Joint component separation for mm-LIM

Carlos Sierra
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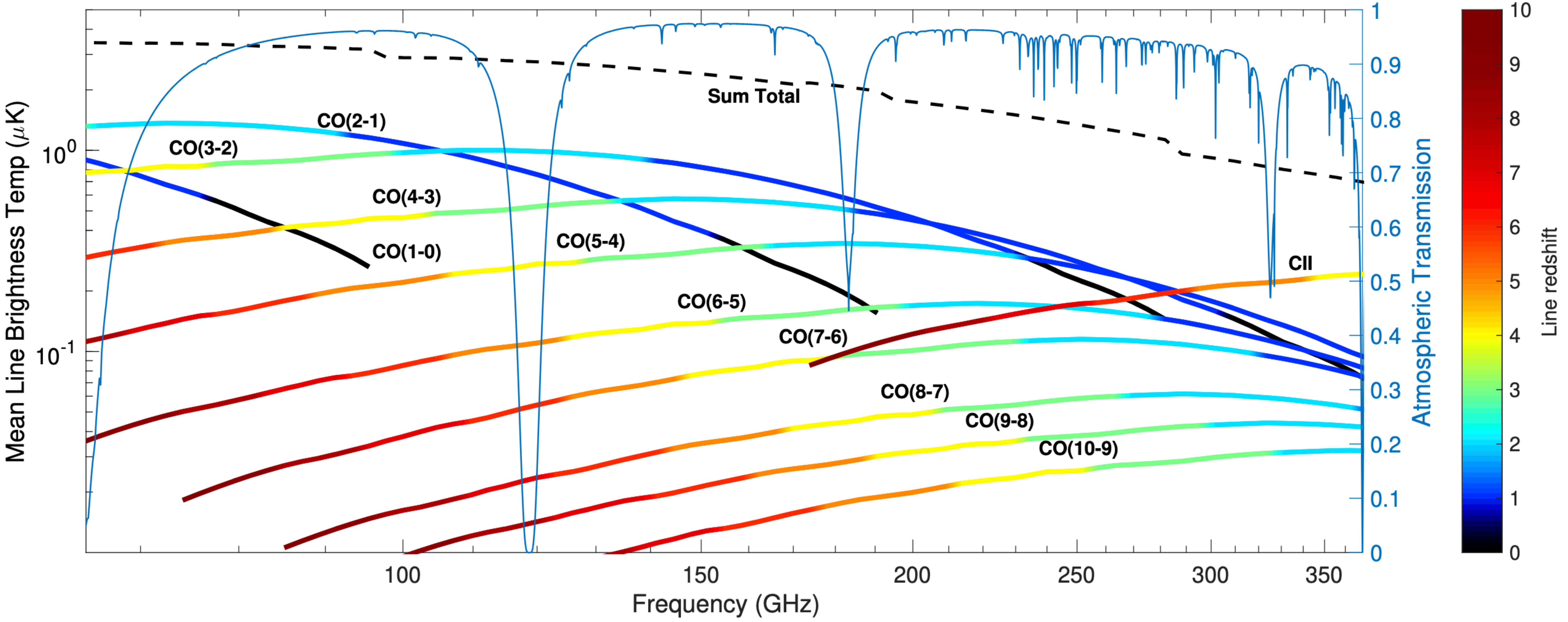
+ Kirit Karkare (*Boston U*)

Why mm-LIM?

1 to 3 mm

(300 to 100 GHz)

e.g. SPT-SLIM, CCAT, TIME, CONCERTO…



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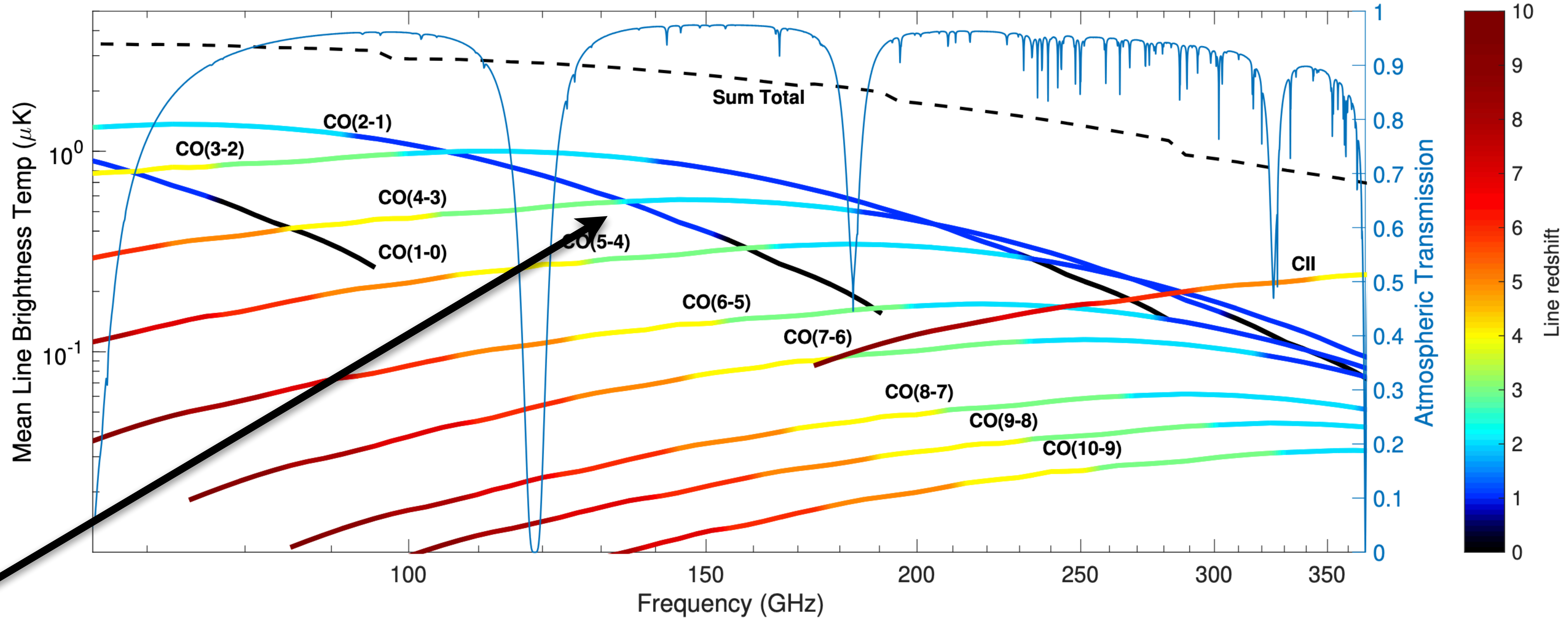
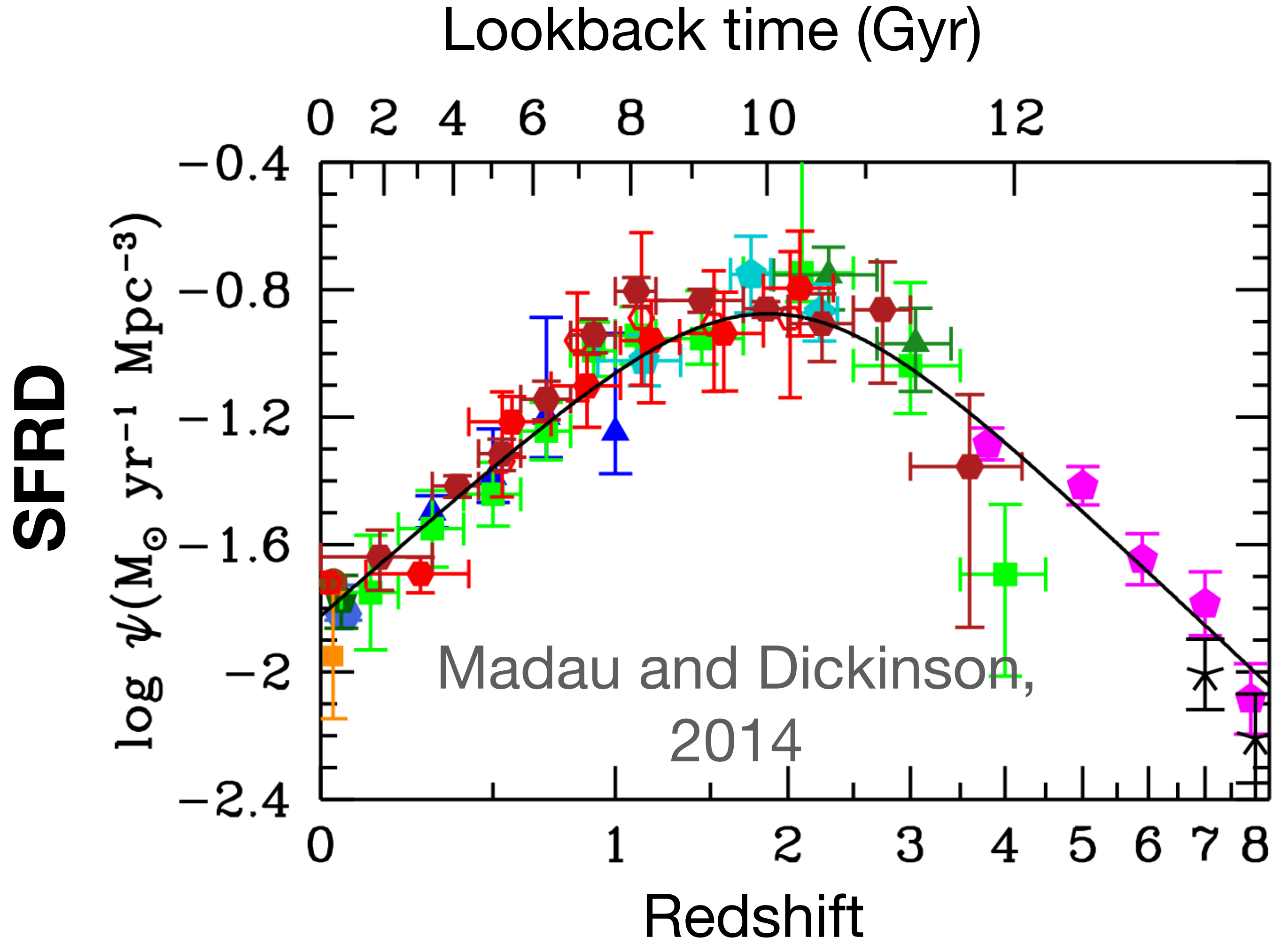
Narrow band, rich observables



Cosmic star formation with CO



Probes molecular gas content up to $z \sim 4$

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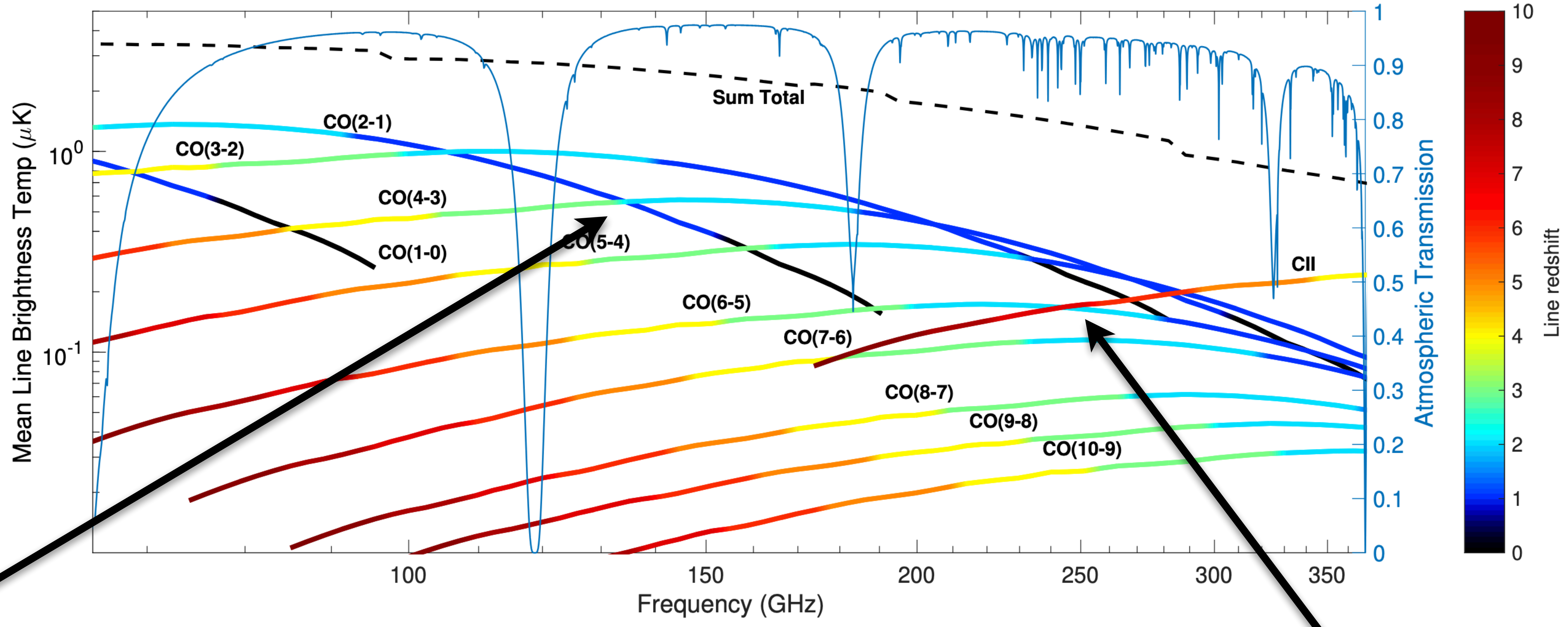

