Mid-Infrared Observations of the Dwarf Galaxy NGC 1569 with AKARI*

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ABSTRACT

We report the results of recent near- to mid-infrared imaging and spectroscopic observations of the starburst dwarf galaxy NGC 1569 with the Infrared Camera (IRC) on board *AKARI*. Infrared imaging observations with 6 bands of the IRC (3, 4, 7, 11, 15, and 24 μm) indicate that super star clusters (SSCs) are faint at 7 μm (S7 band) relative to 15 and 24 μm, while a structure associated with a Hα filament is clearly seen at S7. Since the S7 band efficiently probes the 6.2 and 7.7 μm unidentified infrared (UIR) band emissions, which are attributed to polycyclic aromatic hydrocarbons (PAHs), the filament should contain an appreciable amount of PAHs. Follow-up observations of near- to mid-infrared spectroscopy (2–13 μm) also with the IRC indeed confirm the presence of the 6.2, 7.7, and 11.2 μm band features in the filament for the first time. The spectrum has a strong 11.2 μm band relative to the 7.7 μm band compared to that of SSC A taken with IRS on *Spitzer*. The filament encloses the X-ray emitting gas and is thought to be created by the outflow from the galaxy. Because the destruction time scale of PAHs in the plasma gas is quite short, it is suggested that the PAHs in the filament are produced from the fragmentation of large carbonaceous grains in the shock. The near-infrared spectrum also suggests the presence of excess emission in 3–5 μm in the filament for the first time, which may come from very small grains.

Subject headings: galaxies: ISM — infrared: galaxies — infrared: ISM — dust, extinction — galaxies: individual (NGC 1569)

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1. Introduction

The unidentified infrared (UIR) bands, whose major features appear at 3.3, 3.4, 6.2, 7.7, 8.6, and 11.2 μm, are ubiquitously seen in the diffuse Galactic radiation and external galaxies (Onaka et al. 1996; Mattila et al. 1996; Helou et al. 2000). They are also seen even in distant galaxies (Lutz et al. 2005) and thus will be a useful means for the study of physical conditions of remote objects if we correctly understand its properties. The UIR bands are thought to originate from the emitters or emitting atomic groups containing polycyclic aromatic hydrocarbons (PAHs) or PAH-like atomic groups of carbonaceous materials although the exact nature of the band carriers has not yet been understood completely (Léger & Puger 1984; Allamandola et al, 1985; Sakata et al. 1984; Papoular et al. 1989). While asymptotic giant branch (AGB) stars are one of the major sources of the band carriers (Galliano et al. 2008), they may also be formed by fragmentation of large carbonaceous grains (Jones et al. 1996; Greenberg et al. 2000). The carriers are efficiently destroyed by interstellar shocks (Jones et al. 1996). It is therefore a quite interesting question where and how the band carriers are produced and processed in a galaxy. Particularly interesting are their distribution and properties in active environments or low-metallicity galaxies since their characteristics may represent just-born galaxies.

In this paper we report the results of infrared imaging and spectroscopic observations of the dwarf galaxy NGC 1569 with the Infrared Camera (IRC) on board *AKARI* satellite. *AKARI* is the Japanese satellite mission fully dedicated to infrared astronomy (Murakami et al. 2007). As part of the interstellar and nearby galaxy (ISMNG) study of the *AKARI* mission program (Kaneda et al. 2008), several dwarf galaxies were observed in the pointing observation mode with the IRC (Onaka et al. 2007). NGC 1569 is a nearby starburst dwarf galaxy with the metallicity of about a quarter of solar (Kobulnicky & Skillman 1997). It is known to have several super star clusters (SSCs) and the recent starburst event is estimated to have occurred about 10 Myr ago (Galliano et al. 2003). Several Hα filaments are detected (Hunter et al. 1993), which delineate the X-ray emission, suggesting the presence of superbubles resulting from significant mass flow from the galactic disk that interacts with the surrounding gas and produces the Hα emitting shocked gas (Martin 1998; Martin et al. 2002). HI observations further suggest the presence of HI inflow from an external source (Stil & Israel 1998; Mühle et al. 2005). The Hα filaments in the southern and western regions may come from the interaction of the outflow with the incoming HI flow. ISOCAM observations indicate that the UIR bands are indicated to be present ubiquitously in the entire galactic disk of NGC 1569 (Madden et al. 2006). We report here the detection of the UIR bands in one of the Hα filaments, which will be discussed in relation to the possible supply source of the band carriers.

