Probing the Epoch of Reionization

with the

***T**omographic **I**onized-carbon **M**apping **E**xperiment (TIME)*

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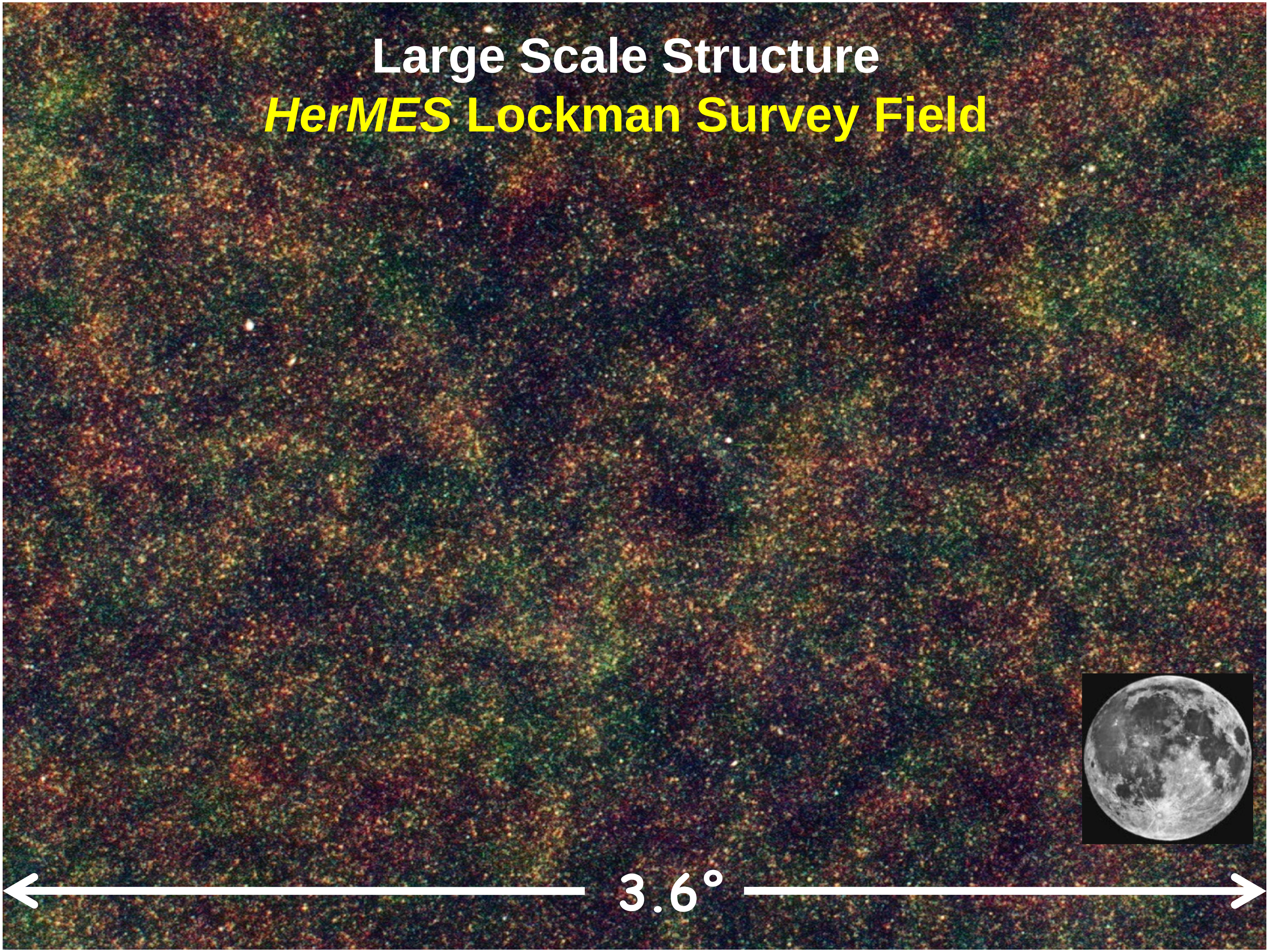
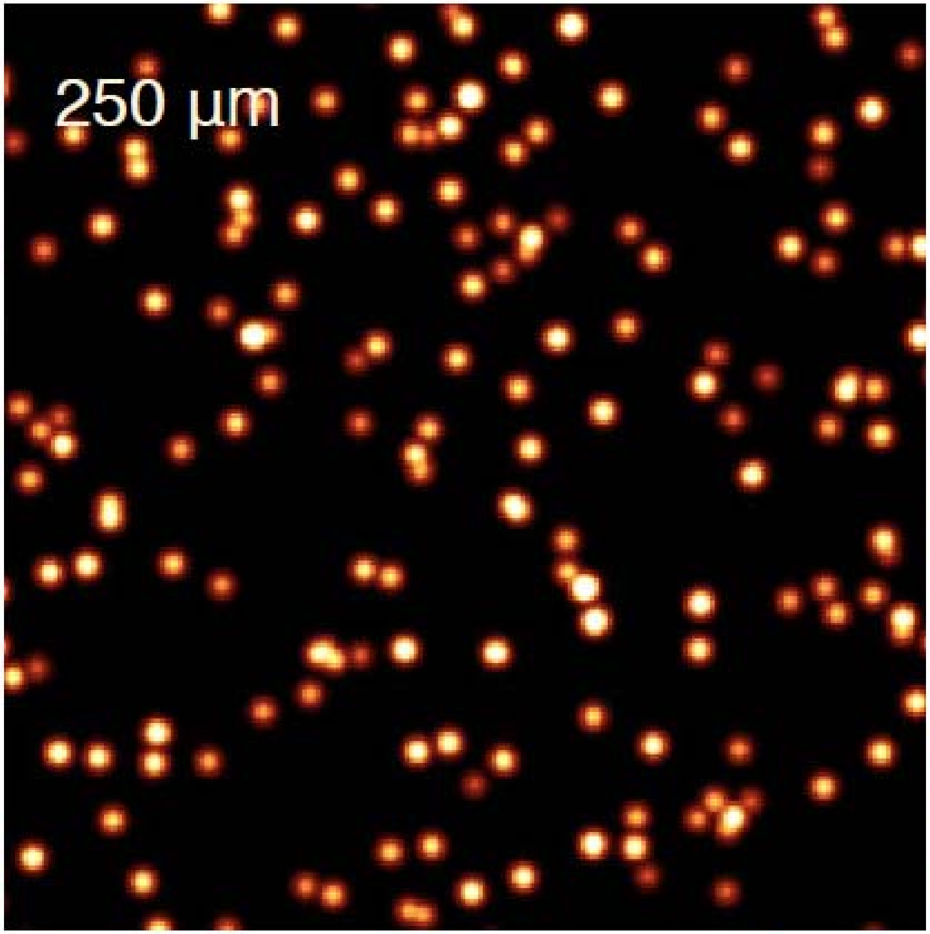
Caltech / JPL

