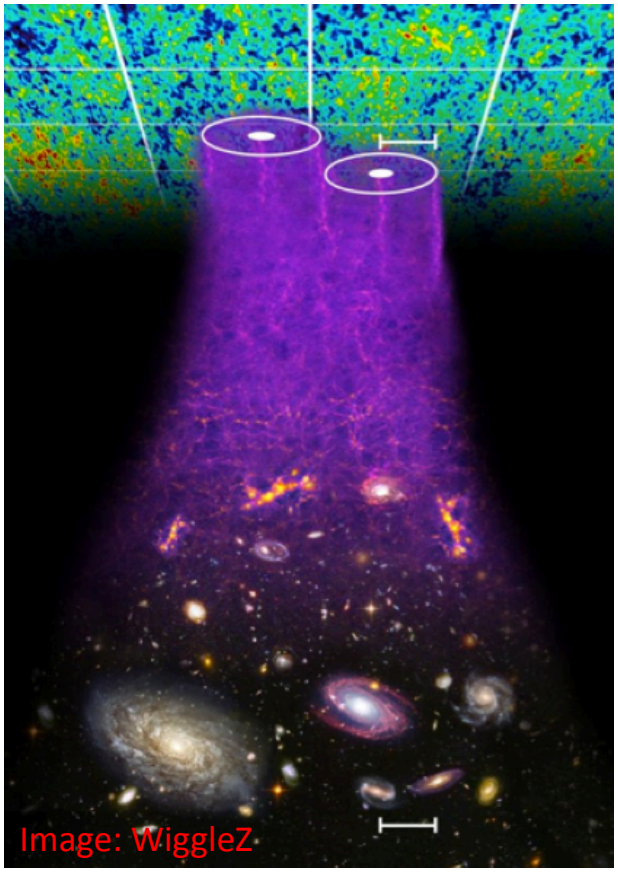
21 cm Intensity Mapping with the Green Bank Telescope

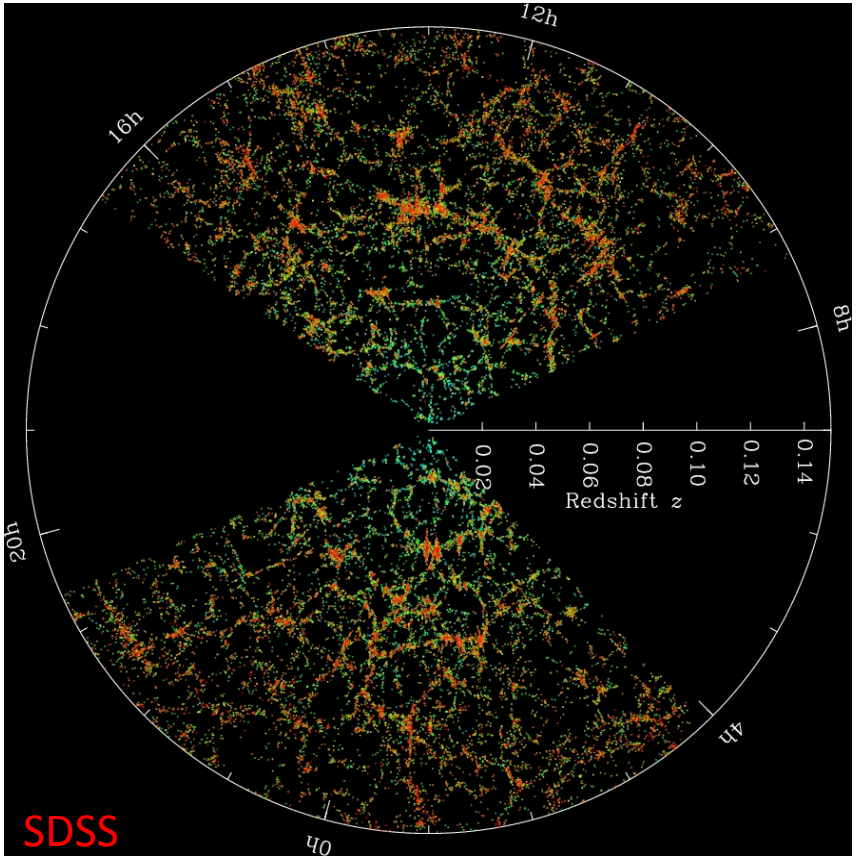
Eric Switzer (CITA)

