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Observations of Umbral Flashes

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Abstract.

We present observations of oscillations in the chromosphere of the umbra of sunspots. The observations were obtained with the Swedish Vacuum Solar Telescope (SVST) and the Dutch Open Telescope (DOT) on La Palma, comprising spectrograms and filtergrams in the Ca II H line. The sawtooth pattern in the spectroscopic time evolution of the Ca II H core is shown as well as evidence for a connection between umbral flashes and running penumbral waves from image sequences. Running waves, coherent over a large fraction of the penumbra, seem to be excited by flashes that occur close to the umbra-penumbral boundary. Comparing the intensity oscillations in the Ca II H line with TRACE observations in the 1600 Å passband, we find a phase difference of approximately 25° with 1600 Å leading the Ca II H intensity oscillation which we attribute to complex dynamical behaviour.

1. Introduction

Observations in the Ca II H and K lines of the umbra of sunspots display a very dynamic chromosphere. Dramatic brightenings appear in parts of the umbra for short duration with a typical period of 2-3 minutes. Due to the large intensity contrast and short duration, these intensity oscillations are called umbral flashes. Being one of the most dramatic dynamic phenomena in sunspots and being known for more than 30 years (discovered by Beckers and Tallant in 1969), there is still no convincing theoretical explanation. In his comprehensive review, Lites (1992) concluded that umbral flashes are produced by hydrodynamic processes of upward propagating waves steepening into shocks in the umbral chromosphere.

The observations presented in this poster can be used to test hydrodynamic simulations that model the umbral atmosphere. The Ca II H observations were recorded by the Swedish Vacuum Solar Telescope[1] (SVST, Scharmer et al. 1985) and the Dutch Open Telescope[2] (DOT, Hammerschlag and Bettonvil 1998) on La Palma.

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[1]http://www.astro.su.se/groups/solar/solar.html

[2]http://dot.astro.uu.nl/

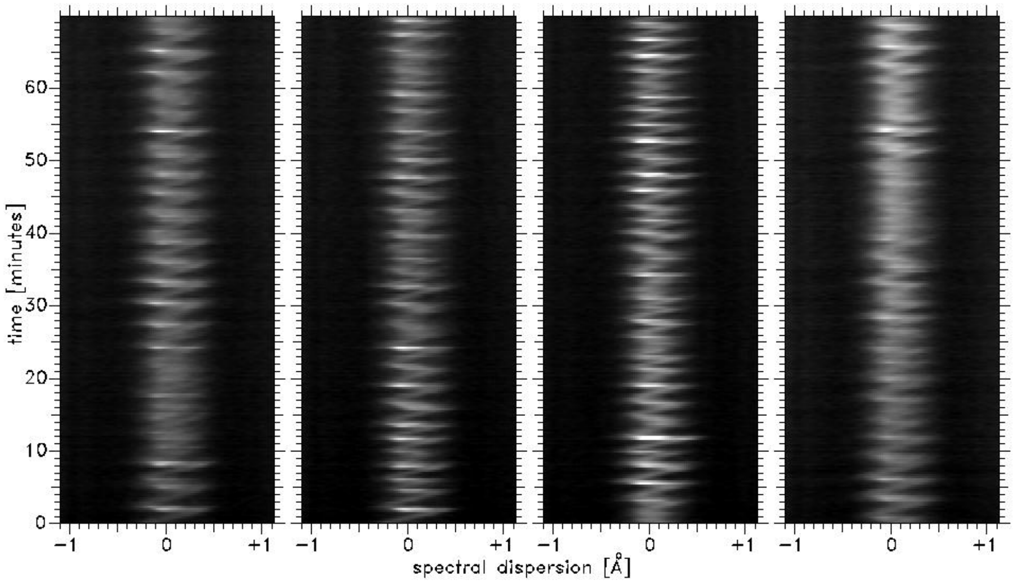

Figure 1. Time evolution of the emission reversal peak of the Ca II H core at four locations in the umbra. Along the horizontal axis of the time-slices spectral dispersion is shown centered on Ca II H line-center, tick-marks in 0.1 Å. Time runs along the vertical axis spanning a total duration of 69 minutes.

Specific observations discussed here include an image sequence and the temporal evolution of the Ca II H core. Movies and time slices constructed from the images suggest a relation between umbral flashes and running penumbral waves. In addition, we present preliminary results of an ongoing comparison between Ca II H flashes and intensity oscillations observed in the 1600 Å passband on the Transition Region and Coronal Explorer[3] (TRACE) satellite (Handy et al. 1999).

