

Line Intensity Mapping

Kana Moriwaki (RESCEU, UTokyo)

Challenges at the CMB Frontier @ Suwa University of Science

29 June - 3 July 2026

Line Intensity Mapping (LIM)

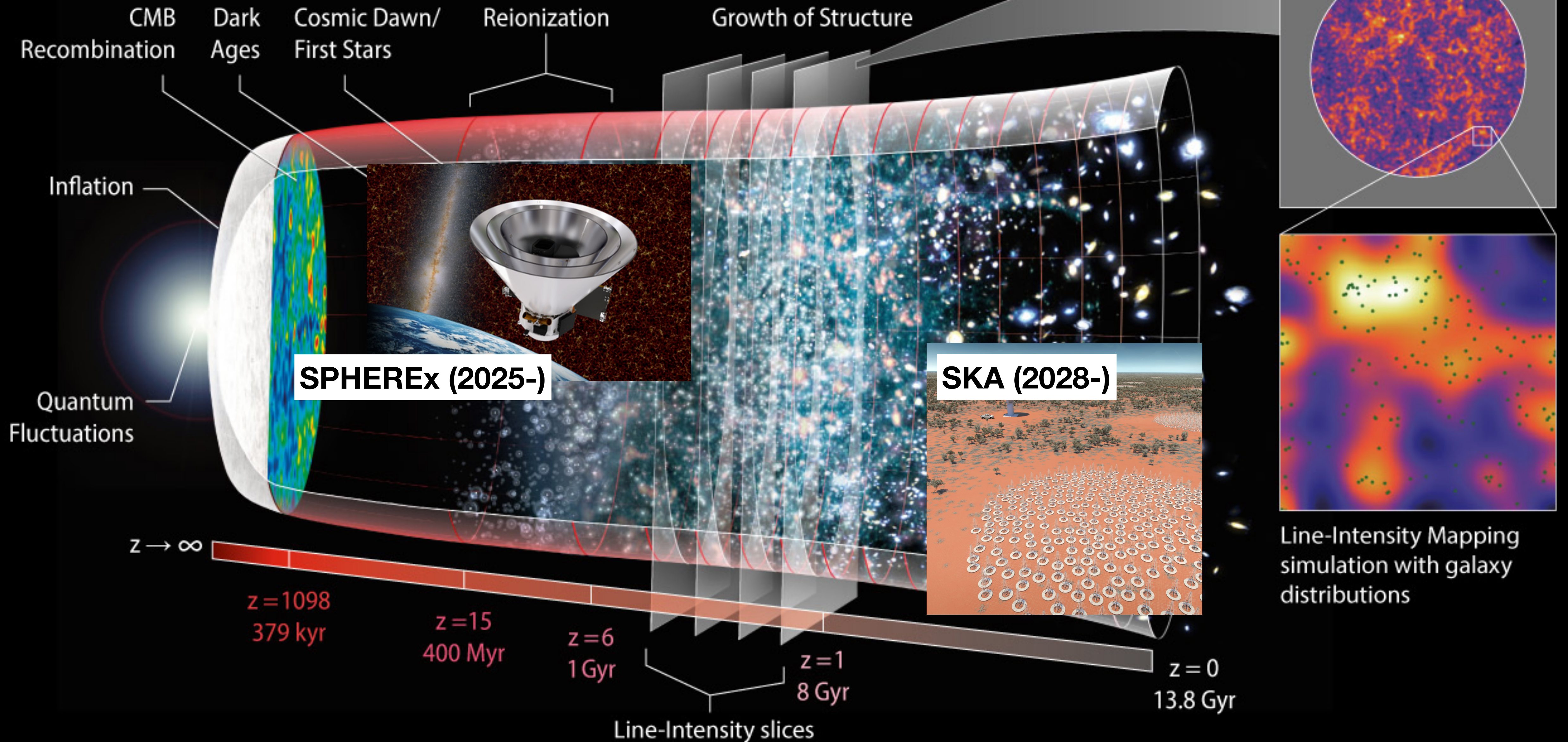
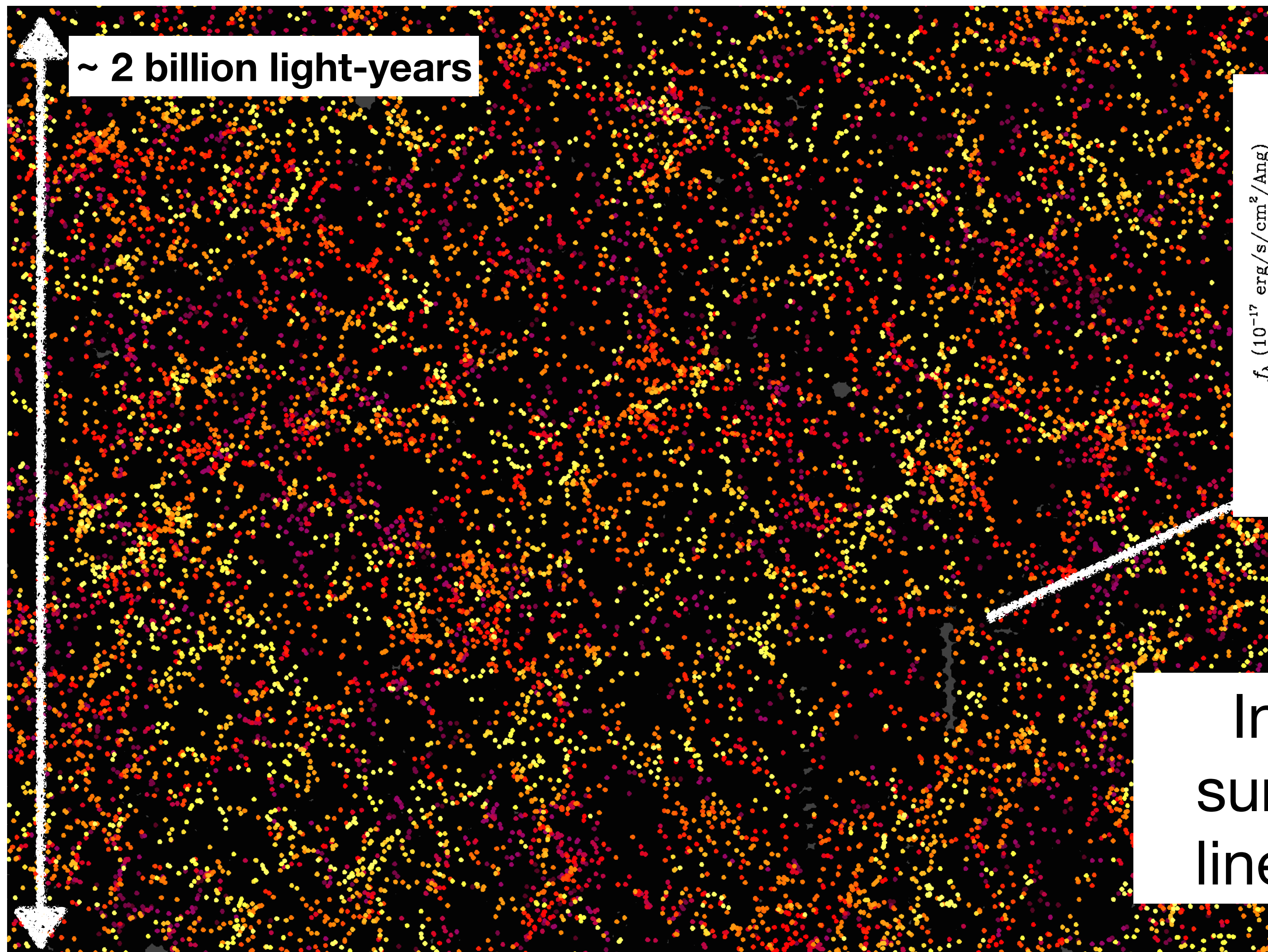
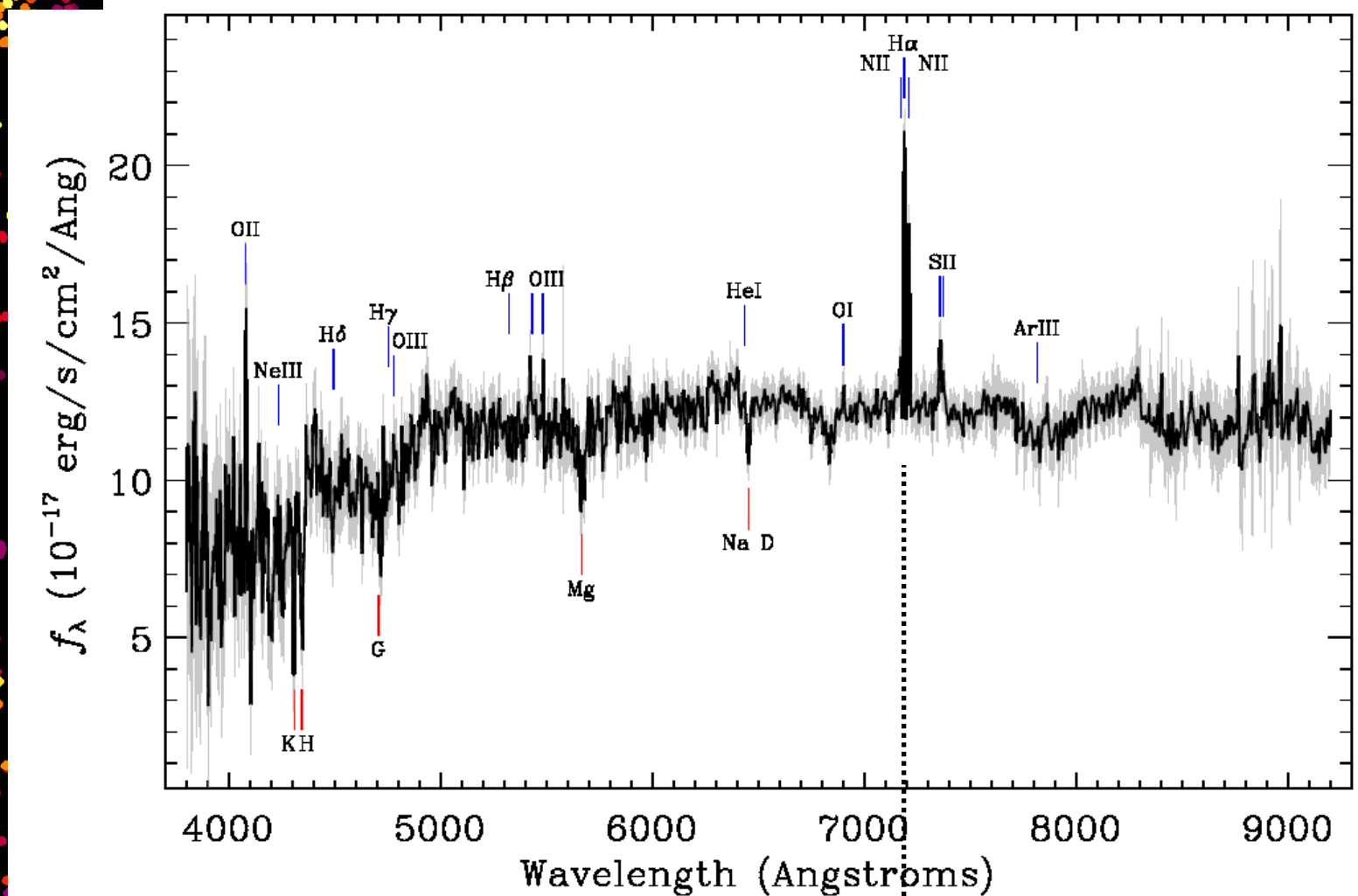


Image Credit: NASA / LAMBDA Archive Team

What is line intensity mapping?



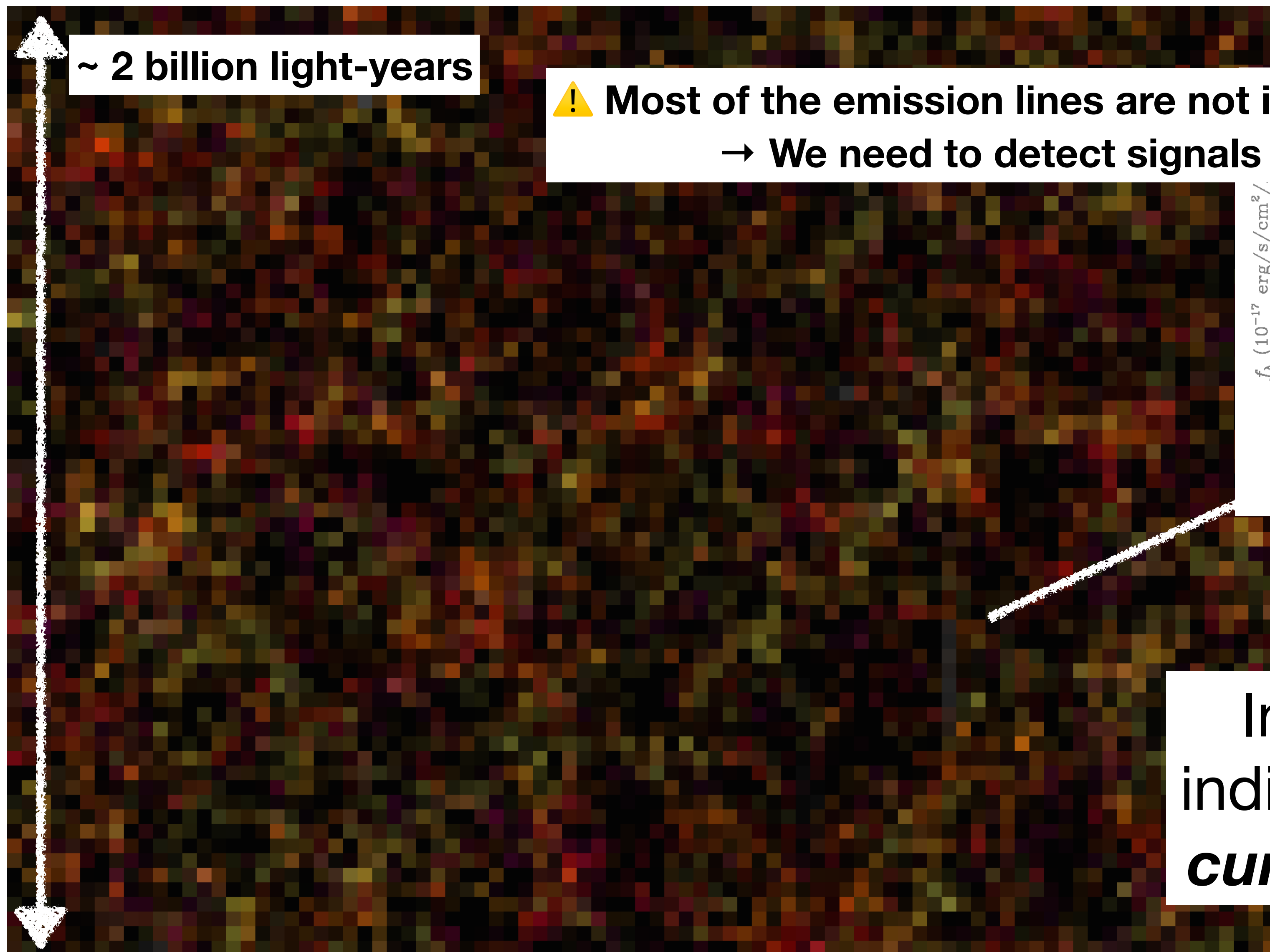
Emission line detection!



$$\lambda_{\text{obs}} = \lambda_{\text{rest}} (1 + z)$$

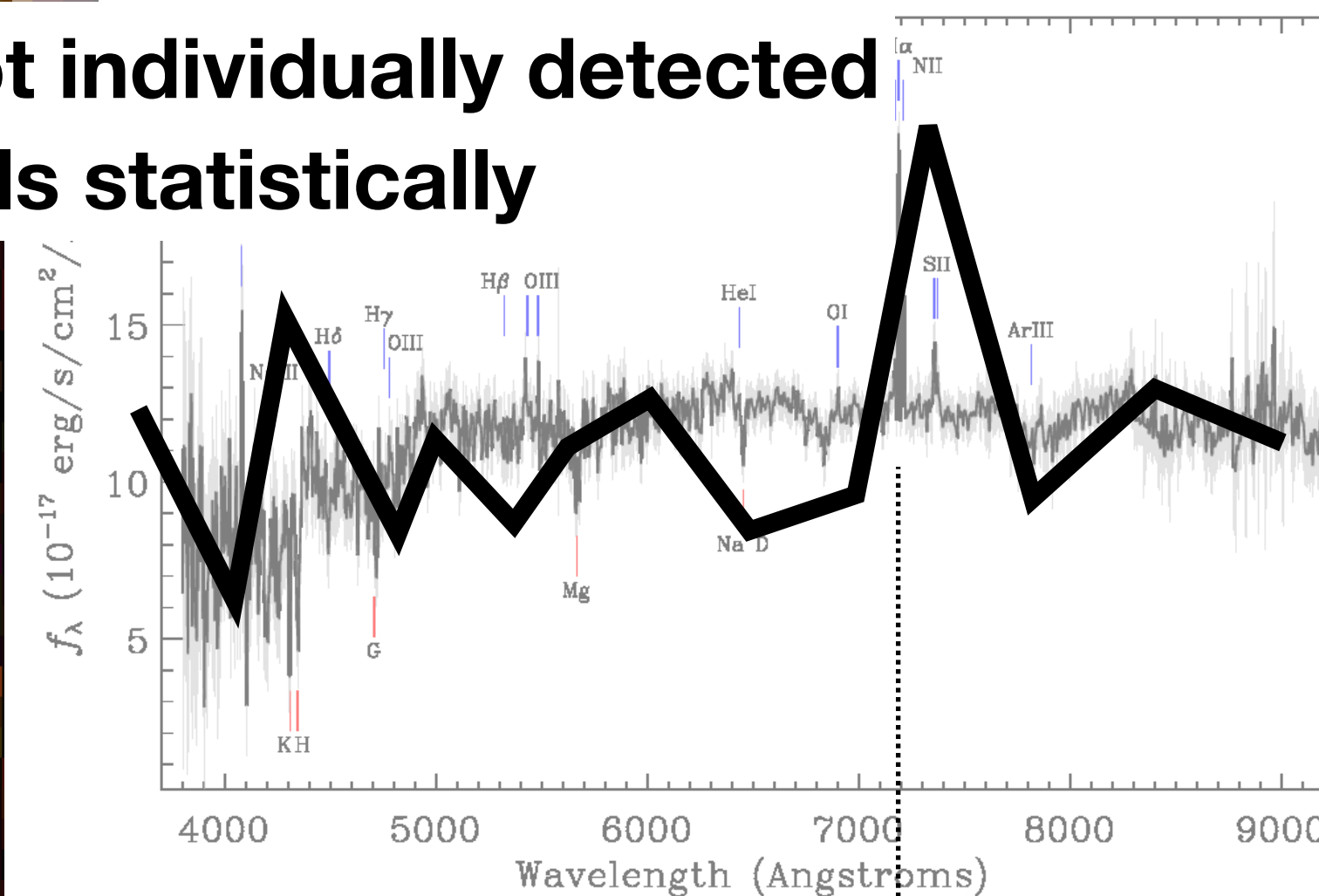
In ordinal galaxy redshift survey, we detect emission line(s) to determine redshift

What is line intensity mapping?



⚠ Most of the emission lines are not individually detected
→ We need to detect signals statistically

Emission line detection?



$$\lambda_{\text{obs}} = \lambda_{\text{rest}} (1 + z)$$

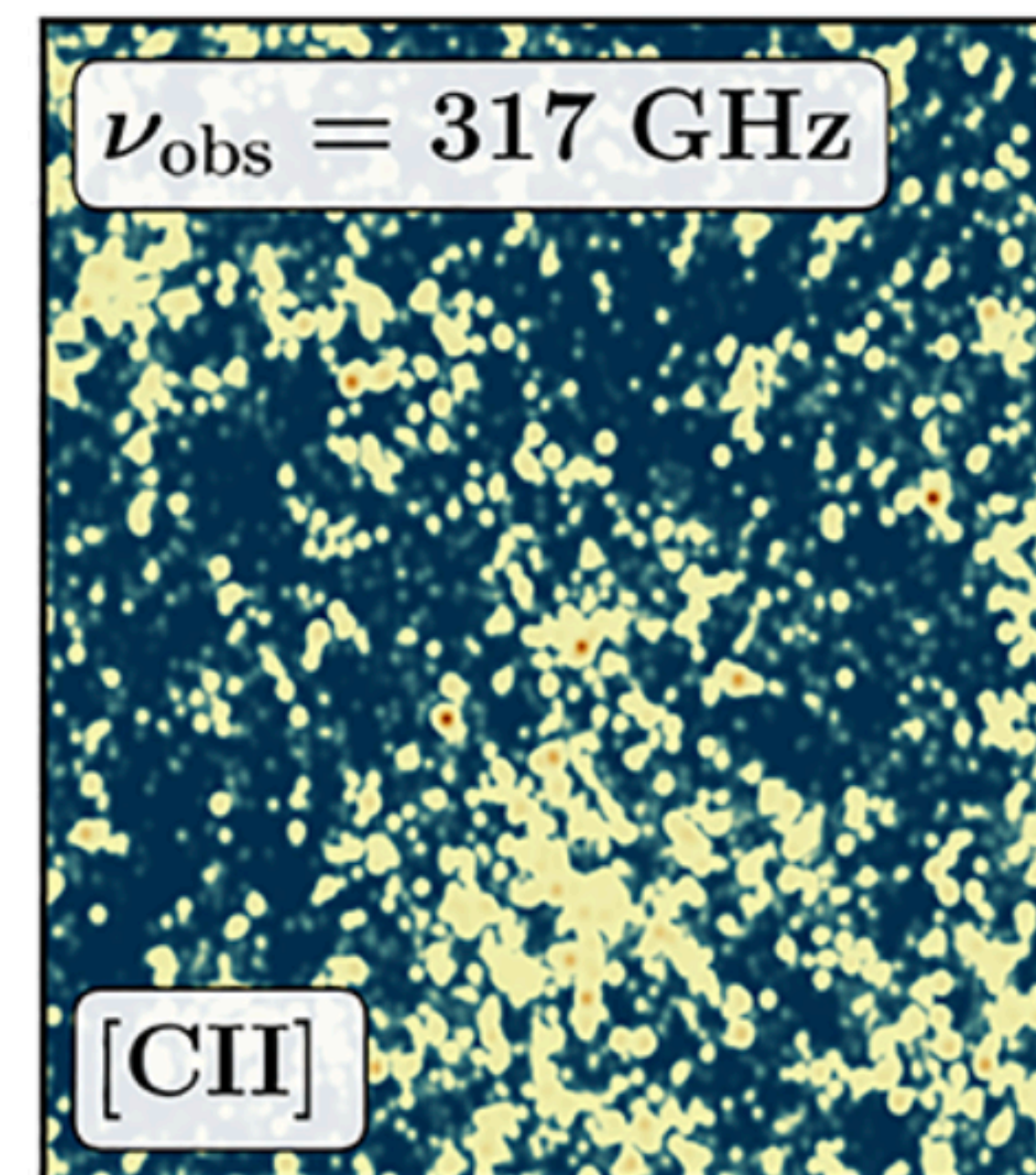
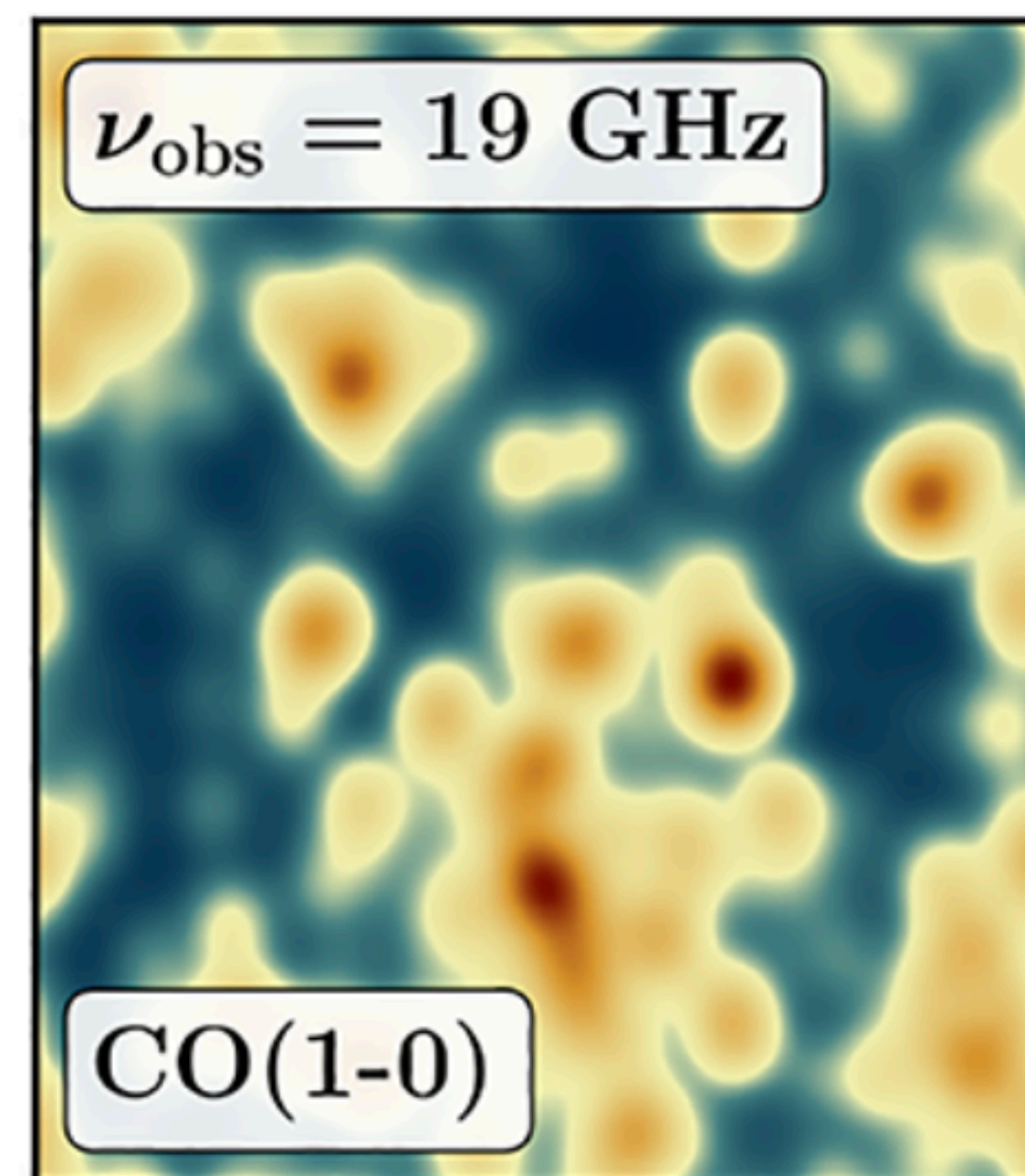
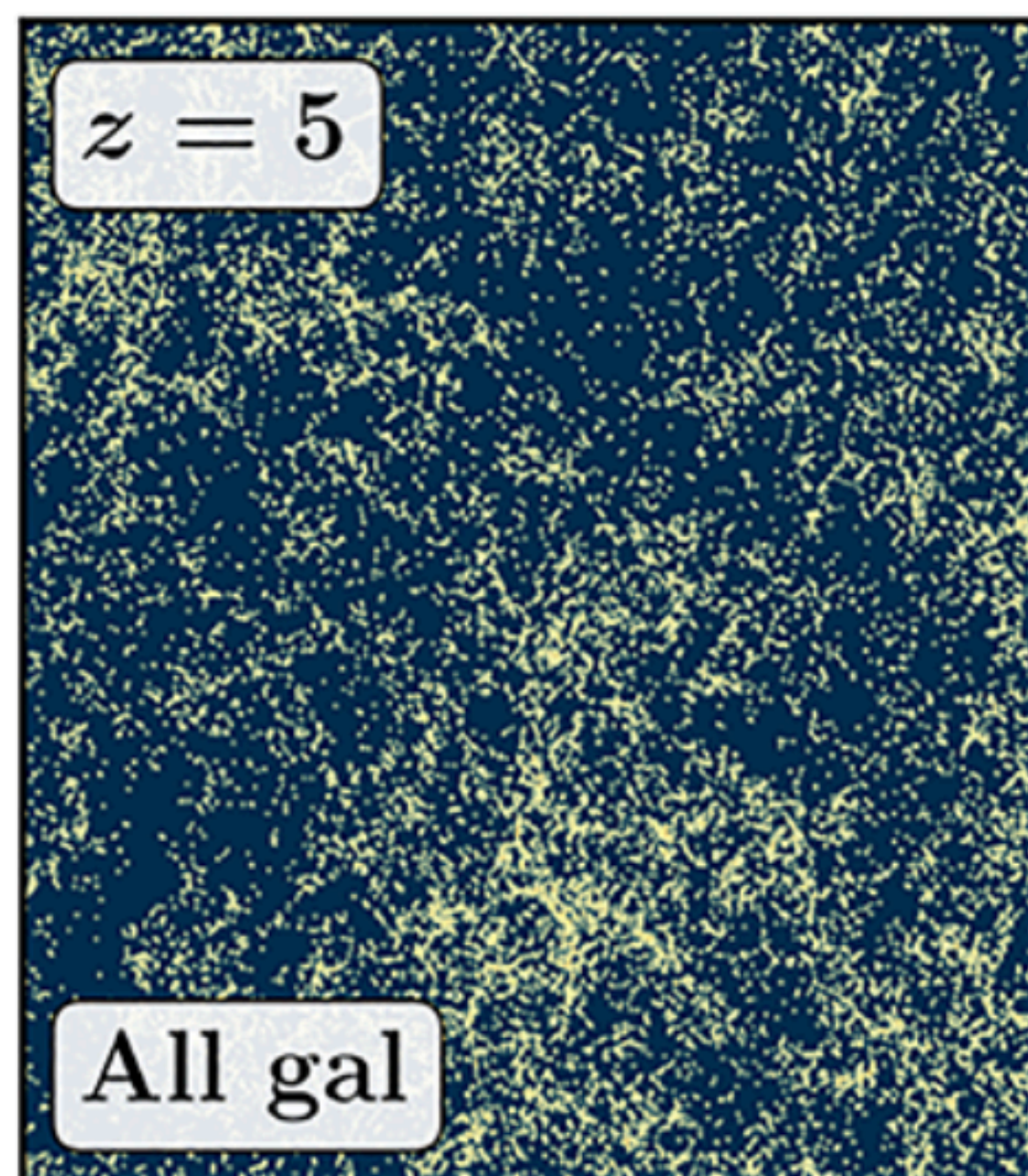
In LIM, we do not detect individual line(s) but measure ***cumulative line fluctuation***

