Star-formation history from multi-bands counts

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- Introduction: Lilly-Madau plot and galaxy counts
- Non-parametric inversion of infrared galaxy counts
- Perspectives with Herschel

Introduction

- Lilly-Madau plot : volume-averaged SFR(z)
  - Luminosity density => star-formation rate density.
  - Which is the best monochromatic tracer ?
    - $H\alpha$: powerful but too red at high redshift
    - $H\beta$, etc. : accessible but extinction by dust
    - OII, OIII : calibration issues, dust
    - UV : dust correction uncertain
    - mid IR : rather good but PAHs in the way (24um= 8um at z=2)
    - Far IR : good census but calibration (SEDs) uncertain
    - Any other empirical tracer from simulations ?
- Idea : use multi-wavelength data simultaneously, statistically (volume average)

Introduction : galaxy counts

- Powers
  - Cheap and immediate : no redshift needed !
  - Large or deep sky areas probed
  - Simple measurement (except for confusion)
  - Weak constrains on models for monochromatic counts
  - No k-correction used for measurements (unlike LFs)

- Issues
  - Projected information : redshift is forgotten
  - Multi-wavelength
    - Calibration
    - Correlations
    - Modeling : panchromatic SED models

Idea

- **Model the multi-λ IR counts** with
  an evolving total infrared luminosity function (LF)
  Implies a knowledge of SEDs (k-corrections), cosmology

- **Derive the cosmic star-formation history**
  from the modeled LF and provide new constraints at high redshift

- Establish a **model with conservative uncertainties**, and give predictions for future observations of Herschel, SPICA, and SCUBA2.

  => Not another parametric model !

Inversion of IR counts

Empirical "modeling"

non-parametric inversion of *multi-λ* counts from 15 to 850 μm

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

Counts — **Chary & Elbaz 2001 library of SEDs** — **Total IR Luminosity Function**

Then

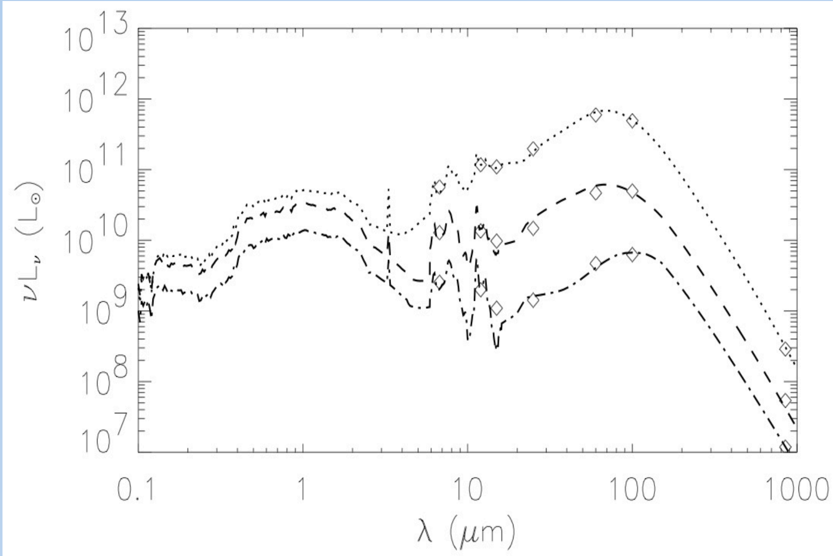
$$\boxed{SFRD(z) = A \int_{L_{IR\,\mathrm{min}}}^{L_{IR\,\mathrm{max}}} X(z, L_{IR})\, \mathrm{d}L_{IR}}$$

With A=1,72 10^{-10} Msun/yr/Lsun

In practice:

- 10^6 elements matrix
- regularization :
  penalization = smooth LF
- positivity => iterative
- filtered to match CIRB
- takes a few days

Hypotheses



- The IR SEDs of galaxies at any redshift depend *only* on their total IR luminosities.

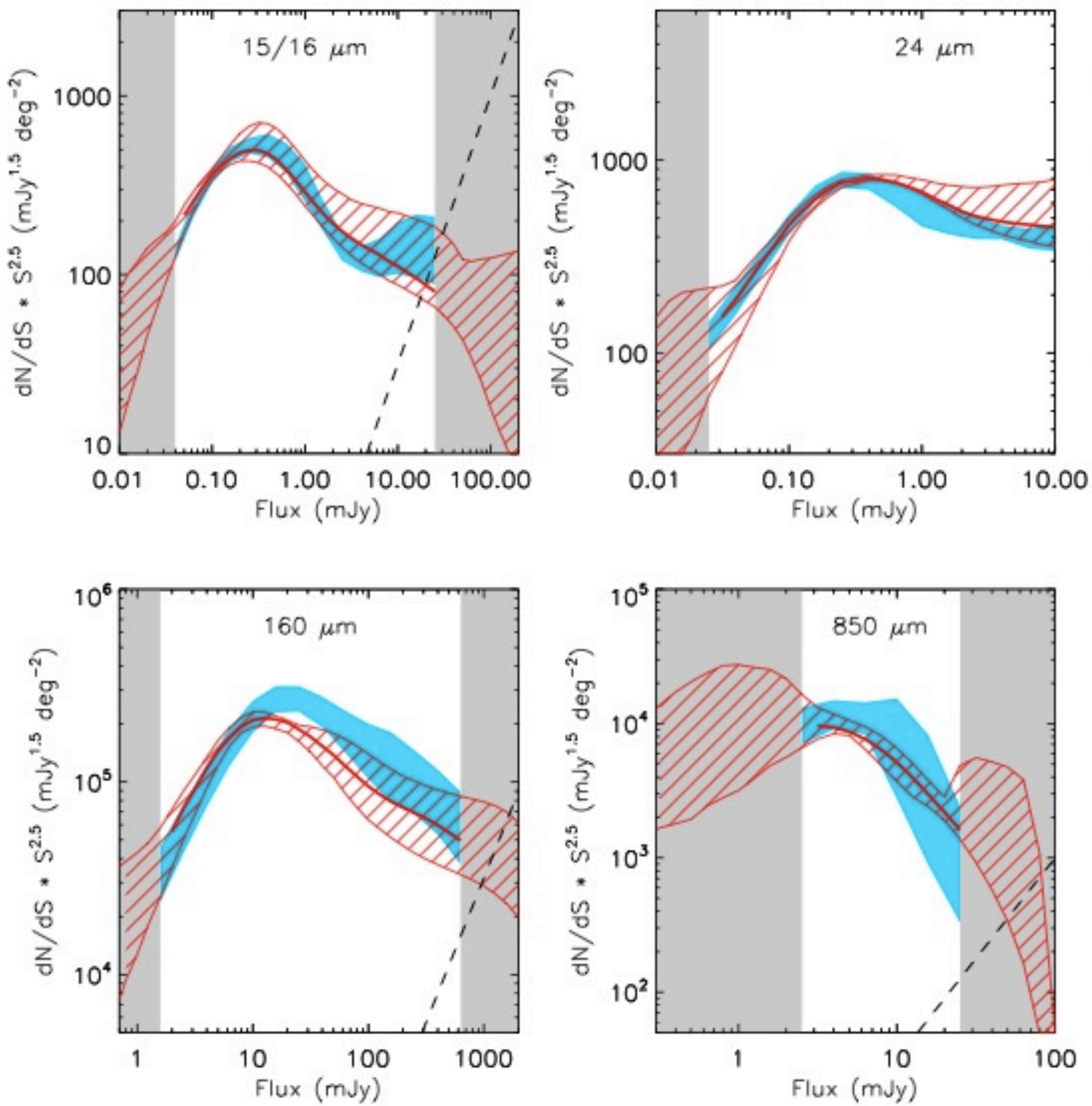
- The Chary & Elbaz (2001) library calibrated at z=0 is used. Other libraries (including or not evolution) can be easily tested.