For the GBT 21 cm intensity mapping collaboration

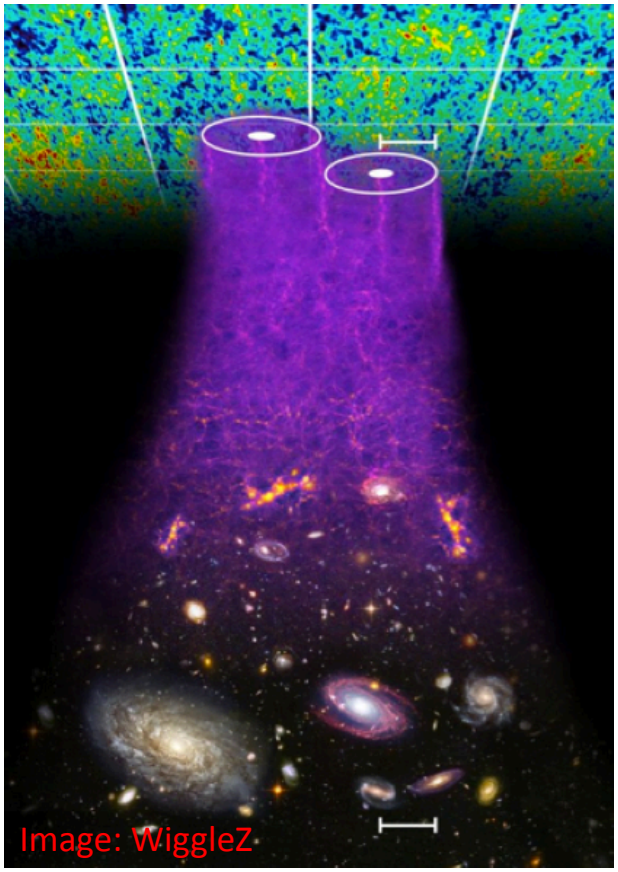
Jan. 20, 2012

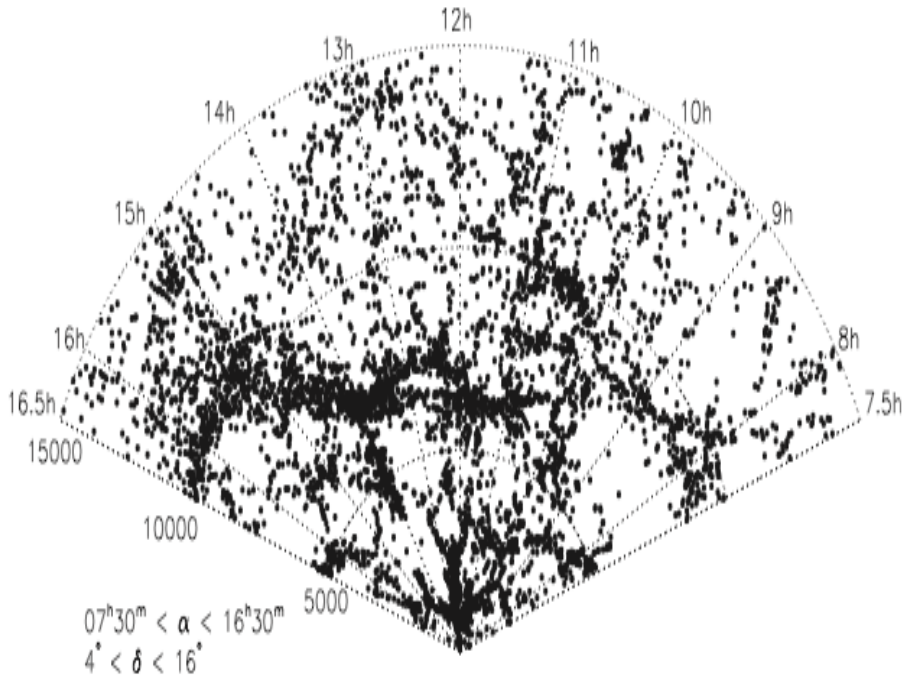
Galaxy surveys





Galaxy surveys



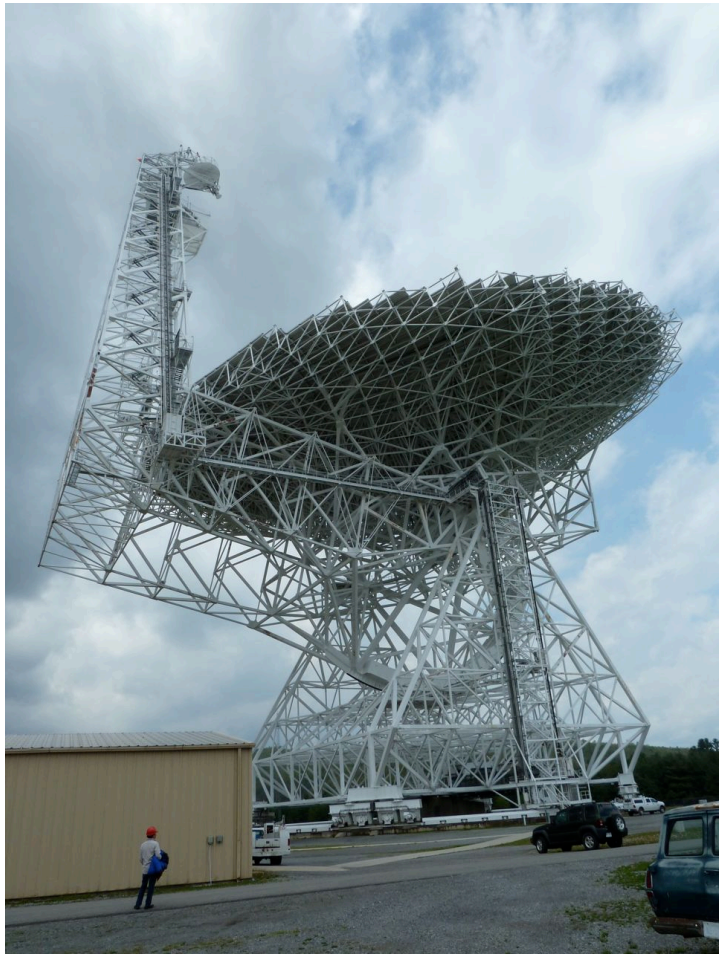


Martin et al. 2010
Arecibo ALFALFA galaxy survey
z<0.1

Instead of cataloging individual sources, map the diffuse 21 cm emission.

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 Green Bank Telescope

100 m diameter, largest steerable single dish; very tight surface tolerance.
FWHM~0.3 deg

The 680-920 MHz feed
We use: 700-900 MHz or z=0.58 to 1
System temperature ~30 K
Out of the galactic plane
Insensitive to weather
Scripted remote observing

Extending previous efforts

"An intensity map of hydrogen 21-cm emission at redshift z~0.8"
Tzu-Ching Chang, Ue-Li Pen, Kevin Bandura, and Jeffrey B Peterson
Nature Vol 466 (2010).

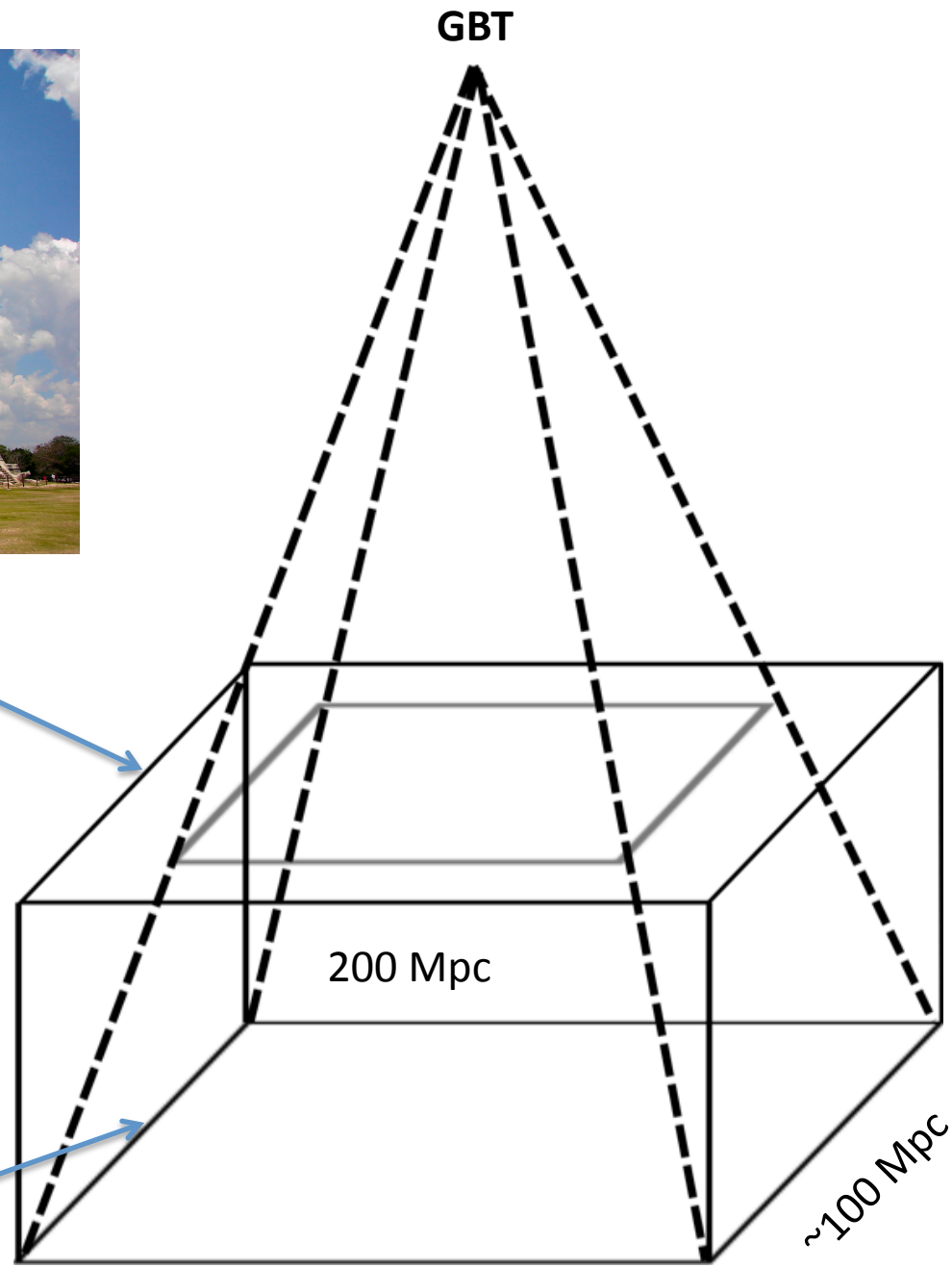
Main conclusion: Ω_{HI} = (5.5±1.5) 10^{-4} (1/rb), T =157±42 μK

1. Cross-corr with DEEP2 ➔Cross-power with WiggleZ and first detection of diffuse 21 cm auto-power.
2. Drift scan in two fields ➔Constant-elevation mapping in three fields.
3. SVD of map, separability ➔ Line-of-sight covariance modes, XSPEC power spectra.
4. **15 hr on ~2 deg^2 ➔224 hr on ~75 deg^2**; nearly identical redshift range. Here: 109 hours obs., ~5°x3° "deep field" in WiggleZ 15 hr field, down to k≈0.1 h Mpc^{-1}.
5. Updated data acquisition and processing; greatly improved.

