Evolution of Dust Emission around PNe, from *AKARI*/*Spitzer* to *SPICA*

Ryou Ohsawa,[1] Takashi Onaka,[1] Itsuki Sakon,[1] Tamami I. Mori,[1] Hidehiro Kaneda,[2] Mikako Matsuura,[3] Jeronimo Bernard-Salas,[4] Olivier Berné,[5] and Christine Joblin[5]

[1]*Department of Astronomy, The University of Tokyo, Japan*
[2]*Graduate School of Science, Nagoya University, Japan*
[3]*University College London, United Kingdom*
[4]*Open University, United Kingdom*
[5]*Université de Toulouse & CNRS, France*

ABSTRACT

The evolution of Polycyclic Aromatic Hydrocarbon (PAH) emission of carbon-rich Galactic planetary nebulae (PNe) is investigated based on *AKARI*/IRC and *Spitzer*/IRS observations. Systematic variations in band peak positions and relative intensities are discovered in terms of evolution of PNe. The results show that PAHs in evolved PNe tend to show similar features as interstellar PAHs. The *SPICA*/MRS will have the advantage to investigate the evolution of dust emission in the 15–40 μm region. We discuss potential observations with *SPICA* to develop our understanding of the evolution of dust emission.

1. EVOLUTION OF PAH EMISSION IN GALACTIC PNE

Planetary nebulae (PNe) are in the final phase of low- and intermediate-mass star evolution. They are typically surrounded by a large amount of dust which is formed during the asymptotic giant branch phase. Their circumstellar dust is finally injected into the interstellar medium. They are supposed to be one of the major dust suppliers in galaxies. Investigating the dust in PNe is important to understand the physics and chemistry of the interstellar matter.

The 2.5–14.0 μm spectra of 19 Galactic PNe which show carbon-rich dust features were obtained with the *AKARI*/Infrared Camera (IRC) and *Spitzer*/Infrared Spectrograph (IRS). The 2.5–5.0 μm spectra were obtained with the IRC using the grism spectroscopy mode, while the 5.0–14.0 μm spectra were obtained using the Short-Low (SL) module of the IRS. The intensity of PAH emission features are measured by spectral fitting. The spectral profile of the PAH features is approximated by a Lorentzian function. The peak position of the 6.2 μm PAH feature is also measured.

The variations in the PAH emission are investigated in terms of the PN evolution. Theoretical studies indicate that the effective temperature of a PN increases monotonically as the PN evolves (e.g., Blöcker 1995). Thus, the effective temperature obtained from the literature is used as an estimator of the evolutionary stage of PNe. The intensity ratio of the 7.7 to 11.3 μm features is shown in the top panel of Figure 1. The 7.7 to 11.3 μm intensity ratio is sensitive to the ionization fraction of PAHs (Bregman & Temi 2005), since the 7.7 μm feature becomes strong when PAHs are ionized. The ratio decreases as the effective temperature increases. It indicates that the PAH ionization fraction decreases with PN evolution. The intensity ratio of the 3.4 to 3.3 μm features is shown in the middle panel. The 3.4 μm feature is generally attributed to aliphatic components attached to PAHs (Joblin et al. 1996; Sloan et al. 1997). This ratio increases with increasing temperature, indicating that the amount of aliphatic components in PAHs increases as the PN evolves. The bottom panel shows the evolution of the peak wavelength of the 6.2 μm PAH feature. PAHs in the interstellar medium generally show the peak of the 6.2 μm feature around 6.22 μm, while PAHs in circumstellar regions typically show the peak at 6.24–6.28 μm (Peeters et al. 2002). The former emission feature is referred to as Class $\mathcal{A}$ and the latter as Class $\mathcal{B}$. The figure indicates that the PAH emission evolves from Class $\mathcal{B}$ toward Class $\mathcal{A}$ along with the PN evolution. Thanks to the high sensitivity of the *AKARI*/IRC and *Spitzer*/IRS, a number of near- to mid-IR spectra were collected enough to statistically investigate the evolution of PAH emission in PNe. The origin of the evolution will be discussed in a separate paper (Ohsawa et al., in preparation).

