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Mid-infrared all-sky survey with AKARI

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Abstract. *AKARI* (formerly called ASTRO-F) is the first Japanese astronomical infrared satellite and it is now in a sun-synchronous polar orbit at the altitude of 700 km. One of the major programs of *AKARI* observations is an all-sky survey in the mid- to far-infrared spectral region with 6 photometric bands. *AKARI* has a 685mm telescope, which is cooled down to about 6K by superfluid liquid helium and mechanical coolers. The expected liquid helium holding time is longer than one year. The *AKARI* mid-infrared (MIR) survey is being carried out with the 9 and 18 μm bands and the 5σ sensitivities are estimated to be better than 80 and 130 mJy, respectively. The spatial resolution is better than 10 arcseconds at both bands. The sensitivity and spatial resolution of the MIR survey have been verified in orbit. The *AKARI* MIR survey will achieve a deeper sensitivity and a finer spatial resolution by about an order of magnitude than the previous survey of the 12 and 25 μm with *IRAS*. It will provide a unique and significant database for studies of various fields of astronomy, ranging from star-formation and debris disk systems to cosmology. The first *AKARI* point source catalogue is planned to be released to the public 2 years after the completion of the survey. This paper reports the flight performance and the current status of the *AKARI* MIR survey.

Key words. Surveys – Infrared: general – Galaxy: general – ISM: general

1. Introduction

More than two decades have passed since the *Infrared Astronomical Satellite (IRAS)* carried out an all-sky survey for the first time in the infrared with four broad bands centered at

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12, 25, 60, and 100 μm (Neugebauer et al. 1984). Later, the *Midcourse Space Experiment (MSX)* surveyed the regions of the sky confused to *IRAS*, such as the Galactic plane and the Magellanic Clouds, as well as those areas not observed by the *IRAS* mission. MSX had higher sensitivity and spatial resolution ($\sim 18''$) than *IRAS*, with four broad bands at 8.28, 12.13, 14.65, and 21.34 μm, and two narrow bands at 4.29 and 4.35 μm (Price et al. 2001).

AKARI is the first Japanese satellite mission dedicated to infrared astronomical observations (Murakami 2004). It was launched on 2006 February 22 (JST) and successfully brought into a sun-synchronous orbit at an altitude of 700 km. It has a Ritchey-Chretien-type cooled telescope with a primary-mirror aperture size of 685 mm (Kaneda et al. 2005) together with two scientific instruments on board: the Infrared Camera (IRC) that covers the spectral range 2–26 μm (Onaka et al. 2004) and the Far-Infrared Surveyor (FIS) that operates in the range 50–180 μm (Kawada et al. 2004). The focal-plane configuration is shown in Fig. 1. The scientific instruments and the telescope are cooled down by super-fluid liquid helium and mechanical coolers. The expected helium holding time is longer than one year at present. One of the major objectives of the *AKARI* mission is an all-sky survey in four far-infrared (FIR) bands with FIS and two mid-infrared (MIR) bands with IRC, which will surpass the *IRAS* survey in sensitivity, spatial resolution, and spectral coverage.

The IRC MIR survey is being carried out with two MIR wide bands centered at 9 μm and 18 μm. The spatial resolution is about $10''$ at both bands and the sensitivity verified in orbit is better than 80 and 130 mJy (5σ), respectively. Details of the IRC all-sky survey and its expected performance prior to the launch have been given in Ishihara et al. (2006a), most of which have been verified in orbit. In this paper we present an overview of the all-sky survey with the IRC together with the current status and on-orbit performance.

