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# The ISOPHOT far-infrared serendipity north ecliptic pole minisurvey*

**M. Stickel[1], S. Bogun[1**], D. Lemke[1], U. Klaas[1,2], L. V. Tóth[1,3], U. Herbstmeier[1], G. Richter[4], R. Assendorp[4], R. Laureijs[2], M. F. Kessler[2], M. Burgdorf[2], C.A. Beichman[5], M. Rowan-Robinson[6], and A. Efstathiou[6]**

[1] Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany
[2] ISO Science Operations Centre, Astrophysics Division, Space Science Department of ESA, Villafranca, P.O. Box 50727, E-28080 Madrid, Spain
[3] Department of Astronomy of the Loránd Eötvös University, Ludovika tér 2., H-1083 Budapest, Hungary
[4] Astrophysikalisches Institut Potsdam, An der Sternwarte 16, D-14482 Potsdam, Germany
[5] Infrared Processing and Analysis Center, JPL, California Institute of Technology, MS 100/22, Pasadena, CA 91125, USA
[6] Imperial College of Science, Technology and Medicine, The Blackett Laboratory, Prince Consort Road, London SW7 2BZ, UK

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**Abstract.** The ISOPHOT Serendipity Survey fills the otherwise unused slew time between ISO's fine pointings with measurements in an unexplored wavelength regime near 200 $\mu$m. In order to test point source extraction software, the completeness of the detected objects as well as the astrophysical content we investigate a $100\Box^\circ$ field near the North ecliptic pole, dubbed ISOPHOT Serendipity Minisurvey field. A total of 21 IRAS point sources were detected on the Serendipity slews crossing the field. 19 of these objects are galaxies, one is a planetary nebula and one is an empty field without a bright optical counterpart. The detection completeness is better than 90% for IRAS sources brighter than 2 Jy at 100 $\mu$m and better than 80% for sources brighter than 1.5 Jy. The source detection frequency is about 1 per $40^\circ$ slew length, in agreement with previous estimations based on galaxy number counts. After the end of the ISO mission, about 4000 point sources are expected to be found in the Serendipity slews.

**Key words:** surveys – infrared: galaxies – infrared: general

## 1. Introduction

The Infrared Space Observatory (ISO, Kessler et al. 1996) performs, in contrast to the IRAS survey mission, pointed observations on selected targets. This requires slewing of the telescope between the individual measurements, which, depending on the sequence of the scheduled observations, can be quite long and can cross a significant part of the sky. From a standpoint of observing efficiency, it is highly desirable to utilize this slewing time for scientific purposes also.

Early in the ISO mission, it was decided that the ISOPHOT C200 array (Lemke et al. 1996), which is sensitive up to more than 200 $\mu$m, would be the most useful instrument for such a slewing survey. A wavelength much longer than the IRAS 100 $\mu$m limit together with a broad band filter has the prospect of gathering data serendipitously not only for cold point or marginally extended sources but also of cold FIR emitting material distributed on large scales in the Galaxy.

The implementation of this so-called Serendipity Survey was successfully tested during the Performance Verification Phase of ISO and has since then run smoothly and delivered data of the expected quality (Bogun et al. 1996). Here we describe the first systematic attempt to do bulk processing of these data and to extract astrophysically relevant information for *point* sources lying on the slews. Emphasis is put on the detection and completeness of point sources in comparison with previously known IRAS sources. In view of the early stage of the data analysis, the repeatability and reliability of sources and fluxes is also investigated. Large scale structures from the Galaxy such as molecular clouds and cirrus regions are the subject of a parallel investigation and will be described in subsequent publications.

## 2. The minisurvey field

The Serendipity slew data is an almost one-dimensional cut across the sky, lacking, at first approximation, practically any redundancy. Only if a particular source is crossed several times during different slews, independent information can be obtained. The derivation of parameters of crossed sources, the most important of which are the positions and total fluxes, uses

*Send offprint requests to*: M. Stickel

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** Present address: Data Management and Operations Division, ESO, Karl-Schwarzschild-Str. 2, D-85748 Garching bei München
*Correspondence to*: stickel@mpia-hd.mpg.de