CCAT Workshop, Boulder CO

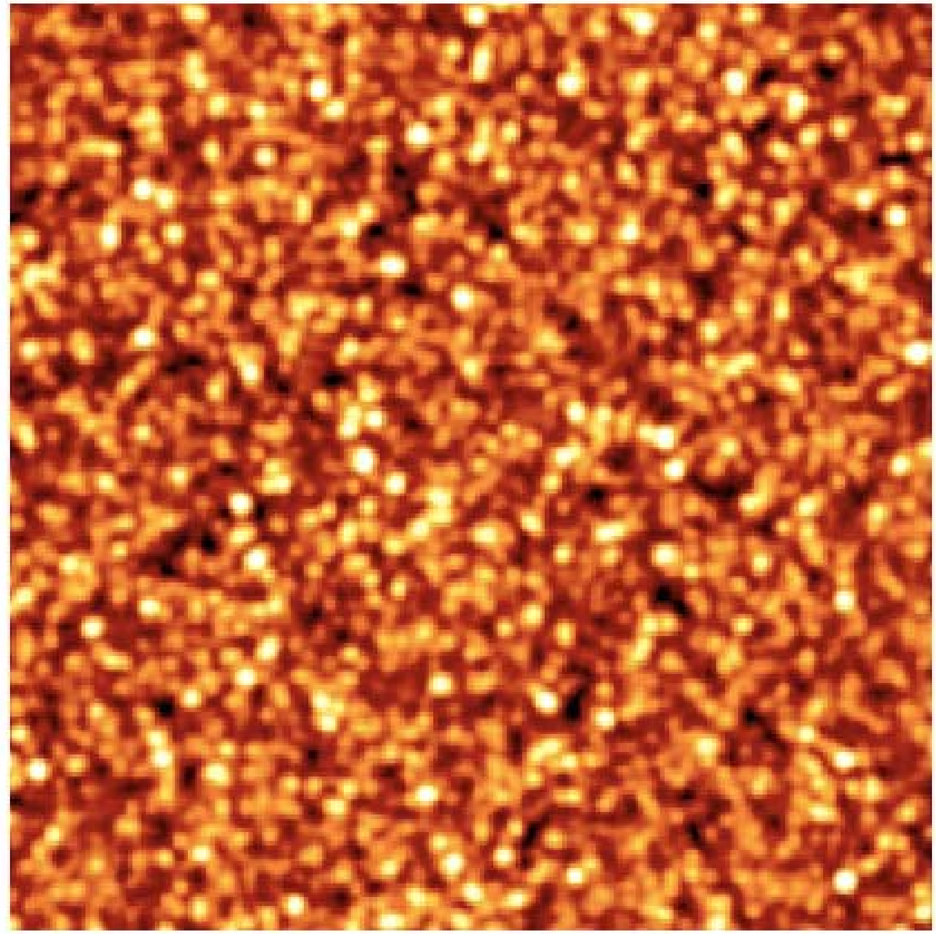
21 September 2012


Large Scale Structure
HerMES Lockman Survey Field
3.6°

Use Maps to Measure Clustering

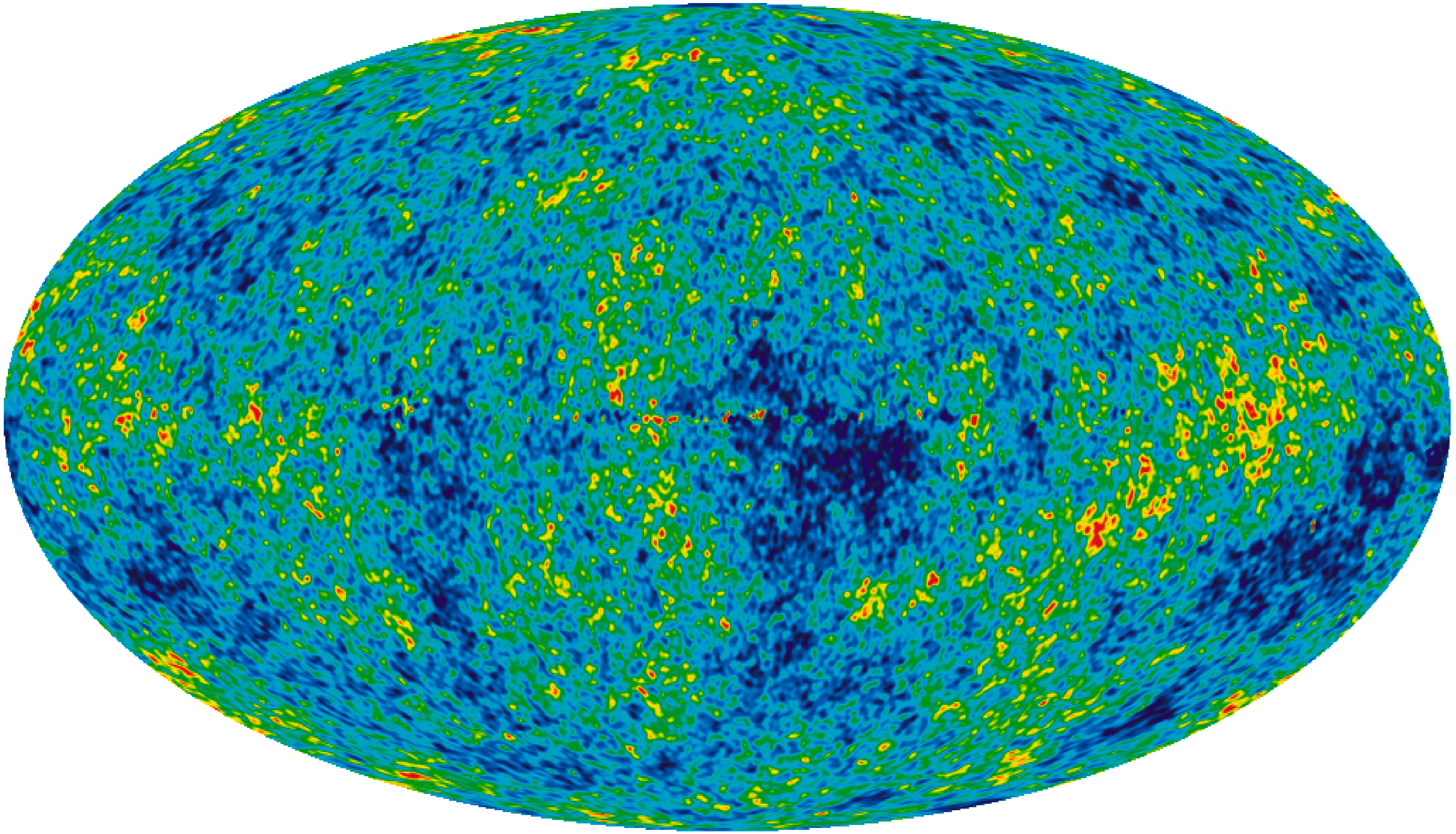


S > 20 mJy : 1,200/deg^2



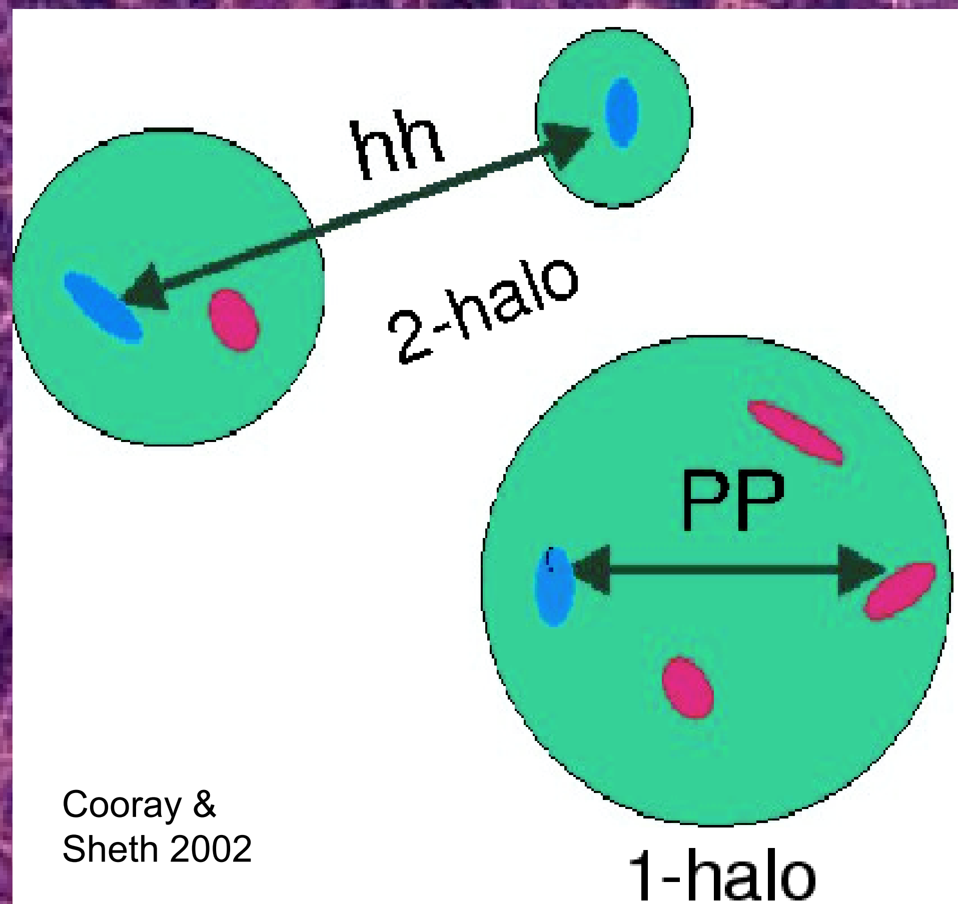
S < 20 mJy : 480,000/deg^2

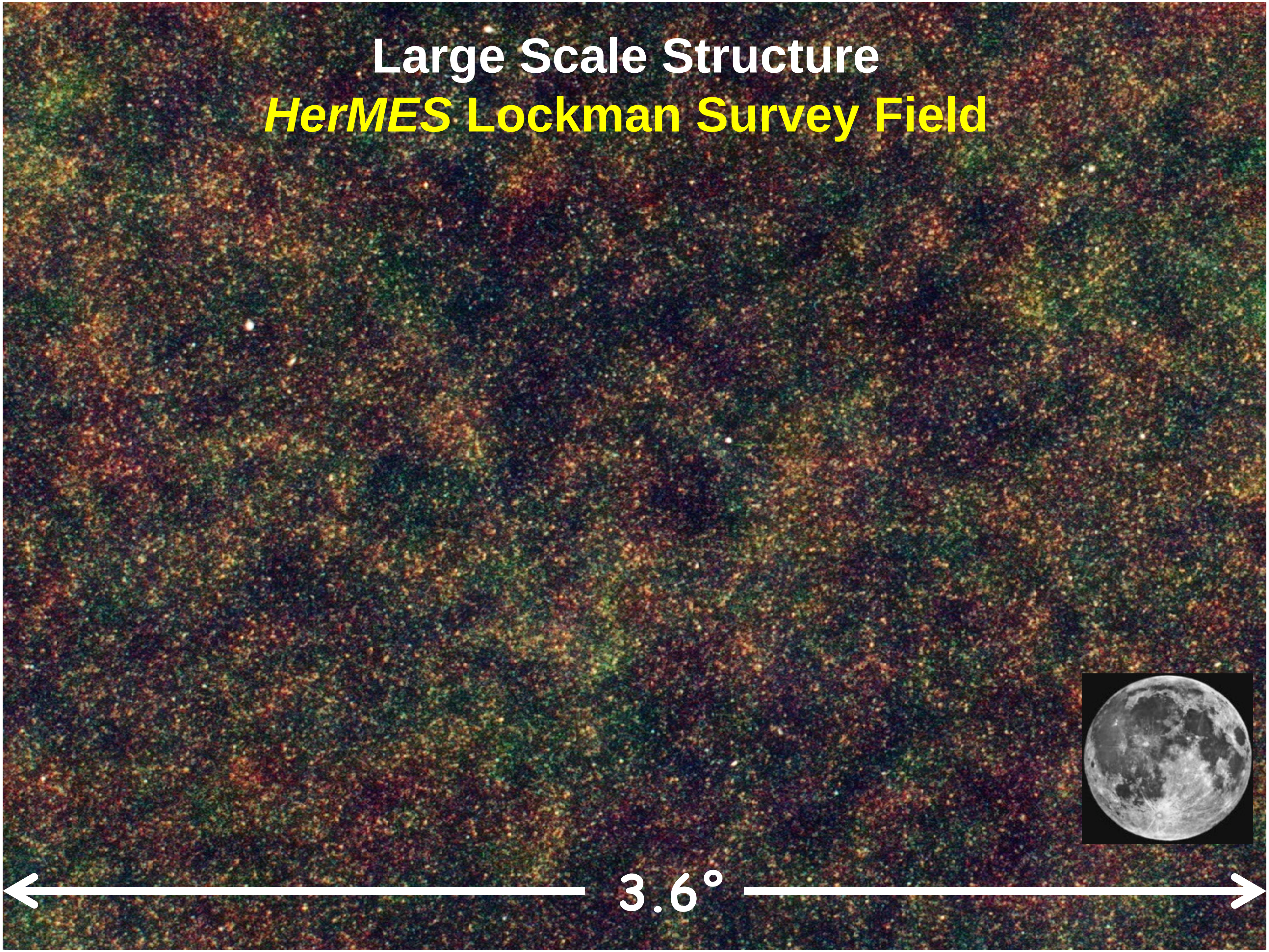
An Example of Intensity Mapping



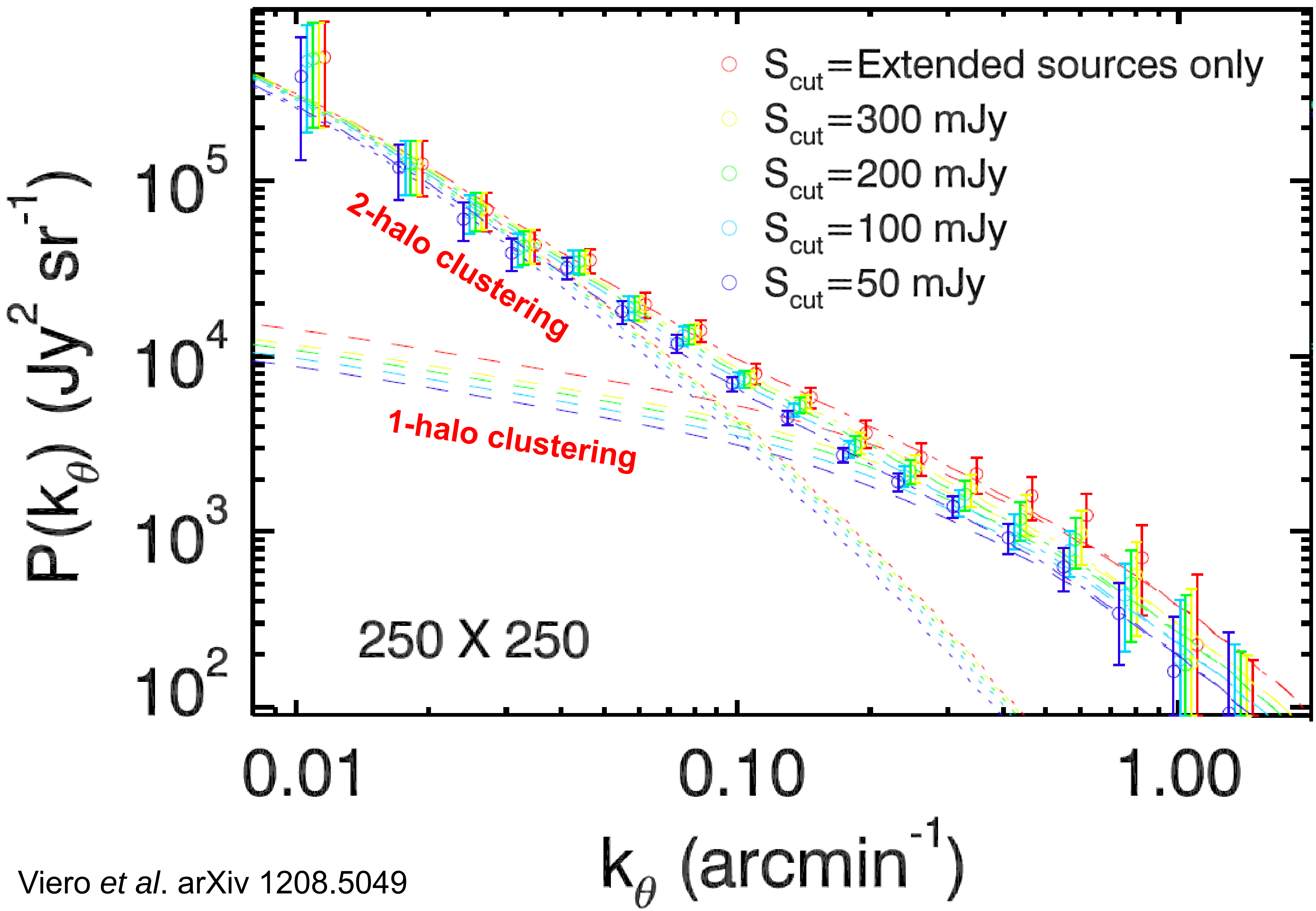
Relationship Between Dark Matter and Galaxies

Halo Clustering Model




Large Scale Structure
HerMES Lockman Survey Field
3.6°

Spatial Power Spectrum of SPIRE Maps



Viero *et al*. arXiv 1208.5049

Advantages of Intensity Mapping

Measuring to the Galactic Ensemble

- Luminosity function
- Total photon production
- Large-scale structure

Science Applications

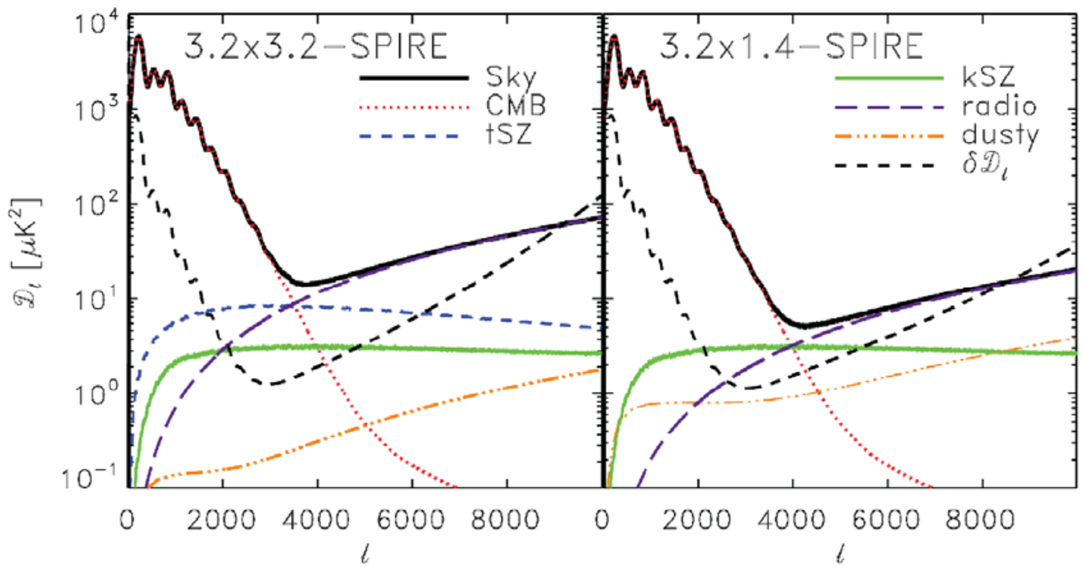
- Galaxy evolution
- Link between dark matter and galaxy formation
- Epoch of Reionization?
- Baryon Acoustic Oscillations?

