LARGE-SCALE MUTUAL RELATIONS OF SPOT GROUPS IN PROTON COMPLEX

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Abstract. The large-scale configuration of spot groups was investigated within a complex proton region. The probability of occurrence of accompanying spot groups (satellites) was studied according to the classification types, the direction of their occurrence, and the distance with respect to the proton spot group. The results obtained indicate that the condition for the generation of a proton spot group will not only rest with the known small-scale interaction of a few magnetic systems and the creation of a single group, but also with the existence of 'satellites' in the neighbourhood of the proton group up to a distance of several tens of degrees.

1. Introduction

In a number of papers it has been indicated that one of the characteristic factors of the generation of a proton flare will not only be the small-scale interaction of several magnetic systems, leading up to the creation of a single group comprising certain special types, but that a further condition will be the occurrence of accompanying groups in the neighbourhood of the proton spot group (KOPECKÝ and KŘIVSKÝ, 1966; KLECZEK and OLMR, 1967).

For purposes of verifying the hypothetical existence of this large-scale configuration within a complex active region, the authors decided to investigate the probability of the occurrence of accompanying groups according to their type, the direction of their occurrence, and the distance from the proton group.

The results obtained indicate that the condition for the generation of a proton spot group is the existence of a physical relationship between this group and the neighbouring groups. This relationship will probably be determined by the long-term history of several magnetic field systems, which are in contact, or which penetrate each other, creating groups of spots in the photosphere (BUMBA *et al.*, 1968).

In the present work we have investigated only those complexes in which proton flares occurred, and in this meaning, these formations keep the name of 'proton complex' throughout the whole paper. But it should be emphasized once more, that we do not know whether this association of groups is peculiar to proton groups or not.

2. Initial Data and Method of Treatment

For the purpose of investigating the mutual relations of proton spot groups (with the occurrence of flares accompanied by type IV radio bursts) and spot groups in their neighbourhood, the catalogue of proton flares published by ŠVESTKA and OLMR (1966)

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and the data on spot groups from 'Heliographische Karten der Photosphäre' (Zürich) were used. The time interval covered in this study is from February 1956 to August 1963. From the proton flare catalogue the flares generated at the edge of the disc (up to a distance of 15° from the limb) were excluded, which also applies to the cases in which the source of the radio type IV, i.e. the flare, was uncertain. The number of cases considered was 140.

From the neighbourhood of the proton spot group all groups occurring on the day of the flare were selected, provided they were within 30° of the proton spot group. If there was no group within a radius of 30°, the nearest group beyond this limit was selected. For each accompanying spot group (this type of spot group will be called a 'satellite') the satellite type, the distance in degrees d, and the position angle α between the parallel passing through the centre of the proton group and the line joining the centres of both groups (the proton group and the satellite) were recorded.

3. Results

A. PROTON GROUP TYPE AND SATELLITE TYPE

Figure 1 shows the frequency of occurrence relation between the proton group type (horizontal axis) and the type of the nearest satellite (vertical axis). The graph indicates that the most frequent occurrence of proton flares is in the E, F and H type groups, which corresponds to the results of the paper by Kopecký and Křivský (1966). From

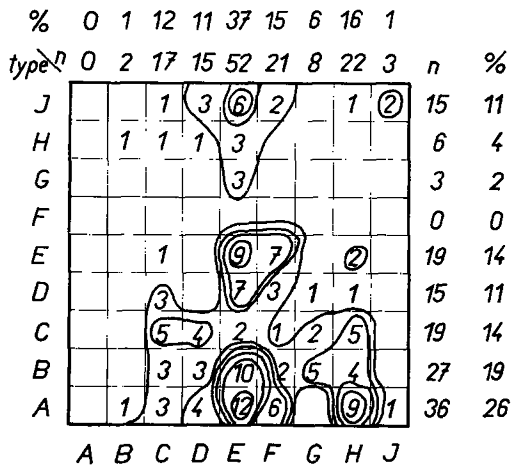

Fig. 1. For each proton group from a circle of 30° radius the nearest satellite group has been selected and their distribution by types is shown at the Figure depending on the type of proton group. Horizontal axis – proton group types, vertical axis – satellite group types.

