21cm Intensity Mapping

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on behalf of

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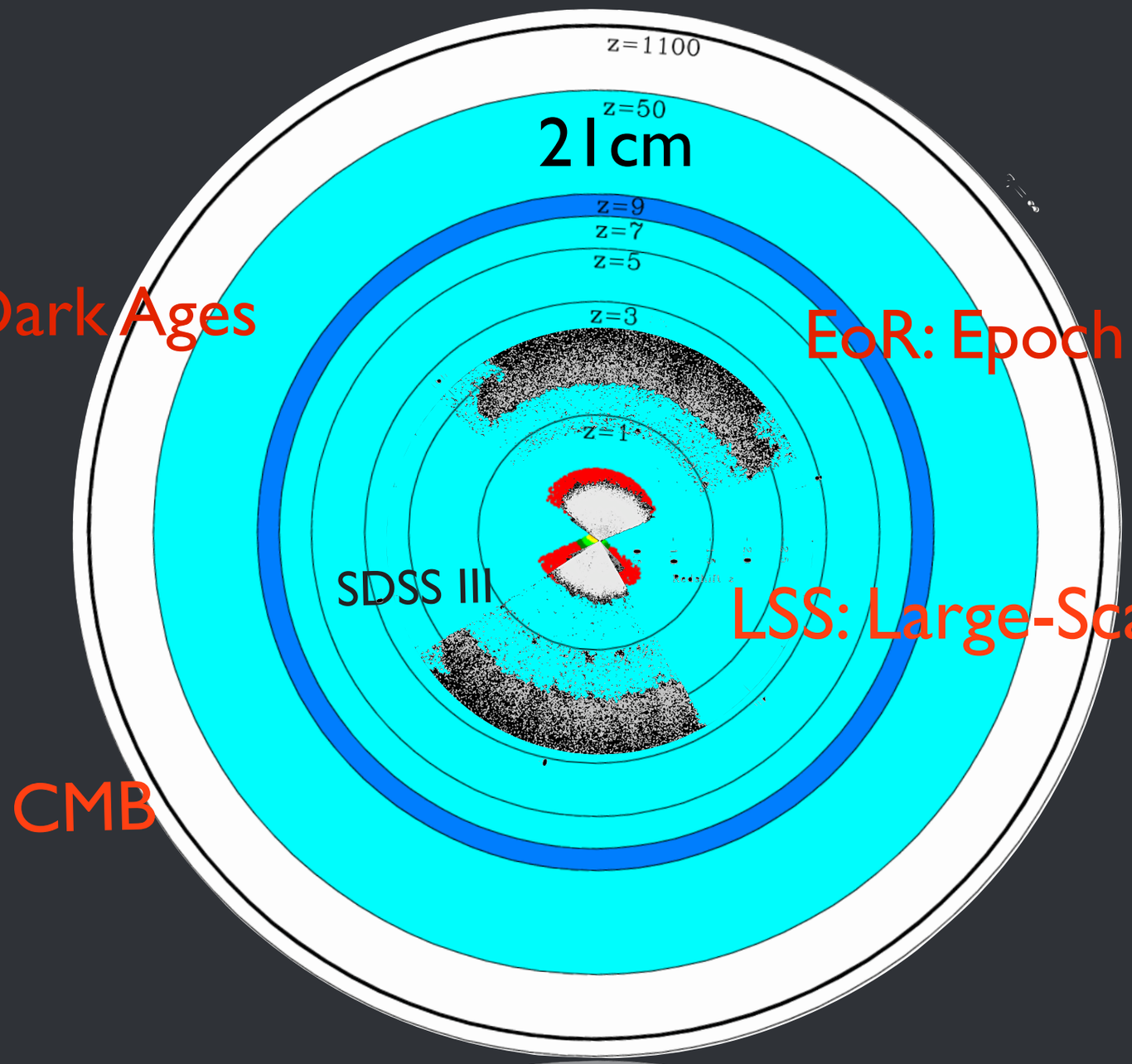
Chris Anderson, Peter Timbie (U. Wisc)
Yuh-Jing Hwang, Ching-Ting Ho, Chi-Chang Lin(ASIAA)
Rich Bradley, John Ford, Sri Srikanth, Steve White (NRAO)

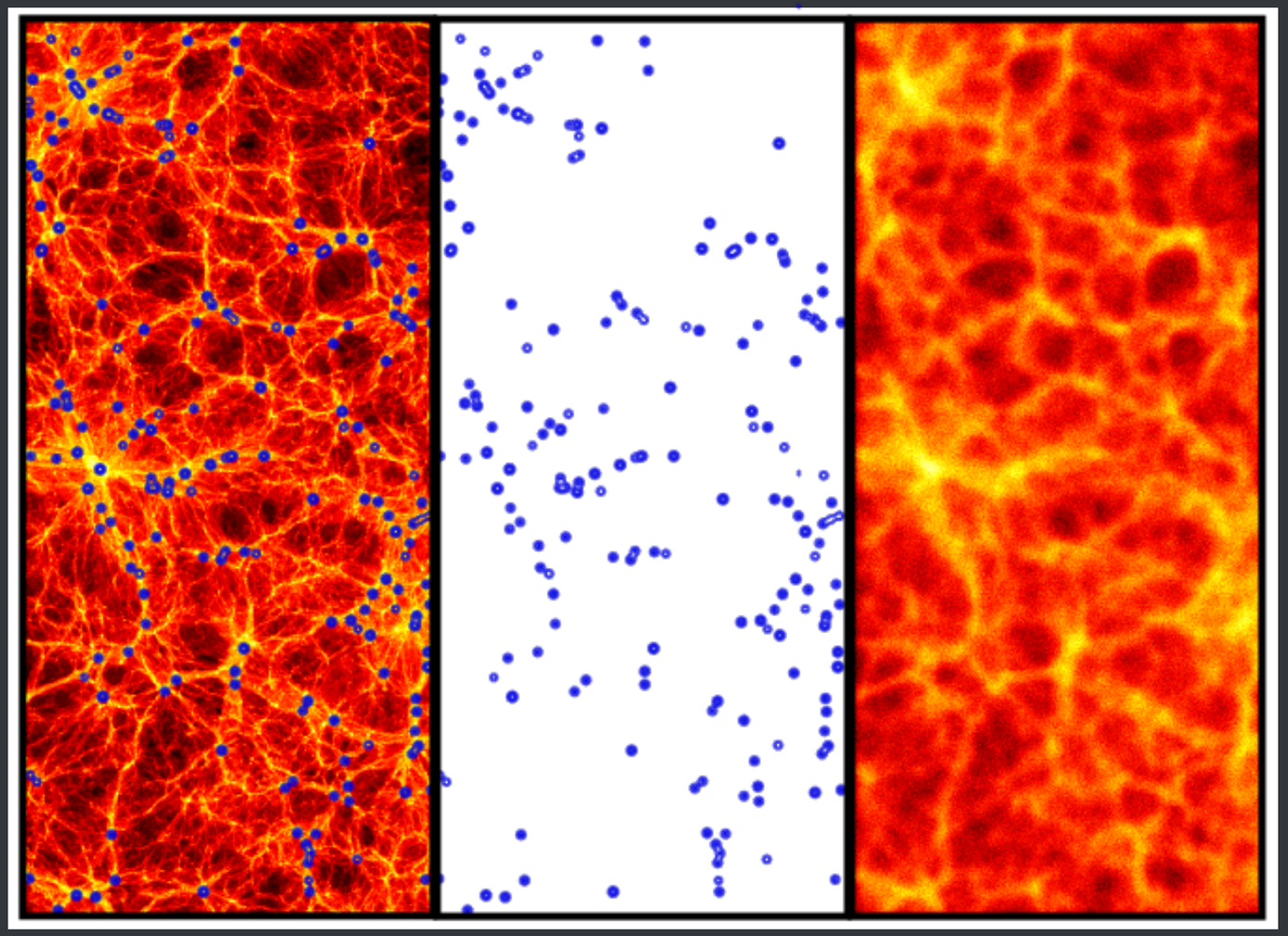
21cm Cosmology



- Up to 10^{16} modes to z~50 $(\text{Hubble/Jeans})^3$

derived from Tegmark & Zaldarriaga 08

Line Intensity Mapping



courtesy of Phil Krongut (Caltech)

