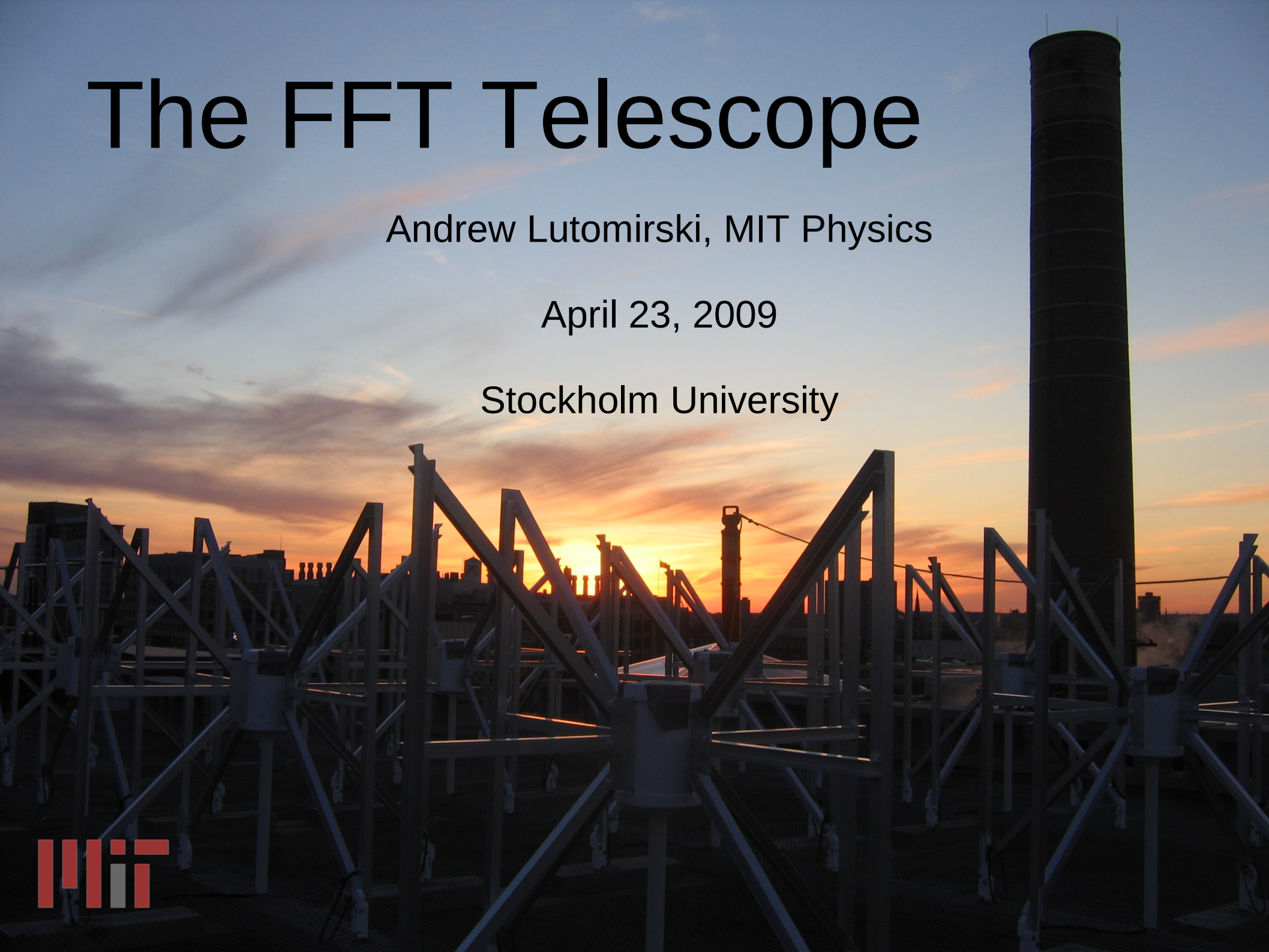


The FFT Telescope

Andrew Lutomirski, MIT Physics

April 23, 2009

Stockholm University

The FFT Telescope

- Why 21cm cosmology?
- Basics of radio astronomy
- The FFT telescope design
- What's that thing on our roof?

