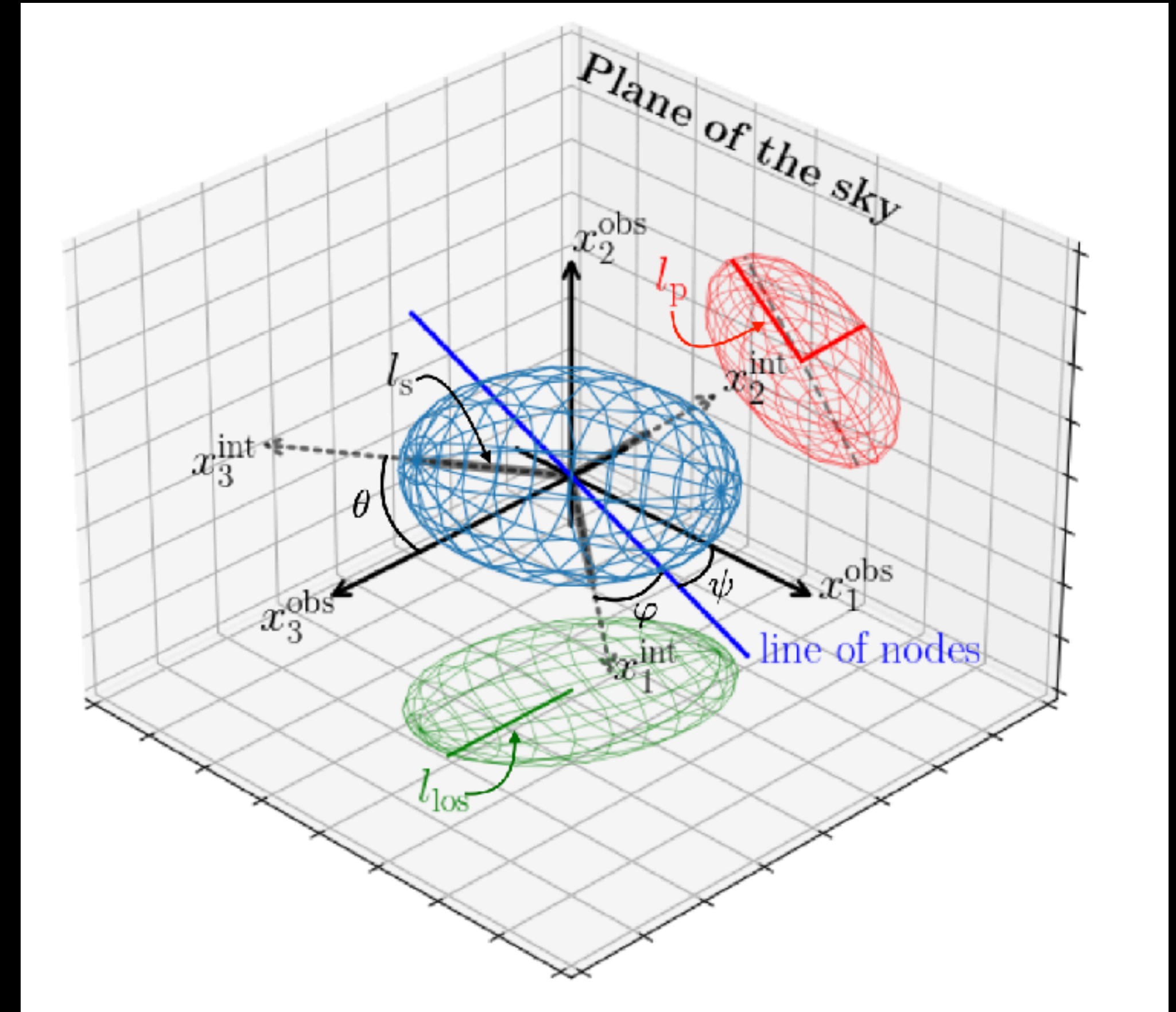


PSZ2 G313.33+61.13 (Abell 1689): Model Fit

- The analysis effectively constrains the model geometry at the few percent level.
- Compared to the similar gas-only analysis using X-ray and SZ data presented in Sereno et al. (2012), the axial ratios and elongation parameters in our study demonstrate a substantial improvement, with uncertainties an order of magnitude lower.

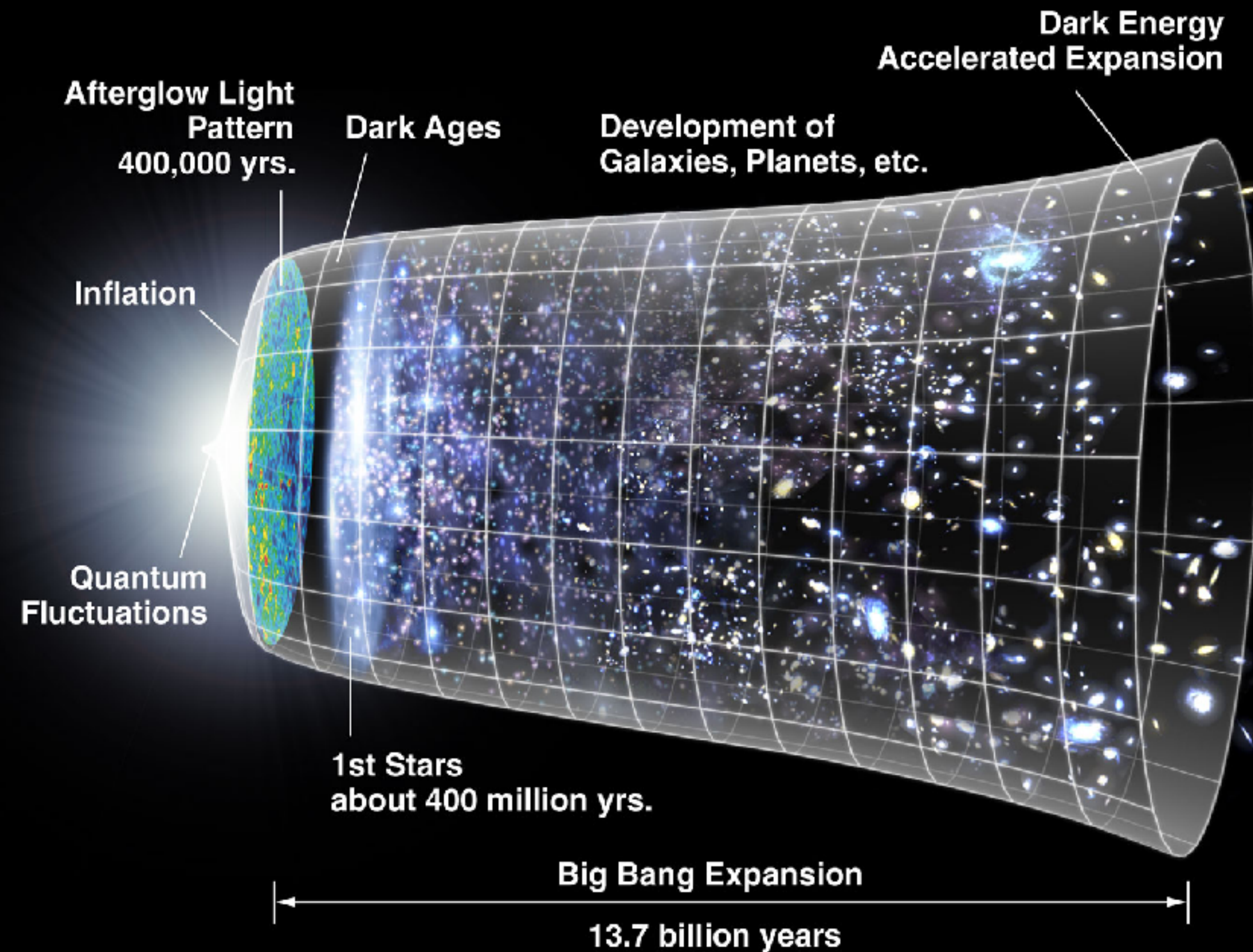
$q_{\text{ICM},1}$	$q_{\text{ICM},2}$	$\cos \theta$	e_{\parallel}	Reference
0.70 ± 0.15	0.81 ± 0.16	0.70 ± 0.29	1.68 ± 0.53	Sereno et al. (2012)
0.63 ± 0.14	0.70 ± 0.16	0.93 ± 0.06	1.16 ± 0.10	Umetsu et al. (2015)
0.65 ± 0.02	0.79 ± 0.02	≥ 0.96	1.24 ± 0.03	This work