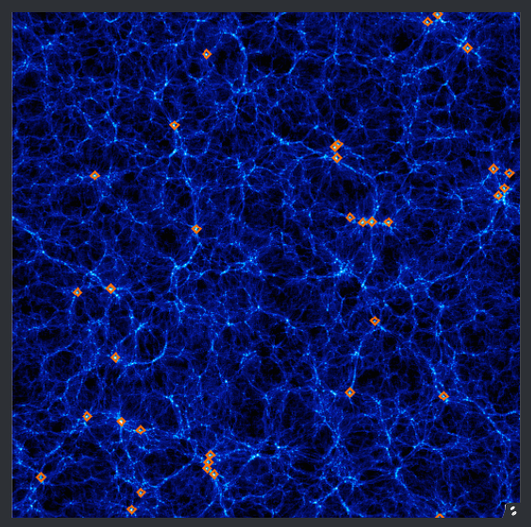
- "Intensity Mapping" (Chang+ 2008, Wyithe & Loeb 2008):
  - Measure the collective emission from a large region, more massive and luminous, without spatially resolving down to galaxy scales.
- Retain high frequency resolution thus redshift information
- Brightness temperature fluctuations on the sky: just like CMB temperature field, but in 3D
- Low-angular resolution redshift surveys: LSS sciences, economical
- Confusion-limited. Foreground-limited.

Current 21cm Intensity Mapping Efforts

Intensity mapping: low-resolution, not resolving individual sources, CMB-like, in 3D

1 10 z

LSS; BAO

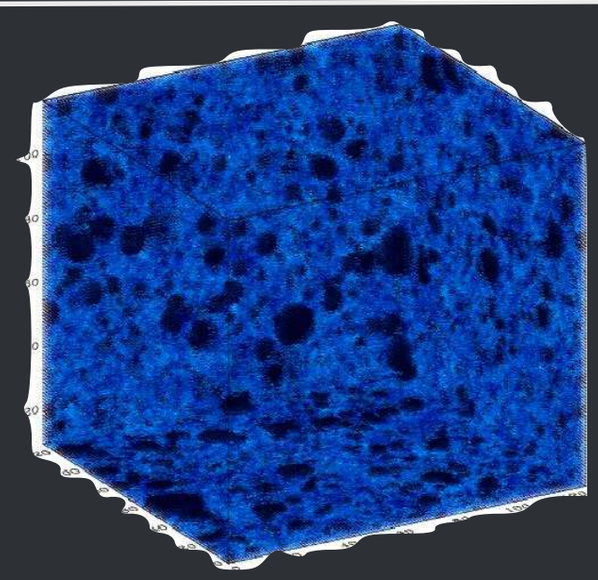


M. White

- 0.5<z<2.5, HI traces underlying matter distribution, can be used to measure Baryon Acoustic Oscillations (BAO), 109 h^{-1} Mpc scale => dark energy

- CHIME, Tianlai, HIRAX, GBT-HIM

EoR



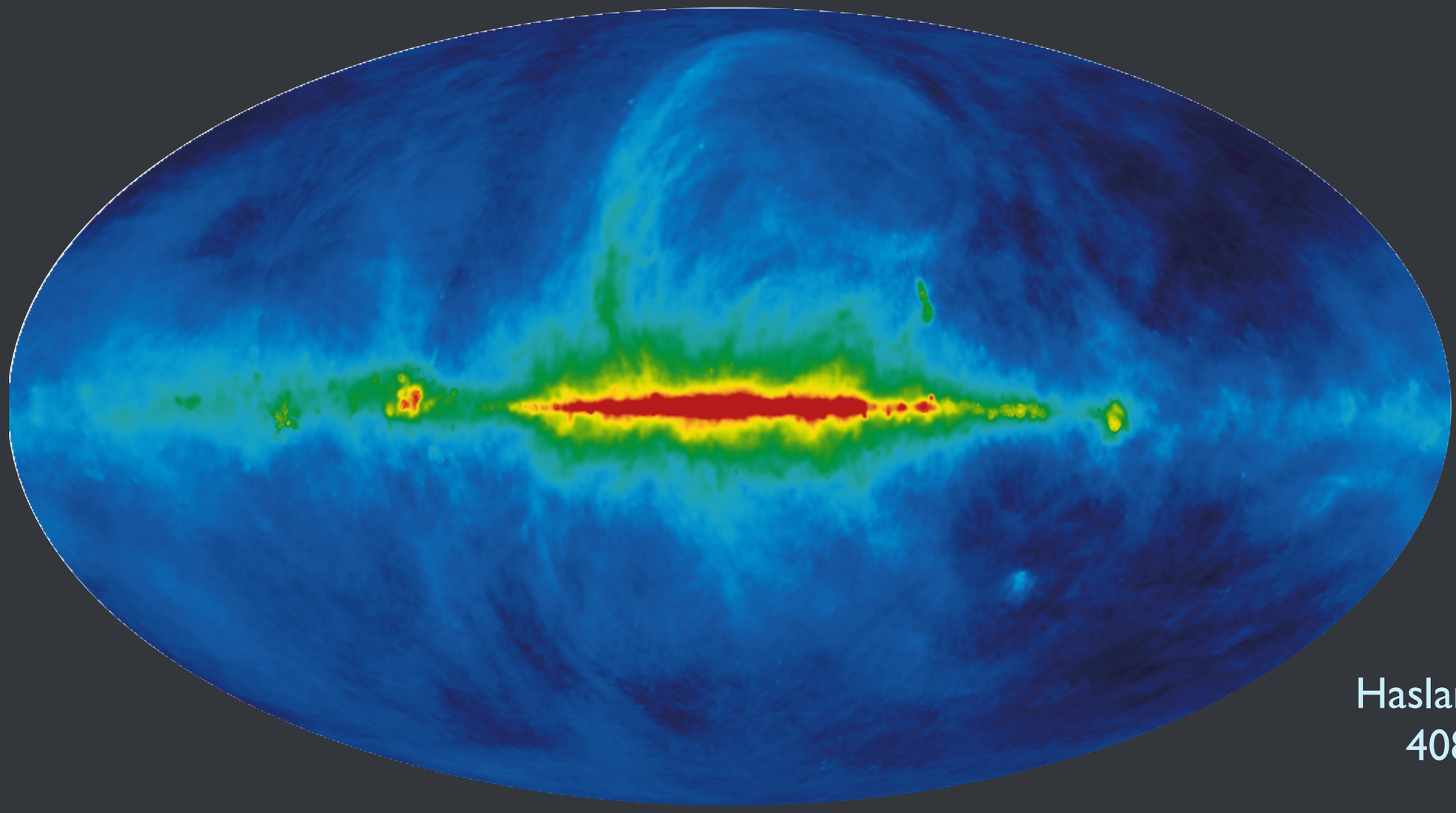
- 6<z<10, Epoch of Reionization (EoR), HI shows tomographic history of reionization, ~20-50 Mpc scale => astrophysics