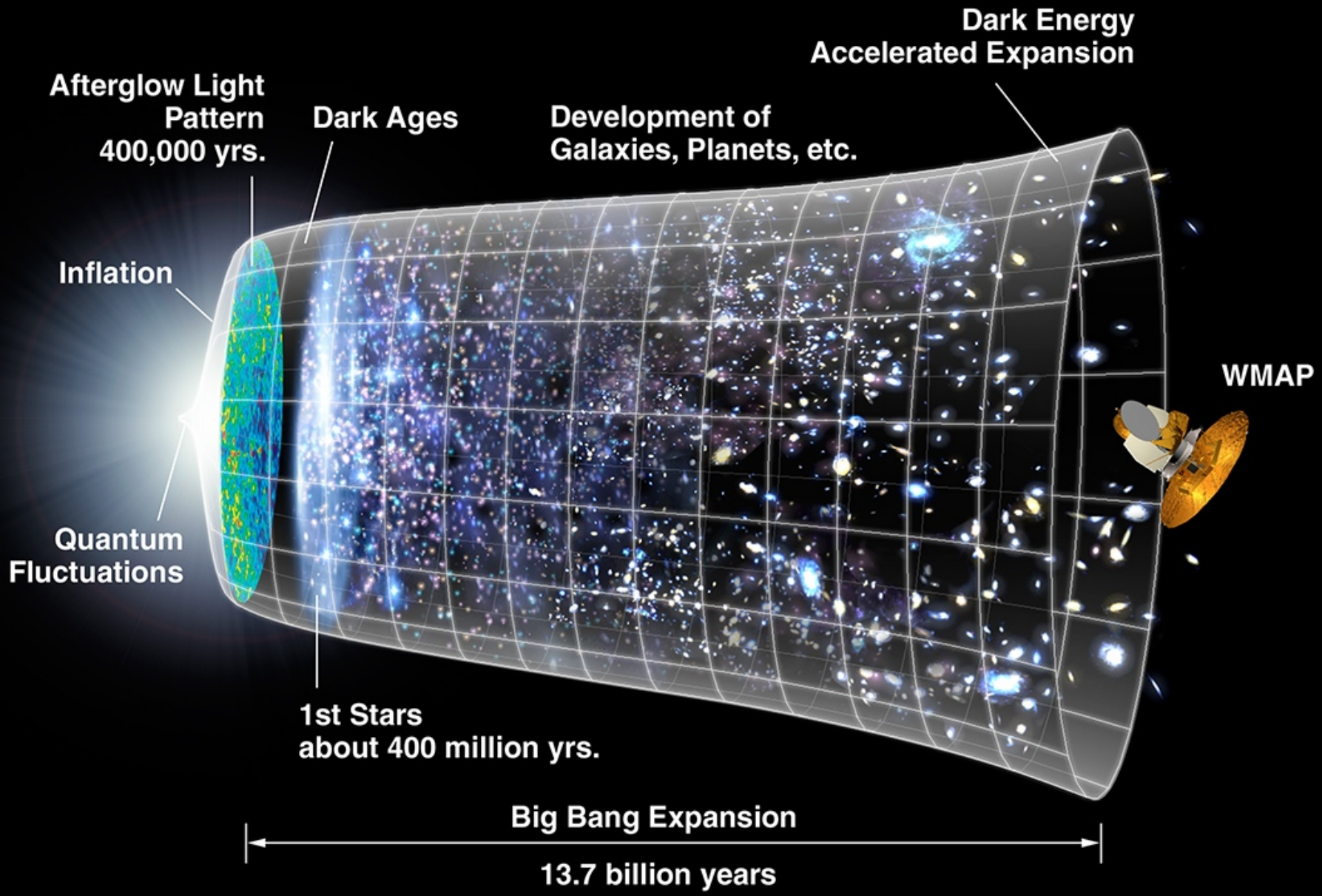