CO Intensity Mapping for Capturing Star-formation History in the Early Universe



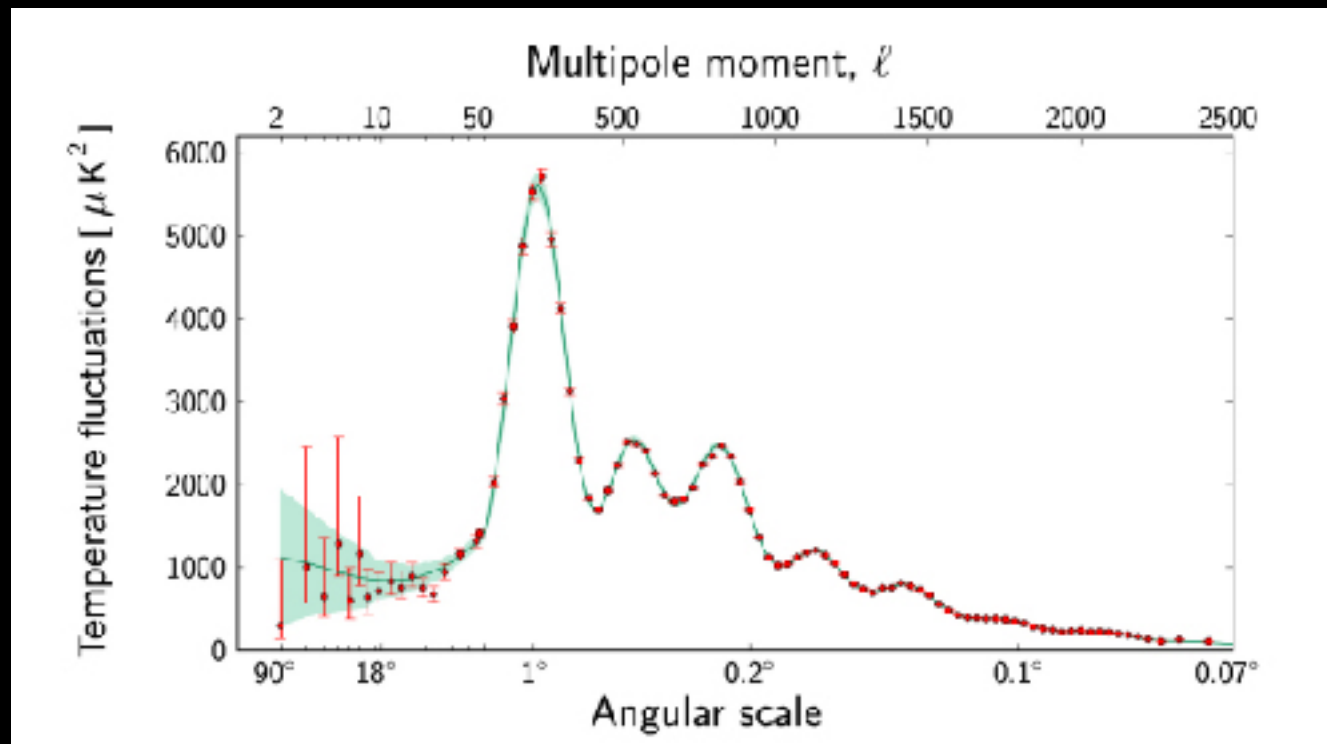
History of the Universe



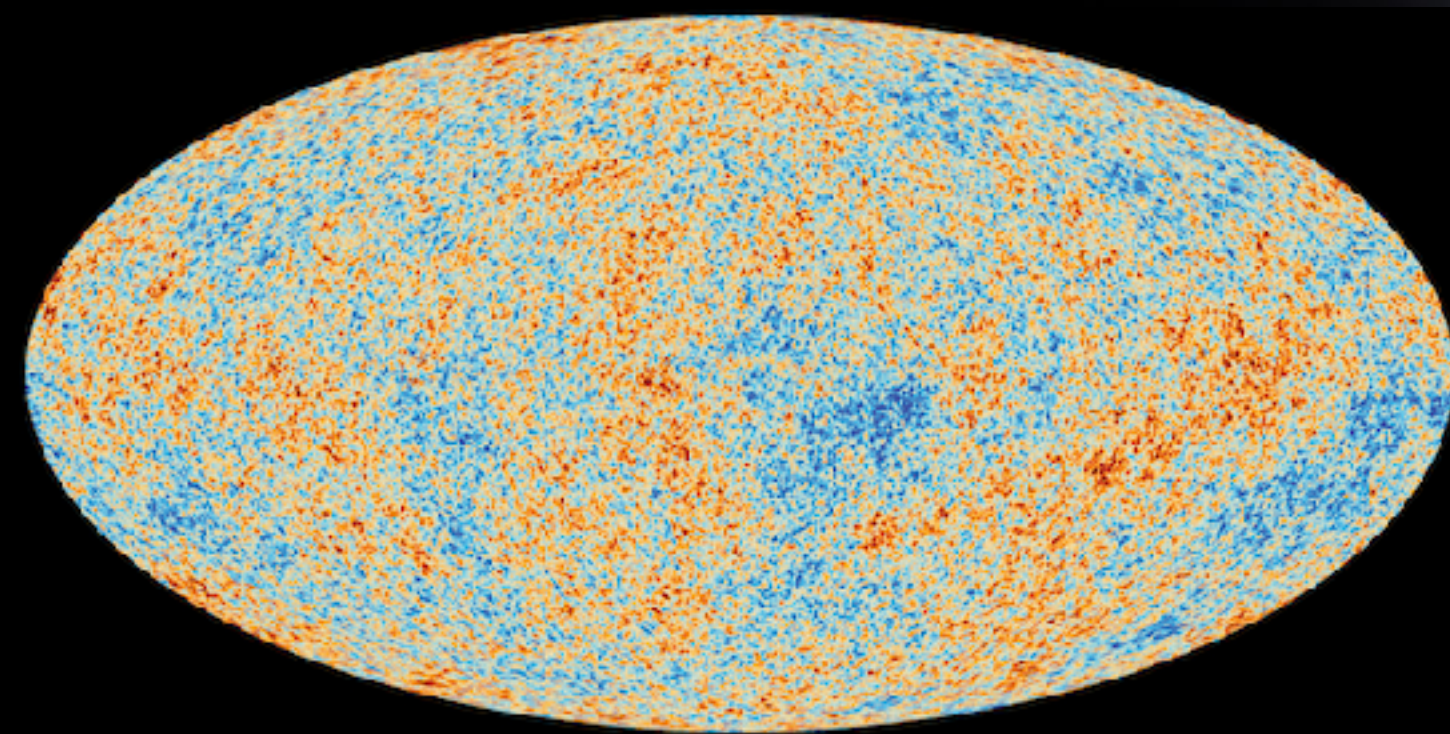
NASA/WMAP Science Team

