Mid-Infrared Spectropolarimetric Constraints on the Core-Mantle Interstellar Dust Model

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ABSTRACT

In the framework of the silicate core-carbonaceous organic mantle interstellar dust model, the bulk of the visual/near-IR extinction and the entire polarization are from nonspherical and aligned core-mantle grains. The 3.4\,\mu m C-H and 9.7\,\mu m Si-O absorption features, respectively arising from the hydrocarbon mantle and the amorphous silicate core, are expected to be polarized to a modestly different degree. Spectropolarimetric observations toward the same lines of sight both in the 3.4\,\mu m region and in the 9.7\,\mu m region would be of great value to test the core-mantle dust model. The fact that the 3.4\,\mu m feature is not polarized along the line of sight toward the Galactic center source IRS 7 is not yet sufficient to reject the core-mantle model due to the lack of spectropolarimetric observation of this region in the 9.7\,\mu m region.

Subject headings: dust, extinction — Galaxy: center — infrared: ISM: lines and bands — polarization

1. Introduction

Although its total mass is only \sim 0.1\% of that of galaxies, interstellar dust plays an important role in the galactic evolution, the formation of stars and planetary systems, and possibly, the origins of life. The physical and chemical nature of interstellar dust is characterized by its composition, size, shape, and structural form. Current major observational information includes the wavelength dependent extinction, scattering (albedo), and polarization curves, the absorption and emission spectra, and the elemental depletions.
The extinction curve is a sharp discriminator of (dominant) size ($\gtrsim 100 \, \text{Å}$), but a very poor discriminator of composition. Interstellar polarization is not a separate subject but should be treated as part of the extinction data, except that it indicates that some fraction of the interstellar grains are both nonspherical and significantly aligned. It is the extinction (absorption) and emission spectral lines instead of the overall shape of the extinction curve provides the most diagnostic information on the dust composition. Based on the 2175 Å extinction hump and the ubiquitous 3.4 µm C-H stretching mode, 9.7 µm Si-O stretching mode, and 18 µm O-Si-O bending mode absorption features seen in interstellar regions as well as the elemental depletions, it has now been generally accepted that interstellar grains consist of amorphous silicates and some form of carbonaceous materials (see Li & Greenberg 2002 for a recent review).

However, the spectroscopic absorption/emission profiles are unable to tell what structural forms dust grains may take; i.e., no definite conclusion can be drawn yet on the physical relationship between the silicate and carbonaceous grain components. As a matter of fact, three distinctly different grain morphologies are proposed for the three most common dust models – (1) in the silicate-graphite model (and its updated versions) the bare silicate and graphite grains are assumed to be physically separated (Mathis, Rumpl, & Nordsieck 1977 [hereafter MRN]; Draine & Lee 1984; Siebenmorgen & Krügel 1992; Dwek et al. 1997; Li & Draine 2001; Weingartner & Draine 2001); (2) in the silicate core-carbonaceous mantle model the silicate grains are assumed to be coated with a layer of carbonaceous materials in the form of organic refractory (Greenberg 1989a; Désert, Boulanger, & Puget 1990; Li & Greenberg 1997) or hydrogenated amorphous carbon (HAC; Jones, Duley, & Williams 1990); (3) in the composite dust model interstellar grains are taken to be fluffy aggregates of small silicates, vacuum, and carbon of various kinds (amorphous carbon, HAC, and organic refractories; Mathis & Whiffen 1989, Mathis 1996). Assuming reasonable elemental depletions, all dust models are reasonably successful in reproducing the observed interstellar extinction and polarization curves (MRN; Draine & Lee 1984; Mathis 1986; Mathis & Whiffen 1989; Mathis 1996; Li & Greenberg 1997; Weingartner & Draine 2001), the silicate absorption/polarization features (Draine & Lee 1984; Greenberg & Li 1996; Mathis 1998), and the dust thermal emission from the near-IR to submillimeter (Désert et al. 1990; Dwek et al. 1997; Li & Draine 2001) except that the composite grains may be too cold and produce too flat a far-IR emissivity to be consistent with the observational data (Draine 1994; Dwek 1997).

