Dark matter and line-intensity mapping

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with José Luis Bernal, Andrea Caputo, Cyril Creque-Sarbinowski, and Francisco Villaescusa-Navarro

IDME
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Who did the work

- Dark matter:
  - Creque-Sarbinowski & MK, 1806.11119
  - Bernal, Caputo, & MK, 2012.00771
- Neutrinos:
  - Bernal, Caputo, Villaescusa-Navarro, & MK, 2103.12099

- Other LIM collaborators:
  - E. Kovetz, P. Breysse, G. Sato-Polito, K. Boddy

- General background:
  - "Line-Intensity Mapping: 2017 Status Report," Kovetz et al., 1709.09066 [astro-ph.CO]
  - "User's guide to extracting cosmological information from line-intensity maps," Bernal, Breysse, Gil-Marín, & Kovetz, 1907.10067.

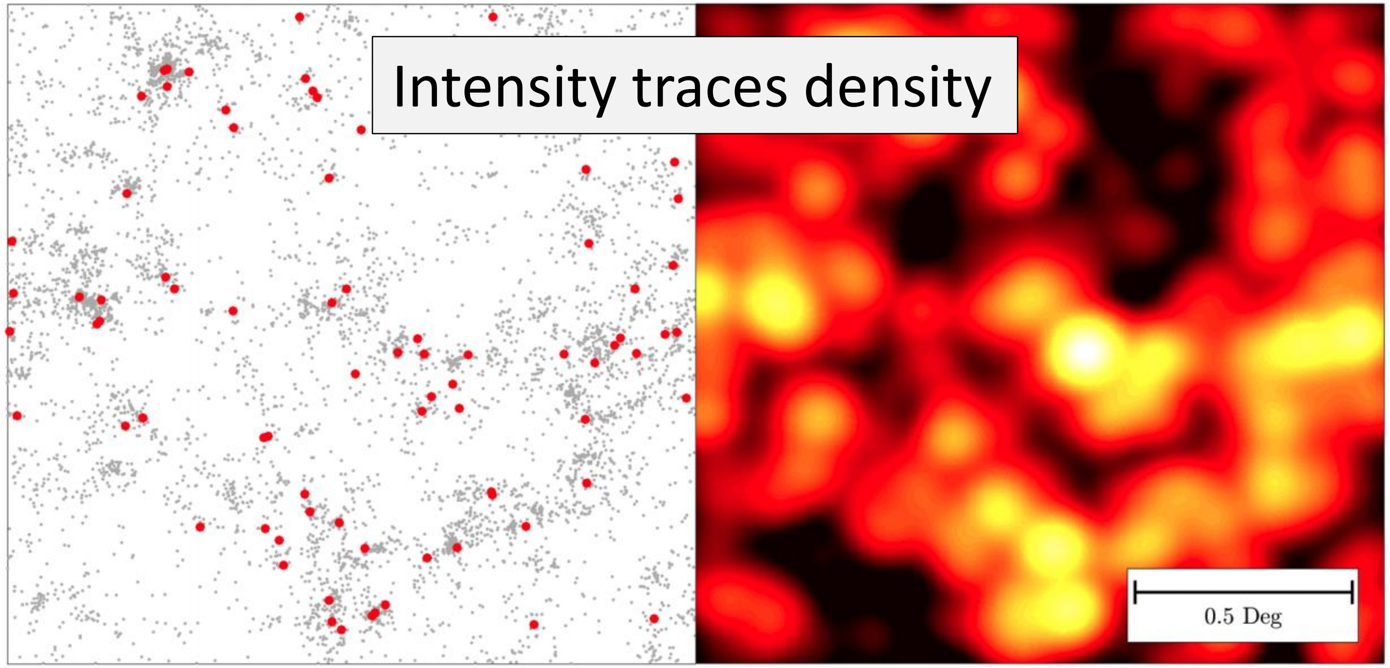
Line-Intensity Mapping

- LIM: use integrated light in given pixel on sky
- Information from all galaxies and IGM along LoS
- Use redshift of identifiable spectral line $\rightarrow$ 3D maps

Galaxy surveys: detailed distribution of brightest galaxies

Intensity maps: noisy distribution of all galaxies and IGM

~ 4.5k hours of VLA can detect ~ 1% of CO-emitting galaxies



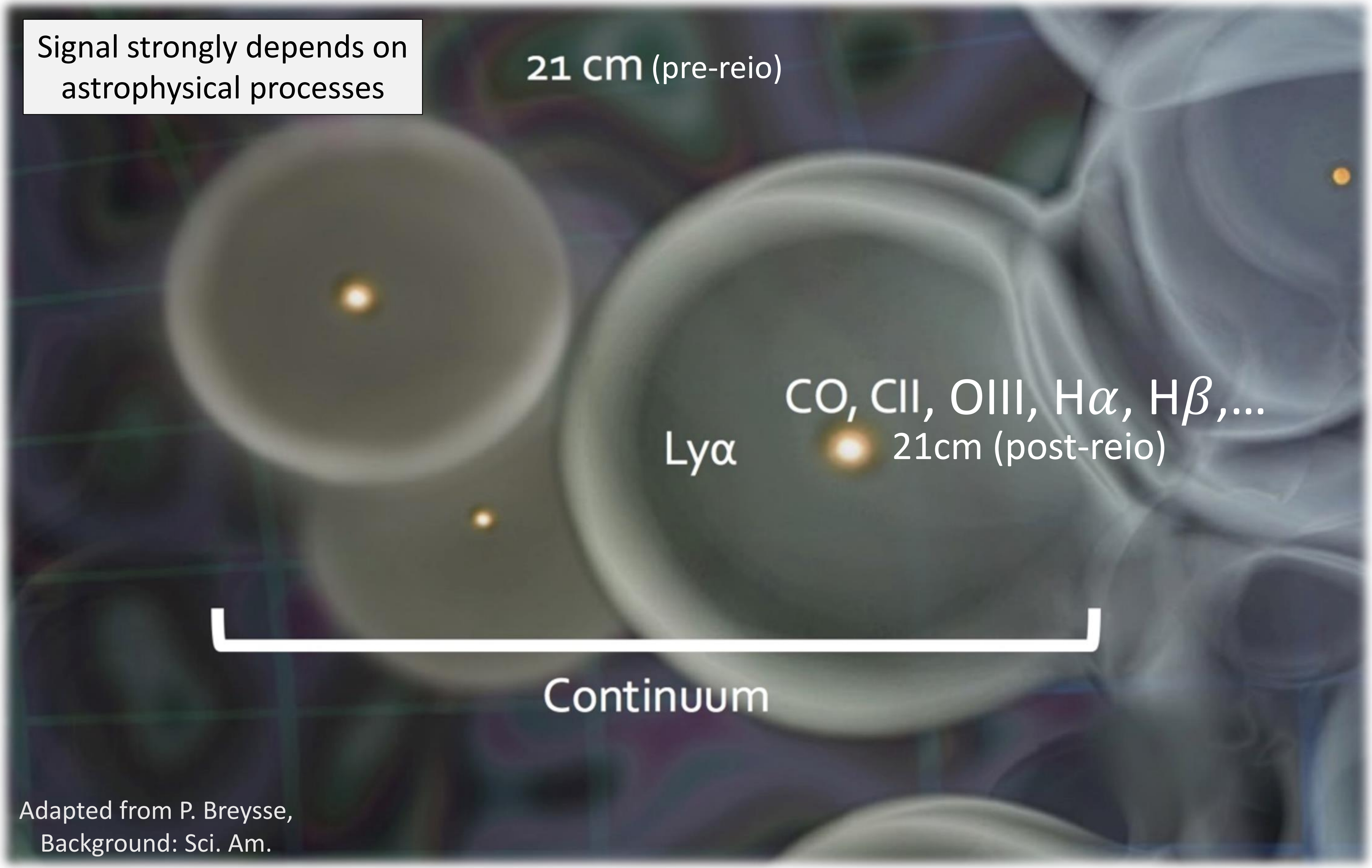
~ 1.5k hours of COMAP mapping CO intensity fluctuations

