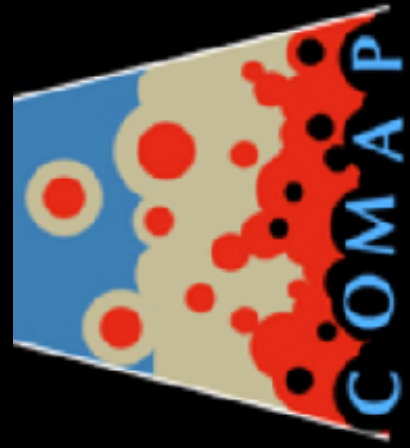


# CO Mapping Array Project COMAP

**SKAO Science Working Group Meeting, Manchester 2023**

**Stuart Harper, University of Manchester, January 19 2023**



# COMAP Collaboration

## 37 Members across 11 Universities

### Caltech

Kieran Cleary (PI)  
Morgan Catha-Garrett  
Delaney Dunne  
Rick Hobbs  
Junhan Kim  
James Lamb  
Timothy Pearson  
Anthony Readhead  
Bade Uzgil  
David Woody



Patrick Breysse



Clive Dickinson  
Stuart Harper  
Thomas Rennie

### UiO : Universitetet i Oslo

Ingunn Wehus  
Jowita Borowska  
Hans Kristian Eriksen  
Håvard Tveit Ihle  
Jonas Lunde  
Marta Silva  
Nils-Ole Stutzer  
Duncan Watts



Andrew Harris



Joshua Gundersen

### Stanford

Sarah Church  
Risa Wechsler



Richard Bond  
Dongwoo Chung  
Norman Murray  
George Stein



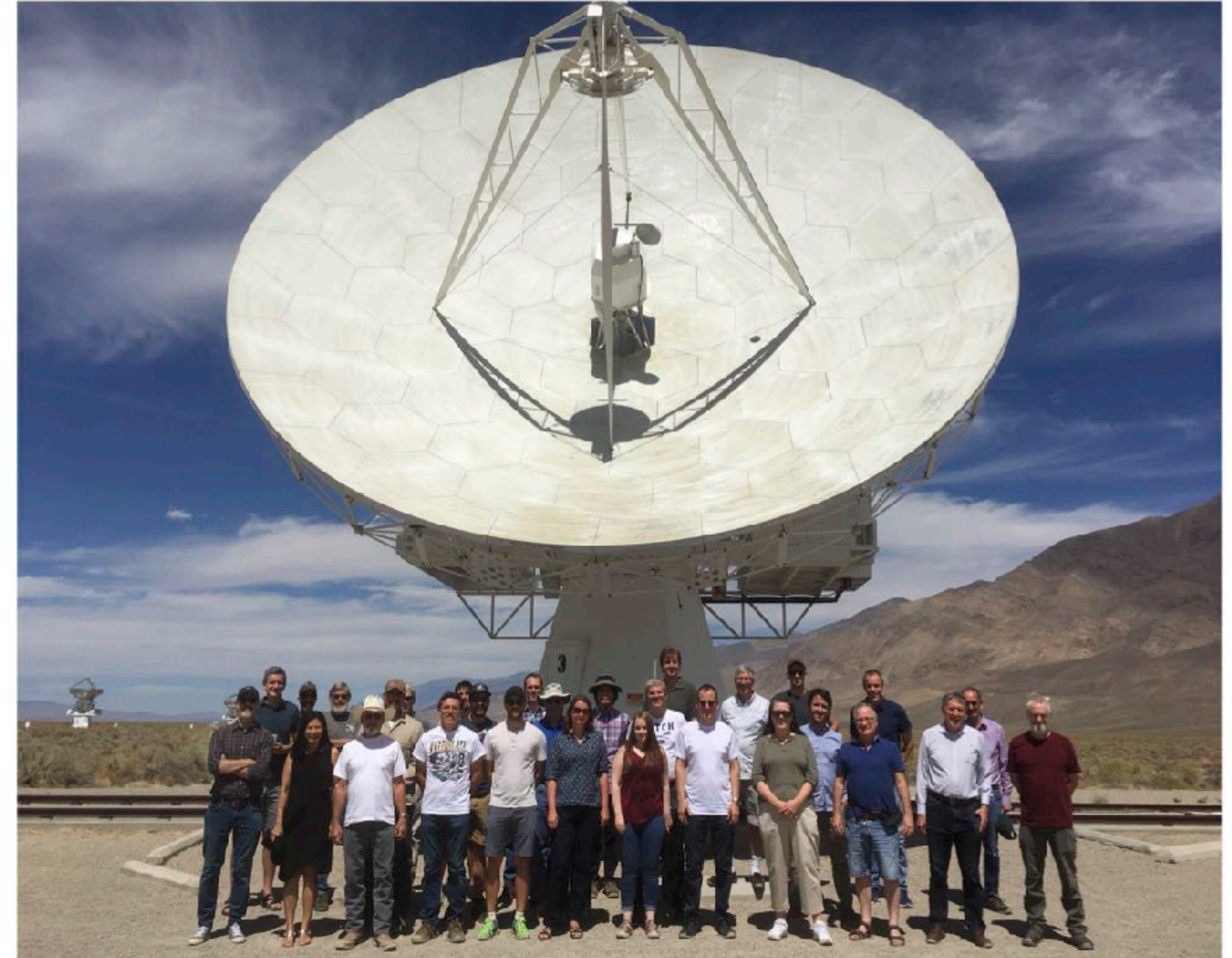
Charles Lawrence  
Tzu-Ching Chang  
Todd Gaier  
Joseph Lazio  
Liju Philip

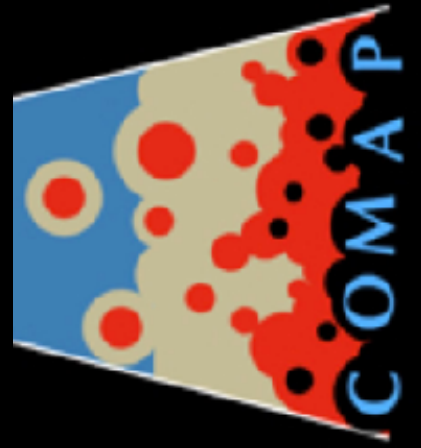


Brandon Hensley



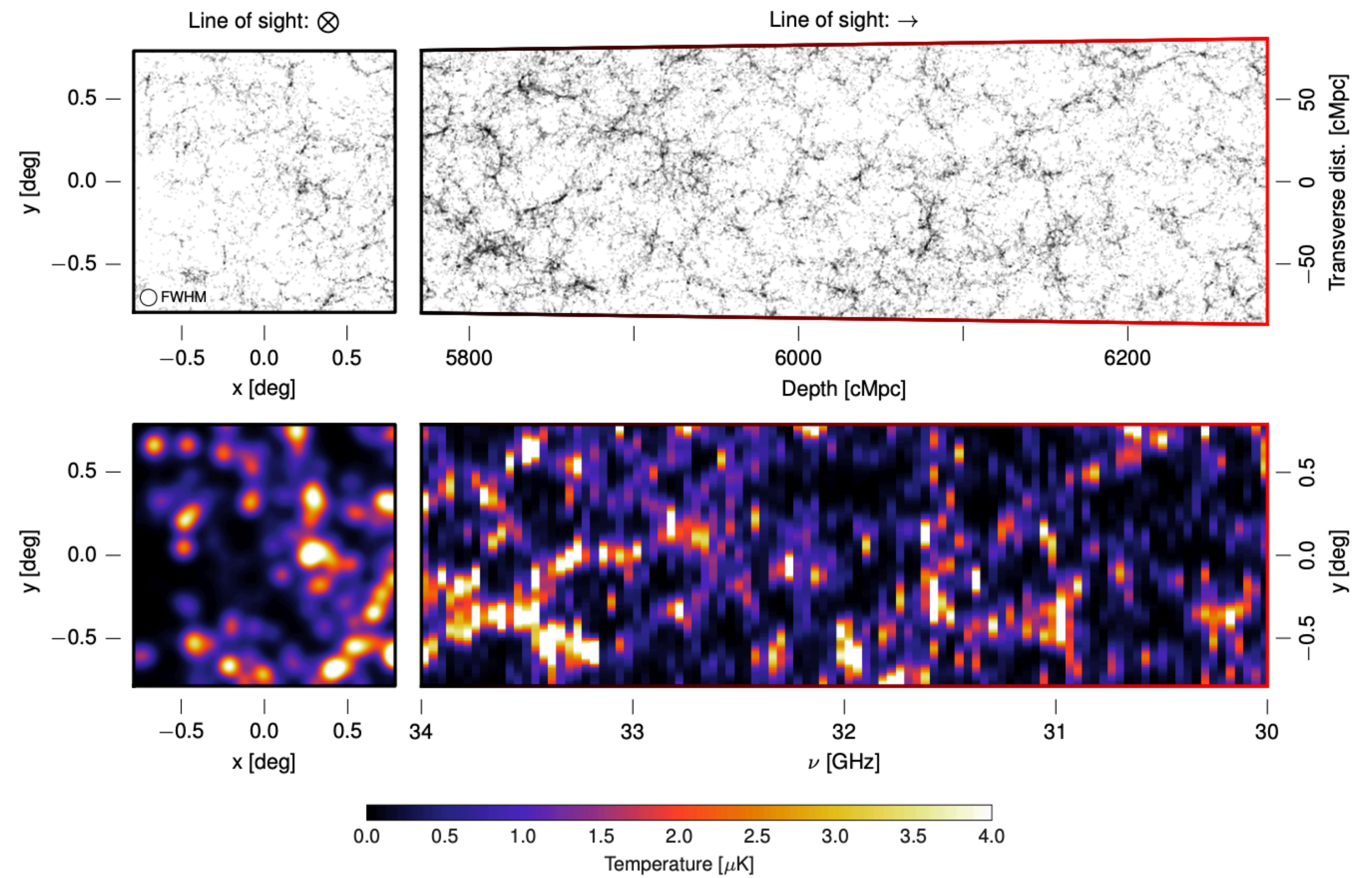
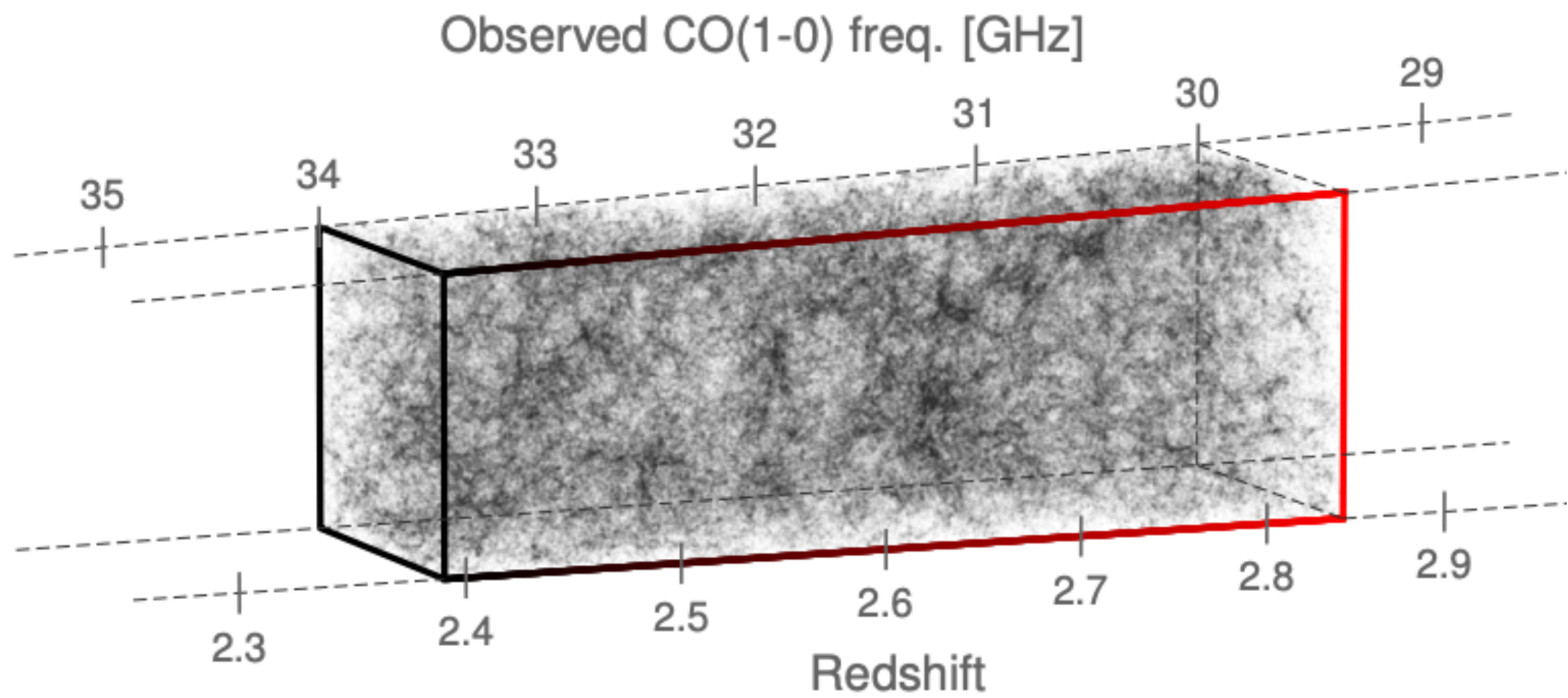
Hamsa Padmanabhan

