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# The Extreme Solar Activity during October–November 2003

K. M. Hiremath[1,*], M. R. Lovely[1,2] & R. Kariyappa[1]
[1]*Indian Institute of Astrophysics, Bangalore 560 034, India.*
[2]*Sree Krishna College, Guruvayur, Kerala 680 102, India.*
**e-mail:hiremath@iiap.res.in*

**Abstract.** The positional measurements of sunspots from the Kodaikanal Observatory and Solar Geophysical data are used to study the association between occurrence of the abnormal activities of big sunspot groups that were observed during the period of October–November 2003 and occurrence of the flares. During the evolution of the sunspot groups, we have investigated the temporal variations in (i) areas; (ii) rotation rates; (iii) longitudinal extents; and (iv) number of small spots produced in a sunspot group. Among all these activity variations, we find that the spot groups that experience abnormal rotation rates during their evolutionary phases eventually trigger the flares.

*Key words.* Sunspots—rotation—flare—extreme activity.

## 1. Introduction

The Sun influences the Earth's environment significantly (Hiremath & Mandi 2004 and references therein) that requires constant observations and understanding the solar activity phenomena. The solar activity is mainly caused by the sunspots that are supposed to be tracers of subsurface dynamics (Howard 1996; Hiremath 2002 and references therein).

Using Kodaikanal Observatory daily white light pictures and H$\alpha$ flare data, we (Hiremath & Suryanarayana 2003) have shown that either leading or following or both of the bipolar spots that experience abnormal rotation rates eventually trigger the flares. Since we used the daily data we were unable to pinpoint exactly, after sunspot experiencing the abnormal rotation rates, at what time of the day the flare occurs. Moreover, it is interesting to know whether the sunspots with complex magnetic activity (considered in the present analysis) also experience the abnormal rotation rates and eventually produce the flares. In the present analysis, we use high temporal resolution (varies from $\sim 30$ minutes to $\sim 10$ hours) of the positional measurements of the sunspot groups that occurred during October–November 2003.

## 2. Data and analysis

We are interested to study the extreme activities of the sunspot groups (10484, 10486 and 10488 according to NOAA classification) that occurred during the period of

October–November 2003 and produced many flares and CMEs. The positional measurements of the sunspot groups and the occurrence of the H$\alpha$ flares are considered from the archive of Solar Geophysical data (*http://sgd.ngdc.noaa.gov/sgd/jsp/solarindex.jsp*) that is contributed from different observatories all over the world. In order to have better statistics, we add the data of the sunspot positional measurements obtained from the Kodaikanal Observatory to the data of Solar Geophysical sunspot positional measurements. The data of positional measurements consists of the time of observations, the heliographic latitude, the longitude from the central meridian, the area (A), the number of small sunspots in a group (NS) and the longitudinal extent (LE).

We compute rotation rate $\omega_i$ of the sunspot groups as follows:

$$\omega_i = \frac{(l_{i+1} - l_i)}{(t_{i+1} - t_i)}, \tag{1}$$

where $l$ is the heliographic longitude from the central meridian, $t_i$ is the time of observation, $i = 1, 2, 3, \ldots, n$, and $n$ is the *lifespan* of the spot group.

The typical white light images on 29 and 30 October 2003 that are taken from the Kodaikanal Observatory are presented in Fig. 1. The different activity parameters such as $A$ (millionth of hemisphere), $NS$, $LE$ (degrees) and $\omega$ (deg/day) are presented in Fig. 2. In Fig. 2, the blue continuous line is variation of different activity parameters for the sunspot group number 10484, the red dotted line for the group number 10486 and, the green dashed line for the group number 10488 respectively. In the same figure the red continuous vertical bars represent the occurrence dates of the flares. The dates along the $x$ axis are counted from the beginning of January 1. For example, on January 1, the date is counted as 1; February 1 as 32 and so on. Thus for the sunspot activity 10484 that occurs on October 18, the date along the $x$ axis starts from 290.