2. Observations

NGC 1569 was observed in the imaging and spectroscopic modes of the IRC (Onaka et al. 2007). The imaging observations were carried out with the 3 (N3), 4 (N4), 7 (S7), 11 (S11), 15 (L15), and 24 μm (L24) bands on 2006 September 9, whereas the spectroscopic observations were made for 2–13 μm with the spectral resolution of about 20–40 on 2007 March 8. In the present observations, the slit spectroscopy with the prism mode in the near-infrared (2–5 μm) and the grism mode in the mid-infrared (5–13 μm) were employed. For details of the IRC spectroscopy modes, refer to Ohyama et al. (2007).

The imaging data were processed with the standard IRC imaging toolkits and all the band images are convolved with the 3″ Gaussian beam to have the same spatial resolution. Fig. 1 shows the *AKARI* 6-band images of NGC 1569. The 7 μm (S7) image shows a filamentary structure at the west end of the disk, which well correlates with the Hα emission. A similar structure is not well recognized in the 15 μm image. Since the 7 μm band covers the UIR 6.2 and 7.7 μm very efficiently (Sakon et al. 2007), this result indicates a possible presence of the UIR bands in the filament.

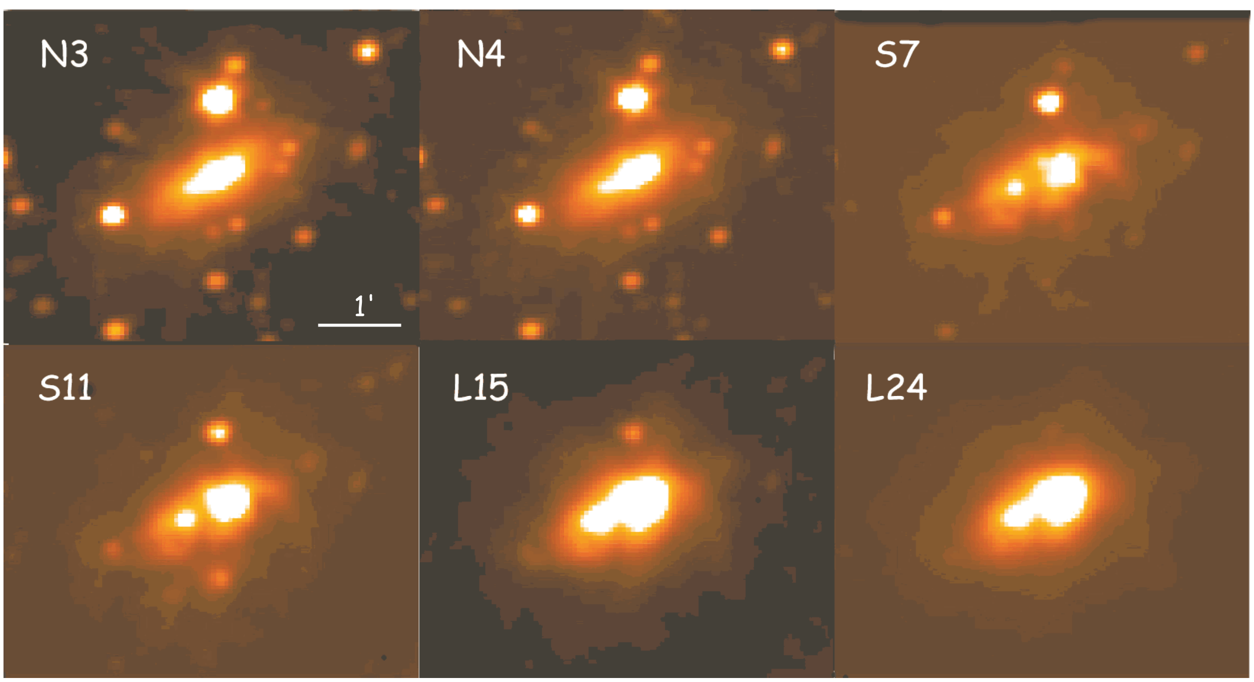

Fig. 1.— *AKARI* 6-band images of NGC 1569. From the top left to the bottom right, shown are 3 (N3), 4 (N4), 7 (S7),11 (S11), 15 (L15), and 24 (L24) μm images. The size of all the images is $5' \times 4'$.