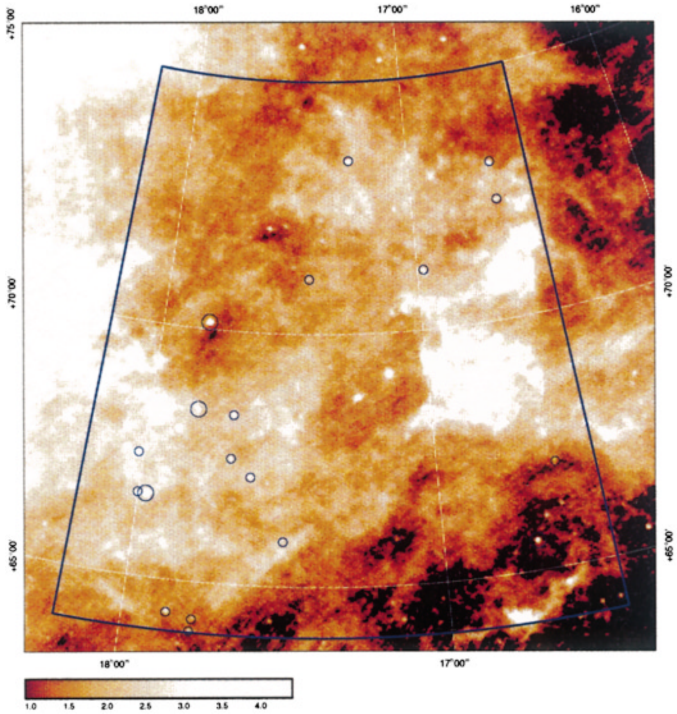

**Fig. 1.** The IRAS 100$\mu$m map of the Minisurvey field. The field is delimited by the blue line. It is completely located on the IRAS Sky Survey Atlas (ISSA) map 418. The circles locate the sources found on the slews (cf. Table 2). The larger circles denote sources with $f_{100}$ >1.5 Jy, the smaller denote sources with $f_{100}$ <1.5 Jy.

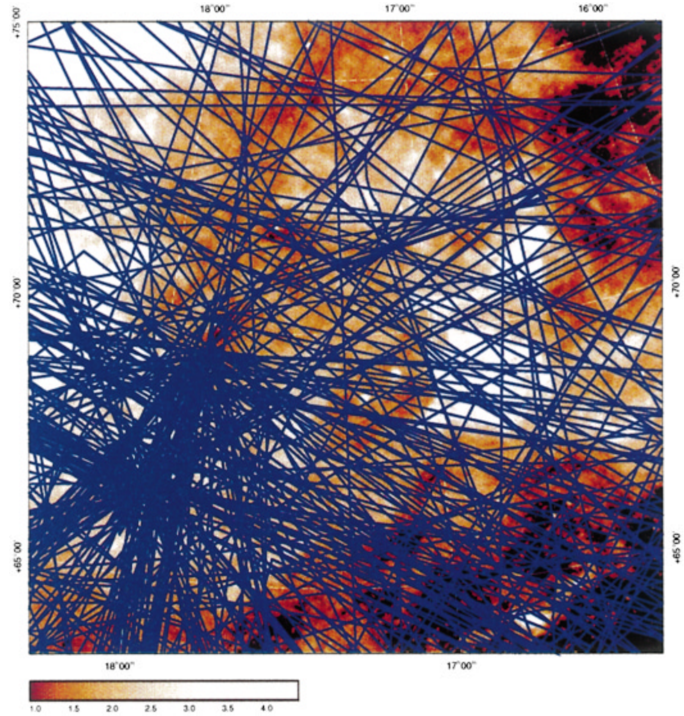

**Fig. 2.** The IRAS 100$\mu$m map of the Minisurvey field, with all Serendipity slews crossing the field indicated as blue lines.

different data analysis algorithms than are available for other astronomical data utilizing larger two-dimensional detectors.

To develop and test the software necessary for the slew processing and analysis the Consortium on the ISOPHOT Serendipity Survey (CISS) has defined a $100\Box^{\circ}$ field at high galactic latitude $(16^{\rm h}28^{\rm m}00^{\rm s} \leq \alpha_{2000} \leq 18^{\rm h}12^{\rm m}00^{\rm s}, +64^{\circ}00'00'' \leq \delta_{2000} \leq +75^{\circ}00'00'')$, close to the north ecliptic pole, the so-called ISOPHOT Minisurvey field (Figs. 1,2). It has the advantage that the foreground emission due to galactic cirrus is rather low, thereby minimizing the cirrus confusion (Herbstmeier et al. 1998).

