Breaking the stellar activity barrier to characterizing small planets

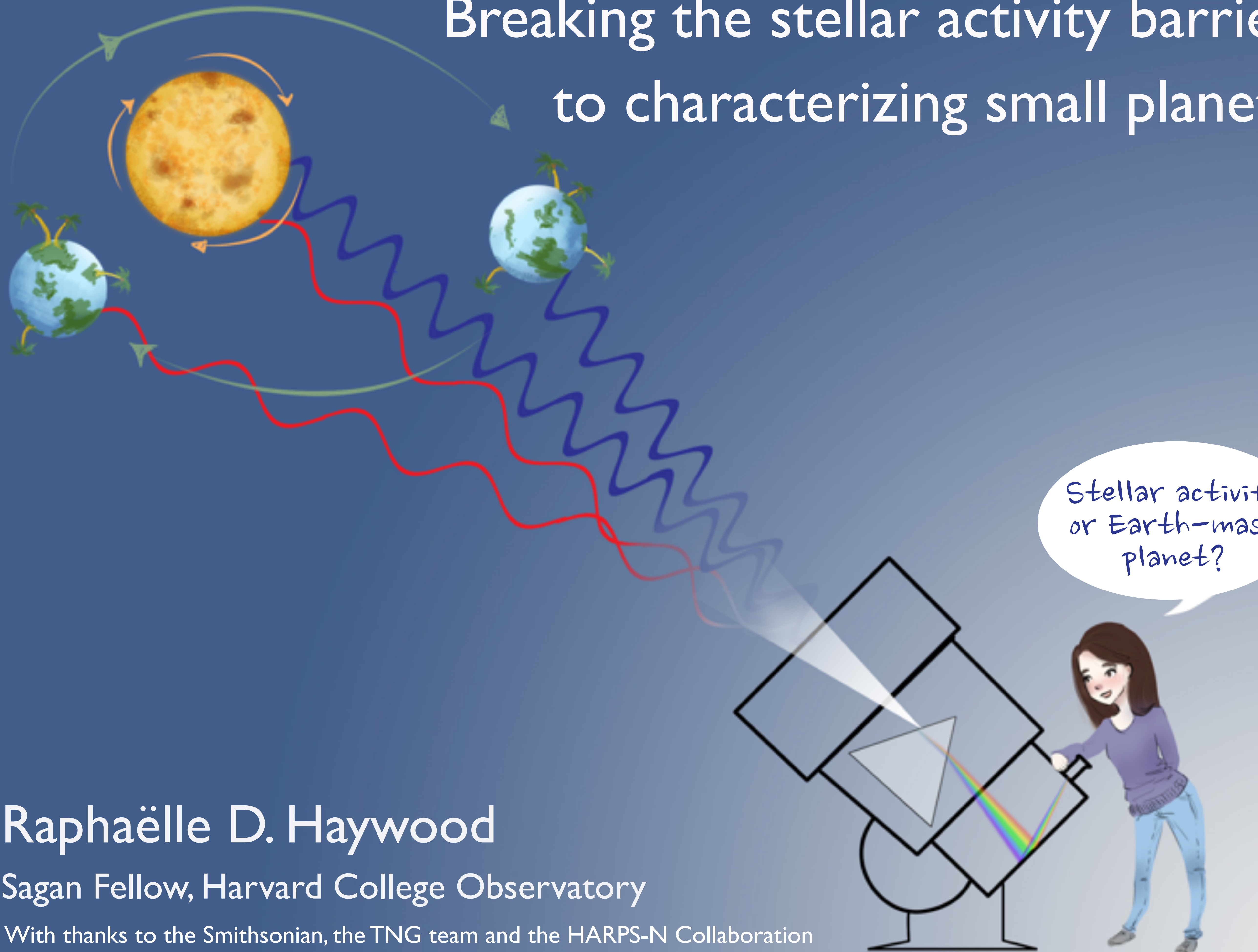


Image credit: Natalie Cameron

Raphaëlle D. Haywood

Sagan Fellow, Harvard College Observatory

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

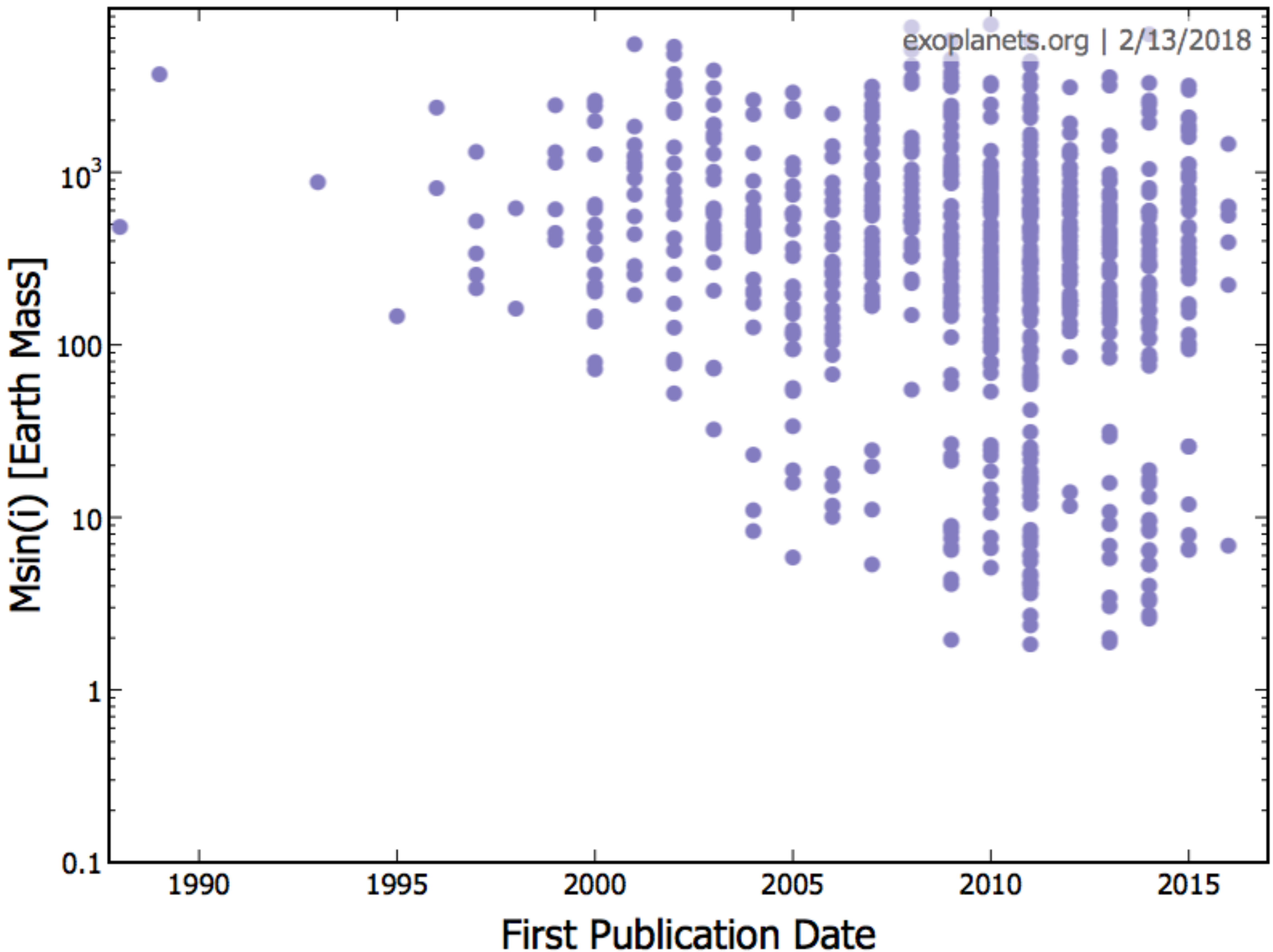
Outline

- Stellar activity is the main limitation in exoplanet radial-velocity (RV) mass determinations.
- What are we learning from observing the Sun as a star?
- Can we identify a good proxy for intrinsic stellar RV variations?

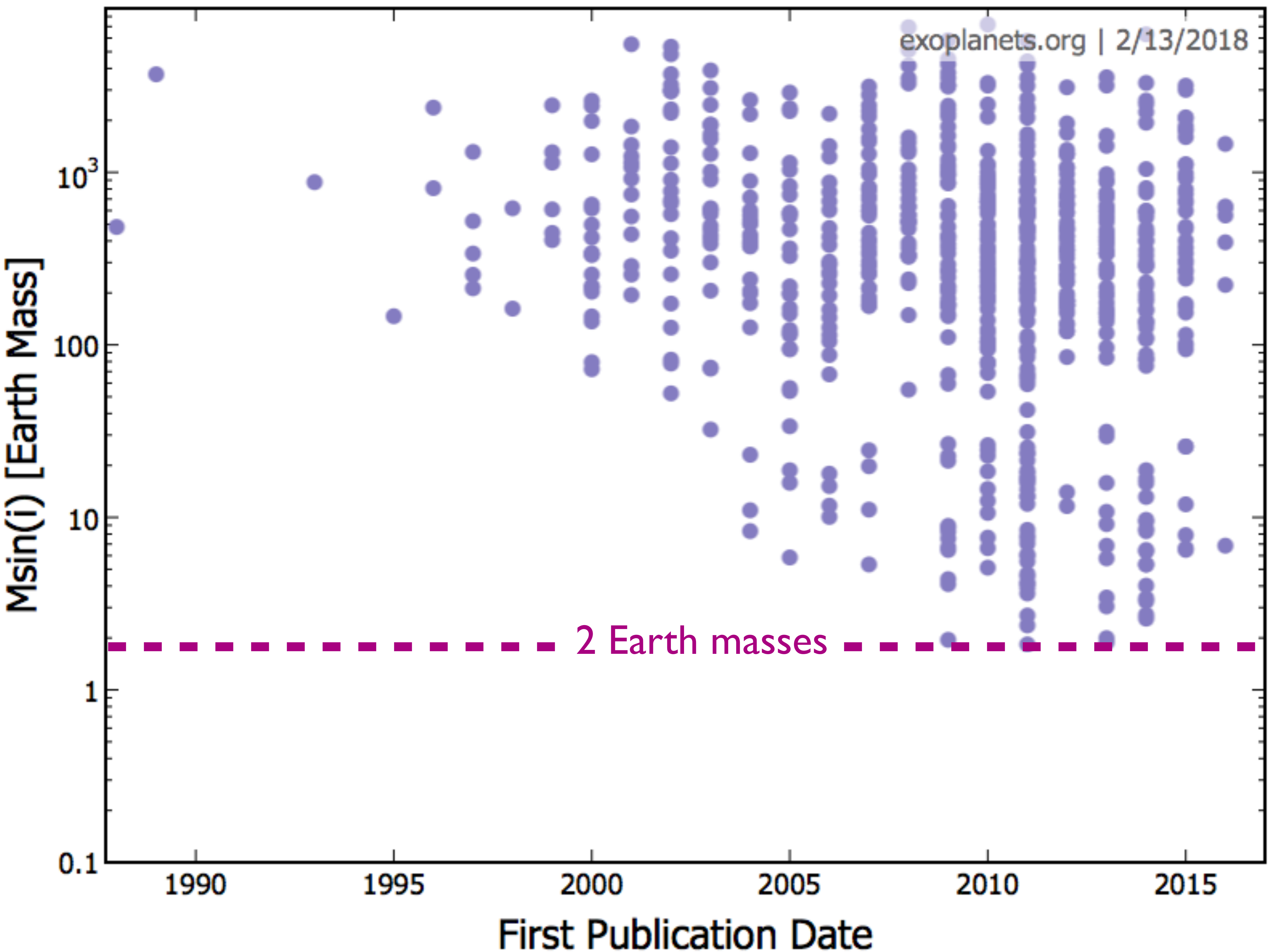
Solar/HARPS-N

SDO/HMI

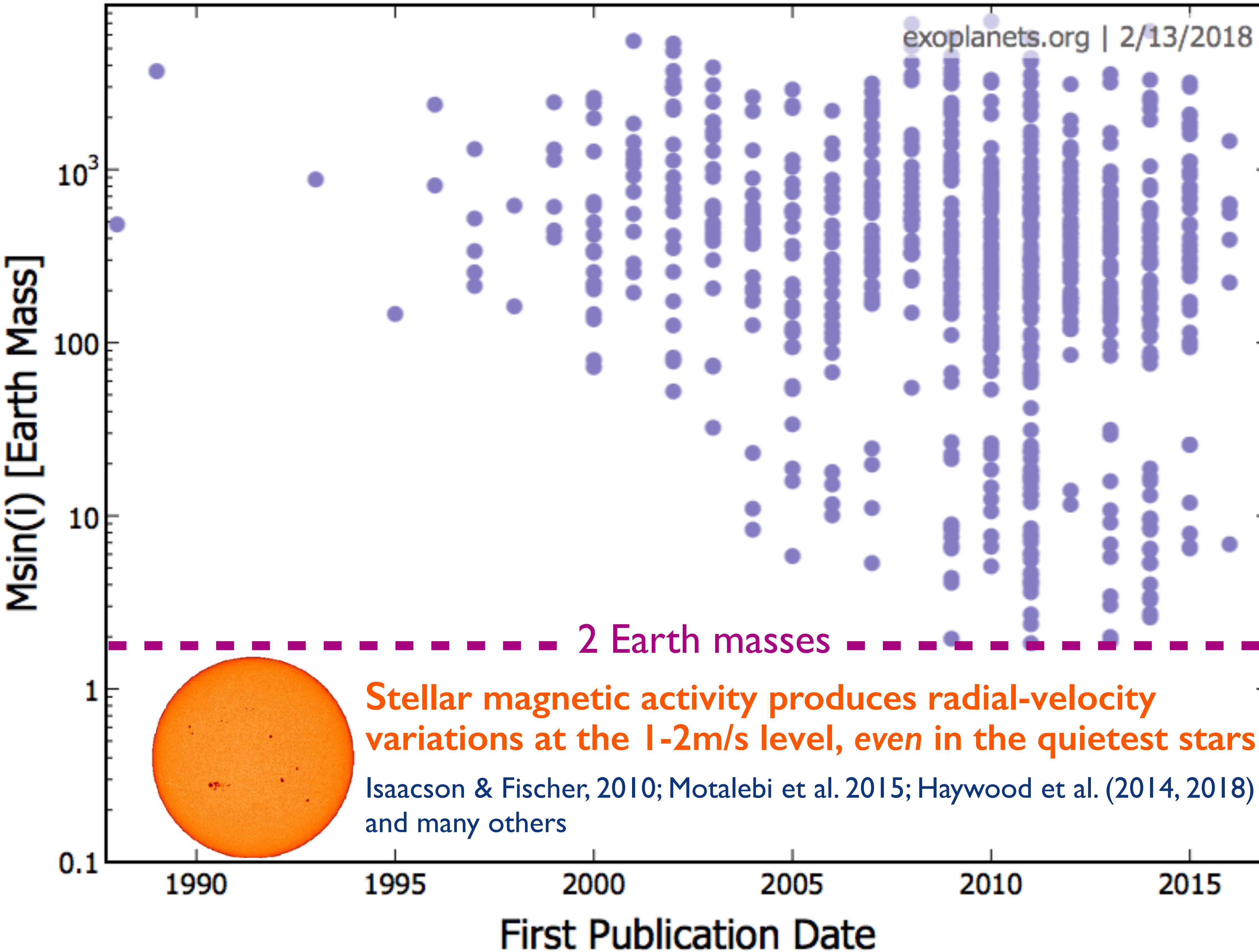
We cannot yet measure reliable masses of small, rocky planets



