Using modern data to understand historical solar observations

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Introduction

- Total solar irradiance (TSI): Varies in phase with solar cycle by about 0.1 %. Spectral solar irradiance: The variability increases towards shorter wavelengths.
- Driver of the variability: Competition between dark sunspots and bright faculae[4].
- Long-term changes in TSI and variability in UV can affect **Earth's climate**[3]**.** Since direct irradiance observations are available only from 1978, reconstructing past variability is essential to estimate the climate impact of solar irradiance changes.
- Main **open questions**: (a) Long-term changes in TSI and (b) the amplitude of the variability in UV[5].
  Main issue: Limited understanding of facular evolution and radiative properties.
- Large volume of Ca II K images available since late 19th century ⇒ can help address the open questions.
- **Key problem:** Different observatories have different spectral bandpasses[1] => brightness of solar disc and the individual features changes (Figure 1).
- **Objective:** To find the empirical relationship between different Ca II K bandpass images using data from the SUSI[2] instrument of the SUNRISE III mission.

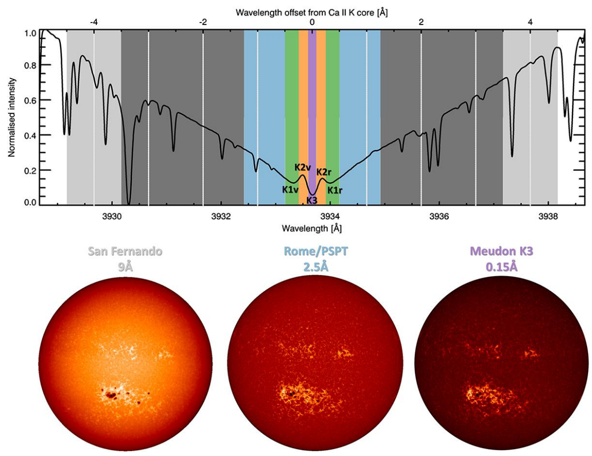

Figure 1. Disc-integrated quiet-Sun spectrum in a 10 Å interval. Different color bands indicate different bandwidths (9, 7, 2.5, 1, 0.5, and 0.15 Å) centered at line core. The bottom panel shows observations taken on the same day (11 July 2012) from three different observatories. From Chatzistergos et al. 2024

Methodology

- **Data**: Three scans of emerging flux region at disc center (each with a scan time of 37 minutes) from SUSI instrument of SUNRISE III.
  - FOV 20"x40"
  - Pixel scale: 0.03"/Px (Spatial) and 10mÅ/px (Spectral)
- To **simulate** different **bandpasses**, we used a Gaussian window centered at the Ca II K line core, with FWHM set to the desired passband bandwidth. A Gaussian-weighted average of the spectral images then yields an image representative of what would be observed through the corresponding passband (Figure 2).
- As the spatial resolution varies across different observatories, we resampled the images by convolving them with a two-dimensional Gaussian kernel and trimming the edges to remove artifacts introduced by the convolution.
- Since the focus is on bright faculae, we excluded dark features such as spots and pores.
- We tried **power-law** and **logarithmic** fits to the intensity-intensity relationship and found that power-law fits better than logarithmic (Figure 3).

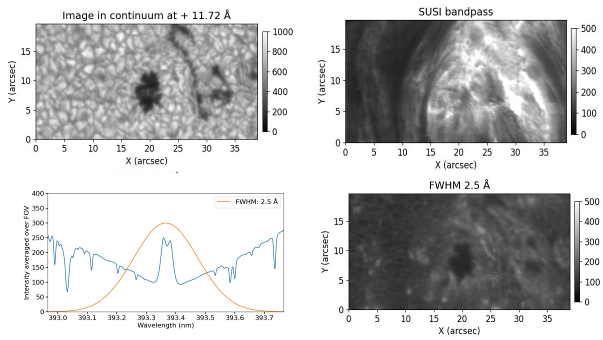

Figure 2. Image from one of the three scans, shown in: continuum (top left), SUSI bandpass with 10 mÅ bandwidth centered at line core (top right), and a synthetic passband with 2.5 Å bandwidth centered at the line core (bottom right). The bottom left panel shows the average Ca II K line profile with a Gaussian window of FWHM 2.5 Å centered at the line core.

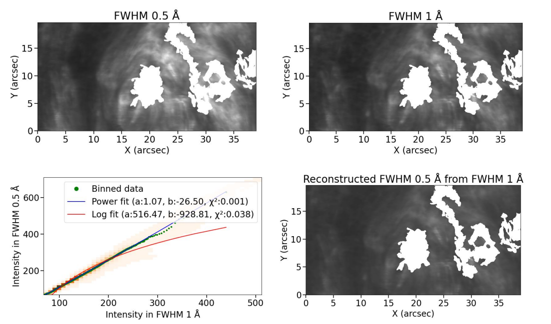

Figure 3. Images in synthetic bandpasses of bandwidth 0.5 Å (top left) and 1 Å (top right), both centered at the line core. Bottom left: Histogram showing the intensity–intensity relationship between the images of 1 Å and 0.5 Å passband. Green points represent binned data along the x-axis; blue and red curves correspond to the fitted power-law and logarithmic models, respectively. Bottom right: Reconstructed 0.5 Å passband image derived from the 1 Å image.

Results

- To validate the robustness of the power-law fit, we reconstructed one passband image from the another. Figure 3 (bottom right) shows an example using images in the 0.5 Å and 1 Å passbands.
- The power-law coefficients depend on both the bandpasses and the spatial resolution (Figure 4).

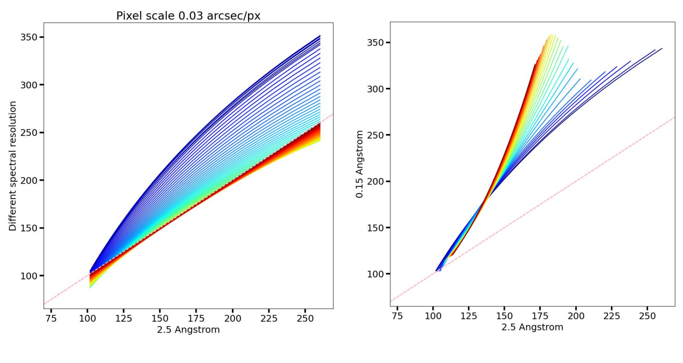

Figure 4. Left: Power-law fits for the intensity in different pairs of bandpasses at a spatial pixel scale of 0.03 arcsec/px. The x-axis represents the intensity in the 2.5 Å bandpass, while the y-axis shows the intensity in other bandpasses ranging from 0.15 Å to 2.5 Å (color-coded from blue to red) in steps of 0.03 Å.
Right: Power-law fits for the intensity in the 0.15 Å and 2.5 Å bandpasses at different spatial pixel scales, ranging from 0.03 arcsec/px to 5 arcsec/px (color coded from blue to red) in steps of 0.2 arcsec/px.

Conclusions

- The empirical relationship between intensities in different passbands is best described by power law in form $y = a \cdot x^b + c$.
- This relationship can be used to cross-calibrate different Ca II K observations.

References

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