Studying small-scale magnetic features in the Quiet-Sun

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Motivation

- First Sunrise mission on June 9, 2009 provided seeing-free observations of the quiet sun region on the solar disc.
- Diffraction limited observations with high spatial, spectral and temporal resolution.
- Observations were carried over different spectral regions: at the visible, violet, and near ultraviolet wavelengths, sampling different heights of the photosphere.
- Relation between the continuum brightness in the visible and the magnetic field (important for the solar irradiance models reconstruction).
- Relation between the photospheric magnetic field, and the emission in the UV, which was never with such high resolution before.
- Evolution of small scale magnetic features $\Longrightarrow$ Origin of the quiet-Sun photospheric magnetic fields.

Data

1. Imaging Magnetograph eXperiment (IMaX)
   - Disk center (quiet granulation region)
   - Data recorded from 00:36 to 00:59 UT (42 quiet Sun magnetograms).
   - V5-6 mode (Full Stokes Vector measured in 5 wavelength points + 6 accumulations per wavelength point).
   - Fe I (λ_0 =5250.2 Å) spectral line (g=3).
   - cadence = 32 sec.
   - $\Delta\lambda = \{-80, -40, +40, +80, +227\}$ mÅ.
   - level-2 data (phase-diversity reconstructed data).
   - plate scale = 0.054458 arcsec/pixel (40 km/pixel).
   - FOV = 50 arcsec $\times$ 50 arcsec (936$\times$936 pixels).
2. SUNRISE Filter Imager (SuFI)
   - Data at 300 nm and 397 nm (Ca II H core).
   - Level-3 data (Phase-diversity reconstructed data).
   - Plate scale = 0.02069 arcsec/pixel (at 300 nm) & 0.0198 arcsec/pixel (at 397 nm).
   - FOV = 15 arcsec $\times$ 40 arcsec (714$\times$1972 pixels).

Data preparation - Resampling

- SuFI data (397 nm and 300 nm) are resampled to a common plate scale (IMaX plate scale of 0.054458 arcsec/pixel) by bi-linear interpolation.
- New size of Sufi images(300 nm) $= 272 \times 750$ pixels
- New size of Sufi images(397 nm) $= 261 \times 719$ pixels

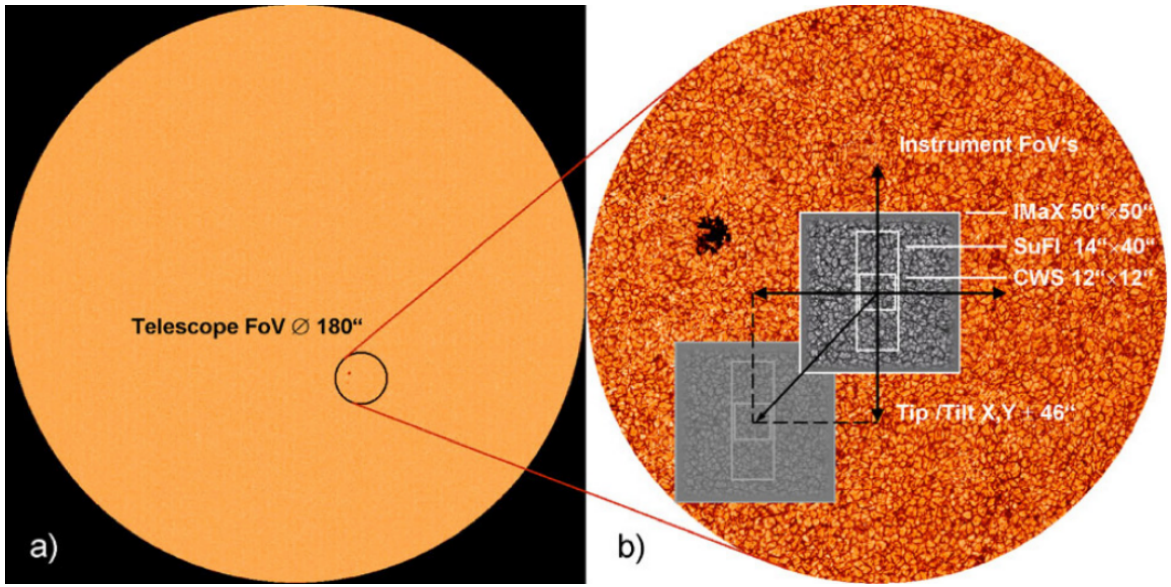


Figure : a) FOV of SUNRISE, b) FOV of IMaX and SuFI.

Data preparation - Image Alignment

- Selected SuFI 300 nm images whose observing times are closest to IMaX Stokes I continuum images.
- Selected SuFI 397 nm images whose observing times are closest to IMaX Stokes I line core images.
- IMaX Stokes I continuum (line core) images are cropped to the same FOV of SuFI 300 nm (397 nm) images.

