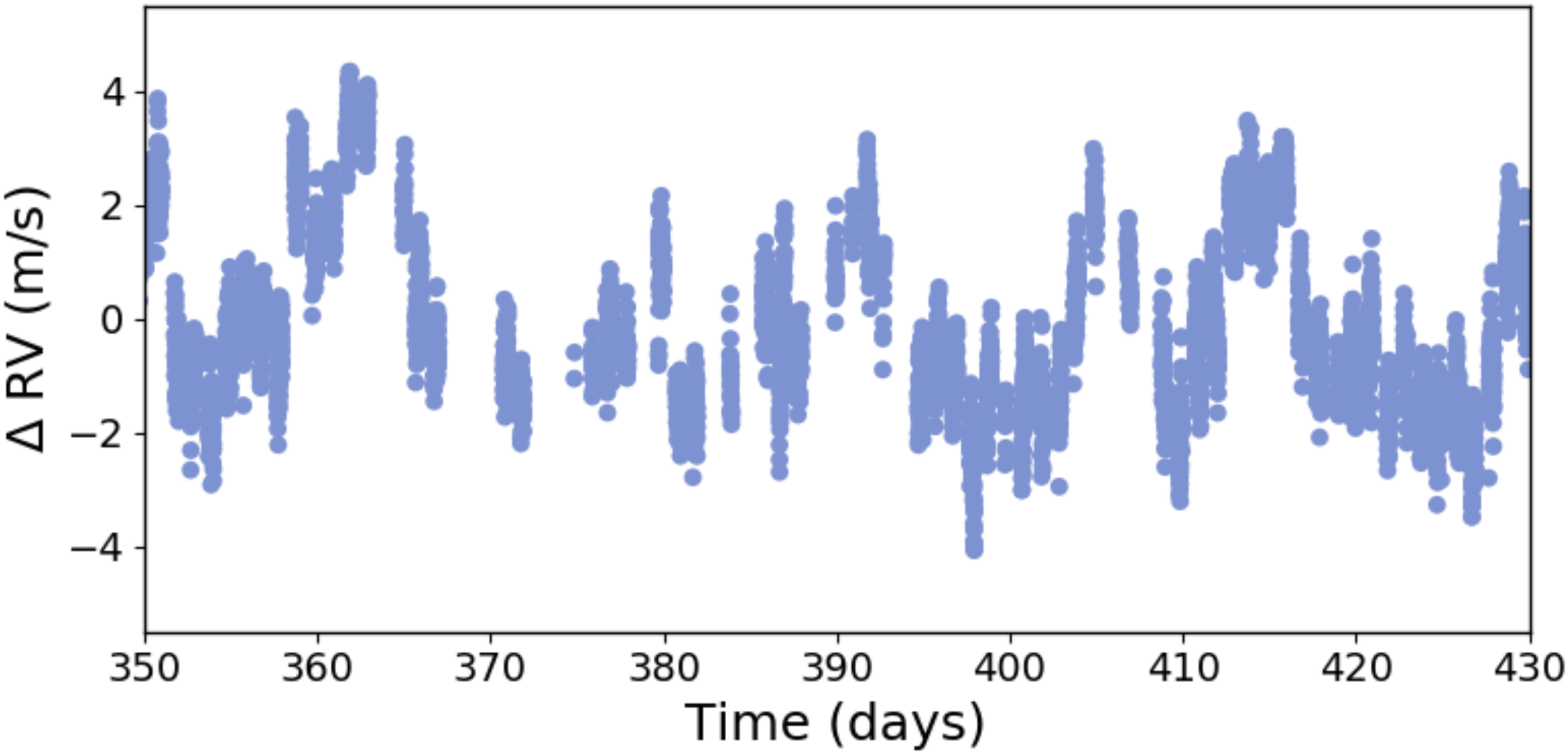
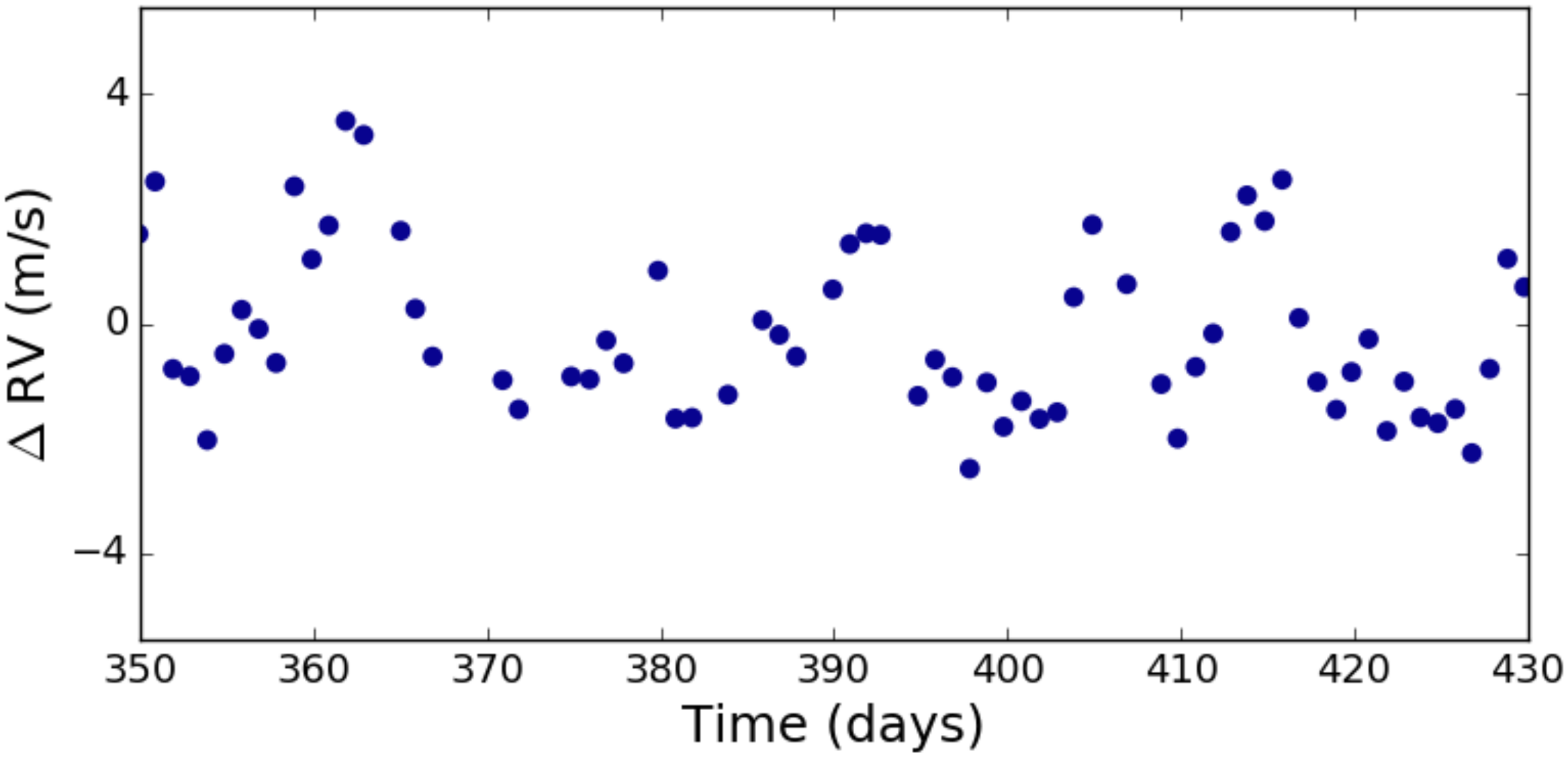


