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Optical polarimetry: tracing magnetic fields in Bok globules

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Abstract. The relative role played by the magnetic field and the turbulence in cloud formation and evolution and in different stages of star formation is a matter of serious study. By using linear polarization measurements in optical wavelengths of stars that are located behind the clouds, one can map the plane-of-sky component of magnetic field. Here we present the preliminary results of the linear polarimetry of background stars projected on three clouds, namely, IRAM 04191+1522 (R band), L1521F (V band) and L1014 (R band). These clouds, previously classified as starless, are found to harbour very low luminosity objects (VeLLOs, $L \leq 0.1L_{\odot}$) detected during observations with Spitzer Space telescope (SST). A protostar located on the stellar/substellar boundary ($M = 0.08M_{\odot}$) would have an accretion luminosity of $L \sim 1.6L_{\odot}$, assuming a spherical mass accretion predicted by the standard model onto a protostellar object of typical radius $R \sim 3R_{\odot}$. VeLLOs, with luminosities more than an order of magnitude lower than this, are difficult to understand in the context of standard model of star formation.

Keywords : ISM: magnetic fields – polarization – star: formation

1. Introduction

Understanding the role that magnetic fields play in the evolution of interstellar molecular clouds is one of the challenges to modern astrophysics. Lack of understanding related to star formation concerns the competition between magnetic field and turbulence. Molecular-line observations showed that the dark nebulae contain copious amount of cold material (Myers & Benson 1983). By using linear polarization measurements in optical wavelengths of stars that are located behind the clouds, the plane-

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of-sky component of magnetic field can be mapped over the dark clouds. Dichroic extinction of background starlight by magnetically aligned dust particles at the periphery of dark molecular clouds in the Galaxy, introduces polarization in the starlight according to Davis & Greenstein (DG) mechanism (Davis & Greenstein 1951). In this work, we introduce the general results of optical polarimetry conducted for three dark clouds namely IRAM 04191+1522 (hereafter IRAM04191), L1521F and L1014. These dark clouds were supposed to be starless, but the recent studies with the help of Spitzer Space Telescope (SST) prove that they harbour Very Low Luminosity Objects (VeLLOs) in their cores. Here we also probe the relative orientations of bipolar outflows and that of the peripheral magnetic field.

2. Observations

Polarimetric observations were carried out using the Aries IMaging POLarimeter (AIMPOL) (Rautella et al. 2004), (Medhi et al. 2007, 2010) mounted at Cassegrain focus of the 104-cm Sampurnanand telescope of Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital, India, coupled with TK 1024×1024 $pixel^2$ CCD camera. AIMPOL consists of a half-wave plate (HWP) modulator and a Wollaston prism beam-splitter. The observations were carried out in R and V filters ($\lambda_{Rc_{eff}}$ = 0.670 μm, $\lambda_{V_{eff}}$ = 0.530 μm) photometric bands. Plate scale of CCD is 1.73 arcsec/pixel and field of view is $\sim$ 8 arcmin in diameter. The full width at half maximum (FWHM) varies from 2 to 3 pixels. The Read out noise and gain of CCD are 7.0 e^- and 11.98 e^-/ADU respectively. Polarized standards (Schmidt et al. 1992) were observed for the calibration of polarization position angle.

3. Results

3.1 IRAM 04191, L1521F, L1014

We observed 33 stars and 17 stars in the fields of IRAM04191 and L1014 respectively in R-band and 29 stars in the field of L1521F in V-band. The sky projection of R-band

Table 1. Polarimetric results.

cloud name	$\bar{P} \pm \sigma_P$ (%)	$\bar{\theta} \pm \sigma_\theta$ (°)	θ_{GP} (°)	direction of outflows (°)
IRAM04191	1.9±0.5	110±15	139	28†
L1521F	3.2±1.9	26±18	135	–
L1014	1.5±0.7	18±13	57.8	30††

