Sun-as-a-star variability of Ha and Ca II IR lines

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Motivation

- Spectroscopy is a power tool to retrieve properties of stars. Spectral variability allows to infer properties of stellar magnetic fields.

- UV and shorter wavelengths are ideal to track stellar magnetic variability. However:

  1)Short wavelengths are accessible only from space.

  2)Absorption from interstellar medium complicates the issue.

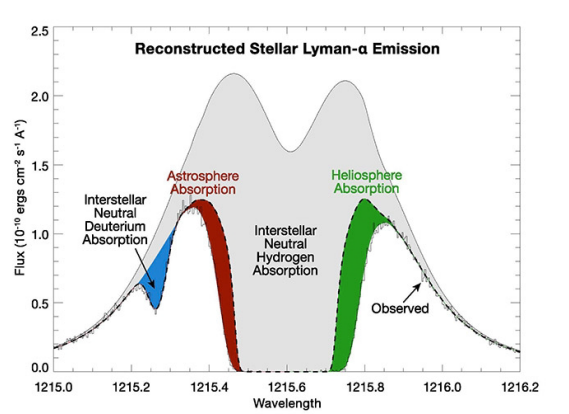
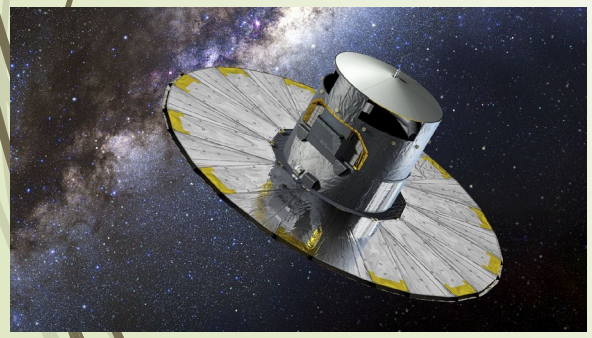


Image Credit:The Linsky group and Steve Burrows, JILA

- Ca II K and H emissions are accessible from the ground. Long term records exist for the Sun, and a few stars.



However, not all future/current instruments observe the UV Ca range. This is the case for GAIA, who observes in Ca II IR triplet.

We study long-term (decadal scale) variability of solar Ha and Ca II 854.2 nm lines, which also form in the chromosphere, with the intent to:

1. Investigate whether these lines are suitable magnetic activity indicators

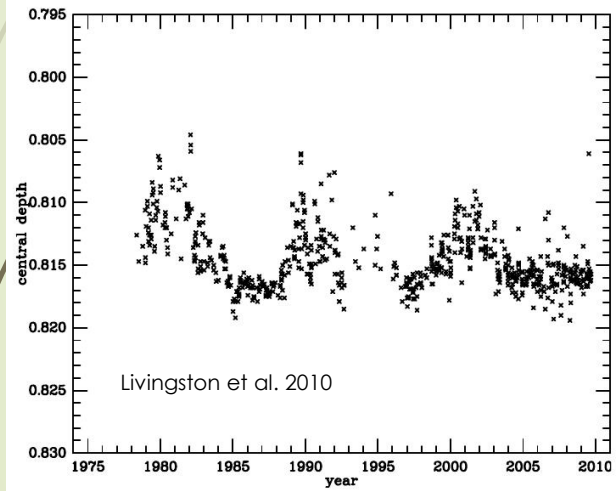
2. Investigate which specific line property best traces magnetic activity

3. Compare with spatially resolved observations of the Sun

The Ca II IR line at 854.2 nm

Large samples of solar-like stars show that indices derived from the Ca II IR triplet are positively correlated with Ca II K indices (e.g. Lanzafame et al. 2023)

Small contamination from telluric lines.

