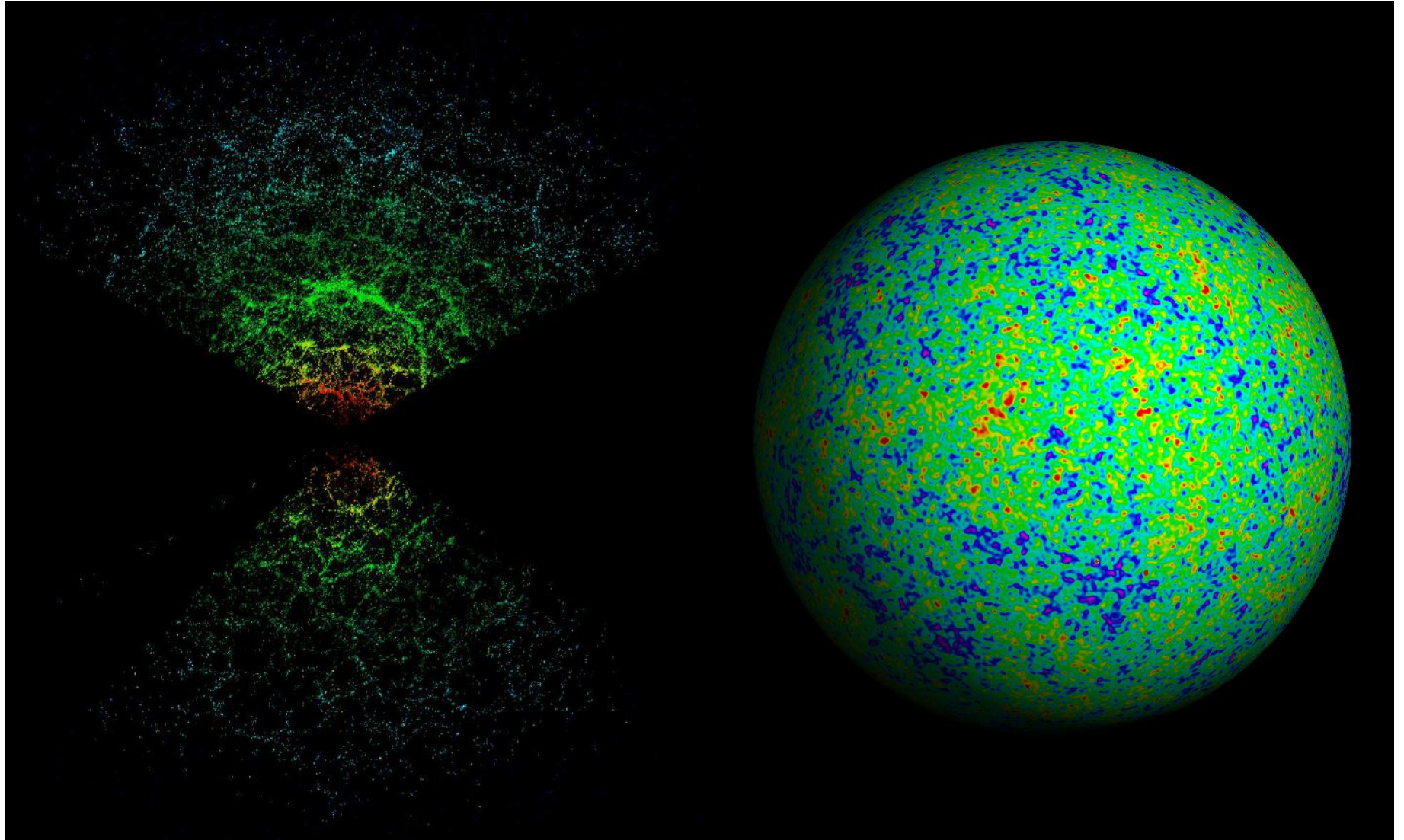
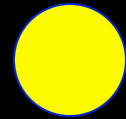


