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THE *INFRARED ASTRONOMICAL SATELLITE (IRAS)*[1] MISSION

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ABSTRACT

The *Infrared Astronomical Satellite* (*IRAS*) contains a cryogenically cooled telescope orbiting above the Earth's atmosphere to make an unbiased all-sky survey at 12, 25, 60, and 100 μm. The instrumentation, its capability, and its mission are described.

Subject headings: infrared: general — instruments

I. INTRODUCTION

Infrared observations over the last two decades have proved increasingly important in understanding solar system objects and regions of star formation, in revealing astronomical sources obscured by interstellar dust, in identifying galaxies with large bursts of newly formed stars, and in delineating the emission mechanisms present in active galactic nuclei. Infrared astronomy has been hampered, however, by the lack of a sensitive survey over a significant portion of the sky.

Unbiased and sensitive all-sky surveys at infrared wavelengths are difficult because of the obscuration of the Earth's atmosphere and because of the thermal emission from warm telescopes and the atmosphere. The *IRAS* mission was designed to overcome these difficulties by conducting an all-sky survey from a space satellite with a cooled telescope. The primary goal of *IRAS* was to survey more than 95% of the sky at wavelengths from 10 to 100 μm with a sensitivity as close as practical to the limitation set by the fluctuations in the thermal emission from the zodiacal background. The point-source catalog produced from this survey is intended to be highly reliable (> 99.8%) and reasonably complete over the unconfused portion of the sky (98%) away from the galactic plane and other confused regions like the Magellanic Clouds and the Gould belt (Rowan-Robinson *et al.* 1984). In addition to the survey, special pointed observations are done to study preselected targets at higher sensitivity or angular resolution.

In this *Letter* we describe the *IRAS* instrumentation and mission. In the accompanying *Letters* in this issue, we present some preliminary results of the mission.

II. INSTRUMENTATION

The *IRAS* satellite consists of a spacecraft, described by Pouw (1983), and a liquid helium cryostat containing a cooled telescope. The telescope is a f/9.6 Ritchey-Chrétien design with a 5.5 m focal length, a 0.57 m aperture, and beryllium mirrors cooled to less than 10 K. A system of internal cold baffles reduces the system's response to off-axis radiation. External baffles and the sunshade (at ~ 100 K) reduce the heat load on the cold optical system from the Sun and Earth. The combined flux at the focal plane from all bright sources of off-axis emission during normal survey is less than a few percent of the thermal emission of the zodiacal dust particles over the range of observing angles used.

The focal plane assembly, located at the Cassegrain focus of the telescope, and cooled to less than 3 K, is shown schematically in Figure 1; its characteristics are summarized in Table 1. Sixty-two infrared detectors in the survey array are arranged so that every source crossing the field of view can be seen by at least two detectors in each of four wavelength bands. Each detector is preceded by a field lens and spectral filters. The spectral characteristics of the filters are shown in Figure 2. The electronics are direct coupled, permitting a measurement of the total flux entering the telescope. The long slits in Figure 1 are silicon detectors used to detect stars at visible wavelengths for position control and reconstruction.

The low-resolution spectrometer (LRS) is a slitless spectrometer with a wavelength range from 7.5 to 23 μm. On the

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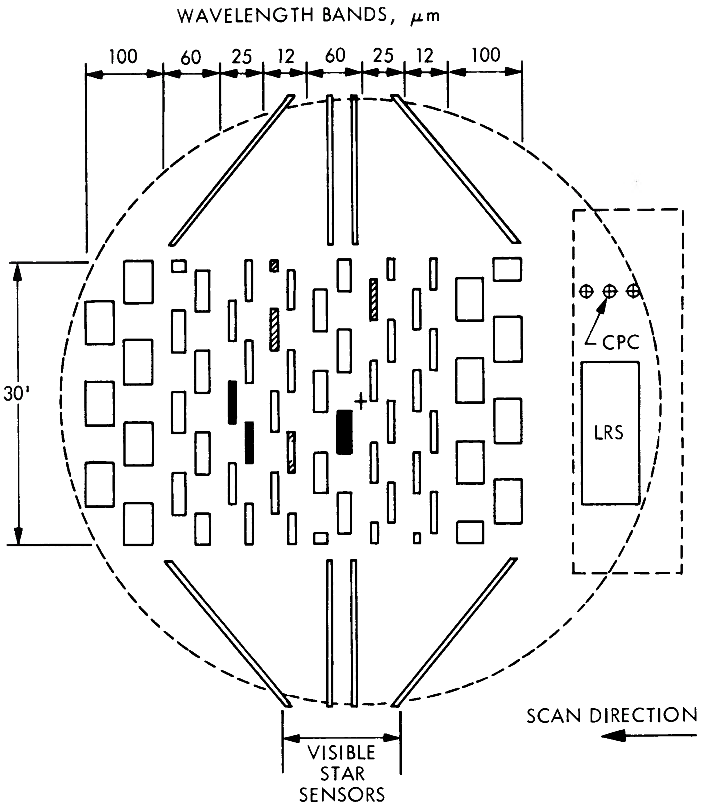