- SuFI 300 nm (397 nm) images are aligned to the cropped IMaX Stokes I continuum (line core) images by means of a cross-correlation function computing shifts in x and y.
- All images from all data sets are cropped to the common FOV of $14'' \times 39''$

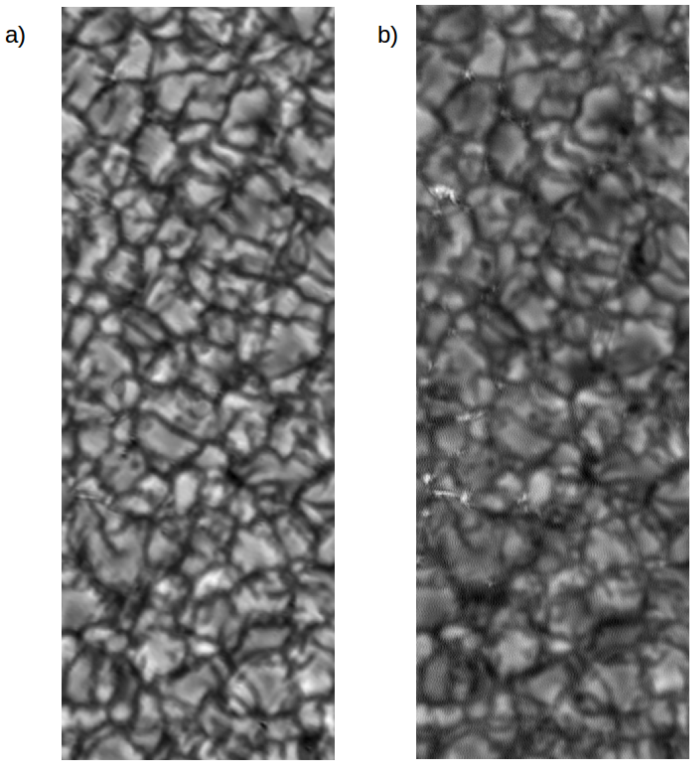


Figure : a) Stokes I continuum b) Sufi 300 nm

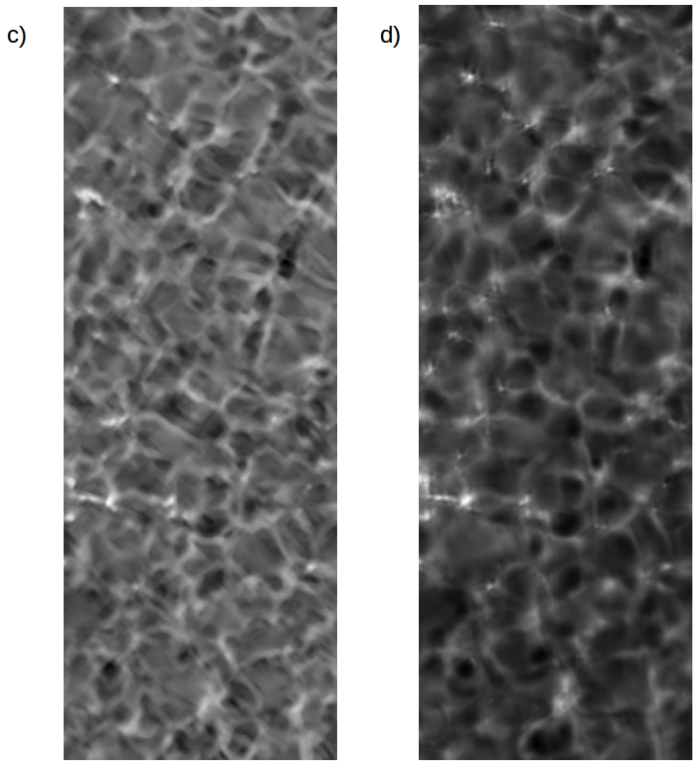


Figure : c) Stokes I Line core d) Sufi Ca II H

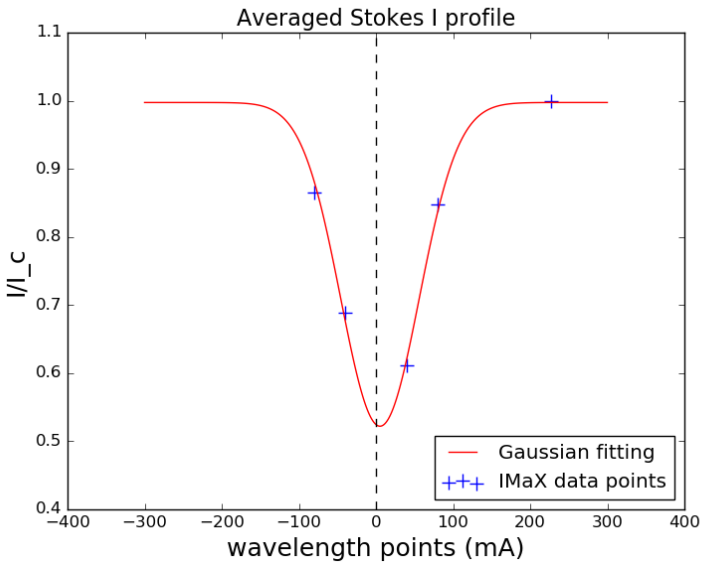
STOKES I & V

- For each magnetogram, Stokes V averaged over the 4 wavelength points (within the line) is calculated for each pixel:

$$V = \frac{1}{4 \times I_c} \sum_{i=1}^{4} a_i V_i \tag{1}$$

with I_c is the local continuum, and $a_i = [1, 1, -1, -1]$ to avoid cancellation.

- Gaussian fits are preformed to the Stokes I profiles and the following quantities are derived:
  - Line-of-sight velocity.
  - Line core Intensities.
  - Line depth Intensities.



LOS Magnetic Field

- The LOS component of the magnetic field is determined using the COG (Center-of-gravity) technique (Rees & Semel 1979):

$$B = \frac{\Delta\lambda_G}{C_0 \times g \times \lambda_0^2} \qquad (G) \qquad (2)$$

with $C_0 = 4.67 \times 10^{-13} m^{-1} G^{-1}$, g is the Landé factor, and λ_0 is the central wavelength.
And

$$\Delta\lambda_G = \frac{\int_{-\infty}^{+\infty} V \Delta\lambda d\Delta\lambda}{\int_{-\infty}^{+\infty} (I_c - I) d\Delta\lambda} \qquad (m\mathring{A}) \qquad (3)$$

The wavelength difference of the COG of $I + V$ and $I - V$ profiles.

