

Solar Irradiance Variations in Chromospheric Spectral Lines

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Motivation: Identification of Physical Processes for solar brightness variation.

- Solar basal quiet atmosphere is immutable (Livingston and Wallace, 2003).
- Solar cycle variation of Solar Spectral Irradiance is the consequence of multiple active region outbursts (Woods et al, 2015).
- The variation in Fraunhofer lines define the amplitude of the solar brightness variability (Shapiro et al 2015). Continuum variations only contribute negligibly compared to spectral-line to the total irradiance variations on solar-cycle time scales (Unruh et al, 1999, AA, 345, 635).
- Deep photospheric lines show little or no variation with solar cycle unlike the chromospheric lines (White, Livingston, Wallace, 1987).
- Complex relationship with magnetic field was found and areas of strong magnetic field can appear either dark or bright, depending on wavelength (Norris et al, 2017).



High Resolution Full Spectra Observations

- The Solar Spectral Irradiance from UV to IR through visible wavelengths depend on non-LTE effects in chromosphere, coronal radiation and photodissociation of molecules. (Fontenla et al, 2011, JGR, 116, D20108)
- No continuum intensity enhancement with respect to the quiet photosphere can be ascertained of bright facular or network points from Ca II K spectra with spatial resolution better than 1". (del Toro Iniesta et al 1990, AA, 233, 570)
- Magnetic Bright Points (MBP) and faculae are distinct radiative signatures of the magnetic field:

MBPs have a constant or slightly decreasing contrast with increasing magnetogram signal, while facular contrast increases linearly with signal. Faculae are much larger than MBPs, with an average radial width of 400 km.

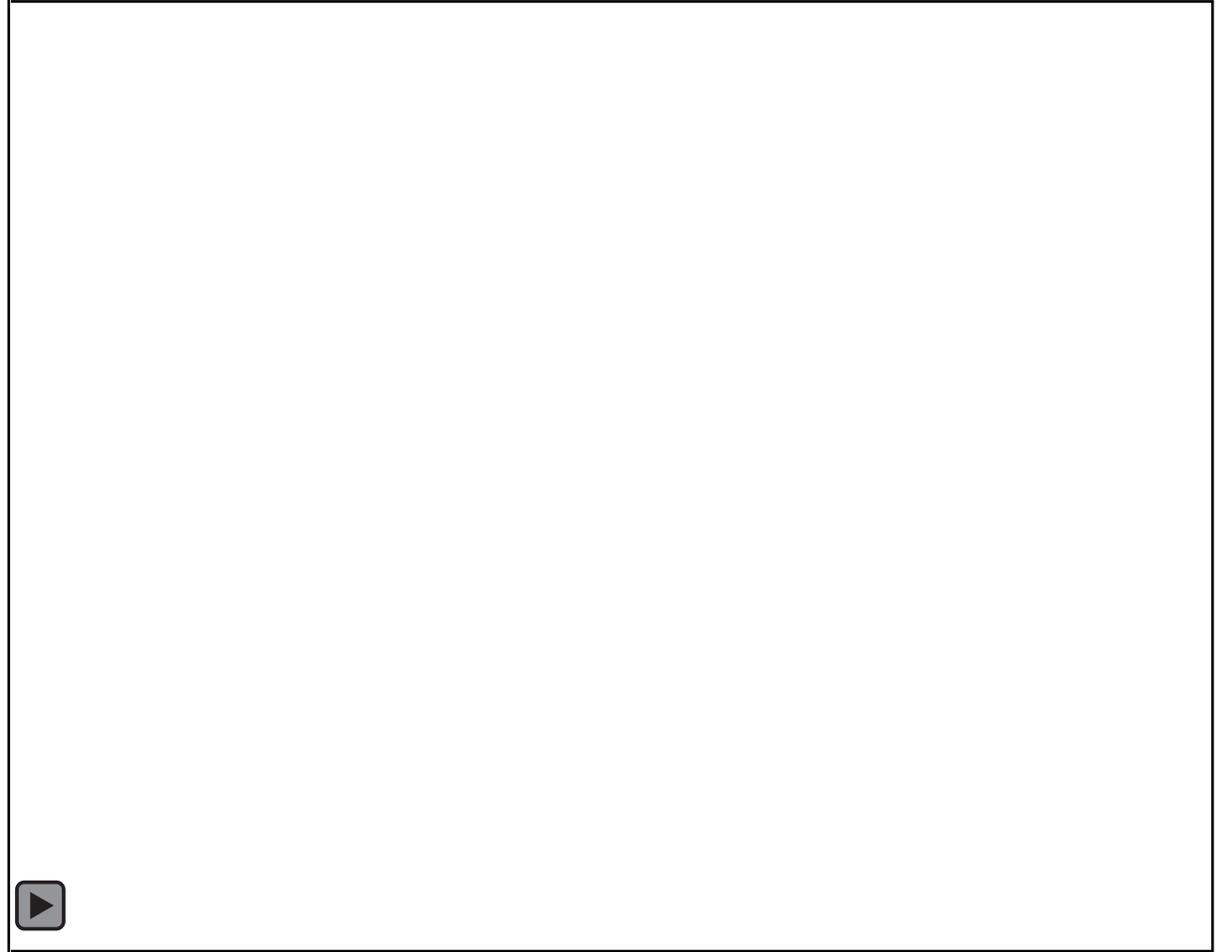
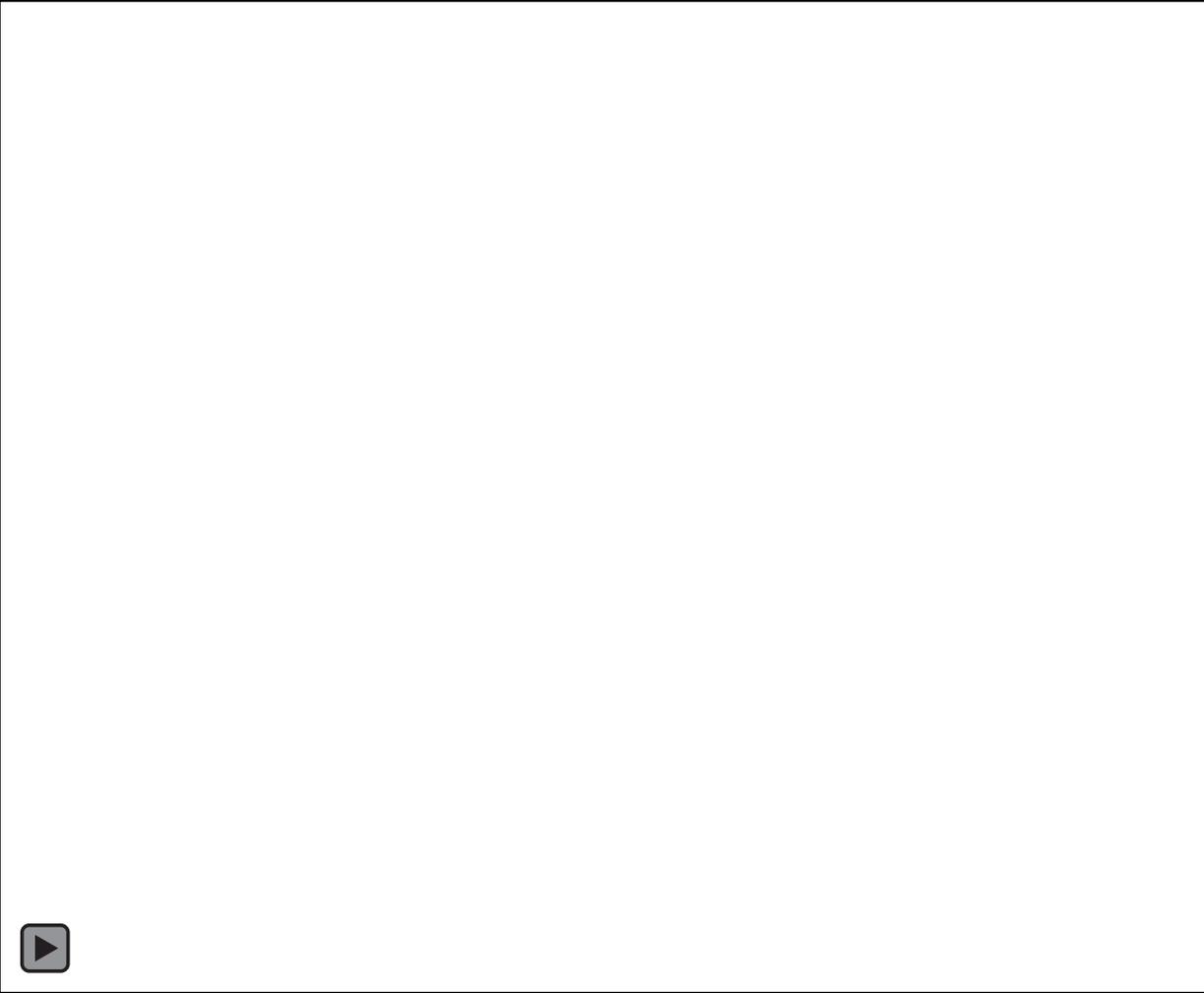
(630.25 nm magnetogram, 430.5 nm G band and 436.4 nm “continuum” bandpasses. Berger et al, 2007, ApJ 661, 1272)

Variability in irradiance and photometric indices during the last two solar cycles (Choudhary et al 2020)

