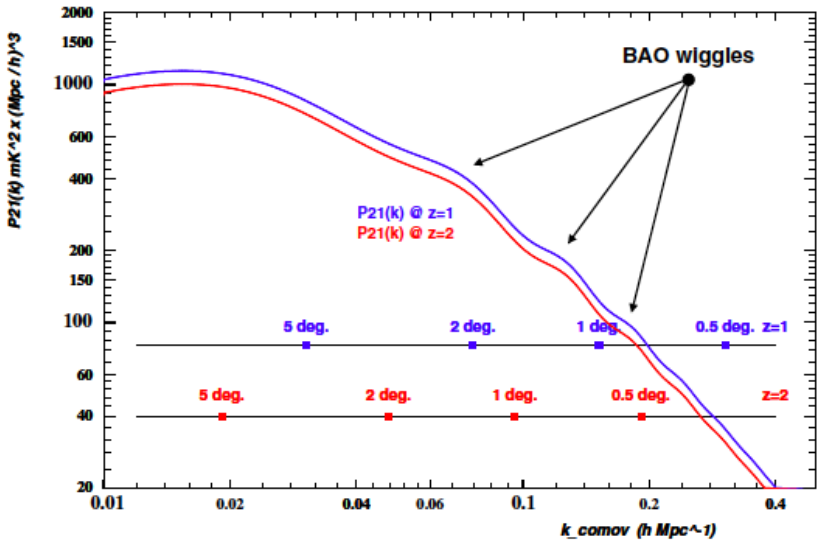
21cm Intensity Mapping/BAO Following Ger's footsteps: Gerfeest 2013

Ue-Li Pen

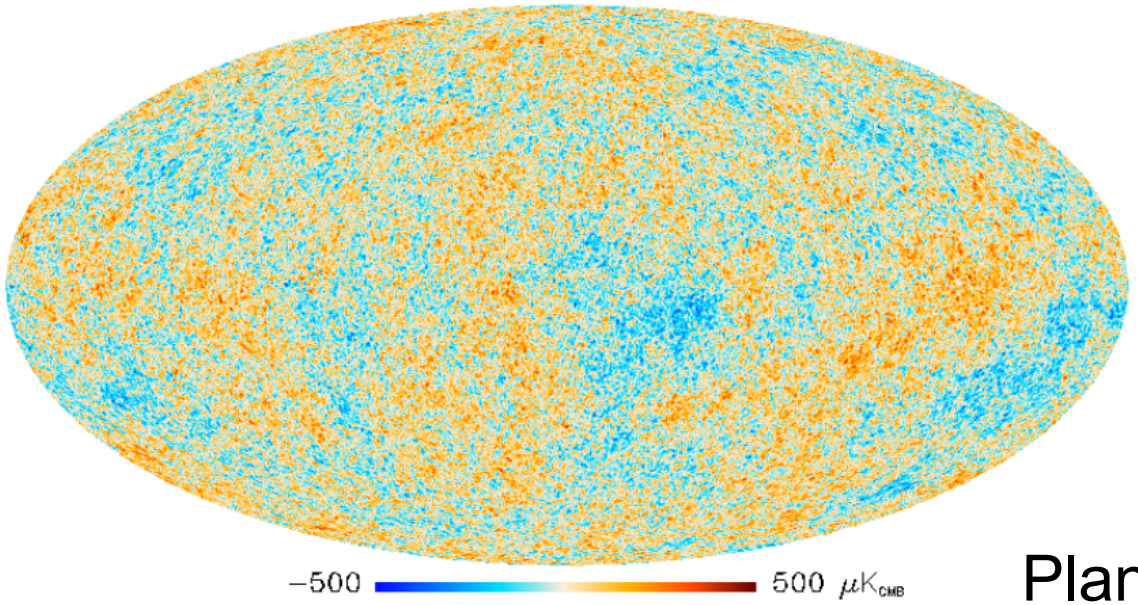
21cm BAO

http://www2.iap.fr/pnc/Enoire2007/Yeche.pdf

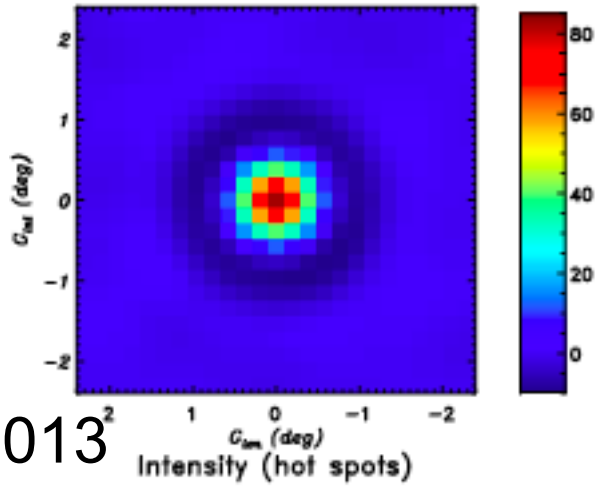
- Universe transparent to redshifted 21cm in optical 'redshift desert' 1<z<2
- Ansari+ 2006+: dark energy, etc



