Dichroic extinction and the infrared polarization of young stellar objects in the L1641 dark cloud

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ABSTRACT
33 young stellar objects (YSOs) in the L1641 dark cloud have been studied using near-infrared polarimetry and imaging. The polarization values were found to correlate with the infrared colour of each source. Point-like sources were found to have a strong wavelength dependence on the polarizations with \( \langle P_\lambda/P_K \rangle = 1.4 \) and \( \langle P_\lambda/P_K \rangle = 2.5 \). The results were compared with the polarization behaviour expected from dichroic extinction, as well as scattering models. Dichroic extinction from aligned dust grains in the circumstellar core most naturally explains the observed polarization in reddened sources, although it is likely that a scattering component dominates in relatively unreddened objects, such as T Tauri stars. There is only a poor alignment of the YSO polarization vectors over the cloud, suggesting that the magnetic field was not dominant in the collapse dynamics of L1641.

Key words: polarization – stars: formation – dust, extinction – ISM: individual: L1641 – ISM: magnetic fields – infrared: stars.

1 INTRODUCTION
The large-scale alignment of dust grains with the galactic magnetic field is known to be the cause of the dichroic extinction and the resulting interstellar polarization seen in the direction of field stars. An emissive polarized component is also present in many star-forming regions in the mid-infrared, dominating at far-infrared wavelengths (Gonatas et al. 1990; Aitken et al. 1993). Similarly, the high linear polarization caused by scattering off dust grains in the optical and near-infrared (1–3 \( \mu \)m), has been observed many times in spatially resolved reflection nebulae (Heckert & Zeilik 1985; Minchin et al. 1991); sometimes there is evidence of overlying dichroic absorption which reveals the magnetic field configuration (Chrysostomou et al. 1994).

The radiation from YSOs has measurable linear polarization at most wavelengths, and it is probable that the mechanism producing this is associated with the large amounts of circumstellar dust that often surround YSOs. Thus, polarized radiation can serve as an important diagnostic of the circumstellar environment if its physical origin can be understood.

The problem is of particular relevance in the near-infrared, since this is the most sensitive wavelength range for the study of embedded YSO populations, and it is possible to measure polarization at these wavelengths for many low-luminosity sources within an individual cloud in a modest amount of time. Unfortunately, dust scattering can be significant in the near-infrared, and its contribution to the overall polarization in any particular source is unclear. In the case of a YSO with an obvious extended reflection nebula much of the scattering geometry may be modelled, clarifying the distribution of the circumstellar material (Bastien & Menard 1990). But K-band infrared imaging shows that this is not a typical YSO; most appear to be point-like on arcsec scales (Eiroa & Casali 1992). It is therefore uncertain whether aligned grains, circumstellar scattering or a combination of both is the source of the observed polarization in these cases.

Since dichroic extinction can be expected to result in a different wavelength dependence compared to that arising from scattering processes, a potentially important tool for discriminating between the two mechanisms is the use of multiwavelength polarimetry. Unfortunately, most infrared polarimetry surveys of young stars have tended to be in a single band, although Whittet et al. (1994) recently published a multiwavelength study of the Chamaeleon I association. In order to extend such studies it was decided to carry out a \( JHK \) polarimetric study of a sample of YSOs in a nearby dark cloud.

The L1641 cloud is situated some 3° south-east of the Orion nebula, and is \( 10 \times 40 \) pc in size with an estimated mass of \( 2 \times 10^4 M_\odot \). The \( IRAS \) point-source catalogue lists 123 sources within the molecular cloud boundaries and the region is an active site of star formation. The young population in the cloud, studied by Strom et al. (1989), provides an excellent sample for near-IR polarimetry, with many diverse conditions...
2 OBSERVATIONS

Near-IR polarimetry of the 33 sources in L1641 was carried out on the UK Infrared Telescope (UKIRT) on the nights of 1991 December 8–10. In the normal polarimetry configuration, a rotating achromatic half-wave plate (IRPOL) is situated before the telescope tertiary mirror which feeds an InSb photometer (UKT6) with cold internal analyser. An aperture of 7.8 arcsec diameter was selected for all the observations, as well as a chop throw of 20 arcsec and a chopping frequency of 3.5 Hz. The combined system has low instrumental polarization, measured to be less than 0.1 per cent by observing unpolarized standard stars. The polarization efficiency was 76, 90 and 96 per cent at H, K and respectively, and calibration was checked against Tau #19. (UKIRT polarisation standard) for which values of \( P_K = 1.36 \) per cent, \( P_H = 1.94 \) per cent, \( P_J = 3.06 \) per cent and \( \theta_K = 38^\circ \) are known.

