Magnetically inactive regions can dominate solar RVs

Ben Lakeland[1]
bsl204@exeter.ac.uk
Raphaëlle Haywood[1], Federica Rescigno[1], Shweta Dalal[1], Tim Naylor[1], Annelies Mortier[2], Sam Thompson[3], Nadège Meunier[4], & the HARPS-N GTO Science Team

Magnetically inactive regions on the Sun produces RV variability consistently around 1 ms^{-1}, often greatly exceeding the rotationally-modulated variability from magnetically active regions.

Radial velocities of magnetically inactive regions

Previous Sun-as-a-star studies[1,2,3] have used images from the Helioseismic and Magnetic Imager aboard the Solar Dynamics observatory (SDO/HMI) to calculate the RV variability arising from magnetically active regions on the solar disc. The two components accounted for in these RVs are the photometric shift of flux-imbalanced regions traversing the rotating solar disc, and the suppression of convective blueshift. They found that the dominant process in these RVs is the suppression of convective blueshift[1], that the RVs are dominated by large, bright magnetic regions[2], and that these RVs correlate extremely well with the unsigned magnetic flux[3].

To investigate the RV variability signature of the magnetically **inactive** regions, we subtract the RVs calculated from SDO/HMI images (RVs from active regions) from RVs from the HARPS-N solar telescope (RVs from the whole Sun). The residual RV signal has an overall RMS of 0.95 ms^{-1}.

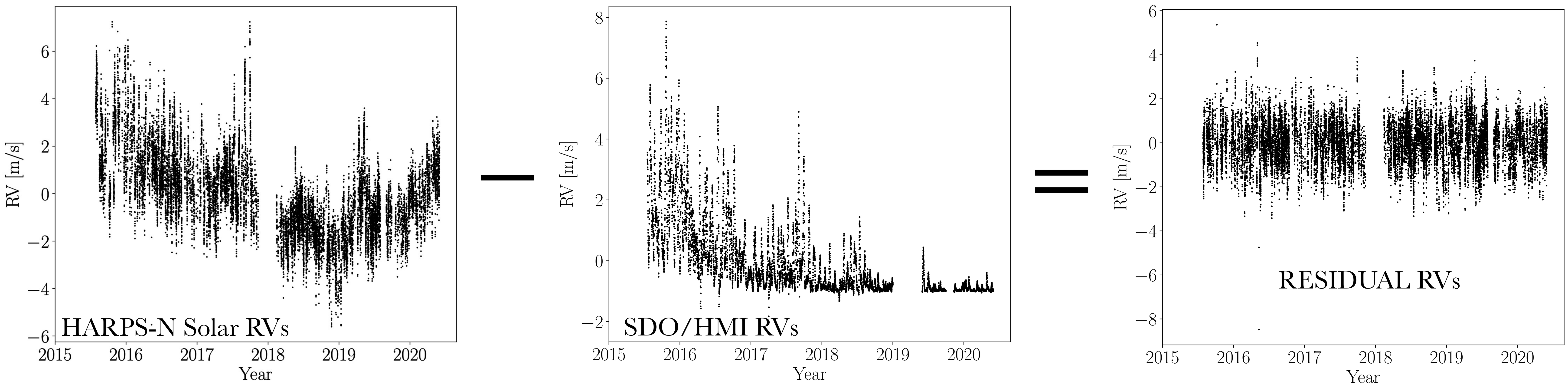

Fig.1. (Left) The HARPS-N solar RV time series. (Middle) The time series of RVs obtained from SDO/HMI images. (Right) The residual RV timeseries formed by subtracting the SDO/HMI RVs from the HARPS-N Solar RVs. To remove the effect of long-term trends, we detrend the residual RVs with a 100-day rolling mean. This is much longer than any timescale we investigate here so doesn't impact our results

How do we analyse the variability?

The structure function of a time series **directly shows the level of variability present at each timescale.**

For a timeseries $f(t)$, the structure function at a given timescale τ is calculated as

$$SF(\tau) = \left\langle \left(f(t) - f(t+\tau)\right)^2 \right\rangle .$$

Fig. 2 shows how this is calculated. Identifying the timescale beyond which there is no increase in structure function gives the **intrinsic variability timescale of the time series**. The flat structure function shown in Region 3 of the second panel of Fig. 2 is typical of an uncorrelated signal.