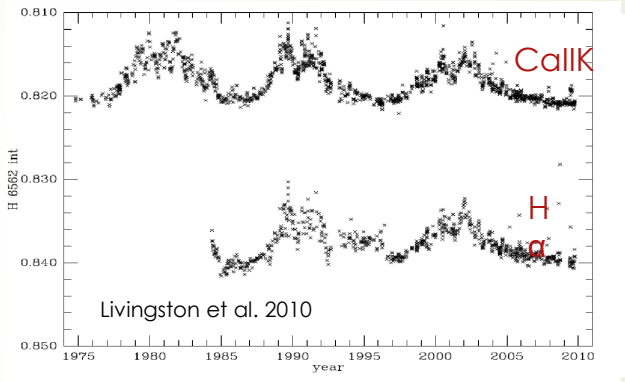


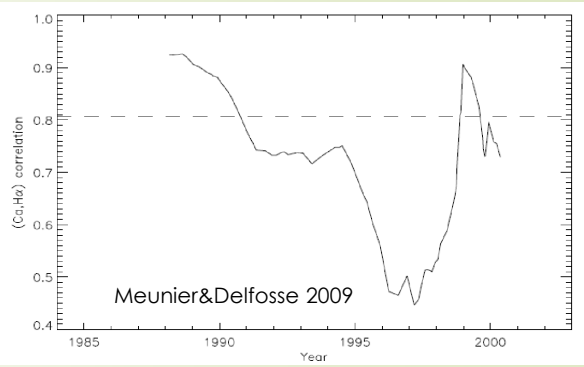
The core intensity of Ca II 854.2 nm is positively correlated with the Ca II K index

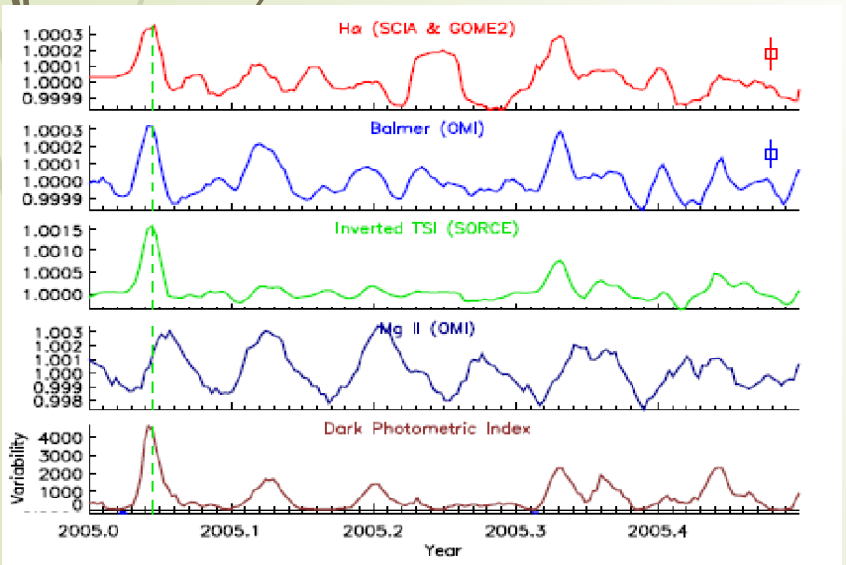
The Ha line at 656.3 nm

Large samples of *solar-like* stars show that the **Ha-index core-to-wing ratio** anticorrelated, no-correlation, correlated with Ca II K index (e.g. Meunier et al. 2022).

For the Sun, Ha-Ca II K index correlations show wide range of values, depending on temporal scales considered and phase of the cycle!







Hα core-to-wing ratio index closely follows the inverted-TSI, and often deviate from the variability measured in chromospheric indices, thus **resembling the behavior of photospheric rather than chromospheric indices**.

Criscuoli, Marchenko, DeLand, Choudhary, Kopp 2023
Marchenko, Criscuoli, DeLand, Choudhary, Kopp 2021

The Integrated Sunlight Spectrometer (ISS) @ SOLIS

Daily, disk-integrated observations in 10 spectral bands.

