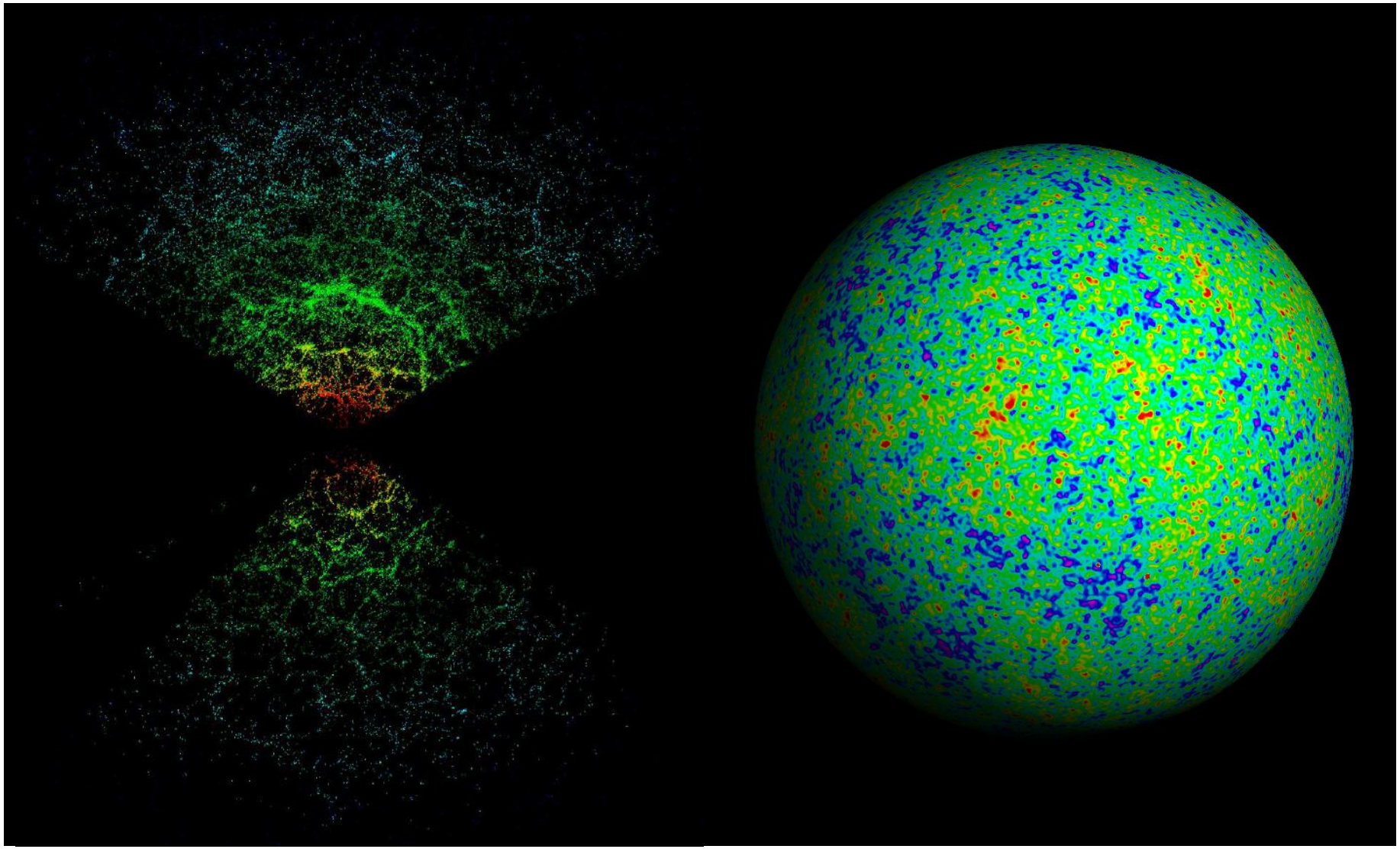
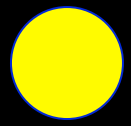
# The Mysterious Universe