We cannot yet measure reliable masses of small, rocky planets

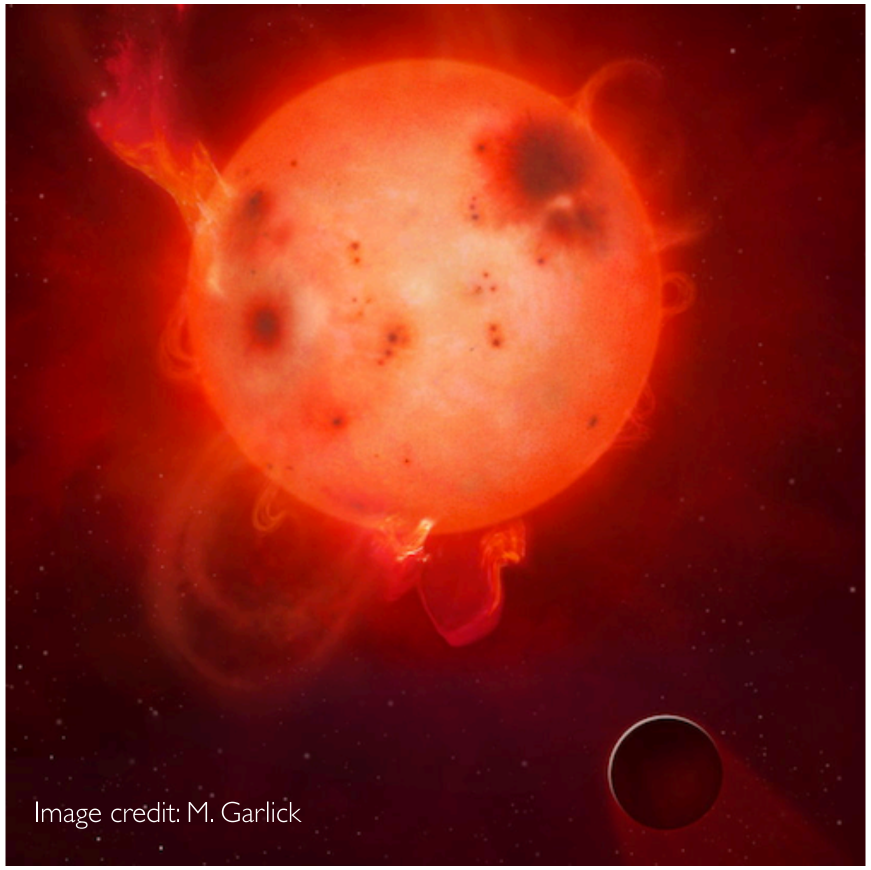


We cannot yet measure reliable masses of small, rocky planets



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

Fischer et al. (2016), Haywood et al. (2014, 2016),
Dumusque et al. (2017) and many others



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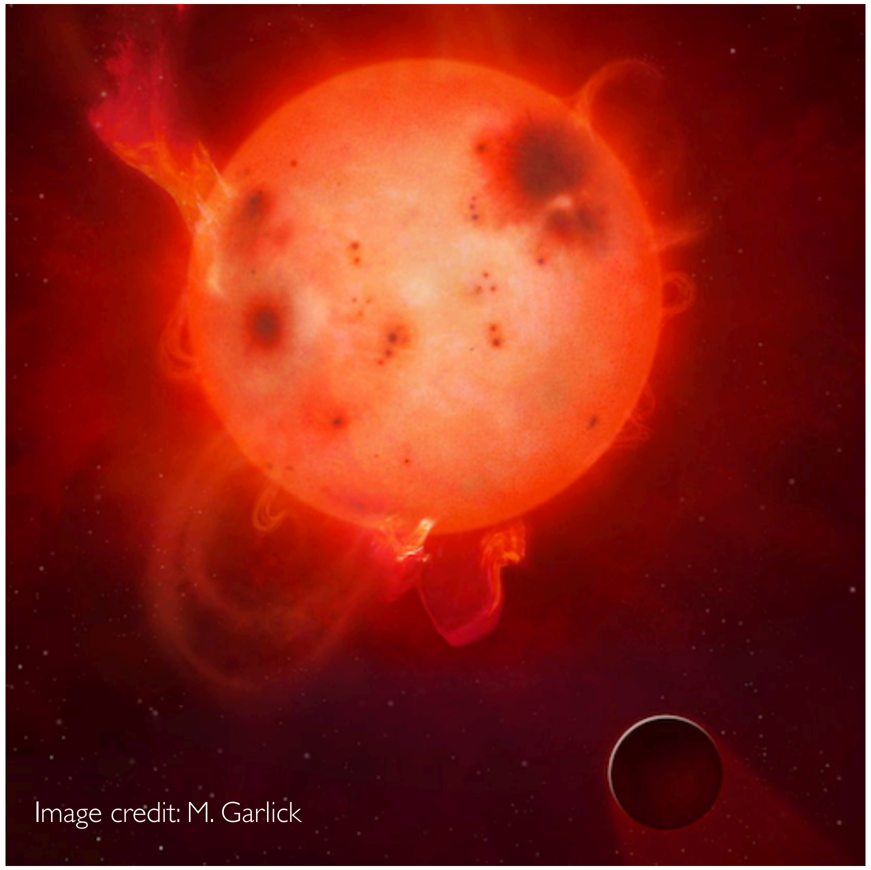


Image credit: M. Garlick

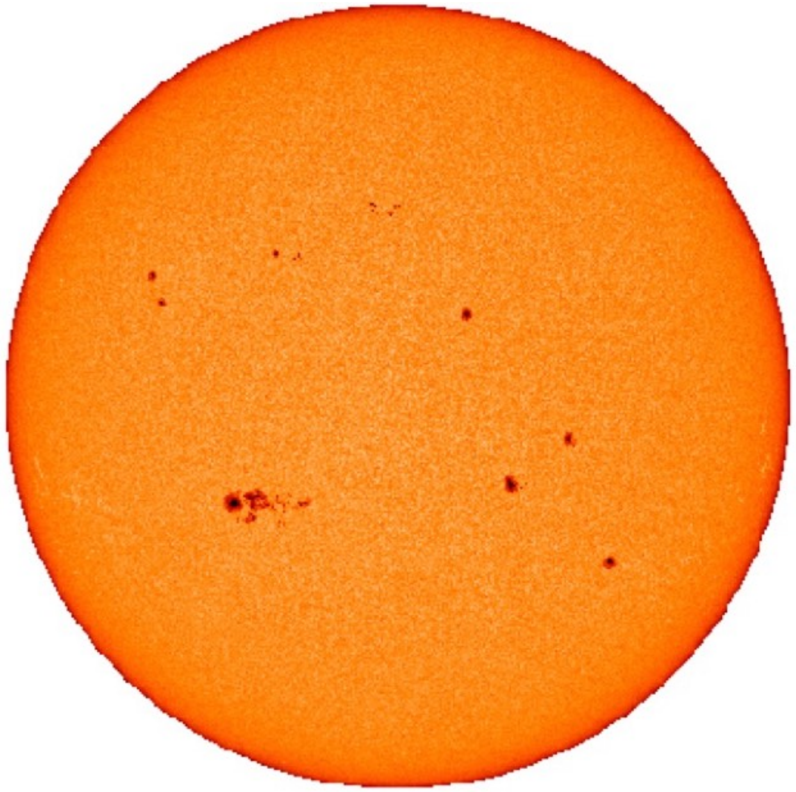
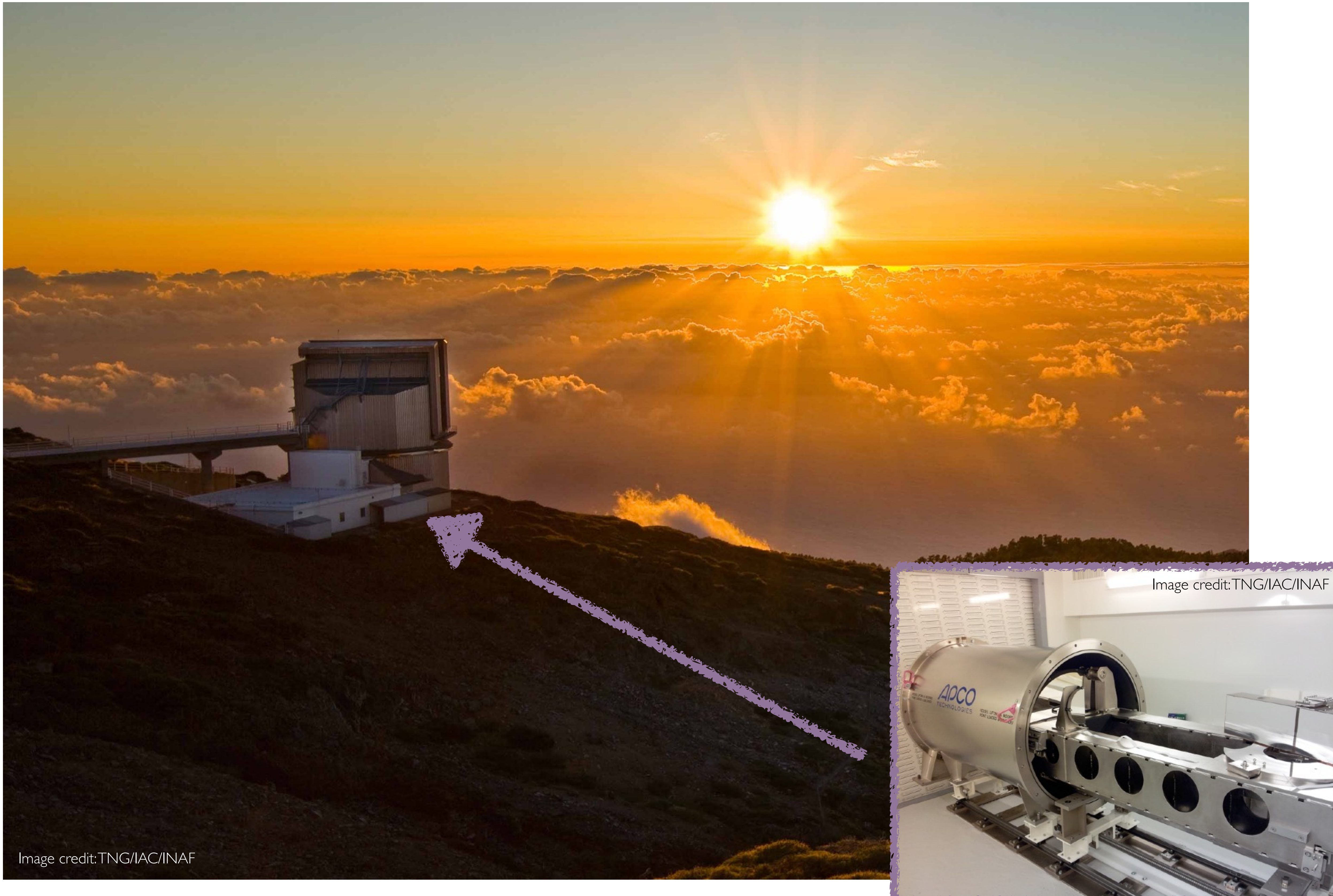


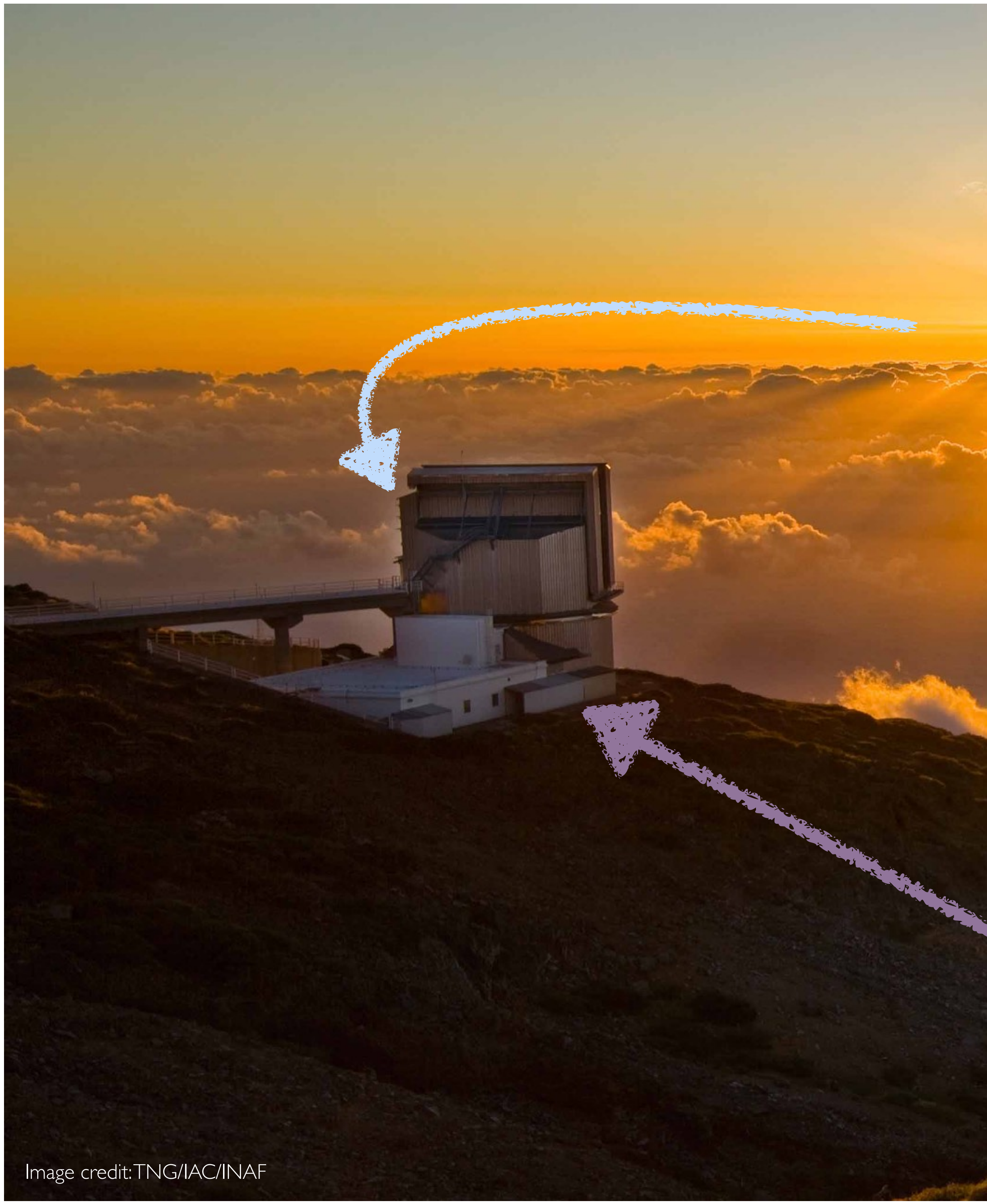
Image credit: SDO/HMI

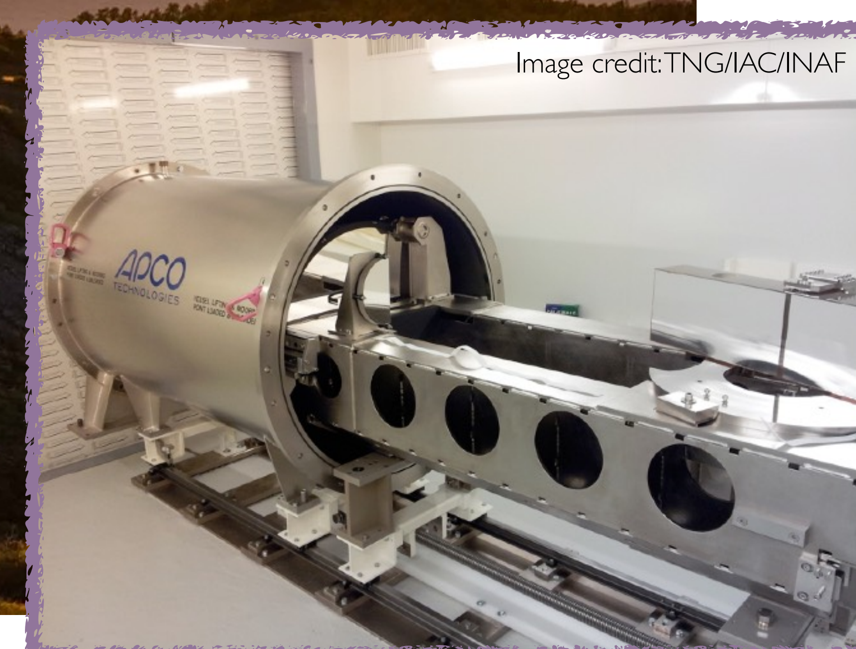
We can do this by studying the Sun!

