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Sublime-TIFUUN

Characterizing Foreground CO Emitters Using SUBLIME-TIFUUN on ASTE

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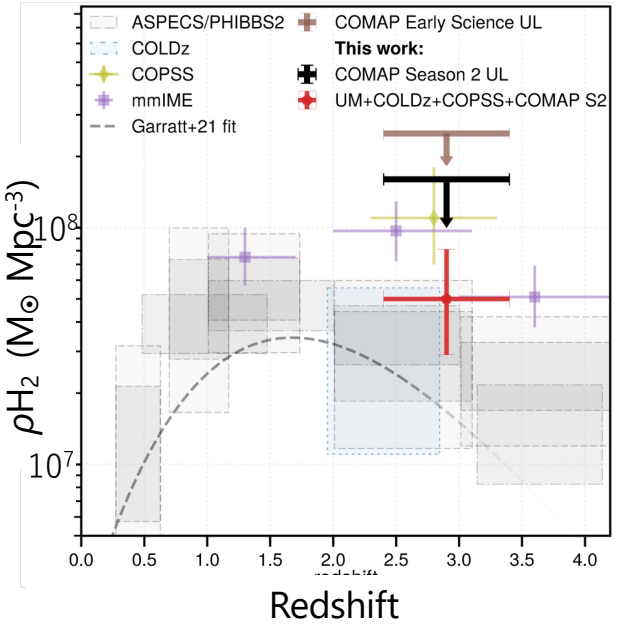
LIM for cosmic molecular gas at $z \gtrsim 4$

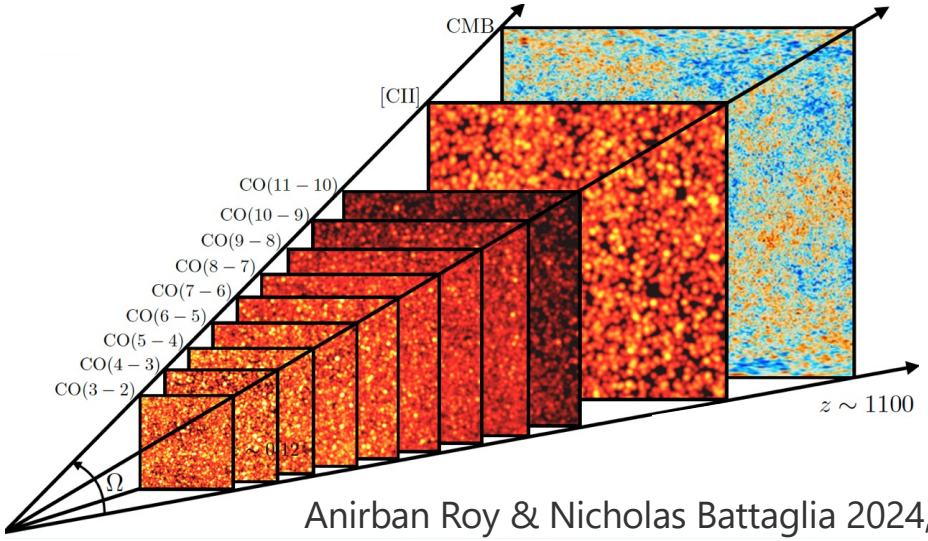
- Molecular gas mass density at $z \gtrsim 4$ remains poorly constrained (Riechers et al. 2020)
- Line surveys miss most contributors due to the dominance of faint galaxies (Tacconi et al. 2020)
- [C II] LIM can probe molecular gas, including faint galaxies
  - A good tracer of molecular gas in low-metallicity environments (Zanella et al. 2018; Casavecchia et al. 2025)
  - Linked to the mass-metallicity relation
- Study of Universe By Line Intensity Mapping Experiment (SUBLIME) – Terahertz Integral Field Units with Universal Nanotechnology (TIFUUN) project targets the [C II] power spectrum at $z \sim 6$



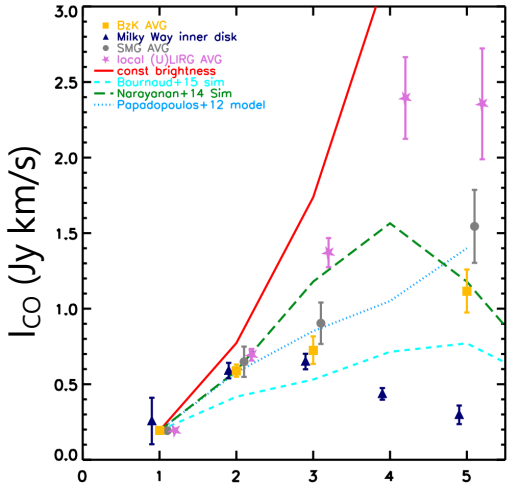
D. T. Chung et al. 2024, *A&A*, 691, A337

