SUNSPOT CHANGES FOLLOWING PROTON FLARES

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ABSTRACT

Although the area of some sunspot groups declines suddenly after a flare that produces energetic protons, other groups show a delayed or gradual decline, or continue to grow for several days after the flare. The mean area of sunspot groups that produced flares with polar-cap absorption declines gradually and continuously, beginning within a day after the flare.

This paper describes a search for a characteristic change in sunspot area at the time of a major flare in the group. The total energy released by such a flare, in the form of particles and electromagnetic radiation, sometimes amounts to a noticeable fraction of the total magnetic energy in the sunspot group, and no other energy supply is sufficient. Cases in which the total magnetic flux and the field gradient declined measurably after a particularly energetic flare have been described (Gopasyuk *et al.*, 1963; Howard and Severny, 1963), and Howard (1963) noted that the total area of the sunspot group decreased after several flares that produced an increase in cosmic-ray flux at ground level (GLE). On the other hand, Bruzek (1960) found that both sunspots and their magnetic fields developed smoothly around the time of major flares, and Newton and Howe (1952) found no unusual area change, on the average, at the time of flares of importance 3 and 3+. We ask here whether a measurable decrease in sunspot-group area is usual after flares that produce protons of relativistic (GLE) or sub-relativistic (PCE) energy.

First, the area and appearance of the sunspot group at the time of 3 proton flares were examined in some detail. The first of these flares occurred early on July 7, 1966, and was accompanied by a ground-level cosmic-ray increase and by rather weak polar-cap absorption. Routine daily measurements of the total area (penumbra and umbra) of the sunspot group made at different observatories each showed that the group continued to grow after the flare (Table 1). The growth was rapid enough that even the projected area increased although the group was already West of central meridian. Figure 1 shows the total corrected area of the sunspot group through its passage. A more detailed look at the group's development convinces us, however, that the total area is not relevant. Figure 2 shows the spot group before the flare, with the flare position indicated. Although both the leading and following parts of

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Table 1

Sunspot-group area measured before and after proton flares

A_H (mill. hem.) = A_D (mill. disk) × $\frac{1}{2}$ × secant of central angle

Flare time	Time of measurement	Projected area, A_D (mill. disk)	Corrected area, A_H (mill. hem.)	Source
1966				
July 07·0	July 06·2	1134	797	*Solnechnye Dannye*
	07·2	1282	1235	
	July 06·3	1082	780	Rome
	07·3	1400	1255	
	July 06·4	1151	887	U.S. Naval Observatory
	07·4	1175	1140	
1966				
Aug 28·6	Aug 28·2	814	425	*Solnechnye Dannye*
	29·2	1564	810	
	Aug 28·2	738	387	Rome
	29·2	859	448	
	Aug 28·5	241	125	U.S. Naval Observatory
	29·5	799	416	
1966				
Sept 02·2	Sept 02·2	1048	904	*Solnechnye Dannye*
	03·2	712	934	
	Sept 01·3	1273	917	Rome
	02·3	986	967	
	03·3	620	989	
	Sept 01·4	872	636	U.S. Naval Observatory
	02·6	872	939	

the group grew after the flare, the umbrae in the central portion that lay directly under the flare did decay. Figure 3 shows the area development of two separate umbrae: the growing Northern umbra in the leading part of the group, and the Northernmost central umbra, which lay under intense flare emission and which decayed after the flare. At the same time, the penumbra in the central region, which was particularly dark before the flare, became weaker and broken with bright patches. These changes began, as closely as can be determined (within several hours), at the time of the flare. The close spatial and temporal association leads us to consider this group as a case in which significant decay of the sunspot-group area followed a major flare. The magnetic field of this group varies quite differently than its area (Severny, 1967). Integrated energy, net flux, and gradient of the longitudinal field all reach a maximum a day before the flare, and decline thereafter.

Now we turn to the sunspot group that produced on August 28, 1966 a flare with moderate polar-cap absorption and on September 2, a still more energetic flare with fairly large PCA. Table 1 and the corrected-area curve sketched in Figure 4 show that

