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Mid-Infrared Spectrum Variation of Long-Period Variables in the Large Magellanic Cloud

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Abstract. We carried out time-variation observations of the mid-infrared (MIR) spectrum of two long-period variables in the Large Magellanic Cloud with the Infrared Spectrograph (IRS) on board *Spitzer*. HV 2446 and IRAS 04544−6849 were observed 6 times over one variability cycle with the IRS short and long low-resolution modules. Both stars show prominent silicate emission and their MIR spectra vary with their variability cycles in a manner similar to that found in the Galactic Mira variable Z Cyg. The 10 to 18 μm band emission ratio increases at maximum and becomes low at minimum. The variation can be accounted for by the change of the dust temperature due to the luminosity variation of the central star with a single silicate dust emissivity. Based on the relation between the infrared luminosity and the dust shell temperature, the emissivity of silicate grains is derived, which is found to be quite similar to each other and to that of astronomical silicate. The present observations indicate that silicate dust properties in long-period variables in the LMC are similar to those in silicates in the Galaxy. Also the variation pattern observed in Z Cyg is not a special case, suggesting that sporadic dust formation is common rather than continuous formation in the outflow of evolved stars.

Keywords. stars: AGB and post-AGB, circumstellar matter, stars: variables: other, Magellanic Clouds, infrared: stars

1. Introduction

Stars in the asymptotic-giant branch (AGB) are losing their mass and enriching heavy elements in the interstellar medium. It is one of the key processes of chemical evolution in galaxies. There are, however, still several unresolved issues in the mass-loss and dust formation process in AGB stars. Major uncertainties originate from the dust optical properties and the dust formation temperature, which are mutually coupled. Silicate dust properties in different environments, such as low-metallicity, is also an important issue to be investigated. Variability observations of mid-infrared spectra of the dust shells around AGB stars are an efficient method to investigate the dust optical properties as well as the dust formation process in AGB stars because dust formation is related to pulsations and the way dust grains react to the variation in the central star luminosity depends on their optical properties (Onaka et al. 2002). We investigate time-variations of mid-infrared (MIR) spectra of two oxygen-rich long-period variables in the Large Magellanic Cloud (LMC), which is known to have spatially-varying sub-solar metallicity ($Z \sim 0.3$–$0.5\ \mathrm{Z}_{\odot}$) to investigate the silicate dust properties in low-metallicity environments.

Table 1. Observation dates and variability phases.

IRAS 04544−6849		HV 2446	
Date	Phase[1]	Date	Phase[1]
2004 October 3	−0.11	2004 August 29	0.05
2005 January 13	0.00	2005 January 9	0.27
2005 September 6	0.36	2005 March 16	0.38
2006 January 23	0.56	2005 July 14	0.58
2006 May 15	0.71	2005 November 15	0.79
2006 September 7	0.88	2006 March 17	2.00

[1]The variability phase is estimated from Whitelock et al. (2003) with modifications based on the present observations. The period of HV 2446 is assumed to be 596 d and that of IRAS 04544−6849 is estimated to be 700 d from the present data.

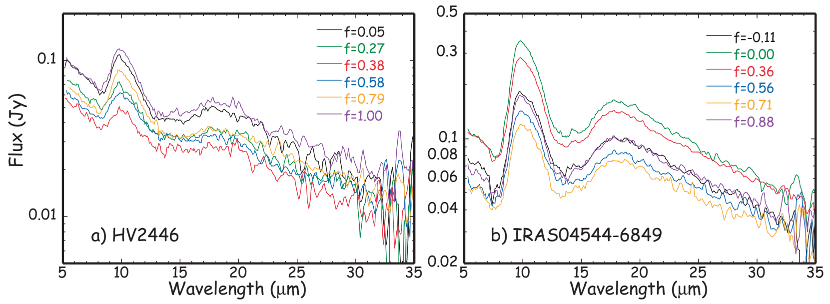

Figure 1. Observed spectrum variation of IRAS 04544−6849 (a) and HV 2446 (b).

