Simulation for LIM with TIFUUN

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SUBLIME-TIFUUN All Hands Meeting
14-15 Oct. 2025

Today's talk

- Simulation and emission models for LIM mock

https://sublime-tifuun.kibe.la/notes/34

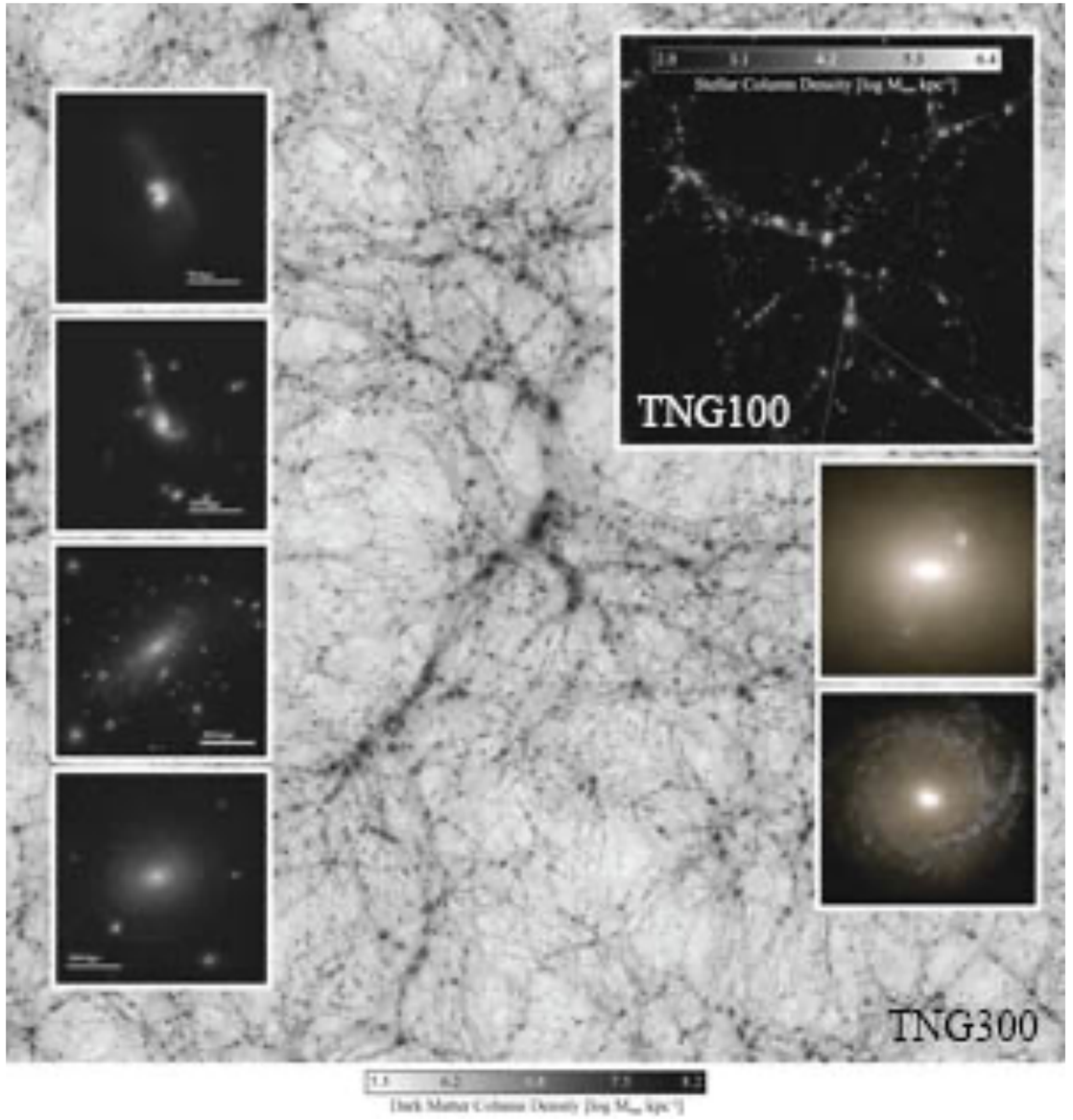
- Power Spectrum Calculation

- Future prospects (what if we have a much better mapping speed?)

Simulation and Emission Models for LIM Mock

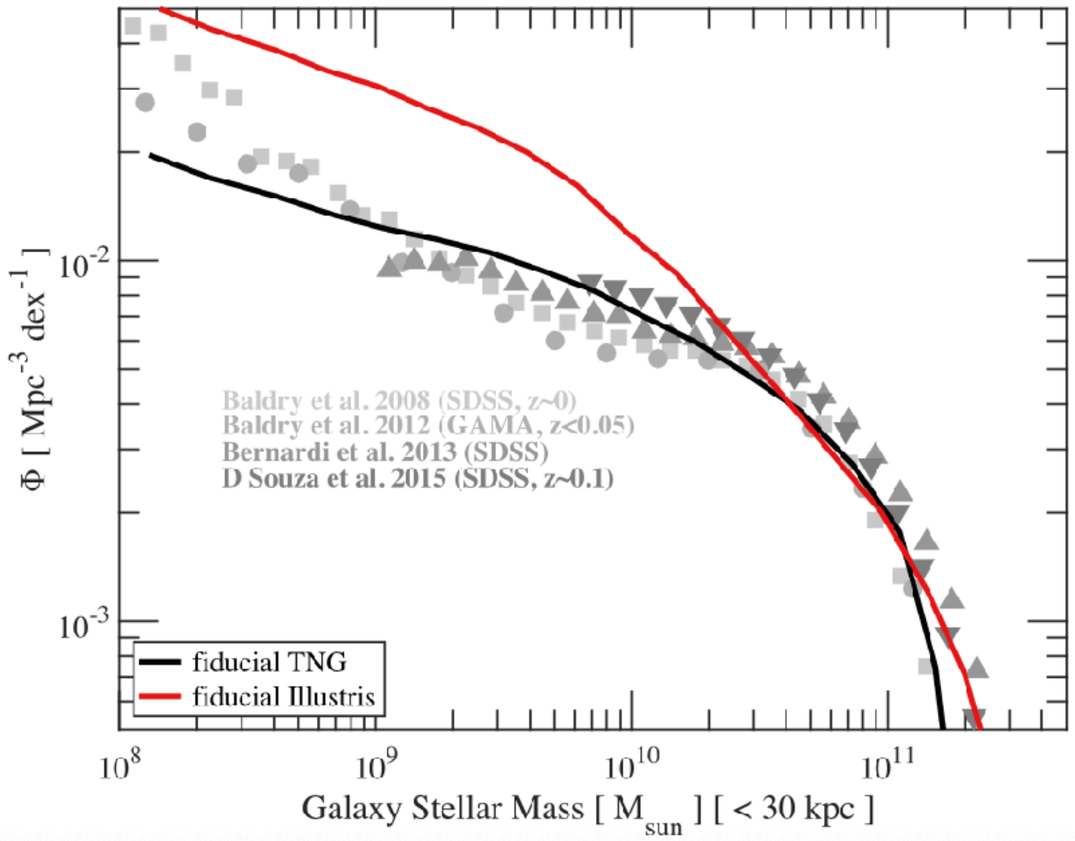
IllustrisTNG simulation

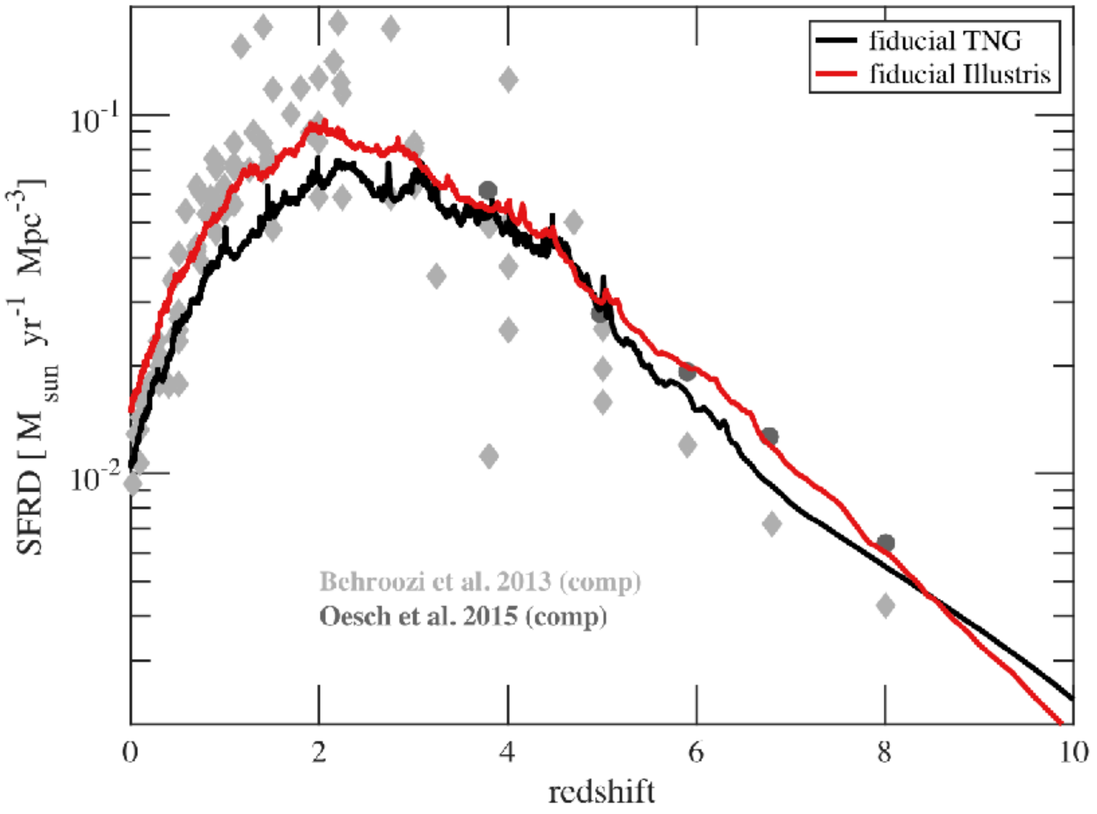
- Cosmological hydrodynamics simulation IllustrisTNG (Nelson+2019)
- Outputs are publicly available
- Follow star formation with *subgrid models*
- Subgrid model parameters are tuned to reproduce observations (e.g., stellar mass function, stellar-to-halo mass relation, cosmic SFRD at z < 10, etc.)



Simulation for LIM Mocks

- Subgrid model parameters are tuned to reproduce observations (e.g., stellar mass function, stellar-to-halo mass relation, cosmic SFRD at z < 10, etc.)