The specification and performance of the IRC all-sky observations predicted prior to the launch are summarized in Table 1. Comparison with other wide-area survey projects are shown

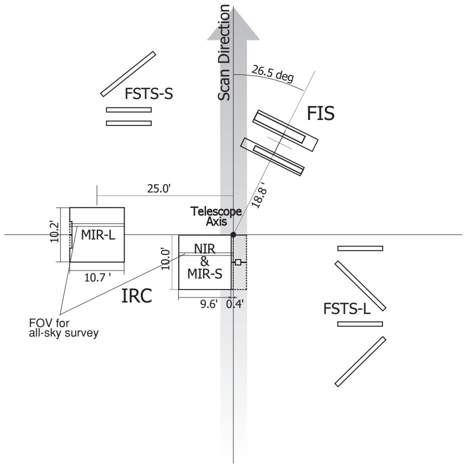

Fig. 1. Focal plane configuration of *AKARI*. The NIR and the MIR-S share the same field-of-view (FOV), whereas the FIS and the MIR-L have different FOV locations. The pixels used for the IRC all-sky observation are indicated.

in Fig. 2. The IRC MIR survey can reach a T Tauri star at a distance of 100 pc and a debris disk system of β Pictoris type at 200 pc. Therefore it will provide a unique and significant database for the statistical study of young stellar objects and debris disk systems. Its spatial resolution, much higher than *IRAS*, will be efficient for the detailed study of star-formation process in a relatively large scale. The IRC all-sky survey will enlarge the sample of mass-losing late-type stars and provide a significant impact on the study of the mass-loss process in the late stage of stellar evolution. It can also detect a number of solar system objects as well as extragalactic sources (see Pearson et al. 2004). A serendipitous survey of interesting objects is also greatly anticipated.

2. Infrared Camera (IRC) in the survey mode

AKARI has two observation modes: pointing and survey. In the pointing mode, the telescope stares at a target object in order to carry out deep imaging and spectroscopic observations. In the survey mode, the telescope is continuously directed perpendicular to the Sun, almost in a great circle, to perform an all-sky sur-

Table 1. Specification and expected performance of the IRC all-sky survey observation

Channel	Filter	Wavelength coverage	Spatial resolution[a]	Detection limit[b,c]	Saturation limit[c,d]
MIR-S	S9W	6–12 μm	$9.4'' \times 9.4''$	80 mJy	36 Jy
MIR-L	L18W	14–26 μm	$10.0'' \times 9.4''$	130 mJy	93 Jy

a The pixel scale in the 4×4 mode (see text).
b The detection limit (5σ) for point sources on the ecliptic plane in one scan based on the measured readout noise and the estimated throughputs of the camera optics.
c The size of the point spread function (PSF) is small compared with the pixel size and thus the filling factor of the PSF on a pixel depends on the detected position on the detector. The indicated numbers are conservative values (see Ishihara et al. (2006a) for more detail).
d Estimated based on the deviation by 20% from the linearity relation.

