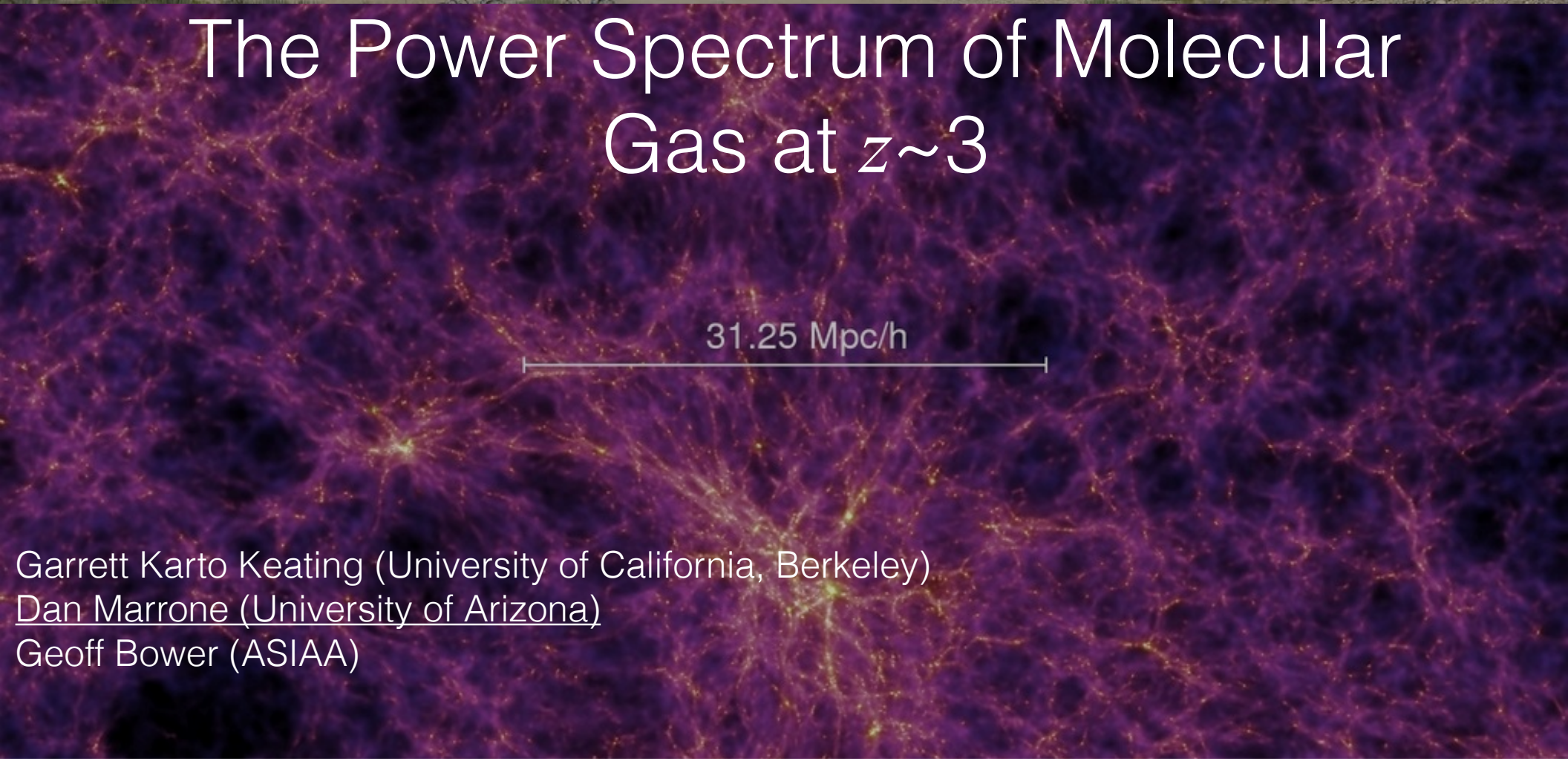
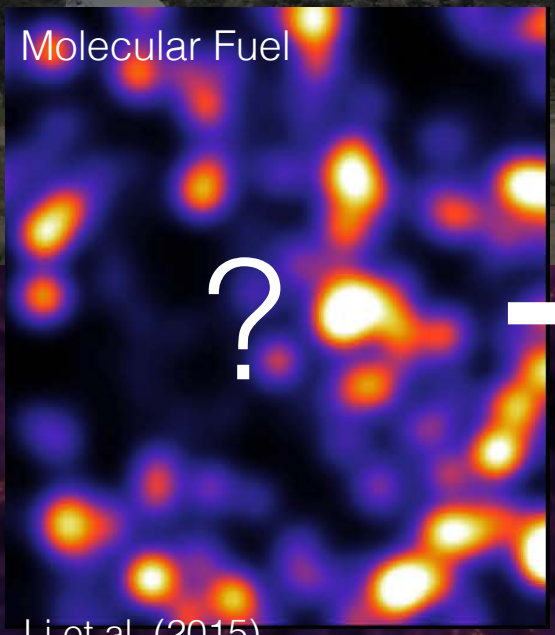
CO Intensity Mapping: The Power Spectrum of Molecular Gas at z~3

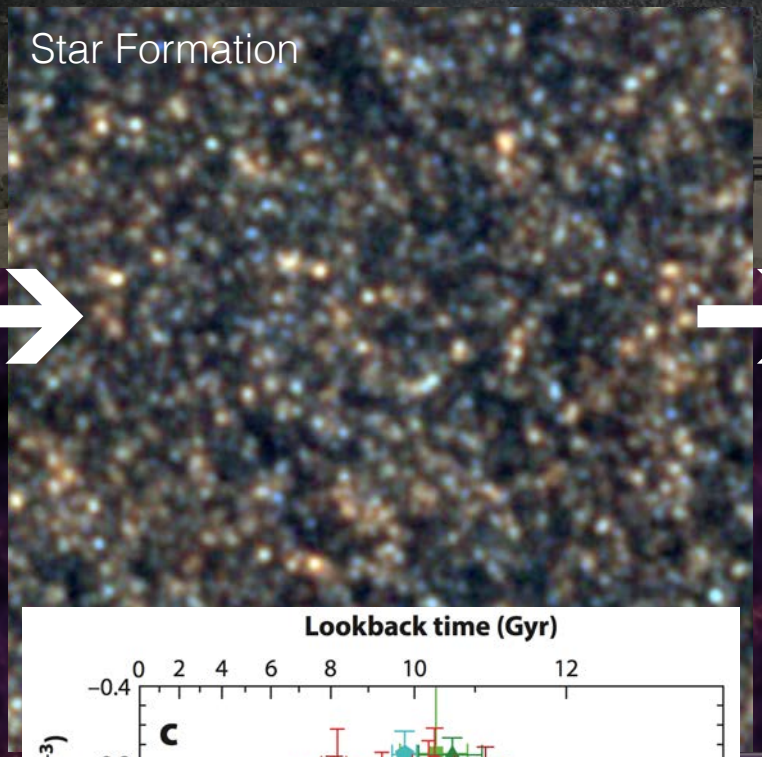


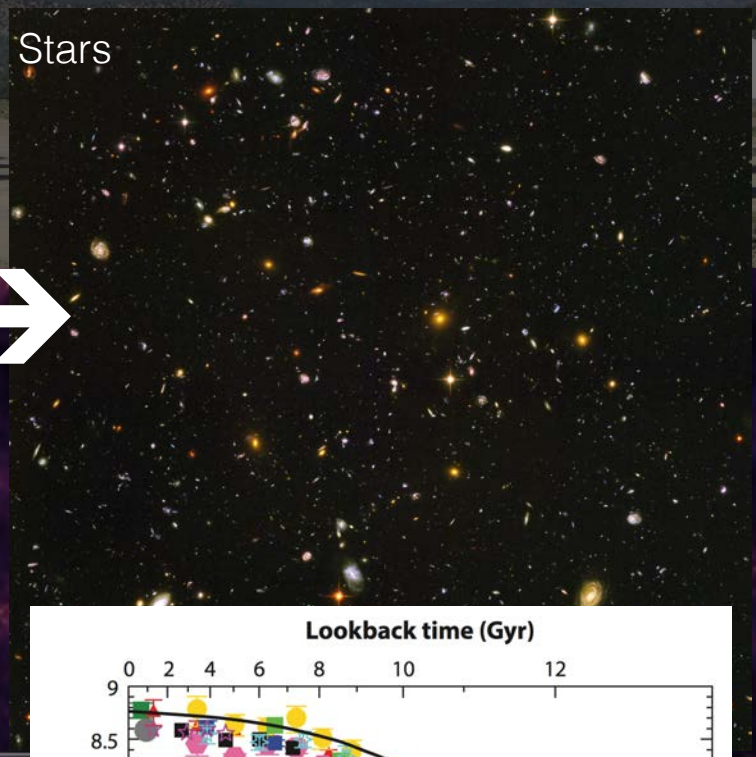
Garrett Karto Keating (University of California, Berkeley)
Dan Marrone (University of Arizona)
Geoff Bower (ASIAA)

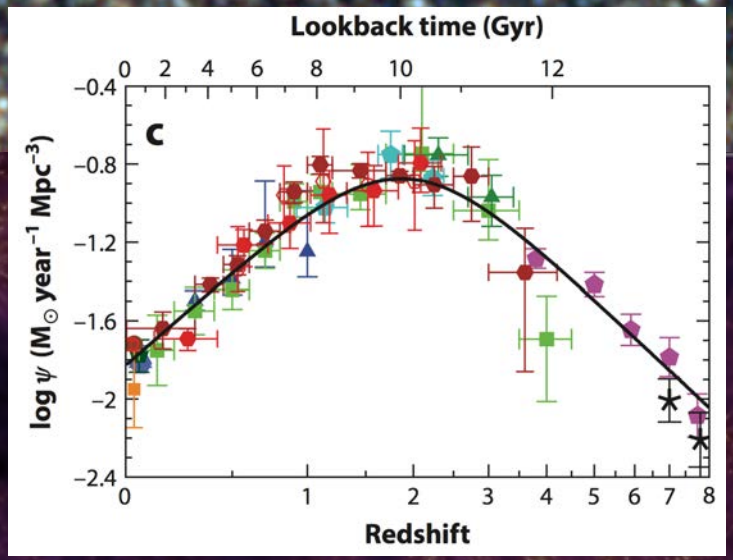
Mapping Distant Galaxy Formation

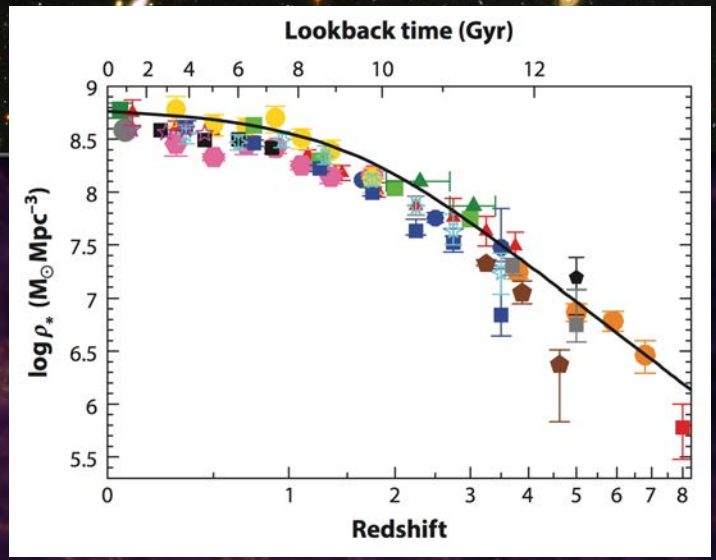


Li et al. (2015)