<https://map.gsfc.nasa.gov/media/060915/index.html>

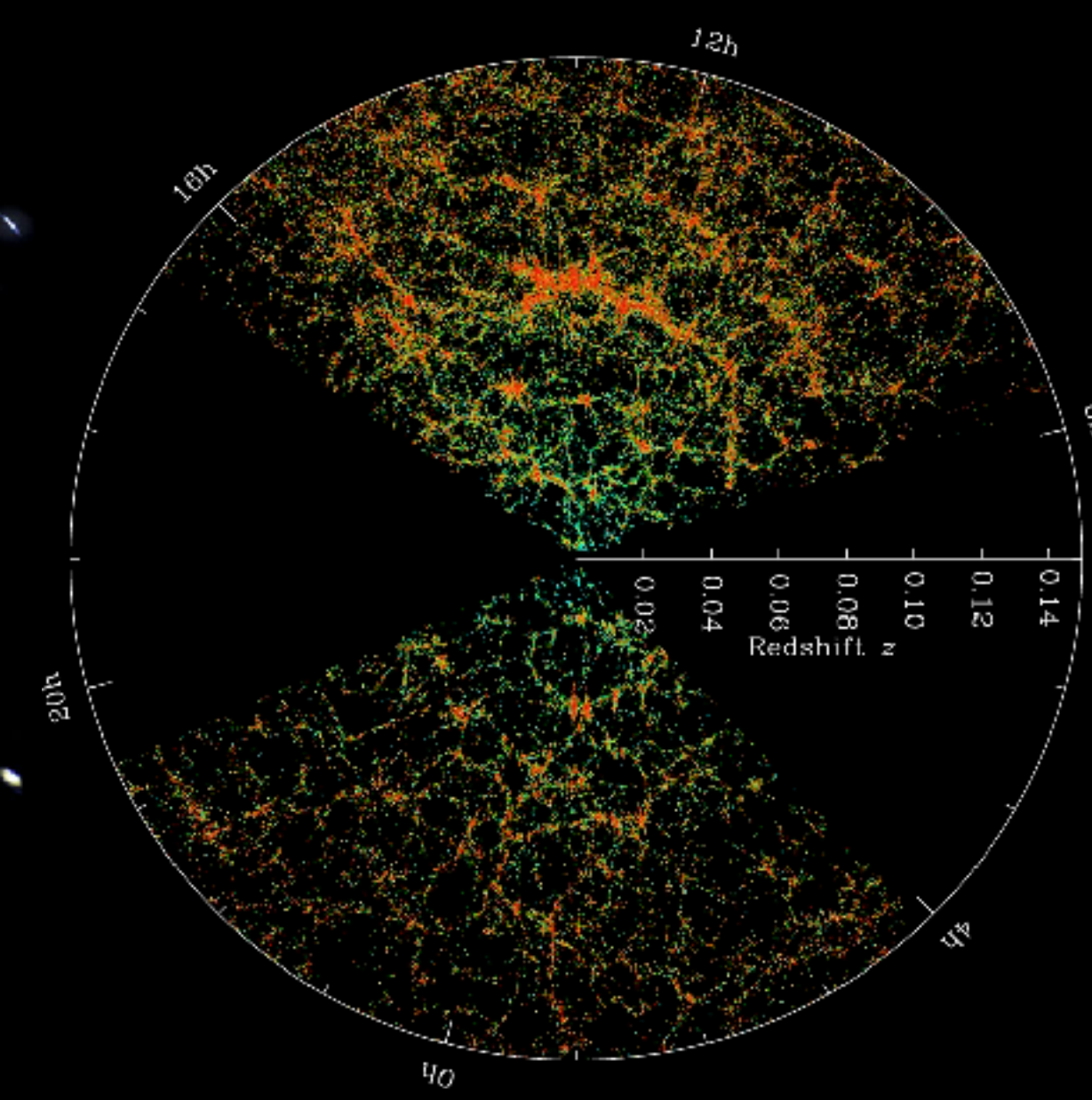
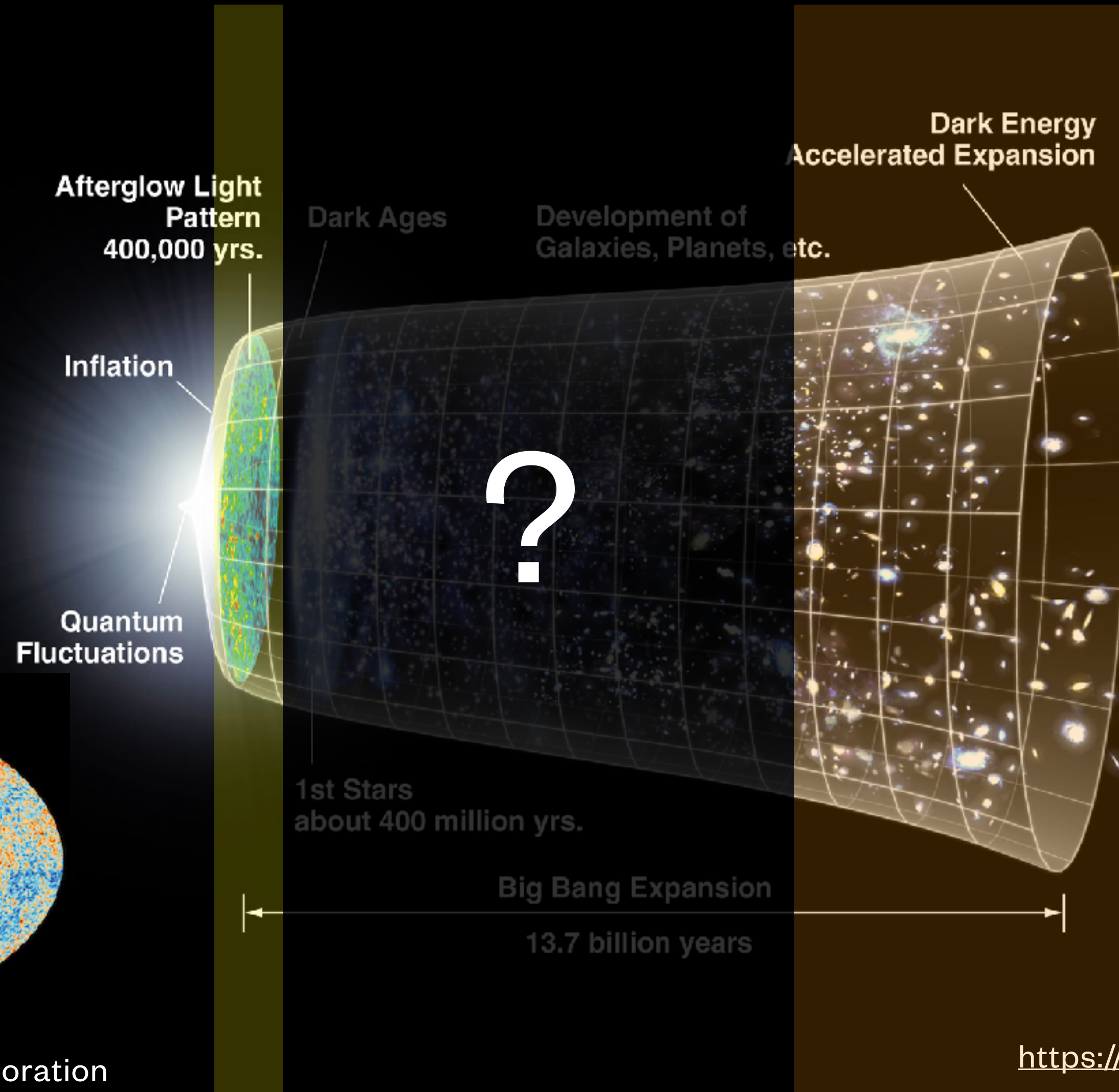
History of the Universe



Cosmic Microwave Background (CMB)



