(Partially) nulling statistical contributions from interlopers to the LIM power spectrum

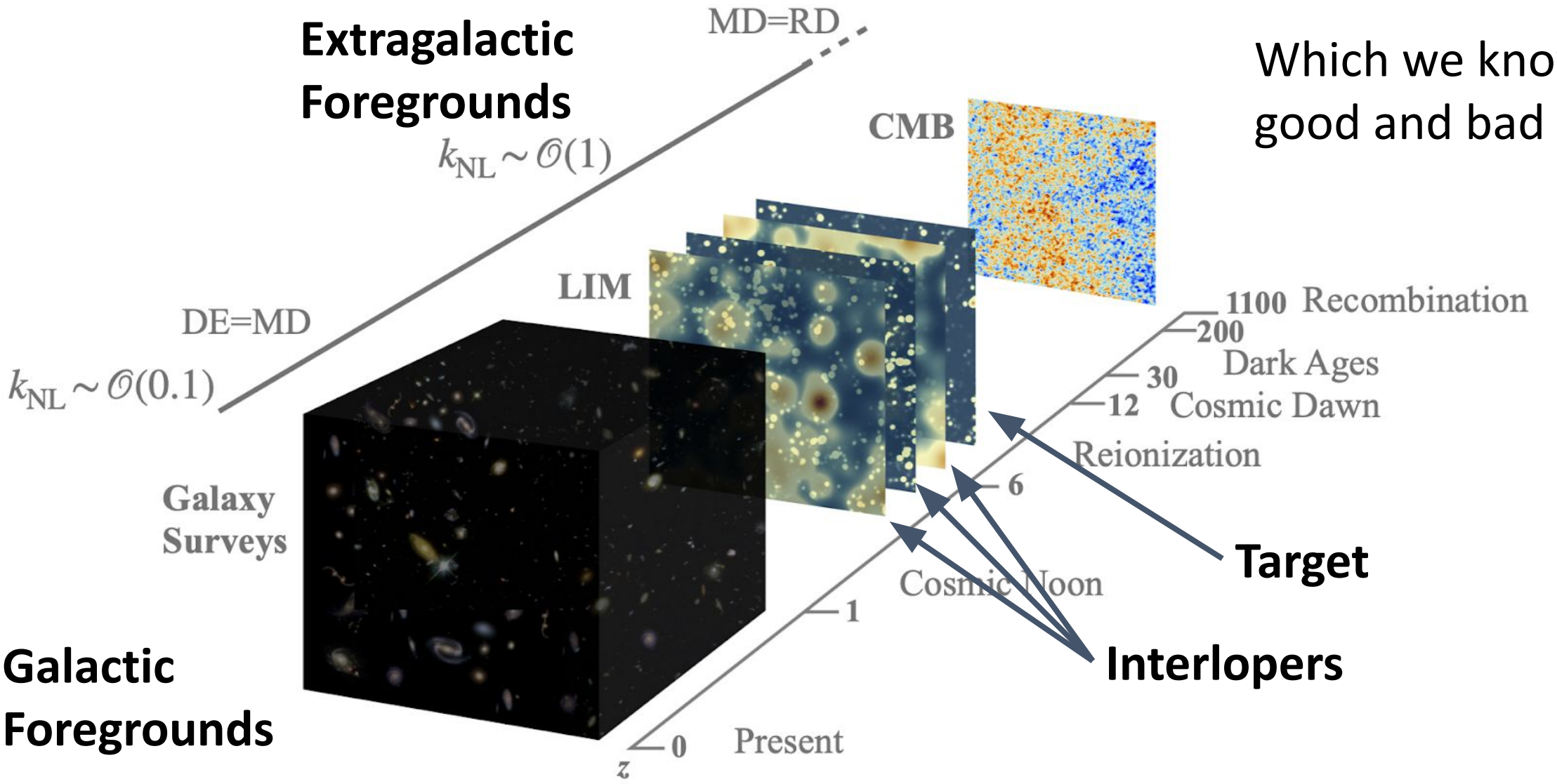
José Luis Bernal
Instituto de Física de Cantabria

(with Antón Baleato-Lizancos)
(arXiv:2406:XXXXX)

LIM 2024

13/06/2024

LIM reaches further, and collects all…

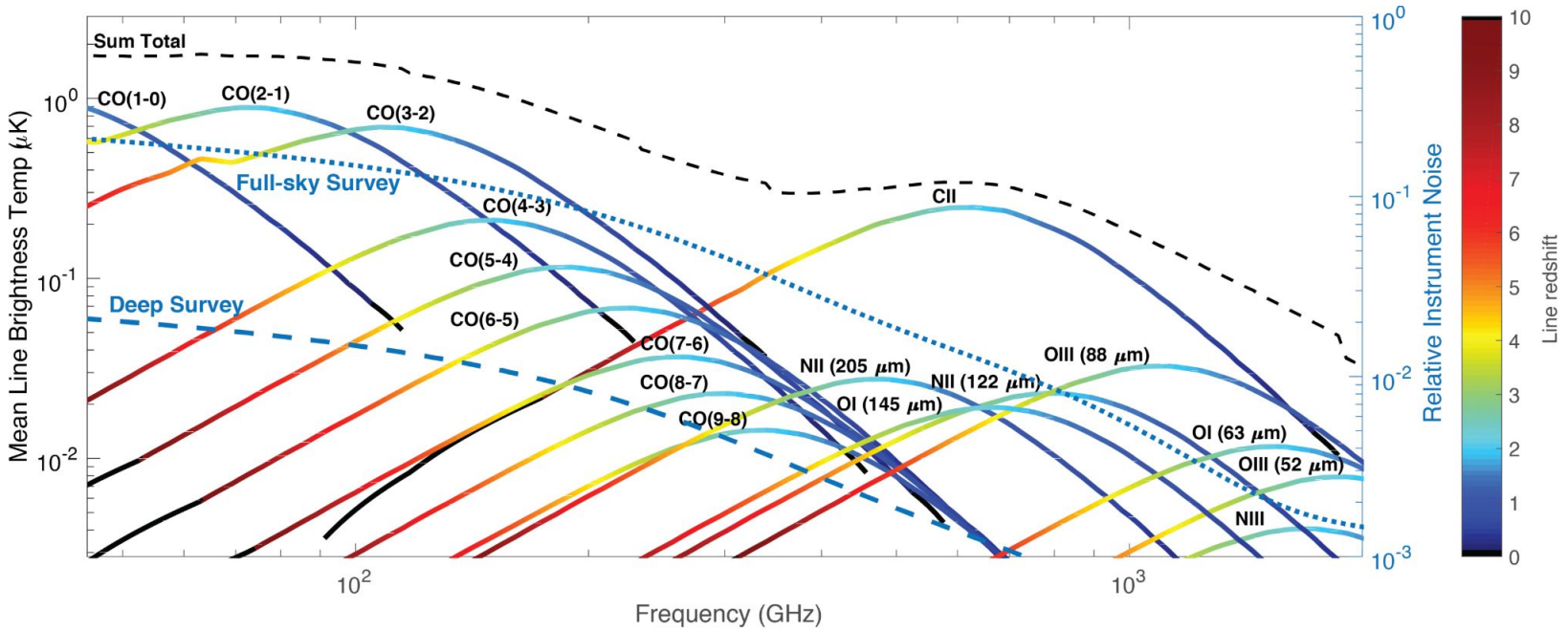


Which we know is good and bad

Bernal & Kovetz (2022)

