The Herschel heritage Tension between Herschel and SCUBA-2 results

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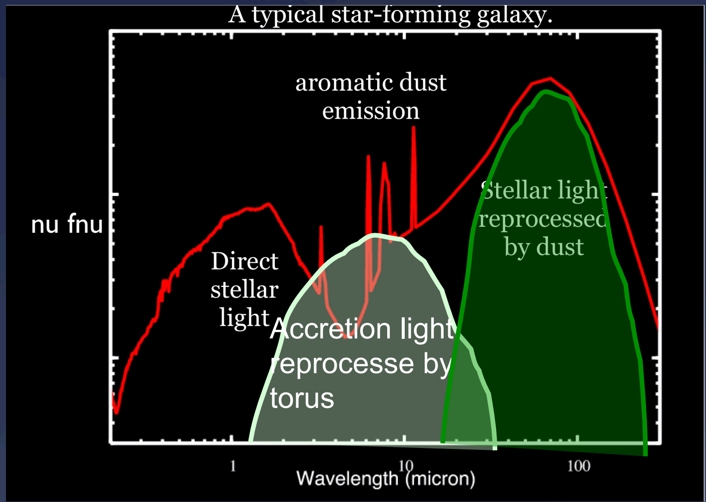
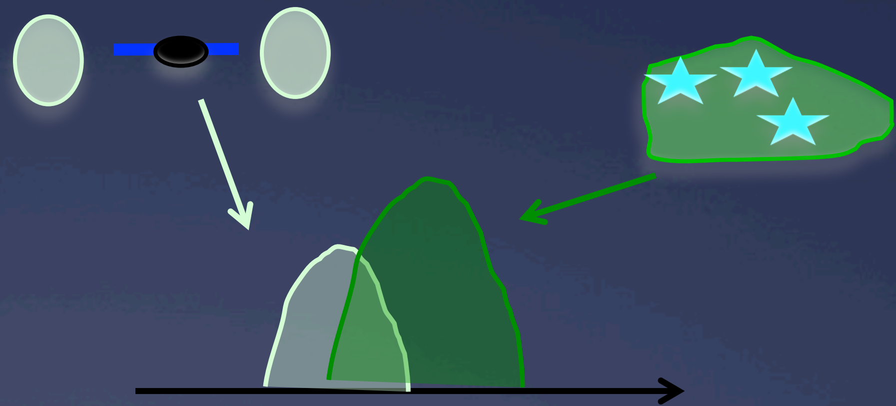
The need for IR studies

1) Recover the radiation absorbed and re-emitted in the IR **-> Measure SFR, L_{BH}**



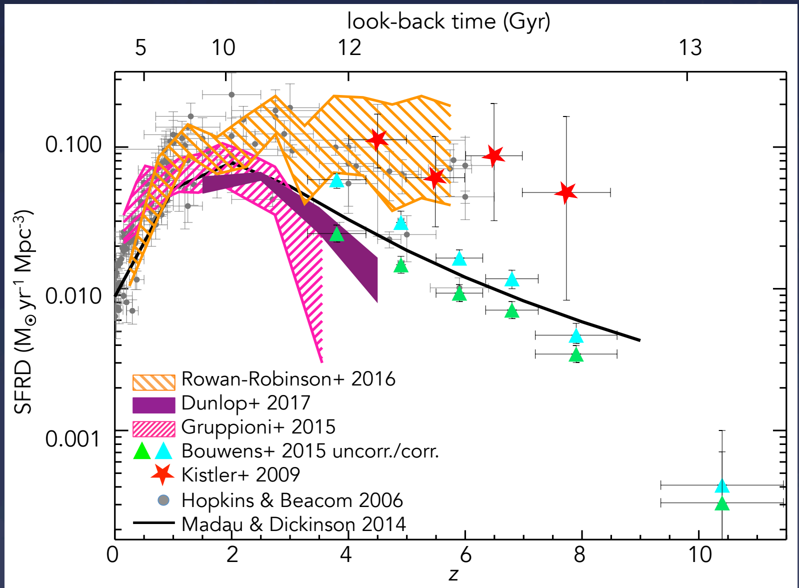


2) Recover the dust mass **-> Baryon Cycle**

$$M_{dust} = \frac{S_{250} D_L^2}{(1+z) k B(\nu, T)}$$

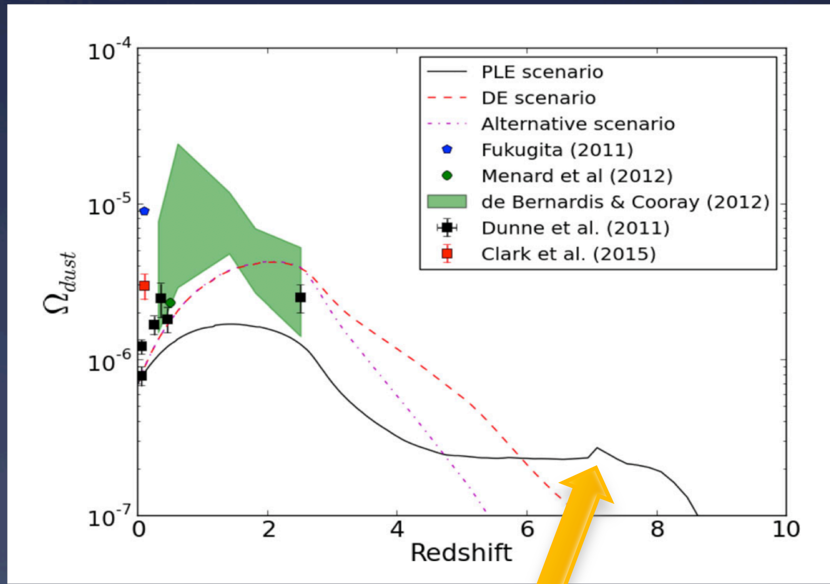
The need for IR studies

- Star formation and the obscured accretion history.



Gruppioni+17

- Evolution of the ISM content



Gioannini+18

ALMA

$T_{Universe}$(z~7)~ 0.7 Gyrs

(i.e. Venemans+17 Marrone+17)

Talk outline

1. Herschel IR luminosity functions

    Tension between Herschel and SCUBA-2 results
    Can (sub-)mm survey reliably trace the SFRD ?

    Koprowski+ 2017 work and our reply

    Gruppioni & Pozzi 2019

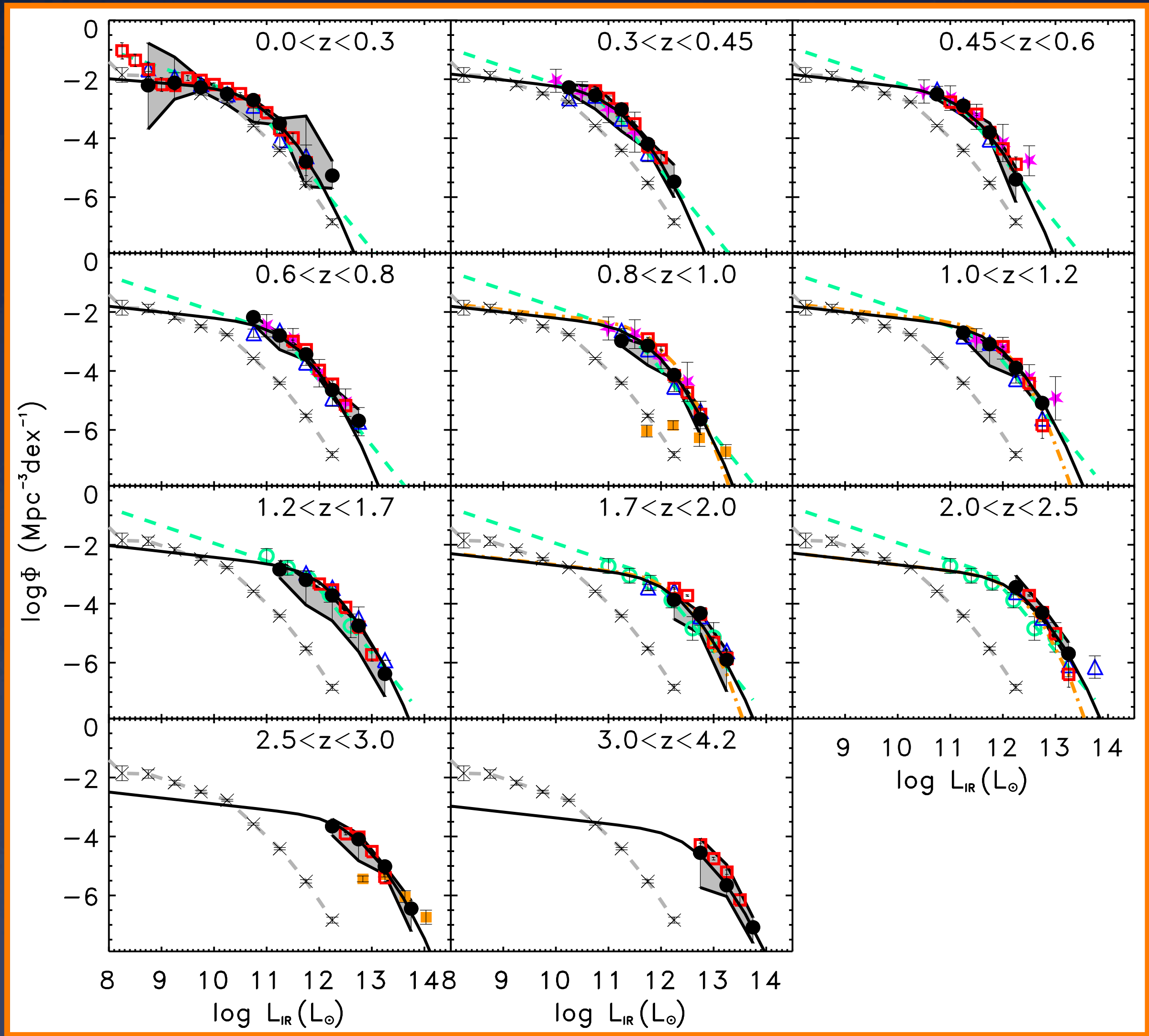
2. Dust density

4. The SPICA mission

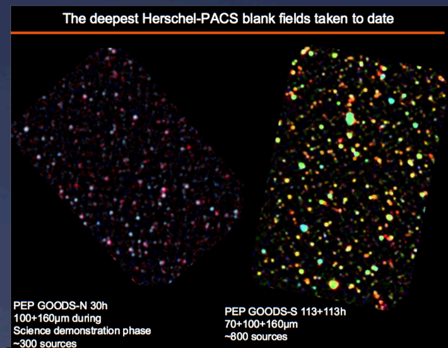
Part I: The LF luminosity function from a global SED fitting IR

I: The IR luminosity function from HERSCHEL survey

Gruppioni, Pozzi+13



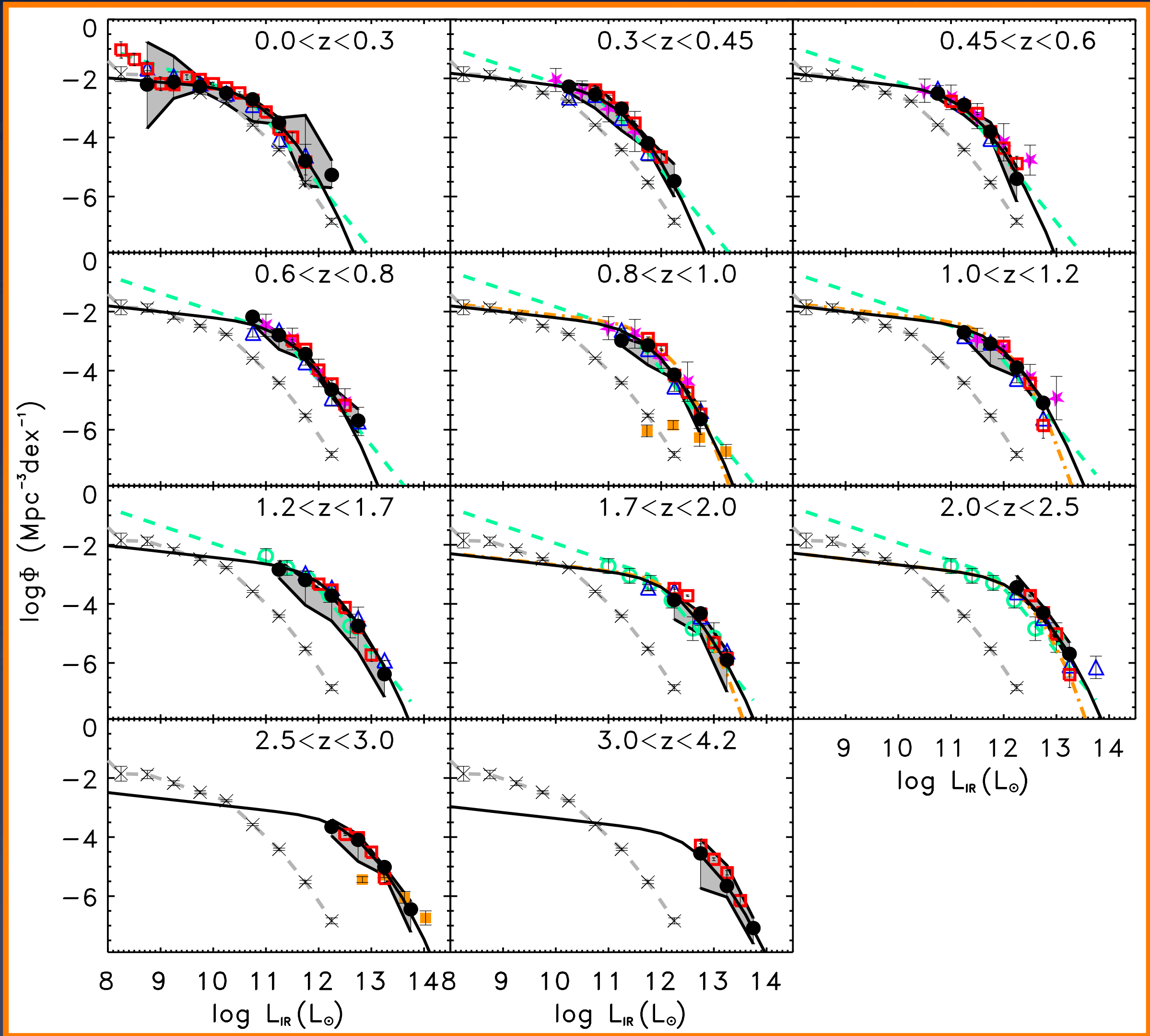
- Herschel Survey:
PEP (PI: Lutz)
- N. sources: ~7000
- Fields: COSMOS/GOODS



●		PEP Gruppioni+13
X		Sanders+ 03
■	sub-mm	Chapman 05
*	24 μm	Le Floc'h+ 05
O	24 μm	Magnelli+ 09, 11
△	24 μm	Rodighiero+ 11
□	HerMES	Vaccari+ in prep.