the occurrence distribution of the satellite groups it follows that the A and B type is the most frequent type. The reason for this, of course, may be in the general maximal frequency of occurrence of these types. In order to compare and explain, whether the occurrence distribution of the individual satellite types in the radius investigated is random, Figure 2 shows the occurrence of all types of spot groups on the disc (KOPECKÝ and KŘIVSKÝ, 1966), and Figure 2b shows the occurrence of the spot group types of the nearest satellites in the interval around the proton spot group investigated. It can be seen that the E group type with the satellites occurs twice as frequently as might be expected from the natural random occurrence. By comparing

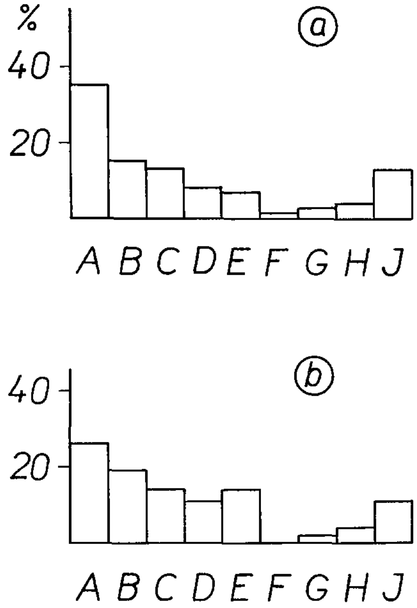

Fig. 2. Frequency of occurrence of the nearest satellite groups according to their type (b); for comparison the frequency occurrence distribution of all spot groups on the disc according to their types is also shown (a).

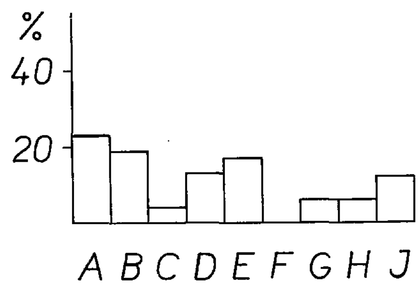

Fig. 3. Occurrence of satellite groups according to their types, accompanying E type proton groups.

the occurrence of spot group types between 1938 and 1950 (KLECZEK, 1953) percentage-wise, an analogous result is obtained. The neighbourhood of the E type proton group with the E type satellite thus appears not to be random.

It is also remarkable that in the predominant occurrence of E type proton groups, the occurrence of the D and E type satellites is nearly the same as with the A and B types (see Figure 3), which differs significantly from the normal distribution of occurrence of these types.

Figure 1 also shows that the F type groups never were the nearest satellites of a proton group, and that with the H type proton groups there were never other satellite types than small groups of A, B, and C types. For clarifying the result in Figure 1, and for judging its significance, the graph was remade so that from the investigated

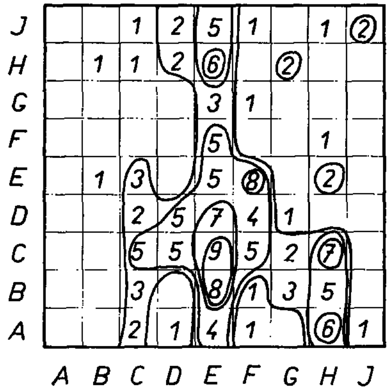

Fig. 4. For each proton group from a circle of 30° radius the most developed satellite group has been selected and their distribution by types is shown at the Figure depending on the type of proton group. Horizontal axis – proton group types, vertical axis – satellite group types.

radius not the nearest groups, but those which were the strongest were selected, in the following order of magnitude (from largest to smallest: F, E, D, G, H, C, J, B, A). The result is shown in Figure 4. The graph indicates that there were never larger or stronger groups in the vicinity of H type proton groups, but in each case they were small groups of the A, B, and C types. Only with 18% of the H type proton groups later types than the A, B, and C types existed. It can hardly be said that this mutual configuration is a result of a random process.

