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THEMIS : a powerful solar telescope for spectro-polarimetry ⋆

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Abstract. The scientific results obtained with THEMIS are shortly presented. In addition some indications about the improvements which are essential to maintain THEMIS in the group of the most relevant solar telescopes in the world are given.

Key words. SUN – Solar Physics – Magnetic Field –

1. Introduction

THEMIS solar telescope is operated in Tenerife (Canary islands, Spain) by a company constituted by the French CNRS-INSU (Conseil National de la Recherche Scientifique - Institut National des Sciences de l'Universe, Paris) and the Italian CNR (Consiglio Nazionale delle Ricerche, Rome), in the frame of the international agreement for astrophysics signed by Spanish government and many other countries.

In this frame we want remember that THEMIS is member of the European Northern Observatory. *The prime aim of ENO is the provision of essential services to the research community . . . ENO will promote actions, projects and other initiatives with a view to setting up common facilities, constructing common instrumentation, training of scientists and technologists . . .* (extract from the ENO convention).

The construction of Themis was based on the following scientific baselines (Heyvaerts 1982):

Coronal Heating: capability to measure the EM flux (Alfven Waves,Surface Waves) in the small scale magnetic structures and the time variation of the total current emitted by the photosphere.

Magnetic Field Concentrated Structures: Investigation of the mechanism of concentration, formation process and cancellation of sunspot.

MHD Turbulence: Study of the small scale turbulence.

Flare Studies: Measure of the vertical component of rot B, and extrapolation of the magnetic field at coronal layers.

Radiative Transfer in Presence of Magnetic Field

These scientific objectives imposed severe instrumental constraints which spans from

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⋆ Based on observations made with THEMIS telescope operated on the island of Tenerife by THEMIS SL in the Spanish Observatorio del Teide of the Instituto de Astrofisica de Canarias

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the very low instrumental polarization, to the multi-lines spectro-polarimetry over a wide range of wavelengths, together with the high spectral and spatial resolution.

2. THEMIS in 2002

2.1. Polarimetry

The polarization analyzer located at the primary focus of the telescope (Ritchey-Chretien mounting) represents the major characteristic of Themis together with the multi lines capability of the spectrograph. The analyzer is constituted by two quarter wave plates and a beam-splitter. Successive rotations of the quarter wave plates allow sequential measurements of the Stokes parameters (I ± Q, I ± U, I ± V) and using the *inversion beam* method it is possible to improves the accuracy of the polarimetric measurements. An accuracy of 10^{-4}(integrating data along the slit) or 10^{-3} on single profile is indicated by several observers.

Three types of polarimetric configurations can be select between:

2 x 2 arcmin: the 2 beams of orthogonal polarization reach two different cameras. The covered field of view is of two arc min. However, there are limits imposed by the use of:

- 2 two independent optical paths in F2 for the two polarization states
- 2 two separated entrance slits of the spectrograph
- 2 two independent cameras for the two polarization states

2 x 1 arcmin: with this configuration the 2 beams are recorded on a single camera with a field of view reduced to one arc minute. The use of a single camera for the two beams increases the accuracy (no limitation coming from the flat-field precision). However, there are limits imposed by the use of:

- 2 two independent optical paths in F2 for the two polarization states
- 2 two independent entrance slits of the spectrograph

Grid: this configuration (Semel, 1980), uses a single slit in the focal plane of the spectrograph with a single camera and the field of view is split in different sub-areas of 16 arcsec each.

2.2. High spectral resolution

The main characteristics of Themis telescope is the capability to observe in a multi-line and spectro-polarimetric mode optimized between 500-900 nm. Three different and complementary configurations are allowed:

Spectroscopy (MTR) with two spectrographs in series: a predisperser (150 gr/mm) followed by an echelle spectrograph (79gr/mm) allowing up to 7 spectral ranges simultaneously

Spectro-Imagery (MSDP) up to 5 wavelengths available with 2 simultaneous (Mein 1991, 2002)

Imagery (IPM) up to 6 spectral ranges available with wavelength scanning ($\lambda/\Delta\lambda$ = 256.000 at 550nm)(Cavallini 1998)

Polarimetric measurements can be performed with the spectroscopic and spectro-imagery modes.

