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Tracing magnetic field orientation in starless cores

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Abstract. It is now well understood that stars are formed in the interiors of dense, gravitationally bound molecular cloud cores that are both magnetized and turbulent. But the relative role played by the magnetic field and the turbulence in cloud formation and evolution and in the subsequent star formation is a matter of debate. In a magnetically dominated scenario, the magnetic field geometry of the cores is expected to be inherited unchanged from their low-density envelope, even for an hour glass geometry of the field, unless the action of turbulence disturbs it. We carried out polarimetry of stars projected on starless molecular clouds, LDN 183 and LDN 1544, in R-filter. The comparison of these fields with those in the interiors of the cloud cores inferred from the sub-mm polarization shows that both magnetic field and turbulence are important in the cloud formation and evolution of star formation.

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

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1. Introduction

A great deal is now known about dense cores (both isolated and in molecular clouds), which are progenitors of protostars, through observations that constrain their physical parameters. What is less clear is the manner in which the cores are formed, their further evolution and the role played by the magnetic field in the entire process. The evolution of these cores certainly depends on the formation mechanism and the dominant physics involved in their formation. Of the several models available, one of the two with extreme ideas is a slow, quasi-static evolution, in which a core gradually becomes more condensed centrally. This evolution may be controlled either by the magnetic field (e.g., Mouschovias and Ciolek, 1999) or by the slow dissipation of low-level turbulent velocity fields (e.g., Myers, 1998, 2000). The other is a very dynamical scenario in which highly turbulent gas creates large density inhomogeneities, some of which become gravitationally unstable and collapse to form stars (see Ward-Thompson, 2002). Here also magnetic field may play an important role in the later stages, in which magneto-hydrodynamic (MHD) waves may be responsible for carrying away excess turbulent energy (e.g., Ostriker et al., 1999).

In the magnetic field mediated theory of star formation, neutrals flow across the field lines (i.e. ambipolar diffusion) allowing an initially subcritical (i.e. magnetically supported) core to become supercritical as the mass to magnetic flux ratio reaches a certain critical value for collapse (Mouschovias 1976). The theory of ambipolar diffusion requires that the magnetic field lies parallel to the minor axis of the cores (e.g., Ciolek & Basu 2000). On the other hand, in the theory of gravo-turbulent form of star formation, field lines will not be smooth but chaotic, with random small-scale structure. Simulations (Balsara et al., 2001; Padoan et al., 2001) show that matter may flow onto cores along filaments connecting them with the field being stretched along the filaments. This would predict that the field will tend to be along the major axis of elongated low-density structures connected with higher-density cores. Some of the limited observations carried out to test these theories have shown that there exists an offset between the position angle of the magnetic field and the minor axis of each core indicative of the importance of both magnetic field and turbulence in the evolution of these clouds (Ward-Thompson, 2000). However, more comprehensive observational efforts are required to understand the role played by magnetic fields in the process of cloud formation and their subsequent evolution. We made observations of starless cores, LDN 1544 and LDN 183, to study the relationship between the plane-of-sky magnetic field orientation at the periphery of the cloud, inferred from our observations, to that at the cloud interiors inferred from the sub-mm polarimetric observations.

One of the most informative techniques of studying magnetic fields in molecular clouds is based on the use of background starlight polarization and polarization emission arising from the aligned dust. The regions where the extinction is $\sim 1-2$ mag, use of optical polarization of background stars to infer the cloud magnetic field geometry is most effective. The rotating interstellar grains are believed to get aligned due to their direct interaction with the magnetic field (Devis & Greenstein 1951). The background starlight which passes through these aligned grains gets polarized due to selective extinction also known as dichroism.

2. Observations

Observations were carried out during the observing runs between 2007 to 2009 using IUCAA Faint Object Spectrograph (IFOSC) in polarimetric mode at the Cassegrain focus of the 2m telescope at IUCAA Girawali Observatory (IGO). The field-of-view was about $2' \times 2'$. The polarization measurements were made in R-filter. In order to trace the magnetic field lines, we needed to select stars which were reddened due to the foreground cloud material. The background reddened stars were selected from J-H, H-K color-color (CC) of stars projected to the clouds. The stars located in the reddening zone of CC diagram with J-K colors ≥ 1 were selected as background stars to trace the cloud magnetic field.