P. Breysse

Targeted lines

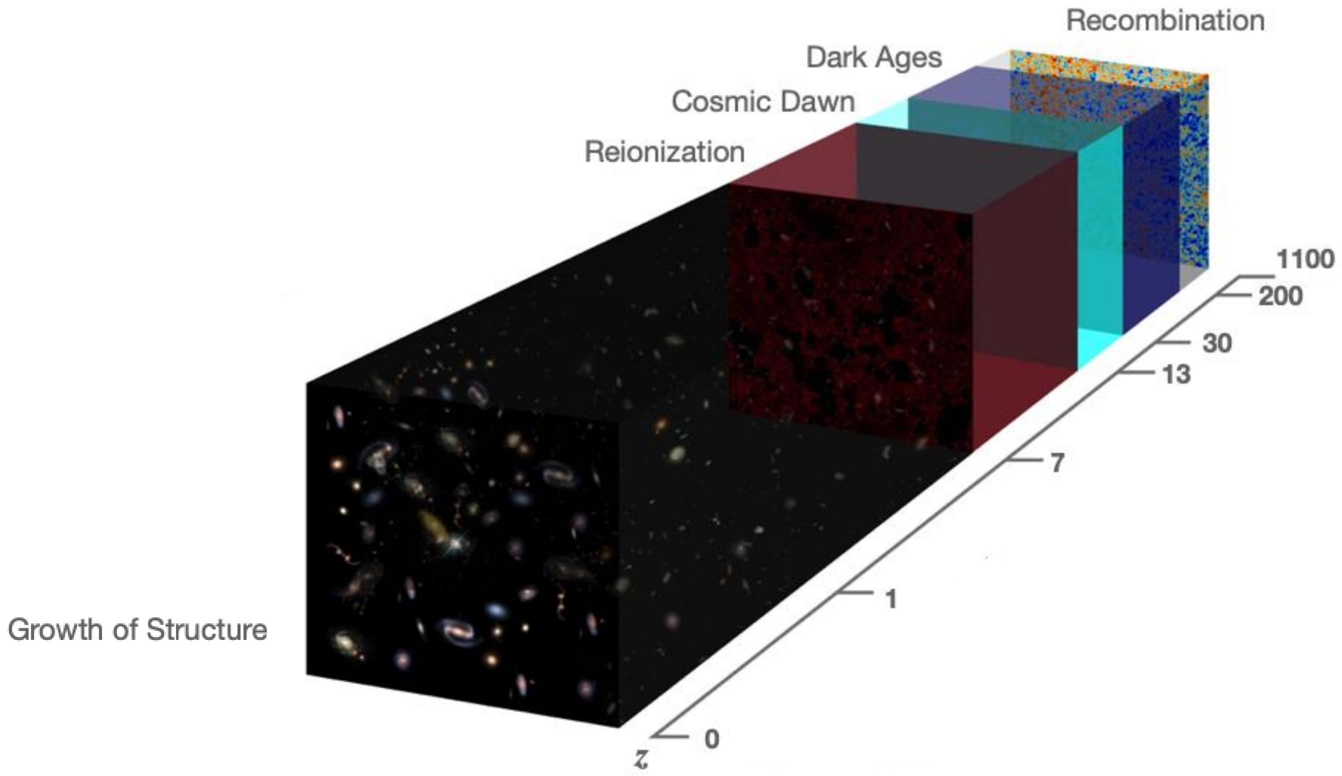
- $\nu_{obs} = \nu_0/(1+z)$

Signal strongly depends on astrophysical processes



Adapted from P. Breysse,
Background: Sci. Am.