Very recently, Adamson et al. (1999) suggest that spectropolarimetric studies of the 3.4 µm hydrocarbon and 9.7 µm silicate absorption features would provide a powerful constraint on the dust morphology. The ubiquitous 9.7 µm silicate absorption feature is often found to be polarized; some sources also have the 18 µm O-Si-O polarization feature detected (see Smith et al. 2000 for a summary). Another ubiquitous strong absorption band in the diffuse interstellar medium (ISM)

\footnote{Smaller grains are in the Rayleigh limit at the ultraviolet (UV), and their extinction cross sections per unit volume are independent of size. Infrared (IR) emission provides a stronger constraint on their sizes (see Li & Draine 2001).}
is the 3.4 µm feature, commonly attributed to the C-H stretching mode in saturated aliphatic hydrocarbons (see Pendleton & Allamandola 2002, Li & Greenberg 2002 for summaries). If, for the very same region, only the 3.4 µm feature or the 9.7 µm feature is polarized while the other is not, one can then conclude that the silicate and carbonaceous dust components are physically separated. An attempt to measure the polarization of the 3.4 µm absorption feature was recently made by Adamson et al. (1999) toward the Galactic center source IRS 7. They found that this feature was essentially unpolarized. This appeared to pose a severe challenge to the core-mantle dust model (see §4 for discussions).

In this Letter, we explore the IR absorption and polarization properties of the silicate core-carbonaceous mantle model with emphasis on the polarization of the 3.4 µm C-H feature. In §2 we discuss the optical properties of interstellar hydrocarbon dust material. In §3 we predict the relative degrees of polarization of the 3.4 µm C-H and 9.7 µm Si-O features. This will allow comparison with future observations and provide a potentially powerful test on the core-mantle dust model. In §4 we compare our model results with the available observational data and discuss its implication. In §5 we summarize our main conclusions.

2. Optical Properties of Interstellar Hydrocarbon Material

The interstellar organic hydrocarbon dust component reveals its presence in the diffuse ISM through the 3.4 µm absorption feature. Since its first detection in the Galactic center sources, it has now been widely seen in the Milky Way Galaxy and other galaxies (see Pendleton & Allamandola 2002 for a summary). Although it is generally accepted that this feature is due to the C-H stretching mode in saturated aliphatic hydrocarbons, the exact nature of this hydrocarbon material remains uncertain. Nearly two dozen different candidates have been proposed over the past 20 years (see Pendleton & Allamandola 2002 for a review). The organic refractory residue, synthesized from UV photoprocessing of interstellar ice mixtures, provides a perfect match, better than any other hydrocarbon analogs, to the observed 3.4 µm band, including the 3.42 µm, 3.48 µm, and 3.51 µm subfeatures (Greenberg et al. 1995).

However, the absorption spectra of organic residues display a strong 3.0 µm O-H feature and a broad 5.5–10 µm band which are inconsistent with the diffuse ISM observations. We note that these features, largely attributed to the combined features of the O-H, C=O, C-OH, C≡N, C-NH₂, and NH₂ stretches, bendings, and deformations, will become weaker or even fully absent if the organics are subject to greater UV photoprocessing which will result in photodissociation and depletion of H, O, N elements. We also note that the organic residue samples presented in Greenberg et al. (1995) were processed at most to a degree resembling one cycle (from molecular clouds to diffuse clouds). According to the cyclic evolutionary dust model, interstellar grains will undergo ~ 50 cycles before they are consumed by star formation or becomes a part of a comet (Greenberg & Li 1999).
With a rather weak 5–10 μm band and absent in the 3.0 μm O-H feature, the IR spectrum of the organic extract from the Murchison meteorite is also very close to the observed 3.4 μm interstellar feature (Pendleton et al. 1994). We therefore adopt the Murchison meteorite 2.5–25 μm transmission spectrum (Cronin & Pizzarello 1990) to construct the complex refractive index $m(\lambda) = m'(\lambda) + i m''(\lambda)$ for the interstellar carbonaceous organic material.