As of August 14, 1997, the Minisurvey field had been crossed by 336 slews of various individual lengths, totaling 1263 degrees inside the Minisurvey field, corresponding to 4.22 hours of observing time.

## 3. Observational data and standard reduction

The ISOPHOT C200 is a $2\times2$ pixel array of stressed Ge:Ga with a pixel size of $89\farcm4$, which is used in conjunction with the C_160 broad band filter (central wavelength 170 $\mu$m, equivalent width 89 $\mu$m) to obtain the Serendipity slew data. Since the highest slewing speed of the satellite is $\approx 8'{\rm s}^{-1}$ a fast readout with an integration time of 1/8 s was chosen, during which 4 detector readouts take place.

From the acquired raw detector voltages as a function of readout time, signals are derived by fitting a straight line to the integration ramps. The signals are converted to surface brightness using either the default detector responsivities for short slews or with responsivities derived from a preceding measurement of the on-board Fine Calibration Source. This standard reduction makes use of the ISOPHOT Interactive Analysis.[1]

Only for long slews, the angular velocity is constant except for the acceleration and deceleration phase at the beginning and end of the telescope movement. For short slews, a constant angular velocity is not reached. Therefore, the angular distance between successive integration ramps is not necessarily constant. To avoid loss of resolution, the flux calibrated data streams for the four detector pixels are not rebinned to a constant angular distance between signals, but kept as a function of signal number. For each pixel, a background is subtracted, where features up to a certain width several times larger than the expected width of point sources at low slew speeds are kept in the difference.

The background subtracted data streams for the four pixels are averaged and subsequently the mean is wavelet filtered (Starck & Murtagh 1998). Regions of source candidates are defined by setting a cut on the filtered mean surface brightness. This cut is currently rather low, 2 $\sigma$ of the local noise level, which is non-constant due to crossing of regions with different background levels such as the galactic plane. No other criterion such as a detection with a predefined signal-to-noise ratio

[1] The ISOPHOT Interactive Analysis (PIA) is a joint development by the ESA Astrophysics Division and the ISOPHOT consortium led by the Max–Planck–Institut für Astronomie, Heidelberg. Contributing ISOPHOT Consortium institutes are DIAS, RAL, AIP, MPIK, and MPIA.

in several pixels has been required. The low threshold for the source candidate selection guarantees that even faint sources will be found, which was the main goal of the investigation of the minisurvey field. On the other hand, this method leads to a large rate of false faint source candidates, mostly unremoved detector hits by cosmic rays. These, however, can easily be recognized and discarded because their fitted widths are well below those expected for unresolved point sources.

A non-linear least-squares fit of a two-dimensional gaussian together with a tilted plane is applied to each of the regions containing source candidates, resulting in source widths, peak fluxes, source positions, and total fluxes derived thereof. The currently used two-dimensional gaussian is only a first approximation to the real point source profile and ignores important effects such as detector drifts, which lead to asymmetric profiles along the slew direction. As a result, the fits occasionally converge to undoubtedly incorrect values for the parameters, mostly in such a way that an extremely bright source is positioned very far away from the slew to accommodate the observed brightness profiles.

## 4. Results

### *4.1. Completeness*

To get a measure for the completeness of the serendipity processing, the Minisurvey slews were searched for IRAS sources lying closer than $2'$ to one of the slews. Only sources with a 100 $\mu$m quality flag greater than 1 were considered to be potential serendipity sources. The majority of expected IRAS point sources are galaxies with a the spectral energy distribution peaking in the wavelength range between 100 $\mu$m and 200 $\mu$m. The 170 $\mu$m flux will therefore be close to the IRAS 100 $\mu$m flux.

Table 1 summarizes the cumulative statistics in several 100 $\mu$m flux bins, where each crossing of a particular source has been counted separately. For sources brighter than 5 Jy, all expected sources have been found. Only one source is missing in the flux region between 2 - 5 Jy, namely IRAS 16452+6418. An inspection of the IRAS 100 $\mu$m IRAS Sky Survey Atlas (ISSA) map showed that this source sits on top of an extended cirrus region, and in fact, the Serendipity processing did detect the cirrus structure but an automatic separation of the point source from the cirrus was not possible. It is intended to overcome this problem by using the IRAS ISSA 100 $\mu$m maps. A larger region around the source candidates will be analyzed and the Serendipity slews will be cross-correlated with road maps extracted from the ISSA plates.