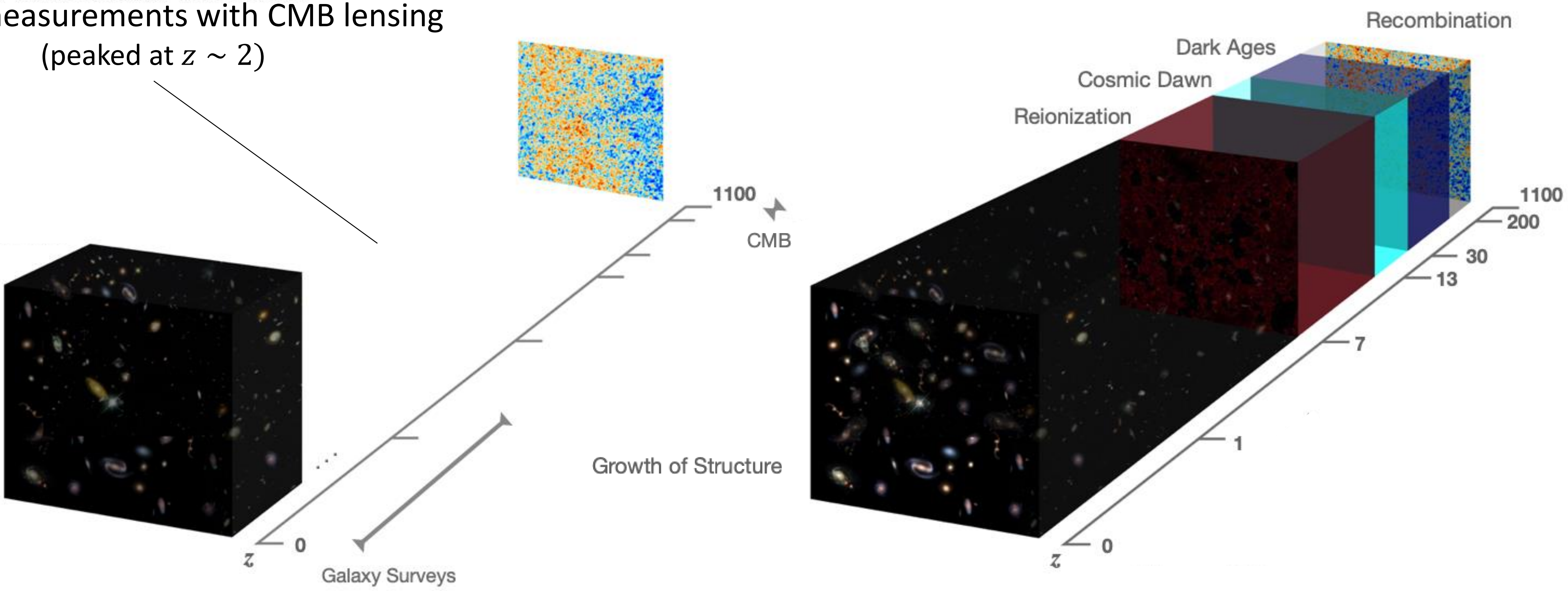
Probing the Universe



E. D. Kovetz

Probing the Universe

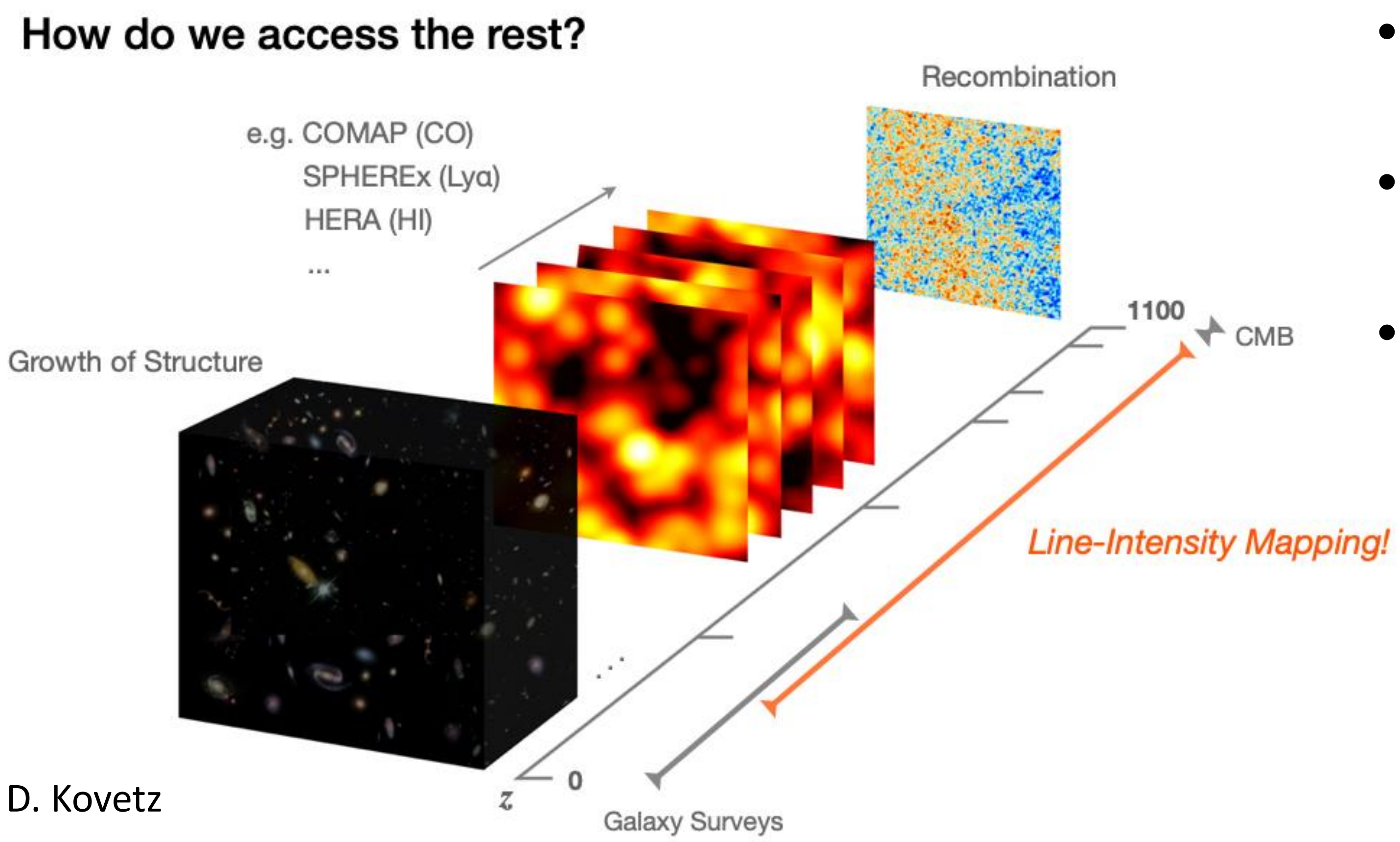
Indirect measurements with CMB lensing
(peaked at $z \sim 2$)



