Imaging Polarimetry of Nearby Molecular Clouds

Ramaprakash A. N., Tandon S. N. and Gupta R.

Inter-University Centre for Astronomy and Astrophysics, Ganeshkhind,
Pune - 411 007, India

Abstract. In order to study the role played by the magnetic fields in the dynamics of the interstellar medium (ISM) a two-channel imaging polarimeter (IMPOL) has been constructed. The instrument is capable of multi-wavelength observations in the visible and very near infrared (IR) wavelengths, has a *sensitive* CCD detector and a built-in acquisition and guidance unit. When used with a 1.2m, $f/13$ telescope IMPOL gives a field of view of 6 $\times$ 6 arcmin with an angular resolution of $2''$ so that it is well-suited to observe both faint extended objects and moderately crowded stellar fields. The instrumental polarization is less than 0.05% and the accuracy of the measurements is primarily limited by photon noise in a typical observation. In this paper, we present a brief description of the instrument and observational techniques, as well as the results of a successful observation of a molecular cloud close to the open cluster IC 5146.

1 Introduction

The importance of polarimetry in understanding the structure of the interstellar medium (ISM) has been amply emphasized many times (e.g. Tinbergen 1996, review by Carl Heiles in this meeting). Even though optical polarimetry has been employed in astronomy since the 1950s (Hiltner 1949, Hall 1949), it became a regular part of the astronomers' toolkit only recently with the advent of more sensitive detectors and larger telescopes; polarimetry is always photon starved. Even after those advances the aperture photometric techniques were still very time-consuming, difficult to carry out, lacked angular resolution and produced only small samples (Sen & Tandon 1994).

With the introduction of the imaging methods in polarimetry the situation improved greatly. In the following section we briefly describe an imaging polarimeter (IMPOL) which uses a sensitive (liquid nitrogen cooled) CCD as the detector. In the third section the results of a successful observation of a molecular cloud close to the open cluster IC 5146 is presented to illustrate how the instrument can be employed to study the local ISM.

2 The Polarimeter

Only the essential details of the instrument are presented here. For a more detailed description of the design, handling of errors and observational techniques, please refer to Ramaprakash et al. (1997).

As shown in Fig. 1, a single camera lens is used to produce focal reduction by a factor of about 3.8 and obtain the correct image scale at the CCD. A half-wave plate modulator and a beam-splitting Wollaston prism analyzer placed in the beam path enable measurement of linear polarization. The half-wave plate rotates the position angle of the polarization vector of the incoming light by twice the angle that itself has been rotated. This light is split by the Wollaston prism into two beams of linear polarization components in a coordinate system fixed with respect to the instrument. Since the Stokes parameters are defined with respect to this coordinate system, care has to be taken while mounting the instrument on the telescope to align it with the conventional reference axis on the sky, i.e., the celestial north-south axis.

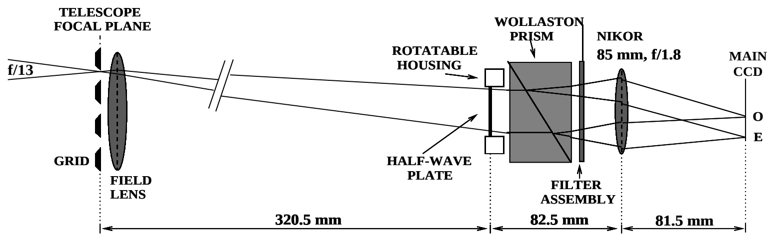

Fig. 1. Block schematic of the IMPOL optical system

The two beams (the so called ordinary and extraordinary beams) produced by the Wollaston prism propagate in slightly different directions separated by about 0.5 °. Therefore the camera lens produces two images on the CCD for every point at the telescope focal plane. In order to avoid overlapping of the ordinary and extraordinary images of adjacent points, a set of properly spaced, parallel obscuring strips of the correct width are placed at the telescope focal plane.

The ratio R of the difference between the intensities of the ordinary ($I_{\rm o}$) and the extraordinary ($I_{\rm e}$) beams to their sum (Eq. 1) is by definition, the Stokes' parameter q, when the half-wave plate fast axis is aligned to the reference axis. Similarly when the half-wave plate is at 22.5 °, the above ratio becomes the Stokes' parameter u.

$$R(\alpha) = \frac{I_{\rm o} - I_{\rm e}}{I_{\rm o} + I_{\rm e}} \ . \tag{1}$$

Now the fractional polarization (p) and the position angle (θ) can, in principle, be recovered from these two ratios as

$$p = \sqrt{q^2 + u^2} \qquad \text{and} \qquad \theta = \frac{1}{2}\tan^{-1}\left(\frac{u}{q}\right) \tag{2}$$

Since the above method allows determination of the Stokes parameter from a single exposure, it is free of the effects due to atmospheric scintillation, varying sky transparency, etc. To facilitate observations of faint objects that demand long exposures, the instrument is provided with an off-axis acquisition and guidance unit. Special precautions have been taken to minimize errors in the polarization measurement and it is seen that the polarimetric accuracy is limited by photon noise for typical observations. The instrumental polarization is found to be about 0.05%.

