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THE ISO EXTRAGALACTIC SURVEYS: AN ALTERNATIVE VIEW OF THE DISTANT UNIVERSE

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ABSTRACT. We review the results of a number of deep extragalactic surveys performed with the *Infrared Space Observatory* at various mid- and far-IR wavelengths. Because of the ISO telescope's limited size and the corresponding confusion limitation, the depths of these surveys are a strong function of wavelength, with the mid-IR data allowing the most sensitive exploration of the distant universe over a substantial redshift interval up to $z \sim 1.5$. We also compare these results with longer wavelength observations obtained with the bolometer array SCUBA/JCMT in the sub-millimeter, and with estimates of the spectral intensity of the extragalactic IR background radiation recently detected in the COBE database. The ISO deep 15 micron galaxy counts incontrovertibly demonstrate for the first time that faint IR sources evolve on a very fast cosmic timescale up to redshift of at least one, a result fitting well with the intense flux measured from the IR background. Altogether, the integrated flux emitted by distant galaxies in the IR, mostly due to dust reprocessing of light emitted by young stars in the optical-UV, may be two times larger then their total optical/near-IR output from 0.1 to 10 μm. These results, currently being extensively followed-up with observations in the optical and near-IR of faint ISO sources, show that the IR is an essential vehicle of information about how galaxies and their stellar populations have formed during the past history of the universe.

1. THE ISO MISSION

The Infrared Space Observatory has been the most important infrared astronomical mission of the 1990s. Launched by the European Space Agency, the mission consisted in a 60 cm telescope operated from a highly eccentric 70000 Km orbit. It included four instruments: a mid -IR 32×32 camera (ISOCAM, 4 to 18 μm), a far-IR imaging photometer (ISOPHOT, with small 3×3 and 2×2 detector arrays from 60 to 200 μm, a short-wavelength (SWS) and a long-wavelength (LWS) spectrograph. The whole payload was cooled to 2 K inside a large Dewar containing 2500 liters of superfluid helium. The cooling system worked so well that it allowed ISO to operate for 30 months, from November 1995 to April 1998, instead of the nominal 18 months. This most complex ESA astronomical mission has also been the most successful, and, together with complementary ground-based instrumentation (e.g. the UK JCMT telescope equipped with the sub-mm bolometric camera SCUBA), is a key element of the leadership of European astronomy at long wavelengths.

2. MOTIVATIONS FOR DEEP ISO SURVEYS

While designed as an observatory-type mission, the vastly improved sensitivity offered by ISO with respect to the previous IRAS surveys suggested to some of us to propose to dedicate a significant fraction of ISO (both Guaranteed and Open) observing time to a set of deep sky explorations at mid- and far-IR wavelengths. The basic argument for this was to parallel optical searches of the deep sky with complementary observations at wavelengths where, in particular, the effect of dust is far less effective in extinguishing optical light. This could have been particularly relevant for investigations of the distant universe, given the large uncertainties implied by the unknown extinction corrections for high redshift objects (e.g. Pettini et al. 1999).

Observations in the mid- and far-IR also sample the portion of the e.m. spectrum dominated by dust re-processed light, and are then ideally complementary to optical surveys to evaluate the global energy output of stellar populations and active nuclei. In this context, one important event close to the beginning of ISO operations was the discovery of the far-IR/sub-mm background (CIRB, Puget et al. 1996; see also Hauser et al. 1998), a diffuse isotropic emission detected in the all-sky COBE maps after subtraction of the Galactic and Interplanetary dust emissions, as well as of the CMB spectrum. The substantial intensity of the CIRB, which immediately was interpreted as the integrated emission of cosmic sources (starburst galaxies in particular) at any redshifts, seems to imply that a substantial fraction of the whole energy emitted by high-redshift galaxies should have been reprocessed by dust at long wavelengths.

Though surprising at first sight, this result may be understood considering what happens in local starburst galaxies: the more violent the star-formation event, the more luminous is the galaxy, and the larger is the fraction of the bolometric flux absorbed and emitted in the far-IR. This is partly due to the spatial re-organization of the dust-rich interstellar medium following the dynamical event (a galaxy merger of strong interaction) triggering the starburst. Also, empirically, the bulk of star formation inside our Galaxy happens within dusty optically thick clouds. The energetics of the CIRB is then consistent with the fact that the bulk of the star formation in distant galaxies (at redshifts say ~ 1 and higher) happened in the active starbursting IR-luminous mode, rather than in the quiescent mode as in local galaxy disks, where only 30% of the stellar light on average is reprocessed to longer wavelengths.