Challenge: Uncertain Properties of Foreground CO Emitters

- CO foreground contamination: a major obstacle for LIM
- Existing models based on bright-galaxy CO-SLEDs (Keating et al. 2020)
- CO-SLEDs vary with ISM conditions across galaxy types (Daddi et al. 2015)
- CO-SLEDs of faint CO emitters at z = 1–3 remain largely unconstrained



Anirban Roy & Nicholas Battaglia 2024, *ApJ,* 969**,** 2



Daddi, E., et al. 2015, *A&A*, 577, A46

Goal:

- Constrain/Extract the [C II] signal at redshift $z \sim 6$

Key questions in this presentation:

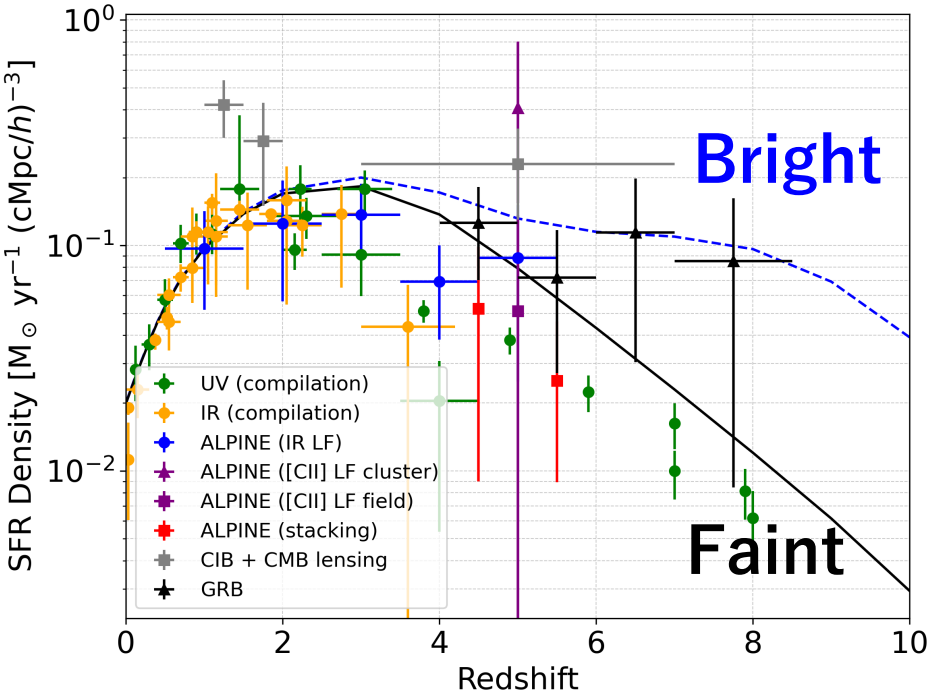
- What types of CO-emitting galaxies contribute to the foreground contamination?
- How can we constrain the CO-SLEDs in faint CO-emitting galaxies?

Realistic Mock with illustrisTNG300-1

A first attempt to construct a continuous light cone with a hydrodynamics simulation

- Realistic SFR solved in hydro sim.
- Foreground emission included
- Suitable for ~1 deg^2 LIM observations

(Nelson+2019)



Emission line models with empirical relations
CO: Sargent et al. 2014, Daddi et al. 2015, Liu et al. 2015
[C II]: DeLooze et al. 2014
We applied a scatter of 0.2 dex.

