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THE THEMIS SOLAR TELESCOPE IN 2006: SITUATION AND PERSPECTIVES

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Abstract. Recent technical improvements like a new image stabilizer, coupled to a set of comprehensive progress in data analysis and inversions software and have quite significantly raised the level of performances achieved at THEMIS. Spectropolarimetry at a relative precision of 10^{-5} is now accessible, opening whole new fields of discovery, and exceeding by far the original specs of 10^{-3}. In addition, and despite a lack of background, speckle imaging has proven to be possible and of obvious interest to couple with the current spectropolarimetry capabilities.

1 Introduction

THEMIS is a joint operation from France (CNRS) and Italy (CNR) national research agencies. It is a 90 cm solar telescope, currently the third larger in the world, located at Izaña, 2400 m, within the Teide Observatory from the Instituto de Astrofisica de Canarias, on Tenerife (Canary Islands, Spain), and started operating in 1999. Its specific design for high-quality polarimetry includes an alt-az mounting, a helium filled telescope tube, a Stokes polarimeter located at prime focus, and a multi-mode spectrograph.

THEMIS delivers routinely vector polarimetry with an accuracy ranging from 10^{-3} to 10^{-6} in some configurations. The spectrograph design allows the observation of up to 10 wavelengths simultaneously, opening the possibility to perform 3D inversion of the magnetic field structures in the solar atmosphere.

2 The science case: a reminder

THEMIS was started during the '80s thanks to the iniative of a reputed Paris/Meudon team of solar physicists very much involved in high precision spectropolarimetry, this explaining largely the design and further exploitation of this telescope up to now. THEMIS has been built to explore the physical processes underlying the solar magnetic field generation and transport across the star's convection zone. This includes addressing the problems of (i)solar dynamo generation, (ii) interaction convection/ rotation / magnetic field generation, and (iii) atomic physics and polarized radiation transfer. Because the magnetic field is present at all spatial scales from the larger (the heliosphere) to the smaller (intergranular or smaller magnetic fields scales, ohmic dissipation scales of few km), the observations must match a corresponding challenge. THEMIS current dynamics in spatial scales is about 10^4 (and even larger when it comes to the detection of below- the diffraction magnetic features. At the smaller scales we have:

- structure and evolution of the photosphere
- quiet sun magnetic field, diagnosis of small scale features
- active sun, spots and filaments
- 2nd solar spectrum, Hanle effect
- proeminences in the visible and IR, eruptions
- chromosphere structure and dynamics,
- coronal heating

. Toward the larger scales, we intend to provide magnetic maps at the highest possible resolution to monitor solar terrestrial relationship and solar variability at the large temporal scales. Finally, starting in 2006 and taking advantage of the newer instrumental changes, we started exploring planetary spectropolarimetry and very high resolution stellar spectropolarimetry, both on a limited set of (very bright) objects.

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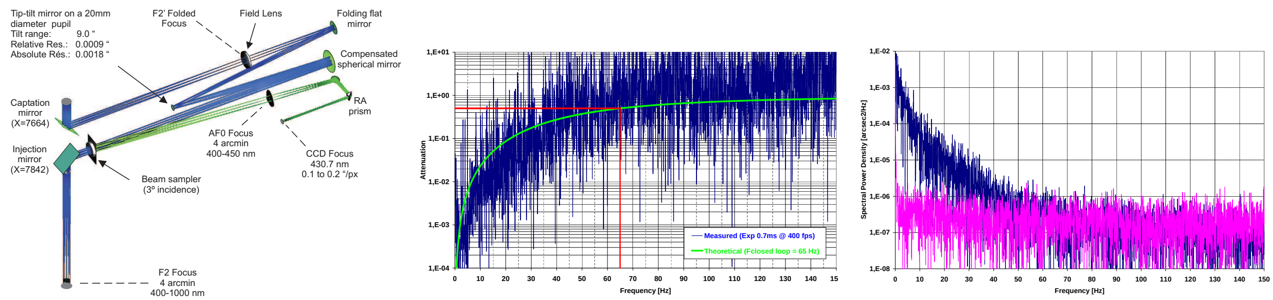

Fig. 1. The THEMIS image stabilizer entered into service in 2006. **Left:**Optical scheme of the detour above the F2 focus. **Middle:** Performances of the stabilizer over granulation: spectra of remaining image motion with and without tip-tilt correction. **Right:** attenuation curve with a superimposed fit to help locate the crossover frequency (at -3dB) of the closed loop; Its value is currently close to $\nu_{-3db} = 65Hz$ for any solar disk scene, including granulation.