ESA/Planck Collaboration

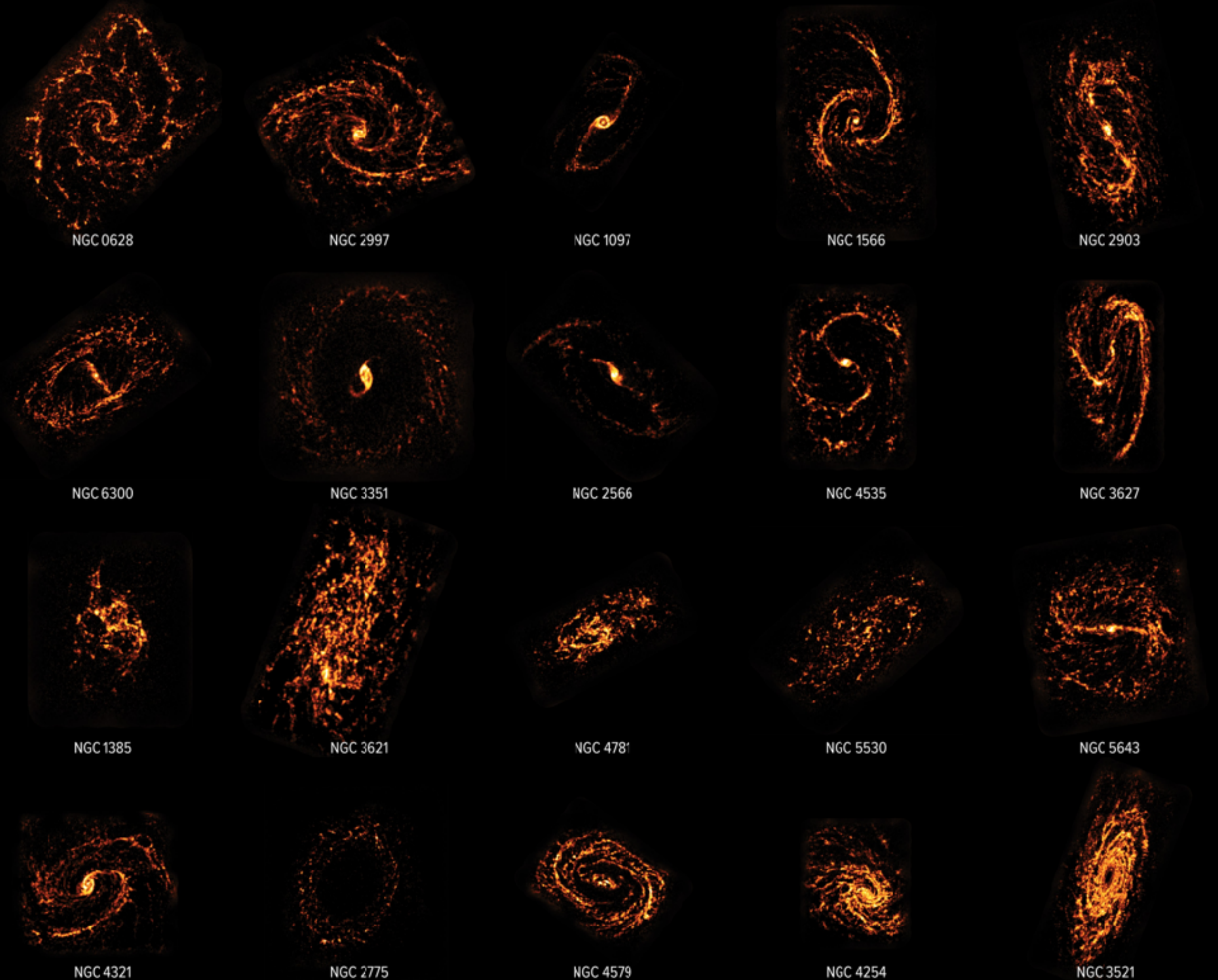
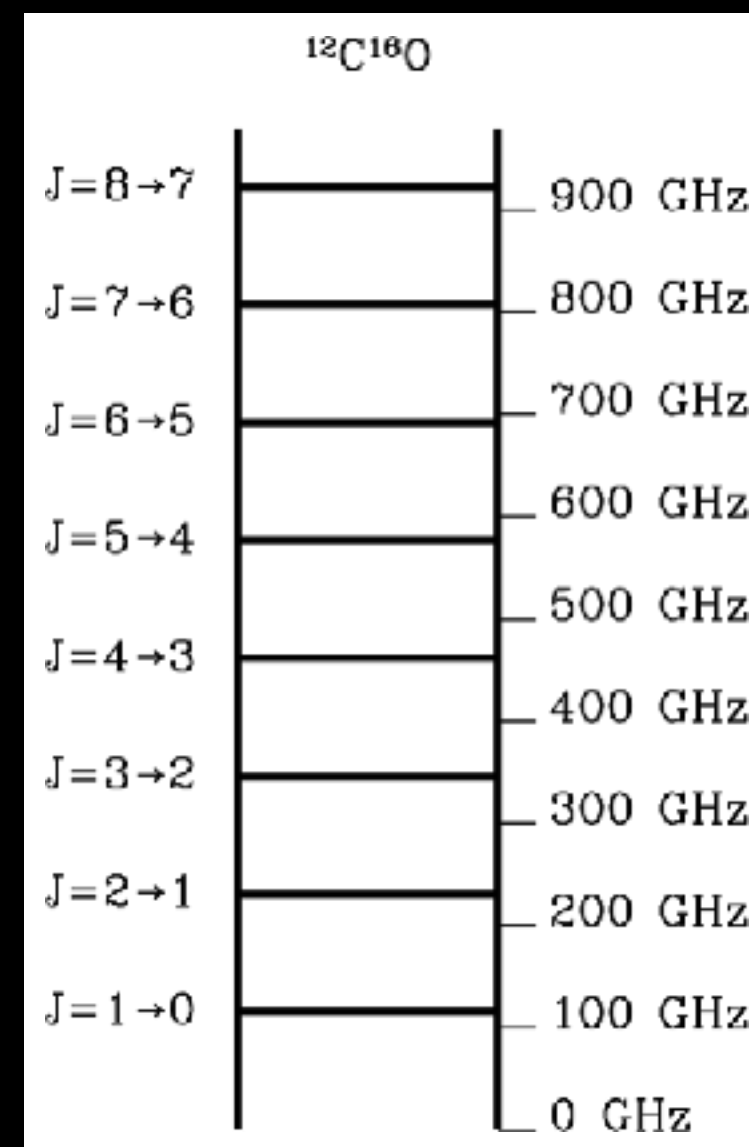


Galaxy surveys $z = 0-1+$

NASA/WMAP Science Team
<https://map.gsfc.nasa.gov/media/060915/index.html>

Carbon Monoxide (CO)

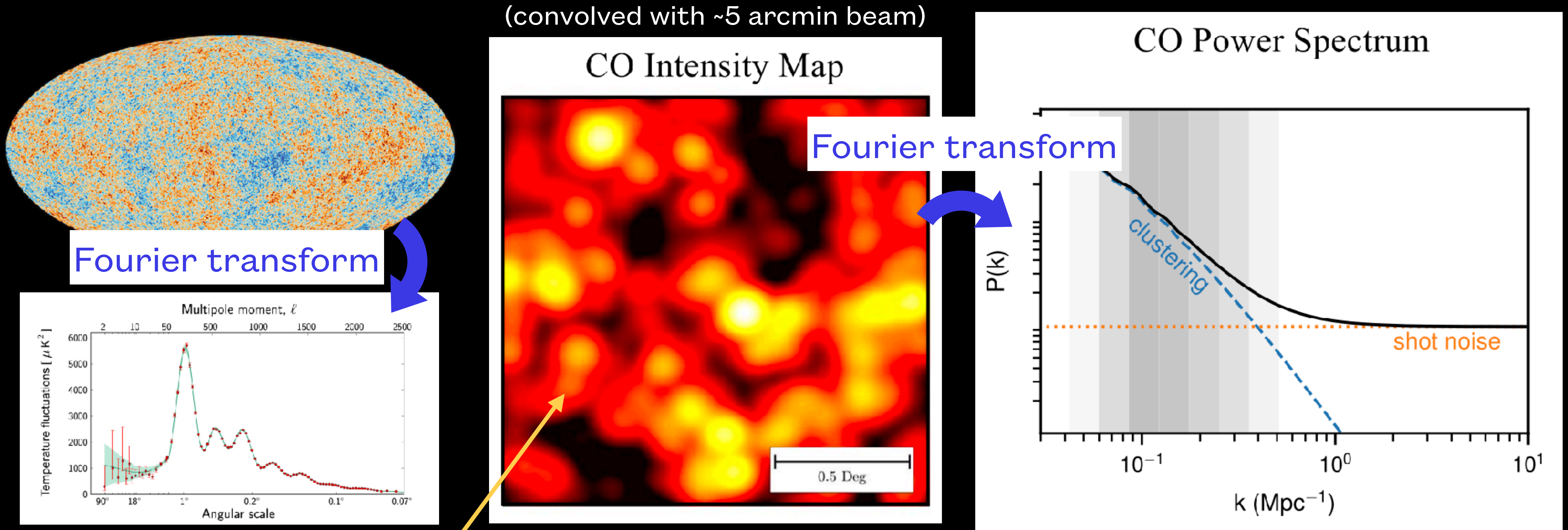
- Tracer of cold molecular gas, the fuel for star formation.
- The second most abundant molecule in the gas phase.
- Line emissions at multiples of ~ 115 GHz.