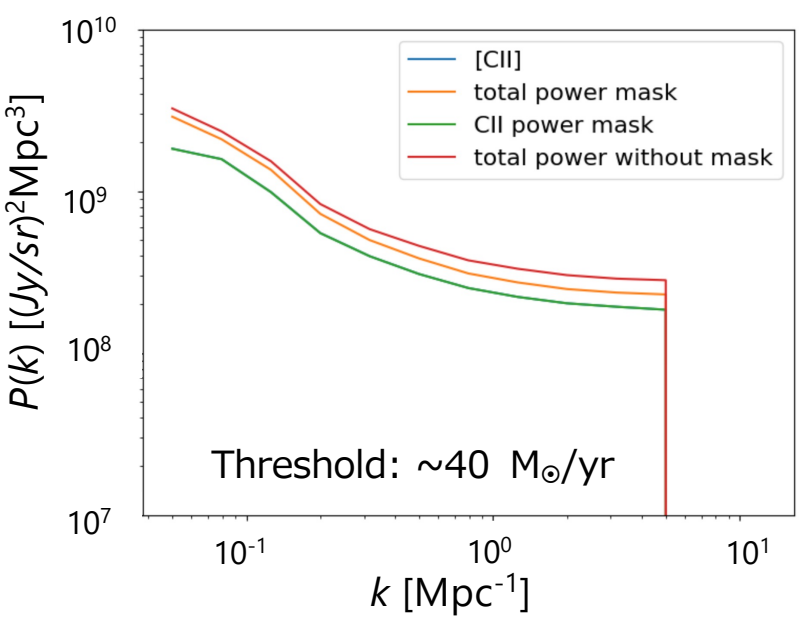
Two models of cosmic SFR density history

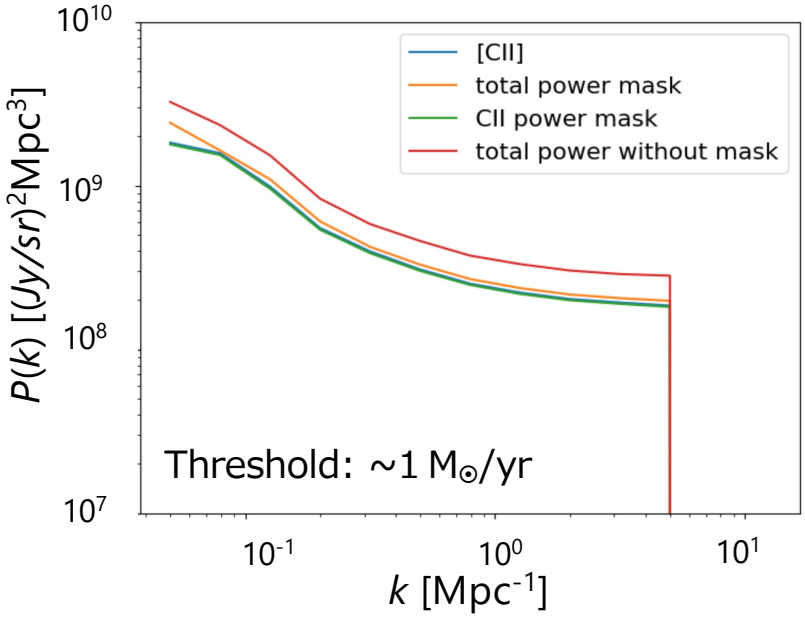
$$\mathrm{SFR}_{\mathrm{bright}} = (\alpha\,\mathrm{Sigmoid}(z - z_0) + 1)\,\mathrm{SFR}_{\mathrm{TNG300-1}}$$

α = 14 and z_0 = 8 for bright model

Result 1: Faint CO emitters with SFR ~ 1 $M_\odot$/yr dominate the foreground

- Comparison of cases removing CO emitters with SFR $\gtrsim 40\,M_\odot$/yr (left) and $\gtrsim 1\,M_\odot$/yr (right).
- Need to carefully characterize faint foreground CO emitters.





If the total power mask and [CII] power mask get closer, it indicates that foreground CO has been successfully removed.

Estimating Average CO Line Ratios via Galaxy–Line Cross-Correlation

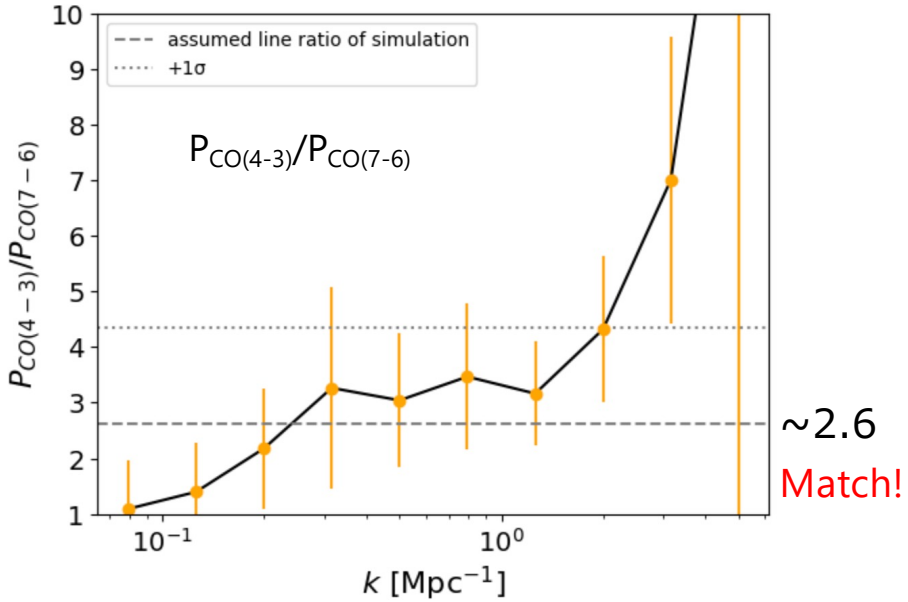
$$\frac{P_{1,g}}{P_{2,g}} = \frac{r_{1,g} b_1 b_g \langle I_1 \rangle P_m}{r_{2,g} b_2 b_g \langle I_2 \rangle P_m} \sim \frac{\langle I_1 \rangle}{\langle I_2 \rangle}$$

