Image Processing using PSPT

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1) Abstract

To understand Earth's climate, we must first understand the Sun. However, there are still significant uncertainties associated with both the fundamental mechanisms of solar variability and how they enter into the Earth's climate system. An important method to study the causes of solar variability can be found through the analysis of solar images. The Precision Solar Photometric Telescope (PSPT) located at the Mauna Loa Solar Observatory (MLSO) acquires images of the Sun in three different photometric bands to monitor the evolution of the solar surface features that change over the course of a solar cycle. These images provide a complete knowledge about the Sun by focusing on different layers of the solar atmosphere. Though raw images are meaningful and important, precision image processing is required to remove instrumental artifacts and false features that may appear in these images prior to usage for scientific purposes. Foremost among the artifacts that must be removed is the detector flat field that is determined by analysis of sixteen offset images that are analyzed through the Kuhn-Lin method. This algorithm is computationally intensive and the usage of a graphic processor unit (GPU) was studied to evaluate its effectiveness in improving code efficiency. A scientific application of the high precision solar images is investigated by analyzing a set of narrow bands of Calcium II K core and wing images. The core and wing images are processed to remove the influence of the center-to-limb variation; the resultant core-to-wing ratio image enhances the appearance of network structures on the entire solar disk along with the more obvious facula and plage brightening associated with the passage of active regions.

2) Solar Irradiance Problem

Earth's climate is entirely dependent on the Sun. Variations in the solar cycle alone constitute for 0.1% of the Earth's total energy. Therefore there compelling reasons to understand, analyze, and be able to predict changes in the Sun's features that affect the irradiance. However, it is not always so simple.

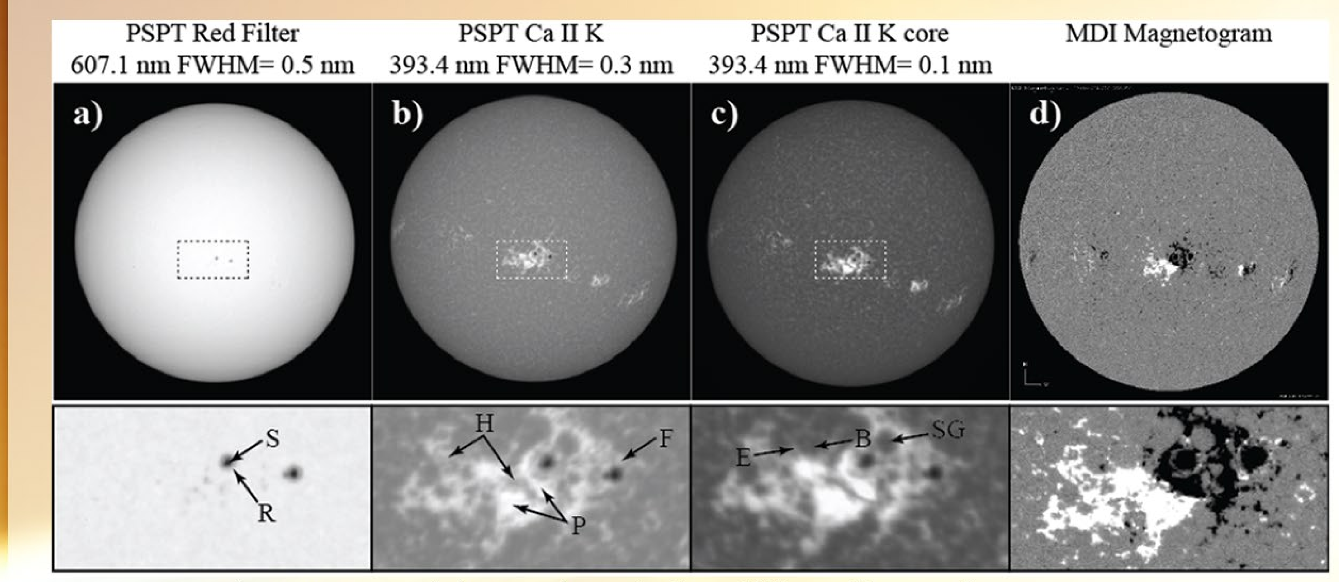

Fig. 1: Features of the Sun shown in three different filters and a magnetogram, all taken on June 7, 2006