Let $\kappa_{\text{abs}}(\lambda)$ be the mass absorption coefficient at wavelength $\lambda$. For spherical grains in the Rayleigh limit we have $\kappa_{\text{abs}}(\lambda) = \frac{6\pi}{\rho} \text{Im} \left( \frac{m^2-1}{m^2+2} \right)$ where $\rho$ is the dust mass density. Furton, Laiho, & Witt (1999) measured $\kappa_{\text{abs}}(3.4 \mu m) \approx 1.4 \times 10^3 \text{ cm}^2 \text{ g}^{-1}$ for a HAC sample with a hydrogen to carbon ratio of H/C $\approx 0.5$ considered as “a viable analog to the true interstellar HAC material”. Most recent measurements by Mennella et al. (2002) found $\kappa_{\text{abs}}(3.4 \mu m) \approx 1.6 \times 10^3 \text{ cm}^2 \text{ g}^{-1}$ for a H/C $\approx 0.7$ HAC sample. We therefore adopt $\kappa_{\text{abs}}(3.4 \mu m) = 1.5 \times 10^3 \text{ cm}^2 \text{ g}^{-1}$ for the interstellar carbonaceous organic dust. Taking $\rho = 1.5 \text{ g cm}^{-3}$ (Furton et al. 1999) and $m'(3.4 \mu m) = 1.7 \pm 0.1$ (at 3–4 μm $m' \approx 1.81$ [Zubko et al. 1996]; 1.65 [Alterovitz et al. 1991]; 1.67 [Furton et al. 1999]), we obtain $m''(3.4 \mu m) \approx 0.095 \pm 0.007$ from $\kappa_{\text{abs}} = 1.4 \times 10^3 \text{ cm}^2 \text{ g}^{-1}$.\footnote{Greenberg & Li (1996) derived $m''(3.4 \mu m) \approx 0.026$ from the mass absorption coefficient $\kappa_{\text{abs}} \approx 440 \text{ cm}^2 \text{ g}^{-1}$ measured for “yellow stuff” (“first generation” organic refractory material; Greenberg 1989b).}

Neglecting reflection, the 2.5–25 μm imaginary part of the index of refraction can be calculated from the transmission spectrum of the Murchison meteorite: $m''(\lambda) = m''(3.4 \mu m) \left( \frac{\lambda}{3.4 \mu m} \right) \left( \frac{\ln T_\lambda}{\ln T_{3.4 \mu m}} \right)$ where $T_\lambda$ is the transmittance. For 0.09 μm $\lesssim \lambda \lesssim 1$ μm we take the $m''$ values measured from the heavily processed organic residue (Jenniskens 1993). For $\lambda > 1$ μm we take $m''(\lambda) = m''(1 \mu m)/\lambda$ and then smoothly add the Murchison meteorite $m''$ to this continuum. Finally, the real part of the index of refraction $m'(\lambda)$ is calculated from $m''(\lambda)$ through the Kramers-Kronig relation. The resulting $m'$ and $m''$ are shown in Figure 1 for 2 μm $< \lambda < 20$ μm.

3. Polarization of the 3.4 μm Feature

To calculate the polarization of the 3.4 μm C-H absorption feature, for simplicity, we consider spheroidal silicate core-carbonaceous organic mantle dust grains. We consider both confocal spheroidal core-mantle grains and equal-eccentricity spheroids (both the core and the mantle have the same eccentricity [i.e. the same shape]). Undoubtedly, real interstellar grains must be more complicated. Since our ability to compute scattering and absorption cross sections for nonspherical particles is extremely limited, we use the confocal and equal-eccentricity spheroidal shapes as a first approximation. The discrete dipole approximation (Draine 1988) may be taken to study more complicated shapes. Quantitative differences are expected but this will not affect the conclusion of the paper, i.e., both the 3.4 μm C-H absorption feature and the 9.7 μm Si-O feature are expected to be polarized for nonspherical and aligned core-mantle grains.