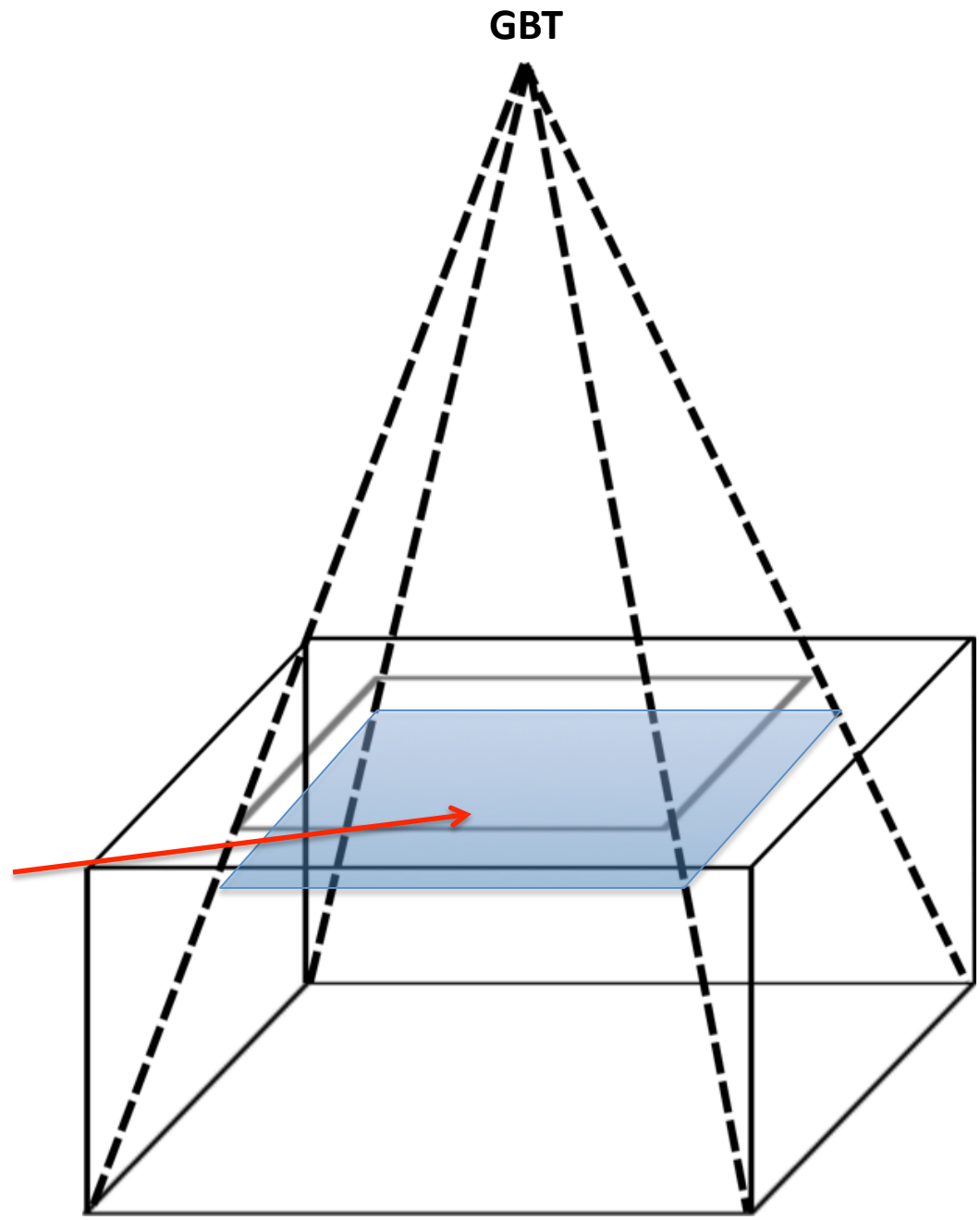
900 MHz, z=0.6, 2.1 Gpc

256 spectral slices.
~ 3-4 Mpc/slice.
Each is a map of
diffuse emission.
(like the CMB)

