Models of the CO background via Measurements of the Cosmic Infrared Background

Marco Viero — KIPAC/Stanford
w/
Lorenzo Moncelsi, Jason Sun (Caltech),
Dongwoo Chung (KIPAC/Stanford)
and the COMAP and TIME Collaborations

Motivation: Typical CO Model Design

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L_{CO} (units of $L_\odot$) is

$$L_{CO} = 4.9 \times 10^{-5} L_\odot \left(\frac{\nu_{CO,rest}}{115.27 \text{ GHz}} \right)^3 \left(\frac{L'_{CO}}{\text{K km s}^{-1} \text{ pc}^2} \right) \quad (4)$$

Tony Li et al. 2016

where $\nu_{CO,rest} = 115.27$ GHz is the rest-frame frequency of the CO transition.

To resummarize the model:

1. Halos $\rightarrow$ SFR: Get $\overline{\mathrm{SFR}}(M, z)$ from the results of Behroozi et al. (2013a)
2. Add log-scatter, σ_{SFR}
3. SFR $\rightarrow L_{IR}$: Get L_{IR} from SFR $= \delta_{MF} \times 10^{-10} L_{IR}$
4. $L_{IR} \rightarrow L'_{CO}$: Get L'_{CO} from $\log L_{IR} = \alpha \log L'_{CO} + \beta$
5. Add log-scatter, $\sigma_{L_{CO}}$

Not all halos the same (*assembly* bias): *Add scatter*. → (step 2)

Not all galaxies star-forming: *Add scatter*. → (step 5)

with fiducial parameter values:

$$\sigma_{SFR} = 0.3, \ \sigma_{L_{CO}} = 0.3,$$
$$\delta_{MF} = 1.0, \ \alpha = 1.37, \ \beta = -1.74.$$

be absorbed into σ_{SFR}

Luminosity

minosity, we assume

Figure 2 shows the combined result of these steps, plotting the mean $L_{CO}(M_h)$ relation from our fiducial model, as well as the equivalent relation from previous studies. Notably, L_{CO} in this model is not linear in M, a simplifying assumption that has

While this paper was under review, the values of (α, β) in Dessauges-

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Stellar Mass – M*

Use empirically derived $L_{IR}(z, M_*)$

with fiducial parameter values:

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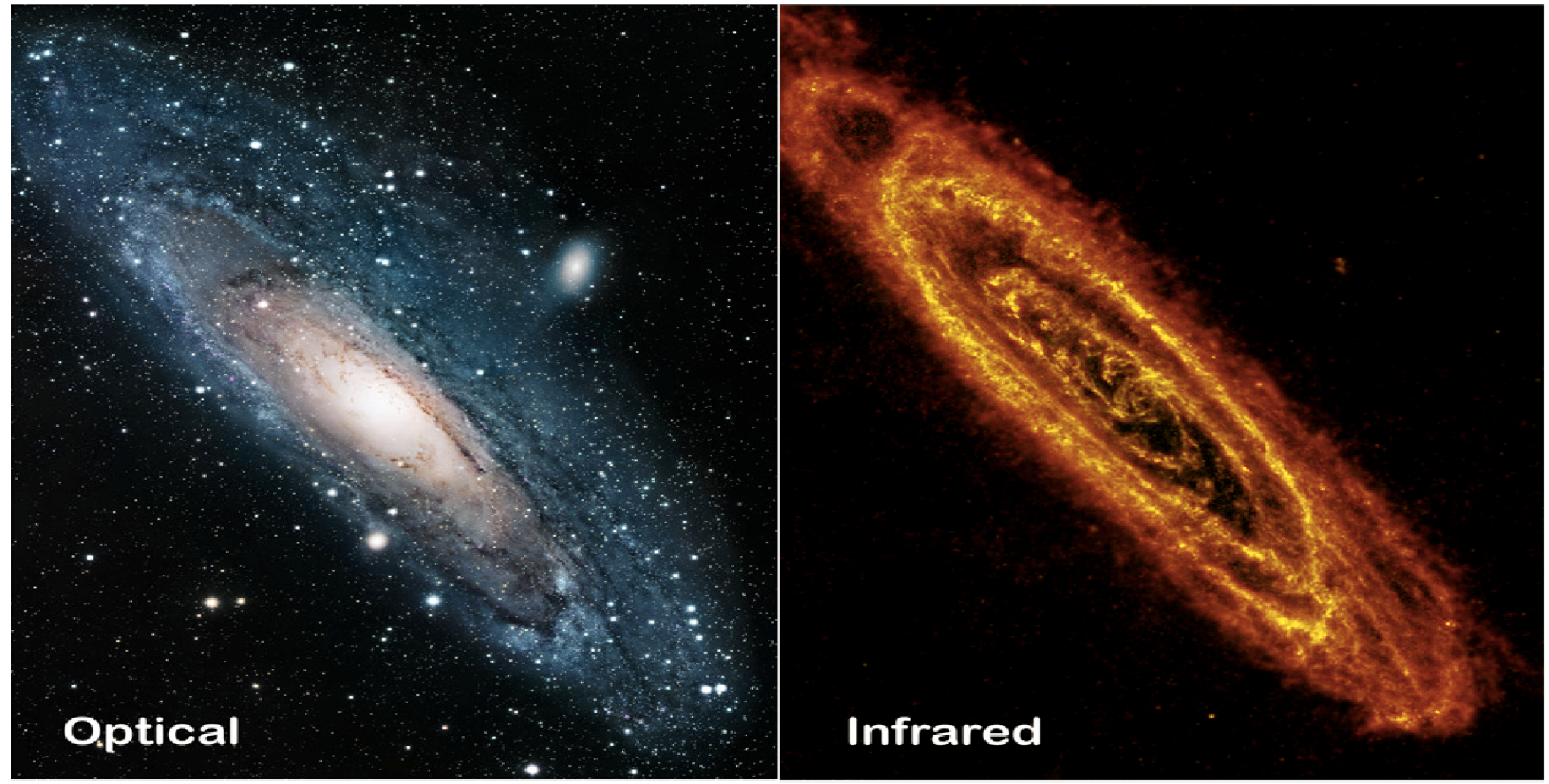
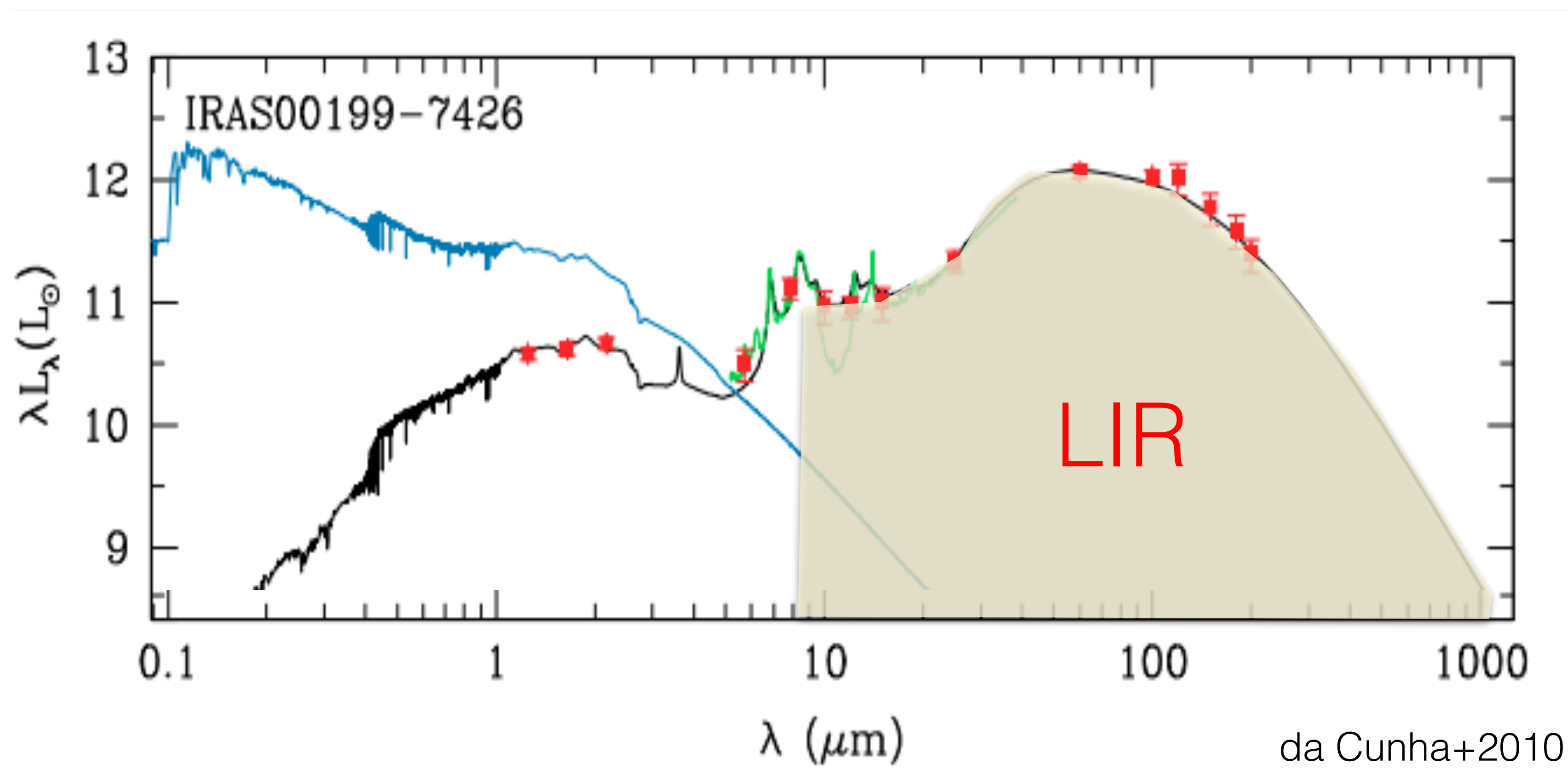
Challenge

