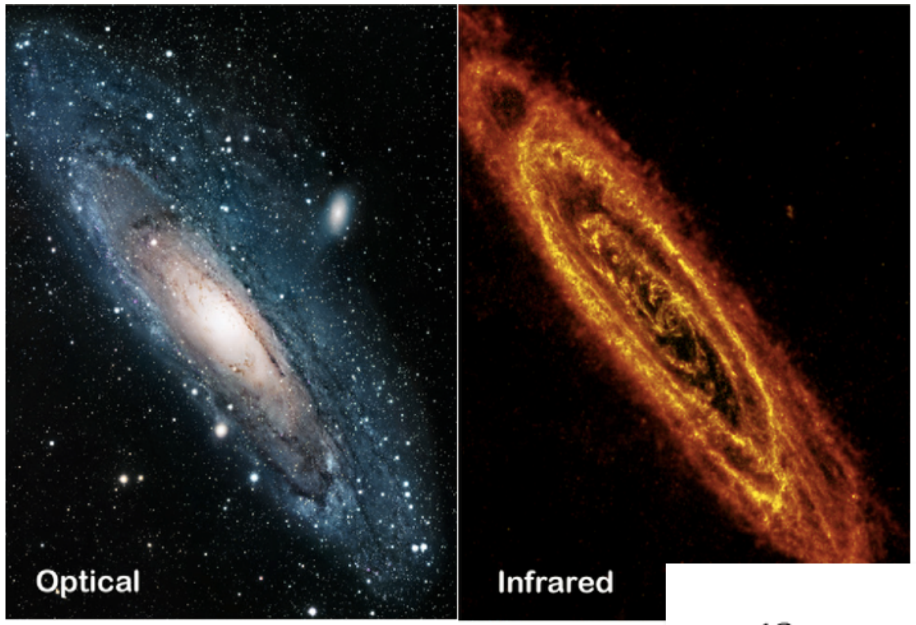
Beating Confusion with Simultaneous Stacking

Marco Viero — KIPAC/Stanford

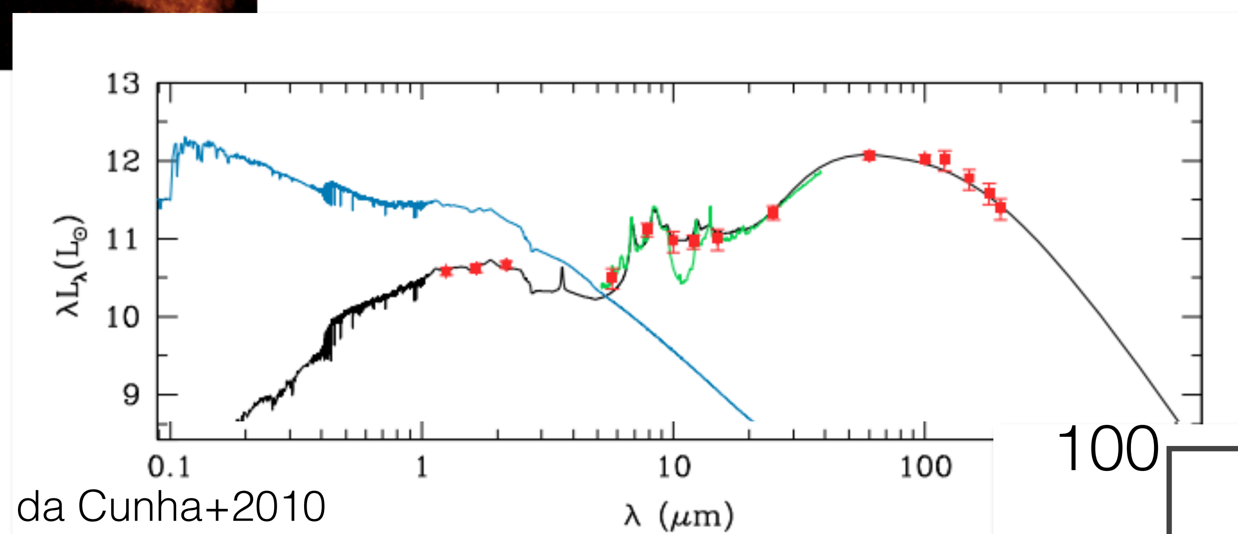
w/

Lorenzo Moncelsi (Caltech), Ryan Quadri (Texas A&M), Jason Sun (Caltech), and the HerMES Collaboration

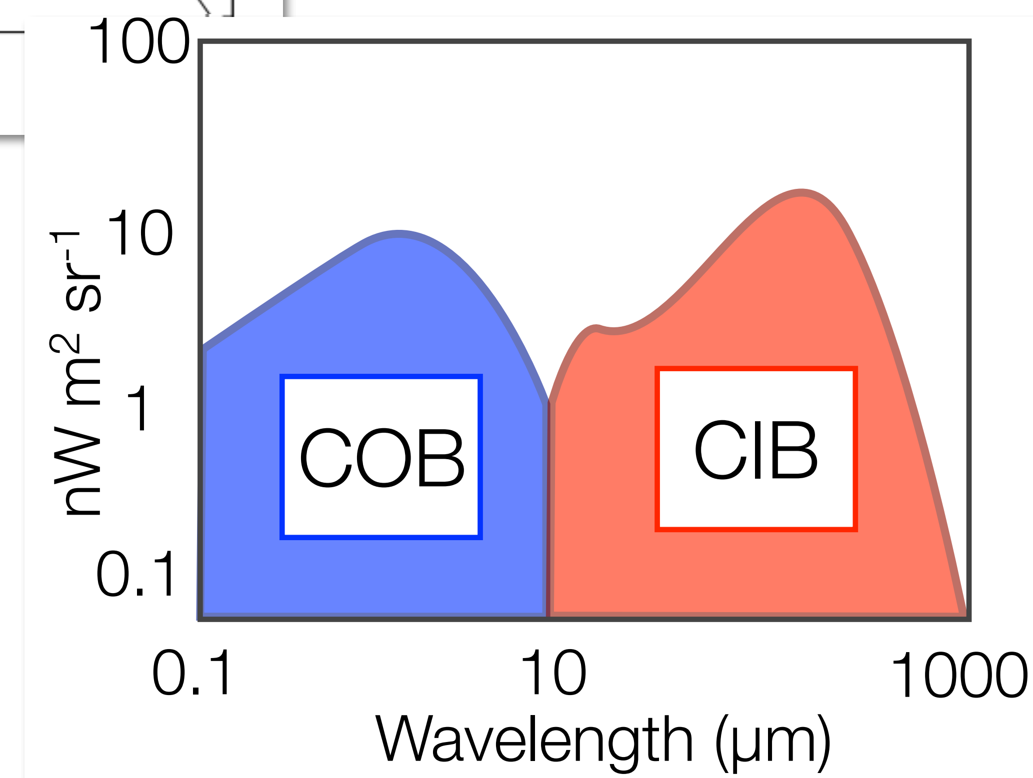
Motivation



- Infrared/Submillimeter emission reprocessed starlight by dust
- IR/Submm traces star formation
- Half the emission is tied up in dust

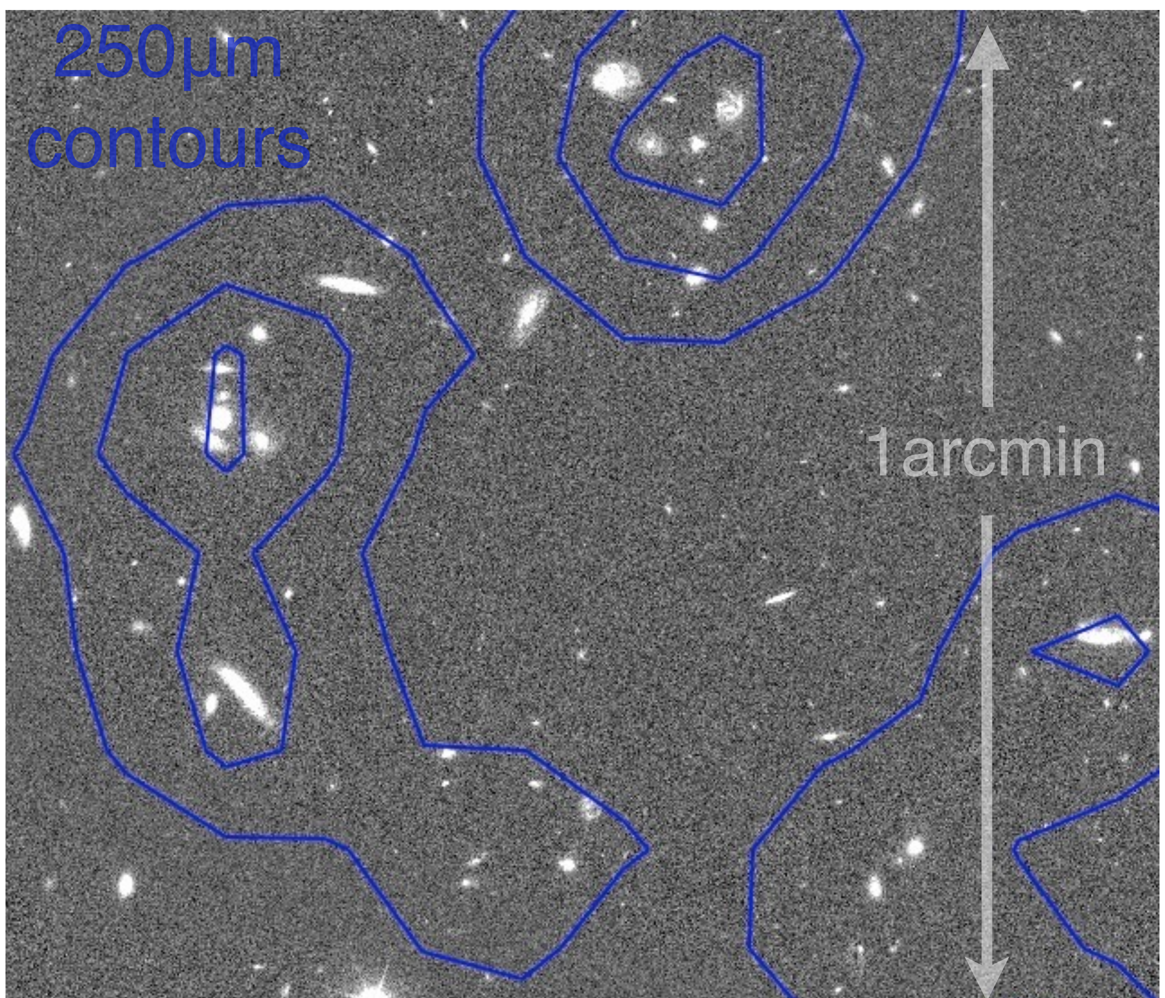


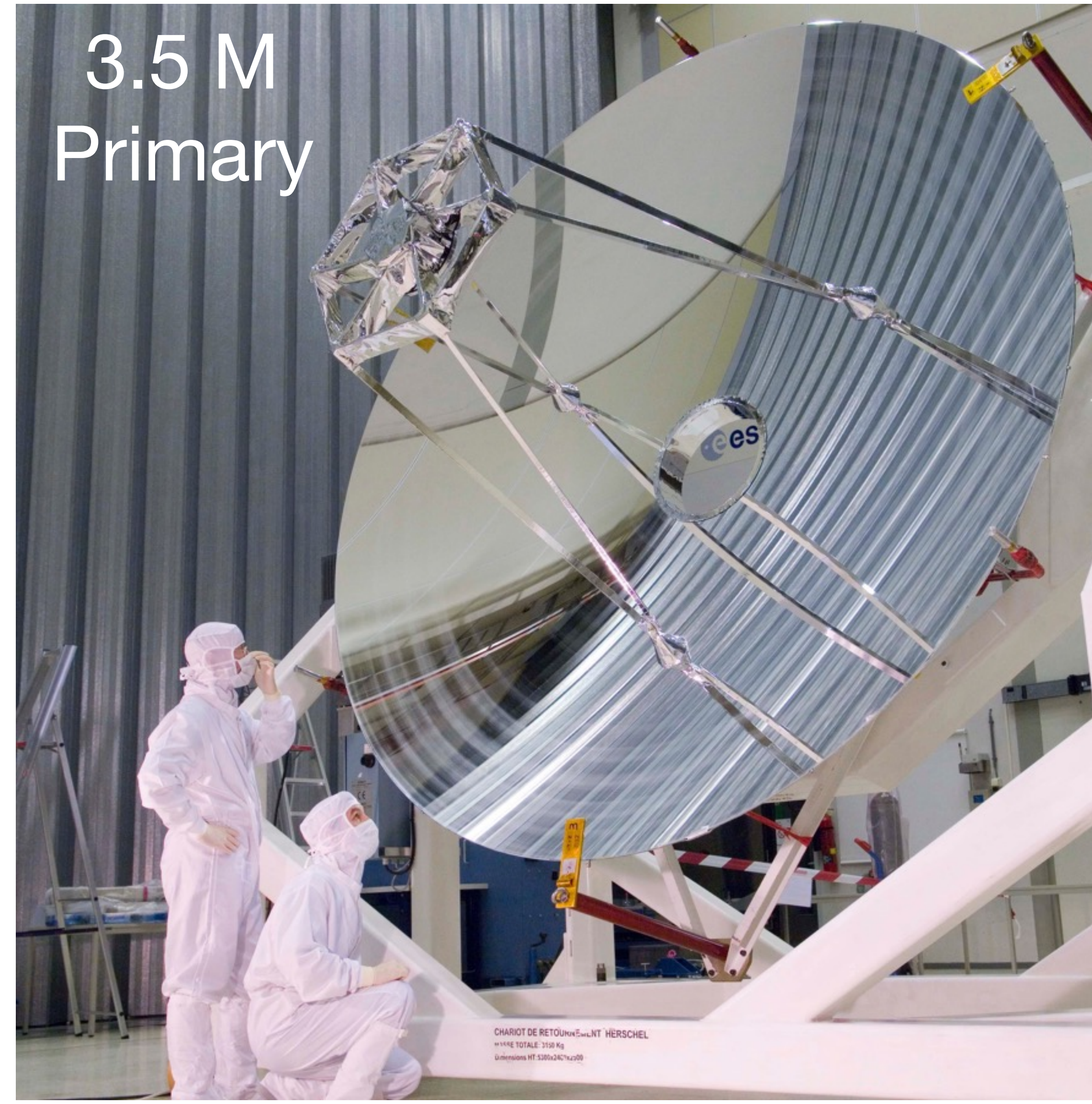
- How do we reconcile COB and CIB?
- Want to know:
  - ➡which galaxies make up CIB?
  - ➡how much of the CIB is accounted for?
  - ➡what limits does this place on models?



Herschel/SPIRE

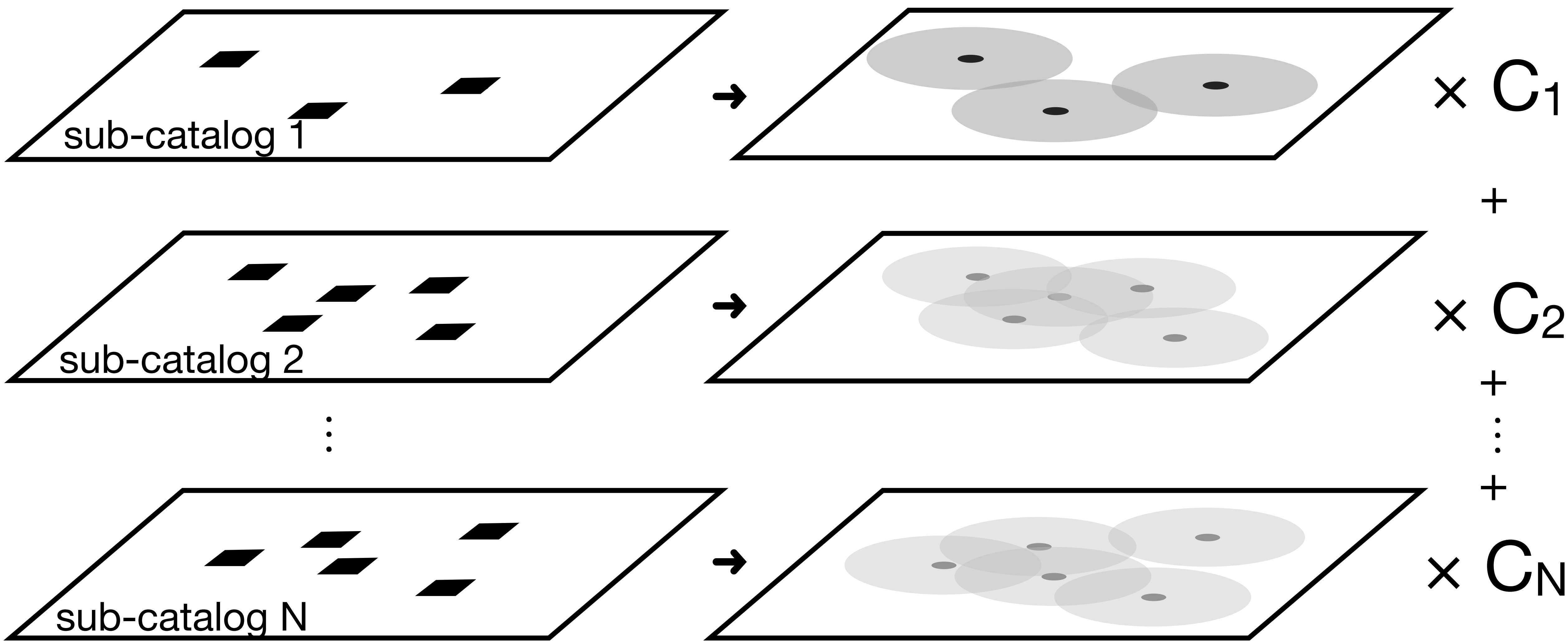
Band	PSF size (FWHM)	Confusion Limit (5σ)
250 μm:	18”	24.0 mJy
350 μm:	25”	27.5 mJy
500 μm:	36”	30.5 mJy



