The ISO-IRAS Faint Galaxy Survey: ISOCAM Results

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Objectives

The ISO-IRAS Faint Galaxy Survey (IIFGS) is a program designed to produce one of the largest and deepest samples of luminous infrared galaxies possible with present facilities. The IIFGS consists of a sample of ~3700 candidate luminous infrared galaxies for which short observations could be scheduled to fill short gaps in the ISO observing schedule not usable by other programs. The sample was extracted from the IRAS Faint Source Survey based on unconfused 60 micron point source detections at fluxes of 0.1-0.3 Jy. Two phases of the ISO program exist; the first employs pairs of 12 micron ISOCAM and 90 micron ISOPHOT observations of these targets, while the second consists only of deeper ISOCAM images. As of the conclusion of the ISO mission, over 500 fields have been observed, representing about 14% of the entire database.

The ISOCAM detection rate of about 90% has allowed us to obtain fluxes magnitudes fainter than possible with IRAS (median ISO fluxes are 1-2 mJy) and allowed the unambiguous identification of optical counterparts allowing for ground-based spectroscopic follow-up observations. The program has proven to be highly successful at detecting a large population of moderate-redshift (z=0.1-0.6) luminous and ultraluminous galaxies. The high 12 micron sensitivities of ISO have allowed us to construct a more complete picture of these objects. In addition the large arial coverage of the survey (about one square degree) has produced a selection of serendipitous field galaxy detections that allow us to study 12 micron background counts.

Redshifts and spectrophotometry are being obtained for a complete subsample of the over 500 Luminous Infrared Galaxies (LIGs) from the IIFGS. Over 100 redshifts have been obtained for galaxies with $0.1 < z < 0.6$ and $\log L_{fir} > 11\ L_{sun}$. The spectrophotometric characteristics of the sample galaxies are comparable to nearby LIGs, with most systems exhibiting HII/Liner excitation and about 10% showing true AGN spectra. Similarly the infrared-optical spectral energy distributions may be compared with those of nearby LIGs spanning the range from pure starburst (e.g. Arp 220) to infrared QSO (Mrk 231). Preliminary spectroscopic observations have been made of 12 micron sources identified outside our IRAS fields -- the 12Micron ISO Serendipitous Survey. Spectra for six sources observed in 98 April indicate that three are low redshift ($z < 1$) QSOs. The IIFGS sample and the accompanying Serendipitous Survey are among the deepest samples of infrared-luminous galaxies, promising to be a rich sample for studying LIGs up to $z \sim 1$, and for understanding the evolution of infrared galaxies and the star-formation history of the Universe.

Why an IIFGS?

■ ISO-IRAS Faint Galaxy Survey Science

- ◆ *Faintest Possible* Database of IRAS Galaxies
  - Use lowest Faint Source Survey 60 μm sources
  - Detect LFIRGs at higher redshifts
- ◆ Investigate Properties of AGN/Starbursts
  - Luminosity dominated by FIR thermal dust radiation, powered by starburst and/or AGN
  - Distant Type 2 AGN at intermediate redshifts may be underrepresented in catalogs due to IRAS detection limits
  - Identification of more distant starbursts allows evolution to be addressed
- ◆ Background Source Counts
  - Serendipitous 12 μm ISO sources at high sensitivity (>0.8 mJy) can characterize background source counts

■ Goals of IIFGS

- ◆ PHOT
  - Confirm faint IRAS 60 μm detections
  - Determine FIR spectral energy distribution
- ◆ CAM 12 μm images:
  - Photometry good to ~0.5 mJy
  - Positions good to ~6"
    - Optical Identifications
    - Ground- and Space-Based Follow-Up's

The IIFGS Sample

■ Implemented as "Filler" Project

- ◆ *Largest* non-GTO US ISO program
- ◆ Consists of short (~12 min.) CAM [& PHOT] obs.
- ◆ 3776 sources selected from IRAS Faint Source Cat.
- ◆ Fills in gaps in schedule between slews, helping to *increase observing efficiency* of ISO

■ Selection Criteria

- ◆ Faintness (*greater distances*)

  60 μm flux < 0.3 Jy
- ◆ Reasonable Detections (*avoid cirrus*)