# The History of the Universe in One Hour

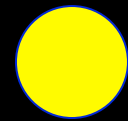


Max Tegmark, MIT

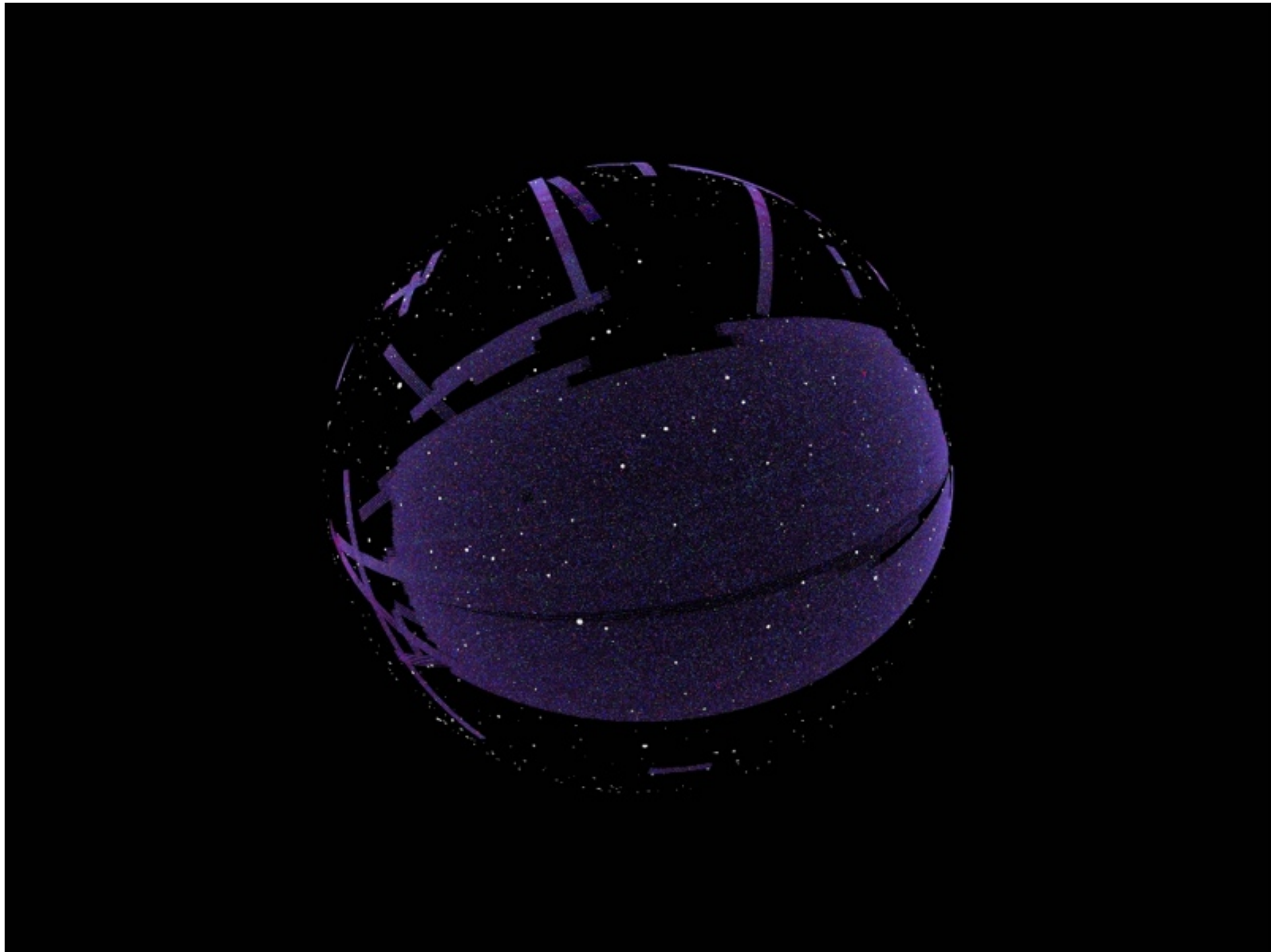
# OUR PLACE IN SPACE

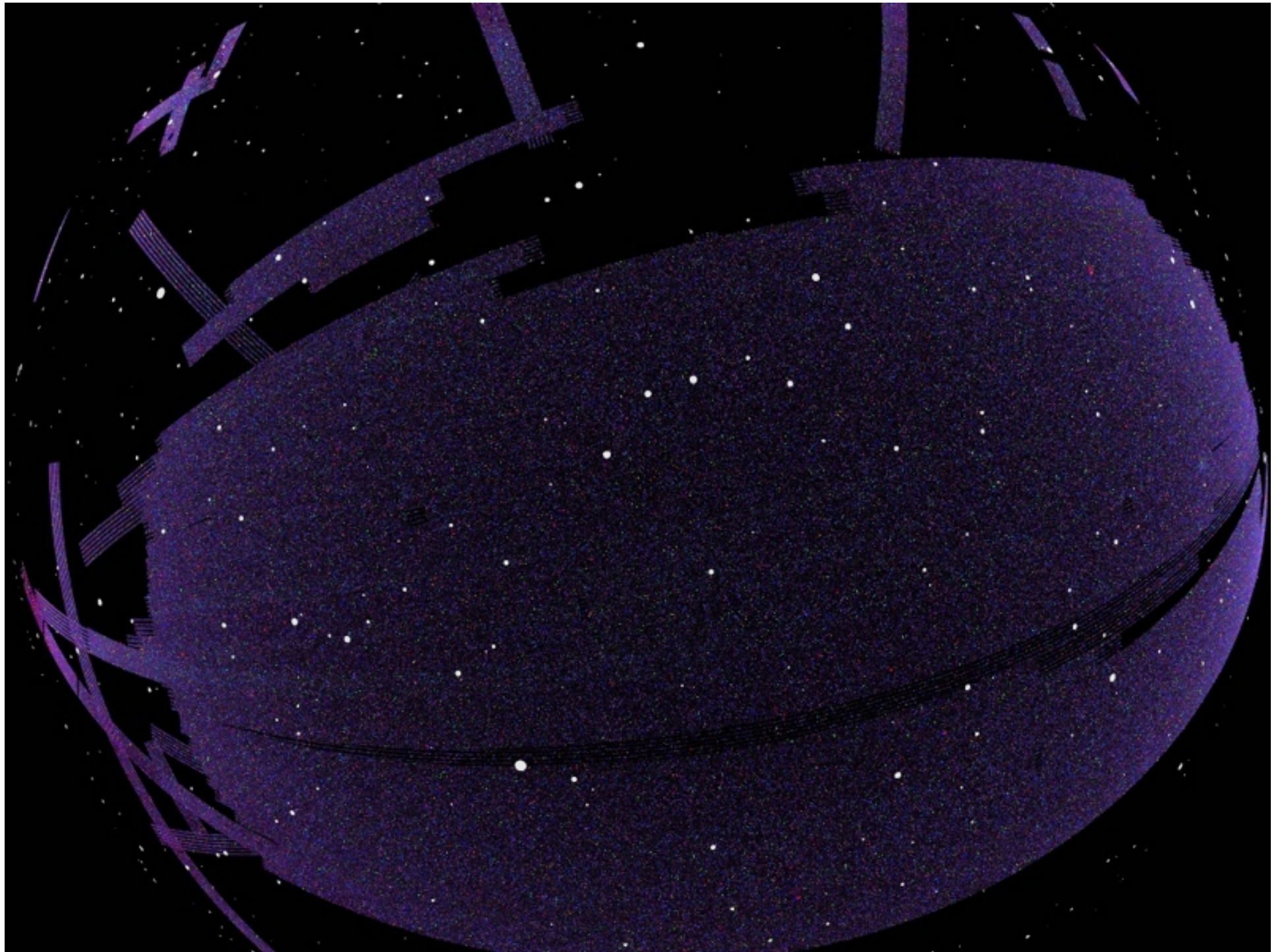


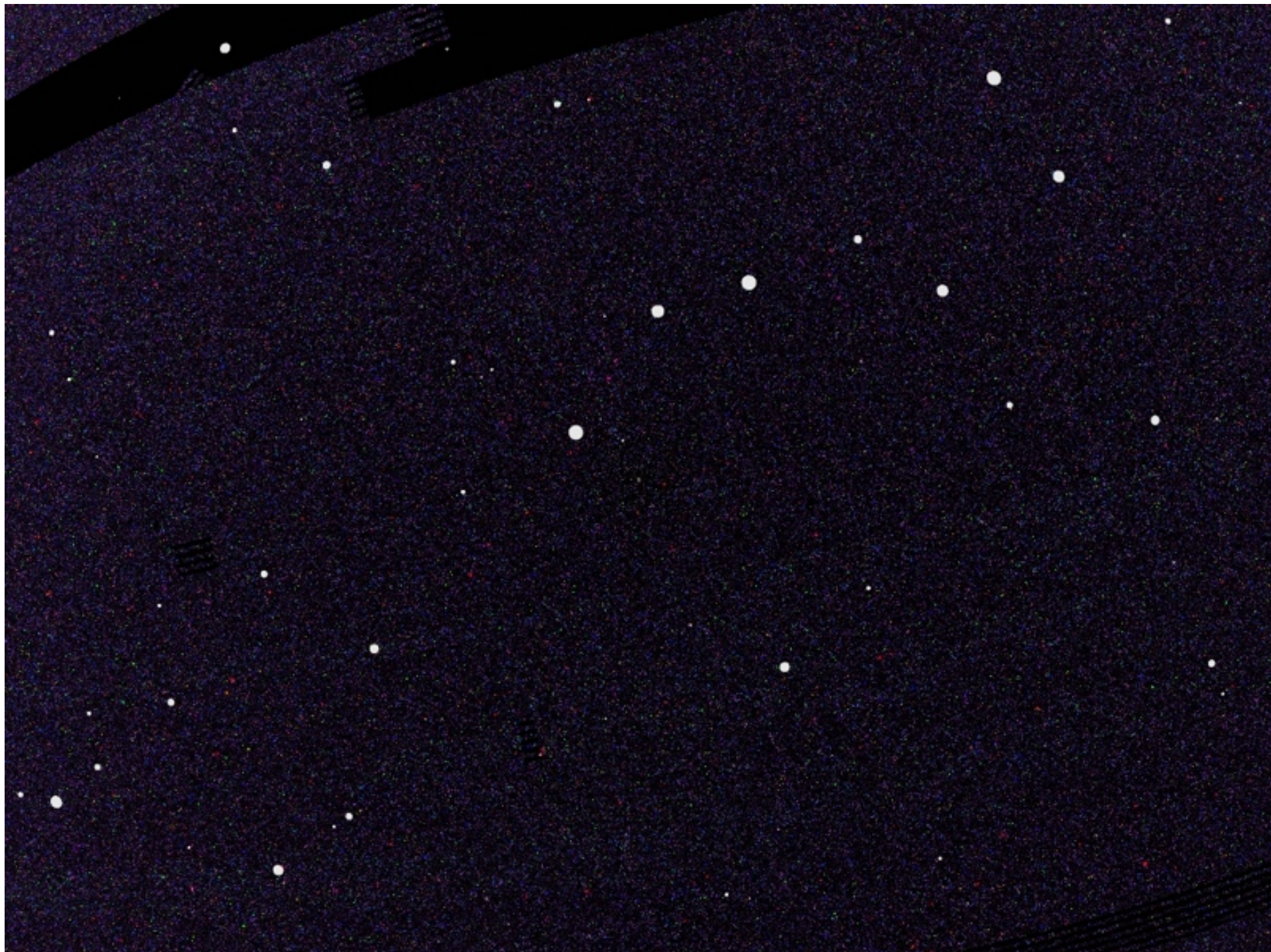
GE Zoomout



DSE



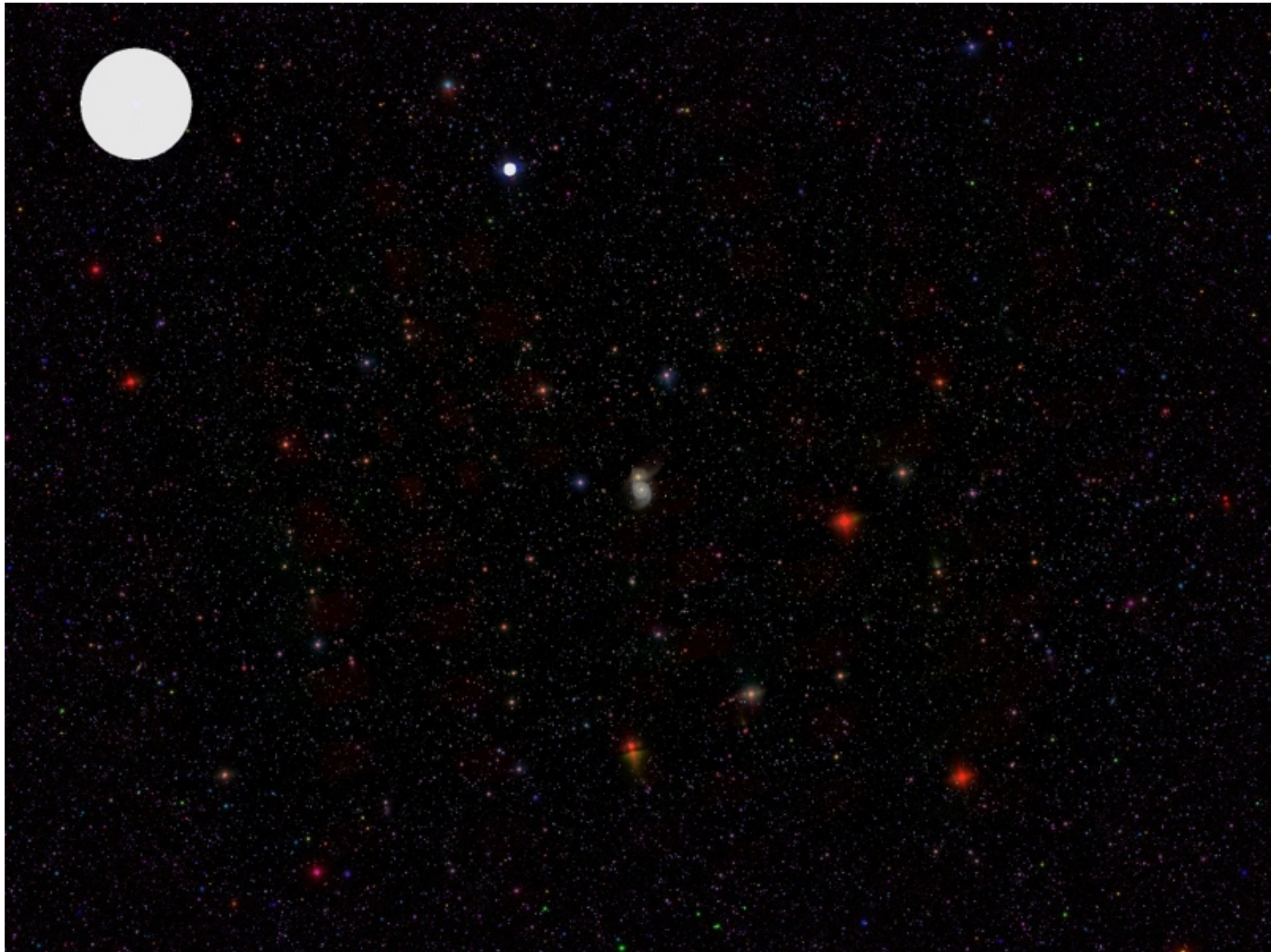


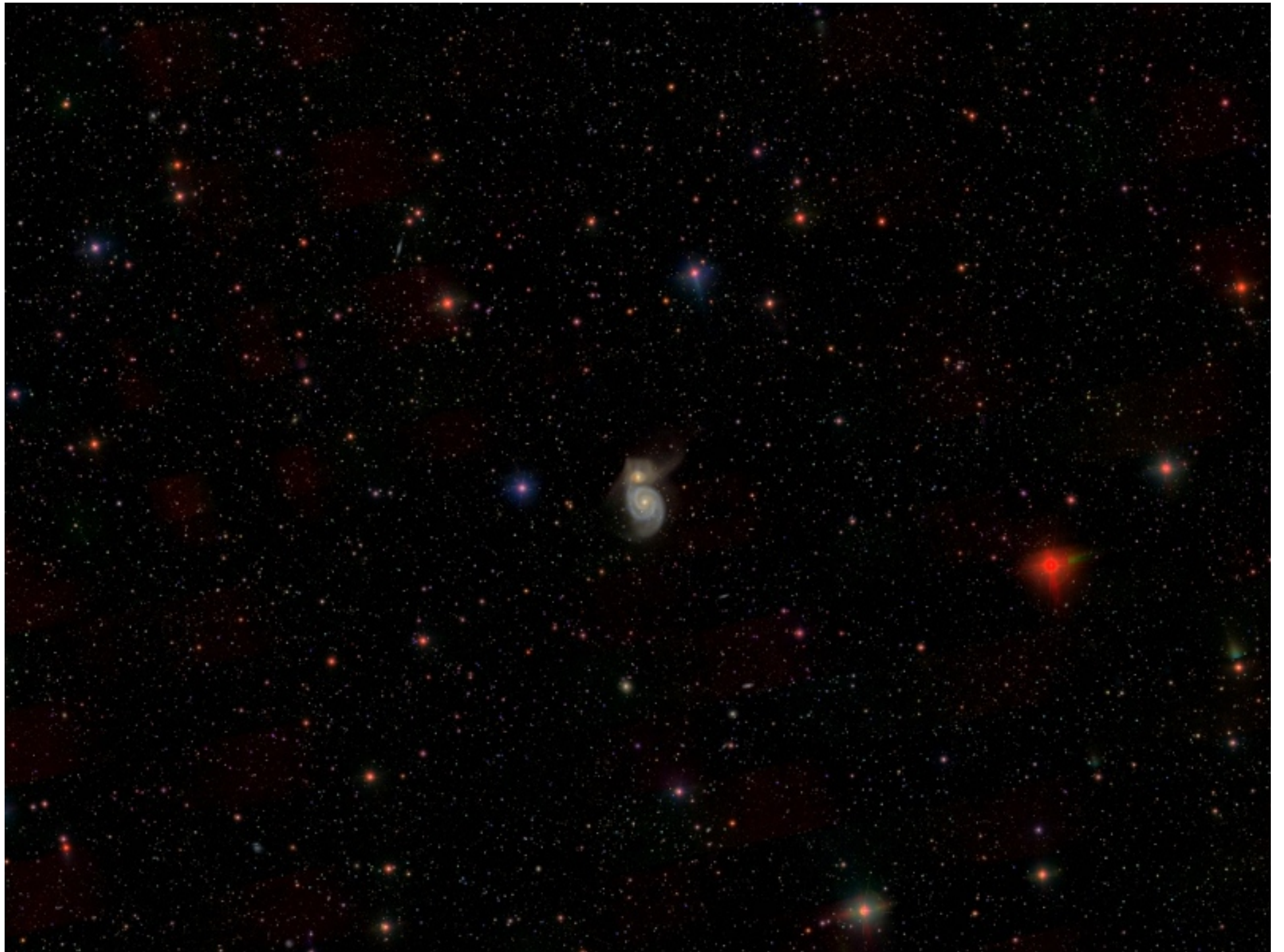














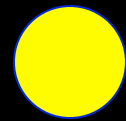












SDSS movie

from MW

# OUR PLACE IN TIME

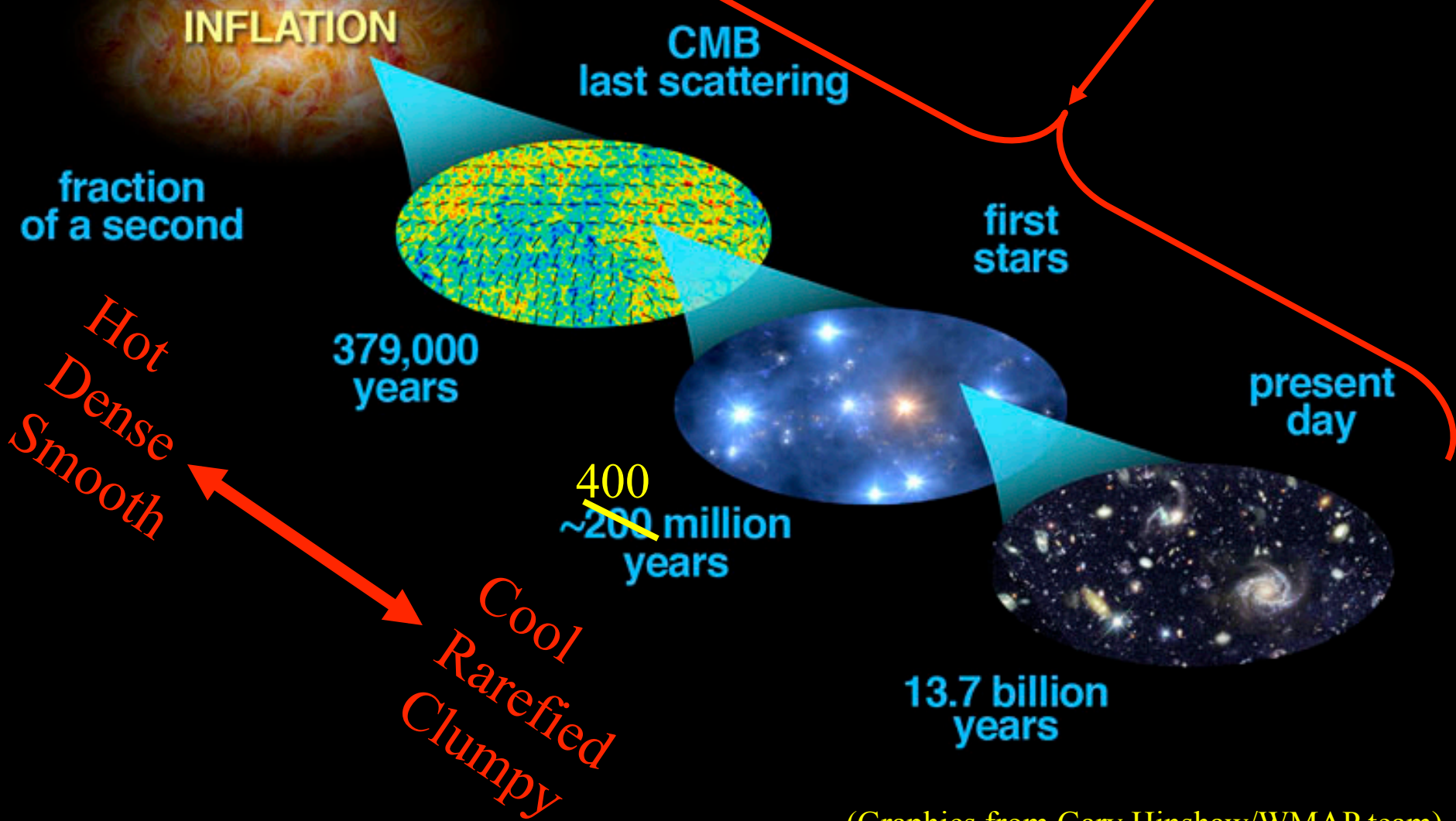
The sky as a time machine



# Brief History of our Universe

Fluctuation generator

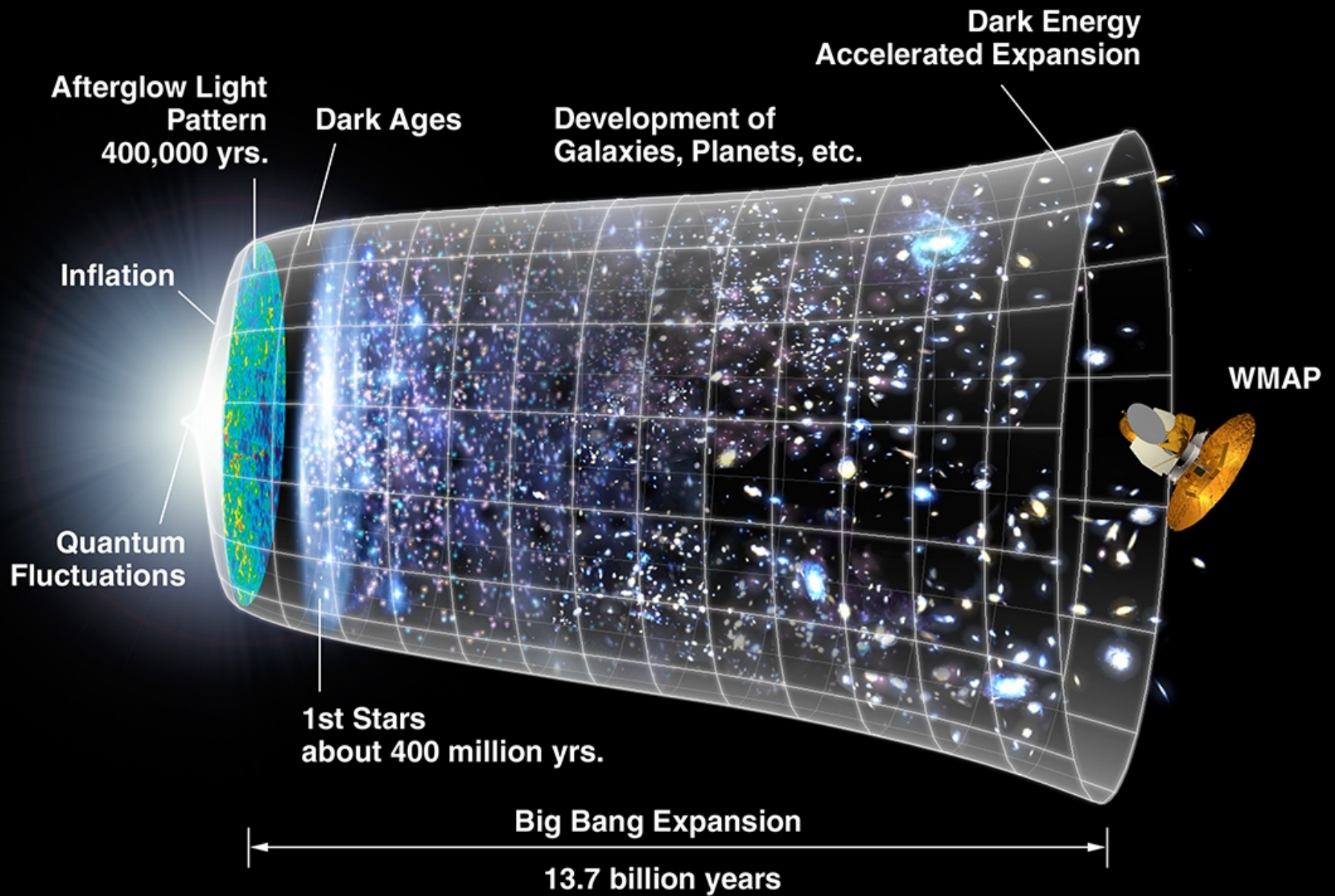
Fluctuation amplifier

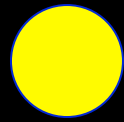


(Graphics from Gary Hinshaw/WMAP team)

