Contributions of extragalactic emission lines to ground-based CMB observations

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with

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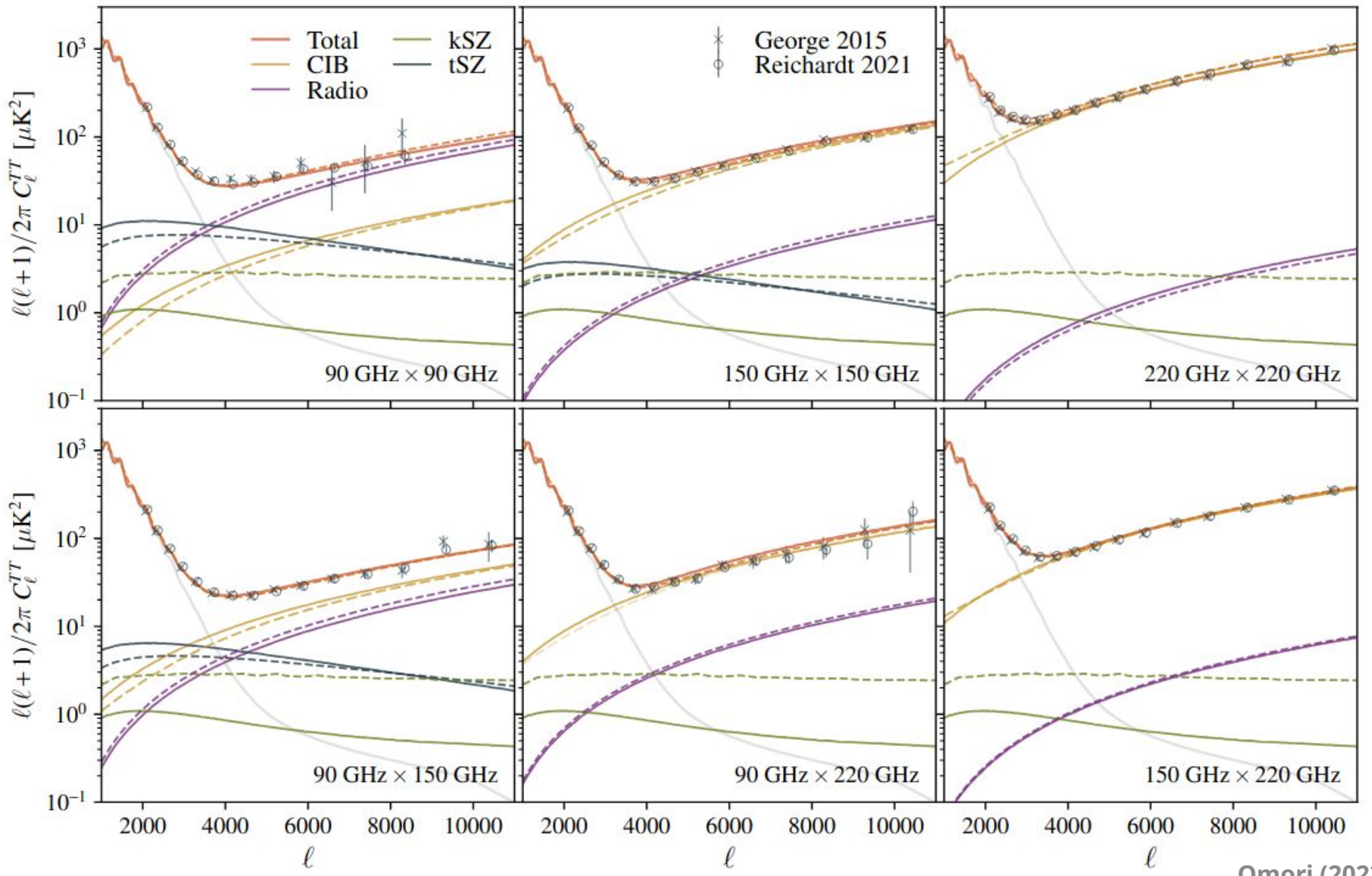
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
AGENCIA ESTATAL DE INVESTIGACIÓN
IFCA Instituto de Física de Cantabria
CSIC Consejo Superior de Investigaciones Científicas
UC Universidad de Cantabria

CMB TT spectra at small scales



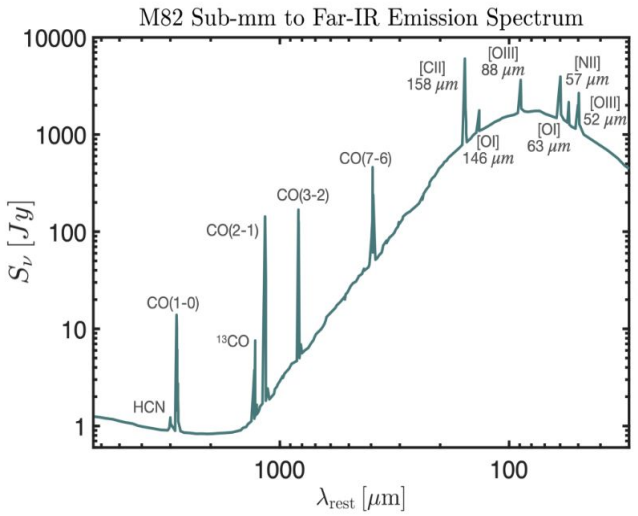
Omori (2022)

Emission lines within CMB bands

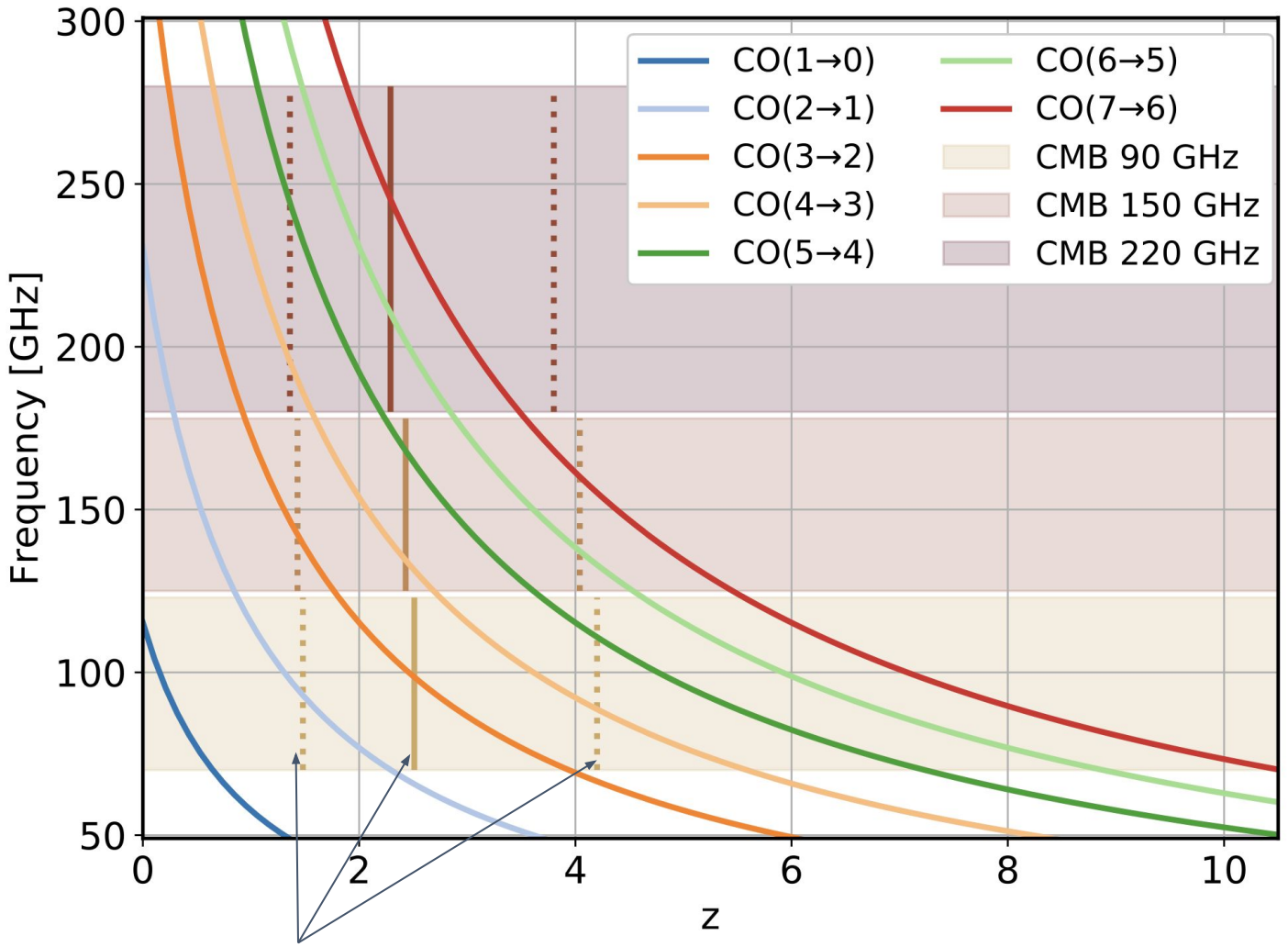
- Sub-mm lines are related to SFR (as CIB)

$$L \sim \frac{\int P(\nu)\Phi(\nu)d\nu}{\int P(\nu)d\nu} \underset{\text{If LIM}}{\sim} \frac{P(\nu_0)}{\Delta\nu}$$

- Righi+ 2008: collected but suppressed $(1/\Delta\nu)^2$
- Maniyar+ 2023: CO x CIB (only $1/\Delta\nu$)



Bernal & Kovetz (2022)

