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Proposal for UV observations of star forming clouds

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Abstract. The small, compact dark clouds (also known as Bok Globules), are undergoing gravitational collapse that can result in the production of low mass stars. Light from background stars is scattered in forward direction by magnetically aligned dichroic dust grains. The degree and direction of alignment is proportional to the strength and direction of ambient magnetic field in the cloud. Background star polarimetry provides the technique to probe this field. In order to relate the physical conditions within the cloud to the background star polarization and to know the dust properties, we need to determine $E(B-V)$ for each background star and relate it to the corresponding observed polarization (p). However, observed data, do not always show a correlation between polarization and extinction. Due to this the question arises whether the grains that produce polarization also produce observed extinction?

The observation that the polarization is not related to the extinction, can be explained if polarization and extinction are caused by two different grain populations. Polarization is mainly caused by short grains, whereas the extinction is caused by larger ones. Based on these findings, justifications are made here to detect these small grains (0.0035-0.01 μm) in the star forming clouds through UV observations to be made by TAUVEX. These particles can be best detected through the UV observations, as they show far-UV excess and characteristic features of 2175 Å bump. We propose imaging of these clouds through the three bandpass filters of TAUVEX. We expect to resolve many unanswered questions associated with star forming clouds, through this set of proposed observations.

Keywords : polarization – stars: formation – ISM: clouds – (ISM:) dust, extinction – ultraviolet: ISM – instrument: TAUVEX

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1. Introduction

Small compact dark clouds (also known as Bok Globules) are undergoing gravitational collapse and may form low mass stars (Bok & Railey 1947). These are cold dense clouds of H_2, with temperature $T \simeq 30$ K, density $= 10^4 H_2$ cm^{-3} and masses 10 to 100 $M_{\odot}$, with sizes 1-2 pc.

In order that a cloud contracts towards formation of star(s) the self gravity has to overcome the forces due to thermal outward pressure, rotation in the equatorial plane and magnetic field pressure. 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). The degree and direction of alignment is directly related to the strength and direction of ambient magnetic field in the cloud. Background star polarimetry provides a technique to probe this magnetic field. With this aim, several authors in the past have reported background star polarimetry of such clouds : Vrba et al. (1981); Joshi et al.(1985); Goodman et al.(1989); Myers & Goodman (1991); Kane et al.(1995), Sen et al.(2000) to mention a few. However, Goodman et al. (1995) observed a lack of dependence of observed polarization on extinction and questioned the validity of this technique.

More recently Sen et al. (2005) have analysed the data on eight such dark clouds (CB3, 25, 39, 52, 54, 58, 62, 246) previously observed by the same group in another work (Sen et al. 2000). In this recent work the relation between background star polarisation and physical properties of clouds was explored. A typical map of background star polarization taken from Sen et al. (2000) for one of the clouds CB39 is reproduced here as Fig. 1.

Sen et al. (2005) found that the background star polarization is not independent of the ambient physical conditions within the cloud like temperature, molecular turbulence etc. Therefore it was concluded that, the polarization measurements can still be used to explore physical conditions within the cloud, though apparently the observed polarization values do not show any relation with extinctions. To resolve this discrepancy, at this stage one should know the role of grains within the cloud, which are generally held responsible for producing polarization as well as extinctions. In the present work, we perform some analysis of the light scattering properties of various sizes of grains, to understand this issue better. Finally we find that, observations of these clouds in the UV part of the spectrum may resolve many key issues connected with the role of grains and star formation in general.

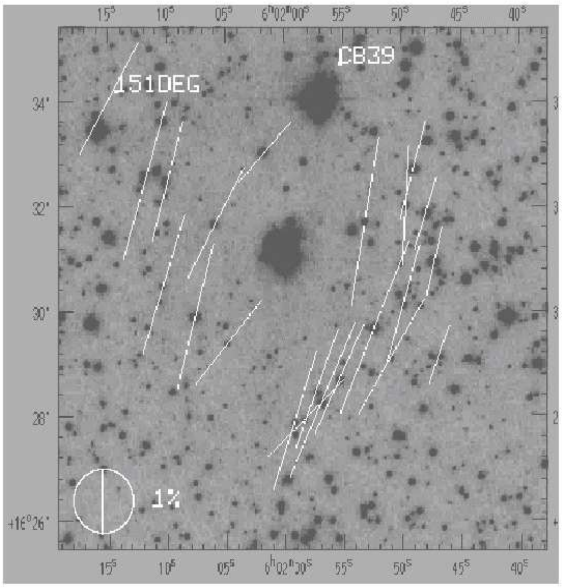

Figure 1. A map showing background star polarization for a typical cloud CB39, taken from Sen et al. (2000).

