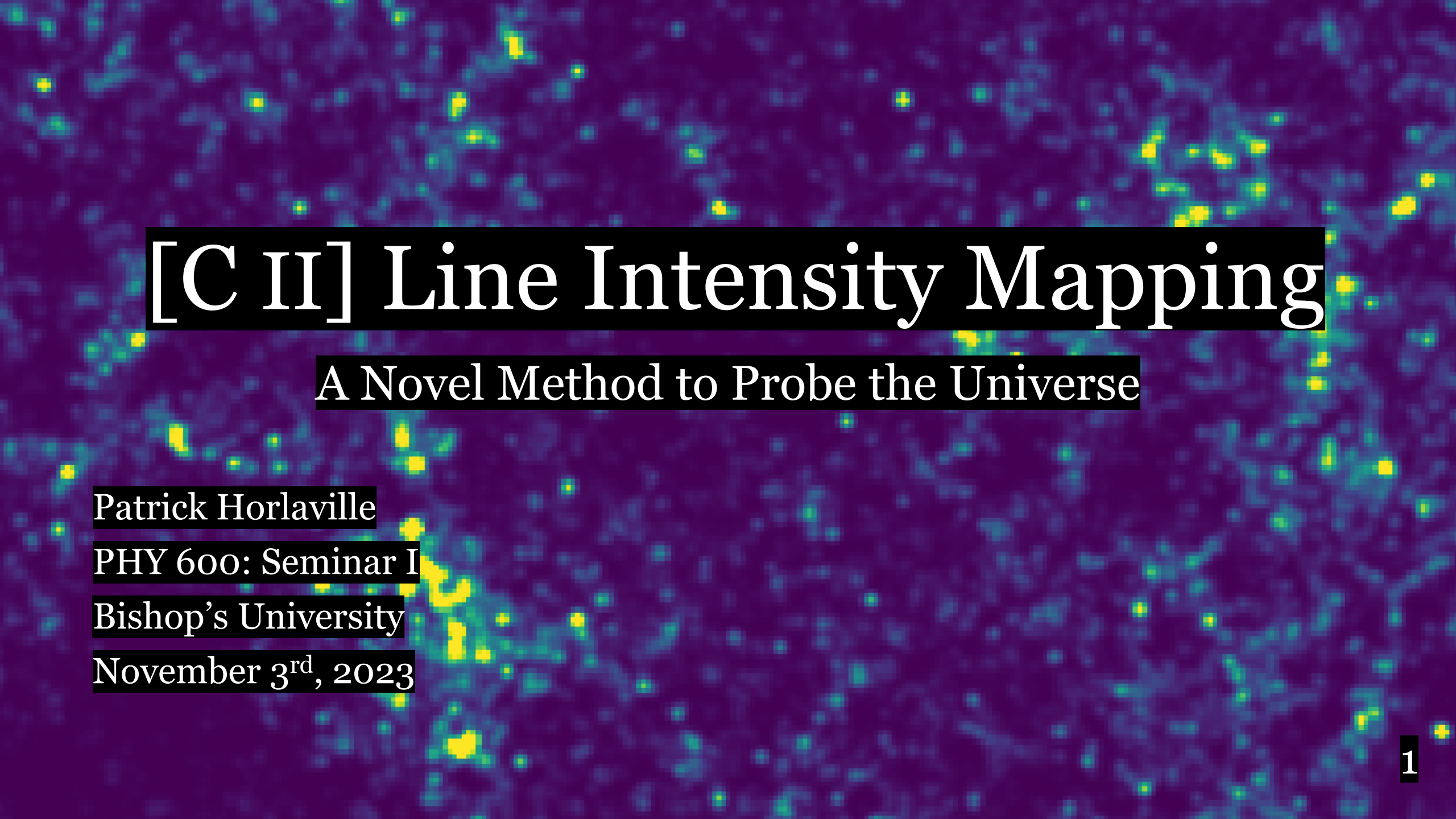

[C II] Line Intensity Mapping

A Novel Method to Probe the Universe

Patrick Horlaville

PHY 600: Seminar I

Bishop's University

November 3rd, 2023

Collaborators

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- Dr Lichen Liang (CITA)
- Nathan Carlson (CITA, UofT)
- Doğa Tolgay (CITA, UofT)
- Dr Patrick Breysse (NYU)
- Dr Zack Li (UC Berkley)







Outline

- History of the Universe
- What is Line Intensity Mapping?
- The Origins of the [C II] Line
- FIRE Simulations
- Where Do Galaxies Live?
- Connecting [C II] to Halos
- Simulation Results
- Perspectives

History of the Universe

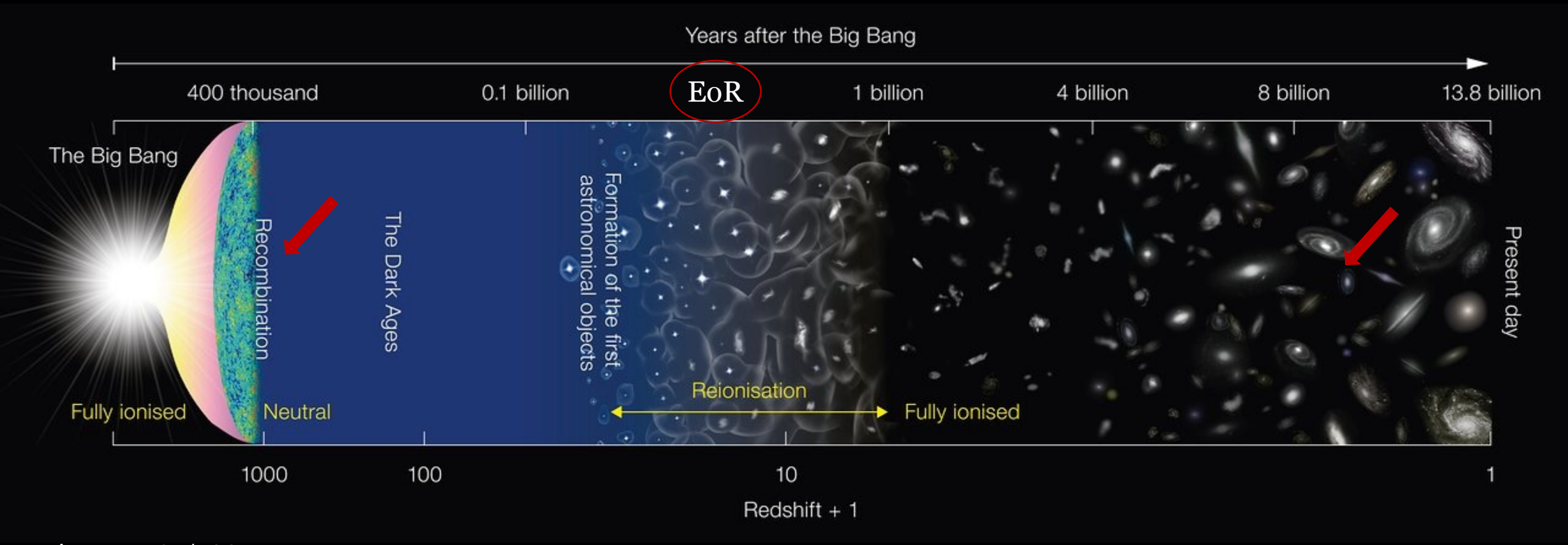
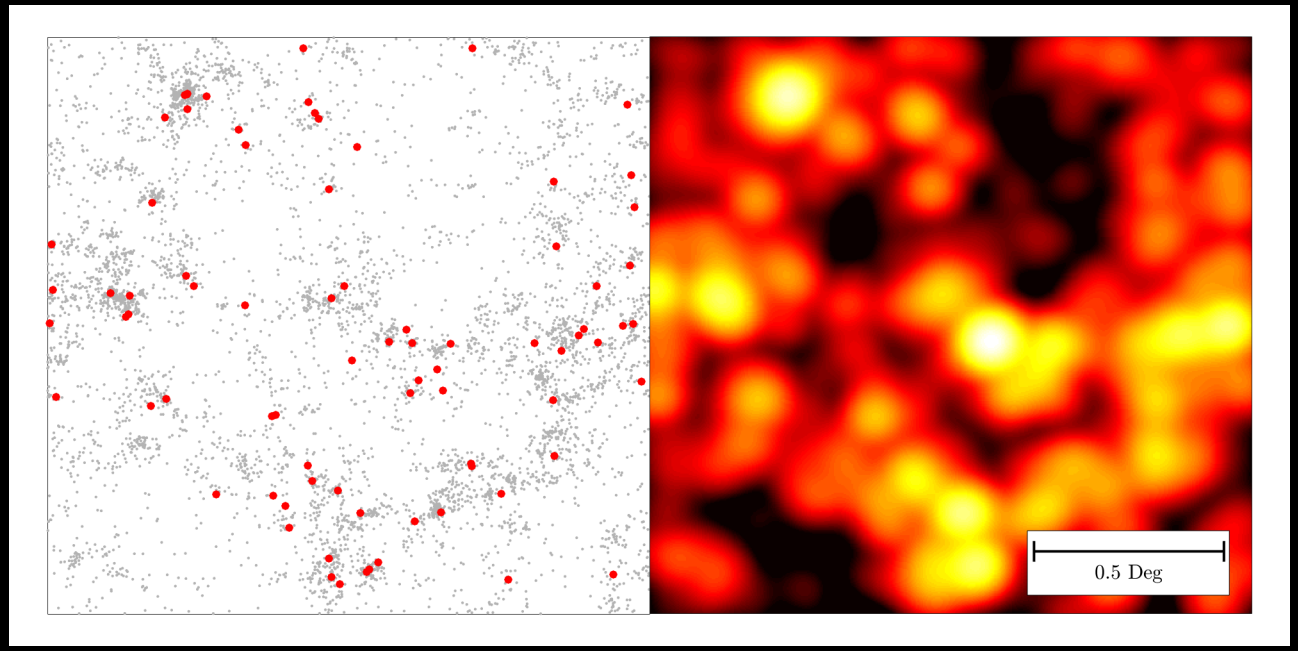


Figure: NAOJ/ESO

Line Intensity Mapping

Galaxy survey:

CO LIM:

