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ULTRALUMINOUS DISTANT ELLIPTICALS REVEALED IN $ISO + SPITZER$ SURVEYS

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Abstract

The galaxy populations discovered in the deepest UV-optical and infrared surveys appear so different that the basic physics of galaxy evolution is still debated. In Rocca-Volmerange et al., 2007 (hereafter RVLS2007), we proposed an interpretation of the deepest mid-IR faint galaxy counts in accordance with the already-published UV-optical-NIR count analysis (Fioc & Rocca-Volmerange, 1999).

The main constraint is to reproduce the galaxy number excess observed at 12 μm in the ISO-ESO-Sculptor Survey (Seymour et al., 2007) as at 15 μm and 24 μm in other ISO and $SPITZER$ surveys. The originality of the analysis is to follow continuously the evolution of stellar and dust emissions from UV to infrared as a function of galaxy type. We use the new version of our evolutionary code PÉGASE.3, extended to dust emission. Evolving UV to IR SEDs allow to compute robust k- and e- (evolution) corrections for all z and types to predict high z luminosities.

We find that the fractions by galaxy types from the optical counts are all detected in the mid-IR counts, with the exception of a minor fraction of ellipticals ($<$ 10% of all galaxies) which appear ultra-bright and dusty. The differential brigthness excess (-2.5 mag at 12 μm, -5 at 24 μm) confirms the presence of dust, while the bump is explained by strong redshifted stellar emission of ellipticals (k+e corrections). The model is valid at 12 μm, 15 μm and 24 μm. It does not need any redshift-dependent starbursts. No number density evolution is included in our models. These ULIRGs are massive evolved galaxies formed at early epochs and likely hosts of AGNs. They will be essential targets for the future telescopes SPICA, HERSCHEL and ALMA.

Key words: Galaxies: evolution, faint counts, infrared – Cosmology – Missions: SPICA, ISO, SPITZER

1. Introduction

The impressive number of multi-wavelength deep surveys is the most efficient way to solve the main keys of galaxy evolution. But the present results appear contradictory. From the optical, faint galaxy count (down to the B=29 HDF-North (Williams et al., 1996)) are dominated at the highest redshifts by massive ellipticals. This is confirmed by the bulk of star formation associated with the massive ($10^{12} M_{\odot}$) ellipticals hosting the z>4 radio galaxies (Rocca-Volmerange et al., 2004). From the infrared, faint counts detected by deep surveys with ISO and $SPITZER$ satellites, are mostly interpreted as ad-hoc huge starbursts that are supposed to be induced by hierarchical mergers and/or massive spiral disks, respectively called ULIRGs and LIRGs (see Caputi et al., 2008 and references therein). Ellipticals appear as a minor population, hardly detected by infrared satellites, due to their gas-dust deficiency (Xilouris et al., 2004). Whatever the sources of luminosity (respectively stars and dust), mass and star histories ruling the metallicity and dust emission as well as the main parameters of galaxy evolution (time-scales of mass accumulation, cooling/heating, AGN feedback) must be fundamentally coherent for all types. For these reasons, we propose to interpret mid-infrared number counts by using the 8 evolution scenarios defined in the optical with the help of the code PÉGASE.2 (http://www.iap.fr/pegase). The scenario parameters by types (star formation rate, galactic winds and accretion) are fitted on colors and spectra of nearby galaxies (Fioc & Rocca-Volmerange, 1997) as well as accurate photometric redshifts at z>2 (Le Borgne & Rocca-Volmerange, 2002).

- The fractions by types of galaxy populations were found from the UV-optical-nearIR faint counts by Fioc & Rocca-Volmerange, 1999.
- We recently extended the PÉGASE models by types to the infrared, including the dust emission coherently with stellar emission (Fioc, Dwek & Rocca-Volmerange, in prep.). SEDs include the redshifted mid-IR (12 μm, 15 μm and 24 μm) and may be used to interpret mid-IR counts.
- We compute galaxy counts in the mid-IR by adopting the number fractions and scenarios defined in the optical. Cosmology is standard. To reproduce the typical excess at $\simeq$0.3 mJy of the galaxy number density observed at 12 μm, 15 μm and 24 μm (Papovich et al., 2004), we need the change of normal by more luminous ellipticals. Because our elliptical scenario is characterized by a very-short time scale of mass accumulation and a bulk of star formation within 1 Gyr starting at

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z=10 (see Fig. 3a in Rocca-Volmerange, 2004), this result has implications on galaxy formation models.

