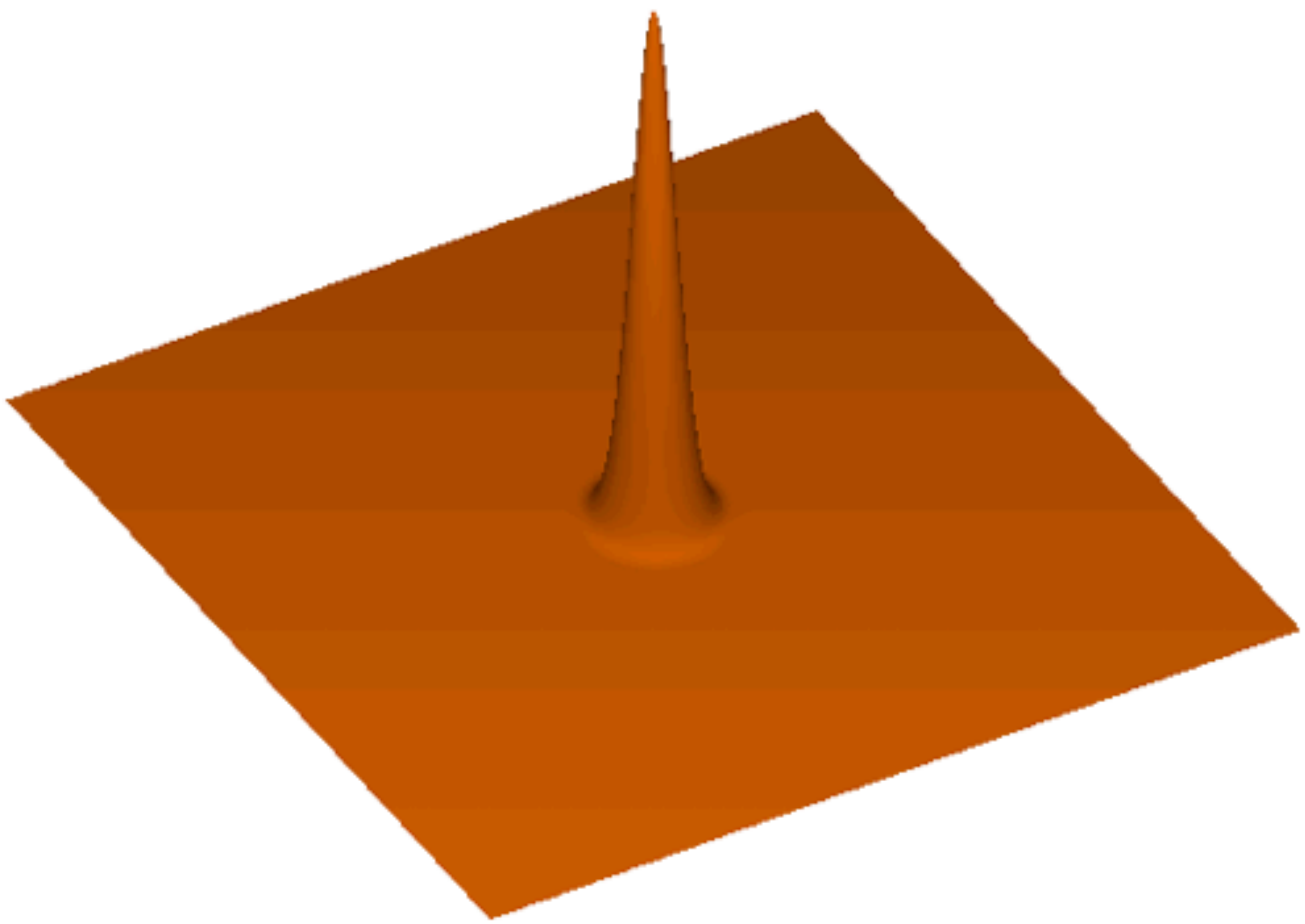
HI Intensity Mapping for large-scale structure studies

Tzu-Ching Chang (ASIAA)

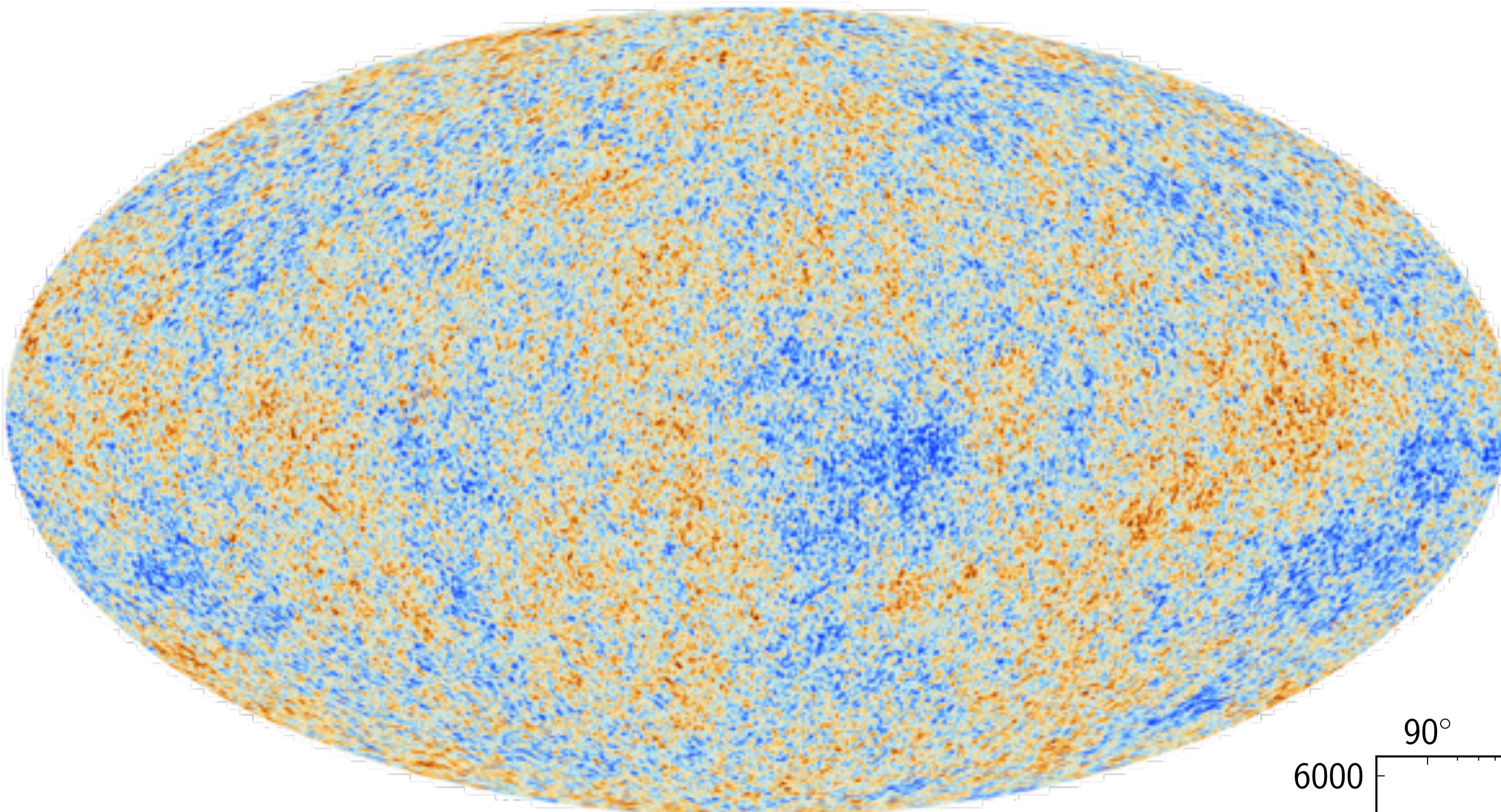
Science goal: Baryon Acoustic Oscillations (BAO)



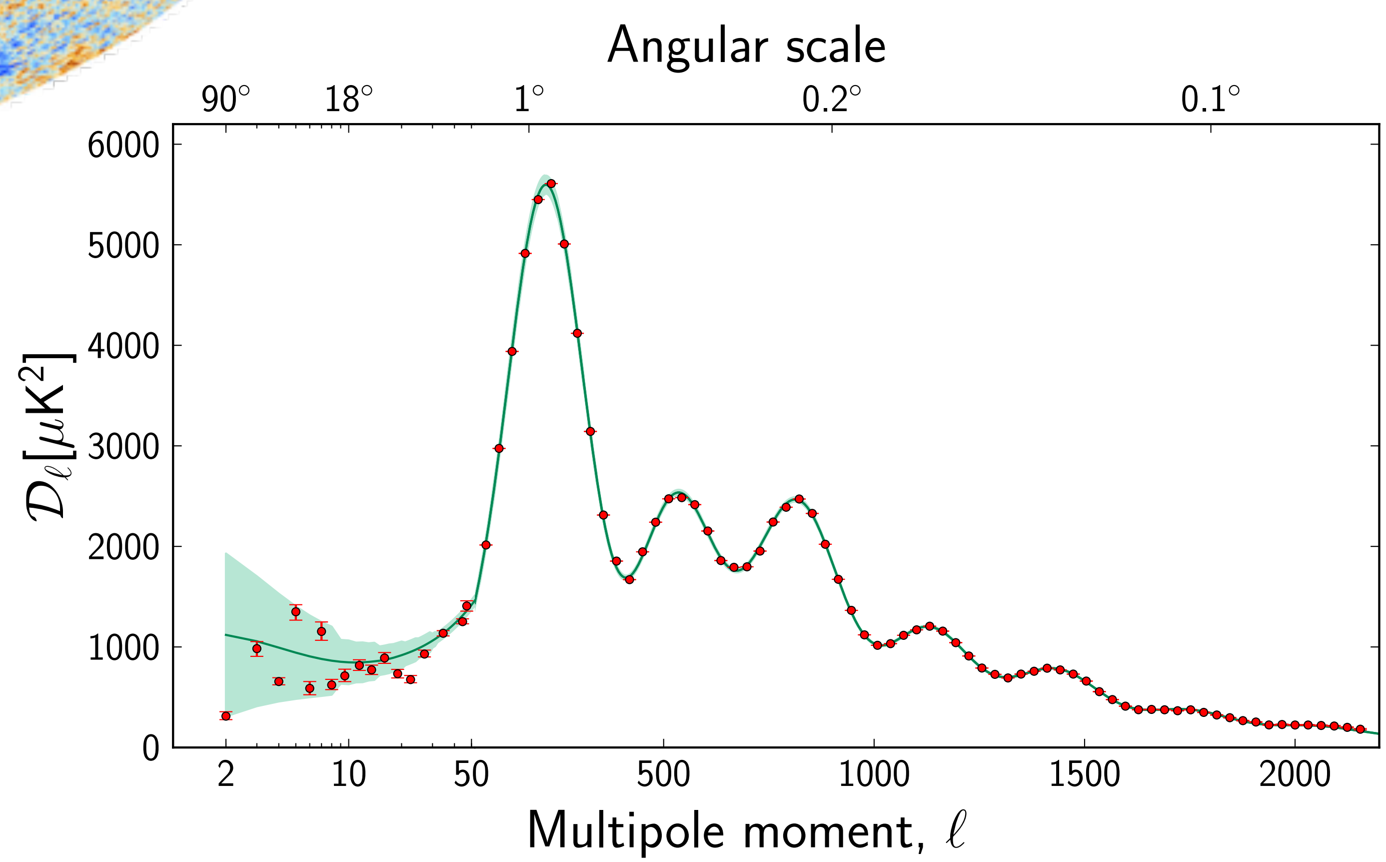
Courtesy of D. Eisenstein

- Sound waves in the photon-baryon plasma in the early universe propagate from density perturbations;
- Waves freeze out when universe transited from radiation to matter domination (recombination).
- Thus they have a characteristic scale of 109 h^{-1}Mpc (~150 Mpc), corresponding to the sound horizon at recombination at z~1100.

