MODELING THE SUN'S RADIAL VELOCITY WITH SOAP USING SDO OBSERVATIONS: COMPARISON WITH HELIOS RADIAL VELOCITY DATA.

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Context

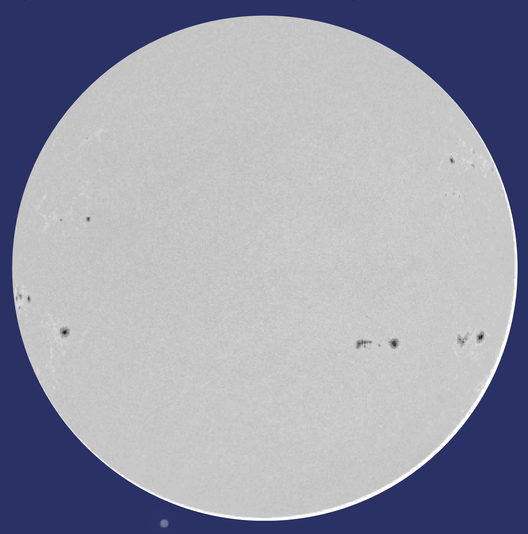
One of the primary objectives of the Exoplanets community nowadays is finding rocky planets in the habitable zones of solar-type stars. High-resolution spectroscopy is crucial for obtaining precise RVs to detect these planets. However, stellar contamination from spots and faculae can obscure or mimic planetary signals, complicating their detection.

Objectives

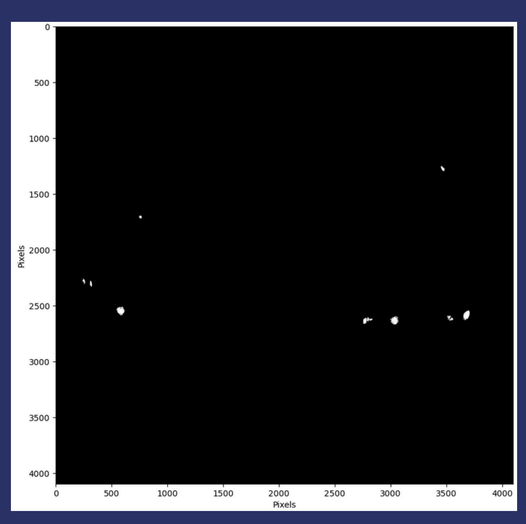
From SDO observations, we identify and characterize spots on the solar disk. Using SOAP (Spot Oscillation And Planet, Boisse et al., 2012; Dumusque et al., 2014), we simulate their impact on the RV signal and compare the results with solar disk-integrated RV data from HELIOS, the solar telescope feeding HARPS.

Spot and faculae detection

274 observations from 01/06/2023 to 08/08/2023 every 6 hours.
Spots detection from SDO/HMI (Fe 6173 Å), Limb Darkening corrected observations.
Faculae detection on SDO/AIA observations (UV 1700 Å), higher intensity contrast with solar surface.
We conducted the detecion and analysis using the "Coimbra" code (Carvalho et al., 2020), based on image morphological transformations.



