*The Magellanic System: Stars, Gas, and Galaxies*
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# *AKARI* IRC survey of the Large Magellanic Cloud: A new feature in the infrared color—magnitude diagram

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**Abstract.** We observed an area of 10 deg$^2$ of the Large Magellanic Cloud using the Infrared Camera on board *AKARI*. The observations were carried out using five imaging filters (3, 7, 11, 15, and 24 $\mu$m) and a dispersion prism ($2 - 5\,\mu$m, $\lambda/\Delta\lambda \sim 20$) equipped in the IRC. The 11 and 15 $\mu$m data, which are unique to *AKARI* IRC, allow us to construct color-magnitude diagrams that are useful to identify stars with circumstellar dust. We found a new sequence in the color-magnitude diagram, which is attributed to red giants with luminosity fainter than that of the tip of the first red giant branch. We suggest that this sequence is likely to be related to the broad emission feature of aluminium oxide at 11.5 $\mu$m.

**Keywords.** stars: AGB and post-AGB, circumstellar matter, stars: mass loss, galaxies: individual (LMC), Magellanic Clouds

## 1. Introduction and observations

The Japan Aerospace Exploration Agency launched an Infrared Satellite, *ASTRO-F* (Murakami *et al.* 2007) at 21:28 UTC on February 21st, 2006 from the Uchinoura Space Center. Once in orbit *ASTRO-F* was renamed "AKARI". *AKARI* has a 68.5 cm telescope and two scientific instruments, namely the InfraRed Camera (IRC; Onaka *et al.* 2007) and the Far-Infrared Surveyor (FIS; Kawada *et al.* 2007). Both instruments have low- to moderate-resolution spectroscopic capability. The IRC has nine imaging bands and six dispersion elements covering from 2.5 to 26 $\mu$m wavelength range (Unfortunately, one of the dispersion elements that was expected to cover 11 to 19 $\mu$m range became opaque during the ground test operation, and defunct in orbit). The FIS observes in 4 far-infrared bands between 50 and 180 $\mu$m. One of the primary goals of the *AKARI* mission is to carry out an All-Sky survey with FIS and IRC at six bands from 9 to 180 $\mu$m (Ishihara *et al.* 2006; Kawada *et al.* 2007). As a result, the entire LMC has been mapped in 9, 18, 65, 90, 140, and 160 $\mu$m wavebands.

In addition to the All-Sky survey in mid- and far-infrared, *AKARI* carried out two large-area legacy surveys (LS) in pointed observation mode. The LMC survey project (PI. T.Onaka) is one of the two LS programs. The other is the North Ecliptic Pole survey project (PI. H.Matsuhara; Matsuhara *et al.* 2007). These survey areas are located at high ecliptic latitudes, where the visibility is high for *AKARI*'s sun-synchronous polar orbit. Therefore a batch of observing time can be allocated for pointed observations in these areas after allocating scan paths for the All-Sky survey. Using the opportunities we use the IRC to make imaging and spectroscopic mapping observations of the main part of the LMC. To cover a wide range of the spectral energy distribution of a celestial body, we obtained not only imaging data at 3 (N3), 7 (S7), 11 (S11), 15 (L15), and 24 $\mu$m (L24), but also low resolution ($\lambda/\Delta\lambda \sim 20$) 2.5 − 5 $\mu$m (NP) spectral data at three dithered sky positions in a pointing opportunity. Details of the observations, data reduction procedures, and some initial results are described in Ita *et al.* (2008). Some first results on the spectroscopic data are presented in Shimonishi *et al.* (2008), and Shimonishi *et al.* in this volume.

## 2. Preliminary catalog

We constructed a preliminary photometric catalog of bright point sources for the LMC from the imaging data. More than $5.9 \times 10^5$ near-infrared and $6.4 \times 10^4$ mid-infrared point sources are detected. The $10\sigma$ detection limits of our survey are about 16.5, 14.0, 12.3, 10.8, and 9.2 in Vega-magnitude at 3, 7, 11, 15, and 24 $\mu$m, respectively. These detection limits are comparable to those of the *Spitzer* SAGE survey (Meixner *et al.* 2006). The IRC's imaging filters cover the wavelength range continuously from 2.5 to 26 $\mu$m. In particular, it has 11 $\mu$m (S11) and 15 $\mu$m (L15) imaging bands, which fill the gap between IRAC (Fazio *et al.* 2004) and MIPS (Rieke *et al.* 2004) on board *Spitzer*. The wavelength range that IRC's S11 and L15 bands cover contains interesting spectral features such as the silicate 10 and 18 $\mu$m bands. In addition, we took 2 − 5 $\mu$m low resolution spectra ($\lambda/\Delta\lambda \sim 20$ at around 3 $\mu$m) for all bright stars that are detected. These characteristics make our survey unique and complementary to the SAGE survey. Refer to Onaka *et al.* (2007) for instrumental details and imaging performance of the IRC. General information on the IRC spectroscopic mode, particularly on the slit-less spectroscopy, is given in Ohyama *et al.* (2007). The first *AKARI*/IRC LMC point source catalog is planned to be released to the public in 2009.