T = 2007-2017.8, only 2007-2014.5

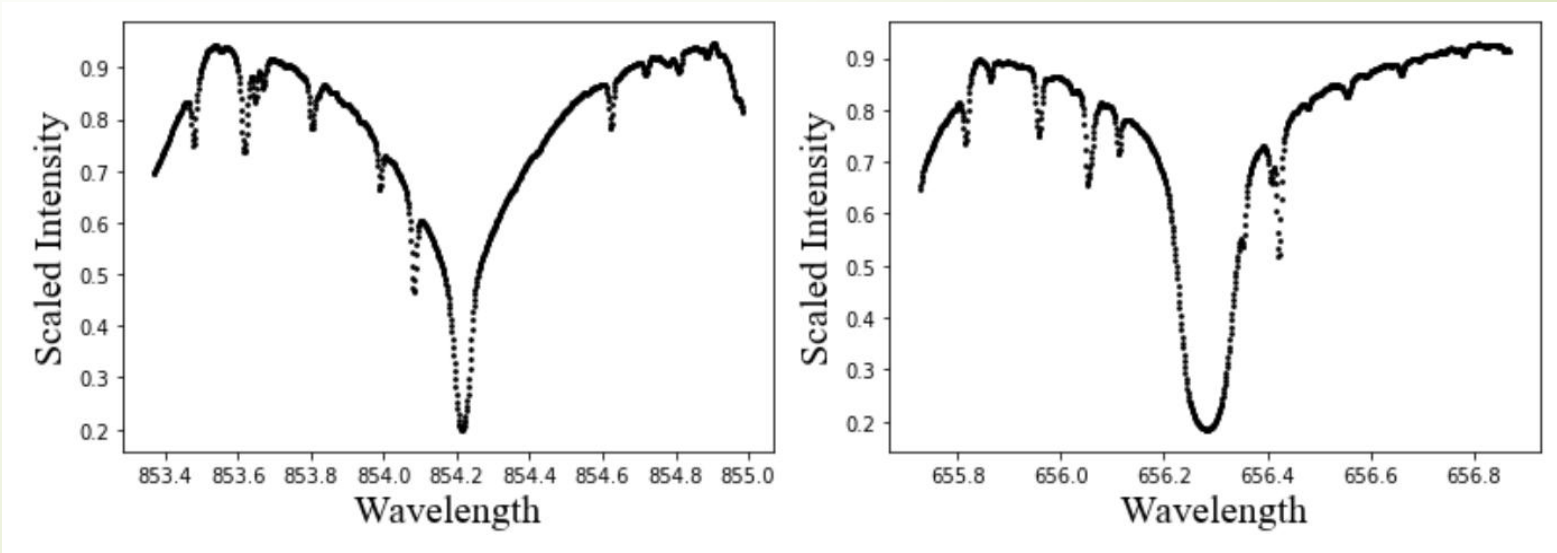
R ~ 3 x 10^5

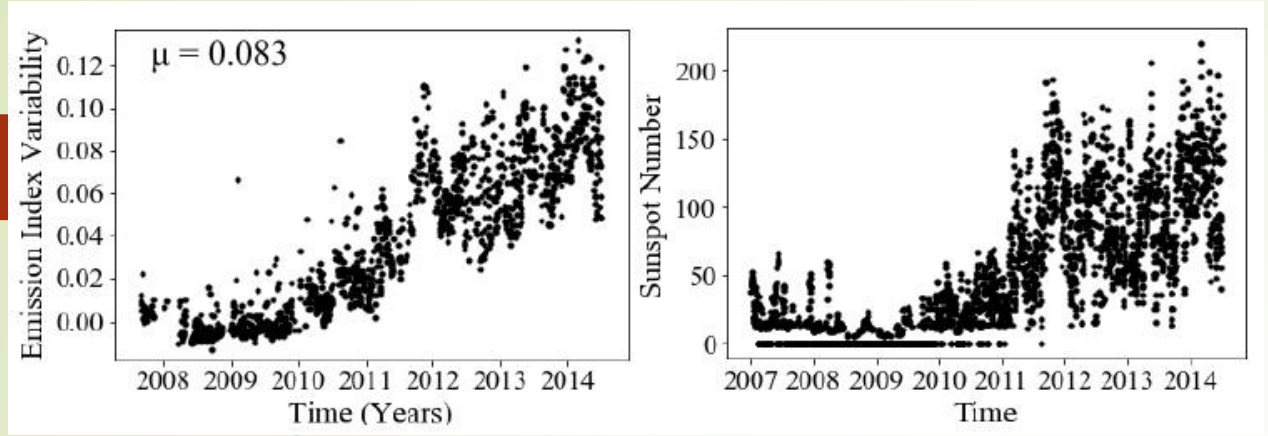