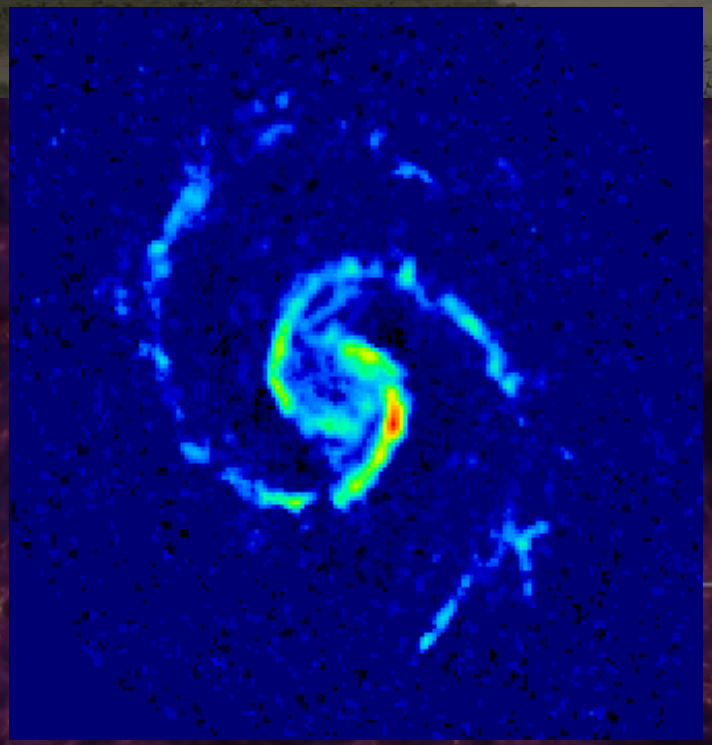


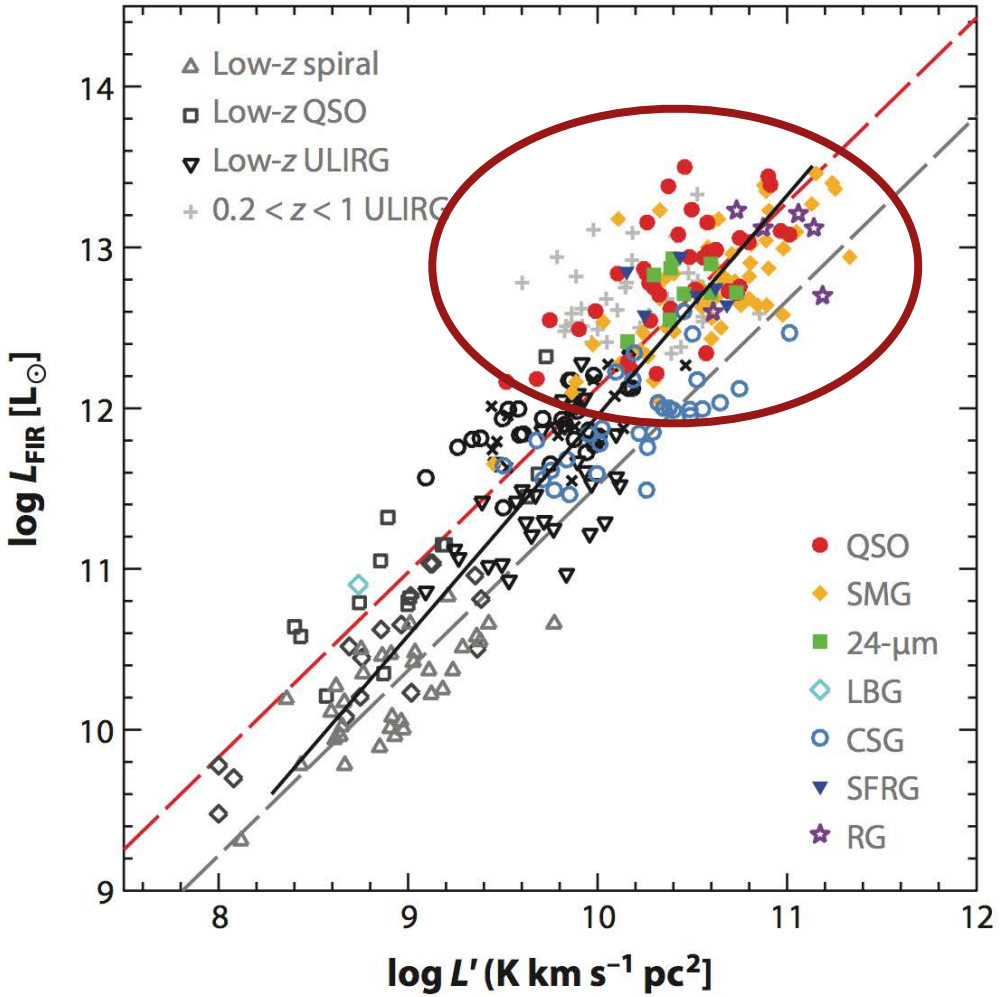




Madau & Dickinson (2015)

Molecular Gas





Carilli & Walter, ARA&A, 2013

Figure 7

(*a*) L'_{CO} as a function of L_{FIR} for all systems detected at $z > 1$ (*colored points*).

Molecular Gas

ALMA Project

ALMA Scientific Specifications and Requirements

Doc # : ALMA-09.00.00.00-001-A-SPE
Date: 2006-05-17
Status: *Released*
Page: 9 of 24

2. Level-1 Scientific Requirements[2]

The primary science requirement for ALMA is the flexibility to support the breadth of scientific investigation to be proposed by its creative scientist-users over the decade's long lifetime of the instrument. However, three science requirements stand out in all the science planning for ALMA done in both Europe and in North America. These three Level-1 primary science requirements are the following:

1. The ability to detect spectral line emission from CO or C II in a normal galaxy like the Milky Way at a redshift of z=3, in less than 24 hours of observation.

Molecular Gas

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2. Level-1 Scientific Requirements[2]

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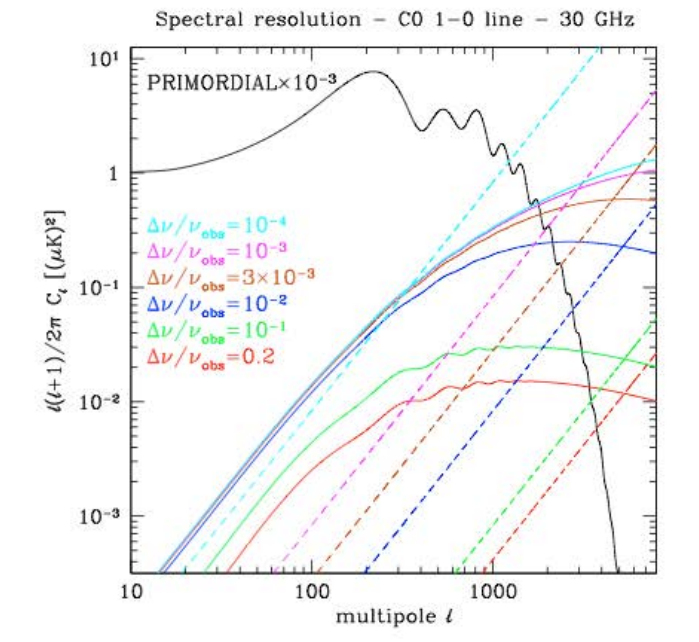
ALMA is so small!

Intensity Mapping - Think Small

- Search for aggregate signal from growing structure
- Measure 3D spectrum of fluctuations in this structure
  - Clustered formation of galaxies
  - Poisson fluctuations on fine scales ($P \sim N_{gal} * T^2$)



Righi, Hernandez-Monteagudo, Sunyaev 2008
CMB contamination from galaxies

Measuring the 3D clustering of undetected galaxies through cross correlation of their cumulative flux fluctuations from multiple spectral lines

Eli Visbal[a,b] and Abraham Loeb[b]

