SUNSPOT POPULATIONS AND THEIR RELATION WITH THE SOLAR CYCLE*

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Abstract. The joint consideration of theoretical and observational arguments is used to conclude that two different spot populations co-exist in the Sun.

1. Introduction

If present cycle 21 behaves in the same way as previous cycles of solar activity, we can expect to observe an increase in the percentage of large sunspot groups and a new maximum in the terrestrial effects of solar activity, around year 1982 (see Section 4).

That fact, produced by a different frequency of apparition of large and small sunspot groups, is considered with some theoretical discussions (Section 2), observations of spot formation (Section 3) and some reports about features depending on the size of the spot: speed of rotation (Ward, 1966); type of spot disintegration (Bumba, 1963); presence of spiral structures (Richardson, 1941); etc.

From the above aspects we conclude the existence of two different sunspot populations (Section 5).

2. Theoretical Discussion

Generally, it has been accepted that magnetic flux, after emerging through the photosphere, is swept by horizontal motions and concentrated to form spots in the corners where several supergranules meet.

In order to be transported by convective motions, the magnetic fields must be kept within a certain strength B_e given by the equipartition between the local magnetic energy density and the kinetic energy density of the motions ($B_e^2/8\pi \approx (\frac{1}{2})\rho v^2$).

At the visible surface of the Sun, the observed velocity of the horizontal motions in supergranules is ≈ 0.4 km s^{-1} (Leighton, 1963) and $\rho \approx 3\times 10^{-7}$ g cm^{-3} yields a B_e of ≈ 100 G.

The magnetic flux through a spot is $\Phi \sim 0.45.\ B(0)A$ (A: area, $B(0)$: central magnetic field) (Gokhale and Zwaan, 1972). Areas of sunspots range from $\lesssim 10$ to $\gtrsim 3000$ units (10^{-6} solar hemisphere) and B's from $\lesssim 500$ G to $\gtrsim 4000$ G. Two general examples of spots are: a large spot with $A = 1000$ units and $B(0) = 3500$ G

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($\Phi \times 10^{22}$ Mx.) and small one with $A = 20$ units and $B(0) = 1000$ G ($\Phi = 2.7 \times 10^{20}$ Mx.)

Recalling that magnetic field strength must remain below B_e, we get, for the large spot, a field of strength 100 G spread over an area of 4.7×10^{20} cm^2 (some 66 supergranule cells) and, as discussed by Piddington (1978), instead of a bipolar group we should end up with several concentrations of flux scattered over the area.

The result for the small spot is however qualitatively different because a field of 100 G would occupy an area of only 2.7×10^{18} cm^2 (about 0.4 that of a supergranule cell) to possess a flux of 2.7×10^{20} Mx. In this case the magnetic flux can easily be concentrated to form spots.

3. Observations

It seems from the previous section that, on theoretical grounds, two different mechanisms of sunspot formation *can* exist. If they *do* indeed exist, differences would readily be detected when birth and development of active regions are observed.

We have started a programme of observations to search for those differences and, although there are several aspects to be observed, in the first stage we have restricted ourselves to the study of the birth of active regions, especially to the motions of pores.

This set of observations includes the birth and first stages of development of twenty active regions, recorded in white light pictures taken with a 10–15 min interval. Observations were made at the Observatory of the IAC at Izaña (Canary Islands) during three periods in 1980 (April 3 to 6; May 29 to June 15 and July 21 to August 16), with a 40 cm-vacuum telescope with 5.5″ mm^{-1} scale at the focal plane.

As a summary of the preliminary results of the data analysis, two typical examples are discussed.

Spot group A: Born at 11° S, 60° E on May 31. It reaches a maximum area of 100 units and $\Phi \approx 2.4 \times 10^{21}$ Mx, so it can be considered as a small group (recall Section 2). It has been observed for a mean of 7 hr per day.

Spot group B: Born at 5° S, 43° E on August 3. It reaches an $A_{max} = 340$ units and $\Phi \approx 10^{22}$ Mx which allows us to consider it as a large group. Observations have been made for a mean of 8.5 hr per day.

More extreme cases were observed, with fluxes as low as 6.7×10^{19} Mx and as high as 6.2×10^{22} Mx, but they were scarce.

The following characteristic has been observed (Figure 1):

Spot group A:

(i) Magnetic flux is restricted to an area of the order of a supergranule cell (Figure 1(a), (b)).

(ii) Pores are concentrated at the edges of the active area.

(iii) Ordered motions of pores with velocities $\sim 0.1 \text{ km s}^{-1}$ are observed to carry them towards the two opposite corners where the *p*- and *f*-spots are going to be formed.