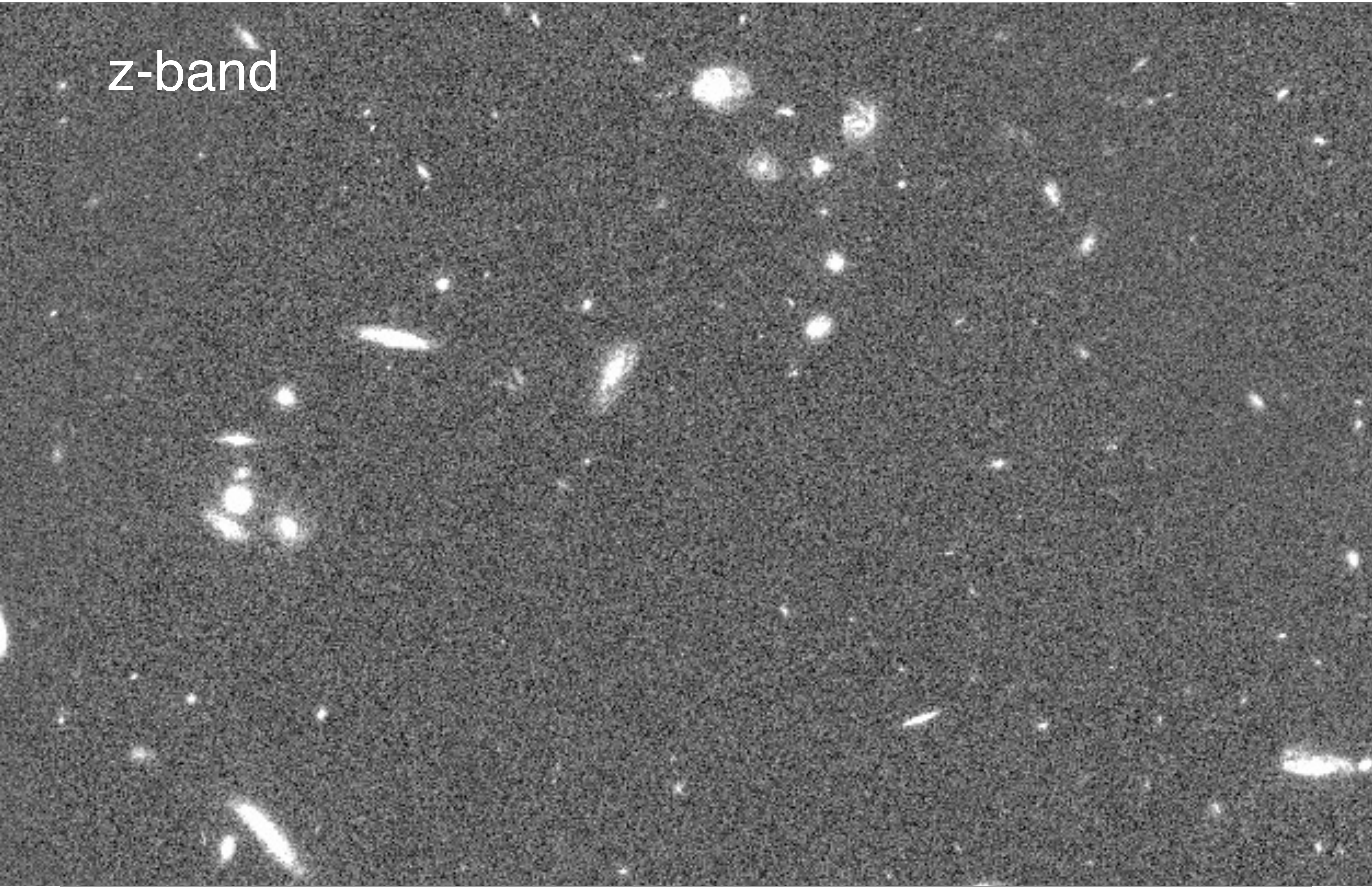
- Infrared/Submillimeter emission reprocessed starlight by dust
- IR/Submm traces star formation
- Half the emission is tied up in dust
- Want to know:
  - ➡ what about the Optical SED predicts the Thermal Infrared





da Cunha+2010

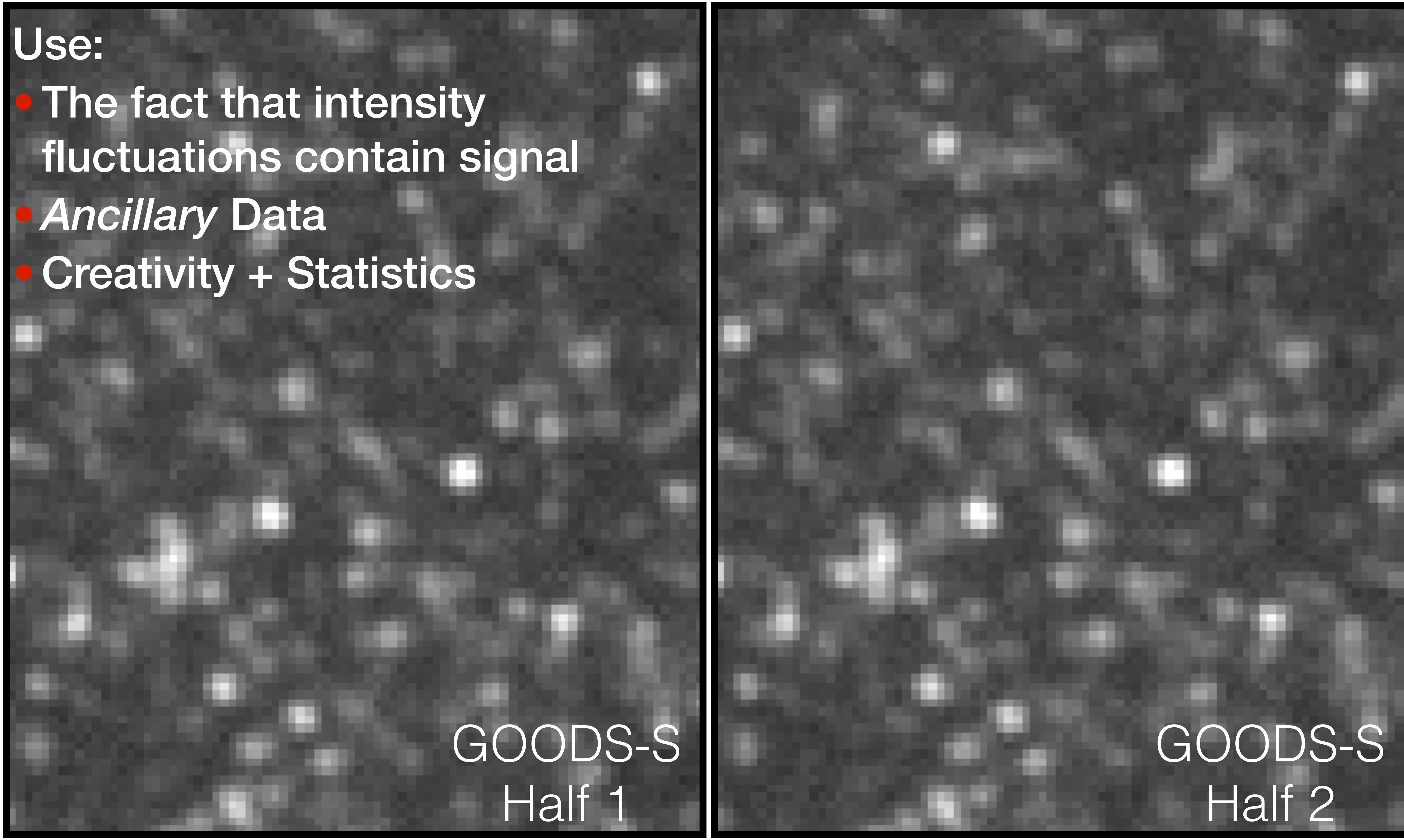
Challenge: Source Confusion



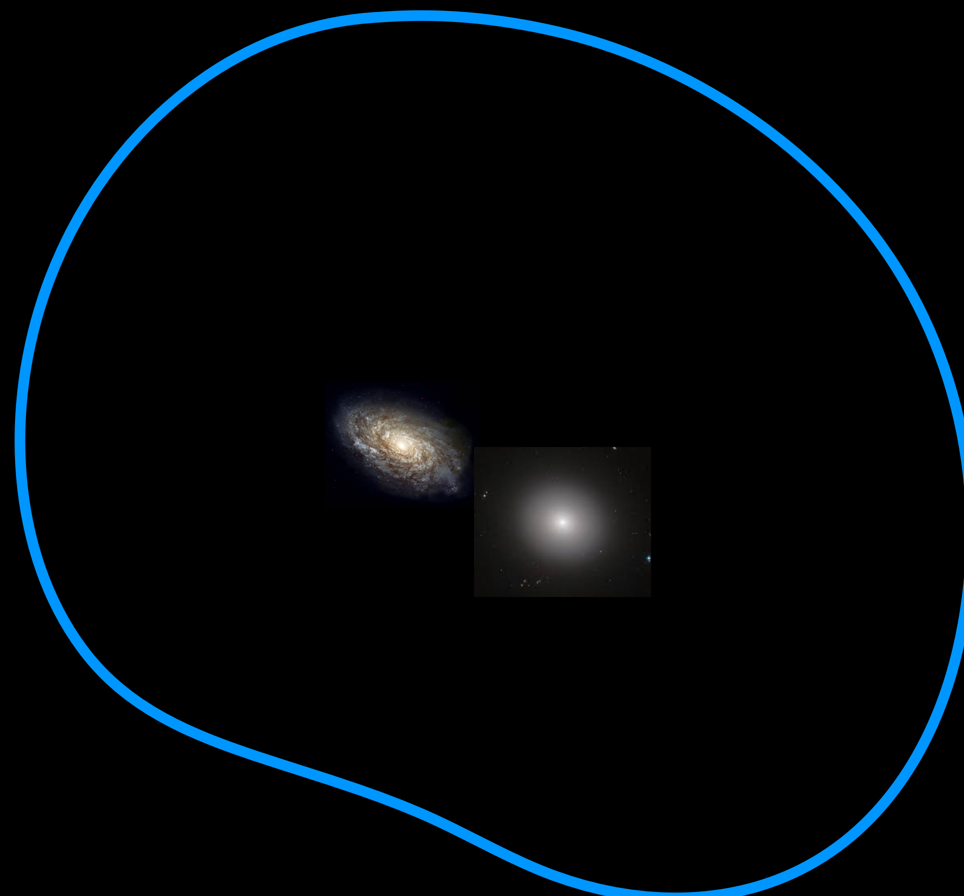
Solution

Use:

- The fact that intensity fluctuations contain signal
- *Ancillary* Data
- Creativity + Statistics