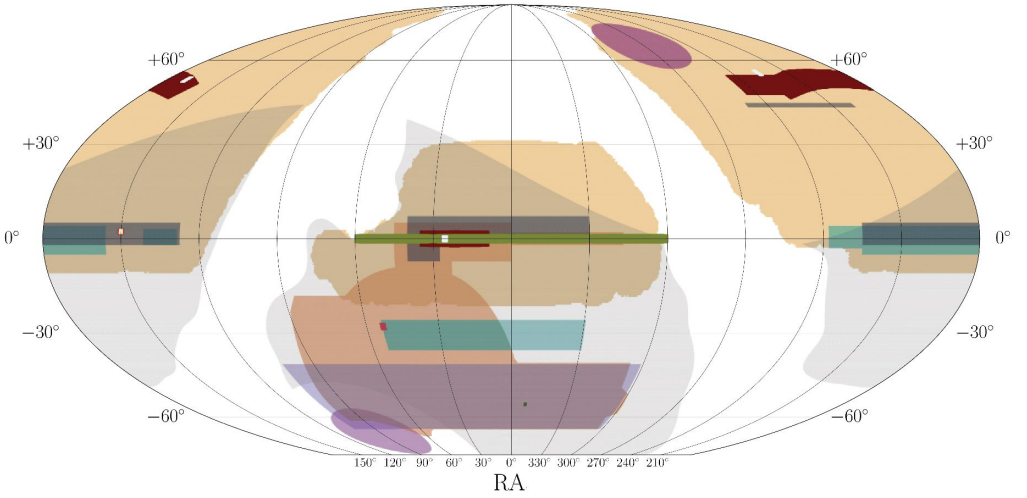


Redshift for which CIB peaks

ACT-like / SPT-like bandpasses

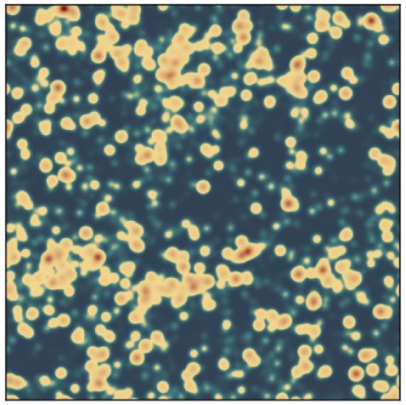
All probes in one sky

- **SkyLine**: Mock line observations (almost any line, contaminants, etc), LRGs and ELGs, …
- Coherent with **Agora**: CMB secondaries, extragal. foregrounds, and galaxy lensing

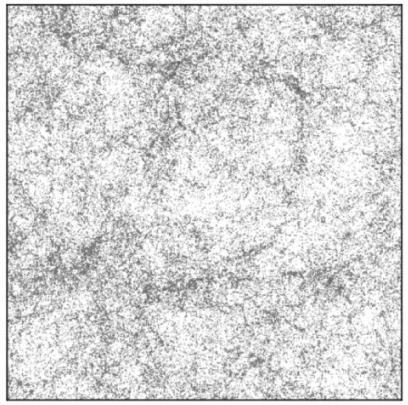


Bernal & Kovetz (2022)

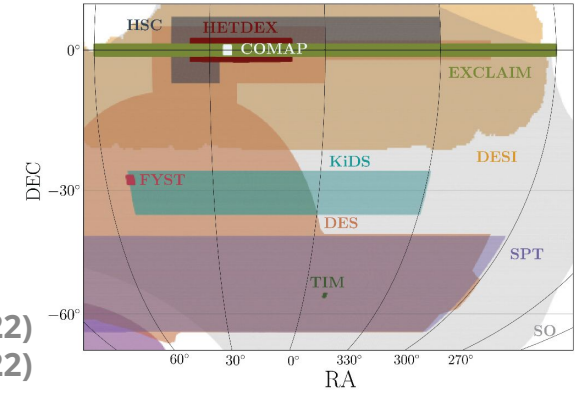
LIM

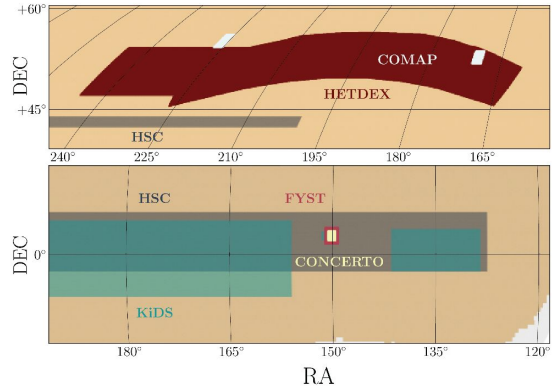


LRGs/ELGs

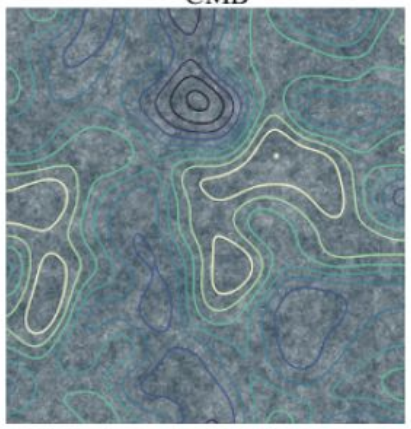


Sato-Polito, Kokron, Bernal (2022)
Omori (2022)

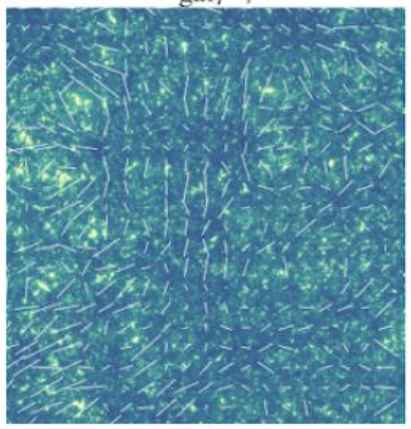




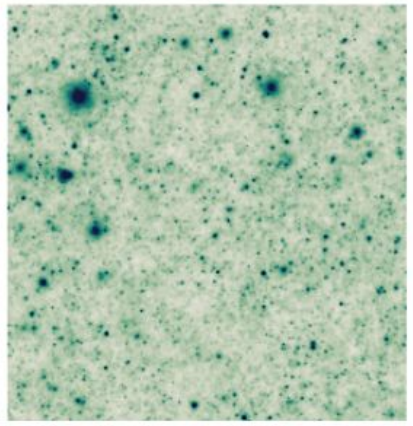
$\kappa_{\rm CMB}$



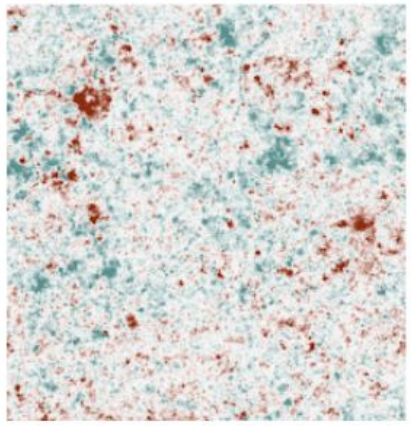
$\kappa_{\rm gal}/\gamma$



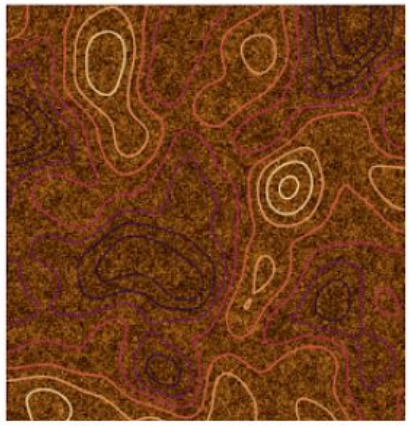
tSZ



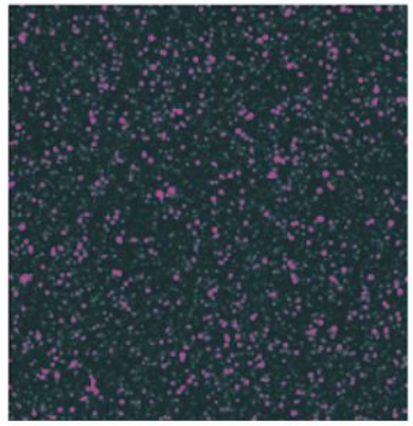
kSZ



CIB

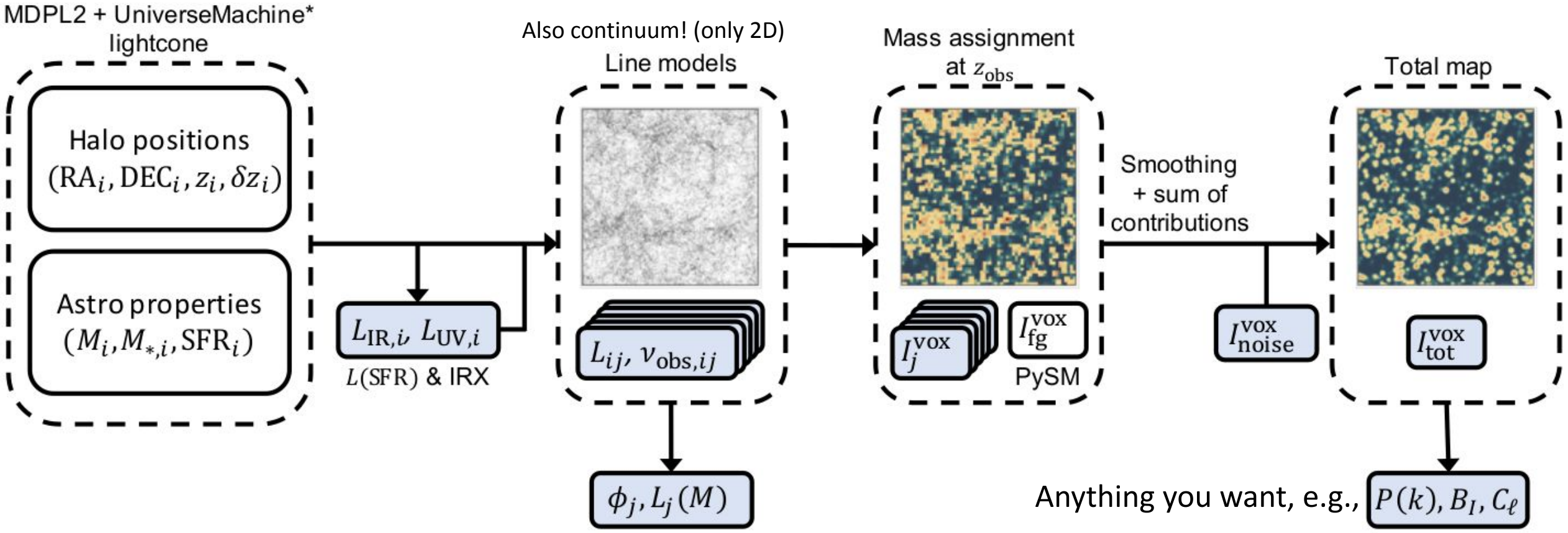


Radio



SkyLine

- Coherent multi-line, multi-probe simulated sky
- Mock map for a given experiment with *all* contributions, coherent with other probe