(iv) After the first two days no more flux emerges at the surface (Figure 1(c), (d)) and a certain degree of stability it is observed.

Spot group B:

(i) The area containing magnetic flux is very elongated in the E–W direction and its longer dimension ($\approx 4.6 \times 10^4$ km) is doubled during the emergence of flux.

(ii) Pores are not observed encircling any area of supergranule size, but on the contrary they move along more or less straight paths from the region's centre towards both *p*- and *f*-extremes of the region, with velocities of the order of 0.2 km s^{-1}.

(iii) New flux is observed continuously emerging during several days (≈ 8 days). A certain amount of it, emerges already concentrated (not in the form of pores, but larger elements) right at the *p*- or *f*-parts of the region, leaving the existent flux almost undisturbed.

From the analysis of the whole set of data (13 small spots and 7 large spots) it can be concluded that the differences between large and small spots are deeper than the amount of flux contained.

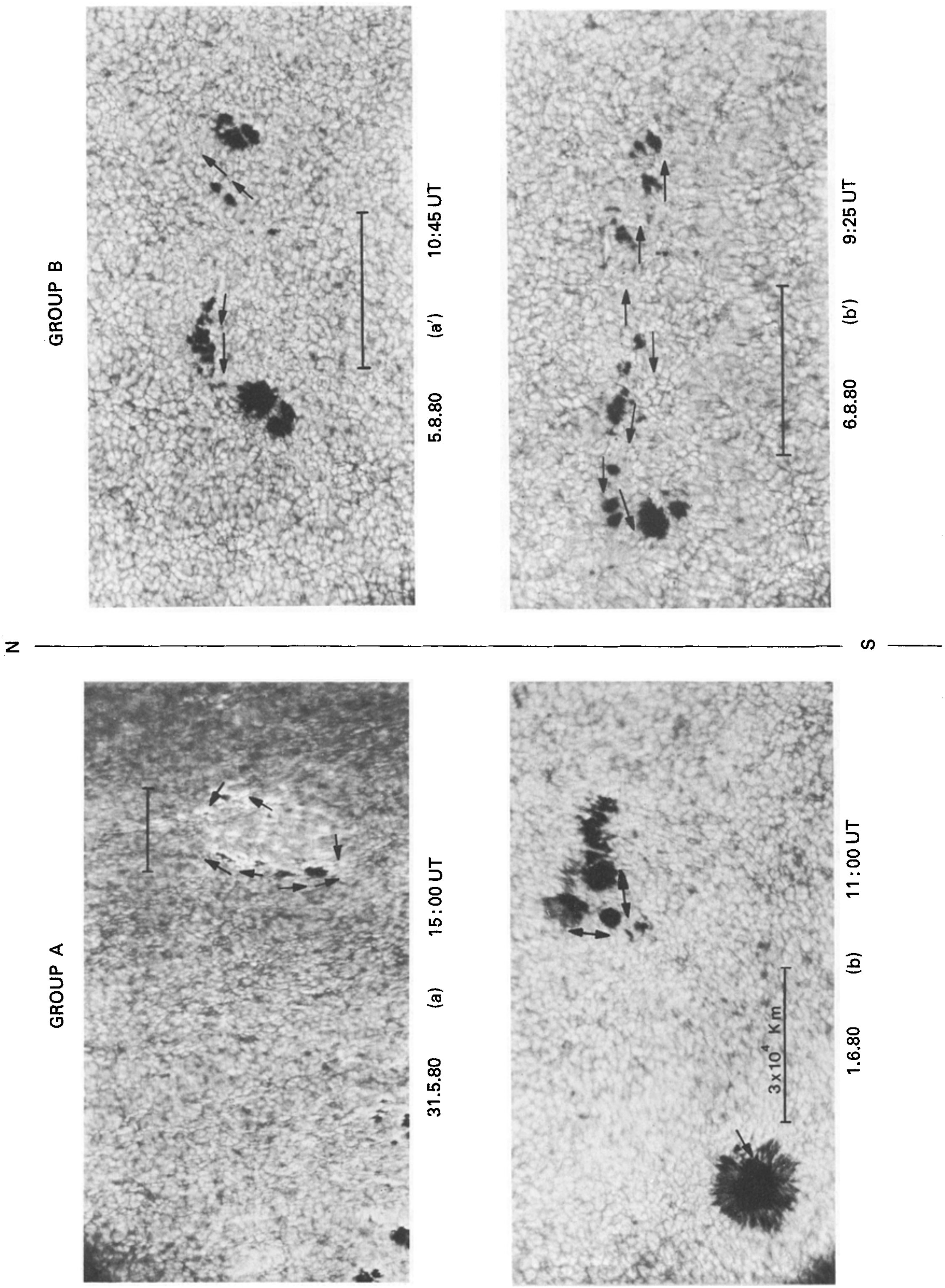
4. Two Maxima of the Solar Cycle

A remarkable feature of the 11-year cycle is the presence of two maxima when suitable parameters are considered. In fact, if the areas of the spots are considered, different frequency distributions are obtained; for instance, in Figure 5 of Gnevyshev's paper (1967) it is shown that the number of spots with areas smaller than 200 units displays no double maximum, this being however very conspicuous when areas greater than 500 units are considered.

The first maximum coincides with that of the Wölf Number, while the second one appears about two or three years later, showing an increase in the percentage of large spot groups. This fact besides the restriction of the second maximum to low latitudes (a more convenient position for the Earth) makes it important for terrestrial effects.

For example, some observed phenomena displaying the two-maxima law, are: The 5303 Å coronal line intensity (Gnevyshev, 1977); occurrence of proton flares displaying either PCA's (Polar Cap Absorption) or GLE's (Ground Level Effect) (Křivský and Krüger, 1966; Hakura, 1974); variability of the H component of the geomagnetic field (Bhargava and Yacob, 1974); geomagnetic index ΣK_p and number of auroras where the second maximum is the most prominent; etc.

Two important features which should probably be included in the above list are the predominance of long-lived streams of high-speed solar wind during the second


GROUP B
5.8.80 (a') 10:45 UT
6.8.80 (b') 9:25 UT
N
S
GROUP A
31.5.80 (a) 15:00 UT
1.6.80 (b) 11:00 UT
3x10⁴ Km

