Understanding Astrophysical Noise from Stellar Surface Magneto-convection

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Astrophysical Noise
Sun-as-a-Star Model Observations
Parameterisation

- Separate based on:
  - Continuum Intensity
  - Magnetic Field
- Four Components
  - Granules
  - Non-Magnetic Lanes
  - Magnetic Lanes
  - MBPs
Wavelength (Angstroms)

Flux

Avg Rel Err: 0.00048

200 G Reconstruction
Recovered Granulation RVs from Parameterization

Residuals

$\text{RV (m s}^{-1})$

$\text{Time (Minutes)}$
Initial Results
Initial Results

![Graphs showing correlation between velocity and area under profile](image)

In this section we demonstrate the effectiveness of each of the granulation noise diagnostics for each of the noise reduction techniques is shown in Table 7.1.

| Diagnostic   | Line Depth | Bisector Curvature | Brightness |
|--------------|------------|--------------------|------------|
|              | 13.0       | 15.5               | 10.5       |
|              | 36%        | 24%                | 49%        |
|              | -0.84      | -0.78              | -0.89      |

The standard deviation of the corrected RV measurements has been shown to reduce the standard deviation of the disc-integrated line profile RVs to 20.4 cm s⁻¹ from 20.4 cm s⁻¹, indicating that such photometric variability measurements are likely to be among the best ways to identify RVs induced from granulation.

Accordingly, high precision simultaneous photometry from space-based transit missions, targeting bright stars, could be the key to pinning down the granulation noise within the spectroscopic observations necessary for most exoplanet confirmations.

The standard deviation of the corrected RVs was calculated; this was found to be

\[ \text{Corrected RV} = \text{Uncorrected RV} - \text{Granulation Noise} \]

In this formula, the uncorrected disc-integrated line profile RVs is subtracted to remove the granulation noise. First, the standard deviation, followed then by the brightness or integrated area under the line profile (49%). A marginal noise reduction was also achieved to correct for the granulation noise. By far the largest reduction of noise was obtained with the line depth (36% reduction) and bisector curvature (35% reduction). All of these values, as well as the correlation coefficient between each diagnostic and RV, are listed in Table 7.1.
Initial Results

| Diagnostic | $V_\sigma$ (cm s$^{-1}$) | Fractional Reduction (%) | Pearson’s R |
|------------|--------------------------|--------------------------|-------------|
| –          | 20.4                     | –                        | –           |
| BIS        | 37.8                     | -85                      | -0.48       |
| C          | 13.3                     | 35                       | -0.84       |
| $V_b$      | 15.5                     | 24                       | 0.80        |
| $A_b$      | 16.2                     | 21                       | -0.78       |
| bi-Gauss   | 46.1                     | -126                     | -0.40       |
| $V_{asy}$ | 9.0                      | 56                       | 0.91        |
| FWHM       | 77.0                     | -277                     | 0.26        |
| Line Depth | 13.0                     | 36                       | -0.84       |
| EW         | 17.4                     | 15                       | -0.76       |
| Brightness | 10.5                     | 49                       | -0.89       |
Next Steps...

• Continue to make model observations more realistic:
  • Instrumental profile, photon noise, finite exposures, additional noise sources, various magnetic fields, injecting planets
• Test observationally
  • Solar data, highest RV precision targets
• Expand to a suite of stellar lines with varying:
  • Formation heights, absorption strengths, excitation and ionisation potentials
• Expand to other spectral types