The subsequent spectroscopic observation was executed to confirm the UIR bands in the filament. The slit was located on the filament near the disk as shown in Fig. 2. The spectroscopic data were also processed with the standard IRC spectroscopy toolkits and the spectrum of NGC 1569 filament was derived by subtracting the spectrum of the west edge of the slit to remove the contribution from the zodiacal light and the Galactic emission. The thus derived spectrum is shown in Fig. 3a. It clearly shows the presence of the UIR bands at 6.2, 7.7, and 11.2 μm. There may be weak emission at 8.6 μm, but the detection is marginal.

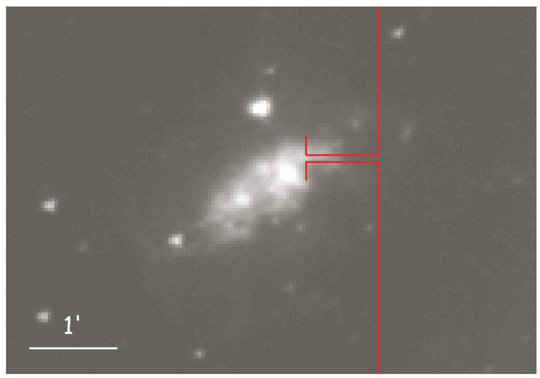

Fig. 2.— Slit position indicated by the red lines on the 7 μm image.

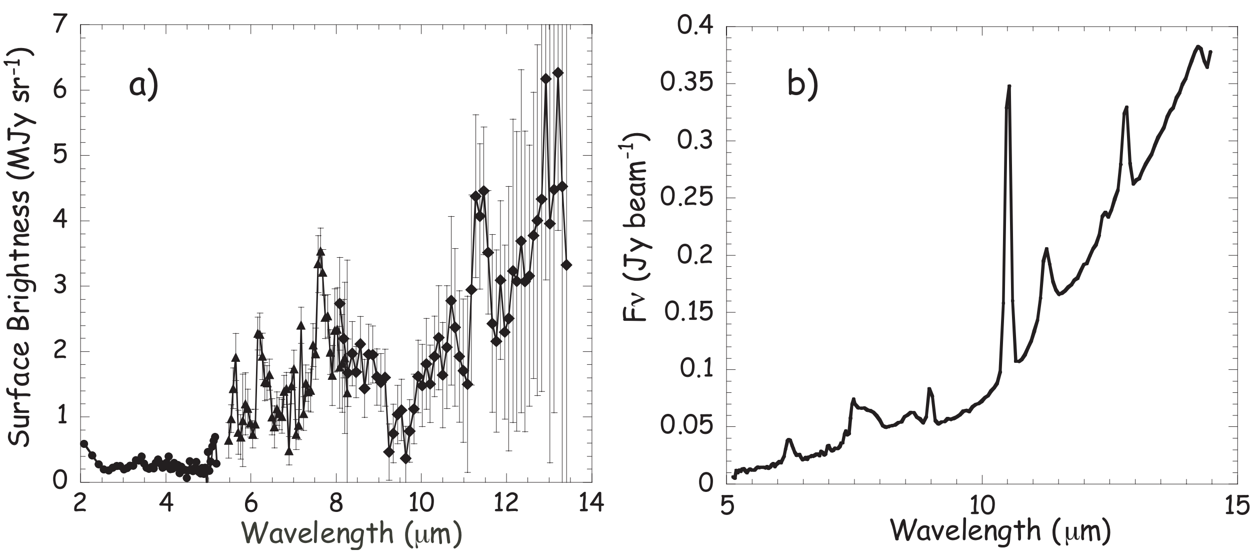

Fig. 3.— (a) IRC spectrum of the filament of NGC 1569 and (b) IRS spectrum of the disk of NGC 1569 (Tajiri et al. 2008).

