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Recent results from the infrared satellite *AKARI*

Takashi Onaka[1*], Itsuki Sakon[1], Hideaki Fujiwara[1],
Takashi Shimonishi[1], Ho-Gyu Lee[1], Daisuke Ishihara[2],
Hidehiro Kaneda[2] and Yoko Okada[3]
[1]*Department of Astronomy, The University of Tokyo, Tokyo 113-0033, Japan*
[2]*Graduate School of Science, Nagoya University, Chikusa-ku, Nagoya 464-8602, Japan*
[3]*I. Physikalisches Institut, Universität zu Köln, Zülpicher Str. 77, 50937 Köln, Germany*

Abstract. *AKARI* is the second Japanese infrared satellite mission, which performed astronomical observations within the near- to far-infrared spectral range. It was launched on 2006 February 21 (UT) by the JAXA M-V rocket and brought into a sun-synchronous polar orbit at an altitude of 700 km. *AKARI* carried a 68.5 cm aperture telescope together with two focal-plane instruments that were cooled by 180 litres of super-fluid liquid Helium (LHe) and mechanical coolers. The focal-plane instruments consist of the Infrared Camera (IRC) and the Far-Infrared Surveyor (FIS). Thanks to the on-board cryocoolers the LHe lasted for 18 months and ran out on 2007 August 26. Until then *AKARI* carried out an all-sky survey at 9, 18, 65, 90, 140, and 160 μm together with more than 5000 pointing observations in the 2–180 μm band. After the LHe was exhausted, *AKARI* telescope was kept below 50 K by the on-board cryocooler and near-infrared observations continued. This paper gives an overview of the *AKARI* mission together with some recent results.

Keywords : space vehicles – *AKARI* satellite – all-sky survey – infrared observations

[*]e-mail: onaka@astron.s.u-tokyo.ac.jp

1. Introduction

Following the successful observations of the Infrared Telescope in Space (IRTS) on board the Space Flyer Unit in 1995 (Murakami et al. 1996), *AKARI*, the second Japanese infrared mission, formerly known as ASTRO-F, was launched on 2006 February 21 (UT) to carry out observations in the infrared wavelengths of 2–180 μm. It was brought into a sun-synchronous polar orbit at an altitude of approximately 700 km and an inclination of 98.2 deg by the JAXA M-V rocket (Murakami et al. 2007). *AKARI* carries a Ritchey-Chrétien-type telescope with a primary-mirror effective aperture of 685 mm (Kaneda et al. 2007a). It has two focal-plane instruments: the Infrared Camera (IRC) for the near- to mid-infrared (NIR and MIR) band (Onaka et al. 2007) and the Far-Infrared Surveyor (FIS) that works in the far-infrared (FIR) band (Kawada et al. 2007). The whole telescope and the focal-plane instruments were kept cold by 180 litres of super-fluid liquid Helium (LHe) and mechanical coolers (Nakagawa et al. 2007). The mechanical coolers reduced the LHe consumption significantly and the LHe lasted for about 18 months until 2007 August 26. After the LHe was exhausted, the telescope and instruments were kept below 50 K and NIR observations were continued thanks to the on-board cooler.

AKARI flies over the day-night boundary of the Earth or on the plane of the solar elongation angle of 90 degree in the sun-synchronous orbit with a period of about 100 min. With its telescope looking at the opposite direction to the Earth center and avoiding the sun shine coming into the telescope, *AKARI* performed an all-sky survey in the course of the 18-month cold mission at 9, 18, 65, 90, 140, and 160 μm, which surpasses the 25-year old *IRAS* all-sky survey database (Neugebauer et al. 1984) in sensitivity, spatial resolution, and spectral coverage. *AKARI* also has the capability to make pointed observations at a given target for approximately 10 min for imaging and spectroscopy from 2 to 180 μm. The pointing mode requires about 20 min for maneuvering the satellite and 3 pointing observations can be executed in one orbital period at a maximum. The attitude control system allows operations within $\pm 1^\circ$ degree from the solar elongation of 90° and thus the visibility is largely restricted. This paper gives an overview of the *AKARI* mission as well as some of the recent results of *AKARI* observations. Highlights of early *AKARI* observations can be found in Onaka (2009) and Onaka and Salama (2009). Early results have also been published in two special issues of Publications of the Astronomical Society of Japan (volumes 59 SP2 and 60 SP2) as well as in Onaka et al. (2009).

