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Umbral and Penumbral Waves in a Chromospheric Sunspot

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Abstract. We observed an isolated sunspot, located near the center of the disk, on October 3, 1994 with the Multicahnnel Subtractive Double Pass (MSDP) spectrograph operating in Hα at the VTT in Tenerife. We analyse a 30 min time series obtained with a cadence of 36 sec. Two dimensional intensity and Doppler velocity maps at ± 0.3 Å and ± 0.6 Å were computed. One dimensional radial cuts across the sunspot show several clear cases where waves that originate inside the umbra continue to propagate in the penumbra. We thus confirm that sunspot oscillations and running penumbral waves are closely associated and are probably manifestations of the same phenomenon. Inside the umbra the amplitude of the waves is about 6 km s^{-1} and their period about 170 sec.

1. Introduction

Oscillatory phenomena are common in sunspots. Running penumbral waves appear in Hα as successive bright and dark bands expanding outwards in spots with well developed penumbrae (Zirin & Stein 1972, Giovanelli 1972). Their propagation velocity is between 10 and 25 km s^{-1}, their periods in the range of 180 – 240 s and their horizontal wavelengths in the range 2350 – 3800 km. On the other hand, inside the umbra, one often sees structures with size of $1-3''$ which oscillate with periods of 150–200 s and velocity amplitude up to 3 km s^{-1} (Beckers & Shultz 1972).

An obvious question is whether umbral oscillations and penumbral waves are different manifestations of the same phenomenon. Spruit (1981) stated that in a movie by Lites the umbra was covered with running waves which often propagated through the penumbra as penumbral waves. Using a subtractive technique to remove the sharp intensity gradient in Hα center images, Alissandrakis et al. (1992) detected waves which started in umbral elements with a size

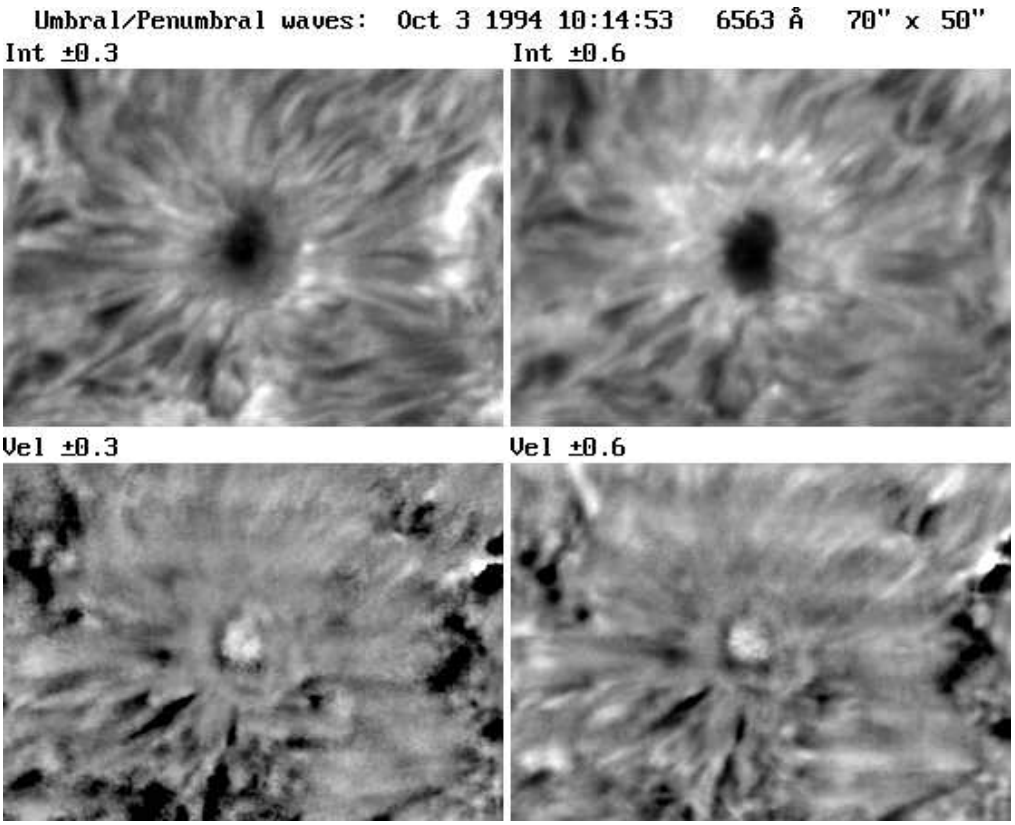

Figure 1. Intensity and velocity images of a spot observed with the MSPD on the VVT in Tenerife at Hα ± 0.3 and ± 0.6 Å.

of a few arcseconds, covered the umbra and subsequently propagated through the penumbra. Tsiropoula et al. (1996), using Hα velocity images, detected waves which started in the outer third of the umbra and propagated through the penumbra; they also found that the propagation speed decreased from about 24 km s^{-1} inside the umbra to 13 km s^{-1} in the penumbra. More recently, Brisken & Zirin (1997) also found deceleration in the propagation velocity of running penumbral waves.