- LOFAR, PAPER, MWA, GMRT-EoR, HERA, SKA1-LOW

21cm Intensity Mapping

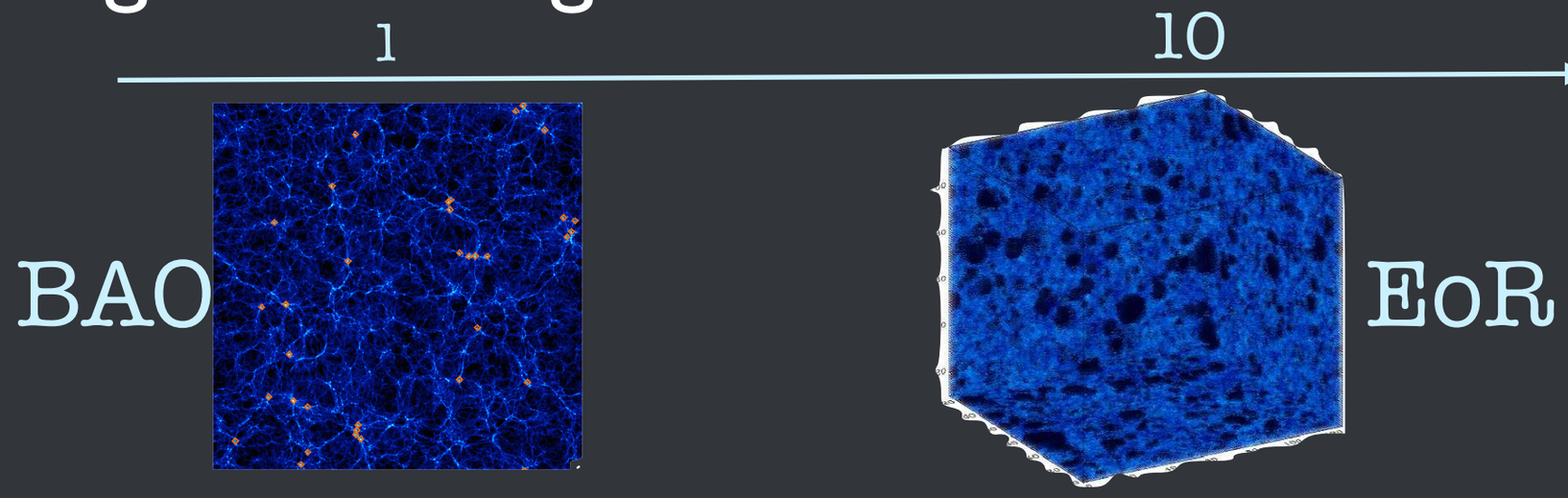
Observational Challenges:

- Galactic/extra-galactic Synchrotron foregrounds > 10^3 x HI signals
- Radio Frequency Interference, ionosphere fluctuations
- Require high-precision control of systematics



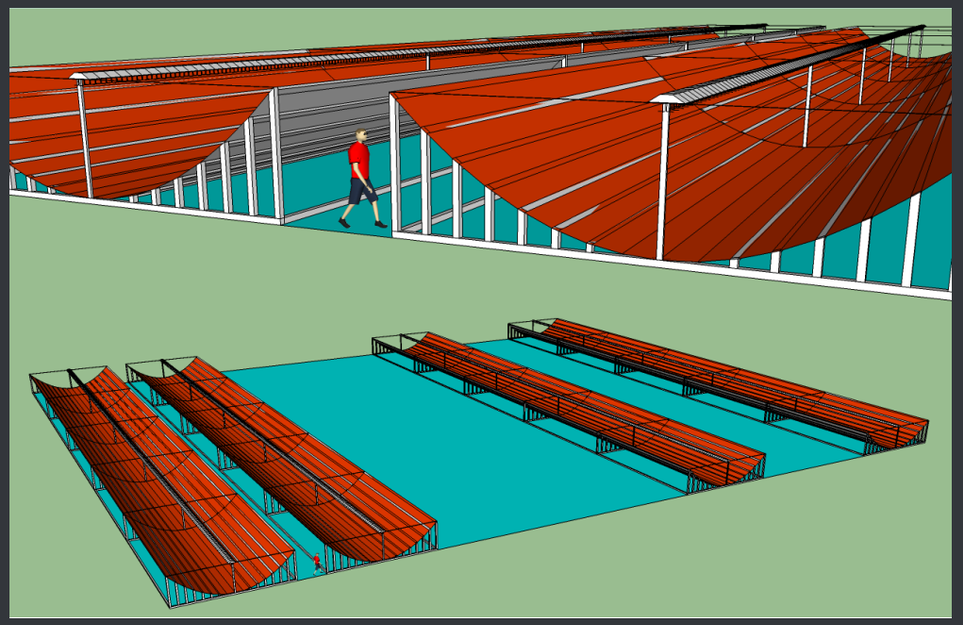
Haslam Map at
408 MHz

Observing 21cm Large-Scale Structure



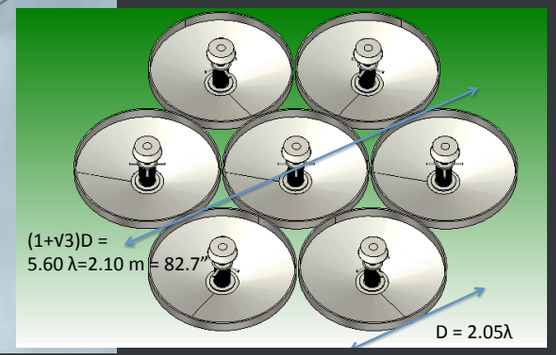
z	~1	~10
Science goal	Large-scale structure; BAO,RSD	Cosmic Reionization
Signal (mK)	0.1	10
Tsys (K)	30	300
Foreground spatial fluctuation (K)	0.1	10
Size scale	~10' - 1.4 deg; 109 h (non-linear scale - first peak)	~10'-30'; 20-50 Mpc (bubble scale)
First proposed	~2007	1970's?
First measurement	2010; cross-correlation	>2014; upper limit
Strategy	single dish; Interferometers	Interferometers

Low-z 21cm Intensity Mapping Experiments

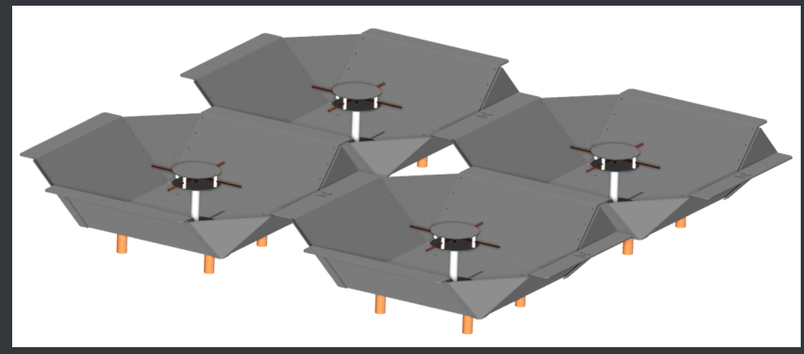


CHIME/Tian-Lai/CRT/BAORadio

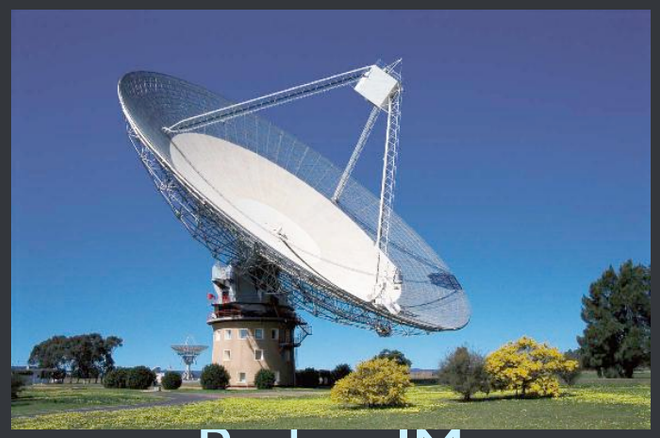
GBT-HIM multi-beam



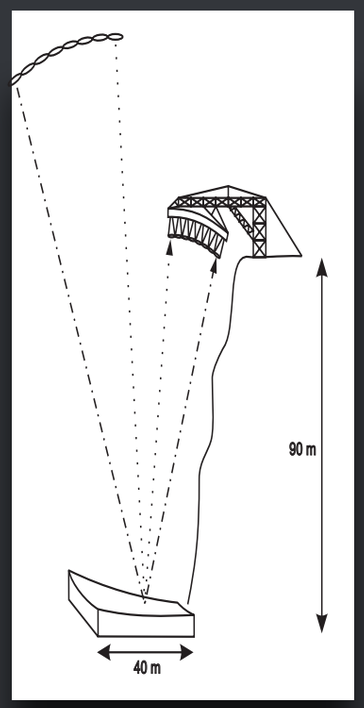
HIRAX



BAOBAB



Parkes IM



BINGO

SKA-mid Telescope

CHIME

Canadian Hydrogen Intensity Mapping Experiment

The CHIME telescope array will search for a particular kind of hydrogen emission from ancient galaxies.