A major intent of the deep ISO surveys was to follow a mandate to start to physically characterize these distant sources of the CIRB background, and to understand a fundamental mode of galaxy formation/evolution. Also resolving the CIRB background into discrete sources was necessary to single out the fraction contributed by nuclear non-thermal activity in AGNs.

Finally, exploring the sky to unprecedented sensitivity limits provides an obvious potential for discoveries of new unexpected phenomena in our local environment up to the most distant universe.

3. OVERVIEW OF ISO SURVEYS

Deep surveys with ISO have been performed in two mid-IR ($\lambda = 6.7$ and 15 μm) and two far-IR ($\lambda = 90$ and 170 μm) bands. The diffraction-limited spatial resolutions were ~5 arcsec at 10 μm and ~50 arcsec at 100 μm. Because of the corresponding source confusion, this implied that the sensitivity limits in the mid-IR are 1000 times better than at the long wavelengths (0.1 mJy versus 100 mJy). At some level the problem of confusion will remain a fundamental limitation also for future space missions (SIRTF, FIRST, IRIS).

A kind of compensation to these different performances as a function of wavelength for the various ISO surveys derives from the typical far-IR spectra of galaxies and AGNs, which are roughly two orders of magnitude more luminous at 100 μm than at 10 μm.

We detail in the following the most relevant programs of ISO surveys.

3.1. The ISOCAM Guaranteed Time (GT) Extragalactic Surveys (GITES)

Five Extragalactic Surveys have been performed in the ISOCAM Guaranteed Time (GITES, P.I. C.Cesarsky), including large-area shallow surveys and small-area deep integrations. In order to reduce the effect of large-scale structures, two of them were carried out in the Lockman Hole and three in a southern field, the "Marano" area. These two areas were selected for their low foreground emission (low zodiacal and cirrus emission) and because of the existence of data at other wavelengths (optical, radio, X). The observations have been carried out with two of the most sensitive ISOCAM filters, LW2 (5-8.5 μm) and LW3 (12-18 μm). More than one thousand sources have been detected over a total area of about 1.5 square degree (see Table 1 for more details).

Since the 7 μm band catalogues include a large fraction of Galactic stars, we will limit our analysis in the following sections to the LW3 15 μm data, which are expected to be dominated by dust emission.

3.2. The European Large Area ISO Survey (ELAIS)

ELAIS is the most important program in the ISO Open Time, with 377 hours awarded (Rowan-Robinson *et al.* 1998). This time was used to survey both blank sky fields and areas already studied at other wavelengths, and finally to derive the IR spectral energy distribution (SED) of IR sources identified during early stages of the survey.

A total of 12 square degrees have been surveyed at 15 μm with ISOCAM and at 90 μm with ISOPHOT, while 6 and 1 sq. degrees have been covered with the two instruments at 6.7 and 170 μm, respectively. To reduce the effects of cosmic variance these surveys have been split into 4 fields of comparable area, 3 located in the northern hemisphere and one in the southern (see Table 2). Six smaller areas (named as Phoenix, Lockman 3, Sculptor, VLA 8, TX0211-122, and TX1436+157) are also part of the survey.

While the data analysis is still being refined, a highly reliable source list of over 1000 sources (mostly detected at 15 μm) is being published. A systematic effort of identification of the ELAIS sources with optical, radio and sub-mm telescopes is in progress, as well as several attempts to cross-correlate these sources with those identified in deep X-ray surveys in the same areas. Hard X-ray data in particular are useful to

Tab. 1 - ISOCAM surveys

Name	λ (μm)	Area ($'^2$)	depth (mJy)	# objs [(a)]	Ref.	coord.(2000)
CAM parallel	7,15	1.2e5	5	>10000	1	–
ELAIS	7,15	4e4	1,3	~1000	2	–
Marano2 FIRBACK	15	2700	1.4	29	3	03 13 10 -55 03 49
Lockman Shallow	15	1944	0.72	180	4	10 52 05 +57 21 04
Comet Fields	12	360	0.5	37	5	03 05 30 -09 35 00
Lockman Deep	7,15	500	0.3	166	6	10 52 05 +57 21 04
CFRS 14+52	7,15	100	0.3	23,41	7	14 17 54 +52 30 31
CFRS 03+00	7,15	100	0.4		8	03 02 40 +00 10 21
Marano2 Deep	7,15	900	0.19,0.32	180	9	03 13 10 -55 03 49
A370	7,15	31.3	0.26	18	10	02 39 50 -01 36 45
Marano Ultradeep	7,15	90	0.14	142	11	03 14 44 -55 19 35
Marano2 Ultradeep	7,15	90	0.1	115, 137	12	03 13 10 -55 03 49
A2218	7,15	16	0.12	23	10	16 35 54 +66 13 00
ISOHDF South	7,15	25	0.1	63	13	22 32 55 -60 33 18
ISOHDF North	7,15	24	0.05,0.1	7;44	14	12 36 49 +62 12 58
Deep SSA13	7	9			15	13 12 26 +42 44 24
Lockman PG	7	9	0.034	15	16	10 33 55 +57 46 18
A2390	7,15	5.3	0.030	32,31	17	21 53 34 +17 40 11

[(a)] If only one number appears, it refers to the longer-λ survey.