In this work we present preliminary results from the analysis of a high quality time series of a sunspot, in which both umbral oscillations and penumbral waves were present and we discuss their properties and association.

2. Observations and Data Reduction

The observations were obtained on October 3, 1994 with the MSDP (Mein 1977), operating in Hα at the Vacuum Tower Telescope (VTT) in Tenerife (Canary Islands); more details on the observations are given by Tsiropoula et al. (1997). A sunspot located near the center of the solar disk (NOOA/AR 7783 at S06W13) was observed from 09:00 UT to 10:00 UT. Three adjacent elementary fields of view were recorded every 36 sec to cover the spot and secure a high image rate

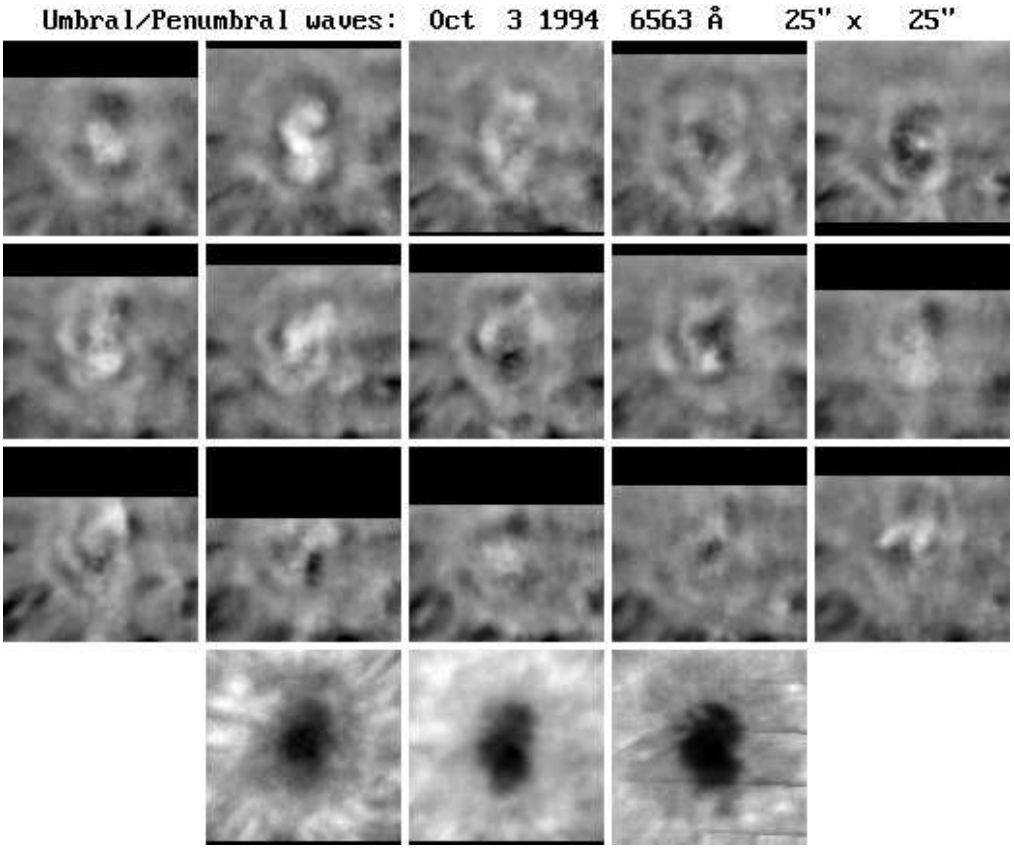

Figure 2. A sequence of velocity images of the spot at Hα $\pm$0.3 Å, with a time step of 36 sec. The bottom row shows intensity images at Hα $\pm$0.3 and Hα $\pm$0.6 Å simultaneous with the third velocity image and a monochromatic image at Hα $-$0.9 Å taken one hour later.

at the same time. Line profiles were reconstructed using the standard reduction methods for this type of data. Intensity and Doppler velocity images were computed from the line profiles at +0.3 Å and +0.6 Å, using a code simulating the "lambdameter" technique (Mein 1977).

Figure 1 shows intensity and velocity images of the spot and part of its superpenumbra at $\pm$0.3 and $\pm$0.6 Å. A bright patch over the umbra and a bright ring above the penumbra in both velocity images are velocity maxima associated with umbral oscillations and penumbral waves respectively. The evolution of the waves over 8 min is shown in Figure 2; here one can clearly see disturbances originating inside the umbra to propagate in the penumbra.

