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MODEL PREDICTIONS FOR DEEP COSMOLOGICAL SURVEYS WITH *SPICA-SAFARI*

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Abstract

We use a new backward evolution model to make predictions for the cosmological surveys in the far-infrared to be conducted by the *SAFARI* instrument on board of *SPICA*. The model, which is able to reproduce all the main constraints provided by *ISO* and *Spitzer* (source counts, redshift and luminosity distributions), considers different evolutionary properties for four IR populations, defined through a detailed SED-fitting analysis. The fraction of sources with identified AGN signature (∼50%) is higher than in other models available in the literature, but is consistent with very recent *Spitzer* results. We discuss the extragalactic surveys that could be carried on for different scientific purposes (i.e. confusion limited, large and shallow) in the bands covered by *SAFARI*.

Key words: Cosmology: observations – Galaxies: evolution – Galaxies: luminosity function – Infrared: galaxies – Missions: SPICA

1. Introduction

In the past years strong observational evidence of high rates of evolution for IR galaxies has been obtained by means of two independent findings: the detection of a large amount of energy contained in the cosmic infrared background (CIRB, Hauser & Dwek 2001), and the number counts from several deep cosmological surveys (from 15 μm to 850 μm) largely exceeding the no-evolution expectations. Both results agree in requiring a strong increase in the IR energy density between the present time and $z\sim1$–2. The availability of new space facilities in the coming years, such as *Herschel*, *JWST* and further *SPICA*, opens new perspective to study in detail the population of IR galaxies beyond $z=1$, requiring new models to explain the high rate of evolution observed at lower redshifts. Two main weaknesses exist in the current models for IR sources: 1) the failure in reproducing the observed redshift distributions; 2) the severe underestimate of the AGN contribution. Any new models should take into account that IR galaxies can host both star-formation (SF) and AGN activity (i.e. Lutz et al., 1998) and that in the far-infrared (FIR) even the emission from Seyferts and Quasars is dominated by SF (Schweitzer et al., 2006). We can no longer neglect the AGN contribution in the modelling and interpretation of IR data, but rather should understand and quantify the AGN presence within IR galaxies and its connection with SF activity. In particular, the key cosmological question that needs to be answered by models and by future observations regards the role of AGN in galaxy formation and evolution. The discovery that all massive galaxies in the local Universe harbour super-massive black holes (SMBH) implies that all massive galaxies have hosted an AGN at some time during their life (i.e. Magorrian 1998). Recent work in the X-rays, optical and mid-infrared (MIR) has shown that many heavily obscured AGNs escape even the deepest optical and X-ray observations, but, as expected from their high level of obscuration, reveal themselves in the IR (i.e. Fiore et al., 2008). When planning future IR surveys with new facilities it is therefore necessary to consider models that properly account for the presence of AGNs within a significant fraction of the IR population, in order to answer open questions about galaxy formation and evolution. Here we present the predictions for future Surveys with *SPICA-SAFARI* obtained with a new backward evolution model (Gruppioni &Pozzi 2009, in preparation), considering four different IR populations (including obscured and unobscured AGNs) and fitting all the observational constraints provided by the MIR surveys over a broad redshift and luminosity range.

2. The Model

The model is based on the classical approach of evolving a local luminosity function with redshift, and considers four distinct populations of IR sources with different evolving properties. The model parameters are constrained by all the MIR observables (source counts, redshift and luminosity distributions). The relative fractions of sources within the different classes are defined on the basis of a detailed broad-band SED-fitting analysis performed on a large sample of MIR selected sources, all with spectroscopic redshift and classification (Gruppioni et al. 2008). Based on the SED-fitting technique we have classified the MIR sources, identifying AGN signatures in about 50% of them. This fraction is significantly higher than that derived from optical spectroscopy (∼29%), particularly because of the identification of AGN activity in objects spectroscopically classified as galaxies. This might be in

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part due to the fact that the spectroscopic classification can be somewhat unreliable because of host galaxy dilution in the optical. It is more likely that in most of these objects, the AGN is either obscured or of low-luminosity, and thus it does not dominate the energetic output at any wavelength, except in the MIR, showing up just in the range where the host galaxy SED has a minimum. Similar AGN fractions have recently been found in IR surveys of local samples and through different identification techniques (e.g. Goulding & Alexander 2009).