Sato-Polito, Kokron, Bernal (2022)

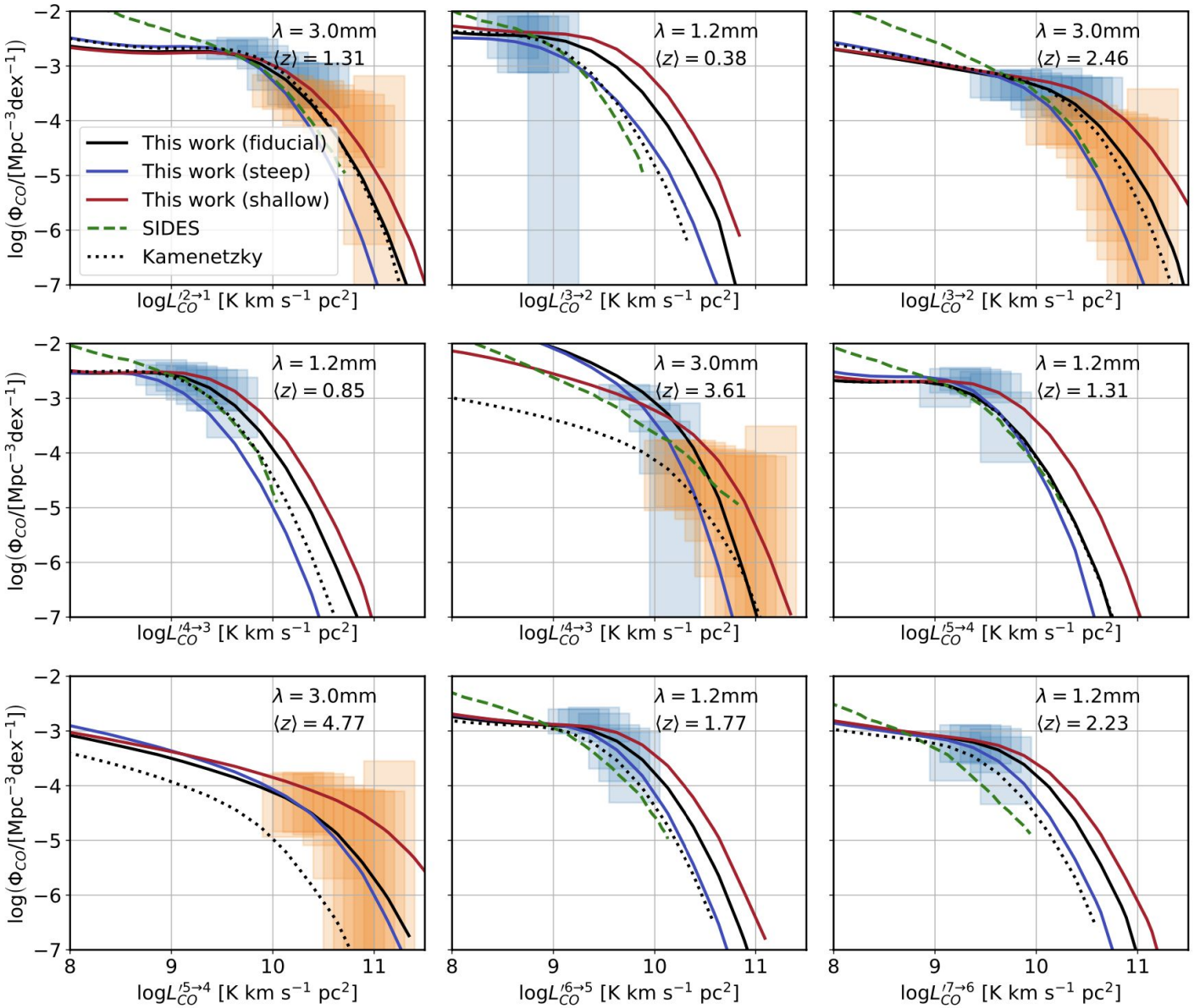
Modeling CO contributions to CMB bands

- Healpix maps using SkyLine (MDPL2+UniverseMachine SFR, M*, etc)
- Agora-like IR model, connected to CO

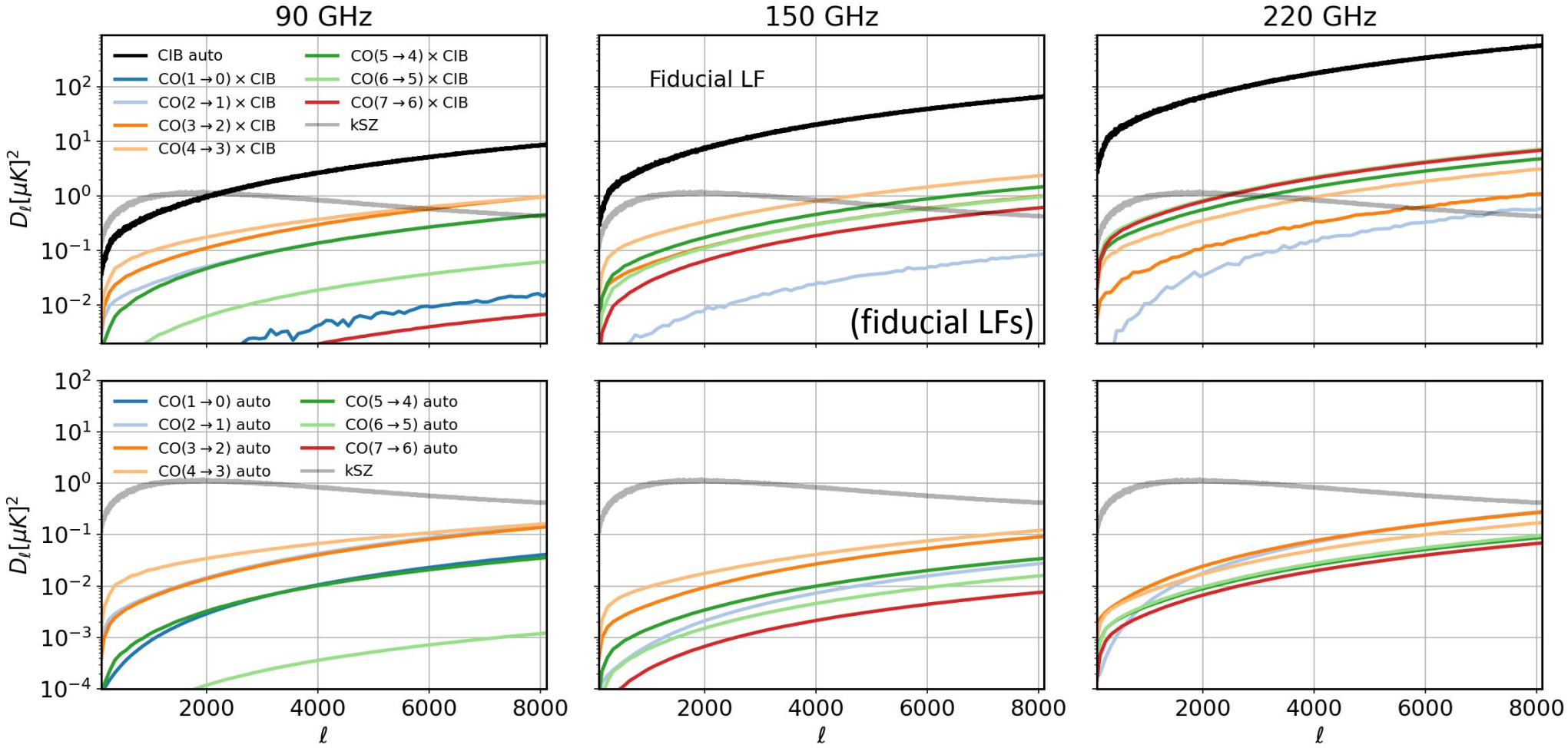
$$\log L_{\mathrm{CO,J}} = \frac{\log L_{\mathrm{IR}} - \alpha_J}{\beta_J}$$

- Conditioned on CO LF surveys at 100 GHz, 250 GHz through J=7 (ASPECS+NOEMA)
- Uncertainty in the “knee”/high-L tail (3 models, account for uncertainty)
- Contributions from each halo:

$$I_\nu^{\mathrm{CO},J}(\boldsymbol{\theta}) = \sum_i \delta^{(D)}(\boldsymbol{\theta} - \boldsymbol{\theta}_i) \frac{L_i^{\mathrm{CO},J}}{4\pi\chi^2(z_i)(1+z_i)^2\Delta\nu}$$



