J. Astrophys. Astr. (2000) **21**, 241-244

Stokes Polarimetry at the Kodaikanal Tower Tunnel Telescope

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Abstract. A Stokes Polarimeter has been developed using a masked CCD arrangement for the measurement of the vector magnetic field of sunspots. Charge shifting within the CCD is used to record near simultaneous orthogonal polarisation. The testing of the Stokes Polarimeter and the behavior of the integrated system combined with the Kodaikanal tower tunnel telescope will be discussed.

Key words. Solar polarimetry—charge shifting—vector magnetic field.

1. Introduction

Stokes spectro-polarimetric approach has been adopted at the Kodaikanal Tower Telescope (KTT) (Bappu 1967) in order to study sunspots and other active regions. The accurate estimation of vector magnetic field requires high accuracy in the polarisation measurements apart from the high spectral resolution. This can be achieved by using a two beam Polarimeter (like the Advanced Stokes Polarimeter (ASP), Elmore *et al.* 1994) or by using high frequency chopping mechanism (like the ZIMPOL, Povel 1995) which eliminates seeing induced spurious polarisation signals. In an earlier attempt at the KTT (Ananth *et al.* 1994), a chopping scheme was utilised with a peltier cooled CCD detector achieving a rate of 0.5 Hz. However, this CCD had an inherent limitation on bias and flat fielding accuracies.

A new Stokes Polarimeter was designed for the KTT using a masked CCD sensor. An EEV P8603 CCD chip of size 578 × 385 pixels, is used as the sensor. The sensor array is divided into three regions using an aluminium mask of 1 mm thickness and 4 mm width which is held on to the surface of the CCD. This mask allows the central region (197 pixels) to be exposed to light and the upper and lower regions shielded from the light beam. The chopping mechanism used here is very similar to the one used by Stockman *et al.* (1982). The working principle of the Stokes Polarimeter with the masked CCD and the image acquisition system has been discussed already (Srinivasulu *et al.* 1999).

2. Testing of the Polarimeter

A laboratory test was carried out to look for the mis-alignments of the polarisation optics used in the Polarimeter. A linearly polarised collimated beam at 6302 A is sent

Table 1. Measurement of the mis-alignments of the optical axis of the polaroid, QWP and the retardance error of QWP.

Component	Parameters for an ideal polarimeter	Parameters measured
QWP-Axis	45° from the slit direction	43.0 ± 0.3° from the slit direction
QWP-Retardance	90°	95.5 ± 0.5°
Analyser-Axis	45° from the slit direction	45.0 ± 0.3° from the slit direction
Compensating polaroid	45° from the slit direction	44.0 ± 0.5° from the slit direction

through the Polarimeter. The Polarimeter consists of a rotating Glan-Thompson polariser (GTP) and an insertable quarter waveplate (QWP). Stokes Q, U and V are measured for different azimuth of the transmission axis of the input linearly polarised light. The mis-alignment in the fast axis of the QWP and the retardance error is found from the modulation in the measured V/I. The mis-alignment in the azimuth of the GTP's transmission axis is identified from the measured Q/I and U/I modulation. The composite Mueller matrix of the optical set up is modeled with three free parameters, viz. (a) the angular deviation of the fast axis of the QWP from the design angle (45°), (b) the angle of deviation of the azimuth of the GTP's transmission axis from 45°, and (c) the retardance error of the QWP. A non-linear least square fit is used to identify the best fit parameters with the observed data points. The parameters for an ideal Polarimeter and the derived values from the best fit are compared in Table 1.

The Stokes Polarimeter is then tested by integrating it with the KTT and the Littrow mount spectrograph. The response of the grating to light which is linearly polarised at different angles to the grating ruling was measured to compensate for the varying angle of the polarisation of the analysed light in the Q, U and V measurement respectively. A simple model for the grating response has been developed in order to estimate the response coefficients. Since the grating acts as a partial polariser, the output intensity can be written as,

$$I(\theta) = G_{11} + G_{12}\cos(2\theta) \tag{1}$$

where G_{11} and G_{12} are the response coefficients for the grating. The response coefficients derived after the model fit are, $G_{11} = 1.0$ and $G_{12} = 0.80$.

