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Magnetic fields in molecular clouds

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Abstract. Though it has been realized for a long time that magnetic fields play a vital role in shaping the evolution of the interstellar medium, only a handful of techniques exist for determining the field strengths. However, polarimetry offers a powerful tool for studying the orientation of magnetic fields, particularly in molecular clouds where they leave their signature in the distribution of dust grains. With primarily this aim in mind, an imaging polarimeter (IMPOL) has been constructed at the Inter-University Centre for Astronomy and Astrophysics. We present here the salient features of this instrument and the results of some observations of the Northern Streamer molecular cloud near the open cluster IC 5146.

Key words : polarimetry : techniques, ISM clouds

1. Introduction

About 10% by mass of the matter in the interstellar medium is in the form of molecular clouds which range from tiny specks or teardrops which are just a fraction of a parsec in size to the Giant Molecular Cloud Complexes, which are several tens of parsecs across. Molecular hydrogen, which is the main constituent of these clouds at temperatures of about 10 K - 100 Kand densities above 100 particles per cm^3, is almost impossible to observe directly except at mid-infrared wavelengths where it has some weak rotational transitions. Dust grains made of silicates, graphite etc., spewed out from the atmospheres of evolved stars etc., provide active sites where atoms can come together and form molecules. These dust grains absorb/scatter light at optical and shorter wavelengths and the earlier observations of these molecular clouds were limited to extinction studies by "star count" techniques. Later it became possible to observe the density structure and kinematics of these clouds using radio lines produced by rotational and vibrational transitions of molecules like ^{12}CO, ^{13}CO, NH_3 etc. as tracers. With these observations it became clear that the presence of magnetic fields must be playing a key role in the physical processes taking place in these clouds.

Though only few techniques exist which can determine the strength of astronomical magnetic fields, it is relatively easy to determine the orientation of the magnetic field vectors in molecular clouds, as projected in the plane of the sky. This became possible with the observations by Hiltner

(1949) and Hall (1949) who showed that reddened starlight is partially linearly polarized. Davis and Greenstein (1951) tried to explain this by suggesting that the interstellar dust grains which are slightly aspherical in shape, are also spinning rapidly due to collisions with gas molecules and through paramagnetic relaxation, their short axes (which also is, in general the spin axis) tend to align with the ambient magnetic field. These aligned dust grains preferentially scatter the electric field component along their long axes, thereby resulting in partial linear polarization of light in a direction parallel to the ambient magnetic field.

The earlier attempts at mapping magnetic fields in these clouds met with only partial success mainly due to the limitations of the single-aperture techniques used (Sen & Tandon, 1994). With the introduction of imaging methods, employing array detectors, to polarimetry, many of these difficulties were overcome. In the following sections we present the essential details of an Imaging Polarimeter (IMPOL), which has been constructed at the Inter-University Centre for Astronomy and Astrophysics, Pune, India. We also discuss the advantages of the method employed and illustrate the application of the instrument in mapping the magnetic field pattern in a molecular cloud near the open cluster IC 5146.

2. The optical scheme of IMPOL

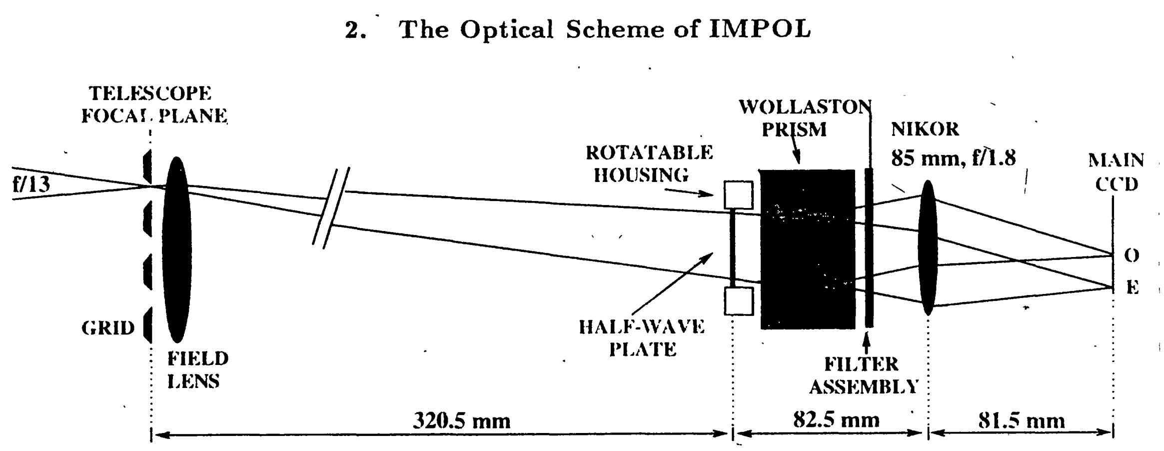

Figure 1. Schematic of the IMPOL optical layout

The basic technique employed in this instrument appears in a review of polarimeters by Serkowski (1975), listed as item 4 of Table III. A complete description of the instrument is given by Ramaprakash et al. (1997). In this method an achromatic half-wave plate is rotated in discrete steps of 22.5° which results in the plane of polarization of the incoming light being rotated through steps of 45°. A Wollaston prism analyzer then splits this light into two beams (called ordinary and extraordinary) of orthogonal polarization components which are focussed on the CCD detector surface by the camera lens to form two images separated by about 33 pixels (see Fig. 1). The ratios of the difference between the intensities in the ordinary (I_o) and the extraordinary beams (I_e) to their sum are by definition, the Stokes parameters q and u, when the half-wave plate is at 0° and 22.5° respectively, Thus

$$q = \frac{I_o(0°) - I_e(0°)}{I_o(0°) + I_e(0°)} \quad \text{and} \quad u = \frac{I_o(22.5°) - I_e(22.5°)}{I_o(22.5°) + I_e(22.5°)} \tag{1}$$

