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ABSTRACT

A systematic examination of 1836 images of the sky constructed from scans made by the Infrared Astronomical Satellite has resulted in the detection of 466 objects which are shown to be in Earth orbit. Analysis of the spatial and size distribution and thermal properties of these objects, which may include payloads, rocket bodies and debris particles, is being conducted as one step in a feasibility study for space-based debris detection technologies.

INTRODUCTION

The Infrared Astronomical Satellite (IRAS) was launched, as a joint project, by of the United States, Netherlands and the United Kingdom to survey the sky in four broad wavelength bands centered at 12, 25, 60 and 100 microns. IRAS was placed into a circular orbit at an altitude of 900-km and an inclination of 99°. The plane of the orbit precessed at a rate nearly equal to one degree per day thereby maintaining its position above the Earth's terminator. Over most of the mission IRAS scanned the sky at a solar elongation near 90° and was restricted to solar elongation angles between 60° and 120°. The focal plane contained an array of 62 infrared detectors divided into eight modules (Figure 1). For each passband there were two detector modules, in order to provide redundant detections on short timescales (seconds).

So that fixed astrophysical sources would be reliably discriminated from transient objects, multiple scans were made of the sky. The paired detector modules scanned the same location seconds apart in time (seconds-confirmation), allowing random cosmic ray strikes and detector noise to be distinguished from real sources. As IRAS orbited the focal plane, it swept out a 0.5° wide strip of sky. After each orbit, the satellite scan would generally be shifted by 0.25° near the ecliptic. As a result a source observed on one half of the focal plane would be observed on the other half 103 minutes later (hours-confirmation or HCON). Fast-moving asteroids and comets did not hours-confirm. Three surveys, designated HCONs 1, 2 and 3, were made of the sky during the 11 month mission. HCONs 1 and 2 each covered 96% of the sky and were alternated on timescales of weeks, after which HCON 3 began. HCON 3 covered 76% of the sky before IRAS exhausted its supply of liquid helium cryogen. Additional information about the IRAS mission can be found in the IRAS Explanatory Supplement /1/.

Although not designed to detect Earth orbiting objects specifically, as a consequence of the above observing strategy, IRAS was able to discriminate between such sources and true astrophysical sources of infrared emission. We show here that valuable information concerning Earth orbiting objects may be obtained by suitably analysing IRAS data.

OBSERVATIONS

Examination of multi-band false color IRAS skyflux images indicated the presence of many non-seconds-confirming sources best explained as objects in Earth orbit. Systematic study of these images is part of an ongoing survey of solar system dust trails /2,3/. Each skyflux image was constructed from all the scans contained within a 16.5° × 16.5° field during a single HCON. The scans were averaged into 2' × 2' pixels. The sky was divided into 212 such fields, which were mapped in each of the four IRAS passbands. In constructing the images, the detector outputs were "phased" so that flux from a fixed source observed by different detectors would map onto the same location. Consequently, a moving source appears at two

Fig. 1. The IRAS focal plane detector array /1/.

locations in a single passband image because of the pairs of detector modules; also, it appears in different locations from band to band.

Two types of rapidly moving sources are identified in this study. They are characterized as either near-field (Figure 2a) or far-field (Figure 2b). A near-field source illuminates many or all detectors of the focal plane array at a given time as it moves across the field of view, while a far-field source illuminates only a few detectors.

Twelve near-field sources were detected in the survey which can be attributed to either a particle passing near the front of the telescope or to a shower of electrons simultaneously exciting many detectors as a result of a cosmic ray event. This type of near-field source is clearly seen on single wavelength images (Figure 2a). One hundred forty three of the brightest of these sources were removed in the data processing prior to the general release of the skyflux images /4/.

A total of 454 far-field sources were detected in the skyflux images. The objects were found to be distributed randomly in right ascension and declination. No concentration at the poles or at any specific latitude has been observed (Figure 3).

ANALYSIS

Each observation of these moving objects consists of a single scan by IRAS. Skyflux images, however, are averages of several scans, therefore the motion and flux of an object can not be reliably determined from these images. Instead, individual detector outputs must be inspected. The time-ordered Calibrated Reconstructed Detector Data (CRDD) was examined for two near-field and three far-field sources. The scan containing the source is characterized by sharply peaked profiles in the CRDD plots. The detectors showing the greatest flux determine the track of the object across the focal plane.

One of the near-field sources is a cosmic ray event. This is demonstrated in the CRDD plots by the single simultaneous excitation of all the detectors. The second near-field source exhibits motion across the detector array, but the illumination of the detectors indicates that the object is possibly irregular in shape and is rotating.

The far-field sources examined in this paper are extremely bright and have a wide range of peak flux densities: 40-800 Jy (12 μm), 45-1000 Jy (25 μm), 25- 400 Jy (60 μm) and 180-300 Jy (100 μm). The 12 μm /25 μm flux ratios yield color temperatures of approximately 300-K, consistent with a blackbody at 1 A U from the Sun. The 25 μm /60 μm and 60 μm /100 μm temperatures, however are systematically lower than that value. A more sophisticated thermal model will have to be applied to understand the thermal behavior of these sources.

The altitude of the far field sources above the Earth can be calculated by measuring the angular motion as observed by IRAS, removing the component of angular motion due to the IRAS scan rate and assuming the

Fig. 2. (a) A far-field source seen in this composite of 12, 25, and 60 μm images. Note that the pattern matches the sequential detector crossings that would be made by an object scanned by IRAS (see Figure 1).

Fig. 2. (b) A near-field source is seen in this 25 μm image having illuminated all the detectors within both 25 μm detector modules. The separation of the two "module" images arises from the motion of the source.

orbit is circular. The angular motion of the object observed by IRAS is determined by measuring on the CRDD plots the length of time the source takes to cross between two detectors of known angular separation. The altitude is then constrained according to the following formula:

$$n' = (n_{scan} - n_{IRAS}) - (n - n_{IRAS}) \left(\frac{R}{R - r} \right)$$

where n' is the apparent angular motion of the object across the IRAS detector plane, n_{scan} is the IRAS scan rate ($3.85/\cos[\phi]$) arcminutes per second where ϕ is the solar elongation, n_{IRAS} angular motion of IRAS as seen from the center of the Earth (3.5 arcminutes per second), $n = \sqrt{GM_{\oplus}/R^3}$ - the true angular motion of the object as seen from the center of the Earth, r is the distance of IRAS from the center of the

Fig. 3. Far-field sources observed in all three HCONs in the IRAS skyflux images.

earth, and R is the distance between the source and the center of the earth. Using this approximation, the three far field objects were found to be at altitudes ranging from 4,000-km to 71,000-km above IRAS.

An equivalent diameter for each of the far-field sources can be calculated given a distance and a flux and assuming a spherical blackbody. These objects were determined to have diameters ranging from five to thirty two meters and are upper limits as thermal loading and reflected thermal radiation from the earth are neglected.

CONCLUSION

IRAS detected 466 thermally bright objects, which are shown to be in earth orbit. Plans by NASA for a permanent manned space station has resulted in increased concern about the characterization and detection of low Earth orbital debris. The characterization of the thermal properties of hundreds of Earth-orbiting objects observed by IRAS will provide significant constraints on future space-based debris detection systems. Such systems can be designed to maximize detection probability or even discriminate among objects of different thermal properties. The sources detected on the skyflux images are the brightest sources identified by the criteria discussed in this paper. There may be thousands of much fainter objects waiting to be found in the IRAS database.

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