THE ISOPHOT 170 MICRON SERENDIPITY SKY SURVEY : A PLEA TO FIRST

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Abstract

The ISOPHOT Serendipity Survey utilized the slew time between ISO's pointed observations with strip scanning measurements of the sky in the far-infrared (FIR) at 170μm. The integral 170μm fluxes for compact sources derived from the slews are put on an absolute flux level by using a number of galaxies as calibrator sources observed with ISOPHOT's photometric mapping mode, supplemented by Serendipity Survey observations of two planets and two asteroids with available model fluxes. A first group of 115 well-observed sources with a high signal-to-noise ratio in all four detector pixels having a galaxy association were extracted from the slew data with low ($I_{100\mu m} \leq 15$ MJy/sr) cirrus background. For all but a few galaxies, the 170μm fluxes are determined for the first time, which represents a significant increase in the number of galaxies with measured FIR fluxes beyond the IRAS 100μm limit. The large fraction of sources with a high $F_{170\mu m}/F_{100\mu m}$ flux ratio indicates that a very cold ($T < 20$ K) dust component is present in many galaxies. The typical mass of the coldest dust component is $M_{Dust} = 10^{7.5\,\pm\,0.5}$ $M_{\odot}$, a factor 2 – 10 larger than that derived from IRAS fluxes alone. As a consequence, the gas-to-dust ratios are much closer to the canonical value for the Milky Way. A similar Serendipity Survey with FIRST has the prospects of delivering FIR data with a much higher angular resolution (PACS) or at longer wavelengths (SPIRE) than ISOPHOT, thereby providing either crucial information for the identification of compact sources in confused regions or extending the spectral coverage for a large number of sources and finding rare classes of very cold FIR emitters.

Key words: surveys — catalogs — infrared: galaxies — galaxies: ISM

1. Introduction

The Infrared Space Observatory (ISO, Kessler et al. 1996) had been designed as a telescope for dedicated pointed observations of pre-selected targets. Due to the prohibitively long integration time required, dedicated surveys with thousands of target objects or covering a significant fraction of the whole sky were not envisaged. Since ISO provided the first access to the wavelengths region beyond the 100μm IRAS limit, it was nevertheless highly desirable to collect data in this wavelength range over a sky area as large as technically possible. Of particular interest is the cold interstellar medium (ISM) of galaxies with only low-level star-forming activity and dust temperatures below 30 K, where the peak of the spectral energy distribution (SED) is longwards of 100μm.

The ISOPHOT Serendipity Survey overcame the restriction on observing time by taking data at 170μm in a random and unbiased fashion during the otherwise unused slewing time. Initial results received already during the ISO misson have been described by Bogun et al. (1996), while the development of the data analysis for compact extragalactic sources and its testing in the North Ecliptic Pole region were described in detail in Stickel et al. (1998a,b;1999). A group of 115 well observed galaxies were selected from all compact Serendipity source candidates to get a first overview of their FIR properties, the details of which can be found in Stickel et al. (2000).

2. Observations and Data Reduction

Serendipity Survey slew measurements were acquired with the ISOPHOT C200 2 × 2 pixel array camera (pixel size of 89.′′4) (Lemke et al. 1996) used in conjunction with the C_160 broad band filter (reference wavelength 170 μm, equivalent width 89 μm) and 1/8 s reset interval time during which four detector readouts took place. During the lifetime of the ISO mission, about 550 hours of measurements have been gathered with more than 12000 slews. The total slew length exceeds 150000° resulting in a sky coverage of ≈ 15 %.