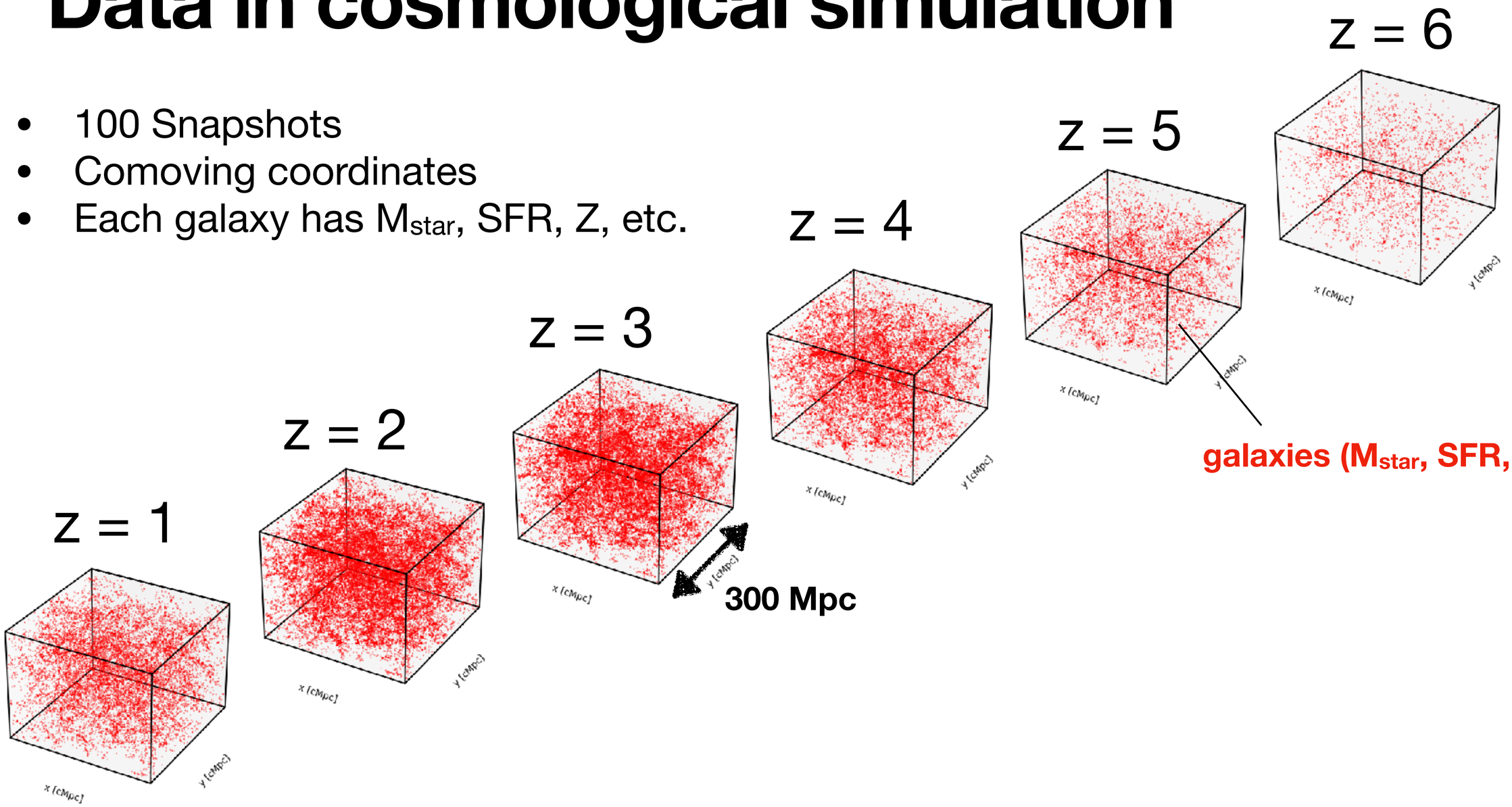




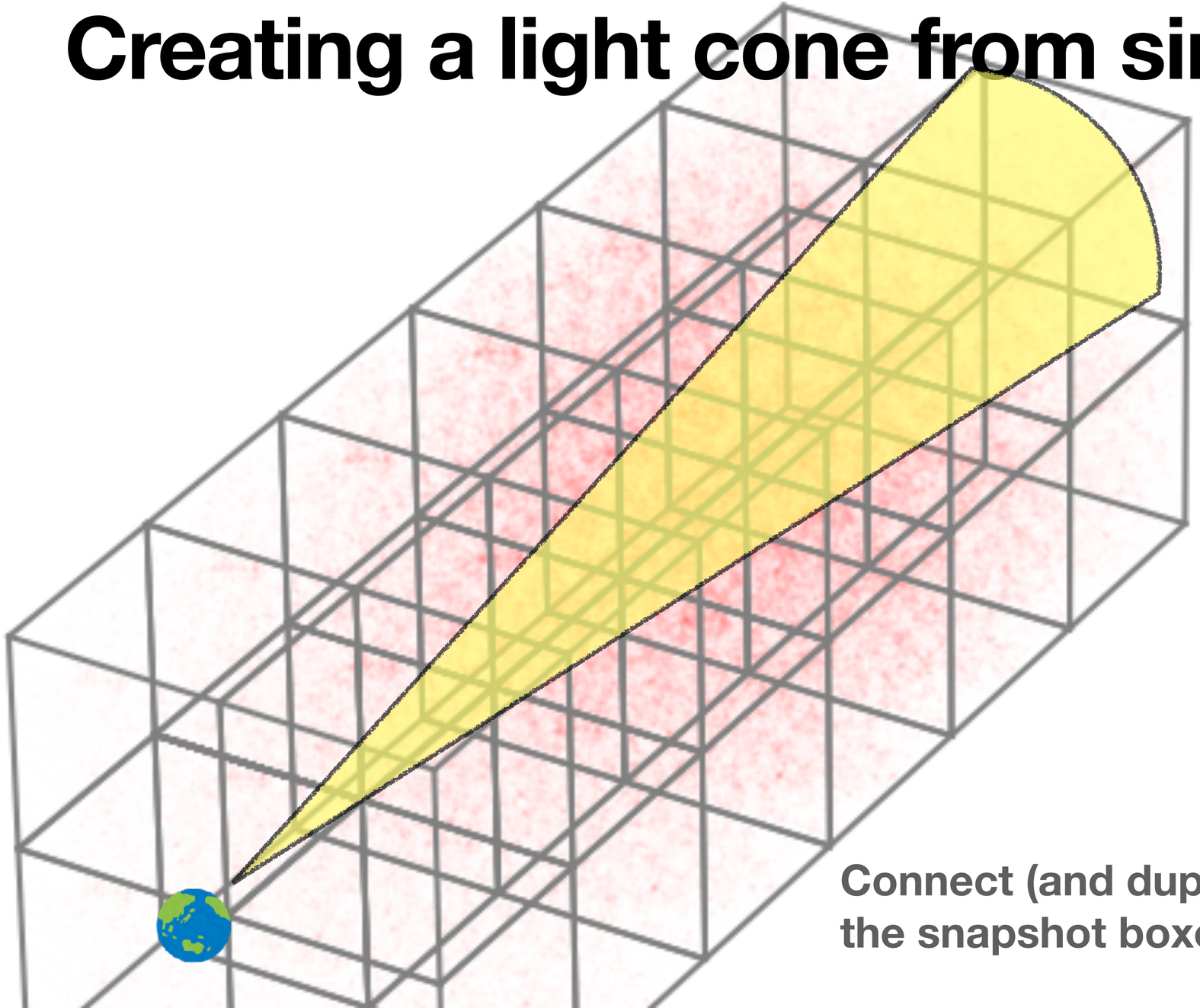
Data in cosmological simulation

z = ...

- 100 Snapshots
- Comoving coordinates
- Each galaxy has M_{star}, SFR, Z, etc.

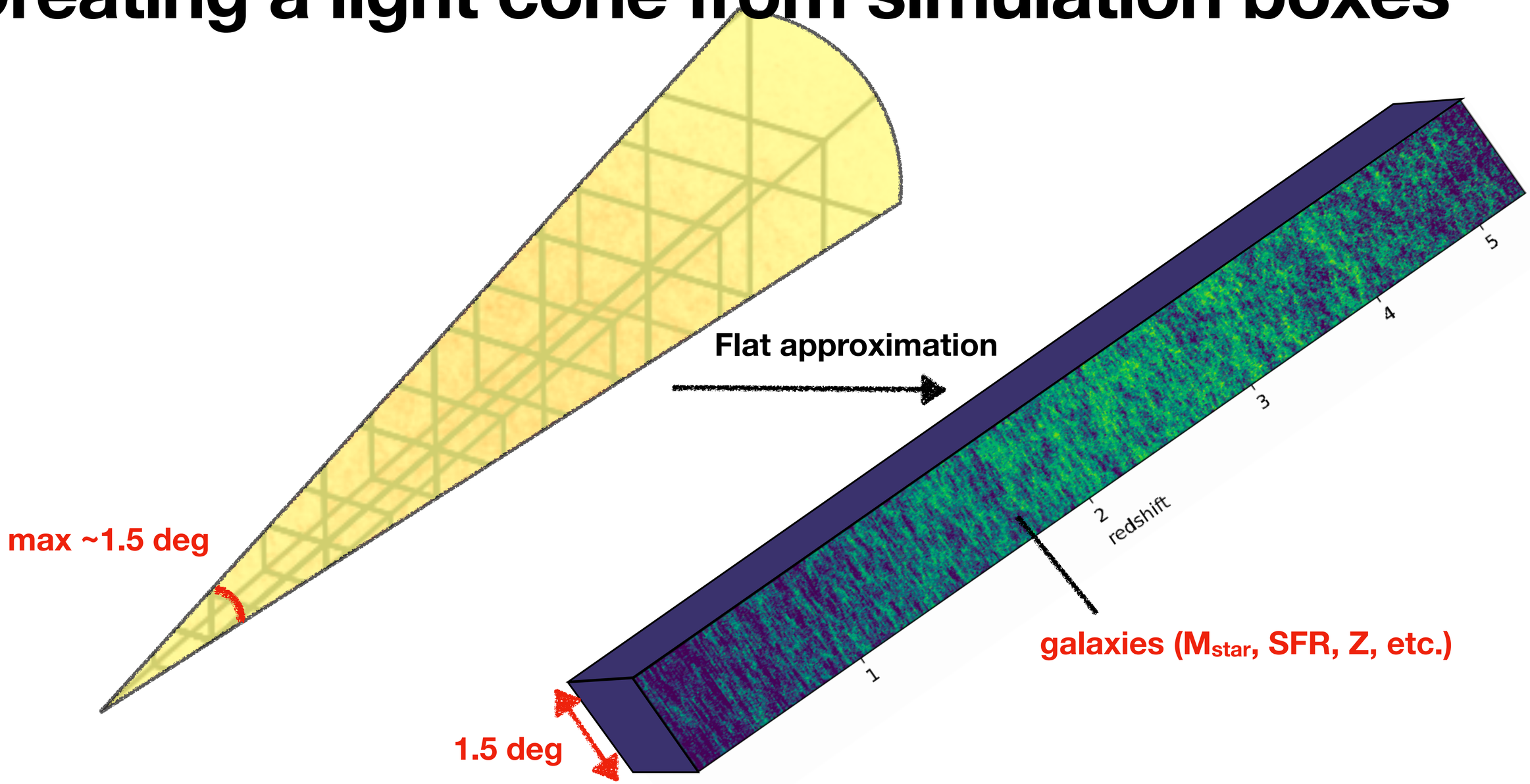


Creating a light cone from simulation boxes



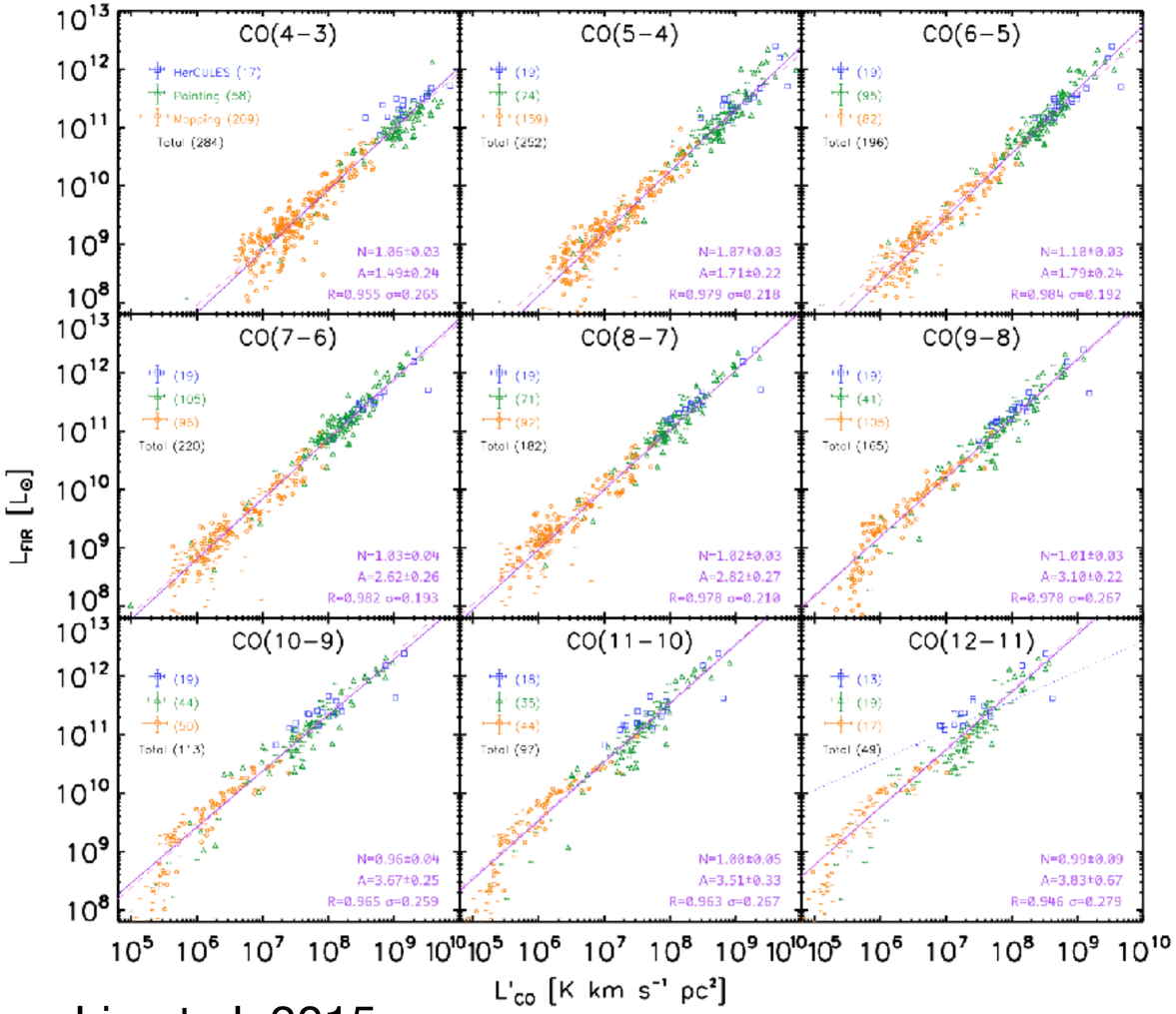
Connect (and duplicate if necessary)
the snapshot boxes to fill the space.