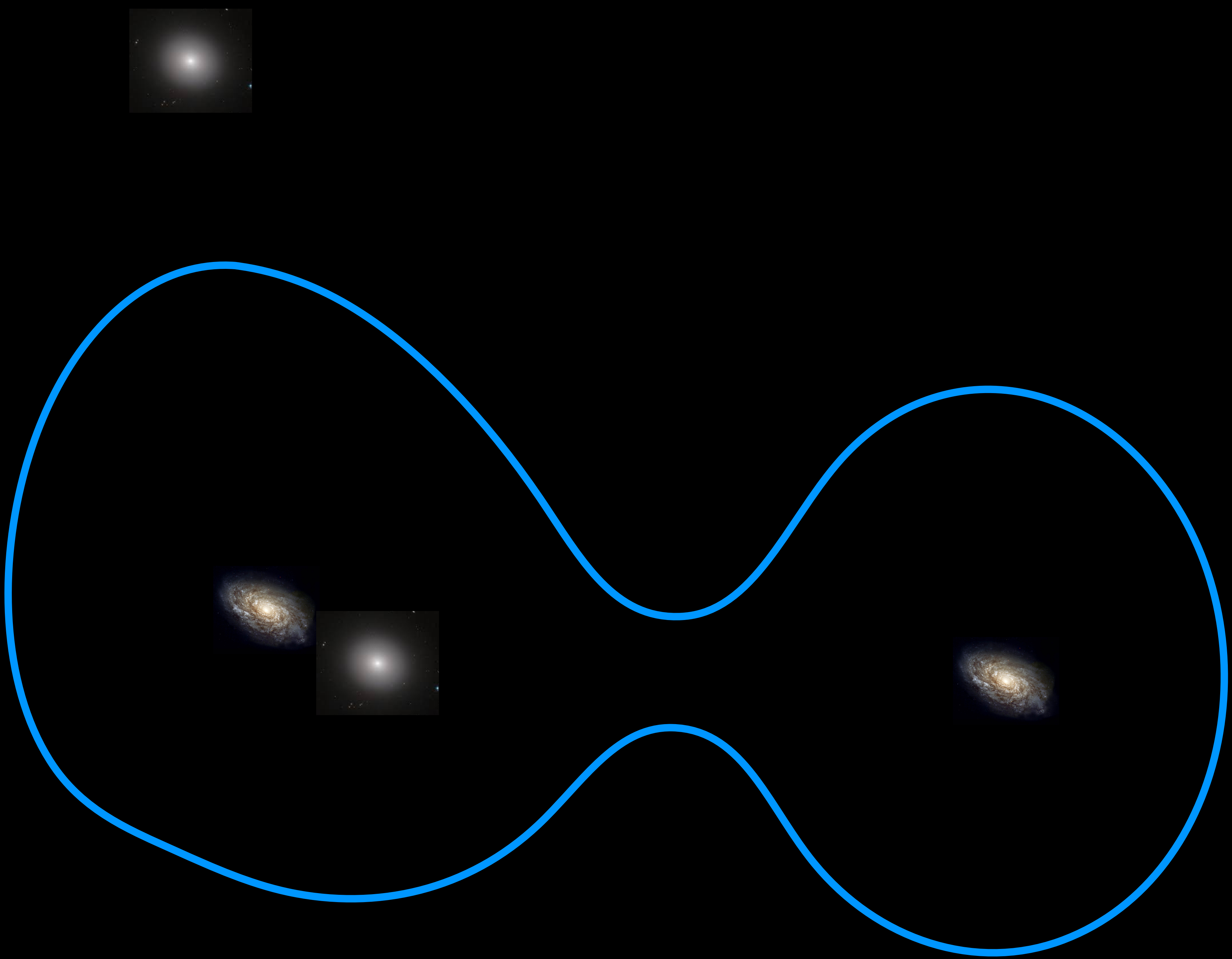


SPIRE Contour



- Difficult to attribute an individual submillimeter “source” to any single galaxy

SPIRE Contour



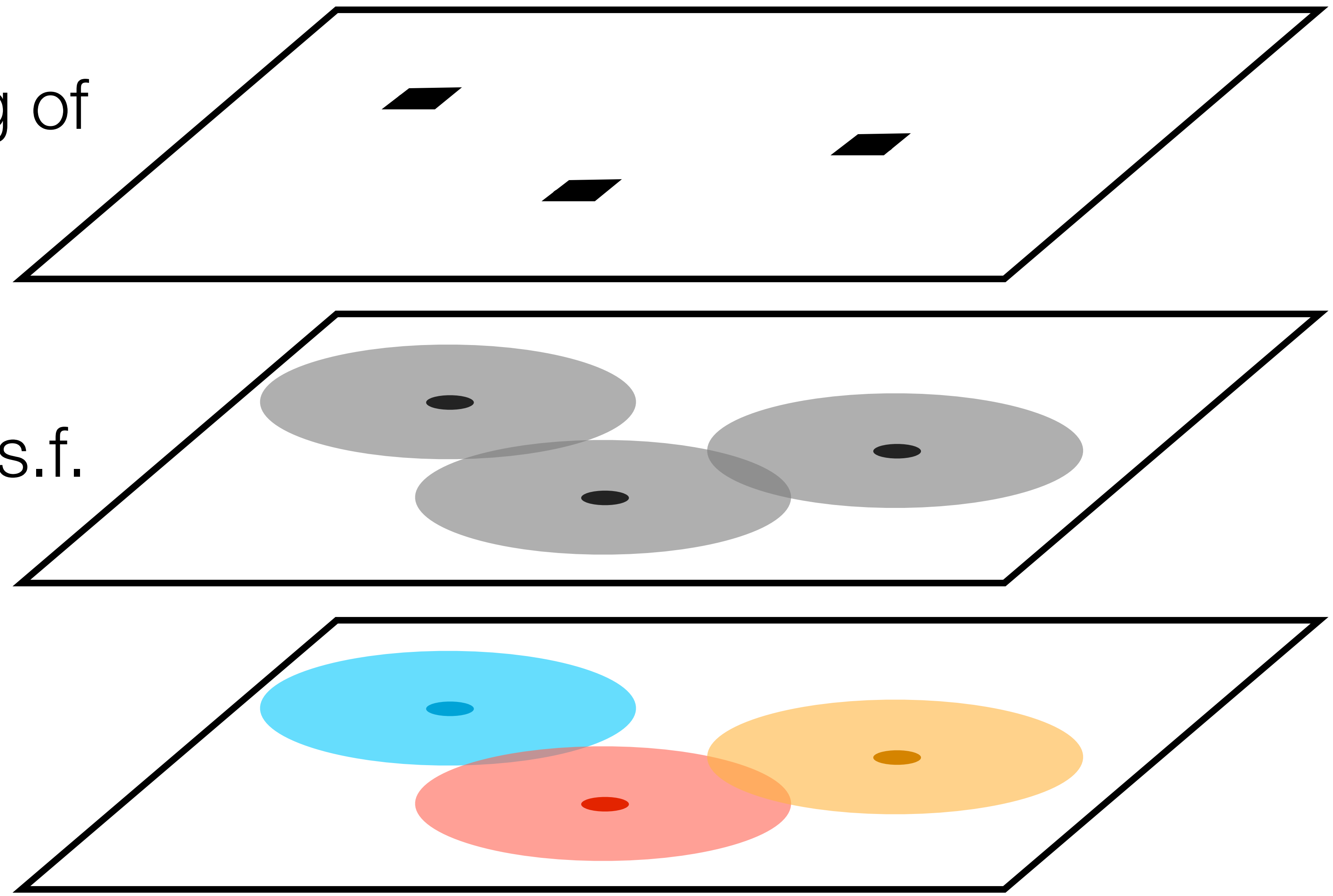
- Key is to identify galaxies with similar *physical* properties, and then rely on ***statistics to fit fluctuations***

SIMSTACK: Simultaneous Stacking Algorithm

make hits map from catalog of similar objects

convolve with instrument p.s.f.