2. The mid-IR galaxy count excess

A new ISOCAM deep survey ISO-ESS through the large filter LW10 (similar to the 12 μm IRAS filter) has been observed on the ESO-Sculptor area (Seymour et al., 2007). This field takes advantage of a redshift survey and a deep BVR photometry (de Lapparent et al., 2003 and references therein). Due to these optical-IR observations on the same area and to the 12 μm IRAS calibration, the ISO-ESS flux calibration and optical-infrared colors of the field galaxies are robust. The survey results show a steep slope in cumulative galaxy counts and a typical excess at $\sim$0.3 mJy of differential counts (compared to Euclidean predictions) (Fig.1). Our results are compatible with those from the comparably deep 15 μm GTO surveys in the areas of ELAIS, the LOCKMAN HOLE and the MARANO FIELD by Aussel et al., 1999, Elbaz et al., 1999, Flores et al., 1999, Altieri et al., 1999, Oliver et al., 2002, Sato et al., 2003 (see all references in RVLS2007). A SPITZER/MIPS (24 μm) survey (Papovich et al., 2004) also shows the steep slope of cumulative galaxy counts and a typical excess at 0.3 mJy of differential counts (compared to Euclidean predictions). Surprisingly, faint galaxy counts from the 175 μm FIRBACK survey (Puget et al., 1999) does not show such an excess.

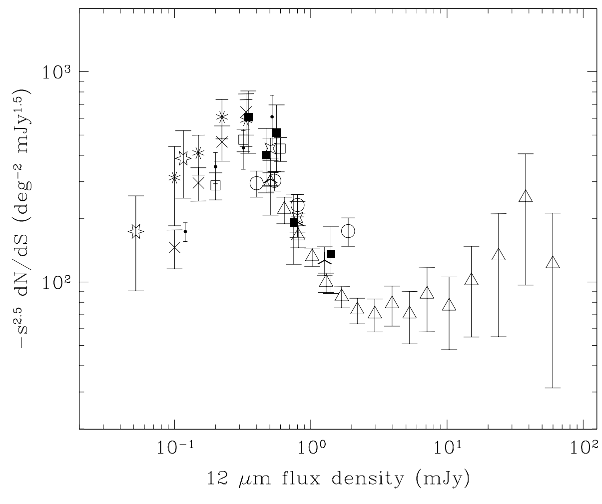

Figure 1. The differential excess of faint galaxy counts observed at 12 μm (black squares) and 15 μm (empty symbols), see Seymour et al. (2007) and references therein.

3. UV-optical-NIR faint counts

Fig. 2 shows the best fits of the UV-optical-NIR faint galaxy counts fitted with respective fractions: 26% of ellipticals, 24% of early spirals Sa+Sb+Sbc, 50% of late Sc+Sdm+starburst (Fioc & Rocca-Volmerange, 1999). The best fit is for standard cosmology : Ω_m=0.3, Ω_λ=0.7, H_0=70km s^{-1} Mpc^{-1}), $z_{formation}$=10 .

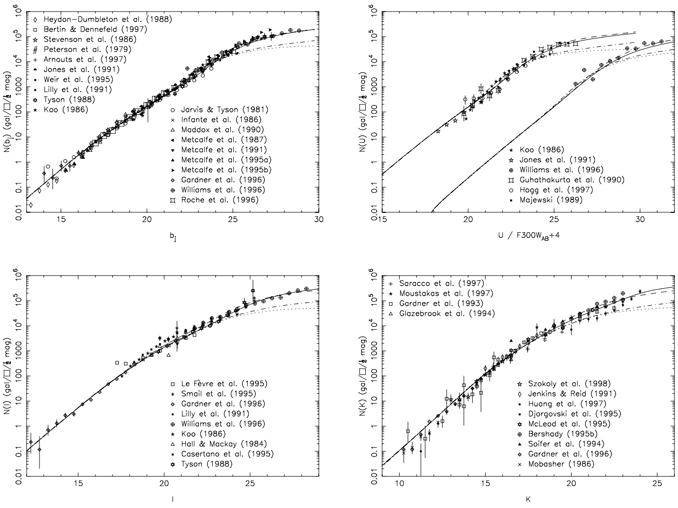

Figure 2. UV-optical-NIR number counts fitted by the PÉGASE model with galaxy type effects. Lines trace various cosmologies, the best fit corresponds to the standard cosmology (see details in Fioc & Rocca-Volmerange, 1999)