Creating a light cone from simulation boxes



Emission Line: Empirical L-SFR relations

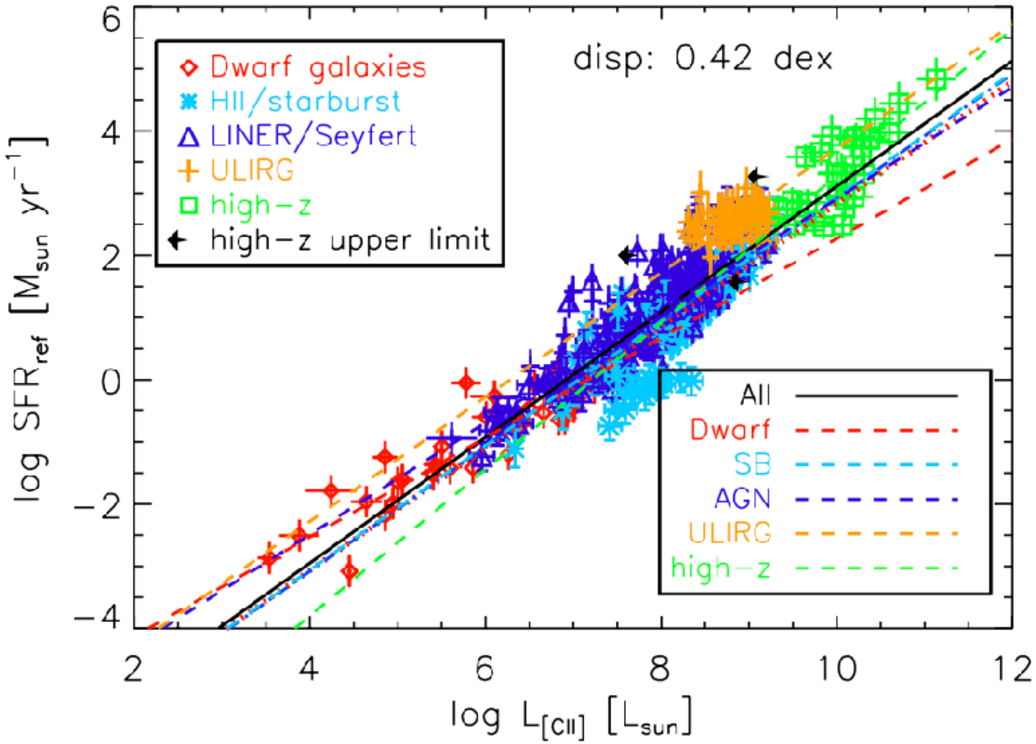
CO lines



Liu et al. 2015

We do not assume any CO-SLED model for now

[CII] line

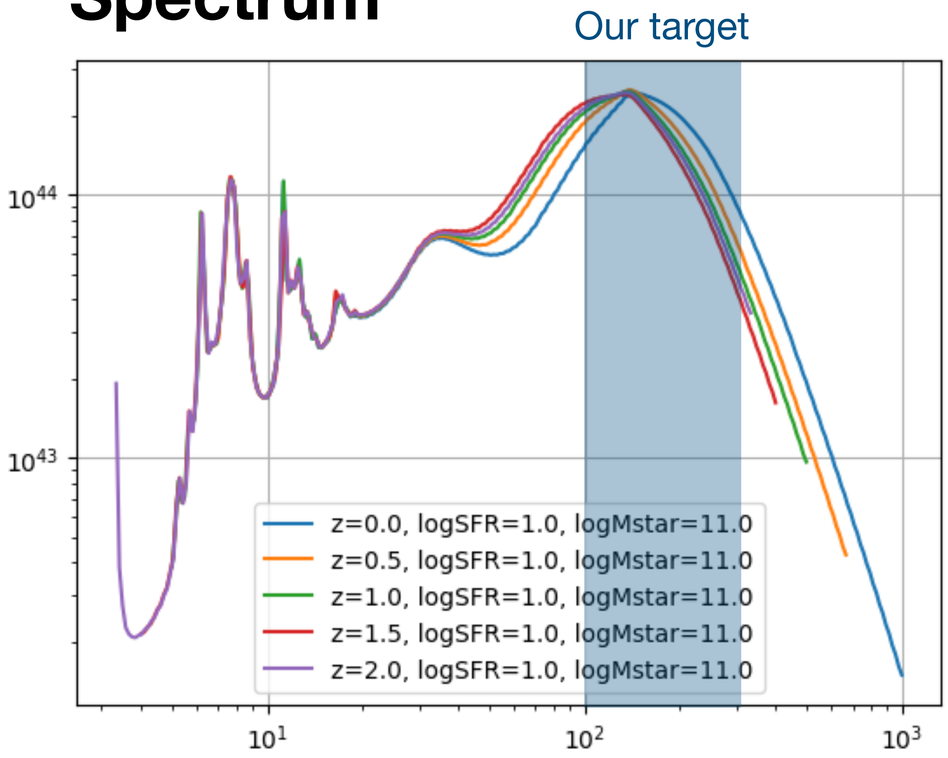


De Looze et al. 2014

↑ Local relation — might be different at high-z

Continuum model: Bethermin et al. 2017 (CONCERTO)

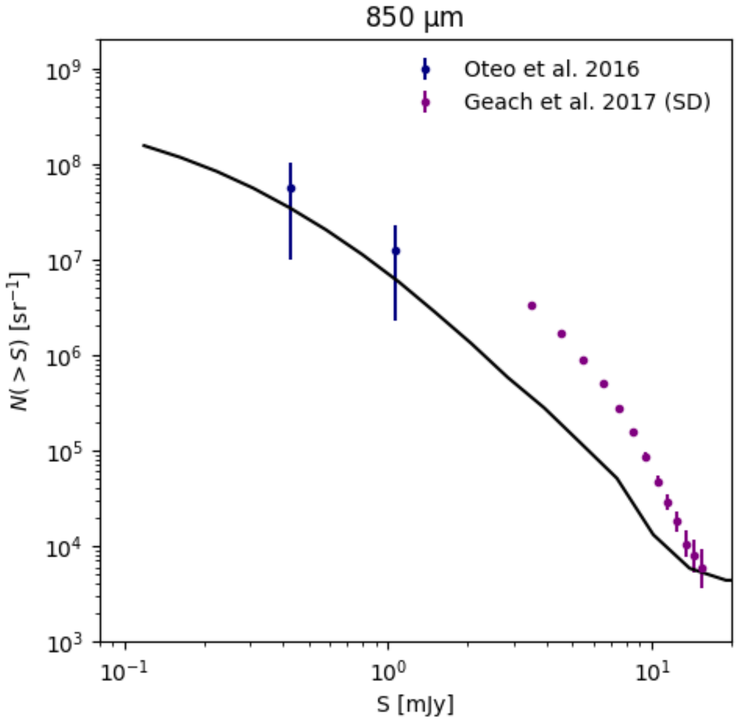
Spectrum

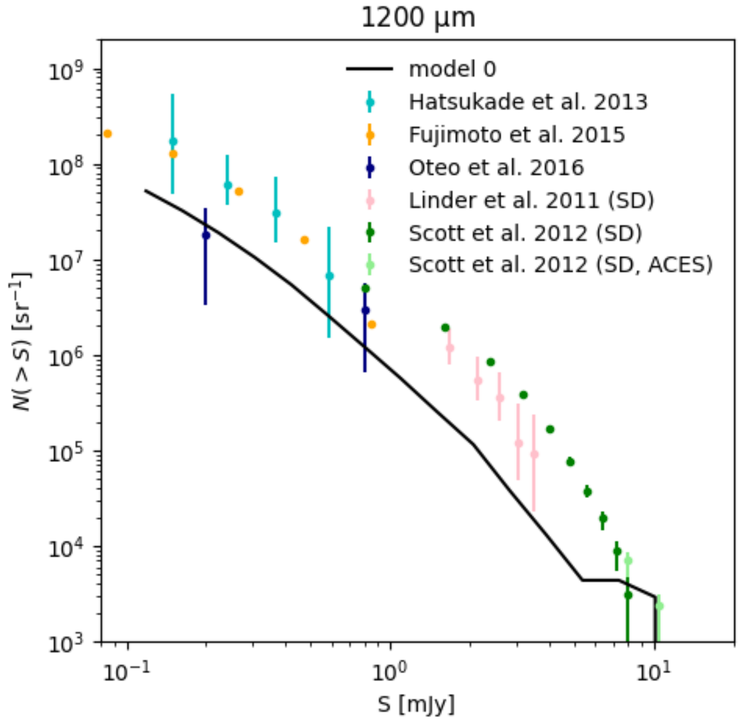


Spectrum shape depends on z, SFR, M*

Bolometric luminosity ∝ SFR

Result: Number counts





lensing effect is not considered

Intensity Map

Example spectrum at a randomly chosen pixel

Total

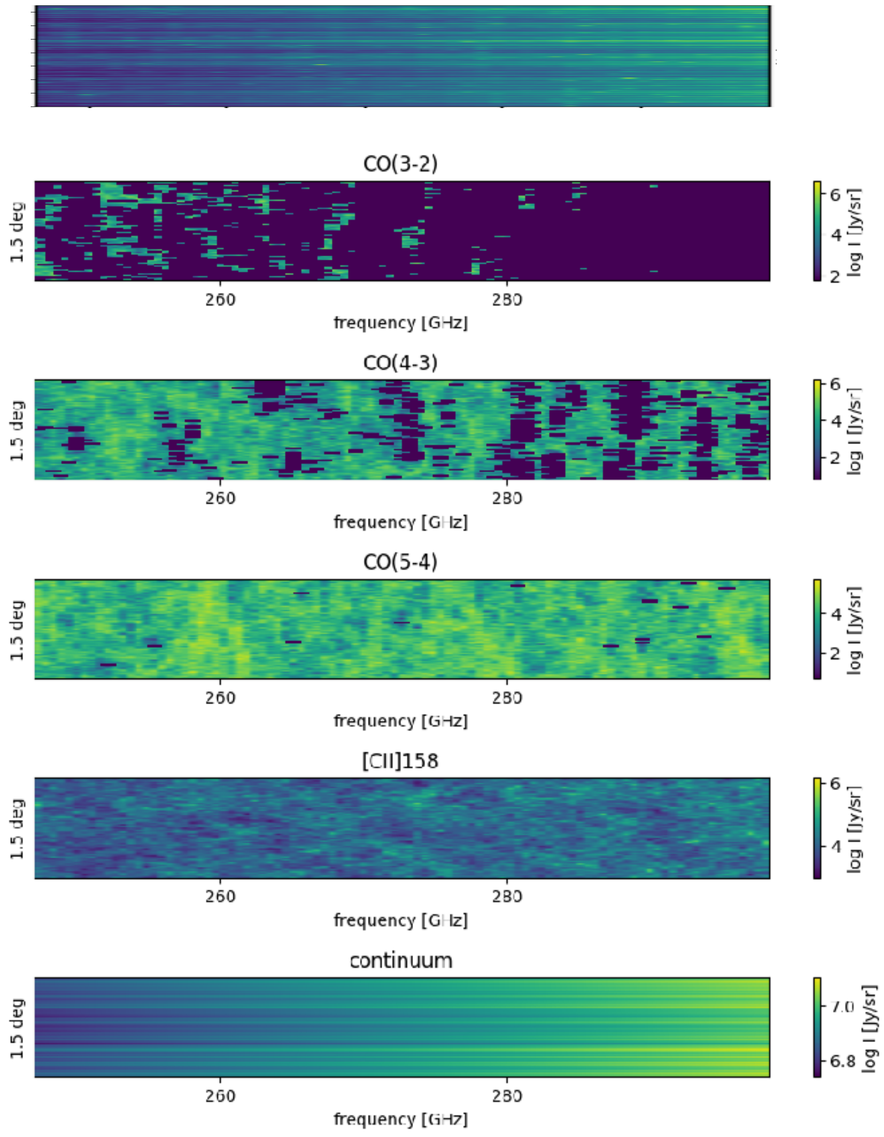
CO(3-2)

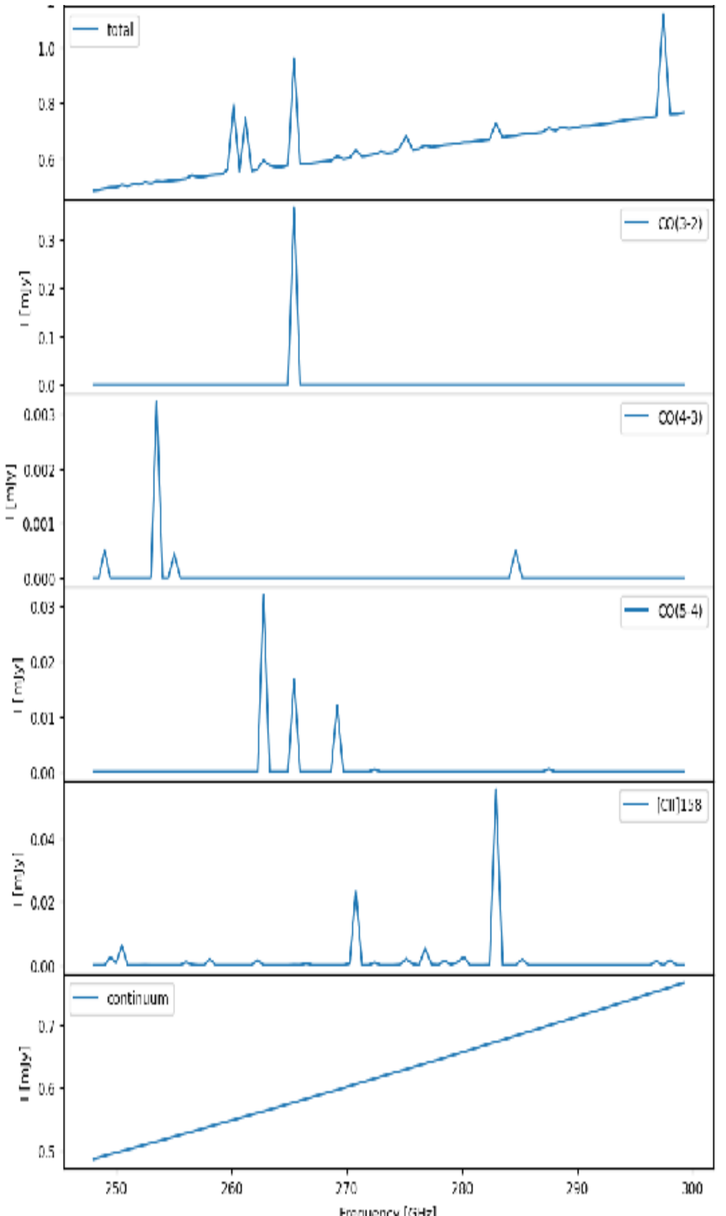
CO(4-3)

CO(5-4)