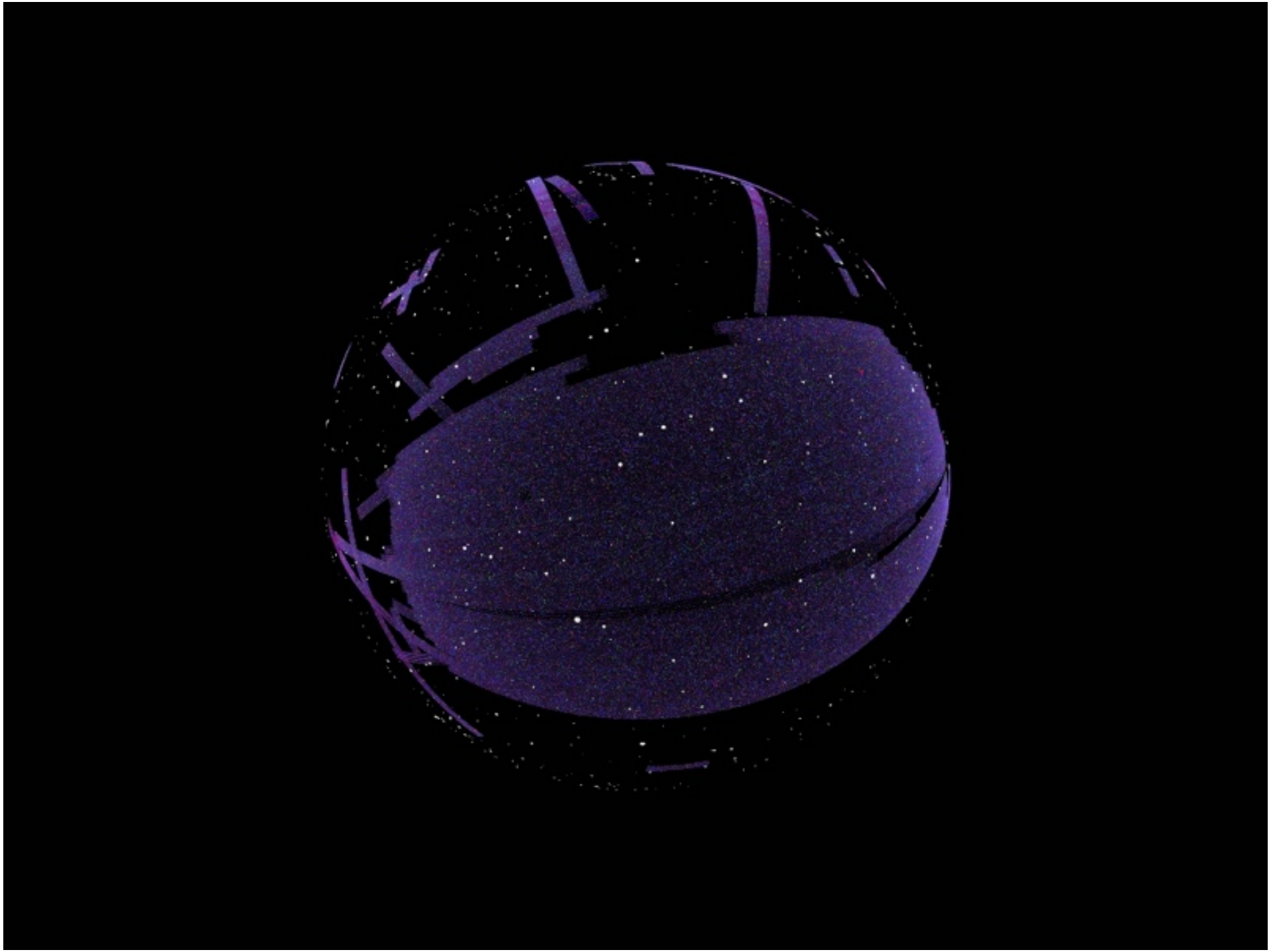


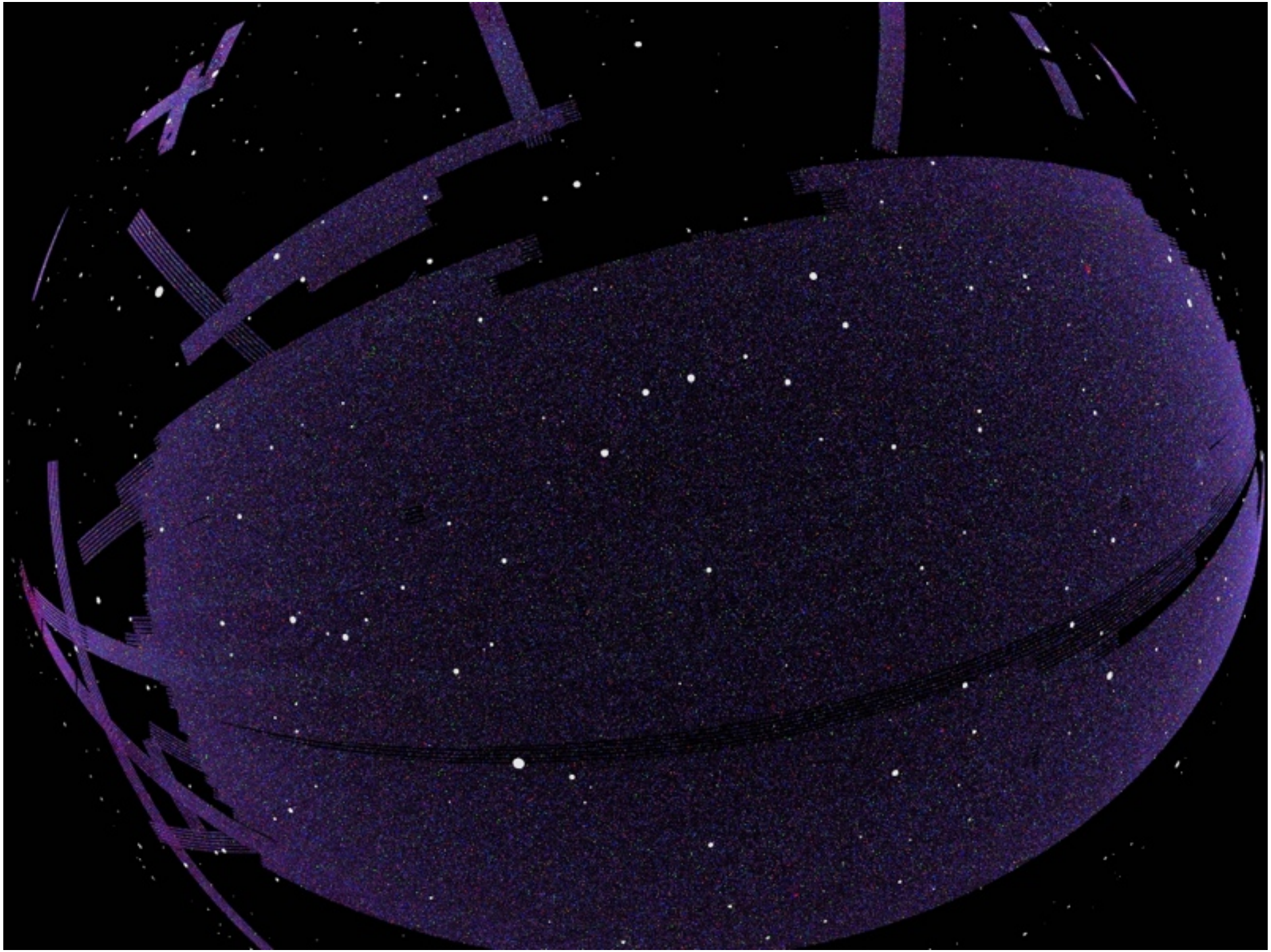
Max Tegmark, MIT

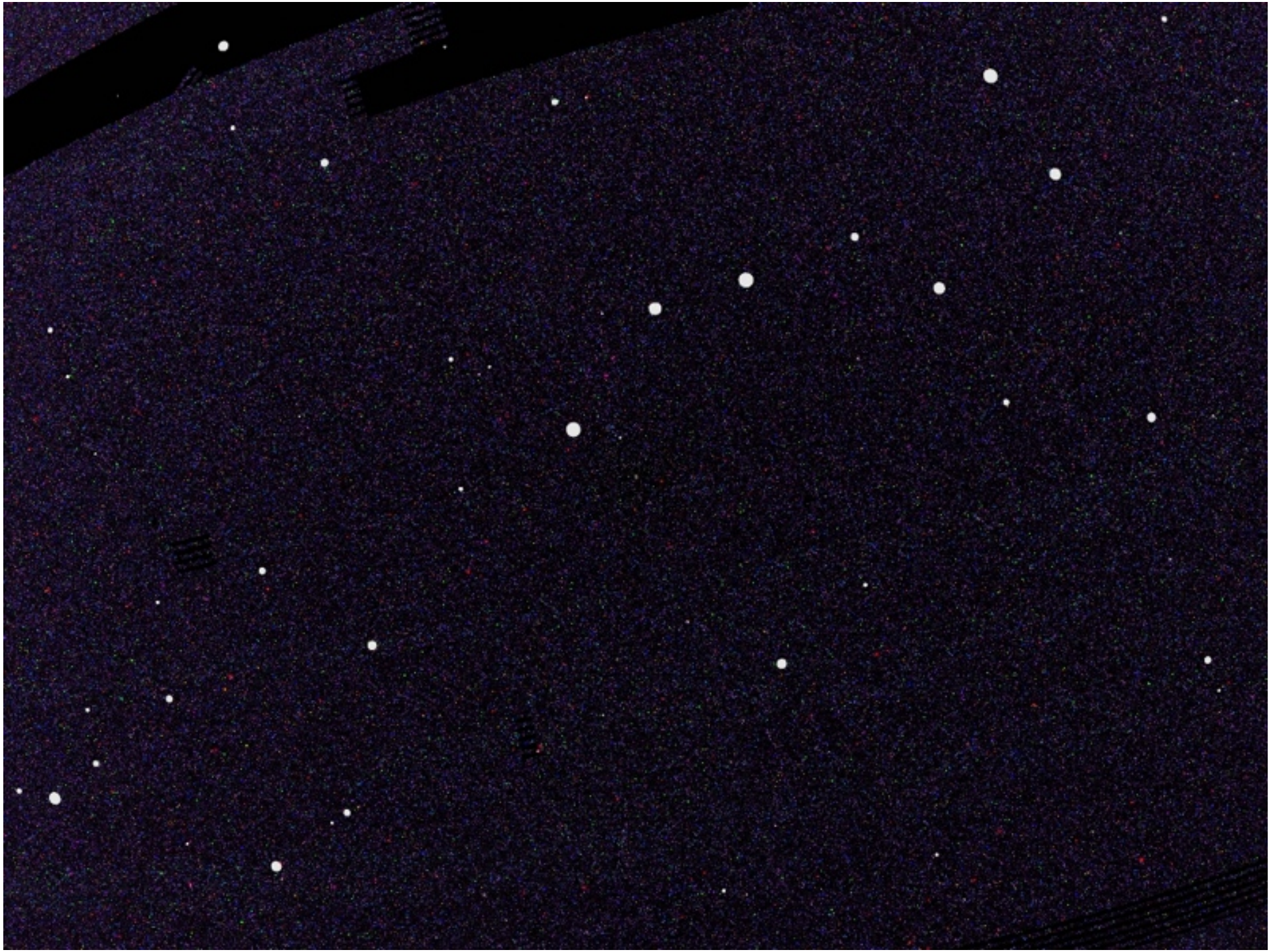
# OUR PLACE IN SPACE

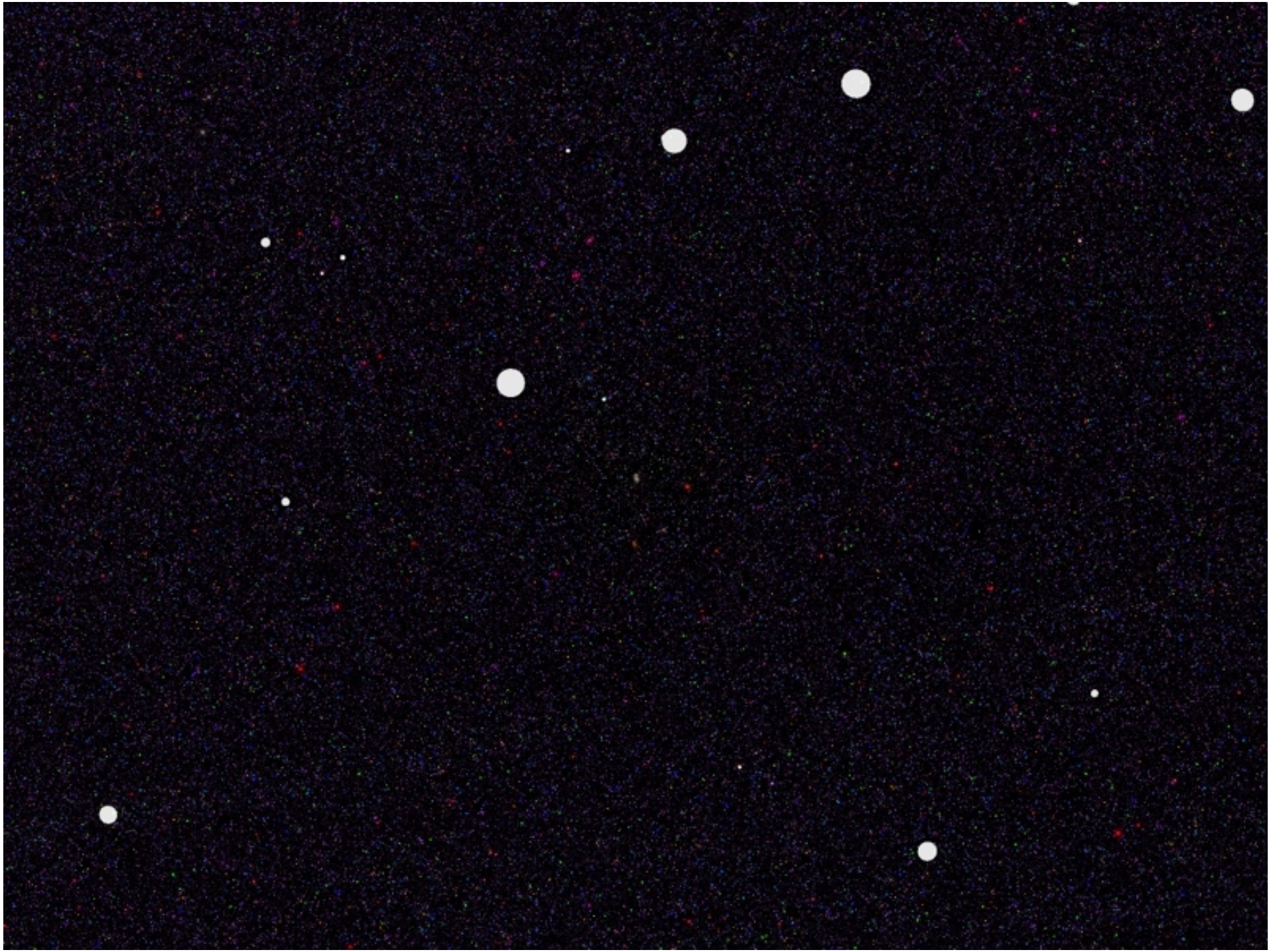


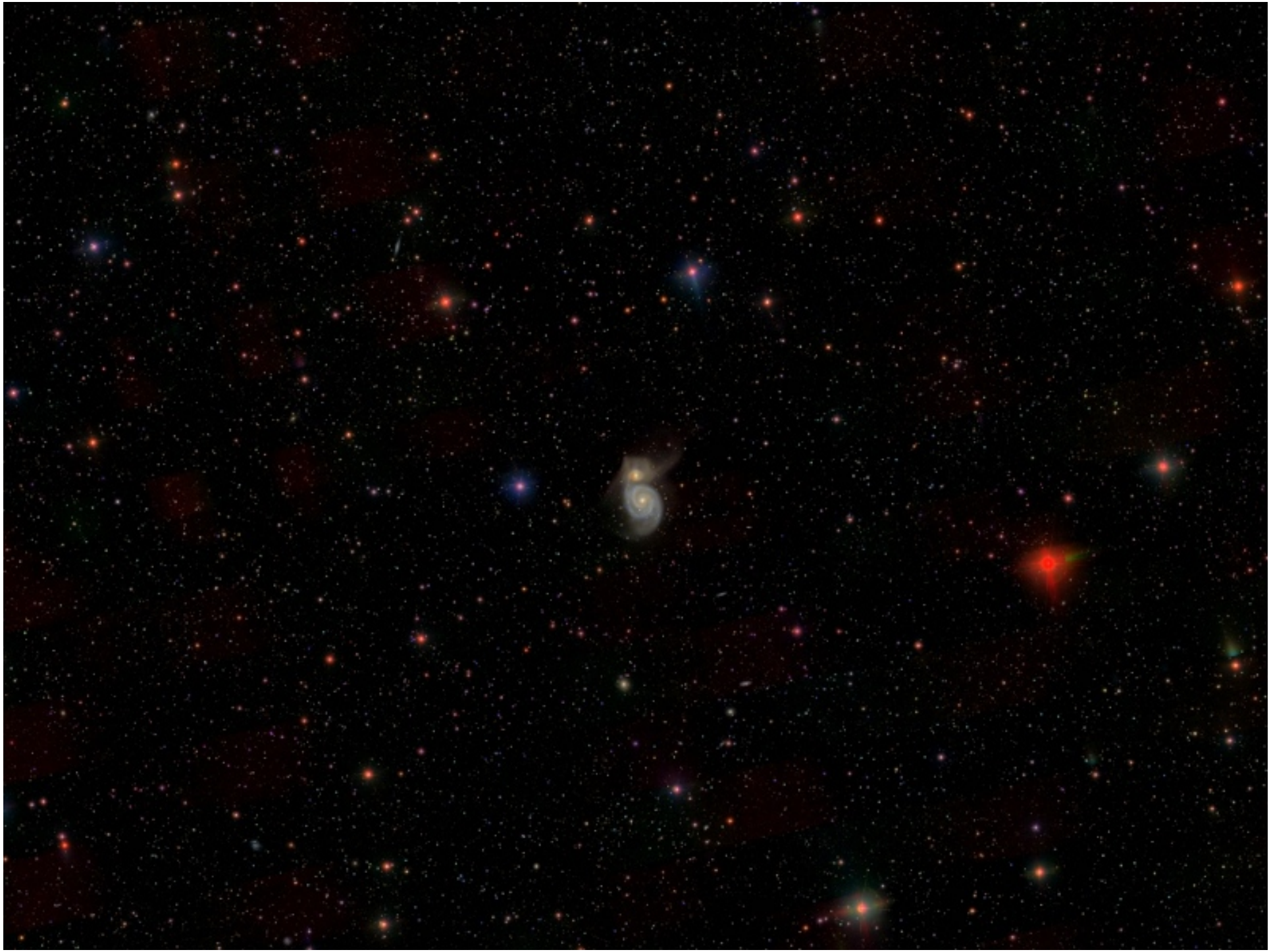
DSE

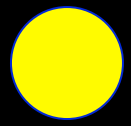










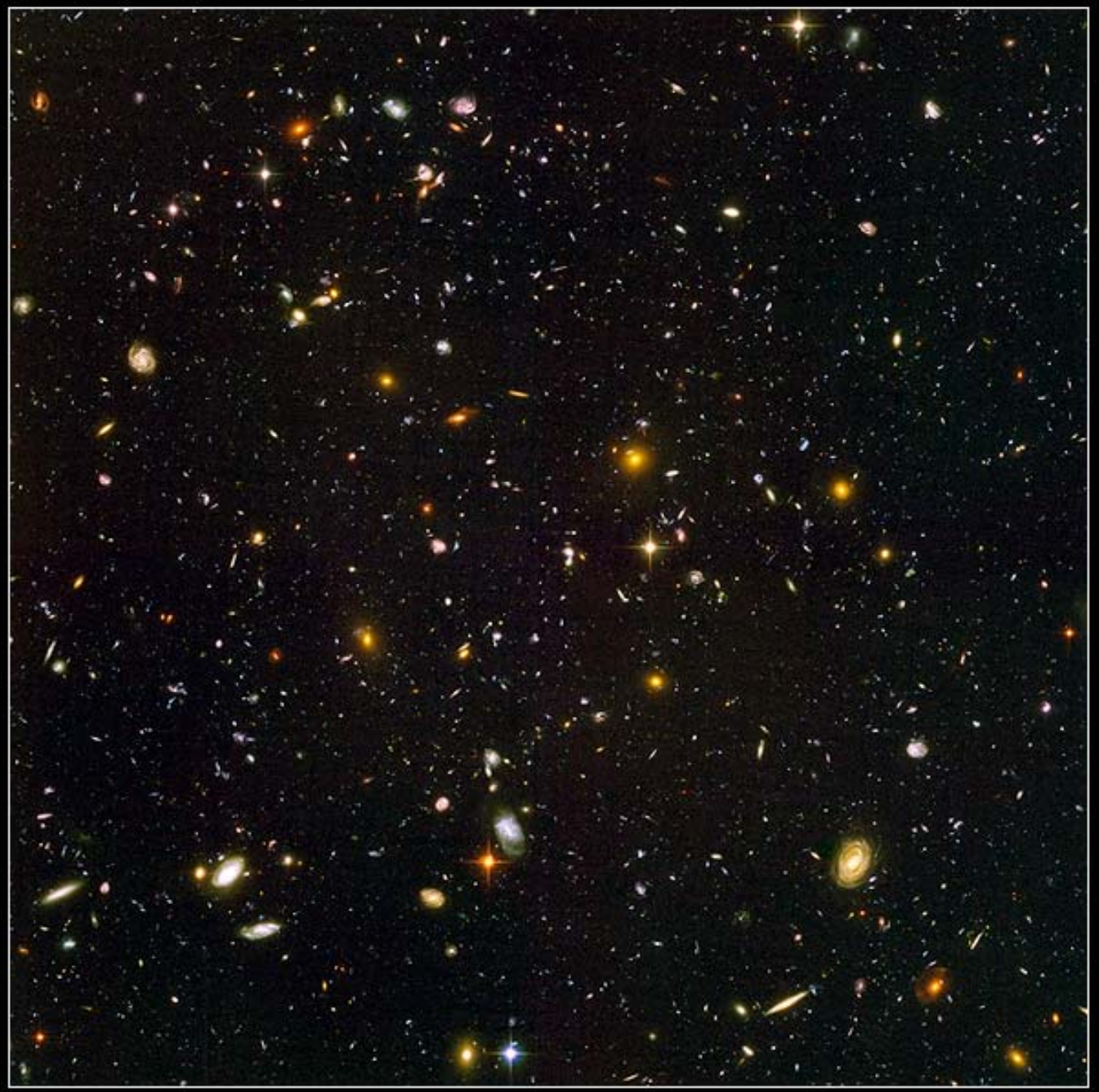


SDSS movie

from MW

# OUR PLACE IN TIME

# The sky as a time machine



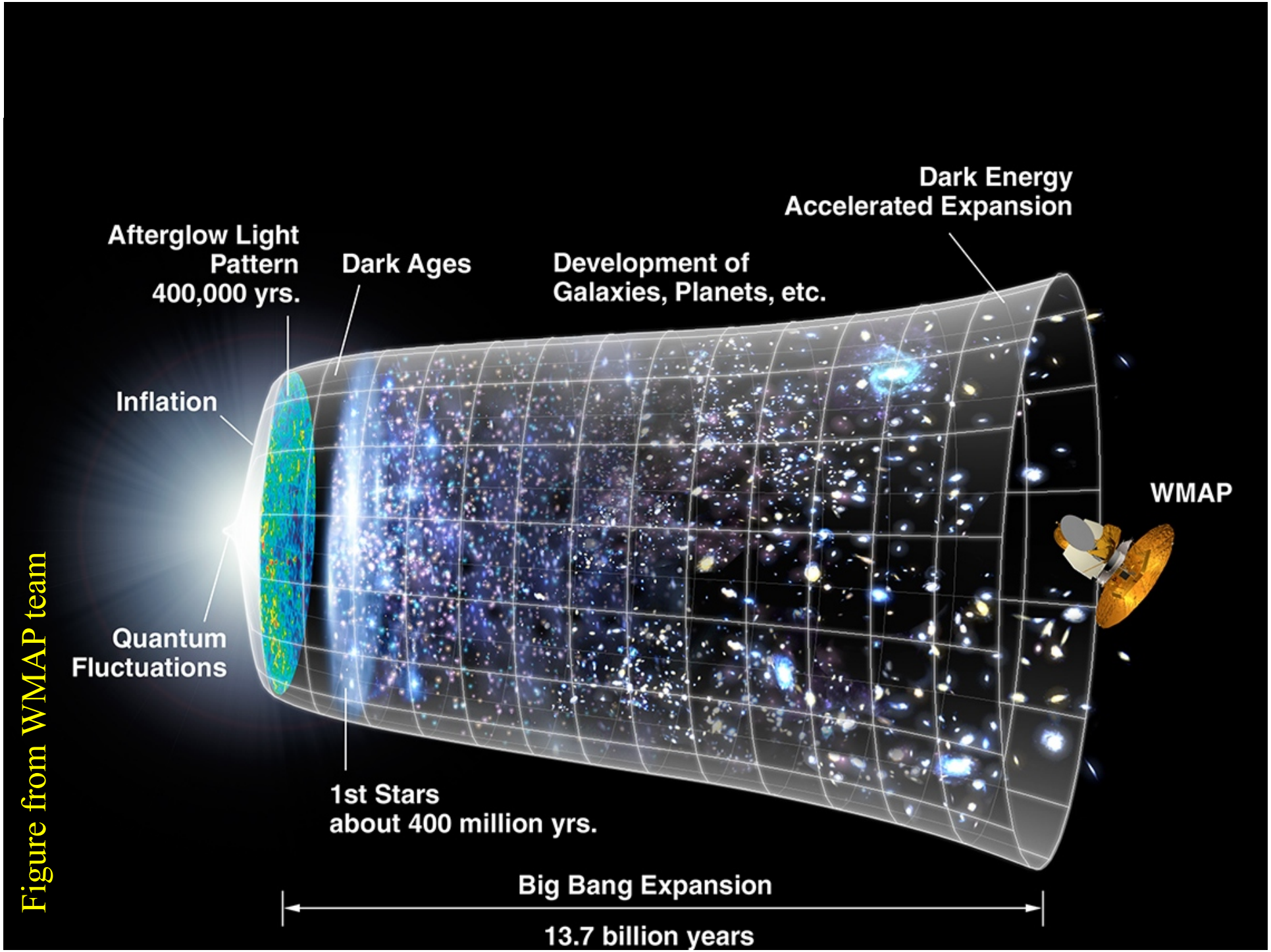
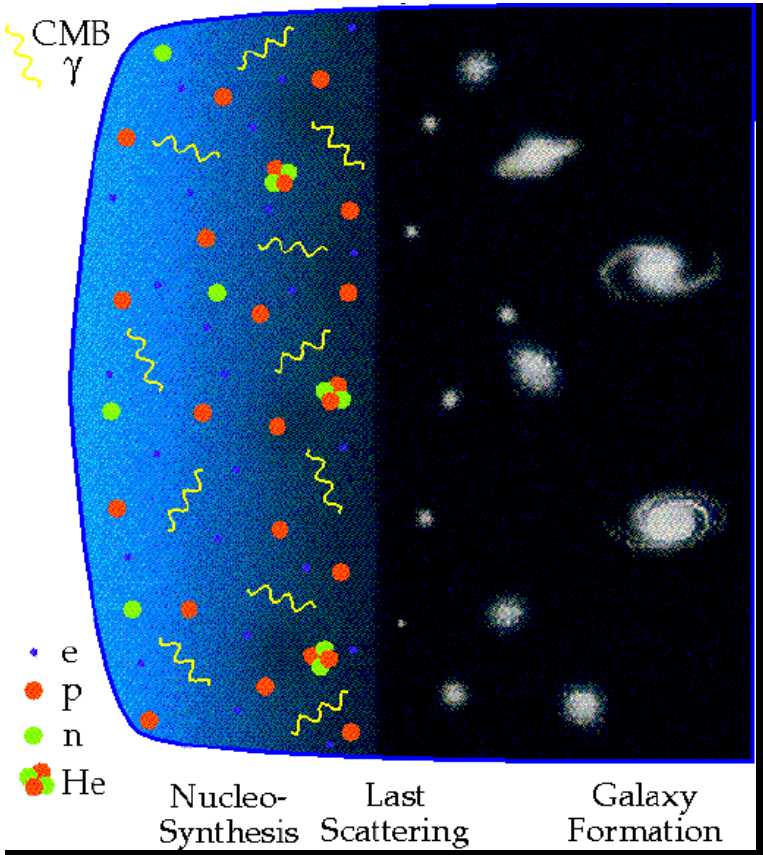
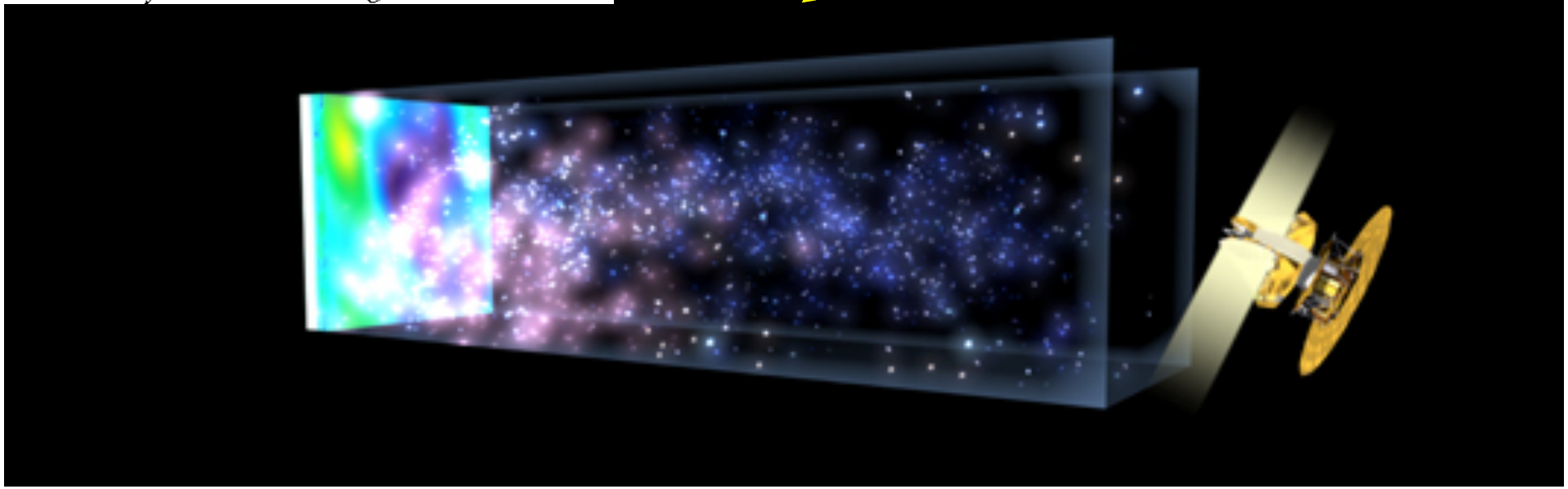


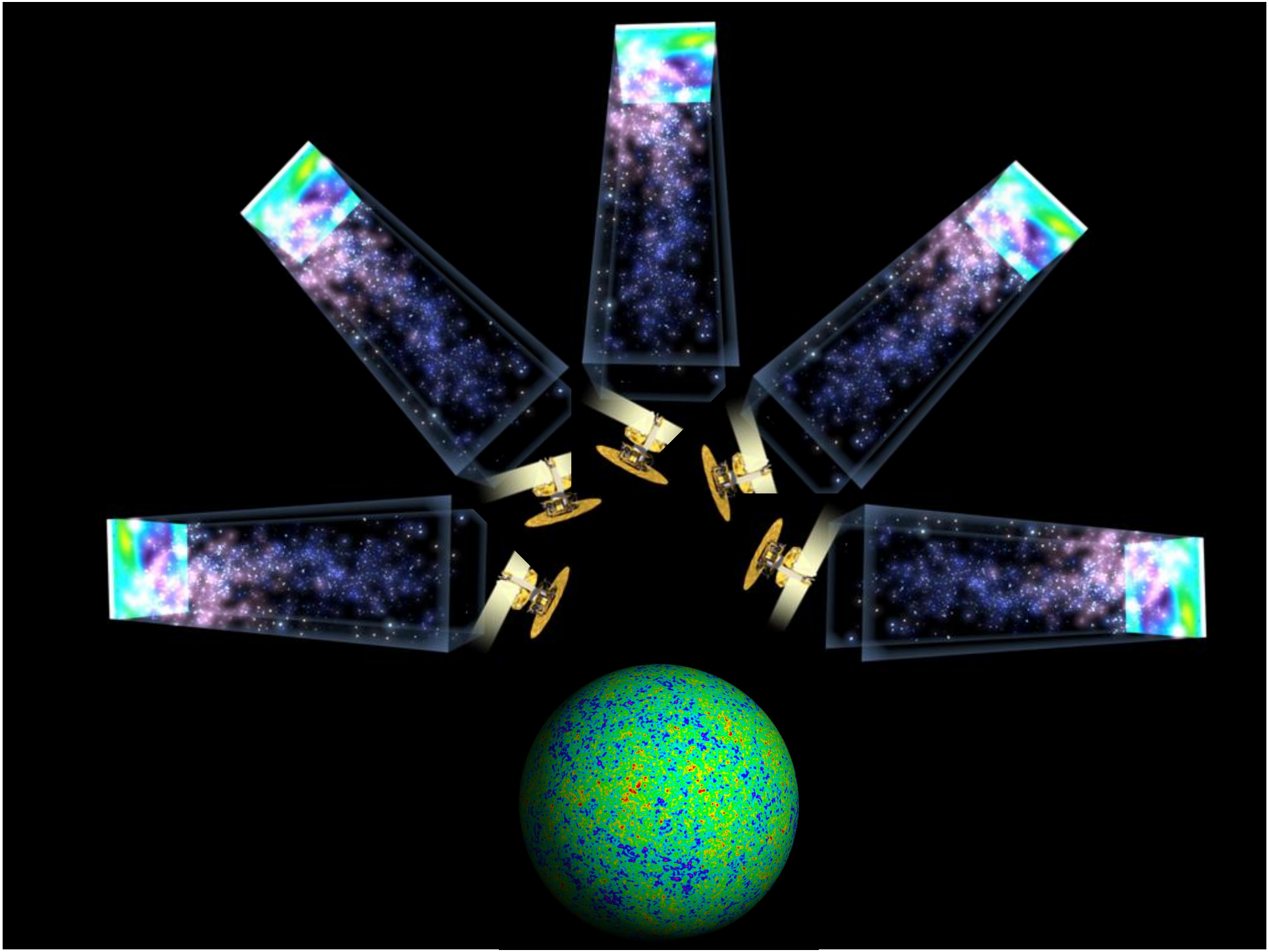

Figure from WMAP team



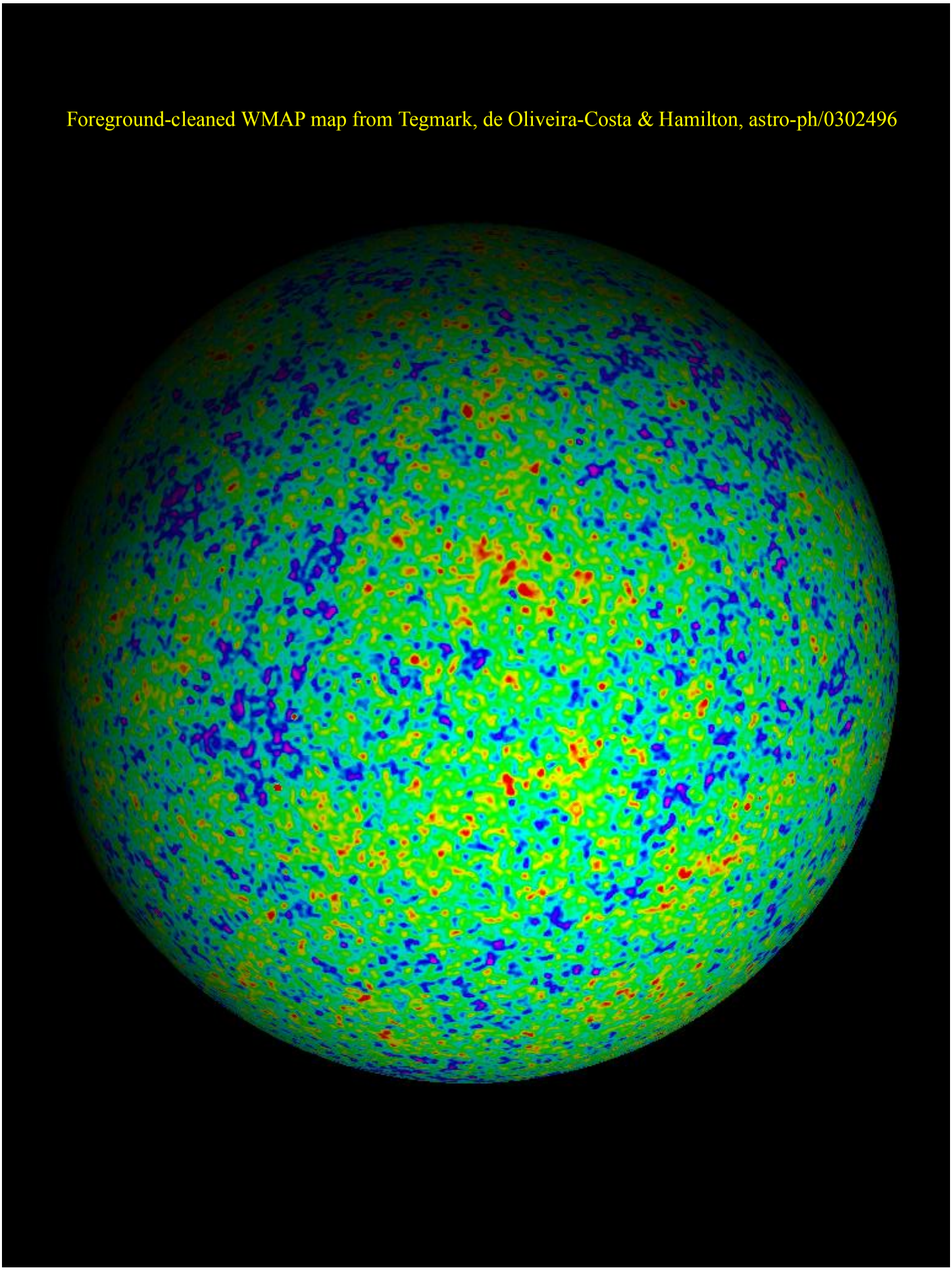

(Figure from Wayne Hu)

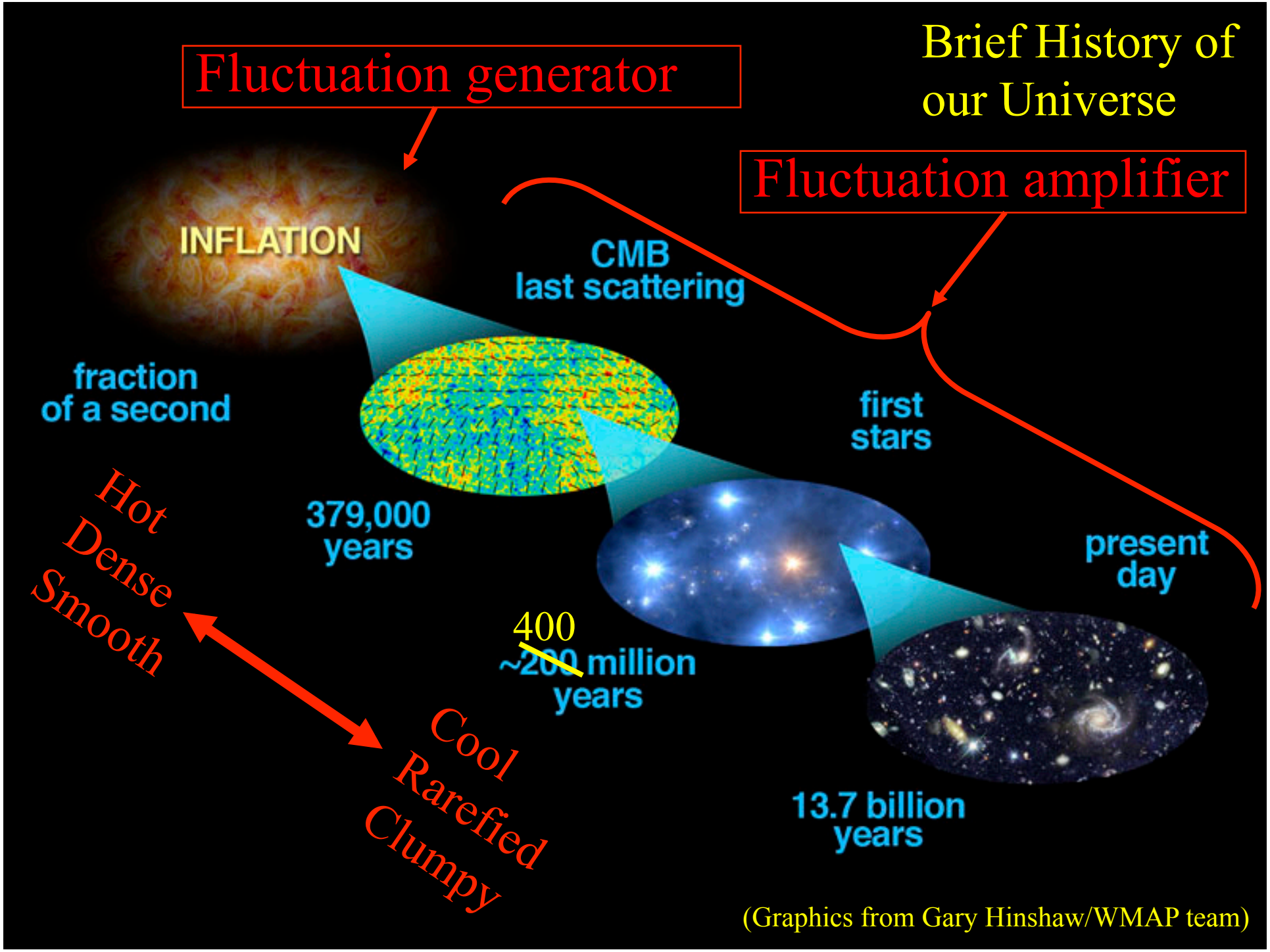
(Figure from WMAP team)