4. SEDs from stellar + dust emissions by types

PEGASE.3 (Fioc, Dwek, Rocca-Volmerange, in preparation) is built to simultaneously predict the stellar + dust emissions, accounting for chemical evolution. At all ages, dust amount evolves with metal enrichment for the 8 types of the Hubble sequence (1 elliptical, 5 spirals, 1 IM and 1 starburst). Grain emission from Draine's models is computed in two radiation fields – ISM and HII regions – with a transfer code through slab or spheroid geometries, depending on types. Scenarios of galaxy evolution were fitted in the optical. As an example, Fig.3 shows the continuous evolution of the IM type. SEDs are similarly computed for all the 8 types. This atlas is then used to compute the k- and e- (evolution) corrections at high z. Note that k-corrections are crucial for their negative (brighter) values at high z (z=3-4), in particular for ellipticals, which show a strong typical gap from a small dust amount to an intense stellar emission (see Fig. 9 in Xilouris et al., 2004).

5. Ultra-luminous ellipticals in the mid-IR

Faint galaxy counts in the mid-IR (RVLS2007) are computed with evolution by type on the basis of the new UV to IR atlas from PÉGASE.3. Results for ISO counts are shown on Fig.4. The luminosity functions are from IRAS

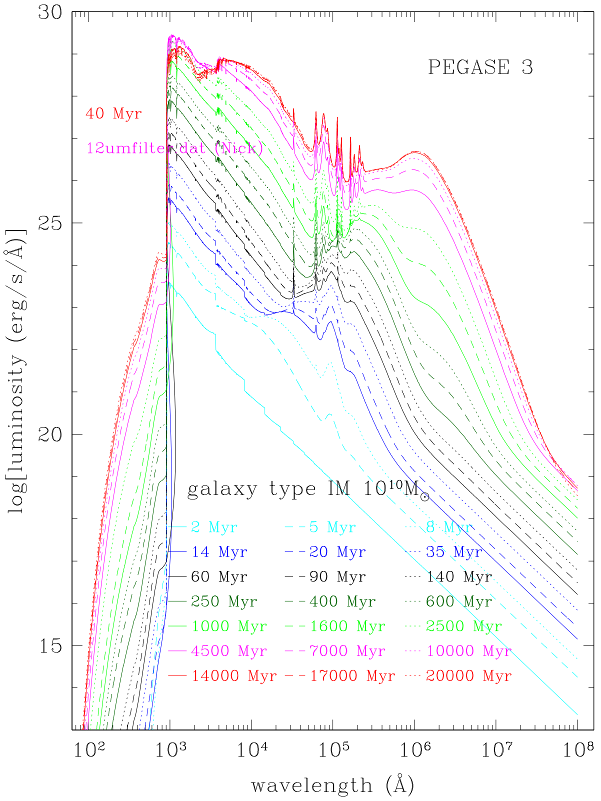

Figure 3. An example of evolutionary SEDs (irregular magellanic IM galaxies) predicted by the new version of the code PÉGASE.3 by combining stellar and dust emissions

Table 1. Galaxy fractions by types in the infrared. Normal at 12 μm means predicted from the optical-12 μm colors by types with PÉGASE.3. At 24 μm, magnitudes are normal- 5 (see RVLS2007)

Type	fraction	12μm magnitude
ULIRG-Ell	9%	normal -2.5
normal-Ell	17%	normal
early spirals	24%	normal
late spirals+Im	50%	normal

at 12 μm (Rush et al., 1993) and at 24 μm (Shupe et al., 1998) (L^*_{12} and L^*_{24} are for Sbc type). Colours $m_{bJ} - m_{12}$ and $m_{bJ} - m_{24}$ are computed from the optical L_{bJ} luminosity function by types from the 2dF survey (Heyl et al., 1997) and used to predict type effects of luminosity functions normalized to Sbc (see details in RVLS2007). As a first result, the optical fractions by types are unable to reproduce the 0.3mJy excess in the mid-IR. We succeed in reproducing the excess by replacing 1/3 of normal ellipticals (9 % of all galaxies) by infrared ultraluminous ellipticals (ULIRG-Ell), the rest of galaxy fractions is unchanged from the optical (Table 1). The same model also fits the $\simeq$ 0.3 mJy excess in the 24 μm faint counts. This confirms the validity of the interpretation with the same ultra-bright population. The excess does not need starbursts at high redshifts depending on filter passbands.