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

- The infrared LF evolves smoothly

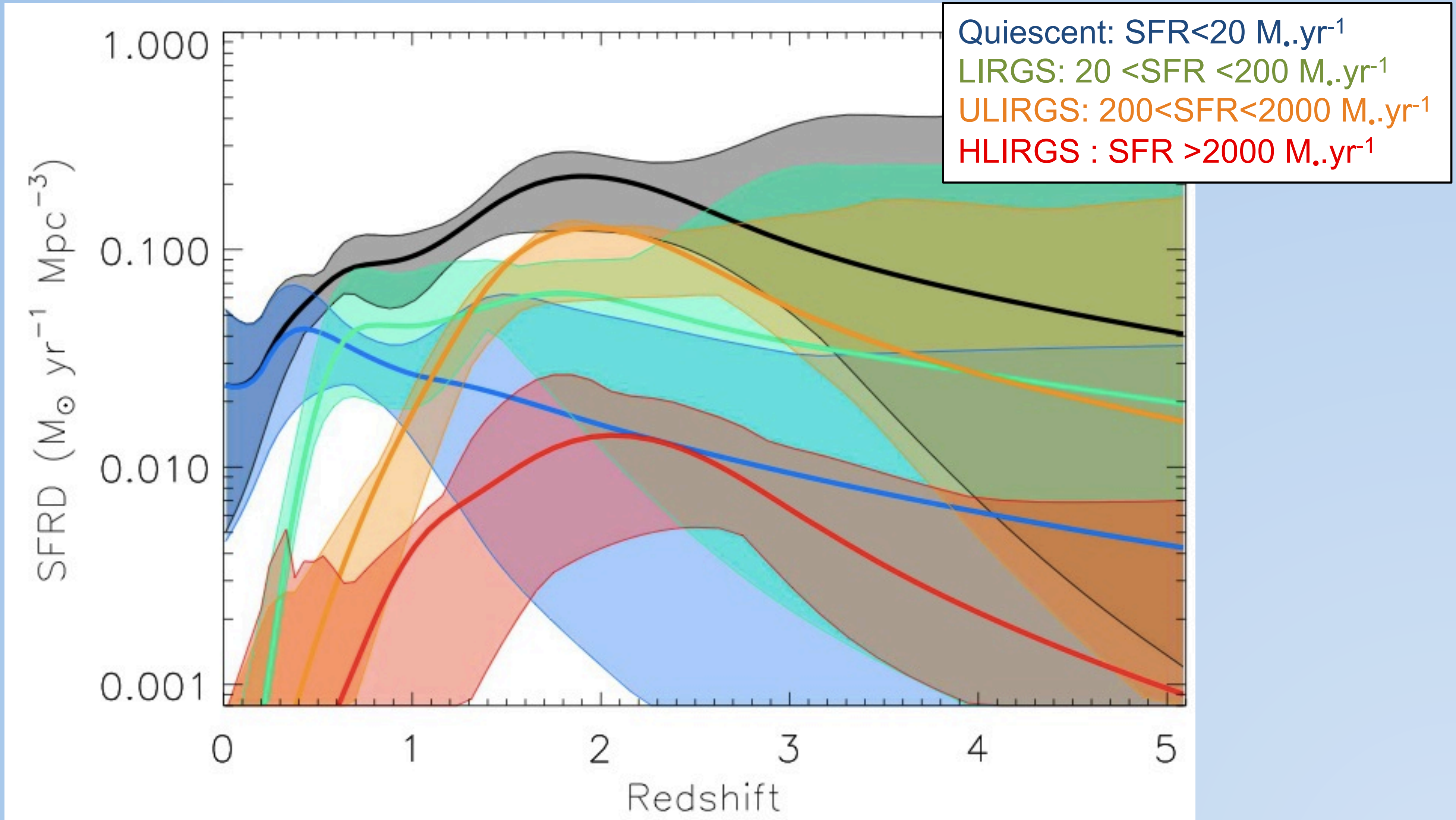
- Optional prior (not used in this talk): low-z measured LF (using redshifts)

Inversion of IR counts



Le Borgne, Elbaz, Pichon & Ocvirk (2009)

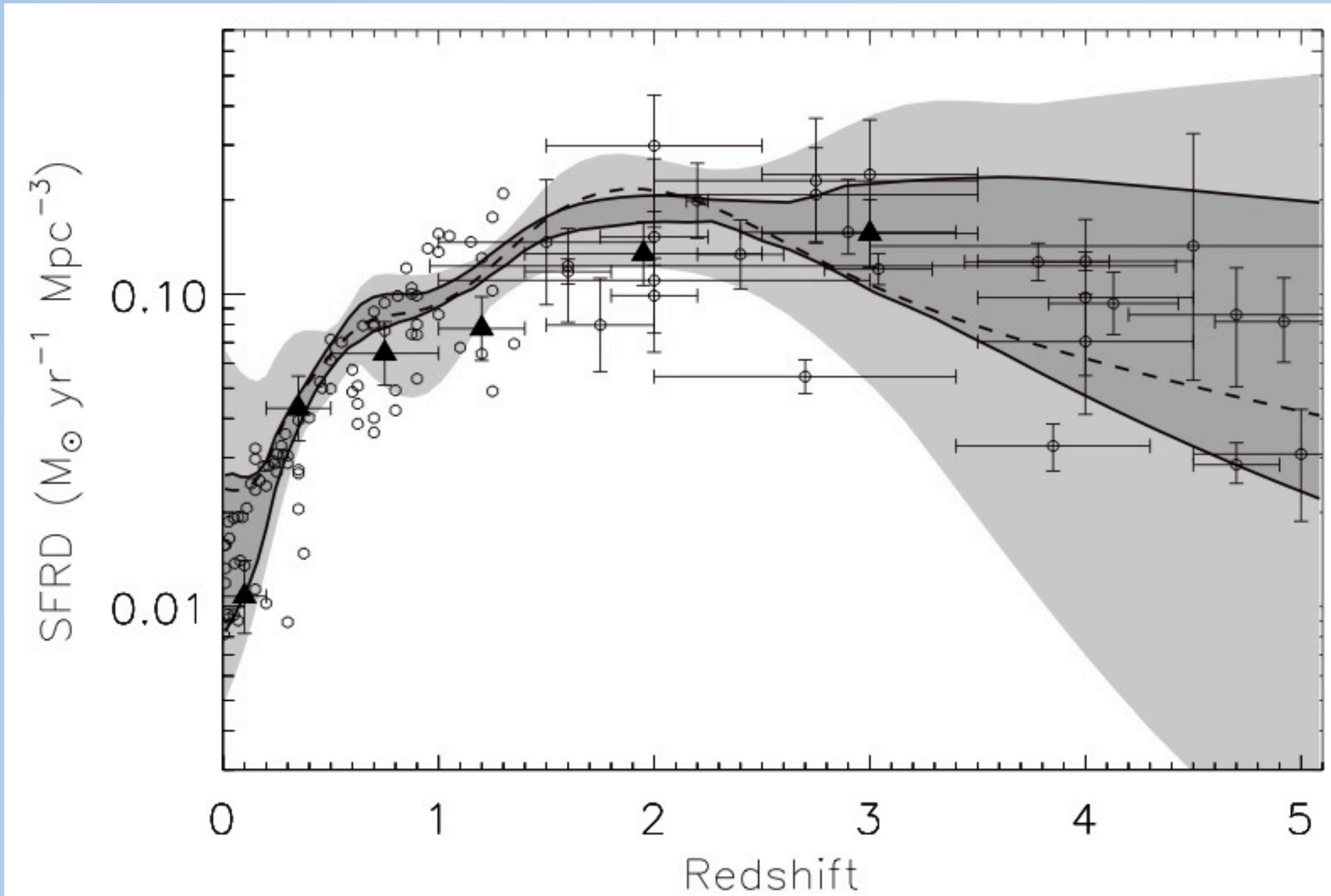
Deriving the cosmic star-formation history



