GREEN CORONAL INTENSITY ENHANCEMENTS AND THEIR RELATION TO THE UNDERLYING PHOTOSPHERIC/CHROMOSPHERIC ACTIVITY

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Abstract. Analysis of the photospheric and chromospheric activity at the sites of enhanced 5303 Å coronal intensity revealed some important aspects of their association. We have examined the daily maps of 5303 Å coronal line intensity of Lomnický Štít for the low sunspot activity years 1985 and 1986 in association with the cotemporal daily maps of sunspots, plages and Stanford magnetograms and identified strong field gradients at the sites of enhanced intensity regions. We found that the peak intensity does not depend on the strength of the underlying magnetic field though the coronal intensity-enhanced feature is almost sure to occur at the locations of sunspots with strong magnetic fields and at the locations of plages having larger areas.

1. Introduction

The 5303 Å coronal line forms at a temperature of about 2 MK (see Altrock, 1993) and being the strongest among all forbidden lines arising from the corona, is relatively easy to observe using ground based techniques. Observations of 5303 Å intensity provide a good possibility tool for studies of large-scale structures in the corona (e.g., Guhathakurta and Fisher, 1994). Guhathakurta, Fisher, and Altrock (1993) showed that the distribution of coronal temperature inferred from Fe X/Fe XIV ratio associated with large scale magnetic structures differs in its spatial and temporal characterization from the traditional picture of sunspots and active region (manifestations of small-scale strong magnetic field regions) evolution over the sunspot cycle. The high temperature regions tend to lie in the vicinity of the line of polarity reversal of the large-scale weak magnetic fields (Guhathakurta, Fisher, and Altrock, 1993; Altrock *et al.*, 1996).

Using *Yohkoh* SXT data, Hara *et al.* (1992) inferred temperatures of $5{-}6\times10^6$ K for the corona above active regions and 2.7×10^6 K for the quiet coronal regions. Through a comparative study of *Yohkoh* SXT data and Fe XIV and Fe X data obtained from National Solar Observatory/Sacramento Peak, Hick *et al.* (1996) have shown that the Fe X/Fe XIV intensity ratio is sensitive to coronal plasma with temperature in the range 1–2 MK and is therefore useful for studying the 'quiet corona'. They have also inferred that, during solar maximum conditions, the Fe XIV intensity does not correlate with coronal magnetic field. Altrock *et al.* (1996) state that the temperature derived from the Fe X/Fe XIV ratio technique will be difficult

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to interpret in active regions due to the basic assumption of a uniform temperature along the line of sight.

The green line emission is, in general, intense around active regions with large maxima appearing in the vicinity of sunspot latitudes. In addition to bright active region emission, weaker maxima are often seen at high latitudes (Altrock, 1987). The 5303 Å green line emission is well studied for its temporal characteristics (see Rybanský *et al.*, 1994; Sýkora, 1994, and references therein). The morphological features of the green line intensity enhancement associated with underlying activity were reported earlier by Nagasawa (1961) and Sýkora (1969). Nagasawa (1961) showed that the limb passage of a spot group is almost always associated with a coronal intensity peak. The green line intensity depends more on the complexity of the magnetic situation than on the strength of the magnetic field alone or on the importance of the larger but more isolated sunspots (Sýkora, 1969). Rybanský and Rušin (1987) communicated that the enhanced intensities are observed mainly in the principal zones above the plage areas. Plages, though not all, in turn, are associated with sunspots. However, the coronal index (CI) derived from the limb observations of 5303 Å line intensity does not seem to correlate well with photospheric activity (Ramesh, 1998a,b). In a recent study, Fe XIV 5303 Å line emission was shown to be closely related to the underlying photospheric field strength (Wang *et al.*, 1997). Therefore, the enhancements in the green line intensity, used to derive the green coronal index (CI), remains to be studied in greater detail for their association with the underlying activity.

2. Data

The data base used in this study consisted of homogeneous data set (HDS) of 5303 Å green coronal intensity measured at position angle intervals of 5° on any given day from several stations (see Rybanský *et al.*, 1994) and reduced to the common scale of Lomnický Štít. Daily maps extending from the north pole to the south pole and covering 14 days (7 days from the days preceding the given day for eastern hemisphere and 7 days from the days following the given day for western hemisphere) are constructed to represent the green line intensities across the disk. Each intensity pixel on this map therefore, corresponds to a latitude interval of 5° and a longitude interval of nearly one day. Daily maps of sunspots, generated by using Mt. Wilson sunspot data and Ca plages, generated by using Big Bear calcium plage data, are then superposed on the green line intensity maps of the corresponding day. The missing data of sunspots and calcium plages were supplemented by Kodaikanal data and the data from several stations published in the Prompt Reports of *Solar Geophysical Data*. These composite maps are then compared with the Stanford magnetograms published in *Solar Geophysical Data*.