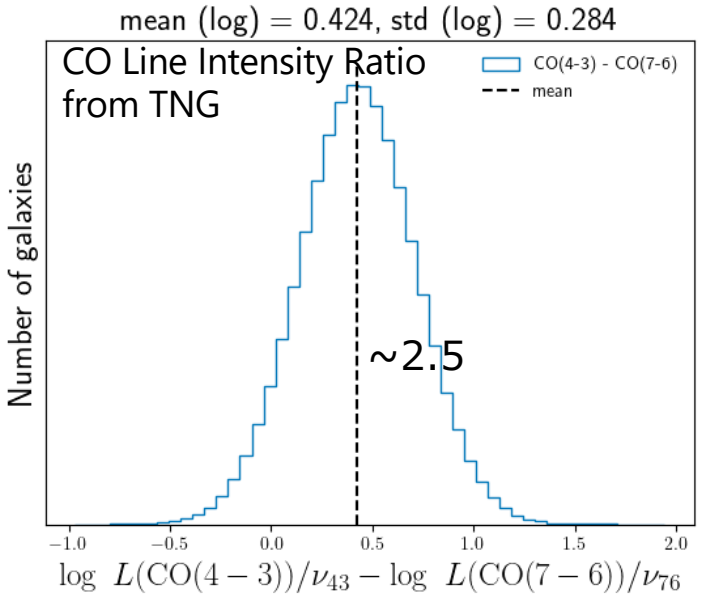
$$\text{assuming } \frac{r_{1,g}}{r_{2,g}} \sim 1 \text{ and } \frac{b_1}{b_2} \sim 1$$

P_{ig}: Cross-power spectrum between line(i) and galaxy catalog(g)
$r_{i,g}$: Cross-power spectrum correlation coefficient (1 for perfect correlation, 0 for no correlation)
b : bias
$\langle I \rangle$: mean intensity
P_m: matter power spectrum

Result 2: Cross-Power Ratios Trace CO Line Ratios

- Simulated with R = 500 and 48″ angular resolution
- Detected the galaxy-line cross-power spectrum of CO(4–3) and CO(7–6) at redshift 1.72–2.24
- Cross-power ratios approximately match CO line intensity ratios

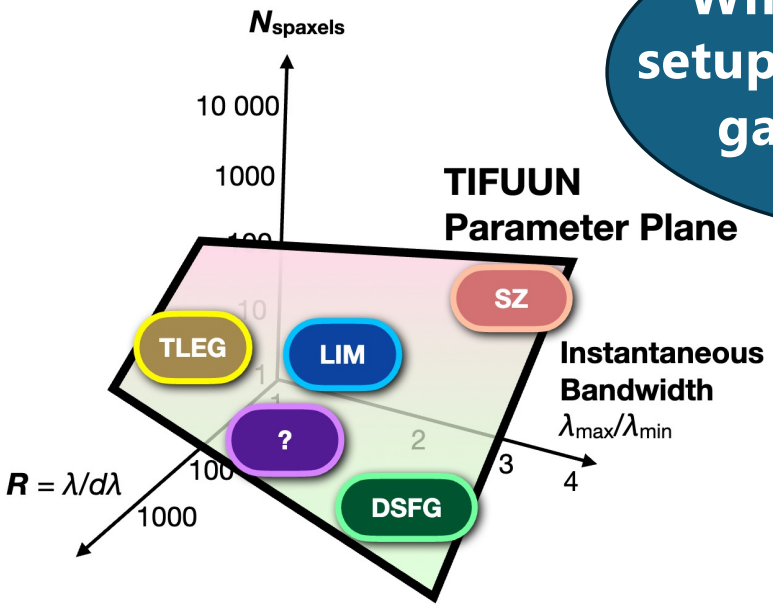




Optimizing configurations of SUBLIME-TIFUUN

- TIFUUN (PI: A. Endo, TU Delft) provides instrumentation for dual-band sub/mm LIM observations.
  - Flexibly configurable to match the science goals
  - To be mounted on ASTE (D=10m)

What is the optimal setup for implementing galaxy-line cross-correlation ?



