The Time Evolution of Faculae and Plage in Solar Cycle 23

Brendan Lamarre
Mentors: Jerry Harder and Mark Rast
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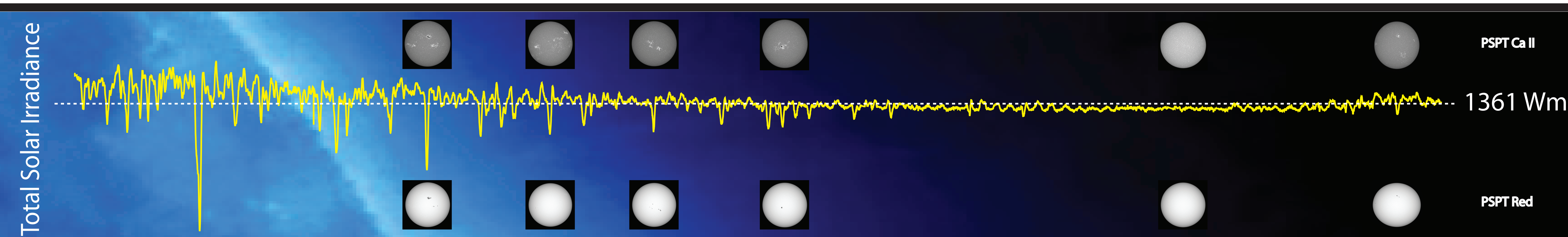


1) Abstract

The Sun is a variable star and its irradiance has been measured and analyzed since the 1800's. Early astronomers noted that the sun has a distinct solar cycle in which the total radiative output of the sun is highest at solar maximum, lowest at solar minimum, and there is an average variation in irradiance of about .1 to .15% over the 11 year solar cycle. However, recent observations of the irradiance at different wavelengths using the Solar Irradiance Monitor (SIM) have revealed that this decline in irradiance when approaching solar minimum does not hold for all wavelengths. There are offsetting trends in the variation of irradiance such that their additive effects produces the Total Solar Irradiance graph seen at the top of this poster. This is an important discovery towards further understanding how the Sun works because it is now known that the progression from solar maximum to minimum does not affect individual components of the sun in the same way. This poster aims to demonstrate that these offsetting trends can also be seen when searching for facular and plage regions in analysis of Precision Solar Photometric Telescope (PSPT) images. I identify these regions as either dark or bright and show that their variation over the descending portion of Solar Cycle 23 reinforce the assertion that the offsetting irradiance trends do, in fact, exist and that the sun is a much more dynamic star than first thought.

2) Offsetting Trends at Different Wavelengths

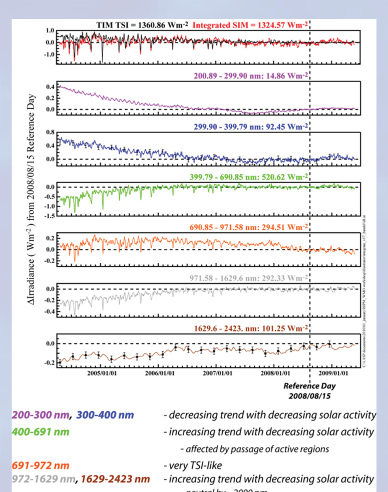


Figure 1: Change in irradiance vs time for different wavelengths compared to a solar minimum-like condition indicated by the vertical dashed line