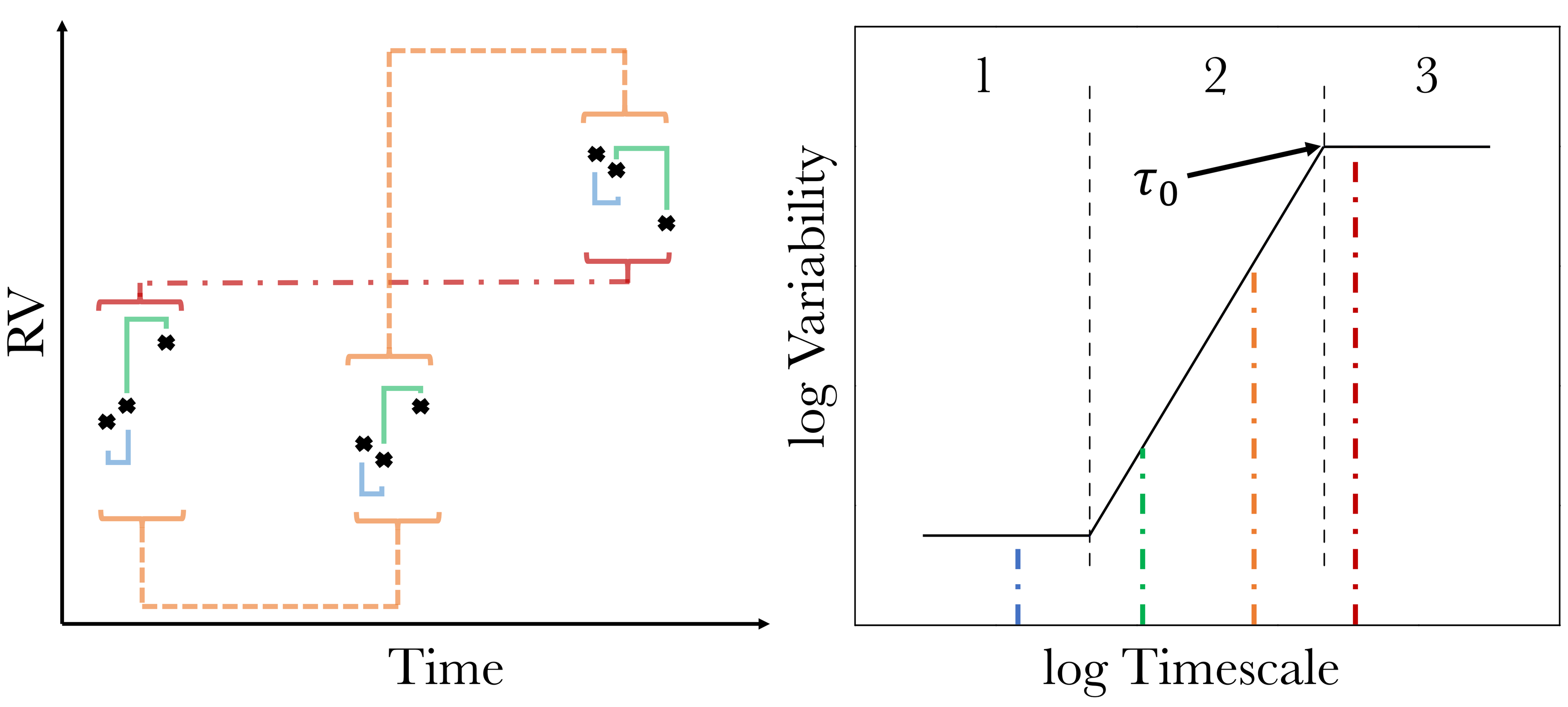

Fig. 2. (Left) An example time series with different timescales highlighted. (Right) A schematic structure function with the corresponding timescales highlighted. We also highlight how to identify the characteristic variability timescale, τ_{brk}, from a structure function. Adapted from [4].

How do the residual RVs behave?

