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## **Time evolution of fine structures of a main sunspot in the SD108 and SD284 groups**

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### **RESUMEN**

Mediante el cifrado de fotoheliogramas tomados en la Estación de Montaña de Pamir (resolución espacial de 0.3"), con ancho de banda de 40 nm centrado en los 650 nm, se obtuvo una secuencia de imágenes estandarizadas para el estudio dinámico de detalles de la umbra y la penumbra de la mancha principal del grupo. Se presentan los elementos básicos de la metodología de estandarización, así como los resultados morfológicos y fotométricos obtenidos.

Si bien nuestras imágenes muestran, por simple inspección visual, la presencia de filamentos brillantes y oscuros en la penumbra, no se encontró un claro indicio de dos niveles fotométricos de brillo distintivos. Se determinó que el valor característico de la intensidad de la penumbra varía con el tiempo, lo que será investigado posteriormente. Se detectó la presencia de puntos y núcleos umbrales, analizándose su distribución espacial. Se determinó un valor característico del diámetro para los puntos umbrales.

**PALABRAS CLAVE:** puntos umbrales, núcleos umbrales, filamentos penumbrales, manchas solares.

### **ABSTRACT**

Photoheliograms taken at the Pamir Mountain Station (spatial resolution 0.3 arcsec) centered on 650 nm with a 40 nm bandwidth are used to obtain a standardized sequence of images for the dynamical study of some umbra and penumbra details of the main sunspot.

Our images show, through visual inspection, the presence of bright and dark filaments in the penumbra. However, a clear indication of two distinct photometric levels was not found. A temporal variation of the characteristic penumbra intensity value was detected, which will be investigated later. Umbral dots and nuclei were detected and their spatial distributions were analyzed. A characteristic value for the umbral dots diameter was obtained.

**KEY WORDS:** umbral dots, umbral nuclei, penumbral filaments, sunspots.

### **INTRODUCTION**

The dynamics of fine structures is an important aspect in the study of sunspots. While the study of proper motions is related to the large-scale characteristics of the solar interior, the dynamics of the details is more linked to the energy transfer processes, in particular to the characterization of the force-free fields. An indispensable requirement for these studies is a sequence of high-resolution photoheliograms with appropriated contrast and time intervals.

In the last years, some archive material has been rescued and digitized (Rodríguez, 1995; Györi *et al.*, 1998). Many researchers have created methods to obtain different morphologic and geometric parameters from this digital information (Rodríguez E. R. *et al.*, 1997; Rodríguez R. E. *et al.*, 1997; Pettauer and Brandt, 1997; Doval *et al.*, 1999; Rodríguez and Gámez, 2000). In this paper we combine these aspects to study sunspot fine structures and their temporal evolution.

### **MATERIALS AND METHODS**

White-light photographs were taken with a 50 cm reflector (120 m focal length) at the Pamir Mountain Station (4300 m above sea level), with a spatial resolution of 0.3 arcsec ("). For detailed information about this telescope and the observation site see Parfinenko and Miklalev (1978).

The characteristics of the photographic material (120 mm format) are a 3 DIN sensibility and a resolution of 120 lines per millimeter. For these observations a 40 nm bandwidth centered in 650 nm was obtained from film-filter spectral response combination. The exposure time was 1.5 ms and the quality of the photoheliograms is excellent (Parfinenko, 1999).

We analyze the possibility to work with prints of the photoheliograms (positives) to study the high-contrast details in the penumbra. For this analysis 16 negatives taken in October 1978 were converted to positives and scanned to

150 p.p.i. (pixels per inch) and 256 gray levels. To study umbral details the negatives on September 30th (1977), October 4th and 6th (both of 1978) were scanned to 300 p.p.i. and 256 gray levels. A total of 19 work images were obtained (Table I). The used informatics tools were the image processors UNESCO Bilko for Windows (version 2.0) and DIPSY (version 1.0).

In previous works, the fundamental tool for the determination of the structure of different solar regions has been the determination and analysis of cumulative histograms (Rodríguez, 1995; Rodríguez R. E. *et al.*, 1997). The cumulative histogram is not addressed to analyze a particular feature, but to analyze statistically the photometric characteristics of an image without a detailed processing of many individual structures. This is the main advantage of the method.