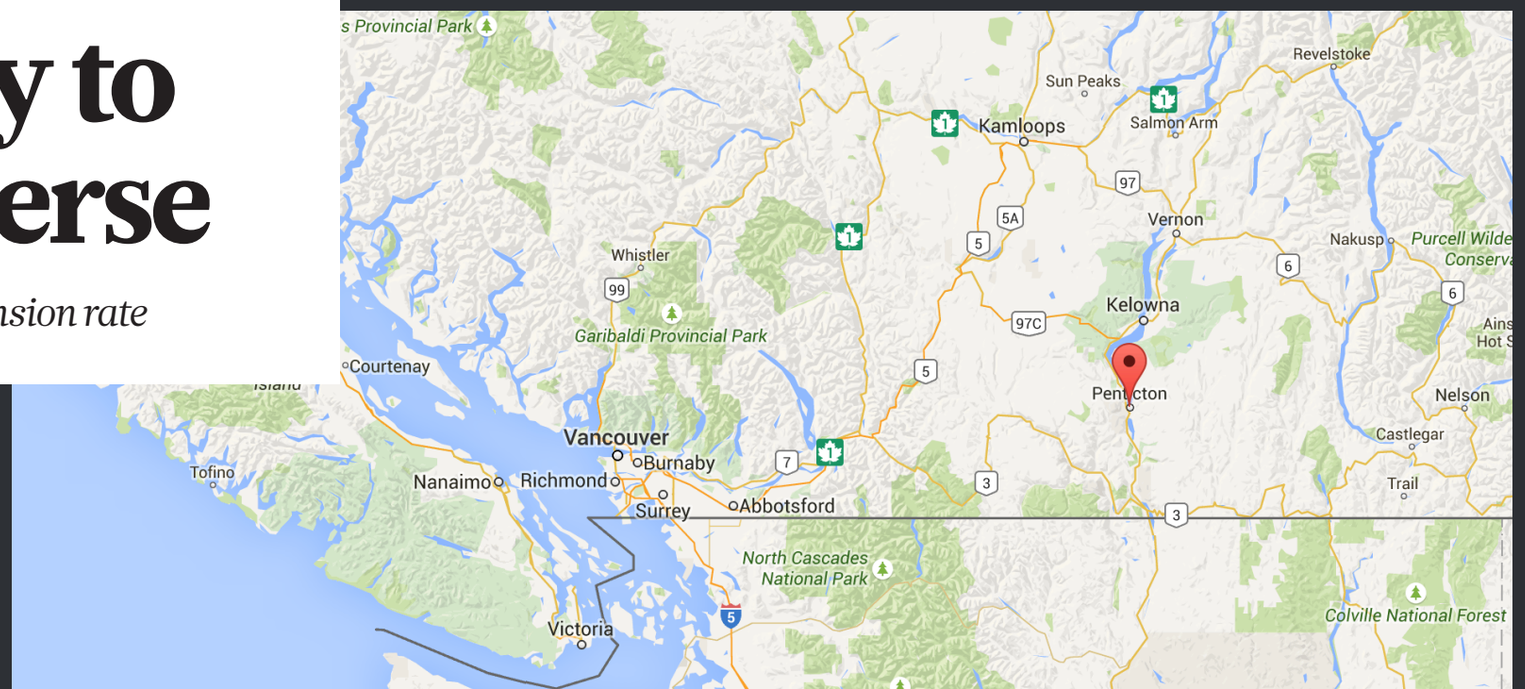
- Five 100m x 20m cylinder telescopes, 1280 dual-pol feeds
- 400-800 MHz, $0.8 < z < 2.5$, 20,000 deg^2 drift-scan sky coverage.
- At DRAO, British Columbia. PI: Mark Halpern (UBC)
- Full CHIME constructed ~2 weeks ago.

COSMOLOGY

Half-pipe array to map teen Universe

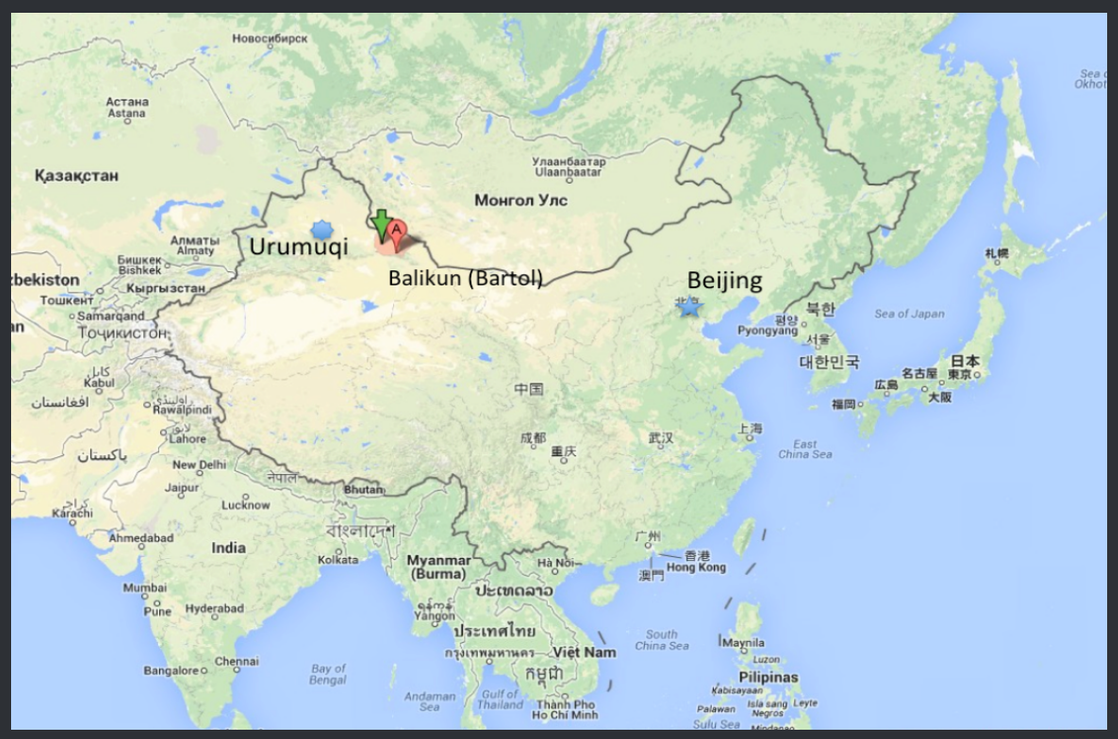
Canadian telescope aims to chart cosmic expansion rate between 10 billion and 8 billion years ago.

Nature article, July 29, 2015



Tianlai

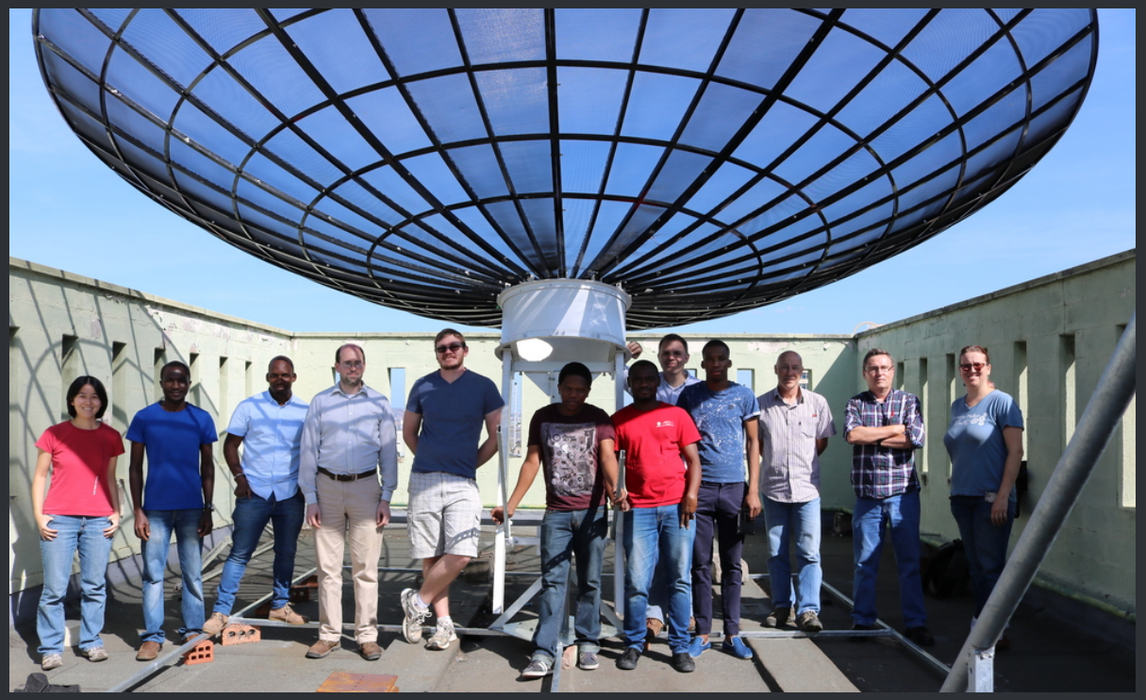
Heaven Sound



- Prototype constructed: three 45m x 15m cylinders and 16 6-m dishes constructed. Evaluating the performance.
- At 700MHz with 100MHz bandwidth (250-1000 MHz tuneable).
- At Balikun in western China. PI: Xuelei Chen (NAOC).
- Four 5-m dishes prototype constructed in Nancay. PI: Reza Ansari (LAL).