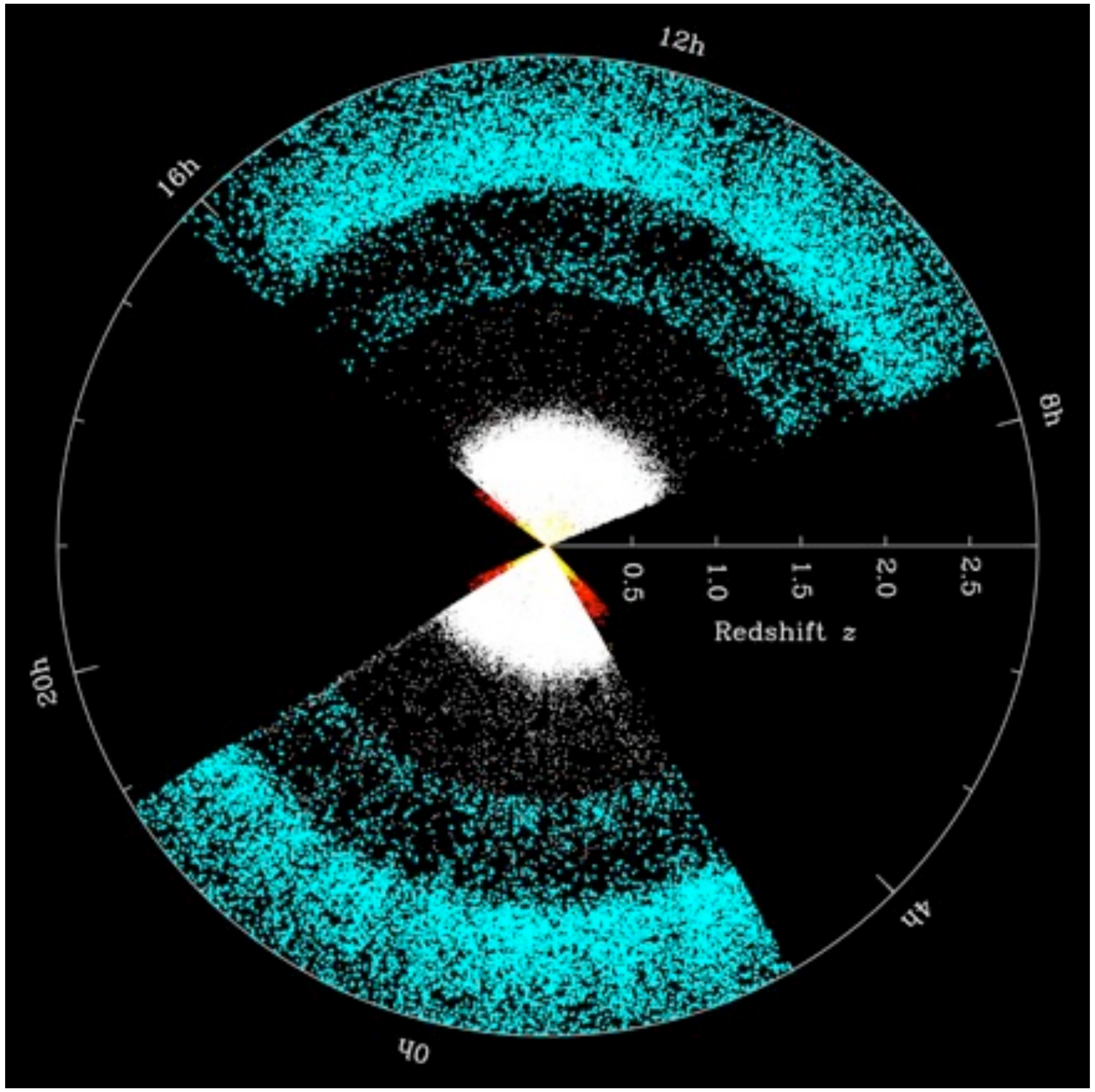
The oscillation peaks and troughs on the CMB power spectrum are obvious



PLANCK

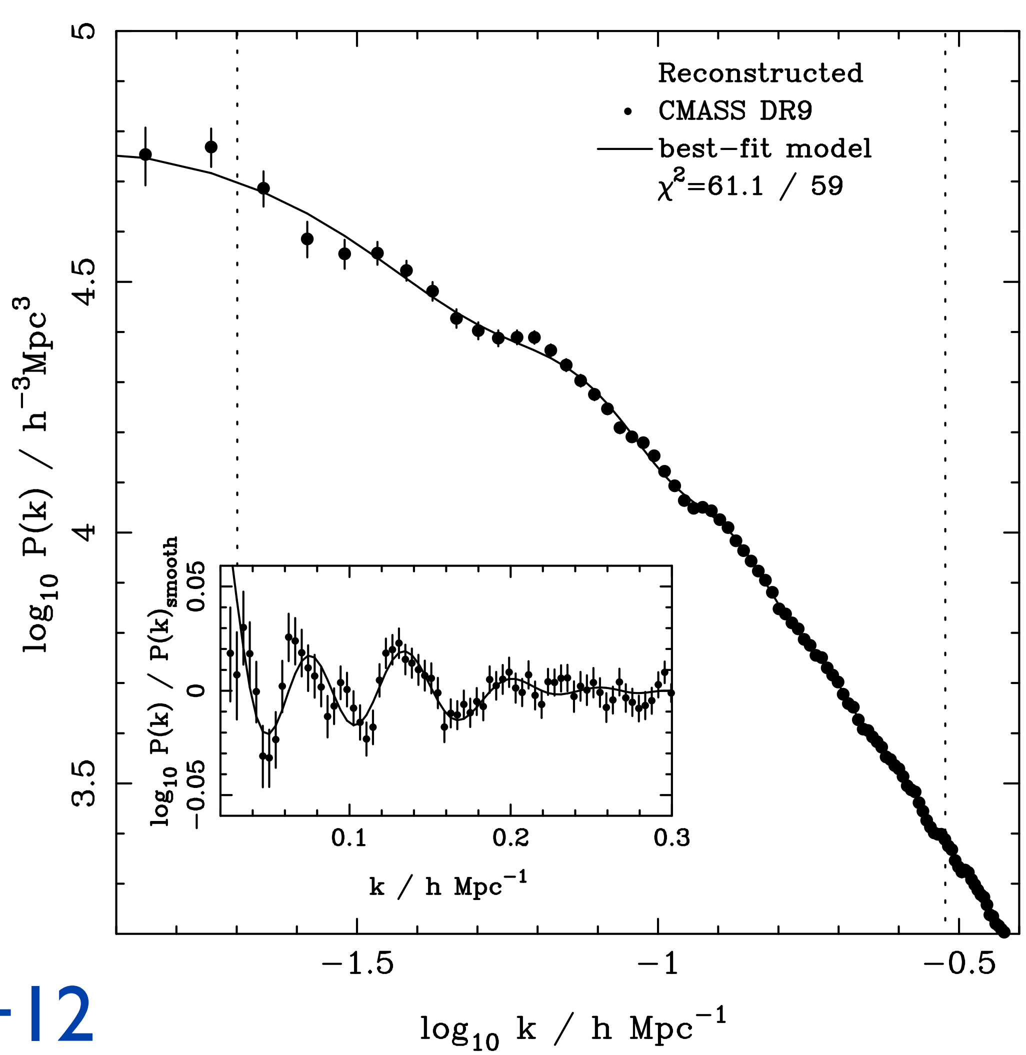


The oscillation features on the large-scale matter power spectrum have also been measured