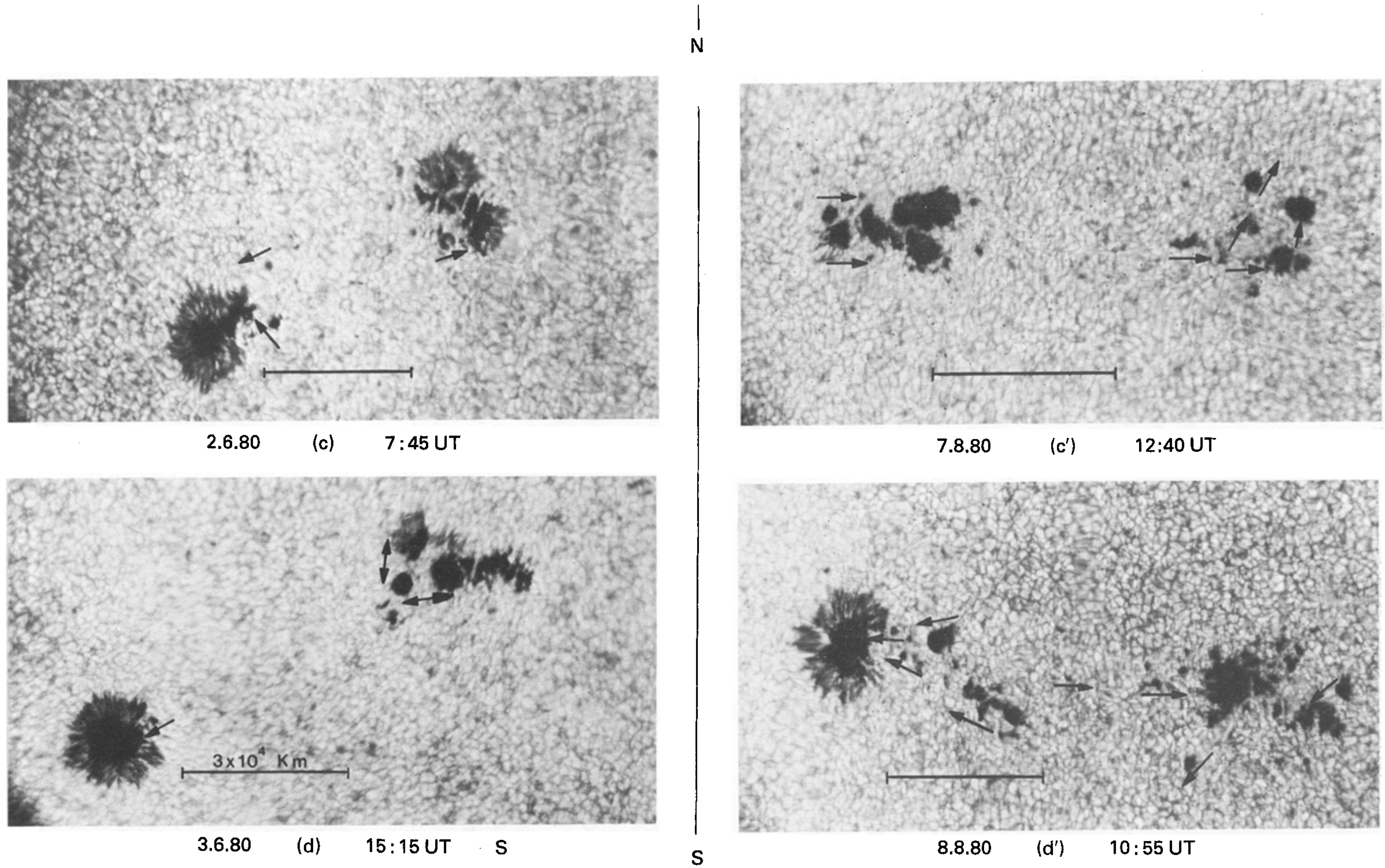


Fig. 1. Birth and development of relatively small (left) and large (right) sunspot groups. Arrows indicate directions of observed motions. Scale length is 3×10^4 km.

maximum ($\approx$1972) of cycle 20 (Hundhausen, 1979) and the predominance of an almost rigid law of solar rotation during the same maximum (Antonucci and Svalgaard, 1974).

5. Discussion and Conclusions

The important departures from the single-maximum law cast doubts about the adequacy of the Wolf number as the best index of solar activity, suggesting instead of it, an index taking into account the size and importance of the sunspot groups.

At this stage of the subject we have to accept the rough and inaccurate classification into large and small spot groups, until analysis of other aspects can clarify where the limit is.

Studies on the buoyancy of magnetic flux tubes, carried out under different approximations (Parker, 1979; Schüssler, 1977), conclude that, weaker flux tubes show much smaller rising velocities than larger ones. So, if they are observed to coexist at the surface and the timescales involved are of the same order, one must conclude that they start at very different levels of the Sun, reinforcing the idea of different origins for large and small groups.

Much work remains to be done, but preliminary conclusions are:

(1) Two spot populations exist in the Sun. One is formed by large and stable groups, which are already concentrated when they emerge through the surface, displaying a double maximum in their frequency of apparition. The other one is formed by small and unstable groups, concentrated by the convective motions at the upper layers of the solar atmosphere and showing a single maximum in their frequency of apparition along the 11-year cycle.

