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ABSTRACT

The Jet Propulsion Laboratory's Scientific Data Analysis System will process Infrared Astronomical Satellite data and produce a catalog of perhaps a million infrared sources in the sky, as well as other vital information for astronomical research.

INTRODUCTION

The Infrared Astronomical Satellite (IRAS), to be launched in 1982, will systematically survey the sky in the wavelength region of 8 to 120 microns. This highly sensitive earth-orbiting infrared observatory is expected to detect an extremely large number of objects during its planned one-year lifetime. The uniqueness of IRAS is that the entire sky will be covered over a large percentage of the infrared spectrum at sensitivities a hundred times greater than previously achieved from high-altitude observatories, aircraft, balloons, or sounding rockets.

IRAS is directly supported by a team of eighteen leading astronomers, nine from the United States and nine from Europe. The program is expected to make major contributions in many areas, notably in investigations of the formation of stars and of the explosive phenomena in the nuclei of galaxies. Table 1 lists the number of different celestial sources expected to be seen at 10 and 100 microns during the IRAS survey.

From Vandenberg Air Force Base in Lompoc, California, the satellite will be launched into an orbit 900 kilometers above the earth to provide a clear view of the sky, unobstructed by infrared absorption in the earth's atmosphere. The orbital altitude and an inclination of 99 degrees were selected to produce a sun-synchronous orbit - one in which the orbital plane will remain perpendicular to the earth-sun line. The telescope will point radially outward from the earth, so a 360-degree ring of width equal to the instrument's field of view (1/2 degree) will be observed during each orbit. In the simplest case, the complete sky would be covered in six months, since in six months the orbit will precess 180 degrees. In actuality the complete sky will be observed in less time because the satellite can articulate the telescope 30 degrees off the local vertical.[1]

The satellite (see Figure 1) will consist of a cylindrical spacecraft and a large infrared telescope.[2] The vehicle will be twelve feet long and six feet in diameter, and will weigh 2400 pounds. The spacecraft will provide support functions such as electrical power,

Table 1. Expected numbers of celestial sources.

Source type	10 microns	100 microns
Stars–photosphere	10^6	
Stars–dust shells	10^6	$10^{4\pm1}$
Stars–A_e, B_e, T-Tau	10^4	
HII regions	10^4	10^4
Planetary nebulae	10^4	10^4
Compact sources–galactic	10^5	
Galaxies–Seyfert	10^3	$10^{4\pm1}$
Galaxies–other	10^3	
Quasi-stellar objects	$10^{2\pm1}$	
Asteroids	2×10^4	

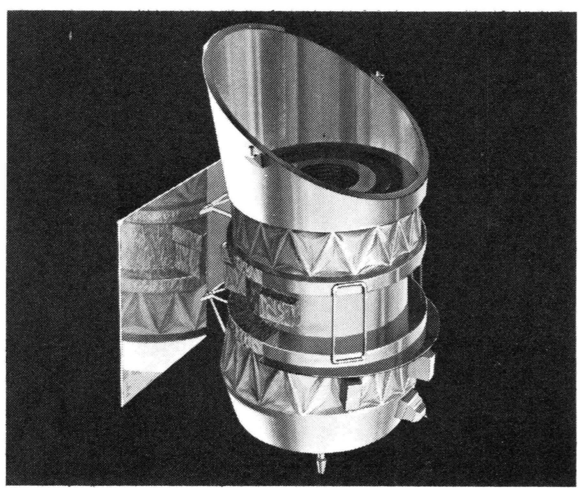

Figure 1. Infrared Astronomical Satellite.

attitude control, telecommunications, and computing. Data storage will be provided by two identical tape recorders, each capable of holding 450 million bits of data. The power source will be a solar panel and a battery designed to handle a nominal load of 250 watts.[3,4]