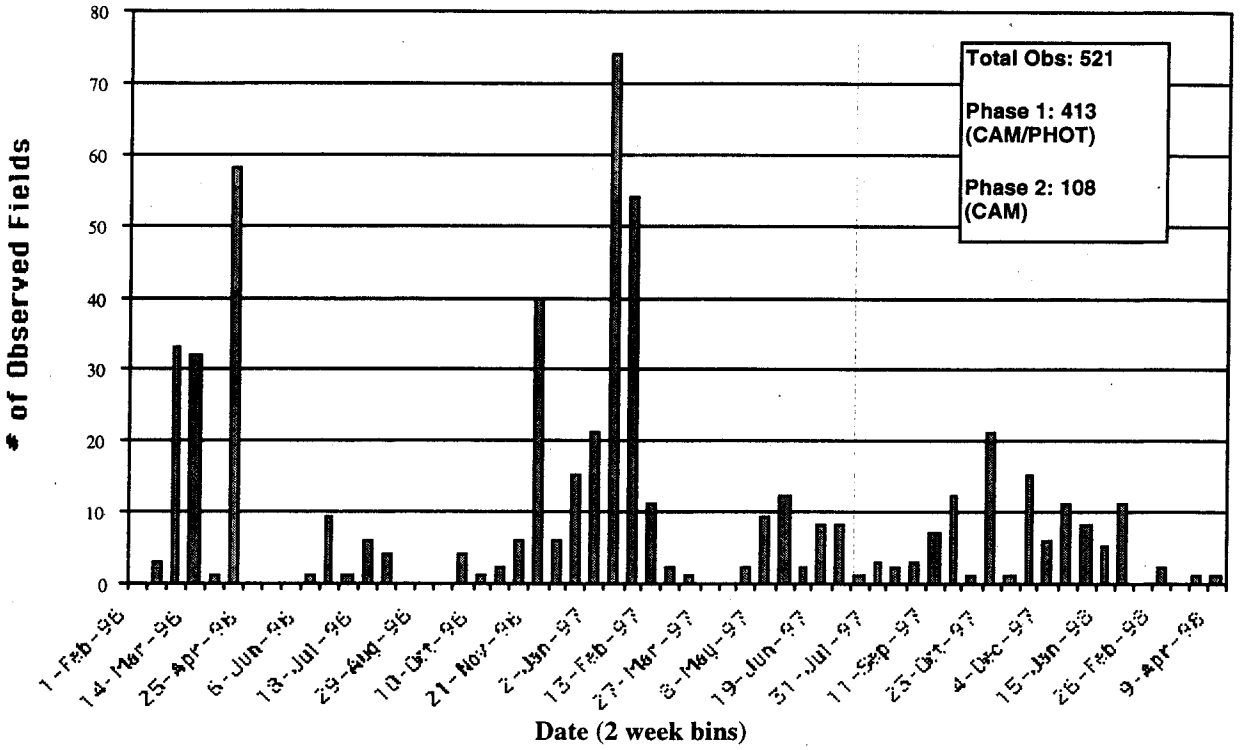
  |b| > 30°to minimize Galactic confusion

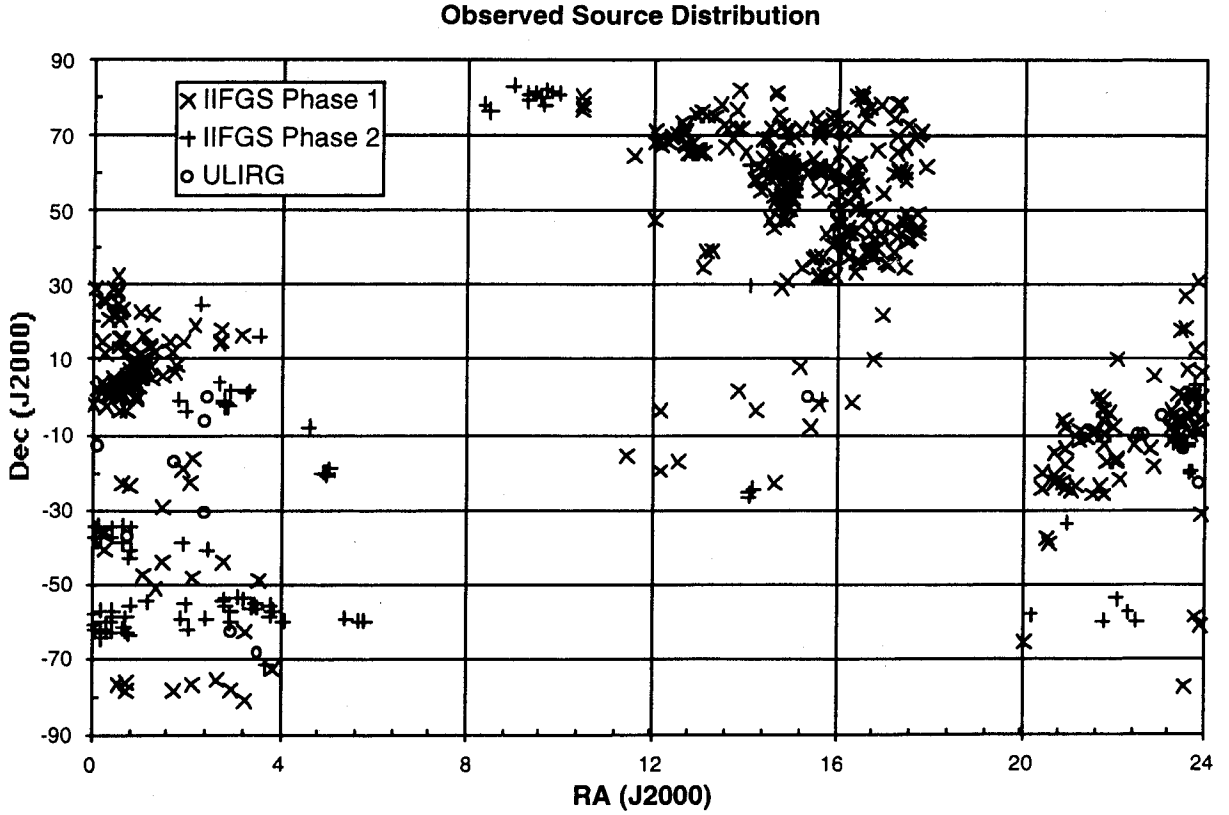
  ADDSCAN's inspected to reject marginal detections & cirrus features
- ◆ Non-Stellar Colors (*exclude stars*)