i

Figure from WMAP team



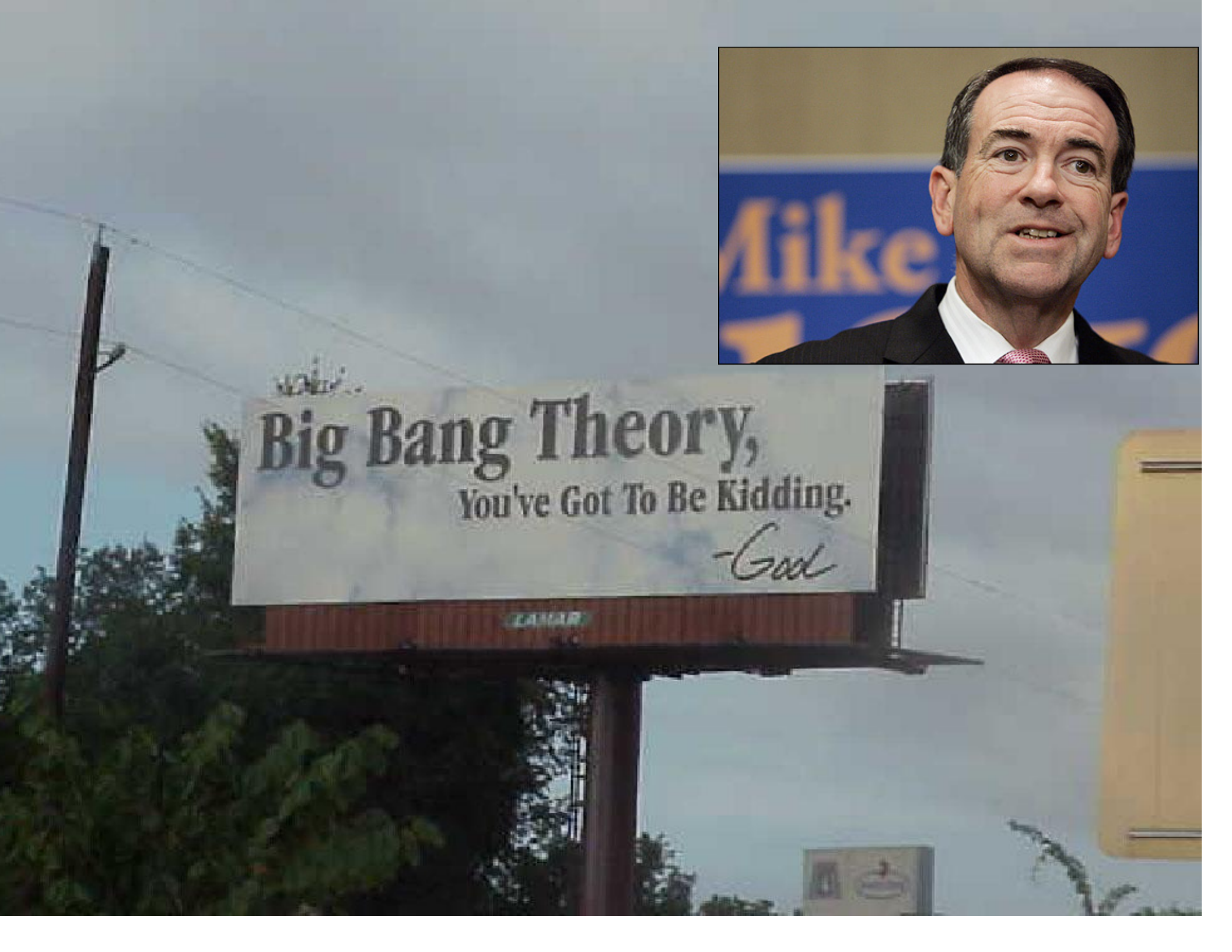


Formation movies

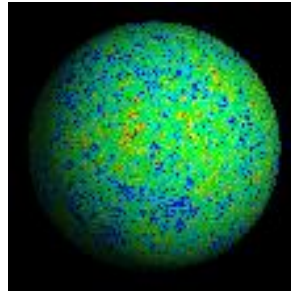


Big Bang Theory,  
You've Got To Be Kidding.  
*-God*

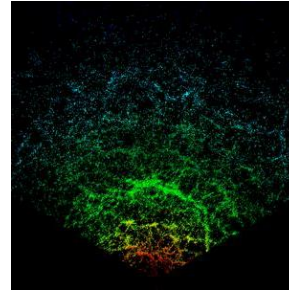
LAMAR



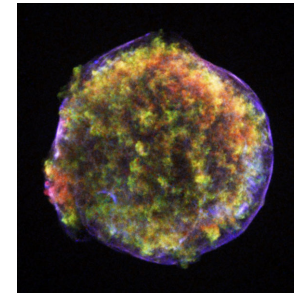
ga



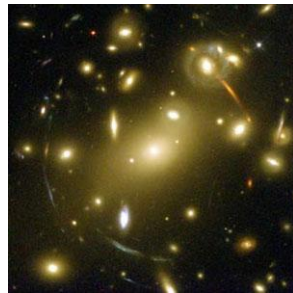
Microwave background



Galaxy surveys

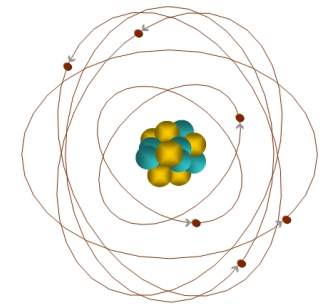


Supernovae Ia



Gravitational lensing

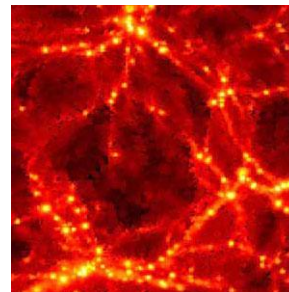
# THE COSMIC SMÖRGÅSBORD



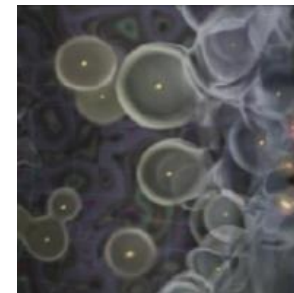
Big Bang nucleosynthesis



Galaxy clusters



Lyman  $\alpha$  forest



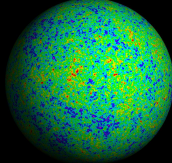
Neutral hydrogen tomography



Max Tegmark  
Dept. of Physics, MIT  
tegmark@mit.edu  
Bright Horizons Cruise  
May 30, 2010



## Evidence for Big Bang:

- Observed galaxy recession (Hubble's law)
- Existence of CMB 
- Correct predictions of big bang nucleosynthesis
- Darkness of night sky! (Olber)
- Distant objects look younger

*Plenty enough bang  
for most people to  
call "big" ...*

## Evidence for *what, exactly?*

Our entire observable universe was once as hot as the core of the Sun, doubling its size in a under a second.

- *Not* evidence for a singularity

# EVIDENCE:

The Universe is  
expanding!

$$v=Hr$$



Alexander  
Friedmann

1888-1925

(Russian; 1922  
paper)



George Lemaître 1894-1936

(Belgian; indep. 1927 paper)



Arthur Geoffrey  
Walker 1909-?