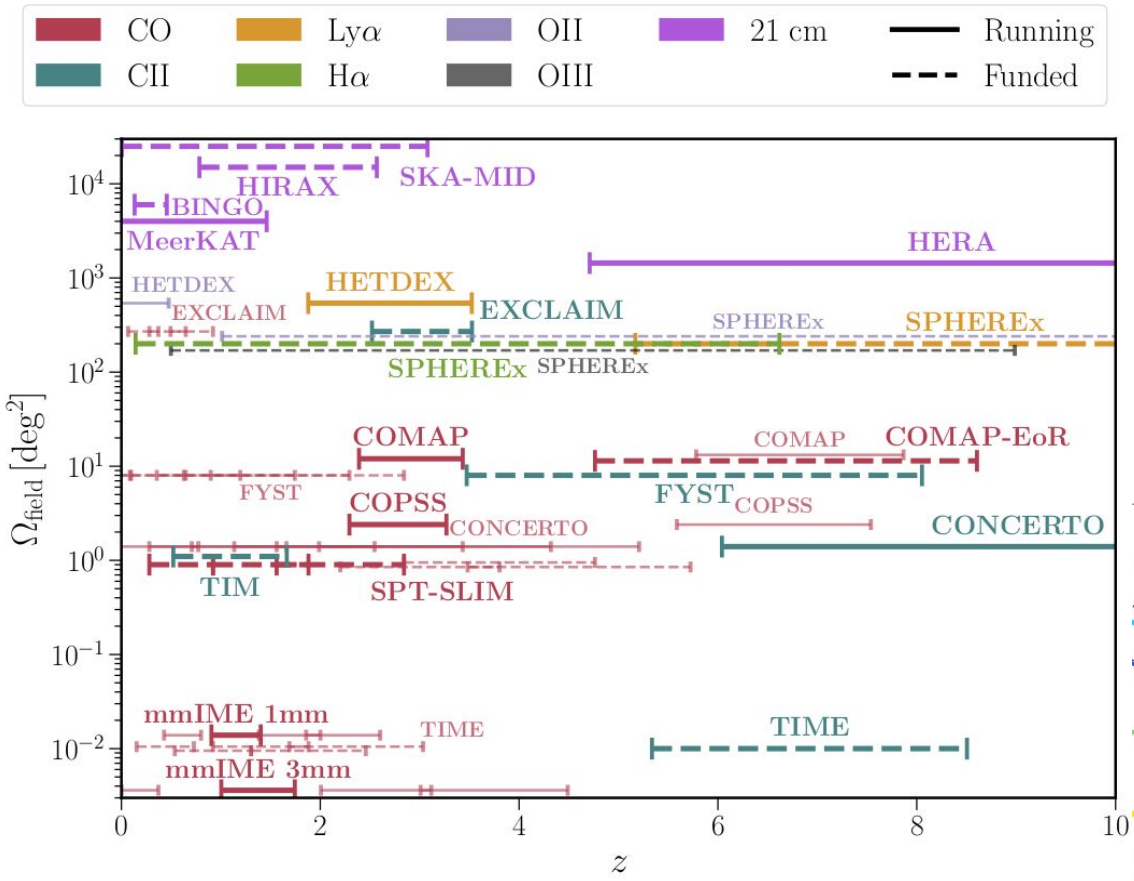
Line-interloper contamination

Silva + (2021)

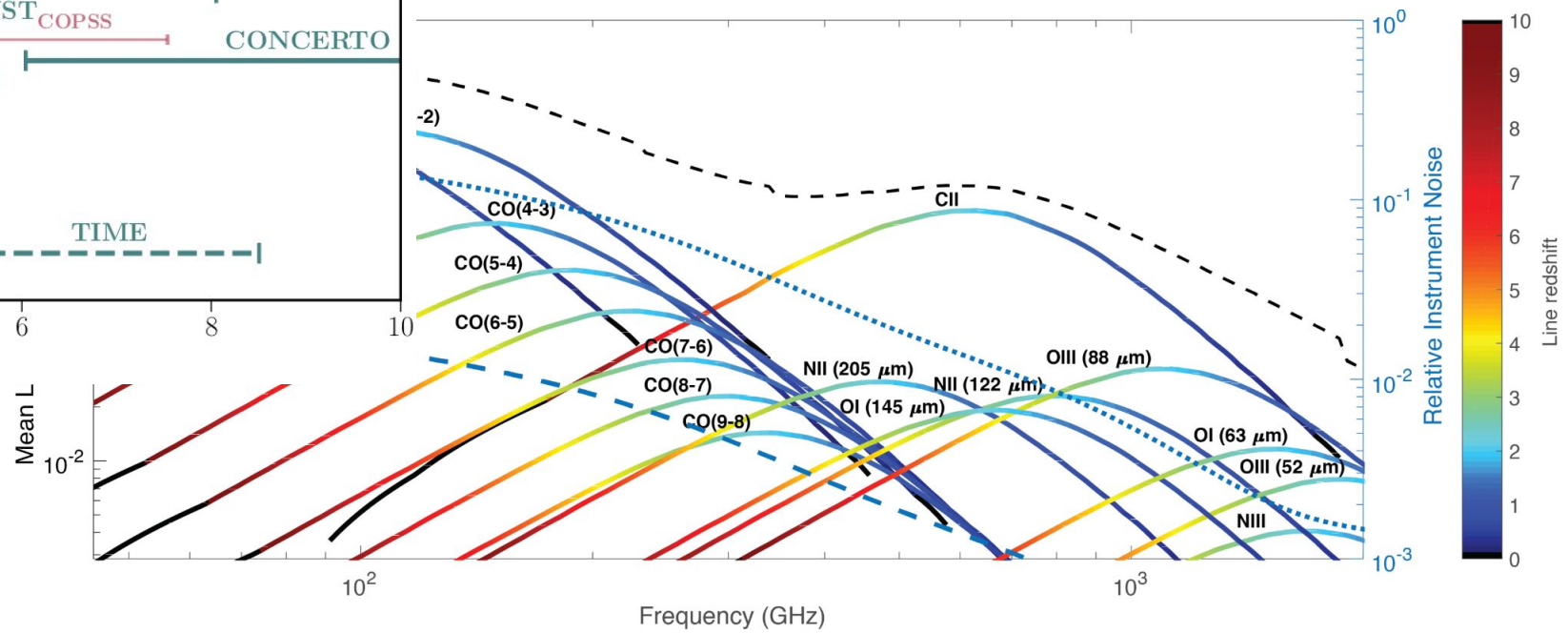


Line-interloper contamination

Bernal & Kovetz (2022)