References: (1) Siebenmorgen et al. (1996); (2) Rowan-Robinson M., et al. (1998); (3) Puget et al. (1999); (4) Désert, F.-X., *et al.*, to be submitted (tbs); (5) Clements et al. (1999); (6) Fadda, D., *et al.*, tbs; (8) P.I.: F.Hammer; (9) Désert, F.X., *et al.*, tbs; (11) Elbaz, D., *et al.*, tbs; (12) Aussel, H., *et al.*, tbs; (13) Oliver, S.J., *et al.*, tbs; (16) P.I. Y.Taniguchi;

evaluate the contribution of AGN emission in the sources. Preliminary identifications, fully consistent with model predictions, suggest that the vast majority of the ELAIS sources are either starburst galaxies or AGN (both type-1 and type-2), mostly at $z < 0.5$, with several quasars found up to the highest redshifts.

3.3. The ISOCAM observations of the two Hubble Deep Fields

Very successful programs by the Hubble Space Telescope have been the two ultradeep exposures in black fields areas, one in the north and the other in the south, called the Hubble Deep Fields (HDF). These surveys promoted a substantial effort of multi-wavelength studies aimed at characterizing the SEDs of distant and high-z galaxies. These areas, including the Flanking Fields for a total of $\sim$ 50 sq. arcmin, have been observed by ISOCAM (P.I. M. Rowan-Robinson) at 6.7 and 15 μm, achieving completness to a limiting flux of 100 μJy at 15 μm.

These have been among the most sensitive surveys of ISO and have allowed to discover luminous starburst galaxies over a wide redshift interval up to $z = 1.5$ (Rowan-Robinson et al. 1997; Aussel et al, 1999b). In the inner 5 sq. arcmin the exceptional images of HST provide a very detail morphological information for ISO galaxies at any

Tab. 2 - ISOPHOT surveys

Name	λ (μm)	Area (sq.deg.)	depth (Jy)	# objs	Ref.	coord.(2000)
PHOT Serendipitous	170	7000	1.5	4000	1	–
ELAIS	90,170	12,1	0.05,0.1	~500	2	16 11 00 +54 25 00
FIRBACK	170	3	0.1	200	3	03 13 10 -55 03 49
Lockman PG	90,170	1.1	0.1,0.1	–	4	10 34 00 +57 46 00
SA 57	60,90	0.42	–	–	5	13 06 00 +29 42 00

References: (1) Stickel M., et al. (1998); (2) Oliver S., et al. (1999); (3) Puget J.L., et al. (1999); (4) Kawara K, et al. (1998); (5) Mattila K, et al. (1999, in prep.); Noorgaard-Nielsen H.H., et al. (1999, in prep.).

redshifts. The outcome of these analyses (Elbaz et al. 1998; Aussel et al. 1999a) was that more than half of sources at $z > 0.4$ are classified as Irregulars/Mergers.

3.4. The ISOCAM Survey of two CFRS fields

Two fields from the Canada-France Redshift Survey (CFRS) have been observed with ISOCAM to the same depth as observations of the Lockman Deep GITES: the '14+52' field (observed at 6.7 and 15 μm) and the '03+00' field (with only 15 μm data, but twice as deep). The CFRS is, with the HDFs, one of the best studied fields with multi-wavelength data. Studies of the galaxies detected in both fields have provided the first tentative interpretation of the nature of the galaxies detected in ISOCAM surveys (Flores *et al.* 1999).

3.5. The ISOPHOT FIRBACK survey program

FIRBACK is one of the deepest cosmological surveys in the far-IR, specifically aimed at detecting at 170 μm the sources of the far-IR background (P.I. J.L. Puget). Part of this survey was carried out in the Marano area, and part in collaboration with the ELAIS team in ELAIS N1 and N2. This, as well as the other ISOPHOT surveys, is heavily limited (to $S_{170} \geq 100$ mJy) by extragalactic source confusion in the large ISOPHOT beam (43 arcsec). Some constraints on the counts below the confusion limit obtained from a fluctuation analysis of one Marano/FIRBACK field are discussed by Lagache & Puget (1999). The roughly 200 sources detected are presently targets of follow-up observations, especially using deep radio exposures of the same area to help reduce the large ISO errorbox and identify the optical counterparts. Also an effort is being made to follow-up these sources with sub-mm telescopes (IRAM, SCUBA): this would provide significant constraints on the redshift of sources which would be otherwise very difficult to measure in the optical (because they are very faint and red).

