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FAST VECTOR MAGNETOGRAPHS: THEMIS/MSDP AND EST PROJECT

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Abstract. Imaging spectro-polarimetry with Multichannel Subtractive Double Pass (MSDP) is able to provide vector magnetic fields with high temporal resolution. We present some results obtained with THEMIS and reduced with the UNNOFIT code, as well as a new method to achieve off-line the required spectral resolution. Performances of slit- and imaging-spectroscopy are briefly compared, together with the high capabilities expected from the EST project.

1 Why is imaging-spetroscopy faster than slit-spectroscopy ?

Imaging spectroscopy by Multichannel Subtractive Double Pass (MSDP) produces simultaneously 2D images at different wavelengths by means of a number N of channels. Figure 1 shows an example of MSDP observation at the Meudon Solar Tower. The same field of view is recorded in 9 channels covering the H_α profile. The wavelengths increases from one channel to the next one, and also inside each channel from one side to the other side. If a wider field of view is desired, a scan is possible. Since the width of the channels is large (more than 1 arc minute in this example), it is easy to understand that such scan will be much more faster than the scan which should be necessary with slit-spectra, if a reasonable spatial resolution (equal to the scan-step in the case of slit-spectroscopy) is needed.

Fig. 1. Example of MSDP data in the H_α line (Meudon Solar Tower,June 10, 2007, *courtesy* G. Molodij).

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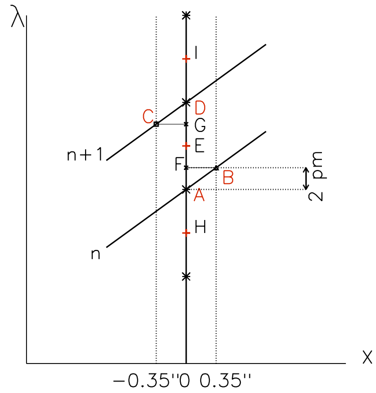

Fig. 2. Off-line increase of spectral resolution: the spectral sampling (distance AD) between channels n and n+1 is divided by 2 (point E) by means of neighbouring points B and C (see the text).

Imaging spectro-polarimetry is more sophisticated, since the Stokes parameters I,Q,U,V must be observed. The observing procedure with the 16 channel THEMIS/MSDP is detailed in the paper by Mein (2004). We use a grid to record simultaneously I+S and I-S (S=Q,U,V,-Q,-U,-V successively).The width of channels is 9 arcsec, and the scanning step generally 5 arcsec to save a reasonable overlap. We see that the scanning-speed is roughly one order of magnitude larger than in the case of slit-spectroscopy with a 0.5 arcsec scanning step.

2 Best compromise between spatial and spectral resolution

The main performances of MSDP are the temporal and spatial resolution. But the spectral resolution is limited by the wavelength distance between channels. This distance (around 8 pm in the case of THEMIS/MSDP) is quite sufficient for strong line profiles, but not for photospheric ones, such as the profile of 610.27 CaI.

Fortunately, it is possible to increase the spectral resolution during the data reduction, by a suitable compromise with spatial resolution. This takes advantage of the following reason. Let us consider the location of pixels in the plane x - λ, where x is the direction parallel to the smaller sides of channels (roughly parallel to the dispersion of spectrograph), and λ the wavelength (fig.2). In each channel, the intensity fluctuations between neighbouring pixels are mainly due to the wavelength variations, and not to the spatial shift on the solar disk. So, intensities observed at A and B (channel n) can be combined with intensities observed at C and D (channel n+1) to determine the intensity at point E. The spectral resolution increases by a factor 2, while the spatial resolution is degraded by ± 0.35 arcsec (see Mein et al., 2004).

3 Example of fast vector magnetic map observed with THEMIS/MSDP

Figure 3 shows an example of vector magnetic map deduced from THEMIS/MSDP data and UNNOFIT inversion (Landolfi at al., 1984) in the 610.27 CaI line. The field-of-view was 120x160 arcsec, and the scanning time roughly 11 minutes. It can be compared to the vector magnetic map deduced from THEMIS/MTR data on the same day, in the 630.2 FeI line. Comparative scatter-plots have been presented in Mein et al.(2004).