  Increasing flux density from 12 to 60 μm
- ◆ Large $L_{60\mu m}/L_{blue}$ Ratio (*select greatest luminosities*)

  Blue magnitude limits of Mb > 19, 17.5 for the southern, northern equatorial skies to select for the most luminous sources

Observation Summary





Observing Strategy

- **Phase 1 Observations (Revolutions 96–613)**
  - ISOCAM: LW10 ("IRAS" 12 μm) Filter
    - 6" pixels, ~3 x 3' field of view
    - 2 x 2 raster positions, 30" offsets
    - 6 frames per raster, T_{int} = 2.1 sec/frame
  - ISOPHOT: C90 (90 μm) Filter
    - Chopped PHT22 photometry
    - 64 sec on-source integrations
    - Data reduction awaiting calibration information
- **Phase 2 Observations (Revolutions 614-866)**
  - ISOCAM updated for better sensitivity/redundancy
    - 3 x 2 raster positions, 18 x 30" offsets
    - 20 frames per raster, T_{int} = 2.1 sec/frame
    - 300% increase in on-source integration time
  - ISOPHOT obs. suspended for this phase
- **Observation Status**
  - Total Observed to Date: 521 fields
  - All 413 Phase 1 CAM Fields Processed
    - All have been reduced under ISO On-Line Processing (OLP) versions 6.0 and later and run through custom processing
  - About a dozen PHT datasets reduced manually
  - 108 Phase 2 Fields Awaiting Processing
    - Reduction pipeline using Cam Interactive Analysis package under development; longer observing times allow use of "standard" data reduction tools

ISOCAM Reduction

■ Automated Pipeline Developed in IDL

- ◆ Cosmic Ray Glitches Identified and Masked
- ◆ Correct for Detector "Transient" Response

  Detector stabilizes slowly to sky background; source signals small in comparison to background. The background transient response is treated as a polynomial baseline and subtracted

  Frames are Averaged and Rasters are Mosiaced

- ◆ Point Source Detection

  Sources are identified by their significance above the background as well as in the time domain; a source in a fully-sampled sky position should appear as a discrete step in 4 different pixels; reduction is iterated excluding sources from transient fitting

  Simulated Data for Calibration

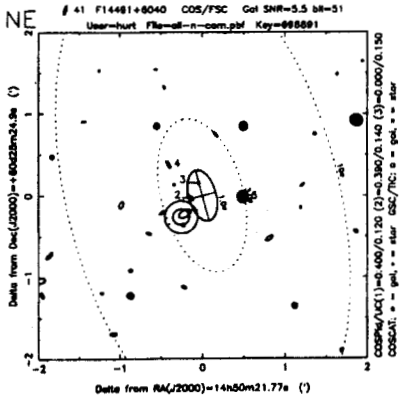
  Synthetic sources are introduced into each field at a variety of fluxes and run through the pipeline to measure systematic effects introduced by the processing and identify the source identification completeness as a function of source flux