Ha: 656.28 ± 0.825 nm

Ca II IR: 854.2 ± 0.775 nm

IC: Core intensity

FWHM: full-width-at-half maximum

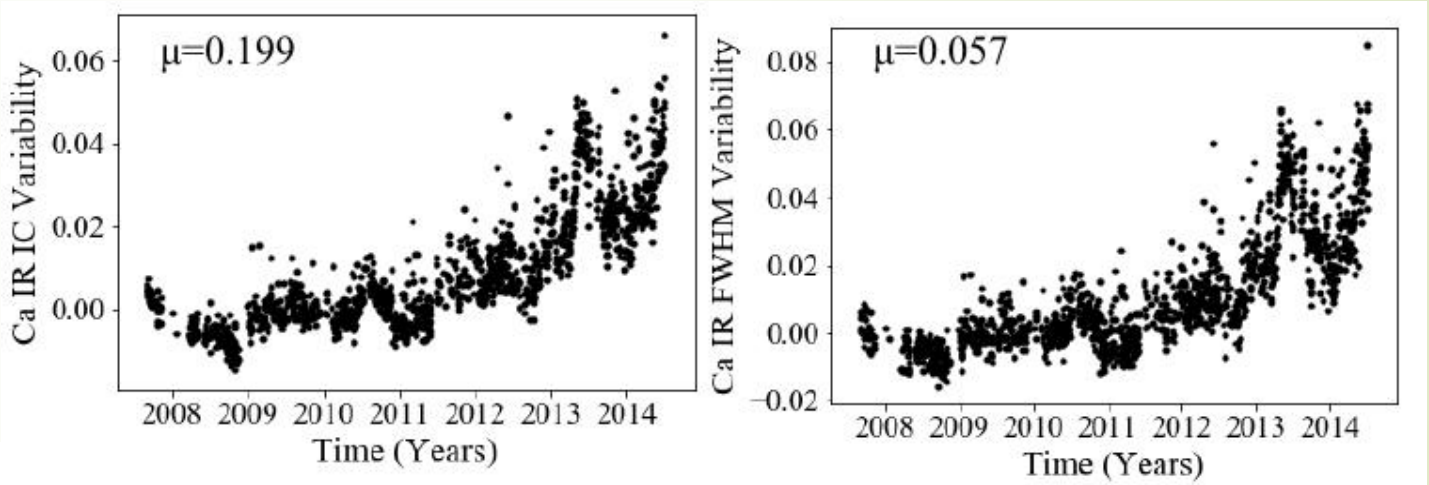


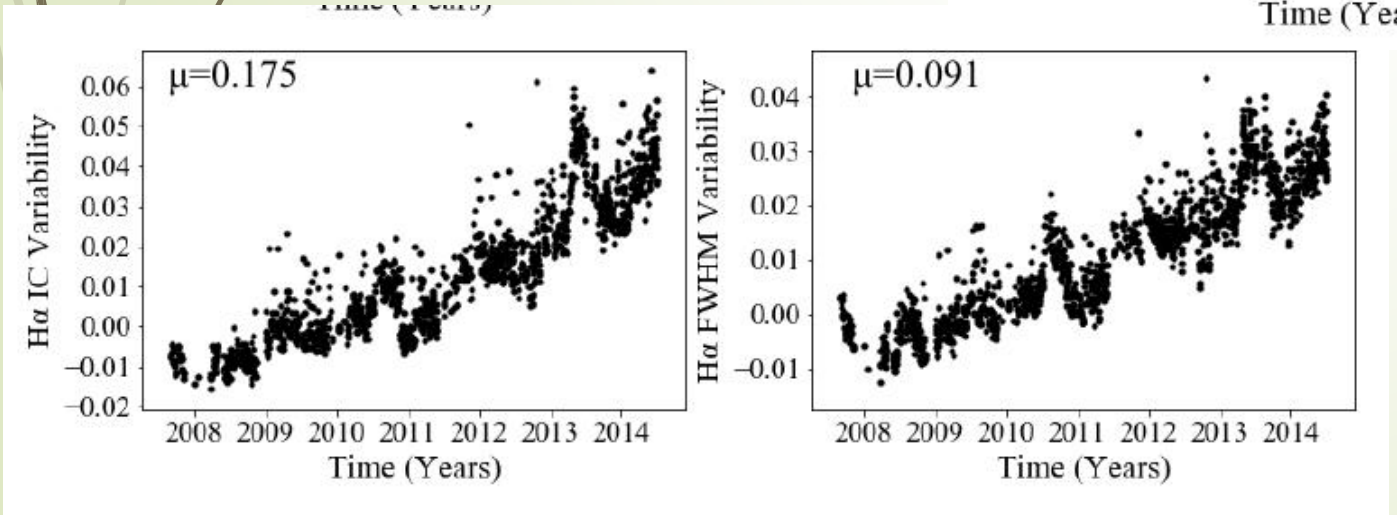


NSO Ca II K emission index (Bertello 2016)