We are currently observing the Sun with the exoplanet hunter HARPS-N



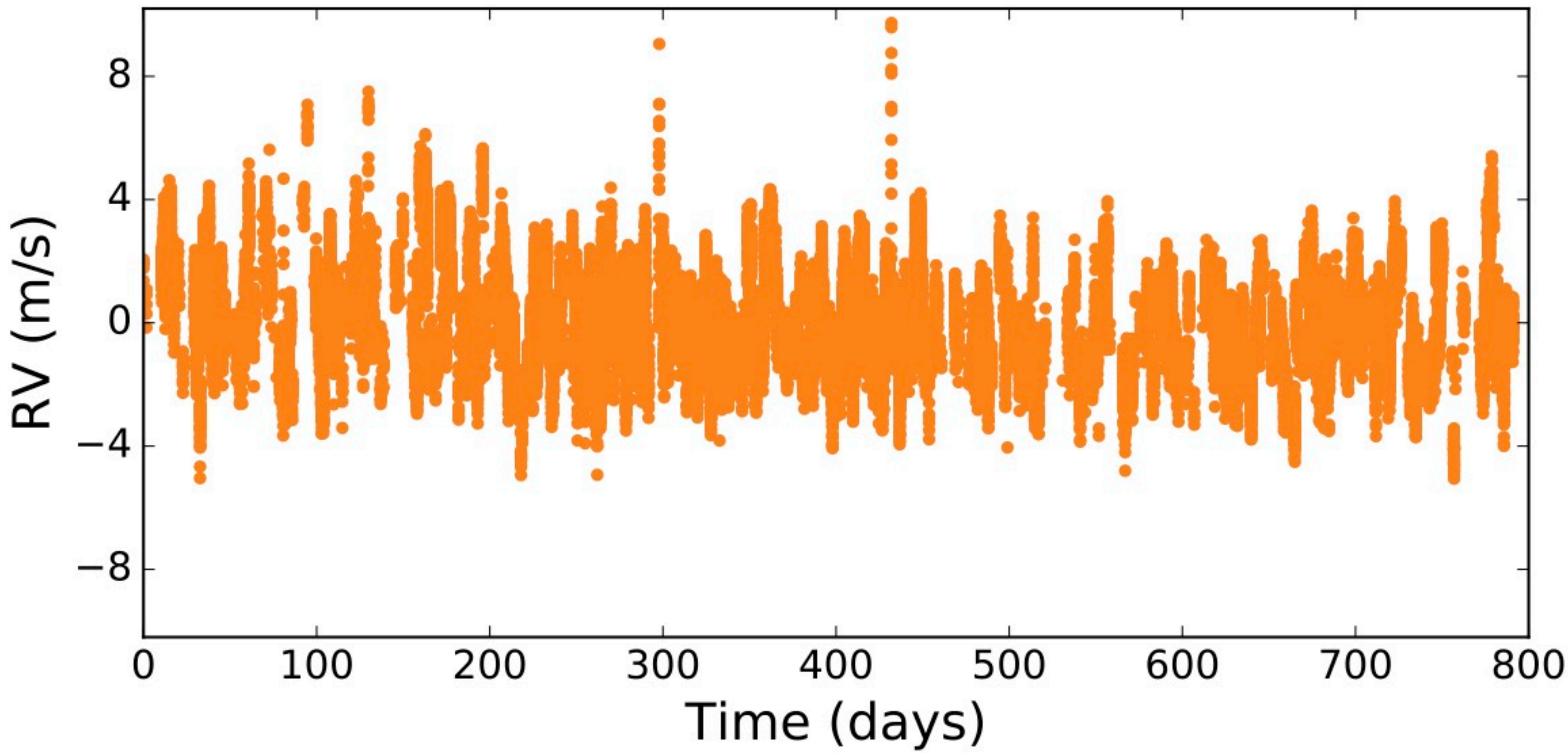
We are currently observing the Sun with the S-N

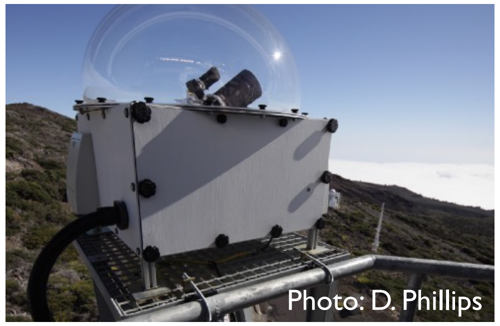




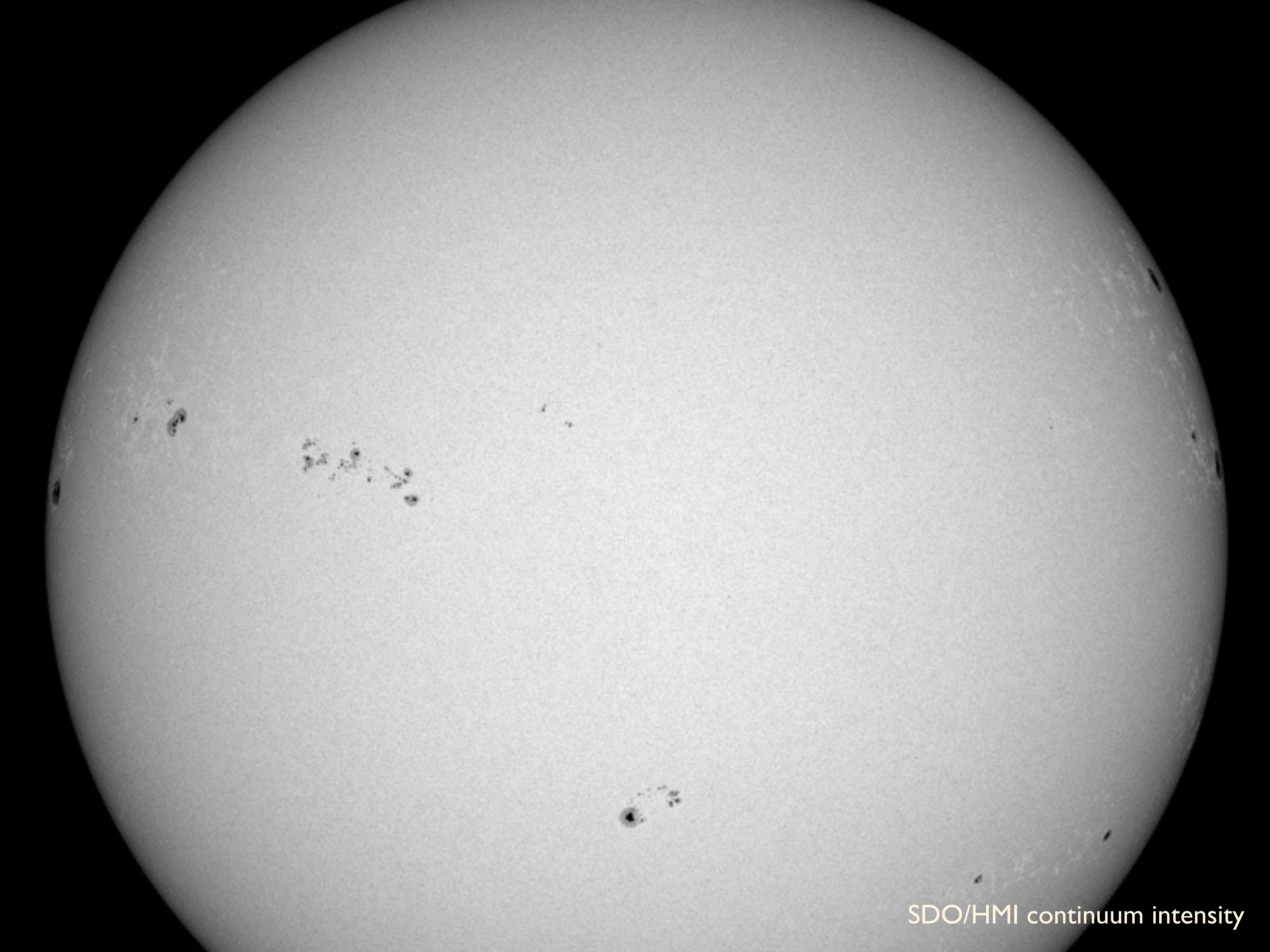
RV variations of the Sun as a distant, point-like star, with no planets orbiting it!

>26000 observations, 5-min exposures, photon noise rms scatter: 40-50 cm/s

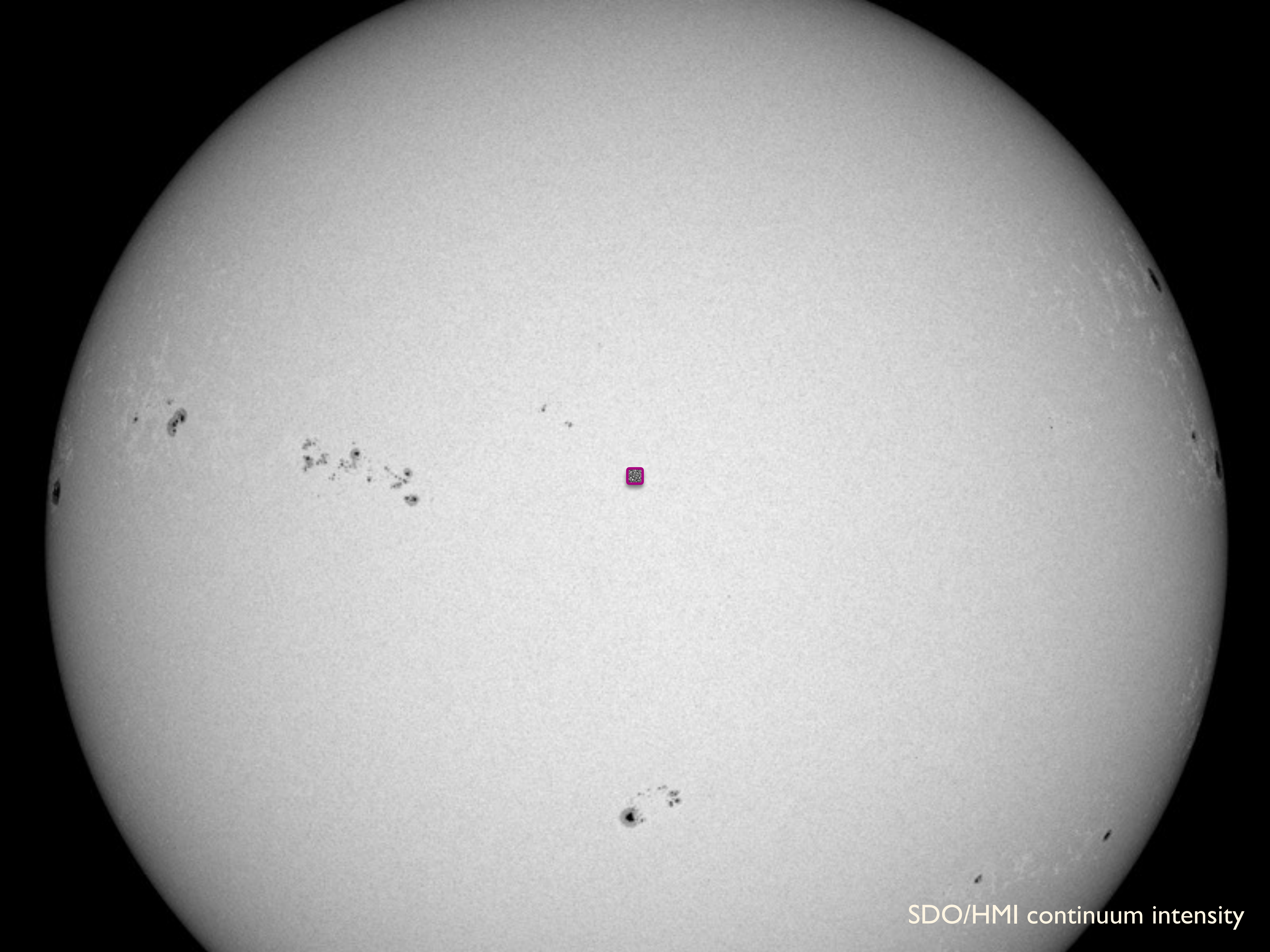


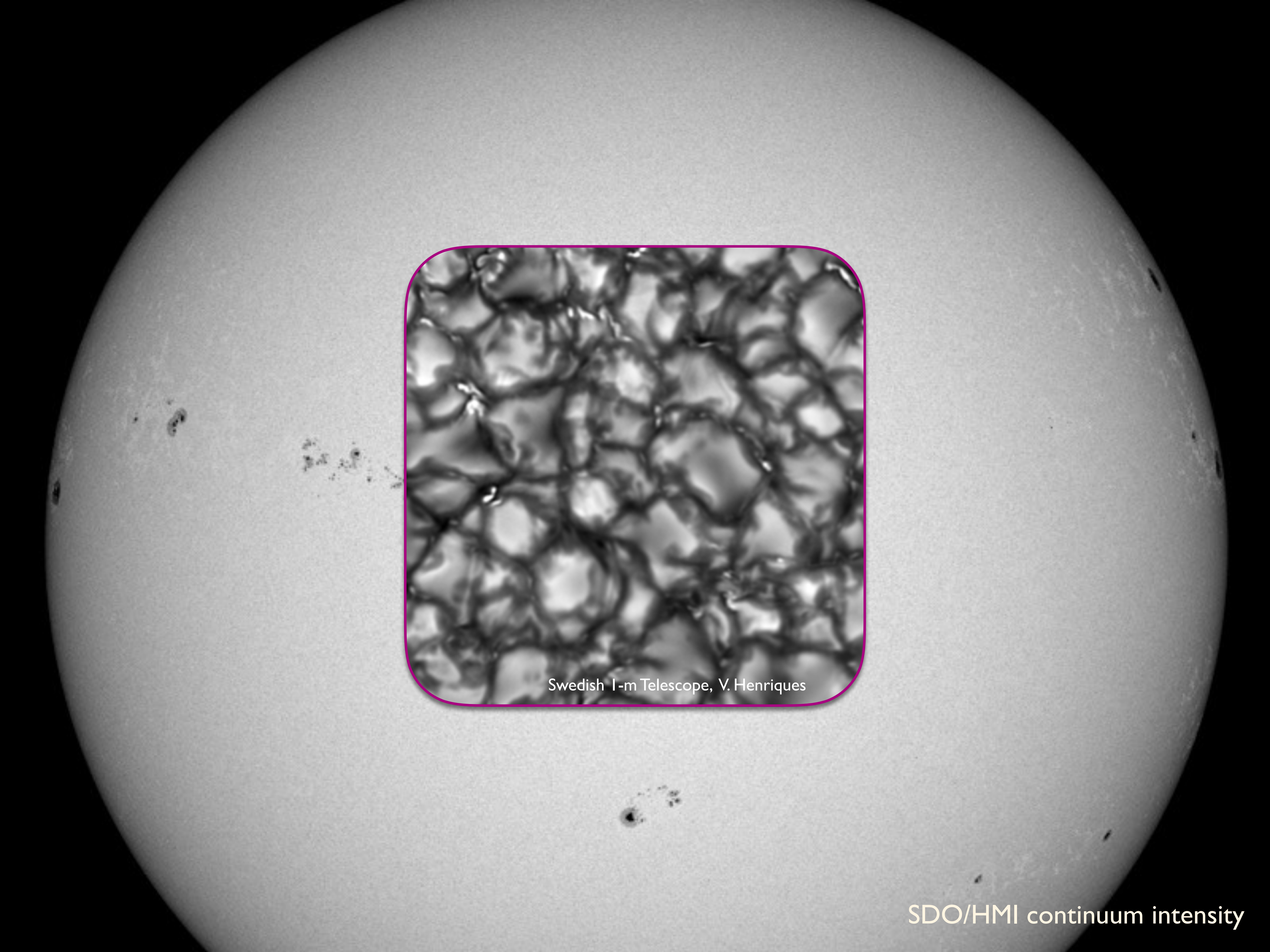


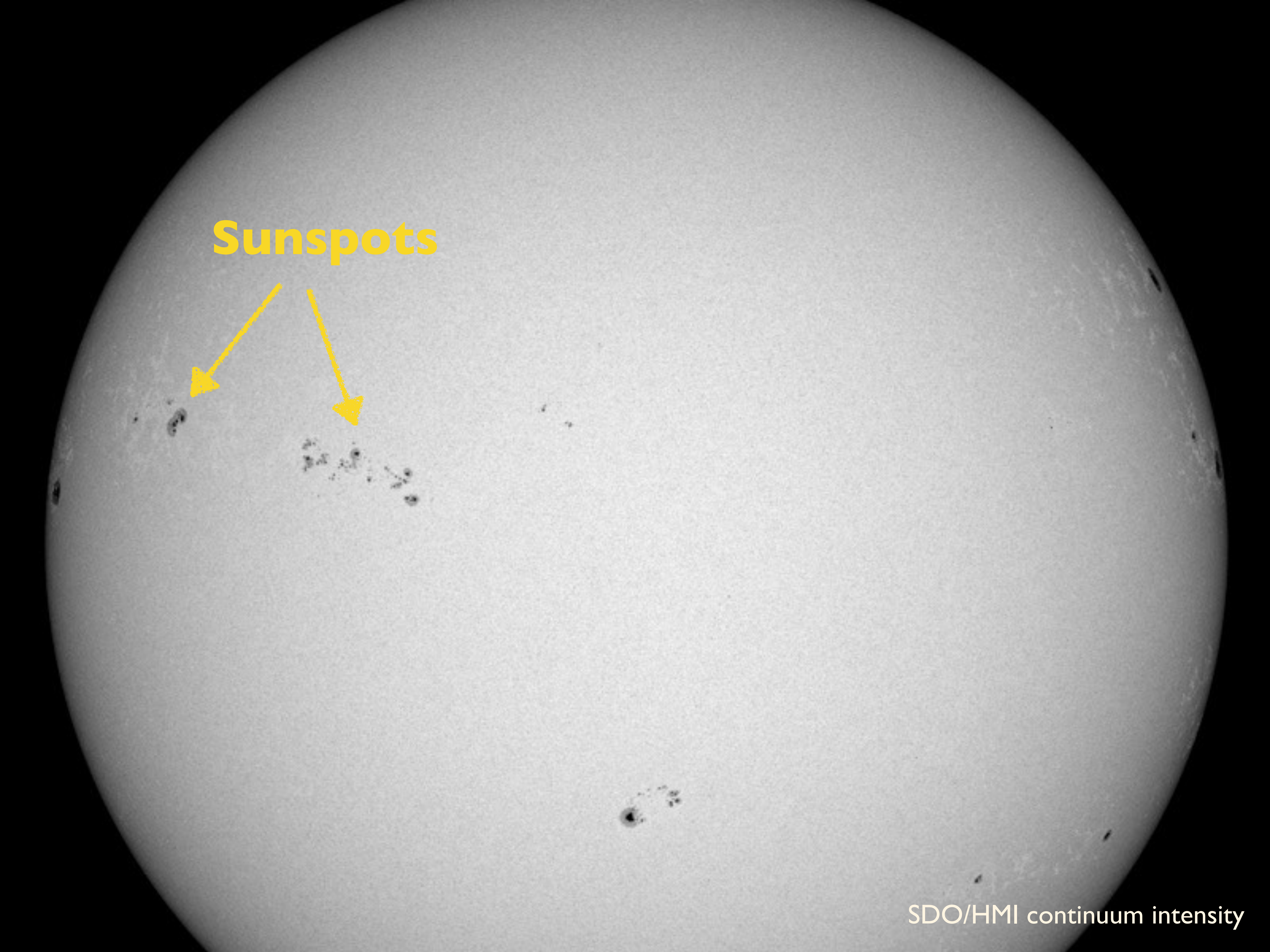
Solar/HARPS-N Project:
Glenday, Phillips et al. (2012), Dumusque et al. (2016), Phillips et al. (2016)