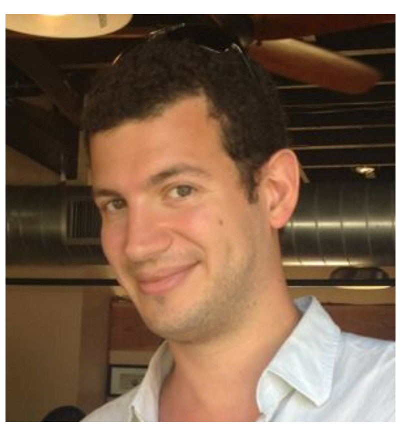


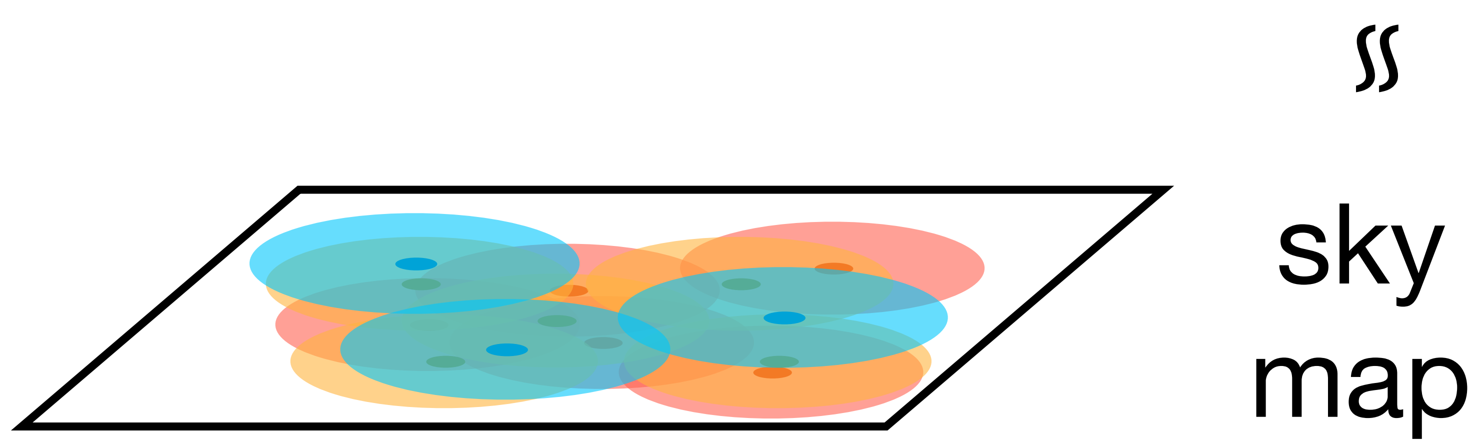
- < 1% of sources resolved at 5σ due to source confusion
- Strength is surveys, with ~1000 deg^2 observed

SIMSTACK: Synthetic Intensity Fitting Algorithm



Formalism developed w/ Lorenzo Moncelsi (Caltech)

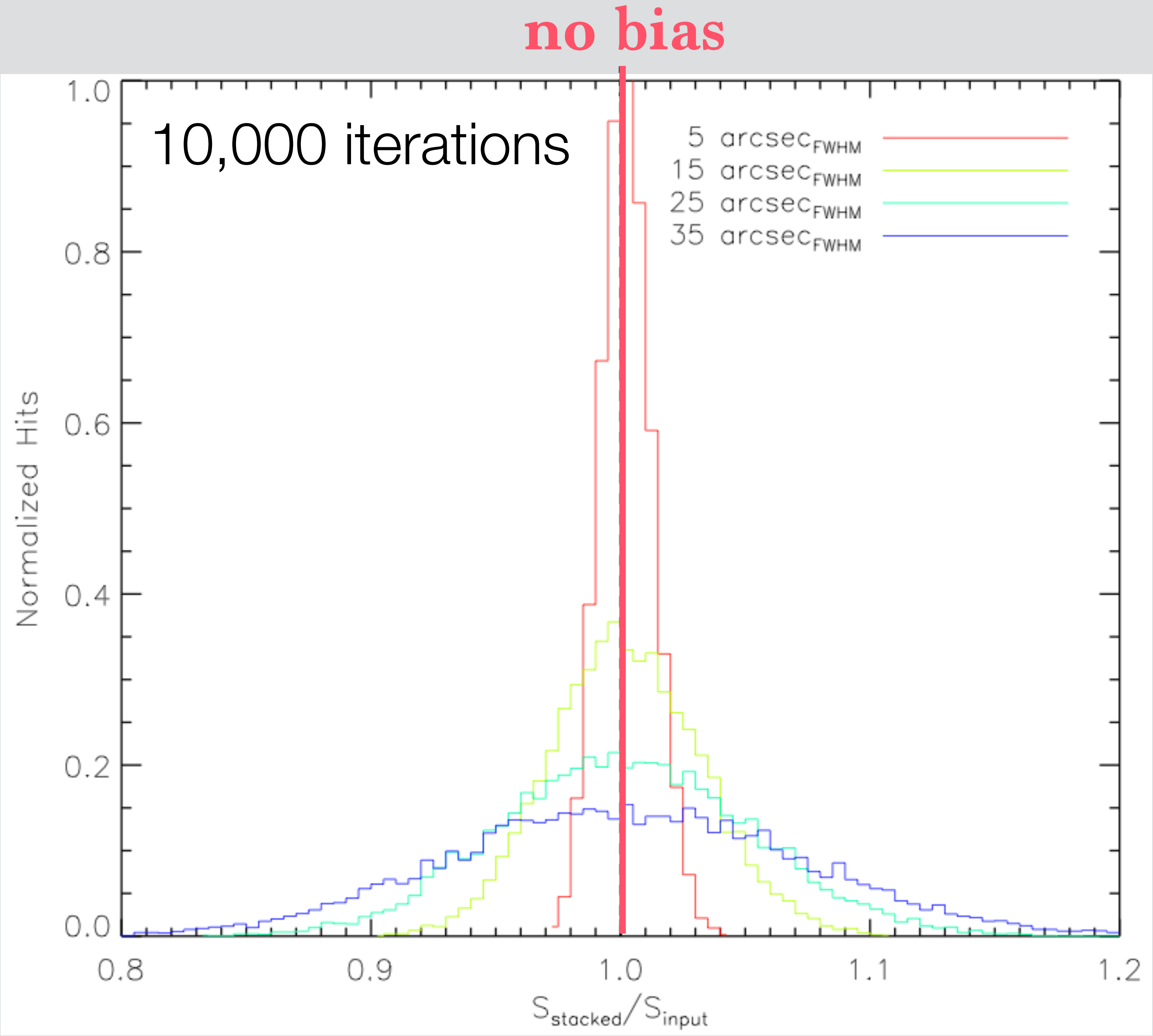




SIMSTACK code publicly available (see arXiv:1304.0446):
IDL (old) — https://web.stanford.edu/~viero/downloads.html
Python (under development!) — https://github.com/marcoviero/simstack

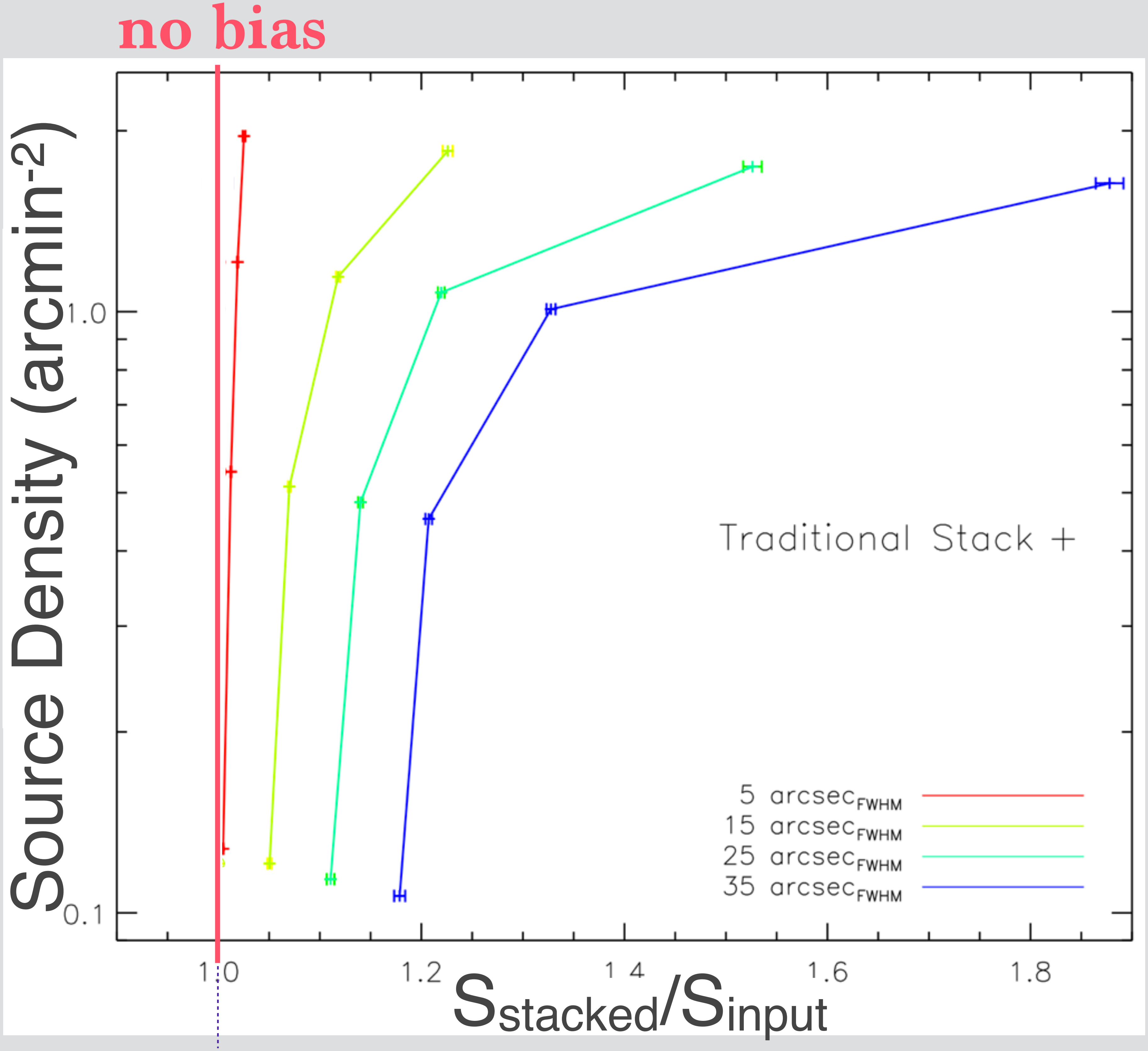
Aside: Correlated vs. Uncorrelated Emission

- Uncorrelated emission does not bias result, only increases noise



Aside: Correlated vs. Uncorrelated Emission

- Correlated emission does bias the result, and more with increasing beam



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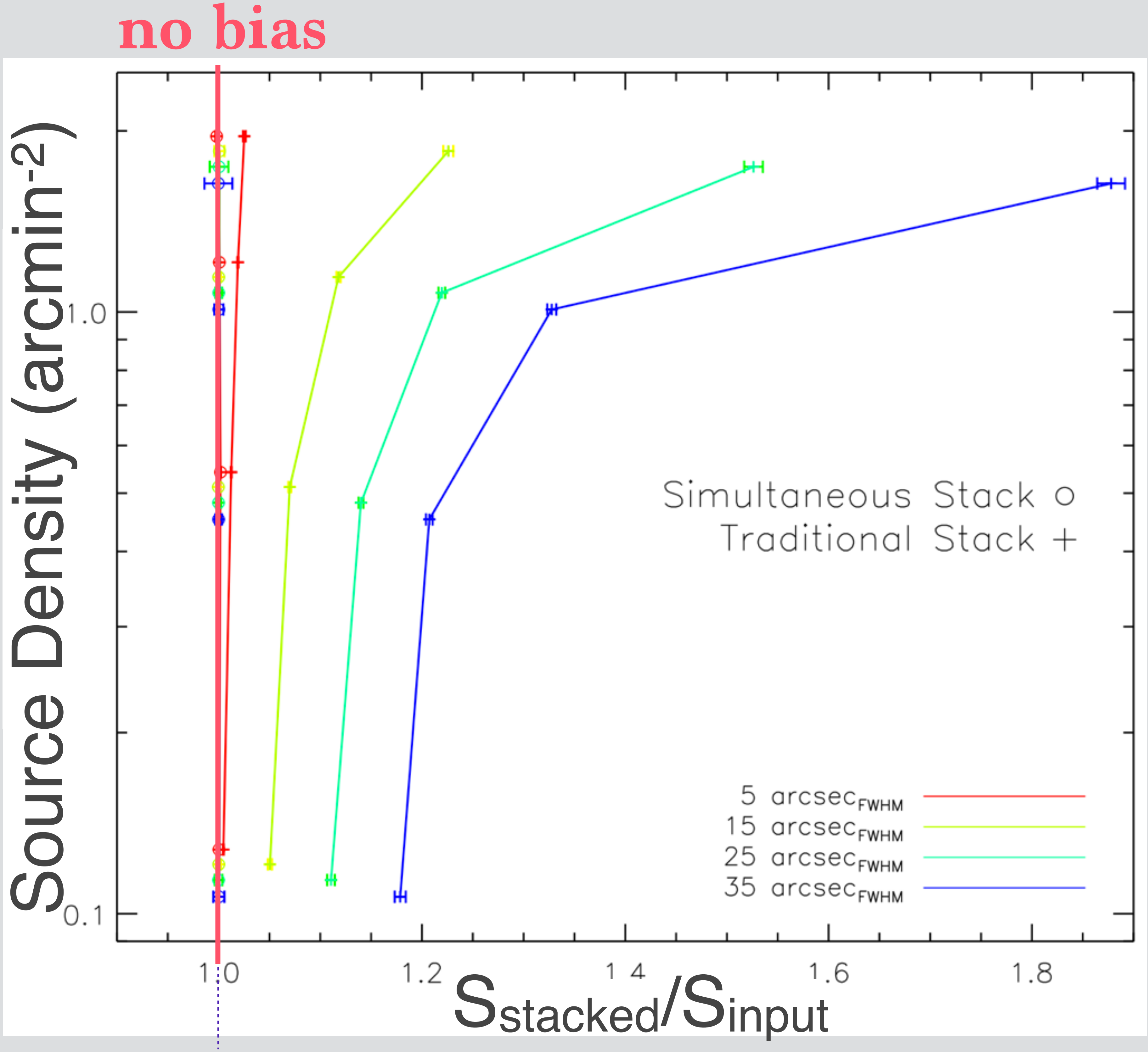
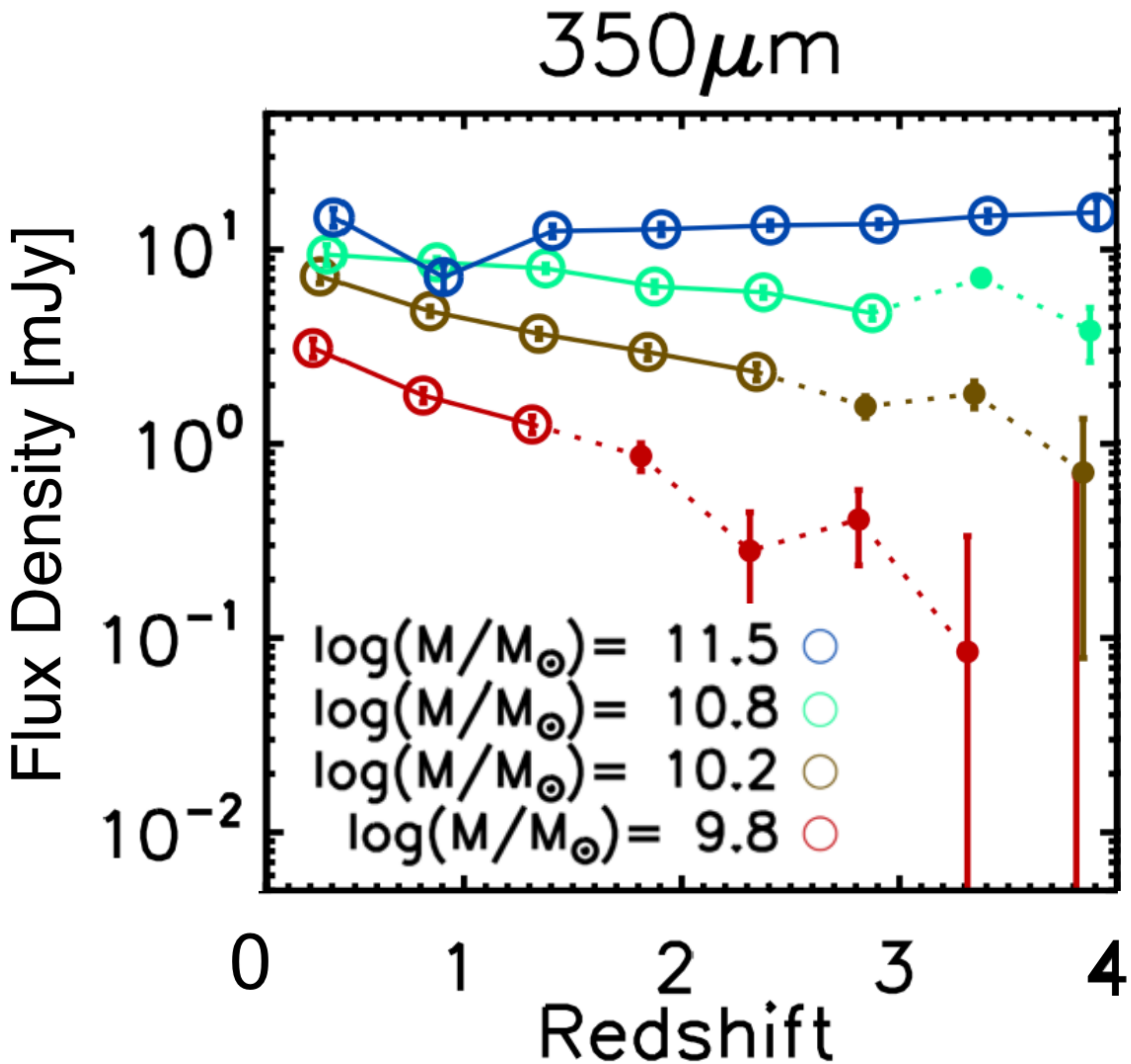


SIMSTACK: Flux Densities (M,z)



