DEEP COSMOLOGICAL SURVEYS WITH FIRST: A REVISED CASE

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Abstract

The ESA FIRST mission, the first 4-m class observatory in space, will allow drastic improvements in mapping for faint sources with respect to previous far-IR telescopes, and will provide complementary spectral coverage with respect to major projects like NGST and ALMA. FIRST will be a powerful tool to investigate phases in the evolution of galaxies at long wavelengths, whose relevance has only recently been fully understood. The present contribution is aimed at revisiting the scientific case for deep cosmological surveys that will be performed with FIRST, in the light of recent discoveries by the Cosmic Background Explorer, the Infrared Space Observatory and large millimetric telescopes on ground. All these are showing that crucial phases in galaxy formation and evolution at high-redshifts can only be investigated at long wavelengths, in particular phases of enhanced activity of star formation, consequent to merging, bringing to the formation of galaxy spheroids. FIRST will be the only planned instrument for many years to come working in the far-IR with imaging capabilities comparable to those of optical telescopes on ground, allowing, in particular, to accurately measure the bolometric emission of galaxies and active nuclei at any redshifts. This will be essential when attempting to recover the history of baryon transformations, through both stellar thermonuclear reactions and gravitational accretion onto supermassive black holes.

Key words: Galaxies: formation – Stars: formation – Missions: FIRST – macros: LaTeX

1. Introduction

1.1. The history of baryon transformations

Although baryons contribute a negligible fraction to the global mass density in the universe, their transformations and the associated energy release play a fundamental role in the complex history bringing from the primeval undifferentiated medium to the highly structured present-day universe. Two main driving mechanisms are able to transform and circulate baryons in astrophysical systems: one is related with thermonuclear processes occurring in stars, the other with gravitational contraction of gas onto supermassive black holes in Active Galactic Nuclei and quasars.

A basic aim of the present studies of the distant universe is indeed to clarify the history of baryon circulation, and in particular the paths through which the various different galaxy populations, which we observe in the local universe, have built their stellar content, created their hosted nuclear BH's and accumulated material in them.

High-redshift objects and the generation of stars during the past cosmic history are most usually investigated by targetting the stellar integrated emissions in the UV optical near-IR with large telescopes. A complementary approach is to look at the diffuse media – atomic and molecular gas and dust – in high-z systems, and their progressive transformation into stars. While observations of the redshifted starlight emission in the optical near-IR can exploit large telescopes on ground and very efficient photon detectors, reliable probes of the diffuse media require longer-wavelength observations in the far-IR and sub-millimeter. A large variety of lines from atomic species and molecules in the Inter-Stellar Medium (ISM) at all ionization levels are observable here in principle. Dust grains, the other fundamental component of the ISM present in all astrophysical settings from planetary disks to nuclear accretion torii around quasars, have the property to emit at these wavelengths, between a few μm to 1000 μm. Typically, peak emission from dust occurs around 60-100 μm for a vast variety of cosmic sources, due to the shallow dependence of dust grain equilibrium temperature T_g on the intensity I_r of the illuminating radiation field: $T_g \propto I_r^{1/6}$.

Observations at long$-\lambda$ are then essential to study diffuse media in galaxies and *are particularly useful to study the early phases in galaxy evolution, when a very rich ISM is present in the forming system.*

The definition of *galaxy activity* indicates transient phases in the secular evolution of a galaxy during which the various transformations of the baryons undergo a significant enhancement with respect to the average rate. These phenomena concern both enhanced rates of conversion of the ISM gas into stars (the *starburst* phenomenon), and phases of increased activity of the nuclear emission following an event of fast accretion of gas into the supermassive BH (the quasar phase). IR and sub-mm wavelengths provide a privileged viewpoint to investigate galaxy

Proc. Symposium *'The Promise of the Herschel Space Observatory'* 12–15 December 2000, Toledo, Spain
ESA SP-460, July 2001, eds. G.L. Pilbratt, J. Cernicharo, A.M. Heras, T. Prusti, & R. Harris

"activity" in general: (a) this λ-interval typically includes a dominant fraction of the whole bolometric output of active objects; (b) at long wavelengths the screening effect of diffuse dust, usually present in large amounts in "active" galaxies, is no more effective and an impeded access to even the most extreme column-density regions is possible.

Long wavelength IR observations are then particularly critical to trace events of starburst activity in galaxies, likely to produce fundamental morphological transformations and to generate a substantial fraction of the galactic stellar content.

1.2. Observational issues

Unfortunately, the IR and sub-millimeter constitute a very difficult domain for cosmological explorations: observations even from space are seriously limited here by several factors. To reduce the large instrumental background the telescope has to be cooled, either actively through large dewars or passively with a very efficient shielding. Stray-light control is also a requirement, to reduce the impact of the large Zodiacal and Galactic backgrounds and to keep under control the system response to strong off-beam sources. All this is technologically very demanding and tends to limit the duration of space IR missions (because of the finite coolant reservoir) and the size of the primary photon collector. Such modest sizes cause the most fundamental limitation for space IR observatories: the source confusion due to the poor angular resolution implied by long-wavelength photon diffraction.