Observationally Expedient

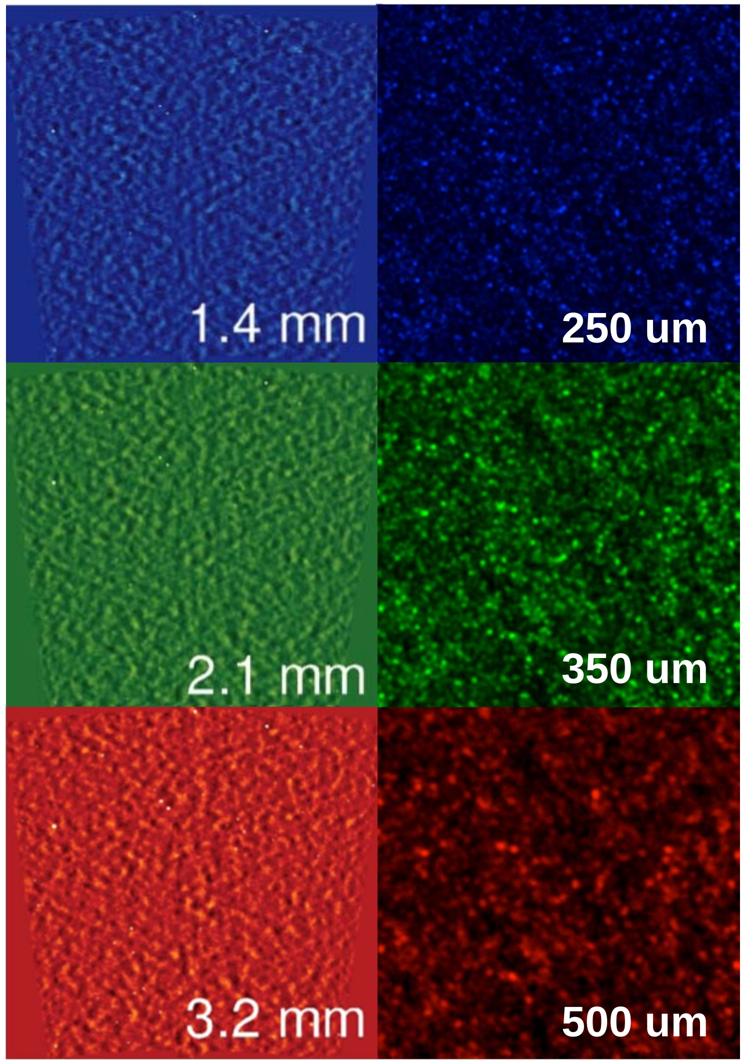
- Does not require a large telescope!

kSZ and Galaxies: SPIRE & mm-wave

Precise Measures of kSZ and tSZ

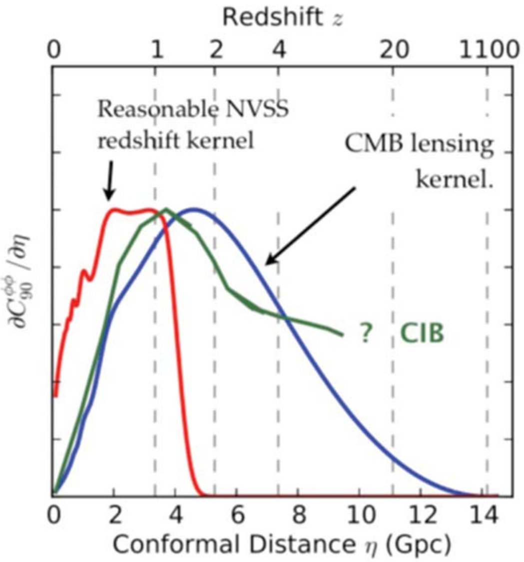


SPT **Herschel/SPIRE**

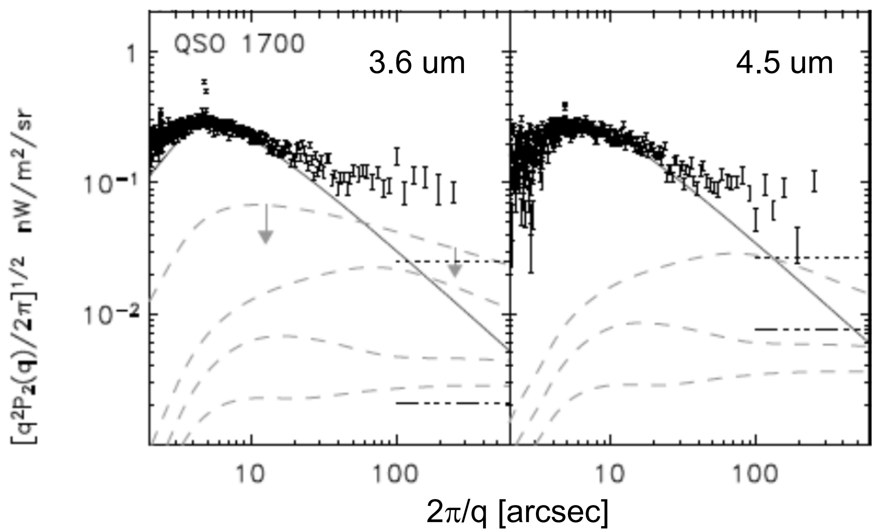


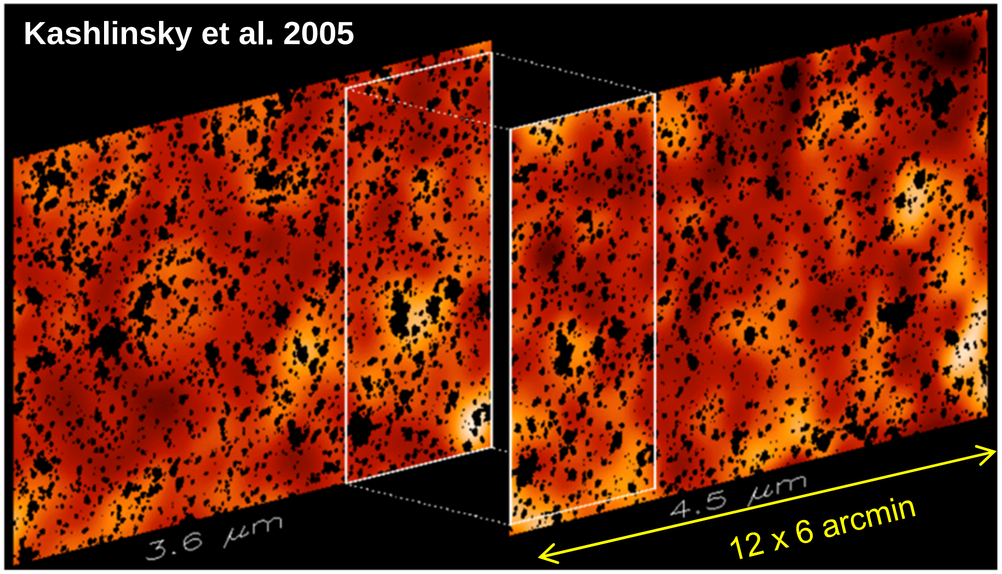
Correlate FIR galaxies with CMB lensing projected potential:

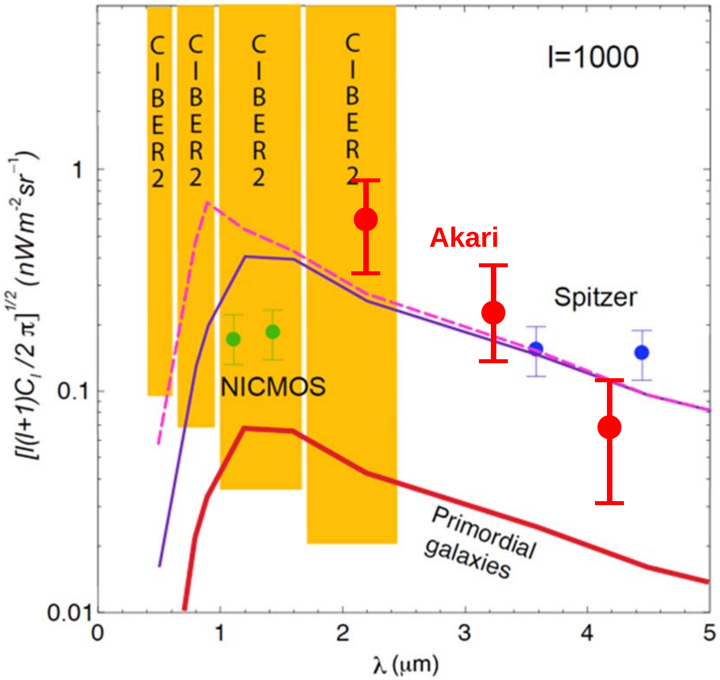
CMB lensing x CIB

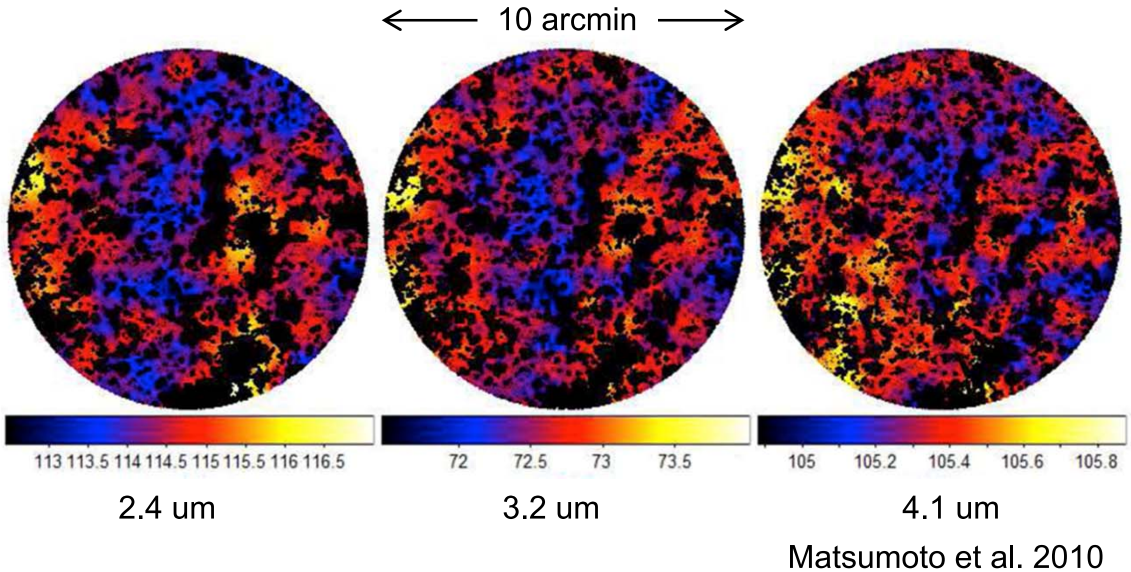


Near-IR Fluctuations from the EOR?