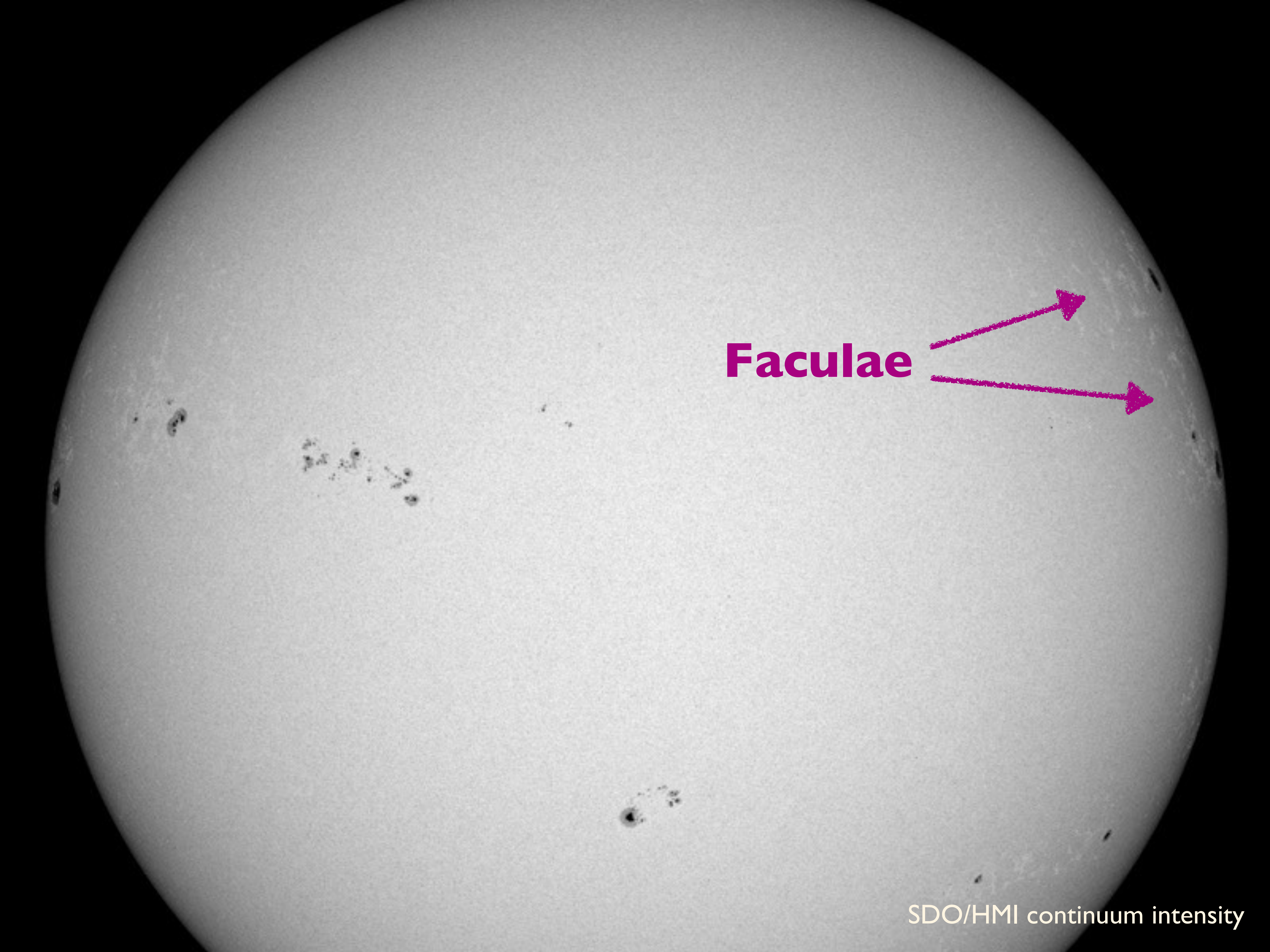


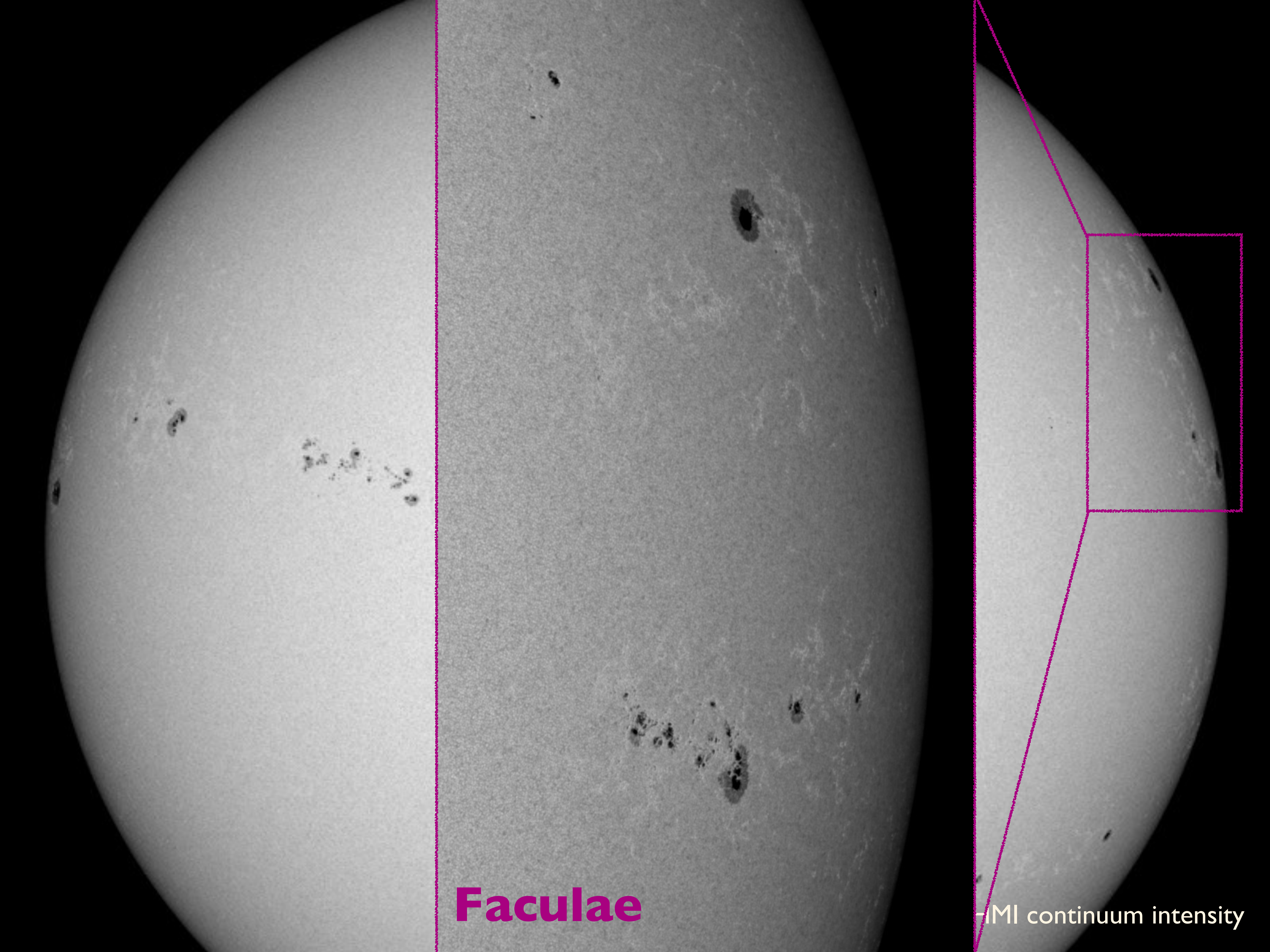
SDO/HMI continuum intensity


SDO/HMI continuum intensity


Swedish 1-m Telescope, V. Henriques
SDO/HMI continuum intensity

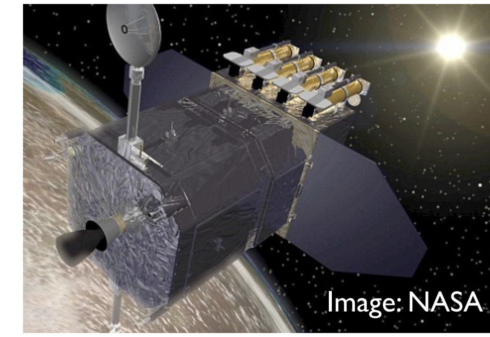

Sunspots
SDO/HMI continuum intensity

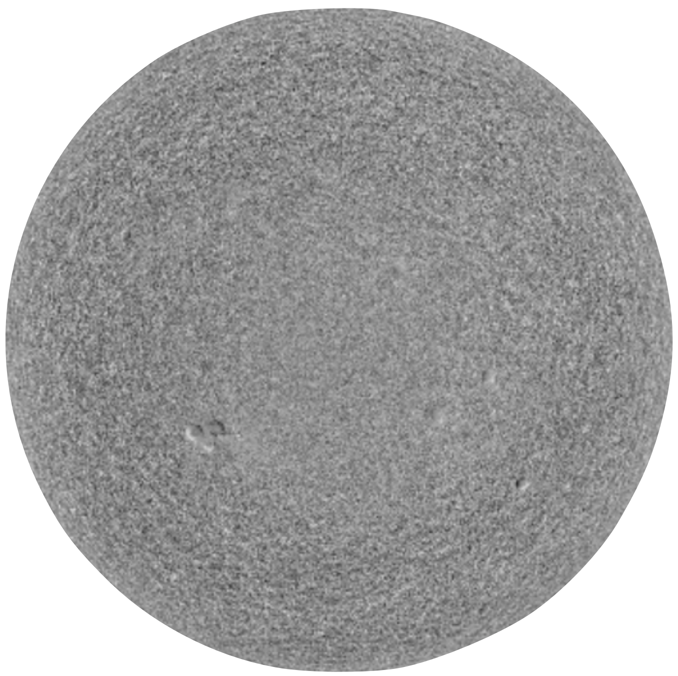

Faculae
SDO/HMI continuum intensity


Faculae
HMI continuum intensity

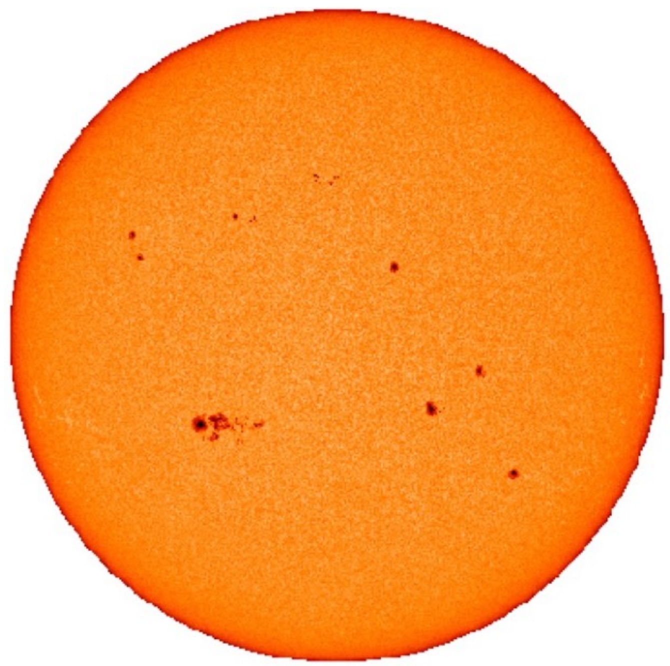
We reconstruct the full-disc RV variations of the Sun

Using high spatial resolution images (Fe I 6173Å line) from the Helioseismic & Magnetic Imager onboard the Solar Dynamics Observatory (SDO/HMI)

