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Dust and PAHs in X-ray plasma of elliptical galaxies

Hidehiro Kaneda[1], Takashi Onaka[2], Toyoaki Suzuki[3], Tatsuya Mori[1], Mitsuyoshi Yamagishi[1], Toru Kondo[1], and Akiko Yasuda[1]

[1]Graduate School of Science, Nagoya University, Nagoya, Aichi 464-8602, Japan

[2]Department of Astronomy, Graduate School of Science, University of Tokyo, Bunkyo-ku, Tokyo 113-0003, Japan

[3]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagamihara, Kanagawa 252-5210, Japan

email: kaneda@u.phys.nagoya-u.ac.jp

Abstract. Many elliptical galaxies possess an appreciable amount of X-ray-emitting hot plasma, providing a harsh interstellar environment for the survival of dust grains and polycyclic aromatic hydrocarbons (PAHs). Despite such a hostile environment, it has been found that a significant fraction of X-ray elliptical galaxies contain a considerable amount of dust, which cannot be explained solely from replenishment by old stars. Some of them even show the presence of PAHs. We present the results of AKARI and Spitzer observations of dust and PAHs in X-ray elliptical galaxies. We investigate their possible origins and discuss the implications of their presence for the evolution of elliptical galaxies.

Keywords. ISM: dust, extinction — infrared: galaxies — galaxies: elliptical and lenticular, cD — galaxies: ISM

1. Introduction

The interstellar environment of elliptical galaxies is characterized by the dominance of X-ray-emitting hot plasma and old stellar radiation fields with little UV. Submicron dust in X-ray plasma is easily destroyed by sputtering on timescales of $10^6 \sim 10^7$ yr (Draine & Salpeter 1979), while old stars cannot replenish a large amount of dust into the interstellar space (Knapp *et al.* 1992). Despite such hostile conditions, a significant fraction of elliptical galaxies contain a considerable amount of dust (e.g., Knapp *et al.* 1989; Goudfrooij & de Jong 1995; Temi *et al.* 2007a). Spitzer revealed the presence of polycyclic aromatic hydrocarbons (PAHs; Kaneda *et al.* 2008), which was even more surprising because PAHs are much more easily destroyed on timescales of $\sim 10^2$ yr (Micelotta *et al.* 2010). In this paper, we present the results of AKARI and Spitzer observations of dust and PAHs in elliptical galaxies to investigate their possible origins.

2. Observations

We observed 18 nearby IRAS-detected elliptical galaxies with AKARI and Spitzer. For each target, we obtained near- to far-infrared (IR) 10-band images from the AKARI nearby galaxy program (Kaneda *et al.* 2009), and mid-IR ($5 - 36$ μm) spectra from the 3 Guest Observers programs of Spitzer (PI: HK; PIDs: 3619, 30483, 50369). In addition, AKARI surveyed all the sky in the mid- and far-IR 6 bands, from which we obtained a complete sample of early-type galaxies with the far-IR flux limit of ~1 Jy. Figure 1 shows typical spectral energy distributions (SEDs) of elliptical galaxies in the IR to

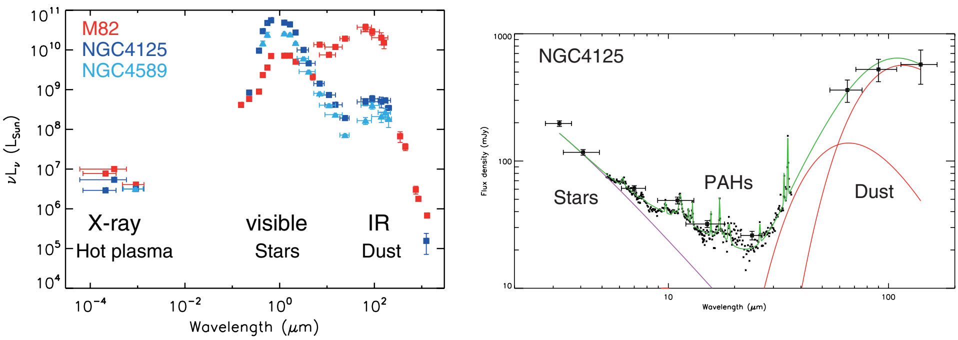

Figure 1. (Left) SEDs of the elliptical galaxies, NGC4125 and 4589, compared with that of the starburst galaxy M82. (Right) IR (2−200 μm) SED of the central 30″ region of NGC4125, composed of the AKARI photometric fluxes and the Spitzer/IRS spectrum (Kaneda *et al.* 2011).

X-ray, where the AKARI 10-band fluxes are plotted in the IR. As compared with the SED of the starburst galaxy M82, the elliptical galaxies are indeed very bright in the stellar emission in the visible to near-IR relative to dust emission in the mid- to far-IR, while their total X-ray luminosities are comparable with each other. The right panel in Fig. 1 shows the detailed IR (2−200 μm) SED of NGC4125, where we can recognize the presence of the PAH features. It should be noted that the spectrum shows an unusually faint PAH 7.7 μm feature. Most of our sample elliptical galaxies show similarly faint 7.7 μm features relative to prominent 11.3 μm and 17 μm features, probably reflecting the dominance of neutral PAHs due to soft radiation fields.

