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The Infrared Astronomical Mission AKARI*

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Abstract

AKARI, the first Japanese satellite dedicated to infrared astronomy, was launched on 2006 February 21, and started observations in May of the same year. AKARI has a 68.5 cm cooled telescope, together with two focal-plane instruments, which survey the sky in six wavelength bands from mid- to far-infrared. The instruments also have a capability for imaging and spectroscopy in the wavelength range 2–180 μm in the pointed observation mode, occasionally inserted into a continuous survey operation. The in-orbit cryogen lifetime is expected to be one and a half years. The All-Sky Survey will cover more than 90% of the whole sky with a higher spatial resolution and a wider wavelength coverage than that of the previous IRAS all-sky survey. Point-source catalogues of the All-Sky Survey will be released to the astronomical community. Pointed observations will be used for deep surveys of selected sky areas and systematic observations of important astronomical targets. These will become an additional future heritage of this mission.

Key words: infrared: general — space vehicles: instruments

1. Introduction

ASTRO-F was planned as a Japanese space mission dedicated to infrared astronomy (Murakami 2004; Shibai 2007). It was successfully launched on 2006 February 21 (UT) on the M-V-8 rocket, which was developed by the Japan Aerospace Exploration Agency (JAXA), from Uchinoura Space Center (USC). It was renamed AKARI after a confirmation of successful insertion of the satellite into orbit.

AKARI is the second Japanese space mission to carry out infrared astronomy, following the Infrared Telescope in Space (IRTS; Murakami et al. 1996) onboard the Space Flyer Unit (SFU). AKARI is designed as an All-Sky Survey mission in the infrared region. The primary purpose of the mission is to provide second-generation infrared catalogues so as to obtain a better spatial resolution and a wider spectral coverage than the first catalogues produced by the Infra-Red Astronomy Satellite (IRAS) mission (Neugebauer et al. 1984). AKARI is equipped with a cryogenically cooled telescope of 68.5 cm aperture diameter and two scientific instruments, the Far-Infrared Surveyor (FIS; Kawada et al. 2007) and the Infrared Camera (IRC; Onaka et al. 2007). The wide fields of view ($\sim 10'$) covered by the large-format arrays in these instruments makes them highly suitable for efficient surveys. AKARI has the capability to make pointed observations in addition to the All-Sky Survey, although it is not a fully observatory-type mission in the same guise as the Infrared Space Observatory (ISO; Kessler et al. 1996) and the Spitzer Space Telescope (Werner et al. 2004), due to the nature of its low-Earth Sun-synchronous orbit.

AKARI has operated normally since its launch, and is now generating large amounts of high-quality data on infrared sources ranging from nearby solar-system objects to galaxies at cosmological distances.

This paper gives an overview of the design, operation, and observations of AKARI. Details of the scientific instruments and initial astronomical results based on data mainly taken in the performance-verification phase (the first month after opening the aperture lid) are given in companion papers in this special issue.

2. AKARI Satellite

The AKARI satellite consists of two main sections: the satellite bus module and the science module, as shown in figure 1. The science module is a cryostat that contains the telescope and focal-plane instruments. The cryostat with a sun shield is mounted on the bus module through carbon-fiber reinforced plastic (CFRP) trusses, and is thereby thermally isolated from the bus. The satellite bus module includes the subsystems, which provide various functions, such as power supply, communications, command and data handling, attitude and orbit control, and temperature control and monitoring. The key structure of the bus module is a cylindrical thrust tube (1 m high and 1.2 m diameter), also made of CFRP. The propellant tanks of the reaction control system are stored inside this thrust tube. Subsystems of the bus module are installed on eight instrument panels, and the panels are integrated together around the thrust tube. The lower end of the thrust tube is connected to the top of the third stage of the M-V rocket. Two solar paddles are secured around the bus module in the launch configuration, and are deployed in orbit. Major features of AKARI are summarized in table 1.