3.6. The Lensing Cluster Surveys

Three lensing galaxy clusters, Abell 2390, Abell 370 and Abell 2218, have received very long integrations by ISOCAM (Metcalfe *et al.* 1998; Altieri *et al.* 1999). The lensing has been exploited to achieve even better sensitivities with respect to ultra-deep blank-field surveys (e.g. the HDFs), and allowed detection of sources between 30 and 100 μJy at 15 μm. However this was obviously at the expense of distorting the areal projection and ultimately making uncertain the source count estimate.

3.7. The Japanese Guaranteed Time survey

An ultra-deep survey of the Lockman Hole in the 7 μm band was performed by Taniguchi *et al.* (1997). This field does not overlap with the GITES performed in the Lockman Hole region. Another field, SSA13, was also covered to a similar depth by the same team (P.I Y.Taniguchi). The Lockman region was also target of an ISOPHOT survey by the same team (see Table 2).

3.8. The PHOT Serendipitous and CAM Parallel Surveys

These are side-benefits of the ISO mission. The former utilizes the slew time between ISO's pointed observations, and consists of scanning strips of the sky with the PHOT camera at 170 μm. In such a way roughly 15% of the sky has been observed with a 50% completeness for sources brighter than 1.5 Jy (Stickel et al. 1998).

The CAM Parallel survey has been possible because ISO can have 2 instruments simultaneously working and observing two sky regions 10' to 20' apart (though one should be in a non-optimal configuration). The survey is performed (mostly using the 6.7 μm broad-band filter) when one of the other three instruments were observing the prime target (Siebenmorgen et al. 1996). In this way a total (unbiased) area of 33 sq.deg. has been observed during the ISO mission. However, given the moderate limiting flux, we expect that the vast majority of the detected sources should be galactic stars.

4. DATA REDUCTION

In addition to the usual procedures for CCD-based imaging data reduction, ISOCAM data need particular care to remove the effects of glitches induced by the frequent impacts of cosmic rays on the bulky detectors (the 960 pixels register on average 4.5 events/sec). This badly conspired with the need to keep them cryogenically cooled to reduce the instrumental noise, which implied a very slow electron reaction time and longterm memory effects. In conclusion, there was a risk that the memory of a previous cosmic ray impact might be interpreted as a faint cosmic source. To correct for that, tools have been developed by various groups for the two main instruments (CAM and PHOT). They are essentially based on identifying patterns in the time history of the response of single pixels, which are specific to either astrophysical sources (a jump above the average background flux when a source falls on the pixel) or cosmic ray glitches (transient spikes followed by a slow recovery to the nominal background).

The problem required particular care for ISOCAM observations in both the regime of moderately bright fluxes and large survey areas (e.g. ELAIS), because the redundancy was kept to a minimum, but also in the case of very deep small-area surveys (the HDFs and GT Ultradeep surveys) because the faintness of the sources and the corresponding small differential response when the source falls on the pixel may be easily confused with long-term glitches. The most widely adopted algorithms for CAM data reduction were those exploiting multi-resolution wavelet transforms (in the 2D observable plane of the position on the detector vs. time sequence) called Pattern REcognition Technique for ISOCAM data (PRETI, the Saclay procedure, see Stark et al. 1999), and the 'Triple Beam-Switch' (TBS) technique developed by Désert *et al.* (1999), consisting in a subtraction of the off-source image from the on-source image to efficiently remove the effects of cosmic rays. The former is so far the most efficient tool to reliably extract very faint mid-IR sources from CAM frames. Other tools have been developed at the Istitute for Radio Astronomy (CNR) in Bologna (C. Lari et al.) and at Imperial College London (S. Serjeant et al.).

These various detection schemes and photometry algorithms have been tested in particular at the Service d'Astrophysique de Saclay, by means of very sophisticated Monte Carlo simulations, including all possible artifacts introduced by the analyses. In such a way both the detection reliability, completeness and photometric accuracy are simultaneously controlled, as a function of the flux threshold. The photometric accuracy was found to be as good as ~10% even for very faint mid-IR sources where enough redundancy was available (as for the case for CAM HDFs and Ultradeep surveys). Also in these cases the astrometric accuracy was very good (of order of 1-2 arcsec), allowing straightforward identification of the sources. The same simulations have also been tailored to account for the Eddington bias, which added to the photometric and completeness checks and to the Poisson errors, allows a reliable estimate of the source counts from the CAM GITES surveys (see Figure 1 below).

