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AKARI observations of interstellar dust grains in our Galaxy and nearby galaxies

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ABSTRACT

The infrared (IR) emission from interstellar dust grains is a powerful tool to trace star-formation activities in galaxies. Beyond such star-formation tracers, spectral information on polycyclic aromatic hydrocarbons (PAHs) and large grains, or even their photometric intensity ratios, has deep physical implications for understanding the properties of the interstellar medium. With the AKARI satellite launched in 2006, we have performed a systematic study of interstellar dust grains in various environments of galaxies including our Galaxy. Because of its unique capabilities, such as mid-/far-IR all-sky surveys and near-/far-IR spectroscopy, AKARI has provided new knowledge on the processing of dust, particularly carbonaceous grains including PAHs, in the interstellar space. For example, the near-IR spectroscopy has revealed structural changes of hydrocarbon grains in harsh environments of galaxies. In this paper, we focus on the properties of the PAH emission obtained by the AKARI mid-IR all-sky survey and near-IR spectroscopy.

1. Introduction

In star-forming regions, large grains and polycyclic aromatic hydrocarbons (PAHs; i.e., smallest form of carbonaceous grains) absorb a significant fraction of stellar ultraviolet photons and re-radiate them in the infrared (IR). Hence the IR luminosities due to PAHs and large grains are both powerful tools to trace star-forming activities in galaxies or search for young stellar objects embedded in clouds. However they are not merely star-formation tracers. Spectral information on PAHs and large grains, as well as relative abundance of PAHs to large grains, would have much deeper physical implications for understanding the properties of the interstellar medium (ISM).

With the Infrared Camera (IRC; Onaka et al., 2007) and the Far-Infrared Surveyor (FIS; Kawada et al., 2007) on board AKARI, the first Japanese infrared astronomical satellite launched in 2006 (Murakami et al., 2007), we have performed a systematic study of interstellar dust grains in various environments of galaxies including our Galaxy. Because of its unique capabilities, such as all-sky coverage in the mid- and the far-IR combined with near- and far-IR spectroscopy, AKARI has provided new knowledge on the processing of dust, particularly carbonaceous grains including PAHs, in the interstellar space.

For example, we obtained all-sky diffuse maps in the 9, 18, 65, 90, 140, and 160 μm photometric bands by the all-sky surveys. Among them, the 9 μm diffuse map is the world-first all-sky map of the PAH emission, while the other maps mostly trace warm and cool components of large grains. In addition to such photometric datasets, we obtained near-IR (2–5 μm) spectroscopic data for more than 10,000 targets by pointed observations (Ohyama et al., 2007), most of which were performed during the warm mission phase after the boil-off of liquid helium cryogen. We also obtained far-IR (70–170 μm) spectroscopic data using the imaging Fourier Transform Spectrometer of the FIS (Kawada et al., 2008). For example, the near- and the far-IR spectroscopy have revealed structural changes of hydrocarbon particles (e.g., Yamagishi et al., 2012) and formation of large graphite grains (Kaneda et al., 2012b), respectively, in harsh environments of galaxies.

In this paper, we focus on the properties of the PAH emission obtained by the AKARI mid-IR all-sky survey and near-IR spectroscopy. We discuss (1) spatial variations in the photometric intensity of the mid-IR emission due to PAHs relative to that of the far-IR emission due to large grains, based on the all-sky diffuse maps, and (2) spectral variations in the ratio of the aliphatic to the aromatic feature, based on the near-IR spectra.