The telescope, representing 75 percent of the satellite's volume, consists of a Ritchey-Chretien optical system, a cryostat, a focal-plane assembly, and instrument data processing and sequencing electronics. Two beryllium mirrors in the optical system will focus intercepted space radiation onto the infrared detectors. The primary mirror has a diameter of 57 cm and a focal length of 55 cm. The cryostat is a toroidal tank that will hold 600 liters of superfluid helium. The tank is mounted within the evacuated main shell (the telescope's primary support structure) and completely surrounds the optics barrel and critical sensing components. This cryogenic temperature control system will maintain the optical system and infrared detectors at two degrees Kelvin so that the limiting sensitivity of the survey will be determined by the natural backgrounds of the thermal emission from the zodiacal dust. The focal plane assembly (Figure 2) contains 62 infrared detectors (designated the survey array), five low-resolution-spectrometer (LRS) detectors, two chopped-photometric-channel (CPC) detectors, a short-wavelength-channel (SWC) detector, and eight visible-star detectors.

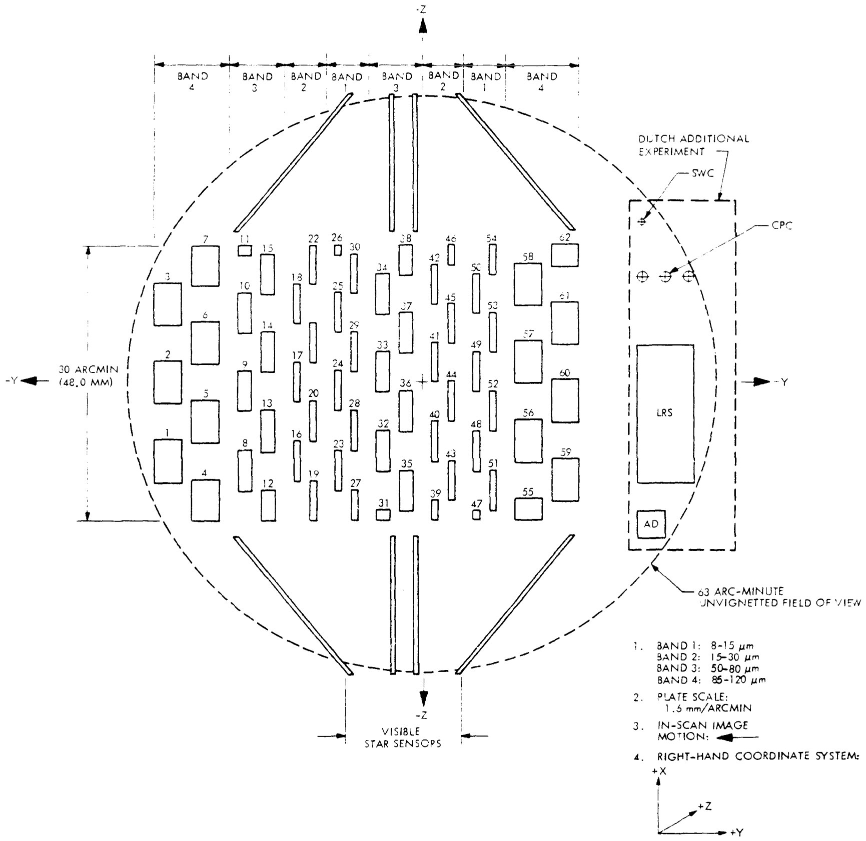

Figure 2. Focal-plane layout of the infrared detectors.

Data from the focal plane assembly will be digitized and compressed within the telescope and recorded on the spacecraft tape recorder. These stored data will be dumped to a tracking station in Chilton, England twice a day. At the same time, the observation plan for the next twelve hours will be transmitted to the satellite. The IRAS preliminary analysis facility and operations control center will also be located in Chilton. The preliminary analysis facility, using a small fraction of the data, will confirm that the instrument has operated correctly for the past twelve hours and that the desired sky region has been observed. The operations control center will control the satellite, monitor its "health", and forward the raw science data to the Scientific Data Analysis System (SDAS) at the Jet Propulsion Laboratory (JPL) in Pasadena, California. The data will be transferred over a wide-band link at a rate of 56 kilobytes per second, using land lines and communication satellites. At SDAS, the raw data will be processed to obtain the intermediate and final data products required by the IRAS science team. This paper provides an overview of the SDAS catalog processing.