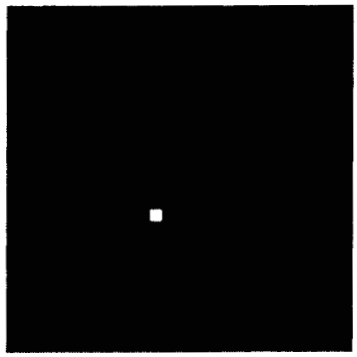
  Sources Individually Inspected

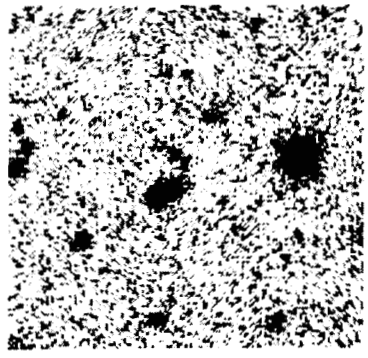
  False detections are screened out by inspecting all sources by hand; ~120 sources (of 600) rejected

■ Sample Field: F14491+6040

- ◆ OPTID chart for field, ISOCAM image, Optical image







ISOCAM Results

■ Statistics for Processed CAM Data:

- ◆ Observed flux range is ~0.58–100 mJy
- ◆ Average/Median flux: 4.7/3.4 mJy

■ Determining Affiliation with FSS Sources

- ◆ Source affiliation determined using *Likelihood Ratio*

  LR = probability(true ID)/probability(false ID)

  Prob(true ID) from source location & IRAS error ellipse

  Prob(false ID) from source flux & bkgnd source counts

- ◆ Most CAM detections appear to be affiliated with FSS sources!

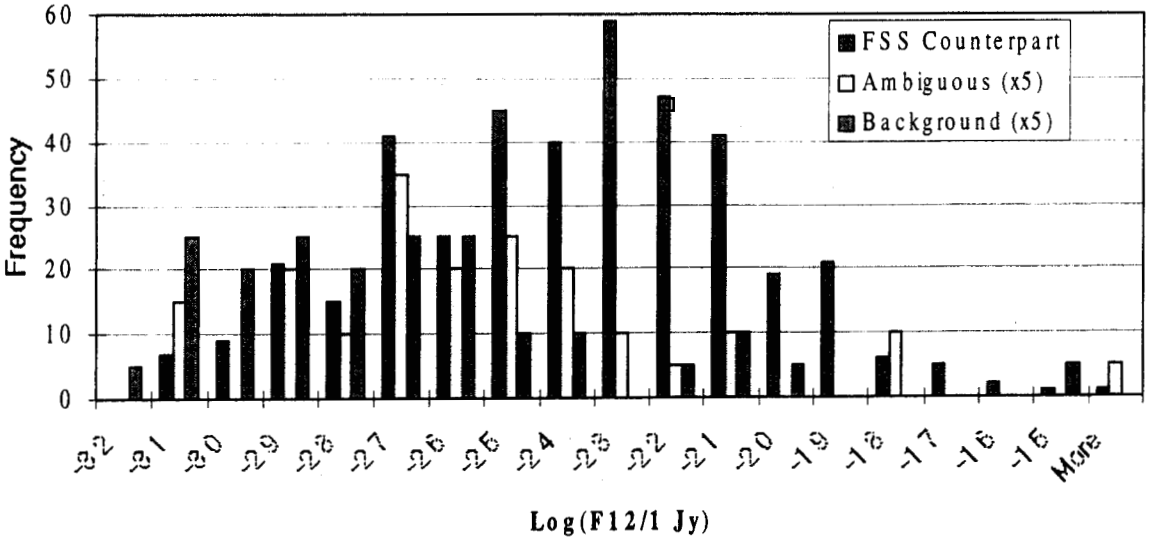
  Accurate source positions for follow-up

  12 μm fluxes can be compared with 60 & 90 μm fluxes

■ Optical Counterparts

Blue magnitudes of optical counterparts are identified by matching ISOCAM positions against APM/COSMOS catalogs extracted using OPTID tool for the IRAS FSS catalog