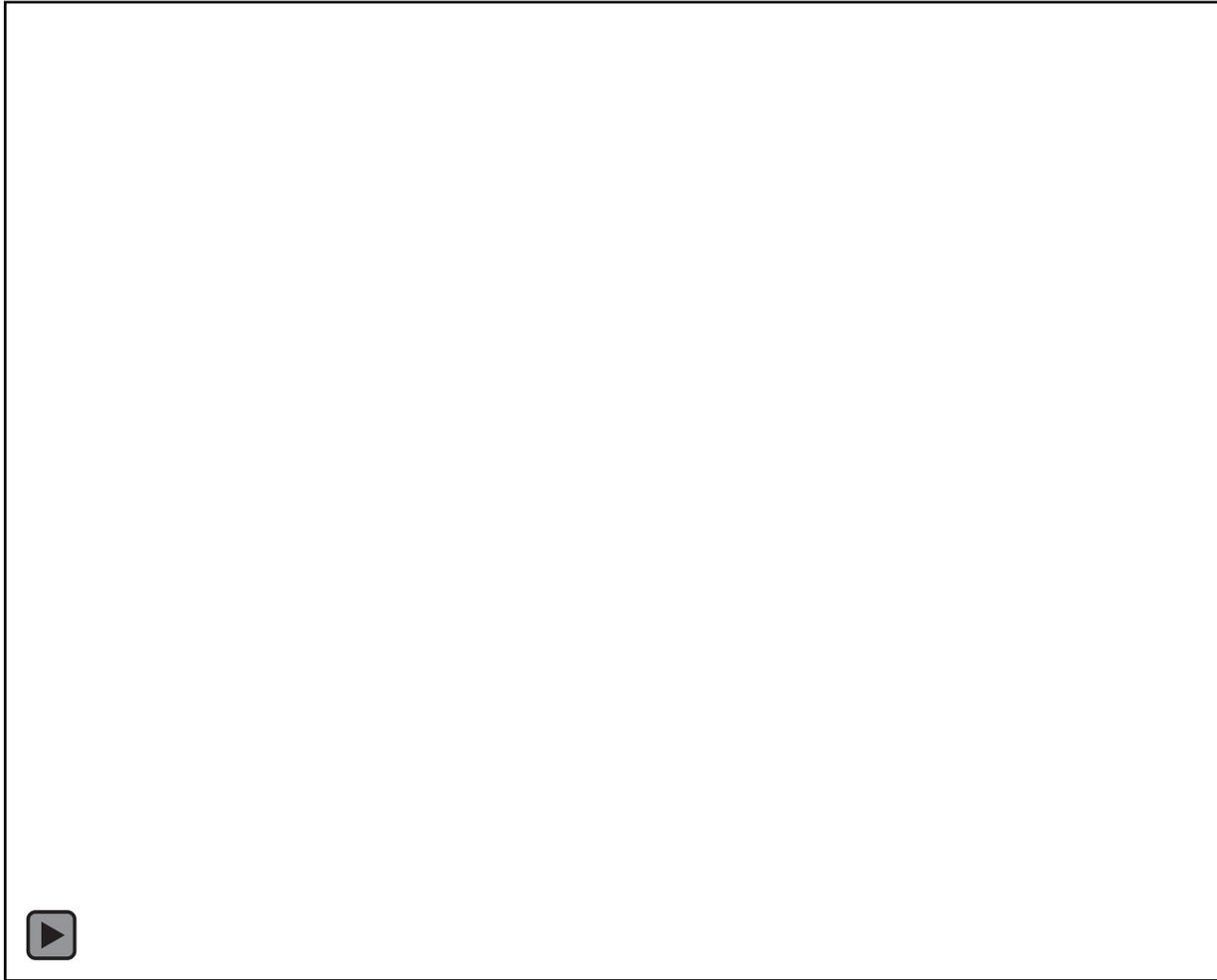
1. The photometric indices and TSI have three main statistically significant periods in the solar rotation scales. (27, 29/30 and 34/35 days)
2. During the solar maxima, TSI and Sigma_r exhibit common high power at solar rotation scales.
3. During the solar minimum phase Sigma_K captures in large part the information carried by magnetic flux. This indicates that the TSI changes during the minimum are due to the reduced line-blanketing effect of the Ca II K-line by the diffused magnetic field.
4. While the magnetic flux and TSI signals are in-phase, Sigma_K appears to lead the TSI variations.

