
AKARI: Space Infrared Cooled Telescope

Takashi Onaka · Alberto Salama

Abstract *AKARI*, formerly known as ASTRO-F, is the second Japanese space mission to perform infrared astronomical observations. *AKARI* was launched on 21 February 2006 (UT) and brought into a sun-synchronous polar orbit at an altitude of 700 km by a JAXA M-V rocket. *AKARI* has a telescope with a primary-mirror aperture size of 685 mm together with two focal-plane instruments on board: the Infrared Camera (IRC), which covers the spectral range 2–26 μm and the Far-Infrared Surveyor (FIS), which operates in the range 50–180 μm . The telescope mirrors are made of sandwich-type silicon carbide, specially developed for *AKARI*. The focal-plane instruments and the telescope are cooled by a unique cryogenic system that kept the telescope at 6K for 550 days with 180 liters super-fluid liquid Helium (LHe) with the help of mechanical coolers on board. Despite the small telescope size, the cold environment and the state-of-the-art detectors enable very sensitive observations at infrared wavelengths. To take advantage of the characteristics of the sun-synchronous polar orbit, *AKARI* performed an all-sky survey during the LHe holding period in four far-infrared bands with FIS and two mid-infrared bands with IRC, which surpasses the *IRAS* survey made in 1983 in sensitivity, spatial resolution, and spectral coverage. *AKARI* also made over 5,000 pointing observations at given targets in the sky for approximately 10 minutes each, for deep imaging and spectroscopy from 2 to 180 μm during the LHe holding period. The LHe ran out on 26 August 2007, since which date the telescope and instrument are still kept around 40K by the mechanical cooler on board, and near-infrared imaging and spectroscopic observations with IRC are now being continued in pointing mode.

Keywords Infrared telescope · Cryogenics · Space missions · All-sky survey

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1 Introduction

AKARI, formerly known as ASTRO-F, is the second Japanese space mission to perform infrared astronomical observations [1, 2], following the Infrared Telescope in Space (IRTS) on board the Space Flyer Unit [3]. *AKARI* was launched on 2006 February 21 (UT) and successfully 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. Details of the *AKARI* mission are given in [4].

AKARI has a cooled telescope with a primary-mirror aperture size of 685 mm [5] together with two focal-plane instruments on board: the Infrared Camera (IRC) that covers the spectral range 2–26 μm [6] and the Far-Infrared Surveyor (FIS) that operates in the range 50–180 μm [7]. Cryogenically cooled telescopes enable very sensitive observations in the infrared despite the small telescope size. The focal-plane instruments and the telescope of *AKARI* are cooled by super-fluid liquid helium (LHe) of 180 liters and mechanical coolers [8]. The on-board coolers helped reduce the consumption of LHe considerably and the LHe lasted until 2007 August 26, 550 days after the launch. After the LHe exhaustion, the telescope and the instruments are still kept around 40 K owing to the cooler, and near-infrared (NIR) observations with IRC are being carried out. Photographs of the *AKARI* satellite and telescope system are shown in Figure 1.

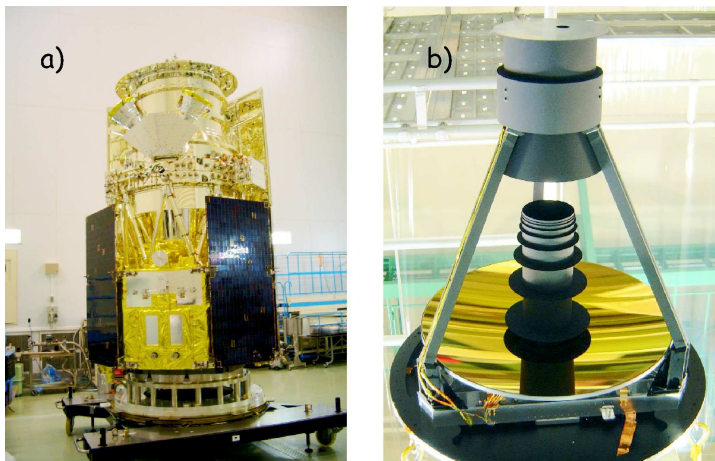


Fig. 1 Photographs of the *AKARI* satellite (a) and telescope (b).