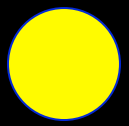




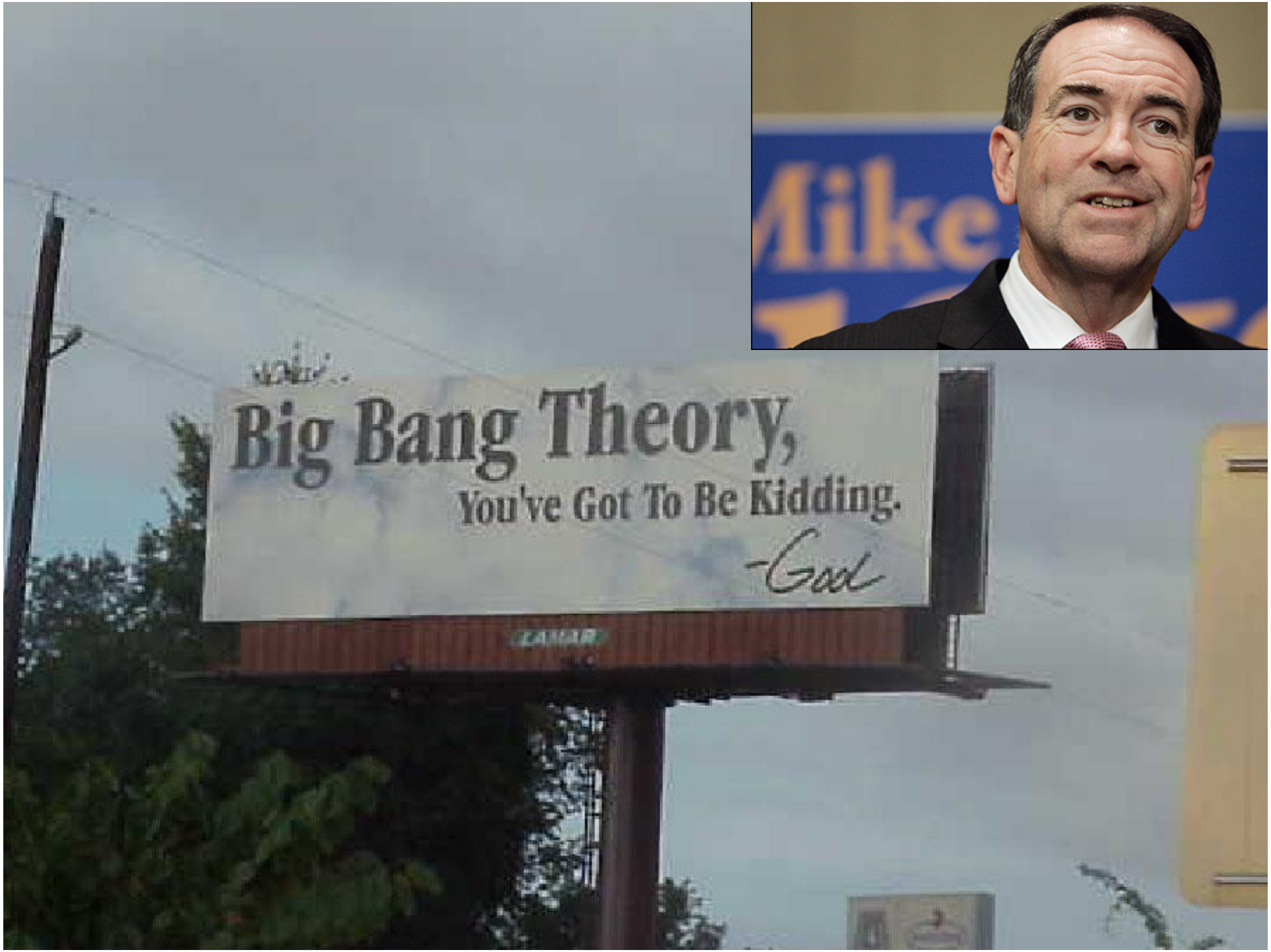
Foreground-cleaned WMAP map from Tegmark, de Oliveira-Costa & Hamilton, astro-ph/0302496



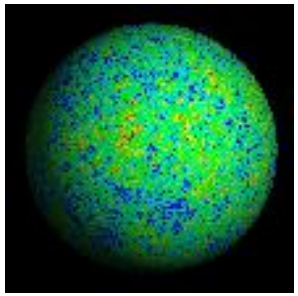

Brief History of our Universe
Fluctuation generator
Fluctuation amplifier
INFLATION
CMB last scattering
fraction of a second
379,000 years
first stars
present day
Hot Dense Smooth
400 million years
Cool Rarefied Clumpy
13.7 billion years
(Graphics from Gary Hinshaw/WMAP team)



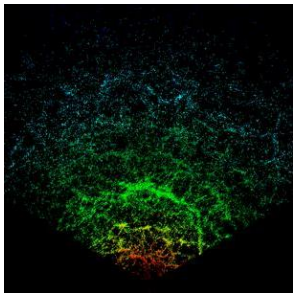
Formation movies


Mike
Big Bang Theory,
You've Got To Be Kidding.
-God
LAMAR

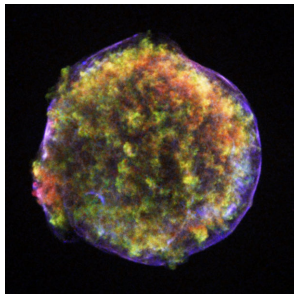
# THE COSMIC SMÖRGÅSBORD



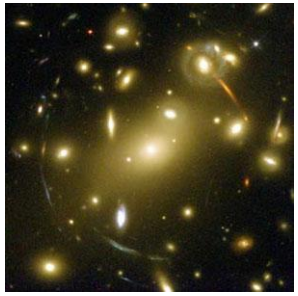
Microwave background



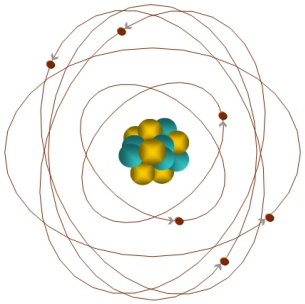
Galaxy surveys



Supernovae Ia

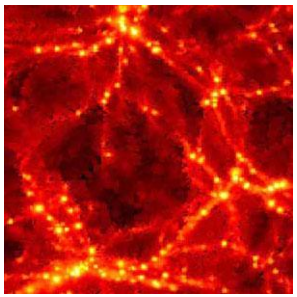


Gravitational lensing

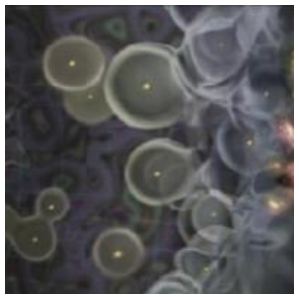


Big Bang nucleosynthesis

Galaxy clusters

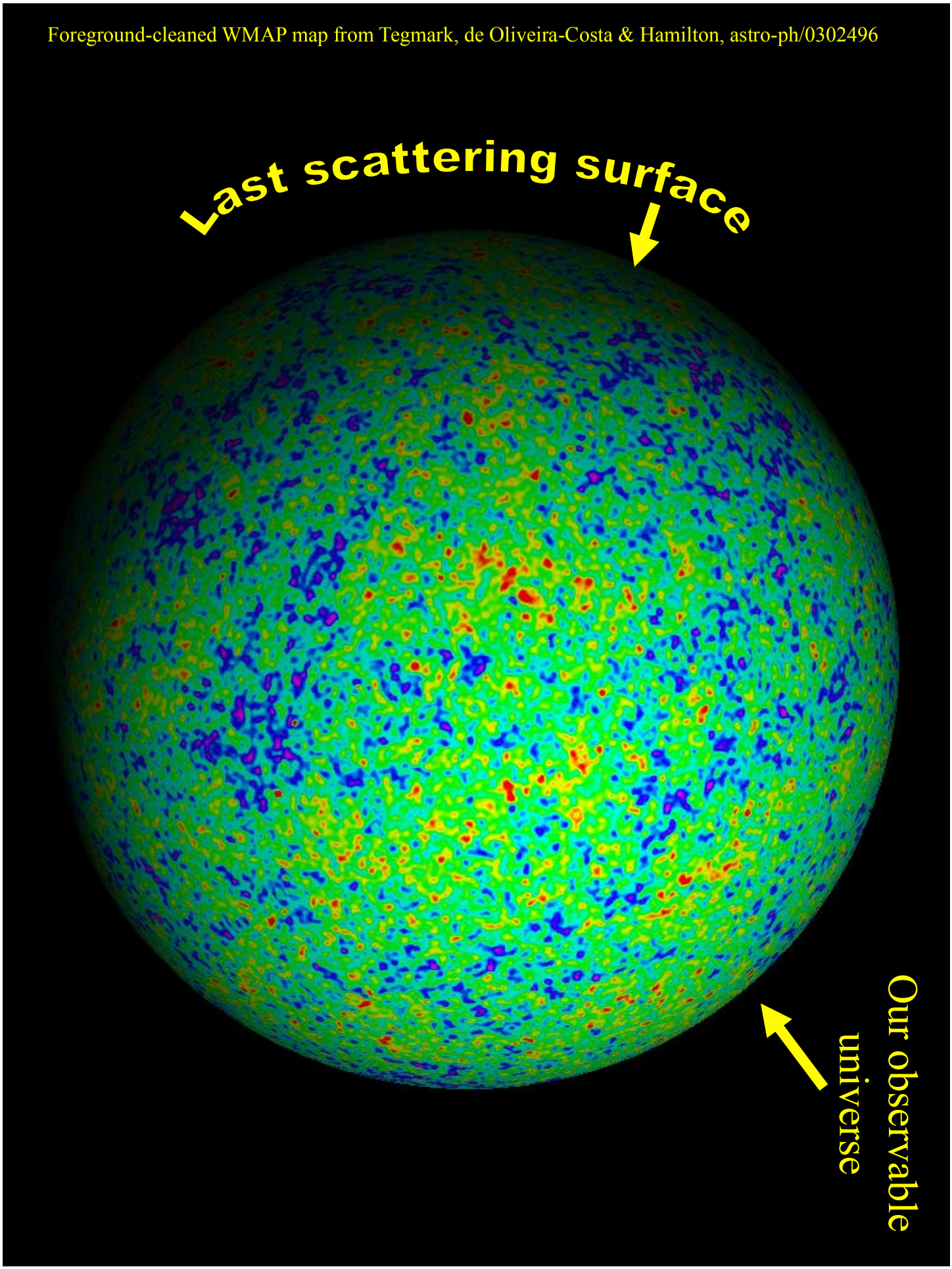


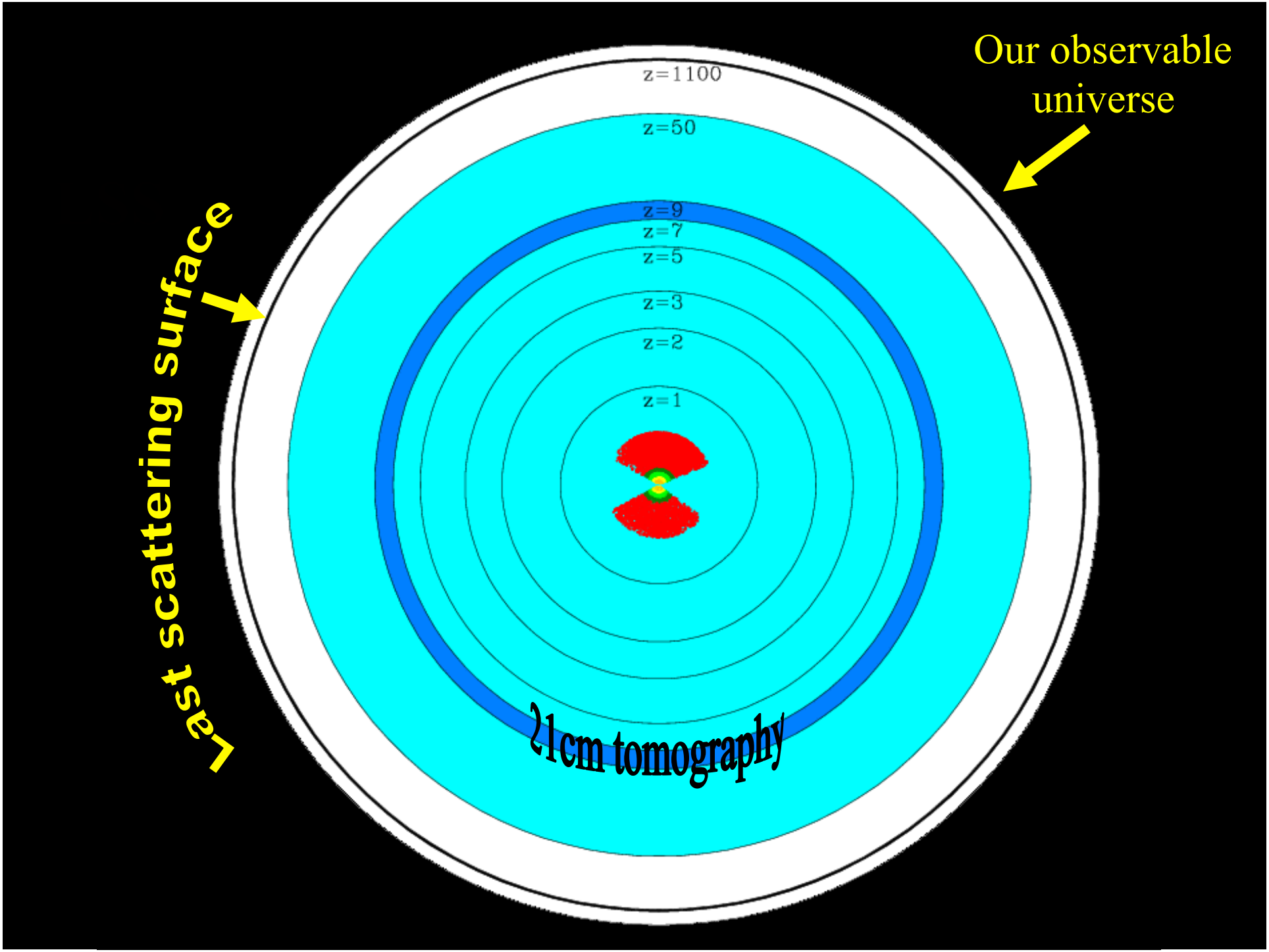
Lyman α forest

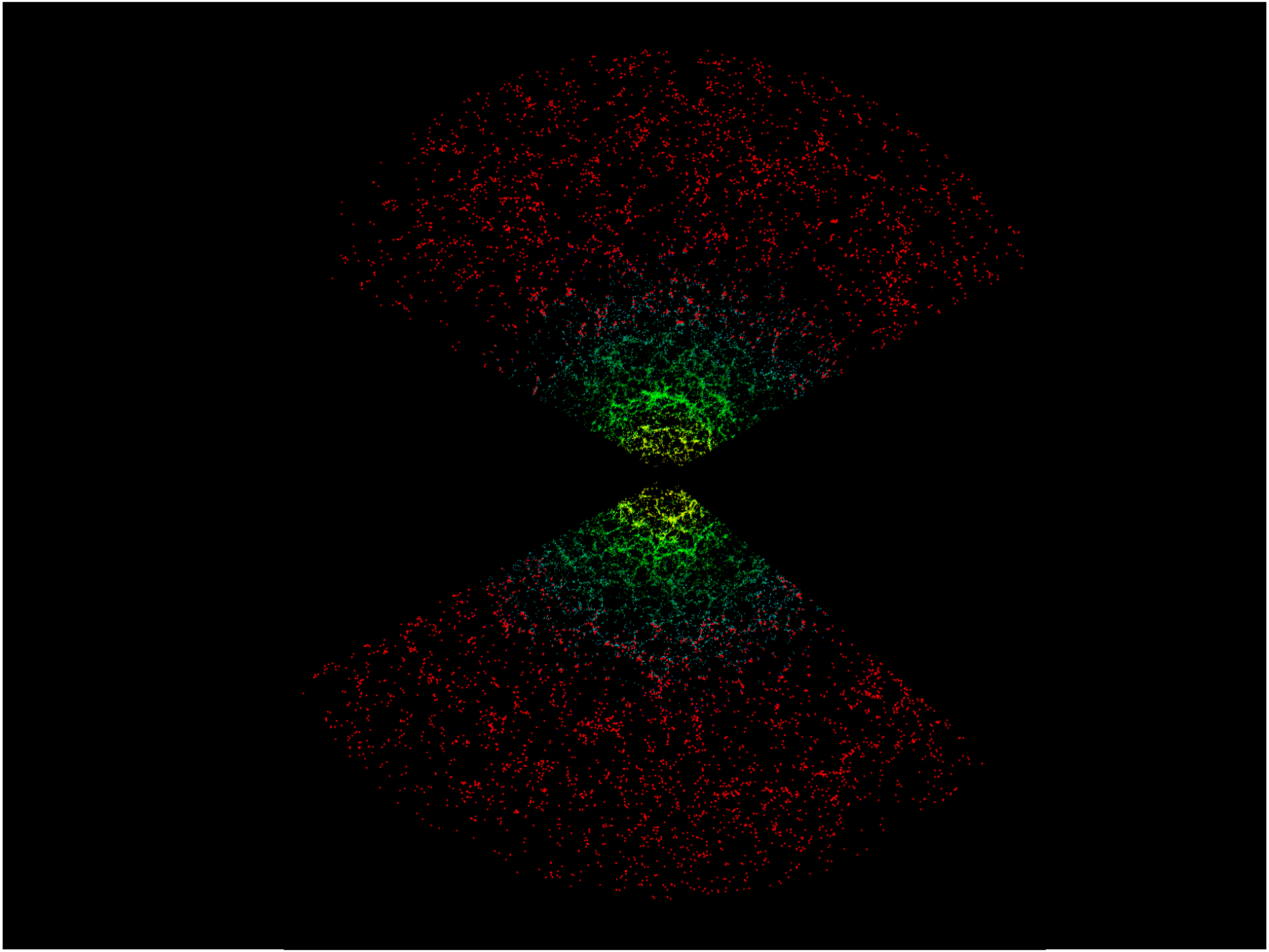


Neutral hydrogen tomography

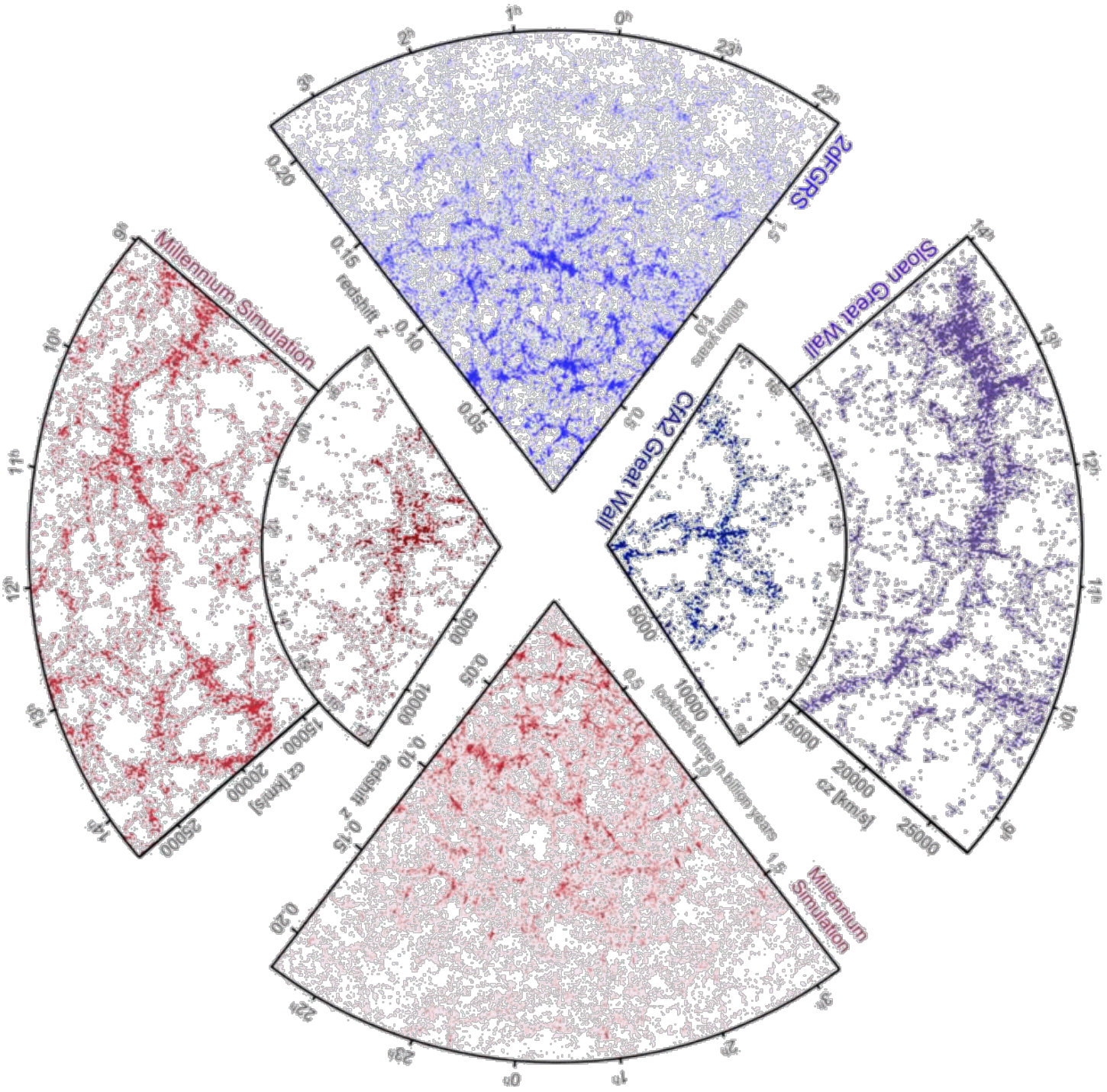
Max Tegmark
Dept. of Physics, MIT
tegmark@mit.edu
Bright Horizons Cruise
May 9, 2011

