Title: 21cm cosmology

Date: Jul 10, 2013 09:30 AM

URL: http://pirsa.org/13070010

Abstract: I will overview the progress of 21cm cosmology, with emphasis on intensity mapping. Current and future experiments have the potential for precision measurements of dark energy, neutrino mass, and gravitational waves.


21cm Cosmology: Present and Future
Ue-Li Pen
K. Masui, E. Switzer, R. Shaw, L. Cailin, G. Paciga, K. Bandura, J. Peterson, T. Chang, Y. Liao, X. Chen, Y. Li, T. Voytek, A. Natarajan, M. Dobbs, M. Halpern, J.R. Bond, G. Hinshaw, J. Roy, Y. Gupta, R. Nityananda, and many more

Overview

Broad picture: optically thin view of 10^{18} modes (redshifts)

Theory: dark energy, gravity waves, neutrinos, enhanced 21cm pre-reionization structures.

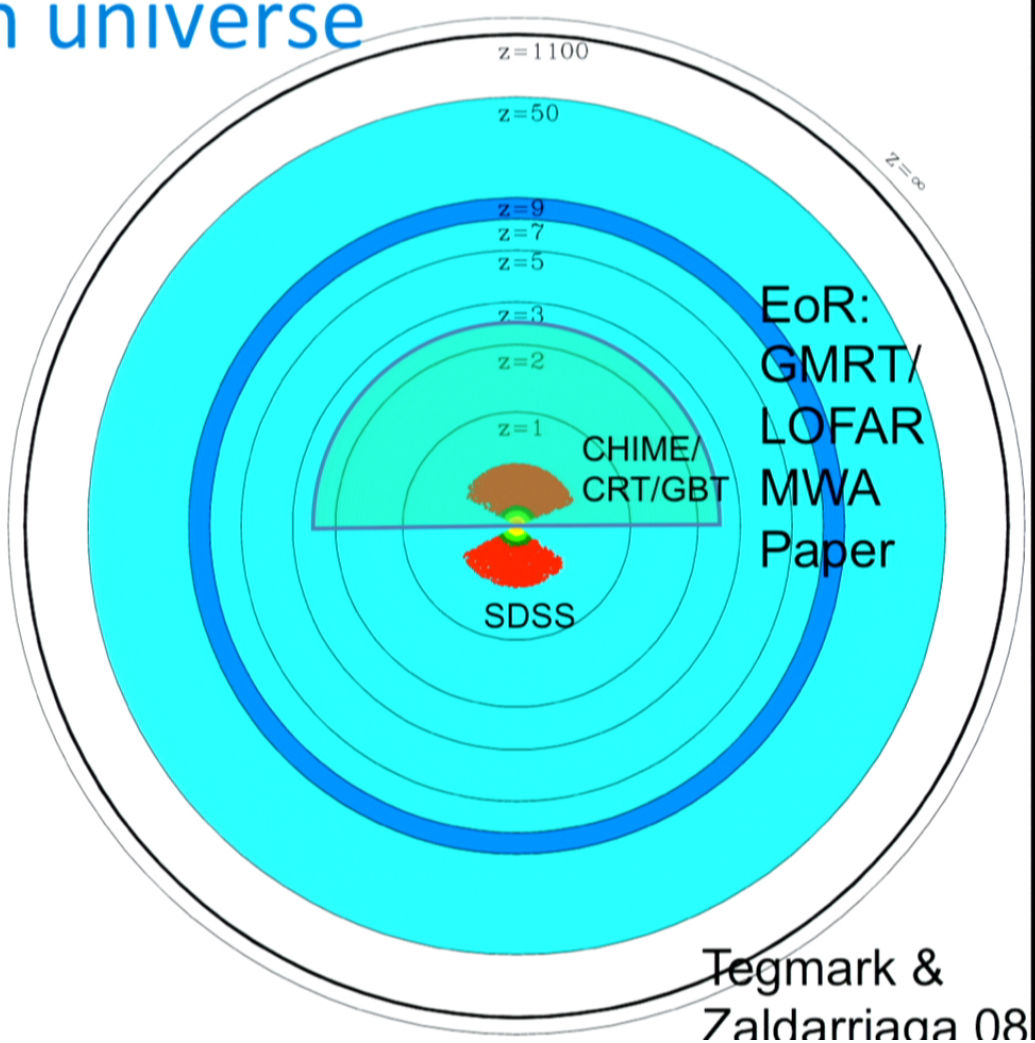
Analysis: Foreground removal

Observations: first detections and upper bounds (GBT)

Future: dedicated surveys (CRT, Tianlai, CHIME, etc)

The 21 cm universe

- Cosmological LSS treasure trove (UP04, Loeb&Zaldarriaga 04, Lewis&Challinor 07, etc)
- Up to 10^{18} modes: (Jeans/Hubble)^3
- Physics: Lensing, gravity waves, primordial NG, BAO, AP
- GW to r ~ 10^{-8}
- f_{NL} ~ 10^{-4}
- Astrophysics: EoR, galaxy evolution
- Experiments NOW



Fundamental Physics

- 0<z<2: neutrino masses, dark energy, BAO
- z>2: Large angle lensing: modified gravity (Lu & UP 2009, Masui et al 2010)
- z>10: gravitational waves

Intensity Mapping

- Stars get fainter with distance: hard to see individually at cosmological distance. Galaxies still visible.
- Galaxies get fainter with distance: hard to see in HI. Large scale structure still visible?
- Large scale structure is LARGE: degree scale. High resolution not needed.
- Modest size, monolithic radio telescopes needed. (CPPM 2008, Wyithe&Loeb 2008)

