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Oscillatory Phenomena in a Solar Network Region

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Multi-wavelength, multi-instrument observations, obtained during a coordinated observing campaign on October 2005 by the ground-based Dutch Open Telescope (DOT), and by instruments on the spacecraft Solar and Heliospheric Observatory (SoHO) and Transition Region and Coronal Explorer (TRACE), are used to study oscillatory phenomena in a solar network region. Temporal variations of the intensities and velocities in a region of the quiet Sun containing several dark mottles and in a region with several bright points defining the network boundaries (NB) are investigated with the aim of finding similarities and/or differences in the oscillatory phenomena observed in these two regions and in different spectral lines formed from the chromosphere to the transition region, as well as propagation characteristics of waves. A wavelet, phase difference and coherence analyses were performed indicating a periodicity around 5 min in all considered lines for both regions. V-V phase differences in the NB region point to an upward propagation of, most probably, acoustic waves, while in the region of mottles they indicate a non vertical propagation of waves, due to the presence of several inclined mottles along the line-of-sight. In mottles, for periods of 250-400 s the phase difference is mainly negative suggesting that propagating waves encounter a boundary and are refracted and reflected. However, limitations arising from the complex topology of the magnetic field, the formation conditions and heights of the examined spectral lines and the low spatial resolution of the space instruments influence the exact interpretation of the phase differences.

Oscillatory phenomena in a solar network region

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Introduction

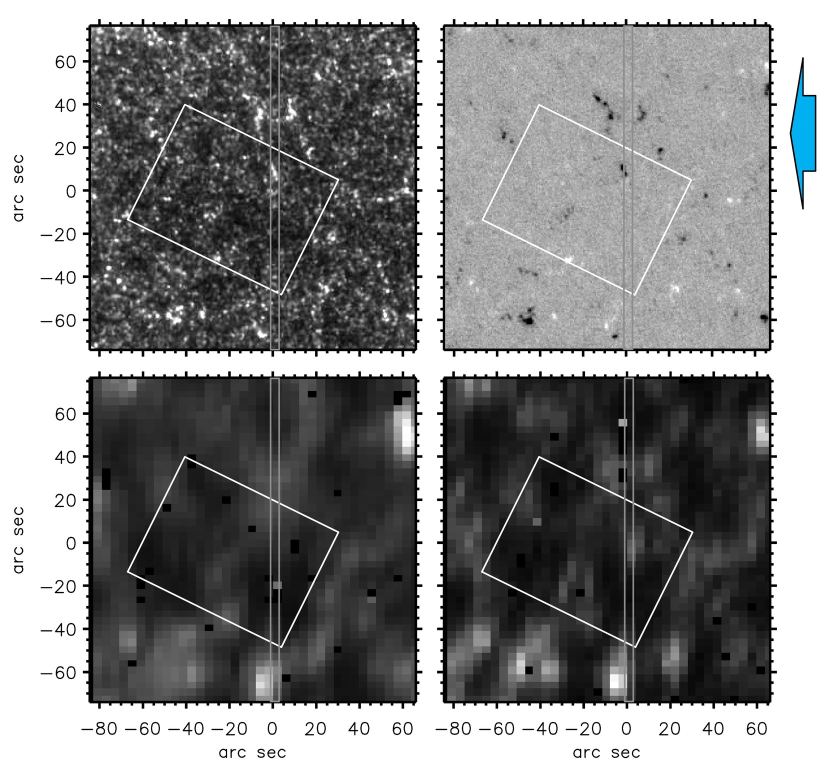
⇨ The solar photosphere is permeated with strong magnetic fields, which occur preferentially at the boundaries of the supergranular cells.
⇨ In the chromosphere, the quiet Sun displays a distinct network appearance identical to the supergranular structure. In the Hα line, especially in its wings, several elongated dark structures, called mottles, outline the cell boundaries.
⇨ In the transition region, the network stands out as more stable cellular patterning with bright patches identifying the network boundaries (NB) and enclosing dark areas which correspond to the internetwork (IN). This spatial dichotomy is also apparent in the power spectra leading to the suggestion that different physical mechanisms may dominate in each region.
⇨ Although so far there are different and sometimes contradictory reports, the general conclusion is that NB regions show no particular power below ~5 min in contrast to IN regions which display enhanced power at ~3 min.
⇨ The mode of the observed waves, the dominant restoring force and the resulting propagation through the atmosphere have been the subject of much deliberation, with difficulties rising from the modeling of the formation of the spectral lines and the complexity and dynamics of the magnetic field. Several attempts have been made to describe these oscillations both theoretically and numerically.

