Time variability of the Evershed effect

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Abstract. The time variability of the Evershed effect in the penumbra of a sunspot is studied from a series of high-spatial-resolution spectrograms obtained with the Swedish Vacuum Solar Telescope on La Palma. Photospheric reference images from the Dutch Open Telescope were used to study the solar scene around the region covered by the spectrograph slit. From a comparison of two 1-hour velocity profiles, one with significant Evershed signal and one without, it is found that the Evershed effect varies on a typical time scale of more than 10 minutes.

Key words: Sun

1. Introduction

The Evershed effect in the penumbra of sunspots is commonly interpreted as a radial outflow of gas along penumbral filaments. From studies with tunable filtergram instruments it has been discovered that the Evershed effect is time dependent (Shine et al. 1994, Rimmele 1994). Movies of Dopplergrams revealed moving structures of enhanced Doppler signal moving radially outwards in the penumbra. These velocity packages, also called “Evershed clouds”, have a radial extent of about 1000 km and are radially separated by 2000—3000 km. The pattern of moving velocity packages was found to have a quasi periodic variability on a time scale of 10—15 minutes.

In this contribution, I present preliminary results of the first spectroscopic study on the time variability of the Evershed effect based on high-spatial-resolution observations obtained with the Swedish Vacuum Solar Telescope (SVST, Scharmer et al. 1985) and the Dutch Open Telescope (DOT, Hammerschlag & Bettonvil 1998).

2. Observations

The sunspot in AR8704 was observed on September 20, 1999 ($\mu = 0.77$), with the spectrograph slit crossing the penumbra during a period of 64 minutes. At a cadence of 19 s, spectrograms were recorded, covering a spectral range that included the Ca II K line core and a large part of extended damping wings. The exact location of the spectrograph slit with respect to the Sun was determined from simultaneous slit-jaw images, recorded with a 3 Å wide interference filter, centered on the Ca II K line. At a lower cadence of 60 s, photospheric reference images were recorded with a G-band filter, which were later used to co-align simultaneous G-band images from the DOT. More details about the observations and reductions can be found in Rouppe van der Voort (2002).

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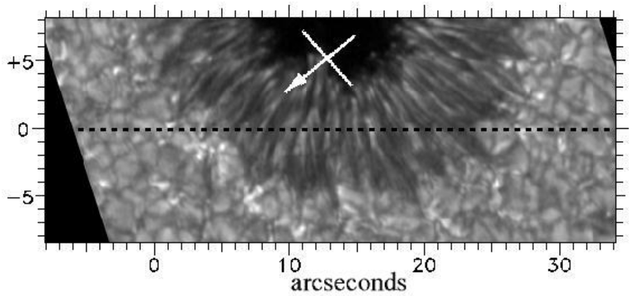

Fig. 1. G-band image of sunspot AR8704 recorded by the DOT. The approximate location of the spectrograph slit is indicated by the dashed line. The white arrow in the umbra points towards disk centre.

The DOT images were recorded at a cadence similar to the spectrogram/slit-jaw image pairs (20 s), a sample image is shown in Fig. 1. More details about the DOT observations can be found in Balthasar, Sütterlin & Collados (2001).

3. Analysis and results

The Evershed flow in the penumbra was measured from Doppler shift measurements of the line cores of a selection of

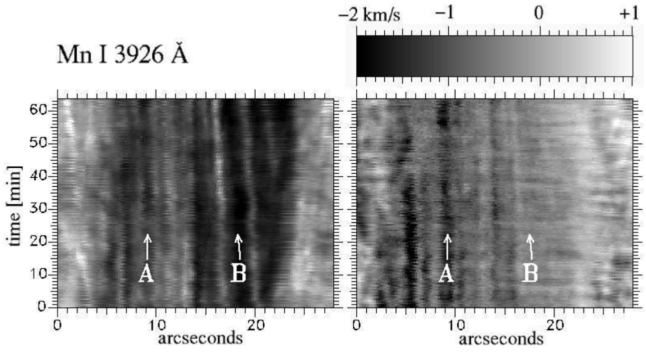

Fig. 2. Space/time diagrams for Mn I 3926 Å: line core intensity in the left diagram, line core Doppler shift (velocity) at right. The spatial coordinates have the same origin as in Fig. 1.