SCIENTIFIC DATA ANALYSIS SYSTEM DESCRIPTION

SDAS is an off-line data processing facility. Its primary function is to produce a catalog of inertially fixed infrared-emitting point sources (mainly stars and galaxies) observed during the IRAS survey. Other functions include generating specialty catalogs (subsets of data in the primary catalog), flux maps of sky sectors including the galactic plane region, moderate-resolution images of extended sources such as nebulae and dust clouds, spectra of bright sources, telescope pointing history files, sky coverage summaries, and source detection statistics. SDAS also will provide specialized processing in support of a deep sky experiment, which will allow weak sources to be detected below the survey flux threshold in selected areas of the sky by increasing the observing time per spatial resolution element approximately a hundredfold over the observing time in the normal survey.

A final purpose of SDAS is to provide analytical tools for members of the IRAS science team resident at the processing facility. These tools will be used to verify the catalog processing, a crucial function since the catalog will be a major scientific publication. In addition, the analytical tools will be used to identify corrections and refinements of the existing astrophysical sky models using IRAS results and finally, to generate associations of IRAS sources with objects discovered in previous surveys, both infrared and noninfrared.

Figure 3 shows the major SDAS processing units. All software except the science analysis package will be operated on IBM System/360 Model 75 computers at JPL's mission control and computing center. The science analysis software resides on an IBM Series/1 computer located in the IRAS mission support area. Data can be transferred from the catalog production computer to the science analysis computer through an electrical interface or by means of magnetic tape.

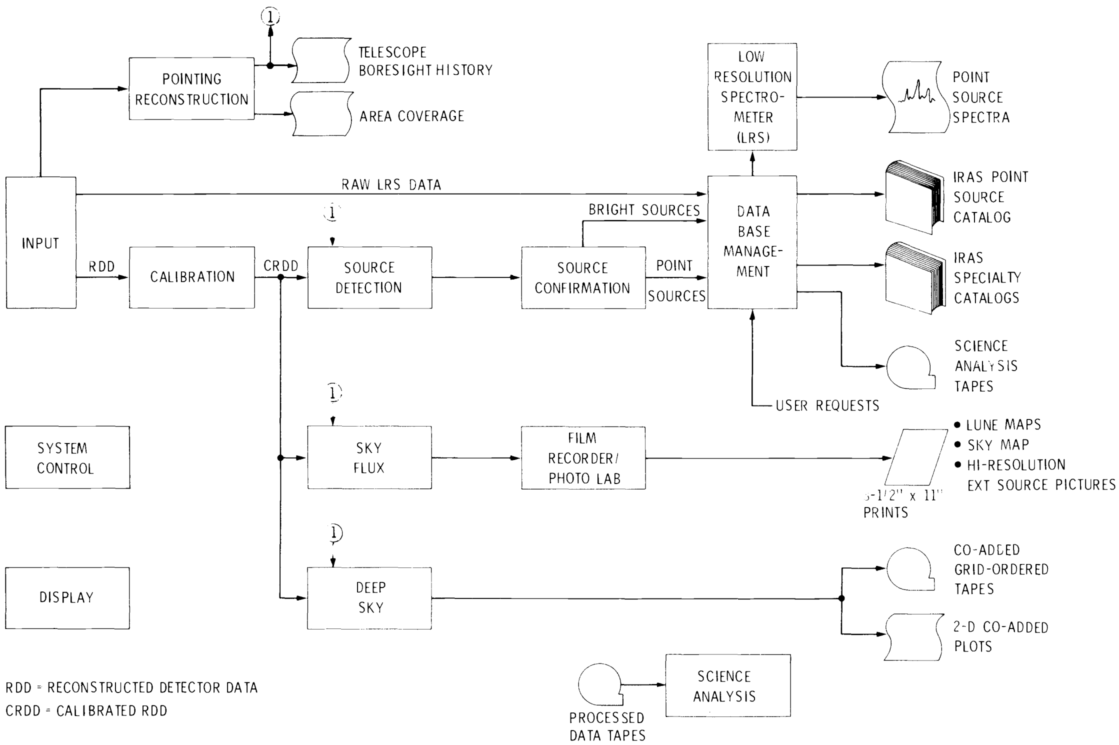

Figure 3. Block diagram of major SDAS processing units.