As an example for verifying the significance of the result, the authors found that in 1956 there were 180 days when H type groups were on the disc, and in 54% of the cases later types of groups than A, B, and C were to be observed in the neighbourhood of the H type group. The probability of occurrence of the A, B, and C types in the vicinity of the H type group may also be determined in another way. The probability of the random occurrence of the later types and of the earlier types (A, B, C) can be seen in Figure 2a. If in the 30° radius region investigated, besides the proton group, there is also one satellite, and if the probability of occurrence of the satellite type were independent of the probability of occurrence of the proton group, then a repeated investigation of the occurrence probability of the later types (than the A, B, C types) would yield 37%. If more than one satellite is present in this region, then the occurrence probability of the later types increases; for two satellites it amounts to 60% and for three to 75%. If the results of KLECZEK (1953) are used for comparison, the occurrence probability of the later types amounts to 48, 75 and 87% for one, two and three satellites, respectively. All these occurrence probabilities of the later groups in the neighbourhood of the H type proton group are large, but, as we know, this is not the case (18%). We may thus conclude that the actual determined occurrence of earlier and rapidly developing spot groups appears to be a typical property of the neighbourhood of the H type proton groups. Worth mentioning is that the secondary maximum of occurrence of flares in H type groups is peculiar just to proton flares (KLECZEK, 1953; KOPECKÝ and KŘIVSKÝ, 1966).

In this connection it is interesting to note the results of BUMBA and HOWARD (1965), that the newly developing groups always stem from the old decayed regions, or from their immediate vicinity.

From the graphs mentioned earlier, it may be seen that in the neighbourhood of the F, E, and D type proton regions there is an increased occurrence of satellites of the same types. A similar result from the point of view of occurrence probability could appear to be random, if in the region investigated there were more than 3 satellite groups on the average, however, also in this case it would be hard to explain the increased occurrence of the near, E type satellites (Figure 2 and Figure 3).

We obtained roughly the same distribution, with respect to mutual relations, when we selected for this investigation from the proton flare catalogue used only the cases in which there was a PCA effect (polar cap absorption), i.e. when sub-cosmic radiation particles from proton flares reached the earth.

B. PROTON GROUPS AND SATELLITE DISTANCES

First of all, the distance of the nearest spot group from the proton group in degrees was determined. The average distance of the groups owing to the variable number of groups on the disc, changes with the solar cycle phase. Figure 5 shows the spot group distances versus time from the Carrington rotation No. 1370 to 1470. The