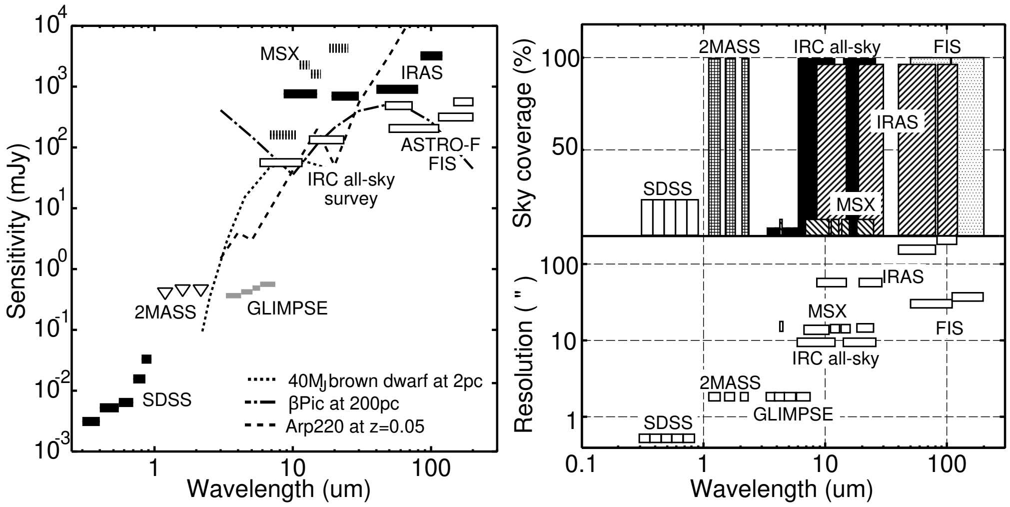

Fig. 2. Sensitivity for point sources (left) and spatial resolution and sky coverage (right) of the IRC all-sky survey observation in comparison with other wide area survey projects: The Sloan Digital Sky Survey (SDSS) is a ground-based astrometrically and photometrically calibrated imaging survey of π sr above $|b| \geq 30°$ in five optical bands to a depth of $g' \sim 23$ mag (York et al. 2000). The SDSS also provides spectroscopic survey data. The Two Micron All Sky Survey (2MASS) has observed the entire sky simultaneously in three near-infrared bands J, H, and K_S using two ground-based telescopes located at the northern and southern hemispheres (Cutri et al. 2003). The *MSX* was a space-based project initiated by the Strategic Defense Initiative Organization, and surveyed the entire Galactic plane within $|b| \leq 5°$ in four mid-infrared bands covering the 6–29μm range (Price et al. 2001). The Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE) is a *Spitzer Space Telescope* Legacy Science Program, a confusion-limited infrared survey of the Galactic disk ($|b| \leq 1°$ and $|l| = 10 - 65°$) with four bands (covering 3–10μm) of the InfraRed Array Camera (IRAC) (Benjamin et al. 2003). *IRAS* surveyed 98 % of the entire sky for the first time in the infrared with four broad bands between 8.5–120 μm (Neugebauer et al. 1984). The Far-Infrared Surveyor (FIS) on-board *AKARI* will survey the entire sky with four far-infrared bands from 50–200 μm (Kawada et al. 2004). For the IRC all-sky survey the 5σ detection limit is plotted and the quoted values are shown for the other surveys.

vey for half a year. *AKARI* observations have been optimized to maximize the scientific return from the survey and pointing observations. Large area surveys with *AKARI* pointed observations have been described in Matsuhara et al. (2005, 2006).

The IRC is uniquely designed for deep imaging and spectroscopy for pointed observations. It consists of three channels: NIR (2–5 μm), MIR-S (5–12 μm), and MIR-L (12–26 μm). Each channel has two dimensional array detectors with three broad band filters for imaging and two spectroscopic dispersers for low-resolution spectroscopy. A schematic view of the IRC is shown in Fig. 3. The all-sky survey is being performed with the MIR-S and MIR-L in fixed bands. Both channels employ a Si:As CRC-744 detector array of 256×256 format. Each has a $10'$ width in the cross scan direction and thus more than a half region will be overlapped in adjacent survey scans even on the ecliptic plane. As indicated in Fig. 1, however, the MIR-S and MIR-L look at different fields of the sky on a survey scan. They are also different from the field-of-view of the FIS. The relative spectral response (RSR) curves employed for the IRC all-sky survey (S9W and L18W bands) are shown in Fig. 4 together with the *IRAS* and *MSX* filter bands. Further details of the IRC design can be found in Onaka et al. (2004) and Ishihara et al. (2006a).

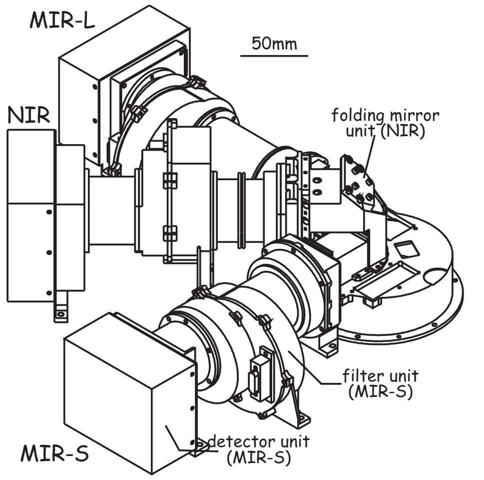

Fig. 3. Elevated view of the IRC.