Credit: ALMA (ESO/NAOJ/NRAO)/PHANGS, S. Dagnello (NRAO)

Line Intensity Mapping (LIM)

- LIM is sensitive to the “aggregate line emission from all galaxies in the line of sight”.



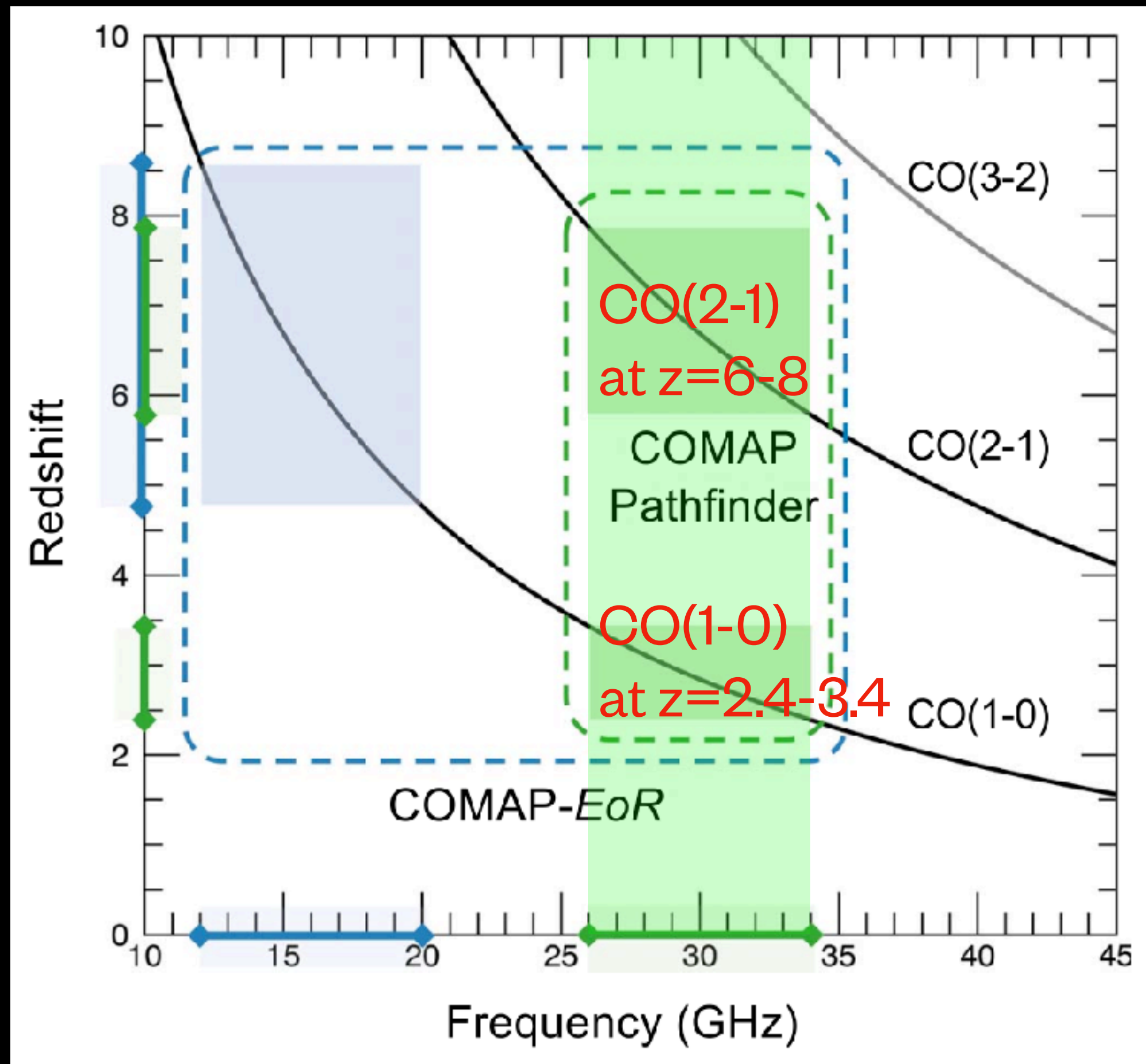
all of the photons!

Kovetz et al. (2017), Cleary et al. (2022), Credit: Patrick Breysse & Dongwoo Chung

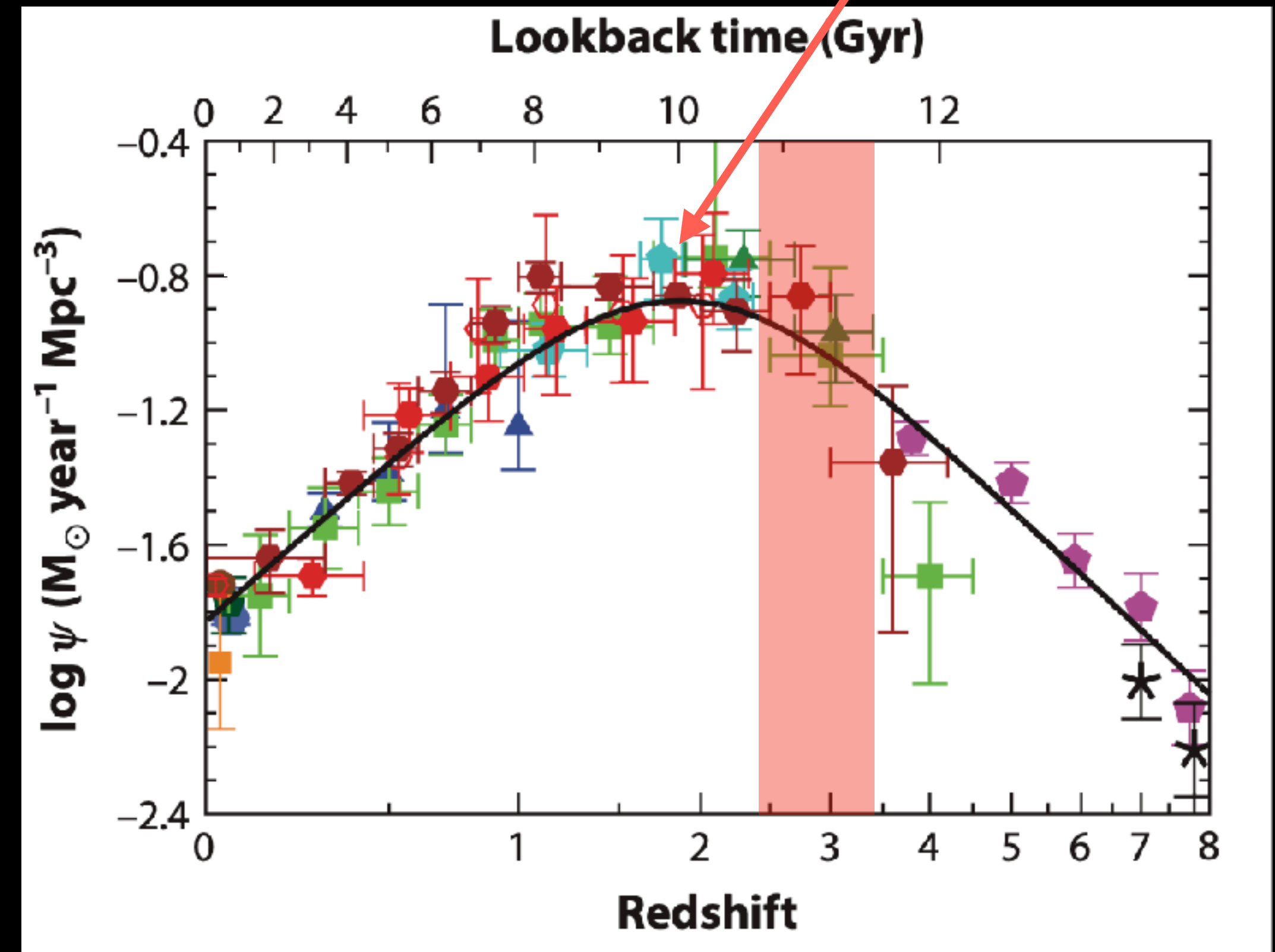
CO Mapping Array Project (COMAP)

- CO probes cold molecular gas, the fuel for star formation.