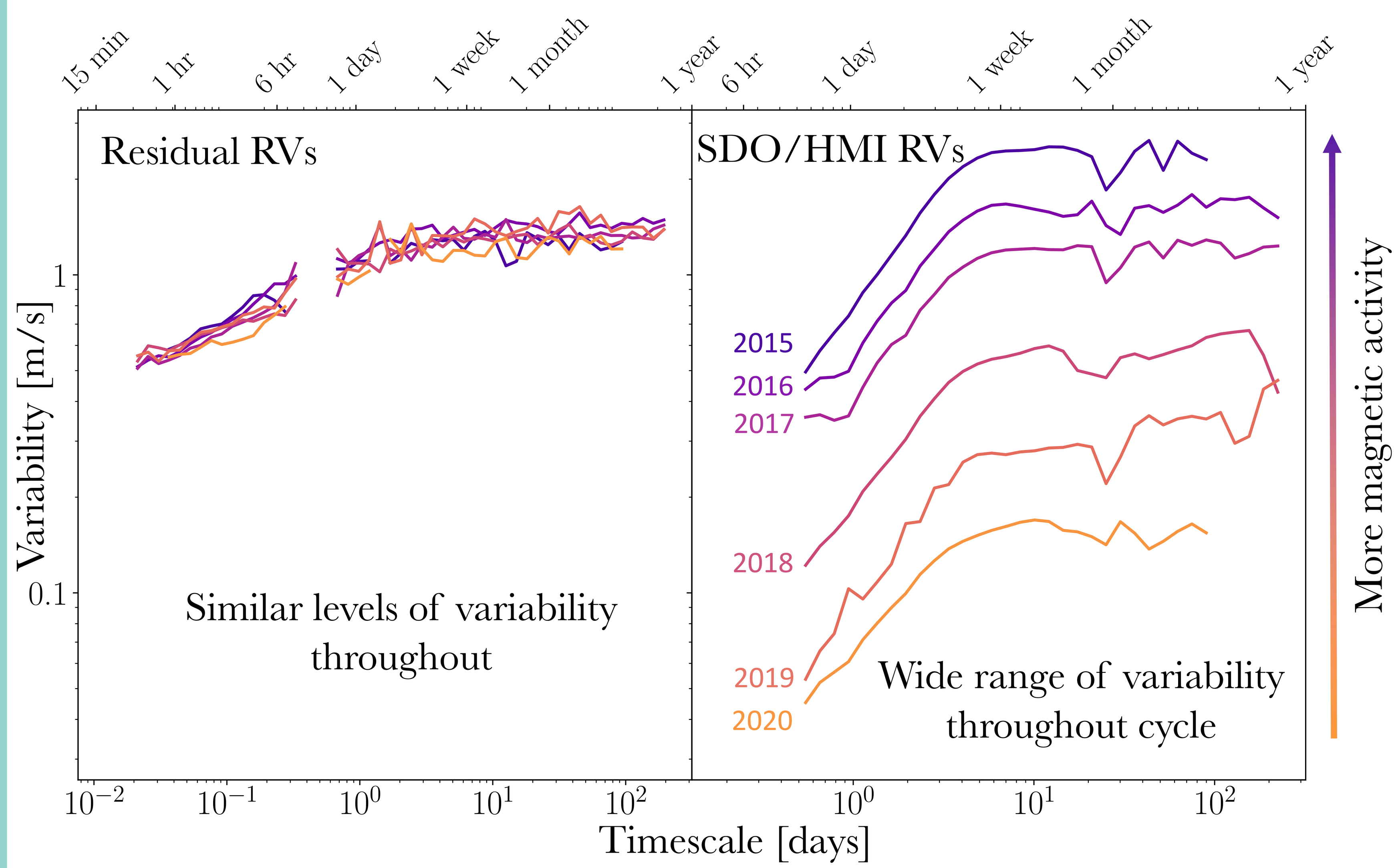

Fig. 3. Structure functions of the residual RVs (left) and RVs calculated from SDO/HMI images (right), coloured by calendar year. Taken from [5]

We find that the RVs from the magnetically inactive regions have a **constant level of variability** which can be **over an order of magnitude higher** than the RVs from the magnetically active regions, especially towards solar minimum.

We can reproduce most of the RV variability from the magnetically inactive regions with simulated **oscillation, granulation, and supergranulation** RV time series.