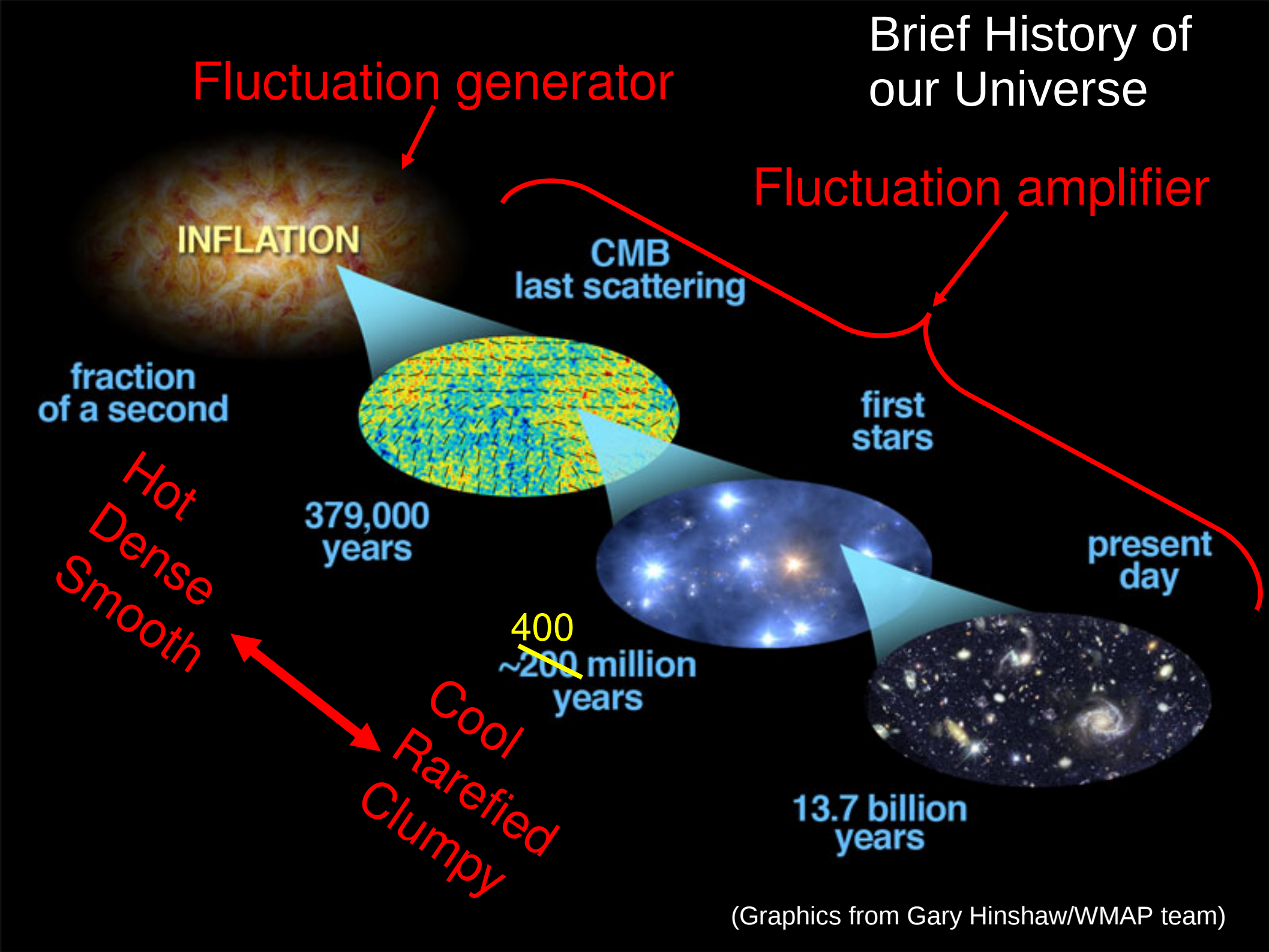