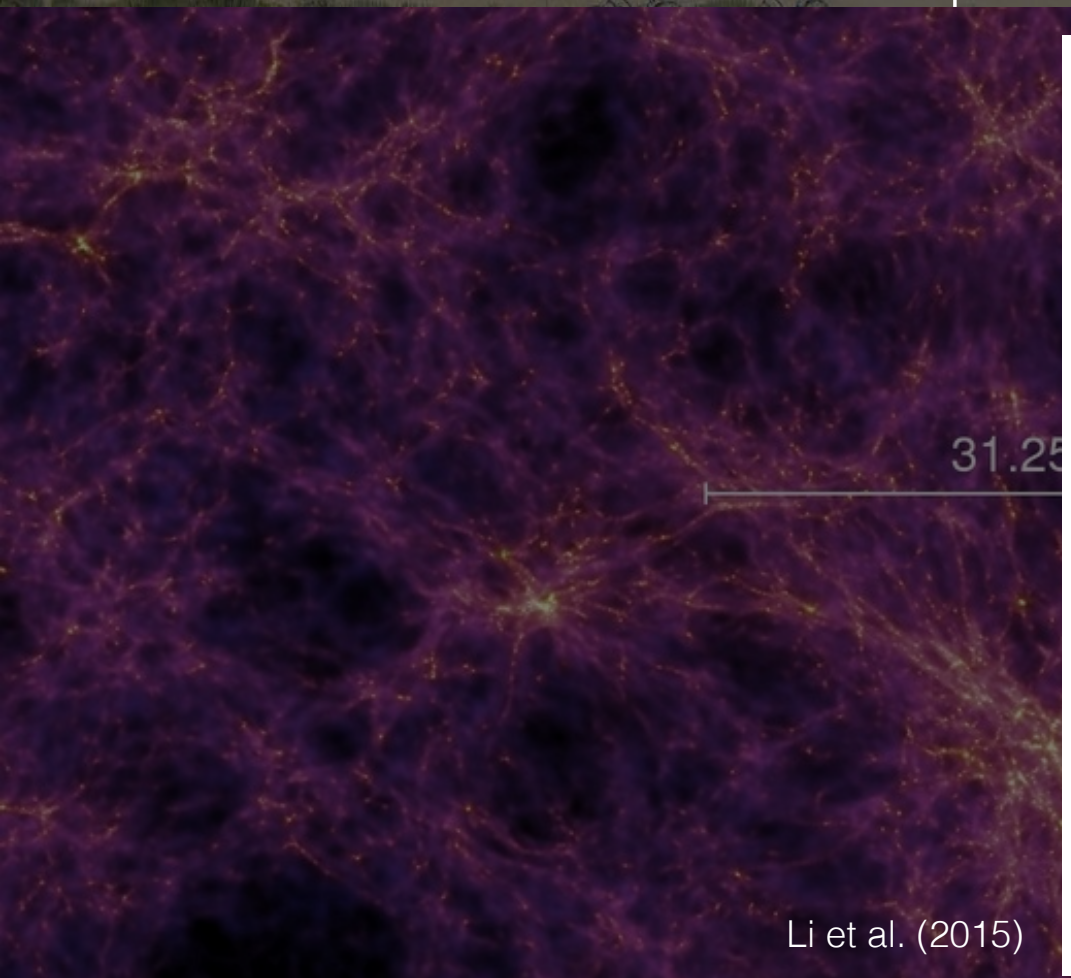
[a]Jefferson Laboratory of Physics, Harvard University, Cambridge, MA 02138, U.S.A.
[b]Harvard-Smithsonian CfA, 60 Garden Street, Cambridge, MA 02138, U.S.A.

E-mail: evisbal@fas.harvard.edu, aloeb@cfa.harvard.edu

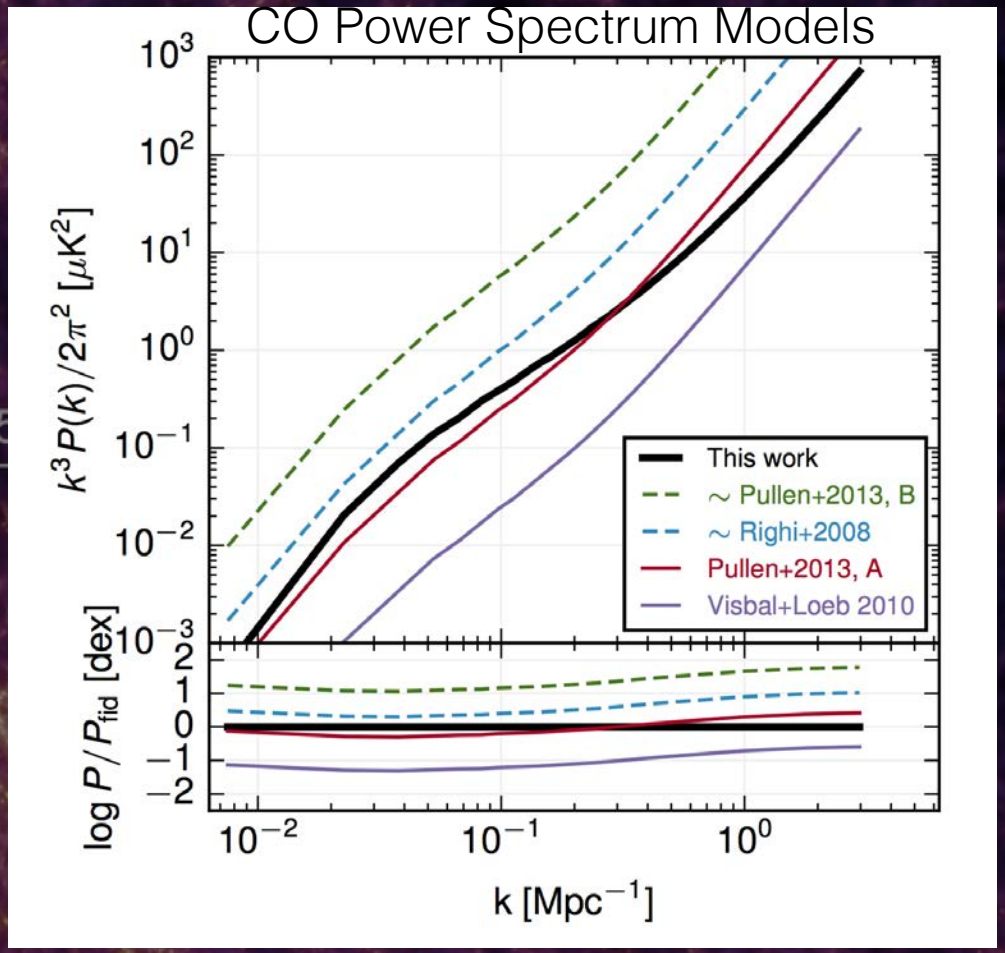
JCAP11(2010)016

Intensity Mapping - Think Small

- Search for aggregate signal from growing structure
- Power level unknown!
  - 2 OOM variation in extrapolations from z=0