E. D. Kovetz

Probed Universe

Probing the Universe

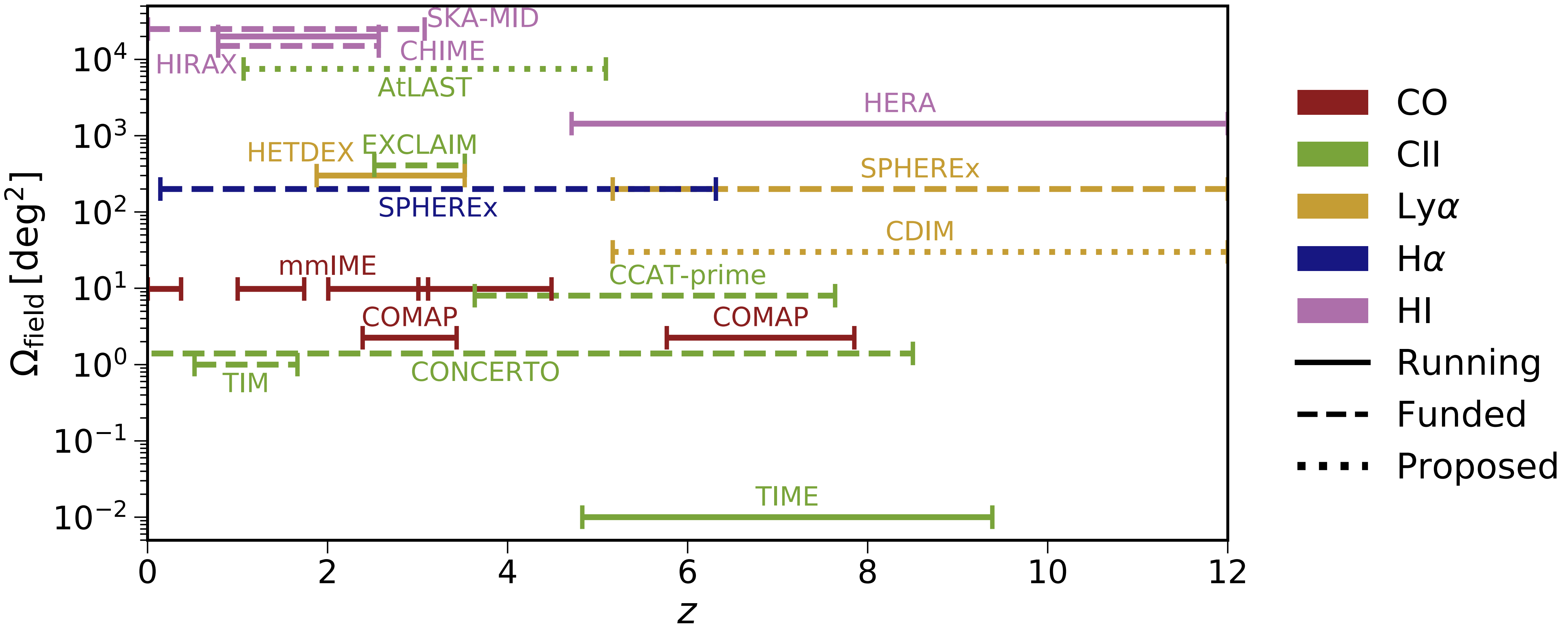


E. D. Kovetz

- Different stages of evolution across time
- But we have only exploited a small part
- LIM: fills the gap!

Probing the Universe with LIM

- Exciting experimental landscape!



Observables

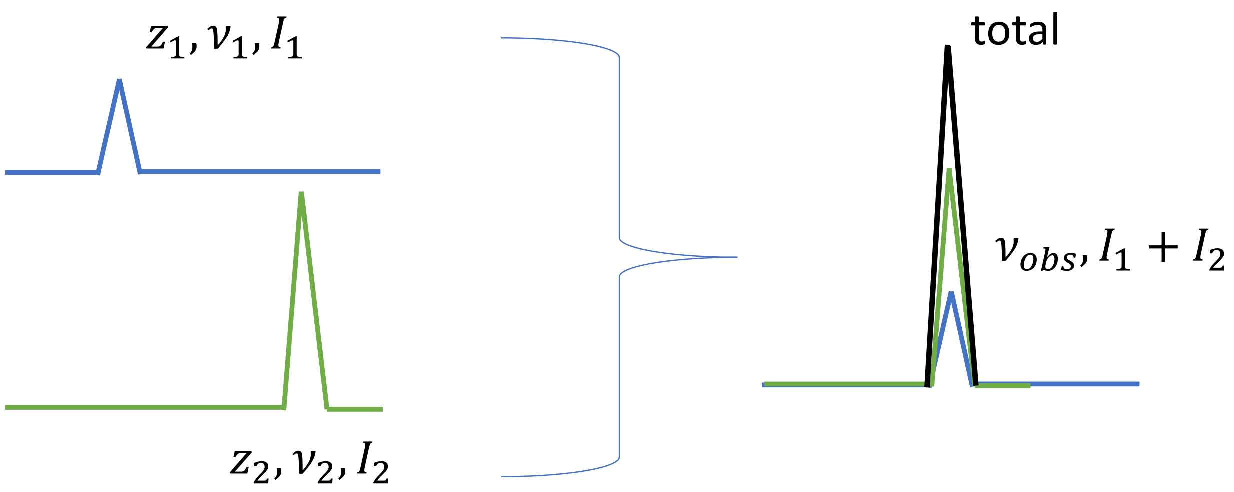
- Clustering anisotropy parametrized by monopole, dipole, quadrupole, hexadecapole in angle wrt LOS
  - Clustering along line of sight
  - Angular clustering

- Voxel-intensity distribution (VID) (one-point PDF)

Contamination of intensity maps

- Continuous foregrounds: problem for HI surveys, less severe at higher frequencies

- **Line interlopers**: Main problem for higher freq. LIM surveys
  - $\nu_{obs} = \nu/(1+z) = \nu'/(1+z') \rightarrow$ other lines redshifted to same ν_{obs}



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  - Two approaches:
    - Masking: targeted (external data) and blind (contaminated voxels are expected to be brighter)
    - Model the effect of known interlopers in the likelihood and analyses

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Exotic radiative decays would be inadvertently detected as a line interloper!!

Exotic radiative decays

- Decaying dark matter: $\chi \rightarrow \gamma + \gamma$

$$\nu_\gamma = m_\chi c^2 / 2h_P$$

$$\rho_L^\chi(\boldsymbol{x}, z) = \rho_\chi(\boldsymbol{x}, z) c^2 \underbrace{\Gamma_\chi f_\chi f_{\gamma\gamma} f_{esc}}_{\Theta_\chi} \left(1 + 2\mathcal{F}_\gamma\right)$$