2. Umbral flashes

Figure 1 shows the characteristic time evolution of the Ca II H core in the umbra observed with the Littrow spectrograph at the SVST. In the umbra, the core has a single emission reversal peak that displays sharp brightenings during the flash phase. The sawtooth waveform of the oscillations—a sharp shift from red to blue followed by a more gradual drift back to the red—and the large amplitude of the excursion are highly suggestive of nonlinear shock behavior of the oscillation.

When flashes occur close to the umbral-penumbral boundary they sometimes continue propagating through the penumbra as a running penumbral wave. Running penumbral waves are coherent over a large fraction of the penumbra, propagate with horizontal velocities between 10–25 km/s through the inner

[3] http://vestige.lmsal.com/TRACE/

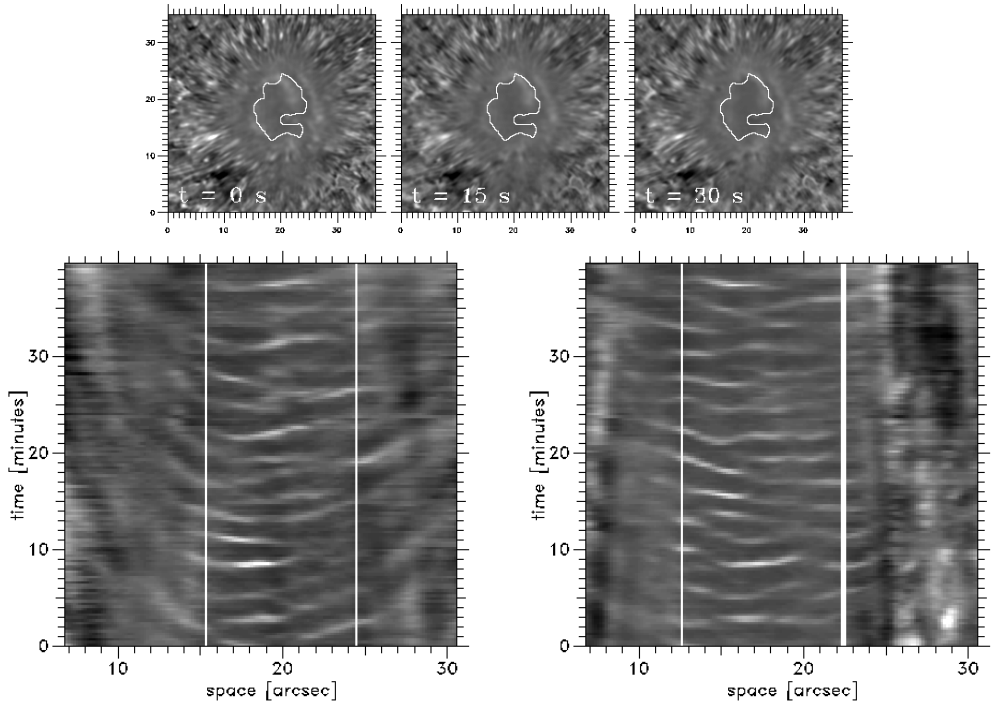

Figure 2. The three images at the top form a short 30-sec sequence showing running penumbral waves as large arcs. The large intensity contrast between umbra and penumbra is removed by subtracting the mean image from the whole 40 minute image sequence. The umbra-penumbra boundary is marked with the white contour. Two time-slices below show spatial cuts along the x- and y-direction through the data cube. White vertical lines mark the umbra-penumbra boundary. In the umbra, the flashes have large intensity amplitudes and typical spatial scales of several arc-seconds. These observations of AR 9214 were taken by P. Sütterlin with the DOT, using a 1 Å wide Ca II H filter, on November 1, 2000.

penumbra, and die out in the outer penumbra. The three images at the top in Fig. 2 constitute a short sequence of 30-second duration where the running penumbral waves appear as large arcs in the inner penumbra. The two time-slices at the bottom illustrate the relation between umbral flashes and the penumbral waves. At the umbra-penumbra boundary, several flashes spawn intensity enhancements in the penumbra which travel through the penumbra. They appear as inclined trajectories in these time-slices.