The confusion noise is easily computed from the diffraction limited angular resolution θ of a telescope of size D: $\theta[FWHM] \simeq 30\ \lambda_{100\mu m}/D_{1m}\ [arcsec]$. Confusion sets in at a flux level S_{conf} corresponding to a source density $n \sim 0.04$ sources per areal resolution element (Franceschini 2001), or

$$n(> S_{conf}) \simeq 570\ D^2_{1m}/\lambda^2_{100\mu m}\ sources/degree^2. \qquad (1)$$

It is worth anticipating that a variety of recent observations (see Sect. 2) have revealed that the far-IR sky is very much populated by luminous extragalactic sources, which implies that confusion starts to manifest already at relatively bright fluxes for even large space telescopes.

Mostly for this reason, past (IRAS), present (ISO) and to some extent also future space observatories (SIRTF, ASTRO-F) provide quite limited capabilities to explore the distant universe in the far-IR.

1.3. Paper's content

The Herschel Space Observatory (formerly Far-Infrared Space Telescope, FIRST) will dedicate a 4-m class telescope to the exploration of the sky at long wavelengths, over a large waveband interval from ~ 60 to 500 μm. At the higher frequency side, FIRST will allow imaging performances comparable with those of optical surveys, while at the long wavelength side it will allow continuous coverage of substantial sky areas with sensitivities enough to provide unbiassed selection of tens of thousands high-redshift galaxies and quasars (see Fig. 3 below).

The present contribution revisits the case for deep cosmological surveys in empty sky regions with FIRST. This was identified as one of the main goals for FIRST early on in the process of definition and planning of the mission. We will argue that recent discoveries by pioneering observations with COBE, ISO and millimetric telescopes (Sections 2 and 3) are quite strenghtening this case. We will show in particular that, without the planned deep surveys with FIRST, our view of *the history of baryon transformations* will always be limited by a fundamental unknown, the - otherwise unmeasurable - bolometric energy output by distant sources.

Finally, we will discuss in Sect. 4 few topics where we expect maximum impact by FIRST's cosmological surveys, and mention some related more technical aspects. We assume $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$, and $H_0 = 65\ Km/s/Mpc$.

2. Cosmology at long wavelengths: recent facts

To put the future deep explorations by FIRST in the context, we summarize in this Section recent developments for cosmology from observations at long-wavelengths.

2.1. Discovery of the Cosmic IR Background

The detection of the Cosmic IR Background (CIRB) in the all-sky COBE maps provided the first evidence that important phases of galaxy evolution are observable in the far-IR. This allowed to measure for the first time the integrated emission of distant galaxies, in the form of an intense isotropic signal between 100 and 1000 μm. The original detection of the CIRB by Puget et al. (1996) has been later confirmed with independent analyses by various other groups using FIRAS on COBE (Fixsen et al. 1998), as well as data from the DIRBE experiment in three broad-band channels at $\lambda = 240$, 140 and 100 μm (Hauser et al. 1998, see Figure 1).

Altogether, adding to the observed integrated CIRB intensity between 100 and 1000 μm the presently unmeasurable fraction between 100 and 10 μm using the constraints summarized in Fig. 1 brings the total CIRB energy density between 7 and 1000 μm to the value: $\nu I(\nu)|_{FIR} \simeq 40\ 10^{-9}\ W/m^2/sr$. This flux is substantially larger than the integrated bolometric emission by distant galaxies between 0.1 and 7 μm (the "optical background", Madau & Pozzetti 2000): $\nu I(\nu)|_{opt} \simeq (17{\pm}3)\ 10^{-9}\ W/m^2/sr$. Consider that for local galaxies only 30% on average of the bolometric flux is re-processed by dust into the far-IR. *Then the CIRB's intensity exceeding the optical background suggests that galaxies in the past should have been much more "active" in the far-IR than in the optical, and very luminous in an absolute sense.*

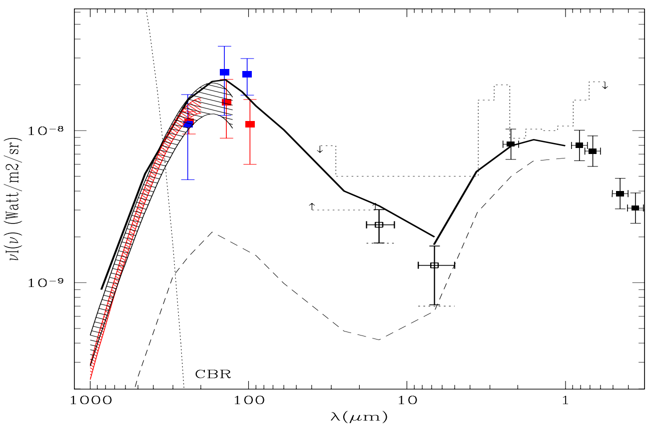

Figure 1. The Cosmic Infrared Background (CIRB) spectrum as measured in the all-sky COBE maps compared with estimates of the optical background based on ultradeep HST surveys (see text). The lower dashed line marks the expectation based on the assumption that the IR emissivity of galaxies does not change with cosmic time. The thick line is the predicted CIRB intensity by the presently discussed model for IR galaxy evolution. The upper limits marked by the dotted histogram come from determinations of the TeV cosmic opacity in MKN 501 (z=0.034) by Stanev & Franceschini (1998).

