The CO Cosmological Origins and Abundances Project: The Search for CO at $z \approx 3$

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CARMA Symposium, July 9th 2013
Exploring the Early Universe

Neutral Hydrogen

Ionized Gas

The Multitude of Galaxies: Milky Way Building Blocks

Massive Galaxies
Exploring the Early Universe

- Afterglow Light Pattern 380,000 yrs.
- Dark Ages
- Development of Galaxies, Planets, etc.
- Dark Energy Accelerated Expansion
- Inflation
- Quantum Fluctuations
- 1st Stars about 400 million yrs.
- Big Bang Expansion 13.7 billion years

\[ z \approx 10 \]
\[ z \approx 6 \]
\[ 2 < z < 6: \text{Onset of Molecular Gas?} \]
A Tale of Two Models

Model A
Halo Mass $\rightarrow$
SFR $\rightarrow$
CO

- Forward from EoR
- Theoretical
- Set by $M_{\text{min}}$

Model B
UV Luminosity Function $\rightarrow$
SFR $\rightarrow$
CO

- Backward from now
- Empirical
- Set by $SF$

$R_{\text{min}}$
“How the sausage gets made”
Suitability of the SZA

Frequency range covers:
\[ z = 2.3 - 3.3 \ (J = 1 \rightarrow 0) \]
\[ z = 5.6 - 7.5 \ (J = 2 \rightarrow 1) \]  
(OPTIMAL)

- Compact nature means greater sensitivity (OPTIMAL)
- Earth rotation synthesis/changing UV positions (NOT OPTIMAL)
- Existing data is “wide and shallow” (NEUTRAL)
- Data already exists (OPTIMAL)

\[ \Delta \downarrow N \uparrow 2 \ (k) \propto \tau \downarrow \text{int} \uparrow - 1 \ \mathbb{R} \uparrow - 1/2 \]
\[ N \downarrow \text{point} \uparrow - 1/2 \]

Higher payoff   Lower payoff
The Original SZA Survey

Survey originally ran from 2005-2007, covering 44 individual fields over a wide range of RAs/Decs.

- Each field has an effective integration time of ~20 hours a piece, spread across ~40 days.
Current Results

Power Spectrum (with 2σ error bars)

χ^2_red = 17.2
p < 0.001

Δ^2_{CO} (μK^2)

k-Mode (Mpc^{-1})

Model A
Model B
SZA Legacy
1 σ limit
GOODS–N
1 σ limit
Measured
**Jackknife Tests**

By combining/differencing the data in different ways, we can test our results. Aside from “simple” differencing, jackknife tests include:

- **Cross-window** (wipe out CO signal, preserve wideband instrumentation effects and continuum source contamination)

- **Cross-field** (wipe out CO signal and astronomical sources, preserve narrower instrumentation effects)
Future Directions

Currently observing GOODS-N for 150 hours (maybe 150 more?), which has overlapping coverage with HST, HETDEX and other high-redshift surveys.

Sensitivity will match that of the entire legacy survey.
Future Directions

Cross-correlation with other datasets:

- 3 mm system with AMiBA ($J=3\rightarrow2$ transition)
- Optical LAE surveys (HSC/HETDEX)
- $^{13}$CO ($J=1\rightarrow0$) (“free” result!)
Conclusions

Possible detection...
- Further work to be done with contaminant removal

Can rule out some permutations of Model B
- If galaxies are similar to today, some minimum SFR (metallicity?) needed for CO ($\geq 0.1 \frac{M_{\odot}}{yr}$)
Foreground Elimination

Contaminants assumed to have flat spectra ($\eta=0$), so foregrounds can be removed by rejecting any k-mode in the $\eta=0$ plane.