1. H_I 21 cm emission power spectrum at redshifts $z = 1$ (blue) and 2 (red), with neutral gas fraction $f_{H_I} = 2\%$.

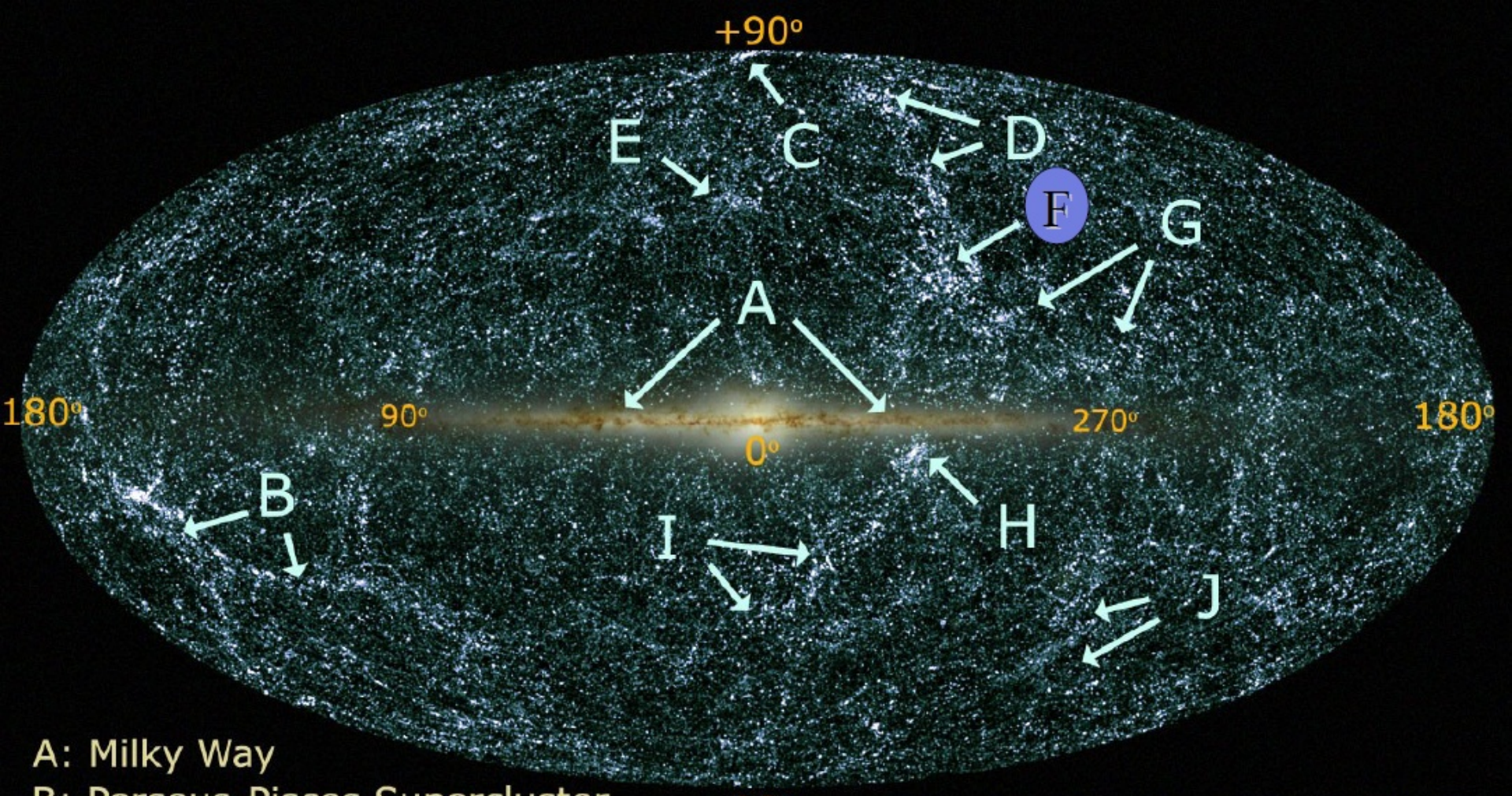


Planck 2013



Intensity Mapping

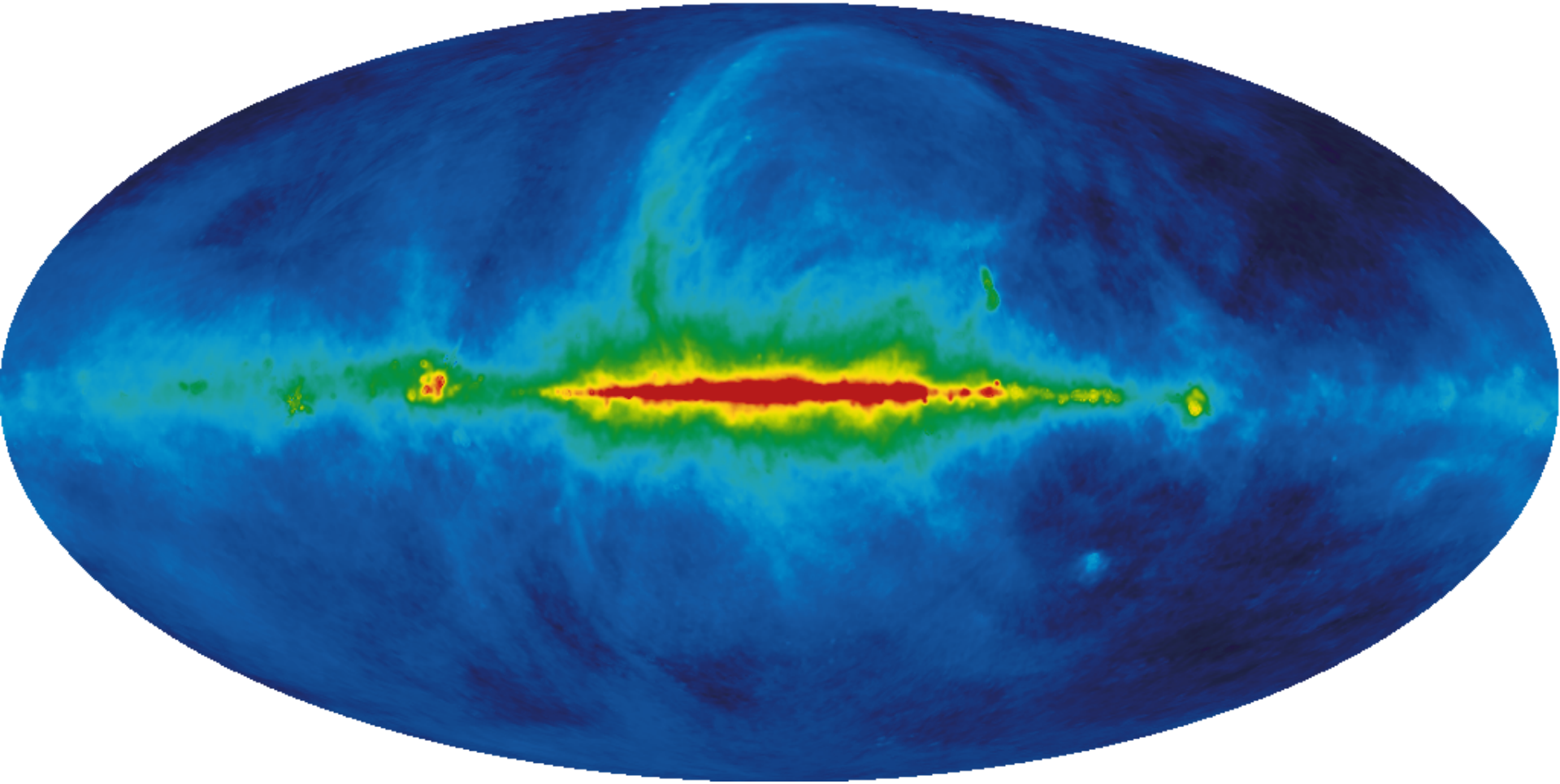
- Stars get fainter with distance: hard to see individually at cosmological distance. Galaxies still visible.
- Galaxies get fainter with distance: hard to see in HI. Large scale structure still visible?
- Large scale structure is LARGE: degree scale. High resolution not needed.
- Modest size, monolithic radio telescopes needed. (Ansari+ 2006+,CPPM 2008, Wyithe&Loeb 2008)
- How much 21cm structure is there at z=1?