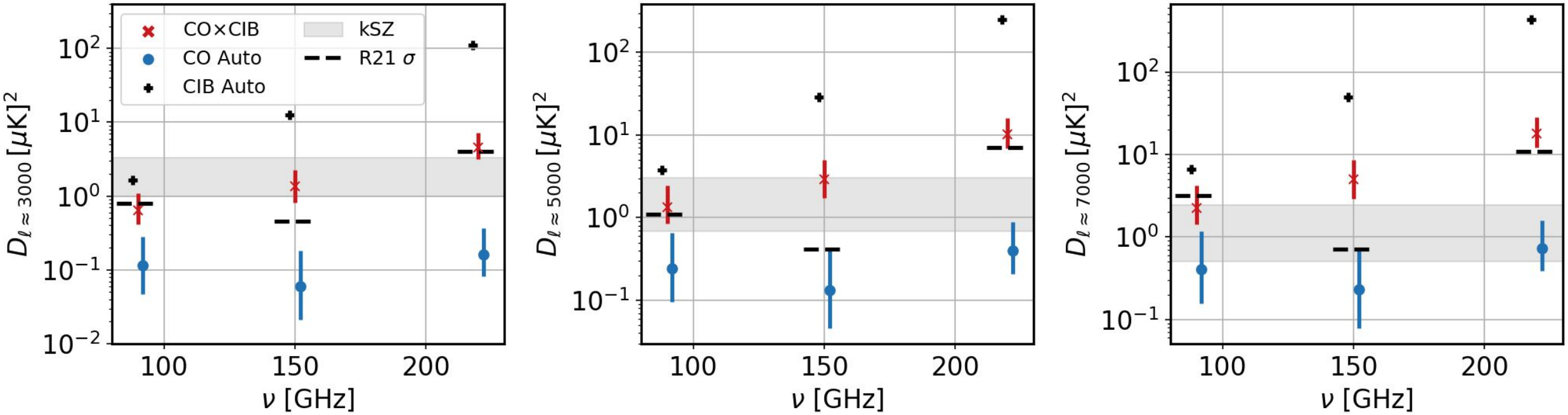
CO contributions to Cls



- At ℓ>3000, spectra are **shot-noise dominated**
- **Strong CO x CIB shot noise** (driven by same IR luminosity)
- Dominant line usually those that **overlap with peak of SFR** / CIB

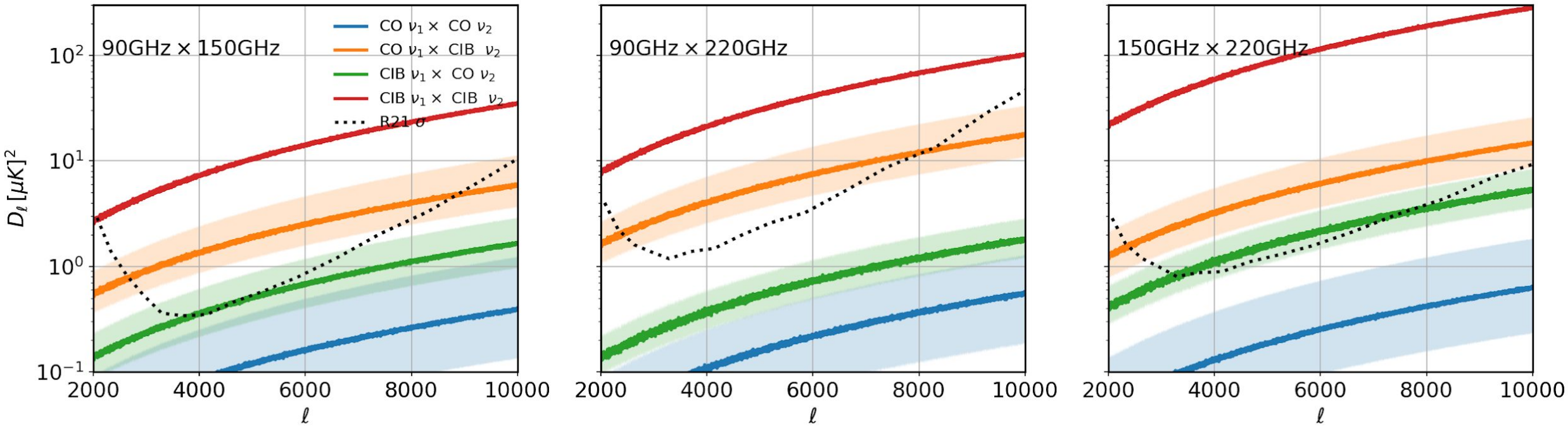
CO contributions to CMB TT (SPT)

Shown is 2<CO x CIB>



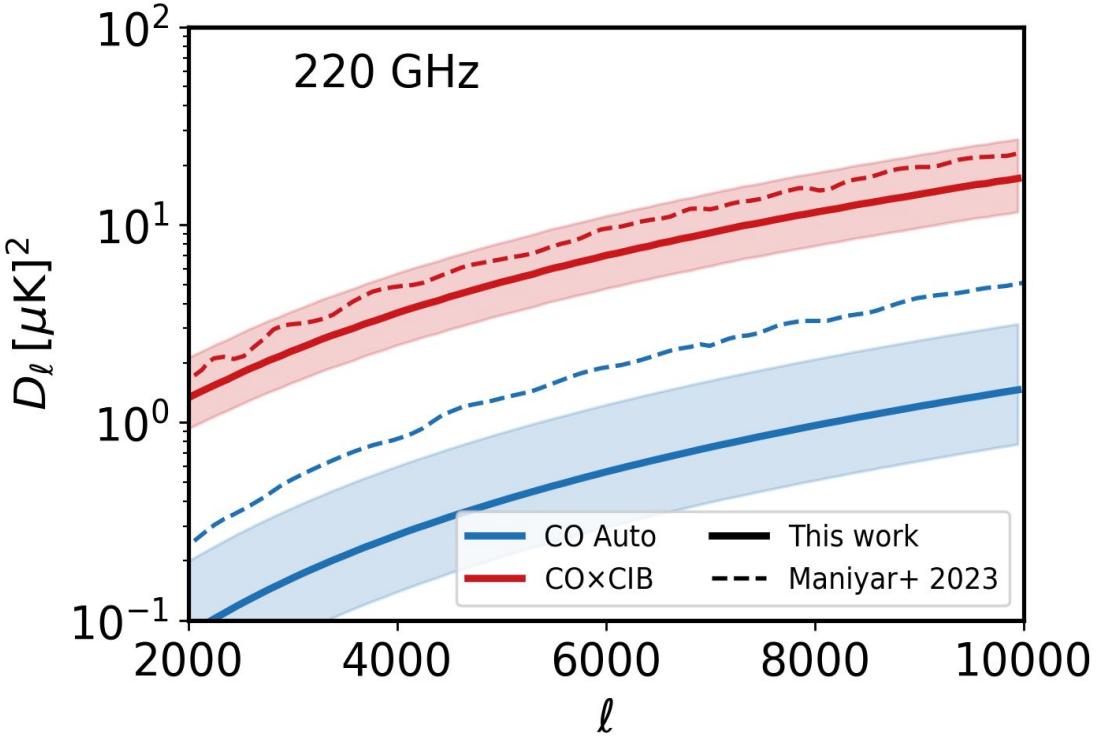
- Aggregate CO auto lower than kSZ, but CO x CIB is same order, around SPT sensitivity
- Uncertainties in CO LFs lead to ~factor 6 uncertainty in the CO auto
- At 90 GHz, other, non-considered foregrounds are more relevant (synchrotron, radio point sources, etc)
- SPT reported ~3σ detection of kSZ, higher than hydro sim. expectations: interpreted as patchy reio kSZ, but maybe CO emission?

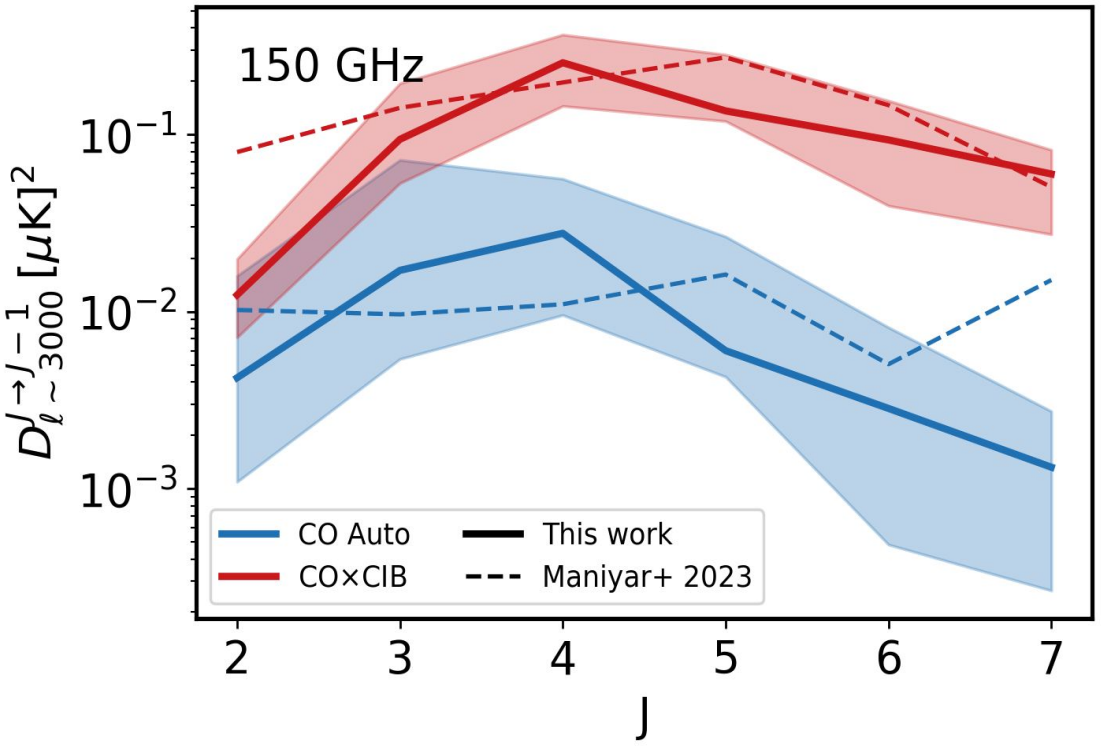
CO contributions to Cls



- Cross-frequency power spectra are much cleaner (key for comp. separation & template-based analyses)
- All scenarios have CO correlations above the SPT uncertainties: Potentially high SNR when compared to SPT uncertainties
- This should be detectable (?) -> Way to constrain CO in very different regime than sub-mm telescopes?