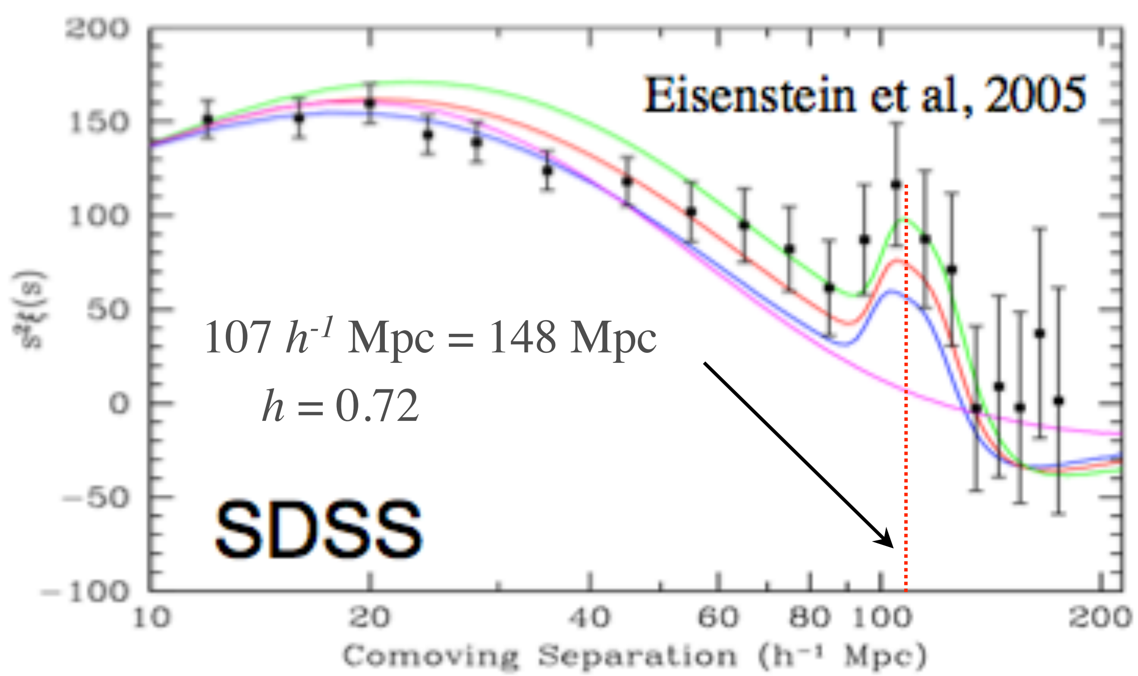
courtesy of M. Blanton

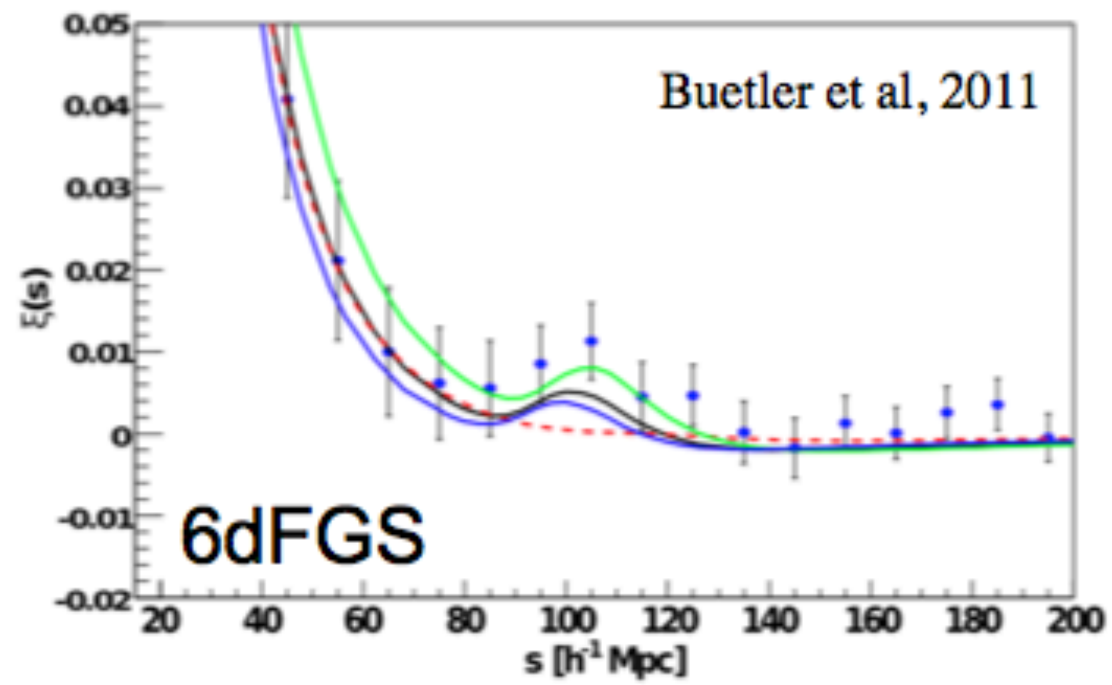
SDSS III BOSS

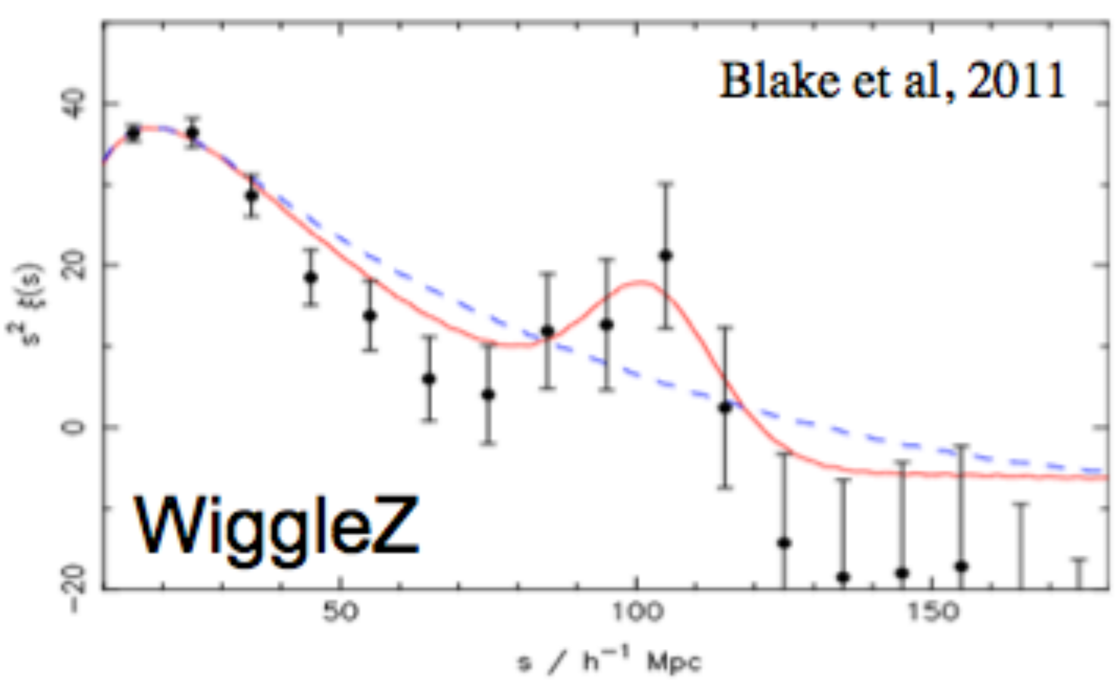


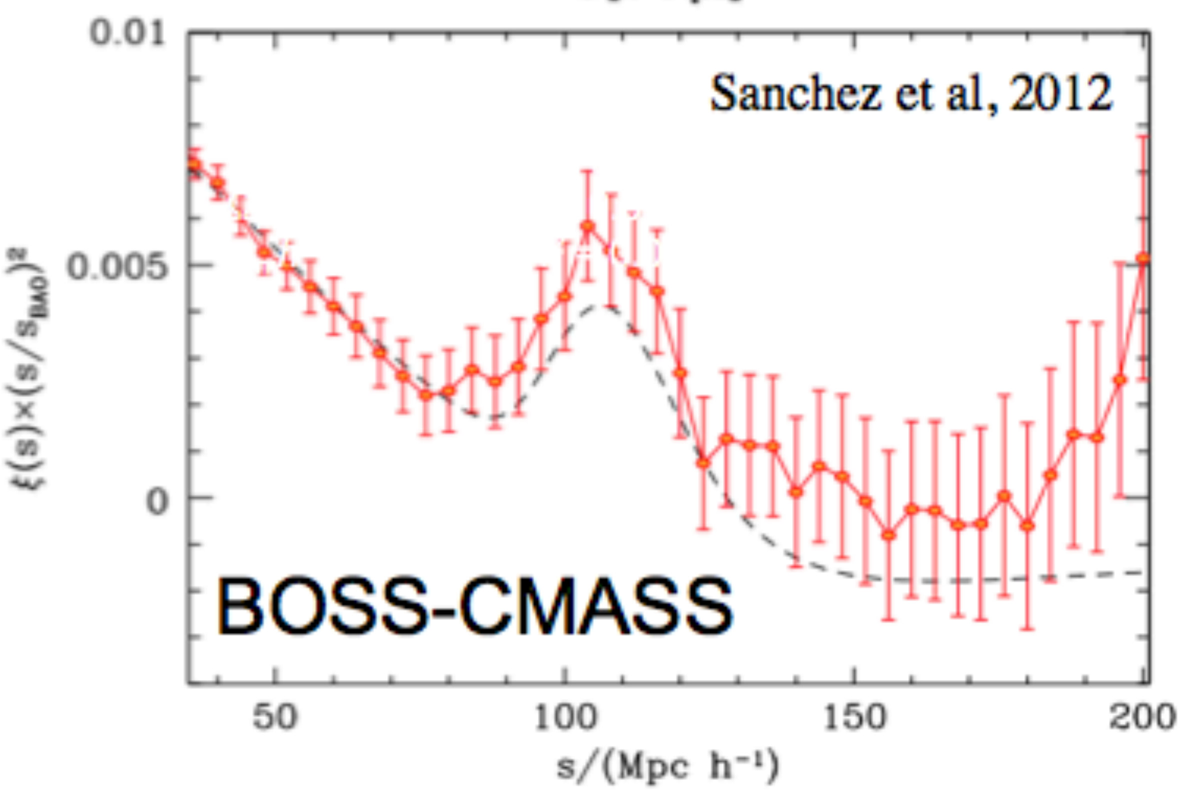
Anderson+12

BAO detected in multiple surveys

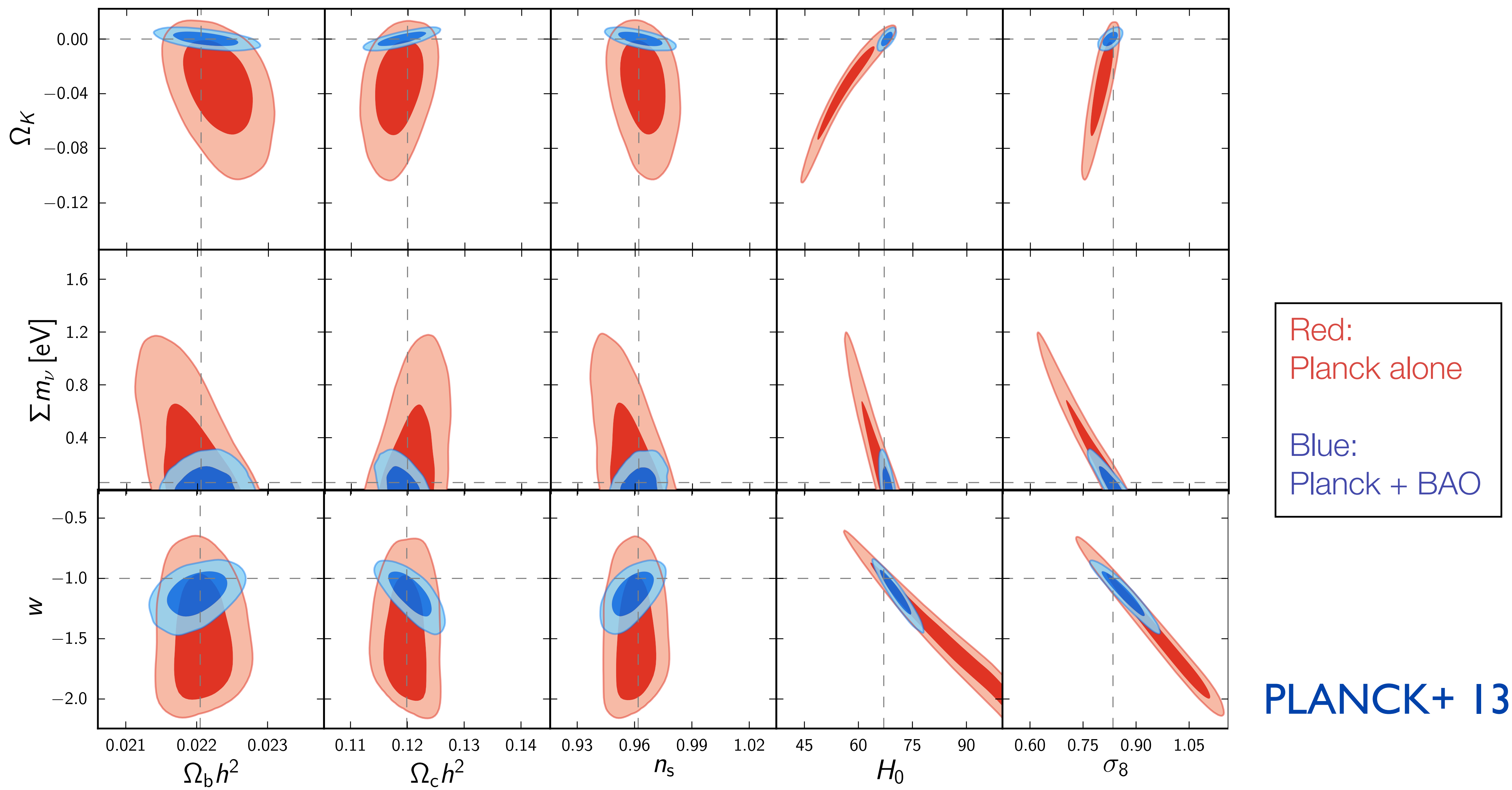








BAO: great tool for precision cosmology



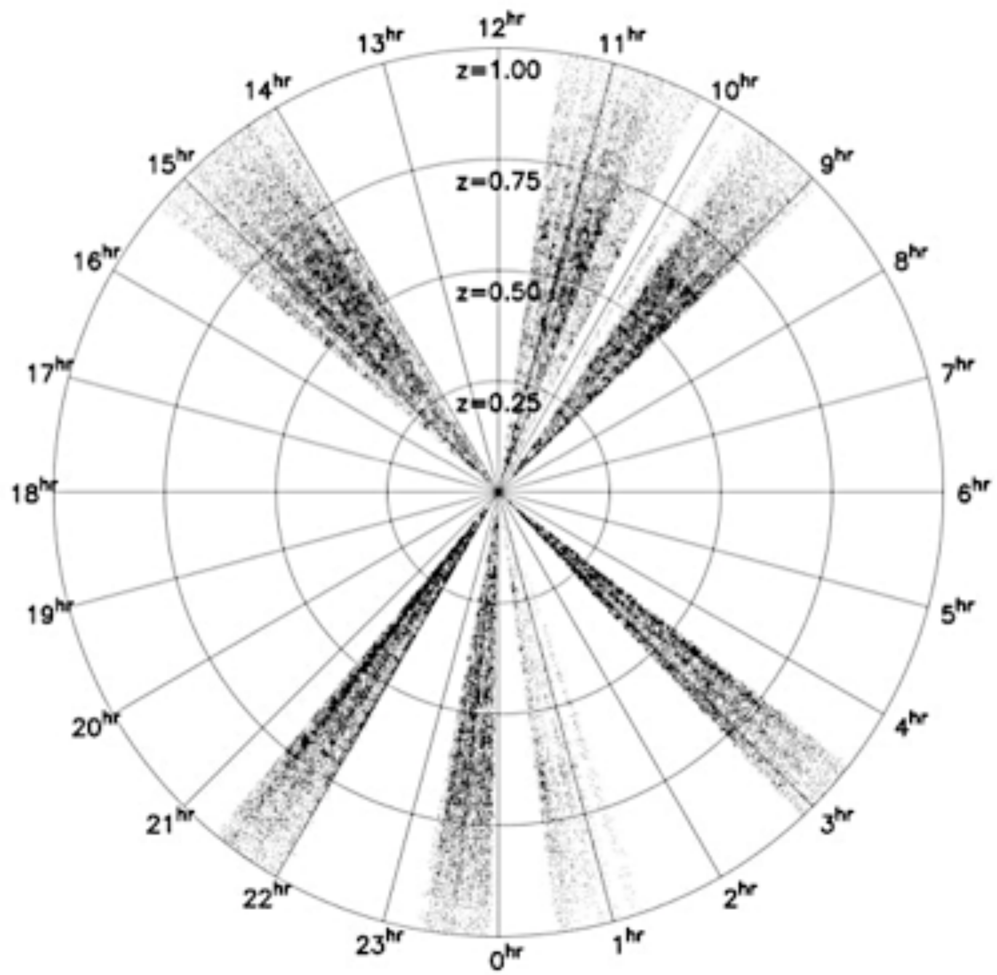
- CMB-like acoustic oscillations: imprinted standard ruler, 150 Mpc.
- Present in current matter distribution that can be traced by galaxies and HI
- Efforts: e.g., WiggleZ, BOSS, PFS, HETDEX,DESI, Euclid, LSST, WFIRST

CAN WE USE HI INTENSITY MAPPING ?