2. Telescope system and on-board instruments

2.1 Telescope

The *AKARI* telescope employs specially developed sandwich-type SiC mirrors. The cryogenic performance of the SiC mirrors has been extensively investigated at the ground facility at ISAS and confirmed to show negligible deformation at cryogenic temperatures (Kaneda et al. 2003). The actual telescope performance is dominated by the deformation due to the mirror supporting structure (Kaneda et al. 2005b). The in-flight performance is confirmed to be diffraction-limited at 7.3 μm in the cold mission phase after the operation of the secondary mirror adjustment in orbit (Kaneda et al. 2007a). The secondary mirror was adjusted again to correct for the movement due to warming up after the LHe was exhausted. The telescope performance in the warm mission becomes slightly worse and is diffraction-limited at about 8 μm as expected from the ground test (Onaka et al. 2008). Table 1 summarizes the basic characteristics of the *AKARI* telescope system.

Table 1. Characteristics of the *AKARI* telescope system.

Telescope type	Richey-Chrétien
Effective diameter of the primary mirror	685 mm
Mirror material	sandwich-type silicon carbide (SiC)
Total weight of the telescope system	30.56 kg
Weight of the primary mirror	10.7 kg
Focal length	4197.2 mm
Total effective collecting area	287042 mm^2
Performance in cold mission	diffraction-limited at 7.3 μm
Performance in warm mission	diffraction-limited at 8 μm

2.2 Focal-plane instruments

AKARI has two focal-plane instruments. The FIS is designed to carry out an all-sky survey at 4 FIR wavelengths with Ge:Ga and stressed Ge:Ga 2-dimensional rectangular arrays of about $10'$ wide (Kawada et al. 2007). It was also used in the pointing mode with a slow scan to perform high-sensitivity imaging observations (Shirahata et al. 2009). The FIS is equipped with a Fourier-transform spectrometer (FTS) (Kawada et al. 2008). The FIS-FTS was used in the pointing mode. The other instrument IRC comprises three channels, NIR, MIR-S, and MIR-L (Onaka et al. 2007). Each channel has a field-of-view of about $10' \times 10'$ and a 2-dimensional array of InSb (NIR) or Si:As (MIR-S and MIR-L). It was originally designed for pointing mode observations, but the MIR-S and MIR-L were also used for the all-sky survey observation with a specially developed array operation (Ishihara et al. 2006). Each channel has three band filters for imaging and two transparent dispersive elements (prism or grism) for spectroscopy (Ohyama et al. 2007), which are installed in a filter wheel. For the all-sky survey observations, the filters of the MIR-S and MIR-L channels were fixed at S9W (9 μm) and L18W (18 μm), respectively. The good stability of the IRC during the cold phase has been well demonstrated (Tanabé et al. 2008). The FIS and IRC can be operated simultaneously. In addition to the two instruments, two NIR focal-plane star sensors (FSTS-L and FSTS-S) were equipped to obtain accurate position information during the all-sky survey (Fig. 2).

The characteristics of the focal-plane instruments are summarized in Table 2 and also plotted in Fig. 1. Fig. 2 shows the focal plane layout. Each of the two bands (WIDE-S and WIDE-L, and N60 and N160) of the FIS observe almost the same sky position at the same time, whereas the NIR and MIR-S of the IRC share the same field of view and the MIR-S observes a sky about $20'$ from the NIR/MIR-L position. FIS, MIR-S, and MIR-L are not aligned along the scan direction. Thus an object was not observed by the three instruments in the same scan.

Table 2. Characteristics of the *AKARI* Focal-Plane Instruments.