(British; 1935 paper  
with H P Robertson  
showed that **FLRW**  
metric is *only*  
homogeneous &  
isotropic metric)

**MIT PhD!**





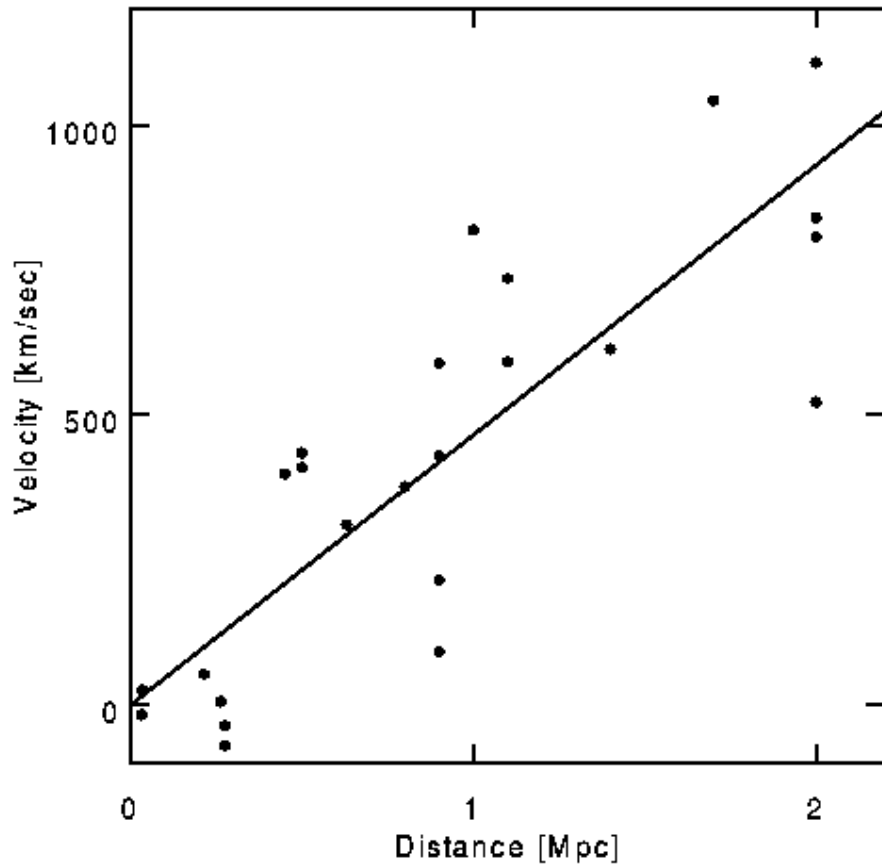
Edwin Hubble 1889-  
(American; 1930 paper)



Mt. Wilson Observatory 1931

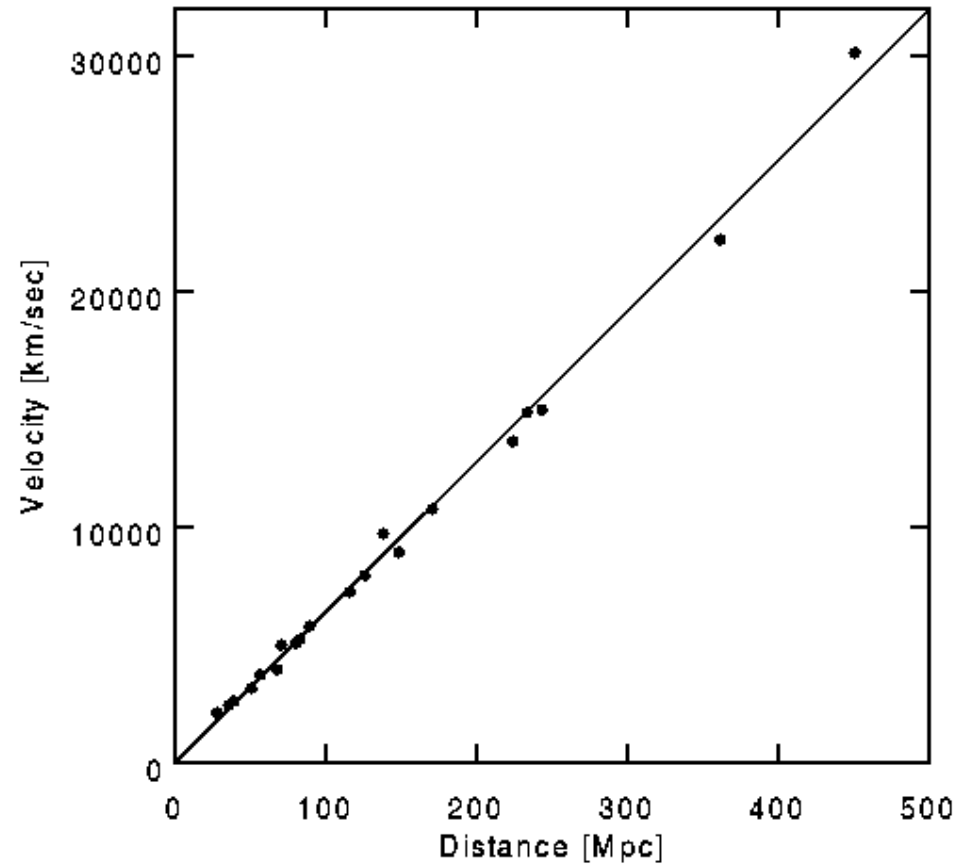
Hubble 1929:

$H \approx 550 \text{ km/s/Mpc}$

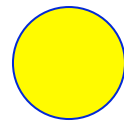


Riess et al 1996:

$H \approx 70 \text{ km/s/Mpc}$

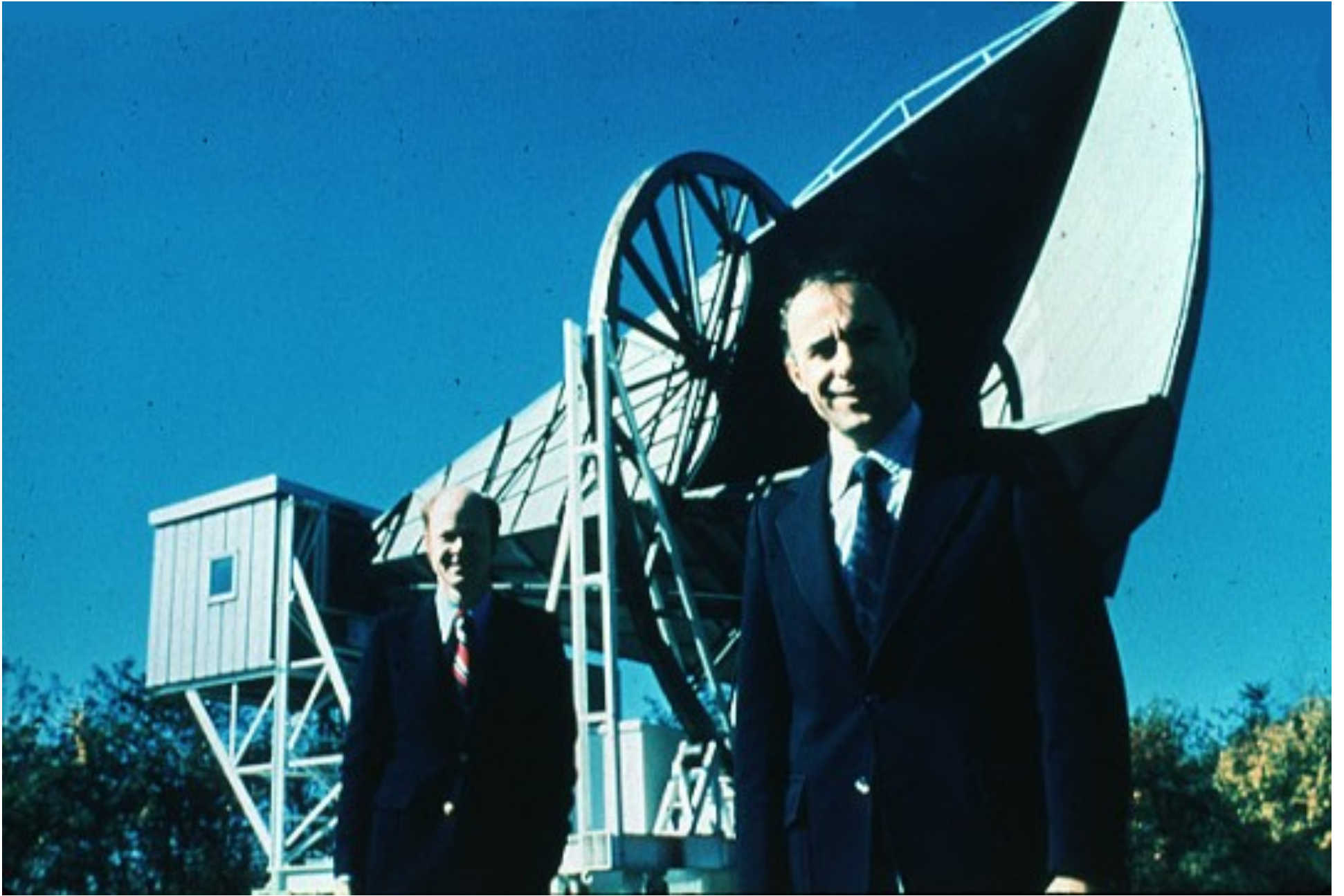


**How measure distance & redshift?**



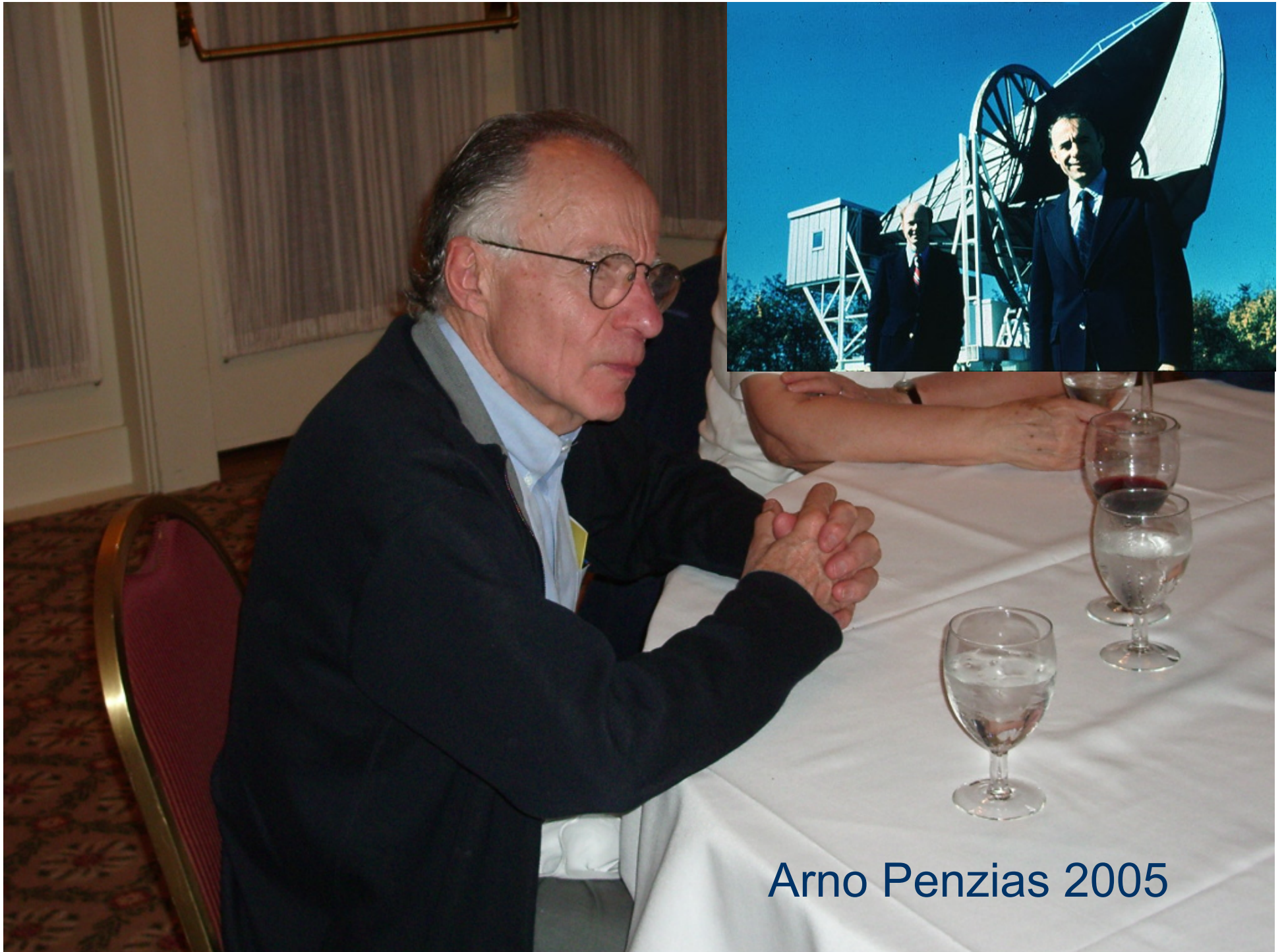
# EVIDENCE:

The Cosmic Microwave  
Background Radiation  
exists

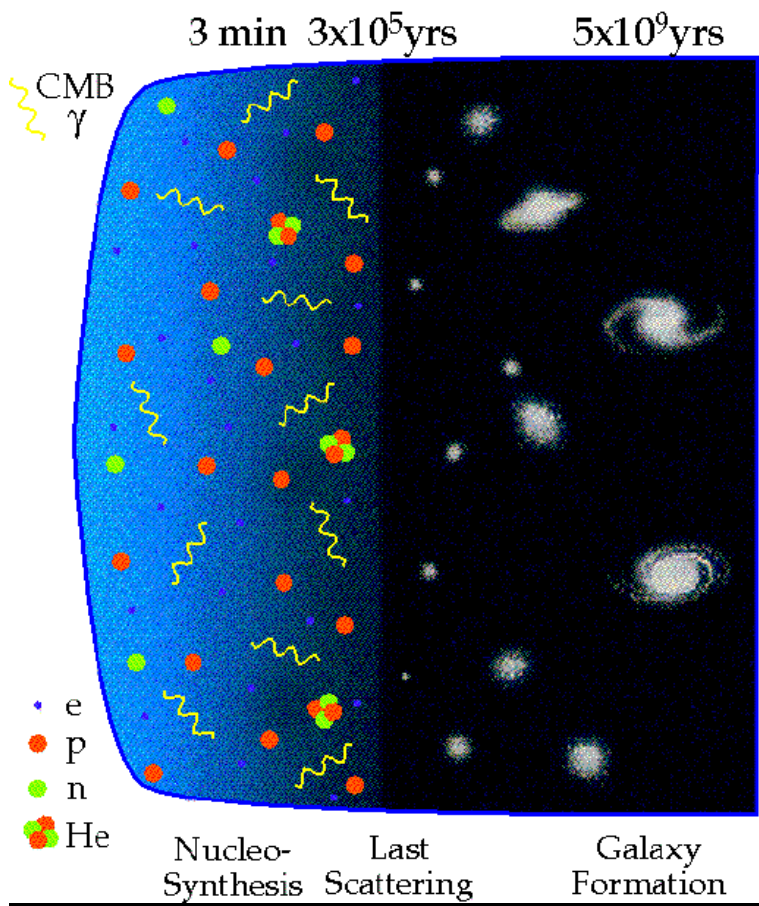


Arno Penzias & Robert Wilson 1965

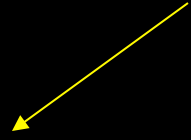




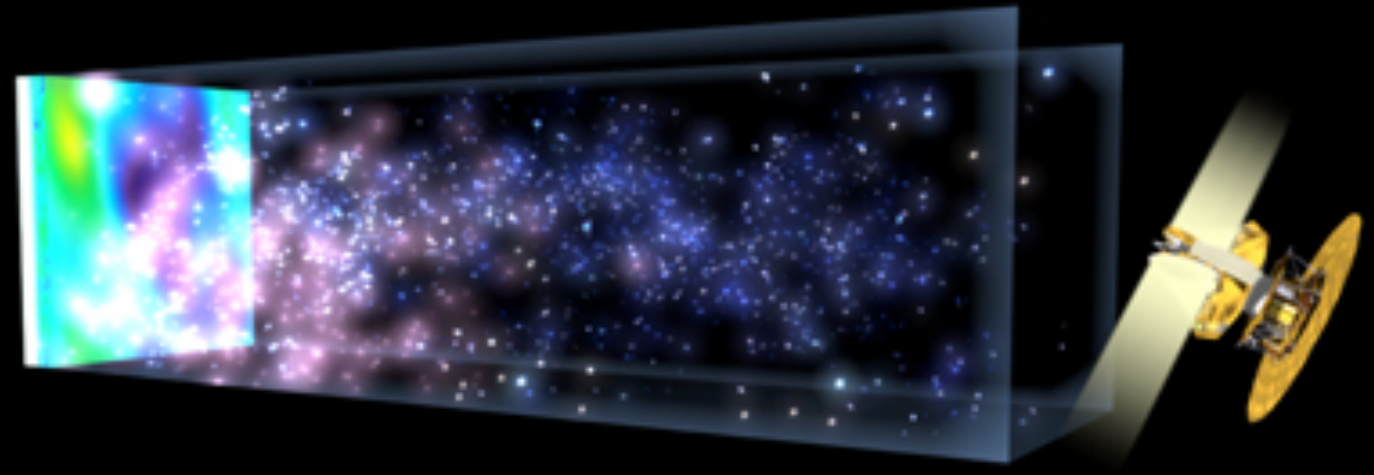
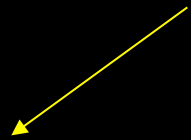
Arno Penzias 2005



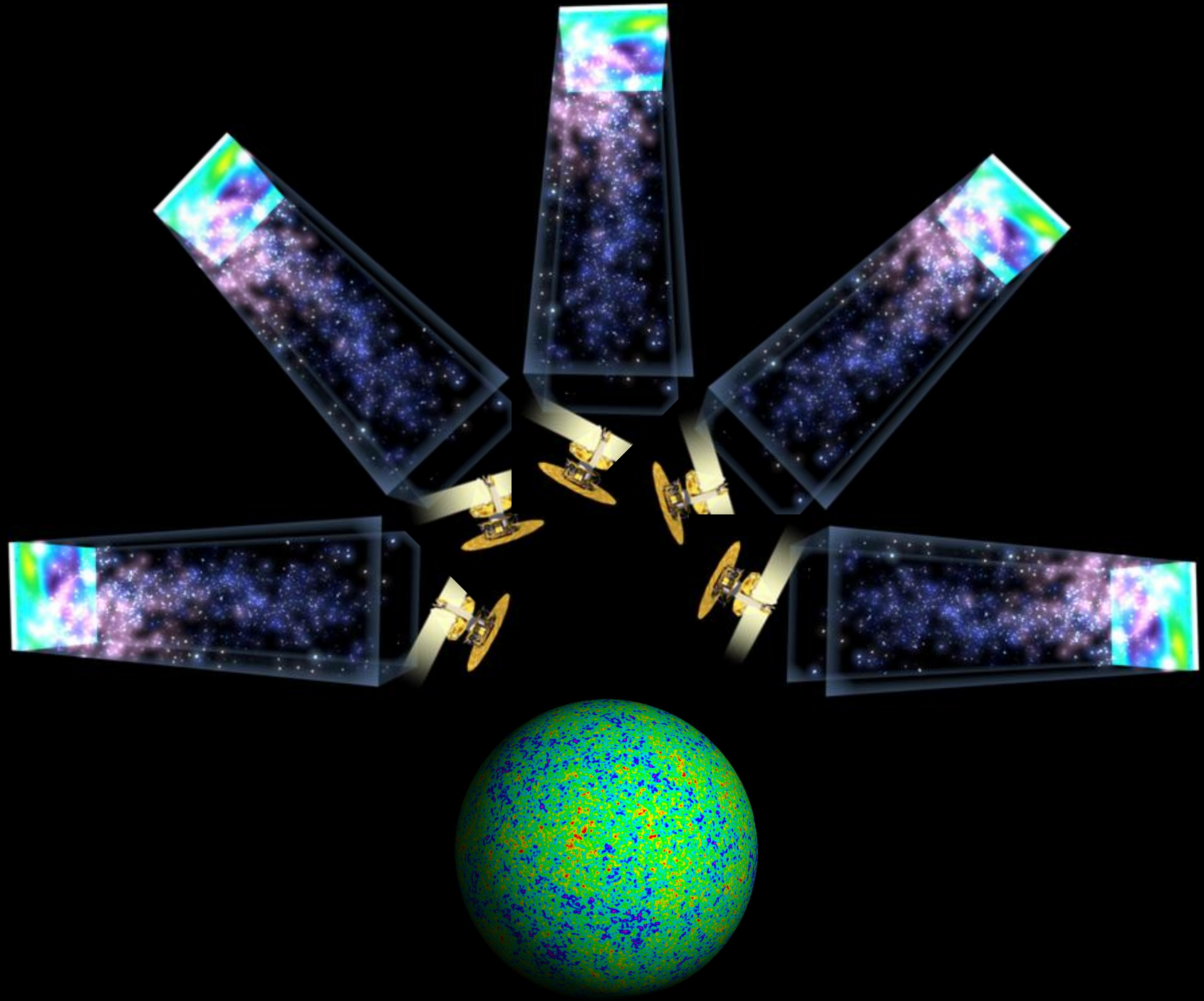
(Figure from Wayne Hu)