CATALOG PROCESSING

Based on the nominal instrumentation sensitivity of IRAS, it is estimated that the primary catalog will list about a million sources. The parameters to be reported for each source are sky location, flux for each of the four IRAS wavelength bands, uncertainties in position and flux, a flux variability indicator, number of independent observations, source classification, and association of the source with known infrared or noninfrared objects. The final catalog will be provided on both magnetic tape and microfiche. (A hard-copy version would require a stack of line-printer paper seven feet high, assuming one source record per line.) To produce the catalog, the following basic processing steps will be applied to the raw detector data:

* Reconstruction of signals
* Conversion to astrophysical units
* Detection of sources
* Confirmation of sources
* Construction of a working survey data base
* Production of spectra for bright confirmed sources
* Extraction of the final catalog and specialty catalogs from the working survey data base

Signal reconstruction and conversion to astrophysical units

The infrared detector data received at SDAS will be encoded by the telescope into eight-bit numbers, each number representing a difference value between consecutive detector samples. The data for each point will be added to the prior value of the point to obtain a number which eventually must be converted to the actual detector output voltage. Every four seconds, the telemetry data stream for each detector will also provide a sample of the non-differenced output. That value will be compared with the reconstructed value to guard against data processing errors on the ground. The input subsystem contains the algorithms for signal reconstruction and correction.

The calibration subsystem will convert the reconstructed science signals described above to data streams proportional to the infrared flux incident on each detector. This conversion, from telescope hardware units to astrophysical units, will allow subsequent processing to be undisturbed by peculiarities and nonlinearities of the science instrument. This is particularly important for the processing of large extended sources such as nebula and dust clouds. (This processing, which is provided by the sky flux subsystem, is discussed in considerable detail in Ref. 5.) The telescope hardware elements to be modeled and removed in this signal conversion process are the analog-to-digital converter, commandable gain of the analog electronics, commandable offset of the preamplifier electronics, preamplifier offset, load resistor nonlinearity, and detector responsivity.

After calibration processing, the relative accuracy of photometry in the IRAS wavelength, bands will be about 20 percent for an hours-confirmed observation of a source not limited by signal-to-noise considerations. The absolute calibration of the IRAS survey will be analyzed throughout the mission, primarily on the basis of IRAS observations of infrared sources of independently known absolute fluxes. The result of this analysis will be applied to the IRAS sources in the working survey data base in the process of generating the final IRAS data products at the end of the mission.

Source detection

A challenging requirement for SDAS is that the final catalog is to include at least 98 percent of all infrared point sources having a brightness of 10^{-18} watts per square centimeter or greater in unconfused regions of the sky. This is referred to as the catalog completeness requirement. In addition, the number of false sources in the catalog is not to exceed 0.2 percent of the total sources reported. This is the catalog reliability requirement. The design of the IRAS point source recognizer is critical, since it is the first of two serial processors whose combined performance will directly determine the catalog's completeness and reliability. (The second processor is the source confirmation software; it is described in the next section.) The point source recognizer must be able to "see" bumps in the data stream which represent the real inertially-fixed point sources. This task is extremely difficult. The data stream will be complex because of the many types of infrared sources that simultaneously and randomly register their different signatures on the detectors in the presence of a widely varying sky background. The discrete sky contributors will be asteroids, meteoroids, dust, space junk in earth orbit, some planets and their natural satellites, man-made earth satellites, galactic sources, and extragalactic sources. The contributors to the background component will be zodiacal light and scattered radiation from the sun, moon, and earth (see Figure 4). The dynamic range of the sky background (varies with telescope look direction) is about 5×10^4.