Below 2 Jy the fraction of detected objects drops to 50%, which is easily understood since only sources which are almost centrally crossed are expected to show up in more than 1 pixel with a sufficiently high signal-to-noise ratio. Moreover, since the pointing information of the ISO satellite is still preliminary, with uncertainties during long slews of up to $1'$, IRAS sources that are nominally close enough to be seen might actually lie more than $2'$ away and hence are not detected. Therefore, the completeness is expected to be improved in the near future, when better ISO slew pointing data will be available. Consequently, sources with $f_{100} < 1.5$ Jy have currently not been used for the statistical assessment, but some of them are nevertheless listed below.

**Table 1.** Cumulative statistics of the source detection completeness in the Minisurvey field for IRAS sources nominally closer than $2'$ to any Serendipity slew.

| Flux range IRAS 100 $\mu$m | # expected sources | # found sources | percentage completeness |
|---|---|---|---|
| $>$ 10 Jy | 11 | 11 | 100% |
| 5 - 10 Jy | 5 | 5 | 100% |
| 2 - 5 Jy | 10 | 9 | 90% |
| 1.5 - 2 Jy | 12 | 6 | 50% |
| total | 38 | 31 | 82% |

Table 2 lists all the individual sources with $f_{100} > 1.5$ Jy found in the Minisurvey field, sorted in order of decreasing IRAS 100 $\mu$m flux. For each source it gives its name, its J2000 position, optical magnitude, type of the optical counterpart, and redshift, all of which have been taken from the NASA Extragalactic Database (NED). Three redshifts have kindly been provided by W. Saunders (University of Edinburgh) in advance of publication. Finally, the IRAS 60 $\mu$m and 100 $\mu$m fluxes are given. Table 2 also lists detected sources with 100 $\mu$m fluxes below 1.5 Jy, which, as noted above, comprise only an inhomogeneous and incomplete subset. The total number of different sources listed with $f_{100} > 1.5$ Jy in Table 2 is much smaller than the total number of detections (38, see Table 1), since several sources have been crossed more than once.

To illustrate the data processing, Fig. 3 shows the results for three sources covering a wide 100 $\mu$m flux range, namely the planetary nebula NGC6543 (IRAS 17584+6638) as well as the galaxies IC 1228 (IRAS 16418+6540) and UGC 11099 (IRAS 18012+6725). For each source the observed background subtracted slew data together with the two-dimensional fit is shown in the upper panel, while the lower panel shows the residuals after subtraction of the fit. For NGC6543, it is apparent that the two-dimensional source model leaves residuals much larger than the noise, indicating that the Serendipity point source profile is not a simple gaussian. A much better result is obtained for IC 1228, where the residuals hardly exceed the noise in the regions adjacent to the source. For the faintest source, only two detector pixels show a clear signal, which is well represented by the gaussian used. At such low flux levels, distortions due to not completely removed glitches become important, as can be seen in the residuals of detector pixel no. four (rightmost).

### *4.2. Nature of the detected sources*

From the type of optical counterparts listed in Table 2, it is clear that almost all of the objects are of extragalactic nature and are classified as galaxies. This confirms the expectation based on the cumulative number counts of planetary, galactic and extragalactic sources (Bogun 1995). The only detected galactic