The expected level of emission by galaxies assuming that the local volume emissivity as observed by IRAS keeps constant back in cosmic time is marked by the dashed line in Fig. 1: while this no-evolution prediction gets close to explain the background from 1 to 7 μm, it falls short by a large factor to match the longer-wavelength background.

2.1.1. Constraints from Background Observations

Further insights can be obtained from the observed energy densities in the CIRB and optical backgrounds. These can be compared with the fraction f_* of the universal mass density in baryons Ω_b which has to be transformed at redshift z_*, assuming a radiative efficiency ϵ (Franceschini et al. 2001).

Let us assume that the optical/NIR BKG in Fig. 1 mostly originates by quiescent star-formation (SF) in spiral disks and by intermediate and low-mass stars. In such moderately active environments the stellar IMF should follow the Salpeter law with standard low-mass cutoff and $\epsilon \sim 0.001$. By transforming at redshift $z_* \sim 1.5$ a fraction $f_* \simeq 10\%$ of baryons into stars we get: $\nu I(\nu)|_{opt} \simeq 20\ 10^{-9} h^2_{50} \left(\frac{\Omega_b}{0.05}\right) \left(\frac{f_*}{0.1}\right) \left(\frac{2.5}{1+z_*}\right) \left(\frac{\epsilon}{0.001}\right)\ W/m^2/sr$. A local density in low-mass stars is generated in this way consistent with the observations, $\rho_b \simeq 3.4\ 10^8\ M_\odot/Mpc^3$, with a corresponding density in metals of $\rho_Z \simeq 7\ 10^6 M_\odot/Mpc^3$.

As for the CIRB background, since luminous starbursts emit a negligible fraction of the energy in the optical-UV and most of it in the far-IR, let us assume that it originates from dusty star-forming galaxies at median $z_* \simeq 1.5$. This process had to explain the huge energy content in the CIRB without exceeding the mass of stellar remnants in local galaxies. A solution could be to assume for the starburst phase a top-heavy IMF (e.g. a Salpeter distribution cutoff below $M_{min} = 2\ M_\odot$, with $\epsilon = 0.002$): $\nu I(\nu)|_{FIR} \simeq$

$$4\ 10^{-8} h^2_{50} \left(\frac{\Omega_b}{0.05}\right) \left(\frac{f_*}{0.1}\right) \left(\frac{2.5}{1+z_*}\right) \left(\frac{\epsilon}{0.002}\right)\ W/m^2/sr.$$

This requires that a similar amount of baryons, $f_* \simeq 10\%$ are processed with higher efficiency during the starbursting phases, producing a two times larger amount of energy and metals. Most of these metals have to be released by the galaxies into the diffuse cosmic media, as observed for example in the intracluster plasmas.

2.2. Surveys at millimetric wavelengths

The implementation of arrays of bolometers (SCUBA and MAMBO) on JCMT and IRAM has allowed to resolve $\sim 20\%$ of the CIRB background at 850 and 1200 μm into a population of faint distant, mostly high-z, sources (e.g. Eales et al. 2000). These very long-wavelength surveys offer a unique advantage to naturally generate volume-limited samples from flux-limited observations, due to the peculiar K-correction due to the shape of galaxy spectra $[L(\nu) \propto \nu^{3.5}]$. A sensitive sub-mm survey preferentially selects sources at very high redshifts, providing a direct picture of the high-redshift universe impossible to obtain at other frequencies. The extragalactic source counts show a dramatic departure from the Euclidean law $[dN \propto S^{-3}\, dS$ in the interval from 2 to 10 mJy], a clear signature of the strong evolution and high redshift of mm-selected sources.

2.3. Deep Explorations of the IR Sky with ISO

The Infrared Space Observatory has allowed to perform the first systematic exploration of the IR sky with sensitivities sufficient to detect sources at cosmological redshifts (Franceschini et al. 2001). In the mid-IR (12-18 μ, $\lambda_{eff} = 15\ \mu$), a variety of extragalactic surveys have been performed with thousands of sources detected over a large z-interval between 0 and 1.5 (Elbaz et al. 1999, Oliver et al. 2000).

In the far-IR, the most important survey project, FIRBACK, was carried out with ISOPHOT to detect at 170 μm the sources of the CIRB (roughly 200 detected, Dole et al. 2001). This survey is limited by extragalactic confusion in the large ISOPHOT beam (90 arcsec) to $S_{170} \geq$ 100 mJy.

