Cosmic star-formation history from the mid- and far-infrared up to z=5

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Aims [1]

1) To **model the multi-λ IR counts** with an evolving total infrared luminosity function (LF)

2) To **derive the cosmic star-formation history** from the modeled LF and provide new constraints at high redshift

3) To establish a **model with conservative uncertainties**, and give predictions for future observations of Herschel, SPICA, and SCUBA2.

Originalities of this work

1) Uses **2 independent methods** to obtain IR Luminosity functions

2a) Uses **all the information available** in the IR (luminosities, **multi-λ IR counts**, priors on the **known low-z LF** and **CIRB**)

2b) Uses **simultaneously** various unrelated IR surveys, with both deep and wide fields

3) Provides a **conservative range of star formation histories** compatible with current observations in the IR

4) Provides a **test for evolution in the galaxies IR SEDs** : it is possible to rule out the validity at high redshift of the IR spectral libraries empirically calibrated at z=0.

Hypotheses

1a) The IR SEDs of galaxies at any redshift depend only on their total IR luminosities.

1b) The Chary & Elbaz (2001) library calibrated at z=0 is used. Other libraries (including or not evolution) can be easily tested.

2) The total IR luminosity is a good tracer of the star-formation activity in a galaxy. The conversion is SFR = 1.7 10^{-10} L_{IR} [4]

Total infrared luminosity functions

Method 1: Direct measurements using redshifts

Sample :

- GOODS North (including HDF-N) and South (including CDFS)
- Total area~0.1 sq degree
- Spitzer/MIPS$_{24}$ sources : $S_{24\mu m}$>30 uJy

Redshifts:

- Spectroscopic redshifts
- Photometric redshifts using ZPEG [4]

Results :

- Good match with LeFloc'h et al 2005 (slightly shallower).
- In agreement with the LF modeled from method 2 up to z=3.
- Confirmed strong evolution in luminosity up to z=2, extended to z=3.