700 MHz, z=1, 3.3 Gpc

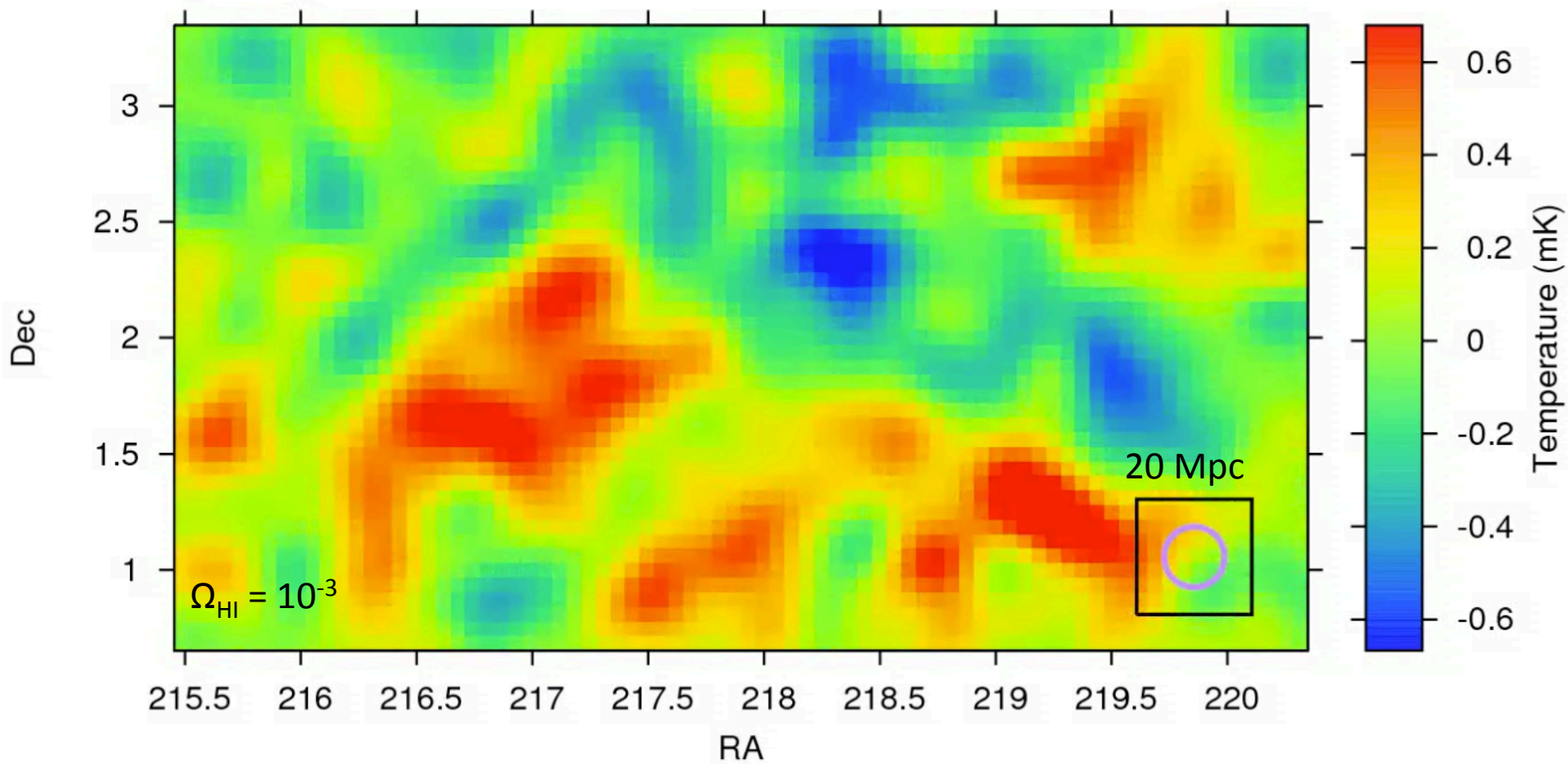


Maps shown here are from
a slice at 870 MHz
(movies available)

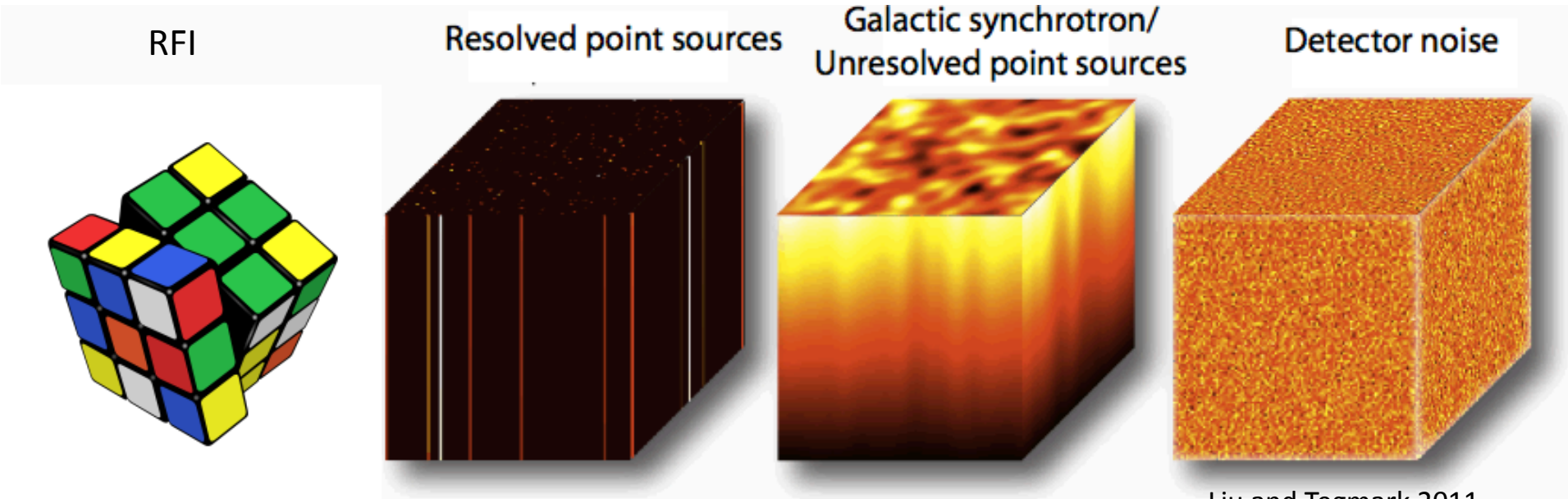


Signal-only simulations

$$T_b = 0.4\left(\frac{\Omega_{\rm HI}}{10^{-3}}\right)\left(\frac{\Omega_m + a^3\Omega_\Lambda}{0.29}\right)^{-1/2}\left(\frac{1+z}{2.5}\right)^{1/2}\ \mathrm{mK}$$