I: The IR luminosity function from HERSCHEL survey

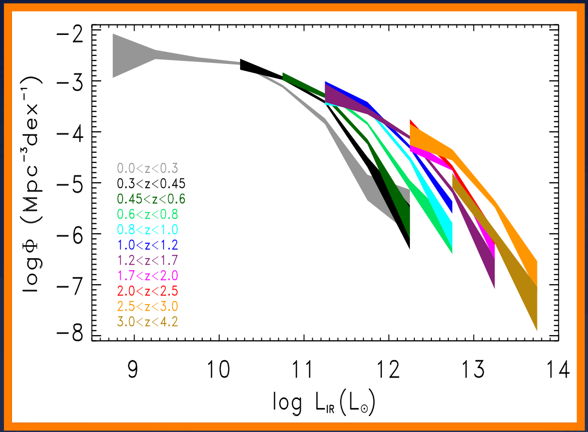
Gruppioni, Pozzi+13

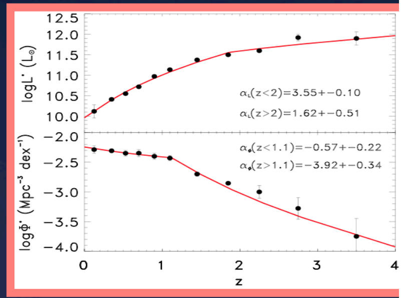


- 3<z<4 : first LF
- z<2.5 agreement Spitzer-based LF
- Strong evolution compared to local

● ▬		**PEP Gruppioni+13**
X - - - -		Sanders+ 03
■	sub-mm	Chapman 05
✱	24 μm	Le Floc'h+ 05
O	24 μm	Magnelli+ 09, 11
△	24 μm	Rodighiero+ 11
□	HerMES	Vaccari+ in prep.

Strong global evolution

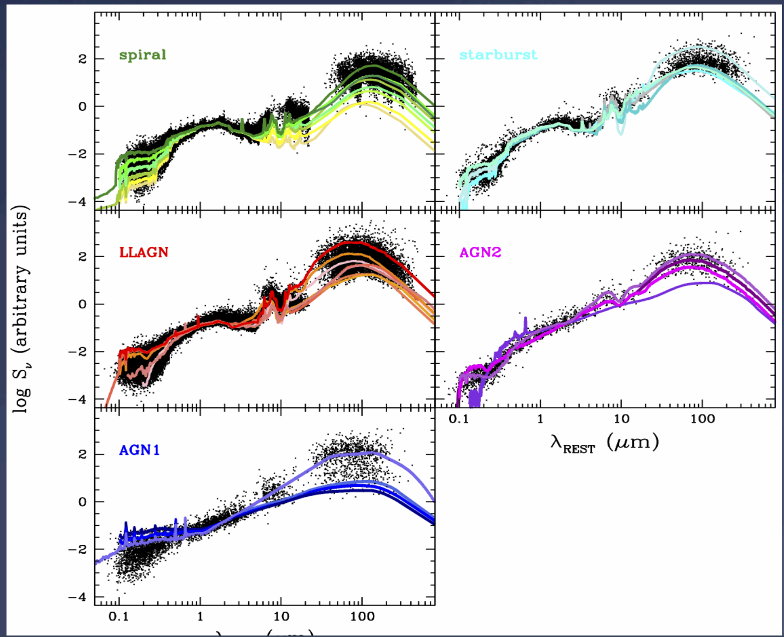


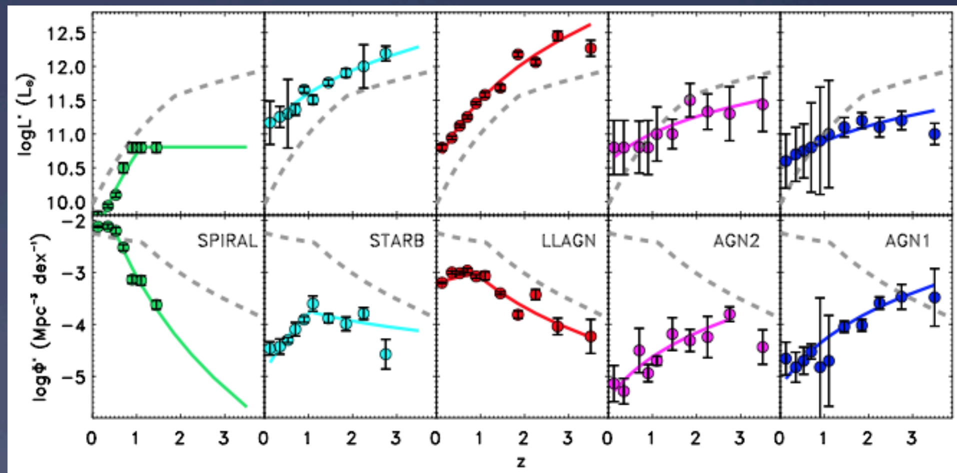


- **Global SED-fitting**
  Code: LePhare Code (Arnouts+02)
  Libraries: ~40 Templates (Polletta +07, Rieky+09 ,Gruppioni+10)

- **Templates divided into 5 Pop:**
  Spiral, Starburst (no AGN)
  AGN1, AGN2, SF-AGN (with AGN)
  SF-AGN AGN feature appear only on the 3-20 μm range (Seyfert 1.8/2, LINER. i.e. NGC6240, IRAS 20551-4250)

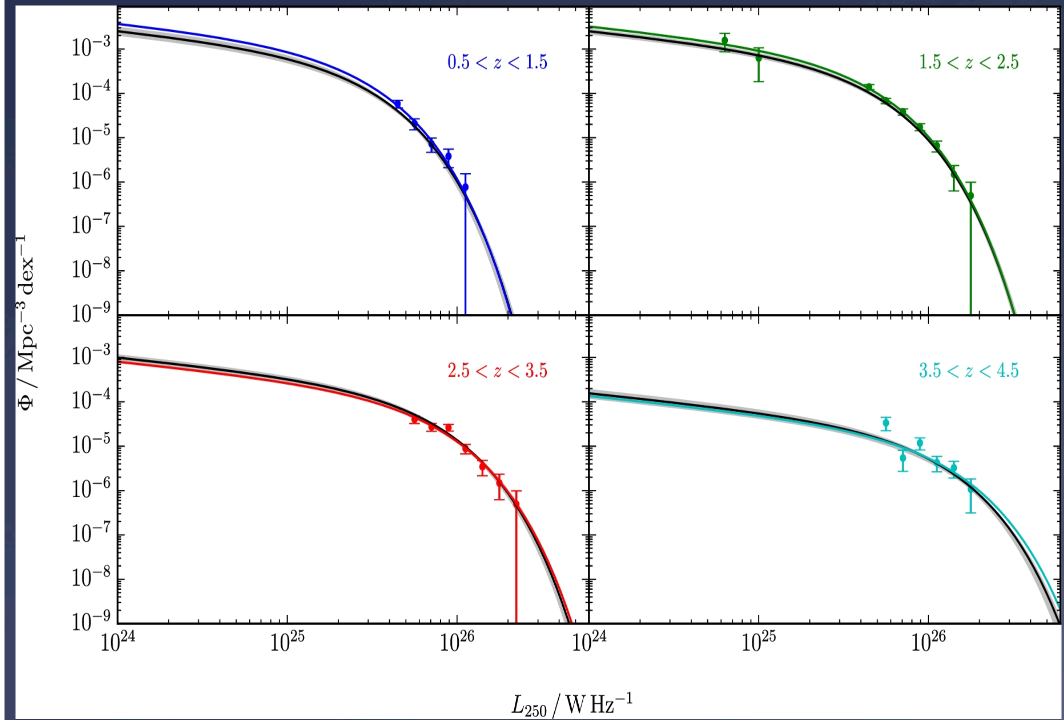
But different Populations evolve Differently





Disagreement between Herschel and SCUBA-2 results

Koprowski+ 2017: *"A number of recent studies have already provided indications that the high values of ρ_{FIR} inferred from pushing the" Herschel surveys beyond z ≃ 2 are incorrect."*



Sample:

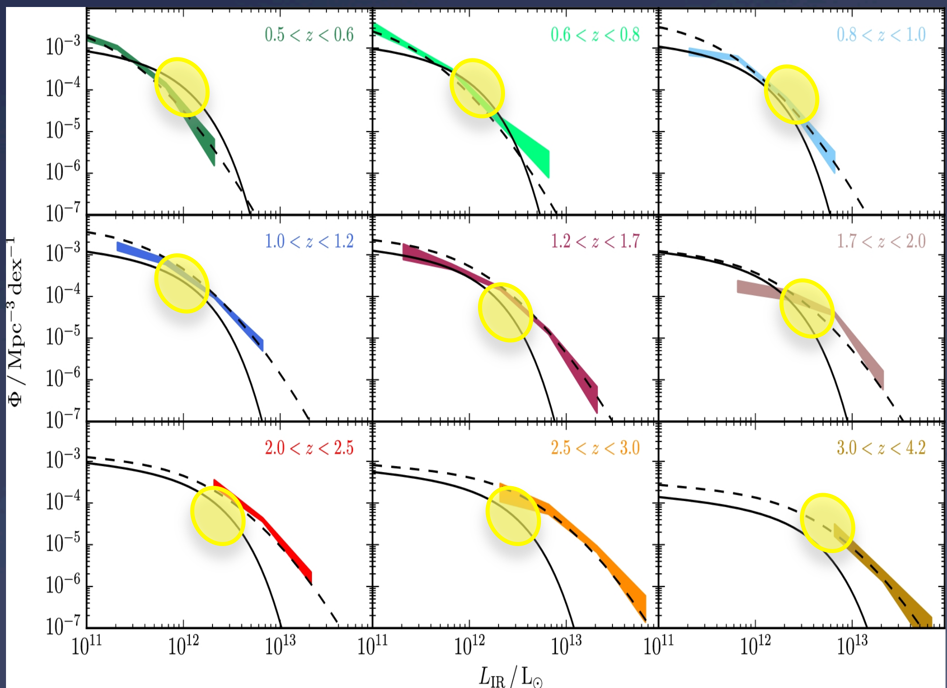
- 577 src with $S_{850\mu m}$ SCUBA-2 > 3.75 mJy
- 1.58 deg^2 (COSMOS+UDS)

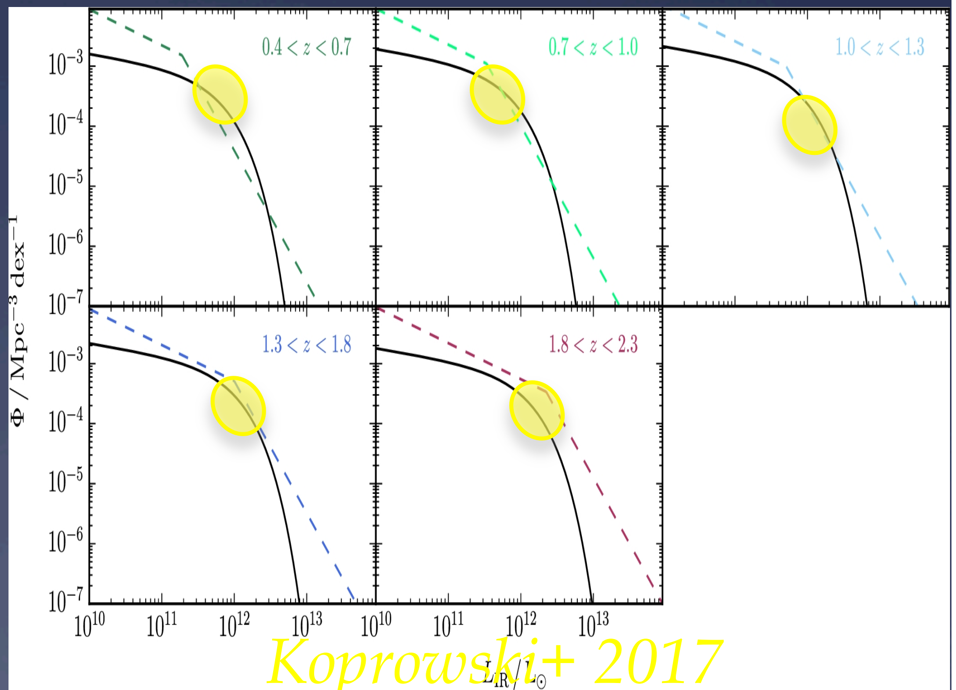
Koprowski+ 2017

SCUBA-2 LF results versus Herschel cosmological surveys

b) PEP/HERMES survey
Gruppioni+13
Black lines: SCUBA-2
Colored lines: Herschel

a) H-GOODS survey
Magnelli+13
Black lines: SCUBA-2
Colored lines: Herschel

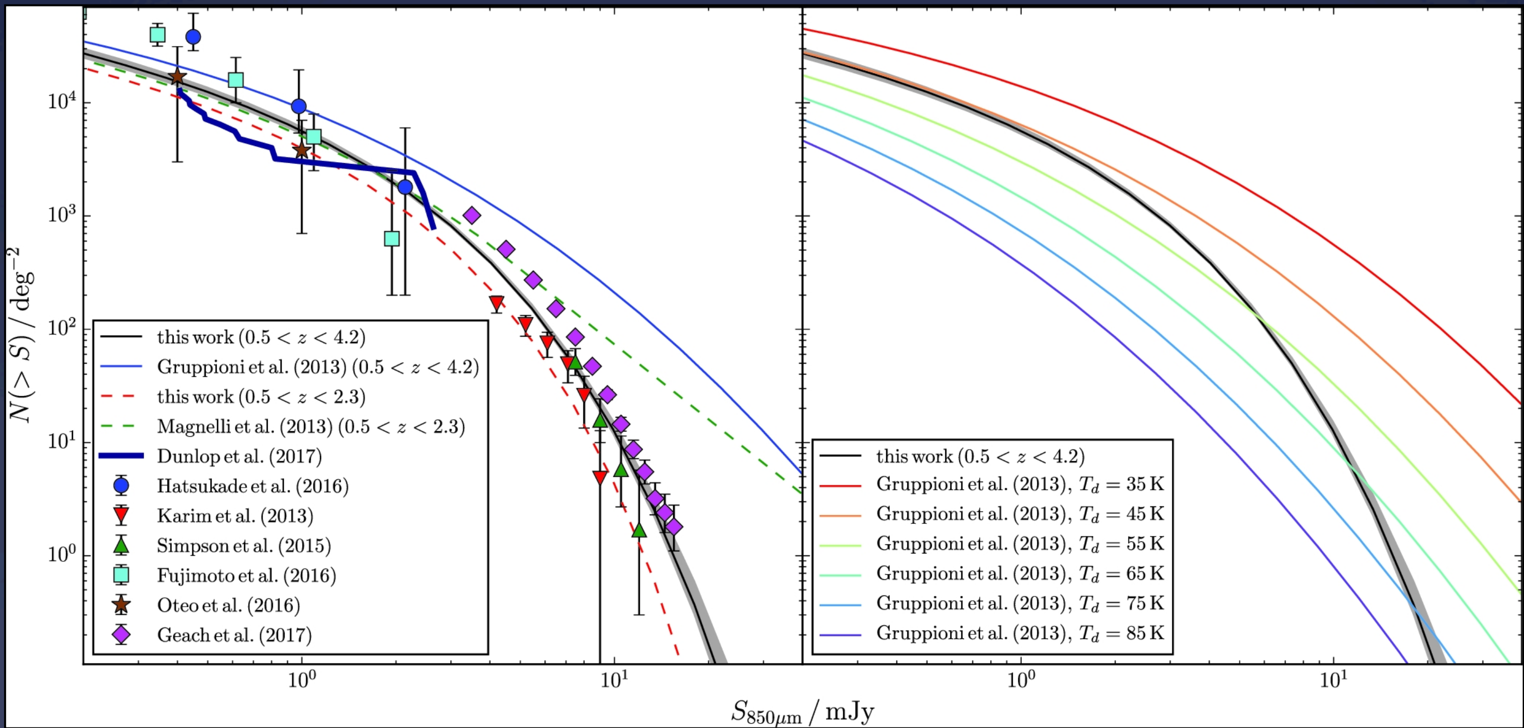




Source counts at 850 μm

Koprowski+ 2017

"Clearly, the *Herschel*-derived LFs wildly overpredict the actual number of bright 850-μm sources. […] by a factor of 15-20"