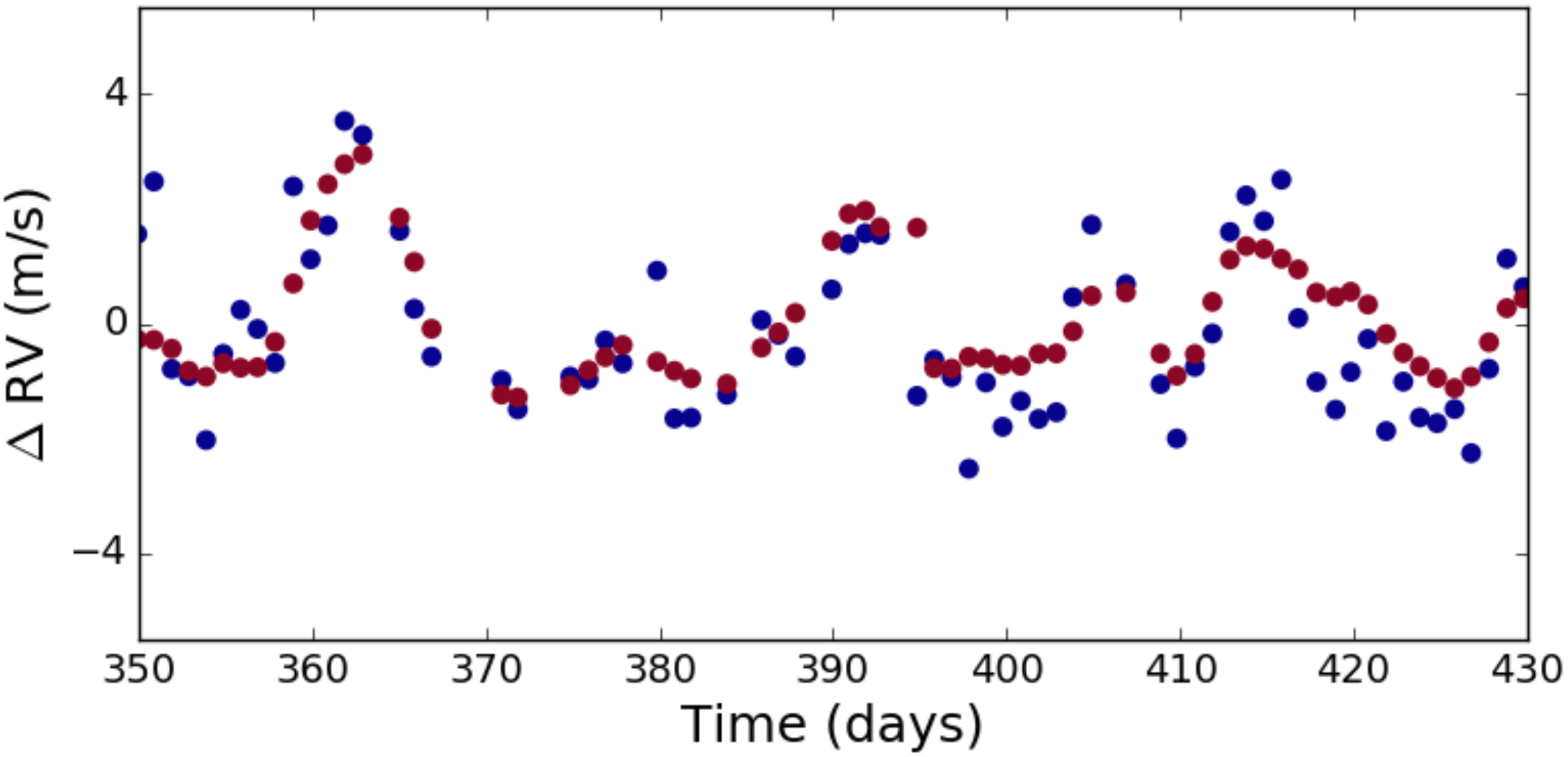
Solar/HARPS-N Project:
Glenday, Phillips et al. (2012), Dumusque et al. (2016), Phillips et al. (2016)

RV variations of the Sun over a few solar rotations (daily averages)



Milbourne, Haywood et al. (2019)

RV variations of the Sun over a few solar rotations (daily averages)

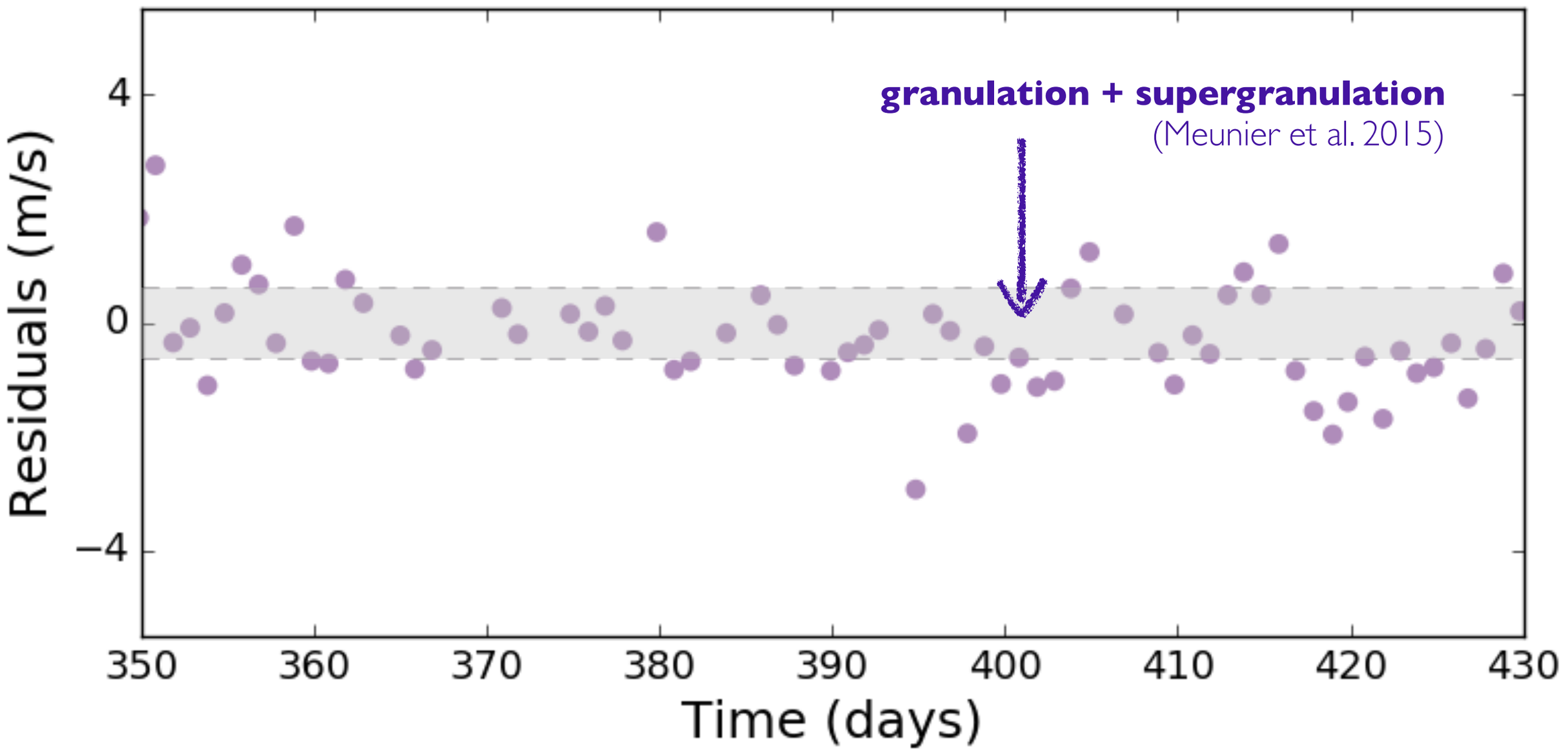


RVs estimated from SDO/HMI images

Haywood et al. (2016)