2.1. The Infrared Populations

The four populations considered in the model are: galaxies (from Sb spiral to extreme starburst, like Arp 220), composite AGN+starburst (like Markarian 231), type 2 AGN (Seyfert 2/Seyfert 1.8), type 1 AGN (QSO). For the galaxy population we have assumed a SED evolving with luminosity from a Sb spiral ($L_{15\mu m}<10^9$ $L_\odot$) to a Sdm spiral ($L_{15\mu m}\simeq10^9$ $L_\odot$), to a moderate starburst galaxy (NGC6090, $L_{15\mu m}\simeq10^{10}$ $L_\odot$), up to an extreme one (Arp220, $L_{15\mu m}>10^{11}$ $L_\odot$), with fine interpolations between these known templates. All the template SEDs used for the SED-fitting analysis are from the IR library of Polletta et al., (2007). Different evolutionary paths have been considered for the four populations: for the galaxy, composite and type 2 AGN populations both luminosity and density evolution are required in order to fit the observables, while for the type 1 AGNs just luminosity evolution is needed, not density. The shape of the evolution function considered here is not the commonly used $(1+z)^k$ with a z_{break}, but a smoother function that peaks at a given redshift and descendd to zero towards the high redshifts, with different peaks and decreasing/increasing skew rates for the different populations. The agreement between the model and all available observational constraints from MIR surveys is always very good, as shown in Figures 1 and 2: the model is able to reproduce well the observed source counts, as well as the z (and L) distributions at both 15 and 24 μm. In the FIR the model is complemented by a physical treatment of the early evolution of spheroidal galaxies, when they formed most of their stars in a dusty environment (Negrello et al. 2007).

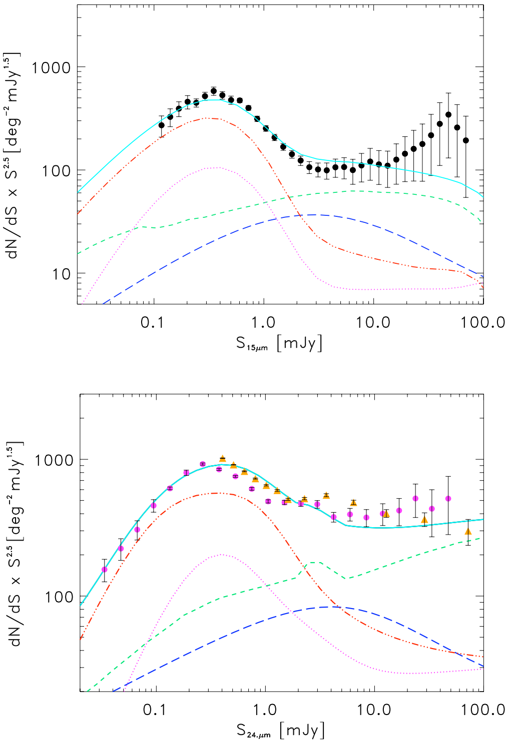

Figure 1. Observed ISOCAM 15-μm (top panel) and MIPS 24-μm (bottom panel) differential source counts normalised to Euclidean. Several surveys data have been compared to model predictions (15 μm: Elbaz et al., 1999, Gruppioni et al., 2002, + others; 24-μm: Papovich et al., 2004; Shupe et al., 2008). The different coloured lines represent the different populations' contributions (cyan solid: total; green dashed: galaxies; magenta dotted: composite; red dot-dot-dot-dashed: AGN2; blue long-dashed: AGN1).