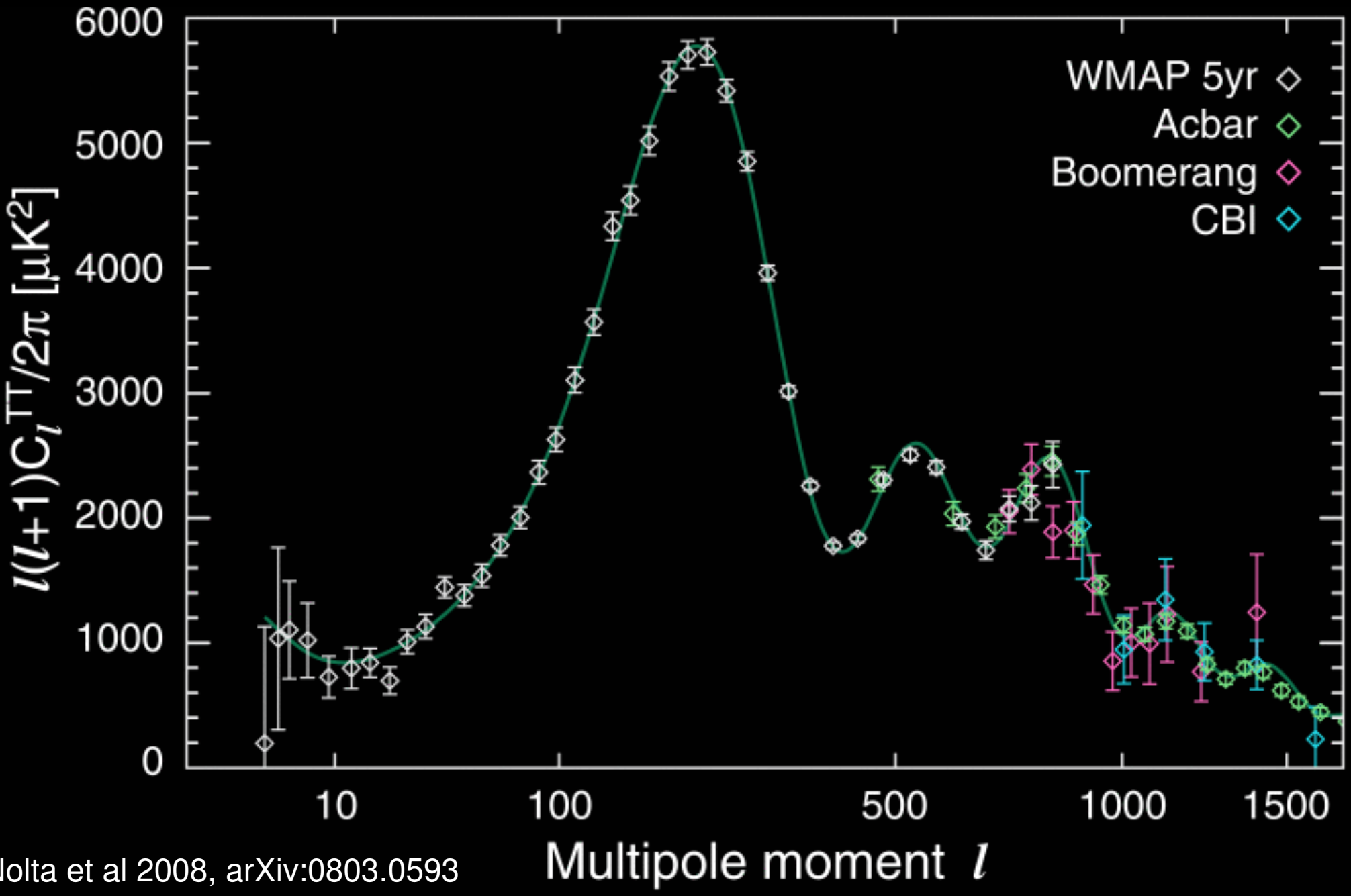
Figure from WMAP team

Brief History of our Universe



(Graphics from Gary Hinshaw/WMAP team)

The CMB is a sphere, so measure spherical harmonics!