Peak of the
Star-formation History



Cleary et al. (2022)



Madau & Dickinson (2014)

CO Mapping Array Project (COMAP)

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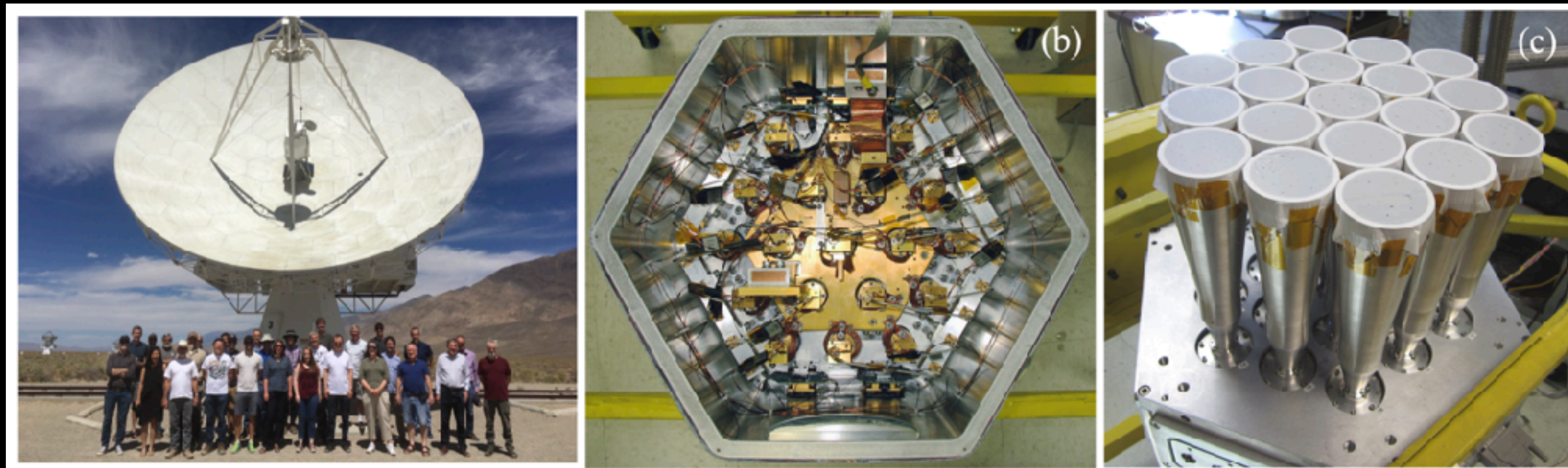
Thomas Rennie



<https://comap.caltech.edu/team.html#>

COMAP Pathfinder

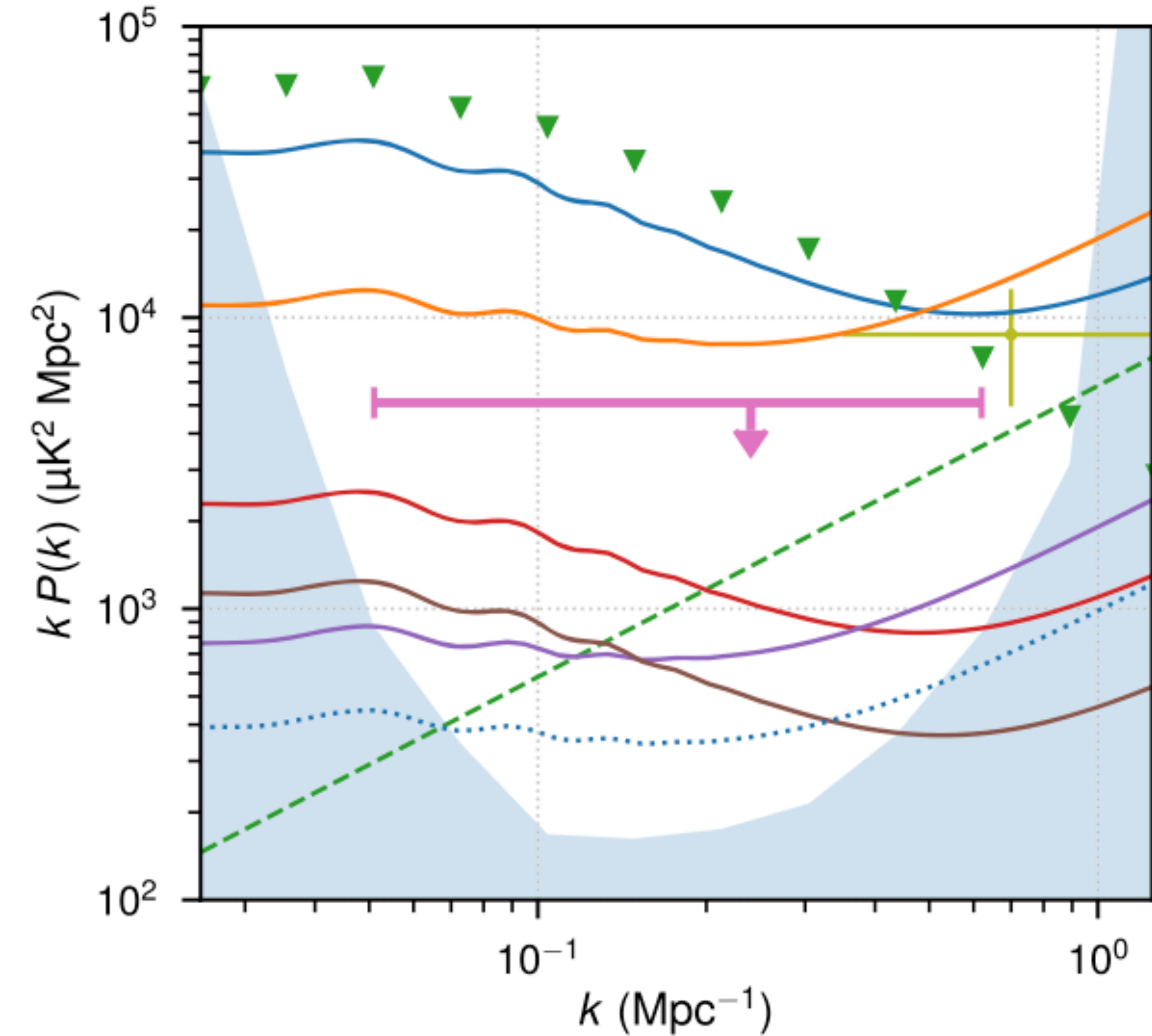
- Site: Owens Valley Radio Observatory (OVRO), CA
- Telescope: “Leighton” dish (10.4 m)
- Receiver: 26-34 GHz ($z=2.4-3.4$)
 - 19-pixel, single-polarization focal plane array
- Backend digitization
 - 38 ROACH2 spectrometers, 2 MHz resolution



Cleary et al. (2022)