Analysis - Measurements

Continuum contrast

- The continuum contrast at each pixel of a given FOV is calculated:

$$Con(x, y) = \frac{I_c(x, y) - I_{qs}}{I_{qs}} \tag{4}$$

Where I_{qs} is the mean continuum intensity of the corresponding FOV.

Line-Core Intensity

- As a proxy for the line core intensity, the average of the -40 and +40 $m\AA$ line positions at each pixel of the stokes I are averaged:

$$LC = \frac{I_{+40} + I_{-40}}{2 \times I_c} \tag{5}$$

Where I_c is the local continuum.

Sufi Brightness

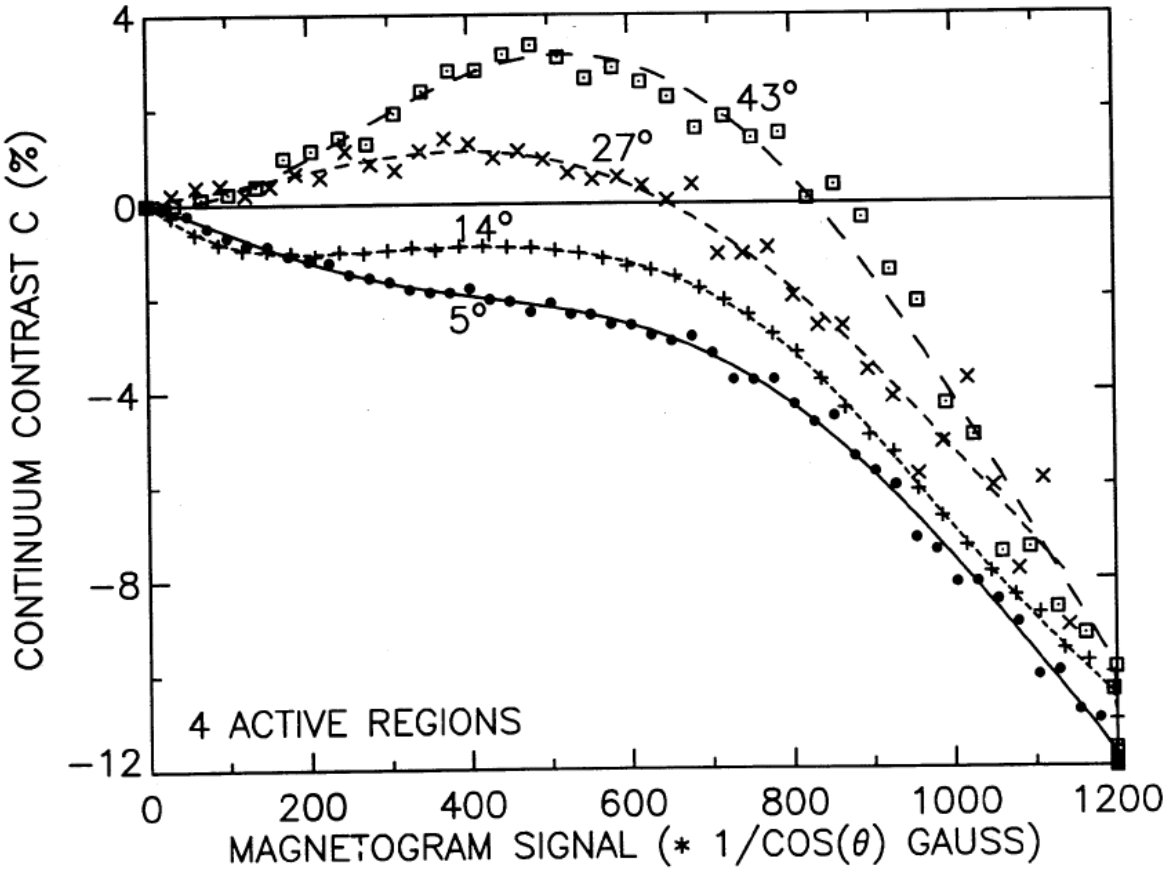
- For each IMaX continuum (line core) image, the best quality SuFI image at 300 nm (397 nm) is chosen.

Analysis - Continuum Contrast vs B

- Small scale magnetic elements contribute to the solar irradiance variations.
- Contrast in the visible continuum is a proxy for the temperature excess with respect to the quiet photosphere.
- How spatial resolution affects the relation between the contrast and the magnetogram signal.
- Pixel-by-pixel study of the continuum contrast at 5250.02 $\AA$ vs longitudinal magnetic field.