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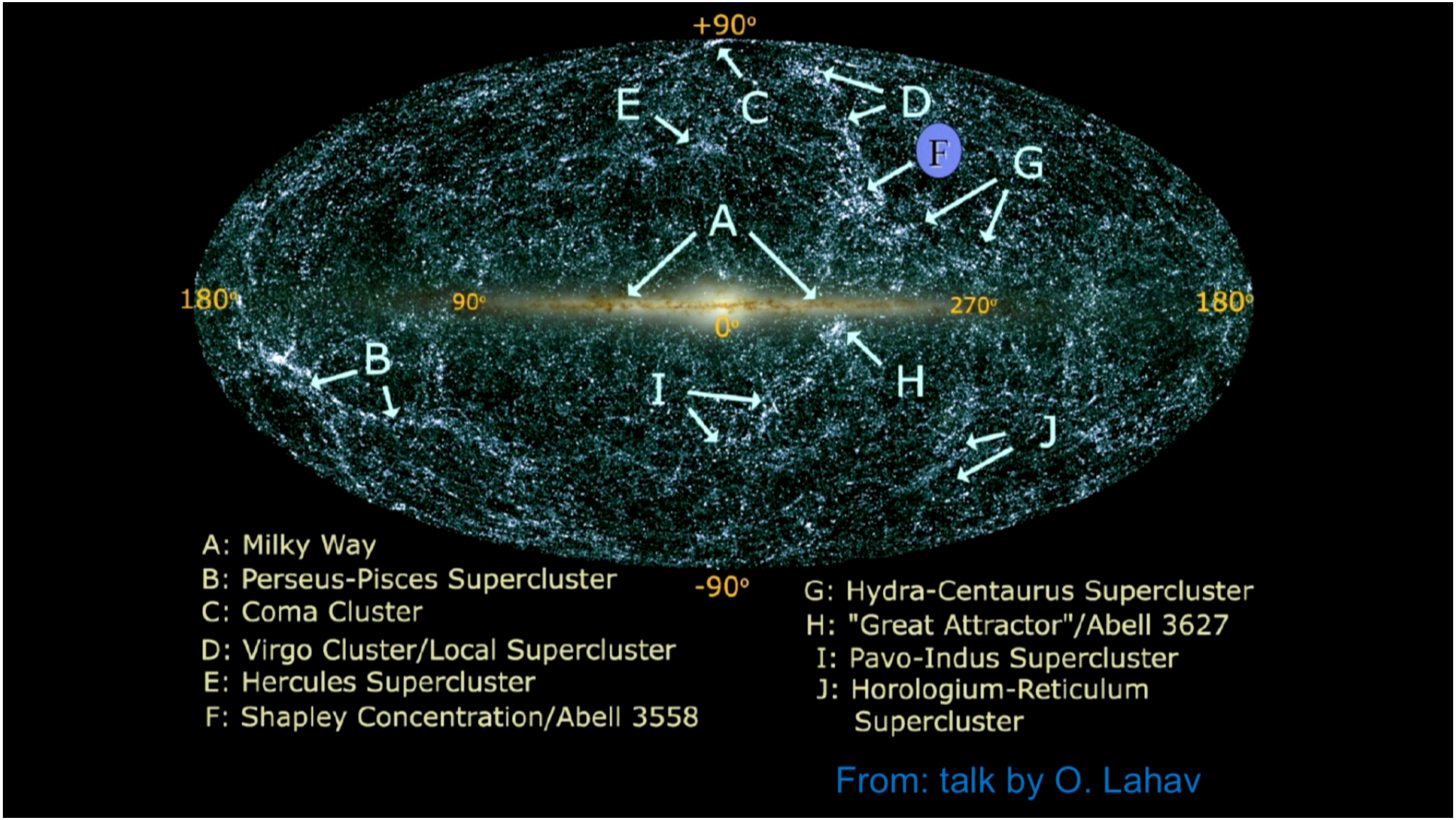
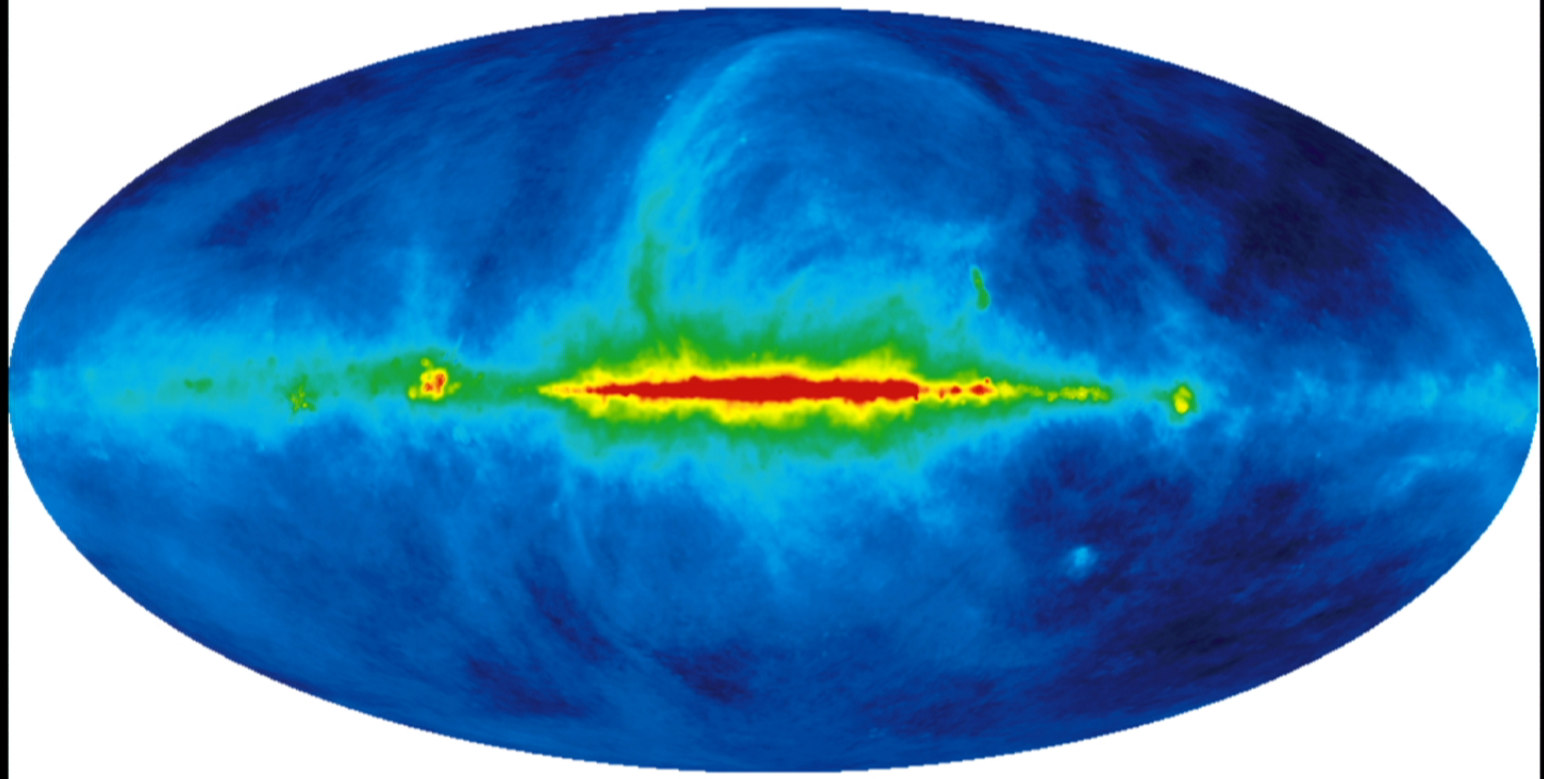

+90°
E
C
D
F
G
A
180°
90°
270°
180°
0°
B
I
H
J
-90°
A: Milky Way
B: Perseus-Pisces Supercluster
C: Coma Cluster
D: Virgo Cluster/Local Supercluster
E: Hercules Supercluster
F: Shapley Concentration/Abell 3558
G: Hydra-Centaurus Supercluster
H: "Great Attractor"/Abell 3627
I: Pavo-Indus Supercluster
J: Horologium-Reticulum Supercluster
From: talk by O. Lahav

Foreground: Galactic Synchrotron



Haslam 408 MHz

Much brighter than signal, but no spectral structure

ARAA review article May 2010 (Morales and Wyithe) comparing to z ~ 10:

The impending EoR measurements will teach the observational community how to perform precision cosmological measurements at low radio frequencies. This experience will be invaluable for both subsequent EoR measurements and first generation intensity mapping machines.

Two months later:

Vol 466|22 July 2010|doi:10.1038/nature09187 nature

LETTERS

An intensity map of hydrogen 21-cm emission at redshift $z \approx 0.8$

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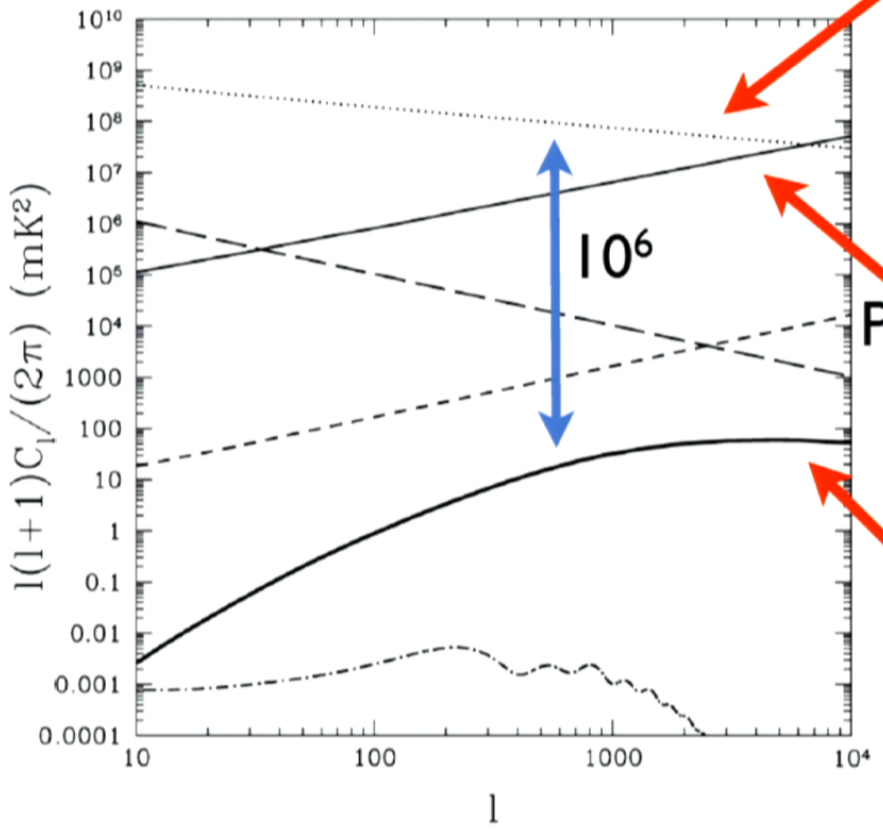
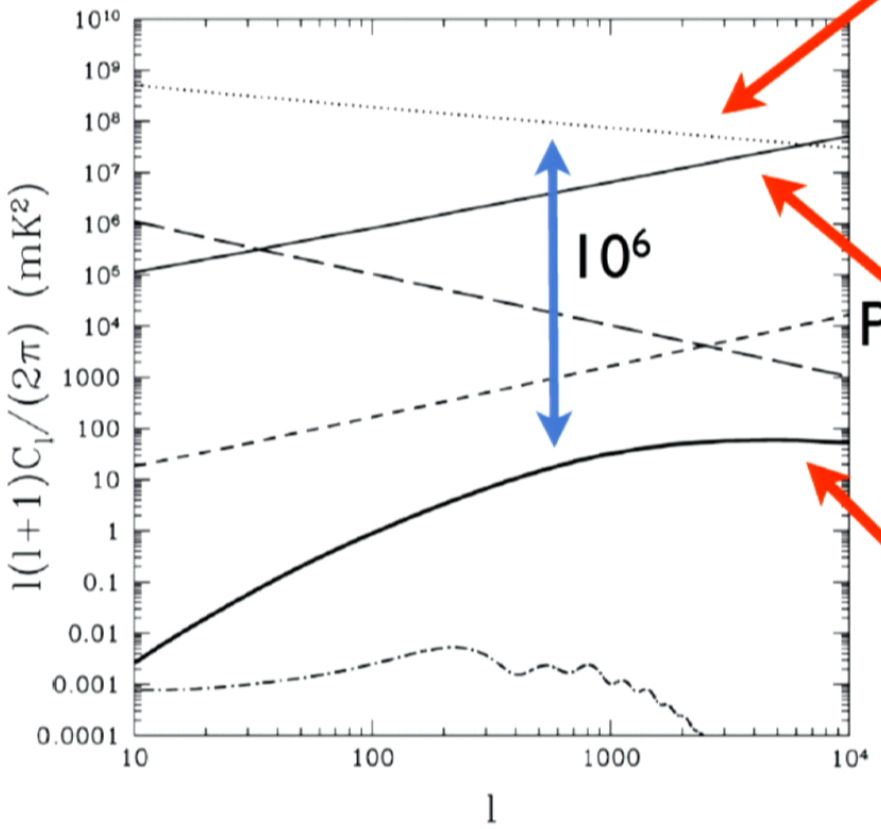
Foregrounds



Santos, Cooray and Knox, 2005, http://arxiv.org/pdf/astro-ph/0408515

Foregrounds



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GBT 21 cm intensity mapping collaboration

Academia Sinica (Tzu-Ching Chang, Victor Yu-wei Liao)

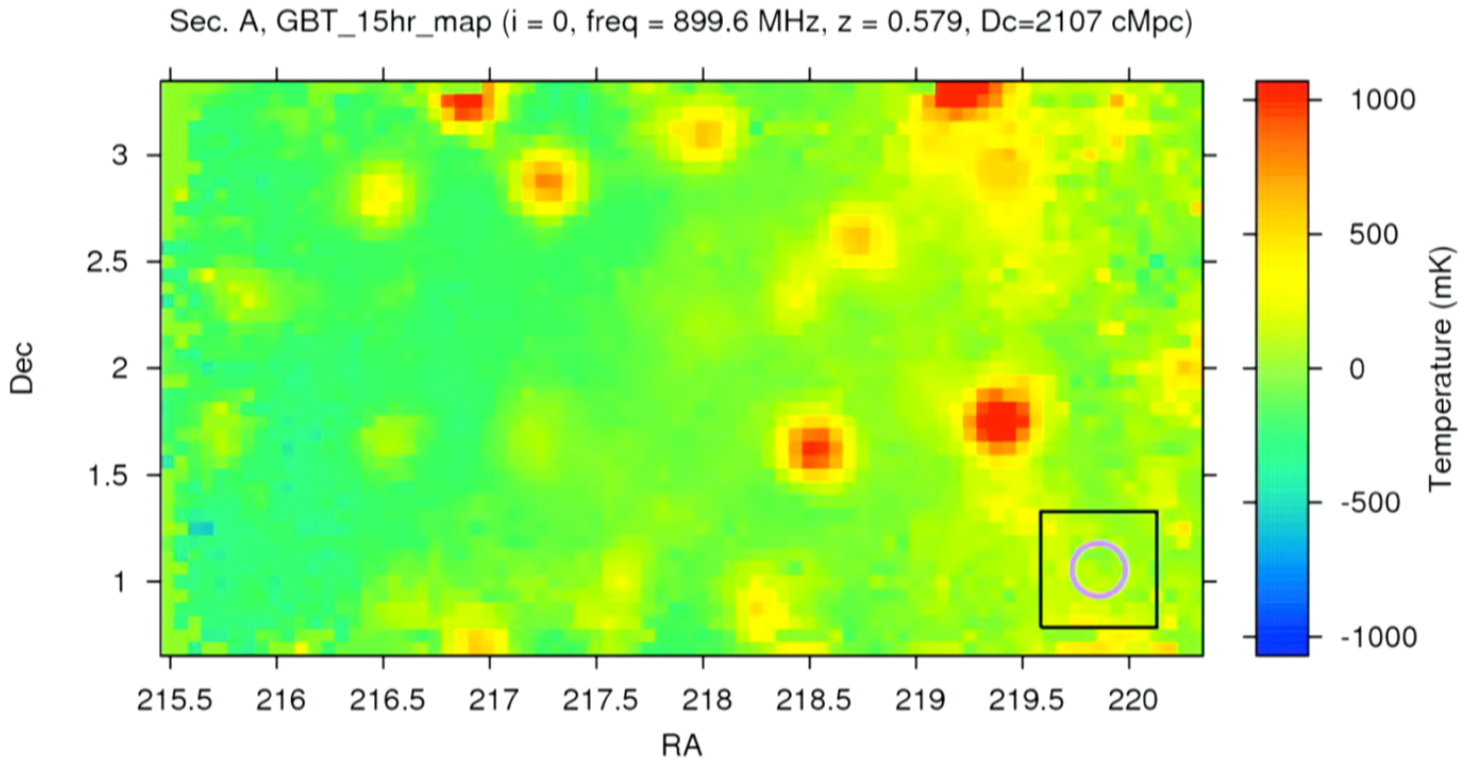
Beijing (Xuelei Chen, Yi-Chao Li)

Carnegie Mellon University (Aravind Natarajan, Jeff Peterson, Tabitha Voytek)