3. Analysis and Discussion

In spite of the known fact that the line-of-sight effects and evolution between differing times of observations for the limb and disk measurements obscure the association between the coronal structures and other solar features, we made an attempt to identify the disk features which, to a large extent, can be associated with coronal green line intensity enhancements. We have used the composite maps of green line intensity, sunspots and calcium plages for the low sunspot activity years 1985 and 1986 to identify the features of enhanced green line intensity. Identification of the intensity enhanced features during the period of low sunspot activity would be relatively easier when compared to the times of high sunspot activity. Moreover, simultaneous daily data of sunspots, calcium plages and Stanford magnetograms were available for these two years of low sunspot activity. In the present study, we have considered the regions with peak intensity greater than 59 coronal units (millionths of the intensity of the solar disk) which is the sum of the average ($\bar{x} = 11.0$) of the entire data (number of data points $= 72 \times 365 \times 2$) used here and their 3.2 times standard deviation ($3.2\sigma = 48$), as the intensity enhanced features. In other words, the intensity enhancements considered here are the ones with confidence level greater than 99.9%. However, the intensities seen on the disk will not follow the evolution on the disk in the visible hemisphere. Since the standard deviation ($\sigma = 15$) is larger than the average of all intensity points, we consider the intensities between $\bar{x}$ and $\bar{x} + 3.2\sigma$ would arise due to the errors in the observations or due to the errors arising in the process of generating HDS by comparing one station's data with others though it may not be true all the time.

The enhanced green line intensity features (Gs) and the associated photospheric/chromospheric activity are identified using the composite maps of green line intensity, sunspots and calcium plages. The following procedure is adopted to identify spots and plages associated to a given G. First, the composite daily maps are scanned to identify all the available spots and plages falling within the area of G. Then the magnetic signature corresponding to the identified G is marked in the magnetograms. Through a careful scrutiny of the maps of sunspots, plages and the magnetograms, the spots and plages, which are associated with the identified magnetic signature, are then considered as the actually associated ones with Gs. A total of 57 isolated intensity enhanced features are seen during the years 1985–1986; 38 of them are associated with both sunspots and plages while 10 of them are associated with only plages. However, these plages are associated with spots in the previous rotations. Among the remaining 9 events, which are not associated with either spots or plages, 4 are associated with spots and/or plages in the previous rotations, and the other 5 are not associated with any activity.

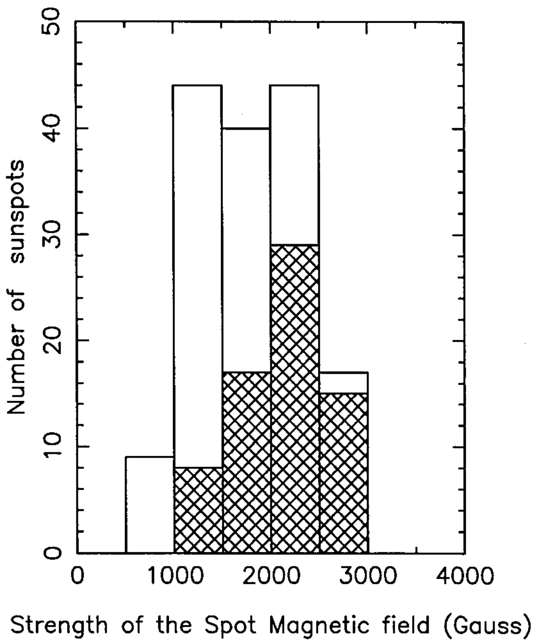

Figure 1. Histograms of number of sunspots with maximum field strength observed during 1985–1986. The distribution is shown in the field strength interval of 500 G. Open histograms show the total number of spots observed in the given range of field strength while hatched portions show the number of spots in a given interval of field strength which are associated with Gs.

3.1. Green line intensity enhancements and their association with sunspots

A total of 154 spot groups are listed during the period chosen for the present analysis. As explained in the previous section, we have identified 69 spot groups which are associated with 38 Gs. Nearly 30 Gs have two or more spots associated with them. Figure 1 shows histogram of number of spots with maximum field strength observed during their disk passage. The spot magnetic field values are collected from the Mt. Wilson listing of spot groups, where the strength of the magnetic field measured in each group is represented in a coded form and given to the nearest 500 G. Hence, the grouping of spots was made in the field strength intervals of 500 G. While the open histograms show the total number of spots in a given range of field strength, hatched portions represent the number of spots in a given field strength range which are associated with Gs. Spot groups in the field strength range of 1000–1500 G, which are associated with Gs generally have companions with higher field strength. Only two exceptions in that range of field strength are found to be independently associated with Gs. We, therefore, fix a threshold minimum field strength of 1500 G for spots if they are involved with the enhancement of green line intensity. Figure 1 further indicates that the higher the strength of the