3. Discussion

Recent studies indicate the presence of the UIR bands in halos of galaxies (Irwin & Madden 2006; Irwin et al. 2007) or in filaments produced by outflows (Tacconi-Garman et al. 2005) based on infrared imaging observations. Whereas Engelbracht et al. (2006) have detected the UIR bands of the 17 μm complex in a filament of M82, the present observations spectroscopically detect the UIR bands at 6.2, 7.7, and 11.2 μm at a position off the galactic disk for the first time. The detected 7 μm emission shows a strong similarity to the Hα emission. Since PAHs are easily destroyed in the hot plasma, the emission must come from the PAHs that are formed in the shocked region. Thus it seems to be most likely that the PAHs are formed in the shocks by fragmentation of large carbonaceous grains. It is unlikely that the inflowing HI gas carries a significant amount of carbonaceous grains since there is no indication of the infrared emission associated with the inflow. Therefore, the large carbonaceous grains should be carried by the outflow from the galaxy.

The IRC spectrum of the filament can be compared with the IRS spectrum taken at the NGC 1569 disk, which includes the super star cluster A (Fig. 3b). The mid-infrared emission is very strong in the NGC 1569 disk compared to the filament, which is attributed to the larger contribution of emission from very small grains in active star-forming regions in the disk (cf. Sakon et al. 2006). It is also suggested that the band ratio of the 7.7 to 11.2 μm is larger in the disk than in the filament. This ratio is thought to indicate the ionization degree of PAHs (cf. Sakon et al. 2007). The low ratio may be attributed to the low ionization degree in the filament.

Fig. 4 shows an enlargement of the near-infrared spectrum. It suggests the presence of a series of hydrogen recombination lines as well as the UIR 3.3 μm band, although the detection needs to be confirmed by further observations. It also indicates the presence of the excess continuum emission, which cannot be attributed to the stellar emission. A similar excess emission has been indicated in external galaxies (Lu et al. 2003) as well as in the diffuse Galactic emission (Flagey et al 2007). The present observations indicate that similar excess emission also exists in the filament.

4. Summary

Infrared imaging observations of the starburst dwarf galaxy NGC 1569 with *AKARI* /IRC indicates the presence of the UIR bands as well as excess continuum emission in the near-infrared at one of the Hα filaments for the first time. The presence of the UIR bands at 6.2, 7.7, and 11.2 μm is confirmed by subsequent spectroscopic observations with the IRC.

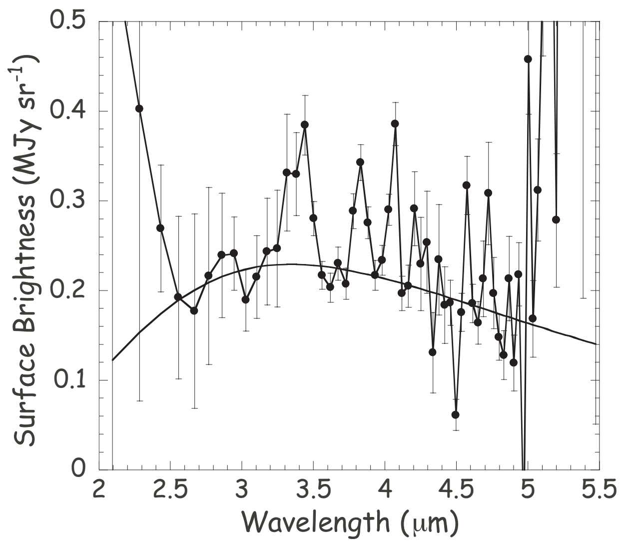

Fig. 4.— NIR spectrum of the filament of NGC 1569. The solid line indicates the fit of the Planck function of $T = 868\,\mathrm{K}$ with the λ^{-2} emissivity.

The band ratio of 7.7 to 11.2 μm seems to be smaller than that in the galaxy disk, suggesting a lower ionization degree in the filaments. PAHs are rapidly destroyed in superbubbles and thus there must be supply sources in the filament. Fragmentation of large carbonaceous grains in shocks appears to be the most likely source for the PAHs in the filament.

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