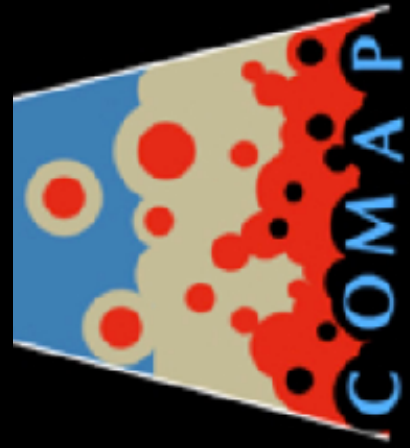




# COMAP

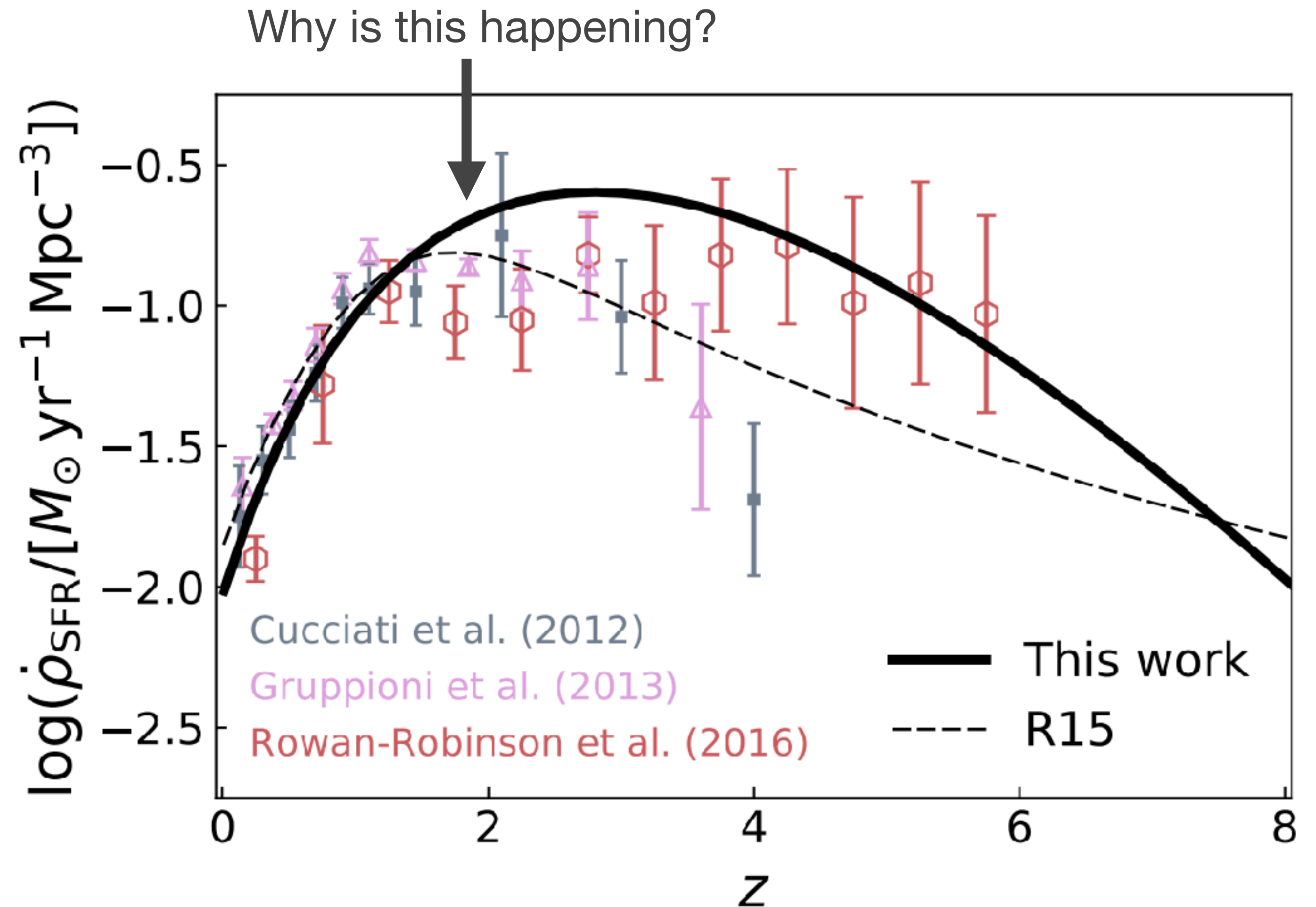
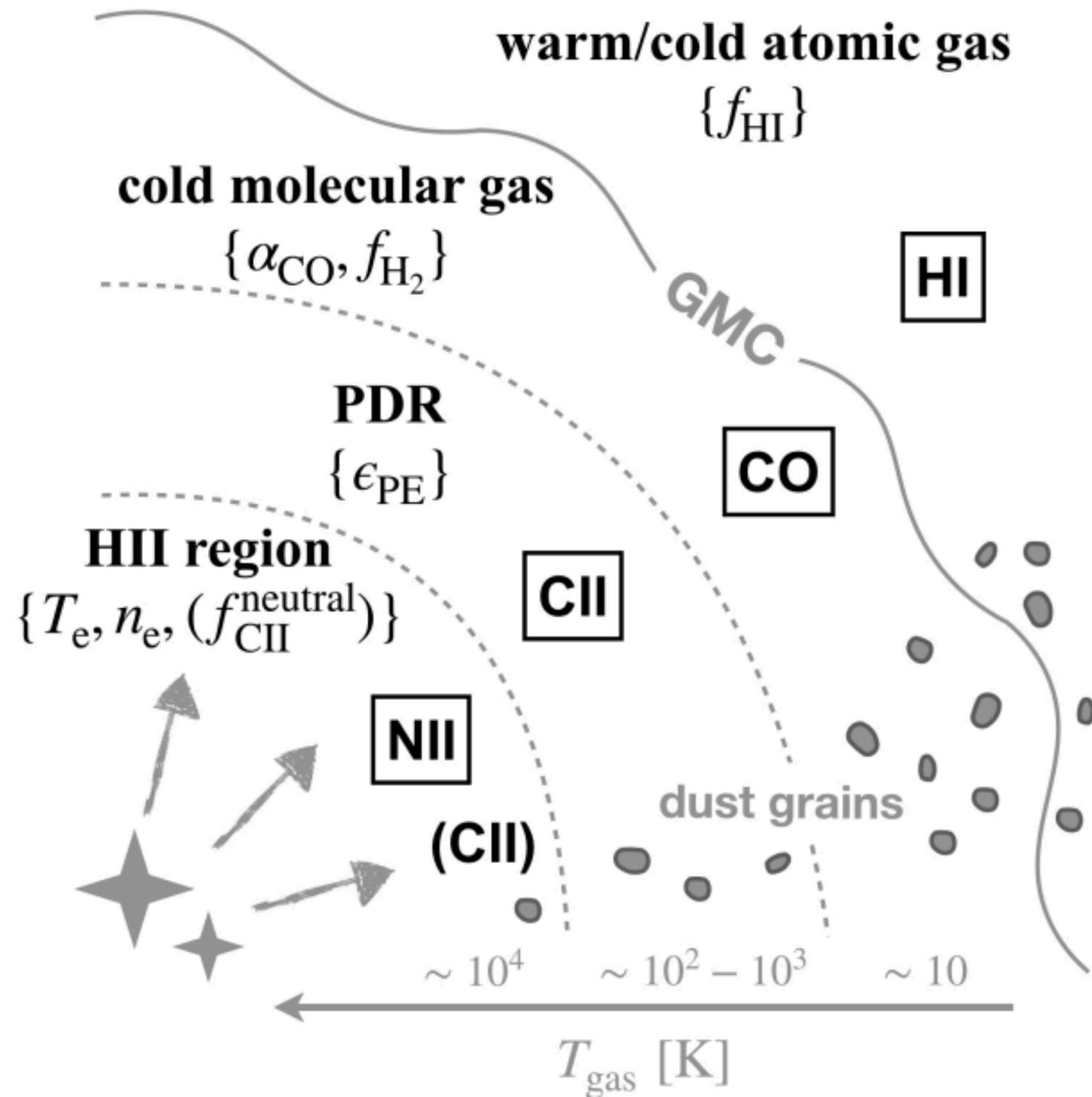
## Some motivation