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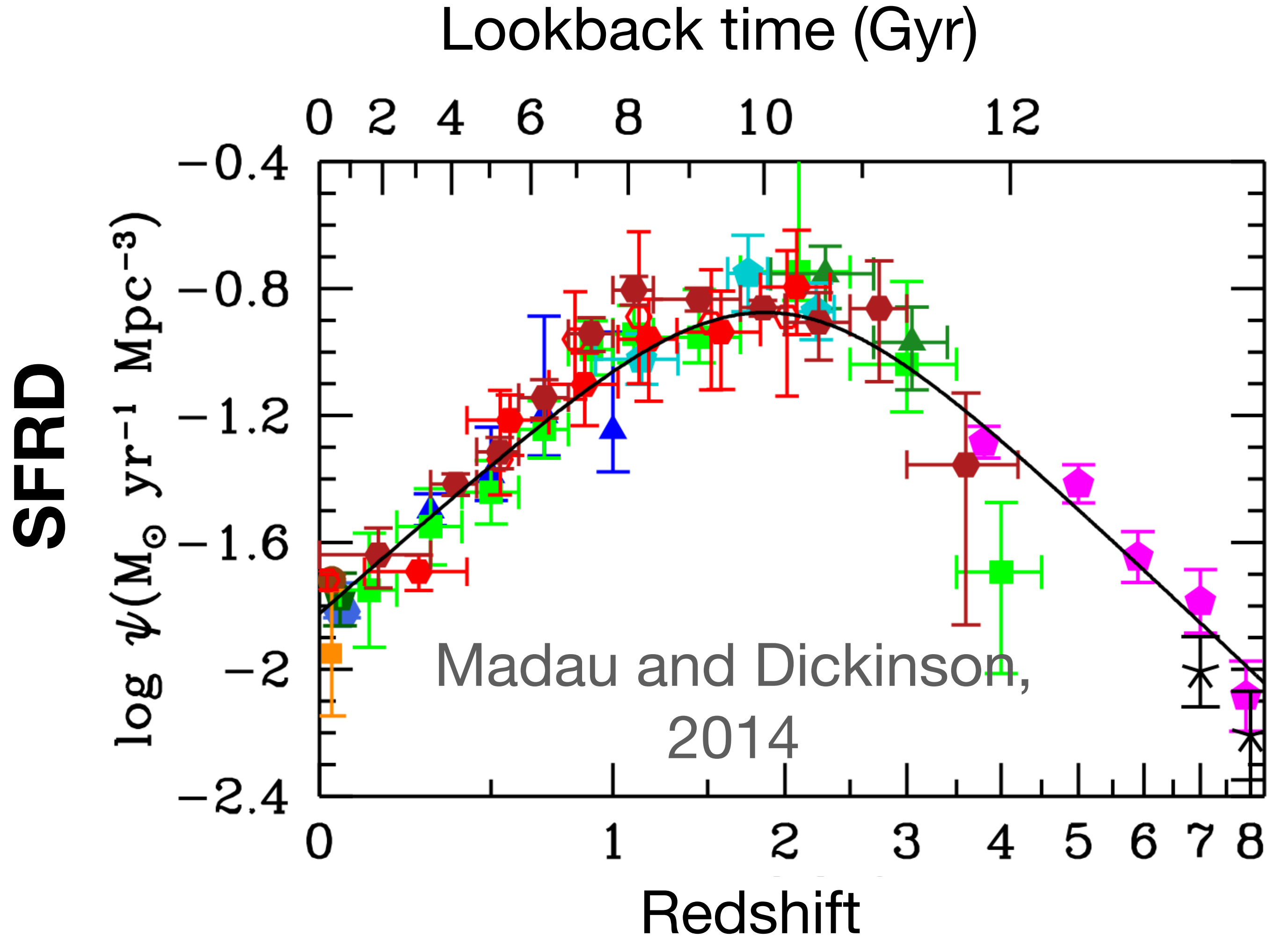
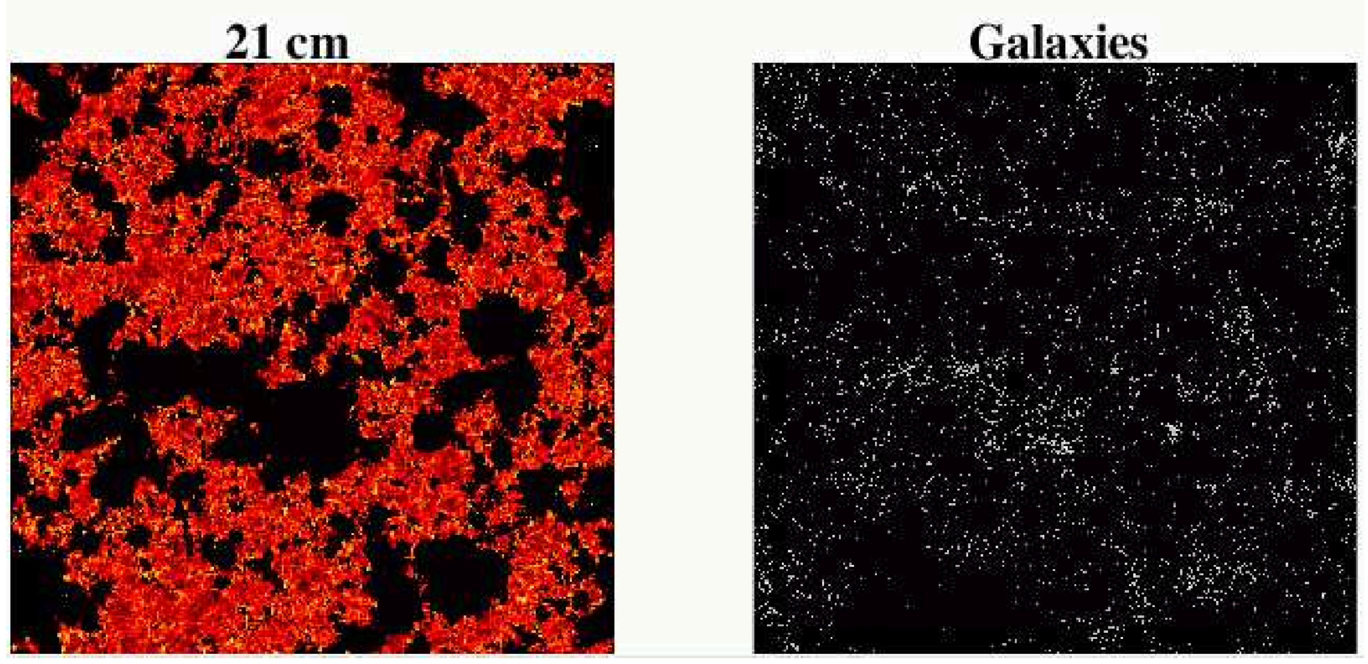


Probes molecular gas content up to $z \sim 4$

Reionization with [CII]



Lidz+ 2009

Complementary to 21 cm

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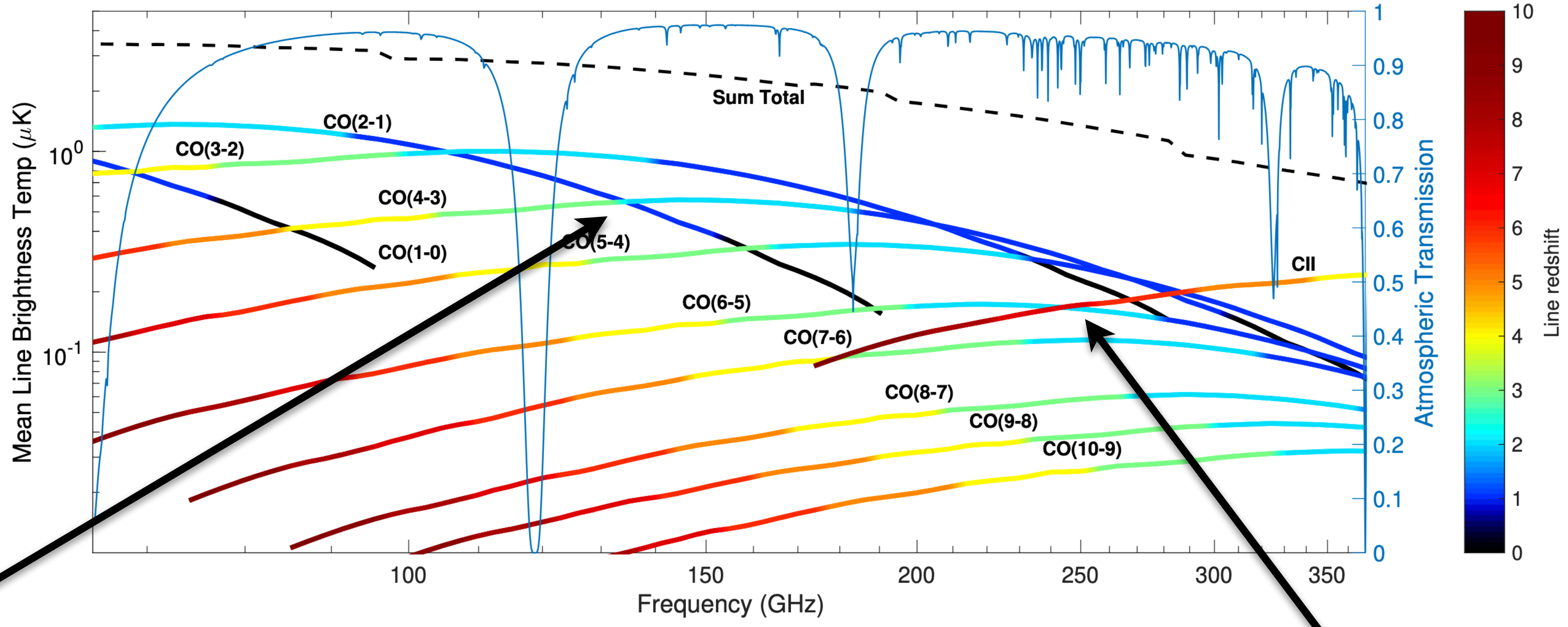
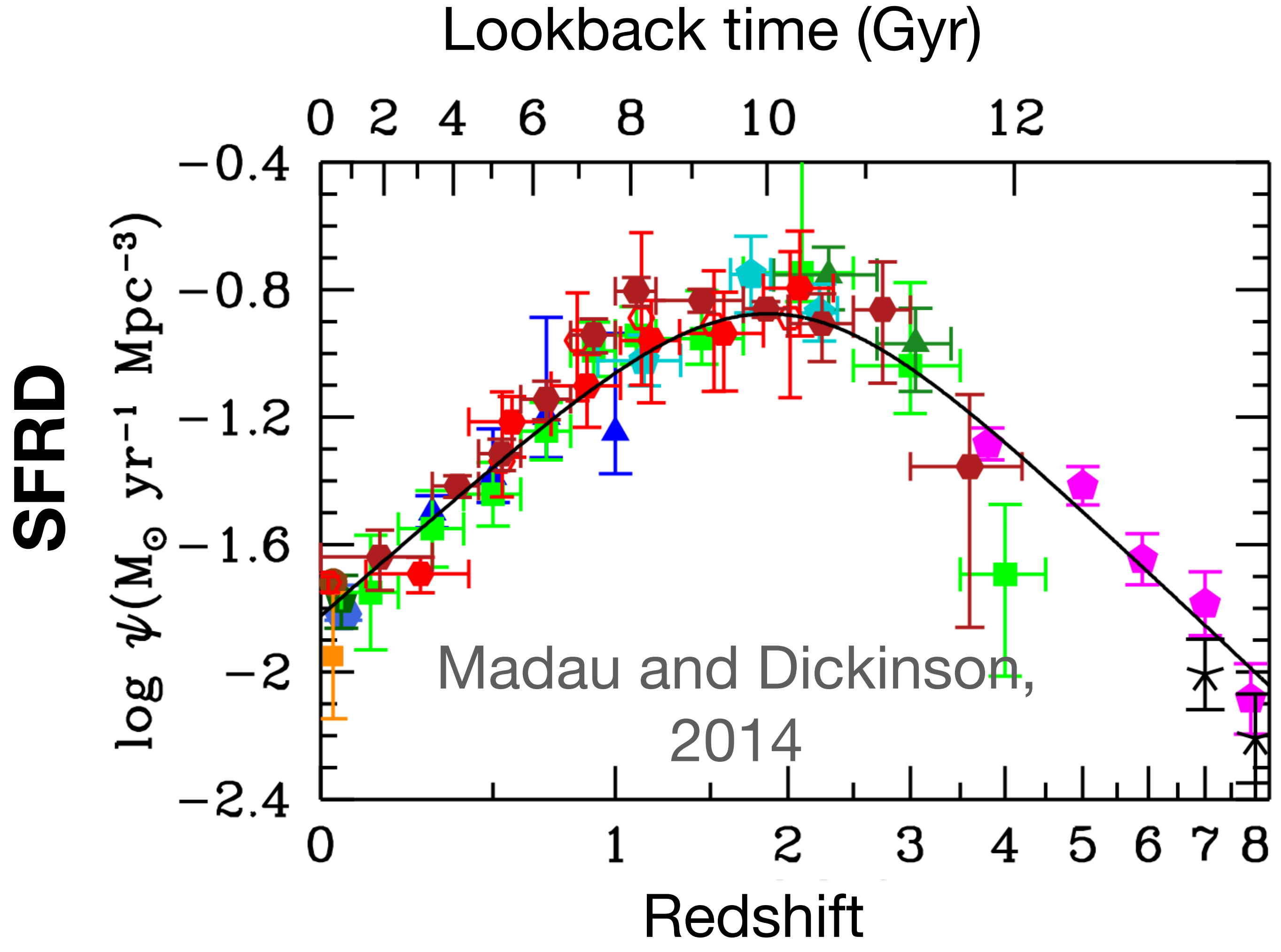
1 to 3 mm (300 to 100 GHz)