2. POSSIBLE FUTURE OBSERVATIONS WITH *SPICA*

The Mid-IR Camera and Spectrometer (MCS) installed on-board *SPICA* has two special modules for spectroscopy, the Mid Resolution Spectrograph (MRS) and High Resolution Spectrograph (HRS). The MRS will explore the 12–38 μm range with a spectral resolution of $R > 1000$. The MRS will allow us to investigate some of the dust features in the mid-IR. Since image slicers are implemented, the MRS has the advantage to observe extended objects and investigate the spatial variation in the spectral profile of dust emission. In this paper, observations of crystalline silicates, fullerenes, and the 30 μm feature are proposed as future observations with the MRS.

Crystalline Silicate—Emission from crystalline silicate has narrow peaks in the mid-IR and silicates with a different crystalline structure, such as pyroxene and olivine, show a different spectral profile (e.g., Koike et al. 2003; Chihara et al.

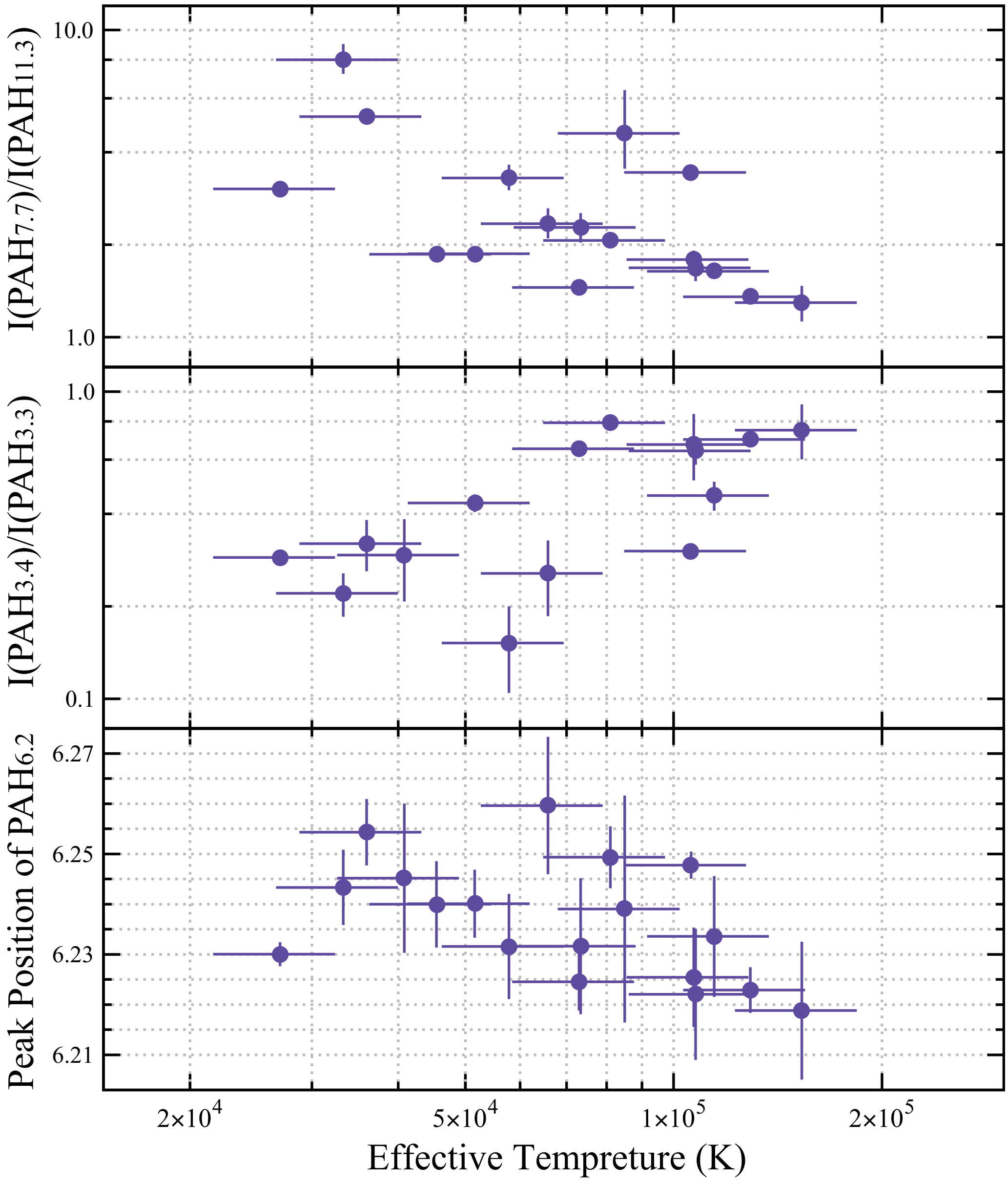

Figure 1. *Top*: the 7.7 to 11.3 μm intensity ratio, indicating the ionization fraction of PAHs. *Middle*: the 3.4 to 3.3 μm intensity ratio, indicating the aliphatic to aromatic ratio of PAHs. *Bottom*: the peak wavelength of the 6.2 μm feature, an indicator of the PAH emission class.