The fraction of linearly polarized light p and its position angle θ are related to these Stokes parameters by

$$q = Ip \cos 2\theta \quad \text{and} \quad u = Ip \sin 2\theta \tag{2}$$

where $I = I_o + I_e$, is the total intensity and hence can be recovered by fitting a cosine curve to the values of q and u obtained.

3. Advantages of the scheme

The imaging mode offers several advantages over single aperture polarimetry, like large multiplexing, simultaneous sky estimation, better angular resolution etc. The dual channel principle employed allows each of the two Stokes parameters to be determined from a single exposure thereby eliminating the effects of atmospheric scintillation, transparency fluctuations, variations in exposure times etc. The analyzer is fixed with respect to the CCD and hence any polarization sensitivity of the detector can be easily eliminated. With only one moving optical component, namely the half-wave plate and having a built-in acquisition and guidance unit, the images on the CCD are kept fixed so that the flat fielding effects can be minimized. Thus by giving careful consideration to these and other sources of errors, an instrument could be constructed with only standard optical and electrical components, but giving photon noise limited performance.

The instrument has a field of view corresponding to about 30 × 30 sq. arcmin at the focal plane of the telescope and can be used for studying stellar fields or extended objects with an angular resolution of about 2". The self-polarization of the instrument is less than 0.05% over visual wavelengths.

4. Magnetic field in the northern streamer near IC 5146

Presented here are the preliminary results of observations made on the Northern Streamer part of the molecular cloud complex found to the NW of the open cluster IC 5146 (Lada et al., 1994). These observations were made using the 1.2m, f/13 Gurushikhar Infrared Telescope (GIRT) at Mt. Abu, Rajasthan[1]. The general alignment of the magnetic field vectors in the region is quite

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

obvious from the map given in Fig.2. The mean position angle of all vectors along the northern periphery of the cloud is about 50°. The same is true at the southern periphery, if stars with right ascension greater than about 21:46:50 alone are considered. However for right ascensions less than 21:46:50, the mean position angle is about 70°. On the CO and CS contour maps given by Lada et al. (1994), it can be seen that the distribution of material on the northern periphery of the cloud and SE corner are very irregular and possibly explains the twist in the magnetic fields here. On the other hand, the contour lines are fairly parallel and aligned EW below right ascension 21:46:50.

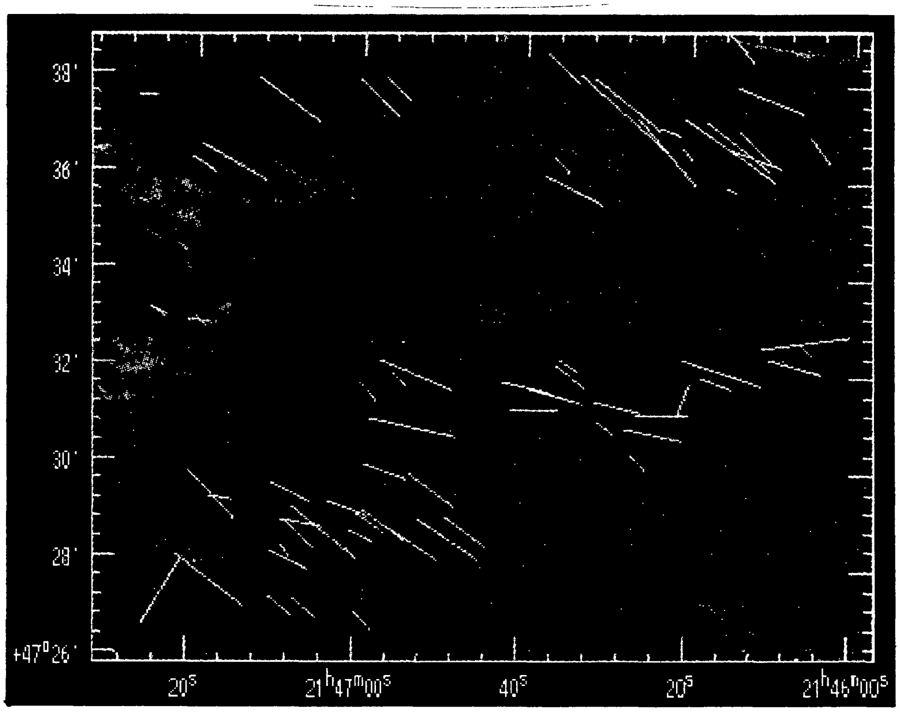

Figure 2. Polarization map of two fields in the Northern Streamer region near IC 5146. The small horizontal vector on the NE corner is 1%.

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