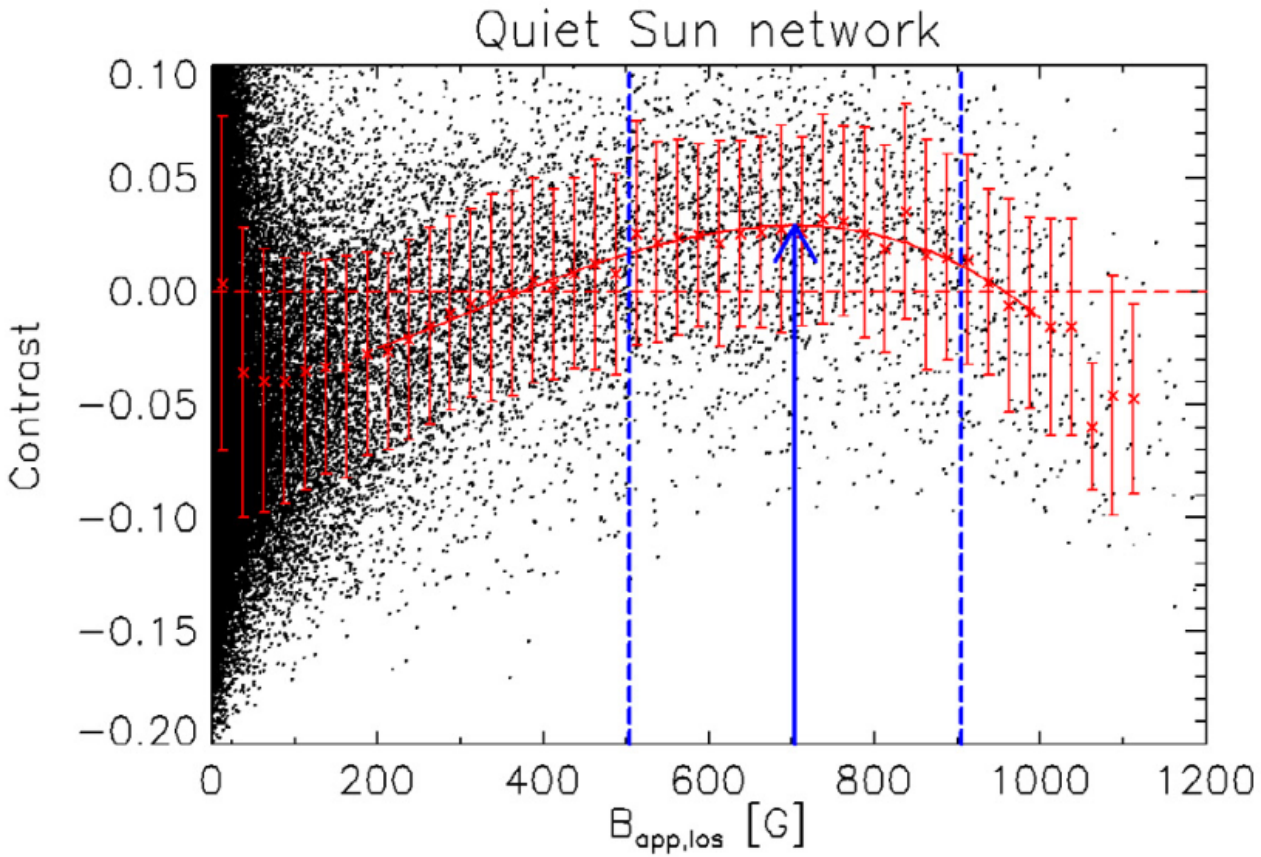
Analysis - Continuum Contrast vs B

- Topka et al.(1992): Ground-based Observations of continuum intensity in facular and quiet Sun regions near the disc-center.
- Continuum contrast was negative for all values of magnetogram signal for data near disk center (pores extracted).