  - Traces directly the DM density field

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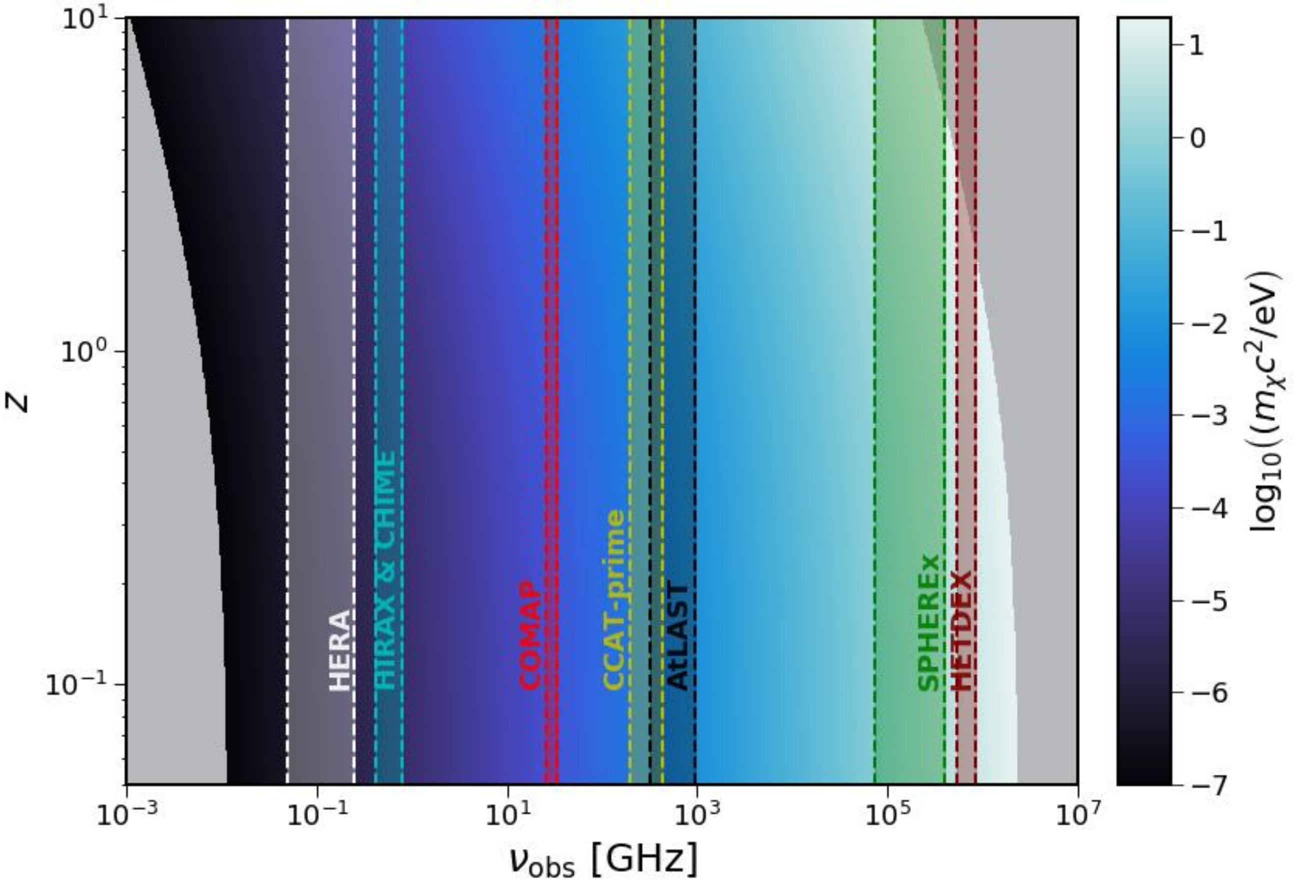
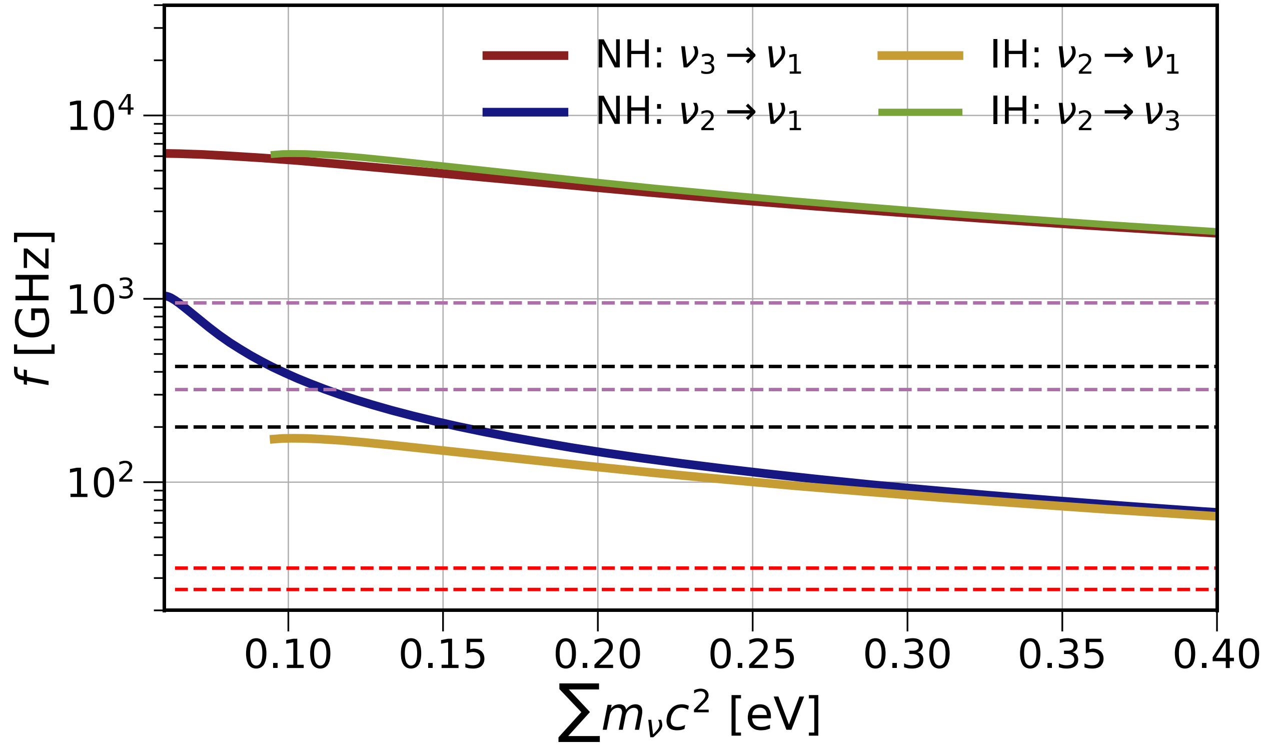


Exotic radiative decays



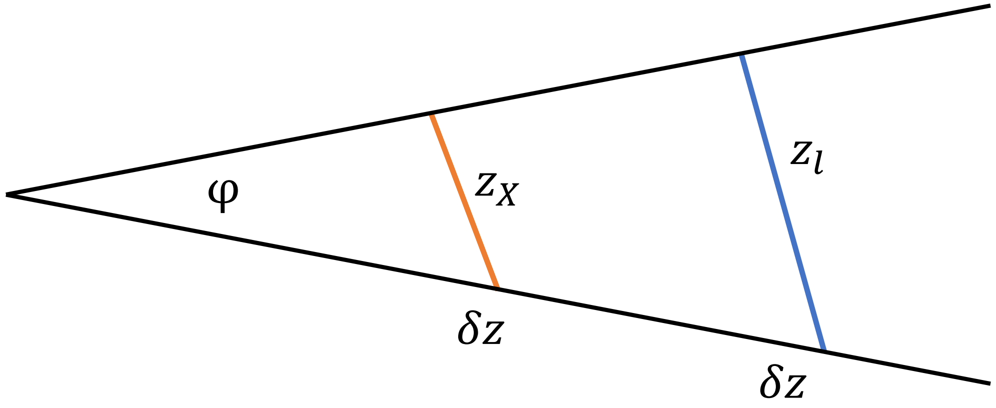
- Neutrino decay: $\nu_i \rightarrow \nu_j + \gamma$

$$f_{ij} = (m_i^2 - m_j^2)c^2/2h_P m_i \qquad \rho_L^{ij}(\boldsymbol{x}, z) = \frac{1}{6}\rho_\nu(\boldsymbol{x}, z)c^2\Gamma_{ij}\left(1 - \frac{m_j^2}{m_i^2}\right)$$