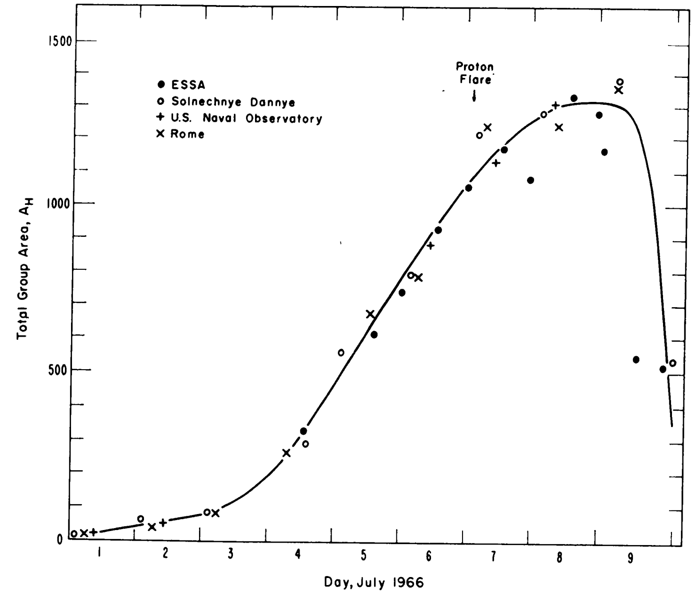

FIG. 1. *Total area, corrected for foreshortening, of the sunspot group in which occurred the proton flare of July 7, 1966.*

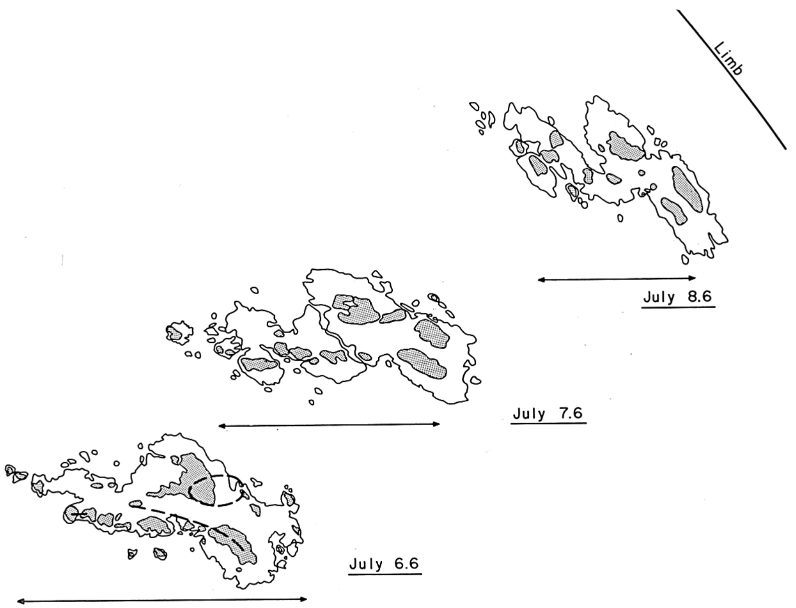

FIG. 2. *Sketches of the spot group before and after the proton flare of July 7, 1966. The position of the flare is indicated in the earliest sketch. The straight line under each sketch, proportional to the cosine of the central angle of the sunspot group, helps to estimate the effect on the apparent area of foreshortening. Note the decay of the two umbrae that were largest before the flare and that lay directly under the flare and note also the break-up of the penumbra in the flare region.*

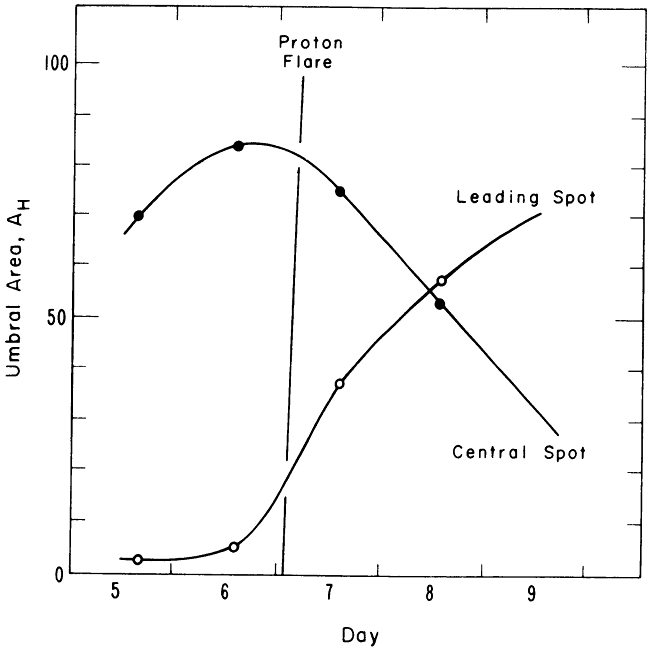

FIG. 3. *Corrected area of the Northernmost umbra in the central portion of the spot group and of the Northern umbra in the leading part.*