For the present study we used images covering 30 min. We measured the Doppler velocity along cuts through the center of the spot in four directions, 45° apart. The velocity as a function of position and time for each cut is shown in Figure 3. The figure shows a very characteristic pattern of alternating bright and dark bands, representing the velocity maxima and minima. In most cases there is a clear connection of the pattern above the umbra (near the center

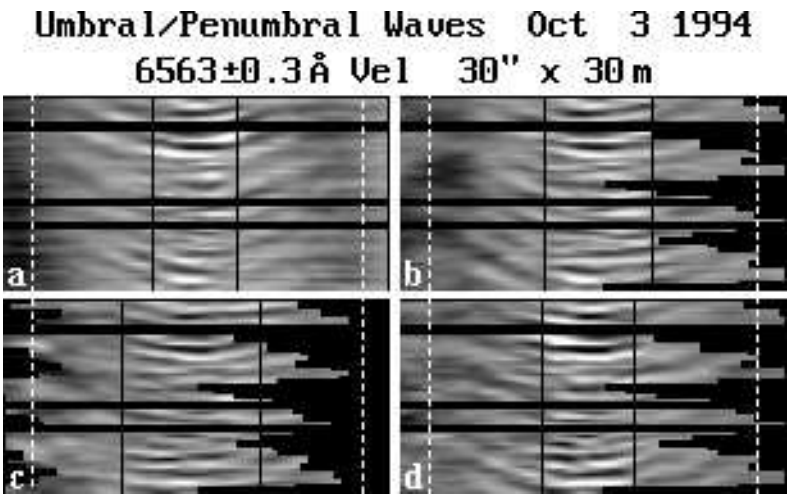

Figure 3. The velocity as a function of position (horizontal axis, from $-15''$ to $15''$) and time (vertical axis, increasing upwards, over 30 min), along four cuts through the center of the spot at Hα ± 0.3 Å. Dark areas are due to missing data. Dark vertical lines mark the boundaries of the umbra, dashed lines those of the penumbra.

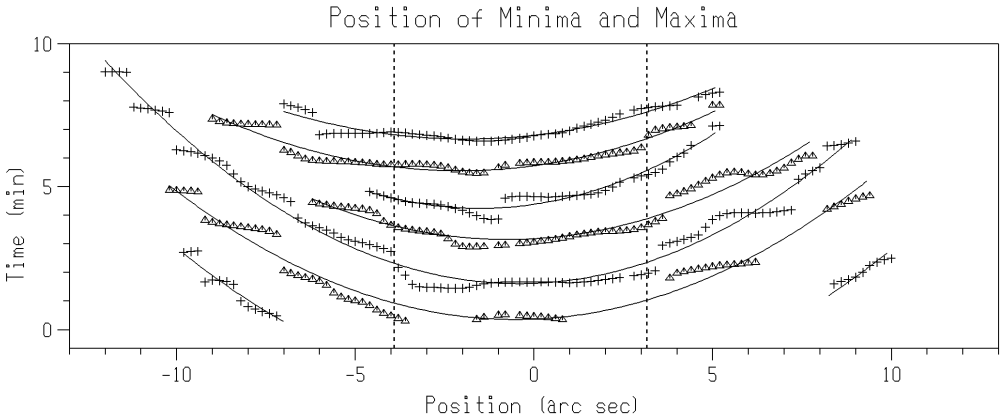

Figure 4. Position of the maxima (crosses) and minima (triangles) of waves in cut *d* of Figure 3 as a function of time; the continuous curves are parabolic fits. Dashed vertical lines mark the boundaries of the umbra.

of each panel) and the penumbra, showing that penumbral waves in Hα are a continuation of umbral oscilations. The amplitude of the waves decreases with distance from the center of the umbra, yet they are detectable at a distance of about 12″, more than twice the umbral radius. Inside the umbra the amplitude is about 6 km s^{-1} and the period about 170 sec.

Another important characteristic of the wave pattern is that it is concave upwards, which shows that the wave velocity decreases as they propagate from the umbra to the penumbra. This is shown clearly in Figure 4, where we plotted the position of the wave minima and maxima along a cut as a function of time. The velocity is very high in the umbra; in the inner penumbra the velocity is 20 – 30 km s^{-1}, while in the outer penumbra we measured values between 10 and 16 km s^{-1}.

3. Summary and Conclusions

MSDP observations in Hα of an isolated spot near the center of the disk showed clearly both umbral oscillations and penumbral waves. Our preliminary analysis shows several cases in which the pemumbral waves appeared as the continuation of the oscillations in the umbra, which points out to a common origin of the two phenomena. We plan to extend the analysis to the entire time series and perform a spectral analysis of the data.

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