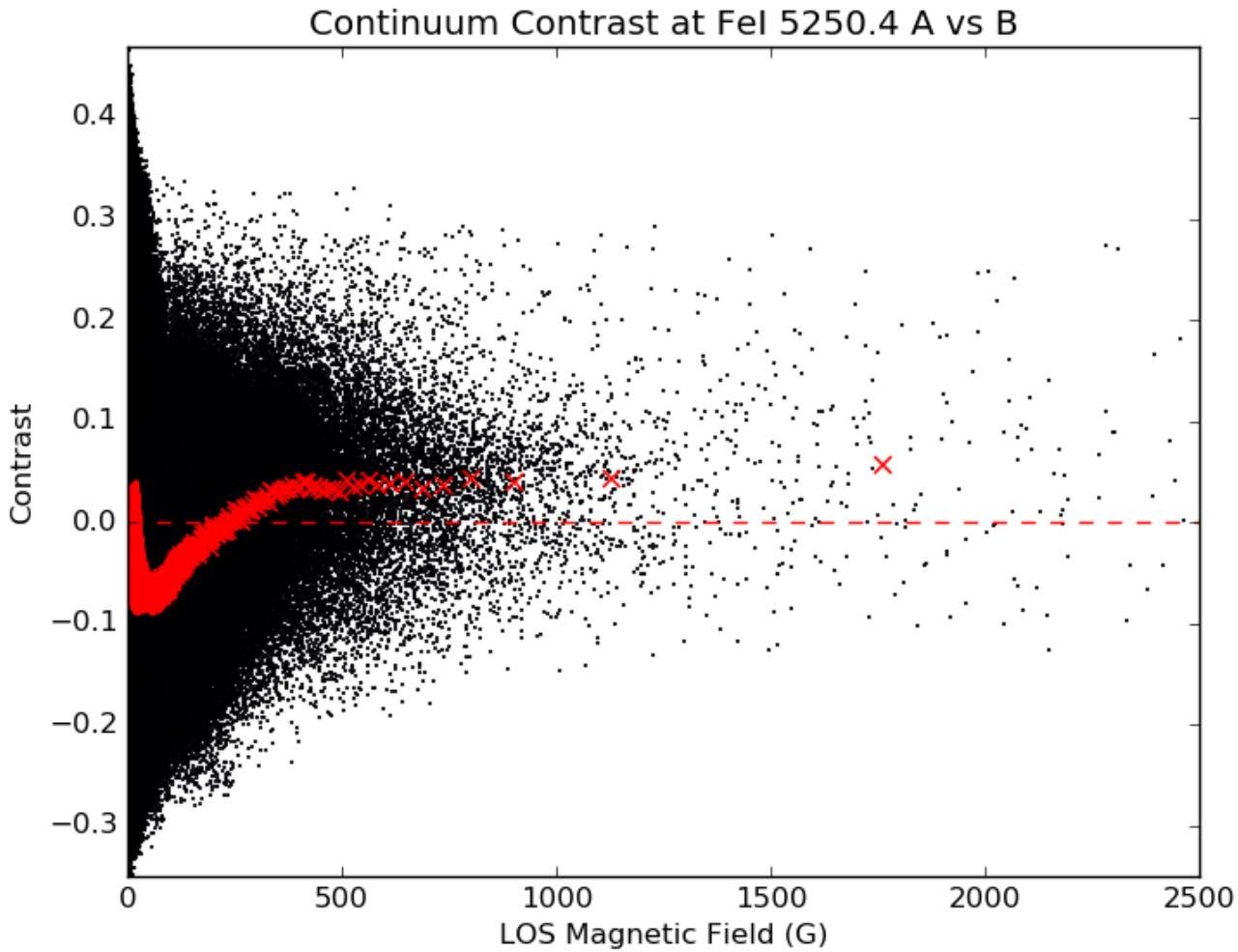
Analysis - Continuum Contrast vs B

- Kobel et al.(2011): Spectropolarimetric scans by Hinode/SP (resolution 0.3")
- The average contrasts decrease for B $<$ 200 G, then increase to reach a peak at B $\approx$ 700 G, then decrease again.



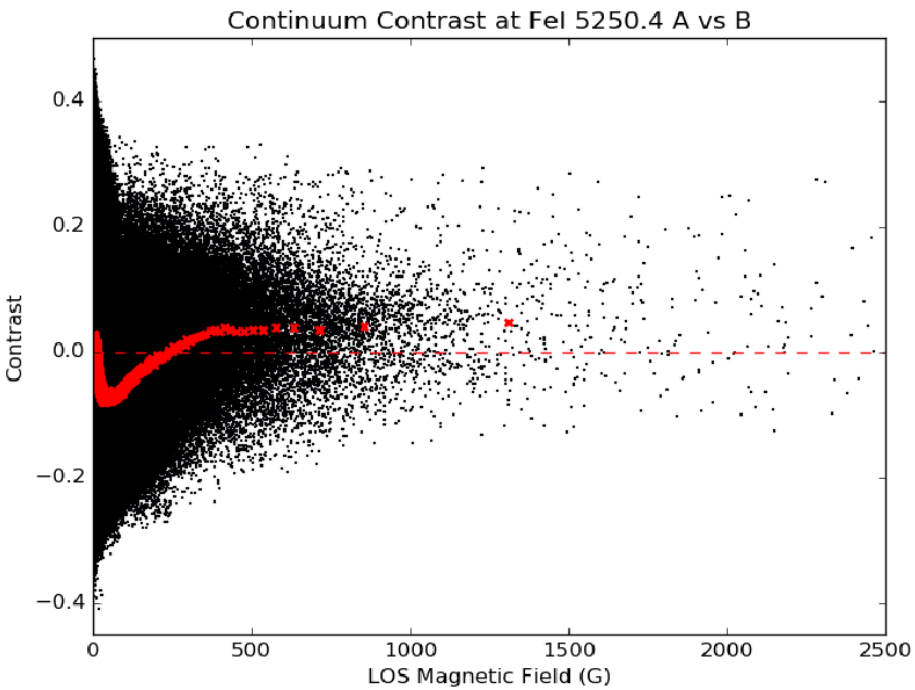
Analysis - Continuum Contrast vs B

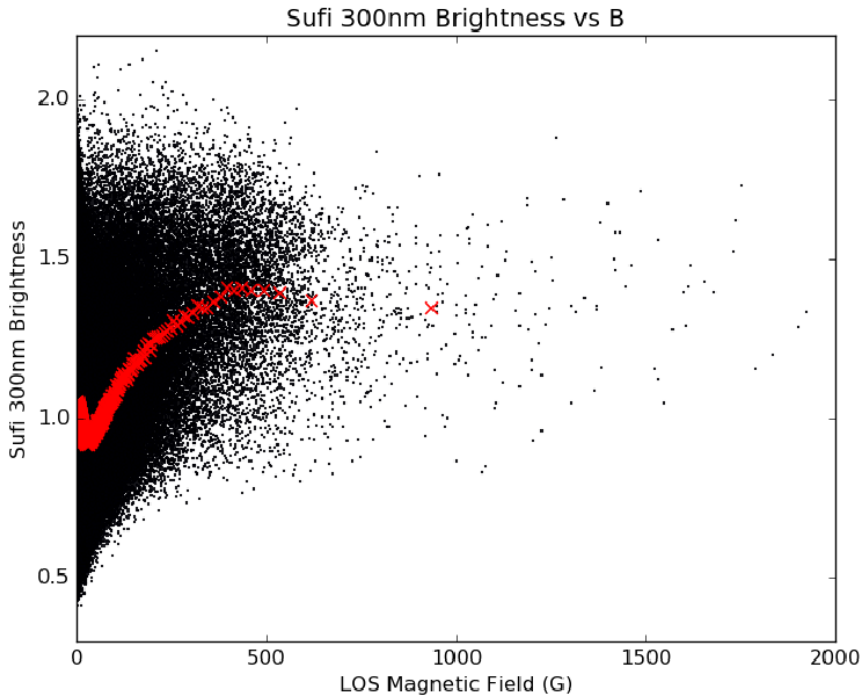
- Spectropolarimetric data from Sunrise-I/IMaX of the quiet sun near disc region with higher resolution (0.15").