Line Intensity Mapping

Bernal & Kovetz 2022

Conventional
galaxy survey

Line intensity mapping

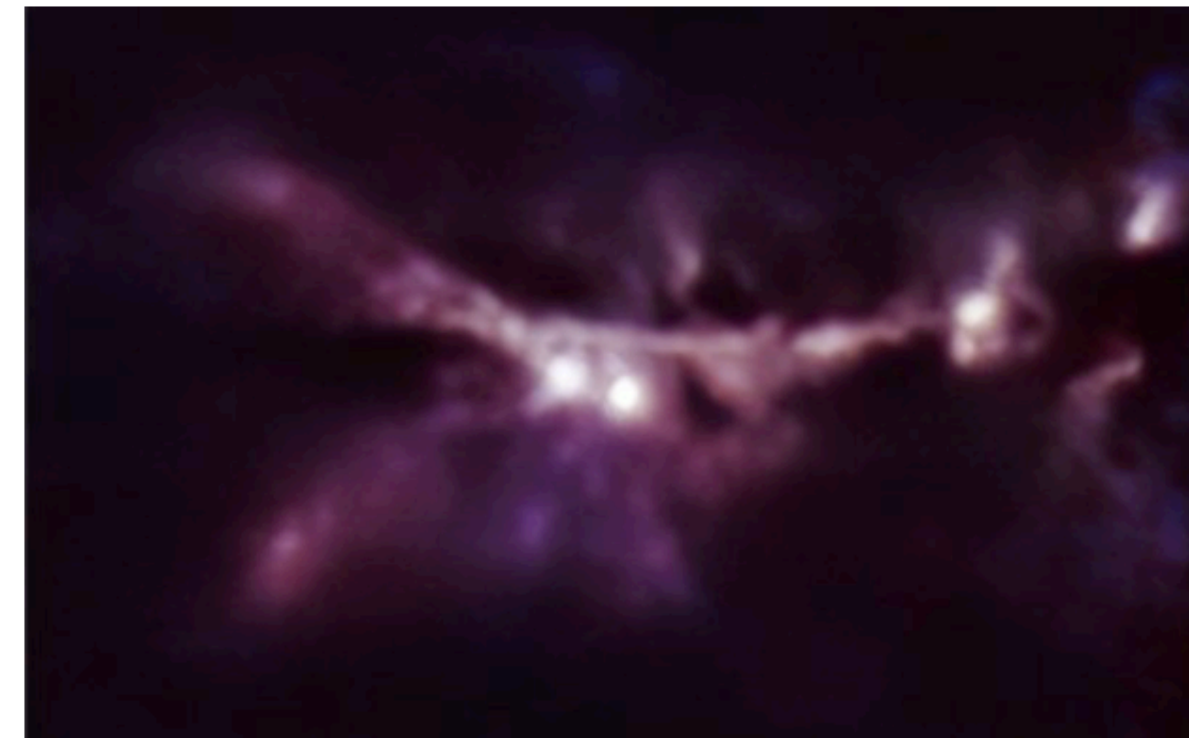


LIM captures the integrated emission from both resolved and unresolved faint populations. Its efficient mapping capability may enable wide-area surveys and observations at higher redshifts.

past and future observations

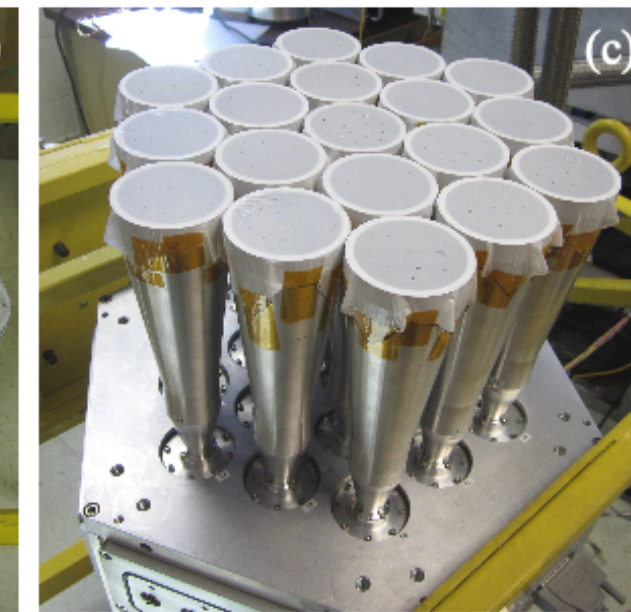
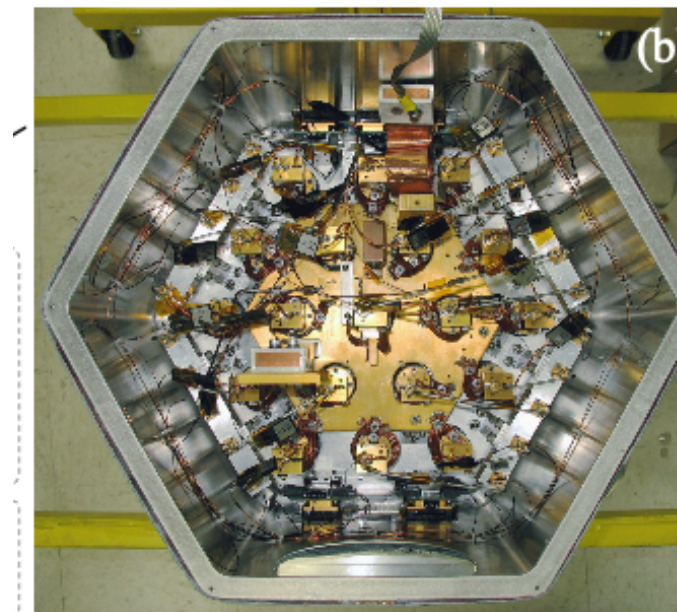
Past and Future Line Intensity Mapping Projects

SKA (2028-)

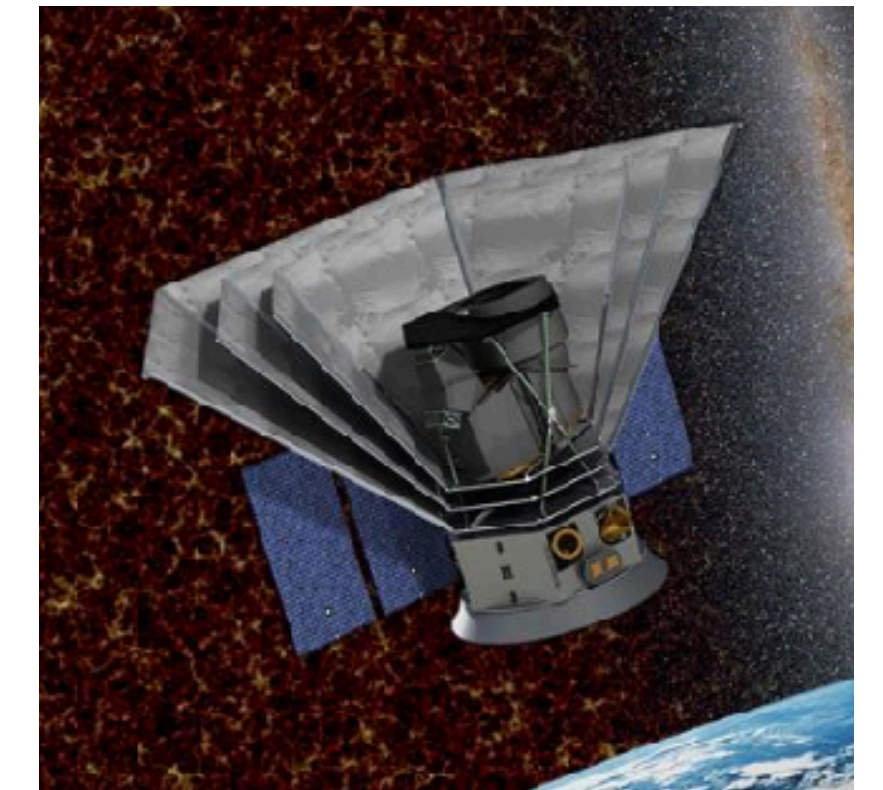


CONCERTO first light (2021)

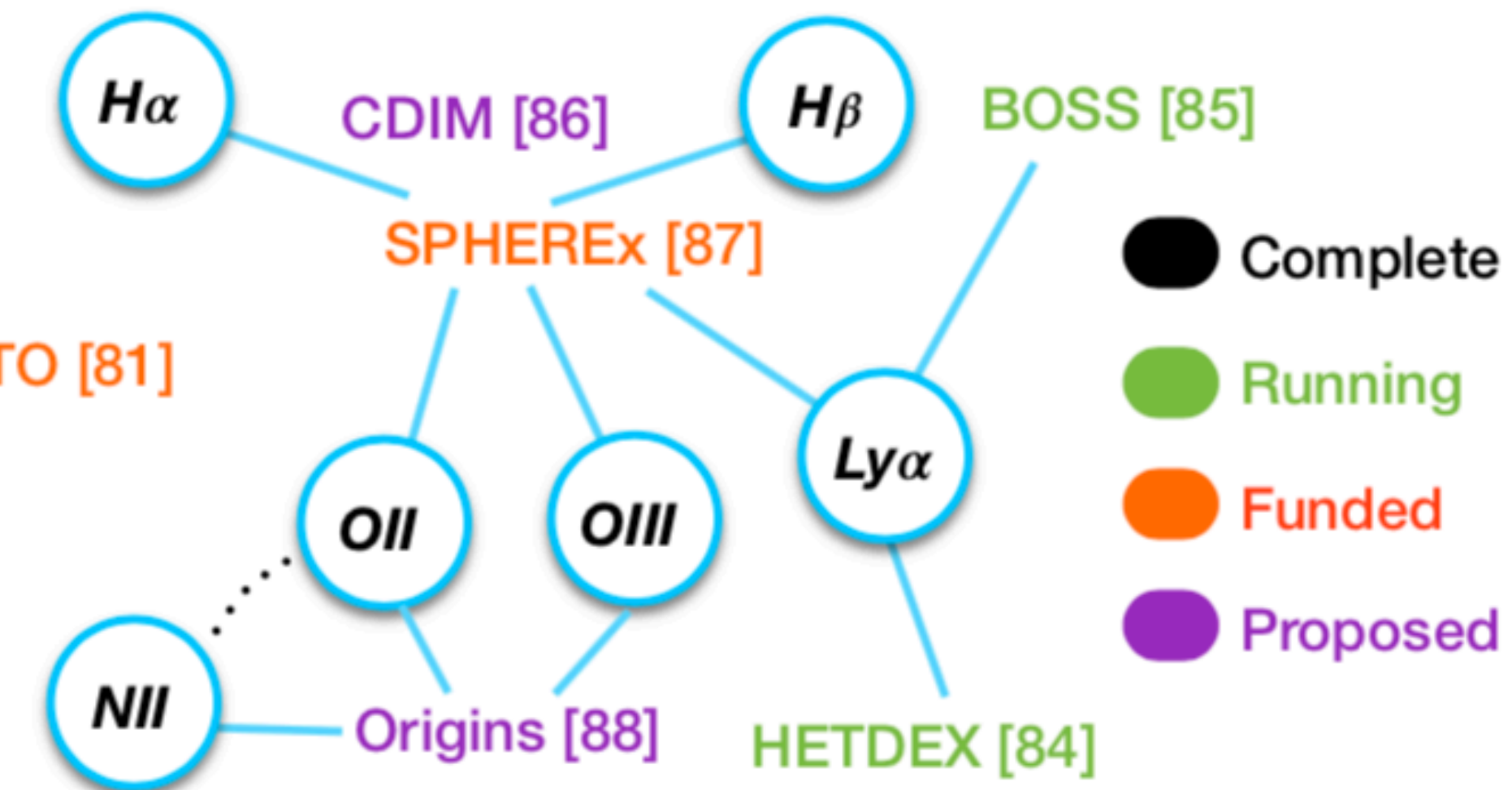
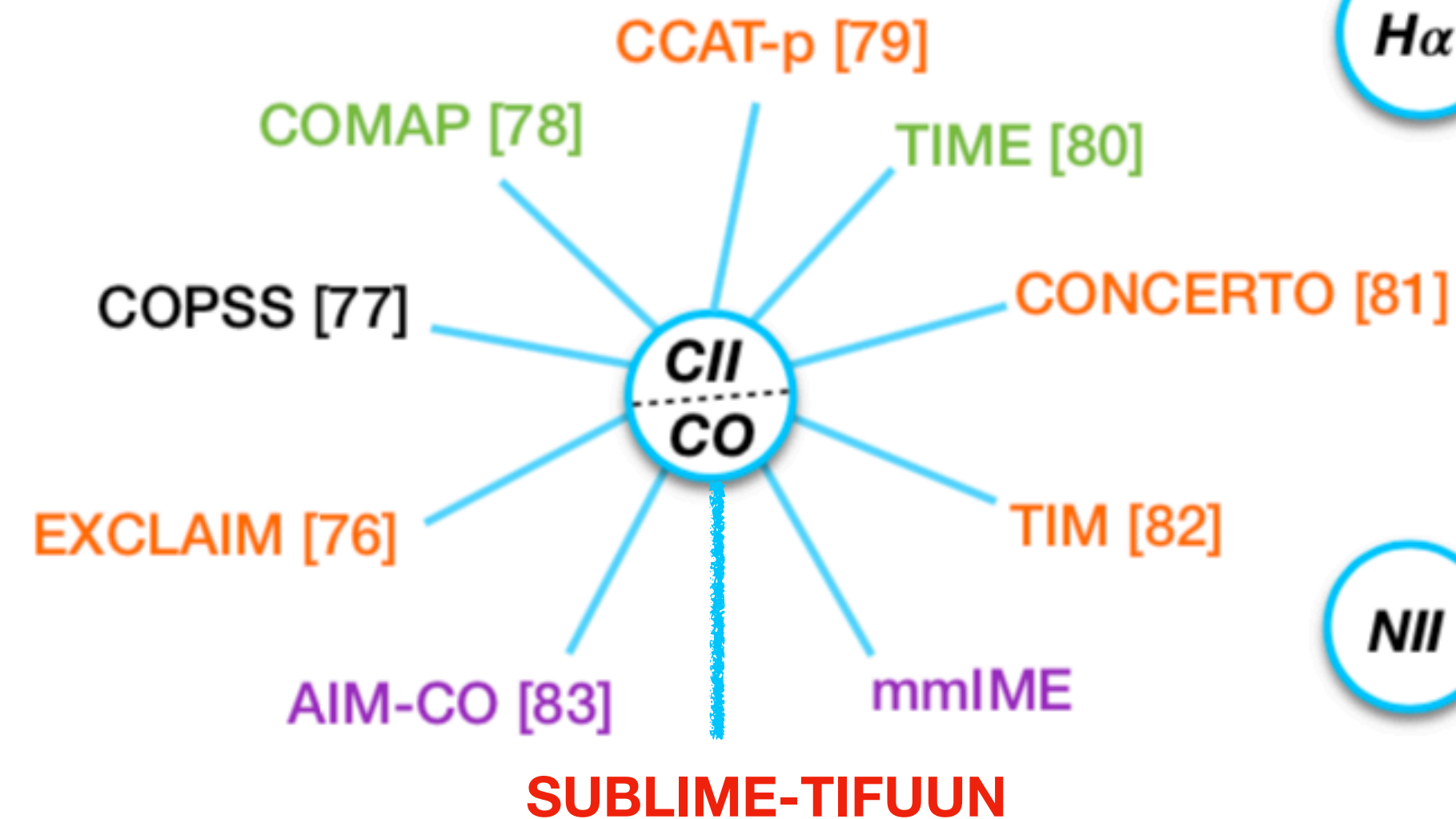
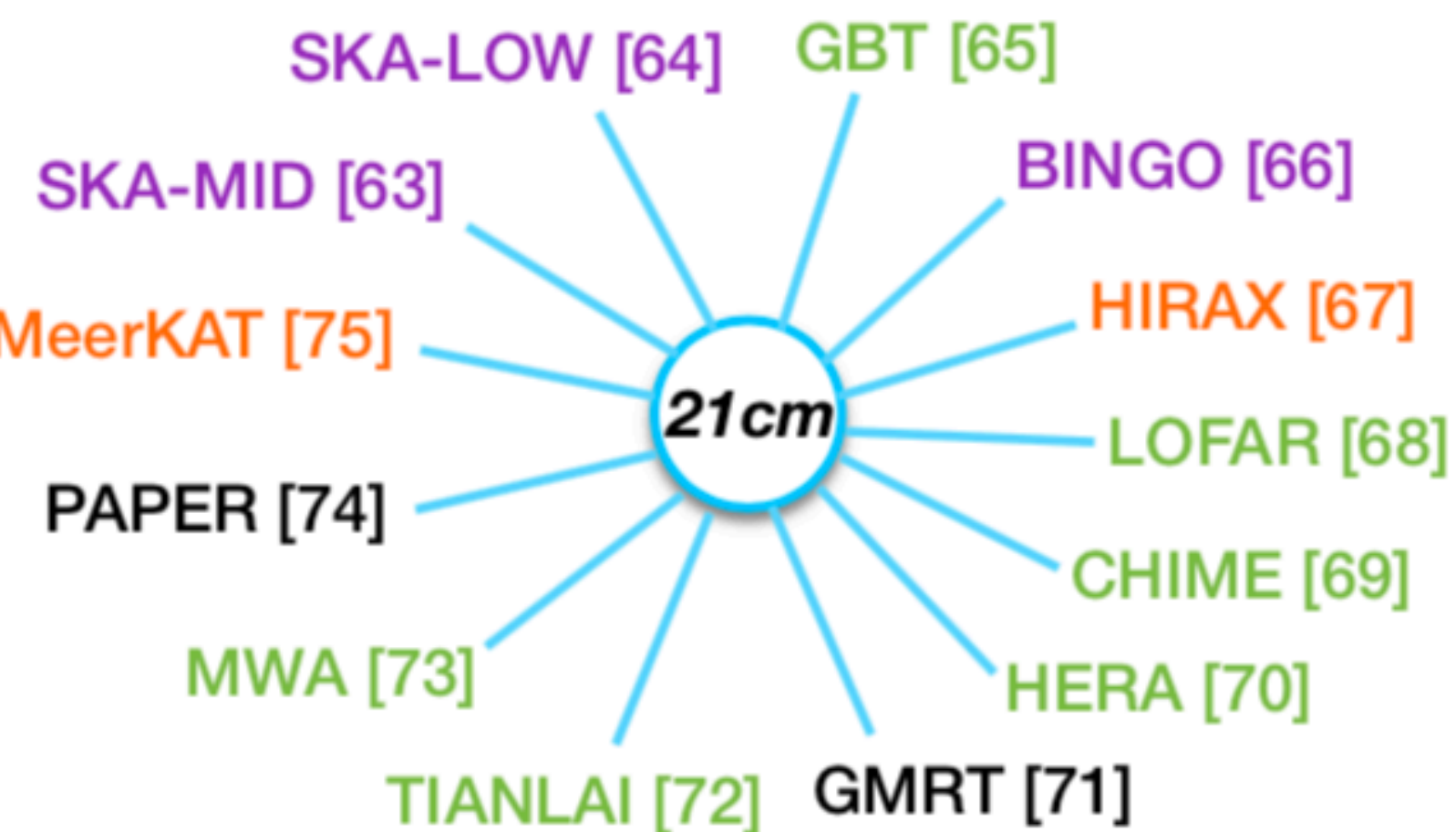
<https://www.eso.org/public/announcements/ann21010/>



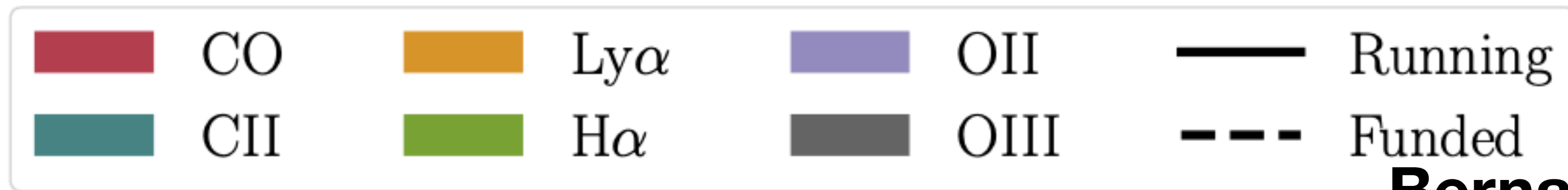
COMAP (2021-)



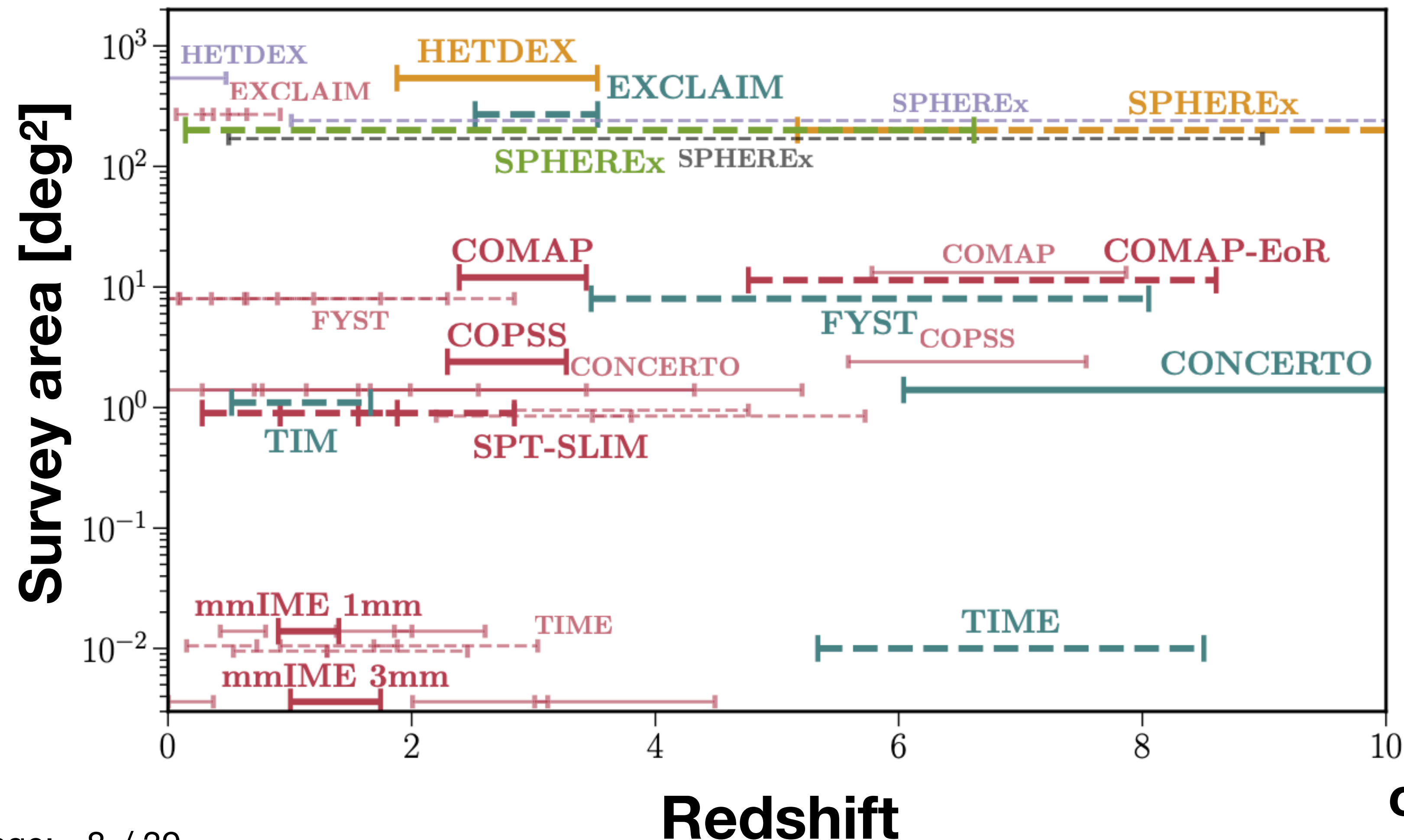
SPHEREx (2025-)



Past and Future Line Intensity Mapping Projects



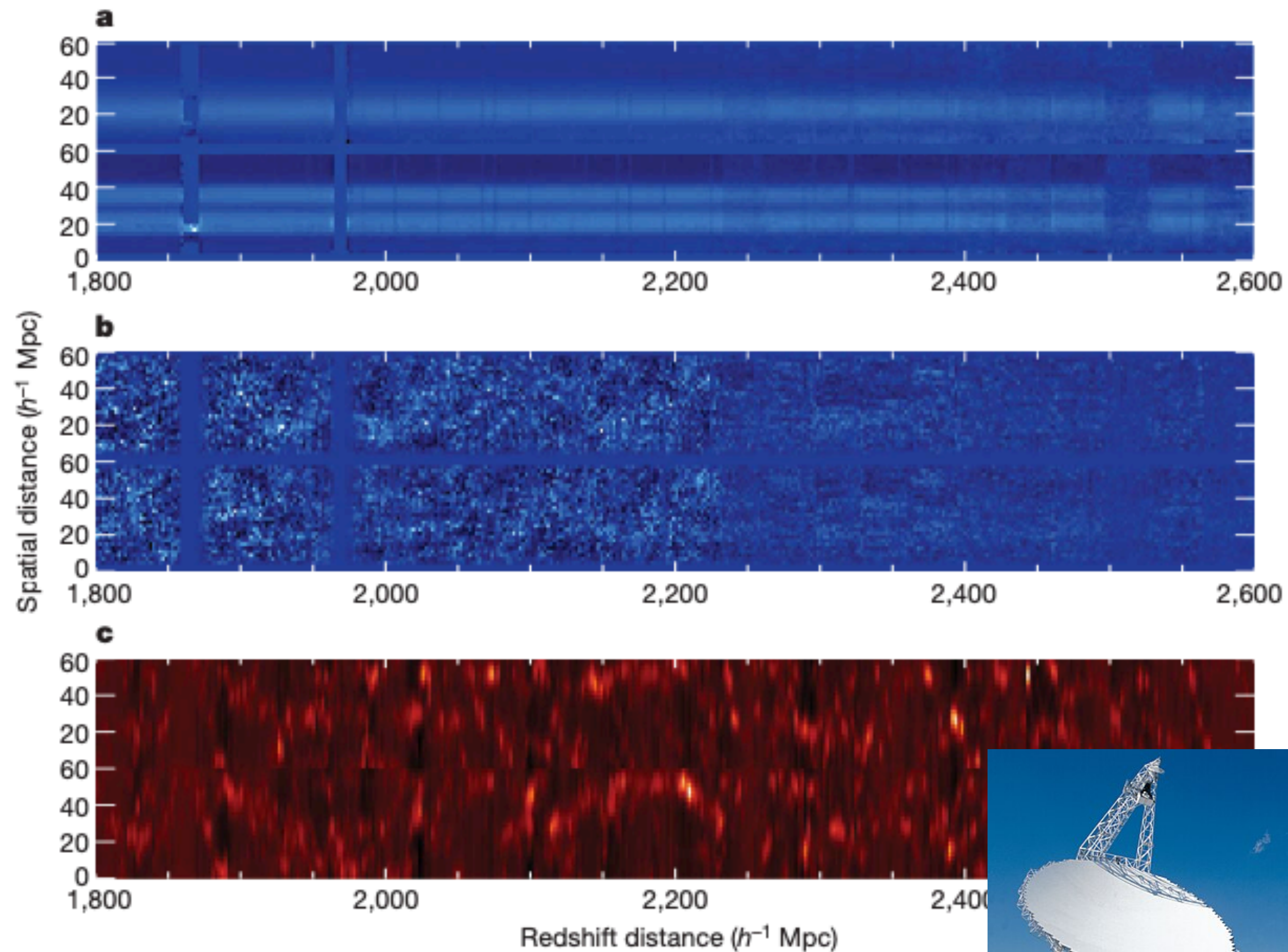
Bernal & Kovetz 2022



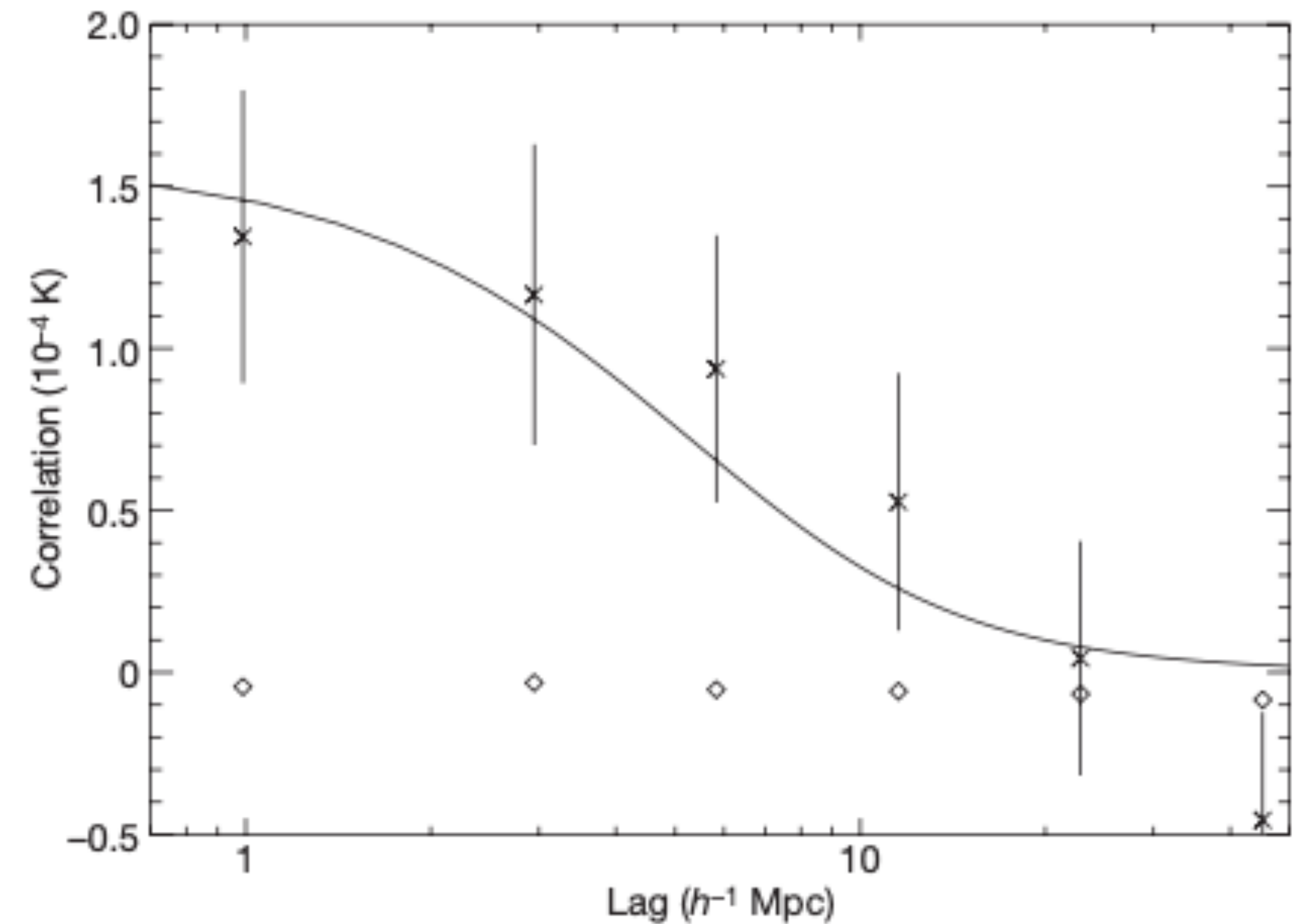
Higher redshifts and wider areas in the future

→ Complementary to conventional galaxy surveys

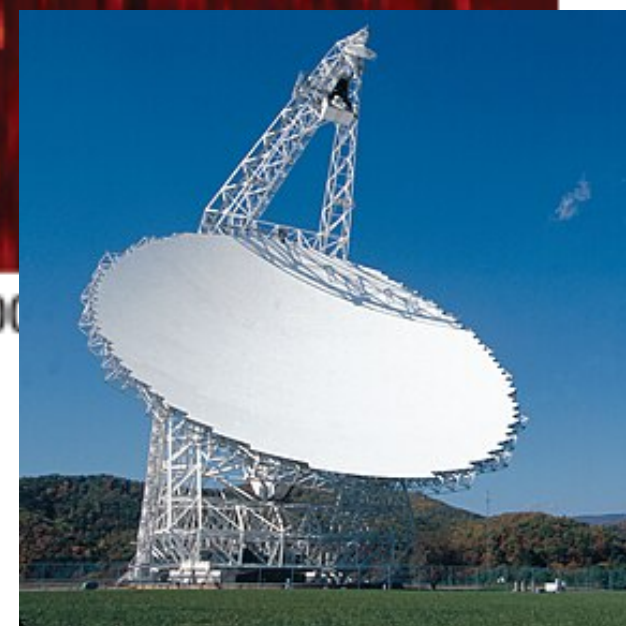
Detections of Low- z Cross-Correlation Signals



Cross-correlation function between galaxies and 21 cm map at $z = 0.8$ (Chang+2010)

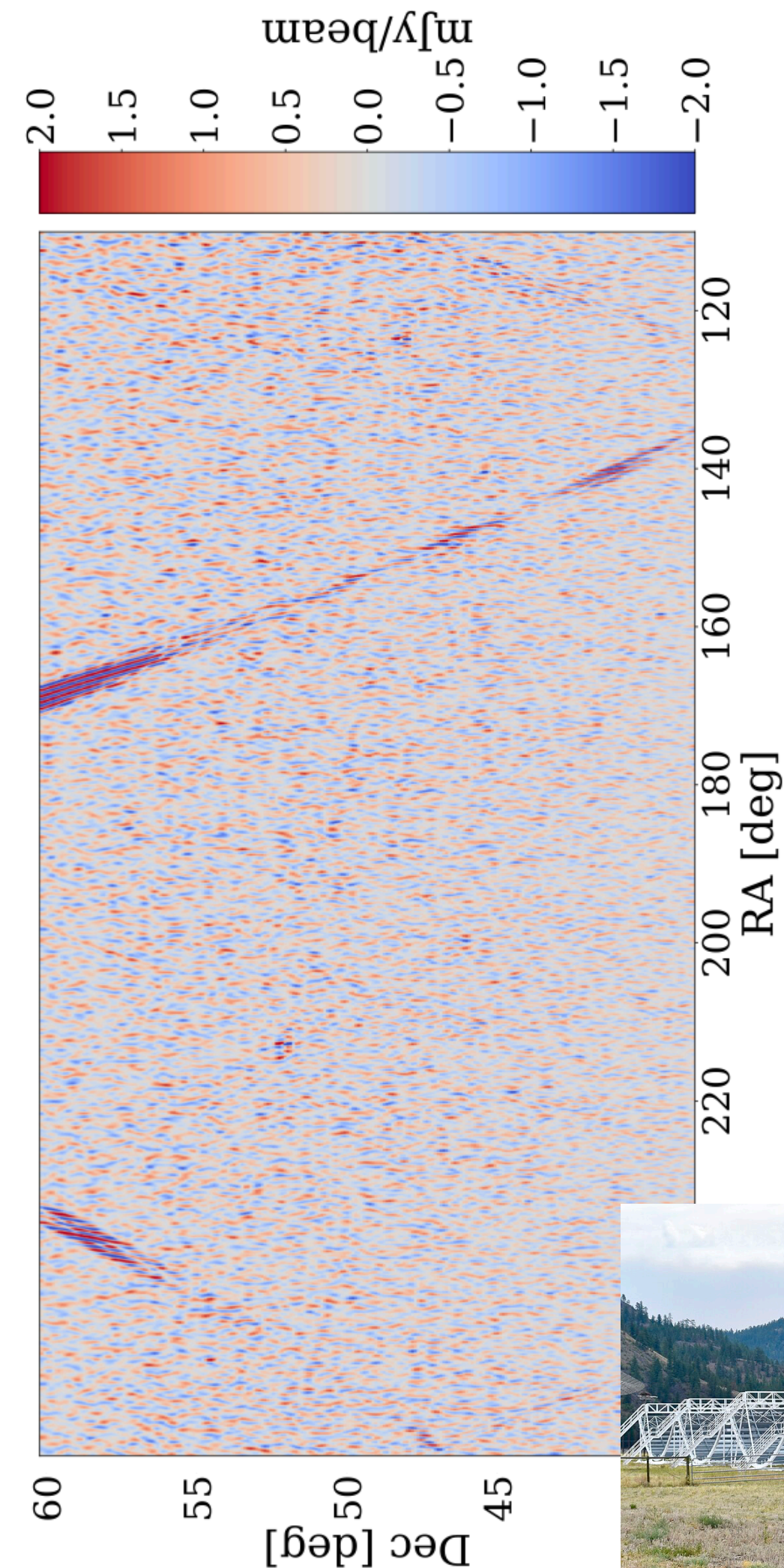


↑ First detection of LIM signals!