FIG. 1.—A schematic drawing of the *IRAS* focal plane. The rectangles in the central portion each represent a detector, filter, and field lens combination of the survey array. The image of a source crosses the focal plane in the direction indicated. The shaded detectors are inoperative or essentially so; these anomalies were known before launch.

TABLE 1

CHARACTERISTICS OF THE FOCAL PLANE ASSEMBLY CENTER

Center Wavelength (μm)	No. Working Detectors	Detector Field of View (arcmin)	Wavelength Interval (μm)	Detector Material	Dwell Time (ms)	Average 10 σ Sensitivity (Jy)
			Survey Array			
12.............	16	0.75 × 4.5	8.5–15	Si:As	190	0.7
25.............	13	0.75 × 4.6	19–30	Si:Sb	190	0.65
60.............	15	1.5 × 4.7	40–80	Ge:Ga	390	0.85
100.............	15	3.0 × 5.0	83–120	Ge:Ga	780	3.0
			Chopped Photometric Channel			
100.............	1	1.2 (diameter)	84–114	Ge:Ga	1,000	7.0
50.............	1	1.2 (diameter)	41–63	Ge:Ga	1,000	7.0
			Low-Resolution Spectrometer			
					Resolving Power	
... .	3	5.0 (width)	8–13	Si:Ga	14–35	
... .	2	7.5 (width)	11–23	Si:As	14–35	

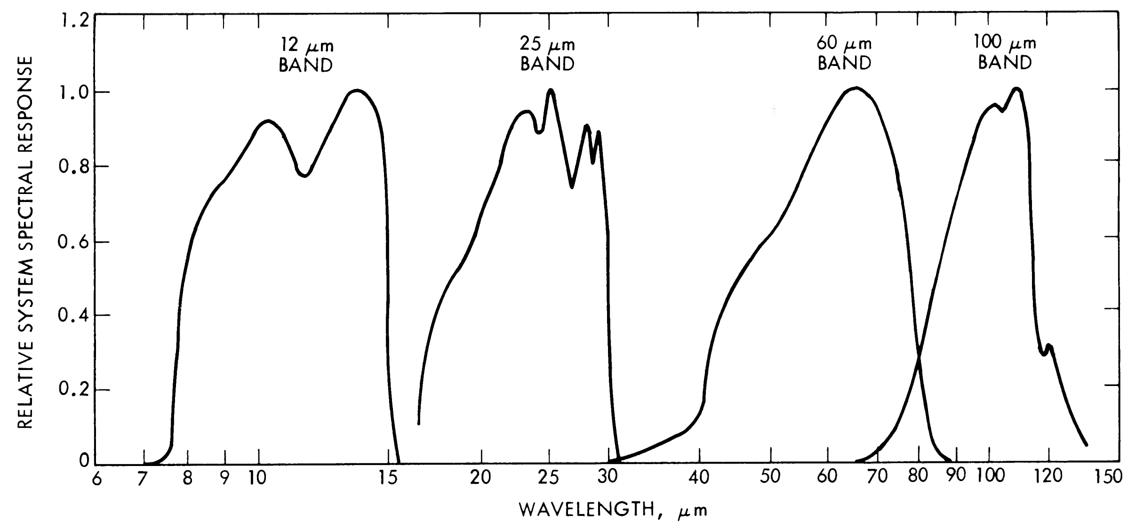

FIG. 2.—The spectral response of the detector, field lens, and filter combination of the survey array. Quoted flux densities have been calculated at wavelengths of 12, 25, 60, and 100 μm assuming the energy distribution of the source is flat in flux per logarithmic frequency interval.