as a tracer of Large-scale Structure

- Different bias compared to other optical tracers
  - good for e.g. RSD measurements (Buetler+12)
  - useful for multi-tracer technique to get rid of cosmic variance (Seljack & McDonald 09)
- Different systematics
- In principle economical and efficient

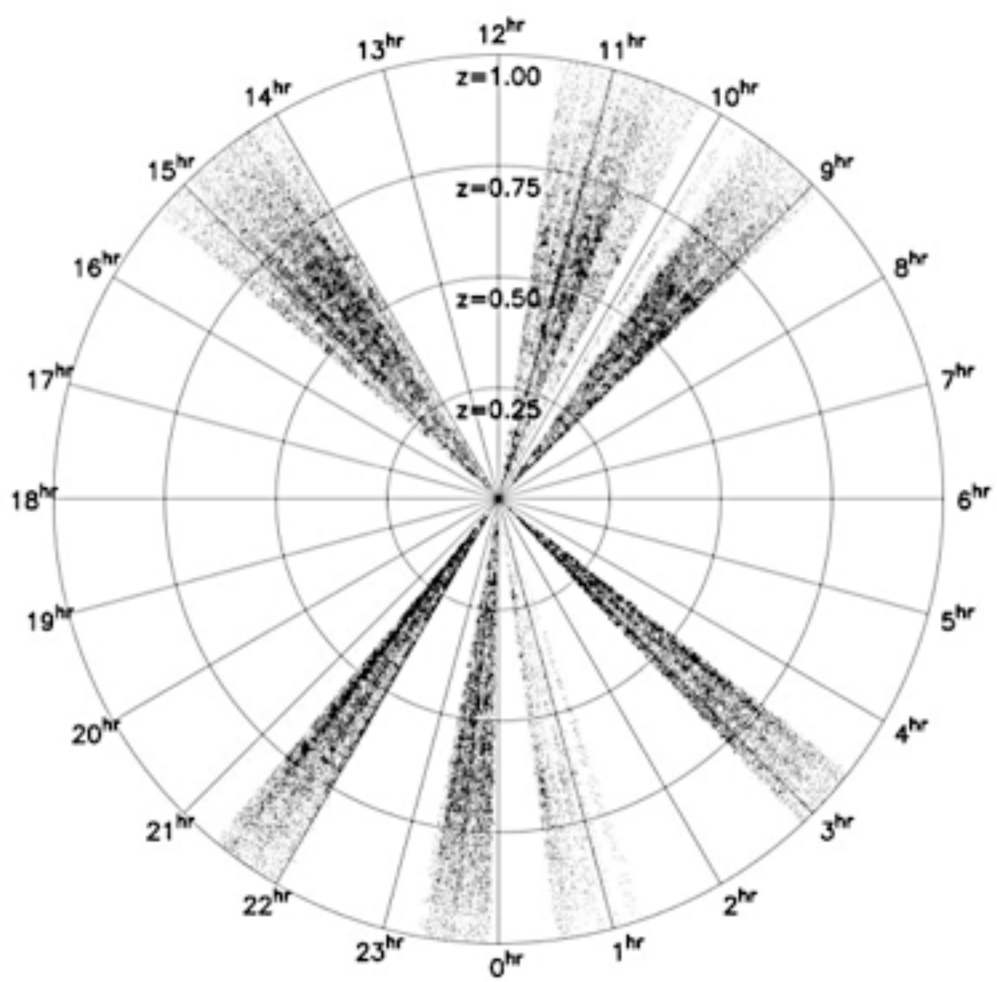
Intensity Mapping



WiggleZ

- Due to small emissivity, HI in emission is difficult to detect.
- Previously, HI direct detection at z~0.2 (Verheijen et al 2010), stacking at z~0.37 (Lah et al. 2007); both on galaxy scales.

Intensity Mapping



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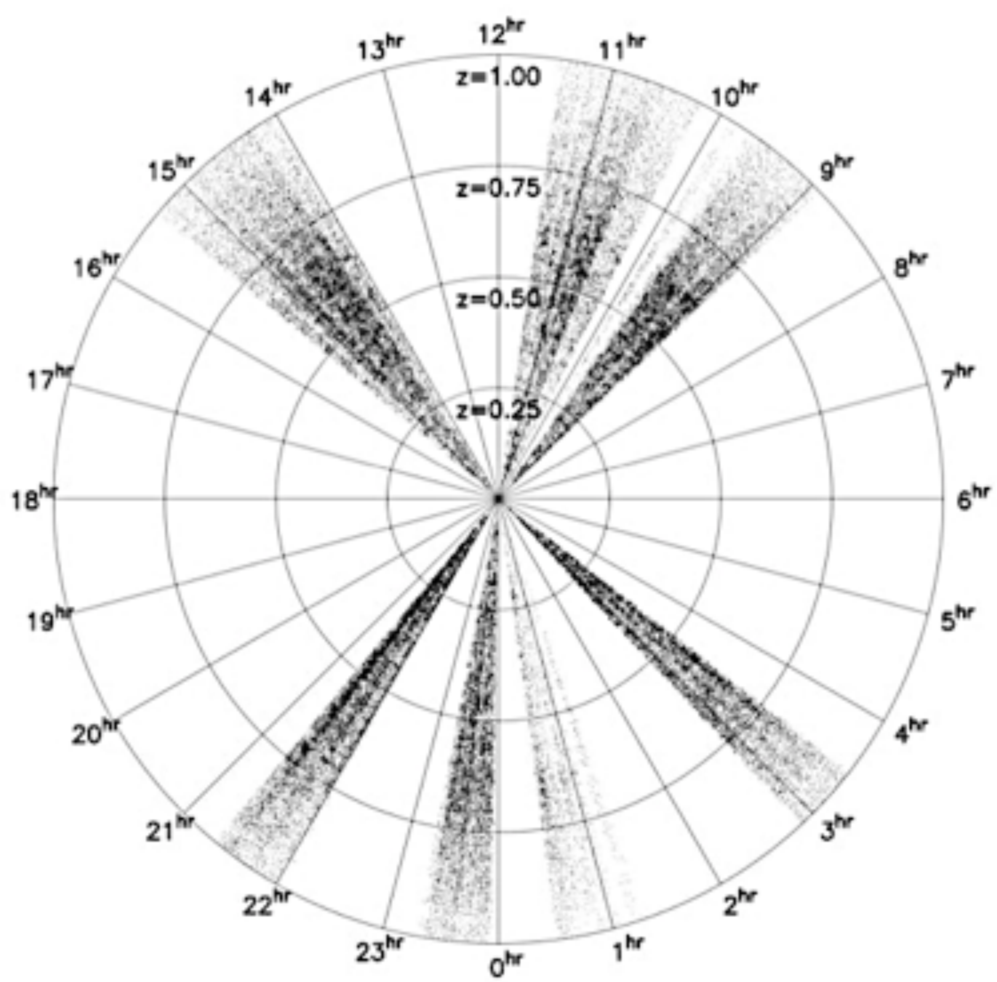