Let $a_c$ and $b_c$ be the core semiaxis along and perpendicular to the symmetry axis, respectively;
Fig. 1.— Refractive indices of interstellar carbonaceous organic (solid line; see §2) and silicate (dashed line; taken from Draine & Lee [1984]) dust materials dust. The imaginary part $m''$ of the “astronomical” silicate is reduced by a factor of 5.

$a_m$ and $b_m$ be the mantle semiaxis along and perpendicular to the symmetry axis, respectively; $e_c$ and $e_m$ be the core and mantle eccentricities, respectively; $f_{\text{sil}}$ and $f_{\text{carb}} (\equiv 1 - f_{\text{sil}})$ be the volume fractions of the core and the mantle, respectively. For confocal spheroids, $e_c$ relates to $e_m$ through $f_{\text{sil}}$.

Let $C_{\text{abs}}^\parallel$ and $C_{\text{abs}}^\perp$ be the absorption cross sections for light polarized parallel and perpendicular, respectively, to the grain symmetry axis. For an ensemble of grains spinning and precessing about the magnetic field, the polarization cross section is $C_{\text{pol}}^\text{pro} = \left( C_{\text{abs}}^\parallel - C_{\text{abs}}^\perp \right) / 2$ for prolates, and $C_{\text{pol}}^\text{obl} = \left( C_{\text{abs}}^\perp - C_{\text{abs}}^\parallel \right)$ for oblates; the absorption cross section is $C_{\text{abs}} = \left( C_{\text{abs}}^\parallel + 2C_{\text{abs}}^\perp \right) / 3 - \Phi C_{\text{pol}} \left( 3 - 2 / \cos^2 \gamma \right) / 6$ where $\Phi$ is the polarization reduction factor; $\gamma$ is the angle between the magnetic field and the plane of the sky (Lee & Draine 1985). We take $\Phi = 1$ and $\gamma = 0$.

In the wavelength of interest here, tenth-micron interstellar grains are in the Rayleigh limit. We therefore calculate the absorption cross sections of confocal spheroids using the “dipole approximation” (Gilra 1972; Draine & Lee 1984). For equal-eccentricity spheroids we take the approach of Farafonov (2001) and Voshchinnikov & Mathis (1999). We adopt the Draine & Lee (1984) dielectric functions for silicate dust.
Let $V_{\text{sil}}$ and $V_{\text{carb}}$ be the silicate core and carbonaceous mantle volumes, respectively. The volume fraction of the carbonaceous mantles $f_{\text{carb}} \equiv V_{\text{carb}}/(V_{\text{carb}} + V_{\text{sil}})$ can be estimated from the observed $3.4 \mu m$ C-H ($\tau_{3.4}$) and $9.7 \mu m$ Si-O ($\tau_{9.7}$) optical depths: $V_{\text{carb}}/V_{\text{sil}} \approx (\tau_{3.4}/\tau_{9.7}) (\rho_{\text{sil}}/\rho_{\text{carb}})$ is the 9.7 $\mu m$ silicate mass absorption coefficient (Draine & Lee 1984); $\kappa_{\text{carb}}^{3.4 \mu m} \approx 1500 cm^2 g^{-1}$ is the $3.4 \mu m$ C-H mass absorption coefficient of carbonaceous organic dust (see §2). However, a much thicker mantle ($V_{\text{carb}}/V_{\text{sil}} \approx 1$) is required to account for the visual/near-IR interstellar extinction (Li & Greenberg 1997). The mass ratio of carbonaceous organics to silicates in the coma of comet Halley, measured in situ, was approximately 0.5 (Kissel & Krueger 1987). This also points to $V_{\text{carb}}/V_{\text{sil}} \approx 1$ – it is often suggested that cometary dust is of interstellar origin (Greenberg 1982). In dense clouds thicker organic mantles would be expected (but the $3.4 \mu m$ C-H band strength also changes; see §4). Therefore, we will consider 3 cases: $V_{\text{carb}}/V_{\text{sil}} = 0.25, 1, 2$.