3. SVST Ca II H - TRACE 1600 Å

On August 9, 2000, SVST and TRACE observed NOAA Active Region 9115. Between 8:20–9:40 UT, SVST observed the trailing sunspot in Ca II H with a time cadence of approximately 17 seconds. TRACE covered the whole active

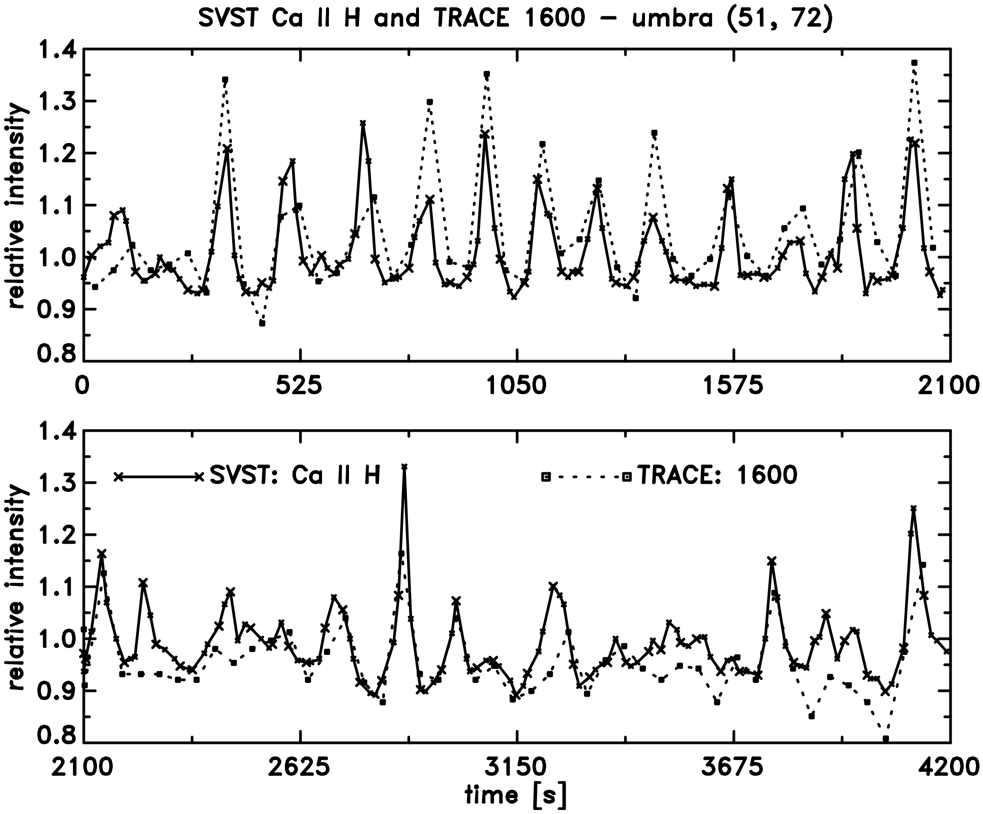

Figure 3. Time evolution of the intensity oscillations in the umbra at the location of strongest three-minute power. The SVST observations have a faster cadence than the TRACE observations, the larger crosses mark the intensity in the Ca II H images that are closest in time to the TRACE images.

region with several filters including the continuum filter centered at 1600 Å and with a time cadence of 45 seconds. These observations were obtained from the TRACE archive. To compare the Ca II H umbral flashes with the intensity oscillations in the TRACE observations, the SVST images were re-sampled to match the TRACE resolution (0.5 arcsec pixel) and were carefully co-aligned to the TRACE images.

Figure 3 shows the intensity oscillations for one location in the umbra. The selected location is the location with strongest 3-minute power and the two signals show oscillations that are clearly closely related which is further investigated using Fourier techniques.

In order to facilitate such Fourier analysis of the oscillation signals observed with the two filters, Ca II H images were selected from the data sequence that are closest in time to the TRACE images (marked with large crosses in Fig. 3). Figure 4 gives a comprehensive overview of the obtained spectral Fourier information.