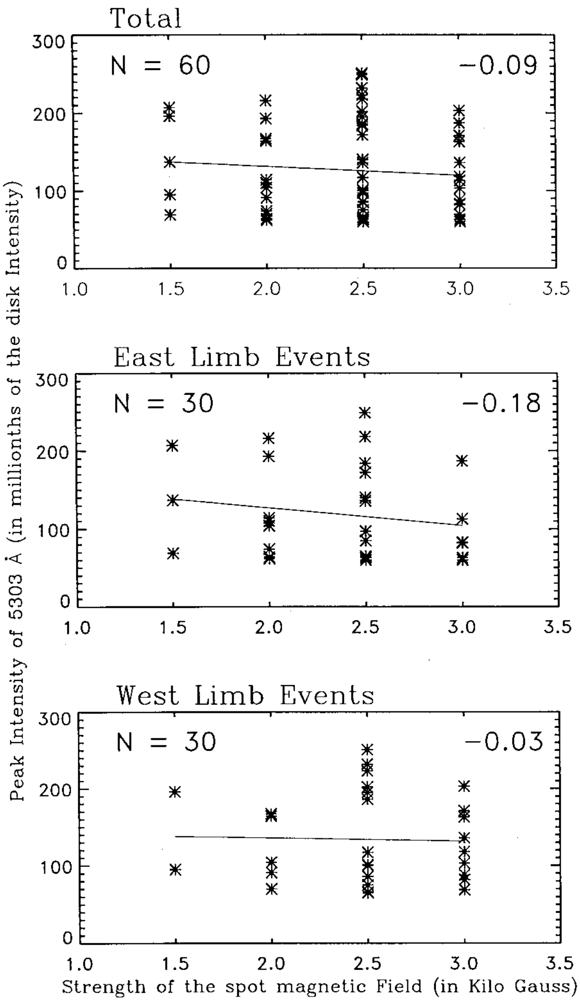

Figure 2. Scatter plots of peak intensities of Gs against the maximum strength of their associated spot magnetic field.

spot magnetic field, the greater is the probability that they are associated with Gs. In fact, the spots with field strengths greater than 2500 G are almost certain to be associated with the 5303 Å intensity enhancements (Figure 1). However, many spots with moderate field strengths are not associated with Gs. Detailed inspection of such spots showed that they do not undergo limb passages. The low correlation (Ramesh, 1998) of the daily index of coronal green line intensity, CI (Rybanský, 1975) with the number of sunspots can, therefore, be easily visualized following these characteristics of the spots for their association with Gs.

The peak intensity of Gs does not seem to depend on the strength of the spot magnetic field. Figure 2 shows the scatter diagrams of peak intensities of Gs with

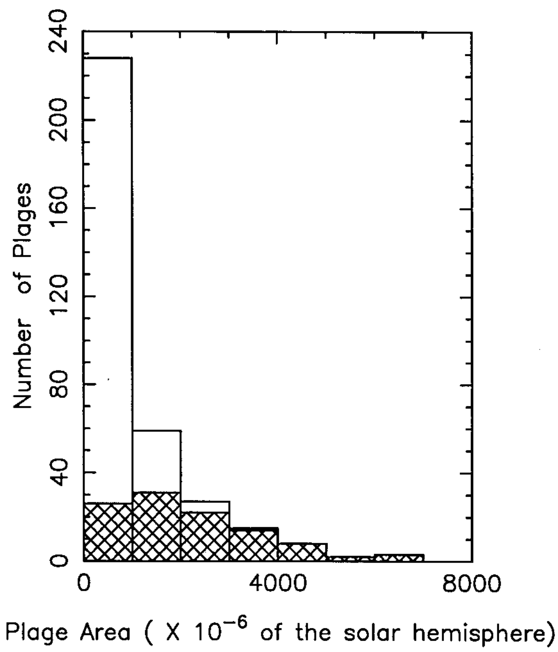

Figure 3. Histograms of the number of plages observed during 1985–1986. The distribution is shown in the area intervals of 1000 millionths of the visible hemisphere. Open histograms show the total number of plages observed in the given interval of area while the hatched portions show the number of plages in a given interval of area which are associated with Gs.

the maximum field strength of their associated spot. While constructing this plot we have considered the Gs whose associated spots were definitely observed beyond the central meridian distances (CMD) of 65°. The top panel represents all Gs while the middle and lower panels represent the east and west limb events, respectively. In the top left corner of each panel is shown the number of data points and in the top right corner are shown the correlation coefficients. The correlations for all the three sets of data are not significant even at 95% level, indicating the absence of a systematic association between the peak intensity of Gs with the strength of the corresponding spot magnetic field. Exactly similar results (not shown) were obtained when the analysis of the peak intensity with the strength of the spot magnetic field taken around 65° CMD was performed. We did not use the strength of the spot magnetic field near limb in order to avoid errors due to foreshortening. Further detailed analysis has been carried out to identify the characteristics of photospheric active regions for their role in the enhancement of 5303 Å line intensity. These are discussed later in a separate section of this paper.

3.2. Green line intensity enhancements and their association with Ca plages

We have studied the characteristics of a total of 340 plages observed during 1985 –1986 for their association with Gs. Figure 3 shows the histogram of the total number of plages (open histograms) observed during 1985–1986 and the number of plages associated with Gs (hatched histograms) against their area binned in the intervals of 1000 millionths of the solar hemisphere. We find that only 105 (31%) plages are associated with the identified 48 Gs (Figure 3). These statistics again confirm that two or more plages are together associated with a single G. Only 13 of them are found to be independently associated with individual Gs, while 7 of them have associated spots in the respective rotation. The remaining six events with associated spots in the previous rotations were in decaying phase and did not recur in the following rotations. The plages which have one or more companions in causing Gs, either one or more plages have associated spots. This further indicates that the coronal green line intensity enhancement, though located above plage areas, are almost all the time associated with sunspots.

