NEW INSIGHTS INTO DUST GRAIN PHYSICS: THE POLARIZATION SPECTRUM OF THE OMC-1 CORE

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Abstract

Although our understanding of the physics and chemistry of dust grains within molecular clouds impacts many areas of star formation (e.g., disk and envelope structure, magnetic field geometry, and the formation of planetary systems), the composition, shape and degree of alignment of grains is still poorly constrained. A primary tool in dust grain analysis is the polarization spectrum, or the variation of polarization percentage with wavelength. If two or more grain populations exist along a line of sight, the spectral index and polarization percentage of each can be separately determined from multi-wavelength flux and polarization data (Hildebrand et al. 1999; Greaves et al. 1999). However, investigations of the polarization spectrum have been limited by the paucity of data, particularly longward of 350 μm. This paper is a review of the importance of the polarization spectrum and what these data can reveal about the nature of grains in the envelope of the OMC-1 massive, star-forming core and molecular clouds in general. We also present a three wavelength spectrum for the NGC 2024 region of Orion B.

Key words: techniques: polarimetric – ISM: dust – ISM: structure – ISM: clouds

1. Introduction

The principle tool in the study of magnetic field geometries within molecular clouds is polarimetry of emission from rapidly spinning dust grains which are aligned by magnetic fields, provided their rate of rotation is rapid enough. Longward of 60 μm, dust emission is optically thin and absorption and scattering off the grains is negligible (Hildebrand 1988). Hence, interpretation of polarization data is relatively straight-forward and the position angles of the polarization vectors trace magnetic field geometry (e.g., Schleuning 1998; Matthews, Wilson & Fiege 2001). However, no information is available about field strengths since the fractional polarization (the ratio of polarized to total emission from grains) is a function not only of magnetic field strength, but also of the grain composition and shape and the degree of alignment, all of which are unknowns that could differ through the cloud.

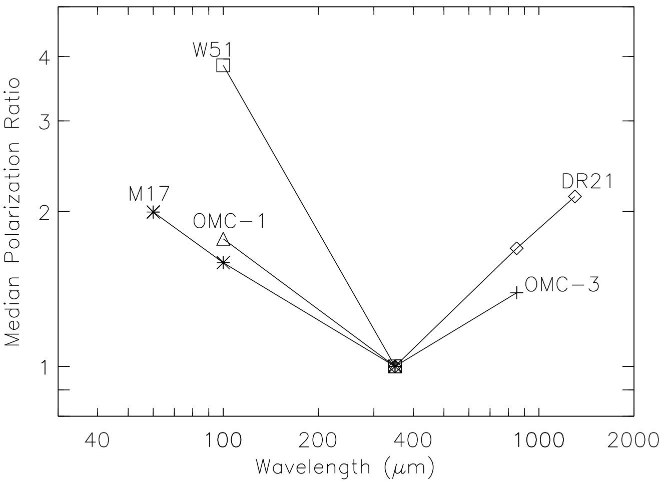

Figure 1. A composite polarization spectrum using all objects for which multiple wavelength data exist as of 2001 (Vaillancourt 2002).

The distribution of polarization percentage with wavelength is called the polarization spectrum. The fractional polarization of dust emission is seen to vary with wavelength for a number of observed sources, as shown in Figure 1.

