The Diffuse Interstellar Bands
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Unidentified Species in Envelopes around Carbon Stars

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Abstract. The infrared (IR) spectra of many evolved carbon-rich stars exhibit two prominent dust emission features peaking around 21 μm and 30 μm, with the former exclusively seen in proto-planetary nebulae (PPNe), while the latter seen in a much wider range of objects, including AGB stars, PPNe and planetary nebulae (PNe). The 30 μm feature is seen in all the 21 μm sources, but no correlation is found between these two features. Over a dozen carrier candidates have been proposed for the 21 μm feature, but none of them has been widely accepted and the nature of the 21 μm feature remains a mystery. The carrier of the 30 μm feature also remains unidentified. MgS dust, once widely accepted as a valid carrier, was ruled out because of the sulfur budget problem. In this work we examine nano-sized FeO dust as a carrier for the 21 μm feature. We calculate the IR emission spectrum of FeO nanodust which undergoes single-photon heating in PPNe. It is found that the 21 μm feature emitted by FeO nanodust is too broad to explain the observed feature. For the 30 μm feature, we argue that graphite could be a viable carrier. Graphite, provided its d.c. conductivity $\sigma_{\rm d.c.}$ exceeds $\sim$100 ohm^{-1} cm^{-1}, exhibits a pronounced band at 30 μm.

Keywords. stars: carbon, (stars:) circumstellar matter, dust, infrared: stars

1. Introduction

In the late stage of evolution, the low- and intermediate-mass stars lose a large amount of mass and produce circumstellar shells. Various dust species are present in the cold and dense shells of asymptotic giant branch (AGB) stars, post-AGB stars and planetary nebulae (PNe), among which silicate dust in O-rich shells and SiC dust in C-rich shells are well identified through their spectral features.

There are two prominent spectral features respectively peaking around 21 μm and 30 μm. Both features are observed in circumstellar shells of C-rich stars in both the Milky Way and the Magellanic Clouds (MC). So far, the 21 μm feature is detected in about 18 Galactic objects (Cerrigone *et al.* 2011) and 9 MC objects (Volk *et al.* 2011). The 21 μm feature is only seen in proto-planetary nebulae (PPNe), a transient phase in stellar evolution. In contrast, the 30 μm feature is detected in the whole late stage of stellar evolution, from AGB to post-AGB to PN (Hony *et al.* 2003).

All the 21 μm sources also display the 30 μm emission feature as well as the so-called "unidentified infrared (UIR)" emission bands at 3.3, 6.2, 7.7, 8.6 and 11.3 μm. The UIR bands are commonly attributed to polycyclic aromatic hydrocarbon (PAH) molecules (Léger & Puget 1984, Allamandola *et al.* 1985). As shown in Figure 1, the 30 μm feature does not correlate with the 21 μm feature, implying that their carriers are not related. Figure 1 also shows that the 21 μm feature does not correlate with the UIR features. This argues against large PAH clusters as a possible carrier for the 21 μm feature. Moreover, it appears that the 30 μm feature and the UIR features weakly anti-correlate, suggesting

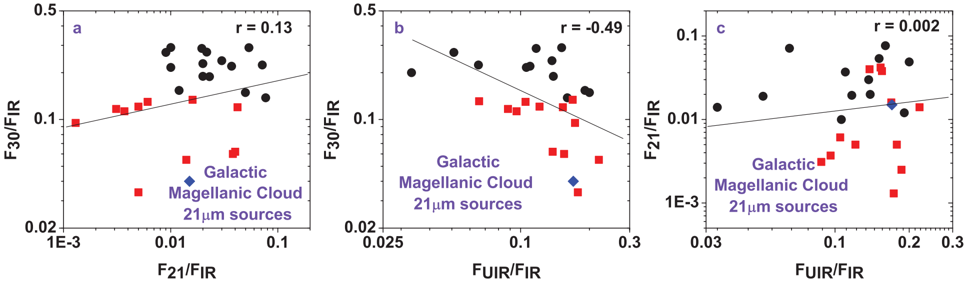

Figure 1. Interrelations among the 21 μm, 30 μm, and UIR features of Galactic (circles) and MC (squares) 21 μm sources: (a) $F_{30\mu\mathrm{m}}$ vs. $F_{21\mu\mathrm{m}}$, (b) $F_{30\mu\mathrm{m}}$ vs. F_{UIR}, and (c) $F_{21\mu\mathrm{m}}$ vs. F_{UIR}. All quantities are normalized by F_{IR}, the total near- to mid-IR emission obtained by *ISO*/SWS in the 2–45 μm wavelength range, to cancel out their common proportionality to F_{IR} (i.e. the illuminating starlight intensity and the bulk dust quantity).