Careful assessment of the plage statistics (Figure 3) indicates that the larger the plage area, the higher the probability that they are associated with Gs. In fact, the plages with area greater than 2000 millionths of the solar hemisphere are almost sure to be associated with Gs. We found 5 exceptions to this threshold area, one in the interval 3000–4000 and four in the interval 2000–3000. Further analysis showed that these plages did not undergo limb passages for them to be associated with the limb observations of the enhanced green line intensity features. Important aspects of the plages (59 in number) in the area range of 1 to 2000 (two intervals: 1–1000 and 1000–2000 taken together) which are associated with Gs are that these plages are not independently associated with Gs but they have companion plages with area greater than 2000 millionths of the solar hemisphere. Therefore, the fixed threshold area of 2000 millionths of the solar hemisphere for the plages to be associated with Gs is reasonable.

3.3. Comparing green line intensity maps with Stanford magnetograms

In order to examine the relationship of the coronal green line intensity enhancement and the active-region magnetic field we have carefully examined the Stanford magnetogram maps for the entire period of 1985–1986 in association with the composite maps of the green line intensity, sunspots and plages. As explained in an earlier section, we have first identified the magnetic signature corresponding to a given G. Later we have confirmed their association by tracing the magnetic signature for their limb passages simultaneous with the corresponding G. Careful inspection of these magnetic signatures revealed the persistent presence of a polarity inversion (neutral) line with either one or more sunspots associated with it. The peak intensity of G is found to be in the vicinity of the polarity inversion line. From our samples we conclude that the formation of a neutral line alone can not be a reliable marker of the enhanced green line intensity. An unmistakably noticeable feature of this activity is a moderate (contour levels placed very close to one another) to high (highly packed contour levels) field gradients along the polarity inversion line. However, we could not quantify the field gradients at this juncture due to lack of digital magnetogram data. In spite of this drawback, the role of moderate (Figure 4) to high (Figure 5) field gradients in enhancing the green line intensity may be seen visually.

Figure 4 shows a typical example of the green line intensity enhancement associated solely with a plage (19626). The maps in the first row show the Stanford magnetograms and the maps in the second and third rows show respectively the sunspots and Ca plages. In the fourth row the intensity maps generated using Lomnický Štít data of 5303 Å coronal intensity are shown. The inner semi-circle in the intensity maps represent the Sun's disk and the second semi-circle, placed very close to the Sun's disk, represents the location (0.15 $R_\odot$ above the limb) of the observations of 5303 Å line intensity. The intensity trace is then taken in the radial direction and represented in a linear scale with the location of observations (second semi-circle) as the origin. The third semi-circle represents the threshold limit (59 coronal units) used for identification of enhanced features. The plage 19626 was the recurrence of plage 19615 in the previous rotation, which had an associated spot (4667). A moderate field gradient is maintained at the polarity inversion line associated with the plage region 19626. Green line intensity maximum of 85 coronal units was observed centered around 15° N on 8 July 1985. The west limb enhancement with a peak intensity of 87 coronal units associated with this region was seen on 22 July 1985 at a central latitude of 5° N.

A typical example of the green line intensity enhancement associated with both spot (4750) and a plage (19824) is shown in Figure 5. High field gradients associated with this active region are seen all through the disk passage with the spot field strength greater than 2500 G. Plage area also was very large (about 6000 millionths of the solar hemisphere) and the intensity enhancement at the east limb is attributable to the activity behind the disk, the green line intensity of 203 coronal units observed at the west limb can undoubtedly be attributed to the activity associated with region 4750. Eye estimate of the gradients in our entire sample shows that a given degree of gradient does not always produce the same degree of coronal intensity. However, quantitative estimation of gradients needs to be done to substantiate this result. We have already initiated the laborious process of estimating the gradients and results will be reported elsewhere.

In order to check the validity of this result, we have scrutinized all the magnetograms available for these two years and found many more cases with neutral lines during their disk passages not associated with any green line intensity enhancement. Careful inspection of all such cases showed that the gradients relax, in the wake of the disappearance of spot or plage or both, near the polarity inversion line before their limb passages. A typical example for the relaxation of field