Narrow band, rich observables



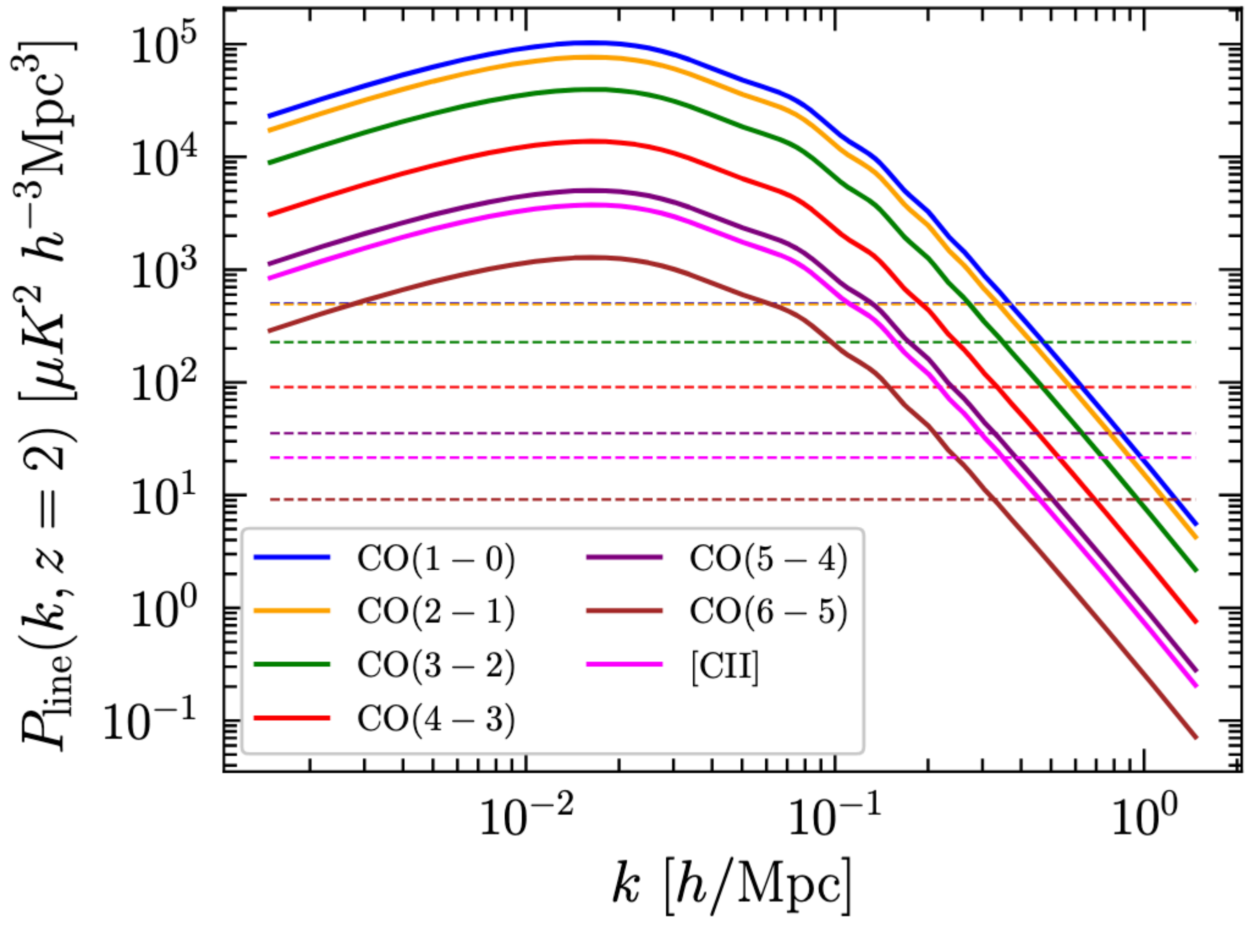
Cosmic star formation with CO



Probes molecular gas content up to $z \sim 4$

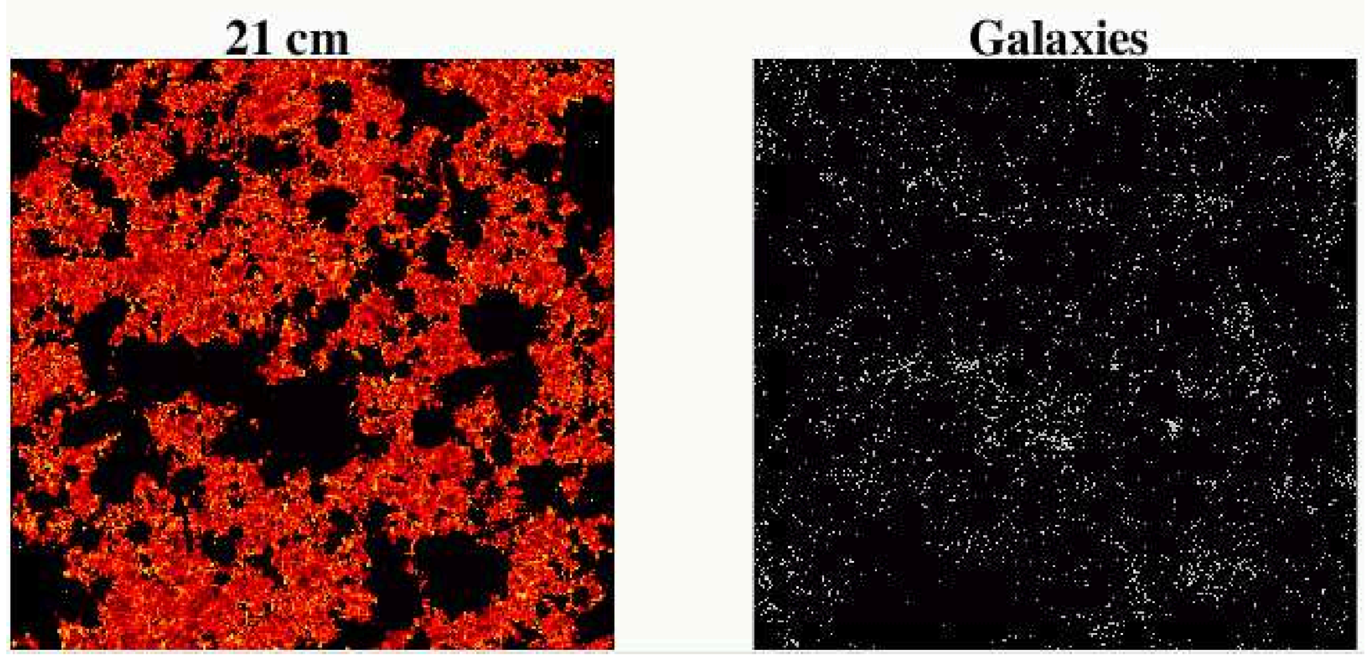
Cosmology

Higher redshift + statistics



Moradinezhad Dizgah+ 2021

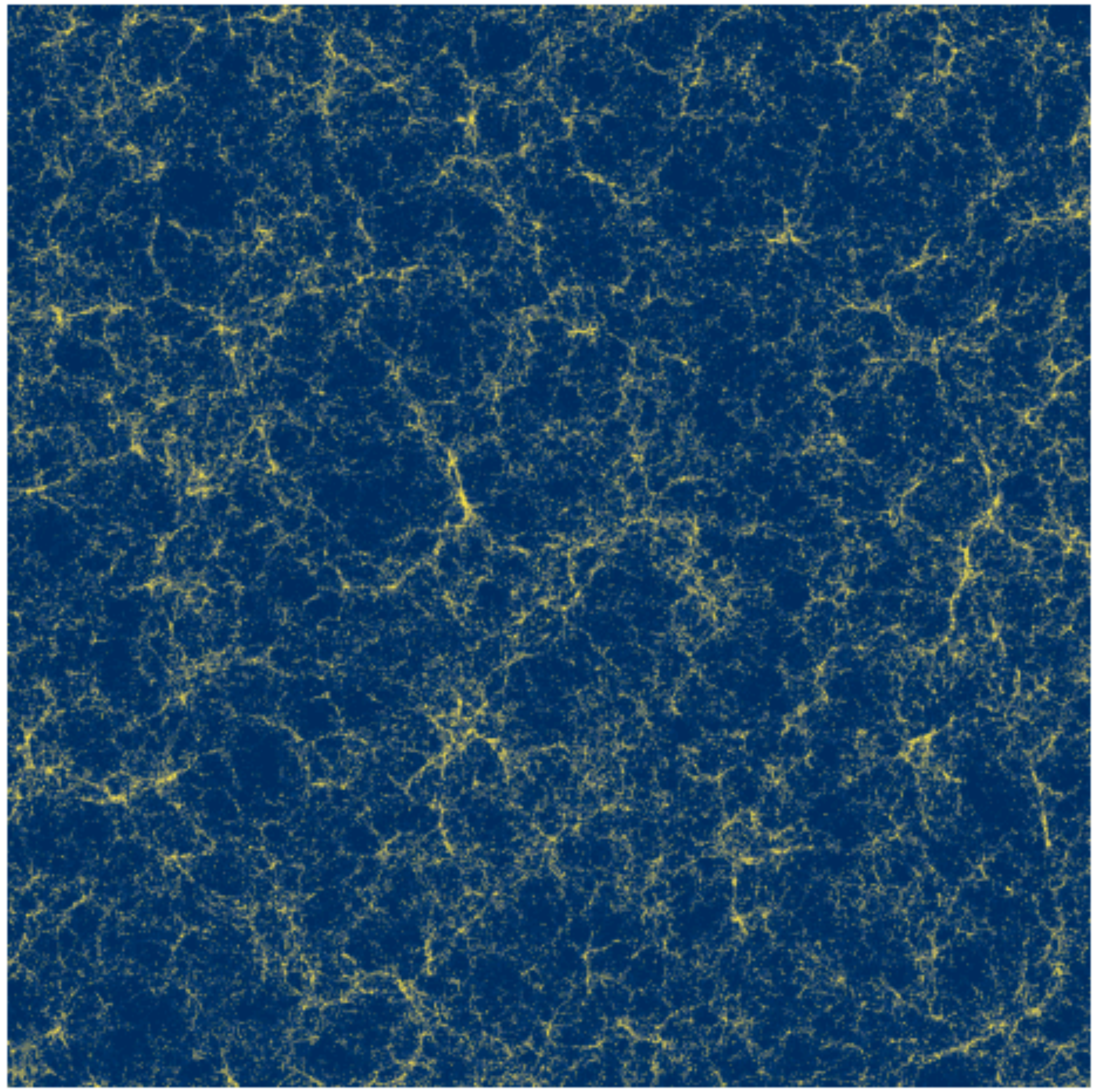
Reionization with [CII]