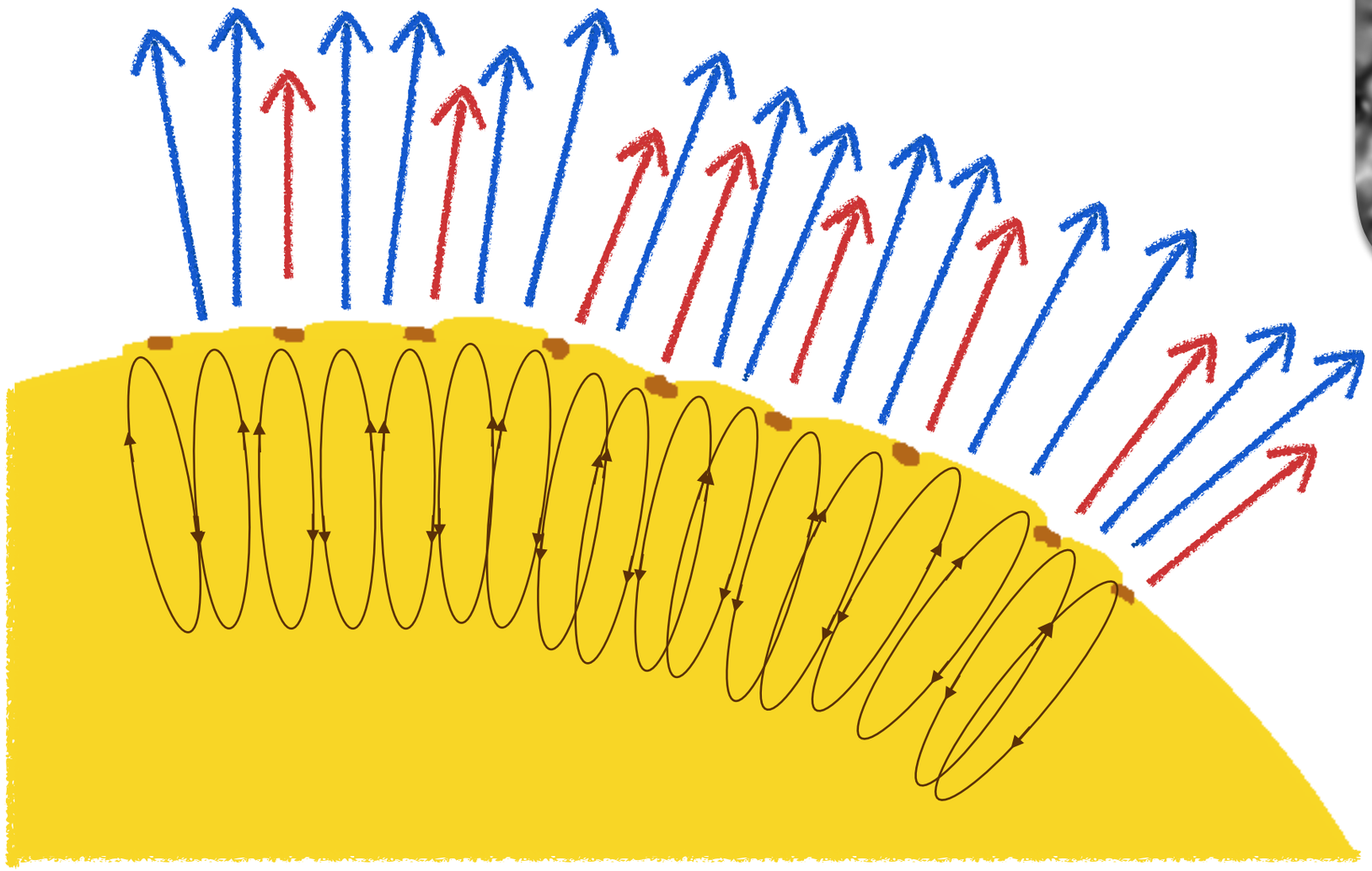
Milbourne, Haywood et al. (2019)

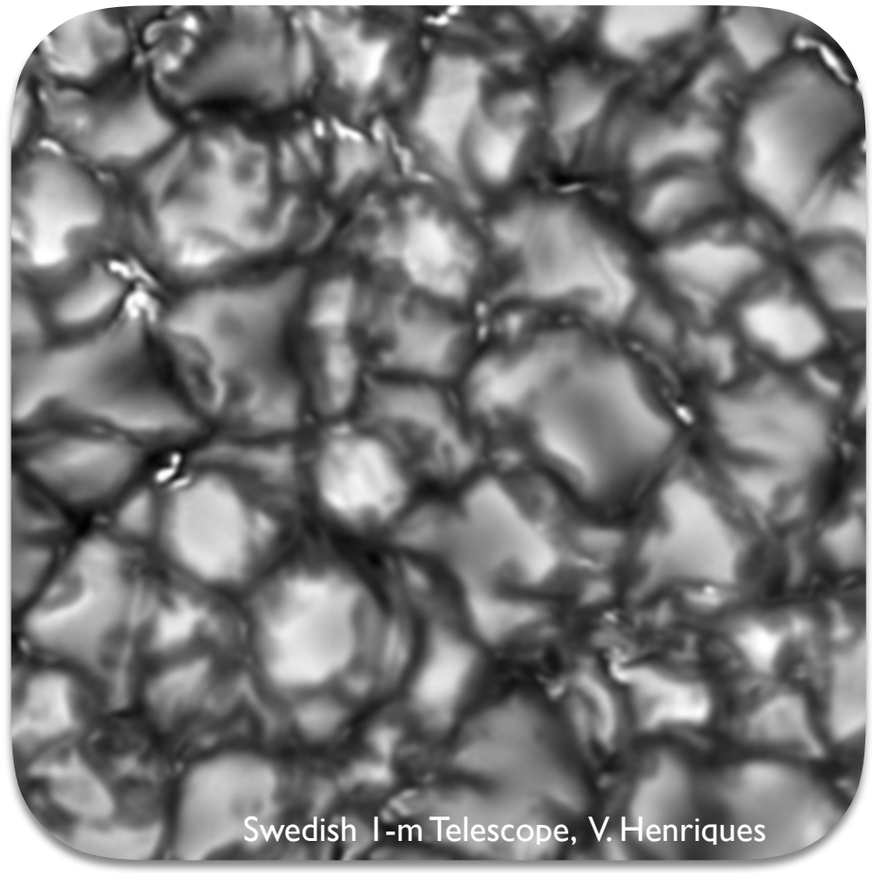
Our model accounts well for rotationally modulated solar activity



Milbourne, Haywood et al. (2019)

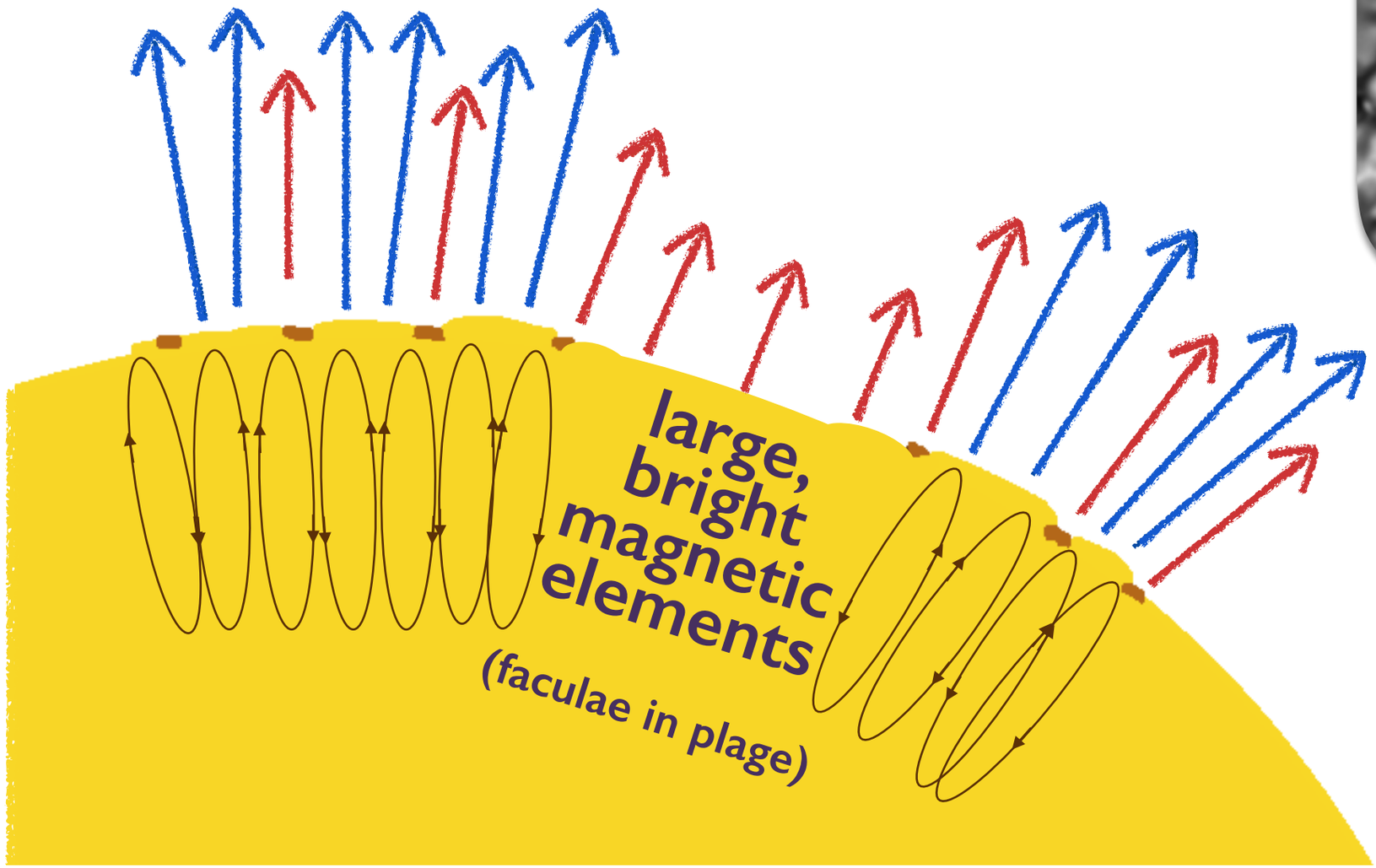
The Sun's RV variations are dominated by the suppression of convective blueshift