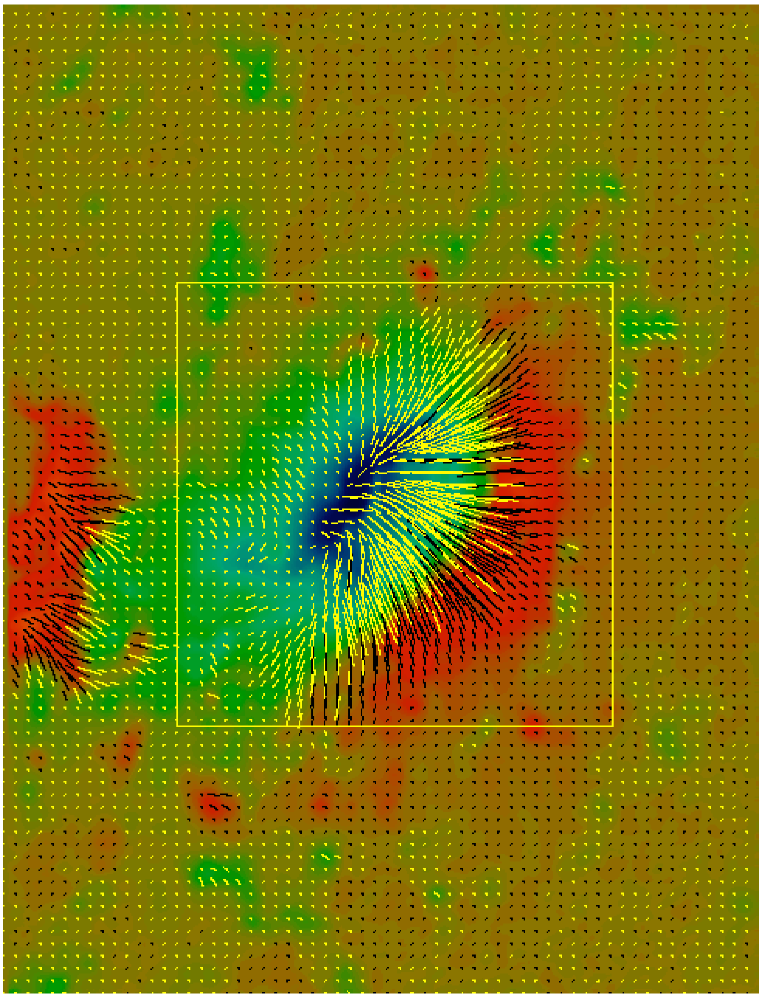

Fig. 3. Vector magnetic map deduced from THEMIS/MSDP observations and UNNOFIT inversion (line 610.3 caI).The field of view is 120x160 arcsec. Background colours show the longitudinal field, and dashes the transverse field.

4 The MSDP included in the EST project

Let us present shortly a sketch of the EST/MSDP project. As in THEMIS/MSDP, two successive spectrographs ensure the dispersion subtraction, and the reduction of scattered light. Figure 5 presents the optics of both spectrographs, seen from above. Three lines (A,B,C) can be observed simultaneously. The transfer optics between both spectrographs is shown for the A line only (from MA1 to MA4). Each line is resorded by 40 channels, with a 2 pm bandwidth and a 3 pm sampling.

The 3 lines can be exchanged automatically within very short time lags. Table 1 shows some sets of lines proposed in the EST project for different scientific programmes.

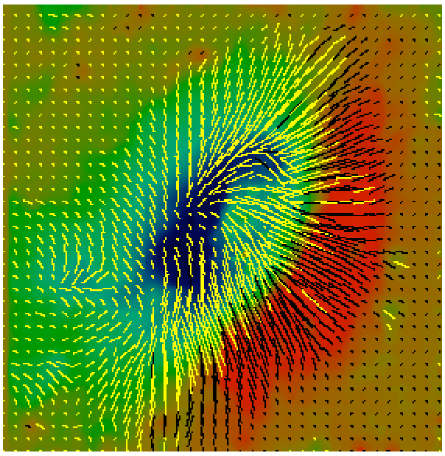

Fig. 4. Vector magnetic map deduced from THEMIS/MTR observations and UNNOFIT inversion (line 630.2 FeI).

