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A SYSTEMATIC STUDY OF DUST IN EARLY-TYPE GALAXIES WITH AKARI

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ABSTRACT

Early-type galaxies (ETGs) are generally dominated by old low-mass stars, which are not very productive of dust, and hot interstellar plasmas, which are very destructive of dust. Thus ETGs provide harsh environments for survival of dust. It has been found that some ETGs contain a large amount of dust, and yet its supply mechanism is not understood well. We present the result of a systematic study of dust in ETGs with the AKARI mid- and far-infrared all-sky surveys. From the AKARI result and the Ks band data obtained by ground-based telescopes, we find that there is a global correlation between the dust mass and stellar luminosity. We also compare the AKARI all-sky survey result with the CO data to discuss origins of dust in ETGs.

Key words: galaxies: elliptical and lenticular, cD; galaxies: ISM; infrared: galaxies; ISM: dust, extinction

1. INTRODUCTION

Early-type galaxies (ETGs) have been thought to be poor in dust, because their interstellar space is dominated by hot X-ray plasma, which destroys dust through sputtering on typical timescales of 10^6–10^7 yr (Draine & Salpeter, 1979), and old stellar populations, which cannot efficiently supply ETGs with dust. However, in spite of such harsh conditions for survival of dust, recent infrared (IR) observations, including Spitzer, AKARI, and Herschel, have revealed that ETGs possess appreciable amounts of dust, and even polycyclic aromatic hydrocarbons, which can be easily destroyed by sputtering as compared to dust grains (Kaneda et al., 2008).

It is likely that stellar mass loss from old stars alone cannot replenish the amount of dust detected from the ETGs. Hence, other supply sources, such as merger events and cooling flows, are proposed, although they are still controversial. In this paper, we present the result of a systematic study of dust in ETGs with the AKARI all-sky survey, and discuss its origin comparing the AKARI result with the CO and K_s band data.

2. SAMPLE AND OBSERVATIONS

In order to investigate the properties of dust in ETGs, we analyzed the data derived with the AKARI mid- and far-IR all-sky surveys for our ETG sample. The sample is composed of the elliptical and lens galaxies listed in Knapp et al. (1989), from ∼50% of which the IRAS satellite detected cool dust emission in the 60 and 100 μm bands. We also include the ATLAS^{3D} galaxies, a volume-limited sample, selected based on morphology to cover every type of ETGs (Cappellari et al., 2011). Knapp et al. (1989) and the ATLAS^{3D} sample contain 1152 and 260 ETGs, respectively, in which 176 ETGs are overlapped. We used the results of the AKARI all-sky survey in the 9, 18, 90, and 140 μm bands for the sample galaxies (Ishihara et al., in prep; Doi et al., 2015), and performed aperture photometry in each band to obtain their fluxes. An aperture radius of the photometry is fixed at $10'$ for the galaxies listed in Knapp et al. (1989). For the ATLAS^{3D} galaxies, we define photometry apertures based on the half-light effective radius listed in Cappellari et al. (2011).

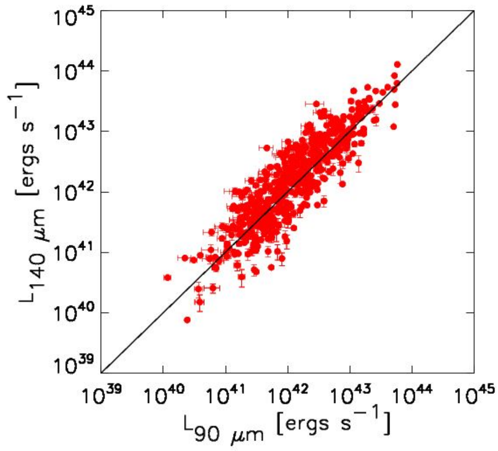

Figure 1. Correlation plot between the 90 and 140 μm luminosities derived with the AKARI all-sky survey for our total sample of early-type galaxies.