## 3. Infrared color-magnitude diagrams

The preliminary catalog was cross-identified with the *IRSF*/SIRIUS Magellanic Clouds Point Source Catalog (Kato *et al.* 2007), which contains JHK$_s$ photometry of over $1.4 \times 10^7$ sources in the central 40 deg$^2$ area of the LMC. Compared to the contemporary DENIS (Cioni *et al.* 2000a) and 2MASS (Skrutskie *et al.* 2006) catalogs, the *IRSF* catalog is more than two magnitudes deeper at K$_s$-band and about four times finer in spatial resolution.

In figure 1, we show infrared color-magnitude diagrams using *AKARI* IRC and SIRIUS bands. Units of vertical axes are the apparent magnitudes. It can be scaled to the absolute magnitude by subtracting the distance modulus. The corresponding wavebands for the vertical axes are indicated at the top of each panel. The employed colors for the horizontal axes are indicated at the bottom of each panel. All of the color-magnitude planes are binned by $0.1 \times 0.1$ mag$^2$ to calculate the number of sources in each bin, and the fiducial color is given according to the number density levels in a logarithmic scale (see the wedge at the bottom).

The (K$_s$ − S11) vs. K$_s$ panel indicates which red giants show circumstellar dust emission. It is clear that excess in S11 ($K_s - S11 > 0.5$ mag) is seen not only among the sources brighter than the tip of the first red giant branch (TRGB, $K_s \sim 12.5$ mag, Cioni *et al.* 2000b), but also among the sources below the TRGB. Since the brighter sources exceed the K$_s$ luminosity of the TRGB, they should be an intermediate-age population and/or metal-rich old population AGB stars. On the other hand, the interpretation of the fainter sources is difficult. They can be metal-poor and old AGB stars that do not