Advantages of Line Intensity Mapping

Measuring to the Galactic Ensemble

- Luminosity function
- Total photon production
- Large-scale structure

Science Applications

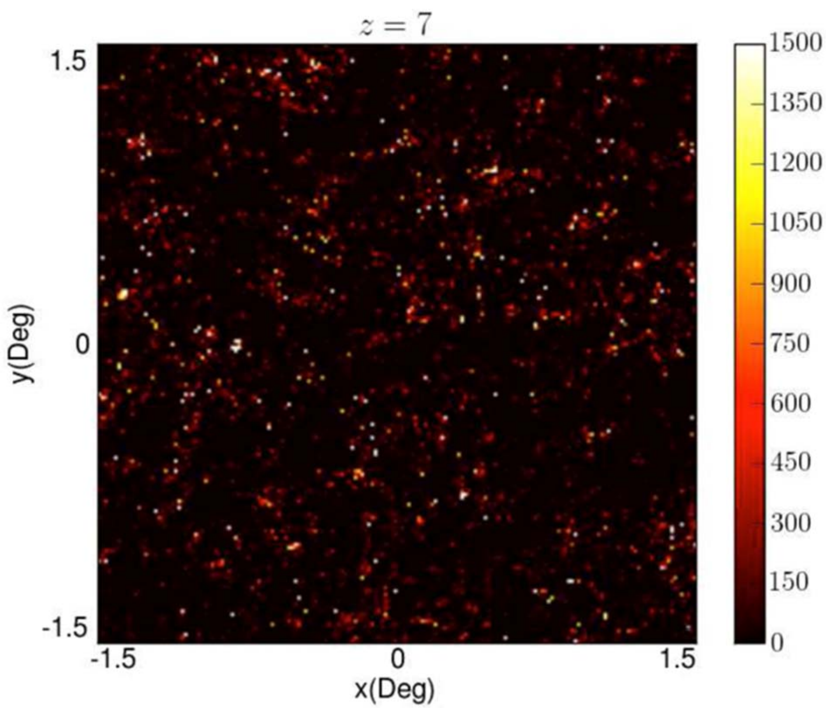
- Galaxy evolution
- Link between dark matter and galaxy formation
- Epoch of Reionization!
- Baryon Acoustic Oscillations!

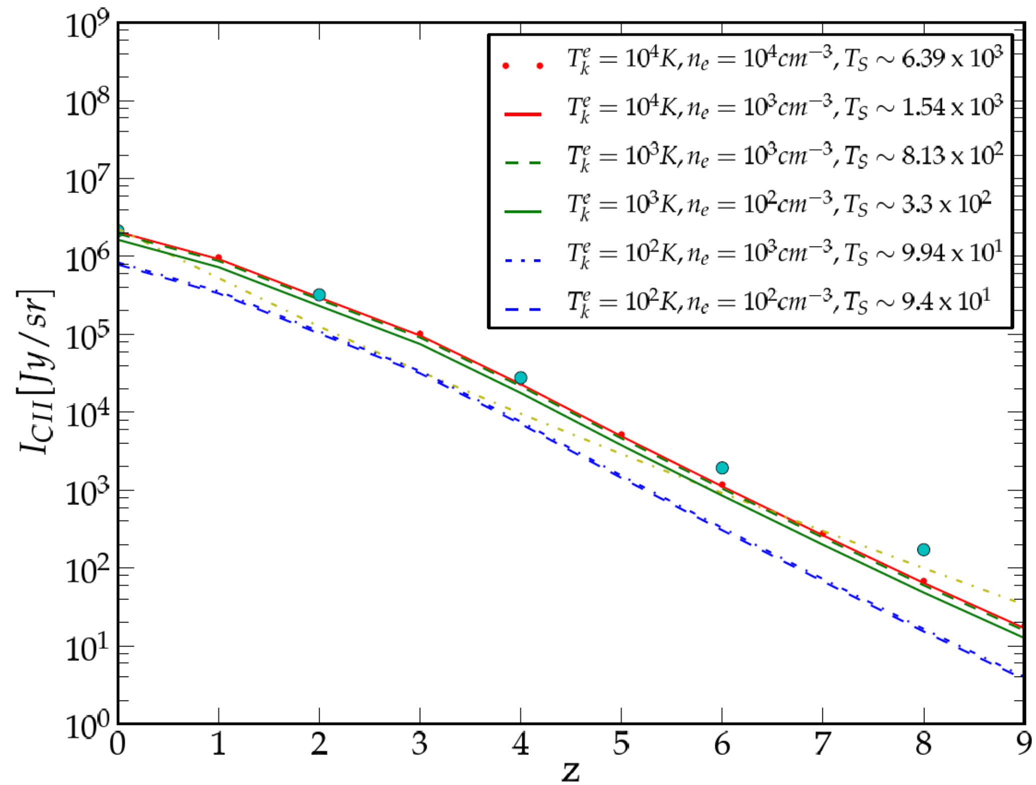
Observationally Expedient

- Does not require a large telescope!
- Does require a high-AΩ spectrometer

C+ Theory Predictions

Simulated Sky in C+

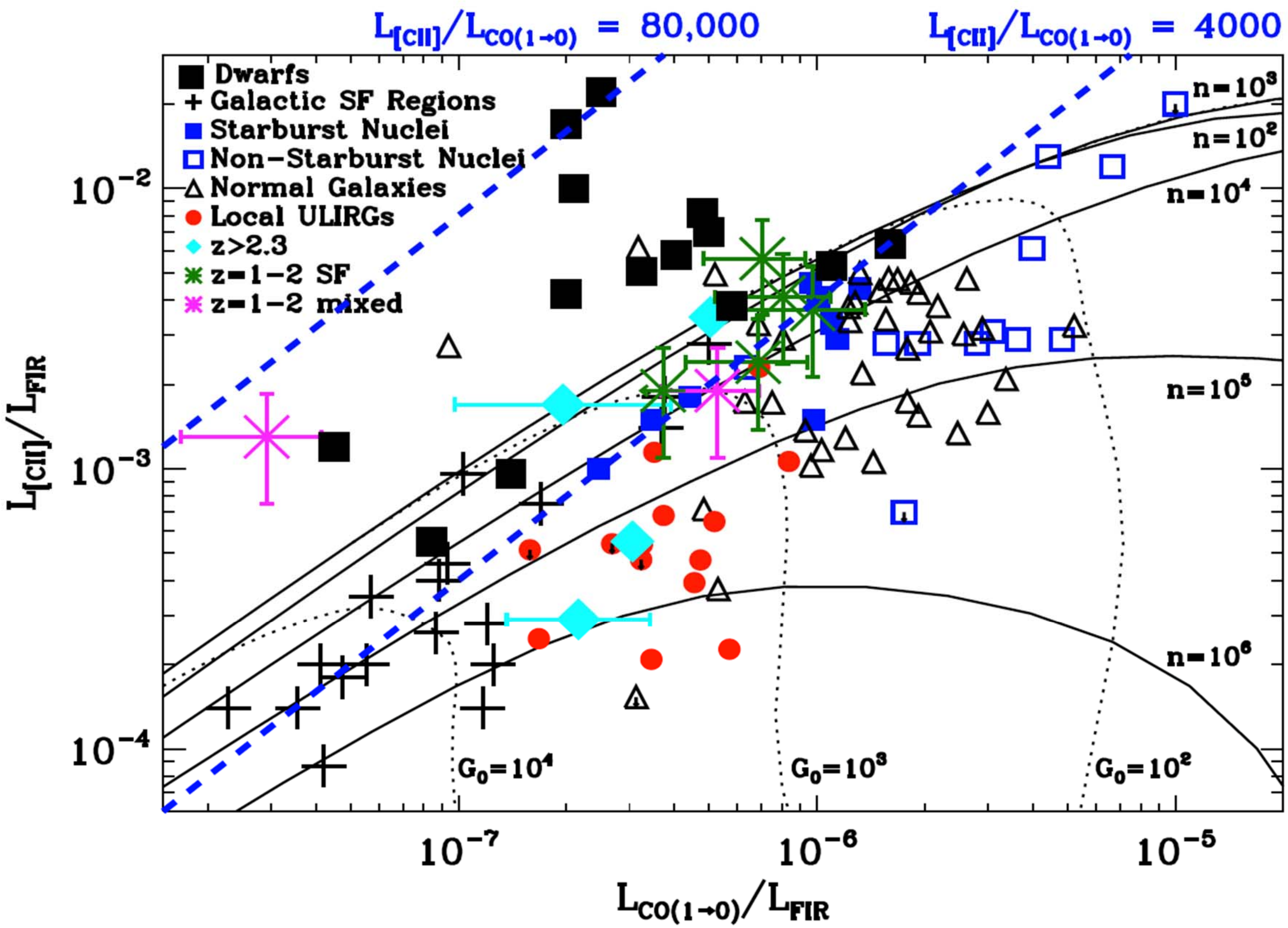




Gong, Cooray et al. 2012, ApJ 745, 49G

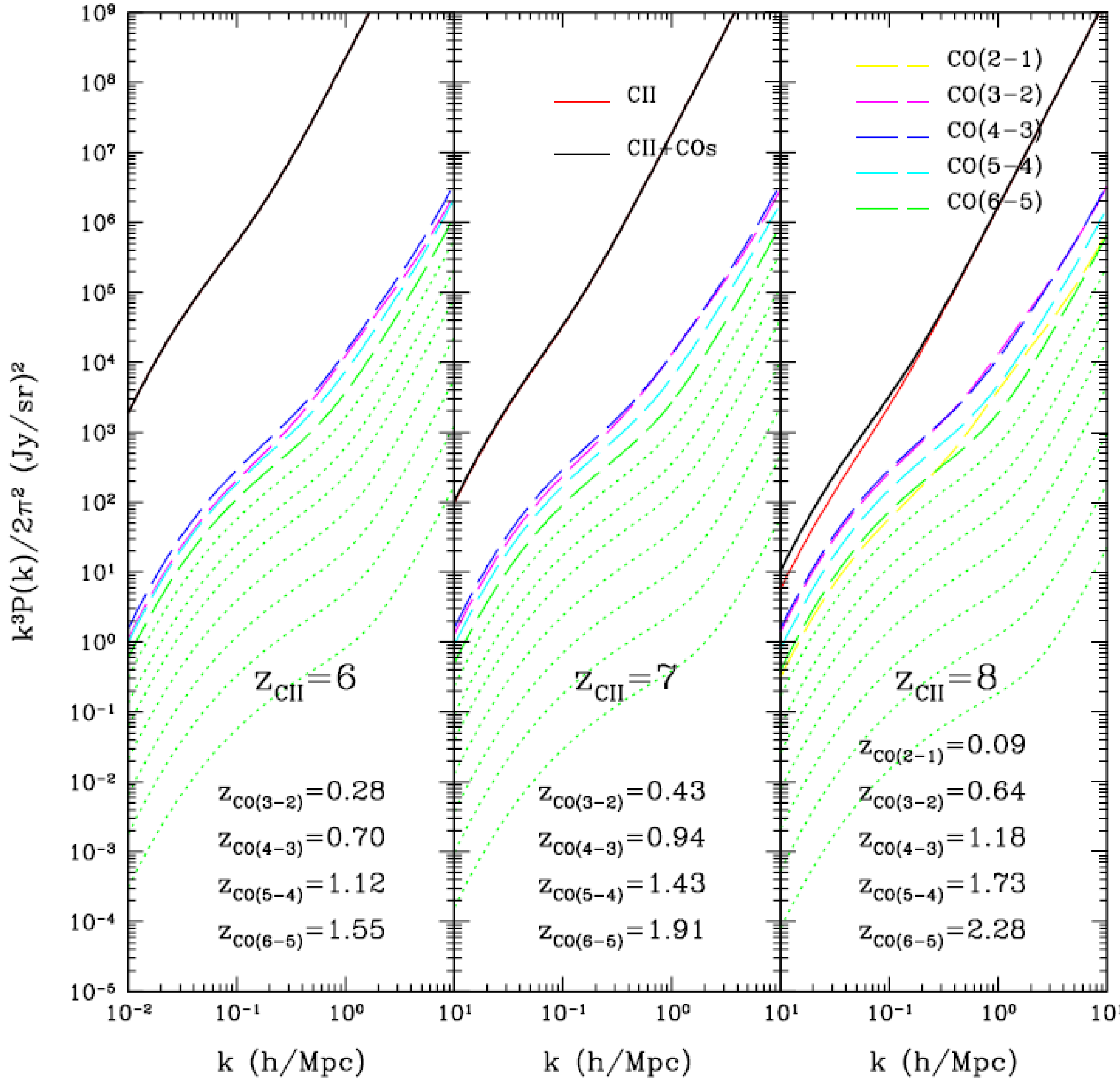
- **C+ serves as a tracer of star formation**
- **The clustering signal traces total luminosity**
  - **-> unlike a flux-limited galaxy survey**
- **Use C+ to spatially trace SF during the reionization epoch**

CO vs C+



CO for EOR studies: Visbal & Loeb 2010, Carilli 2011, Lidz et al. 2011, Gong et al. 2011

CO Foreground Contamination?