2002). Mid-IR spectroscopy enables us to identify the structure of silicate. There have been several studies on crystalline silicates focusing on the silicate feature around 10 μm. Emission around 10 μm is mostly attributed to hot (> 300 K) silicates. Spectroscopy in the 18–38 μm is more effective to identify the structure of warm (~100 K) silicate. Observations of the 30 μm silicate feature may provide new insights into when and how the crystallization of silicates occurs.

Fullerene—Fullerenes have been discovered in circumstellar (Cami et al. 2010) and interstellar (Sellgren et al. 2010) regions based on observations with the *Spitzer*/IRS. Although several studies have been made, their formation process and excitation mechanism still remain to be understood. Emission features of C_{60} and C_{70} appear around 17.6 and 18.9 μm and they are suitable targets for the MRS. A spatially-resolved observation of fullerene emission is important to identify their excitation mechanism (Bernard-Salas et al. 2012). The MRS will provide the 17–20 μm spectrum at the spatial resolution of ~1.″6, which will be useful to resolve the fullerene emitting region.

The 30 μm feature—The 30 μm feature is a broad emission feature which appears around 25–40 μm in a variety of evolved stars. The carrier of the feature is not identified. Magnesium sulfide (MgS) was proposed as a candidate (Goebel & Moseley 1985), as well as hydrogenated amorphous carbon (HAC, Duley 2000). Hony et al. (2002) have proposed that the 30 μm carrier could be heated by the infrared radiation or the carriers could be located far from the central star. The MCS has the potential to investigate the spatial distribution of the 30 μm feature. It would be useful to investigate the nature of the carrier of the 30 μm feature.

3. SUMMARY

The high sensitivity achieved by the *AKARI*/IRC and *Spitzer*/IRS has increased the number of objects which we can observe in the infrared. We were able to investigate the variation of the PAH emission in PNe in terms of the evolution of PNe. *SPICA* will achieve higher spatial resolution and sensitivity than *AKARI* and *Spitzer*. The MRS installed on-board *SPICA* has a great advantage to investigate the dust emission in the 15–40 μm range such as crystalline silicates, fullerenes, and MgS. The MRS will enable us to investigate the variations in these dust features along with PN evolution.

These results are in part based on observations with *AKARI*, a JAXA project with the participation of ESA and on archival data obtained with the *Spitzer Space Telescope*, which is operated by the Jet Propulsion Laboratory, California Institute of Technology under a contract with NASA. We fully appreciate all the people who worked in the operation and maintenance of those instruments. This work is supported in part by a Grant-in-Aid for Scientific Research (258492) by the Japan Society of Promotion of Science (JSPS).

REFERENCES

Bernard-Salas, J., Cami, J., Peeters, E., et al. 2012, ApJ, 757, 41
Blöcker, T. 1995, A&A, 299, 755
Bregman, J., & Temi, P. 2005, ApJ, 621, 831
Cami, J., Bernard-Salas, J., Peeters, E., et al. 2010, Science, 329, 1180
Chihara, H., Koike, C., Tsuchiyama, A., et al. 2002, A&A, 391, 267
Duley, W. W. 2000, ApJ, 528, 841
Goebel, J. H., & Moseley, S. H. 1985, ApJLetters, 290, L35
Hony, S., Waters, L. B. F. M., & Tielens, A. G. G. M. 2002, A&A, 390, 533
Joblin, C., Tielens, A. G. G. M., Allamandola, L. J., & Geballe, T. R. 1996, ApJ, 458, 610
Koike, C., Chihara, H., Tsuchiyama, A., et al. 2003, A&A, 399, 1101
Peeters, E., Hony, S., van Kerckhoven, C., et al. 2002, A&A, 390, 1089
Sellgren, K., Werner, M. W., Ingalls, J. G., et al. 2010, ApJLetters, 722, L54
Sloan, G. C., Bregman, J. D., Geballe, T. R., et al. 1997, ApJ, 474, 735