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Spectropolarimeter for the Vainu Bappu Telescope

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Abstract. Fabrication of an Optical spectropolarimeter for the Vainu Bappu Telescope, consisting of a Pancharatnam half-wave plate and a modified Glan-Taylor polarising beam splitter fitted as an add-on facility to an existing astronomical spectrograph is described. A special technique of measuring the instrumental polarisation using a rotating half-wave plate as de-polariser is described.

1. Introduction

Spectropolarimetry is a very powerful technique which has been relatively neglected in observational astronomy. Measurement of the polarisation properties of astronomical sources can provide important diagnostic information not available by direct imaging or spectroscopy. In particular data on the scattering properties of dust or electrons and on magnetic field strengths can be collected and crucial orientation-dependent information and important geometries within an object can be determined. The book, "Planets, Stars and Nebula – Studied with Photopolrimetry," edited by Gehrels (1974), gives an extremely good overview of polarimetry.

Within the last 15 years the technique has been applied to a number of research fields including dust in the SMC (Rodrigues et al. 1997), and to comets (Perrin et al. 1987, Myers et al. 1984).

Despite considerable success, relatively few astronomers have actually used spectropolarimetry in their own research. Partly this is due to the complexities of both data reduction and analysis. Estimation and elimination of instrumental polarisation pose a great headache.

A recent design of a spectropolarimeter described by Miller et al. (1988) uses an achromatic half-wave plate and a thin-film polarising beam-splitter, which gives very high efficiency over a somewhat limited wavelength range. The need for dual-beam spectropolarimetry is discussed. Single-beam instruments, which completely throw away one of the senses of polarisation, can operate only if the polarisation is modulated at a frequency higher than that at which system parameters change, which means a frequency of about 10Hz or higher in the case of astronomical seeing changes and guiding errors.

The advantage of the dual-beam spectropolarimeter or polarimeter, is that one can apply a differential technique between the two beams, to eliminate the sky contribution (this technique is similar to differential photometry). Apart from elimination of the sky contribution, one can in an efficient manner remove the instrumental polarisation during the reduction of spectropolarimetric data (Walsh 1992)

Most often, the polarimetric optics are fitted onto an existing or previously designed spectrograph. This is convenient and cost effective, since the spectrograph will also serve for normal astronomical spectroscopy. Here, we describe such a spectropolarimeter which has been built for the Vainu Bappu Telescope (VBT) of the Indian Institute of Astrophysics (IIA).

2. Basic Experimental Design

Light or electromagnetic radiation can be fully described by four parameters known as the Stokes parameters (Born & Wolf): I, the total intensity, Q and U describing linear polarisation, and V describing circular polarisation. All these parameters depends on the wavelength λ. Therefore to obtain maximum information from light, the task of observational astronomy is to study I, Q, U and V as a function of wavelength, position in the sky and time. Most of the standard astronomical instruments measure only the first parameter $I(\lambda)$, but polarimeters provide more information from the electromagnetic radiation, namely I, Q, U and V. Our basic experiment here will be to measure only the linear polarisation (eg. the first 3 parameters).

To measure Q and U, the wave front needs to be sampled from different angles through a polariser. To achieve this one could either (a) rotate the analyzer (consisting of a polariser) or (b) rotate the incoming wave front relative to the analyzer. Due to physical constraints, especially in dual beam polarimeters, the latter (b), is generally adopted in modern polarimeters. Rotation of the incoming wave front relative to the analyzer is possible with a wave retarder like a half-wave plate (HWP). A simple HWP is λ dependent. Pancharatnam in 1955 had demonstrated how to make a very achromatic wave plate by stacking three normal wave plates together.

In our spectropolarimeter, we adopt (b) with a super-achromatic half-wave plate (HWP) and a polarising modified Glan-Taylor prism ($MGTP$) (Fig. 1) to act as a dual-beam analyzer.

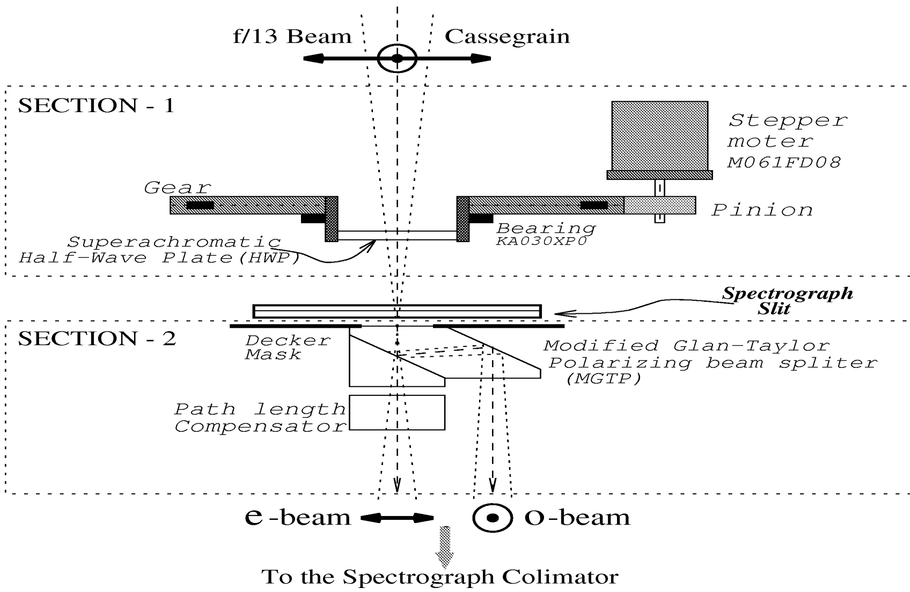

Figure 1. The Two Sections attachments to the spectrograph to convert it to a Spectropolarimeter (*Figure not to Scale*).