Ca H

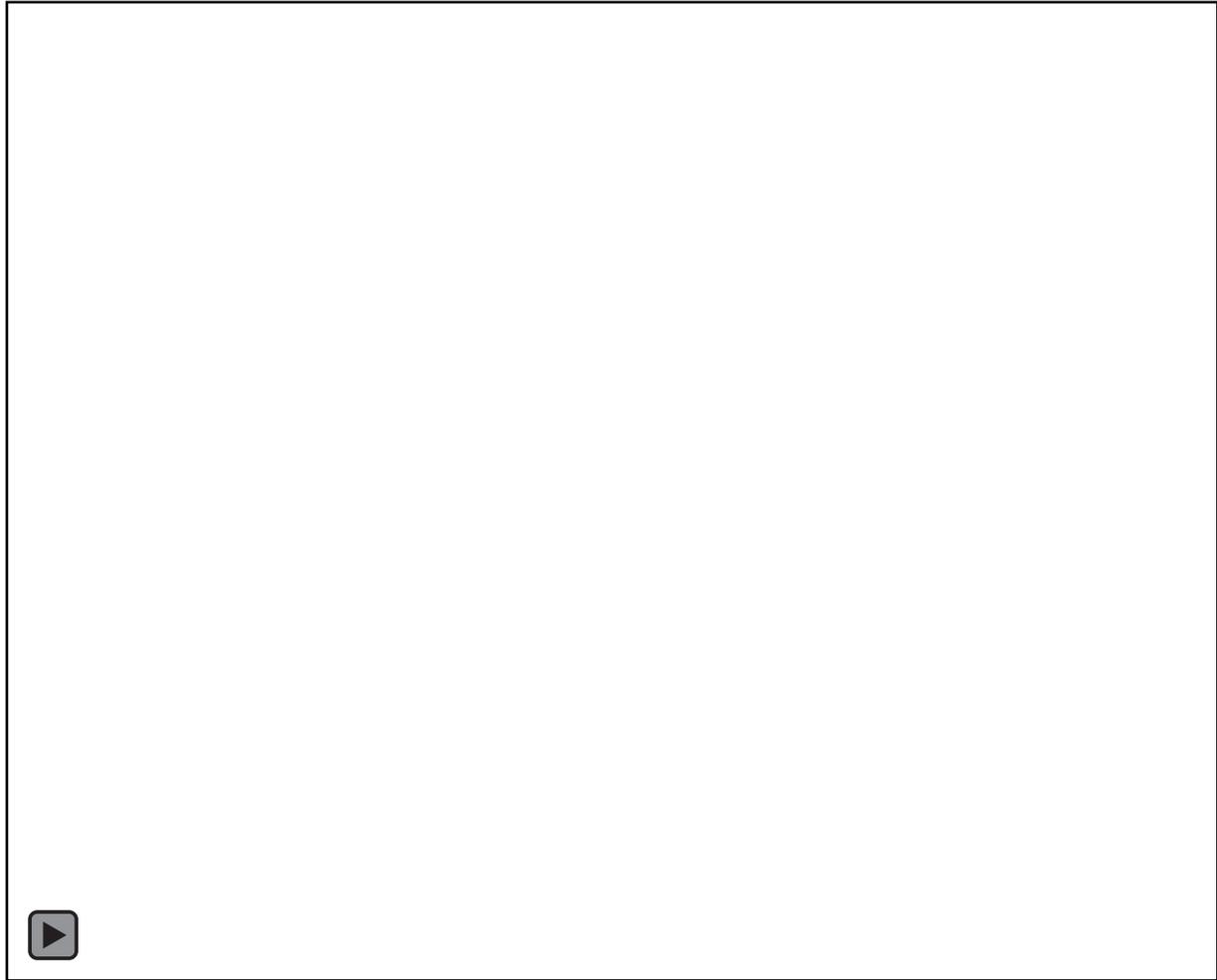
Call 8542



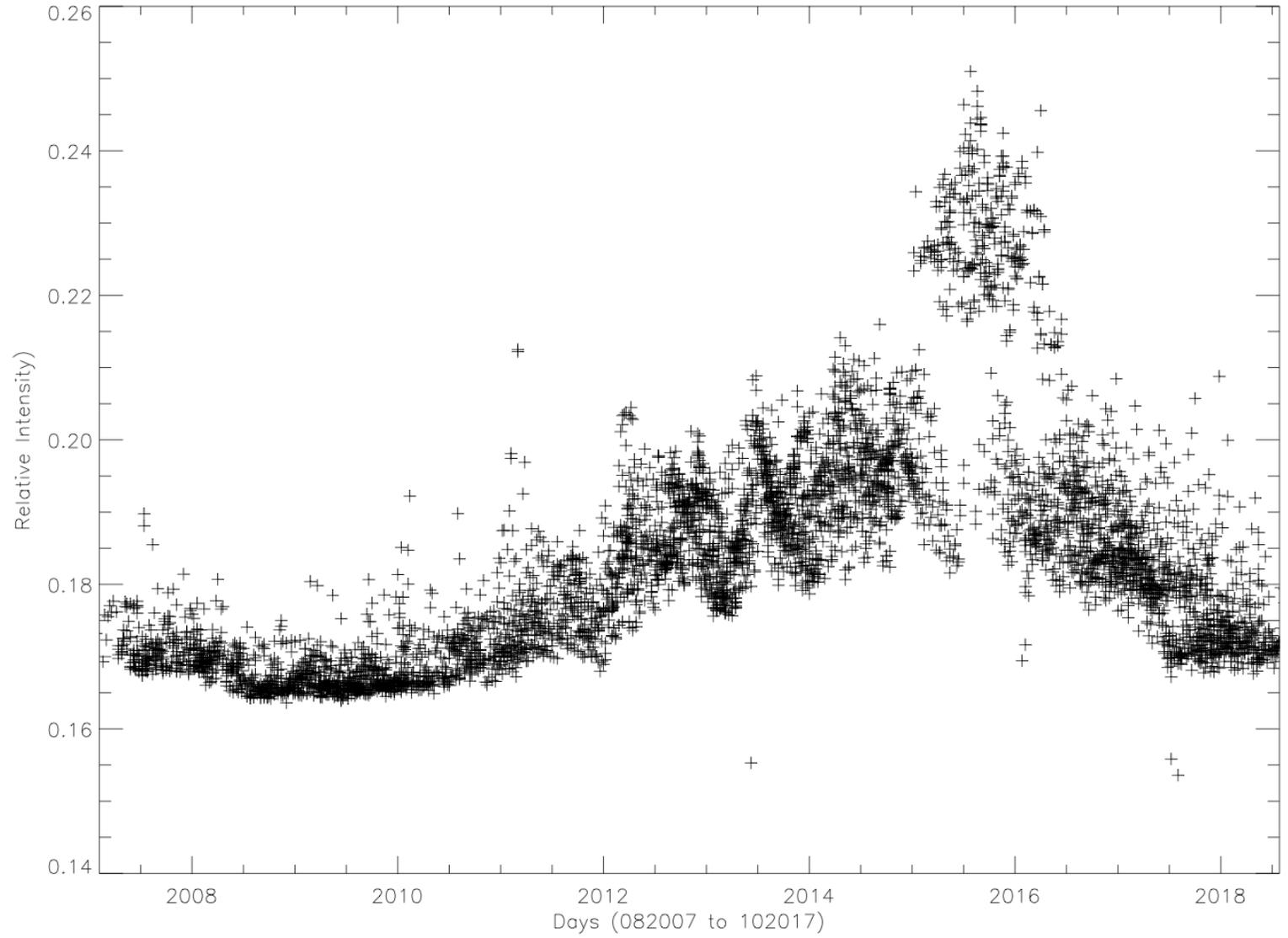
H α



Mn



H α Line Depth



Equivalent width

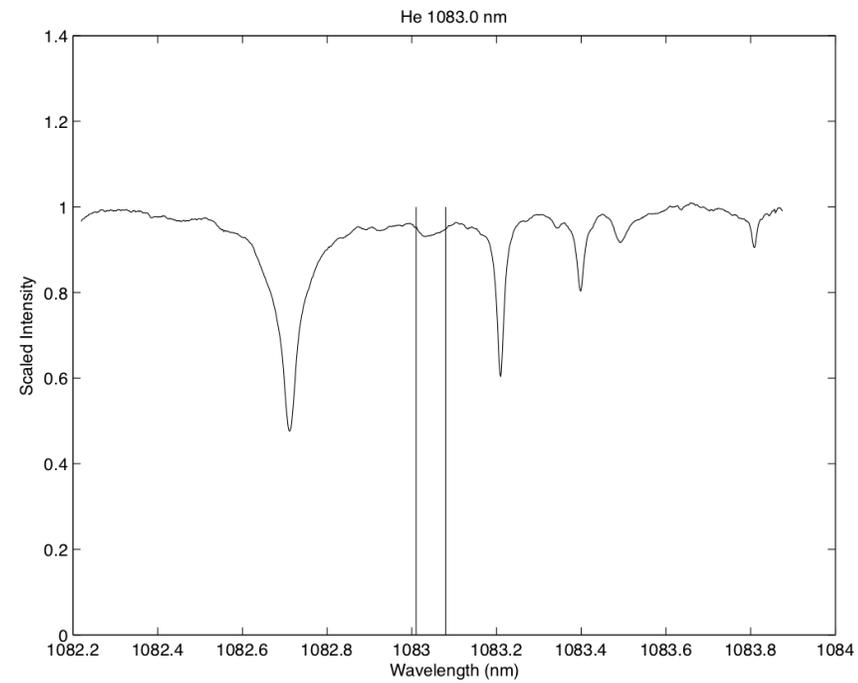
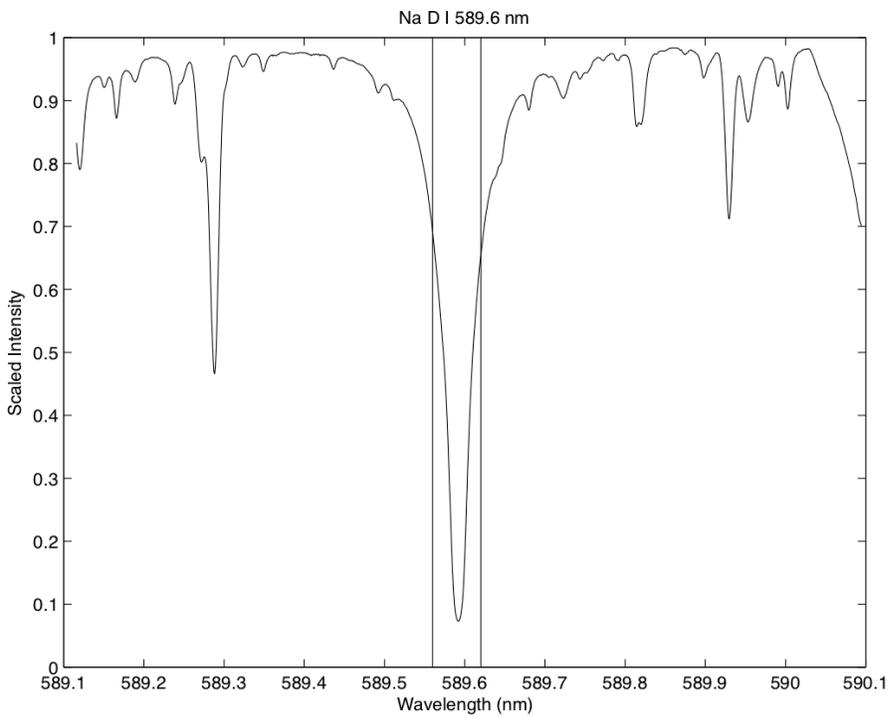
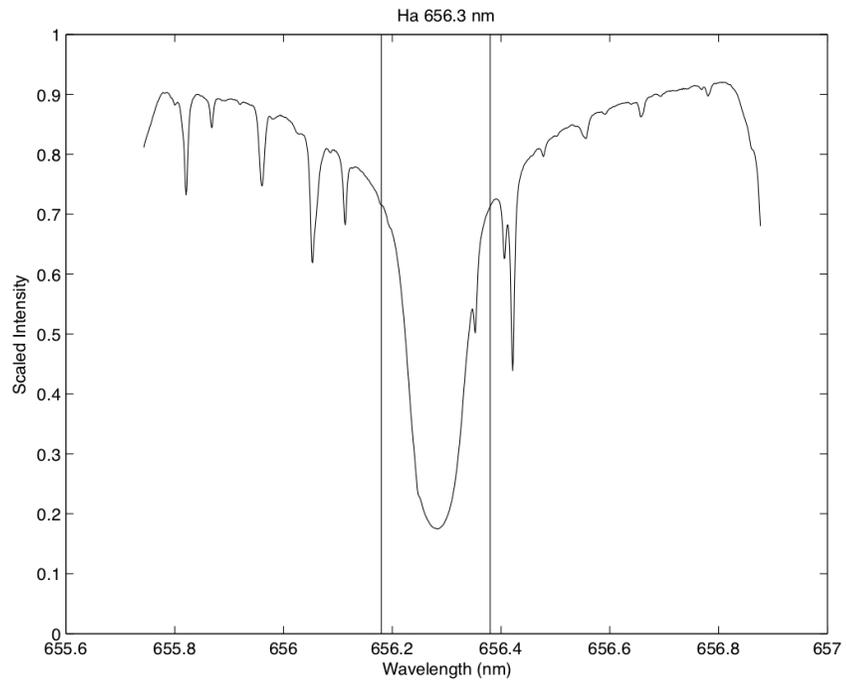
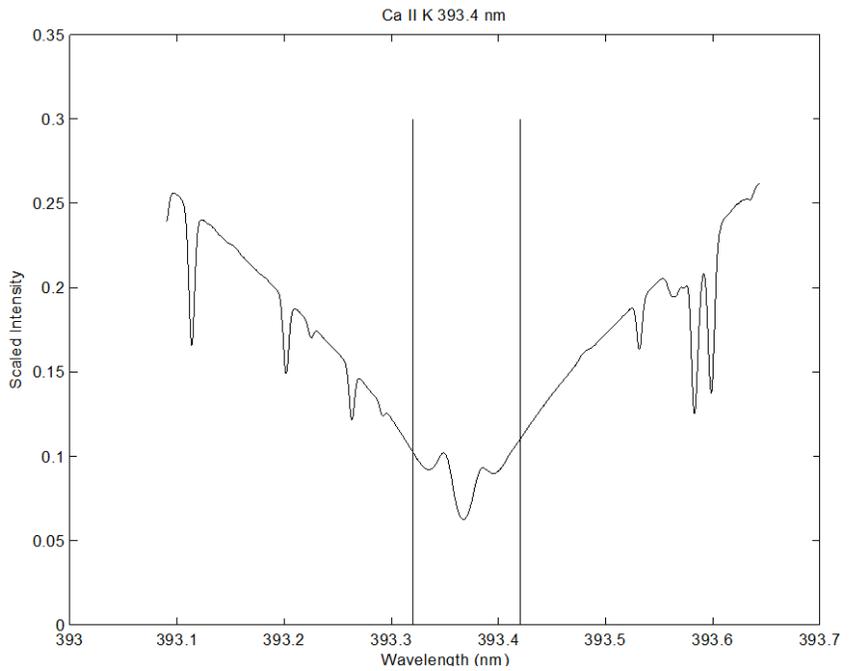
- $$W_\lambda = \int_{\lambda_1}^{\lambda_2} \left(\frac{F_c - F_\lambda}{F_c} \right) d\lambda$$

By normalizing the continuum to 1.