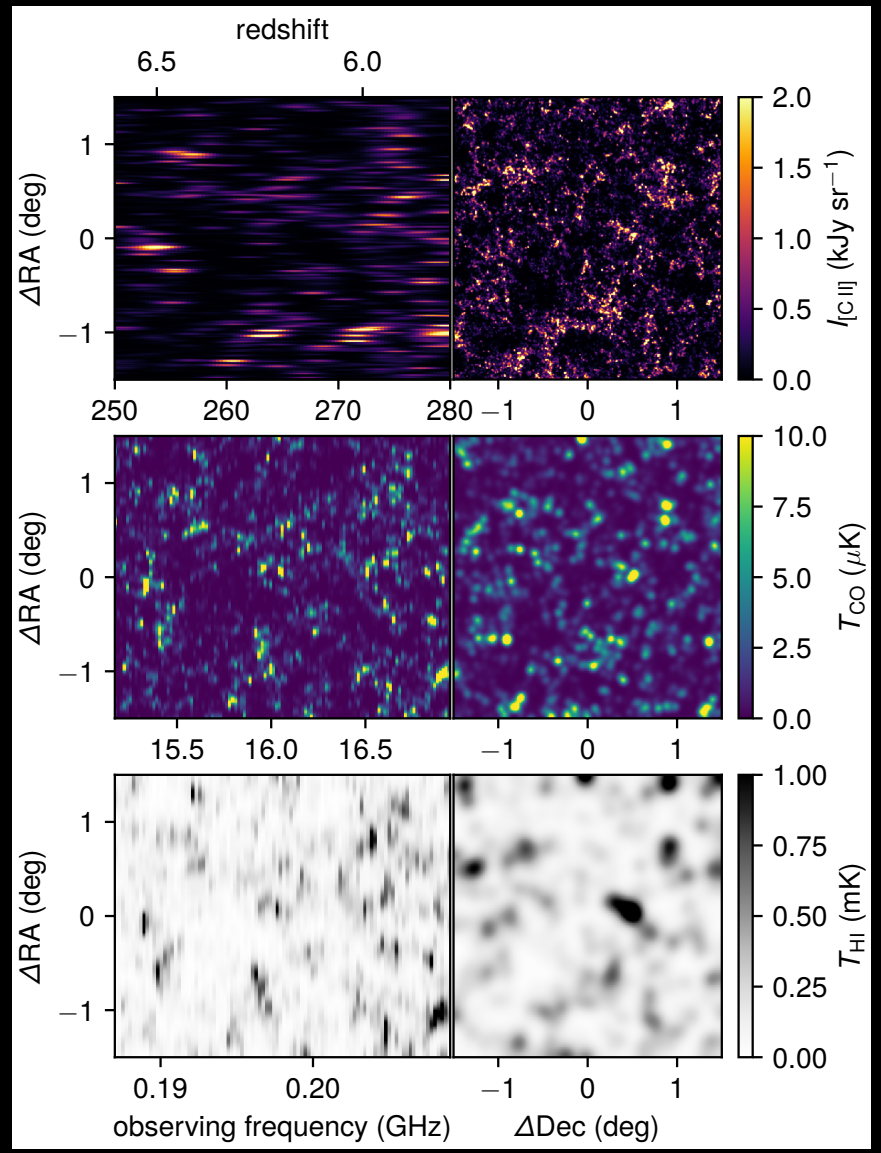


Kovetz et al., 2017
(Figure by Patrick Breysse)

[C II]:

CO:

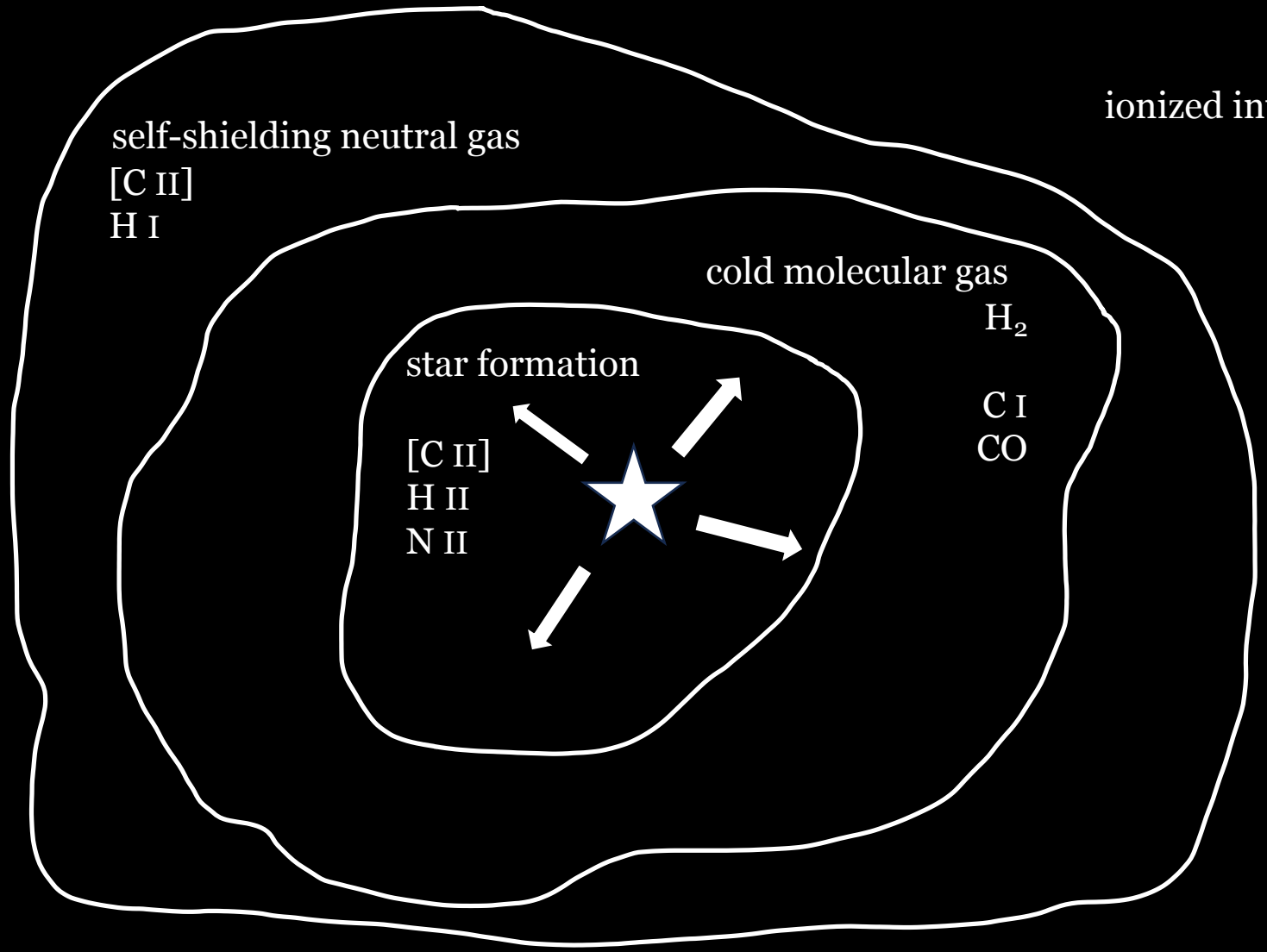
H I:



Horlaville et al., 2023

LIM can trace cosmic structure!