Comparison to previous work





- We extended the analysis to lower frequencies and also investigated cross-frequency correlations
- When comparable, our results are broadly comparable to CONCERTO-SIDES simulation (Maniyar+ 2023) with a different approach

Conclusions

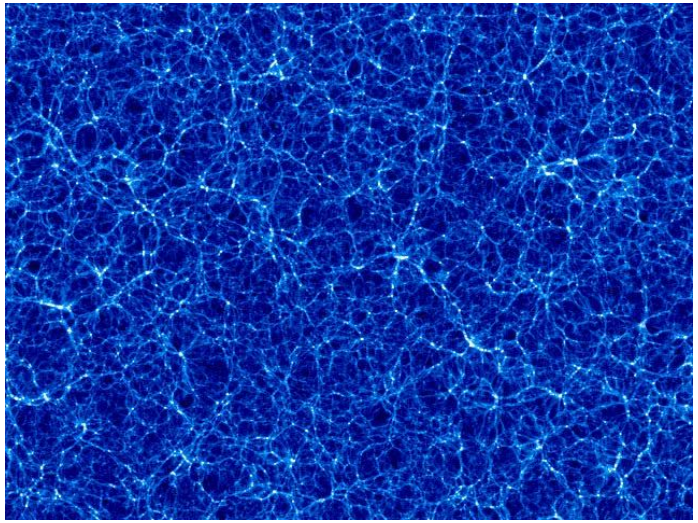
- Complicated signal, complicated instrument and analysis, intrinsic multitracer nature
  1. Empirical simulated skies might be the perfect tool! => SkyLine + Agora
  2. Playground for exploring synergies, validate modeling and pipeline, checking end2end effects, …

- Lines in CMB maps? Potential problem for component separation, contribution to account for in template-based analyses, potential detection opportunity
  1. SPT reported unusually high (wrt hydro) kSZ signal – interpreted as strong patchy kSZ → CO emission?
  2. Effects in component separation techniques at larger scales? e.g., suboptimal or biased CIB / tSZ maps
  3. Can we systematically use CMB experiments to detect LIM?

Back up slides

Ingredients for (multi-tracer) cosmological line emission

Cosmological N-body simulation (MultiDark Planck 2)
Volume =1 $(Gpc/h)^3$
N=$(3840)^3$ particles
$M_{particle}$=1.59/h



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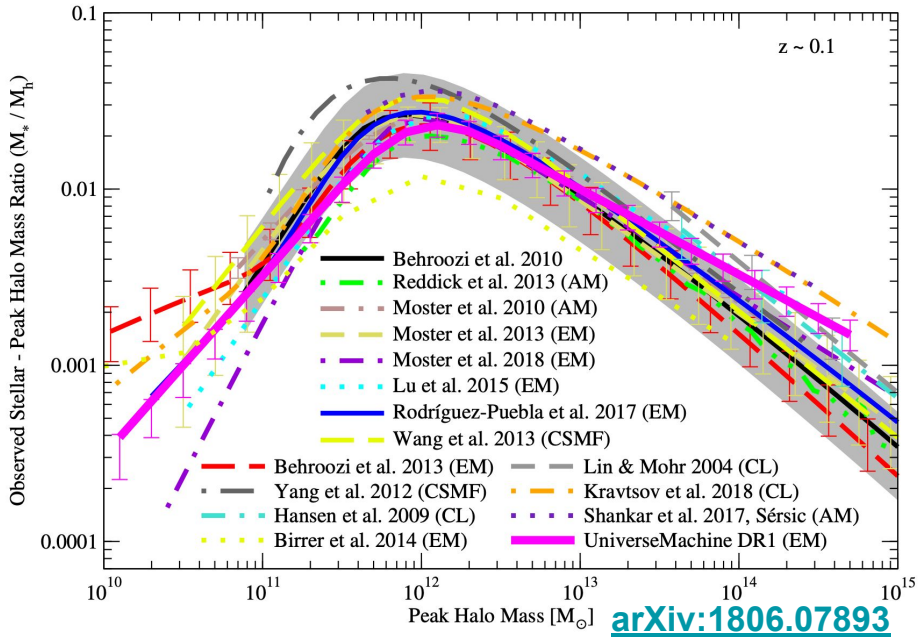
UniverseMachine's best-fit model for the evolution of SFR, M_* across redshift



arXiv:1806.07893

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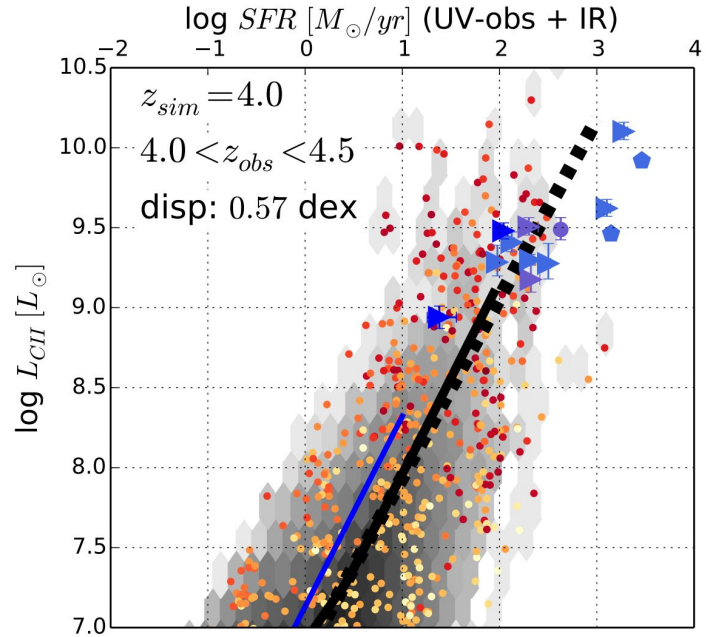
Scaling relations between line luminosity and galaxy observables



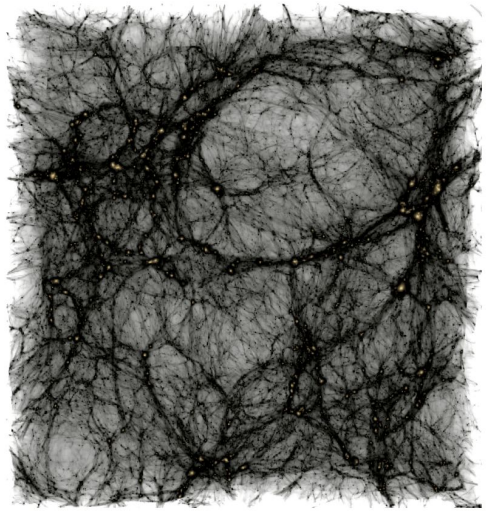
arXiv:1711.00798

(See Li++ 2016 for some of the first work in this vein, applied to CO)

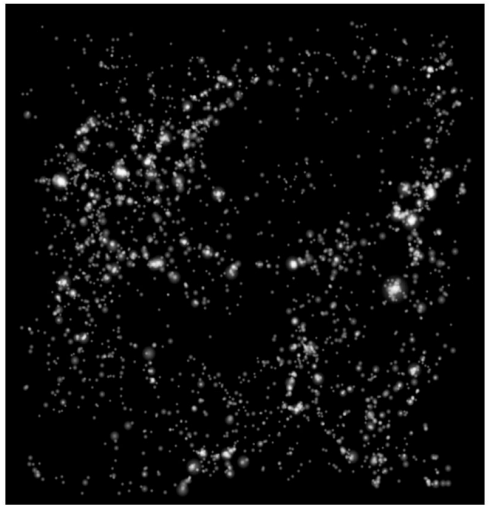
Slide credit: Nick Kokron

Choice of set up

DM Sims (e.g., Nbody)



galaxy-halo connection



Connect astro prop. with line intensity

Approaches to modeling the galaxy-halo connection

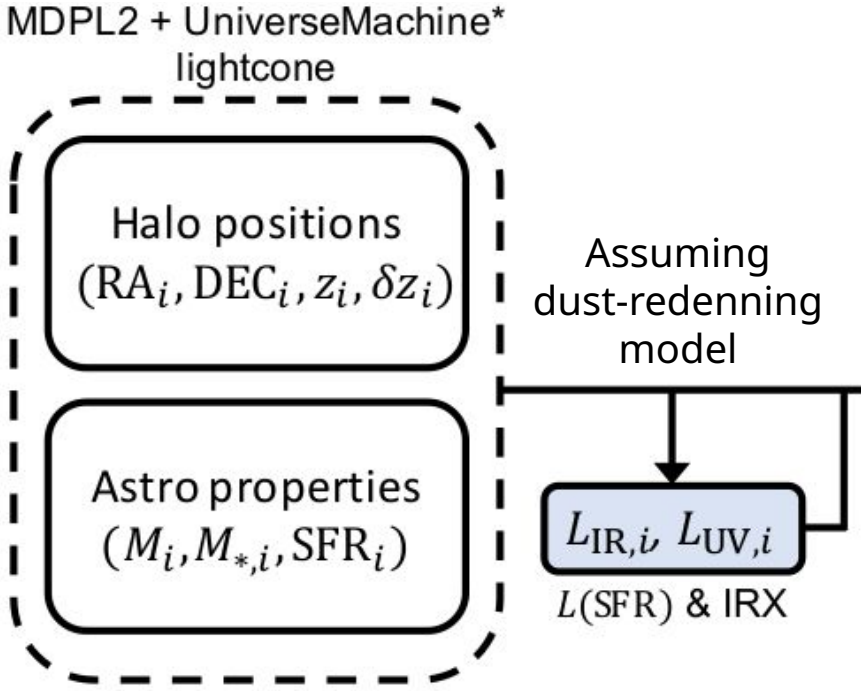
physical models ← → empirical models

Hydrodynamical Simulations	Semi-analytic Models	Empirical Forward Modeling	Subhalo Abundance Modeling	Halo Occupation Models
Simulate halos & gas; Star formation & feedback recipes	Evolution of density peaks plus recipes for gas cooling, star formation, feedback	Evolution of density peaks plus parameterized star formation rates	Density peaks (halos & subhalos) plus assumptions about galaxy—(sub)halo connection	Collapsed objects (halos) plus model for distribution of galaxy number given host halo properties