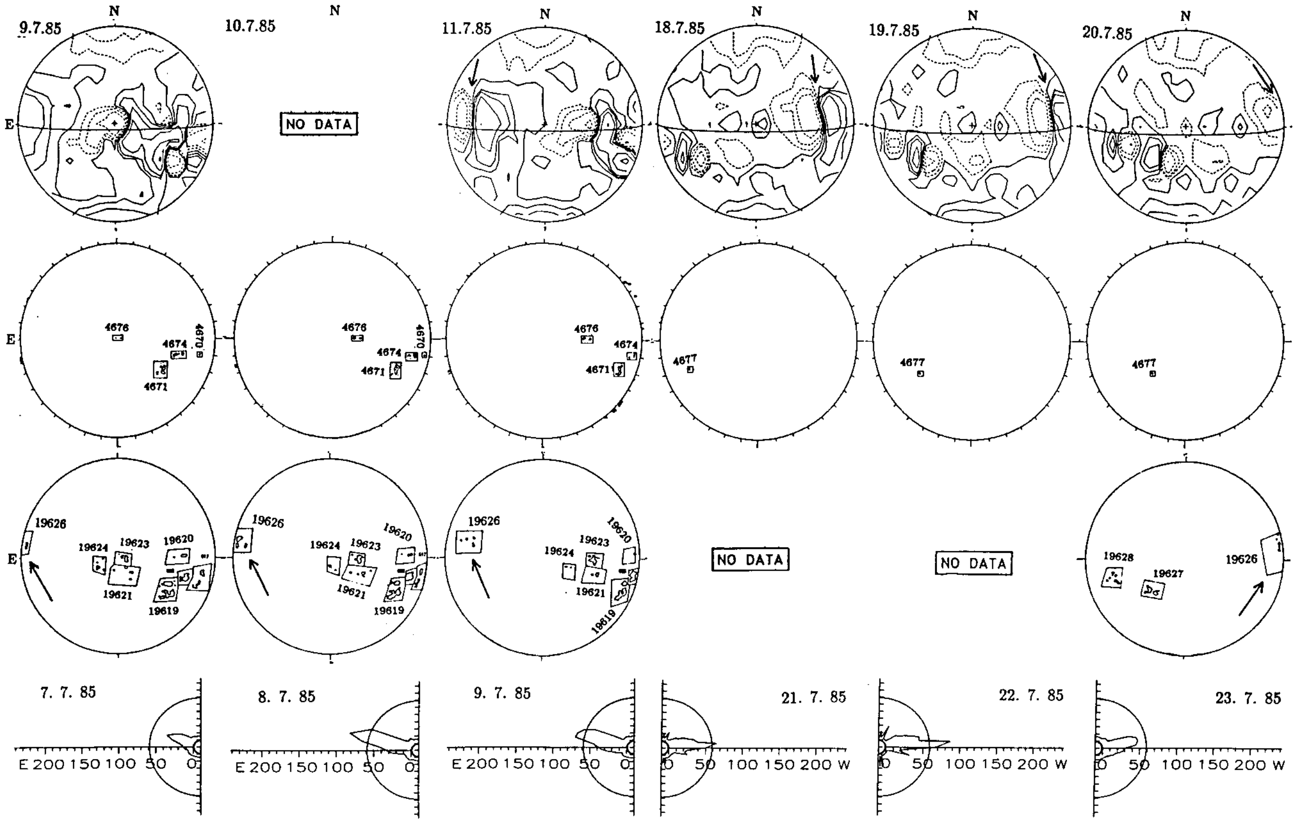

Figure 4. Typical example of the green line intensity enhancement associated solely with a plage. First row shows the Stanford magnetograms. Solid and dashed lines represent the positive and negative field contours respectively. Second and third rows show respectively the sunspot and Ca plage maps for the corresponding days of magnetograms in first row. The active regions corresponding to the green line intensity enhancement are indicated with arrows. The green line intensity maps for east as well as west limbs are shown in fourth row. The dates of observations of 5303 Å intensity are shown at the top of the corresponding intensity maps.