The Origins of the [C II] Line

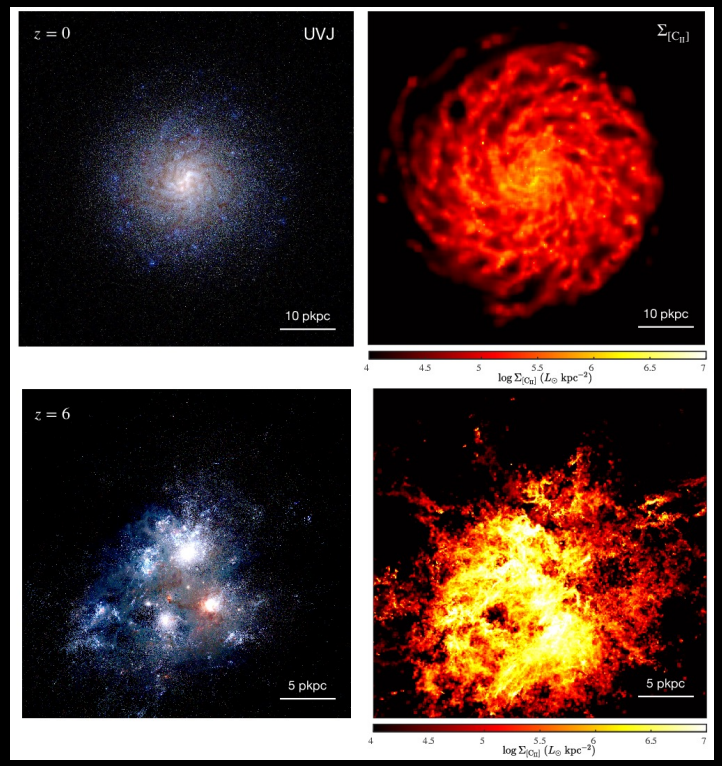


Need to meticulously probe the galactic scale…

schematic adapted from: E. Switzer

FIRE Simulations

Snapshots of FIRE galaxies

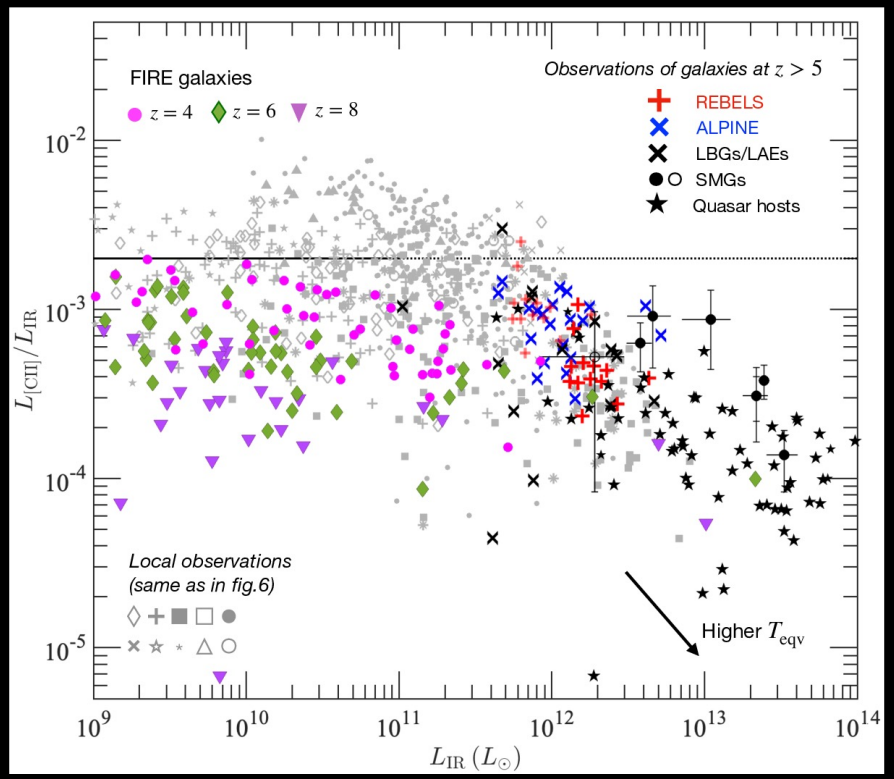


High-resolution galaxy simulations

⇓

Larger-scale cosmology

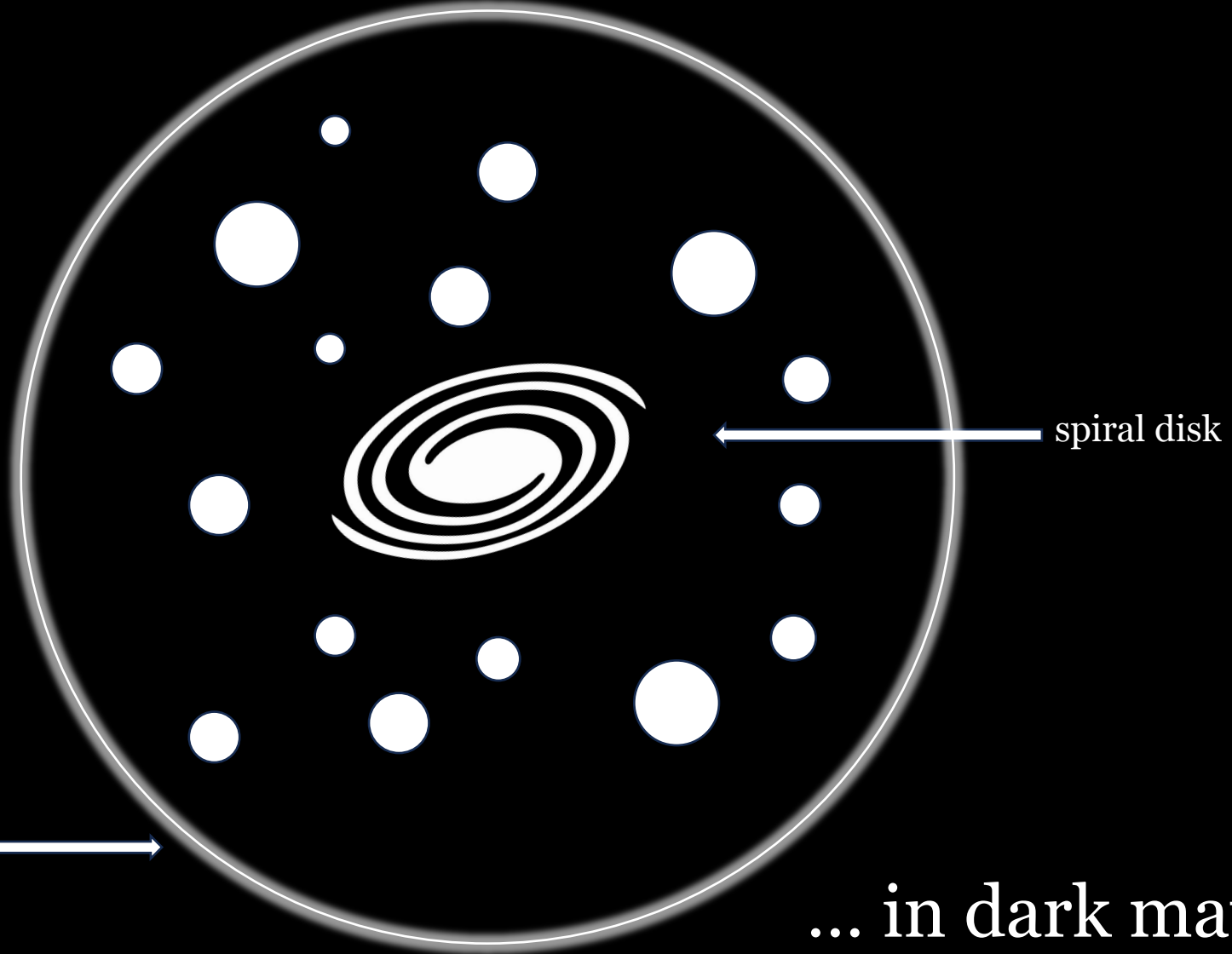
[C II]/IR luminosity relationship



Liang et al., 2023

$$L_{[CII]} \propto f_{[CII]} M_{gas} \bar{Z}_{gas} \Rightarrow L_{[CII]} \propto M_{HI} \bar{Z}_{gas}$$

Where Do Galaxies Live?



… in dark matter halos!

Connecting [C II] to Halos

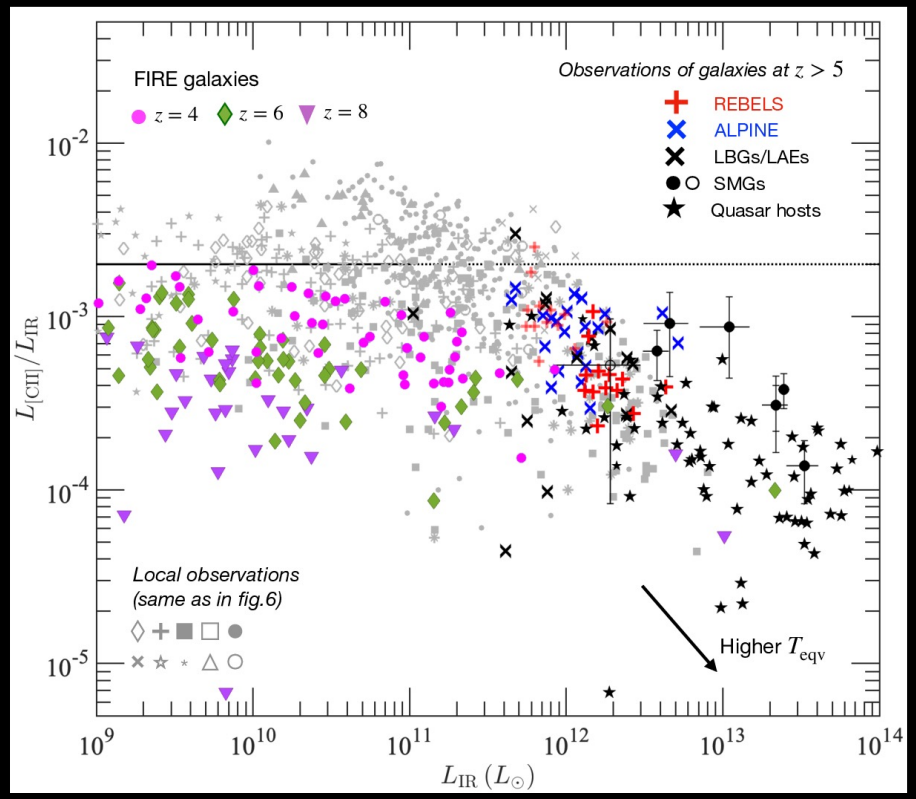
- Simulation input: halo lightcones (variable: M_{halo})
- Simulation output: line intensity map (variable: $I_{[CII]}$)

$$\frac{L_{[CII]}}{L_\odot} = 0.024^{\alpha_{[CII]}} \frac{M_{HI}(M_{halo})}{M_\odot} \frac{Z_{gas}^{\sigma_Z}(M_{halo})}{Z_\odot}$$

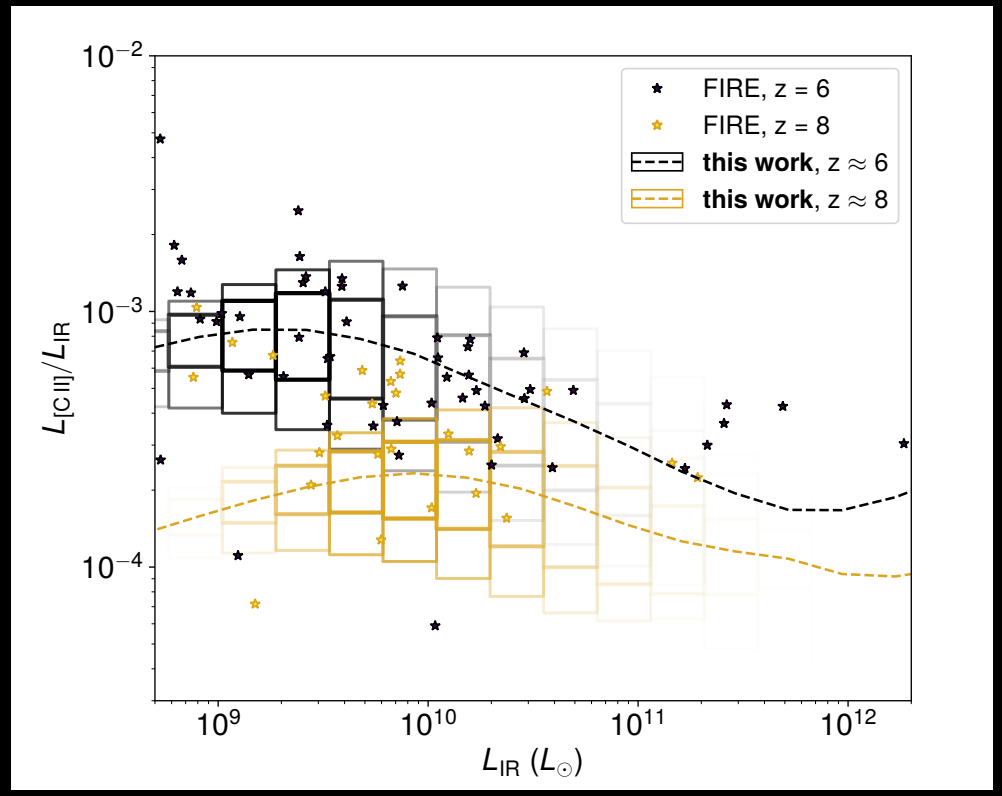
$$\Rightarrow I_{[CII]} = \frac{c}{4\pi \nu_{rest} H(z)} \frac{L_{[CII],vox}}{V_{vox}} \quad (+Beaming\ \&\ White\ Noise)$$

We can make intensity maps!