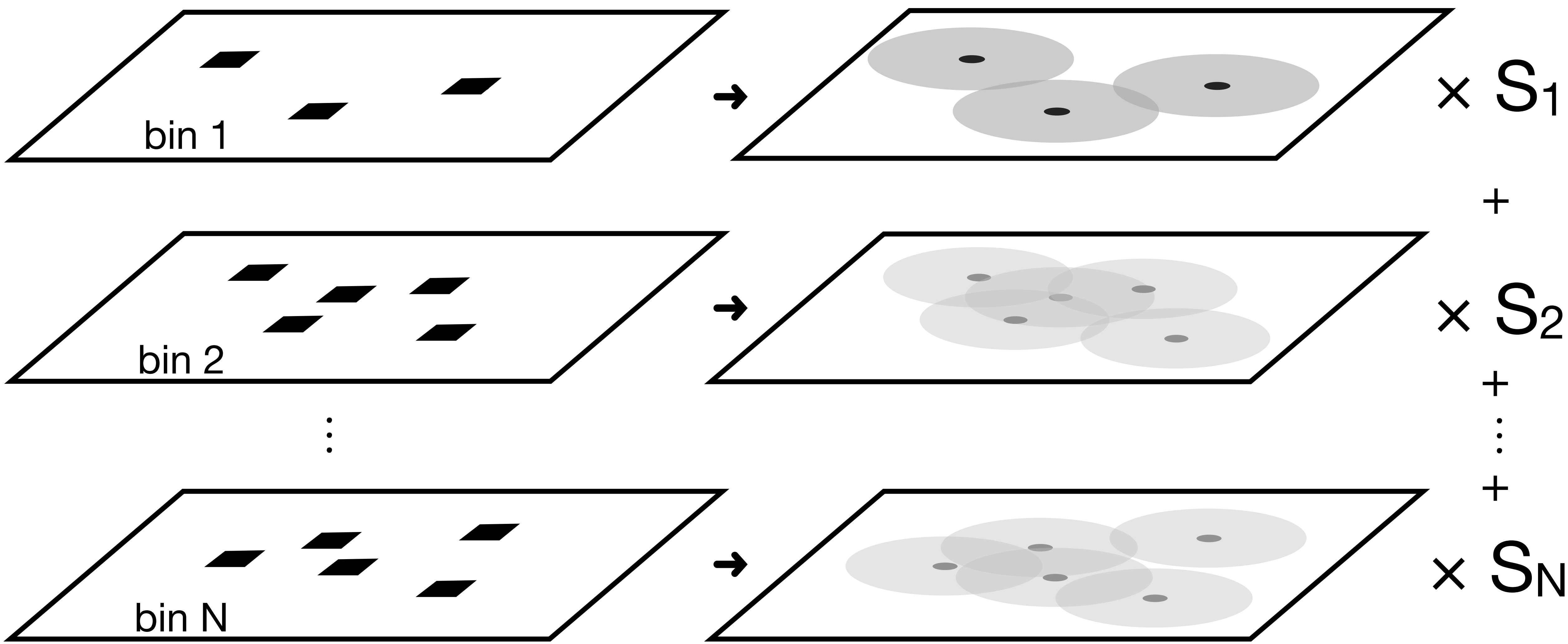
regress to find *mean* flux density, S

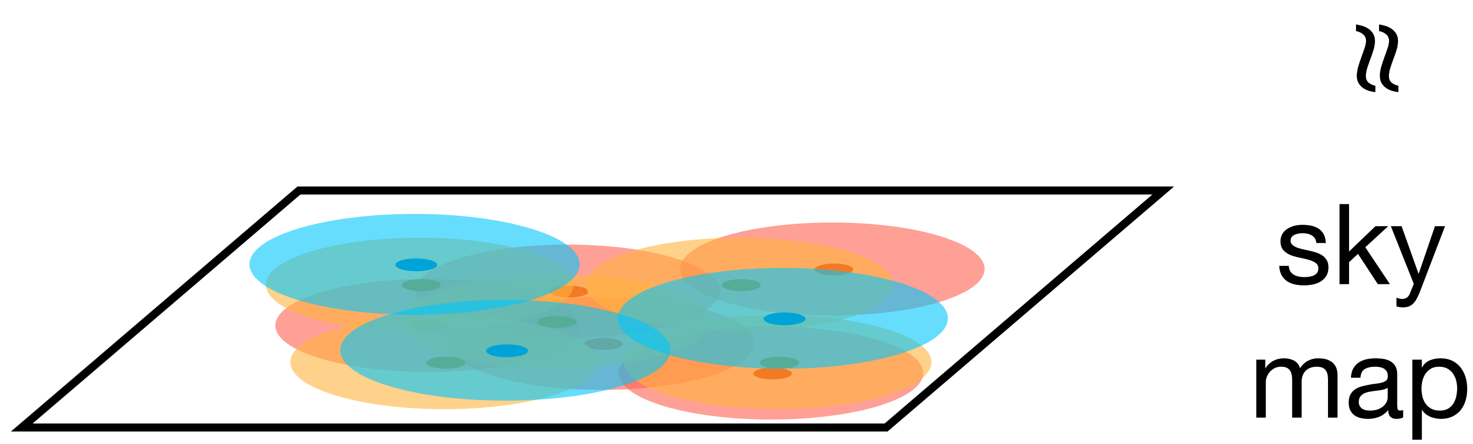


Formalism developed w/ Lorenzo Moncelsi (Caltech);
also see Kurczynski & Gawiser (2010), Roseboom et al. (2010)

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

SIMSTACK: Simultaneous Stacking Algorithm





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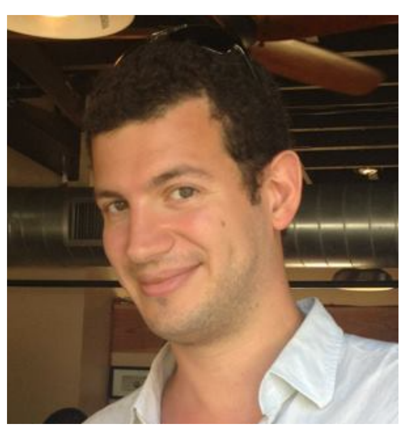

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z=1.0 to 1.5

M = 9.5-10

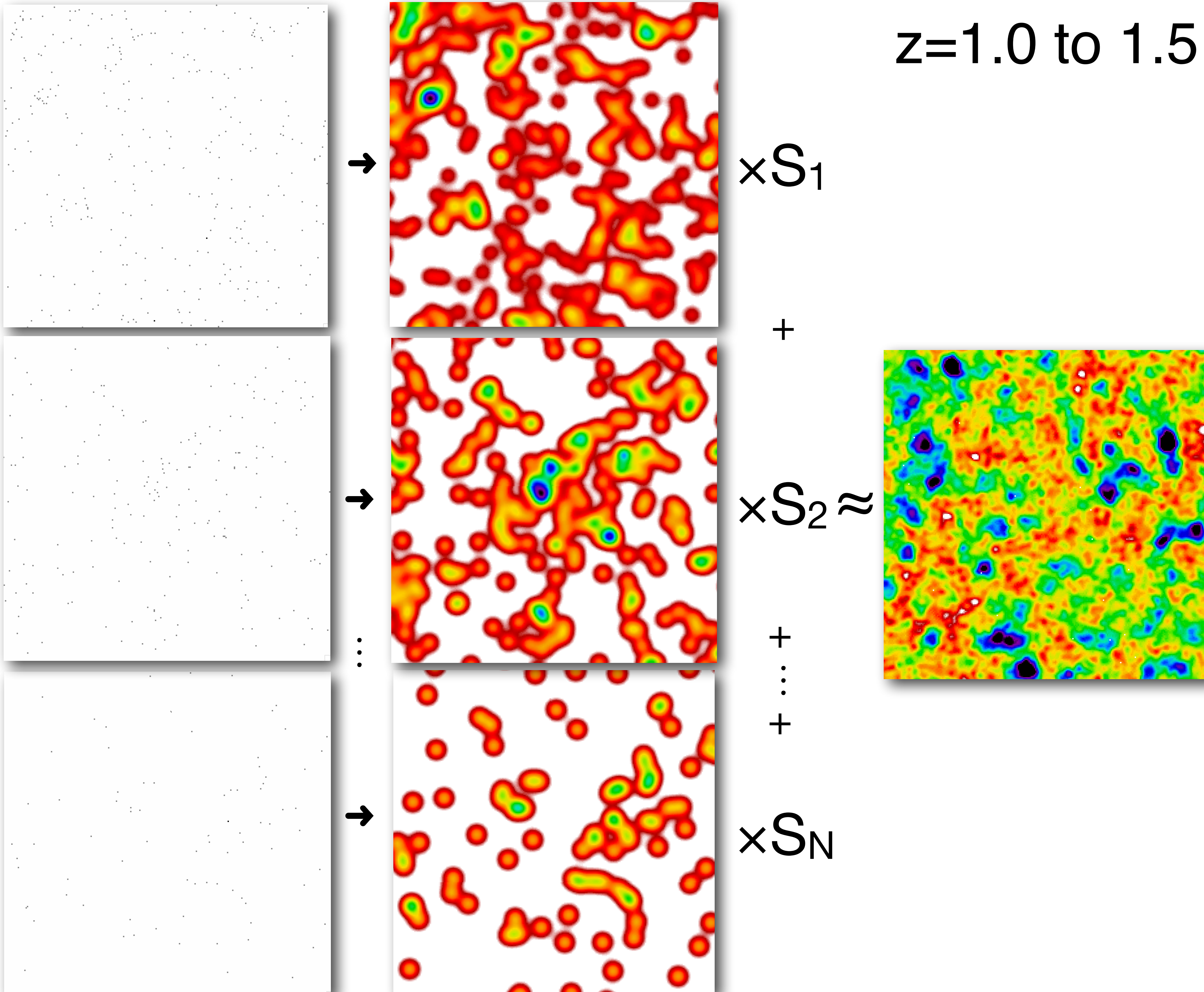
X	Y
996	1009
55	1011
187	1010
501	1011
336	1012
127	1011
⋮	

M = 10-10.5

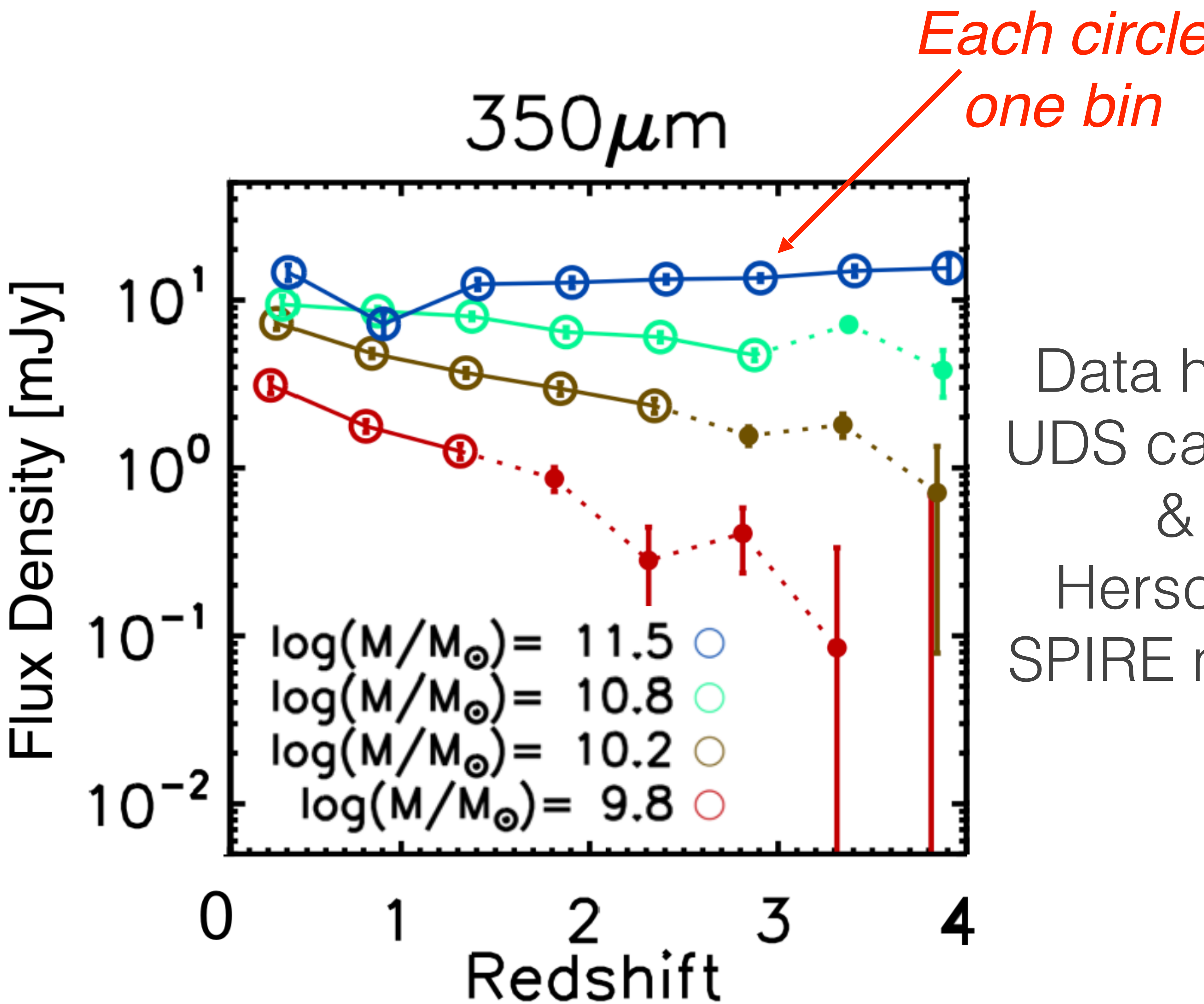
X	Y
535	1026
345	1029
340	1029
517	1027
805	1031
805	1031
⋮	