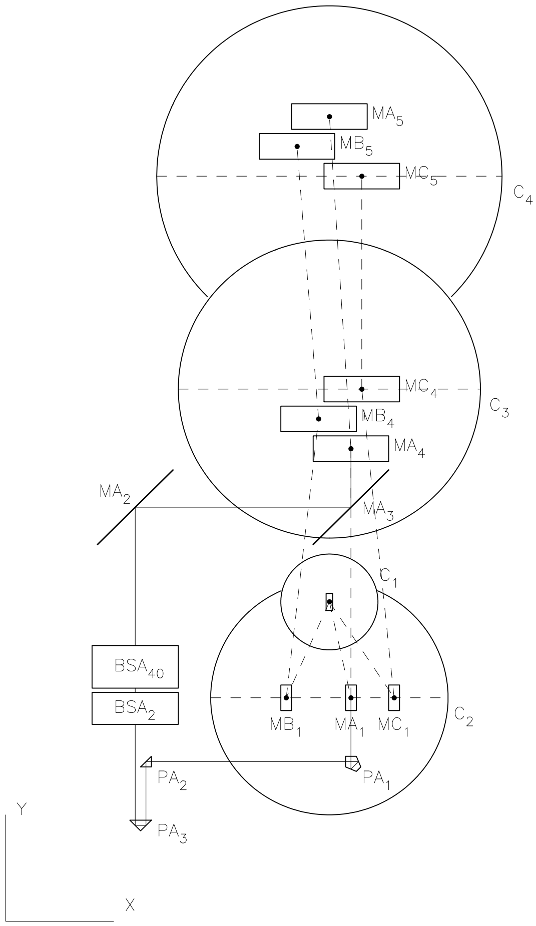

Fig. 5. Sketch of the optical design proposed for imaging spectro-polarimetry with EST/MSDP. The optical path between the first and the second spectrograph (from MA1 to MA4) is plotted for only one of the 3 lines A,B,C, recorded simultaneously.

5 Present and expected capabilities of THEMIS/MSDP and EST/MSDP

Table 2 and Fig.6 show approximate capabilities of some vector magnetographs using slit-spectroscopy (THEMIS/MTR, Hinode in fast mode) and 2D-spectroscopy (THEMIS/MSDP with 16 and 32 channels, EST/MSDP with 40

Table 1. Some sets of 3 lines proposed for EST/MSDP

flux emergene			
	FeI 1564.8	FeI 630.2	CaII 854.2 or HI 486.1
	Ca 610.2 or FeI 868.8	NaI 589.6	HI 656.3
	FeI 630.2 or FeI 868.8	HeI 1083.0	CaII 866.2
filaments and prominences			
	FeI 1564.8 or FeI 630.2	HeI 587.6	HI 486.1
	HeI 587.6	HeI 1083.0	HI 656.3
flux tubes			
	CaI 610.2 or FeI 868.8	NaI 589.6	HI 656.3
	FeI 630.2 or FeI 868.8	HeI 1083.0	CaII 866.2 or CaII 396.8
second sppectrum			
	SrI 460.7	CrI 427.5	BaII 455.4
	BaII 455.4	CaII 393.3	FeI 440.5
	SrI 460.7	MnI 1526.5	CaII 849.8

Table 2. Rough specifications of some vector magnetographs

	Themis MTR (slit)	Themis MSDP 16 ch (2D)	Themis MSDP 32 ch. (2D)	Hinode fast mode (slit)	EST MSDP (2D)
spatial resolution:					
pixel	0.2”	0.2”	0.2”	0.32”	0.15”
slit-width	0.5” - 1”			0.16”	
scanning step	0.7”			0.32”	
x-λ interpol.(see text)		$\pm$0.4”	$\pm$0.2”		$\pm$0.15”
off-line moothing		<1”	<1”		
spectral resolution:					
bandwidth	3-5 pm	4 pm	4 pm	2 pm	2 pm
sampling					
without x-λ interpol.	1 pm	8 pm	4 pm	2 pm	3 pm
with x-λ interpol.		4 pm	2 pm		1.5 pm
number of lines:	6	1	1	1	3
temporal resolution:					
target 100”x160”	100 mn	9 mn	9 mn	19 mn	5 mn ?

channels). The present set-up of THEMIS uses 16 channels. It is possible to turn to 32 channels, if necessary. Let us note that, with the 16 channels set-up, two strong lines providing longitudinal magnetic field in upper levels of the atmosphere can be observed at the same time with still higher scanning speeds (circular polarization only).

We see that:

- The high scanning speed of MSDPs results in temporal resolutions higher than in the case of slit-spectroscopy, even for Hinode in fast mode.