H and K polarization measurements were made for all 33 objects and J measurements for those that were sufficiently bright (12 objects). Polarization values were corrected for noise bias using \( P = P_0 [1 - (\sigma_0/P_0)^2]^{1/2} \) (Clarke & Stewart 1986), although corrections were only significant for sources with a polarization of less than one per cent.

Near-infrared images were also obtained at H and K of all 33 sources using the UKIRT common-user infrared camera IRCAM, on 1991 October 4. The pixel scale was 0.6 arcsec, and total exposures of 1 min per filter per object were used. Nearby sky frames were also taken and subtracted off the on-target frames.

3 RESULTS

The infrared images show that the majority of the 33 sources are point-like, without any obvious extended nebulosity. Frequently, however, more than a single point source was found on each square 38-arcsec frame; presumably these are other embedded YSOs or background stars seen through the cloud. Fortunately, they were usually found to be sufficiently far away that no contamination of the photometer beam occurred. In only four cases were the secondary sources liable to be included within the 7.8-arcsec aperture of the polarimeter. Two of these are close doubles (IRS100 & IRS17) and one a multiple (IRS42).

Extended diffuse emission was found around four objects only (IRS 42, 55, 99b and 93). IRS55, in particular, has been well-studied previously by Reipurth & Bally (1986) and Casali (1991), and has shown variations in nebular surface brightness over periods of years. IRS99b is not in the original list of Strom et al. (1989), but appears as a nebulous object in the near-infrared images, some 9 arcsec south and 5 arcsec west of the IRS99 position. The original IRS99 source has been renamed IRS99a.

Images of the six extended/multiple sources (as well as IRS36, although it was not studied polarimetrically) are shown in Fig. 1. It should be noted that extended emission or binary separations of size less than 1 arcsec (480 au), or so, will not have been resolved by these images. Given recent studies of close binaries in YSOs (Ghez, Neugebauer & Matthews 1993) it is clear that a high incidence of unresolved binarity should be expected in the sample.

All 33 sources were observed with the polarimeter at \( H \) and \( K \), and all were found to be linearly polarized at the level of a few per cent in these bands. Since the sources were quite red and faint however, only 12 could be observed at J. The results of the polarimetry are shown in Table 1. Note that \( a \) is the mid-infrared spectral index. In general, the polarization was found to increase towards shorter wavelengths.

One of the reasons that the L1641 cluster was chosen for study was because of the complete spectral information available for each source. The analysis of results involved checking for correlations between the polarimetric and spectral data. In agreement with other studies the degree of polarization appears to be well-correlated with near-infrared colours such as \( H - K \) (or \( K - L \), \( K - [12] \)) as shown in Fig. 2. The correlation was poorer with \( R - J \), probably because very red sources had no \( R \) or \( I \) detection, thus restricting the sample to sources of modest reddening and consequently low polarization values. There was also little or no evidence of significant correlations of polarization with any combination of mid- or far-infrared colour such as \([12] - [60] \) or \([60] - [100] \).

The variation of polarization with wavelength can provide important clues to the polarization mechanism, and was measured simply by the ratio of \( H \)-band to \( K \)-band polarization, \( P_H/P_K \), in each source. As shown in Fig. 3 this ratio turns out to be in the range 1.6–1.8, and also seems reasonably independent of colour. The exceptions are the sources with the largest polarizations, for which \( P_H/P_K \) tends to 1.0. These sources also tend to have extended nebulosity. \( P_H/P_K \) is in the range 2–3 for most sources, except for extended objects in which, again, the ratio is closer to 1.

The position angle of polarization shows quite a lot of variation from source to source, beyond that expected from errors, especially for sources with \( P_K \) of less than 2 per cent. For \( P_K \) greater than 2 per cent the scatter decreases somewhat and \( \theta_K \) tends to lie between 50° and 100°. There is no evidence, within errors, for rotation of the polarization angle with wavelength, so the only polarization angle listed in Table 1 is \( \theta_K \). No other correlations or trends were found between \( \theta_K \) and any other independent parameters.

A number of sources in our sample were also observed in the radio by Chen, Fukui & Yang (1992). They found evidence of outflows in IRS28, 31, 54, 55 (extended) and 93 (extended), but not in IRS12, 16, 18 or 34.