* AKARI is a JAXA project with the participation of ESA.
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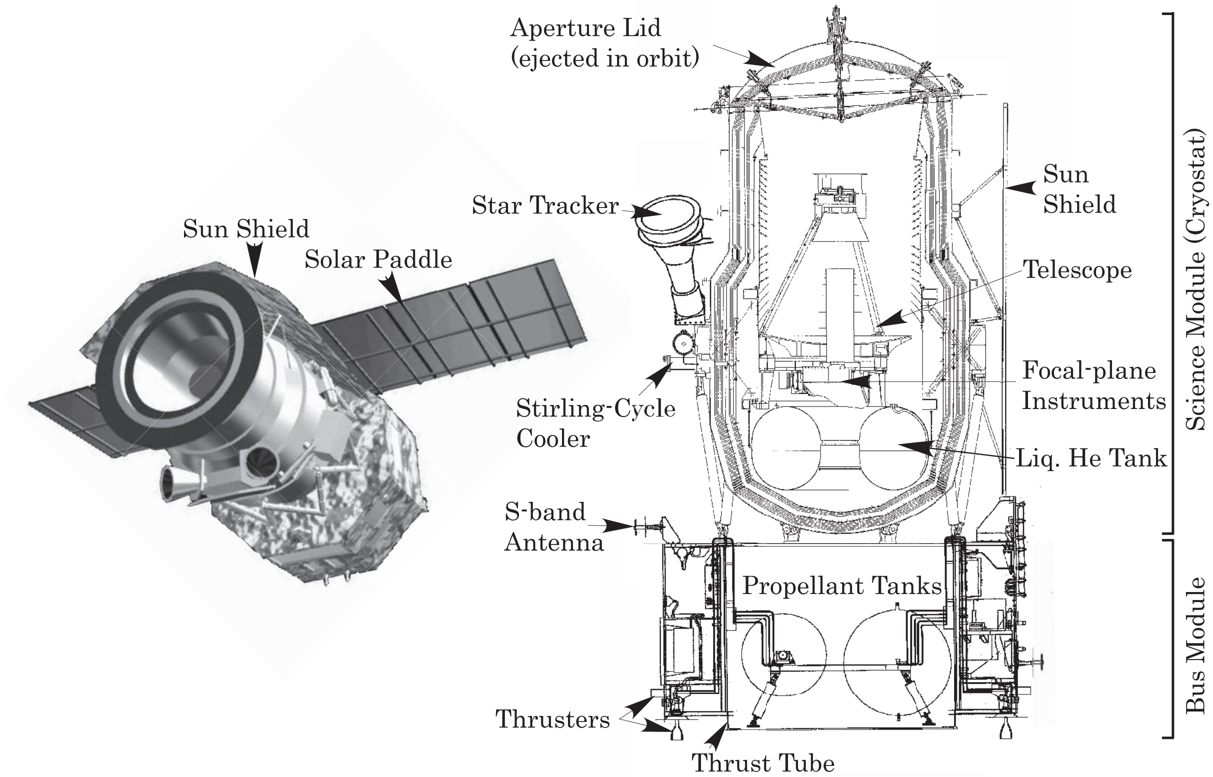

Fig. 1. Illustration of AKARI in orbit (left panel) and a sectional view (right panel).

Table 1. Design features of the AKARI satellite.

Size	diameter 2.0 m max., hight 3.7 m (launching configuration)
	width 5.5 m, hight 3.3 m (observation configuration in orbit)
Mass	952 kg in the launch configuration
Orbit	Sun-synchronous polar orbit, altitude 700 km
Downlink rate	4 Mbps for scientific data
Data generation rate	approximately 2 GBytes d^{-1}
Data recorder capacity	2 GBytes

3. Scientific Instruments

3.1. *Cryogenics*

A liquid-helium cryostat of very high efficiency, providing a long cryogenic lifetime with a small amount of liquid helium, was specifically designed for AKARI (Nakagawa et al. 2007). This small helium tank can provide enough room for a large-aperture telescope in the cryostat within the weight and volume limits imposed by the launch vehicle. The amount of cryogen is only 179 liters at launch, and the expected hold-time of the liquid helium in orbit is about one and a half years. This high efficiency has been realized by utilizing mechanical cryocoolers and efficient radiative cooling. The cryocoolers on board AKARI are two-stage Stirling-cycle coolers (Narasaki et al. 2004). The outer shell of the cryostat is shaded from the sunlight by a sun-shield, and is cooled down to about 200 K by radiative cooling.