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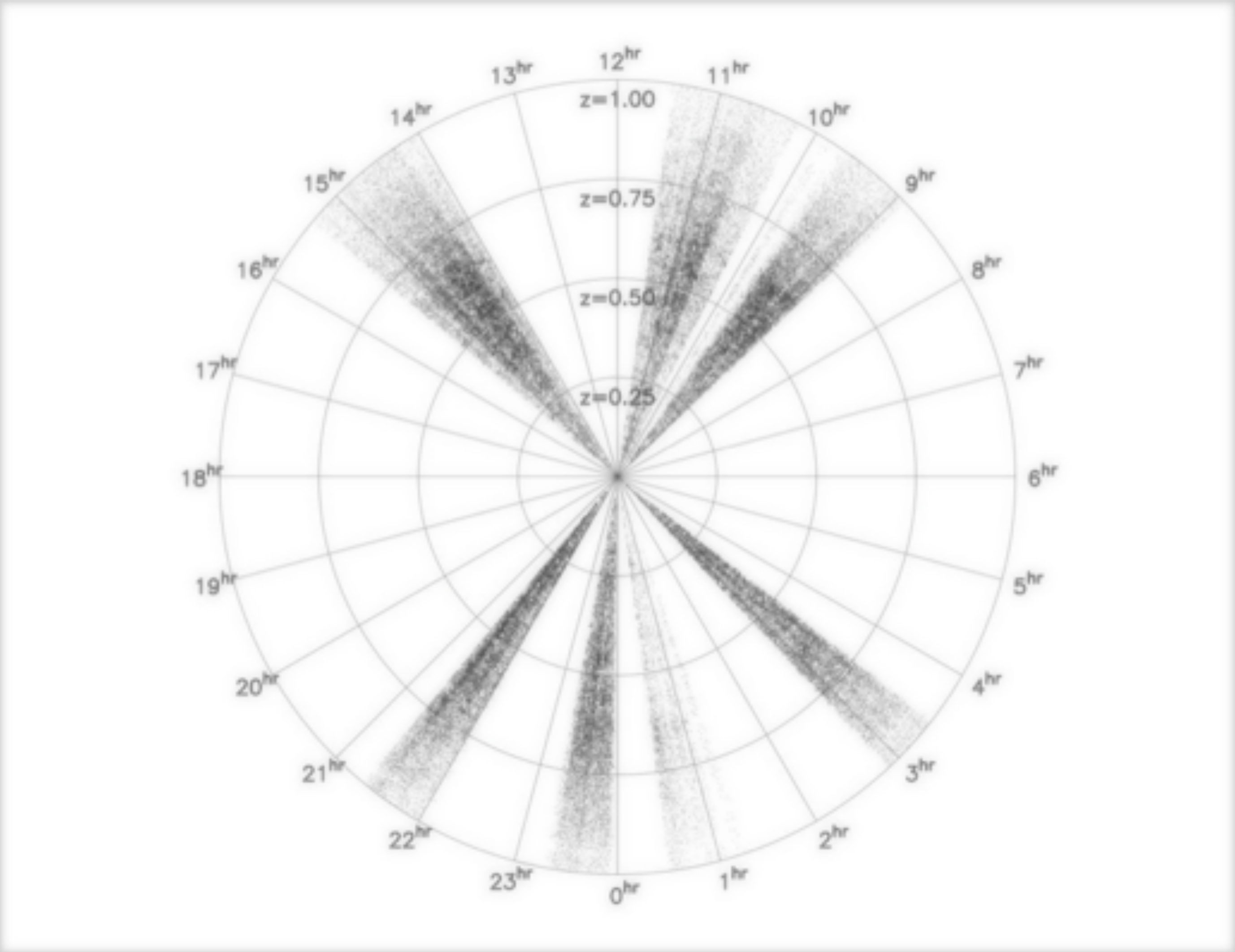

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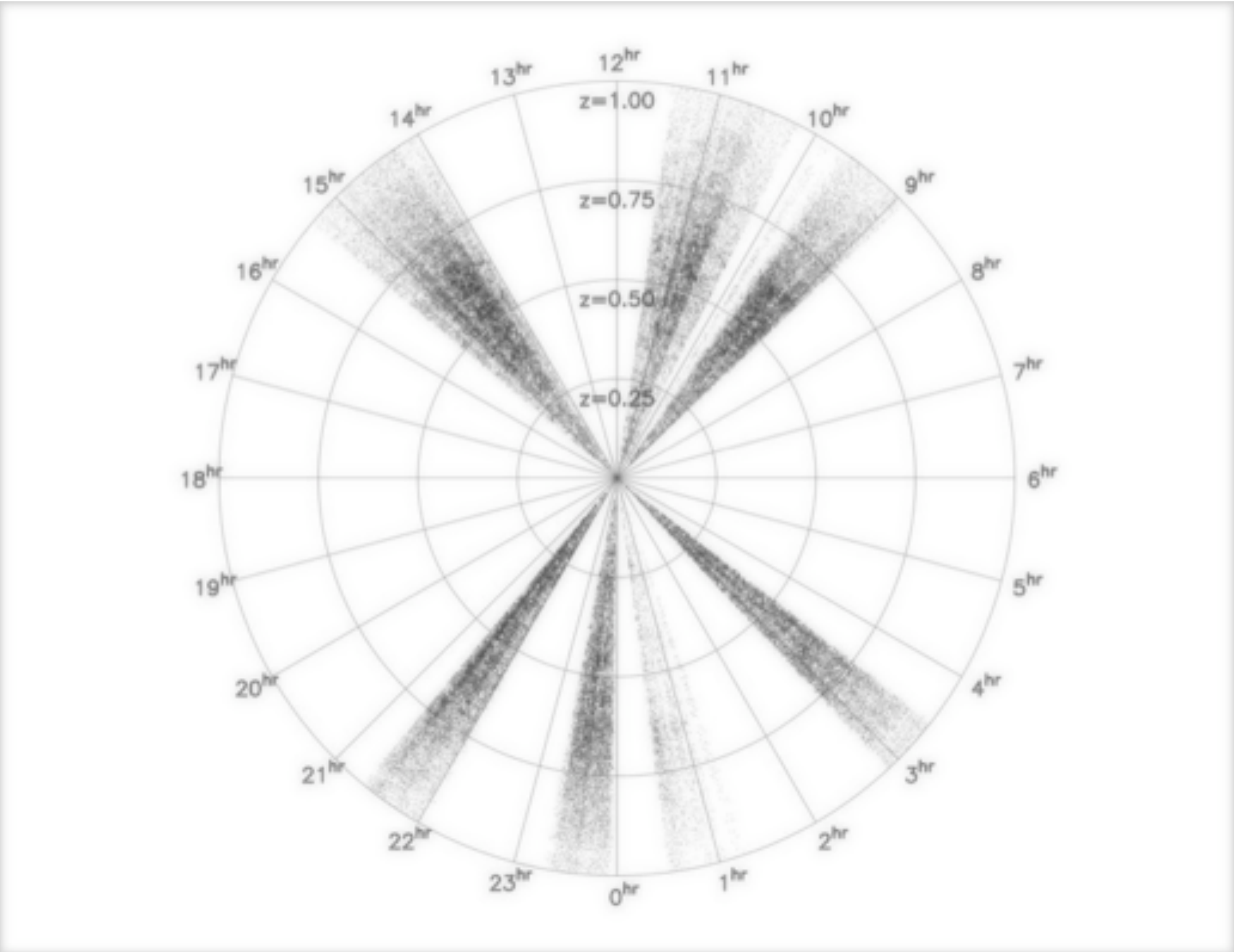


WiggleZ

- "Intensity Mapping" (Wyithe & Loeb 2008, Chang et al 2008):
  - instead of HI associated with galaxies, interested in HI associated with large-scale structure
  - measure the collective HI emission from a large region, more massive and luminous, without spatially resolving down to galaxy scales.
- Measurement of spatially diffused spectral line, in the confusion-limited regime, but redshift information is retained.
- Brightness temperature fluctuations on the sky: just like CMB temperature field, but in 3D
- Low-angular resolution redshift surveys: LSS science, economical

21cm Intensity Mapping for Dark Energy Constraints

- HI Intensity Mapping Experiment: economical and competitive to DETF stage III experiment (BOSS, DES, PFS) for dark energy constraints with 10,000 m^2 of collecting area.

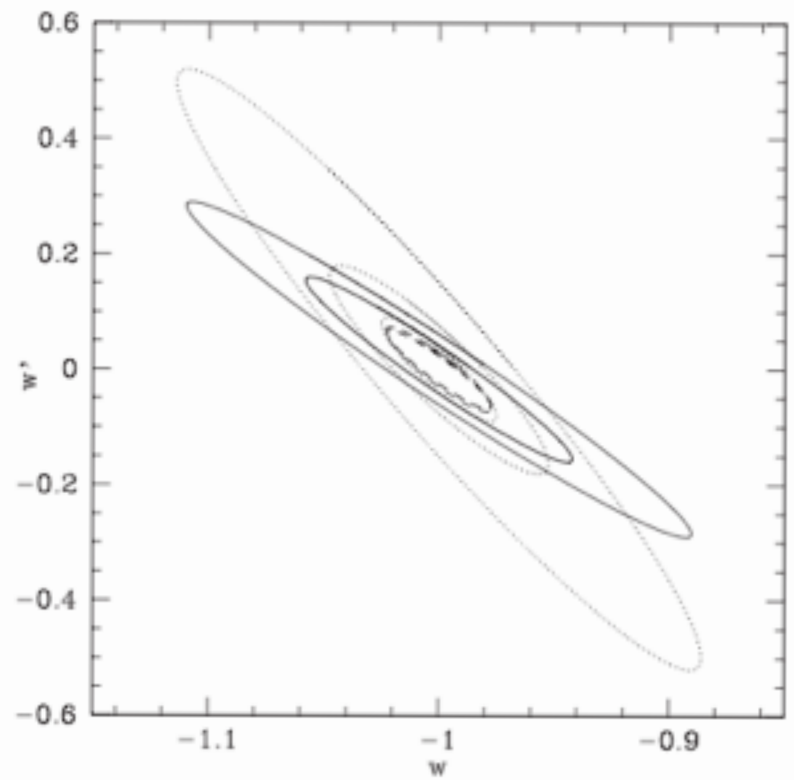


FIG. 4. The $1-\sigma$ contour for IM combined with Planck (inner thick solid for baseline model, outer thin solid for worst case), the Dark Energy Task Force stage I projects with Planck (outer dotted), the stage I and III projects with Planck (intermediate dotted), the stage I, III, and IV projects with Planck (inner dotted), and all above experiments combined (dashed, again thick for baseline, thin for worst case; the two contours are nearly indistinguishable).

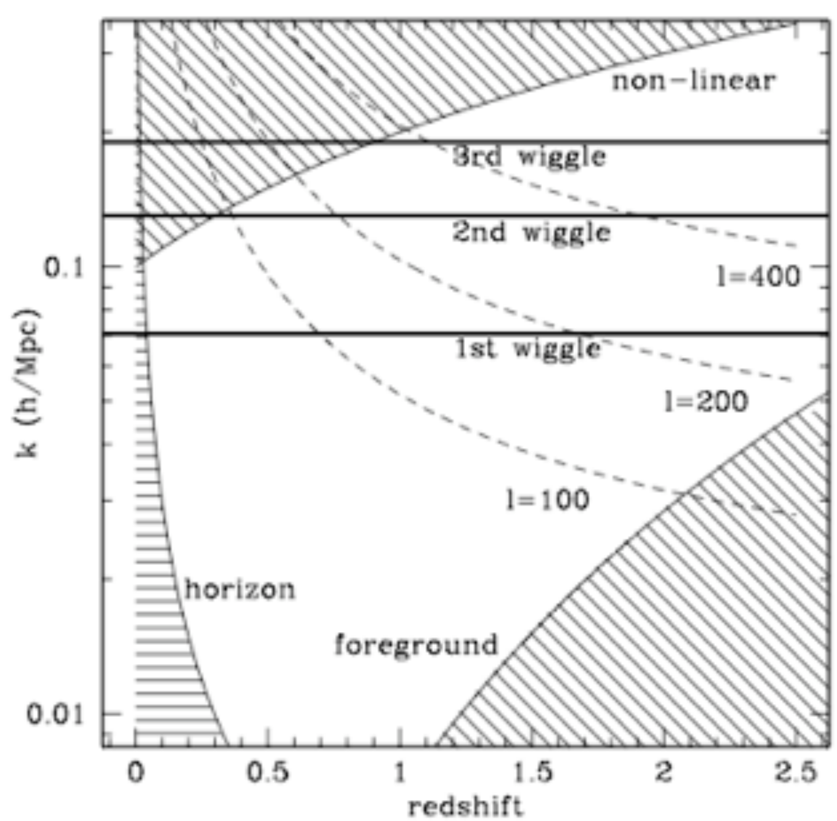
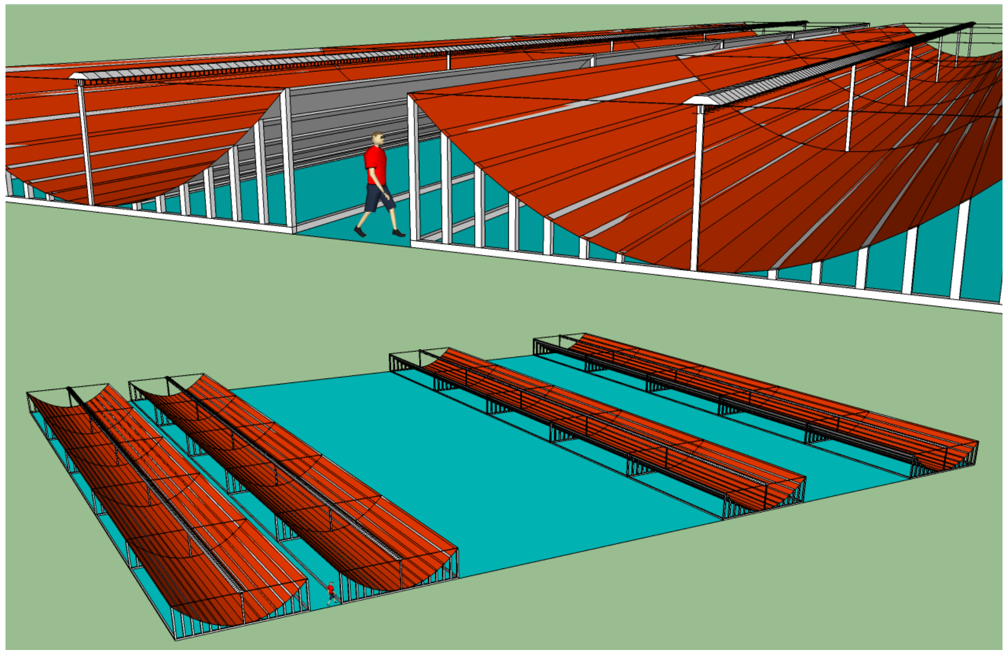