2. Background star polarization and ambient physical condition in clouds

The average polarization p of various clouds as reported by Sen et al. (2005) was not found to be 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 in our previous work (Sen et al. 2005), based on classical Davis-Greenstein mechanism. Accordingly the polarization observed in a cloud (p) should be related to the dust and gas temperatures (T_d and T_g respectively) by the following relation:

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

In a special case, if $T_d = T_g$ the cloud itself will not introduce any polarization in the star light and the observed polarization will be only a contribution from interstellar medium. In the present analysis, the values of T_d, T_g were obtained from Clemens et al. (1991). These authors used deep IRAS image analysis and ^{12}CO spectroscopy to calculate dust and gas temperatures. They calculated fluxes at 12, 25, 60 and 100 μm bands and the spectrum was not found to fit a single black body. This resulted in different

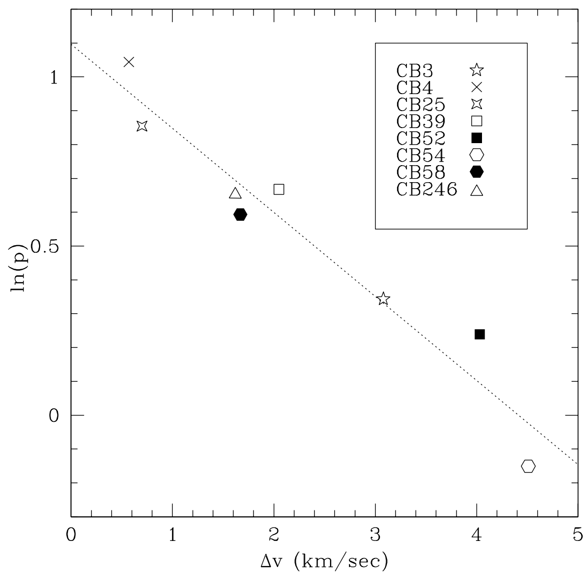

Figure 2. The log of average of observed polarization $ln(p)$ is plotted against the turbulence Δv (km s^{-1}) for various clouds. The line of best fit $ln(p) = 1.0831 - 0.2424\Delta v$ is shown.

temperatures for different band pairs, which was explained as the IR emissions coming from many different dust populations each at somewhat different temperatures. This according to the authors may be expected, as the shape of the interstellar extinction curve justifies a range of dust grain sizes as shown by Mathis et al. (1977). One can see from Eq. (1) that p has a linear dependence on $1/(T_d)$. Therefore, in Sen et al. (2005) the value of harmonic mean of the three dust temperatures $T(12/25)$, $T(25/60)$ $T(60/100)$ was taken as representative dust temperature of the clouds.

Clemens et al. (1991) from their CO spectroscopy have also determined the radiation temperature (T_R) for all the CB clouds, from which Sen et al. (2005) had calculated cloud gas kinetic temperature (T_g). With these values of T_d, T_g a plot was made by Sen et al. (2005) and it was found that the plot does not look like what is expected from Eq. (1). Sen et al. (2005) also showed that, the plot even does not look like what can be expected out of a modified grain alignment mechanism suggested by Lazarian et al. (1997).

Thus the problem remained unresolved why the observed background star polarization does not appear to be related to cloud dust and gas temperatures (T_d and T_g).

The molecular turbulence present in the cloud can be measured from, ^{12}CO line width in terms of Δv km s^{-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. 2, 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 and resulting in a low value of observed polarization.

Thus it can be ascertained that, the physical conditions within the clouds are capable of influencing the polarization that we observe for background stars to these clouds.

But if this is the case, one should also expect the polarization that we observe for the background stars, to be related to the corresponding extinction values. Because, once there are grains present to produce certain amount of polarization, the same grains will also produce extinctions.

3. The background star polarization and extinction

In order to look for any possible relation between polarization and extinction, we can determine the value of colour excess $E(B - V)$ for each star for which we have the corresponding polarization (p) values available from Sen et al. (2000).

A comparison of $E(B-V)$ and p of stars at different distances from cloud centre will help to answer the following questions. Are the grains which produce polarization also be responsible for observed extinction (measured by$A(V)$ or $E(B-V)$)? If yes, we can put more constraints (from p as well as from $E(B-V)$) on grain properties and characterise them.

If no, we should separate the two components and understand them. And we should also take more care to use polarimetry as a tool to understand several properties related to star formation.

In order to determine $E(B - V)$ one needs to find the observed magnitudes and spectral types of individual stars. The background stars are in some cases very faint and the determination of their spectral types are difficult from 2m class telescopes. So we took help of some numerical techniques to determine their spectral types from the observed magnitudes itself. Based on the fact that extinction caused in the B band is much higher than that in V and then in R band, one can determine $E(B-V)$ to a reasonable accuracy, by a suitable iterative technique (Bernabei & Polcaro 2001).