3. Results

The left panel in Fig. 2 shows the dust masses derived from the AKARI all-sky survey 90 and 140 μm fluxes for the sample of early type galaxies with the ∼1 Jy far-IR flux limit, plotted against the B-band luminosity. The asterisks correspond to the results of the above 18 galaxies, for which we performed deep pointed observations with AKARI and Spitzer. The lines in the figure represent the dust masses expected by the balance between supply from old stars and sputtering in X-ray plasma with the denoted destruction timescales (Knapp *et al.* 1992). Thus the presence of the excess dust is beyond doubt. Besides the figure suggests a notable trend that the dust mass increases with the stellar luminosity, implying some connection between dust supplying sources and galaxy evolution. Most of the excess dust may originate in past galaxy mergers, because many elliptical galaxies are believed to have been evolved through mergers. However, considering the current smooth stellar distributions, look-back times for the mergers are typically $\gtrsim 10^9$ yr (e.g. Bournaud *et al.* 2008), much longer than the lifetime of dust. Thus the presence of dust suggests that they were likely supplied very recently.

It is known that the intensities of the PAH features are correlated well with those of the dust emission from galaxy to galaxy (Kaneda *et al.* 2008). The presence of PAHs even suggests that there are some ways for them to avoid interaction with the X-ray plasma. Therefore spatial information on the dust and PAHs is crucial to understand their origins. The right panels in Fig. 2 show examples of 90 μm contour maps of our sample galaxies, together with their 15 μm (PAHs + stars) contours and 3 μm (stars) images. Our results suggest that some galaxies reveal extended far-IR distributions of dust. Figure 3 shows the results of our Spitzer/IRS spectral mapping. With the spectroscopy, we unambiguously obtain the spatial distribution of PAHs in elliptical galaxies for the first time, which

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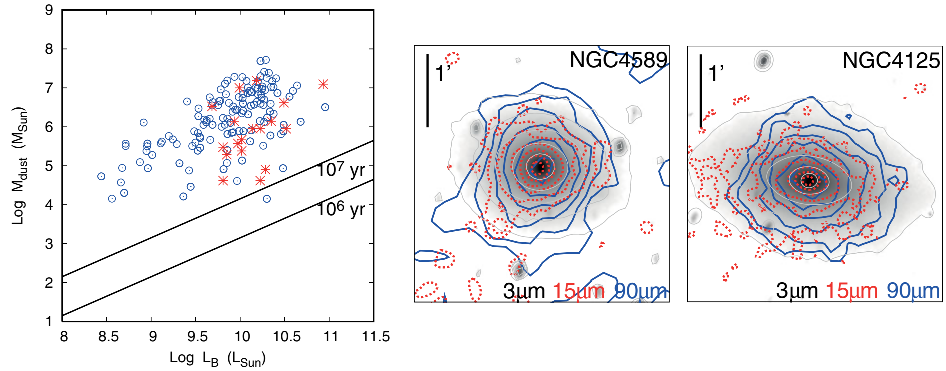

Figure 2. (Left) dust masses of early-type galaxies derived from the AKARI all-sky survey, plotted against their B-band total luminosity. (Right 2 panels) AKARI images of 2 elliptical galaxies in our sample; the 90 μm (solid lines) and 15 μm (dashed lines) contours are overlaid on the 3 μm band grey image, with logarithmic spacings from 80 to 10 % (90 μm) and 2 % (15 μm) of the peaks.