FIG. 3: The observable parameter space in redshift and in scale (k) for BAO. The shaded regions are observationally inaccessible (see text). The horizontal lines indicate the scale of the first three BAO wiggles, and the dashed lines show contours of constant spherical harmonic order ℓ.

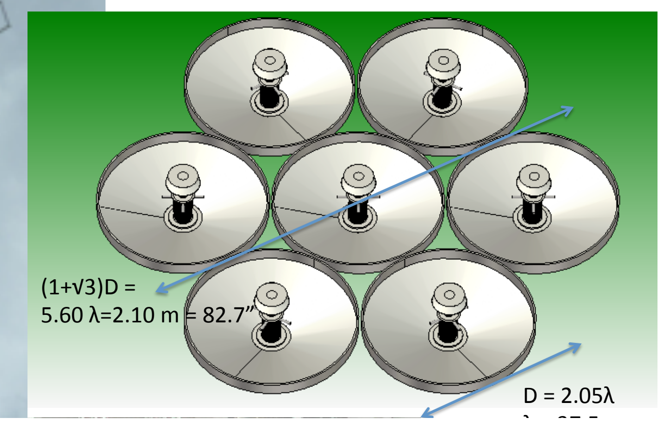
Chang et al. 2008

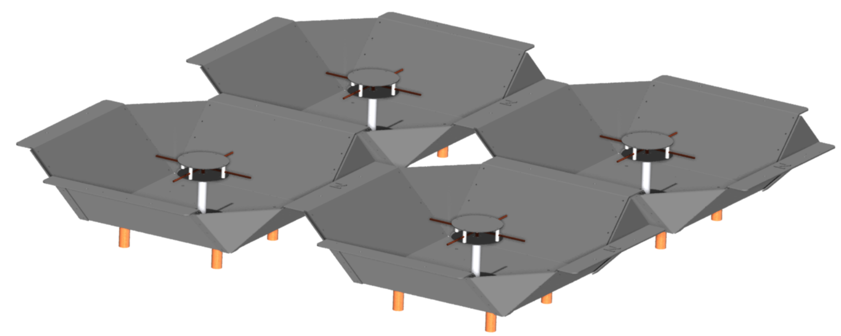
21cm Intensity Mapping current/future telescopes



CHIME/Tian-Lai/CRT/BAORadio

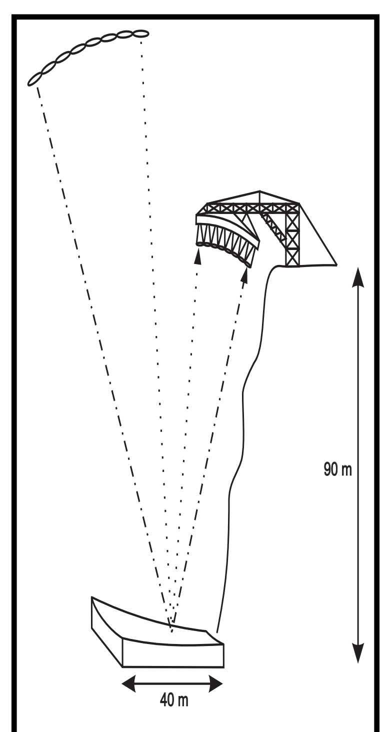
GBT-HIM multi-beam





BAOBAB

FFT/OMNISCOPE Telescope



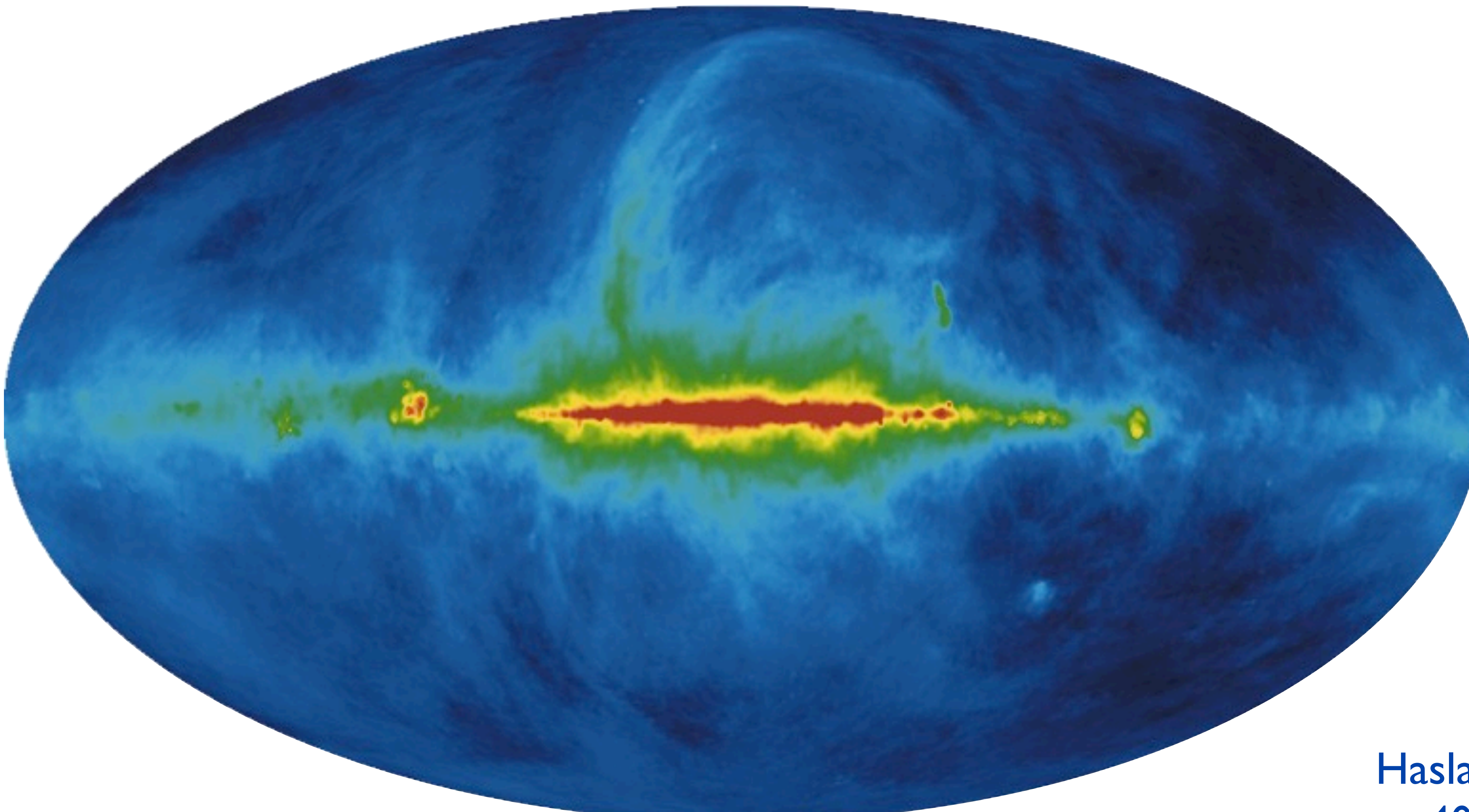
BINGO

SKA-low and SKA-mid Telescope

21cm Intensity Mapping

Observational Challenges:

- RFI, Galactic Synchrotron foregrounds > 10^3 signal
- HI content, distribution at high-z uncertain