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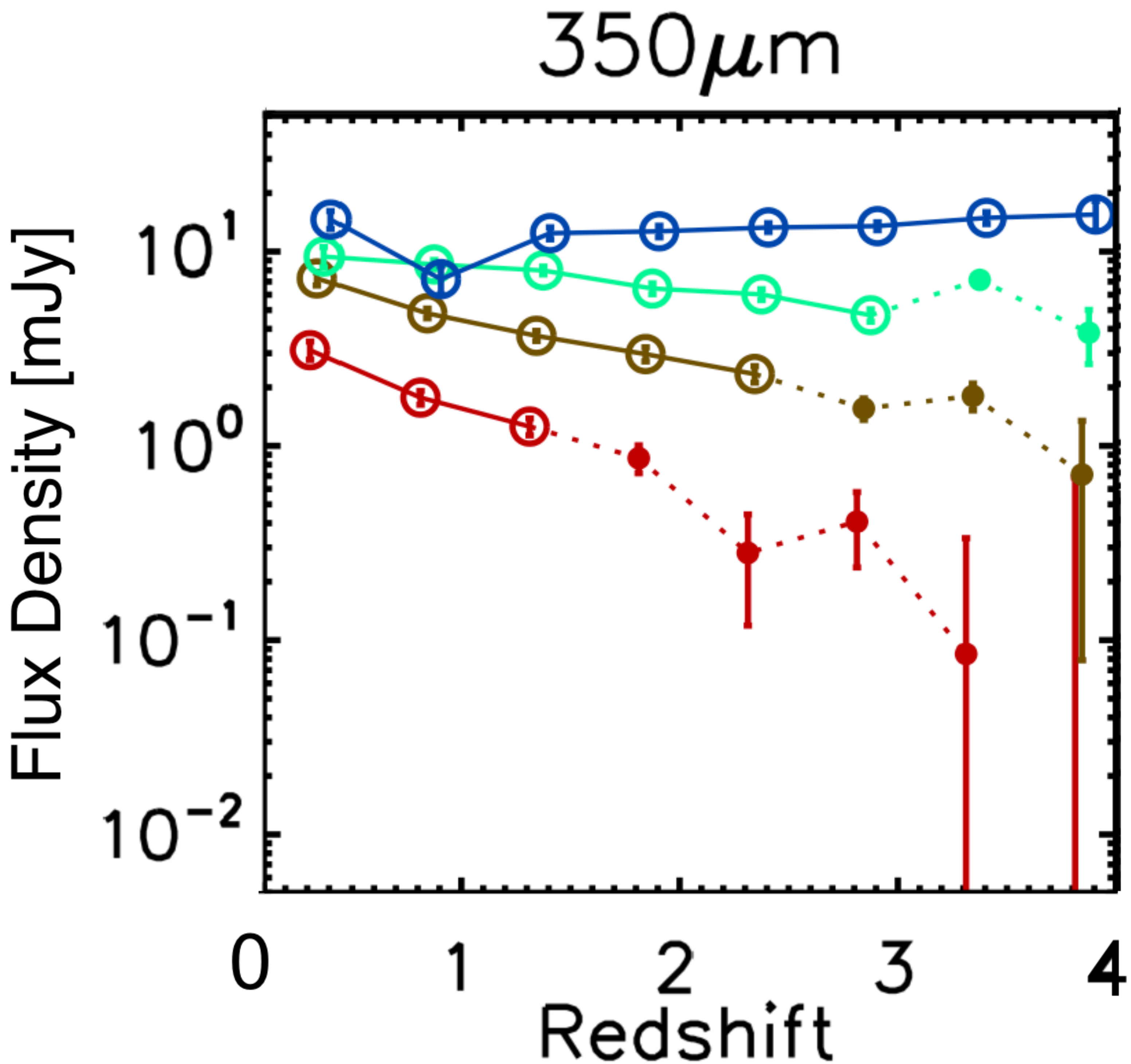

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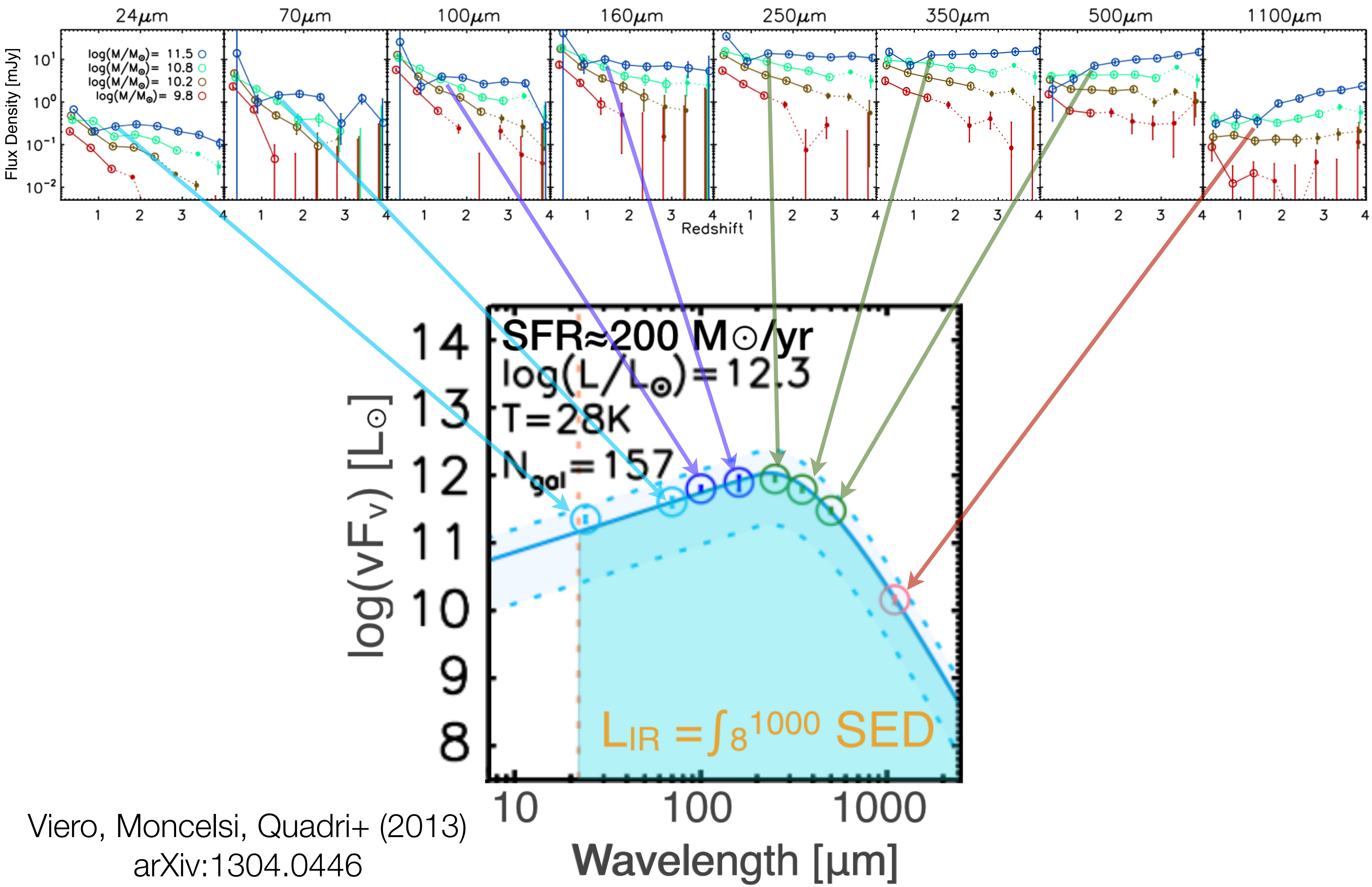
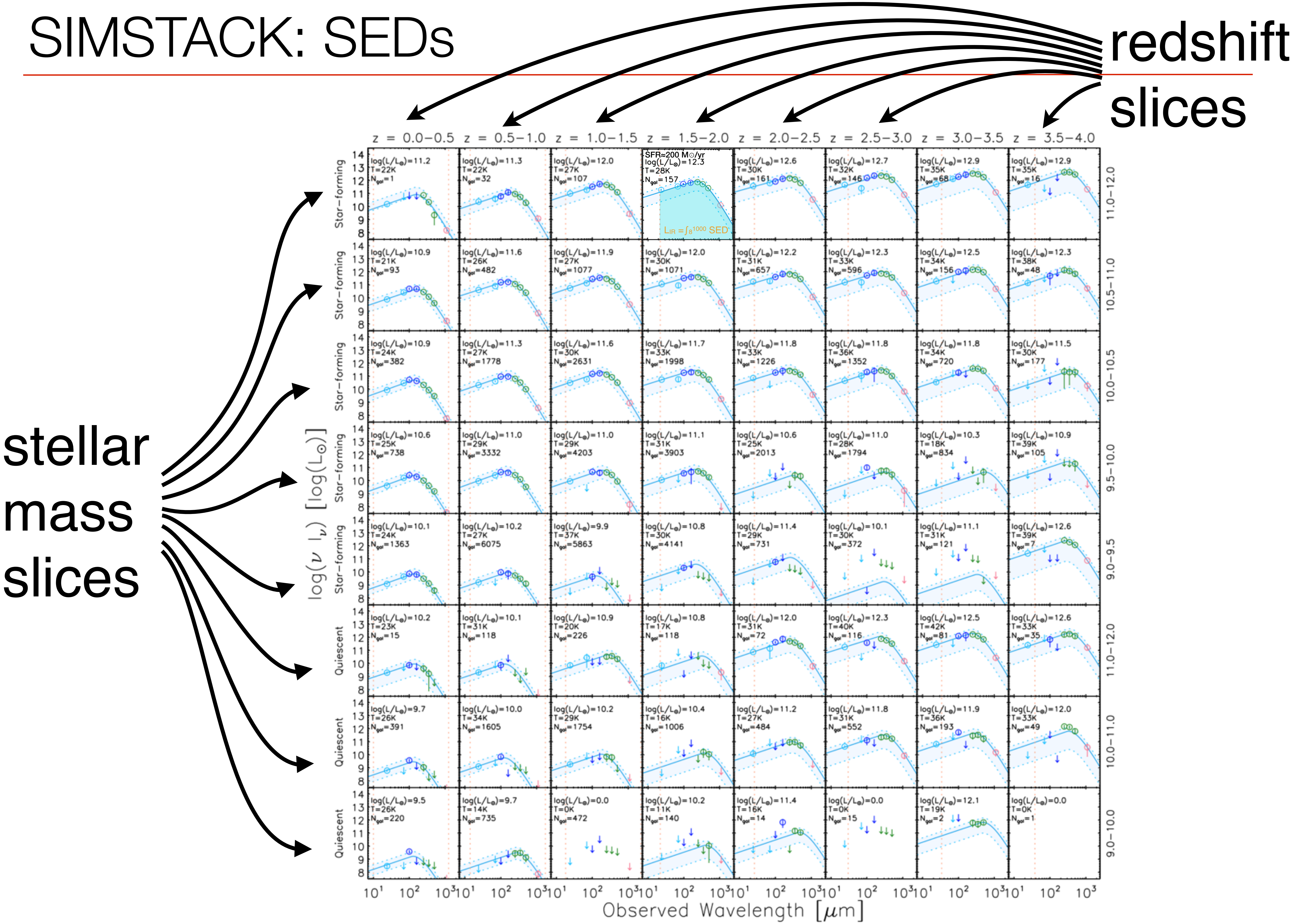
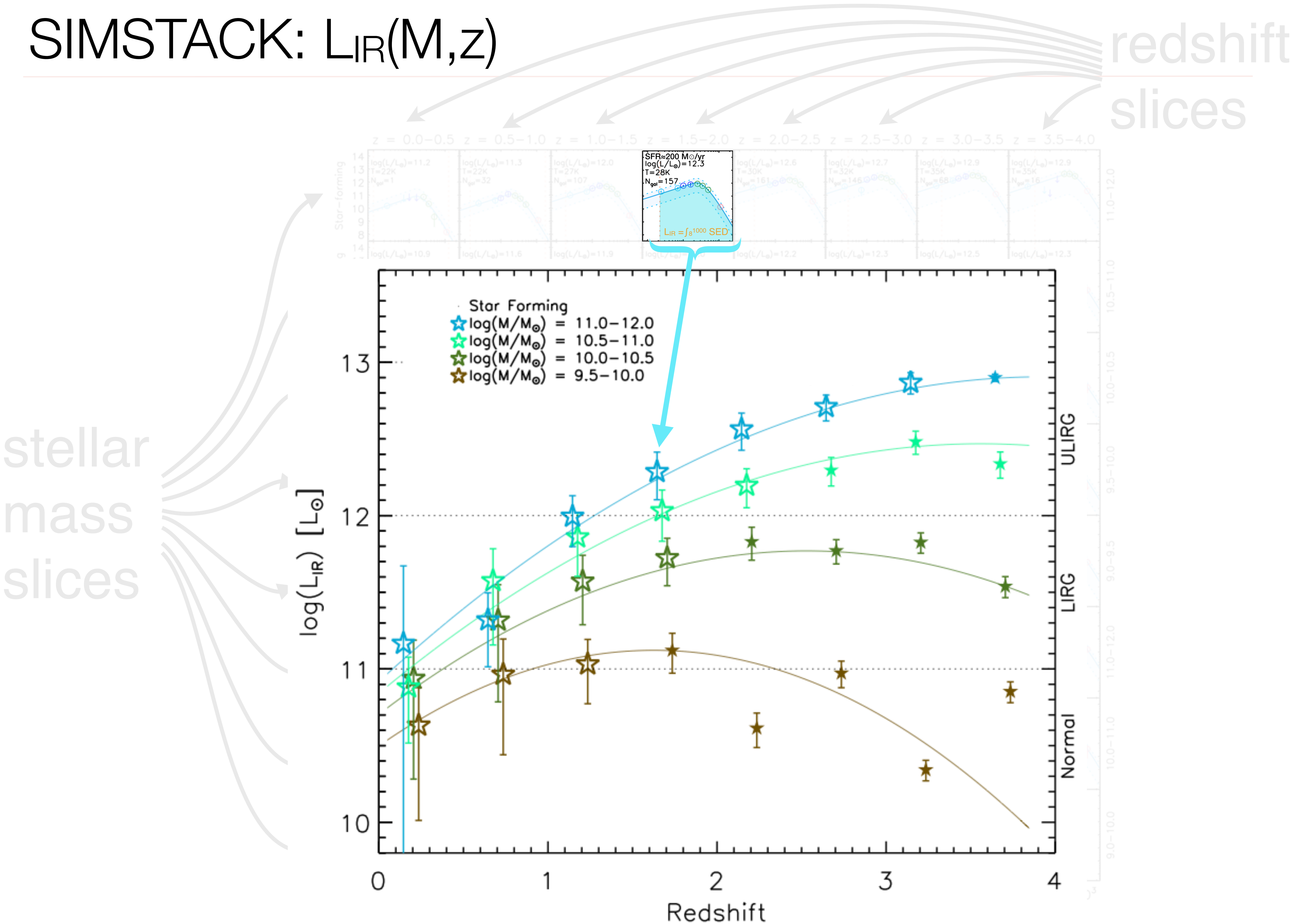


Viero, Moncelsi, Quadri+ (2013)
arXiv:1304.0446

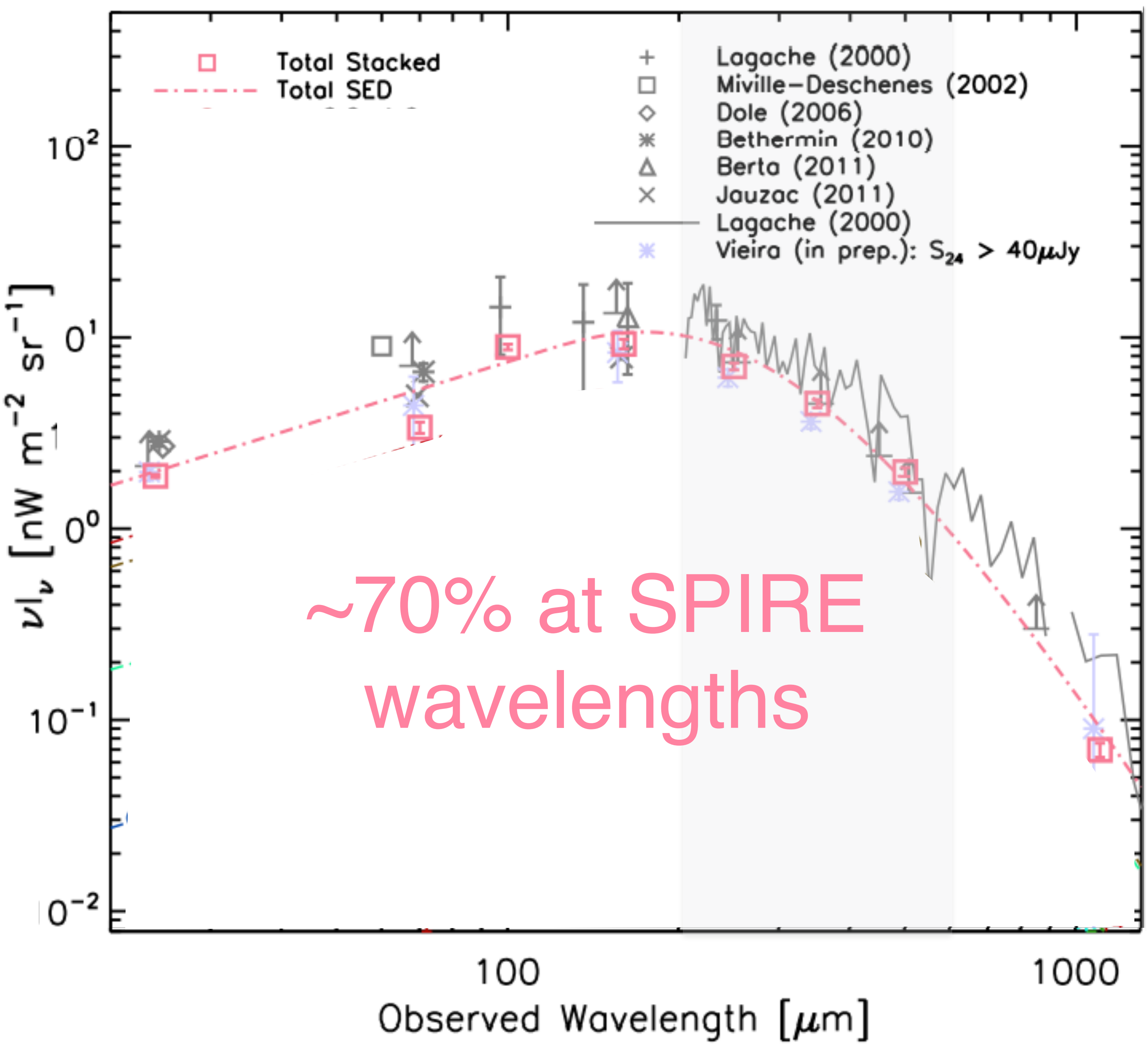
SIMSTACK: SEDs



SIMSTACK: L_{IR}(M,z)