3. Preliminary results on faint IR sources

3.1. Evidence for evolution

Deep counts at the various observed wavelengths (see Figs. 2 and 3) display significant departures from the no-evolution

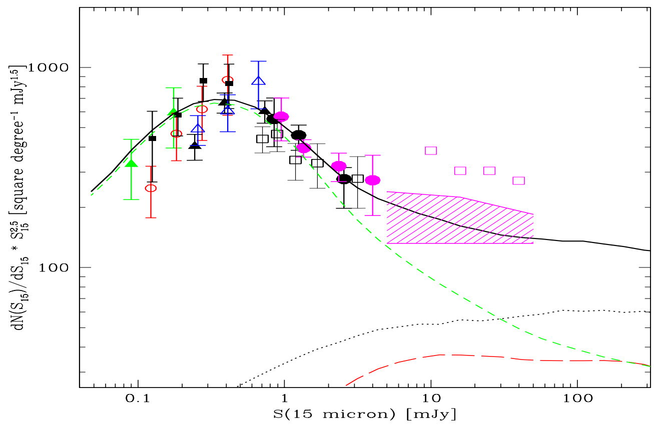

Figure 2. *Differential counts at $\lambda_{eff} = 15\ \mu m$, normalized to the Euclidean law $S^{-2.5}$ (see Elbaz et al. 1999).*

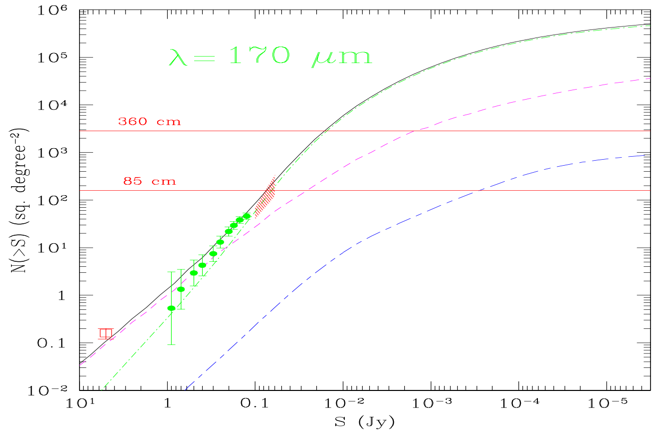

Figure 3. *Integral counts at $\lambda_{eff} = 170\ \mu m$. The line marked "360 cm" corresponds to the limit of confusion for deep FIRST observations ("85 cm" is for SIRTF). Our model predicts that the confusion limit stabilizes around $S \simeq 25\ mJy$ at $\lambda > 200\ \mu m$.*

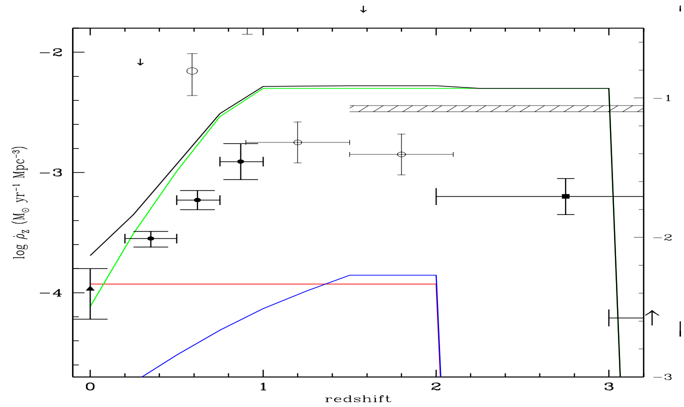

Figure 4. *Evolution of the metal production rates (left axis) and of the star formation rates (in $M_{\odot}/yr$, right axis) based on our best-fit model. Data points come from optical observations. From top to bottom, the lines are: total, starburst, quiescent population and AGNs. Note that these are purely modellistic predictions, while for their measure deep surveys by FIRST will be needed (see Sect. 4.2).*

expectations. The most detailed information on faint IR counts come from the ISO 15 μm surveys. The differential counts in Fig. 2 reveal various remarkable features, in particular a sudden upturn at $S_{15\mu} < 10\ mJy$, where the counts increase as $dN \propto S^{-3.1}dS$ (Elbaz et al. 1999). ISO has essentially reached the confusion limit at 15 μm, with an areal density of sources at the survey limits of $\sim$5 arcmin^{-2}.

The confusion limitation has obviously played a major role for all ISO far-IR surveys. However, some level of cosmological evolution for faint IR sources is revealed by deep surveys at 170 μm (Dole et al. 2001) and at 90 μm (Efstathiou et al. 2000).

The sudden upturn below a few mJy in the ISO differential counts at 15 μm in Fig. 3, in particular, require very fast evolution for at least a population of IR sources. Franceschini et al. (2001), among others, find that counts and z-distributions can be explained by assuming very fast increases of the comoving number density ($\rho(L[z], z) \propto [1 + z]^{4.2}$) and of the luminosity ($L(z) \propto [1 + z]^{3.8}$) for a population of active galaxies amounting to roughly 10% in number of the local galaxy population at 12 μm.

The evolution of the IR volume emissivity based on this model is reported in Figure 4. The contribution of IR-selected sources to the high-z luminosity density significantly exceeds those based on optically selected sources, and the excess may be progressive with redshift up to $z \simeq 1$. The rate of evolution for the IR volume emissivity of galaxies at $z < 1$ (top line) is even higher than that of optical/X-ray AGNs (bottom line). This fast evolution should turn over at $z_{break} \simeq 0.8$, with the comoving IR emissivity keeping flat above, to allow consistency with the observed z-distributions for faint ISOCAM sources and to fit the observed shape of the CIRB (thick line in Fig. 1, see also Gisper et al. 2000). Apparently, the galaxy activity sampled by long-λ observations is not confined to the very high-redshifts, as sometimes suggested, but shows a peak around $z \sim 1$.