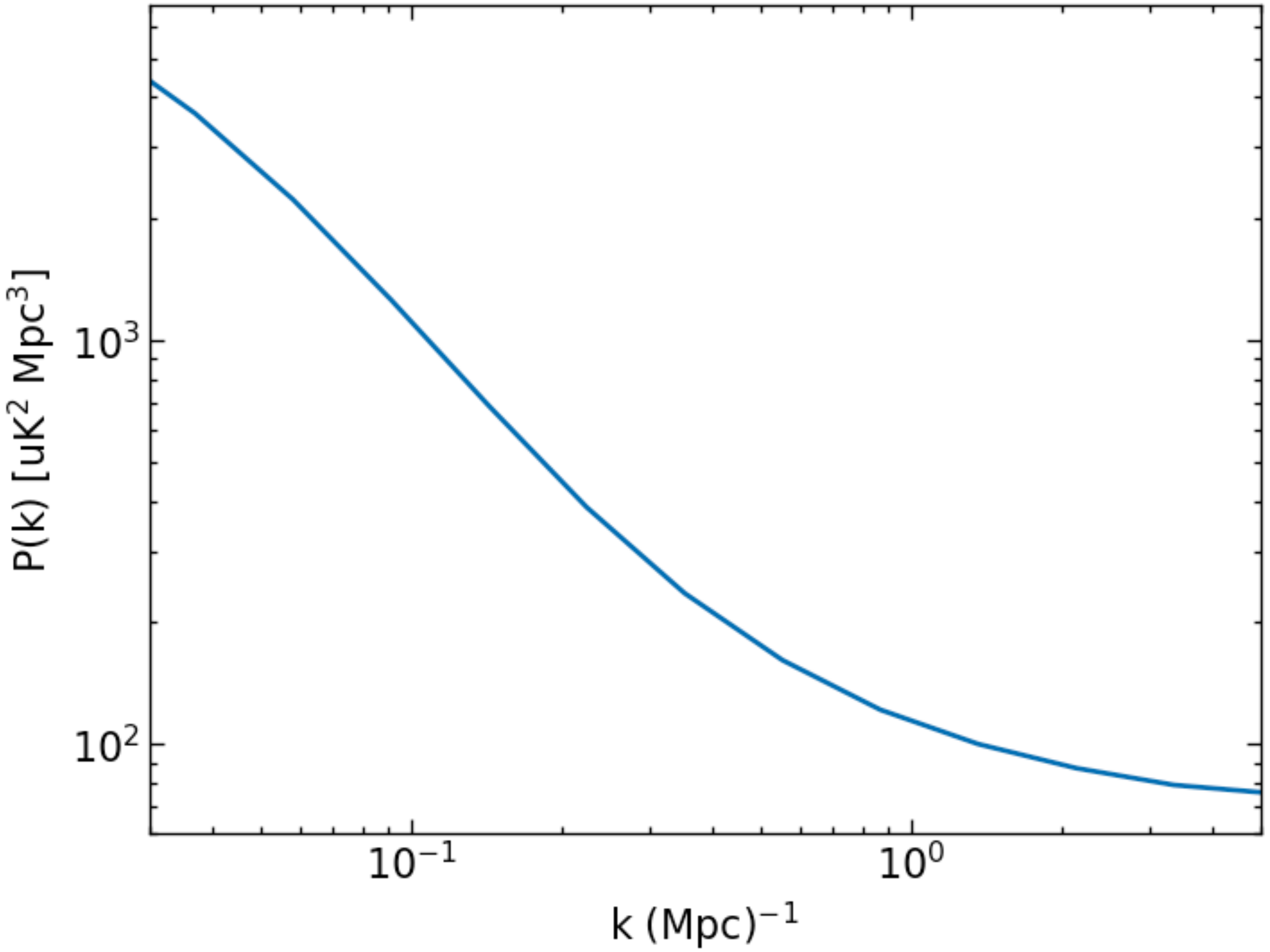


Lidz+ 2009

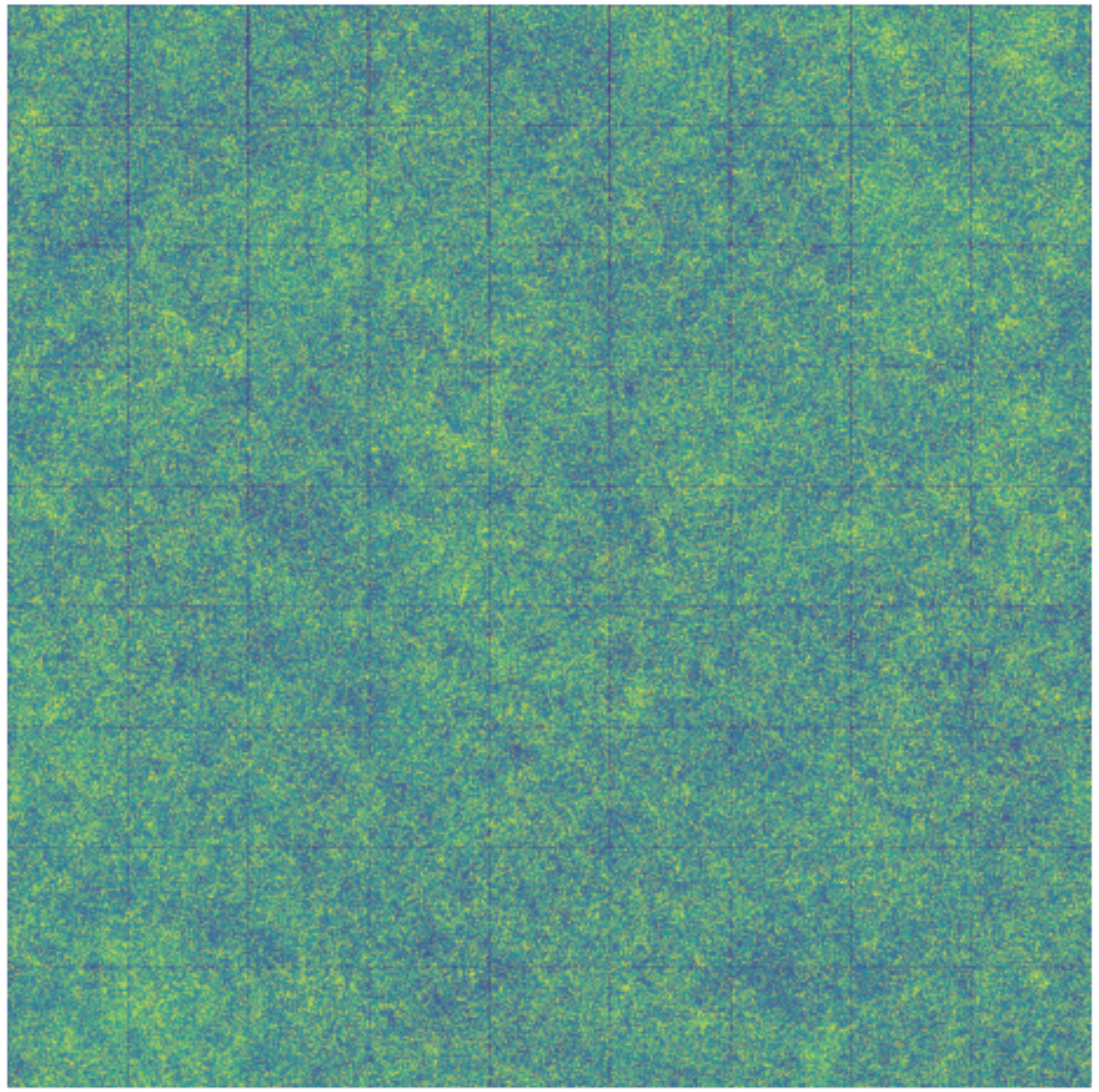
Complementary to 21 cm

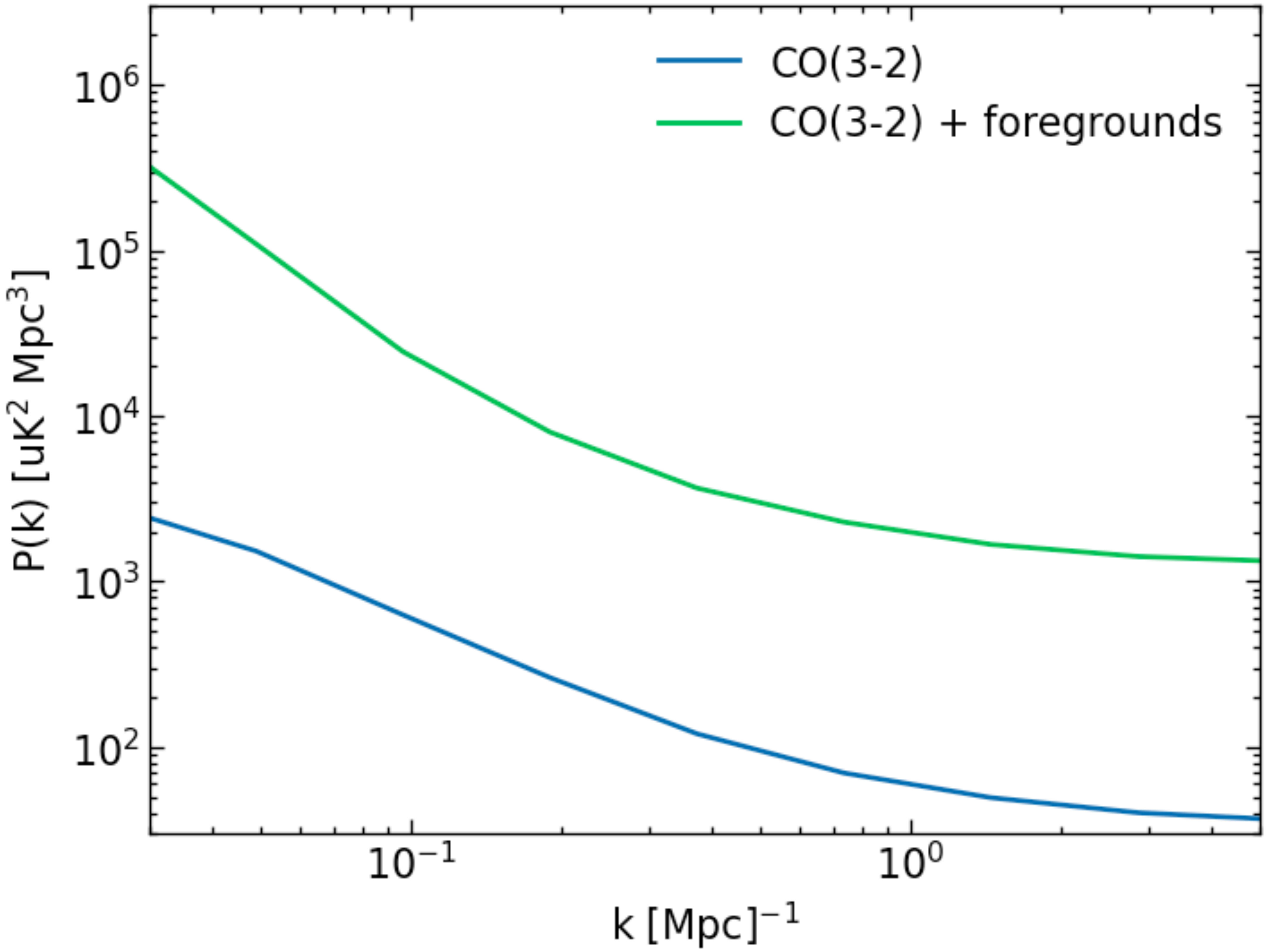
CO(3-2) at 150 GHz (z=1.3)



