ISSN (Online) 2394-6849

International Journal of Engineering Research in Electronics and Communication Engineering (IJERECE)
Vol 5, Issue 6, June 2018

Study of Variation of Chromospheric Plages for the year 1917 from Ca-II K Spectroheliograms using Image Processing Tools

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Abstract- **The long-term synoptic observations in the resonance line of Ca-II K (singly ionized calcium) provides the basis for a fundamental database to a variety of retrospective analysis of the state of solar magnetism. The Ca-II K observations in Kodaikanal Solar Observatory (KSO) is extremely important as it provides a unique dataset in the world for the study of chromospheric activity and its variability as a function of the well-known solar magnetic 11-year cycle. It is known that Ca-II Kline is a very good indicator of chromospheric activity and variability of the Sun and Sun-like stars. The spectroheliograms will be used as a proxy for magnetic elements of the chromosphere i.e., the intensity of the chromospheric features is well correlated with the strength of the magnetic field associated with them. That means there is the one-to-one correspondence between the chromospheric emission features with underlying photospheric magnetic elements. In this paper, the digitized and calibrated Ca-II K spectroheliograms observed at KSO in the period 1917 is used for analysis. The paper proposed segments of the plages and derives their intensity and area. This helps in the estimation of the total contribution of plages to the variability of the chromosphere. Various image processing techniques for this analysis are implemented using MATLAB 2016a.**

Index Terms— Sun-Chromosphere, Spectroheliograms, Plages, KSO, Image Processing, MATLAB.

I.INTRODUCTION

The Sun is our closest star. It provides all the light, heat and energy that are required for life on earth. The Sun is the geometrical and gravitational center of our solar system. It has its influence over a vast region; this region is called the Heliosphere. Many properties of the Sun remain mystery even today. A close track on the Sun's past, current and future behavior is extremely essential as the activities of the Sun have a great impact on the earth and the entire solar system. This study of Sun also helps us to understand the rest of the astronomical universe, which still remains beyond the reach of today's science.

II. BACKGROUND STUDY

A. The Sun

The Sun is nearly perfect sphere of hot plasma and is by far the most important source of energy for life on Earth. Its diameter is about 1.39 million kilometres i.e. 109 times that of Earth and its mass is about 330,000 times that of Earth, accounting for about 99.86% of the total mass of the Solar System. The Sun can be divided into six layers. The layers of the Sun from the center out are, solar interior composed of the core, radiative zone, and convective zone, visible surface known as the photosphere, chromosphere and the outermost layer, corona.

B. Chromosphere and Plages

The name chromosphere stands for the sphere of colour and appears bright red. We can see the chromosphere only during a solar eclipse. However, specialized equipments which filter out all other wavelengths given off by the Sun to observe the chromosphere wavelengths of light can be used. The features of chromosphere include the Sunspots, the plages, the active network and the quiet network as shown in Fig. 1.

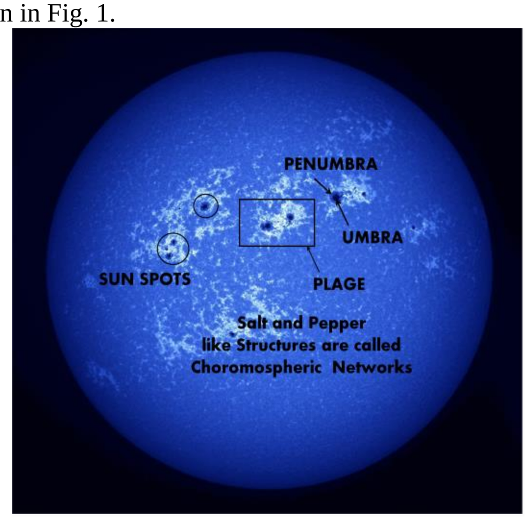

Fig. 1. Ca image of chromosphere showing its features.

ISSN (Online) 2394-6849

International Journal of Engineering Research in Electronics and Communication Engineering (IJERECE)
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Umbra and Penumbra are the regions where the magnetic field is high with cooler temperature of around 3000-3500K and hence appear dark compared to their surroundings (5800K). Spots consist of a dark central region (umbra) surrounded by an annular region of dark and bright filaments called the penumbra. The Sunspots without a penumbra are called as pores and have a relatively short lifespan. The pores can also develop a penumbra and become a fully developed spot. Active regions can contain either a single spot or a great number and can last from only a day up to 60 days. The structure of these features is very similar to those seen in white light.
Plages are the magnetically active chromospheric structures prominently visible in Ca-II K line (393.4nm). It is a bright region in the chromosphere of the Sun, typically found near Sunspots. The plage regions map closely to the faculae (bright regions in the photosphere below), but have much smaller spatial scales. A plage may or may not be associated with a Sunspot.
Chromospheric network is a web like pattern easily seen in the emission of the ultraviolet line of Calcium. It has two subdivisions namely enhanced and quiet network. A chromospheric network becomes the enhanced network when plages fragment over time and embed themselves within the quite network.