[CII]158

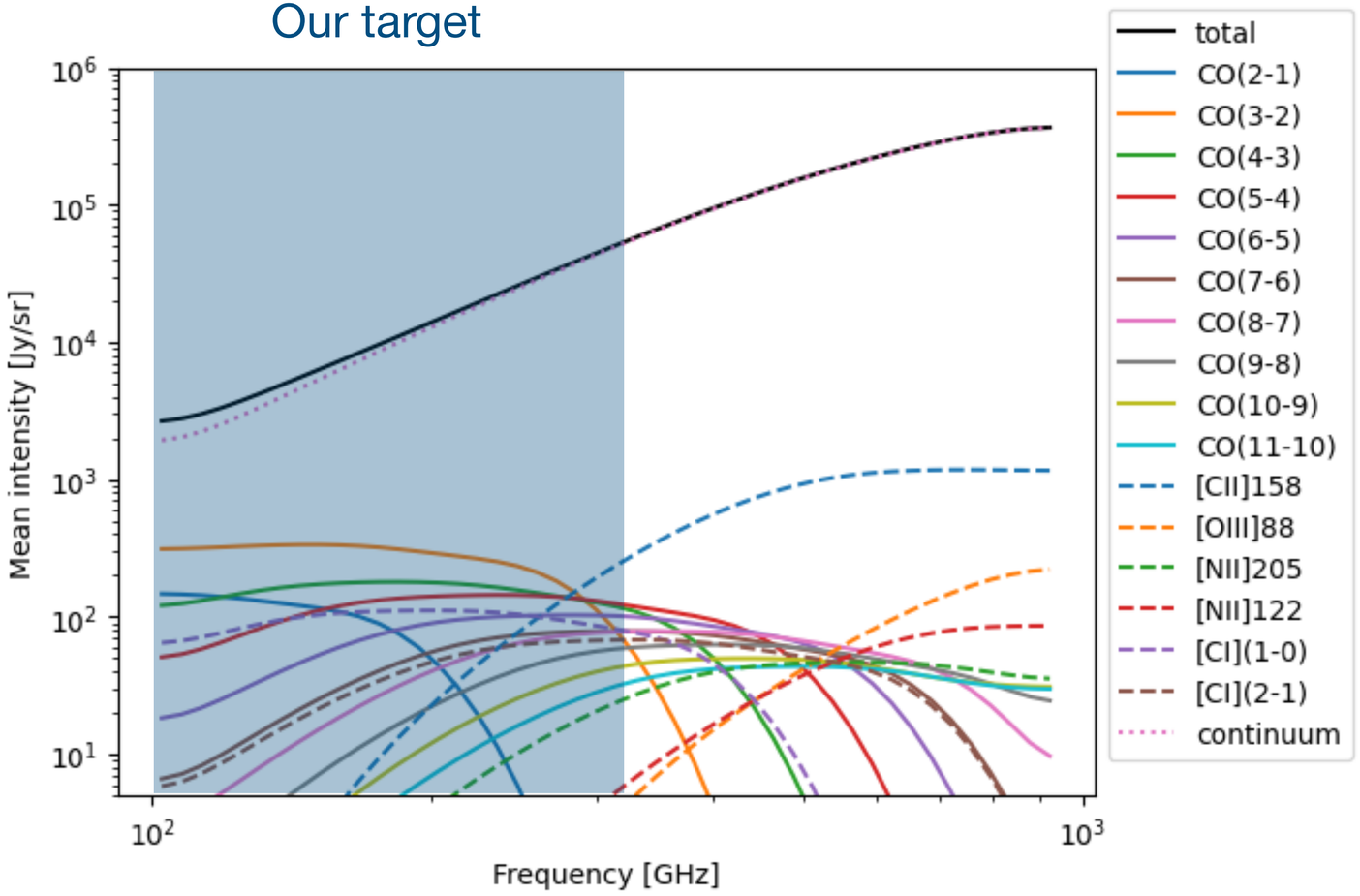
Continuum



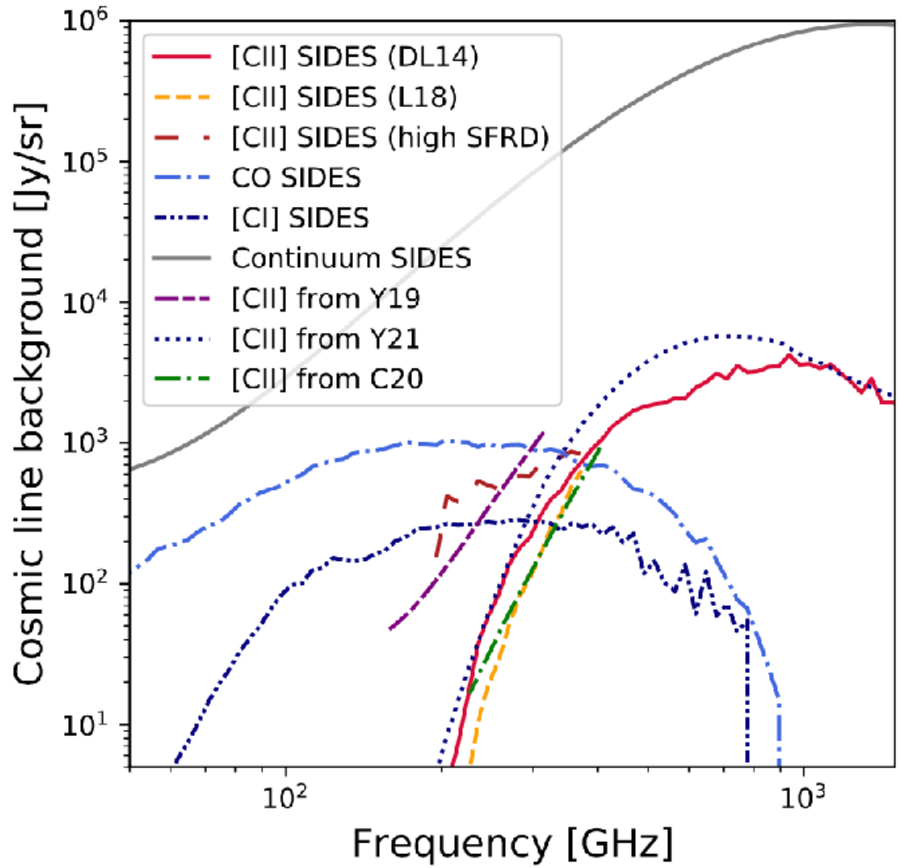


Mean intensity

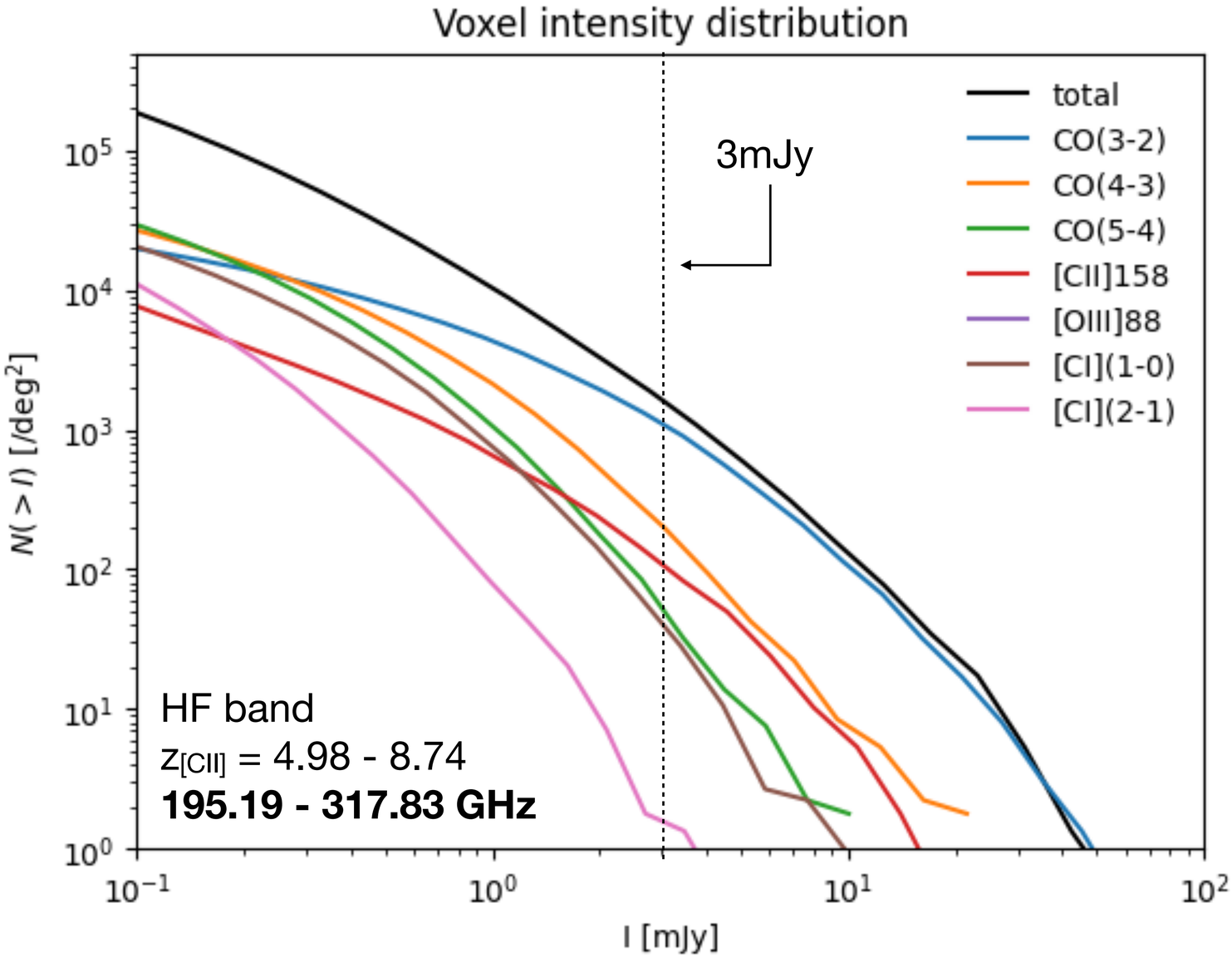
Our target



Cf. Bethermin+22 (CONCERTO)

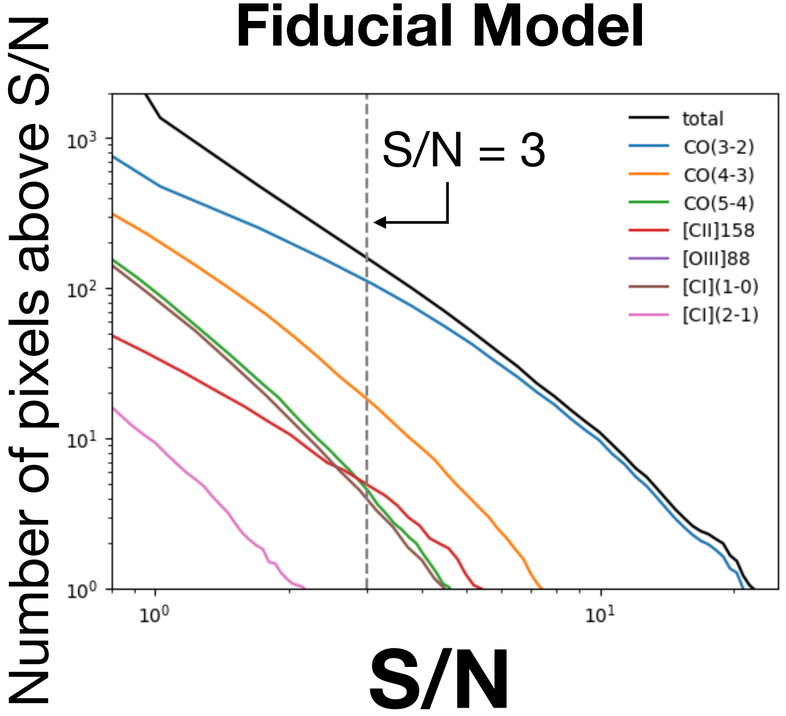


Intensity Distribution and Individual Detection

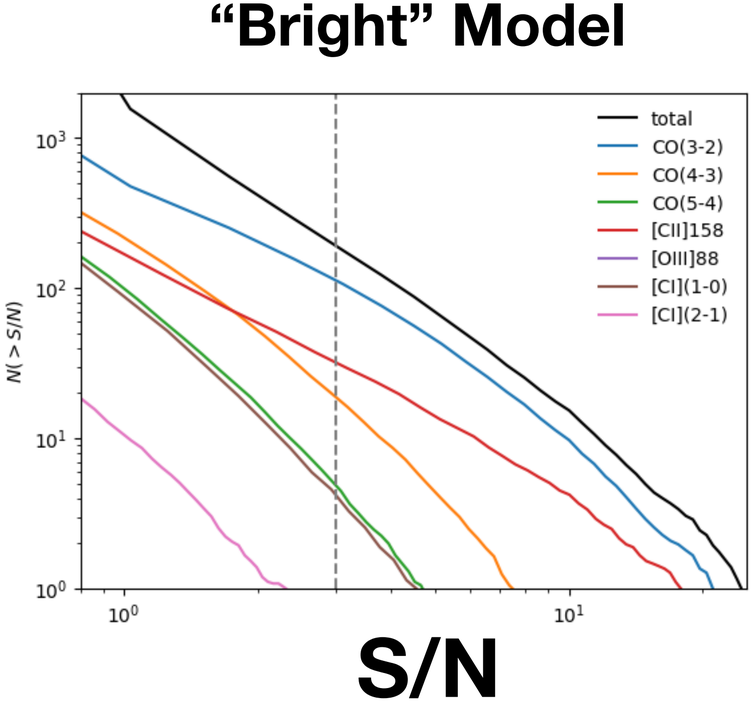


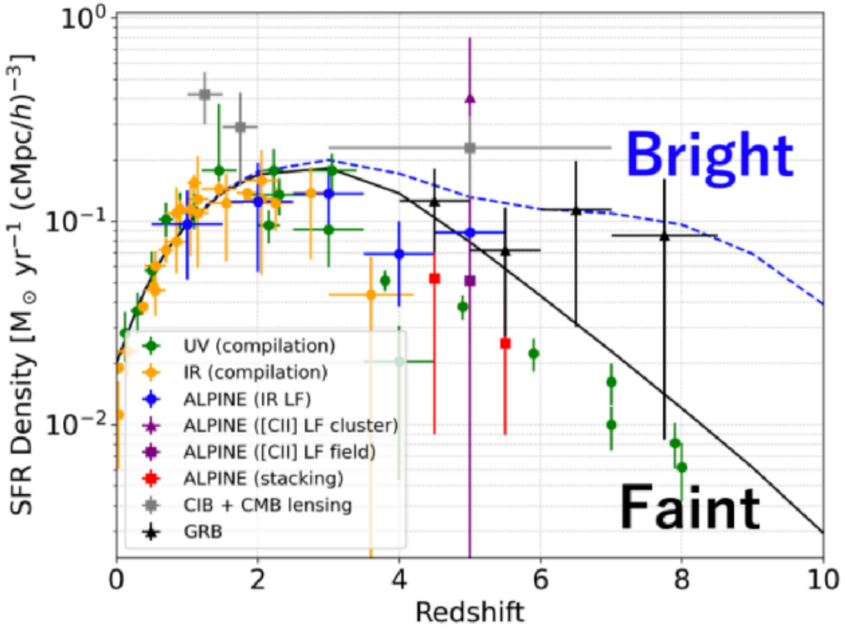
Individual Galaxy Detection (LB) with Vici