M = 10.5-11

X	Y
345	1029
340	1029
517	1027
805	1031
805	1031
238	1032
359	1033
841	1034
⋮	

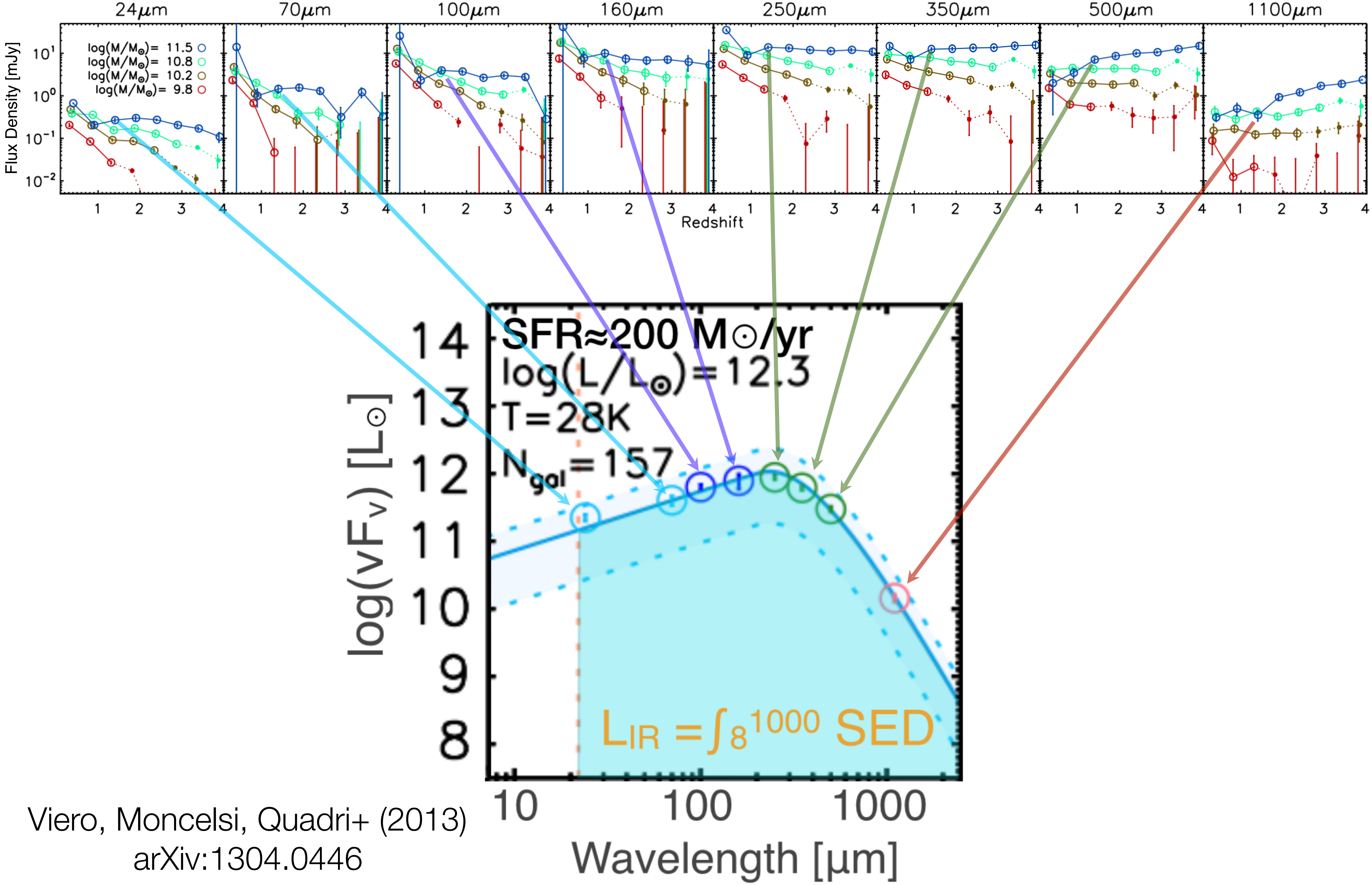


SIMSTACK: Flux Densities (M,z)



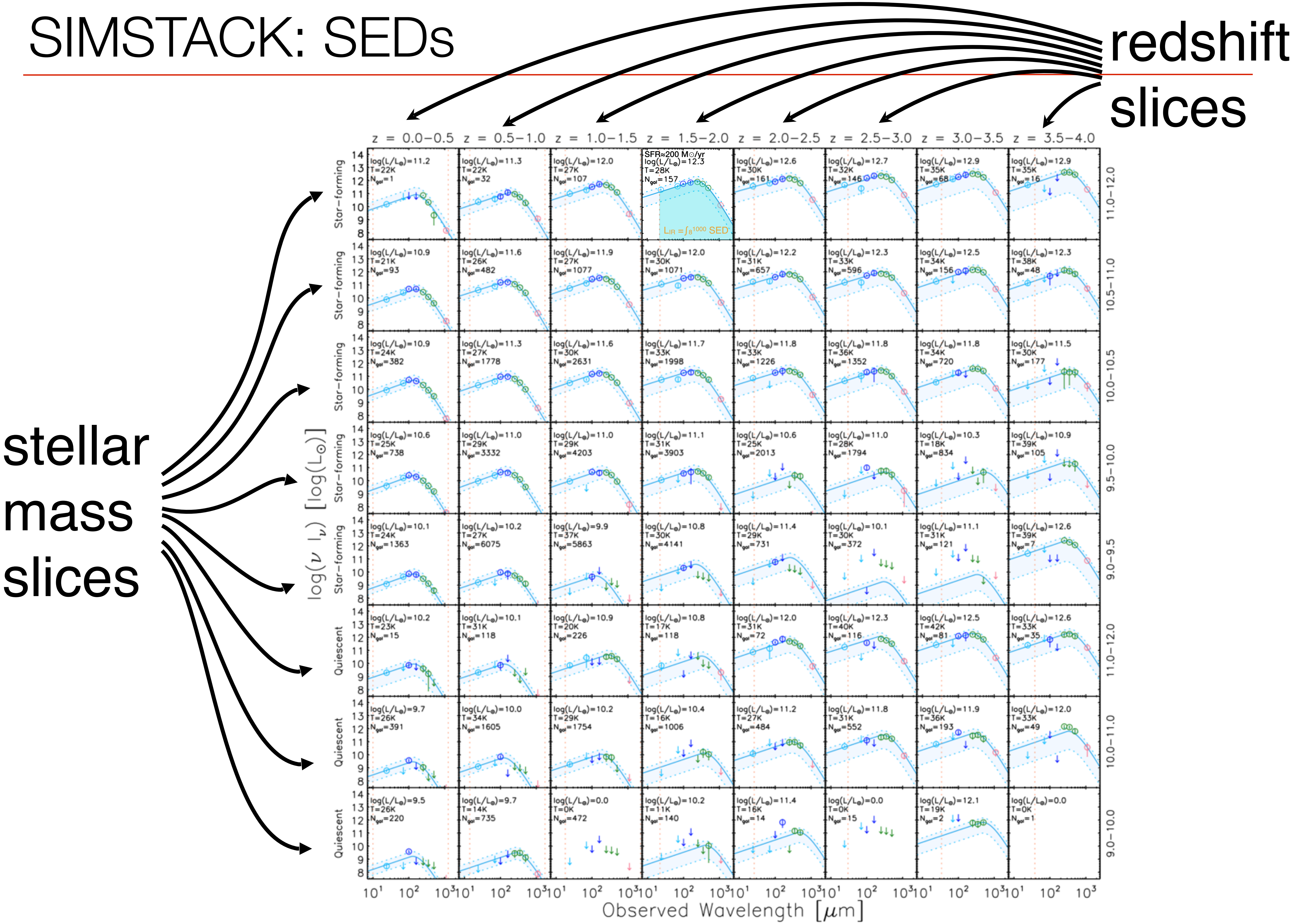
Data here:
UDS catalog
&
Herschel
SPIRE maps