3.2. *Telescope*

The AKARI telescope system is a Ritchey–Chretien type with an effective aperture size of 68.5 cm and an $f/6$ system (Kaneda et al. 2005, 2007). Its focal plane is shared between two infrared instruments and focal-plane star sensors; it has a clear field of view of 38′ in radius. The mirror material is sandwich-type Silicon Carbide (SiC), which consists of a porous SiC core coated with CVD (Chemical Vapor Deposition) SiC. The high stiffness of SiC enables us to make very light-weight mirrors. The primary mirror, which has a physical diameter of 71 cm, weighs only 11 kg.

3.3. *Focal-Plane Instruments*

One of the focal-plane instruments, FIS (Kawada et al. 2007), is designed to perform an All-Sky Survey in four far-infrared wavelength bands using Ge:Ga and stressed Ge:Ga

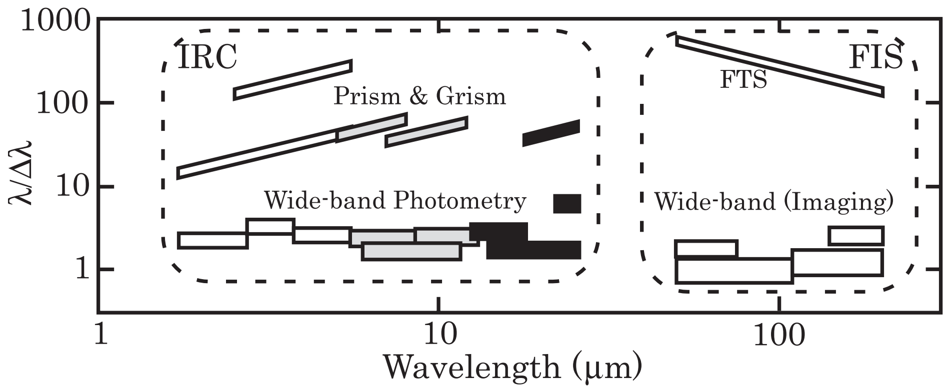

Fig. 2. Wavelength coverage and resolution of IRC and FIS.