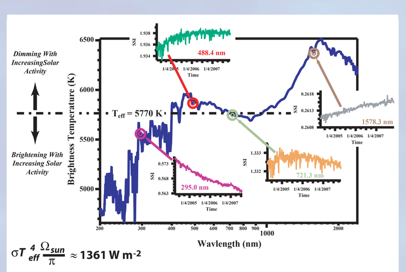


Figure 2: Temperature brightness of different wavelengths

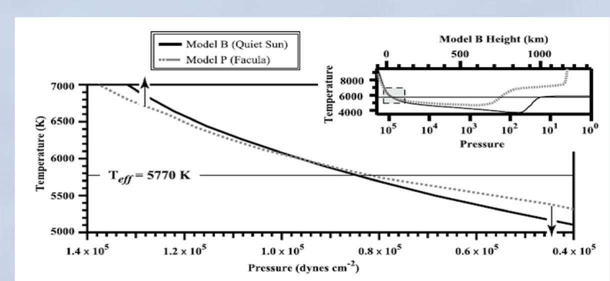
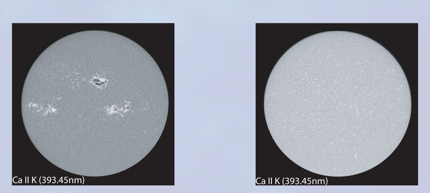
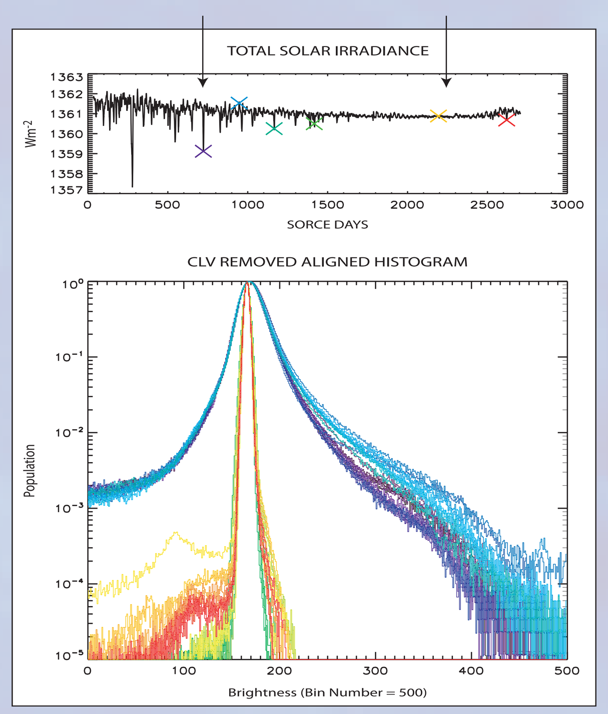


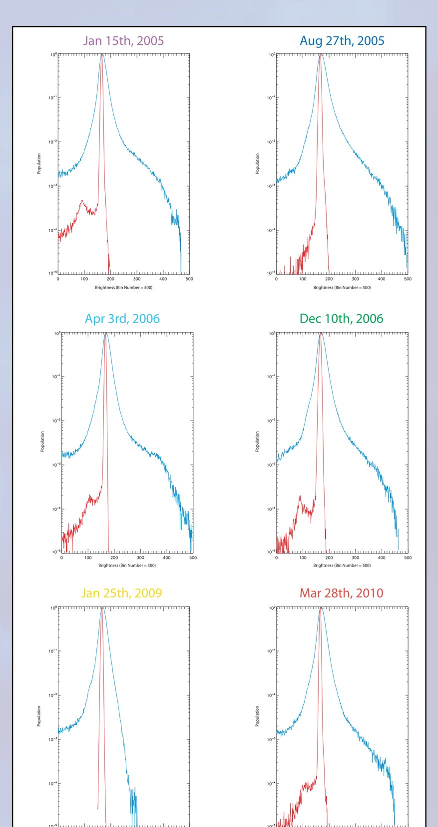
Figure 3: The temperature of faculae and quiet sun as compared to pressure

Recent SIM observations have unearthed offsetting irradiance trends at different wavelengths. Figure 1 shows how the irradiance at certain wavelengths varies when approaching solar minimum. Wavelengths with a higher brightness temperature than the sun's estimated black body temperature, T_{eff} = 5770 K, show an increase in irradiance with the approach to solar minumum whereas wavelengths with a lower brightness temperature go through a decrease.

3) Analyzing Ca II K and Red Images







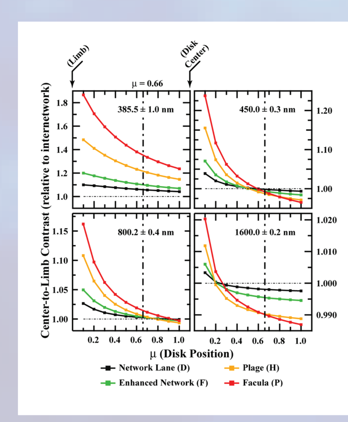


Figure 4: Contrasts of certain solar features are variable. As the graph above shows, a feature may appear bright at the limb of the sun, but towards solar center, it may not be visible or may even appear dark depending on the viewing wavelength. This further demonstrates why viewing the sun at the Ca II K wavelength (393.45 nm) is useful for identifying faculae because they always appear bright compared to the surrounding sun.

Active solar features can be identified using histograms of Ca II K and Red images. The red continuum is useful for picking out sun spots as their contrast relative the quiet sun is relatively independent of disk position at that wavelength. Facular and plage regions are identified in the Ca II K wavelength because they always appear bright relative to the surrounding sun (see Figure 4).

