Early Results from the ISO/IRAS Faint Galaxy Survey

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Abstract

We present preliminary results for AGNs and starburst galaxies the ISO-IRAS Faint Galaxy Survey (IIFGS). The goal of the survey is to produce a database of infrared-luminous galaxies at redshifts of about 0.1–1 to help explore the AGN-starburst relationship, study the cosmological evolution of luminous infrared galaxies, and identify possible protogalaxy candidates. The candidate list of ~3700 sources has been extracted from the IRAS Faint Source Survey using criteria selecting for faint, infrared-bright galaxies. The ISO observations confirm the IRAS detections, yield sensitive 12 & 90 μm fluxes, and provide positions to ~6″ accuracy which yield unambiguous optical identifications. We are obtaining optical magnitudes and accurate redshifts for identified sources with ground-based observations. To date, ~400 fields have been observed by ISO, ~350 of which have been delivered and reprocessed with custom software to maximize ISOCAM sensitivity. Early results for the ISOCAM 12 μm images indicate we can reliably detect sources as faint as ~0.2 mJy; ~80% of the fields contain at least one source.

1 Introduction

One of the significant discoveries of the Infrared Astronomical Satellite (IRAS) was the population of Luminous Far Infrared Galaxies (LFIRG's) which radiate the bulk of their energy at wavelengths longwards of 10 μm. Such emission is almost certainly powered by warm dust surrounding starbursts and/or AGN[5, 2, 6]. However, such samples of IR-bright galaxies are limited by the sensitivity of IRAS and most likely underrepresent such sources at intermediate and large redshifts. The Infrared Space Observatory (ISO) offers a unique opportunity to expand this sample.

Here we present a description of and progress report for the ISO-IRAS Faint Galaxy Survey (IIFGS [4]). The goal of the IIFGS is to compile a catalog of several hundred LFIRG's at a redshift range of ~0.1–1. Such a sample will allow studies of the mechanisms driving these objects to extend to greater distances and earlier times, and to potentially address issues of evolution. The sample is based on the faintest LFIRG candidates that can be obtained from the IRAS database; ISO can confirm these detections and obtain improved photometry and positions. We also expect to be able to use the occurrence of serendipitous sources in these fields to determine background 12 μm source counts useful in cosmological galaxy evolution models.

1.1 Source Selection

The source list for the IIFGS was compiled from IRAS Faint Source Survey (FSS) using criteria to select for distant LFIRG's. The sources were required to have non-stellar colors (i.e. increasing flux density from 12 to 60 μm). To bias the sample towards distant, luminous galaxies, the 60 μm fluxes were constrained to be less than 0.3 Jy (to assure faintness) with ratios of L_{fir}/L_{blue} exceeding 10 (implying $L_{fir} > 10^{11}$ $L_\odot$, using the strong correlation between L_{fir}/L_{blue} and L_{fir}). Blue magnitudes and upper limits were obtained using IPAC's Optical Identification Database, OPTID[3], which matches FSS sources against digitized sky survey plate data. To further optimize the sample, only candidates at Galactic latitudes exceeding 30 deg were included in the sample to avoid cirrus contamination. The remaining candidates were inspected individually and only those passing a rigorous cirrus rejection procedure were included in the final sample of 3776 sources.

1.2 Observing Strategy

The IIFGS has been implemented in the ISO mission as a "filler" survey. The IIFGS sources populate most ISO sky bins and are intended to fill in between other observations, helping to optimize the observing efficiency of the satellite. The survey consists of linked short-wavelength ISOCAM and long-wavelength ISOPHOT observations with a total target-dedicated time of 12 min for each object.

The ISOCAM observation uses the broadband LW10 filter (the "IRAS" 12 μm band) for maximum sensitivity. The pixel scale of 6″/pixel. provides a total field of view of about 3′x3′. Each source is observed with a 2x2 raster using 30″ offsets, allowing confirmation in multiple detector pixels. The integration time is 2.1 sec with a total effective exposure time of about 70 sec. Most of the IIFGS sources have 12 μm counterparts that were too faint to be seen with IRAS. The positional accuracy of 6″ allows us to make unambiguous optical identifications.

The ISOPHOT observation is a chopped PHT22 exposure at 90 μm. Total on-source integration time is 64 sec. In addition to confirming the IRAS detection, the ISOPHOT fluxes help characterize the shape of the FIR spectral energy distribution for these sources.