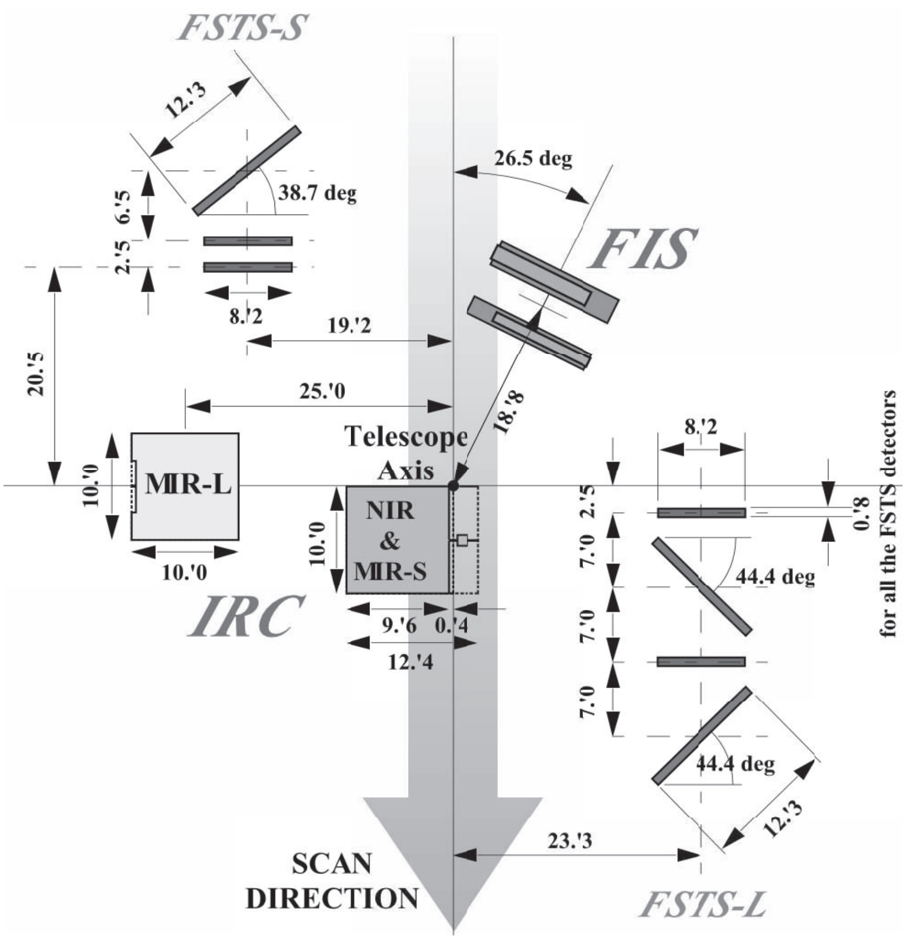

Fig. 3. AKARI focal-plane layout. This figure shows a projection onto the sky. FSTS-S and FSTS-L are focal-plane star sensors. The scan direction in the All-Sky Survey is in a sense that, in this figure, FOV moves downward on the sky and stars go upward.

detector arrays. This instrument also has a spectroscopic capability via a Fourier-transform spectrometer. The other instrument, IRC (Onaka et al. 2007), consists of three channels: NIR, MIR-S, and MIR-L, which cover the 1.8–5.5 μm, 4.6–13.4 μm, and 12.6–26.5 μm wavelength range, respectively. Each channel has three broad-band filters and additional dispersive elements. The FIS and IRC instruments can be operated simultaneously.

The IRC was originally designed to perform imaging and spectroscopic observations with large-format array detectors, pointing the telescope to a given object. However, the additional acceptable performance of continuous survey-type observations with two rows of the array was confirmed in ground tests (Ishihara et al. 2006), and the All-Sky Survey

Table 2. AKARI scientific instruments.

Cryogenics	Liquid-helium cryostat with Stirling-cycle coolers 179-liter super-fluid liquid helium
Telescope	Ritchey–Chretien type optics Effective aperture 68.5 cm, total $f/6$ system SiC light-weight telescope
Far-Infrared Surveyor (FIS)	All-Sky Survey, imaging and spectroscopy with FTS Bands: *N60* (65 μm), *WIDE-S* (90 μm), *WIDE-L* (140 μm), *N160* (160 μm) Detectors: 20 × 2 & 20 × 3 Ge : Ga arrays for *N60* and *WIDE-S* bands 15 × 3 & 15 × 2 stressed Ge : Ga arrays for *WIDE-L*, *N160* bands Pixel pitch: $29''\!.5$ for *N60* and *WIDE-S* bands, $49''\!.1$ for *WIDE-L* and *N160* bands Resolution for spectroscopy: $\Delta\nu = 0.19$ cm^{-1}
Infrared Camera (IRC)	All-Sky Survey, imaging and spectroscopy with grisms and a prism Photometric bands: NIR: *N2* (2.4 μm), *N3* (3.2 μm), *N4* (4.1 μm) MIR-S: *S7* (7.0 μm), *S9W* (9.0 μm), *S11* (11.0 μm) MIR-L: *L15* (15.0 μm), *L18W* (18.0 μm), *L24* (24.0 μm) Detectors: InSb 512 × 412 array for NIR, two 256 × 256 Si:As arrays for MIR-S and MIR-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-S Effective pixel scale in the All-Sky Survey: $10''$ (4 pixels are binned.) Resolution for spectroscopy: $\Delta\lambda = 0.0097$–0.17 μm

Table 3. Major events in the AKARI operation timeline.