SIMSTACK: SEDs



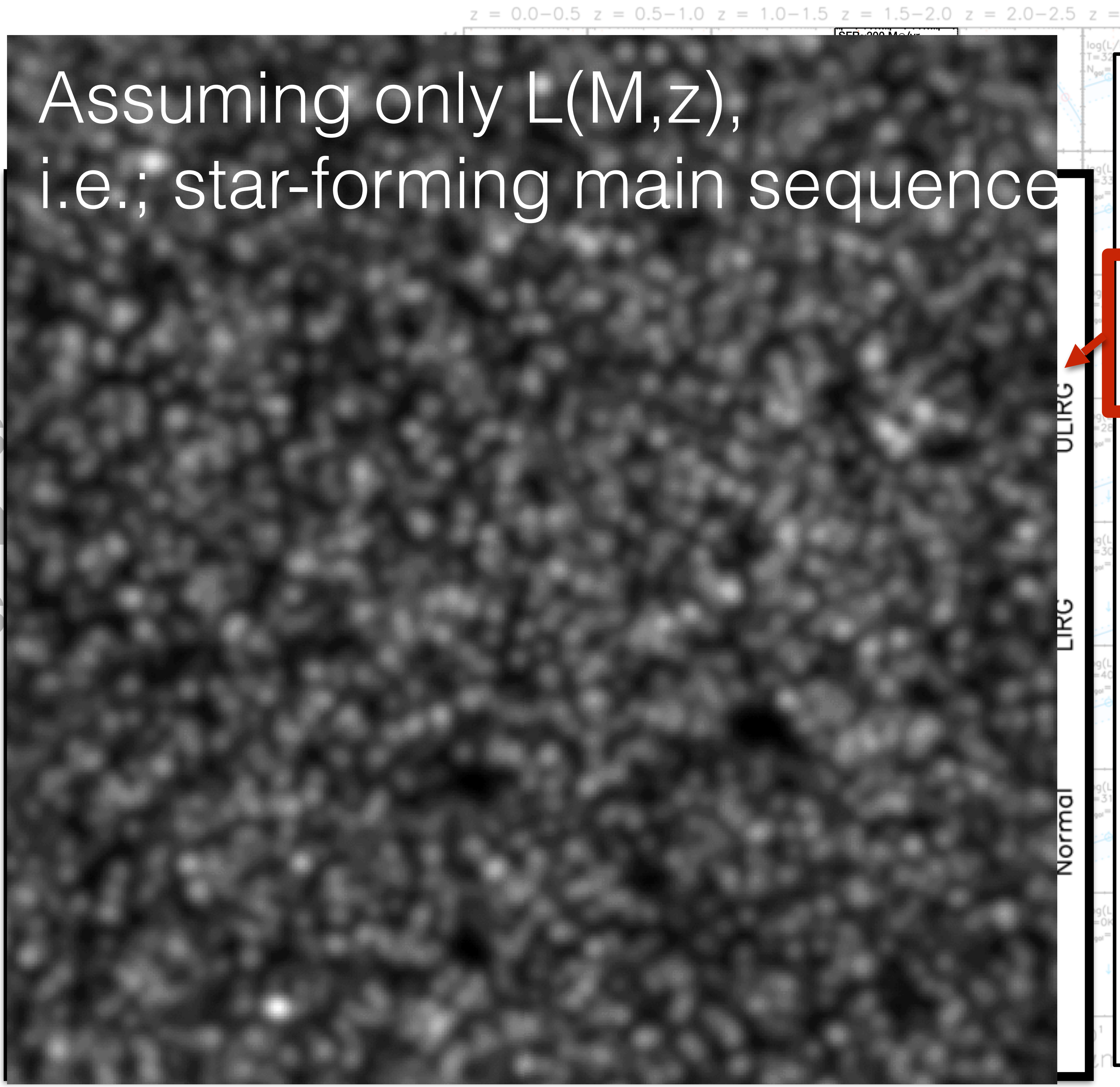
Viero, Moncelsi, Quadri+ (2013)
arXiv:1304.0446

SIMSTACK: SEDs



SIMSTACK: L_{IR}(M,z,…)

redshift slices

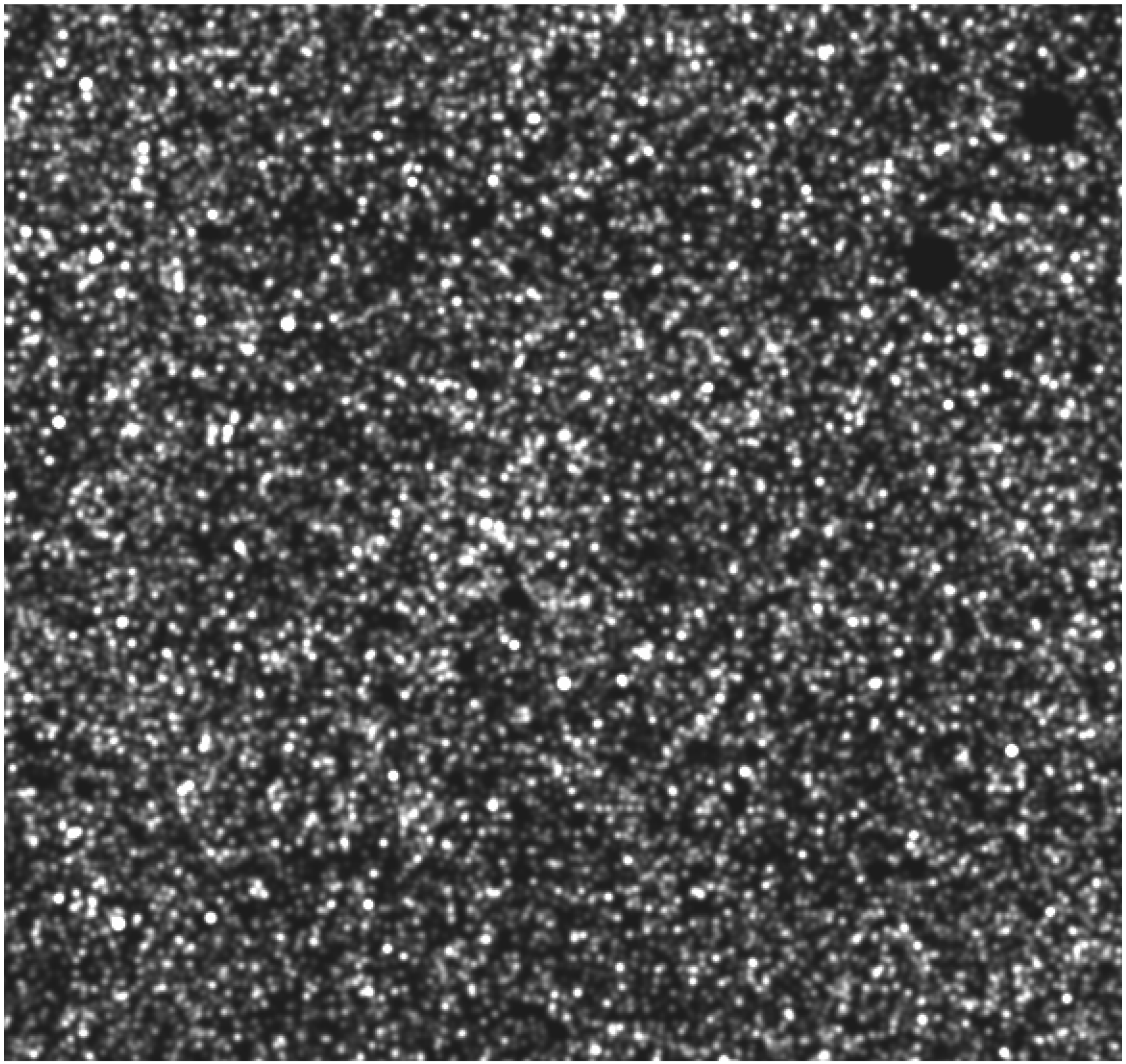


- Deep ancillary data can be fit with SED models, providing:
  - Stellar Mass
  - Redshift
  - Extinction/UV slope
  - AGN fraction
  - Age/Tau…

Each bin therefore has <M>,<z>, <Av>, $<F_{agn}>$, etc., which can be fit with function of form:

- $LIR=P(z)^{\alpha}P(M)^{\beta}P(Av)^{\gamma}$ ...

SIMSTACK: L_{IR}(M,z,Av,Fagn)



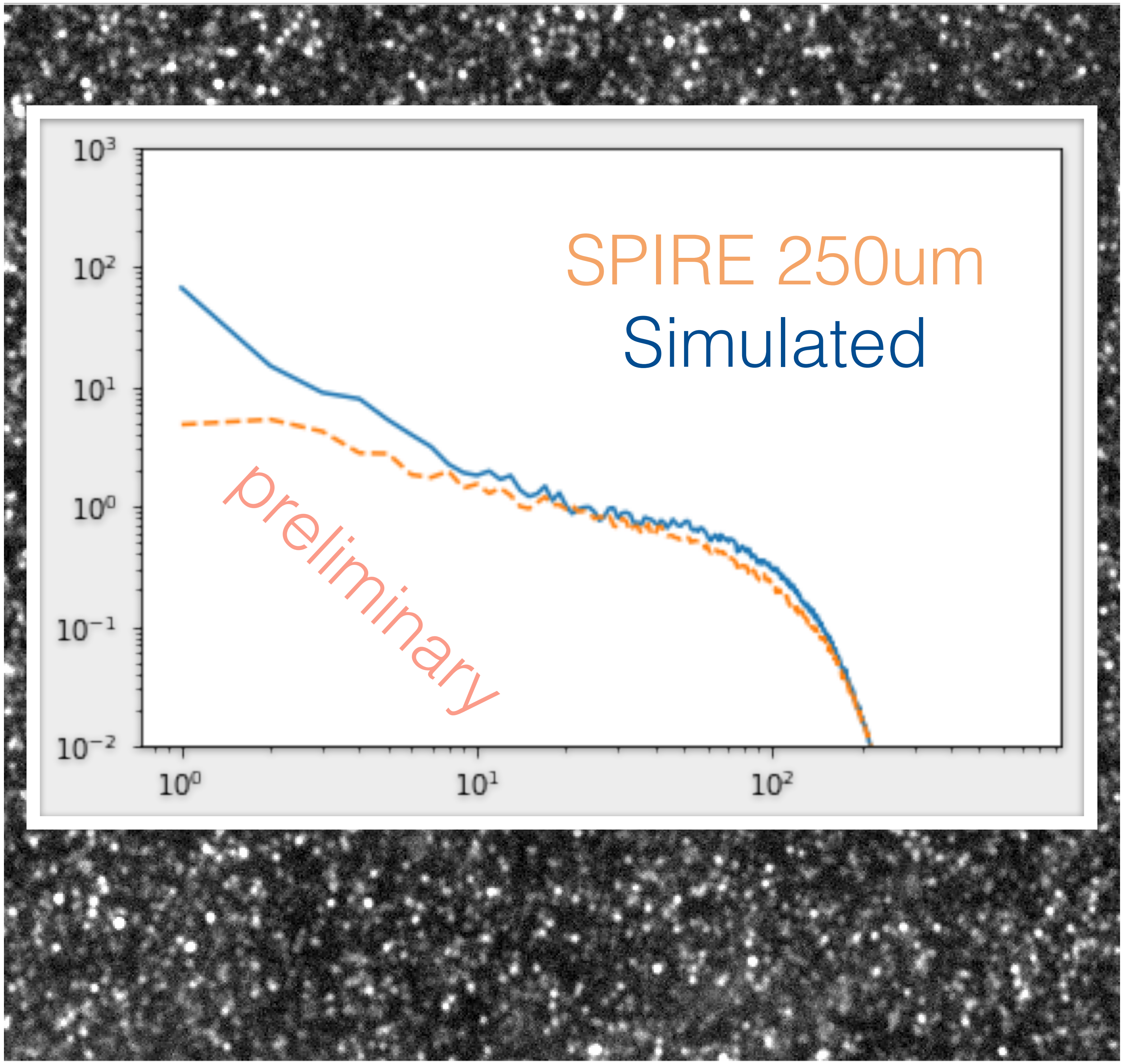
Fit can be improved by splitting the sample into finer subsamples, isolating e.g,;