C. Spectroheliograms

Spectroheliograms are the images of the Sun obtained from the spectroheliograph, which shows light of a particular wavelength, such as calcium and the distribution of that element over the entire surface of the solar atmosphere. The spectroheliograph is an instrument used in astronomy which captures the image of the Sun at a single wavelength of light i.e., a monochromatic image. The wavelength is chosen such that it coincides with a spectral wavelength of one of the chemical elements present in the Sun. Solar magnetic plages and networks are most easily observed in the strong chromospheric absorption lines, such as the resonance line of Calcium II (called Ca II K) in the violet at 393.4 nm, which is the strongest solar spectral line observable from the ground. The photographic imaging obtained from the spectrograph is digitized and calibrated.

D. Calcium II K line

The K line is one among the Fraunhofer line series and is associated with the calcium (hence called the Calcium K line). The fundamental wavelength of calcium K line is 393.4nm. At this wavelength in the solar spectrum, singly ionized calcium in the lower solar atmosphere or chromosphere strongly absorbs light. The residual light in the narrow range of wavelengths (several tenths of nm) that are darkened due to absorption is used to photograph the Sun effectively and to produce an image of the chromosphere (or "color sphere"). These images are therefore different from more familiar "white light" images—images that show the Sun's visible surface or photosphere ("light sphere"). The significance of Ca II K is that this line is very sensitive to the presence of magnetic field and temperature in the solar atmosphere. If magnetic fields are present, absorption is less (more light is transmitted). Therefore, magnetic field with moderate strength shows up as a bright region in the images but with the exception of very strong magnetic field, such as in a Sunspot where they appear very dark. Ca II K images are generally invisible to the human eye. Ca II K-line filters use the light that is not absorbed at the position of the K-line to produce Ca II K-line images of the Sun. That is, the dark absorption line is not completely dark or black. Instead, residual amounts of energy in this line passes through the K-line filter to produce a solar chromospheric image. In stars having atmospheres both cooler and hotter than the Sun, singly ionized calcium lines (Ca II lines) become weaker. Since the higher temperatures cause singly ionized calcium to ionize further, these stellar lines disappear in very hot stars. In cooler stars, less calcium becomes ionized so the lines of Ca II also weaken.

E. Database

It is a well known fact that the solar activity varies over 11-year cycle approximately. In this period the observations show that there is a rise from solar minima (less or no solar activity period) to solar maxima (high solar activity period). In this study the spectroheliograms of the maxima year i.e. 1917 of the solar cycle 15 is used. The solar cycle 15 ranges over the period 1913 to 1923.

II. APPLIED ALGORITHM

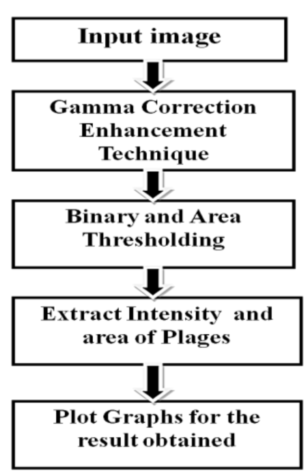

Fig. 2. Algorithm used for analysis

ISSN (Online) 2394-6849

International Journal of Engineering Research in Electronics and Communication Engineering (IJERECE)
Vol 5, Issue 6, June 2018

Each step in the flowchart is as follows:

A. Input image

The input digitized and calibrated Calcium II K spectroheliograms used for the analysis are in FITS file format. FITS stands for Flexible Image Transport System. Images taken in this format have no compression of data and are therefore most widely used for astronomical data acquisition and archiving. An example of the input image captured in the month of August, 1917 is shown in Fig. 3.

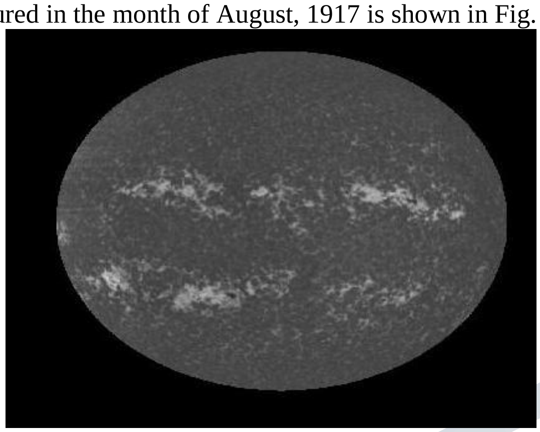

Fig. 3. Original Gray Scaled image.