3. Results

The polarization vectors, which are assumed to trace the plane-of-sky magnetic fields, are plotted over the IRAS 100μm image as shown in Fig.1. The preliminary results for LDN 183 and LDN 1544 are shown in the left and right panel respectively. The position angles in the equatorial coordinate system are measured from the north increasing eastward.

The mean value of P in case of LDN 183 is found to be 2.8% with a standard deviation of 0.8% and that of θ_p is 95° with a standard deviation of 12°. The region where sub-mm observations were carried out (Crutcher et al. 2004) is identified by a circle in Fig.1. The S/N-weighted mean position angle observed in sub-mm (after rotating them by 90°) is found to be $\sim 28°$. The cloud morphology as seen from the IRAS 100μm image at 1-2 pc scales and from the MAMBO 1.2mm map at $\sim 0.1-0.2$ pc produced by Kauffmann et al. (2008) is oriented in the north-south direction. Therefore, the magnetic field lines inferred from the optical polarimetry of the low-density regions of LDN 183 are oriented parallel to the minor axis of the cloud, in line with what is expected from a magnetically dominated scenario. However, the direction of the magnetic field lines inside the core, as inferred from the sub-mm polarization, present a different picture. The mean direction of the magnetic field inside the core shows an offset of $\sim 67°$ with the mean direction of the magnetic field in the low-density region.

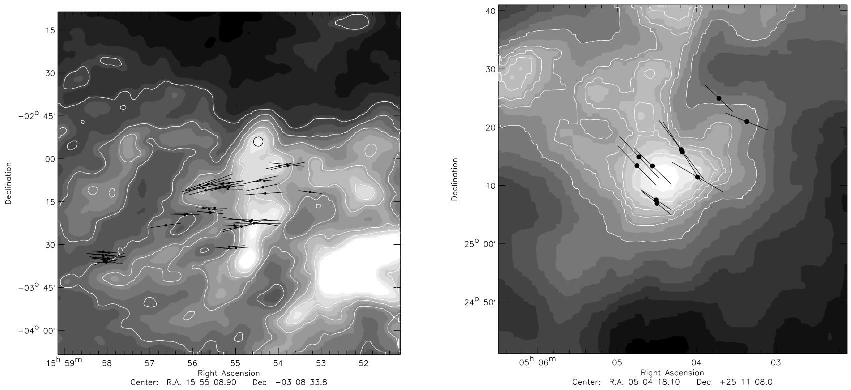

Figure 1. Polarization vectors overplotted on the IRAS 100μm images of LDN 183 (left panel) and LDN 1544 (right panel).

The mean value of P in case of LDN 1544 is found to be 3.2% with a standard deviation of 0.8% and that of θ_p is 51° with a standard deviation of 10°. The minor axis of the cloud is oriented at a position angle of $52° \pm 5°$ (Ward-Thompson et al. 2000). As in LDN 183, in LDN 1544 too, the magnetic field lines in the low density regions are found to be parallel to the minor axis of the cloud. Again, the weighted mean position angle of the magnetic field lines (averaged over eight positions) inside the core as inferred from the sub-mm observations is found to be $23° \pm 2°$ (Ward-Thompson et al. 2000), an offset of 28° with respect to the mean direction of magnetic field in the low density region.

4. Discussion and conclusions

Towards LDN 183, there exists evidence for an external influence on the cloud. The large scale distribution of dust from IRAS 100μm images shows an elliptical structure with LDN 183 on its rim. The variation of the local standard of rest velocity across the LDN 183 shows a velocity gradient in the position angle of $-49° \pm 1°$ (Crapsi et al. 2005). Therefore our preliminary results indicate that both the turbulence and the magnetic field are important in the formation and evolution of clouds.

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