Koprowski+ 2017

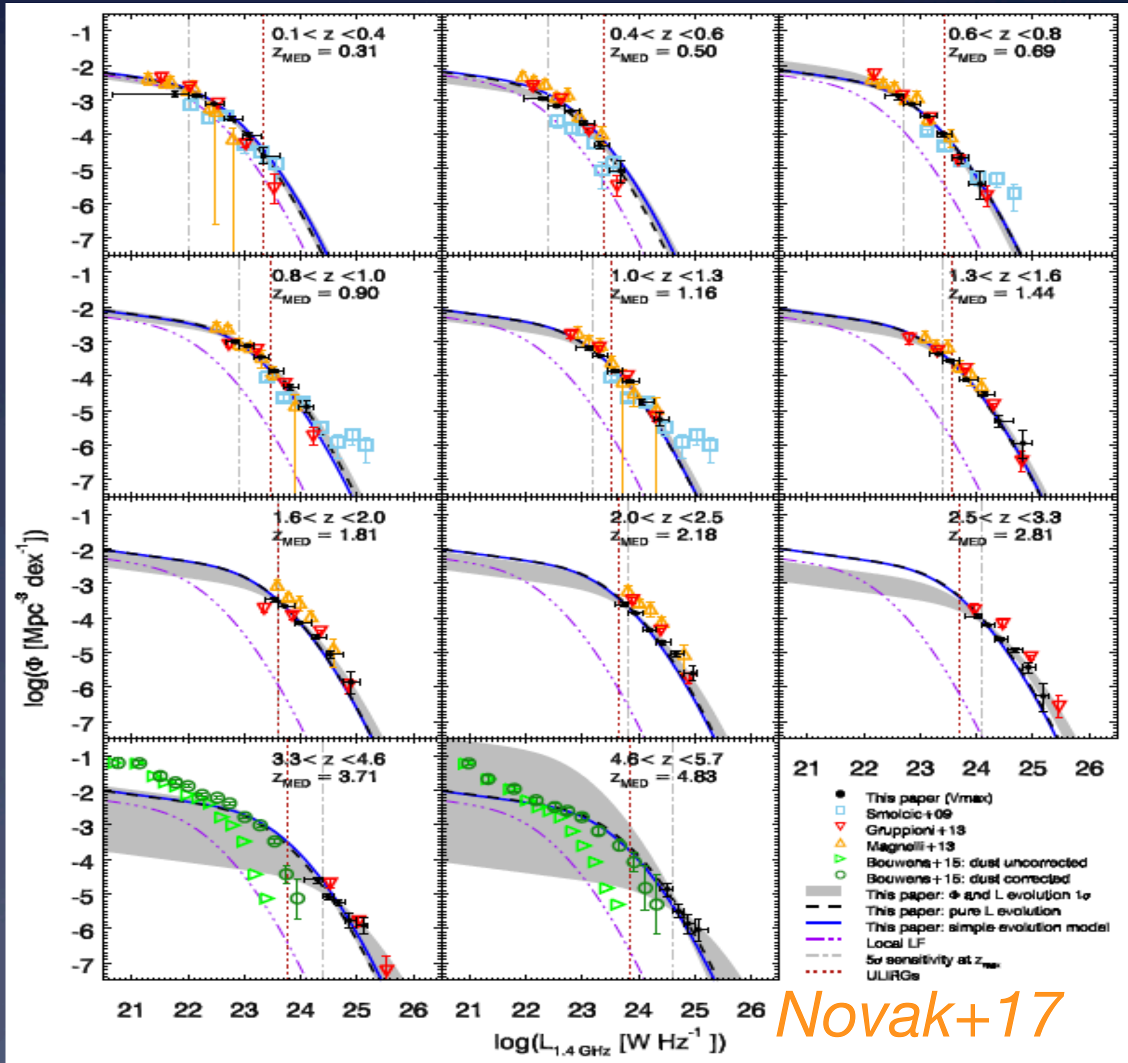
Herschel LF versus other independent IR LF

I) Radio luminosity

L_{IR} → $L_{1.4GHz}$

$q = \log(L_{IR}) - \log(L_{1.4GHz})$

Novak+17



Herschel LF versus other independent IR LF

II) CO luminosity

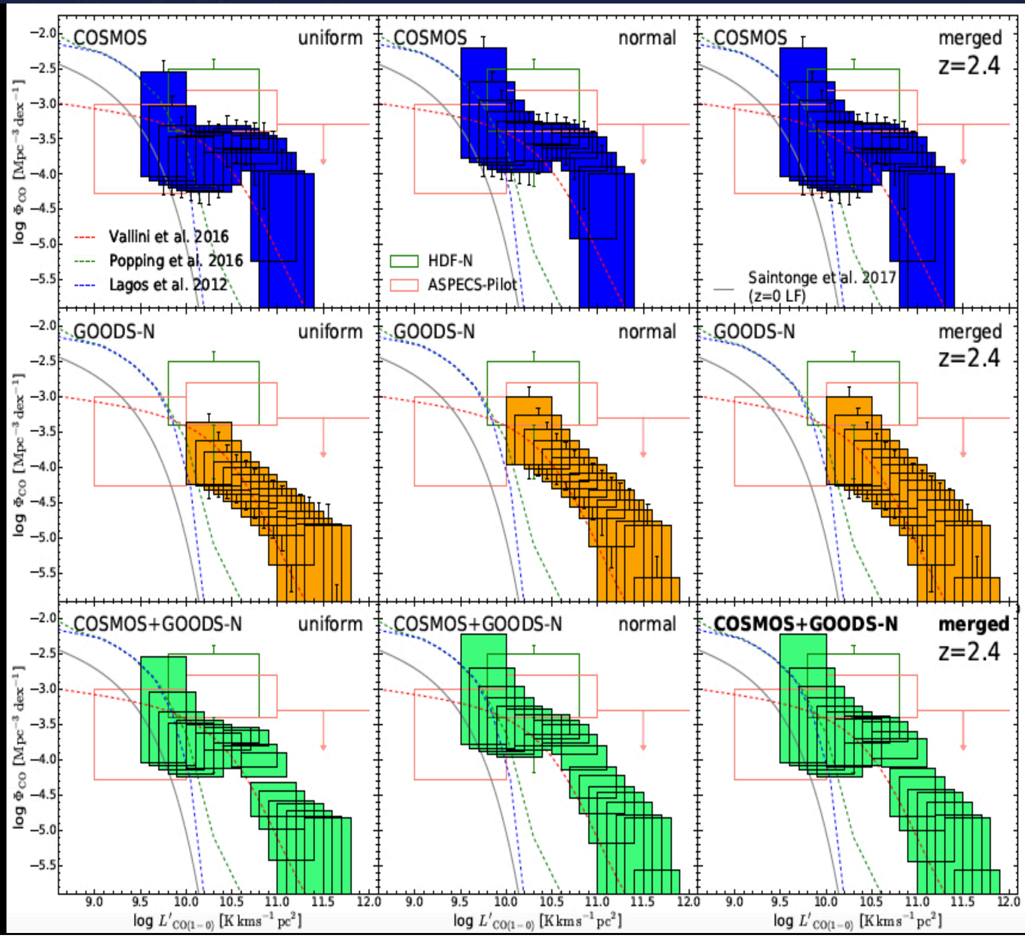
L_{IR} → L_{CO}

$log(L'_{CO})=\alpha \cdot log(L_{IR})+\beta$

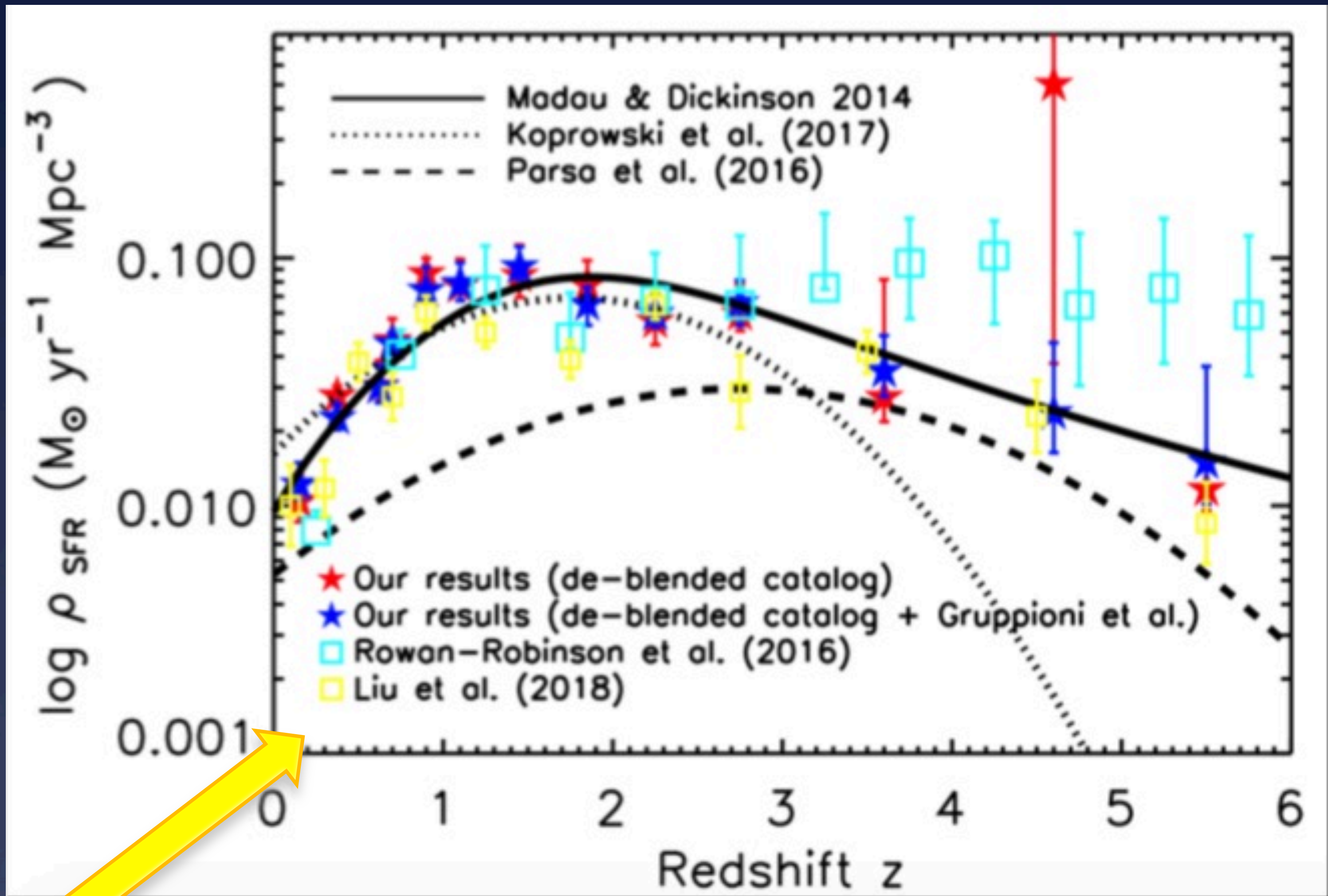
IR LF: Gruppioni+13

Vallini, Gruppioni,Pozzi+16

good agreement between Herschel LFs and totally independent derivations.



Riechers+ 2018: the characteristic luminosity and bright end of the CO luminosity function are higher than predicted by semi-analytical models, but consistent with empirical estimates based on the infrared luminosity function at **z**=2.