Events	Time (UT)
Launch	2006 February 21 21:28:00
Injection into initial orbit (Satellite separation)	2006 February 21 21:36:39
Completion of orbit change maneuver to the observation orbit	2006 March 4 08:39
Aperture lid ejection (Start of performance-verification phase)	2006 April 13 07:55
Start of Phase 1 observation	2006 May 8
Start of Phase 2 observation	2006 November 10

in *S9W* and *L18W* bands were subsequently added to the operation modes.

The wavelength coverage and the spectral resolution of FIS and IRC are shown in figure 2, while figure 3 shows the focal-plane layout. A brief summary of AKARI's scientific instruments is given in table 2. In addition to the two scientific instruments, AKARI is also equipped with focal-plane star sensors (referred to as FSTS-S and FSTS-L), which are used to determine the telescope boresight during the All-Sky Survey.

4. Satellite Operations

AKARI was initially launched into an elliptical orbit by the M-V rocket. A reaction control system then drove up the perigee altitude to bring the satellite to the observing orbit, a circular Sun-synchronous polar orbit at an altitude of approximately 700 km and an inclination of $98^\circ\!.2$. AKARI flies along the day–night border with an orbital period of approximately 100 min. This orbit is similar to that of the previous IRAS satellite, and is the most suitable orbit for scanning the sky while keeping the telescope direction away from the Sun and the Earth, whose strong emission would be ruinous to the cooled telescope.

Just after the launch, it was found that the Sun aspect sensors could not detect the Sun properly. The cause of this problem is still unknown. This problem forced us to rewrite the on-board software for the attitude and orbit control subsystem, and delayed the opening of the aperture lid by one month. The aperture lid was finally opened on 2006 April 13, after which AKARI began to observe the sky. In the performance-verification phase, one month after the aperture lid opening, tuning of the scientific instruments and the attitude and orbit control subsystem, and telescope focus adjustment were performed. AKARI started an All-Sky Survey on 2006 May 8. Major events in the AKARI operation timeline are summarized in table 3.

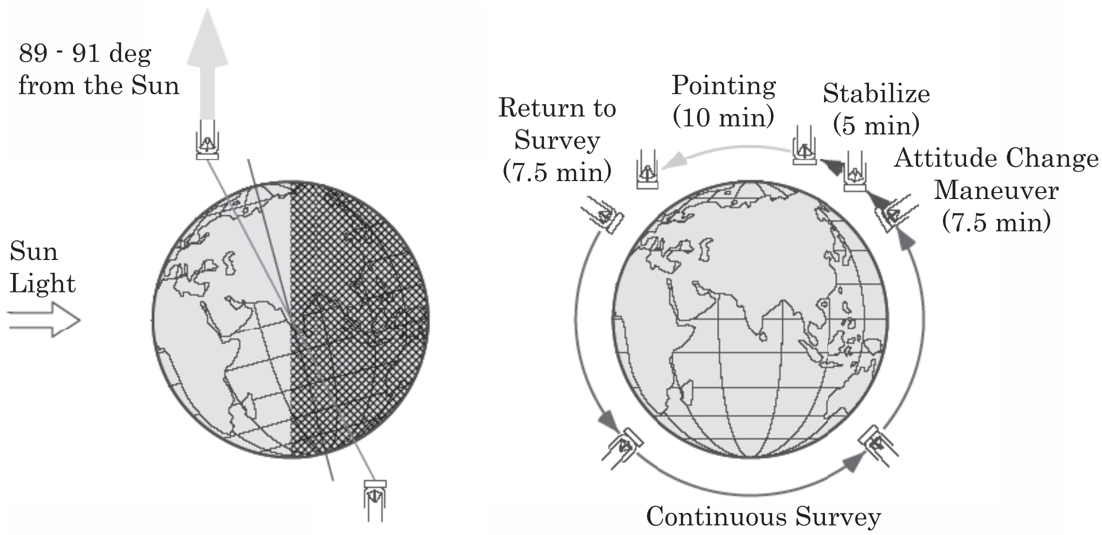

Fig. 4. Attitude control for observations.