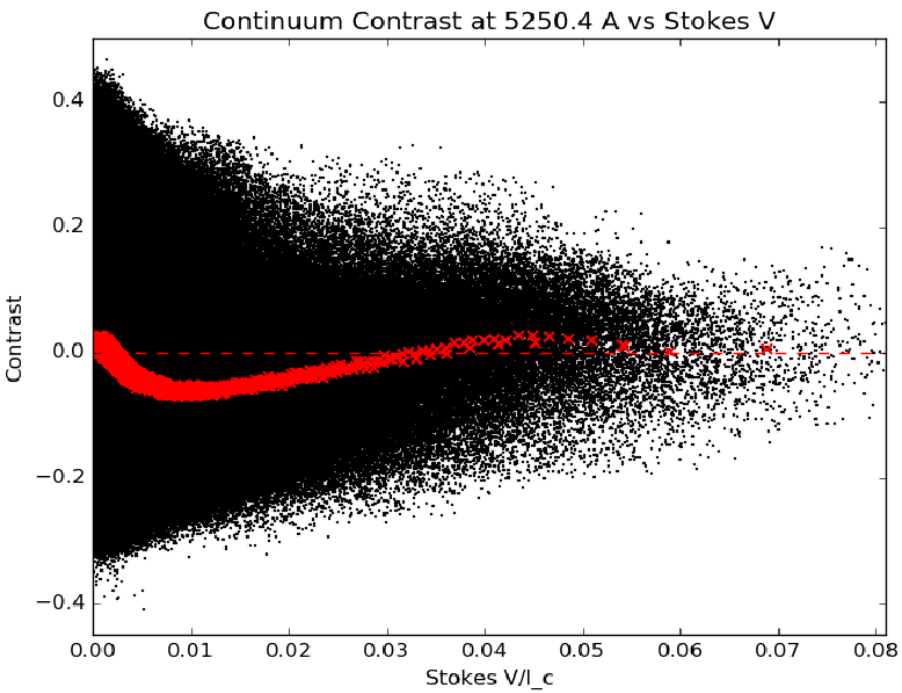
Analysis - Continuum Contrast vs B

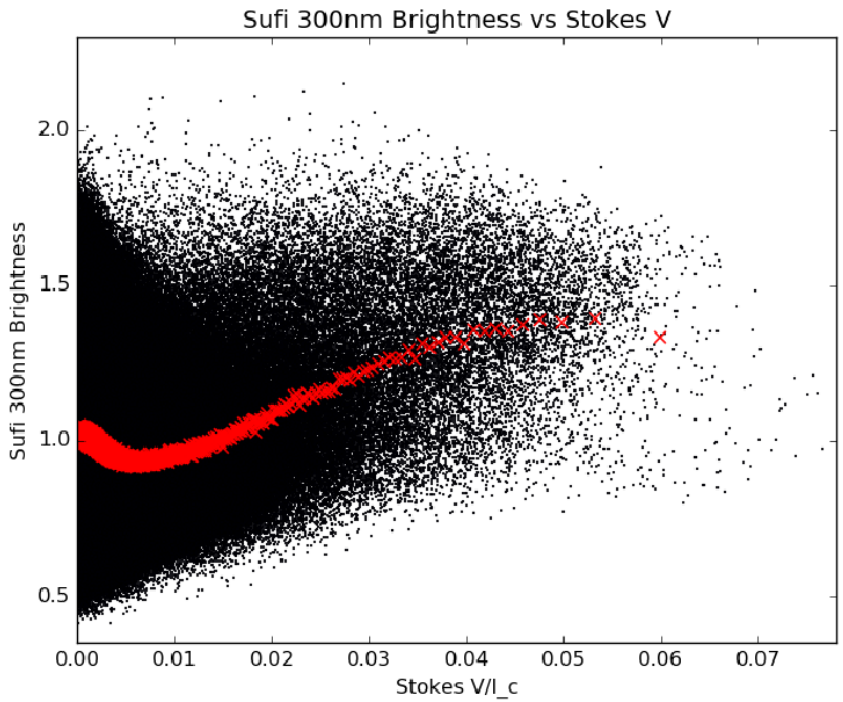
- Scatter plots of both the continuum brightness and the brightness at 300 nm show approximately the same trend.