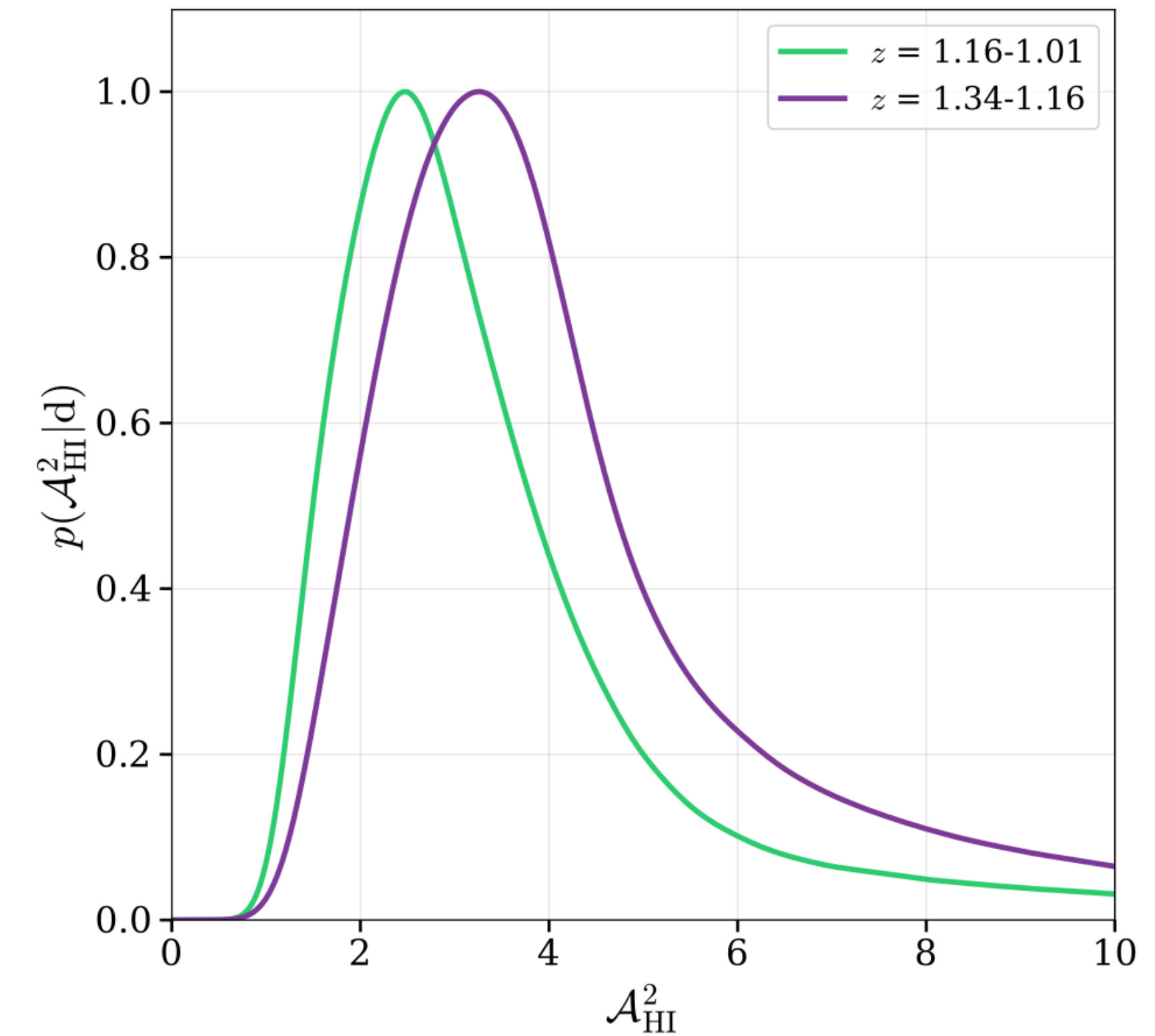
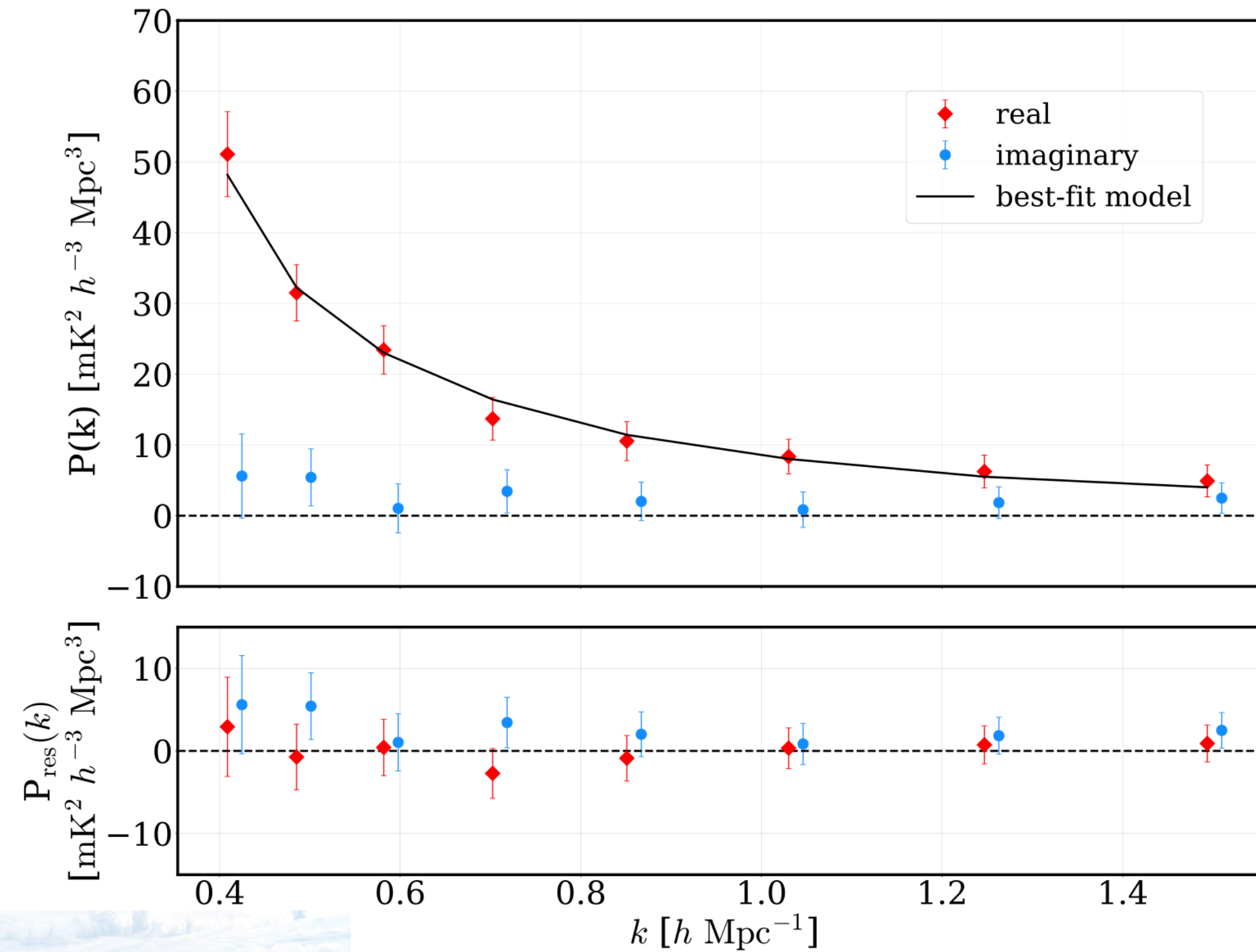


Green Bank Telescope

Recent LIM Measurements: CHIME



21cm auto-power spectrum at $z \sim 1$



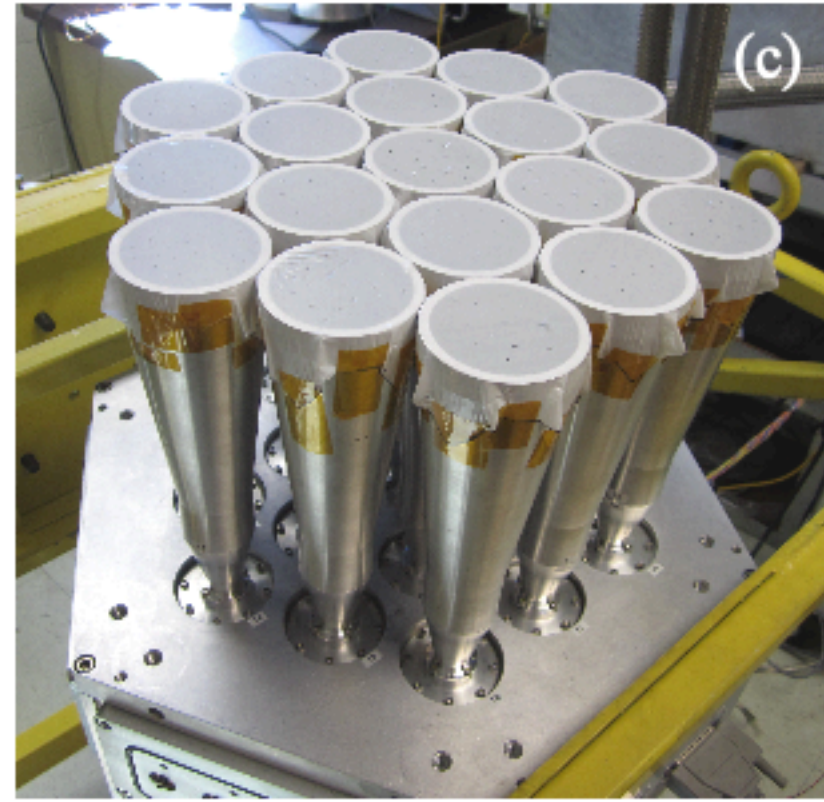
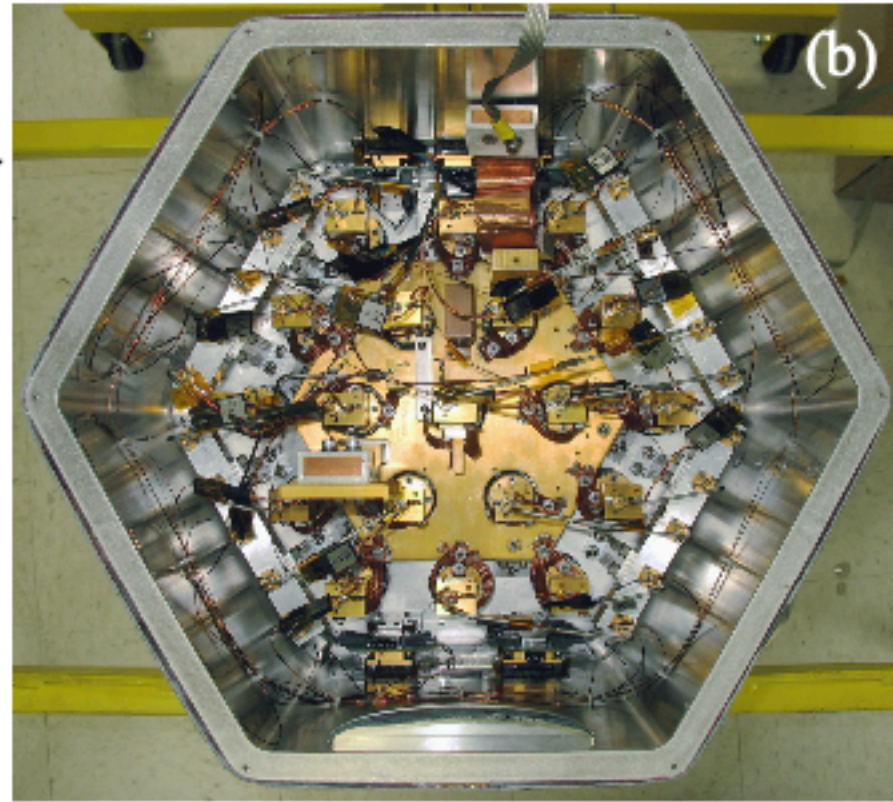
$$\mathcal{A}_{\text{HI}}^2 \equiv 10^6 \Omega_{\text{HI}}^2 (b_{\text{HI}} + \langle f\mu^2 \rangle)^2$$

Constrain power spectrum amplitude

Canadian Hydrogen Intensity
Mapping Experiment (CHIME)

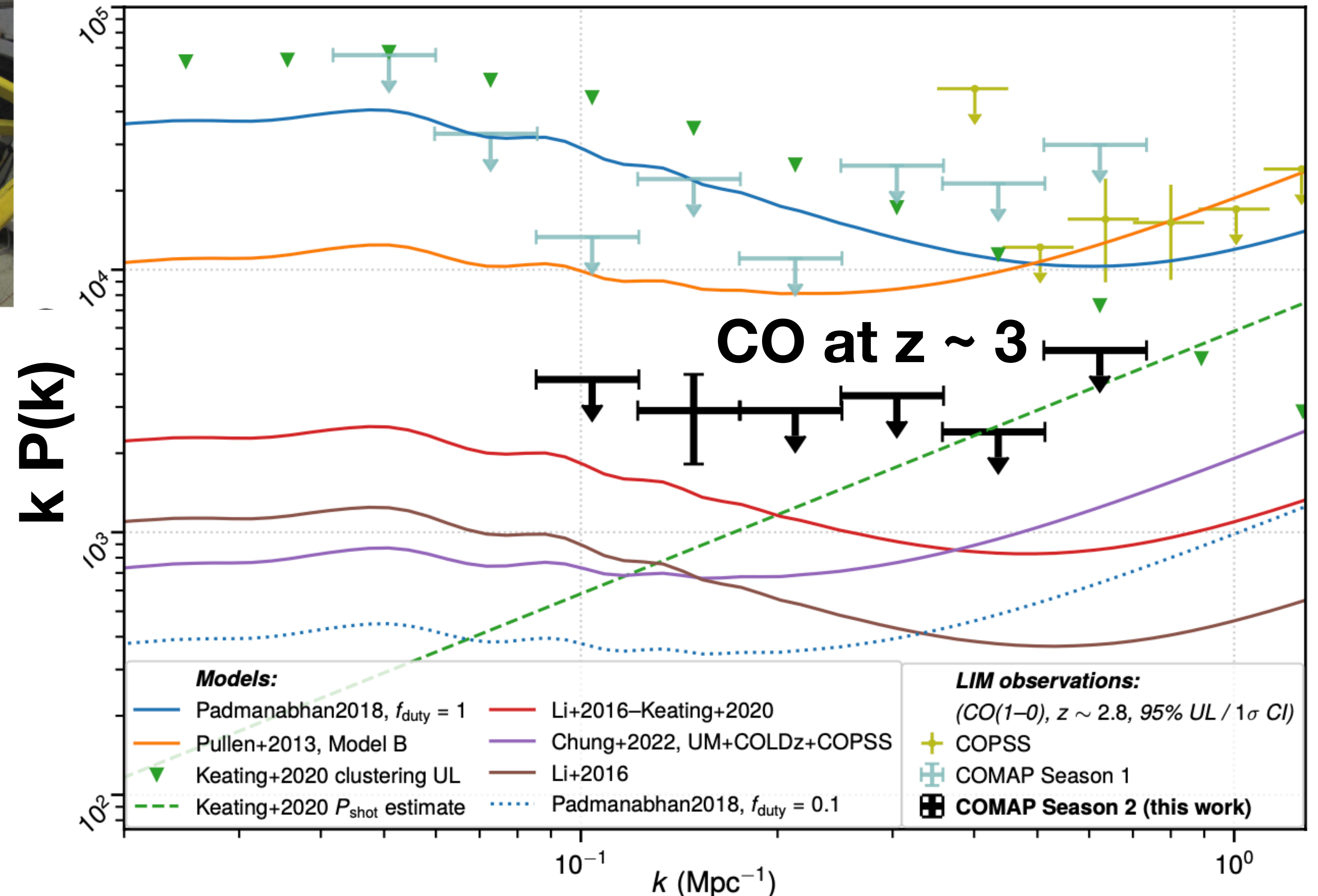
Recent LIM Measurements: COMAP

Cleary+2021



Chung+2024

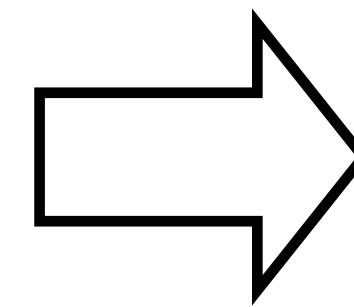
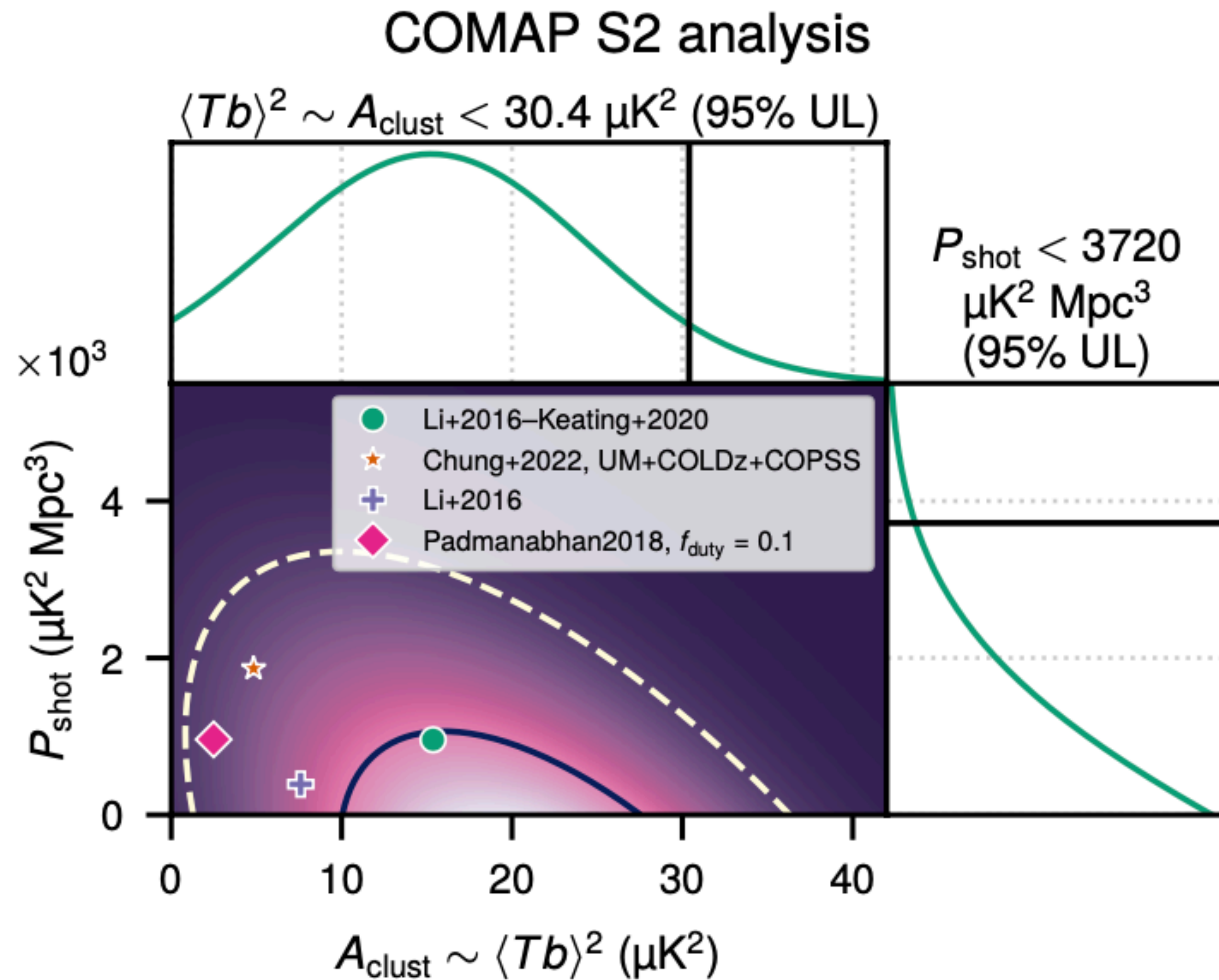
Upper limits at $k \sim 0.1-1$



