A Spatially-resolved Study on the Processing and Destruction of Dust Grains in Local ULIRGs

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ABSTRACT

A merging process in infrared (IR) galaxies plays an important role in accelerating the processing of dust grains, which may alter the properties of dust grains, e.g. the relative abundance of polycyclic aromatic hydrocarbons (PAHs) to classical grains. In fact, with *AKARI*, we find that the ratio of the PAH 3.3 μm to IR luminosity, $L_{\rm PAH3.3}/L_{\rm IR}$, considerably decreases toward the luminous end of $L_{\rm IR} > 10^{11.5}\,{\rm L}_\odot$, using the near-IR (2.5–5 μm) spectra of 100 IR galaxies without AGN signatures. We conclude that local ULIRGs intrinsically possess a smaller amount of PAHs relative to classical grains than less-luminous IR galaxies. Some fraction of PAHs may have been destroyed once by a shock during a merging process, whereas large dust grains survive, which may explain the systematically low abundance ratios of PAHs to classical grains observed for the ULIRGs. To prove this scenario, we should observe a systematic change of the ratio from an interacted region to others, or from outer to inner areas, within a galaxy. With *SPICA*, especially coronagraphic spectroscopy with the SCI, we can perform a spatially-resolved study of local ULIRGs in both PAH and dust emission, which will reveal the scene of the processing and destruction of dust grains with shocks during merging processes of galaxies.

1. INTRODUCTION

It is well known that a merging process of galaxies plays an important role in the infrared (IR) galaxies which are dominated by star formation activity. From morphological studies, many local ultra-luminous IR galaxies (ULIRGs) seem to have experienced recent mergers. Such merger events are likely to accelerate the processing and destruction of dust grains initially present in galaxies, as well as to trigger star-burst activity. Then the properties of dust grains, e.g. the relative abundance of polycyclic aromatic hydrocarbons (PAHs) to classical grains or dust size distributions, may systematically change with the IR luminosity if their activities originate from mergers. In order to reveal the effect of merging processes on dust grains and relationship with star-forming activity, we study the relative abundance of PAHs to classical grains in galaxies with a wide range of infrared luminosity (Yamada et al. 2013).

2. EVIDENCE FOR THE DESTRUCTION OF THE PAHS IN LOCAL ULIRGS

2.1. Sample Selection and Data Analysis

We selected our targets from the two *AKARI* mission programs, Mid-infrared Search for Active Galactic Nuclei (MSAGN; Oyabu et al. 2011) and Evolution of ULIRGs and AGNs (AGNUL). We obtained the *AKARI* near-IR spectra of the 184 galaxies which satisfy the criterion $F(9\,\mu{\rm m})/F(Ks) > 2$, and classified into three populations of galaxies according to their $L_{\rm IR}$, where $F(9\,\mu{\rm m})$ and $F(Ks)$ are the flux densities at 9 μm and the *Ks*-band taken with *AKARI* and 2MASS, respectively, and $L_{\rm IR}$ is the IR (8–1000 μm) luminosity derived from *IRAS* (Sanders & Mirabel 1996). Eighteen galaxies are defined as IR galaxies (IRGs: $L_{\rm IR} < 10^{11}\,{\rm L}_\odot$), 89 luminous IR galaxies (LIRGs), and 55 ULIRGs. The other 22 galaxies have no information on $L_{\rm IR}$, because they were not detected with *IRAS*.

2.2. Result

We detect the PAH 3.3 μm feature from 134 out of 184 galaxies. Most of them show the Brα emission line. The other galaxies show a red continuum typical of Active Galactic Nucleus (AGNs). We excluded sources which are likely contaminated by AGN activity, based on the rest-frame equivalent width of the PAH 3.3 μm feature (< 40 nm; Moorwood 1986) and the power-law index representing the slope of continuum emission (> 1; Imanishi et al. 2010). As a result, 100 objects are defined as star-forming galaxy (SFG). Figure 1 shows the relationship between the ratio of the PAH 3.3 μm luminosity, $L_{\rm PAH3.3}$, to $L_{\rm IR}$ and $L_{\rm IR}$. At low $L_{\rm IR}$ (10^8–$10^{11.5}\,{\rm L}_\odot$), $L_{\rm PAH3.3}/L_{\rm IR}$ is $\sim 10^{-3}$, which is a typical value for starburst galaxies (Mouri et al. 1990; Imanishi 2002). At higher $L_{\rm IR}$ ($\gtrsim 10^{11.5}\,{\rm L}_\odot$), however, $L_{\rm PAH3.3}/L_{\rm IR}$ shows a significant decline with $L_{\rm IR}$.