Based on the intrinsic colour of a large number of MS stars Bernabei & Polcaro (2001)

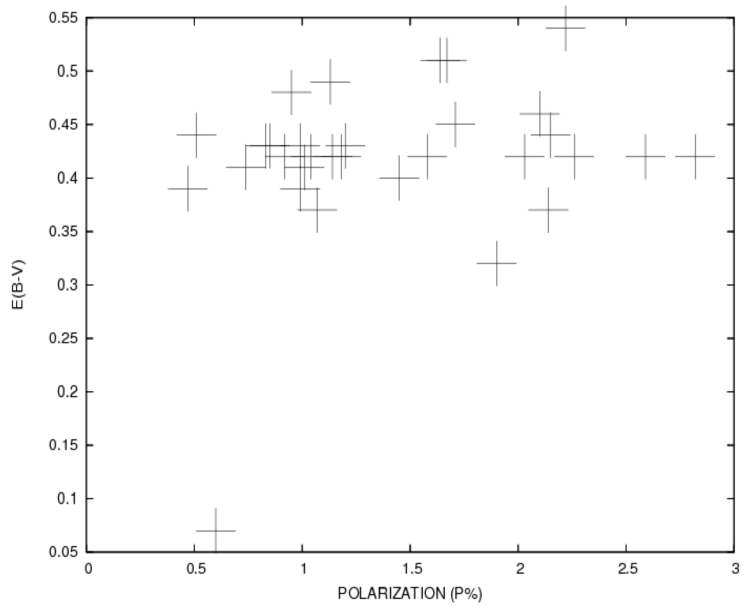

Figure 3. The polarization values observed for individual stars in the cloud CB3 are plotted against the corresponding colour excess $E(B-V)$ values. The error values in polarization are typically less than 0.5 per cent (Sen et al. 2000).

have used the following relation between $(B-V)$ and $(V-R)$ colours

$$(B-V) = -0.104(V-R)^2 + 1.355(V-R) - 0.080. \tag{2}$$

From Cardelli et al. (1989), the mean extinction law at different wavelengths $\lambda(0.3-8.0\mu\text{m})$ is given by

$$A(\lambda)/A(V) = a(\lambda) + b(\lambda)/Rv \tag{3}$$

where $Rv = A(V)/E(B-V)$. One may take (a, b) values as (0.9982, 1.0495), (1,0) and (0.8686, −0.3660) at wavelengths B, V, R respectively and choose Rv=3.1 for IS medium (Cardelli et al. 1989). The values of $A(B)$, $A(V)$ and $A(R)$ are utilised to correct (de-redden) the observed magnitudes B, V, R in an iterative loop from Eq. (2). After reasonable level of convergence, we calculate the final de-reddened values of B,V and R.

The colour excess $E(B-V)$ is now calculated from the difference between the observed $(B-V)$ and de-reddened $(B-V)$, as is usually done.

Based on our photometric observations and following the above iterative procedure, we calculated $E(B-V)$ values for thirty one stars in the dark cloud CB3, for which polarization (p) values are already available from Sen et al. (2000). A plot showing polarization p vs colour excess $E(B-V)$ is shown in Fig. 3. As it is seen clearly, the polarization p does not seem to depend on the extinction $E(B-V)$.

Under such a situation, the question naturally arises, are polarization and extinction arising out of two different types of grain populations ?

However, at this stage while drawing the above conclusions we note two points (i) the relation (2) that we used above assumes all the stars are of main sequence. However, in actual case all the stars that we have observed in the periphery of cloud CB3, may not be of main sequence. (ii) Further, in estimating colour excess for each star we have primarily assumed $R_v = 3.1$ a value which is true only for interstellar medium. However, we have also tried with $R_v = 5$ a value which is more appropriate for dense molecular clouds and found that our conclusions essentially do not change. So we retained the value $R_v = 3.1$, with which we are more familiar.

4. The role of smaller grains

We may now summarise what we have observed about the relation between polarization and other physical properties of these clouds, in the following:

1. The background star polarization (p) does not depend on dust and gas temperature as is theoretically expected.

2. Dust temperature values were taken as harmonic mean from Clemens et al. (1991) who reported several temperatures for different IRAS band pairs (16, 25, 60 and 100 μm). According to the authors, the different temperature values can be explained, if there are small grains which are strongly forward scattering in UV, so that interior of the globules are filled with UV light and these can be absorbed by grains leading to high non-equilibrium temperature.

3. High non-equilibrium temperature can be a reason why polarization (p) was not found to be related to temperature as theoretically expected.

4. Small (≤ 0.0035 μm) grains are optically thick to UV and they account for 2175 Å bump and far UV excess. They account for 35% of stellar energy absorbed in solar neighbourhood (Boulanger et al. 1994).

5. Our observation that p is not related to $E(B-V)$, can be explained if polarization and extinctions are caused by two different grain populations. Polarization may be mainly caused by short grains, where the extinction is caused by larger ones.