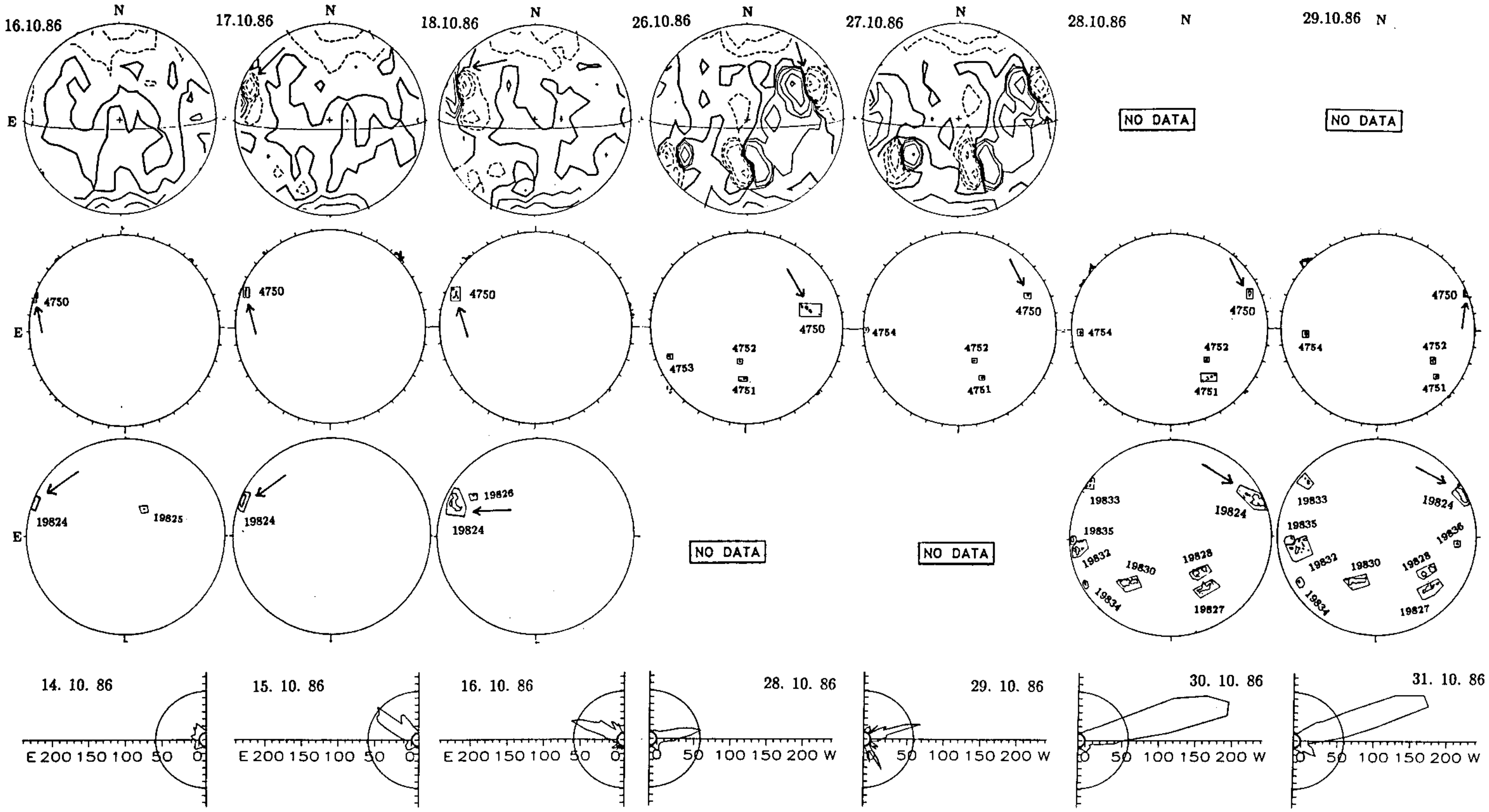

Figure 5. Same as Figure 4, but for the green line intensity enhancement associated with spots and Ca plages.