2. Observational Results and Analysis

Two target stars in the LMC are selected from Whitelock et al. (2003) based on the criteria that they are in the constant visibility zone of *Spitzer* and sufficiently bright. Observations are carried out with the short and long low-resolution modules of Infrared Spectrograph (IRS: Houck et al. 2004) as part of our Guest Observer Program (PI: T.O., PID: 3583). Table 1 summarizes the observation date and variability phase, whereas Figure 1 shows the observed spectra.

Both stars show prominent silicate features and the observed variations in the MIR spectra exhibit a good periodicity. The 10 to 18 μm band ratio is larger when the star is brighter and it becomes smaller when the star gets fainter, indicating the variation in the dust shell temperature with the variability cycle. If dust grains are formed at fainter phases as theories predict, the dust shell emission should have a constant temperature. The present results indicate that the dust shell emission changes as the central star luminosity changes, contradicting the theoretical prediction. This is the same trend as that seen in the variation of the MIR spectra of Z Cyg (Onaka et al. 2002). We assume that the variation correspond to the central star variation and apply the same analysis that was employed for the Z Cyg spectrum to derive silicate emissivity of the two stars.

We derive the trial dust emissivities from the MIR spectrum near maximum and fit the observed spectra. Figure 2 plots examples of the fit spectra with different emissivity models, indicating that the spectra at different epochs can be fitted by a single silicate emissivity fairly well. In other words, the observed spectra can be interpreted simply in terms of the temperature variation. No additional dust emissivity is required except for a weak feature around 15 μm. A similar feature has also been suggested by Onaka et al. (2002) and Sloan et al. (2006). It seems to be a real feature and further studies are needed

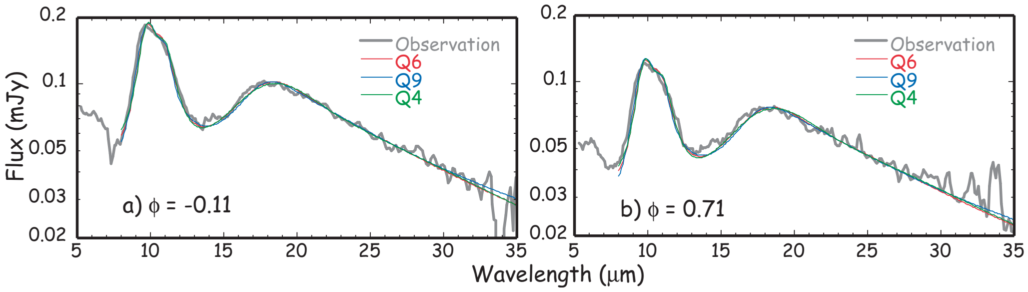

Figure 2. Examples of the model fit for IRAS 04544−6849 for the variability phases ϕ of -0.11 (a) and 0.71 (b) with the dust emissivities $Q4$ (inner dust shell temperature of 400 K), $Q6$ (the inner dust shell temperature of 600 K), and $Q9$ (inner dust shell temperature of 900 K).

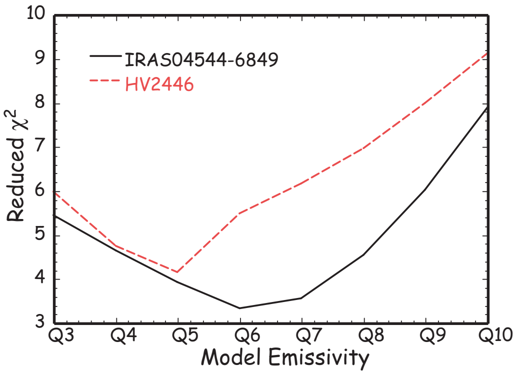

Figure 3. Reduced χ^2 values for the fit with the integrated flux variations for the different emissivity models. The number after Q indicates the inner dust shell temperature (K) at maximum for the emissivity, divided by 100.

for the investigation on the origin of the component. Figure 2 indicates no appreciable difference in the quality of the fit with all the trial emissivity models and thus the dust emissivity (and the inner dust shell temperature) cannot be derived from the quality of the fit.

