The 22 micron emission feature in supernova remnants and massive star-forming regions

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ABSTRACT

Spitzer/IRS observations have confirmed the presence of the broad emission feature around 22 μm in the Carina nebula suggested by *ISO*/SWS observations. They have indicated that the feature peak is located around 23 μm and the band width/profile may vary in the nebula. It has been suggested that the feature originates from dust grains formed in supernovae since a similar feature has also been reported in Cas A SNR. IRS observations of Cas A confirm the feature, but it seems to peak at a little shorter wavelength (about 21 μm) and has a sharper profile than that seen in the Carina nebula. IRS spectra of some HII regions also show a broad emission feature similar to the Carina spectrum. These results suggest that dust grains relating to SNe or massive star-formation have a feature around 20–23 μm, which may originate from dust grains with similar optical characteristics. We suggest that the shape effect of surface modes of FeO grains could account for the observed variety of the features if the shape distribution evolves from a nearly mono-shape (spherical shape) distribution to a continuous shape distribution possibly by coagulation. The understanding of the nature of the feature is important for the investigation of recent star-formation activities in external galaxies.

Subject headings: dust, extinction — supernovae: general – supernova remnant — HII regions

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1. Introduction

Supernovae (SNe) are thought to be a major dust supply source in galaxies. While theoretical studies suggest efficient dust formation in SN ejecta (Kozasa et al. 1991; Todini & Ferrera 2001; Nozawa et al. 2003), observational evidence for a significant amount of dust grains that are formed in or associated with SNe has not yet been confirmed (e.g., Dunne et al. 2003; Morgan et al. 2003; Krause et al. 2004; Sugerman et al. 2006; Meikle et al. 2007; Sakon et al. 2007). It also remains uncertain observationally what kind of dust grains are really formed in SNe.

Arendt et al. (1999) have detected a broad 22 μm band emission in one of the knots in Cas A and suggested that it originates from dust grains newly formed in the SN. Based on ISO/SWS observations, Chan & Onaka (2000) reported the presence of a similar broad emission feature in the Carina nebula, one of the most active star-forming regions in the Galaxy. Since a similar feature is also detected in M17 (Jones et al. 1999), Chan & Onaka (2000) suggest a possible link of this feature to dust grains formed in SNe. However the SWS instrument had a change in the slit size within the feature and it is therefore difficult to unambiguously confirm the presence of a broad feature and investigate the band profile in the 20 μm region for extended sources (Peeters et al. 2002).

As part of a GTO program (PI: T. L. Roellig) *Spitzer*/IRS observations of the Carina nebula as well as supernova remnants and starburst galaxies have been carried out to further examine the presence and the relation of the feature to supernova remnants (SNRs) and massive star-forming regions. The IRS long-wavelength low-resolution module has the same slit size for 14–38 μm and thus is suitable to quantitative investigation of a broad feature in the 20 μm region. Its long slit also enables us to examine the spatial distribution of the feature efficiently. The presence of a broad feature around 23 μm is confirmed in the IRS spectrum of the Carina nebula (Onaka et al. 2008). This report investigates the features seen in the Carina feature in relation to those of Cas A and other HII regions and discusses possible band carriers.

2. Observations and Results

The Carina nebula was observed with the IRS long-low module in the spectral mapping mode. Details of the IRS observations of the Carina nebula are given in Onaka et al. (2008). Although the signal was saturated at the position where the SWS observation detected the 22 μm feature, a broad feature around 23 μm was clearly detected in the ionized region, but the feature was not seen in the molecular cloud region (Fig. 1). The feature appears to be the strongest at the ionization front (position B), the Carina I-E complex (Brooks et al. 2003). The origin of the difference in the peak position between the IRS spectrum and the SWS spectrum is not clear since the IRS spectra at the SWS position were saturated and no useful spectra were extracted.