CIB Breakdown



Viero, Moncelsi, Quadri et al. (2013)
arXiv:1304.0446

CIB Breakdown

HERMES

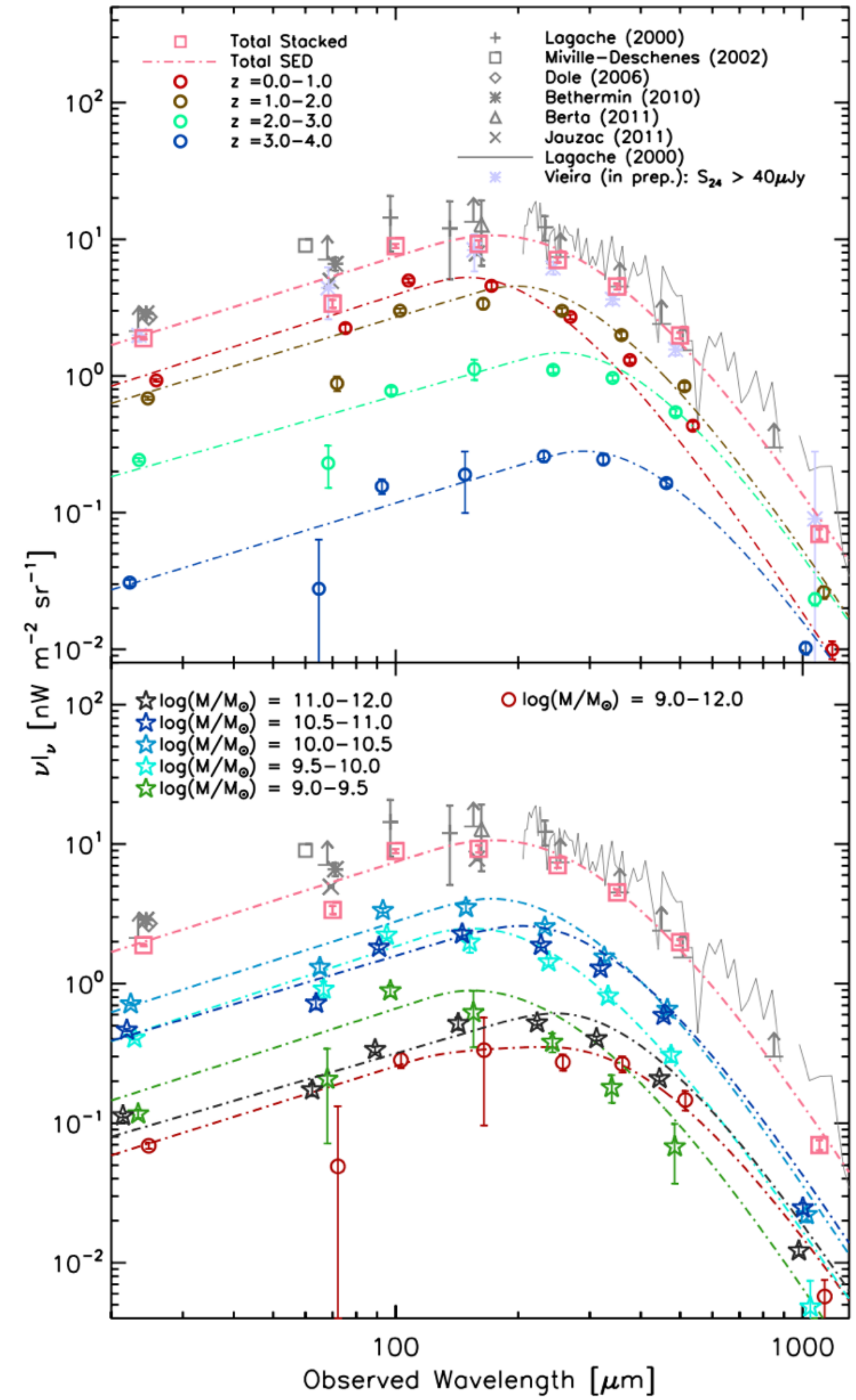
Split Sample by:

- redshift

z = 0-2 @ < 200um
z = >1 @ > 200um

- stellar mass

log(M/M⊙~10-11)
i.e., M ≲ M*



Viero, Moncelsi, Quadri et al. (2013)
arXiv:1304.0446

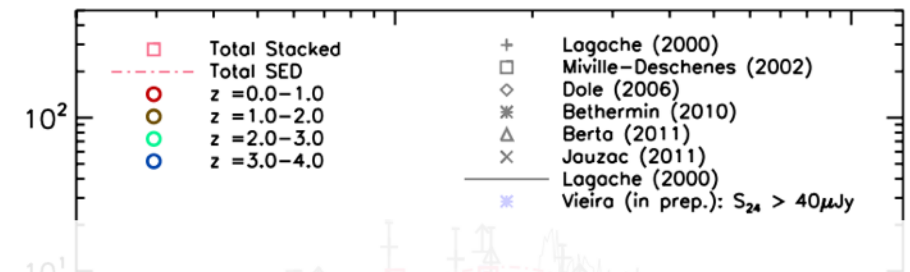
HERMES

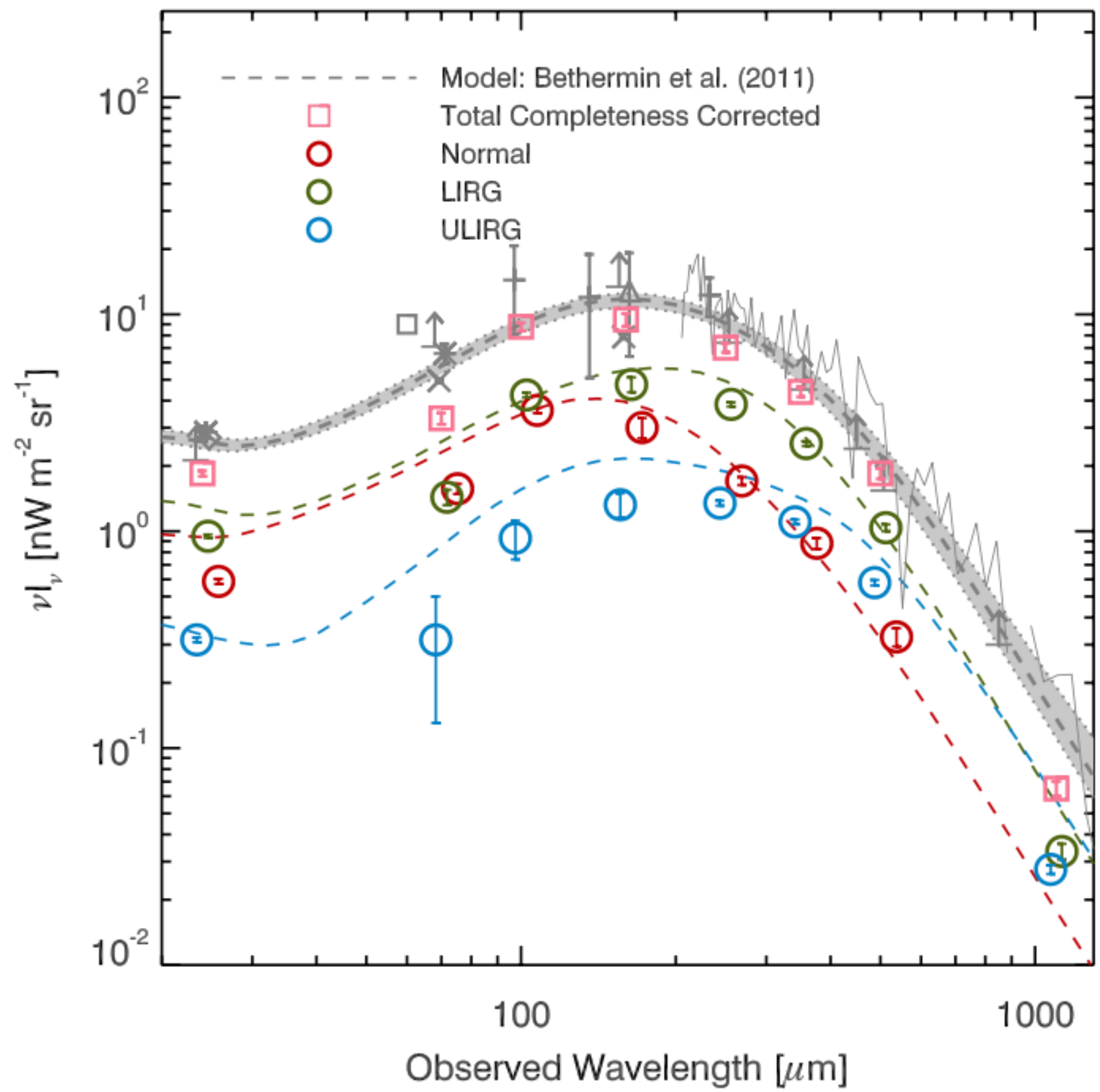
Split Sample by:

ULIRGS

LIRGS

Normal





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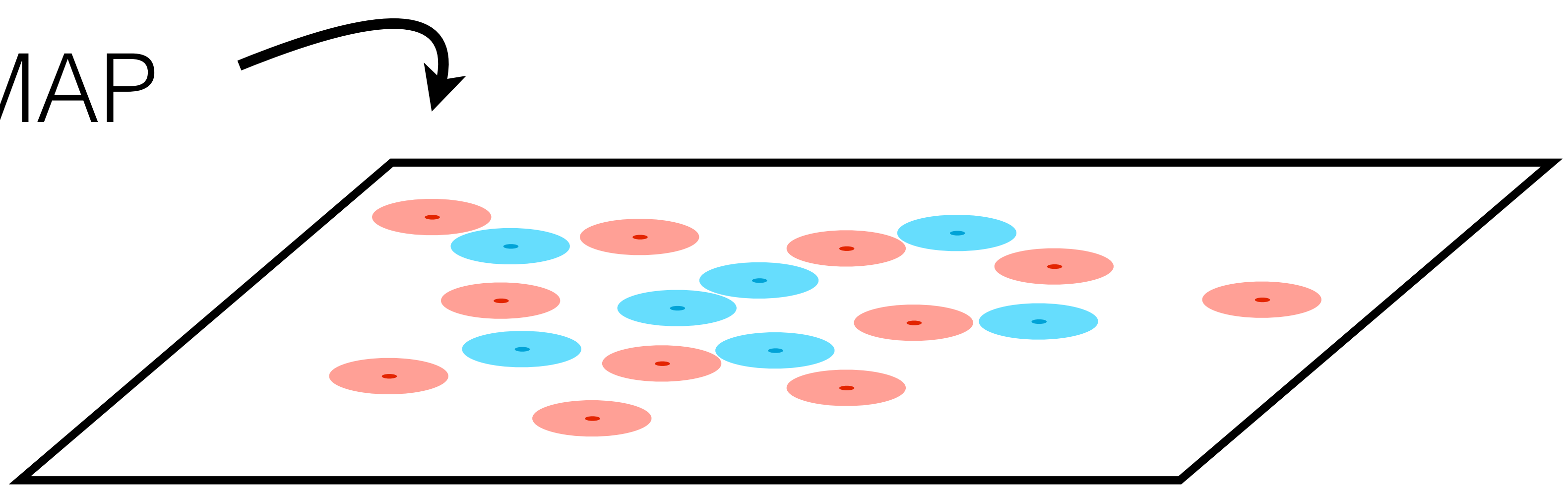
So, 70% of CIB resolved… what about the rest?

A New Accounting of the CIB

Imagine this is a SKY MAP



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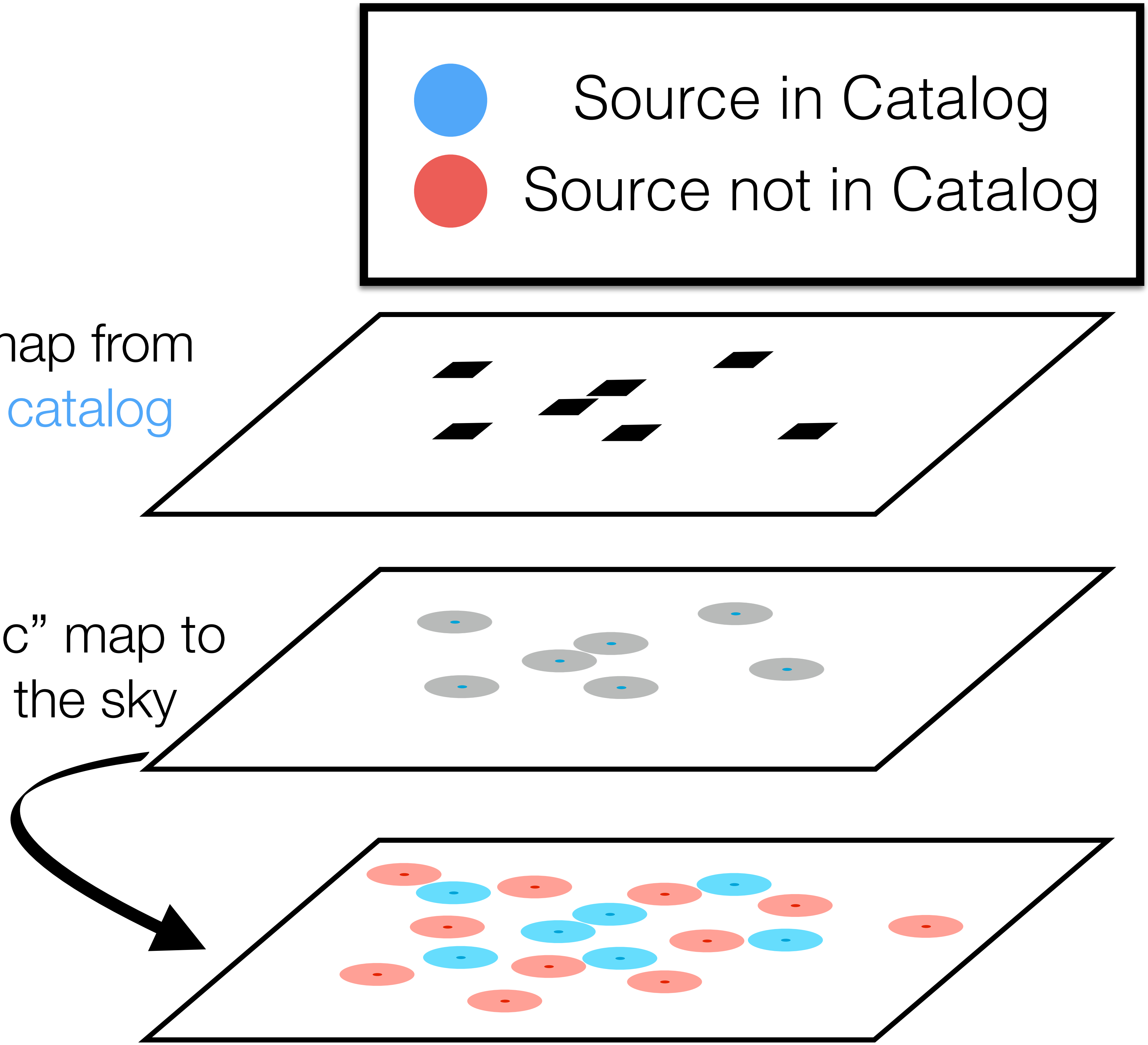
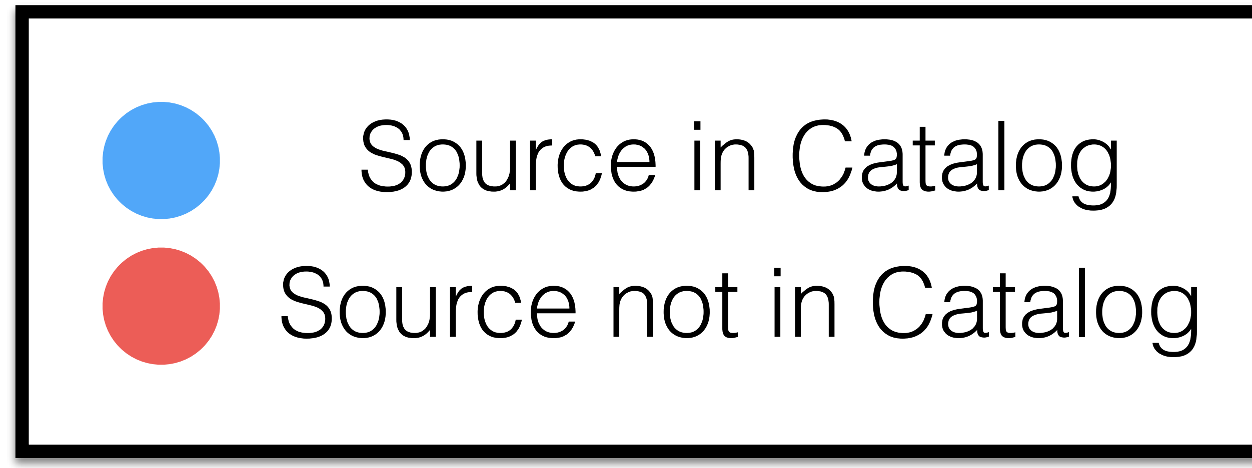


make synthetic “hits” map from positions of sources in catalog

fit “synthetic” map to the map of the sky

***Un*biased if :**
-beam is small

A New Accounting of the CIB



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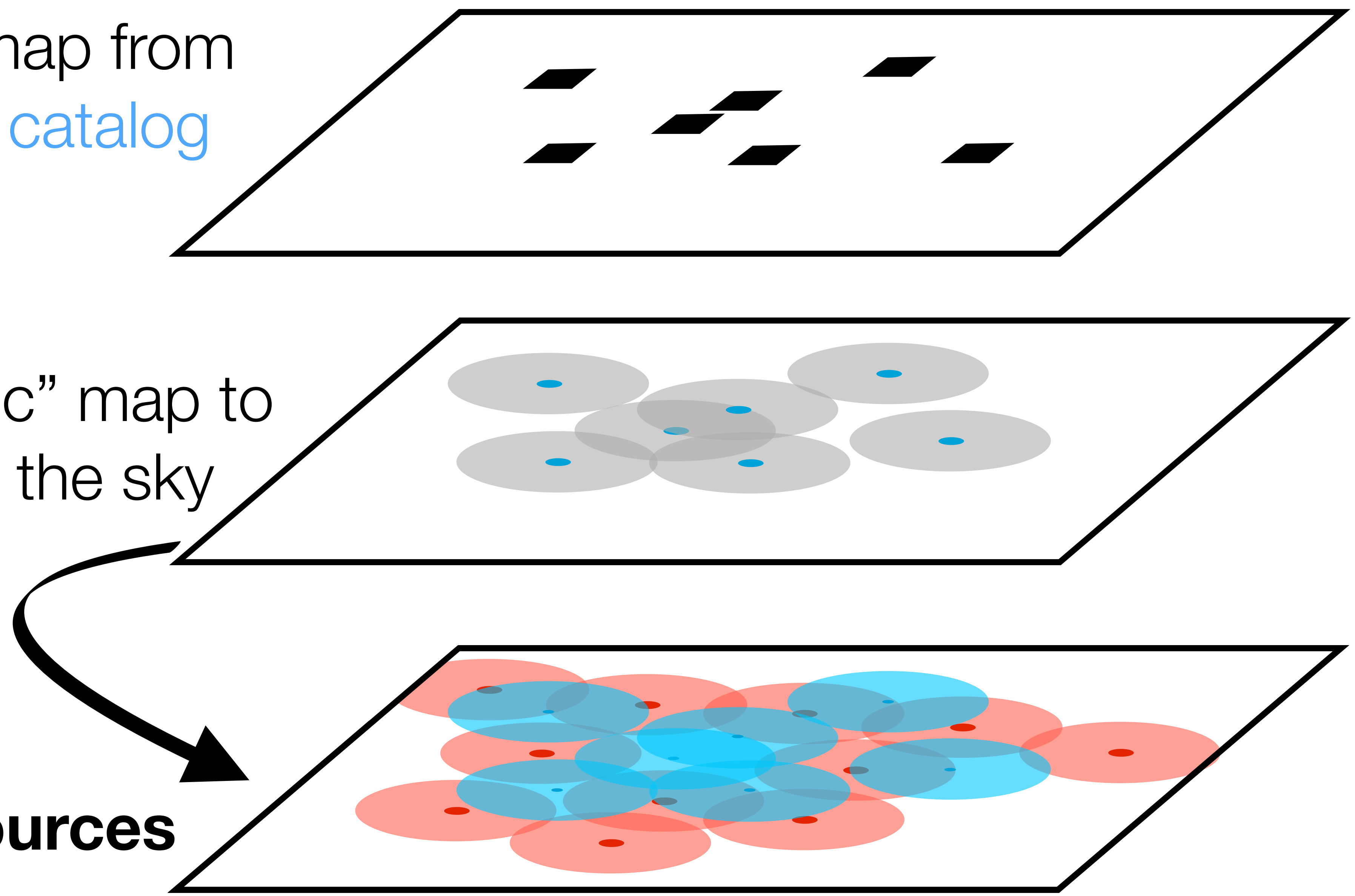