† Belloche et. al. 2002; †† Bourke et al. 2005

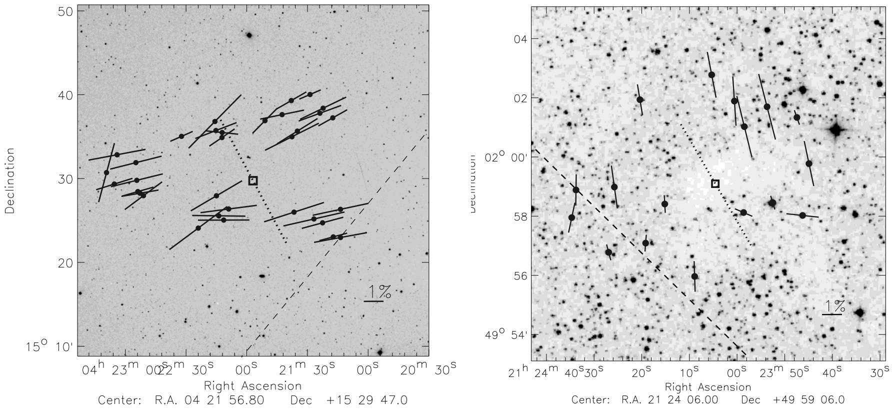

Figure 1. Optical polarization vectors over-plotted on 0.7 degree DSS image of IRAM04191 and 12 arcmin image of L1014 in left and right panels respectively.

polarization vectors are drawn on Digital Sky Survey (DSS) images of IRAM04191 and L1014 in Fig.1. The squares in the centres of images indicate the positions of VeLLOs in IRAM04191 and L1014. The positions of VeLLOs in IRAM04191 and L1014 are adopted from Dunham et al. 2006 and Young et al. 2004. The DSS image of L1521F with polarization vectors is not shown here but the position of VeLLO in this core is given in Bourke et al. 2006. The directions of outflows in IRAM04191 (Belloche et al. 2002) and L1014 (Bourke et al. 2005) are shown as dotted lines in the Fig.1. Galactic planes are also indicated with long-dashed lines on the images. Polarimetric results of these three clouds (IRAM04191, L1521F and L1014) are shown in Table 1.

4. Discussion

Observations of magnetic fields in molecular clouds are essential for understanding their role in the evolution of dense clouds and in the star formation process. Self-gravitating clouds are supported against collapse by magnetic fields, with ambipolar diffusion reducing support in cores and hence driving star formation (Mouschovias& Ciolek 1999). In our results we found the outflow direction in IRAM04191 is more or less perpendicular to magnetic field orientation in periphery, but Matthews et. al. 2009, pursued sub-mm polarimetry of IRAM04191 and found that outflow direction is parallel to magnetic field inside the core. The reason behind this misalignment is still an open question. Whereas in the case of L1014 we found direction of outflows parallel to magnetic fields geometry in periphery. A flattened disk of cloud having peripheral magnetic fields perpendicular to major axis of core is visible in the case of L1014. In L1521F we did not find any reference indicating the proper direction of outflows but Bourke et. al. 2006, found some features of an east-west nebulosity in this cloud which also looks parallel to mean magnetic field direction. Previously these cores were supposed to be starless but recent studies with the help of SST have found that they harbour VeLLOs. Dispersions in the polarization position angles can be used to estimate the magnetic field strength for the observed fields from the modified Chandrasekhar-Fermi relation (Chandrasekhar & Fermi 1953; Ostriker et al. 2001).

5. Conclusions

With this study of optical polarization of background stars we found the magnetic field morphology on the periphery of these dark clouds (IRAM04191, L1521F and L1014). We can conclude that out of these three dark clouds, L1014 has outflow direction parallel to the orientation of peripheral magnetic field in agreement with the ambipolar diffusion and IRAM 04191 has an outflow direction more or less perpendicular to the magnetic fields. In L1521F we did not find any reference giving idea about the direction of outflows, but Bourke et. al. 2006 have shown an east-west nebulosity in this core. The positions of VeLLOs in the cores of these three clouds are taken from literature and shown on the images.

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