HIRAX

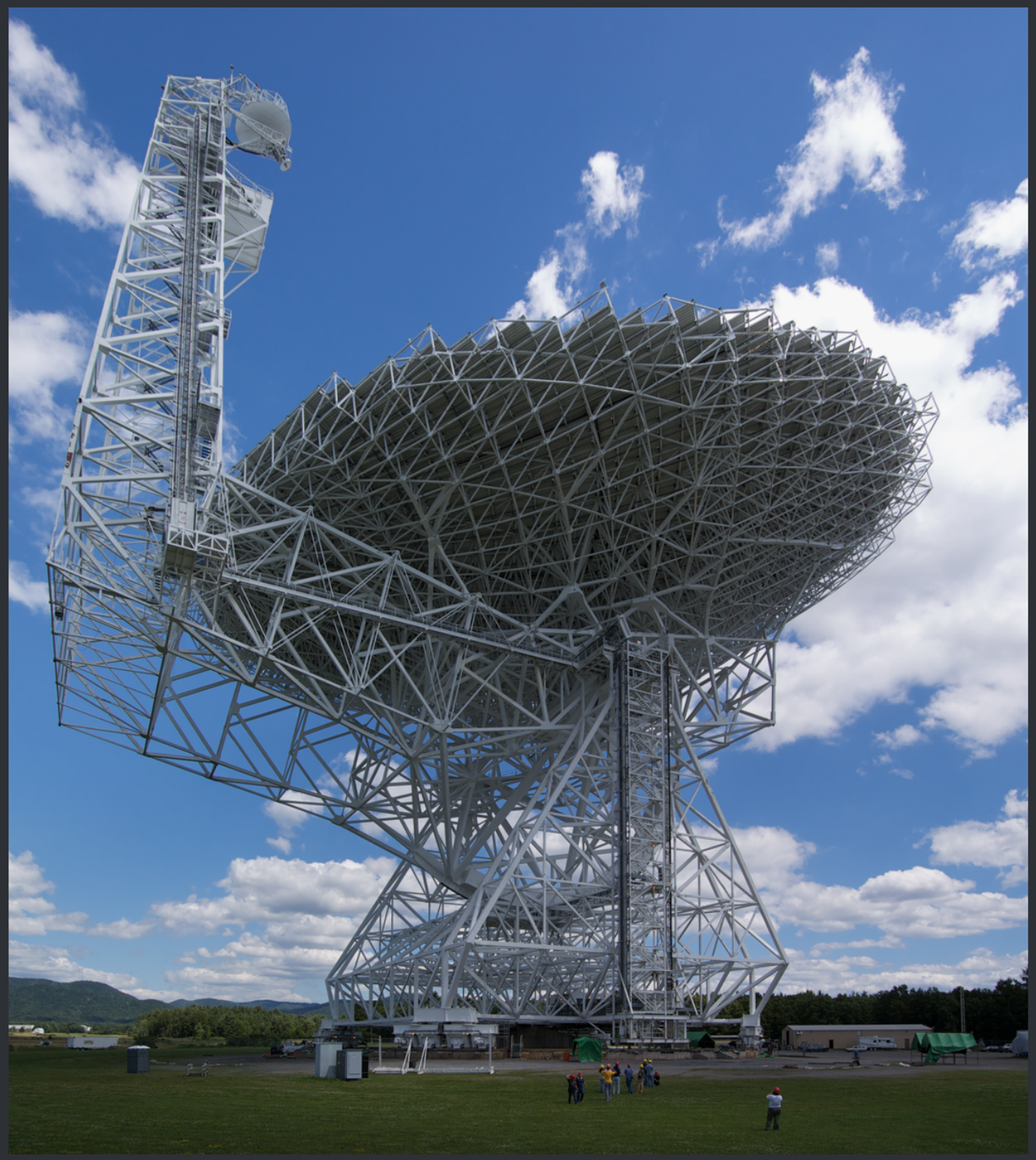
Hydrogen Intensity and Real-time Analysis eXperiment



- 1024 5-6m close-packed dish array
- 400-800 MHz, $0.8 < z < 2.5$
- Planned at the SKA SA site in Karoo dessert. PI: Jon Sievers (UKZN)
- First prototype dish assembled last week.

GBT-HIM

Pilot program at the Green Bank Telescope (GBT)

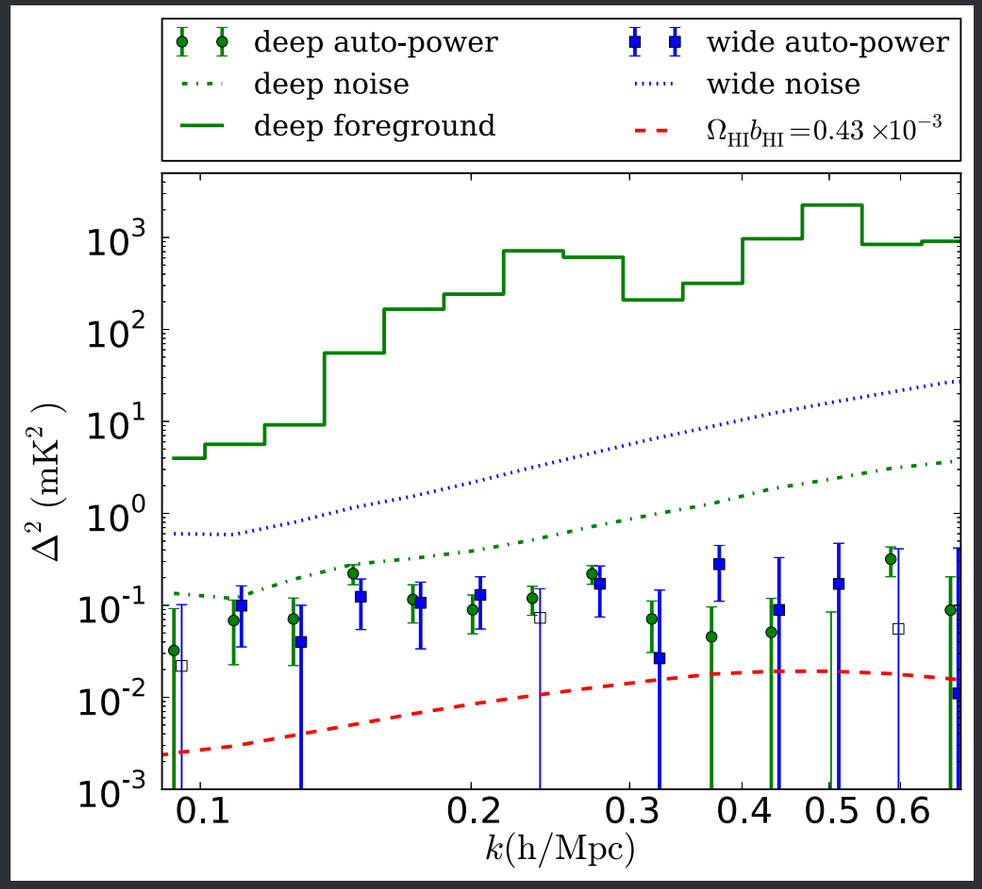


- Frequency: 700-900 MHz
  - $0.6 < z < 1$
- Spatial beam ~ 15”
  - 9 h^{-1} Mpc at z~0.8
- Spectral channel ~ 24 kHz
  - binned to 0.5 MHz
  - ~2 h^{-1} Mpc
- 100-m diameter. Large collecting areas
- First detection in cross-correlation with DEEP2 galaxies at z=0.8 (Chang+10)