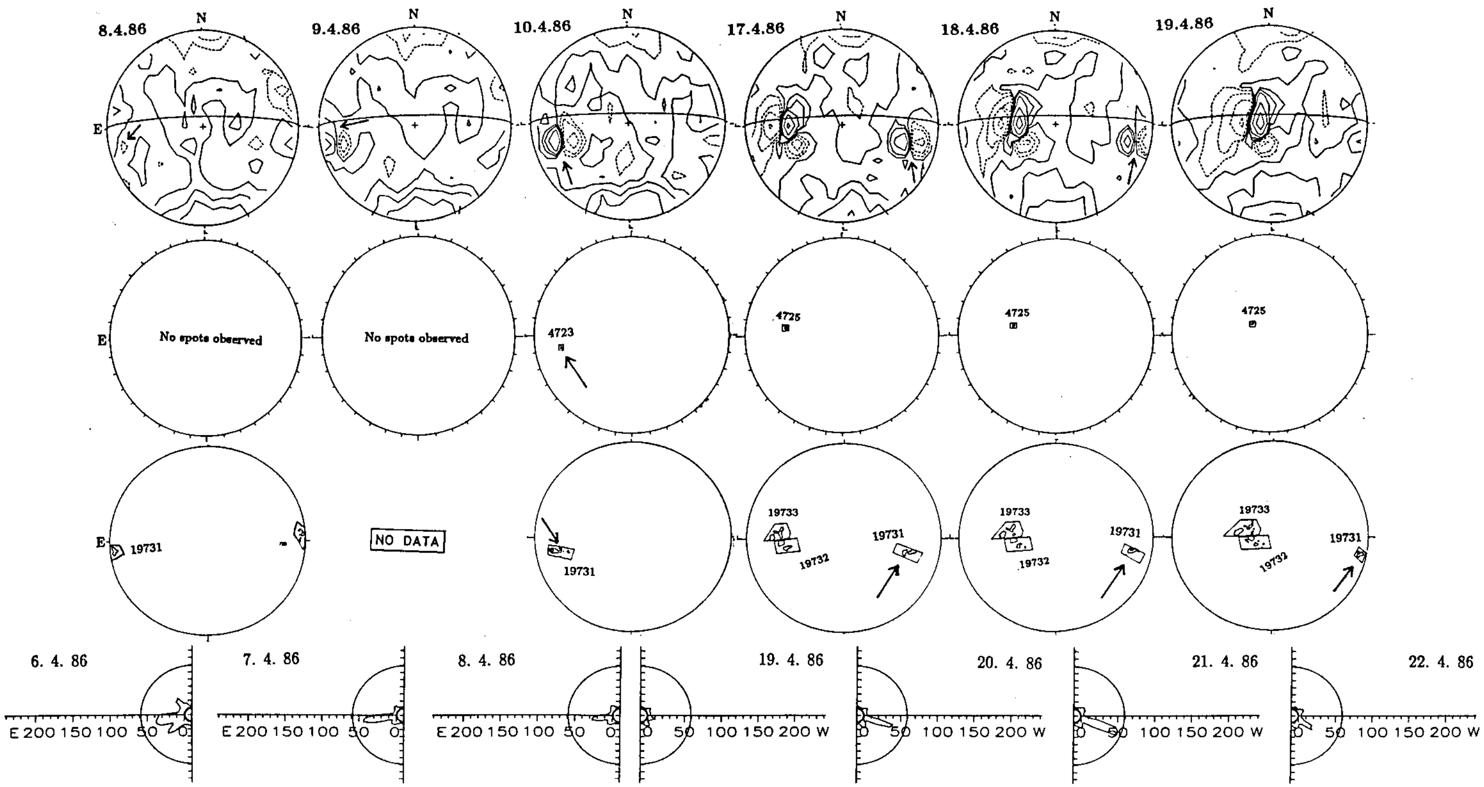

Figure 6. Typical example of an active region without an associated green line intensity enhancement.

gradients before the limb passage of the observed magnetic signature is shown in Figure 6. A negative polarity field emerged on 8 April 1986 near east limb and developed into a moderate field gradient region during disk passage. A spot (4723) formed on 10 April 1986 and disappeared on 14 April 1986 when it was around the center of the disk. However, the associated plage (19731) was seen all through the disk passage. Near both the limbs, the plage area was found to be less than 2000 millionths of the solar hemisphere. The green line intensity at the west limb observed on 20 April 1986 and 21 April 1986, associated with this region, was less than 59 coronal units.

Schwenn *et al.* (1997), using SOHO/LASCO 5303 Å emission data, found that the Fe XIV loops in the corona match well with the magnetic structures with neutral line as seen in the photospheric magnetograms. Ichimoto *et al.* (1995) have shown the coexistence of the hot (as seen in *Yohkoh* SXT data) and cool (as seen in the ground-based Fe XIV and Fe X data) components of coronal plasma. Using *Yohkoh* SXT data, Falconer *et al.* (1997) have concluded that strong shears in the magnetic field along the neutral line are good markers of sites of enhanced coronal heating. Our present finding, therefore, might indicate that the moderate to high field gradients (as seen in the longitudinal magnetograms) along the neutral line in an active region is a reliable marker of enhanced coronal heating, at least in the lower corona as represented by the enhancements in 5303 Å line intensity. In fact, active regions with persistent field gradients during their disk passage can be taken as forerunners of 5303 Å intensity enhancement at the west limb, while the observations of the enhanced green line intensity at the east limb can be used to foresee an active region at those latitudes in the vicinity of the east limb, with moderate to high field gradients associated with it. Neither the strength of the photospheric magnetic field (Figure 2) nor the level of gradients (eye estimate) controls the degree of intensity enhancement. Hence, it can be argued that, as suggested by Falconer *et al.* (1997) in the case of X-ray brightenings, some hidden process such as the reconnection accompanying flux cancellation at or near the level of the photosphere might control the process of coronal heating which, in turn, might determine the measure of Fe XIV line emission.

3.4. Intensity Enhanced Features without an Underlying Active Region

In our sample we found 9 green line intensity enhanced events which do not have any activity directly below them. Four of them, which appear as the east limb events, have associated spots and plages in the previous rotations. In these cases, activity disappearing one day prior to their limb passage at the east limb, the intensity enhancement may still be found, probably with reduced intensity, since the coronal cooling time is of the order of one day. Besides, these events did not recur at the west limb indicating that they are associated with dying active regions in their previous rotation. On the other hand, among the remaining 5 events, four are west limb events without any associated underlying activity. One east limb event also did not have an associated underlying activity in the previous rotation indicating that all these five events are quite independent events.

Enhancements in 5303 Å coronal line intensity on the time scales of 30–40 min due to coronal loop interactions (CLI) were reported by Smartt, Zhang, and Smutko (1993). Airapetian and Smartt (1995) report that outside an active region the frequency of CLI or loop brightenings is $\sim$ 20 times lower than in active regions and interpret this as the sharing of magnetic flux between active regions leading to the formation of giant loop structures with a corresponding lower heating rate. The extent both in longitude ($\sim 13°$) and latitude ($\sim 5°$) of the above mentioned five events (4 in west limb and one in east limb), without an underlying active region, are much less (same as the one pixel size of the green line intensity maps used here) and the intensity enhancements (65–74 coronal units) are also very low. We, therefore, arrive at a conclusion that these 5 events in our sample could be due to the chance coincidence of the occurrence of CLI or loop brightenings outside active regions during the period of photometric observations of 5303 Å line intensity. However, detailed studies of such events are needed to identify the actual cause of these small-scale intensity enhancements.