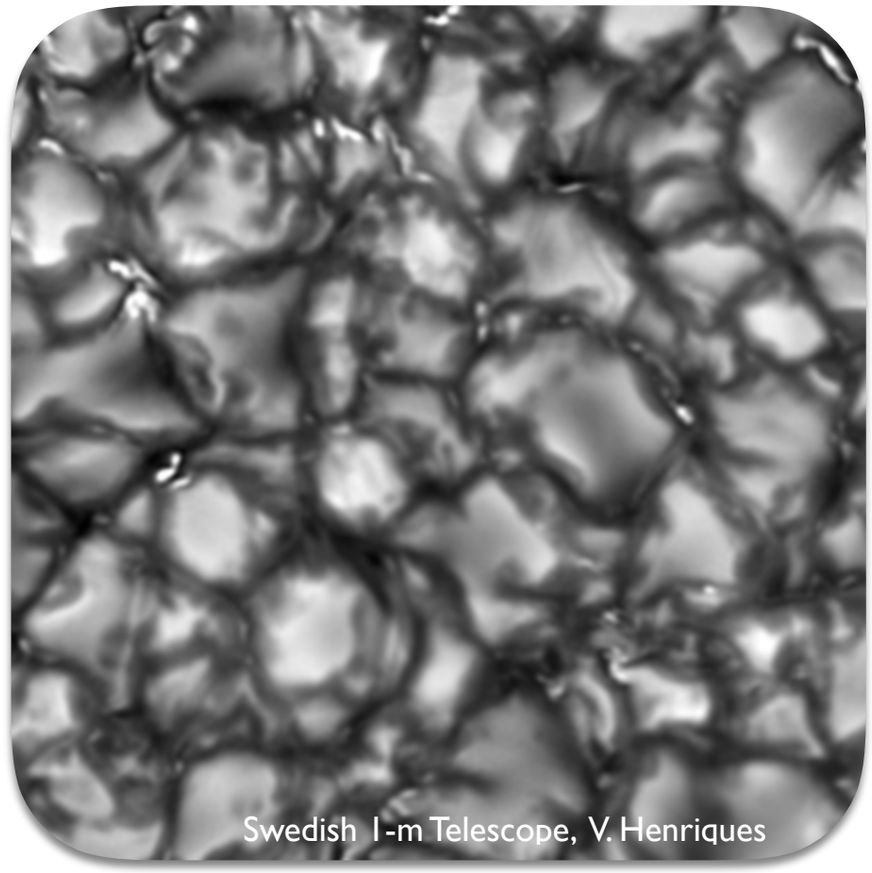




Haywood et al. (2016)
Meunier et al. (2010a,b)
Dumusque et al. (2014)

The Sun's RV variations are dominated by the suppression of convective blueshift

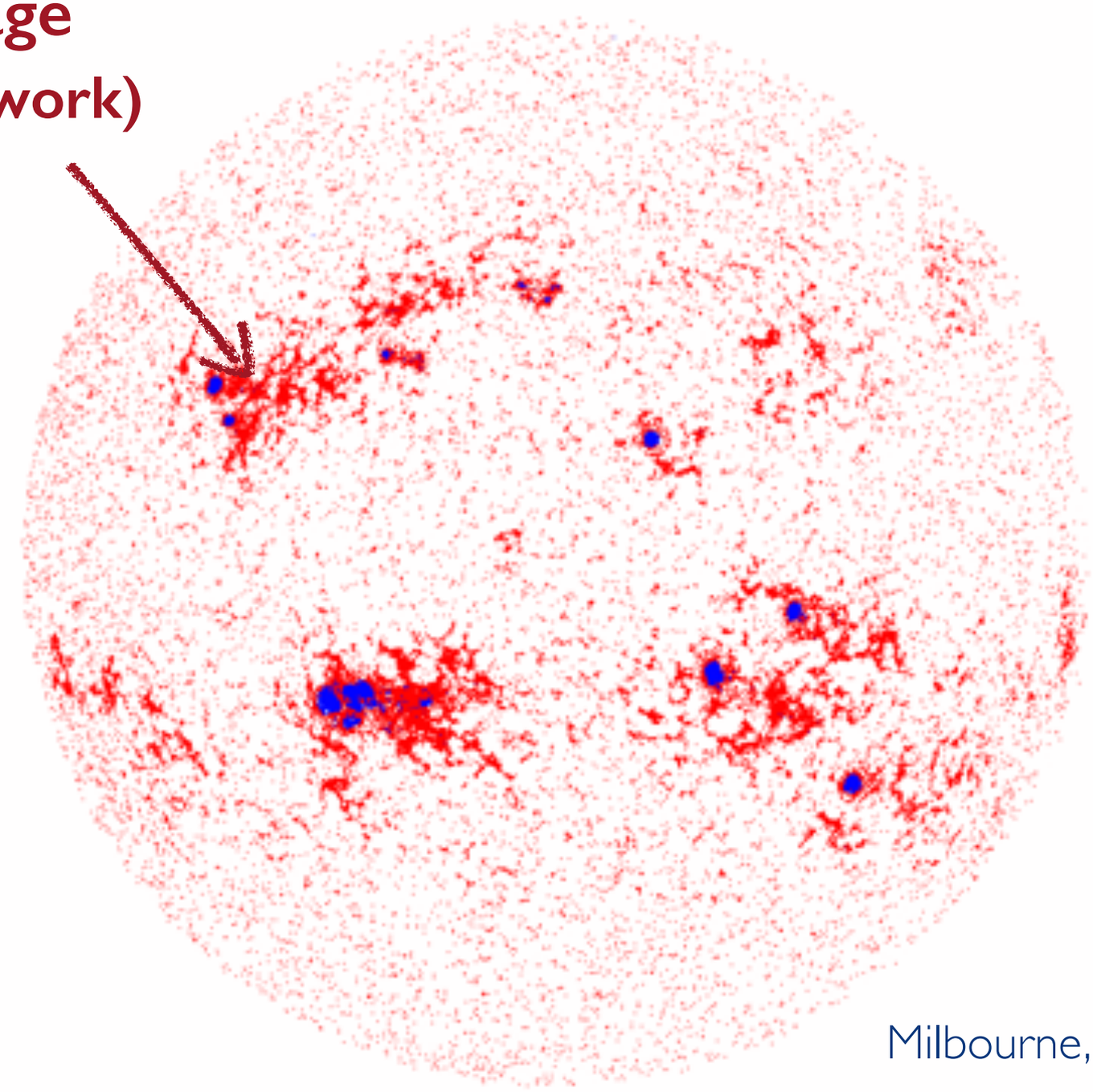




Haywood et al. (2016)
Meunier et al. (2010a,b)
Dumusque et al. (2014)

Faculae *in plage* are the dominant features at play

Faculae in plage
(not in the network)