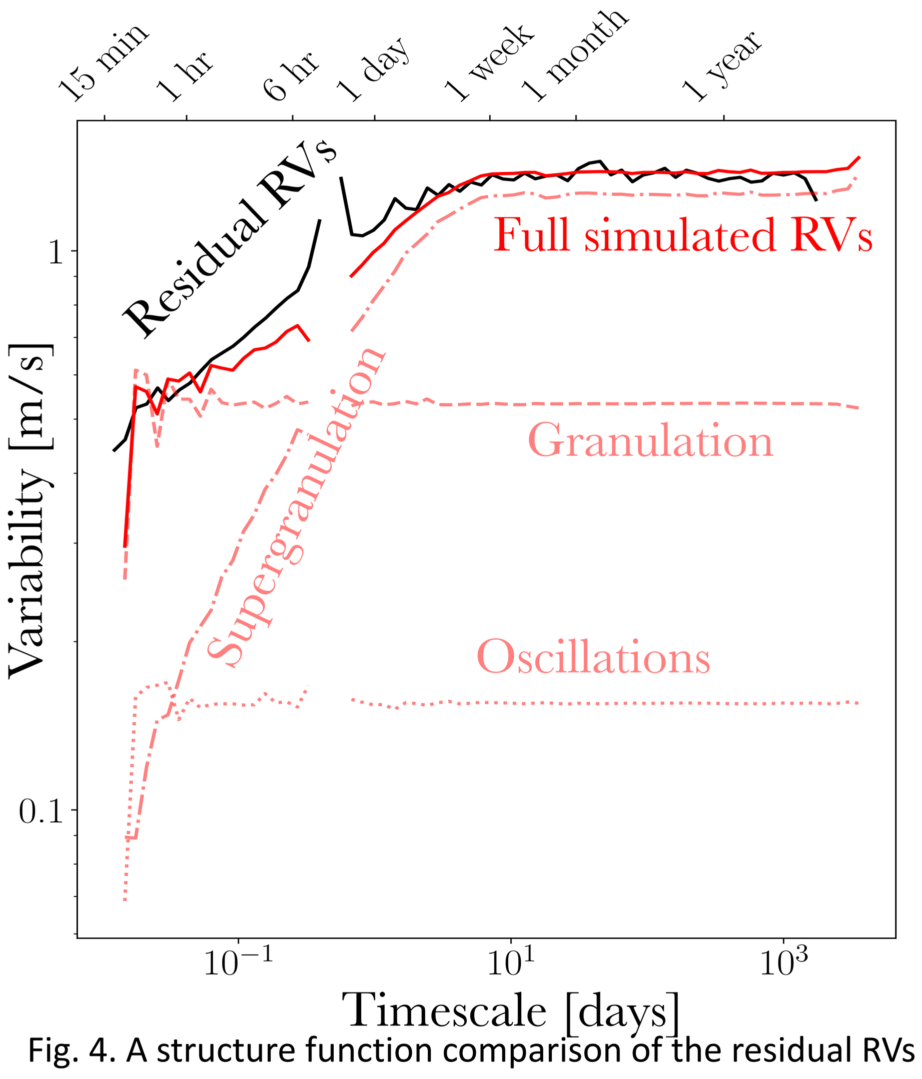

Fig. 4. A structure function comparison of the residual RVs (black) and simulated RVs (red)[6]. Taken from [5].

Conclusions

We isolate the RV contributions from magnetically inactive regions and find that these 'residual' RVs have a consistent level of variability over the six-year baseline of around 1 ms^{-1}, often exceeding the RV contributions from the magnetically active regions. We compare these RVs to simulations of oscillations, granulation, and supergranulation, and find good agreement. This suggests that, at low magnetic activity, the solar RVs are dominated by granulation and supergranulation.

Acknowledgements

References: [1] Haywood, R. D., *et al., MNRAS* **457**, 3637 (2016)
[2] Milbourne, T., *et al., ApJ* **874**, 107 (2019)
[3] Haywood, R. D., *et al., ApJ* **935**, 6 (2022)
[4] Sergison, D., *et al., MNRAS* **491**, 5035 (2020)
[5] Lakeland, B. S., *et al., in prep.*
[6] Meunier, N., *et al., A&A* **583**, A118 (2015)

Affiliations: [1] University of Exeter, U.K.
[2] University of Birmingham, U.K.
[3] University of Cambridge, U.K.
[4] Université Grenoble Alpes, France

The HARPS-N project has been funded by the Prodex Program of the Swiss Space Office (SSO), the Harvard University Origins of Life Initiative (HUOLI), the Scottish Universities Physics Alliance (SUPA), the University of Geneva, the Smithsonian Astrophysical Observatory (SAO), the Italian National Astrophysical Institute (INAF), the University of St Andrews, Queen's University Belfast, and the University of Edinburgh.