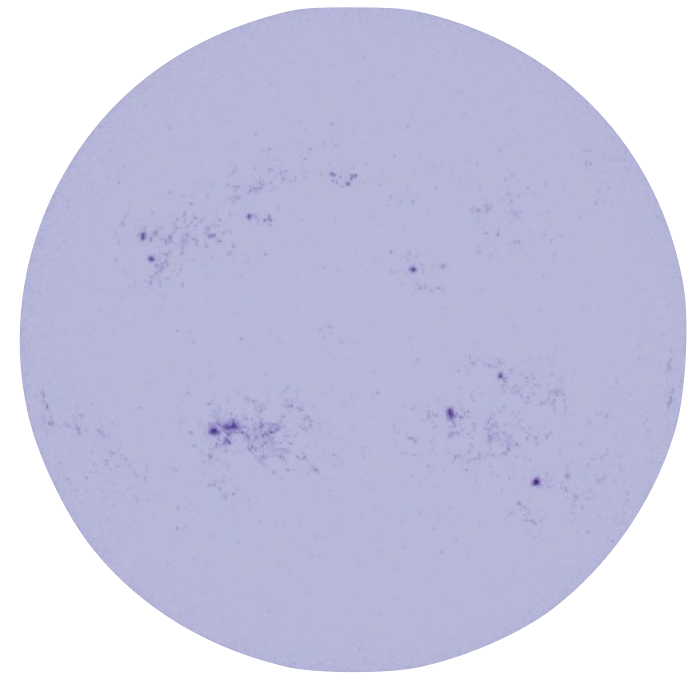




Doppler velocity



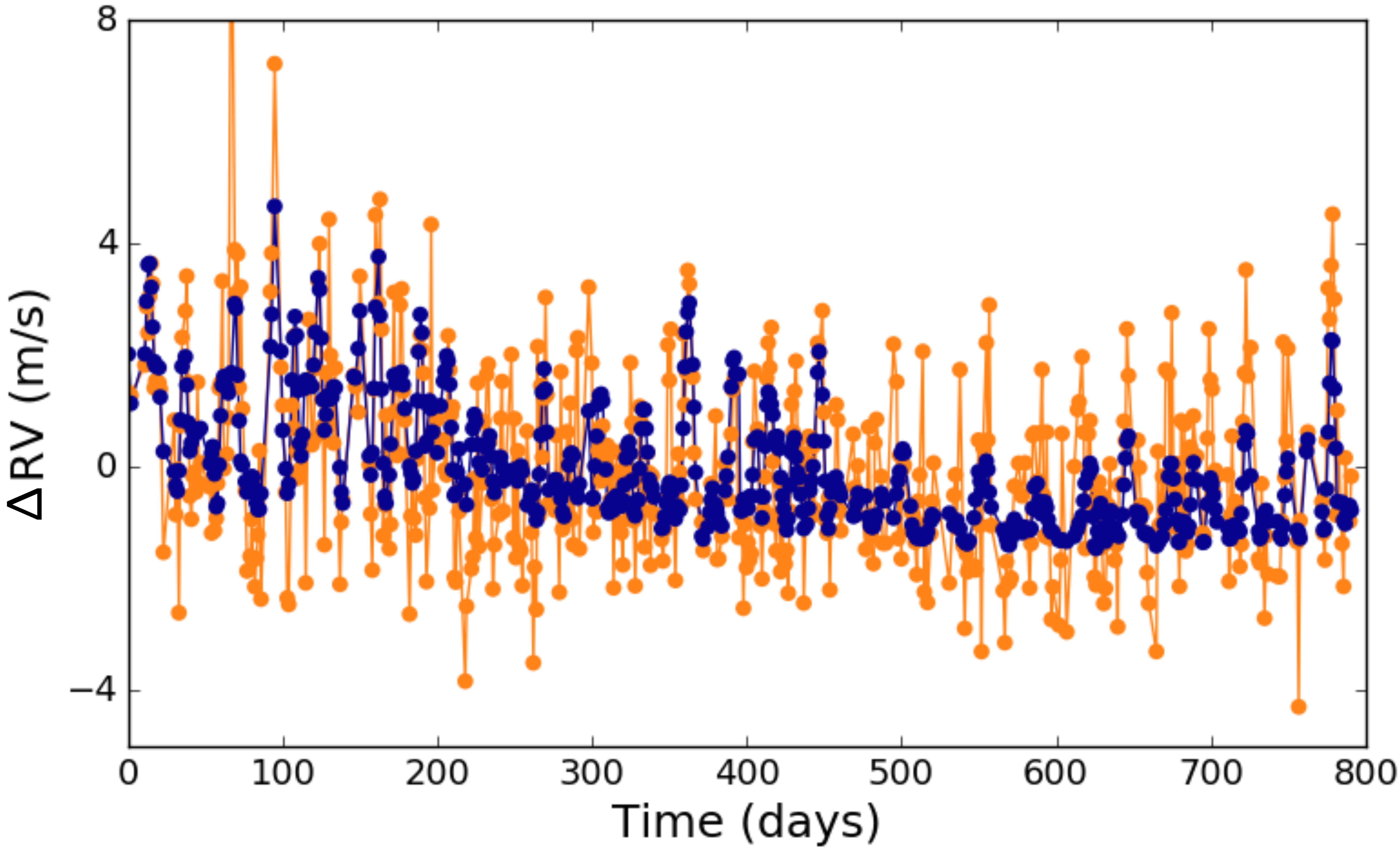
Continuum intensity



Magnetic field

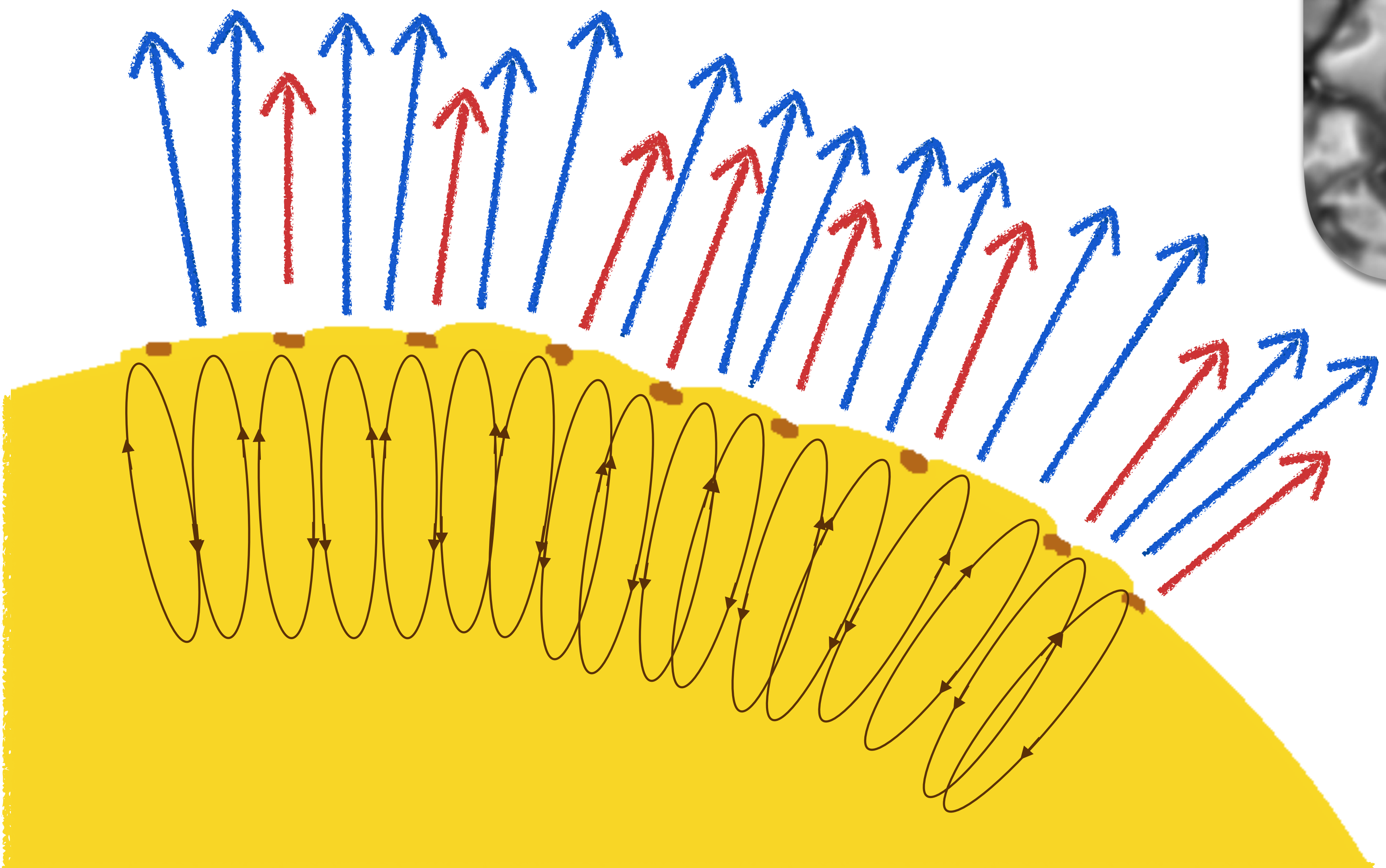
Haywood et al. (2016)

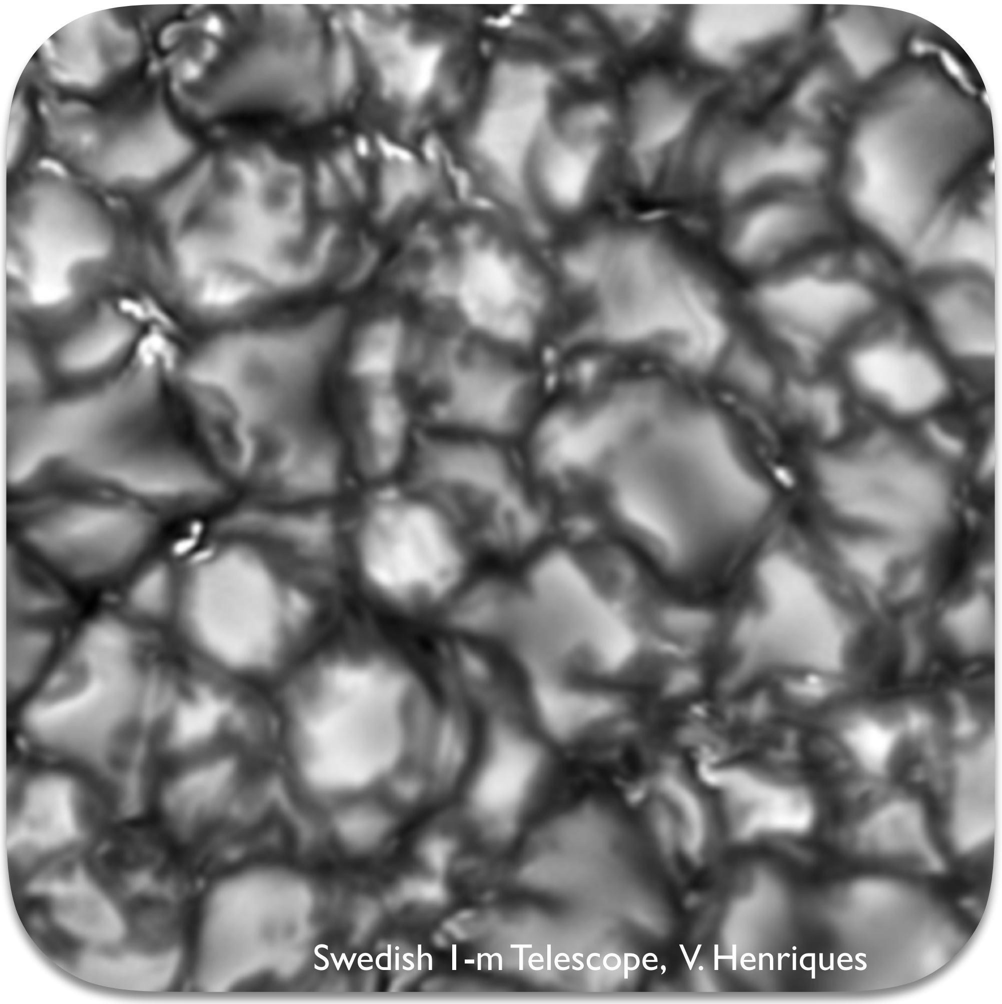
Reconstructing HARPS-N solar observations with SDO/HMI images



Milbourne, Haywood et al. (submitted)

The Sun's RV variations are driven by suppression of convective blueshift from magnetic regions

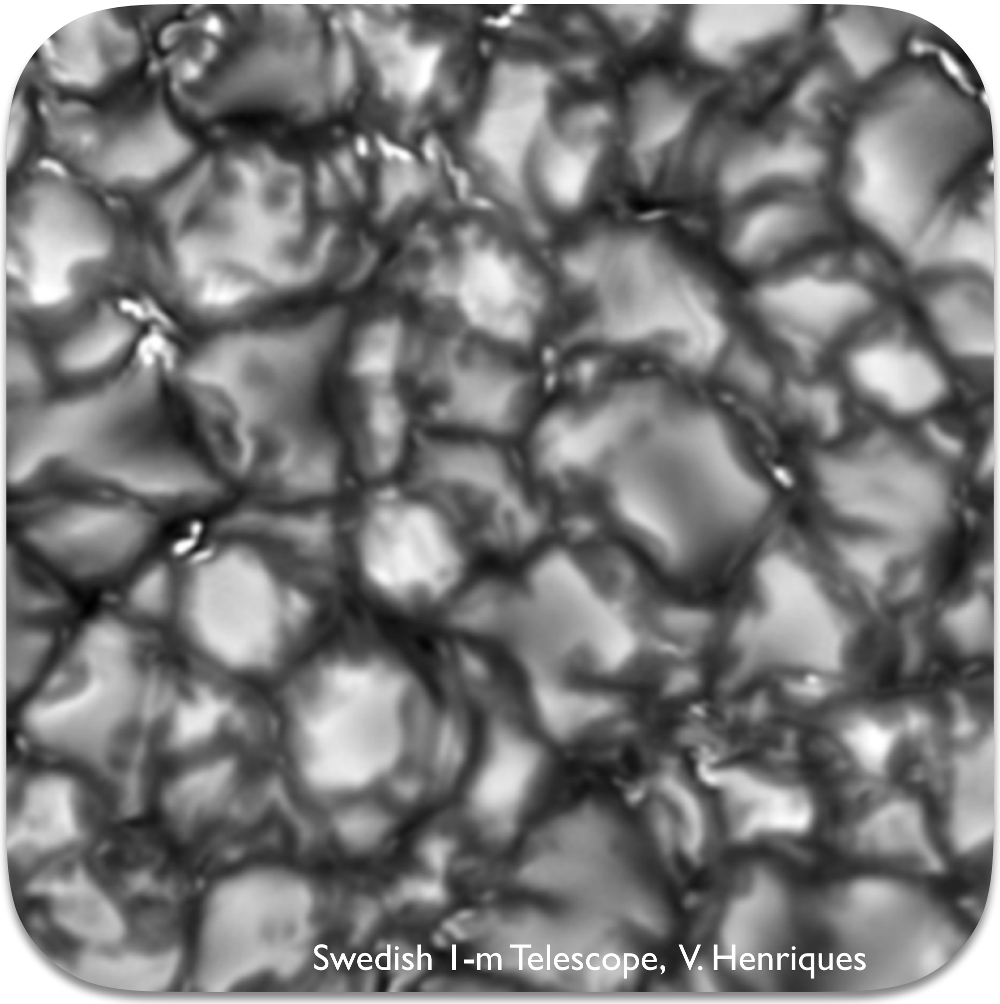


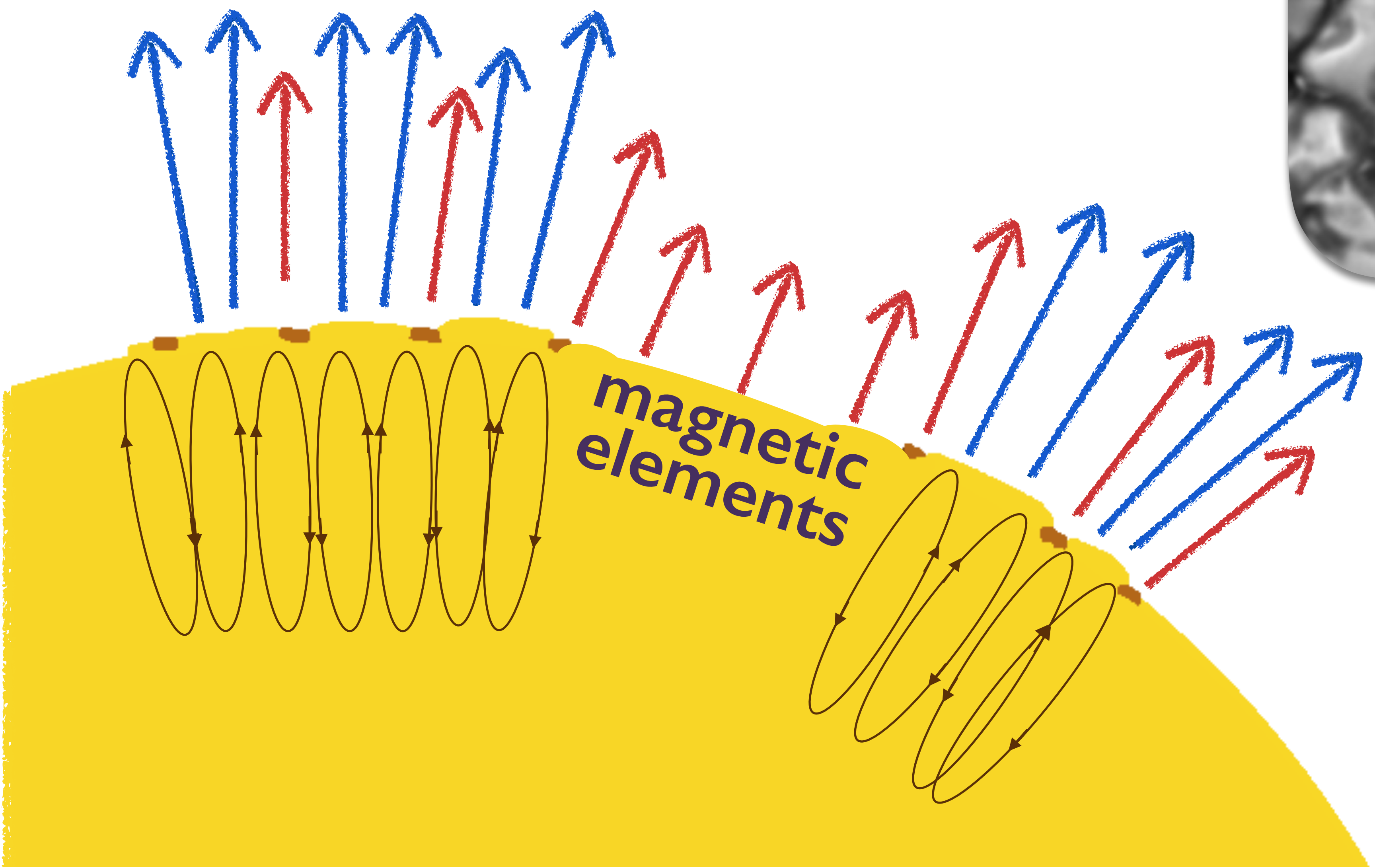


Milbourne, Haywood et al. (submitted),
Haywood et al. (2016),
Meunier et al. (2010a,b)

The Sun's RV variations are driven by suppression of convective blueshift from magnetic regions