Nolta et al 2008, arXiv:0803.0593

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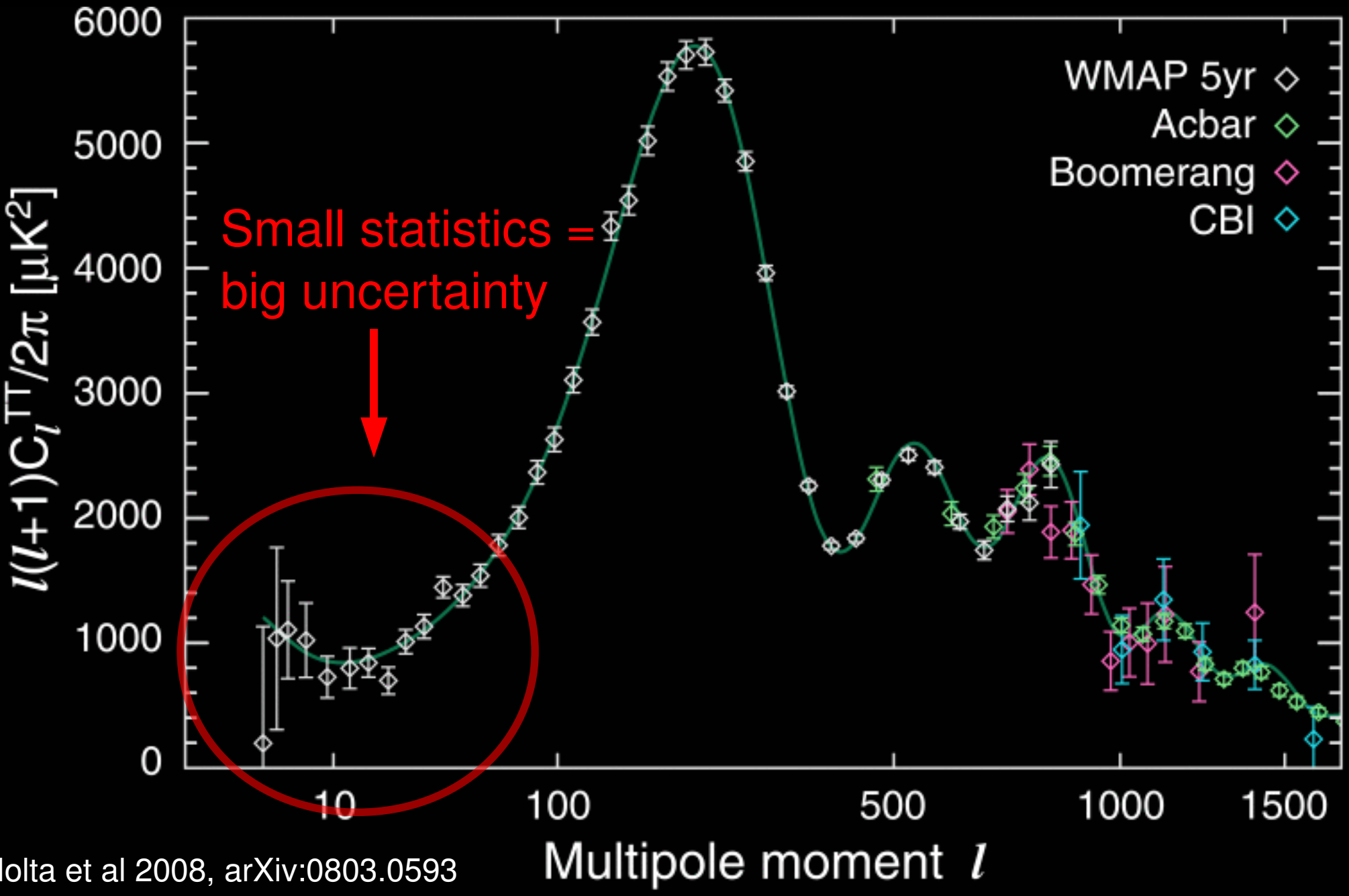
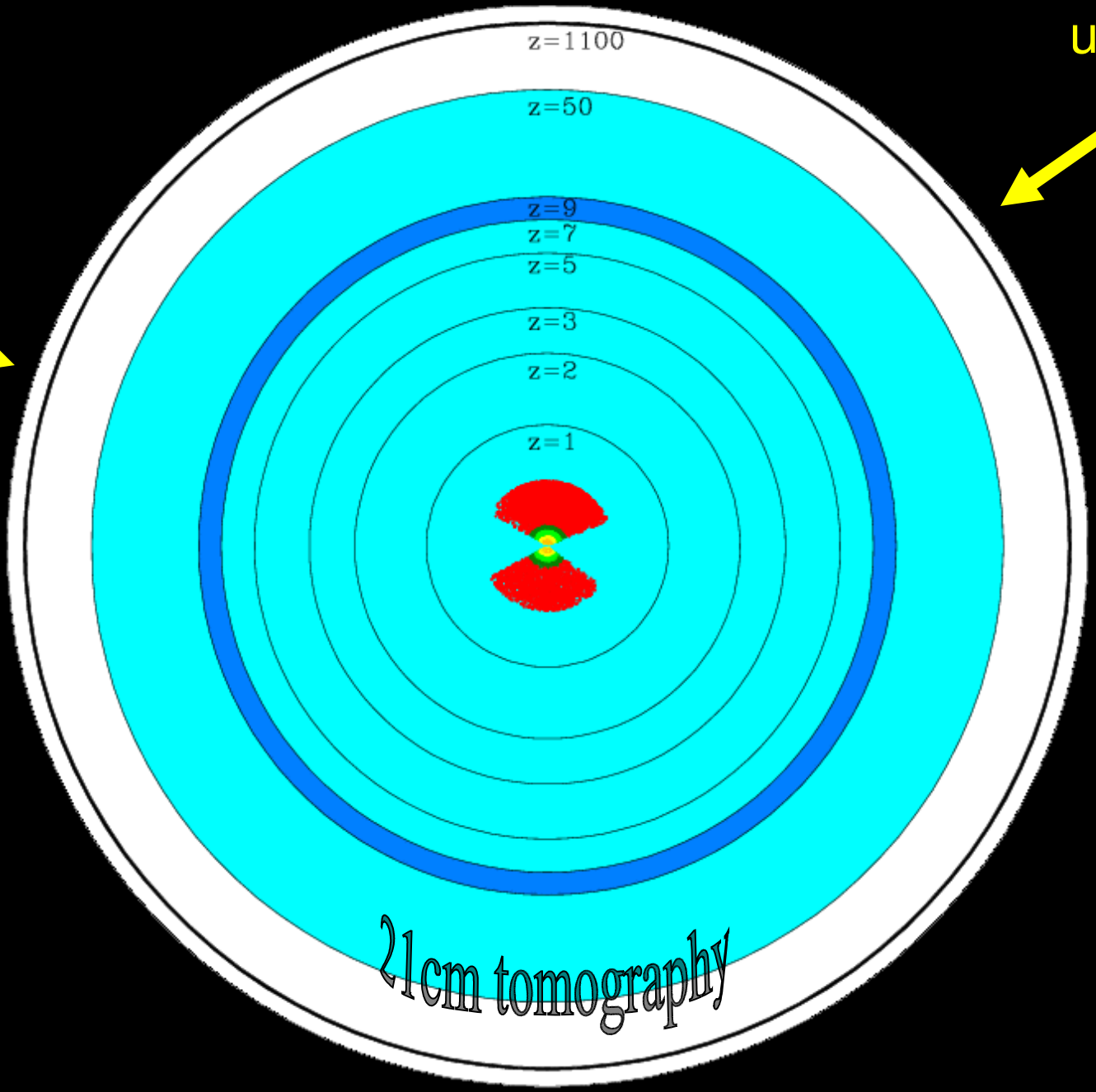