Far-infrared Surveyor (FIS)	Imaging bands	N60(65 μm), WIDE-S(90 μm), WIDE-L(140 μm), and N160(160 μm)[a]
	Detectors	20×3 and 20×2 Ge:Ga arrays for N60 and WIDE-S 15×3 and 15×2 stressed Ge:Ga arrays for WIDE-L and N160
	Pixel pitch	$29.''5$ for N60 and WIDE-S and $49.''5$ for WIDE-L and N160
	Spectroscopy	Resolution $\Delta\nu = 0.19\,\mathrm{cm}^{-1}$
Infrared Camera (IRC)	Imaging bands	N2(2.4 μm), N3(3.2 μm), N4(4.1 μm) S7(7 μm), S9W(9 μm), S11(11 μm), L15(15 μm), L18W(18 μm), and L24(24 μm)
	Detectors	512×412 InSb array for NIR 256×256 Si:As arrays for MIR-S/L
	Pixel scale	$1.''46 \times 1.''46$ for NIR, $2.''34 \times 2.''34$ for MIR-S, and $2.''51 \times 2.''39$ for MIR-L
	All-sky survey[b]	S9W and L18W with the effective pixel scale of $10''$
	Spectroscopy	Resolution $\Delta\lambda = 0.01 - 0.17\,\mu$m

[a]All the 4 FIS bands are used in the all-sky survey.
[b]See Ishihara et al. (2006) for details.

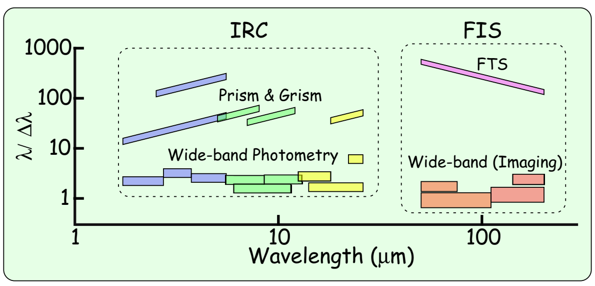

Figure 1. Wavelength coverage and spectral resolution of the IRC and FIS.

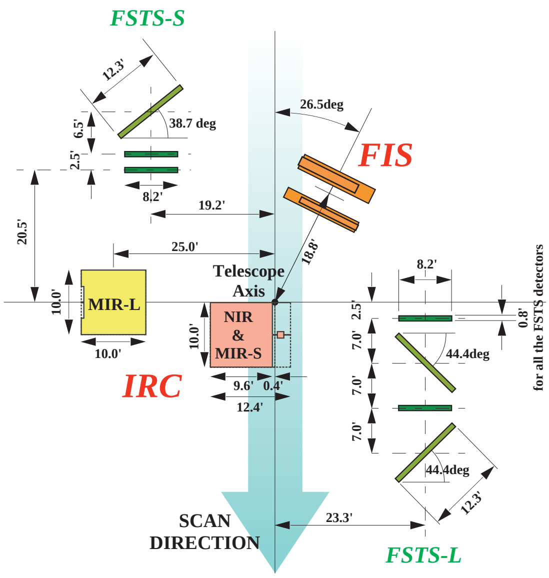

Figure 2. Focal-plane layout of *AKARI*. The scan direction in the all-sky survey is indicated by the large arrow. The field-of-view of WIDE-S and WIDE-L, and N60 and N160 overlap with each other as do NIR and MIR-S.

3. AKARI All-Sky Survey

AKARI All-Sky Survey was carried out with S9W (9 μm), L18W (18 μm), N60 (65 μm), WIDE-S (90 μm), WIDE-L (140 μm), and N160 (160 μm) bands. Fig. 3 shows the detected point sources in the All-Sky Survey and Fig. 4 plots the detection limits for point sources and the spatial resolution at the present stage of the data processing together with those of the *IRAS* database.

As indicated in Fig. 4, the disk of β Pic at 100 pc can be detected by

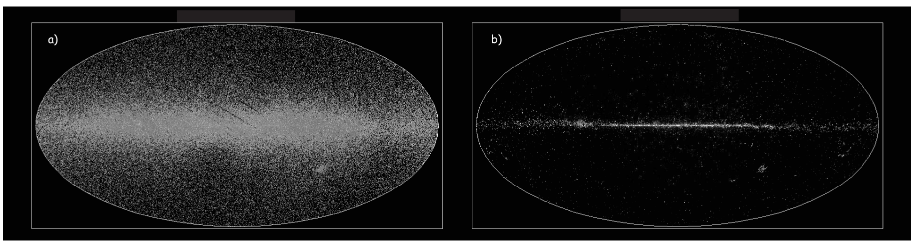

Figure 3. Distribution of point sources detected in the *AKARI* All-Sky Survey at 9 μm (a) and 90 μm (b) in the Galactic coordinates (provided by JAXA).

the *AKARI* All-Sky Survey at 9 and 18 μm. In fact, preliminary search for debris disks in the IRC All-Sky Survey has found several tens of candidate objects (Fujiwara et al. in prep.). Follow-up observations of one of the objects HD106797 with the Gemini-S confirm the *AKARI* detection and suggest that it may contain processed dust grains rather than amorphous silicates in their debris disk (Fujiwara et al. 2009).