**Table 2.** Classification of the objects found on Serendipity slews in the Minisurvey field.

| Name | Position $\alpha_{2000}$ | Position $\delta_{2000}$ | Magnitude [mag] | Type[1] | Redshift $[\mathrm{km\,s^{-1}}]$ | IRAS fluxes[2] 60$\mu$m [Jy] | IRAS fluxes[2] 100$\mu$m [Jy] | Note[3] |
|---|---|---|---|---|---|---|---|---|
| $\mathrm{F}_{100} > 1.5$ Jy | | | | | | | | |
| NGC 6543 | $17^h58^m33^s$ | $+66°37'58''$ | 15.0 | PN | | 133.30 | 62.68 | |
| NGC 6503 | $17^h49^m27^s$ | $+70°08'42''$ | 10.9 | S, Liner | 44 | 7.16 | 25.39 | |
| IC 1228 | $16^h42^m07^s$ | $+65°35'05''$ | 14.2 | SB | 7598 | 3.45 | 7.37 | |
| KUG 1750+683B | $17^h49^m54^s$ | $+68°24'23''$ | 15.2 | Gal.-Pair | 15366 | 2.73 | 5.20 | |
| UGC 10803 | $17^h16^m04^s$ | $+73°26'12''$ | 13.1 | E? | 1255 | 1.01 | 3.24 | * |
| IRAS 17517+6422 | $17^h51^m59^s$ | $+64°21'38''$ | | G | 26169 | 2.02 | 3.06 | |
| UGC 10425 | $16^h28^m56^s$ | $+64°12'24''$ | 15.3 | Sb | 5963 | 1.32 | 2.99 | |
| UGC 10963 | $17^h42^m15^s$ | $+68°20'57''$ | 15.1 | SBb | 7530 | 1.26 | 2.65 | |
| IRAS 18001+6638 | $18^h00^m10^s$ | $+66°38'42''$ | | G | 7942[4] | 2.04 | 2.17 | * |
| UGC 10995 | $17^h47^m32^s$ | $+64°01'38''$ | 14.9 | S? | 8154 | 0.69 | 1.99 | |
| NPM1G +71.0155 | $16^h58^m30^s$ | $+71°11'22''$ | 16.8 | G | 20841 | 0.93 | 1.91 | |
| UGC 10502 | $16^h37^m37^s$ | $+72°22'25''$ | 12.9 | S | 4307 | 0.47 | 1.91 | |
| IRAS 16384+7313 | $16^h37^m36^s$ | $+73°07'42''$ | | EF | | (0.40)[5] | 1.78 | * |
| NGC 6395 | $17^h26^m30^s$ | $+71°05'36''$ | 13.0 | Scd | 1164 | 0.57 | 1.58 | |
| $\mathrm{F}_{100} < 1.5$ Jy | | | | | | | | |
| NPM1G +64.0172 | $17^h47^m14^s$ | $+64°15'50''$ | 16.8 | G | 10700[4] | 0.81 | 1.48 | |
| IRAS 16358+6709 | $16^h35^m59^s$ | $+67°03'50''$ | | Gal.-Pair | | 0.59 | 1.37 | * |
| NGC 6456 | $17^h42^m13^s$ | $+67°29'02''$ | 15.4 | G | | 0.43 | 1.30 | |
| NPM1G +65.0155 | $17^h31^m02^s$ | $+65°53'14''$ | 17.1 | G | | 0.40 | 1.29 | |
| IRAS 17089+6558 | $17^h09^m03^s$ | $+65°55'17''$ | | G | | 0.51 | 1.22 | * |
| IRAS 17380+6709 | $17^h38^m00^s$ | $+67°08'16''$ | | G | 28236[4] | 0.74 | 1.19 | * |
| UGC 11099 | $18^h01^m07^s$ | $+67°25'34''$ | 14.9 | SBcd? | 3695 | 0.46 | 1.01 | |

[1]Type : PN = Planetary Nebula; S = Spiral Galaxy; SB = barred Spiral Galaxy; E = Elliptical Galaxy; G = Galaxy; EF = Optically Empty Field
[2]For 170 $\mu$m fluxes see Table 3
[3]Note : for sources with an asterisk, see notes in the text
[4]Redshift from W. Saunders (University of Edinburgh), personal communication
[5]Upper limit

source is the Planetary Nebula NGC 6543, which is also the brightest object in the field at 100 $\mu$m.

For the five Serendipity sources identified only with IRAS 100 $\mu$m sources in NED, Digital Sky Survey images were retrieved and checked for possible optical counterparts. For all but IRAS 16384+7313, an optically extended counterpart, i.e. a galaxy, could be found at the position of the IRAS source. The counterpart of IRAS 16358+6709 is an interacting pair of galaxies, as shown in Fig. 4. Only in the field of IRAS 16384+7313 no bright optical object is seen at the IRAS position. A subsequent inspection of the IRAS 100 $\mu$m ISSA image revealed that this FIR source is most likely a compact knot of galactic cirrus.

From the total of 19 galaxies (including those classified using the Digital Sky Survey) in the Minisurvey field, 8 are already known or are most likely normal or barred spirals, while two more are galaxy pairs. One interesting source is IRAS 17172+7329 (UGC 10803), which has an uncertain classification as an elliptical galaxy. Redshifts are available for all galaxies with $f_{100} > 1.5$ Jy as well as for three of the fainter galaxies. From the redshift distribution it can be seen that the Serendipity survey will not only detect nearby galaxies, but also objects out to redshifts z $\approx$ 0.1.