1.3 Current Status

The IIFGS in presently at an early stage of production with only preliminary results available[1]. To date, ~400 sources have been observed by ISO (about 10% of the source list); we hope for another 100 or more before the end of the mission. Data from the CAM and PHOT detectors are being evaluated and reduction strategies are being developed for the dataset. The IIFGS data product to be made available to the community shall include positions, fluxes, redshifts, and images of the sources.

2 ISOPHOT Results

To date we have not made a detailed analysis of ISOPHOT observations. Simple studies of a subset of the data suggest we can easily obtain a detection rate of 50% for the sample, though this will likely increase significantly with a more careful analysis. More detailed results from this segment of the survey will be presented at a later time.

3 ISOCAM Results

At present, 337 ISOCAM datasets (out of about 400 observations) have been delivered to IPAC. We have performed a preliminary analysis on this sample which is described below.

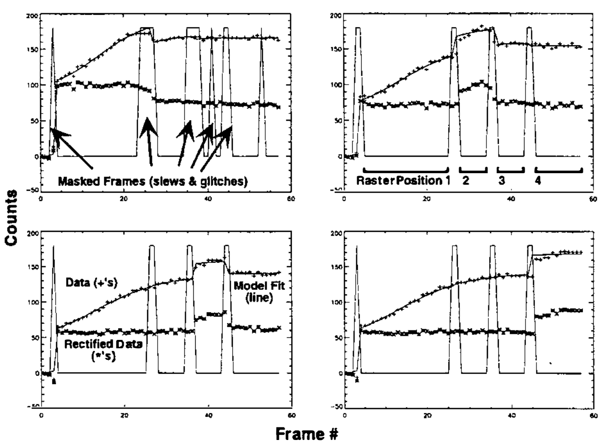

Figure 1: ISOCAM Transient Response and Removal. The '+' symbols represent detector responses of an individual pixel for the sequence of frames in the observation. The solid line is the best-fit model of the detector response, and the '*' symbols represent the data with the 'slow' response subtracted out. The vertical "columns" indicate frames that have been masked due to telescope slews or cosmic ray glitches.

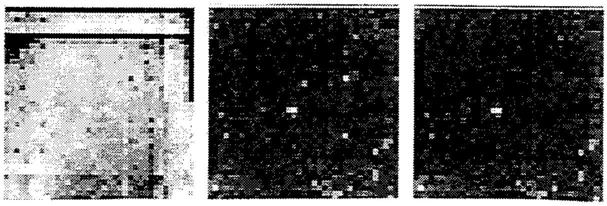

Figure 2: ISOCAM Images Before and After. These three images present the same ISOCAM field for the IRAS source F12513+7605. The first is the standard pipeline-processed image in which the source is visible but flatfielding artifacts seriously corrupt the image. The second is the same image after applying the transient model of Fig. 1; the background is flatter and the SNR is improved by a factor of ~7. In the third image, cosmic ray glitches responsible for ghost sources have been flagged out (the lower left source is probably also real, associated with a bright star).

3.1 Data Reduction

The ISOCAM pixels have a characteristic time response to illumination which affects the quality of flat-fielding and coadding. Typical detector responses to an observation are illustrated in Figure 1. The four graphs show the responses of four pixels exposed to the same sky position at different times during the 2x2 raster map. The horizontal axis represents frame number (with an exposure of 2.1 sec/frame). The upper points (indicated with '+' markers) are the standard processed data (SPD) for the pixel. Evident is the ~1 min timescale required for the detector to stabilize against the background illumination.

One must compensate for this slow response to illumination in order to properly flat-field and coadd ISOCAM data. One technique in development at IPAC is to model the detector data time sequence with constant "instantaneous" and slowly varying "transient" components. The data is "rectified" by subtracting the transient component from the data, leaving the instantaneous component plus photometric noise (Fig. 1, '*' markers). The rectified data may then be flatfielded and mosaiced.

The improvements attained using this approach may be seen in Figure 2. The first image is an ISOCAM field as processed by the standard data reduction pipeline. The second is the same dataset after transient processing. In the third, pixels affected by cosmic ray glitches have been suppressed. Overall sensitivity improvements are factors of 7 or more over the standard pipeline products, mostly due to better flatfielding.

3.2 Source Detections & Identifications

We are developing software at IPAC to automatically identify ISOCAM sources and extract their fluxes. The algorithm takes into account both the signal strength in the mosaiced image and the characteristic time-domain responses expected for real sources in each of the pixels contributing to an observation. We find that 85% of the observed fields contain at least one source; 420 total sources are detected in 289 fields.