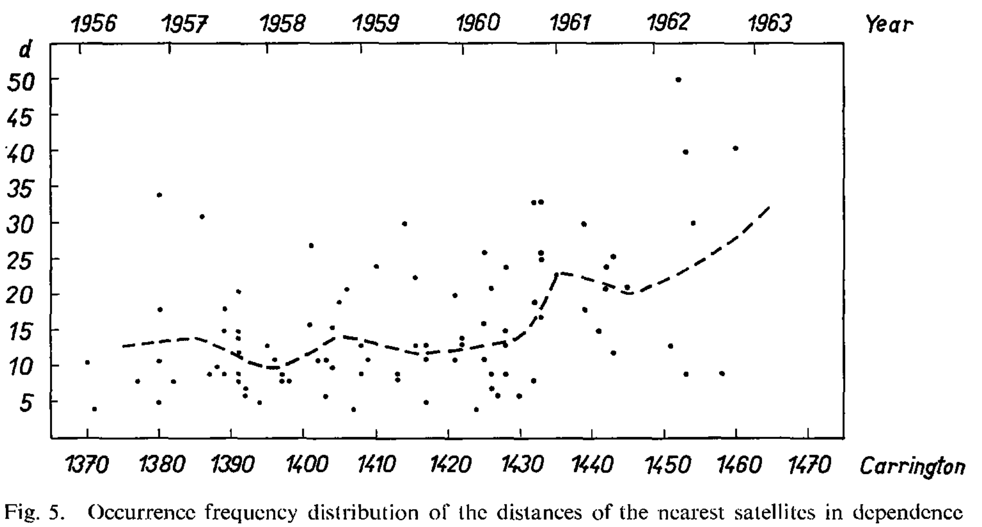

Fig. 5. Occurrence frequency distribution of the distances of the nearest satellites in dependence on the solar cycle phase.

dashed curve connects the mean values obtained from ten rotations. The minimum distance of spot group increases, as we could expect, towards the solar activity minimum. Due to the small change of this mean curve and also to the unchanging scatter, only the time interval from February 1956 (from rotation 1370) to August 1960 (to rotation 1430) was investigated.

Figure 6 shows the dependence of the occurrence distance of the nearest identified

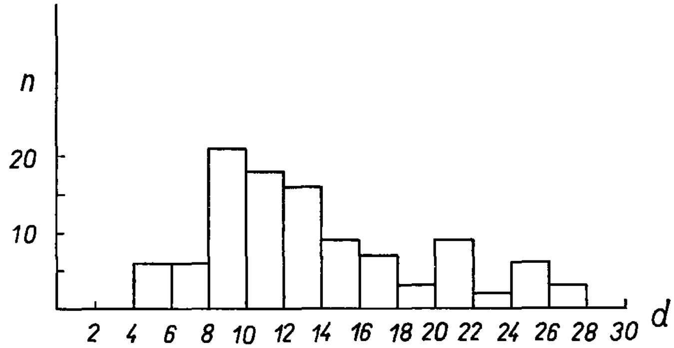

Fig. 6. Occurrence of the nearest satellite distance from the proton group.

satellites from the proton groups in degrees. The most frequent distance of the satellites from the proton group is about 9°, and another weaker secondary maximum may be seen around 21°. This second maximum, however, is not fully statistically substantiated, as it would first have to be proved by referring to more extensive data. It seems, however, that this maximum will not be quite random, due to the considerations in Section 4.

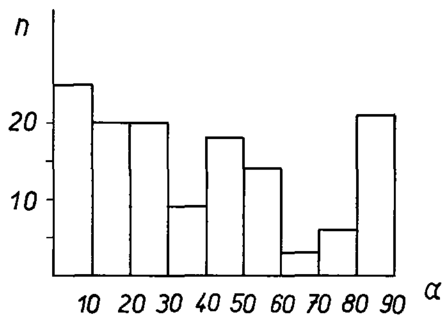

Fig. 7. Occurrence of nearest satellite groups in dependence on the position angle α, determined with respect to the proton group.

C. DIRECTIONAL LOCATION OF SATELLITES AROUND PROTON GROUPS

The directional location of the occurrence of the nearest satellite groups around the proton groups is shown in Figure 7. Besides the main maximum around 0°, which is due to the fact that the occurrence of active regions in the course of the cycle is mostly elongated in longitudinal zones, two subsidary maxima may be seen at 45° and 90°.

The 90° maximum seems to be a typical directional distribution of satellite occurrence around proton groups (e.g. ANTALOVÁ, 1967). This is proved by previous experience which indicates that in the neighbourhood of a certain type of spot group with proton flares the accompanying groups are usually located in the meridional direction with respect to the proton group centres.