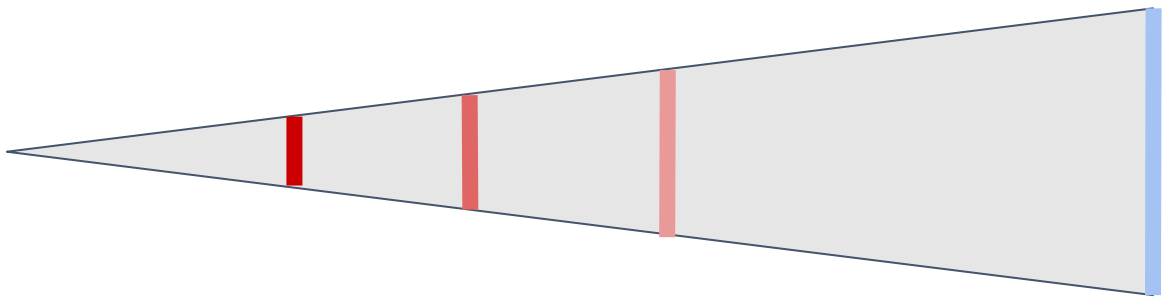


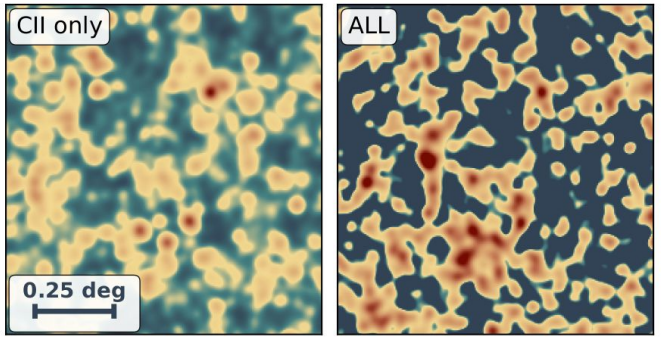
Silva + (2021)

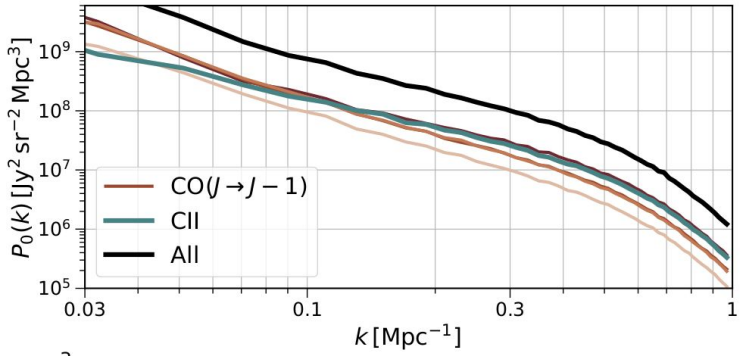


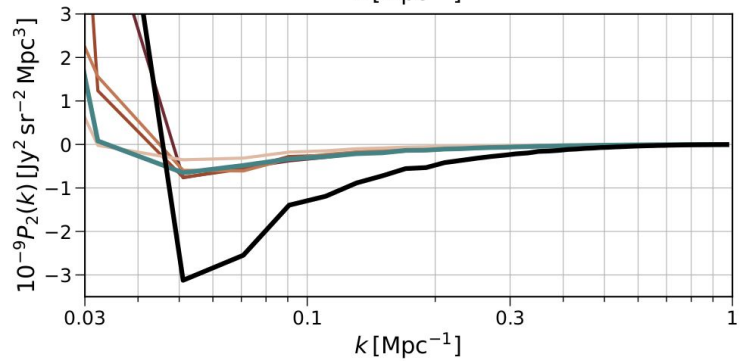
Line-interloper contamination

- Line interlopers (redshift and signal confusion):
  - Masking: targeted or blind **Breysse+ (2015), Sun+ (2018), van Cuyk+ (2023)**
  - Model them:projection effects **Lidz & Taylor (2016), Sun+ (2018), Gong+ (2020)**
  - Spectral templates: de-project at pixel level **Cheng+(2020)**
  - Multi-LIM (X-freq. Cls) **Cheng+(2024)**
  - Exotic unknown signals!! DM and/or neutrino decay **Creque-Sarbinowski & Kamionkowski (2018), Bernal+ (2021), Nishikawa (2021), Bernal+ (2022)**

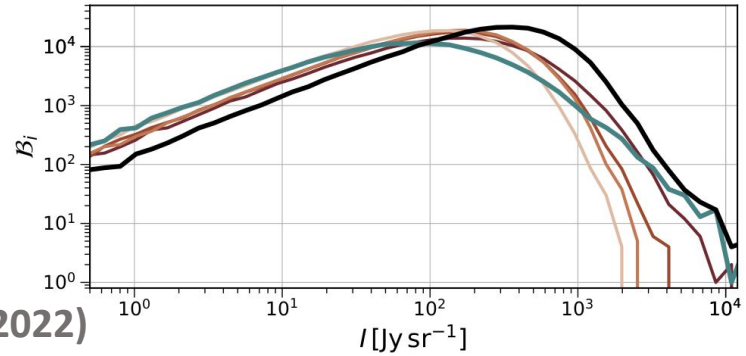








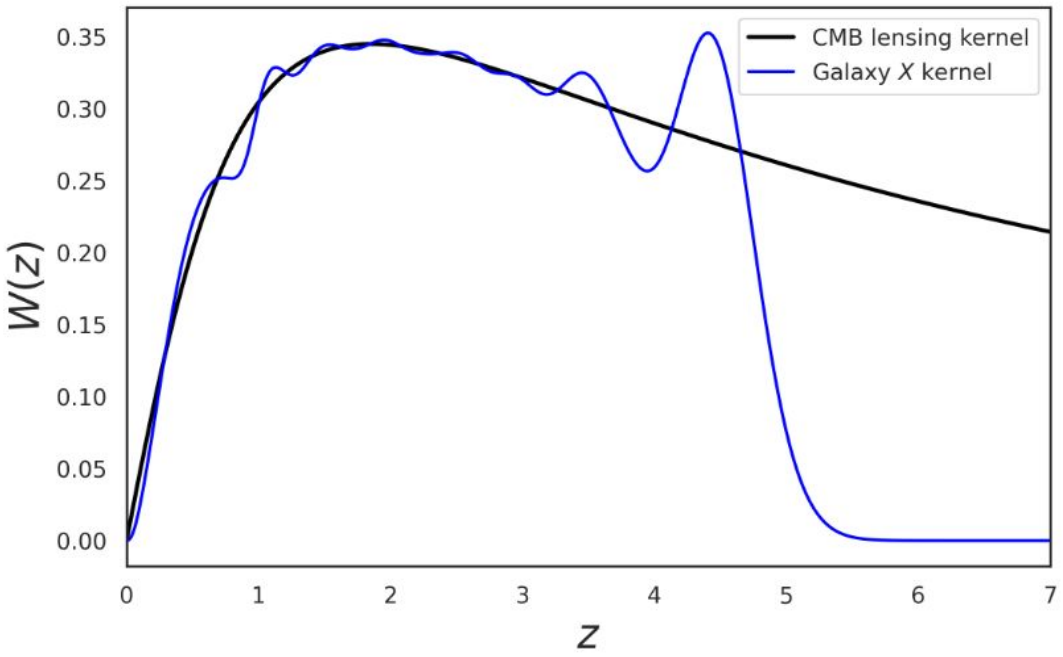
- Targeting CII at z = 5
- CO lines:
  - J = 4 at z = 0.46
  - J = 5 at z = 0.82
  - J = 6 at z = 1.18
  - J = 7 at z = 1.55
- Brighter red, higher J



Sato-Polito, Kokron, Bernal (2022)