A histogram illustrating the range of observed fluxes can be found in Figure 3. The range of detected fluxes at the 4 sigma level or better is 0.2–150 mJy. The average and median fluxes are 3.2 and 1.8 mJy, respectively. There is some hint of two populations of fluxes, one peaking at about 1.4 mJy, with the other at around 0.8 mJy (though the latter is likely a truncated

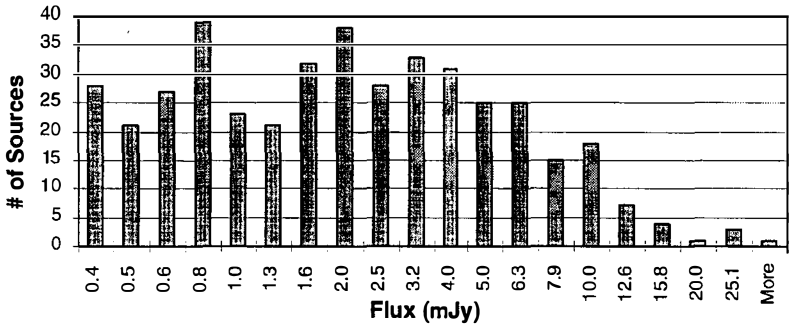

Figure 3: ISO CAM Source Fluxes. This histogram displays the fluxes of all 420 sources detected at 12 μm. These sources include both counterparts to the 60 μm FSS sources and unrelated background galaxies. Bins are spaced logarithmically. Due to varying sensitivity effects and zodaical backgrounds the faint end of the flux range (less than approximately 1 mJy) is not complete at and likely contains a small number of spurious (false) sources.

trend for increasing numbers of even dimmer sources that we do not detect).

The ISOCAM obervations in the IIFGS contain detections of 12 μm counterparts to the IRAS FSS 60 μm sources as well as chance background sources that appear in the same field. To better separate the background sources from the LFIRG candidates we compute a likelihood ratio, essentially the ratio of the probability that the source is spatially coincident with the IRAS error ellipse to the probability that it is a chance superposition of a background source. Such an analysis depends on a model for background source counts and in practice must be calibrated against magnitude. Early results indicate that over 80% of the fields with 12 μm detections contain at least one probable counterpart to the FSS source. The bulk of the remaining sources are serendipetous background sources. Granted the large area covered by this survey (about 0.8 square degrees so far) we also hope to compile extensive background source counts unrelated to the FSS galaxies.

3.3 Optical Follow-Up

Once an ISOCAM source is determined to be associated with a given FSS 60 μm LFIRG candidate, we are then able to use its position to determine the corresponding optical source in the field. While a few fields posess unambigous optical counterparts to the large FSS error ellipse, some crowded fields have many possible counterparts. With the 12 μm positions, good to about 6″, the correct optical sources are much easier to identify. Figure 4 shows sample OPTID fields with ISOCAM detections superimposed as concentric circles.

Ground-based observations for the IIFGS are already underway using these OPTID results. Observing time at Lick and Palomar has been allocated to the project for determining optical magnitudes and redshifts. With redshifts, we can determine luminosities and begin to study the statistical properties of the sample. To date we have obtained spectra for about 45 IIFGS galaxies which have redshifts ranging from 0.1–0.58. By the concusion of this survey we hope to extend this range to highly luminous sources as far out as redshifts of 1.

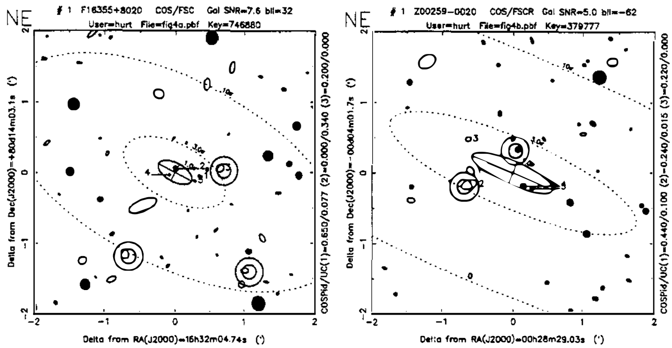

Figure 4: Optical Identifications. These two OPTID fields show the IRAS FSS error ellipse (center of field), optical sources in the field (open and filled ellipses), and identified ISOCAM sources (concentric circles). Overall there is an excellent correspondence between the ISO positions and corresponding optical candidates; a small systematic pointing offset can be seen on the left figure. In some cases, the closest optical sources to the IRAS FSS source are not the best CAM match; on the right the two CAM sources may well contribute to the single FSS source 60 μm source.

References

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