2. All-sky survey in the mid-IR PAH emission

Fig. 1a displays a diffuse map of the Galactic plane in the AKARI 9 μm band. It should be noted that the AKARI 9 μm band (the reference wavelength and the band width of 9.0 μm and 6.7–11.6 μm respectively; Onaka et al., 2007) efficiently covers

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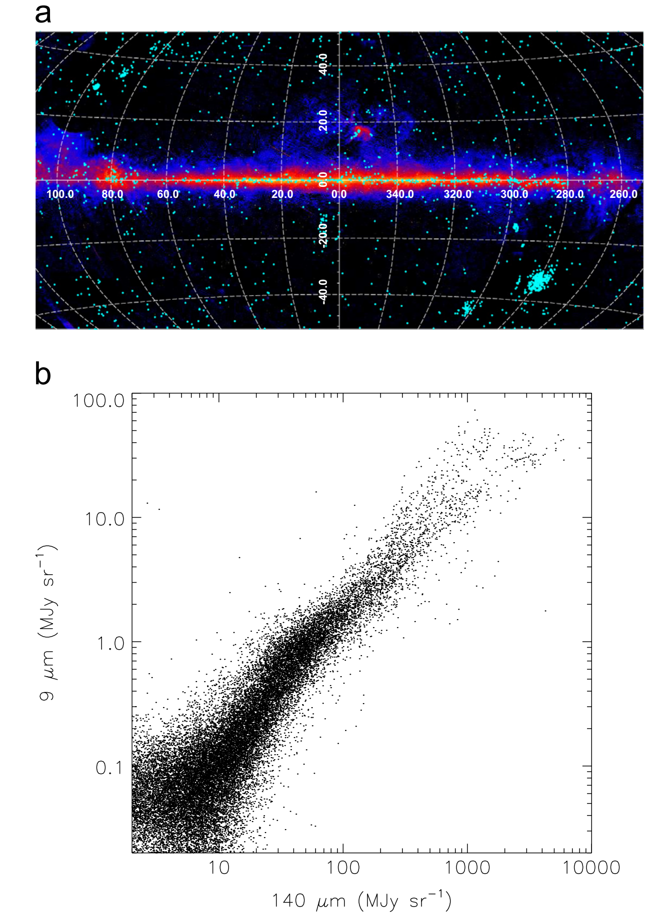

Fig. 1. (a) AKARI 9 μm-band all-sky diffuse map in the galactic coordinates, shown together with the observational positions of AKARI near-IR (2–5 μm) spectroscopy. (b) A correlation plot between the AKARI 9 μm and 140 μm band intensities for the all-sky images regridded to a spatial scale of 60 arc m × 60 arc m.

the major PAH emission features at wavelengths of 6.3, 7.7, 8.6, and 11.3 μm, as compared to the all-sky maps in the WISE or IRAS bands at similar wavelengths (Ishihara et al., 2010a). Fig. 1b shows a correlation plot between the AKARI 9 μm and 140 μm band intensities for the all-sky images regridded to a spatial scale of 60 arc m × 60 arc m. The plot exhibits a tight correlation over a range of 4 orders of magnitude with the linear-correlation coefficient of 0.94. This correlation demonstrates that PAHs and large grains are mixed well in the ISM, as pointed out by many authors (e.g., Onaka et al., 1996; Kaneda et al., 2012a).

Utilizing the AKARI all-sky point-source catalogs, we derived the spatial distributions of carbon-rich (C-rich) and oxygen-rich (O-rich) asymptotic giant branch (AGB) stars, based on the color–color diagrams of the 9 and 18 μm band fluxes with the 2MASS *J*, *H*, and *K* band fluxes (Ishihara et al., 2011). As a result, we find that the O-rich AGBs are more concentrated toward the Galactic center, while the C-rich AGBs are rather uniformly distributed throughout the Galactic plane. As can be seen in Fig. 1b, interstellar PAHs and far-IR dust grains are similar in the spatial distribution on both global and local scales, which do not follow well the distribution of either C-rich or O-rich stars. It is generally thought that silicate grains, a major far-IR dust component, are supplied into the interstellar space by O-rich stars, while carbonaceous grains including PAHs are produced by C-rich stars (e.g., Dwek, 1998). Thus our results show that PAHs and large grains are well mixed in the ISM whereas their suppliers have different spatial distributions. It is also worth to note that variation of the 3.4 μm aliphatic hydrocarbon absorption feature seems to follow that of the 9.7 μm amorphous silicate absorption feature; their optical depths relative to the visual extinction in the Galactic center are both about twice as large as those in the local diffuse interstellar medium (Gao et al., 2010). This is an open issue to be addressed in future works.