The source detection subsystem contains the algorithms that will identify point sources in data streams from the individual detectors. Identical processing will be performed for all 62 detectors in the survey array. No attempt will be made at this point to correlate detections from the separate data streams; that task will be performed by the source confirmation subsystem. A more detailed description of the source detection subsystem design is given in Ref. 6.

Source confirmation

The main protection against the entry of spurious (noncelestial) sources into the IRAS data base will be the survey's redundant coverage of the sky. The point source confirmation subsystem (Figure 5) contains filtering logic designed to take advantage of redundant coverage. Previously detected point sources will be passed through several stages of filtering to one of several files, depending on the type of infrared source observed. Known celestial sources will provide verification that the confirmation filters are passing the celestial sources as intended.

The first stage of confirmation, called seconds-confirmation, will provide a filter against events local to the spacecraft, such as dust particles entering the field of view, electrical cross talk, and unfiltered high-energy particle pulses. Because the focal plane geometry and scan rate of the telescope are known, it is possible to predict the time delay in source sightings by different detectors of either the same band or different bands. This delay will be used to group individual sightings first into sources seen by more than one detector in a particular infrared band (seconds-confirmed) and, second, those seen in more than one band (band-merged). Because the completeness of the catalog at the nominal sensitivity limits of the survey is an important consideration, it will be necessary at this stage not to delete any detections that fail seconds-confirmation. Thus each detection will be carried in one of two categories to the next stage of confirmation, referred to as hours-confirmation. The two categories are seconds-confirmed, band-merged sources and non-seconds-confirmed detections.

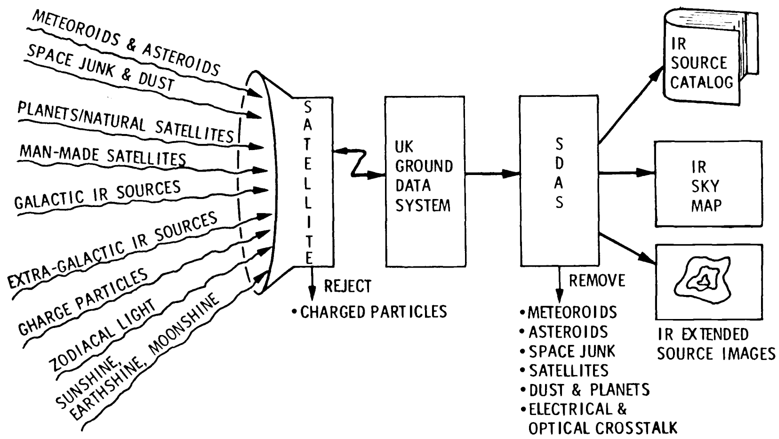

Figure 4. The science processing task.