We define *abnormal activity* as follows: For each spot group and for all the time of observations, first we compute the mean ($\bar{x}$) and the standard deviation ($\sigma$) of the respective activity parameters: $A_i$, $NS_i$, $LE_i$ and $\omega_i$; where $i = 1, n$ and $n$ representing the number of time of observations (for example $i = 1, 37$ for the spot group 10484, $i = 1, 39$ for the spot group 10486 and $i = 1, 29$ for the spot group 10488 respectively) during the lifespan of a spot group. For each time of observations, if absolute value of the difference $(\bar{x} - x_i) > 1\sigma$ (where $\bar{x}$ is the mean and $x_i$ represent respective parameters as defined above), then we consider the corresponding parameter at that time as *abnormal activity* of the spot group. For example, for the spot group 10484 that has 37 number of observations during its 12 days lifespan, $\bar{A}$ is the mean area and $A_i$ are the area values of the sunspot group for $i$ number of observations. For each $A_i$ value, we compute the difference $(\bar{A} - A_i)$ and if its absolute value is $>1\sigma$, then we consider the abnormal activity of area of the sunspot group on the particular time of observation.

## 3. Results and discussion

A typical data set that relates the occurrence numbers of the abnormal activity of different parameters and correspondingly the occurrence numbers of the flares for each day is presented in Figs. 3 and 4 respectively.

In order to know the association between the occurrence of the abnormal activity and occurrence of the flares, we compute the correlation coefficient and its significance.