### *4.3. Fluxes*

The two aspects of importance concerning the source fluxes are the internal accuracy, i.e. the agreement of the fluxes derived from repeated crossings of a particular source, and the external accuracy, i.e. the agreement between the fluxes derived from dedicated photometric measurements and the serendipity slews. The current status of the internal accuracy is summarized in Table 3. It lists for those sources in Table 2 with an acceptable fit the number of detector pixels having a signal-to-noise ratio of three or higher, the serendipity fluxes, and the distance between

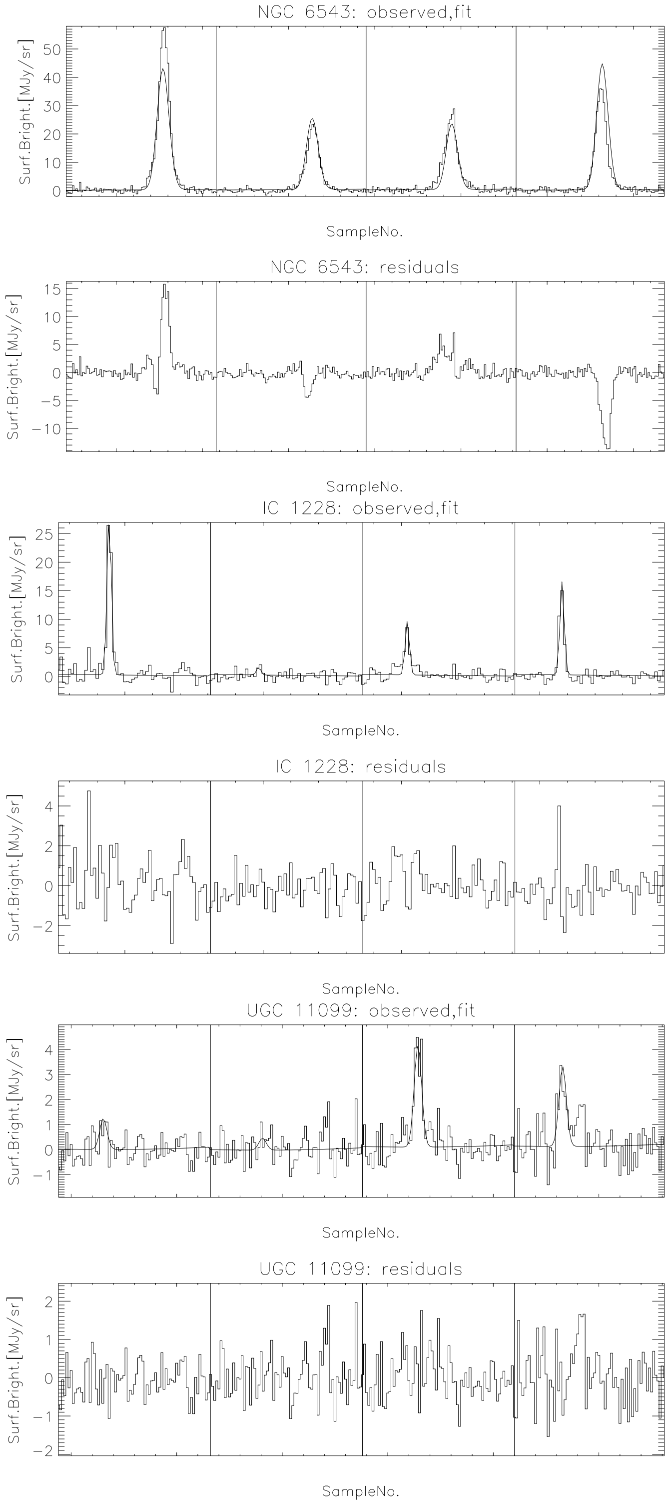


**Fig. 3.** Serendipity slew data for NGC6543 (IRAS P17584+6638), IC 1228 (IRAS P16418+6540) and UGC 11099 (IRAS P18012+6725). Each panel shows for all four detector pixels the region used for the two-dimensional fit side-by-side. For each source the upper panel shows the background subtracted data (histogram) together with the fit results (continuous line), while the lower panel shows the residuals after subtraction of the fit.

