UMBRAL DOTS: A CASE OF PENETRATIVE CONVECTION BETWEEN SUNSPOT FRAGMENTS

J. I. GARCÍA DE LA ROSA
Instituto de Astrofísica de Canarias, 38200 – La Laguna, Tenerife, Spain

(Received 15 June, 1987)

Abstract. A study of the observations made on the development and, in some cases, even the decay of 15 large active regions is presented. It is shown that the mature spots result from the subphotospherically controlled attraction of several large fragments of \(1-2 \times 10^{21} \text{ Mx}\), which are themselves made of smaller elements. The fragments are more stable structures than the spots they constitute; and usually survive after the spot decay. In the process of coalescence of fragments to form the spot, the fusion is never complete and properly exposed photographs reveal light bridges or saddle-like distributions of umbral dots in the interstices between fragments. These are also the regions along which the break up of the spot occurs. For us, these observations fit within the expectations of the penetrative convection mechanism for umbral dots proposed by Parker (1979b).

1. Introduction

Nowadays, penetrative convection is likewise: overstable convection (Cowling, 1976), Joule heating (Bruzek, 1977), and non-thermal heating (Kitai, 1986), one of the rival mechanisms trying to explain the nature of umbral dots.

Penetrative convection (Parker, 1979b) results from the occasional upward intrusion to the surface of hot field free gas, driven into strong vertical oscillations by the convective forces at a few hundred kilometers beneath the surface. Those oscillating columns of hot gas are supposed to exist between each of the many isolated magnetic tubes which, according to the cluster model, constitute the sunspot (Parker, 1979a).

Three years ago, Knobloch and Weiss (1984) in an attempt to criticize the penetrative convection mechanism, used the following argument: "Hot field-free gas, penetrating between the flux tubes, should form a bright network, outlining the individual tubes. Had such a network been observed, it would have provided a powerful argument in favour of the cluster model." This paper deals with the search for that 'powerful argument', despite the well-established observation that umbral dots are found in every place of the umbra (Bumba and Suda, 1980). However, not all the umbral dots are alike. This is also well established by the observations which show that inside the well developed and regular umbrae there are several dark nuclei only prevaded with extremely tiny bright points (Bray and Loughhead, 1964). In fact, Grossmann-Doerth et al. (1986) have emphasized the need for a division of the umbral dots into two groups: Peripheric Umbral Dots (PUD), being the most conspicuous and widely discussed in the literature and the Central Umbral Dots (CUD), corresponding to the tiny samples in the dark nuclei, which are very difficult to detect.

In the present paper, the observation of the developing and stable phases of several sunspot groups (Section 2) shows us that sunspots result from the coalescence of a few
fragments, which keep their identity even until the sunspot decay (Section 3). It is concluded (Section 4) that the close correspondence between the PUD's and the periphery of the fragments, indicates that, at least, those umbral dots make the bright network expected by Knobloch and Weiss (1984) although at a somewhat larger scale than predicted by the cluster model (Parker, 1979a).

2. Observations

The analysed material was obtained during an observing campaign related with the birth of active regions, where a sample of 73 cases was recorded. There are two main observational requirements for the present study: (i) active regions should be large enough to develop a fairly regular spot (types C to F in the Zürich classification); (ii) observations should be long enough to cover not only the birth but also the developing, the stable or even the decaying phases. Only 15 out of the 73 regions fulfil these requirements and have been therefore selected for the present study. Their mean magnetic flux (maximum) is $1.6 \times 10^{22}$ Mx and the mean observing period is 6 days/region; in contrast with $2 \times 10^{21}$ Mx and 2.6 days/region for the rejected cases. It is worth mentioning that no bias was introduced during this selection process, because almost all the rejected active regions are classified as small, according to the division proposed by the author (Garcia de la Rosa, 1984). In this division, the small active regions ($\Phi_{\text{max}} < 5 \times 10^{21}$ Mx) show small fragments which generally fail to coalesce into a single spot, making them useless for the present study.

Exceptionally, three of the rejected regions show $\Phi_{\text{max}} > 5 \times 10^{21}$ Mx (large active regions) but in those cases, the rejection is just due to the poor quality or length of the data.

The observations were made at the Observatorio del Teide using the 40 cm Vacuum Telescope of the Kiepenheuer Institut (F.R.G.) with a scale of $5.5'' \text{mm}^{-1}$ at the focal plane. Six out of the fifteen regions were recorded in white light during 1980 and the other nine in both H$\alpha$ and H$\alpha - 0.5$ Å and $-1$ Å during 1981–82, with a Halle filter tunable $\pm 1$ Å with 0.5 Å passband. The mean daily observing time was 9.5 hr with an average of two hours with very good seeing.

3. Results

These are the main results of our analysis of the data:

3.1. Sunspots result from the coalescence of a few large fragments, which are themselves made of typically 2–3 smaller elements. The mean flux content of the large fragments is $1-2 \times 10^{21}$ Mx

Although this is a well-established result (Zwaan, 1985) it should be emphasized that even though a whole hierarchy of fragments exists, the final spot only results from the coalescence of the largest fragments instead of the smallest units.