2D spectroscopy and science with THEMIS

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Abstract

We present observations obtained during the 2000 campaign of the French-Italian solar telescope THEMIS with the Multichannel Subtractive Double Pass (MSDP) spectrograph. The MSDP instrument permits the simultaneous recording of line profiles at every pixel of a two-dimensional solar image. We show the inversion methods developed for the study of THEMIS observations, based either to the use of a grid of line profiles obtained from non-LTE calculations or the use of response functions. We discuss results concerning observations of sunspots and in particular the study of magnetic field gradients and oscillatory phenomena in sunspots like, umbral flashes and running penumbral waves.

1 THEMIS and the MSDP spectrograph

The THEMIS solar telescope is situated on Tenerife in the Canary Islands. The main characteristics of the telescope are presented in Table 1.

Table 1. The THEMIS solar telescope main technical characteristics and its observing modes

Technical characteristics	
Optical design	Alt-azimuthal Ritchey-Chretien telescope
Primary mirror	90 cm
Focal length	15.04 m
Aperture	f/16.7
Polarization analyzer	Located at F1
Telescope observing modes	
MTR	Multiline slit spectropolarimetry
IPM	Narrow band imaging
MSDP	Multiline 2D spectroscopy

In this paper we will focus on observations obtained with the MSDP spectrograph. We refer the reader to Mein (1991,2001) for a detailed description of the instrument. Below we present a schematic overview of the concept of the MSDP spectrograph. A grid located at the first focus F1 of the telescope results to a slice selection of the observed field of view. Then the beam goes through the field stop located at the second focus F2 of the telescope. After the first spectrograph, a multiple slit S1 (see left figure of Fig. 1) selects the wavelengths and then a second multiple slit S2 reflects the odd beams while the even beams go through. Thus, the final image recorded on a CCD camera (see right figure of Fig. 1) consists of two groups of channels where the wavelengths of the first group are intercalated between the wavelengths of the second group. The same two-dimensional field of view is seen simultaneously in I+sp and I-sp where sp represents one of the three remaining Stokes parameters V, Q or U. The I-sp image is recorded on the empty slice that the

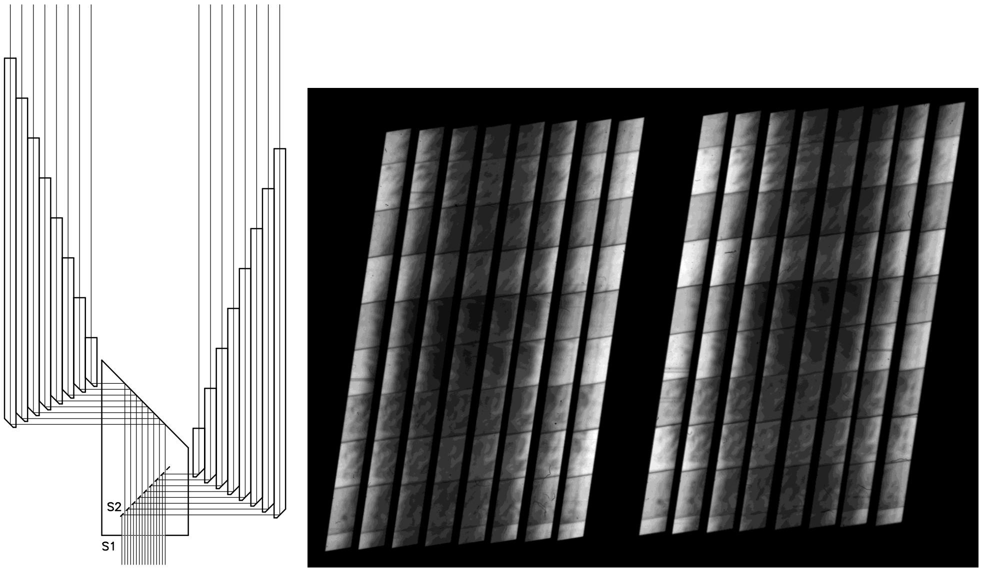

Figure 1. Left: Schematic of the MSDP beamshifter where S1 and S2 represent multiple slits used for wavelength selection. Right: A recorded MSDP image obtained with the grid located at the first focus F1 of the telescope.

grid at F1 produced. This technique ensures that the recorded Stokes parameters are not affected by differential seeing effects. We can thus scan with the telescope a two-dimensional region and then with the MSDP data reduction program we finally reproduce two dimensional images, for which we have the line profile and the corresponding Stokes parameters at each pixel.