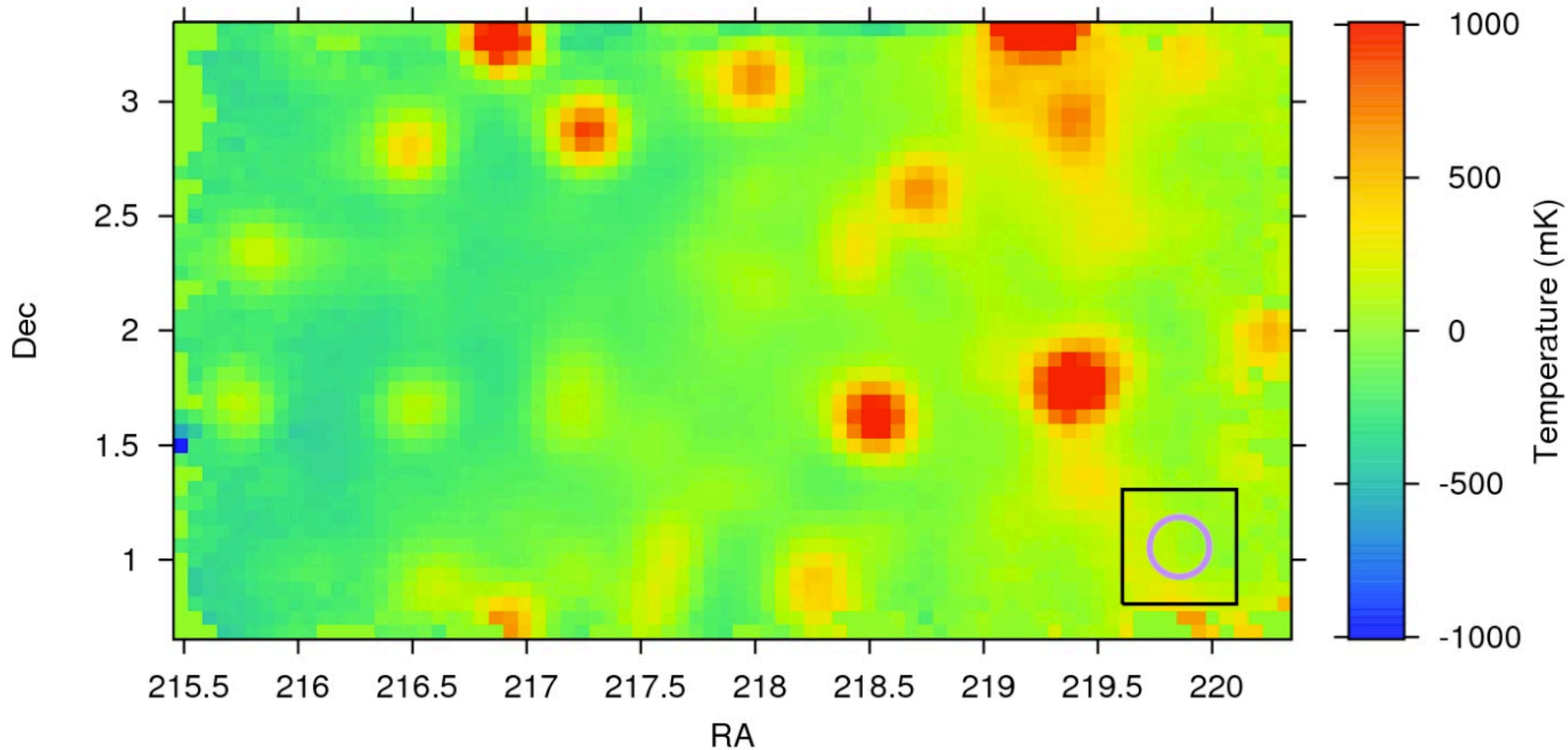


Box: 78x43x256, FWHM~0.3 deg, pixel = 0.25 FWHM



Liu and Tegmark 2011

Observations

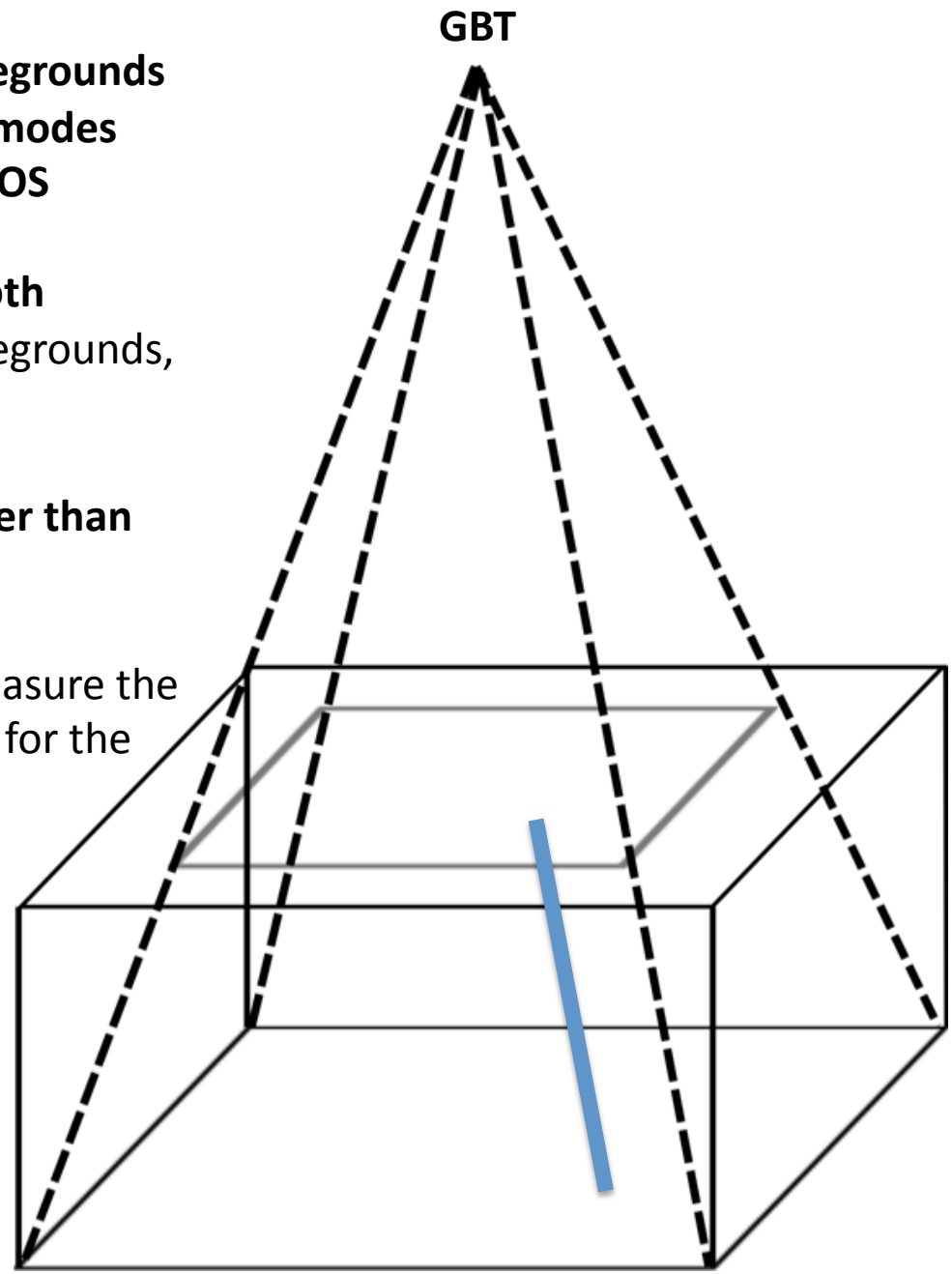


1. **Find v v' covariance of the foregrounds**
2. **Diagonalize, find line-of sight modes**
3. **Subtract N modes from each LOS**

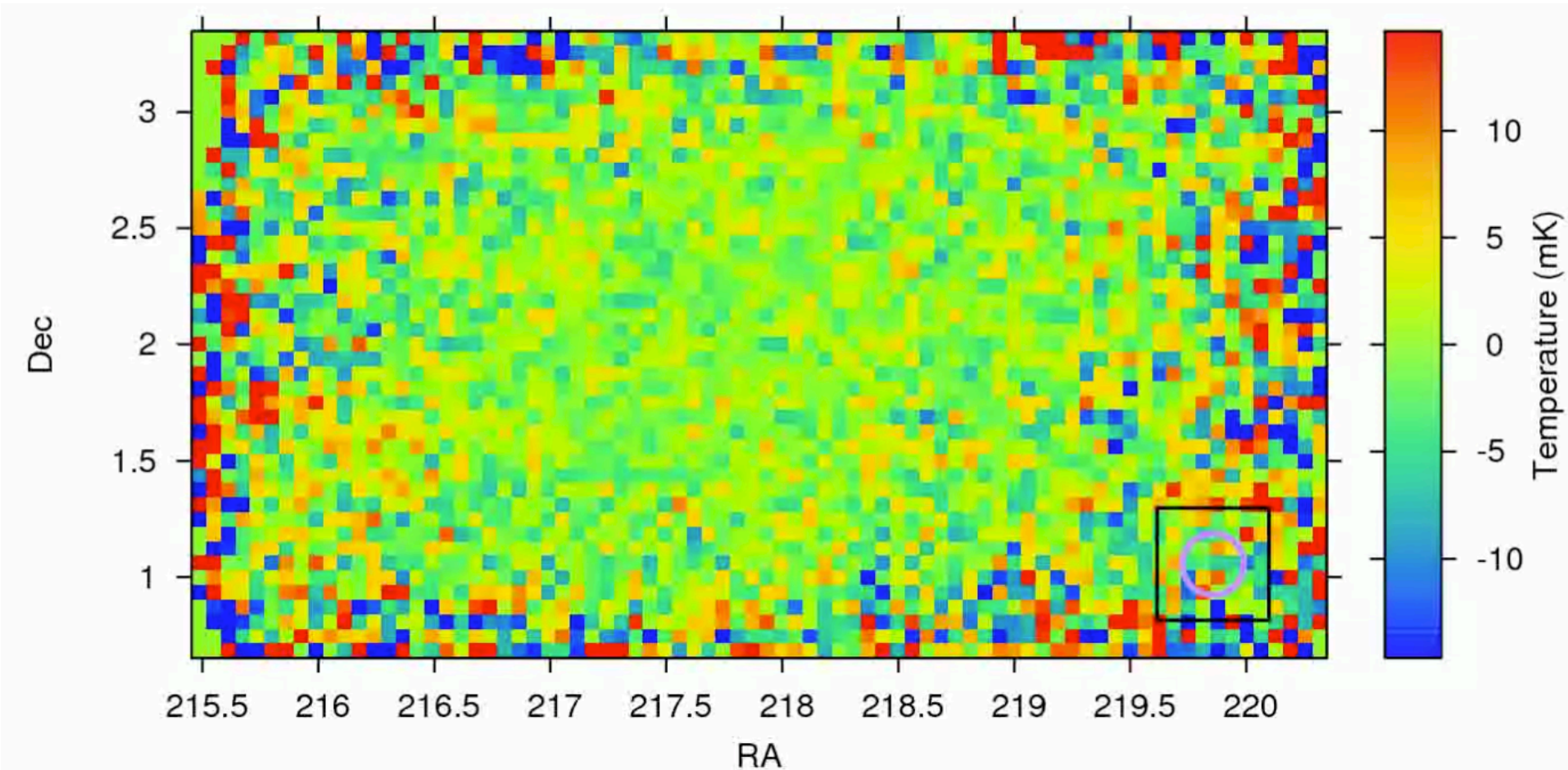
Note: these modes are NOT smooth polynomials. Calibration, real foregrounds, etc.