Cross-Checking with FIRE Galaxies



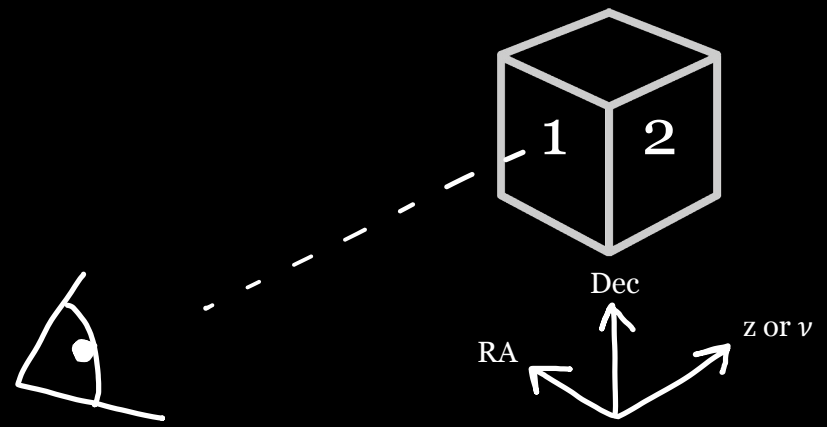
FIRE Galaxies

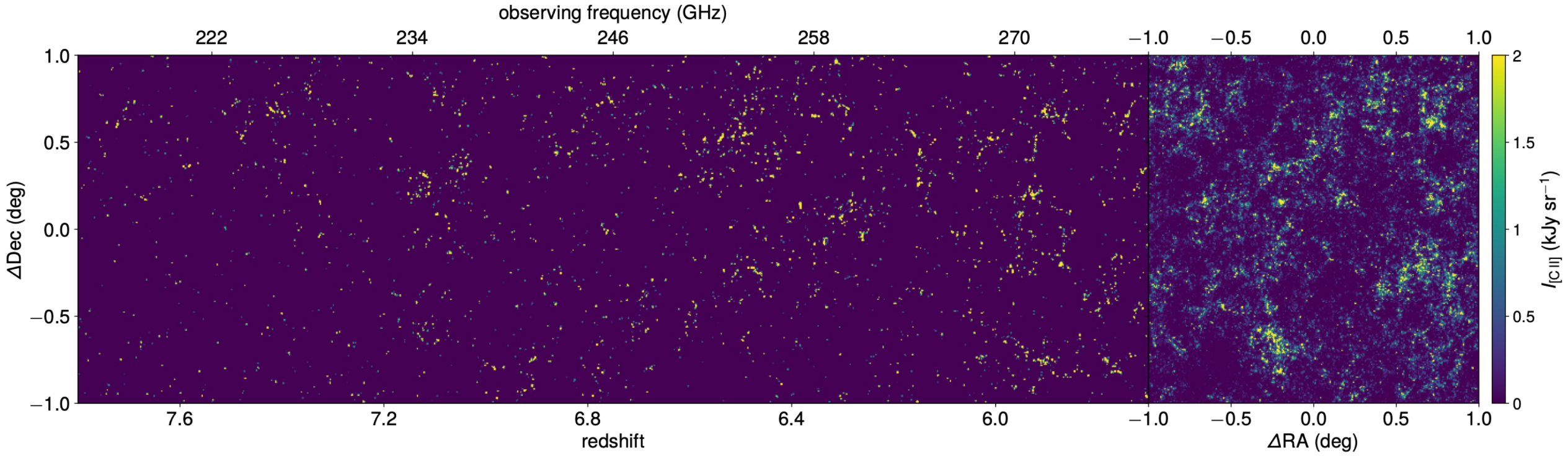


Our Model

Similar shape!