Fiducial Model



"Bright" Model

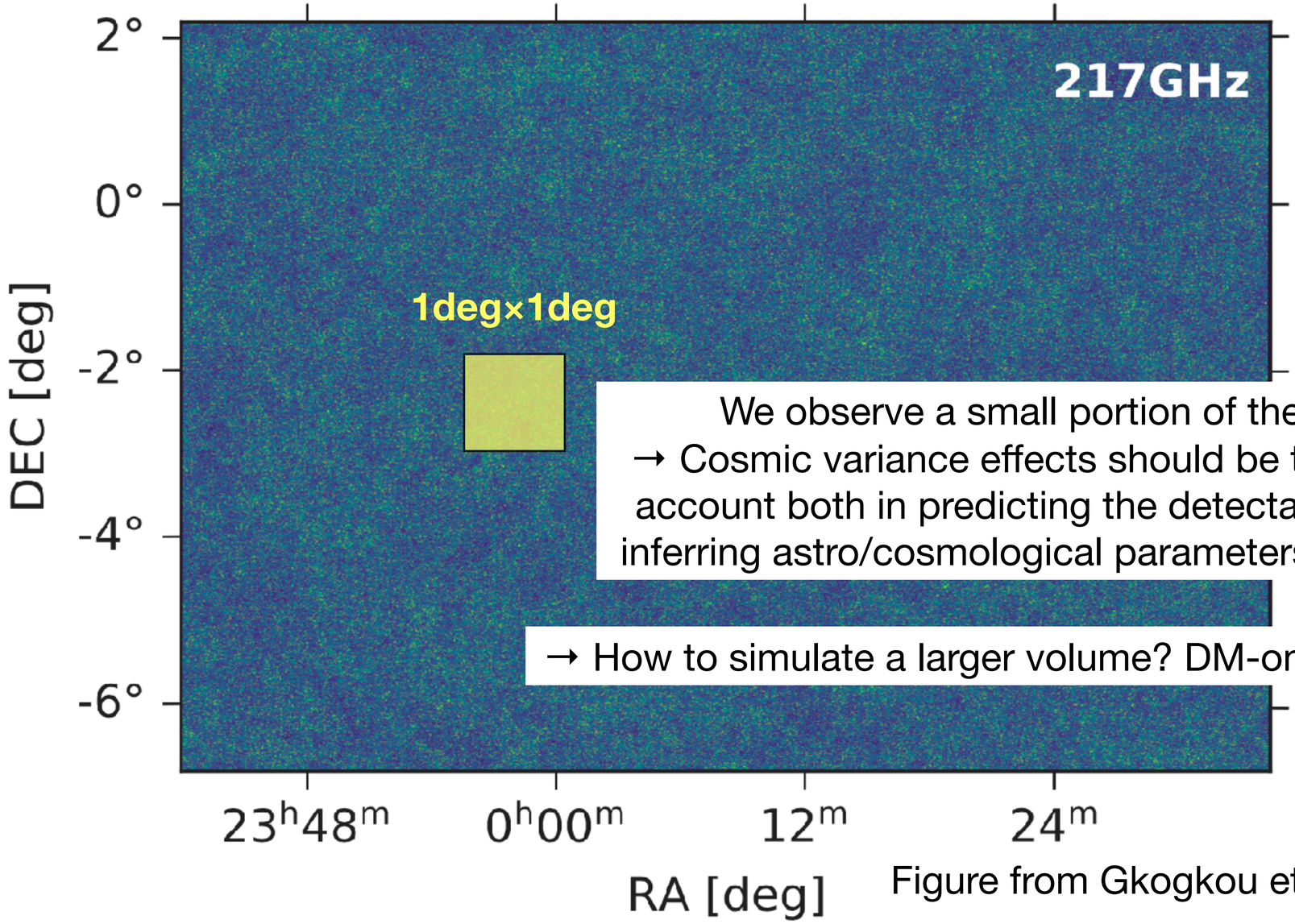




$$\mathrm{SFR}_{\mathrm{bright}} = (\alpha\,\mathrm{Sigmoid}(z - z_0) + 1)\,\mathrm{SFR}_{\mathrm{TNG300-1}}$$

α = 14 and z_0 = 8 for bright model

Challenge: Simulation Volume is Limited



We observe a small portion of the sky
→ Cosmic variance effects should be taken into account both in predicting the detectability and inferring astro/cosmological parameters/relations

→ How to simulate a larger volume? DM-only? (Yoshida-san's talk?)

Figure from Gkogkou et al. 2022

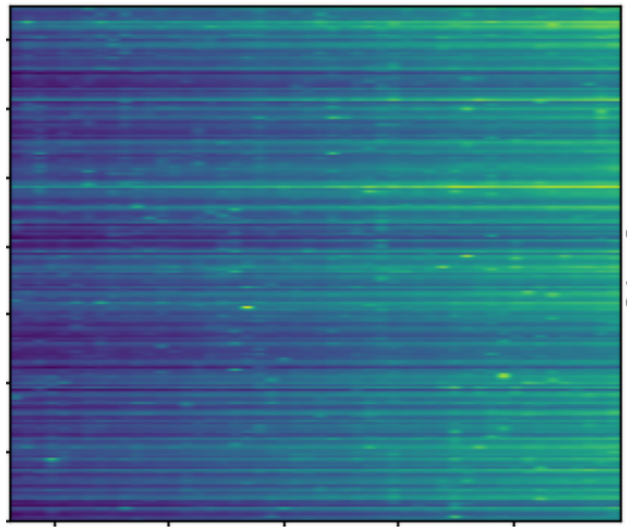
see also
Ihle et al. 2021 (COMAP) arXiv:2111.05930
Stutzer et al. 2024 (COMAP) arXiv:2406.07511

Power spectrum calculation

- Step 1: Convert to comoving scales
- Step 2: Compute power spectrum
- Step 3: Average over |k| ~ k
- Power spectrum with gateau's output
- Note: Transfer function

Step 1: Conversion to comoving scales

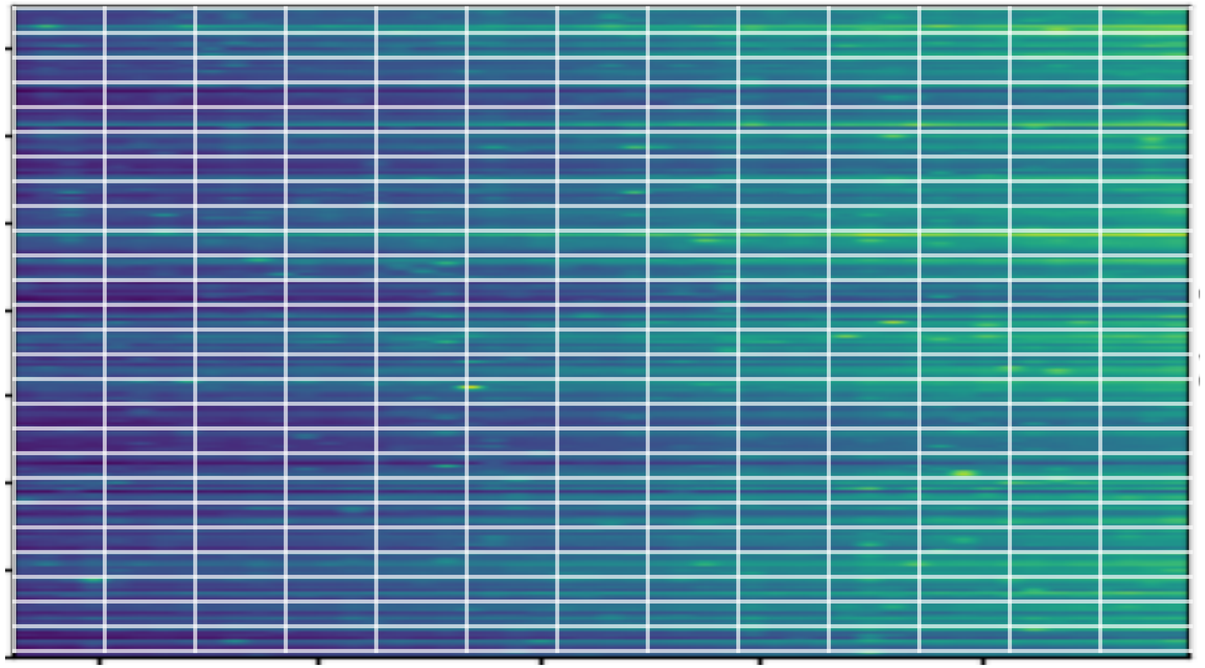
[CII]: z = 5.7 - 6.4



1deg
dx = 30 arcsec

e.g., 258 GHz - 285 GHz
R = 500

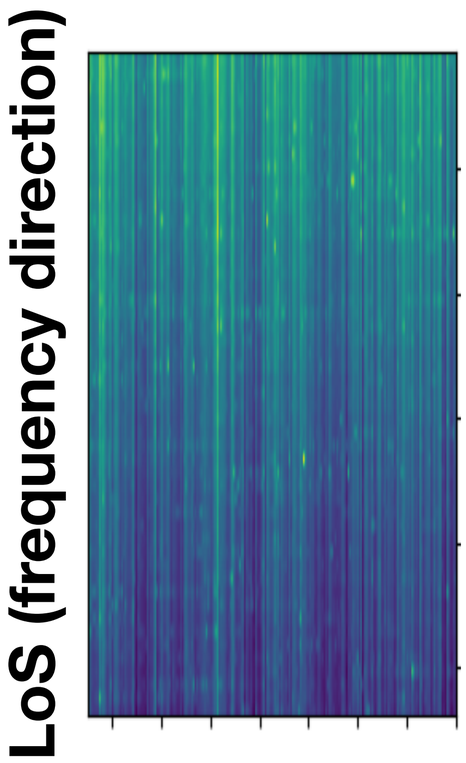
Comoving scales at z ~ 6



150 Mpc
dx = 1 Mpc
(Nx ~ 150)

300 Mpc
dx = 6 Mpc
(Nz ~ 50)

Step 2: Compute power spectrum



LoS (frequency direction)

angular direction

Fourier transform

frequency direction

small

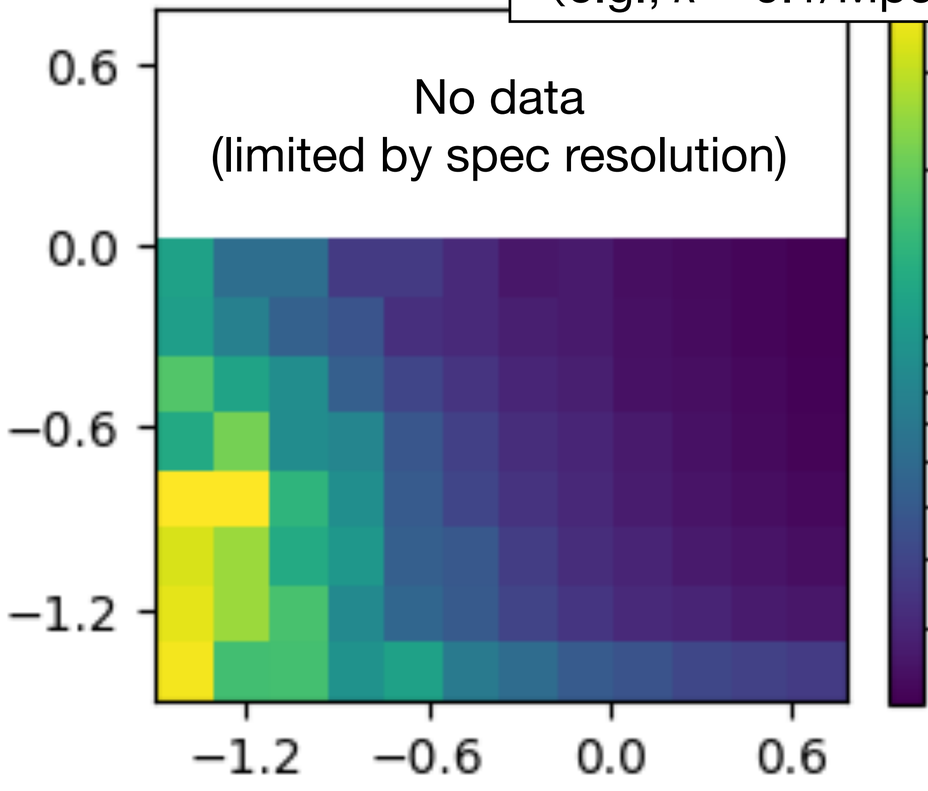
non-smooth

large

smooth

$\log_{10} k_\parallel$ [h/Mpc]