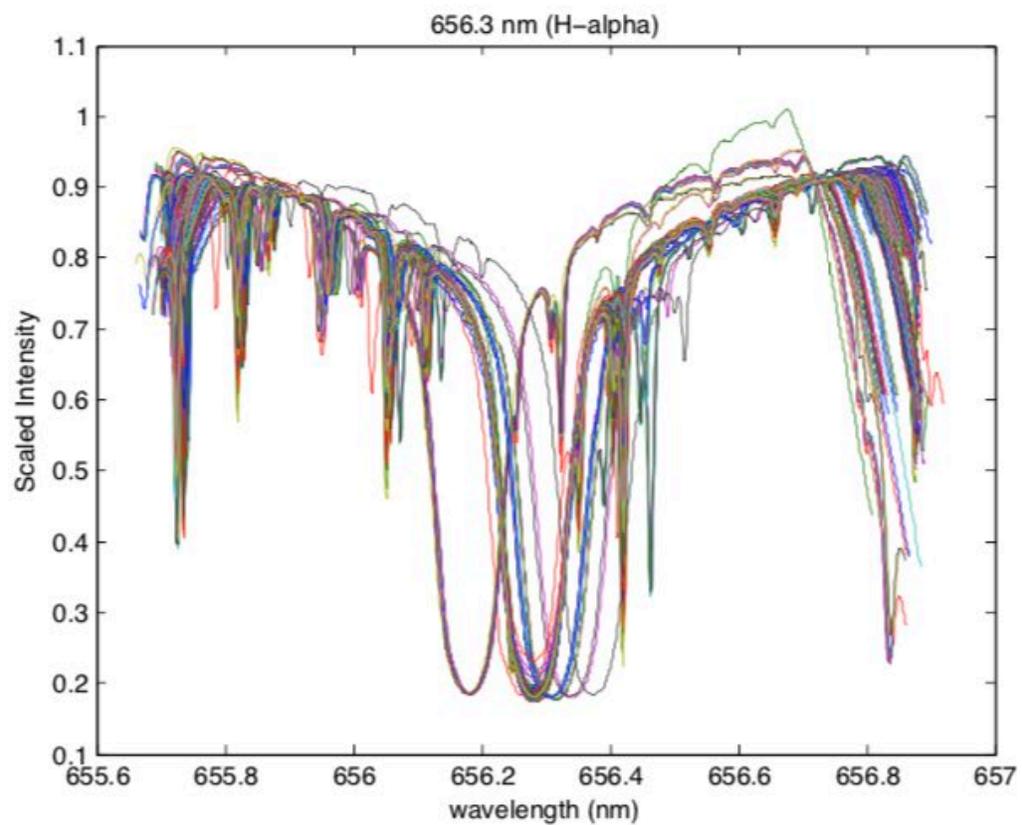
- $$W_\lambda = \int_{\lambda_1}^{\lambda_2} (1 - F_\lambda) d\lambda$$

In an absorption spectrum, the the darkest absorption lines are those whose equivalent widths are greatest while the faintest spectra have smaller equivalent widths. The equivalent width is dependent on the number of atoms that are in the correct state in which they can absorb the specific wavelength. When the line depth become brighter, the equivalent width become smaller.

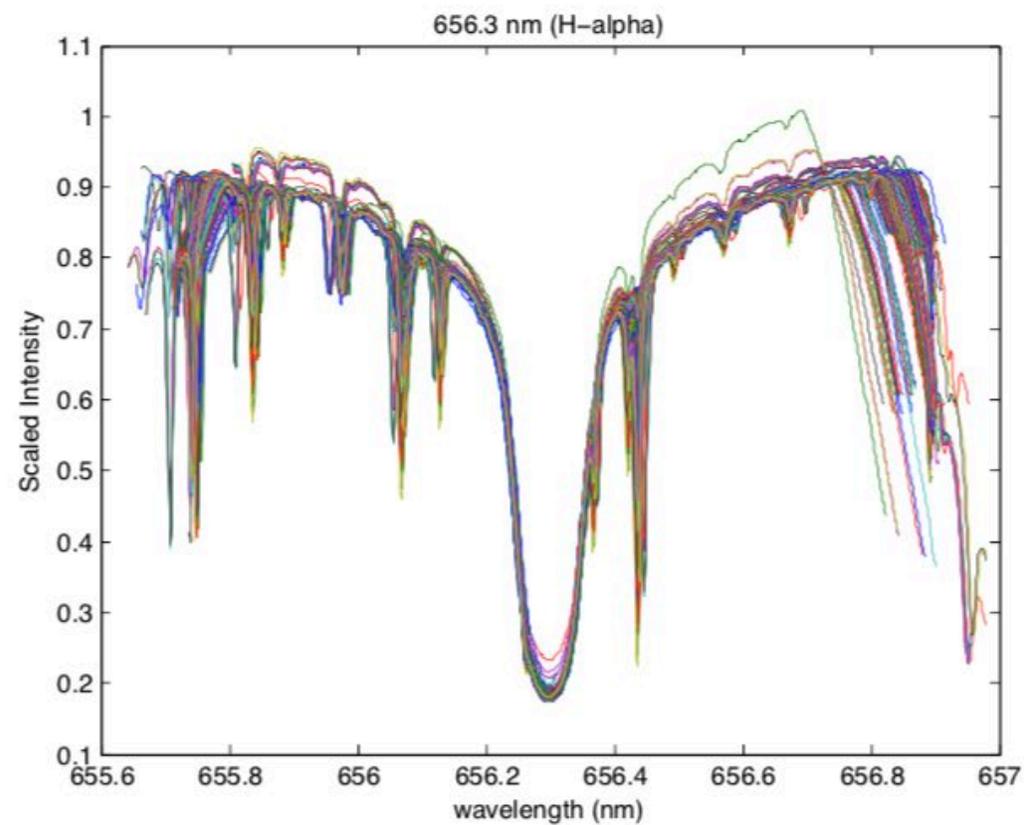
Equivalent Width (EW) of Chromospheric lines



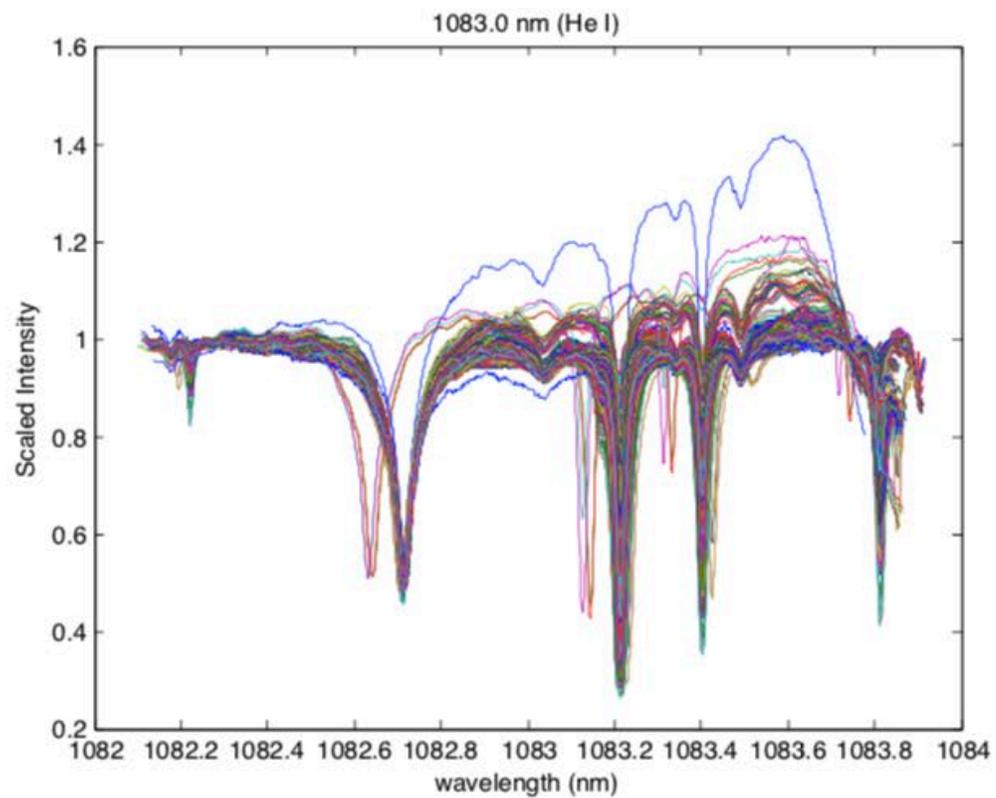
**SOLIS Full Disk Spectra.
Sun-as-a-Star**



