OSCILLATIONS AND WAVES IN A SUNSPOT

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(Received 25 April, 1972)

Abstract. Observations have been made in Hα of the vertical velocity distribution in a sunspot. Over the umbra the pattern consists of structures of scale-size 2–3″. The velocity distribution undergoes oscillations with a period of about 165 s and typical amplitude ± 3 km s^{-1}, but the pattern breaks down after one or two cycles because the period of oscillation varies typically by ± 20 s from place to place. Transverse waves develop in the outer 0.1 of the umbral radius and propagate outwards with a velocity of about 20 km s^{-1}, becoming gradually invisible by or before the outer penumbral boundary; the amplitude is about ± 1 km s^{-1} at the umbra-penumbra border.

The penumbral waves are believed to be basically of the Alfvén type, with $\varrho \approx 3 \times 10^{-8}$ g cm^{-3}. The umbral oscillations presumably represent gravity waves. In both cases the fluxes are inadequate by two orders of magnitude to account for the sunspot energy deficit.

1. Introduction

Beckers and Tallant (1969) described rapidly changing inhomogeneities ('umbral flashes'), of average diameter about 3″, in the H and K lines above sunspot umbras. These were visible in filtergrams obtained with a passband of 0.3 Å centred on the K line, but they were hardly visible, or even invisible, in Hα filtergrams. Many umbral flashes tended to repeat at regular intervals in the same location, one repeating as many as 18 times. The average time interval between repeating flashes was 145 s, but individual flashes had repetition times as short as 110 s or as long as 190 s. Spectra showed vertical velocities which were mainly upwards, of the order of 6–7 km s^{-1} at the time of maximum brightness, but briefly downwards shortly before the rise to the next brightness maximum.

In Hα one can find somewhat analogous phenomena which may be related to the H and K umbral flashes. These are revealed not so much as intensity fluctuations but as oscillations in velocity, seen by comparing narrow-band filtergrams obtained at similar positions in opposite wings of Hα. Since differences are due solely to Doppler shifts, subtraction of one filtergram from the other shows the pattern of line-of-sight velocities (Giovanelli and Jefferies, 1961; Leighton *et al.*, 1962).

Observations of this type have been made with the Culgoora 12-in. telescope and a Halle 0.55 Å Hα filter, modified so as to present side-by-side for simultaneous photography, two images of a portion of the Sun separated in wavelength nominally by 0.55 Å. For this the filter has been reversed from its usual orientation, so that light passes first through the 1.1 Å contrast element. The end polarizer of the 0.55 Å element is replaced by a polarizing beam splitter, this yielding two beams of orthogonal linear polarizations and hence of mean wavelengths separated by the pass-band of the final element (0.55 Å); the transparencies of the two paths in the beam splitter have been made identical to better than one per cent. To tune the filter, a

$\lambda/2$ plate is rotated between the filter and beam splitter; this is normally adjusted so that the two polarized beams are equally spaced on either side of line centre.

When due allowance is made for the shape of the Hα profile, the mean wavelengths of the two beams then lie at $\Delta\lambda = \pm 0.25$ Å. The advantage of having simultaneous observations in the two wings is compelling: the two images are identically affected by seeing, so that no spurious velocity can be introduced, though the velocity pattern may, of course, be blurred by poor seeing.

2. Oscillations in a Stable Sunspot Umbra

Observations were made on 3 November 1971 to study in some detail the Hα velocity pattern in a stable sunspot, then at 11°N 31°W. This spot had appeared first at the E limb on 28 September, 1971. In its second rotation, the spot retained a fairly uniform size and shape during its passage across the disk. The spot was sufficiently close to disk centre for the observations to refer primarily to vertical components of the motion.

Photographs were obtained on Kodalith Pan film with an exposure appropriate to the normal chromosphere and the brighter sunspot features, followed 3 s later by a denser exposure aimed at showing the Hα umbral core. This sequence was repeated at 0.5 min intervals between 0118 and 0320 UT, during which the seeing was largely mediocre, though with some short good periods. Both exposure times turned out to be adequate for yielding qualitative umbral velocity pictures.

Figure 1a shows a composite Hα photograph of the sunspot obtained by superimposing two low-gamma transparent prints from opposite wings. The effects of Doppler shifts which decrease the intensity in one wing and increase it in the other are thereby greatly reduced (though not completely eliminated), and 1a approximates a filtergram obtained with a pass band of about $\frac{3}{4}$ Å centred on Hα. Figure 1b shows similarly the core of the sunspot in Hα.

Figures 1c, d show for the umbra the difference between photographs obtained in the two wings; these have been obtained by photographic subtraction and show the umbral velocity pattern in the sense that dark features represent receding (or downwards) motions, and bright features are approaching (or rising). Figures 1c, d were obtained respectively from the denser and lighter exposures with a 3 s time difference. The patterns are intricate and closely similar, differences being due primarily to substantial decreases in photographic gamma for densities below 1.0 in the original negative (lowering the sensitivity in the core of Figure 1d), and to saturation effects which limit the range of the photographic subtraction process in 1c to a slightly smaller part of the umbral core than in 1d. In no case has any significant change in umbral velocities been detected in intervals of 3 s. The agreement leads to substantial confidence in the significance of the velocity patterns.

Figure 2 shows an array of velocity patterns in the umbra, at 0.5 min intervals over a period of 20 min, obtained by TV subtraction of the normal-exposure frames. The pattern is confined to about 75% of the umbral diameter due to the limited dy-