Deep surveys at various IR/sub-mm wavelengths can be exploited to simultaneously constrain the evolution properties and broad-band spectra of faint IR sources. In particular, assuming for the IR evolving sources a typical starburst spectrum (like the one of M82) allows to reproduce most of the observed properties of IR galaxy samples and the CIRB spectrum. Best-fits to the counts based on our fiducial model and adopting a spectral template similar to the M82 spectrum are given in Figs. 2 and 3.

The good match to the multi-wavelength counts found by assuming a typical starburst spectrum for the evolving population *is an indication that the faint IR-selected pop-*

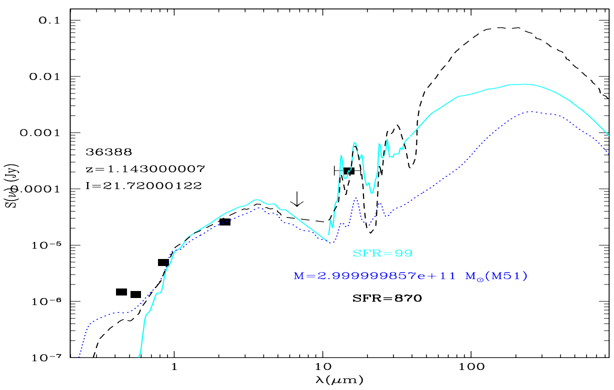

Figure 5. *Broad-band spectrum of a typical mid-IR source selected by ISOCAM at 15 μm in the HDFN, compared with the SED's of M82, Arp 220 and M51. Estimates of the SF rate and stellar mass are indicated.*

ulation is dominated by star-formation rather than AGN emission (the latter producing rather different IR spectra).

3.2. Properties of the IR Source Population

Because of the different K-corrections, faint sources selected by mm telescopes and by ISO display complementary properties as of redshift coverage (typically $z < 1$ for ISO and > 1 for SCUBA sources) and luminosities ($L_{bol} < 10^{12}\ L_{\odot}$ by ISO, larger by SCUBA). *SCUBA sources provided the first evidence of the existence of very luminous phases in the evolution of galaxies at high and very high redshifts.* Unfortunately, the poor spatial resolution of mm telescopes combined with the faintness of the optical counterparts implies that only a handful mm sources have been identified. The deep ISO mid-IR surveys provide various advantages when investigating the nature of the IR source populations: their optical counterparts are easy to identify bacause of the moderate redshift; they are responsible for a large fraction of the CIRB; catalogues of thousands ISO mid-IR sources are available.

The optical-IR SED of a typical faint 15 μm source at $z = 1.14$ is reported in Figure 5. The dotted line fitting the optical-NIR spectrum and corresponding to the SED of a quiescent spiral (M51) falls short by a factor ~ 10 of explaining the mid-IR emission, whereas SEDs of IR starbursts (e.g. Arp220 and M82) provide better fits. The vast majority of faint ISO sources show similar mid-IR flux excesses. The HST images indicate that a large fraction (30 to 50%) of the sources show evidence of morphological peculiarities and multiple structures (Aussel et al. 1999), in keeping with the local evidence that galaxy interactions trigger luminous IR starbursts. These sources are also typically found in galaxy groups (Cohen et al. 2000).

The baryonic masses in these objects have been estimated by fitting template SEDs of local galaxies to the observed near-IR spectrum (assuming a Salpeter IMF with $M_{low} = 0.15\ M_{\odot}$). The values found ($M \sim 10^{11}\ M_{\odot}$ at $z > 0.4$, with 1 dex typical spread) indicate that massive galaxies preferentially host these sources.

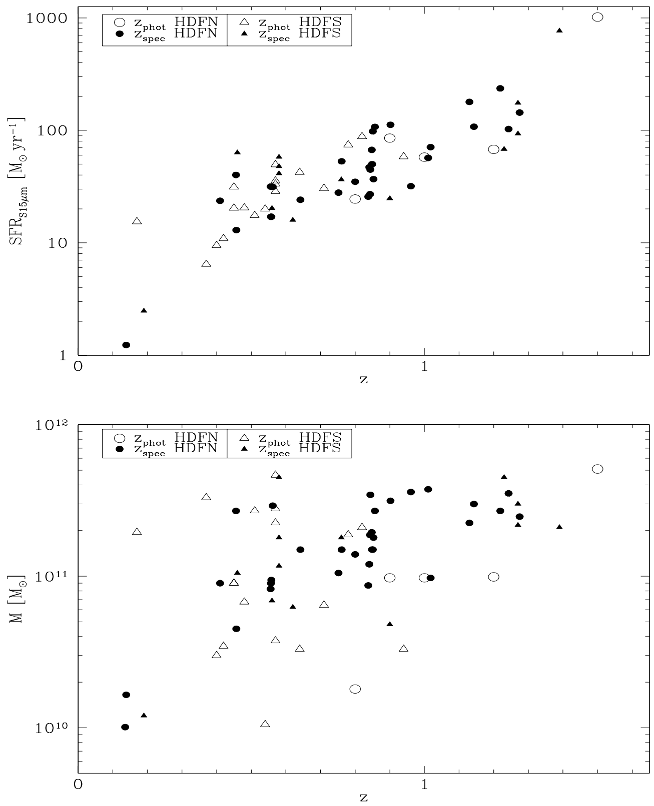

Figure 6. *Evaluations of the star formation rates [based on the mid-IR flux] and baryonic masses [from fits of the NIR SED] as a function of redshift for galaxies selected by ISOCAM at 15μm in the HDFs.*