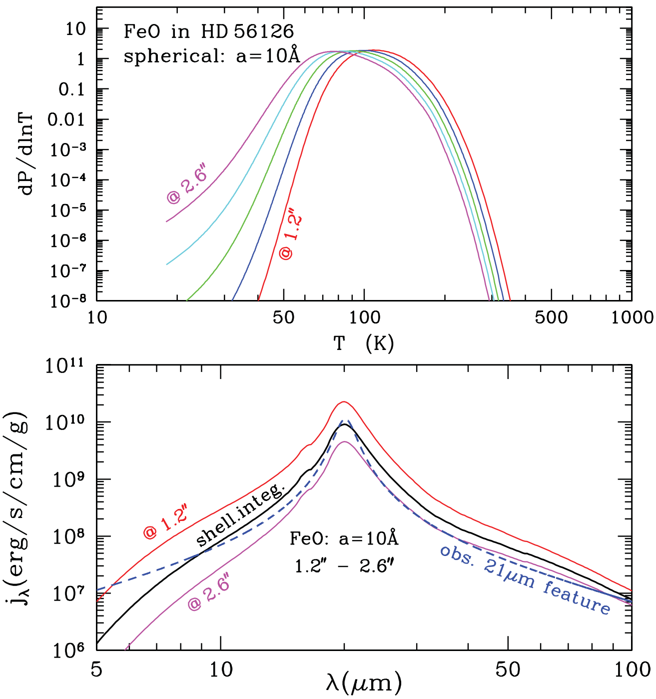

Figure 2. Upper panel: the temperature probability distribution functions dP/dT of FeO dust of $a = 1$ nm at various distances from the illuminating star HD 56126. Lower panel: The emission spectra of FeO dust of $a = 1$ nm at the inner and outer shells (i.e., 1.2″ and 2.6″ from the central star), as well as that obtained from integrating the whole dust shell. Also shown is the observed 21 μm emission feature.

that the UIR carriers (e.g. PAHs) may result from the decomposition or shattering of the 30 μm-feature carrier.

2. FeO nanodust as a carrier of the 21 μm feature

Zhang *et al.* (2009a) examined nine inorganic carrier candidates for the 21 μm feature, including nano TiC, fullerenes with Ti, SiS_2, doped SiC, the SiC and SiO_2 mixture, FeO, Fe_2O_3 and Fe_3O_4. We found that except FeO nanodust, they are all problematic: they

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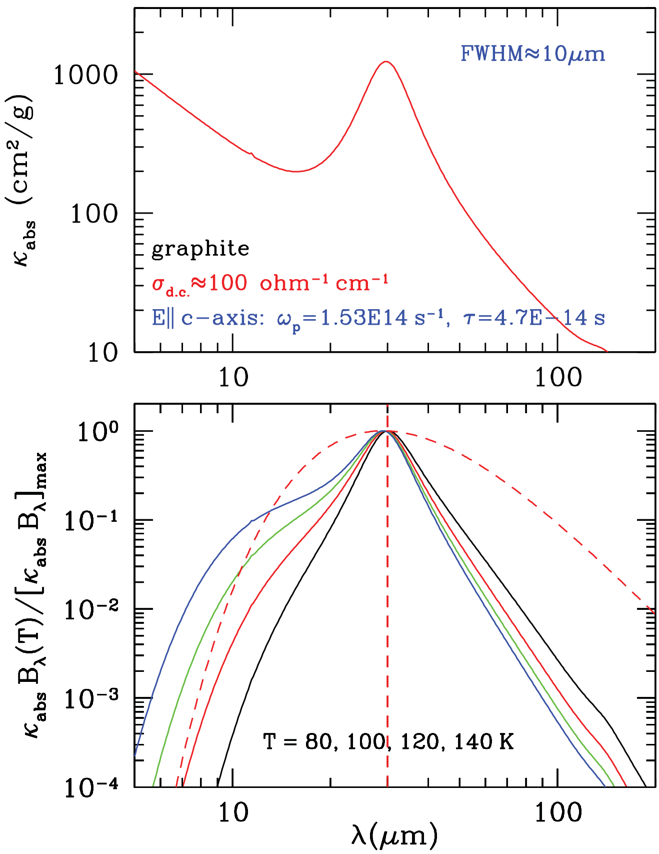

Figure 3. Upper panel: the opacity of graphite with a d.c. conductivity of $\sigma_{\rm d.c.} = 100\,{\rm ohm}^{-1}\,{\rm cm}^{-1}$. A prominent 30 μm feature with a FWHM of $\sim$10 μm is clearly seen. Lower panel: the emission profiles of graphite with $\sigma_{\rm d.c.} = 100\,{\rm ohm}^{-1}\,{\rm cm}^{-1}$ at $T = 80$, 100, 120, 140 K. Dot-dashed line: the $T = 100$ K blackbody.

either require too much material (i.e., violating the abundance constraint) or produce extra features which are not seen in astronomical objects.