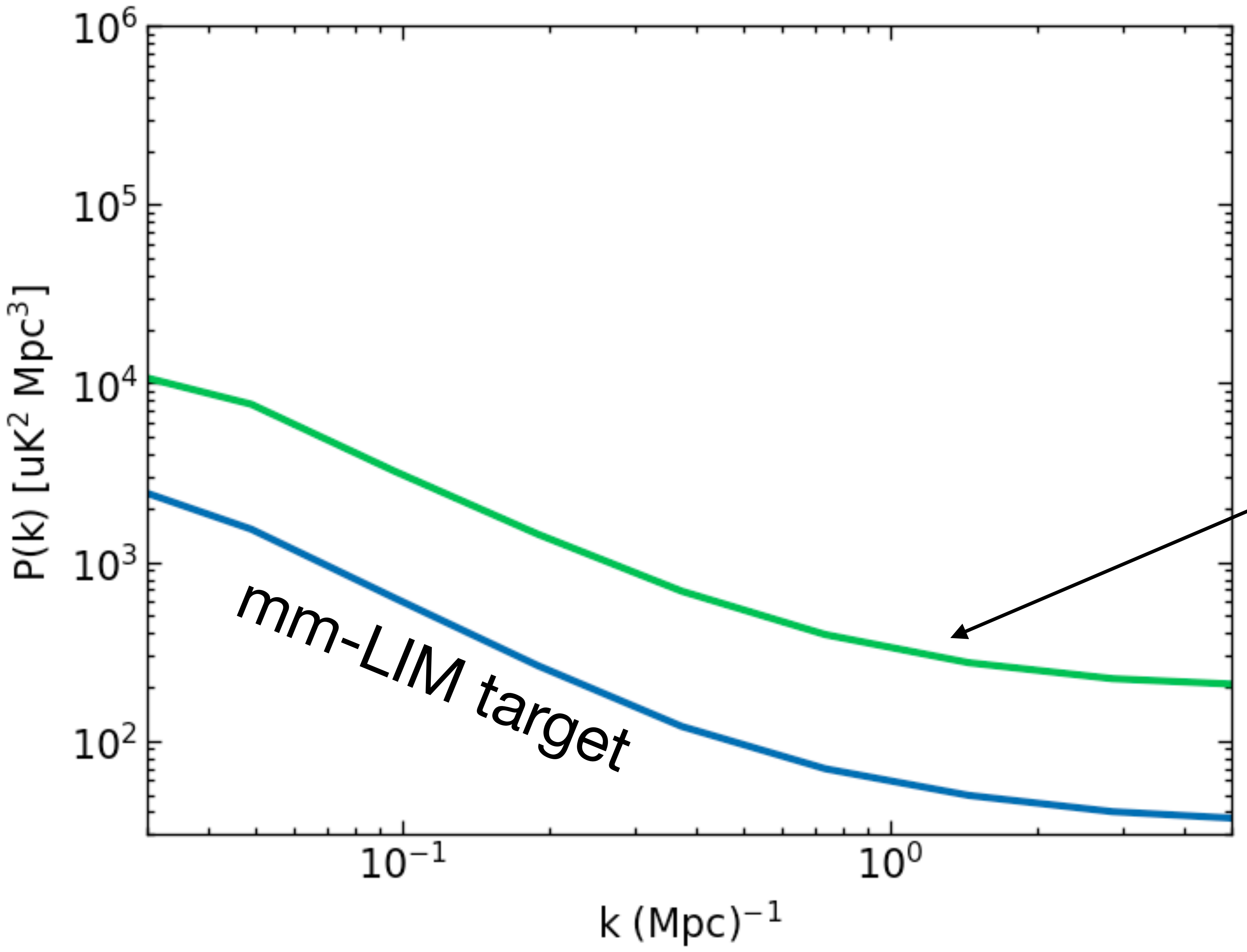


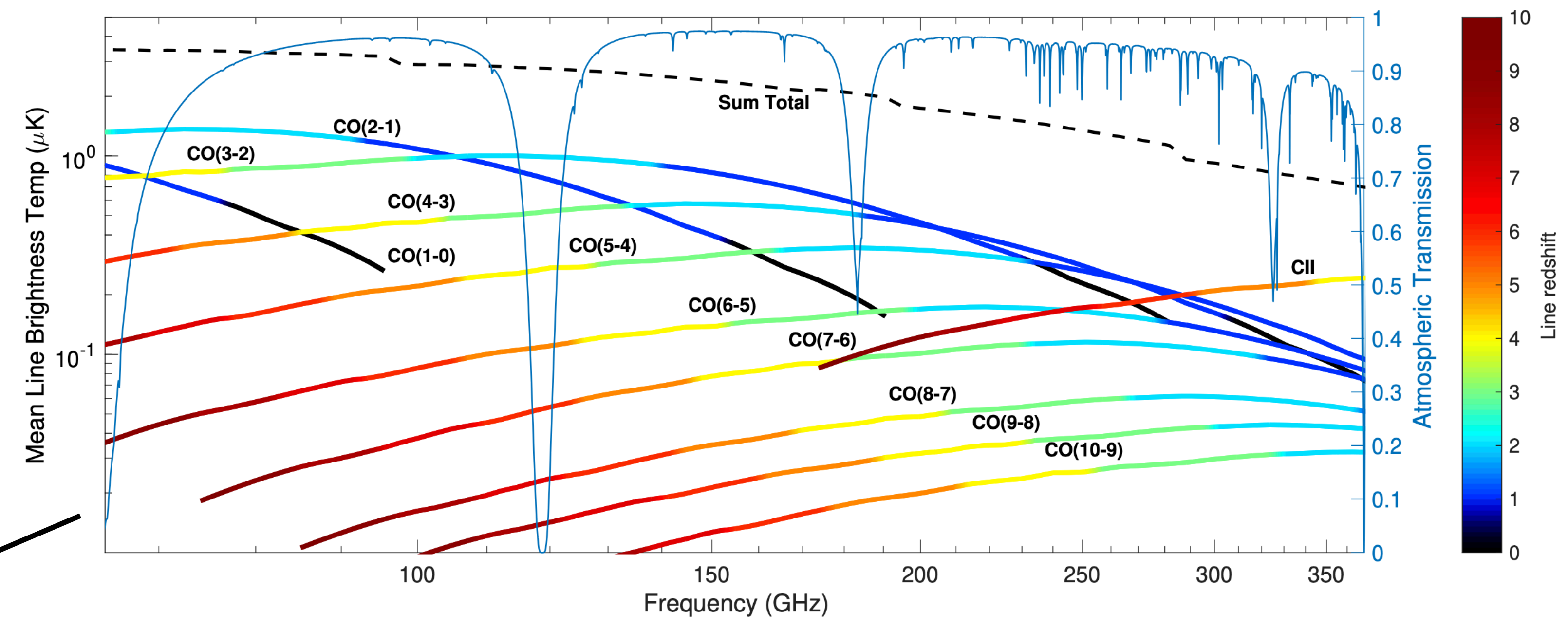
Full sky at 150 GHz (CMB-subtracted)