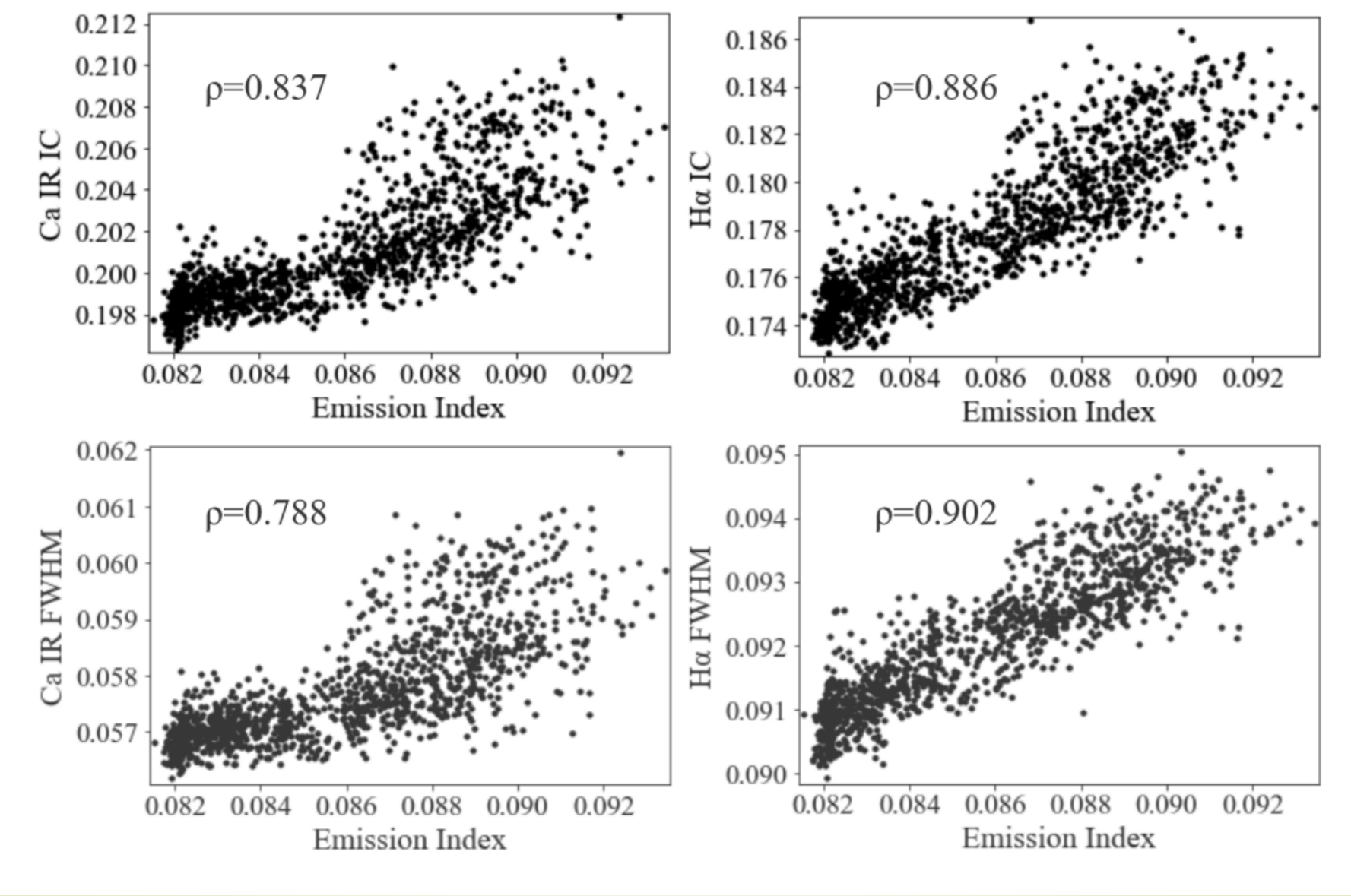
SSN from SILSO

Ca II K variability ~12%
Ca II 854.2 nm and Ha indices: 4-6%

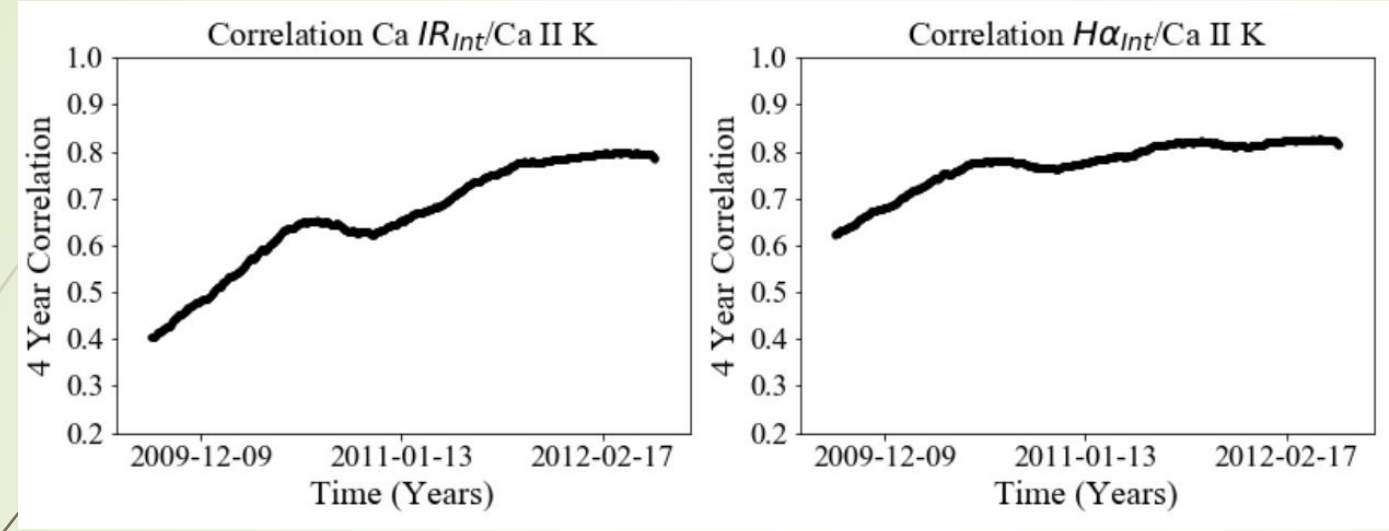


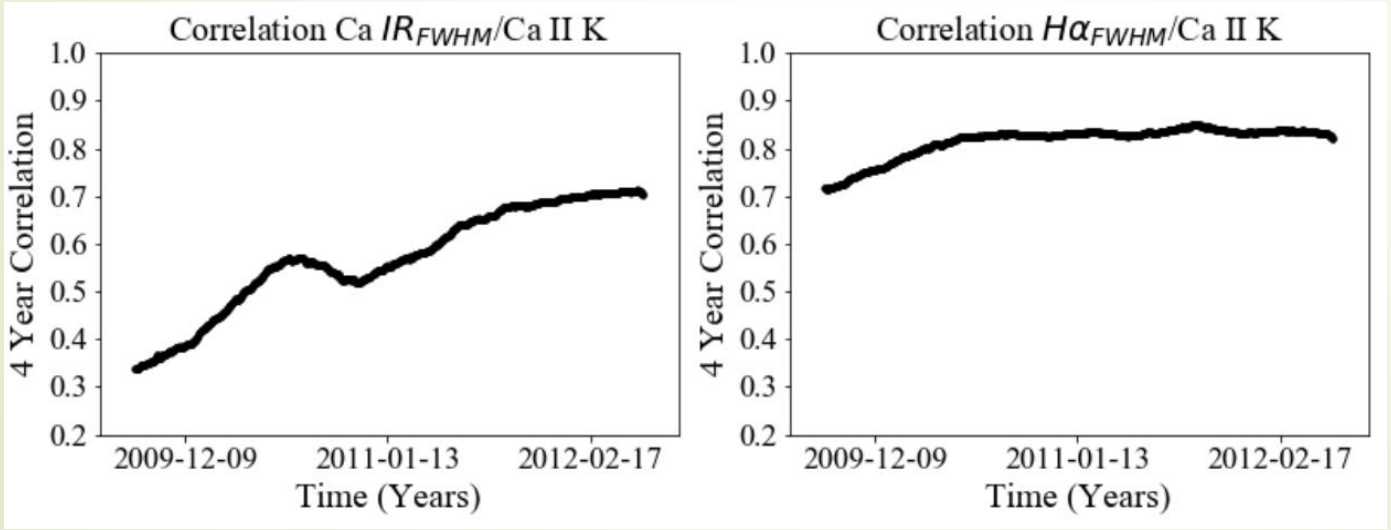


Overall (Spearman) Correlations



4-years Correlations





Ha indices overall higher and more constant correlation over time with Ca II K Emission index

Ha FWHM best tracer of activity.