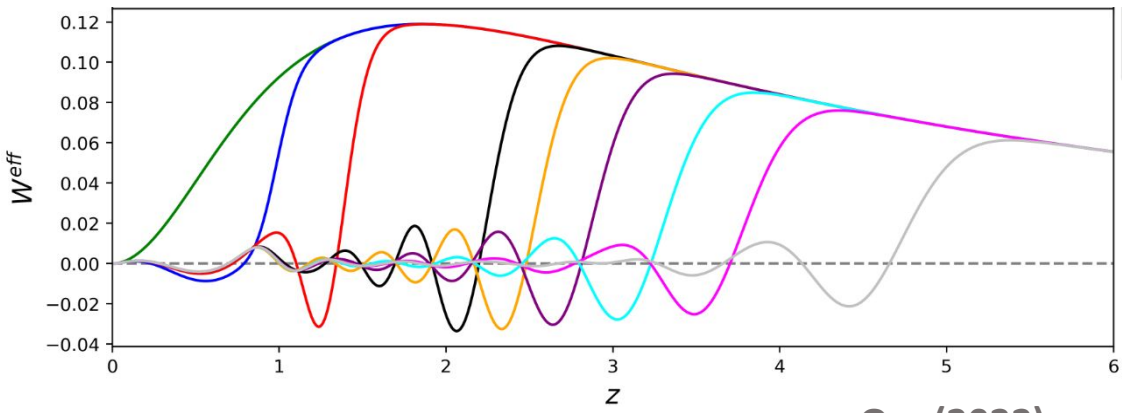
Analogous to CMB lensing

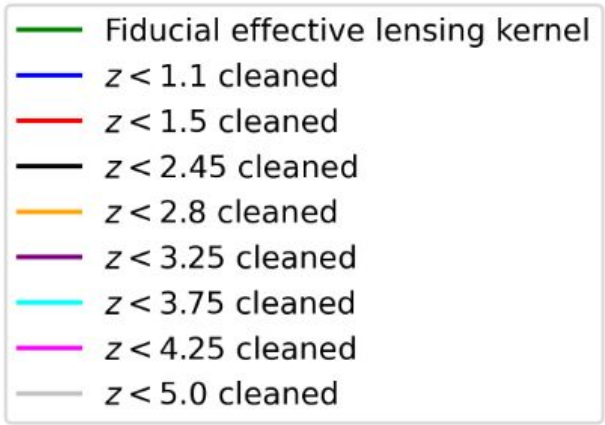
Nulling techniques: Huterer & White (2005)



CMB Delensing / Lensing nulling:

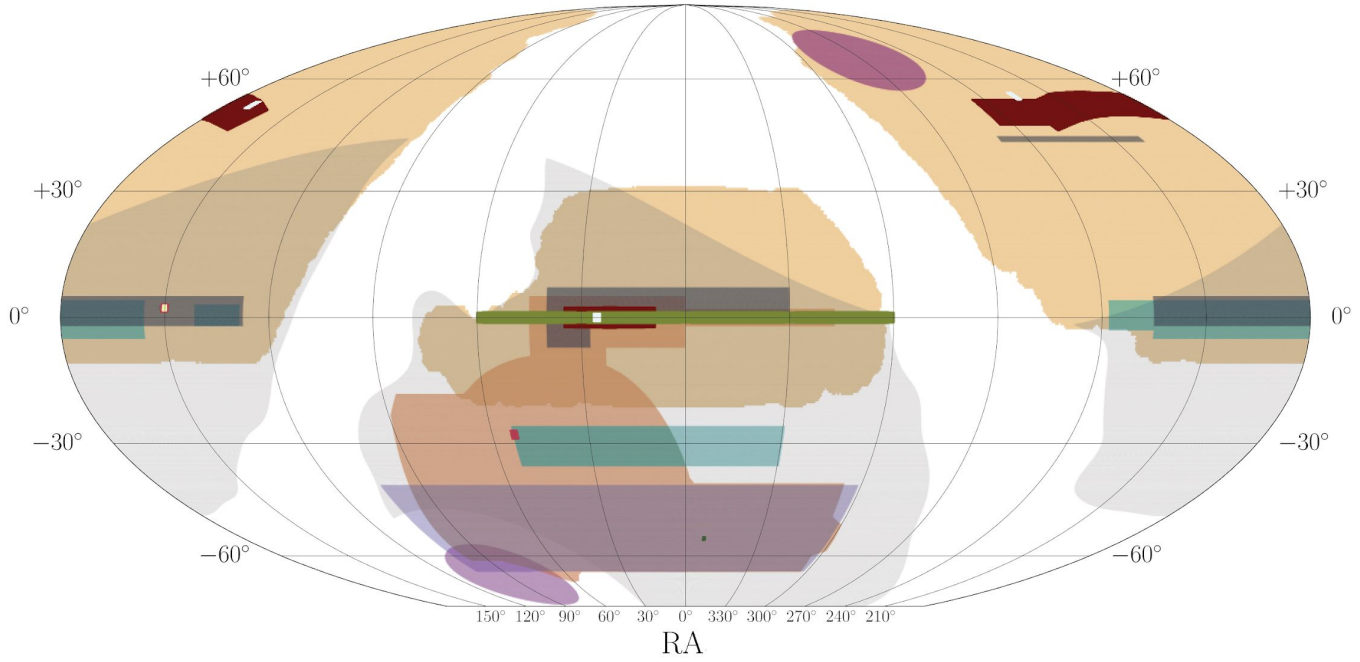
- Want to remove low-z contribution to kernel
- Use external LSS tracer to apply a cleaning filter
- Effective statistical reduction of low-z contributions
- (similar kernels, but at disjoint z-ranges)





Qu+(2022)

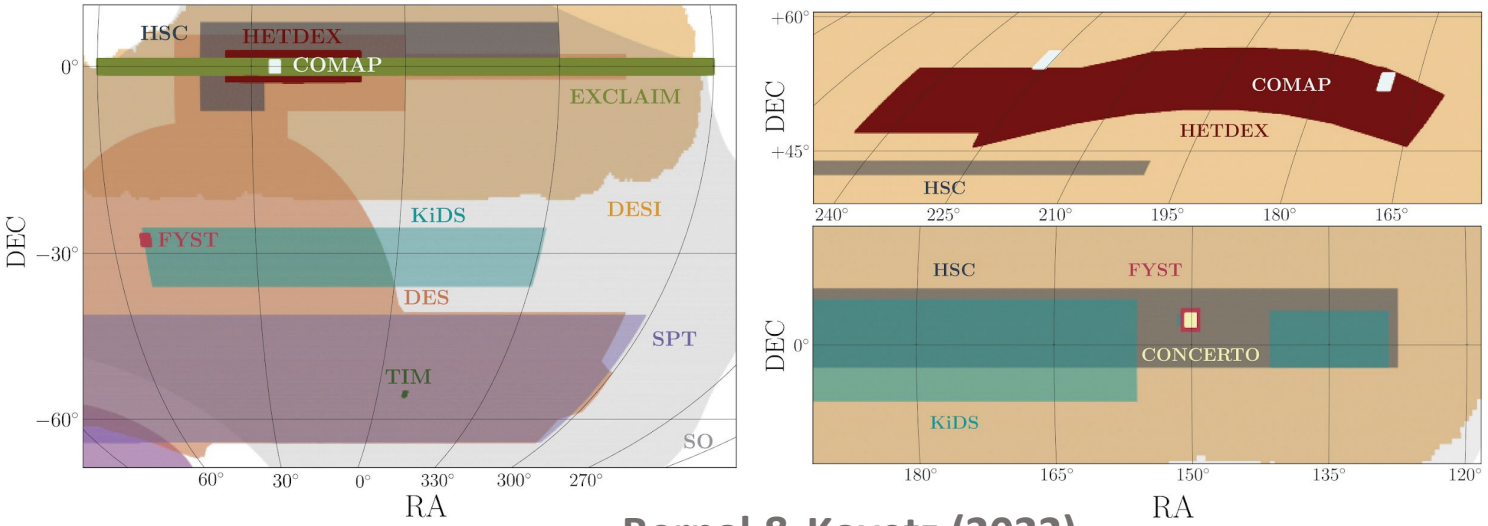
De-interloping



$$\delta I(\boldsymbol{k}) = \delta I_{\rm int}(\boldsymbol{k}) + \delta I_{\rm target}(\boldsymbol{k}) + \delta_{\mathcal{N}}$$

We only need some tracer of the LSS overlapping in volume with the interlopers

Granted!