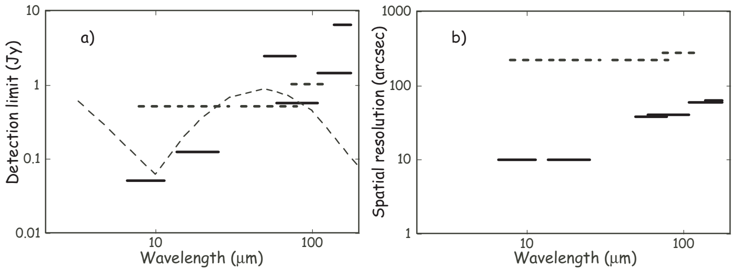

Figure 4. (a) Detection limit for point sources and (b) spatial resolution of the *AKARI* All-Sky Survey observations at the present stage of the data processing. The thick solid lines indicate *AKARI* All-Sky Survey and the thick dotted lines show those of the *IRAS* survey. The thin broken line in (a) indicates the expected flux of the debris disk object βPic at 100 pc. The spatial resolution of the 9 and 18 μm data can be improved by further processing of the data taken in an interlaced manner (Ishihara et al. 2006).

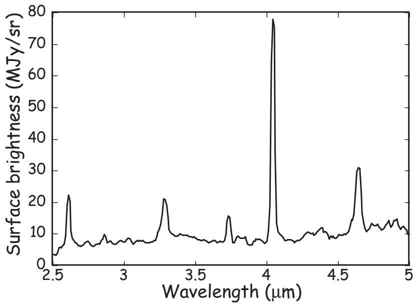

Figure 5. Example of the IRC NIR spectrum of a HII region taken during the warm mission phase. Strong emission features are mostly hydrogen recombination lines. The 3.3 μm UIR band is also clearly seen.

4. AKARI observations of Galaxies and Galactic objects

AKARI makes significant contributions to the study of Galactic objects. Thanks to its continuous spectral coverage, IRC observations clearly delineate the supernova ejecta and the circumstellar material in the supernova remnant G292.0+1.8 (Lee et al. 2009), whereas the imaging spectroscopic capability in the FIR of FIS-FTS enables us to do a detailed study of the physical properties of Galactic HII regions (Okada et al. 2009).

The Large Magellanic Cloud (LMC) is located in a high visibility zone for *AKARI* and about a 10 $\deg^2$ region of the LMC was surveyed with the IRC at 3, 7, 11, 15, and 24 μm together with the slitless prism mode in 2–5 μm (Ita et al. 2008). The data of 11 and 15 μm gave us unique information, which the *Spitzer* SAGE survey does not have (Meixner et al. 2006), suggesting a population of stars with 11 μm excess (Ita et al. 2008). The 15 μm data are also useful in the investigation of the nature of infrared emission from supernova remnants (Seok et al. 2008). The prism survey provides a powerful means to investigate the nature of detected sources. With the absorption features of water ice at 3 μm and CO_2 ice at 4.3 μm, young stellar objects can be unambiguously identified in the prism spectrum (Shimonishi et al. 2008), whereas carbon stars are easily recognized by their absorption features around 3.0 and 3.7 μm (Yamamura and de Jong 2000).

AKARI has also made interesting observations for other galaxies. The unidentified infrared (UIR) emission bands are ubiquitously seen in the diffuse Galactic radiation as well as in galaxies (e.g., Onaka et al. 1996, Helou et al. 2000). The UIR bands and the MIR continuum emission are a useful means to locate the star-formation site (Ishihara et al. 2007). However, the origin and destruction of the band carriers are not yet understood. *AKARI* observations indicate that the spatial distribution of the UIR band emission in elliptical galaxies has a strong correlation with submicron sized grains, suggesting their interstellar origin (Kaneda et al. 2008). MIR spectra of elliptical galaxies show that the usually strong 6.2 and 7.7 μm bands are very weak or absent despite the clear presence of the 11.3 μm band (Kaneda et al. 2005a). Whereas the MIR and UIR bands have been extensively studied with *ISO* and *Spitzer*, the shortest UIR band at 3.3 μm has not yet been investigated with sensitive instruments. The IRC provides a unique capability for NIR spectroscopy of high sensitivity (Ohyama et al. 2007). Kaneda et al. (2007b) report that the IRC spectrum of the elliptical galaxy NGC1316 shows no 3.3 μm band with the presence of the 11.3 μm band, suggesting that the band carriers are dominated by large and neutral species. Imanishi et al. (2008) employs the 3.3 μm UIR band for diagnosis of buried AGN based on the *AKARI* IRC NIR spectroscopy.