3. Measurement of instrumental polarisation

The instrumental polarisation of the 3-mirror coelostat system was measured with the above mentioned Polarimeter. The continuum polarisation was measured on 16th April 1999 at the disk center. We chose a continuum region near 6302 Å. Fig. 1 shows the measured data points for different observing times. The geometry of the KTT was used to calculate the theoretical instrumental polarisation using spherical trigonometry. The solid line shown in Fig. 1 is the best theoretical fit for the observed data points. The free parameters used are the refractive indices of the three mirror coating (aluminium) with an oxide layer. The oxide layer refractive index is fixed at a constant value of 1.77 and its thickness is varied. It was found that the fit is even better without the oxide layer. These observations are carried out within a few months of the mirror

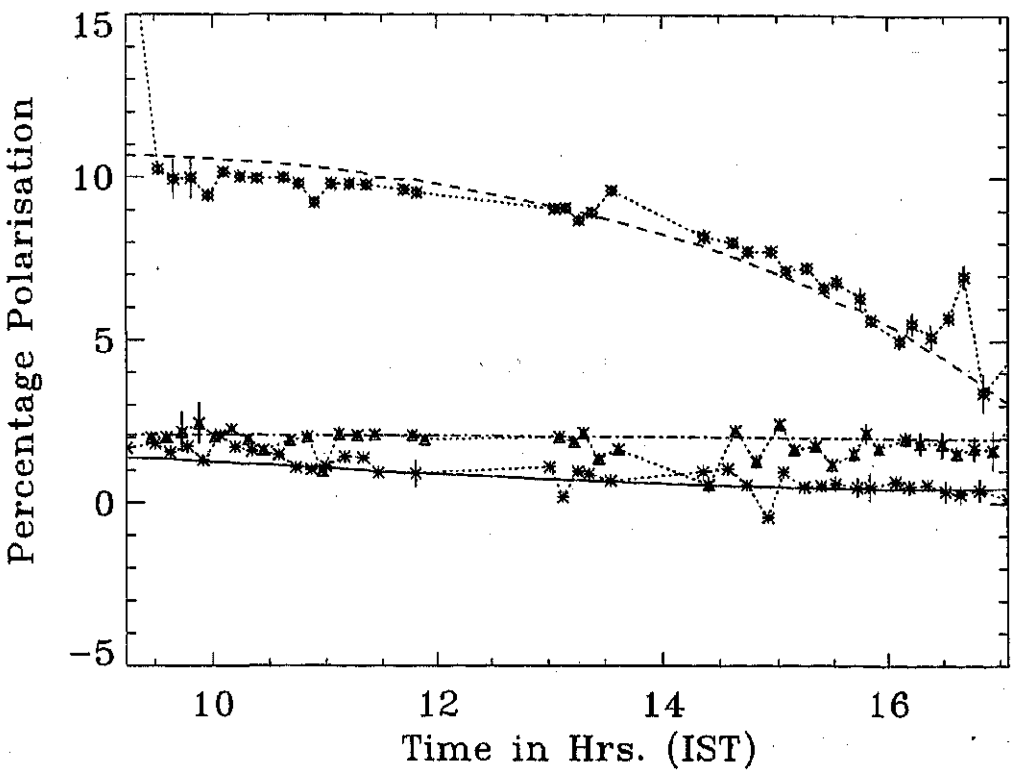

Figure 1. The measured polarisation at the disk center in the continuum for different observing time given in Indian Standard Time (IST). The star symbol is for Q/I, the diamond is for U/I and the triangle is for V/I. The solid, dashed and dot-dashed line is the best fitted model.