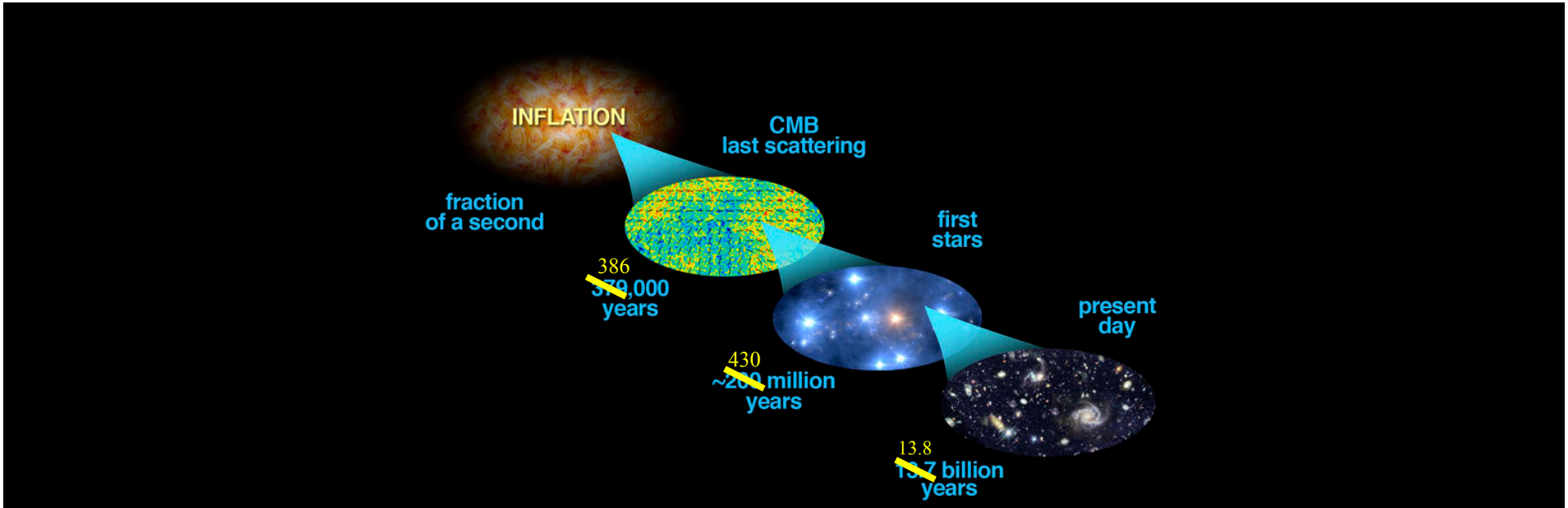

Foreground-cleaned WMAP map from Tegmark, de Oliveira-Costa & Hamilton, astro-ph/0302496
Last scattering surface
Our observable universe


Our observable universe
Last scattering surface
z=1100
z=50
z=9
z=7
z=5
z=3
z=2
z=1
21cm tomography



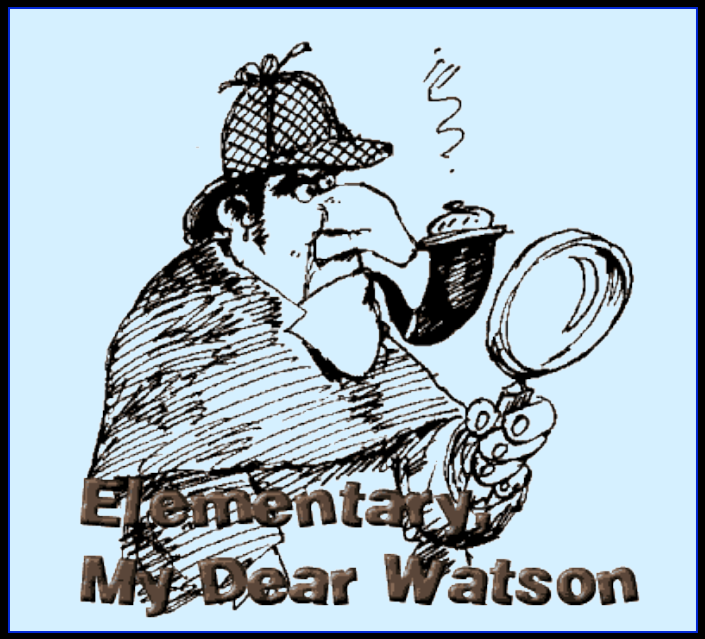
Springel, Frenk & White 2006, Nature, 440, 11



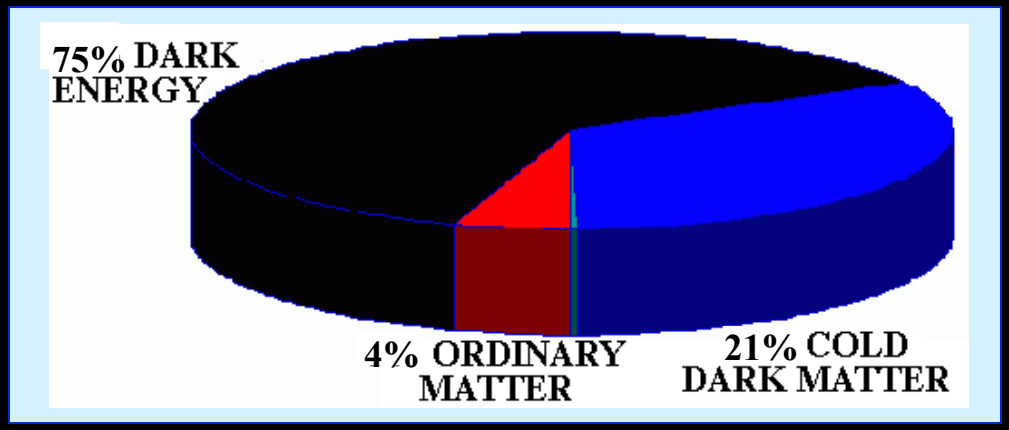


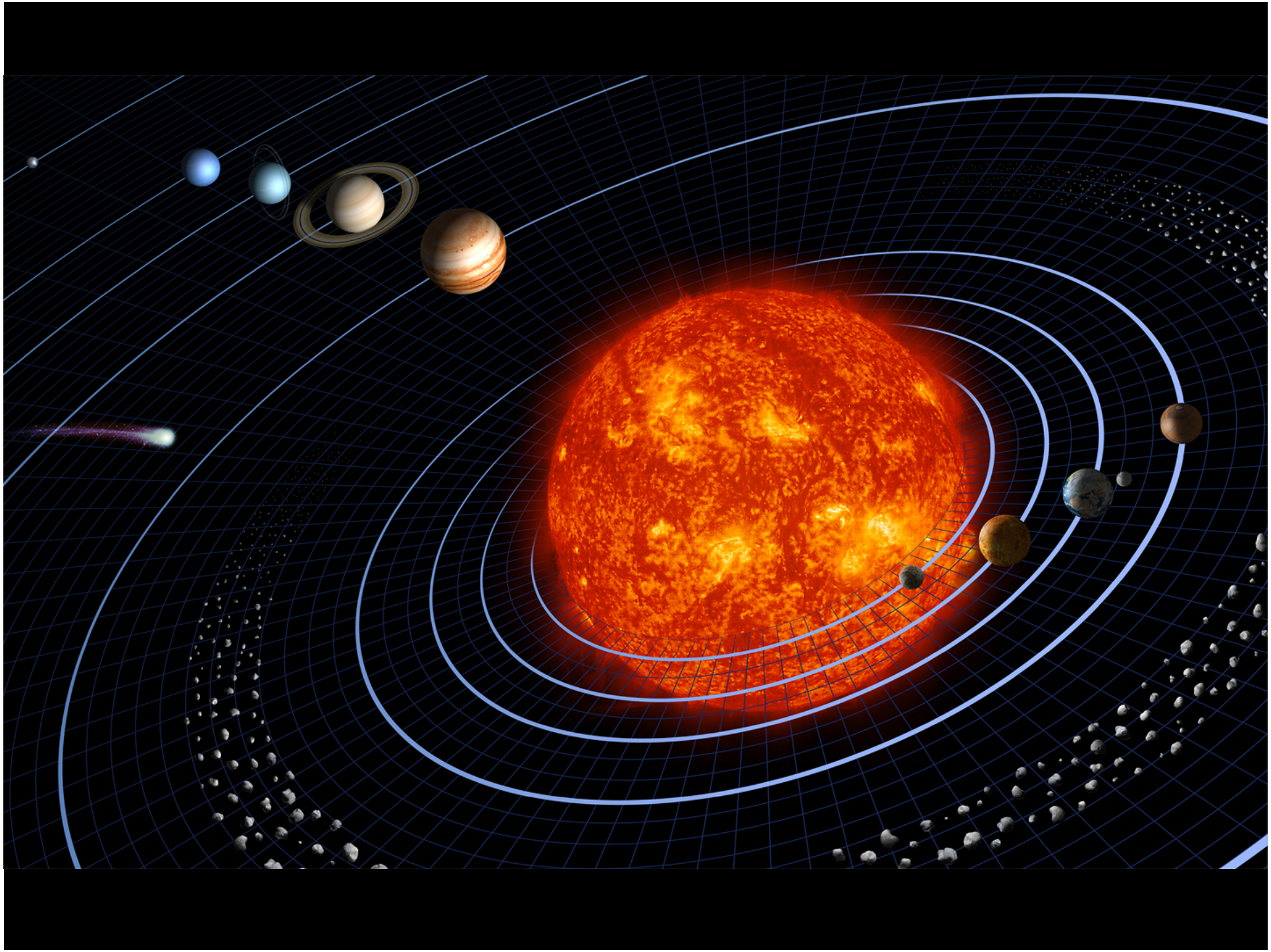

| Cosmic history parameters: | | |
|---|---|---|
| $z_{\rm eq}$ | $3057^{+105}_{-102}$ | Matter-radiation Equality redshift |
| $z_{\rm rec}$ | $1090.25^{+0.93}_{-0.91}$ | Recombination redshift |
| $z_{\rm ion}$ | $11.1^{+2.2}_{-2.7}$ | Reionization redshift (abrupt) |
| $z_{\rm acc}$ | $0.855^{+0.059}_{-0.059}$ | Acceleration redshift |
| $t_{\rm eq}$ | $0.0634^{+0.0045}_{-0.0041}$ Myr | Matter-radiation Equality time |
| $t_{\rm rec}$ | $0.3856^{+0.0040}_{-0.0040}$ Myr | Recombination time |
| $t_{\rm ion}$ | $0.43^{+0.20}_{-0.10}$ Gyr | Reionization time |
| $t_{\rm acc}$ | $6.74^{+0.25}_{-0.24}$ Gyr | Acceleration time |
| $t_{\rm now}$ | $13.76^{+0.15}_{-0.15}$ Gyr | Age of Universe now |

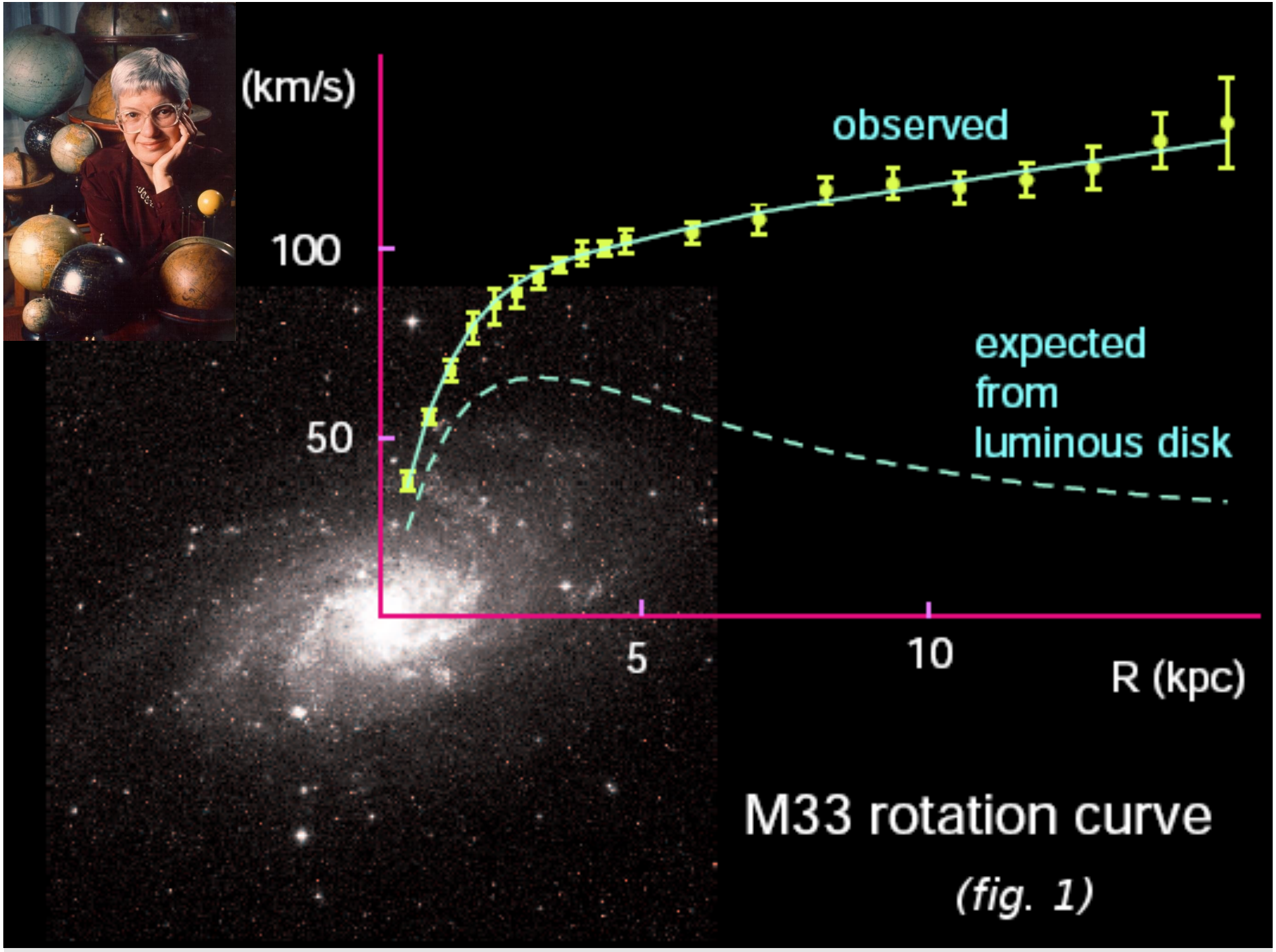
# Mysteries



# Dark matter






(km/s)
100
50
observed
expected
from
luminous disk
5
10
R (kpc)
M33 rotation curve
(fig. 1)

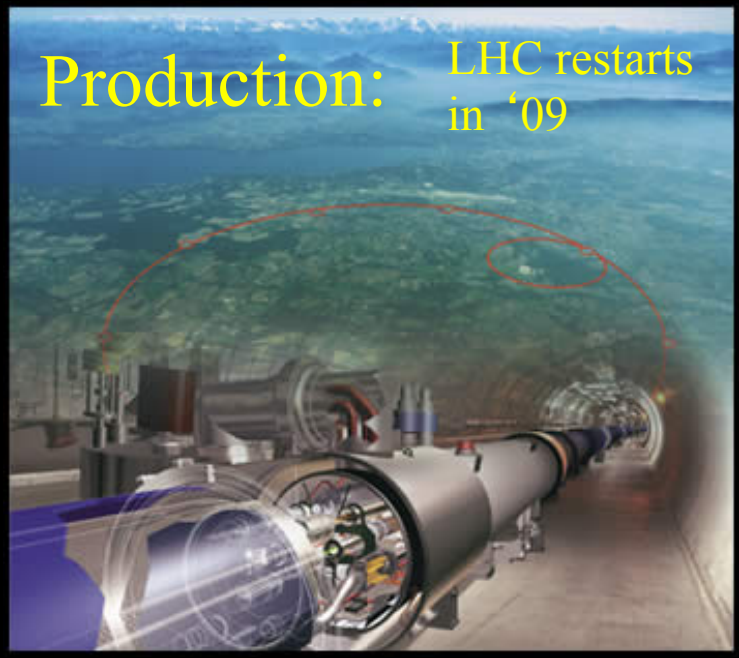
Bullet Cluster, Clowe et al 2006, ApJ, 648, L109

# Four roads to dark matter: *catch it, infer it, make it, weigh it*

## Direct:

## Production:

LHC restarts in ‘09

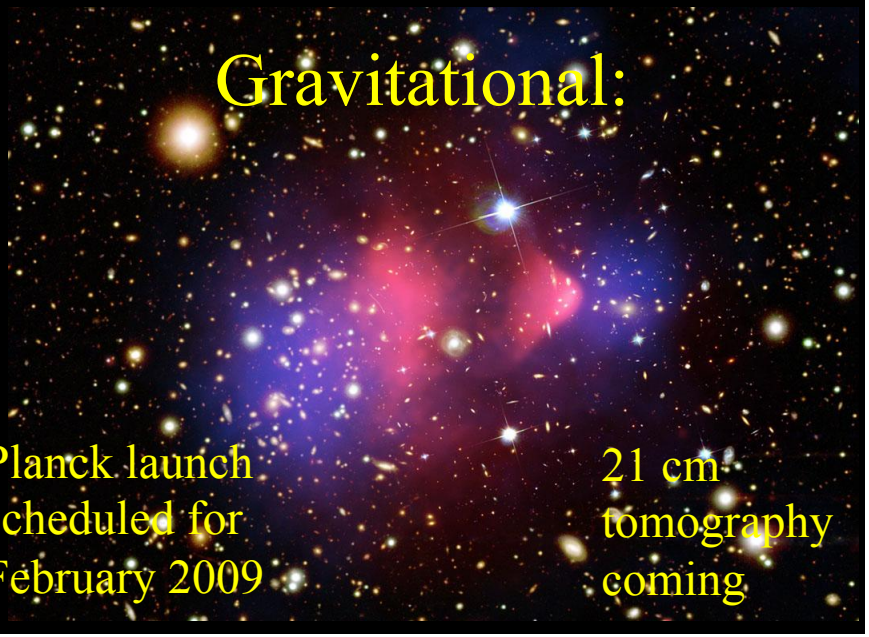


## Indirect:

Fermi (né GLAST) launched 6/11-08,

Pamela

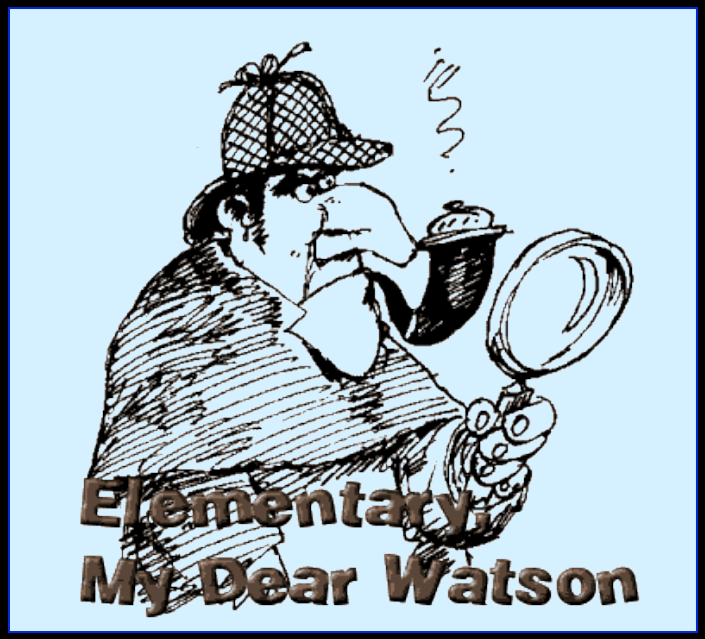
## Gravitational:



Planck launch scheduled for February 2009

21 cm tomography coming

# Dark energy



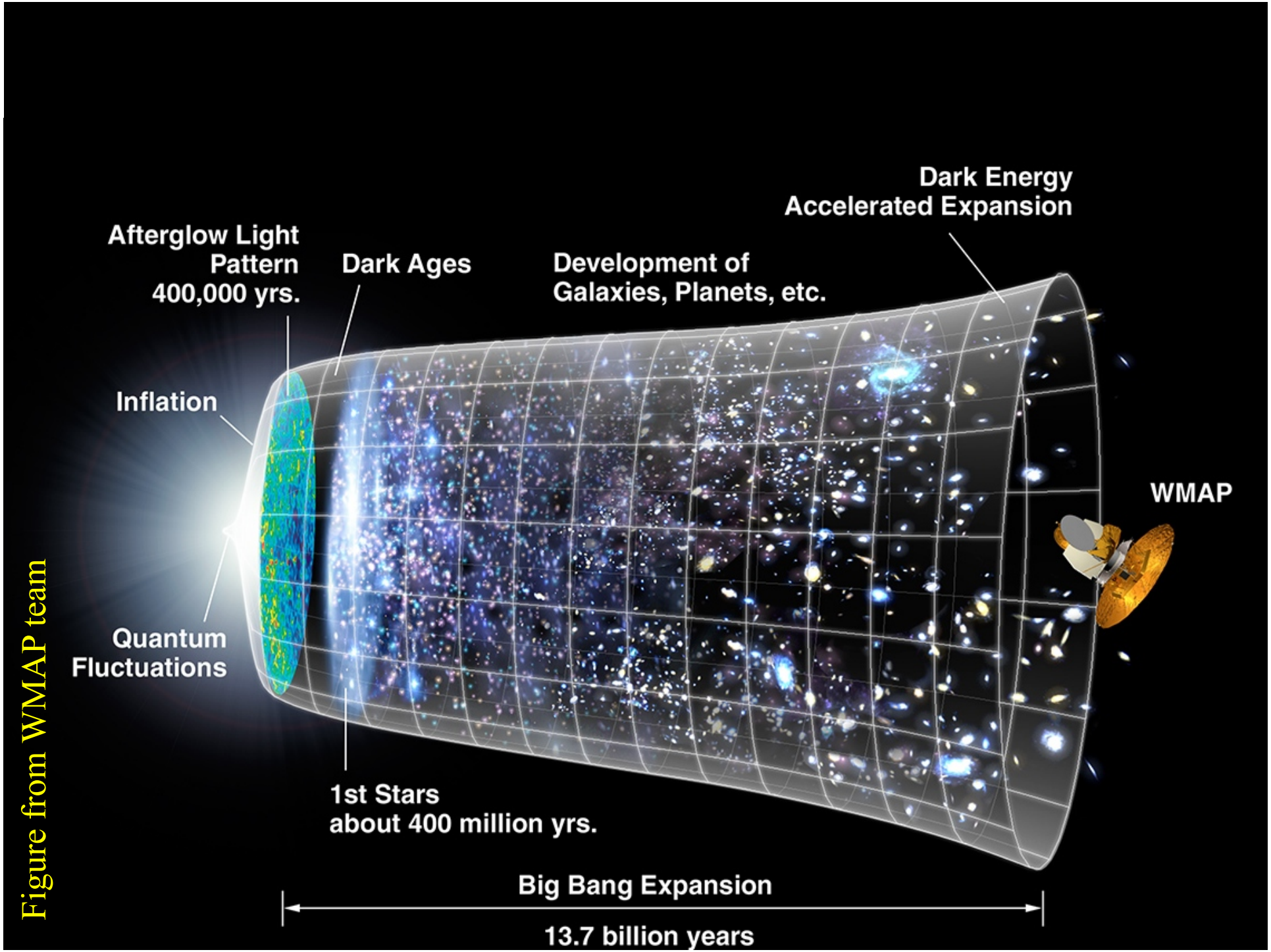
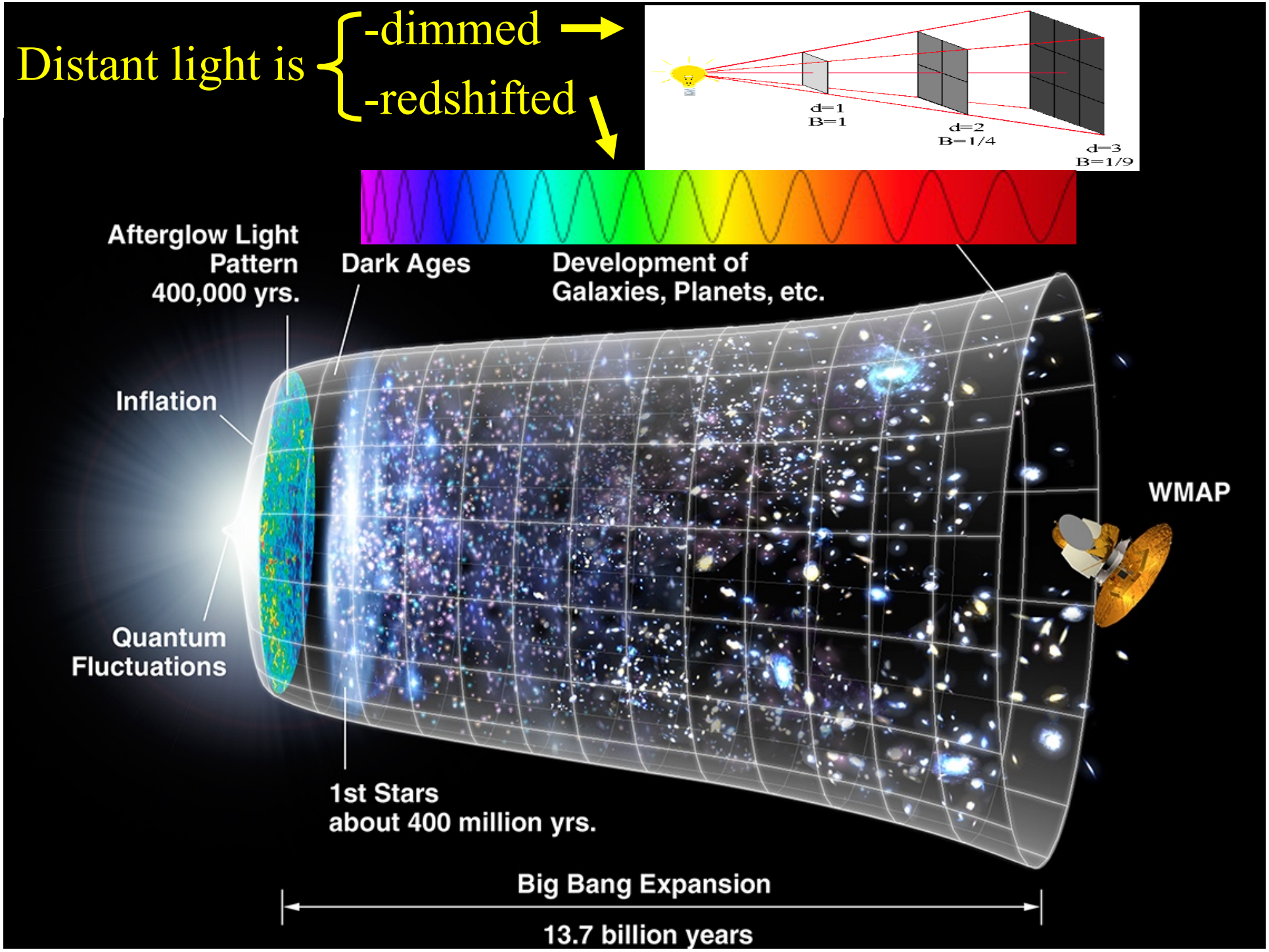
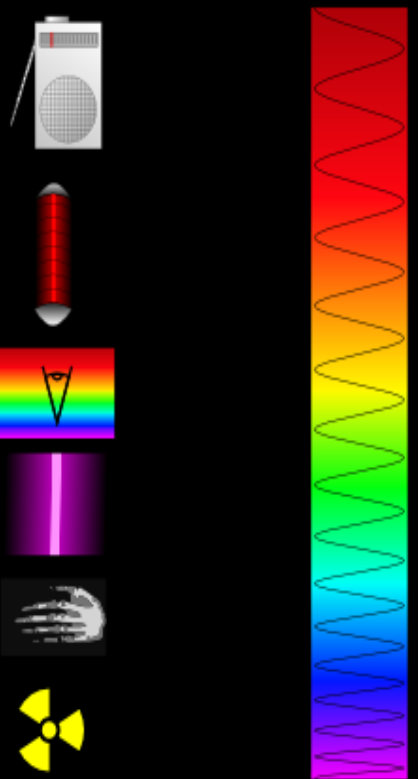


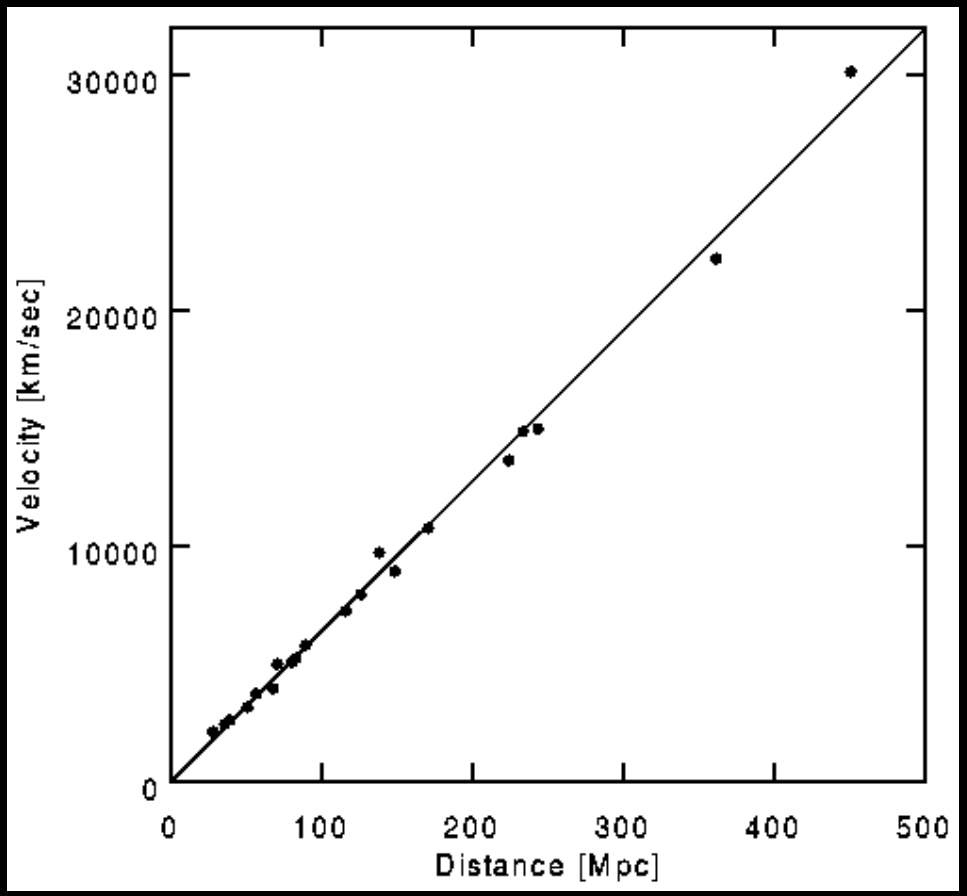

Figure from WMAP team


Distant light is
-dimmed
-redshifted
d=1
B=1
d=2
B=1/4
d=3
B=1/9
Afterglow Light Pattern 400,000 yrs.
Dark Ages
Development of Galaxies, Planets, etc.
Inflation
WMAP
Quantum Fluctuations
1st Stars about 400 million yrs.
Big Bang Expansion
13.7 billion years

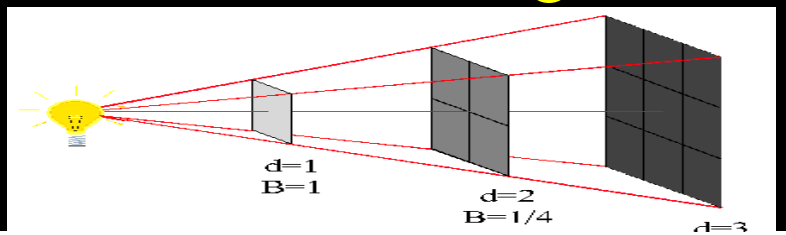
Distant light is { -dimmed
-redshifted



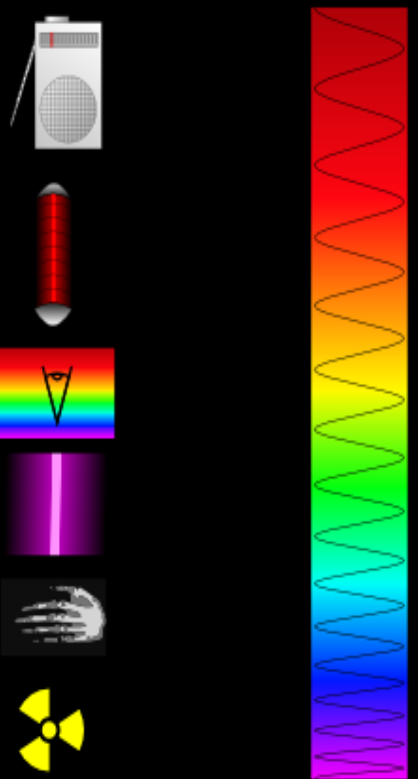
Redshift



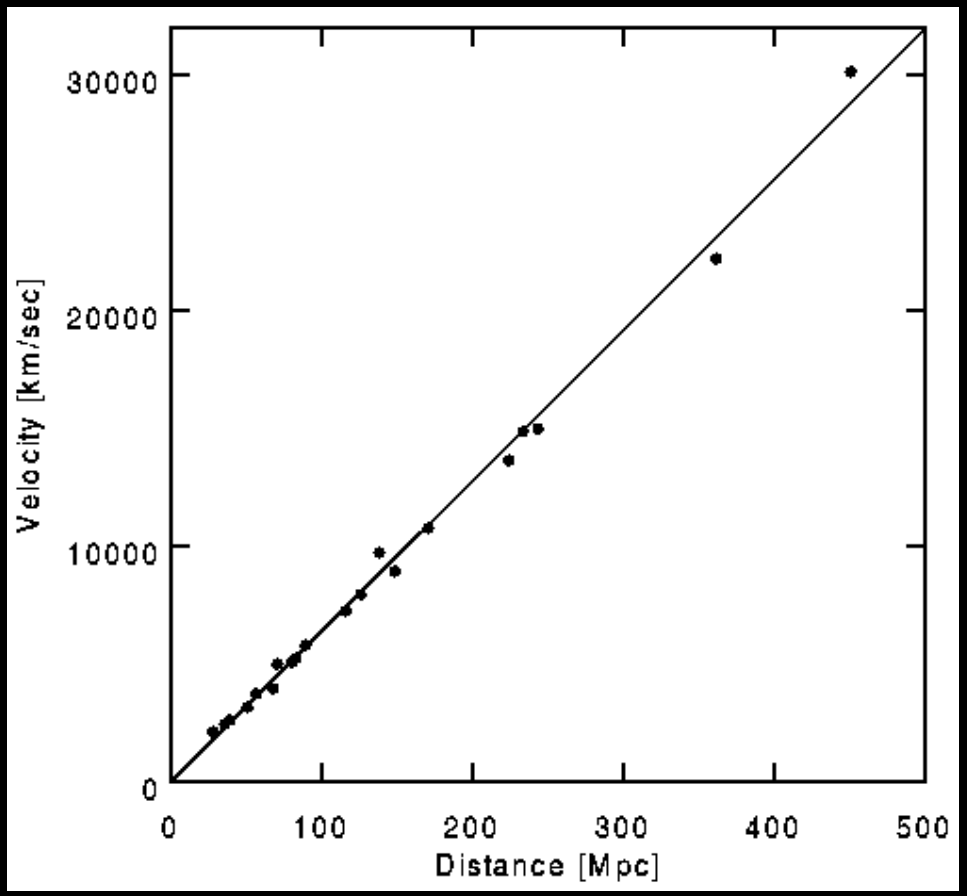

Dimming



Distant light is { -dimmed
-redshifted

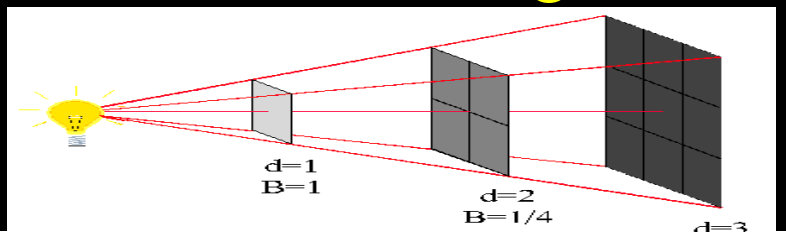


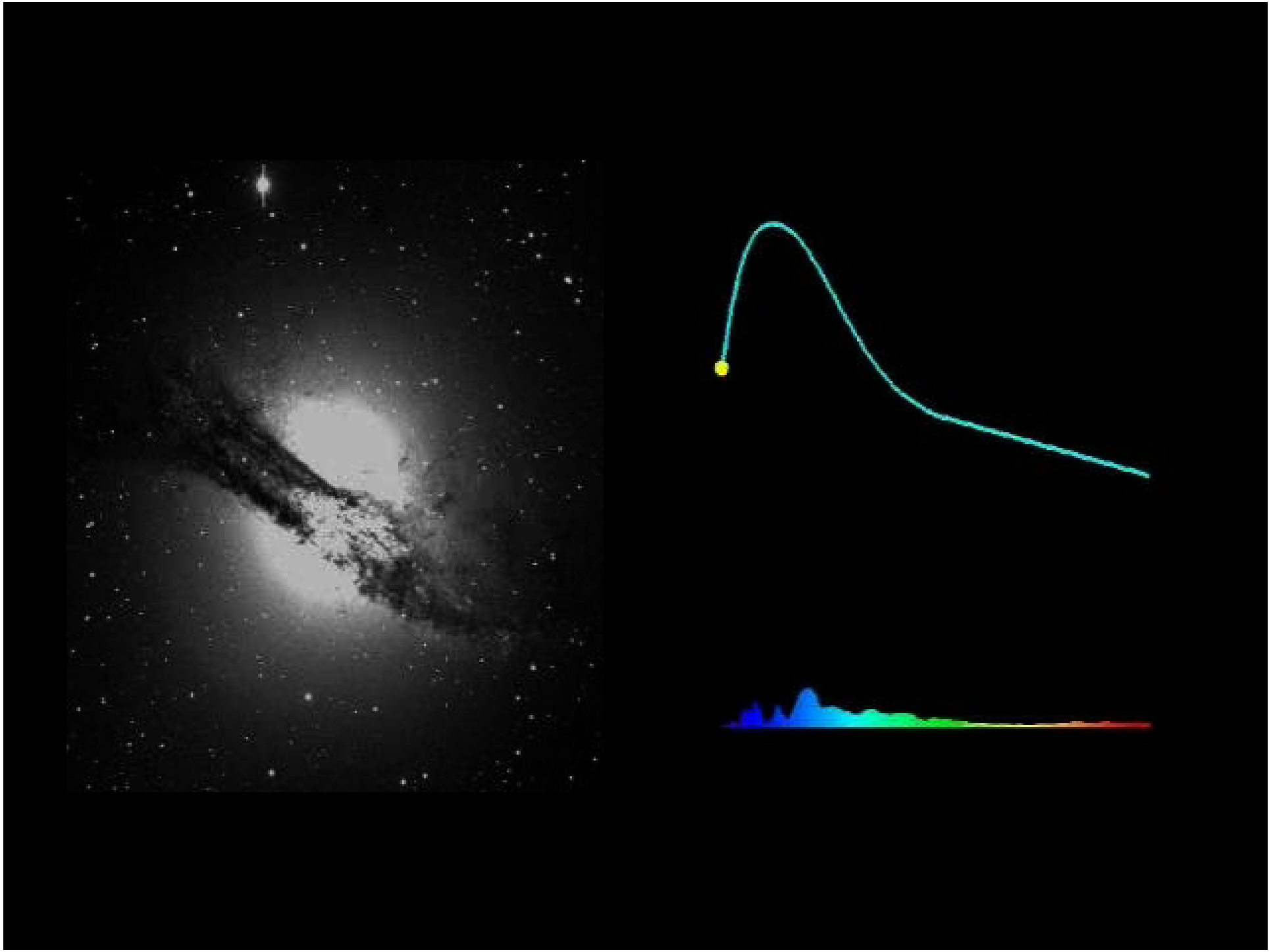
Redshift




Dimming

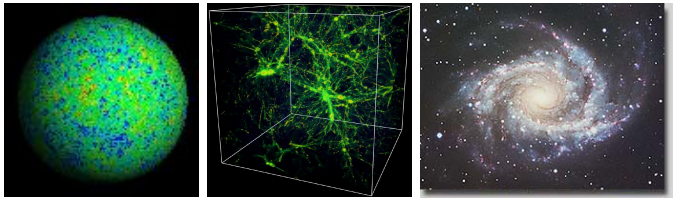
Standard candles,
rulers or clocks





Max Tegmark
Dept. of Physics, MIT
tegmark@mit.edu
Bright Horizons Cruise
May 9, 2011

**Cosmological data**



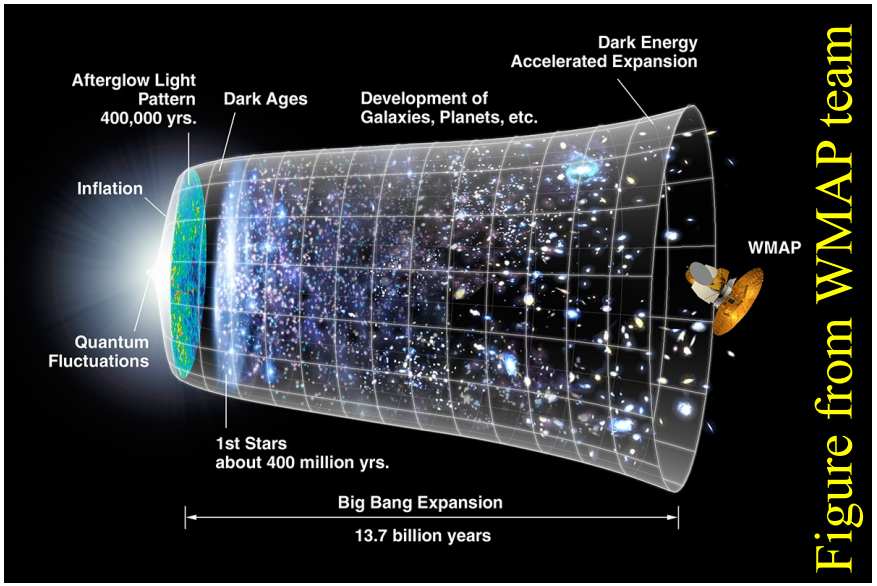
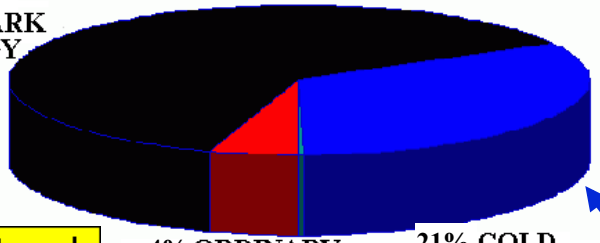



Figure from WMAP team

**Cosmological Parameters**




$\Omega, \Omega_b, \Lambda, \tau, h$
$n, n_T, Q, T/S$

Why these particular values?

