ON THE MUTUAL INFLUENCES OF SPATIALLY REMOTE SUNSPOT GROUPS UNITED INTO FLARE-ACTIVE COMPLEXES

V. V. KASINSKII
Sib IZMIRAN, Irkutsk, U.S.S.R.

Abstract: The microspots activity of a large sunspot group (δ-configuration) taking place on the sun's disk from 1st to llth August, 1972 and generating five strong flares among which geoeffective took place is analysed. It is found that this group was accompanied by the intensive eruptions of a magnetic flux becoming apparent in appearance and further disappearance of nine satellite groups.

It is shown that observed jumps in the area and magnetic flux of the nearest satellites are going on synchronously with the appearance of flares and there is a noticeable space-time connection between the satellites and the flares. In four from six cases the satellite appearance preceded the flare for some hours. It is shown by the method of superimposed epoch that both a satellite activity (a magnetic flux eruption) and microflare one are the precursors of strong flares.

A considerable space remotness of the satellites and the absence of an immediate contact of old and new (eruptive) magnetic fields makes one to take the conception of the interaction of magnetic systems at the distance, which can be realized in a wave-like manner. By cautious estimations the interaction velocities are of order 10—50 km s^{-1} in corresponding layers.

1. Introduction

In a number of papers it was noted that a large scale interaction of several magnetic systems and the appearance of so-called satellite sunspot groups in the vicinity of a proton complex [1, 2], can be signs of proton flare events. This assumption was verified by the author on the material of 160 flares of different classes from 1 + to 3 + for the period July to December 1957. It was shown [3] that accompanying satellites are a characteristic feature both of weak flares of importance 1 + and of strong ones of 3+. The percentage of accompanying satellites is 67 and 92 %, respectively.

The satellites were classified into four different types of development: 1. the new-born sunspot group of types A or B in the Zürich classification, 2. the vanishing group of H or J classes, 3. the short-lived groups of 1–3 days with an impulsive character of development, 4. groups of larger range classification A, B, C, D,...., G, H, J, existing earlier but with a strong increase or decrease of the area [4].

The fast nature of development, connected with the appearing and disappearing of a group ±2 days from the time of the flare was attributed to 73 % of all the satellites and 30 % of them were the short-lived groups of the total number of 100.

Of the total number of 134 flare locations only 69 % showed the presence of accompanying satellites. The following analysis has shown that the first population (69 %) relates to quasi-stationary developed sunspots, while the second one (31 %) to the groups with rather abrupt changes of area, as well as common morphology. The comparison of the dynamic development of the sunspots with satellites, the satellites themselves and the groups without satellites is given in Table 1, where the ratio of the r. m. s. to the mean number of sunspots N in a given group per day is shown on the first line.

Table 1

Group with satellites	Satellites only	Groups without satellites
0.04—0.01	2.25	1.9—2.5
	Flare's cases	
92	0	42

The 92 cases of flares when the groups were accompanied by satellites, were subject to a spatial analysis: the correlation coefficient between the satellite position angle and the mean azimuth of the flare was calculated. The spatial correlation coefficients appeared to be very high — 0.80 [4], however, the time analysis was necessary.

If the appearing and disappearing of a satellite is only known with a 1-day accuracy, it is difficult to say which precedes, the satellite or the flare. However, if it turned out that only 65 % of all satellites appeared at the time of flares, or preceded them, this would not be sufficient evidence that the satellite is the cause and the flare the consequence.

30 proton flares, which occurred during a period of 11/2 years from June 1957 to December 1958, were investigated.About 40 satellites accompanied the groups in which proton flares took place; the satellite azimuth — flare azimuth correlation coefficients were found to be 0.58 with a reliability of 0.99. As for the time distribution of the satellites, relative to the time of occurrence of flares, it was found that in 47 % of the cases the satellites preceded the proton events by 12 hours, in 39 % of the cases they coincided with the times of the flares with an accuracy of ±6 hours, and only in 14 % of the cases were they delayed by 24 hours or more. As we can see, in 86 % of all the cases the satellites preceded the flares, or were observed at the same time as the flares.

It should be noted that all the results are of a statistical nature, i. e. they are only correct as an average over the whole set of groups, accompanied by satellites and each individual case requires special investigation.