- Star-forming/Quiescent
- AGN
- Starbursts

We find features most influential are, for 4 subsamples:

- $\log(LIR) = C + \alpha(z)\times\log(1+z) + \beta(z)\times\log(M) + \gamma(z)\times\log(Av) + \delta(z)\times\log(F_{agn})$

SIMSTACK: L_{IR}(M,z,Av,Fagn)



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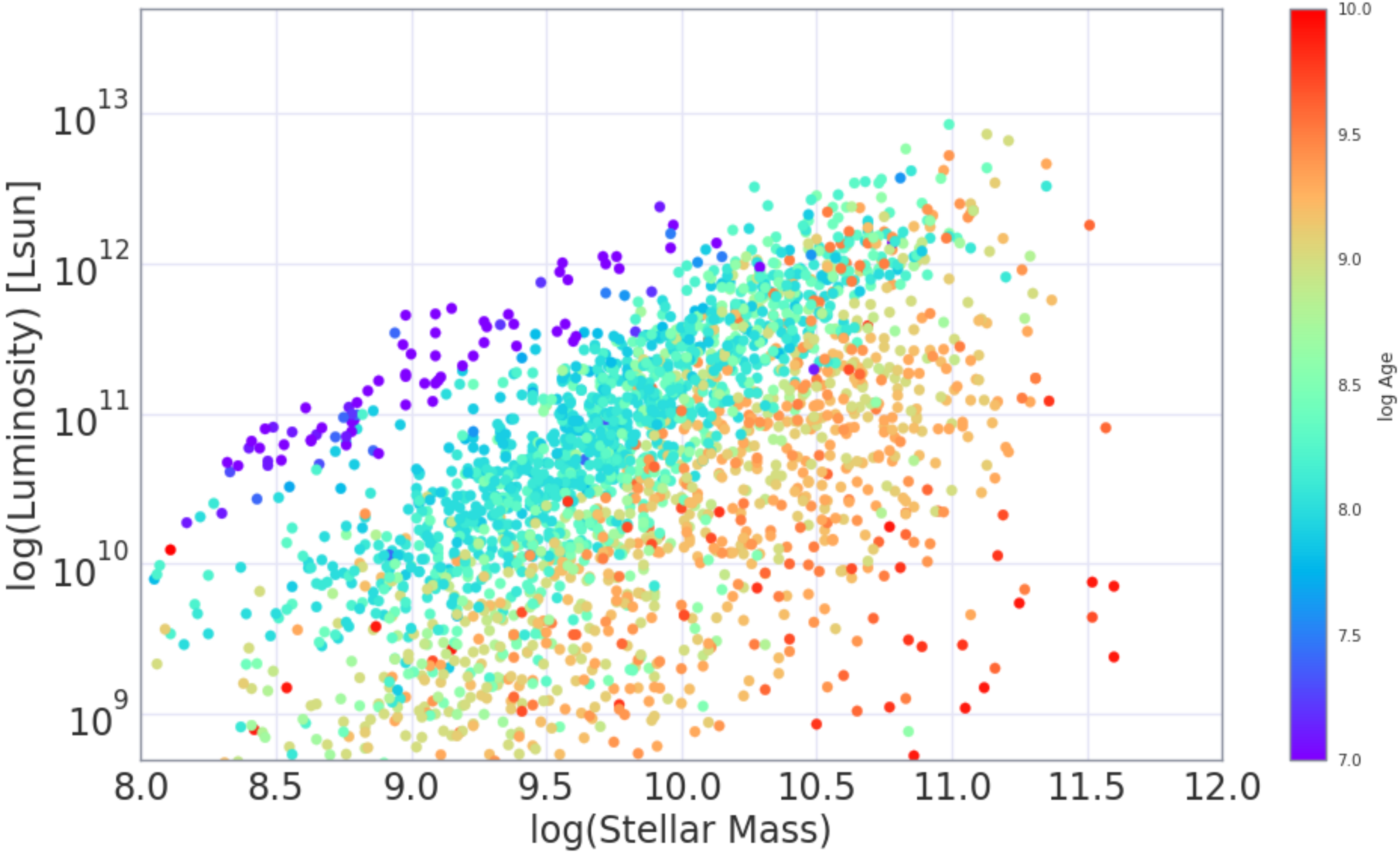

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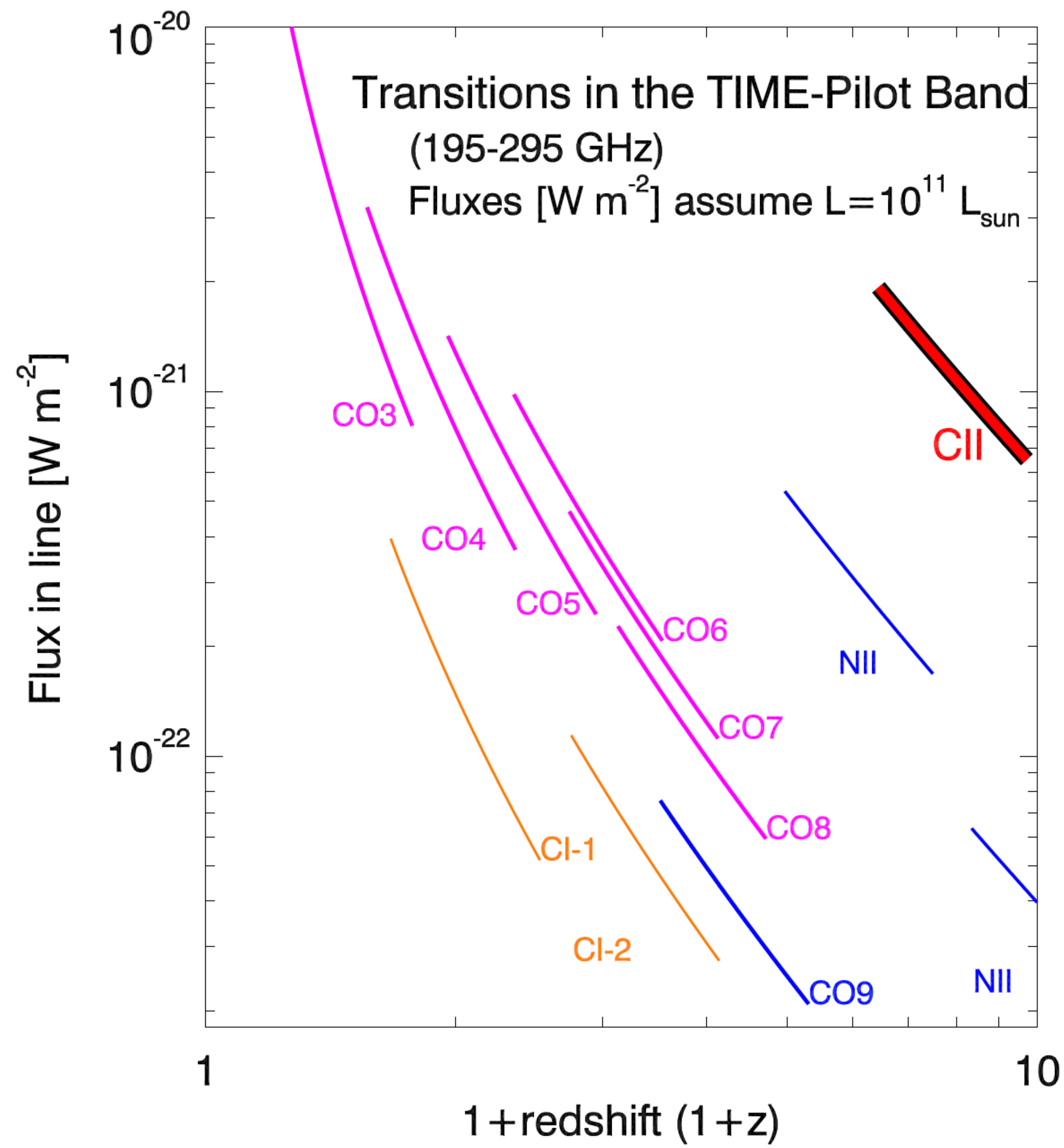
Applications

- Signal
  - ➡Connect to Halo properties (including assembly bias) to:
    - estimate CO levels,
    - construct covariances,
    - test different estimators (i.e., beyond power spectrum),
    - Details being discussed during this meeting!
  - ➡Extend to other lines that correlate with thermal dust SED
    - CII, OII, OIII, NII
    - r.f. 850um as tracer of ISM Mass.

- Foregrounds
  - ➡Predict CO contamination in CII data cubes (e.g, Sun and the TIME collaboration, 2017)

Masking CO in CII line-intensity maps

- Targeting CII at z = 6-10 means separating signal from lower-z CO.
- In deep fields (e.g., COSMOS, UDS, GOODS), all potentially significant CO emitters (z=1-3) will be cataloged in the UV, optical, and NIR with great detail.
  - ➡ In these cases, we can construct an estimator for CO from optical predictors of the mean LIR.
  - ➡ How much variance is there from the mean, and how aggressively does masking need to be to play it safe?