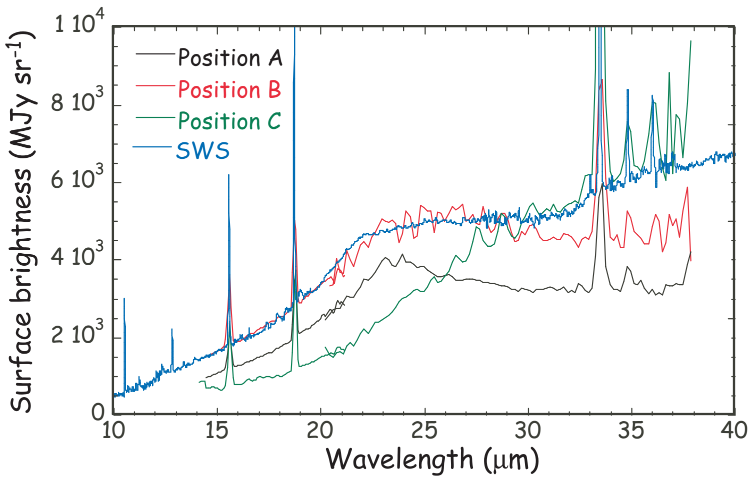

Fig. 1.— Long-low IRS spectra of the Carina nebula. The black line (position A) indicates the IRS spectrum in the ionized region, the red line that near the Car I-E radio complex (position B), and the green line that in the molecular region (position C; see Onaka et al. (2008) for the accurate position). The SWS spectrum is also shown for comparison by the blue line, which is scaled to match with the IRS spectrum at position B.

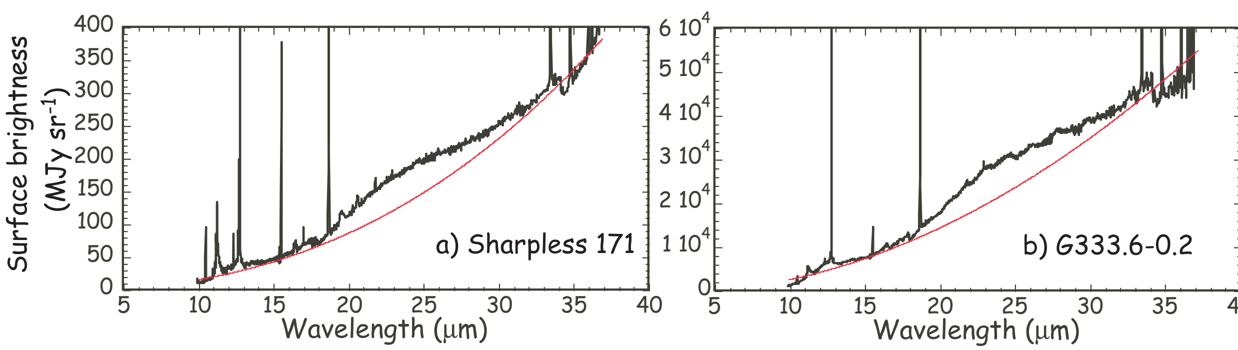

Fig. 2.— IRS spectra taken with the long high-resolution module. (a) Sharpless 171 (b) G333.6-0.2. See Okada et al. (2008) for details of the observations. The red lines indicate the assumed continua.

IRS spectra at several positions in Cas A clearly show a broad 22 μm feature (Ryo et al. 2008). We have also found that similar features are seen in IRS high-resolution spectra of HII regions (Okada et al. 2007). Fig. 2 shows some examples of HII region spectra, whereas comparison of the features in these objects is shown in Fig. 3, where continua have been subtracted from the spectra and the profiles are normalized at the peak. The band feature of G333.6-0.2 is quite similar to that of Sharpless 171 (S171) and is not shown. It is clearly seen that the Cas A feature peaks around 21 μm, which is distinctly shorter than the Carina and S171 features. The feature at position A is sharper, while that at position B seems to be similar to the S171 feature.