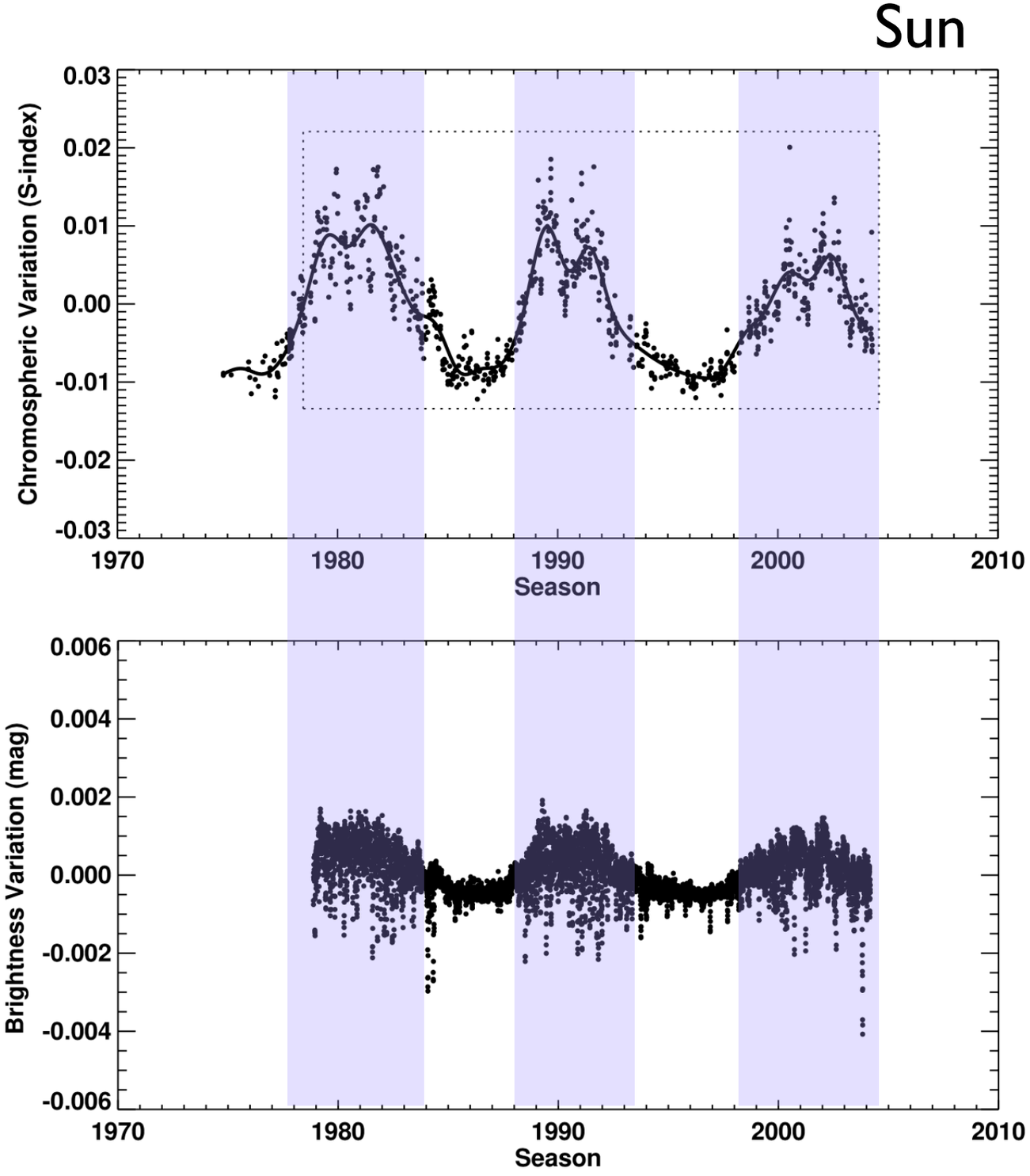
Milbourne, Haywood et al. (2019)
Haywood et al. (2016)
Meunier et al. (2010a,b)

SDO/HMI continuum image

Old, slowly rotating stars like the Sun are faculae-dominated

Ca H&K emission

Optical photometry



Mount Wilson HK Project (Mt Wilson Observatory, Lowell Observatory)

Radick et al. (1988), Lockwood et al. (2007), Radick et al. (2018)

Figure from Lockwood et al. (2007)

Going from the Sun to other stars: can we identify a direct proxy for RV variations?

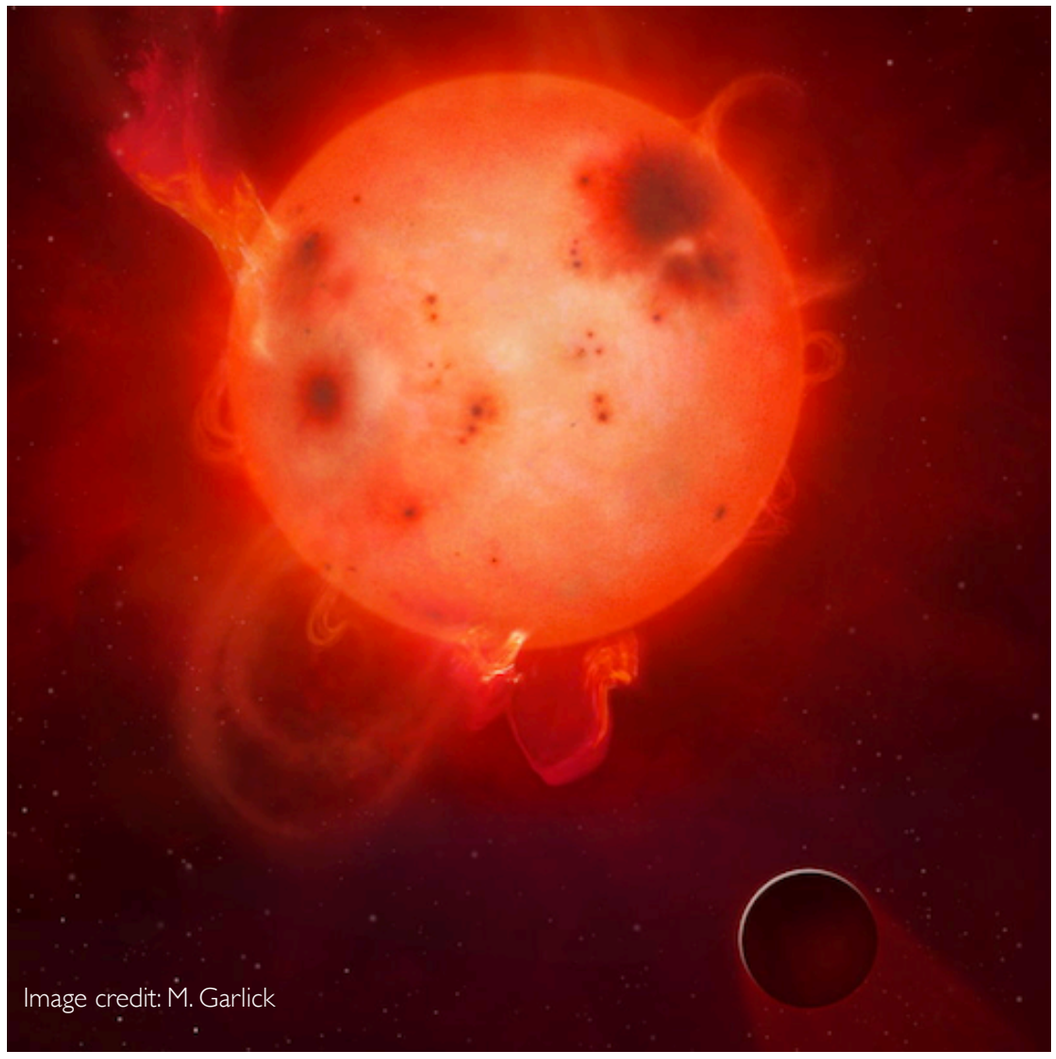
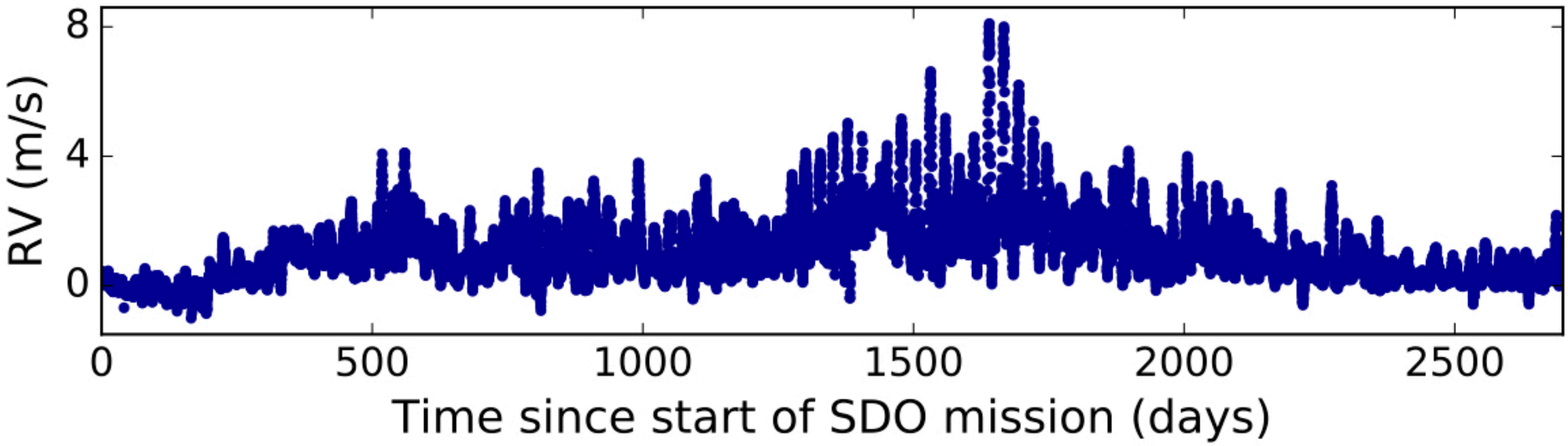