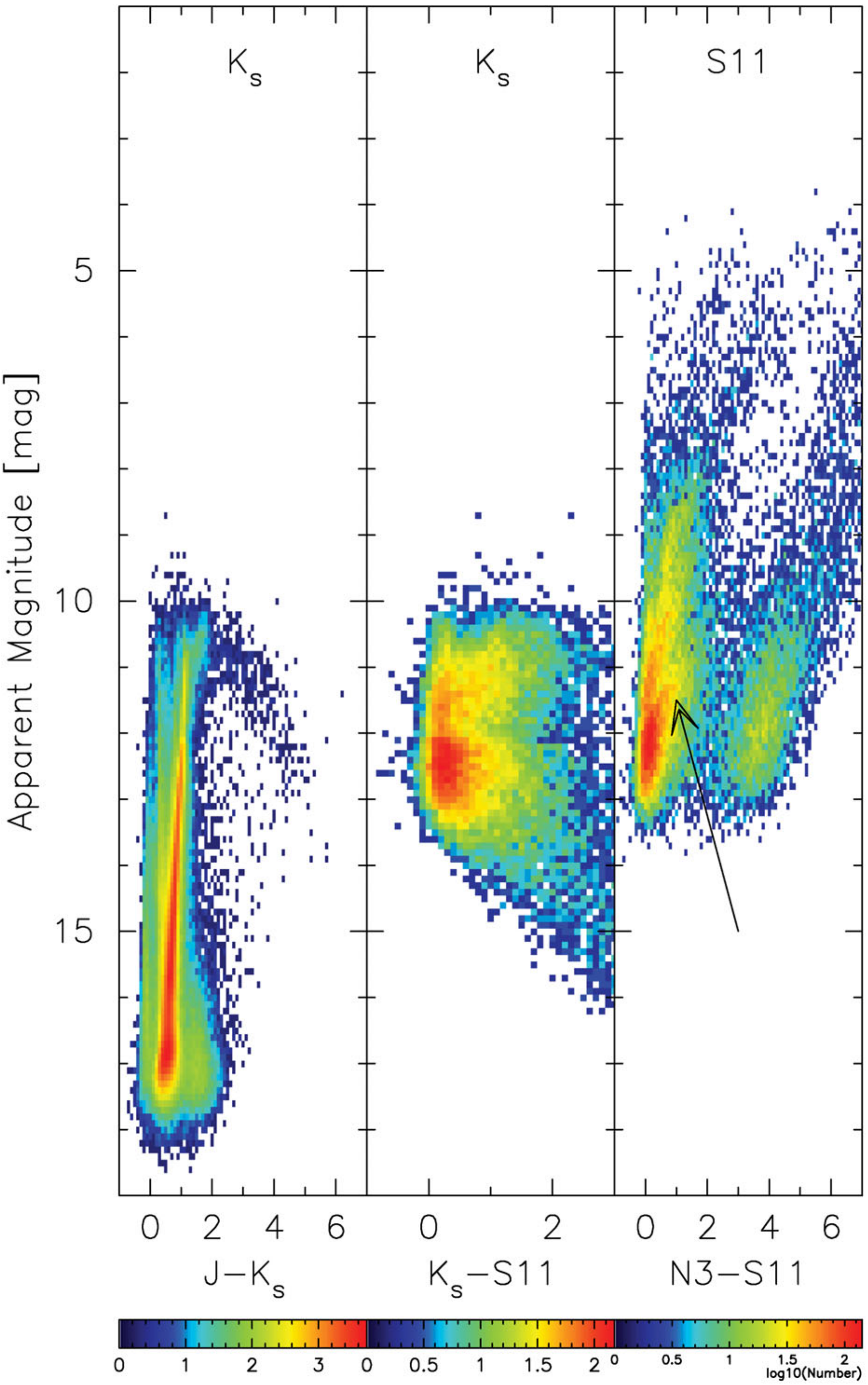

**Figure 1.** Color magnitude diagrams of *AKARI* LMC sources using several combinations of IRC and *IRSF*/SIRIUS bands. The vertical axis is in apparent magnitude at the corresponding wavebands, which are indicated at the top of each panel. The arrows indicate the newly found feature, which is attributed to the red giants that have luminosities below the tip of the first red giant branch.

exceed the TRGB luminosity, or red giants on the first red giant branch (i.e., RGB stars). It is well known that the number ratio of AGB to RGB stars near the TRGB should be about 1/3 for the intermediate age stars (Renzini 1992). Thus, there are more RGB populations below the TRGB. Ita *et al.* (2002) pointed out the possible existence of variable stars on the first red giant branch, which had been commonly believed as a non-variable population. They found many variable stars with luminosities fainter than that of the TRGB, and concluded that a substantial fraction of them could be RGB variables.

Evidence for the mass-loss from the fainter sources is also seen in other panel. We see a bristle-shaped feature in (N3 − S11) vs. S11 panel, which is indicated by the arrow. What makes the bristle-shaped feature? Lebzelter *et al.* (2006) obtained low-resolution mid-infrared (7.6–21.7 $\mu$m) spectra of a star (V13) in the NGC 104 with *Spitzer*. The $K_s$ band luminosity of the star is fainter than the TRGB luminosity of NGC 104. They showed that the star is devoid of the 9.7 $\mu$m emission band feature of amorphous silicate, but it has broad emission features at 11.5 $\mu$m (likely to be amorphous $Al_2O_3$, or alumina) and 13 $\mu$m (likely to be crystalline $Al_2O_3$, or corundum). The IRC S11 band includes all of these emission features. Therefore, the feature indicated by the arrow in the (N3 − S11) vs. S11 panel may be attributed to the red giants with aluminium oxide dust but without the silicate feature.

Aluminium oxide features have been detected from low mass-loss rate oxygen-rich red giants (Onaka *et al.* 1989, Kozasa & Sogawa 1997). Dijkstra, Speck & Reid (2005) found that the dust mineralogy changes from an amorphous alumina and amorphous olivine mixture into an amorphous silicate-only composition with increasing mass-loss rate. Circumstellar dust condensation models (e.g., Tielens 1990) predicted that $Al_2O_3$ is the first solid to condense in the gaseous outflows from oxygen-rich red giants. However, it is not known yet whether $Al_2O_3$ condenses directly or by adsorption onto $TiO_2$ seeds (e.g., Jeong, Winters & Sedlmayr 1999). Spectroscopic follow-up observations to identify the S11 excess with the $Al_2O_3$ band would be interesting. Also, we will study the relation between the variabilities found in the faint red giants and the TRGB stars with 11 $\mu$m excess.

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