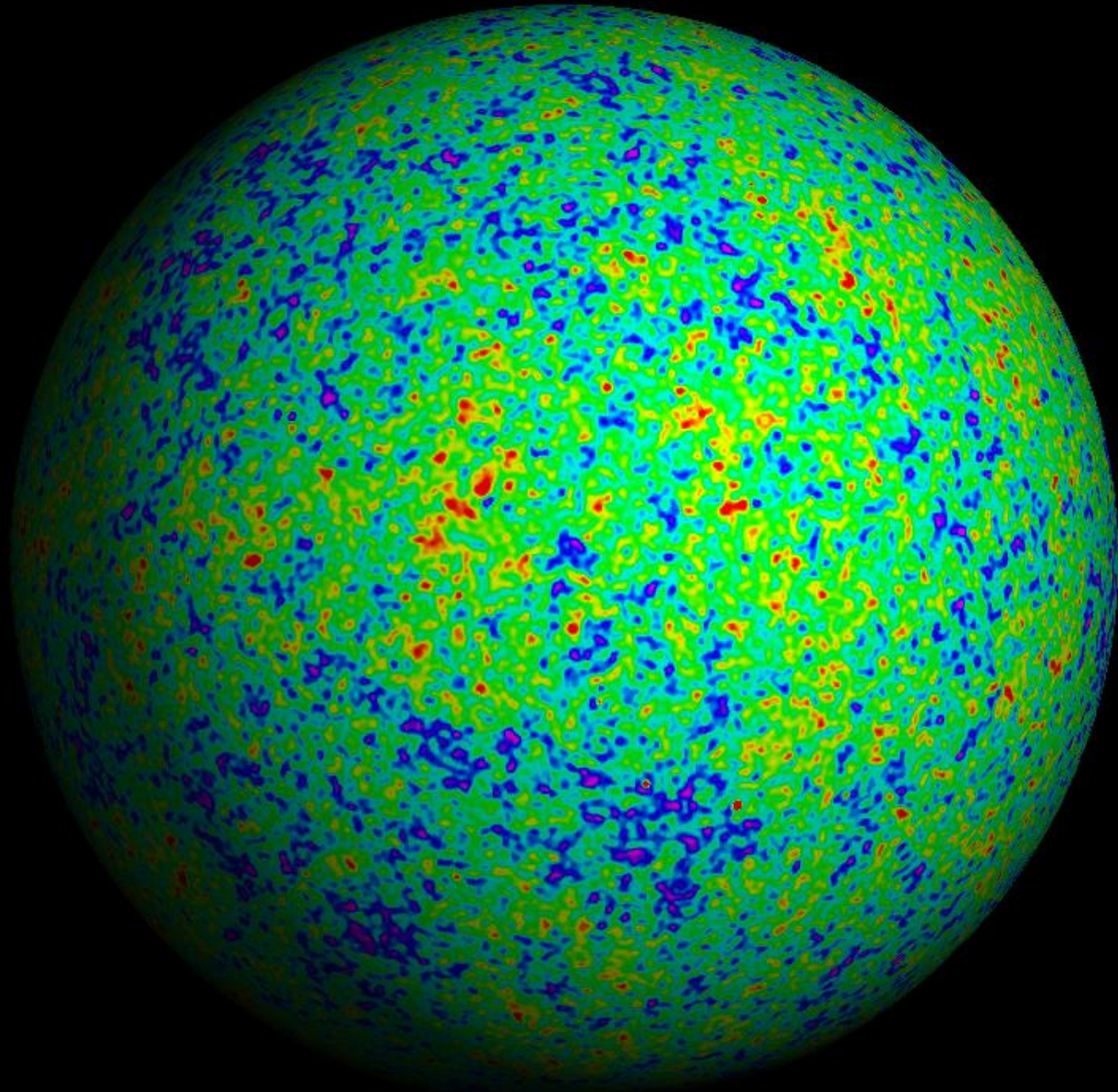
(Figure from WMAP team)

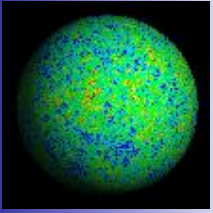


ry



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

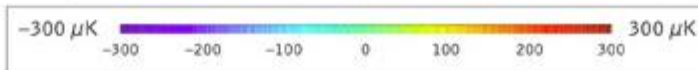
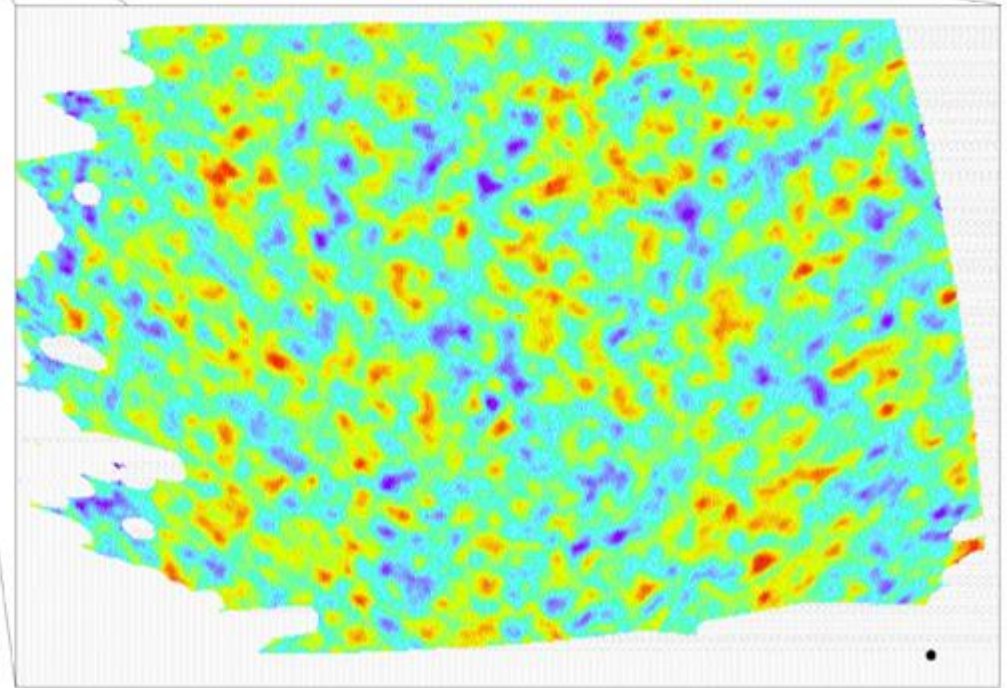
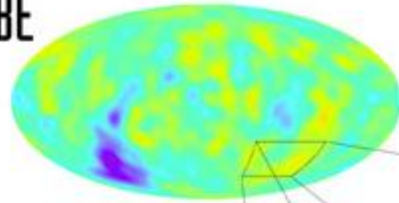




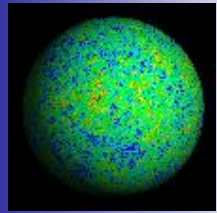
**CMB**

De Bernardis et al 2000, Lange et al 2000

COBE



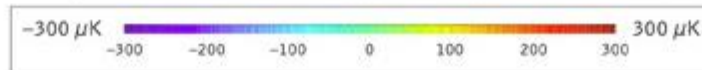
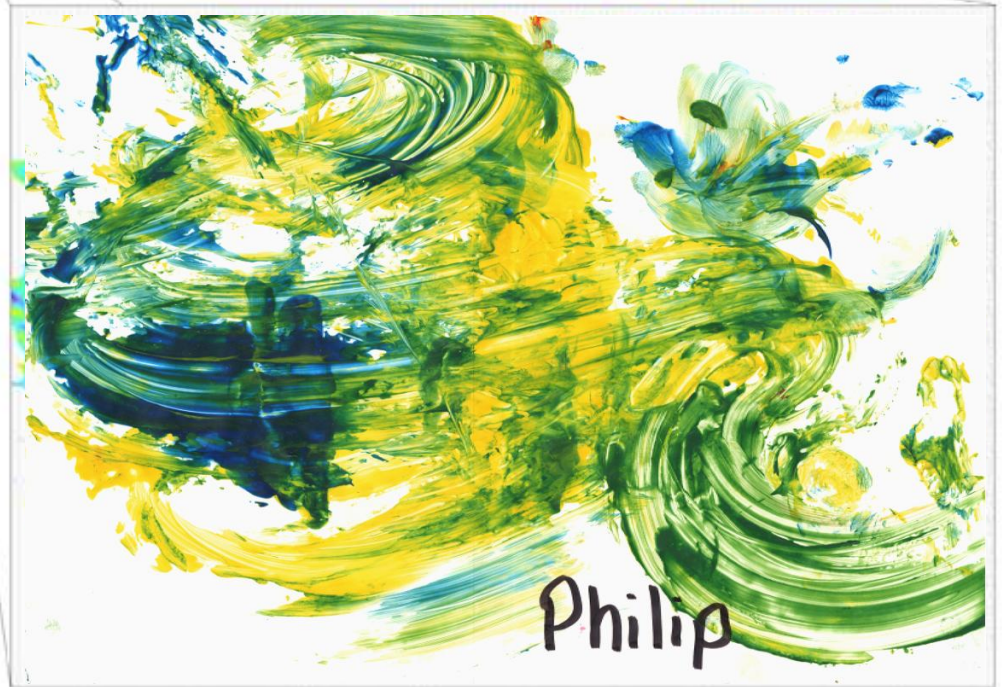
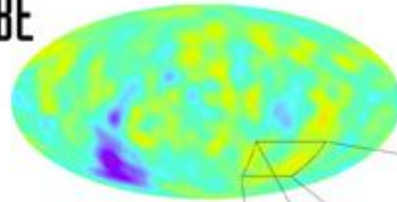
Max Tegmark  
Dept. of Physics, MIT  
tegmark@mit.edu  
Bright Horizons Cruise  
May 30, 2010