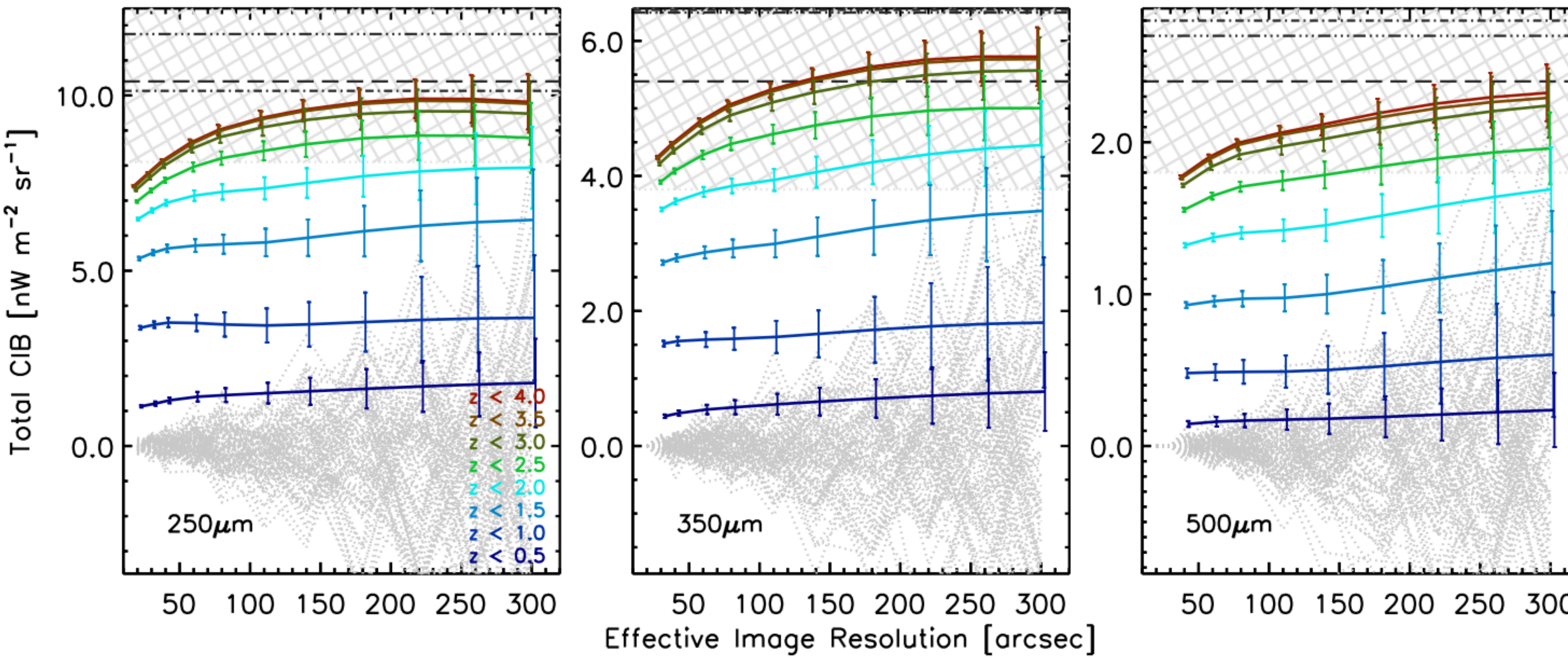
***Biased* if :**

-beam is big

-missing a lot of sources

A New Accounting of the CIB

COBE: Fixsen 1998 ------------------



Viero, Moncelsi, Quadri et al. (2015)
arXiv:1505.06242

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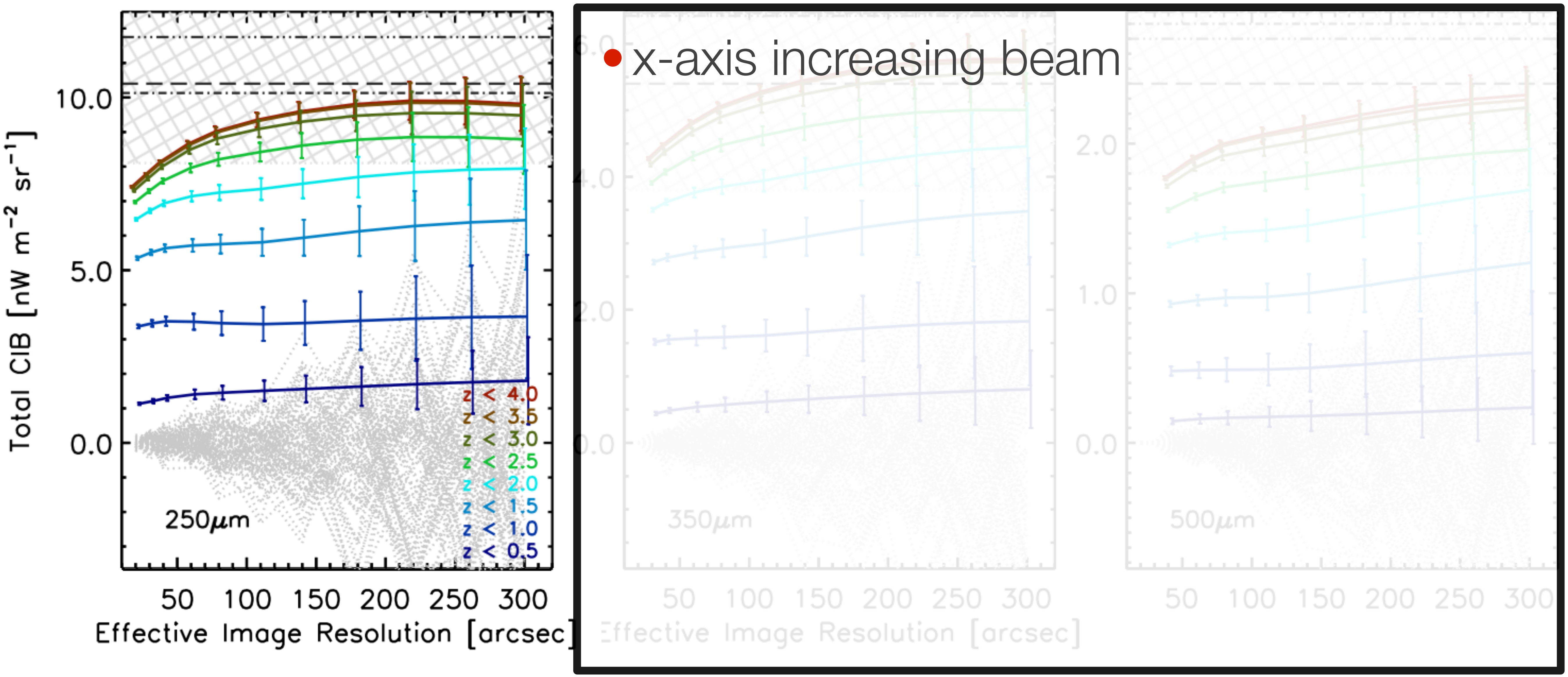

Smooth with bigger beam →

Viero, Moncelsi, Quadri et al. (2015)
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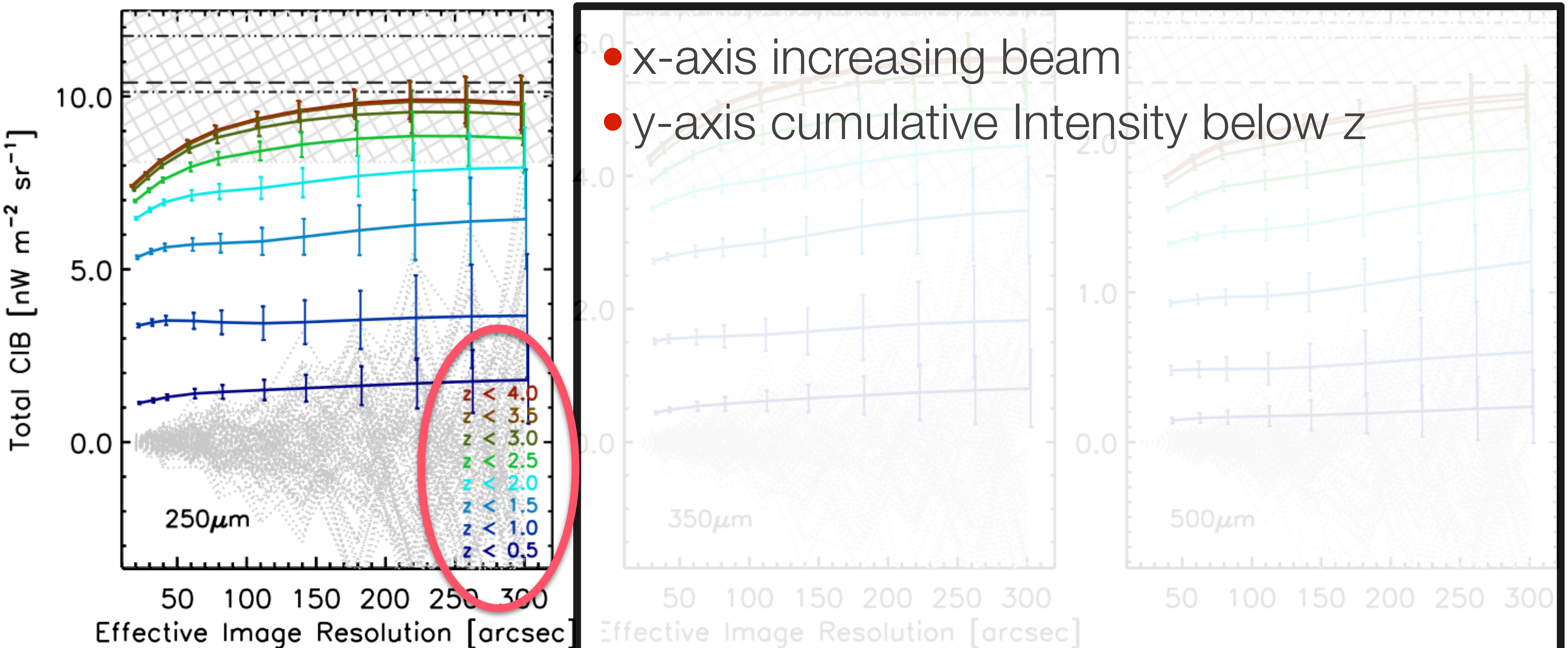

- x-axis increasing beam
- y-axis cumulative Intensity below z

Smooth with bigger beam →

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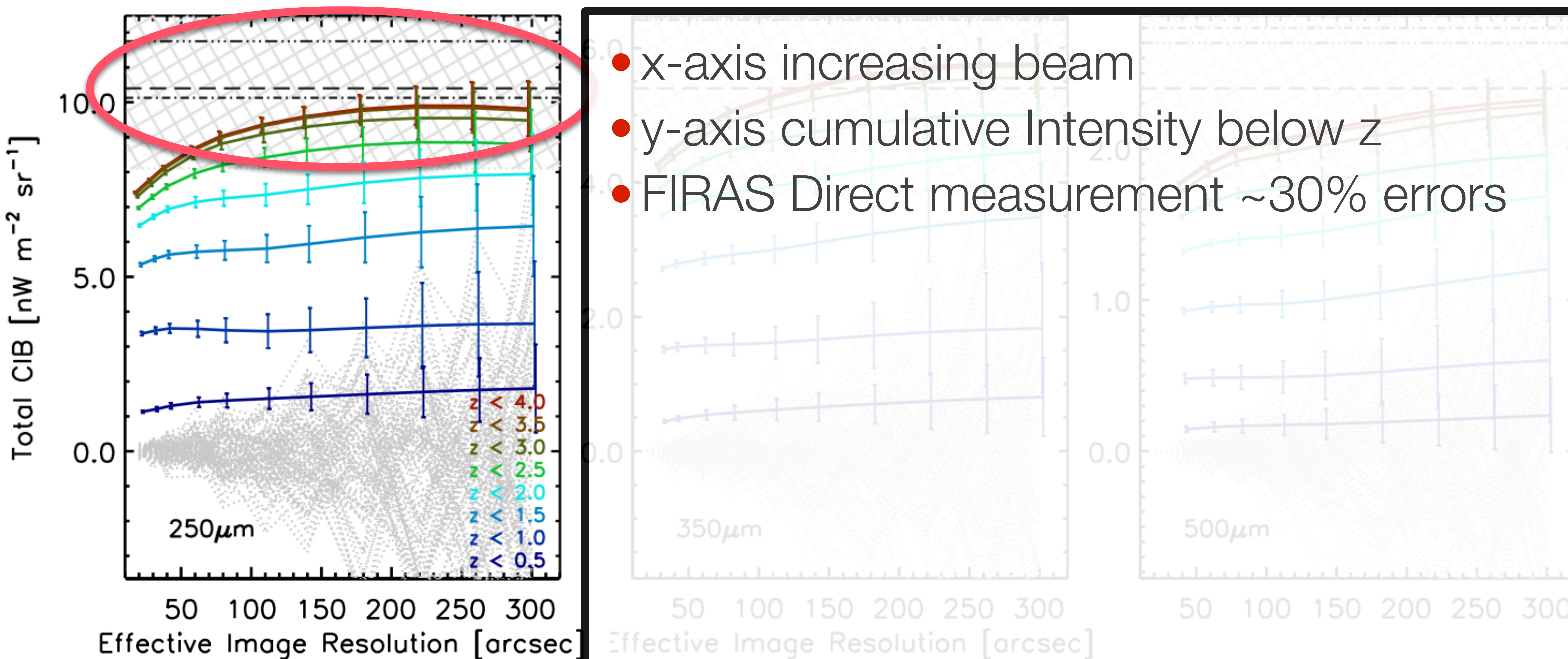

- x-axis increasing beam
- y-axis cumulative Intensity below z
- FIRAS Direct measurement ~30% errors

Smooth with bigger beam →

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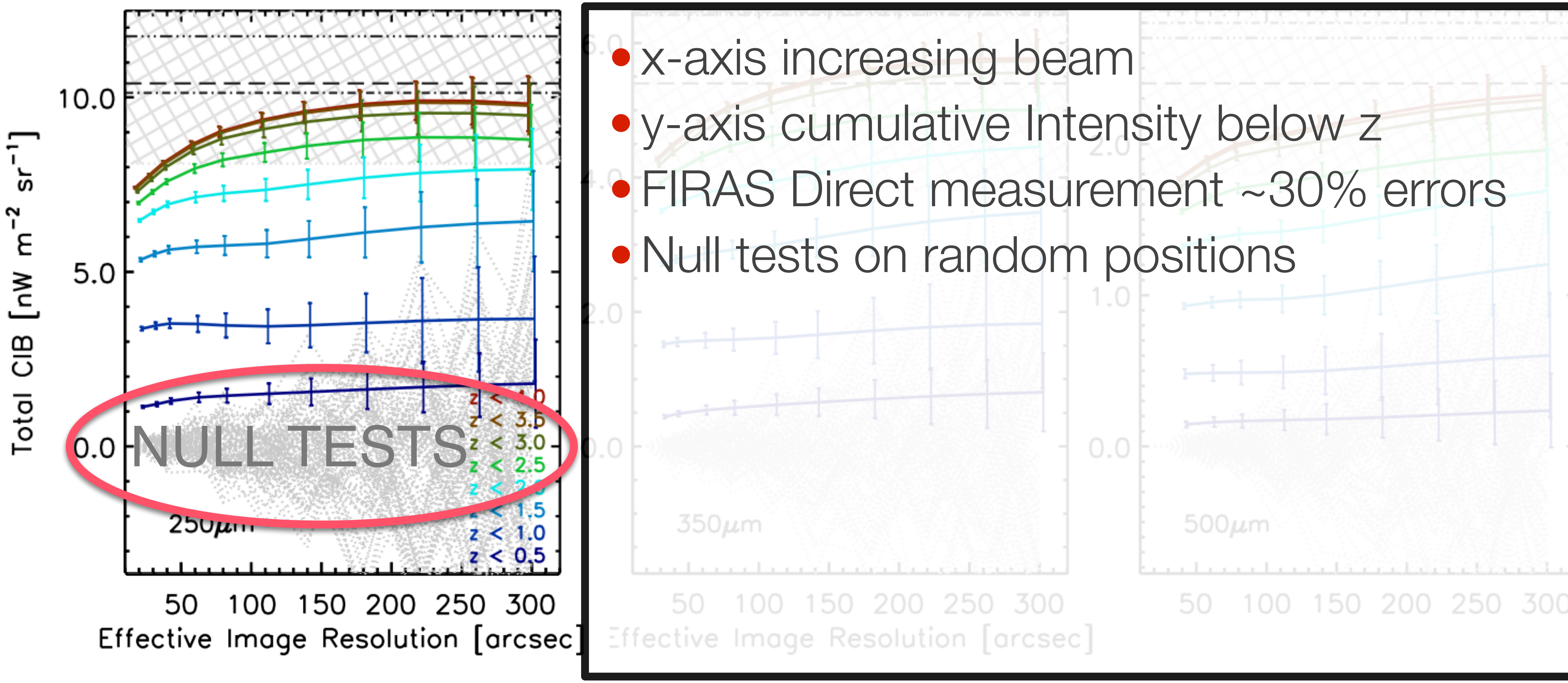

- x-axis increasing beam
- y-axis cumulative Intensity below z
- FIRAS Direct measurement ~30% errors
- Null tests on random positions

