CHROMOSPHERIC INHOMOGENEITIES IN SUNSPOT UMBRAE

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Abstract. The properties of rapidly changing inhomogeneities visible in the H and K lines above sunspot umbrae are described. We find as properties for these 'Umbral Flashes':

(a) A lifetime of 50 sec. The light curve is asymmetrical, the increase is faster than the decrease in brightness.

(b) A diameter ranging from the resolution limit up to 2000 km.

(c) A tendency to repeat every 145 sec.

(d) A 'proper motion' of 40 km/sec generally directed towards the penumbra.

(e) A Doppler shift of 6 km/sec.

(f) A magnetic field of 2100 G.

(g) A decrease in this field of 12 G/sec. This decrease is probably related to the flash motion.

(h) At any instant an average of 3–5 flashes in a medium-sized umbra. A weak feature often persists in the umbra after the flash. This post-flash structure initially shows a blue shift, but 100–120 sec after the flash, it shows a rapid red shift just before the flash repeats.

1. Introduction

The study of the chromosphere above sunspot umbrae has so far been restricted to the measurement and interpretation of the spatially averaged profiles of some Fraunhofer lines. The lines which were most frequently examined are the H and K lines of Ca^+. In these lines the K_3 reversal disappears above the umbra (ST. JOHN, 1911; SUEMOTO, 1951; SMITH, 1960; MUSTEL, 1955; MUSTEL and TSAP, 1960; PACIOREK, 1965) or becomes very weak (BUMBA, 1960; MOHLER, 1960; ENGVOLD, 1967a, b). The K_2 emission relative to the continuum is greatly strengthened compared to that on the quiet sun. To our knowledge no investigation had so far been made of the spatial inhomogeneities in the chromosphere above the umbrae.

Structures can be seen in the H and K lines above sunspots even with moderate resolution. These structures are very short-lived which is why we call them 'Umbral Flashes'. This paper describes the properties of these flashes. In Section 2 we briefly review the existing knowledge on the behaviour of chromospheric lines above the umbra. Section 3 describes the observational technique, Section 4 the properties of the umbral flashes, and Section 5 concludes with a discussion of the nature of the flashes.

2. Previous Observations of Umbral Chromospheres

A spectrum of the K line taken across a sunspot shows the K_2 peaks to contract when approaching the umbra where eventually they merge into one. There has been

some discussion on whether or nor there is any K_3 reversal left. MUSTEL and TSAP (1960) indicate that K_3 only disappears in the core of the umbra so that presence of scattered light or low resolution may be of significance in determining whether K_3 is present. Everyone agrees, however, that the K_3 absorption in the umbra is much weaker than that on the quiet sun.

The umbral K_2 line shows an interesting behaviour when the spot is observed near the limb (BUMBA, 1958, 1960; ENGVOLD, 1967a, b; BAPPU and SIVARAMAN, 1968). The region over which the K_2 line narrows seems displaced towards the limb with respect to the sunspot umbra outside K_2. This indicates that the umbral K_2 line is formed a few thousand km above the umbral photosphere (BUMBA, 1960).

Various observers measure very different half widths of the umbral K_2 emission. The measurements vary from 60 mÅ (BUMBA, 1958) to 300 mÅ (ENGVOLD, 1967a, b; PACIOREK, 1965; SMITH, 1960). The K_2 line is often shifted or asymmetric. ST. JOHN (1911) reports a red shift corresponding to a 1.5 km/sec downward motion. However, recent observers report the contrary (PACIOREK, 1965; BUMBA, 1960; MUSTEL and TSAP, 1960).

The H and K lines are almost the only lines in which the umbra has been examined. Even in these lines the umbra has only been studied in spectra, not in spectroheliograms or filtergrams. MUSTEL and TSAP (1958) report, however, about the appearance of the infrared calcium triplet lines in sunspot umbrae. These lines show a behaviour in the umbrae and flocculi very similar to that of the H and K lines. We partly confirm this behaviour (Section 4).

3. Present Observations

For the present observations, we used the Sacramento Peak 30-cm coelostat and 40-cm coronagraph telescopes. The coelostat telescope fed the East Bench system (BECKERS and SCHRÖTER, 1968a) in which a Halle 0.3 Å K filter and a Zeiss 0.25 Å Hα filter were used. The coronagraph fed the 13-m Littrow spectrograph to give spectra in the H and K lines with or without magnetic-field optics. The dispersion is 6.6 mm/Å, which resulted in an exposure time of 12 sec for the umbra on Kodak 5375 film. The solar-image diameter in both systems is 25 cm. The 0.3 Å K filter image was photographed with an exposure time of 2 sec. This allowed the rapid sequence (5 sec rate) of umbral images, which is necessary for the study of umbral fine structures. In the K filter image we also use 5375 emulsion, in the Hα image Kodak SO 392.

4. Results

GENERAL

Figure 1 illustrates the structure of the umbra in the K_{232} line. When the seeing is fairly good (1–2 sec of arc), one can see in the K umbra bright regions which change very rapidly. In Figure 1 two such regions can be seen very clearly. One has a maximum intensity at 25 sec, the other at 85 sec. The latter has a size less than 1500 km, which