5. SOURCE COUNTS

In this and the following Sections our analysis will concentrate on mid-IR samples selected from the CAM GITES and HDF surveys (see Sect.3.1) in the LW3 (12-18 μm) filter, because they include the faintest, most distant and most numerous ISO-detected sources. They are also easier to identify because of the small ISO error box at these wavelengths. Altogether, the mid-IR CAM surveys have already provided new relevant information on high-redshift galaxies, whereas far-IR selected samples still need a substantial identification effort to understand their nature and redshift distribution.

IR-selected galaxies have typically red colors (though not so unusually red), because of the dust responsible for the excess IR emission. The most distant are also quite faint in the optical. As a consequence, redshift information is available only for very small subsamples (i.e. the HDF north and CFRS samples, see Sect. 3.3, 3.4) of the faint CAM-selected population. Given the lack of extensive spectroscopic information, the simple inspection of the number counts, compared with predictions based on a knowledge of the local luminosity function, already provides an important constraint on their evolution properties.

Surveys of different sizes and depths are necessary to cover a wide dynamic range in flux with enough source statistics. We report in Figure 1 a plot of the extragalactic differential number counts obtained from seven independant surveys using the ISOCAM 15 μm band (Elbaz et al. [1999]): the GITES, the HDF north (Aussel *et al.* 1999a) and the A2390 cluster lens (from Altieri *et al.* 1999). These surveys of different depths cover

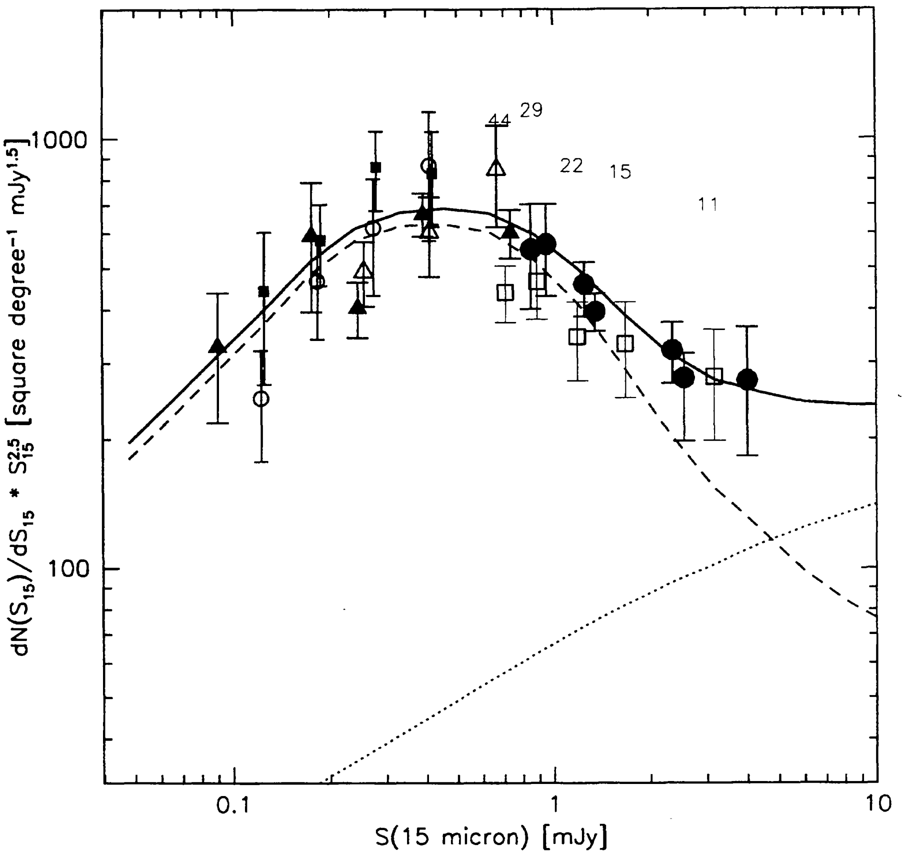

Fig. 1. Differential source counts at 15 μm normalized to the [ ]Euclidean law ($N[S] \propto S^{-2.5}$). The data come from an analysis of the GITES surveys by Elbaz et al. (1999). The differential form of the counts is such that all data points in the figure are statistically independent. The dotted line corresponds to the expected counts for a population of non-evolving spirals. The dashed line comes from our modelled population of strongly evolving starburst galaxies.

five different sky regions over two decades in flux from 50μJy up to 5mJy. For each of these surveys we included only flux bins which were reliably complete, still having enough sources for a good statistics. Including the ELAIS and IRAS survey data, the range in fluxes would reach four orders of magnitude, but both ELAIS and IRAS counts are still being assessed, so that at this stage we prefer to confine our analysis to the data in Fig.1. After all, it is precisely in this flux range that the most important evolutionary effects are apparent.