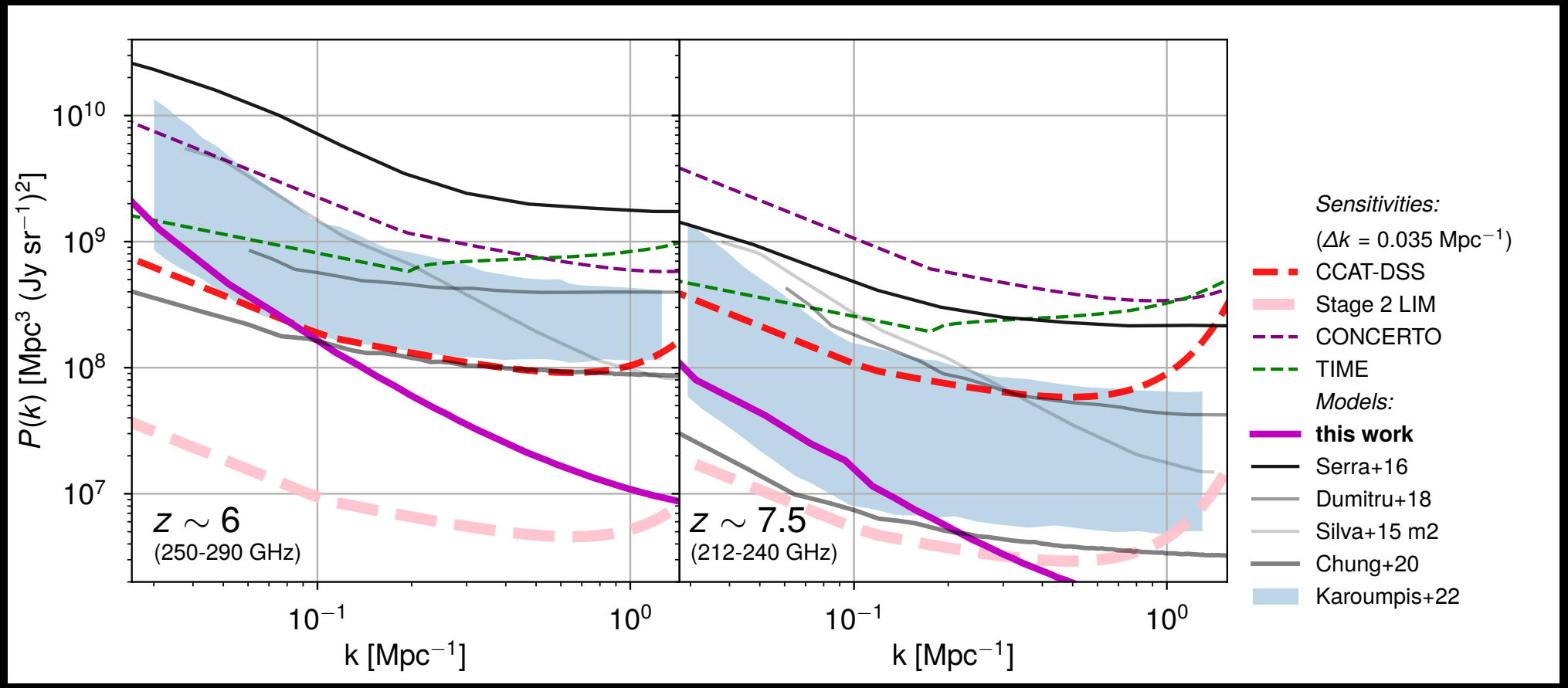
[C II] Intensity Map





② Tracing cosmic structure! ①

Power Spectrum



- Large scales ⇒ mean luminosity
- Small scales ⇒ variance of luminosity

Signal detection! But…

Limitations of the Power Spectrum

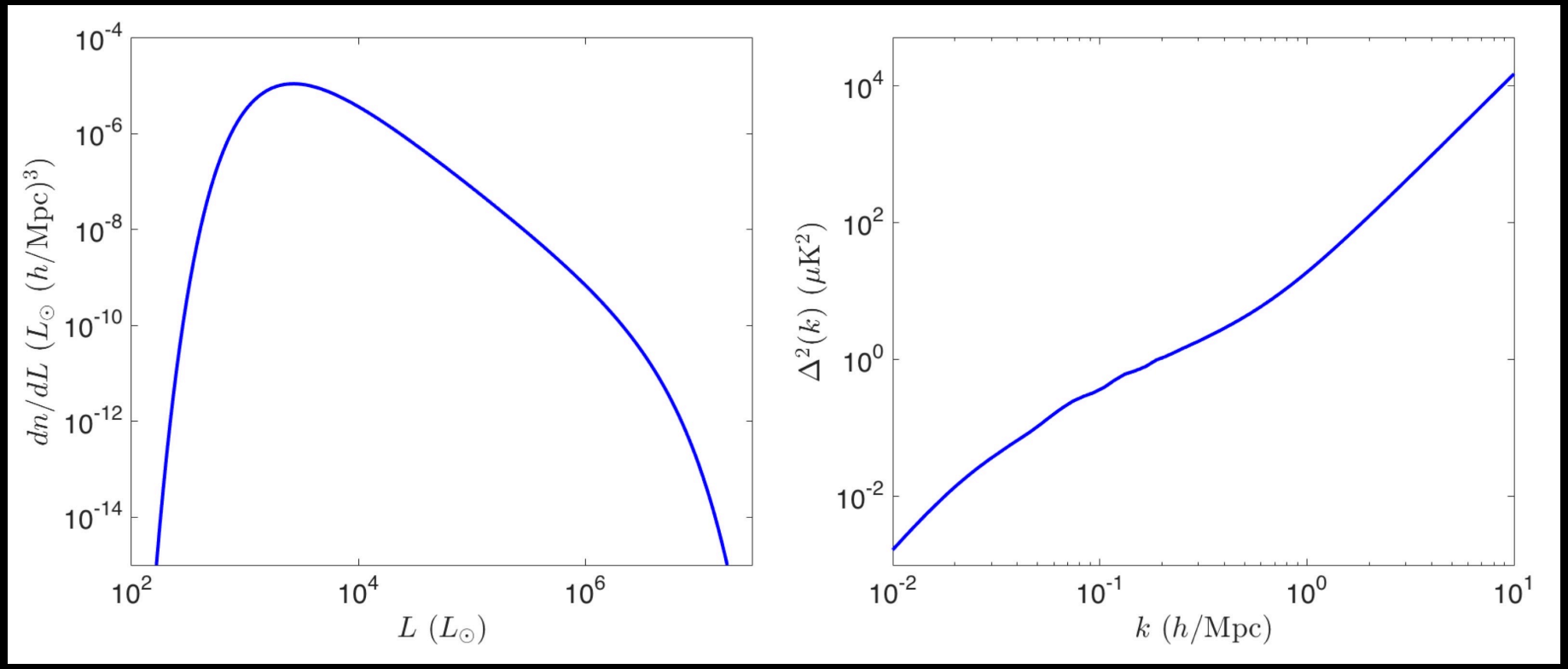


Figure: courtesy of Patrick Breysse

- Traces the information content of the signal for Gaussian distribution…

Limitations of the Power Spectrum

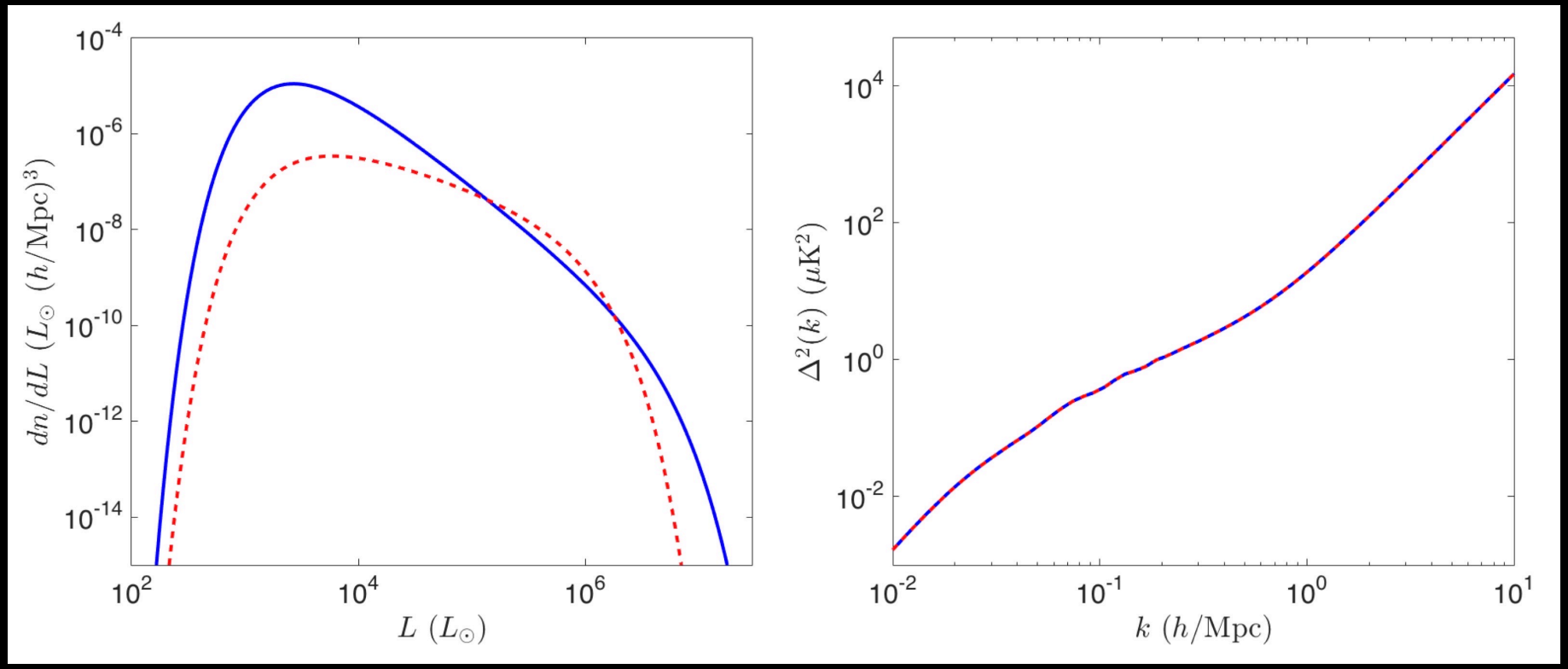


Figure: courtesy of Patrick Breysse

- … degeneracy possible for Non-Gaussian distributions

One-Point Statistics' Formalism

- Integrand of relative entropy:

$$dS_{rel}(P \parallel Q) = -P(I) \ln \frac{P(I)}{Q(I)} \equiv PRE$$

Pointwise Relative Entropy

- Take a deviate from the model $P(I)$:

$$dS_{rel}(\Delta\lambda) = -P(I) \ln \frac{P(I)}{Q(I; \lambda = \lambda_0 + \Delta\lambda)}$$

- How does it change with $\Delta\lambda$?

$$\frac{\Delta(dS_{rel}(\Delta\lambda))}{\Delta\lambda} = -\frac{P(I)}{\Delta\lambda} \ln \frac{P(I)}{Q(I; \lambda = \lambda_0 + \Delta\lambda)}$$

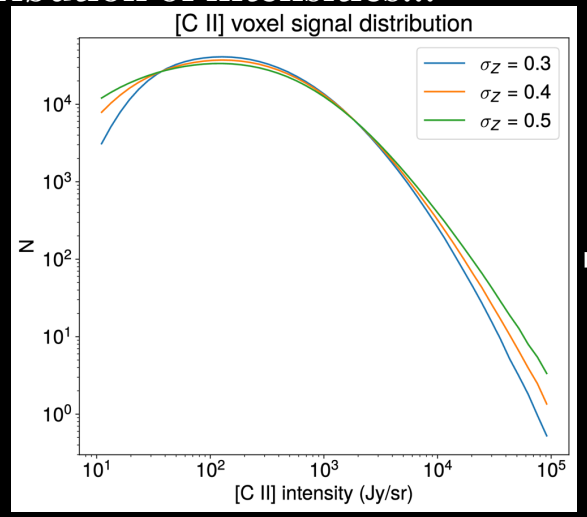
$$\frac{d(dS_{rel})}{d\lambda} = P(I) \frac{d}{d\lambda} [\ln Q(I; \lambda)]$$

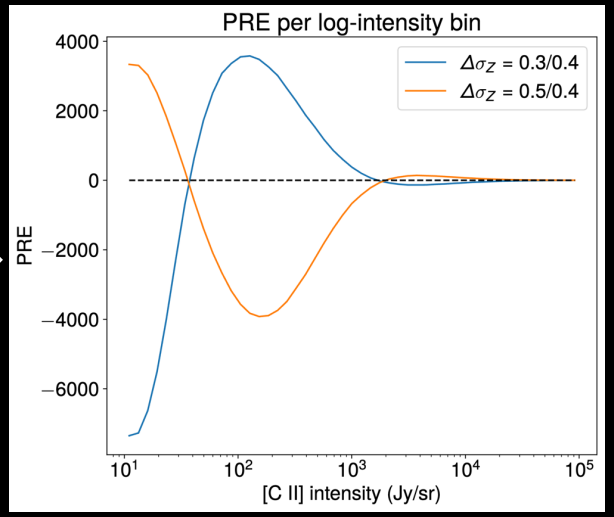
PRE Applied on [C II] Maps

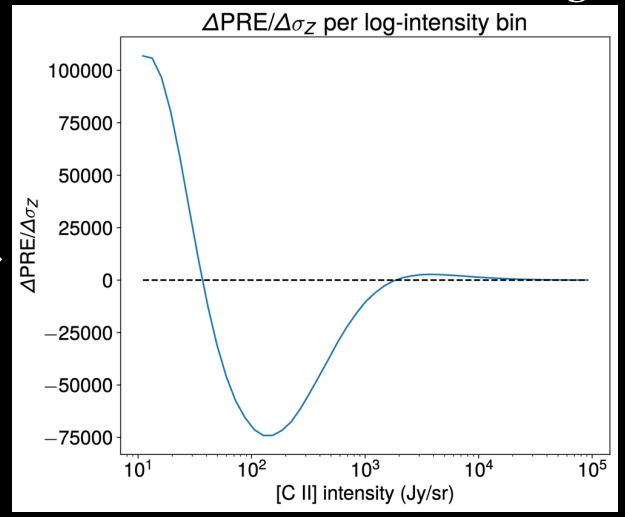
From distribution of intensities...