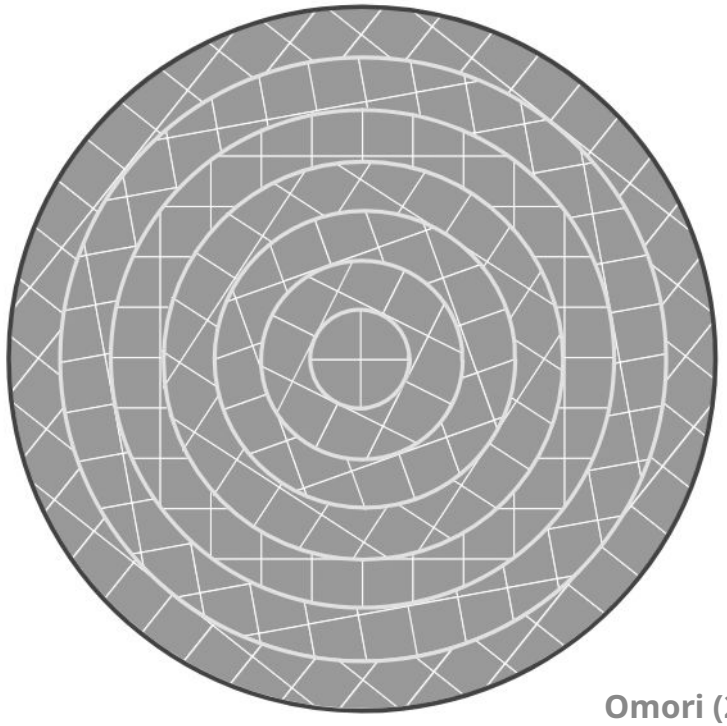
"A (sub)-halo's star formation rate is tightly correlated with its potential well depth, redshift, and assembly history"

SkyLine

- First get the lightcone with all the halos and their astrophysical properties



Astro properties from UniverseMachine, or any mean relationship with given scatter (problems associated)



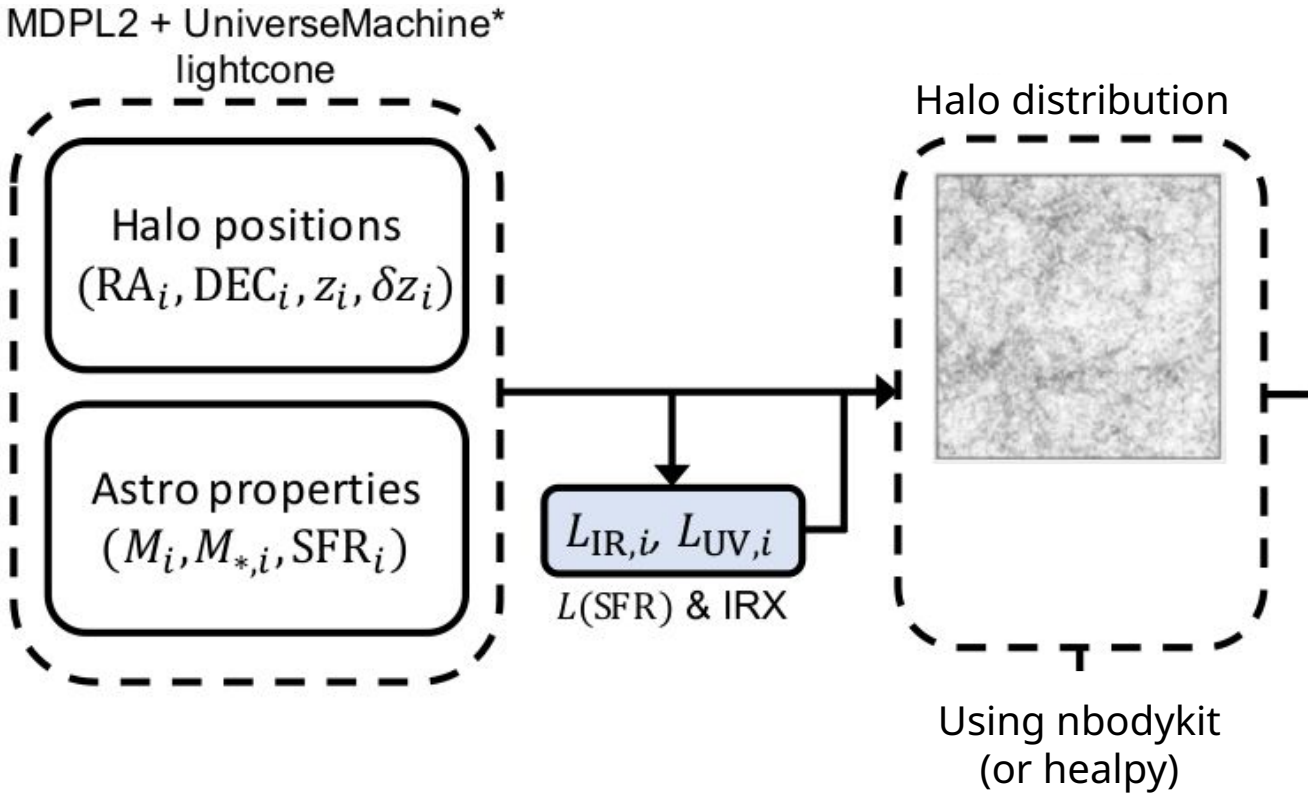
Omori (2022)

Figure 3. The shell rotation scheme used to generate the lightcone from the MDPL2 simulation boxes. Each individual grid represents a 1 h^{-1}Gpc box.

Sato-Polito, Kokron, Bernal (2022)

SkyLine

- Angle and z to 3d position, voxelize the space, mass assignment for halos



Distribution of galaxies in the M_*-sSFR is bimodal:

- Star-forming galaxies (ELGs)
- quenched galaxies (LRGs)

Cut in sSFR to distinguish, and later in M_* as proxy of flux. Selecting for a given n(z)