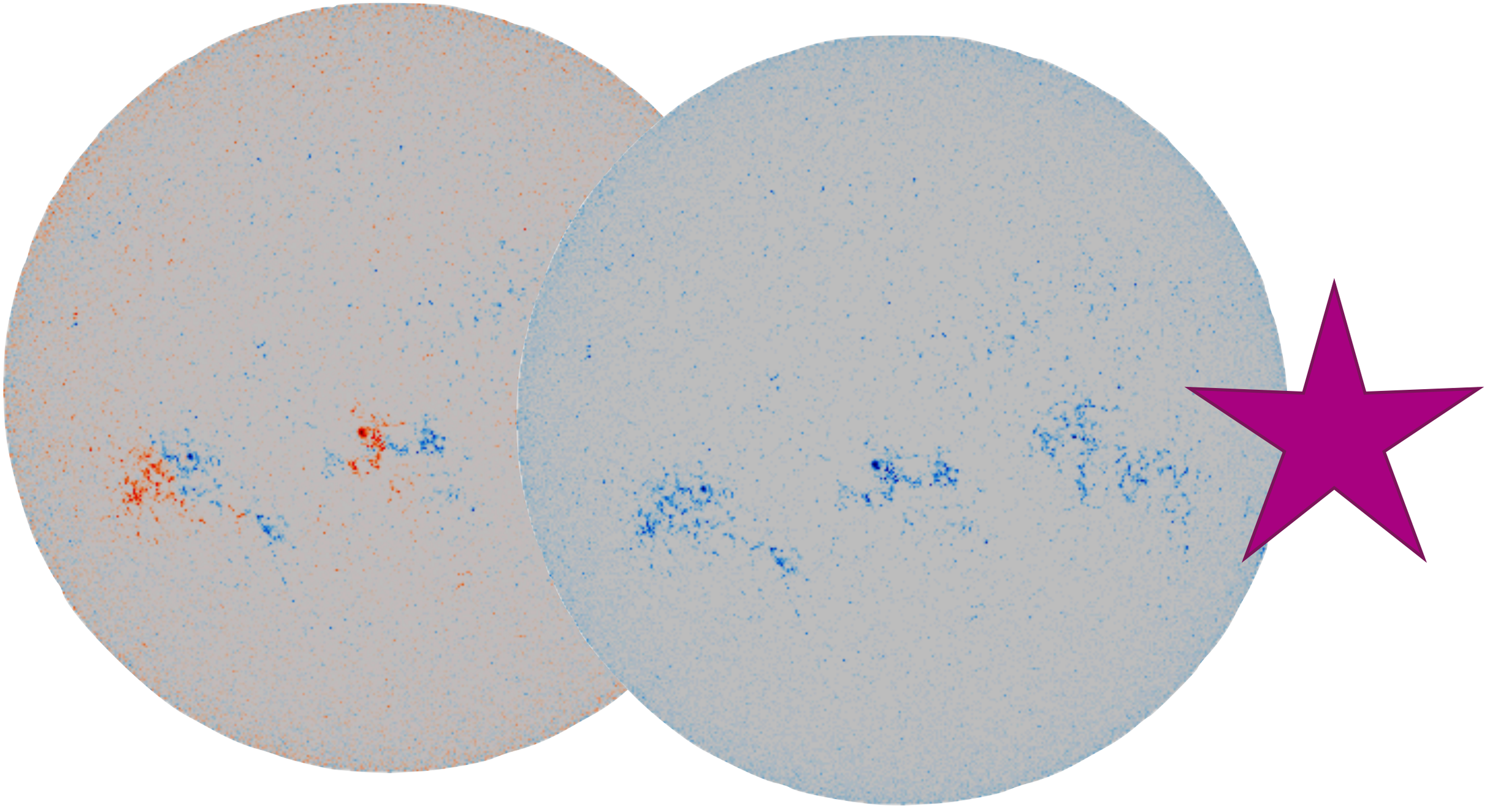
Image credit: M. Garlick

RV variations of the Sun estimated from SDO/HMI images



Haywood et al. (in prep.)

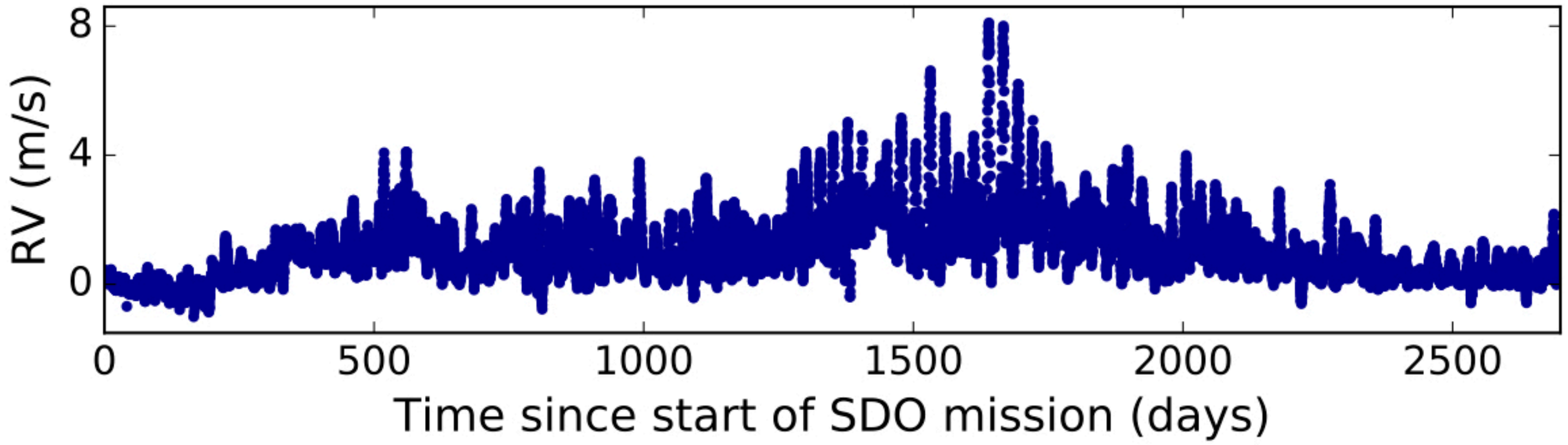
Full-disc, unsigned magnetic flux from SDO/HMI magnetograms