For each detector pixel, the raw detector voltages as a function of read-out time (ramps) are converted to signals per sky position by fitting a straight line to the integration ramps. The conversion to slew surface brightnesses follows standard data reduction techniques within the ISOPHOT Interactive Analysis (PIA[1]) software package (Gabriel et

[1] The ISOPHOT data presented in this paper was reduced using PIA, which is a joint development by the ESA

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ESA SP-460, July 2001, eds. G.L. Pilbratt, J. Cernicharo, A.M. Heras, T. Prusti, & R. Harris

al. 1997). Surface brightnesses are derived from the fitted read-out ramp slopes either by using a measurement of the on-board Fine Calibration Source (FCS) preceding the slew observation, or, for short slews, the default C200 calibration.

The deglitched and background subtracted signals of the four detector pixels are phase-shifted according to the roll angle of the detector, and a signal-to-noise ratio weighted mean signal is derived. Source candidates are selected by setting a cut of three times the local noise level on the background subtracted coadded brightness. This cut is varying along the slew due to crossing of regions with different background levels such as the galactic plane. The ratio of the four peak fluxes to the highest flux among the four pixels is used in comparison with the expected ratios from a gaussian source model to estimate the minimal source distance perpendicular to the slew direction. The total source flux is then determined by a non-linear least-squares fit of a two-dimensional circular symmetric gaussian with fixed slew offset together with a tilted plane to the data from the four background subtracted data streams.

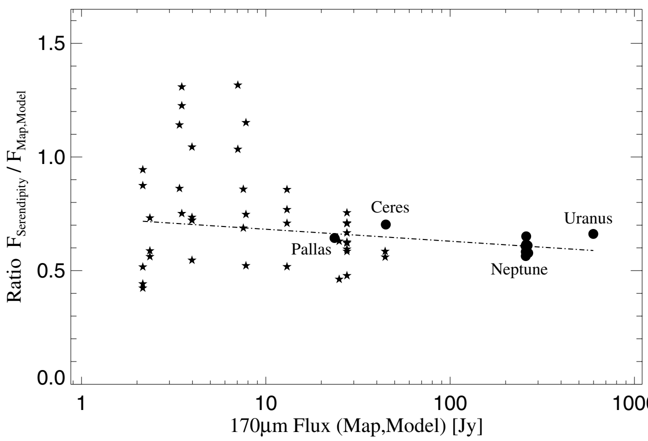

Figure 1. Ratio of Serendipity Survey slew fluxes to photometric mapping fluxes vs. their photometric flux for all crossings of the 12 galaxies used as calibration sources (asterisks). Two planets and two asteroids with useful Serendipity Survey crossings and 170μm model fluxes are shown as labelled filled circles. These newly added solar system objects extend the calibration range to $F_{170\mu m} \lesssim 600\,Jy$. Except for the faint end, repeated slew observations of the same source agree within $\lesssim$ 30 %.

3. Calibration

The Serendipity Survey point source fluxes are tied to an absolute level by means of dedicated photometric calibration measurements of 12 galaxies repeatedly crossed with varying impact parameters during the slew survey. Raster maps were obtained with the C200 detector and the C_160 broad band filter and fluxes derived using synthetic aperture photometry. Additionally, the Serendipity Survey database has been cross-correlated with the positions of solar system objects (Müller et al. 2001). This has resulted in finding one crossing of Uranus, several crossings of Neptune, and useful crossings of the asteroids Ceres and Vesta. For all of them accurate 170μm fluxes are available from thermodynamical models (Müller & Lagerros 1998), which makes these measurements highly important for checking the reliability and extending the Serendipity Survey calibration to higher flux levels.

The ratio of the Serendipity Survey and the mapping / model fluxes as a function of the mapping/model fluxes is shown in Fig. 1. It indicates that the slewing observations miss some signal. For the fainter sources the ratio shows a significantly increased scatter, which can be understood as the influence of the noise on the observed brightness distribution of the four detector pixels. The high flux end of the dedicated Serendipity Survey calibrators is covered by the two asteroids and shows an excellent agreement in the flux ratio, thereby demonstrating the consistency of the ISOPHOT calibration. The upper end of the observed flux range is solely covered by the bright planets, and the small scatter in the repeated crossings of Neptune gives an indication for the good reproducability (relative accuracy) of the higher fluxes from the Serendipity measurements. The Serendipity to photometric/model flux ratios are rather constant throughout the covered flux range $1\,\mathrm{Jy} < \mathrm{F}_{170\mu\mathrm{m}} < 600\,\mathrm{Jy}$.