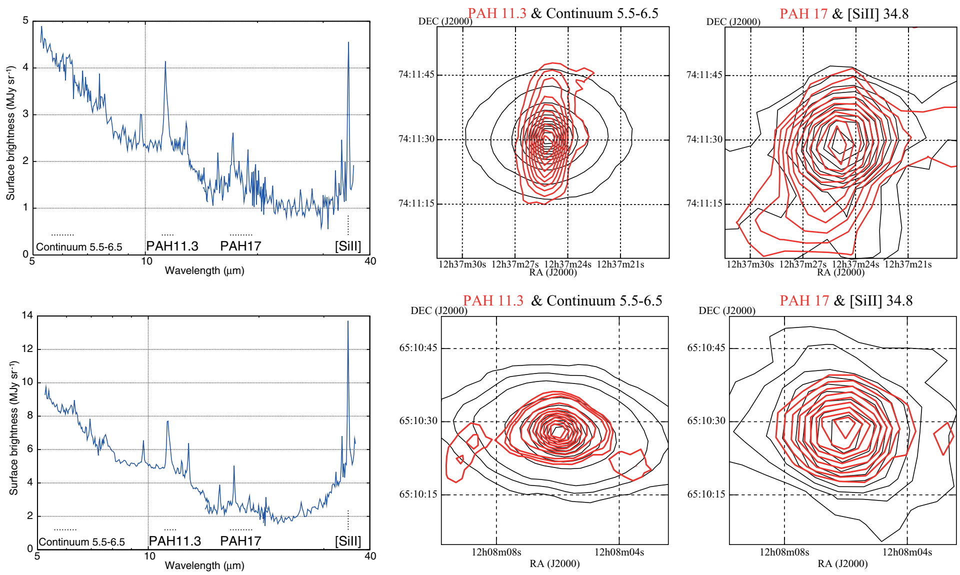

Figure 3. PAH spectral maps obtained with the Spitzer/IRS for NGC4589 in the upper and NCG4125 in the lower panels (Kaneda *et al.* 2010; 2011). (Left) the spectra of the central 15$''$ regions. (Middle) the contour maps of the PAH 11.3 μm feature (thick lines) on those of the 5.5–6.5 μm stellar continuum emission (thin lines). (Right) the contour maps of the PAH 17 μm feature (thick lines) on those of the [SiII] 34.8 μm line emission (thin lines). In each map, the contours are drawn on a linear scale from 10% to 90% of the peak.

reveals that the PAHs are compactly distributed near the centers of the galaxies. Large PAHs responsible for the 17 μm feature (Peeters *et al.* 2004) seem to be more extended than PAHs of typical sizes emitting the 11.3 μm feature, and far-IR dust grains are far more extended than PAHs because their emission is significantly extended even with poor spatial resolution in the far-IR. Furthermore the distributions of the dust and PAHs are entirely different from the stellar distribution (Figs. 2 and 3).

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4. Discussion

One possibility to explain the extended excess dust is very minor mergers, i.e. accretion of dust-rich dense cold gas, which do not appreciably disturb the stellar distribution. Another possibility is outflows assisted by a low-luminosity AGN (LLAGN); we expect the presence of dust reservoirs near the center by analogy with the dusy tori of AGNs or from optical dust lanes. LLAGNs may produce buoyant outflows in response to infalling gas, distributing the dust from the central reservoirs to outer regions (Temi *et al.* 2007b). Alternatively X-ray plasma may not dominate the interstellar space, possibly localized by magnetic confinement, whereby dust survives for a long time. Our observational results suggest that larger grains are extended farther from the center, supporting the second possibility; for the outflow velocity of $\sim$400 km^{-1}, dust of 0.1 μm size reaches $\sim$ 5 kpc in a sputtering lifetime of $\sim 10^7$ yr (Temi *et al.* 2007b), while PAHs cannot be distributed because their destruction timescales are too short ($\sim 10^2$ yr; Micelotta *et al.* 2010). Near the center, the PAHs and dust are likely to have been protected from the interaction with the X-ray plasma inside the dense molecular gas (i.e. dust reservoirs). The trend seen in Fig. 1 would imply that the dust may have been recycled from the ISM brought in by mergers and being accumulated near the center. For NGC4125, softer X-ray emission is extended toward directions similar to the dust emission, indicating that the dust is interacting with the X-ray plasma, thus cooling the plasma (Kaneda *et al.* 2011). In fact, Spitzer detected very strong [SiII] 34.8 μm emission from many elliptical galaxies (see Fig. 3), suggesting abundant gas-phase Si through sputtering of silicate dust.

5. Summary

With AKARI and Spitzer, we have shown that considerable amounts of dust and PAHs exist in X-ray elliptical galaxies, which cannot be accounted for by stellar mass loss alone. For NGC4125 and 4589, we have spatially resolved PAH and dust emissions; PAHs are centrally concentrated, while dust is more distributed. We have obtained signature of interaction between the dust and X-ray plasma. Reservoirs of dust and PAHs seem to exist near the centers of the galaxies. The dust may be distributed by LLAGN-assisted outflow from the central reservoir to outer interstellar space, where the X-ray plasma is cooled. The PAHs cannot be distributed due to their short destruction timescale. To further verify this interpretation, we require a larger sample of elliptical galaxies in which both dust and PAHs are spatially resolved.

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Discussion

WANG: In one of your 70 μm images, the dust emission distribution seems to be much narrower than that of the X-ray morphology. Do you have an explanation?

KANEDA: The dust is likely to be outflowing from the centre, being destroyed by spultering in X-ray plasma. The 70 μm image traces smaller grains, and their destruction timescales are shorter. That's why the 70 μm image shows a narrower distribution.

GALLAGHER: There seems to be a range in the optically detected dust in the Ellipticals - some cases with only compact central structures, and others with spatially extended dust lanes. Do you see any differences in the PAH properties associated with the scale of dust distributions in ellipticals?

KANEDA: We don't see significant differences in the PAH properties.

FERRERAS: In the M_{dust} vs. L_B plot, all galaxies fall above the expected value for mass loss. How do you reconcile this result with the fact that 2/3 of the sample from Martin Bureau have no misalignement of the CO kinematics?

KANEDA: It is probably due to the relatively high detection limit of the AKARI all-sky survey. The galaxies must be relatively bright in the FIR.

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