

Tenerife Infrared Polarimeter II

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Abstract. Since May 2005 the Tenerife Infrared Polarimeter II (TIP-II) has been operational at the Vacuum Tower Telescope on Tenerife. The core of the polarimeter is a 1024×1020 pixel infrared camera allowing for high precision measurements of the full Stokes vector with a pixel size of 0.18", corresponding to the diffraction limit of the telescope at 1 μm . The polarimeter is able to reach a polarimetric accuracy of a few times 10^{-4} , covering a wavelength range of 1 to 1.8 μm . With an upgrade in July 2006, the slit size has been increased to 77" allowing most active regions to be covered with a single scan. Here we present the technical details of the polarimeter and the camera. We also show some data illustrating the power of this new instrumentation.

1. Introduction

The Tenerife Infrared Polarimeter (TIP, Martínez Pillet et al. 1999) has been operating at the German VTT of the Observatorio del Teide since 1999, as a common use instrument. It is based on a pair of ferroelectric liquid crystals (FLCs) followed by a polarizing beamsplitter. Depending on an applied external voltage, the FLCs alternate the orientation of their fast axis between two orientations, separated by an angle close to 50 degrees at ambient temperatures. The four different orientation combinations allowed by the two FLCs give rise to four independent linear combinations of the Stokes parameters. As demonstrated by Collados (1999), del Toro Iniesta & Collados (2000), and Collados (2007), very good efficiencies can be obtained with this type of polarimeter. The polarizing beamsplitter generates two beams that, when combined, allow to minimize the crosstalk from intensity to the other Stokes parameters (Collados 1999). As shown by Collados (2007), a single pair of FLCs only have good efficiencies in a range about $\pm 15\%$ of the central wavelength. For this reason, TIP uses two different sets of FLCs to cover the full wavelength range from 1 to 1.8 μm .

Up to now, the most used and successful observed spectral ranges are those centered at 1.083 μm and 1.565 μm . The first one includes several photospheric lines and the chromospheric HeI triplet, making possible the study of chromospheric magnetism (Trujillo Bueno et al. 2002, Solanki et al. 2003, Sasso et al. 2007) and its relation to photospheric phenomena (Centeno et al. 2006, Bloomfield et al. 2007). The second spectral range includes the highly magnetically sensitive $g = 3$ FeI 1.5648 μm line, that allows for the study of weak magnetic field strengths (Khomenko et al. 2003) or its small fluctuations (Bellot Rubio et al. 2000).

Sensor	Rockwell TCM-8600 HgCdTe
Size	1024 × 1020 px
Pixel	18 μm (sq.)
Well depth	320000 e ⁻
Gain	20 e ⁻ /ADU
Max. fr. rate	36 fr/s
Quantum effc.	> 55%
Wavel. range	0.9-2.5 μm
Read noise	80 e ⁻
Dark current	220 e ⁻ /s

Filter	Jlow	Jhigh	H
Maximum transmission	70%	82%	90%
$\lambda_{\text{center}}(\mu\text{m})$	1.105	1.265	1.635
FWHM(μm)	0.15	0.19	0.29

Table 1. Properties of the detector used in TIP-II (left table) and of the filters located inside the dewar to isolate the adequate diffraction order (right table).

In a collaboration between IAC and MPS, the system has been upgraded to a second version, named TIP-II (Tenerife Infrared Polarimeter II). To that aim, the detector and the polarization beamsplitter have been changed, which provides three major advantages: (i) the spatial sampling is reduced to match the value required to reach the diffraction limit of the VTT at 1 μm; (ii) the observed spectral range is increased, allowing more spectral lines to be observed. This may be useful for a better recovery of the magnetic and thermodynamical conditions of the observed regions using appropriate inversion codes; (iii) the spatial coverage along the slit has been doubled, making possible the coverage of large active regions with a single scan. The detector change was implemented during the 2005 observing campaign (with the old beamsplitter), while the new beamsplitter was installed in 2006.

In the following, the properties of the new elements are described. The performance of TIP-II at the VTT is given, together with its expected capabilities at GREGOR (Volkmer et al. 2006, Collados et al. 2007). The comparison with TIP operating at the VTT is also shown. Finally, some example data are presented.

2. Detector

The properties of the new detector are summarized in Table 1. The sensor is placed inside a cryostat that keeps it at liquid N₂ temperature (77 K). A filter wheel inside the cryostat permits the selection of the appropriate grating order for wavelength selection. Presently three filters are available (see the right part of Table 1). The filter wheel still has three unused positions for potential new filters.