4. Results

A first set of galaxies has been compiled to demonstrate the scientific potential of the slew measurements and the immediate impact on understanding the FIR emission of normal galaxies. This initial Serendipity Survey source catalogue is intended to cover the most reliable extragalactic sources off the galactic plane. It is not a statistically complete sample, but it represents an unbiased subset of all crossed extragalactic sources at high galactic latitudes. In the following, the sample properties of this initial Serendipity Survey source list will be described. The complete source catalogue can be found in Stickel et al. (2000).

The Serendipity Survey source candidate database was searched for compact sources at galactic latitudes $|b| > 15°$ with a signal-to-noise ratio of at least 5 in all 4 pixels and a fitted gaussian source width of $0.5' \leq \sigma \leq 1.25'$ located in an area where the 100 μm cirrus brightness does not exceed 15 MJy/sr. Only those sources were considered where the extragalactic databases listed a galaxy with an optical diameter $< 6'$ within $3'$ from the Serendipity source position. These selection criteria led to a list of 115 high quality Serendipity sources providing the first determination of 170 μm fluxes for all but a few galaxies. It represents the largest set of galaxies with measured 170 μm fluxes to

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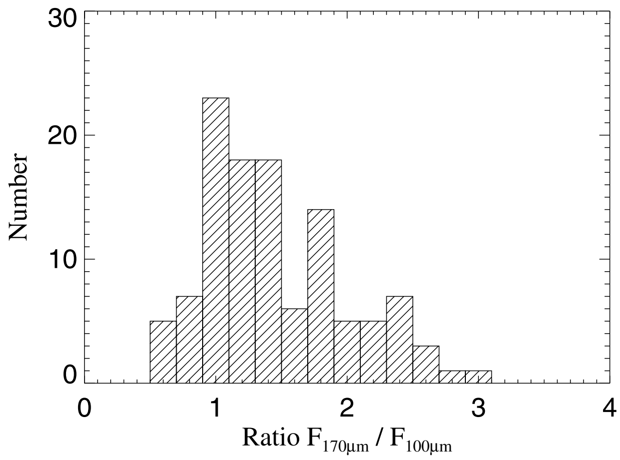

Figure 2. The distribution of the ratio of Serendipity Survey 170 μm and IRAS 100 μm fluxes for 115 galaxies.

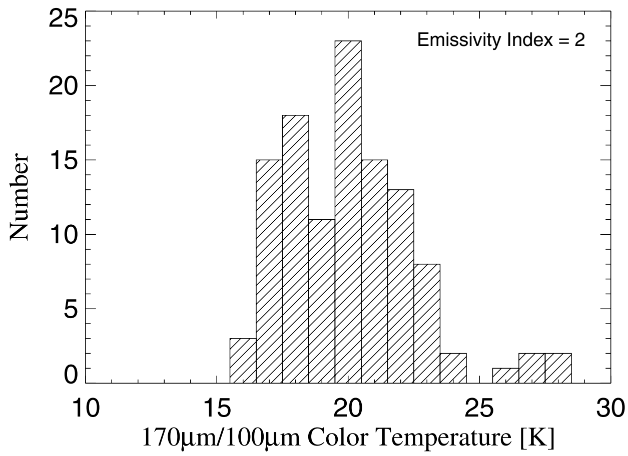

Figure 3. The color temperature distribution, corrected for the ISOPHOT 170 μm and IRAS 100 μm bandpass profiles using an emissivity index β = 2.

date. The redshift distribution shows that, although the majority of the sources lies at low redshifts of z < 0.02, the Serendipity Survey observations also detect galaxies with redshifts up to z ≈ 0.05.

