Interstellar Extinction and Polarization and Star Formation in Dark Clouds

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Polarimetry of stars background to dark clouds provides an important tool to map the magnetic field in the cloud. These polarimetric measurements have significance as the magnetic field plays a key role in star formation dynamics. However, simultaneous interpretation of extinction and polarization for such clouds poses problems for theoreticians. Some of these problems are discussed in the present work and possible explanations are provided.

1 Introduction

It is well known that light from celestial sources, when passes through the interstellar medium, gets polarized due to the aligned dichroic interstellar dust grains. At times, the light passes through denser parts of the interstellar medium which usually contain *interstellar clouds*. Some of these clouds are undergoing gravitational collapse and may form stars. The amount of the polarization caused by such intervening clouds provides valuable information and acts as a good diagnostic to understand various processes associated with star formation.

The dichroic grains present in such clouds generally get aligned by various mechanisms, where the magnetic field is an important component [1]. The same magnetic field also plays a key role in the dynamics of star formation and helps in deciding the shape of the clouds [2]. Some of these clouds have rotations, which together with the magnetic field sometimes impede the gravitational collapse [3]. The grains, on the other hand, absorb radiation at shorter wavelengths and *reradiate in the infrared,* helping the energy balance mechanism. The thermally re-radiated emission also shows polarization [4, 5].

In our galaxy we have many small compact dark clouds (known as Bok globules), undergoing gravitational collapse, that may form low mass stars [6, 7]. They mainly contain molecular gas and dust, having the gas temperature ∼10–30 K and density $\sim 10^4$ cm^{-3}, the total mass about 10–100 $M_\odot$ and the

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size about 1–2 pc. The role of gravity is to be understood in a situation, where we have thermal outward pressure, turbulence, rotation and the magnetic field (also electrostatic charging [8] and so on). Towards the cloud core the total extinction can be as large as $A_V > 25$ mag, whereas in the outer periphery, where most of the optical polarimetric observations are carried out, $A_V < 5$ mag (see, e.g., [9]).

With this background, over the last few decades many dense interstellar clouds were astronomically observed by various groups in polarimetry, to understand the star formation processes in them. In spite of that, we still have a number of unresolved critical issues associated with such observation and analysis, namely: *Are background star polarimetry and re-emission polarimetry really capable of estimating magnetic field? Why the extinction data most often do not seem to be related to the polarization data? How interstellar polarization measurement is related to background star polarimetry?*

In this paper, we go through some of these issues and draw conclusions.

2 Interstellar extinction and polarization

The interstellar extinction and polarization over a wide wavelength range have been studied by many authors, which helped to characterize the grains' composition, shape and size, and also the number density distribution and the magnetic field. For instance, Gupta et al. [10] considered mixtures of silicate and graphite oblate spheroidal grains of the aspect ratio $a/b = 1.33$ within the wavelength range 0.1–3.4 μm to simulate the interstellar extinction. On the other hand, Das et al. [11], considering homogenous carbonaceous and silicates spheroids containing C, O, Mg, and Fe and the imperfect Davis-Greenstein (DG) alignment mechanism, explained the interstellar extinction as well as polarization curves. Voshchinnikov, Henning [12] also made such studies with a special emphasis on the dust composition and found that the dust phase abundance of Si, Fe, Mg played an important role to decide some of the observed phenomena. Many other aspects of interpretation of the interstellar polarization and extinction observations have been recently reviewed in [13].

3 Background star extinction and polarization for dark clouds

For the stars background to diffuse clouds, we know that the dichroic grains absorb optical radiation from background stars, resulting in the optical polarization. The same set of dust reradiates thermally resulting in the sub-mm and IR polarization. In past, Vrba et al. [14], Joshi et al. [15], Goodman et al. [16], Myers, Goodman [17], Kane et al. [18], Sen et al. [19], Whittet [20], Andersson, Potter [21] and other authors made such optical polarimetric studies. The works on polarization by the thermal re-emission were reported, e.g., by Ward-Thompson et al. [22] and Henning et al. [23] among others.

The background star polarimetric results are generally analyzed in the same way as interstellar polarization values. But since sometimes we encounter many problems while interpreting results of background star polarimetry, it appears that, understanding the processes in the background star polarimetry is not as simple as understanding the interstellar polarization.