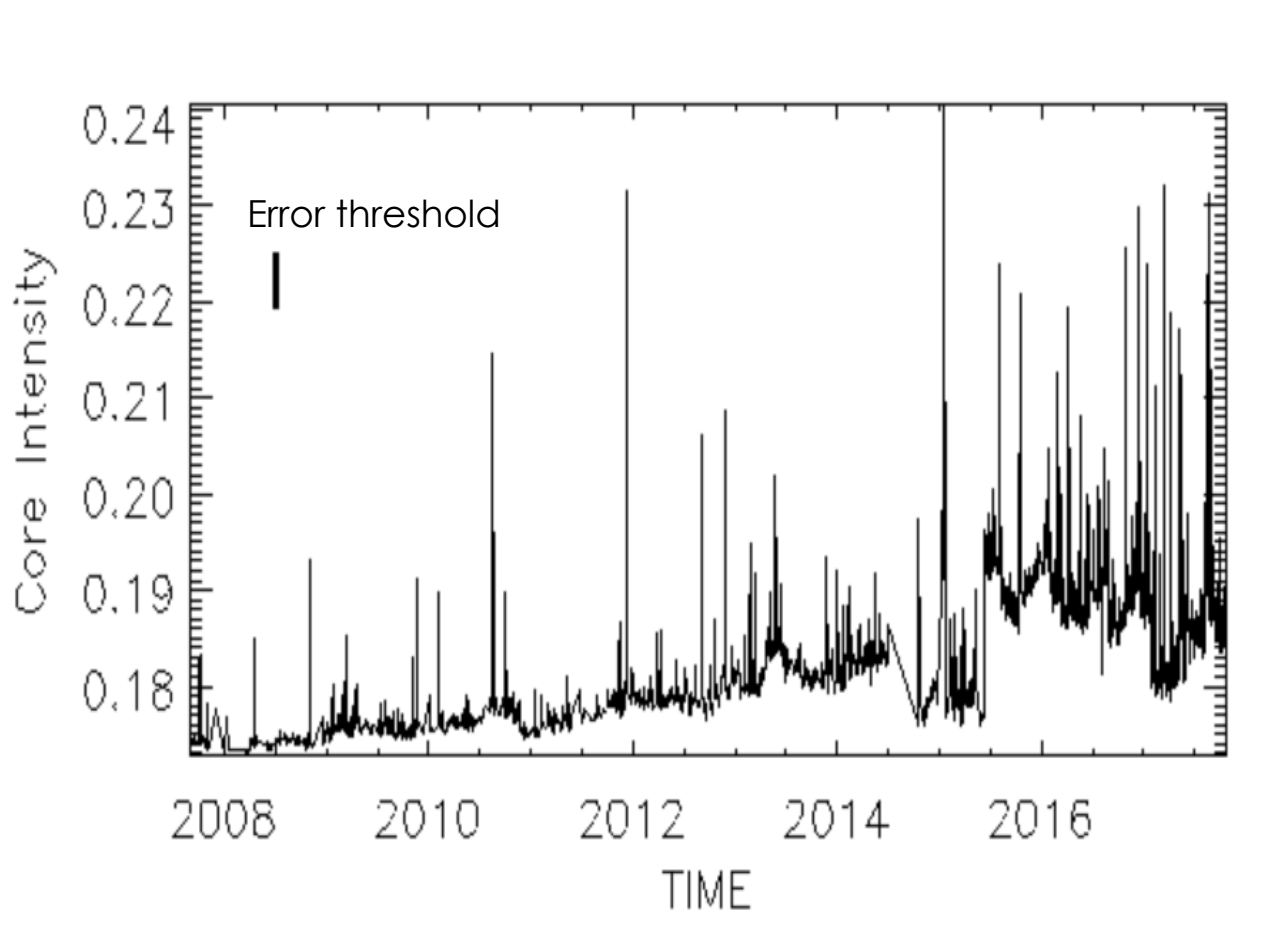
Discussion

Ha trends. In line with what expected from spatially resolved observations. Cauzzi et al. 2009 showed that the Ha FWHM is more sensitive to magnetic fields than Ha IC, in line with spectral syntheses in Criscuoli et al. 2023. Tarr et al. 2023 showed that the Ha FWHM well correlates with brightness temperatures measured with ALMA.

Ca IR trends. From Cauzzi et al. 2009 we expected Ca II 854.2 nm IC to show higher and more stable correlation with the Ca II K emission index than Ca II 854.2 nm FWHM and Ha IC.

Observational and Instrumental effects cannot be excluded.
We need inter-calibration with other instruments!

Does the Ha core vary in counter phase with the activity?



R 2007-2014.5 = 0.886

R 2007-2018, no selection = 0.33

R 2007-2018, no selection, Pearson = 0.1

R 2007-2018, no selection, core-to-wing=-0.1

R 2015-2018 = 0.6

The Devil is in the details!

Conclusions

All line indices investigated are very good tracers of activity (as defined by the Ca II K emission index). Pearson correlation coefficient >~ 0.8

The correlations with the Ca II K emission index changes over time. The Ha FWHM showed the smallest variations (14%), while Ca II 854.2 nm indices the largest (100% from min. to max.)

Ha FWHM best tracer of magnetic activity.

Results obtained for Ca II 854.2 nm line are not entirely compatible with results obtained from high spatial resolution observations and deserve more investigation.

Inter-calibration with other instruments is essential.

Thank you