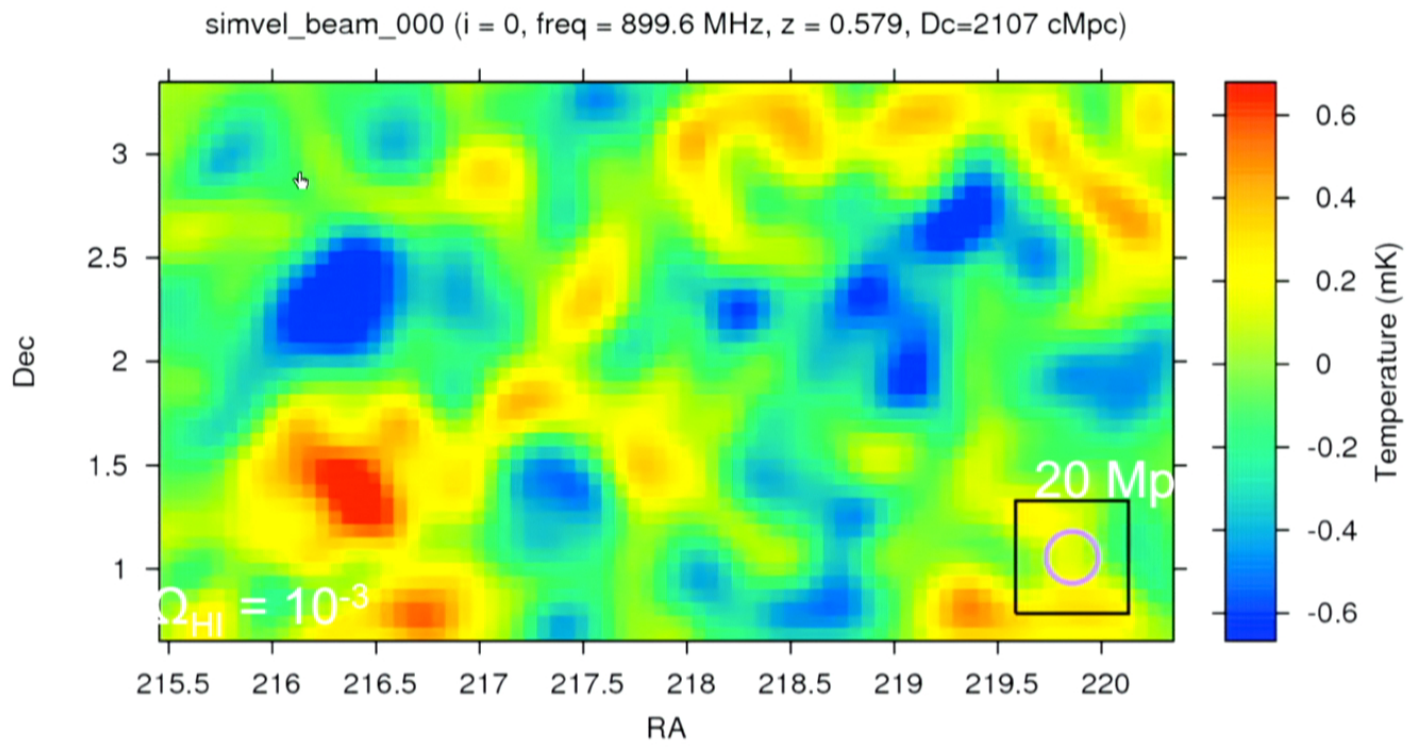
CITA/UToronto (Nidhi Banavar, Liviu Calin, Adam Lewis, Kiyo Masui, Ue-Li Pen, Richard Shaw, Eric Switzer)

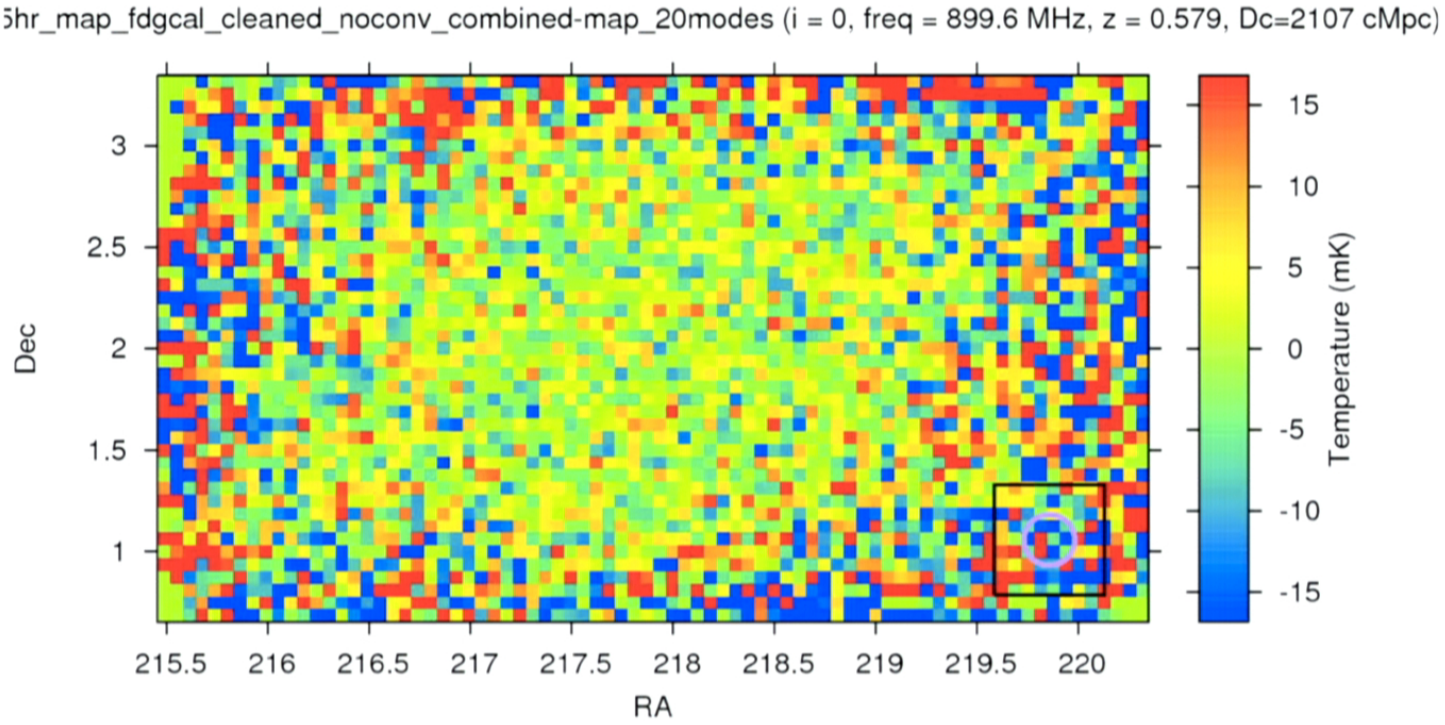
McGill (Kevin Bandura)