2.3. Discussion

The decline of $L_{\rm PAH3.3}$ with $L_{\rm IR}$ (Figure 1) can be caused by (1) effects of hidden AGNs (Kim et al. 2012), (2) photo-dissociation of PAHs under intense ultraviolet (UV) radiation due to star-formation activity, (3) effects by heavily obscured star-forming region (Kim et al. 2012), and (4) intrinsically low abundance ratios of PAHs to classical grains. We compared

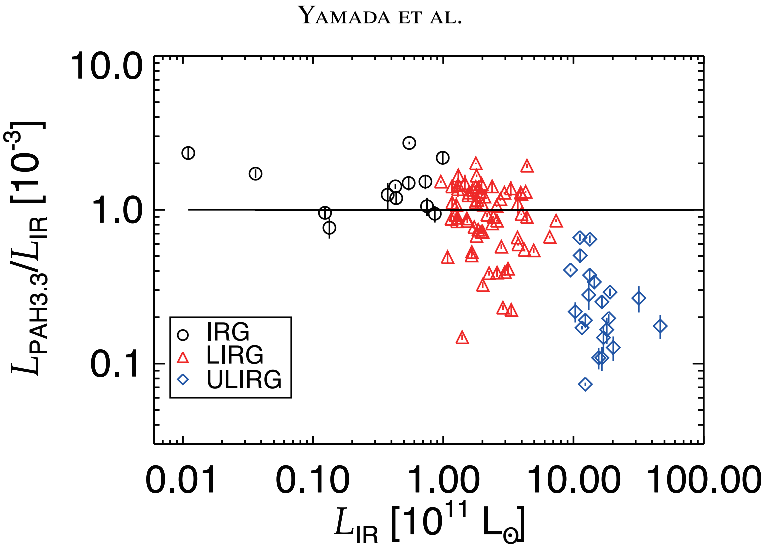

Figure 1. $L_{PAH3.3}/L_{IR}$ plotted against L_{IR} for the galaxies with no AGN signatures: IRGs (circles), LIRGs (triangles), and ULIRGs (diamonds). The solid line shows $L_{PAH3.3}/L_{IR}$ of 10^{-3} (Mouri et al. 1990; Imanishi 2002).

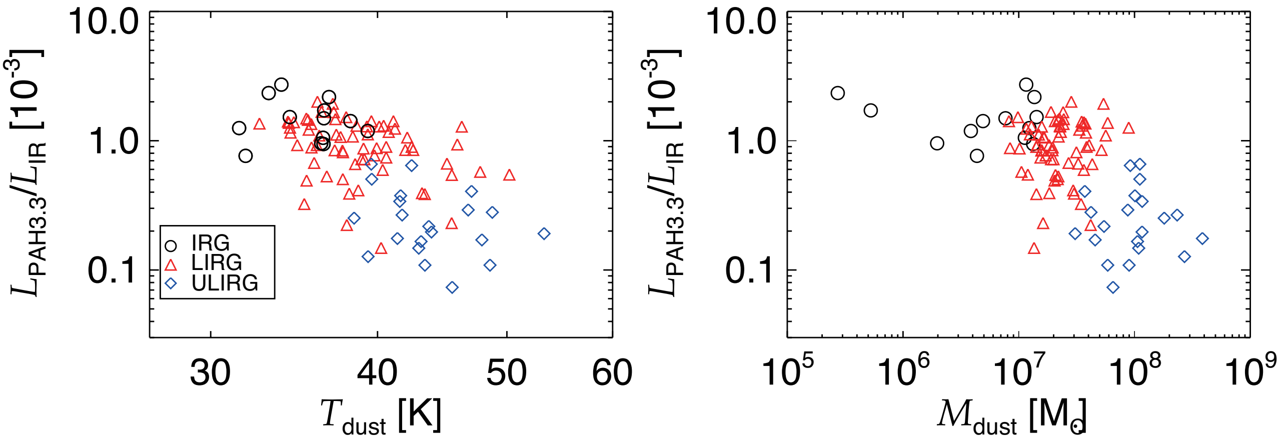

Figure 2. $L_{PAH3.3}/L_{IR}$ plotted against T_{dust} (*Left*) and M_{dust} (*Right*) for the galaxies with no AGN signatures: IRGs (circles), LIRGs (triangles), and ULIRGs (diamonds).

$L_{PAH3.3}/L_{IR}$ of the SFGs with that of the galaxies with AGN signatures. As a result, we confirm that IRGs and LIRGs with AGN signatures show systematically lower $L_{PAH3.3}/L_{IR}$ ratios than those with no AGN signatures. However, for the ULIRGs, there is no systematic difference between galaxies with and without AGN signatures. This suggests that the hidden AGNs, if any, may not appreciably decrease $L_{PAH3.3}/L_{IR}$ for our sample ULIRGs.

Figure 2 displays $L_{PAH3.3}/L_{IR}$ against the dust temperature, T_{dust}, and dust mass, M_{dust}, which are obtained by the ratio of the *IRAS* 60 to 100 μm flux densities with the emissivity power-law index $\beta = 1$. The ratio $L_{PAH3.3}/L_{IR}$ systematically changes from population to population. LIRGs and ULIRGs span a wide range of T_{dust} and do not show correlation within each population, which implies that the photo-dissociation by UV radiation is not a major cause because T_{dust} is determined from the intensity of UV radiation.