3 Observations

IC 5146 is an open cluster in Cygnus. Associated to it, there is a long, filamentary molecular cloud complex extending about 2° EW and about 0.5° NS in the Palomar prints. The extent and structure of this complex has been studied using ^{12}CO and ^{13}CO as tracers by Dobashi et al. (1992). Combining the classical star count methods and infrared colour excesses of reddened background stars, Lada et al. (1994) obtained detailed extinction maps of what they called the Northern Streamer part of the complex.

Here we present the results of imaging polarimetric observations on two fields of the Northern Streamer region, obtained using the IMPOL. The observations were carried out with the 1.2 m, Gurushikhar Infrared Telescope (GIRT) at Mt. Abu, Rajasthan, India[1]. In the polarization map shown in Fig. 2, we see that the magnetic field vectors form three distinct regions. The average position angle of the vectors in the northern periphery of the cloud is about 50°. In the southern periphery, for right ascention (RA) greater than $21^h46^m50^s$, the average position angle is about 55°, while below this RA it is about 69°. This matches quite well the contour maps of Lada et al. (1994), where it can be seen that the material distribution along the northern periphery is quite irregular and probably explains the twist in the magnetic field (see their Fig. 1a and b). On the other hand, for RA lower than $21^h46^m50^s$, the contours along the southern periphery are fairly aligned along EW, while those at the SE corner show kinks around a dense clump.

Future Prospects The IMPOL can be very useful in the study of the local ISM. Gvaramadze (this meeting) and several others (e.g. Brand et al. 1983, Bertoldi & McKee 1990) have studied the effects of shock waves and ionization fronts on dense obstacles like cloudlets and clumps in the medium in which they propagate. The role of magnetic fields in providing pressure support to the obstacles against the invading front has been clearly realized, but not yet

[1] GIRT is operated by the Physical Research Laboratory, Ahmedabad, India.

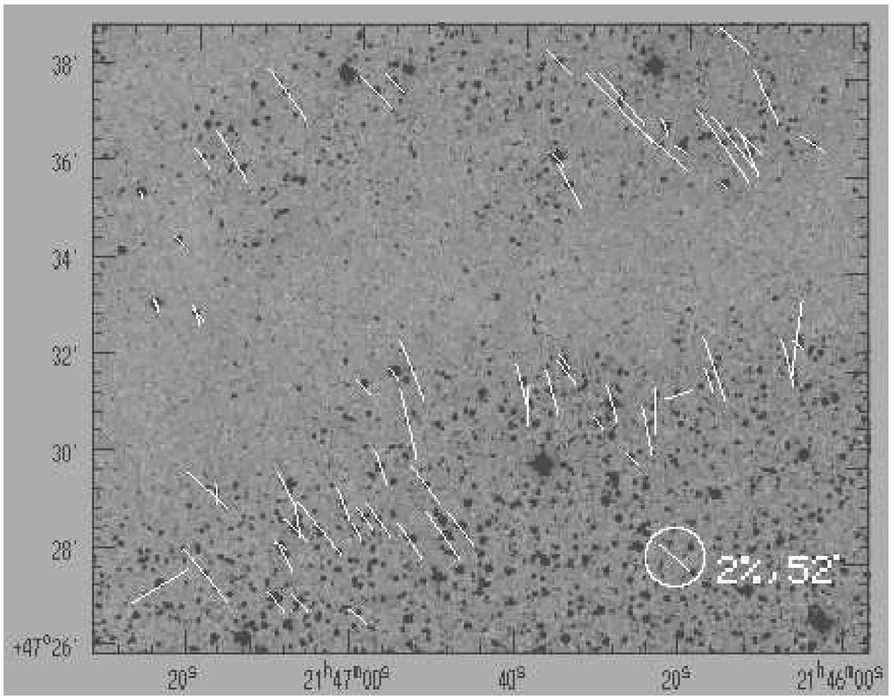

Fig. 2. Polarization map of two fields in the Northern Streamer region near IC 5146. The small horizontal vector on the NE corner is 1%

fully understood (Sridharan et al. 1996). Cometary globules and teardrops are supposed to evolve out from such interactions (Reipurth 1983). Observations of two cometary globules have been made using this instrument aiming to study the presence and nature of the magnetic fields along the tails. The analysis of this data is currently in progress.

A similar observation of the clouds found embedded in the hot plasma in the local ISM (e.g. Herbstmeier & Wennmacher, Beckman et al. in this meeting), can throw light on the magnetic field structure in these objects which might also explain what keeps these clouds from evaporating off, given the harsh environment they are in. Multi-wavelength polarimetry can be employed to determine the average grain sizes in these clouds.

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