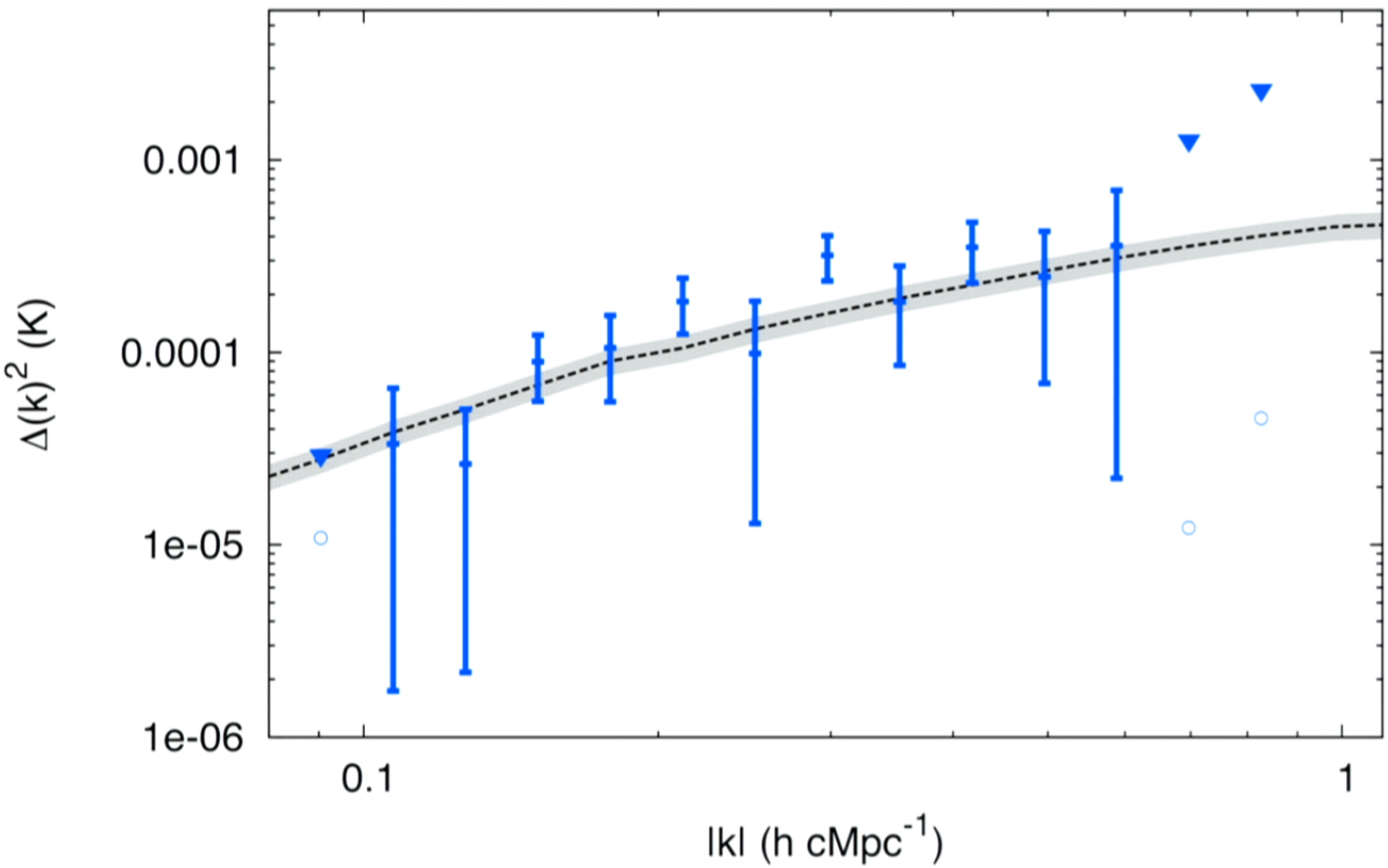
The real data



Signal-only simulations



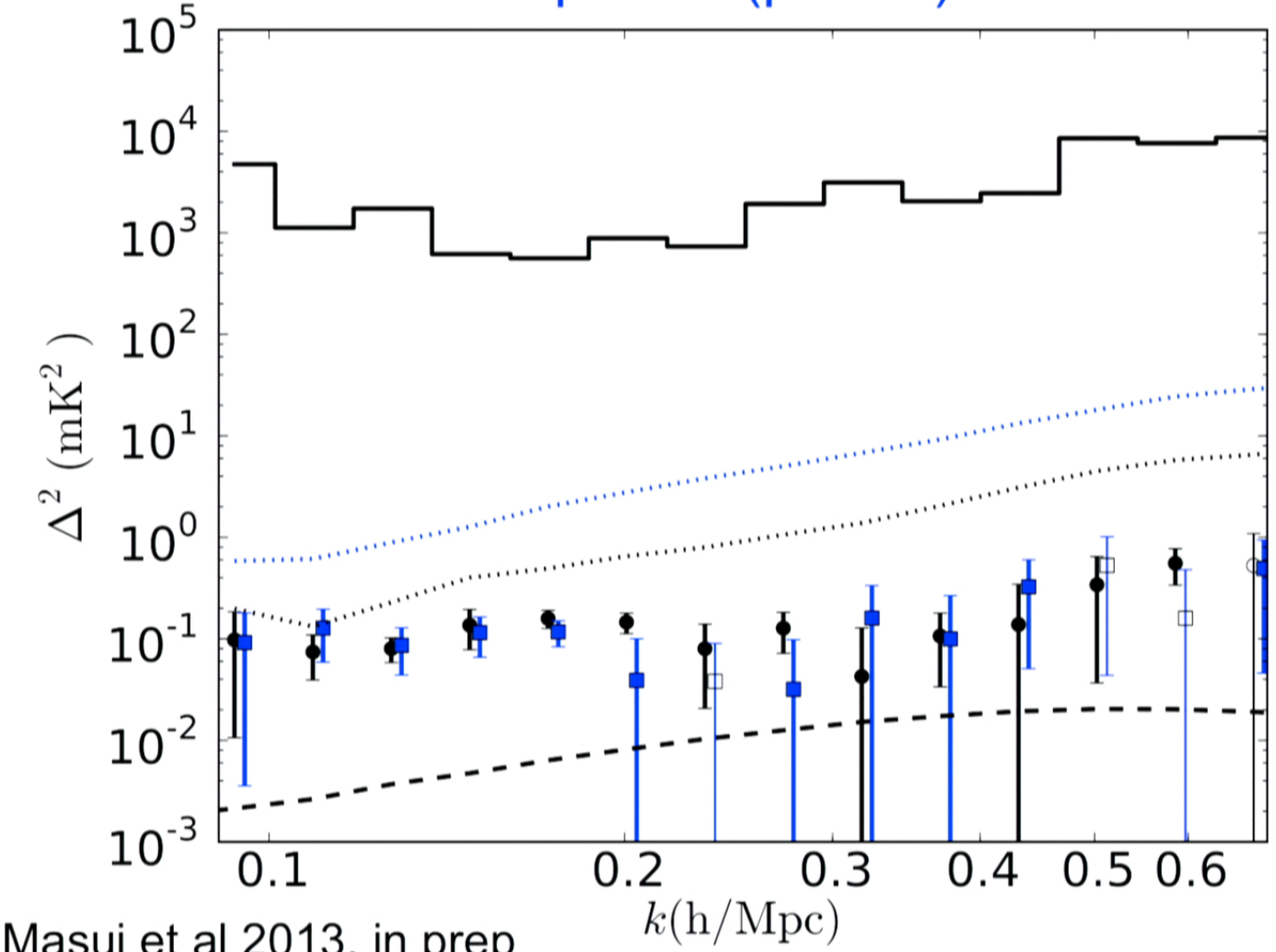

5hr_map_fdgcal_cleaned_noconv_combined-map_20modes (i = 0, freq = 899.6 MHz, z = 0.579, Dc=2107 cMpc)
Dec
3
2.5
2
1.5
1
215.5
216
216.5
217
217.5
218
218.5
219
219.5
220
RA
15
10
5
0
-5
-10
-15
Temperature (mK)



0.6<z<1, Masui et al 2013, GBT-IM collaboration.

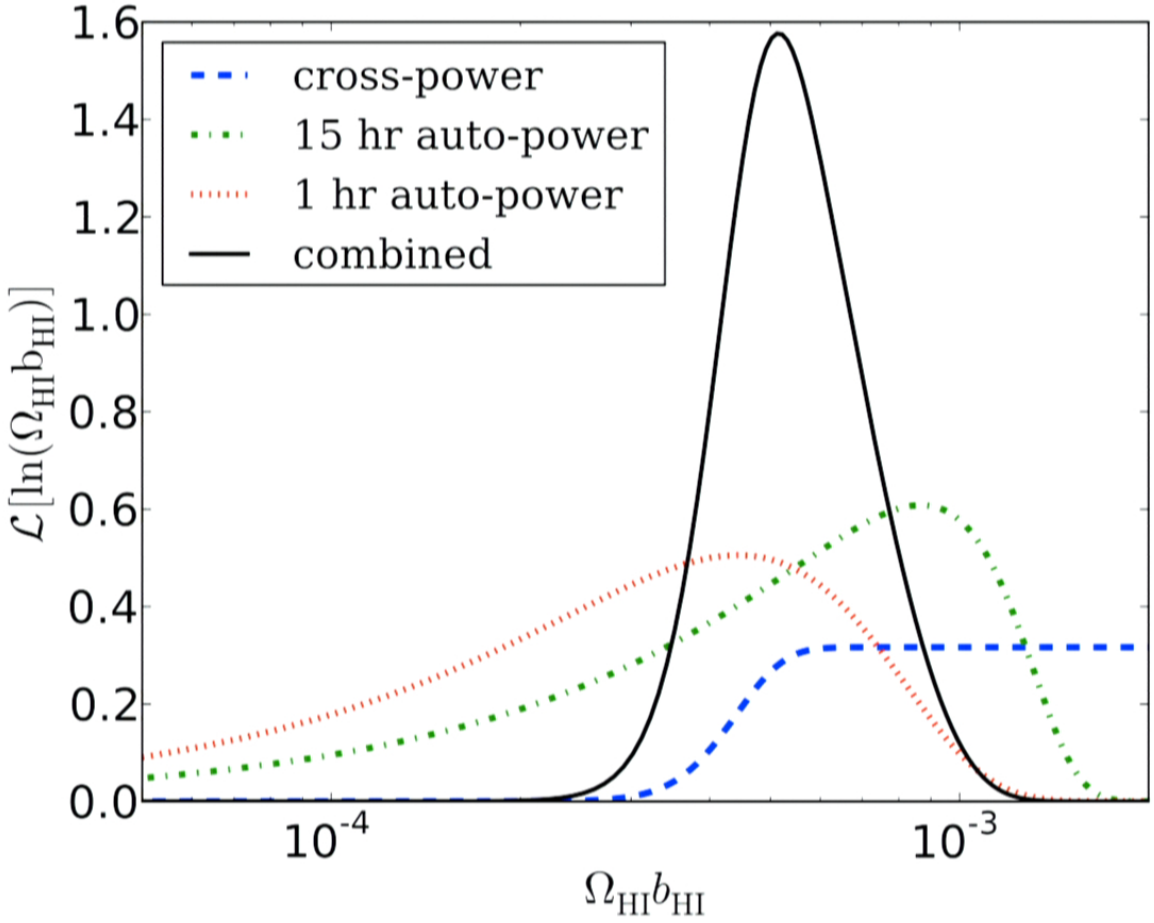
$$\Omega_{\rm HI} b_{\rm HI} r = [0.43 \pm 0.07({\rm stat.}) \pm 0.04({\rm sys.})] \times 10^{-3}$$