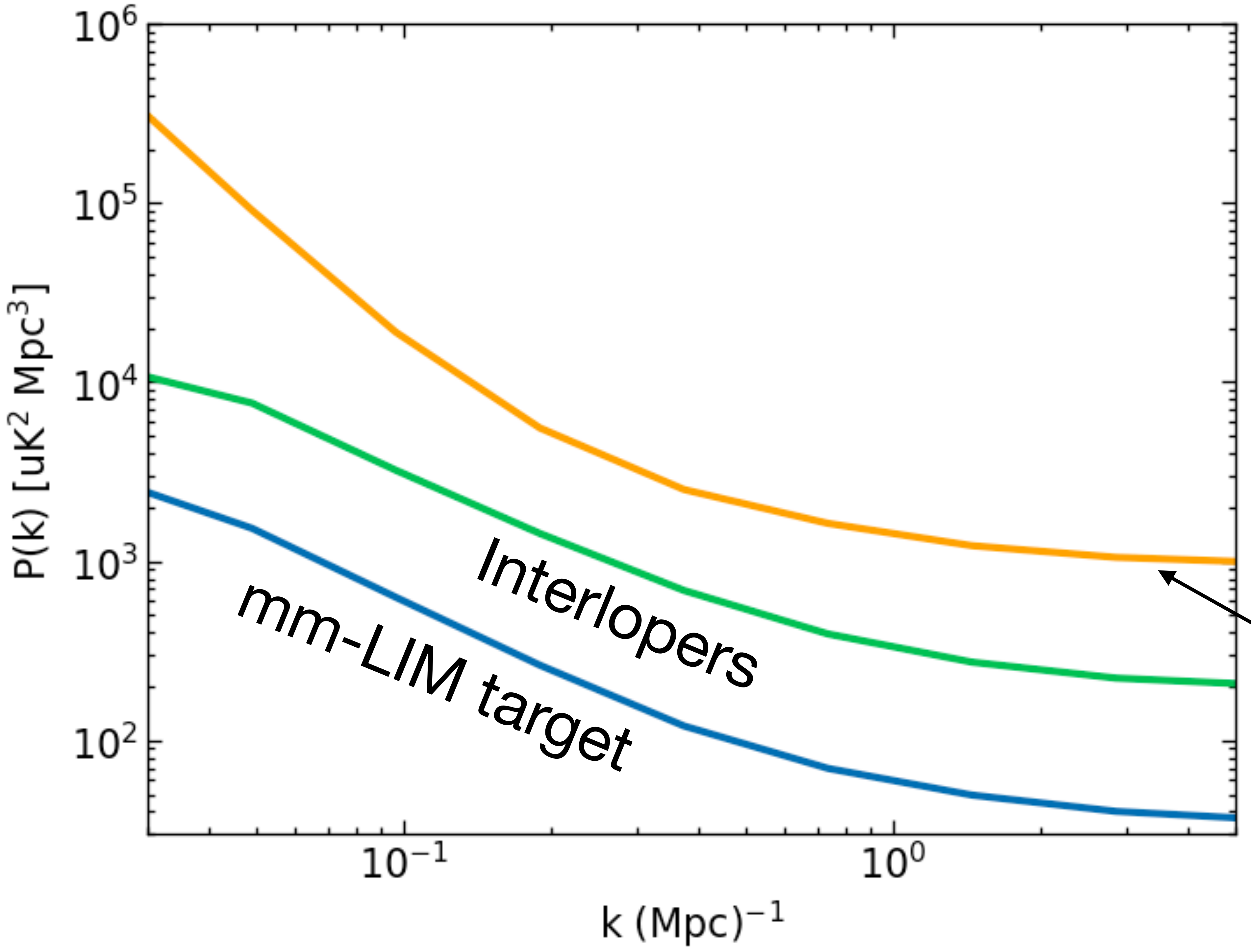




Interlopers







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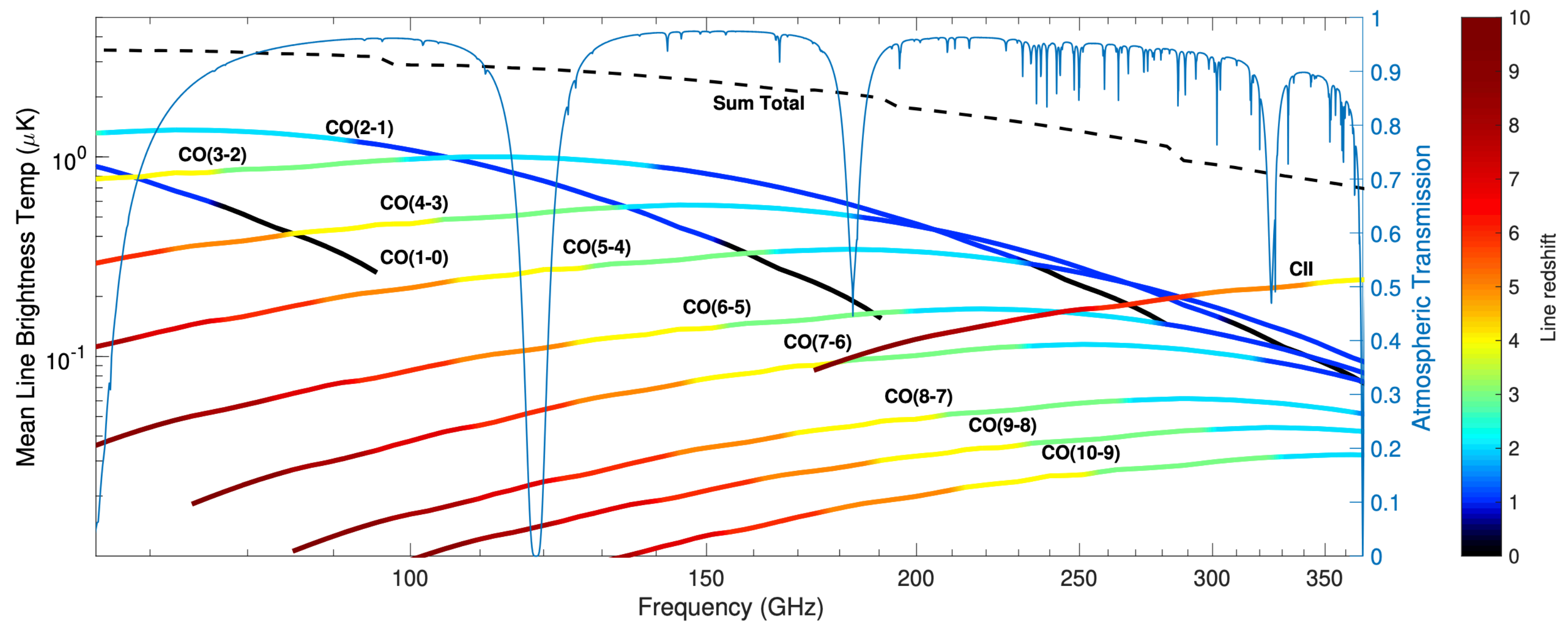
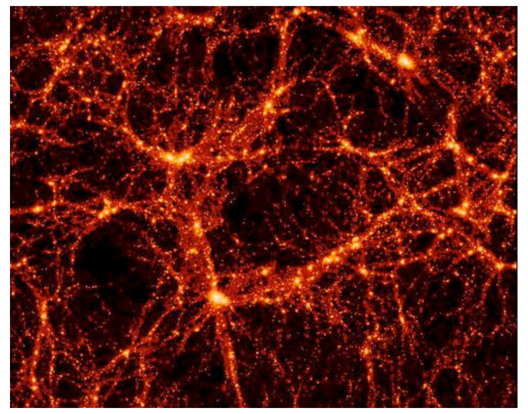
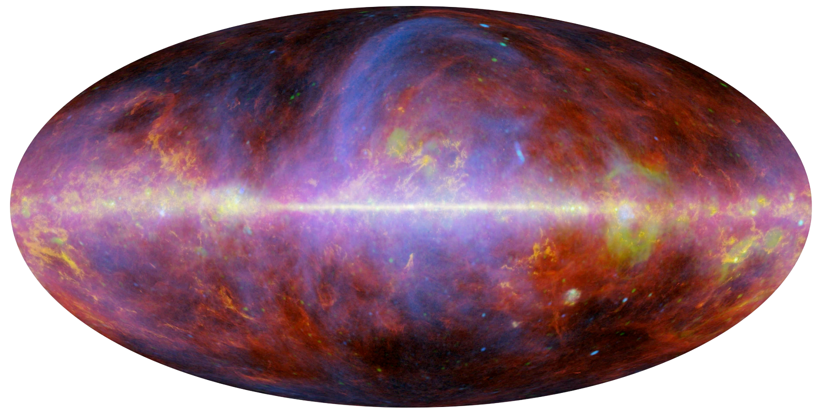


Continuum foregrounds

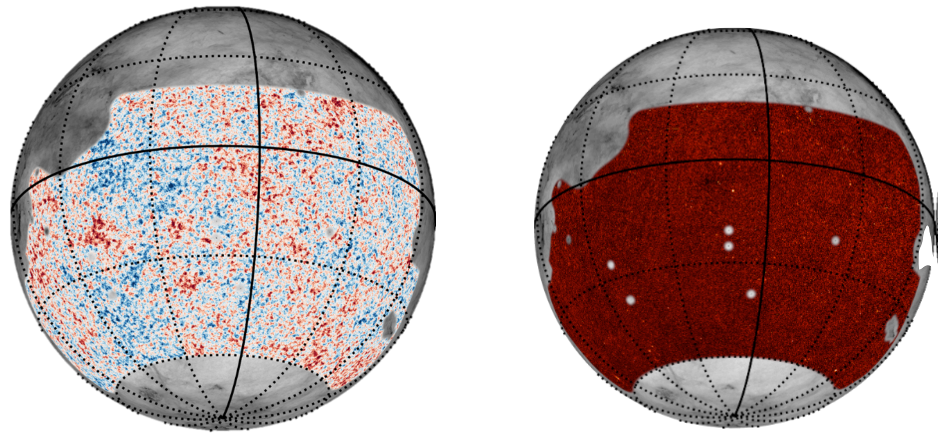
CIB

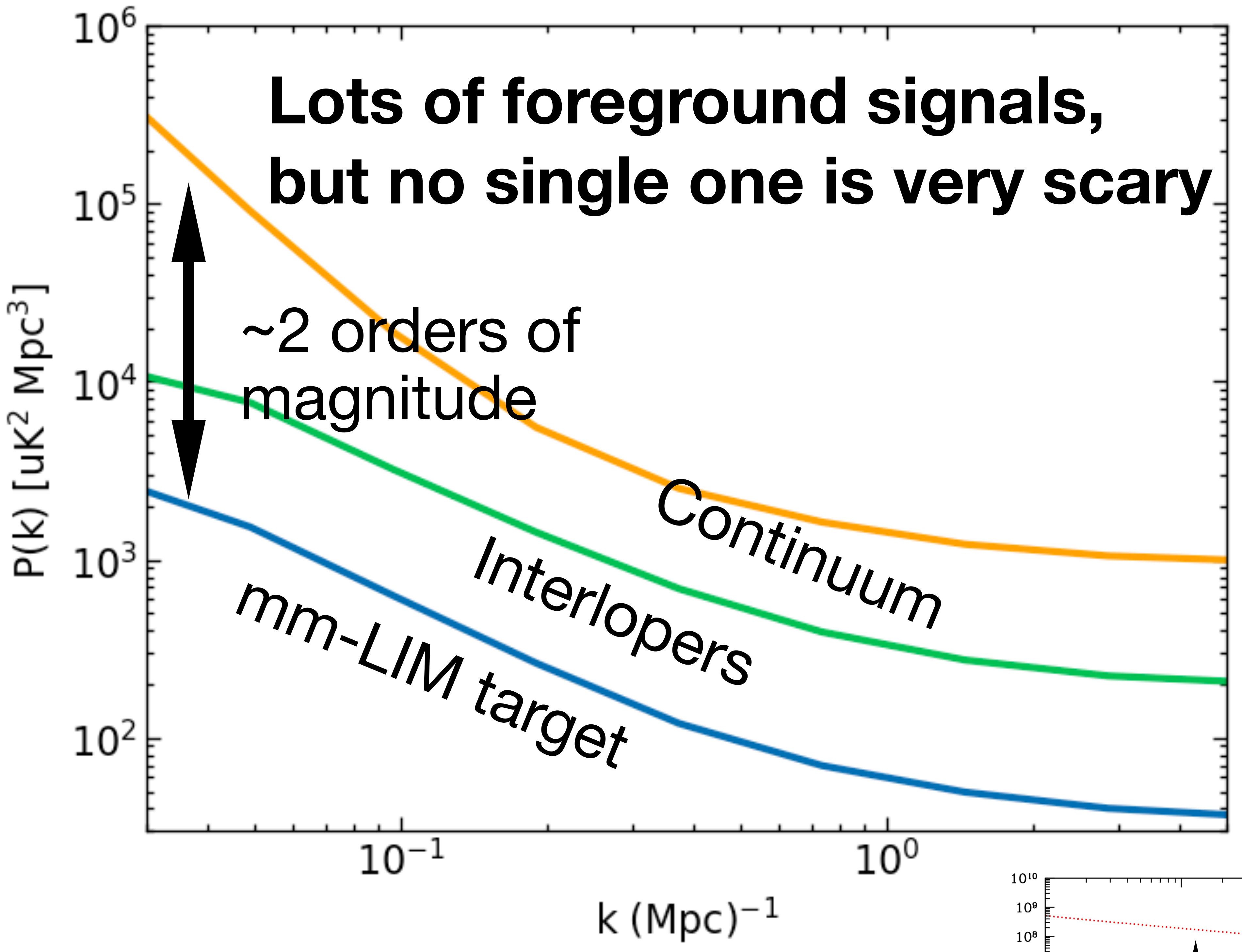


Galaxy



CMB primary + secondaries





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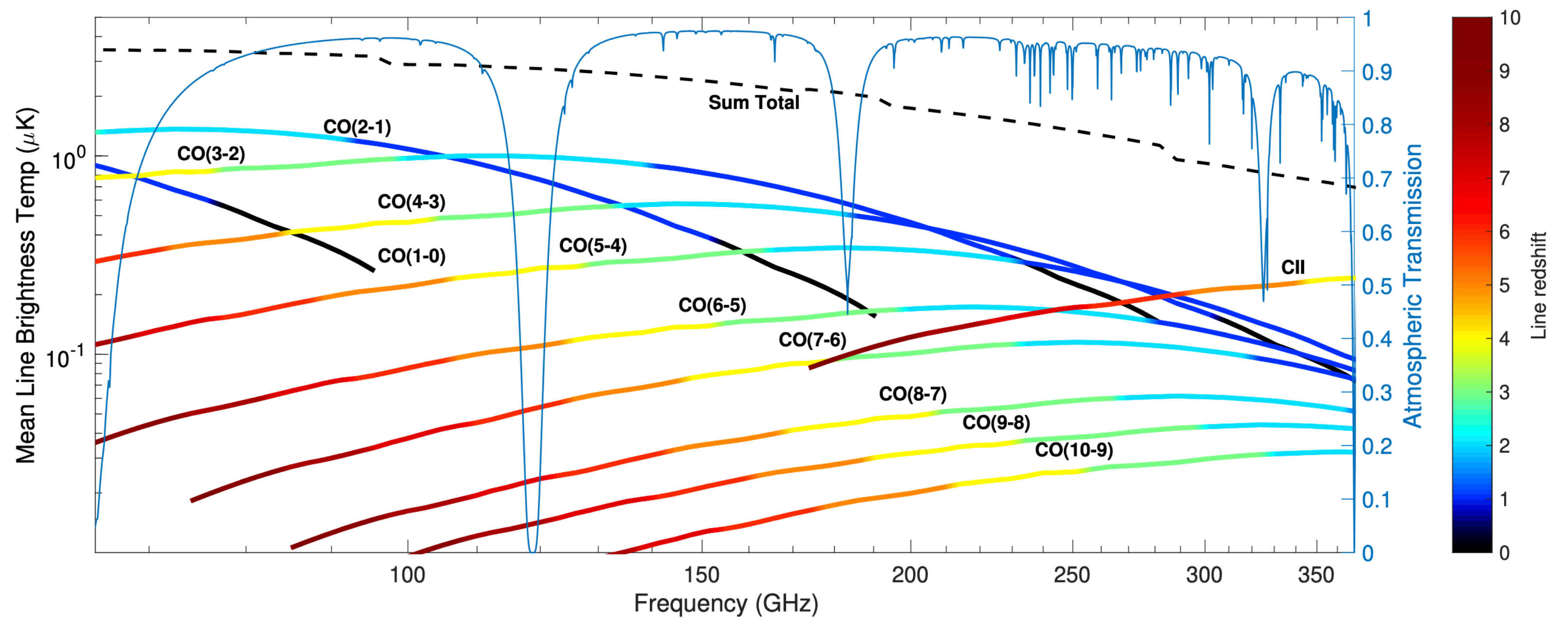

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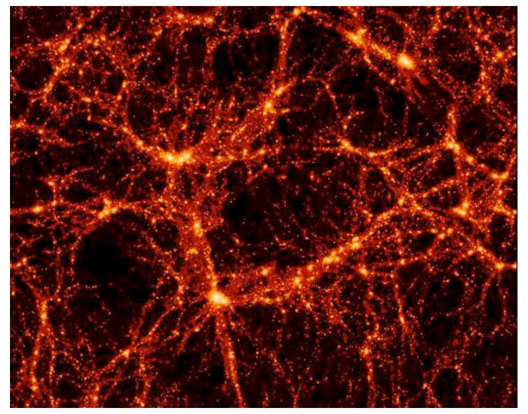