A first inspection of Fig.1 shows that there is very nice agreement between so many independent samples (consider the very expanded scale on the ordinate). The corresponding areal density of ISOCAM 15 μm sources at the limit of ~50-80 μJy is ~5 sources/arcmin^2. This is nominally the ISO confusion limit at 15 μm, if we consider that the diffraction-limited size of a point-source is $\sim$ 50 arcsec^2 and that confusion sets in when the source areal density exceeds the value of 0.05/resolution element, or 3.6/arcmin^2 in our case.

The counts are normalized in Fig.1 to the prediction for a Euclidean law ($N[S] \propto S^{-2.5}$). A non-evolving population in the real expanding universe would produce a flat curve or, considering the effects of cosmological dimming on the flux, one converging towards faint fluxes. What we see here is in fact a very sharp turn-up of the counts at fluxes fainter than $S_{15} = 4$ mJy and continuing down to 0.2-0.4 mJy.

Our first attempt was to compare this result with the expectations of models assuming no-evolution for cosmic sources. Any such calculations have to account for the effects of the very complex spectrum of galaxies in the mid-IR (including strong PAH emission features and absorption features for the silicates) in the K-correction factor that determines the relationship between luminosity and flux. The effect may be particularly important in the wide LW3 (12-18 μm) filter.

Local mid-IR luminosity functions (LLF) have been published by Rush et al. (1993), Xu *et al.* (1998) and Fang *et al.* (1998) based on the 12 μm all-sky IRAS survey. However, in spite of the proximity of the CAM LW3 and IRAS 12 micron bands, at the moment we do not have a reliable LLF at 15 μm because of: a) uncertainties in the IRAS 12 μm photometry, b) the effects of local inhomogeneities, particularly the local Virgo super–cluster; and c) the conversion between the IRAS and CAM-LW3 bands.

The dotted line in Fig. 1 corresponds to our present best estimate of the contribution from a non-evolving population with a luminosity function consistent with that in the IRAS 12 μm band derived by Xu *et al.* (1998) and Fang *et al.* (1998). The correction to the CAM LW3 band is made assuming a 12 to 15 μm flux ratio which is a function of the 12 μm luminosity: for the less luminous objects the ratio is based on the observed mid-IR spectrum of quiescent spirals, while for the highest luminosity galaxies the ratio is the one expected for ultraluminous IR galaxies, and for intermediate objects it is the typical starburst spectrum. The 15 to 12 μm flux ratio increases continuously with luminosity, the far-IR flux being dominated by starburst emission.

Note that our estimates fully account for the effect of the CAM LW3 and IRAS transmission curves to the incident flux for the various kinds of model spectra.

It is clear that the no-evolution prediction, even taking into account the effects of the PAH features on the K-corrections, is very short of the observed counts at fluxes fainter than 1 mJy. Also the observed slope in the 0.4 to 4 mJy flux range ($N(S) \propto S^{-3\pm0.1}$) is very significantly different from the no-evolution prediction $N(S) \propto S^{-2}$. The extrapolation to the bright fluxes is instead consistent, by construction, with the IRAS 12 μm counts with a slope close to Eclidean.

6. EVIDENCE FOR A STRONGLY EVOLVING POPULATION OF LUMINOUS IR GALAXIES

We have modelled the excess 15 μm counts with a strongly evolving population of starburst galaxies. The shape of the differential counts shown in Fig.1 already contains an