FeO seems to be a promising candidate carrier for the 21 μm feature for two reasons: (1) Fe is an abundant element; and (2) FeO has a pronounced spectral feature around 21 μm (Posch *et al.* 2004, Zhang *et al.* 2009a). However, it is not clear how FeO forms in C-rich environments as the 21 μm sources are all C-rich. Posch *et al.* (2004) argued that FeO nanodust could form in these environments. We therefore model the excitation and emission processes of FeO nanodust in PPNe. As FeO nanodust will experience temperature fluctuation, we calculate its temperature probability distribution function dP/dT and then calculate its emission spectrum from dP/dT.

Taking a 3-D Debye model (with a Debye temperature of $\Theta_{\rm D} = 430$ K) for the specific heat of FeO and the refractive indices at T = 10 K, 100 K, 200 K and 300 K from Henning & Mutschke (1995, 1997), we calculate dP/dT and the emergent spectrum of spherical FeO of radius $a = 10$ Å for HD 56126, a proto-typical 21 μm source (see Figure 1). The IR emission spectrum exhibits a strong band at 21 μm. However, it is too broad (with FWHM $\sim$4 μm) to explain the observed FWHM of $\sim$2.2–2.3 μm (see Kwok *et al.* 1989). For nonspherical dust, the predicted 21 μm feature is even broader. Finally, to account for the power emitted from the 21 μm feature in HD 56126, the FeO model

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requires Fe/H $\approx 4.3 \times 10^{-6}$, exceeding the iron budget of Fe/H $\approx 3.2 \times 10^{-6}$ available in HD 56126. Therefore, FeO nanodust is unlikely a valid carrier for the 21 μm feature.

3. Graphite as a carrier for the 30 μm feature

The 30 μm feature, extending from $\sim$24 to $\sim$45 μm, is very strong and accounts for up to $\sim$30% of the total IR luminosity of the emitter. MgS dust, once widely accepted as a carrier (Begemann *et al.* 1994), was ruled out by Zhang *et al.* (2009b) who showed that the MgS model would require too much S. Even with a very generous assumption of UV/optical absorbing coefficient, the required MgS dust exceeds what is available by over an order of magnitude. This was later confirmed by Messenger *et al.* (2013) (but also see Lombaert *et al.* 2012).

We propose graphite as a carrier of the 30 μm feature seen in evolved stars. Graphite has been identified as a presolar stardust species in primitive meteorites through its isotropic anomaly. Graphite is also key component in standard interstellar grain models. A feature around 30 μm is already recognizable in the absorption coefficient of graphite (Draine & Lee 1984). Depending on its d.c. conductivity $\sigma_{\rm d.c.}$, the 30 μm feature could be very strong. Our preliminary calculations show that graphite could account for the observed 30 μm feature, provided $\sigma_{\rm d.c.} > 100\,{\rm ohm}^{-1}\,{\rm cm}^{-1}$ (see Figure 1). Experiments have shown that graphite can have a wide range of $\sigma_{\rm d.c.}$, ranging from $\sim$1 to $\sim$200 ohm^{-1} cm^{-1} (Primak 1956).

Acknowledgements

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References

Allamandola, L. J., Tielens, A. G. G. M., & Barker, J. R. 1985, *ApJ*, 290, L25
Begemann, B., *et al.* 1994, *ApJ*, 423, L71
Cerrigone, L., Hora, J. L., Umana, G., Trigilio, C., Hart, A., & Fazio, G. 2011, *ApJ*, 738, 121
Draine, B. T. & Lee, H. M. 1984, *ApJ*, 285, 89
Henning, T. & Mutschke, H. 1995, *A&AS*, 112, 143
Henning, T. & Mutschke, H. 1997, *A&A*, 327,743
Hony, S., *et al.* 2003, *A&A*, 402, 211
Kwok, S., Volk, K. M., & Hrivnak, B. J. 1989, *ApJ*, 345, L51
Léger, A. & Puget, J. 1984, *A&A*, 137, L5
Lombaert, R., de Vries, B. L., de Koter, A., *et al.* 2012, *A&A*, 544, L18
Messenger, S., Speck, A., & Volk, K. 2013, *ApJ*, 764, 142
Posch, Th., Mutschke, H., & Andersen, A. 2004, *ApJ*, 616, 1167
Primak, W. 1956, *Phys. Rev.*, 103, 544
Volk, K., Hrivnak, B. J., Matsuura, M., *et al.* 2011, *ApJ*, 735, 127
Zhang, K., Jiang, B. W., & Li, A. 2009a, *MNRAS*, 396, 1247
Zhang, K., Jiang, B. W., & Li, A. 2009b, *ApJ*, 702,680

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