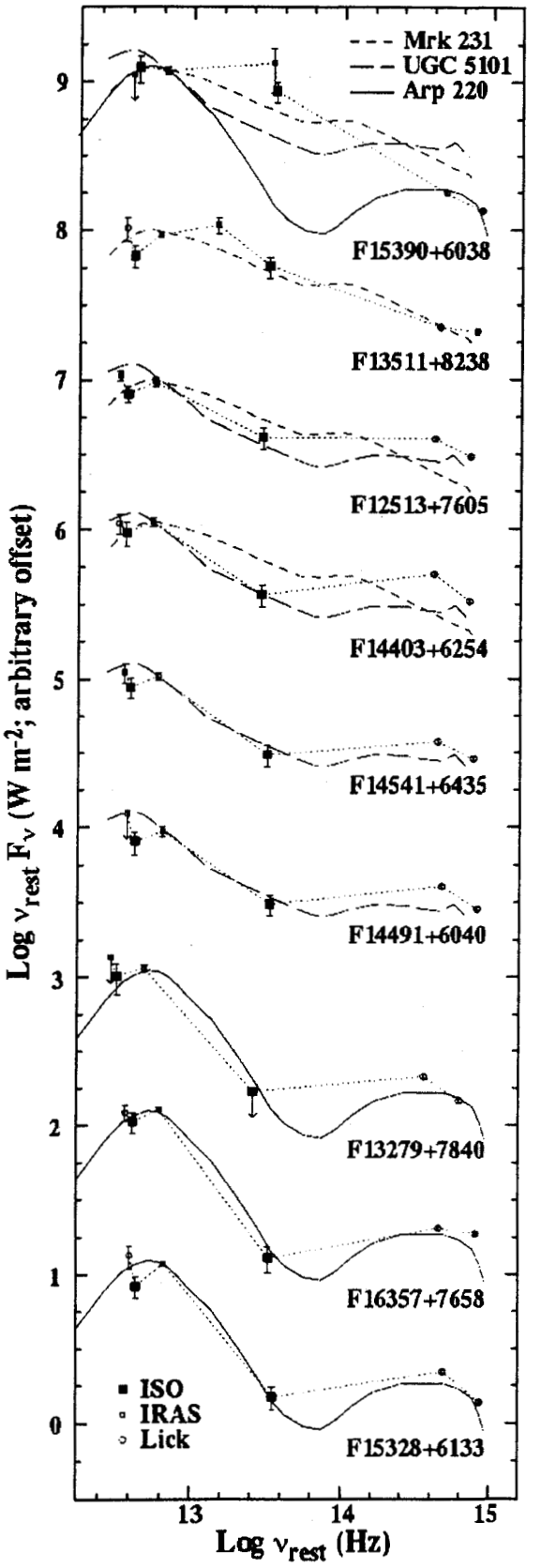
Histogram of Detections



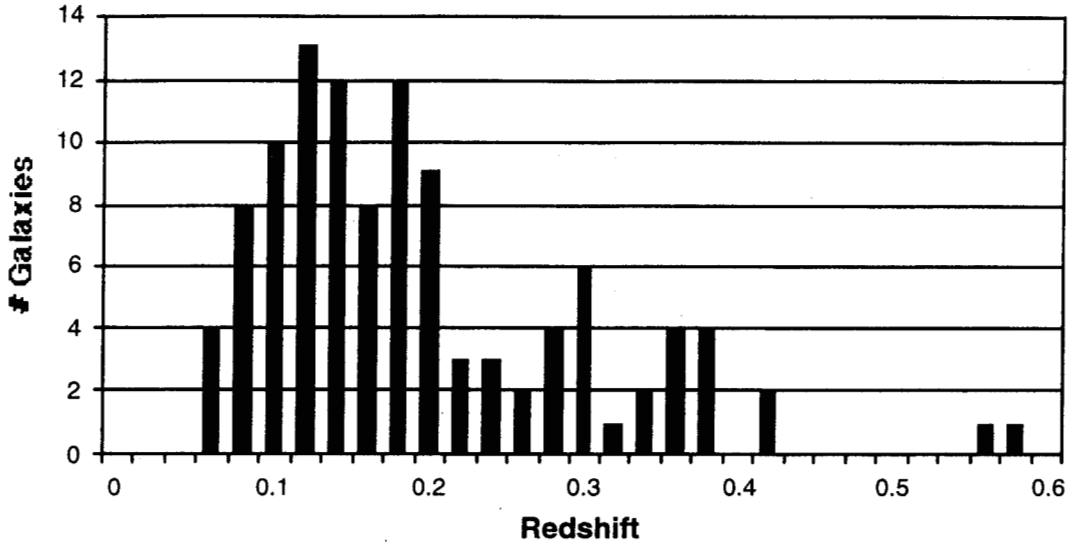
Spectral Energy Distributions

■ Spectral Energy Distributions

- ◆ SEDs for 9 galaxies with good photometry are shown. Local Luminous Infrared Galaxies (LIG) SEDs are plotted for comparison. THE IIFGS galaxies are similar to the local LIGs spanning the range from Pure Starburst (eg Arp 220) to Infrared QSO (Mrk 231).
- ◆ As with local samples, however, the SED and optical excitation do not give a consistent picture of the underlying power source; spectroscopic studies required.