To take advantage of the characteristics of the sun-synchronous polar orbit, *AKARI* performed an all-sky survey in four far-infrared (FIR) bands with FIS and two mid-infrared (MIR) bands with IRC, which surpasses the *IRAS* survey made in 1983 [9] in sensitivity, spatial resolution, and spectral coverage. *AKARI* also made pointing observations at a given target in the sky for approximately 10 minutes to carry out deep imaging and spectroscopy from 2 to 180 μm . This paper has been prepared during the post-LHe period. It gives an overview of the *AKARI* mission and describes the in-orbit performance as well as the observation highlights so far obtained.

2 *AKARI* telescope and on-board instruments

The basic characteristics of the *AKARI* telescope system are summarized in Table 1. The mirrors of the *AKARI* telescope are made of a sandwich-type silicon carbide (SiC) specially developed for *AKARI*. The deformation of the SiC mirror and the telescope system at cryogenic temperatures have been tested extensively in the laboratory. The deformation of the SiC mirror is shown to be negligible [10], while the deformation originating from the supporting structure is found to dominate in the wavefront errors of the telescope [11].

Table 1 Characteristics of the *AKARI* telescope system

Telescope type	Ritchey-Chrétien
Effective diameter of the primary mirror	685 mm
Mirror material	sandwich-type silicon carbide (SiC)
Truss material	beryllium
Total weight of the telescope system	30.56 kg
Weight of the primary mirror	10.7 kg
Focal length	4197.2 mm
Focus adjustment resolution	0.466 μm at the secondary mirror or 13.1 μm at the focus
Total effective collecting area	287042 mm ²

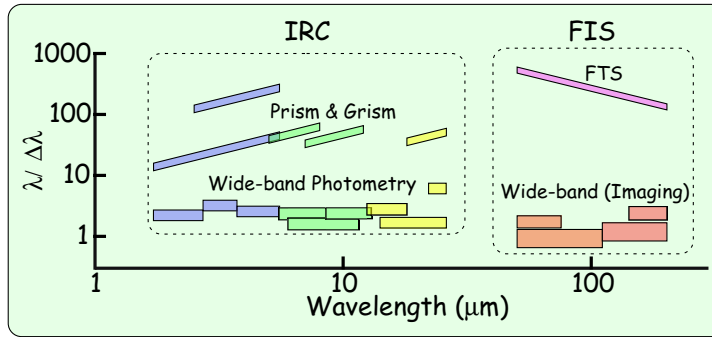


Fig. 2 Wavelength coverage and spectral resolution of the IRC and FIS.

The *AKARI* telescope is equipped with a focus adjustment mechanism at the secondary mirror [5]. The telescope focus was adjusted twice: at the beginning of the observation and after the exhaustion of LHe. The in-orbit imaging performance was investigated based on observed images of stars and found to be diffraction-limited at 7.3 μm and 8 μm at 6K and 40K, respectively [5, 12].

Figure 2 summarizes the observational capability of the *AKARI* on-board instruments. Both the IRC and FIS have spectroscopic capability in addition to the imaging [13, 14]. The FIS has rectangular arrays of monolithic Ge:Ga and stressed Ge:Ga detectors, with which FIR images in four bands at 65, 90, 140, and 160 μm are obtained simultaneously in the all-sky survey and slow scan observations [7]. The IRC comprises

three channels, each of which has a field of view of about $10' \times 10'$. The IRC was originally designed for pointing observations, but the MIR channels are operated also in the all-sky survey mode with the special array operation to take data at 9 and $18\mu\text{m}$ simultaneously [15].

3 AKARI Observation Highlights

The *AKARI* observations provide a significant database for a wide range of astronomical fields, ranging from solar-system objects, star formation, aged stars, interstellar medium, nearby and remote galaxies, to cosmology. One of the primary objectives of the *AKARI* mission was to make an all-sky survey in six bands at 9, 18, 65, 90, 140, and $160\mu\text{m}$. By the time of the LHe exhaustion on 26 April 2007, *AKARI* had observed more than 90% of the entire sky at least twice in the five bands. In addition *AKARI* had carried out more than 5,000 pointing observations. The in-orbit performance of IRC and FIS imaging observations both for the all-sky survey and pointing observations in the LHe- holding period is summarized in Table 2.