3 Themis technical evolution

The telescope team started to develop an image stabilizer ("tip-tilt") in 2004 that has gone into service this year. Its technical details are being published elsewhere (Gelly et al. 2006), but so far it is within its original specifications that where: (i) stabilization must be available to all observing modes, (ii) it must not use a significant fraction of the current science channels, (iii) it must work on all typical solar objects, e.g. granulation, spots and limb. Fig. 1 shows that we managed to successfully close the servo loop at $65Hz$ on any solar disk feature. Scanning of the solar surface while the tip-tilt is allowed an permit to build much improved vector magnetic maps. See for example Bommier (2006) in these proceedings.

An example (without scanning) of the additional quality brought by this device is visible on Fig. 2 left, which shows the Li 6708 line over the quiet Sun. The understanding of Lithium surface abundance of solar type stars remains a difficult topic with huge implications, from the history of the star angular momentum and mixing to the existence of internal gravity waves, to the diagnosis of extrasolar planets on solar type stars (Charbonnel et al., 2006). While this light element is still barely distinguishable in intensity, its linear polarized spectra is quite above the noise level which in this case was only a few 10^{-6}. Indeed we are now much better than the original 10^{-3} specs.

Several pieces of software have been crafted and made available to simplify the data analysis and the access of non-specialists to THEMIS data products. The SQUV code (Sainz Dalda et al. 2006) is a public domain package aiming at a seamless reduction of any THEMIS polarimetric raw data at the 10^{-4} precision level. Another tool (DeepStokes) allows better than 10^{-4} in specific conditions. These reduction codes are backed with an inversion code (INVFE, also pd) to get vector magnetic field maps in the case of FeI 6203 observations. This code takes advantage of a PCA technique (López Ariste et al. 2001) to provide fast and reliable results. All these codes are available in the telescope control room, SQUV and INVFE are freely downloadable.

Using an off-the shelf CMOS camera and our tip-tilt, a first attempt at speckle imaging has been done during some technical time in spring. We assume the reader familiar with such image reconstruction algorithm (Von der Lühe 1993) and we just remind that this procedure estimate and correct for the Speckle Transfer Function (STF) of the image modulus in Fourier space and uses an extended Knox-Thompson method to find out the object phase in the statistical cross-spectrum of the time serie. Final image is then inversed from its Fourier modulus and phase. Post processing of the selected burst images has been done using KISIP V, a speckle imaging package from the Kiepenheuer Institute fur Sonnenphysics (KIS, Freiburg). This package and some test runs on our data have been kindly provided provided to us by O. von der Lühe. An encouraging enough diffraction limited image is shown on Fig. 2 right.

4 THEMIS: 2012 and beyond

So far, high quality spectropolarimetry has been greatly improved by the stabilization of the images. The full exploitation has only started, helped by the availability of suitable reduction codes, and boosted also by the arrival of modern cameras for both the MTR and MSDP observing modes. To complement this set of new

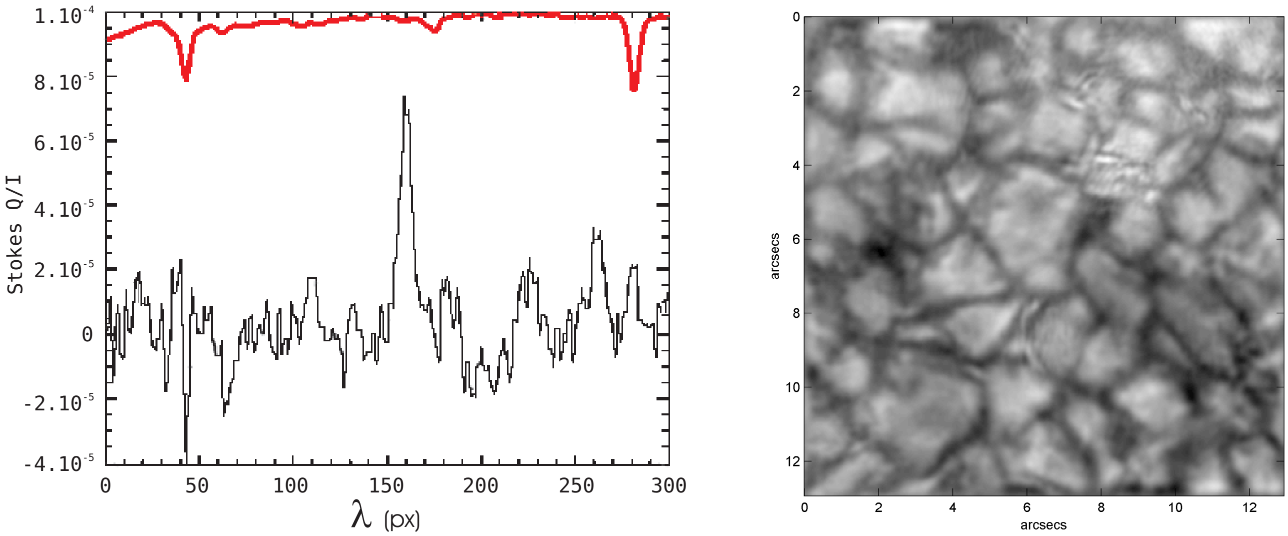

Fig. 2. Left: Linear Q/I polarization of the 670.8 nm Lithium over the quiet Sun. Top line is the reference intensity. The unprecedented quality of this result is largely coming from the stabilisation of the spectra. **Right:** Speckle imaging can also take advantage of the tip-tilt. This diffraction-limited picture is processed about 100 raw images using KISIP V, a package from the KIS institution.