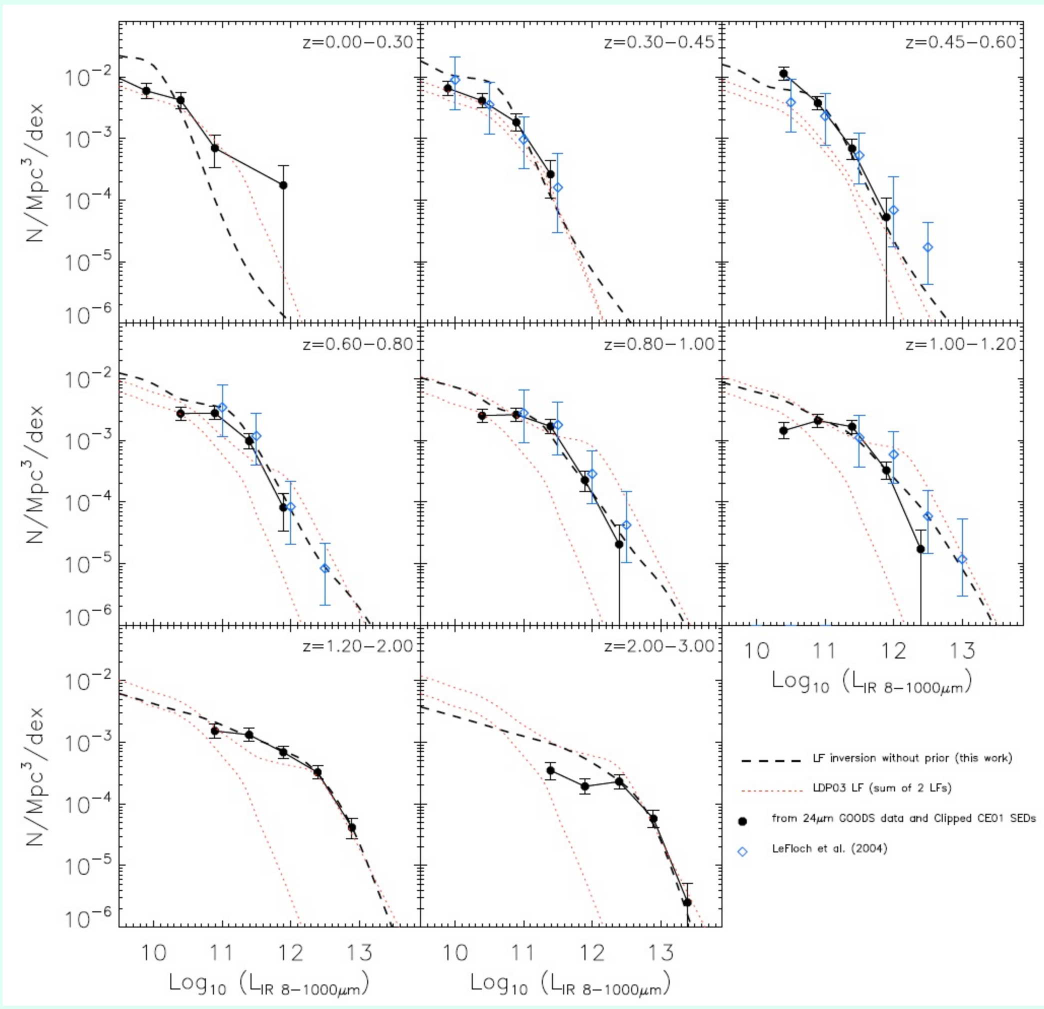


Fig. : Evolution of the total IR luminosity function measured from 24μm sources in the GOODS fields (using templates calibrated at z=0 [2] for 24 μm to L_{IR} conversion)

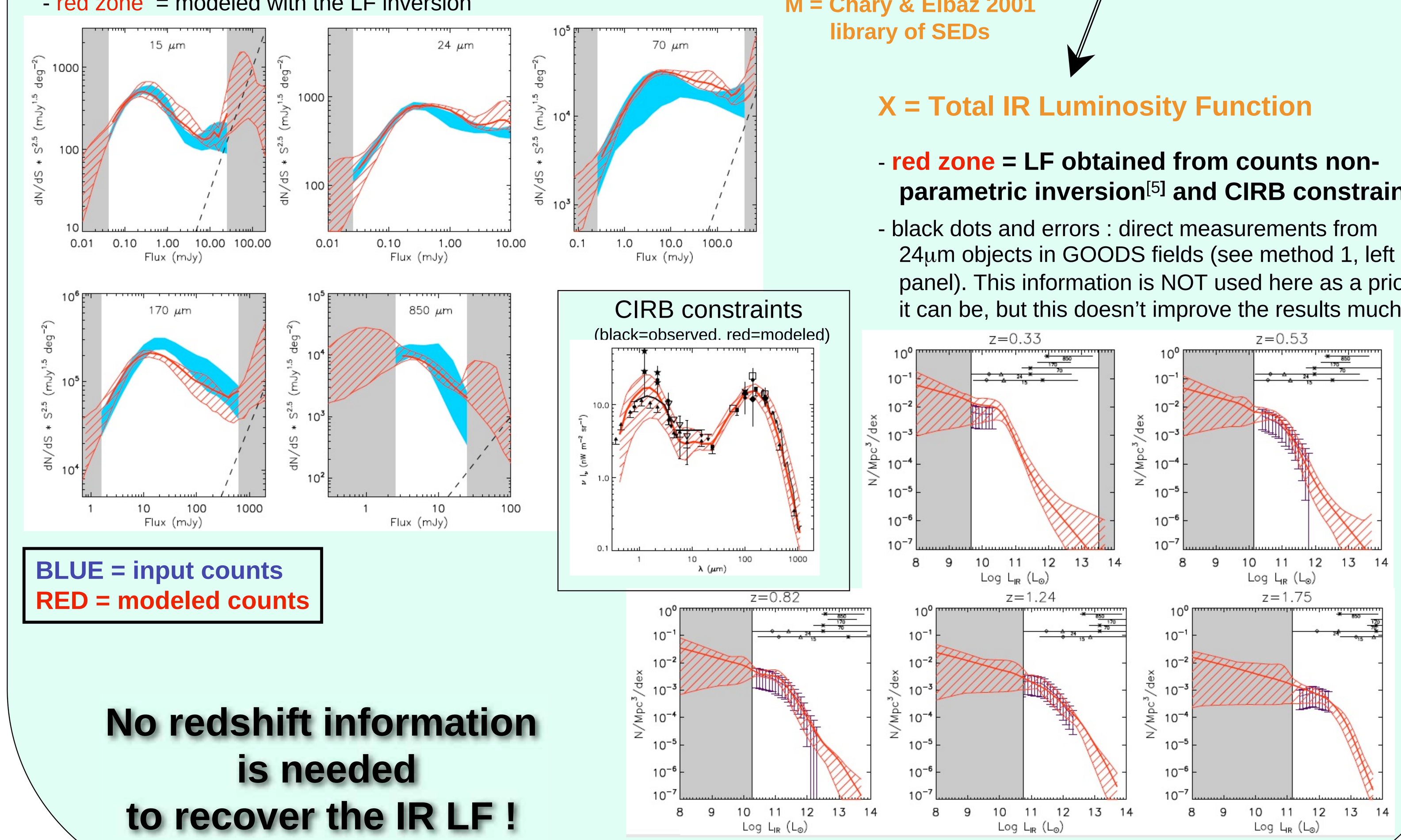
Method 2: Empirical modeling
non-parametric inversion of *multi-λ* counts from 15 to 850 μm

$$\mathbf{Y}(\lambda, S) = \mathbf{M}(\lambda, S, z, L_{\rm IR}) \cdot \mathbf{X}(z, L_{\rm IR})$$