Thanks to the on-board cryocooler, the IRC NIR spectroscopy is being continued and further NIR spectroscopic observations are being executed. Fig. 5 shows an example of the IRC NIR spectrum of a HII region taken with the grism during the warm mission phase. It shows the 3.3 μm UIR band as well as several hydrogen recombination lines clearly, demonstrating the great power of the IRC NIR spectroscopy.

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References

Fujiwara H., Yamashita T., Ishihara D., et al., 2009, ApJL, 695, L88
Helou G., Lu N. Y., Werner M. W., et al., 2000, ApJL, 532, L21
Ishihara D., Wada T., Onaka T., et al., 2006, PASP, 118, 324
Ishihara D., Onaka T., Kaneda H., et al., 2007, PASJ, 59, S443
Ita Y., Onaka T., Kato D., et al., 2008, PASJ, 60, S435
Kaneda H., Onaka T., Kawada M., & Murakami H., 2003, App. Opt. 42, 708
Kaneda H., Onaka T., & Sakon I., 2005a, ApJL, 632, L83
Kaneda H., Onaka T., Nakagawa T., et al., 2005b, Appl. Opt., 44, 6823
Kaneda H., Kim W., Onaka T., et al., 2007a, PASJ, 59,, S423
Kaneda H., Onaka T., & Sakon I., 2007b, ApJL, 666, L21
Kaneda H., Suzuki T., Onaka T., et al., 2008, PASJ, 60, S467
Kawada M., Baba H., Barthel P. D., et al., 2007, PASJ, 59, S389
Kawada M., Takahashi H., Murakami N., et al., 2008, PASJ, 60, S389
Lee H.-G., Koo B.-C., Moon D.-S., et al., 2009, ApJ, 706, 441
Meixner M., Gordon K. D., Indebetouw R., et al., 2006, AJ, 132, 2268
Murakami H., Freund M. M., Ganga K., et al., 1996, PASJ, 48, L41
Murakami H., Baba H., Barthel P., et al., 2007, PASJ, 59, S369
Nakagawa T., Enya K., Hirabayashi H., et al., 2007, PASJ, 59, S377
Neugebauer G., Habing H. J., van Duinen R., et al., 1984, ApJL 278, L1
Ohyama Y., Onaka T., Matsuhara H., et al., 2007, PASJ, 59, S411
Okada Y., Kawada M., Murakami N., et al., 2010, A&A, 514, 13
Onaka T., Yamamura I., Tanabé T., et al., 1996, PASJ, 48, L59
Onaka T., 2009, Earth, Moon and Planets, 104, 337
Onaka T., Matsuhara H., Wada T., et al., 2007, PASJ, 59, S401
Onaka T., Kaneda H., Wada T., et al., 2008, Proc. SPIE, 7010, 70102X
Onaka T., & Salama A., 2009, Exper. Astron. 27, 9
Onaka T., White G.J., Nakagawa T., & Yamamura I. (eds.), 2009, Proc. of *AKARI*, a Light to Illuminate the Misty Universe, ASP Conf. ser 418, in press
Seok J.-Y., Koo B.-C., Onaka T., et al., 2008, PASJ, 60, S543
Shimonishi T., Onaka T., Kato D., et al., 2008, ApJL, 686, L99
Shirahata M., Matsuura S., Hasegawa S., et al., 2009, PASJ, 61, 737
Tanabé T., Sakon I., Cohen M., et al., 2008, PASJ, 60, S375
Yamamura I., & de Jong T., 2000, Proc. of ISO beyond the peaks: The 2nd ISO workshop on analytical spectroscopy, ESA SP 456, 155