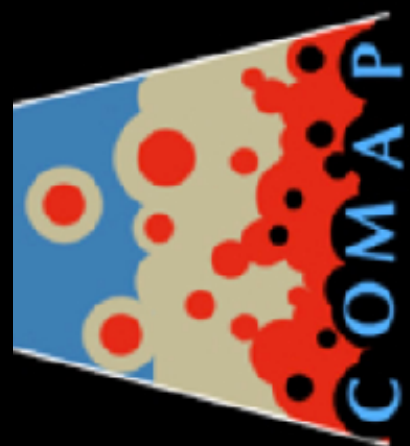




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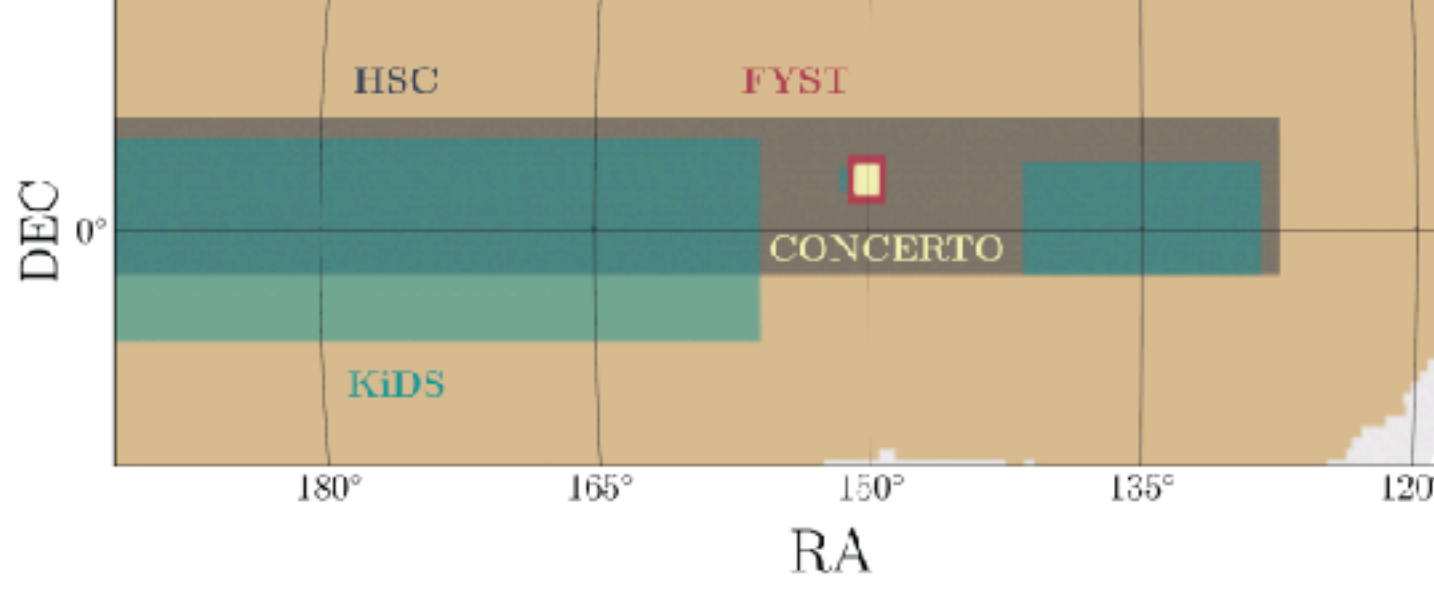
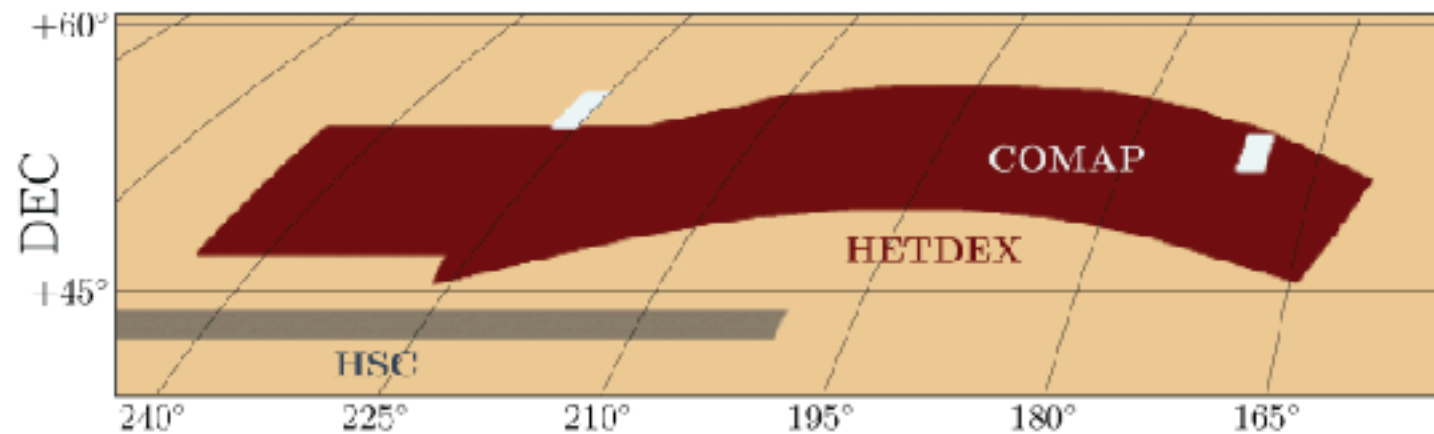
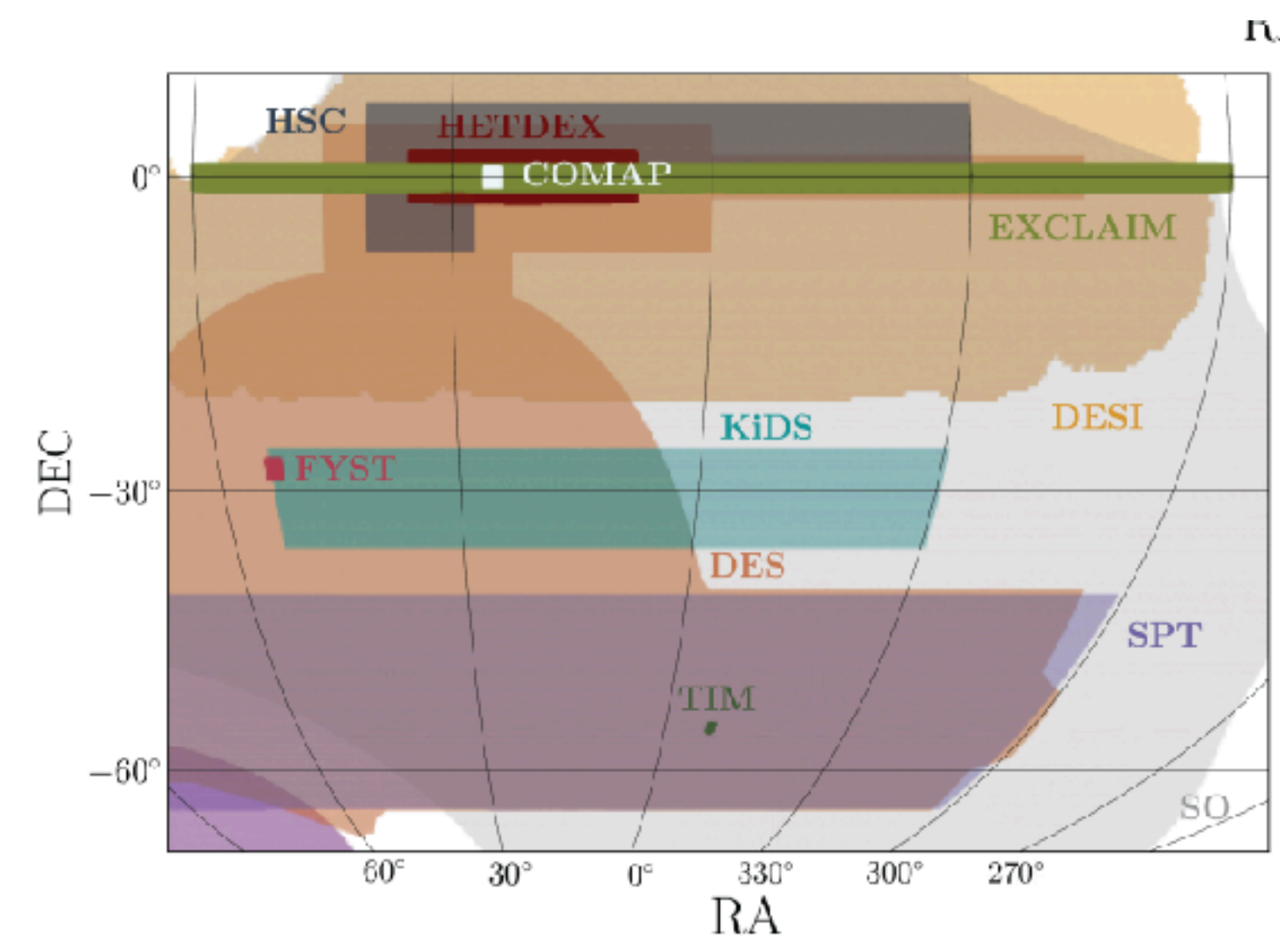
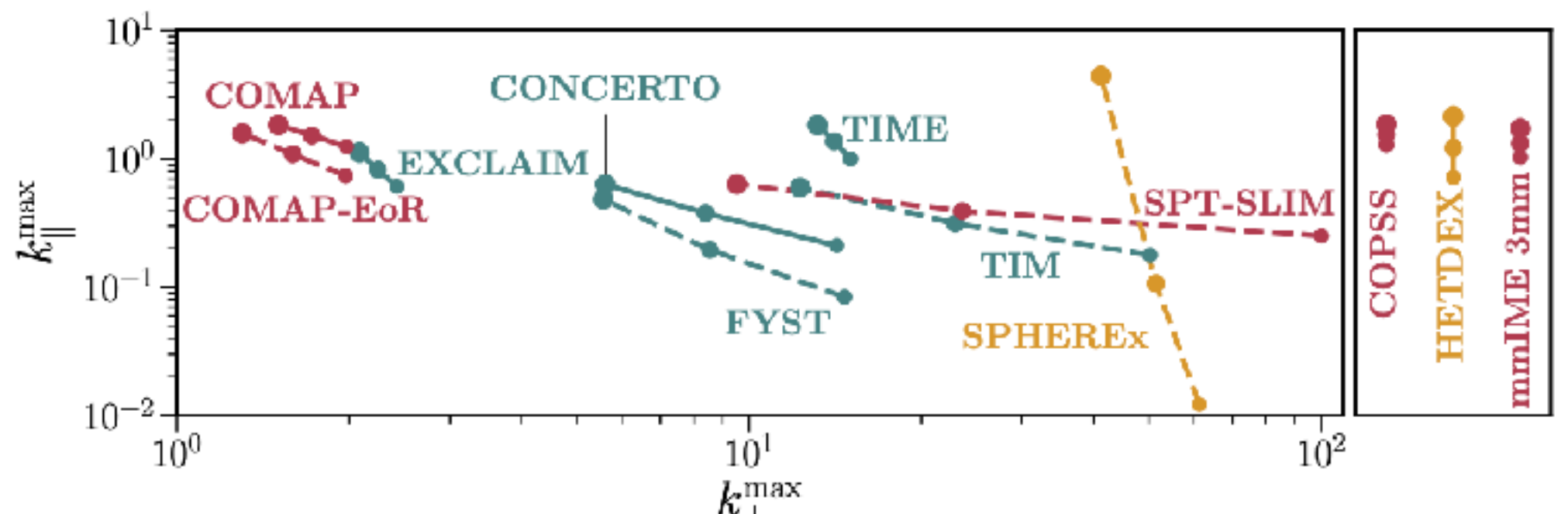
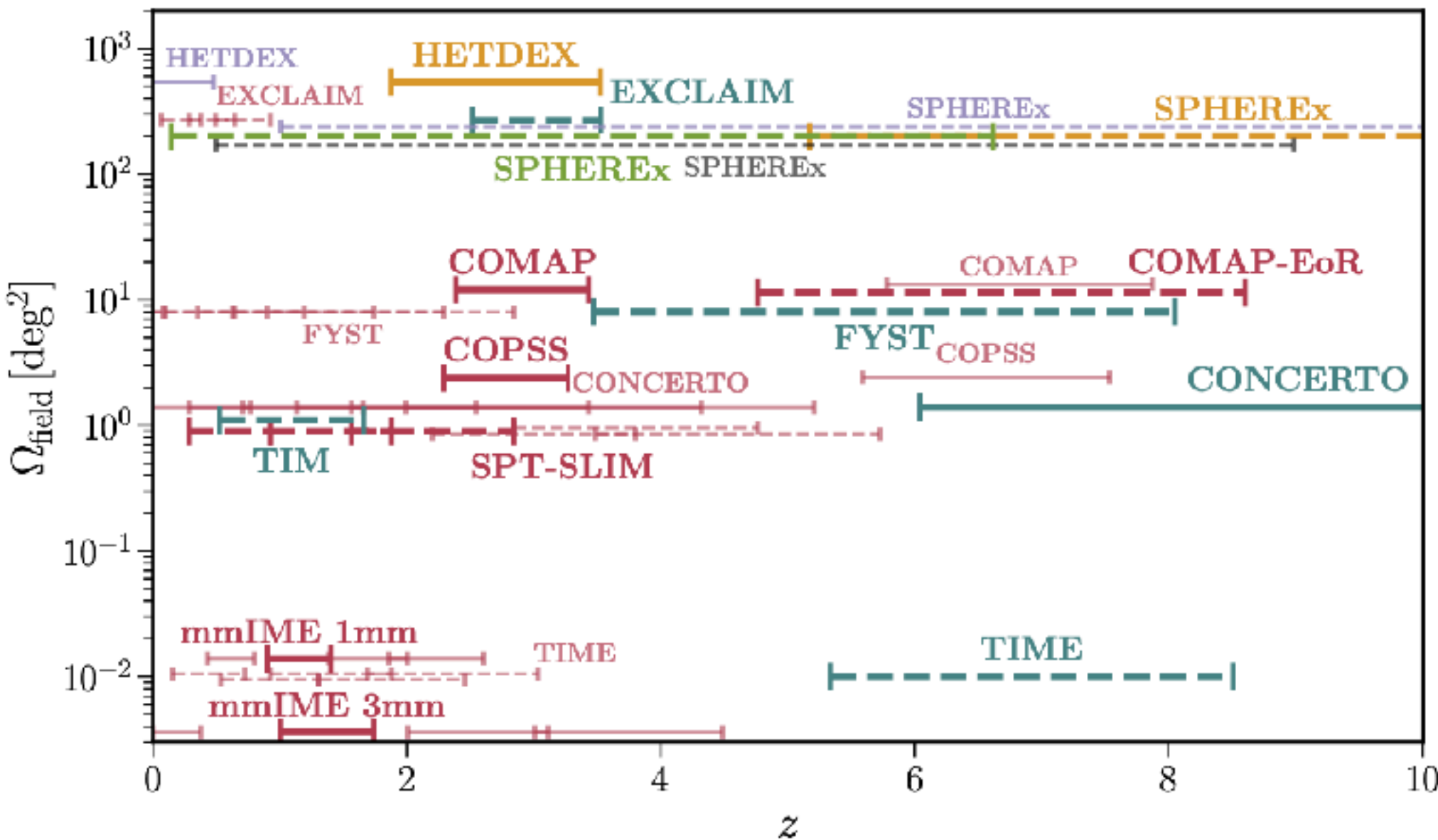
## Some Motivation