The attitude of AKARI observations are controlled as follows: during the All-Sky Survey, the spacecraft rotates around the axis directed toward the Sun once every orbital revolution, avoiding the Earth. This results in a continuous scan of the sky at a scan speed of $3\overset{\prime}{.}6\ \mathrm{s}^{-1}$ (figure 4). The whole sky can in principle be covered in half a year. The FIS and the IRC are also operated in a pointing mode, where the instruments observe a certain sky position for a longer exposure (approximately 10 minutes for one pointing with a maneuvering time of 20 minutes).

The attitude control system provides additional capabilities to shift the pointing direction by small amounts during pointed observations, i.e., micro- and slow scans. In the micro-scan, the pointing direction is shifted by less than $30''$ for the purpose of dithering the IRC images. The slow scan is a continuous scan at a much slower scan speed (4–$30''\ \mathrm{s}^{-1}$) compared to the All-Sky Survey. This is used to obtain sky images to significantly higher sensitivities than the All-Sky Survey.

The communications subsystem provides a command uplink in the S band, and a telemetry downlink in the S and X bands. The commands are uplinked from the JAXA Uchinoura Space Center. The telemetry data are stored in the onboard data recorder, which has a 2 GB memory, and then transmitted to the ground. The S-band telemetry normally includes low-rate engineering housekeeping data, while the high-rate (4 Mbps) X-band telemetry is used for scientific data transmission. The telemetry data are received at Uchinoura station, ESA's Kiruna station, and also at the KSAT Svalbard station. The AKARI data amounts to approximately 2 GB per day.

5. In-Orbit Performance

The scientific instruments are all operating normally in orbit. The temperature of the telescope and the IRC structure is 5.8 K, and the temperature of the FIS detectors and the structure is 2 K, or lower. Measurements of the helium content performed in orbit has shown that the expected hold-time of the liquid helium in orbit is longer than 500 days (Nakagawa et al. 2007), which means that the All-Sky Survey can be executed more than twice within the cryogen lifetime. The telescope has a diffraction-limited performance for wavelengths longer than $7.3\,\mu$m (Kaneda et al. 2007). The telescope pointing error is less than $3''$. The attitude stability in the pointing mode is approximately $1''$, and the rate stability in the All-Sky Survey is less than $10^{-4\circ}\ \mathrm{s}^{-1}$. These numbers meet the scientific specifications for the requirements of the mission.

The point-source flux detection limits at $S/N > 5$ for one scan in the All-Sky Survey are 0.05, 0.13, 2.4, 0.55, 1.4, and 6.3 Jy for the *S9W*, *L18W*, *N60*, *WIDE-S*, *WIDE-L*, and *N160* bands, respectively. These were estimated on the basis of the noise measured in orbit using a preliminary version of the pipeline software, and could be improved with upgraded data-reduction techniques. The chief advantage of the AKARI survey over the IRAS survey will be a wide spectral coverage and a higher spatial resolution. The detection limits in the two mid-infrared bands are much better than those of IRAS. In the far-infrared bands, the higher spatial resolution of AKARI is expected to improve source detection and flux estimations significantly, particularly in confusing regions (Jeong et al. 2007).

More details about the in-orbit performance of the focal-plane instruments are described by Kawada et al. (2007), Onaka et al. (2007), and Ohyama et al. (2007).