4 POLARIZATION OWING TO DICHROIC EXTINCTION

Multiwavelength polarimetry of field stars seen through interstellar clouds gives details of two important characteristics of the polarization arising from dichroic absorption. First, the polarization will increase with the extinction in the line of sight, depending on the grain alignment efficiency, optical properties, and magnetic field geometry. So it is useful to define a ‘polarization efficiency’ as the ratio of the observed polarization to the line-of-sight extinction; the latter quantity is usually derived from reddening measurements. Secondly, the polarization will vary with
wavelength, and this has been well-studied in the interstellar medium. Typically, the polarization reaches a peak in $V$ or $R$ band and decreases steeply into the near-infrared (Whittet et al. 1992).

Then a straightforward test of the importance of dichroic extinction towards the L1641 YSOs would be to compare polarization efficiencies and wavelength dependence with the observed behaviour in the interstellar medium.

### 4.1 Polarization efficiencies

A heterogeneous study by Jones (1989) of a large number of polarimetric measurements towards various galactic sources showed that the relation $P_\lambda = 2.23 \tau_\lambda^6$ could fit the data well. In that study, sources with extended emission or a flat wavelength dependence of polarization were excluded to avoid contamination by scattered light. Assuming a normal reddening law ($\tau_\lambda \propto \lambda^{-1.8}$), this relation predicts $P_\lambda = 3.0[E(H-K)]^{0.4}$, where $E(H-K)$ is the reddening owing to extinction. On the other hand, Klebe & Jones (1990) found from polarimetry of field stars seen through Bok globules that $P_\lambda = 0.5[E(J-K)]$ which, again assuming a normal reddening law, gives $P_\lambda = 1.3E(H-K)$. These two relations, based as they are on very different types of sources, may be considered broadly independent estimates of the infrared polarization-to-extinction efficiency in the dense interstellar medium. Both can be compared with the L1641 YSO data, and this is shown in Fig. 2. The two relations bound the data (without any free parameters), if extended sources are excluded. The latter point is important because extended, scattered light can be expected to enhance the polarization. The reasonable fit implies that, provided the $H-K$ values in the L1641 sources are primarily indicators of extinction, then the near-infrared polarization-to-extinction efficiency is consistent with that caused by aligned dust grains in the dense interstellar medium.

How does the polarization efficiency compare with values for the more diffuse medium? To make this comparison, infrared quantities need to be converted to equivalent visual values. For a normal reddening law, infrared colour can be converted to visual extinction by $A_v = 16E(H-K)$. Data from a number of different regions in Whittet et al. (1992)
suggest that $P_J/P_K$ lies between 2 and 4 for red sources. Alternatively, if a Serkowski law is assumed, with $\lambda_{\text{max}} = 0.7$ μm (appropriate for dense clouds), then $P_J/P_K = 4.2$. Adopting a value of 4 for this ratio in L1641 and estimating $A_V$ from $H-K$, the visual polarization efficiency $P_J/A_V$ was calculated for each source. Results are plotted in Fig. 4. It is clear that beyond $A_V = 10$, $P_J/A_V$ seems to level out at ~0.3–0.5 per cent mag$^{-1}$. This is lower than the values found in regions of low extinction ($A_V = 1–2$) by at least a factor of 5, but is not inconsistent with an extrapolation of the Whittet et al. (1994) values to large extinctions (e.g. their fig. 7). Other studies by Goodman et al. (1990) and McGregor et al. (1994) find similarly low polarization efficiencies towards sources of higher extinction. Presumably, the higher gas density changes either the dust alignment efficiency, the optical properties of the dust, or possesses less homogeneous magnetic fields.

Although dichroic extinction seems to adequately fit the L1641 data, an important discrepancy should be noted. As the reddening tends to zero, so should the polarization owing to dichroic extinction. This is clearly not the case and a number of nearly unreddened YSOs both in L1641, and in other studies (e.g. Tamura & Sato 1989) have significant polarizations at the level of 1–2 per cent. This point is discussed further in Section 5.4.