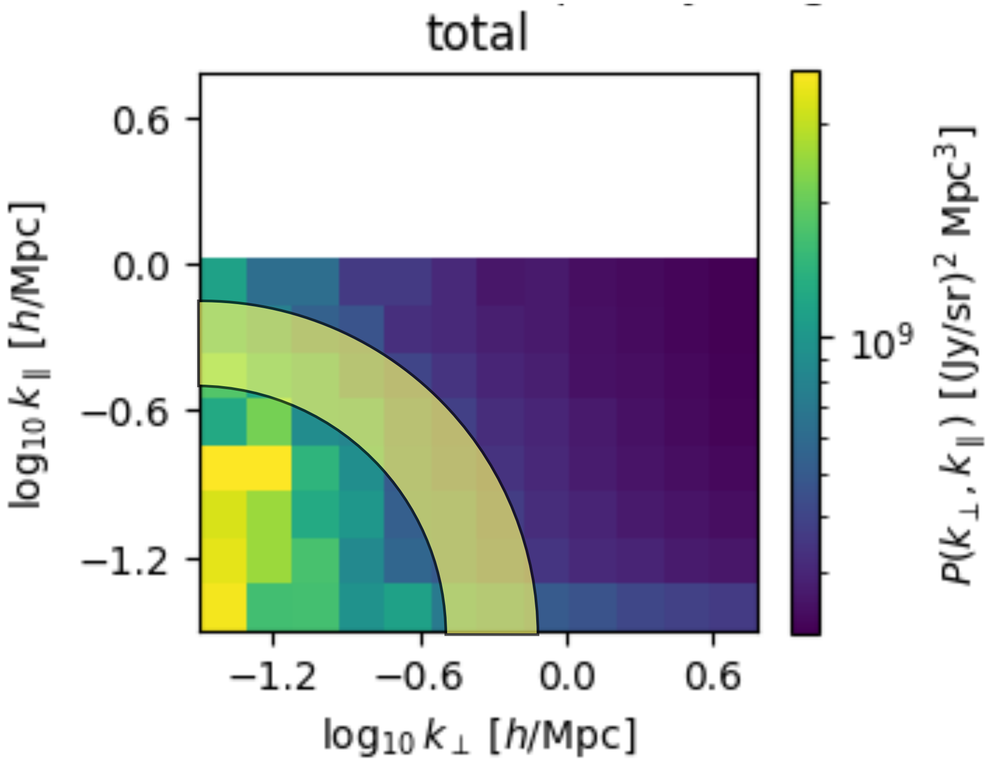
wavenumber k corresponds to wavelength $\lambda = 2\pi / k$
(e.g., k = 0.1/Mpc ↔ λ = 60 Mpc)

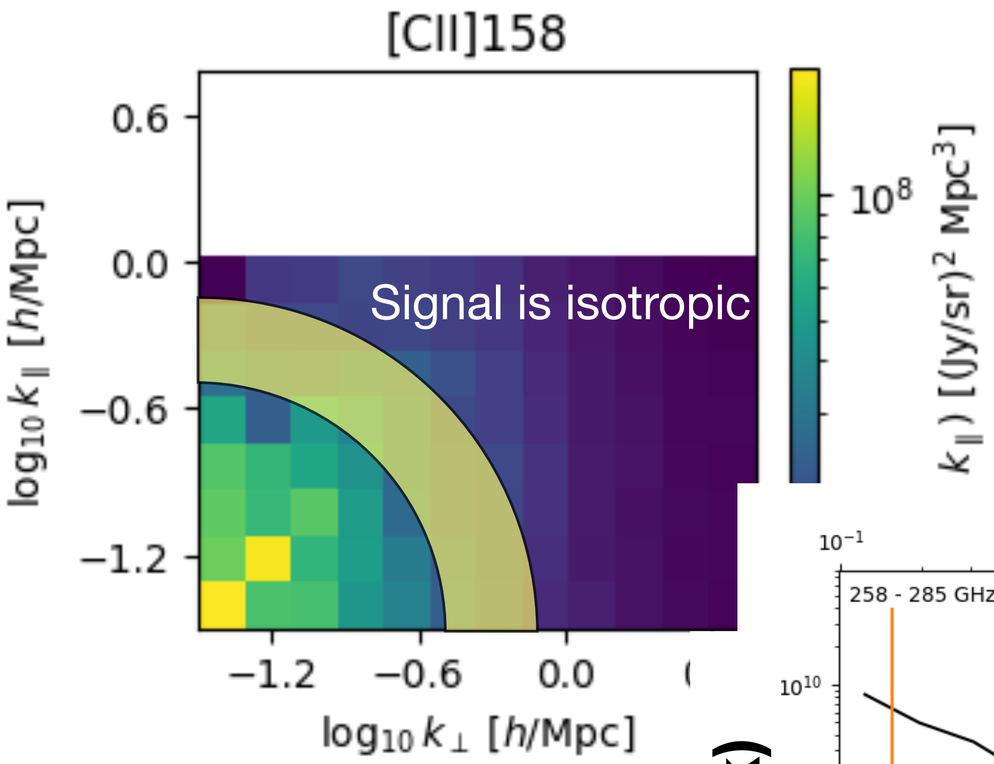


large ◄····► small

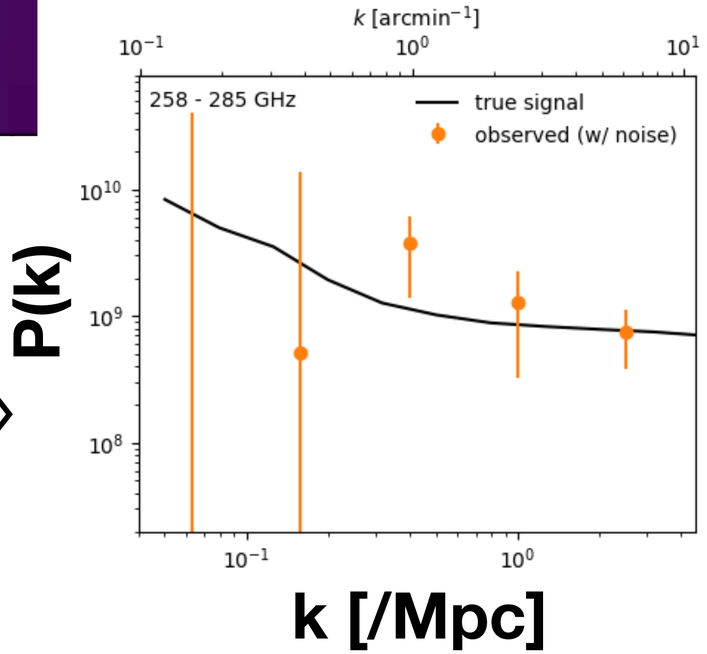
angular direction

Step 3: Average over |k| ~ k





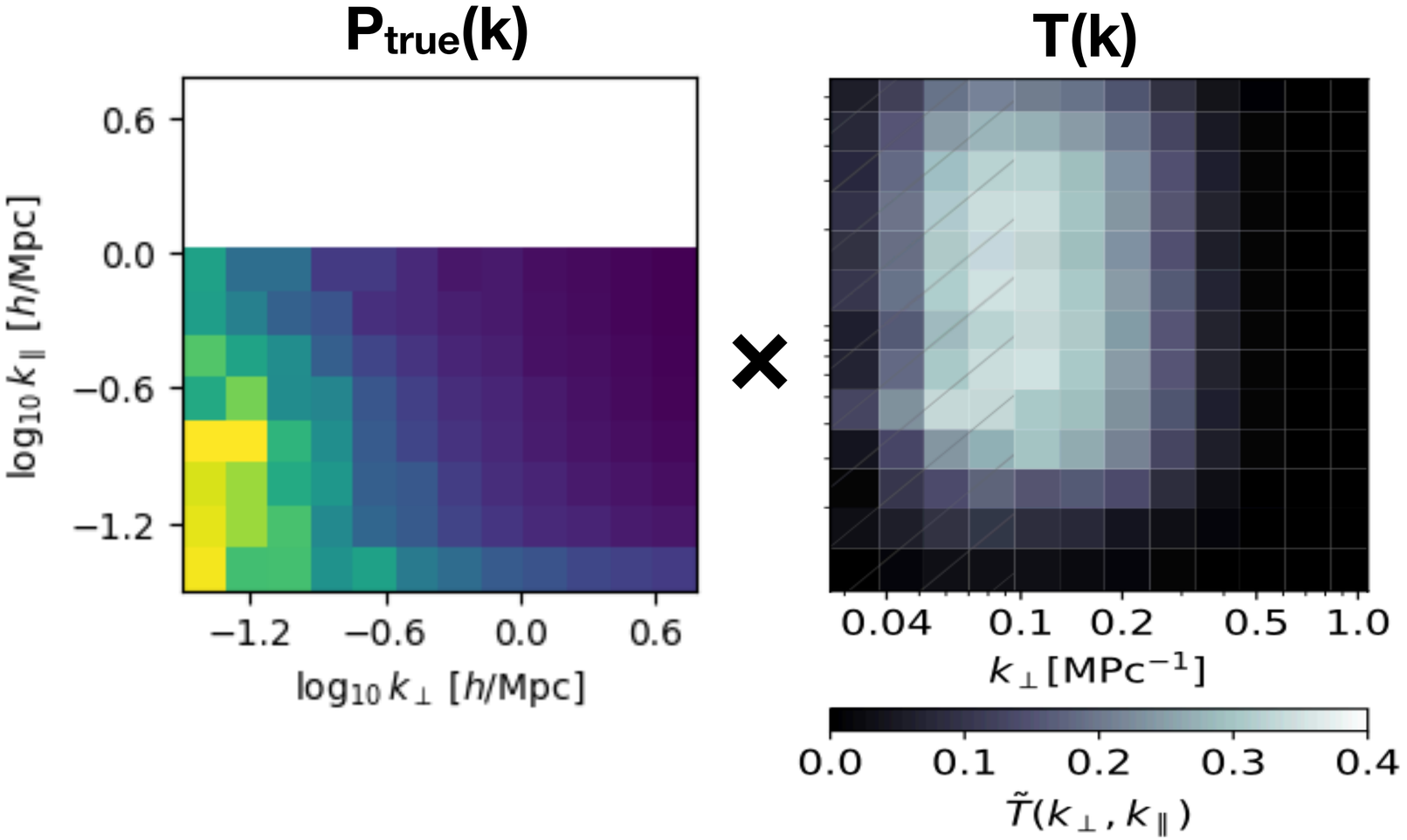
Compute angle average



Note: Transfer function

$P_{obs}(\mathbf{k}) = T(\mathbf{k})\, P_{true}(\mathbf{k})$

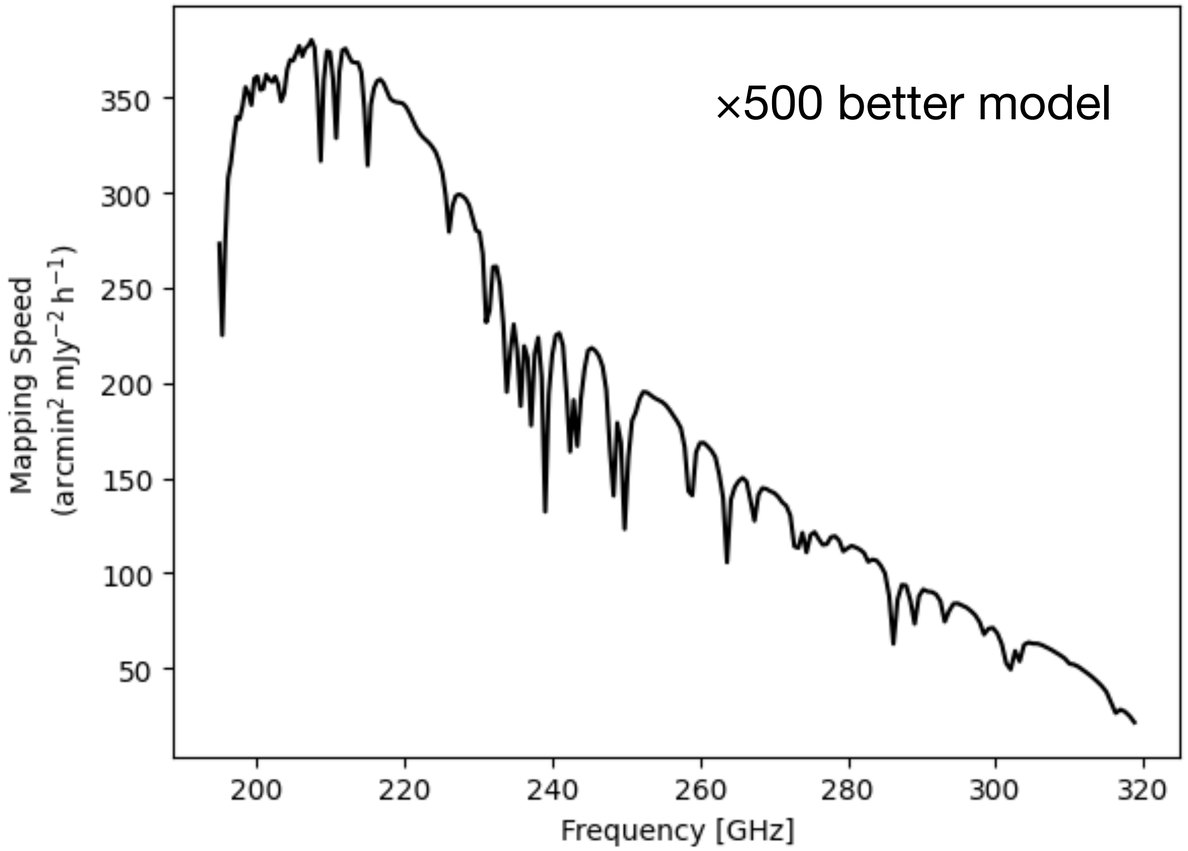
- Some modes will be reduced in data analysis (e.g., foreground removal). The transfer function describes how much they are reduced
- In the observation, we need to de-bias this effect by taking P_{obs} / T