Bernal & Kovetz (2022)

De-interloping

B(k) is a tracer of LSS overlapping in redshift with the interloper line (e.g., spectroscopic galaxies)

$$\delta I(\boldsymbol{k}) = \delta I_{\rm int}(\boldsymbol{k}) + \delta I_{\rm target}(\boldsymbol{k}) + \delta_{\mathcal{N}}$$

$$\delta \hat{I}\,(\boldsymbol{k}) = \delta I(\boldsymbol{k}) - \mathcal{F}(\boldsymbol{k}) B(\boldsymbol{k})\,; \qquad \mathcal{F} = \frac{\tilde{P}_{IB}}{\tilde{P}_{BB}}$$

Unbiased fluctuation and minimize variance;
model independent!

De-interloping

B(k) is a tracer of LSS overlapping in redshift with the interloper line (e.g., spectroscopic galaxies)

$$\delta I(\boldsymbol{k}) = \delta I_{\rm int}(\boldsymbol{k}) + \delta I_{\rm target}(\boldsymbol{k}) + \delta_{\mathcal{N}}$$

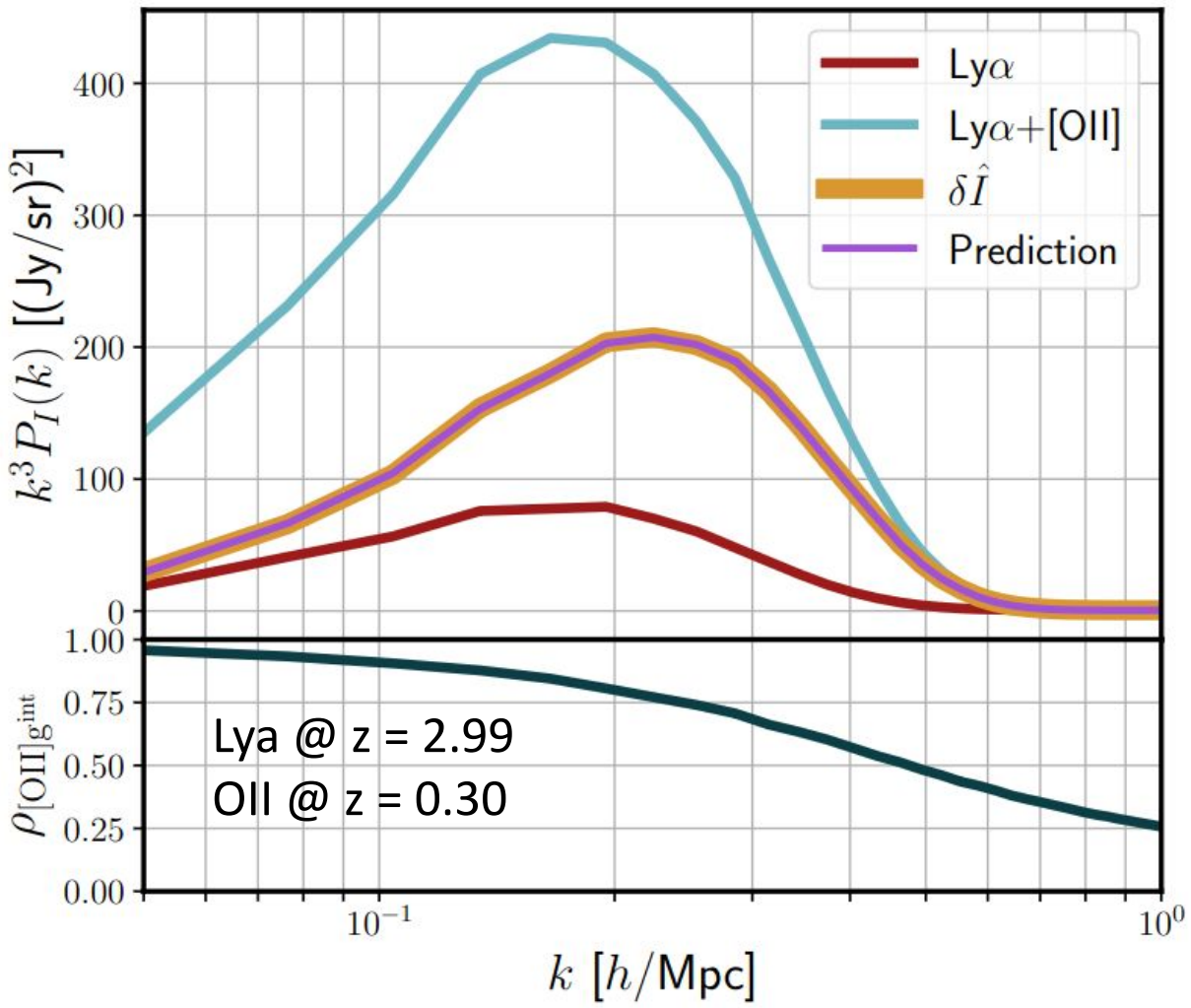
$$\delta \hat{I}\,(\boldsymbol{k}) = \delta I(\boldsymbol{k}) - \mathcal{F}(\boldsymbol{k}) B(\boldsymbol{k})\,; \qquad \mathcal{F} = \frac{\tilde{P}_{IB}}{\tilde{P}_{BB}}$$

Unbiased fluctuation and minimize variance;
model independent!

$$P_{\hat{I}} = P_{I_{\rm target}} + P_{I_{\rm Int}}(1 - \rho^2_{I_{\rm Int}B}) + \mathcal{N}_I = \\ = \tilde{P}_{I_{\rm tot}}(1 - \tilde{\rho}^2_{I_{\rm tot}B})$$

Also very relevant for cross correlations to reduce covariance!

De-interloping



Test with lognormal sims (SIMPLE; Lujan Niemeyer, Bernal, Komatsu 2023)
100 sims, (256 Mpc/h)^3

$$\delta I(\boldsymbol{k}) = \delta I_{\mathrm{int}}(\boldsymbol{k}) + \delta I_{\mathrm{target}}(\boldsymbol{k}) + \delta_{\mathcal{N}}$$

$$\delta\hat{I}(\boldsymbol{k}) = \delta I(\boldsymbol{k}) - \mathcal{F}(\boldsymbol{k}) B(\boldsymbol{k}); \qquad \mathcal{F} = \frac{\tilde{P}_{IB}}{\tilde{P}_{BB}}$$

Unbiased fluctuation and minimize variance;
model independent!