For the IRC all-sky survey observations, only the data of two out of 256 rows of the array are read every 44 ms, which corresponds to a quarter of the dwell time for a point source on a pixel in the scan direction. Thus the virtual pixel size in the scan direction is 4 times the actual pixel size. In the cross scan direction, the signals in 4 pixels are also binned together. The data from the final virtual pixel size (4×4 of the intrinsic pixel size) matches the allowed data down link rate. The virtual pixel size is then about $10''$ (see Table 1 and Fig. 1). Signals from two rows are effective for rejection of glitches from high-energy ionizing particle hits. The two rows are also read in an interlaced manner to increase the spatial information. The IRC array detectors are operated in an integrating signal mode. Resets are executed every 13.45 s. Saturation of the signals hardly occurs except for very bright source passages, and does not affect the efficiency of the survey observations.

3. On-orbit performance

The integrated signals of the IRC all-sky survey data are first differentiated in a simple manner and then point sources are extracted. The pointing reconstruction is carried out with the data of the focal-plane star-sensor by the European Space Astronomy Center (ESAC). Source associations of the IRC survey data are carried out first with the *IRAS* and *MSX* data based on the pointing reconstruction information and the position of the IRC survey is determined. A goal of the accuracy of the position determination is about $1''$.

Absolute calibration of the MIR survey in orbit is now being carried out based on observations of an all-sky network of 615 bright standard stars from an enlarged version of that published by Cohen et al. (1999), and similarly consisting of K and M-giants. This assures that the MIR survey is tied to the absolute calibration validated by *MSX* (Price et al. 2004). Fainter standards for the IRC are taken from the set of 249 far-UV to MIR calibrators built by Cohen to support the calibration of *Spitzer* IRAC, from which the IRAC routine standards are drawn (Reach et al. 2005).

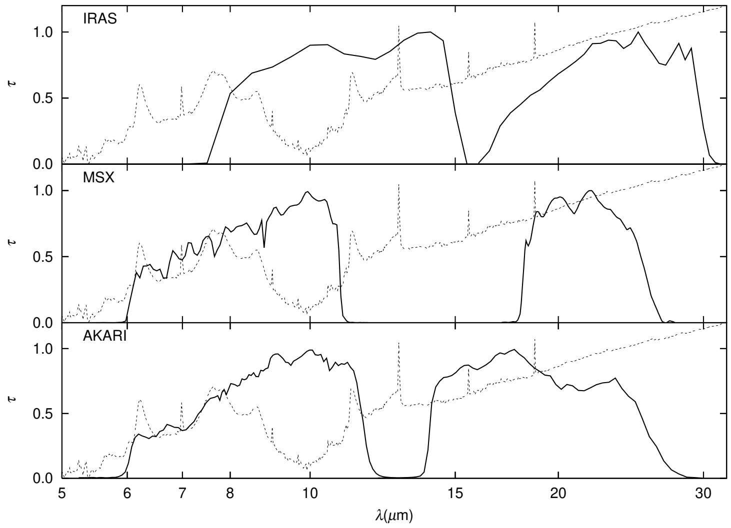

Fig. 4. (Bottom) Relative system response curves of the IRC all-sky survey observations (the S9W and L18W bands). (Middle) Two of the MSX MIR bands (8.3 and 21.3 μm; Egan et al. 1999). (Top) The RSRs of the IRAS 12 μm and 25 μm bands (Neugebauer et al. 1984) and the spectrum of M82 taken by the ISO SWS (Sloan et al. 2003) are also shown by the dotted lines for comparison.

All these stars were constructed based on the methods detailed by Cohen et al. (2003), and conform to the absolute calibration by *MSX*. 131 of these calibrators constitute a standard star network for the ecliptic polar regions, for which the visibility from *AKARI* is very high (Ishihara et al. 2006b).

The sensitivity of the IRC all-sky survey is limited by detector noise (Ishihara et al. 2006a). The noise performance in orbit has been confirmed to be about the same as pre-flight data. Based on the observations of standard stars and the measured noises, the 5σ sensitivity in orbit has been estimated to be about 50 mJy and 120 mJy for the S9W and L18W bands, respectively, which are slightly better than the pre-flight predictions. Fig. 5 shows histograms of the detected sources. As seen in the figure, sources well below 80 mJy are adequately detected at this early stage of the data reduction, confirming the detection limits in orbit. Note that these numbers are the sensitivities in one scan. Those in regions where a number of scans overlap should be much improved by further data processing. Examples of the actual images as well as the latest information of the *AKARI* mission can be found at the *AKARI* web sites[1].