The distribution of $F_{170\mu m}/F_{100\mu m}$ flux ratios (Fig. 2) shows that the majority of the galaxies has a flux ratio between ≈ 1 and 1.5, indicating that most FIR spectra are flat between 100 μm and 200 μm. A downward trend in this wavelength range is seen only for very few galaxies, indicating that the coldest dust component in these objects is rather warm with T $\gtrsim$ 25 K. Most important is the large fraction of more than 40 % of the sources which have $F_{170\mu m}/F_{100\mu m} > 1.5$, extending up to $F_{170\mu m}/F_{100\mu m} \approx 3$. These ratios indicate an up-turn in the SED beyond 100 μm similar to that seen in the Milky Way and M51. The new 170 μm fluxes allow a more accurate determination of the total FIR luminosities.

The distribution of the $F_{170\mu m}/F_{100\mu m}$ flux ratios indicates the presence of a cold dust component with dust color temperatures $T_D \lesssim 20$ K in a significant fraction of the galaxies. Since the IRAS as well as the ISOPHOT fluxes refer to a spectrum with νF_ν = constant, dust color temperatures were computed by iteratively correcting the tabulated IRAS 100 μm and Serendipity 170 μm fluxes in the two bandpasses for a modified blackbody (Planck) function with an emissivity index $\beta = 2$. The resulting distribution of dust color temperatures (Fig. 3) is centered at $T_D \approx 20$ K, with all but a few sources lying in the range 16 K $\leq T_D \leq$ 25 K.

The luminosity of the coldest dust component mainly determines the bulk of the dust mass. Approximate total dust masses can thus be inferred from the dust color temperatures (Fig. 3) using a standard dust opacity for the case of optically thin dust emission. The dust mass distribution (Fig. 4) peaks at $M_D = 10^{7.5 \pm 0.5}$ $M_\odot$, with a gradual decrease towards lower dust masses, but a much sharper drop-off towards larger dust masses. These newly

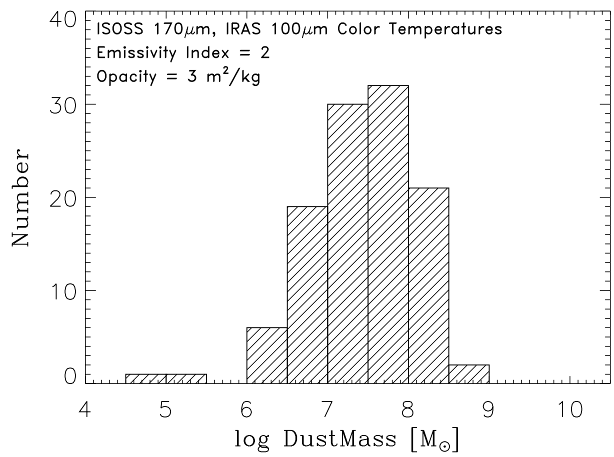

Figure 4. The distribution of dust masses, derived with an emissivity index β = 2 and a dust opacity of 3 m^2/kg. The asymmetric distribution peaks around $M_D \approx 10^{7.5 \pm 0.5} M_\odot$. The two sources at the lower end are the only galaxies unambiguously classified as irregulars.

derived dust masses are larger by a factor 2 – 10 compared to those derived from IRAS fluxes alone. Moreover, these high values are reached without any very cold $T_D < 10$ K dust component usually inferred from sub-mm measurements.