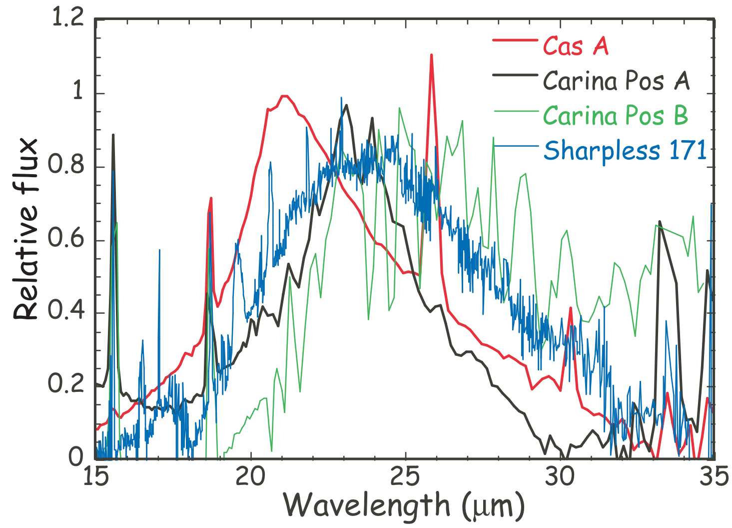

Fig. 3.— Comparison of features around 22 μm in various objects. The red line indicates the Cas A feature, the black line that of the position A of the Carina nebula, the green line that of postion B, and the blue line the feature in the Sharpless 171 spectrum.

3. Candidates for the Feature Carrier

Several candidate materials have been proposed for the 22 μm band carriers, including FeO, proto-silicates, and TiO (cf., Onaka et al. 2008). The present investigation suggests that the features seen in Cas A and HII regions are similar but not exactly the same. In the following we investigate a single carrier material that may account for the observed variety of the 22 μm feature by the particle shape effect.

According to Bohren & Huffman (1983), small particles have surface resonance modes in the spectral range where the real part of the dielectric constants becomes negative and the peak and profile of the resonance band feature depend sensitively on the particle shape or shape distribution. Fig. 4a shows the dielectric constants of FeO (Henning & Mutschke 1997), indicating that the surface resonance occurs in the spectral region from 20 to 30 μm.

Fig. 4b indicates the calculated emissivity of FeO particles of the various shape distributions. Spherical FeO particles (blue dotted line) have a sharp emissivity peaking around 20 μm. FeO particles with a continuous distribution of ellipsoids (uniform CDE; Borhen & Huffman 1983) are indicated by the solid black line, which shows a very broad feature, while those with the continuous distribution weighted on the spherical shape (red dashed line) have an intermediate profile (weighted CDE; Ossenkopf et al. 1992).