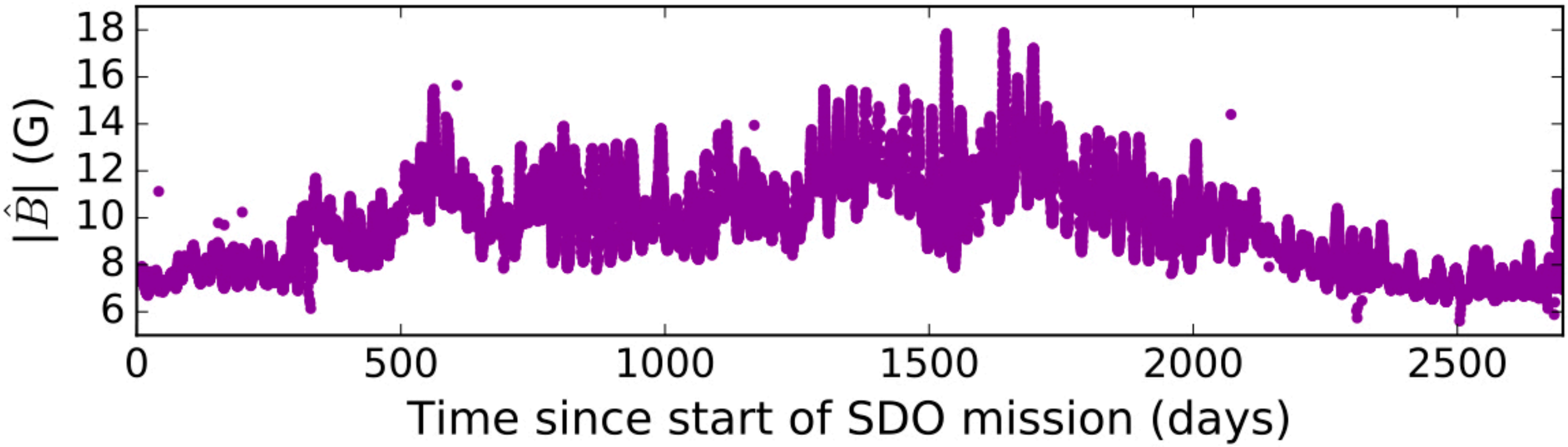


SDO/HMI magnetograms

Haywood et al. (2016)
See also Robinson (1980), Saar (1988, 1986)

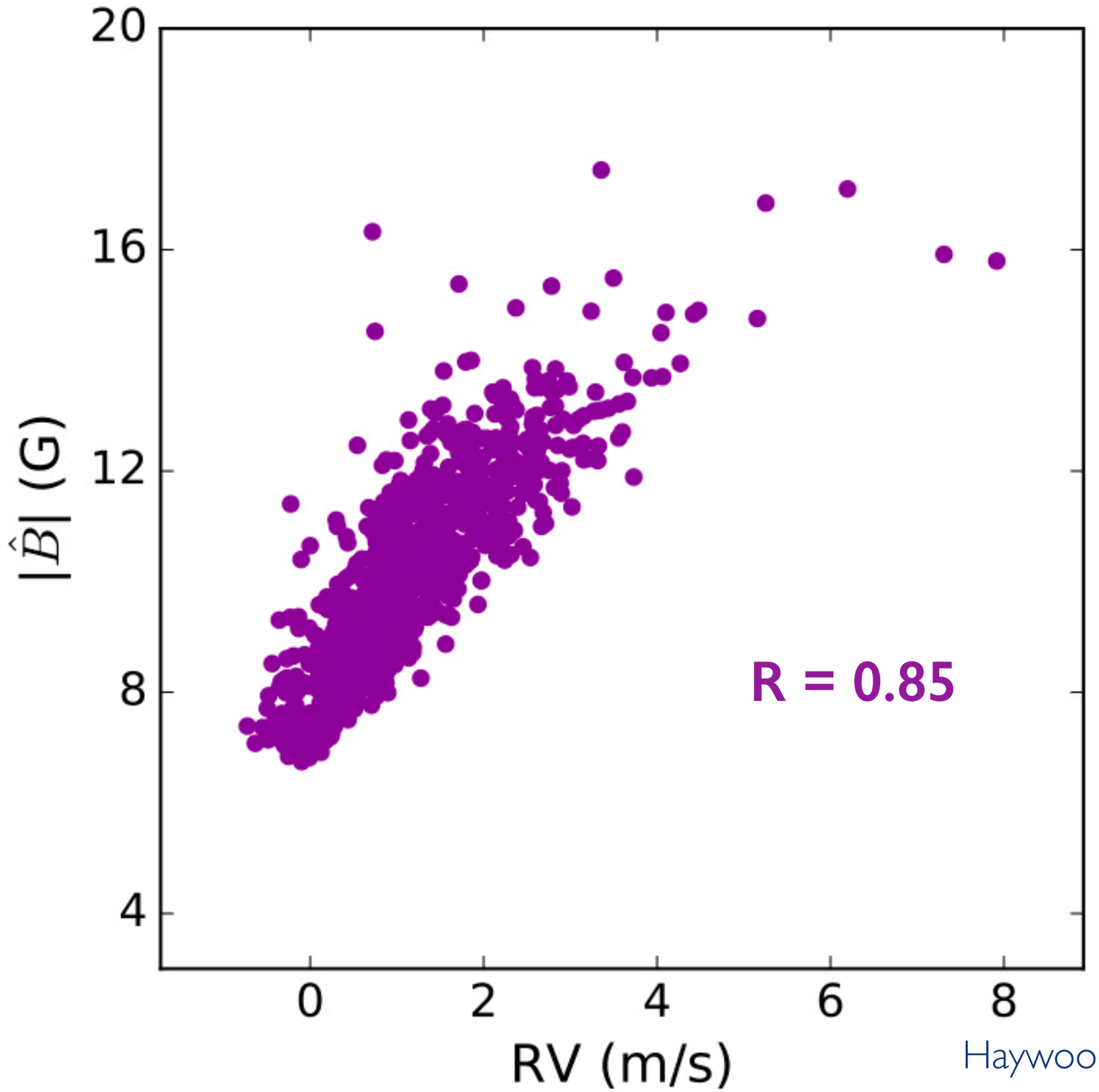
Full-disc, unsigned magnetic flux from SDO/HMI magnetograms





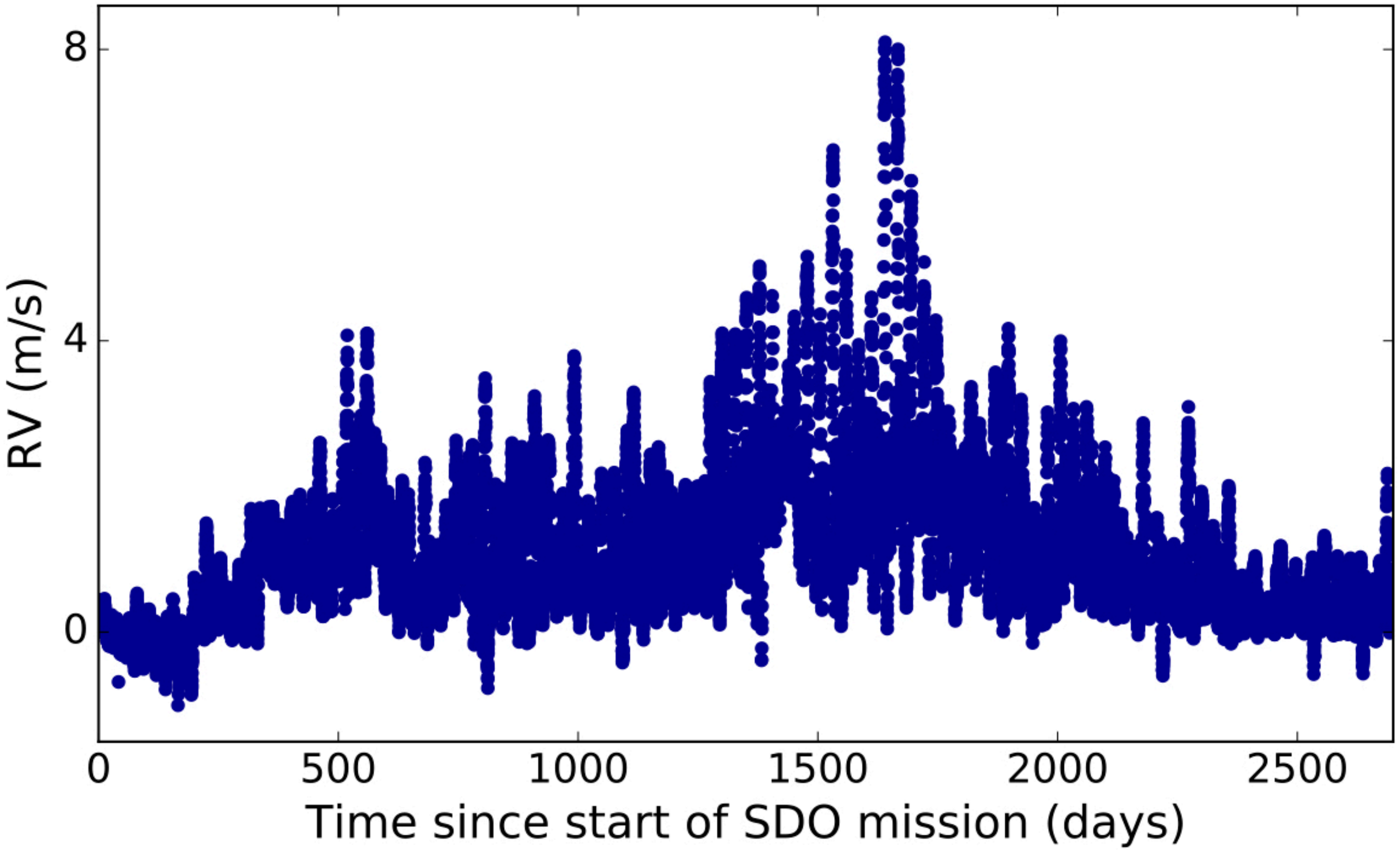
Haywood et al. (in prep.)