### 4.2 Wavelength dependence of polarization

The variation of polarization with wavelength in the L1641 YSOs can also be compared with that in the interstellar medium, to see if they show similar behaviour. The wavelength dependence of polarization in the interstellar medium has been well studied by Whittet et al. (1992) towards a large number of field stars. However, the stars in their observations have lines of sight passing through clouds of different density. Since it is known that the wavelength dependence, particularly the wavelength of maximum polarization $\lambda_{\text{max}}$, varies from diffuse to dense clouds, a sample restricted to stars with a wavelength of maximum polarization $\lambda_{\text{max}} > 0.7$ μm was selected in order to make a better comparison with the dense L1641 cloud studied here. This sub-sample of field stars from the Whittet et al. (1992) study gave $\langle P_J/P_K \rangle = 2.6 \pm 0.4$ and $\langle P_J/P_H \rangle = 1.8 \pm 0.4$ (2σ scatter). Table 1 allows similar ratios to be calculated for the L1641 sources. Only those with $P_K > 1$ per cent were considered however, since lower polarization values have sig-

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Figure 2. The observed K polarization against H-K colour for L1641 sources. Filled diamonds are sources with nebulosity. The dashed line corresponds to $P_K = 3.0E(H-K)^{3/4}$ and the solid line to $P_K = 1.3E(H-K)$ as discussed in the text.

Figure 3. The ratio of H to K polarization against H-K colour.

Figure 4. The derived polarization efficiency $P_l/A_V$ is shown against $A_V$ for point sources (i.e. no extended emission) in L1641. $A_V$ was determined from the near-IR colour of each source by $A_V = 16E(H-K)$ using an intrinsic source colour of 0.1. $P_l$ was assumed equal to $4P_K$.

significant errors. Furthermore, it was decided to exclude sources with extended emission, since these undoubtedly have a scattering contribution to the observed polarization. Then, the resulting polarization ratios for the 15 L1641 sources satisfying these criteria were $\langle P_l/P_K \rangle = 2.5 \pm 0.7$ and $\langle P_H/P_K \rangle = 1.4 \pm 0.2$.

There is obviously a good agreement between these values and those seen towards field stars, and it seems that the polarization in the L1641 YSOs has a similar wavelength behaviour to that arising from dichroic extinction in the general interstellar medium.

5 POLARIZATION DUE TO CIRCUMSTELLAR SCATTERING

5.1 L1641 sources with extended nebulosity

Fig. 1 shows that four of the L1641 sources (IRS42, 55, 93 and 99b) have extended (reflected) K light. The most common reflection nebulae associated with young stars are cometary or bipolar, and are usually modelled as having a low extinction path orthogonal to a disc-like structure around the illuminating source. This results in single scattering in the lobes and local polarization values as high as 20-50 per cent (Aspin et al. 1991). Since the nebulae are not usually circularly symmetric, if photons from the reflection lobes make up a significant fraction of the total measured flux within a finite aperture, then the observed integrated flux can be expected to show substantial net polarization. This is the case in IRS55 (Casali 1991) where scattered light makes up 100 per cent of the flux at J, and probably also the case for IRS93. These are the two most highly polarized objects in our sample with $P_K = 6.2$ and 9.8 per cent respectively. Importantly, the polarization is also flat with wavelength; $P_H/P_K = 1.0$ for IRS55 and 0.98 for IRS93, which is typical for single scattering by small grains. The other two sources, IRS42 and 99b, also have high polarizations suggesting that scattered radiation is making a significant contribution to the total flux within the aperture, although the polarization does show substantial wavelength dependence in these two cases.

5.2 Unresolved scattering in point-like sources

The majority of YSOs in the L1641 sample are point-like, without any obvious reflection nebulosity, and in general have lower polarizations than those with extended nebulae. This does not, however, exclude the possible presence of a compact, unresolved reflection nebula in each of the sources. Bipolar and cometary nebulae exist around young stars at many different spatial scales, from large $10^5$ au structures as in GGD27 (Aspin et al. 1991), to $10^3$ au cometary nebulae only a few arcsec in size, seen in near-infrared images (e.g. Eiroa & Casali 1992). There is no obvious reason why such nebulae should not exist at even smaller (unresolved) scales. In fact, IR speckle observations have shown that many young stars have compact reflection haloes at the subarcsecond scale (Leinert & Haas 1987; Leinert et al. 1993). So might
such small-scale scattering be the cause of the observed polarization values in the point sources?

An important observational result is that the observed polarization is strongly wavelength dependent. Furthermore, this wavelength dependence is reasonably constant from source to source, and independent of the source colours (Fig. 3). On the other hand the polarization resulting from scattering off small grains is not a strong function of wavelength. This contradiction can be explained by adopting a hybrid scattering model, in which the observed flux is the sum of a scattering (polarized) contribution as well as a direct extinguished (but unpolarized) component from the central illuminating source. Since the extinction to the central source will be strongly wavelength dependent \((A_v \propto \lambda^{-1.8})\), so will the observed net polarization. This forms the basis of models such as those of Elsasser & Staudte (1978).