3. Details of the Instrumentation

In 1975, the Boller & Chivens Division of the Perkin-Elmer Corporation, USA, built a long slit fast Cassegrain spectrograph for the Anglo-Australian Observatory (AAO). This spectrograph was acquired by the IIA in 1985, and has served as a cassegrain spectrograph at VBT. This spectrograph was modified, automated and upgraded. It now has a TK1024 Photometric liquid N_2 cooled CCD as detector and an intensifier CCD for remote slit guiding.

The spectropolarimeter was designed as an add-on equipment to this spectrograph. The spectropolarimeter optics, using HWP & $MGTP$, is of a similar design to that of Goodrich et al. (1991). The HWP of 28.6mm diameter is super-achromatic, of a Pancharatnam design, and optimized for 3500 to 10000$\mathring{A}$. The $MGTP$ separates the cross polarisation, with the e and the o beams parallel to each other. Both optical components are optimized to accept the $f/13$ beam of the telescope. The optics were fabricated to the specific design by Karl Lambrecht Corporation, Chicago, USA.

The mechanical design consists of two sections, attached separately to the spectrograph: section 1 was attached from the top of the spectrograph flange, going into the central hole of the telescope's instrument mounting flange, while section 2 replaces the existing filter wheel of the spectrograph. Figure 1 gives a sketch of the attachments (not to scale) with respect to the spectrograph slit. Section 1 is the mount for the HWP centered on the optical axis. It is designed keeping the HWP very close to the slit of the spectrograph. This enables an acceptance of a larger spatial section, without any vignetting. The HWP is mounted to a 1:4 spur gear unit with anti-backlash tension spring mountings. The gear is mounted on a $KA030XP0$ thin bearing supplied by Kaydon Corp. USA. This provides practically no axial deflection to the HWP during its rotation around the optical axis. The pinion is coupled to a stepper motor ($M061FD08$, "Slo-syn" Warner electric, USA) of 0.53 Nm torque.

The rotational accuracy of the HWP is 0.45^o. An angle counting device is also mounted on the main gear consisting of an $MCT8$ IR switch and a disk with holes along the edge, spaced at 7.5^o. The $MCT8$ IR switch pulses as the holes on the disk passes between it. These pulses are fed to a counter which provides a counter check of the angle rotated at a precision of 7.5^o. A limit switch is also provided to reset the gear and thus the HWP. During observation the HWP is held fixed. Breaks are applied to gears by keeping the stepper motor energized.

Section 2 involves a housing for the $MGTP$ polariser coupled with a path length compensator. A horizontal movement of the housing, along the length of the slit, has been provided for fine adjustments of the optical axis of the telescope and the spectrograph. The leveling has been taken care of with accurate surfacing. Possibility for removing the $MGTP$ from the optical axis has been provided by rotating the disk, on which it is mounted. The disc also provides slots for order separating filters, used for regular spectroscopy.

Figure 1 shows a ray diagram through the $MGTP$ providing the dual polarised beam parallel to each other. The beam separation is 10 mm from center to center. This provides $\approx$ 8 mm of spatial axis along the slit. This 8 mm covers $48''$ of the sky.

The fabrication of the spectropolarimeter has been completed and tests on the telescope (VBT) made. The final components were surface treated with electro-blackening to minimize internal scattering in the instrument.

Computer software, using the existing telescope instrument controls, has been developed to remotely operate the instrument from the observing room computer. A de-polarisation technique, useful for obtaining dome-flats, was developed. A similar technique is described by Di Serego Alighieri (1997). Calibrations of the spectropolarimeter were made to estimate the instrumental polarisation and the zero point offset. The zero point offset measurement were made by observing a 100% polarised white light source. A $50W$ halogen lamp with a polarising prism put directly over the spectropolarimeter and imaged on to the slit with a Zenith camera lens (at f/13), providing a 100% polarised light source. The offset in the position angle is measured every time the instrument is mounted on the telescope. Standard stars with known position angles (Hsu & Breger 1982) are regularly observed for computing this offset.

Spectropolarimetric data reduction routines were written using the standard IRAF package. The routine calculates the Stokes' $[Q/I](\lambda)$ and $[U/I](\lambda)$ parameters and with it computes the percentage of polarisation

$P(\lambda)$ and the angle of polarisation $\Theta(\lambda)$. A detailed paper on this instrument is in preparation.

4. Observations

Spectropolarimetric observation are now being made using this instrument. The first observations were of the Comet Hale-Bopp and comet Wild 2. Preliminary analysis of the polarisation of comet Hale-Bopp shows a high polarisation at the outer coma and a low polarisation close to the nucleus of the comet. The continuum polarisation decreases from the red towards blue (Chakraborty & Vasundhara 1998, in preparation).

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