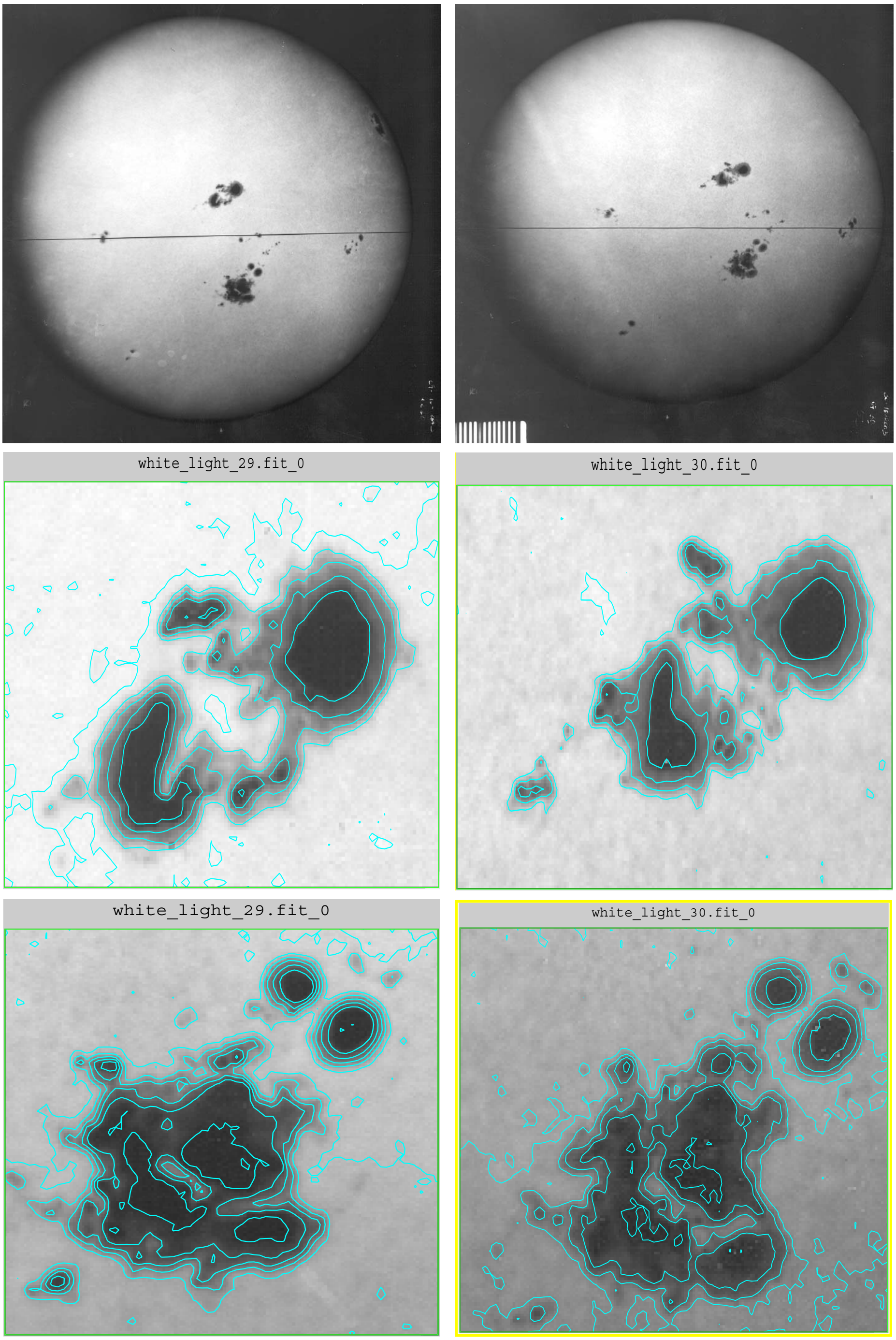


**Figure 1.** The Kodaikanal white light images observed on 29 and 30 October 2003 respectively. **Top panel:** Full disk images. **Middle panel:** The big sunspot group 10488 in the northern part of the solar disk that is close to the equator. **Lower panel:** The big sunspot group 10486 in the southern part of the solar disk that is close to the equator. Different levels of intensity (decreasing from penumbra region to umbra region) contours are superposed on the sunspots.