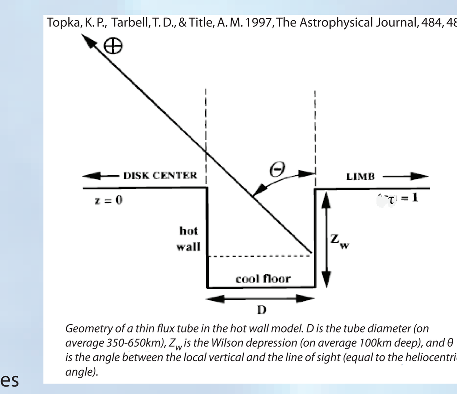
In the histograms to the left, we can see sun spots represented as the 'bumps' in the red wavelength preceding the spike. At the calcium wavelength to the right of the spike, the presence of long wings signifies bright active regions that appear on the images. (The center-to-limb variability work done here is consitant with Figure 4)

4) Quantifying Whether Faculae and Plage are Bright or Dark

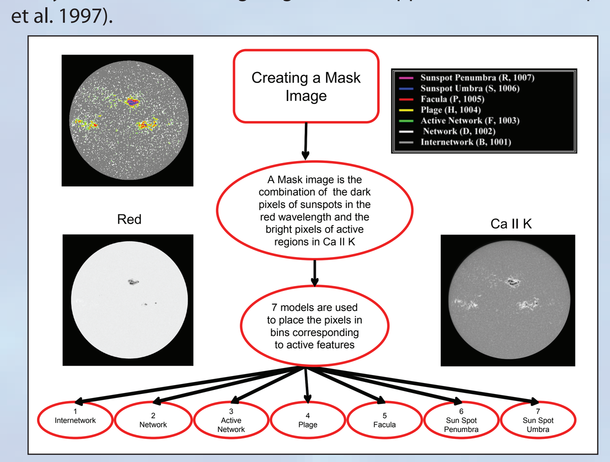
Faculae are produced by the presence of a concentrated flux tube normal to the solar surface. The magnetic field inhibits convection at the 'floor' of the facula causing that area to be cooler. When viewing these flux tubes from directly above, assiociating the internal magnetic pressure with gas pressure equilibrium necesitates that the opacity within the tubes be lower than outside, in turn allowing us to see deeper to the cool floors and creating a viewable depression known as the Wilson depression.

Horizontal flow of plasma is minimally suppressed due to the slightly evacuated status of the flux tube. This causes heating of the facular walls. When observing most faculae on the edge of the solar disk, they appear bright due to the viewing of their hot walls. However, with smaller flux tubes, the horizontal flow of energy can heat up the center of the tube as well, causing it to appear bright anywhere on the solar disk. Larger flux tubes always have cool centers giving them the appearance of a micropore (Topka et al. 1997).

Topka, K. P., Tarbell, T. D., & Title, A. M. 1997, The Astrophysical Journal, 484, 481

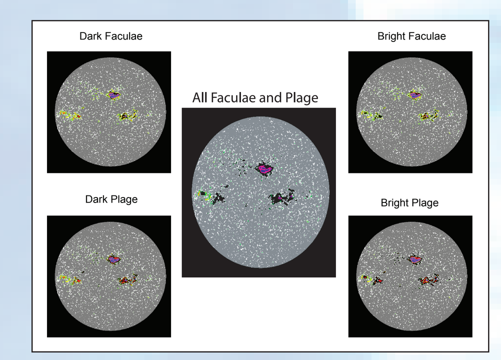


Geometry of a thin flux tube in the hot wall model. D is the tube diameter (on average 350-650km), Z_w is the Wilson depression (on average 100km deep), and θ is the angle between the local vertical and the line of sight (equal to the heliocentric angle).