We consider spheroids with a wide range of elongations. For a given mantle elongation $a_m/b_m$, the elongation of the core $a_c/b_c$ is determined from the mantle thickness $V_{\text{carb}}/V_{\text{sil}}$. We calculate the $3.4 \mu m$ C-H excess extinction $A_{3.4 \mu m}$ and excess polarization $P_{3.4 \mu m}$, and the $9.7 \mu m$ Si-O excess extinction $A_{9.7 \mu m}$ and excess polarization $P_{9.7 \mu m}$ as a function of the mantle elongation $a_m/b_m$ and mantle thickness. In Figure 2 we show $(P_{3.4 \mu m}/A_{3.4 \mu m})/(P_{9.7 \mu m}/A_{9.7 \mu m})$, the ratio of the $3.4 \mu m$ polarization-to-extinction ratio to the $9.7 \mu m$ polarization-to-extinction ratio.

It is seen in Figure 2 that for prolate (both confocal and equal-eccentricity) grains, the $3.4 \mu m$ C-H absorption feature is polarized to a slightly higher degree than the $9.7 \mu m$ silicate feature. For oblate grains, the degree of polarization of the $3.4 \mu m$ feature can be lower in comparison with the $9.7 \mu m$ feature, but even the most extreme case considered in this work still has $(P_{3.4 \mu m}/A_{3.4 \mu m})/(P_{9.7 \mu m}/A_{9.7 \mu m}) > 75\%$. Therefore, we can conclude that the silicate core-carbonaceous organic mantle model predicts a more or less similar degree of polarization for both the $9.7 \mu m$ Si-O feature and the $3.4 \mu m$ C-H feature.

4. Discussion

Observationally, there exists a correlation between the $9.7 \mu m$ silicate and the $3.4 \mu m$ C-H hydrocarbon optical depths (Sandford et al. 1995). Although this is consistent with the core-mantle model, it does not necessarily establish a core-mantle relationship between the silicate and

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3This appears to be consistent with the estimation of Tielens et al. (1996) who found $V_{\text{carb}}/V_{\text{sil}} \approx 0.23$. But we caution that much lower mass densities ($\rho_{\text{sil}} = 2.5 g cm^{-3}$, $\rho_{\text{carb}} = 1.0 g cm^{-3}$) were adopted in Tielens et al. (1996).

4We note that the excess extinction and polarization are the peak values. The polarization peak shifts to a longer wavelength relative to the extinction peak (Kobayashi et al. 1980).
Fig. 2.— Predicted ratio of the 3.4 µm C-H polarization (relative to absorption) to the 9.7 µm Si-O polarization (relative to absorption) for confocal spheroids (upper panel) and spheroids with an equal-eccentricity for both the core and the mantle (lower panel) as a function of mantle elongation for 3 different mantle thicknesses $V_{\text{carb}}/V_{\text{sil}} = 0.25$ (dashed line), 1 (solid line), and 2 (dot-dashed line).

hydrocarbon materials since such a correlation could also be achieved for a proportional distribution of these materials. In §3 we have seen that both the 3.4 µm feature and the 9.7 µm feature are expected to be polarized for aligned, nonspherical silicate core-carbonaceous organic mantle grains. Again, a positive detection of the 3.4 µm and 9.7 µm polarization does not necessary approve the core-mantle model, but a positive detection of one feature together with a negative detection of another would be a fatal judgement for the core-mantle model.