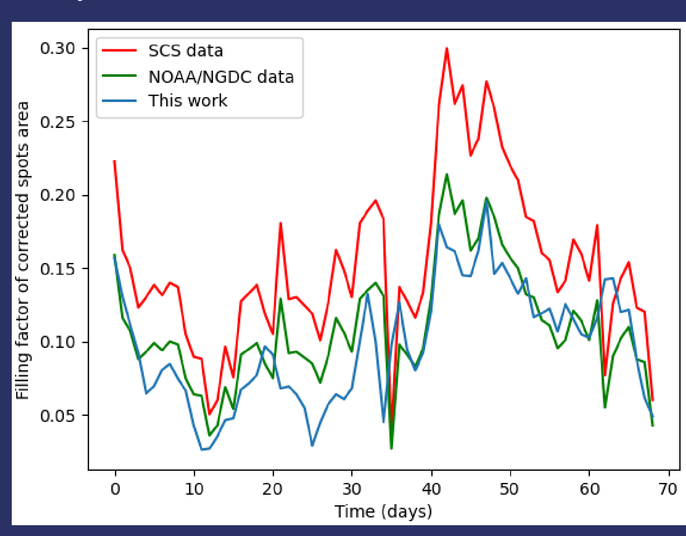
FITS file of the observation



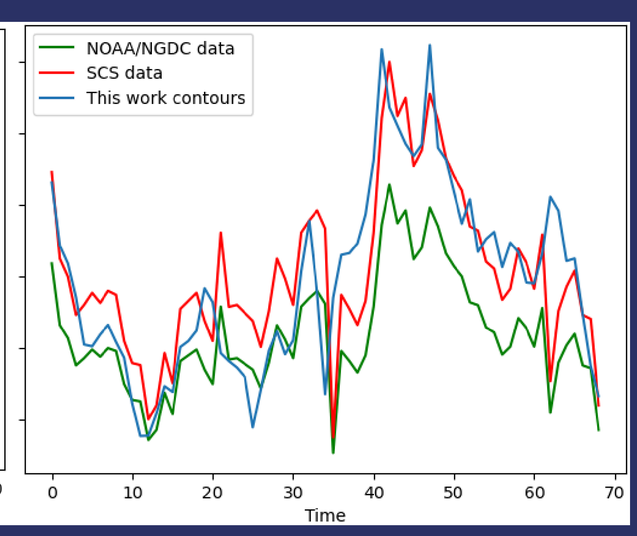
Result of the spots identification

Analysis and code validation

We used cluster analysis with a Gaussian Mixture Model to identify the number, size, and position of sunspots. To validate our results, we compared the filling factors with data from Solar Cycle Science and NOAA/NGDC, showing similar trends but lower values. We also tested a "contour" analysis, which produced the same trend but higher values. Additionally, we separated umbra and penumbra to focus on analyzing only the umbrae. We conducted the 'contour' analysis on faculae as well.



Code validation with cluster analysis



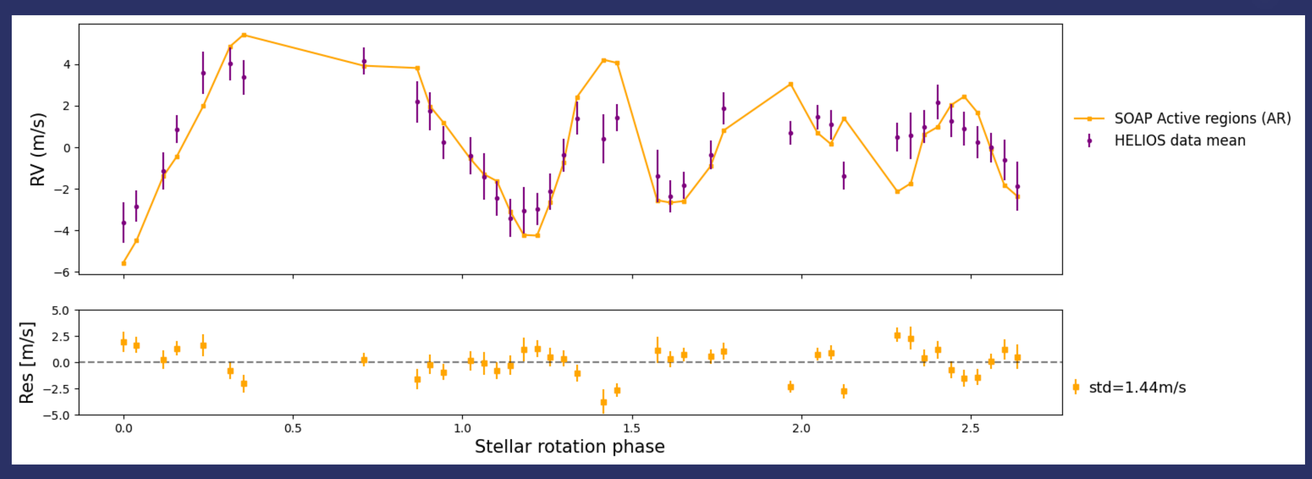
Code validation with contour analysis

SOAP simulations

We conducted simulations for spots, umbrae and faculae using the SOAP (Spot Oscillation And Planet) code, which models the impact of stellar activity on RV and photometry. SOAP uses two spectra from the Fourier Transform Spectrograph, one for the quiet Sun and one for the active region, and calculates CCFs using the G2 HARPS template. The CCF velocities are shifted based on the Sun's rotational velocity and cell position on the disk. We assumed complete inhibition of the convective blueshift (350 m/s) and applied a temperature contrasts of -663 K for spots (Meunier et al. 2010) and +250 for faculae.

Results

Our results indicate significant RV variations induced by the combination of both spots and faculae, with semi-amplitudes reaching up to 6 m/s,The comparison of simulated RVs with observational data from the HELIOS solar telescope reveals a close relations between the two trends, with an std of 1.44 m/s. Our results appear slighlty larger, probably due to detection method.



RVs simulation for the combination of spots and faculae compared with HELIOS data

For the future

In the future, we aim to enhance these results by improving spots and faculae detection and simulation, specifically further developing SOAP. Including solar observations from PoET (Paranal solar Espresso Telescope) we will gain different spectra for various active regions enabling a deeper understanding of the convective blueshift and its effects.

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References

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