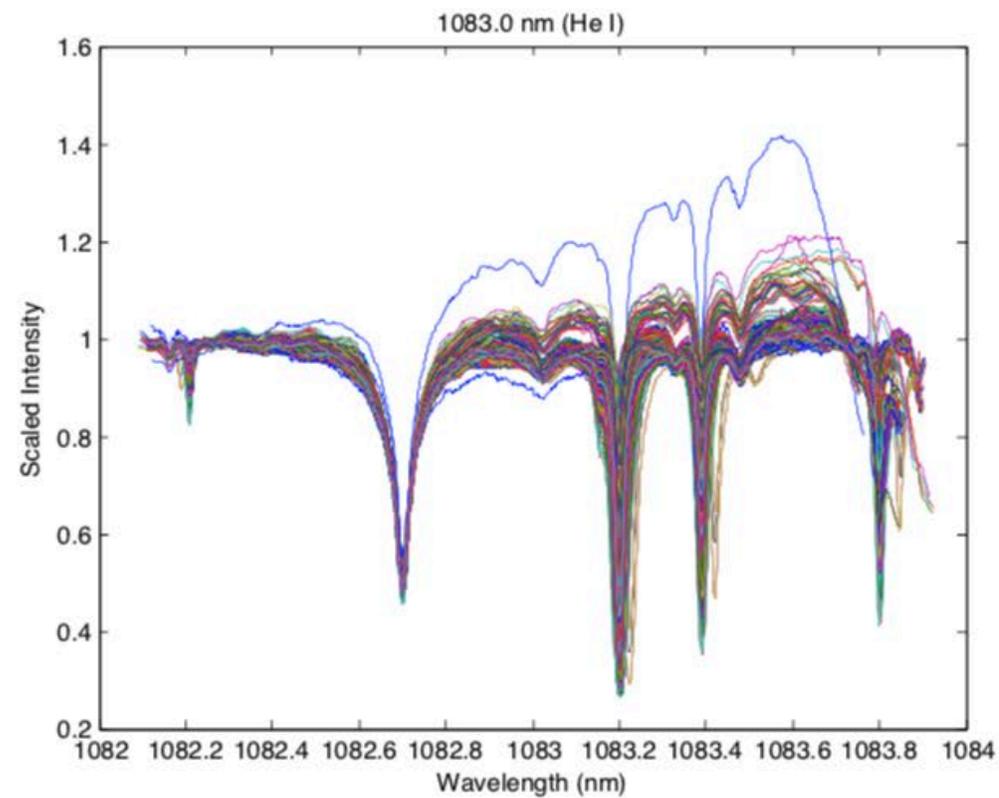
(a) All H- α spectrum



(b) H- α spectrum shifted to 656.3 nm

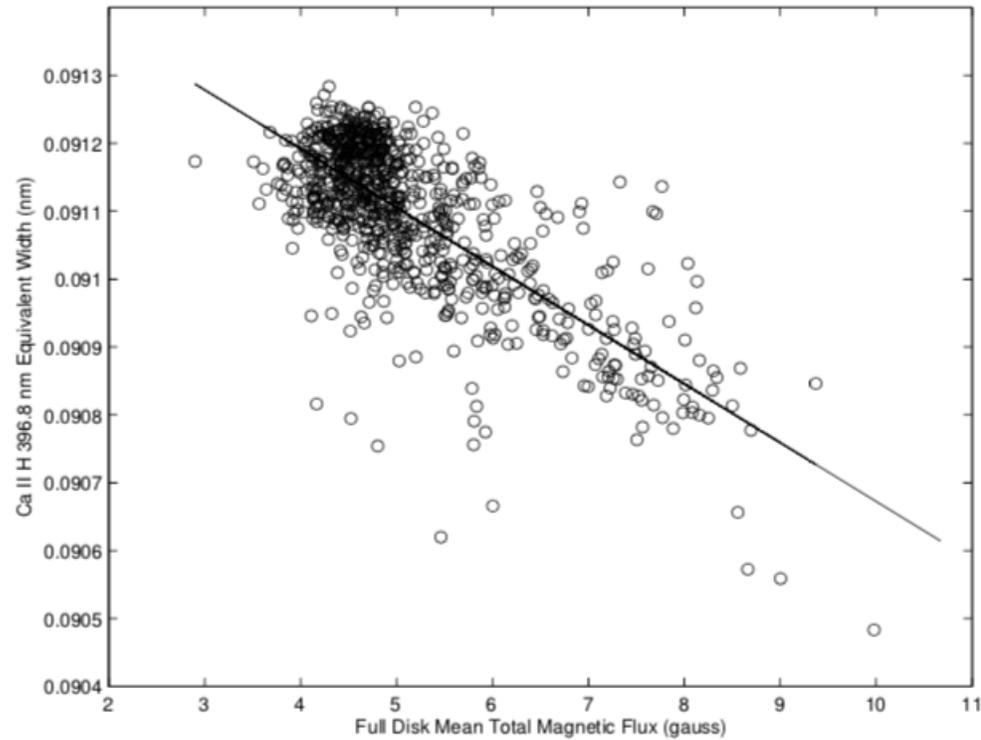


(a) All He I spectrum

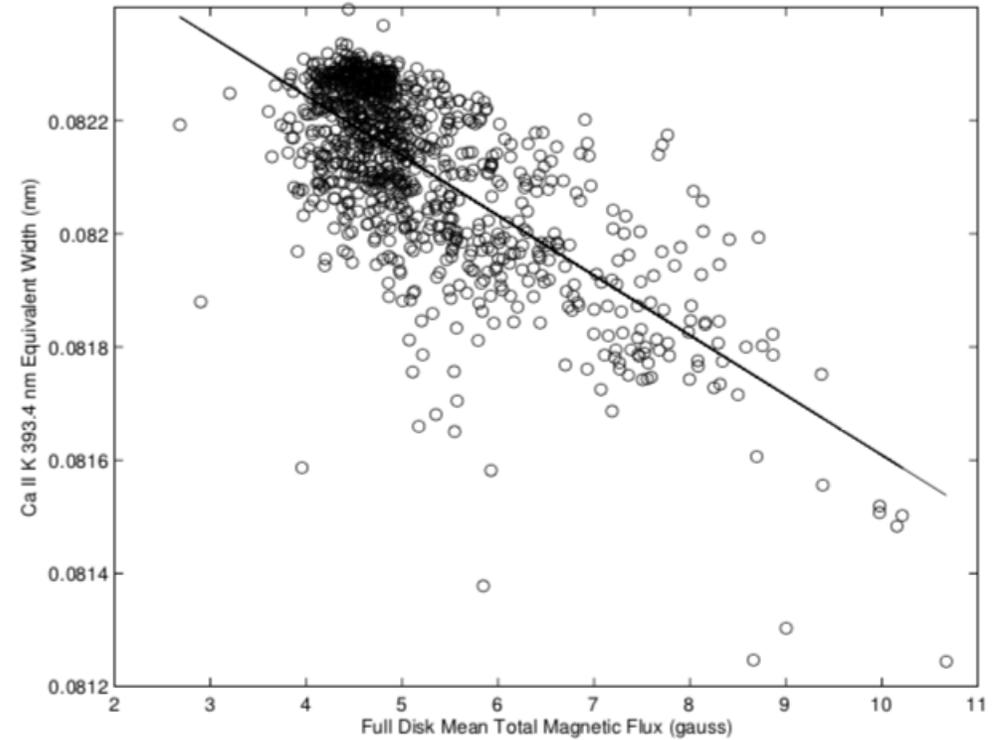


(b) He I spectrum shifted to 1082.7 nm

Magnetic field dependence of Ca H and K EW.

