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Understanding properties of dust in star forming clouds: polarization vs extinction

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Abstract. There are evidences that the small compact clouds (also known as Bok Globules) are undergoing gravitational collapse and some of them may form low mass stars. But as these clouds undergo gravitational collapse, the ambient magnetic field plays a key role in the collapse dynamics. The strength and geometry of the magnetic field are normally estimated through the polarimetry of stars background to the cloud. The optical polarization is caused by selective absorption of background starlight by the magnetically aligned dust (grain) present in the cloud. When observed in NIR (and sub-mm), the same grains are seen in thermal re-emission. In order to study the role of grains and magnetic field, often extinction measurements are also made in such clouds. With these aims, recently such clouds have been studied in photometry, polarimetry and spectroscopy. These results are discussed with possible interpretations.

Keywords : stars: formation – ISM: dust – extinction

1. Introduction

Small compact dark clouds (also known as Bok Globules) are undergoing gravitational collapse and may form low mass stars (Bok & Railey 1947). Magnetic field in terms of its strength and geometry plays a key role in collapse dynamics by mediating accretion, collimating the jets and directing outflows. Background star polarimetry provides a good technique to map the magnetic field. Light from background stars are scattered in forward direction by magnetically aligned dichroic dust grains (Davis & Greenstein 1951). Recently Sen et al. (2005, 2010) have analysed the data on eight such dark clouds (CB3, 25, 39, 52, 54, 58, 62, 246). In past many researchers had undertaken polarimetric studies of such star forming clouds to understand the nature

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of magnetic field. Such studies include work by Vrba et al. (1981), Joshi et al.(1985), Goodman et al. (1989), Myers & Goodman (1991), Kane et al. (1995), Sen et al. (2000), Ward-Thompson et al. (2000) in the optical. However, several people had also observed a lack of dependence of observed polarization on extinction and questioned the validity of this technique of using polarimetry as a tracer of magnetic field (Goodman 1995).

2. Background star polarization and physical condition in cloud

Sen et al. (2005) found that the average polarization p of various clouds was not convincingly related to gas temperature (T_g) and dust temperature (T_d) as is expected from Davis-Greenstein mechanism. In order to understand the variation of average polarization values between different clouds as a function of temperatures, some analysis was made by Sen et al. (2005), based on classical Davis-Greenstein mechanism. Accordingly the polarization observed (p) in a cloud should be related to the dust and gas temperature (T_d and T_g respectively) by the following relation:

$$p(\%) \sim \text{ constant} + \frac{1}{\sqrt{T_g}}\left(\frac{1}{T_d} - \frac{1}{T_g}\right) \quad (1)$$

In their analysis, the values of T_d, T_g were obtained from Clemens et al.(1991), who used deep IRAS image analysis and ^{12}CO spectroscopy to calculate dust and gas temperatures. Clemens et al.(1991) calculated fluxes at 12, 25, 60 and 100 μm bands and the spectrum was not found to fit a single black body. This resulted different temperatures for different band pairs, which was explained as the IR emissions coming from many different dust populations, each at somewhat different temperatures. Owing to these we may not get a clear dependence of polarization on dust or grain temperatures and this was what observed by Sen et al. (2005). Clemens et al. (1991) from their CO spectroscopy have also determined the radiation temperature (T_R) for all the CB clouds, from which Sen at al. (2005) had calculated cloud gas kinetic temperature (T_g). With these values of T_d, T_g, it was found that the dependence does not look like what is expected from Eqn (1). Sen et al (2005) also showed that, the dependence even does not look like what can be expected out of a modified grain alignment mechanism suggested by Lazarian et al. (1997).

The molecular turbulence present in the cloud can be measured from , ^{12}CO line width in terms of $\Delta v \;\; km \;\; sec^{-1}$ values (Clemens et al. 1991). In Sen et al. (2005), it was reported that the average polarization (p) values for various clouds seem to be clearly related to the molecular turbulence by an empirical relation $p = 2.95 * exp(-0.24\Delta v)$. A plot taken from Sen et al. (2005), now reproduced as Fig. 1, clearly explains this trend. This trend is quite expected, as the turbulence can disturb the grain alignment, causing a reduction in the observed polarization values. And when the turbulence becomes too high no alignment may be possible. In the line of sight there may be several independent directions of alignment causing a net depolarization