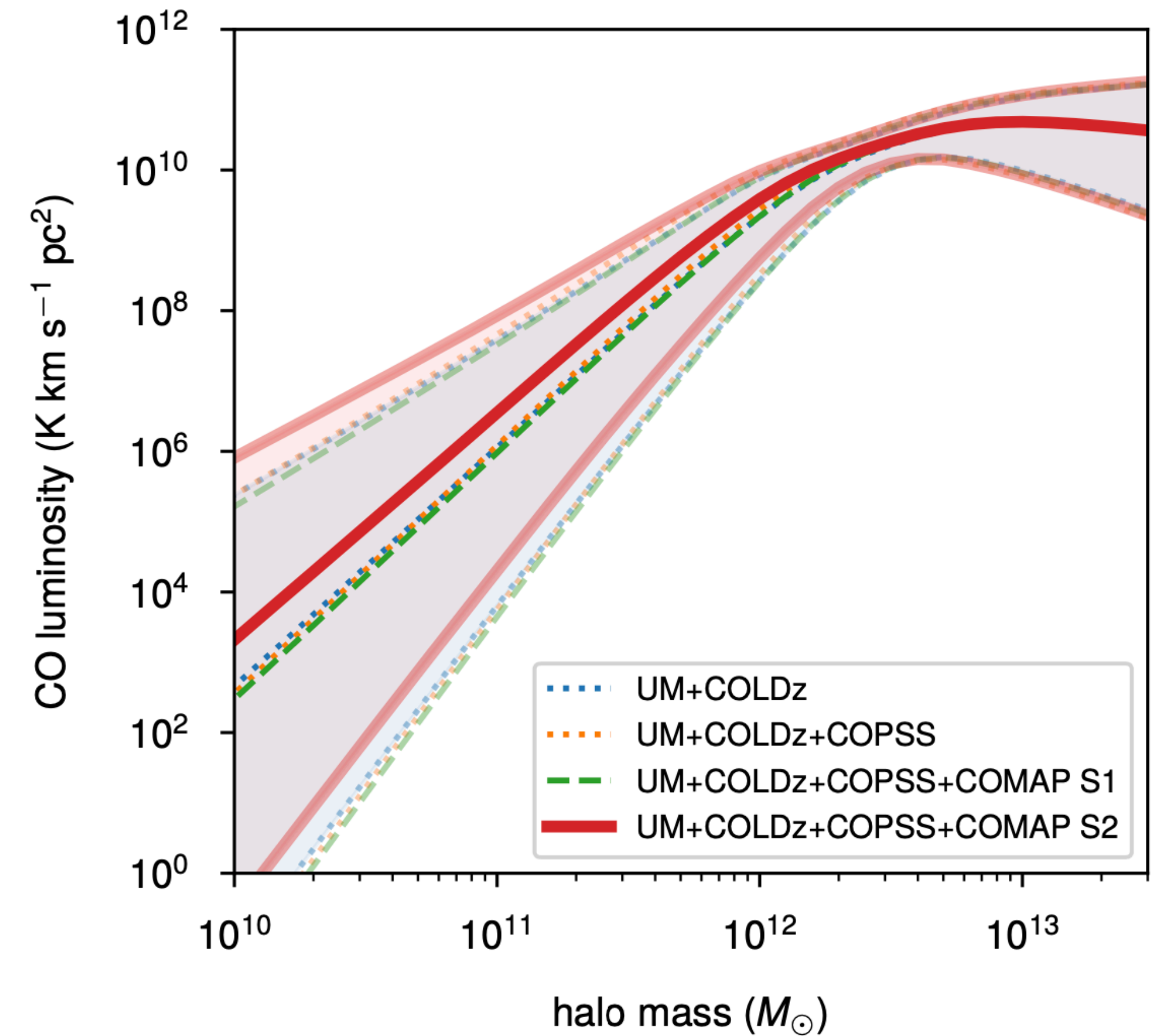
Recent LIM Measurements: COMAP

Chung+2024

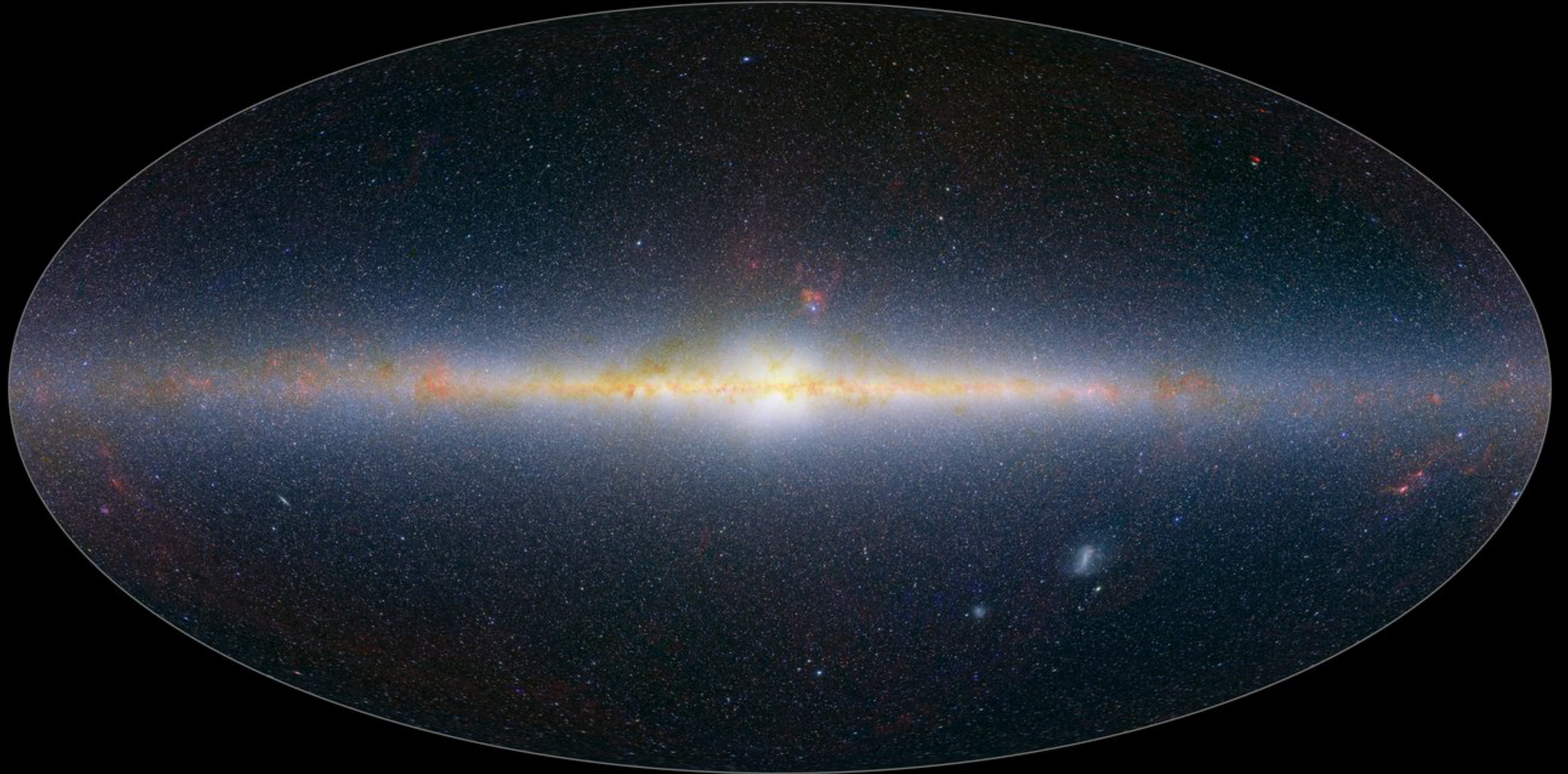
MCMC fitting



Estimate $M_{\text{halo}}\text{-}L_{\text{CO}}$ relation

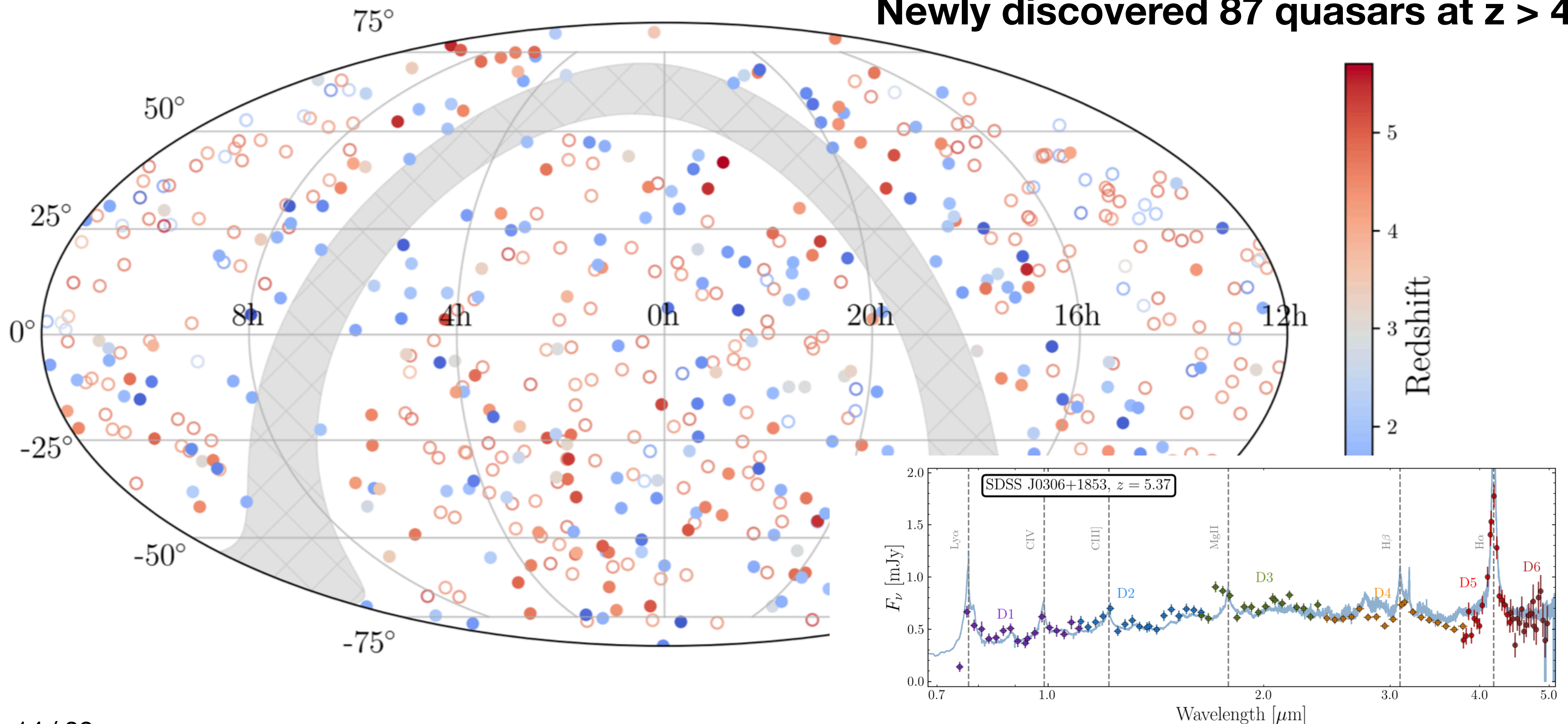


Recent LIM Measurements: SPHEREx



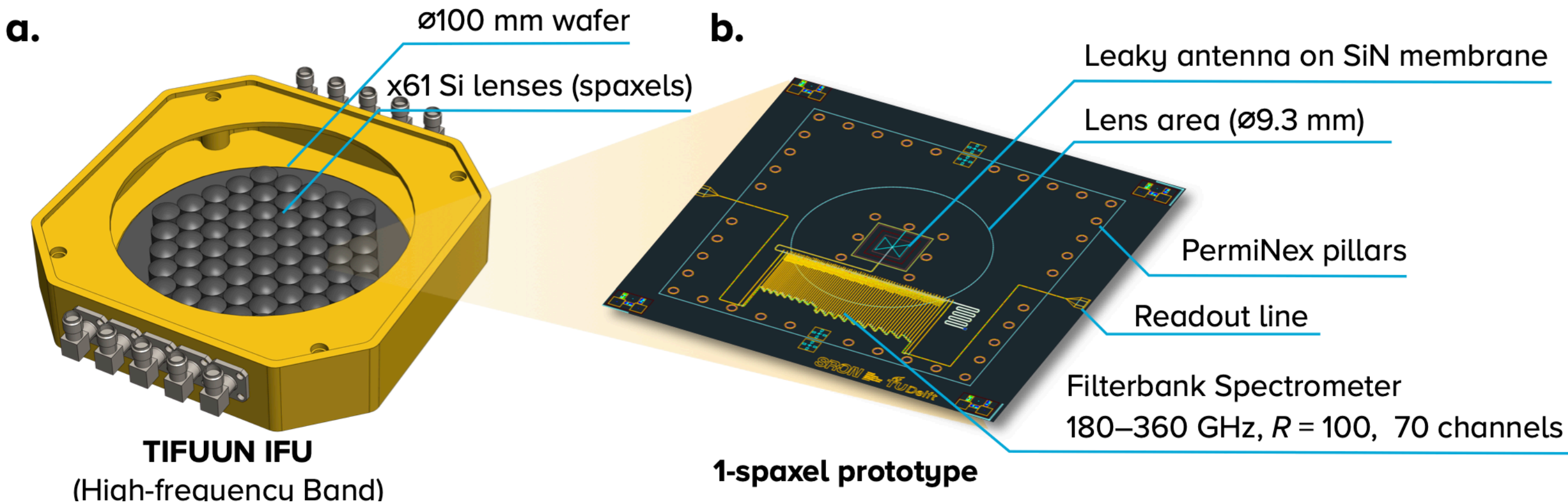
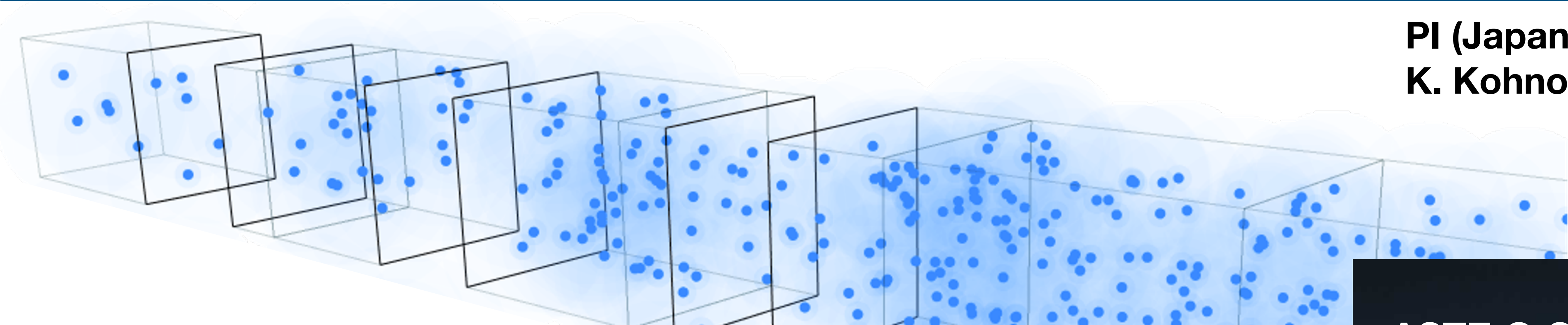
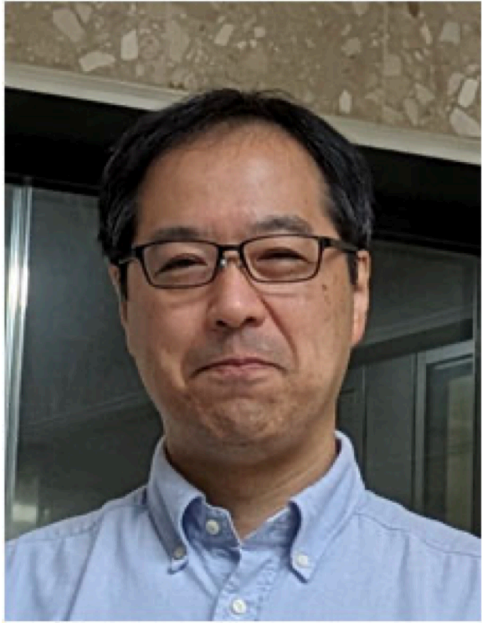
Recent LIM Measurements: SPHEREx

Newly discovered 87 quasars at $z > 4$

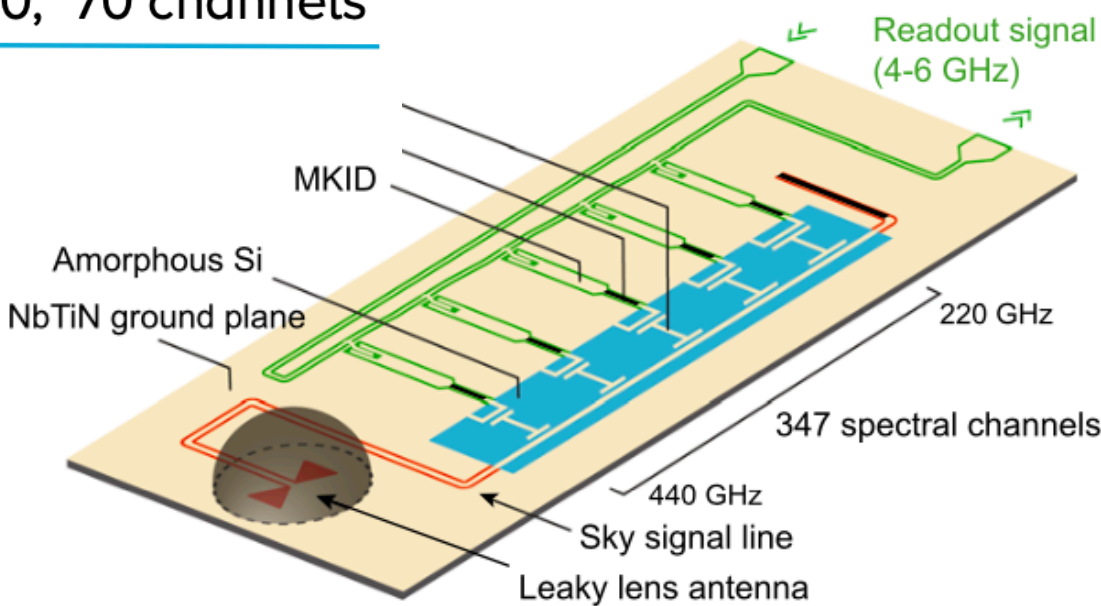


Our project: **SUBLIME-TIFUUN**

PI (Japan side):
K. Kohno



**THz Integral Field Units with
Universal Nanotechnology (TIFUUN)**
Endo et al. 2026 (arXiv: arXiv:2606.21543)

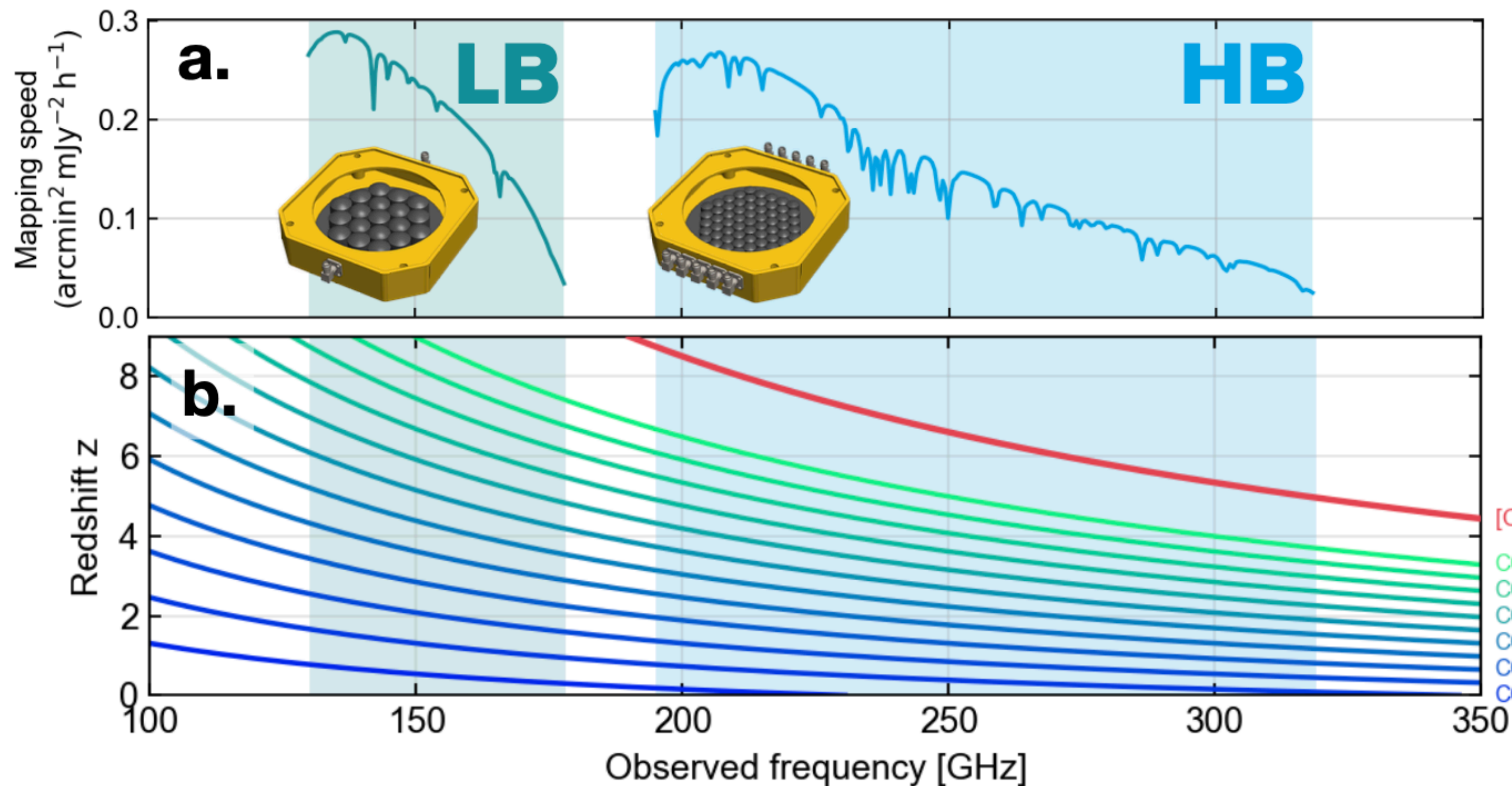


Credit: NAOJ

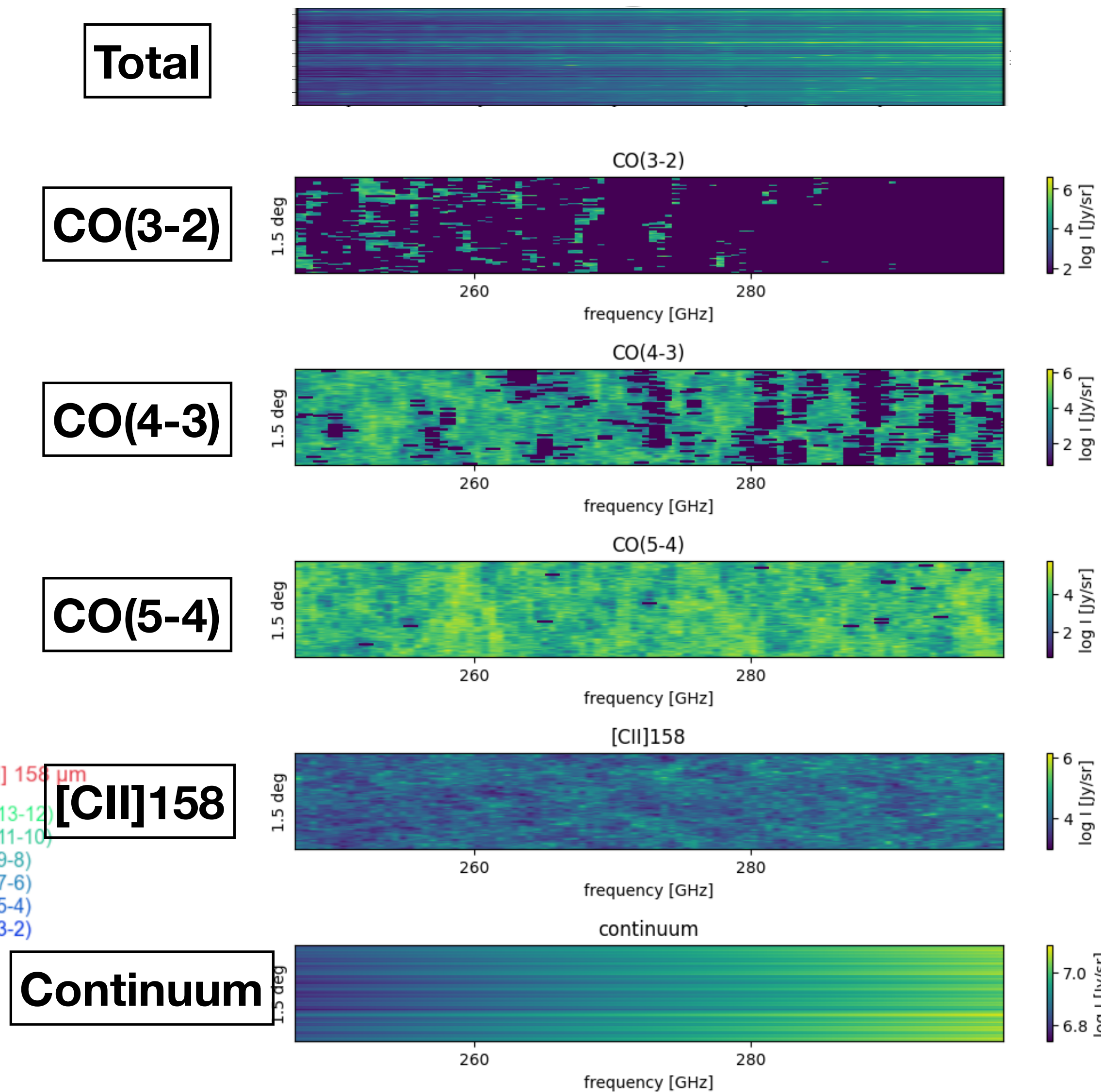
Cf. **DESHIMA 2.0** → Taniguchi-san's talk

Our project: SUBLIME-TIFUUN

SUBLIME-TIFUUN spec:
R ~ 500 at 130-319 GHz targeting at
CO at z = 2-4 and [CII] at z ~ 6

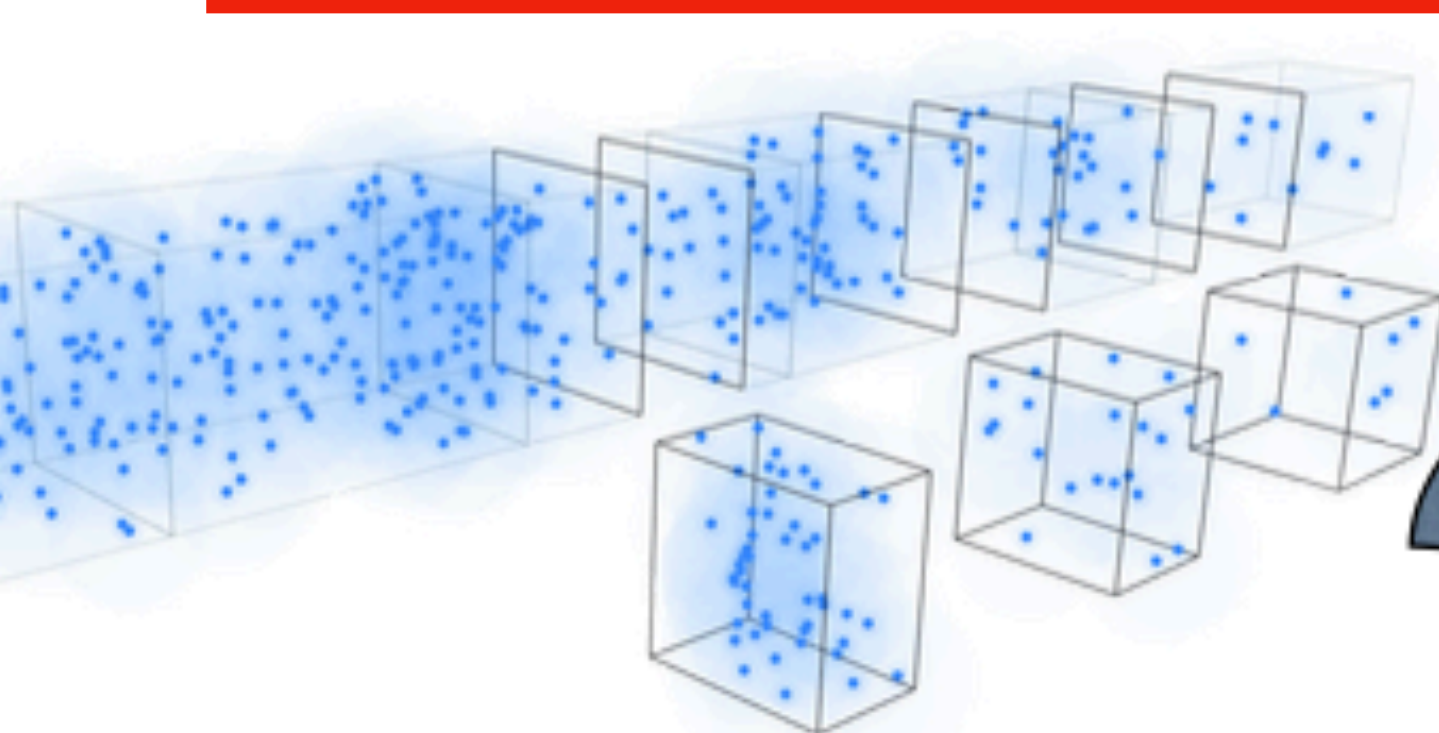


Endo et al. 2026



Our project: SUBLIME-TIFUUN

Cosmological simulations



大規模数値シミュレーションに基づく
輝線強度マッピング信号の予測
重元素からのスペクトル線予測



Data Science

その検出に適したサブミリ波
分光撮像装置の仕様提案と
観測計画策定



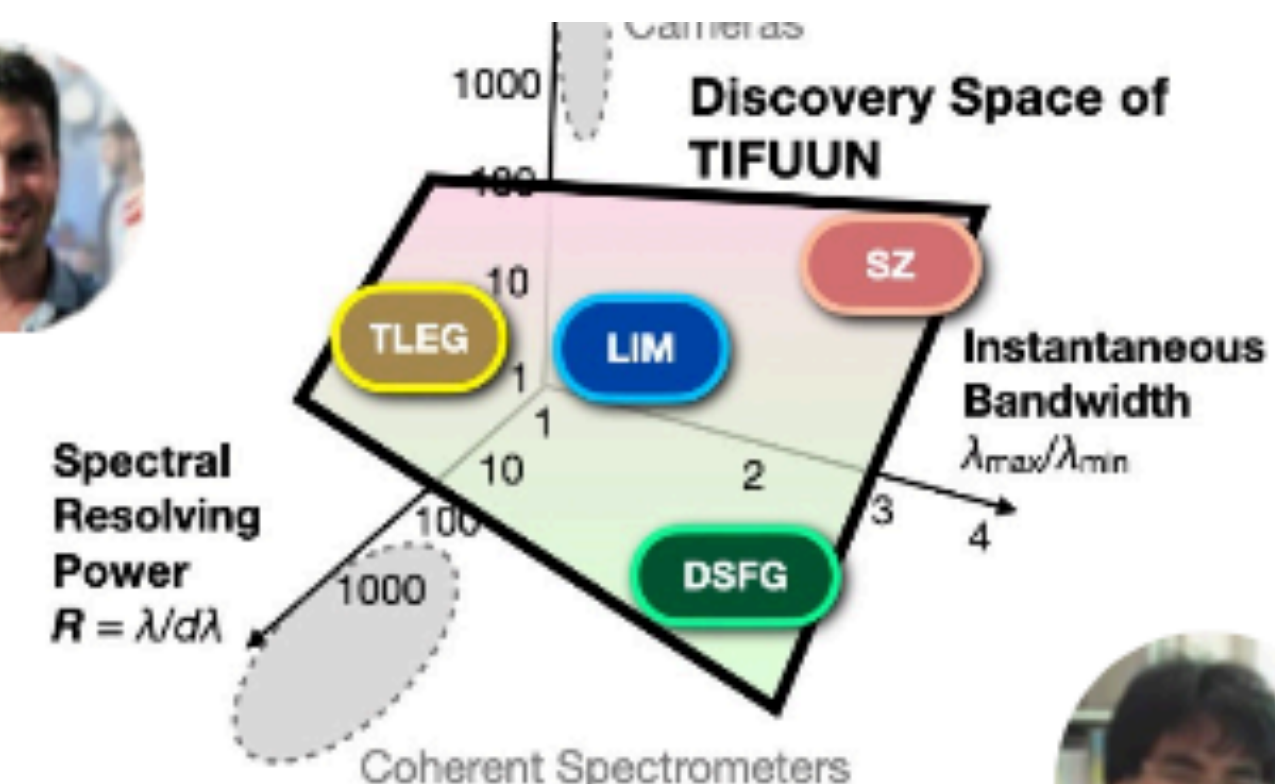
適切な周波数範囲は？周波数分解能は？
望ましい観測領域の広さは？

宇宙における最初の20億年
重元素集積史の解明

効果的な天体信号と大気雑音の分離手法は？
コンタミ信号の分離手法は？

観測装置の性能を最大限に引き出し
輝線強度マッピング信号を抽出する
データ科学的観測・解析手法の開発

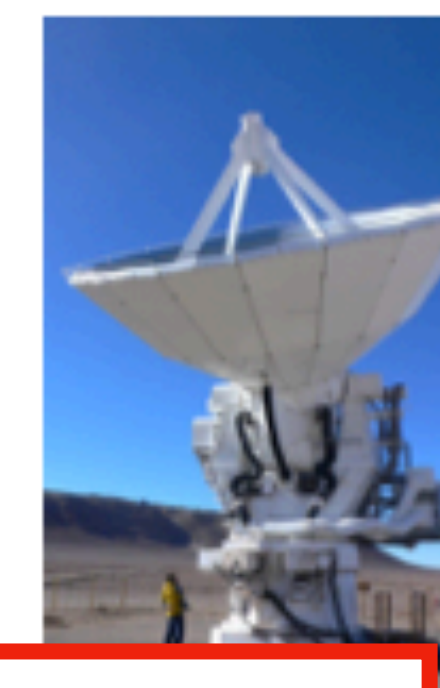
Observational astronomy



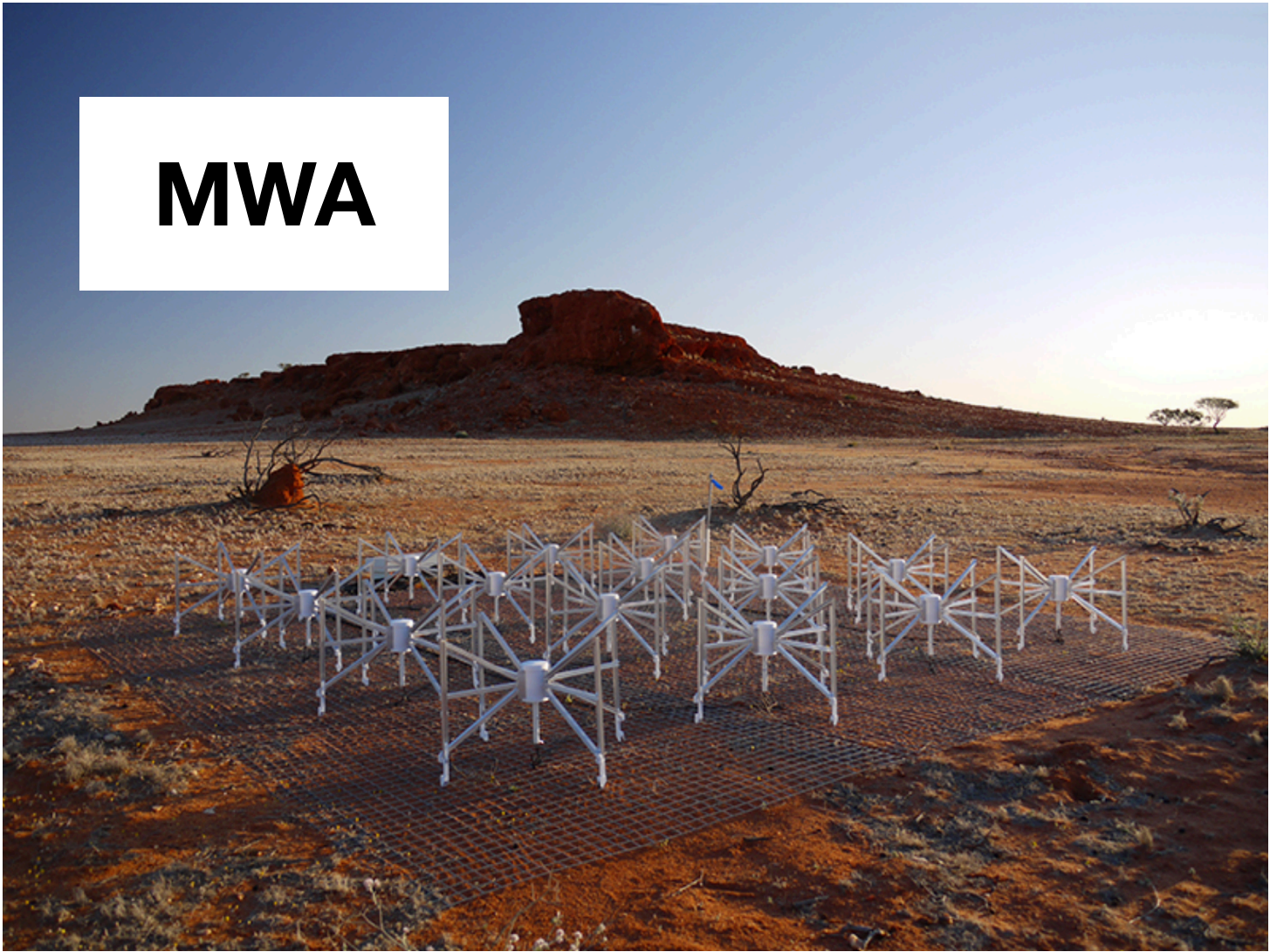
必要な仕様の分光撮像性能を実現する
集積超伝導分光撮像装置の開発と評価
サブミリ波望遠鏡との結合（光学系）