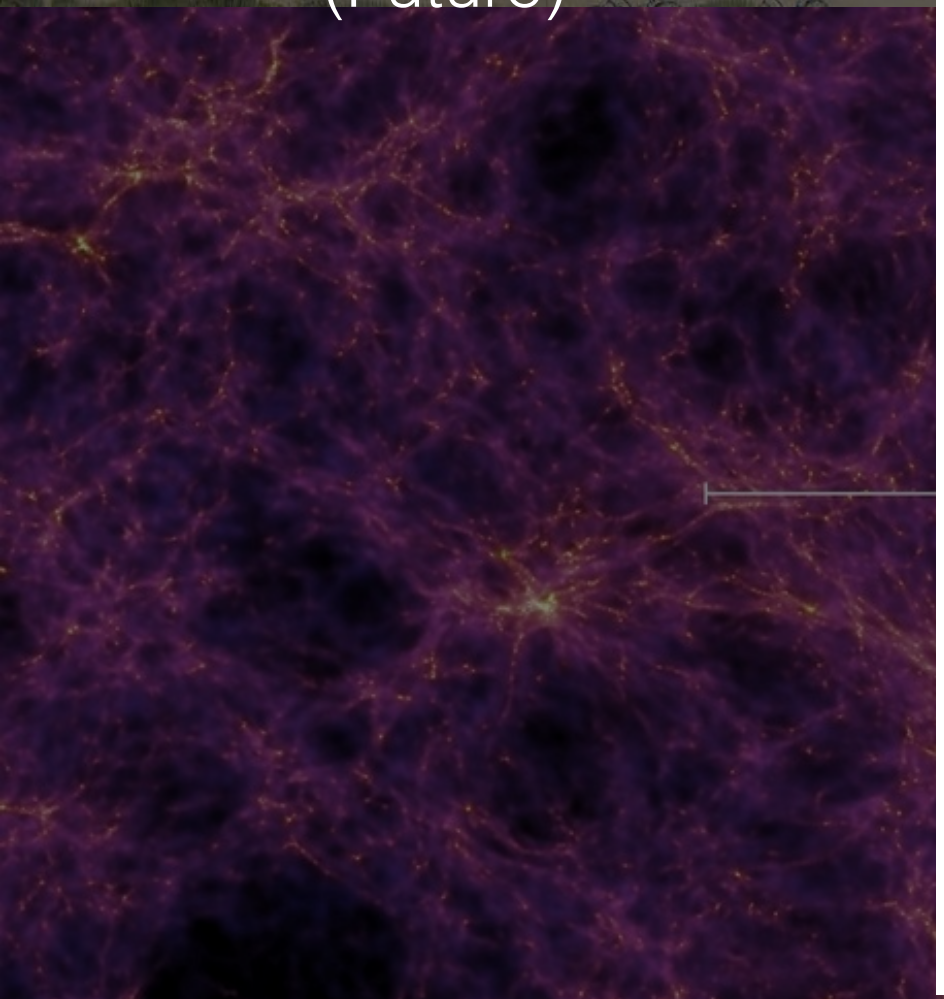


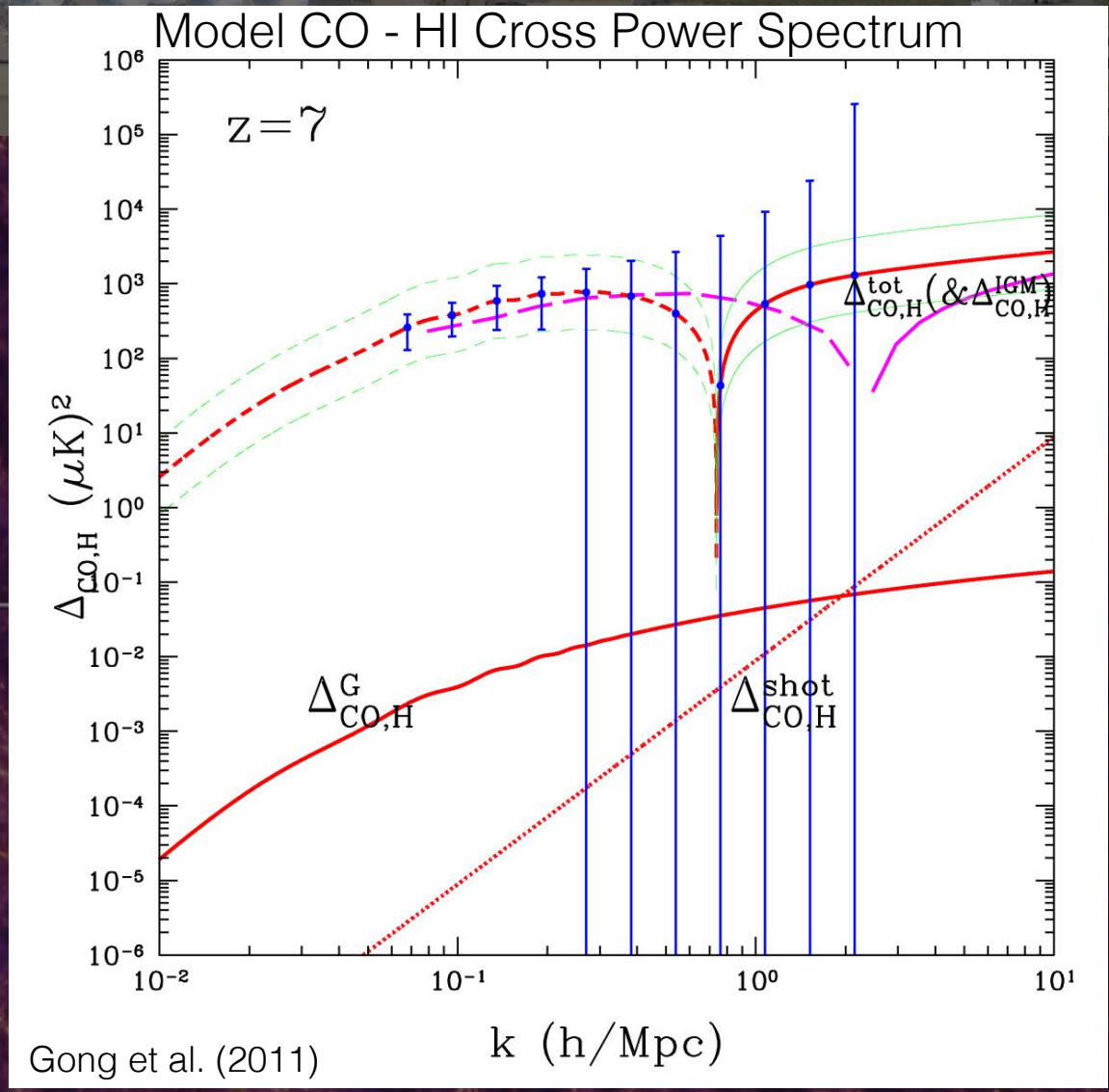
Li et al. (2015)



Intensity Mapping - Think Bigger

- Large scale maps for correlation with 21cm in EoR
  - CO/CII
  - (Future)





Gong et al. (2011)

Starting Point: SZA/CARMA

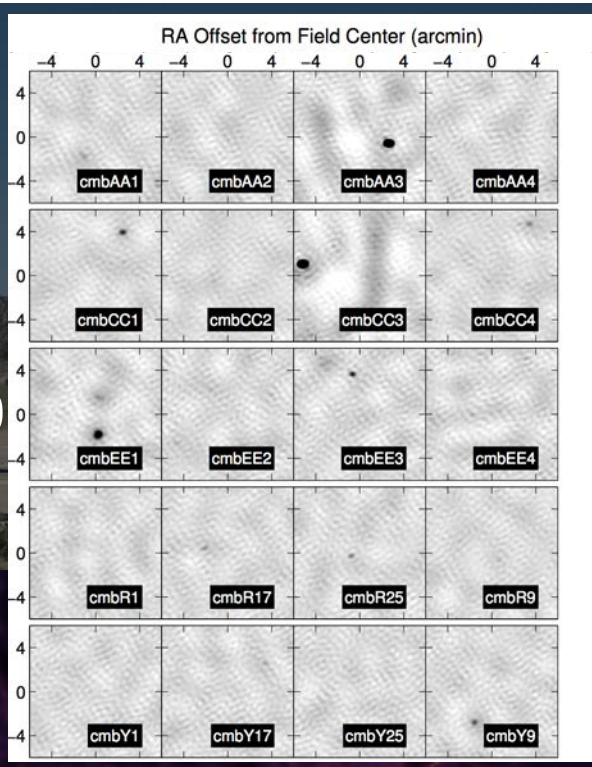
- CO Power Spectrum Survey (COPSS)
  - Thesis work of Karto Keating

- COPSS Team

  Geoff Bower (ASIAA)
  John Carlstrom (Chicago)
  Tzu-Ching Chang (ASIAA)
  Dave Deboer (Berkeley)
  Chris Greer (Arizona)
  Carl Heiles (Berkeley)
  James Lamb (Caltech)
  Erik Leitch (Caltech)
  Dan Marrone (Arizona)
  Amber Miller (Columbia)
  Stephen Muchovej (Caltech)
  Dick Plambeck (Berkeley)
  David Woody (Caltech)

COPSS

- COPSS 1: Keating et al. (2015) ApJ
  - 1400h integration from Sharp, Marrone et al. 20
    - 44 fields, 11’ across, 1.7deg^2 total
    - 27-35 GHz = CO 1-0 @ z=2.3-3.3

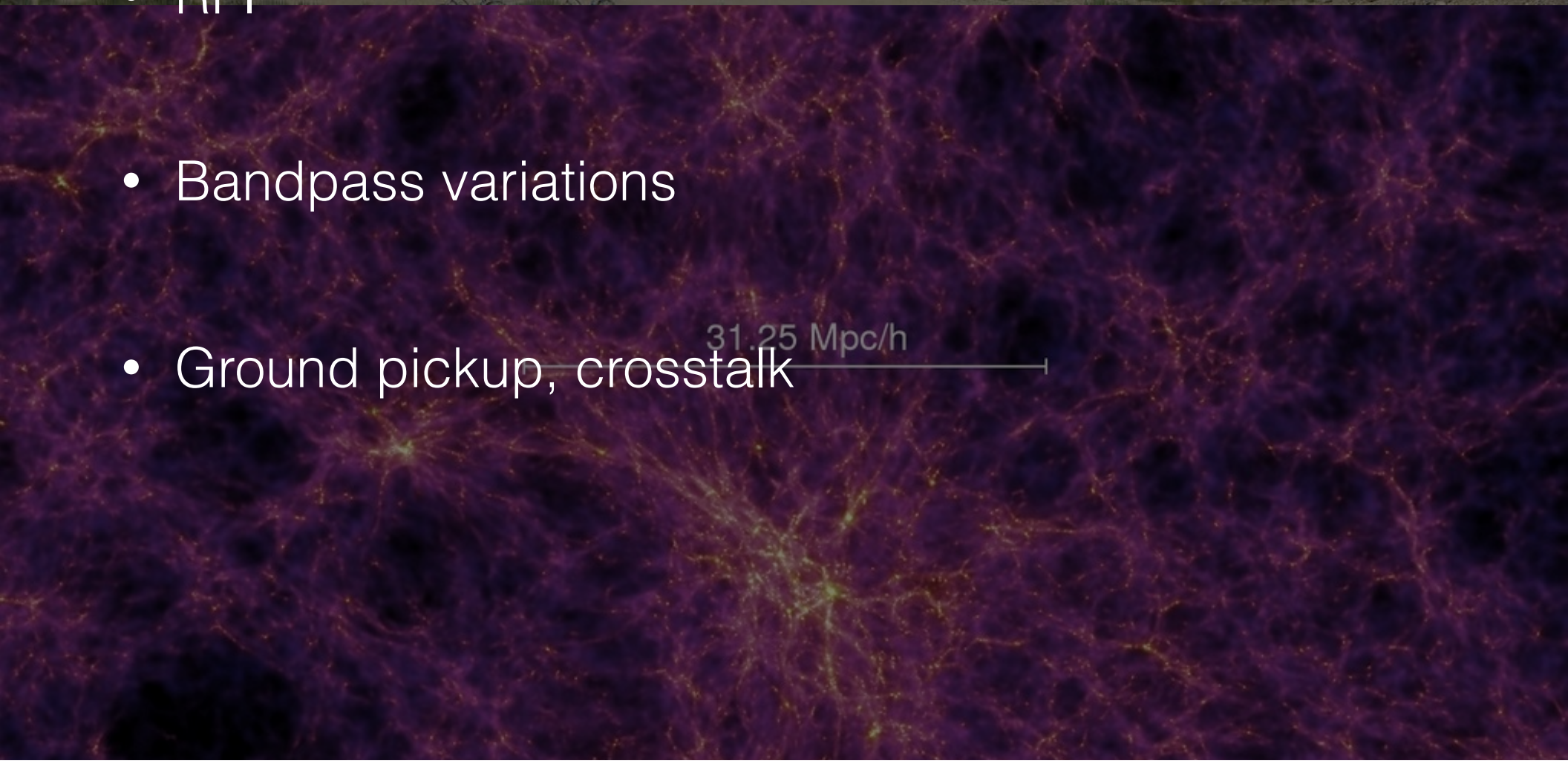


- COPSS 2: Keating et al. (in prep)
  - 5000h on 12 fields
  - Optimized for Intensity mapping