Observations

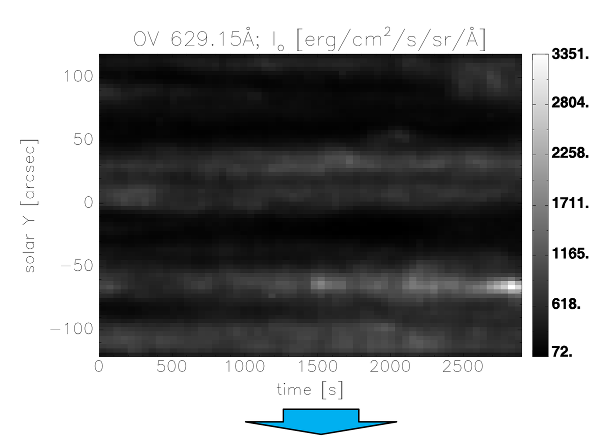
Co-temporal observations of a quiet region at the solar disk were obtained on October 14, 2005 by SoHO (CDS and MDI), the Dutch Open Telescope (DOT) and TRACE.

CDS observations: Sit-and-stare observations in He I, O V and Ne VI (effective pixel size of 4″ in the horizontal and 3.36″ in the vertical direction), with 60 exposures, and cadence of 49 s. Also 154″ × 240″ raster scans used for the co-alignment of the different data sets.

TRACE and MDI observations: C IV image constructed from high cadence TRACE images at 1550, 1600 and 1700 Å through linear interpolation. Used together with high-resolution MDI magnetogram for the co-alignment of the different data sets.

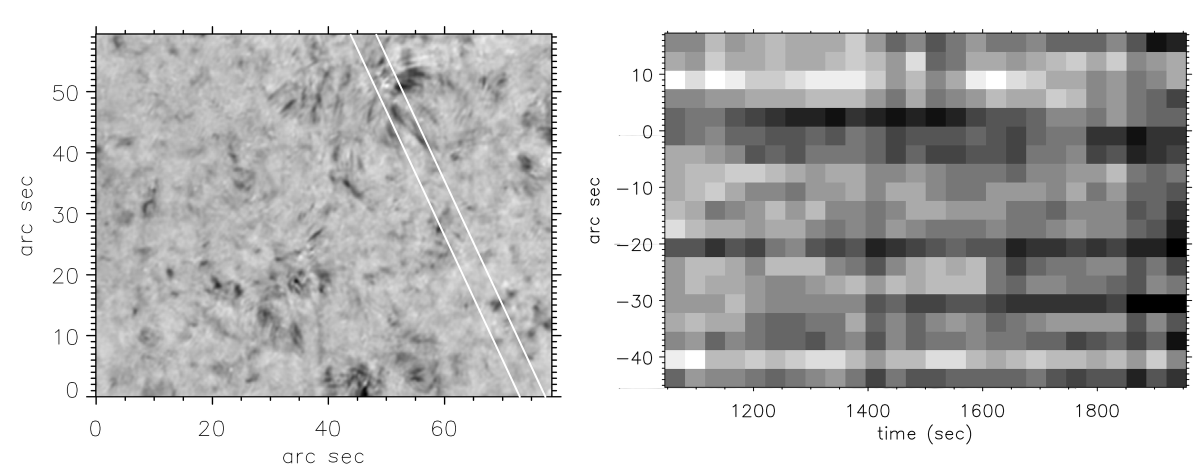


First row: CIV TRACE image and MDI magnetogram. Second row: Cut-outs of the CDS raster observations of intensities at HeI (left) and OV (right) lines. The white rectangle marks the DOT's FOV while the two parallel grey lines mark the location of the sit-and-stare CDS observations.