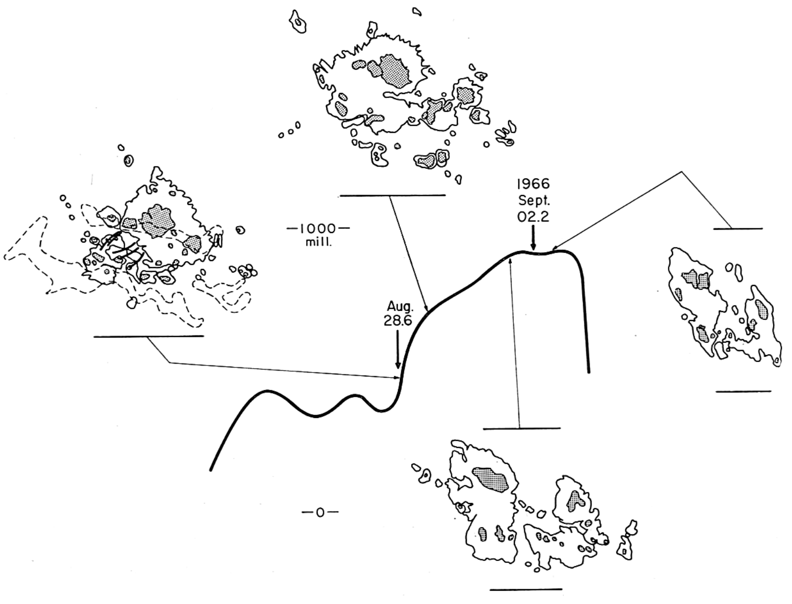

FIG. 4. *The curve of corrected area of the sunspot group from August 22 to September 4, 1966, with sketches of the group before (or during) and after the proton flares of August 28·6 and September 02·2. The length of the horizontal lines with each sketch is proportional to the cosine of the angular distance of the group from disk center. The position of the August 28 flare is indicated by dashed lines. In this case, parts of the group that were directly under the flare of August 28 – for example, the leading Northern umbra, continued to grow after the flare.*

the total area of this group, too, continued to increase during the several days between the two flares, and for about a day after the second flare. In this case, we are unable to find a part of the group that was especially close to the flare and that clearly decayed after the flare. The obvious changes in the group are the separation of the leading portion and the coalescence of the growing, following part with the central portion; these seem to fit the picture proposed by Gopasyuk *et al.* (1963) of the approach of spots of opposite polarity, and ejection of a secondary spot of the same polarity as the principal umbra.

Descriptions found in the literature of spot groups with great flares present an equally ambiguous picture. A flare on February 28, 1942 produced the first recognized cosmic-ray increase and the first recorded solar radio burst. The Greenwich observers note of the parent spot group that "... a marked decline sets in after February 28". Nevertheless, a second cosmic-ray increase was observed a week later, when this region, with area only half its maximum value, was near West limb. On the other hand, the group that produced the GLE flare of July 25, 1946 is described as "remarkably stable, undergoing very little radical change throughout its transit". We may also reread with interest Carrington's (1859) description of the sunspot group in which he observed a white-light flare: "It was impossible, on first witnessing an appearance so similar to a sudden conflagration, not to expect a considerable result in the way of alteration of the details of the group in which it occurred; and I was certainly surprised, on referring to the sketch which I had carefully and satisfactorily (and I may add fortunately) finished before the occurrence, at finding myself unable to recognize any change whatever as having taken place."

The contradictory evidence presented by individual cases leads us to examine the Greenwich measures of sunspot-group areas at the times of a larger number of flares. Figure 5 shows the corrected area of the sunspot group measured before and after 14 GLE flares. The tail of each arrow is at the relative area and central meridian distance of the sunspot group at the time of the daily measurement made before the flare, and the arrowhead at the point representing the measurement made after the flare. The area does indeed decrease in the majority of cases, but there are clear exceptions. Furthermore, since most of these flares occurred when the group was West of central meridian, we should expect in any case that the area would decrease as the group approached the limb.

The shaded curve shows the mean corrected area of large ($A_H \geqslant 400$ mill.) sunspot groups that were observed through a complete or nearly complete disk passage. The curve is very similar to that for a large sample of sunspot groups that produced PCE flares, and although we do not understand the large asymmetry, we believe it is an appropriate estimate of the way a sunspot group's area varies, regardless of individual flares. Most of the area changes at the time of GLE flares are similar to the expected change during normal development and rotation of such a group. Perhaps it is significant that of three groups that showed an anomalous area *increase*, two produced a second GLE flare (connected by broken lines). We should also note that the sunspot group that produced the flare of July 16, 1959 (after PCE flares on July 10 and 14) did reach its maximum area within a day after the GLE flare, declining thereafter.