Spectroscopic Observations



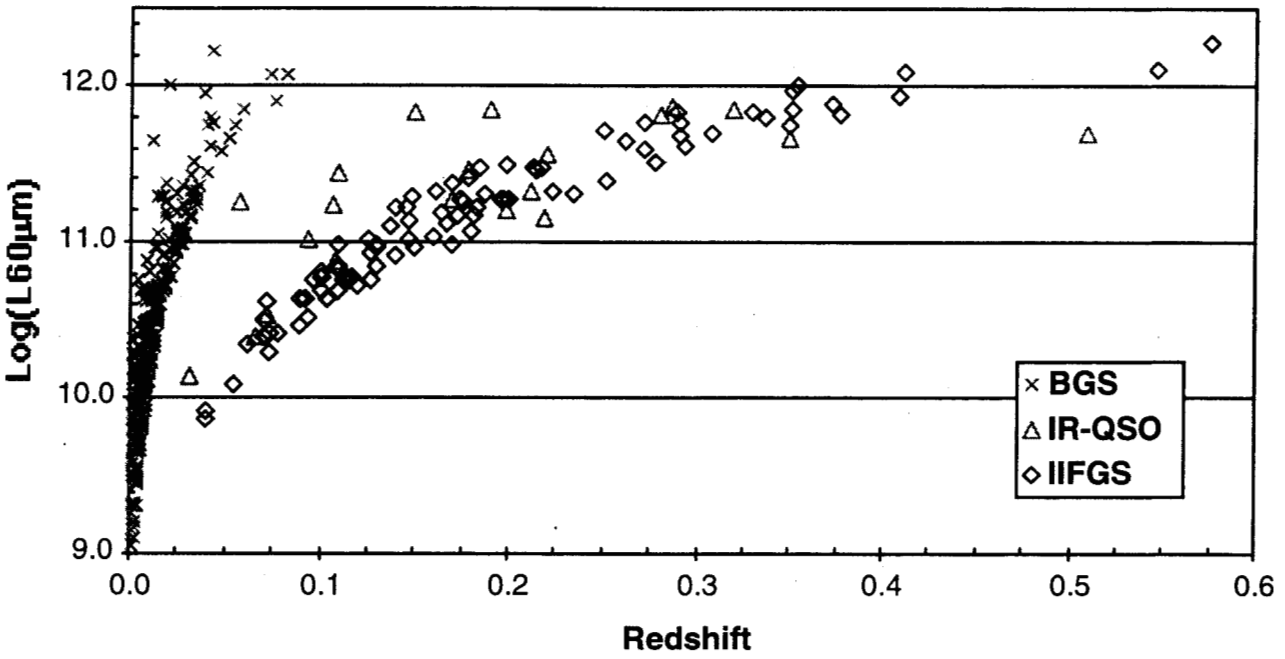
■ 101 redshifts

- ◆ Identified IIFGS CAM detections from Lick & Palomar Observatories.
- ◆ Luminous & Ultraluminous Galaxies
- ◆ Virtually all sources are Luminous Infrared Galaxies with strong emission-line spectra. About half show evidence for interaction (pairs, disturbed morphology, etc.) comparable with nearby LIGs.

■ Complete Sample

- ◆ A complete redshift sample of over 100 galaxies is being constructed from selected areas which will be the basis for modelling the redshift distribution/evolution of the sample. The complex selection characteristics make this a challenging exercise.