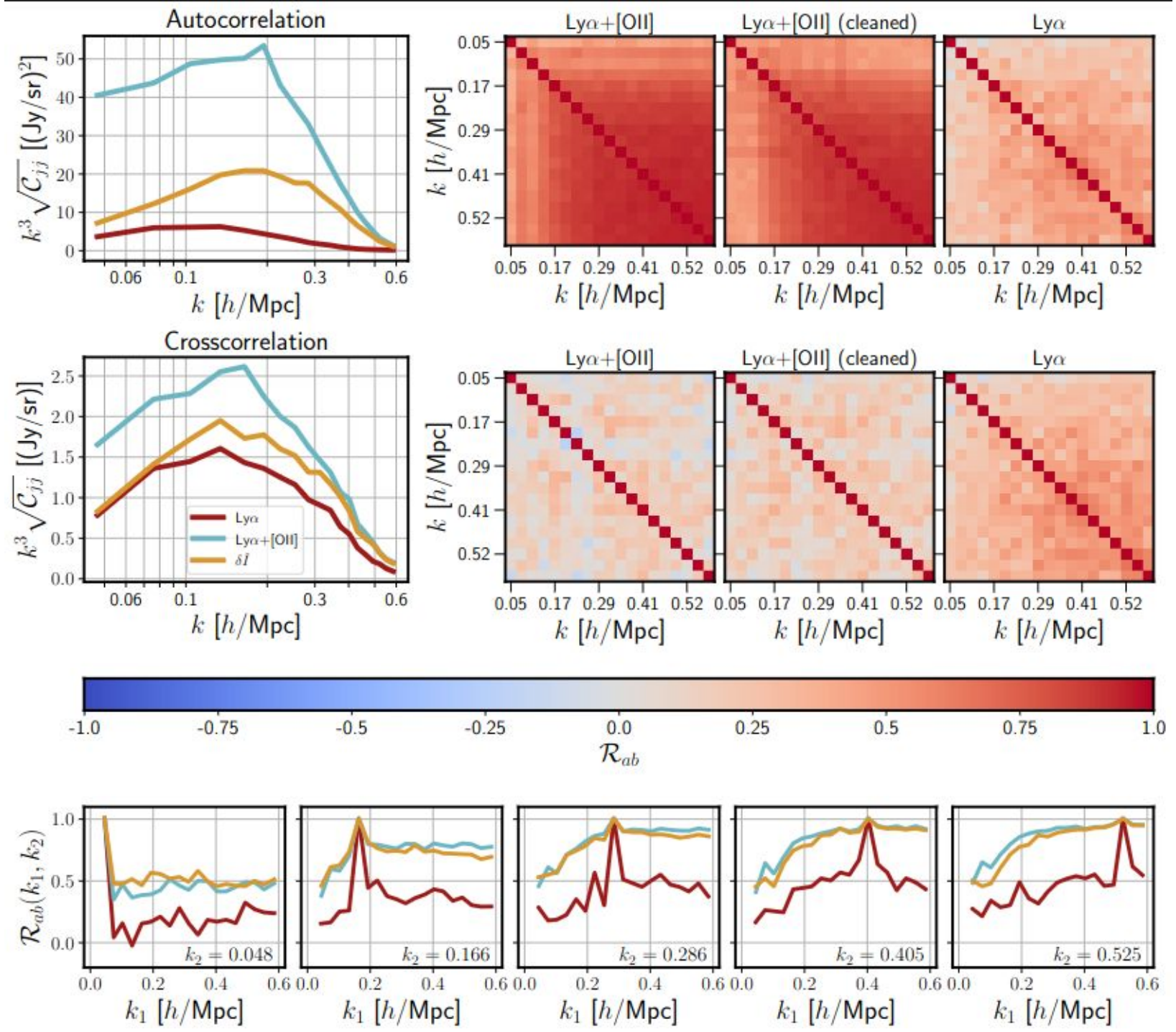
$$P_{\hat{I}} = P_{I_{\mathrm{target}}} + P_{I_{\mathrm{Int}}}(1 - \rho^2_{I_{\mathrm{Int}}B}) + \mathcal{N}_I =$$
$$= \tilde{P}_{I_{\mathrm{tot}}}(1 - \tilde{\rho}^2_{I_{\mathrm{tot}}B})$$

Also very relevant for cross correlations to reduce covariance!

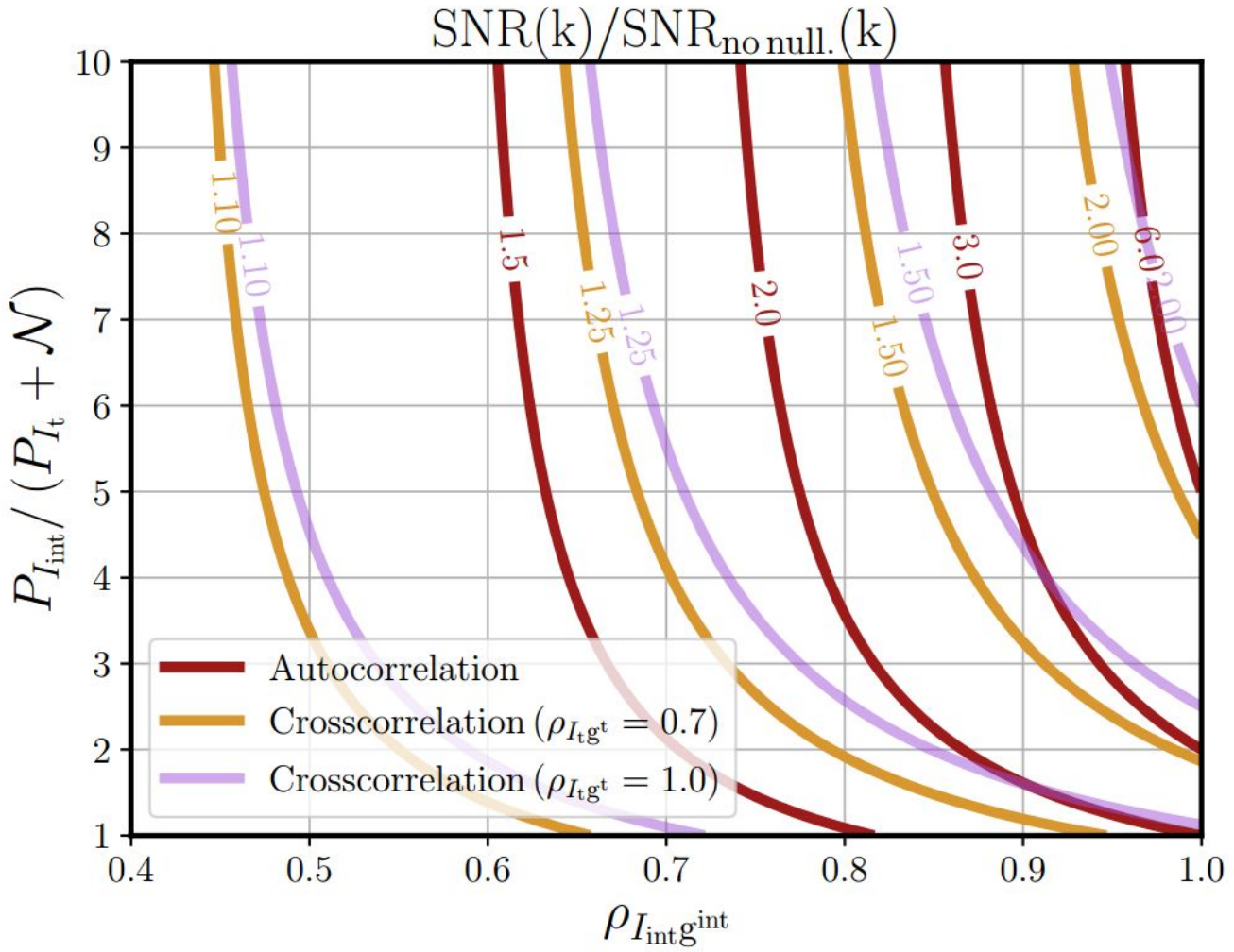
Reduction in covariance

Projection effects introduce a lot of anisotropies:

