Characterization of Magnetic Activity on the Sun Using Disc-Integrated Spectra

M Parvathy[1,4], K B Anagha[1,5], S P Rajaguru[1], T Sivarani[1]

[1]Indian Institute of Astrophysics, Bengaluru

Contact Information: [4]parvathy.m@iiap.res.in, [5]anaghakb662001@gmail.com

INTRODUCTION

Stellar surface inhomogeneities presented by convection, magnetic spots, bright plages, and faculae are recognized as important in the accurate retrieval of exoplanet properties as they can be a source of noise and confusion in stellar radial-velocity (RV) measurements.

The identification and characterization of exoplanets around Sun-like stars are impacted by changes in intensity and other spectral signatures due to such spatial inhomogeneities over time scales spanning a few minutes to years. High-energy events like solar flares and coronal mass ejections (CMEs) also leave characteristic signatures in the activity indices derivable from various spectral lines. In this work, we investigate activity-related features seen in the disk-integrated spectra of the Sun using time series of Sun-as-as-star spectral observations by HARPS-N and NEID instruments. We also look for signatures of high-energy solar events and solar cycle variation in the spectral indices, which in turn help us understand such variations in sun-like exoplanet host stars. Further, we carry out an analysis examining correlations between spot, faculae, and plage fill factors and the stellar activity indices.

DATA

The data used in this study was collected using a 3-inch solar telescope associated with the and High Accuracy Radial Velocity Planet Searcher for the Northern Hemisphere (HARPS-N) instrument at La Palma, Spain. This publicly accessible data spans the period from July 18, 2015 to December 31, 2018. The data covers optical band from 3800 Å to 6900 Å and observes Sun as a point source.

LINE INDICES

We have calculated the line indices of the lines, Ca II H & K, Hα, Hβ, Hγ, Hϵ, Na I D1 & D2, He I D3, Mg I b triplet, Mn I, and Fe I for the observations from July 2015 to July 2018. We defined the bandpasses for Ca II H & K, Hα, Hβ and He I D3 following Pietrow et al. (2024), and the bandpass definitions for the remaining lines, including Hγ, Hδ, Hϵ and Na I D1 & D2 were made by following Maldonado et al. (2019).

REFERENCES

[1] Pietrow, A. G. M., et al. Astronomy & Astrophysics 682 (2024): A46

[2] Maldonado, J., et al. Astronomy & Astrophysics 627 (2019): A118

[3] Da Silva, J. Gomes, et al. Astronomy & Astrophysics 534 (2011): A30

[4] da Silva, J. Gomes, et al. Astronomy & Astrophysics 668 (2022): A174

[5] Sen, Anisha, and S. P. Rajaguru. The Astrophysical Journal 956.2 (2023): 145

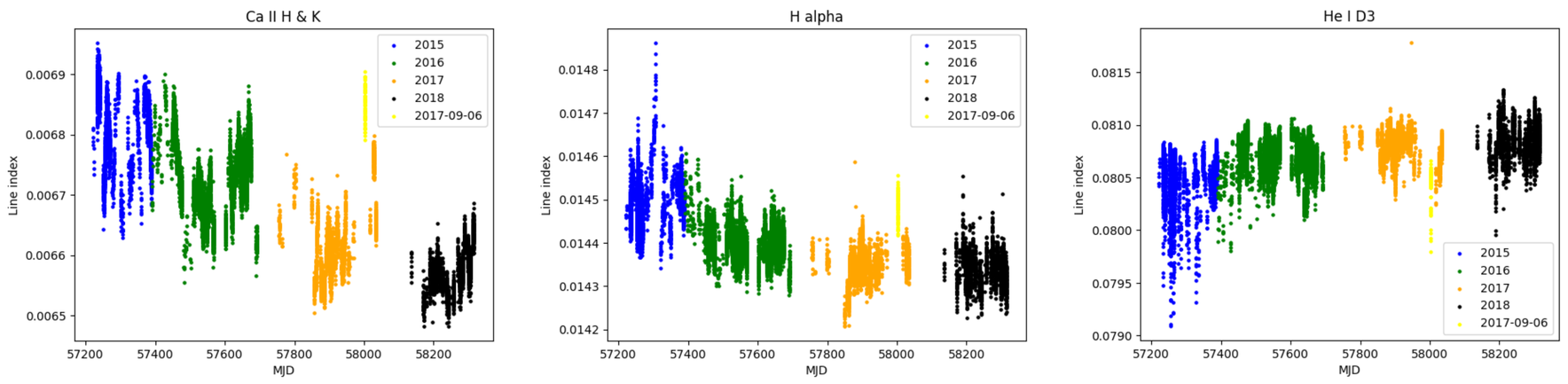

Fig 1: Temporal variation of Ca II H & K and Hα and He I D3 line indices over a period from 2015 - 2018