Comparing the inversion results with direct measurements : SFRD

Data :

Hopkins et al. Compilation (UV corrected for extinction, IR, Hα)



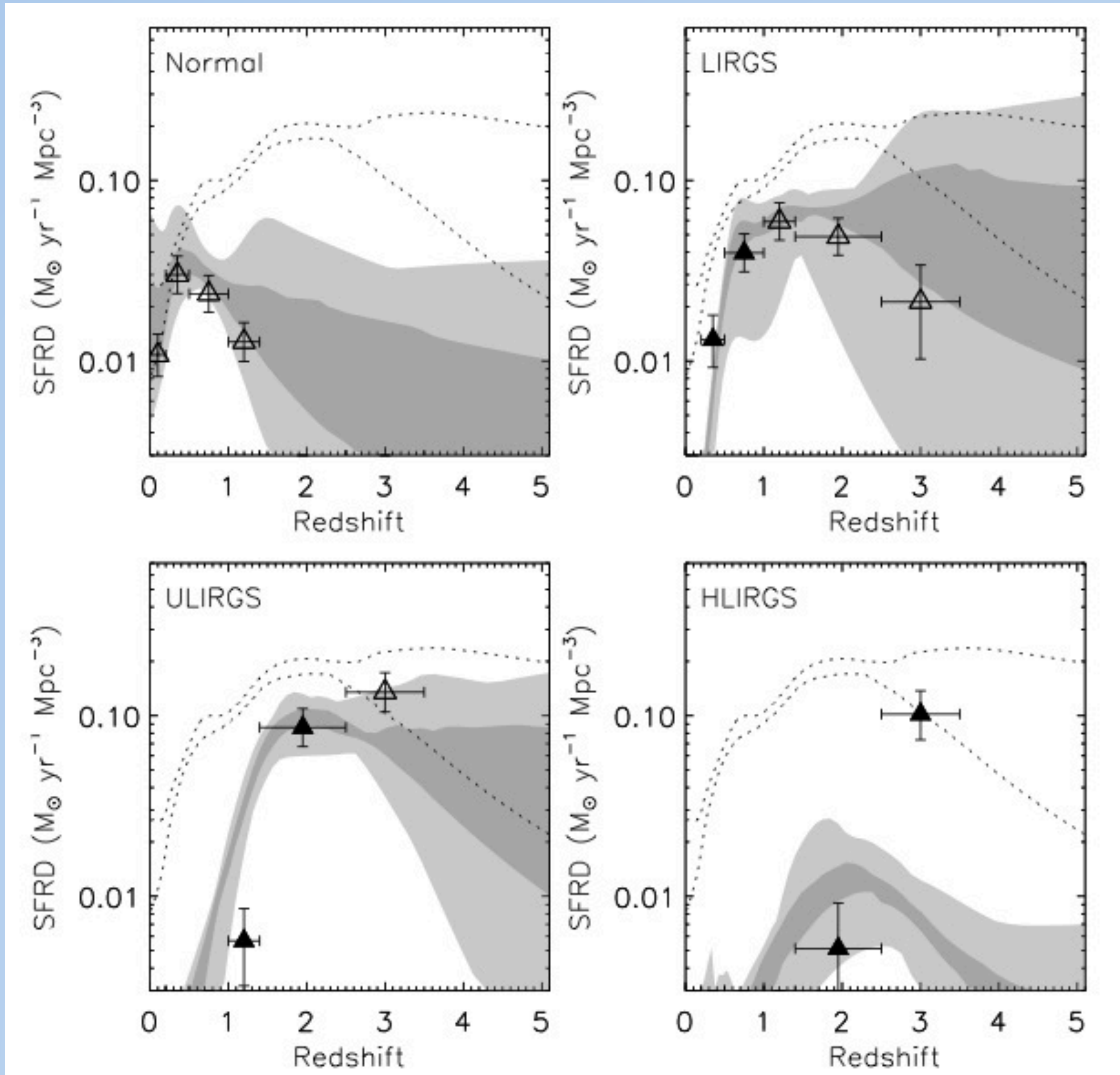
Comparing the inversion results with direct measurements : SFRD

Sample :

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

Redshifts:

- Spectroscopic redshifts
- Photometric redshifts using ZPEG



Comparing the inversion results with direct measurements : LFs

- **Luminosity functions directly measured**

Sample :