One can study the polarization and extinction properties of shorter grains using T-matrix theory for irregular grains. We consider oblate grains with axial ratio 1.33, a shape factor already justified by Gupta et al. (2005) for interstellar scattering. Optical constants of astronomical silicates are taken (Draine 2003) which are (1.6904, 0.0298) at 0.55 μm and (2.101, 0.2601) at 0.16 μm. Using orientation of grain at 90° and performing T-matrix based calculations, we get $p = 1\%$ (for grain size $a = 0.55$ μm) and 10% (for grain size $a = 0.0035$ μm) at wavelength $\lambda = 0.55$ μm. And at same wavelength, we get the extinction co-efficient $Q_{ext} = 2.3$ (for $a = 0.55$ μm) and 0.003 (for $a = 0.0035$ μm). Whereas at wavelength $\lambda = 0.16$ μm, we get $Q_{ext} = 2.24$ (for $a = 0.55$ μm) and 0.04 (for $a = 0.0035$ μm).

From these calculations, it is quite clear that in star forming clouds the polarization is mainly caused by short grains, whereas the extinction is caused by larger ones.

5. The need for UV observations of the star forming clouds

Based on the above findings a case is made here to detect the existence of small grains (0.0035–0.01 μm) in the star forming clouds. These particles can be best detected through UV observations as they show far UV excess and characteristic features of 2175 Å bump.

The UV excess can be detected through the most familiar pair method (Fitzpatrick & Massa 1986, 1988), based on the following procedure:

$$k(\lambda - V) = \frac{E(\lambda - V)}{E(B - V)} \tag{4}$$

or

$$k(\lambda - V) = \frac{m(\lambda - V) - m(\lambda - V)_{STD}}{(B - V) - (B - V)_{STD}} \tag{5}$$

where $m(\lambda - V)$ and $(B - V)$ are the ultraviolet and visual colour of programme stars and $m(\lambda - V)_{STD}$ and $(B - V)_{STD}$ are those of unreddened standard stars. The standard stars and programme stars should be of the same spectral type. List of such unreddened standard stars for comparison are available from Fitzpatrick and Massa (1986). The dark clouds we suggest to observe are of typically $5' \times 5'$ angular size and Tauvex has FOV 0.9 degrees.

We propose imaging of these clouds through the three bandpass filters of TAUVEX namely SF-1 (160 nm), SF-2 (210 nm) and SF-3 (260 nm), along with standard stars. The programme stars are of magnitudes (m_v) ∼14 or fainter.

We expect to resolve many unanswered questions associated with star forming clouds through this set of proposed observations.

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References

Bernabei, S., & Polcaro, V. F., 2001, A&A, 371, 123
Bok, B. J., & Reilly, E. F., 1947, ApJ, 105, 255
Boulanger, F., Prevot, M. L., & Gry, C., 1994, A&A, 284, 956
Cardelli, J. A., Clayton, G. C., & Mathis, J. S., 1989, ApJ, 345, 245
Clemens, D. P., Yun, J. L., & Hayer, M.H., 1991, ApJS, 75, 877
Davis, Jr. L., & Greenstein, J. L., 1951, ApJ, 114, 206
Draine, B. T., 2003, ApJ, 598, 1017 D
Fitzpatrick, E. L., & Massa, D., 1986, ApJ, 307, 286F
Fitzpatrick, E. L., & Massa, D., 1988, ApJ, 328, 734F
Goodman, A. A., Crutcher, R. M., Heiles, C., Myers, P. C., & Troland, T. C., 1989, ApJ, 338, L61
Goodman, A. A., Jones, T. A., Lada, E.A., & Myers, P. C., 1995, ApJ, 448, 748
Gupta, R., Mukai, T., Vidya, D. B., Sen, A. K., & Okada, Y., 2005, A&A, 441, 555
Joshi, U. C., Kulkarni, P. V., Bhatt, H. C., Kulshrestha, A. K., & Deshpande, M. R., 1985, MNRAS, 215, 275
Kane, D. B., Clemens, D. P., Leach, R. W., & Barvainis, R., 1995, ApJ, 445, 269
Lazarian, A., Goodman, A. A., & Myers, P. C., 1997, ApJ, 490, 273
Mathis, J. S., Rumpl, W., & Nordsieck, K. H., 1977, ApJ, 217, 425
Myers, P. C., & Goodman, A. A., 1991, ApJ, 373, 509
Sen, A. K., Gupta, Ranjan, Ramprakash, A. N., & Tandon, S. N., 2000, A&AS, 141, 175
Sen, A. K., Mukai, T., Gupta, R., & Das, H. S., 2005, MNRAS, 361, 177
Vrba, F. J., Coyne, G. V., & Tapia, S., 1981, ApJ, 243, 489