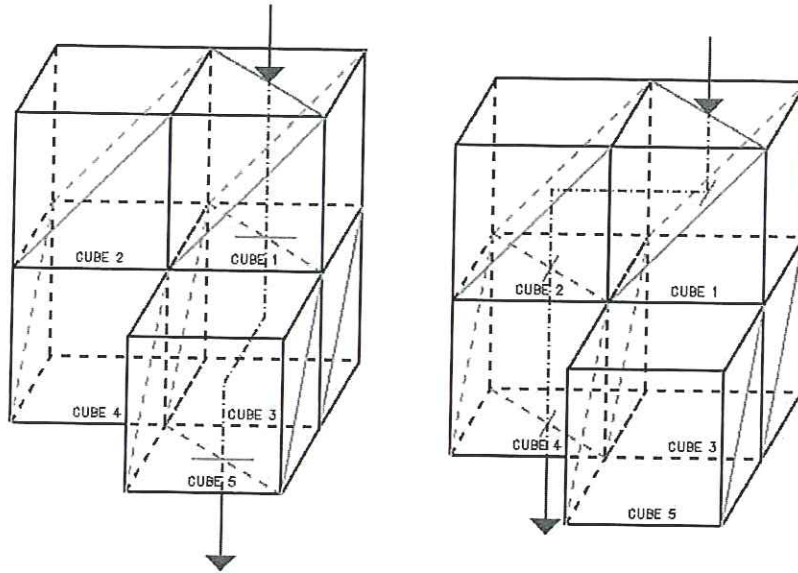


Figure 1. Diagrams showing the optical path followed by the beams. At the exit, two images of the input slit are formed with perpendicular linear polarization and very good polarization purity.

	TIP at VTT (1998)	TIP-II at VTT (2005)	TIP-II at GREGOR (2008)
Spatial sampling	0.36''/px	0.18''/px	0.135''/px
Spatial coverage	36''	77''	60''
Spectral sampling			
1.08 μm	29.6 m \AA /px	11.6 m \AA /px	21.1 m \AA /px
1.56 μm	29.4 m \AA /px	15.6 m \AA /px	44.9 m \AA /px
Spectral coverage			
1.08 μm	7.6 \AA	11.8 \AA	21.7 \AA
1.56 μm	7.5 \AA	15.9 \AA	45.9 \AA
Spectral dispersion			
1.08 μm	1.35 mm/ \AA	1.55 mm/ \AA	0.85 mm/ \AA
1.56 μm	1.36 mm/ \AA	1.16 mm/ \AA	0.40 mm/ \AA

Table 2. Characteristic parameters of TIP-II operating at the VTT. For comparison, the same parameters are given for TIP operating at the VTT and TIP-II at GREGOR.

3. Beamsplitter

Two new beamsplitters with the same optical principles have been installed. One comes from Meadowlark, and uses Versalight material for the separation of the p and s components. The properties of Versalight makes the device valid from 400 nm up to 2 μm . The second unit, from Fichou, uses dielectric coatings for the separation and can be used from 1.0 to 1.3 μm . Both beamsplitters

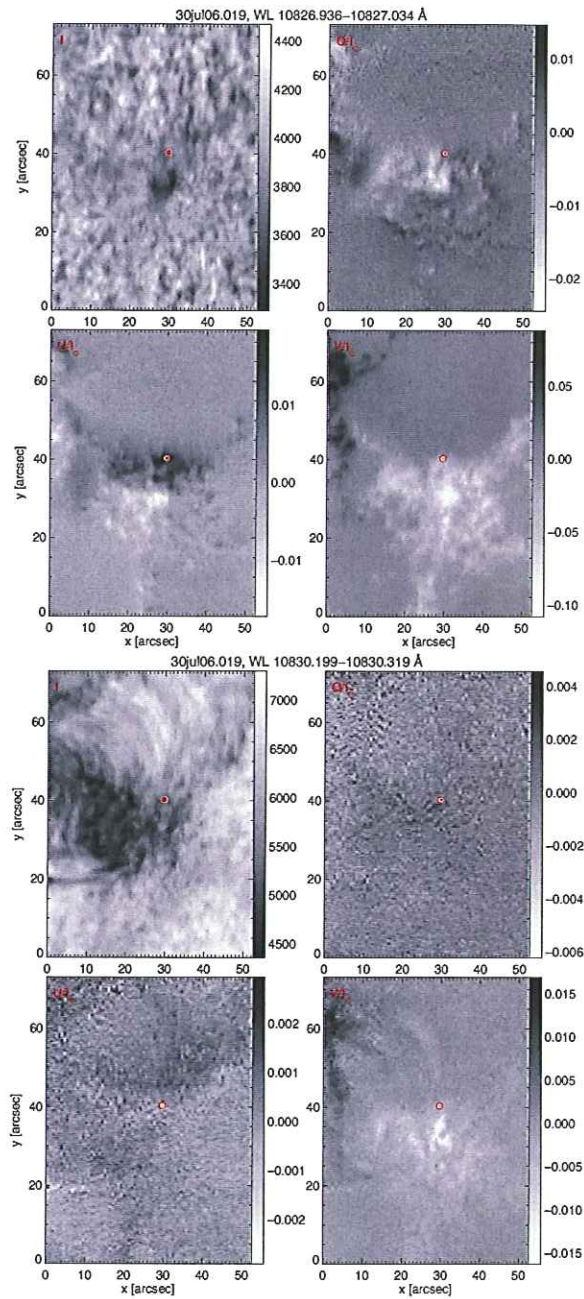


Figure 2. Stokes I , Q , U , and V map of an active region containing a small pore close to the the core of the Si I 10827 Å line (upper four images) and the He I 10830 Å line (lower four images). The images are composite maps of the individual slit spectra for the wavelength ranges given in the image titles.