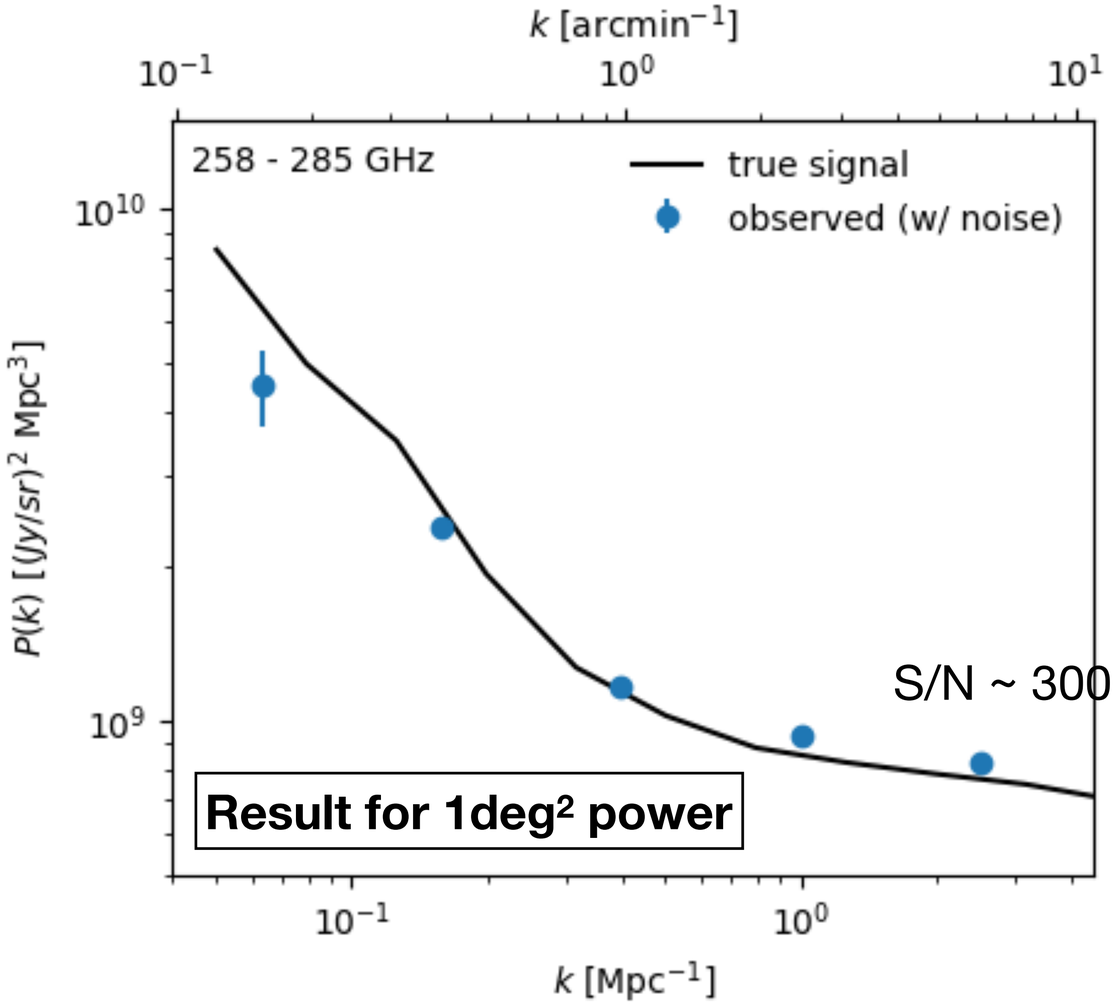


T(k) of COMAP (Lunde et al. 2024)

Future Prospects

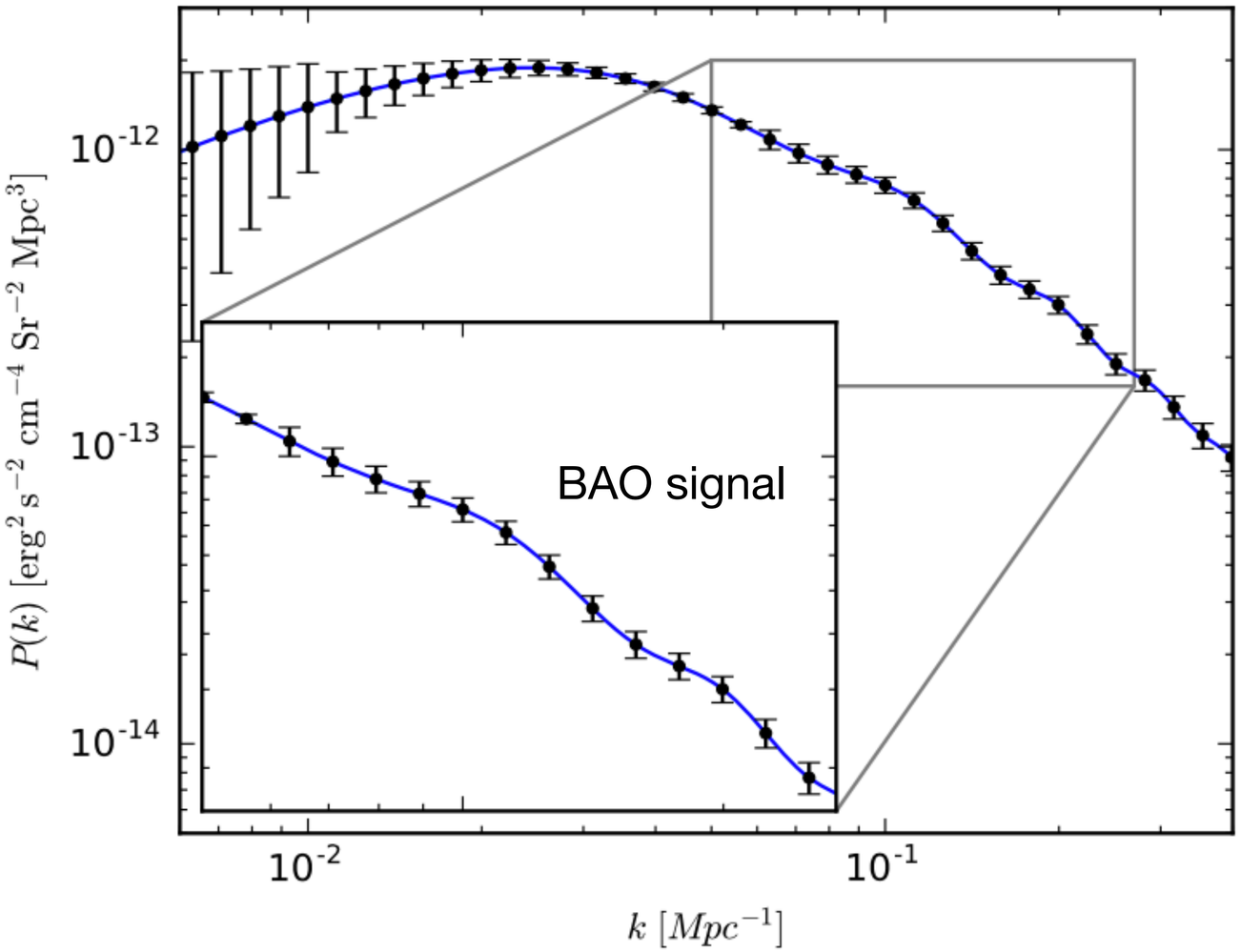
What if we have ×500 better mapping speed?





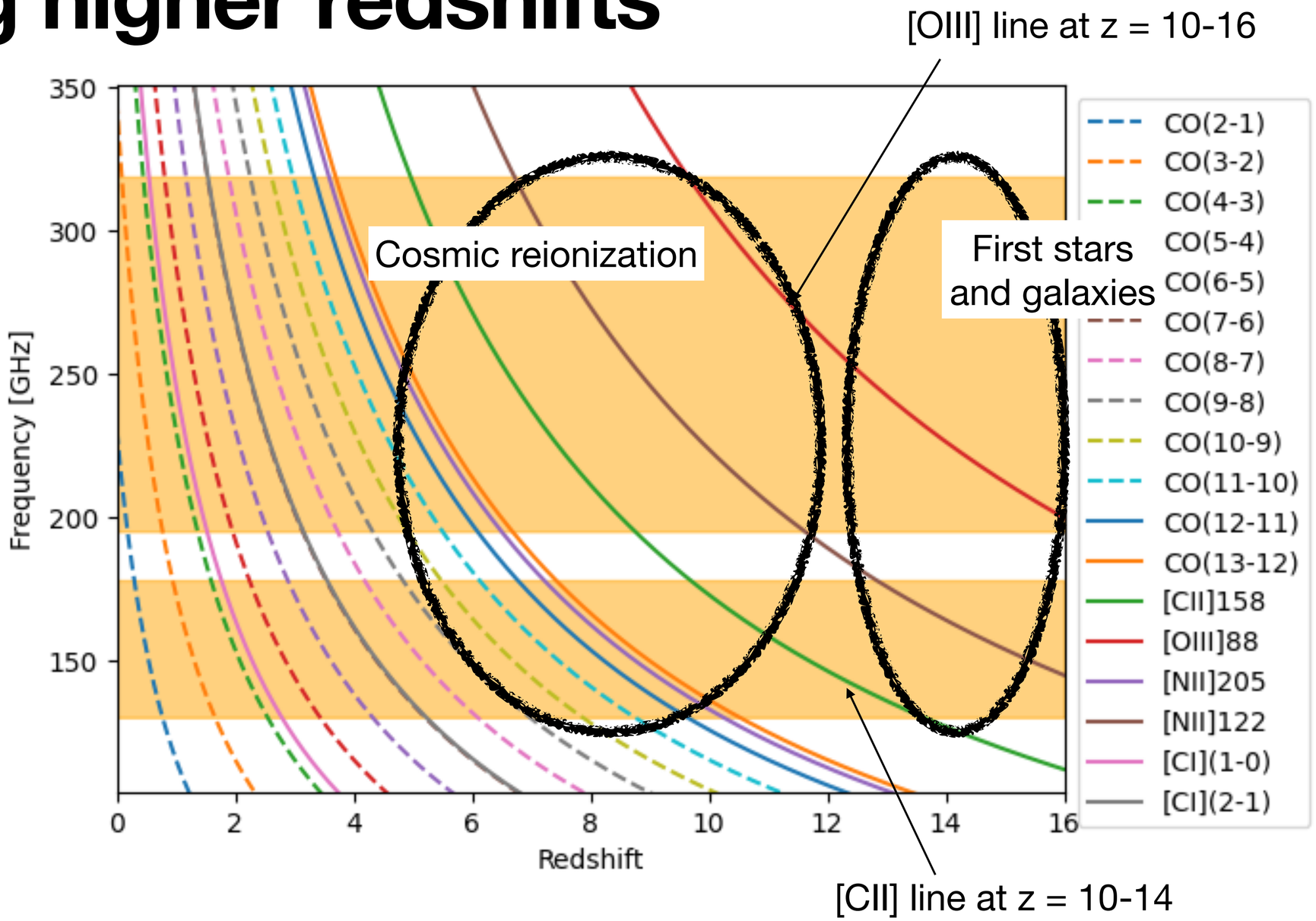
Cosmology — Mapping larger volume

Cf. predicted SPHEREx Hα LIM signal at z = 2

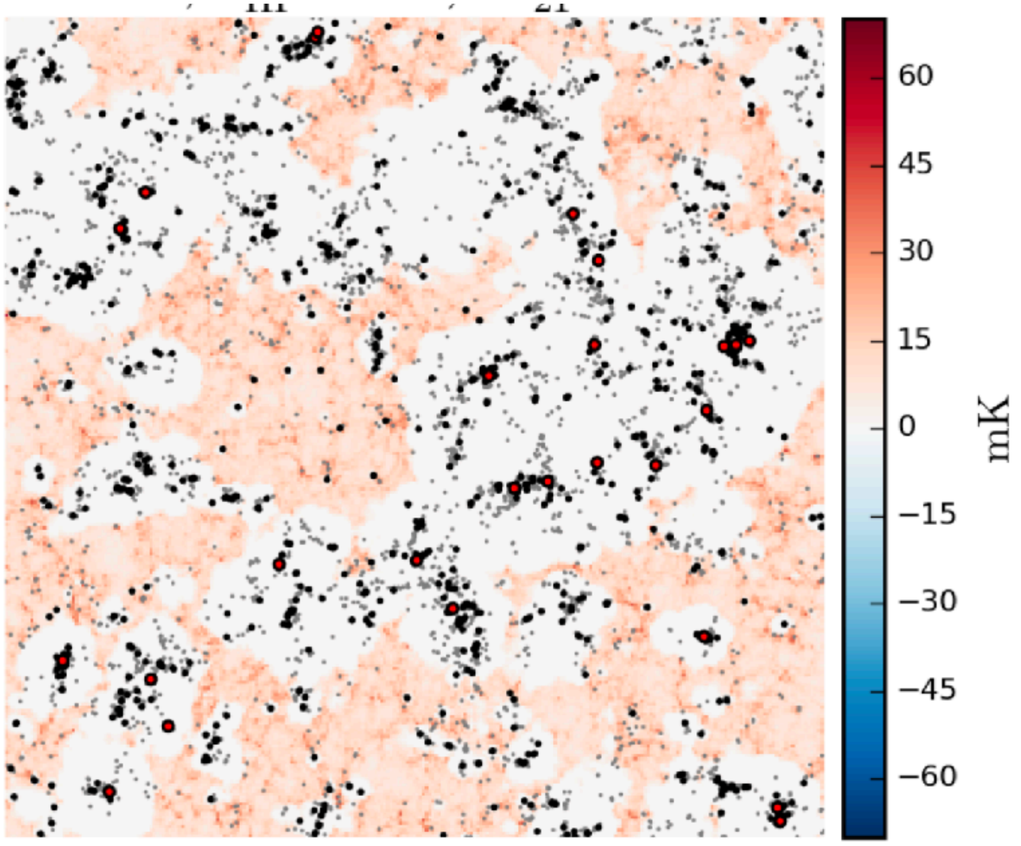


- High-z BAO
- Primordial non-Gaussianity
- Deviation from $n_s = 1$ (Yoshida-san's talk?)
- etc.