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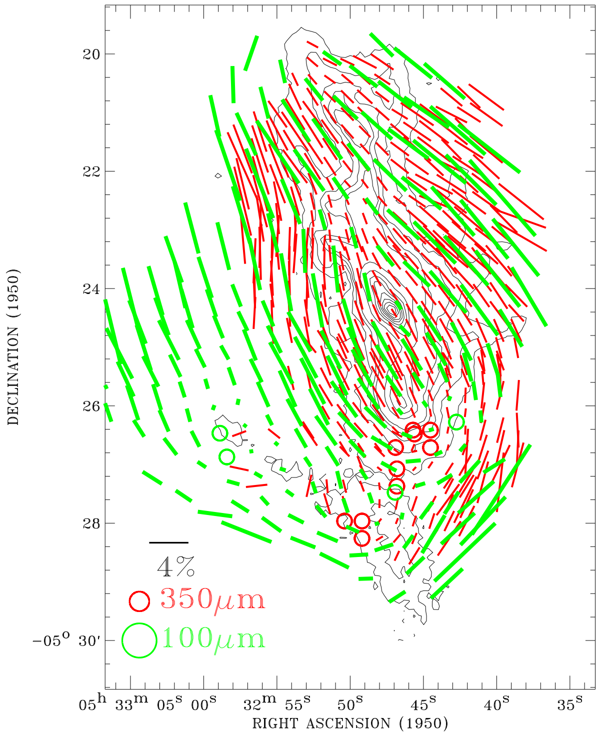

Figure 2. Comparison of the polarization data at 100 μm and 350 μm toward the OMC-1 core in Orion A. We are attempting to match this spatial coverage at 850 μm with SCUBA (Submillimetre Common User Bolometer Array) observations on the James Clerk Maxwell Telescope (JCMT) using scan mapping techniques. Data at 100 μm are from Schleuning (1998); data at 350 μm are from Hildebrand et al. (2000).

2. Increasing the Sampling in the Spectrum

To correctly characterize the polarization spectrum for a given molecular cloud, polarization data must exist at more than two wavelengths. However, as Figure 1 shows, it has proven challenging to measure polarized emission at a sufficient number of wavelengths to adequately sample the spectrum for individual sources. In order to meaningfully compare polarized emission data, Hildebrand et al. (1999) have defined a set of criteria that the data must meet. The vectors must of course be measured in the same regions of the clouds (spatial coincidence); the position angles at those positions must agree to within 10° (if differences are greater, then the vectors may sample different magnetic field geometries and hence different parts of the cloud); points within two beam diameters of bright peaks must be excluded (since optical depths and depolarization effects could alter results in these regions); and more than 5 pairs must remain for comparison.

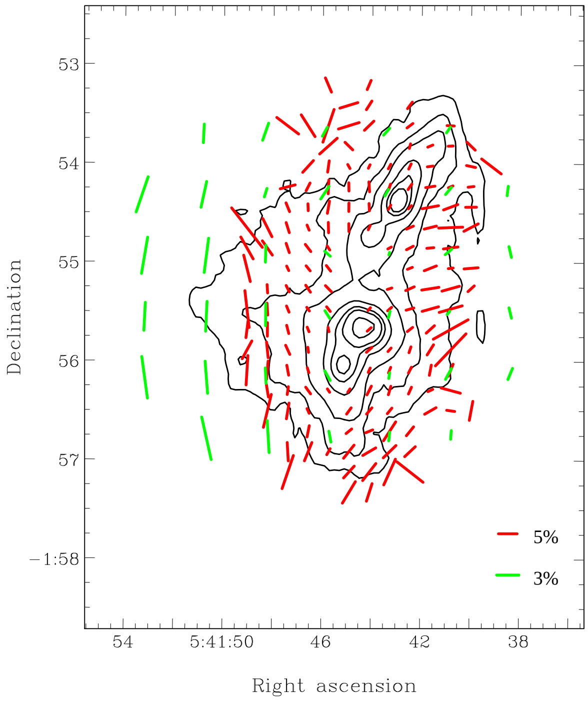

Figure 3. Polarized emission from the NGC 2024 ridge in Orion B has been mapped at 100 μm (green) with the Kuiper Airborne Observatory (Dotson et al. 2000) and at 850 μm (red) with SCUBA (Matthews, Fiege & Moriarty-Schieven 2002). Strong agreement is evident between the position angles of the vectors at these two wavelengths, but the fractional polarization is clearly larger at 850 μm. It is critical to add the 350 μm data of this region, since the lowest polarization percentage should be measured between 100 and 850 μm, if the spectrum of Figure 1 is representative of envelopes of individual objects.