Some of the observations of the background star polarization need attention:

1. Optical and NIR polarimetry does not show an increase in the polarization degree as one goes closer to the center of a dark cloud (signifying an increase in the optical depth) (e.g., [15, 9]).
2. The extinction and corresponding polarization for a set of background stars should be related for dark clouds, but most of the recent studies show they are not. So, Goodman et al. [24] questioned the validity of this technique to study the magnetic fields within the clouds.
3. For a set of eight clouds, Sen et al. [25] found that the perfect DG mechanism could not explain the observed polarization. Many other investigators also noted that the DG mechanism predicted much higher values of polarization than the actually observed ones. The question naturally arises, is polarization in the optical caused by grains which are aligned by DG mechanism or other processes? If we understand the process, then we can map the magnetic field more confidently.
4. Again far-IR observation gives polarization values which are consistent with the thermal re-emission from grains [27, 26].
5. Not only that, these far-IR polarization values are also consistent with the absorption polarization in the optical region. The polarization in this region comes from the low density region ($A_{\rm V}$ ~1–5 mag) of the cloud (near the periphery), while in the sub-mm domain (850 μm) does from near the core ($A_{\rm V}$ ~10–100 mag). The optical polarization direction is parallel to the magnetic field. The sub-mm polarization is due to the preferential emission from aligned elongated grains and should be *perpendicular* to the magnetic field. A comparison of the optical (from the Indian telescope) and sub-mm (from the SCUBA data archive) polarization vectors confirmed these findings [27]. Recent Planck data give a deeper insight on the relation between the sub-mm and visual polarization [5].
6. As found by Sen et al. [25] from a study of eight clouds, turbulence within the cloud was influencing (rather disturbing) the grain alignment and this could be modeled through a mathematical relation (see Fig. 1).
7. As an exception to point (2) above, Sen et al [28] found that at least for some clouds, there was a positive correlation between polarization and extinction.

Basing on points (1) to (3), one could say that the intervening cloud has no role in the polarization that we observe for the stars background to the cloud. But in that case, we can not explain the points (4) to (6) listed above, which suggests that the polarization observed for background stars must have something intrinsic to the cloud.

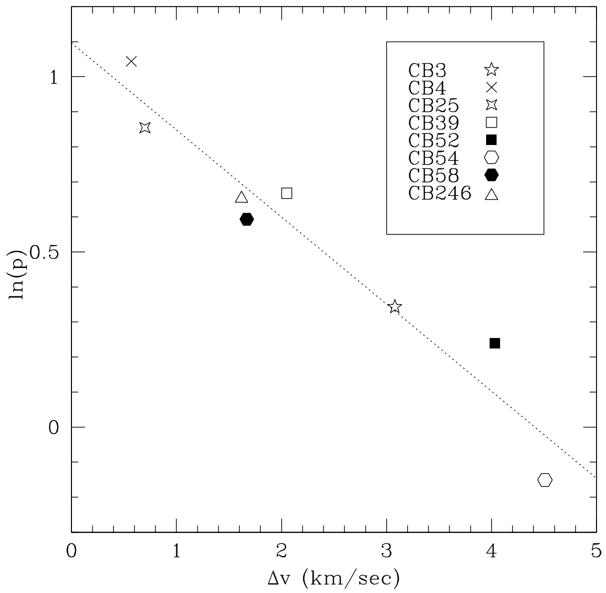

Figure 1: The log of the average observed polarization $\ln(p)$ against the turbulence velocity Δv (in km/s) for different clouds according to [25]. The line of the best fit $\ln(p) = 1.08 - 0.24\,\Delta v$ is shown.

There *exist* various possibilities which can explain the present situation. There are now doubts that the DG-like mechanisms play a role as large as thought earlier, and many researchers believe that the most important aligning force could be radiative torques [29]. However, it does not exclude the role of other mechanisms which can align grains.

It is very possible that some particular mechanism works in some parts of the cloud as compared to others. Also a particular alignment mechanism may be more effective for grains with a particular size and composition. Voshchinnikov [13], while working on the interstellar polarization, discussed such possibilities. And for dark clouds, it may be even more complicated. Within such a cloud, along the line of sight different values of the parameters of the magnetic field (or other aligning forces) are possible.

As listed in [30], a set of conditions should be fulfilled to get polarization out of aligned grains. If these conditions are not satisfied, we can get extinction, but not polarization.

Any misadjustment in these conditions should result in a poor correlation between polarization and extinction. The grain shape, size, magnetic properties (composition), alignment procedure are important parameters and some of these physical properties should vary within the clouds. And recent studies of extinction law, scattered light and sub-mm emissivity have already inferred changes in dust properties with an increase of depth inside a cloud (see [31] and references therein). So, the polarization observed for stars background to dark clouds may appear to be quite different from the polarization observed for the diffuse interstellar medium.

4 Conclusions

We can conclude as follows:

1. It is clear that the polarization values observed for stars behind dark clouds are influenced by the physical processes within these clouds.
2. However, the physical processes responsible for producing the polarization *in* the clouds are not well understood.
3. The processes producing the interstellar polarization and the polarization of background star radiation in dark clouds are definitely not the same.
4. The processes responsible for the polarization in dark clouds should be *more* clearly understood, as we find the situation is not as simple as in the interstellar medium. Only after this, we can use in the full manner the background star polarimetry to investigate star formation processes in dark clouds.

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