(2) It seems likely that each population is related to a different source, located at a distinct level of the Sun. That of the small groups is probably located not very far from the surface, and the source of large regions near the bottom of the convective zone. This last one is perhaps related to a primeval magnetic field, as suggested by Dicke (1979) and Layzer *et al.* (1979), but this is still rather speculative.

References

Antonucci, E. and Svalgaard, L.: 1974, *Solar Phys.* **34**, 3.
Bhargava, B. N. and Yacob, A.: 1974, *Ann. Geophys.* **30**, 487.
Bumba, V.: 1963, *Bull. Astron. Inst. Czech.* **14**, 91.
Dicke, R. H.: 1979, *Astrophys. J.* **228**, 898.
Gnevyshev, M. N.: 1967, *Solar Phys.* **1**, 107.
Gnevyshev, M. N.: 1977, *Solar Phys.* **51**, 175.
Gokhale, M. H. and Zwaan, C.: 1972, *Solar Phys.* **26**, 130.
Hakura, Y.: 1974, *Solar Phys.* **39**, 493.
Hundhausen, A. J.: 1979, *Rev. Geophys. Space Phys.* **26**, 130.
Křivský, L. and Krüger, A.: 1966, *Bull. Astron. Inst. Czech.* **17**, 243.
Layzer, D., Rosner, R., and Doyle, H. T.: 1979, *Astrophys. J.* **229**, 1126.
Leighton, R. B.: 1963, *Ann. Rev. Astron. Astrophys.* **1**, 19.

Parker, E. N.: 1979, *Cosmical Magnetic Fields,* Chap. 8, Clarendon Press, Oxford.
Piddington, J. H.: 1978, *Astrophys. Space Sci.* **55**, 401.
Richardson, R. S.: 1941, *Astrophys. J.* **93**, 24.
Schüssler, M.: 1977, *Astron. Astrophys.* **56**, 439.
Ward, F.: 1966, *Astrophys. J.* **145**, 416.