Full, idempotent subtraction rather than optimal weighting.

End-to-end map simulation to measure the transfer function and compensate for the GBT beam and data cleaning.

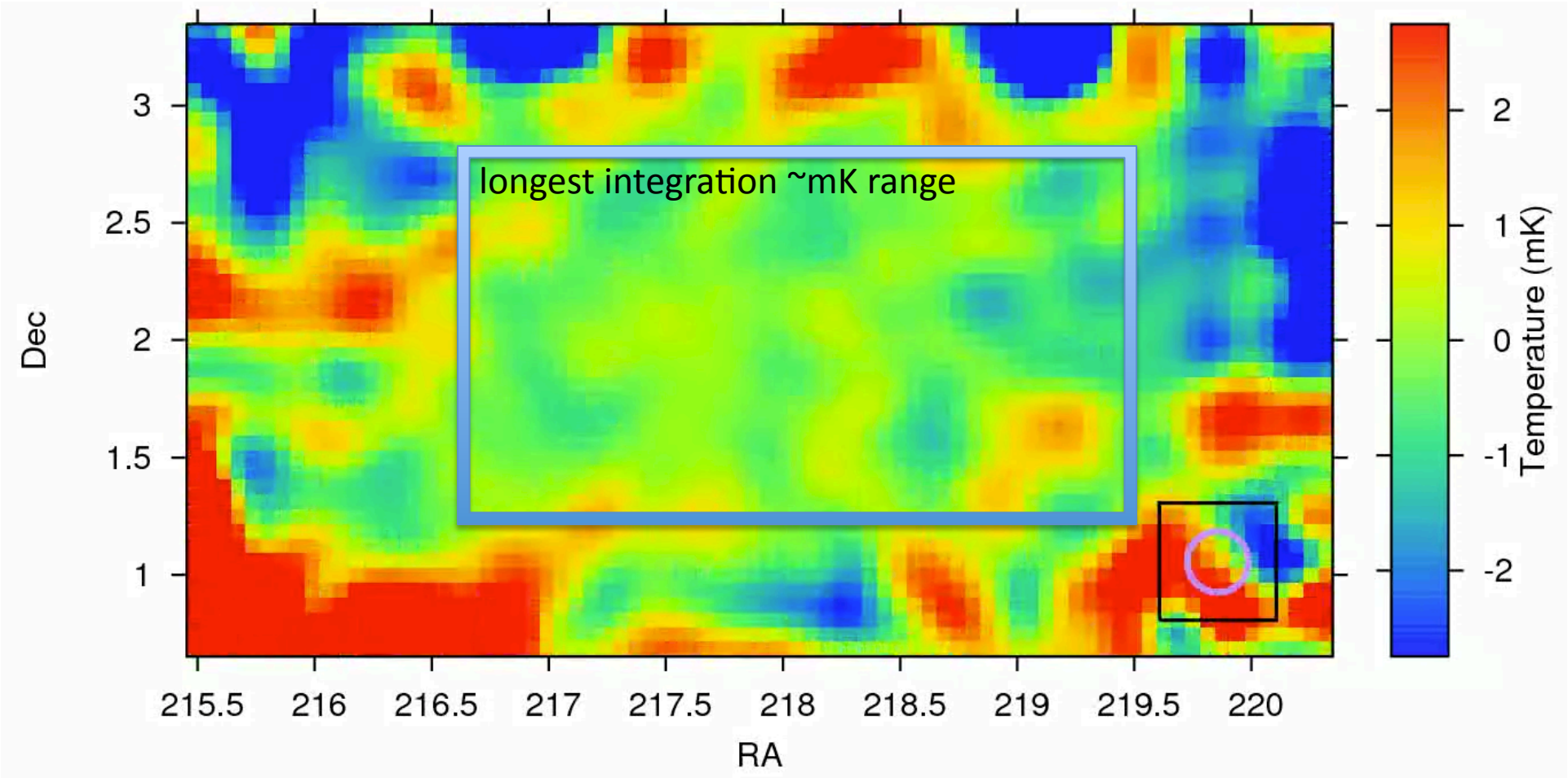


Real data, cleaned



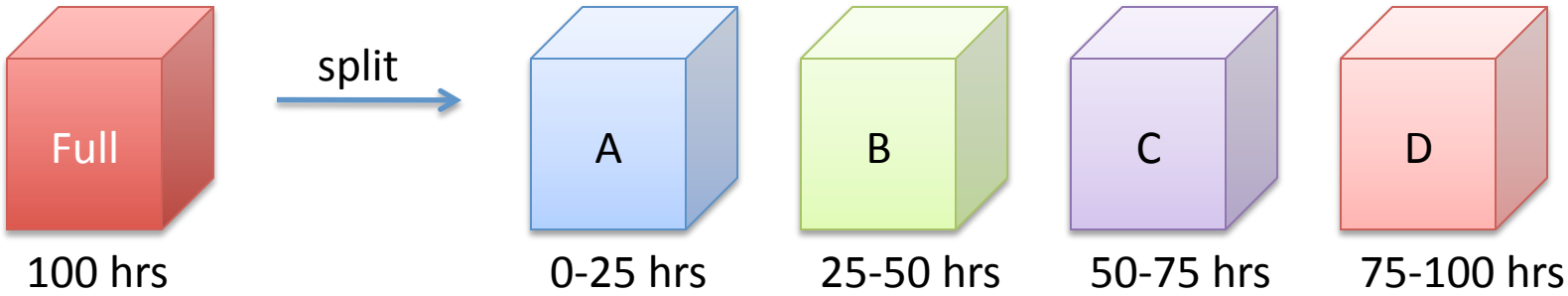
In this treatment, uncorrelated thermal noise.

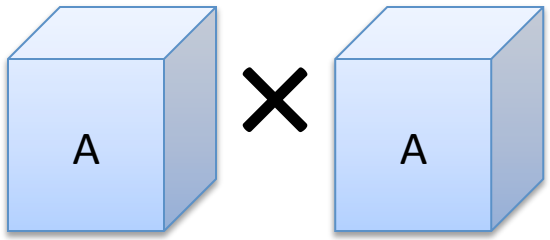
Real data, cleaned, beam convolved



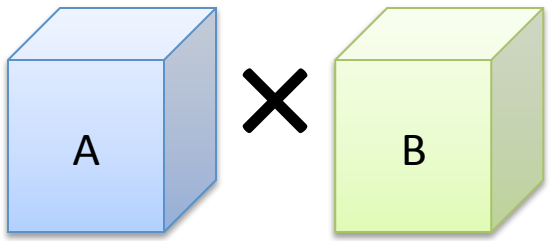
S/N insufficient for image of HI per slice; pursue statistical detection
Signal loss from foreground subtraction at this level is modest.