basis of timing derived from the survey array, spectra with a resolution of approximately 20 are extracted from the data stream for all sufficiently bright point sources that cross the LRS aperture (see Fig. 1). The chopped photometric channel (CPC) operates during selected pointed observations, mapping infrared sources simultaneously at 50 and 100 μm with higher spatial resolution than normally provided by the survey array. The CPC has an internal cooled chopper and thus avoids the need for signal modulation by scanning and provides an absolute flux reference. The LRS and CPC are more fully described by Wildeman, Beintema, and Wesselius (1983).

An electronic discriminator eliminated fast rising pulses, such as those produced by cosmic-ray and trapped radiation events, from the survey array data stream. If the radiation dosage was too high, as was the case in the South Atlantic Anomaly, the dead time from the discriminator plus the "noise" from the remnant pulses invalidated the observations. Thus, no observations were taken during passage through this area. In addition, the dosage radically changed the responsivity and noise of the germanium survey detectors (60 and 100 μm) with responsivity recovery requiring several hours. Ground and flight tests showed that these radiation-induced effects could be annealed by raising the bias voltage on the detectors. This procedure, which was applied during passage through the South Atlantic Anomaly, reduced the radiation-induced responsivity changes to less than 20%.

Responsivities of the infrared detectors were monitored by means of a "stimulator," a source at approximately 100 K located in the telescope secondary mirror structure. This source was turned on before and after each survey scan and in conjunction with each pointed observation. The stability of the emission from this reference has been determined to be better than 3%.

The instruments behaved as predicted from the prelaunch measurements. The detectors remained stable with no obvious degradation after the launch. The DC stability of the electronics has proven to be extraordinary. Total flux measurements in a synthetic 0°5 beam are possible with 1 σ sensitivities of 2.3, 2.3, 2.4, and 5.6×10^4 Jy sr^{-1} at 12, 25, 60, and 100 μm, respectively. Preliminary in-flight tests for spectral leaks using hot stars show that the signal from sources hotter than 3000 K in the 60 and 100 μm wavelength bands contains less than 20% excess from short-wavelength spectral leaks. Analysis is underway to estimate the magnitudes of any long-wavelength spectral leaks.

III. MISSION DESCRIPTION AND CHRONOLOGY

The satellite was launched into a 900 km altitude near-polar orbit on 1983 January 26 GMT. The cryogenic helium supply was exhausted on 1983 November 22 GMT. The orbit has an inclination of 99° with respect to the Earth's equator and precesses so that it remains close to the plane of the terminator. The telescope could point away from the local vertical by up to 30° by rotating the entire satellite. Scans of the sky were performed by rotating about the vector from the satellite to the Sun at fixed solar elongation angles between 60° and 120°. In survey scans, the boresight swept across the sky at a rate of 3°85 per minute.

The cover which kept the telescope free of contamination in the Earth's atmosphere was ejected 6 days after launch, and, after a period of in-orbit checkout and calibration, survey observations were begun on 1983 February 9.

The strategy followed in conducting the survey was based on achieving the goals of completeness and reliability for point sources in the presence of potential contamination from radiation by space debris passing near the spacecraft and energetic particle events, and from moving sources such as asteroids. The strategy involves four steps of confirmation labeled "seconds," "hours," "weeks," and "months" confirmation. Seconds-confirmation is achieved because a source always passes over two rows of detectors in the same wavelength band. Subsequent scans of each area were laid down in pairs; the second scan of each pair half overlapped the first in the cross-scan direction and completed an hours-confirming pair. Each pair of hours-confirming scans was repeated within 7–11 days to yield weeks-confirmation. A third pair of hours-confirming scans made up the months-confirmation.

By the end of the mission, 72% of the sky had been observed with three or more hours-confirming scans, and 95% was observed with two or more hours-confirming scans. Three percent of the sky was covered with only one hours-confirming scan, and 2% was not observed. Most of the area with low confirmation coverage was concentrated in one 5° gap in ecliptic longitude. Initially, in what is termed the "minisurvey," about 300 deg^2 of the sky was surveyed with three or four hours-confirmed coverages (Rowan-Robinson *et al.* 1984).