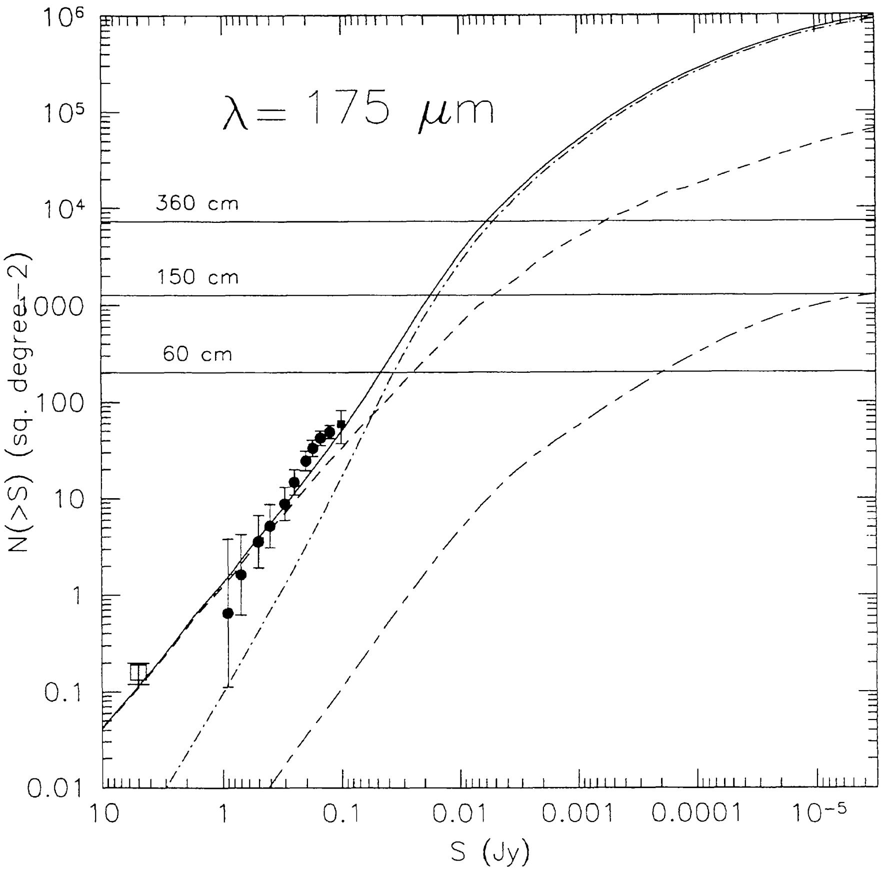

Fig. 2. Integral counts based on the ISOPHOT FIRBACK survey (Sect.3.5) at 170 μm (filled circles) and on the ISOPHOT Serendipitous survey (open square, Sect.3.8). The dashed and dot-dashed lines correspond to the non-evolving and the strongly evolving populations as in Fig.1. The lowest curve is the expected contribution (negligible) of AGNs. The horizontal lines mark the confusion limits for three telescope sizes: the 60cm one corresponds to the ISO limit.

indication about the properties of such populations. In particular the flat (Euclidean) normalized counts extending from the bright IRAS fluxes down to a few mJy, followed by the sudden upturn below, suggests that it cannot be the whole population of IR galaxies that evolve: in this case and for the observed IR galaxy LLF, the super-Euclidean increase in the counts would appear at much brighter fluxes. This behaviour is instead consistent with only a locally small fraction of IR galaxies that evolve.

For these reasons we have assumed that the local fraction of the evolving starburst population is only several percent of the total, consistent with the observed fraction of interacting galaxies ($\sim$ 5% locally). The quick upturn in the counts then requires quite a strong evolution to get a match at the peak in the normalized counts around $S_{15} \simeq 0.5$mJy: a physically credible solution requires a redshift increase of the comoving density of starbursts as

$$n(L(z), z) = n_0(L_0, z) \times (1+z)^6 \tag{1}$$

and at the same time an increase of the luminosities as

$$L(z) = L_0 \times (1+z)^3. \tag{2}$$

The density evolution of the starbursting population could simply be understood as an increased probability with redshift of the interactions as a simple geometric effect. The luminosity evolution can be interpreted as an effect of the larger gas mass available to the starbursts at higher z. To be consistent with the (preliminary) information about the $z-$distributions in the HDFs samples (Aussel et al. 1999), this fast evolution should turn over at $z \simeq 0.8 - 0.9$ and the IR emissivity keep roughly constant at higher z.

This, coming from the deepest IR surveys existing at the moment, is a crucial piece of information about distant IR galaxies. However, much about the nature of this evolving population is still to be understoood: are these low-luminosity, or ultra-luminous IR galaxies, or are they dominated by AGN emission? Relevant constraints are provided by comparisons with other extragalactic IR samples selected at longer wavelengths (in particular the IRAS deep 60 μm surveys, the ISO FIRBACK 170 μm, Sect.3.5, and the JCMT/SCUBA 850 μm surveys), and, ultimately, with the observed spectral intensity of the CIRB. If we assume for the IR evolving population the average spectral template of the ultra-luminous galaxy Arp 220, then we would far exceed the observed far-IR counts and the CIRB intensity.

On the contrary, if we assume for the IR evolving sources a more typical starburst spectrum (like the one of M82, which after all is similar to those of other luminous starbursts observed by ISO), then most of the observed properties of far-IR galaxy samples (number counts, redshift distributions, luminosity functions) are appropriately reproduced. One example is given in Figure 2, where we compare the counts observed at 170 μm with our model prediction, based on the assumption of an M82 spectral template for the evolving population. Model fits imply that the galaxy population dominating the faint GITES counts and the CIRB in the mid-IR is composed of luminous ($L_{bol} \sim 10^{11} - 10^{12}\ L_\odot$) starbursts in massive ($M \sim 10^{11}\ M_\odot$) galaxies at $z \sim 0.5 - 1$. The nature of the 170 μm FIRBACK selected sources, contributing $\sim 10\%$ of the CIRB, is presently the target of intense observational and modellistic investigations.