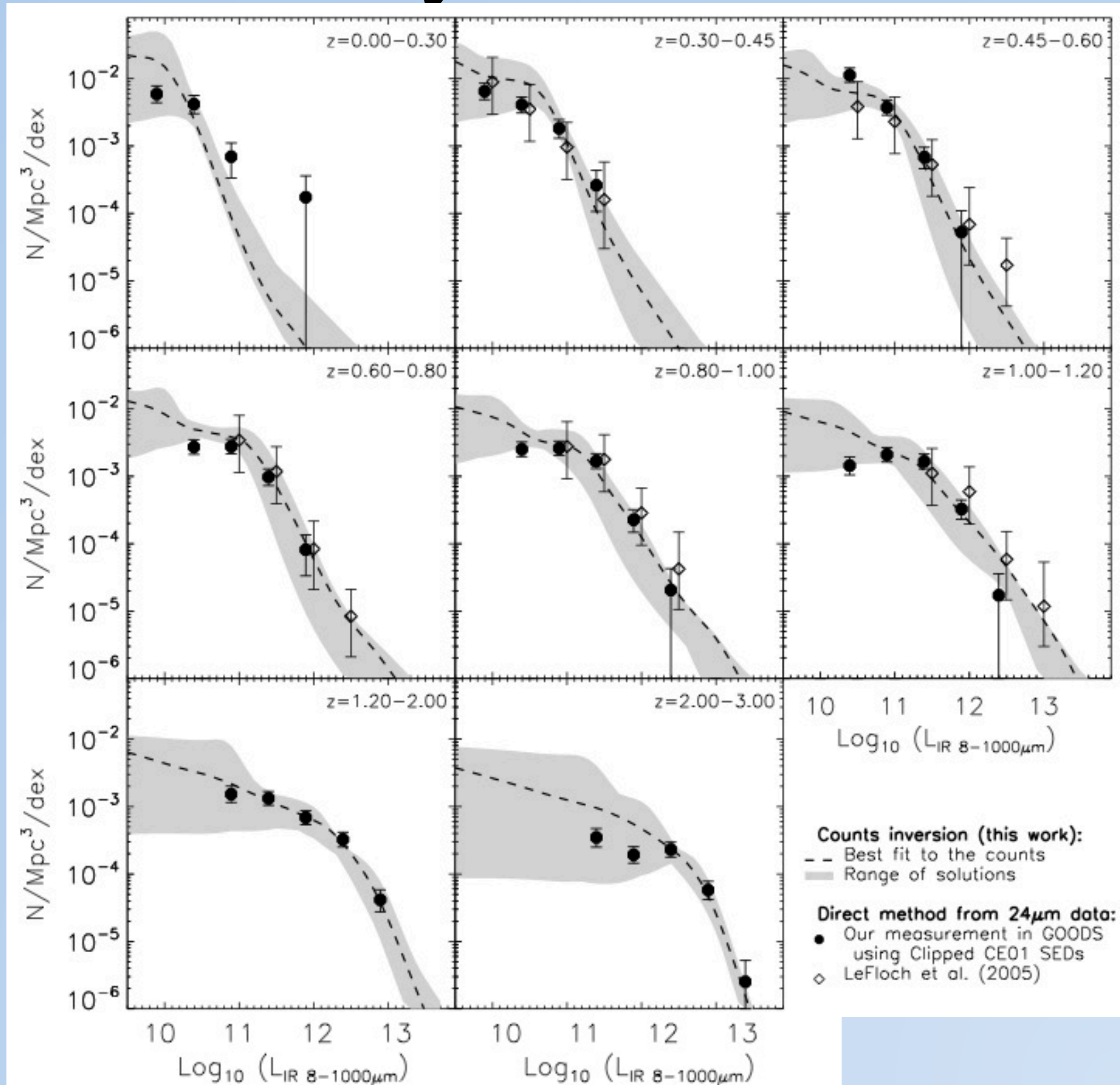
- GOODS North (including HDF-N) and South (including CDFS)
- Total area~0.1 sq degree
- Spitzer/MIPS$_{24}$ S$_{24\mu m}$>30 uJy

Redshifts:

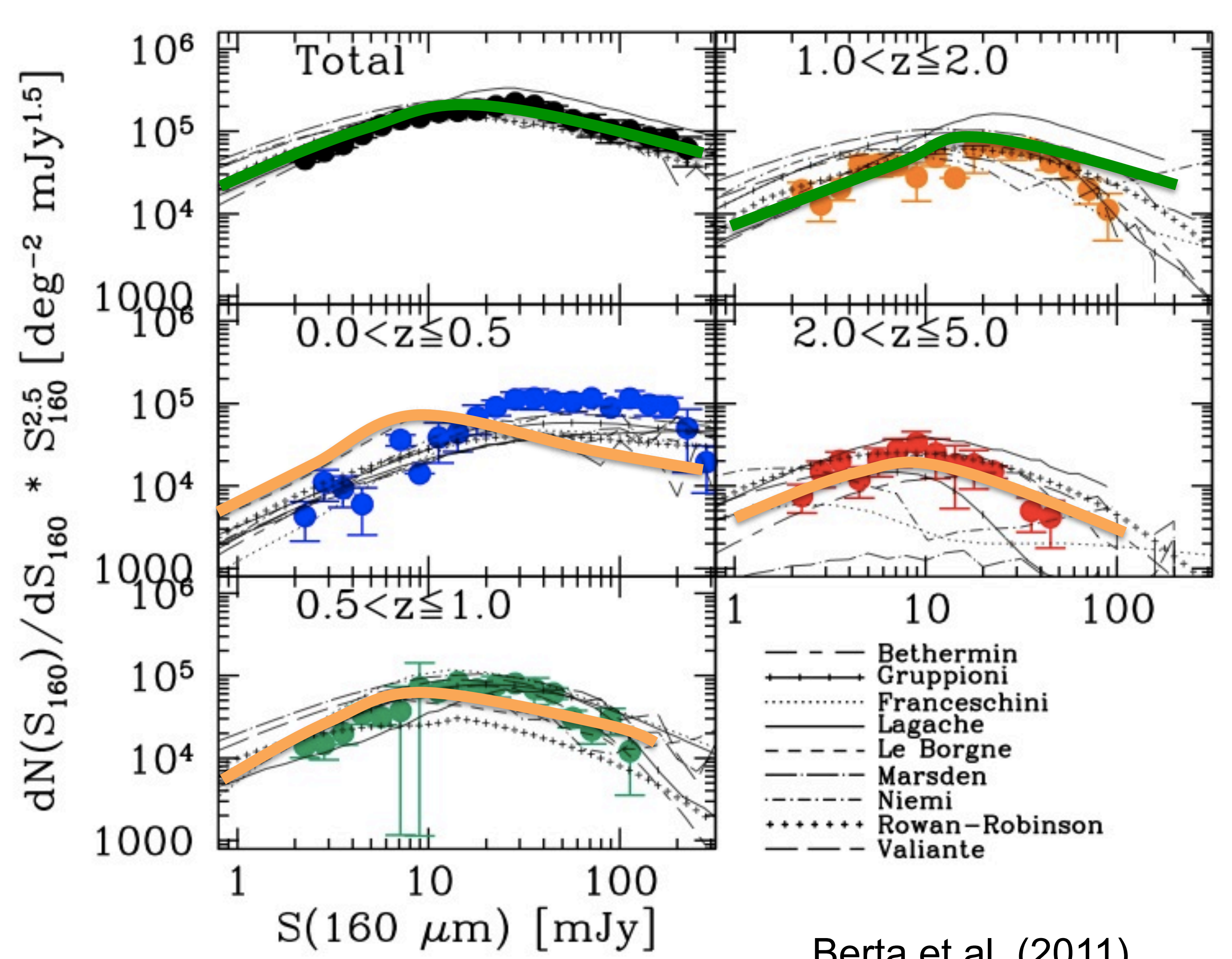
- Spectroscopic redshifts
- Photometric redshifts using ZPEG

Results :