**Table 1**

Images characteristics. The area is expressed in square arcsec. The image Qn contains the SD 108 group, the others the SD 284 group. The images Qn, Rn and Sn have been obtained from negatives. SD - Solnechnye Dannye Classification. Legend: dd-day, mm-month, yyyy-year, IR-intensity range.

| Image          | dd/mm/yyyy | Time<br>(T.U.)                                 | Area            | IR<br>(gray levels) |
|----------------|------------|--|-----------------|---------------------|
| A              | 02/10/1978 | 3 <sup>h</sup> 30 <sup>m</sup> 13 <sup>s</sup> | 39.0'' × 44.4'' | [68,254]            |
| B              | 02/10/1978 | 4 <sup>h</sup> 34 <sup>m</sup> 02 <sup>s</sup> | 39.0'' × 45.6'' | [63,244]            |
| C              | 03/10/1978 | 2 <sup>h</sup> 58 <sup>m</sup> 20 <sup>s</sup> | 41.4'' × 45.0'' | [47,254]            |
| D              | 03/10/1978 | 3 <sup>h</sup> 56 <sup>m</sup> 50 <sup>s</sup> | 46.0'' × 44.8'' | [46,254]            |
| E              | 03/10/1978 | 4 <sup>h</sup> 01 <sup>m</sup> 44 <sup>s</sup> | 47.2'' × 46.8'' | [49,254]            |
| F              | 03/10/1978 | 4 <sup>h</sup> 19 <sup>m</sup> 06 <sup>s</sup> | 46.0'' × 47.4'' | [48,254]            |
| G              | 03/10/1978 | 5 <sup>h</sup> 23 <sup>m</sup> 28 <sup>s</sup> | 43.8'' × 48.0'' | [53,254]            |
| H              | 04/10/1978 | 2 <sup>h</sup> 22 <sup>m</sup> 20 <sup>s</sup> | 49.6'' × 43.6'' | [55,254]            |
| I              | 04/10/1978 | 3 <sup>h</sup> 24 <sup>m</sup> 11 <sup>s</sup> | 48.0'' × 43.6'' | [47,254]            |
| J              | 04/10/1978 | 4 <sup>h</sup> 33 <sup>m</sup> 07 <sup>s</sup> | 46.0'' × 48.0'' | [62,254]            |
| K              | 04/10/1978 | 5 <sup>h</sup> 10 <sup>m</sup> 14 <sup>s</sup> | 45.0'' × 45.6'' | [55,254]            |
| L              | 05/10/1978 | 2 <sup>h</sup> 56 <sup>m</sup> 01 <sup>s</sup> | 57.6'' × 43.8'' | [49,254]            |
| M              | 05/10/1978 | 4 <sup>h</sup> 37 <sup>m</sup> 08 <sup>s</sup> | 54.4'' × 44.4'' | [67,253]            |
| N              | 06/10/1978 | 3 <sup>h</sup> 42 <sup>m</sup> 23 <sup>s</sup> | 60.6'' × 50.8'' | [79,254]            |
| O              | 06/10/1978 | 3 <sup>h</sup> 55 <sup>m</sup> 05 <sup>s</sup> | 62.4'' × 49.2'' | [52,254]            |
| P              | 07/10/1978 | 3 <sup>h</sup> 20 <sup>m</sup> 39 <sup>s</sup> | 69.6'' × 51.4'' | [45,254]            |
| Q <sub>n</sub> | 30/09/1977 | 4 <sup>h</sup> 46 <sup>m</sup> 17 <sup>s</sup> | 48.9'' × 35.7'' | [10,255]            |
| R <sub>n</sub> | 04/10/1978 | 4 <sup>h</sup> 33 <sup>m</sup> 07 <sup>s</sup> | 30.9'' × 35.7'' | [12,255]            |
| S <sub>n</sub> | 06/10/1978 | 3 <sup>h</sup> 42 <sup>m</sup> 23 <sup>s</sup> | 50.3'' × 35.0'' | [23,246]            |

#### Calibration and standardization of the images

The images have a wide intensity spectrum, determined by the temperature difference between the coldest and hottest structures. The images were scanned using 256 gray lev-

els and we found, using selected sections of the negatives and prints that the resulting digitizing step is much bigger than the CCD dark current and the correction for flat field.

The standardization process was based in the digitized densitometric scale. The histogram and the standard deviation of each densitometric scale step were obtained adjusting the measurements to a normal distribution. In this way, we obtained a gray level scale for the densitometric scale of each image that allows us to characterize it. Considering standard deviation of each gray level of the scale and the number of significant densitometric scale steps, we select the "standard image" for prints and negatives independently.