Redshift/Luminosity Relation



■ New Sample of Luminous Galaxies

- ◆ Larger Redshifts

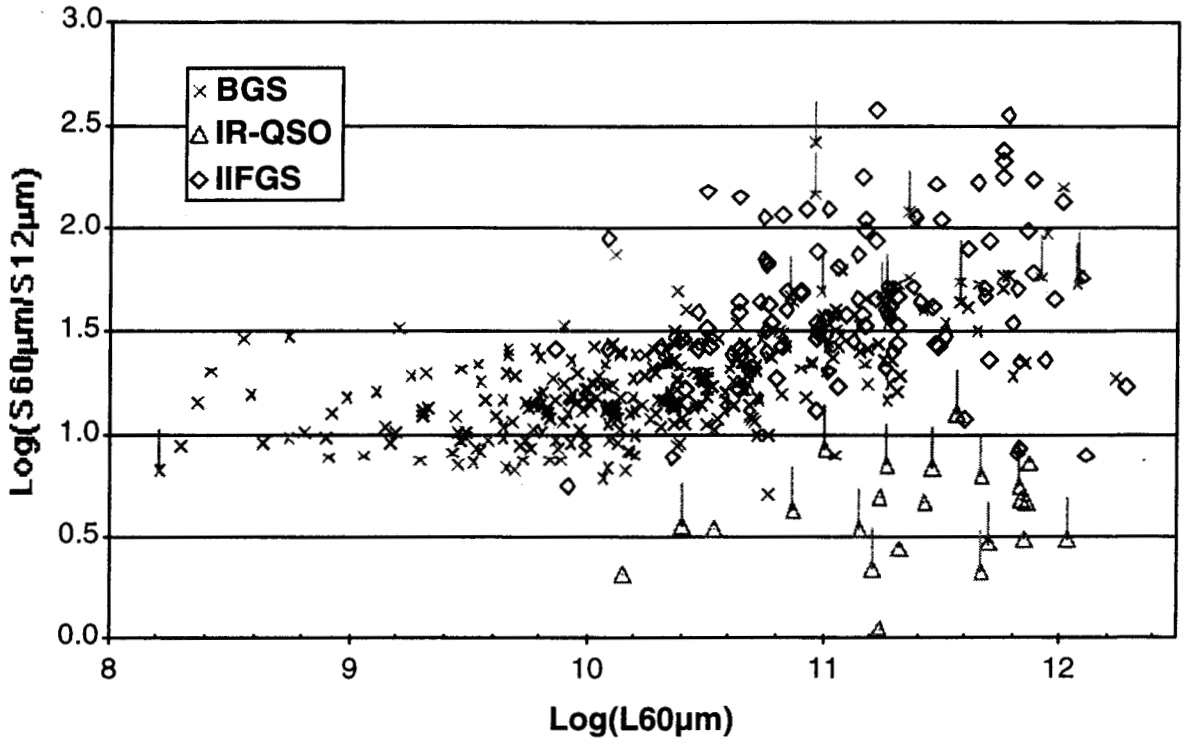
  The IIFGS currently spans a redshift range of ~ 0.04–0.6, much deeper than the Bright Galaxy Sample (BGS) and similar to those spanned by infrared-selected QSO's

- ◆ High Luminosities

  60 μm luminosites (H0 = 75, W = 1) exceed 10^{12} L_0 (no K-corrections applied, which would increase inferred luminosities)

- ◆ Survey criteria successful!

Color-Luminosity Plot



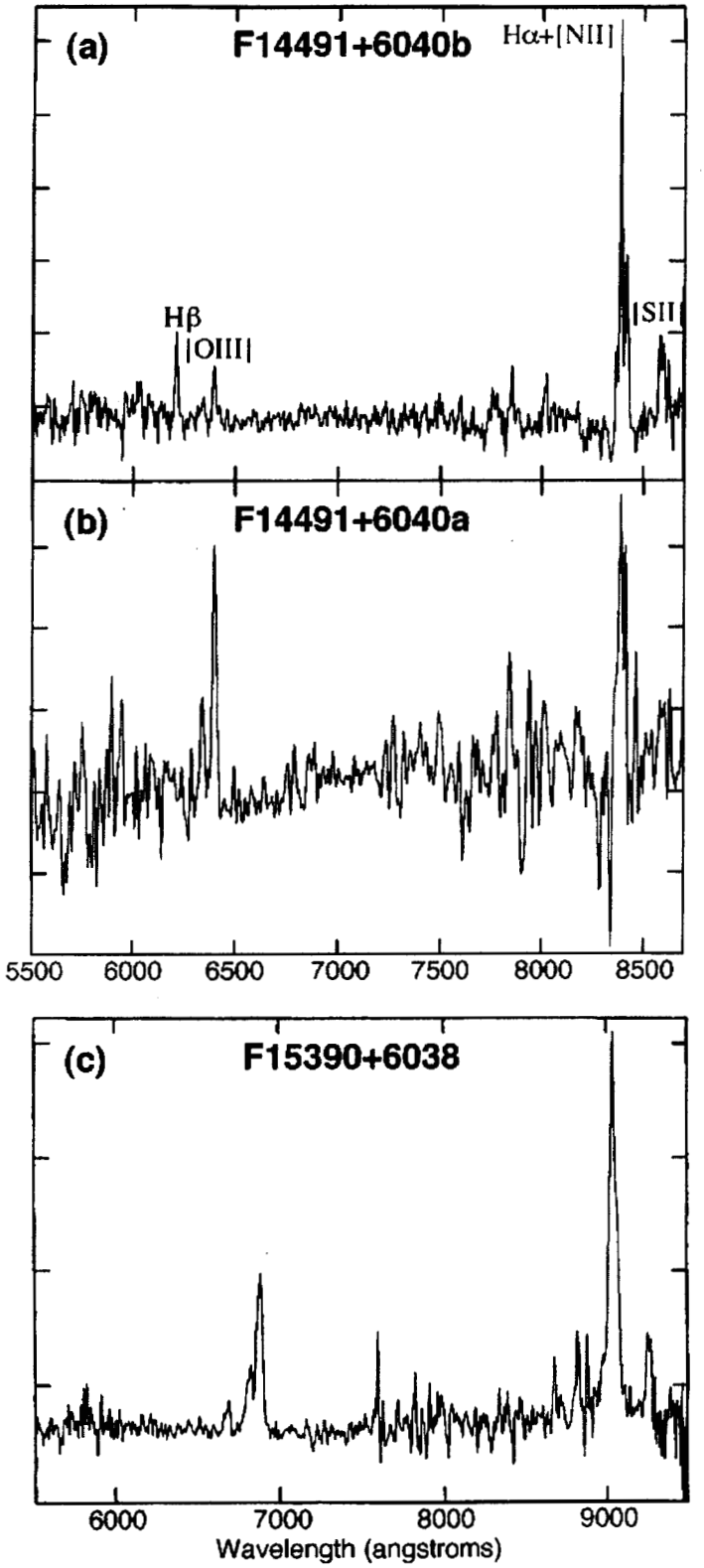
■ "Cold" Luminous Infrared Galaxies!