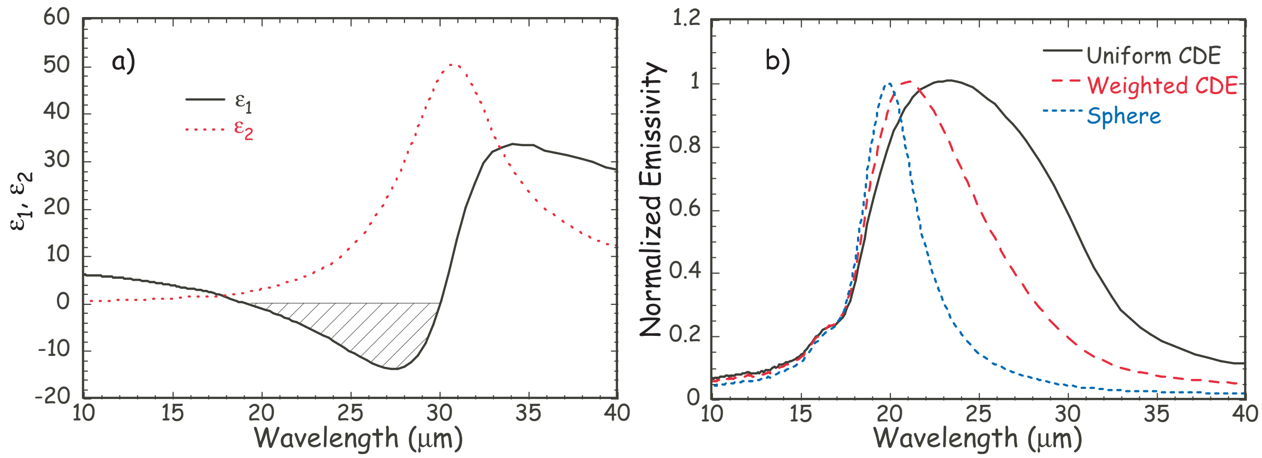

Fig. 4.— (a) Dielectric constants of FeO (Henning & Mutschke 1997). The shaded area indicates the region where the real part (ϵ_1; black solid line) becomes negative and where surface modes can occur. The imaginary part (ϵ_2) is indicated by the red dotted line. (b) Emissivity of FeO of various shape distributions. The emissivity of a sphere is indicated by the blue dotted line, that of the weighted CDE by the red dashed line, and that of the uniform CDE by the black solid line. All the curves are normalized by their peak values.

Fig. 5 shows comparison of the observed features with those calculations. A single temperature is assumed for FeO particles and a smooth continuum is added to fit the observed spectra. Either FeO spheres or FeO with the weighted CDE can account for the sharp feature around 21 μm seen in Cas A. The sharp feature around 23 μm at position B of the Carina nebula may be matched with the emissivity of FeO particles of the weighted CDE, but FeO spheres have a peak at too short a wavelength. The broad features seen at position B of the Carina nebula and in HII regions can be accounted for by FeO of CDEs. Because the CDE is rather an arbitrary assumption and the actual shape distribution could be different, perfect match should not be expected. These investigations suggest that the particle shape effect could account for the observed variety of the 22 μm feature if it originates from surface modes of small particles. It is also suggested by Bohren & Huffman (1983) that coagulation of particles makes the emissivity similar to those with CDEs. Thus the observed variations in the 22 μm feature may be interpreted in terms of the evolution of the particle shape distribution; they may start with being spherical or a nearly mono-shape distribution, showing a narrow feature, when they are formed in SNRs. As they spend their time in HII regions, they get coagulated, for which the shape distribution becomes close to a CDE. FeO is a candidate material that has surface modes in the spectral range in question, but any materials that have similar optical characteristics (negative real part of the dielectric constants in 20–30 μm) could account for the observed variation.