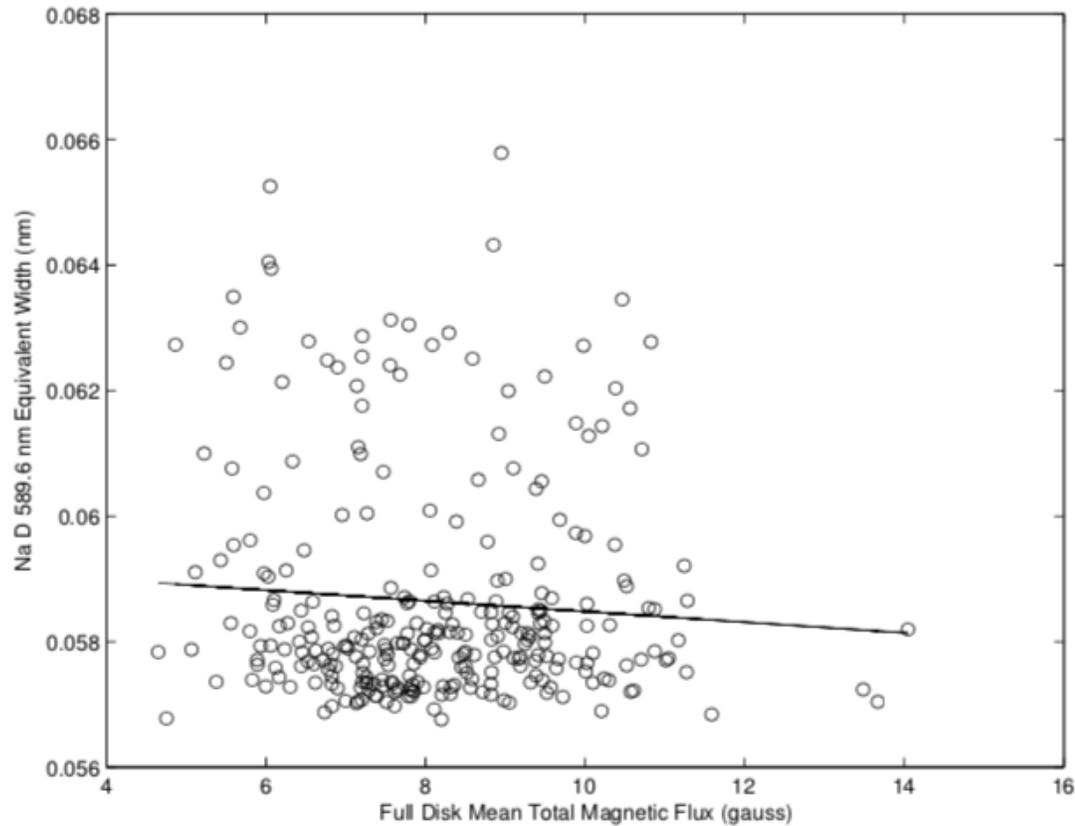


(e) Ca II H EW vs FDMTMF

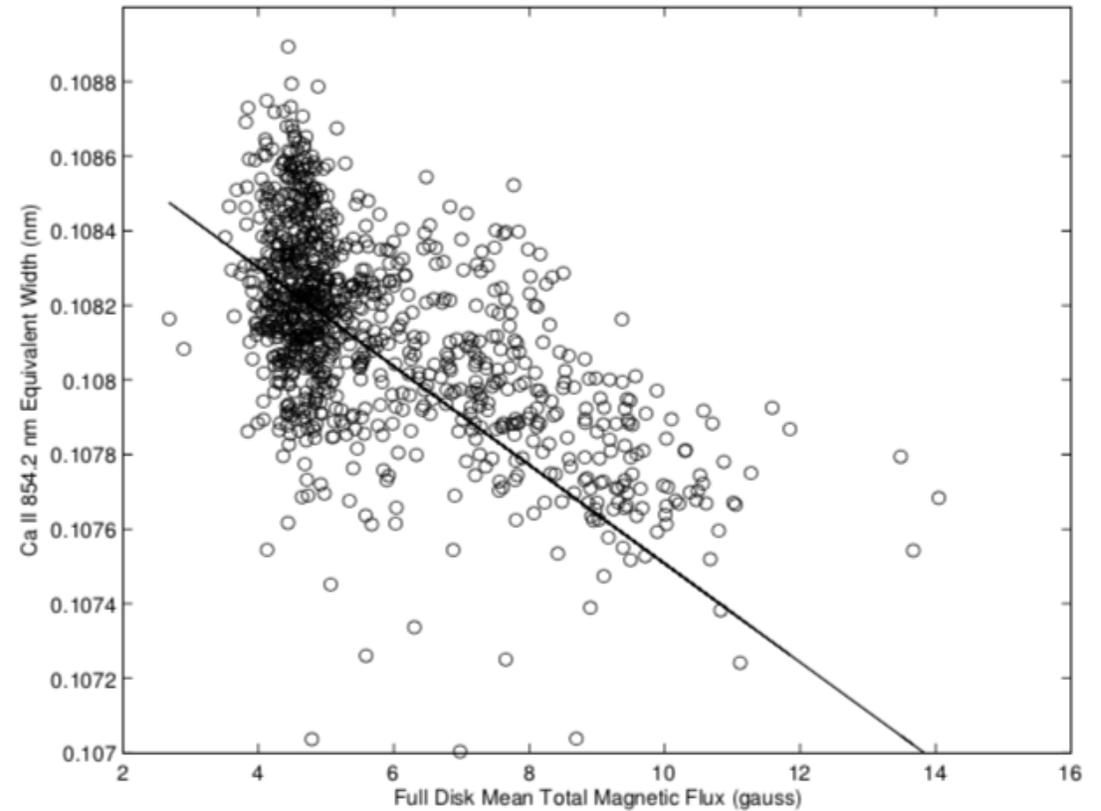


(f) Ca II K vs FDMTMF

Na 589.0 nm and Ca II 854.2 nm EW

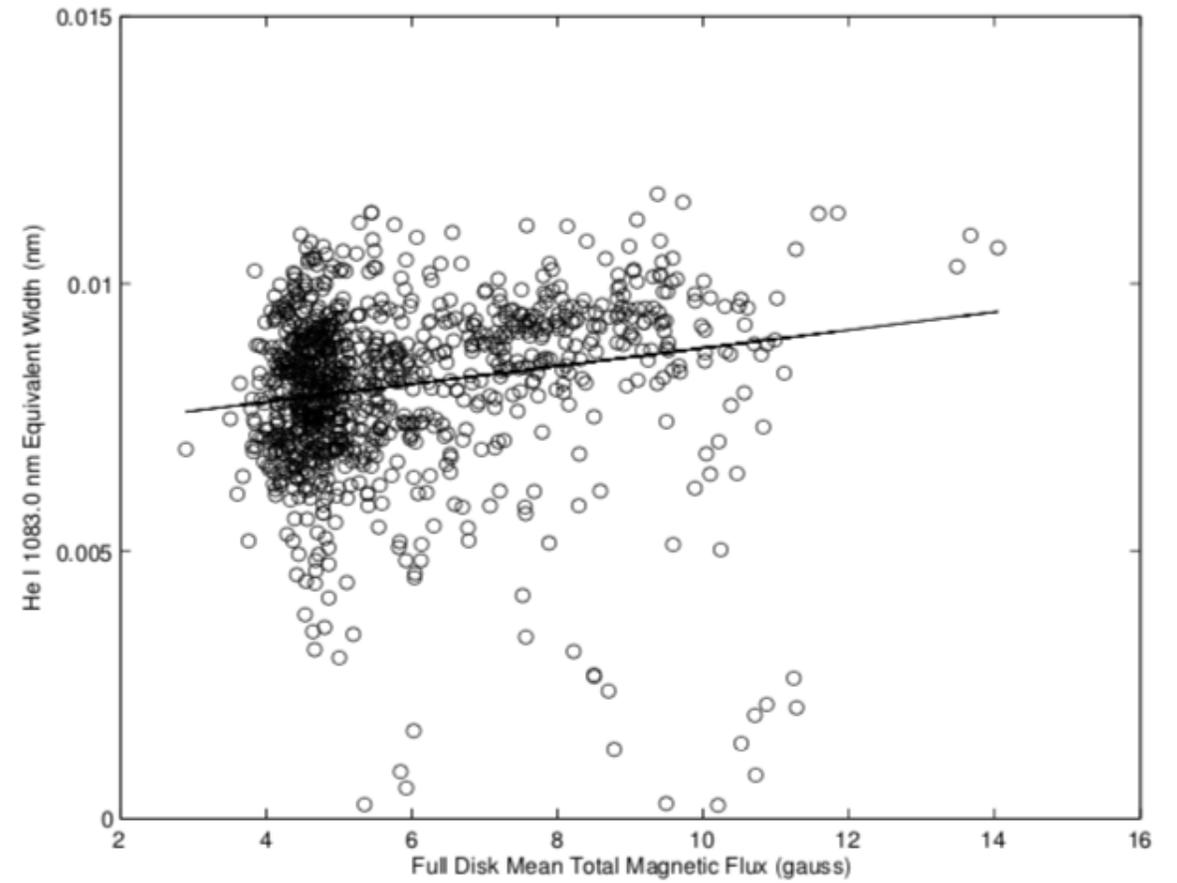
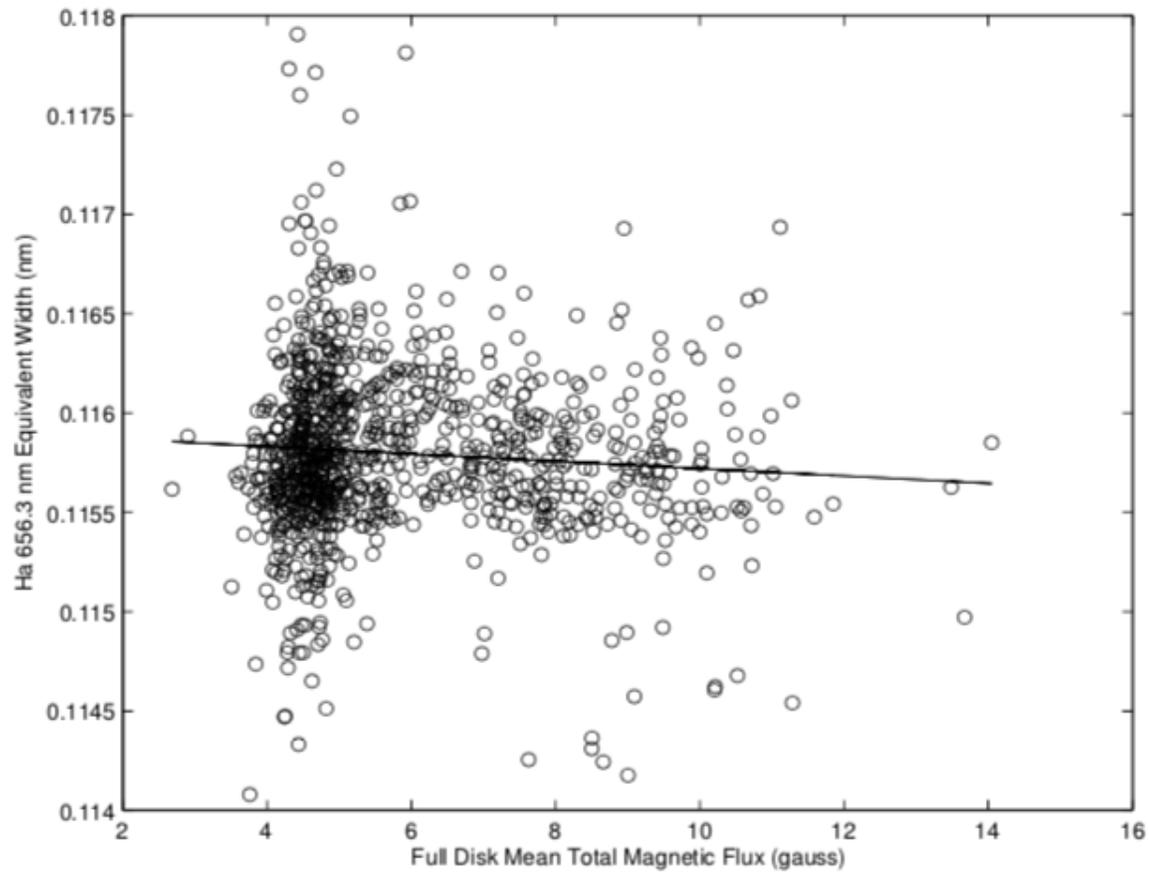