Splitting the season





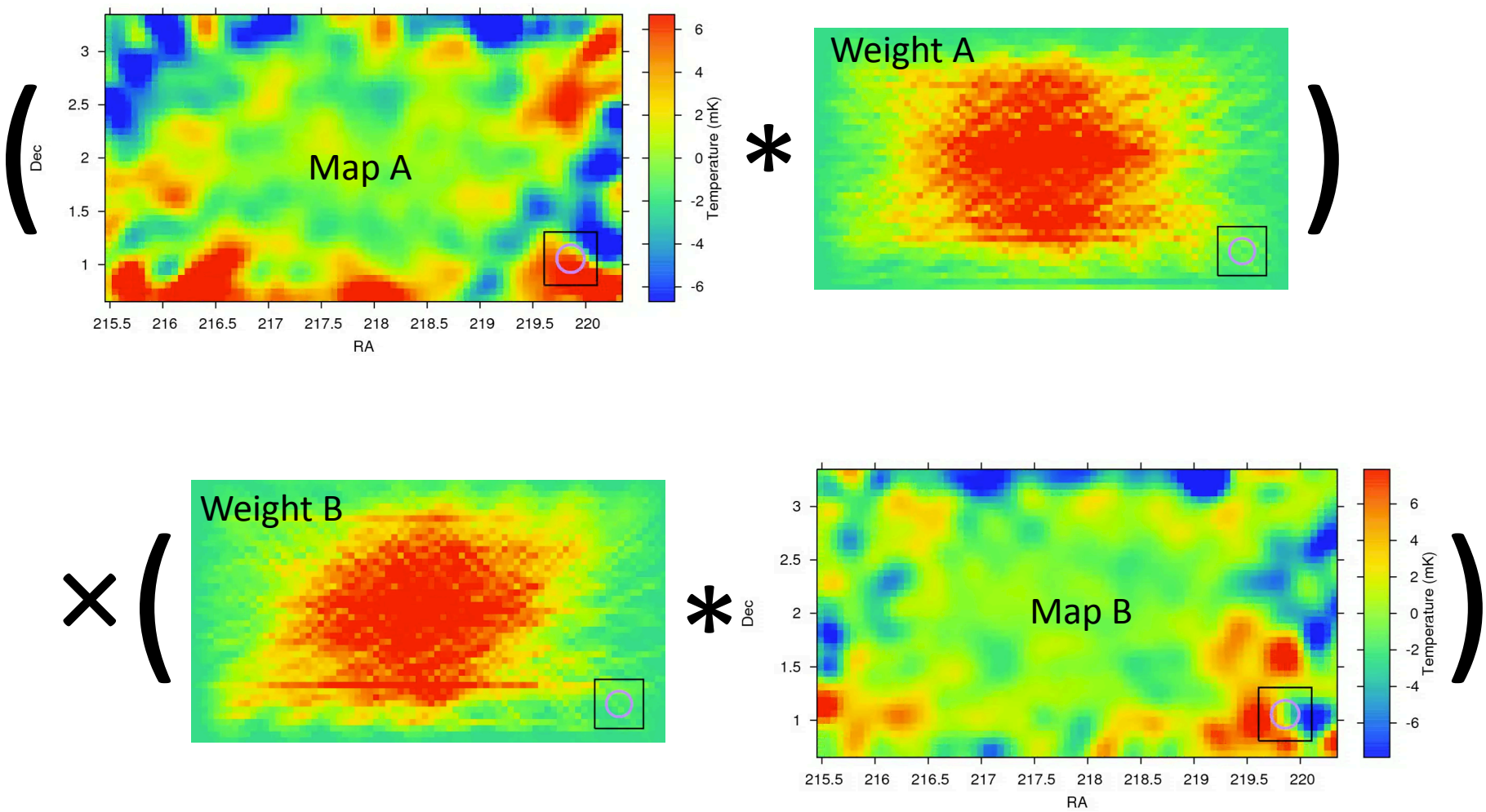
Is signal power plus noise power



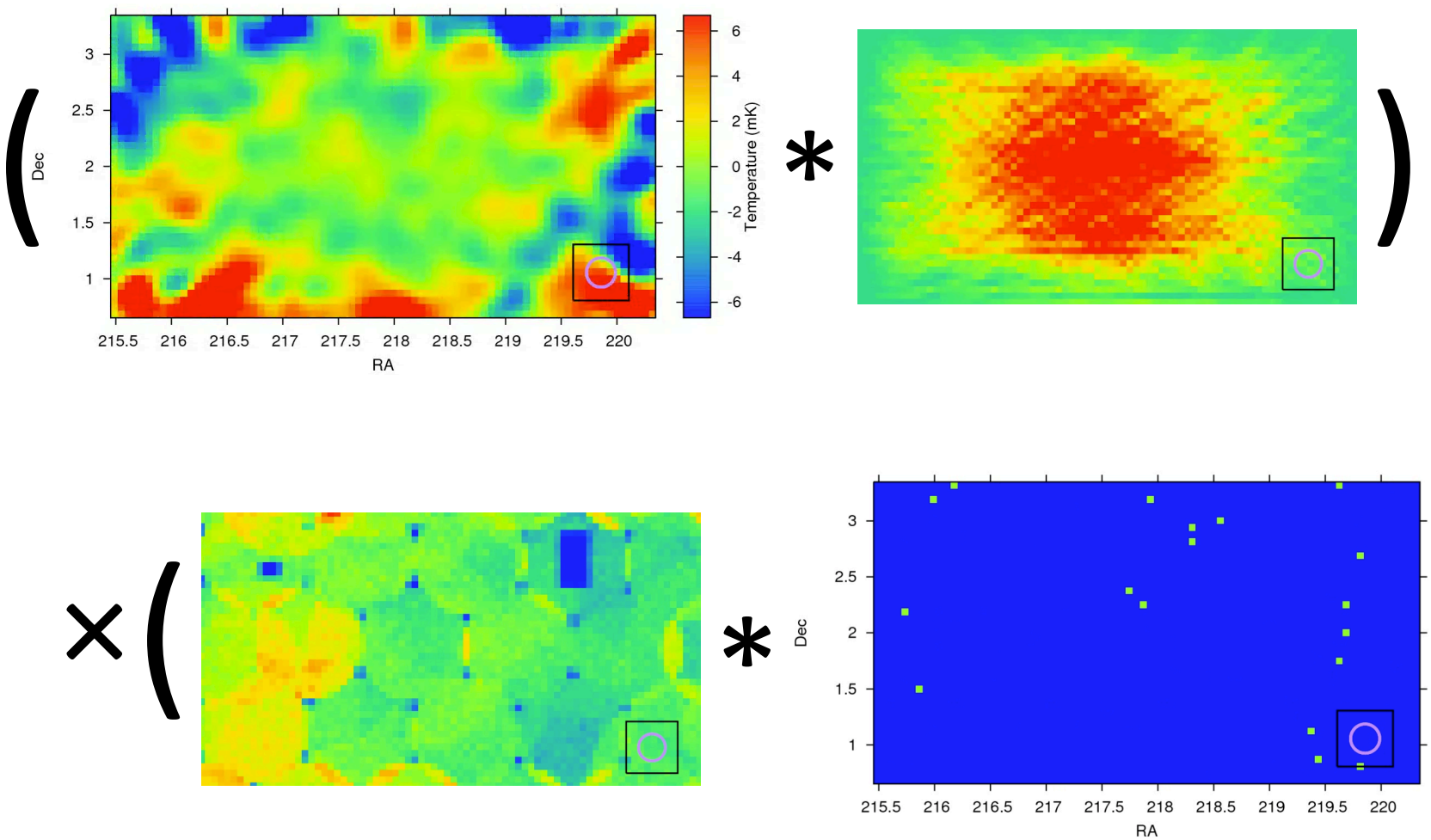
Thermal noise is uncorrelated across time