B. Gamma Correction enhancement technique

Image enhancement is a subjective process of improving the quality of an image by applying various transformation techniques. The Gamma correction function used in this algorithm maps luminance levels to compensate the non-linear luminance effect of display devices. This is a nonlinear transformation that improves the contrast of brighter region, define by equation 1.

$$s = cr^{\gamma} \qquad (1)$$

Where, r defines the input image intensity, s is the transformed image intensity, c is a constant and γ gives the dynamic range of control over the luminance of the image. This enhancement step is primitive for eliminating noise and also enhances the features to be extracted as an added benefit. The gamma corrected image is as shown in Fig. 4.

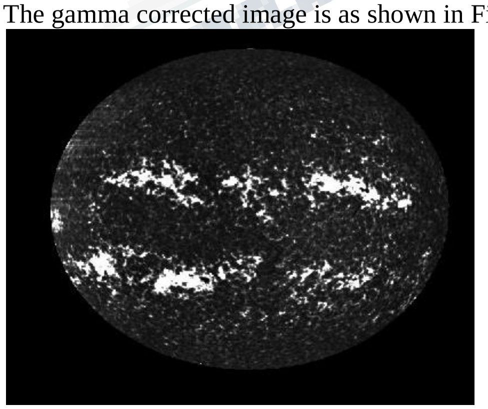

Fig. 4. Gamma Corrected image.

C. Binary and Area Thresholding

Segmentation allows us to partition the image to obtain the desired features effectively. The algorithm identifies all the bright pixels (pixels containing high intensity values), by the method of intensity thresholding. The threshold value 'k' is derived after meticulous analysis of several spectroheliograms, which was then found to be the dynamic average value of mean and standard deviation of individual image as in equation 2.

$$k= ((\text{mean} + \text{standard deviation})/2) \qquad (2)$$

The resulting image is in binary format which contains all the bright pixels above the set threshold value. There is a high probability of enhanced network being detected along with the plages. Thus there is a need to arrive at a method that clearly distinguishes plages from the enhanced network. This can be accomplished by area thresholding, as the plages have comparatively larger areas than the chromospheric networks. Using area thresholding technique continuous pixels with smaller area are eliminated retaining the plages alone as depicted in the Fig. 5.

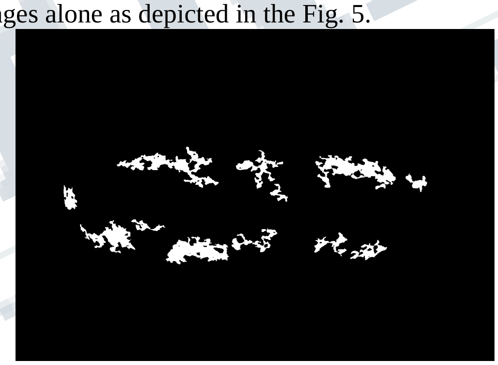

Fig. 5. Binary image of extracted Plages.

D. Extraction of intensity and area of plages

From the segmented image, the intensity and area of plages is estimated by converting the binary image to gray scale image which consists the original image intensities as shown in Fig. 6.

Fig. 6. Gray scaled image of extracted Plages.

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ISSN (Online) 2394-6849

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E. Plotting graphs for results obtained:
The intensity and area of the plages are plotted as a function of time for the year 1917, which helps in the study of variation of the chromospheric plages and its contribution to the total chromospheric variability.

IV. RESULTS

It is important to note that intensity contrast for plages vary with different instruments and passband of the filter or selected wavelength band for spectroheliograms and thus any change made in the experimental set up is likely to affect the uniformity of the data. As stated earlier identification of plages in the chromosphere is done using the intensity threshold and further only the plages were separated by applying area thresholding.
The chromospheric plage identification algorithm discussed in this paper is a new tool for analyzing the solar cycle evolution of the larger and brighter solar surface structures. This algorithm uses spatial information such as size and intensity, as a means of identifying the plages on the solar disk. Use of spatial and intensity information are needed to identify and separate the plages. The plages are successfully extracted from the images in the maxima year (i.e., 1917) of solar cycle 15 and the cumulative intensity is calculated.
Since the plages depend on the underlying magnetic fields[11][15], the variation in the intensity of plages with long periods is likely because of the changes in the solar dynamo processes. To study the long term variations in the intensity of plages, we have computed cumulative value of the intensity and area on daily basis for the year 1917. In Fig. 7 and 8 the cumulative intensity of plages as a function of time and that of the full disk image is shown respectively. This outlines the close connection between the intensity of the plage (Fig. 7) and the resulting change in brightness of the Sun (Fig. 8). The high correlation between these two parameters is shown in Fig. 9. Fig. 10 depicts the fact that during the maxima year the plage area on the solar surface increases considerably.
It is very clear from all the figures that the variation in intensity of plages is closely related to the solar activity. The results are useful for modelling the solar chromospheric/transition region irradiance and also for understanding the solar cycle evolution of the larger solar surface structures.