21cm self power (prelim)



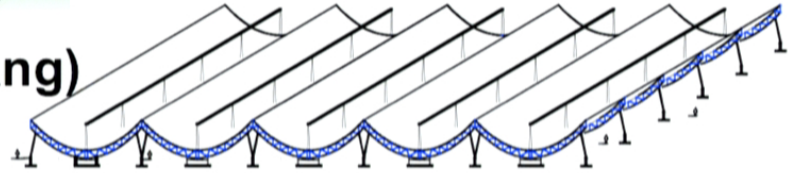
Masui et al 2013, in prep

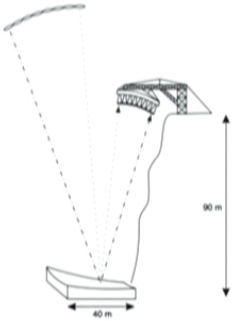
Current measure measurement of cosmic 21cm



Proposed experiments

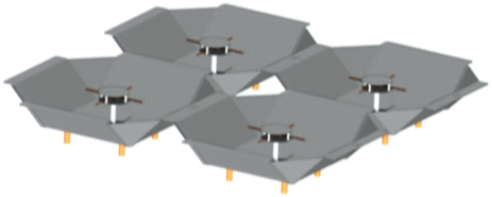
GBT-Multibeam (PI: T.-C. Chang)



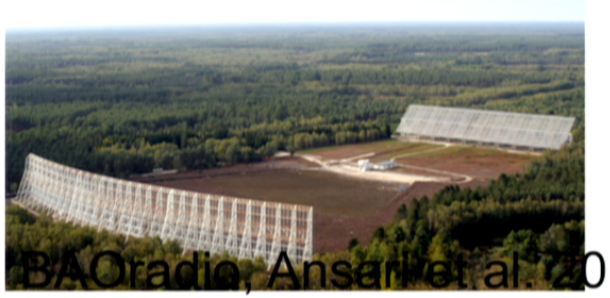


100x100m from 400 MHz to 800 MHz; noise ~50 K.
z=0.7-2.5: map the Dark Energy-driven transition,
20 Glyr/side ~0.2 Gpix. (design similar to CRT)

BINGO Battye et al. 2012



BAOBAB, Pober et al. 201

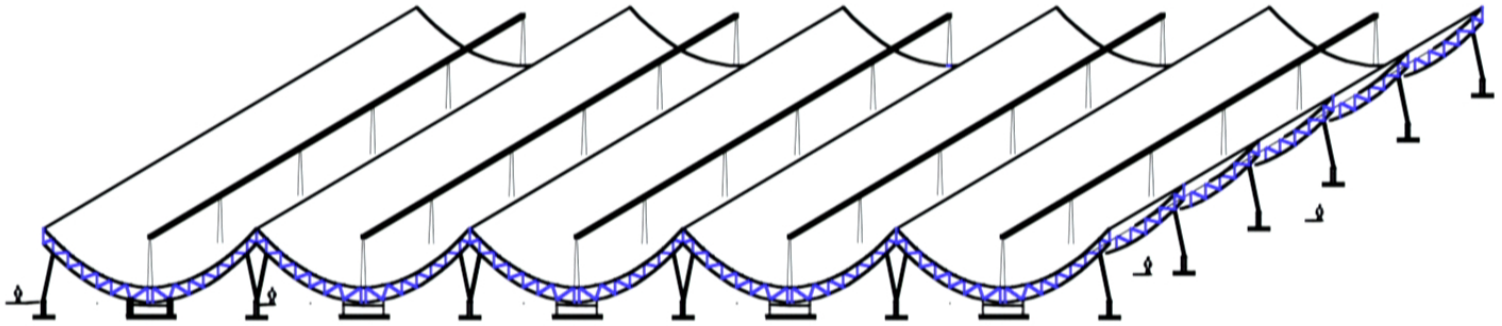


BAOradio, Ansari et al. 2012

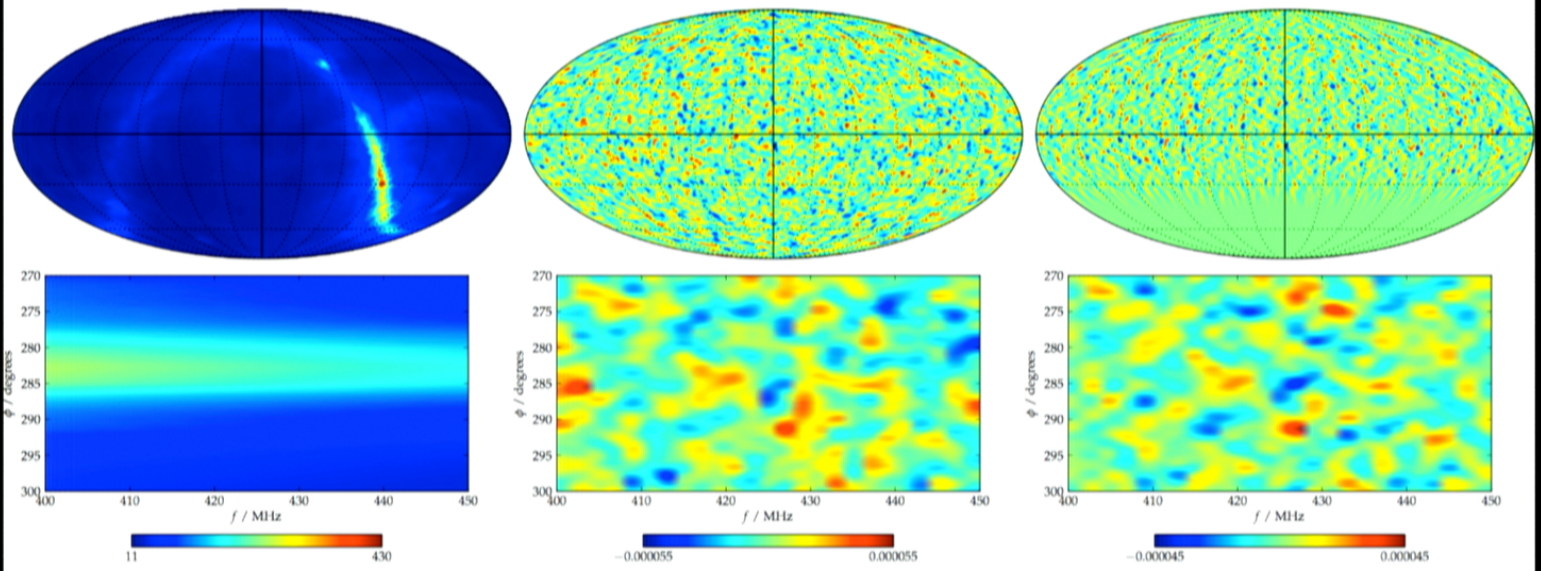
Canadian Hydrogen Intensity Mapping Experiment