31.25 Mpc/h

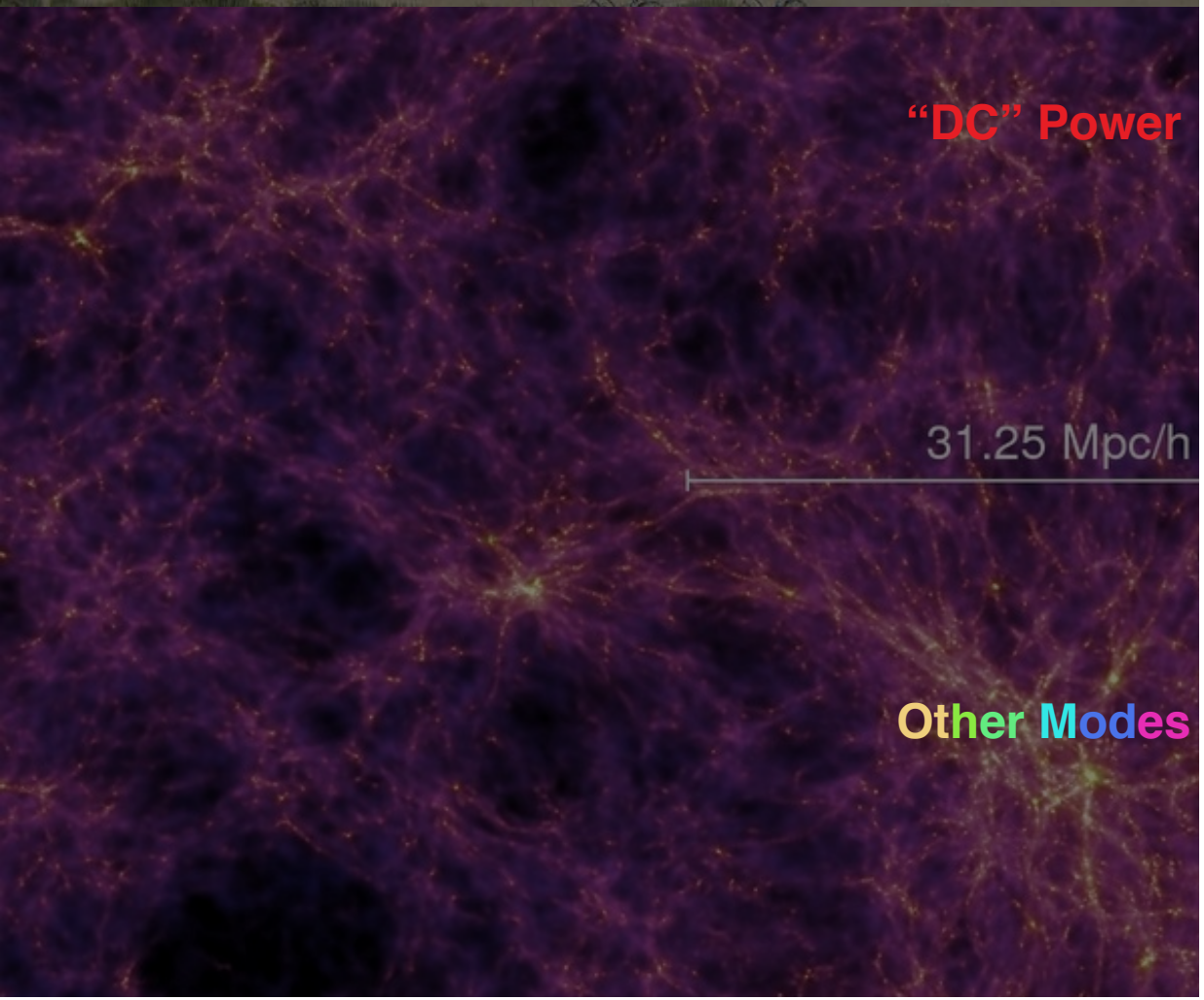
Systematics/Foregrounds

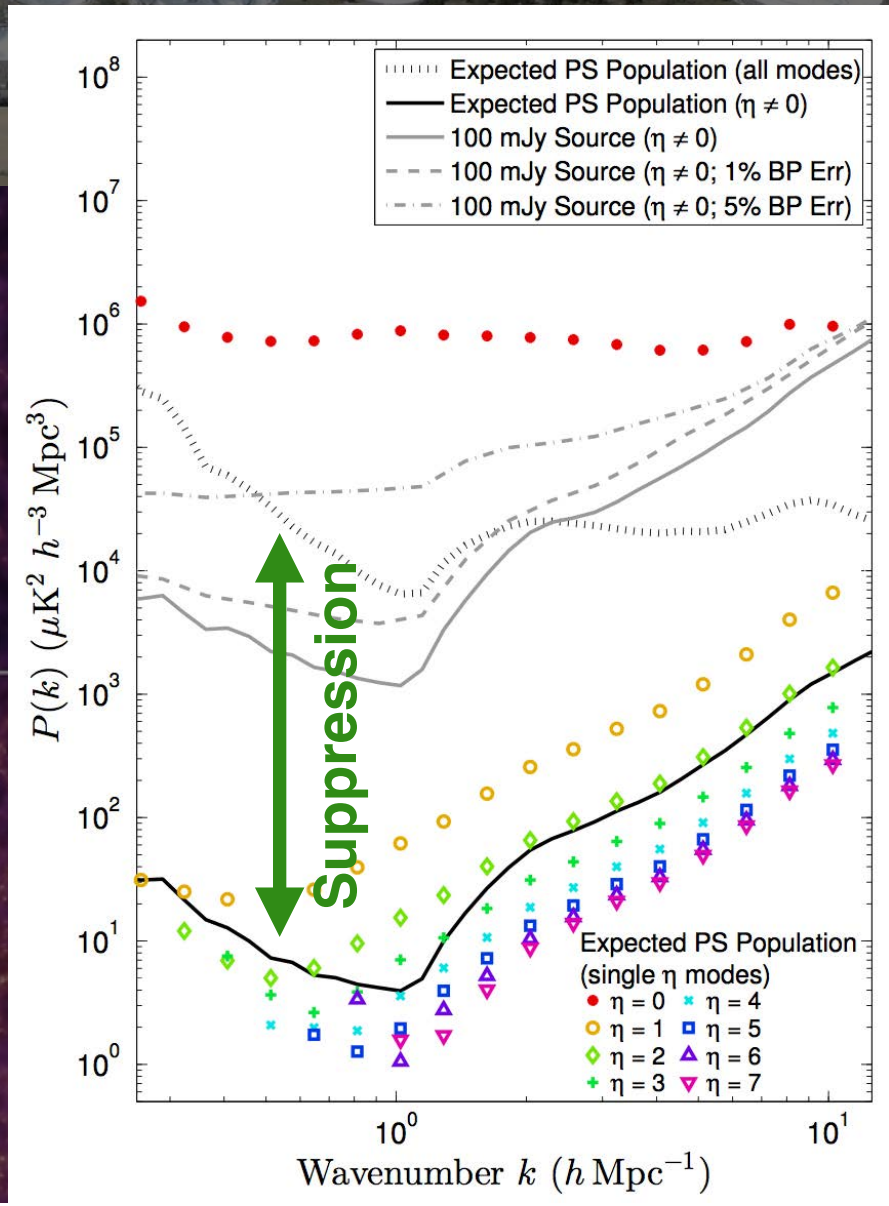
- Detected/undetected radio sources
- RFI
- Bandpass variations
- Ground pickup, crosstalk



Systematics/Foregrounds

- Detected/undetected radio sources
  - Spatial fluctuations create power
  - Spectrally-smooth - exclude DC

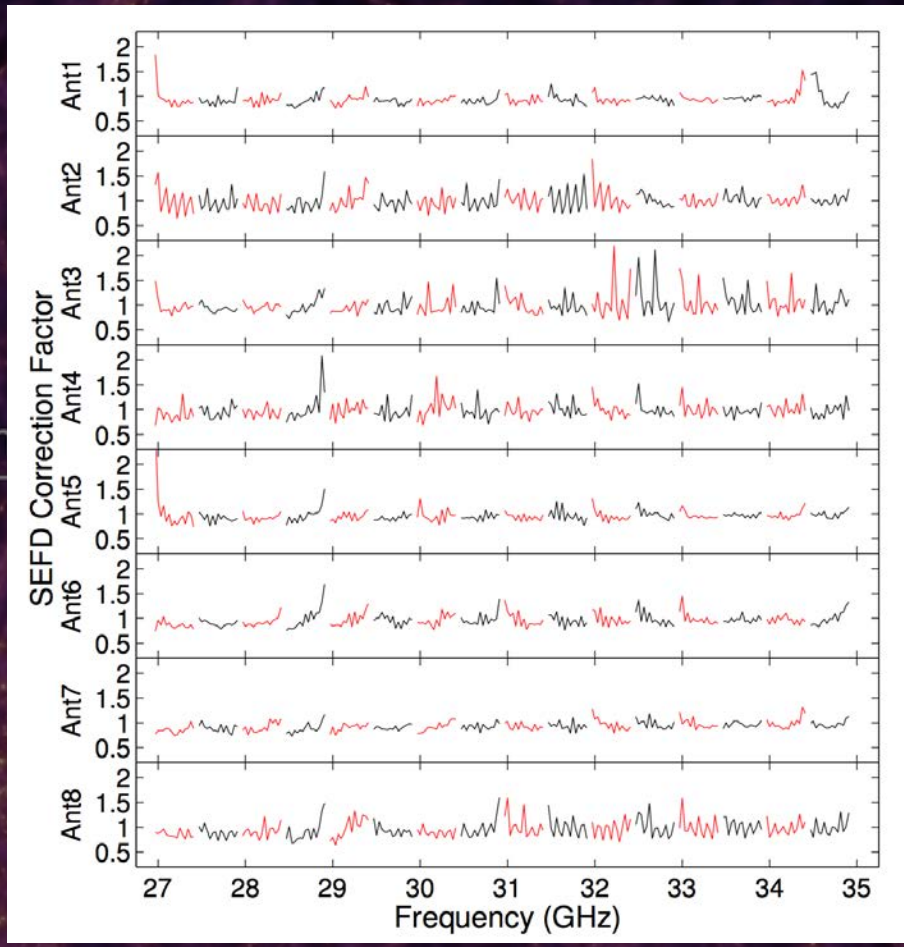




Systematics/Foregrounds

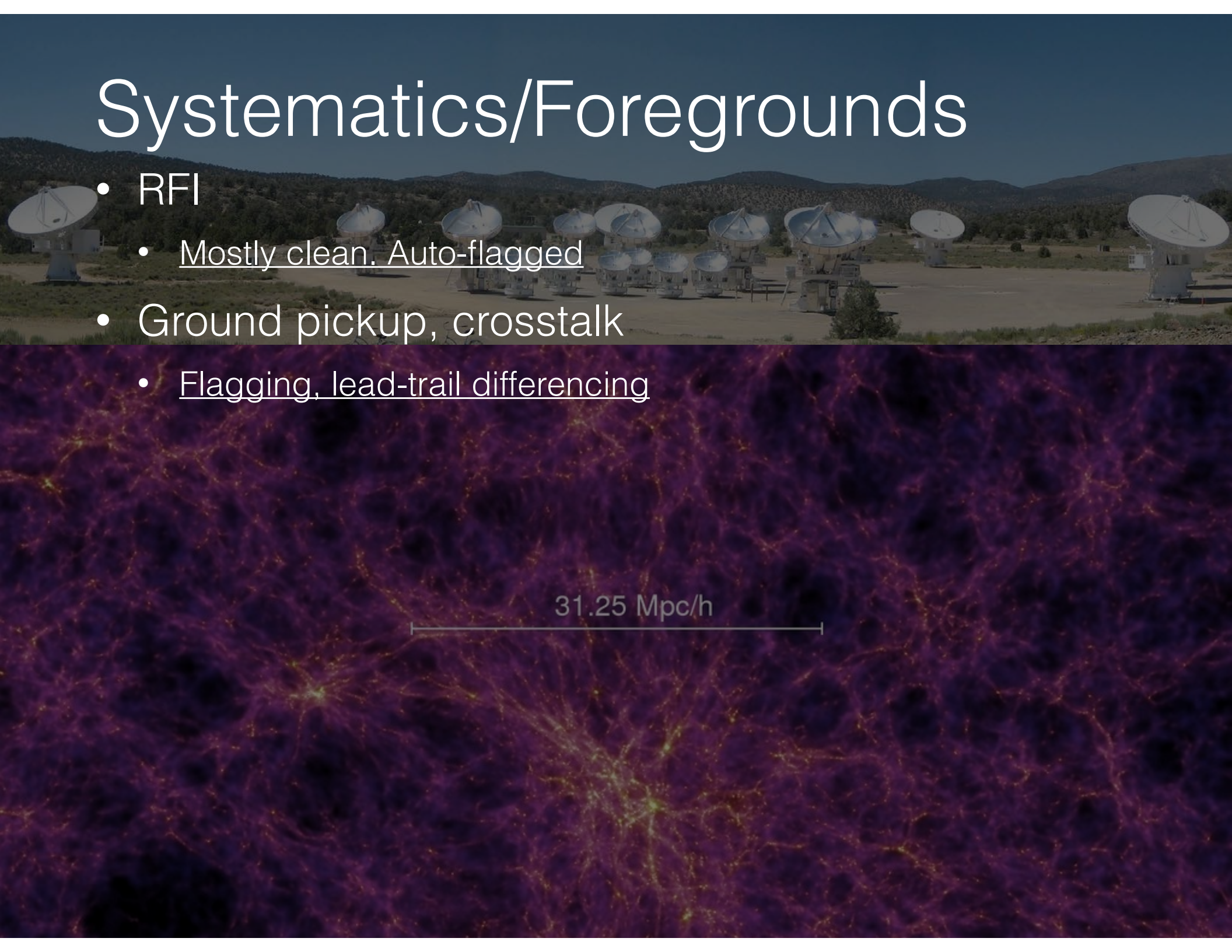
- Detected/undetected radio sources
  - Spatial fluctuations create power
  - Spectrally-smooth - exclude DC