Below we present the temporal and spatial capabilities of the MSDP spectrograph by discussing some recent observations and studies made with THEMIS.

2 Using the temporal resolution of MSDP

We use the temporal resolution of MSDP for the study or rapidly evolving phenomena like sunspot oscillations. In Fig. 2 we present a short sequence of 5 images from recent observations made in the infrared CaII 8542 Å line (Tziotziou etal. 2001b). These observations clearly show umbral flashes which are visible both in intensity and Doppler shift images. Their study showed that they are localized phenomena, occupying in this case only the upper half of the umbra and clearly appearing in three distinct positions. They oscillate incoherently with a frequency around 3 mHz. The observations also show penumbral waves, visible only in the Doppler shift images, with an azimuthal extent of 250 degrees that start at the outer edge of the umbra and propagate through the penumbra up to the super-penumbra boundary. Their propagation velocity decreases with distance from the sunspot center, with an average value of 16 km/sec. The power analysis reveals a frequency for the running waves of about 6mHz. The images suggest that umbral flashes and running penumbral waves are probably due to the same resonator and closely related to the local magnetic field configuration.

3 Using the spatial resolution of MSDP

We use the spatial capabilities of MSDP for the study of solar structures with inversion methods which allow us to recover some of the physical parameters describing them. Two different approaches are usually followed.

1. Non-LTE inversion codes: They are usually used for the study of cloud-like structures (i.e. filaments, mottles etc). With this method we construct a grid

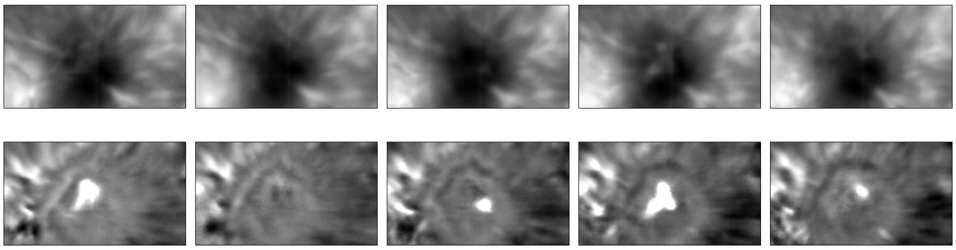

Figure 2. A sequence of five intensity and Doppler shift images of a sunspot observed with a cadence of 46 s. The field of view is 39.15 × 22.20 arcsec. The first row gives intensity while the second row gives Doppler shifts at ±0.12 Å from the line center of the CaII 8542 Å line.

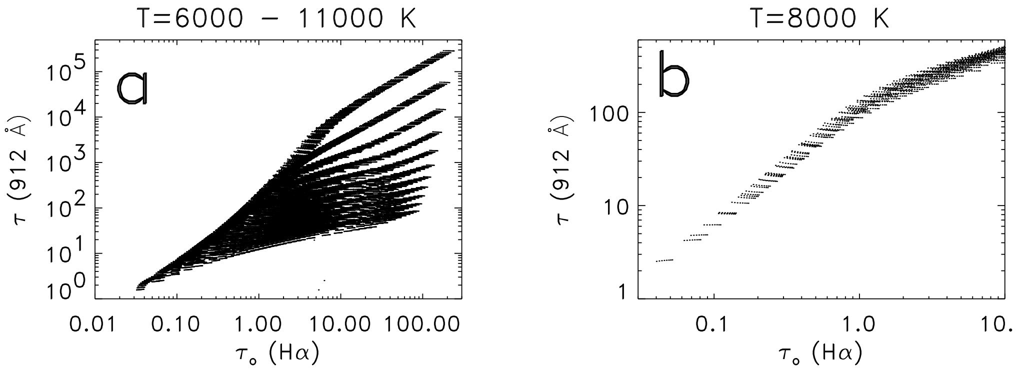

Figure 3. a) Correlation between $\tau_0(\mathrm{H}\alpha)$ and τ_{912} from non-LTE models for different temperatures (top curve for 6000K, step of 500K) and b) same correlation only for T=8000 K. The microturbulence variation is for both figures from 3 to 10 km^{-1}.

of profiles of a line depending on a number of physical parameters (like temperature, electronic density, microturbulence, velocity and geometrical thickness) and then we explore this parameter space to find which atmospheric model best fits the observed profile. Such non-LTE codes have already been developed for the Hα line (Molowny-Horas etal. 1999) and for the CaII 8542 Å infrared line (Tziotziou etal. 2001a) and have been extensively used for the study of filaments.