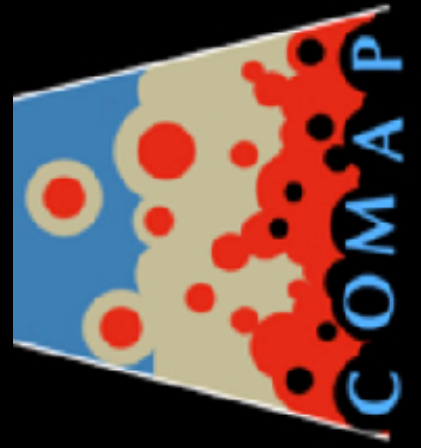




# COMAP

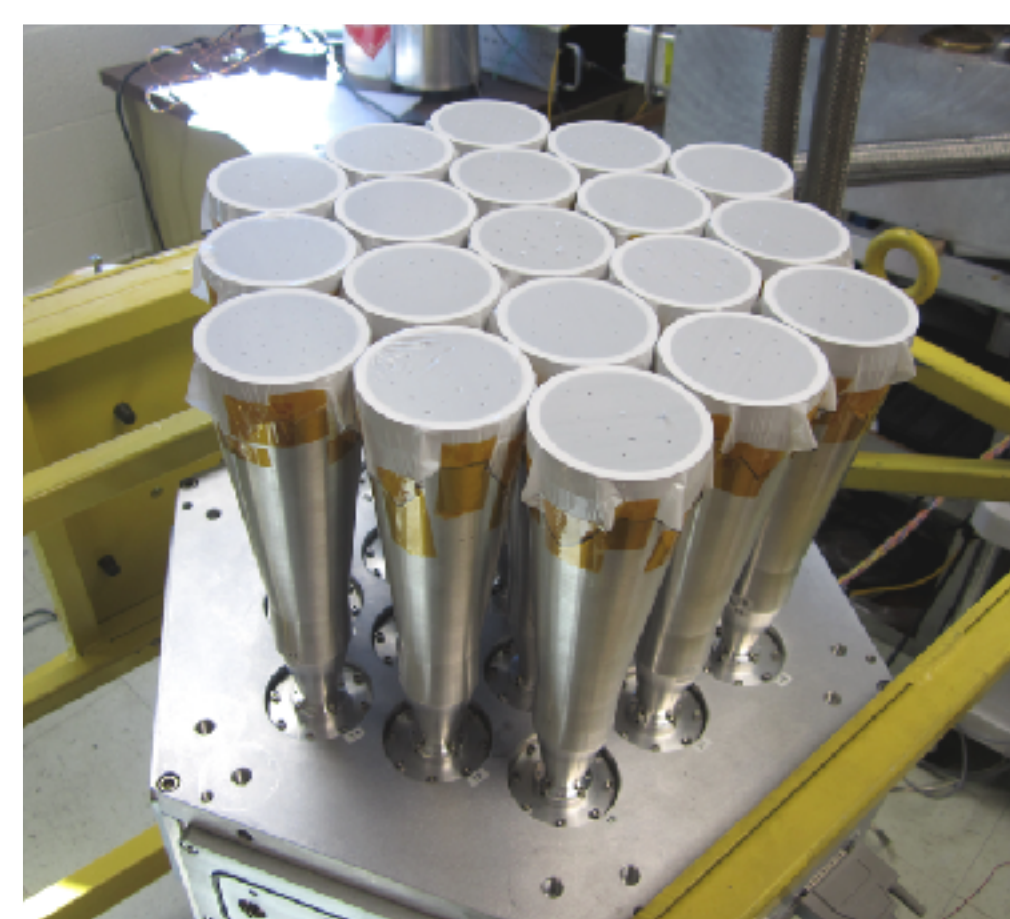
## Line Intensity Mapping Overview

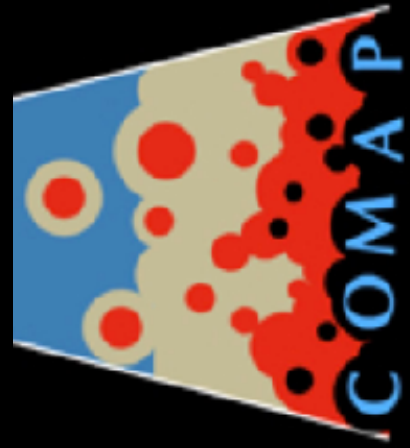




# COMAP Pathfinder Instrument

- 26 – 34 GHz frequency coverage
- 4096 channels with  $\sim 2$  MHz channel bandwidth
- 4.5' beam FWHM at 30 GHz
- 19 forward-facing feeds (pixels) in a hexagonal lattice arrangement
- Intensity only, no polarisation information

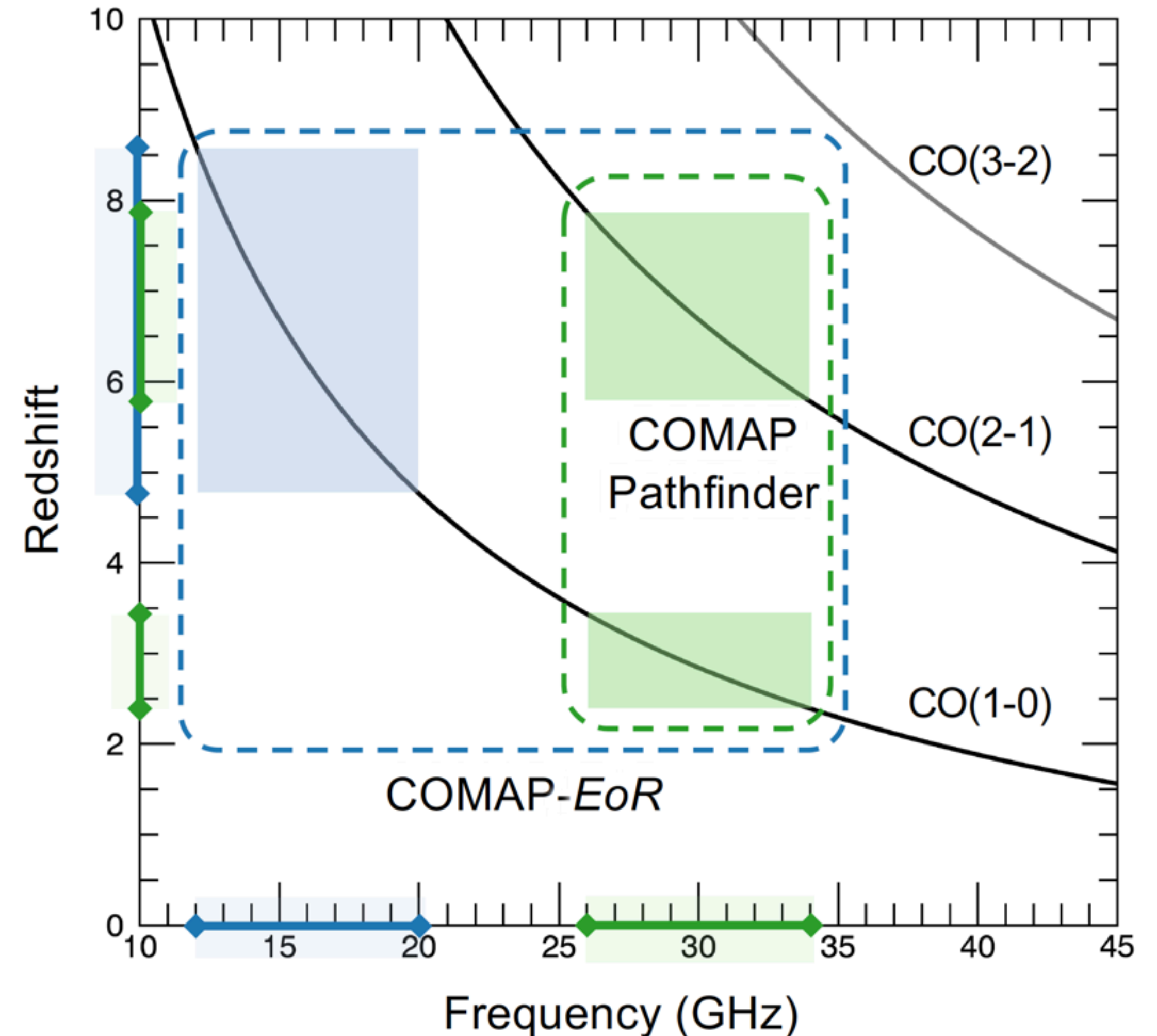


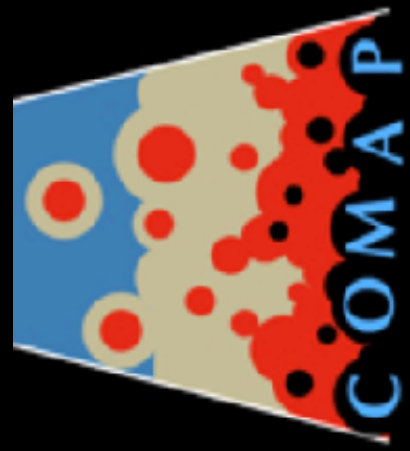


# COMAP Pathfinder

## Science Goals

- Already ruling out several CO models after 1 year of observing (arxiv:2111.05927)
- S/N of 9 to 17 in CO auto-power spectrum after 5 years.
- HETDEX cross-spectrum S/N~7 after 3 years; S/N~19 in 5 years

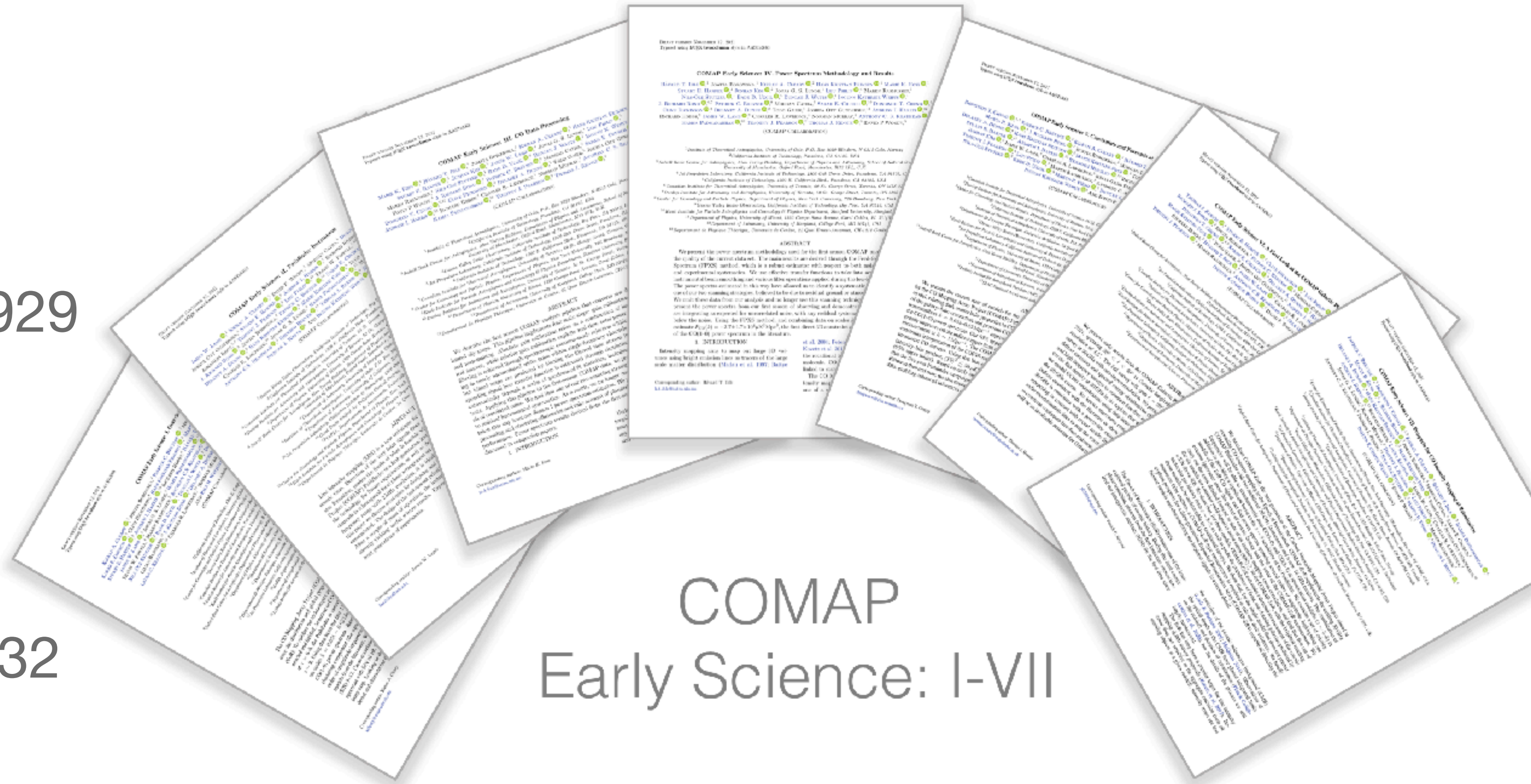




# COMAP Pathfinder

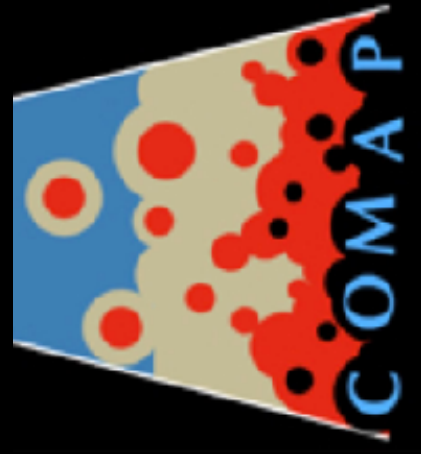
## Recent Papers

- Overview: 2111.05927
- Instrument: 2111.05928
- Data Processing: 2111.05929
- Results: 2111.05930
- Forecasts: 2111.05931
- Galactic Survey: 2111.05932
- EoR: 2111.05933