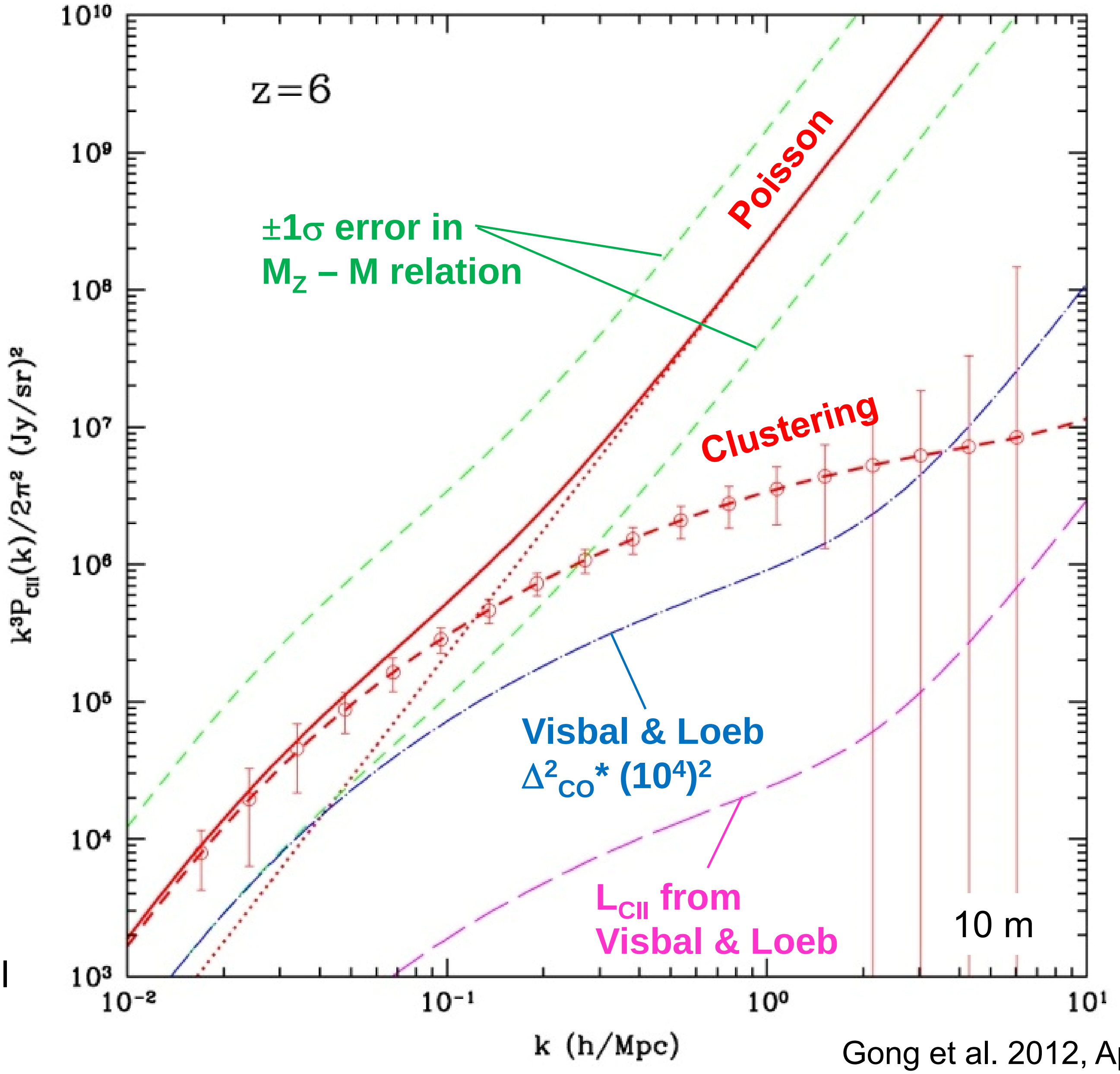


Gong et al. 2012, ApJ 745, 49G

TIME: *Tomographic Ionized-C Mapping Experiment*

Experiment	Units	TIME-Full			TIME-Pilot
Aperture Diameter	m	1	3	10	10
Survey Area	sq. degrees	16			0.01
Total Integration Time	hours	4000			120
Free Spectral Range	GHz	185 - 310			245 - 420
Frequency Resolution	GHz	0.4			0.65
Bolometers	#	20,000			265
Spectral Channels	#	312			265
Spatial Pixels	#	64			1
Beam FWHM	arcmin	4.4	1.5	0.4	0.3
Beams in Survey Area	#	2600	23,000	260,000	200
Noise Equiv. Intensity	MJy√s / sr	2.5			6 – 50
Int. Time per Beam	hours	100	10	1	0.6
$z = 4.5$ P_N^{CII}	$(Jy^2/sr^2)\ Mpc^3/h^3$	-			430×10^9
$z = 6$ P_N^{CII}	$(Jy^2/sr^2)\ Mpc^3/h^3$	5.4×10^9			100×10^9
$z = 7$ P_N^{CII}	$(Jy^2/sr^2)\ Mpc^3/h^3$	4.8×10^9			-
$z = 8$ P_N^{CII}	$(Jy^2/sr^2)\ Mpc^3/h^3$	4.4×10^9			-