Wang+19, A&A submitted

Liu, Daddi+18:

SFRD from super-deblended catalog (radio & 24 μm)

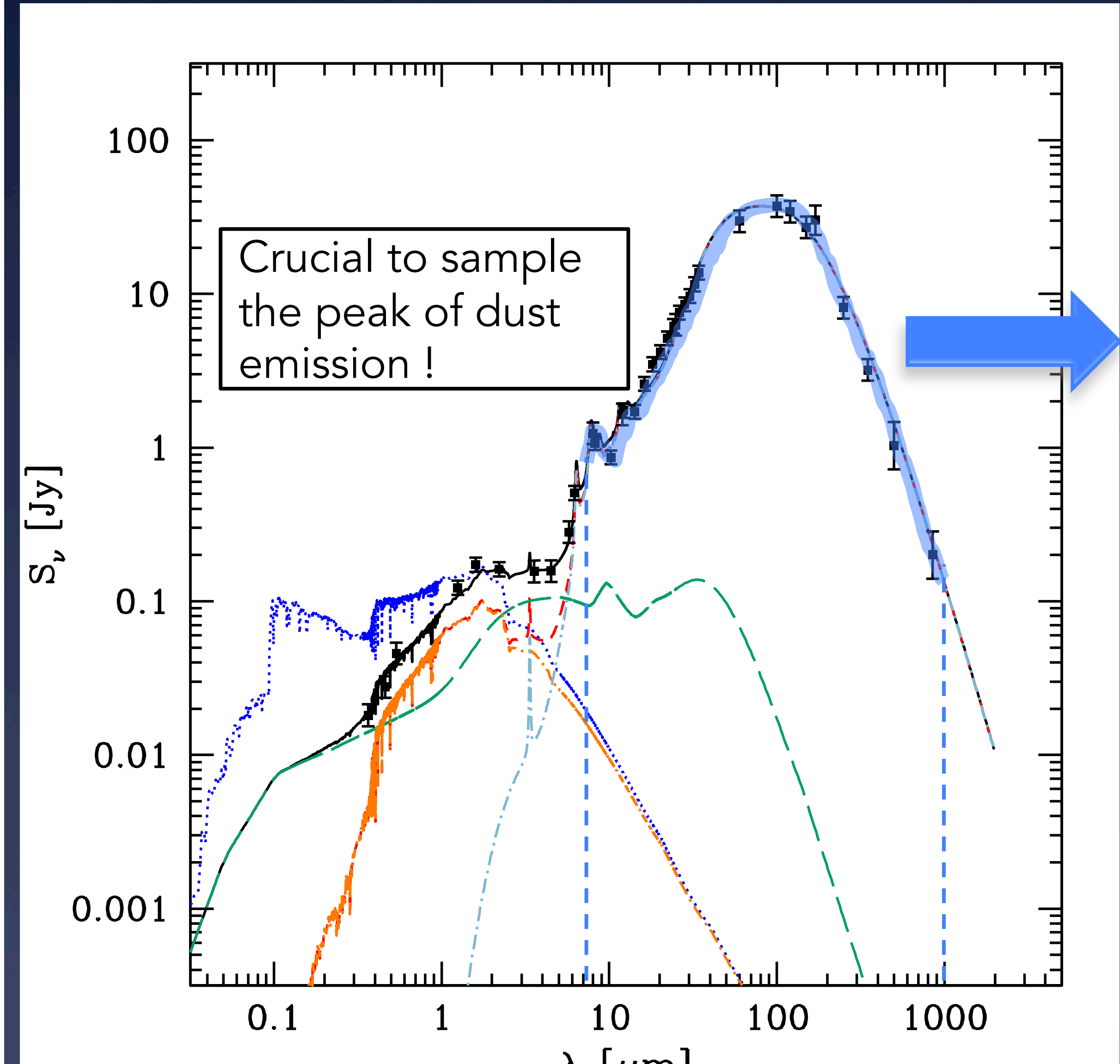
Possible causes of disagreement

Gruppioni & Pozzi 2019

1. Different SEDs to derive L_{IR} (integrated 8-1000 μm)
   -> need to sample the IR bump (~70-100 μm rest-frame)

2. Different selection band and flux limit

Reliable SEDs to derive L_{IR}

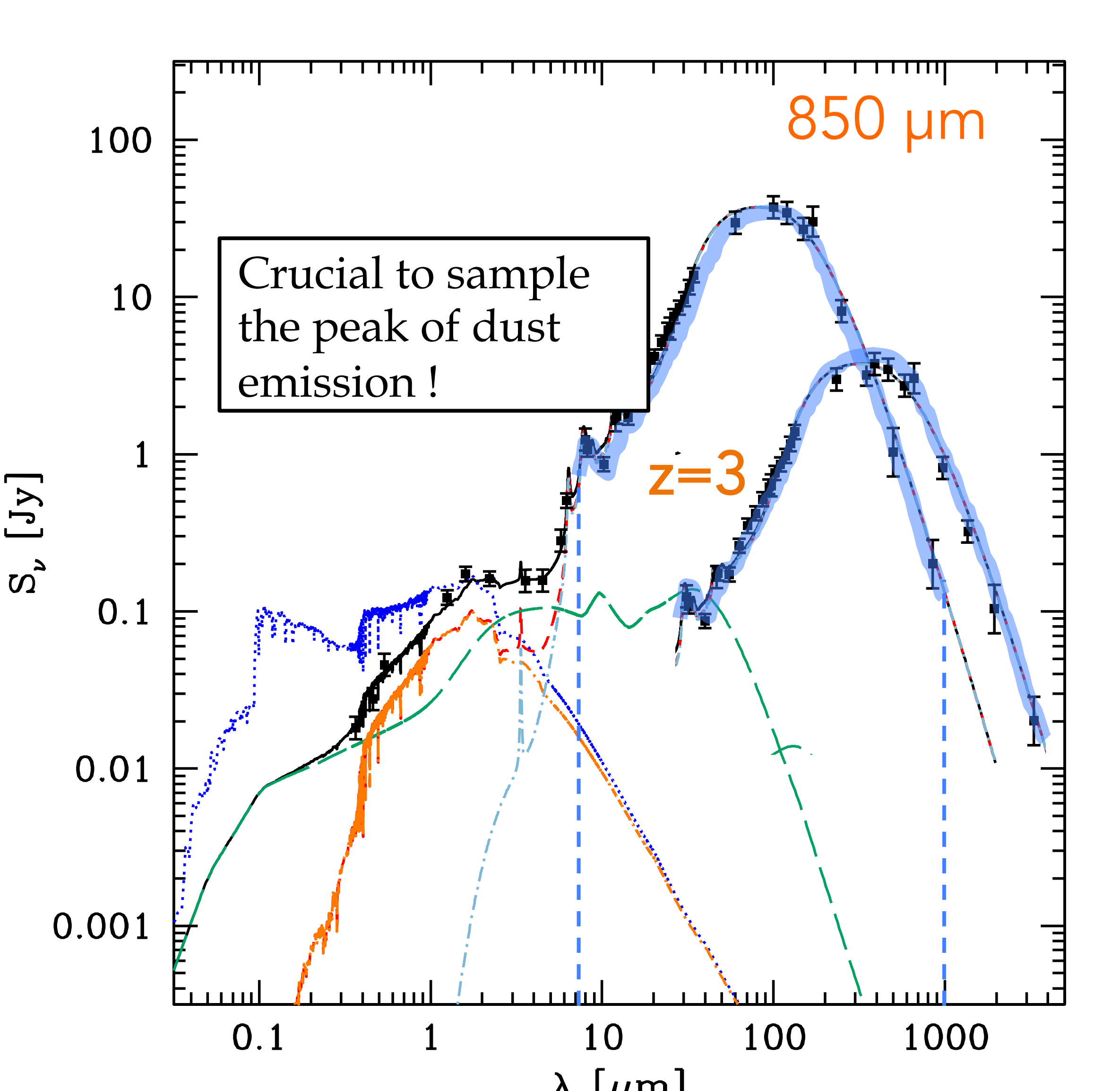


From the galaxy model:

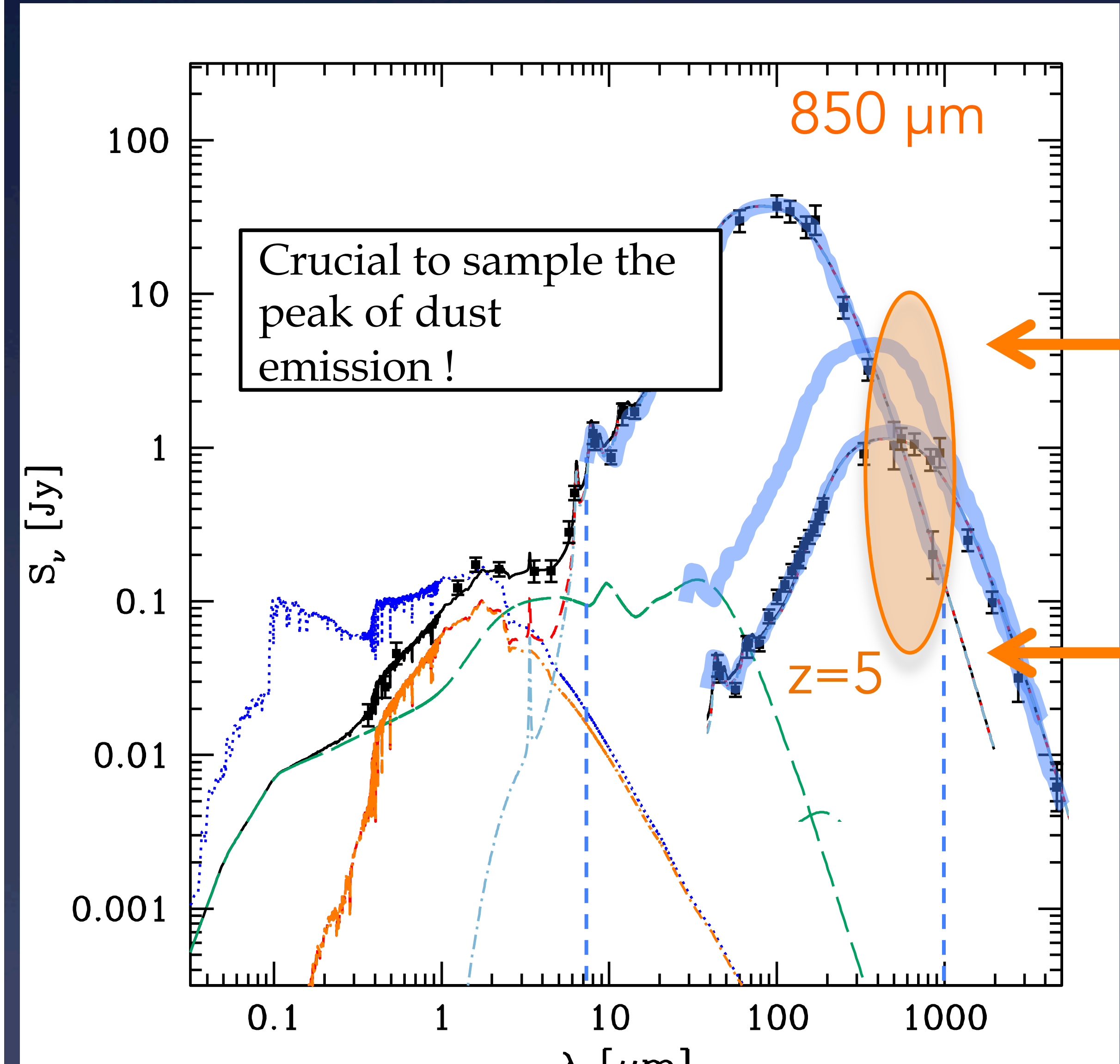
L_{IR}^{SF}

(luminosity re-emitted from dust in the IR = luminosity absorbed in the optical/UV)

Reliable SEDs to derive L_{IR}



Reliable SEDs to derive L_{IR}



Sub-mm range:

@ z>3-4 the sub-mm band starts sampling the IR peak

@ z>5-6 the sub-mm range samples the IR peak

Reliable SEDs to derive L_{IR}

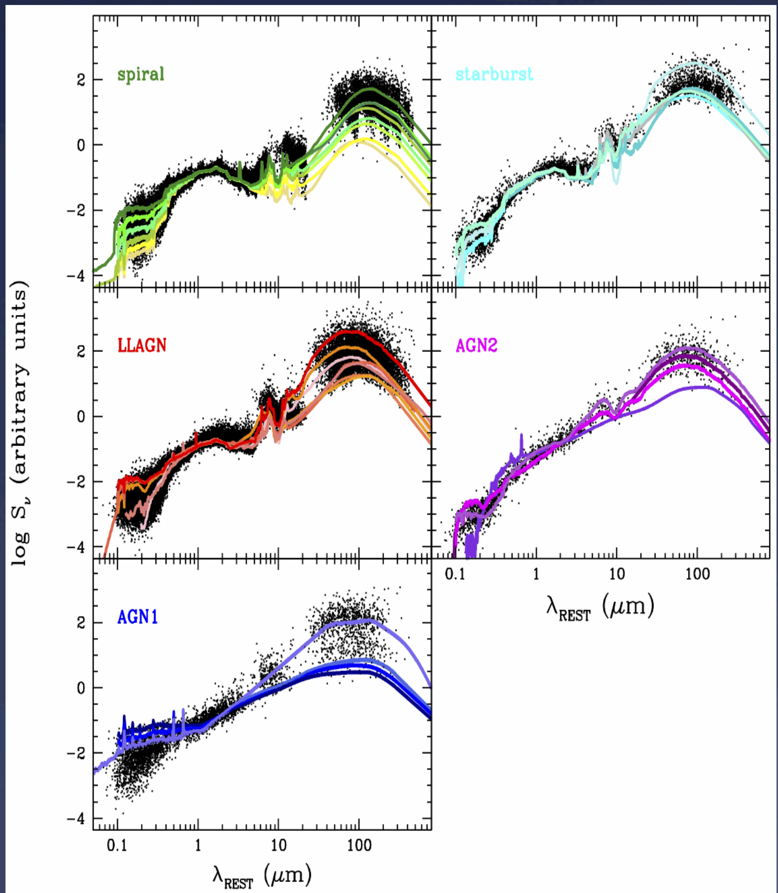
Gruppioni, Pozzi et al. 2013

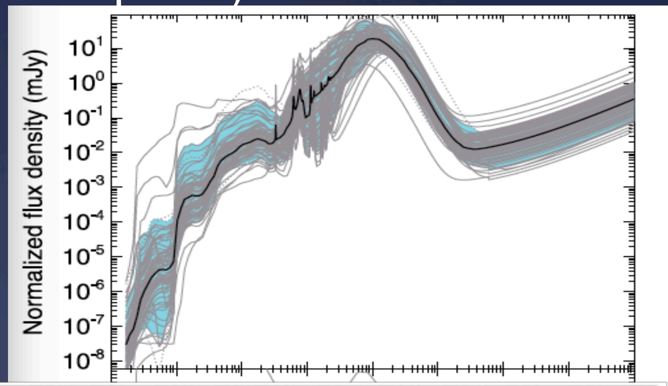
- Herschel (70-500 μm) samples the peak
- 40 SEDS spanning from spirals to AGNS

Koprowski+ 2017:

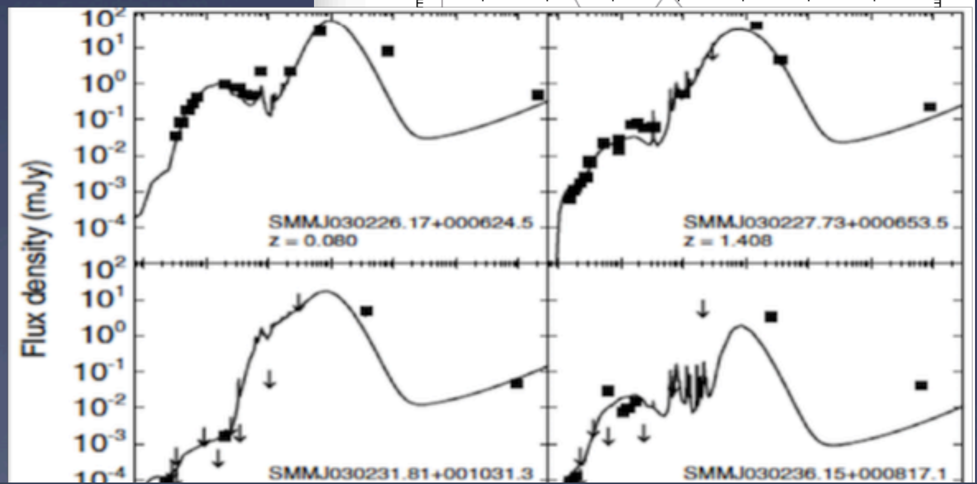
- Sub-mm samples the peak at z>4
- ONE SED for all the sources:the one derived by Michalowski+10 as median SED for SMGs (also Dunlop+16)

Gruppioni et al.13





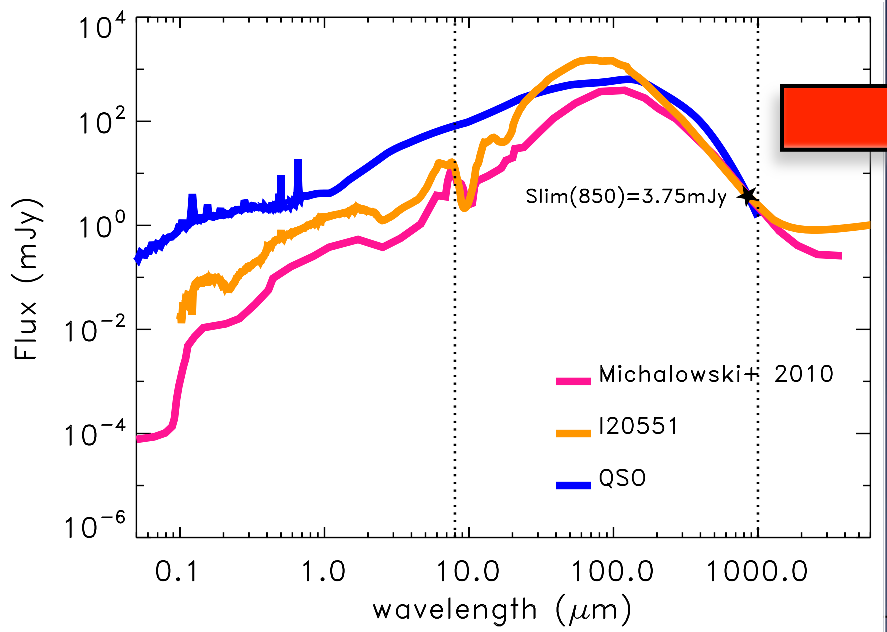
Michalowski 10

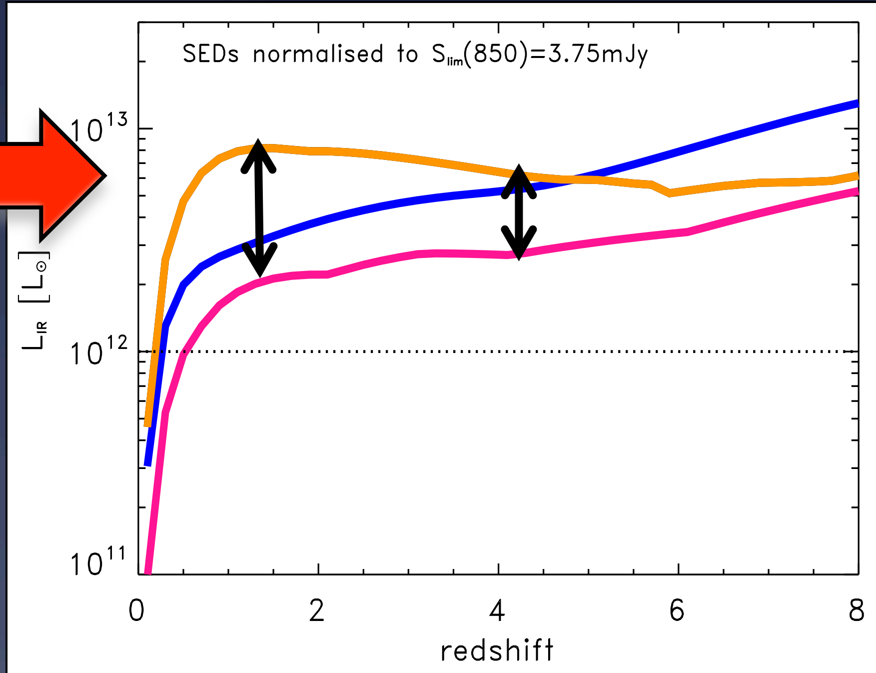


Conseguences SED: *L_{IR} severely underestimated by sub-mm*

3 typical SEDs normalized to the SCUBA limit

I20551, QSO : HERSCHEL
Michalowski 10: SCUBA

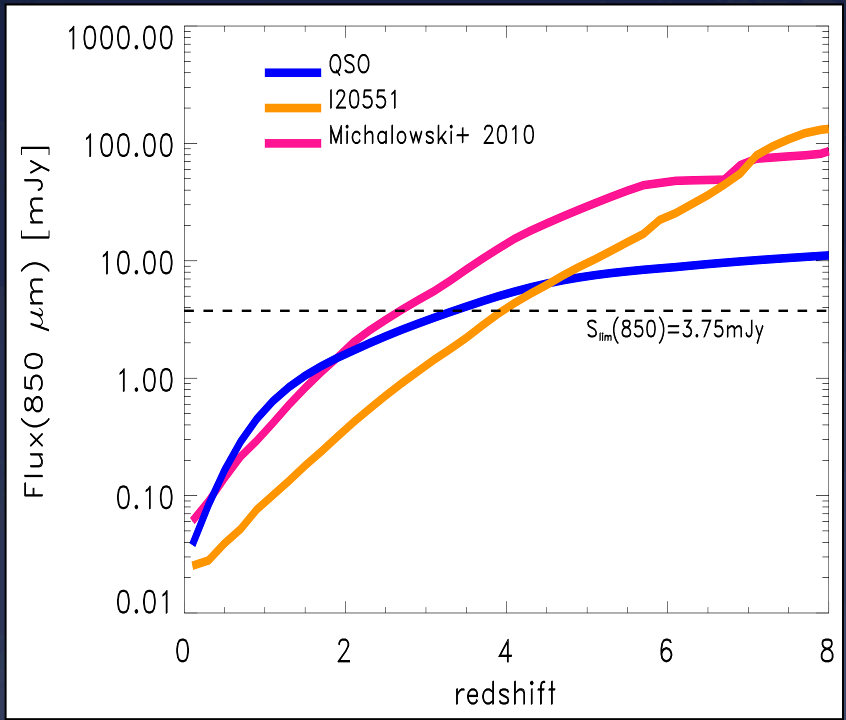


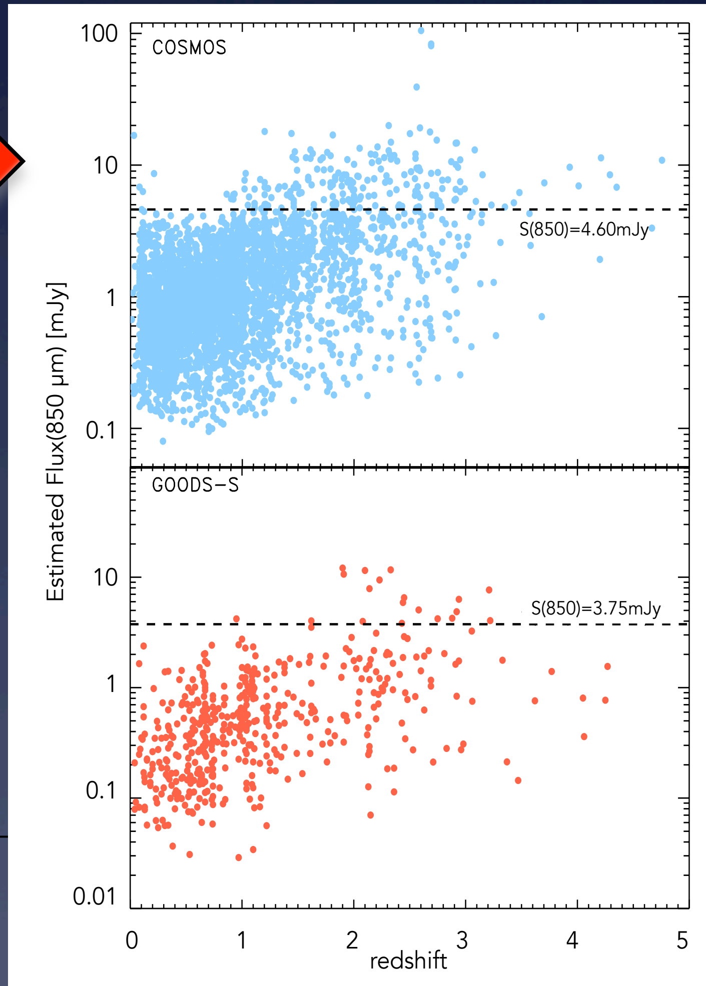


SED effect: *L_{IR} severely underestimated if the proper SED is not considered* the current 850-μm surveys DO NOT miss only low-L sources: at z>0.5 only ULIRGs detectable

Conseguences selections: *Sub-mm selection miss sources*

typical SEDs normalized to the HERSCHEL limit



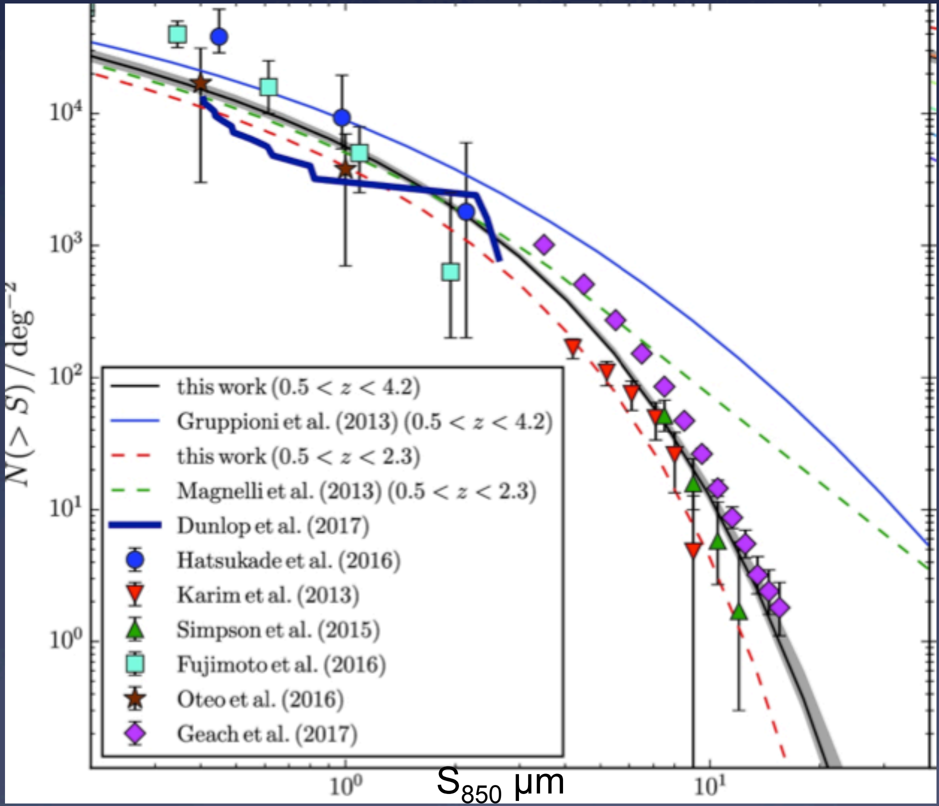


Limiting flux effect: at z<2 (z<4), sources with SEDs similar to the Michalowski+ 2010 (I20551s) template are missed in an 850-μ m survey limited to 3.75 mJy

Sub-mm selection effect: a SCUBA-2 survey with such a limit looses many sources at low z and also the "warmer" ones at high-z

Source counts at 850 µm

Koprowski+ 2017 *"Clearly, the Herschel-derived LFs wildly overpredict the actual number of bright 850-µm sources. […] by a factor of 15-20"*



