AKARI Observations of the ISM in Nearby Galaxies

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ABSTRACT

With *AKARI*, we have observed about 80 nearby galaxies that include various morphological types and thus extensive ranges in ISM environments and star formation history. Among them, we report on some of our recent results for 20 nearby elliptical galaxies, which are combined with those with *Spitzer*. We have detected PAHs and extended dust emissions from many of our sample galaxies. Most of those galaxies have a peculiar PAH emission spectrum with unusually strong 11.3 μm and 17 μm features relative to the 7.7 μm feature. Some of the elliptical galaxies so far observed with *AKARI* also exhibit the presence of the PAH 3.3 μm emission feature (i.e. very small PAHs). On the basis of these results, we conclude that the unusual PAH emission features are attributed mostly to a large fraction of neutral to ionized PAHs in the interstellar space of the elliptical galaxies.

Subject headings: galaxies: ISM — infrared: galaxies — infrared: ISM — ISM: dust, extinction — ISM: structure

1. Introduction

External galaxies provide a wide range of ISM physical conditions. With *AKARI*, we have observed about 80 nearby galaxies that include various morphological types and thus extensive ranges in ISM environments and star formation history. The major scientific objective of the *AKARI* nearby galaxy project is to increase our knowledge on the properties

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of the ISM exposed to the extensive range of environments: the processing, evolution, and destruction of interstellar dust, as well as their connection with physical conditions of interstellar gas and star-forming activity. Among the sample galaxies, we below introduce some of our recent results obtained for 20 nearby early-type galaxies, which are combined with those with *Spitzer*.

Elliptical galaxies provide a unique interstellar environment, old stellar radiation fields with little UV light and interstellar space dominated by hot plasma. Far-IR emission has been detected from many elliptical galaxies (e.g. Goudfrooij & de Jong 1995; Temi et al. 2004; Kaneda et al. 2007a). The dust masses seem to be larger than those determined by the balance between replenishment by stars and sputtering destruction by plasma (Goudfrooij & de Jong 1995), calling for additional dust-supplying sources. Recent studies show even the presence of PAH emission features in elliptical galaxies (Kaneda et al. 2005, 2007b).

2. Observations

We observed 20 *IRAS*-detected nearby elliptical galaxies in a systematic manner in the near- to the far-IR with *AKARI*, 18 of which are also observed with the *Spitzer*/IRS SL&LL in our GO1&GO3 programs (PID3619&30483). Currently, we are also carrying out follow-on near-IR spectroscopy for these galaxies with *AKARI*.

3. Results

We have detected PAHs and extended dust emissions from many of our sample elliptical galaxies. In Fig.1, we show some of the mid-IR spectra obtained in our *Spitzer* GO1&3 programs, which exhibit strange PAH emission features at 11.3 and 17 μm: usually strong features at 6.2, 7.7, and 8.6 μm are very faint in contrast to prominent features at 11.3 and 17 μm. This might be a typical spectrum of the PAH features in evolved systems such as elliptical galaxies, i.e. a dominance of neutral PAHs over ionized ones due to very soft radiation fields from evolved stars. In addition to the unusual PAH features, a series of H_2 rotational lines as well as ionic fine-structure lines (e.g. [NeII] and [NeIII]) are detected from a large fraction of the elliptical galaxies, implying the presence of warm (>200 K) molecular and ionized gases. Their presence is also an enigma, apparently inconsistent with the dominance of neutral PAHs irradiated by soft radiation field.

In Kaneda et al. (2007), the near- to mid-IR spectrum of the giant elliptical galaxy NGC 1316 has been studied with the *AKARI*/IRC (Fig.2). We have clearly confirmed that

NGC1316 has a peculiar PAH emission spectrum with an unusually high ratio of the 11.3 μm to the 7.7 μm emission intensity as detected in the *Spitzer*/IRS observation (Smith et al. 2007), and similarly to the spectra of the elliptical galaxies in Fig.1. In addition, there is no significant PAH emission at 3.3 μm, which reflects the lack of small PAHs most probably through sputtering destruction in the interstellar hot plasma; the overall PAH emission features seem to call for the dominant existence of neutral PAHs of large sizes (Draine & Li 2007). We have detected a strong absorption feature at 4.3 μm, which is reasonably thought to be due to solid-state CO_2 in grain mantles. Then, the PAHs responsible for the prominent 11.3 μm feature may have also been formed on the mantle of dust, which has enabled them to survive for a sufficiently long time against sputtering destruction in hot plasma.