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

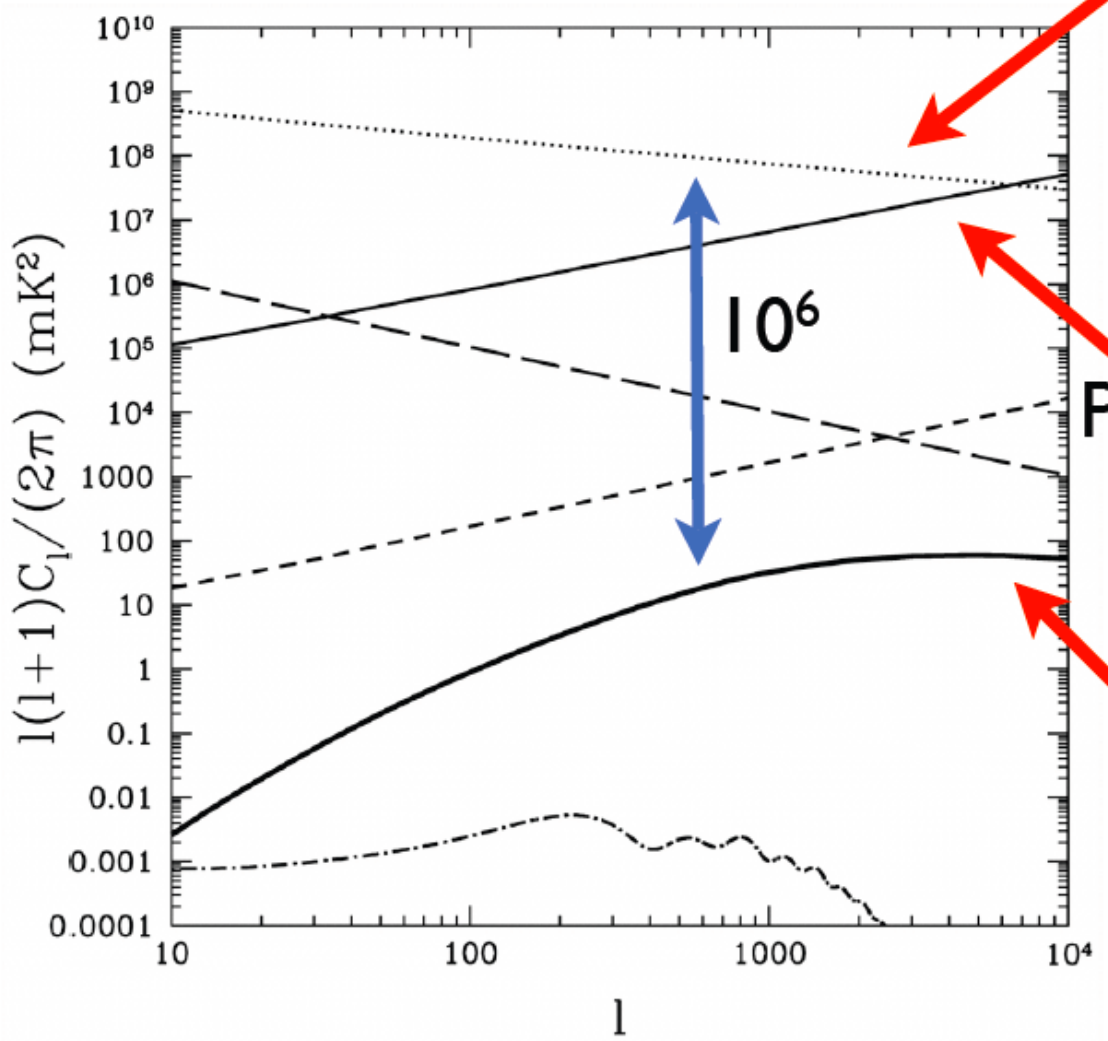
Foreground: Galactic Synchrotron



Haslam 408 MHz

Much brighter than signal, but no spectral structure

Foregrounds



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

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.

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Two months later:

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

LETTERS

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

Tzu-Ching Chang[1,2], Ue-Li Pen[2], Kevin Bandura[3] & Jeffrey B. Peterson[3]

Optimal Foreground Subtraction

Premise: foregrounds are 1000x brighter, but smooth in frequency

Challenge: instrument is always mixes spatial structure with frequency structure: Diffraction limit. Worse for interferometers

Solution: S/N eigenmode analysis. Analogous to Bunn et al CMB E/B mode mixing. Shaw et al 2012, in prep

GBT 21 cm intensity mapping collaboration

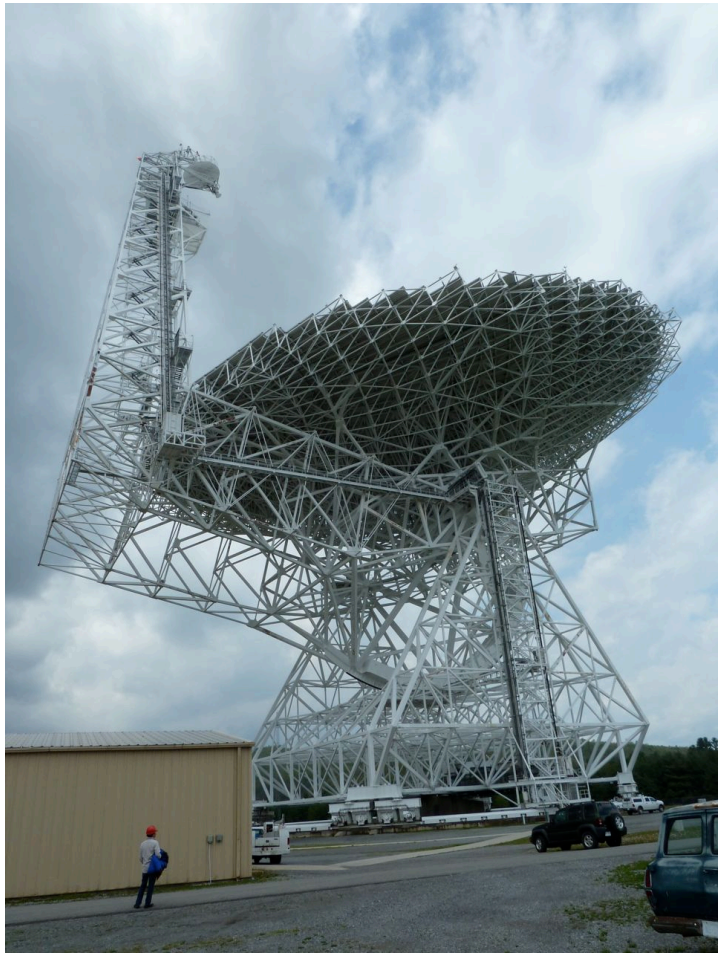
Academia Sinica (Tzu-Ching Chang, Victor Yu-wei Liao)

Beijing (Xuelei Chen, Yi-Chao Li)