``Space-time" plot of peak intensity obtained from the fitted profiles of the sit-and-stare CDS observations of the Ov 629.73 Å line.

DOT observations: 26 speckle reconstructed and carefully aligned 78.5″ × 59.5″ images in 5 wavelengths along the Hα profile (cadence of 35 s, pixel size of 0.071″).



Left: DOT observations in Hα -0.7 Å (the two parallel lines mark the location of the slit during the CDS sit-and-stare observations). Right: DOT Hα line centre sit-and-stare image after degrading to the CDS spatial resolution.

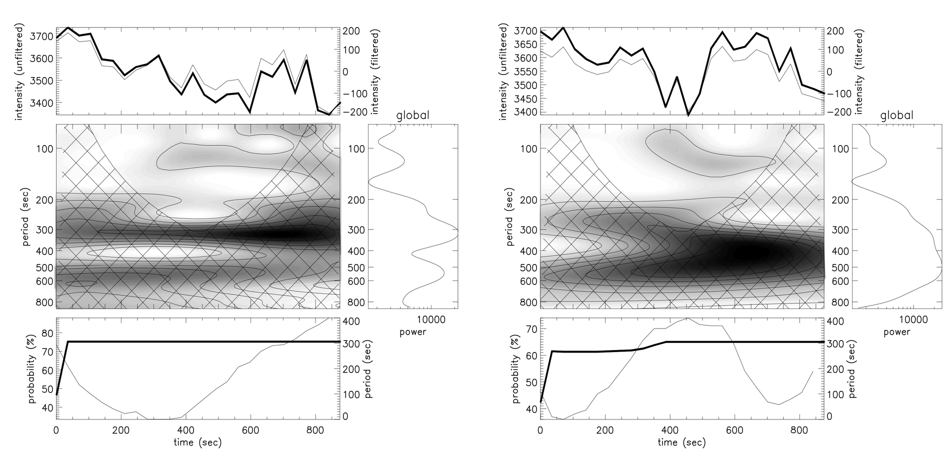
Results and conclusions

⇨ In CDS sit-and-stare observations the quiet Sun is dominated by a pattern of bright streaks defining the NB areas, dark streaks defining the IN areas, while mottles' regions appear darker than the NB, but brighter than the IN.
⇨A strong positive correlation exists between respective peak intensities of the CDS lines suggesting a strong association between different heights of the solar atmosphere and indicating that we are possibly observing manifestations of the same structural topology at different heights.