These criteria are difficult to satisfy, but comparison of data at 350 and 100 μm toward the OMC-1 core in Orion A (see Figure 2) and 100 and 850 μm toward NGC 2024 in Orion B (see Figure 3) show that very similar polarization patterns can be produced at different wavelengths. The alignment of polarization position angles indicates that similar magnetic field geometries are being sampled at both wavelengths which removes the magnetic field strength as a variable from the problem, meaning that the changes in fractional polarization are due to grain physics alone.

2.1. OMC-1

OMC-1 is the most studied molecular cloud core. Due to its high brightness (its peak is 160 Jy at 850 μm) and large size, it also has the most extensive polarized emission data at large radii from its peak, as shown in Figure 2. We have begun using SCUBA's 850 μm capability at the JCMT to extend the spectrum of OMC-1 longward of 350 μm. SCUBA's limited chop throw (with a maximum of $3'$) requires that we use scan mapping methods, which are challenging to reduce. An additional challenge was introduced when we learned (after this meeting) that the data presented there were taken without physical rotation of the waveplate due to a software problem. Since SCUBA is mounted at the Nasmyth focus, however, polarization can still be measured since the waveplate angle on the sky changes with sky rotation. We are currently re-reducing the data to compensate for this problem, and time has been allocated to allow us to expand the existing data set. Figure 2 shows a composite image of the 100 and 350 μm coverage of polarization data in OMC-1. This map shows how extensive the spatial coverage of the previously published polarimetry data is for OMC-1. Comparison of polarization data for several sources over four wavelengths in Figure 4 shows that the peak of the polarization percentage distribution for all vectors above 3σ decreases with increasing wavelength, at least to 350 μm.

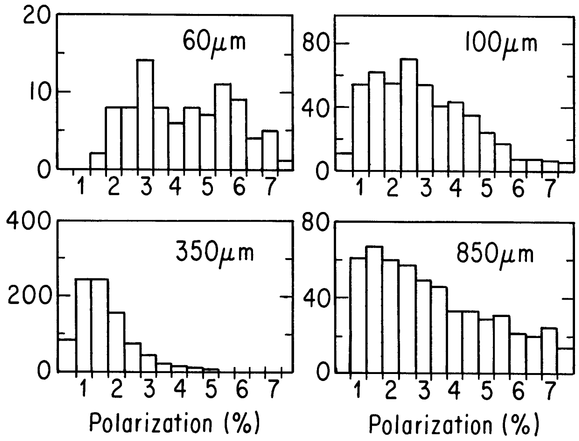

Figure 4. Histograms of all 3σ vectors at four wavelengths for an ensemble of sources show that the peak polarization percentage decreases with increasing wavelength to 350 μm. Data at 850 μm peak at similar polarization percentages as the 350 μm distribution, but exhibit many more vectors (as a fraction of the total) which have higher polarization percentages than the peak (Hildebrand 2001).

2.2. Other Sources

Improving our understanding of mixed grain populations within molecular clouds requires better sampling of both flux and polarization spectra and observations of more objects. These goals can be achieved with current and future detectors. Instruments on SOFIA (i.e., FORCAST, HAWC and the proposed Hale polarimeter [Dowell et al. 2002]) will cover the IR flux peak and new and existing ground-based instruments (e.g., SCUBA, SHARC-2, MAMBO and the Hertz polarimeter) will extend the spectrum out to millimeter wavelengths.

Comparison of data at 100 μm and 850 μm toward the NGC 2024 region of Orion B (see Figure 3) shows strong correlation in polarization position angle. Comparison of these data with 350 μm data from the CSO's Hertz polarimeter produces the spectrum shown in Figure 5, which mirrors the behaviour of the assembled spectrum of Figure 1. We note that the five points of comparison between 100 and 350 μm, and 350 and 850 μm are not the same. In fact, only two points of comparison exist across all three wavelengths. The planned OMC-1 data set will provide many more points of overlap at three wavelengths.