3. Predictions for the SAFARI Surveys

We have used the model described above to estimate what we expect for surveys to be performed with the *SAFARI* instrument on board of *SPICA*. For each observing band (35–60, 60–110 and 110–210 μm) we have computed the expected confusion limits, source counts, redshift distributions, luminosity functions and total infrared luminosity as a function of z and limiting flux. The estimated confusion limits obtained with our evolution model (computed as the flux density above which both the photometric criterion – i.e. sources must be brighter than 5 times the rms due to very faint sources below the detection limit – and the source density criterion – i.e. less than 30% of the sources closer than 0.8×FWHM – are respected, see Dole et al., 2006) are ∼0.01, 0.15 and 3–5 mJy at the centre of the 35–60, 60–110 and 110–210-μm bands respectively. The deep surveys that will be performed with *SAFARI* in the 60–110 and 110–210 μm bands will easily reach these confusion limits. In particular, given the nominal field of view of *SAFARI* of $2'\times2'$, at 60–110 μm it will be possibile to observe down to confusion a field as large as GOODS ($\sim10'\times15'$) in just 20 minutes and a COSMOS-like field (2 deg^2) in ∼13 hours (not considering the overheads). On the other hand, in the 35–60 μm band we would need about 45 hours to cover one GOODS field and ≥400 hours for a larger field like COSMOS. These confusion limited surveys with SAFARI will be >10× deeper than the deepest *Herschel* GT survey (i.e. PEP to 1.6 mJy at 110 μm in the GOODS-S) and cover an area ∼3–150× larger than the ultradeep *Herschel* OT survey (GOODS 110 μm Survey to ∼0.6 mJy in 42 arcmin^2), detecting hundreds of

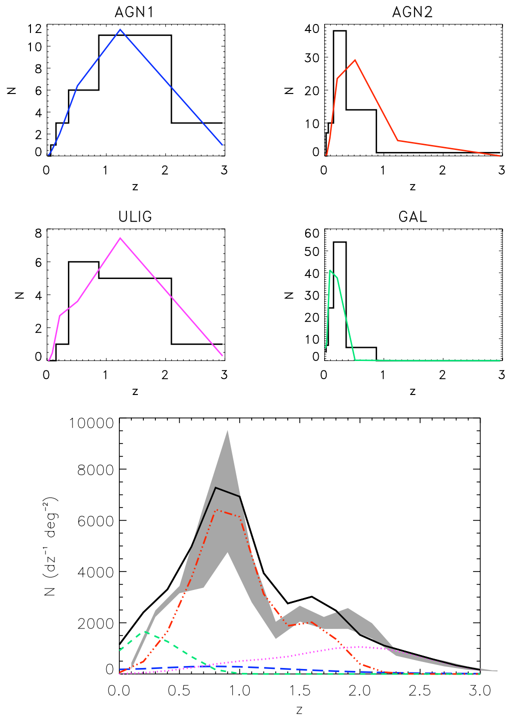

Figure 2. Upper four panels: observed redshift distributions at 15-μm to ∼0.5 mJy (Gruppioni et al., 2008: black histograms), compared to the model results (coloured lines as in fig. 1). Lower panel: redshift distribution of the 24-μm sources (total model distribution: black line) compared to data ($S_{24\mu m}$ >0.15 mJy in COSMOS; Le Floch et al., 2009: grey shaded).

L_{IR}<$10^{10}L_{\odot}$ galaxies at $z\leq1$ and few hundreds of LIGs at $z\sim2$ in a GOODS-like field. In addition, a confusion-limited 35–60 μm survey will detect also of the order of 100 AGN (with $L_{IR}\geq10^{11}L_{\odot}$) at $z>3$. A survey at 110–210 μm will be limited by confusion very quickly: this band is therefore more suited for large and moderately shallow surveys to detect rare and luminous objects. Source counts have been simulated in the 60–110 μm and 110–210 μm bands and compared to the *MIPS* observed data counts at 70 and 160 μm, as shown in Figure 3. While for the 70-μm source counts the agreement between data and model is surprisingly good, at 160 μm the model expectations are lower than observed at $S\lesssim150$–200 mJy. This could be due either to the presence of a cold galaxy population not accounted for in our model, whose contribution is negligible at wavelengths shorter than 160 μm, but could significant at longer wavelengths, or to an evolution in the galaxy and/or AGN SEDs as a function of redshift. The first possibility could be connected to the fact that in our model we do not consider any contribution from elliptical galaxies: their contribution in the MIR is totally negligible, but becomes dominant as we move towards shorter wavelengths (i.e. IRAC and NIR bands). In the galaxy formation and evolution framework there is now a general consensus on a global picture for elliptical/spheroidal galaxy and SMBH formation and co-evolution. According to this picture, SF and accretion represent connected phases in the history of galaxy and SMBH evolution, where most of the SMBH growth phase is hidden by large quantities of dust, causing a huge UV/optical extinction. In this heavily obscured phase, we expect substantial contributions to the FIR/sub-mm emission from both the starburst and the AGN (i.e. Granato et al., 2004). These obscured spheroids at high redshift should then become the elliptical galaxies that we observe at lower redshifts and in the local Universe. If we add the contribution from the speroidal phase at high redshift (as provided by Negrello et al., 2007) to our model predictions at 160 μm, we obtain a very good fit to the observed data counts, as shown in the *lower panel* of Figure 3. It is therefore likely that the discrepancy between the observations and our model expectations are due to the lack of a high-z spheroidal population in our model, the contribution from which is expected to become dominant at the longer wavelengths (i.e. making up most of the observed counts at 850 μm).