In the figure above, three images of the Sun are shown, each featuring a different filter wavelength band taken concurrently. In image (a), the red filter shows the darker regions of the Sun, mainly sunspots, including the umbra and penumbra of the spots. Image (b) highlights the bright regions of the Sun including facula, plage, and active network. The third image enhances the quiet Sun components because it is a narrow filter with high contrast. Finally, image (d) is an MDI Magnetogram showing that the magnetic field is correlated to the intensity of the solar features.

As can be seen from these images, the relationship between solar features and the Sun's magnetic field is complex. To further complicate matters, each filter features a seperate layer of the Sun's atmosphere, meaning each feature affects the solar irradiance in different ways. Though something may show up as bright in certain wavelengths, may actually cause the solar irradiance to be lower at other wavelengths.

Understanding the relationship between each feature and how it affects solar irradiance is a nontrivial task. However, it can be achieved by analyzing images that show parts of the atmosphere as seen in Section 3. The motivation behind this project is first achieving quaility images through a process called flat-fielding. Next, using these highly precise images to analyze the dependence between different layers of the solar atmosphere and their impact on solar irradiance.

3) Precision Solar Photometric Telescope (PSPT)

The Precision Solar Photometric Telescope is located at the Mauna Loa Solar Observatory in Mauna Loa, Hawaii. PSPT has been acquiring daily images of the Sun since April 1998.

Fig. 2: Mauna Loa Solar Observatory, PSPT is housed in the shorter dome on the left

These images of the Sun give complete infomation of the Sun as seen in the figure below. The red filter image is biased towards photosphere and lower chromosphere and best shows the dark features of the Sun, including sunspots. The calcium II image is biased towards the upper chromosphere and highlights the brigher areas of the Sun including facula, plage and active network.