◆ Many Sources Show "Cold" IR Colors

A significant population of IIFGS sources (red diamonds) possess far infrared colors that are dramatically cooler than is seen for infrared-selected QSO's (green triangles) and even for the Bright Galaxy Sample (blue x's); IRAS sensitivites did not allow this region of color space to be explored even for nearby luminous galaxies.

While this data has not yet been K-corrected, we estimate that the corrected colors should be even cooler as the 60 μm observation falls on a much steeper part of the SED than the 12 μm point (models suggest the 12 μm K corrections should be no more than ~20% at z = 0.5).

IIFGS Spectra



■ Sample Spectra

- ◆ Lick Observations

  These spectra are typical of data taken at Lick and Palomar

■ Spectral Features

- ◆ Star Formation

  Most galaxies have HII/Liner excitation and are probably dominated by active star formation.

- ◆ AGN

  About 10% show evidence for true AGN characteristics -- Sy1 or Sy2 excitation, broad emission lines, etc.

Spectroscopy of 12MISS Sources

■ Observations

- ◆ The first phase of spectroscopy for 12Micron ISO Serendipitous Sources (12MISS) was begun at Lick in 1998 April. Spectra were obtained for 6 identified 12 micron sources and imaging obtained for 4 blank fields.
- ◆ Over half of the serendipitous sources are identified with stellar objects as classified by COSMOS or the APM.

■ QSOs

- ◆ Three stellar objects observed in April are low-redshift QSOs $0.17 < z < 0.90$.
- ◆ These are not IRAS sources, but have 12 Micron detections by ISOCAM
- ◆ The detection of three (or more) new QSOs within our approximately 1 square degree at magnitudes brighter than B ~ 19, suggests that there is a substantial population of AGN which may be detected at mid-infrared wavelengths SIRTF.

IIFGS Status

■ Current Status

- ◆ The program was very Successful
  - 520 Observations represent > 85 hrs of ISO time
  - Survey has produced catalog of luminous and ultraluminous galaxies
  - Identification of optical counterparts permits spectroscopic follow-up
- ◆ ISOPHOT
  - Preliminary inspection completed, awaiting calibration info
- ◆ ISOCAM
  - Transient-processing and mosaicing algorithms developed
  - Source identification & extraction algorithm working well
  - New observing strategy doubles CAM on-source time
- ◆ Spectroscopic Follow-up
  - Spectra for over 100 IIFGS and several 12MISS sources have been obtained at Lick & Palomar

■ Future Plans

- ◆ Reduction
  - Fully reduce ISOPHOT data
  - Finalize automated processing for Phase 2 data
- ◆ Detailed ISOCAM Followup
  - About a dozen sources have been observed in ISOCAM narrow band filters allowing for better mid-IR SED's and color corrections; these Phase 1 sources have also been reobserved in the Phase 2 mode to allow better cross-calibration between the two survey subsets
  - Better characterize bkg serendipitious source sample
- ◆ Observations
  - Continue spectroscopic follow-up
  - Cross-ID against other catalogs as they become available (FIRST, 2MASS, etc.)