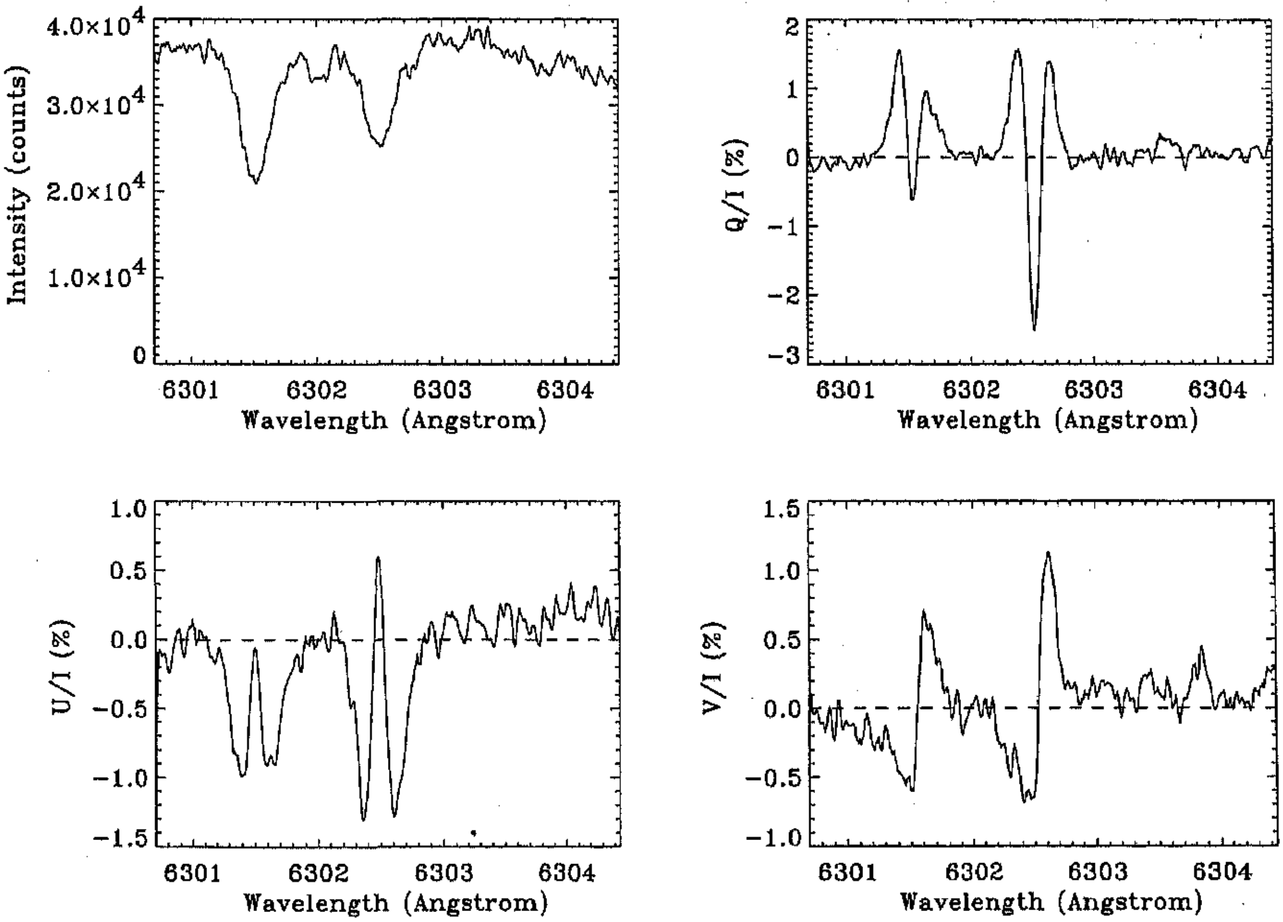

Figure 2. The Stokes profiles at a point in the umbra-penumbra boundary of the sunspot, after elimination of the telescope polarisation.

coating and hence we believe that there is not much oxide layer formed on it. The refractive index derived agreed well with the value for bulk aluminium.

Sunspot KKL21263 was observed for its vector magnetic field on 16th April 1999. The slit width used was 100μ. Fig. 2 shows the observed Stokes profiles at a point on the sunspot, after removing the polarisation introduced by the telescope. The exposure time was 1 sec and the rms noise in the continuum was about 0.3%.

Acknowledgements

We thank Mr. J. P. A. Samson, Mr. Jayavel and the mechanical staff at Kodaikanal and Bangalore for their help in mechanical design and fabrication. Mr. Devendran and Mr. Hariharan are acknowledged for their help during the observing runs.

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