For a given dust emissivity (absorption efficiency factors Q) the variation in the dust shell temperature over the variability cycle can be derived. It must be compatible with the luminosity variation. For instance, if the assumed emissivity leads to too high a dust shell temperature, a larger variation in the dust temperature is required to account for the observed variation of the spectrum and the required variation in the luminosity becomes too large to compare with the observations. The best emissivity model can be derived from the observed variations both in the spectrum and in the integrated flux of the dust shell.

Figure 3 plots deviations of the models from the observed variation in the integrated flux over 8–35 μm. It indicates that the emissivity of $Q6$ (the inner dust shell temperature of 600 K at maximum) provides the best fit for IRAS 04544−6849, while $Q5$ (the inner dust shell temperature of 500 K at maximum) is the best for HV 2446 to account for the observed variations both in the spectrum and the integrated flux consistently.

Figure 4 plots various dust emissivities together with the present results. The emissivities derived for IRAS 04544−6849 and HV 2446 are in good agreement with each other and also with that of astronomical silicate (Draine & Lee 1984). The overall shape is not

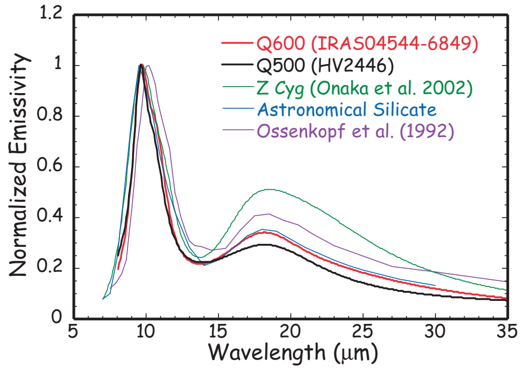

Figure 4. Comparison of various dust emissivities of the present results with various dust emissivities (Draine & Lee 1984; Ossenkopf et al. 1992; Onaka et al. 2002).

much different from that derived for Z Cyg, particularly for the 10 μm band, while the Z Cyg emissivity has a stronger and broader 18 μm band.

3. Summary

We have carried out the time variability observations of two long-period variables in the LMC. The present results indicate that the optical properties of silicate grains formed in long-period variables in the LMC are similar to those of Galactic silicate dust. The band ratio of $Q(18\ \mu\mathrm{m})/Q(10\ \mu\mathrm{m})$ is about 0.3, being similar to the astronomical silicate, but smaller than that derived from observations of Z Cyg. The present observations also suggest that the variations of the MIR spectrum seen in Z Cyg are rather typical. The variation can be accounted for by the change of the dust temperature due to the luminosity variation of the central star with a single silicate dust emissivity.

The derived inner dust shell temperature at maximum is 500–600 K (700 K for Z Cyg), which is too low compared with the predicted condensation temperature of 900–1000 K (Gail & Sedlmayr 1999), but is in agreement with MIR spectrum analysis of Mira variables (Onaka et al. 1989), suggesting that the dust grains may not be forming continuously, but the formation may be rather sporadic.

Acknowledgements

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References

Draine, B. T., & Lee, H.-M. 1984, *ApJ*, 285, 89
Gail, H.-O., & Sedlmayr, E. 1999, *A&A*, 347, 594
Houck, J. R., Roellig, T.L., van Cleve, J., et al. 2004, *ApJS*, 154, 18
Onaka, T., de Jong, T., & Willems, F. J. 1989, *A&A*, 218, 169
Onaka, T., de Jong, T., & Yamamura, I. 2002, *A&A*, 388, 573
Ossenkopf, V., Henning, Th., & Mathis, J. S. 1992, *A&A*, 261, 567
Sloan, G.C., Devost, D., Bernard-Salas, J., Wood, P.R., & Houck, J.R. 2006, *ApJ*, 637, L45
Whitelock, P.A., Feast, M.W., van Loon, J.T., & Zijlstra, A.A. 2003, *MNRAS*, 342, 86