⇒ Produces RV variations of several m/s





Milbourne, Haywood et al. (submitted),
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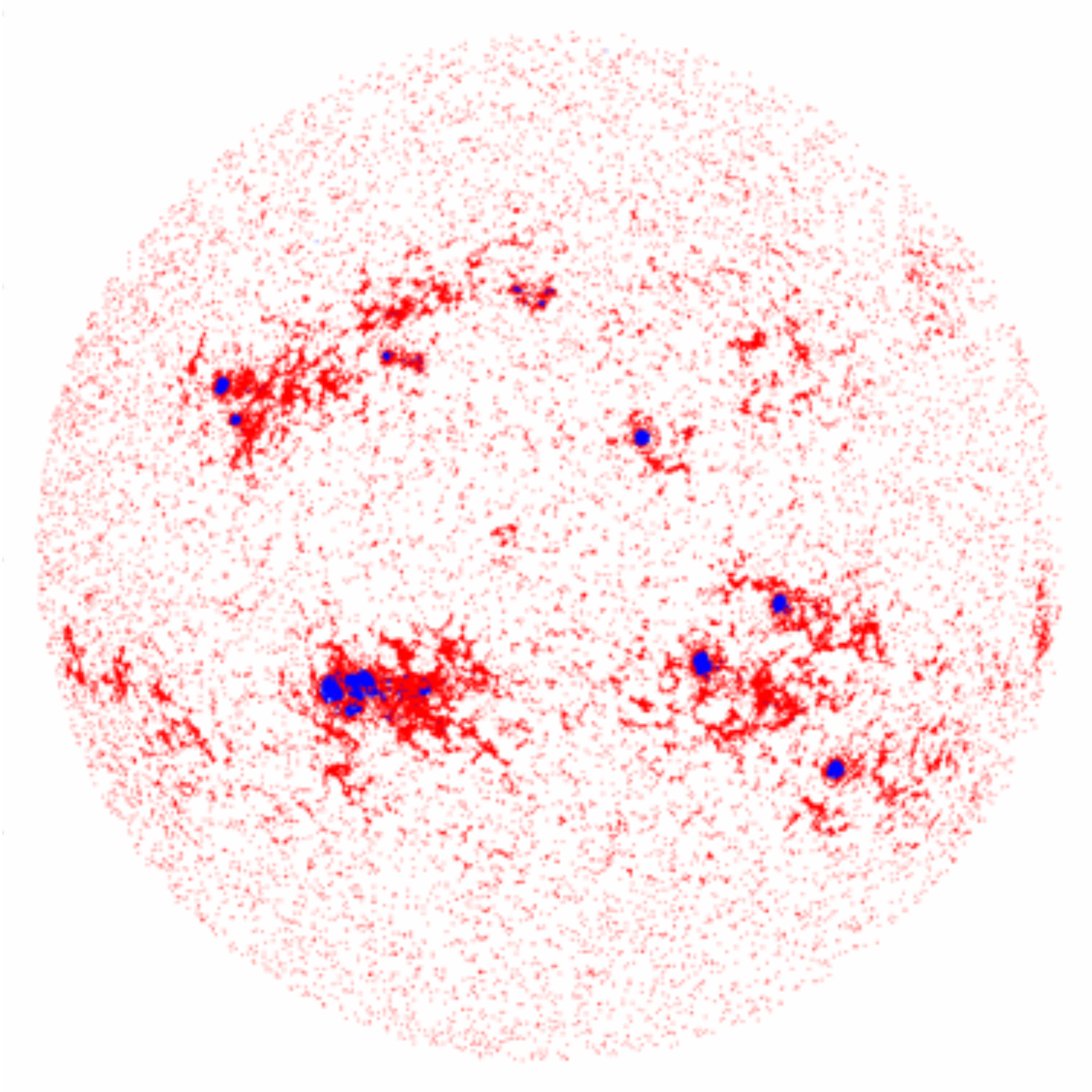
Faculae are the dominant features at play, not sunspots



Milbourne, Haywood et al. (submitted),
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SDO/HMI continuum image

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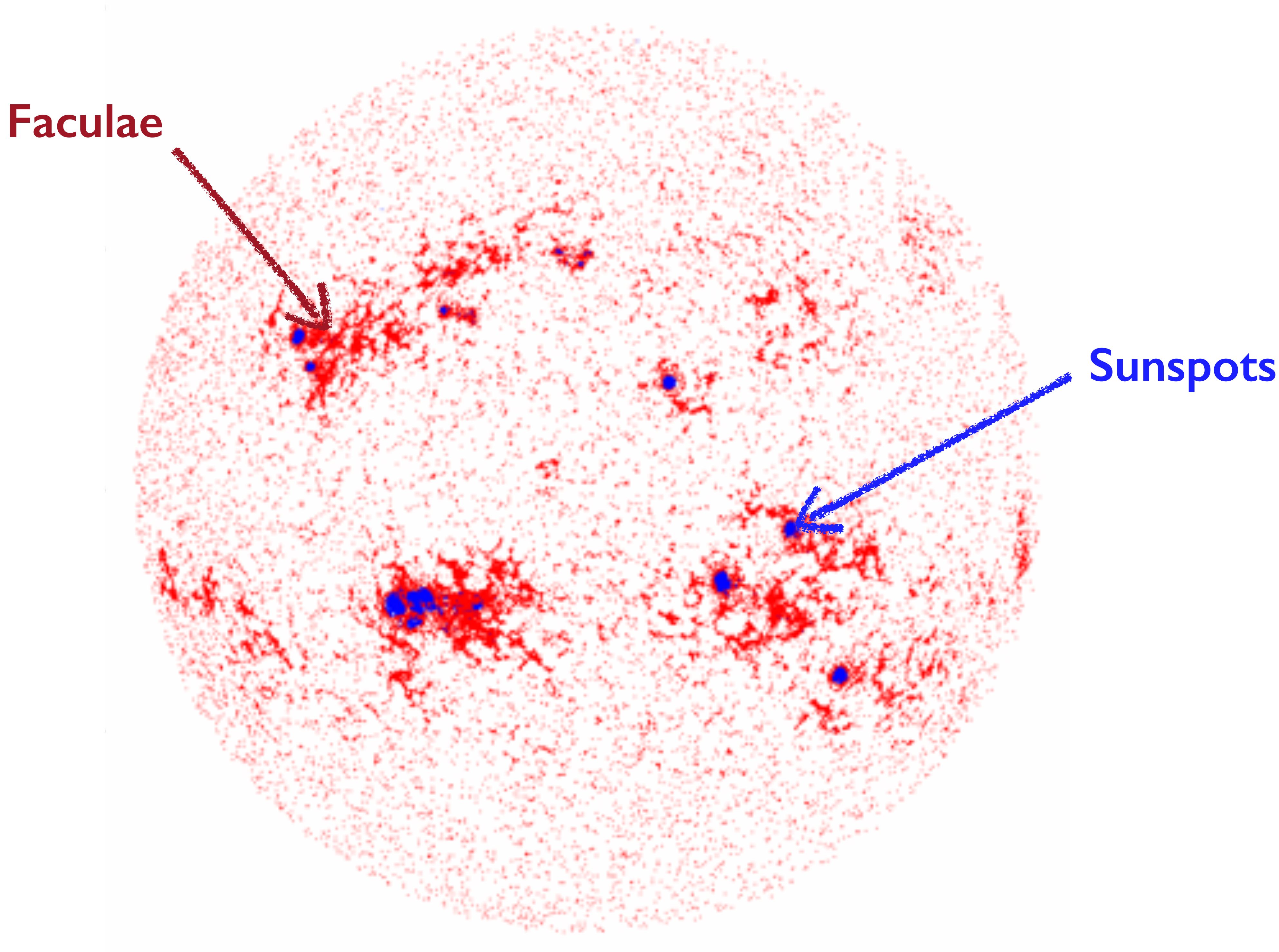
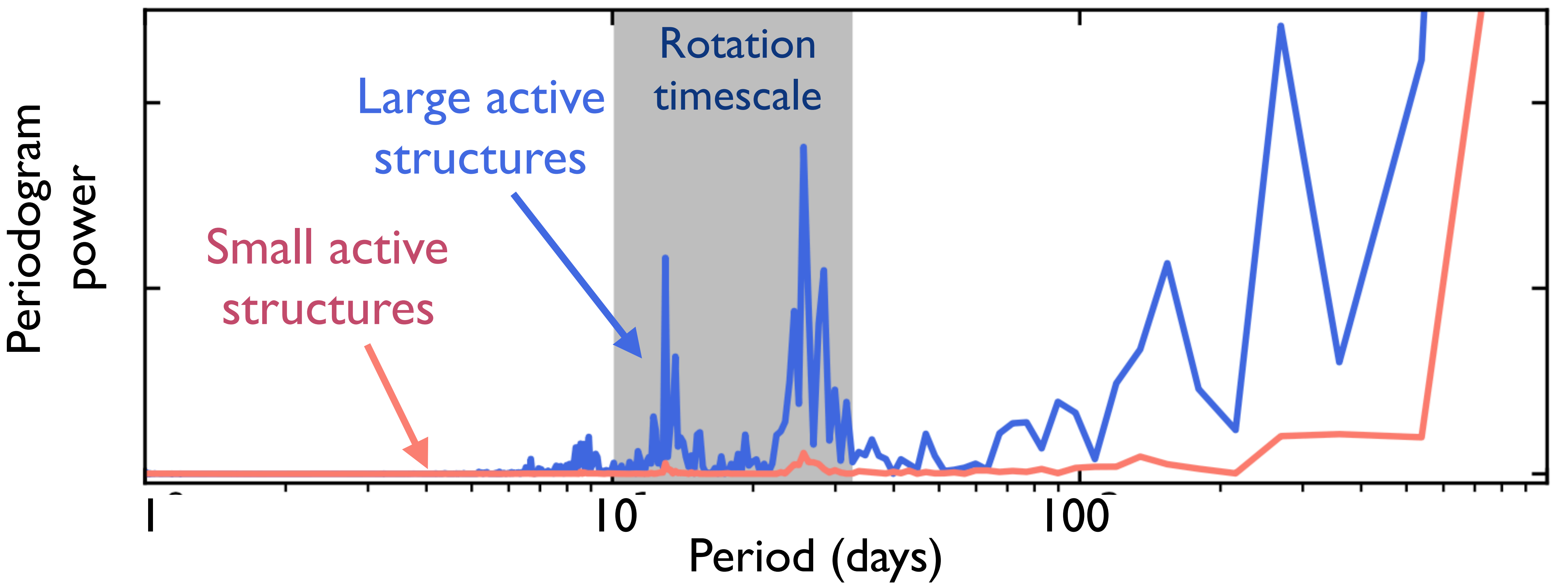
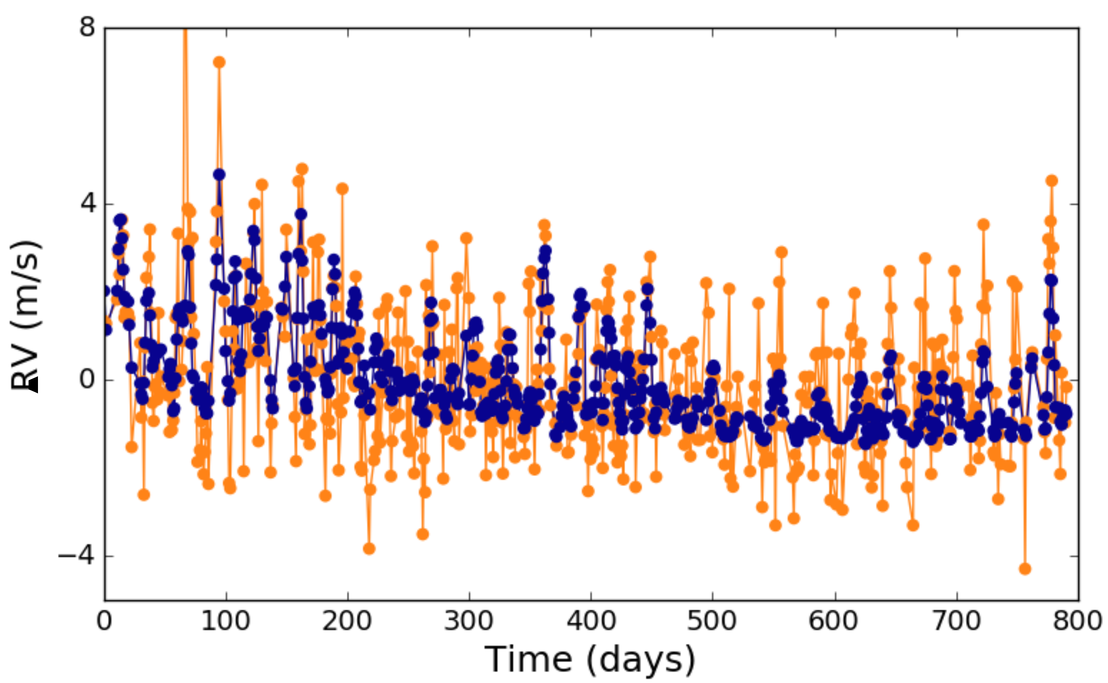


Milbourne, Haywood et al. (submitted),
Haywood et al. (2016),
Meunier et al. (2010a,b)

SDO/HMI continuum image

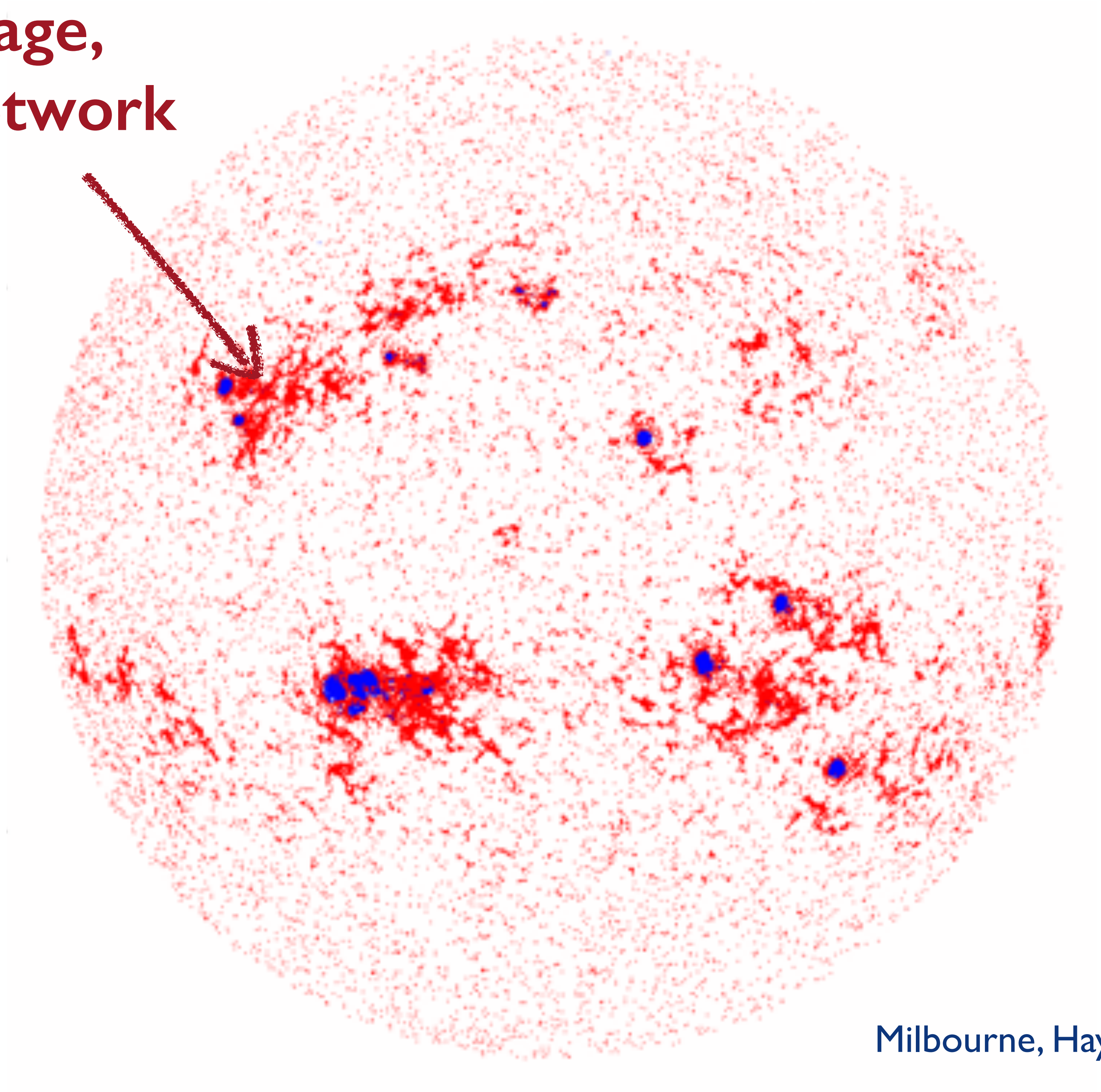
Suppression of convective blueshift is driven by large, bright magnetic regions





Milbourne, Haywood et al. (submitted)