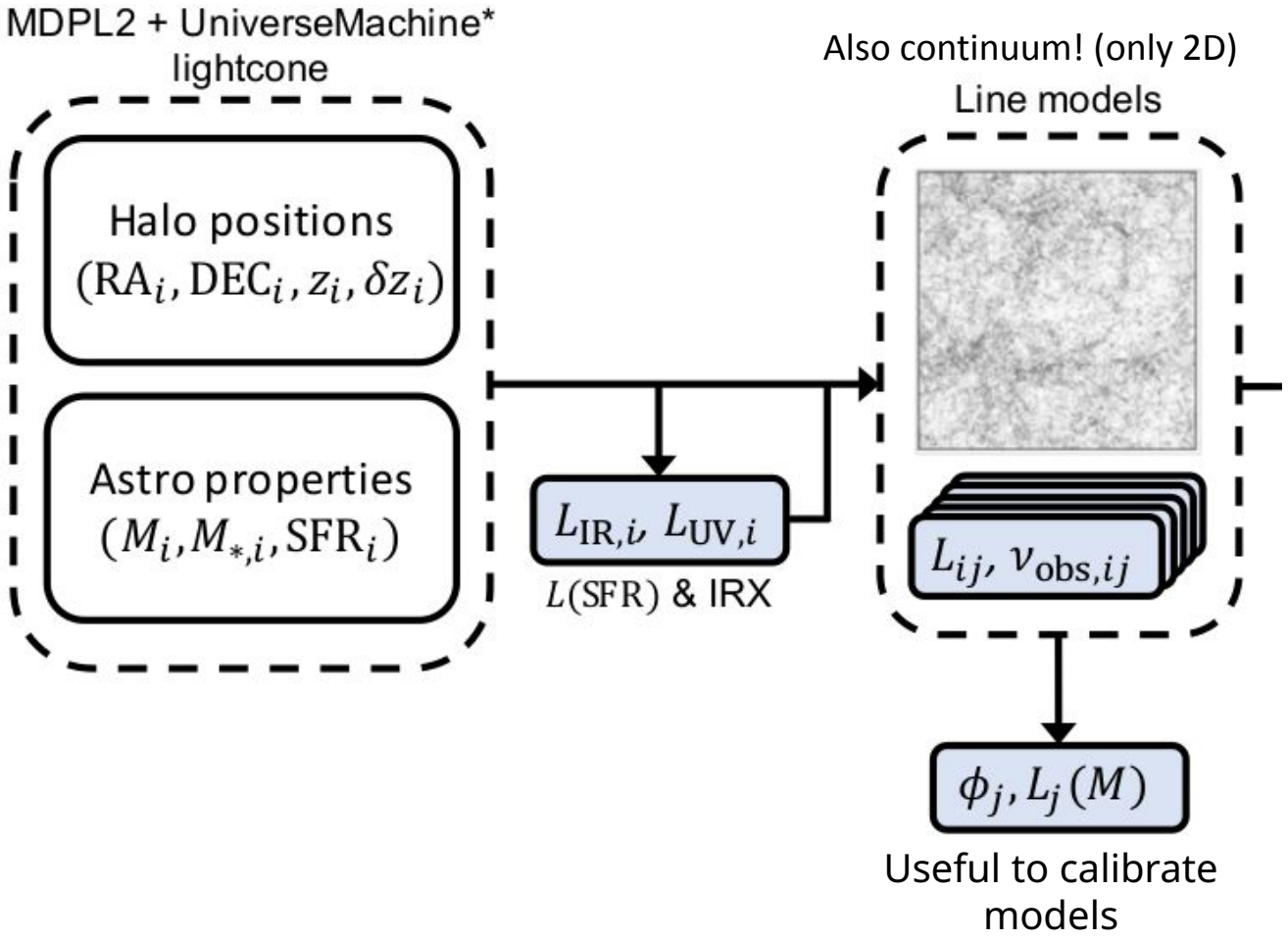
$$\mathrm{sSFR} = \mathrm{SFR}/M_*$$

Also implementing CIB model from Agora simulations

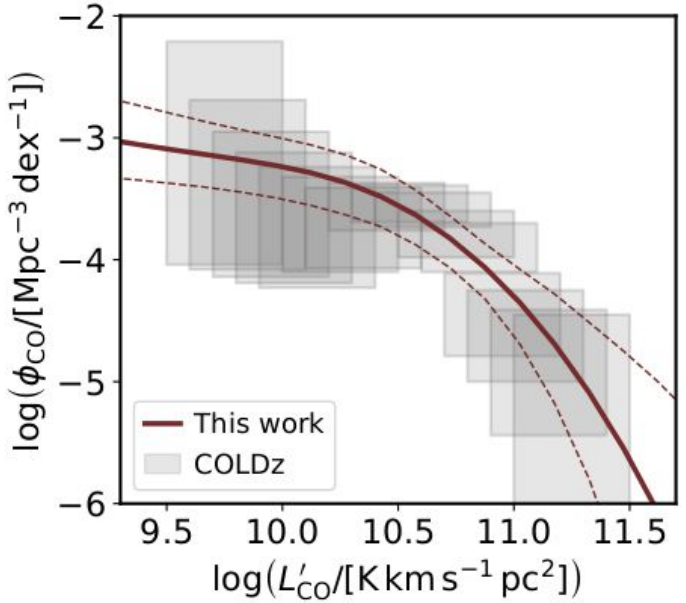
Sato-Polito, Kokron, Bernal (2022)

SkyLine

- Get luminosities for all lines considered



- Currently empirical relations relating halo properties to line luminosity
  - Easy to change to motivated theoretical models, e.g., Sun+(2019)



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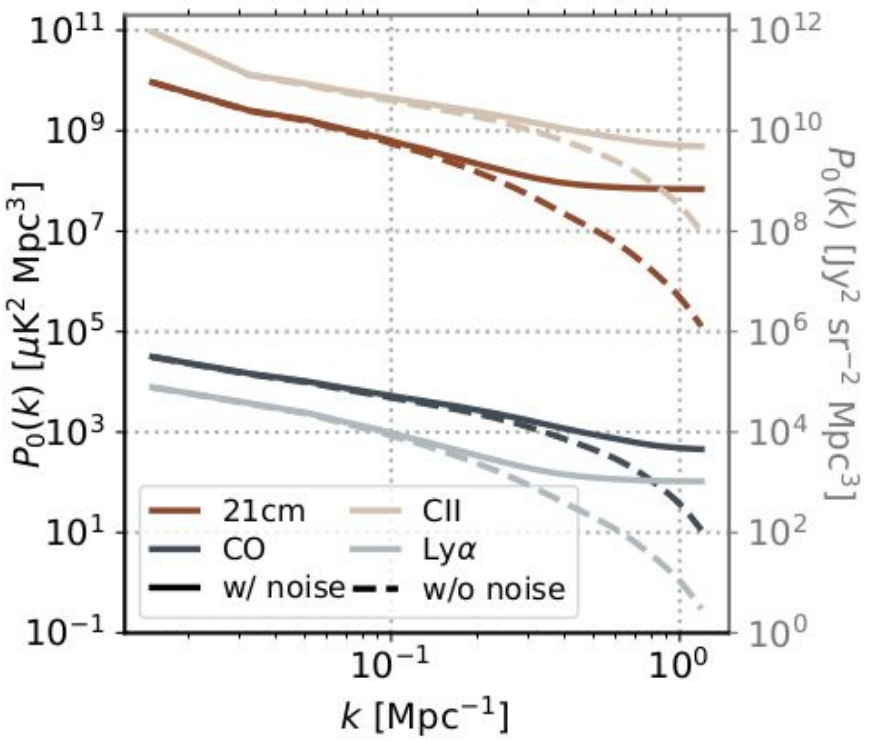
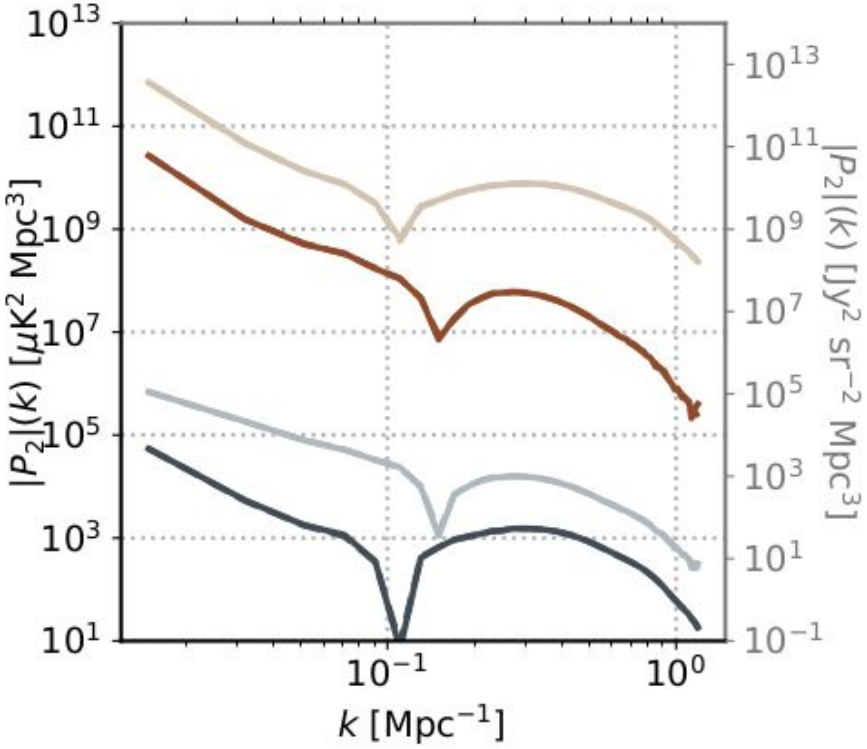
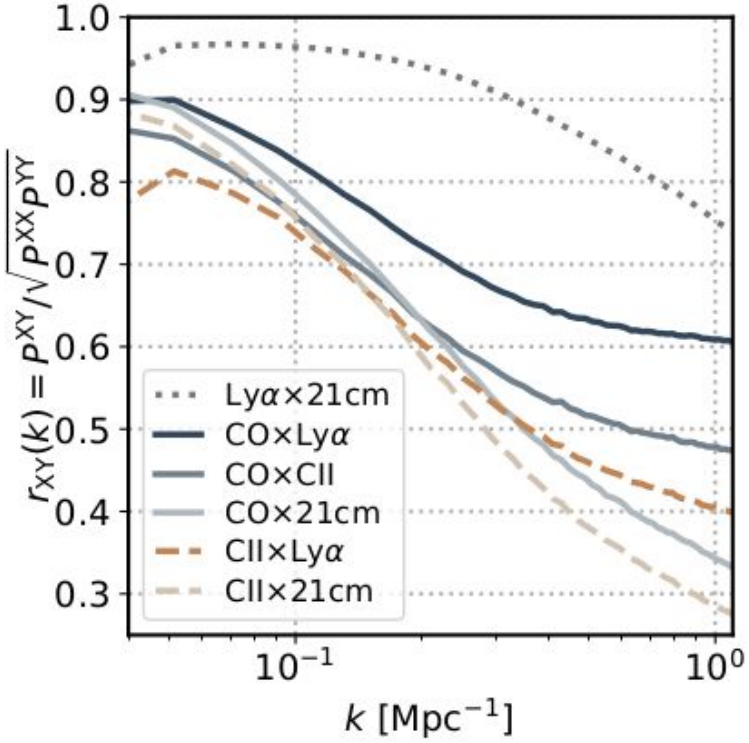
Power spectra and correlation coeff.