... to the PRE signature

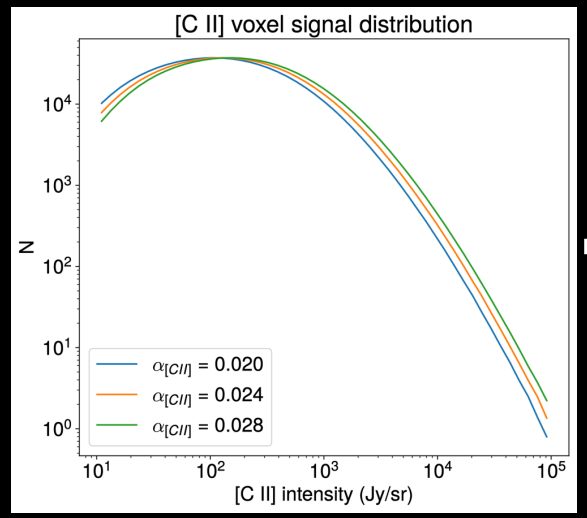
σ_Z

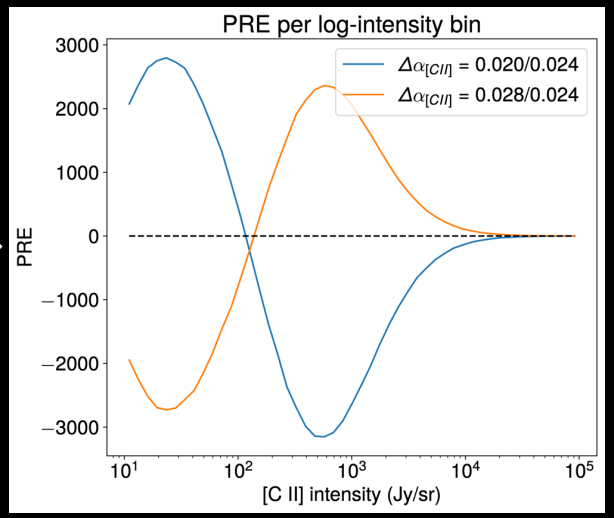


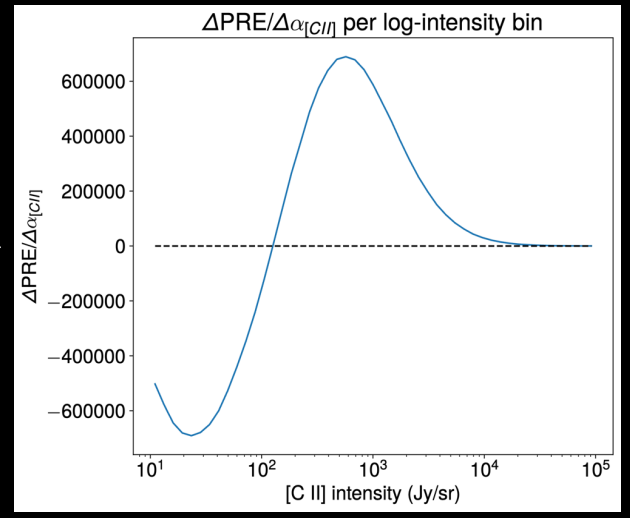




$\alpha_{[CII]}$

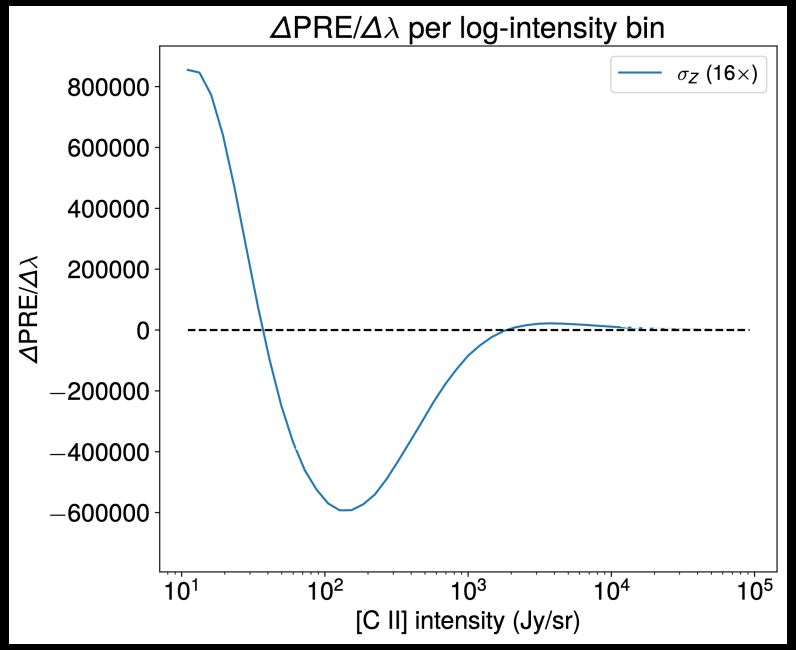


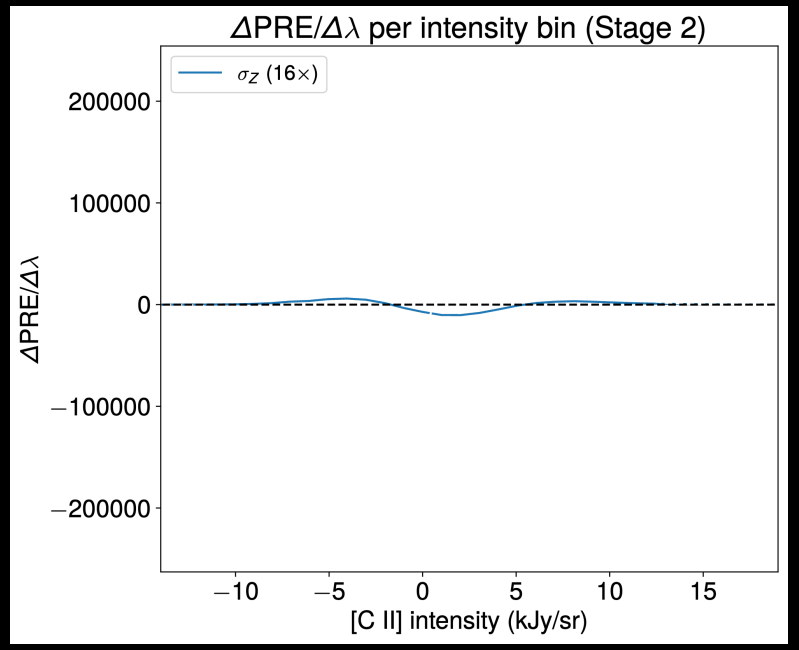




PRE Signatures

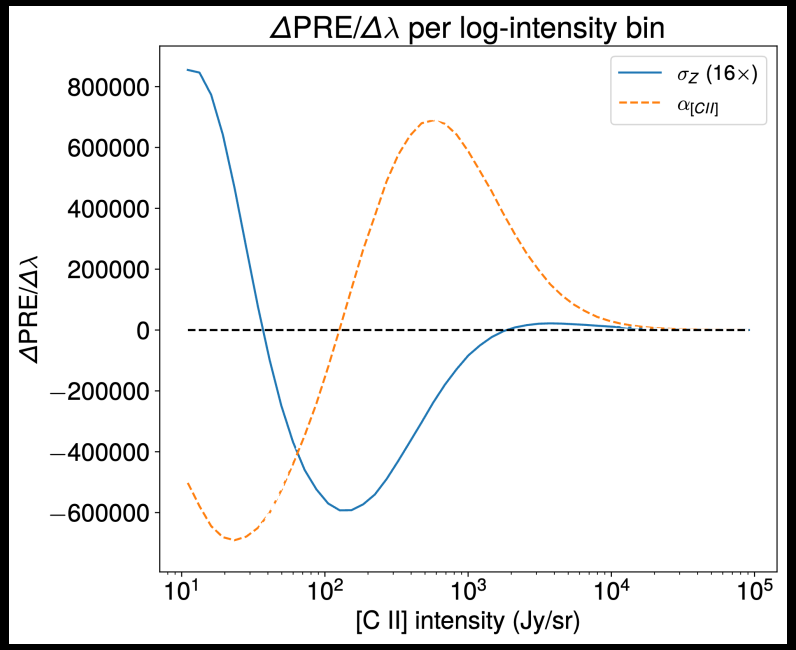
- Apply on various model's parameters

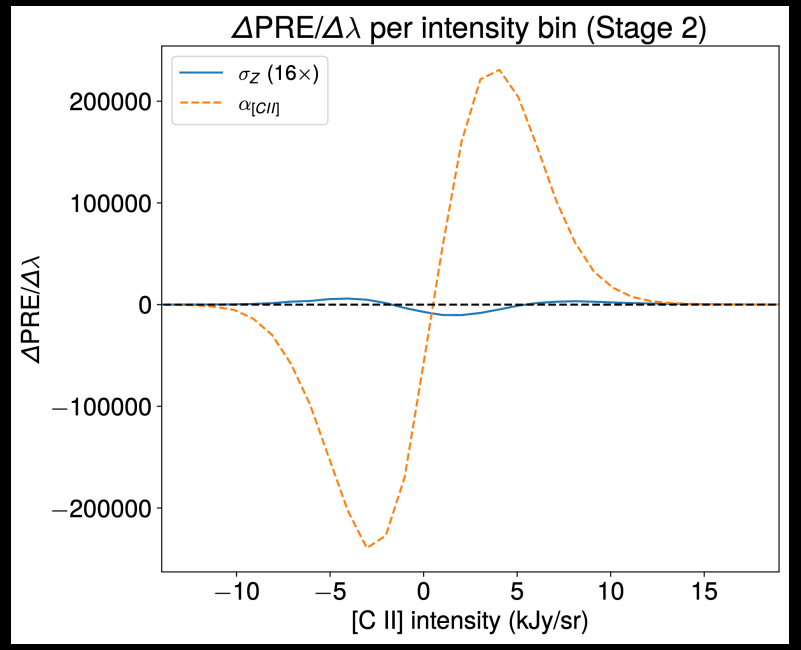