The observed total polarization \(P_t\) from such a hybrid model can be expressed as

\[ P_t(\lambda) = P_0 F(\lambda), \]

where \(P_0\) is the total polarization within the observed aperture of the scattered radiation only (assumed to be approximatively wavelength independent), and \(F(\lambda)\) is the fraction of the total light which comes from scattering. This latter term is wavelength dependent.

It is possible to use equation (1) to test hybrid models in a broad sense, without constructing detailed scattering codes. If the central unpolarized source dominates the total flux, then \(F(\lambda)\) and hence \(P_t(\lambda)\) will be proportional \(10^{0.4A_v}\) where the extinction \(A_v\) is a strong function of wavelength in the near-infrared \((\propto \lambda^{-1.8})\). Since the extinction can also be expected to be proportional to the reddening, \(E(H-K)\), these factors can be combined to give \(P_{H}/P_K \propto 10^{0.4E(H-K)}\). This strong dependence of \(P_{H}/P_K\) on \(E(H-K)\) is definitely inconsistent with the data, since observationally \(P_{H}/P_K\) is approximately constant (Fig. 3) and shows no obvious dependence on \(E(H-K)\). So the central sources cannot be dominating the total flux in most of the YSOs.

On the other hand, if scattered light dominates the total flux the polarization becomes wavelength independent, and \(P_{H}/P_K \approx 1.0\), as has already been seen in the case of extended sources. However, this is also inconsistent with the data, in which \(P_{H}/P_K\) and \(P_{H}/P_K\) average 1.4 and 2.5 respectively. Therefore a carefully tuned mix of polarized and scattered, together with extinguished unpolarized light, is required to produce the observed polarization behaviour in the YSOs. Furthermore, this balance needs to be maintained from source to source despite large variations in infrared colour (and so presumably in extinction), and SED slope. Although such a model cannot be definitely excluded by our observations, it would be contrived when compared with the natural way that dichroic extinction can explain the observed wavelength dependence.

### 5.3 Comparisons with envelope scattering models

More recent, sophisticated models (Whitney & Hartmann 1993, hereafter WH) which predict the integrated polarization from optically thick envelopes can also be compared with the L1641 results. In these models, the net polarization is predominantly a function of three things: (i) the projected asymmetry of the envelope, which is also a function of the inclination angle; (ii) the fraction of the total light which is caused by unpolarized photons from the central source; and (iii) the scattering properties of the grains at a given wavelength.

While a detailed fit of any particular model to Fig. 2 would not be very useful since the models have a number of free parameters including optical depth, envelope shape, grain properties etc., we can expect from (i) and (ii) that in a general sense as a source plus disc is viewed more edge-on, both the polarization and reddening will increase, as observed in Fig. 2. Further, the predicted net polarization is in about the right range as calculated by WH (0–10 per cent, see their table 2).

The WH models, however, fail to correctly predict the observed wavelength behaviour. Since at longer wavelengths escaping photons are scattered, on average, fewer times, the predicted net polarization from the models increases. This can be seen in table 2 of WH, where model 1 (high-albedo, forward-scattering grains, appropriate for optical wavelengths) has a lower net polarization than model 2 (low-albedo, Rayleigh scattering, appropriate for the IR). This is in contrast to the observed behaviour in the L1641 YSOs where the polarization decreases quite strongly to longer wavelengths.

### 5.4 Polarization in sources with low extinction

Although extinction by aligned grains appears to be the dominant polarization mechanism in most of the obscured sources in L1641, scattering may be significant in a minority of cases. Visual polarization is very common in T Tauri stars (Bastien 1985; Menard & Bastien 1992) and is believed to be the result of circumstellar scattering. Since the polarization owing to dichroic extinction will decrease to zero as the extinction goes to zero, any scattering contribution can be expected to become dominant for relatively unreddened objects. In this case, a flat wavelength behaviour in the infrared and weak dependence on reddening should characterize the polarization. Indeed, in an infrared polarization study of T Tauri stars, Tamura & Sato (1989) find no obvious correlation of \(P_{H}\) with \(A_{V}\), while a smaller study by Moneti et al. (1984) shows fairly flat wavelength dependence \((P_{H} = P_{P} = P_{K})\) of polarization among a sample of T Tauri stars. An intrinsic, small, scattering contribution to the polarization could also explain the rise in polarization efficiency for \(A_{V} < 10\) in the L1641 YSOs, apparent in Fig. 4. It may be that in many of these cases, scattering from an unresolved circumstellar volume is the dominant polarization mechanism (Ageorges et al. 1994).