A more serious problem was to estimate the other fundamental indicator of the evolutionary status of IR-selected sources, i.e. the rate of on-going star formation, SFR. The SFR is estimated in Fig. 6 using the mid-IR flux as a tracer of the bolometric (mostly far-IR) flux. SFR values for sources at $z > 0.5$ range from few tens to few hundreds solar masses/yr, i.e. a substantial factor larger than found for faint optically selected galaxies.

3.3. A summary of the present view

Pioneering observations at long wavelenths are providing a new, unexpected view of the universe. *(a)* The IR emissivity of galaxies has been much more strong on average in the past than it is presently. The long-sougth primeval galaxies are hidden by dust in the far-IR and millimeter. *(b)* The distant universe as observed at these long wavelenths appears as much more rich, complex and extreme than predicted based on classical UV-optical-NIR observations. While the latter tend to emphasize relatively quiescent phases of galaxy evolution, far-IR/mm observations are essential to investigate transient phases in galaxy evolution during which very active and efficient transformations of baryons (either through stellar formation or BH accretion) occur. *(c)* During these phases (likely triggered by galaxy dynamical interactions and merging) dominant fractions of the whole energetics are produced, as currently observable in the IR background.

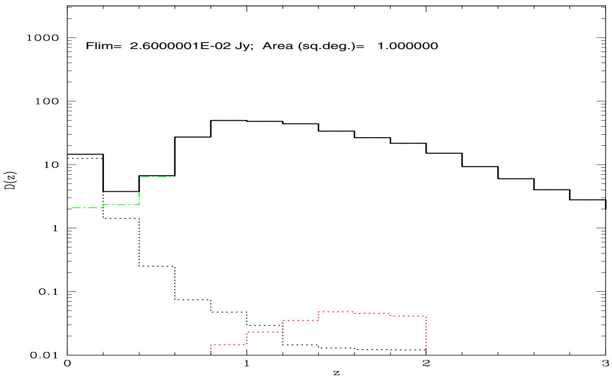

Figure 7. Distributions of redshifts for a flux-limited sample at 450 μm at the limit of confusion for FIRST.

4. Rationale for a cornerstone mission

These recent findings provide full justification and support to the variety of ground-based and space projects (SIRTF, ASTRO-F, SPST, FIRST, NGST, ALMA, among others) that will be dedicated during this decade and later to the systematic exploration and characterization of the universe at the long wavelengths.

In this context, the FIRST mission has its own specific motivation in the unique capability to measure the bolometric radiative output by cosmic sources – galaxies, quasars, AGNs – over wide redshift intervals, and to allow selection of active galaxies by their bolometric flux over large sky areas. For these reasons, deep cosmological surveys in empty sky regions were identified as one of the main goals for FIRST. We summarize in the following some fields in which we expect particular impact by the FIRST surveys.

4.1. Identifing the sources of the CIRB

Figure 3 illustrates the gain in sensitivity for deep surveys at 170 μm allowed by FIRST (the horizontal line marked "360 cm" is the limiting areal density achievable with FIRST) with respect to SIRTF (see line "85 cm"), due to the better spatial resolution and correspondingly lower confusion noise. This implies a substantial improvement in the capability to resolve the CIRB background into sources at its peak wavelengths, from the few % allowed by current instrumentation (ISO, SIRTF) to the roughly 50% resolvable at the confusion limits of FIRST. More specifically, we expect that above the limit of $S_{170\mu} \simeq 20\ mJy$ (see Fig. 3) 25% of the CIRB would be resolved, while above $S_{90\mu} \simeq 2\ mJy$ the resolved fraction would be 55%.

Better sensitivities mean that FIRST will be capable to detect cosmic sources up to very high redshifts, with a favourable coverage of the high-z side: of order of 2/3 of the sources selected in the long-wavelength channel at 450 μm of the SPIRE bolometer array camera are expected to be at $z > 1$ (see Figure 7). The large sky areas that SPIRE will cover with these sentitivities will allow to quantify the clustering properties of sources as a function of z.

An improved spatial resolution will also allow to keep the source positional uncertainty to a minimum, an essential requisite to identify the faint optical counterparts to the high-z sources. To this end, however, only data at shorter far-IR wavelengths by PACS (60 to 180 μm) will allow to get the limiting resolution $FWHM \leq 5$", needed for reliable identifications.

To some extent, the far-IR source SED's determined by FIRST will guide a photometric estimate of the redshift independent of the optical spectroscopic measure. The dependence on z of the far-IR colours is illustrated in Figure 8. As shown in the figure, however, any sensible estimates would require combining the long-λ SPIRE photometry with data at shorter wavelengths by PACS, to extend the dynamic range in λ far enough to get rid of the degeneracies due to intrinsic SED's source-to-source variations.