The actual interpretation of the subsidiary 90° maximum should be approached with caution as it is not quite clear whether this occurrence frequency increase is not due to the general spot group distribution. On the average the mutual distance of the spots in longitude may be larger than in latitude, in which case a subsidiary maximum must always occur at an angle of 90°. A subsidiary maximum of this kind, however, will also exist even in the case of a completely uniform spot distribution. Its size in both cases, however, will be suppressed due to the fact that spot groups do not occur

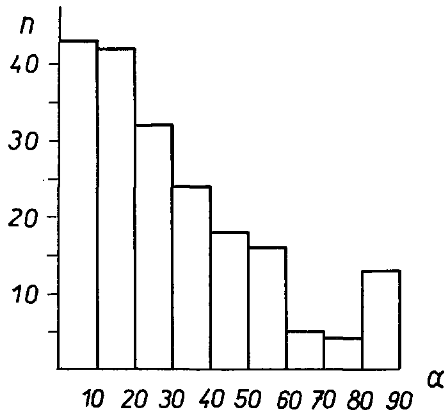

Fig. 8. Occurrence of all satellite groups vs. position angle α.

at high heliographic latitudes and that in this statistical investigation we are considering groups up to a distance of 30° from the reference proton group, so that in a considerable percentage of cases the 30° distance in latitude is no longer within the width of the main zone of active latitudes.

The origin of the 45°–50° subsidiary maximum is not quite clear. In order to clarify this problem it was necessary to treat the directional distribution of all satellites around the proton groups, and not only the nearest satellites.

4. Configuration of the Complex of the Active Region with Proton Spot Groups

In order to elucidate the typical regularities of the generation and occurrence of satellites in the neighbourhood of proton groups, all groups were investigated, which were located within a radius of 30° of the proton group, over a time interval corresponding to Carrington's rotation 1370 to 1430. Figure 8 shows the occurrence frequency of the directional location of all satellites around the proton group. It can be seen that the subsidiary maximum around 50° mentioned, is within the limits of the normal distribution, but the maximum noticeable around 90° is also much weaker.

A more detailed distribution of the occurrence of satellites with a view to the position angle and to distance may be seen in Figure 9. The graph is executed in polar co-ordinates reduced to the 0°–90° sector. It can be seen that the very nearest

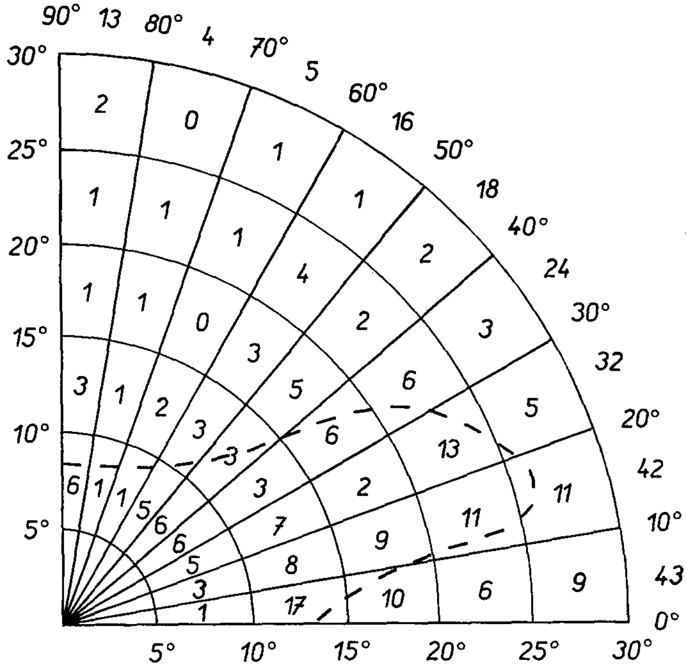

Fig. 9. Division of all satellite groups in dependence on the distance and position angle α. The dashed curve connects the areas with maximum number of satellite groups in the individual sectors.

groups have a tendency to concentrate at large position angles (80°–90°) and at angles between 30° and 50°. The total amount of satellite groups at large angles decreases, but the number of near satellite groups increases at large position angles. The largest relative group concentration within the individual sectors may be seen in the 80°–90° sector for small distances.