Of the 14 orbits available each day, the 9 orbits least affected by the South Atlantic Anomaly were devoted to the main survey except when the Moon was within 25° of the boresight. The remaining orbits were taken up with calibration observations and pointed observations of preselected objects, each typically 10 minutes in duration. Many specific observational sequences were available, but in general the pointed observations using the survey array were in the form of a raster pattern such that an area of about 1°.5 × 0°.5 centered on the preselected position was observed with a sensitivity 5–10 times better than that of the survey. High-resolution CPC maps covered an area 9′ × 9′ with a raster scan pattern and have a sensitivity comparable to the survey. Processing to co-add observations for further increase in sensitivity is available.

IV. POSITION RECONSTRUCTION AND CALIBRATION

For some 2000 stars detected at 12 and 25 μm early in the mission and identified in the SAO catalog (1966), the positional uncertainty ellipse after reconstruction has semimajor and semiminor axes of 45″ × 9″ (99% confidence limits) for an hours-confirmed source. For sources detected only at 60 μm, the estimated uncertainty is approximately 45″ × 15″, while for sources detected only at 100 μm the uncertainty ellipse has dimensions of 45″ × 20″. The boresight positions in the direction perpendicular to the scan motion ("cross-scan") are known, *a priori*, to less than 5″ from a solar limb sensor on the spacecraft. This is not the accuracy of the reconstructed positions of infrared sources, however, because of the cross-scan size of the detectors, typically 4′.5–5′. If a source is determined to cross the region of edge overlap of the detectors, the reconstructed cross-scan positional uncertainty is significantly less than the size of the detectors. Likewise, if one takes advantage of the edge overlap or edge detectors in defining pointed observations, one can significantly improve the cross-scan positional accuracy, the photometric accuracy, and the spatial resolution (see, in particular, Aumann *et al.* 1984).

The *IRAS* point-source calibration at 12 μm is tied to the ground-based 10 μm absolute calibration by observations of α Tauri. The relative responsivity of the other *IRAS* bands is determined with respect to the 12 μm band by modeling the emission of observed asteroids. Finally, the fluxes radiated by a number of astronomical sources were determined and used as secondary standards throughout the mission. The extended emission calibration is obtained from the point-source calibration by measuring the ratio of the DC responsivity to the responsivity in the point-source bandwidth using long and short flashes of the stimulator source.

Alpha Tau was assumed to radiate like a 3700 K blackbody from 7 to 15 μm with a flux density at 10.6 μm of 533 Jy corresponding to −2.99 mag on the scale described by Rieke and Low (1979) and Rieke (1982) who estimate the absolute uncertainty at 10.6 μm to be less than 10%. Observations of the asteroid Fortuna in all four bands coupled with the asteroid model described by Morrison (1973) transferred the calibration to the other wavelength bands. The planetary nebula NGC 6543, located in an area of sky accessible throughout the mission and sufficiently bright in all the wavelength bands, was selected as the secondary standard. It was observed at least once per day and served to calibrate the stimulator flashes. The band-to-band relative calibration uncertainty is estimated to be less than 15% on the basis of intercomparisons of α Tau, γ Draconis, and Fortuna. There is excellent agreement between *IRAS* measurements of stellar sources at 12 and 25 μm and ground-based measurements (Aumann *et al.* 1984). The relative photometry of a source shows a dispersion of 10% because of cross-scan responsivity effects. Although numerous checks are planned to validate the absolute calibration, the present calibration will remain in force until the catalog of *IRAS* sources is produced.

The bandwidths of the spectral filters are sufficiently broad (see Fig. 2) that the flux densities derived from the measurements depend on the true energy distribution of the observed source. The flux densities obtained from the *IRAS* measurements have all been referred to wavelengths of 12, 25, 60, and 100 μm. Unless it is specifically stated otherwise, the flux densities have been calculated assuming that the energy distribution of the source is flat in the flux per logarithmic frequency interval. The flux densities at the assigned wavelengths of 12, 25, 60, and 100 μm must be multiplied by the correction factors given in Table 2 if the input spectral energy distribution differs from the assumed energy distribution.