VERY strong mode coupling



De-interloping



Boost factor in detection significance of the target power spectra

Analytic prediction (signal validated with sims) assuming Gaussian covariance.

$$\delta I(\boldsymbol{k}) = \delta I_{\rm int}(\boldsymbol{k}) + \delta I_{\rm target}(\boldsymbol{k}) + \delta_{\mathcal{N}}$$

$$\delta\hat{I}(\boldsymbol{k}) = \delta I(\boldsymbol{k}) - \mathcal{F}(\boldsymbol{k})B(\boldsymbol{k})\,; \qquad \mathcal{F} = \frac{\tilde{P}_{IB}}{\tilde{P}_{BB}}$$

Unbiased fluctuation and minimize variance;
model independent!

$$P_{\hat{I}} = P_{I_{\rm target}} + P_{I_{\rm Int}}(1-\rho^2_{I_{\rm Int}B}) + \mathcal{N}_I = \\ = \tilde{P}_{I_{\rm tot}}(1-\tilde{\rho}^2_{I_{\rm tot}B})$$

Also very relevant for cross correlations to reduce covariance!

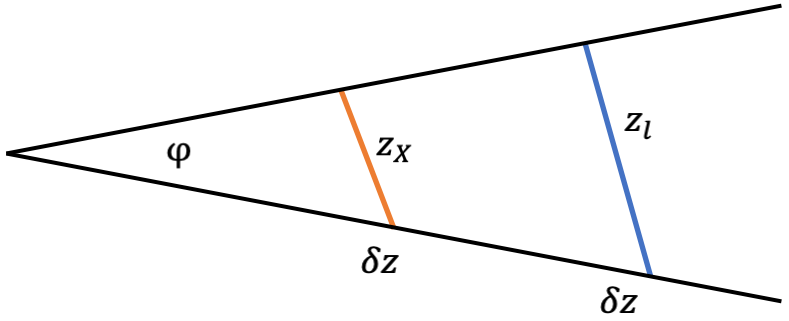
Conclusions

- Line interlopers are about the most problematic showstoppers for LIM surveys (depends on freq)
- Most techniques rely on removing the brightest contaminants and need to make assumptions, but diffuse emission would remain: mode coupling
- De-interloping using external LSS tracers is an easy and model-independent way to remove statistical contaminants at the P(k) level: very complementary to any other interloper cleaning method!
- Boosting robustness and SNR of the target signal through combination of cleaning strategies
  - Mode coupling remains: explore anisotropic filters

Back up slides

Effect in power spectrum

- Confusion in redshift → projection effects → **extra anisotropy**



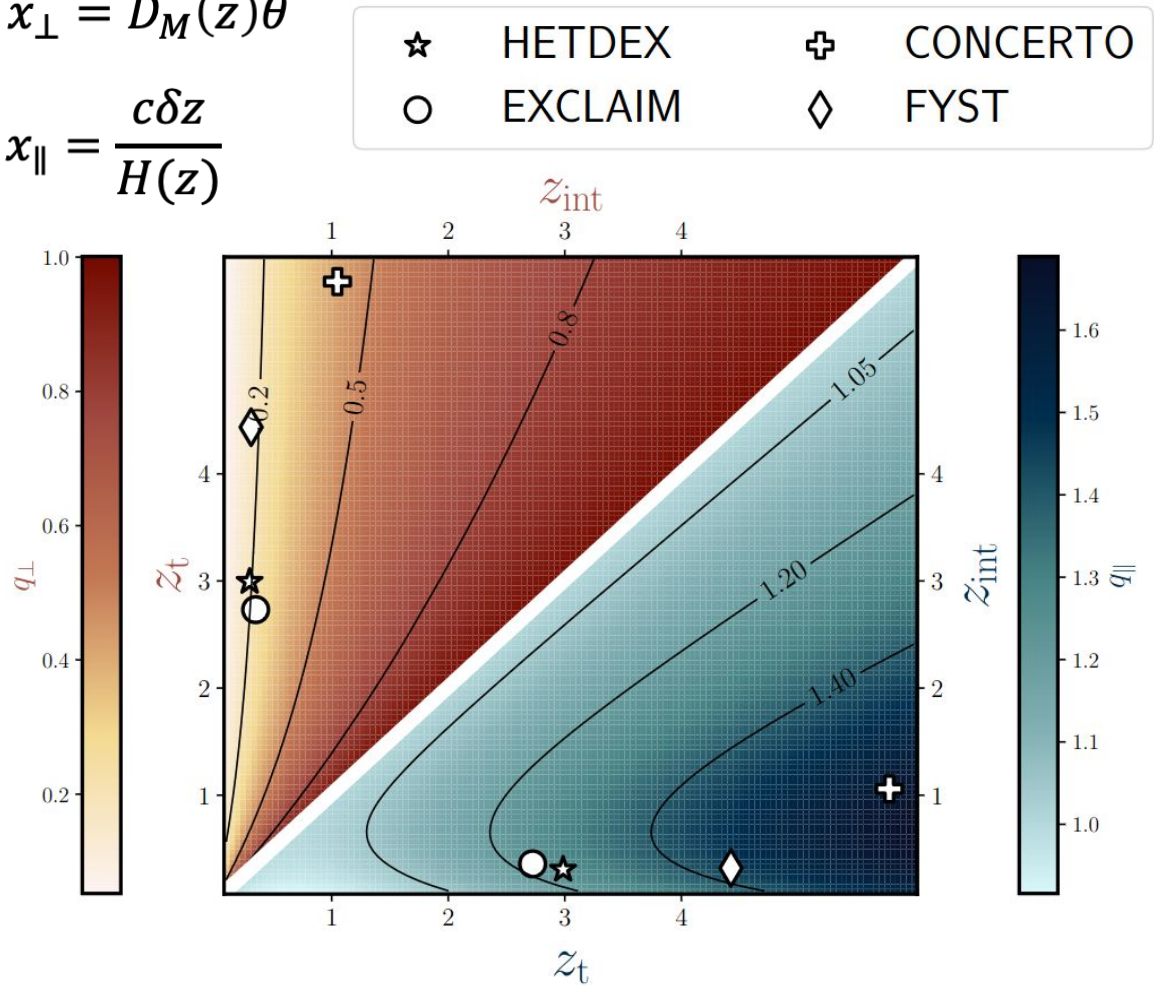
- Model it similar to AP effect: $k_i^{true} \equiv k_i^{infer}/q_i$

