A Broad 22 μm Emission Feature in the Carina Nebula H II Region[1]

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ABSTRACT

We report the detection of a broad 22 μm emission feature in the Carina nebula H II region by the Infrared Space Observatory (ISO) Short Wavelength Spectrometer. The feature shape is similar to that of the 22 μm emission feature of newly synthesized dust observed in the Cassiopeia A supernova remnant. This finding suggests that both of the features are arising from the same carrier, and that supernovae are probably the dominant production source of this new interstellar grain. A similar broad emission dust feature is also found in the spectra of two starburst galaxies from the ISO archival data. This new dust grain could be an abundant component of interstellar grains and can be used to trace the supernova rate or star formation rate in external galaxies. The existence of the broad 22 μm emission feature complicates the dust model for starburst galaxies and must be taken into account correctly in the derivation of dust color temperature. Mg protosilicate has been suggested as the carrier of the 22 μm emission dust feature observed in Cassiopeia A. The present results provide useful information in studies on chemical composition and emission mechanism of the carrier.

Subject headings: dust extinction—infrared: ISM: lines and bands—ISM: H II regions

1. Introduction

Supernovae have been suggested besides evolved stars as one of the major sources of interstellar dust (see Gehrz 1989, Jones and Tielens 1994, Dwek 1998 for review). Supporting evidence includes observations of dust condensation in the ejecta of SN 1987A (Moseley et al. 1989, Whitelock et al. 1989, Dwek et al. 1992, Wooden et al. 1993), and those of the newly synthesized dust in the Cassiopeia A (Cas A) supernova remnant (Arendt, Dwek, & Moseley 1999). The dust

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formation mechanism and the amount of dust that is formed in supernovae are still poorly known. Observations of SN 1987A and Cas A showed that the mass of the newly formed dust is much less than expected, and the discrepancy may be due to the fact that most of the dust is cold and cannot be detected in the far-infrared (Dwek 1998, Arendt et al. 1999). Finding an abundant dust component in the interstellar medium (ISM) which is formed only in supernovae will support the hypothesis that supernovae are a major source of interstellar dust. Furthermore, since the amount of this specific grain is proportional to the number of supernova, its total mass in the ISM can be used as a tracer of the supernova rate or star formation rate in external galaxies. In this Letter we report the detection of a broad 22 μm emission dust feature in the Carina nebula H II region by the ISO guaranteed time observations. We found that the shape of the present 22 μm emission dust feature is similar to the 22 μm emission feature observed in Cas A. We also found a similar emission feature in two starburst galaxies from the ISO archival data.

2. Observations

The observations were made as part of the ISO guaranteed time program (TONAKA.WDISM1) using the Short Wavelength Spectrometer (SWS; de Graauw et al. 1996). All the observations were made with the SWS AOT01 mode with scan speed of 1, which provided full grating spectra of 2.38 to 45.2 μm with a resolution of $\lambda/\Delta\lambda = 300$. The data have been processed through the Off-Line Processing (OLP) 8.4, and reduced with the SWS Interactive Analysis (IA) package developed by the SWS Instrument Dedicated Team. We observed the Car I H II region in the Carina nebula and regions away from it to the nearby molecular clouds (see de Grauuw et al. 1981 for discussions of molecular clouds in the Carina nebula). The Car I H II region is excited by the Trumpler 14, an open cluster containing numerous O-type stars. Totally four positions were observed. Pos 1 is at the Car I H II region with $l = 287^\circ.399$ and $b = –0^\circ.633$. Pos 2 ($l = 287^\circ.349$ and $b = –0^\circ.633$), Pos 3 ($l = 287^\circ.299$ and $b = –0^\circ.633$), and Pos 4 ($l = 287^\circ.249$ and $b = –0^\circ.633$) are at a distance of 2.4, 4.7, and 7.1 pc away from Pos 1, respectively. Throughout our Letter, we adopt a Sun-to-Carina nebula distance of 2.7 kpc (Grabelsky et al. 1988). Since the SWS aperture size varies across the wavelength ranges, we adjusted the difference in fluxes at the SWS band boundaries by scaling the spectra to the shortest band. The above adjustment does not affect the results presented here.