- Bandpass variations
  - Contaminate CO power with ptsrcs
  - SZA: Good bandpass stability
  - Noise variations calibrated



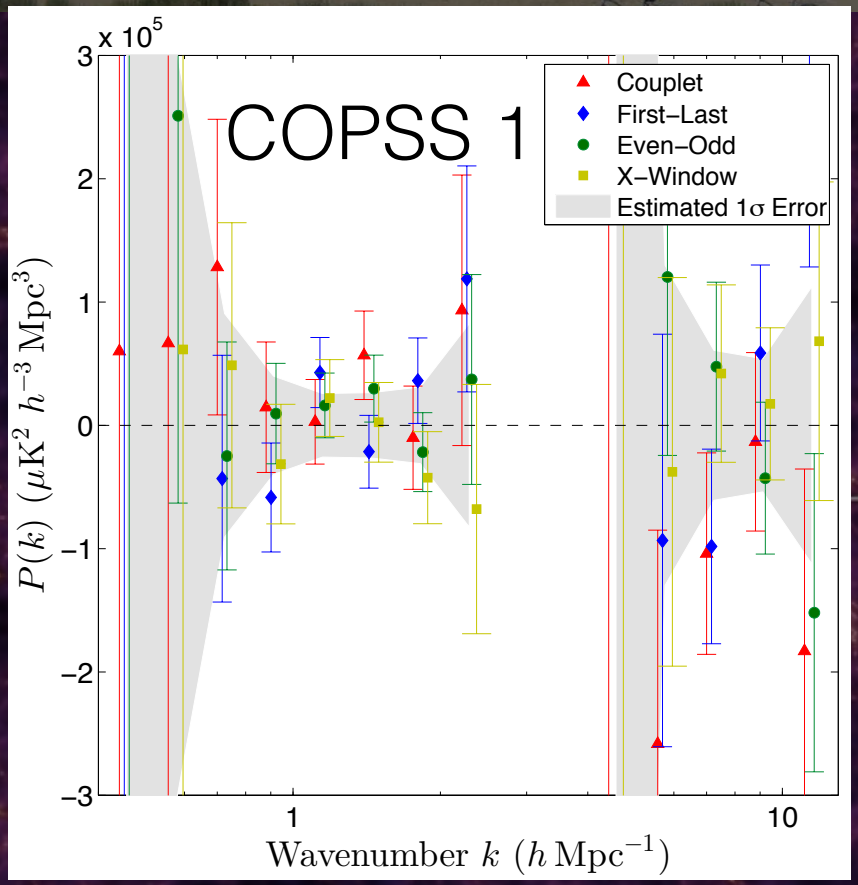
Systematics/Foregrounds

- RFI
  - Mostly clean. Auto-flagged
- Ground pickup, crosstalk
  - Flagging, lead-trail differencing

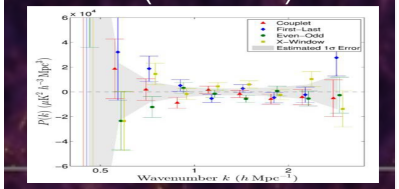


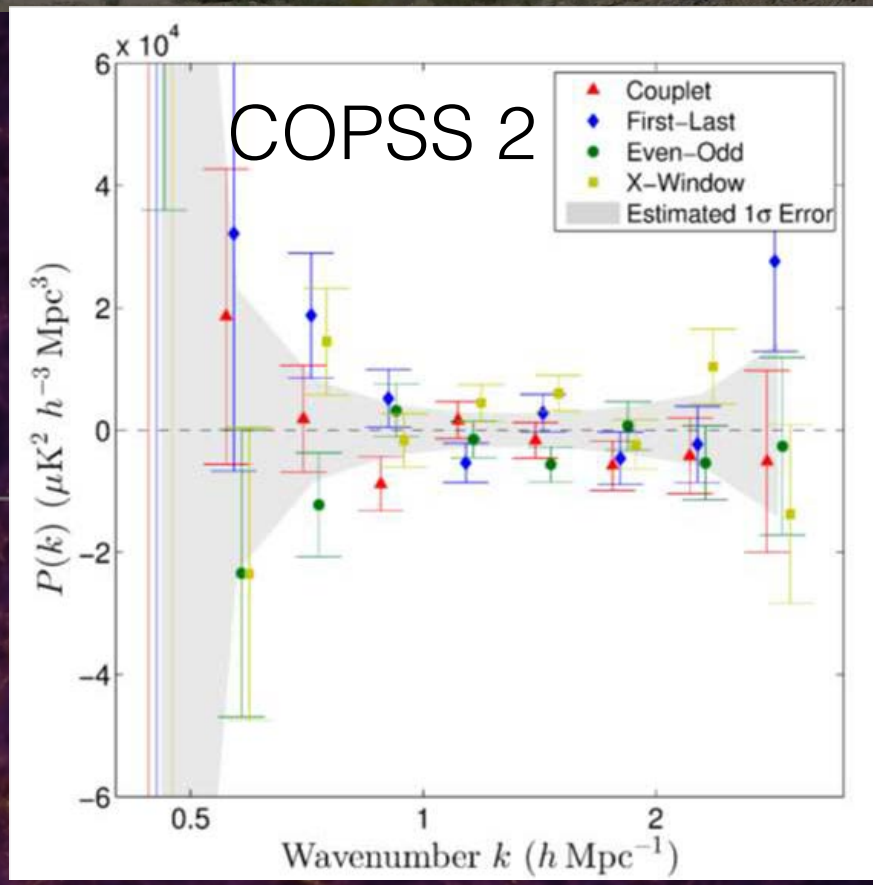
Validation

- Nulling (jackknife) tests
  - Remove astrophysical signal through differencing
  - No residual power



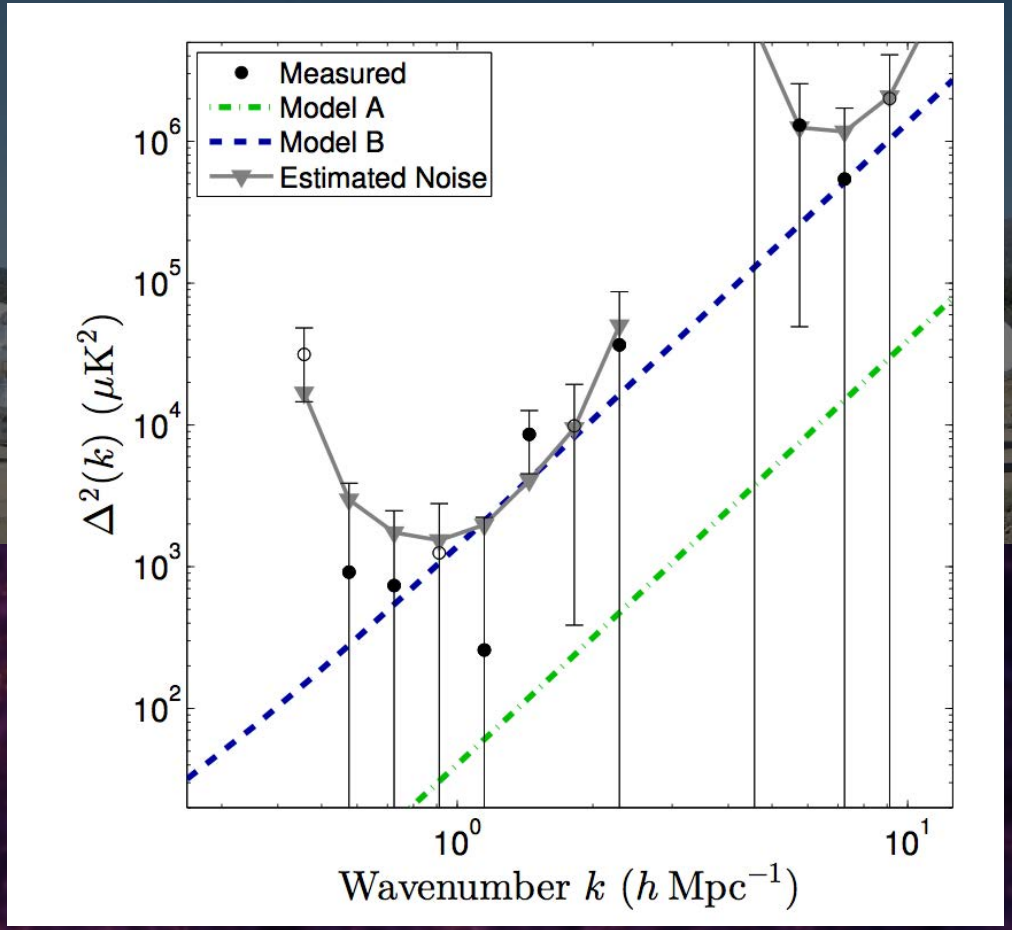
COPSS 2
(to scale)