Gas masses, mainly from HI measurements, are available for about half of the 115 Serendipity sources. The gas-to-dust ratios show a broad peak with a median value of ≈ 250, close to the canonical value of the Milky Way. This indicates for the first time that the gas-to-dust ratio of the Milky Way is representative for other external galaxies, and there is at least some justification in using this value to convert FIR measured dust masses to total gas masses. However, the range of gas-to-dust ratios covers the large range between 10 and 1000, much larger than

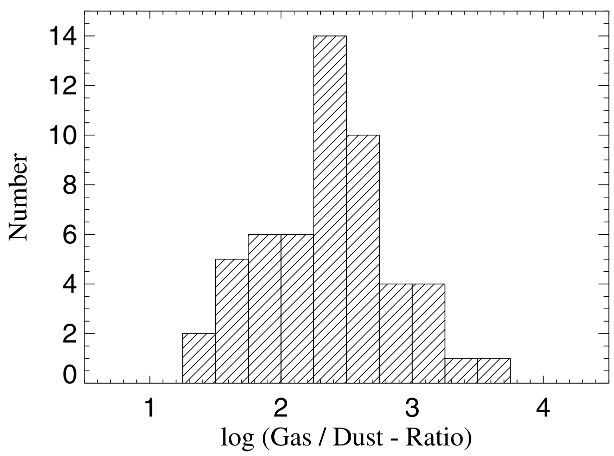

Figure 5. Distribution of the gas-to-dust ratio of galaxies peaks at ≈ 250, close to the canonical value for the Milky Way.

expected from uncertainties in FIR fluxes or HI masses, which on the other hand suggests that there is no fiducial gas-to-dust ratio applicable to all normal late type galaxies.

5. Prospects for FIRST

With its 3.5m mirror, FIRST will provide an unprecedented angular resolution over a much broader wavelength range compared to all earlier FIR space missions. A Serendipity Survey similar to the one carried out with ISO would be a unique possibility to gather high angular resolution data over large areas of the sky at FIR wavelengths, particularly beyond the 200μm limit of ISO and the upcoming SIRTF and ASTRO-F missions. As in the case of the ISOPHOT Serendipity Survey, avoiding the bias of foreknowledge in observing preselected targets and fields has the potential of collecting a sufficient number of objects to study statistical properties of very cold galaxies and even for discovering unknown classes of very cold galactic and extragalactic sources.

The original design of the PACS instrument (Poglitsch et al. 2001) included stressed Ge:Ga detectors similar to those used in ISOPHOT. These would have had a fast enough response to deliver nearly diffraction limited images of compact sources, even in the case of maximum slew velocities similar to that of the ISO satellite. Recently, the Ge:Ga detectors for photometric imaging were replaced by bolometers with a much slower response and an expected limiting read-out rate below 10 Hertz. In a slewing survey, this would lead to an in-scan smearing of compact sources to $\approx 1'$ and severe overlap of the image on adjacent detector pixels. Therefore, a proposal to implement a PACS Serendipity Survey has been put on hold until actual detector parameters will have been measured.

The SPIRE instrument (Griffin et al. 2001) is a second option to make scientific use of the slewing time of FIRST and maximize the scientific return of the mission. The current design foresees bolometers which have a sufficiently fast response and high read-out rate to deliver images of compact sources with only a slight elongation, particularly at the longest wavelength of 500μm. The large scale data with angular resolutions of $\approx 0.5'$ gathered at this wavelength would be unique even years after the FIRST mission. Although the estimated detection limits of the PLANCK HFI all-sky survey are ≈ 100 mJy (Blain 2001), the much coarser angular resolution of only $\approx 5'$ (Tauber 2001) will make it difficult to correctly associate the FIR sources with counterparts at other wavelength in all regions except the rare spots where the galactic cirrus foreground is extremely low. Particularly, if very cold compact structures with temperatures of ≈ 10 K exist throughout the galactic interstellar medium (Egan et al. 1998), they will show up more prominent at wavelength of 200 – 500μm due to their rising SED in this wavelength range. Only high angular resolution observations with SPIRE are able to provide the positional accuracy necessary to unambiguously identify extragalactic point sources. Moreover, only with a large surveyed area can a promising search for a likely rare class of very cold galaxies with overall dust temperature $\lesssim$ 15 K be caried out.

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