Y = Counts
- blue zone = input = bibliographic compilation
- red zone = modeled with the LF inversion

M = Chary & Elbaz 2001 library of SEDs

X = Total IR Luminosity Function
- red zone **= LF obtained from counts non-parametric inversion[5] and CIRB constraints**
- black dots and errors : direct measurements from 24μm objects in GOODS fields (see method 1, left panel). This information is NOT used here as a prior: it can be, but this doesn't improve the results much.



No redshift information is needed to recover the IR LF !

Deriving the cosmic star-formation history

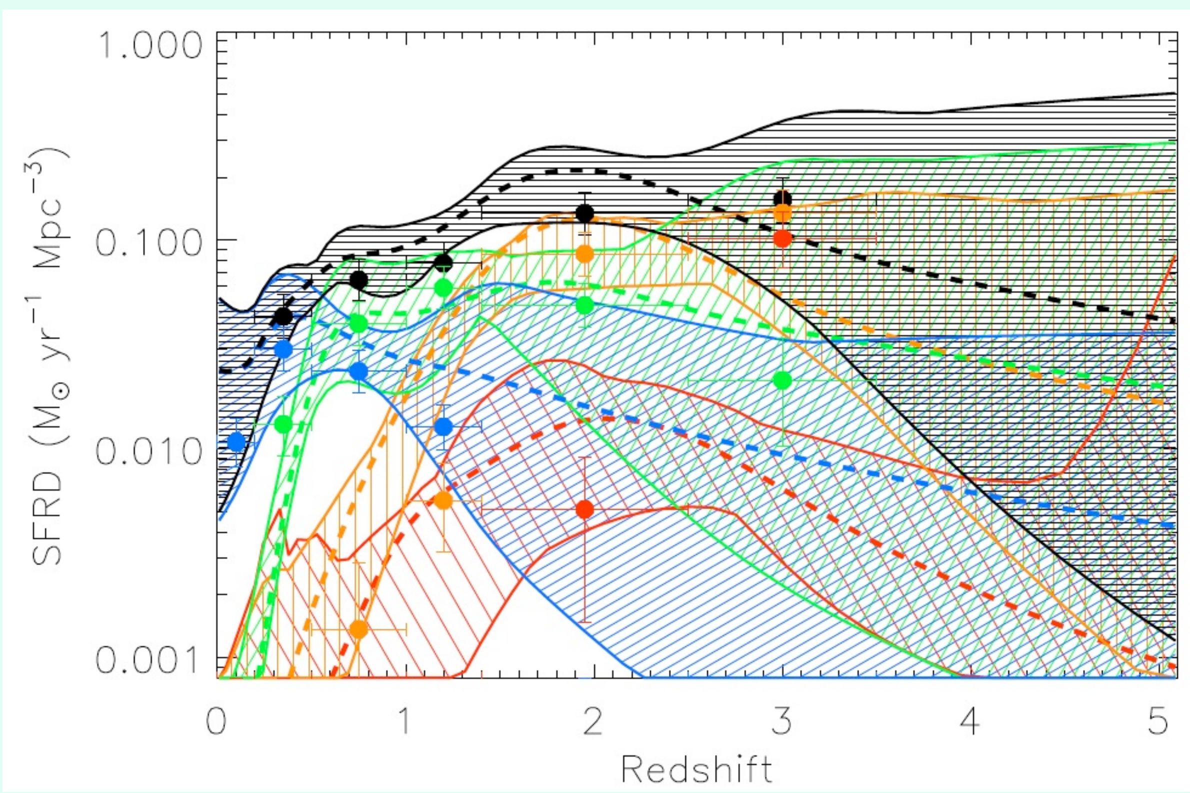
Cosmic star formation rate density (SFRD) and its evolution from methods 1 and 2

The total star formation rate density (black) is decomposed in 4 classes of galaxies :
Quiescent: SFR<20 $M_\odot.yr^{-1}$
LIRGS: 20 <SFR <200 $M_\odot.yr^{-1}$
ULIRGS: 200<SFR<2000 $M_\odot.yr^{-1}$
HLIRGS : SFR >2000 $M_\odot.yr^{-1}$

Filled dots and errors:
Measurements from **Method 1** (mainly lower limits)