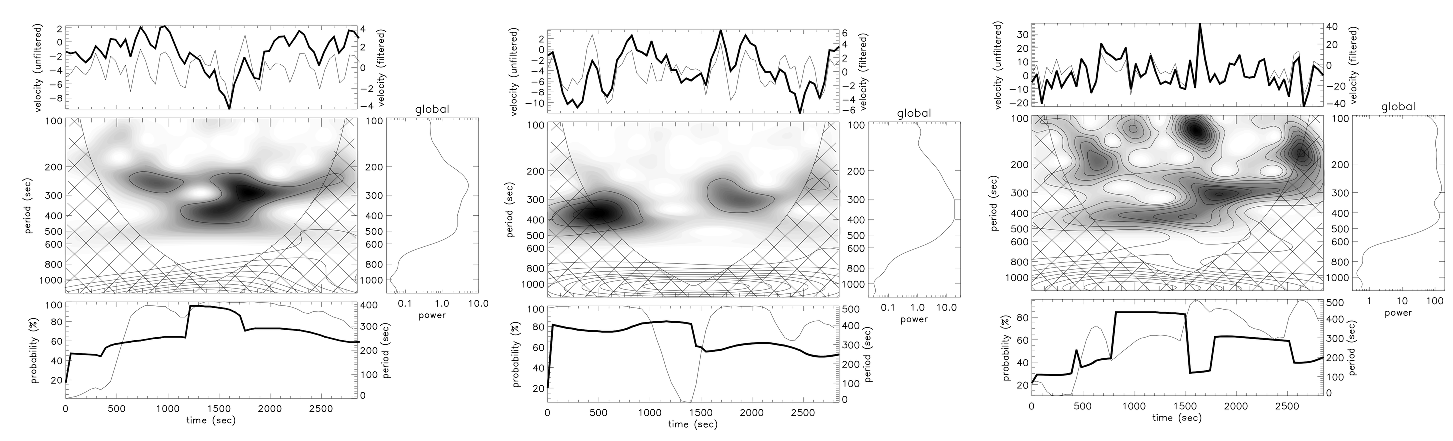
Wavelet power analysis

A wavelet analysis is performed in both intensity and Doppler velocity variations, in two regions (NB and mottles' region), for both unfiltered and filtered with a high pass frequency filter time series.

⇨ Hα line-centre intensity variations show a most prominent peak at ~300 s in the mottle's region and an extended peak at periods of 300 to 600 s in the NB region.
⇨ Unfiltered CDS spectra are dominated by a period ~1000 s which is subjected to edge effects and has an unclear physical importance (lifetime of mottles?).
⇨ Both CDS intensity and velocity filtered power spectra show several periods with significant power within the COI. Most spectra in the mottle's region, as well as in the NB, show dominant oscillation signatures mainly in the 250 s – 400 s range with rather variable probability.



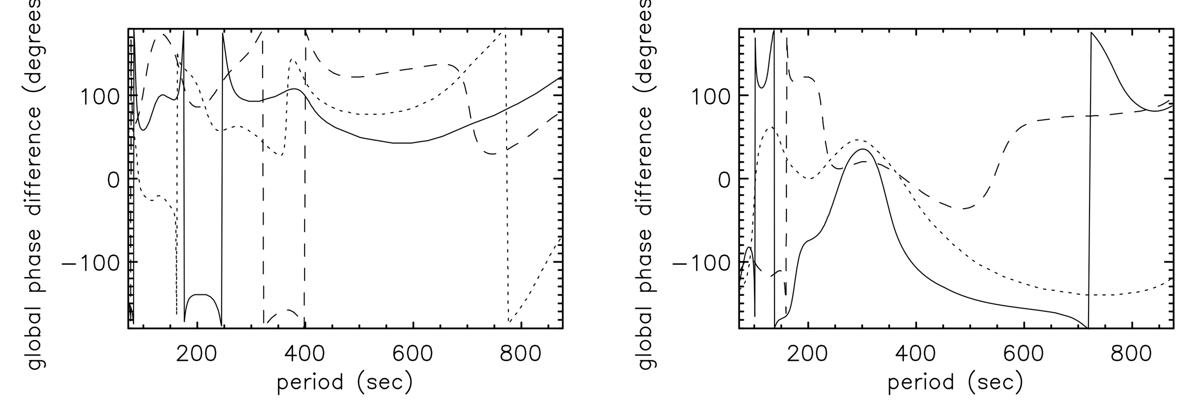
Wavelet analysis at a fixed location in the mottles' region (left figure) and the NB region (right figure) for the Hα line-centre intensity variations. Top panels show the intensity variations of the unfiltered data (thick solid line, left abscissa) and the filtered data (thin solid line, right abscissa). The middle left panels show the calculated power spectra as a function of time and period for both filtered data (filled contours) and unfiltered data (line contours). The cross-hatched regions below the cone of influence (COI) line indicate the regions which are subject to edge effects due to zero padding. The middle right panels show the global power spectrum for the filtered data, that is the average of the wavelet power spectrum of the filtered data over time. Finally the lowest panels show the variations of the probability (thin solid line, left abscissa) obtained with a randomization method for the filtered data and the equivalent period of the maximum power peak (thick solid line, right abscissa) for which this probability was calculated.