PRE Signatures

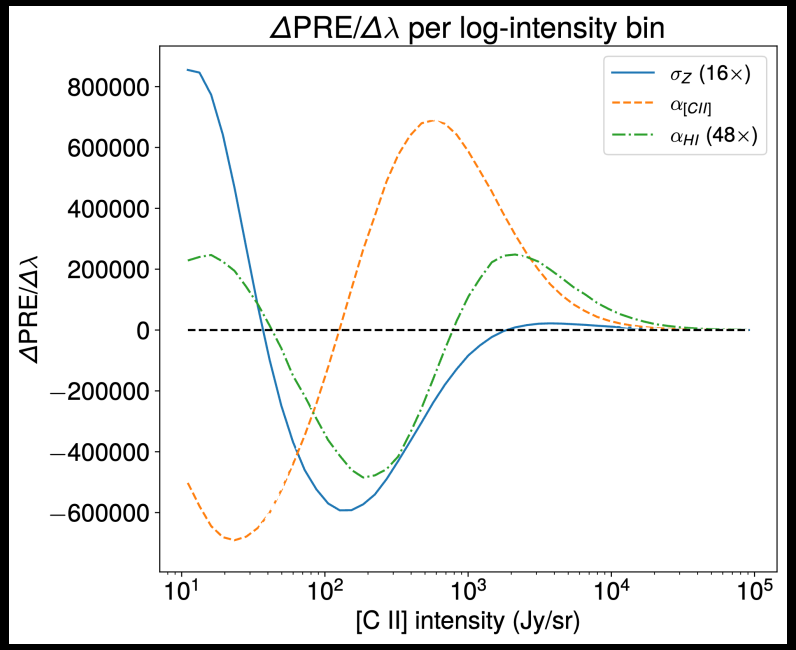
- Apply on various model's parameters

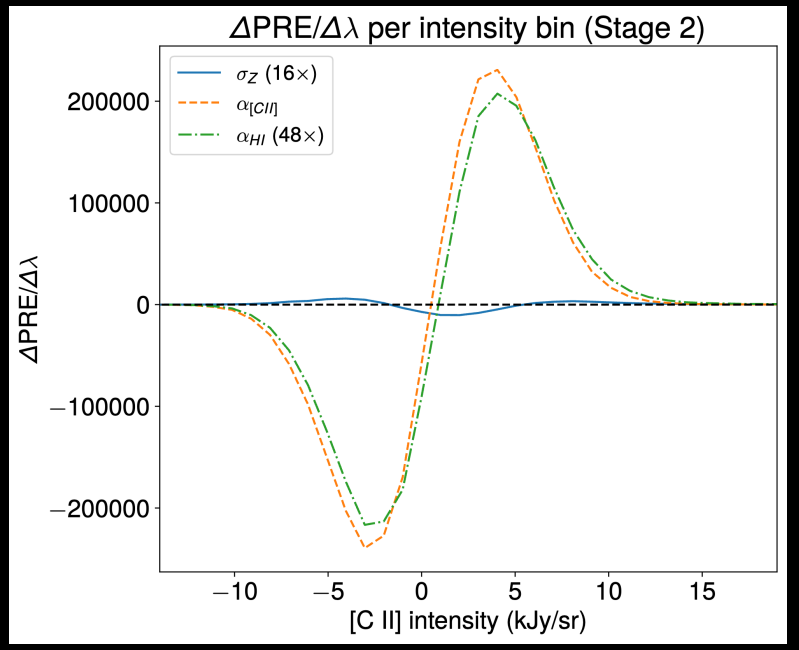




PRE Signatures

- Apply on various model's parameters





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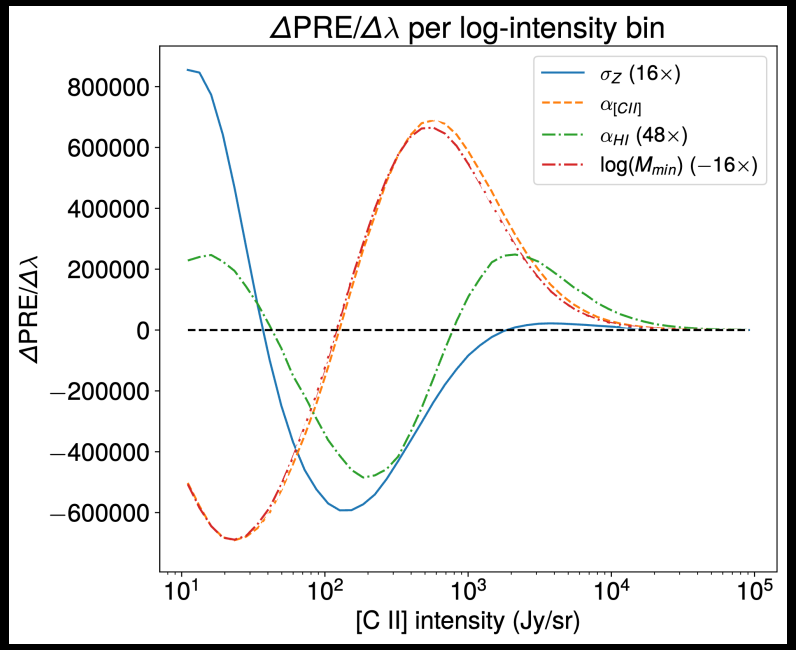
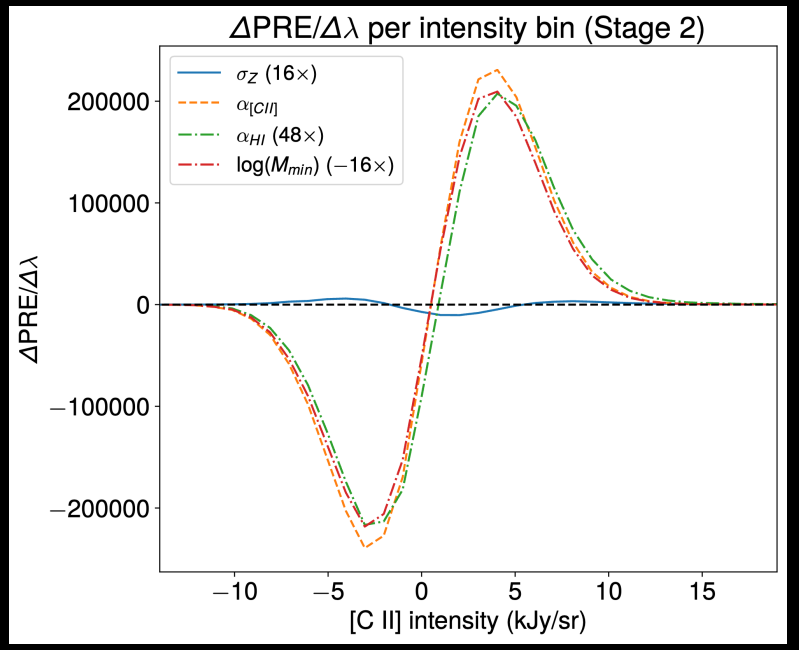
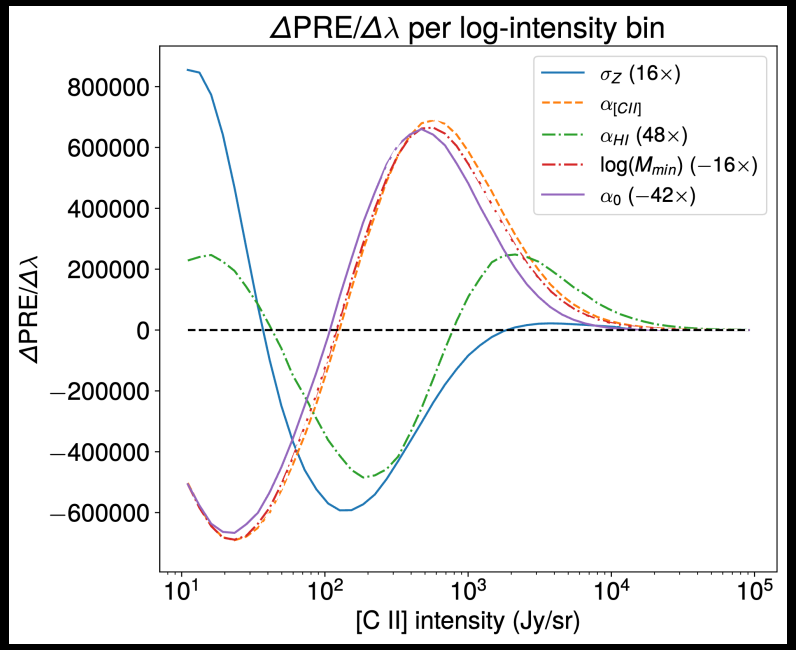
- Apply on various model's parameters