Table 2 In-orbit imaging observation performance of IRC and FIS in the LHe holding period

Band	Band center (μm)	Band width (μm)	Pixel scale (arcsec)	Image quality (arcsec)	5 σ sensitivity all-sky survey ^a (Jy)	5 σ sensitivity pointing mode ^b (mJy)
IRC						
N2	2.4	0.71	1.46	4.3	-	0.020
N3	3.2	8.7	1.46	4.0	-	0.019
N4	4.1	1.53	1.46	4.2	-	0.019
S7	7.0	1.75	2.34	5.1	-	0.091
S9W	9.0	4.10	2.34	5.5 ^c	0.05	0.093
S11	11.0	4.12	2.34	4.8	-	0.16
L15	15.0	5.98	2.39×2.51^d	5.7	-	0.34
L18W	18.0	9.97	2.39×2.51^d	5.7 ^c	0.12	0.34
L24	24.0	5.34	2.39×2.51^d	6.8	-	0.72
FIS						
N60	65	21.7	26.8	37	2.4	110
WIDE-S	90	37.9	26.8	39	0.55	34
WIDE-L	140	52.4	44.2	58	1.4	350
N160	160	34.1	44.2	61	6.3	1350

^a 5 σ sensitivity per scan.

^b 5 σ sensitivity for three-filtre mode per pointing for IRC and $8''\text{ s}^{-1}$ slow scan per pointing for FIS.

^c For the all-sky observation, the pixels are binned into a virtual pixel of about $10' \times 10'$.

^d Pixel scale is different in the orthogonal directions.

Figure 3 shows the all-sky survey map at $9\mu\text{m}$. It has much higher spatial resolution ($< 10''$) and better sensitivity than the *IRAS* $12\mu\text{m}$ data. The sensitivity and spatial resolution are also better than *MSX*, which observed only part of the sky, including the Galactic plane [16]. The pointing reconstruction for the all-sky survey has been carried out at ESAC. About 700,000 point sources are detected at $9\mu\text{m}$. The point source catalogs of the all-sky survey data will be released to the public in 2009.

The $7\mu\text{m}$ and $9\mu\text{m}$ bands of the *AKARI* IRC are quite sensitive to the unidentified infrared (UIR) emission bands in the diffuse radiation [17]. In Figure 4 the image of

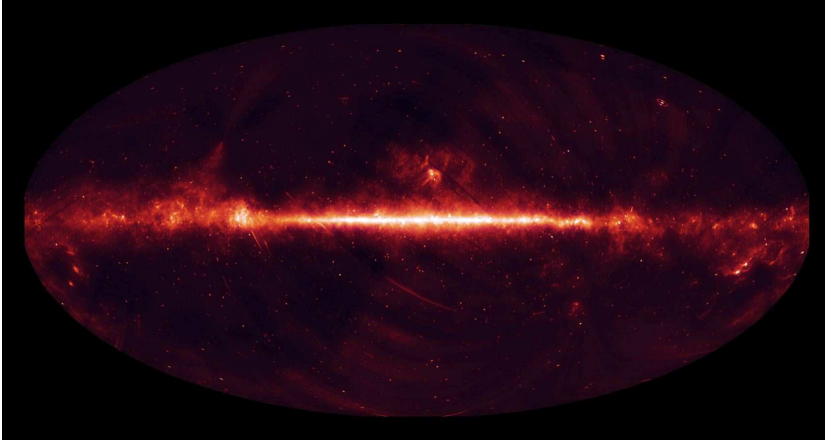


Fig. 3 *AKARI* all-sky survey map at $9\,\mu\text{m}$. It was taken with a special array operation mode developed for the all-sky survey [15].

the nearby dwarf galaxy M82 is shown, with the $\text{H}\alpha$ emission in red [18] and the IRC $7\,\mu\text{m}$ intensity in green. It is clearly seen that the $7\,\mu\text{m}$ emission is extended beyond the $\text{H}\alpha$ emission up to several kpc from the galaxy disk and it shows a rather spherical distribution, suggesting the presence of the UIR band emission in the superwind from the galaxy. The presence of the $17\,\mu\text{m}$ UIR band complex is confirmed spectroscopically by *Spitzer* IRS observations [19]. The presence of the UIR band emission in the outflow from the galaxy disk is also detected in another dwarf galaxy NGC1569 by *AKARI* IRC imaging and spectroscopic observations, suggesting that the band carriers are likely to be produced in shocks [20].