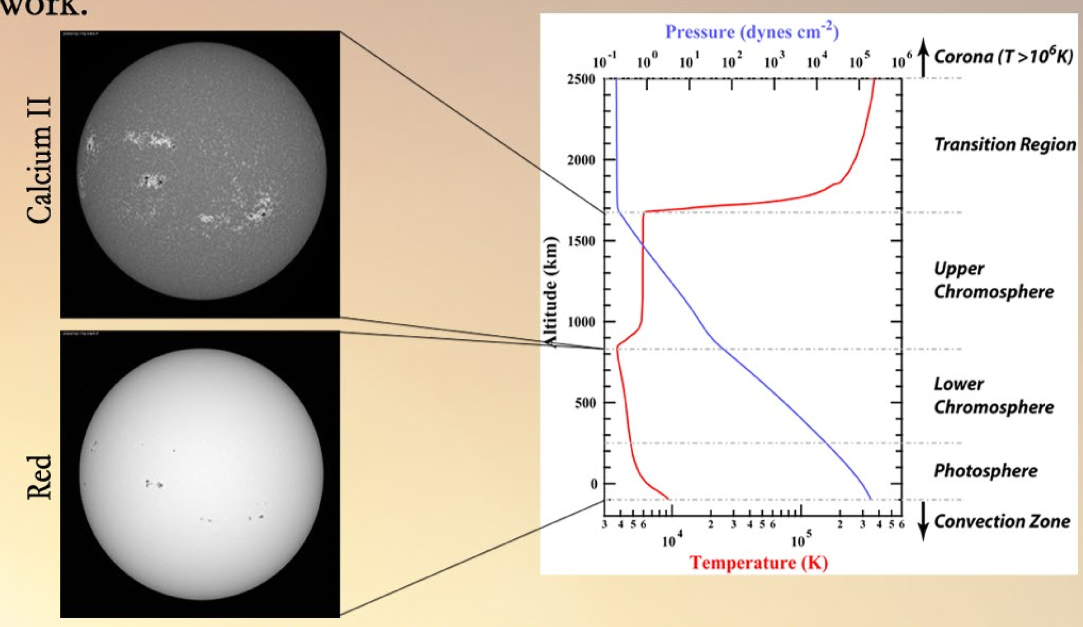

Fig. 3: Red and Calcium II Images and in the solar atmosphere

4) Image Flat-Fielding

The process of removing instrument artifacts from these images is called flat-fielding. Though there are multiple methods to flat-fielding, the Kuhn-Lin method is used for these images. This involves taking sixteen offset images that span across the entire field of view in order to distinguish solar features from artifacts of the instrumentation as shown in the figure below.

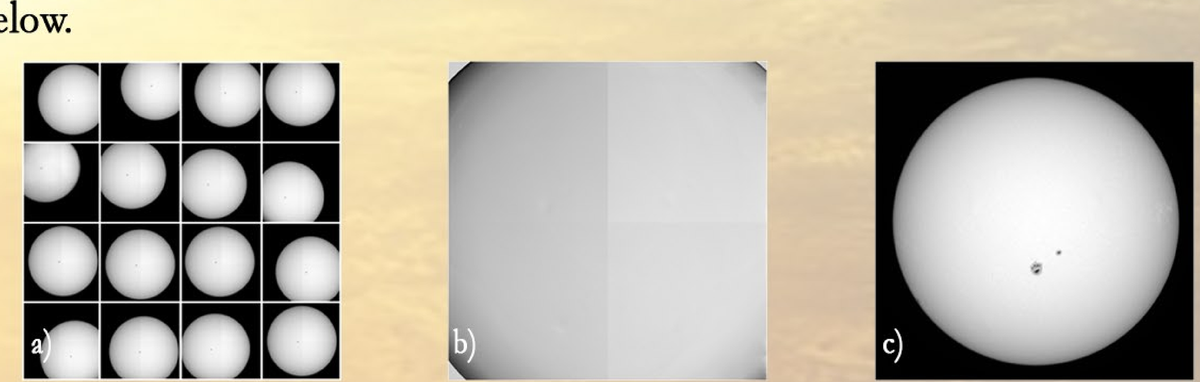

Fig. 4: Evolution from (a) offset images to (b) generated flat field to (c) final image

The algorithm to generate the flat field is shown below. Due to the large data sets and extensive nature of the code, the execution time is around twenty to thirty minutes per flat field.