Superconducting nanoelectronics

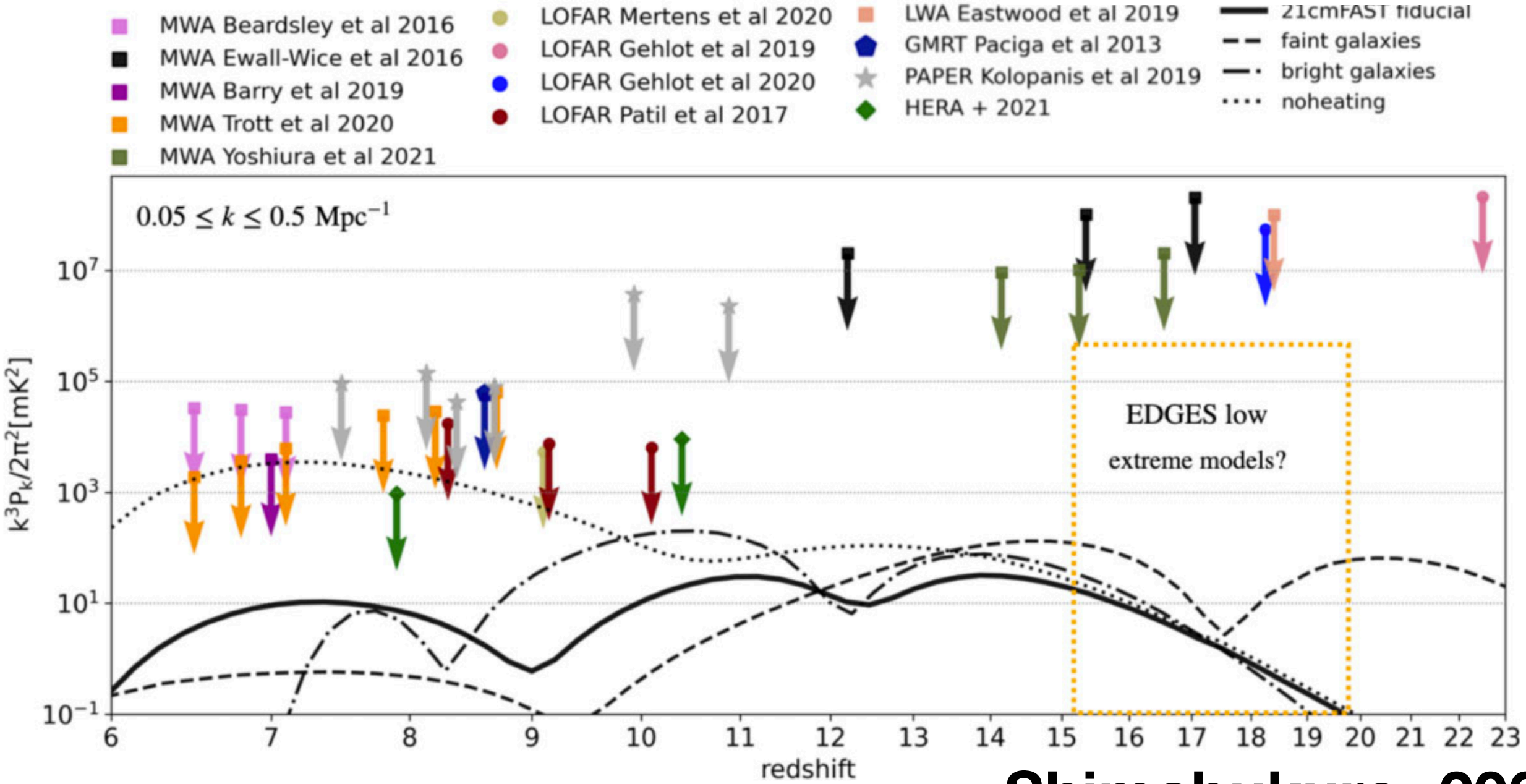
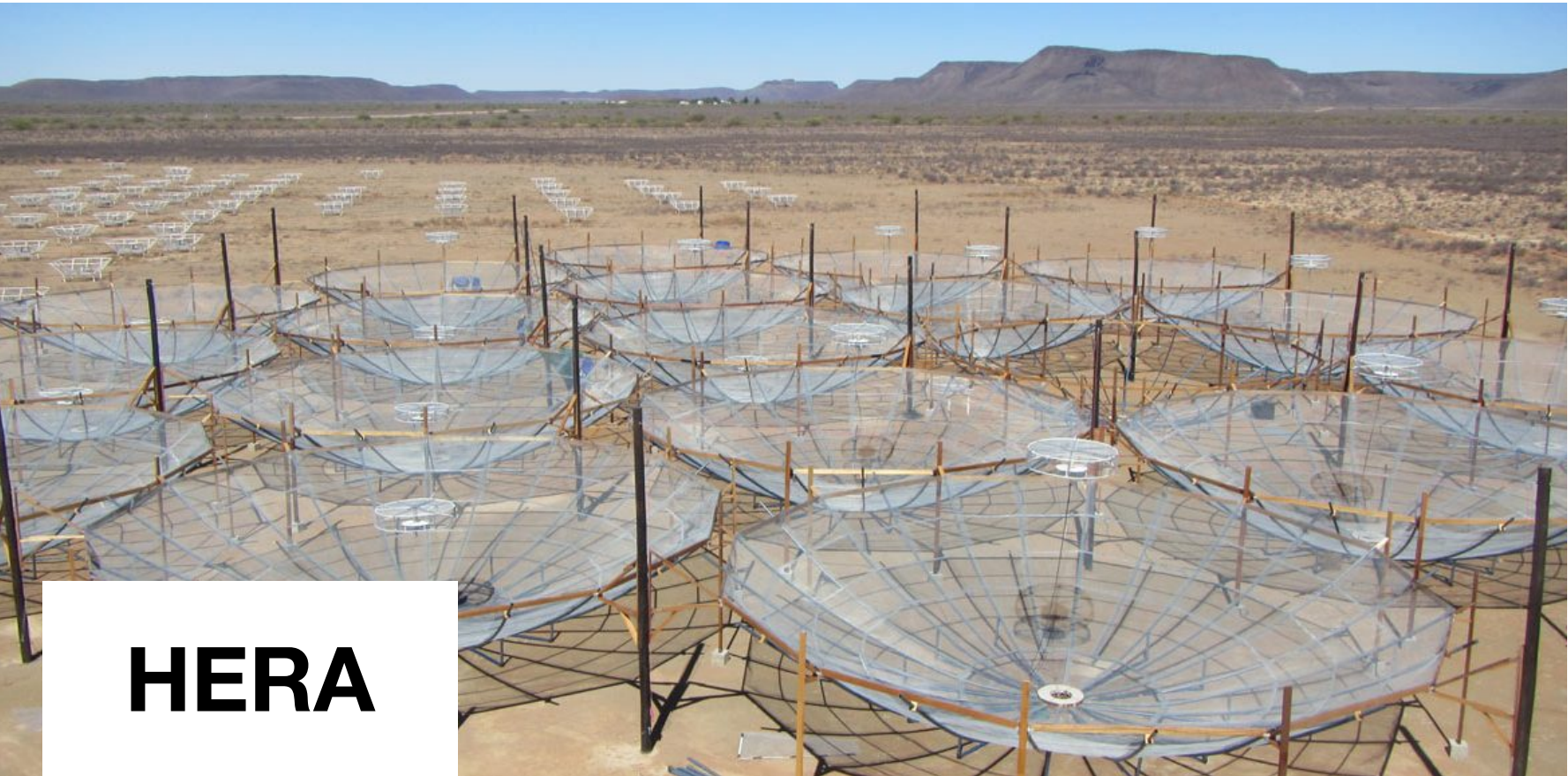
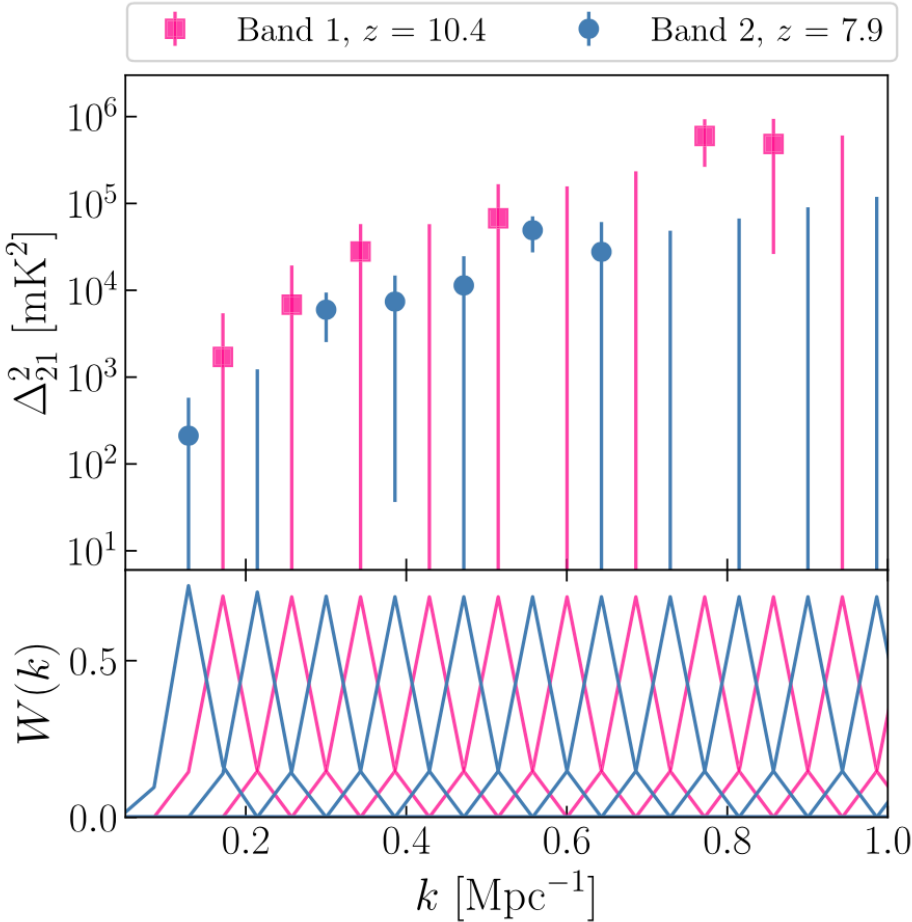


21-cm Observation: Power Spectrum



HERA (Abdurashidova+2023) →

Upper limits so far ↓

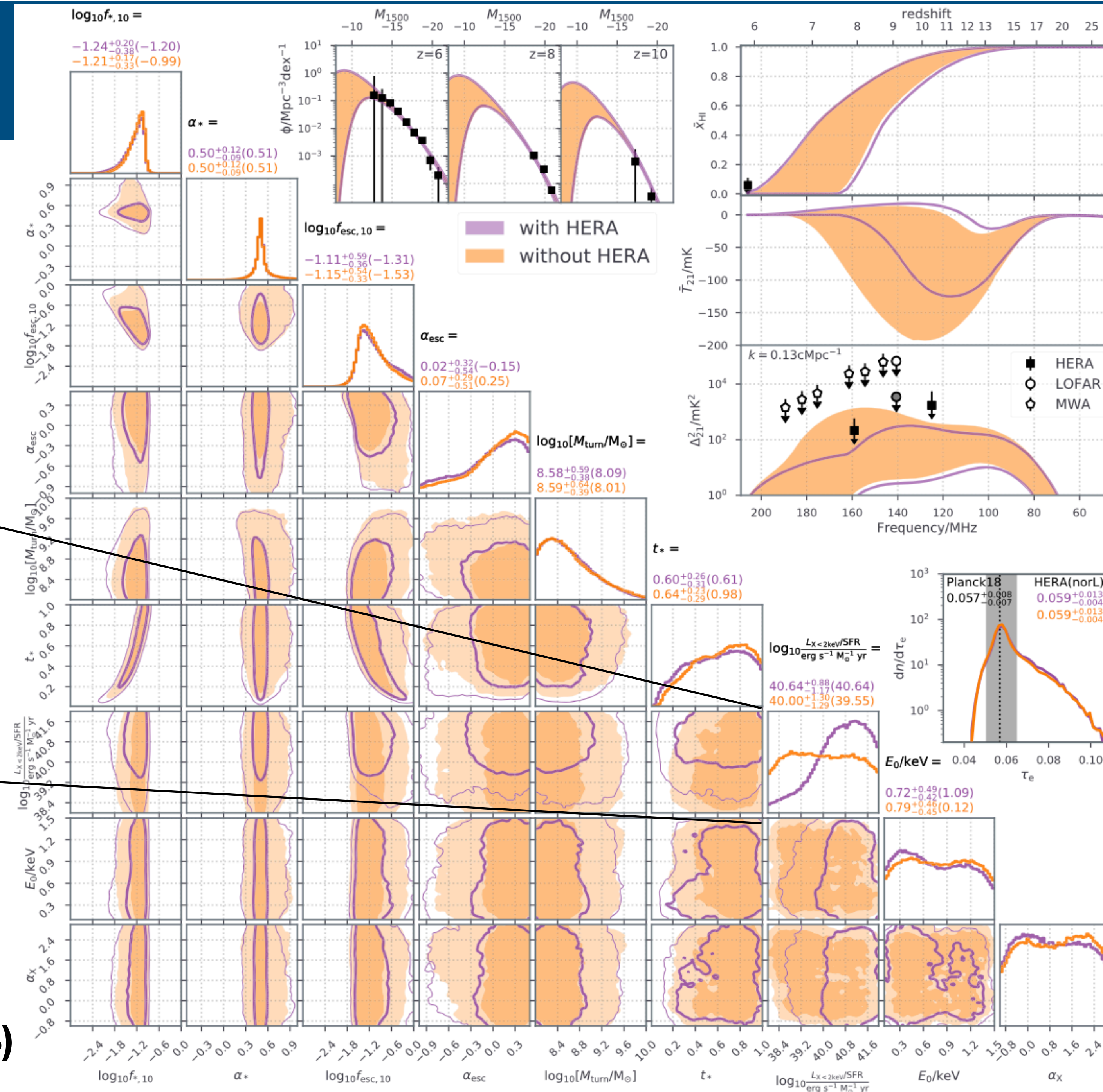
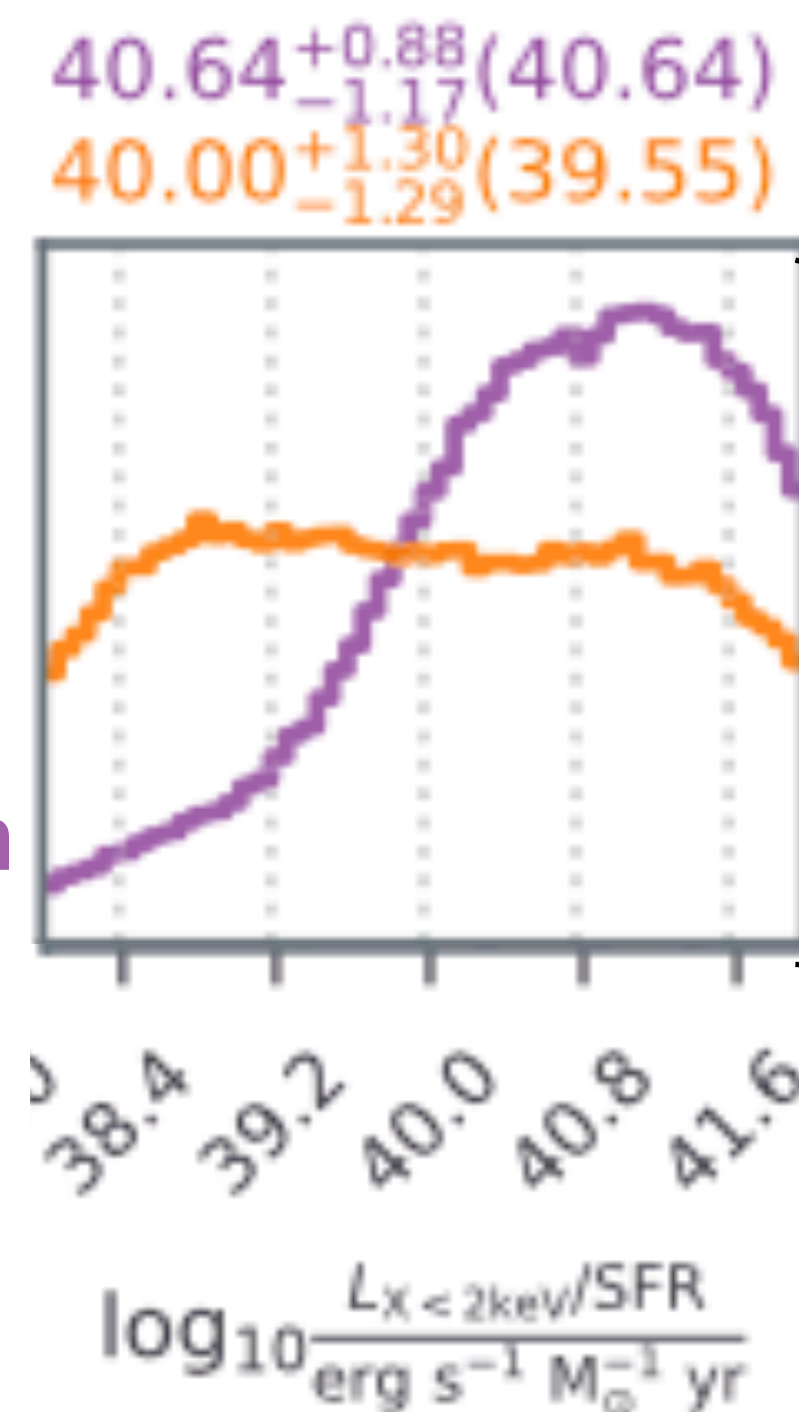


Shimabukuro+2022

HERA Results

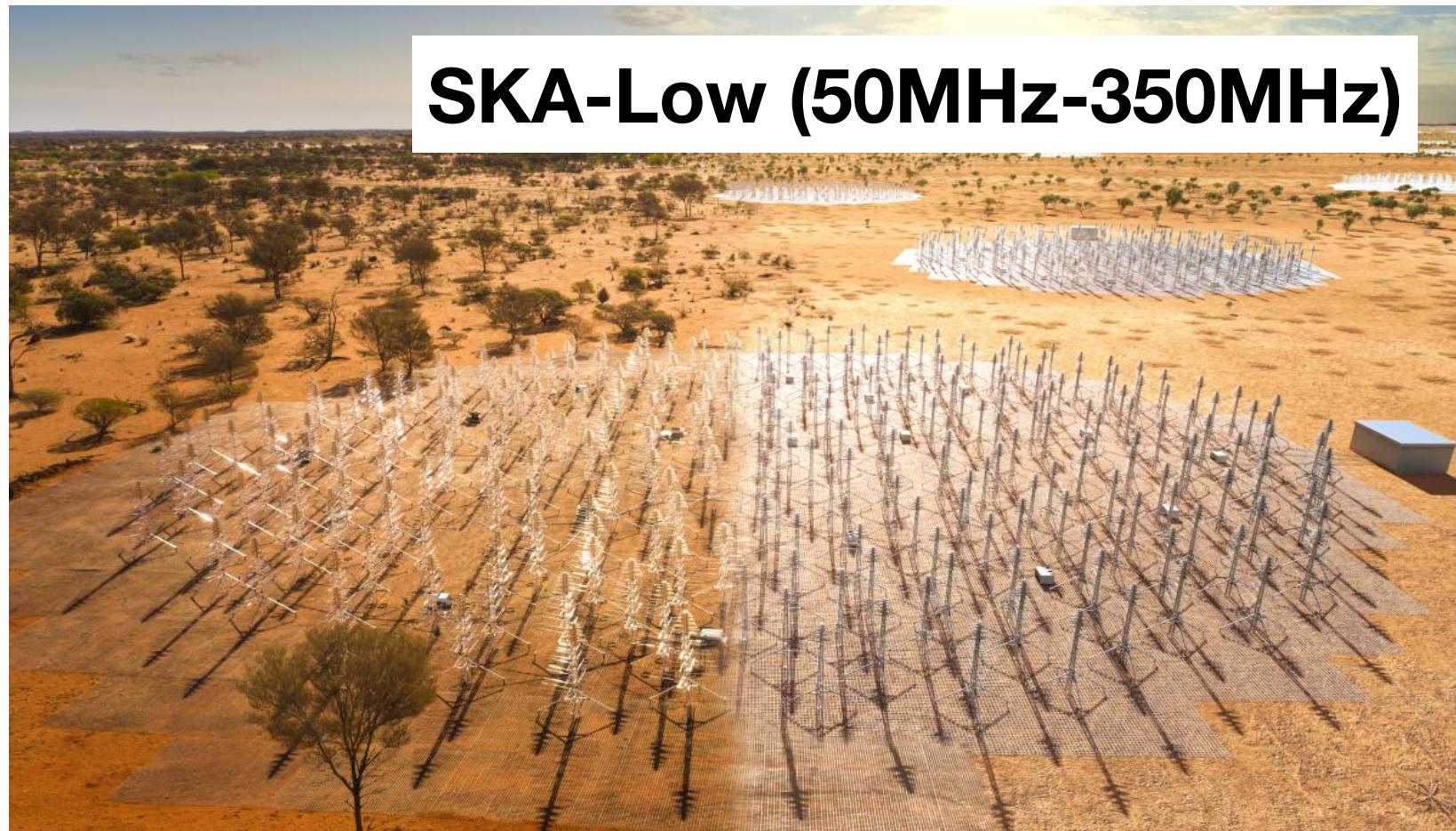
Constraints on parameters like star-formation efficiency, X-ray emissivity

LF + CMB
+ 21cm

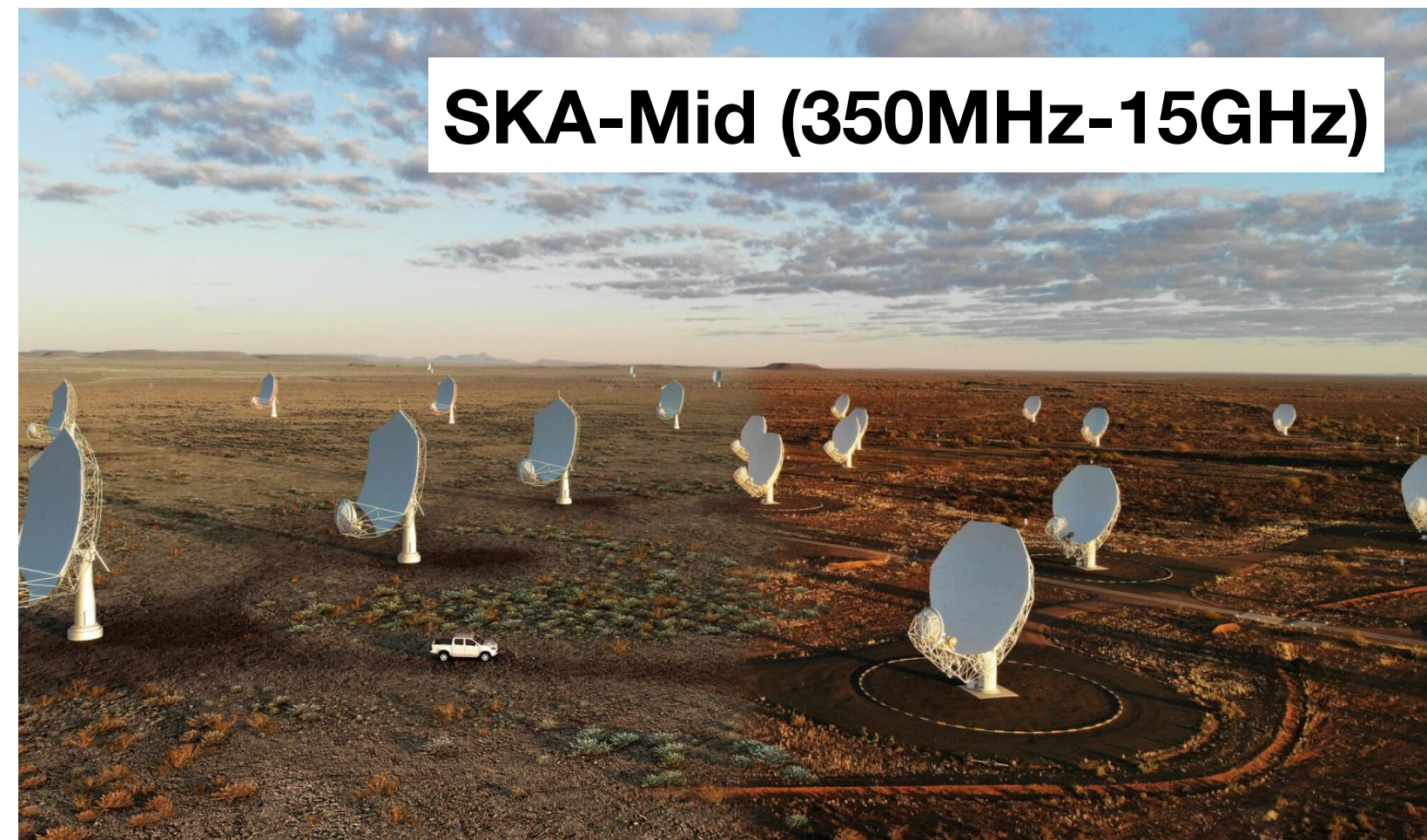


Square Kilometre Array (SKA)

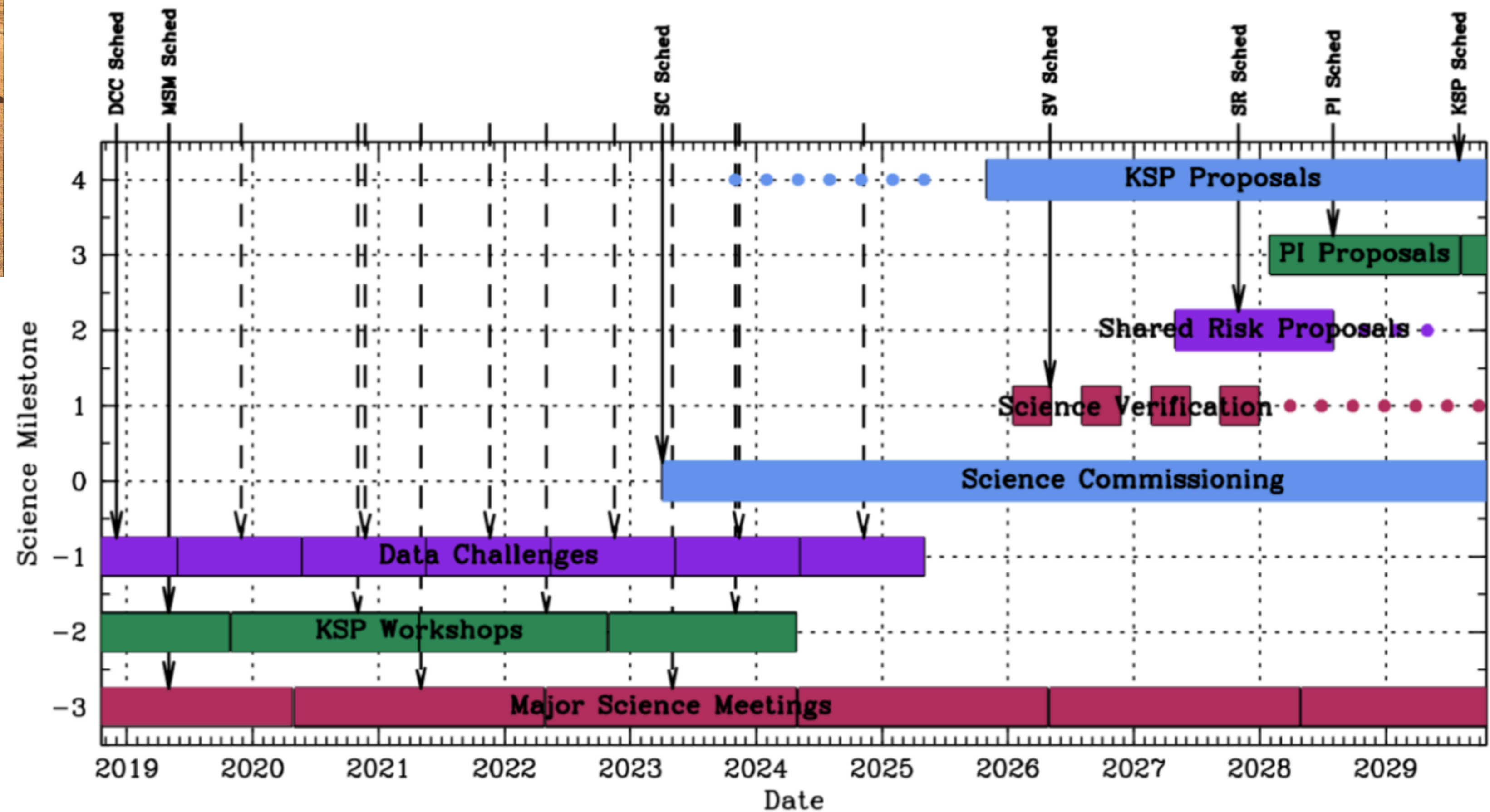
SKA-Low (50MHz-350MHz)



SKA-Mid (350MHz-15GHz)



Interferometer observation with improved sensitivity!

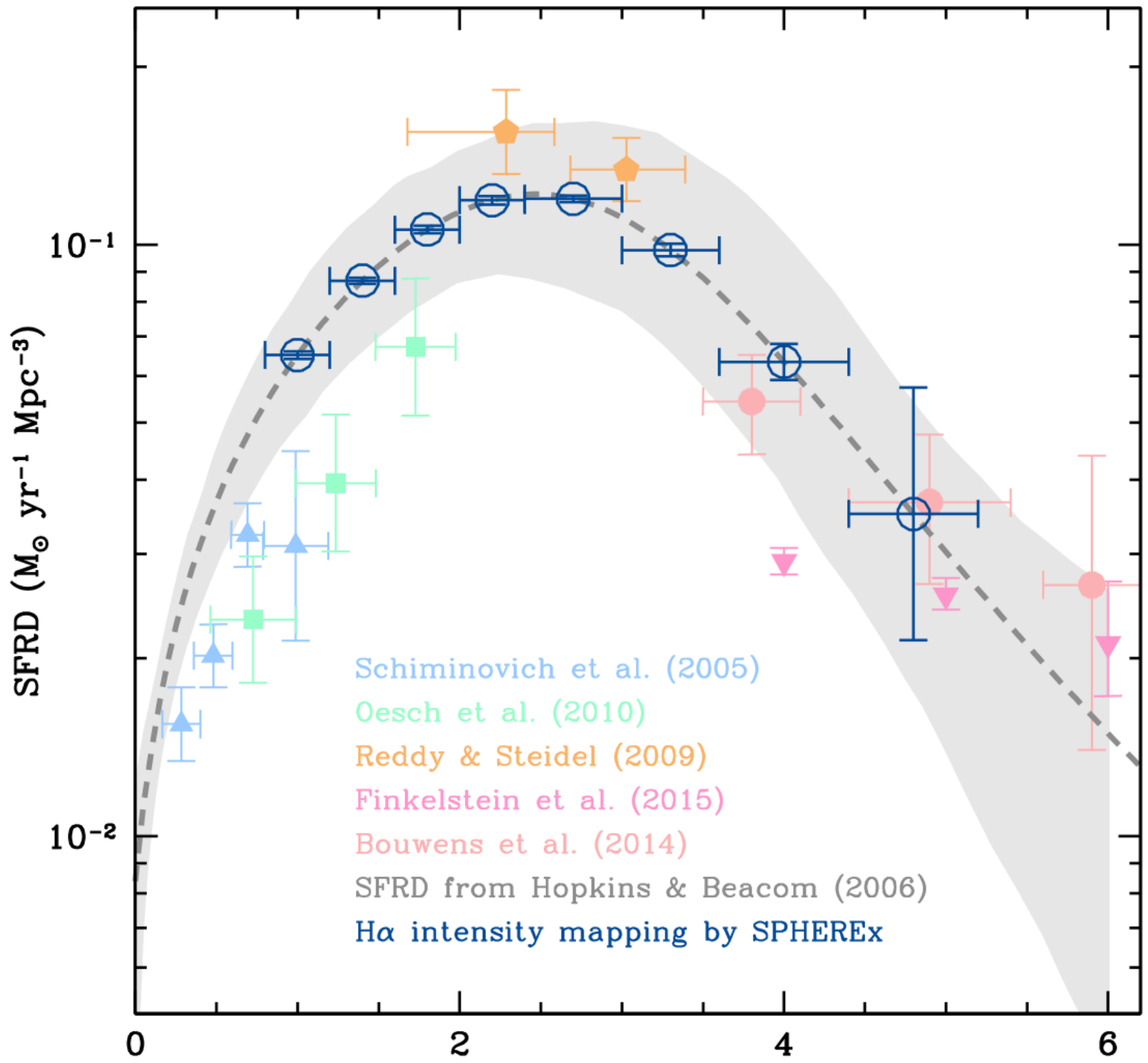


What can we learn from LIM?