Finally, we looked for evidence of a general decrease in sunspot-group area follow-

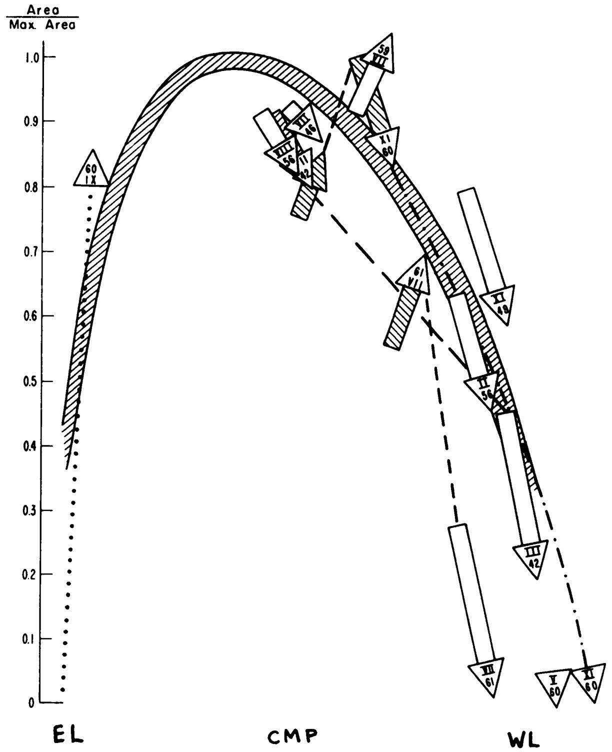

FIG. 5. *The arrows show the relative corrected area and the central meridian distance of the sunspot group before and after each of 14 GLE flares. The shaded curve shows the expected area change during development and rotation of large, long-lived spot groups. Dotted lines connect GLE flares that occurred in the same group, and shafts of arrows representing the early flares are shaded.*

ing a proton flare. Sixty-three PCE flares that occurred between 1956 and 1963 in sunspot groups with area measured within one day both before and after the flare formed the observational sample. The lower, solid curve in Figure 6 shows the mean value of the sunspot-group area on successive days around the flare day. The day of the flare marks the beginning of a consistent decline in area. The area change due to rotation and development of the group was assumed to follow the curve shown in Figure 5, and each area was divided by the relative area appropriate to its central

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distance, to give the corrected area plotted as the upper curve in Figure 6. The run of the corrected areas is generally similar to that of the uncorrected mean areas, except that the correction pushes the maximum ahead to the first measurement after the flare.

We conclude that, in general, sunspot-group area declines after a proton flare (or that the flare occurs near maximum development of the sunspot group). There are clear exceptions to this rule, when the group continues to grow after the flare. Many

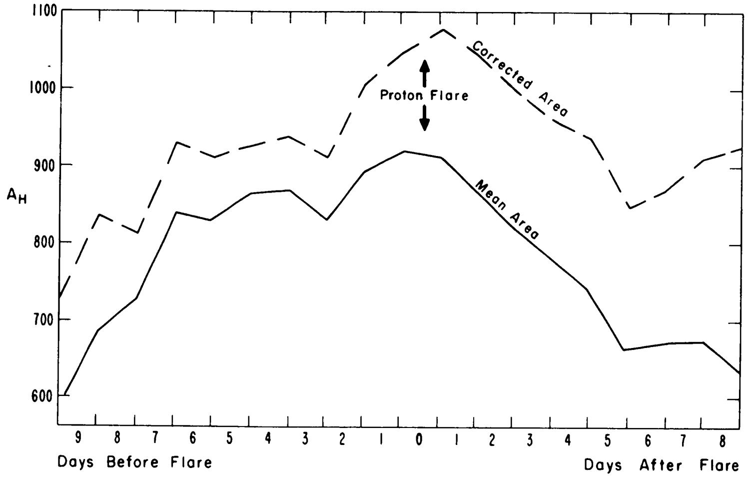

FIG. 6. *Mean sunspot-group area (lower, solid curve) around the time of 63 PCE flares. Areas shown in the upper, broken curve are corrected for effects depending on the central distance (see text). The standard error of the mean corrected area on day 0 is 79 millionths of the solar hemisphere.*

times, the spots show no sign of decay until hours after the flare, and then the area decreases gradually and smoothly. Sunspot area would seem to respond much less sensitively to the occurrence of an energetic flare than do magnetic parameters, and to vary somewhat independently of the field. Isolated cases do exist when the decline of sunspot area sets in suddenly and immediately after the flare, and strongly suggests a physical connection.

Acknowledgements

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DISCUSSION

Bumba: As was shown by Mrs. Fortini and Mrs. Martres, there are some indications that the proton-flare active regions develop from at least two and often from even more sunspot groups. Therefore it may be very difficult to study the relations of the total area changes of this complex situation to the proton-flare events. Usually several days are needed for the individual spotgroup to interact. Maybe the investigation of area changes of the individual components of the complex group may give better results.