COMAP  
Early Science: I-VII

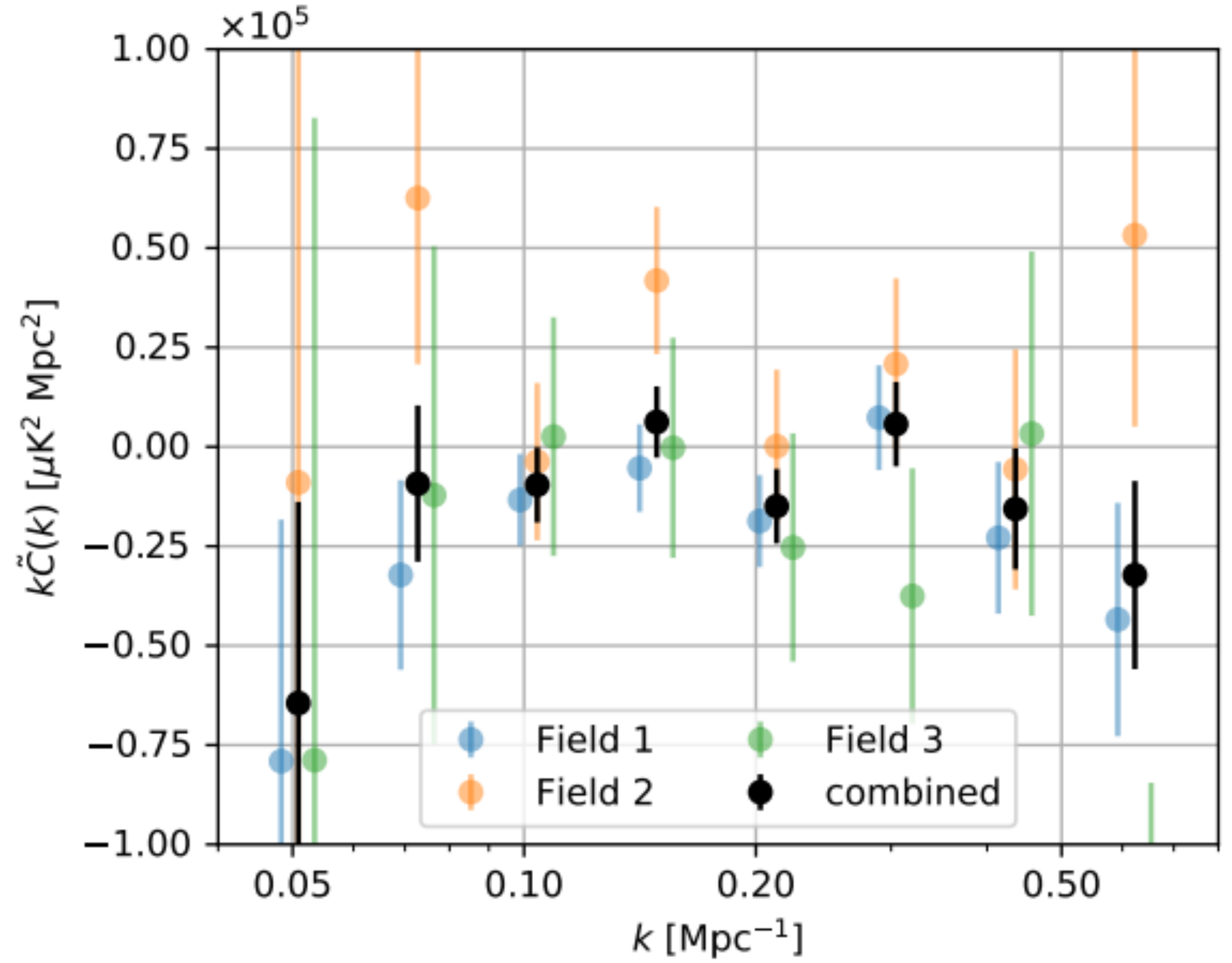


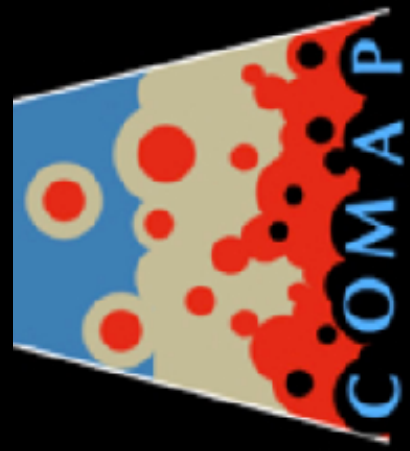


# COMAP Pathfinder

## Power Spectrum Constraints

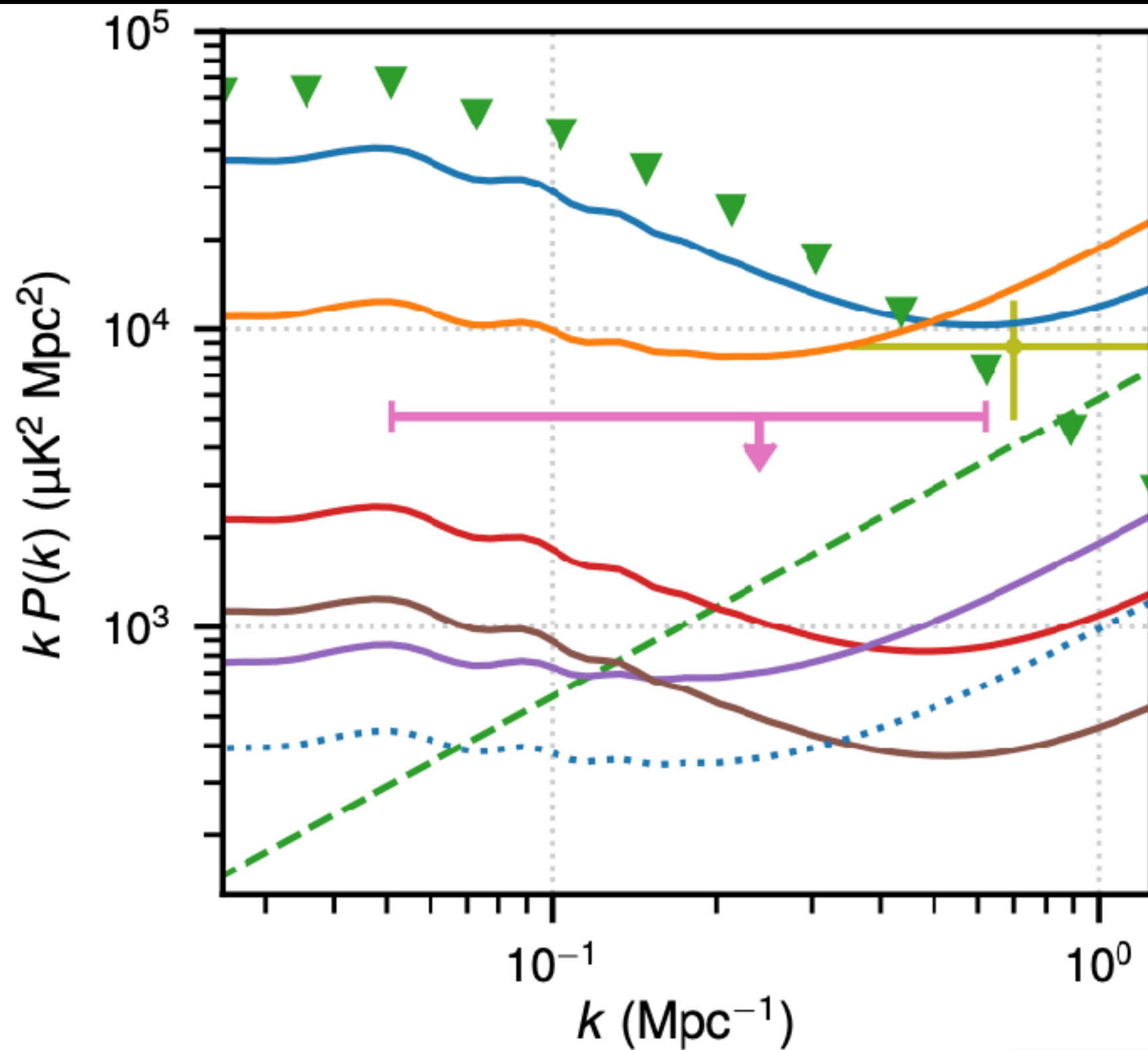
$$P_{\text{co}}(k) = -2.7 \pm 1.7 \times 10^4 \mu\text{K}^2 \text{Mpc}^3$$