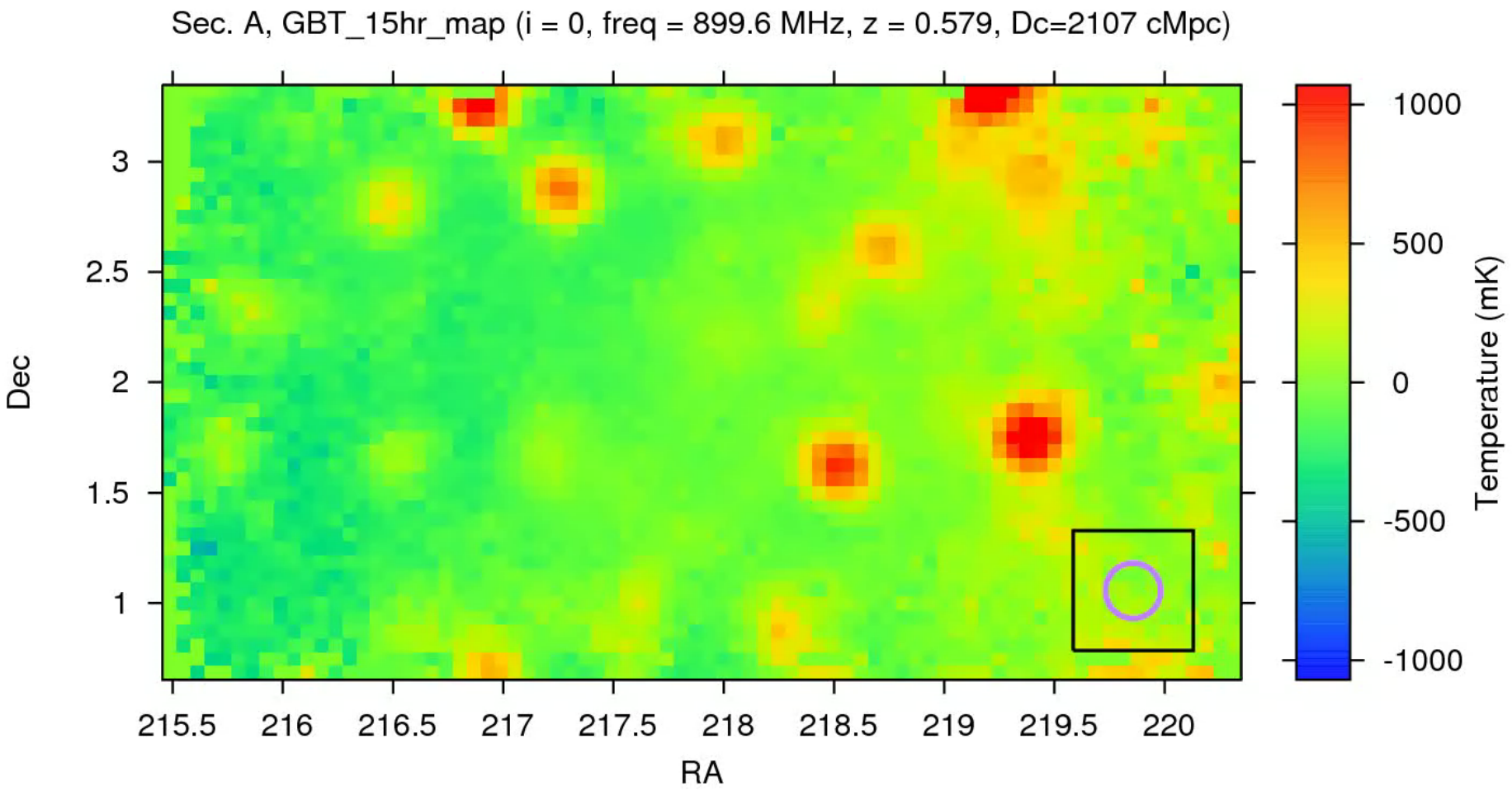
Carnegie Mellon University (Aravind Natarajan, Jeff Peterson, Tabitha Voytek)

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

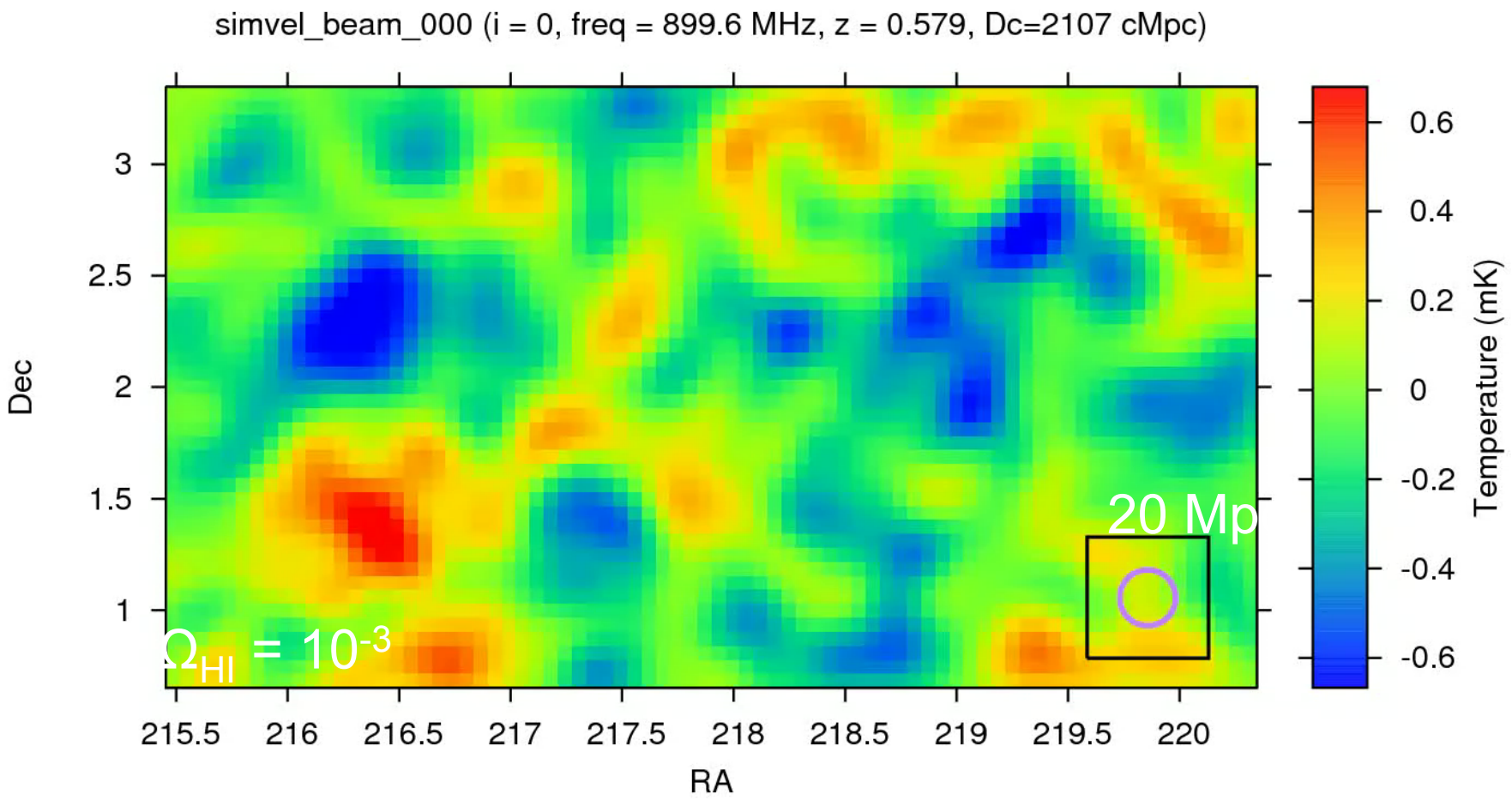
McGill (Kevin Bandura)