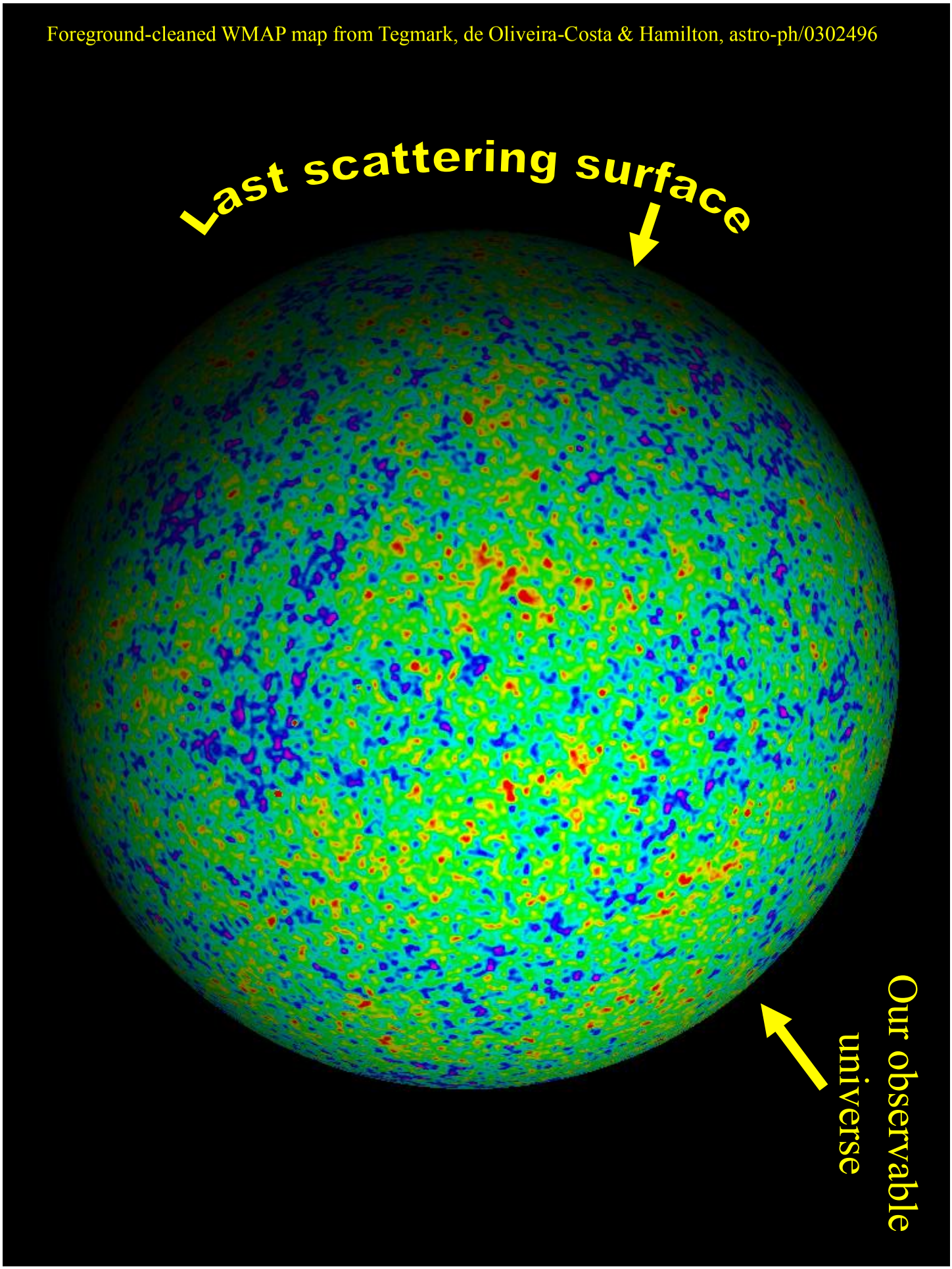
**Fundamental theory**

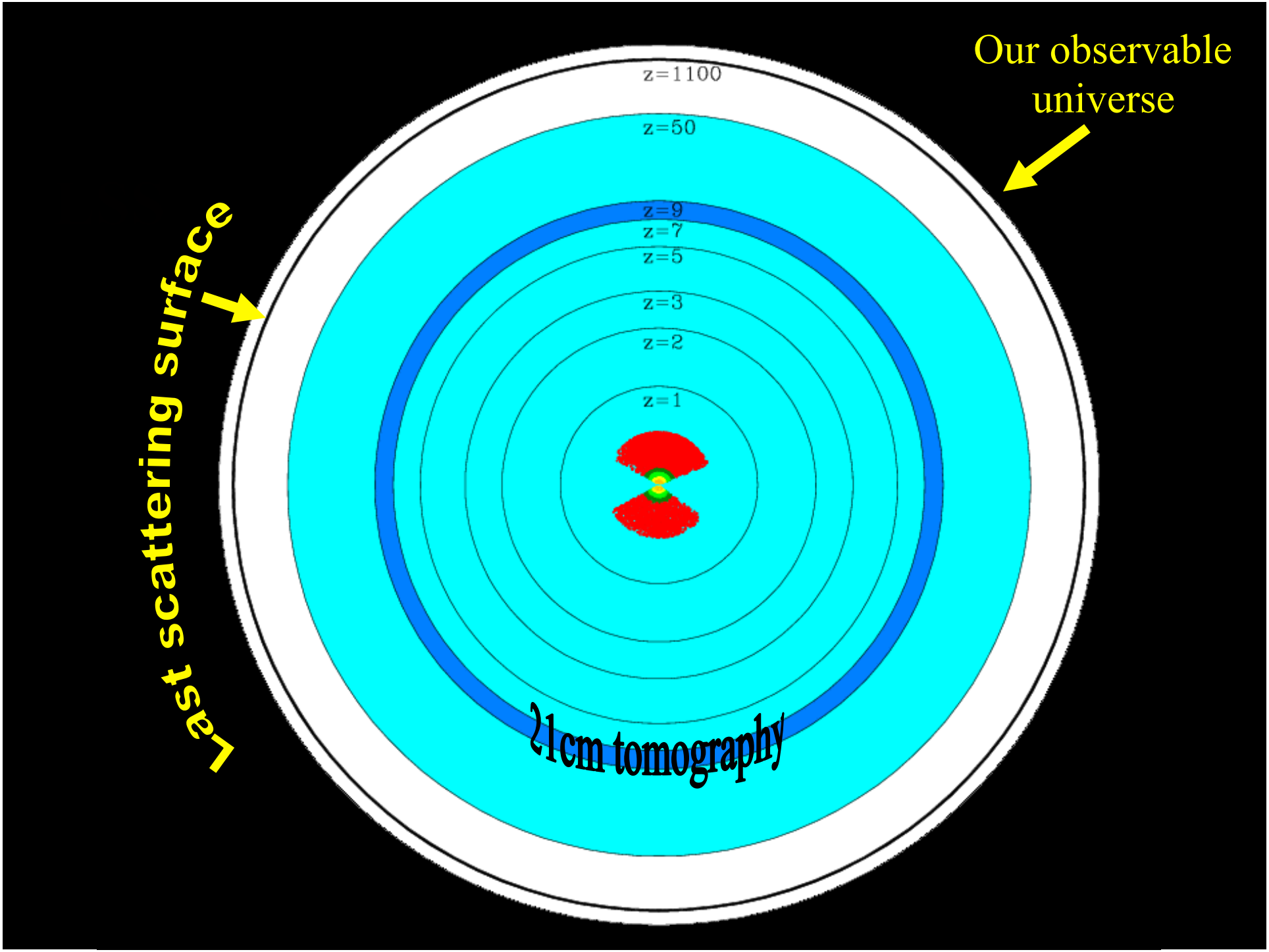
Nature of dark matter?

Nature of dark energy?

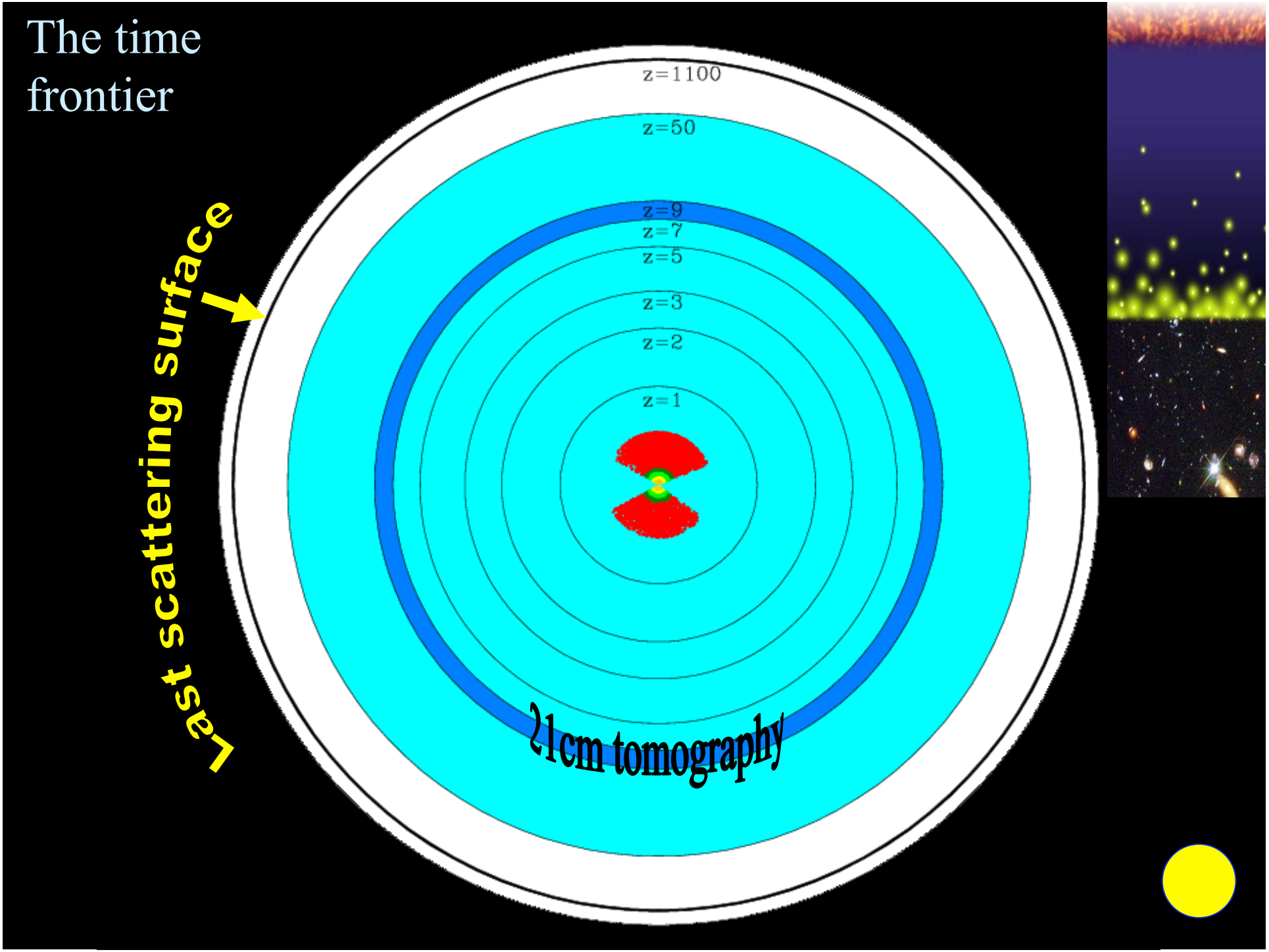
Nature of early Universe?

Map our universe!


Foreground-cleaned WMAP map from Tegmark, de Oliveira-Costa & Hamilton, astro-ph/0302496
Last scattering surface
Our observable universe


Our observable universe
Last scattering surface
z=1100
z=50
z=9
z=7
z=5
z=3
z=2
z=1
21cm tomography

The time frontier



# The Omniscope

M
Dept. of Physics, MIT
tegmark@mit.edu
Bright Horizons Cruise
May 9, 2011

MIT & Matias Zaldarriaga, arXiv:0805.4414, 0909.0001

# How get huge sensitivity at low cost?

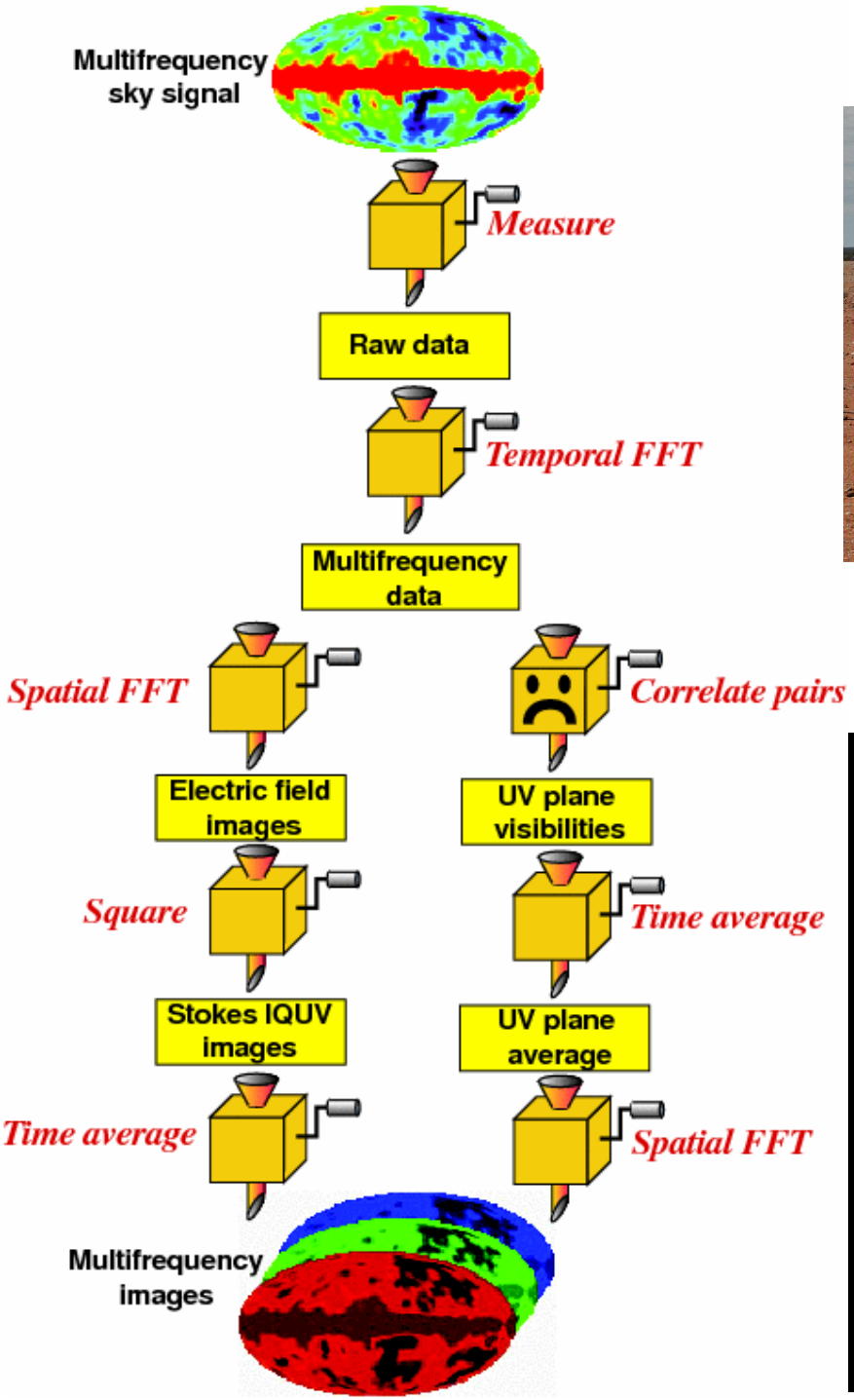
Sensitivity $\delta T \propto (A\Omega)^{-1/2}$

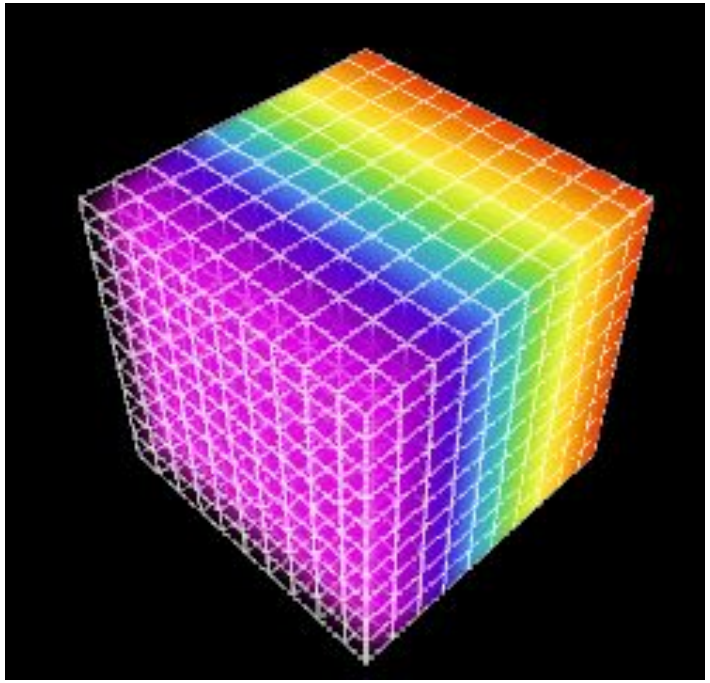
Single-dish telescope:
cost $\propto A^{1.35}$

Interferometer:
cost $\propto N^2 \propto A^2$

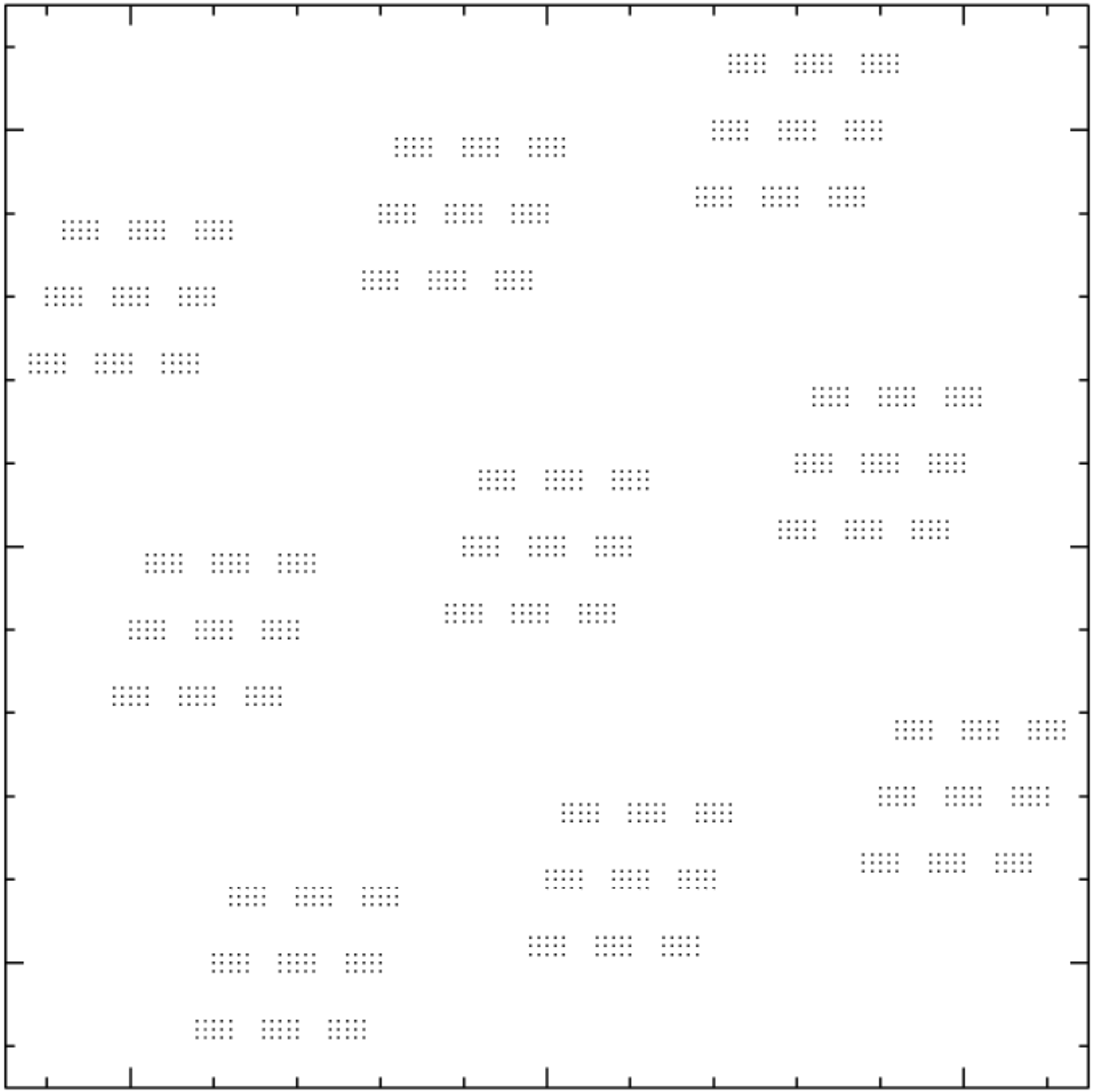
FFT telescope idea:
cost $\propto A$, $\Omega \sim 2\pi$

# Telescopes as Fourier transformers

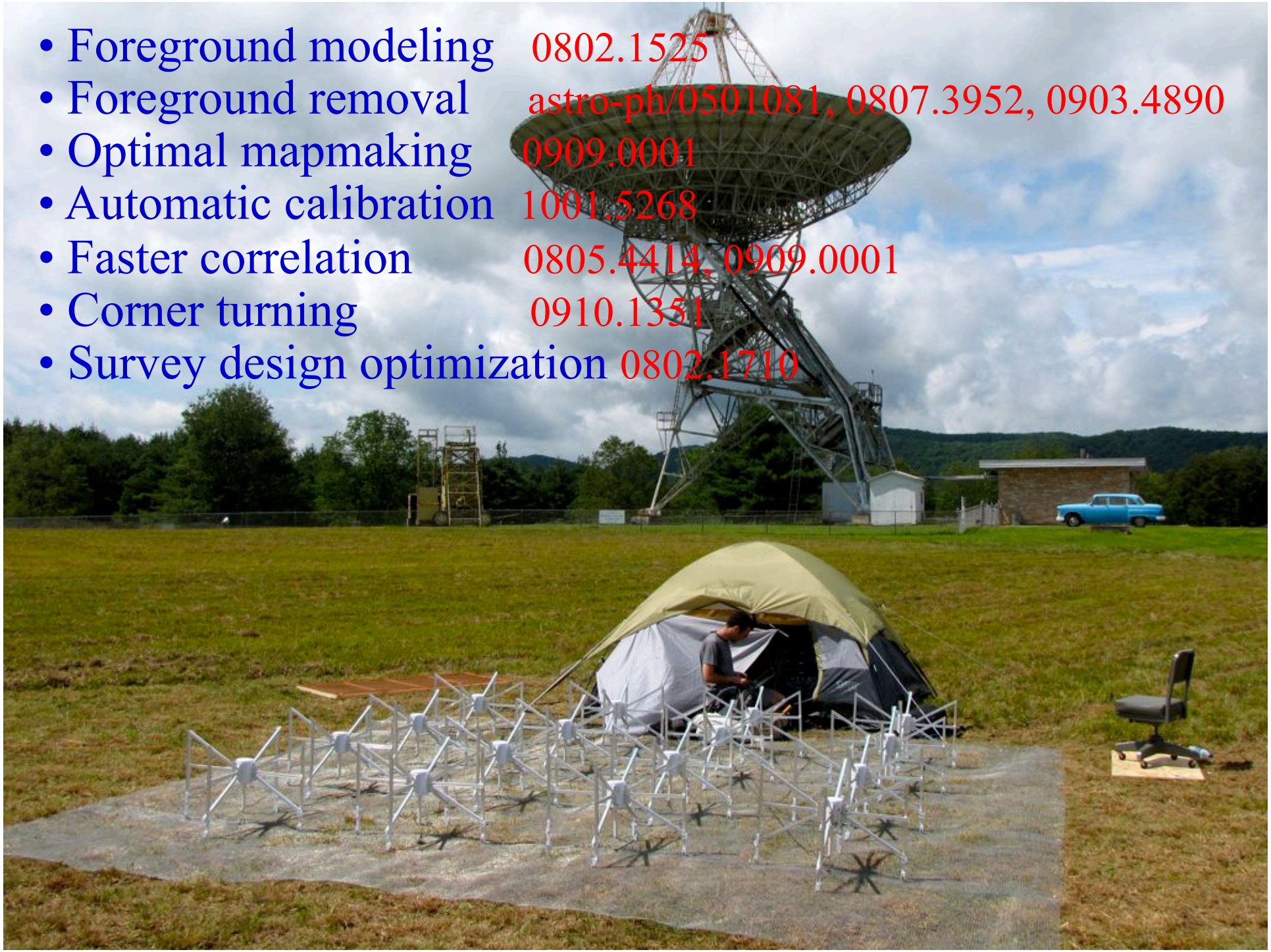


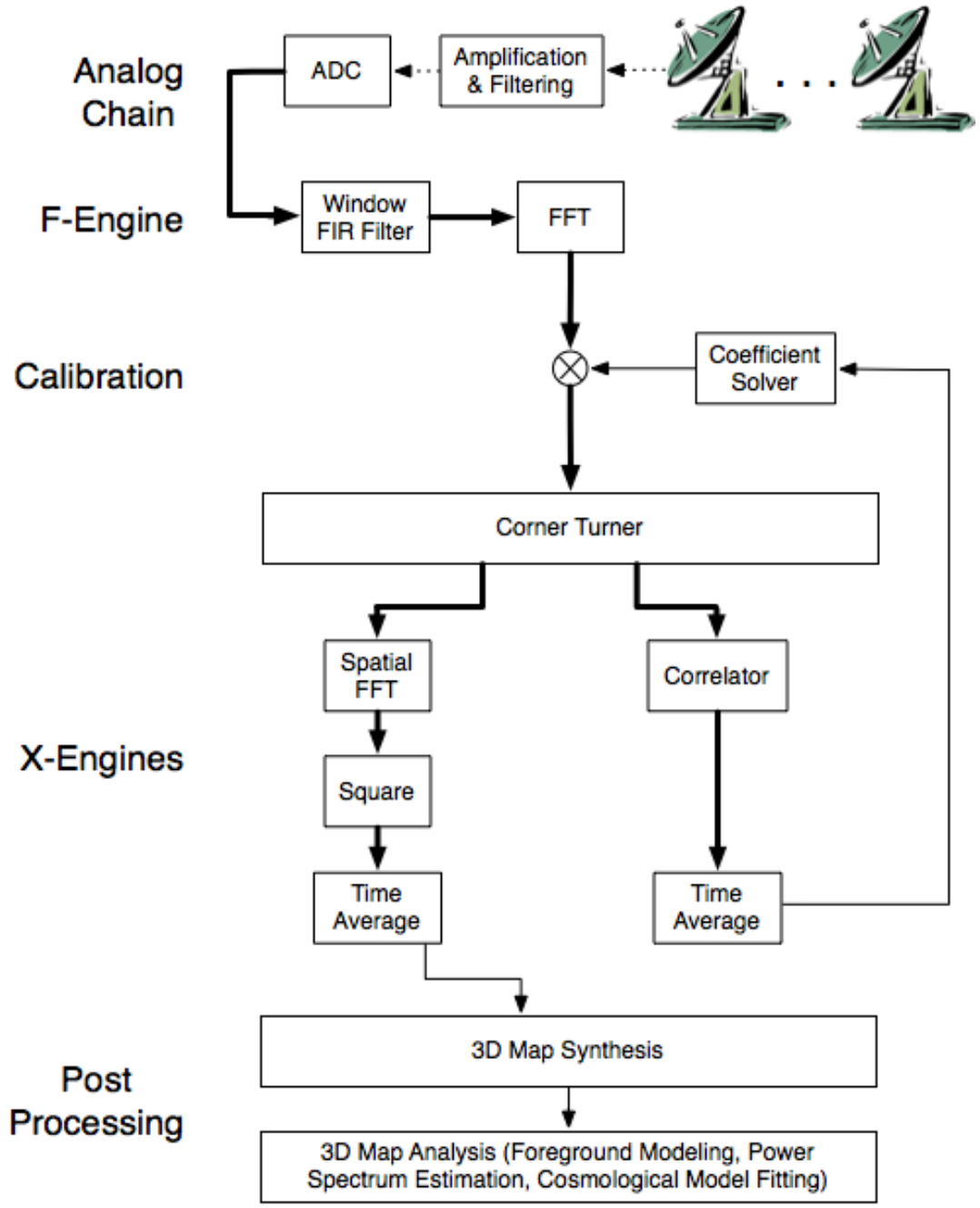


Max Tegmark
Dept. of Physics, MIT
tegmark@mit.edu
Bright Horizons Cruise
May 9, 2011