The small temperature differences between the umbral features and the background produce low contrast details that need a wide intensity range to be detected as in our negatives (see Figure 4). The images taken from prints were not appropriated for umbral studies. They present a narrow intensity range in the sunspot umbrae due to saturation. For this reason we use negatives to study umbral features and prints for high-contrast penumbral details for example the penumbral filaments.

The selection criteria give R as negative standard image and the image C as print standard image. From the relation of the gray level scales on each image we found a standardizing function. For the images from negatives we obtained exponential functions (regression coefficient  $[r] = 0.99$ , in all cases). The images from positives have been adjusted to straight lines ( $r$  between 0.91 and 0.997). Applying the corresponding function to each case, we obtained standardized images.

## RESULTS AND DISCUSSION

### Investigation of the penumbral fine structure

From analysis of the cumulative histogram derivative of each image we notice that the satellite spots were blurring the information for our investigation, the pixels belonging to these sunspots were redefined to 255 and easily eliminated of the image histogram later. The intensity range of the object (main sunspot) has not this extreme value. Thus the main sunspot was isolated to study it. Figure 1 shows the cumulative histogram derivative of the isolated main sunspot in the image N. The first maximum ( $I \sim 100$ ) represents the high-contrast umbral nuclei that were not analyzed. The second one the sunspot penumbra. The exploration of the images in this direction does not give definitive results.

We expected to find a bimodal distribution representing the bright and dark filament structures referred to in the

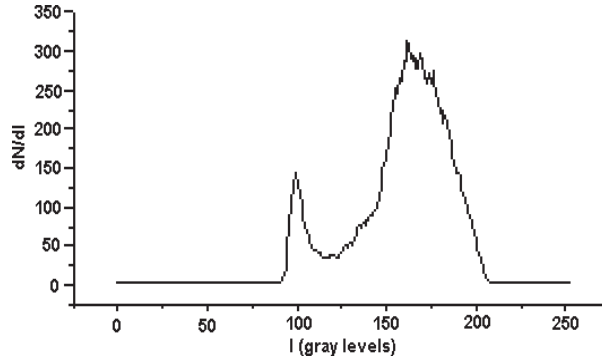


Fig. 1. Cumulative histogram derivative of the image N (main sunspot only). The peak values are 99 and 162, while the minimum value is 122. In the ordinate axis N denote the cumulative function.

literature. However, even if we can observe these structures in our original images, neither the cumulative histogram nor its derivative showed a clear pattern defining a photometrically distinctive two-structured penumbra. This result points to the fact that the brightening and darkening of filaments is related to the local physical conditions in the penumbra.

The characteristic intensity value varies with time (Figures 2 and 3). The measurement sequence in intervals of approximately one hour indicates us that these variations can be significant (bigger than 30 units) in that temporal scale. That could not be determined previously in observations with intervals of approximately one day, that indicated variations of the order of a unit per hour (20 units per day). The variations of brightness in the penumbra could be interpreted as originated by changes in the general physical conditions prevailing in this region. Since we have only one case studied, we consider risky to state any definitive conclusion about this result.

The oscillations in the umbra and penumbra of the main sunspots have been analyzed traditionally through the oscillations of spectral line intensity (Adelatif *et al.*, 1986; Balthasar *et al.*, 1987). It is the first time that we obtain photometrically standardized data in which those oscillations appear. This aspect should be investigated in detail in the future, being a very important aspect in the analysis of the energy balance in sunspots.

#### Fine structures in the umbra

In the Figure 4, the derivative of the cumulative histogram shows many little peaks between the maximum arising from the umbral nuclei and the umbra-penumbra border (tone 175 approximately). To determine if they were associated to some structures in the umbra, we proceed to obtain the images corresponding to the intensity values of each of

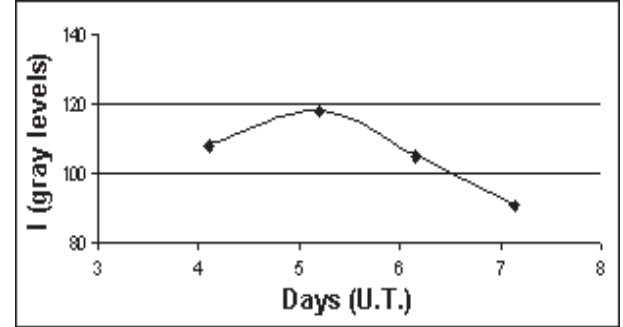


Fig 2. Intensity daily variation corresponding to main sunspot penumbra of the SD284 group.