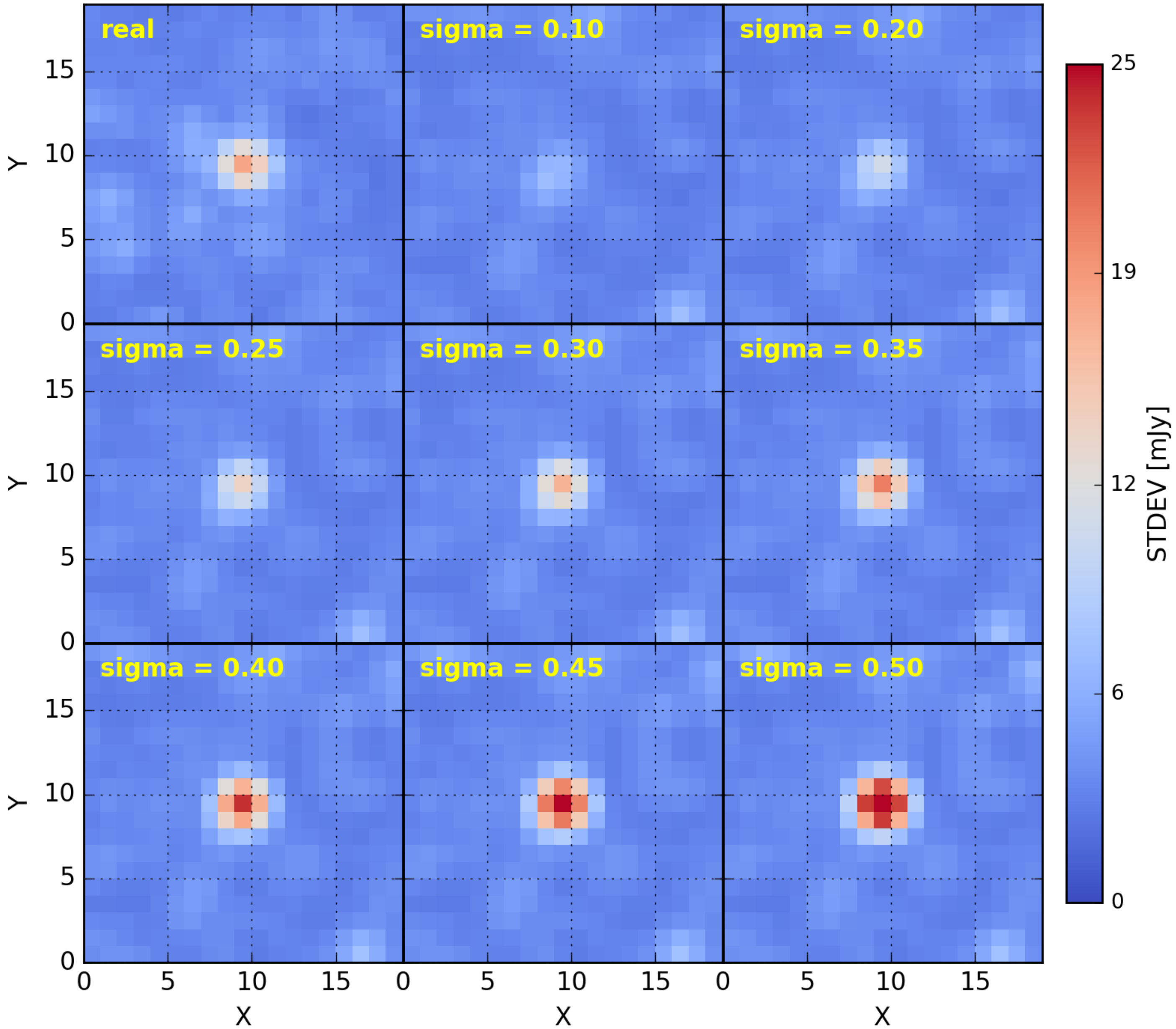


Masking CO in CII data: Sun et al. 2017

Variance in the LIR estimator determined by comparing scatter in the difference map with simulations.

- Find sigma = 0.33

Guaocho (Jason) Sun



Lorenzo Moncelsi

Sun, Moncelsi, Viero & TIME collaboration 2017, arXiv:1610.10095

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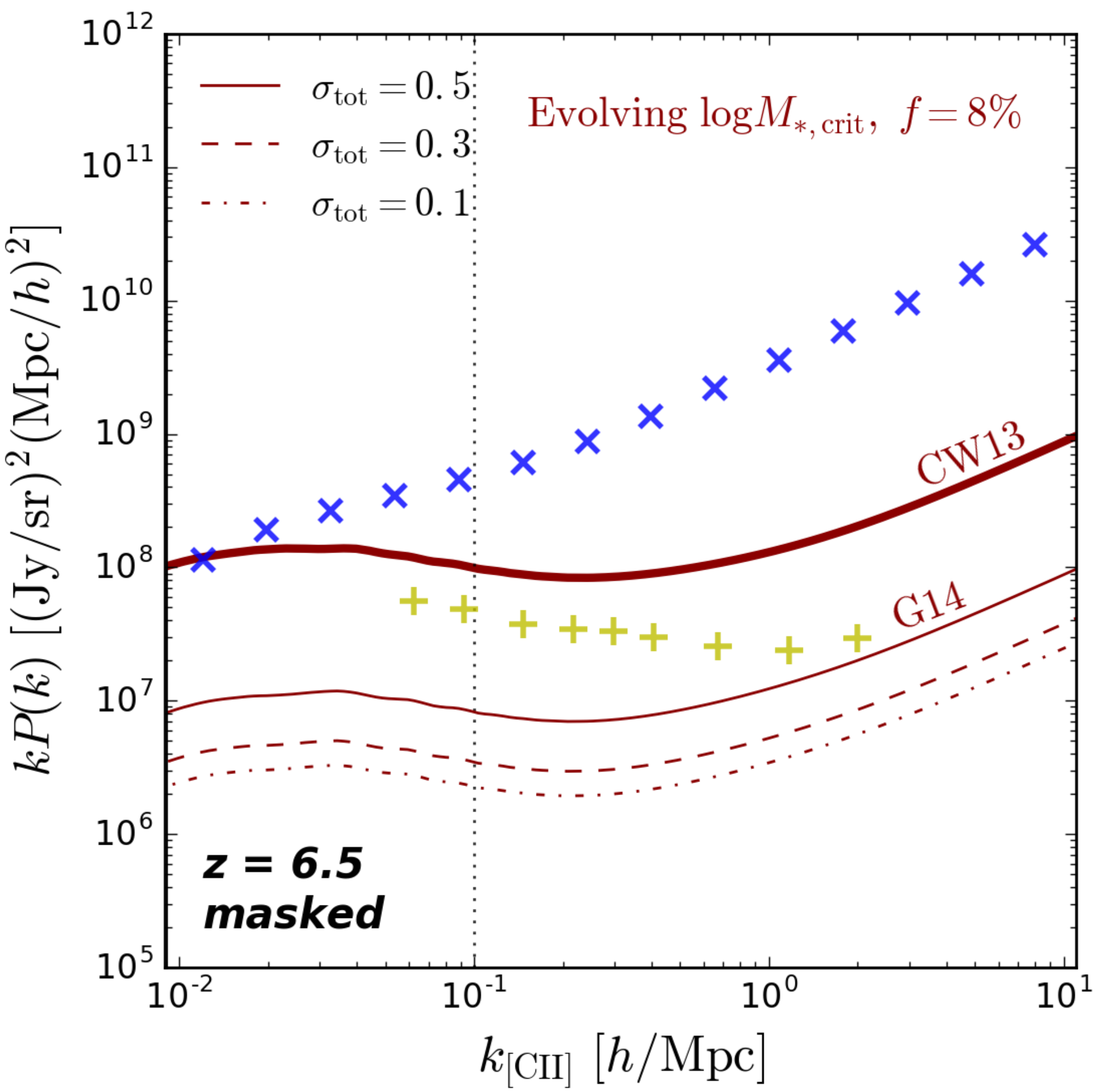

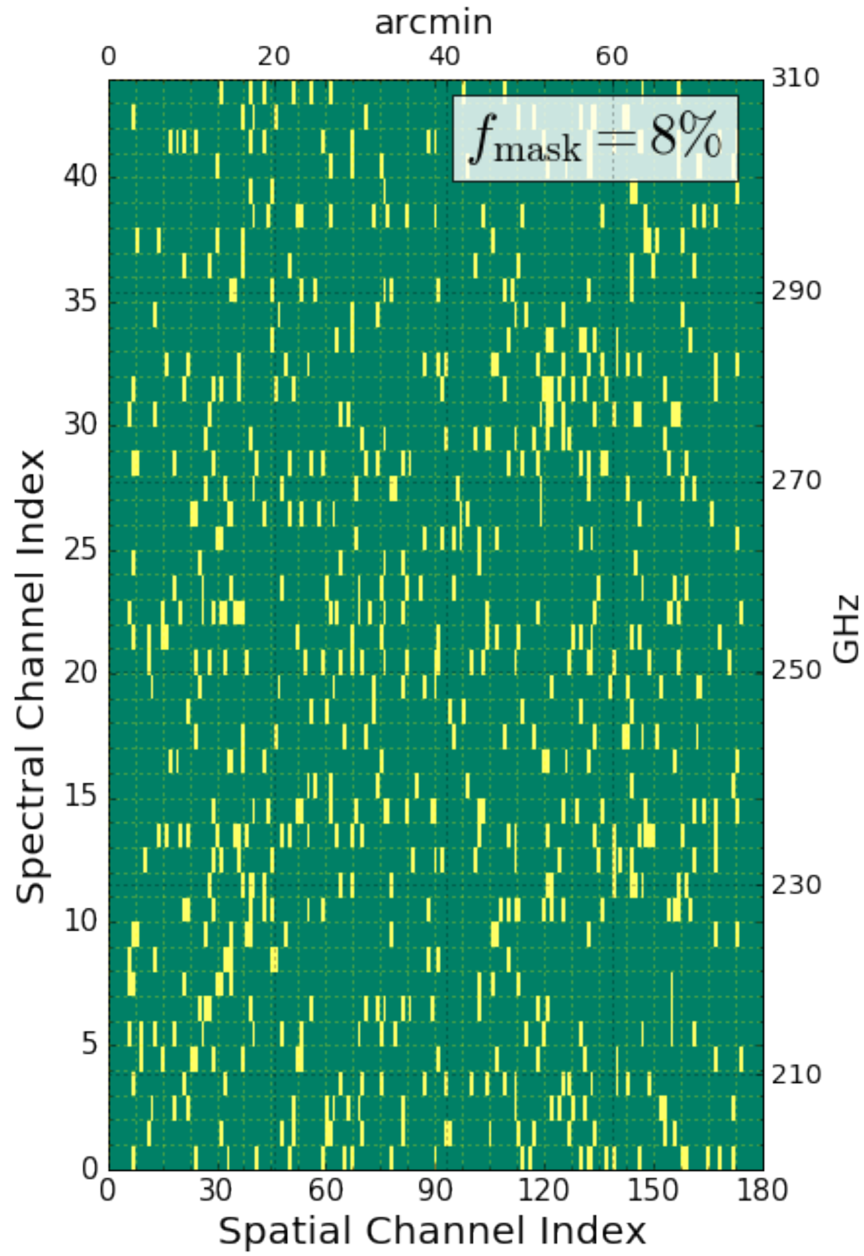

Sun, Moncelsi, Viero & TIME collaboration 2017, arXiv:1610.10095

Summary

- CIB continuum intensities are key to empirically connecting optical features of typical galaxies to their FIR/submm components
- Applications for this model include:
  - ➡Forecasting CO power for:
    - Survey design
    - Covariance construction
    - Testing Estimators
    - Measurement Interpretation
- For this workshop, would like to…
  - ➡Determine how best to populate halos
  - ➡Explore Estimators

- SIMSTACK is easy to use, and available at:
  - ➡https://github.com/marcoviero/simstack