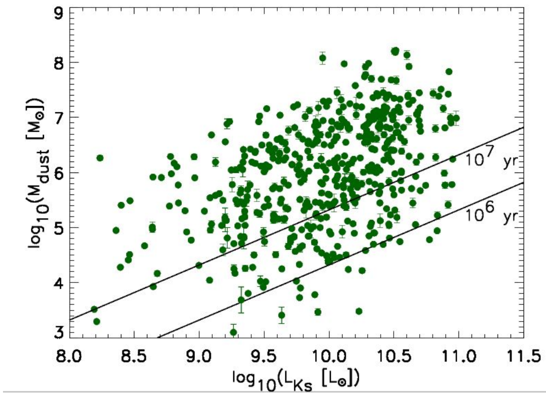

Figure 2. Dust masses of our total sample, plotted against the K_s band luminosities. The lines show the dust masses expected for the sample galaxies, estimated by considering supply from old stars and destruction by X-ray plasma on the denoted timescales.

3. RESULTS AND DISCUSSION

Figure 1 shows a correlation plot between the 90 and 140 μm luminosities for our total ETG sample. The number of ETGs reliably detected in the AKARI far-IR bands is 390 out of 1152 ETGs of Knapp et al. (1989). As can be seen in the figure, the 90 and 140 μm luminosities correlate well with each other. From the 90 μm to 140 μm colors, the temperatures of cold dust are estimated to be in a range of 15 K to 45 K.

Figure 2 shows the dust masses estimated with Equation (2) of Goudfrooij & de Jong (1995); we use the 90 μm flux and the cold dust temperature for the galaxies reliably detected in the AKARI far-IR bands, as a function of the K_s band luminosity derived from the 2MASS extended source catalogue (Skrutskie et al., 2006). The lines in the figure represent the dust masses expected for the galaxies, estimated by considering a balance between supply from old stars and destruction by X-ray plasma on the denoted timescales (Knapp et al., 1992). The figure shows that most of the ETGs have excess dust, and the two quantities are correlated, which may indicate that dust supplying sources are related to galaxy evolution, although their dependence on the distance can make such a trend. In general, ETGs are thought to evolve through mergers, which can cause excess of dust in ETGs. However, judging from the present uniform distribution of stars in ETGs, the mergers seem to have taken place typically $\gtrsim 10^9$ yr ago (e.g., Bournaud et al., 2008), two orders of magnitude longer than the lifetime of dust in X-ray plasma. Thus dust should have been completely destroyed by X-ray plasma in mature ETGs (i.e., ETGs with smooth stellar distributions) of our sample. Therefore there are likely to be other sources which provide ETGs with dust at present.

We also compare the AKARI result with the data obtained by the CO (J=1-0) line survey performed with the IRAM 30-m telescope for the ATLAS^{3D} galaxies (Young et al., 2011). For the CO non-detected galaxies (CO line fluxes are below 3σ), we find that there are correlations between the 9, 18, 90, and 140 μm luminosities and the K_s band luminosity. In contrast, many of the CO-detected galaxies show significant excess in the IR luminosities from the above correlations, implying some connection between the molecular gas and dust in ETGs. Figure 3 demonstrates this trend for the 18 μm luminosity. In addition, we find that the spectral energy distributions of the IR excess have hotter colors (i.e., higher mid- to far-IR ratios) than those of the star forming galaxies, NGC 253 and M 82, indicating that the excess is unlikely of star formation origins. One possibility to explain this result is that a significant fraction of dust in ETGs may reside in central regions around the galactic nuclei which heat the dust.

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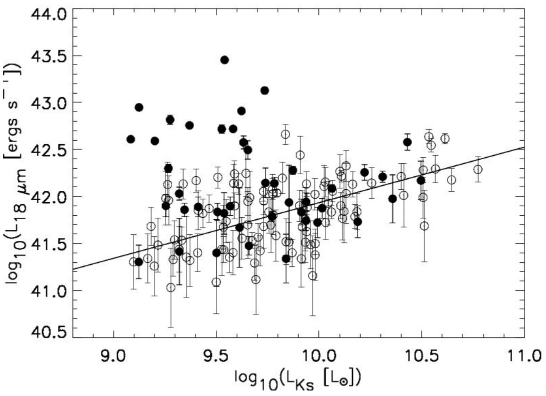

Figure 3. Correlation plot between the 18 μm luminosity and the K_s band luminosity for the ATLAS^{3D} galaxies. Filled circles show the galaxies detected in CO, while open circles show those not detected in CO. The line is fitted to the data points of the CO non-detected galaxies.

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