3. Results

Figure 1a shows the observed SWS spectrum of the Carina nebula at Pos 1. A broad feature from $\sim$ 18 to 28 μm is clearly seen in the spectrum. The adjustment of the observed fluxes due to the different aperture sizes of SWS has no effect on this feature, since the SWS has the same aperture size from 12 – 27.5 μm. It is difficult, however, to derive the spectral shape of this feature correctly since the underlying continuum emission is very strong. We derived the feature shape by assuming the feature starts at 18 μm and ends at 28 μm. Then the assumed underlying continuum emission, as shown in Figure 1a by the dashed line, is subtracted from the observed spectrum. The continuum emission comprises grains of graphite with temperature of 157 K and silicate with temperature of 40 K. Dust optical constants are adopted from Draine (1985). The resultant feature shape is shown in Figure 1b, in which a peak around 22 μm is clearly seen. This new 22 μm feature is distinctly different than the 21 μm feature that was discovered by Kwok, Volk, & Hrivnak (1989). The 21 μm feature, which was only observed in carbon-rich post asymptotic giant branch stars, has a much narrow feature width of $\sim$ 4 μm (Volk, Kwok, & Hrivnak 1999) compared to that of the present 22 μm feature (with width of $\sim$ 10 μm). This suggests that the 21 and 22 μm emission features are arising from different kinds of dust grain. Figure 2a shows another Carina nebula spectrum at Pos 2. The broad feature from 18 to 28 μm is also seen in this spectrum. The continuum emission comprising graphite with temperature of 135 K and silicate with temperature of 42 K is assumed (the dashed line in Fig. 2a) and subtracted from the observed spectrum. The excess emission is shown in Figure 2b. The unidentified infrared (UIR) emission features become stronger at Pos 2, a position farther away from the Car I H II region compared to Pos 1. The slight difference in feature shape between figures 1b and 2b is probably due to the dust temperature effect. The 22 μm emission feature is also seen in Pos 3 and Pos 4 (not shown) but in weaker intensity.

The same broad feature has been reported in the SWS spectra of M17–SW H II region by Jones et al. (1999). They found in their spectra that the intensity of this emission feature decreases with distance from the exciting stars, the same phenomenon we see in the present four observed spectra. The decrease of feature intensity may be due to: (1) dilution by the cool dust emission from the nearby molecular clouds; (2) emission of the feature requiring very high UV radiation intensity to be excited; and/or (3) decrease in the abundance of this specific grain with distance from the exciting stars. Identification of the carrier of the feature will help us to understand the observed decrease in the feature intensity.

Very recently, a broad emission dust feature with peak at 22 μm was reported in Cas A (Arendt et al. 1999). We compare this 22 μm feature and the present feature to see whether there is a similarity in feature shape. The comparison is shown in Figure 3. The Cas A spectrum was observed in the optical knot called N3 (see Arendt et al. 1999 for details), and is obtained from the ISO archival data. In order to obtain a better fit at wavelengths longer than 28 μm, we choose a new continuum emission, as shown in Figure 1a by the dotted line, to give the 22 μm feature more long wavelength emission. The new continuum emission comprises graphite with temperature of 160 K and silicate with temperature of 45 K. In Figure 3 we can see that the feature present in the Carina nebula shows a good agreement with that observed in Cas A. The origin of the excess emission around 13 μm is unknown. It should be noted, however, that the emission in Cas A at wavelengths between 20 and 50 μm may arise mostly from a warm ($\sim$ 90 K) silicate component that originates from the diffuse shell (see Tuffs et al. 1999 for discussions of the spectral energy distribution of Cas A). If this warm silicate component is subtracted from the Cas A N3 spectrum, the resultant 22 μm feature (without emission at wavelengths longer than 30 μm) will give a good fit to our observed 22 μm feature shown in Figure 1b.

4. Discussion

Evolved stars and supernovae have been suggested as the major production sources of interstellar dust. Past observations of evolved stars have found a number of dust features in the near to far-infrared ranges (see Waters et al. 1999 for a recent review). However, the broad 22 μm emission feature that we found in Carina nebula H II region has never been reported in evolved stars. On the other hand, the present broad 22 μm emission feature is quite similar to the emission feature of newly synthesized dust observed in Cas A, suggesting that both of these features arise from the same dust grain, and that supernovae are probably the major production source of this new interstellar grain. The non-detection of the 22 μm feature in SN 1987A (Moseley et al. 1989) does not make the latter suggestion less convincing, since the infrared emission in SN 1987A probably arises from optically thick clumps. Lucy et al. (1991) and Wooden et al. (1993) suggest that the infrared emission in SN 1987A is dominated by the dust in the optically thick clumps, and the low density small grains in the interclump medium contribute to the visual extinction. With this model, the infrared emission in SN 1987A is a graybody emission, but the visual extinction is not.