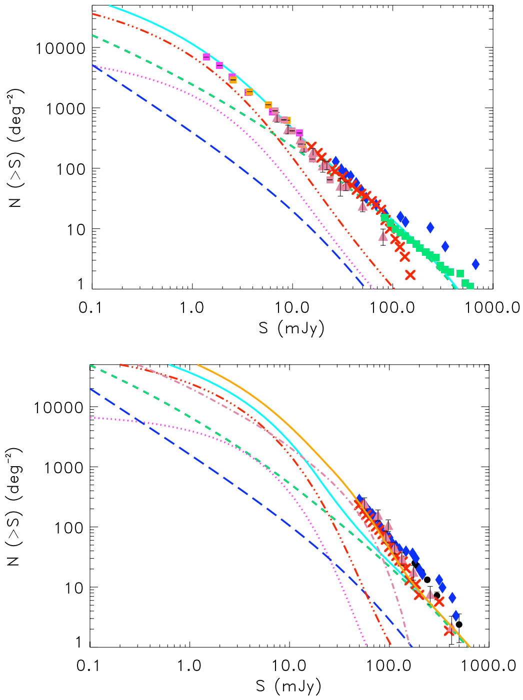

Figure 3. Integral source counts in the 60–110 (top panel) and 110–210 μm bands (bottom panel). The model results are compared to MIPS data from the COSMOS (Frayer et al., 2009), GOODS-N (Frayer et al., 2006a), FLS (Frayer et al., 2006b), Marano, CDFS and Bootes Surveys (Dole et al., 2004) at 70 μm and from the COSMOS (Frayer et al., 2009), Marano, CDFS (Dole et al., 2004) and FIRBACK Surveys (Dole et al., 2001) at 160 μm. Colours for model components are the same as in the previous figures. Bottom panel: additional spheroidal contribution (Negrello et al., 2007): pink dot-dashed line; total counts (including this component): orange line.

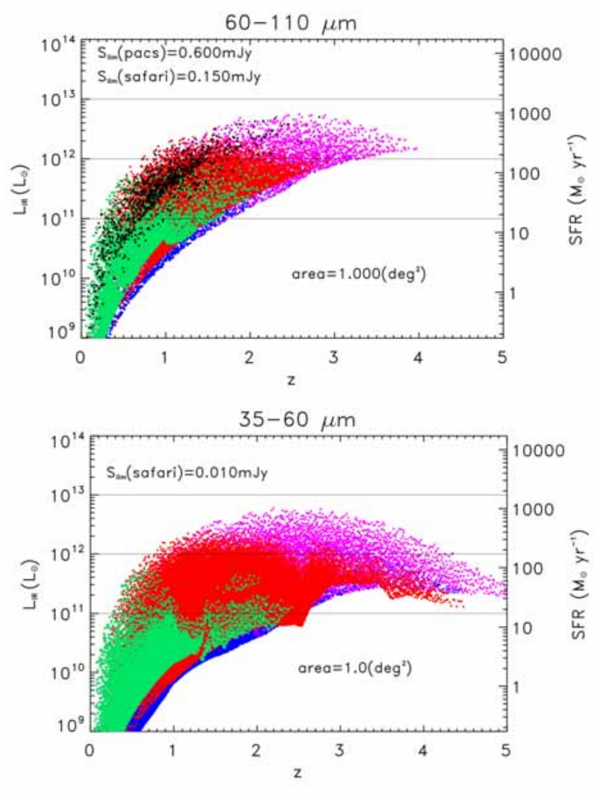

Figure 4. Luminosity-redshift distribution of IR galaxies that will be detected by SAFARI in a 1 deg^2 survey down to the confusion limit at 60–110 μm (top) and 35–60 μm (bottom). Different colours represent the different populations (as in the previous figures). In the top panel the L_{IR} vs. z distribution for the deepest surveys to be performed with Herschel/PACS (i.e. PEP and OT GOODS) is shown by the black dots.