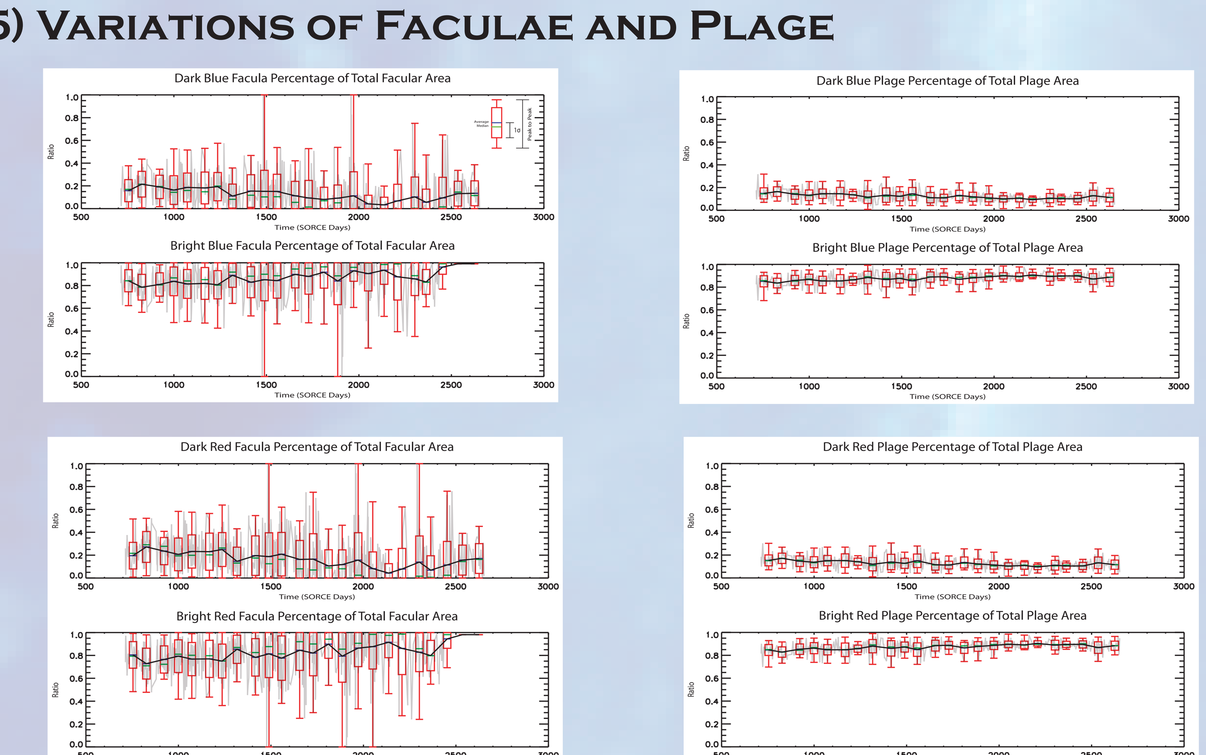


Next, to locate and designate pixels as faculae and plage and then consequently as dark or bright, we use a mask image coupled with the red and Ca II K images. A mask is an image where the value associated with the pixels ranges from one to seven. Different models are used to locate active features and the pixels corresponding to these active regions are given a corresponding value. This way we can locate what pixels in the mask make up faculae and then go look at the blue image, for example, to determine whether those pixels are bright or dark relative to the surrounding sun.

To the right is an example of a mask image from January, 15th 2005 where certain pixels corresponding to either faculae or plage have been blacked out for ease of viewing purposes. One can see from this the contribution to the total area of faculae and plage (center image).