We would expect to find the 22 μm dust feature in astronomical sources with high supernova rate if supernovae are the major production source of this new interstellar grain. Starburst galaxies are an ideal place to search for. From the ISO archival data we found that two starburst galaxies, M82 and NGC7582, show a similar 22 μm emission feature. Figure 4 shows the SWS spectrum of the nuclear region of NGC7582, a narrow-line X-ray galaxy with strong starburst in the central kpc (Radovich et al. 1999, and references therein). The 20 to 30 μm emission is mostly or completely arising from the broad 22 μm emission feature. The spectrum of NGC7582 was taken by the SWS AOT01 with the speed of 2. We processed the data through the OLP 8.4 and reduced with the SWS IA package in a way similar to the Carina nebula spectra. The feature intensity in M82 (not shown) is much weaker, about 10% of the 18 – 28 μm emission if the continuum is assumed to pass through the 18 and 28 μm data points. Two other starburst galaxies, NGC253 and Circinus may also have a 22 μm feature, but they are further weak in intensity and more observations are needed to confirm it.

The findings of the 22 μm dust feature in H II regions and starburst galaxies suggest that this new grain could be an abundant component of interstellar dust. If the amount of this interstellar grain in the ISM is supposed to be proportional to the number of supernovae, its total mass in the ISM can be used as a tracer of the supernova rate or star formation rate in external galaxies. Studies of a large sample of starburst galaxies are required to confirm the above relationship. Only a limited number of galaxies have been observed by the SWS full grating scan mode, and a statistically useful sample of starburst galaxies for this study is not available at present. Future space missions like the Space InfraRed Telescope Facility (SIRFT) and Infrared Imaging Surveyor (IRIS), and the Stratospheric Observatory for Infrared Astronomy (SOFIA) are expected to provide the necessary data base.

The existence of this broad 22 μm emission feature complicates the dust model used in the study of the spectral energy distribution of starburst galaxies. Dust grains like graphite, amorphous carbon, silicates, and polycyclic aromatic hydrocarbons may not be representative of all the dust properties in starburst galaxies. Particularly, this broad 22 μm emission feature could have significant effects in the derivation of the dust color temperature based on the 20 – 30 μm photometric flux (e.g., the Infrared Astronomical Satellite 25 μm data) as well as the number counts of deep surveys in the infrared spectral range to be carried out by SIRTF and IRIS observations, and must be taken into account appropriately.

Arendt et al. (1999) suggested that the carrier of the 22 μm feature observed in Cas A is Mg protosilicate based on the good agreement between the observed feature shape and the laboratory spectrum of the Mg protosilicate taken by Dorschner et al. (1980). They found that FeO can also give a good fit to their observed 22 μm feature, but the required dust temperature higher than expected and the deficient of emission at wavelegths longer than 30 μm led them to rule it out as a promising candidate. If the identification of Mg protosilicate is true, it is the second silicate grain besides the astronomical silicates found in the ISM. More observations are needed to confirm (or test) the suggested identification. Observing the 22 μm feature in a variety of astronomical environments will provide useful information in studies on chemical composition and emission mechanism of the carrier.

The major results of this Letter are: (1) a broad 22 μm emission dust feature is detected in H II regions and starburst galaxies; (2) the 22 μm emission feature is similar in shape with the emission feature of newly synthesized dust observed in the ejecta of Cas A, and both of these features arise from the same carrier; and (3) supernovae are probably the major production source of this new interstellar dust.

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Fig. 1.— (a) The observed SWS spectrum of the Carina nebula at Pos 1. The dashed (dotted) line represents the continuum emission with graphite and silicate at 157 (160) and 40 (45) K, respectively. The spectrum was scaled to the shortest band in order to adjust the difference in the aperture size. The flux unit is Jansky (Jy) per beam with beam size of $14'' \times 20''$ in the shortest band. (b) The resultant 22 μm feature after subtraction of the dashed line continuum emission.

Fig. 2.— (a) The observed SWS spectrum at Pos 2. The dashed line represents the continuum emission with graphite and silicate at 135 and 42 K, respectively. (b) The resultant 22 μm feature after subtraction of the continuum.

Fig. 3.— The Cas A N3 spectrum (the solid line) multiplied by a factor 5.2, together with the 22 μm feature (the + symbol) after subtraction of the dotted line continuum emission shown in Figure 1(a). For easy comparison, the Cas A spectrum has been smoothed to a resolution of $\lambda/\Delta\lambda = 100$.

Fig. 4.— The SWS spectrum of NGC7582, which has been smoothed to a resolution of $\lambda/\Delta\lambda = 300$.