We have used our model to make simulations of what we will observe in terms of total IR luminosity (L_{IR}: 8–1000 μm) versus redshift with *SAFARI* in a confusion-limited 1 deg^2 survey at 35–60 and 60–110 μm. The results of these simulations are shown in Figure 4. While in the 60–110 μm band (matching the peak of SF in galaxies with no or very little AGN contamination) *SAFARI* will be sensitive to many SF galaxies as quiescent as our own ($L_{IR}<10^{10}L_\odot$) out to $z\sim1$, providing the best measurement of SFR in galaxies up to $z\sim3$, in the 35–60 μm band it would be possible to detect large numbers of AGN at high redshift (up to $z\sim5$). In particular, in this band it will be possible to observe moderate luminosity AGNs ($L_{IR}\sim10^{11}L_\odot$) at z∼3–5. This is at exactly the redshift range where the MIR rest-frame, crucial for distinguishing between AGN and SF-dominated sources through a SED-fitting analysis, is shifted into the 35–60 μm band. Thus, a deep survey in the shorter wavelength band of *SAFARI* will be crucial for detecting significant numbers of relatively low luminosity AGN at very high z, and for disentangling the AGN from the starburst contribution.

4. Discussion and Conclusions

A 60–110 μm confusion-limited survey will provide the best measurement of the SFR in distant galaxies, without being affected by e.g. PAH or AGN contamination (also the AGN SEDs are dominated by SF at any redshift in this range) and will resolve >90% of the CIRB. But a deep survey in this band will not be enough to complete the census on the growth of SMBHs by probing the missing population of dust-obscured AGNs responsible for the unresolved peak of the X-ray background. These AGNs are missed by the deepest X-ray surveys, yet reveal themselves in the MIR (as expected from their high level of obscuration), being identified through their infrared signature, which is reprocessed UV emission from the AGN itself. *Spitzer* MIR surveys have been key to complementing X-ray surveys, in identifying sizable samples of obscured AGN at $z < 3$ through the 9.7μm silicate absorption. The combination of the silicate absorption feature, the PAH features and the broad-band contribution from the warm, dusty tori can be used to disentangle the AGN from starburst populations at redshifts $z > 3$ through photometry in the 35–60 μm band. This applies both at high and low L_{IR}. A survey down to a limit of ∼10 μJy would be sensitive to $L_{IR}\sim10^{11}L_\odot$ Seyfert 2/Markarian 231–like sources out to $z\sim5$ (see Figure 4), in particular in the $3\leq z\leq5$ range, where the co-evolution of SF and accretion activity is expected to be already in place. Thus, a deep *SAFARI* survey in the 35-60 μm band will provide a unique means by which to disentangle co-evolving AGN and SF activity in the very distant universe, and would complete the census of accreting SMBH at $z>3$.

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References

Dole, H. et al. 2001, A&A 372, 364
Dole, H. et al. 2004, ApJS 154, 87
Dole, H. et al. 2006, A&A 451, 417
Elbaz, D. et al. 1999, A&A 351, L37
Fiore, F. et al. 2008, ApJ 672, 94
Frayer, D. et al. 2006a, AJ 131, 250
Frayer, D. et al. 2006b, ApJ 647, L9
Frayer, D. et al. 2009, AJ, submitted
Goulding, A., & Alexander, D. 2009, MNRAS, in press
Granato, G.L et al. 2004, ApJ 600, 580
Gruppioni. C. et al. 2002, MNRAS 335, 831
Gruppioni, C. et al. 2008, ApJ 684, 136
Hauser, M.G. & Dwek, E. 2001, ARA&A 39, 249
Le Floch, E. et al. 2009, ApJ, 703, 222
Lutz, D. et al. 1998, ApJ 505, L103
Magorrian, J. et al. 1998, AJ 115, 2285
Negrello, M. et al. 2007, MNRAS 377, 1557
Papovich, C., et al. 2004, ApJS 154, 70
Schweitzer, M. et al. 2006, ApJ 649, 79
Shupe, D.L., et al. 2008, AJ 135, 1050