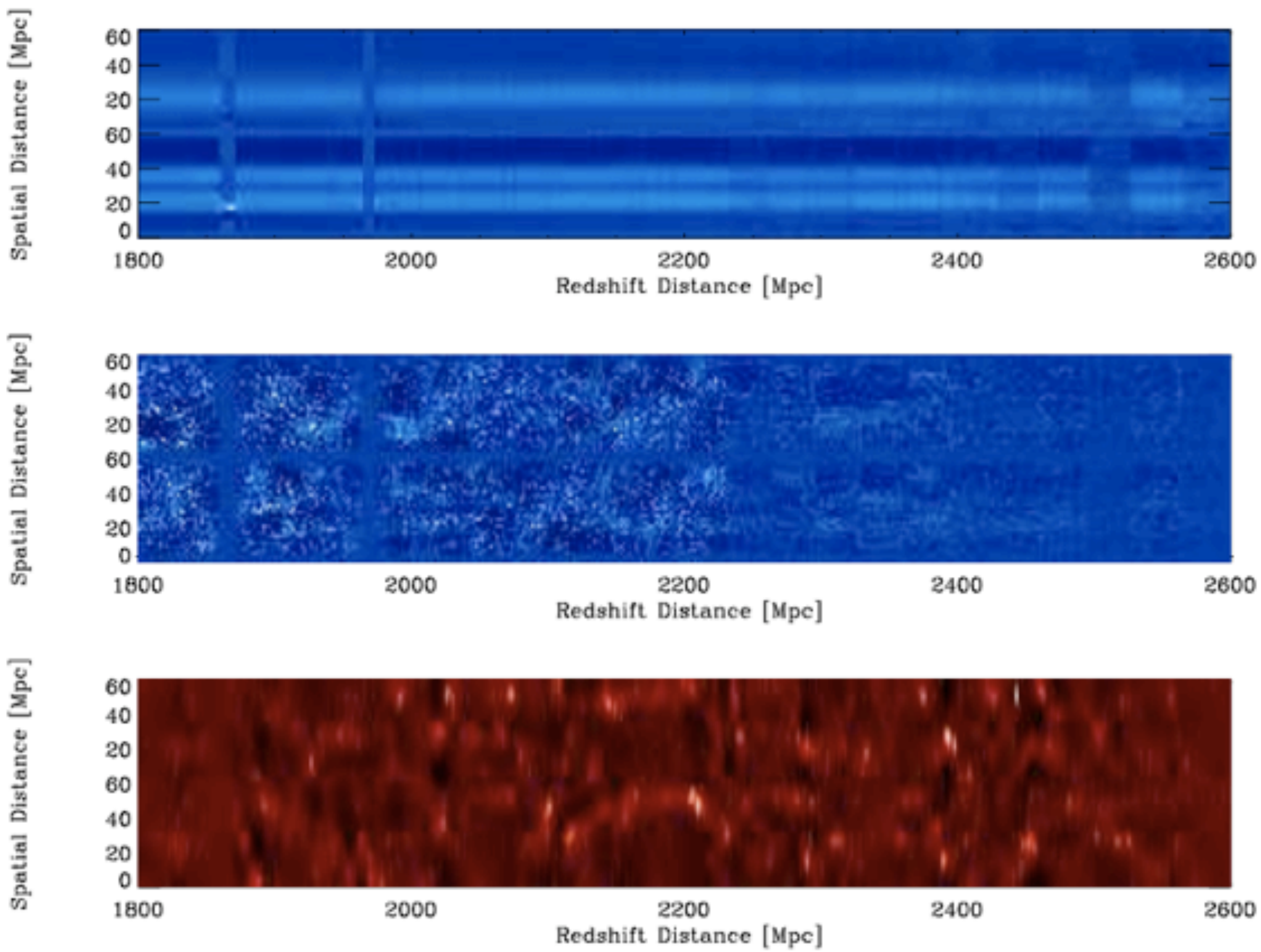


Haslam Map at 408 MHz

HI Intensity Mapping Current Status

Pilot Program at Green Bank Telescope

- HI: 0.58 < z < 1.0 ⟶ 900 MHz > frequency > 700 MHz
- GBT Beam FWHM ~ 15' ⟶ 9 h^{-1}Mpc at z~0.8 Ideal for large-scale structure studies
- Spectral resolution ~ 24 kHz, rebinned to ~500 kHz ⟶ 2 h^{-1}Mpc Ideal for large-scale structure studies



GBT radio continuum sources + HI

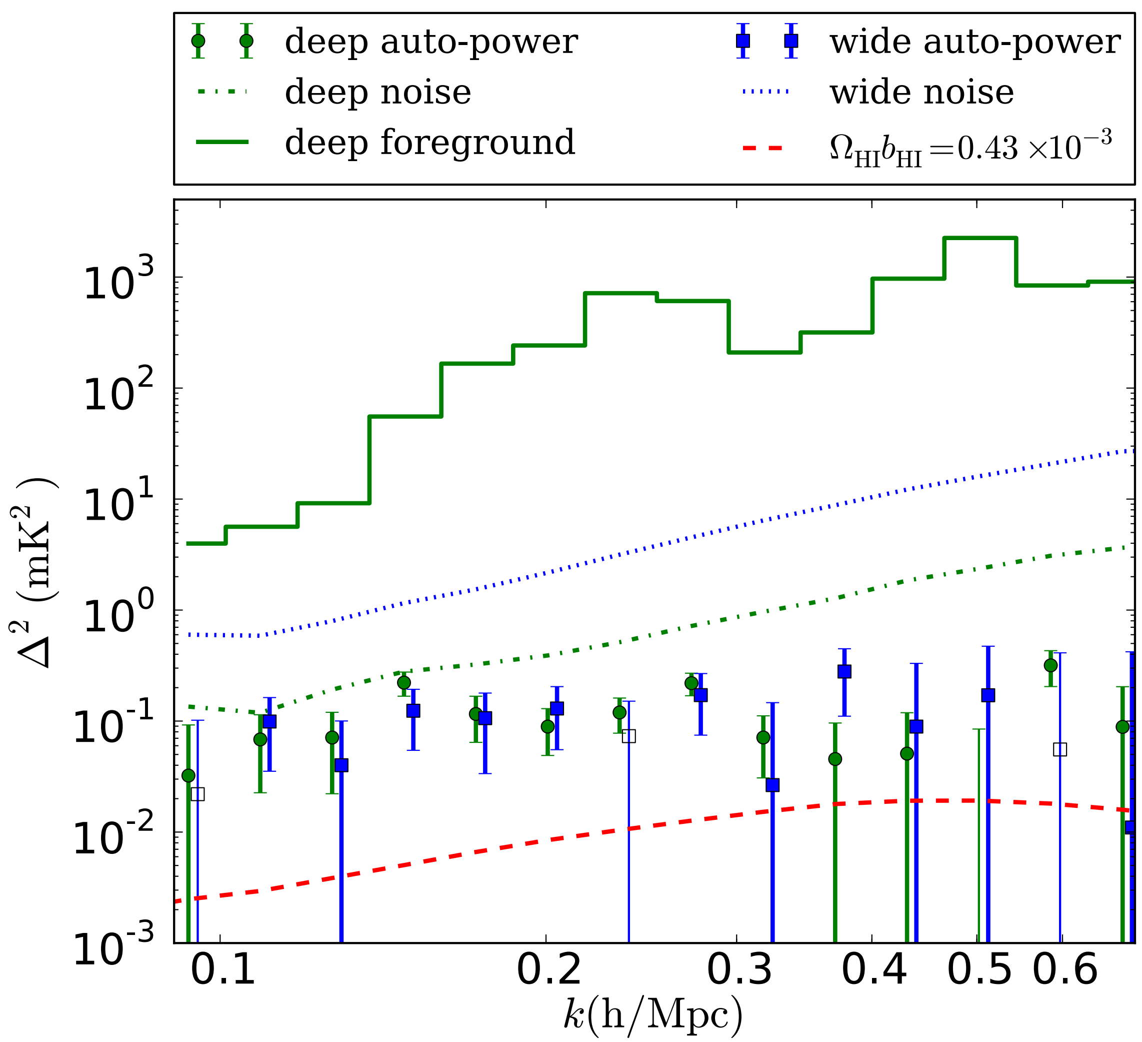
GBT HI

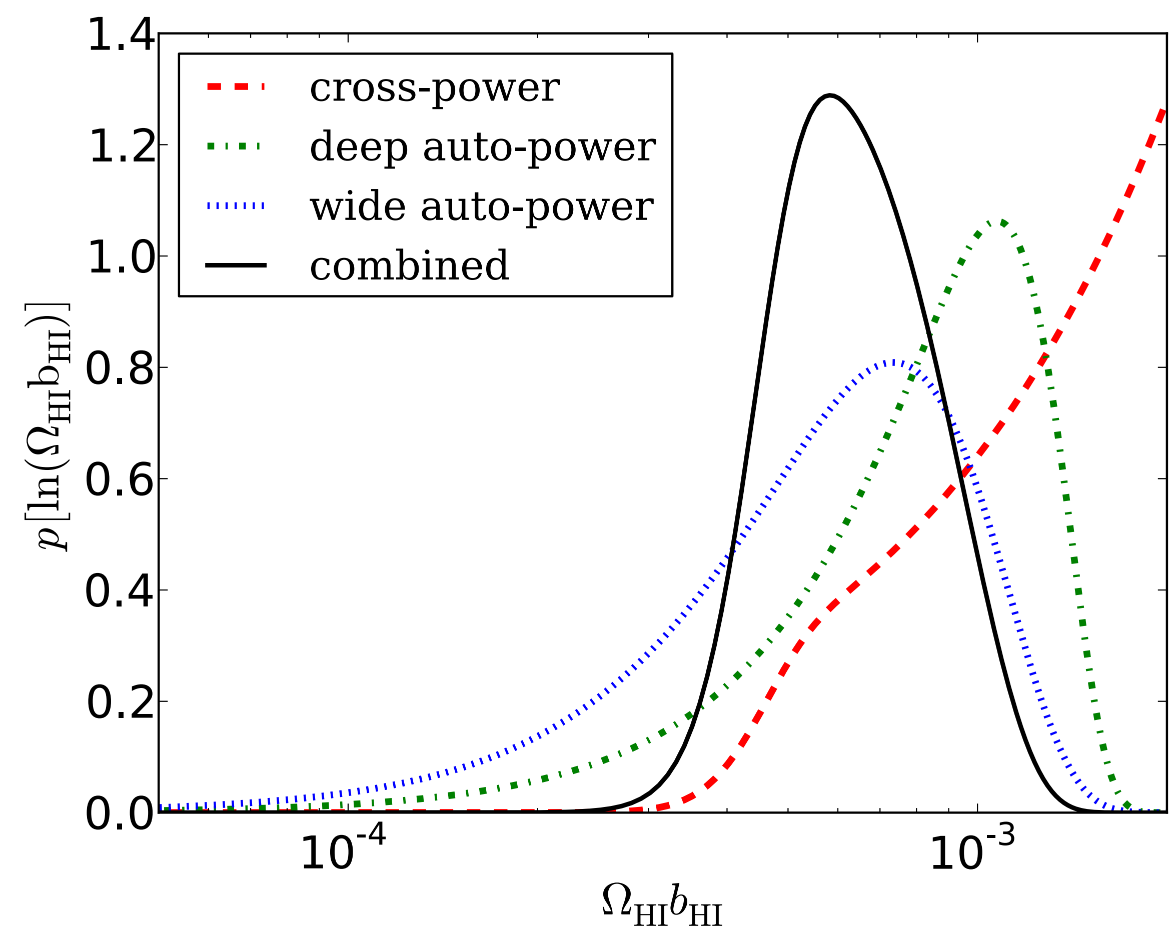
DEEP2 density

Chang+ 2010

HI Intensity Mapping Current Status

Current limits on 21cm auto power spectrum and measurements on $\Omega_{HI} b_{HI}$ at z=0.8 using the GBT by our GBT-HIM science team.