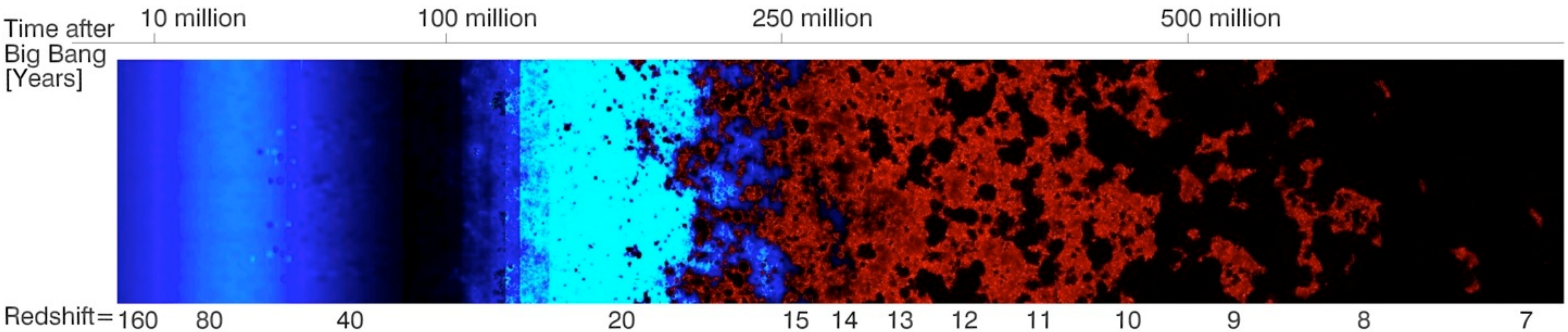
TIME C+ Sensitivity Predictions

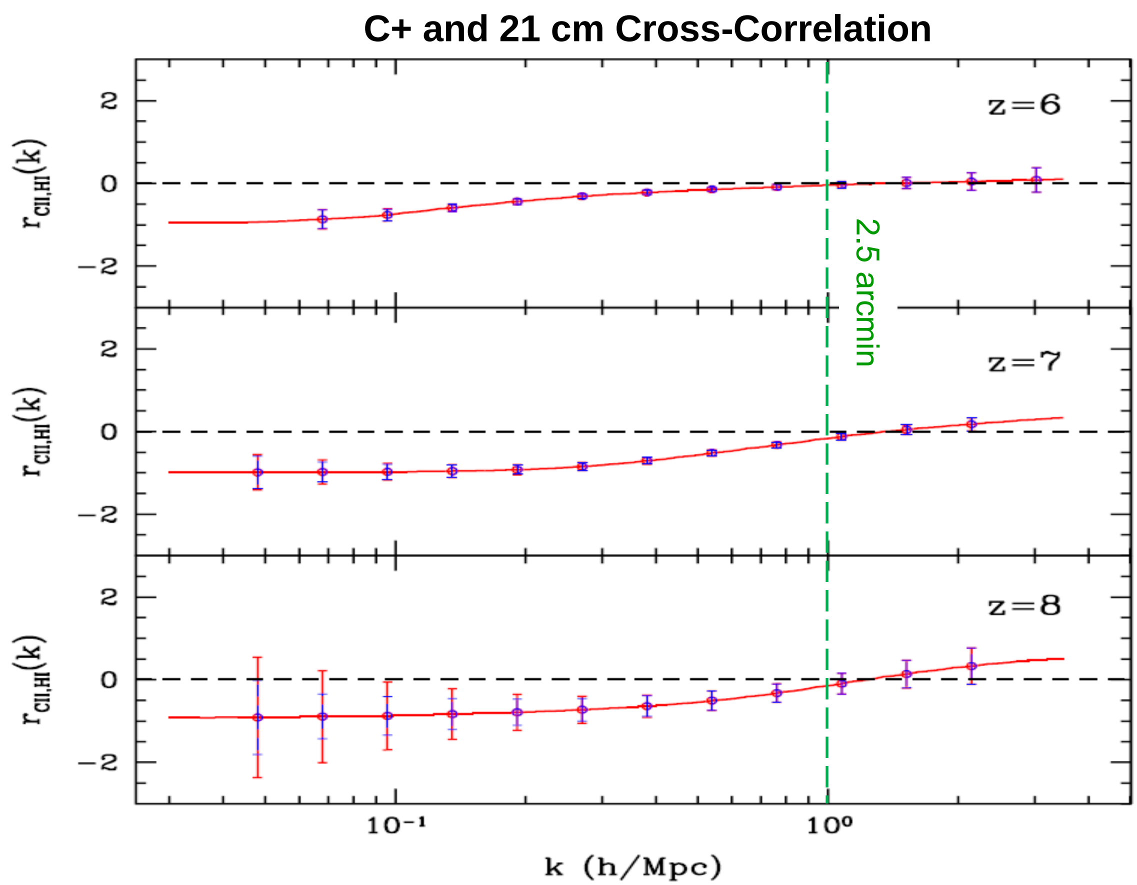


Lidz *et al*. 2011
Δ^2_{CO}*4000^2
agrees with
Gong C+ model
at z = 7

Gong et al. 2012, ApJ 745, 49G

Using 21 cm & C+ Together

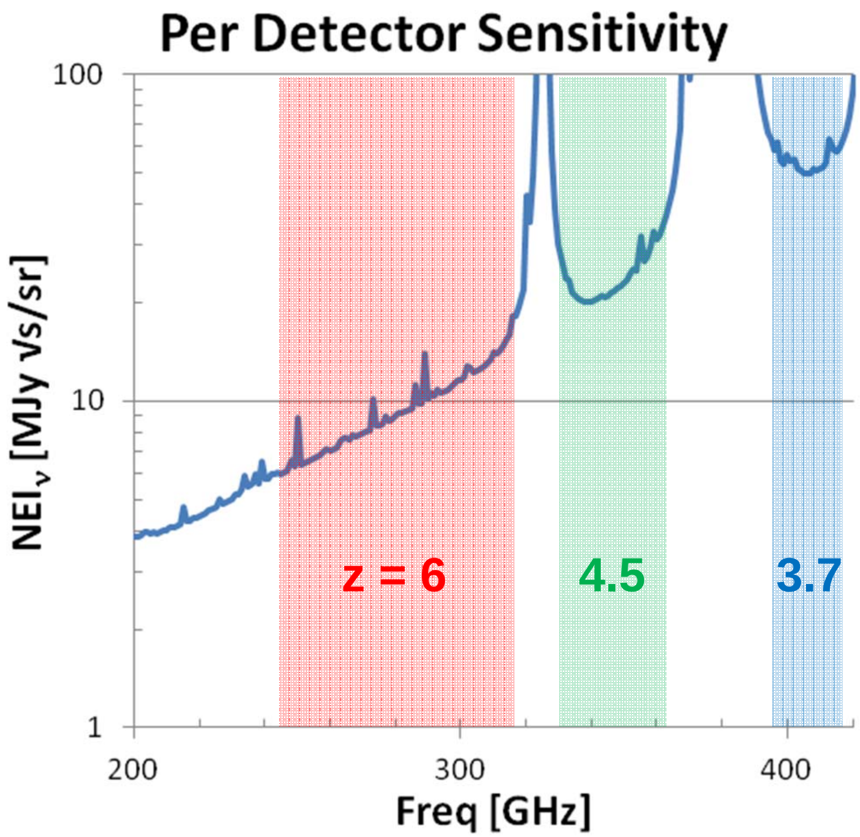


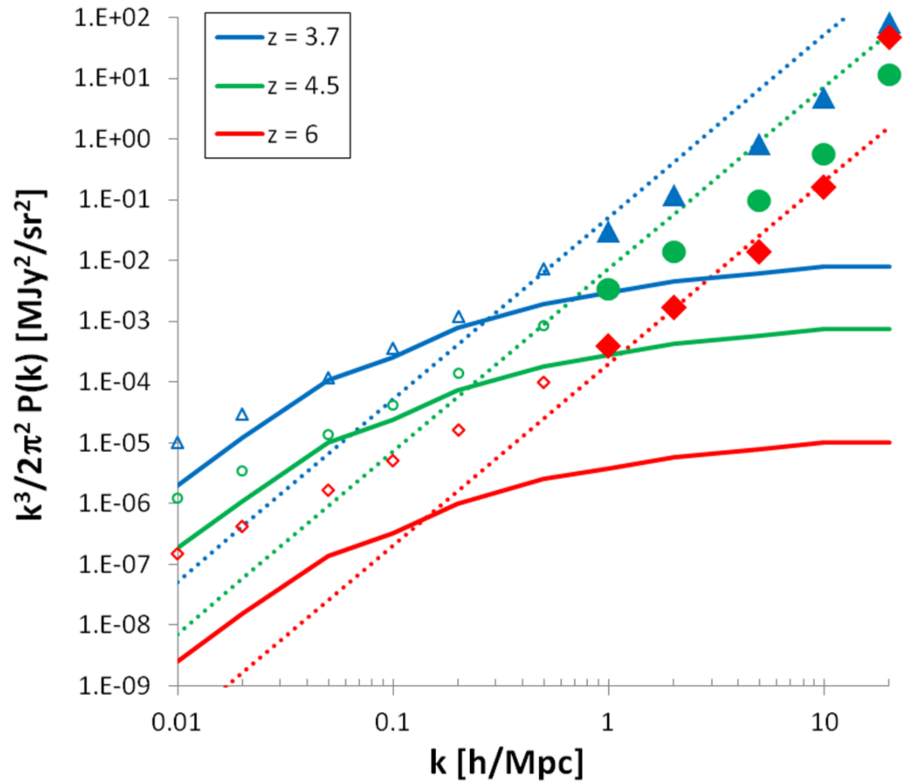


- Star formation rate vs. z
- Ionization state vs. z
- Bubble size

Gong et al. 2012, ApJ 745, 49G

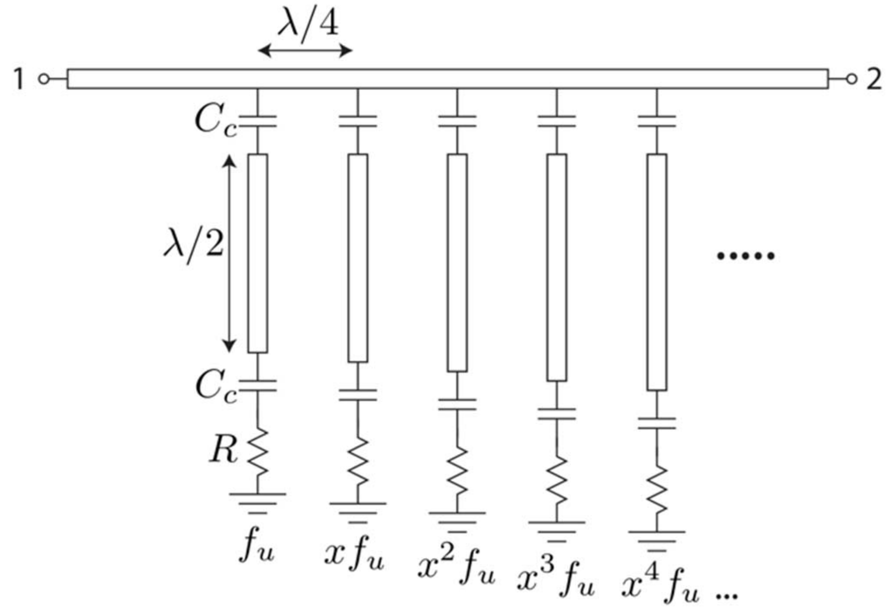
TIME-Pilot Sensitivity





Goals:
- Measure C+ fluctuation amplitude
- Constrain high-J CO fluctuations by cross-band correlations
- Determine atmospheric noise after spectral template subtraction

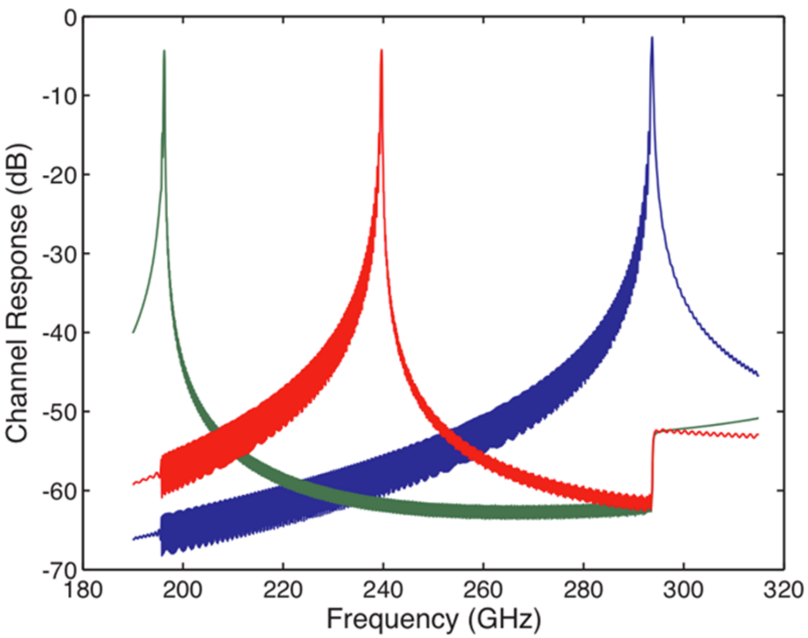
Filter-Bank Spectrometer

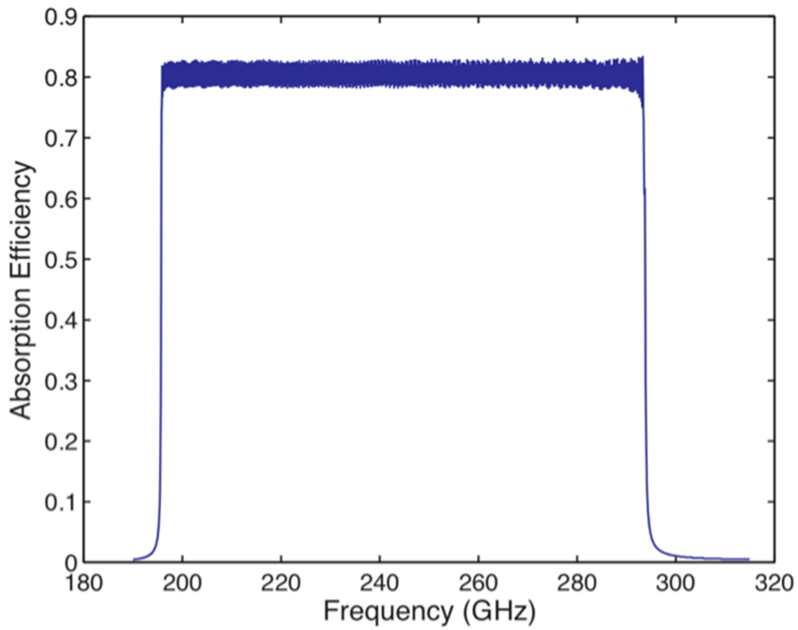


- Radiation propagates down main feed line
- Resonators respond in narrow bands
- Couple to power detector (MKID or TES)

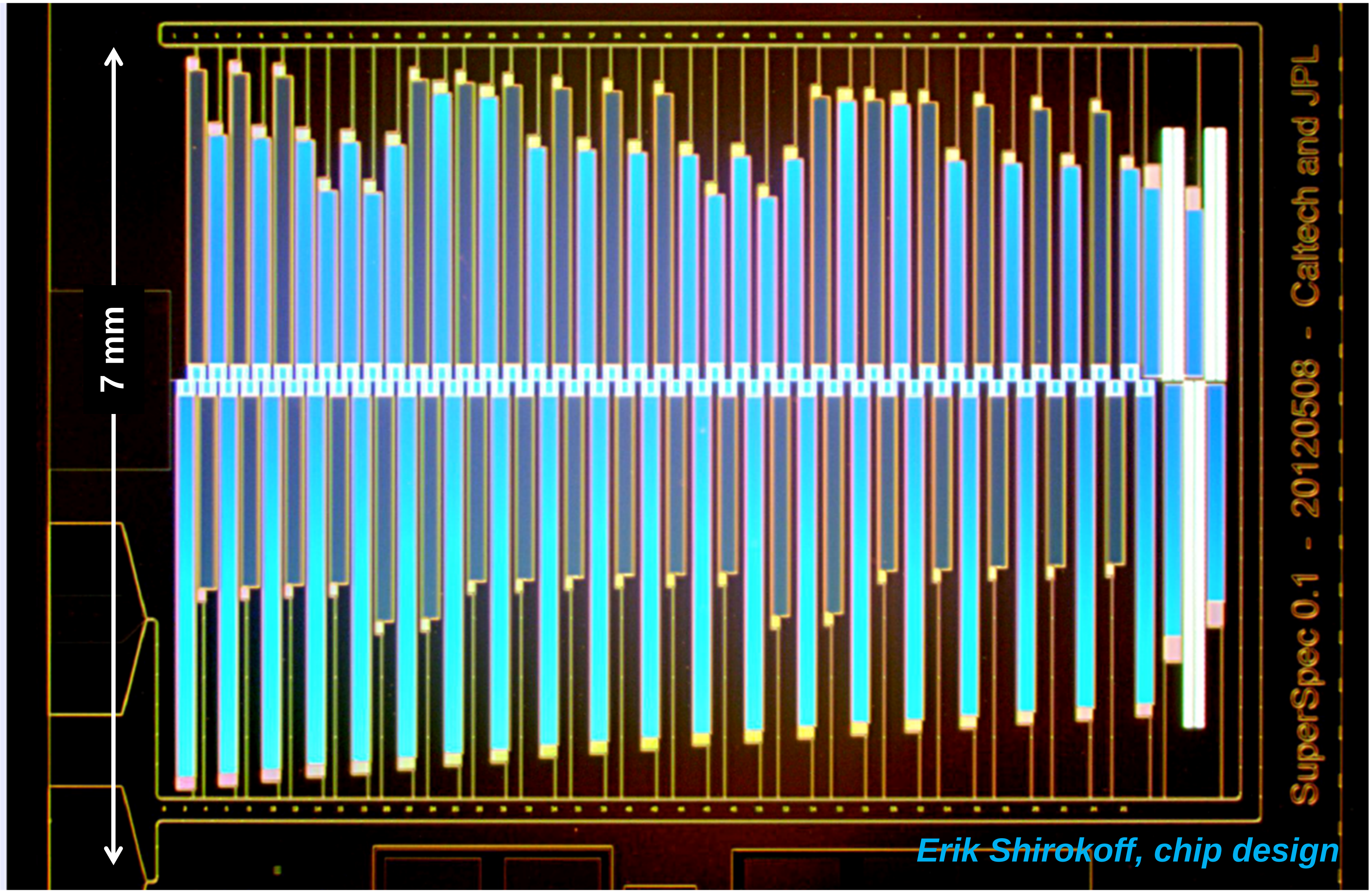
Credit: Jonas Zmuidzinas

See talk by Matt Bradford later today!