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

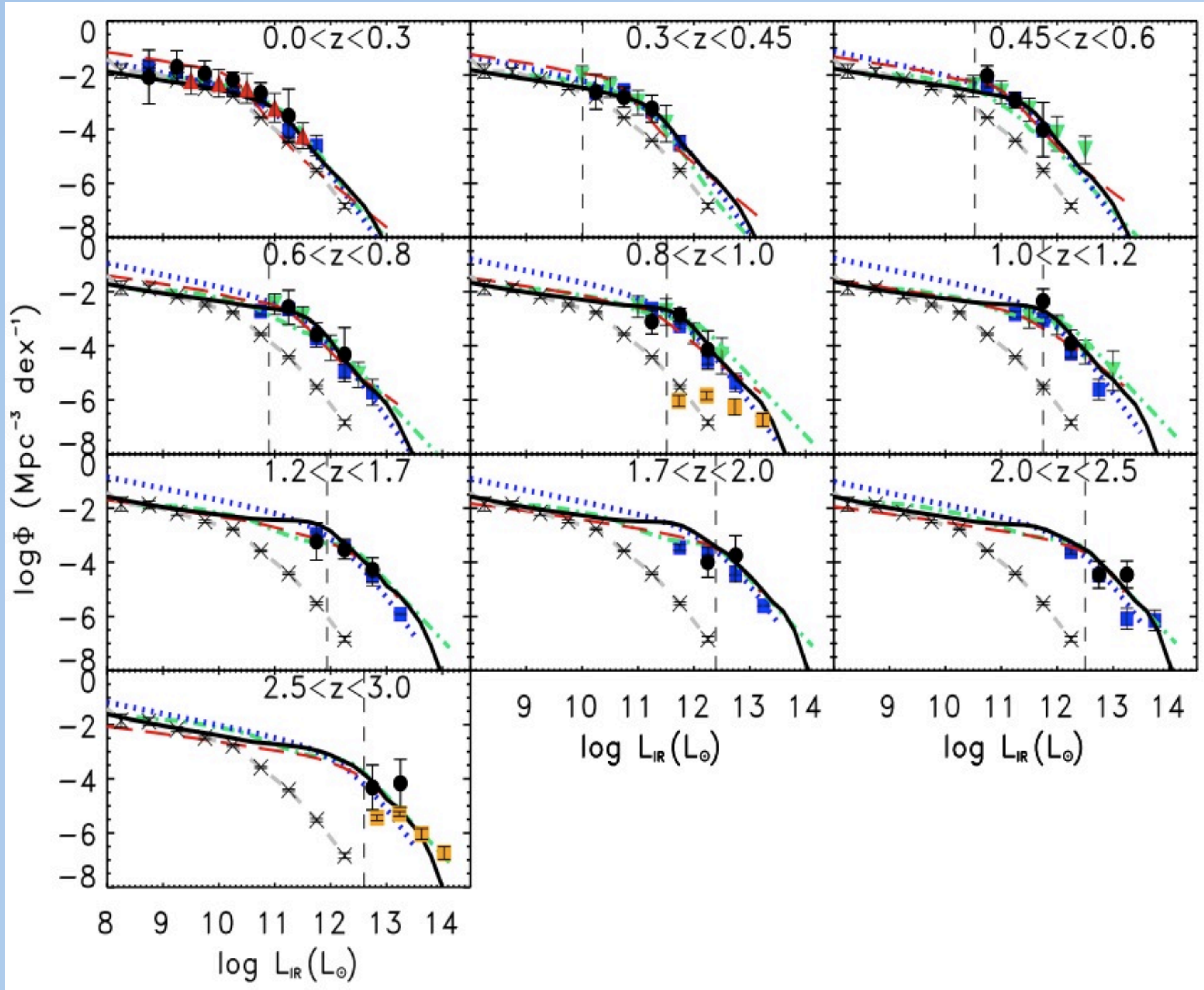


Comparing predictions with Herschel observations at 160um



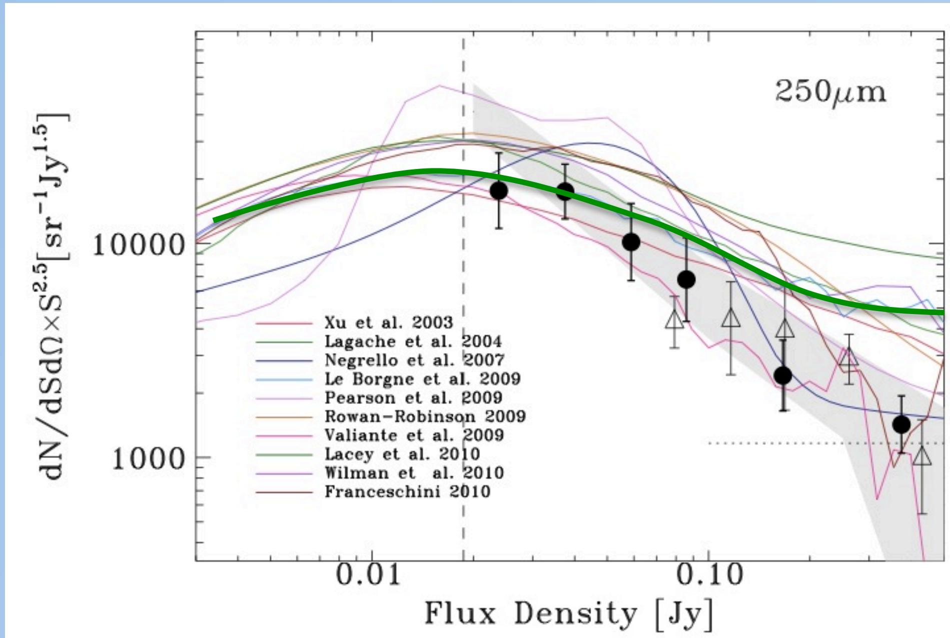
Berta et al. (2011)