### 6 LARGE-SCALE ALIGNMENT

It has been known for some time that the observed grain alignment in many molecular clouds has an overall alignment with the cloud shape. The magnetic field appears to be perpendicular to the long axis in the Chamaeleon I cloud (Whittet et al. 1994) for example, with little dispersion in the polarization angle, and a similar pattern is found in Taurus Auriga (Heyer et al. 1986). These studies used background field stars as a probe of each cloud's magnetic field. This global alignment of polarization vectors is not observed in all clouds, however (Goodman et al. 1990). The L1641 cloud
was studied with visual polarimetry by Vrba, Strom & Strom (1988) who found that compared with other regions there was relatively poor correlation in the alignment over the cloud, with an rms scatter of 33°. They interpreted L1641 then, as a cloud in which the magnetic field did not dominate the collapse.

In contrast to the large-scale organized polarization towards background stars, the evidence that embedded YSOs are similarly aligned varies from cloud to cloud. For example McGregor et al. (1994) find a large spread in the IR polarization position angles of embedded sources in Chamaeleon I, despite a well-organized larger scale magnetic field in the cloud as a whole. On the other hand Sato et al. (1988) find good alignment between YSO polarization vectors in the ρ Oph dark cloud. Given the rather poor global magnetic field alignment in L1641 as observed in field stars, one might expect there to be poor alignment of the YSO polarization vectors, and indeed this is the case. Fig. 5 shows the distribution of position angles in the YSOs. Although there is a maximum in the histogram towards 100°, it is broad, and sources exist at all position angles. If, in order to ensure that YSOs dominated by scattering are not included, those with $P_{H}/P_{K} < 1.2$ are separated from the total sample, the overall distribution is not significantly changed. It remains broad, as shown in Fig. 5. There is little evidence then, that the magnetic field in L1641 was what dominated the collapse dynamics of individual protostars.

The $^{13}$CO map of Bally et al. (1987) for the L1641 cloud showed it to be very clumpy, with clump diameters ranging from 10 arcmin down to near the resolution limit (a few arcmin). The IRAS sources in the cloud are themselves well-associated with these clumpy regions. Further, Strom et al. (1989a,b), in a comparison between $A_{V}$ derived from near-infrared colours and from $^{13}$CO column density, concluded that the bulk of the infrared extinction came from regions smaller than the mm beam; that is, from dense cores surrounding the YSOs. There is further evidence that the bulk of the extinction comes from compact circumstellar regions from the observations of young clusters such as the one associated with IRAS 05338−0624 (Strom et al. 1989a,b), where 20 objects within a 70-arcsec diameter region have estimated $A_{V}$s ranging from 1 to 40 magnitudes. Since the cluster is obviously physically associated, this variation of the extinction cannot arise in the foreground but must come from small circumstellar clumps. It is also clear from mm wavelength polarimetry (Tamura et al. 1993) that circumstellar matter on scales of thousands of au around YSOs contains aligned grains. It therefore appears likely that the aligned grains causing dichroic extinction and infrared polarization also occur in fairly compact regions surrounding each YSO, rather than in the larger scale, more diffuse cloud.

7 CONCLUSIONS

The infrared polarization of YSOs in L1641 scales with source colour, and the deduced polarization efficiency is lower than that found in diffuse clouds, although comparable to that observed in other dense regions.

The wavelength dependence of the polarization, as measured by $P_{H}/P_{K}$, is reasonably constant from point-source to point-source with an average value of $1.4 \pm 0.2$, and $P_{H}/P_{K} \approx 2.5 \pm 0.7$.

Extended nebulous sources have a flatter wavelength dependence, with $P_{H}/P_{K} \approx 1$, as expected for scattering from small grains.

The polarization observed in obscured point sources ($A_{V} > 10$) is most simply and consistently understood as arising in dichroic absorption owing to aligned grains in a dusty core surrounding each YSO, rather than scattering in a circumstellar envelope. The exceptions are sources with extended nebulosity, in which scattered radiation is obviously important, and in relatively unobscured objects such as T Tauri stars where the observed polarization is probably dominated by circumstellar scattering.

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