2. The Space-time Analysis of Microspot Activity (Satellites) in the Case of the Proton Group of August 1—11, 1972

It is well known that the large group of August 1—11, 1972 produced at least 5 strong flares of which most were geoeffective. Less known is the fact that in the neighbourhood of this group no less than 9 satellite groups were observed, 4 of which developed into middle-sized groups and others appeared and disappeared as clusters of pores, i. e. they were proper short-lived groups, existing 1—2 days. In this connection it is interesting to explore the dynamics of the satellite groups, as well as their behaviour and general distribution around the group-generators of the flares.

It is characteristic that the August group, occupying a huge area of as much as 1200 millionths of the hemisphere and magnetically classified as a $\beta - \gamma - \delta$ type configuration, in spite of the large flare activity, displayed surprisingly constant development, reflect in a slow and uniform decrease of its area from 1250 millionths on July 30 to 950 millionths on August 10, 1972. This is in extraordinary contrast to the large changes in a number of sunspots and areas of satellite groups, appearing in the neighbourhood of the fundamental group and in good agreement with earlier conclusions about the small variability of the group-generators of flares, accompanied by satellites [3, 4] (Fig. 1).

The general pattern of the time distribution of flares and satellites is given in Figure 2. It is interesting to note that to the north of the August group there is a minimum of flare decay, as well as a minimum of the satellites, which were located primarily to the south of the main group.

Using flare data from independent sources (Solar Geoph. Data, 1972; Solnechnye Dannye, 1972) we have attempted to establish a mutually simple correspondence between the strong flares and the satellite groups. Using, for the sake of better accuracy, some filtergrams given in [5], we succeeded in establishing such a correspondence between the satellites and flares as on August 3—4, when three satellites appeared as pores at a distances of 28° to the south-eats of the main group.

Sufficiently good correspondence between flare knots and the satellite group was also observed on August 2 and 7. In the other cases, when only individual measurements of the flare coordinates were available, this correspondence is less clear. The extent to which the satellites, spatially identical, are also time-related to flares, requires a separate investigation. The dynamics of satellite development, as shown above, are more abundant and variable than the evolution of the main group.

Combinig the data on the areas and numbers of sunspots from 3 independent sources [5, 6, 7] and also our original sunspot drawings made in the SibIZMIR ($D_{\odot} = 55$ cm) for the period considered, we succeeded in plotting a more or less complete pattern of three large satellite developments. On some days the number of points amounted to 4 or 5. This made it possible to obtain detailed curves of the development of the satellites with respect to the area and number of sunspots, and to find considerable discontinuities of development on them, particularly outstanding in the course of August 5 and 6 prior to the flare of August 7, as well as prior to flares of August 4, and, after careful examination, also of August 2. Frequently, if not as a rule, the strong flares were accompanied by large changes in area of the nearest satellites. In individual cases the satellites display a simultaneous change of area

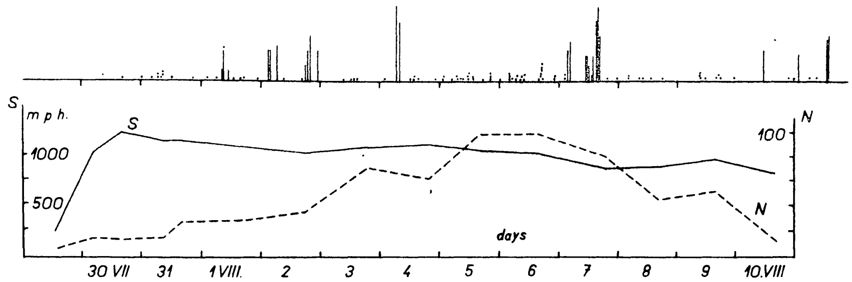

Fig. 1. The development of the sunspot group of Aug. 1–11, 1972: solid line – the area, dashed line – the sunspot numbers.