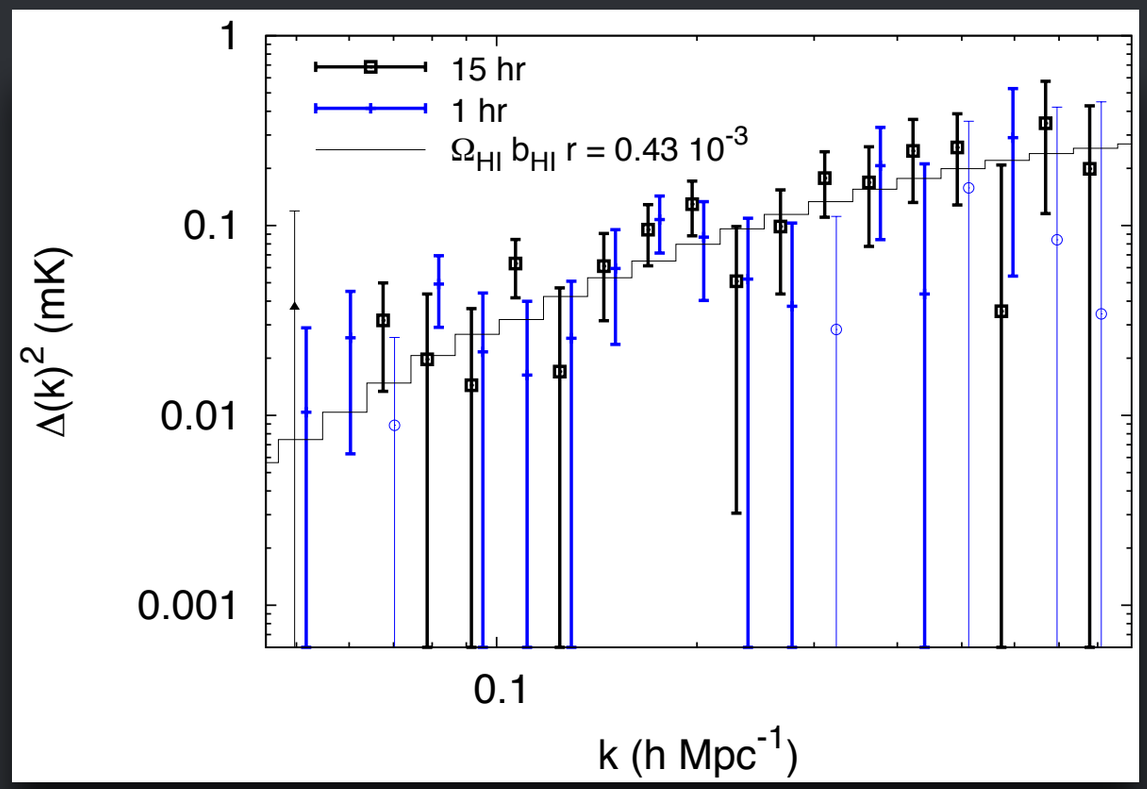
21cm Intensity Mapping at the GBT

- Frequency: 700-900 MHz
  - $0.6 < z < 1$
- Spatial beam ~ 15”
  - 9 h^{-1} Mpc at z~0.8
- Spectral channel ~ 24 kHz
  - binned to 0.5 MHz
  - ~2 h^{-1} Mpc

- 800-hr HI survey of the WiggleZ fields at $0.6 < z < 1$
- HI cross-power and auto-limits in 2013 at z=0.8 implies:
- $\Omega_{HI}\, b_{HI} = [0.62\ ^{+0.23}\ _{-0.15}] \times 10^{-3}$

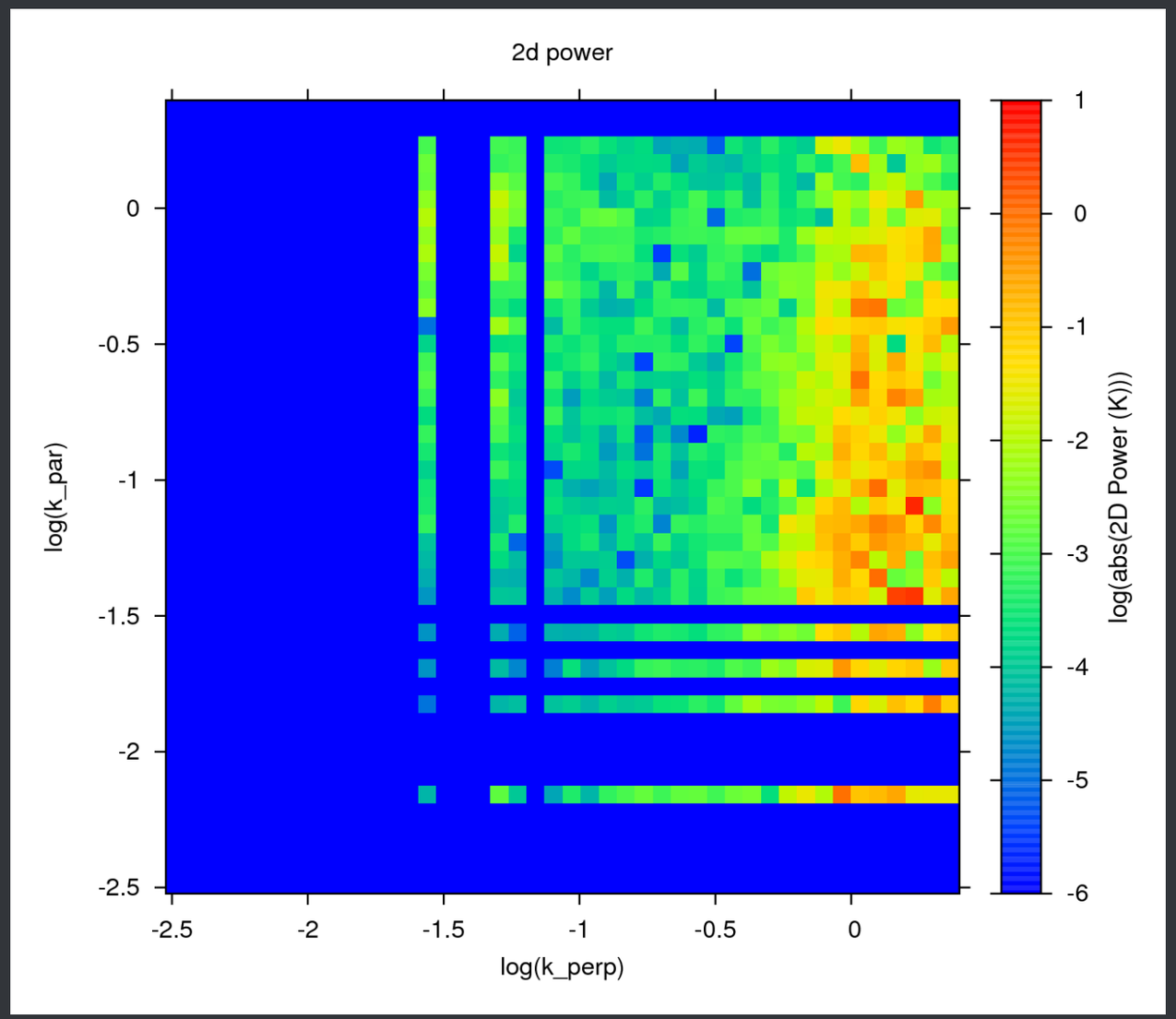


Auto-power limits, Switzer+13, GBT-HIM



Cross-power, Masui+ 13, GBT-HIM

Work in progress: Redshift-space distortions with cross-power spectrum



T.-C. Chang, Cheng-Yu Kuo (ASIAA), GBT-HIM team

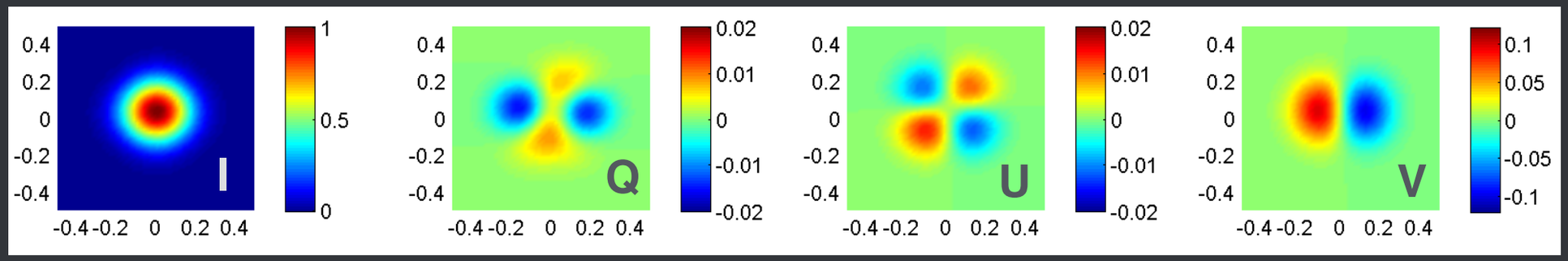
- Redshift-space distortion (RSD) measurement with HI-WiggleZ cross power spectra:

- Anisotropic clustering gives measurement of Ω_{HI} and b_{HI}

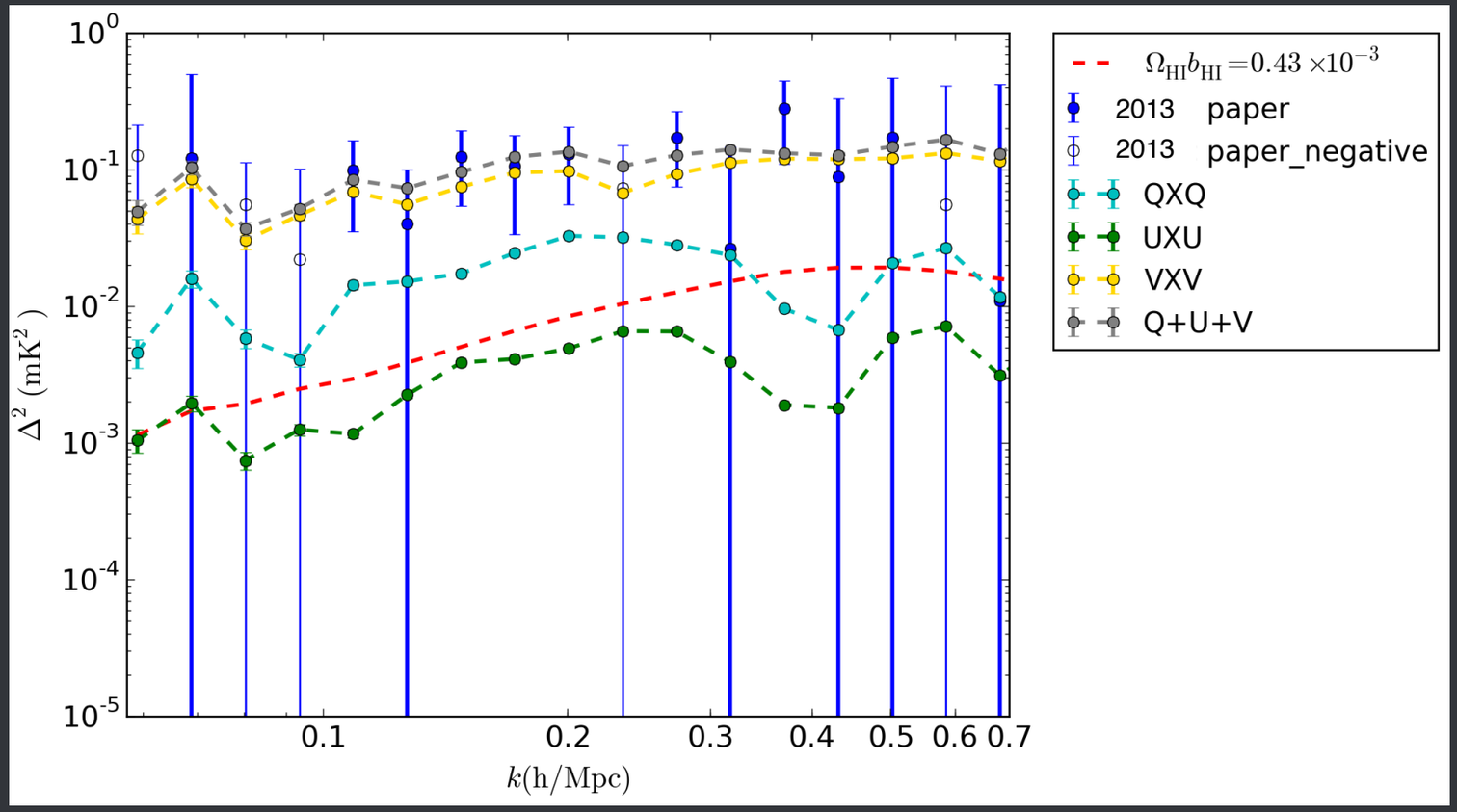
- Currently working on RSD modelling for HI intensity mapping

- Improving cross-power spectra measurements

Work in progress:
Precision polarization calibration
HI auto-power spectrum



Liao et al., in prep

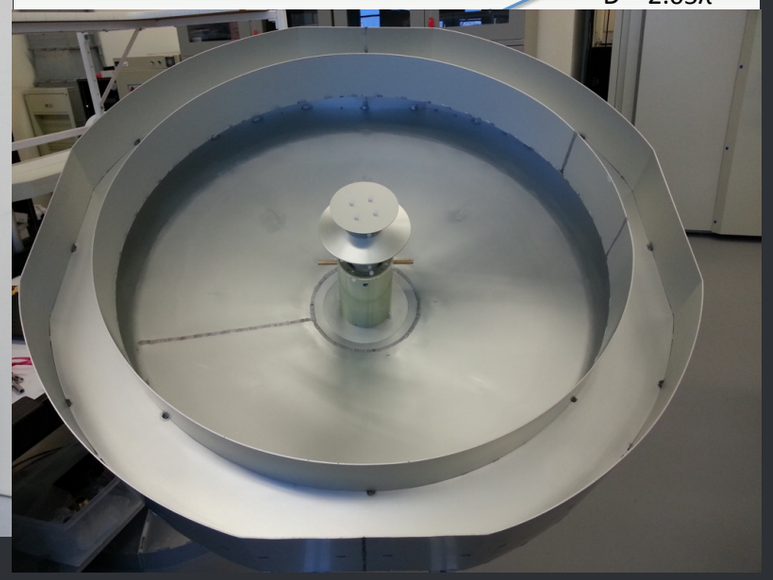


Chun-Hao To (ASIAA), the GBT-HIM team

- Current HI power spectrum P(k)
  - Systematics dominated
  - Improving polarization calibration with full mueller matrix treatment
  - Estimate polarization leakage power spectra
  - Including full polarized beam model in map-making
  - Larger survey field enabling better foreground SVD subtraction