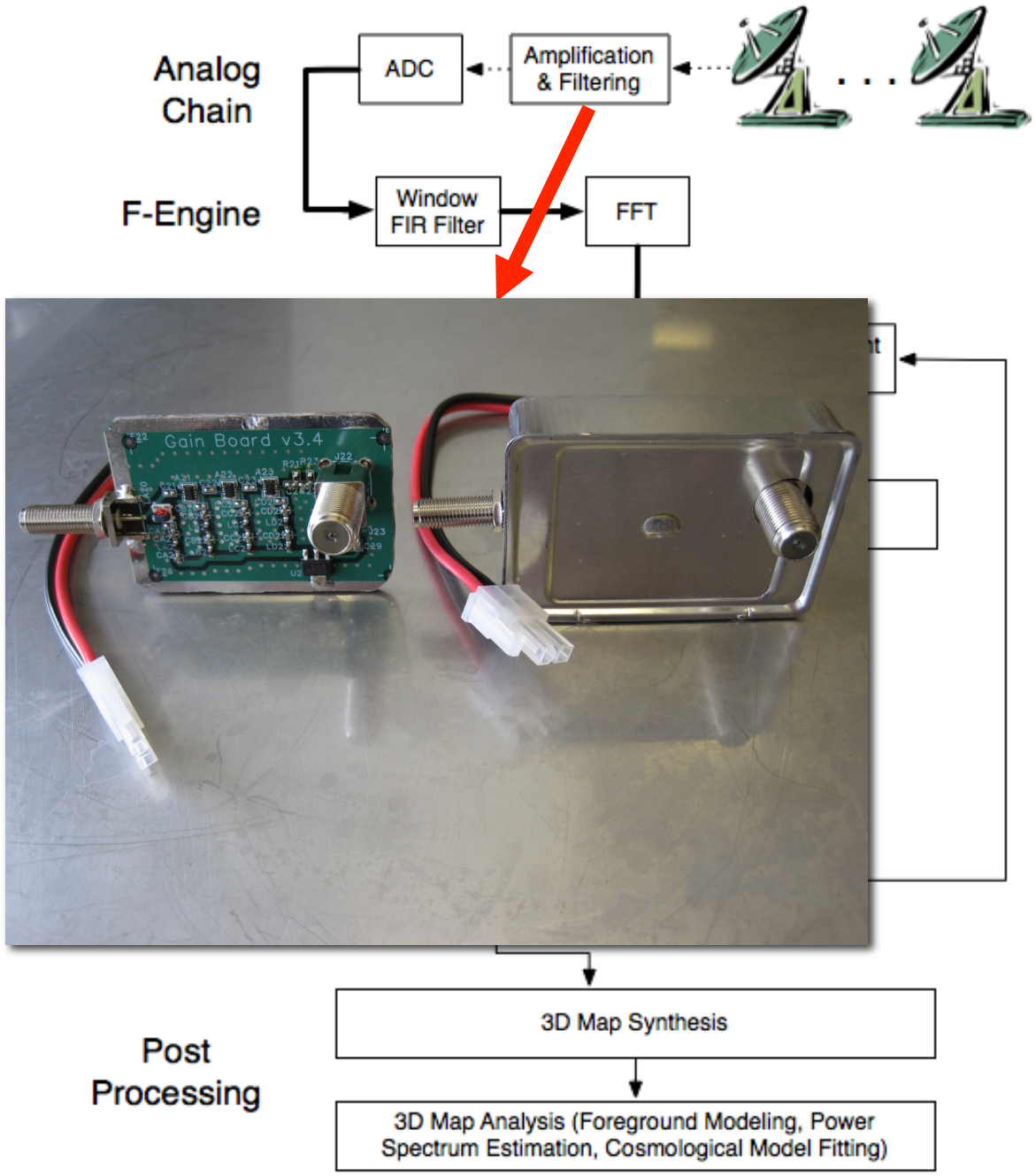


# Where are we now?

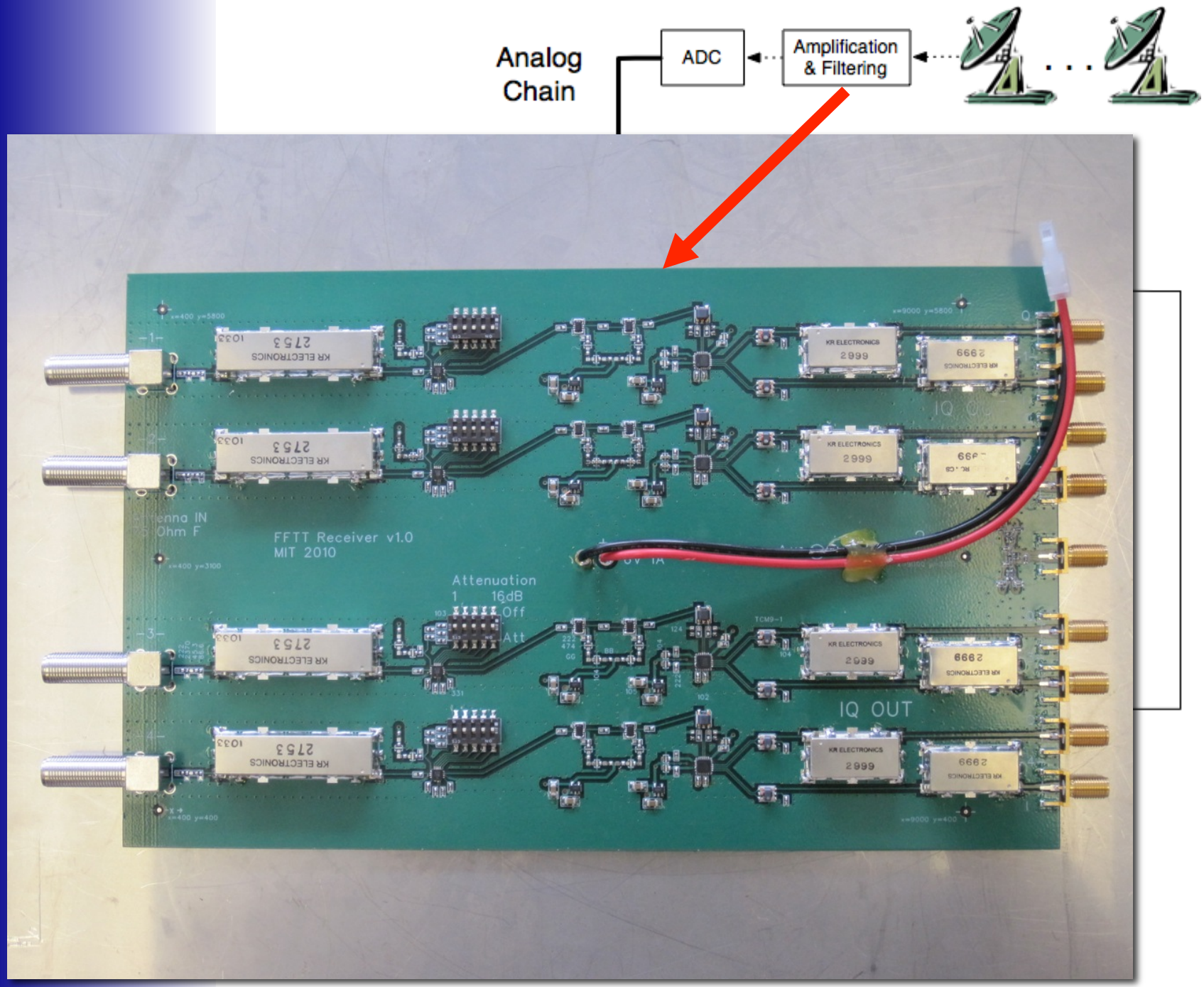

• Foreground modeling 0802.1525
• Foreground removal astro-ph/0501081, 0807.3952, 0903.4890
• Optimal mapmaking 0909.0001
• Automatic calibration 1001.5268
• Faster correlation 0805.4414, 0909.0001
• Corner turning 0910.1351
• Survey design optimization 0802.1710

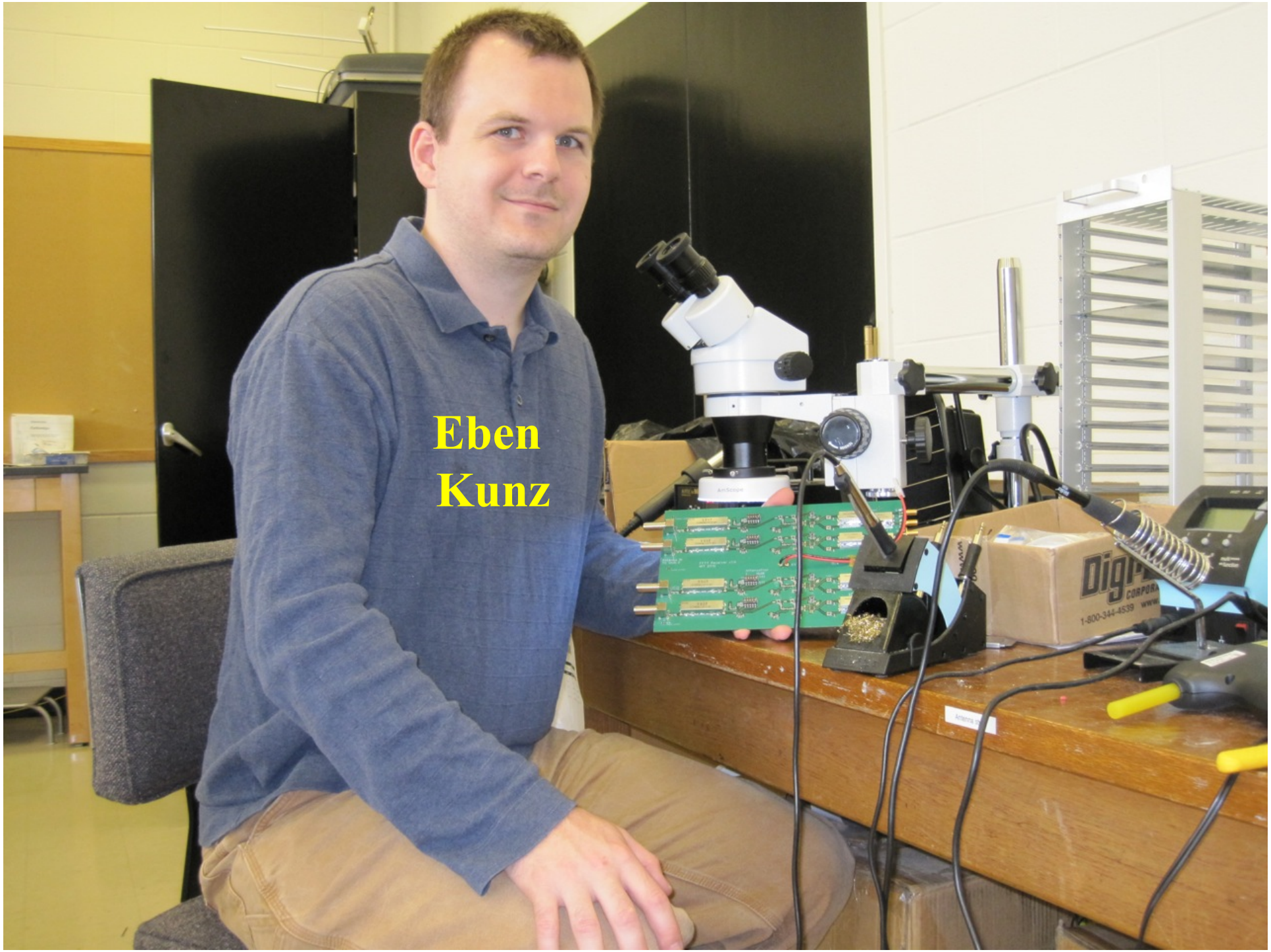


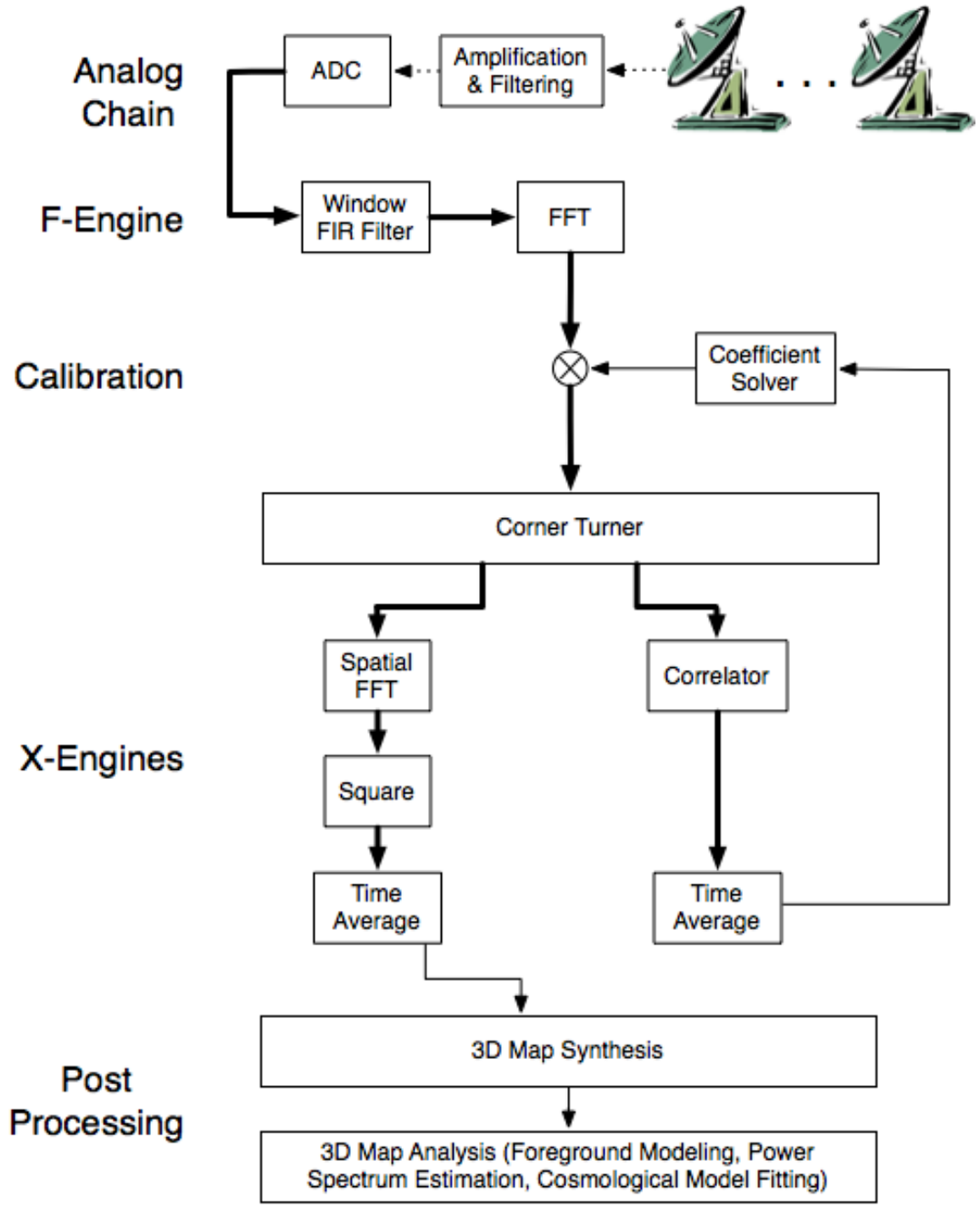

Max Tegmark
Dept. of Physics, MIT
tegmark@mit.edu
Bright Horizons Cruise
May 9, 2011



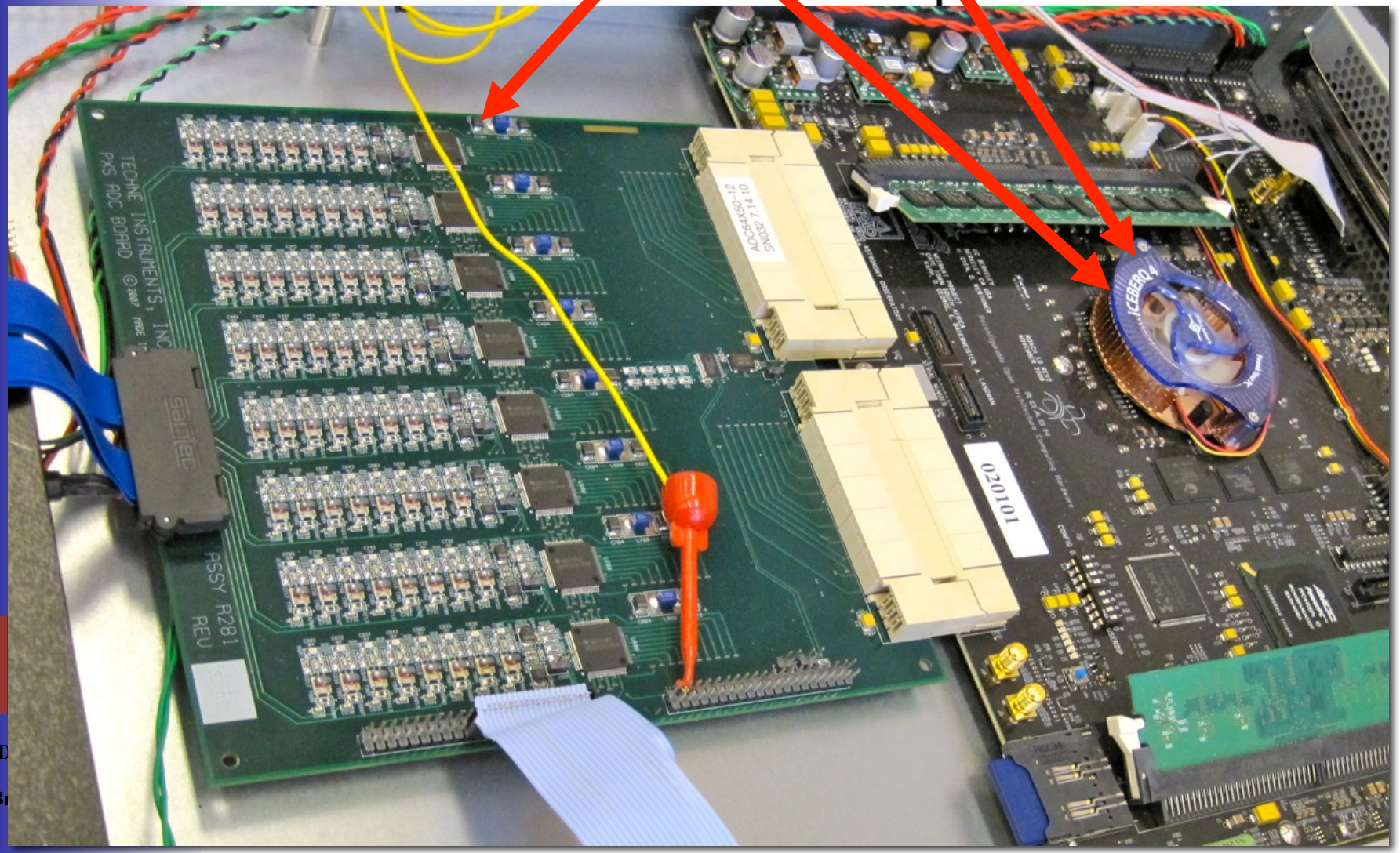

Max Tegmark
Dept. of Physics, MIT
tegmark@mit.edu
Bright Horizons Cruise
May 9, 2011