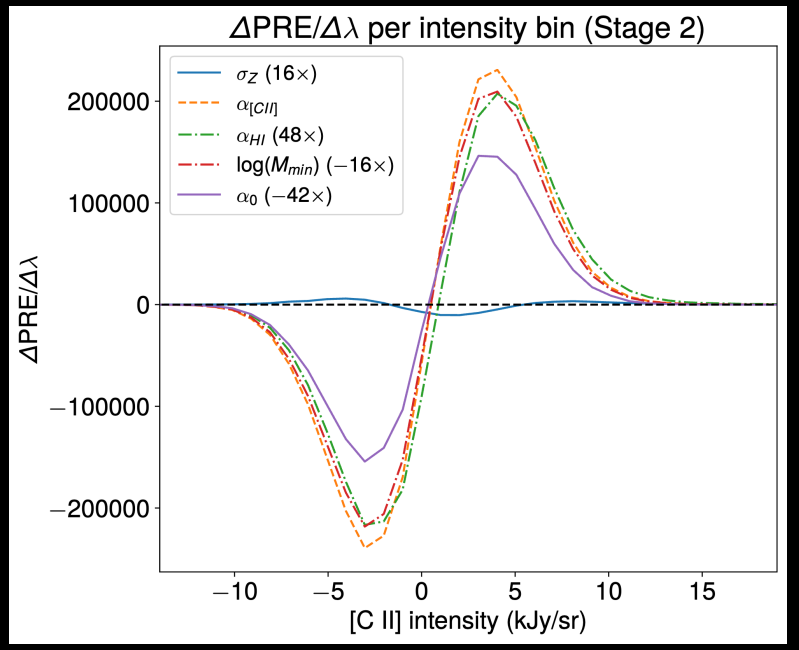




PRE Signatures

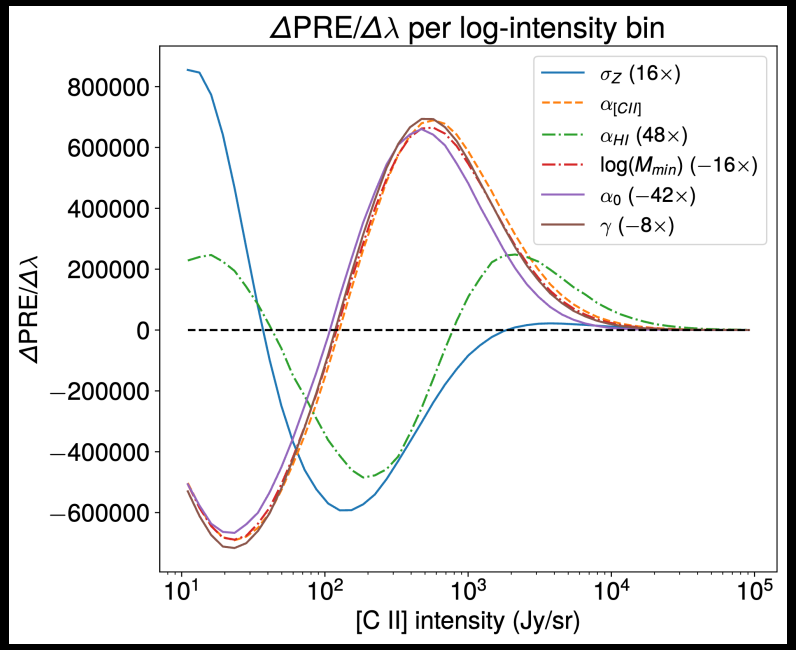
- Apply on various model's parameters

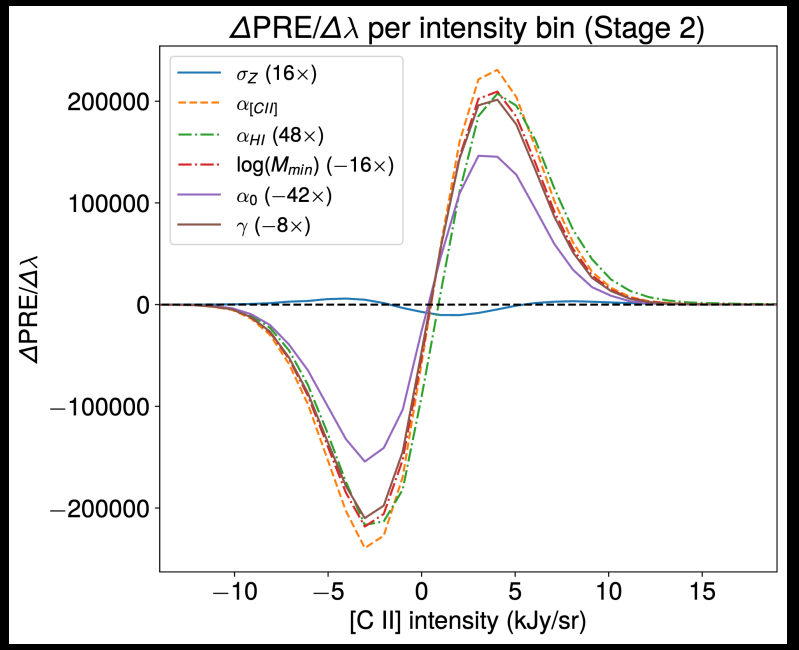




PRE Signatures

- Apply on various model's parameters





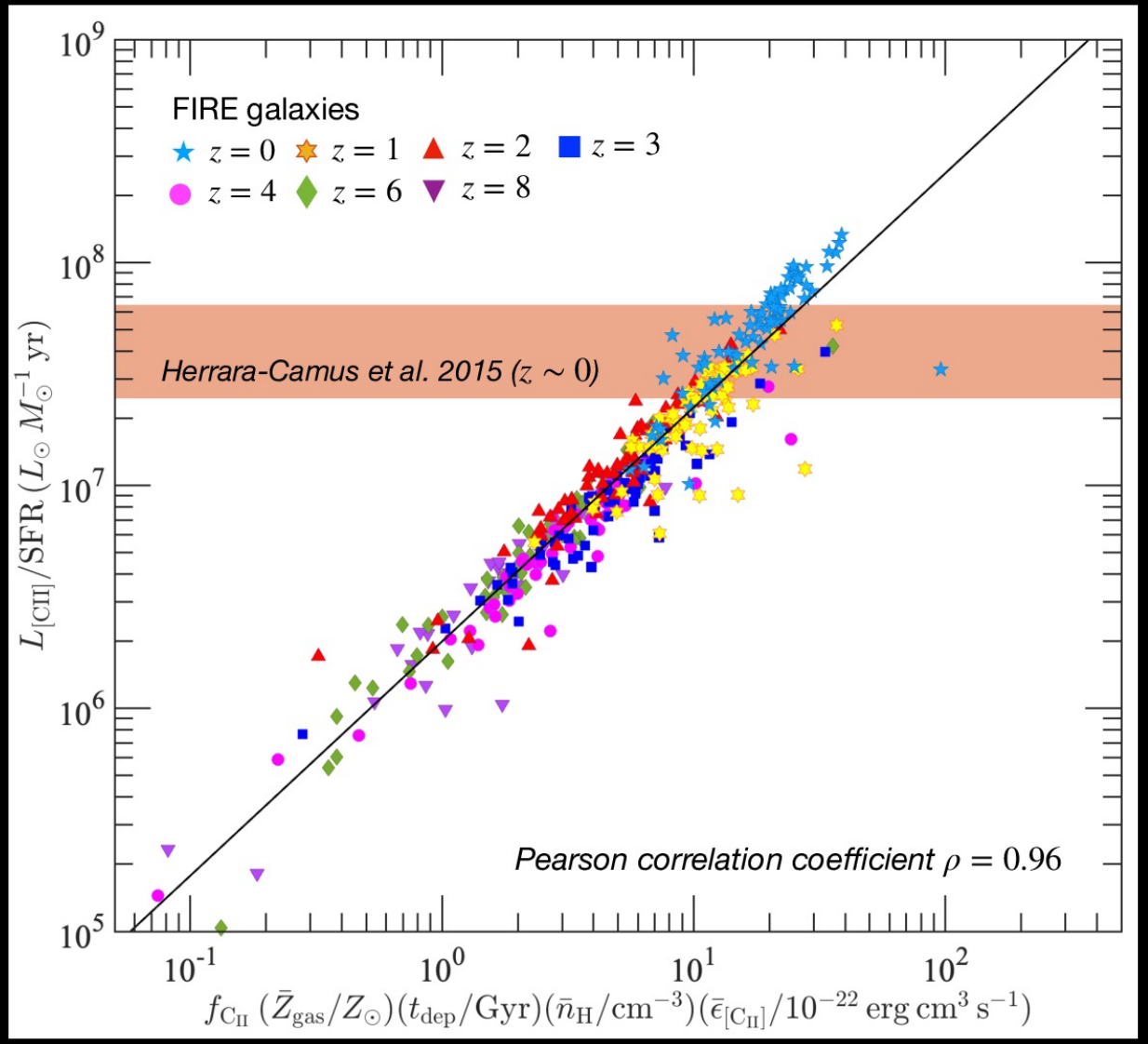
Summary

- LIM can probe the Universe at the Epoch of Reionisation!
- We will soon detect [C II] large-scale structures!
- Our model brings modelling of [C II] to the next sophistication level!
- One-point statistics can extract non-Gaussian information from signal!
  - Degeneracy in the model's parameters encourages further development, whether that be in new statistical methods or cross-correlations
  - There's perspective to discriminate between astrophysical and cosmological non-Gaussian signatures

Paper reference: arXiv:2309.15733 (submitted to MNRAS)
https://arxiv.org/pdf/2309.15733.pdf

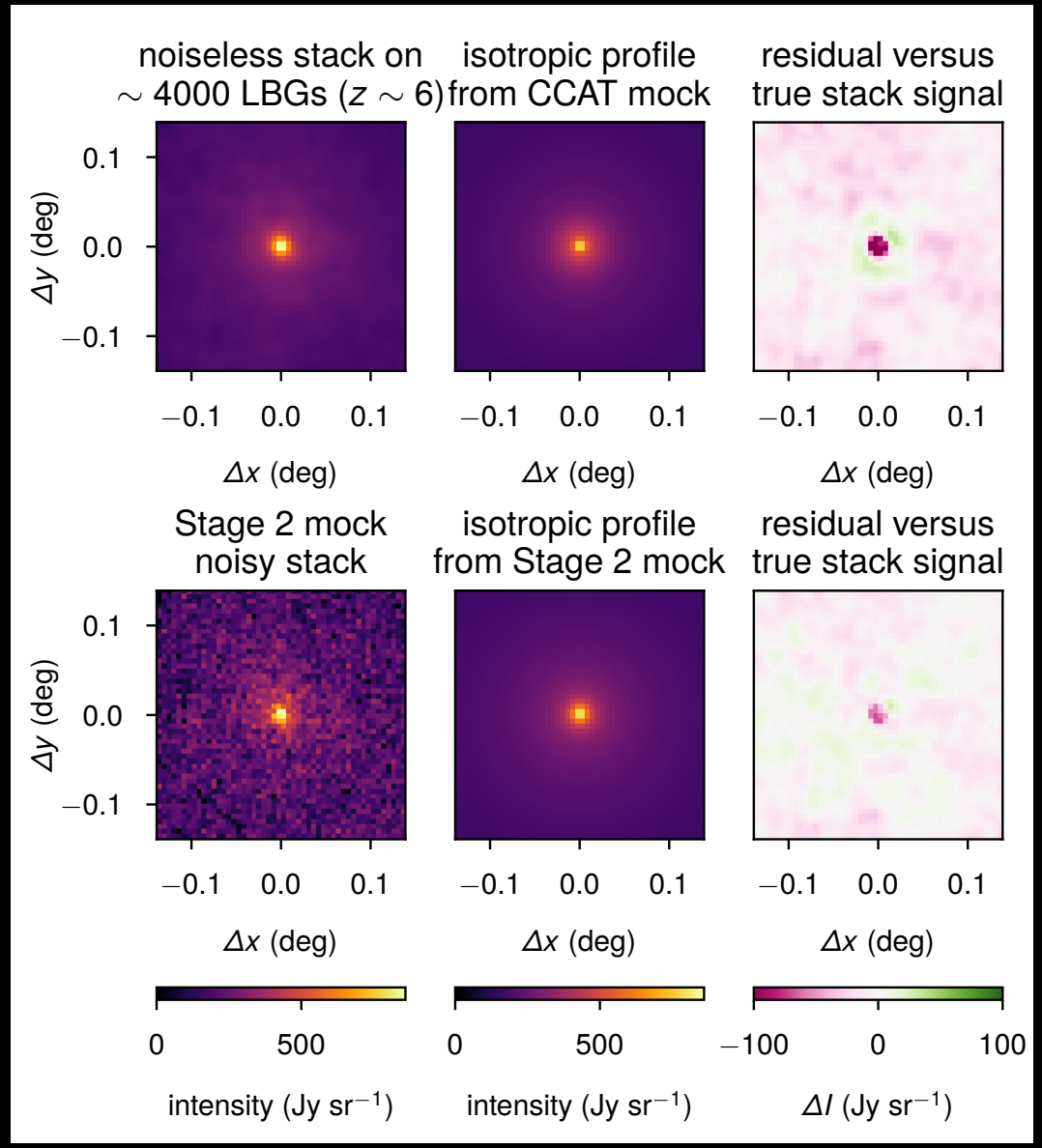
FIRE

$$\frac{L_{[CII]}/L_{\odot}}{SFR/(M_{\odot}\ yr^{-1})} \propto f_{[CII]}\bar{Z}_{gas}t_{dep}\bar{n}_{gas}$$



Results

- Stacking over LBGs



Instrumental parameters

- Adding the noise:

$$\sigma_n = \frac{NEI}{\sqrt{t_{vox} N_{feeds}}}, \text{ where } NEI = \frac{NEFD}{\Omega_{beam}}$$

- CCAT-DSS instrumental values:
  - NEFD ~ 72.5 mJy $s^{1/2}$
  - N_{feeds} ~ 120
  - Ω_{beam} ~ 4 deg^2

Stage 2:

t_{vox} ~ 19 minutes

σ_n ~ 3000 Jy/sr

One-Point Statistics' Formalism

- Information theory:

$$S_{rel}(P \parallel Q) = -\int dI\, P(I) \ln \frac{P(I)}{Q(I)}$$

$$dS_{rel}(P \parallel Q) \equiv -P(I) \ln \frac{P(I)}{Q(I)}$$