Nolta et al 2008, arXiv:0803.0593

Look at more of the universe!

Our observable universe



Spatial curvature:

WMAP+SDSS: $\Delta\ \Omega_{tot} = 0.01$

Planck: $\Delta\ \Omega_{tot} = 0.003$

21cm: $\Delta\ \Omega_{tot} = 0.0002$

What is a radio telescope?

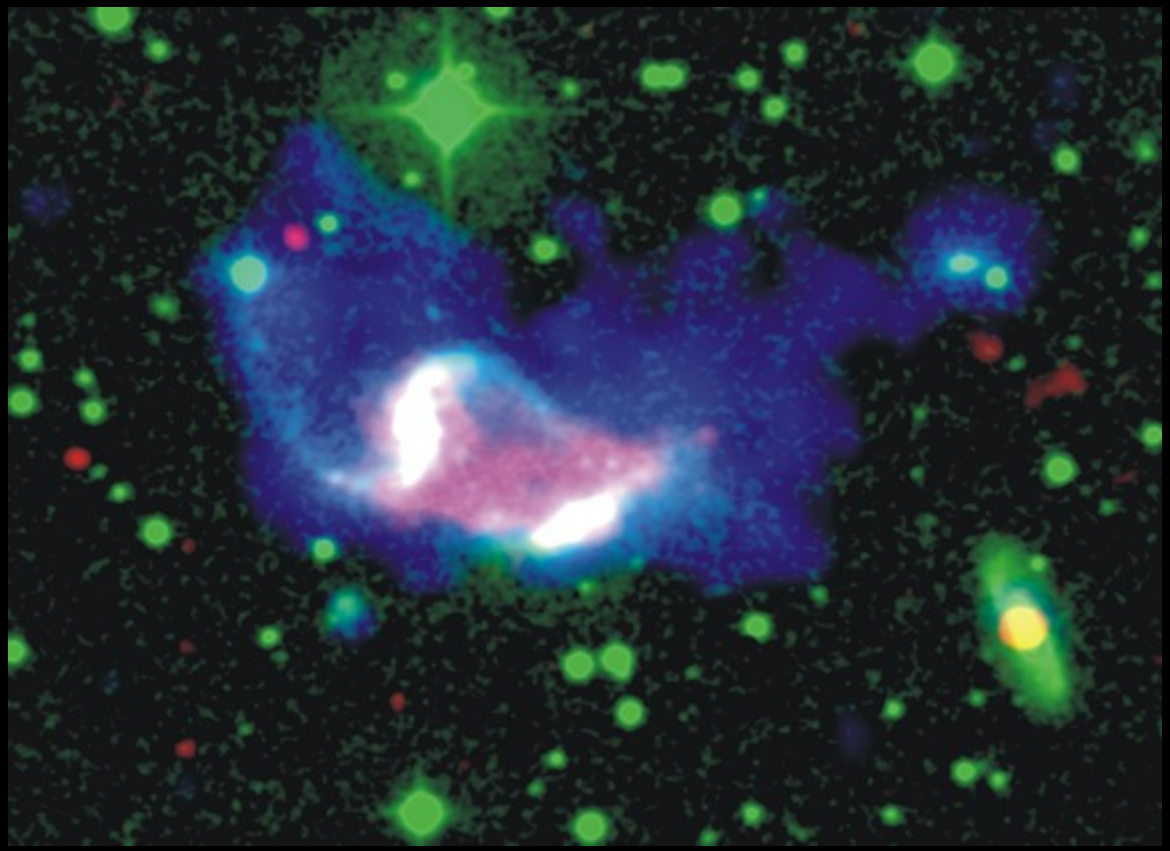


Image courtesy of NRAO/AUI

What is a radio telescope?

- We live in an electromagnetic field $E\left(\vec{r},t\right)$.
- Take the Fourier transform

$$E\left(\vec{r},t\right)=\int A\left(\vec{k},\omega\right)e^{i\vec{k}\cdot\vec{r}-i\omega t}d^{3}\vec{k}d\omega$$

- Measure with a "camera"

$$E\left(x,y,z=0,t\right)=\int A\left(\vec{k}\right)e^{ik_{x}x+ik_{y}y-i\omega t}dk_{x}dk_{y}d\omega$$

- $\omega=c\left|k\right|$, so k_z doesn't matter

- Make a picture, however you like

What is a radio telescope?

“Look ma, a Fourier transform!”

Aperture synthesis, the hard way

- Measure the electric field at various places on the ground.

- For every pair of antennas, calculate the "visibility"

$$\begin{aligned} V_\omega\left(\vec{r_1}, \vec{r_2}\right) &= \left\langle E_\omega\left(\vec{r_1}\right) E_\omega^*\left(\vec{r_2}\right)\right\rangle \\ &= \int I_\omega\left(\hat{k}\right) \exp\left[-i\vec{k}\cdot\left(\vec{r_1}-\vec{r_2}\right)\right] \end{aligned}$$

  - People usually write $(u, v) = \left(x_2 - x_1, y_2 - y_1\right)/\lambda$).

- Buy lots of computers.

Aperture synthesis :)

- You get 1 "pixel" per (u, v) sample.
- You get $O(N^2)$ samples with N antennas.
- The precise position of the antennas is not critical.
- Great for high resolution – computers are cheap.

Aperture synthesis :(

- You need $O(N^2)$ computers for N antennas.
- Collecting area is only $O(N)$.

The FFT Telescope

$$E\left(x, y, z = \cdot, t\right) = \int A\left(\vec{k}\right) e^{ik_x x + ik_y y - i\omega t} dk_x dk_y d\omega$$

Sample on a grid and compute the Fourier transform!

Max Tegmark and Matias Zaldarriaga, arXiv 0805.4414 [astro-ph]

What are we building?