The FIR emission from galaxies consists of emission from dust grains of various temperatures. Dust grains in star-forming regions are hotter than those in the quiet interstellar medium. Four photometric bands in FIR and the good spatial resolution of FIS revolutionise the investigation on the origin of the FIR emission from galaxies. FIS observations allow us to spatially decompose the FIR emission into the warm and cold dust components. Figure 5 shows images of the nearby galaxy M101 that have

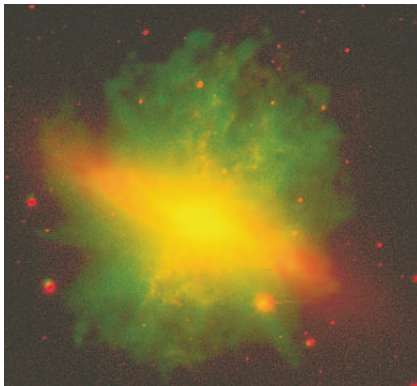


Fig. 4 Image of M82: $\text{H}\alpha$ in red and *AKARI* IRC $7\,\mu\text{m}$ in green. The $\text{H}\alpha$ data are obtained from the SINGS project [18]. The image size is about $10' \times 10'$.

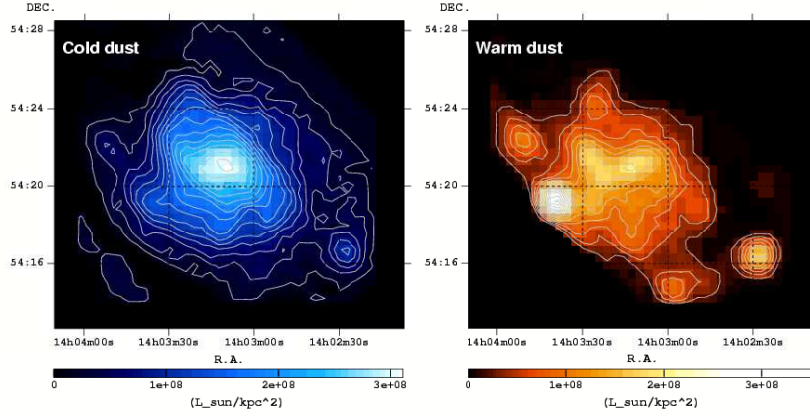


Fig. 5 Images of the cold (left) and warm (right) dust distribution in M101 by FIS observations. The FIS four band data of 65, 90, 140, and 160 μm allow us to decompose the FIR emission of M101 into the cold and warm components [21].

been composed in this way [21]. The left figure indicates the distribution of the cold dust ($T \sim 18\text{K}$), whereas the warm dust ($T \sim 55\text{K}$) image is shown at the right. These figures reveal the concentration of the cold dust at the center and the widely distributed warm dust over the galaxy, the latter characteristic of active star-forming regions in the galaxy. The warm dust component is indeed well correlated with the spiral arms.