All this points to the need to have the same areas observed by both FIRST imaging cameras, SPIRE and PACS, to achieve the best scientific exploitation of the data. Scheduling for such combined observations will be extremely challenging, however, if we consider the very different characteristic integration times and field-of-views of SPIRE and PACS.

4.2. Evaluating the star-formation activity

As anticipated, one of the main features of the FIRST surveys will be to allow selection of cosmic sources by their bolometric emission. This will be the primary way to detect the active phases during the past galaxy evolution. Once these high-z sources will be identified and their cosmic distance measured, the knowledge of the far-IR SED will allow an, otherwise impossible, measure of the bolometric luminosity. This quantity is critical to evaluate the ongoing rate of star-formation SFR, which is the ultimate unknown currently preventing reliable estimates of the evolutionary history of formation of stellar populations in galaxies.

A lively debate is currently taking place about the capabilities of UV-optical observations to recover by themselves the past and present star-formation, based on suitable corrections for dust extinction in the optical spectra. For example, Adelberger et al. (2000) suggest that the observed 850 μm galaxy counts and the background could be

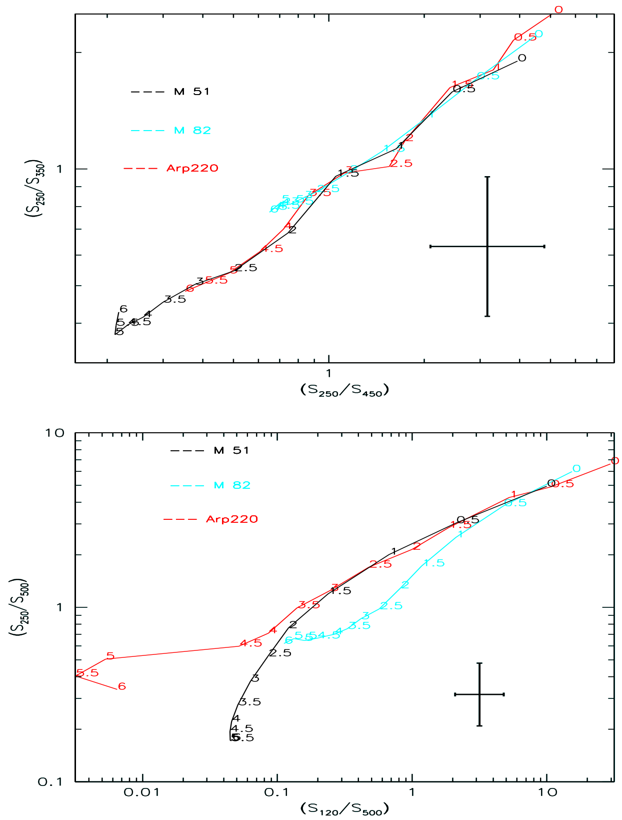

Figure 8. Predicted far-IR colour-colour plots for FIRST-selected sources as a function of redshift (the numbers associated to each line). The three lines correspond to the three templates: Arp 220 (red), M82 (cyan), M51 (black) [note that the most variant SED is that of Arp 220]. The top panel shows colours based on the SPIRE photometry only, while the bottom colours combining SPIRE and PACS observations. The typical photometric errors are indicated.

explained with the optical Lyman drop-out high-z population by applying proportionality corrections to the optical fluxes and by taking into account the locally observed distribution of mm-to-optical flux ratios.

However, a variety of facts indicate that optically selected and IR/mm-selected faint high-redshift sources form almost completely disjoint samples. Chapman et al. (2000) observed with SCUBA a subset of $z \simeq 3$ Lyman-break galaxies having the highest predicted rates of SF as inferred from the optical spectrum, but detected only one object out of ten. Van Der Werf et al. (2000) fail to detect with SCUBA two strongly lensed Lyman-break galaxies selected with the same technique. A similar dichotomy is observed in the local universe, where the bolometric flux by luminous IR galaxies is mostly unrelated with the optical emission spectrum (Sanders & Mirabel 1996).

Poggianti & Wu (2000), Poggianti, Bressan & Franceschini (2001) and Rigopoulou et al. (2000) have investigated in a systematic way the optical and far-IR properties of luminous and ultra-luminous starbursts, using local

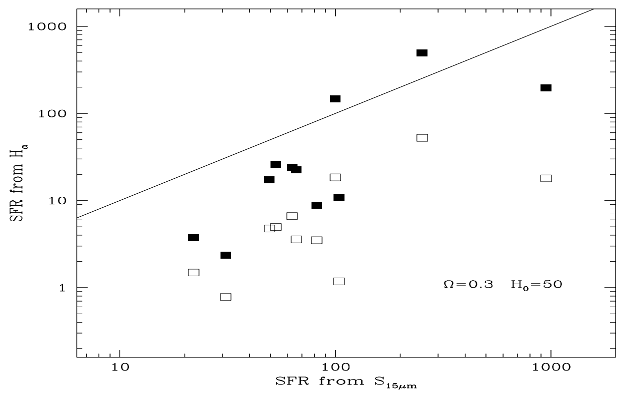

Figure 9. SF rates estimated from the H_α line flux compared with the values based on the mid-IR flux. Open squares: SFR uncorrected for extinction; filled squares: SFR from extinction-corrected H_α flux.