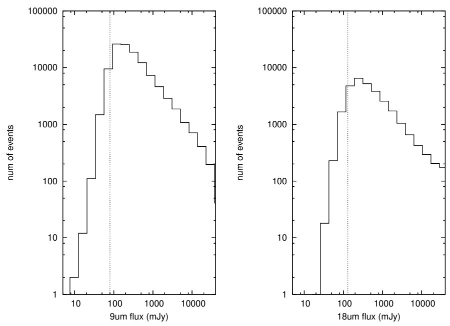

Fig. 5. Histograms of the detected sources with the *AKARI* IRC all-sky survey: 9 μm (left) and 18 μm (right). The vertical lines indicate the expected detection limits.

4. Products

The *AKARI* all-sky survey data will be released to the public. The first *AKARI* point-source cat-

[1] http://www.ir.isas.jaxa.jp/ASTRO-F/ or http://www.astro-f.esac.esa.int/

alog of the IRC all-sky survey, together with that of the FIS all-sky survey, is planned for preparation one year after the end of the survey and will be released to the public after a one year proprietary period for *AKARI* team members. A faint source catalog and a small scale structure catalog are also planned to follow, but the precise schedule has not been fixed. Image data are also planned to be released.

5. Summary

AKARI (formerly called ASTRO-F) has been successfully launched and all the scientific instruments are working fine and executing observations as planned prior to the launch. The IRC all-sky survey is being performed with a spatial resolution better than 9.4″ and with detection limits better than 80 mJy and 130 mJy at 9 μm and 18 μm, respectively. These performances confirm the pre-flight predictions. The *AKARI* IRC all-sky survey will substantially enlarge the MIR dataset of the *IRAS* survey of two decades ago and provide a significant database for studies of various fields of astronomy, ranging from star-formation and debris disk systems to cosmology.

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References

Benjamin, R. A., et al. 2003, PASP, 115, 953
Cohen, M., et al. 1999, AJ, 117, 1864
Cohen, M., Megeath, T. G., Hammersley, P. L., Martin-Luis, F., & Stauffer, J. 2003, AJ, 125, 2645
Cutri, R. M., et al. 2003, VizieR On-line Data Catalog
Egan, M. P., Price, S. D., Moshir, M.M., Cohen. M., & Tedesco, T. *MSX point Source Catalog Version 1.2 Explanatory Guide* 1999 STIN 0014854 E
Ishihara D., et al. 2006a, PASP, 118, 324
Ishihara D., et al. 2006b, AJ, 131, 1074
Kaneda, H., et al. 2005, Appl. Opt., 44, 6823
Kawada, M., Shibai, H., Kaneda, H., & Nakagawa, T. 2004, Proc. SPIE, 5487, 359
Matsuhara, H., Shibai, H., Onaka, T., & Usui, F. 2005, Adv. Sp. Res. 36, 1091
Matsuhara, H. et al. 2006, PASJ, 58, in press
Murakami, H. 2004, Proc. SPIE, 5487, 330
Neugebauer, G., et al., 1984, ApJ, 278, L1
Onaka, T., et al. 2004, Proc. SPIE, 5487, 338
Pearson, C. P., et al. 2004, MNRAS, 347, 111
Price, S. D., Egan, M. P., Carey, S. J., Mizuno, D. R., & Kuchar, T. A. 2001, AJ, 121, 2819
Price, S. D., Paxson, C., Engelke, C., & Murdock, T. L. 2004, AJ, 128, 889
Reach, W. T., et al. 2005, PASP, 117, 1407
Sloan, G. C., Kraemer, K. E., Price, S. D., & Shipman, R. F. 2003, ApJS, 147, 379
York, D. G., et al. 2000, AJ, 120, 1579