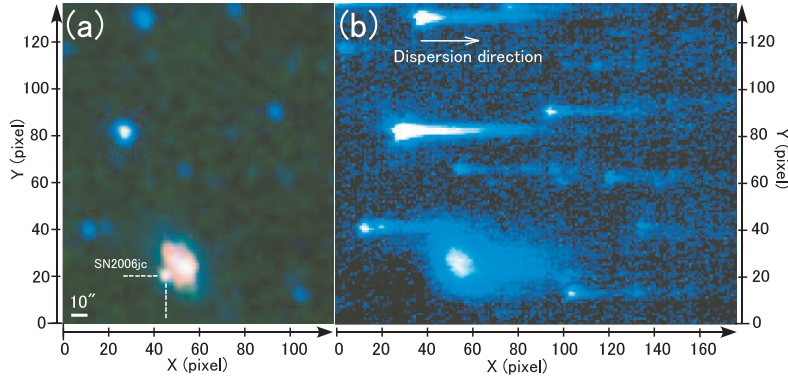


Fig. 6 (a) *AKARI* IRC 3 (blue), 7 (green), and 11 (red) μm artificial color image of SN2006jc taken at 200 days after the explosion. A point source at the left of the host galaxy UGC4904 is the supernova. (b) *AKARI* IRC NIR slitless spectroscopy image of SN2006jc and UGC4904. The supernova spectrum is superposed on the spectrum of the host galaxy [22].

AKARI also detected the infrared light from a supernova (SN). Figure 6 shows a NIR to MIR IRC color image of SN2006jc in the host galaxy UGC4904 (left) and the NIR slit-less spectroscopic image (right) taken at 200 days after the explosion [22]. The

AKARI observation suggests that the dust formed in the supernova ejecta is mostly carbon grains and their mass is less than $10^{-4}M_{\odot}$.

As indicated in Figure 6, the slit-less spectroscopy is a unique capability of *AKARI* IRC and is in fact very efficient for the spectroscopic survey [13]. Figure 7 shows a spectroscopy image taken as part of the *AKARI* survey of the Large Magellanic Cloud [23]. As can be seen in the figure, spectra of a number of sources are obtained in one image. The spectrum of the source indicated by the rectangular box in the image is found to be a young stellar object (YSO) based on its spectrum shown at the left. It clearly shows the absorption features of H_2O and CO_2 ice at 3 and $4.3\mu m$, respectively, for the first time in extragalactic YSOs and the larger abundance of the CO_2 ice in the LMC than in Galactic YSOs [24]. The IRC spectroscopy provides significant information on the nature and classification of detected objects.

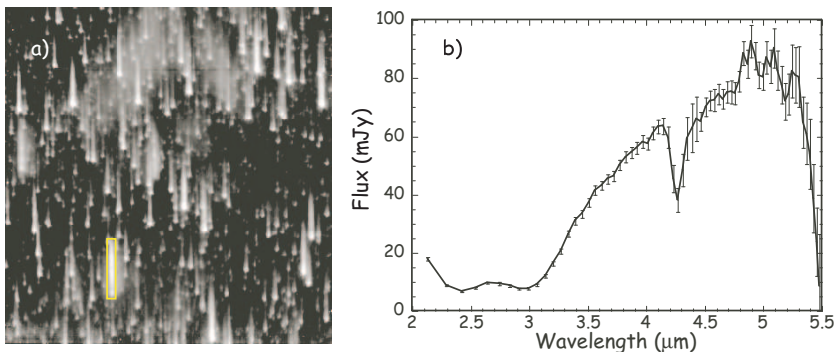


Fig. 7 (a) *AKARI* IRC near-infrared slit-less spectroscopic image of a region in the LMC survey. The size of the image is about $10' \times 10'$. (b) Spectrum of the source indicated by the rectangular box in the image (a). The H_2O and CO_2 ice features are clearly seen in the spectrum, indicating that the source is a YSO. Further analysis indicates that CO_2 ice is more abundant in LMC YSOs than in those in our Galaxy [24].

4 Summary

AKARI, the second Japanese satellite mission for infrared astronomy, was launched in February 2006 and successfully carried out an all-sky survey at 9, 18, 65, 90, 140, and $160\mu m$ until the LHe ran out in August 2007. During the cold mission period more than 5,000 pointing observations were also carried out in imaging and spectroscopic modes in the $2\text{--}180\mu m$ wavelength range. After the LHe exhaustion near-infrared imaging and spectroscopic observations are being continued. Several highlights of the *AKARI* observations are presented, which clearly demonstrate the significance and great power of *AKARI* observations in a wide range of astronomical fields. The point source catalog of the all-sky survey data will be released to the public in 2009. The data of pointing observations in the cold phase will also become available in 2009.

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