Endo, SUBLIME2025
Nishimura et al., LTD2025

	Current Limit
$N_{voxels} = N_{spaxels} * N_{colors}$	<10,000 (20,000 with 2 IFUs)
F_{max}	<360 GHz
F_{min}	>90 GHz
F_{max} / F_{min}	<1:2 per IFU (1:4 with 2 IFUs)
$R = F/\Delta F$	<1000 (<2000?)
$N_{spaxels}$	< ~91 (H-band) < ~37 (L-band)

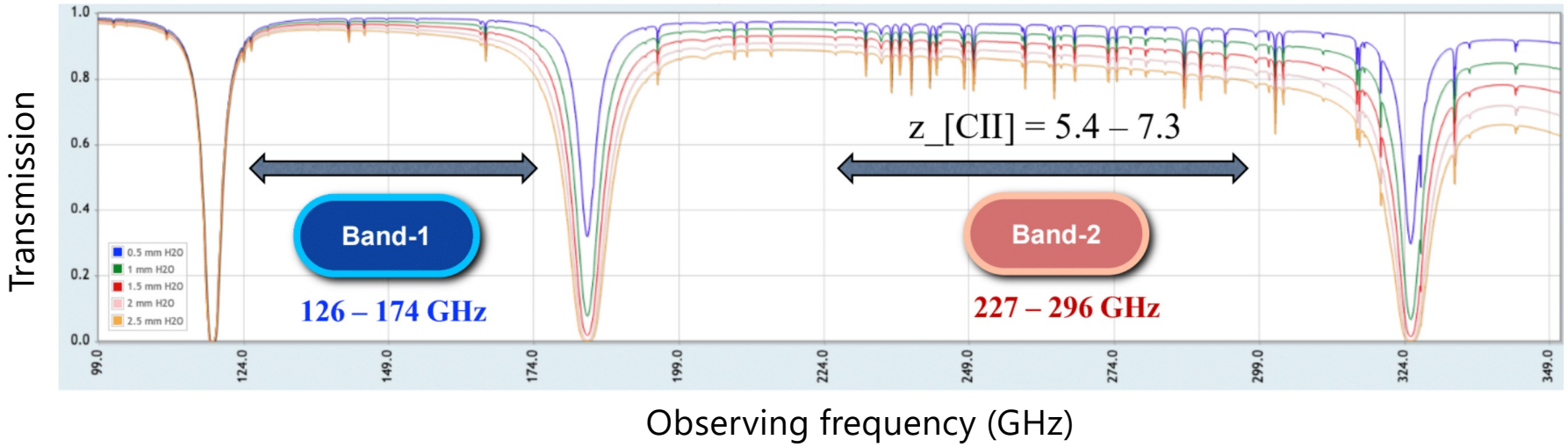
A Possible Configuration for SUBLIME-TIFUUN

Optimized frequency setup for dual-band IFUs, considering constraints on spaxels, detector counts, and atmospheric transparency

- Role of Band-1: Removing interlopers via cross-correlation analysis using CO (3-2)@z~1 and CO (4-3)@z~2
- Role of Band-2 : To constrain the signal of [C II]@z~6, CO (5-4)@z~1 and CO (7-6)@z~2

Band-1
Spaxels: 37
Colors: 162 (R=500)
=5,994 voxels

Band-2
Spaxels: 91
Colors: 131 (R=500)
=11,921 voxels



Take-Home Message

- Faint CO emitters with SFR $\gtrsim 1\,M_{\odot}$/yr dominate the foreground.
- Cross-power ratios approximately trace the average CO line ratios, thereby constraining the CO-SLEDs in faint CO-emitting galaxies.
- Based on these insights and instrumental constraints, we propose a dual-band configuration for SUBLIME-TIFUUN IFUs: CO(3–2)/CO(5–4)@z~1 and CO(4–3)/CO(7–6) @ z~2
- The simulation will be upgraded to incorporate both line and continuum emission components.