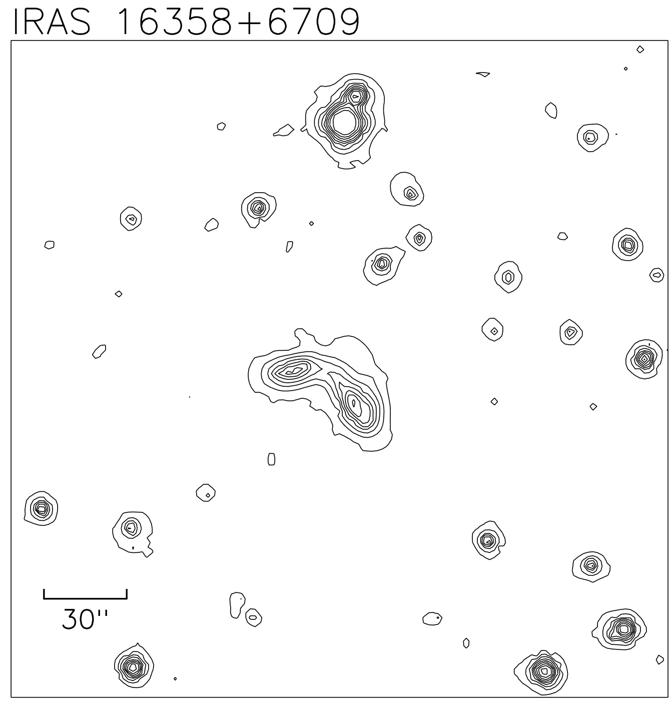


**Fig. 4.** Isocontour plot of the field of IRAS 16358+6709, taken from the Digital Sky Survey. The optical counterpart of this FIR source is an interacting pair of galaxies of unknown redshift.

the detector center and the source. For three sources dedicated photometric calibration measurements using small raster maps are already available, and these photometric fluxes are additionally listed in the last column of Table 3.

As noted above, in some cases the fit gave undoubtedly too high source fluxes, and this is most often accompanied by a large distance ($> 1'$) of the fitted source from the slew or an insufficient number of pixels with a high signal. Ignoring these values, the internal accuracy is $\approx 30$ % and in some cases better. This accuracy is currently most likely limited at least for the brighter sources by the inaccuracy of the two-dimensional gaussian to represent accurately the source profile.

In addition to the three sources listed in Table 3, photometric fluxes have been acquired for three more sources lying outside the Minisurvey field. The comparison of the serendipity fluxes with these currently rather limited number of photometric fluxes indicate a general trend in that the former are almost always somewhat higher. It is expected that further improvements in the Serendipity processing software, particularly the usage of better point source profiles and better source positions will lead to a decrease in the scatter of the derived fluxes. For these improvements a larger database of dedicated calibration measurements is mandatory : additional photometric measurements of calibration sources are currently being performed. If they confirm the general trend of too high serendipity fluxes, we consider the possibility of a constant rescaling factor as an intermediate step before the final recalibration of the whole database in the post-operational phase.

**Table 3.** Range of fitted 170 $\mu$m fluxes for sources of Table 2

| Name | # Pixels SNR $> 3$ | Serendipity flux [Jy] | Distance [arcmin] | Photometric flux[1] [Jy] |
|---|---|---|---|---|
| $F_{100} > 1.5$ Jy | | | | |
| NGC 6543 | 4 | 15.1, 14.7, 15.9 | 0.1, 0.3, 0.2 | 15.40 |
| | 4 | 19.1, 46.7, 20.6, 20.1 | 0.5, 1.1, 0.6,0.5 | |
| | 3 | 32.2, 18.7, 15.1 | 0.6, 2.0, 0.7 | |
| NGC 6503 | 4 | 42.0, 20.9 | 0.2, 0.6 | 30.63 |
| IC 1228 | 4 | 7.6 | 0.3 | 5.37 |
| | 3 | 6.4 | 0.3 | |
| | 2 | 7.5 | 0.5 | |
| KUG 1750+683B | 3 | 0.7 | 0.1 | |
| IRAS 17517+6422 | 3 | 12.5, 5.7 | 1.6, 0.1 | |
| UGC 10425 | 2 | 3.4 | 0.3 | |
| UGC 10963 | 2 | 4.7 | 0.4 | |
| IRAS 18001+6638 | 4 | 1.9 | 0.5 | |
| | 2 | 2.5 | 0.3 | |
| UGC 10995 | 4 | 1.5 | 0.5 | |
| | 2 | 2.8 | 0.4 | |
| NPM1G +71.0155 | 2 | 3.5 | 0.1 | |
| UGC 10502 | 2 | 2.8 | 0.4 | |
| NGC 6395 | 2 | 2.0 | 0.2 | |
| $F_{100} < 1.5$ Jy | | | | |
| NPM1G +64.0172 | 2 | 1.5 | 0.4 | |
| IRAS 16358+6709 | 2 | 7.7 | 0.3 | |
| NGC 6456 | 3 | 1.9 | 0.7 | |
| NPM1G +65.0155 | 3 | 0.9 | 0.4 | |
| IRAS 17089+6558 | 3 | 0.9 | 0.1 | |
| | 0 | 1.0 | 0.3 | |
| IRAS 17380+6709 | 0 | 5.5 | 2.7 | |
| UGC 11099 | 2 | 0.9 | 0.3 | |