Although deeper samples and a much more substantial identification effort and spectroscopic follow-up for far-IR source samples is required to confirm these results, it is tentatalizing to conclude that the good match to all these data obtained assuming a starburst far-IR spectral template for the starbursting population is a clear indication that the phenomenology of faint IR-selected sources is dominated by processes of star-formation in distant galaxies rather than by AGN emissions.

We detail in Figure 3 a match of the expected contribution of faint IR sources (based on the previously discussed evolution model) to the extragalactic background with observational data on the CIRB. The prediction coming out from this analysis is that the

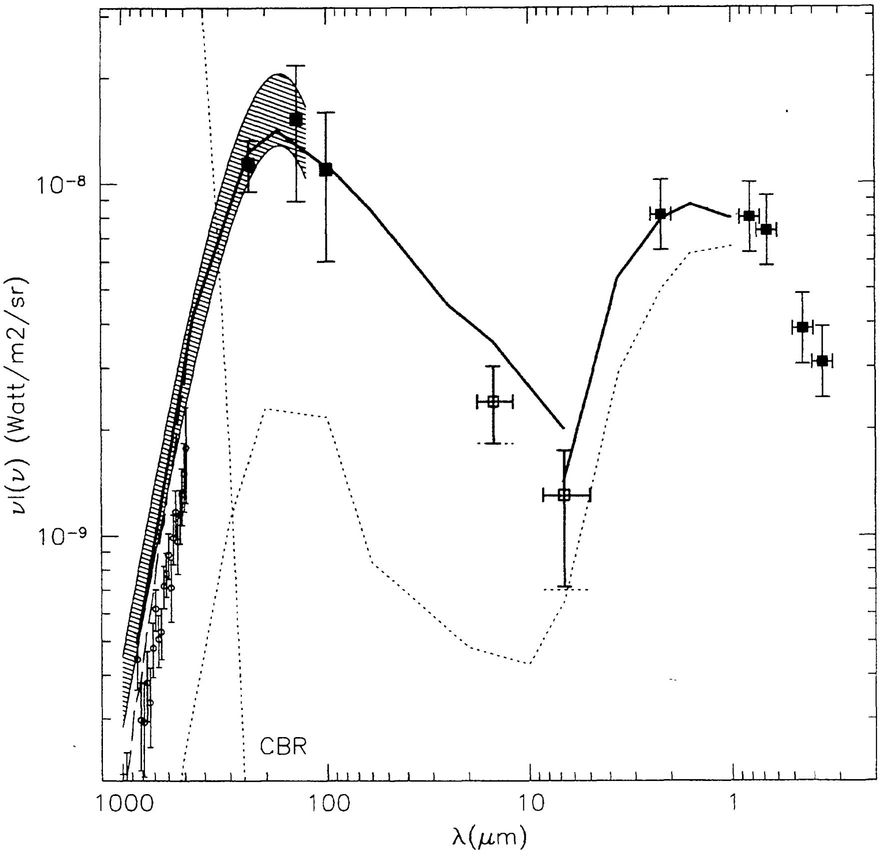

Fig. 3. A comparison of the recently discovered CIRB background (Puget et al. 1996; Hauser et al. 1998) with the optical extragalactic background estimated from ultradeep optical integrations by the HST in the HDF. The dotted line marks the expectation based on the assumption that the IR emissivity of galaxies does not change with cosmic time. Three datapoints in the far-IR are from a re-analysis of the DIRBE data by Lagache et al. (1999), the shaded area from Fixsen et al. (1998). The two mid-IR points are the resolved fraction of the CIRB by the deep ISO surveys GITES. The thick line is the prediction of the model discussed in Sect.6.

integrated emission of all galaxies from 7 to 1000 μm ($I_{tot,IR} \simeq 33\ MJy/sr$) should be roughly two times larger than the that inferred from HST deep surveys from 7 to 0.1 μm ($I_{tot,opt} \simeq 17\ MJy/sr$). A discriminant at $\lambda = 7\ \mu m$ is adopted here to separate the contribution of stellar photospheric and IR dust emission from distant galaxies. Our results suggest that a major part of the whole galactic starlight at any redshifts is hidden in the optical and observable at long wavelengths. This fact makes future missions and projects, like SIRTF, FIRST, ALMA, of crucial importance to understand the distant universe and its past history.

We defer to Franceschini et al. (1999) for a more detailed investigation.

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