$$q_\parallel = \frac{(1+z_X)/H(z_X)}{(1+z_l)/H(z_l)}$$

$$q_\perp = \frac{D_M(z_X)}{D_M(z_l)}$$

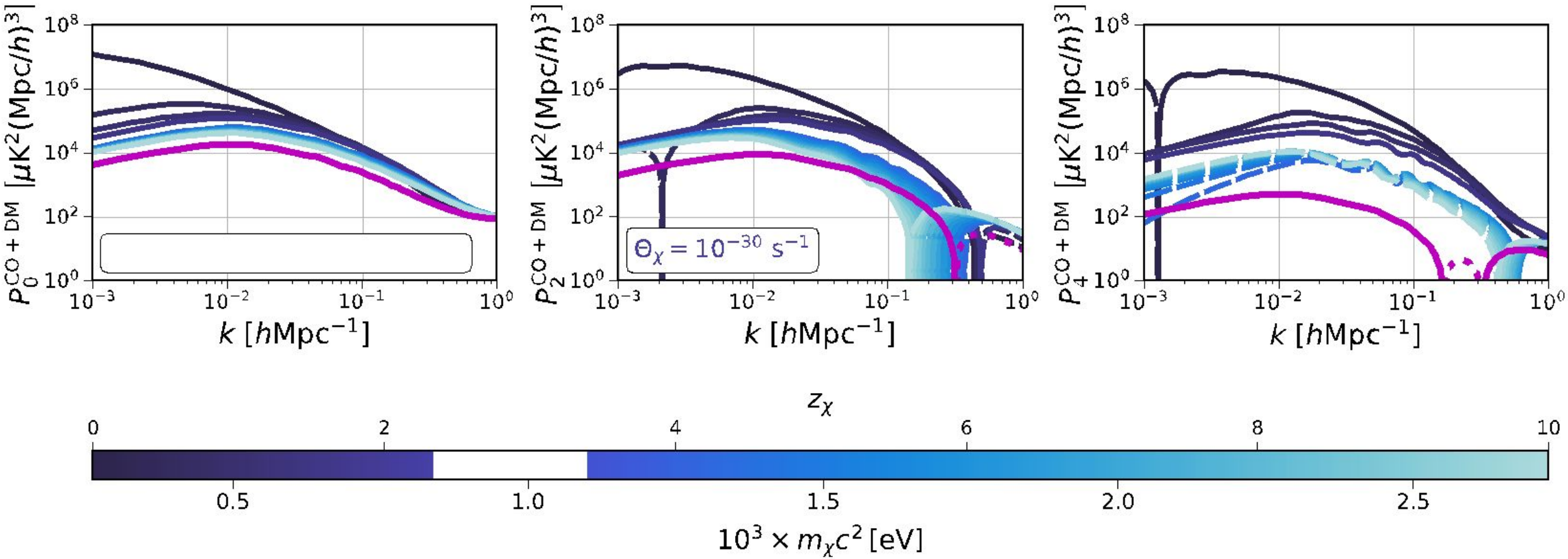
$$x_\perp = D_M(z)\theta$$

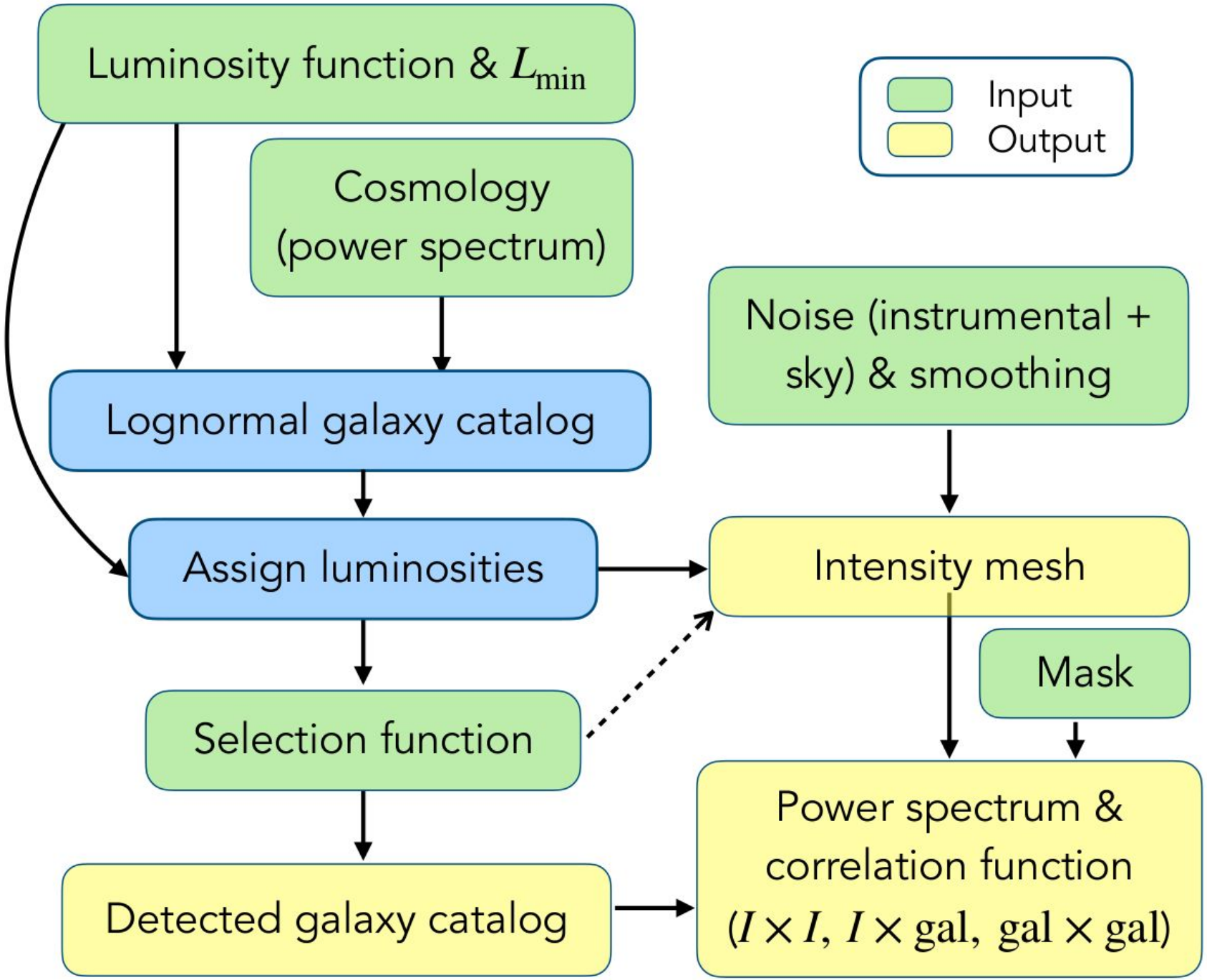
$$x_\parallel = \frac{c\delta z}{H(z)}$$



Effect in power spectrum

- $P_{tot} = P_l + P_X$; $k_i^{true} \equiv k_i^{infer}/q_i$





SIMPLE

- Lognormal simulations with a given LF as input
- Galaxy catalog for a given flux limit / selection function
- Intensity map
- Measurements accounting for masks
- Made for HETDEX, thought for any

Lujan Niemeyer, Bernal, + (2023)