Koprowski+ 2017

Source counts at 850 μm

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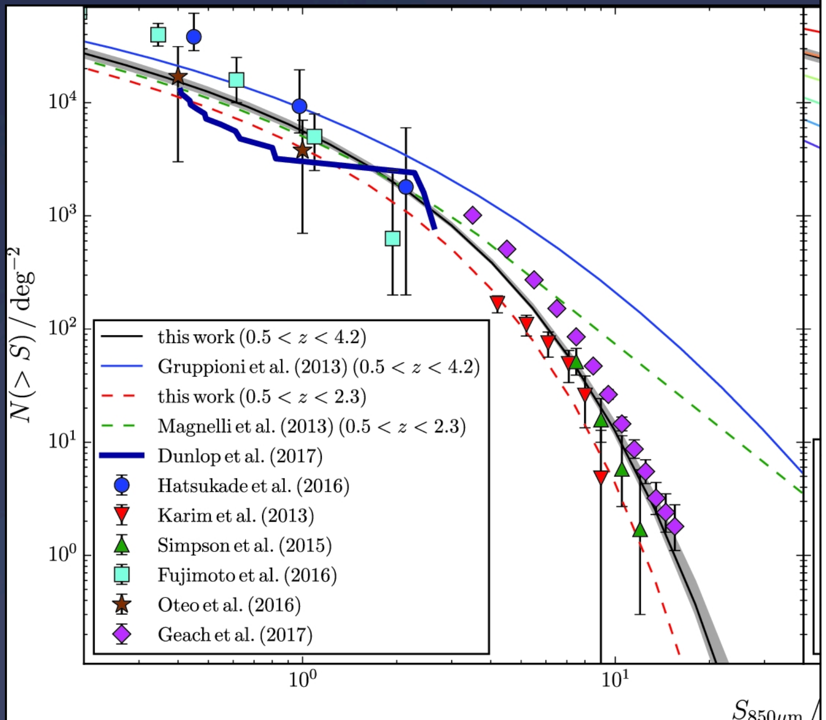
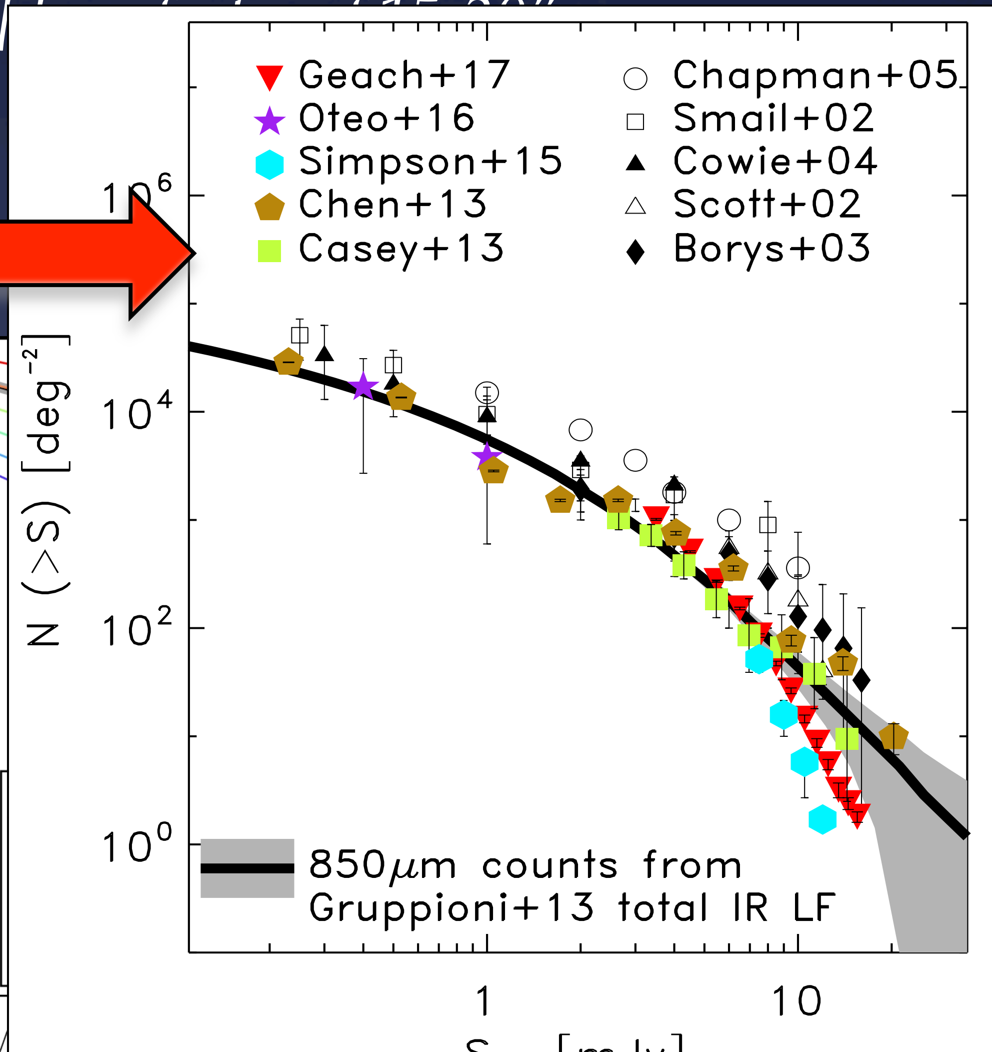
Gruppioni & Pozzi 2019





Summary part I

- Recent SCUBA-2 works IR LFs in strong disagreement with Herschel results

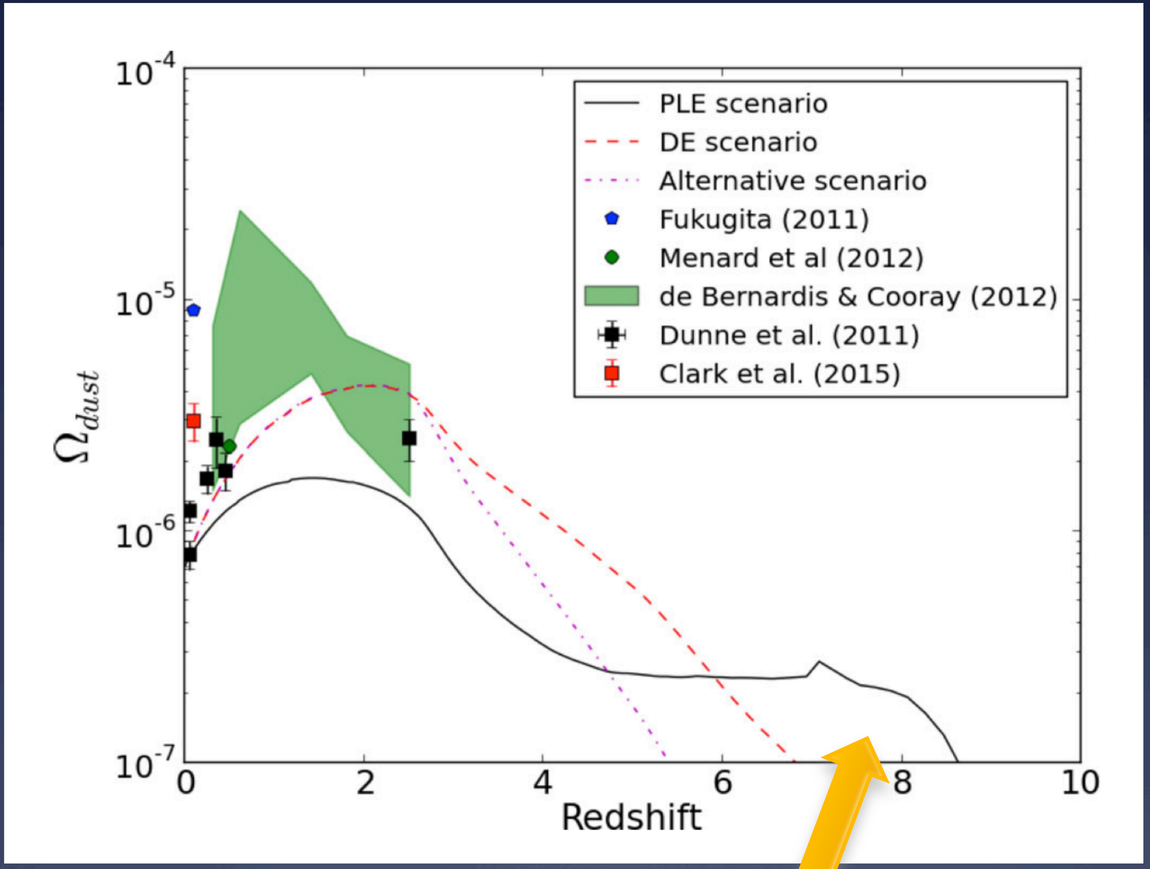
  The conversion to L_{IR} is performed using a single average SED for the whole sample (i.e., not fitting source-by-source)

  L_{IR} is severely underestimated

- The 850-μm selection misses a significant fraction of Herschel sources, mainly those with warmer SEDs, that are found to dominate the bright-end of the IR LF at high-z.

Part II: The dust mass density

Dust mass density from Herschel



Gioannini+2018

ALMA

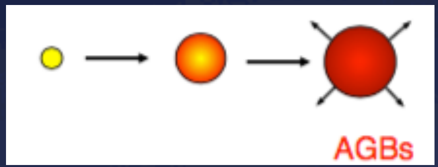
$T_{Universe}$(z~7)~ 0.7 Gyrs

(i.e. Venemans+17

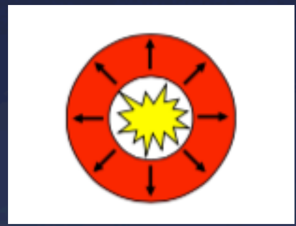
Marrone+17)

WHY Dust production mechanism

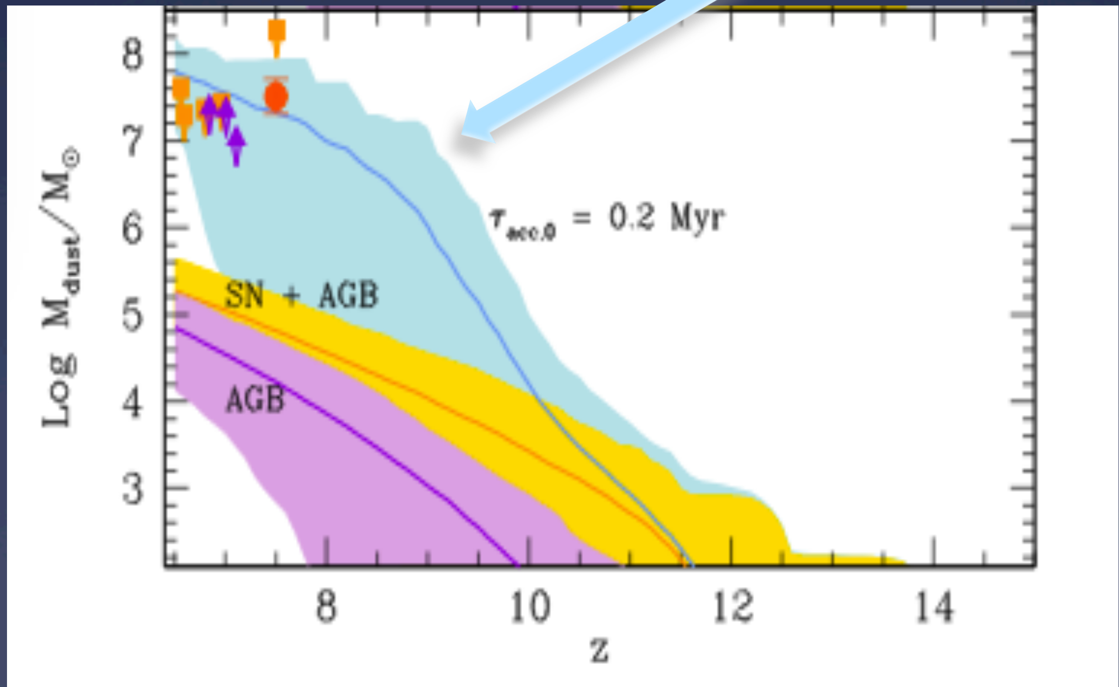
AGB



SNe



Grow in dense ISM



Mancini+15, see also Popping+17

2 critical points

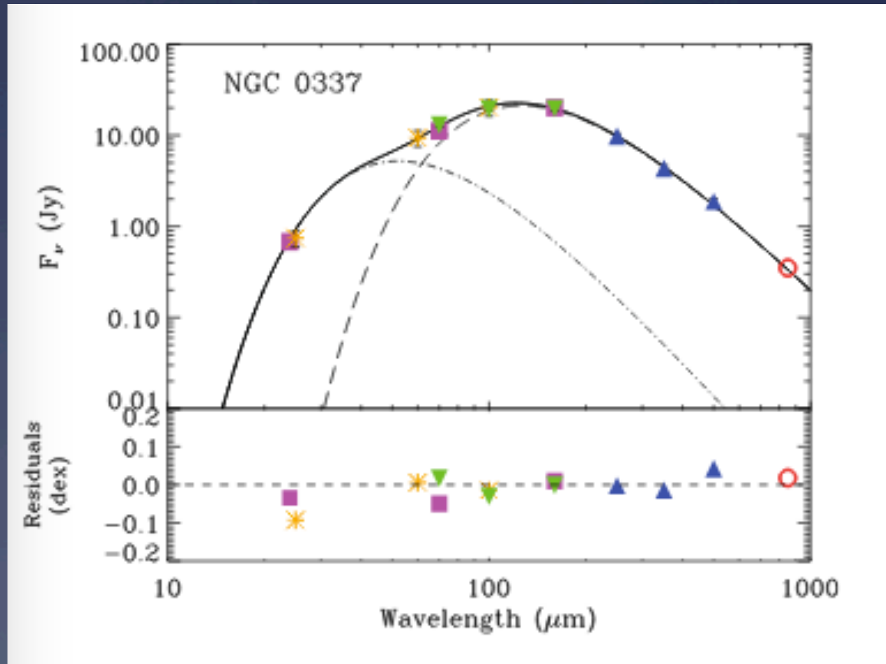
a) *accurate dust masses*
b) *incompleteness*

a) Dust masses

$$M_d = \frac{D_L^2 S_{obs}}{(1+z)kB(T)}$$

1) M_{dust} : Modified Black Body
(e.g. *Bianchi 2013, Hunt+18)*

2) 1 single component
Only ≤20 % in the warm *(Dale+13)*

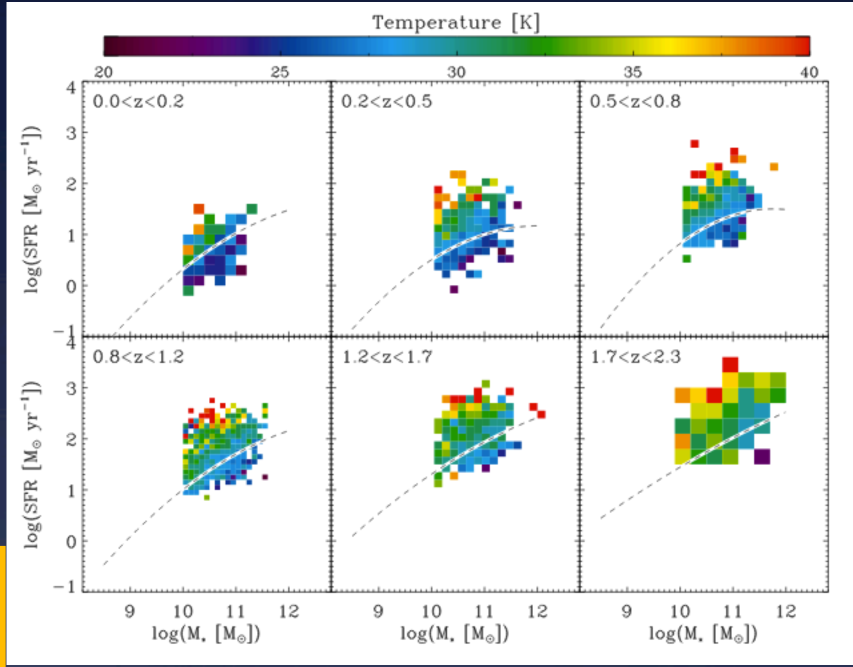


Galametz+12

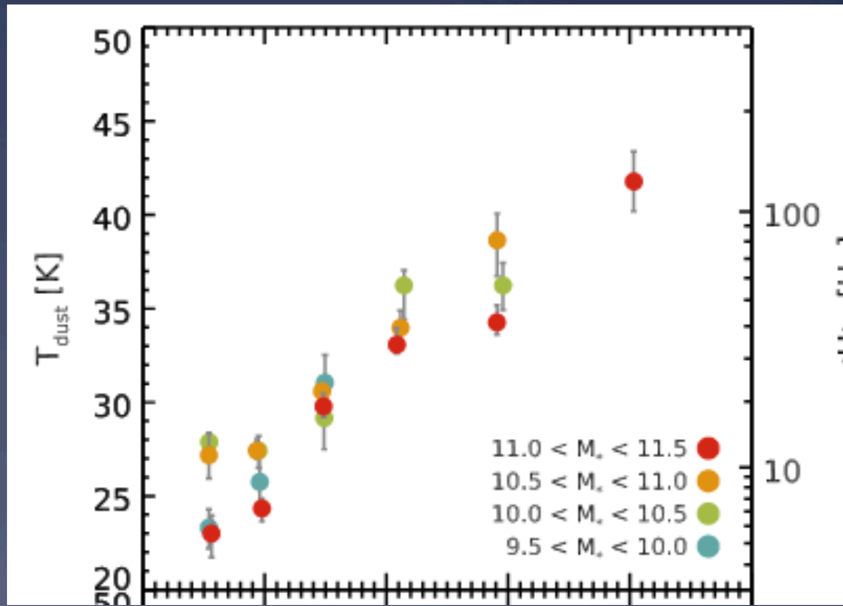
Dust masses

$$M_d = \frac{D_L^2 S_{obs}}{(1+z)kB(T)}$$

3) Temperatures: Magnelli+14
(see also Schreiber+18) stacked data
160-μm selection
✔ for L_{IR} (*see Gruppioni & Pozzi 2019*)
but does not sample the RJ-tail at z~2.