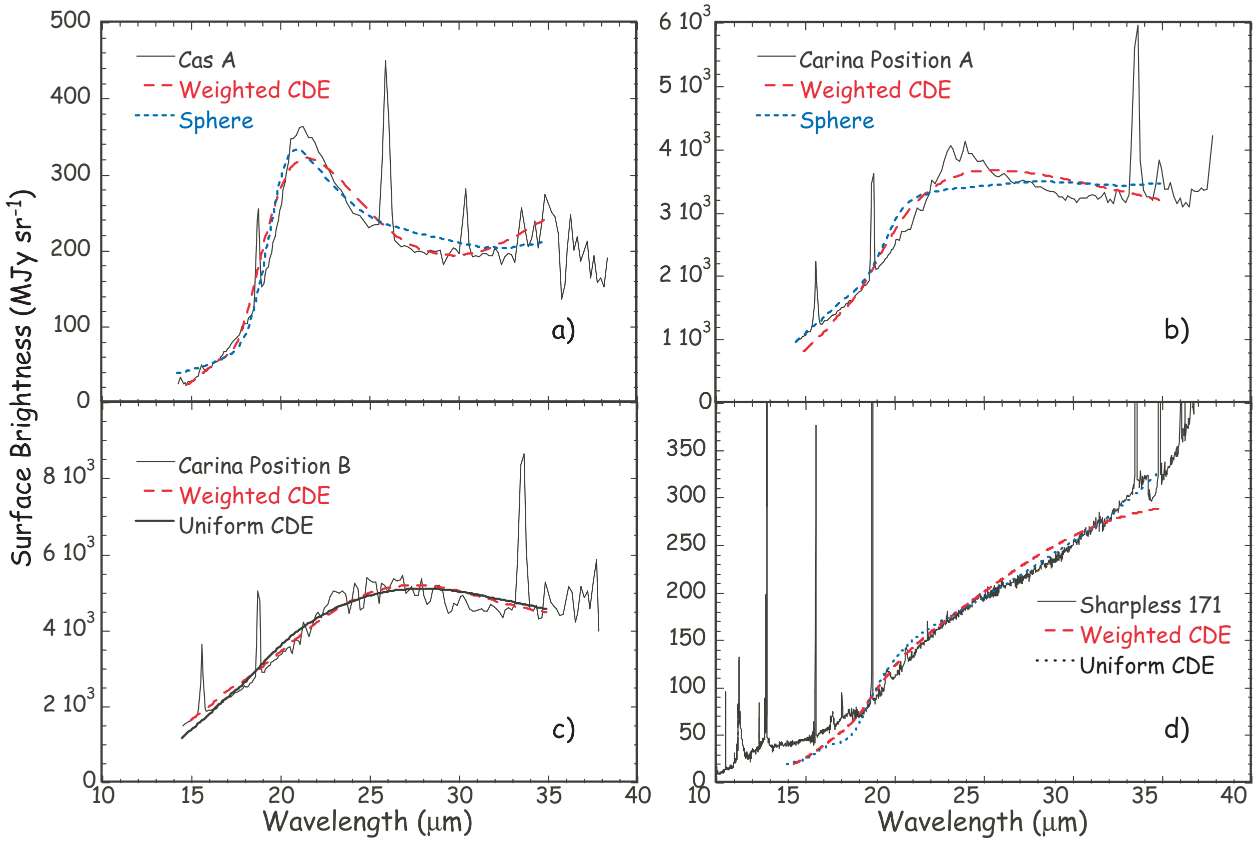

Fig. 5.— Comparison of the 22 μm features with FeO grains of various shape distributions. (a) Cas A, (b) position A of the Carina nebula, (c) position B of the Carina nebula, and (d) Sharpless 171. The observed spectra are shown by the thin black solid lines. Fits with FeO sherical particles are shown by the blue dotted lines. FeO grains of the weighted CDE are indicated by the red dashed lines, whereas those of the uniform CDE are shown by the thick black solid lines.

4. Summary

Spitzer IRS spectra of Cas A SNR, the Carina nebula, and some HII regions confirm the presence of broad features in 21–23 μm. This feature is broader than "21 μm" feature, whose actual peak is at 20.1 μm, seen in carbon-rich post-asymptotic branch stars (Volk et al. 1999), and is different. The present results reveal the variety of the 22 μm feature. It is sharp and peaks at a shorter wavelength ($\sim$ 21 μm) in Cas A, while spectra of HII regions, including that at position B of the Carina nebula, are broad and peak at a longer wavelength ($\sim$ 23 μm). The spectrum of position A of the Carina nebula has a sharp profile peaking around 23 μm.

The observed spectral variety can be interpreted in terms of the shape effect if the feature originates from surface modes of small particles. FeO particles of various shape distributions can account for the observed variety of the features to some extent, although they do not provide a perfect match. It is difficult to estimate the actual shape distribution of dust grains. The observed variation may be understood if the particle shape distribution evolves from a nearly mono-shape (spherical) at the beginning of dust formation and then becomes broad when the particles start to coagulate.

The present investigations suggest that the 22 μm feature is associated with massive star-forming regions and possibly originates from dust grains formed in SNe. Some starburst galaxies indicate a similar feature around 22 μm (Tajiri et al. 2008), suggesting that this feature can be used for diagnosis of recent activities in distant galaxies and could impact on the number count in deep surveys (Pearson et al. 2004).

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