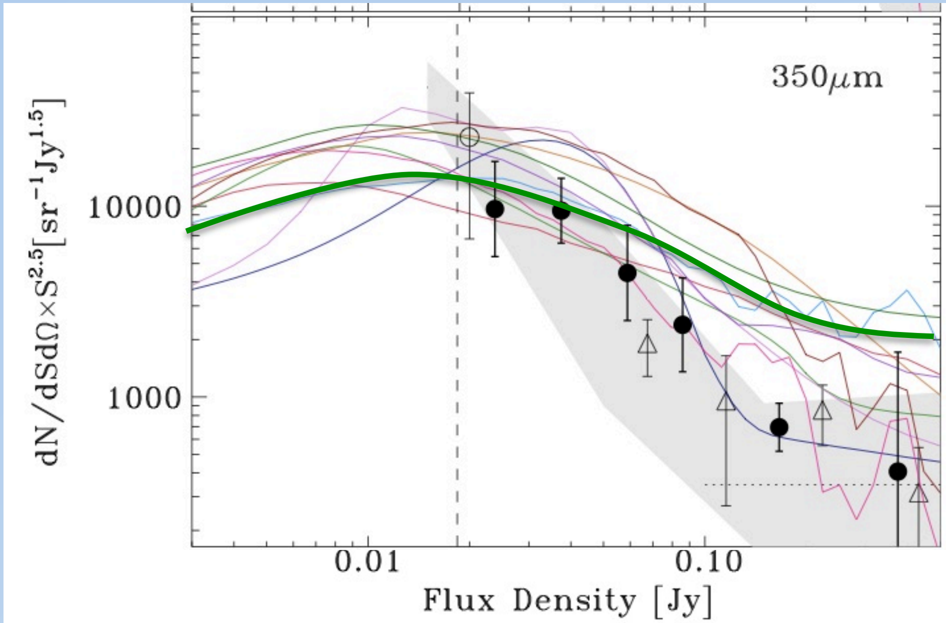
Total IR LF from PEP Herschel

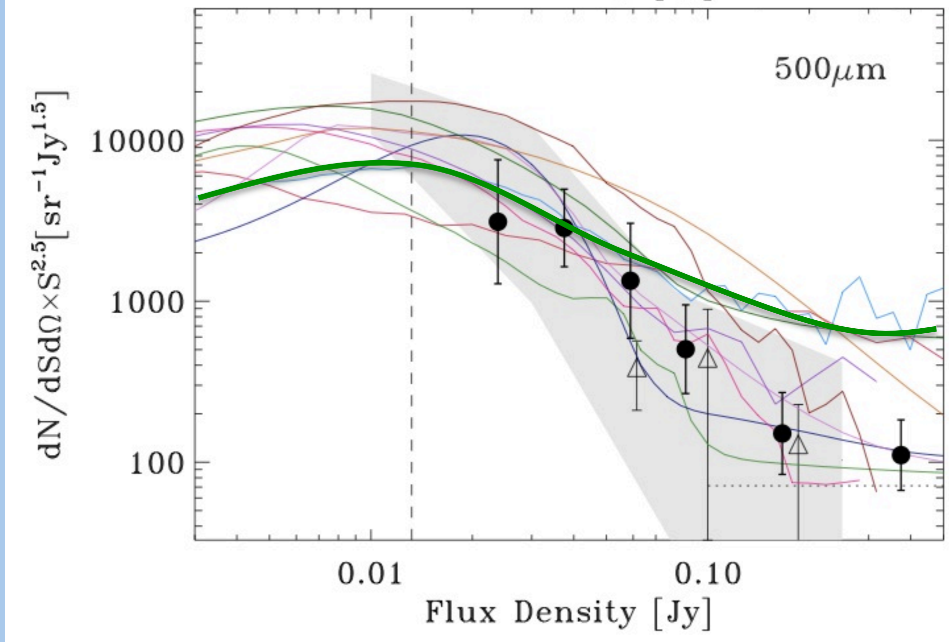


Gruppioni et al (2010)

Herschel counts redder than 250um



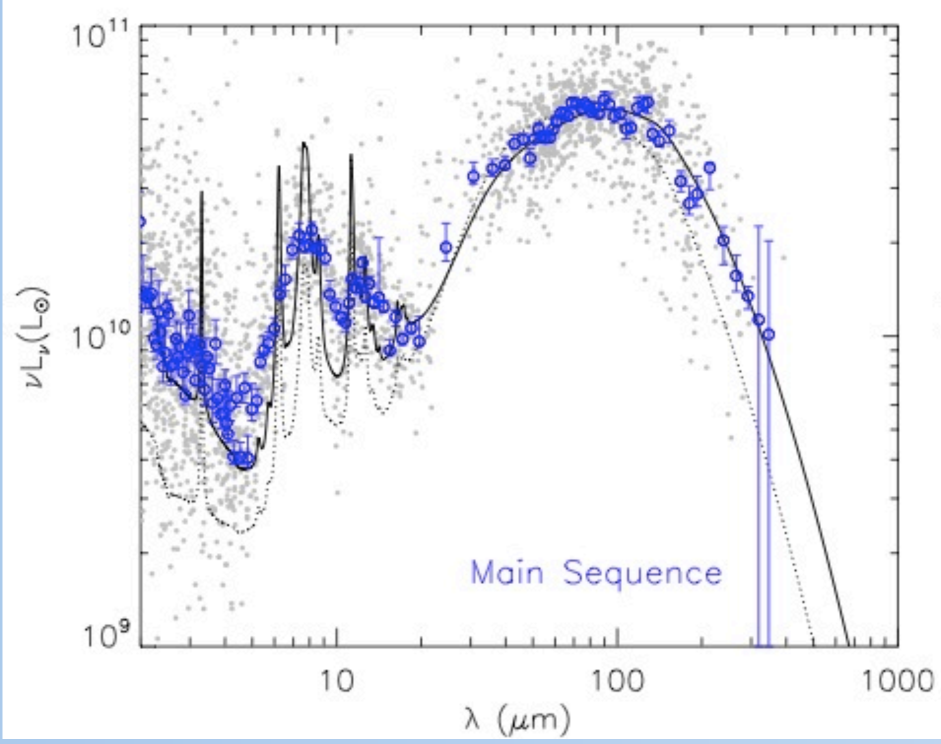


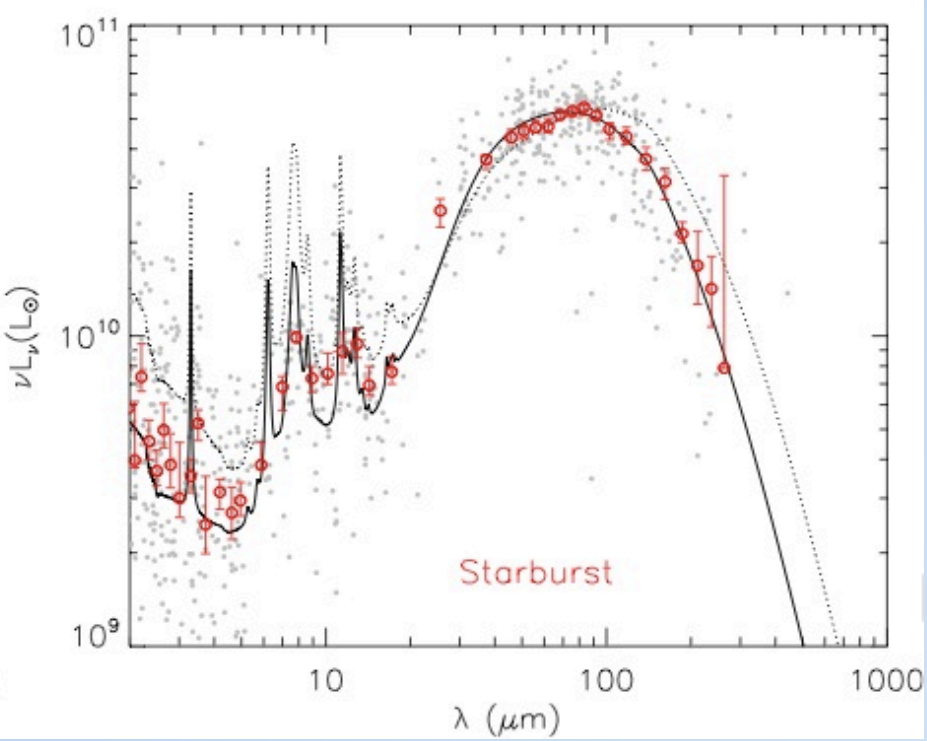


Oliver et al (2010) : HERMES results

Perspectives

- New results from Herschel
  - New SED model from Elbaz et al. 2011 at z<2.5
    - Main sequence : tight SSFR(z), most IR galaxies, redder in IR
    - Starbursts : compact, hotter, bluer in the IR, higher SSFR