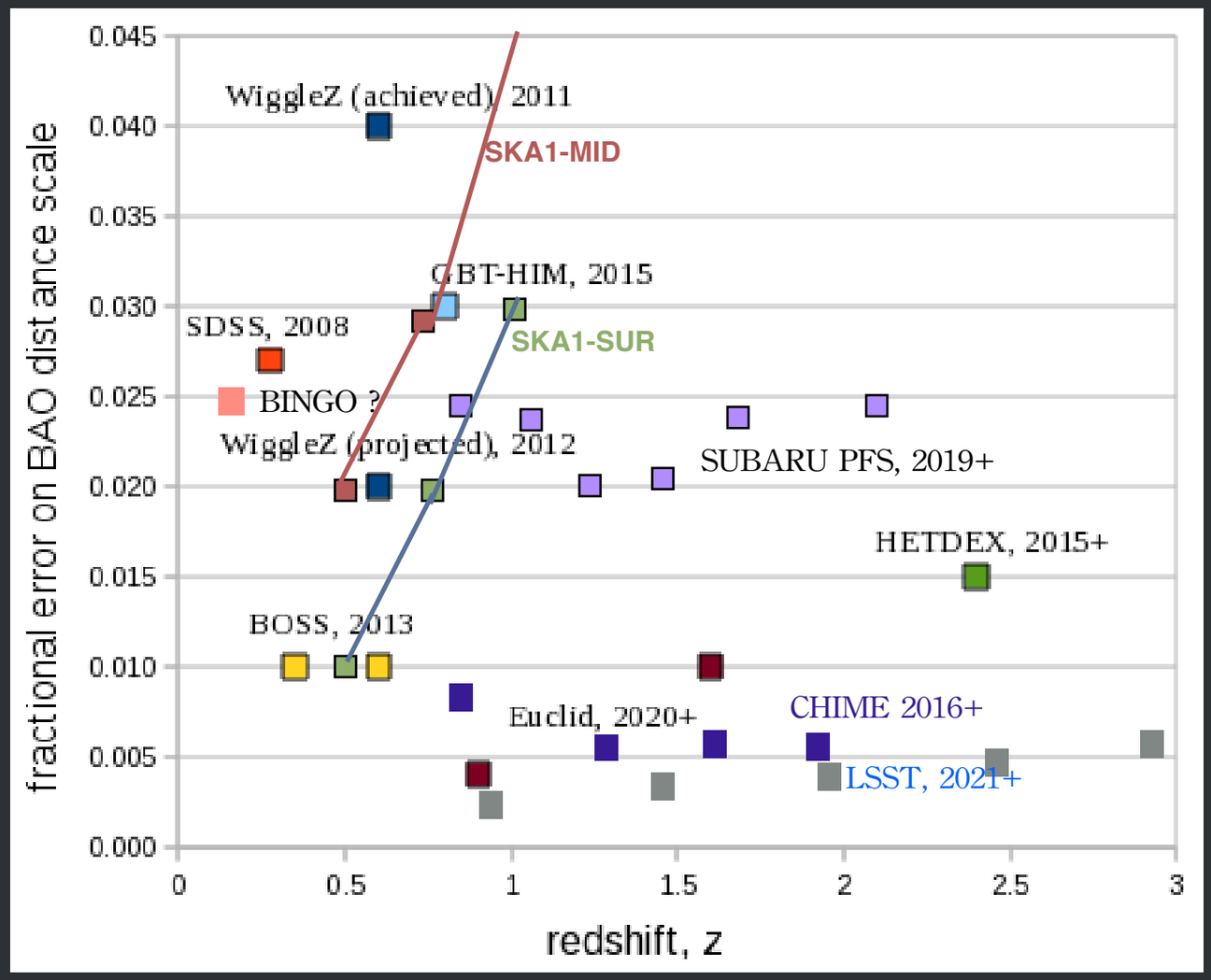
GBT-HIM: 800 MHz multi-beam HIM Project

- GBT-HIM Project (P.I. T.-C. Chang): Building a seven-beam receiver at 700-900 MHz for redshifted HI survey at 0.5< z < 1 for BAO measurements.
- Use Short-backfire Antenna (SBA) with a edge-tapered reflector; with a cryogenic cold finger connecting to the dipole to reduce Tsys.
- Prototype tested on GBT in summer 2013.
- Seven-pixel receiver array commissioning in 2016.
- Instrumentation members: Yuh-Jing Hwang, Chi-Chang Lin, Ching-Ting Ho (ASIAA), Peter Timbie, Chris Anderson (UWisc), John Ford, Steve White, Sri Srikanth, Rich Bradley (NRAO), Jeff Peterson (CMU)

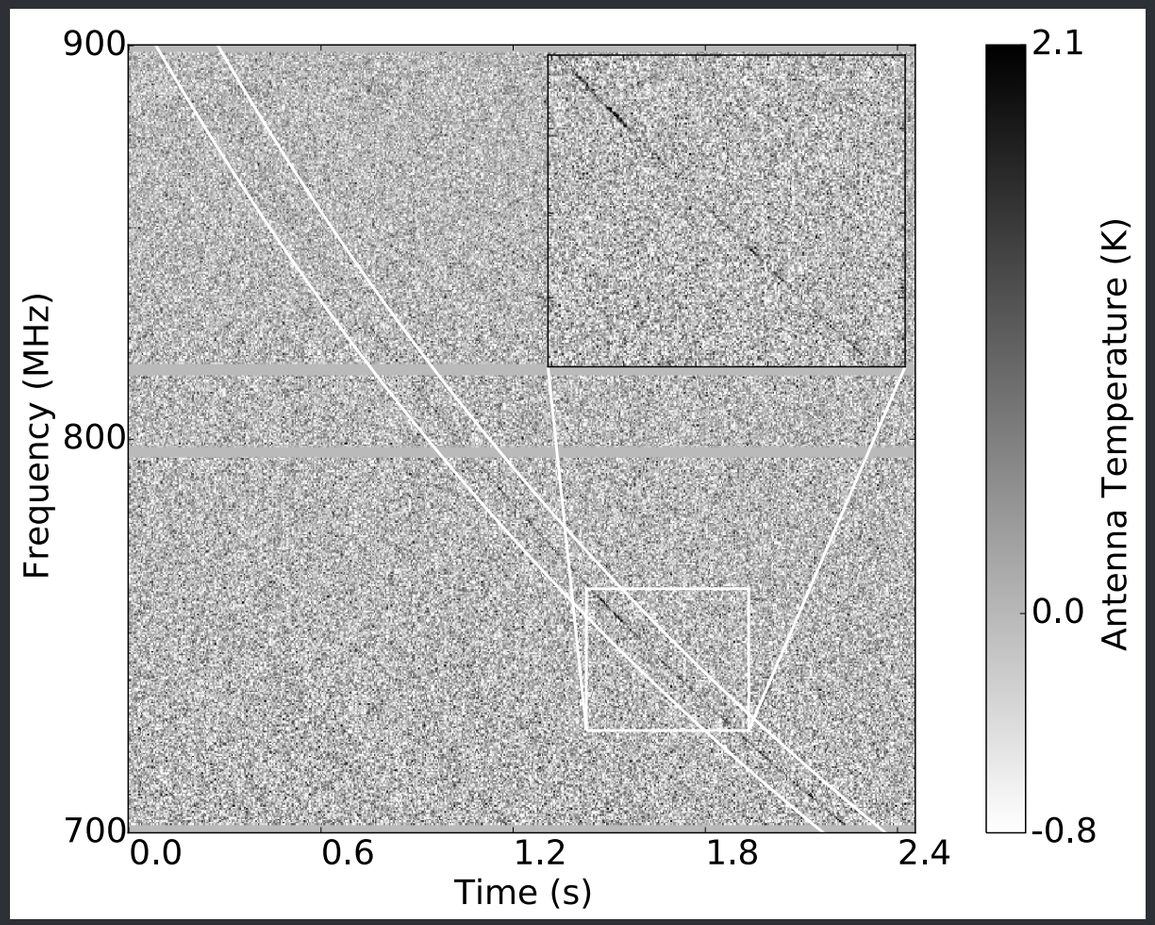


BAO measurements

- Forecasts on Baryon Acoustic Oscillation (BAO) distance scale.



21cm Intensity Mapping at GBT
Fast Radio Burst (FRB) Found!



Masui et al., the GBT-IM team, 2015, submitted

- FRBs are bright, millisecond radio flashes of unknown origin (Lorimer et al. 2007)

- We search through 700 hours of GBT HI data at 700-900 MHz, found one event

- First FRB detection under 1 GHz, with linear polarization and Faraday Rotation Measurements.

- The FRB detection implies a source location in the dense central region of its host galaxy, or the presence of magnetized material associated with the source itself.

Summary

- Intensity mapping (IM) is a new and interesting path to improve our understanding of EoR and probe the large-scale structure.
- Good progress in 21cm IM measurements at both low and high redshifts, but we'd need a detection soon! ~Early days of the CMB.
- Existing facility explorations:
  - PAPER/LOFAR/MWA/GMRT-EoR: 21cm fluctuations upper limit of 23mK at z~8 (Ali et al 2015).
  - GBT-IM: Cross-power spectra measured. Upper limits on HI power spectra at z~0.8
  - CHIME, Tianlai, HIRAX: large-scale 21cm IM experiments. Constructed or in progress.
- Pilot programs are on-going/planned: Time-pilot ([CII]), SPHEREx (Lya), LAMP (Lya), AIM-CO and COMAP (CO), and several on-going HI IM experiments. Stay tuned!