The presence of dust is confirmed by the differential magnitude excess needed to fit the bump: Δm_{12}= -2.5 mag at 12 μm, Δm_{24}= -5 at 24 μm. Because our elliptical model is dust-devoided by earlier galactic winds, its mid-IR SED follows the black-body Rayleigh-Jeans slope from stellar emission. The excess difference Δm between the two wavelengths agrees with the Rayleigh-Jeans slope. The amplified stellar luminosity of ULIRG-Ells reach the mid-IR filters at less for redshifts z= 3-4. For the same reason, our no-dust elliptical model justifies the deficient fit of observations at high flux densities (superior to 10mJy) where dust emission is dominant. Finally, the magnitude excess implying ultra-brightness, is likely due to an embedded AGN.

6. Conclusions

Spirals and normal ellipticals are not bright enough to reproduce the bump observed in the mid-IR counts. Only the strong k-correction of ultra-bright elliptical SED, amplified by a possible underlying AGN, may explain the bump at 12 μm and 24 μm. This also justifies that fact that 175 μm counts do not show such a bump. Evidence of dust is also shown for fluxes > 10mJy. In the UV-optical, ULIRG-Ell appear normal due to absorption by dust. Some may be misclassified as active galaxies. In future work, precise redshifts, temperatures and dust amount of these galaxies need to be estimated.

This population reconciles the interpretation of UV-optical and mid-IR faint counts: both are dominated by a population of massive ellipticals at high z. To form such bright spheroïds at the earliest epochs requires a short time-scale of mass accumulation and star formation history, constraining galaxy evolution. Hierarchical merging at very high z and/or dissipative gravitational processes are then favored. The new generation of telescopes in the IR, submmillimeter and millimeter domains (SPICA, Herschel, ALMA) will confirm these results and bring more constraints to identify the basic physics of galaxy evolution.

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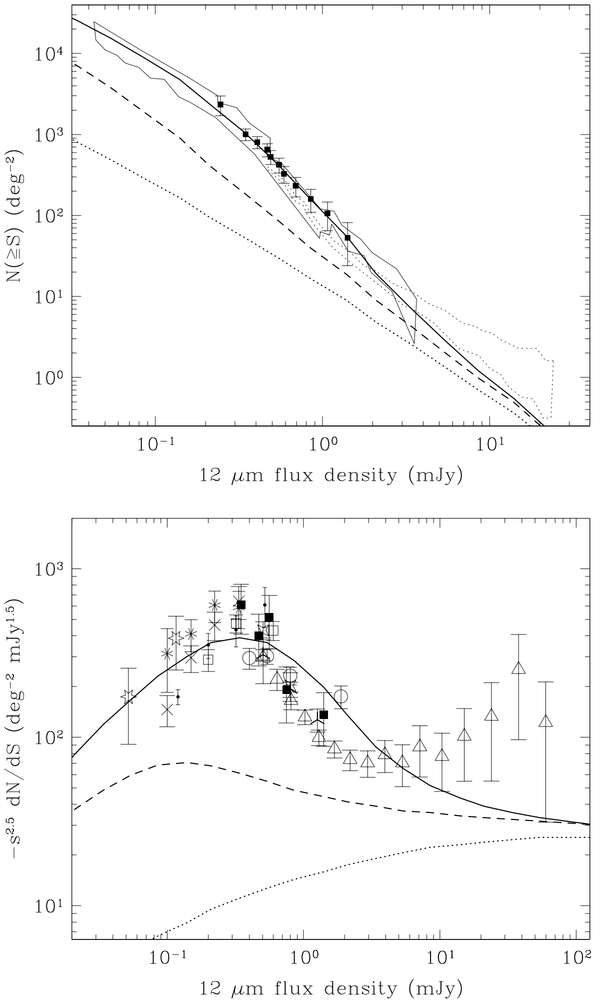

Figure 4. Cumulative and differential galaxy counts at 12 μm fitted using the new model PEGASE.3. Galaxy populations include normal galaxies from the optical, except 9% of Infrared Ultra Luminous galaxies of elliptical types.

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