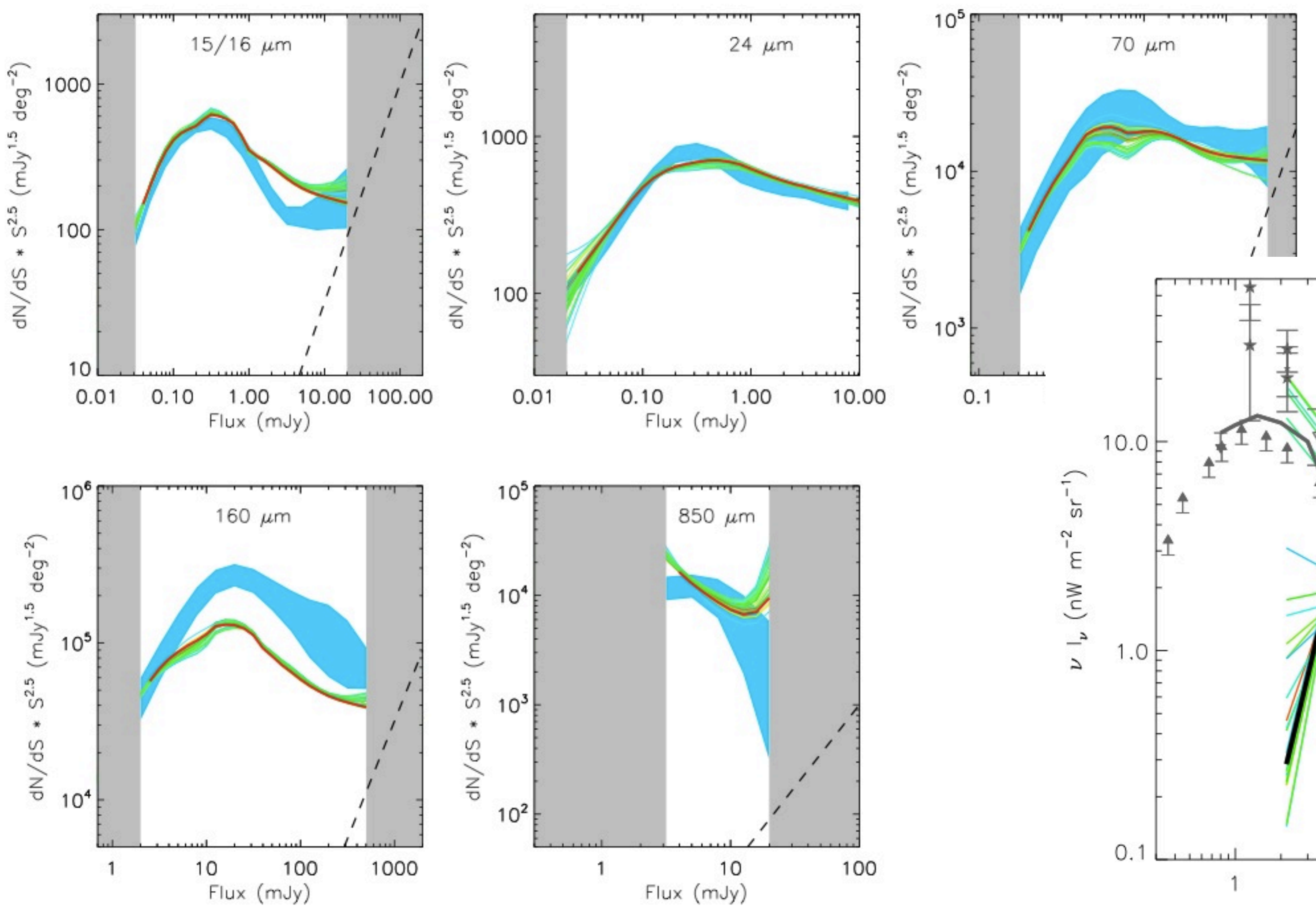


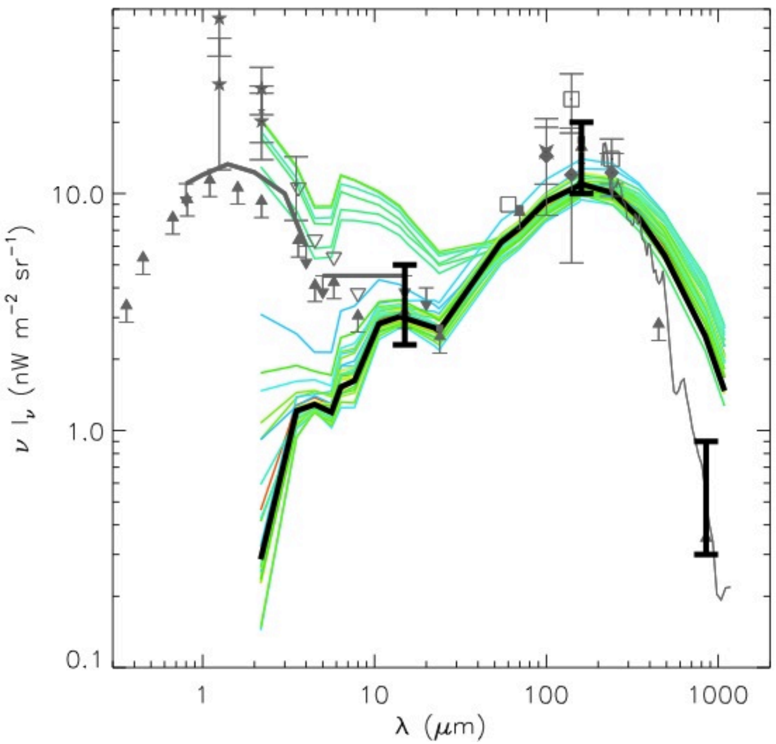
New inversion with these SEDs?

- If we assume all galaxies are main sequence: 1 SED !