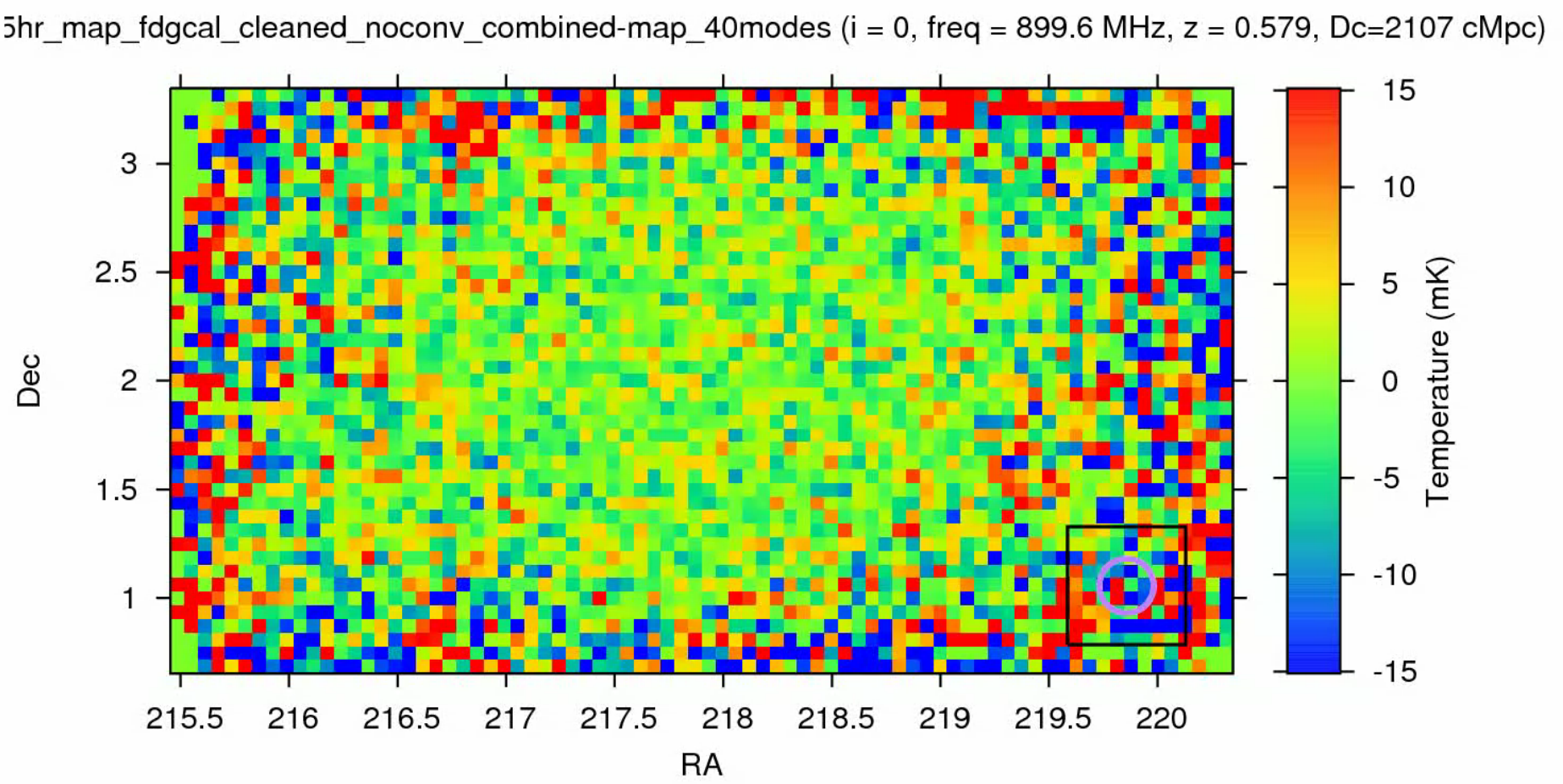
The real data

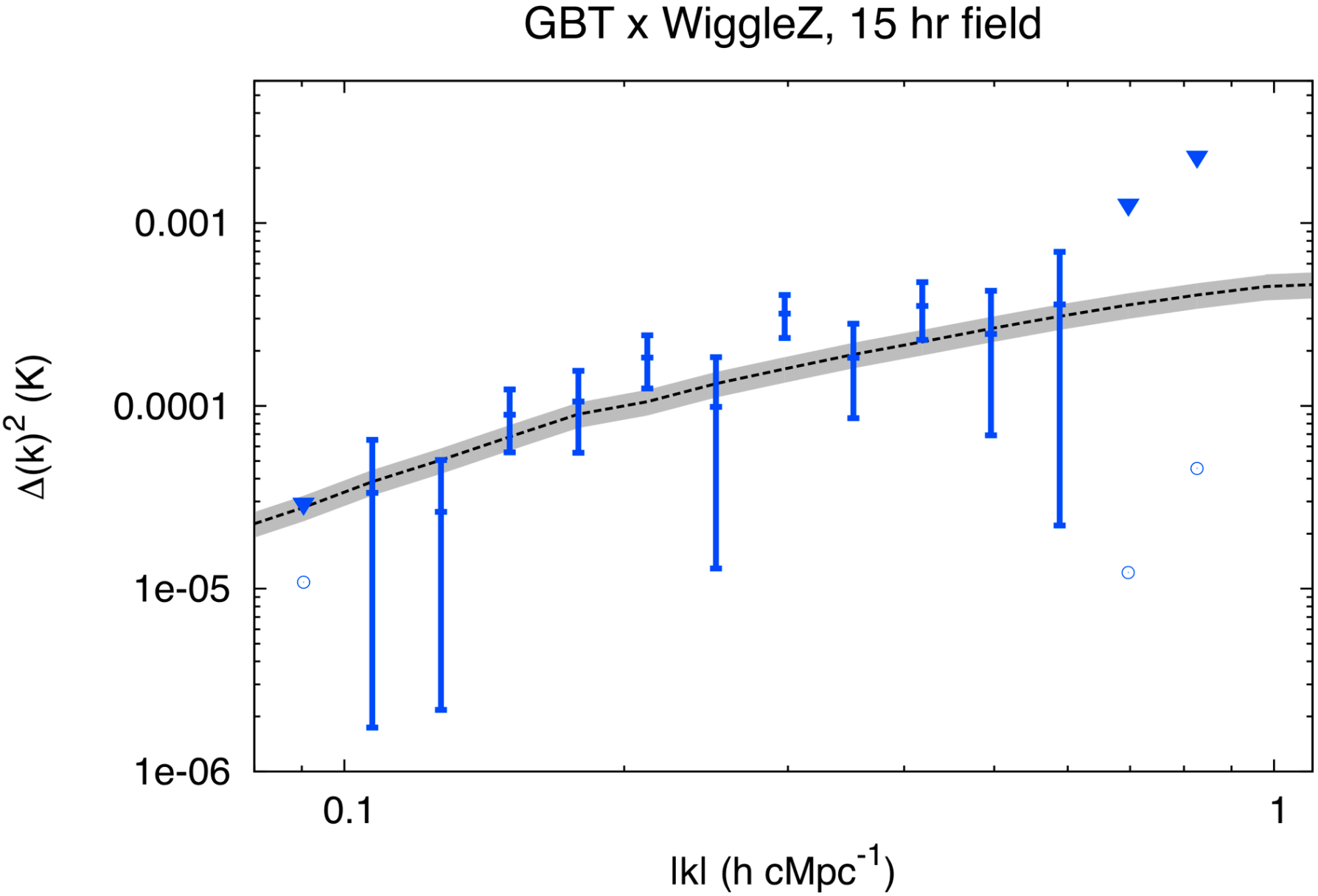


Signal-only simulations



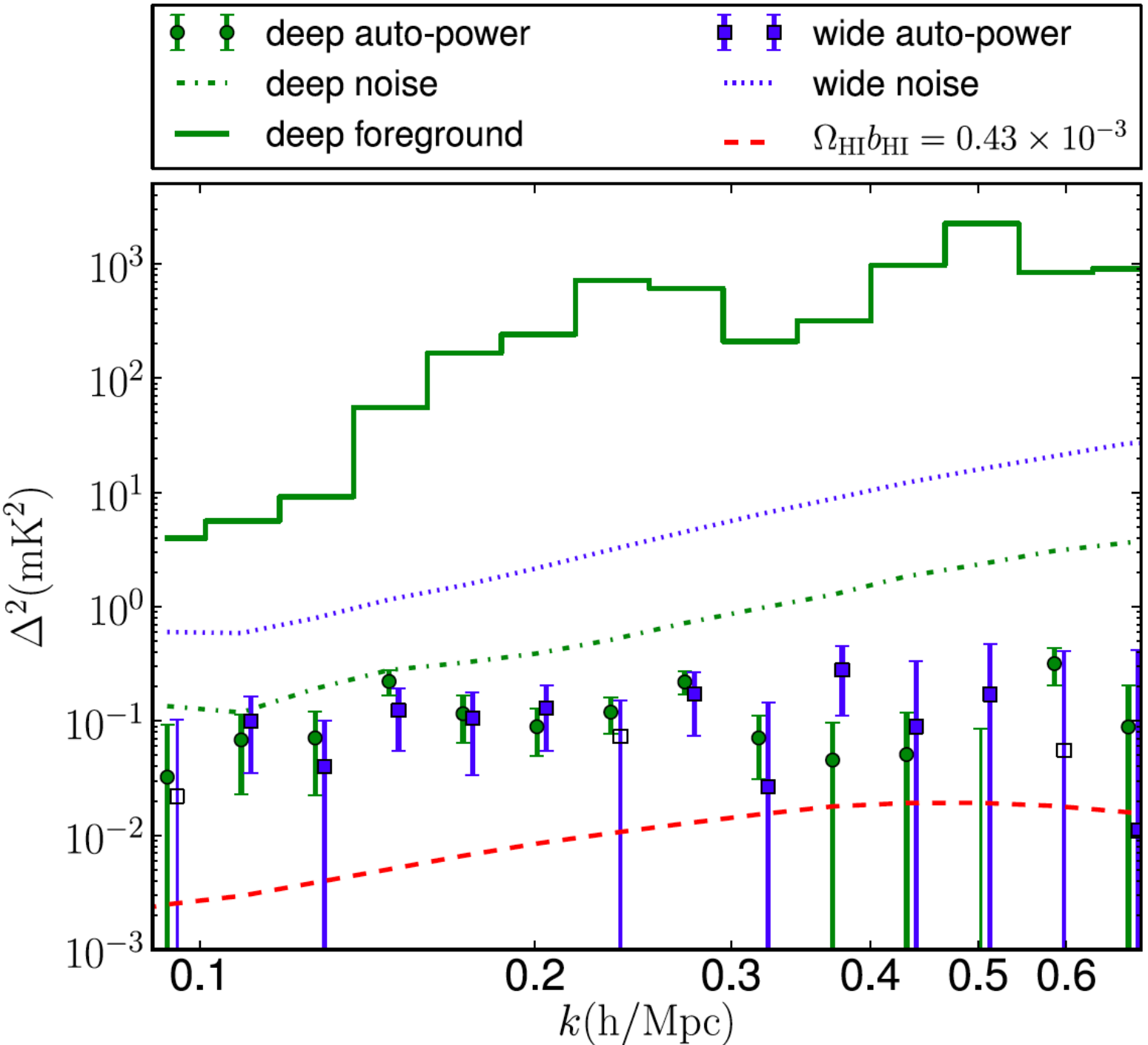
Foreground subtracted



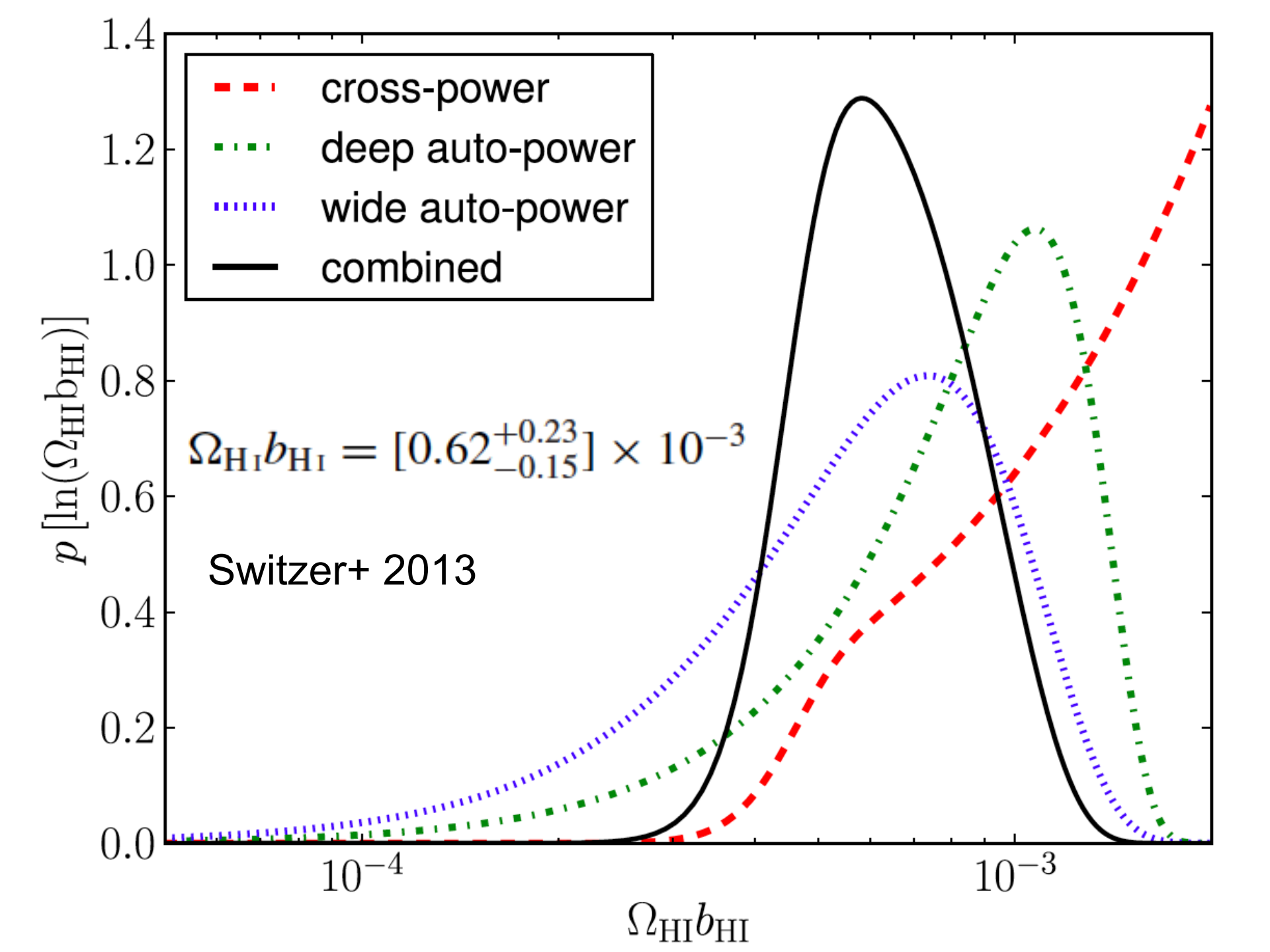


0.6<z<1, Masui et al 2013, GBT-IM collaboration.

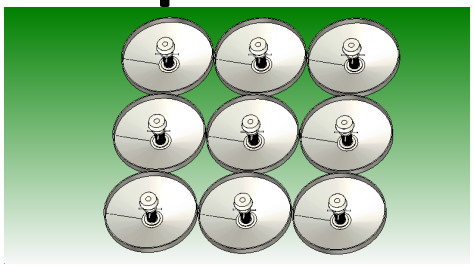