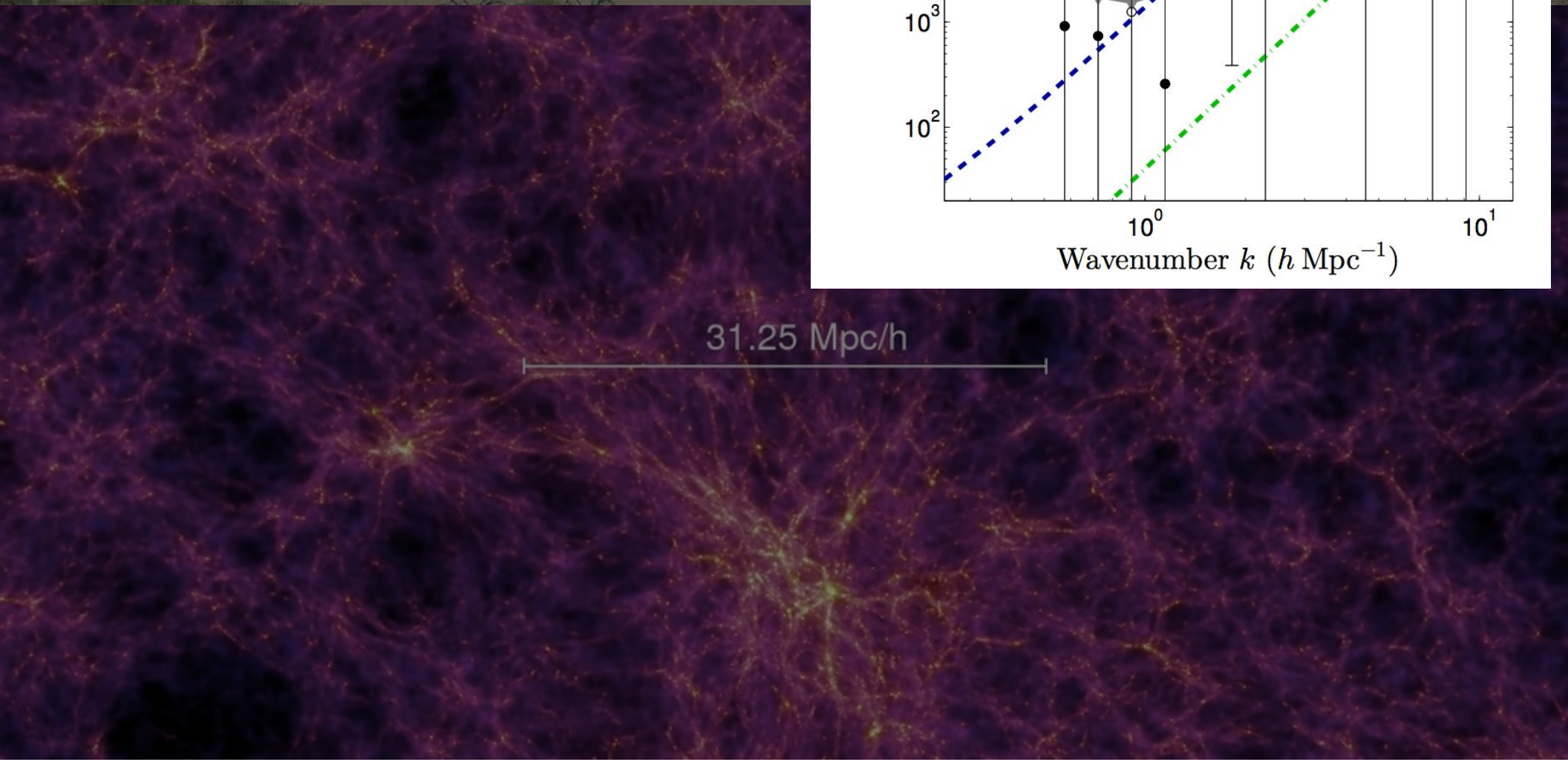




Results

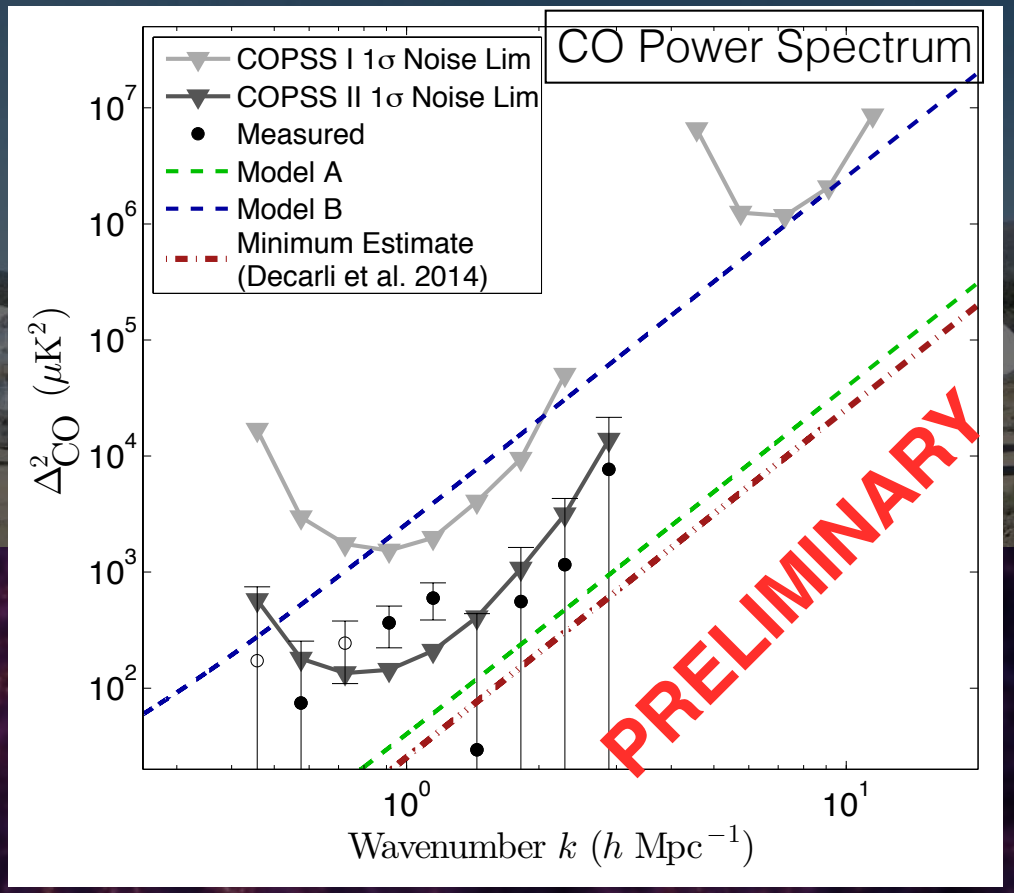
- COPSS 1: No detection

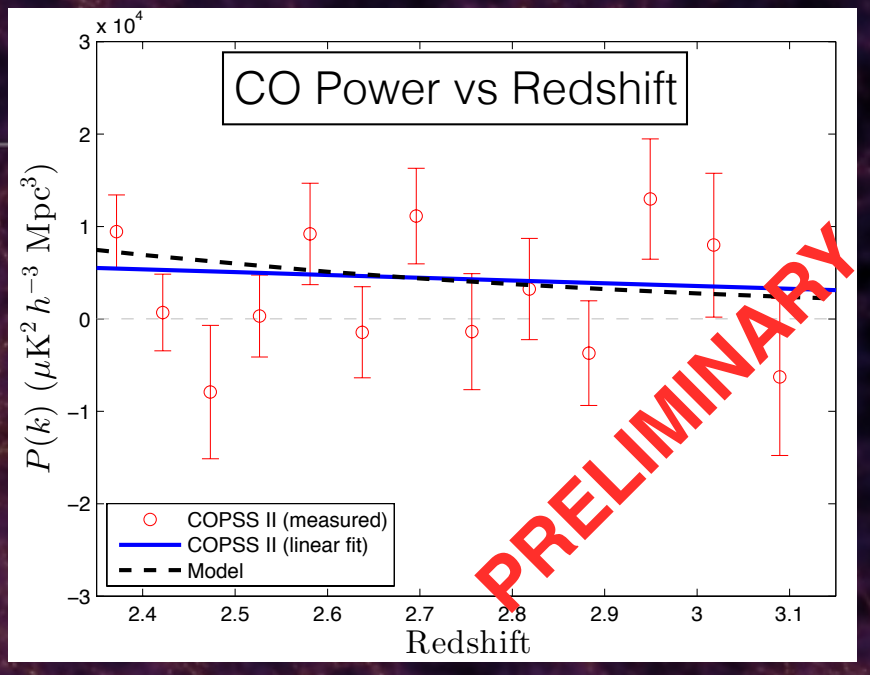




Results

- COPSS 1: No detection
- COPSS 2:
  - ~3 sigma power
  - $p < 0.005$
  - Possible evolution with z