Going higher redshifts

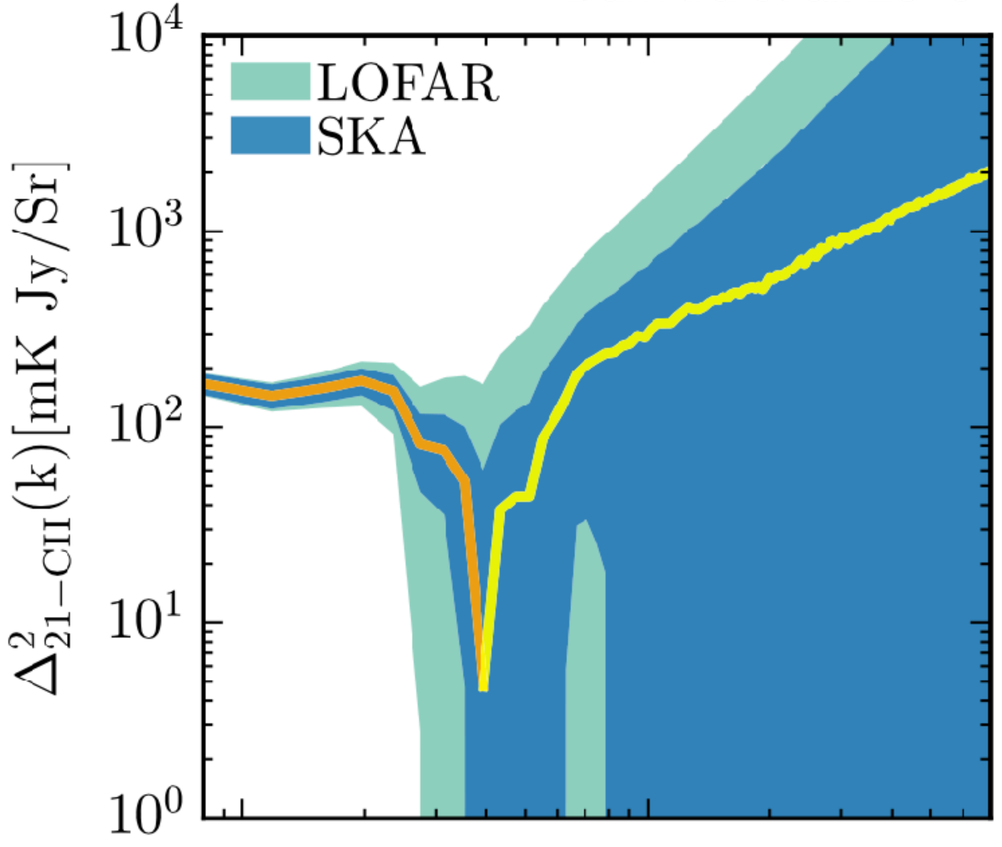


Cross-correlating with EoR 21cm



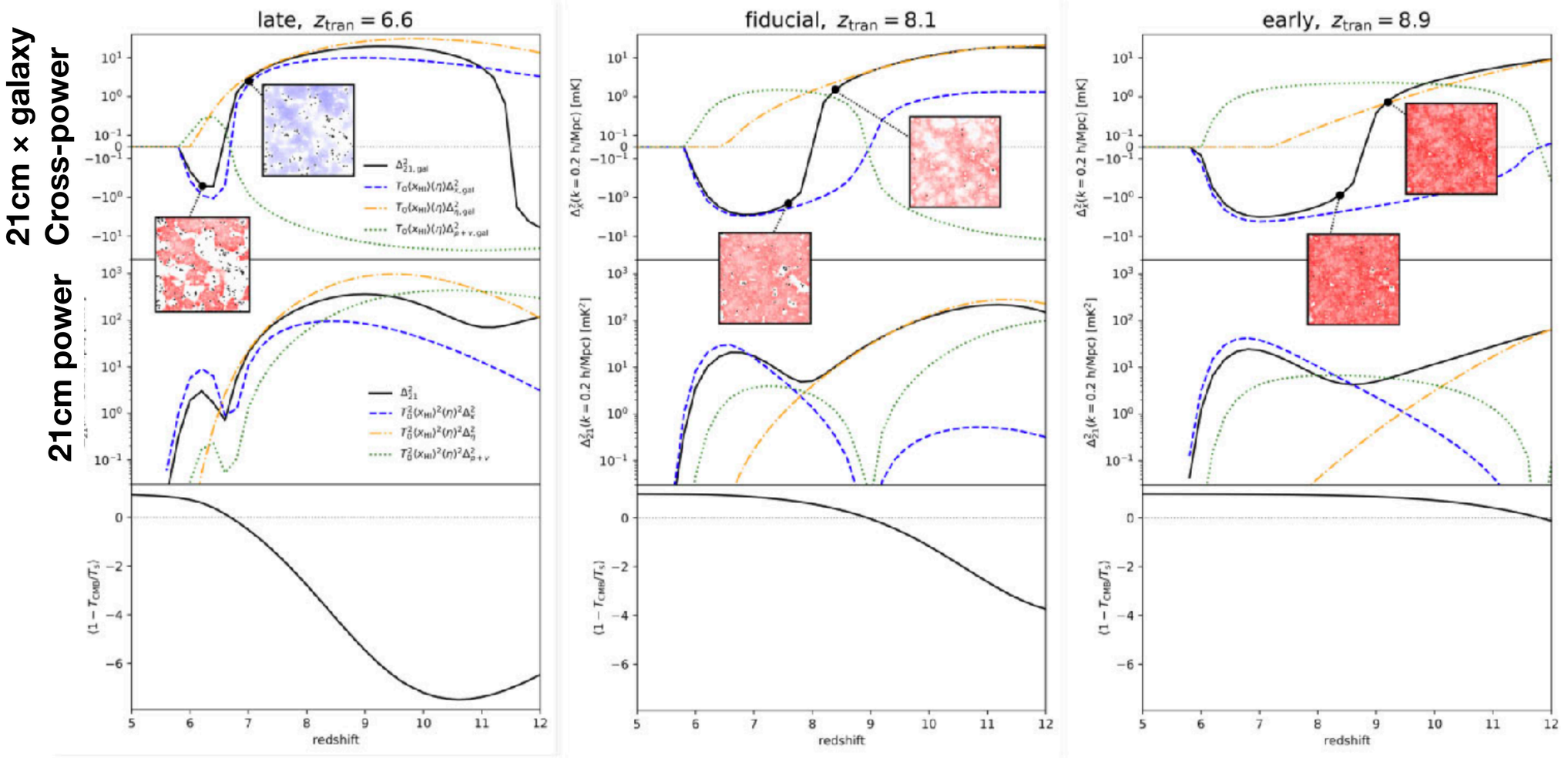
Anti-correlation between neutral gas (21cm) and galaxies ([CII])

Dumitru et al. 2019



21cm signal is weak, but high-S/N [CII] or [OIII] observation can help detection!

Cross-correlating with EoR 21cm



Redshift evolution of cross-power spectrum is the most informative probe of the cosmic reionization and IGM heating (and therefore the formation of the first luminous objects)

Moriwaki, Beane, Lidz 2024

Summary

Mock data

- TNG with empirical line and continuum model
- Reproduce the observed number counts of galaxies
- Limitations: boxsize and resolution (problematic especially for very high-z faint gals)

Power spectrum

- We should evaluate transfer function to obtain unbiased power

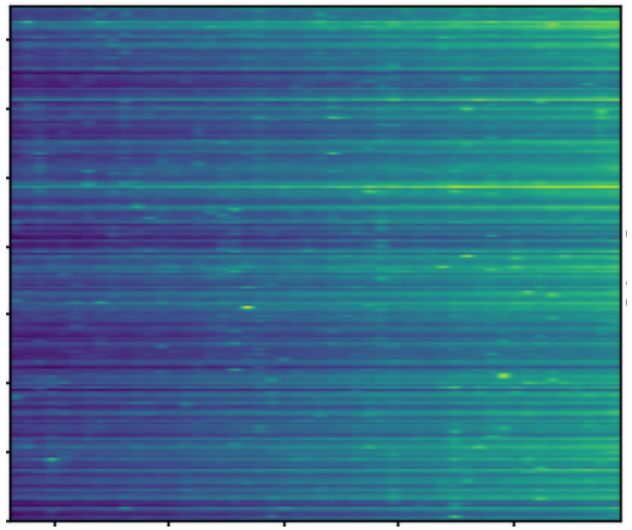
Future prospects

- High-z cosmology, cosmic reionization, first stars and galaxies

Appendix

Cf. What if converting at other lines' redshift?

CO(4-3): z = 0.6 - 0.8

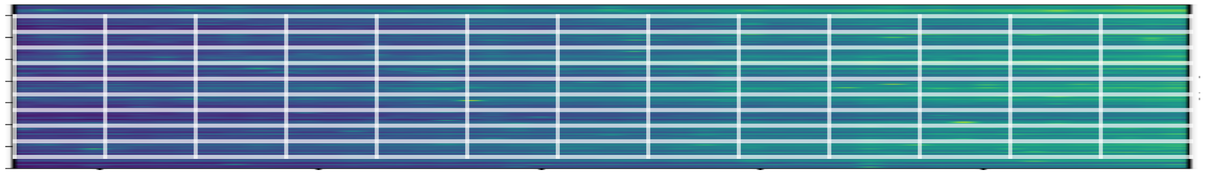


1deg
dx = 30 arcsec

258 GHz - 285 GHz
R = 500

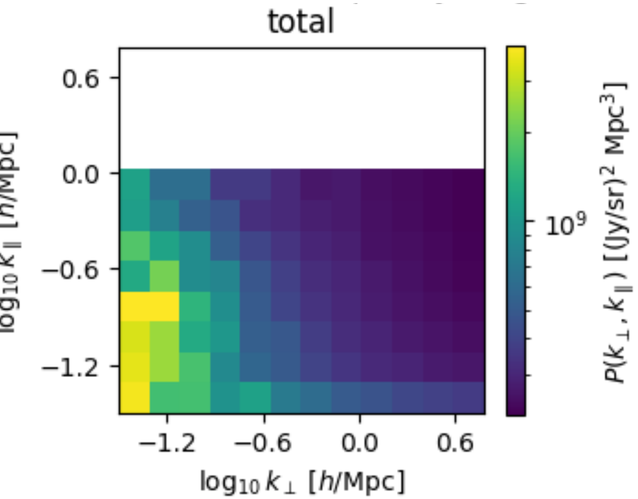
Comoving scales at z ~ 0.7

45 Mpc
dx = 0.4 Mpc



500 Mpc
dx = 10 Mpc

Transfer function predicted in COMAP



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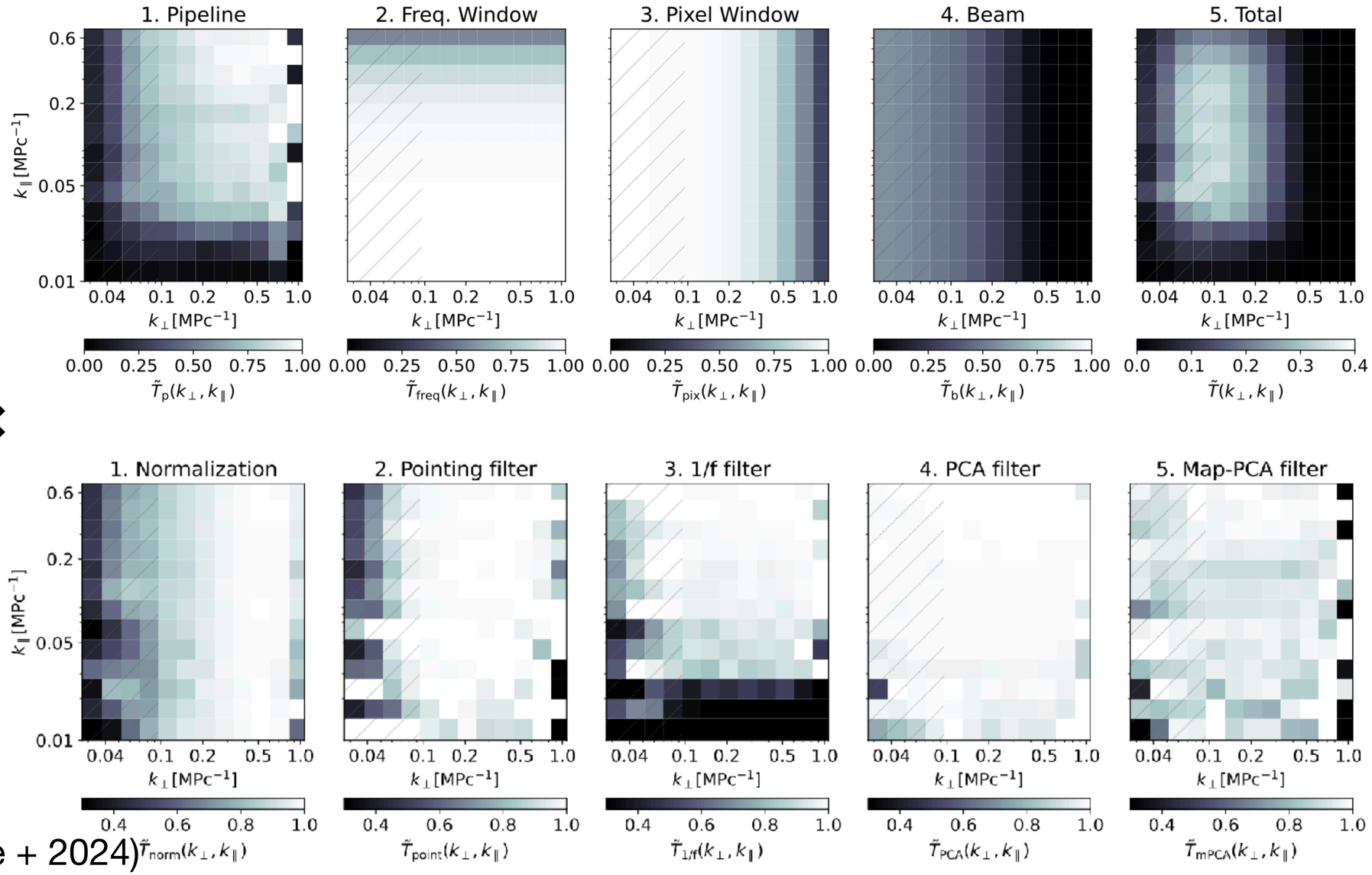

(Lunde + 2024)