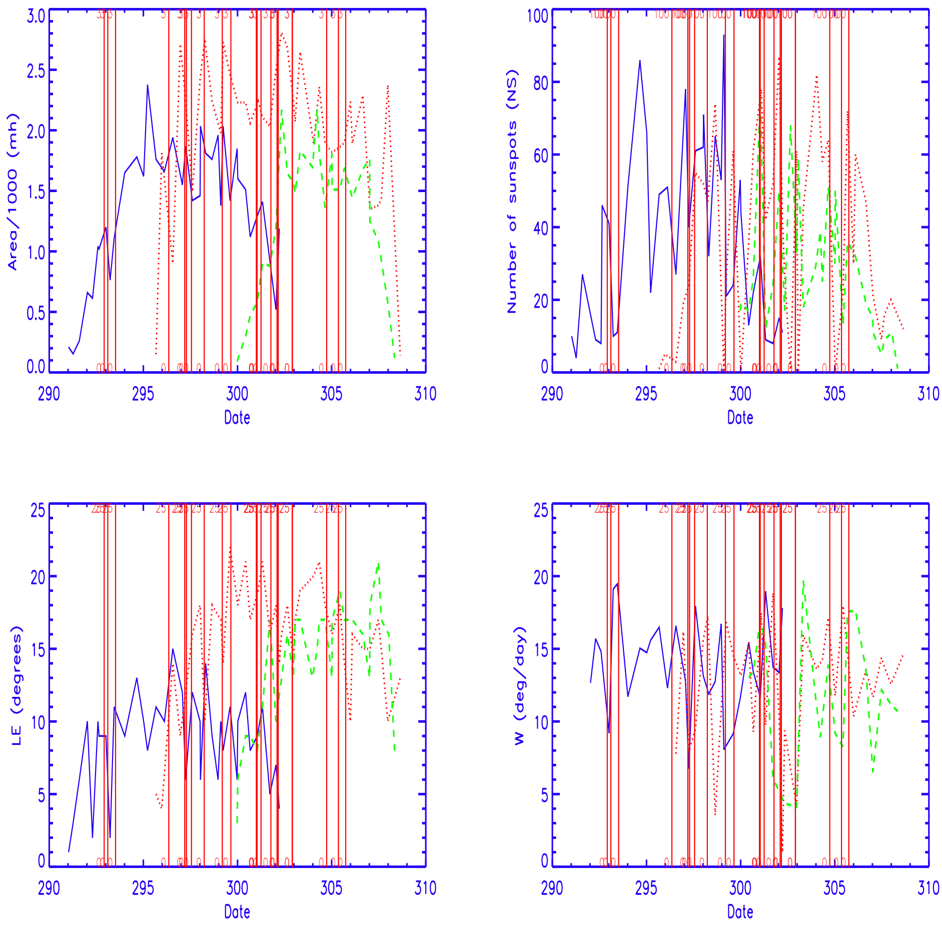


**Figure 2.** The variation of different activity parameters such as area (in millionths of hemisphere), number of sunspots, longitudinal extent (in degrees) and rotation rates (in deg/day) of big sunspot groups that occurred during October 18 to November 4, 2003. The lines in different colours are as follows: the blue continuous line represents the sunspot group number 10484, the red dotted line represents the number 10486 and the green dashed line represents number 10488. The red vertical bars represent the occurrence of dates of the flares.

When we say the correlation coefficient, we mean the Spearman Rank Correlation coefficient (Press *et al.* 1992). This method of finding the correlation between two variabilities is more robust than the correlation found from the usual method. We know (Fisher 1930; Elmore & Woehlke 1996), while deriving the correlation coefficient, that both the variabilities must be linearly related and we should get a good least square fit for the linear relationship of the form $F = A + BS$, where $S$ is occurrence number of abnormal activity and $F$ is occurrence number of the flares, $A$ and $B$ are coefficients in the linear equation. If the correlation is very good, points of both the variabilities should fall closer to the straight line (in red colour for all the figures presented in our study) obtained from the least square fit and significance of the correlation coefficient should be very high.

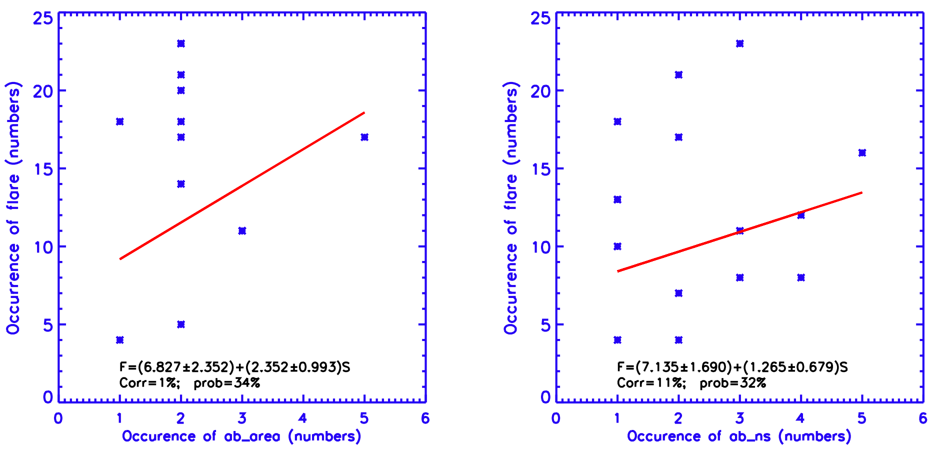


**Figure 3.** The abnormal activity of the sunspot groups *versus* occurrence of the flares. The two figures represent occurrence of the abnormal area and occurrence of the abnormal number of sunspots in a spot group with respect to the occurrence of the flares. The red continuous straight line is obtained from the linear least square fit of both sets of the data. Here $S$ represents occurrence of the respective abnormal activity of either area or the number of sunspots and and $F$ is the occurrence of the flares.