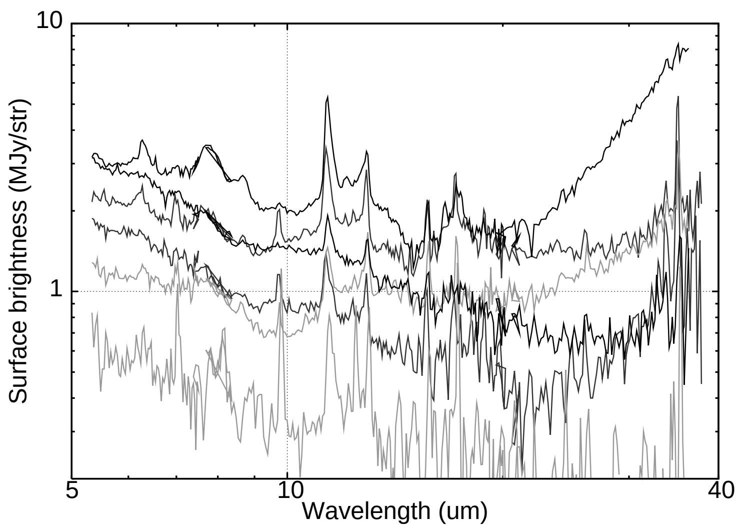

Fig. 1.— *Spitzer*/IRS spectra of elliptical galaxies obtained from our GO1&GO3 programs. Background spectra estimated from the observations of nearby blank skies have been subtracted.

As another typical example, the near- to far-IR spectrum of NGC 4589 obtained with *Spitzer* and *AKARI* is displayed in Fig.3. This is constructed from the *Spitzer*/IRS mid-IR (5-35 μm) and the *AKARI*/IRC near-IR (2-5 μm) spectroscopic data in combination with the *AKARI* and *Spitzer*/MIPS photometric data (Kaneda et al. in prep.). The spectrum exhibits the presence of dust emission, PAH emission features, pure rotational emission lines of H_2 at 28.22, 17.04, and 9.67 μm, and strong atomic emission lines such as [Si II] 34.82 μm. In particular, the PAHs again exhibit the unusual features that are strong only at 11.3 and 17 μm, which suggests the dominance of the large neutral PAHs due to the little UV and hot plasma environment. There also seem to be absorption features due to CO and/or

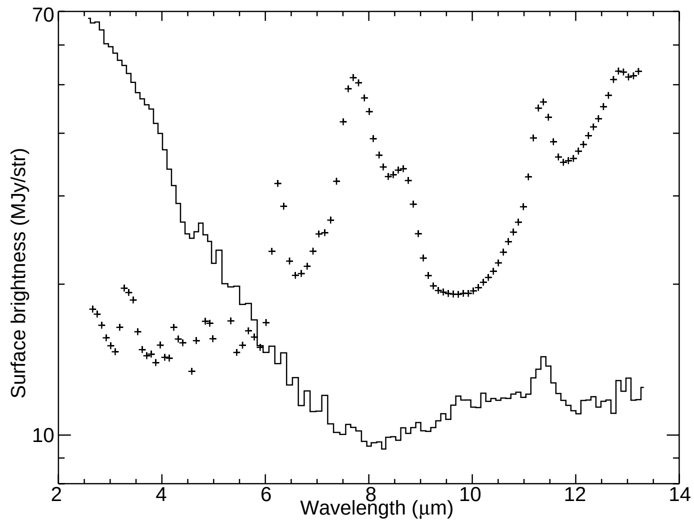

Fig. 2.— Near- and mid-IR spectra of NGC 1316 obtained with the *AKARI*/IRC (Kaneda et al. 2007b). For comparative purpose, the *AKARI*/IRC spectrum of a typical Galactic plane region ($l = 312°$, $b = 0.15°$) processed in the same way is shown together with pluses in arbitrary units.

CO_2 ice at 4.6 and 4.3 μm, respectively. A strong absorption feature is detected around 3 μm probably due to H_2O ice. Significant PAH 3.3 μm emission is detected from some elliptical galaxies such as NGC1052 (Kaneda et al. in prep.), but not from others including NGC 4589. Hence the chemistry of the ISM in the near-IR seems to be quite different among the galaxies.

In Fig.4, we plot the PAH 11.3 μm feature and the far-IR intensities against the X-ray luminosity for each galaxy. There seem to be no significant correlation of either PAH or the far-IR with the X-ray. In some galaxies, we have found that larger grains tend to extend farther away, suggesting AGN-assisted outflows from a central reservoir (Temi et al. 2007). No significant correlation with the X-ray may be explained by considering that the current amount of surviving PAHs and dust is strongly dependent on the time when they were replenished by such an event as encounter with a gas-rich galaxy or feed-back outflow from a center, since their lifetime against sputtering destruction is very short ($< 10^7$ yr).