SuperSpec: 80-Channel Test Device



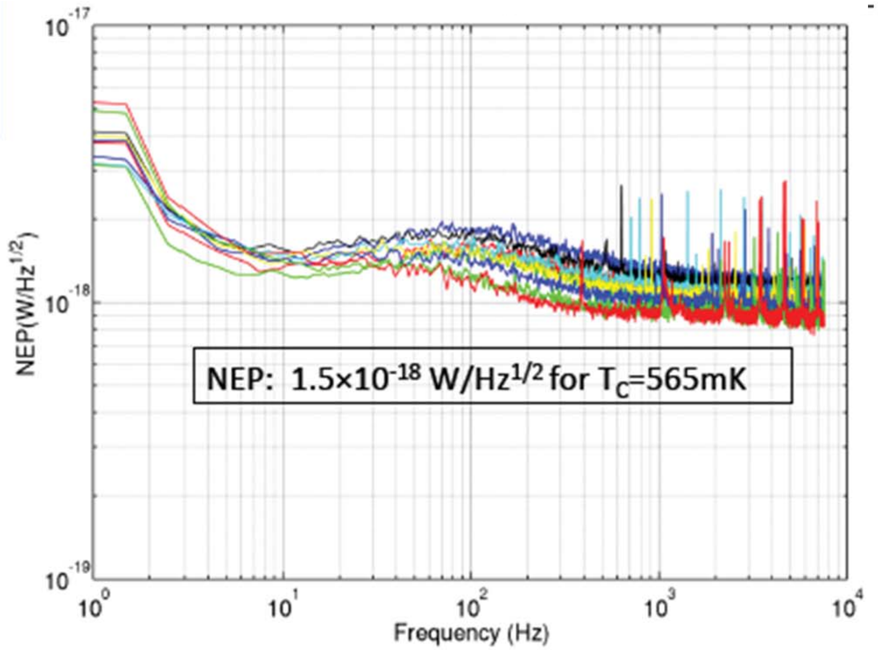
Conclusions

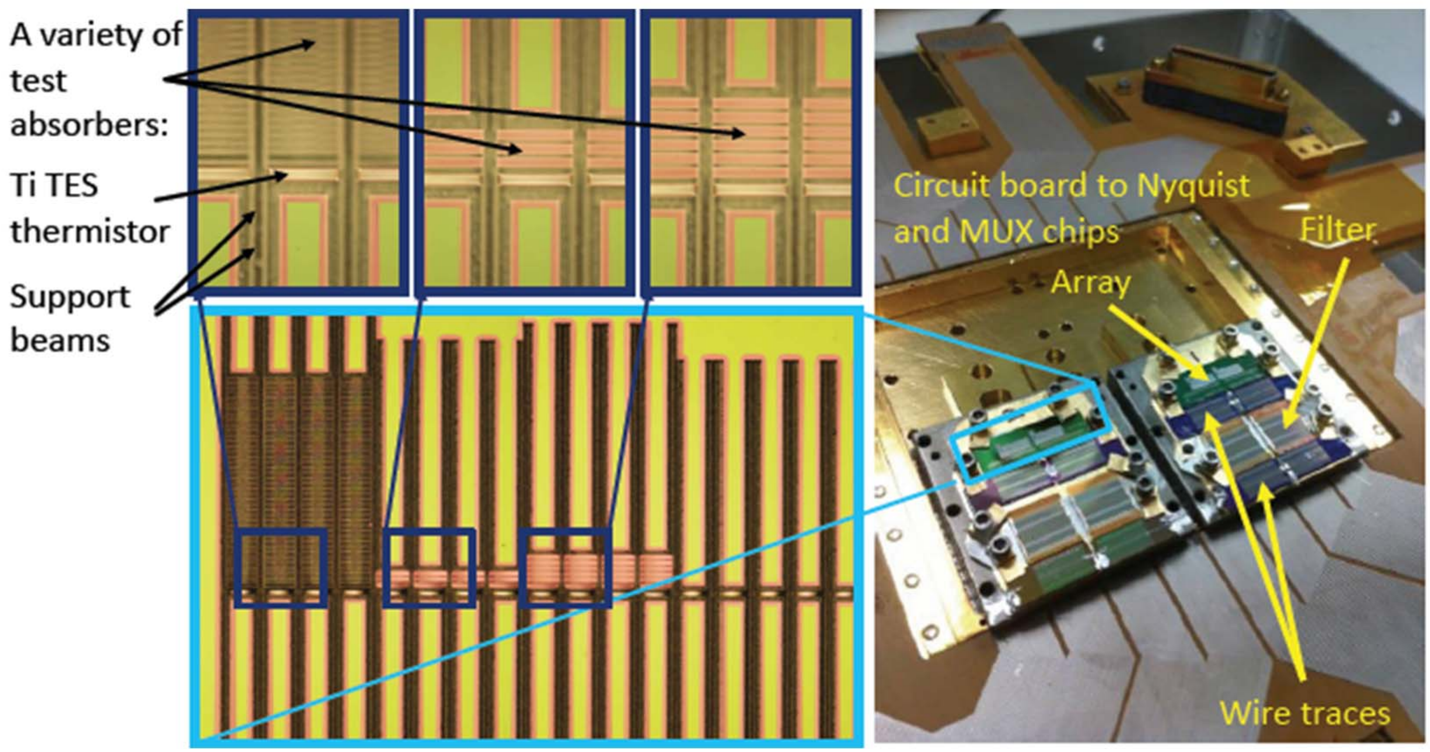
EOR Science accessible with a 3-m class dedicated telescope

A moderate pilot experiment can probe C+ signal amplitude at lower z

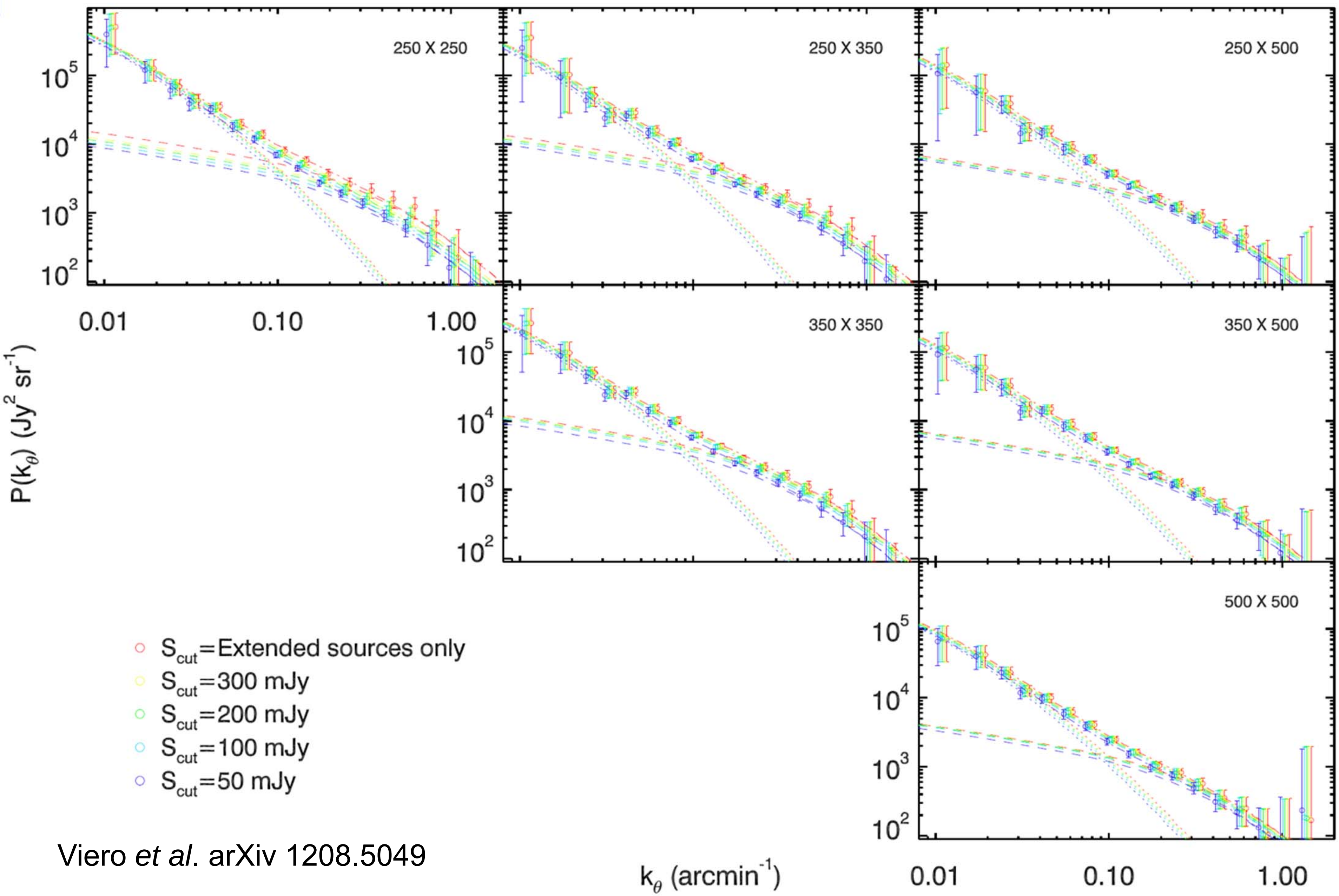
Develop new filter-band spectrometer technologies for CCAT