Fast Fourier Transform Telescope:
CMU, CHIME, Tianlai, CRT, etc

CHIME: construction at Penticton, BC
CFI-funded collaboration: McGill, Toronto, UBC
Pathfinder (20%): Late 2013
Full operation: 2015



CHIME imaging and foregrounds: all sky m-mode



Shaw et al, 2013

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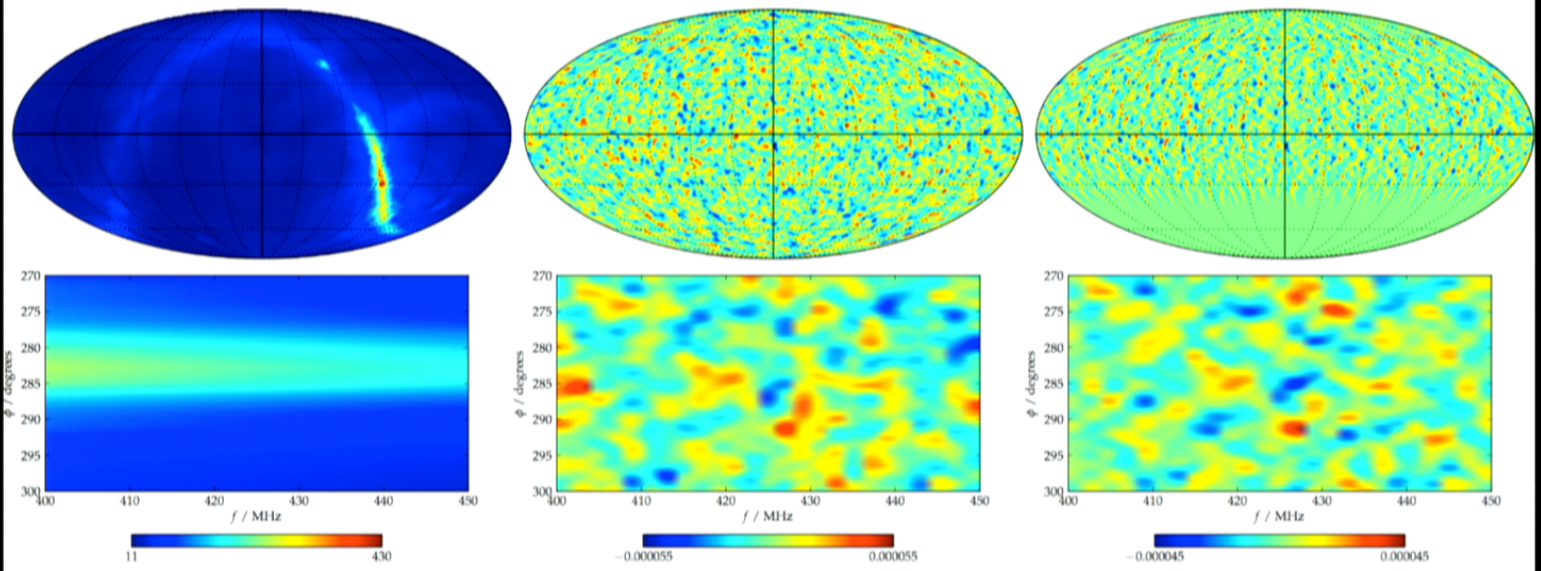
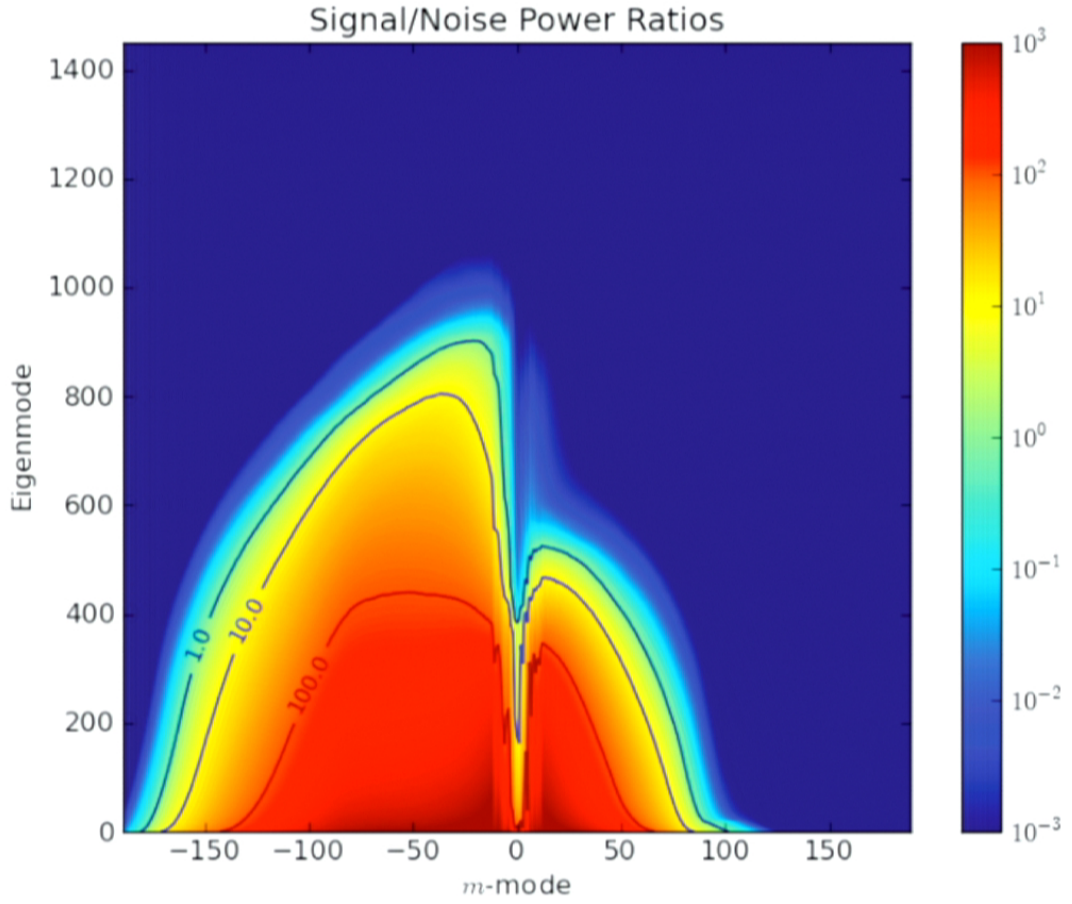