Galaxy Evolution

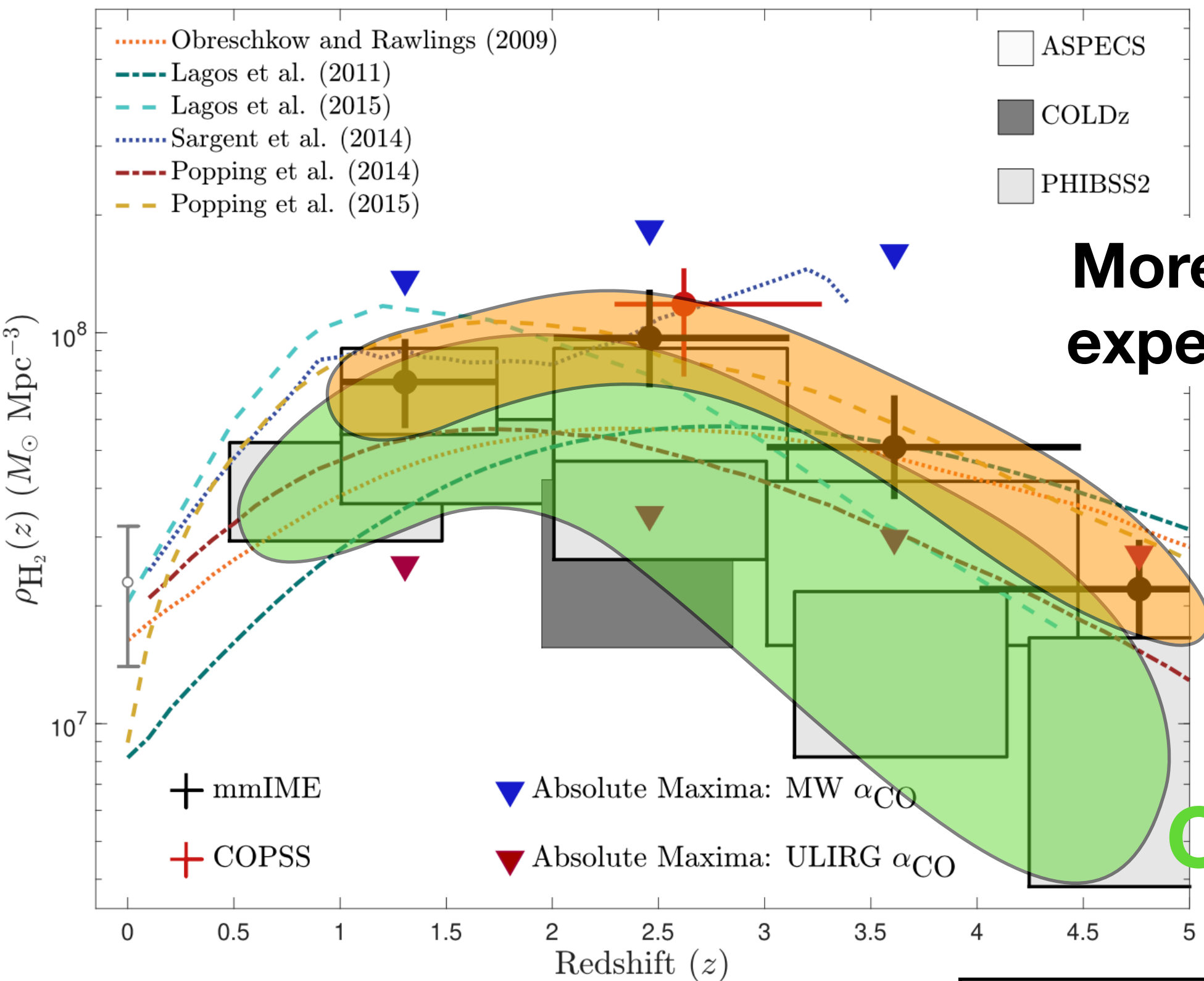
$$P_{\text{line}}^{\text{clus}}(k) = \bar{b}_{\text{line}}^2 \bar{I}_{\text{line}}^2 P_m(k) \quad P_{\text{line}}^{\text{shot}} = \frac{\bar{I}_{\text{line}}^2 \langle L^2 \rangle}{\bar{n} \langle L \rangle^2}$$

Star formation rate density



Gong+2017 (prediction)

Mean molecular hydrogen density



More molecular cloud than expected at high redshifts?

LIM?

Observations so far

Keeting+2020 (mmIME)

$$L_{\text{CO}}(M) = A_{\text{CO}} \frac{M^2}{M_0}; M \leq M_0$$

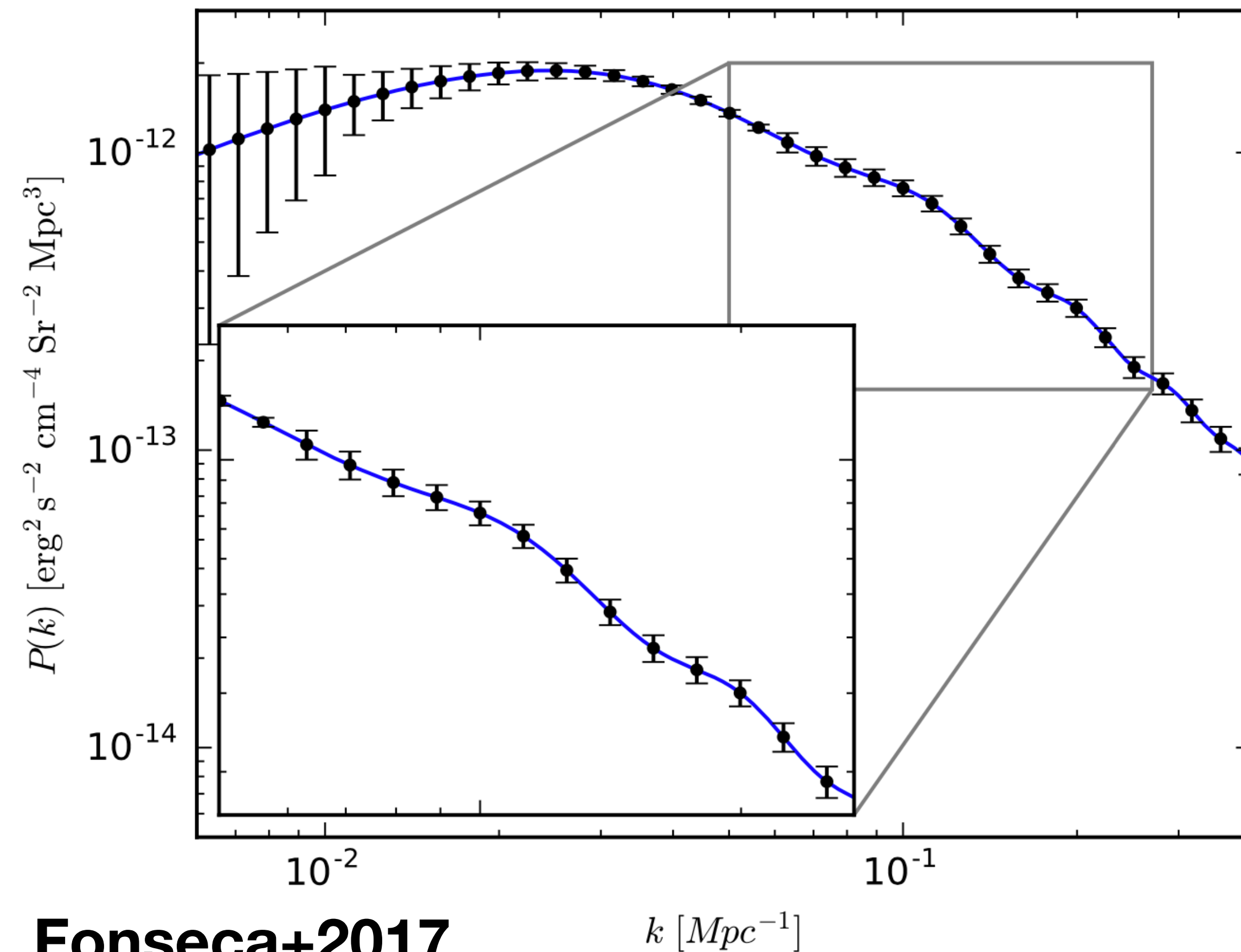
$$L_{\text{CO}}(M) = A_{\text{CO}} M_0; M \geq M_0.$$

Cosmology

Cosmological parameters

$$P_{\text{line}}^{\text{clus}}(k) = \bar{b}_{\text{line}}^2 \bar{I}_{\text{line}}^2 P_m(k)$$

$$P_{\text{line}}^{\text{shot}} = \frac{\bar{I}_{\text{line}}^2}{\bar{n}} \frac{\langle L^2 \rangle}{\langle L \rangle^2}$$



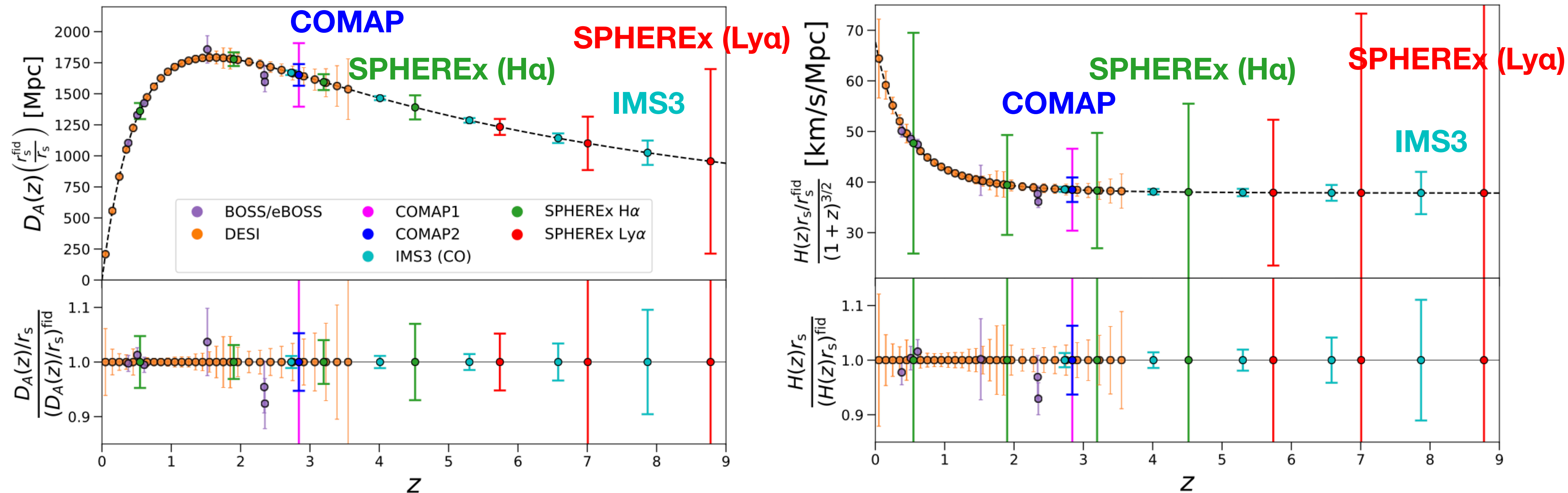
Fonseca+2017

(prediction for H α IM at $z = 1.9$ with SPHEREx)

Cosmology

LIM may be especially important in constraining high- z universe.

Predictions for ongoing/upcoming LIM observations (SPHEREx, COMAP, ISM3) (Bernal et al. 2019)



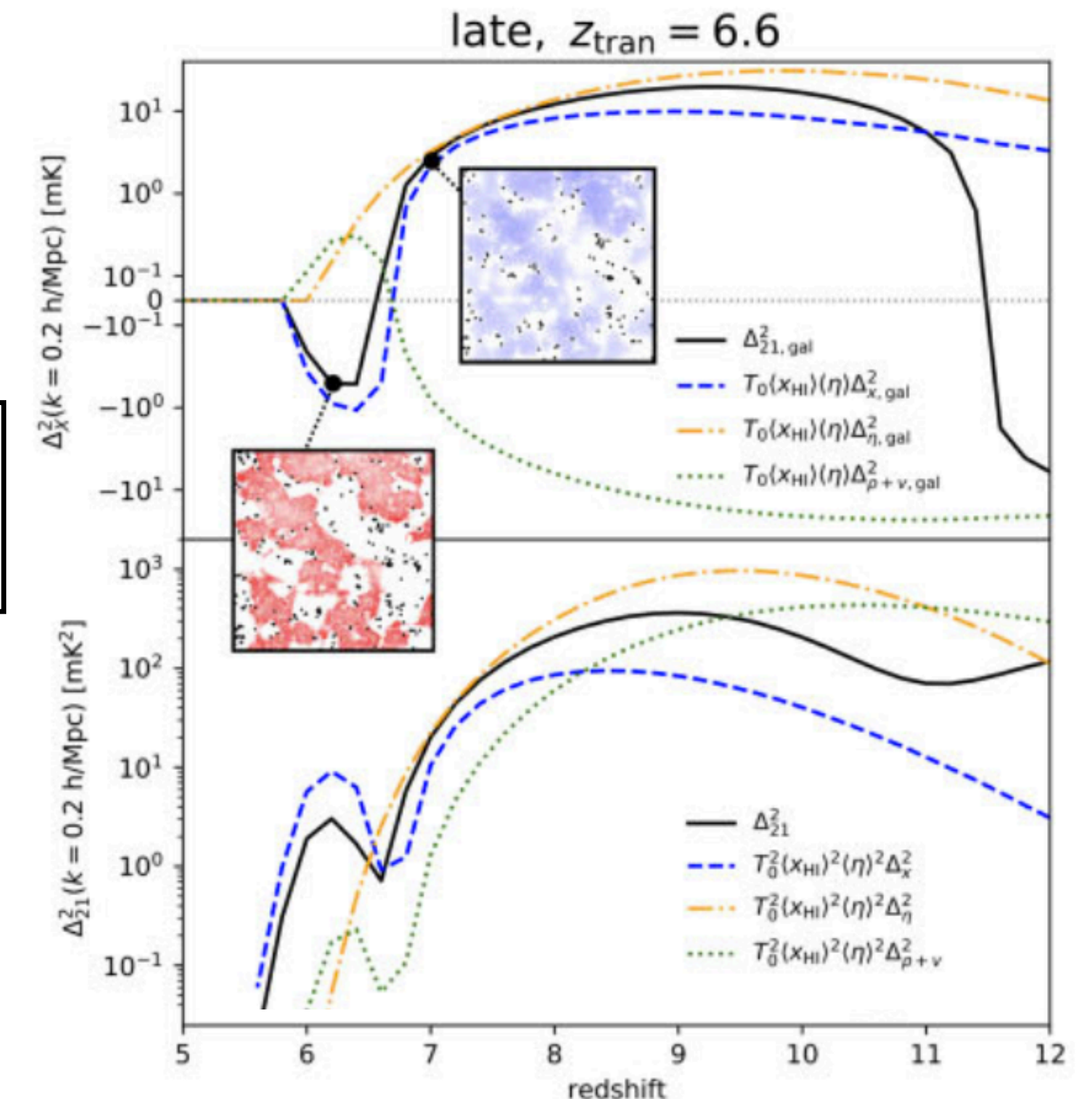
Cosmic Reionization

Cosmic Reionization

Neutral hydrogen
21cm line

Galaxy distribution
from LIM

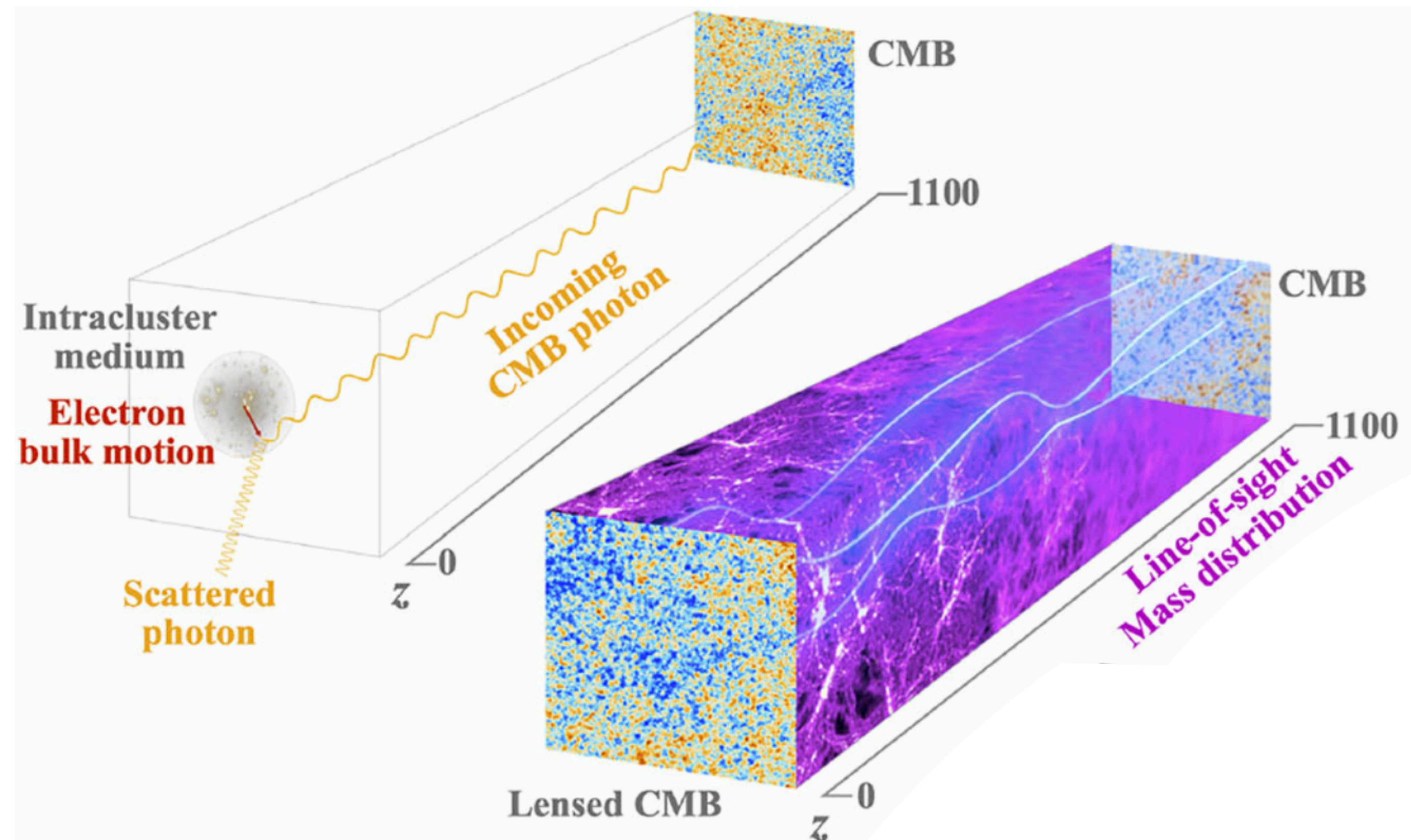
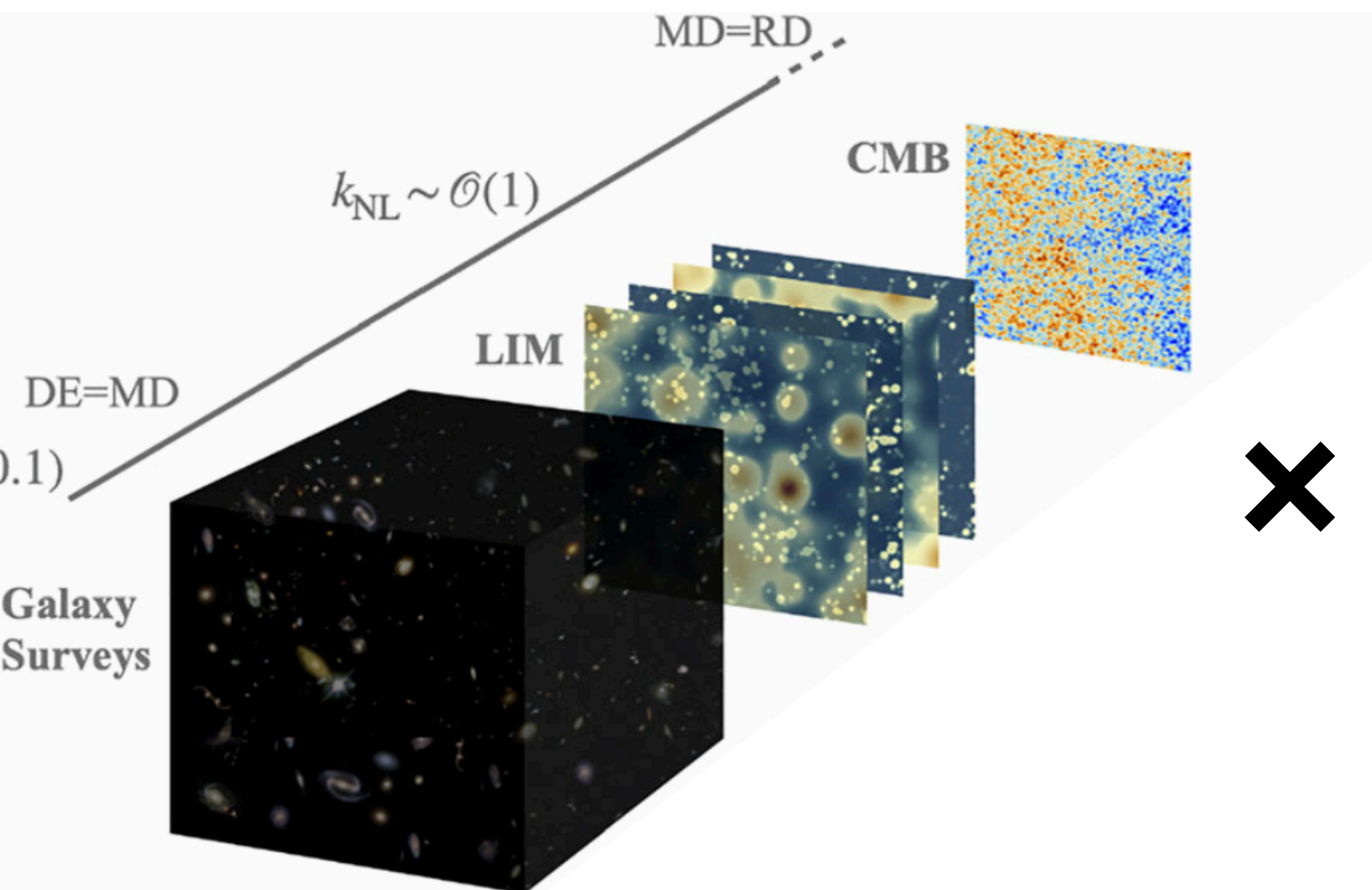
EoR 21cm × LIM
Cross-power spectrum
→ **The onset of reionization**



Synergy with CMB experiments

Synergy with CMB experiments

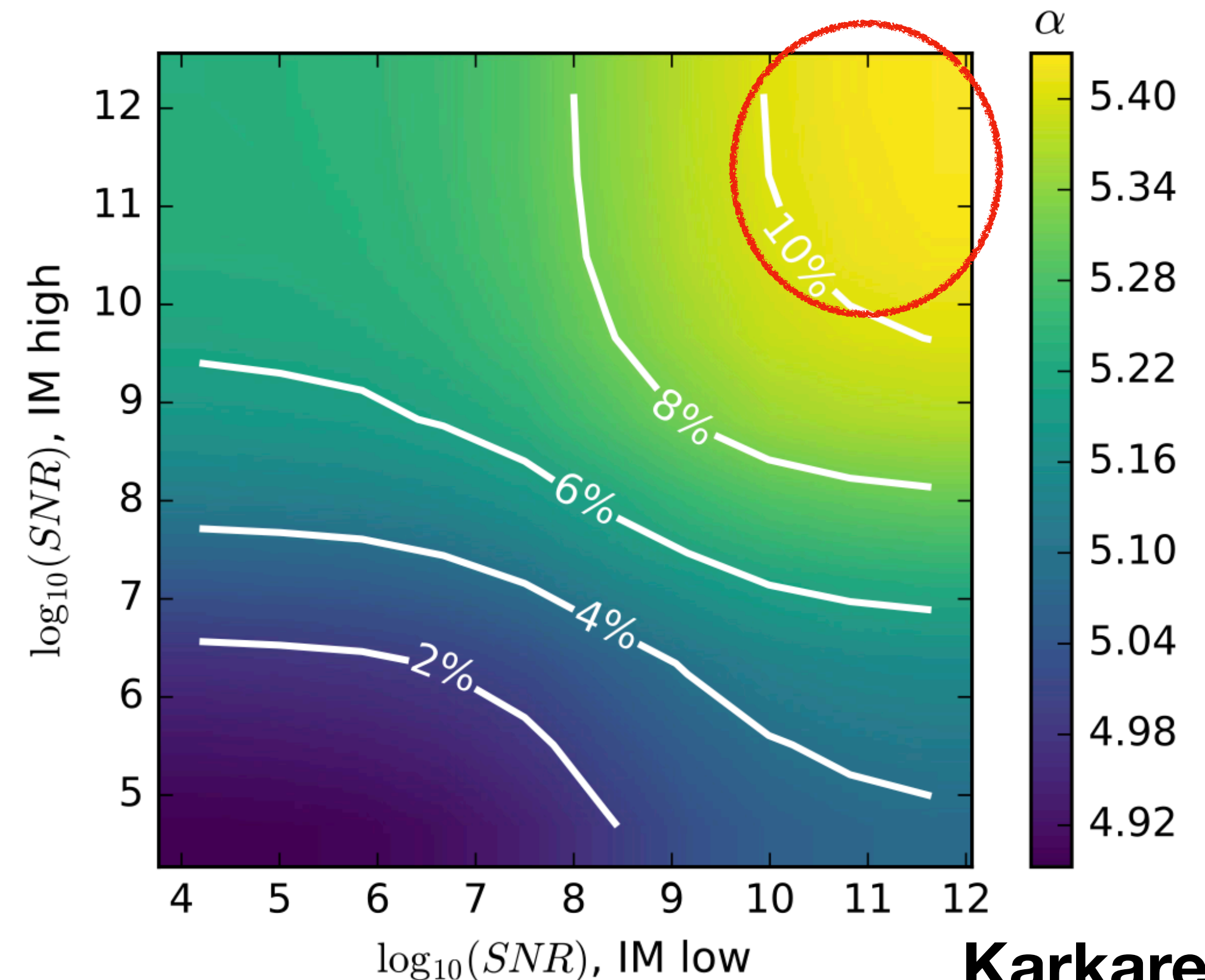
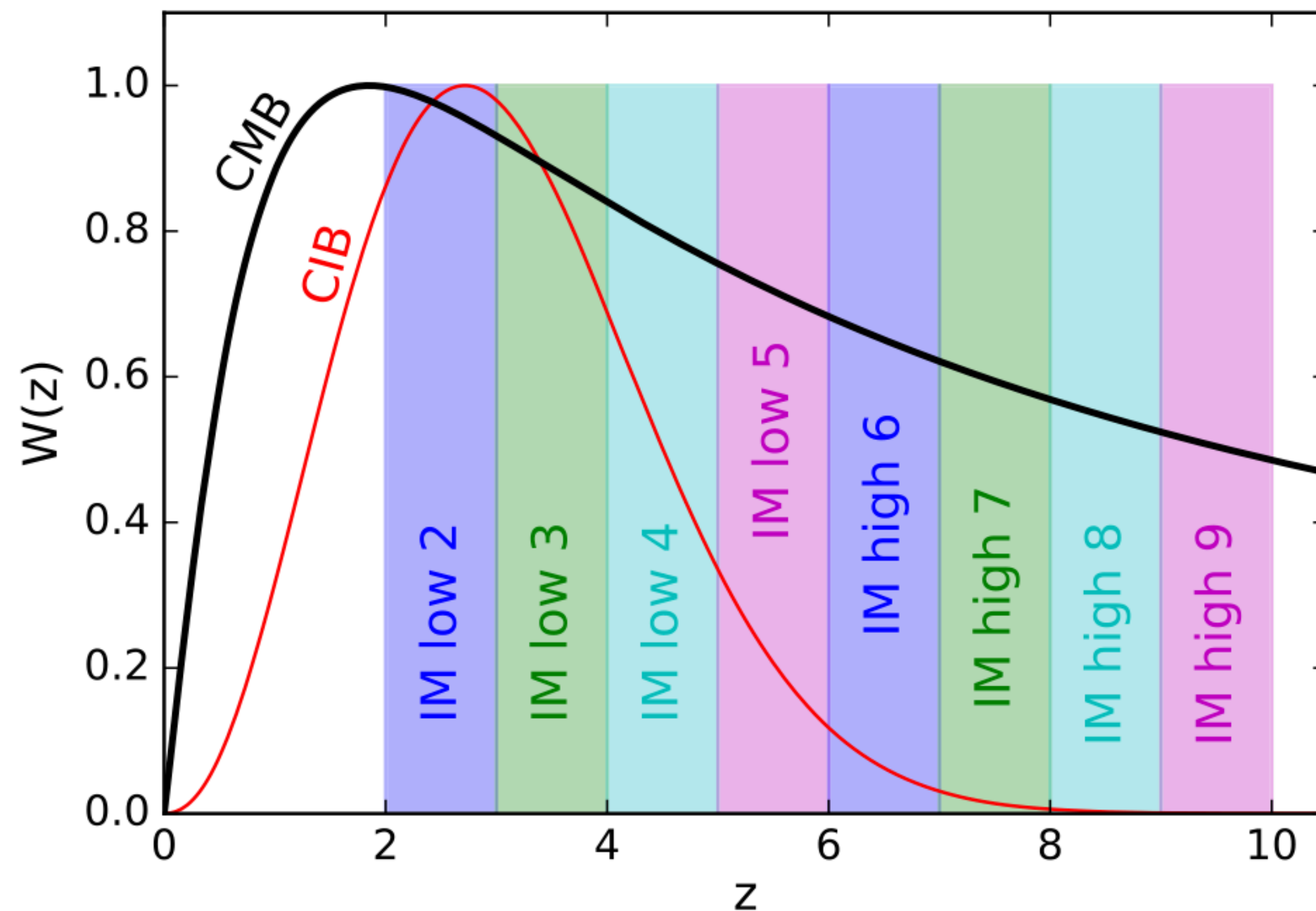
- Effects such as **CMB lensing**, **Sachs–Wolfe effect**, and **SZ effect** can be better isolated from the primary anisotropies in cross-correlation analyses.
- LIM may enable the CMB secondary anisotropies tomography **at higher redshifts** than galaxy surveys.