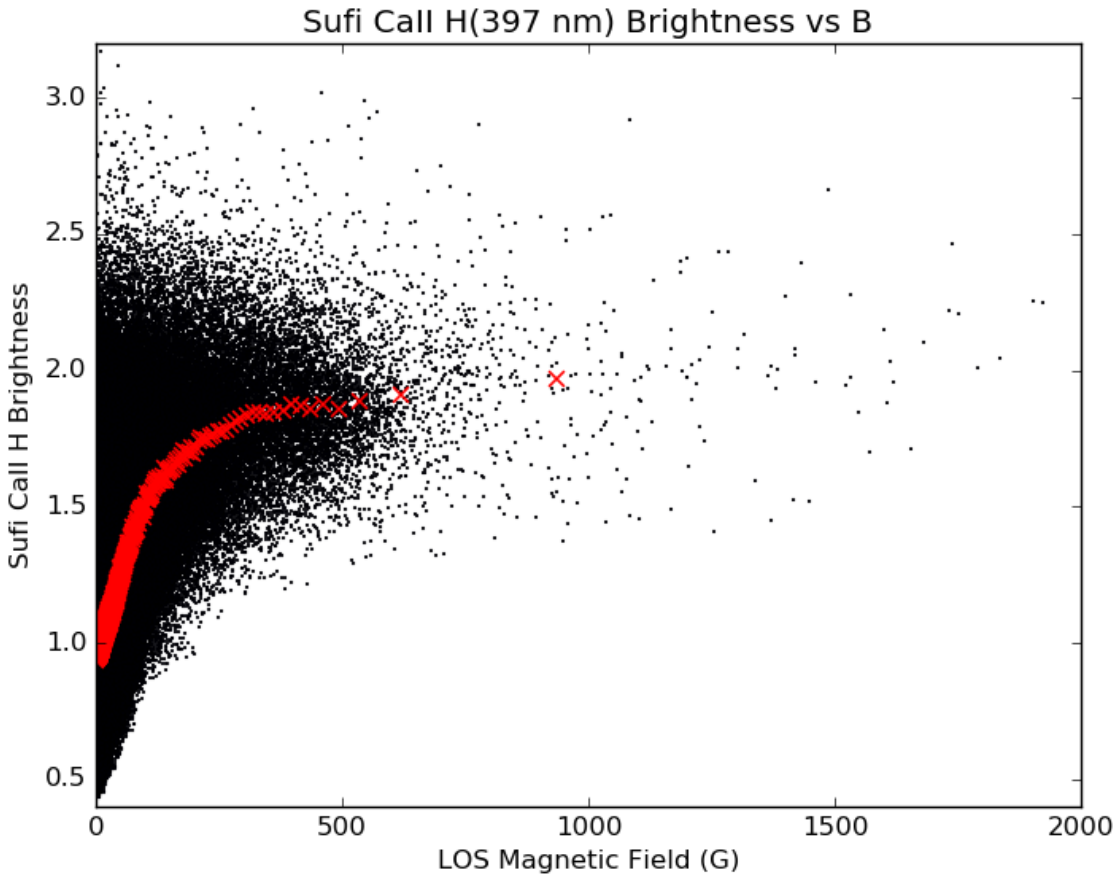
Analysis - Continuum Contrast vs B





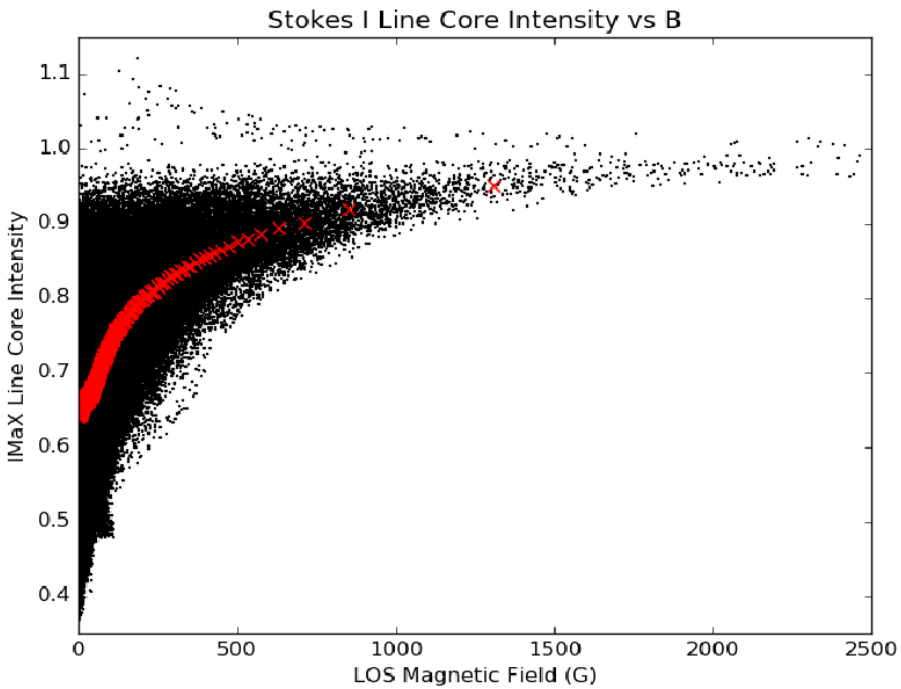
Analysis - Chromospheric Emission And Photospheric B