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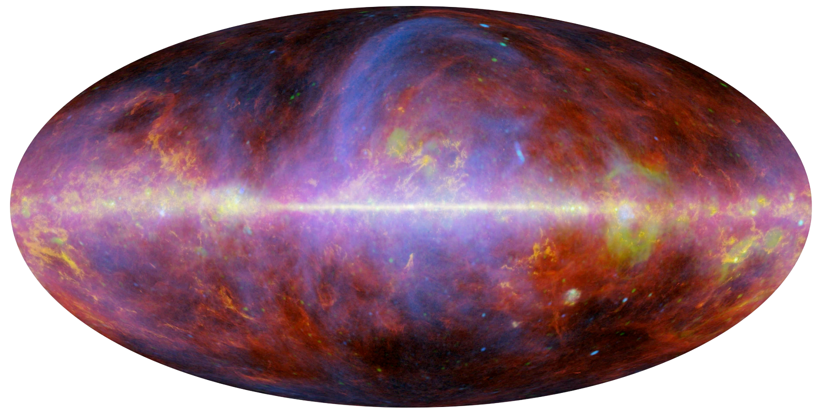

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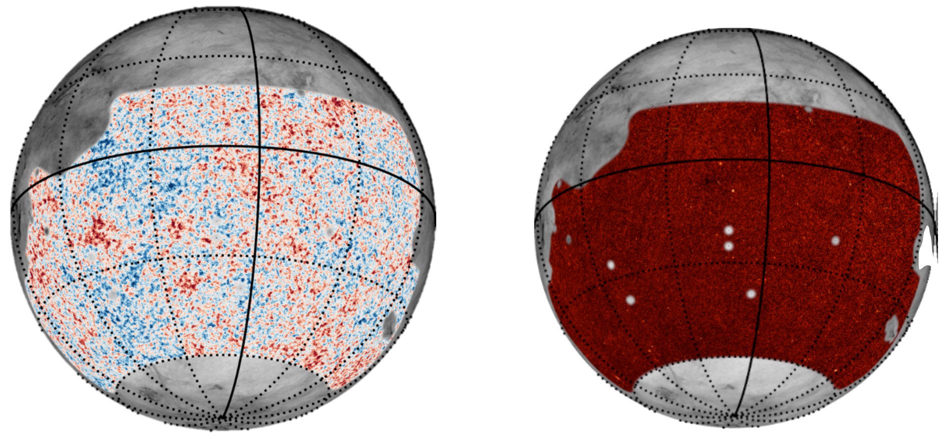
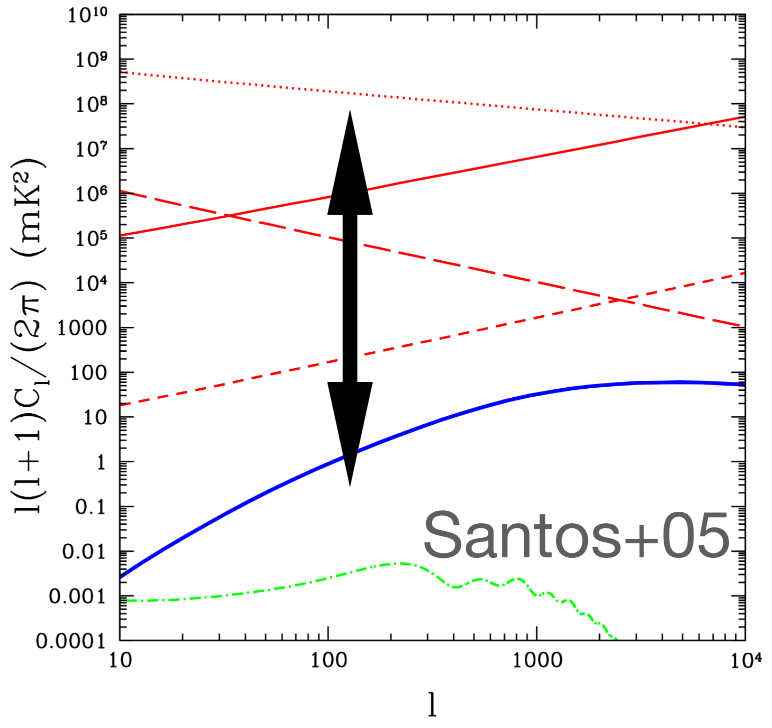




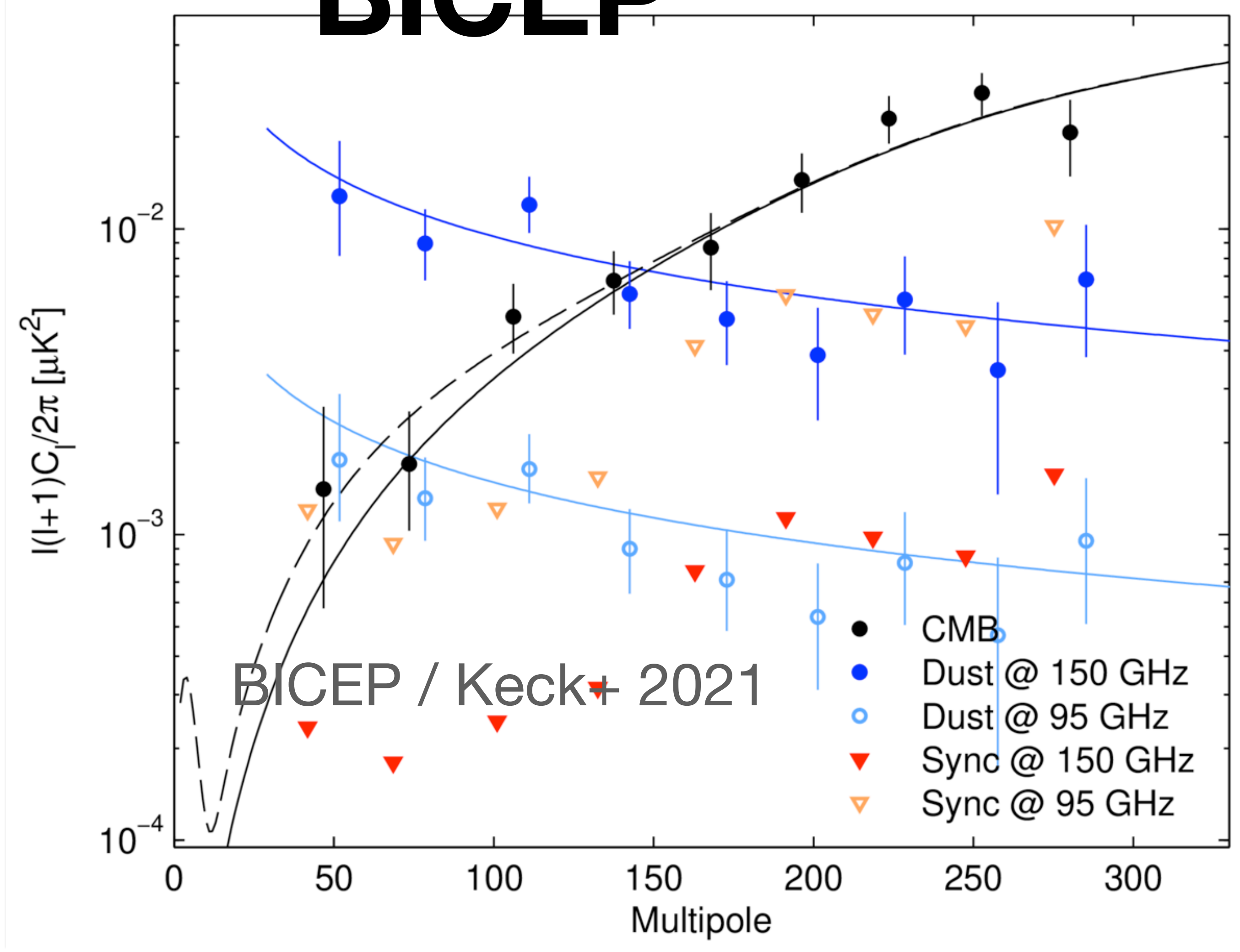
Contrast with e.g. 21 cm

- Foregrounds much brighter
- Modeling is a challenge
- Typically calls for avoidance or removal —> signal loss

The CMB solution: model all of it!

1. Model the spectral and scalar dependence of each sky component
2. Assemble the full data matrix of cross-frequency power spectra $C_\ell^{\nu\nu'}$
3. Estimate their covariance (typically from simulations)
4. Compute joint likelihood and solve for **all** signals simultaneously