Magnelli+14



Schreiber+18

Completeness

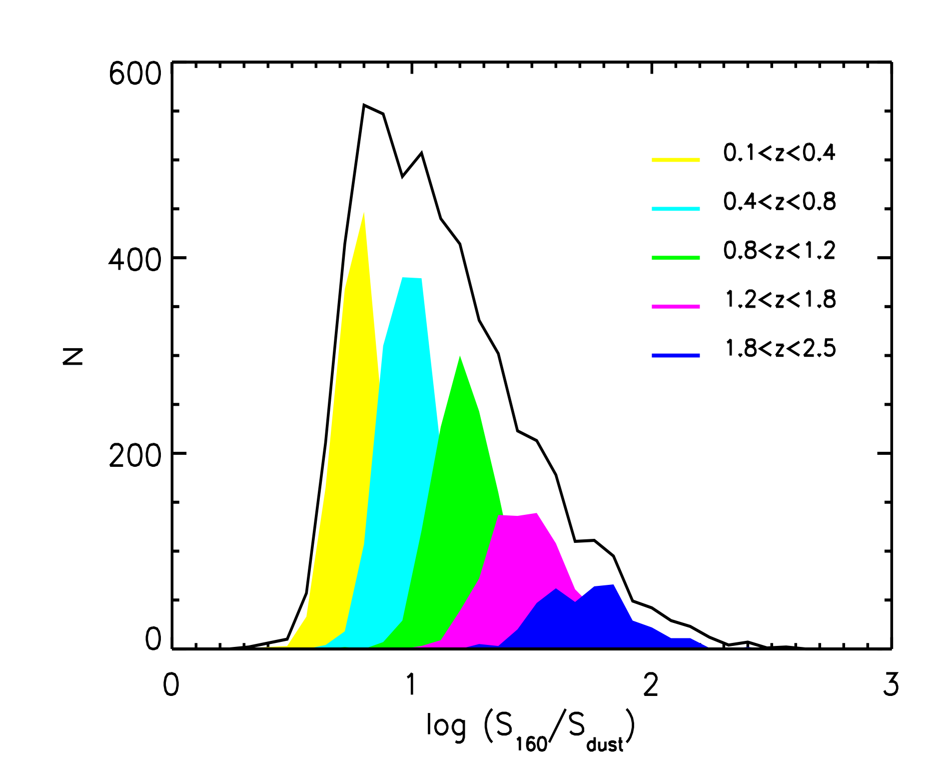
[completess in M_{dust} from an undirect selection (160- μm)]

Convolution of the 160-*μm* counts with the S_{160}/S_d ratio *Delvecchio+14*

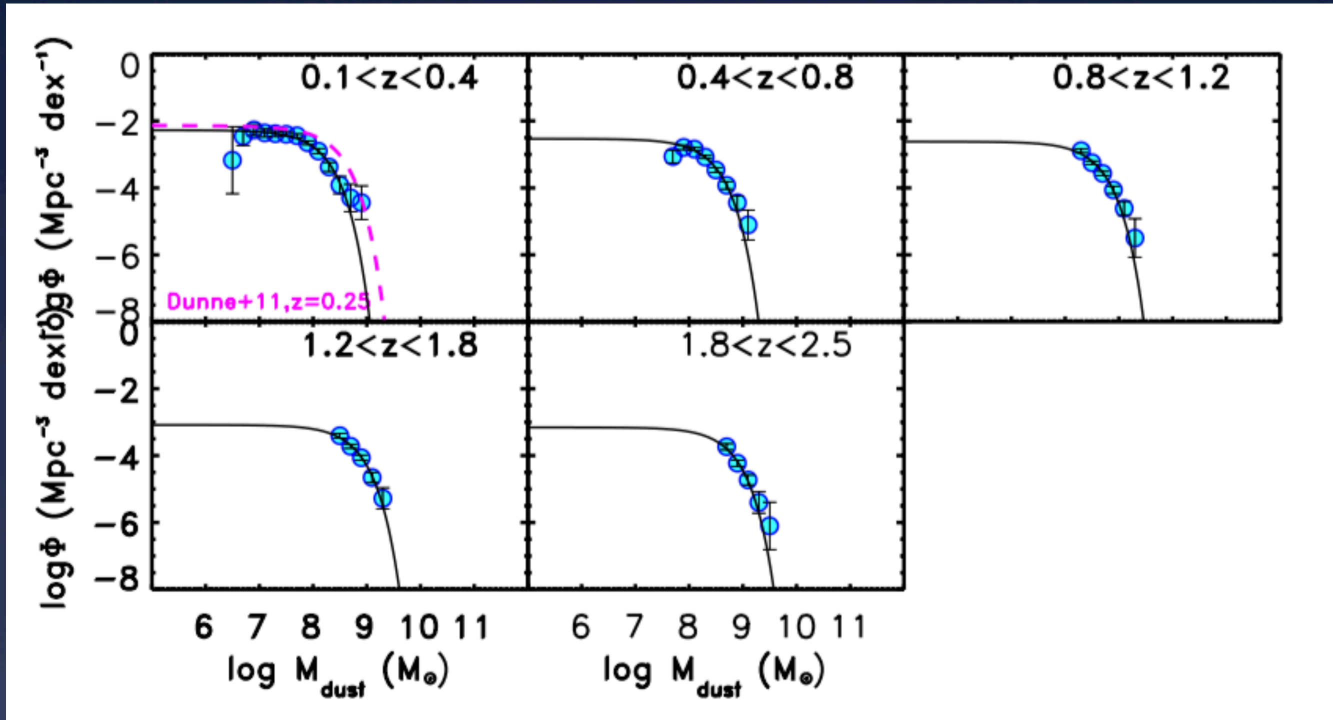
$$f(S_d) = \frac{\int_{S160,\mathrm{lim}}^{S160,\mathrm{max}} \frac{dN}{dS_{160}} g(x) dS_{160}}{\int_{S160,\mathrm{min}}^{S160,\mathrm{max}} \frac{dN}{dS_{160}} g(x) dS_{160}}$$

$S_{dust}=M_{dust}/(4\pi D_L^2)$

g: distribution of the S_{160}/S_{dust} *ratios*



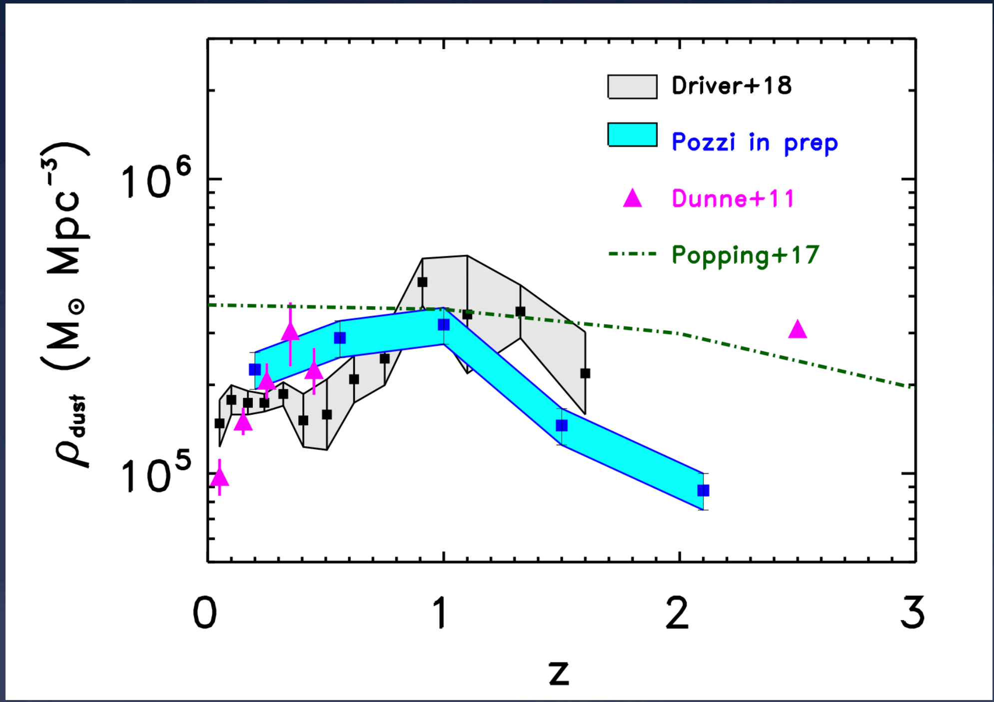
Dust mass function



Pozzi, Calura+in prep

- ✓ First time DMF @ z > 0
- ✓ Well fitted by a Schechter function (α=1 fix from Dunne+11)
- ✓ 1 σ consistent with the value from Dunne @ z=0.25

Dust mass density *Pozzi, Calura+in prep*



- ✓ Constant 0<z<1, sharp decrease at z>1
- ✓ Driver+18: 0<z<1 evolution a factor ~4, but consistent at 2σ
- ✓ Driver+18: 0<z<1: Destruction > Production

Interpretation (work in progress)

0<z<1: Main Dust production: not only from AGB/SNe, but dust grows in dense ISM *see Popping+17 opposite to Ferrara+16*

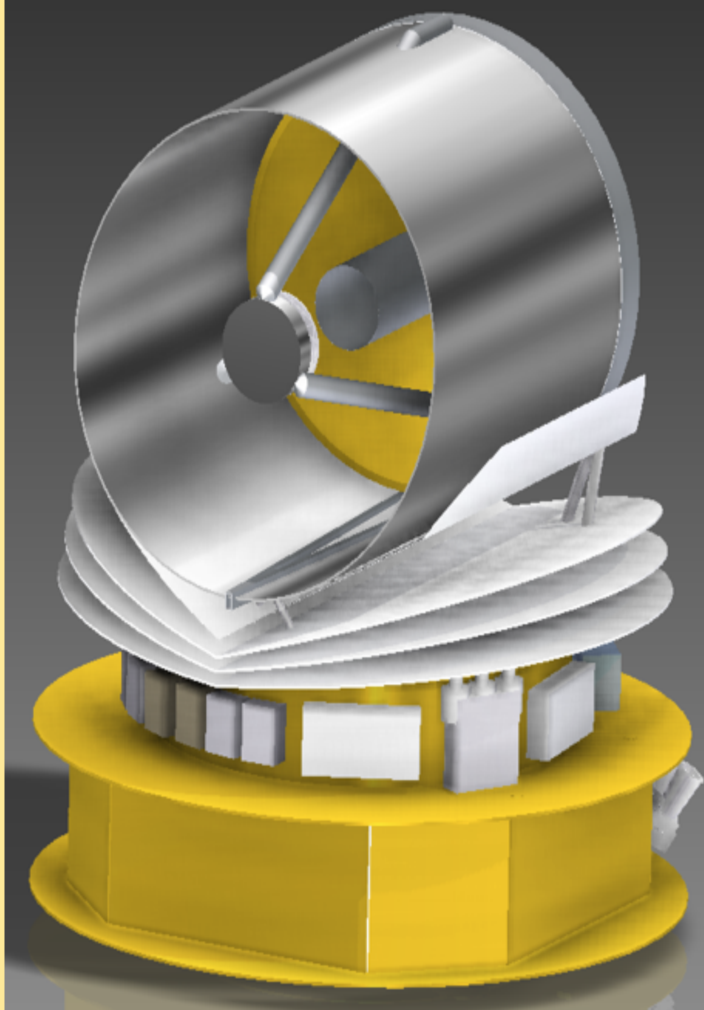
SPICA: the next generation Infrared Space Telescope

- ESA-lead mission with large JAXA partecipation
- PI SPICA Europe: P.Roelfsema
- 2.5 m telescope, **T < 8K**
- 12 - 230 μm spectroscopy
- 12 - 350 μm photometry