Hence the AKARI 9 μm map reveals that PAHs are widely distributed throughout the Galactic plane, similar to large grains. Yet the maps also exhibit significant variations in the relation between the PAH and the far-IR dust emission, depending on local interstellar conditions. For example, in shocked regions associated with supernova remnants (SNRs), PAH emission is extremely suppressed as compared to far-IR dust emission (e.g., Ishihara et al., 2010b), which is attributed to a large difference in the lifetime against strong shocks between PAHs and large grains (Micelotta et al., 2010). In post-shock hot plasmas, lifetimes of PAHs are two to three orders of magnitude shorter than those for equivalent dust grains of roughly the same size, because the sputtering yields of 3-dimensional grains (i.e. the number of sputtered atoms per incident high-energy particle) are much smaller than unity, while the dissociation yields of 2-dimensional PAHs are close to unity. Other than SNRs, Kaneda et al. (2012a) found that the ratios of the PAH to far-IR dust emission show a significant depression (by a factor of ~ 5) near the foot points of the molecular loops revealed by the NANTEN ^{12}CO ($J = 1-0$) observations in the Galactic center region (Fukui et al., 2006). Because the CO observations indicated that a violent motion and shock heating of gas took place in the loops (Torii et al., 2010), the relative decrease in the PAH emission suggests the destruction of PAHs by shocks at the foot points of the molecular loops.

External galaxies provide much wider ranges of physical conditions for the ISM than our Galaxy. Among them, nearby edge-on starburst galaxies with prominent galactic superwinds are important targets to understand the processing of dust in high energetic phenomena. For example, in M 82 (Kaneda et al., 2010) and NGC 253 (Kaneda et al., 2009), we find that copious amounts of large grains and PAHs are flowing out of the galaxies by galactic superwinds, both of which are likely being shattered and destroyed in the galactic haloes. Fig. 2a and b shows correlation plots between the AKARI 9 μm and 140 μm band intensities for M 82 and NGC 253, respectively, where the different symbols and colors are used to discriminate the center, disk, northern and southern halo regions. In each panel, the solid line represents the relationship obtained for our Galaxy (i.e., Fig. 1b). As can be seen in the figure, they exhibit global relations quite similar to our Galaxy, despite the fact that the environments are much harsher in these galaxies. In the halo regions, it appears that the 9 μm to 140 μm ratios are systematically shifted toward lower values. Moreover the data points for NGC 253 exhibit an apparently larger scatter than those for M 82, which may reflect that NGC 253 is a starburst galaxy in a later evolutionary stage than M 82, causing difference in the degree of the dust processing. In the center of M 82, the 9 μm to 140 μm ratios are well above the other regions, which is likely to be caused by a large increase in interstellar radiation field intensity (see Fig. 13 in Draine and Li, 2007).

In interpreting the above results, we have to take into account the photo-dissociation of PAHs exposed to a strong ultraviolet (UV) radiation field (Boulanger et al., 1988; Bendo et al., 2008), although it is much less effective than destruction by shocks; the lifetimes of PAHs against the photo-dissociation are 10^5 years in massive star-forming regions, while they are 10^8 years for the diffuse ISM (Allain et al., 1996). Even for a constant abundance ratio of PAHs to large grains, the 9 μm to 140 μm intensity ratio will change with other parameters such as the UV radiation field and dust extinction (Kaneda et al., 2012a). The ratios increase with the UV radiation field as long as it is stronger than that in the solar neighborhood (Draine and Li, 2007). Larger interstellar extinction in the mid-IR than in the far-IR can systematically lower the ratios of 9 μm to 140 μm intensities in dense gas regions. The dominance