2. Response functions: with response functions (Mein 1971) we investigate which levels in a stratified atmosphere are responsible for the measurements made at a given wavelength. This is done by studying the sensitivity of the emerging profiles to small perturbations of a given physical parameter. Such a method has been recently developed for the NaI D resonance lines (Eibe 2001a) and used for the study of solar granulation.

3.1 Example of an inversion code study

A study of a filament observed with THEMIS/MSDP in Hα and in EUV lines by SOHO/CDS shows that the dark EUV filament is more extended that the Hα filament (Heinzel etal. 2001). Assuming that the EUV filament represents Lyman continuum absorption our non-LTE models indicate that the ratio of the Lyman continuum to Hα opacities can reach a factor of 50-100 (see Fig. 3). Hence the EUV filament is still visible and consequently more extensive even when the Hα contrast is below the detection limit. This means that cool material in filaments is more abundant than one would expect from Hα observations, an important result for the mass content of Coronal Mass Ejections (CMEs) related to filament disruption.

A similar method is currently being applied for the study of mottles which are rapidly evolving filament-like structures.

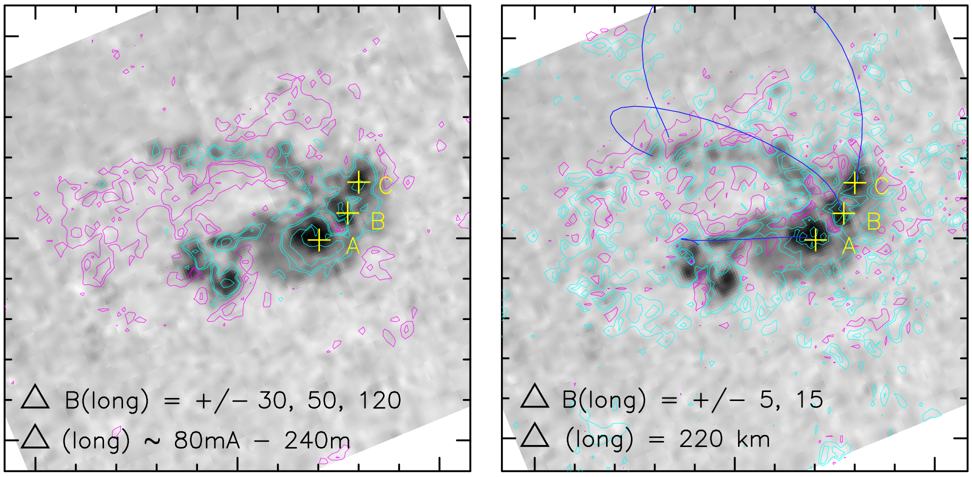

Figure 4. Left: Intensity map of the observed sunspot with isocontours of the gradient of the magnetic field along the line-of-sight. Right: Same but for the longitudinal field derived from the extrapolation.

3.2 Example of a response function study

Recent observations of a sunspot in the NaI D_1 line have enabled us to study the magnetic field gradients in sunspots (Eibe etal. 2001b). The line-of-sight magnetic field has been estimated by means of the Zeeman effect at different altitudes in the photosphere while a method based on response functions was used to estimate these depths at which the Zeeman measurements originated, thus providing us with an estimation of the magnetic field gradients in the sunspot. The results were compared to a magnetic potential field extrapolation (see Fig. 4), for which the observed magnetogram corresponding to the deepest atmospheric level served as a boundary condition for the computations. The study showed that both approaches are in qualitatively good agreement however there is a discrepancy between the calculated magnetic field gradients which requires a better investigation of the magnetic field fine structure.

Acknowledgments

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