  => Bad modeling of counts

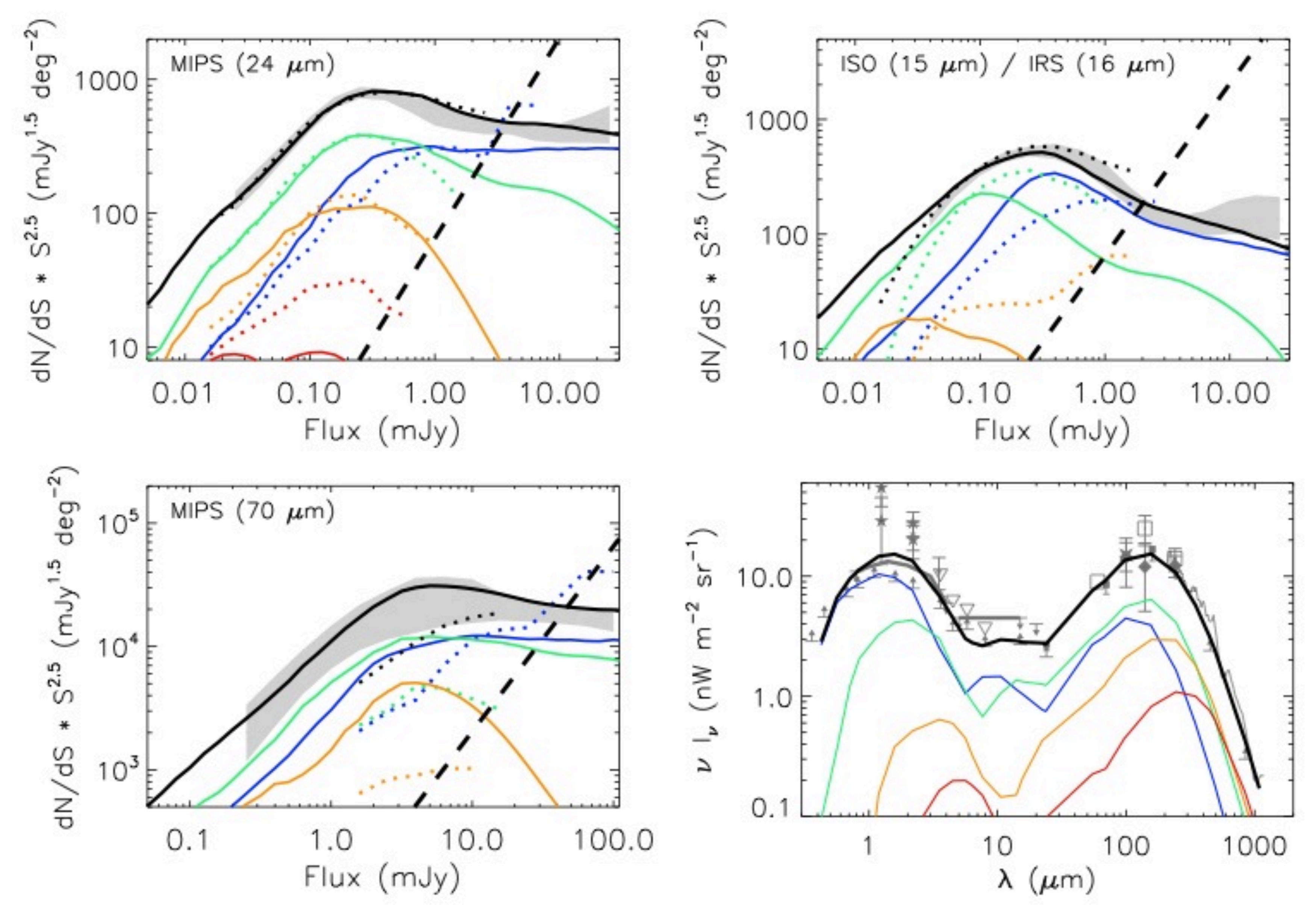
  => averaging over z is too simplistic for galaxy counts.



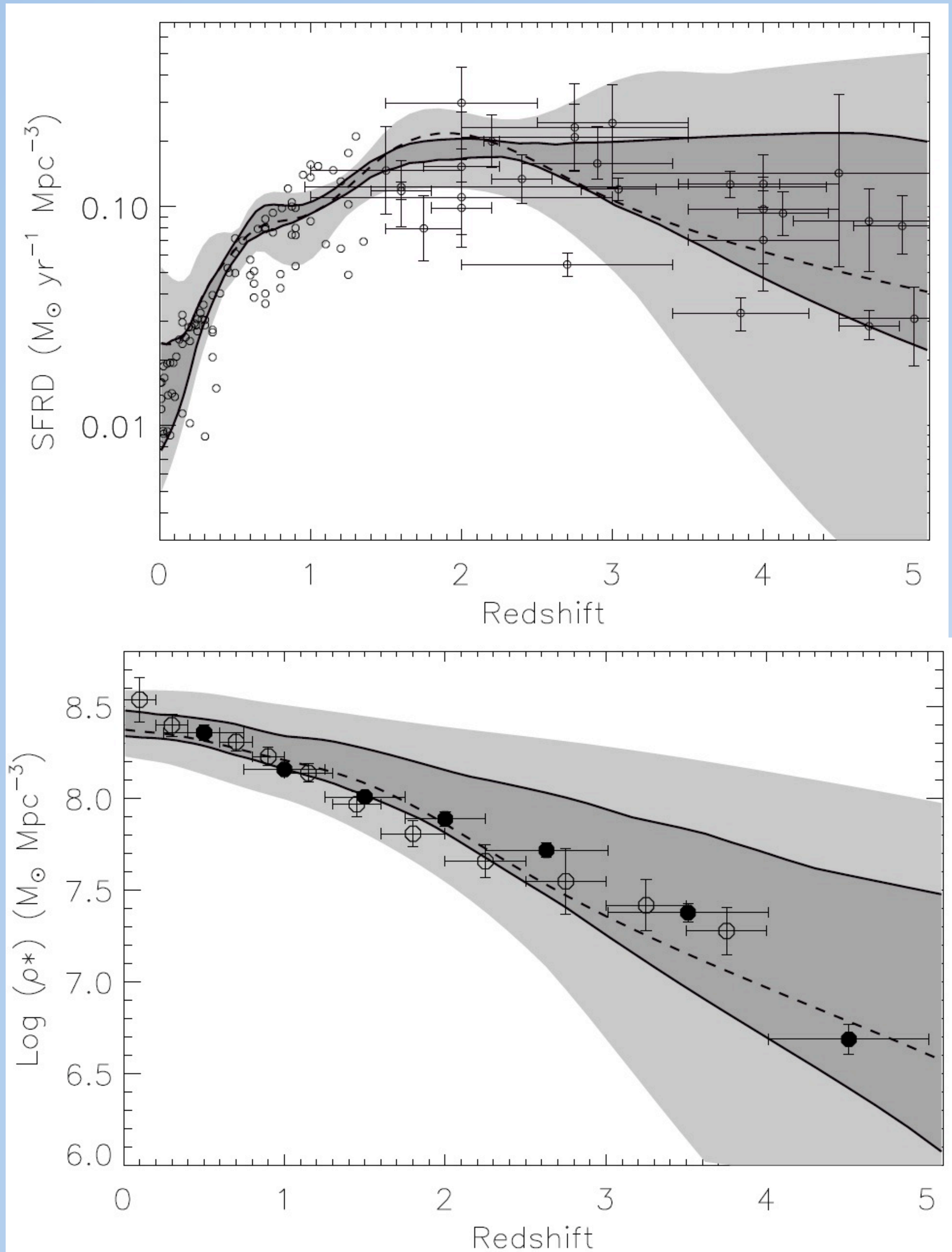


Conclusions

- 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 0.2<z<2** with reasonable uncertainties.
  - b) This inversion enables predictions at high redshift with the associated ***uncertainties***, in contrast to classical models of the star-formation history (which give *a single guess)*.
  - c) The **160 μm counts are slightly under-predicted** by our non-parametric inversion model which contains a maximum number of degrees of freedom. Issues at z<0.2
  - d) The model is marginally compatible with **Herschel counts** at 110, 250, 350, 500 microns
- Making a better model is difficult
  - Depends on the SEDs. Universal Main-sequence + Starbusrts SEDs are not good enough. Use SED physical models (Fioc et al, in prep, GRAZIL, …?)
  - Not one population SED(z, LIR) but two or more:
    LF_1(z,LIR) x LF_2(z,LIR) x …=> **Matrix sizes increase exponentially !**
  - Link optical and IR with consistent model ?



MIPS (24 μm)
ISO (15 μm) / IRS (16 μm)
MIPS (70 μm)
dN/dS * S^2.5 (mJy^1.5 deg^-2)
Flux (mJy)
ν I_ν (nW m^-2 sr^-1)
λ (μm)


SFRD ($M_\odot$ yr^{-1} Mpc^{-3})
0.10
0.01
0 1 2 3 4 5
Redshift
Log (ρ*) ($M_\odot$ Mpc^{-3})
8.5
8.0
7.5
7.0
6.5
6.0
0 1 2 3 4 5
Redshift