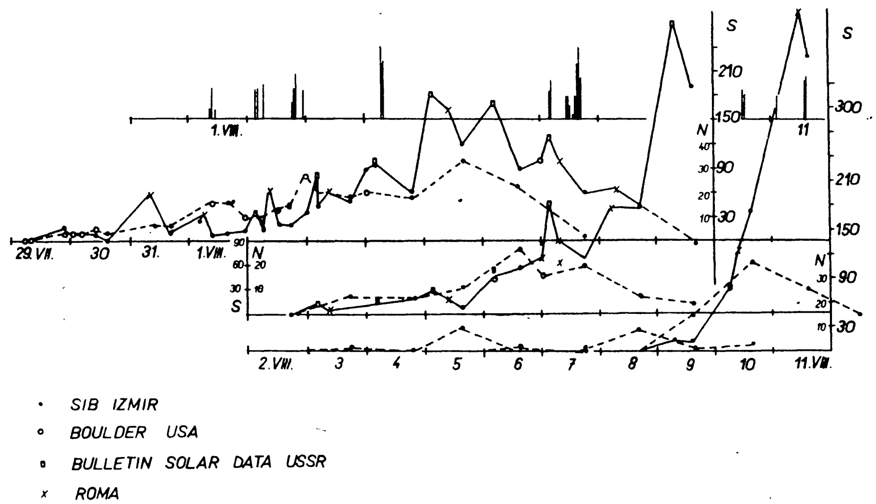

Fig. 2. The positions of strong flares and the curves of the development of the area and sunspot numbers (dashed line) of the satellites.

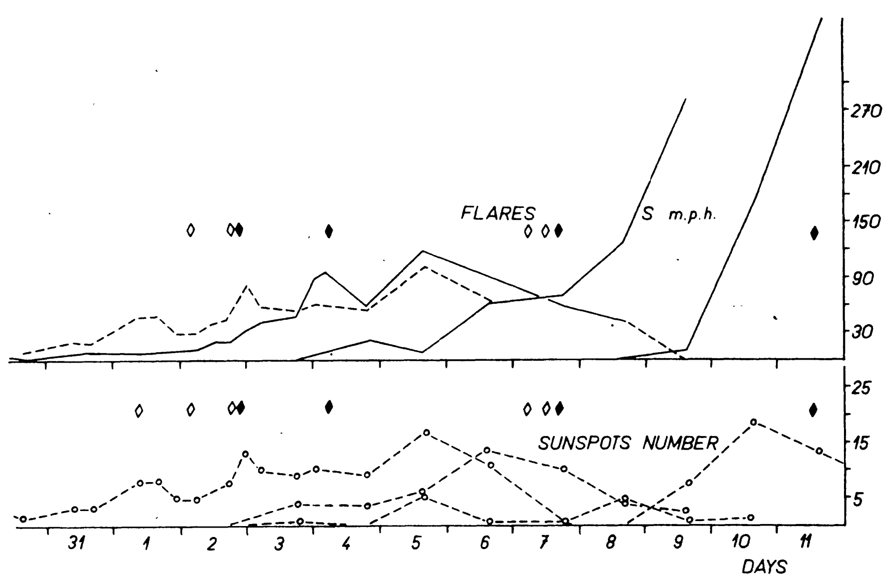

Fig. 3. The curves of development of the area, sunspot number (dashed line) and the beginning of flares (vertical lines) for the three more developed satellites. The areas are in millionths of the solar hemisphere.

which is possibly indicative of a sub-photospheric nature of the increase and decrease of the areas of spatially distributed satellites (Fig. 3).

Using the method of superimposed epochs, applied to the satellite development curves, we succeeded in obtaining a diagram showing the rate of change of the spot number relative to the zero epoch — the time of the flare (Fig. 4). The diagram

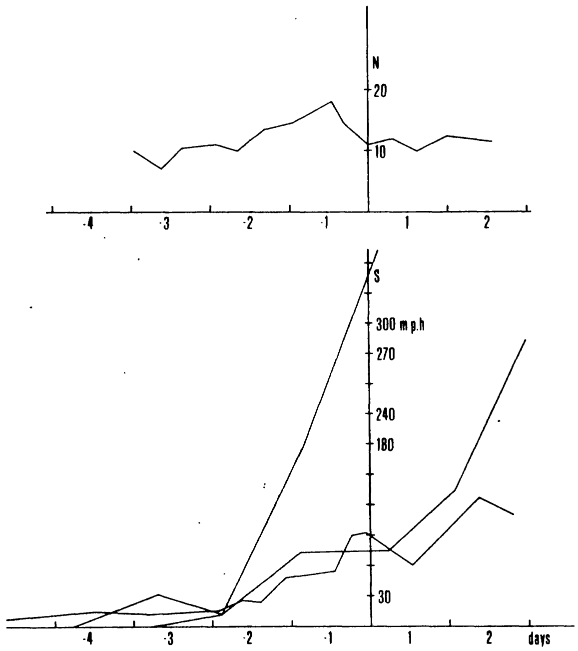

Fig. 4a, b. The changes of sunspot numbers and the areas of some satellites as functions of the "zero" points of flares (above) obtained by the method of superimposed epochs.

shows that the maximum of the sunspot number occurs 18 hours prior to the flare. An estimate of the non-randomness of the spot number, carried out by means of the 2-criterion, indicates that the observed deviation of the sunspot number from the constant rate of change has a probability of 72 %. This allows one to draw the conclusion that the hypothesis of the random increase of the satellite sunspot number is infounded.