COMAP Pathfinder: Season 1 Results



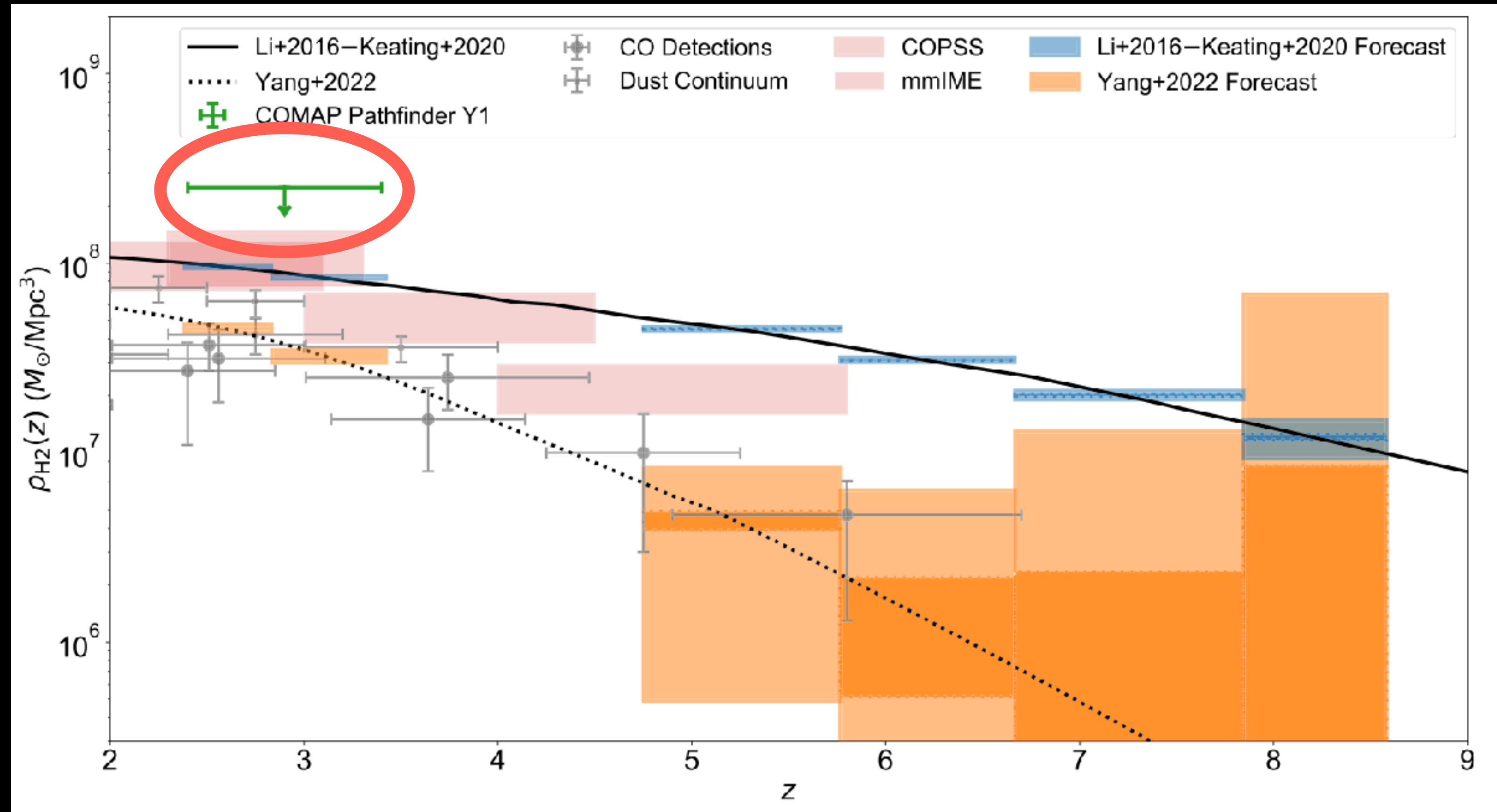
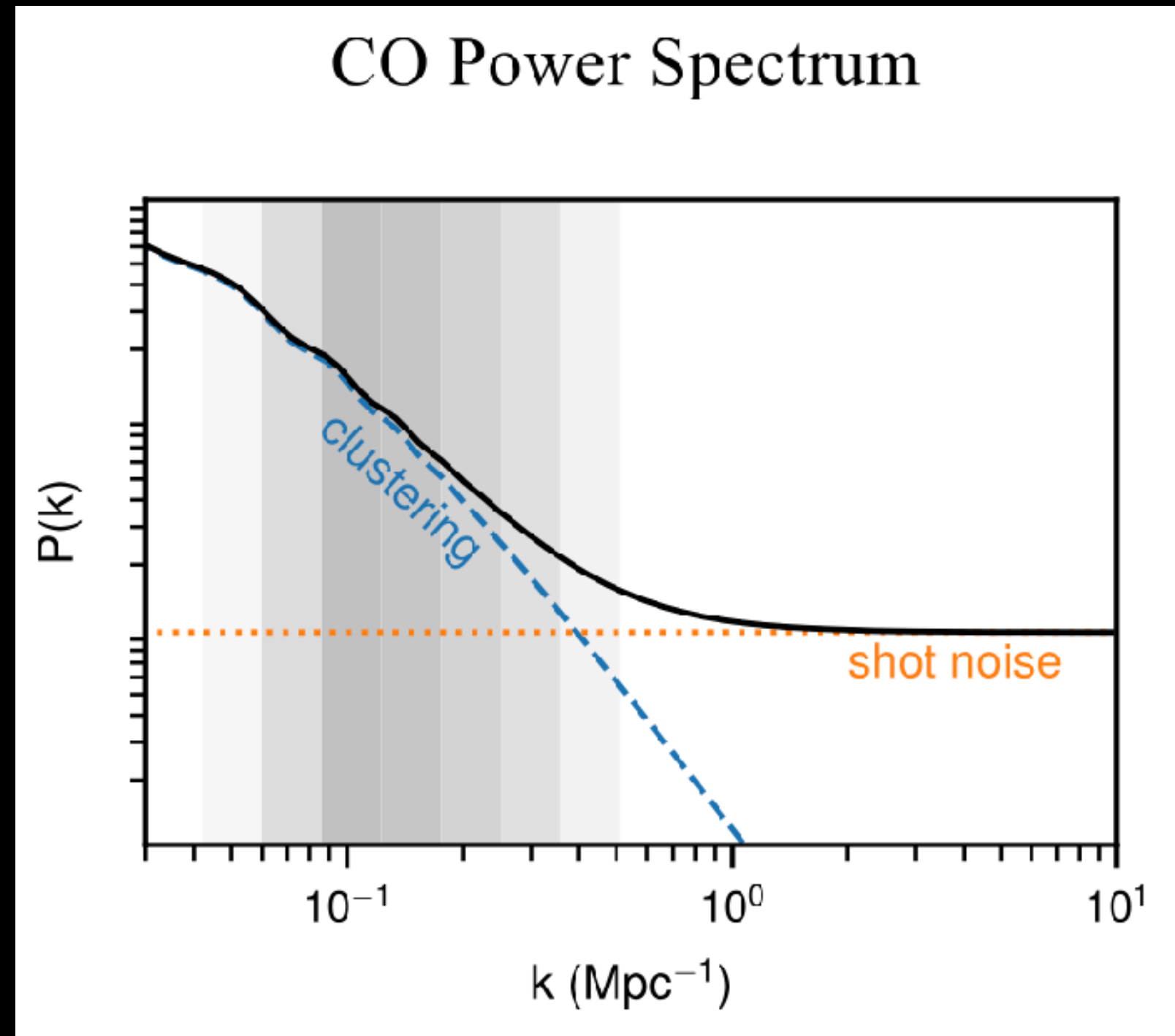
- Models:**
- Padmanabhan2018, $f_{\text{duty}} = 1$
 - Pullen+2013, Model B
 - ▼ Keating+2020 clustering UL
 - - - Keating+2020 P_{shot} estimate (total S/N > 20 by Y5)
 - Li+2016–Keating+2020 (total S/N 17 by Y5)
 - Chung+2021, UM+COLDz+COPSS (total S/N 9 by Y5)
 - Li+2016 (total S/N 8 by Y5)
 - ⋯ Padmanabhan2018, $f_{\text{duty}} = 0.1$ (total S/N 5 by Y5)

- LIM observations:**
- + COPSS, $z \sim 2.8$
 - ⊠ COMAP Y1 95% UL
 - COMAP Y5 forecast 1σ limit

$$\frac{L'_{\text{CO}}(M_h)}{\text{K km s}^{-1} \text{pc}^2} = \frac{C}{(M_h/M)^A + (M_h/M)^B}$$

Cleary et al. (2022), Chung et al. (2022)

COMAP Pathfinder: Season 1 Results



Clustering amplitude \times
(Underlying matter
power spectrum)

+ shot noise

$$\langle T_{\text{CO}} \rangle < 3.6 \mu\text{K} \xrightarrow{\alpha_{\text{CO}}} \rho_{\text{H}_2} < 2.5 \times 10^8 M_{\odot} \text{ Mpc}^{-3}$$

(mean CO temperature) (molecular gas abundance)