V. DATA REDUCTION

The observations are analyzed both in Europe and the United States. A preliminary science analysis of the observations was done in conjunction with the satellite operations in

TABLE 2

COLOR CORRECTION FACTORS

TRUE INPUT ENERGY CONTINUUM	WAVELENGTH BAND (μm) 12	25	60	100
Power-Law				
spectral index = −1	1.00	1.00	1.00	1.00
= 0	0.92	0.93	0.95	0.98
= +2	0.69	0.75	0.75	0.89
Blackbody				
temperature (K) = 1000	0.80	0.79	0.78	0.90
= 300	1.09	0.89	0.82	0.91
= 30	···	0.47	0.98	1.04

England. The method of data analysis was similar to that described below for the final data analysis, but the thresholds were set at a somewhat higher level. Rapidly moving objects, such as comets and Earth-crossing asteroids, were searched for at this time so that confirmation from the ground could be obtained. Reconstructed calibrated images from the CPC, correcting for a number of instrumental effects, are in progress in Holland.

Final reduction of the data using the survey array and LRS is done in America. After pointing reconstruction and calibration, peaks in the data stream are matched with a template which represents the detector response to a point source. A detection requires a correlation coefficient with the template exceeding 0.87 and an amplitude greater than 3 times the rms noise on a single sample. A source is accepted as hours-confirmed if it is seen three of the possible four times on the two scans making up an hours-confirming pair, and it is accepted as a confirmed *IRAS* source when it has been hours-confirmed twice. The data stream is also examined for small extended sources, using square wave filters with a full width up to 8′. The two-dimensional intensity distribution on the sky will be presented in a series of 16°.5 × 16°.5 images with 2′ pixels located on 15° centers.

The *Letters* in this issue are based on data reduced both in Europe and America.

Too many people have contributed to the success of *IRAS* to thank each individually. The *IRAS* project management was cochaired by Peter Linssen and Eugene Giberson. A series of managers have played important roles during the lifetime of *IRAS*. These include: H. Bevan, W. Bloemendal, E. K. Casani, D. Compton, R. Dalziel, J. de Koomen, W. de Leeuw, E. Dunford, J. Duxbury, T. Harmount, R. Holdaway, J. Macdougall, B. Martin, A. Rogers, G. Smith, C. Snyder, G. Squibb, G. Thomas, R. van Holtz, and R. White. The staffs at the headquarters of NIVR, of NASA, and of SERC have steadily supported us for many years.

We thank the several teams from the three participating nations that support *IRAS* operations and analysis at the Rutherford Appleton Laboratory (RAL) and the Jet Propulsion Laboratory (JPL); they have ensured that the necessary observations were scheduled, that the complex performance of the spacecraft and its telescope was understood and optimized, and that the most would be extracted from the observations. Software for operations and analysis at both RAL and JPL was provided by all three participating nations. The success of *IRAS* would of course not have been possible without the efforts of many people over the years who developed the hardware and who were willing to go beyond the specifications in order to get the additional performance and reliability which has now paid off in the flight of *IRAS*. We especially thank Joy Hodges, Conway Snyder, and Mary Burgess for their assistance in producing these *Letters*.

NIVR was responsible for the design and development of the spacecraft and the integration of the satellite. NIVR also was responsible for the ground facility and services for the operation of the satellite while in orbit. The spacecraft was built and the satellite integrated by ICIRAS, an industrial consortium consisting of Fokker and Signaal, with the Dutch National Aerospace Laboratory as subcontractor. The LRS and CPC instruments were built at the Laboratory for Space Research at the University of Groningen.

The SERC carried out the design, development, and operation of the real-time tracking and data acquisition facility which controls the satellite, and supported the design, development, and implementation of the non–real-time control software and the preliminary analysis facility at RAL.

NASA was responsible for the design and development of the telescope. NASA also provided the launch of the satellite by Goddard Space Flight Center with a Delta 3910 Rocket at the Western Test Range and ground tracking and communication during the early weeks after launch. NASA is also responsible for the final data processing of the survey data. The telescope and Dewar were built by Ball Aerospace Systems Division under contract to Ames Research Center and JPL. The mirrors were built by Perkin Elmer Corporation. The original focal plane detector array was rebuilt and retrofitted by JPL with the assistance of Infrared Laboratories and Cornell University.

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