$$\Omega_{\rm HI} b_{\rm HI} r = [0.43 \pm 0.07({\rm stat.}) \pm 0.04({\rm sys.})] \times 10^{-3}$$



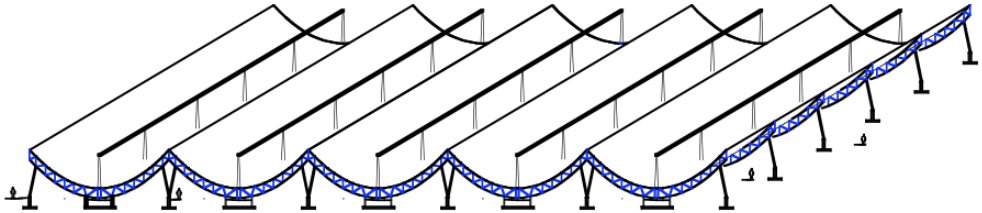
Switzer et al 2013, GBT-IM collaboration


cross-power
deep auto-power
wide auto-power
combined
$\Omega_{\rm HI} b_{\rm HI} = [0.62^{+0.23}_{-0.15}] \times 10^{-3}$
Switzer+ 2013
$p\,[\ln(\Omega_{\rm HI} b_{\rm HI})]$
$\Omega_{\rm HI} b_{\rm HI}$
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
10^{-4}
10^{-3}

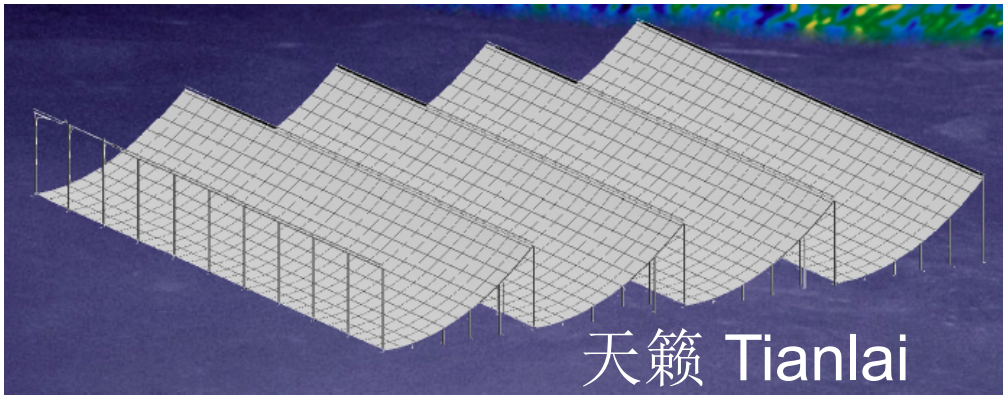
upcoming IM experiments



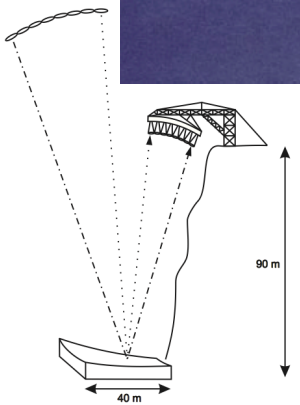
GBT-Multibeam (T.-C. Chang)



CHIME: 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.