COMAP Early Science Papers (2022)

THE ASTROPHYSICAL JOURNAL

Focus on Early Science Results from the CO Mapping Array Project (COMAP)

Editor: Professor Christopher Conselice

PI: Kieran Cleary, California Institute of Technology

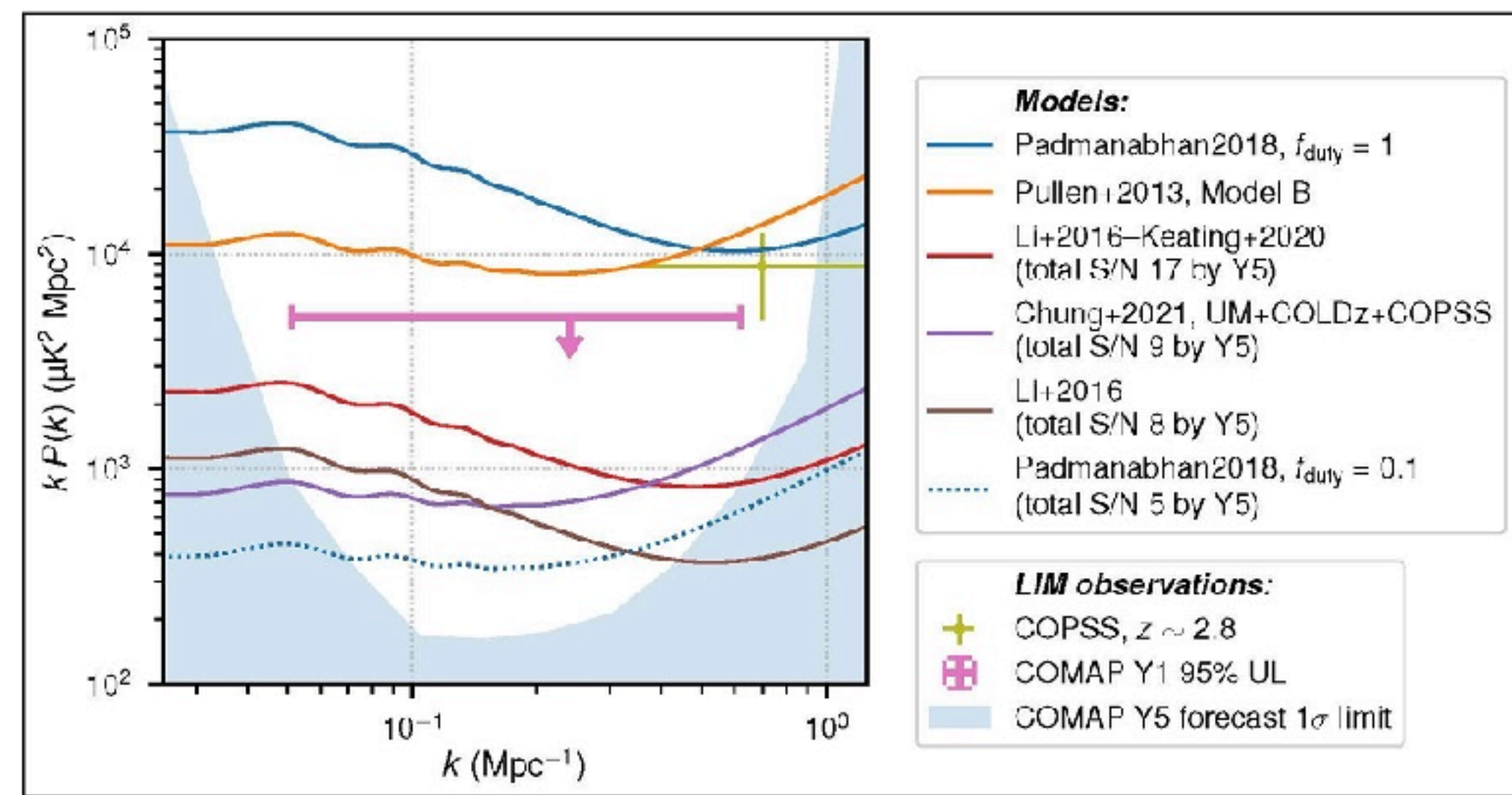


Figure 1. COMAP Pathfinder Season 1 constraint (pink) on the redshift-space CO(1-0) power spectrum at $z \sim 3$, alongside the predictions from various models and our Year 5 Pathfinder sensitivity forecast (blue shaded area). The models include (i) the fiducial COMAP data-driven model from Chung et al. (2021) ("UM+GOLDz+COPSS"), (ii) an alternative model from Keating et al. (2020) ("Li+2016-Keating+2020") with emission from faint galaxies that may be missed by the surveys informing the fiducial model, and (iii) models based on $L(M_h)$ relations from Padmanabhan (2017), Pullen et al. (2013), and Li et al. (2016). Also shown is the result from another CO LIM experiment, COPSS, that targeted the shot-noise component of the power spectrum (Keating et al. 2016). For each, the legend indicates the expected signal-to-noise ratio with which we would reject the null hypothesis (i.e., excluding sample variance from the calculation).

COMAP Early Science. I. Overview

Authors: Kieran Cleary, Christopher Conselice, et al.

Abstract: The CO Mapping Array Project (COMAP) is a next-generation CO(1-0) survey designed to map the evolution of CO emission from galaxies across the redshift range $z \sim 0.5$ to $z \sim 3$. This paper provides an overview of the project's science goals, survey design, and early science results.

COMAP Early Science. E. Pathfinder Instrument

Authors: Kieran Cleary, Christopher Conselice, et al.

Abstract: We describe the design and construction of the Pathfinder instrument, the first of the CO Mapping Array Project's CO(1-0) surveys. The instrument consists of a 100-element antenna array operating at 160 GHz, designed to provide high-resolution, high-sensitivity observations of CO emission from galaxies.

COMAP Early Science. III. CO Line Processing

Authors: Kieran Cleary, Christopher Conselice, et al.

Abstract: We describe the CO line processing pipeline for the Pathfinder instrument. The pipeline includes data calibration, flagging, and line fitting, and is designed to provide high-quality CO line spectra for each observation.

COMAP Early Science. IV. Power Spectrum Methodology and Results

Authors: Kieran Cleary, Christopher Conselice, et al.

Abstract: We describe the methodology for measuring the CO(1-0) power spectrum from the Pathfinder instrument. The methodology includes data reduction, power spectrum estimation, and uncertainty quantification. We present the results of the first season of observations, showing a 95% upper limit on the power spectrum at $k \sim 0.15 \text{ Mpc}^{-1}$.

COMAP Early Science. G. Constraints and Forecasts at $z \sim 3$

Authors: Kieran Cleary, Christopher Conselice, et al.

Abstract: We present constraints on the CO(1-0) power spectrum at $z \sim 3$ from the Pathfinder instrument. The constraints are compared to predictions from various models, including the fiducial COMAP data-driven model and models based on $L(M_h)$ relations. We also present forecasts for the Year 5 Pathfinder survey, showing a 1σ sensitivity forecast limit at $k \sim 0.1 \text{ Mpc}^{-1}$.

COMAP Early Science. VI. A First Look at the COMAP Galactic Plane Survey

Authors: Kieran Cleary, Christopher Conselice, et al.

Abstract: We present a first look at the COMAP Galactic Plane Survey (GPS). The GPS is a CO(1-0) survey of the Galactic plane, designed to provide high-resolution, high-sensitivity observations of CO emission from the Milky Way. We present the results of the first season of observations, showing a 95% upper limit on the power spectrum at $k \sim 0.15 \text{ Mpc}^{-1}$.

COMAP Early Science. VII. Prospects for CO Intensity Mapping at Redshift $z \sim 3$

Authors: Kieran Cleary, Christopher Conselice, et al.

Abstract: We present prospects for CO intensity mapping at redshift $z \sim 3$ from the Pathfinder instrument. The prospects are compared to predictions from various models, including the fiducial COMAP data-driven model and models based on $L(M_h)$ relations. We also present forecasts for the Year 5 Pathfinder survey, showing a 1σ sensitivity forecast limit at $k \sim 0.1 \text{ Mpc}^{-1}$.