- Traces directly the cosmic neutrino density field

Effect in power spectrum

- Confusion in redshift

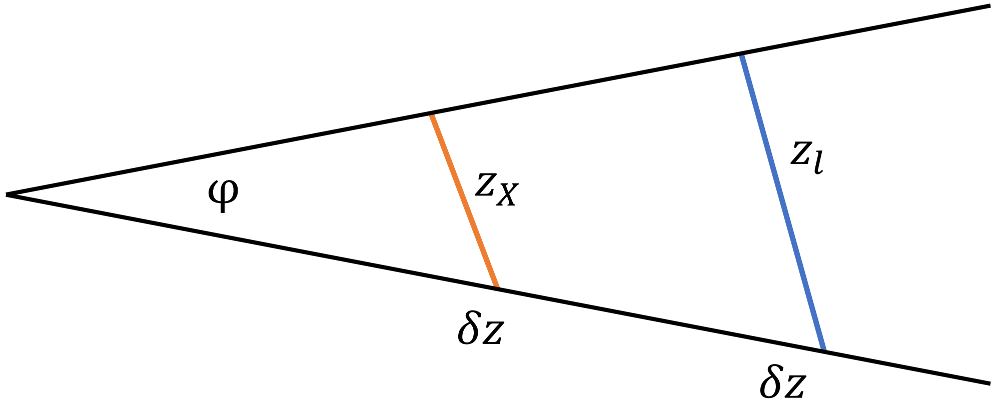


$$x_\perp = D_M(z)\theta$$

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

Effect in power spectrum

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



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

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

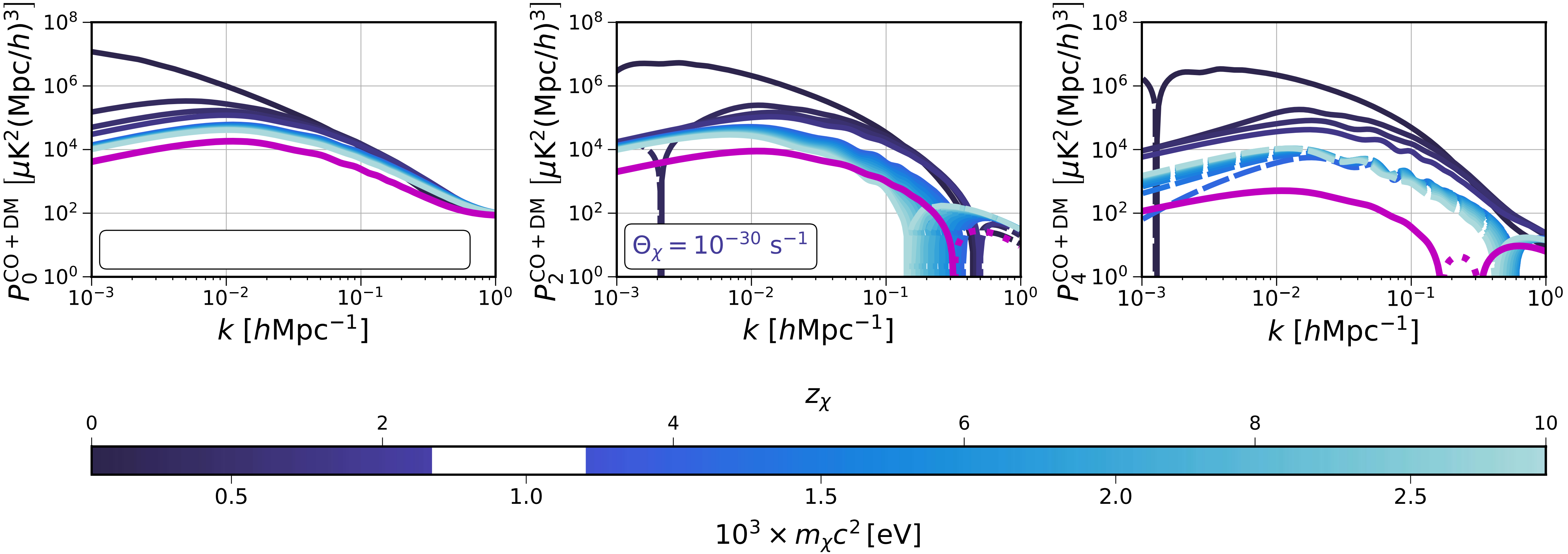
- Model it similar to Alcock-Paczynski effect: $k_i^{true} \equiv k_i^{infer}/q_i$

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

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

Effect in power spectrum

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



Effect in VID

- Each voxel receives contributions from both emissions:

$$T_{tot} = T_l + T_{noise}$$

$$\mathcal{P}_{tot+X}(T) = \big((\mathcal{P}_l * \mathcal{P}_X) * \mathcal{P}_{noise}\big)(T); \qquad \mathcal{P}_X = \mathcal{P}_{\tilde{\rho}}/\langle T_X \rangle$$

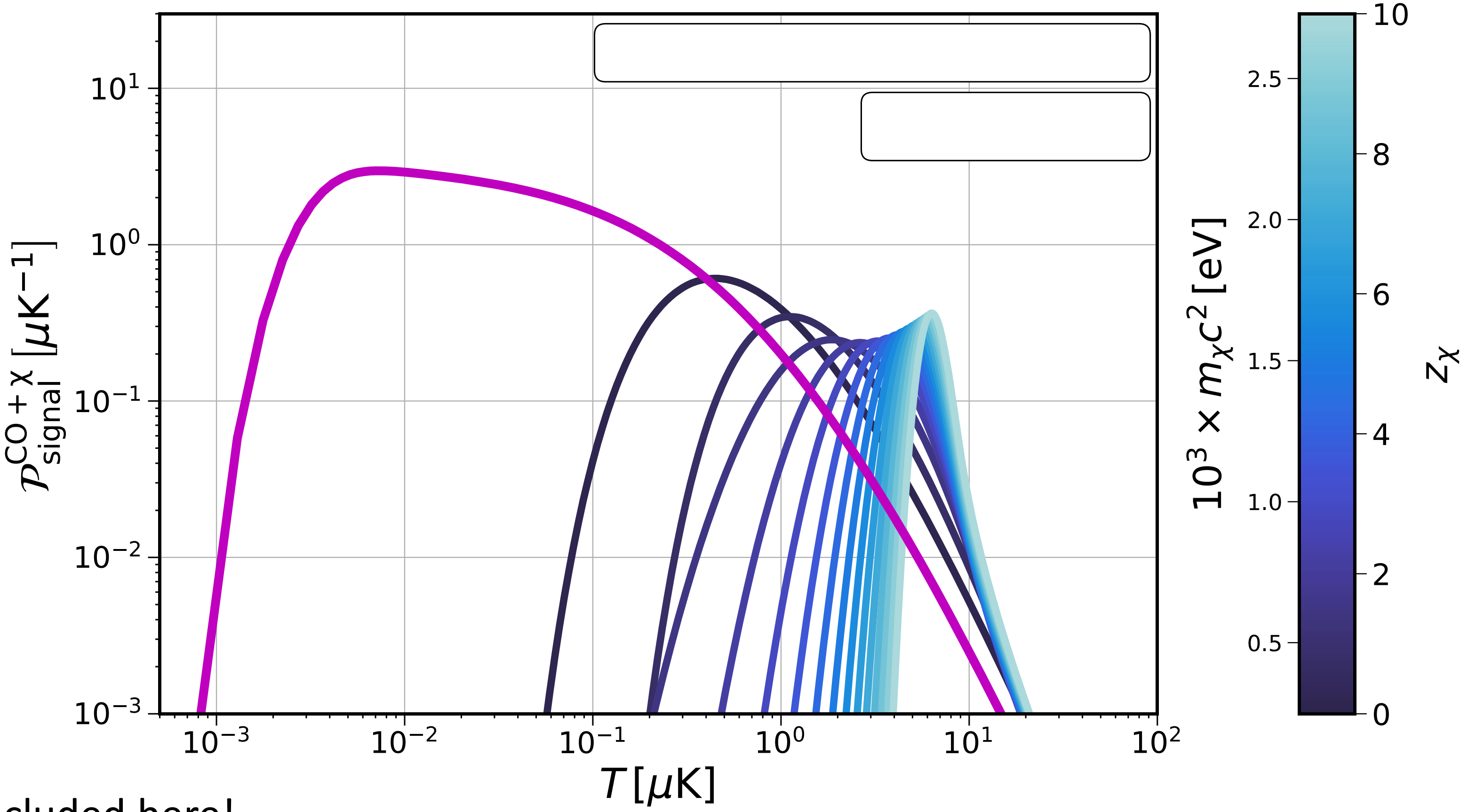
- $\mathcal{P}_{\tilde{\rho}}$: PDF of normalized densities. Obtained from simulations