Smooth with bigger beam →

Viero, Moncelsi, Quadri et al. (2015)
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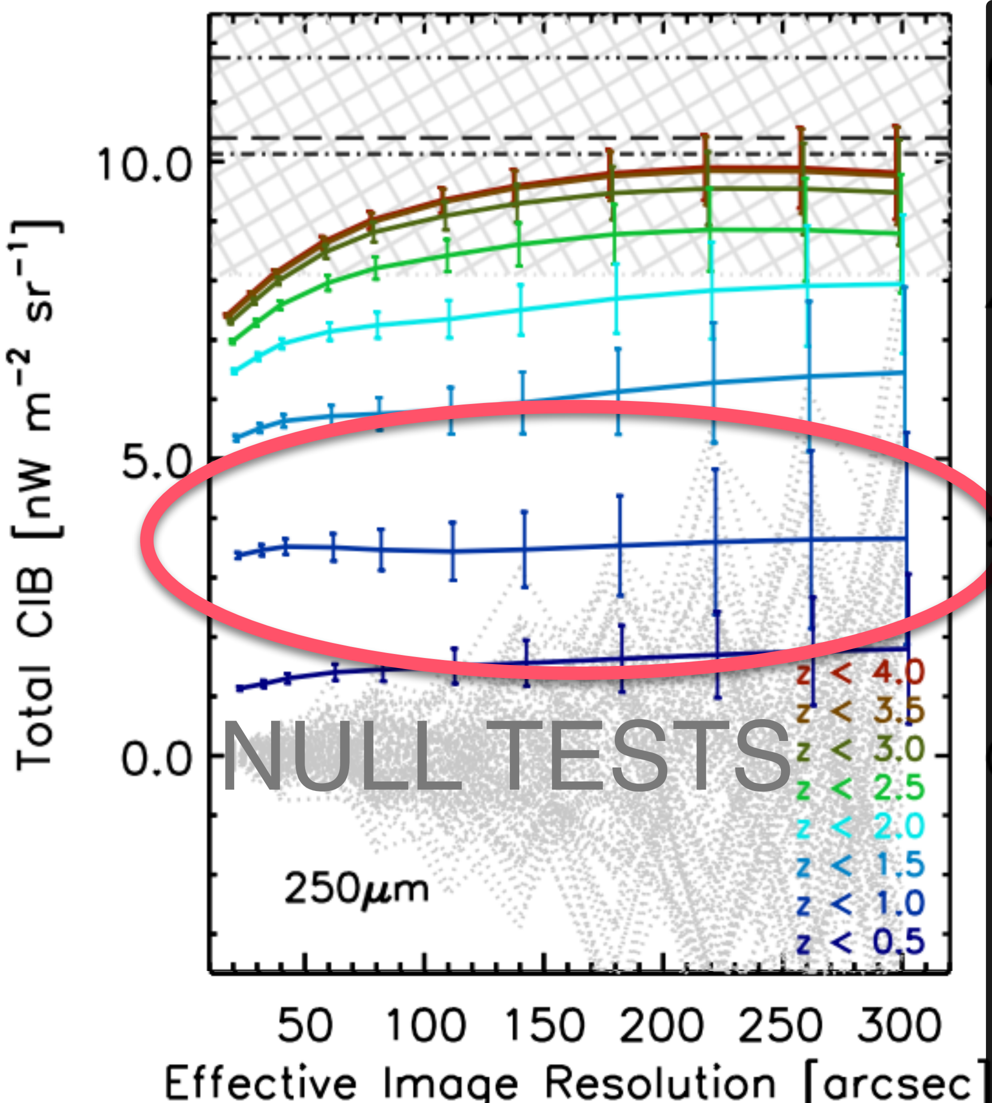

- x-axis increasing beam
- y-axis cumulative Intensity below z
- FIRAS Direct measurement ~30% errors
- Null tests on random positions
- Flat because Catalog is ~100% complete to log(M/Msun) = 9 - 11.5

Smooth with bigger beam →

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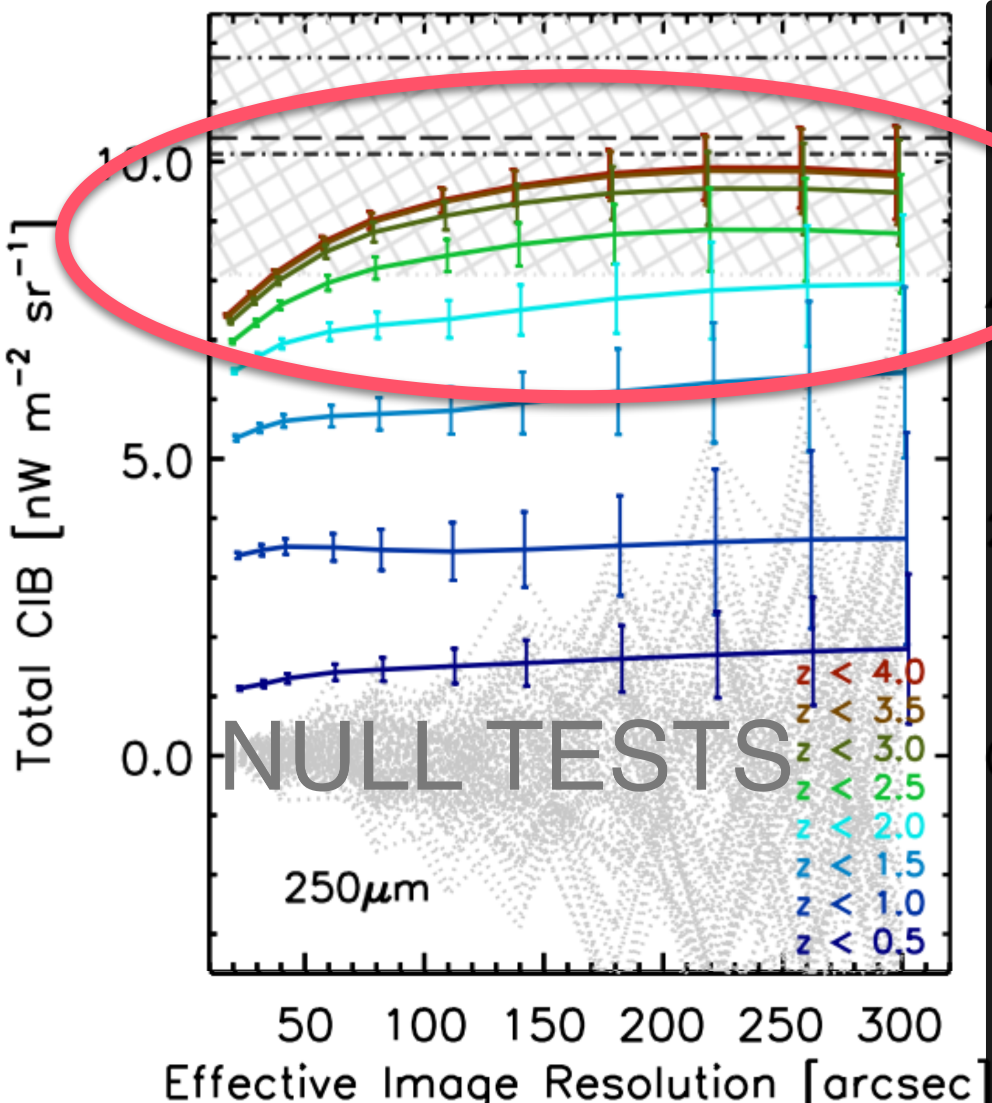

- x-axis increasing beam
- y-axis cumulative Intensity below z
- FIRAS Direct measurement ~30% errors
- Null tests on random positions
- Flat because Catalog is ~100% complete to log(M/Msun) = 9 - 11.5
- Nearly all of the CIB is accounted for by emission correlated with known, cataloged, galaxies. ***But is it necessarily originating from galaxies?***

Smooth with bigger beam →

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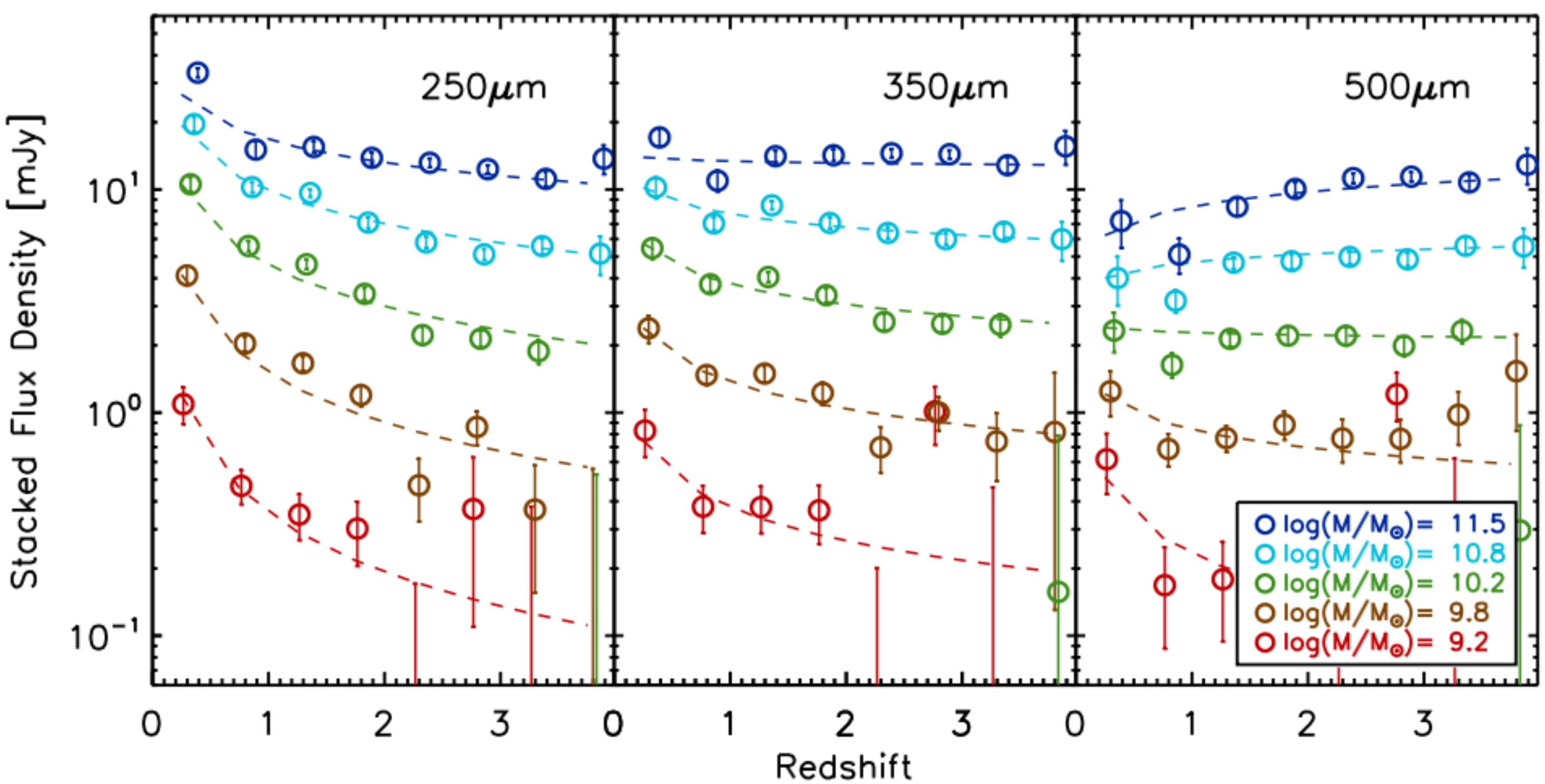
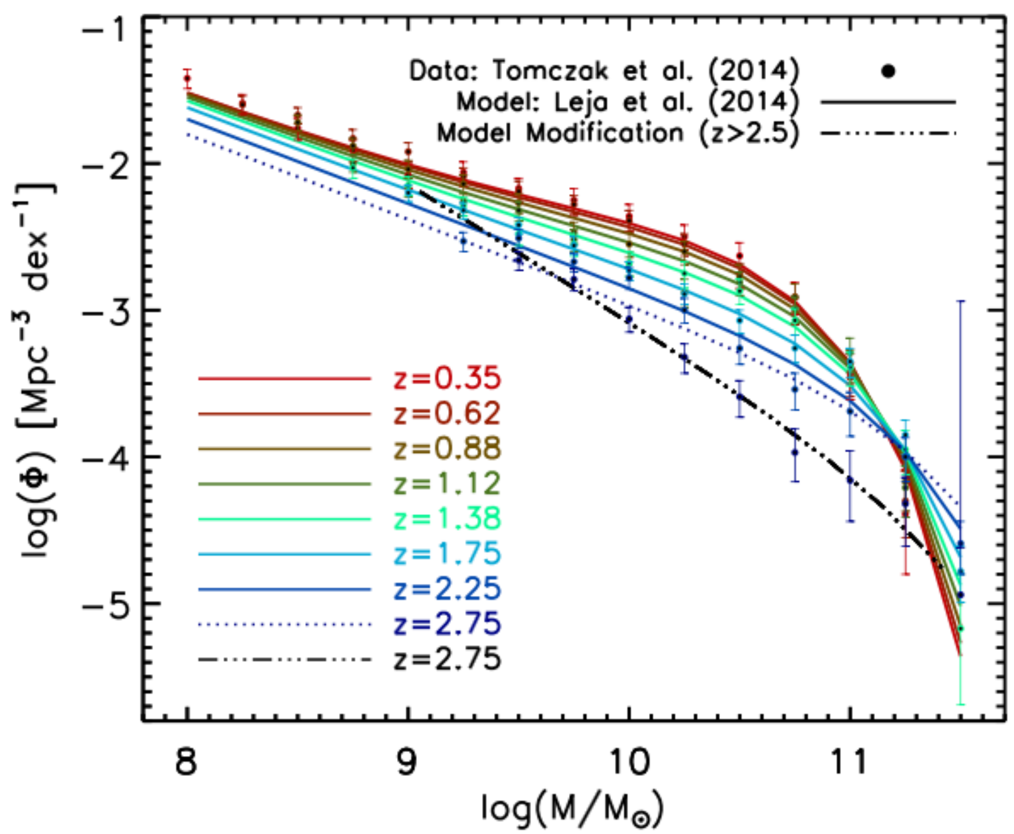
A New Accounting of the CIB

Submillimeter Flux Densities

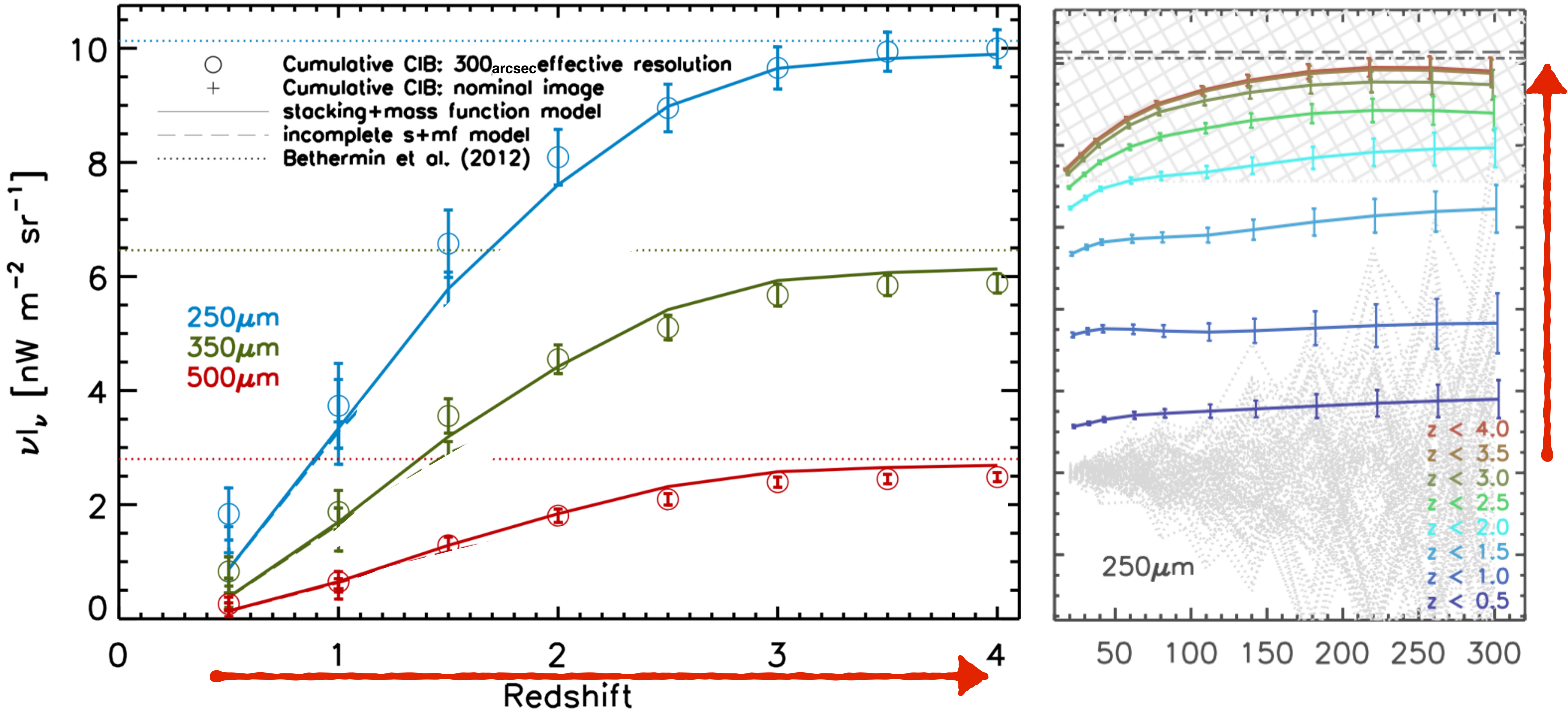


Stellar Mass Functions



- Parametric fit to the (nominally) stacked flux densities (dashed lines)
- Parametric fit to the stellar mass functions from Leja et al. 2014 (solid lines)