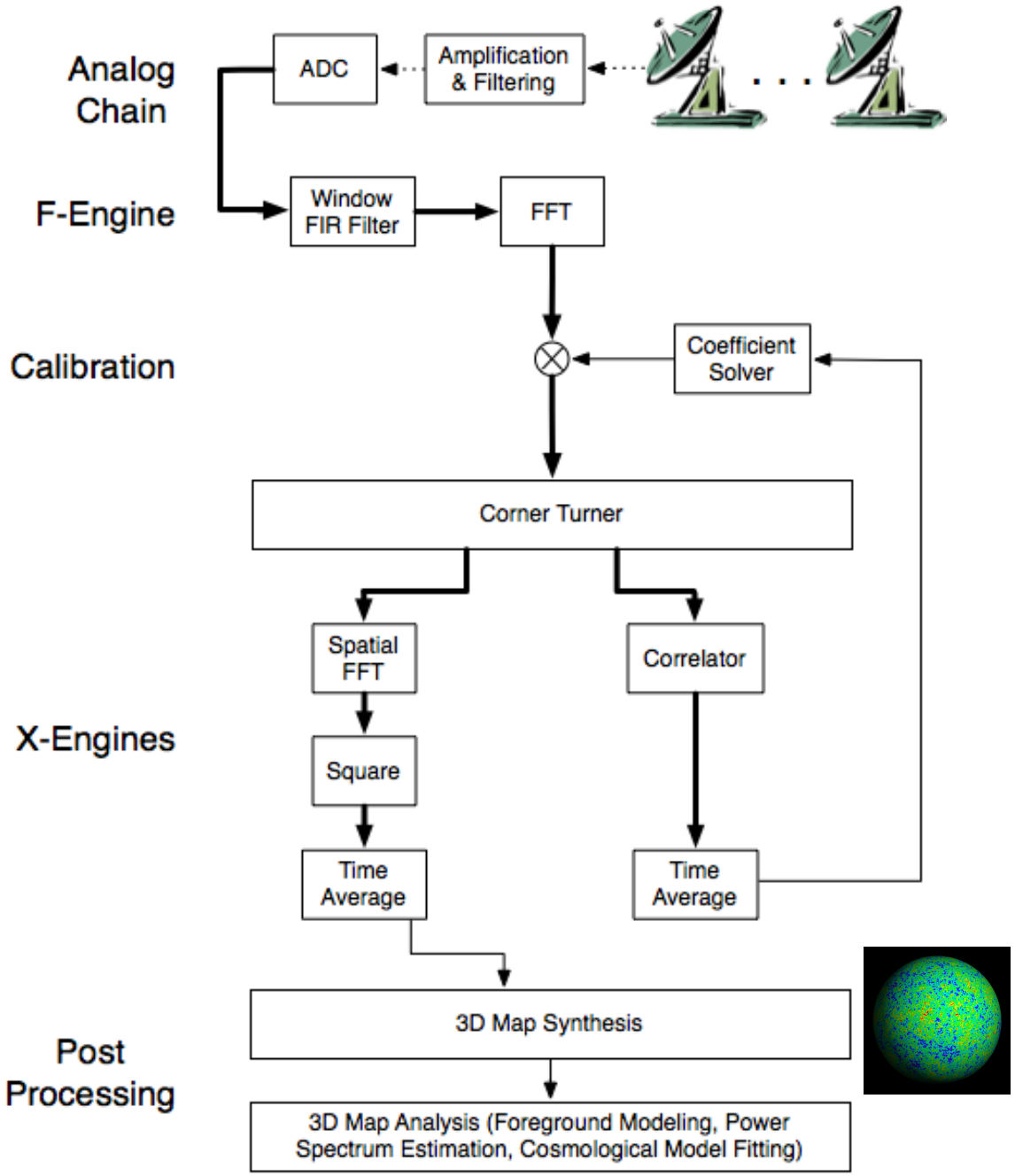

Analog Chain
ADC
Amplification & Filtering
FFTT Receiver v1.0
MIT 2010
Attenuation
16dB
Off
Att
IQ OUT


Eben
Kunz

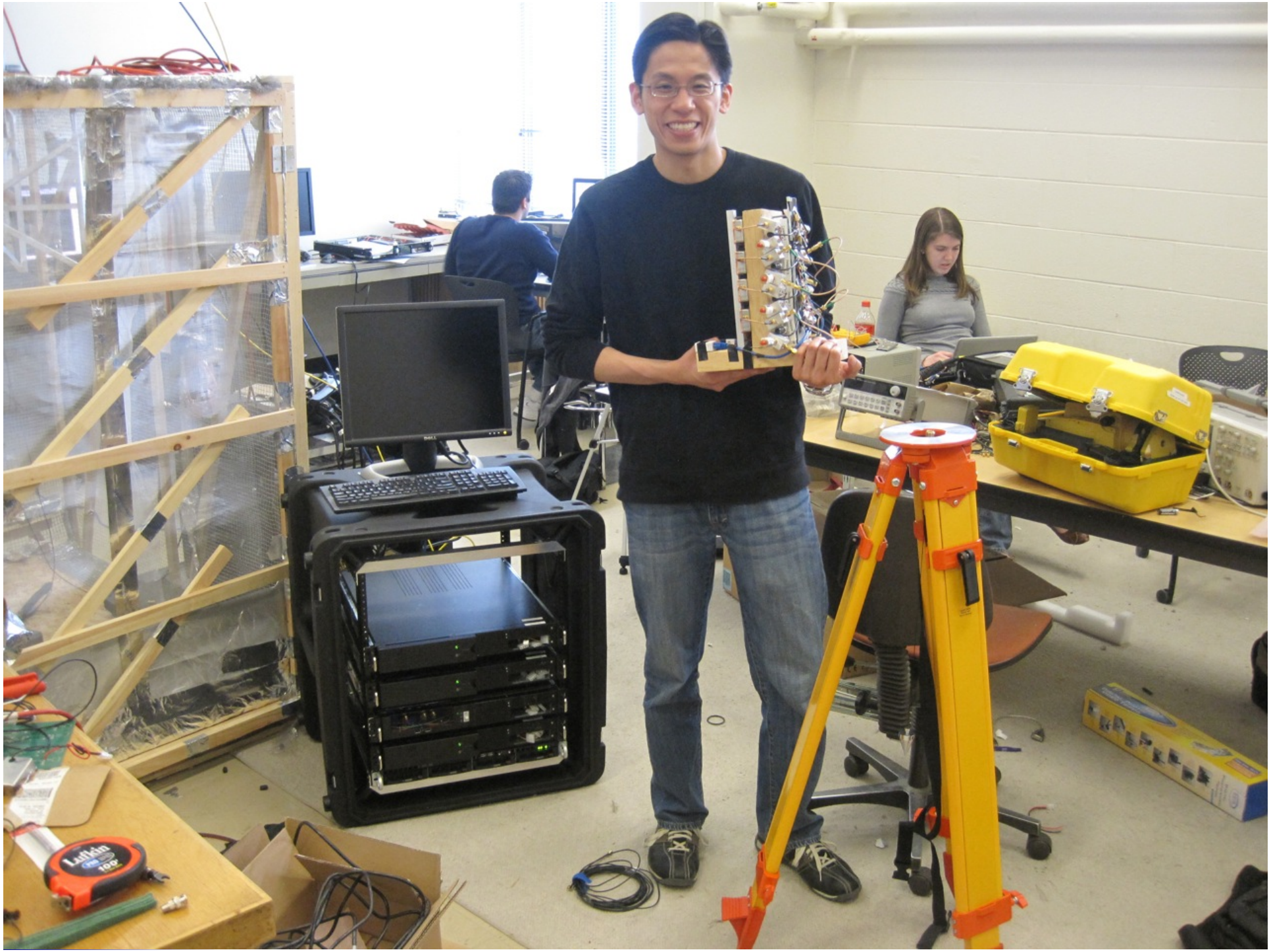



Max Tegmark
Dept. of Physics, MIT
tegmark@mit.edu
Bright Horizons Cruise
May 9, 2011

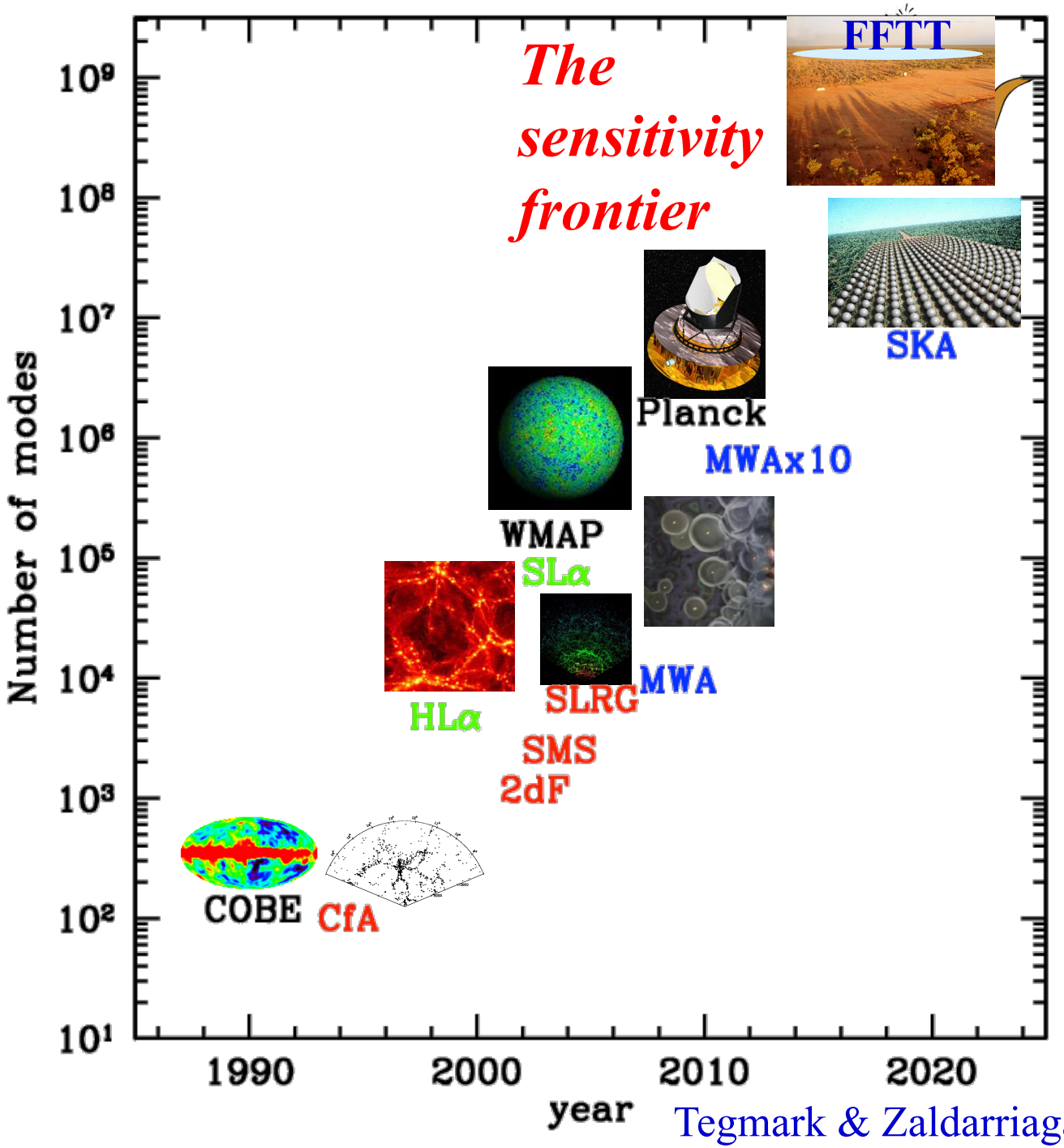

Analog Chain
ADC
Amplification & Filtering
F-Engine
Window FIR Filter
FFT
TECHNE INSTRUMENTS, INC
PXS ADC BOARD
ASSY R281 REV
020101
ICEBERG 4




Max Tegmark
Dept. of Physics, MIT
tegmark@mit.edu
Bright Horizons Cruise
May 9, 2011

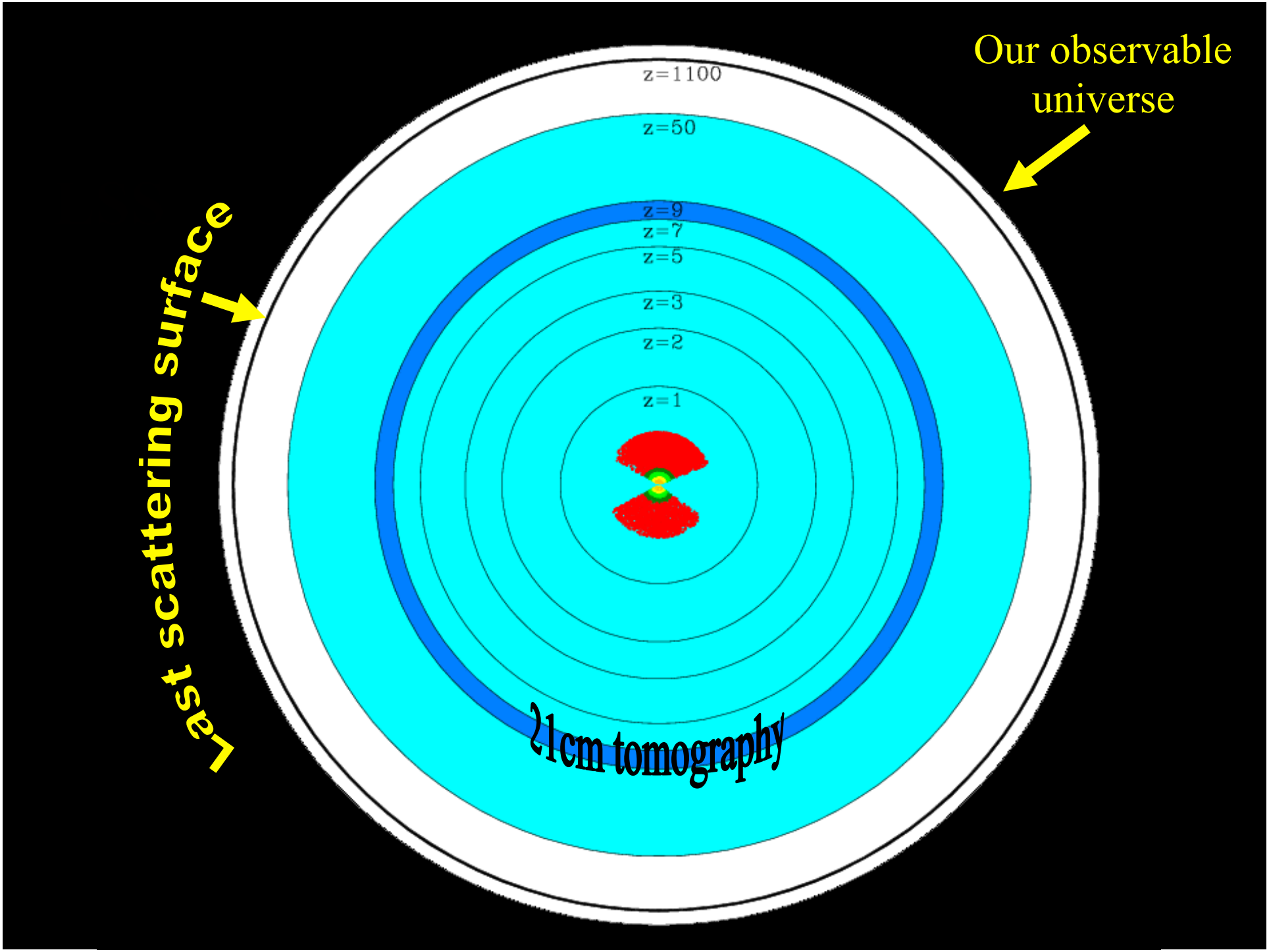

Lufkin
100'

Where are we going?




Tegmark & Zaldarriaga 2008

Max Tegmark
Dept. of Physics, MIT
tegmark@mit.edu
Bright Horizons Cruise
May 9, 2011


Our observable universe
Last scattering surface
z=1100
z=50
z=9
z=7
z=5
z=3
z=2
z=1
21cm tomography

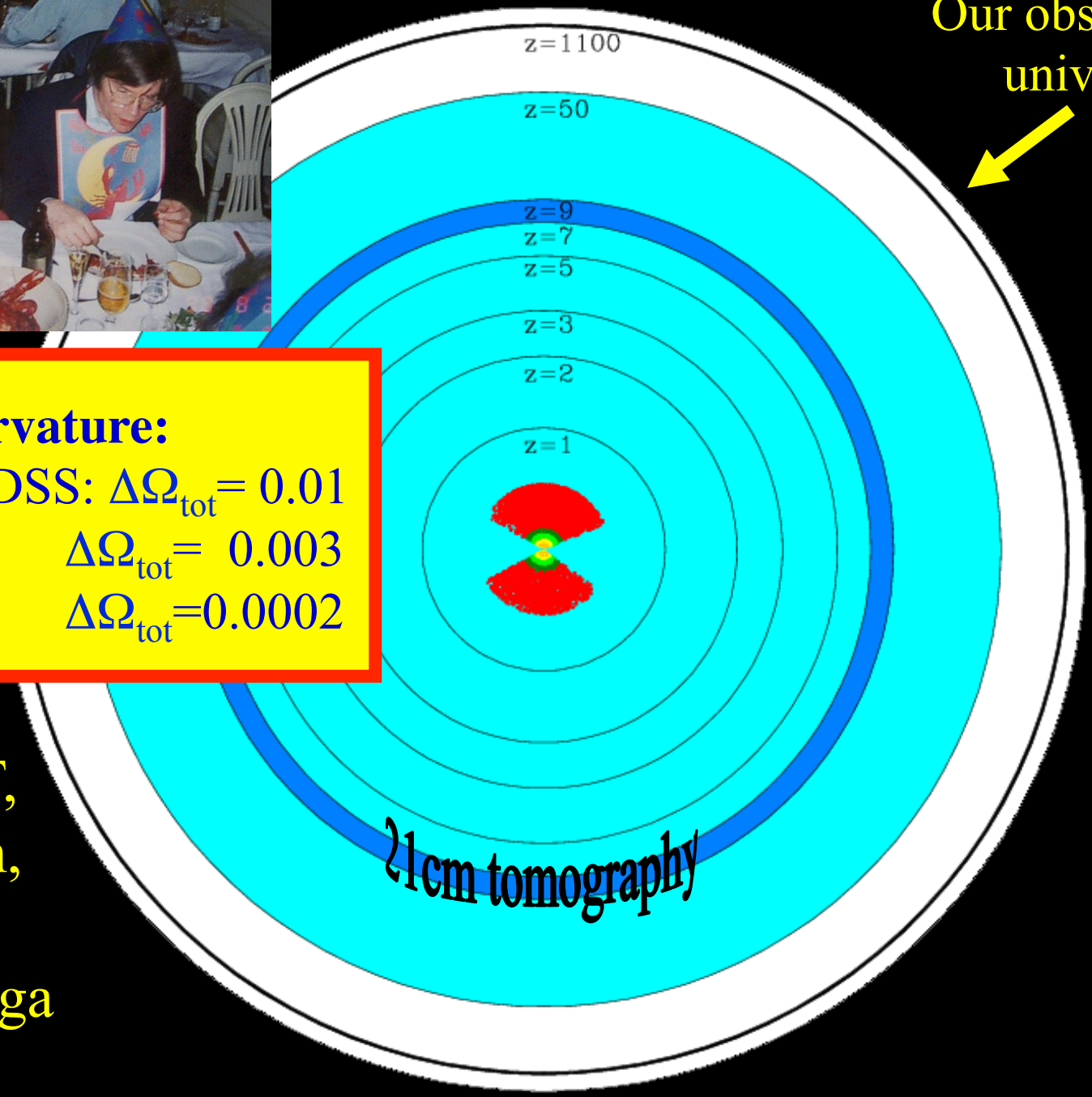
**Spatial curvature:**

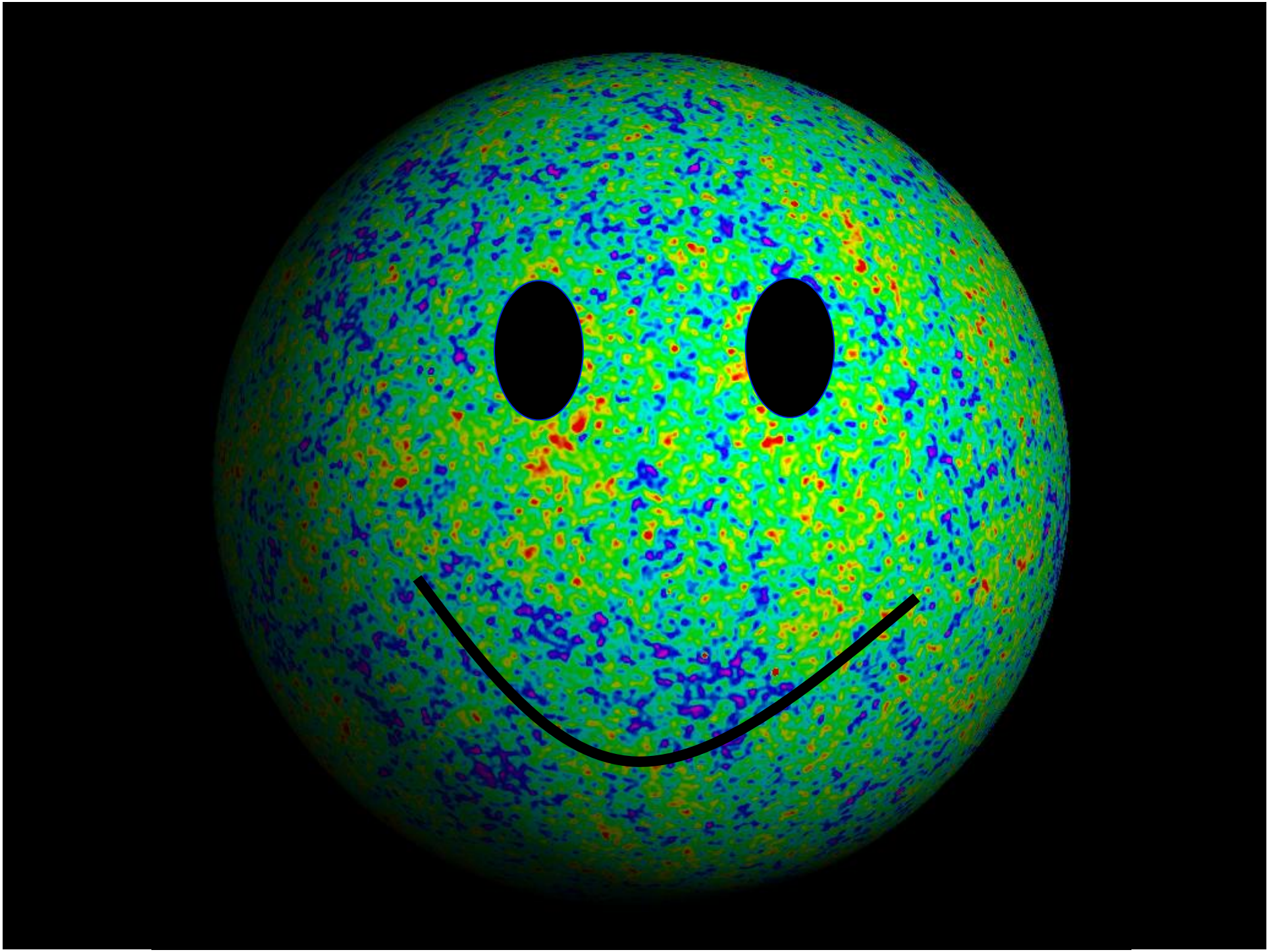
WMAP+SDSS: $\Delta\Omega_{tot}$= 0.01

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

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

Mao, MT, McQuinn, Zahn & Zaldarriaga 2008




Our observable universe