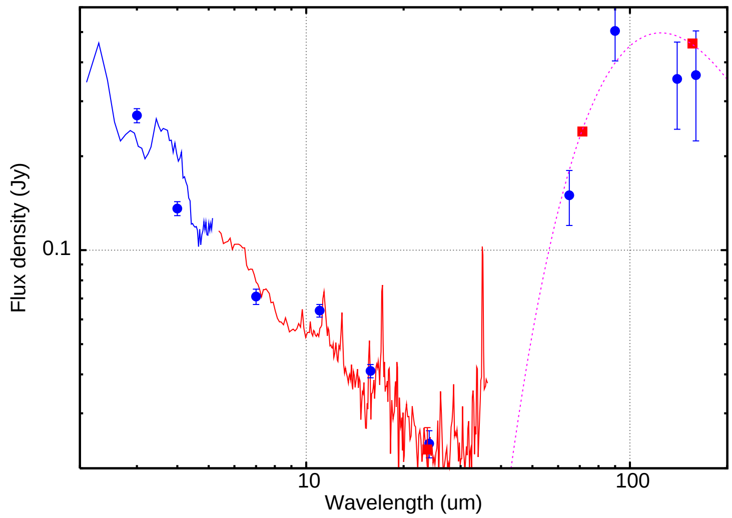

Fig. 3.— Near- to far-IR spectrum of NGC4589, constructed from the *Spitzer*/IRS mid-IR (5-35 μm) and the *AKARI*/IRC near-IR (2-5 μm) spectroscopic data in combination with the *AKARI* (circles) and *Spitzer*/MIPS (boxes) photometric data. The spectroscopic data are matched to the photometric data.

4. Summary

With *AKARI*, we observed about 80 nearby galaxies in order to study the properties of interstellar dust and gas under various environments. Among them, we have reported on some of our recent results for 20 nearby early-type galaxies, which are combined with those with *Spitzer*. We have detected PAHs and extended dust emissions from many of our sample galaxies. Most of those galaxies have a peculiar PAH emission spectrum with unusually strong 11.3 μm and 17 μm features relative to the 7.7 μm feature. Some of the elliptical galaxies observed with *AKARI* also exhibit the presence of 3.3 μm PAH emission feature. On the basis of these results, we have concluded that the unusual PAH emission features are attributed mostly to a large fraction of neutral to ionized PAHs in the interstellar space of the elliptical galaxies. In addition to the unusual PAH features, a series of H_2 rotational lines as well as ionic fine-structure lines are detected from a large fraction of the elliptical galaxies, implying the presence of warm (>200 K) molecular and ionized gases. Near-IR absorption features such as CO_2 ice at 4.3 μm are also detected in some elliptical galaxies.

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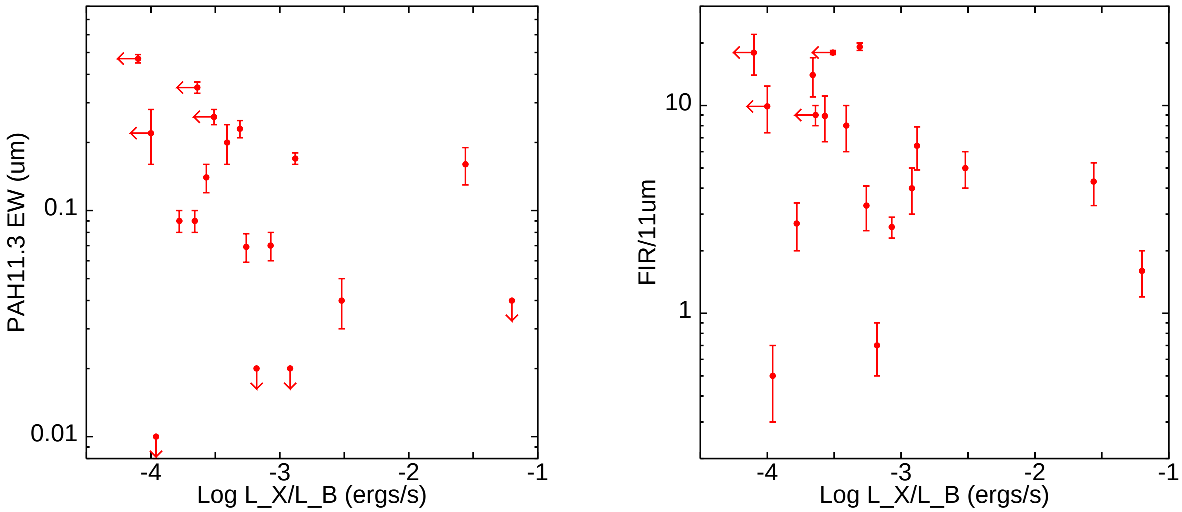

Fig. 4.— Equivalent width of the PAH 11.3 μm feature (left) and the far-IR/11 μm continuum ratio (right), plotted agaisnt the X-ray over blue luminosity for each galaxy.

based on observations made with the *Spitzer* Space Telescope, which is operated by the Jet Propulsion Laboratory, California Institute of Technology under NASA contract 1407.

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