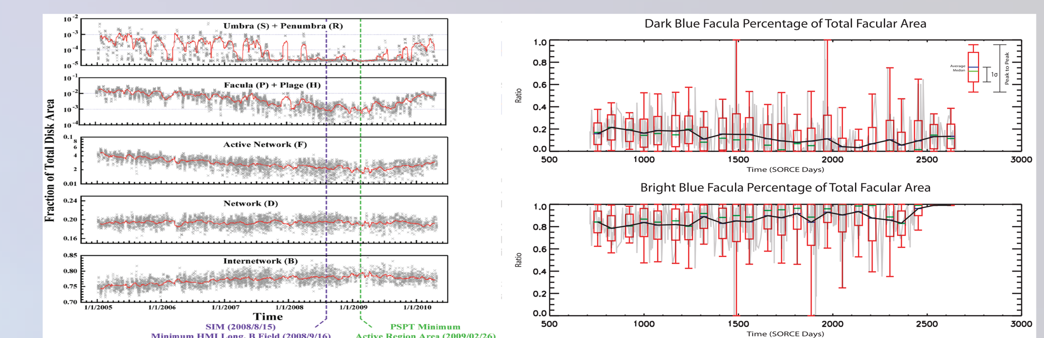
5) Variations of Faculae and Plage



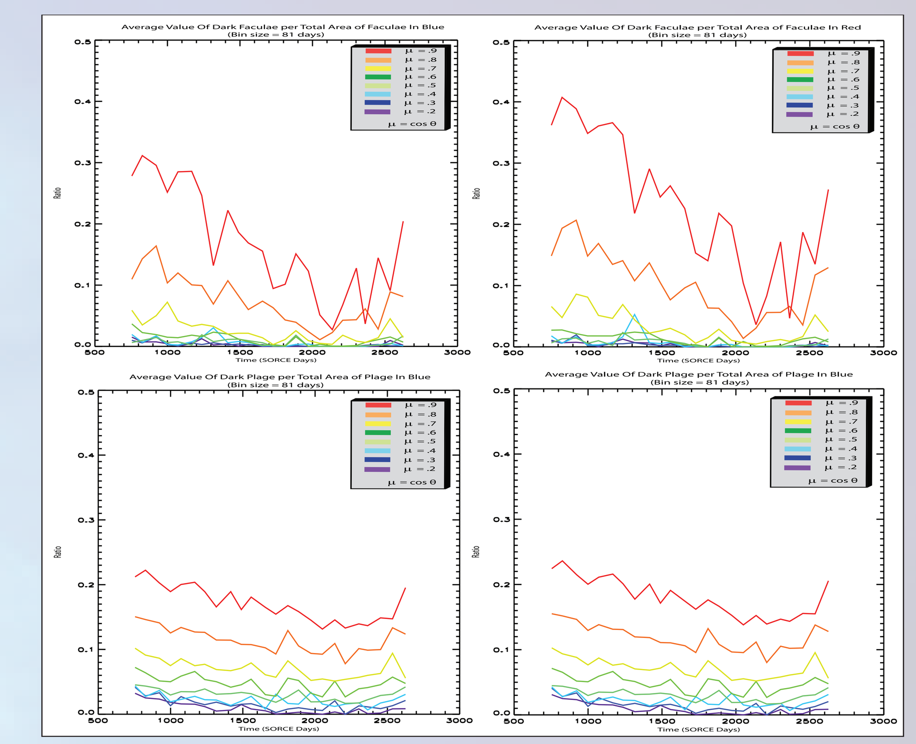
For the figures above, the graphs (grey) show the ratio of dark or bright faculae or plage to the total faculae or plage, both dark and bright. The height of the red boxes corresponds to 2 σ standard deviations while the range indicated by the 'whiskers' represents the peak to peak value in the 81 day bin. The green lines specify the median and the blue lines specify the average. The black lines simply connect the averages from all twenty-four 81 day bins.

What is presented in the graphs above is that as time progresses from solar maximum to minimum, the average percentage of dark faculae and plage at the red and blue wavelengths decreases slightly whereas the bright faculae and plage show an increase. Decreasing numbers of dark faculae and plage act to increase irradiance because there are less of these structures inhibiting radiation. Similarly, the increase in bright faculae and plage increases irradiance. This simply reaffirms recent proposals that at such wavelengths like the 400-691nm range, the sun, in fact, shows an increase in irradiance upon approaching solar minimum.

5) Variationsof Faculae and Plage (Cont.)



The decreasing facular area combined with the decrease in the percentage of dark faculae results in an increase in irradiance. On the other hand, the increase in the percentage of bright faculae does not significantly alter the irradiance because of the decrease in facular area. Therefore, the outcome from this is that there is a decrease in irradiance due to faculae with decreasing solar activity.



Looking at the averages at different heliocentric angles also gives us the same sort of pattern. These graphs, however, demonstrate that there are higher percentages of dark faculae and plage towards the center of the solar disk and these precentages decrease when heading to solar minimum. Furthermore, towards disc center, the average values of facular and plage areas have a more variable nature.

6) Conclusion

Differing irradiance trends have recently been observed in different wavelengths suggesting that the sun is more of a variable star than first thought. These trends can be interpreted in terms of brightness temperature as a function of wavelength. Irradiance increases with decreasing solar activity if the temperature brightness is greater than the effective temperature (T_{eff}) of the sun, defined to be the temperature of a black body that produces the TSI of 1361 Wm^{-2} at 1 AU. Likewise, decreasing irradiance results from a wavelength having a brightness temperature less than $T_{eff.}$ This has contradicted previous beliefs that the sun varies in the same way at all wavelengths for all solar features. What has been shown here is that not only is the total solar irradiance an additive result of these offsetting trends, but we can specifically see these trends when searching for faculae and plage in the PSPT solar images. With this data on how facular and plage regions change over time coupled with knowledge of how faculae work lets us assert that the decreasing percentage of dark facular and plage area at the blue and red wavelengths indicates an increase in irradiance from those areas. An increase in irradiance is also brought about by the increase in bright faculae and plage.

Here's what we have found:

- With High Solar Activity
  - Larger areas of faculae and plage
  - Larger fraction of dark faculae
    - Repression of irradiance
- With Low Solar Activity
  - Smaller areas of faculae and plage
  - Larger fraction of bright faculae
    - Irradiance from bright faculae is about constant due to smaller facular area conflicting with larger fractional area of bright faculae

In conlusion, the evolution of faculae and plage in the descending half of Solar Cycle 23 demonstrates the validity of the claim that there are offsetting trends affecting the TSI

LASP
Laboratory for Atmospheric and Space Physics
University of Colorado at Boulder