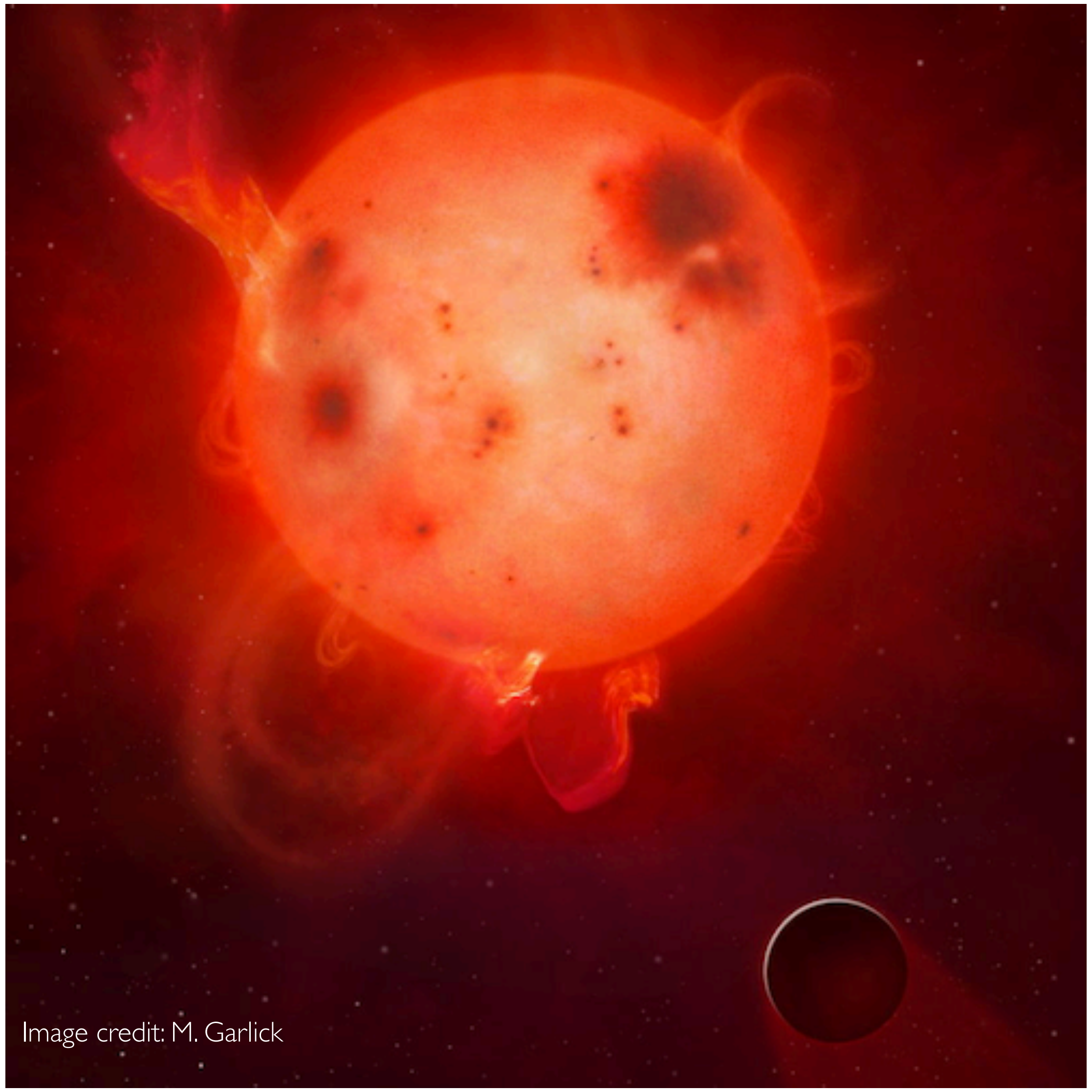
Faculae *in plage* are the dominant features at play



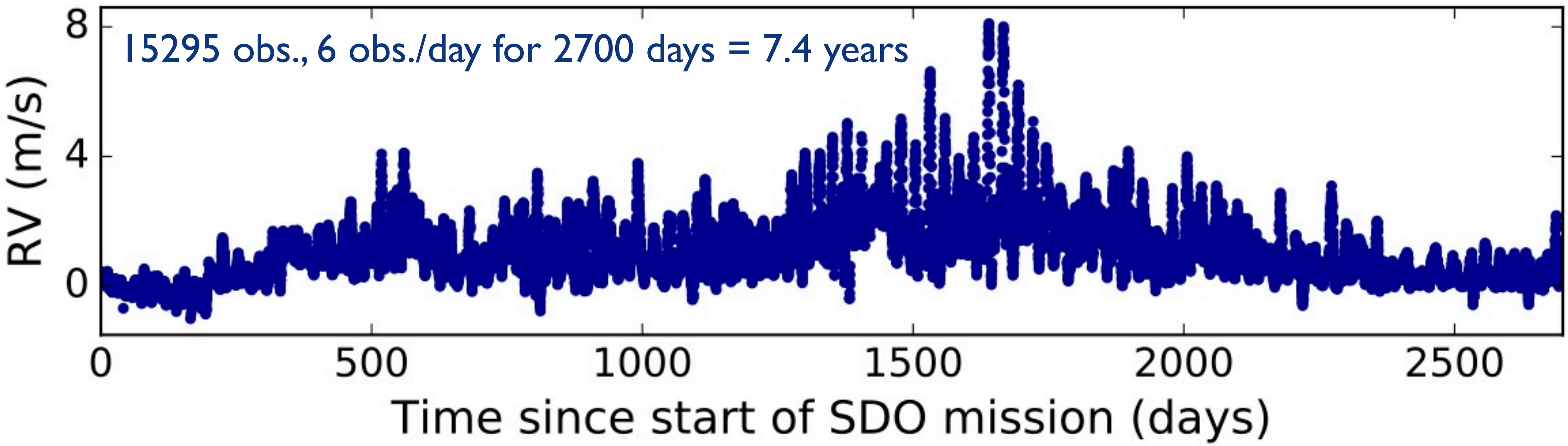
Milbourne, Haywood et al. (submitted),
Haywood et al. (2016),
Meunier et al. (2010a,b)

SDO/HMI continuum image

Can we use solar observations to identify a proxy for rotation-modulated RV variations of Sun-like stars?

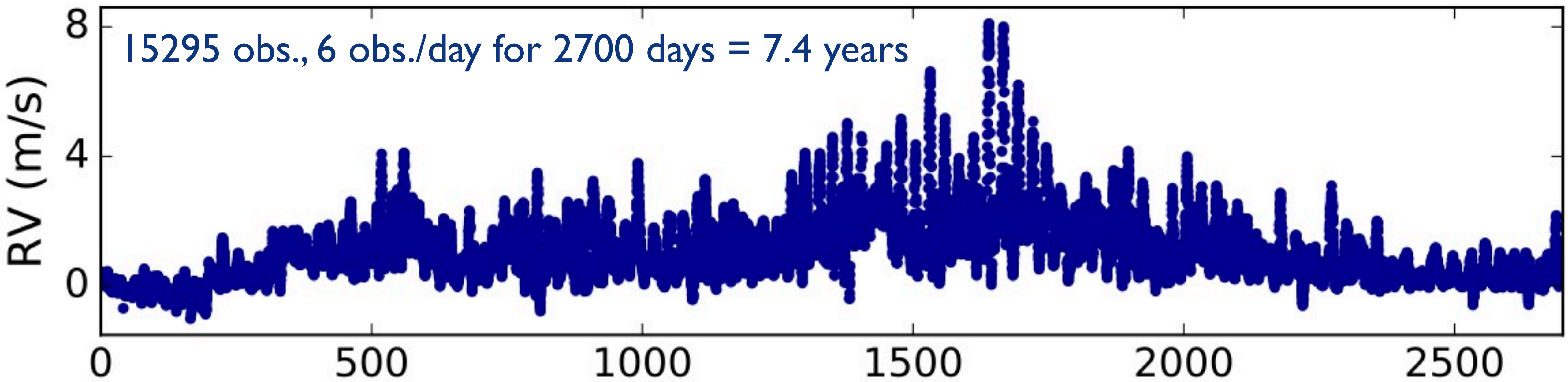


We reconstruct the RV variations of the Sun over the full span of the SDO mission



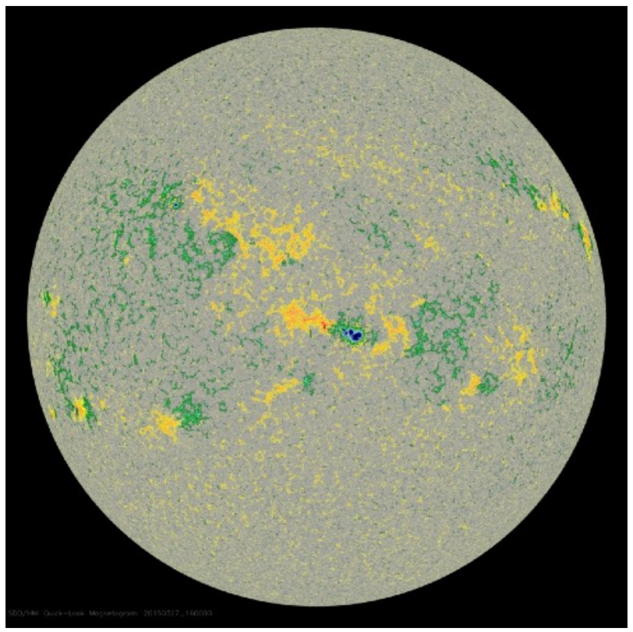
Haywood et al. (in prep.)

We reconstruct the RV variations of the Sun over the full span of the SDO mission



And the full-disc, unpolarised magnetic flux:

SDO/HMI magnetogram



See Robinson (1980), Saar (1988, 1986)

Haywood et al. (in prep.)

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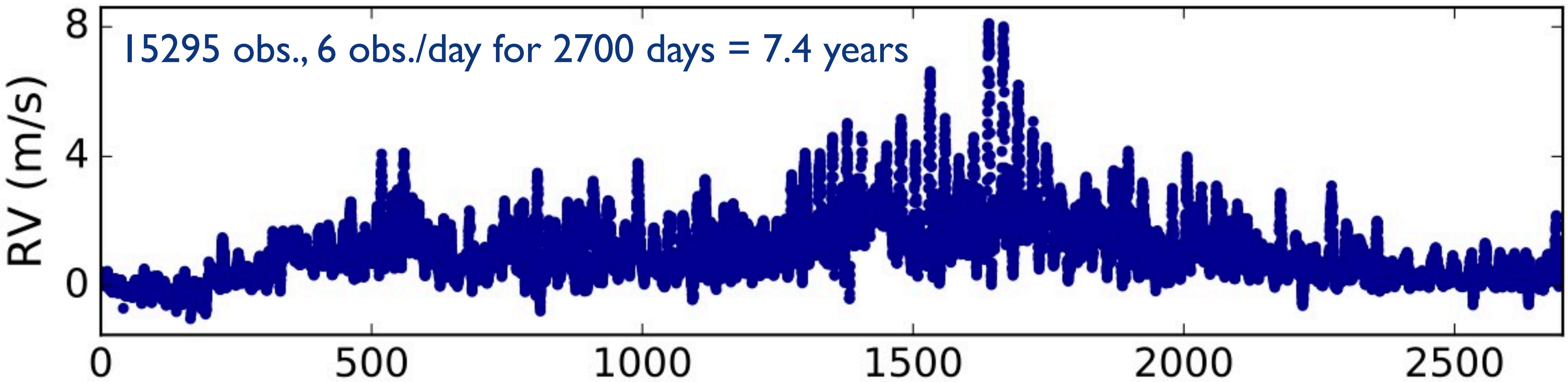

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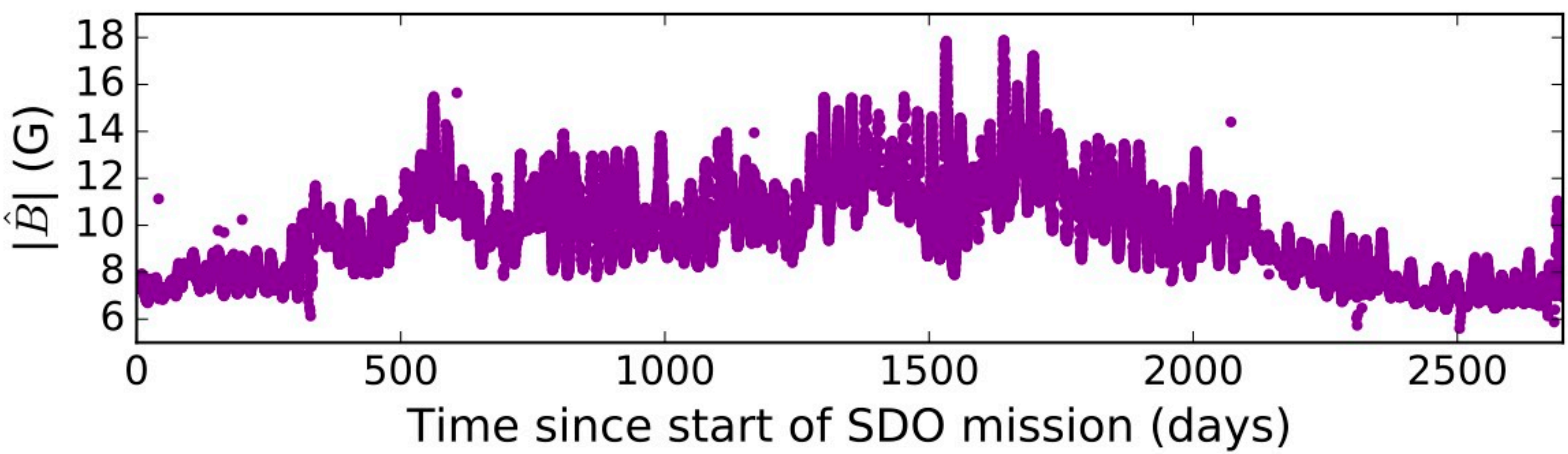
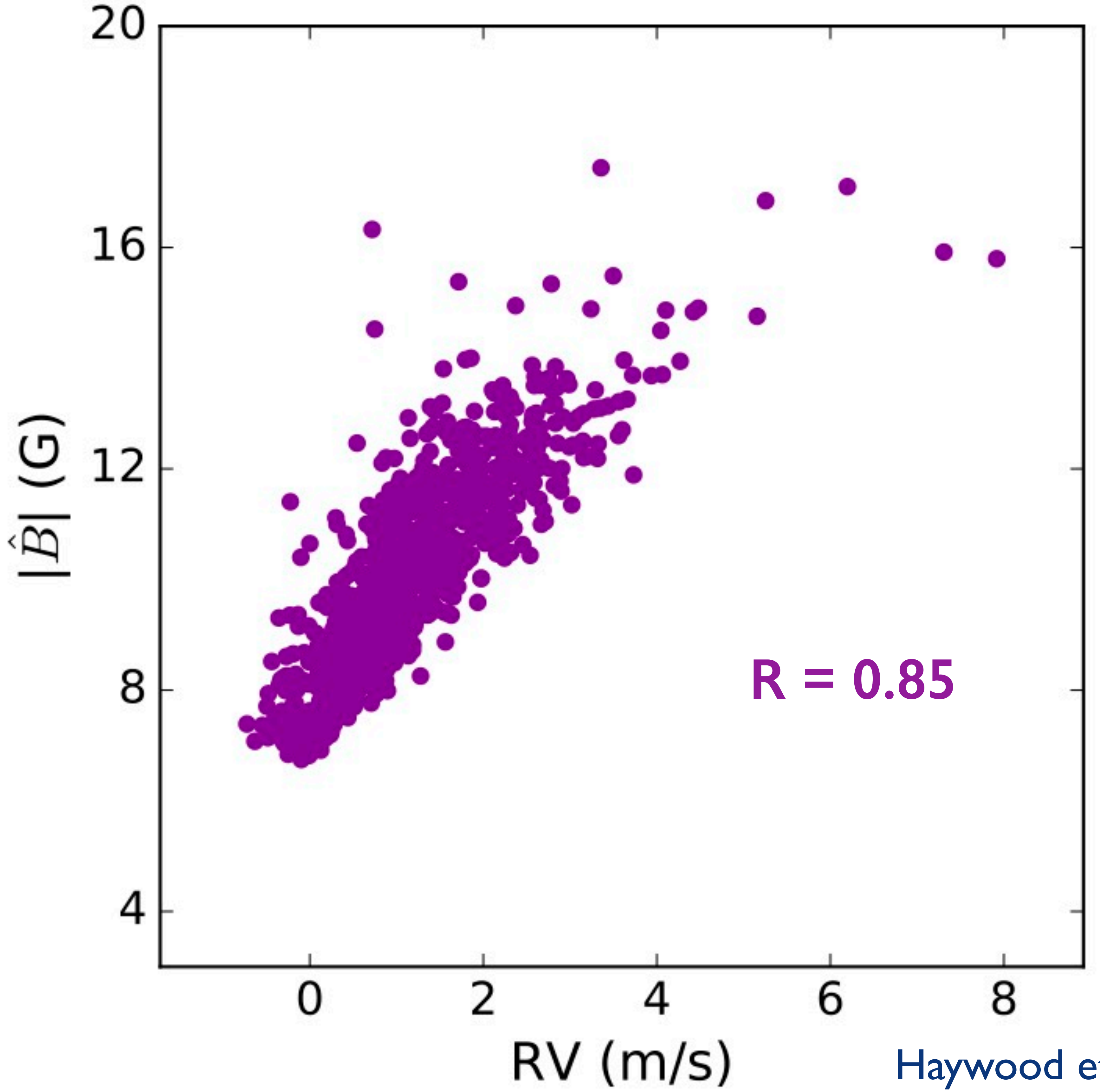


Haywood et al. (in prep.)