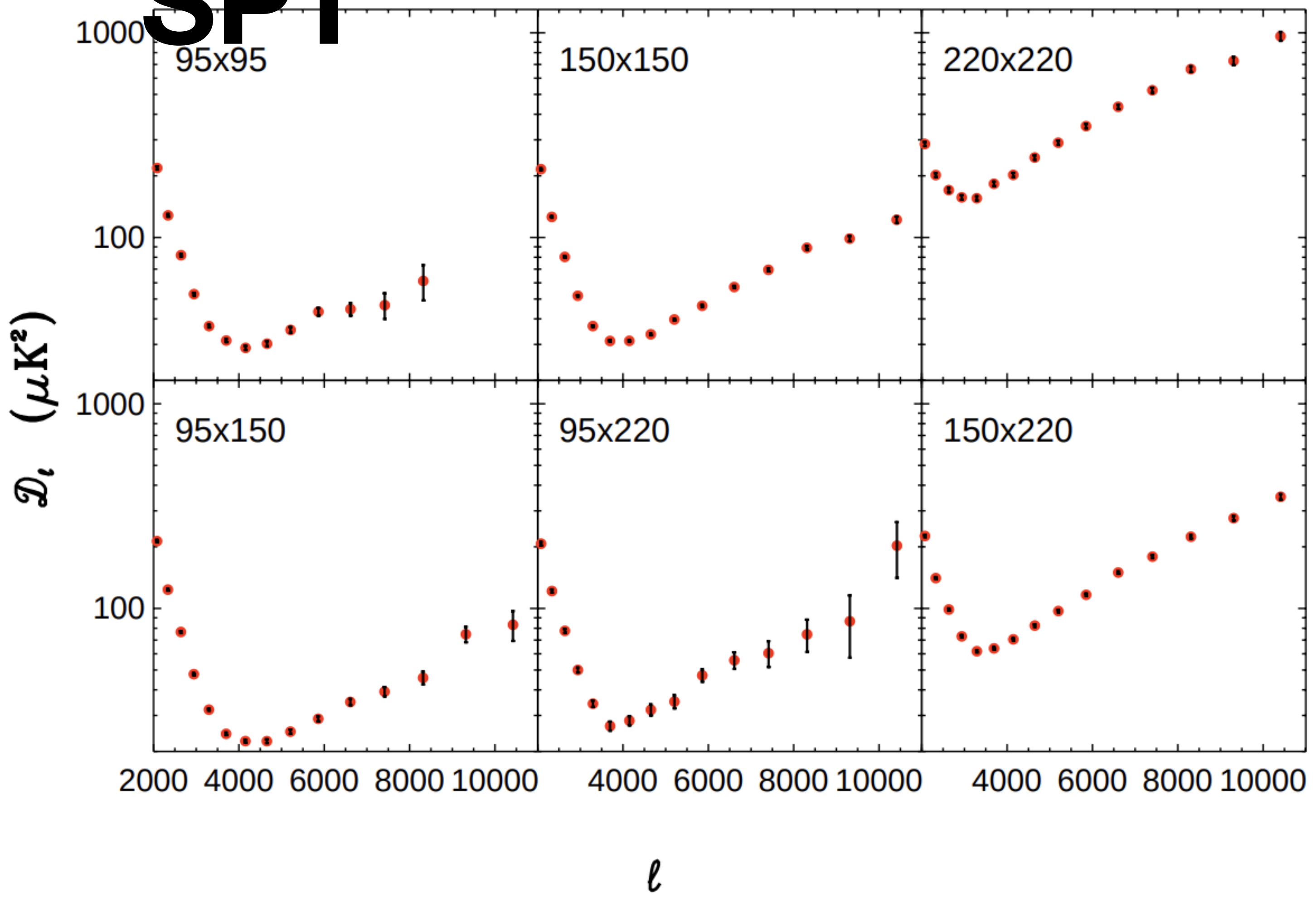
BICEP

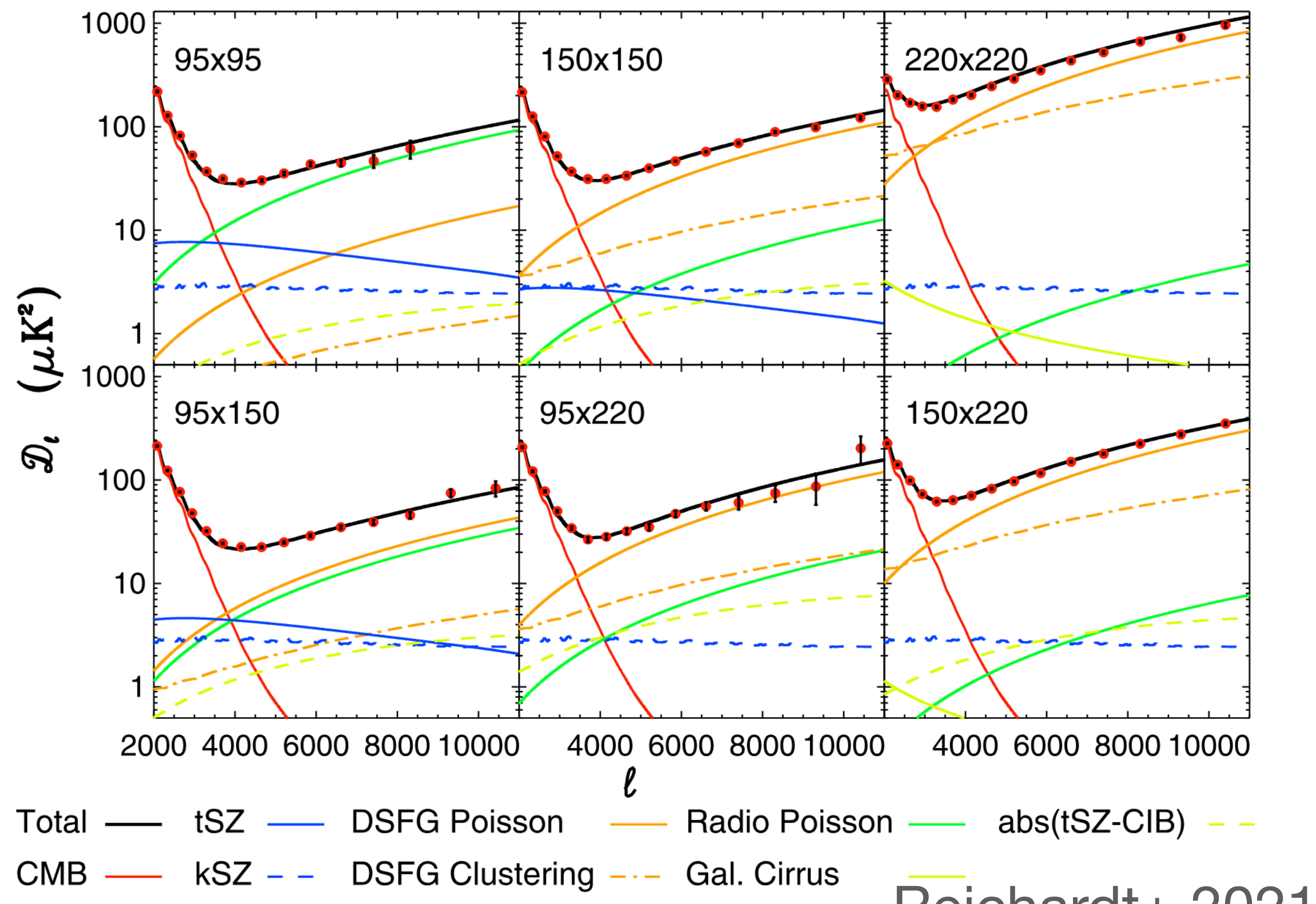


Degree scales

SPT

Data ➡ Inferred model





Reichardt+ 2021

Arcminute scales

Component separation

Assign parametric templates to each of these signals

- **Lines:** CO(2-1), CO(3-2), CO(4-3), [CII]…
- **Smooth foregrounds:** CIB, Galactic foregrounds, CMB, tSZ…
- **Cross-correlations:** COxCIB, CIBxtSZ…
- **External tracers:** photo-z, spec-z galaxy surveys
- **Instrument uncertainties:** passband, beam, gain…

$$C_\ell \sim A\left(\frac{\ell}{\ell_0}\right)^\alpha \left(\frac{\nu}{\nu_0}\right)^\beta$$

$$\rightarrow \mathcal{L}(\mathrm{data}|\theta_{\mathrm{CO}}, \theta_{\mathrm{CIB}}, \theta_{\mathrm{GalDust}}, \theta_{\mathrm{SZ}}, \theta_{\mathrm{CMB}}\dots)$$

$$\downarrow$$

Priors well constrained from decades of CMB observations

Assume Gaussian likelihood

$$-2\ln\mathcal{L} = (\mathbf{D}-\mathbf{M})^\top\,\mathbf{Cov}^{-1}\,(\mathbf{D}-\mathbf{M})$$

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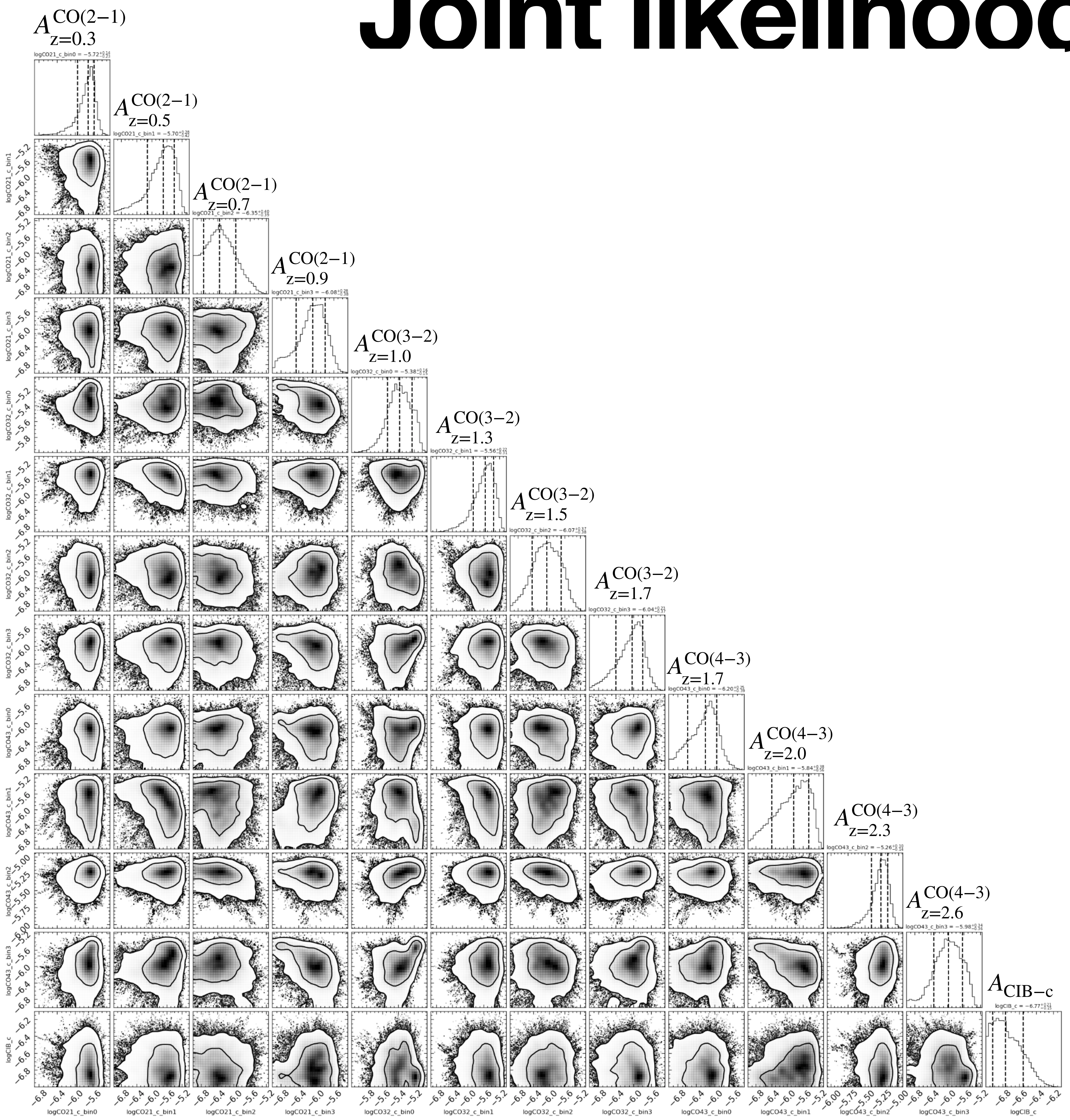
Priors well constrained from decades of CMB observations

Building on previous joint LIM inference methods, e.g.

- Switzer+18: (CIB+[CII] with *Planck*)
- Cheng+24: (Line-line correlations) $\longrightarrow$ Enables self contained interloper separation

Here we adopt this strategy for mm-LIM to solve for **all sky correlations within a unified framework**

Joint likelihood — Preliminary model



- Mock data cubes generated from SIDES simulations
  - Assuming compressed N=10 channels spanning 120—180 GHz over a 1x1 deg sky area
- Simple model includes 3x CO lines + CIB foreground
- Fit $A_{\rm clust} = \langle Ib \rangle^2$ across 4 redshift bins each = **13 free parameters**
- Work in progress —lots of room for improvement:
  - Line degeneracy breaking
  - More correlations (dust, CO-CIB, etc)
  - Larger mock sky coverage —> more modes

Summary

- The mm-wave sky is crowded with interlopers and continuum foregrounds, requiring a robust component separation technique
- We propose that a CMB-style multi-frequency likelihood is the *statistically optimal* method for recovering information in a mm-LIM dataset
- Model all signals— foregrounds + interlopers— simultaneously
- Stay tuned for more!

Extra

Model templates

$$C_{\ell,\nu_i,\nu_j}^{\rm dust} = a_{\rm dust}\left(\frac{\ell}{\ell_0}\right)^{\alpha_{\rm dust}}\left(\frac{\nu_i\,\nu_j}{\nu_0^2}\right)^{\beta_{\rm dust}}\frac{B_{\nu_i}(T_d^{\rm eff})\,B_{\nu_j}(T_d^{\rm eff})}{B_{\nu_0}^2(T_d^{\rm eff})}$$

$$C_{\ell,\nu_{\rm i},\nu_{\rm j}}^{\rm sync} = a_{\rm sync}\left(\frac{\ell}{\ell_0}\right)^{\alpha_{\rm sync}}\left(\frac{\nu_i\nu_j}{\nu_0^2}\right)^{\beta_{\rm sync}}$$

$$C_{\ell,\nu_i,\nu_j}^{\rm CIB-c} = a_{\rm CIB-c}\,C_\ell^{\rm template}\left(\frac{\nu_i\nu_j}{\nu_0^2}\right)^{\beta_{\rm CIB-c}}\frac{B_{\nu_i}(T_d)B_{\nu_j}(T_d)}{B_{\nu_0}^2(T_d)}$$

$$C_\ell^{\rm CO\times CIB} = \xi\,\sqrt{A_{\rm CO}A_{\rm CIB}}\,C_\ell^{\rm template}\left(\frac{\nu_0}{\nu_{\rm CIB}}\right)^{\beta_{\rm dust}}\frac{B_{\nu_0}(T_d)}{B_{\nu_{\rm CIB}}(T_d)}$$

$$C_{\ell,\nu_{\rm i},\nu_{\rm j}}^{\rm tSZ} = a_{\rm tSZ}\frac{f(\nu_i)f(\nu_j)}{f^2(\nu_0)}C_{\ell_0,\ell,\nu_{\rm i},\nu_{\rm j}}^{\rm tSZ}$$

$$\hat{P}_k^{\rm CO_{J\to J-1}} = A_{\rm clust}^{\rm CO_{J\to J-1}}P_m(k) + P_{\rm shot}^{\rm CO_{J\to J-1}}$$

(Limber integrated)

$$C_{\ell,\nu_{\rm i},\nu_{\rm j}}^{\rm tSZ\times CIB} = -\xi\sqrt{a_{\rm tSZ}a_{\rm CIB-c}}\,C_{\ell_0,\ell,\nu_i,\nu_j}^{\rm tSZ\times CIB}\left[\frac{f(\nu_i)\mu(\nu_j,\beta_{\rm CIB-c},T_d)+f(\nu_j)\mu(\nu_i,\beta_{\rm CIB-c},T_d)}{f(\nu_0)\mu(\nu_0,\beta_{\rm CIB-c},T_d)}\right]$$

$$\hat{P}_k^{\rm gal\times CO} = \sqrt{A_{\rm clust}^{\rm CO_{J\to J-1}}}\,b_{\rm gal}P_m(k)$$