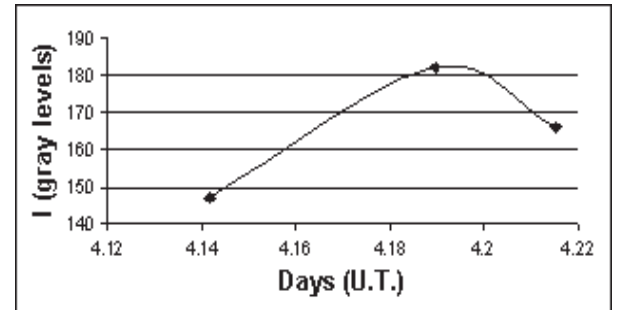


Fig 3. Detail of the intensity variation of the penumbra in intervals of one hour (approximately) during October 4, 1978.

these peaks. The obtained images were rings with broaden zones, composing the original and the obtained images we could associate these wider zones with umbral dots. The rings corresponding to greater values of the intensity are more distant from the center of the umbra where the umbral nuclei lay. This result agrees with the one found by Sobotka *et al.*, 1993.

The diameter of the umbral dots, determined by the classical method (semi-sum of the mayor and minor axis, see Oda (1984) and Rodríguez (1995)) appears in Table 2. There are significant differences between the characteristic values in each sunspot (0.05 significance level  $[\alpha]$  for Q vs. R), being the values in the 0.4 - 1.1 arcsec interval, in agreement with Grossmann-Doerth *et al.*, 1986.

Table 2

| Image          | No. Umbral dots | Mean (") | Standard deviation (") |
|----------------|-----------------|----------|------------------------|
| Q <sub>n</sub> | 58              | 0.57     | 0.07                   |
| R <sub>n</sub> | 37              | 0.82     | 0.10                   |
| S <sub>n</sub> | 44              | 0.72     | 0.11                   |

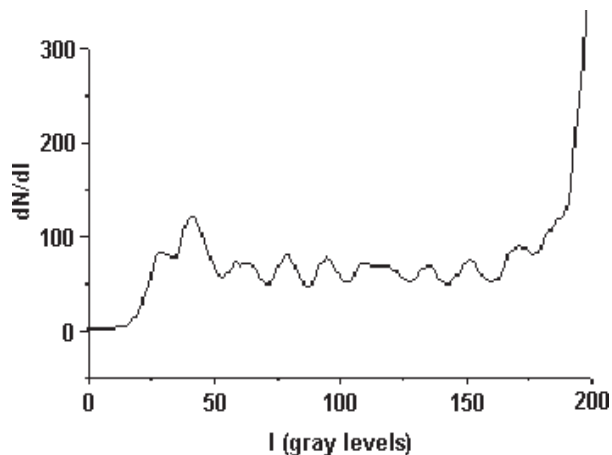


Fig 4. Cumulative histogram derivative for the Qn image. It is shown the characteristic values of the umbral structures for the image main sunspot. In the ordinate axis N denote the cumulative function.

Umbral nuclei were analyzed too. The main maximum in Figure 4 represents the characteristic value of the darker umbral nuclei. The initial exploration of the image shows that they lay very close to each other, and that the isolated ones have intensities similar to the umbral dots closer to the umbral nuclei.

To individualized the umbral nuclei and to measure their size we proceeded to slice the maximum analyzing the growth of the cluster of pixels belonging to the structures, the original image, and false color images of the umbral dot detection. The measurement of these structures was done applying the before mentioned classical method to the main sunspots of image Q, R and S. The values were in the range 1.0-3.0 arcsec and the number of structures measured was 21, 12 and 16, respectively.

### CONCLUSIONS

The methodology employed, based in the analysis of the densitometric scales in negatives and prints, allowed dynamical studies of high and low contrast structures from the same source. The cumulative histogram derivative proved to detect umbral nuclei and dots, features that by their low contrast are not clearly visible in the cumulative histogram.

The penumbra does not present the expected photometric bimodal distribution associated to bright and dark filaments. The characteristic value of the penumbra intensity varies with time. From our photometrically standardized data we observed integral intensity oscillations of the penumbra, aspect which should be studied later.

The umbral nuclei are clustered in the more internal part of the umbra. Umbral dots are brighter as they appear

farther from the umbral nuclei and distribute spatially forming rings resembling the border of the clustered darker umbral nuclei.

For each image the dimensions of the umbral dots adjust to a gaussian distribution, which points to a characteristic value no matter it changes from case to case. The dimensions of the umbral dots are in the 0.4-1.1 arcsec interval. The number of measured umbral nuclei were not enough to determine their size distribution, but the dimensions were in the 1.0-3.0 arcsec interval.

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