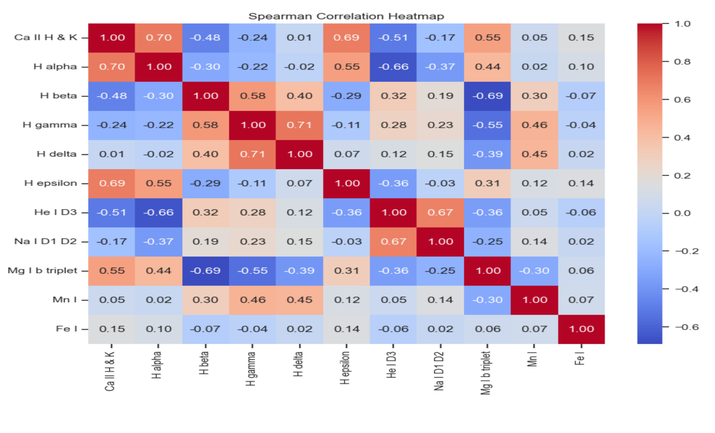

Fig 3: Correlation of various line indices

PRELIMINARY RESULTS & DISCUSSION

- Initially we calculated the temporal variation of line indices of few lines from 2015 (close to solar maxima) to 2018 (close to solar minima). we observed that the line index show a declining behavior from solar maxima to minima for the lines Ca II H & K, Hα, Hϵ, and Mg I b triplet, which is consistent with the expectation. But, Hβ, Hγ, Hδ, and He I D3 showed an inverse response while Na I D1 & D2, Mn I, and Fe I showed no significant variation over time. A few of them are plotted in Figure 1.
- Figure 2 shows the response of different lines toward the steady state phenomena like sunspots and plages. We observed that the trends followed by all the line indices in response to the sunspots, and plages for the declining phase of activity are quite similar to those found in the temporal variation of line indices.
- By calculating the Spearman correlation coefficient between different lines we observed that Hβ, Hγ, He I D3, and Na I D1 & D2 exhibit strong anti-correlation with the S-index. Hα, Hϵ, Mg I b triplet, Mn I, and Fe I all exhibit a positive correlation. Hα has a high positive connection with the S-index, with rho = 0.7.

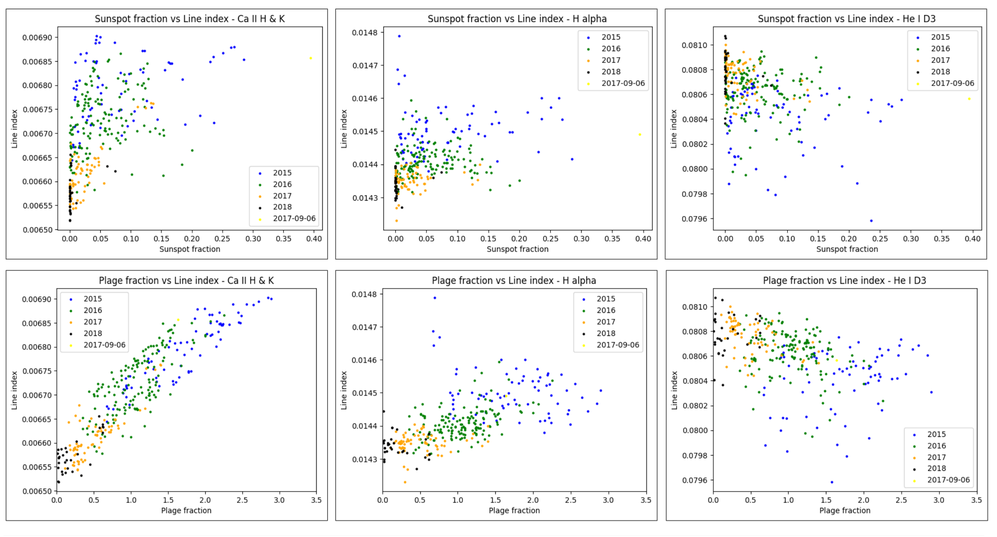

Fig 2: Response of line indices of various lines like Ca II H & K, Hα and He I D3 towards the spot fraction and plage fraction calculated by Sen & Rajaguru (2023)

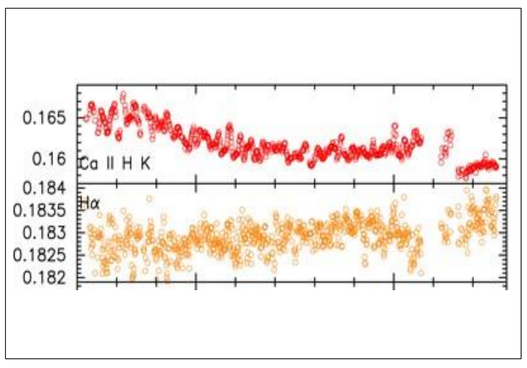

Fig 4: Ca II H & K and H alpha line indices by Maldonado et al. (2019)

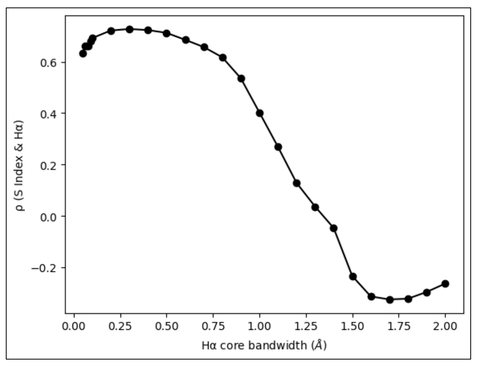

Fig 5: Variation of correlation between S index and Hα index with Hα core bandwidth

- According to Maldonado et al. (2019), the Hα index shows significant anti-correlation with the S-index with rho -0.3865 which is not the expected behaviour as sun is not a metal rich star.
- We have revised the bandwidth to 0.6 Å (Pietrow et al. 2024) and got a positive correlation as expected.
- Gomes da Silva et al. (2022), have reported the effect of changing the Hα bandwidth on the correlation between S index and Hα index in the case of FGK type stars and had found that bandwidth that maximises the positive correlations is between 0.25 - 0.6 Å.
- Figure 5 shows the variation of the Spearman correlation coefficient between S index and Hα index with different Hα core bandwidth from 0.05 - 2 Å.