CMB Delensing

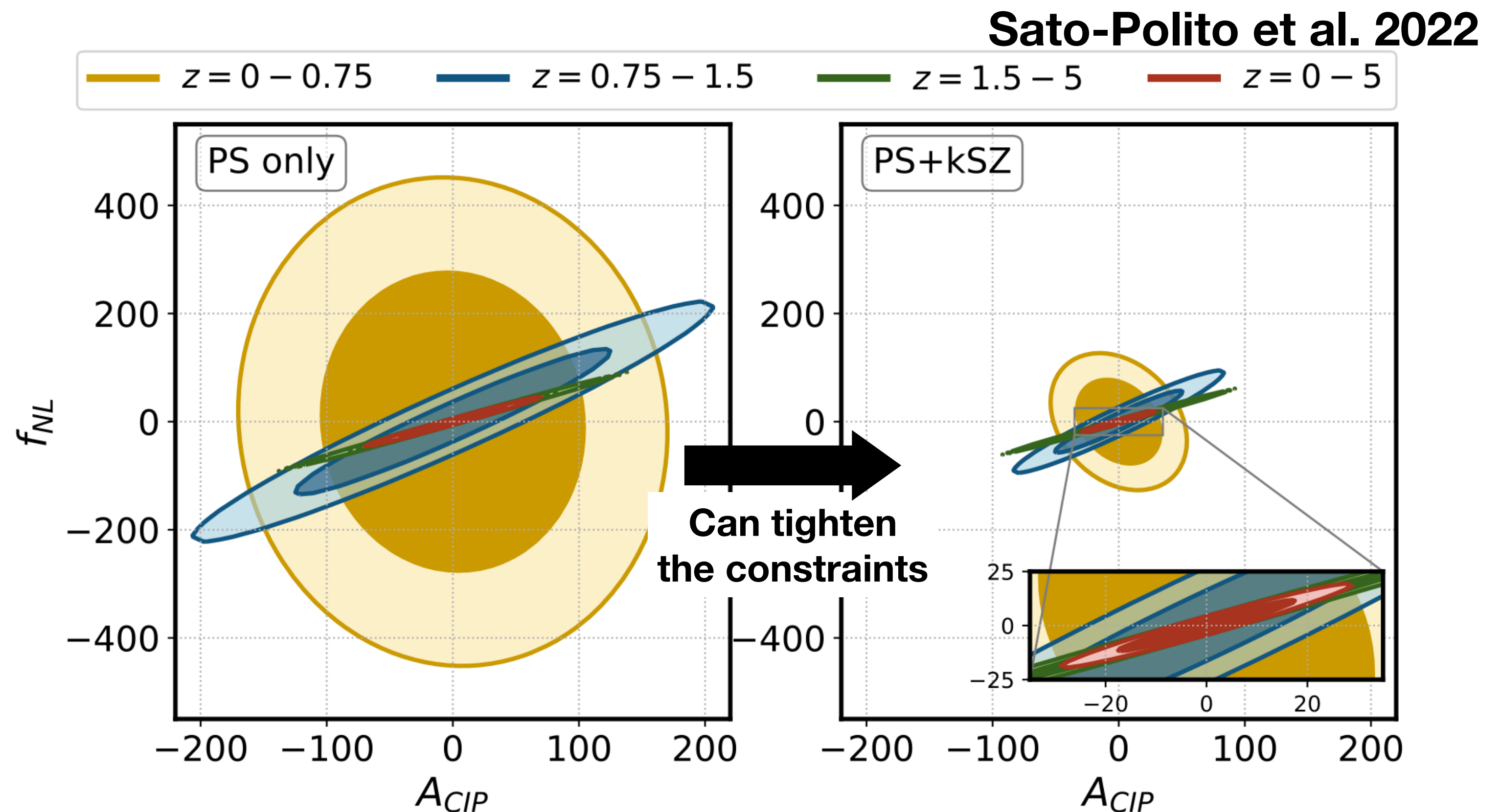
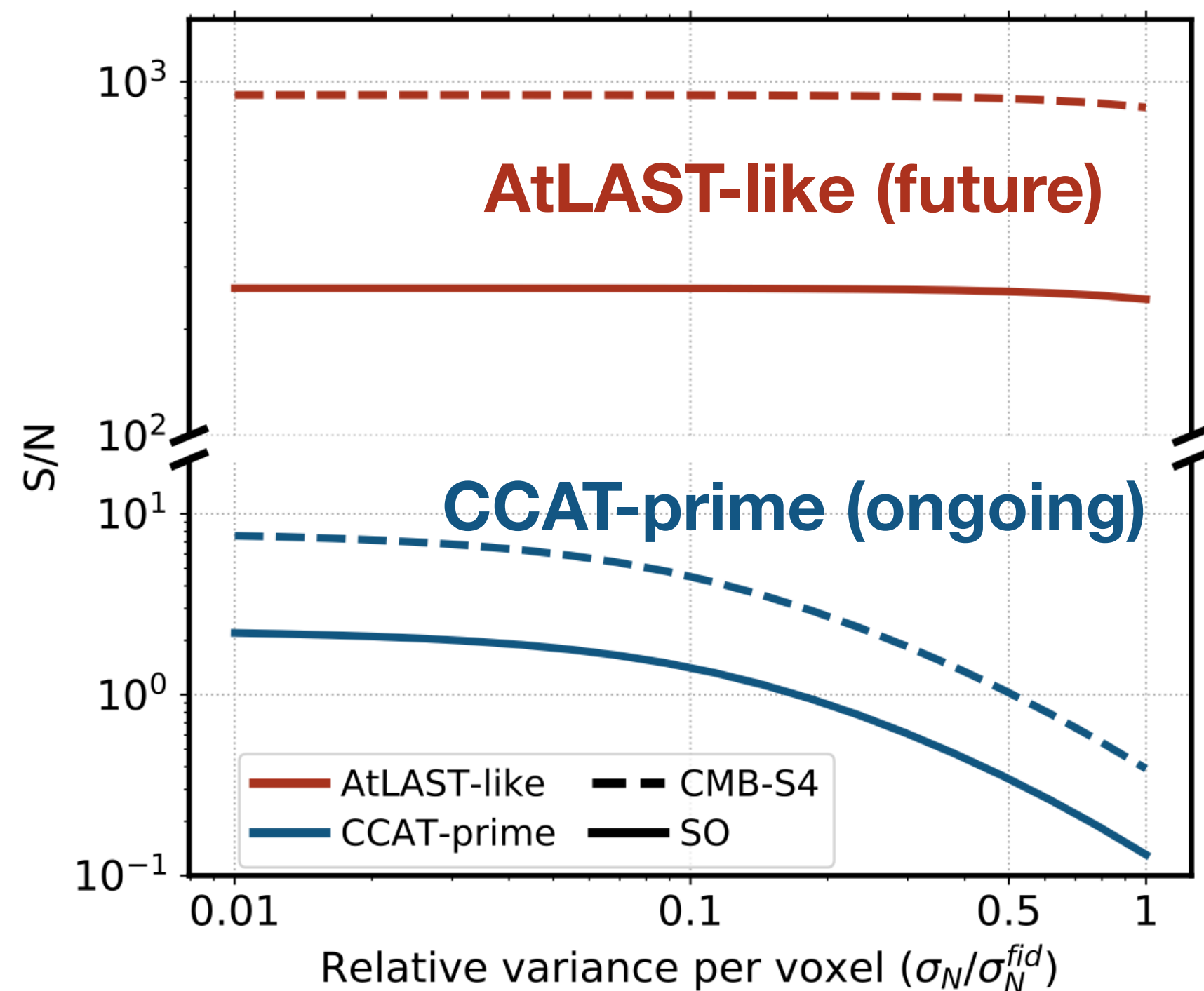
- Up to an **additional ~10% reduction** in residual lensing B-modes with future high-redshift LIM surveys
- Requires low- z and high- z LIM with $\text{SNR} > \sim 10$ and access to low- $k_{\parallel}$ modes
- Good foreground subtraction methods in LIM may be important

> 10% reduction



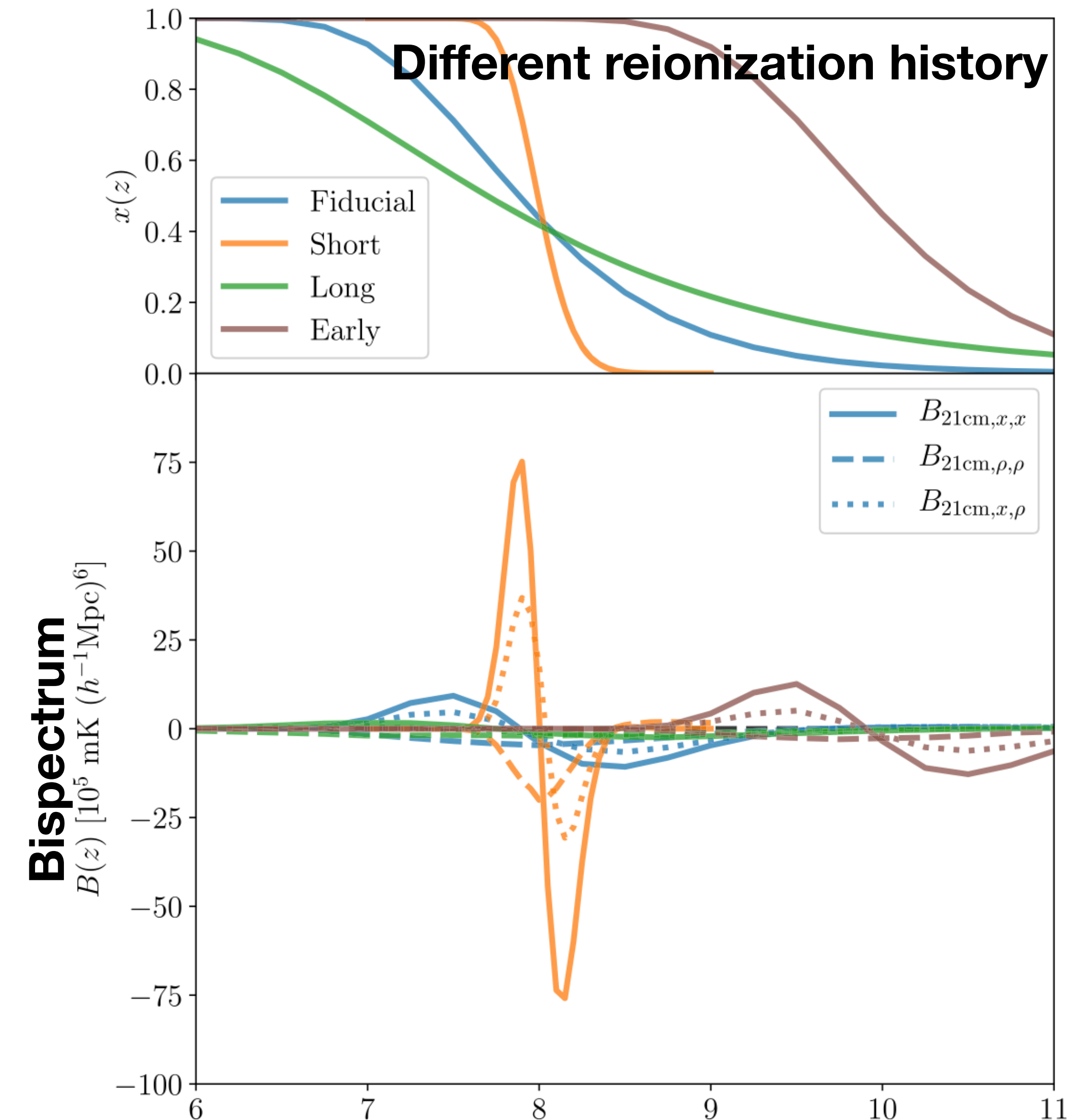
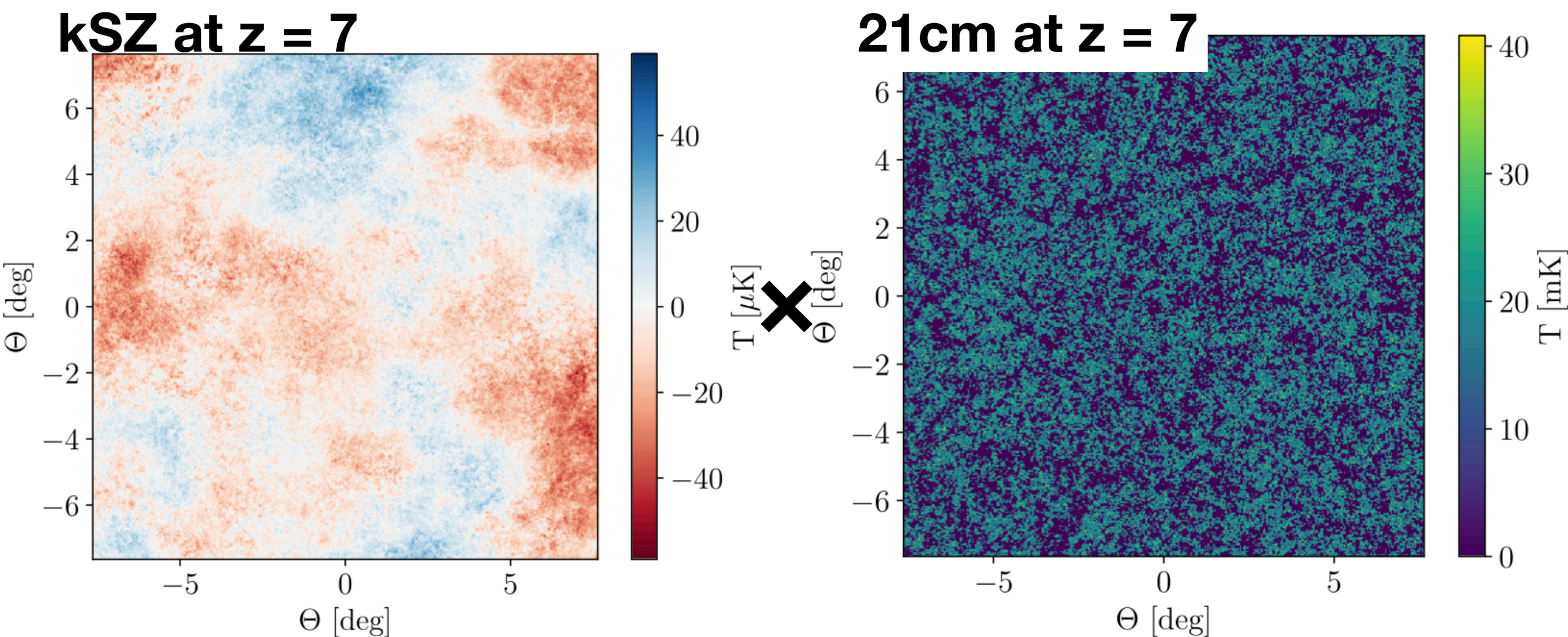
kSZ effect

- Uses line-intensity mapping as a high-redshift LSS tracer for kSZ tomography, enabling reconstruction of the 3D radial velocity field.
- Future CMB $\times$ LIM surveys can detect the signal and improve constraints on primordial non-Gaussianity and related large-scale physics.



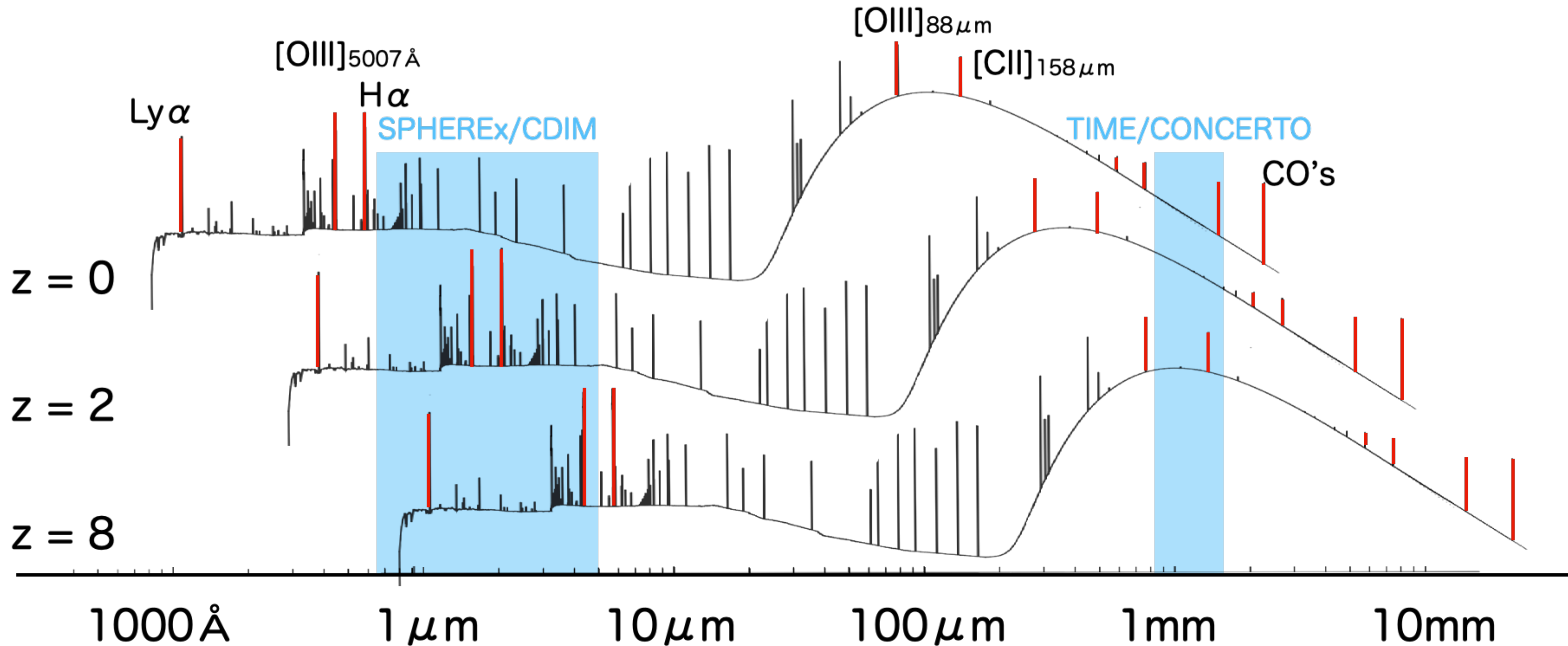
High- z 21cm $\times$ kSZ $\times$ kSZ bispectrum

- Correlation between HI traced by 21 cm emission and ionized regions traced by the kSZ effect.
- In the simple 21 cm–kSZ two-point correlation, the sign cancellation occurs from line-of-sight velocities. Bispectrum can avoid it
- The signal is shown to be sensitive to the reionization history and the ionized fraction



Challenges in line-intensity mapping

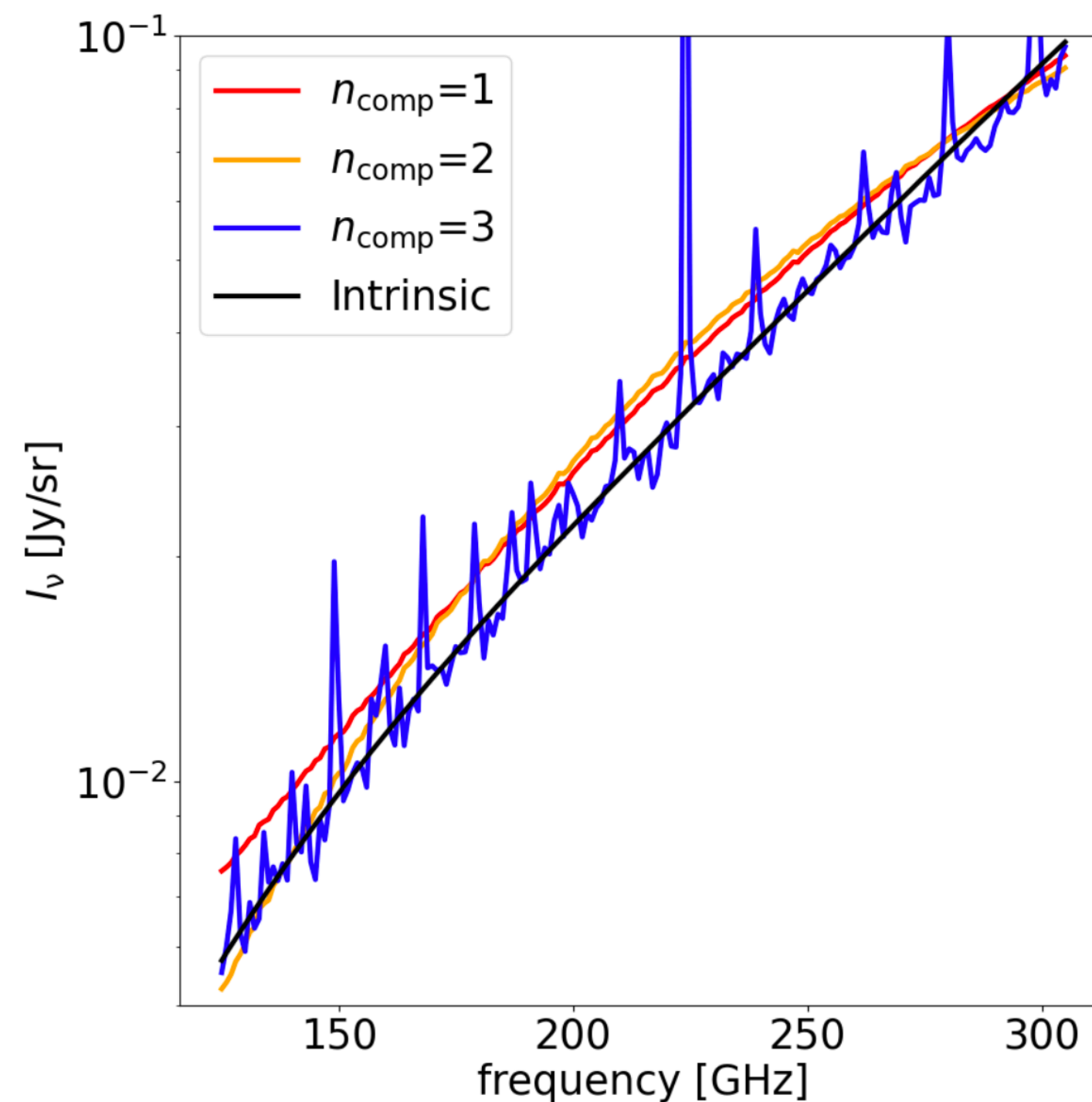
Continuum and other emission lines should be properly removed



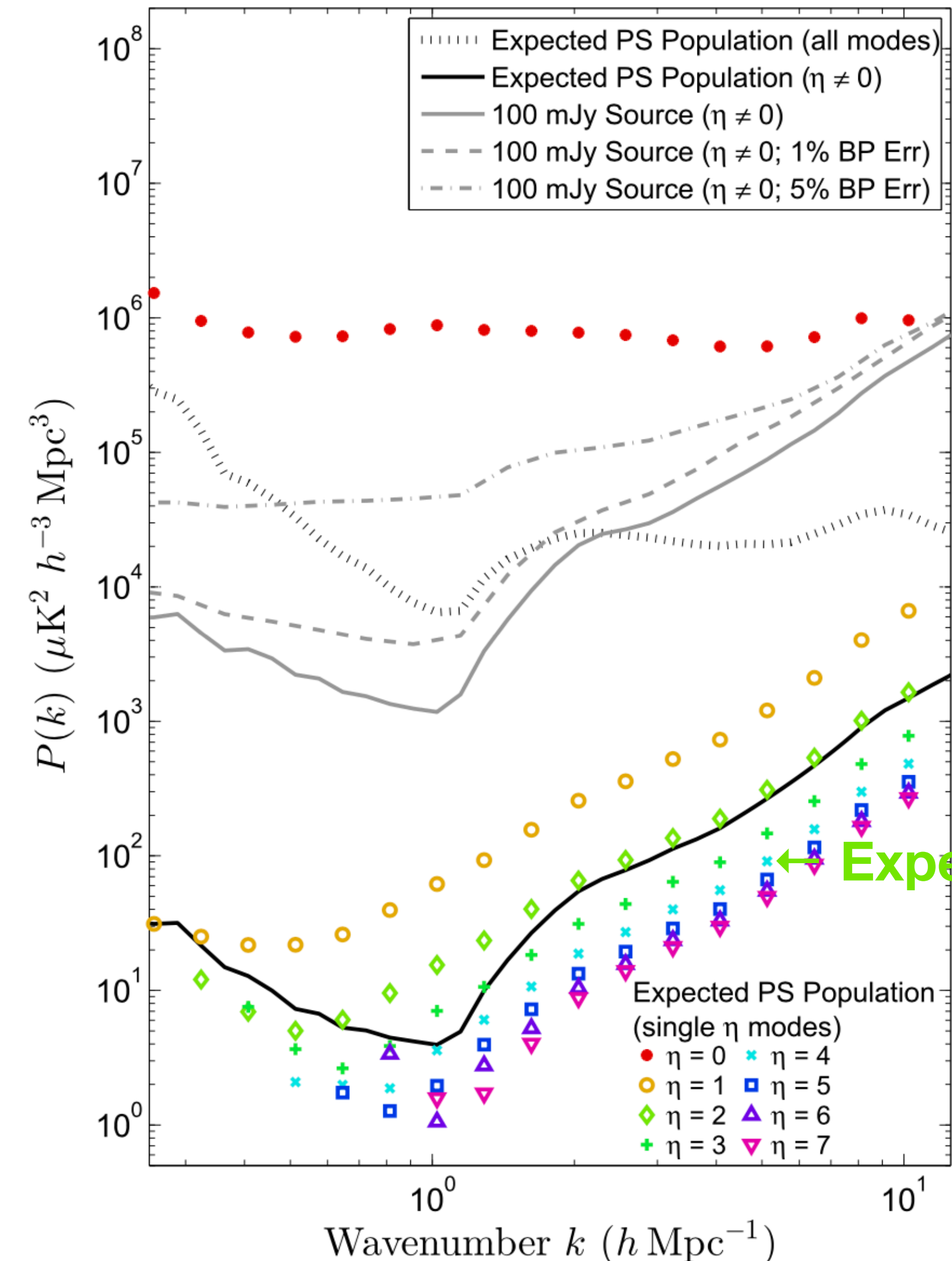
How to remove continuum?

Solution:

- Remove $k_{\parallel} \sim 0$ modes (e.g., Keating+15)
- Use algorithms like PCA and arPLS (e.g., Van Cuyck+23)



Van Cuyck+2023
(CONCERTO collaboration)



Keating+2015
(COPSS I)

← total

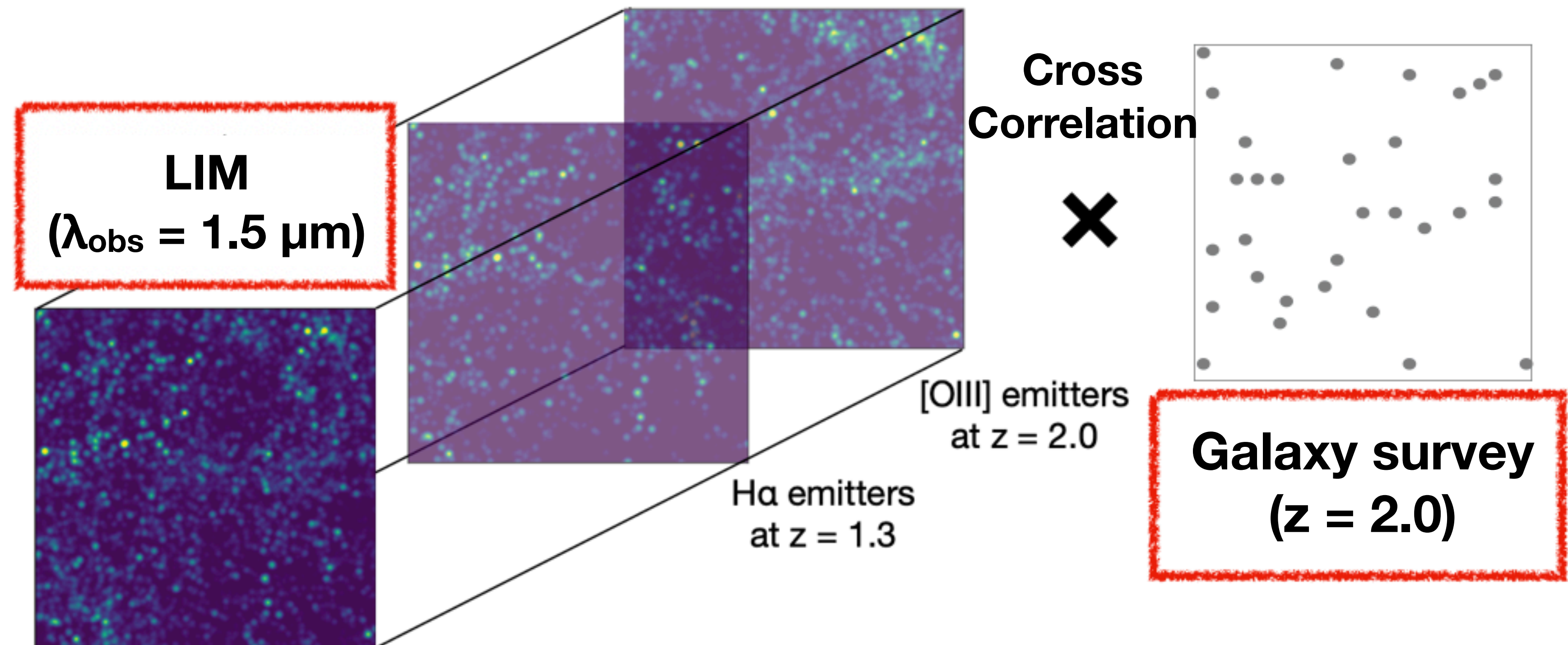
← $\eta = 0$ mode
subtracted

Expected signals

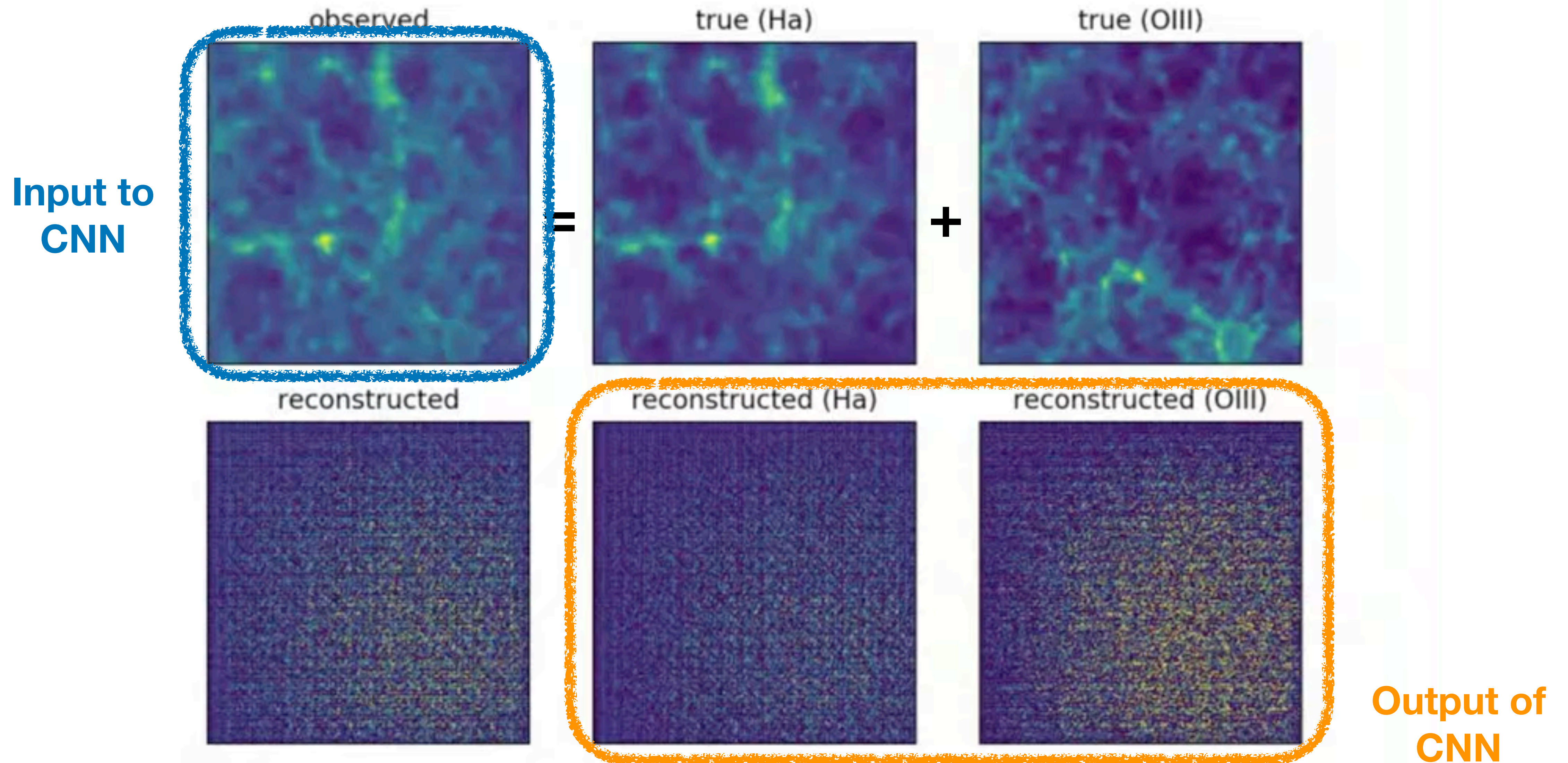
Line contamination

Solution:

- Cross-correlation (e.g., Visbal&Loeb2010)
- Masking (e.g. VanCuyck+2023)
- Power spectrum anisotropy (e.g., Gong+14)
- Machine learning methods (e.g., Moriwaki+20)

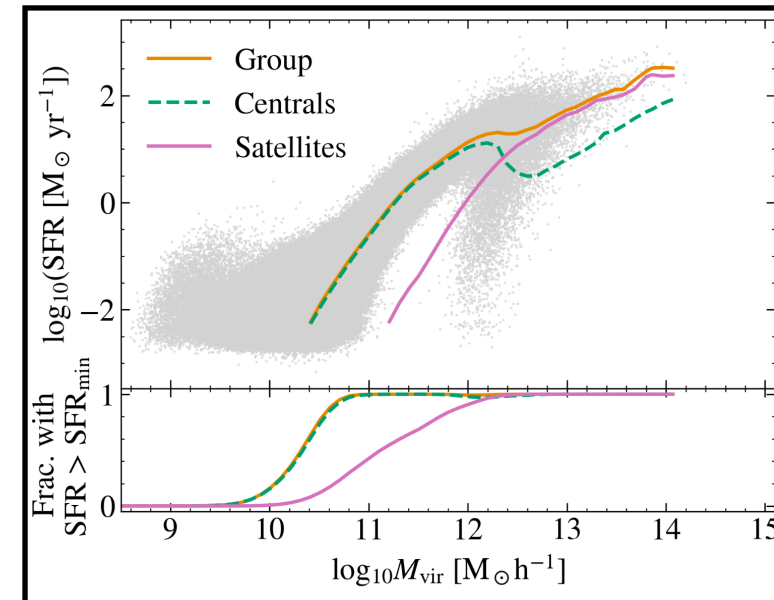


Machine learning for interloper removal

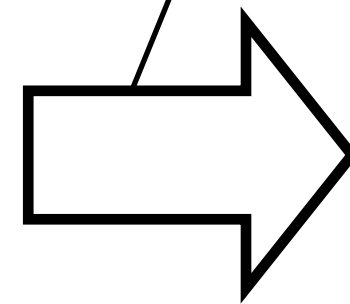
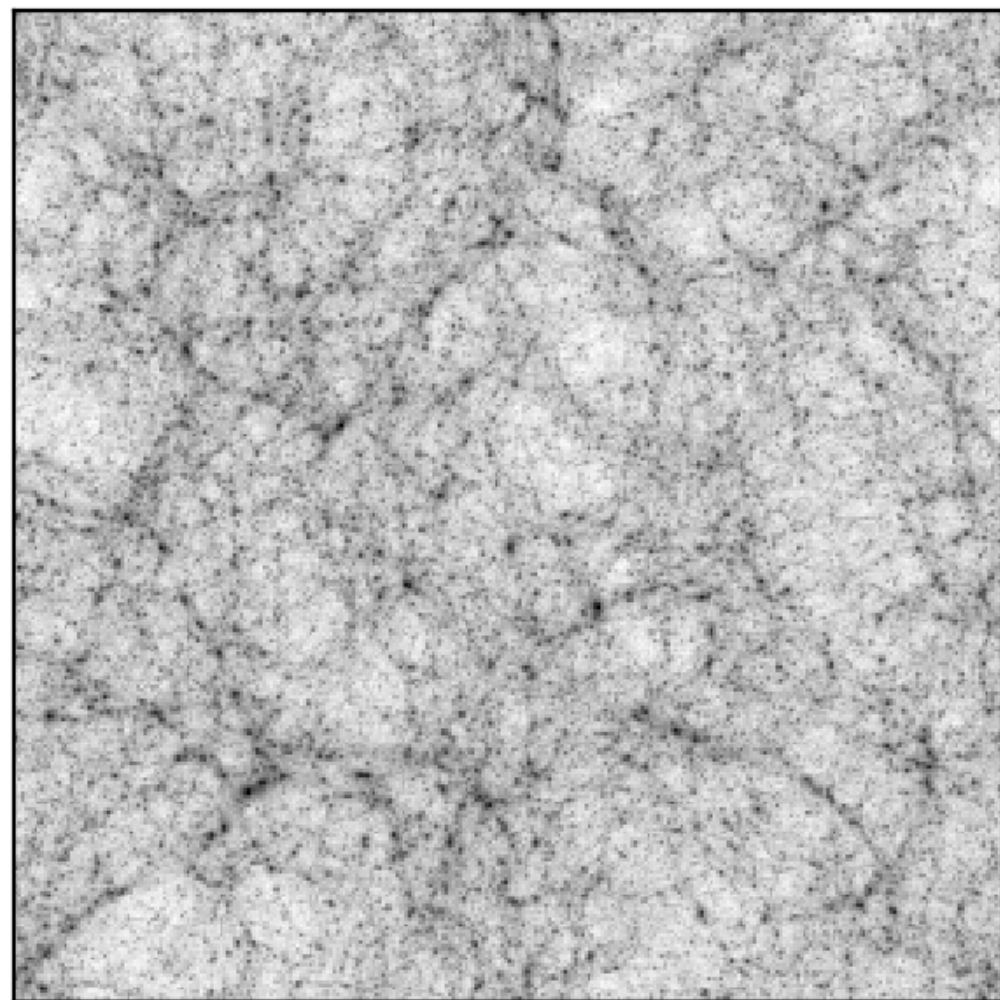


Models for theoretical prediction

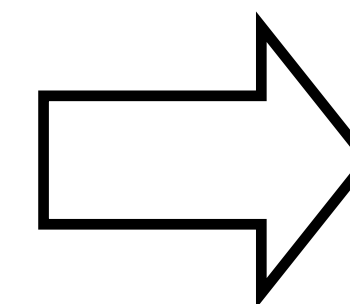
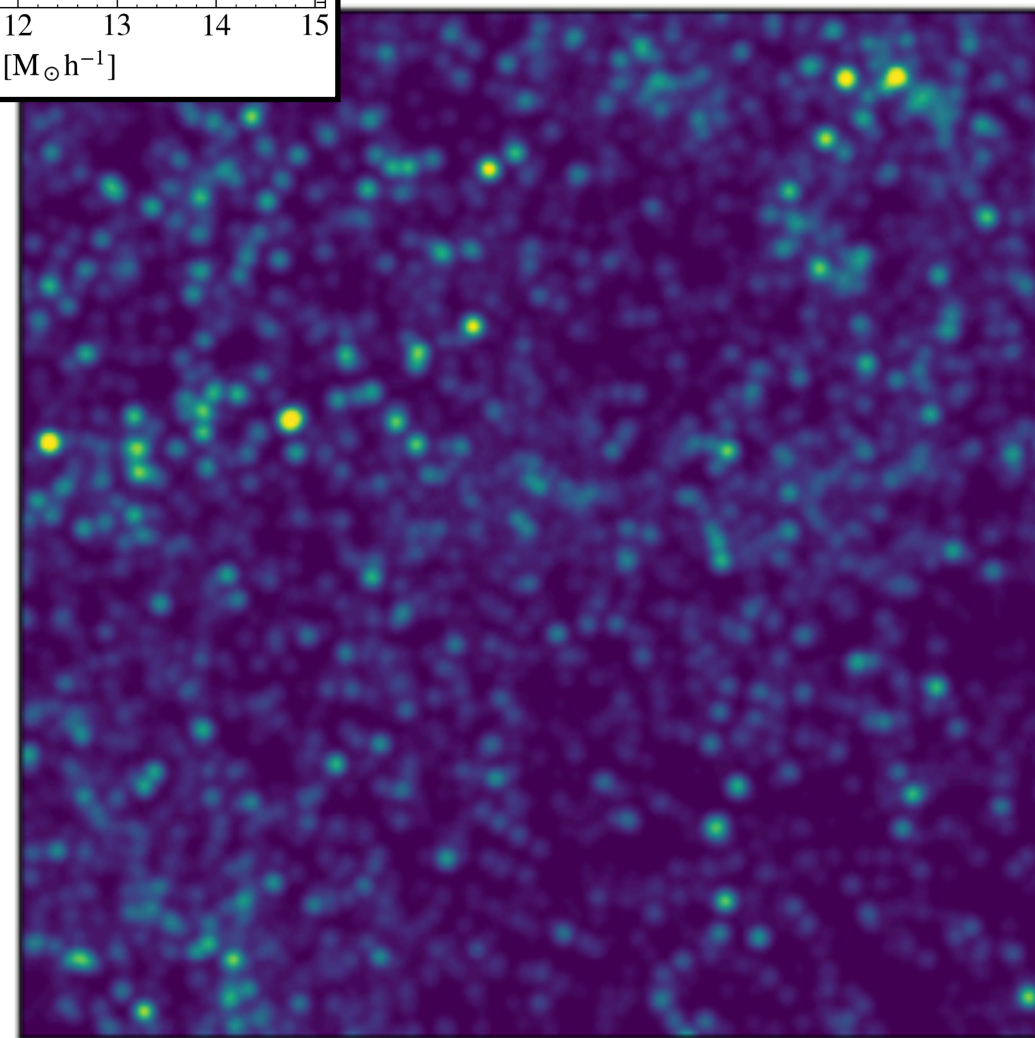
e.g., M_{halo} -SFR relation



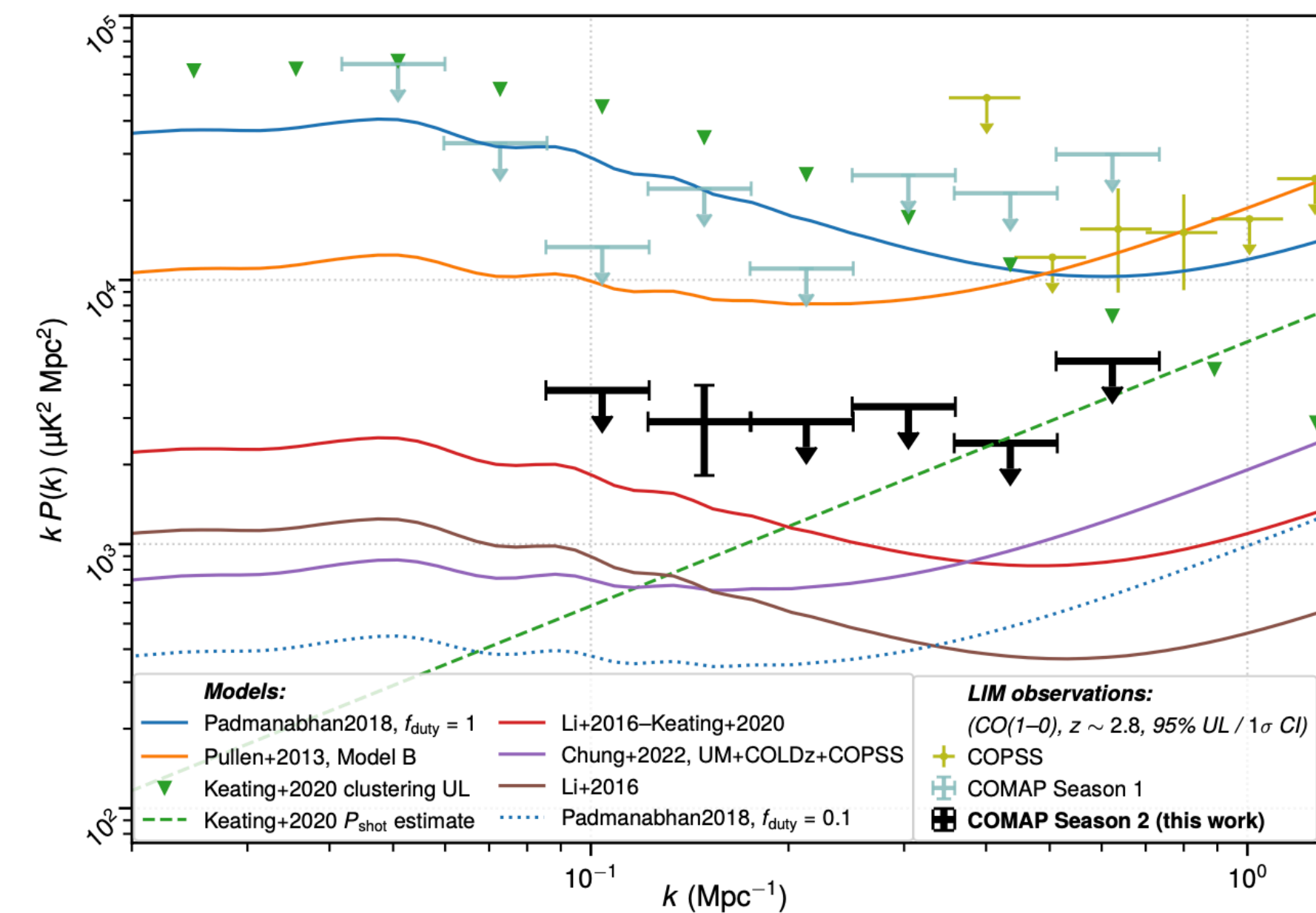
Dark matter distribution
(fast simulation)



Line intensity map

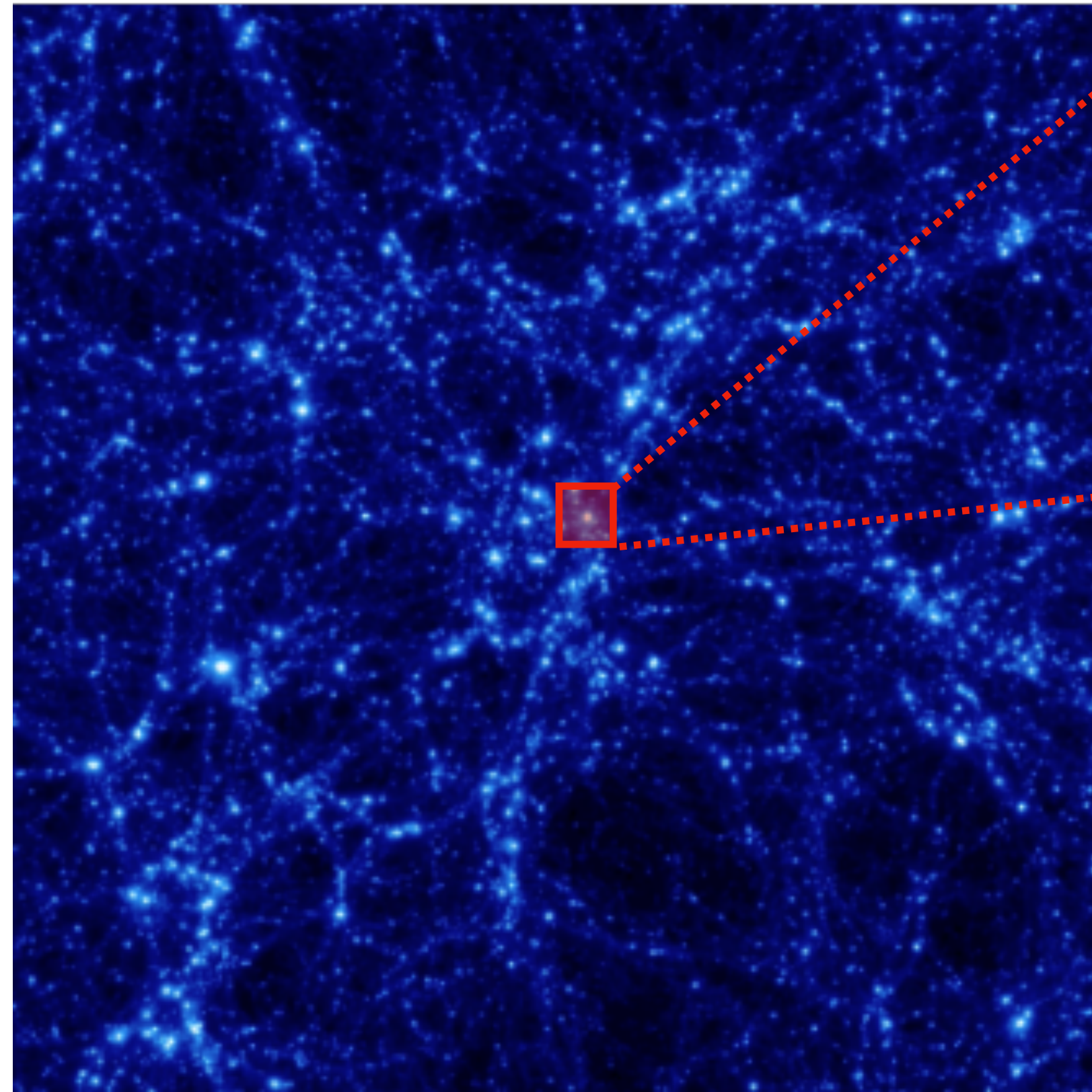


Power spectrum



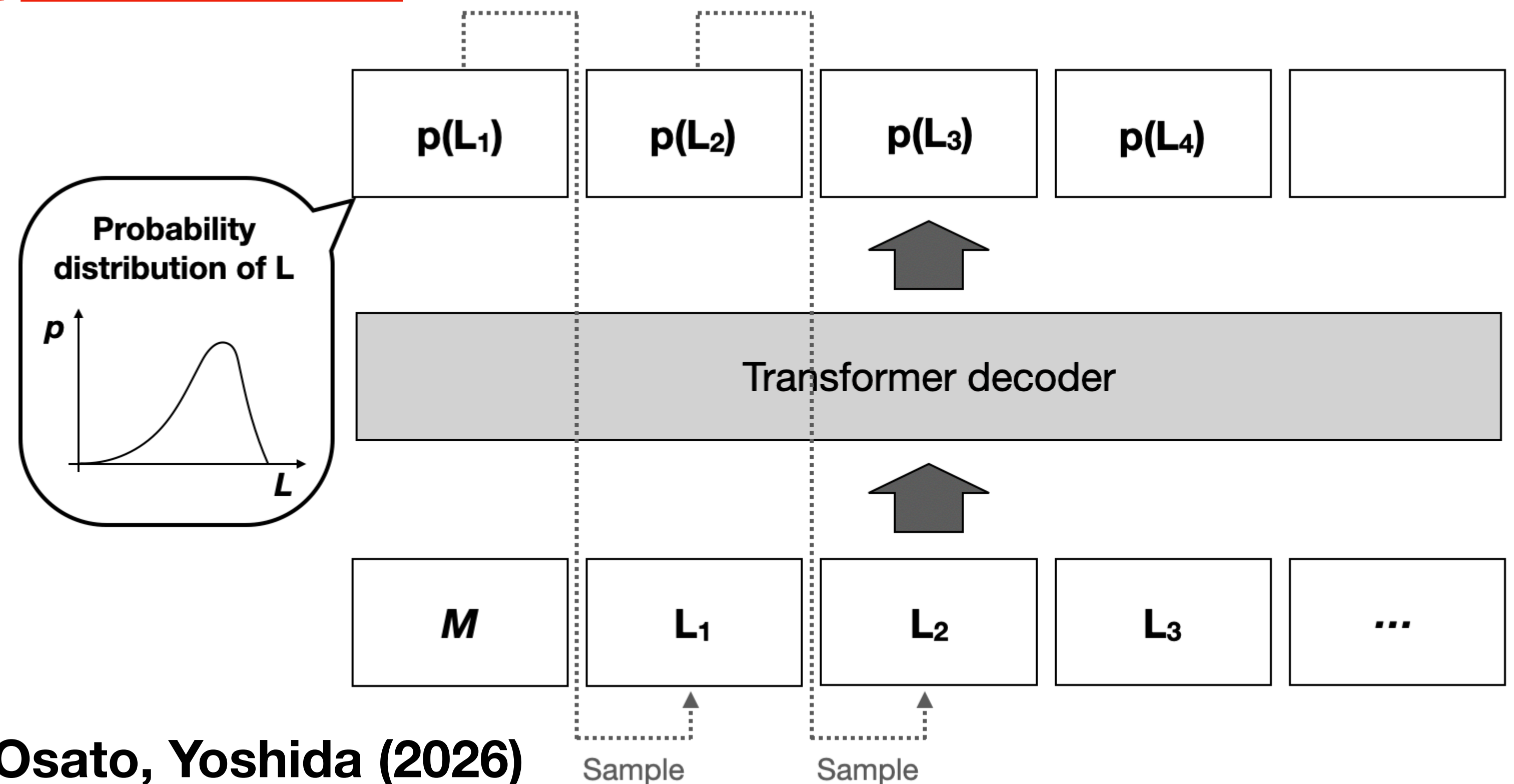
- A common approach to generating mock is to paint galaxies onto DM-only simulations.
- A simple mass-luminosity relation is often used.
- The contribution from satellite galaxies is frequently not treated.

Deep generative model for generating realistic LIM mocks

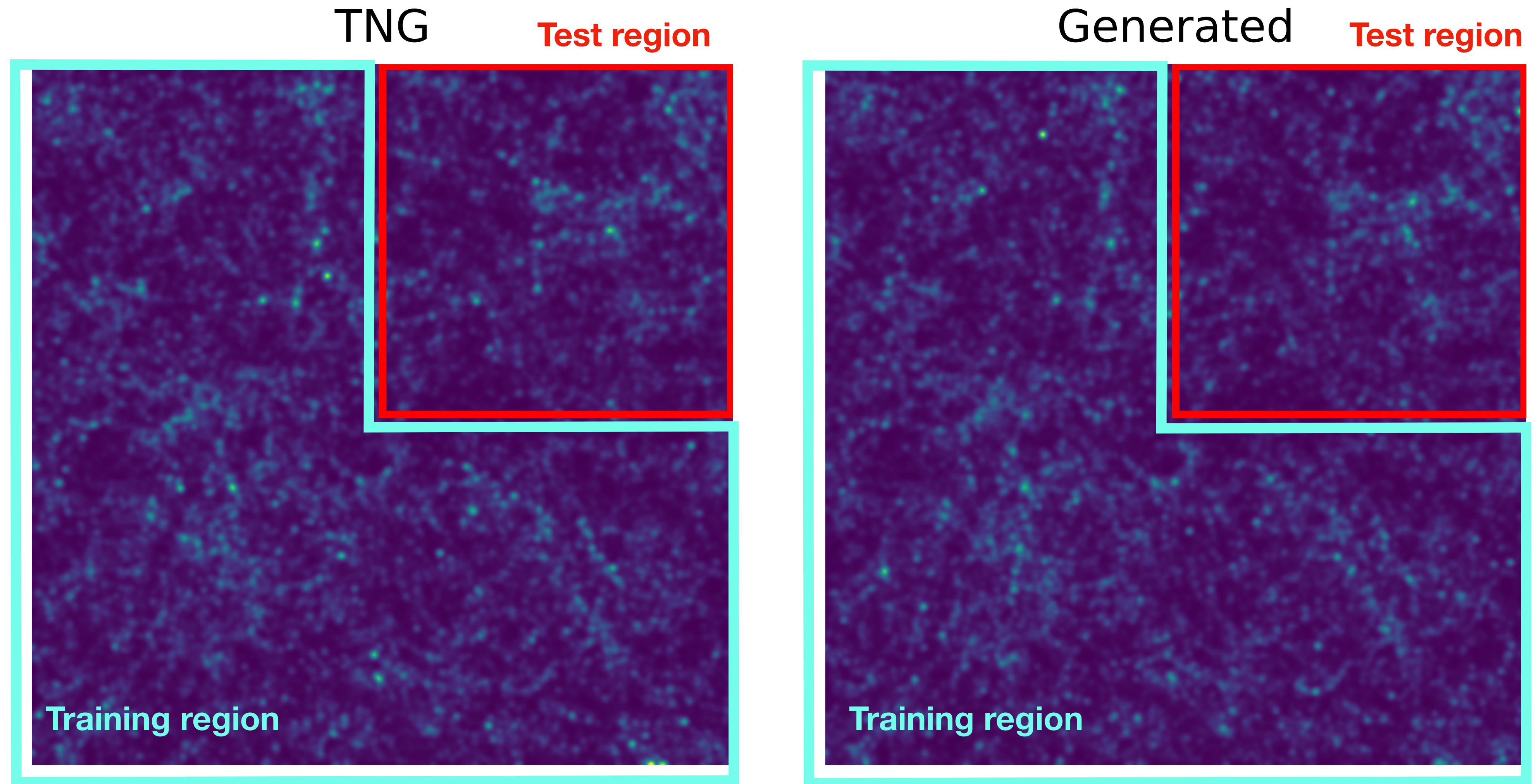


We recently developed an auto-regressive model (a model commonly used in LLM) to generate realistic LIM mocks

<https://github.com/knmoriwaki/cosmoglint>



Populating galaxies to DM-only simulation



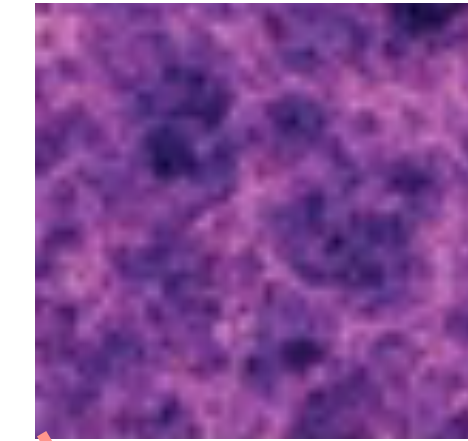
KM+ 2026 Generating $\sim 800,000$ galaxies in $(205 \text{ Mpc/h})^3$ within 20 second
on a single GPU (NVIDIA RTX 6000 Ada)

KM, Jun, Osato, Yoshida (2026)

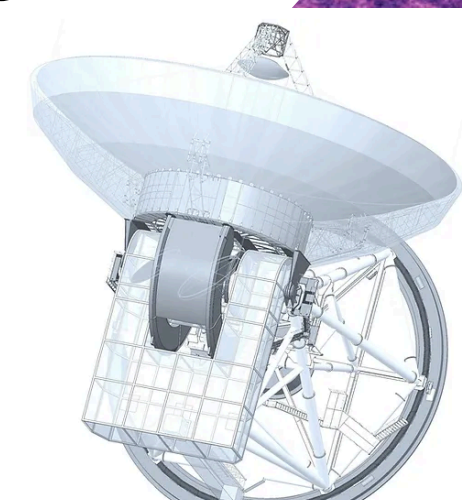
Summary

- **Line-intensity mapping (LIM)** measures the integrated emission from many unresolved sources, providing a **three-dimensional view of large-scale structure across cosmic time.**
- **Several LIM signals have already been detected,** allowing constraints on quantities such as the mean line intensity and clustering bias.
- **Future LIM surveys will extend to larger volumes and higher redshifts,** potentially providing powerful constraints on cosmology and galaxy evolution.
- **Cross-correlations with CMB observables offer promising synergies and additional cosmological information.**
- **Key challenges remain, including foreground removal and theoretical prediction**

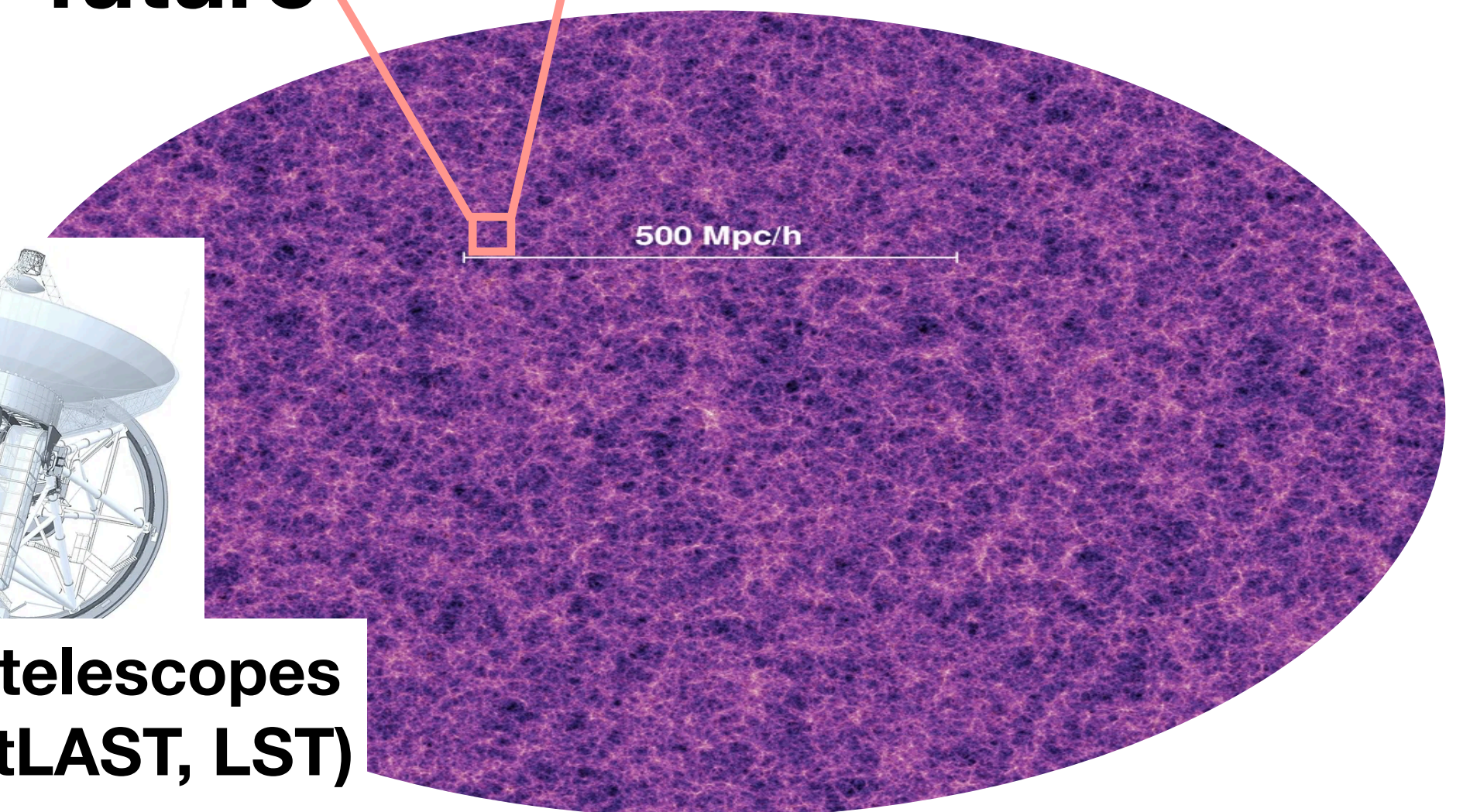
2020s -



future



**~50m telescopes
(e.g. AtLAST, LST)**



**Higher redshifts and/or wider area
→ Much stronger constraints!**