(c) Na D I EW vs FDMTMF

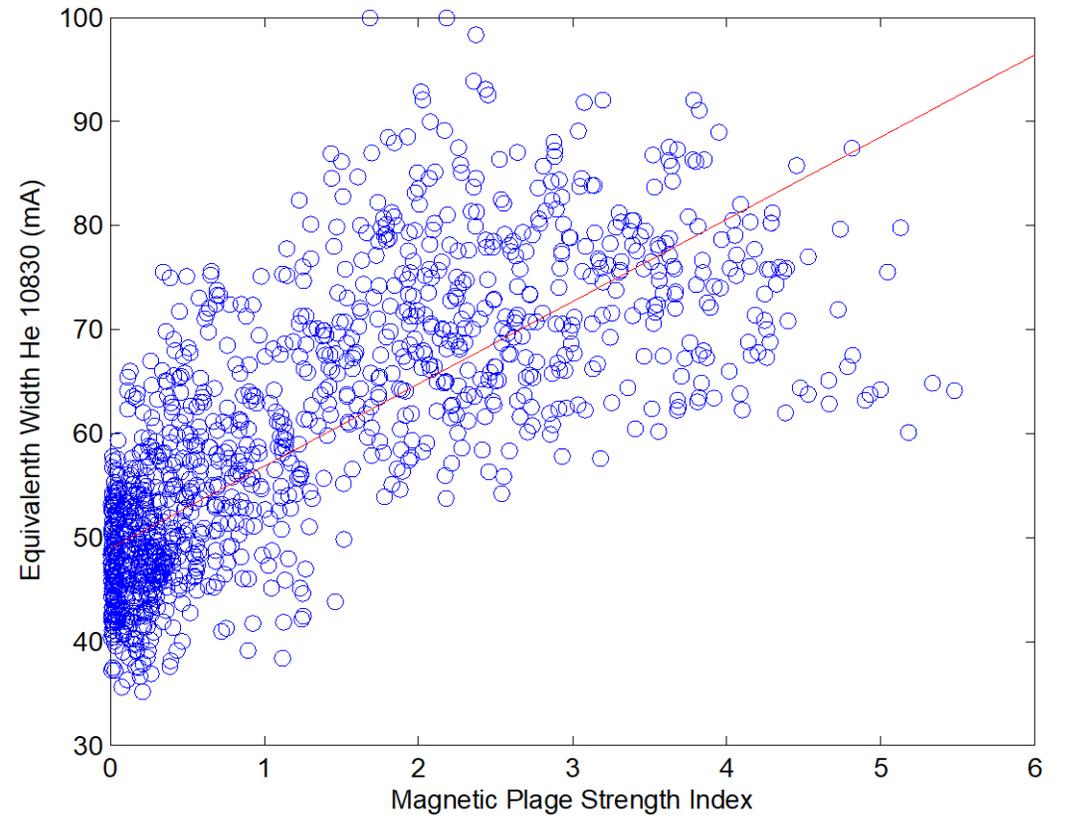
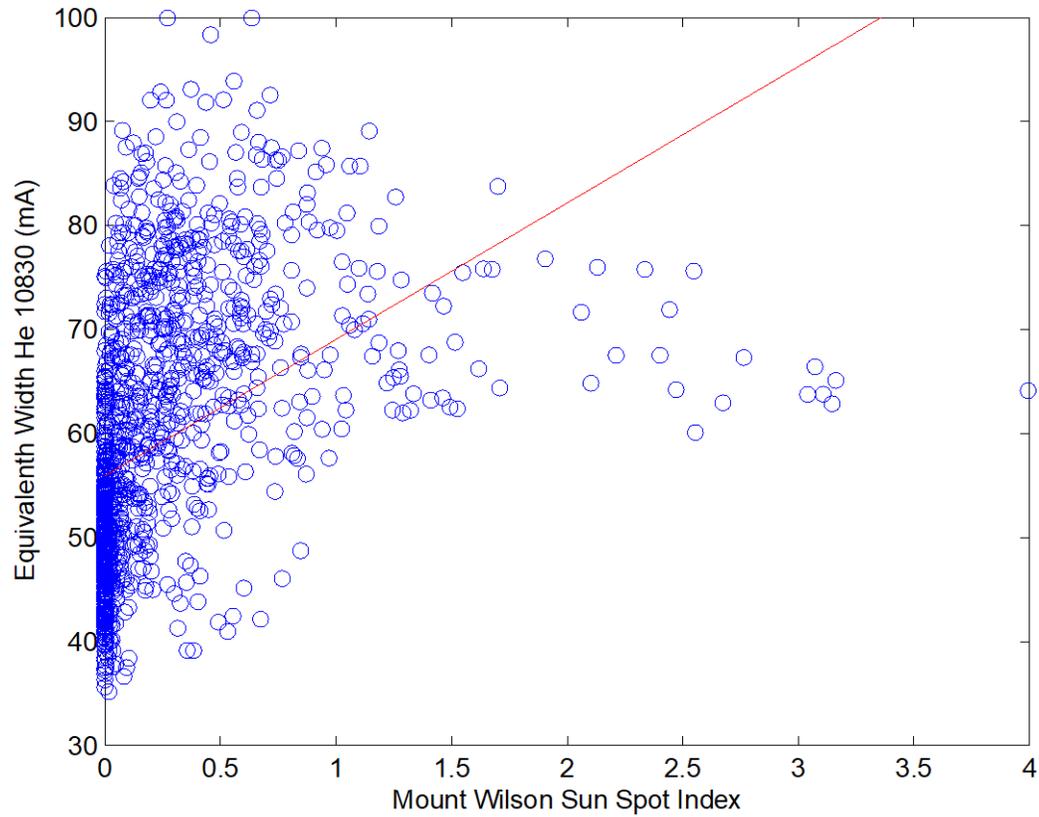


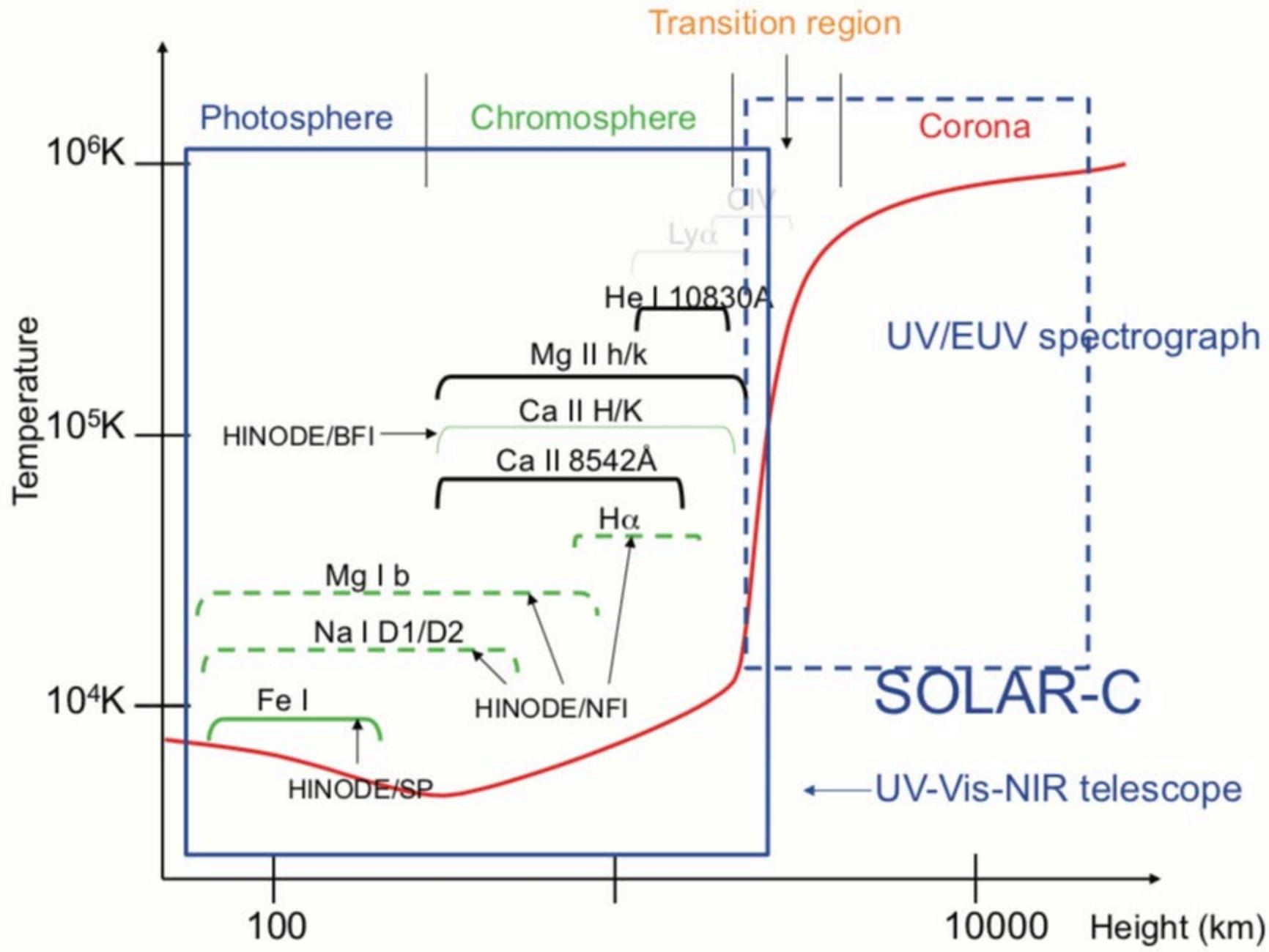
(d) Ca II EW vs FDMTMF

H α and He I 1083.0 nm EW



Magnetic field Vs He I 1083 nm EW.