It can also be seen that with the occurrence of the groups further away their relative and absolute number decreases with increasing position angle. If the generation of satellites in the neighbourhood of a proton group were not due to a physical complex, but due to a random grouping, one would then have to expect that in each sector, and especially for small position angles (0°–30°), the satellite numbers would increase continuously proportionally to the increase of the areas of the sections in the sectors. As the section area of the angular sectors increases proportionally with the distance, the number of satellite groups should also increase proportionally with the increasing distance. This effect, however, does not occur. There is no proportional increment of satellite occurrence with respect to the area, and in fact from a certain distance a decrease may be observed in the sector fields.

Figure 9 shows a curve joining the maximum values of satellite occurrence frequency in the individual angular sector sections. This curve indicates a maximum increase in the satellite number in the sector sections only at larger distances (10°–15°, 20°–25°) for position angles between 0° and 30°; with position angles between 40° and 90° the maximum concentration of satellite occurrence is to be observed at small distances, 5° to 10°.

On the basis of the information from Figure 9, it is possible to determine the average distance of the satellites in the individual angular sectors. These average distances determine the predominant position of the generation of satellites in the complex connected with the proton group. Figure 10 shows a curve illustrating the average distances of satellite occurrence in the appropriate position angle directions. This curve seems to form part of an ellipse and it is in agreement with the shape of the curve connecting the areas of the most frequent occurrence in each sector, as can

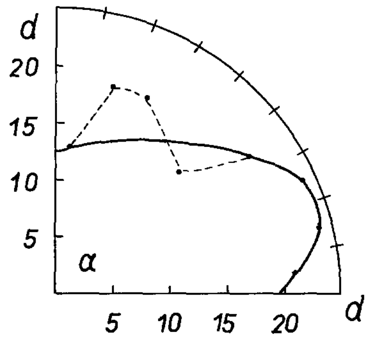

Fig. 10. Average distance curve of satellite occurrence in dependence on the position angles.

be seen from Figure 9. This structure of the active region complex corresponds to the ideas of Bumba and Howard (1964) concerning the elliptic elongation and distribution of spot groups with respect to the initial basic area.

The results mentioned indicate that satellite groups are not randomly distributed around proton groups, but that they are subject to a certain typical distribution in the complex of activity with a proton group.

The structure of the regions with the most frequent generation of satellites allows for the elucidation of the distribution of the nearest satellites according to their distances and position angles. Two maxima in the distances (see Figure 6) agree with the regions of the most frequent occurrence and of the nearest groups. The first maximum corresponds to 5°–10° for the 90° sector, and the second, less expressive maximum around 21° is in agreement with the largest occurrence distance of satellites in the 10°–30° sectors.

The occurrence maxima in the angular distribution around 0° and 90° correspond to the occurrence of the most frequent or the nearest satellites respectively.

5. Conclusion

The occurrence of satellites in the neighbourhood of proton spot groups is considered by the authors to be a physical complex with the following dimensions: 20°–25° in longitude and 10°–15° in latitude.

Around the spot groups, where the proton flares occur most frequently (E, F), there are frequently A to E type groups in the neighbourhood, or groups of decaying types, especially of the J type. Worth mentioning is the increased occurrence of the satellite type E around the proton groups with the E and F types. Around the H type group, which is also very frequent, there are to be found nearly exclusively groups of the younger types.

The problem is whether the interpretations given, based on the comparison with an average distribution, can be used to explain the physical connection and contingency of the proton region cases. This would necessitate a special investigation of the statistical distribution of the group types and their distances at the time of the occurrence of solar activity 'impulses' (Gnevyshev, 1938), when a series of spot groups occurs simultaneously at not too large a distance (a complex, large region composed of individual groups).

The fact remains that the proton spot groups with proton flares are to be found in special group complexes of a certain group type described. We do not know whether our results are applicable to the proton complexes only, or to all 'impulses', but it seems to us that they prove the existence of solar complexes in general.

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