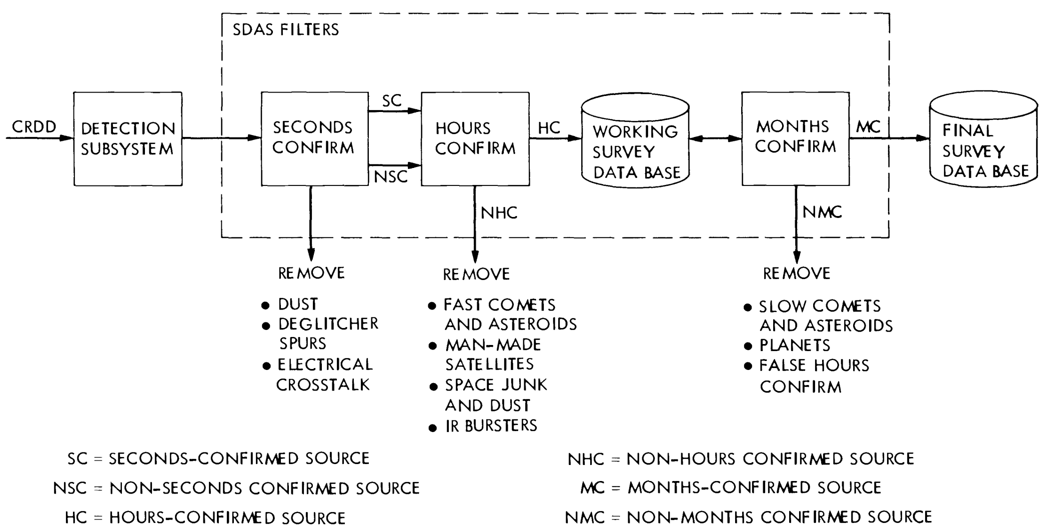

Figure 5. Block diagram of the point source confirmation subsystem.

Using the repeated coverage of the sky within a few orbits (hours), the hours-confirmation filter will separate apparently stationary celestial sources from moving sources. The condition for finding an hours-confirmed source is that any such source (in a given band) must be formed from at least one seconds-confirmed detection and at most one detection that is not seconds-confirmed. For all seconds-confirmed, band-merged sources, matches will be sought among all possible sources, both seconds-confirmed and not, found on other coverages of the same portion of the sky. Sources that pass the hours-confirmation filter will be entered into the IRAS working survey data base. Events that do not pass will be filed in either of two categories: those that are not seconds-confirmed (events generated locally to the satellite) and those that have met the seconds-confirmation criteria and probably are true infrared "far field" events. Infrared sources in the second category will be asteroids and other solar-system bodies having proper motions greater than one minute of arc per hour and inertially fixed infrared sources that vary significantly in intensity over the same time scale (that is, burster events).

Most known asteroids will appear as hours-confirmed infrared sources. Therefore, another stage of filtering will be required. Each object that enters the IRAS working survey data base will be observed approximately three times in three months at the same level of confirmation. These multiple sightings will be merged in a filtering process called months-confirmation. Ultimately the working survey data base will be culled for objects that appear inertially fixed and have been hours-confirmed at least twice. Those objects will then be included in the IRAS catalog. The months-confirmation between successive sightings of an infrared source will be determined on a purely positional basis. Sources that do not meet the above criteria will be put in another file. Among the candidates for that file will be variable infrared sources that are inertially fixed and that exceed the IRAS detection threshold only once in three months, as well as solar-system bodies with proper motions less than one minute of arc per hour but greater than one minute of arc per month.

An important diagnostic of both the IRAS hardware and the detection and confirmation logic will be afforded by the detection of known infrared sources. A file of approximately 30,000 known sources that are bright at infrared wavelengths will be created and maintained. The confirmed IRAS sources will be compared with known sources predicted to appear in the IRAS survey at specified times. These times will be derived from the telescope pointing history. All detections predicted from the file of known infrared sources will be printed out to show that the processing of survey data is being done properly. Failure to detect or confirm any of the known sources will be flagged immediately for inspection and analysis.

Another aspect of the confirmation processing is the refinement of source position as additional sightings of a given source are obtained. The expected improvement in scan and cross-scan position is shown in Figure 6.

Data base management

The SDAS is faced with an extremely large data-handling task. During the one-year mission, raw scientific input to SDAS will amount to some 250 billion bits of data, accumulating at a rate of about 700 million bits a day. These numbers will be immediately doubled at

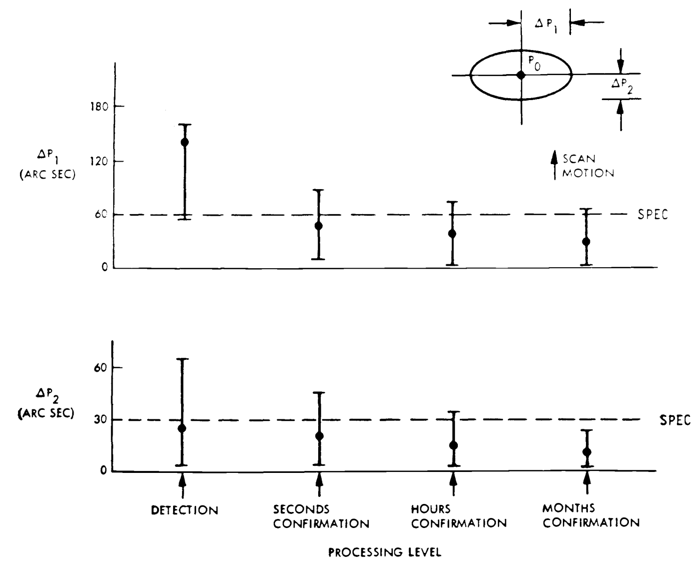

Figure 6. Expected improvement in source position.