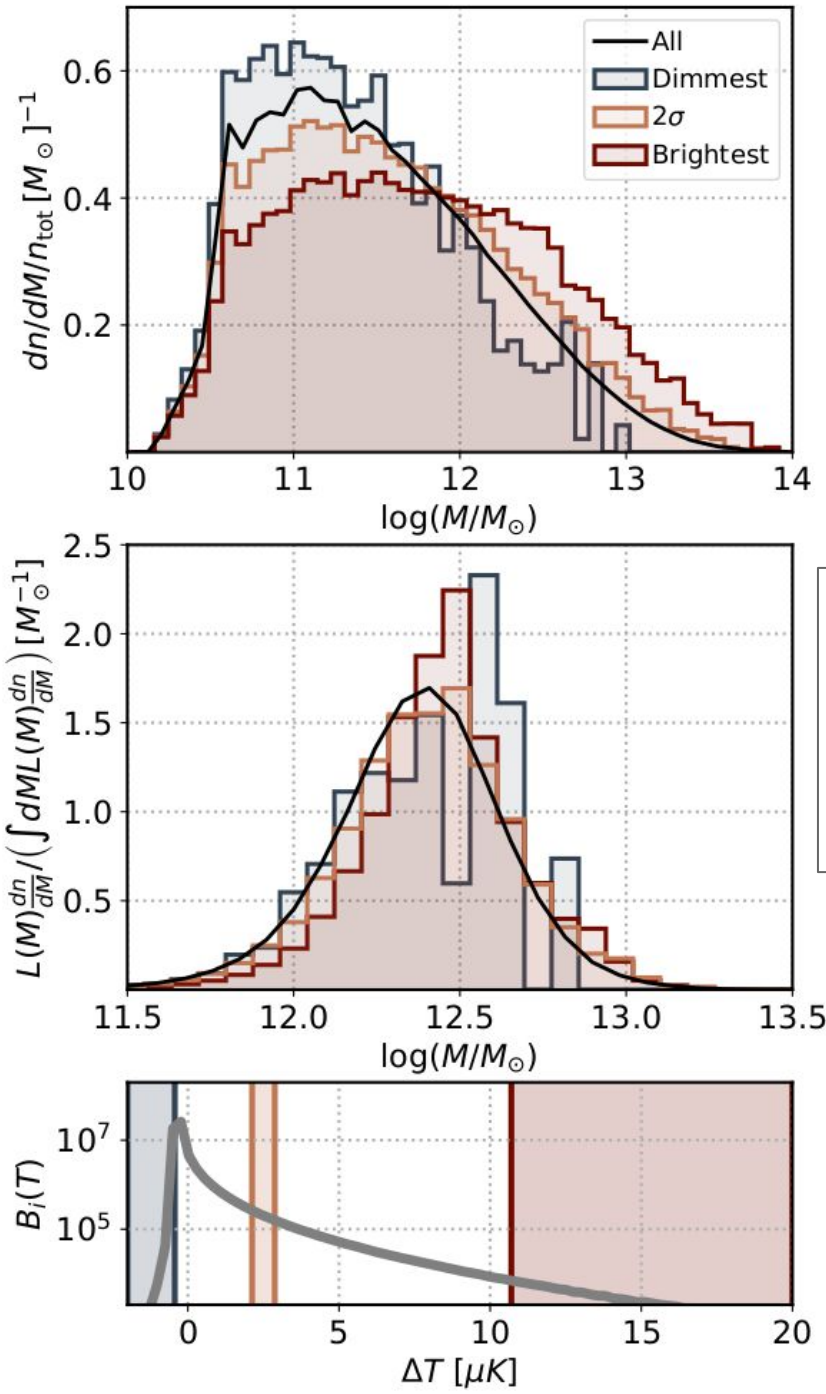


- No specific survey, uniform comparison (S/N=5 at k = 0.1, 2’ resolution, R~230, z = 3)
- r<1 at large scales due to shot noise and non linear biases

Sato-Polito, Kokron, Bernal (2022)

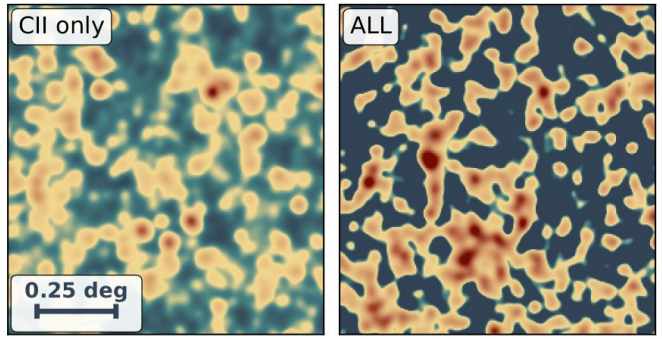
Which halos probed by LIM?

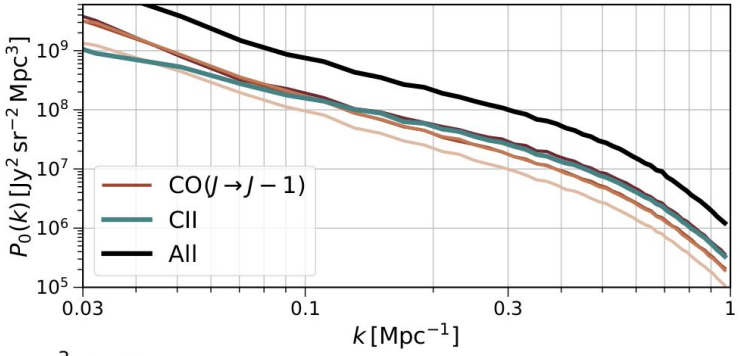
- We can use the maps to study if LIM is actually sensitive to faint emitters (which halos dominate the temperature of each voxel?)
- Many faint halos or few bright ones?
- Dimmest voxels dominated by light halos, more massive halos more common in brightest voxels
- Luminosity weighted distribution is *very* similar

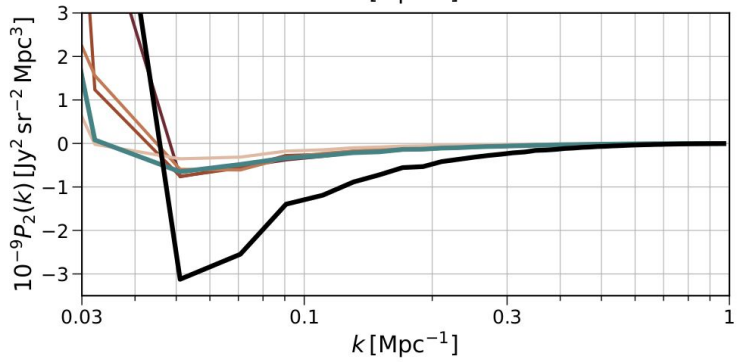


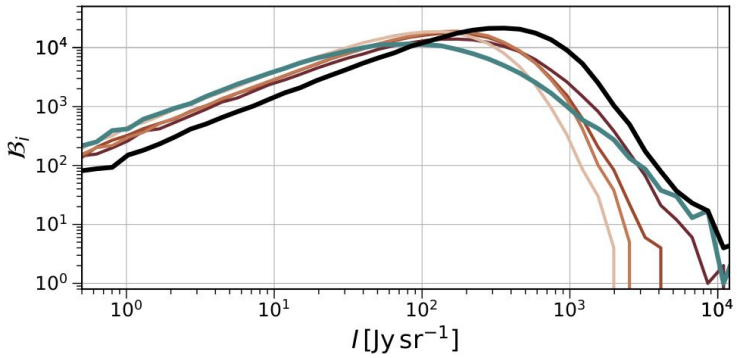
Sato-Polito, Kokron, Bernal (2022)

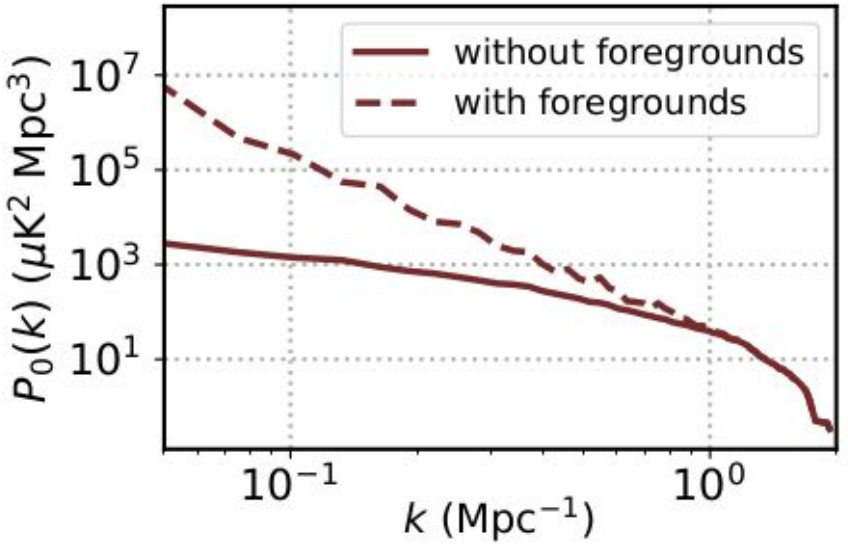
Line interlopers and galactic foreground

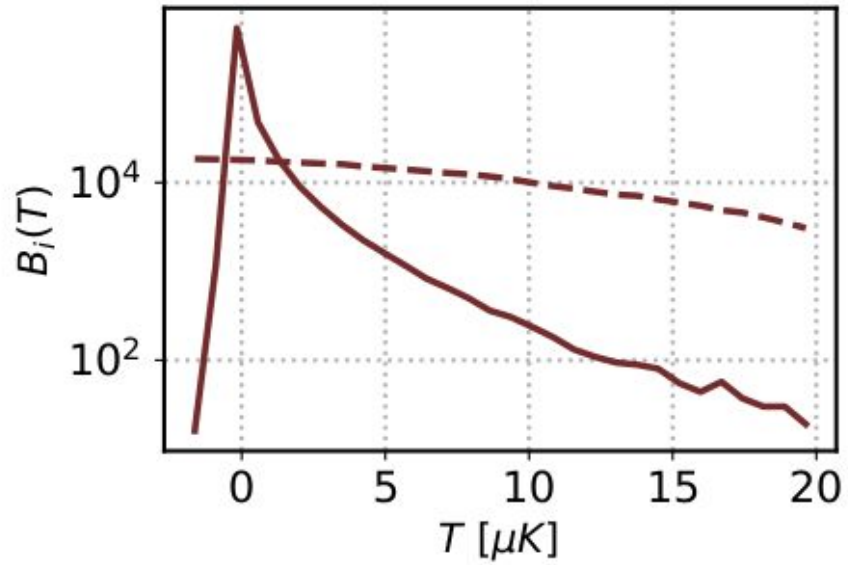












No foreground calibration implemented!

Sato-Polito, Kokron, Bernal (2022)