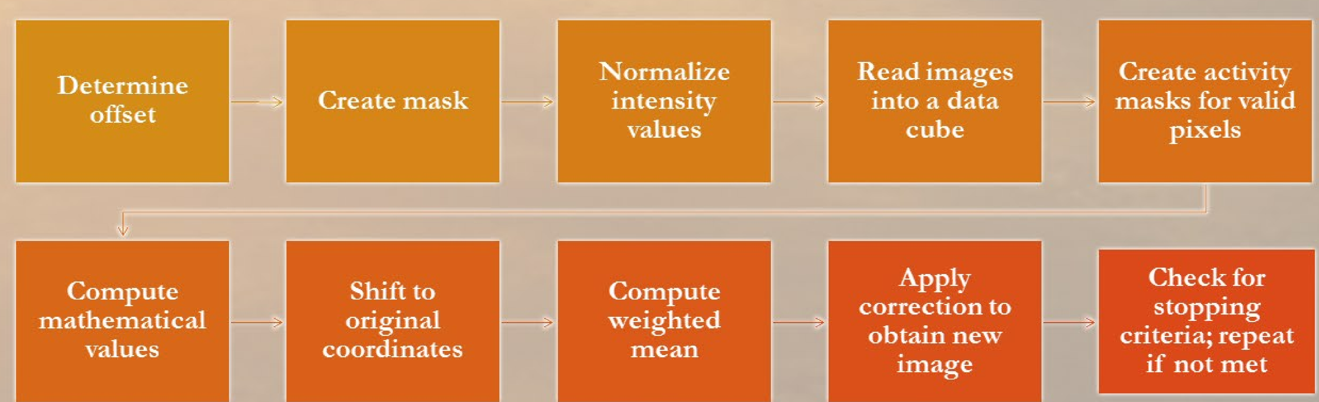

Fig. 5: Algorithm to generate a flat field

However, due to updated code and technology, the algorithm now runs between twelve and fourteen minutes to execute. In order to run the code in the best possible environment, a rewrite is needed to execute it on a parallel processing GPU.

5) Core-to-Wing Imaging in Calcium II

An application PSPT image processing is to analyze solar images measured using narrow band filters centered on the core of the Ca II absorption filter that enhances chromospheric contributions and concurrent observations in its wing that has a greater photospheric contribution. In spite of the fact that the filter centers are only 0.25 nm apart in wavelength, their center-to-limb (CLV) are significantly different. A core-to-wing ratio is found by first ratioing each image by its CLV and then ratioing the core and wing images as discussed below.

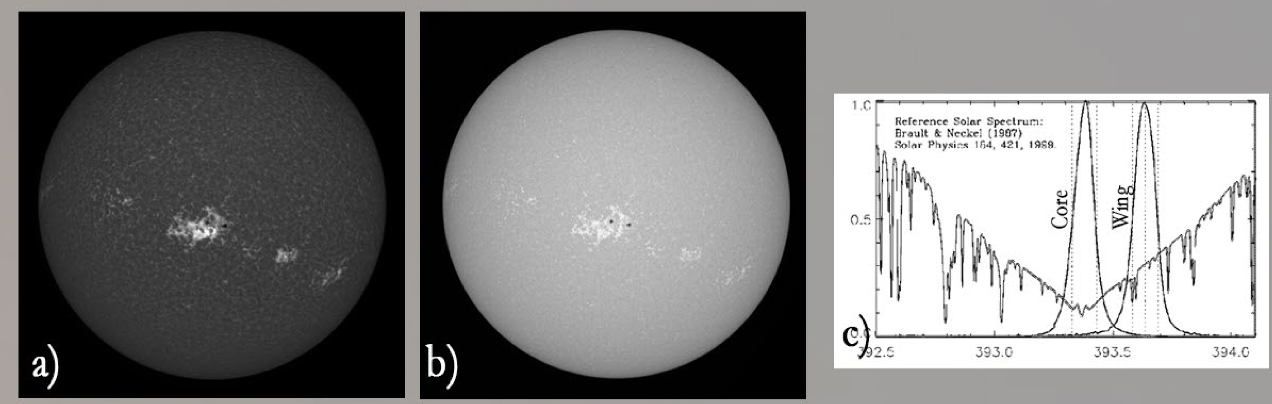

Fig. 6: (a) Calcium II K Core image, (b) Calcium II K Wing image, and (c) shows their wavelengths

From these, we can calculate the CLV for both images and plot them against a slice across these images to show the comparison.

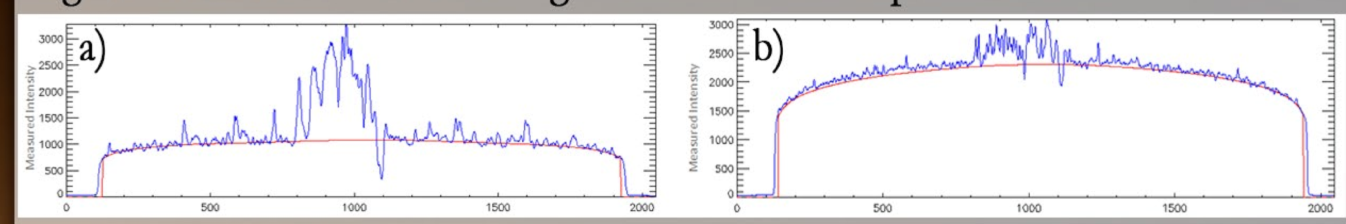

Fig. 7: Plots of the intensity for the image (shown in blue) and the calculated CLV (shown in red) for (a) the core image and (b) the wing image

The next step is to divide out the CLV's from the respective images so we have to ratios: the core ratio and the wing ratio as shown if Fig. 8(a). Finally, we take the ratio of the ratios to create the final image that has no CLV.