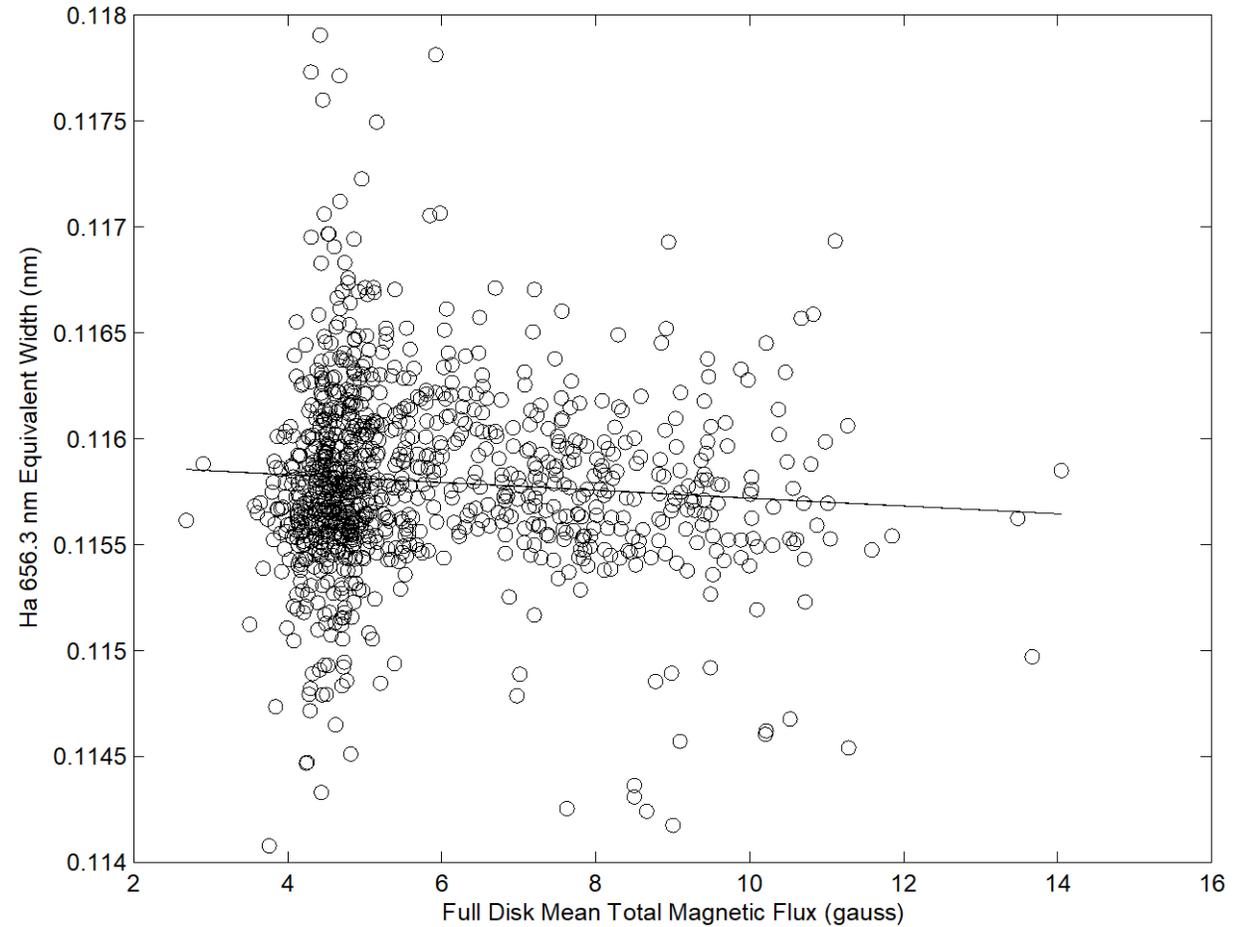
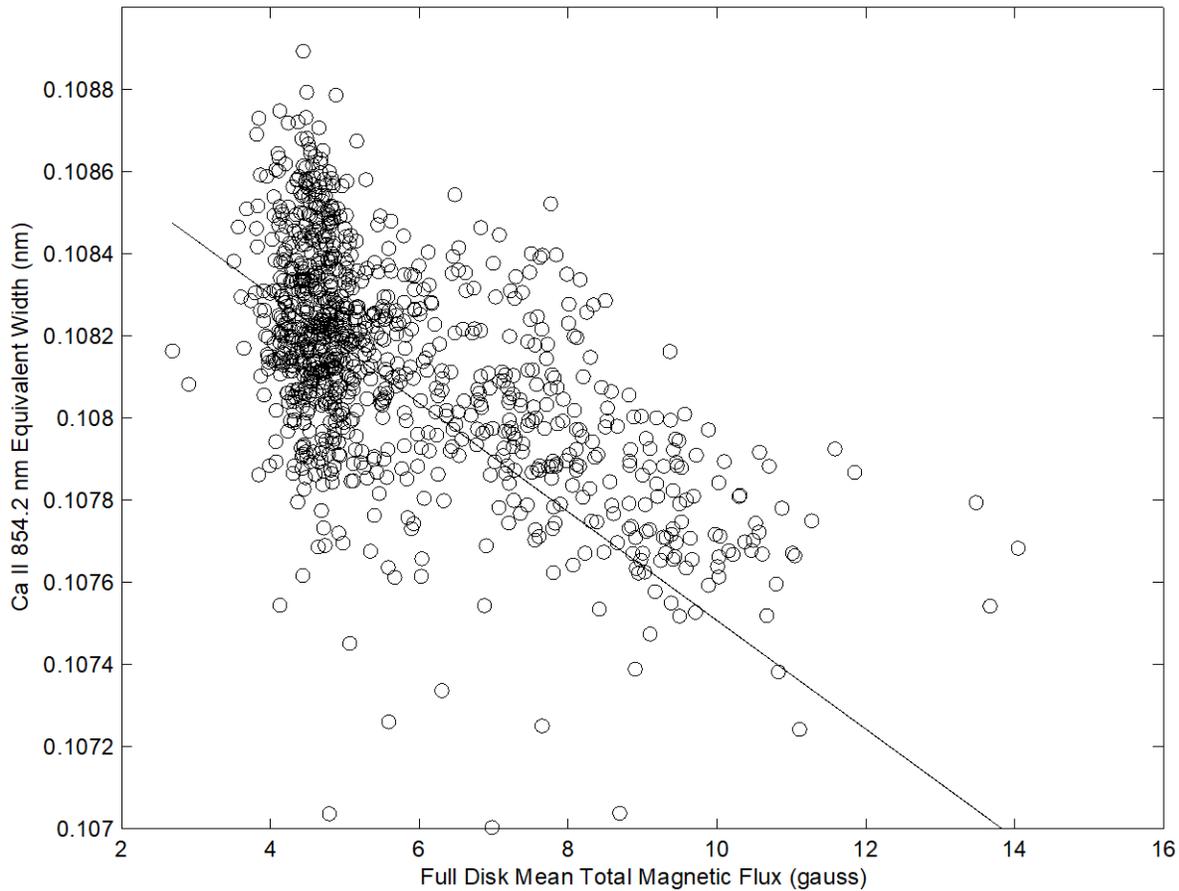
Summary

- EW decrease with full disk mean total magnetic flux (FDMF) for all chromospheric lines except HeI 1083.0 nm. The chromospheric lines become brighter.
- The slope of FDMF versus chromospheric lines are different for the lines forming at different heights. (Fraunhofer lines originating in deep photosphere are unchanged through the solar cycle.)
- Understanding the role of magnetic field in line-formation mechanism of chromospheric lines will help understand the SSI variability.

High Resolution Full Spectra Observations

- Contrasts of the radiation from simulation boxes with different levels of magnetic flux relative to an atmosphere with no magnetic field are a complicated function of position, wavelength and magnetic field strength. Complex relationship with magnetic field was found and areas of strong magnetic field can appear either dark or bright, depending on wavelength. (Norris et al, 2017, AA, 605, A45.)
- Non-LTE radiative transfer codes show that the variations in Fraunhofer lines define the amplitude of the solar brightness variability on timescales greater than a day and even the phase of the total solar irradiance variability over the 11-year cycle. (Shapiro et al, 2015, AA, 581, A116)

Magnetic field dependence of Ca 854.2 nm and H α EW.





Maximum

**M
A
X**

Year

**2
-
M**

Minimum

