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New observational evidences of propagating wave motions in sunspot umbra

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We investigate the line-of-sight velocity oscillations in the sunspot NOAA 0051 during it's disk transit. A favorable concourse of circumstances (observational method, excellent seeing plus intrinsic processes in the sunspot) allowed us to observe in some instances a clear picture of waves propagating in the umbra chromosphere (chevron structure in figure 1). Thus it was possible to measure directly their phase velocity in the immediate region of sunspot umbra. These waves have a period of 2.8 min and propagate from the sunspot center outward with the phase velocity of 45–60 km s^{-1} with the line-of-sight velocity amplitude of about 2 km s^{-1} (figure 2, 3). The waves terminate rather abruptly on the umbra boundary and show no direct linkage with (RPW) running penumbral waves (Zirin and Stein 1972). We pointed out that in our observations the picture of propagation of the waves from the sunspot center in two opposite directions is not accompanied by the propagation of Hα umbral flashes in these same directions. Our investigations showed that three-minute oscillations are very poorly pronounced in Hα intensity, and no "chevron" structure is present. The spatial coherence of the waves at the umbra center is no more than $2''$. No phase delay was found between line-of-sight velocity signals measured in Hα ± 0.2 Å and Hα ± 0.7 Å for a single spatial element. This would imply that the vertical extent of the source is comparable to the observed height scale (1000–1500 km). At the photospheric level there are clearly pronounced periodic motions (T $\sim$5 min) propagating from the umbra and from the superpenumbra to the lines of maximum Evershed velocity. One gets the impression that in some portions the Evershed flow itself is pulsating (Kobanov 2000; Rimmele 1995). Balthasar and Wiehr (1990) developed the idea that the Evershed flows may be a result of superposition of some penumbral structure affected by the underlying oscillating layers. Numerical simulations of wave propagation in a stratified magneto-atmosphere presented by Bogdan et al. (2003) show that the coupling between the fast and slow magneto-acoustic-gravity waves is confined to thin atmospheric layers where the sound speed and the Alfen velocity are comparable in magnitude. Their coherent superposition presents a large variety of Doppler and intensity time series. Interesting, some of their pictures resemble our "chevrons".

Acknowledgements

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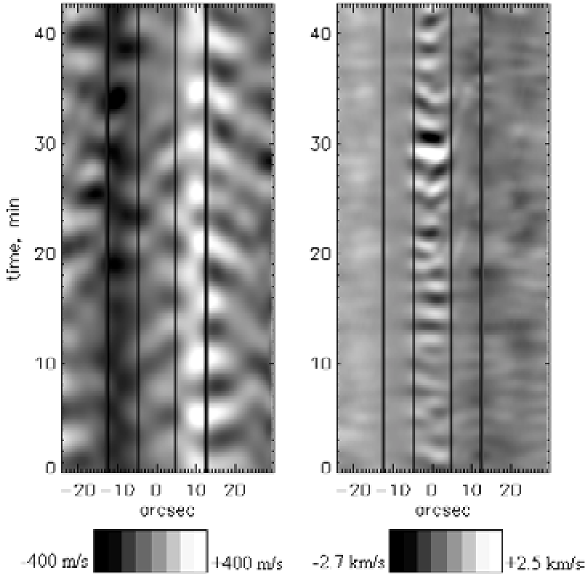

Figure 1. Line-of-sight velocity as a function of position and time (NOAA 0051 time series – 09:08 UT on July 31, $\mu = 0.95$), left panel – photosphere (Fe I 6569 $\pm$ 0.05Å), right – chromosphere (H$\alpha \pm 0.2$Å). The vertical dimension from bottom to top is time (0–45 minute), the horizontal axis is distance from the spot center in arcsec. The vertical dark lines mark the penumbra boundaries.

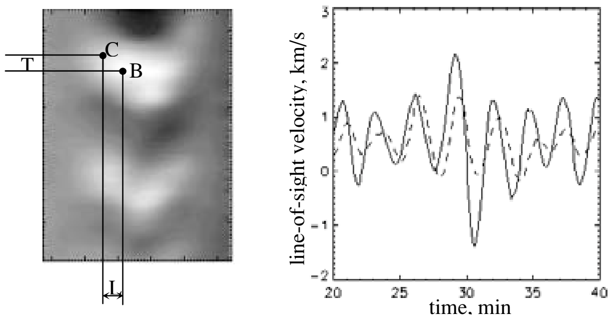

Figure 2. Left panel – the schematic for deducing of phase velocity from chevron. Right panel – the time delay between line-of-sight velocity signals (H$\alpha \pm 0.2$Å) measured at the points C (dashed) and B (solid).

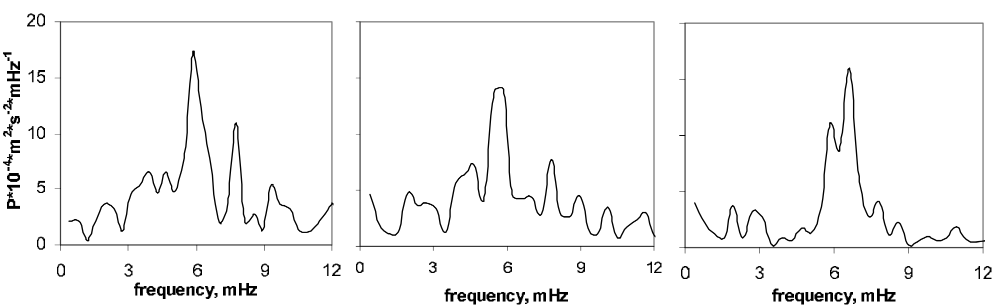

Figure 3. Power spectra for NOAA 0051: left panel – 09:08 UT on July 31, $\mu = 0.95$; middle panel – 03:30 UT on July 31, $\mu = 0.89$; right panel – 00:45 UT on August 2, $\mu = 0.92$.

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