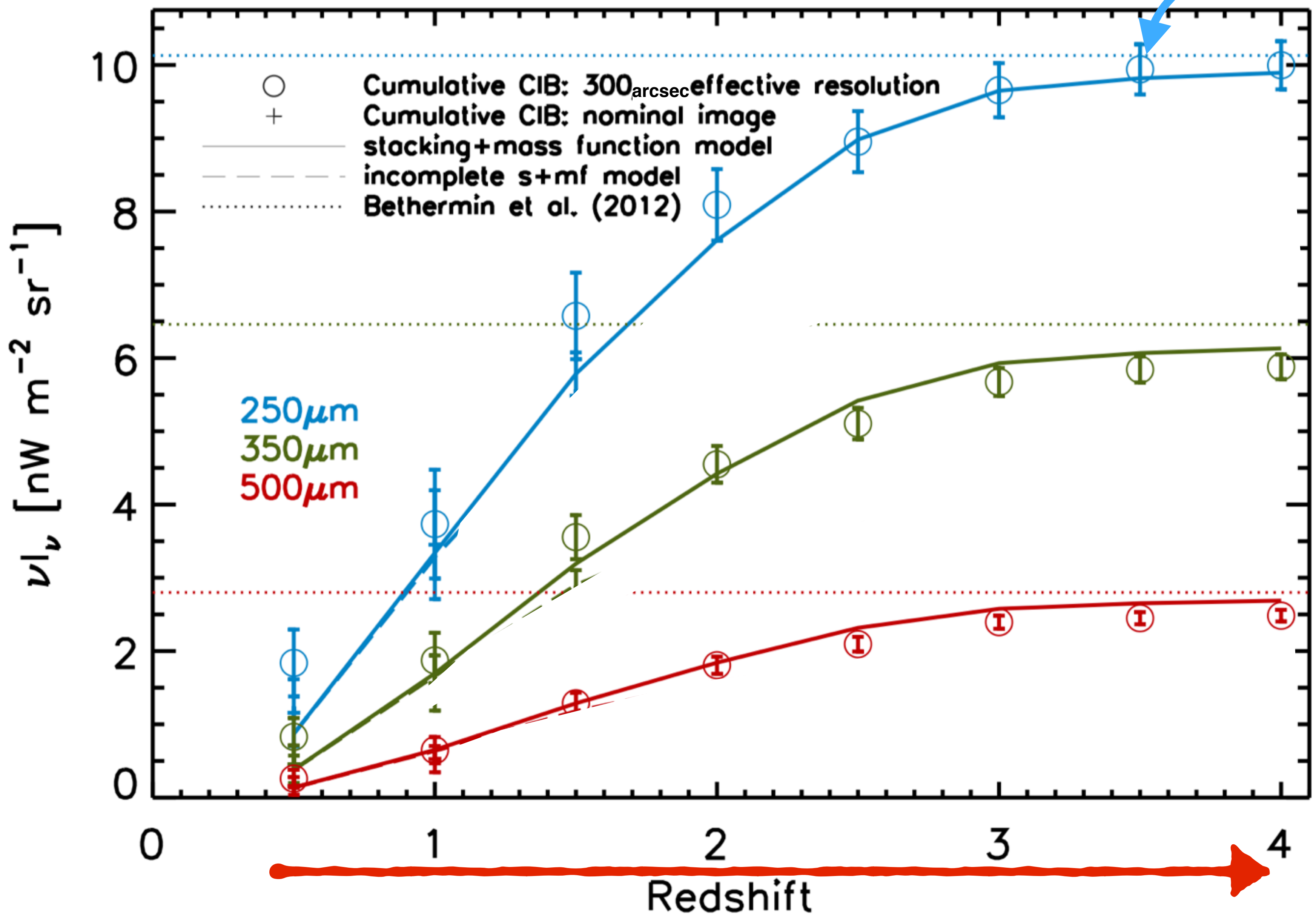
A New Accounting of the CIB

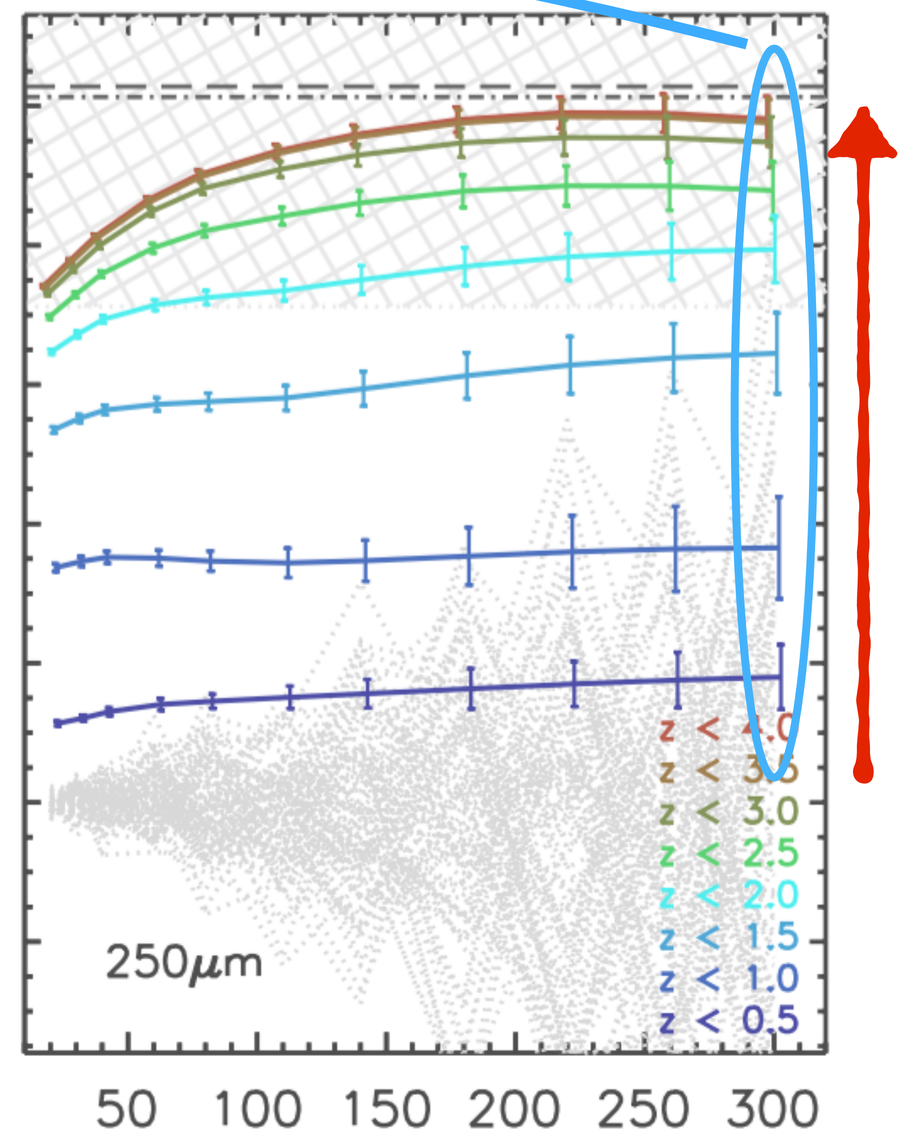


Viero, Moncelsi, Quadri et al. (2015)
arXiv:1505.06242

- Circles/Solid lines: Model compared to total CIB after smoothing to 300 arcsec FWHM.

A New Accounting of the CIB





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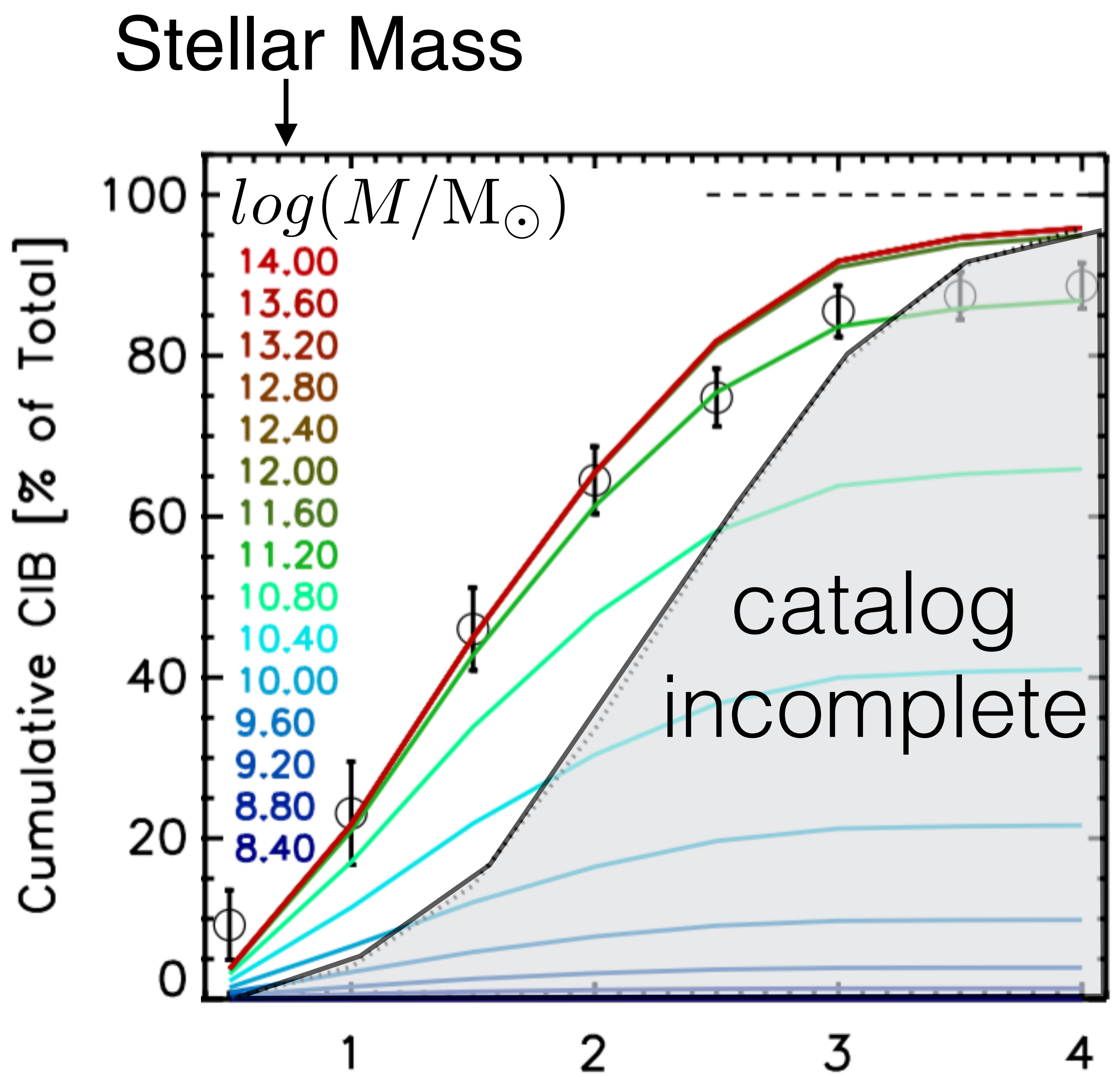


- Most of the CIB comes from galaxies between log(M/Msun)=8.5 - 11.5
- Black line/shaded region is the incompleteness of the catalog

The total CIB places limits on, e.g.,:

➡Low-Mass end of the Stellar mass function

- Any stellar mass model cannot have to many/few IR emitters

➡Star-Formation Rate Density (to z = 4 for now)

- Limits on total obscured star formation

A New Accounting of the CIB: Summary

- Current Estimates of the total CIB can be explained by known galaxies, and their correlated companions, at z < 4
- This technique is not limited to submillimeter maps or CIB studies
  - ➡ as we push to higher redshifts, intensities will be powerful probes of first galaxies, which will be faint, numerous, and highly correlated

Viero, Moncelsi et al. (2016) — arXiv:1505.06242

The Astrophysical Journal Letters, 809:L22 (6pp), 2015 August 20 doi:10.1088/2041-8205/809/2/L22

HERMES: CURRENT COSMIC INFRARED BACKGROUND ESTIMATES CAN BE EXPLAINED BY KNOWN GALAXIES AND THEIR FAINT COMPANIONS AT $z < 4$

M. P. Viero[1,2], L. Moncelsi[2], R. F. Quadri[3], M. Béthermin[4,5], J. Bock[2,6], D. Burgarella[7], S. C. Chapman[8], D. L. Clements[9], A. Conley[10], L. Conversi[11], S. Duivenvoorden[12], J. S. Dunlop[13], D. Farrah[14], A. Franceschini[15], M. Halpern[16], R. J. Ivison[13,17], G. Lagache[7], G. Magdis[18], L. Marchetti[15], J. Álvarez-Márquez[7], G. Marsden[16], S. J. Oliver[12], M. J. Page[19], I. Pérez-Fournon[20,21], B. Schulz[2,22], Douglas Scott[16], I. Valtchanov[11], J. D. Vieira[23,24], L. Wang[25,26], J. Wardlow[27], and M. Zemcov[2,6]

ABSTRACT

We report contributions to cosmic infrared background (CIB) intensities originating from known galaxies and their faint companions at submillimeter wavelengths. Using the publicly available UltraVISTA catalog and maps at 250, 350, and 500 μm from the *Herschel* Multi-tiered Extragalactic Survey, we perform a novel measurement that exploits the fact that uncataloged sources may bias stacked flux densities—particularly if the resolution of the image is poor—and intentionally smooth the images before stacking and summing intensities. By smoothing the maps we are capturing the contribution of faint (undetected in $K_S \sim 23.4$) sources that are physically associated, or *correlated*, with the detected sources. We find that the cumulative CIB increases with increased smoothing, reaching 9.82 ± 0.78, 5.77 ± 0.43 and 2.32 ± 0.19 nWm^{-2} sr^{-1} at 250, 350, and 500 μm at 300 arcsec FWHM. This corresponds to a fraction of the fiducial CIB of 0.94 ± 0.23, 1.07 ± 0.31, and 0.97 ± 0.26 at 250, 350, and 500 μm, where the uncertainties are dominated by those of the absolute CIB. We then propose, with a simple model combining parametric descriptions for stacked flux densities and stellar mass functions, that emission from galaxies with $\log(M/M_\odot) > 8.5$ can account for most of the measured total intensities and argue against contributions from extended, diffuse emission. Finally, we discuss prospects for future survey instruments to improve the estimates of the absolute CIB levels, and observe any potentially remaining emission at $z > 4$.

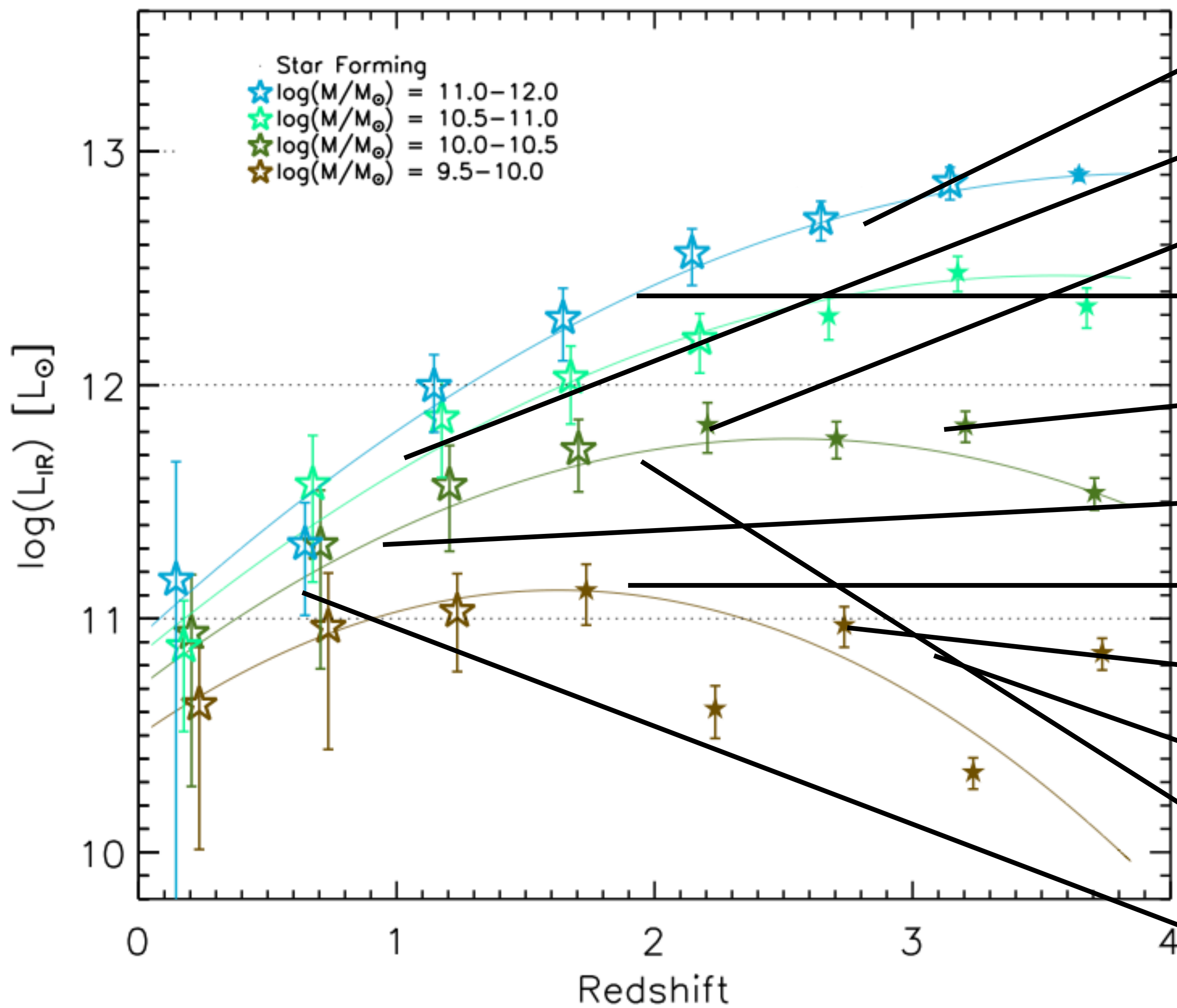
Key words: cosmology: observations – galaxies: evolution – infrared: galaxies – large-scale structure of universe – submillimeter: galaxies

1. INTRODUCTION

Of all the light that has been emitted by stars, about half has been absorbed by interstellar dust and thermally re-radiated at far-infrared to submillimeter wavelengths, appearing as a diffuse, extragalactic, cosmic infrared background spanning 1–1000 μm (CIB; Hauser & Dwek 2001; Dole et al. 2006). Statistically characterizing the sources responsible for this background is necessary to gain a full understanding of galaxy formation and cosmology, and thus remains an ongoing pursuit.