The unsigned magnetic flux as a proxy for RV variations



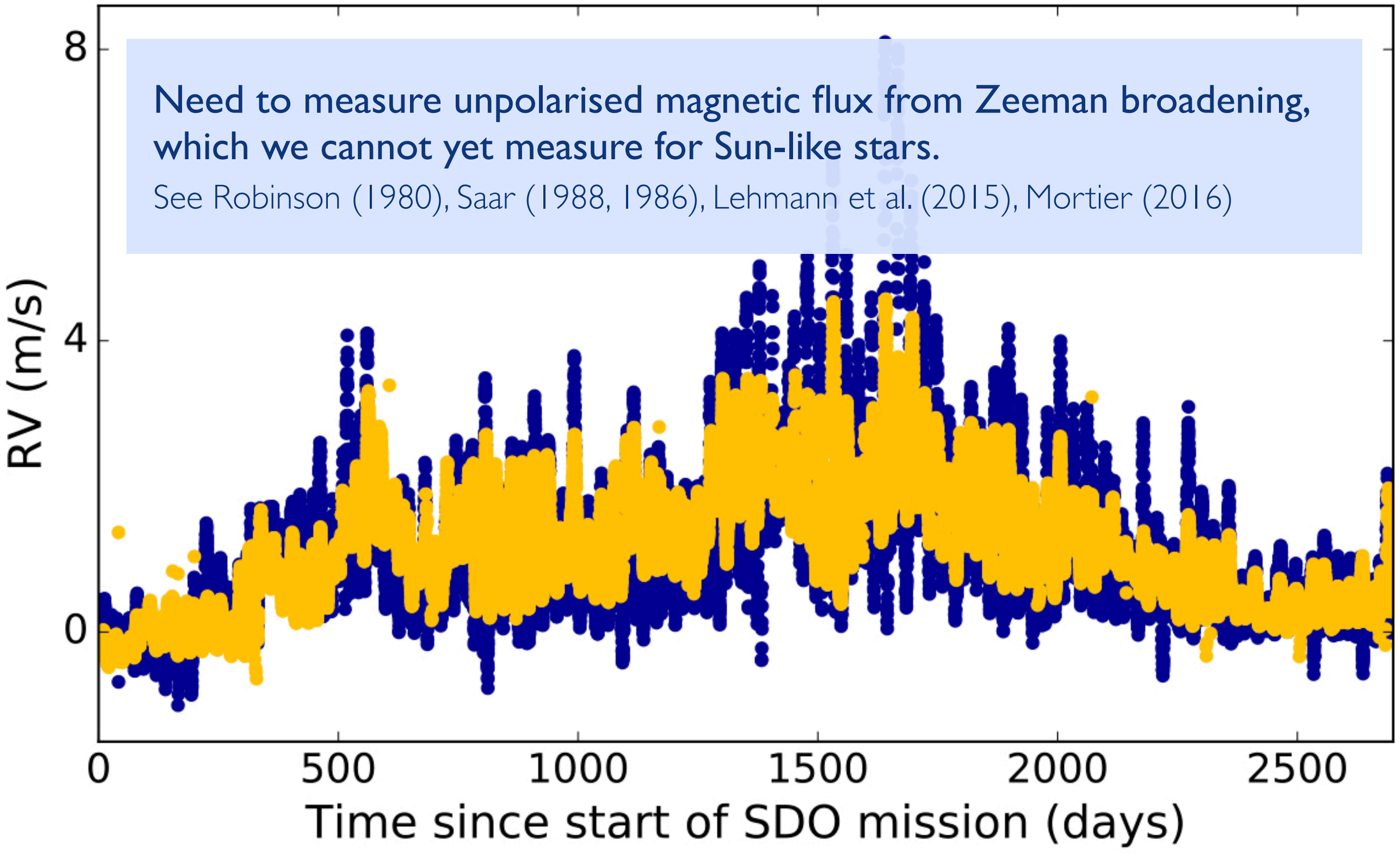
Haywood et al. (in prep.)

The unsigned magnetic flux *B* as a proxy for RV variations



Haywood et al. (in prep.)

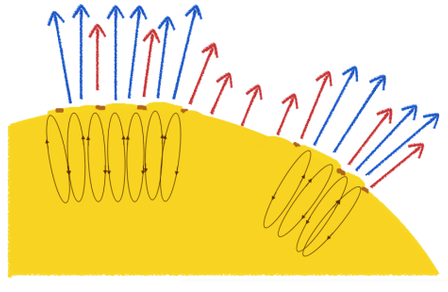
A simple fit with *B* reduces RV variations by 46% down to 55 cm/s



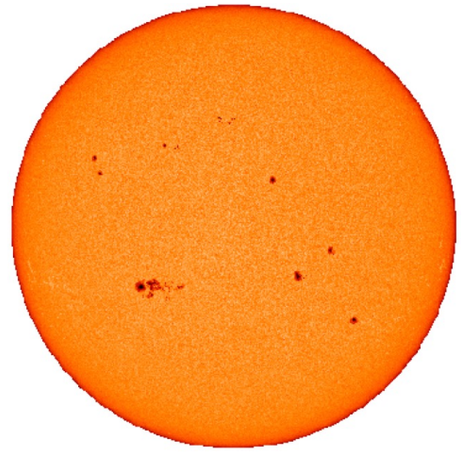
Haywood et al. (in prep.)

Conclusions

- The intrinsic magnetic activity of host stars is a significant obstacle to determining precise and accurate masses of small planets

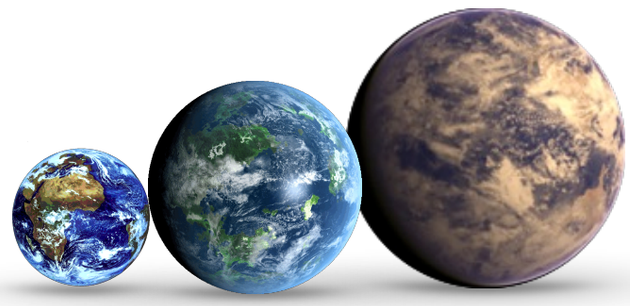


- We can use solar observations (HARPS-N, SDO/HMI) to develop models and identify proxies to account for stellar activity in exoplanet observations



- The Sun's RV variations are dominated by large, bright magnetic areas via suppression of convective blueshift
- The unsigned, full-disc magnetic flux could be an excellent proxy for RV variations

See Tim Milbourne's poster



With thanks to the Smithsonian, the TNG team and the HARPS-N Collaboration

Image credits: M. Garlick, R. Haywood, SDO/HMI, NASA