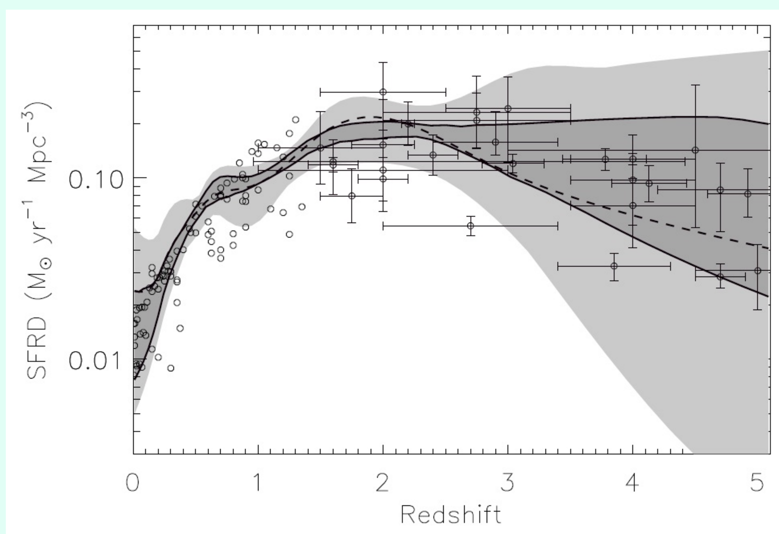
Dashed zones:
SFRD derived from **Method 2** (exhaustive range of possible evolutions)

Dashed lines :
Model best fitting the counts from Method 2

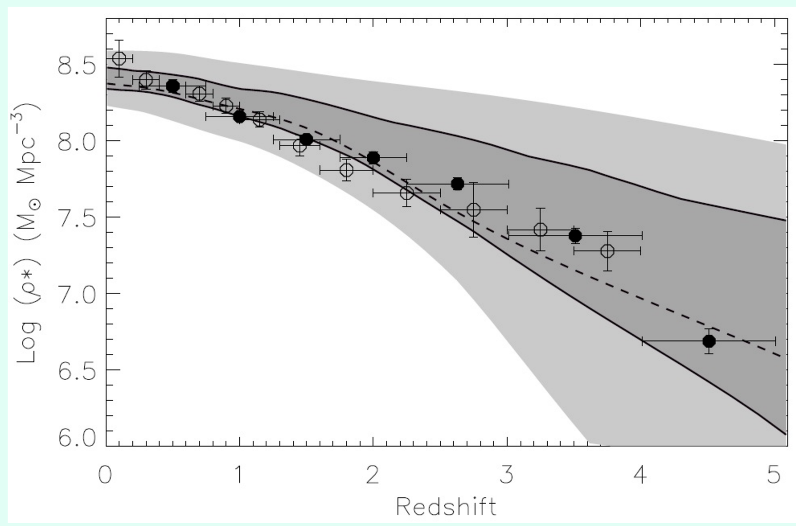


SFR density : "method 2" vs optical indicators

Zones = 68% and 100% models from method 2 (dashed line=best fitting model)
Points and errors(for z>2) : from Hα, UV, … (Hopkins et al. 2006)



We find a good overall agreement with dust-corrected measurements in the optical !



The integral of our star-formation histories (grey zones) match the **stellar mass densities** measured independantly from near IR photometry (dots) unlike previous claims[7] which invoked a non-universal IMF.

Conclusions [1]

1) For the first time, all the IR information available is used *simultaneoulsy* to derive the LF, hence the cosmic star formation history:

a) Multi-λ IR **counts** (15μm to 850μm) inverted with CE SED library **contain enough information to recover the measured evolution of IR LF at z<2** with reasonnable uncertainties, as well as redshift distributions of 24μm sources.

b) This inversion enables **predictions at high redshift** with the associated ***uncertainties***, in constrast to classical models of the star-formation history (which give *a single guess)*.

c) The 160 μm counts are slightly underpredicted by our non-parametric inversion model which contains a maximum number of degrees of freedom. This implies that **the library of SEDs must evolve** to reproduce perfectly the counts **or lacks colder galaxies undetected at z=0.**

2) **The star-formation activity is better constrained at high redshift:**

a) SFRD global evolution :
- SFRD decreased since z=2, confirming previous studies
- an increase is prefered from z=5 to z=2, but a peak at z>5 is not ruled out

b) SFRD budget :
HLIRGS can never dominate between z=0 and z=4 (unless the SEDs evolved strongly)
ULIRGS dominate at z=2, but almost anything is still possible at z>3

References:
[1] Le Borgne et al. 2008, submitted to A&A ; [2] Chary & Elbaz 2001, ApJ 556:562; [3] Le Floch et al 2005, 632:169; [4] Le Borgne & Rocca-Volmerange 2002; [5] Ocvirk et al MNRAS 365:74 ; [6] Kennicutt 1998, A&ARA 36:189 ; [7] Hopkins et al 2006, 651:142