Shaw et al, 2013

S/N Ratio of Modes



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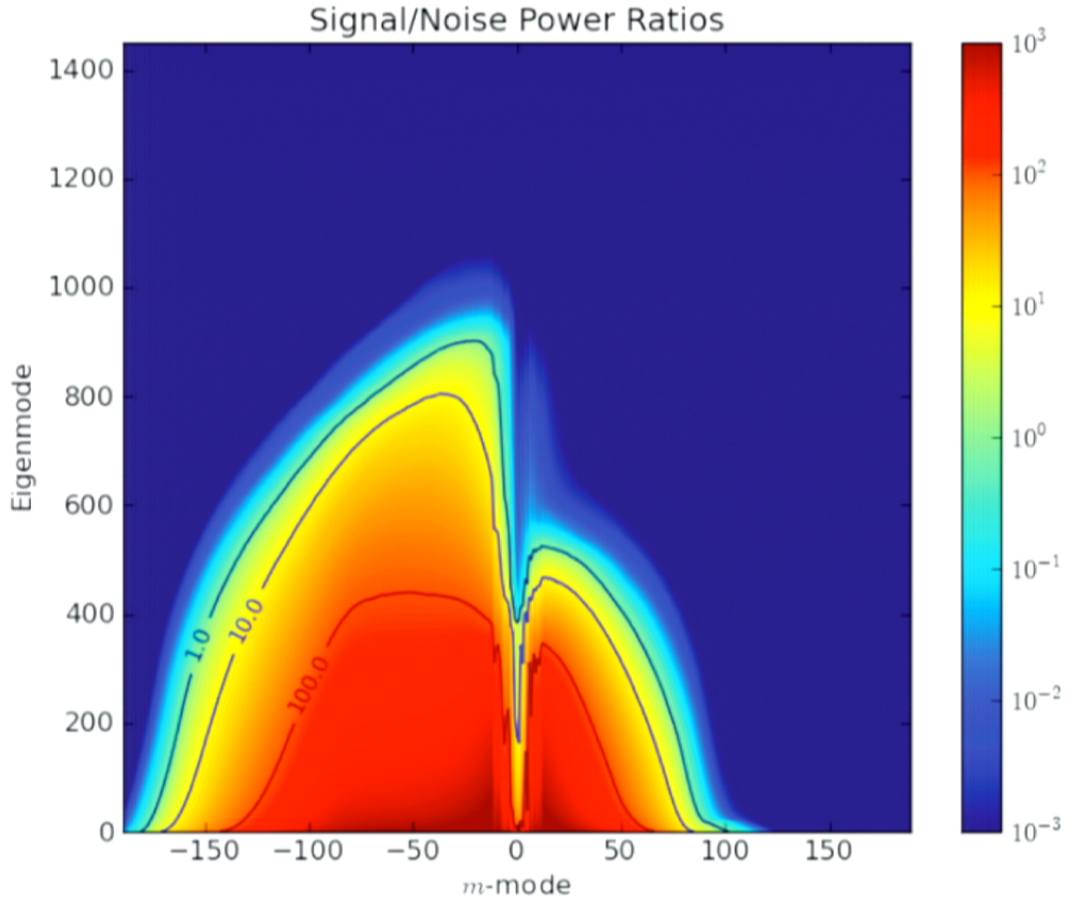

Primordian Gravitational Waves

- Masui & Pen 2010 (PRL 105, 161302)
- Analogous to lensing: shearing of cosmic structure.
- Fossil memory effect: $h \sim 10^{-6}$ (inflation)
- Measure r, n_T at $z \sim 15$
- Requires $1/h^2$ modes
- Separates from lensing: transverse traceless
- Structures available to $k \sim 10^{-3}$-10^{3}:horizon to Jeans scale, $\sim 10^{18}$ modes, peaks at $z \sim 15$

Linear gravity wave memory

- GW in initial condition, then redshifts away

$$ds^2 = a(\eta)^2 \left[-d\eta^2 + (h_{ij} + \delta_{ij})dx^i dx^j\right].$$

$$\tilde{x}^\alpha = (x^\alpha - \frac{1}{2}h_{\alpha\beta}x^\beta),$$

$$P(\overrightarrow{k}) = \tilde{P}(k) - \frac{k_i k_j h_{ij}}{2k}\frac{d\tilde{P}}{dk} + O(\frac{k_T}{k}h_{ij}) + O({h_{ij}}^2)$$

$$h_{ij} \propto \langle \partial_i \delta \partial_j \delta \rangle$$

$$r_{min} \approx 7.3 \left(\frac{1.2\,\mathrm{Mpc}/h}{k_{max}}\right)^3 \left[\frac{200\,(\mathrm{Gpc}/h)^3}{V}\frac{3.3\,(\mathrm{Gpc}/h)^3}{V_H}\right]^{1/2}. \quad (14)$$

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Detectability

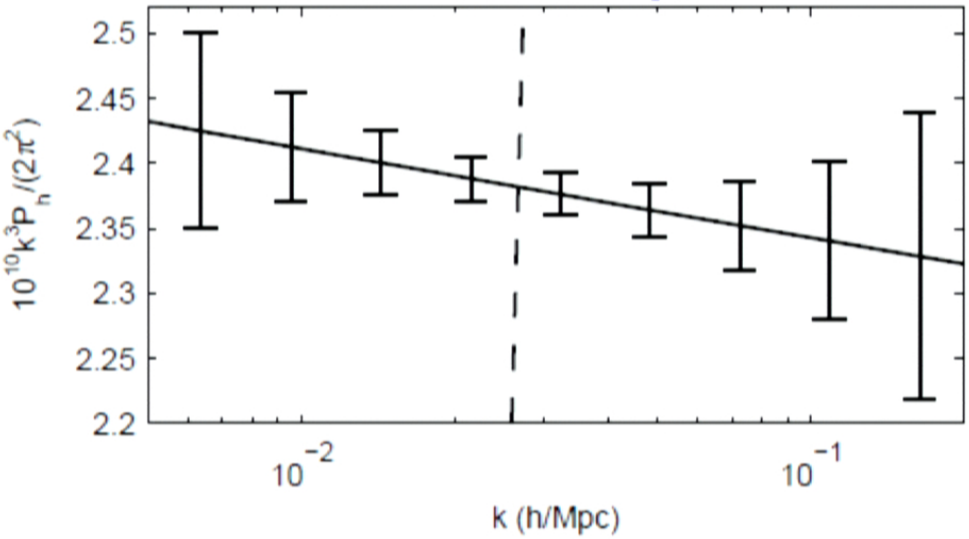

FIG. 1: Primordial tensor power spectrum obeying the consistency relation for $r = 0.1$. The solid line is the tensor power spectrum. Error bars represent the reconstruction uncertainty on the binned power spectrum for a perfect experiment, surveying $200\,(\mathrm{Gpc}/h)^3$ and resolving scalar modes down to $k_{max} = 168h/\mathrm{Mpc}$. The dashed, nearly vertical, line is the reconstruction noise power. The non-zero slope of the solid line is the deviation from scale-free.

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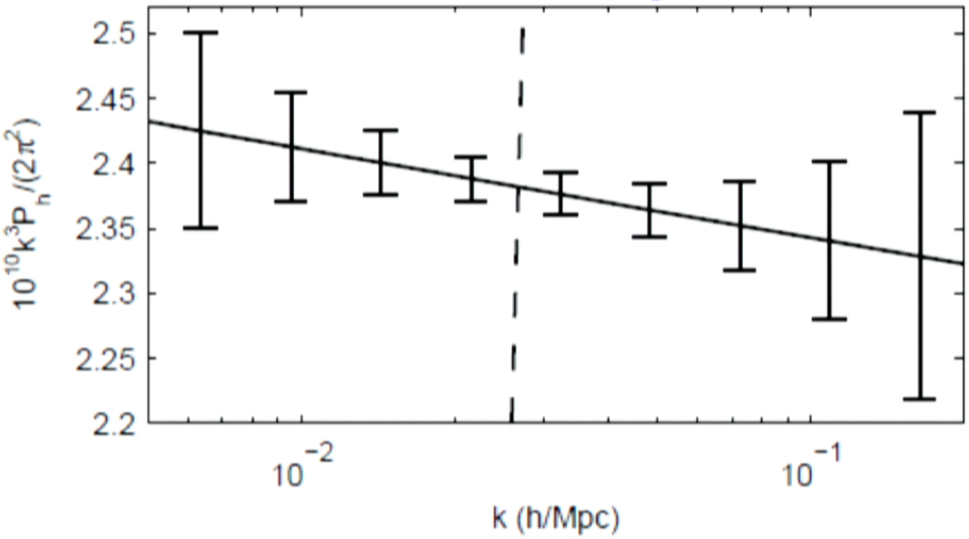

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Conclusions

- 21cm cosmology: probes of neutrinos, dark energy (BAO), Inflation (tensor modes), etc. Potential measure of gravity waves.
- Intensity Mapping: 21cm unresolved galaxies, accessible in redshift desert z=1-3, initial HI detection and surveys with GBT at z~1. Attractive window at z=15.
- CHIME: Canadian world-leading radio initiative
- Challenges in foreground subtraction: new S/N eigenmode theory for optimal subtraction.