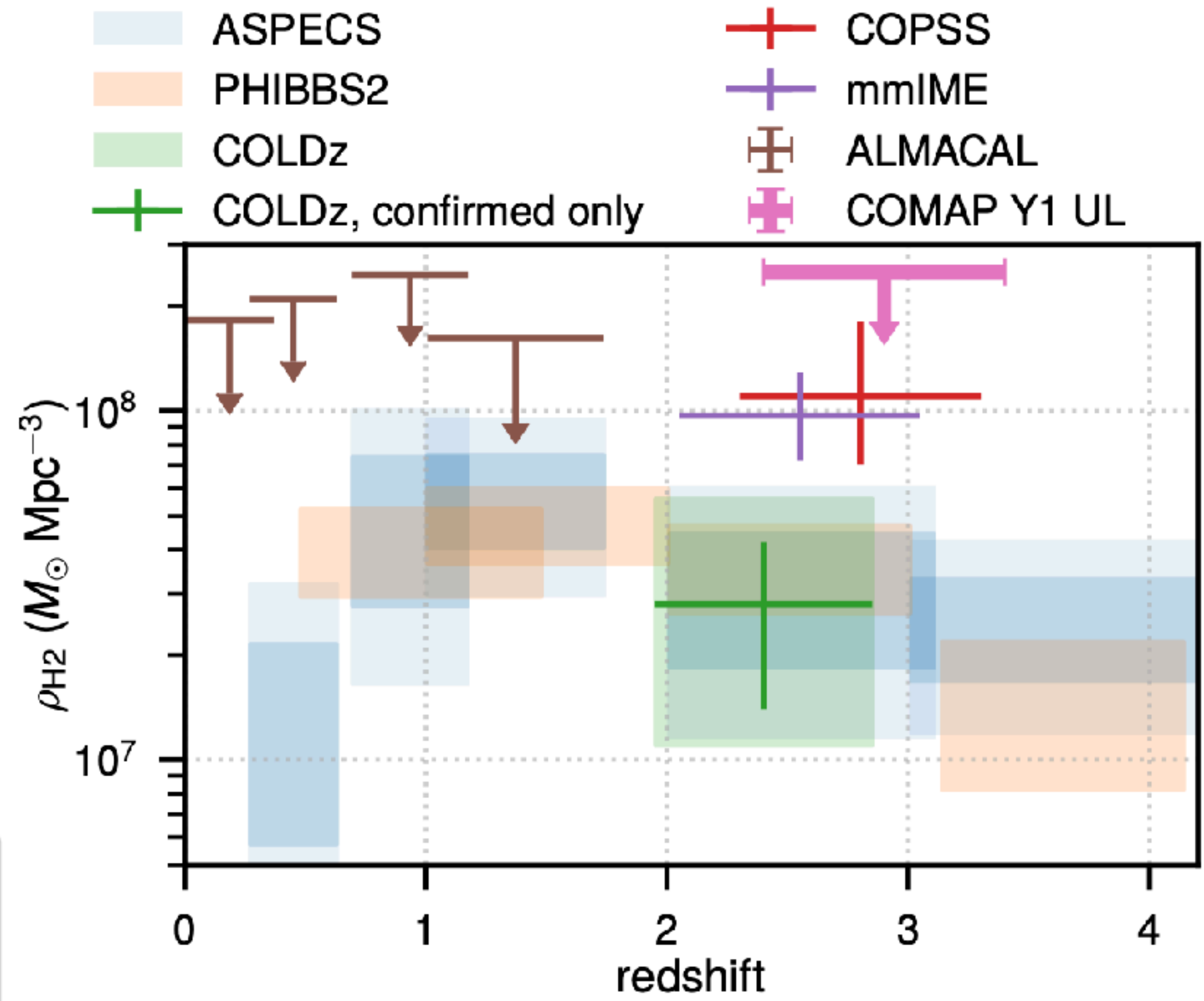
# COMAP Pathfinder

## Constraints on CO and Molecular Gas

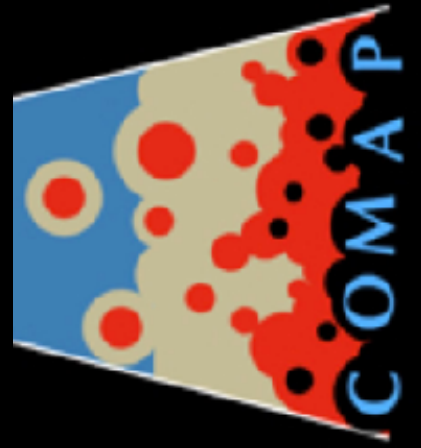


- Models:**
- Padmanabhan2018,  $f_{\text{duty}} = 1$
  - Pullen+2013, Model B
  - ▼ Keating+2020 clustering UL
  - - - Keating+2020  $P_{\text{shot}}$  estimate
  - Li+2016-Keating+2020
  - **this work, fiducial**
  - Li+2016
  - ⋯ Padmanabhan2018,  $f_{\text{duty}} = 0.1$

- LIM observations:**
- + COPSS,  $z \sim 2.8$
  - + COMAP Y1 95% UL



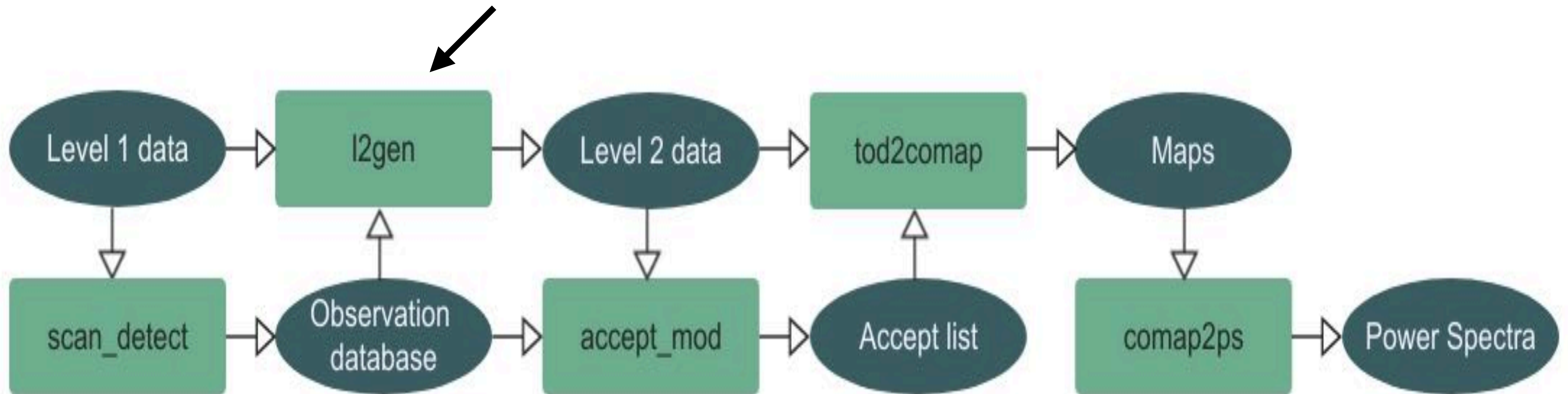
$$\rho_{\text{H}_2} = \frac{\alpha_{\text{CO}} \langle T \rangle H(z)}{(1+z)^2}$$

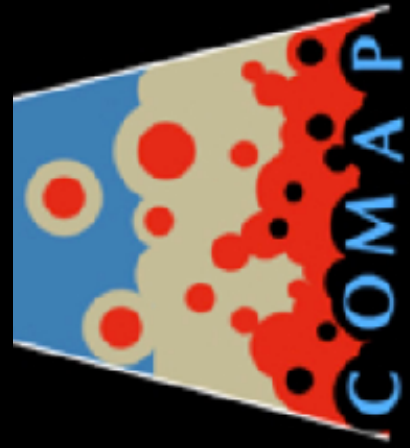


# COMAP Pathfinder

## Data Analysis

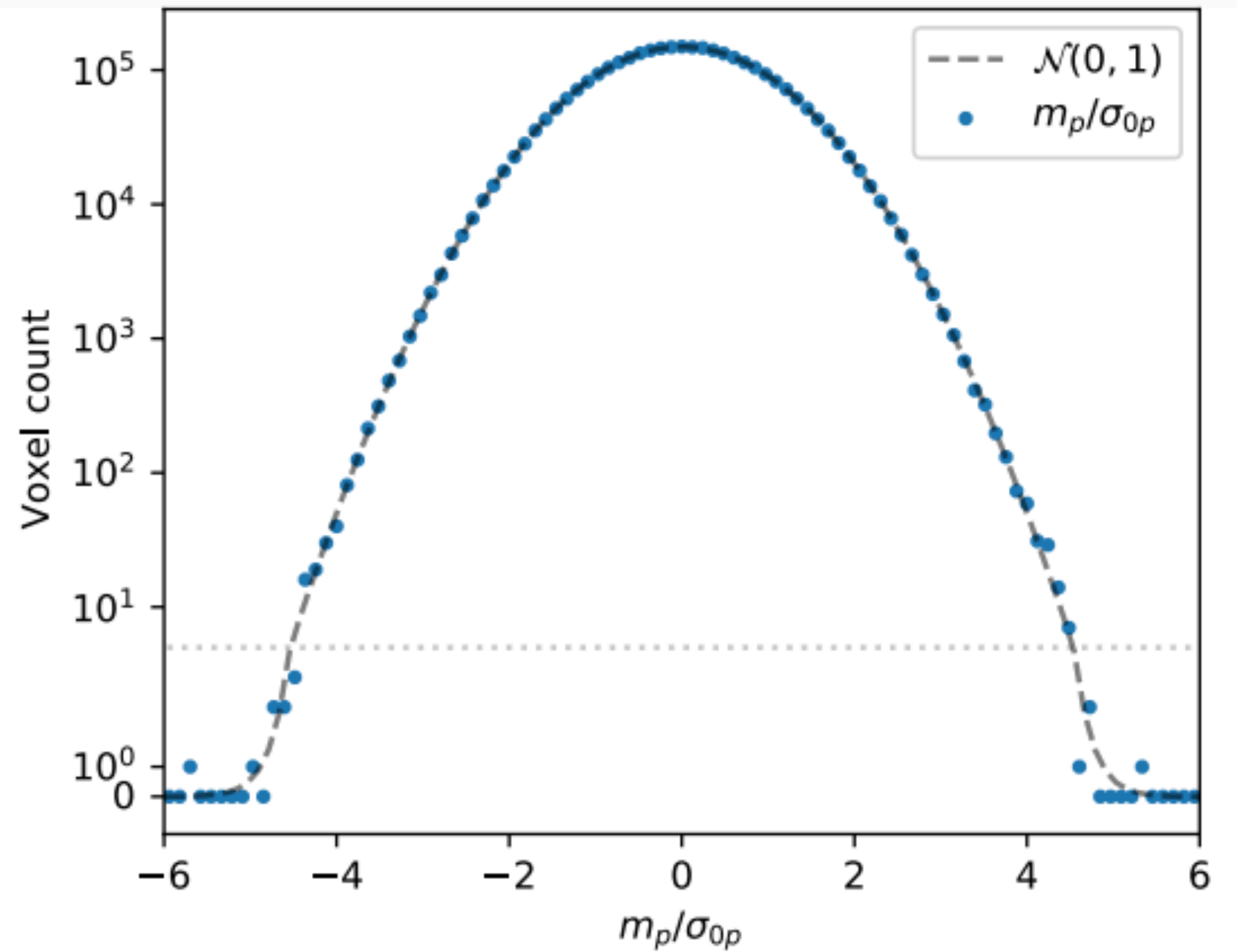
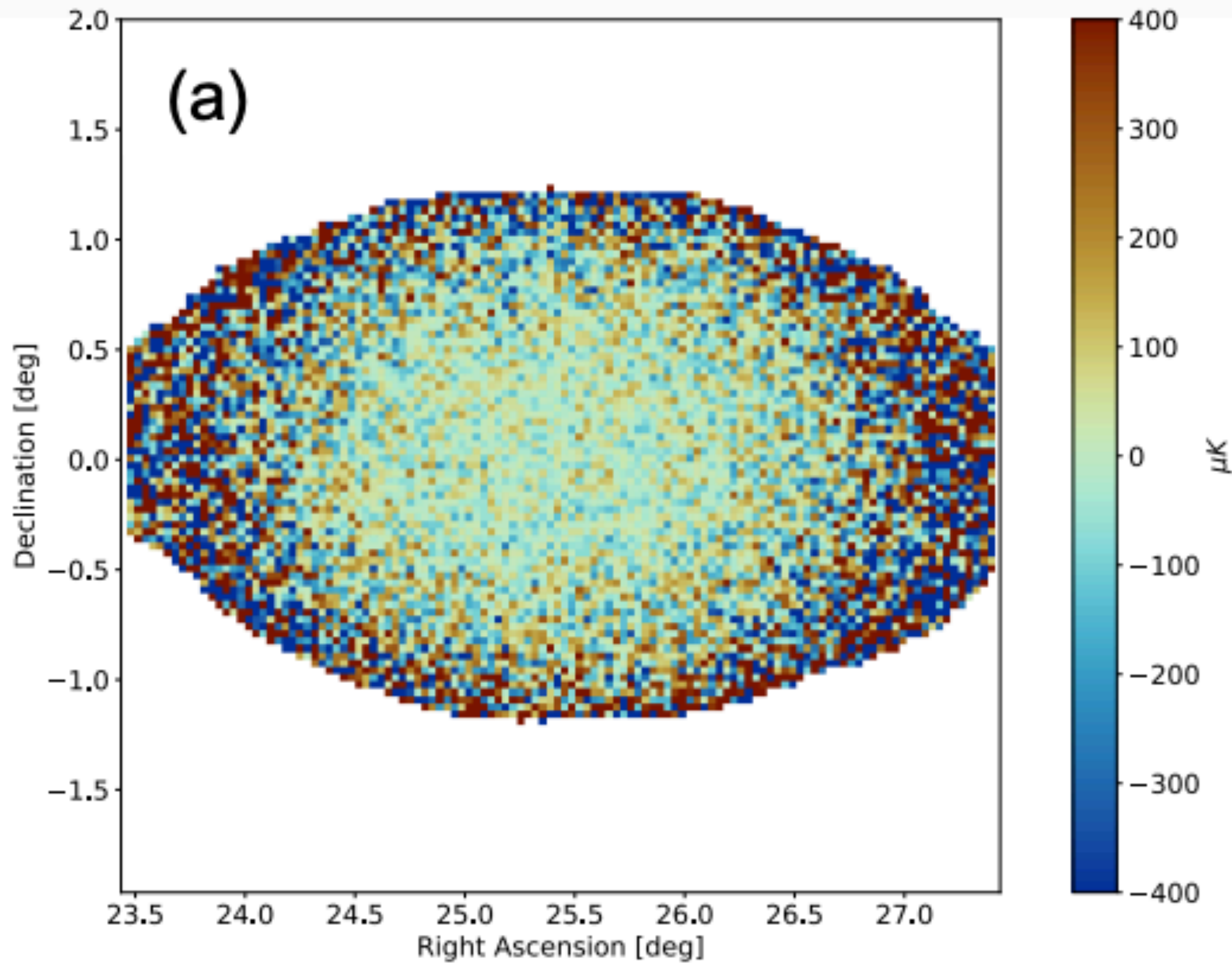
Several temporal and frequency filters