Data at 850 μm also exist toward the NGC 2071 IR core in Orion B (Matthews, Fiege & Moriarty-Schieven 2002). This source is now being observed in polarized emission at 1.3 mm with the BIMA interferometer. However, due to the spatial filtering of the interferometer, comparisons between single dish and interferometric data must be made with additional care. Efforts are underway to calibrate the instrumental polarizations for the SCUBA short wavelength array at 450 μm, which will provide a short wavelength measurement for this source.

3. Why Does Polarization Vary?

Hildebrand et al. (1999) show that one grain species cannot produce the spectrum of Figure 1 for any source since idealized single grain population clouds uniformly produce flat spectra.

Multiple temperatures and/or spectral indices are required to reproduce measurements of flux spectra. The polarization spectra provide further evidence for multiple populations in that they require the different populations to also have different polarization properties. Given the current sparsely sampled state of both flux and polarization spectra, taking these two pieces of information

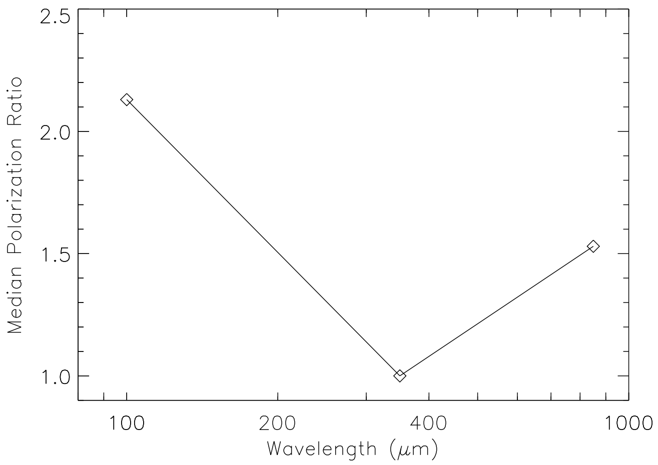

Figure 5. Polarization spectrum for NGC 2024 in Orion B at three wavelengths.

together can go a long way to simultaneously constraining all three properties (i.e., temperature, spectral index and polarization).

Polarization percentage can be reduced by the presence of poorly aligned grains which could reflect either the absence of aligning magnetic fields or the presence of a mechanism capable of destroying alignment, such as the growth of spherical grains. Populations could also differ in composition (graphite vs. silicates), geometry (compact vs. fluffy) and environment (warm vs. cold). It is important to remember that the radiation detected from the ensemble of grains will be mixed, even if the grain populations are not since the dust emission is optically thin. The combination of polarized emission from different grain species will follow the relation:

$$P_{ABC...} = X_A P_A + X_B P_B + X_C P_C + ... \quad (1)$$

where X_i is the fractions of observed flux due to species i and P_i is the degree of polarization due to i alone (Hildebrand et al. 1999). As shown by Hildebrand et al. (1999), rising or falling spectra require two or more grain populations with differing properties. Equation 1 is linear, so the combination of two perfectly aligned species (each with a flat spectrum) could only produce polarization percentages equally invariant with wavelength.

Hildebrand et al. (1999) show that variations in spectra can only be produced if different populations of grains (in composition, temperature or alignment) exist within a molecular cloud. For example, a varying spectrum requires the P_i values to differ between the two populations and the X_i values of the two species to differ with wavelength. The latter condition can be met either by having different temperatures or different spectral indicies.

OMC-1 has recently been analyzed for temperature variation using existing polarization data and a compiled spectral energy distribution from published flux data (Vaillancourt 2002). Information about temperature differences will help interpret the polarization spectrum information.

4. Summary

The polarization spectrum reveals information about the dust grain populations within molecular and dark clouds. Knowledge of the temperature distribution is as important as the polarization data to determine the grain populations involved (Vaillancourt 2002). What is needed is multi-wavelength polarimetry of many molecular cloud envelopes (more sources and better wavelength coverage). The rise in the NGC 2024 spectrum beyond 350 μm could indicate a third grain population with low temperature and high polarization percentage. Once we have obtained our complete 850 μm data set, we will know whether or not a rising spectrum is detected longward of 350 μm in OMC-1.

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