2.3. More Tools for the Observers

Now the observers can dispose of several new improvements:

- Fine scanning up to 0.1 arcsec on the solar disk
- Increase of the tools available on the Observer Interface for MTR (multi-line mode) and inclusion of the MSDP mode control, allowing an easy preparation of the observing sequences
- The instrumental control has been strongly improved allowing an increased reliability together with a better time resolution (Laforgue 2003), (Laforgue 2003)

3. Main Scientific Topics

We give here some examples of results obtained from the observations at THEMIS. The full list of Themis related papers can be found on the web page (http://www.themis.iac.es/).

3.1. Dynamics of the Quiet Photosphere

This kind of observations, performed mainly with IPM and MSDP instruments, requires high temporal, spectral and spatial resolution simultaneously.

The main results concern:

- Presence of two photospheric regimes (Berrilli et al., 2002):
  - Convective overshooting which rules the lower layers
  - A production of cool plumes that dominates the highest level
- Deceleration of central up-flow in exploding granules (Berrilli et al., 2002)

3.2. Turbulent Magnetic Field

The turbulent magnetic field studies, performed with the MTR mode, require an high precision measurement (up to 10^{-4}) of the linear polarization together with a multi-lines observations.

The main results concern:

- Variation of the turbulent magnetic field with solar cycle ? (Faurobert et al. 2001; Bommier and Molodij 2002)
- Exploration of the molecular lines diagnosis capabilities (Faurobert and Arnaud 2002)
- Strong asymmetry of the V profile of the NaD_1 line (Trujillo-Bueno et al. 2001)

3.3. Active Regions

Several types of observations were performed on active regions:

- Time evolution of the active regions
- Flares
- Umbral flashes

This kind of observations performed mainly with MTR and MSDP instruments requires high temporal resolution observations with accurate polarimetric measurements simultaneously in different spectral lines.

The main results concern:

- Ephemeral emergence of magnetic structure with a pure longitudinal component but showing no signature in intensity (Briand et al. 2002)
- Impact polarization signature during the eruptive phase of a flare (Hénoux et al. 2002)
- New measurements of the linear polarization during umbral flashes giving new input for the models (López Ariste et al. 2001)

3.4. Filaments and Prominences

This kind of observations require require high spatial resolution and accurate polarimetric measurements in several lines simultaneously, and are mainly performed with the MSDP and MTR modes.

The main results concern:

- First measurements of the four Stokes parameters in a protuberance (Paletou et al. 2001)
- Dark filament are much more extended in EUV than in Hα, which has important consequences on the filament formation models (Heinzel et al. 2001)

4. High spatial resolution

The theoretical spatial resolution of THEMIS should allow to reach 0.18 arcsec of spatial resolution at λ = 500nm. To understand the limitations of the spatial resolution that we observe (0.4 arcsec) we have realized this year the following :

- A determination of the optical aberrations during daily observation through the method of Phase Diversity/ Speckle
- An analysis of the telescope environment thermal control to search for a limitation due to the turbulence

The optical aberrations explain why we don't have images with a spatial resolution better than 0.4 arcsec, but with the analysis of the thermal environment we want to know the additive effect of the turbulence eventually present.

We performed also some image reconstructions with the Phase Diversity technique and a project for implementing adaptive optics is now under investigation (see below).

4.1. Phase Diversity/Speckle

We obtained from these measurements important information on the power spectrum of the images: significant power is still present at the frequency corresponding to the diffraction limit of the telescope, which could be exploited by an adequate AO system (Del Moro et al. 2003,?).

4.2. Turbulence

To have a better knowledge of the turbulence present in the telescope environment, thermal sensors were implemented at some critical points of the optical path: near the entrance window of the telescope, at the primary focus and in the M5 environment. Micro-thermal measurements (Sensitivity: 0.001°C, acquisition rate: 200Hz) have shown very small internal turbulence (thermal fluctuations of a few 10^{-2} $^{\circ}$C, suggesting to investigate now the external environment.