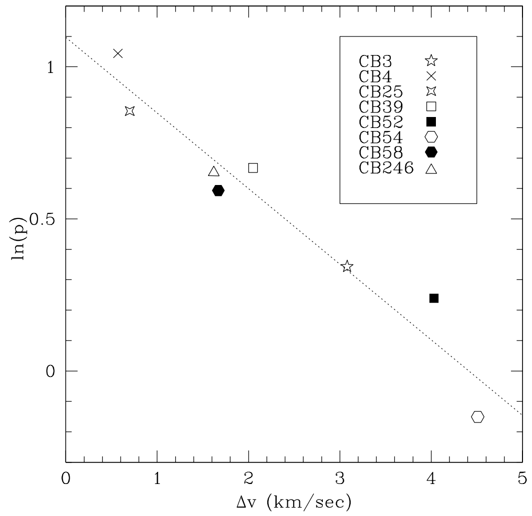

Figure 1. The log of average of observed polarization $ln(p_{av})$ are plotted against the turbulence $\Delta v(km/sec)$ for various clouds. The line of best fit $ln(p) = 1.0831 - 0.2424\Delta v$ is shown along with.

and resulting a low value of observed polarization. Thus it can be ascertained that, the physical conditions within the cloud are capable of influencing the polarization that we observe for stars background to these clouds.

3. The background star polarization and extinction

To understand how effectively background star polarimetry can probe internal conditions within the clouds, Sen et al. (2010) had recently calculated and compared the extinction ($E(B - V)$) and polarization (p) data for a number of such star forming clouds. It was concluded from their analysis,that the polarization p does not seem to depend very clearly on the extinction $E(B - V)$.

Under such a situation, the question naturally arises are the polarization and extinction arising out of two different types of grain populations ? Some calculations done by Sen et al. (2007) showed that in star forming clouds the polarization can be mainly caused by short grains, whereas the extinction is caused by larger ones.

4. The sub-mm and optical polarimetry of background stars

The optical polarimetric data has been recently combined with the sub-mm data from the Cardiff Star formation group. (Ward-Thompson et al. (2009). The optical polar-

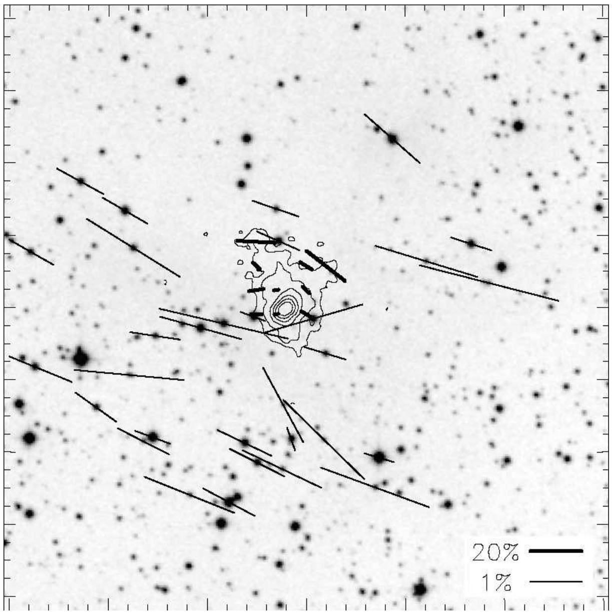

Figure 2. The optical polarization map of CB3 shown with thin vectors. The thick vectors represent sub-mm polarization (rotated through 90). The isophotal contours of SCUBA at 850 m are also seen. CB3 is at a distance of 2.5 Kpc. Contains YSOs and IRAS sources

ization comes from the low density region (A_v ~1-5) of the cloud (near the periphery) and through the high density region (A_v ~ 10 - 100), we do not see the background stars. Grains align with their long axes perpendicular to magnetic field. In the optical, the polarization direction is parallel to magnetic field. In the sub-mm the polarization is caused due to preferential emission from aligned elongated grains. So sub-mm polarization vector should be perpendicular to magnetic field.

After comparison of optical and sub-mm polarimetric data, it was found for CB3, the two sets of polarization vectors are at right angles to each other as expected. From the sub-mm contours it appeared CB3 is elongated and estimated direction of short axis is making an angle 40^o with magnetic field direction. This is consistent with the models of magnetically dominated star formation with a pre-stellar core (Ward-Thompson et al. 2000).

The combined analysis of optical and sub-mm polarimetric data showed that, the two independent methods were tracing one and the same magnetic field within the star forming clouds. Grain alignment mechanism works uniformly well from high to low density region. The magnetic field geometry (as inferred from polarimetry) is consistent with the magnetically dominated models of star formation in proto-stellar (ex. CB3) and pre-stellar (ex. CB246) cores.

5. Conclussions

From the above analysis one may conclude that, (i) The background star polarization (p) does not depend on dust and gas temperature as is theoretically expected. (ii) Polarization observed for the background stars are related to the turbulence present within the clouds. (iii) The observation that p is not related to $E(B-V)$, can be explained if polarization and extinctions are caused by two different grain populations. (iv) The two independent methods optical and sub-mm polarimetry trace the same magnetic field within the star forming clouds, uniformly well from high to low density region.

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