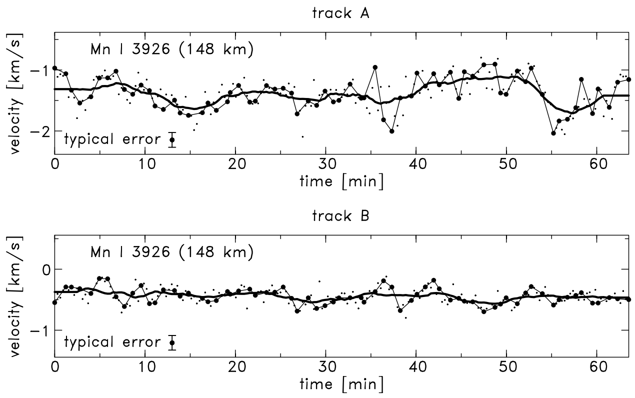

Fig. 3. Velocity profiles for track A (top) and B. Thick dots are from slit positions that have offsets less than 1 slit width, small dots have slightly larger offsets. The thick line is the velocity profile boxcar-smoothed with a period of 5 minutes. Since the Evershed flow in the penumbral filament that is traced by track B is close to perpendicular to the line-of-sight, the mean offset of the velocity signal in track B can be mainly attributed to the uncertain velocity calibration.

line blends in the Ca II K wing. The line blends were selected on the basis of their mean height of formation so that each line samples a different height in the penumbral atmosphere. In this contribution, results are shown for one of the deeper formed lines, Mn I at 3926 Å, which has a mean height of formation of approximately 150 km in a model atmosphere of the quiet sun (Holweger & Müller 1974, see Rouppe van der Voort 2002). The line core Doppler shifts were calibrated to a reference line core position constructed from spectra well outside the penumbra. This velocity calibration has significant bias, on the order of several hundred meters per second, but is accurate enough for this study which focuses on the relative change of the Doppler signal in the penumbra.

Figure 2 shows two space/time diagrams, constructed by subsequently putting an intensity or a velocity profile from each spectrogram on top of each other. In this diagram, the slit crosses the penumbra over a length of roughly 18″, starting at about 5″, where the penumbral filaments point towards disk centre (compare with Fig. 1). This is where the Evershed signal is strongest in the Dopplergram. At the other side of the penumbra, for slit positions after 17″, the Evershed signal is virtually absent. This is where the direction of the Evershed flow is perpendicular to the line of sight.

The Evershed signal in the Dopplergram is clearly not constant. This is partly introduced by seeing effects from disturbances in the Earth atmosphere resulting in variability in the Doppler shift measurements on short time scales. Image motion was reduced by the spot tracker and the residual image jitter was of order 0.″5. Considering that the slit crossed the penumbral filaments at large angles and the large radial extent of the Evershed velocity packages, slit displacements introduce only (small) errors on short time scales. The magnitude of the errors on the Doppler shifts introduced by higher order seeing effects is estimated to be on the order of 200 m s^{-1} and can be regarded as a minor source of error.

Arrows in the space/time diagrams mark the direction of two tracks for which the velocity profiles are shown in Fig. 3. For track A, significant Evershed effect is measured, while track B follows slit positions with a very weak Evershed signal. The velocity profile for both tracks display an variability on a time scale of 5 minutes, which can be attributed to p-mode oscillations. The thick lines in Fig. 3 show the suppression of the short time variability by a 5 minute wide boxcar smoothing. For track A, there is a significant residual variability on a time scale of approximately 10 minutes, while for track B, the variability is smoothed out. This shows that for track A, the variability in the velocity signal on long time scales can be attributed to a variation in the Evershed effect, because in absence of Evershed signal, p-mode suppression results in no significant residual variability on longer time scales. The time scale of the variability in track A, 10 minutes, is consistent with the results of Shine et al. (1994) and Rimmele (1994).

This study will proceed with a comparison of velocity profiles from other tracks, including other spectral lines formed at different heights than Mn I 3926. Also, an 1 hour time series recorded in the morning hours of September 20, 1999, will be included in the study and compared with the data presented here.

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References

Balthasar, H., Sütterlin, P., Collados, M.: 2001, AN 322, 367
Hammerschlag, R.H., Bettonvil, F.C.M.: 1998, NewAR 42, 485
Holweger, H., Müller, E.A.: 1974, SoPh 39, 19
Rimmele, T.R.: 1994, A&A 290, 972
Rouppe van der Voort, L.H.M.: 2002, A&A *accepted*
Scharmer, G.B., Pettersson, L., Brown, D.S., Rehn, J.: 1985, ApOpt 24, 2558
Shine, R.A., Title, A.M., Tarbell, T.D., Smith, K., Frank, Z.A., Scharmer, G.: 1994, ApJ 430, 413