6. Observation Strategy

The AKARI observations are classified into three categories: Large-Area Surveys (Matsuhara et al. 2005, 2006), Mission Programs (MP), and Open-Time programs (OT). The Large-Area Survey of central importance is of course the All-Sky Survey. The field of view is $8'$ for the FIS and $10'$ for the IRC. Successive sky scans cover the same sky area at least twice, and enable an efficient confirmation of the detection of celestial sources, excluding false signals due to cosmic-ray hits and sources of noise. The achieved sky coverage is greater than 90% of the whole sky during the first year, although some areas are left unobserved or observed only once due to the Moon interference and disturbance by charged particles in the South Atlantic Anomaly.

In addition to the All-Sky Survey, we are also conducting two further Large-Area Survey programs, consisting of a survey of the North Ecliptic Pole region (NEP) and the Large Magellanic Cloud. These two regions are covered with pointed observations. Both are located at high ecliptic latitudes, where the density of the scan paths for the All-Sky Survey is high, and thus some observing time can be spared for pointed observations. Approximately 25% of the total available pointed observations for AKARI are for use in the Large-Area Survey programs.

The Mission Programs are organized to interweave a series of pointed observations. Fifteen programs on solar-system objects, star-forming regions, stars, interstellar matter, infrared galaxies, and cosmology are being executed. About 45% of the total pointed observations for AKARI are assigned to the Mission Programs.

In addition to the above observation programs, 30% of the pointed observations in Phase 2 (see below) of the mission are opened to the Japanese, Korean, and European astronomical communities.

Lastly, some pointed-observation opportunities are reserved for the calibration of instruments and Directors discretionary observations.

The observation periods are separated into three phases. Phase 1 observations were made in the first six months after the performance-verification phase. AKARI performed the first All-Sky Survey during this phase, and also some pointed observations at high ecliptic latitudes. The actual period of Phase 1 began on 2006 May 8 and ended six months later on 2006 November 9. Approximately 70% of the sky has been covered with two or more scans in this period. In addition, a part of the Large-Area Surveys in the North Ecliptic Pole region and the Large Magellanic Cloud, were also executed. The Phase 2 period began on 2006 November 10, and will last until all the helium is exhausted. The second All-Sky Survey is to increase the sky coverage, and the pointed observations for the Mission Programs are being executed during this phase. The Phase 3 observations are defined as those after the helium is exhausted. In Phase 3, only pointed observations using the IRC/NIR channel are possible.

The point source catalogues of the All-Sky Survey are planned for release to the astronomical community in a timely fashion after the end of the survey.

7. Summary

The AKARI mission is operating normally, and has been generating 2 GB of data every day since 2006 May. Its All-Sky Survey will provide new infrared source catalogs, which are expected to surpass the IRAS catalogs with higher spatial resolutions and wider spectral coverage. The AKARI mission will provide an important and valuable database for present and future research in galaxy evolution, star formation, and planet formation.

Note added in proof (2007 September 3):

AKARI's liquid helium supply ran out on 2007 August 26.

The AKARI project, formerly known as ASTRO-F, is managed and operated by the Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA), with the participation of universities and research institutes in Japan, the European Space Agency (ESA), the IOSG (Imperial College, UK, Open University, UK, University of Sussex, UK, and University of Groningen, Netherlands) Consortium, and Seoul National University, Korea. The UK participation to the AKARI project is supported in part by PPARC/STFC. The Korean participation to AKARI Project was supported by KRF Grant No. R14-2002-01000-0 and BK21 program to SNU. The FIS instrument was developed by Nagoya University, ISAS/JAXA, the University of Tokyo, and the National Astronomical Observatory of Japan and other institutes, with contributions of NICT to development of the detectors. The IRC instrument was developed by ISAS/JAXA and the University of Tokyo as well as other supporting institutes. ESA/ESAC provides support for All-Sky Survey data processing, through pointing reconstruction. ESAC also provides user support for the observing opportunities distributed to European astronomers. ESA/ESOC is providing the mission with ground support through its ground station in Kiruna.

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