  MIR imaging spectroscopy SMI

  FIR spectroscopy SAFARI

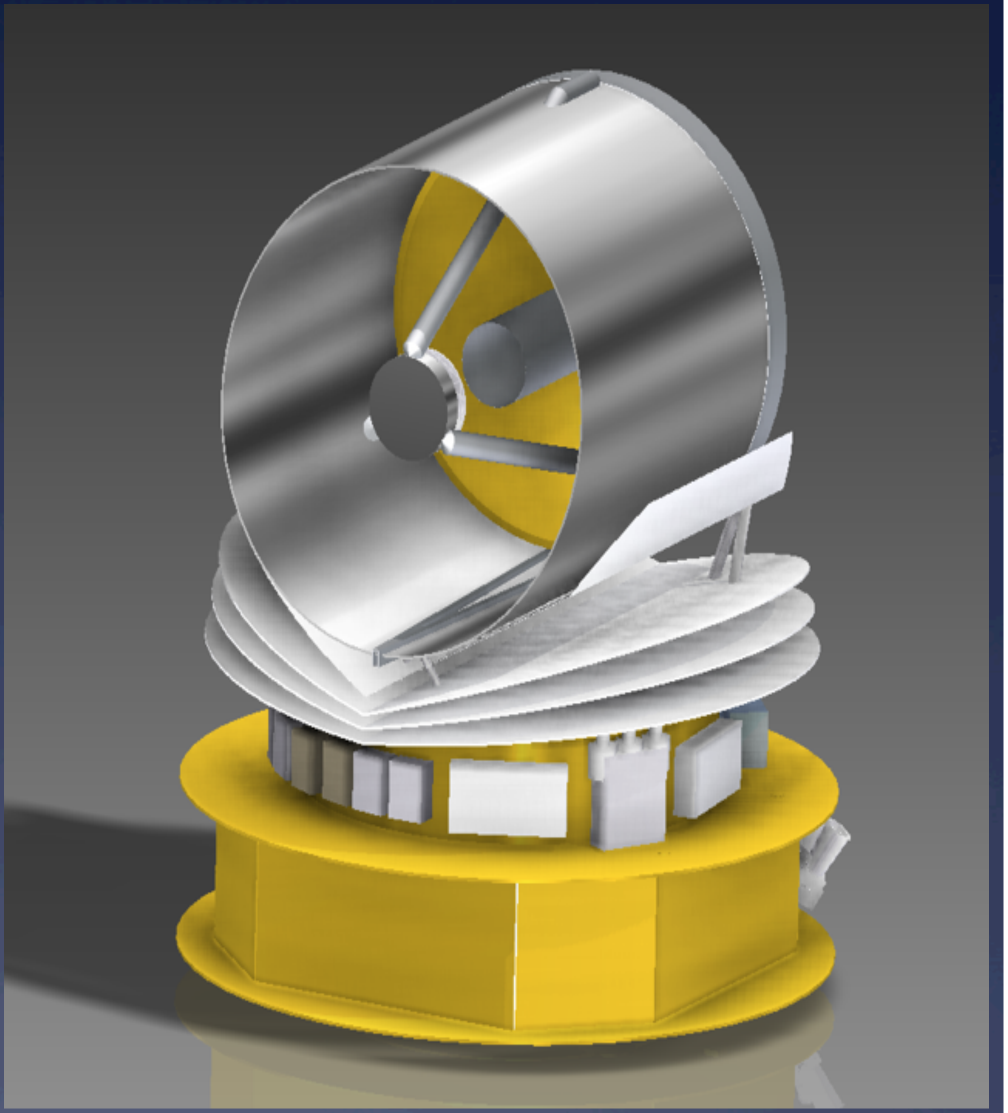
  FIR imaging polarimetry)
- Launch: ~2030



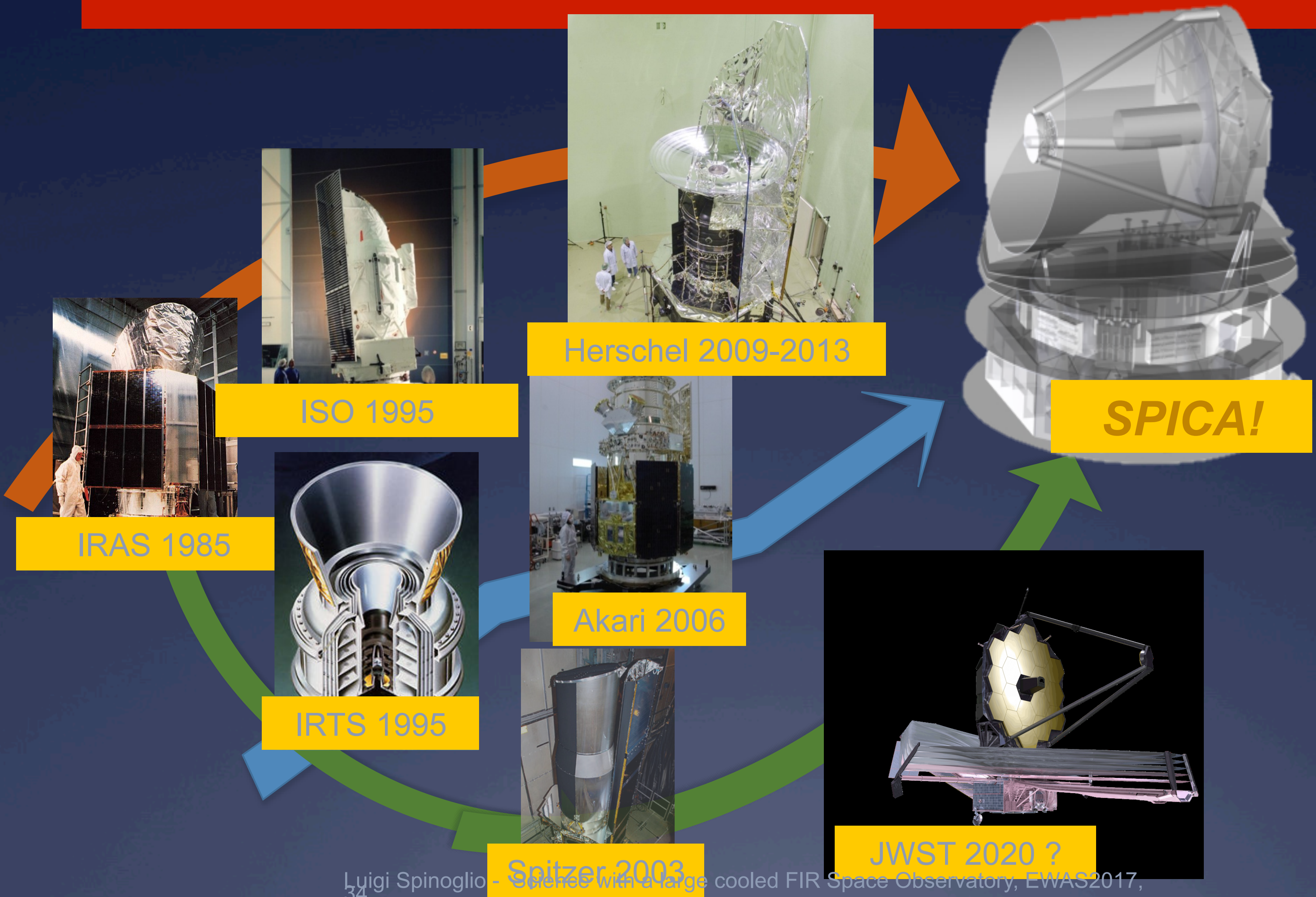
Selected by ESA as M5 candidate !!

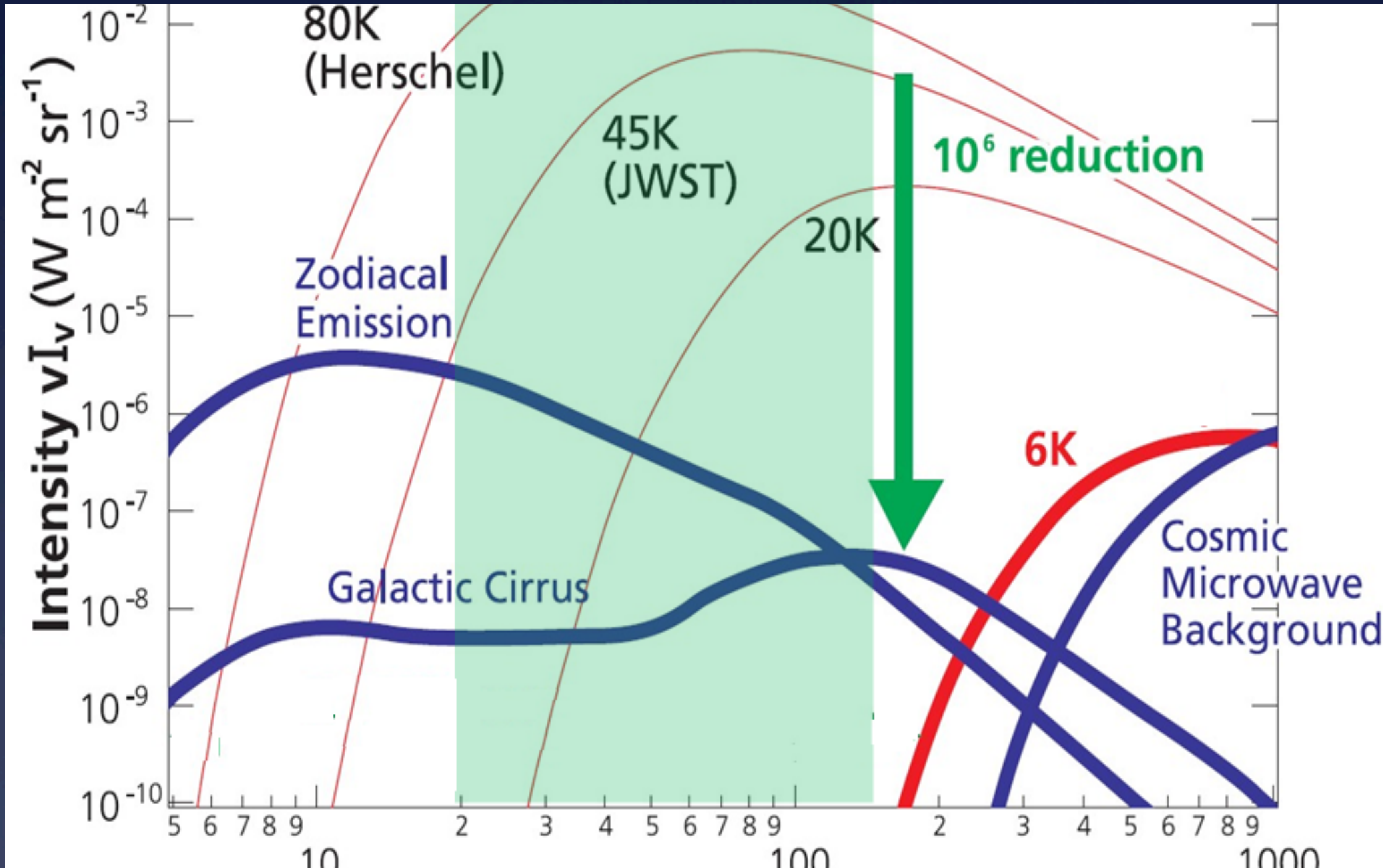
Together with:
Theseus, EnVision

Final decision: 2021



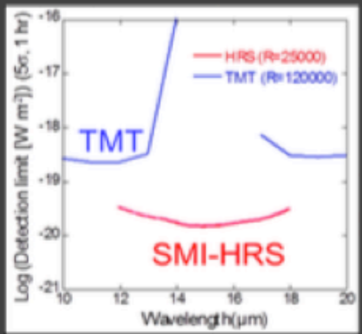
Infrared Space Observatories

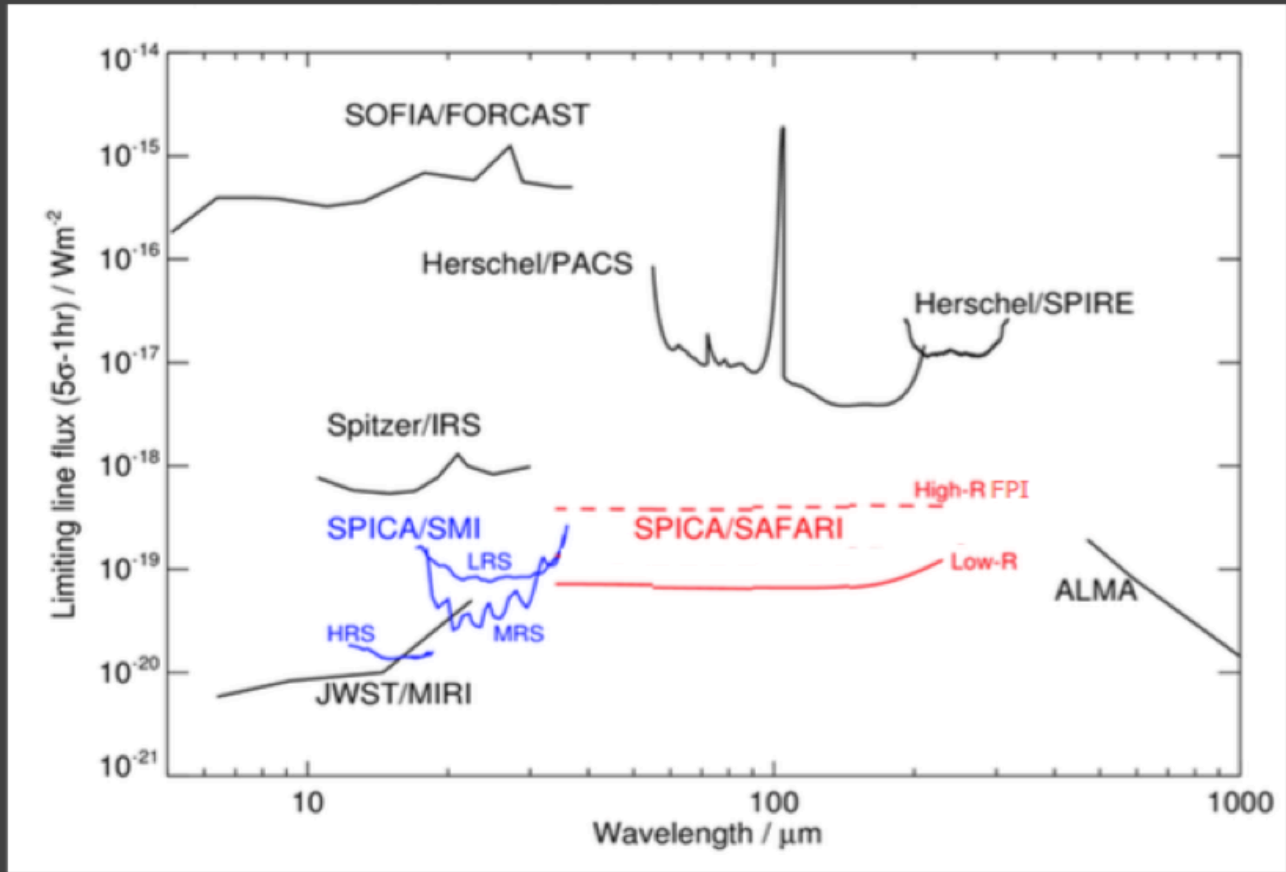




80K
(Herschel)
45K
(JWST)
20K
10⁶ reduction
6K
Zodiacal
Emission
Galactic Cirrus
Cosmic
Microwave
Background
Intensity νIν (W m⁻² sr⁻¹)
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10
100
1000

SPICA's sensitivity; making a huge leap forward!





Raw sensitivity improvement **>2 orders** of magnitude
Instantaneous full spectra → huge step in efficiency

SAFARI

JWST / MIRI vs. SPICA / SMI: FoV: ~1'x2' vs. ~10'x10'