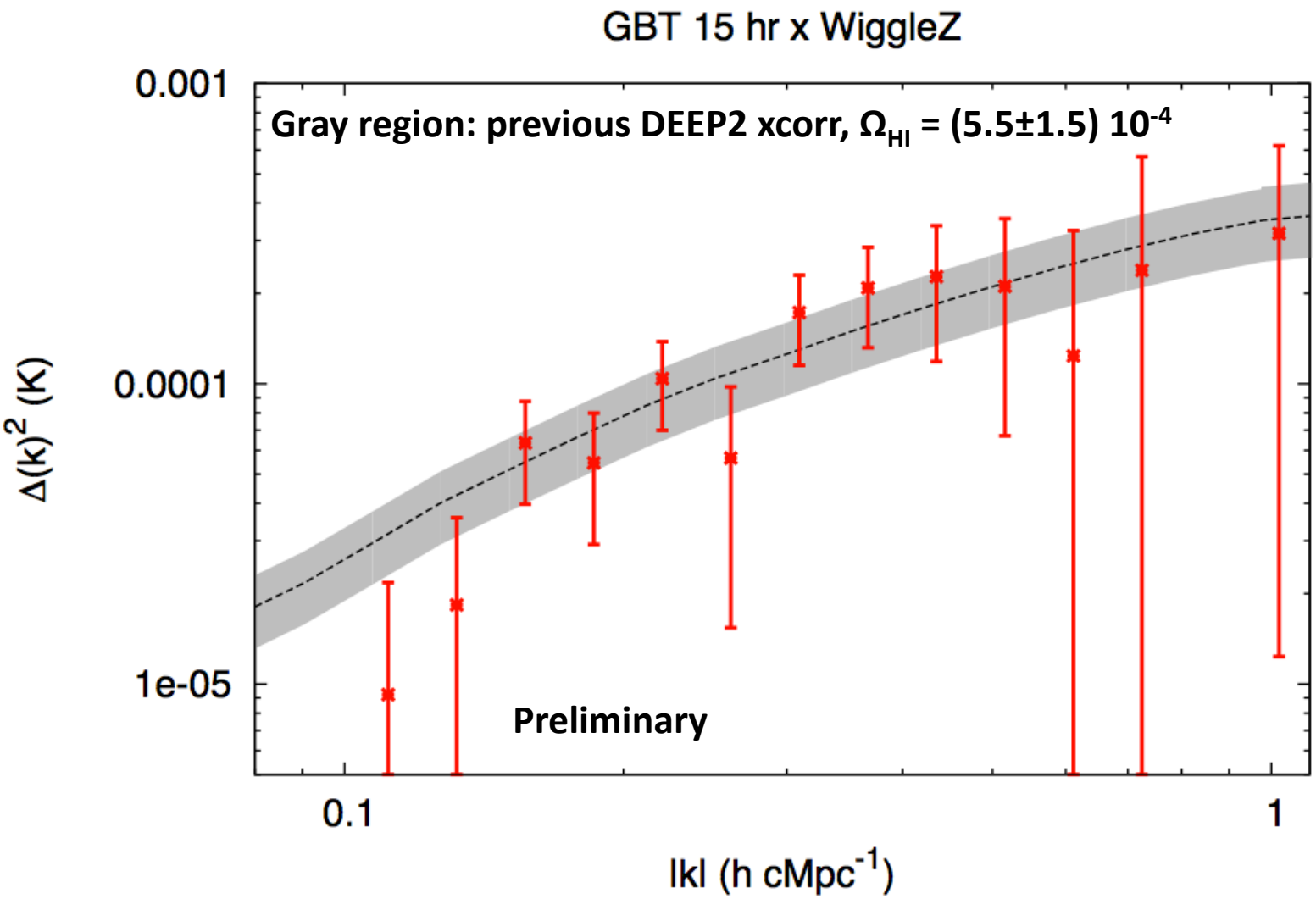
Form 6 unique pairs; rudimentary errors

Cross-pairs: GBT power



Cross-pairs: WiggleZ crosspower

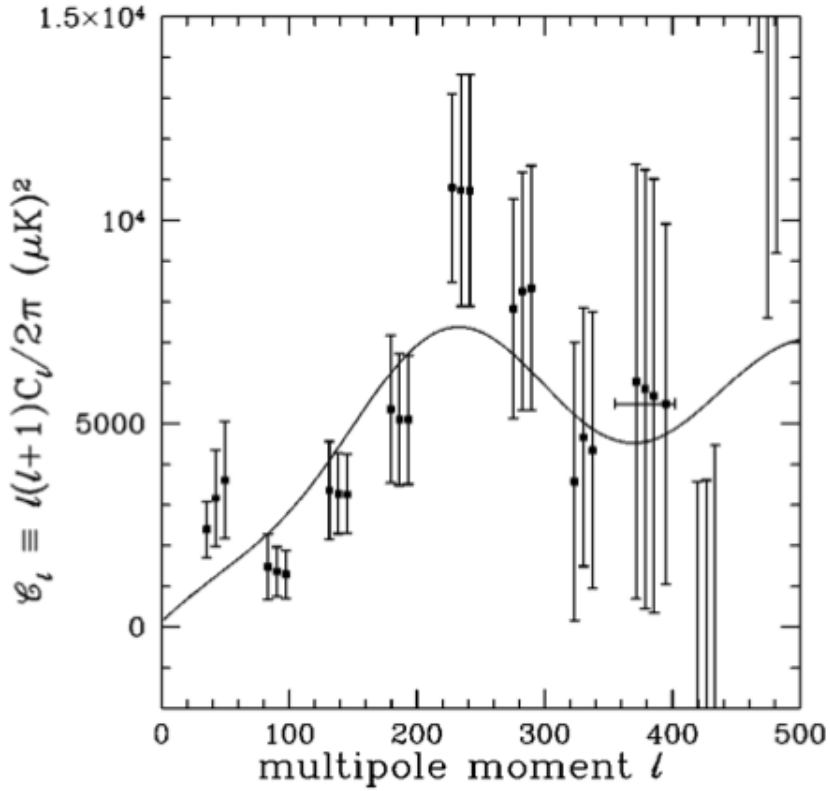




Significant optical galaxy shot noise. Compensated for beam, fg. cleaning.

An ideal timeline

- Discovery of HI in auto-power.
- Lessons for 21 cm reionization studies: foregrounds, instrumental tolerance, methods.
- Evolution of HI abundance, bias, stochasticity (RSD) since at least z~1.
- Complementary BAO information at high redshift and corroborate constraints on dark energy.
- Receiver array on GBT, CHIME.



Bond, Jaffe, Knox, 1998, Saskatoon data