IRAS samples and faint high-z sources detected by ISO in the HDFS. Rigopoulou et al. (2000), in particular, have compared the H_α line fluxes as a measure of the rate of ongoing star-formation with estimates based on the ISO far-IR flux (see Sect. 3.2 and Fig. 6): the results of this analysis are reported in Figure 9. As shown here, *even after correcting for extinction, the H_α flux turns out to explain only $\sim 20-30\%$ on average of the bolometric far-IR emission: the bulk of SF in luminous IR galaxies is unobservable in the optical.* This is quite consistent with the results obtained by Poggianti and Wu (2000) on a local sample of very luminous IR galaxies. Poggianti et al. (2000) interprete the optical spectra of luminous and ultra-luminous IR galaxies (ULIRG) as due to selective dust attenuation, where newly-formed stars spend most of their life embedded into optically thick molecular clouds, while older stars, having already disrupted their parent cloud, suffer less extinction.

Altogether, *independent evidence on both local and high-z luminous starbursts indicates that typically 70% to 80% of the bolometric flux from young stars leaves no traces in the UV-optical spectrum, because it is completely obscured by dust.* As there seems to be no robust "a priory" way to correct for this missing energy, we conclude that only an accurate determinations of the IR SED's can eventually allow to *measure* SF in galaxies at any redshifts. This is precisely what the FIRST surveys are aimed to do for thousands of faint IR-selected sources. Combined with optical/NIR spectral information, this will provide the most precise determination of the history of SF in galaxies, to put datapoints on top of the modellistic expectations in Fig. 4.

4.3. The origin of spheroidal galaxies

The origin of ellipticals, S0s, and the massive bulges in spirals remained for long time a problem, since the luminous starbursts, expected to happen during the merging and violent relaxation processes producing them, were never detected by deep optical surveys. The recent long-wavelength observations summarized in previous Sects. have drastically changed our perspective of the subject. The galaxy populations dominating the faint ISO and SCUBA counts and significantly contributing to the bolometric CIRB intensity appear to be composed of luminous ($L_{bol} \sim 10^{11}$ to 10^{13} $L_{\odot}$) starbursts in massive ($M \sim 10^{11}$ $M_{\odot}$) galaxies over a large z interval, observed during phases of intense stellar formation ($SFR \sim$ few tens $M_{\odot}/yr$ up to 1000 $M_{\odot}/yr$ or even more). The typically red colors of these systems suggest that they are mostly unrelated to the blue galaxy population dominating the optical counts (Ellis 1997), and should be considered as an independent manifestation of (optically hidden) star formation.

Most obviously, this intense stellar activity is likely releated with the assembly of galaxy spheroids in groups and in the field. In particular, the similarity in properties between the high-z SCUBA sources and local ultra-luminous IR galaxies argues in favour of the idea that these represent the long-sought "primeval galaxies", those in particular originating the local massive elliptical and S0 galaxies. This is also supported by estimates of the source volume density, consistent with that of local E/S0's (Lilly et al. 1999). By continuity, the less extreme starbursts ($L \sim 10^{11} - 10^{12}$ $L_{\odot}$) discovered by ISO at lower z are possibly related with the origin of lower mass spheroids in spirals. The large area surveys by FIRST are expected to discover a number of these forming spheroids, allowing to set this issue on a firm statistical ground and to investigate the dependences of the phenomenon on the environment.

4.4. The onset of quasar activity

High spatial resolution spectroscopy by HST has established that super-massive dark objects (likely black holes, BH) exist in virtually all spheroidal galaxies, with a remarkable proportionality between the BH and spheroid mass (Kormendy & Richstone 1995). The obvious expectation, following our present understanding of the quasar activity, is that these massive BH's are the remnants of past quasar phenomena occurring in most galaxies. A close relationship between the origin of the spheroid and that of the super-massive BH is then indicated by these observations. Further support comes from the evidence based on hard X-ray observations that many (possibly the majority) of ULIRG's contain hidden AGN's, producing minor contributions to the global energetics but very prominent in hard X-rays. Very likely, AGN and starburst activities happen concomitantly in these objects, the quasar phase being either anticipated or paralleled by a dusty starburst phase observable at long wavelengths. It is equally plausible that, assuming some kind of proportionality between the bolometric and hard X-ray flux and in consideration of the strong observed cosmological evolution observed for luminous and ultra-luminous IR galaxies, both the CIRB and X-ray backgrounds are synthesized by the same source population.

This population will be very extensively targetted by FIRST. The data on the IR SED's of these high-z sources, on one side, and the high spectral resolution spectroscopic follow-up by FIRST between 60 and 300 μm, on the other, will allow important diagnostic tools to disentangle between a gravitational from a stellar nucleosynthetic origin of the emissions.

5. Conclusions

Though being a relatively old concept requiring a long preparatory and development phase, the FIRST Observatory maintains unaltered its uniqueness in the context of the worldwide astronomy projects of this decade, as far as its capabilities to survey for faint emissions by dust in high-redshift structures over vast sky areas are considered. This complementary long-wavelength view of the high-redshift universe is needed, in addition to the faint optical data, for an exhaustive and reliable description of the history of baryon cycle in the universe.

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