4. Summary of the Results

Daily composite maps of the coronal green line intensity, sunspots and Ca plages are prepared for the low sunspot activity period of 1985–1986 and compared with the Stanford magnetogram maps to study the nature of coronal intensity enhancement and the underlying active region magnetic signatures. Following are the summary of the inferences drawn from this analysis.

The 5303 Å coronal intensity enhancements are almost all the time associated with sunspots. However, all the spots do not seem to be associated with the green line intensity enhancements. A threshold magnetic field strength of about 1500 G seems to be a characteristic for a spot to be associated with the green line intensity enhancement. We found, however, that the peak intensity does not seem to depend on the strength of the spot magnetic field.

Most of the intensity enhancement features are located above plage areas and this finding is in good agreement with the results obtained by Rybanský and Rušin (1987). However, we find that all the plages will not have an associated intensity enhanced feature. Plages leading to intensity enhancement need to have an associated spot in the current rotation or at least in the previous rotation. Analysis of the characteristics of plages show that an area of about 2000 millionths of the solar hemisphere seems to be essential for them to be associated with the coronal green line intensity enhancement.

For the occurrence of a green line intensity enhancement, the corresponding photospheric magnetic signature associated with the spot or a plage needs to have a polarity inversion line with moderate to high field gradients during their limb passages. In fact, a continuous watch on the progress of the level of gradients in a given magnetic signature during its disk passage can be used to foresee an associated coronal intensity enhancement at the west limb. Similarly, the observations of the green line intensity enhanced features at the east limb can be used, to a large extent, to foresee the new appearance or the recurrence of an active region at those latitudes with moderate to high field gradients associated with it.

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References

Airapetian, V. S. and Smartt, R. N.: 1995, *Astrophys. J.* **445**, 489.

Altrock, R. C. (ed.): 1987, *Solar and Stellar Coronal Structure and Dynamics*, Proceedings of Ninth Sacramento Peak Summer Symposium, Sunspot, NM, p. 414.

Altrock, R. C.: 1993, in J. M. Pap, C. Fröhlich, H. S. Hudson, and S. K. Solanki (eds.), 'The Sun as a Variable Star', *Proc. IAU Colloq.* **143**, 172.

Altrock, R. C., Hick, P., Jackson, B. V., Hoeksema, J. T., Zhao, X. P., Slater, G., and Henry, T. W.: 1996, *Adv. Space Res.* **17**(4/5), 235.

Falconer, D. A., Moore, R. L., Porter, J. G., Gary, G. A., and Shimizu, T.: 1997, *Astrophys. J.* **482**, 519.

Guhathakurta, M., Fisher, R. R., and Altrock, R. C.: 1993, *Astrophys. J.* **414**, L145.

Guhathakurta, M. and Fisher, R. R.: 1994, *Solar Phys.* **152**, 181.

Hara, H., Tsuneta, S., Lemen, J. R., Acton, W., and McTiernan, J. M.: 1992, *Publ. Astron. Soc. Japan* **44**, L135.

Hick, P., Jackson, B. V., Altrock, R. C., Slater, G., and Henry, T.: 1996, in K. S. Balasubramaniam *et al.* (eds.), *Solar Drivers of Interplanetary and Terrestrial Disturbances*, Proceedings of Sixteenth International NSO/SP Workshop, Sunspot, NM, p. 358.

Ichimoto, K., Hara, H., Takeda, A., Kumagai, K., Sakurai, T., Shimazu, T., and Hudson, H. S.: 1995, *Astrophys. J.* **445**, 978.

Nagasawa, S.: 1961, *Publ. Astron. Soc. Japan* **13**, 384.

Ramesh, K. B.: 1998a, *Solar Phys.* **177**, 311.

Ramesh, K. B.: 1998b, *Solar Phys.* **183**, 295.

Rybanský, M.: 1975, *Bull. Astron. Inst. Czech.* **26**, 367.

Rybanský, M. and Rušin, V.: 1987, in R. C. Altrock (ed.), *Solar and Stellar Coronal Structure and Dynamics*, Proceedings of Ninth Sacramento Peak Summer Symposium, Sunspot, NM, p. 342.

Rybanský, M., Rušin, V., Gaspar, P., and Altrock, R. C.: 1994, *Solar Phys.* **152**, 487.

Schwenn, R. *et al.*: 1997, *Solar Phys.* **175**, 667.

Smartt, R. N., Zhang, Z., and Smutko, M. F.: 1993, *Solar Phys.* **148**, 139.
Sýkora, J.: 1969, *Bull. Astron. Inst. Czech.* **20**, 70.
Sýkora, J.: 1994, *Adv. Space Res.* **14**(4), 73.
Wang, Y.-M, Sheeley, N. R., Jr., Hawley, S. H., Kramer, J. R., Brueckner, G. E., Howard, R. A., Korendyke, C. M., Michels, D. J., Moulton, N. E., Socker, D. G., and Schwenn, R.: 1997, *Astrophys. J.* **485**, 419.