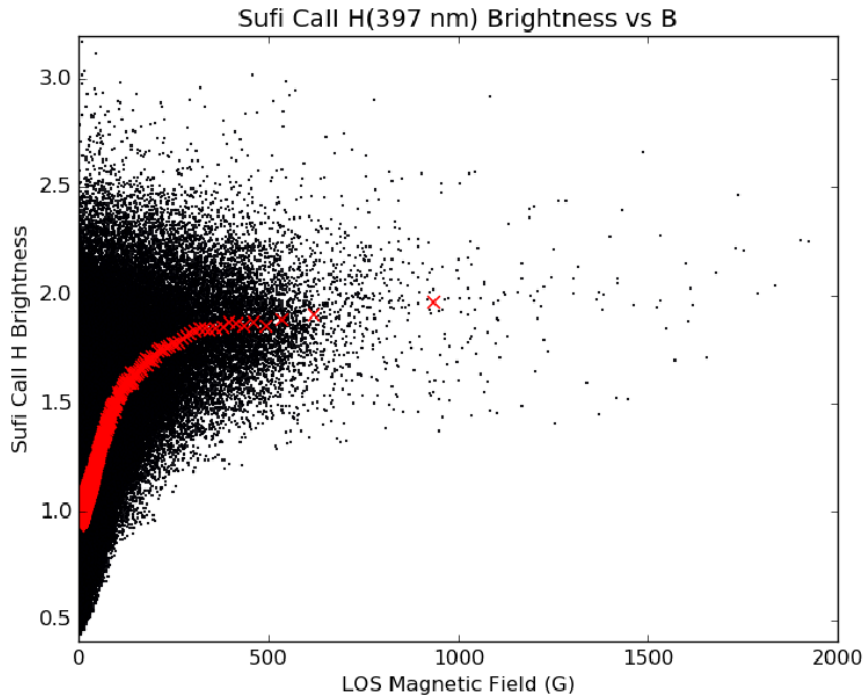
- The Ca II H at 397.6 nm sampled by SuFI is an excellent thermometer for the choromospheric temperature structure.
- Quiet Sun magnetic field is believed to be responsible for the chromospheric structure.



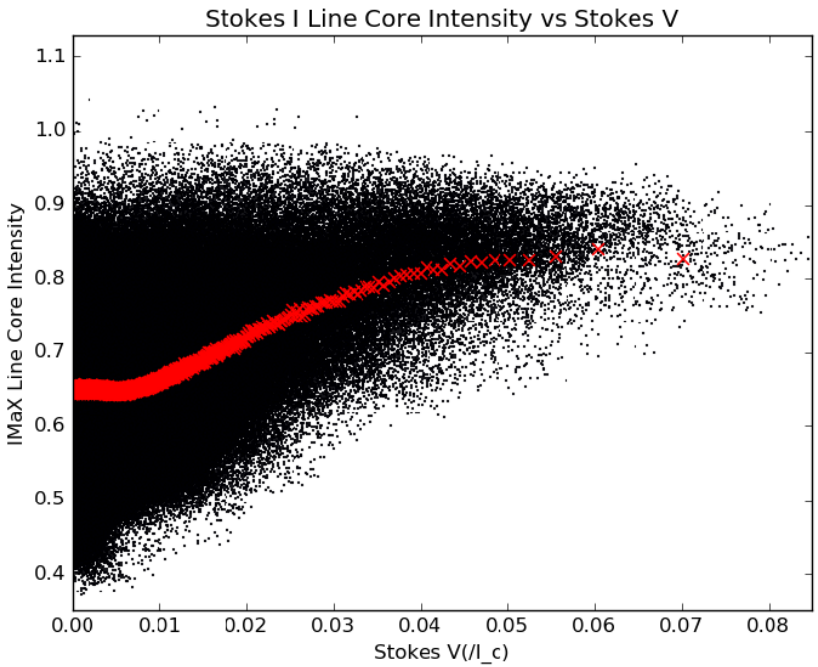
Analysis - Chromospheric Emission And Photospheric B

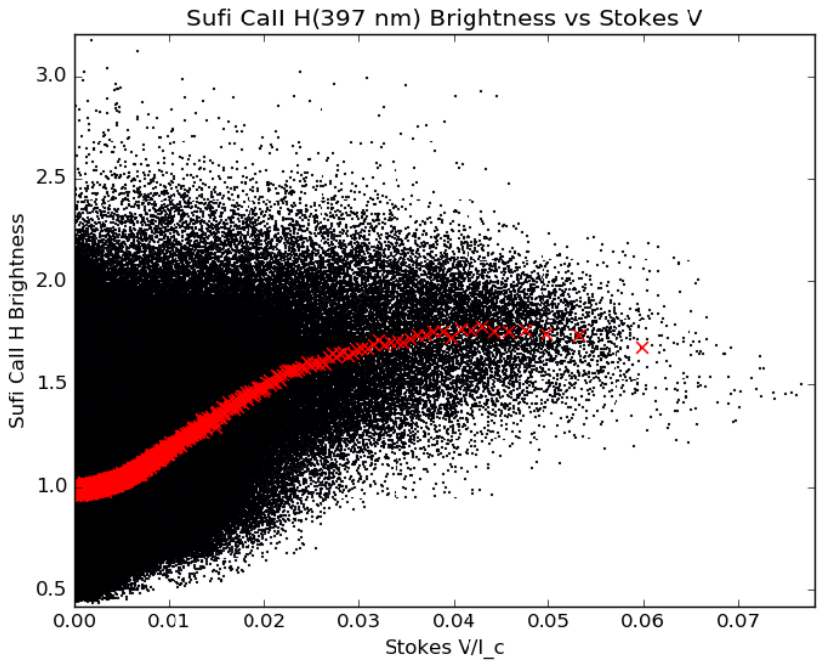
- Similarity of scatter plots for the brightness at 397 nm and stokes I line core Intensity.





Analysis - Chromospheric Emission And Photospheric B





Next topic: Magnetic Reconnection in the Quiet-Sun

- The same time-series data were used to track the evolution of small-scale magnetic features.
- Different physical processes were identified (appearence, disappearence, splitting, merging, emergence and cancellation) between the magnetic features.
- A detailed statistical study was carried for estimating the area, magnetic flux, and lifetime of these features with time.
- We will focus on the cancellation events (of 2 opposite polarity features).
- We will estimate the magnetic energy lost in this process and compare it to the thermal energy in the photosphere.
- Look for enhanced brightness (in all wavelengths).

The End