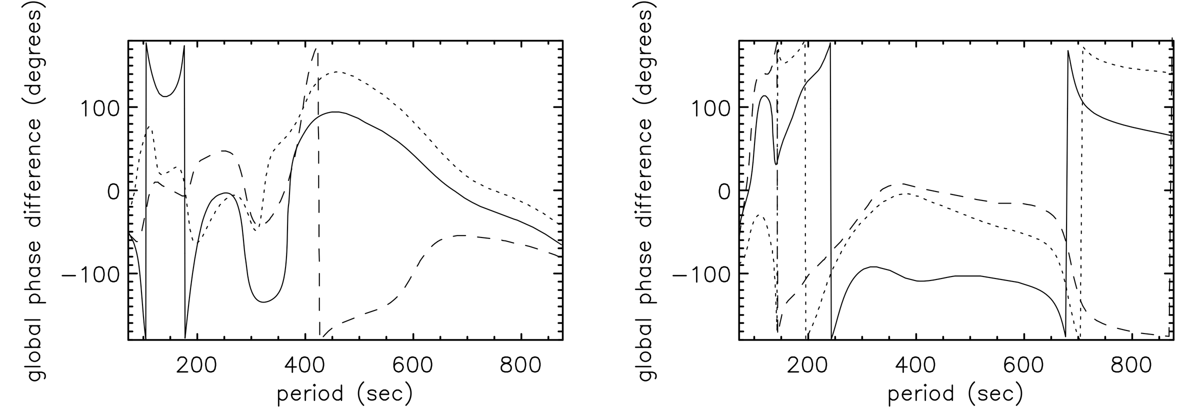
Wavelet analysis at a fixed location in the NB region of the HeI (left), OV (centre) and NeVI (right) velocity variations obtained from CDS observations.

Global phase difference analysis

⇨ Phase difference obtained with a cross-wavelet transform between the Hα line-centre filtered intensity and Doppler velocity time series and the corresponding filtered time series of the CDS lines, is used for the study of propagation characteristics of waves at different heights in the solar atmosphere.
⇨ Phase difference curves have an almost similar behavior indicating a clear interconnection between processes in the lower and higher solar atmosphere and in both mottles' and NB regions. Difference in phase curve inclinations for different spectral lines suggests formation at slightly different heights.
⇨ I--I phase spectra depend on many parameters (i.e. frequency, peculiarities of the line formation) and are difficult to interpret.
⇨ V--V phase differences in the NB show vertically propagating waves, since above ~200 s the inclination of the phase curve with period is constant for all lines as expected from the theoretical behavior of such waves. For periods above ~350 s, the phase difference becomes almost constant indicating no propagation, as expected from the NB cut-off period which is about 350-400 s.
⇨ Non-constant dependence of phase curves on the period above 200 s in the mottles' region probably indicates: a) non-vertical propagation or b) waves propagating at different inclined mottles along the line-of-sight. The mostly negative phase difference, if real, would suggest a downward propagation at least for periods of 250-400 s, representing waves refracted from the inclined magnetic field of mottles or waves converted to other wave types, such as fast or slow MHD modes (depending on the field strength).



Left: Global phase difference (in degrees) of filtered CDS intensities relative to the Hα line-centre intensity as a function of period (thick solid line for HeI, dotted line for Ov and dashed line for NeVI) for the mottles region. Right: The same for the NB region.



Left: Global phase difference (in degrees) of filtered CDS velocities relative to the Hα line-centre Doppler velocity as a function of period (thick solid line for HeI, dotted line for Ov and dashed line for NeVI) for the mottles region. Right: The same for the NB region.