features, we are currently studying the speed up the analysis cycle so as to match the improved speed of the detectors and decrease the seeing induced cross-talk. TTL driven achromatic LCD retarders combinations are now being considered as replacements for our mechanically driven quartz/MgF2 units. Such a device would tentatively be available by mid-2008.

In this framework, plans are seeked to extend the lifetime of this installation so as to continue its scientific exploitation. 2012 is for us a minimum threshold to reach,, even at the expense of changing the current operational model and to progressively move toward a cruise phase requiring less technical support. However, the complexity of the various THEMIS subsystems for the instrumental setups, the handling of the observation, the cold water production, the periodic changes of the helium content of tube, etc., will possibly prevent forever its successful use by non-trained personnel only.

5 OPTICON and the broader European perspective

The Canary Islands are providing a very appropriate test bench for lots of European collaboration in solar astronomy. European countries are currently operating there 4 world-class major solar facilities, soon to be 5: the 1m NSST operated by Sweden (RSAS), the 60 cm DOT operated by the University of Utrecht, the 60 cm VTT operated by the Kiepenheuer Institute fr Sonnenphysics from Freiburg and the 90 cm THEMIS operated by CNRS/CNR. When the 1.5 m GREGOR from KIS will enter into service (mid-2007), it will become the largest and more modern solar telescope in the world.

All these solar telescopes participate to the OPTICON I3 European program, and among them THEMIS has been particularly active in providing "access units" (e.g. days of observations) to not-by-the-law users (Opticon access office, 2004-2006) ; we are currently looking into the possible convergence of the 6 various solar Time Allocation Committees toward one single superTAC, within the OPTICON/FP7 framework (post-2008), as a first step toward a distributed European research infrastructure. Such a step would be a very nice progress in the perspective of the following discussion.

While these meter class telescopes are currently handled at national or university levels, the underlying scientific community, if properly federated, has obviously the expertise and size to conduct and successfully achieve much larger projects than just the upgrading its present facilities. A couple of recent meetings are stating this, like the Mondragone resolution (10/4)(see [3]) *(i)An organization shall be established at the European level with the task to define and to co-ordinate the effort necessary to ensure access of European solar astronomers*

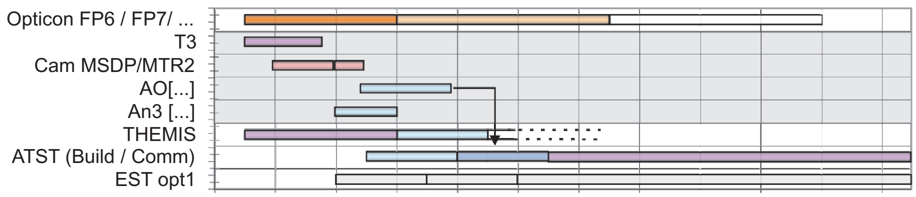

Fig. 3. Possible scenario for the existing solar facilities in operation, and planned. Emphasis is given to the THEMIS telescope where the current and planned technical developments are indicated over a gray shaded area. THEMIS operations at the current funding level will possibly not extend after 2009, however the scientific yield of today's technical improvement are expected to deliver high added value until about 2015.

to, and promote creation of, worldwide leading ground based observing facilities. (ii) The Undersigned shall seek national and European funding for a viable and active partnership in the design, construction and operation of the ATST (Keil et al., 2003) [1]

This meeting was followed by a brainstorming session of telescope operators in Freiburg leading to the creation of a consortium structure (EAST)[2] whose mission is defined like: *[...] ensuring access of European solar astronomers to world-class observing facilities. In order to achieve this goal, EAST shall : (i) develop, construct and operate a next-generation large aperture European Solar Telescope (EST) in the Canaries (ii) co-ordinate the operation and scientific use of optical solar facilities in Europe, (iii) co-ordinate and facilitate efforts of its members to participate in other solar facilities such as the Advanced Technology Solar Telescope*

It is out of the scope of this paper to discuss the pro and cons of the many paths that extend in front us. However, Fig. 3 indicates (with provisions) possible lifetimes for the existing Canarian solar telescopes. If we do not think that only one ATST will be enough to fullfil the needs of both the US and EU community after 2015, we better start immediately planning for the EST.

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[1] Advanced Technology Solar Telescope
[2] European Association for Solar Telescopes