Attempts to measure the polarization of the 3.4 µm absorption feature ($P_{\text{IRS7 obs}}^{3.4\mu m}$) was recently made by Adamson et al. (1999) toward the Galactic center source IRS 7. They found that this feature was essentially unpolarized. Since no spectropolarimetric observation of the 9.7 µm silicate absorption feature ($P_{\text{IRS7}}^{9.7\mu m}$) has yet been carried out for IRS 7, they estimated $P_{\text{IRS7}}^{9.7\mu m}$ from the 9.7 µm silicate optical depth $A_{\text{IRS7}}^{9.7\mu m}$, assuming that the IRS 7 silicate feature is polarized to the same degree as the IRS 3 (another Galactic center source) silicate feature; i.e., $P_{\text{IRS7}}^{9.7\mu m}/A_{\text{IRS7}}^{9.7\mu m} = P_{\text{IRS3}}^{9.7\mu m}/A_{\text{IRS3}}^{9.7\mu m}$ (observational data for $A_{\text{IRS7}}^{9.7\mu m}$, $A_{\text{IRS3}}^{9.7\mu m}$ and $P_{\text{IRS3}}^{9.7\mu m}$ are available). Assuming the IRS 7 aliphatic carbon (the 3.4 µm carrier) is aligned to the same degree as the silicate dust, they expected the 3.4 µm polarization to be $P_{\text{IRS7 mod}}^{3.4\mu m} = P_{\text{IRS7}}^{9.7\mu m}/A_{\text{IRS7}}^{9.7\mu m} 	imes A_{\text{IRS7}}^{3.4\mu m}$. In so doing,
they found $P_{\text{IRS7-obs}}^{3.4\mu m} \ll P_{\text{IRS7-mod}}^{3.4\mu m}$ (Adamson et al. 1999). Therefore, they concluded that the aliphatic carbon dust is not in the form of a mantle on the silicate dust as suggested by the silicate core-carbonaceous mantle models.

We note that, to draw this conclusion, two critical assumptions were made: (1) $P_{\text{IRS7}^{9.7\mu m}}^{3.4\mu m}/A_{\text{IRS7}^{9.7\mu m}} = P_{\text{IRS3}^{3.4\mu m}}^{9.7\mu m}/A_{\text{IRS3}^{9.7\mu m}}$; (2) $P_{\text{IRS7}^{3.4\mu m}}^{9.7\mu m}/A_{\text{IRS7}^{9.7\mu m}} = P_{\text{IRS7}^{9.7\mu m}}^{3.4\mu m}/A_{\text{IRS7}^{9.7\mu m}}$. Although the 2nd assumption does not seem to significantly deviate from the detailed calculations $[0.7 \lesssim (P_{\text{IRS7}^{3.4\mu m}}/A_{\text{IRS7}^{3.4\mu m}}) / (P_{\text{IRS7}^{9.7\mu m}}/A_{\text{IRS7}^{9.7\mu m}}) \lesssim 1.2$ for reasonable dust parameters; see §3 and Figure 2], the 1st assumption is questionable and needs observational support. We urgently need spectropolarimetric observations of IRS 7 in the 9.7 μm region or of IRS 3 in the 3.4 μm region. If we take the most likely dust parameters (1) $a_m/b_m = 1/2$ oblate$^5$ and (2) $V_{\text{carb}}/V_{\text{sil}} = 1$ (Li & Greenberg 1997), our model calculations give $(P_{\text{IRS7}^{3.4\mu m}}/A_{3.4\mu m}) / (P_{\text{IRS7}^{9.7\mu m}}/A_{9.7\mu m}) \gtrsim 0.9$ (see Figure 2), we therefore expect an excess polarization < 0.8% for the IRS 7 9.7 μm silicate feature, and > 0.23% for the IRS 3 3.4 μm C-H feature.

It is worth noting that the absorption features of ices – the “precursor” of organic residue – are seen in polarization in various sources (see Li & Greenberg 2002 for a recent review). The ice polarization feature toward the Becklin-Neugebauer object was well fitted by ice-coated grains (Lee & Draine 1985), suggesting a core-mantle grain morphology.