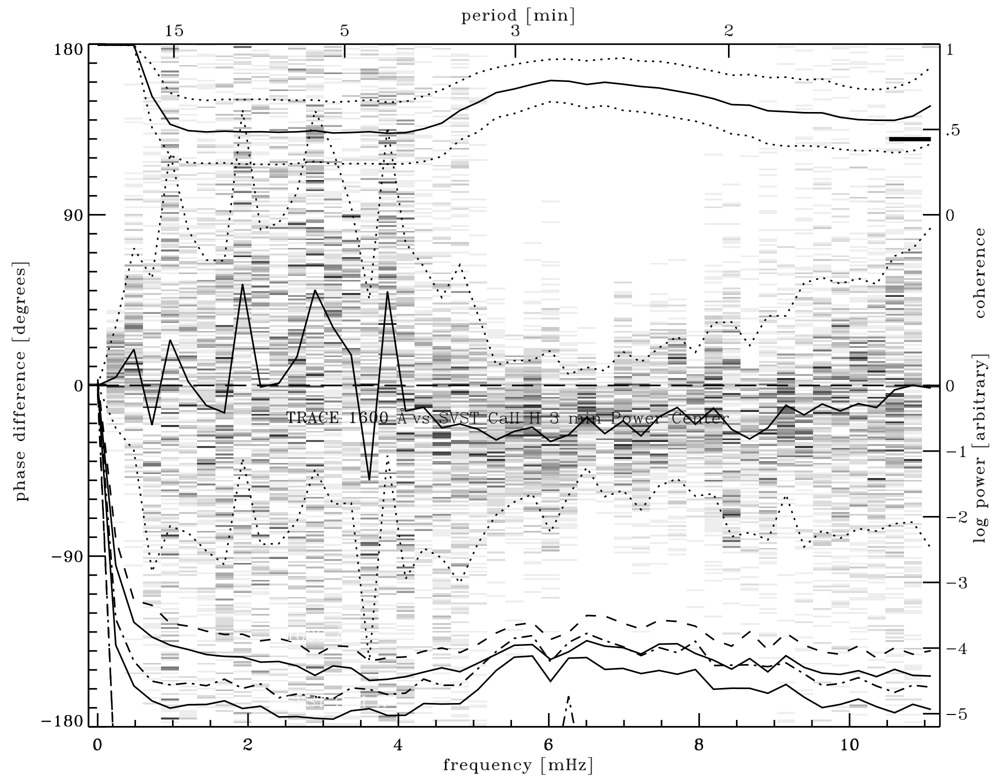

Figure 4. This figure provides various Fourier spectra, spatially averaged over the umbra (553 pixels), for the 1600 Å and Ca II H pair as a function of frequency (lower abscissa) and corresponding periodicity (upper abscissa). The lower solid curves are the standard logarithmic power spectra (scale at the right) with their respective 1σ estimates (dash-dotted and dashed curves), all normalized to zero frequency power. The upper solid curve shows the average coherence C (scale at the right) between the two signals with dotted 1σ estimate curves. Random noise results in $C = 0.45$ in our analysis method indicated by the thick bar on the right. The background scatter diagram shows each individual phase difference (scale at the left) between 1600 Å and Ca II H weighted by the corresponding cross-power amplitude, normalized per frequency bin. A positive phase difference means that 1600 Å is leading Ca II H in brightness. The spatial average phase difference is indicated by the central solid curve, again with dotted 1σ estimate curves. Noise measurements would result in scattered phase differences over all angles. Such behavior is seen around 5 min periodicity.

The power spectra in the lower half show the well-known absence of 5-minute power in the umbral chromosphere and the peak around 3 minutes. The coherence between the two filters (solid curve at top) peaks around 3 minutes, confirming the close agreement of the two signals displayed in Fig 3.

The thick solid line in the center shows the weighted average phase difference. In the 2–3 min band all phase differences are negative around 25° with a slight phase difference decrease.

This phase difference corresponds to a time delay of approximately 10 seconds with Ca II H leading 1600 Å. This is surprising from the naïve viewpoint of formation height calculations in static model atmospheres that put the formation of the continuum at 1600 Å below the Ca II H core. Explaining the umbral oscillations in terms of traveling waves in such a static atmosphere leads to an interpretation in terms of *downward* propagating waves.

However, movie display of Ca II H and K images demonstrates very convincingly that the dynamical character of the umbral atmosphere forbids application of static atmosphere modeling in this case. Note that Socas-Navarro et al. (2001) recently developed a time-dependent semi-empirical model to explain anomalous Stokes I and V Ca II infrared lines in time-series of umbral oscillation observations.

The observational result presented here should be confronted with detailed radiation-hydrodynamics modeling of the umbral atmosphere in the style of K2v grain simulation by Carlsson and Stein (1997).

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