The CIB was first detected in spectroscopy with the Far Infrared Absolute Spectrophotometer (FIRAS; Puget et al. 1996; Mather et al. 1999). Observations of local starburst galaxies with *IRAS* (Soifer et al. 1984) showed that galaxies

SIMSTACK: coming full circle



Flux	RA	DEC
41.4	149.853	2.608
3.5	149.854	2.258
4.4	149.752	2.584
16.7	149.832	2.724
22.5	149.275	2.196
3.6	149.262	2.966
5.8	149.915	2.206
3.1	149.546	2.564
2.3	149.824	2.047
4.0	149.453	2.278
2.1	149.863	2.788
…	…	…

Viero, Moncelsi, Quadri et al. (2013)
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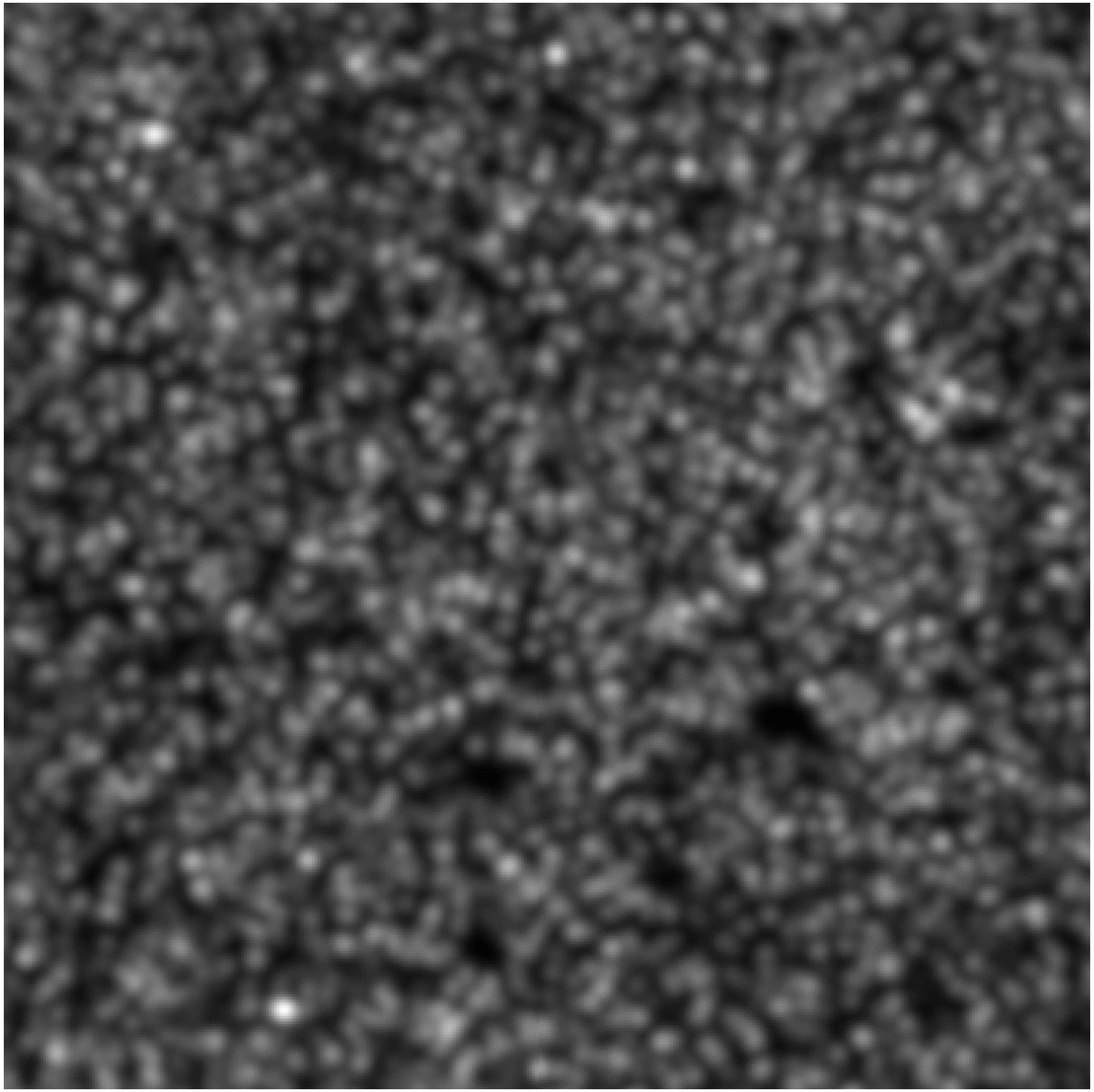

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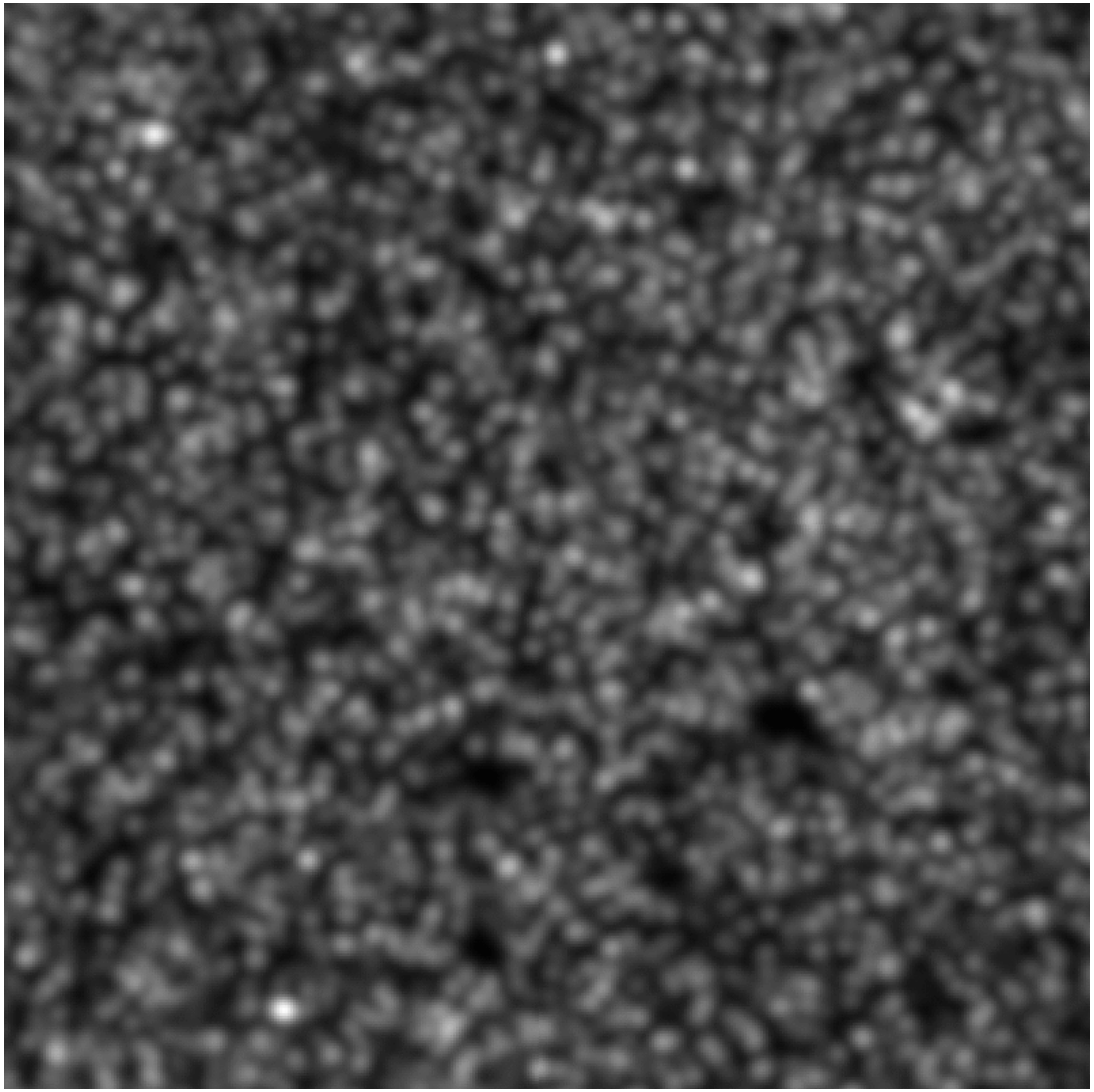

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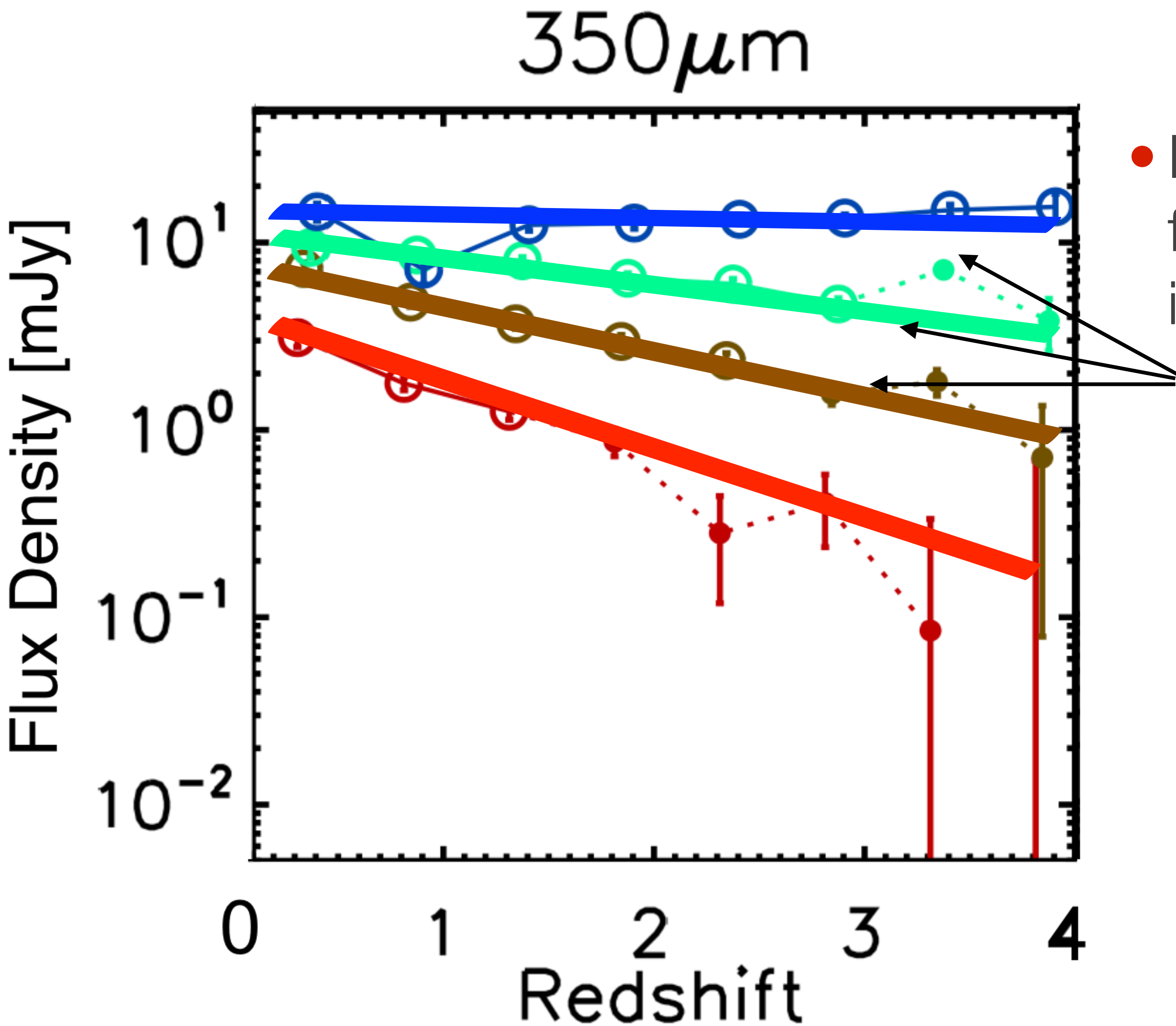
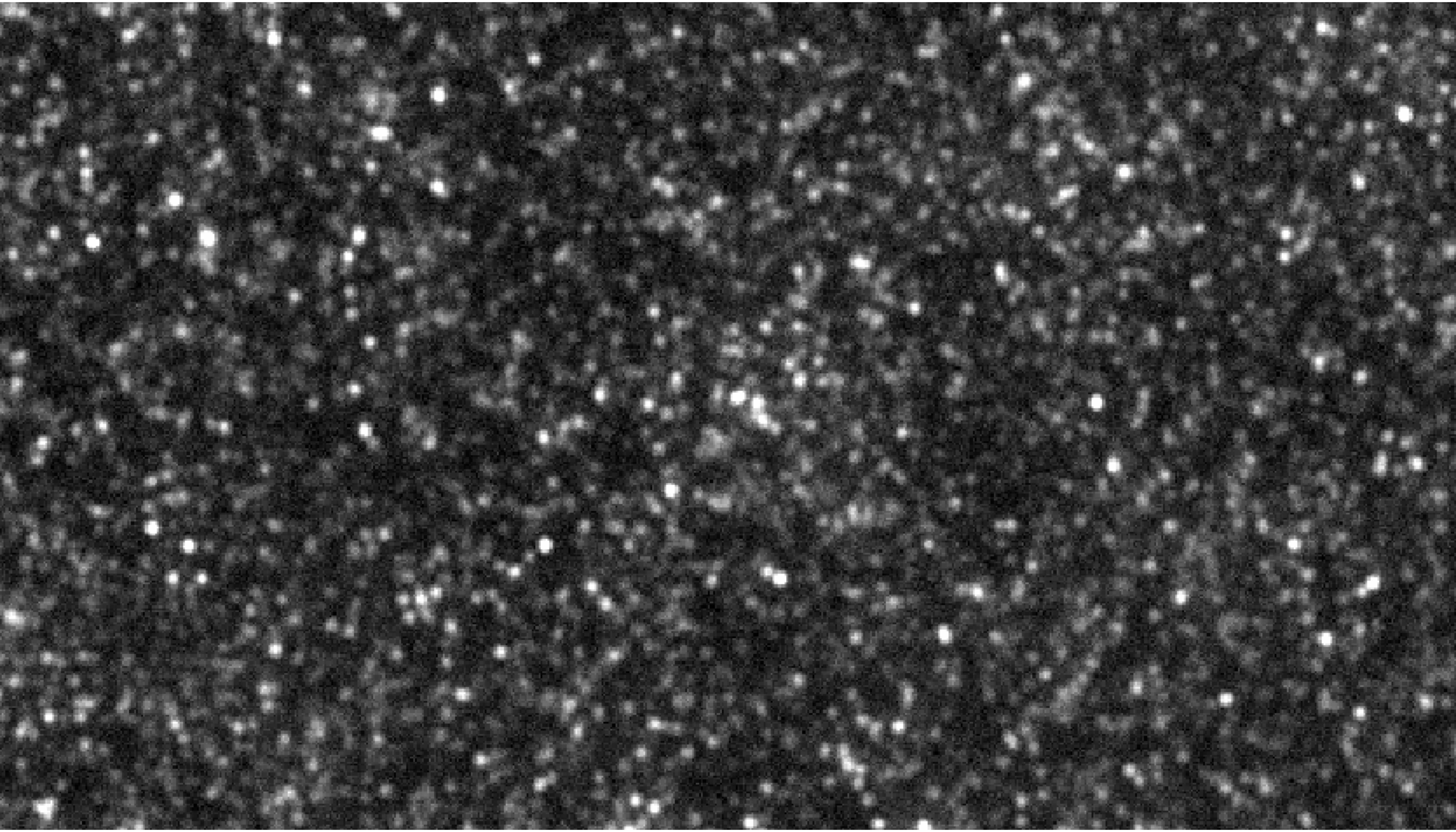
FLUCTFIT: Preview



- Instead of average flux of simulated images
  - ➡ Fit parameters of the model to each object

FLUCTFIT: Preview



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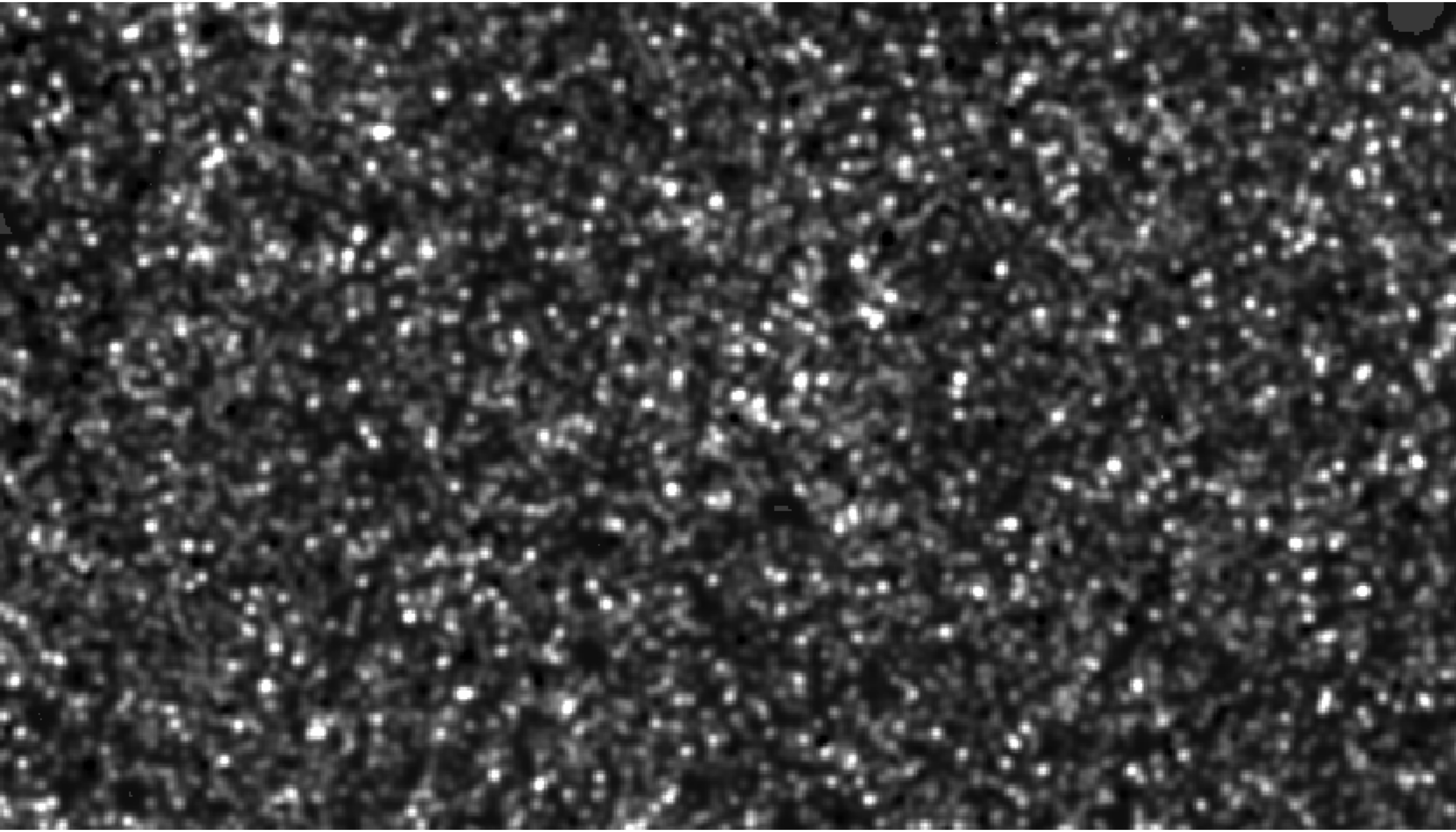

Summary

- Current Estimates of the total CIB can be explained by known galaxies, and their correlated companions, at z < 4
- SIMSTACK works
  - ➡splitting up of sample needs improving.
  - ➡ALMA observations should provide useful priors for more sophisticated algorithms.

- Emission from galaxies predicted by the stellar mass function can account for the entire CIB

- This technique is not limited to submillimeter maps or CIB studies
  - ➡as we push to higher redshifts, intensities will be powerful probes of first galaxies, which will be faint, numerous, and highly correlated

- Absolute CIB level is important, and needs to be improved (might require a dedicated instrument)