5. Mid-Term Projects (2003-2005)

The main projects for the mid term time is to reinforce the polarimetric capabilities of Themis and to improve the spatial resolution.

5.1. IBIS

Ibis will replace IPM with a larger field of view, a larger spectral interval, an better temporal resolution and the capability to perform polarimetric measurements. This instrument, totally financed by Italian agencies, is almost operative. It will be transferred to THEMIS after a test period at Sac Peak in 2003. The importance of such kind of instrument is documented on several publications mainly from Big Bear Observatory (Mathew et al. 1998).

IBIS will make possible studies on fast evolution phenomenons (flares, waves), on extended regions with good time resolution (emergence and cancellation of MF, sunspots time evolution, helicity and topology of AR, filament MF and relationship with CMEs). Other important subjects which can be explored are the small scale features, bright points, turbulent MF, granular MF (Keller 1996; Lin and Rimmele 1999).

6. Adaptive Optics: why ?

Theory predicts a very small scale for turbulent magnetic field: less than 0.1 arcsec (Emonet and Cattaneo 2001). If we want to study the fine structures of an active regions to get information about its topology and helicity high spatial resolution is also required.

Polarimetric measurements require long exposure time which is hardly compatible with the high frequency seeing variations that introduce image motion and blurring. Let's see some consequences of that.

An interesting simulation realized by Sigwarth (Sigwarth 2001), allows to establish that if we observe a V source of 20% (1 KGauss) without AO we get a signal of 0.15%. Instead using low order A0 (15 modes) we get a signal of 6%. A less intense signal (10% V) would not be detected without AO. With AO, the amplitude would be 0.4 and the halo 0.9 arcsec.

Following the same simulation by Sigwarth, if we observe at moderate ($\simeq$ 1 arcsec) spatial resolution, misinterpretation of polarimetric signal can arise. Instead using low order AO (15 modes) we start to resolve true structures and signals much stronger. Finally if we use an over sampling of 2x the diffraction limit of the telescope together with low order AO we can resolve the structures. Finally (Emonet and Cattaneo 2001) show that with a 1 arcsec of spatial resolution only 10% of the true magnetic field is detected.

This means that with the today state of art of technology for Adaptive Optics we can obtain the spatial resolution we need for our observations. We want to recall here a known reality concerning the Tip-Tilt, which up to to now was a preliminary step for the AO system realization. If the tip-tilt can correct up to 80% of the atmospheric aberrations, the period over which the tip-tilt can correctly works is much reduced compared to a full AO system. Several examples on this subject exist (see web pages of VTT Tower of KIS, and of Sac Peak).

All new large solar telescopes, VTT (Tenerife), NSST (La Palma), GREGOR (Tenerife 2005), ATST (? 2010) implement today AO. Studies are under development at VTT (Tenerife - Berkefeld 2002) on MCAO (Multi Conjugate Adaptive Optics which extends the corrected field of view) in view of the implementation on GREGOR and ATST.

Concerning THEMIS the situation is as follows.

On October 2000 an international panel of experts in solar AO encouraged the development of an AO at THEMIS. On February 2001 a first contact was taken with the ONERA company for a preliminary study on AO for THEMIS which was concluded on May 2002.

On june 2002 the French part of the Themis SL company proposed to study unilaterally only a tip-tilt solution to wait for the AO implantation.

No decision has been taken up to know.

7. Conclusion

Besides of all these important activities which are running at Themis, scientific staff also dedicate time for educational activities:

- Visits at telescope (Mean of 3 visits/month)
  - Congress (frequent in Tenerife)
  - European Parliament
  - Journalists + Televisions
  - High Schools and colleges
  - Open Doors Days
- Diffusion towards the local population

- Training Periods for Students (Mean of 3 to 4 / year):
  - French Engineers of High Schools
  - Italian PhD Students for periods of 3-4 months

We foreseen to enhance the educational activities towards the students for the next years.

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