In Figure 2 *Right*, ULIRGs, which show small $L_{PAH3.3}/L_{IR}$, have a copious amount of dust grains. If star-forming regions are heavily obscured by the dust, $L_{PAH3.3}/L_{IR}$ decreases due to dust extinction. This is also the case with the ratio of the Brα emission line to IR luminosity, $L_{Br\alpha}/L_{IR}$, because both Brα and PAH 3.3 μm emission appear at similar wavelengths in the near-IR. Besides, soft radiation from heavily-embedded YSOs may contribute to increasing L_{IR}, but not much to increasing $L_{PAH3.3}$ because it is too soft to excite PAHs. In this case, it is likely that the Brα emission is relatively weak, similarly to the PAH 3.3 μm emission. Figure 3 *Left* shows $L_{Br\alpha}/L_{IR}$ plotted against L_{IR}, from which we find that $L_{Br\alpha}/L_{IR}$ does not significantly decrease with L_{IR}, unlike $L_{PAH3.3}/L_{IR}$. This implies that neither dust extinction nor contribution of soft radiation field on L_{IR} is important.

Figure 3 *Right* displays $L_{PAH3.3}/L_{IR}$ plotted against $L_{PAH3.3}$, revealing that each galaxy population has a different relationship between $L_{PAH3.3}/L_{IR}$ and $L_{PAH3.3}$. The abundance ratios are systematically different between the populations. Consequently, we conclude that the intrinsically low abundance ratios of PAHs to classical grains are likely to cause the

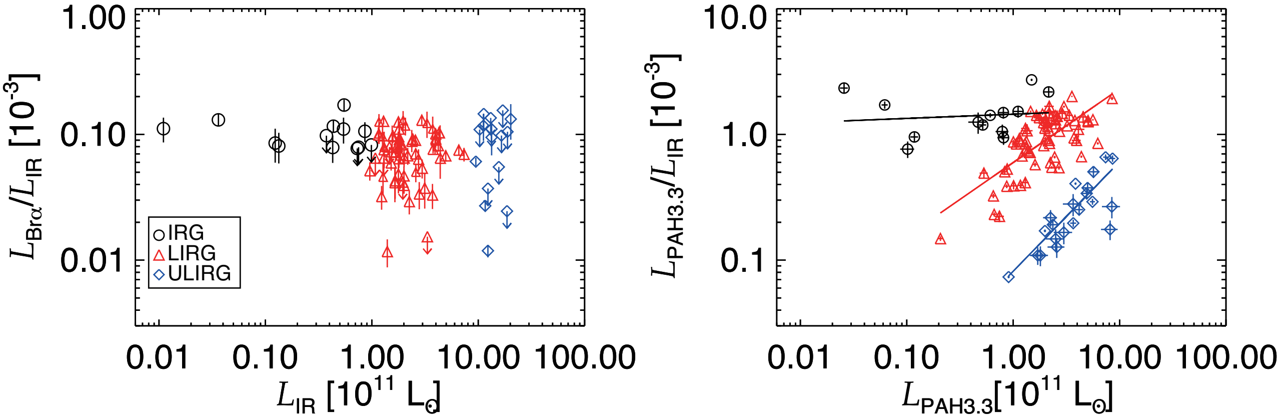

Figure 3. *Left:* $L_{Br\alpha}/L_{IR}$ plotted against L_{IR}, *Right:* $L_{PAH3.3}/L_{IR}$ plotted against $L_{PAH3.3}$ for the galaxies with no AGN signatures: IRGs (*circles*), LIRGs (*triangles*), and ULIRGs (*diamonds*). The black, red, and blue lines show logarithmic regression lines for the IRGs, LIRGs, and ULIRGs, respectively.

small $L_{PAH3.3}/L_{IR}$ in the population of the ULIRGs. A plausible scenario is that PAHs may have been destroyed once by a shock during a merging process, whereas large dust grains survive.

3. STUDY WITH THE *SPICA*/SCI

We aim to observe a systematic change of the ratio from an interacted region to others, or from outer to inner areas, within a galaxy. The spatial resolution of *AKARI* was too poor to discuss the distribution of PAHs and classical grains. Coronagraphic spectroscopy with the SCI can reveal them near bright central nuclei of local ULIRGs. More specifically, spatial variations in the mid-IR continuum shape would provide us with information on those in the dust size distribution decoupled from those in temperature. Utilizing the silicate features as tracers of classical grains, we investigate spatial variations in the relative abundance of PAHs to classical grains within a galaxy. Thermal annealing during merging processes might even crystallize silicate grains, which is probed by changes in the profiles of the silicate features. They will reveal the scene of the processing and destruction of dust grains with shocks during merging processes.

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