Probing the surfaces of Sun-like stars using transiting planets and 3D MHD simulations

Dr Heather Cegla
CHEOPS Fellow
The solar surface

Transiting Stellar Surfaces

Centre-to-limb Variations on the Sun

Centre-to-limb Variations on the Sun

Centre-to-limb Variations on the Sun

Cegla, H. M. et al, in press
ArXiv: 1807.11423
Parameterising the Granulation

Stellar surface magneto-convection as a source of astrophysical noise

Figure 4. Average (thick) and individual (thin) line profiles from the four different contributions to granulation used in the parameterisation: granules (green), MBPs (red), magnetic (blue) and non-magnetic (purple) intergranular lanes, for four different stellar disc centre-to-limb angles. Flux is measured in units of erg s$^{-1}$ cm$^{-2}$ sr$^{-1}$ ˚A$^{-1}$.

photosphere, and therefore these components may also experience a decrease in their thermal broadening. The MBP components also do not decrease significantly in continuum intensity until closer to the limb (see Figure 5); this is likely because they change from point-like structures within the intergranular lanes at disc centre (that are bright due to enhanced continuum intensity and decreased radiation absorption) to also include bright regions on the granular walls known as faculae at higher inclinations. While the granule itself is non-magnetic, as the granulation snapshot is inclined high magnetic field concentrations in the intergranular lanes decrease the opacity and allow the LOS to reach the granular wall. Such regions then have high brightnesses due to the high temperature of the granule, yet a high magnetic field measurement due to the LOS traversing regions of high magnetic field within the relatively transparent intergranular lane. Although these regions are better known as faculae and do not necessarily have point-like surface areas, since they are both magnetic and bright we include them in the MBP category across the stellar disc. As a result, the decrease in brightness of the MBPs as the simulations are inclined is partially

Cegla, H. M. et al
ArXiv: 1807.11423
Centre-to-limb Variations on the Sun

Sun-as-a-star Model Observations

Correlations

Correlations

~40% Noise Reduction

Planets as Probes

Image: Rappaport et al

The Rossiter-McLaughlin effect

Image: Rappaport et al

Local RV (km s\(^{-1}\))

\(V_{\text{eq}} \approx 4.5^{+0.5}_{-0.4} \text{ km s}^{-1}; \ \alpha : 0.3-0.9; > 0.1; i \approx 92^\circ_{+12}{}_{-14}^; \ \lambda \approx -0.4 \pm 0.2^\circ; \ \psi \approx 7^\circ_{+12}{}_{-4}^;

Revised architecture of the WASP-8 system: A cautionary tale for traditional Rossiter-McLaughlin analysis

V. Bourrier, H. M. Cegla, C. Lovis, and A. Wyttenbach

Local RV (km s\(^{-1}\))

\[ V_{eq} \approx 4.5^{+0.5}_{-0.4} \text{ km s}^{-1}; \alpha : 0.3-0.9; > 0.1; i \approx 92^{+12}_{-14}^\circ; \]

\( \lambda \approx -0.4 \pm 0.2^\circ; \psi \approx 7^{+12}_{-4}^\circ \)

ABSTRACT

Probing the trajectory of a transiting planet across the disk of its star through the analysis of its Rossiter-McLaughlin effect reloaded (reloaded RM) technique. This approach allows us to isolate the local stellar CCF emitted by the planet-occulted sky-projected obliquity of the stellar lines from the equator to the poles. Whatever its origin, such an eccentricity variation in the local CCF contrast along the transit chord, which might trace a deepening of the stellar line shape. This distortion of the stellar lines and their correlation with the stellar spin can be directly extracted using the reloaded RM technique. This approach allows us to analyze the shape and measure the RV centroids of the local stellar CCFs, allowing us to analyze their shape and to measure their RV centroids, unbiased by variations caused by stellar oscillations and granulation.

V_{\text{eq}} \approx 4.5^{+0.5}_{-0.4} \text{ km s}^{-1}; \alpha : 0.3-0.9; > 0.1; i_{\star} \approx 92^{+12}_{-14} \degree; \lambda \approx -0.4 \pm 0.2 \degree; \psi \approx 7^{+12}_{-4} \degree

Planets as Probes: HD 189733

Reduced $\chi^2$

Summary

- Stellar surface phenomena alter line profiles & RVs
  - Impacts planet detection/confirmation/characterisation
  - Poses fundamental RV precision limit
  - MHD simulations offer pathway to characterise and disentangle

- Can use planets to spatially resolve stars
  - Probe convection, differential rotation etc.
  - Validate MHD simulations (beyond the Sun!)
  - Study evolution of star-planet systems

- Ask me about oscillations!

H. M. Cegla
What about oscillations…?

Figure 3. Top left-hand panel: residual mode amplitude versus $\Delta t_c$. The vertical dotted line marks the duration corresponding to $\tau_{\text{max}} = 1/\nu_{\text{max}}$. Top-right hand panel: residual amplitude as a function of the equivalent frequency $\nu_{c} = 1/\Delta t_c$ as the independent variable. Bottom panels: frequency axes normalized by $\tau_{\text{max}}$ and $\nu_{\text{max}}$.

We may calculate the p-mode signal amplitude that would remain for a given exposure length by multiplying, in frequency, the mode amplitude $p_n(\nu)$ by the transfer function giving the exposure duration (i.e., like the transfer functions shown in Fig. 1). The integral in frequency of this product gives the total remaining or residual mode amplitude. Fig. 3 shows the results for exposures of different duration $\Delta t_c$ as applied to the solar spectrum in Fig. 2.