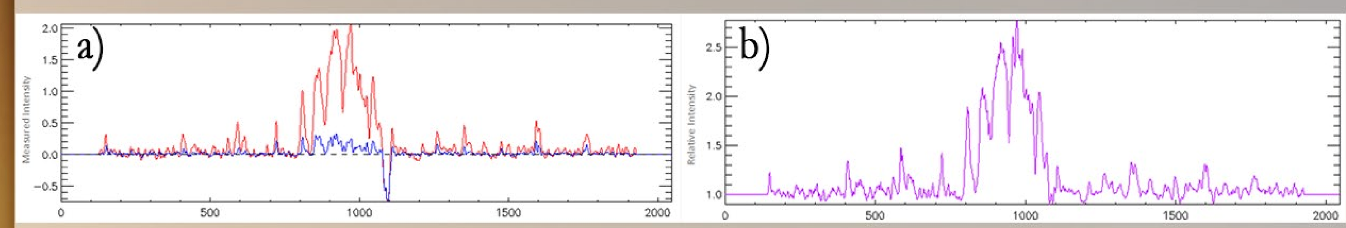

Fig. 8: (a) Shows the two ratios plotted together where the core ratio is shown in red and the wing ratio is shown in blue, (b) the core ratio divided by the wing ratio (core-to-wing ratio)

The final core-to-wing ratio image is shown to the right. By looking at the original images compared to the core-to-wing image, we can see that the final image is biased towards bright spots as the sunspots disappeared. However, network beyond the facula and plage is now brighter and can be analyzed across the entire disk.

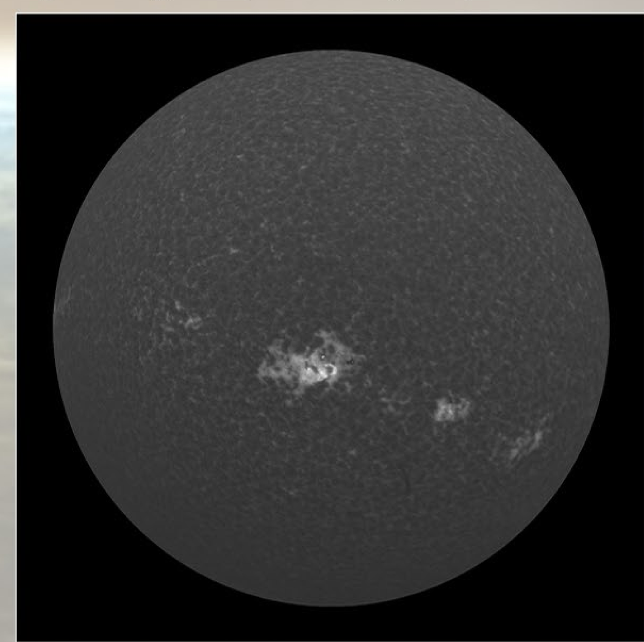

Fig. 9: The final core-to-wing ratio image

6) Conclusion

Solar variability is an important but poorly understood component of the Earth climate system. The relationship between solar irradiance and the activity within the Sun is complicated and nontrivial. However, different layers of the solar atmosphere radiate differently and this can be captured with image processing. Corrective image processing is essential for quality image analysis and advances in computer technology are required to match the advantages gained in image analysis. Core-to-wing image analysis in Calcium II for an entire solar cycle could provide meaningful information about the evolution of solar irradiance.

7) References

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