The unpolarised magnetic flux as a proxy for RV variations



Haywood et al. (in prep.)

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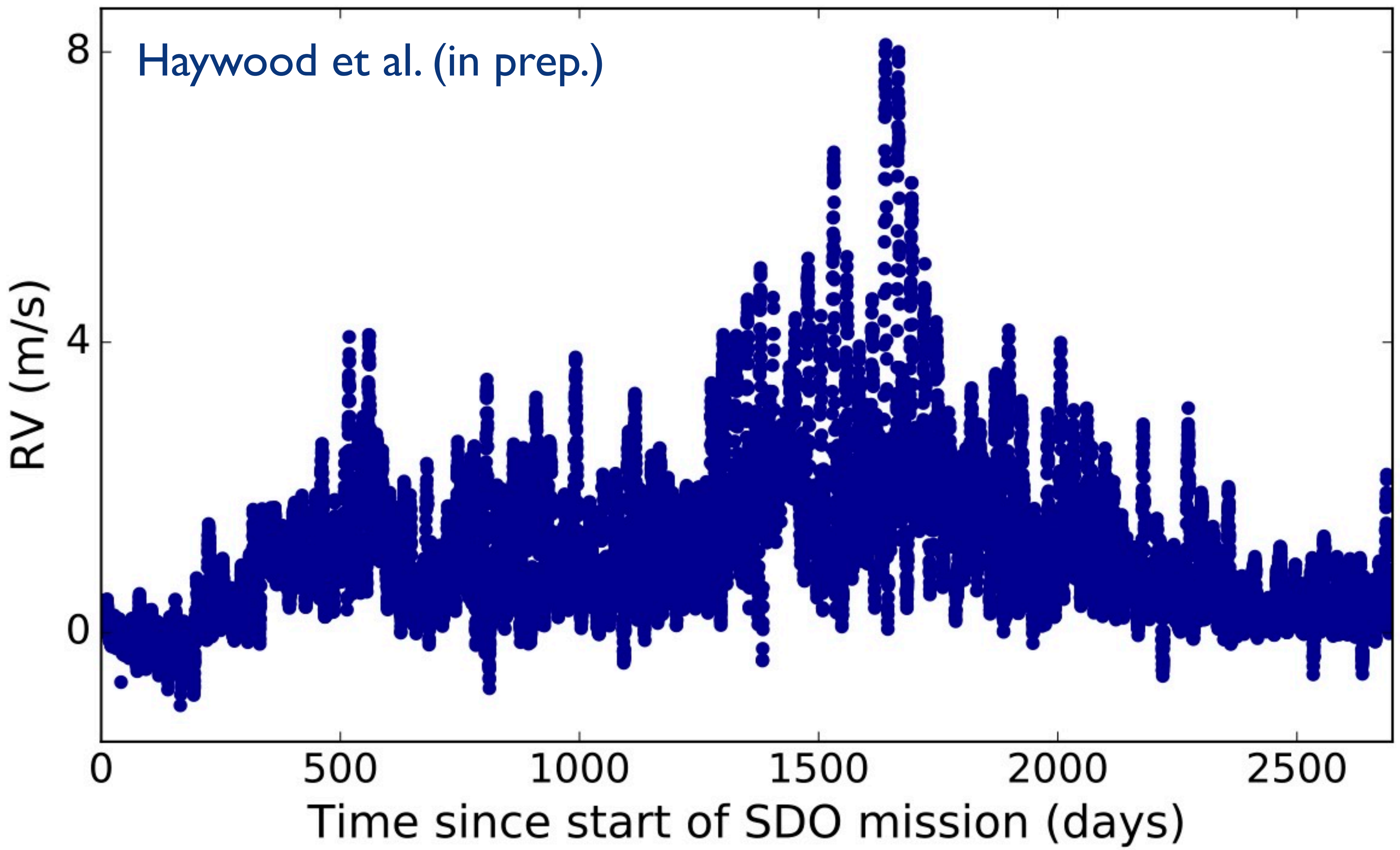
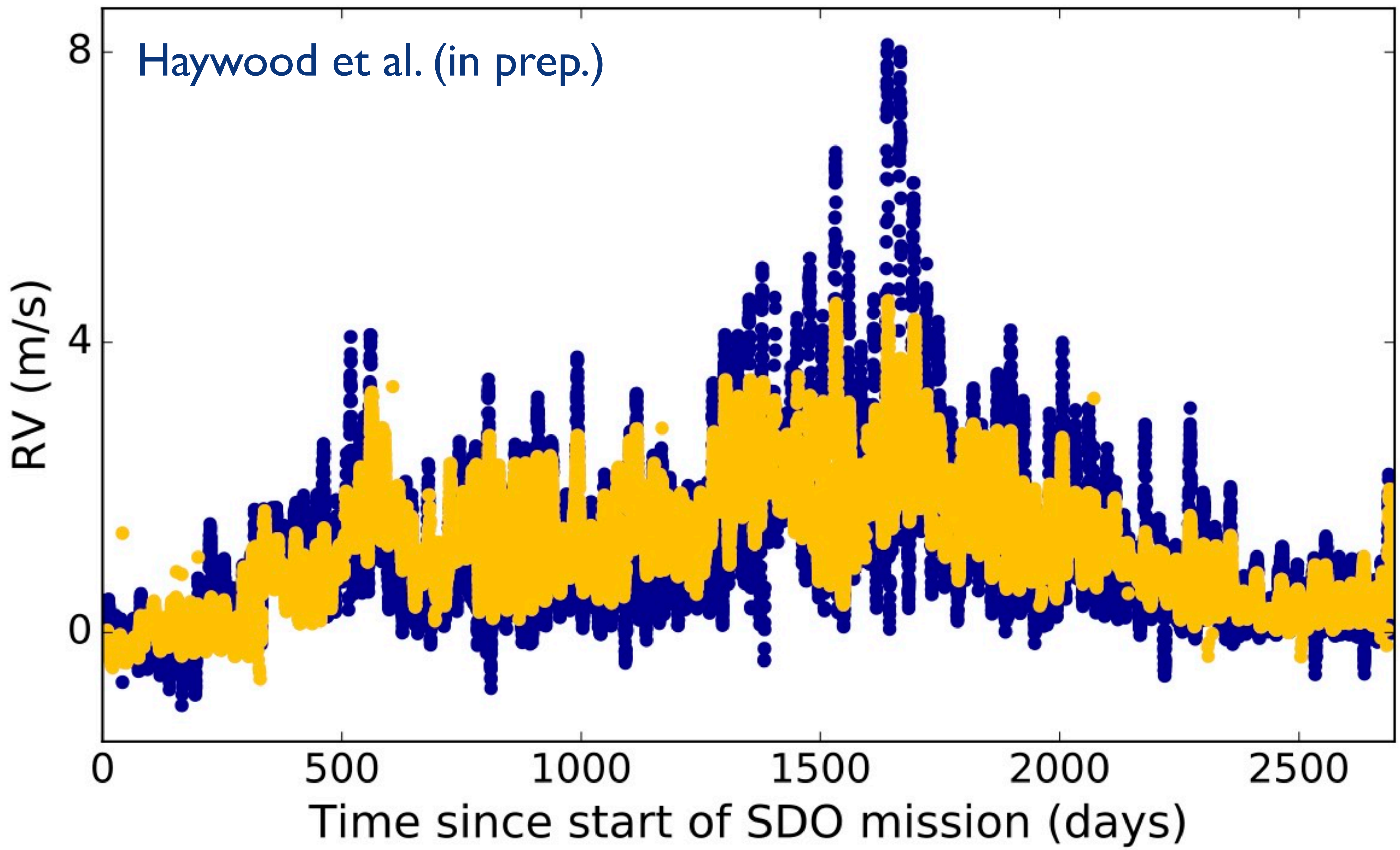


The unpolarised magnetic flux as a proxy for RV variations

Reconstructed RV rms reduced by 46% down to 55 cm/s



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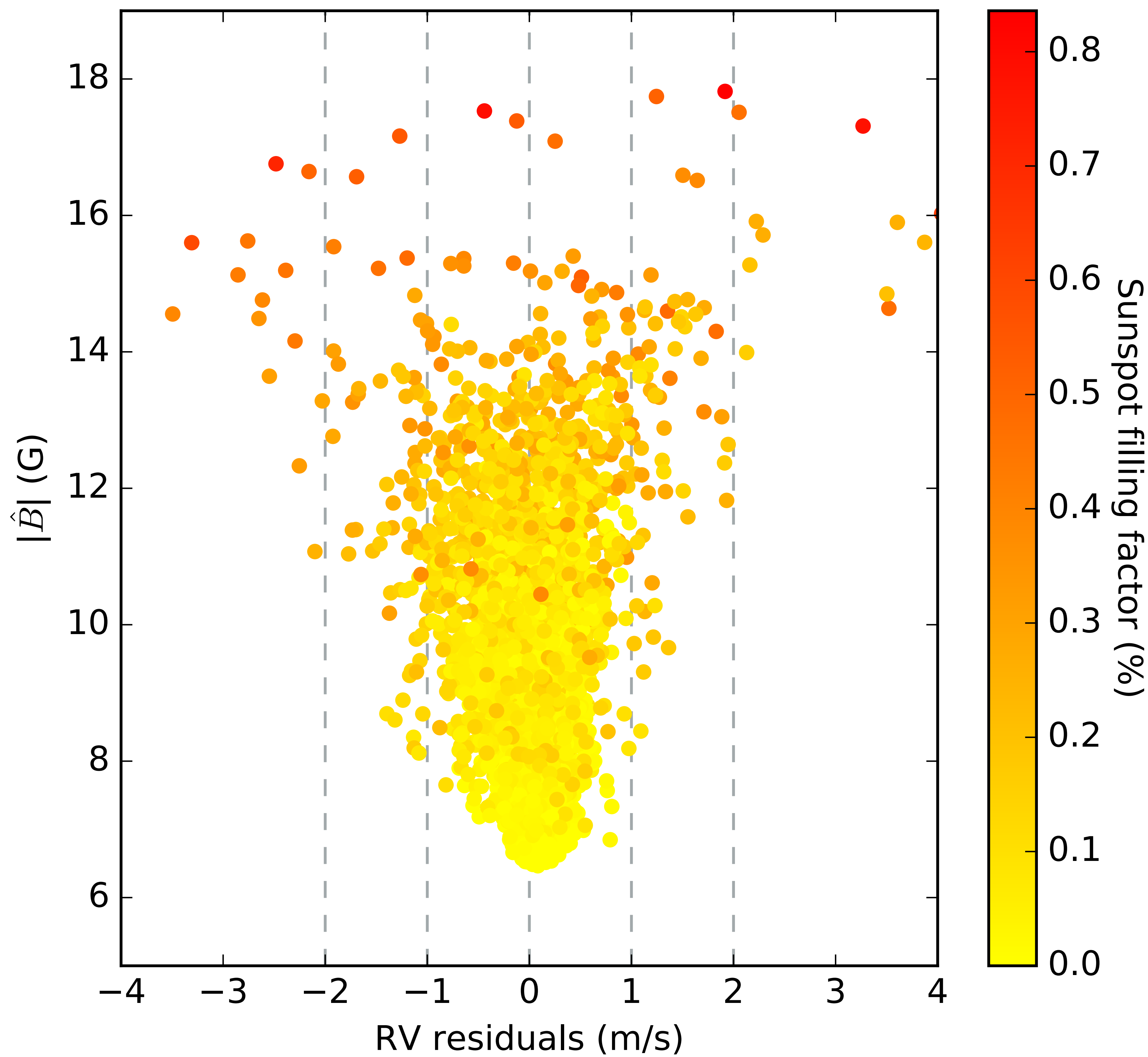

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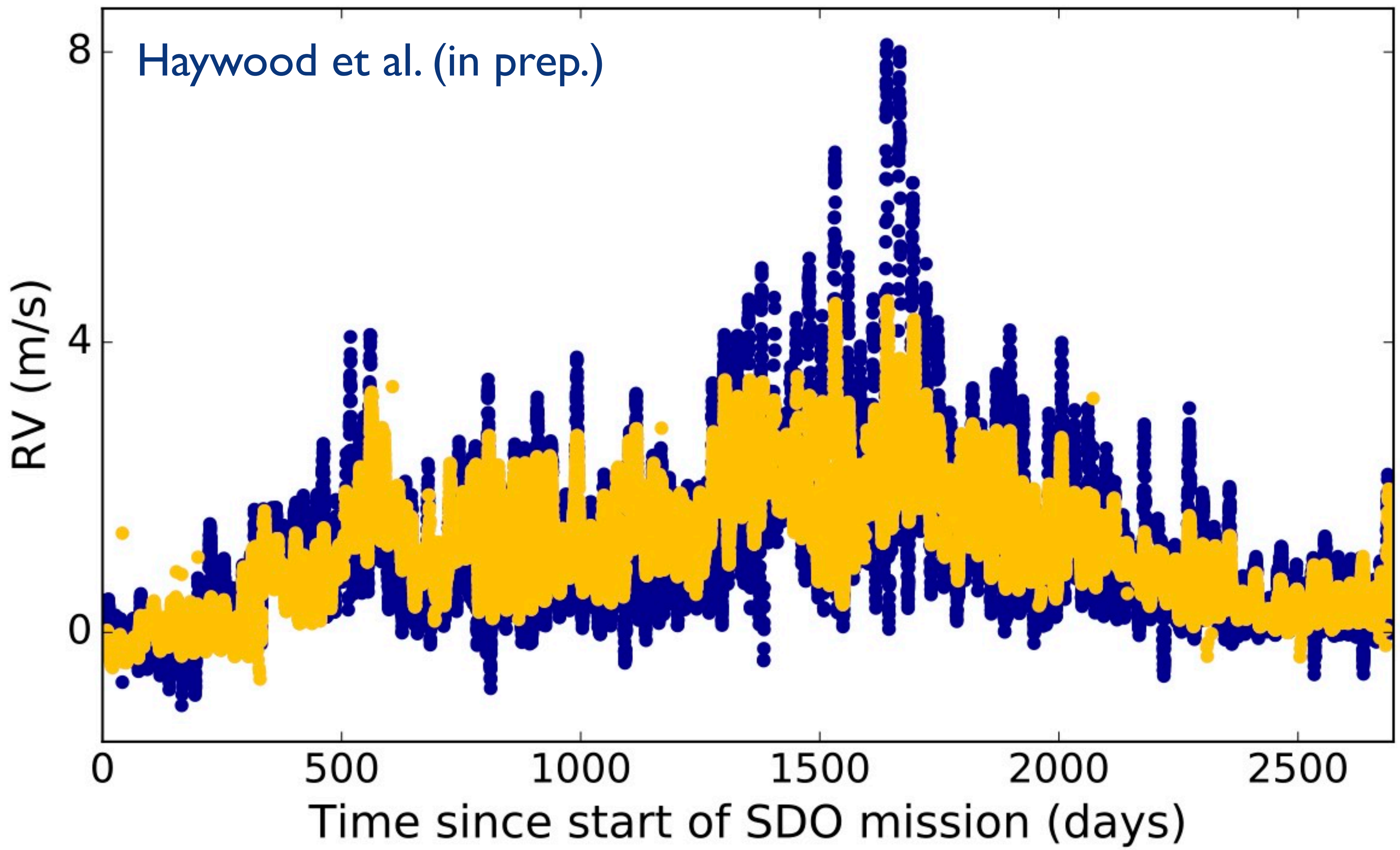

Need to measure unpolarised magnetic flux from Zeeman broadening.
Cannot yet measure for Sun-like stars.

See Robinson (1980), Saar (1988, 1986), Lehmann et al. (2015), Mortier (2016)

Conclusions

Stellar activity is a significant obstacle to determining reliable masses of small planets (and to interpreting exoplanet transmission spectra!)

The Sun's RV variations are driven by faculae in plage (large, bright magnetic regions)

We can use solar observations to develop physically driven models and observational proxies to account for stellar activity in exoplanet observations

The unpolarised magnetic flux would be an excellent proxy for rotation-modulated RV variations

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