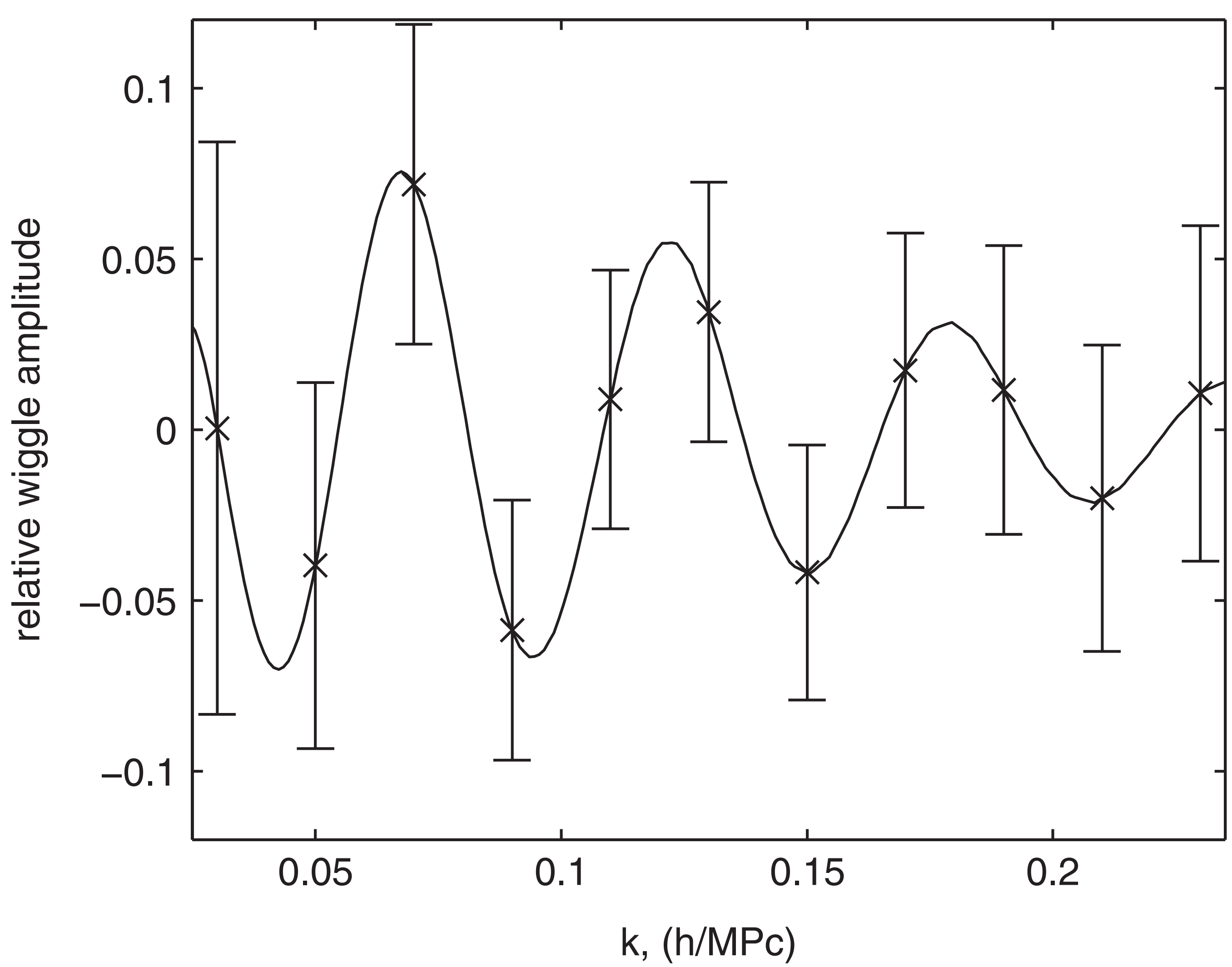




- $\Omega_{HI}\, b_{HI} = [0.62\,^{+0.23}_{-0.15}] \times 10^{-3}$

Switzer+13, the GBT-HIM team
Masui+13, Chang+10

BAO with HI IM



- Signals are on large-scales (150 Mpc comoving)
- HI signals are weak, ~100 microK (z)
- Need high-surface brightness sensitivity at core, similar to EoR requirements (~100-300m baselines depending on redshifts)
- Errors on BAO distance scales prop to (core filling factor)$^{-1}$.
- SKA1-mid, f~0.03 (<400m)
- SKA1-sur, f~0.003 (<400m)
- SKA1-low, f~0.91 (<220m)

BAO signals (150 Mpc) resolved in 3D (with a 100m baseline)

z	freq (MHz)	$d_{comoving}$ (Mpc)	dz	dfreq (MHz)
0.8	789	10.55	0.0038	1.66
1	710	13.93	0.0056	1.98
2	473	33.04	0.022	3.45
2.5	406	43.46	0.036	4.13
3.5	316	68.72	0.077	5.31

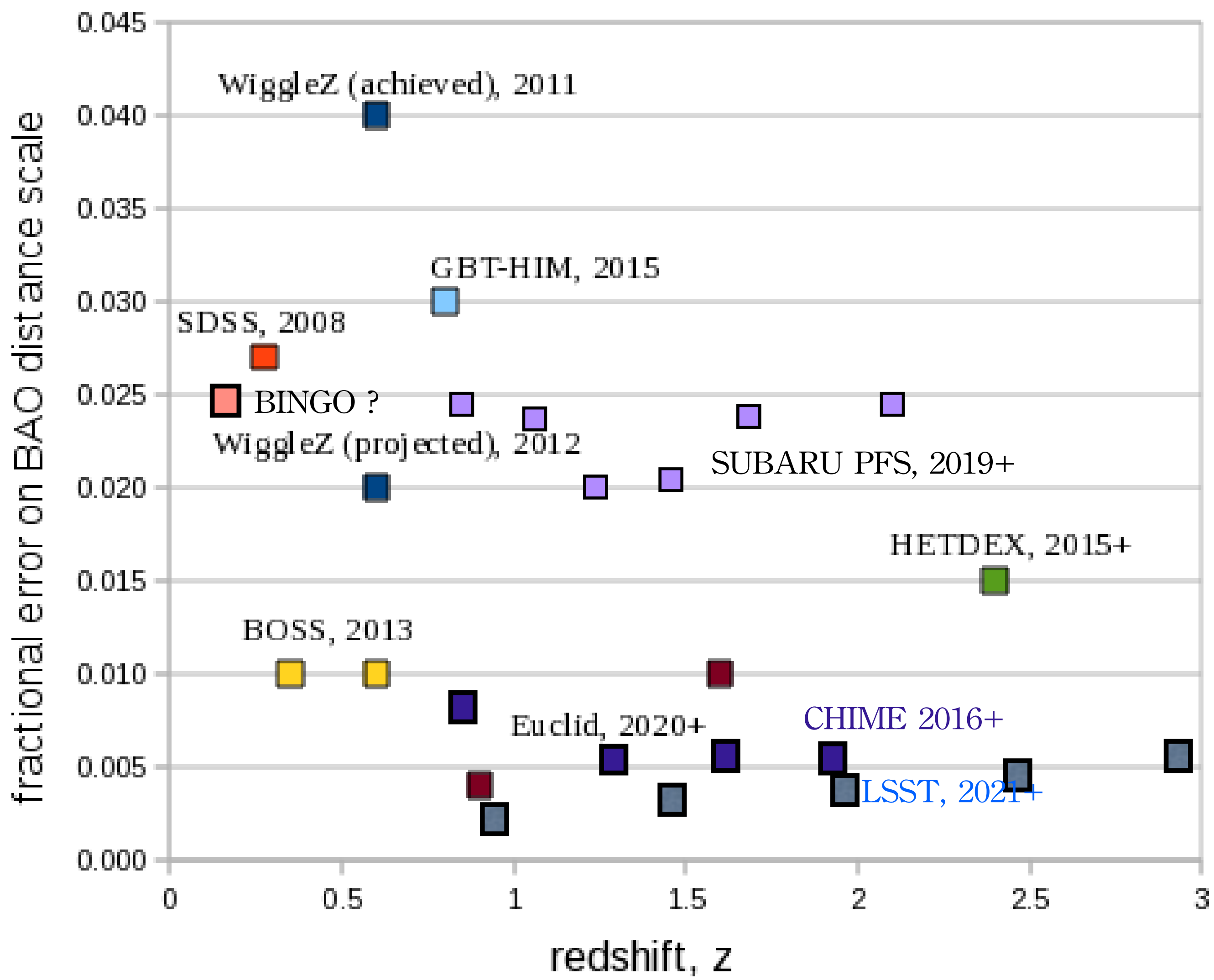
Short baselines (100-500m), low spectral resolution (< 0.1 MHz)

Other constraints

- Need to subtract foregrounds to high accuracy (better than 0.1%)
  - requires polarization purity (so polarized foregrounds won't leak into I).
  - no bandpass frequency structures > MHz scales that may mimic HI signals
  - may require large instantaneous FoV, similar to EoR concerns
- OH megamaser contamination?

BAO measurements

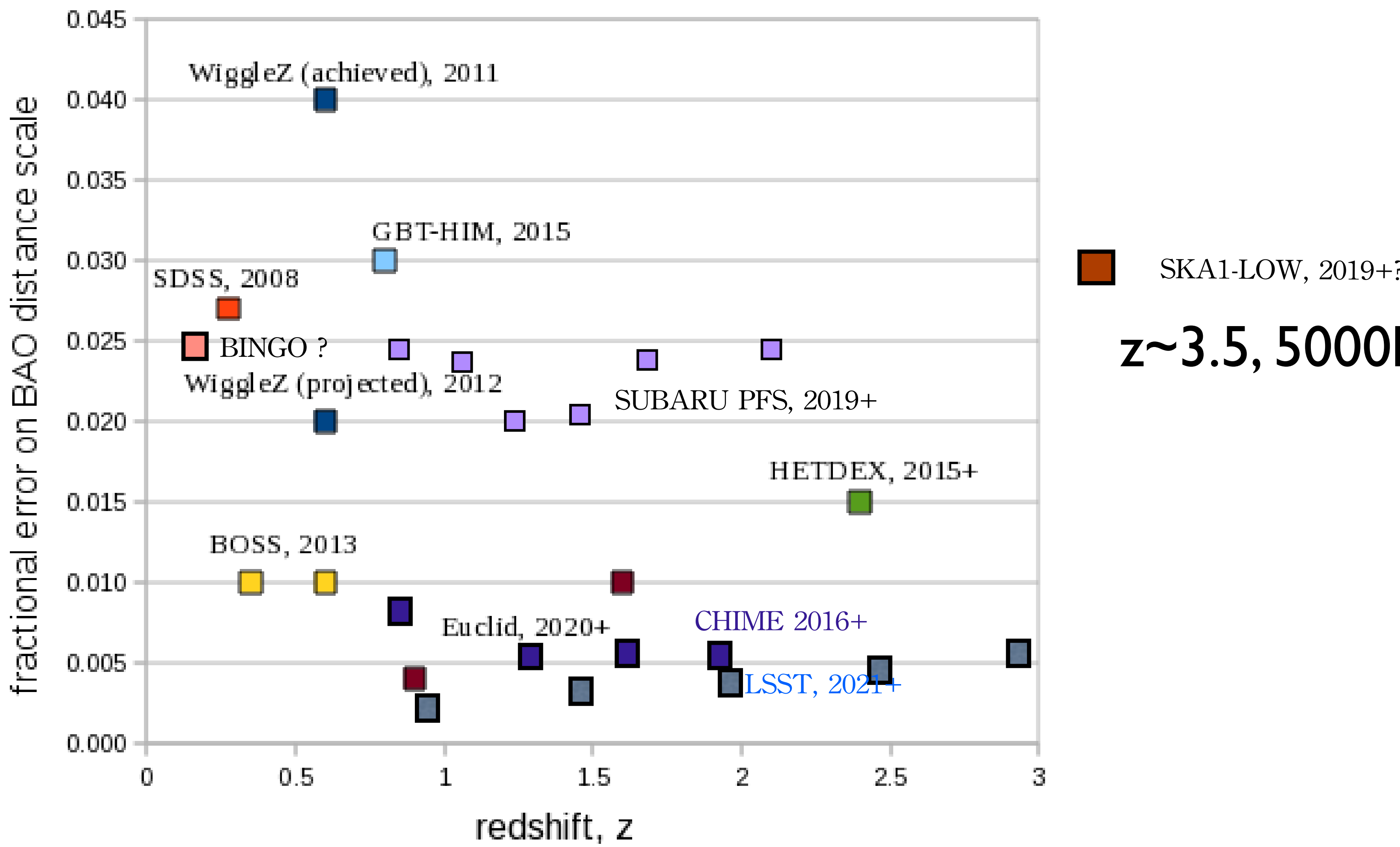
Forecasts on Baryon Acoustic Oscillation (BAO) distance scale.



SKA1-IM, 2019+?

BAO measurements with HI IM

Forecasts on Baryon Acoustic Oscillation (BAO) distance scale.



z~3.5, 5000hrs, 500 deg^2

Summary

- 21cm Intensity Mapping for BAO measurements is a new and promising field
- Dedicated instruments/telescopes (GBT-HIM, CHIME, Tian-Lai) are under-construction for this science goal.
- SKA1-mid and -sur may not be competitive for BAO measurements at $z<3$ (*need to be verified). It will be very useful if central core (<100m) is packed.
- SKA1-low may have a unique measurement at high-z, probing alternative dark energy models and large-scale structure (for e.g., Omega_k and neutrino masses), but foregrounds will be challenging.