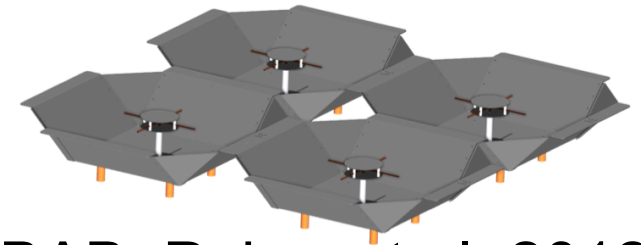


Parkes IM, Staveley-Smith 2013



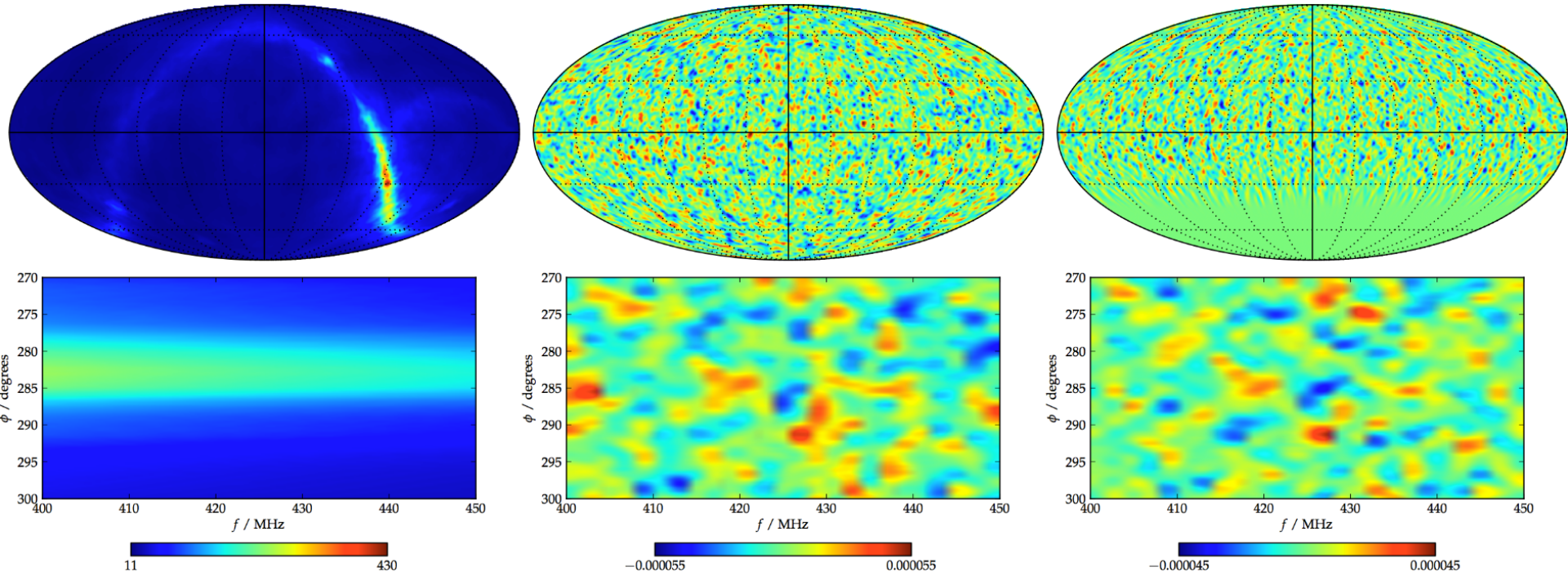
BINGO Battye et al. 2012

BAO



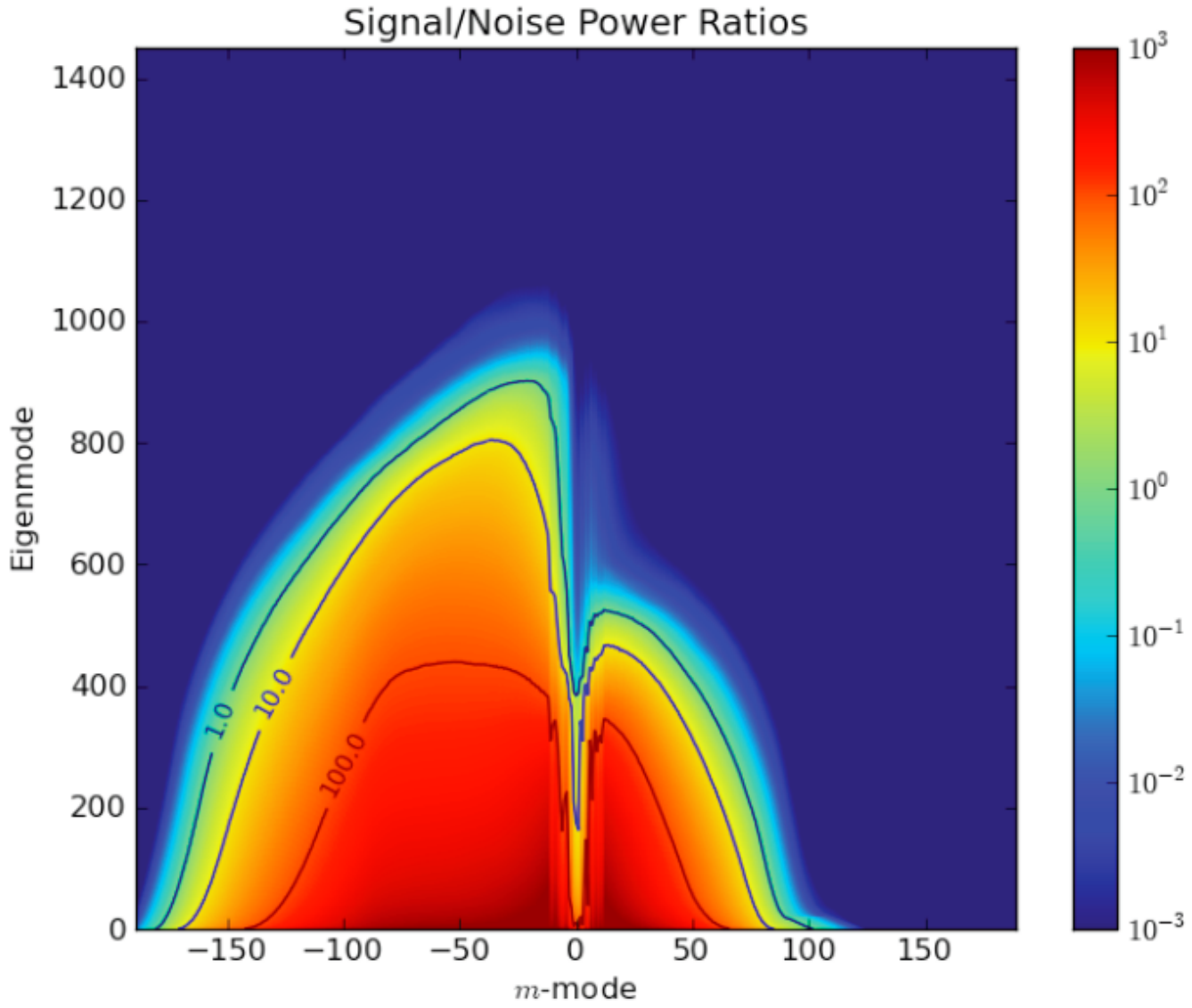
BAOBAB, Pober et al. 2012

CHIME imaging and foregrounds: all sky m-mode



Shaw et al, 2013

S/N Ratio of Modes



IM science

- lensing, tides
- Neutrino dipole distortions
- Fast radio bursts
- Pulsar monitoring
- Pulsar searching
- EoR? Filled aperture? Cylinders?

Conclusions

- Intensity Mapping: 21cm unresolved galaxies, accessible in redshift desert z=1-3, initial HI detection and surveys with GBT at z~1. Multiple surveys under construction.
- First measurement of 21cm fluctuations at z~1, factor of 5 lower than previous optimistic estimates
- CHIME: Canadian world-leading 21cm-IM initiative
- Ancillary science: FRB, pulsar, ESE, RM, any many more
- Challenges in foreground subtraction: new all-sky imaging, S/N eigenmode theory for optimal subtraction.