the start of SDAS processing, as the signal-reconstruction step expands each eight-bit detector difference value to 16 bits. Because of the source confirmation strategy, little data can be thrown away before the final science data products are extracted. Computer storage will not be sufficient to contain the complete IRAS data set on line, so the processed data will be stored on magnetic tape. Each day the new sources discovered will be compared with former IRAS sightings (within the last 36 hours for hours-confirmation, and before then for months-confirmation). Thus a carefully planned data storage and retrieval method must be developed, with comprehensive data directories to enable the off-line data to be recalled, interrogated, updated, and returned to the tape library in an operationally efficient manner. At conclusion of the one-year data acquisition period, it is estimated that there will be more than 10,000 tapes in the IRAS library.

The data base management subsystem is the processing unit assigned to handle these problems. In general, point-source data records will contain both time and position information for access and retrieval. The time information can be obtained at any of three levels: observation (five to fifty minutes), satellite observation plan (twelve hours), or multiple satellite observation plans (days). The primary data base established for the point-source catalog will be the working survey data base. Each day the contents of this data base will change and grow as new hours-confirmed sources are found and their celestial positions refined.

A staggering number of astronomical events will have to be characterized accurately every day and stored for future access. About 30,000 fixed and moving infrared sources with signal-to-noise ratios greater than 2.5 will be seen daily by the telescope. If the spurious events are of the same magnitude, the SDAS detections will number about 125,000 every day. This figure represents approximately 40,000 seconds-confirmed and 25,000 hours-confirmed sources a day.

The data base management subsystem will also generate the final science data products at the end of the mission.

Survey data products

The SDAS will produce intermediate and final data products for the IRAS science team. The intermediate data products will enable resident astronomers to monitor the daily processing and will support scientific analysis during the mission. The final data products will be delivered to the IRAS science team and to the National Space Science Data Center in Greenbelt, Maryland for subsequent dissemination to other researchers. The final data products are described below:

* The final point source data base will contain all data in the working survey data base that satisfy observation and flux criteria defined by the IRAS science team. The data will be organized on magnetic tape by ecliptic position.
* The final point source catalog, formatted according to science team requirements, will contain all sources in the final point source data base. The data will be organized on microfiche by ecliptic position.
* Specialty catalogs, to be available on magnetic tape and on microfiche, will contain subsets of the sources in the final point source data base. For example, there will be a minimum-flux catalog, a correlated extragalactic source catalog, a source color-criteria catalog, and a variable source catalog.
* The final LRS data base, to be available on magnetic tape, will contain records of all LRS (low-resolution-spectrometer) data for point sources that have met IRAS science team criteria for observation frequency and brightness.
* The final LRS atlas will contain hard-copy plots of the LRS spectra for a subset of the sources in the final LRS data base.
* SDAS data directories will provide references to all data stored on magnetic tape. There will be one directory for observation-related data and a second for multi-observation data. Printouts of both directories will be maintained in the SDAS tape library.

CONCLUDING REMARKS

The IRAS mission will observe the entire sky at least three times during its nominal life time. This systematic survey is expected to provide data for the compilation of a highly reliable and comprehensive catalog of infrared emitters. It is estimated that the catalog will contain approximately a million objects having a brightness of 10^{-18} watts per square centimeter or greater. The IRAS catalog is expected to contribute significantly to a better understanding of the universe. It will serve as a primary reference for astronomers as they study the night sky from ground-based telescopes and make their plans for future ground and flight observing programs.

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