- We provide the first analytic fit to $\mathcal{P}_{\tilde{\rho}_\nu}$, using Quijote simulations and symbolic regression

Effect in VID

- Each voxel receives contributions from both emissions:

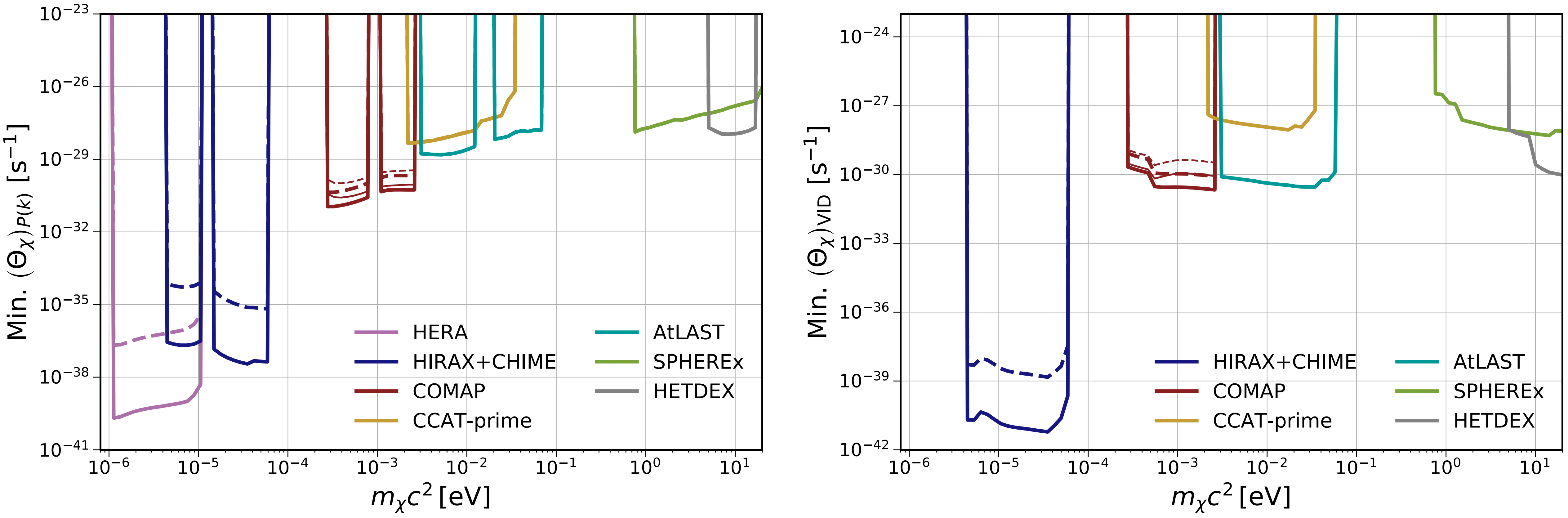
$$\mathcal{P}_{tot+\chi}(T) = \left(\left(\mathcal{P}_l * \mathcal{P}_\chi\right) * \mathcal{P}_{noise}\right)(T); \qquad \mathcal{P}_\chi = \mathcal{P}_{\tilde{\rho}}/\langle T_\chi \rangle$$



No noise contribution included here!