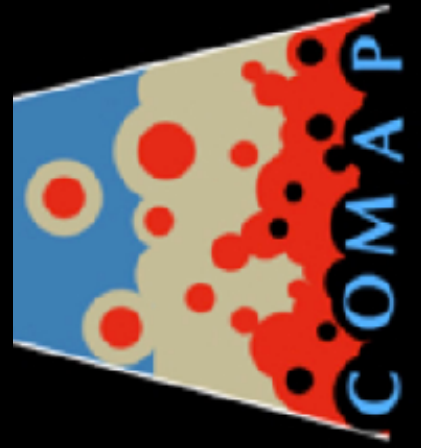




# COMAP Pathfinder

## CO Field Maps: Field 1

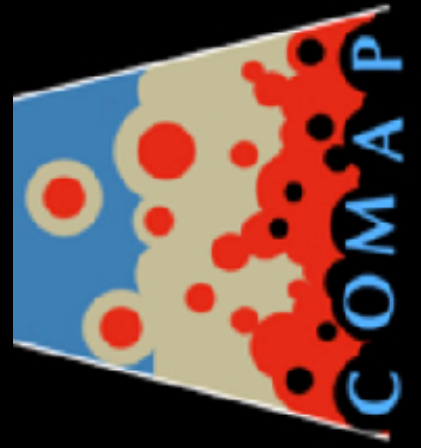




# COMAP Pathfinder

## Systematics

- **Standing Waves? Turn Around Effect? - High**
- **Gain fluctuations or  $1/f$  - Low**
- **Atmosphere and Weather - Low**
- **Ground spillover - Low**
- **Astronomical Foregrounds - Low**
- **Beam sidelobes - ?**

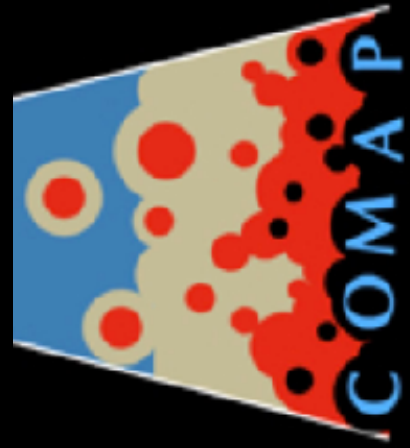


# COMAP Pathfinder

## Systematics

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Easily removed -> Correlated in Frequency

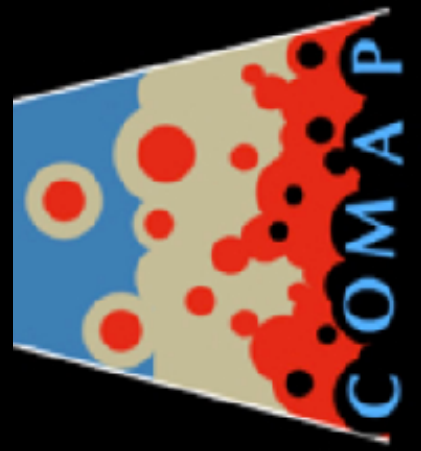


# COMAP Pathfinder

## Systematics

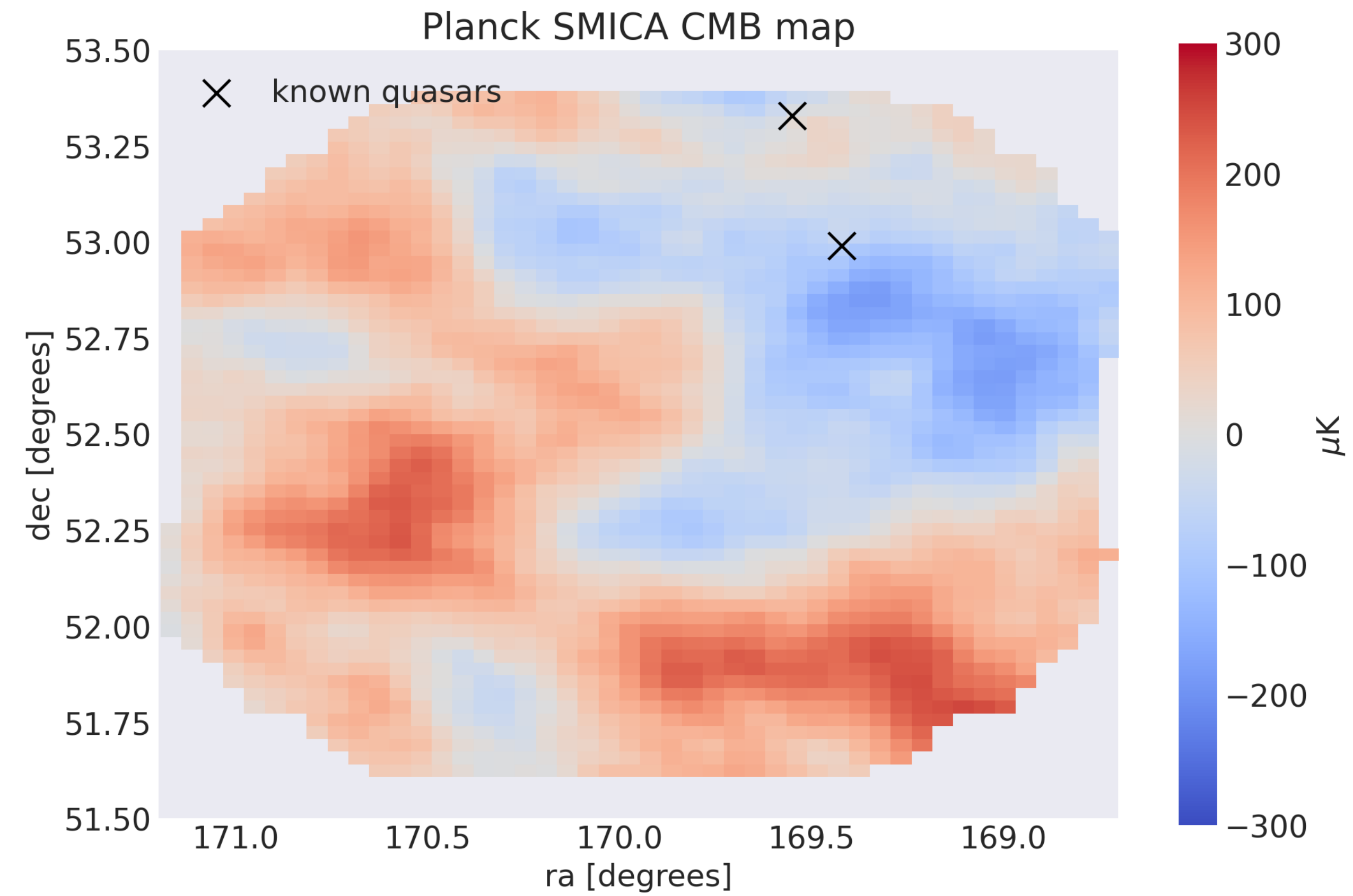
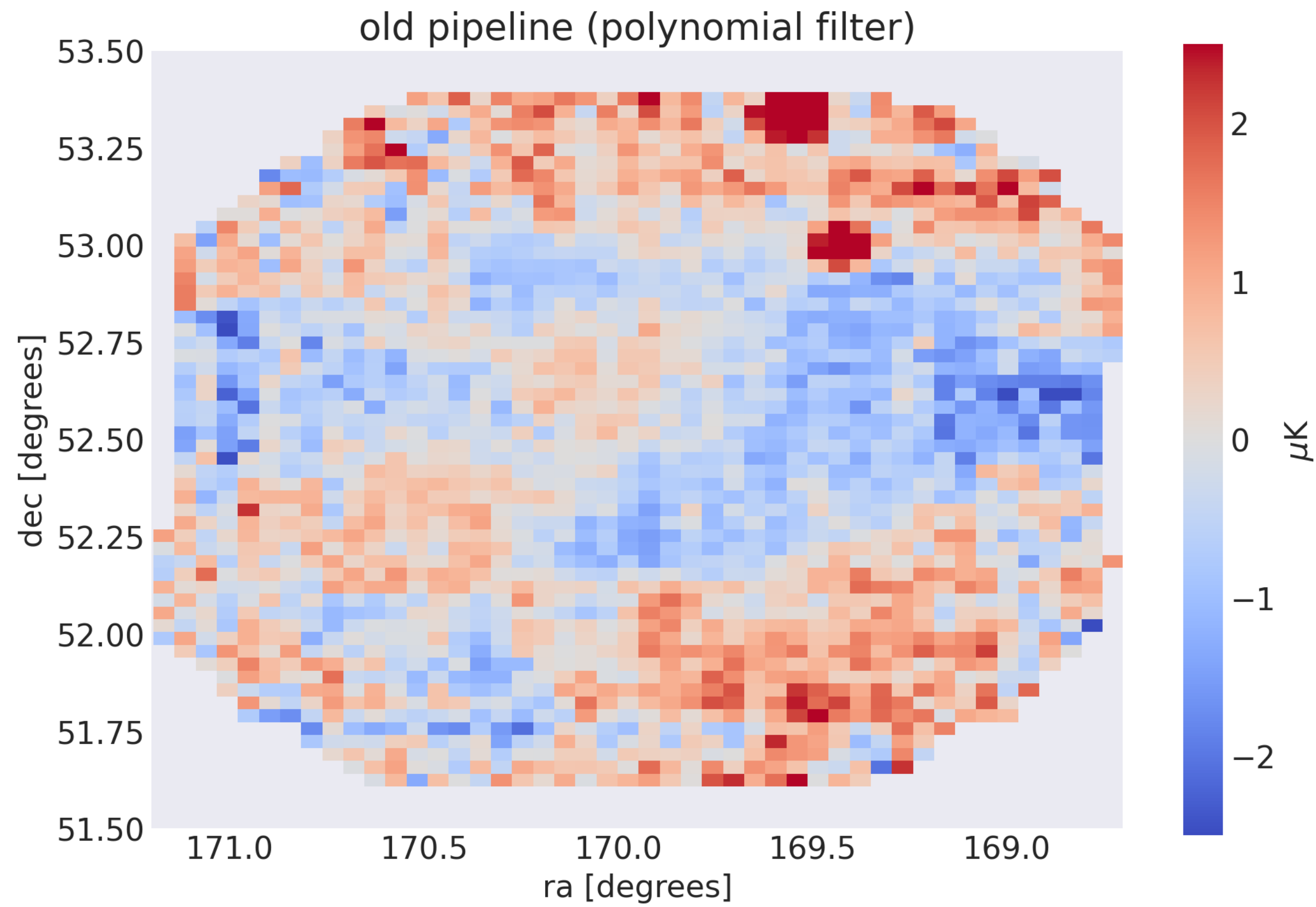
- **Standing Waves? Turn Around Effect? - High**
- **Gain fluctuations or  $1/f$  - Low**
- **Atmosphere and Weather - Low**
- **Ground spillover - Low**
- **Astronomical Foregrounds - Low**
- **Beam sidelobes - ?**