The curves of satellite development have a characteristic behaviour (Fig. 4). The inflexion point at which the area begins to increase sharply comes two days before the flare. The inflexion point separates the stage of development of the spots as clusters of pores from the stage of a bipolar-like sunspot structure. The former stage displays areas of no more than 30 millionths of the solar hemisphere.

In general, we have observed the following pattern of satellite dynamics before flares: the moment of sharp increase in area precedes the beginning of a flare by about one day or more, but the sunspot number maximum only by 18 hours. Therefore, detailed, patrol-like observations of the sunspots may help to verify the changes directly preceding the commencement of a flare.

3. Discussion: Possible Mechanism of the Interaction between the Flare and Satellite Groups

The considerable spatial remoteness of the flare group-generators and the satellites, 10—25° (150,000—300,000 km), is evidence rather in favour of the interaction between magnetic systems in the form of a signal, than of direct contact of the magnetic systems.

Cases of interaction of magnetic systems are well-known in literature. For example, some data about such an interaction were obtained by Bruzek (Smith, Smith, 1966) in examining the activation and vanishing of filaments. Bruzek found that many cases of vanishing filaments were related with the formation of centres of activity in their vicinity, which leads to the disappearance of the filaments. There seem to exist disturbances which, as a rule, are hard to distinguish and which propagated from the new centre up to distances of 300,000 km with a velocity of about 1 km s^{-1}.

In view of what has been said of satellites as short-lived active formations, one may assume that in this case some disturbance, propagating from the satellite, may reach the main group. The velocity of the agent, estimated from the fact that the satellite precedes the flare by one day, amounts to 2—10 km s^{-1}, which is of the same order of magnitude as the velocity of a Bruzek-type disturbance. If it is assumed that the disturbance has to propagate in the photosphere, where the magnetic field is weak (1—10 Gauss) and the density is 10^{-7} g cm^{-3}, one finds that the velocity of Alfvén waves is $H\sqrt{(4\pi\varrho)} \approx 0.1$—$0.5$ km s^{-1}, which is not sufficient. On the contrary, the velocity of sound in the photosphere is somewhat larger than is needed (7—8 km s^{-1}). The velocity of the gravitational waves, $\sqrt{(gH)}$, for the gravity acceleration on the Sun, $g = 0.274$ km s^{-2}, and the scale height in the photosphere of 100—400 km, will be close to

$5—10\ km\ s^{-1}$. More details about gravitational wave propagation can be found in [3]. In this paper it has been shown that the velocity of the gravitational waves will be of the order of $1—10\ km\ s^{-1}$ in the Bilderberg model of the chromosphere. It was also shown that the energy of these waves, if sufficiently long (more then 10,000 km), can reach $10^{30}—10^{31}$ ergs, which is of the order of the flare energy.

We thus come to the conclusion that a disturbance can propagate from one sunspot group to another in the lower chromosphere as a slow gravitational wave ($1—10\ km\ s^{-1}$) with sufficient energy to generate a flare.

References

1. KOPECKÝ, I. M. and KŘIVSKÝ, L. (1966): Bull. Astron. Inst. Czech., *17*, 360.
2. KŘIVSKÝ, L. and OBRIDKO, V. (1969): Solar Phys., *6*, 418.
3. KASINSKII, V. V. (1973): Issledovaniya po geomagnetizmy, aeronomii i fizike Solntsa. Vol. 26, p. 118. Moscow.
4. KASINSKII, V. V. (1972): In: Solnechno-zemnaya fizika. Vol. 3, p. 296—305. Moscow.
5. Solar Geophysical Data, Prompt Report. Colorado, USA, 338, p. 1.
6. Bulletin Solnechnye Dannye, No. 8, 1972.
7. Bulletin Solar Phenomena. Nos 172, 173, 1972. Roma.
8. SMITH, G. and SMITH, E. (1966): Solnechnye vspishki, p. 196. Moscow, Mir.