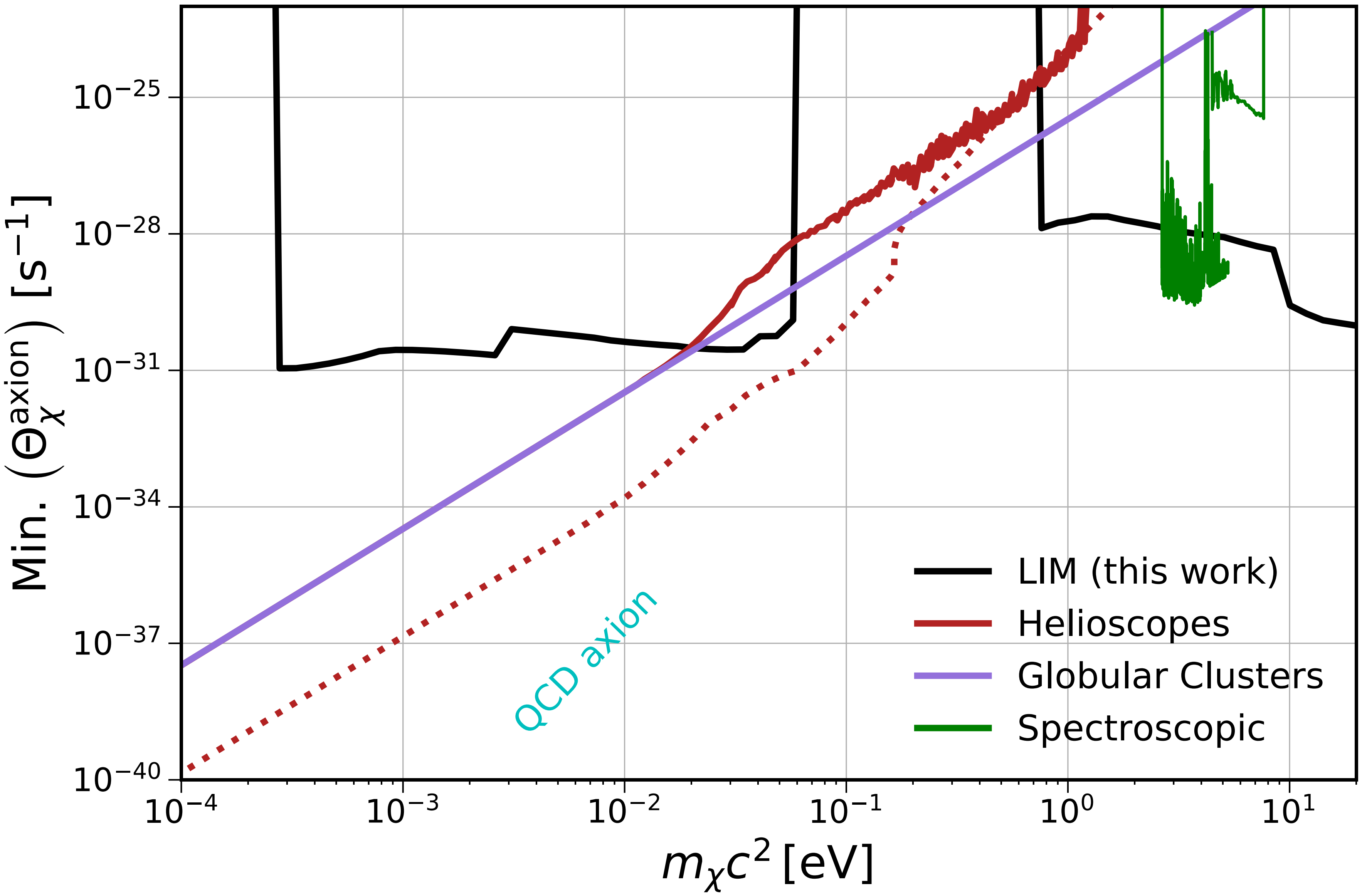
Sensitivity to DM decays

- After marginalizing over astrophysical uncertainties of the target emission line



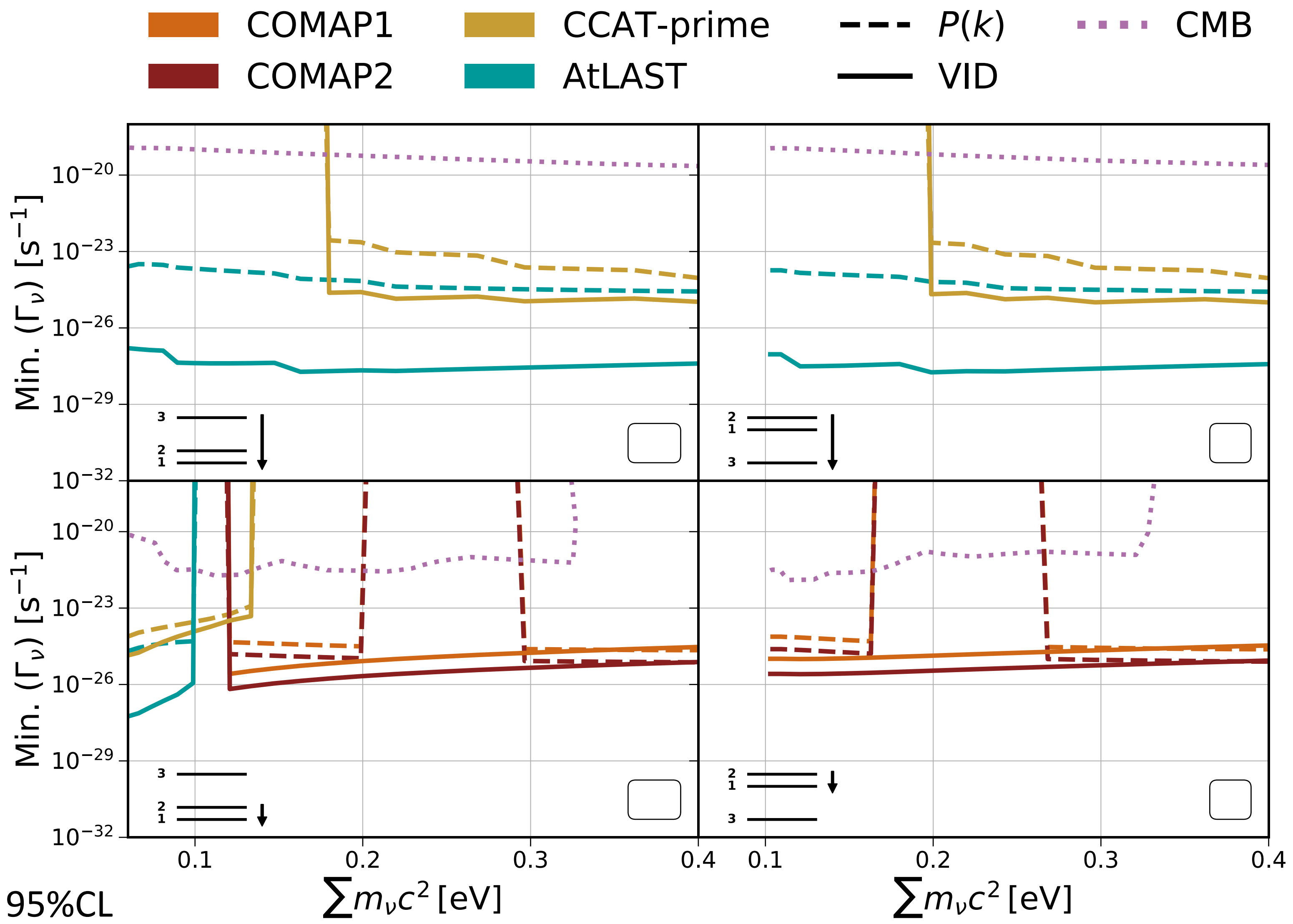
95%CL

Sensitivity to axions



95%CL

Sensitivities to neutrino decay



95%CL

$$\Gamma_{ij} \sim 10^{-28} - 10^{-25}\text{s}^{-1}$$

$$\downarrow$$

$$\mu_{ij}^{eff} \sim 10^{-12} - 10^{-8}\left(\frac{m_i c^2}{0.1\text{eV}}\right)^{1.5} \mu_B$$

- CMB forescast: $3 \times 10^{-11} - 10^{-8}\mu_B$
- Borexino: $< 2.8 \times 10^{-11}\mu_B$
- TRGB: $< 4.5 \times 10^{-12}\mu_B$

Challenges & improvements

- Challenges:
  - Astrophysical uncertainties: marginalized over them
  - Other contaminants: modeled loss information
  - Line broadening

- Reasons to be optimistic:
  - Extendable to other statistics
  - Combination with cross-correlations with galaxy clustering and weak lensing
  - Confusion between DM and neutrino decays: characteristic differences when combining summary statistics and probes
  - Targeted masking to increase relative exotic contributions

Conclusions

- LIM holds a great protential to probe exotic radiative decays
- Adapting techniques to identify and model interlopers is cheap and powerful
- General treatment, for phenomenological DM and neutrino decays that can be translated later to specific models
- Sensitivity extremely competitive:
    - DM: HETDEX & SPHEREx will improve current constraints (1-10 eV) and AtLAST will be similar to IAXO (0.01-0.1 eV)
    - Neutrinos: Improve CMB forecasts and competitive with best constraints