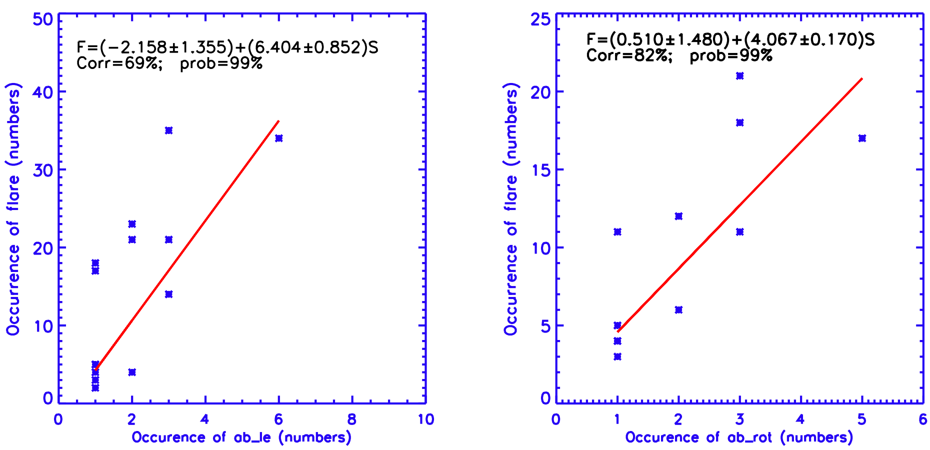


**Figure 4.** The abnormal activity of the sunspot groups *versus* occurrence of the flares. The two illustrations represent the occurrence of the abnormal variations in the longitudinal extent and the rotation rates of the sunspot groups with respect to the occurrence of the flares. The red continuous straight line is obtained from the linear least square fit of both sets of the data. Here $S$ represents occurrence of the respective abnormal activity of either longitudinal extent or rotation rates and $F$ is the occurrence of the flares.

It is interesting to note from Fig. 4 (right) that, compared to other abnormal activities, the occurrence of abnormal rotation rates of the sunspot groups show the strong association (correlation coefficient is $\sim$82% with a very high probability) with the occurrence of the flares. This implies that the unknown perturbations along the longitudinal direction below the surface is one of the main causes for triggering the flares. This view can also be corroborated from the strong association between the occurrence of abnormal activity of the variation of the longitudinal extent of each spot group and the occurrence of the flares.

Presently, it is believed that the flares occur due to magnetic reconnection wherein oppositely directed magnetic fluxes merge and annihilate each other producing the required amount of flare energy. We don't have any conclusive evidences whether reconnection takes place either below or above the photosphere. There are some studies (Zirin & Liggett 1987; Leka *et al.* 1996; Canfield & Pevtsov 2000; Hiremath & Suryanarayana 2003; Hiremath *et al.* 2005; Hiremath 2005) suggesting that reconnection events may be taking place below the photosphere. In both the cases of reconnection events that may be occurring above or below the surface, approaching of sunspots towards each other and then merging of foot points is necessary. From the observed data, we find that during the course of their evolution the three spot groups initially appear to be bipolar and then evolve as complex beta-gamma-delta magnetic regions. It is interesting to note that except the spot group 10488, most of the very high energy ($> X10$) flares occur during late stages of their life times. This suggests that the flux tubes while raising towards the surface, experience inequilibrium at certain regions of the convective envelope eventually bringing together the flux tubes of different polarities in a spot group that ultimately trigger the flare. Inequilibrium of the spot groups can be attained by either strong flows or rotational gradients below the surface (Hiremath & Suryanarayana 2003). In fact the helioseismic inferences show both strong flows (Zhao *et al.* 2001, 2004) and rotational gradients below the photosphere (around 0.935 radius of the Sun). From this study, we cannot estimate the depth of initial anchoring of these spot groups. Thus both the possibilities are not ruled out for the loss of the equilibrium of the clustered flux tubes in a spot group that triggered the flares during October–November 2003.

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