- The spectral sampling of THEMIS/MSDP with 16 channels is improved from 8 to 4 pm by x-λ interpolation (4 to 2 pm with 32 channels). In the case of EST/MSDP, the spectral resolution can reach 1.5 pm in a similar way.

- The spatial resolution of slit-spectroscopy is limited by the slit-width and the scanning step. In the case of MSDP, the 0.2” pixels of THEMIS receive a flux which is not integrated over the spatial width of the slit (0.5” to 1” in the case of THEMIS/MTR). To get a comparable signal-to-noise ratio, a spatial smoothing can be used off-line (1 arcsec for example). Of course, in the case of EST, the very large telescope aperture should allow to avoid any smoothing and any loss of spatial resolution, except to increase the spectral resolution for very faint lines (loss $\pm$0.15 arcsec).

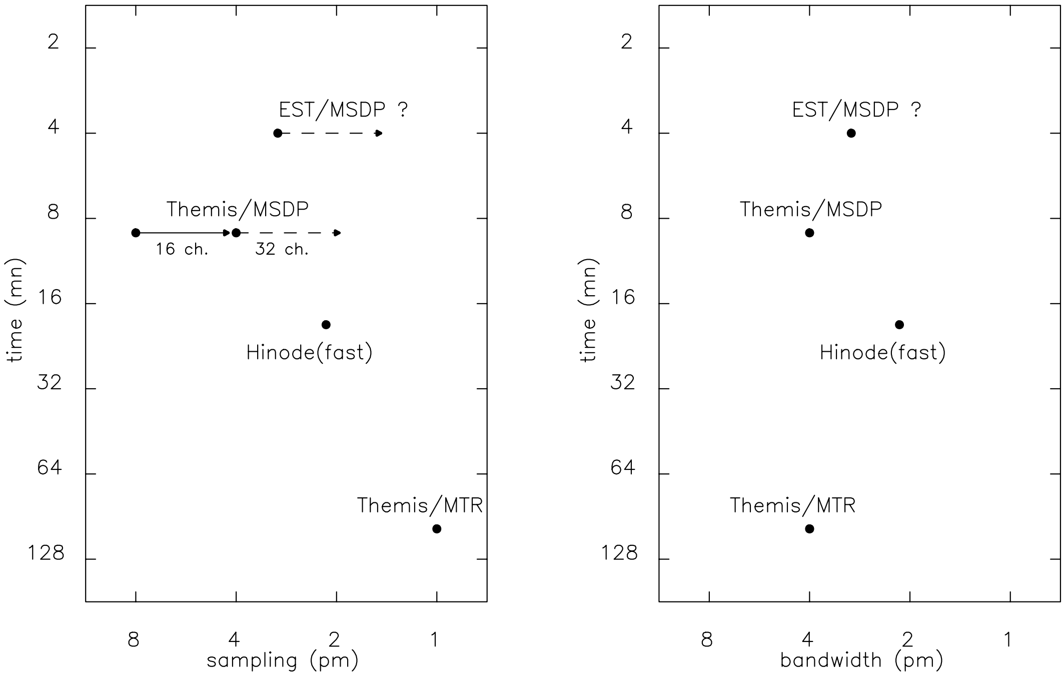

Fig. 6. Approximate scanning-times for targets 100"x160", versus spectral sampling (left) and bandwidth (right), in the cases of THEMIS, Hinode and EST project. Arrows show the improvement of spectral sampling by compromise with spatial resolution. MSDP instruments, with scanning-times shorter than 10 mn, are especially suitable for magnetic field evolutions in flares and CMEs.

6 Advantages of imaging-spectro-polarimetry

We have seen that spectro-polarimetry can cover solar targets with high scanning speed (a few minutes for active regions). MSDP instruments are very efficient for fast solar events such as intabilities, flares, and CMEs. We have seen also that several sets of performances are available with the same data-cube. According to the scientific programme, different reductions are possible, with different compromises between spatial resolution, spectral resolution, and signal-to-noise ratio.

In addition, it is always possible, as with any kind of 2D data, to apply off-line corrections for seeing effects, such as destretching codes, for example.

Finally, with the large aperture and the long spectrographs of EST, the MSDP capabilities should be still extended in terms of speed, spectral resolution, spatial resolution, and signal-to-noise ratio. They should be unique for vector magnetic fields measurements.

References

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