Not smooth in frequency -  
difficult to remove



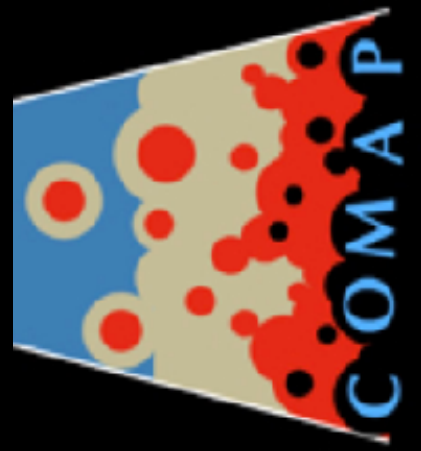
# COMAP Pathfinder

## New Filter



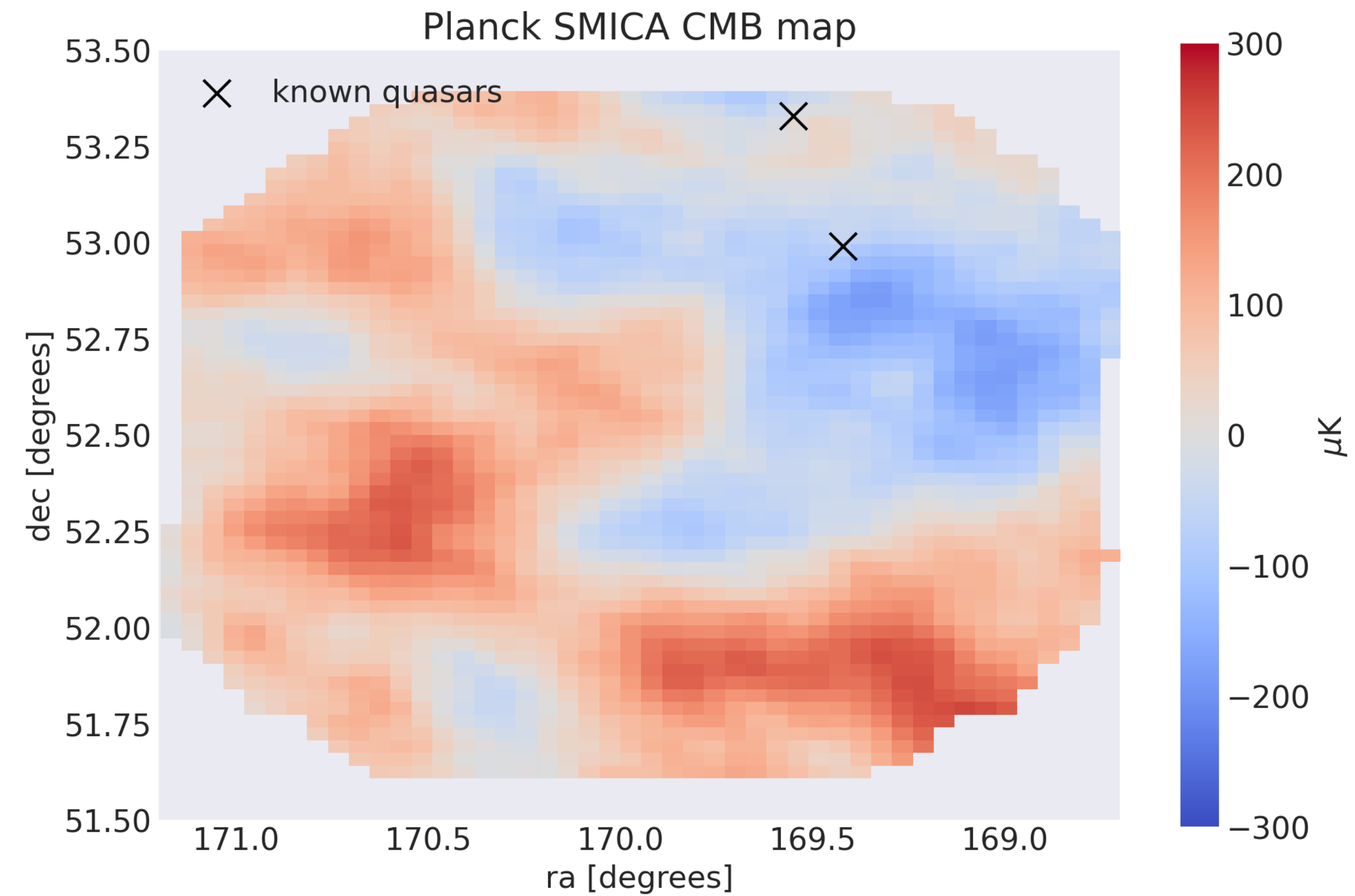
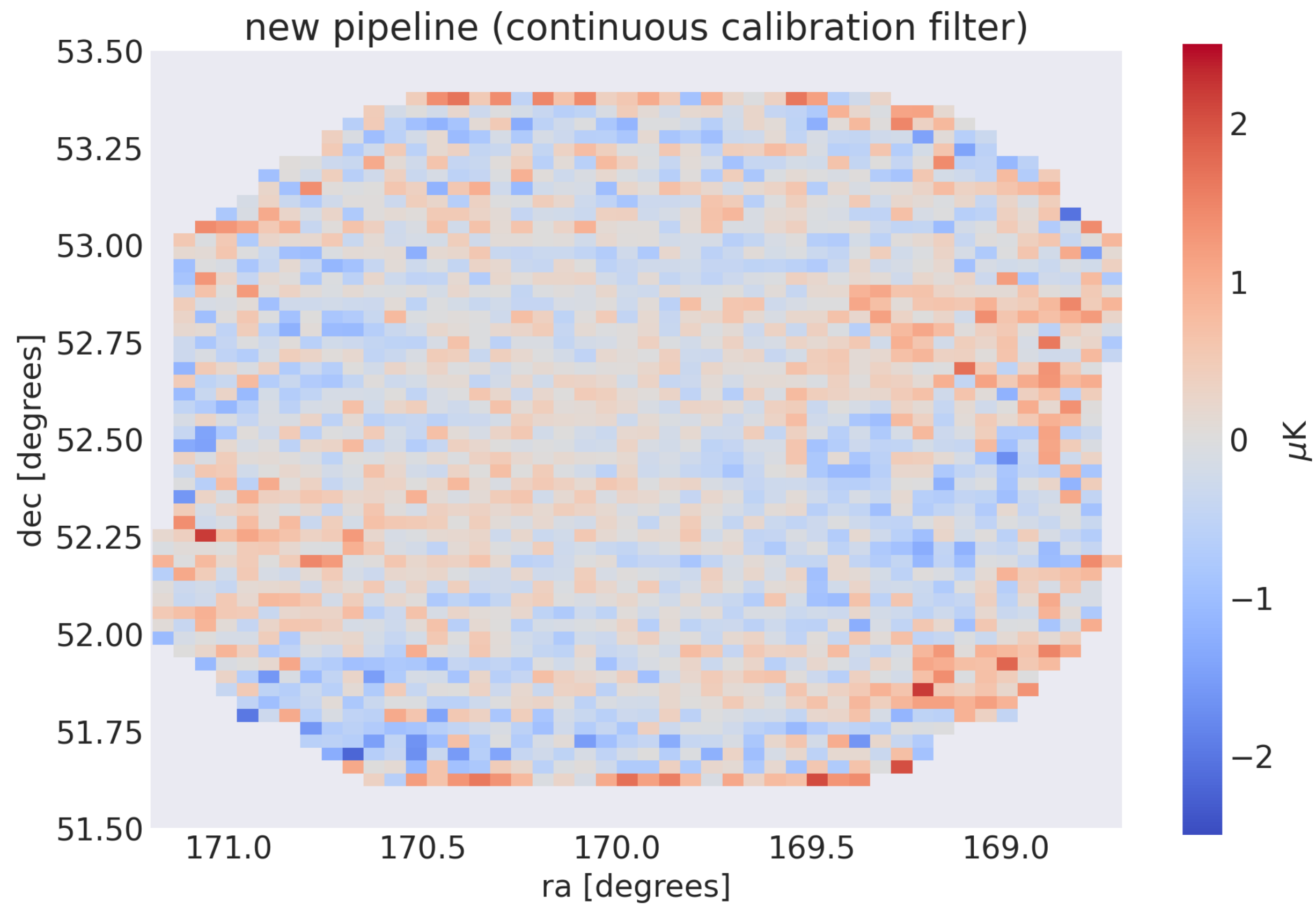
Credit: J. S. Lunde



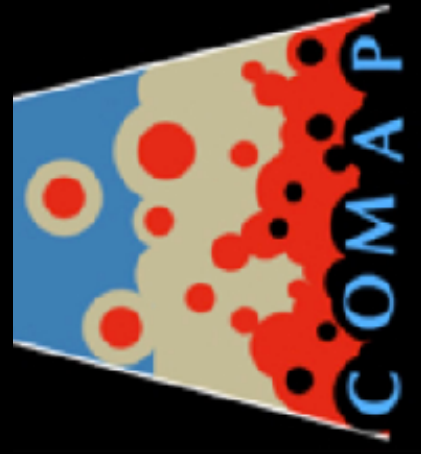


# COMAP Pathfinder

## New Filter

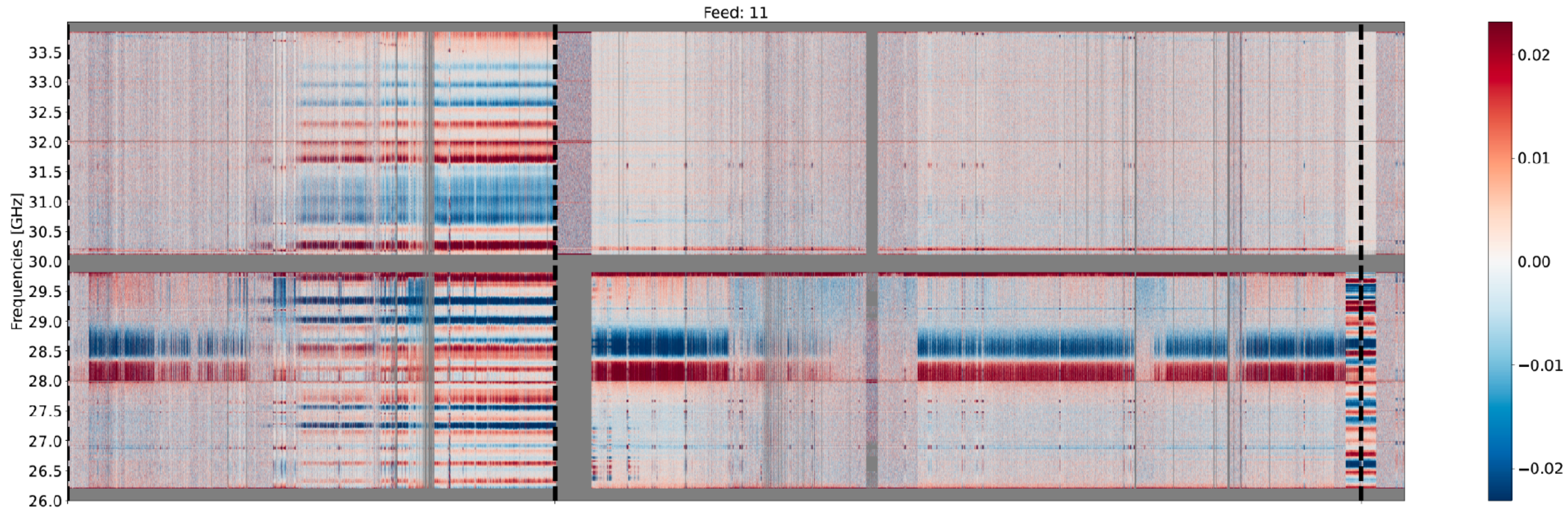


Credit: J. S. Lunde

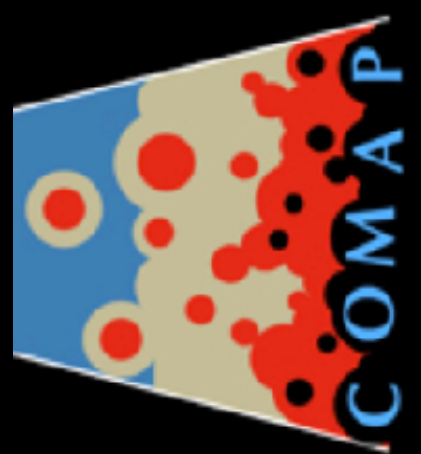


# COMAP Pathfinder

## Systematics - Frequency structure



Credit: N Stutzer



# COMAP Pathfinder

## Summary

- COMAP is a CO line intensity mapping experiment probing cold molecular gas at  $z=3$  and  $z=6$  in the future.
- We are fully funded to complete the pathfinder experiment for 2 more years, and have proposals in for the 15GHz expansion.
- The first year of data we reached the expected noise level, but now we are going deeper new systematics are appearing that we are still working to understand.