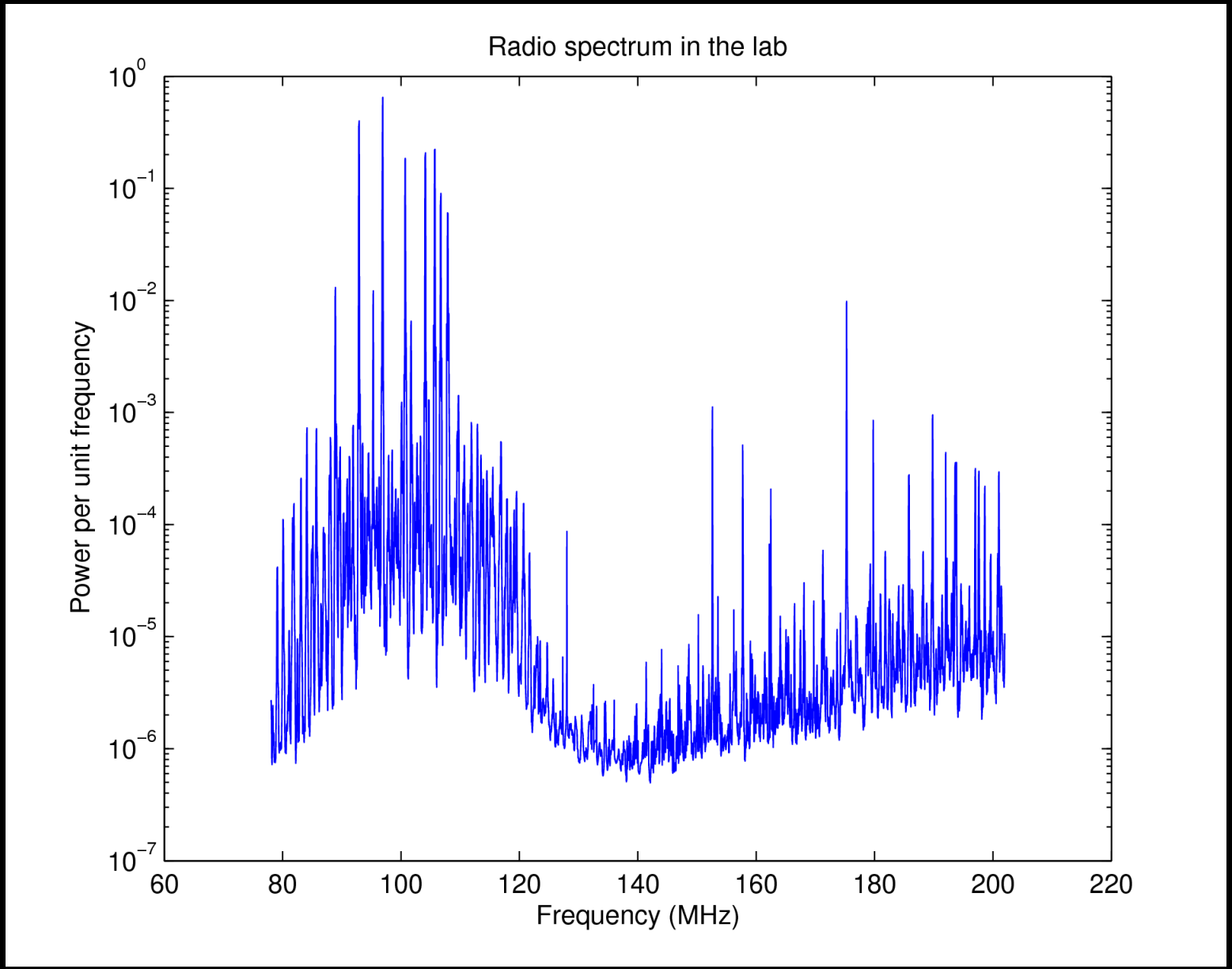
The roof of MIT building 37

Challenges in the FFTT design

- Edge effects
- Spatial aliasing
- Position jitter
- Calibration

Challenges on our roof

- We built the array for about $10,000!
- The hardware is incoherent.
- Cambridge, MA is noisy.


Radio spectrum in the lab
Power per unit frequency
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
60
80
100
120
140
160
180
200
220
Frequency (MHz)

What's next?