[1]Results of dedicated photometric measurements using a mini-map centered on the sources

### *4.4. Reliability*

In a first attempt to assess the reliability of the source detections, i.e. the nature of sources which do not necessarily have an IRAS counterpart, all sources were selected having a detection with a signal-to-noise ratio of more than 3 in at least 3 detector pixels and a fitted width in right ascension and declination of $0.5' < \sigma < 2'$. About 2/3 of these are associated with IRAS point sources, while all others are either contained in the IRAS faint source catalog or are identified on ISSA maps as narrow highly elongated cirrus ridges, which have accidentally been crossed along the short axis. Thus, none of the sources selected with the above mentioned criteria are spurious. All have a counterpart in the sense of an increased 100 $\mu$m flux on the ISSA plates on small spatial scales. Therefore, selecting sources according to their widths definitely eliminates cosmic ray hits and very broad cirrus regions. However, further improvement of the software is needed to separate narrow cirrus ridges from point sources and also to find point sources on top of broad cirrus regions.

A much larger collection of slews has to be analyzed to say something definite about the frequency of strong Serendipity sources having no IRAS counterpart. Such sources require in any case a detailed investigation of the processed data, and also a cross-check against all moving solar system objects. While these cases definitely represent the most interesting result of the Serendipity survey, they are not likely quickly found and their reality is not easily established beyond doubt.

## 5. Concluding remarks

The ISOPHOT Serendipity slews crossing the north ecliptic pole minisurvey field have been analyzed, leading to the detection of 21 sources with 100 $\mu$m larger than 1 Jy. Except for the bright planetary nebula NGC6543, all sources with an optical counterpart are galaxies. Several sources warrant optical follow-up observations, most notably a possible elliptical galaxy and an interacting galaxy-pair.

The completeness of the Serendipity point source extraction in this field is better than 90% for sources with 100 $\mu$m fluxes greater than 2 Jy. The frequency of source detections is $\approx 0.025/^\circ$ or one detected source along a slew length of $40^\circ$, which is equivalent to a surface density of $0.5/\square^\circ$ . The IRAS database of cataloged galaxies and quasars gives an extragalactic source density of $0.5/\square^\circ$ for the Minisurvey field which exactly coincides with the measured source density along Serendipity slews.

Taking these values one can estimate that more than 3000 galaxies have been seen so far on Serendipity slews, which is in agreement with previous estimations (Bogun 1995). By the end of the ISO mission, it is expected that a total of $\approx$ 150000° of strip maps will have been gathered, containing the crossing of $\approx$ 4000 galaxies. The anticipated total sky coverage will be $\approx$ 17%. However, as shown above, the derivation of accurate positions and fluxes will be very difficult for sources lying far off the slews. A more conservative estimate can be obtained under the assumption that a source has to lie not more than about half a detector pixel $(45'')$away from the detector center in order to derive useful flux values. This would bring the effective sky coverage down to $\approx$ 10%, and also decrease the number of galaxies for which reliable fluxes can be obtained from the Serendipity Slews. This condition will be adopted in the upcoming work on the Serendipity Survey.

For a large fraction of the sources, a photometric accuracy of about 30% can eventually be expected. This will provide a large database of 170 $\mu$m fluxes mostly for galaxies. The analysis of the complete set of slews might also give some clues as to whether galaxies with strong FIR excess exist and if so, what their nature is. The investigation of the Minisurvey field is the starting point for a catalog of well detected sources with distances of less than $45''$ to the slews and a signal-to-noise ratio of at least 3 in at least 3 detector pixels. Further work will be directed towards the analysis of the cirrus structures on all spatial scales.

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