Low-NEP TES Bolometers Work with SQUID TD Mux



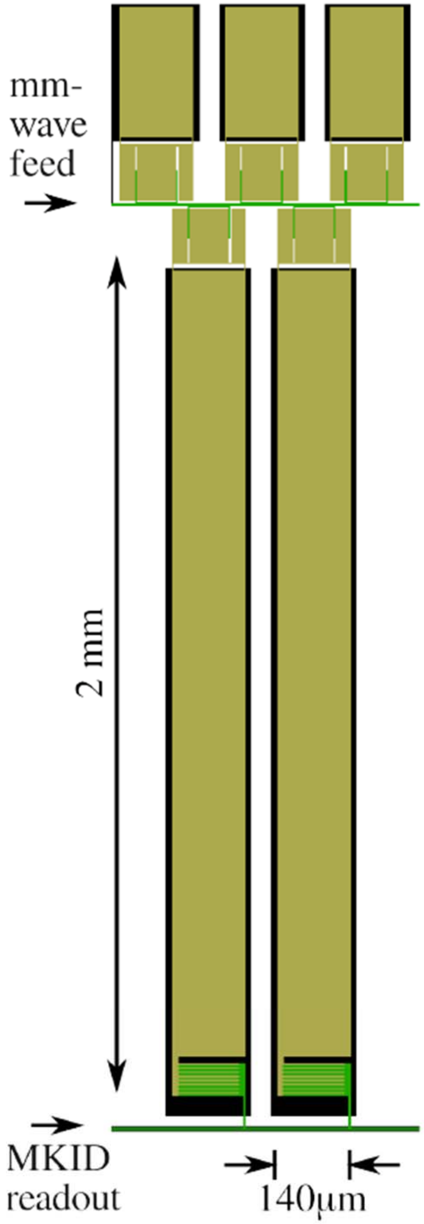


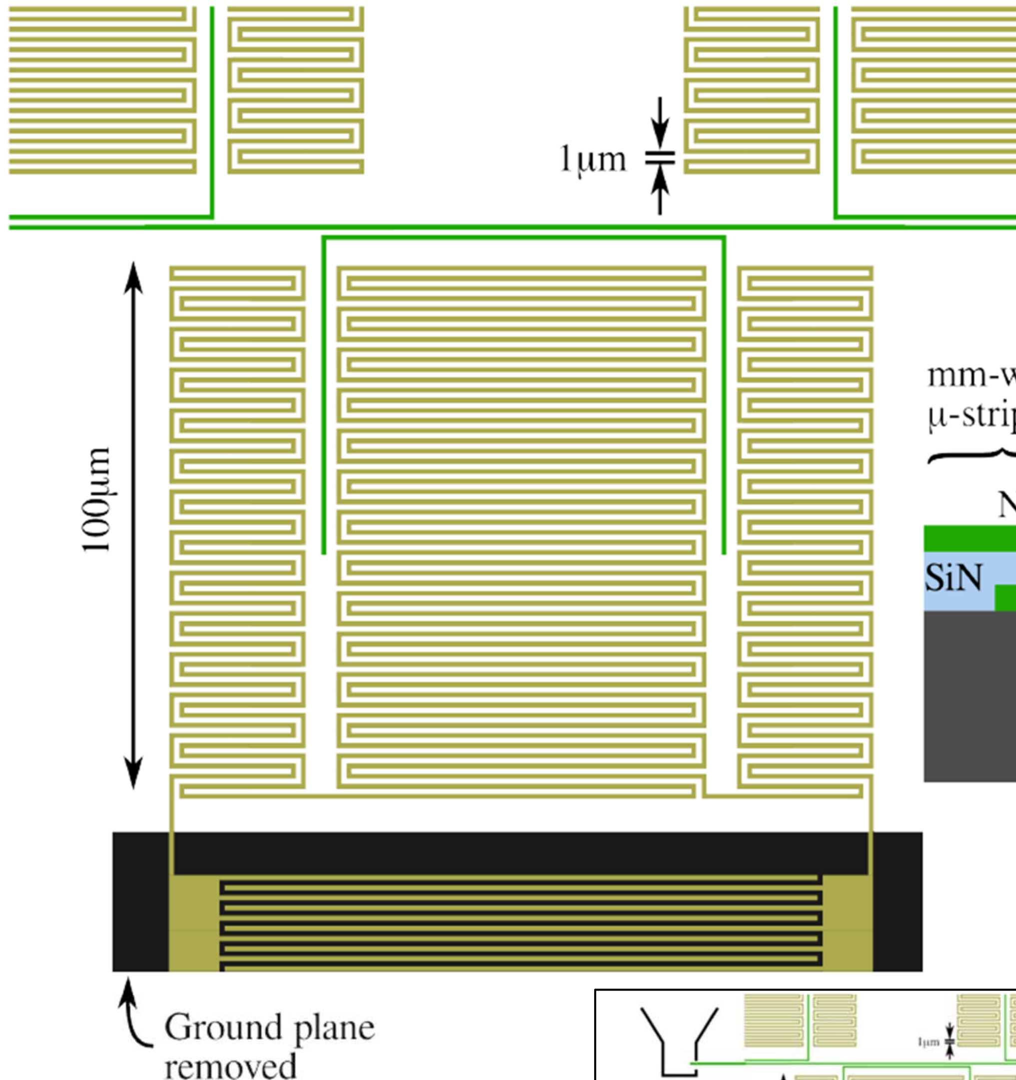
Power Spectra in 3 Bands



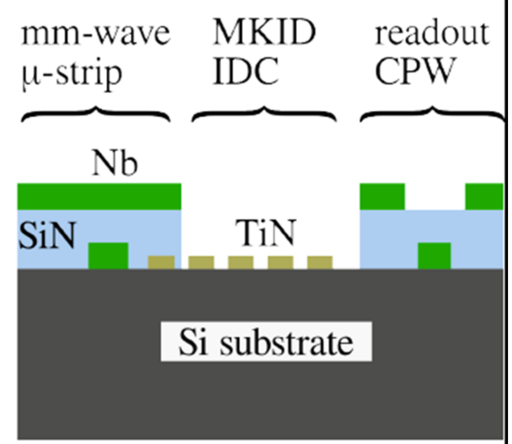
Viero *et al*. arXiv 1208.5049

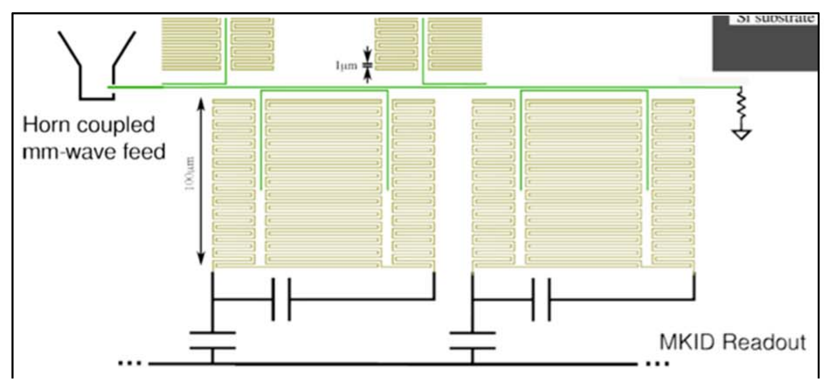
Prototype device layout.





Inverted microstrip stack



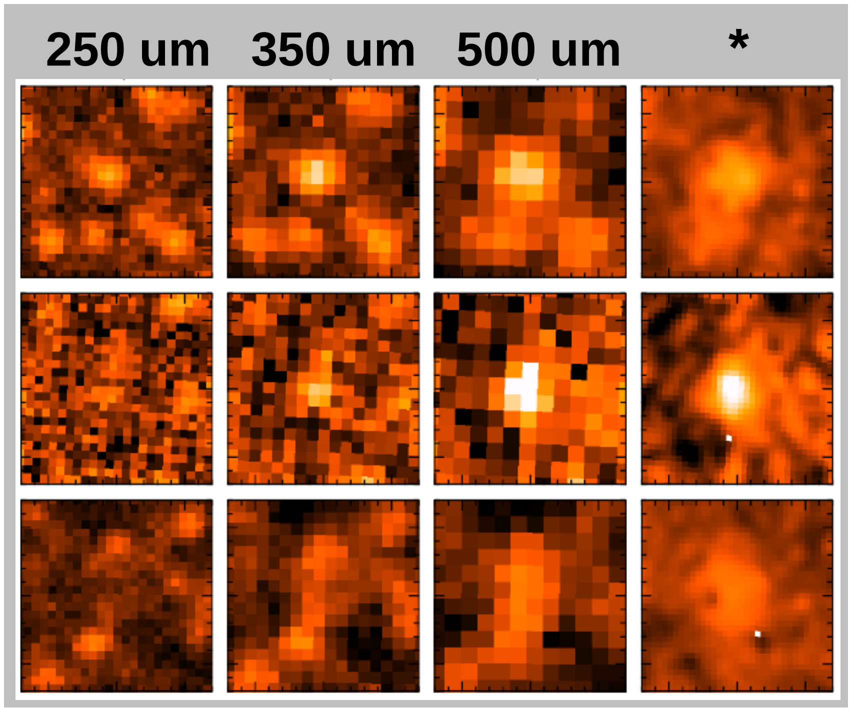


Erik Shirokoff, SuperSpec chip design

High Redshift Galaxies in HerMES

New: Galaxies with Red Colors

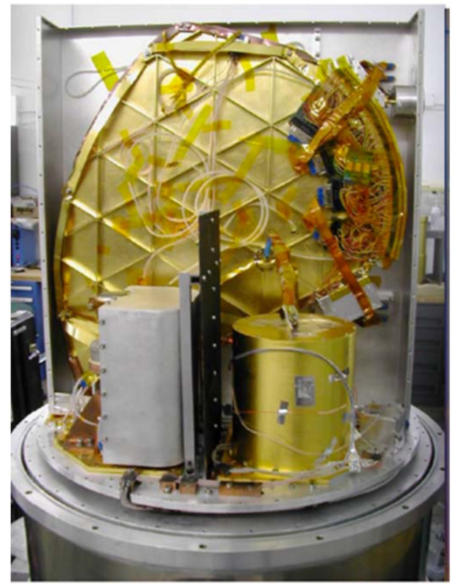
Are they cold or at high redshift (z=4-7)?



***Confusion reduced S(500) – fS(250)**

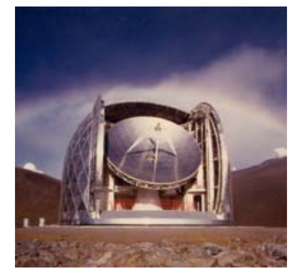
Red Source Abundance Dowell 2011, in prep.
Red Source Case Study Riechers 2011, in prep.

Obtain mm-wave redshifts (CO, C+)!!



ZSPEC: Bolometric spectrometer

APEX



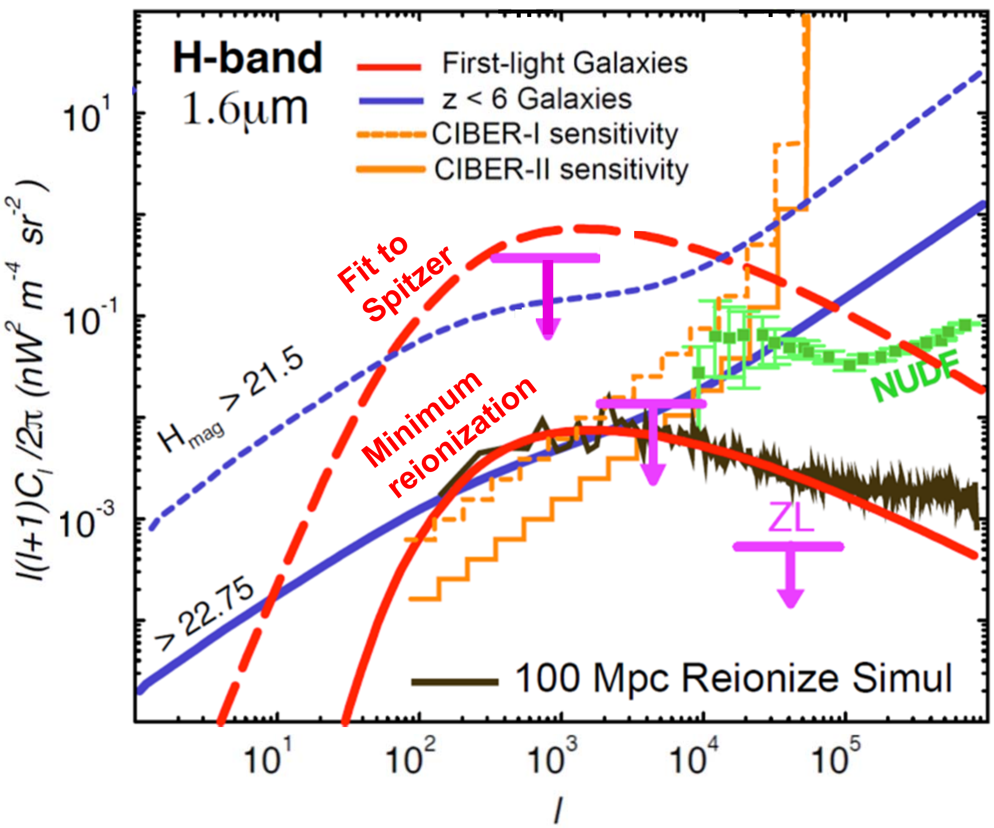
CSO

PdBI

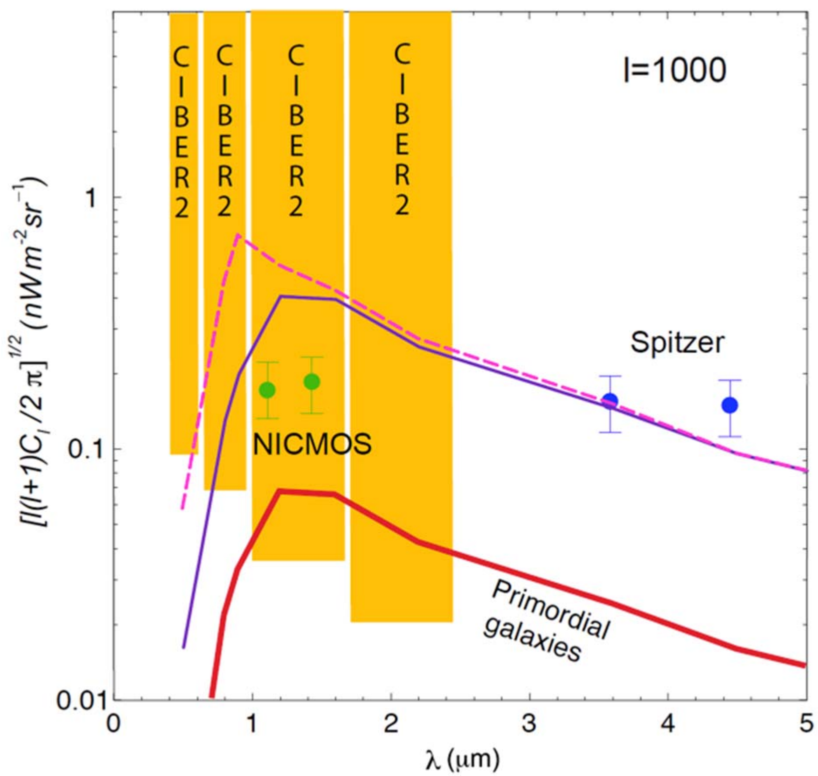
CARMA

Use Clustering to Probe Reionization

Spatial Power Spectrum



Electromagnetic Spectrum



See Cooray et al. 2004, Kashlinsky 2004

Why CIBER is Robust to Systematic Errors

• Zodiacal Smoothness?	Observe at different times of year
• Flat Field?	Use difference images, lab flat
• 1/f noise?	Assess using sky differences
• Galaxies?	Large ℓ separation from EOR
• Foregrounds?	EOR has very different colors
• Anything else?	Cross-correlate with Spitzer