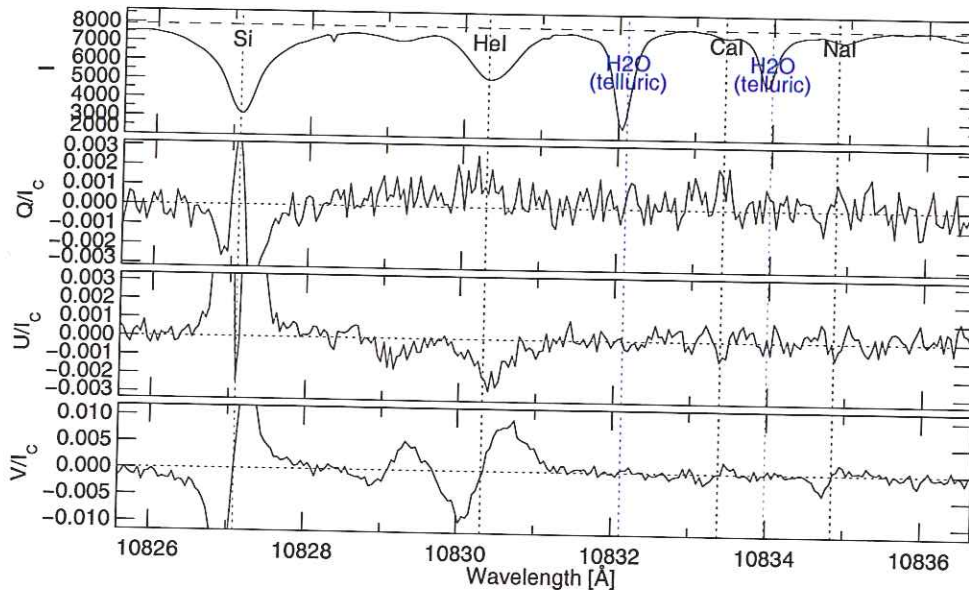


Figure 3. Stokes profiles for position $x = 30''$, $y = 40''$ in Fig. 2 (indicated by red dot), demonstrating the large spectral range and the polarization sensitivity achievable with TIP-II.

are composed by five individual cubes of 20 mm sides, adequately oriented to produce an excellent polarization purity of both beams (see Fig. 1). The optical path length for both beams is absolutely identical.

The beamsplitter is placed together with the FLCs just after the entrance slit of the spectrograph. The longitudinal separation of the beams is 28 mm, which, after the demagnifying factor 2 of the spectrograph camera mirror, become 14 mm. This is larger than the size of half the detector (9.2 mm). A set of prisms located in front of the entrance window of the cryostat make both beams fall onto the detector. This way, the field of view has been increased from $35''$ (TIP) to $77''$ (TIP-II).

4. Comparative performance

Table 2 gives the comparative performance of the systems TIP and TIP-II operating at the VTT, as well as that expected for TIP-II at GREGOR.

5. TIP-II Data

To demonstrate the capabilities of TIP-II we show a scan of an active region recorded during the first observing campaign when the full field of view of $77''$ was available. Figure 2 shows Stokes I , Q , U , and V maps of an active region in the photospheric SiI 10827 Å line and the chromospheric HeI 10830 Å line at the solar position 35°W , 9°N . The inclination angle of the solar vertical to the line-of sight was 35° . The region of $52'' \times 77''$ was scanned in 150 scanning steps

from UT 18:33 until 19:05 on July 30 2006. The exposure time per slit position was 10 s, resulting in a signal to noise ratio of ≈ 1000 (RMS-noise). The image was stabilized using the Kiepenheuer Adaptive Optic System (KAOS, von der L uhe et al. 2003), the estimated spatial resolution of the image was limited by the seeing to $\approx 1.5''$. Standard data reduction routines as provided by the IAC have been used to calibrate the images and to remove instrumental crosstalk.

Figure 3 shows a sample spectrum arbitrarily selected from the map in Fig. 2, binned over four wavelength bins. The spectral region contains 4 major solar spectral lines (Si I, He I triplet, Ca I and Na I) and two telluric H₂O blends. The *Q*, *U*, and *V* signal of the photospheric Si I line is cropped to emphasize the polarization sensitivity and the signal to noise ratio achievable with TIP-II.

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