The exact nature of the 3.4 μm feature carrier remains a subject of debate (see Pendleton & Allamandola 2002, Li & Greenberg 2002). The carbonaceous organic refractory proposal recently receives further support from the very recent discovery of a 6.0 μm feature in dense clouds which was attributed to organic refractory by Gibb & Whittet (2002). They found that its strength is correlated with the 4.62 μm OCN− (“XCN”; Schutte & Greenberg 1997) feature which is considered to be a diagnostic of energetic processing. It would be interesting to see whether heavily processed organic residue is able to provide a close match to the 5.85 μm and 7.25 μm C-H deformation bending modes seen toward the Galactic center source Sgr A* as well (Chiar et al. 2000).

The 3.4 μm feature consists of three subfeatures at 2955 cm$^{-1}$ (3.385 μm), 2925 cm$^{-1}$ (3.420 μm), and 2870 cm$^{-1}$ (3.485 μm) corresponding to the symmetric and asymmetric C-H stretches in CH$_3$ and CH$_2$ groups in aliphatic hydrocarbons which must be interacting with other chemical groups. The amount of carbonaceous material responsible for the 3.4 μm feature is strongly dependent on the nature of the chemical groups attached to the aliphatic carbons. For example, each carbonyl (C=O) group reduces its corresponding C-H stretch strength by a factor of ~ 10 (Wexler 1967). Furthermore, not every carbon is attached to a hydrogen as in saturated compounds; instead, some form an aromatic structure (see Pendleton & Allamandola 2002). The fact that the 3.4 μm absorption is not observed in molecular cloud may possibly be attributed to dehydrogenation or oxidation (formation of carbonyl) of the organic refractory mantle by accretion and photoprocessing in the dense regions (see Greenberg & Li 1999) – the former reducing the absolute number of CH stretches,

$^5$The $a/b = 1/2$ oblate shape was shown to provide a better match than any other shapes to the 3.1 μm ice polarization feature (Lee & Draine 1985) and the 9.7 μm silicate polarization feature (Hildebrand & Dragovan 1995) toward the Becklin-Neugebauer object.
the latter reducing the CH stretch strength by a factor of 10 (Wexler 1967) – the 3.4 µm feature would be reduced per unit mass in molecular clouds.

At this moment, we are not at a position to rule out other dust sources as the interstellar 3.4 µm feature carrier. This feature has also been detected in a carbon-rich protoplanetary nebula CRL 618 (Lequeux & Jourdain de Muizon 1990; Chiar et al. 1998) with close resemblance to the interstellar feature. However, after ejection into interstellar space, the survival of this dust in the diffuse ISM is questionable (see Draine 1990).

5. Summary

The polarization of the 3.4 µm aliphatic hydrocarbon absorption feature is modelled in terms of the silicate core-organic hydrocarbon mantle interstellar dust model. For aligned, nonspherical core-mantle grains, both the 3.4 µm C-H feature and the 9.7 µm silicate feature are expected to be polarized, although unlikely to the same degree. The non-detection of the 3.4 µm polarization in the Galactic center source IRS 7 itself is not sufficient enough to rule out the core-mantle model due to the lack of spectropolarimetric observation of this source in the 9.7 µm region. We call for spectropolarimetric observations of the IRS 7 9.7 µm band and the IRS 3 3.4 µm band. This will promise a powerful test on the core-mantle dust model.

A. Li (the first author of this paper) were deeply saddened by the passing away of Prof. J. Mayo Greenberg (the second author) on November 29, 2001. As a pioneer in the fields of cosmic dust, comets, astrochemistry, astrobiology and light scattering, Mayo will be remembered forever. We thank Prof. B.T. Draine for his invaluable comments and suggestions; Prof. J.I. Lunine for helpful discussions; and Dr. R.H. Lupton for the availability of the SM plotting package. A. Li thanks The University of Arizona for the Arizona Prize Postdoctoral Fellowship in Theoretical Astrophysics. This research was supported in part by NASA grant NAG5-10811 and NSF grant AST-9988126.

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