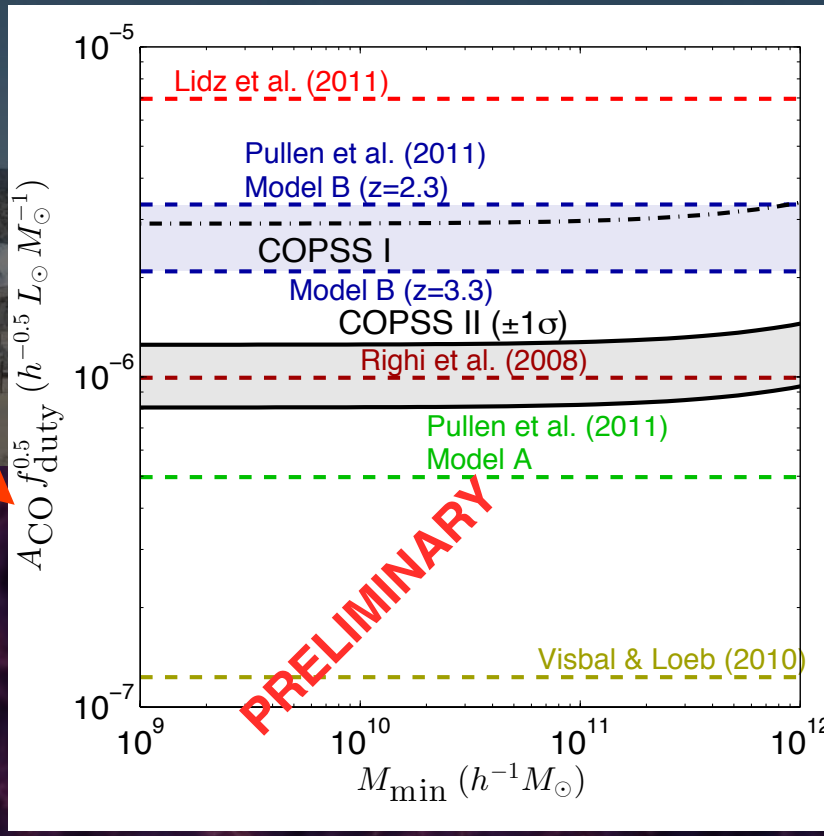




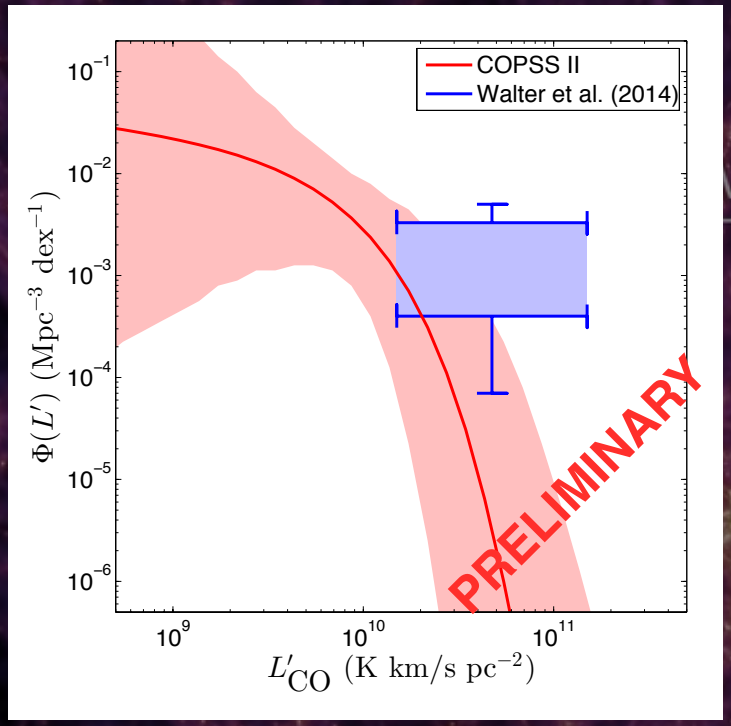
31.25 Mpc/h

Implications

- Model Selection
  - A_{CO}: L_{CO} per M_{halo} parameter
  - Best match: Righi et al. (2008)

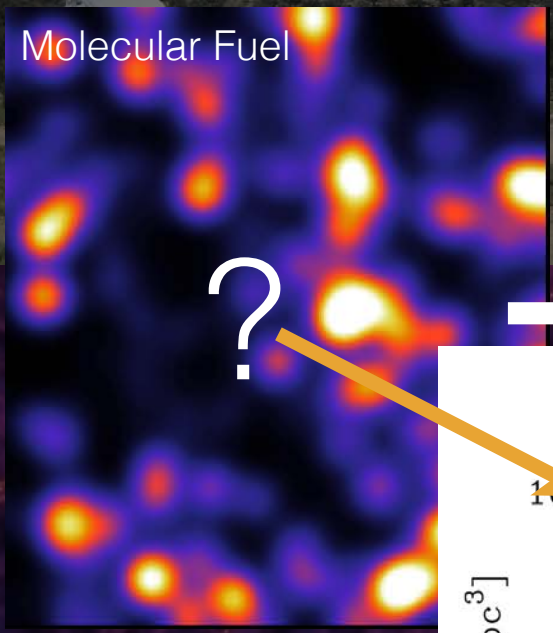


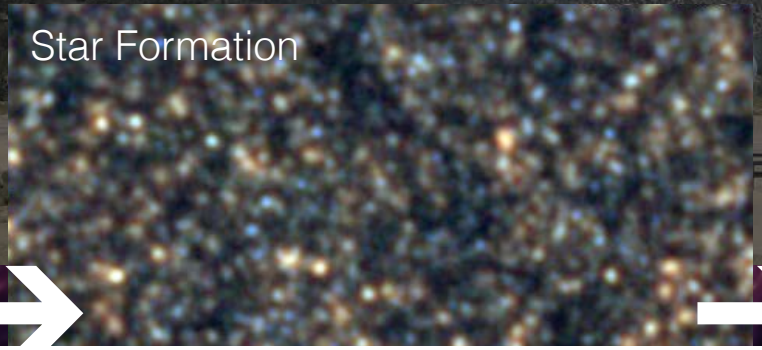
- CO Luminosity Function

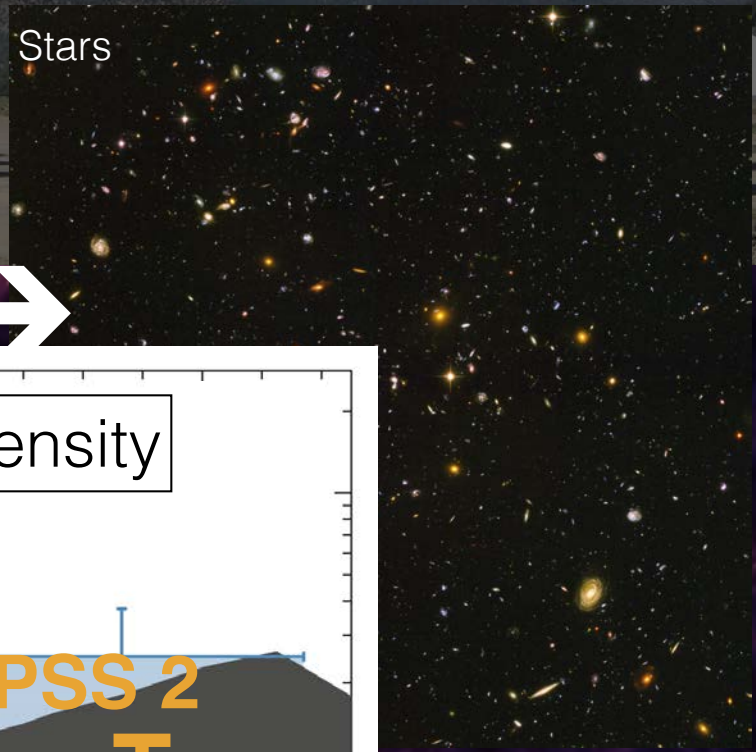


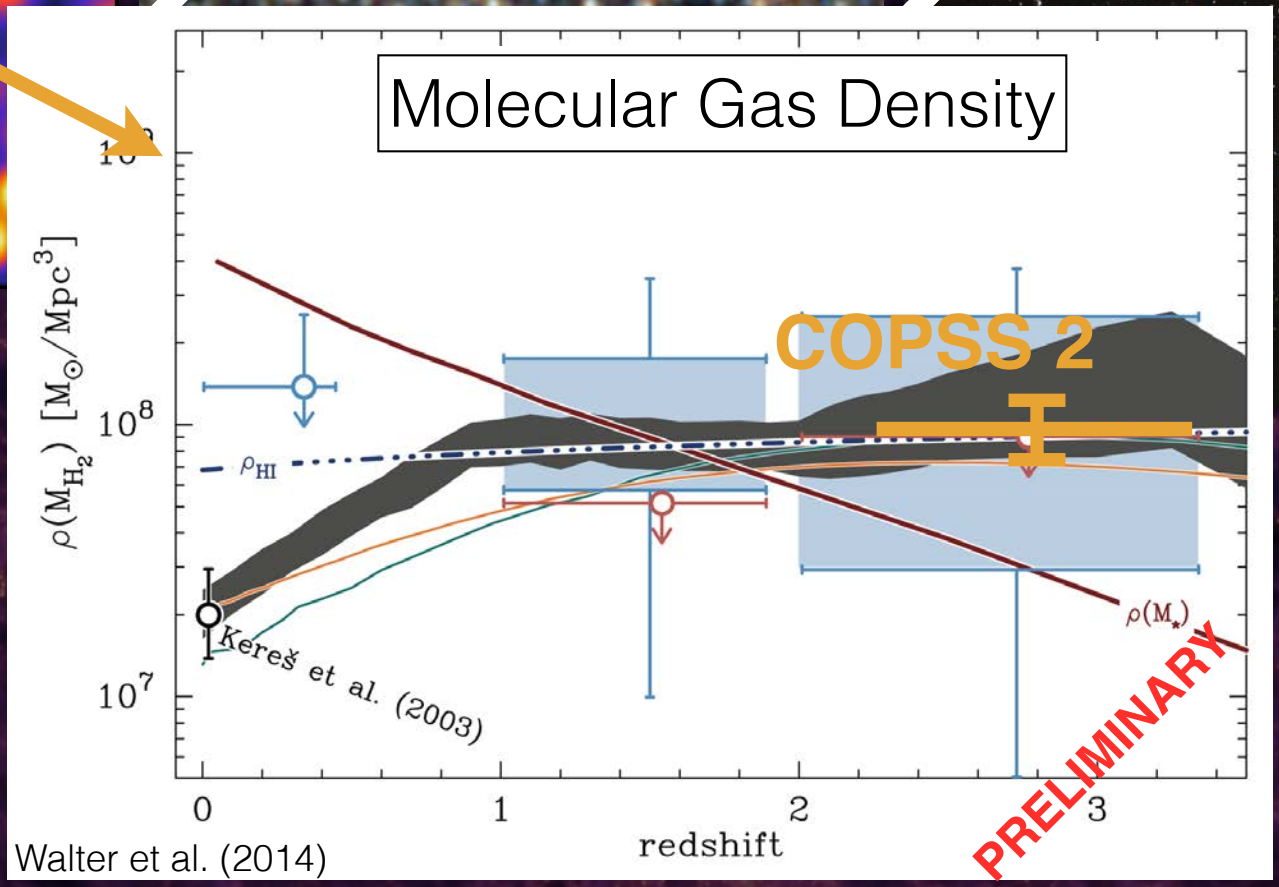
Mpc/h

Implications









Walter et al. (2014)

Future

- Near Term:
  - Improved CO constraints from existing ALMA/VLA data
  - First CII constraints from existing ALMA data

- Longer Term:
  - Larger scale CO mapping for galaxy cross-correlation/stacking
  - Large-scale CII mapping for HI cross-correlation