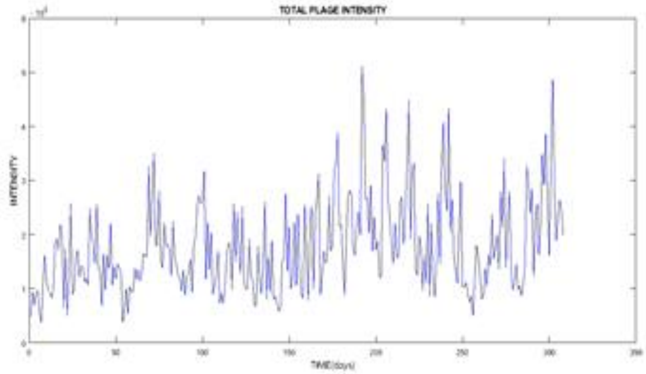

Fig. 7. Variation of total Plage intensity over time

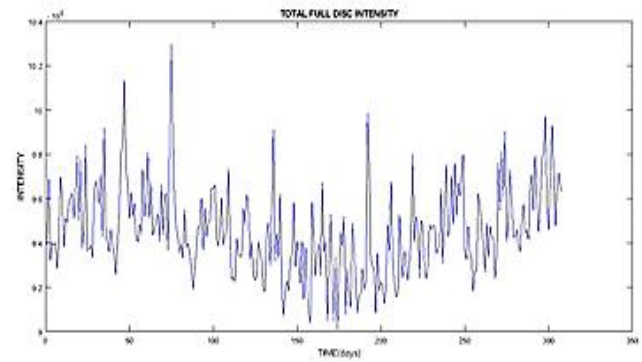

Fig. 8. Variation of full disk intensity over time

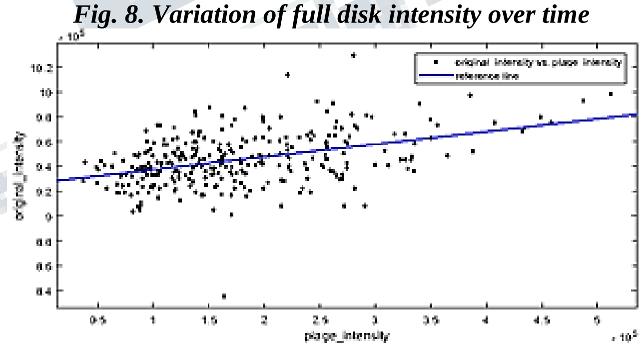

Fig. 9. Relationship between the intensity of plages and the full disk image

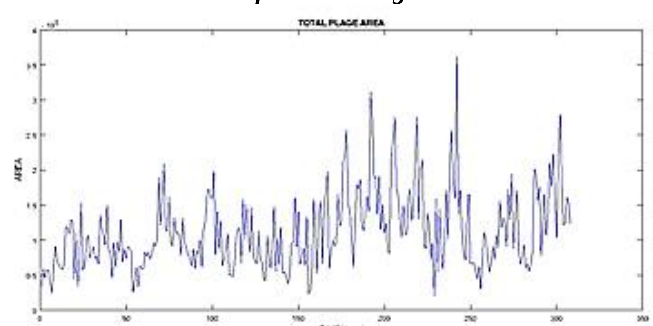

Fig. 10. Variation of Plage area over time

V. CONCLUSION

The individual contribution of plages thus calculated helps to determine the total integrity of the chromospheric variability. The scatter plot clearly indicates that the full disk intensity of the chromosphere in Ca II K line has high correlation with the calculated plage intensity. Using the above results we can conclude that the Sun can be used as a calibrator to study the chromospheric variability in Sun-like stars which show the same Ca II K emissions.

VI. ACKNOWLEDGEMENT

We would like to express our sincere gratitude to the project Coordinators Dr. Sunil H and Mrs. Jayanthi Chandrashekar for their constant guidance. We would like to thank Dr. Vijayasimha Reddy, Principal Vemana IT, Mr. S. M. Chandrashekar, HOD, ECE Dept. and Dr. T Yella Reddy, Dean, Vemana IT for their support. The data used for the project was from Kodaikanal Solar Observatory which was digitized, calibrated and provided by Prof. Jagdev Singh and his team at Indian Institute of Astrophysics.

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