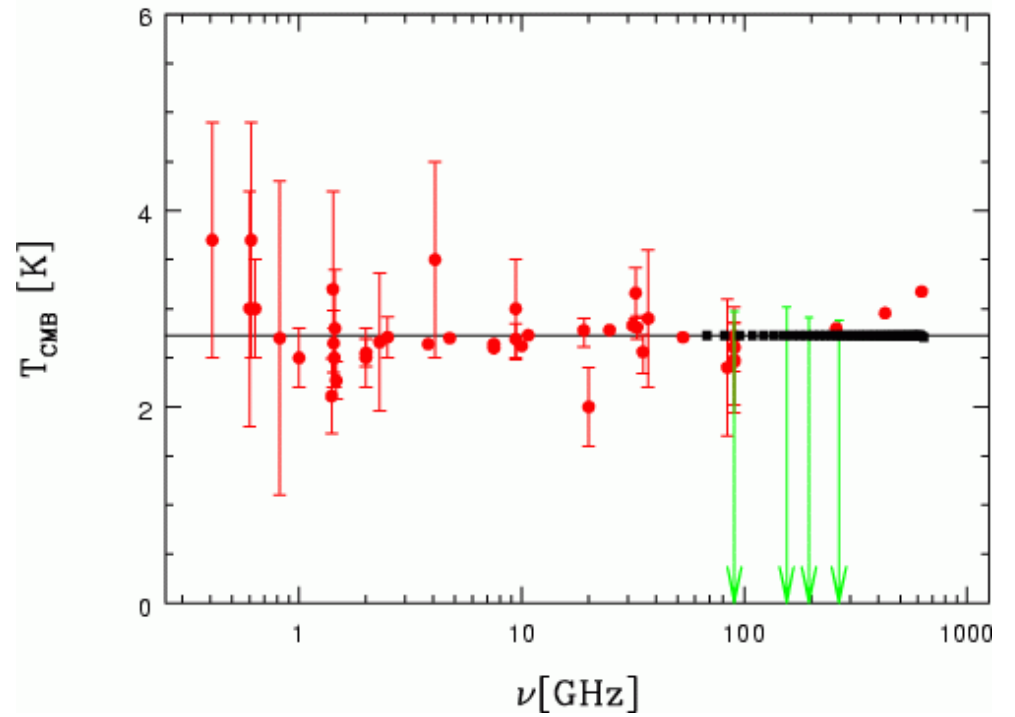
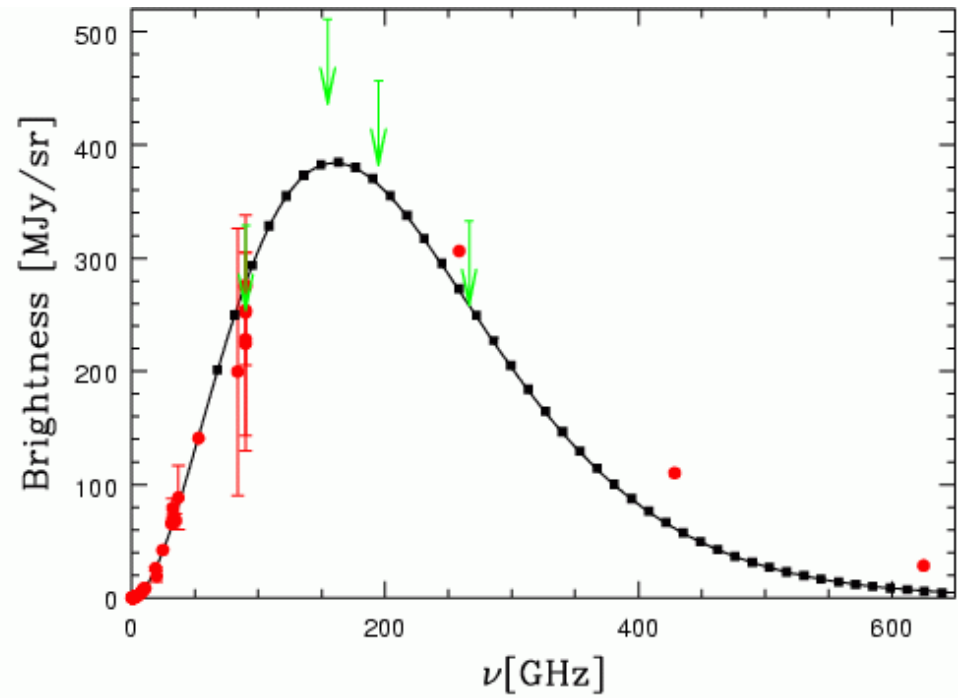
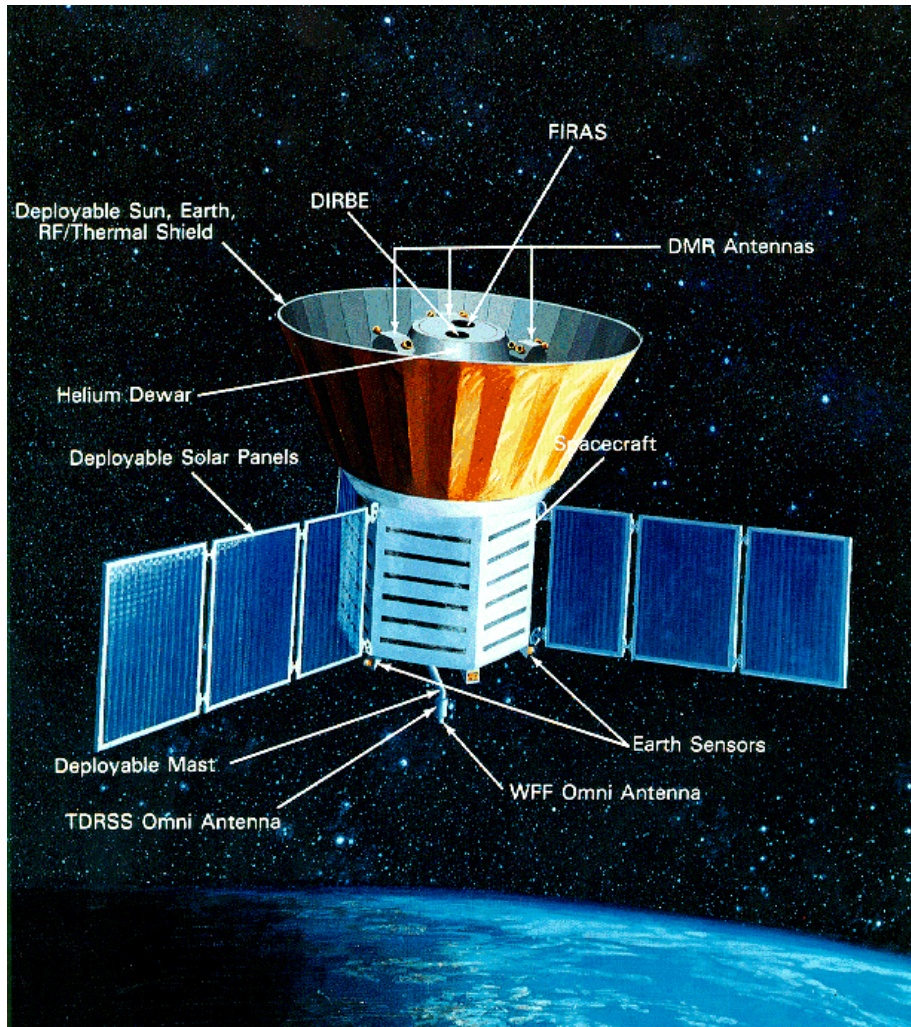
CMB

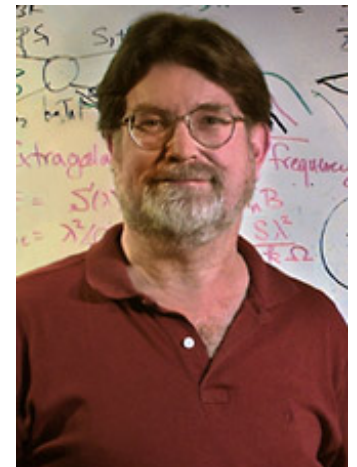
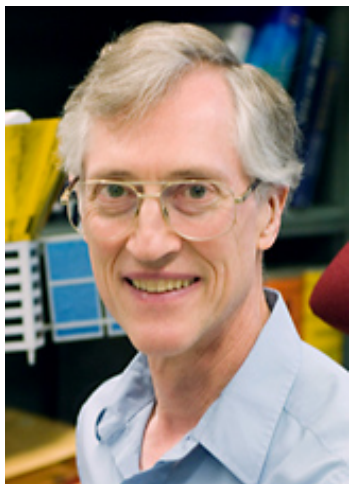
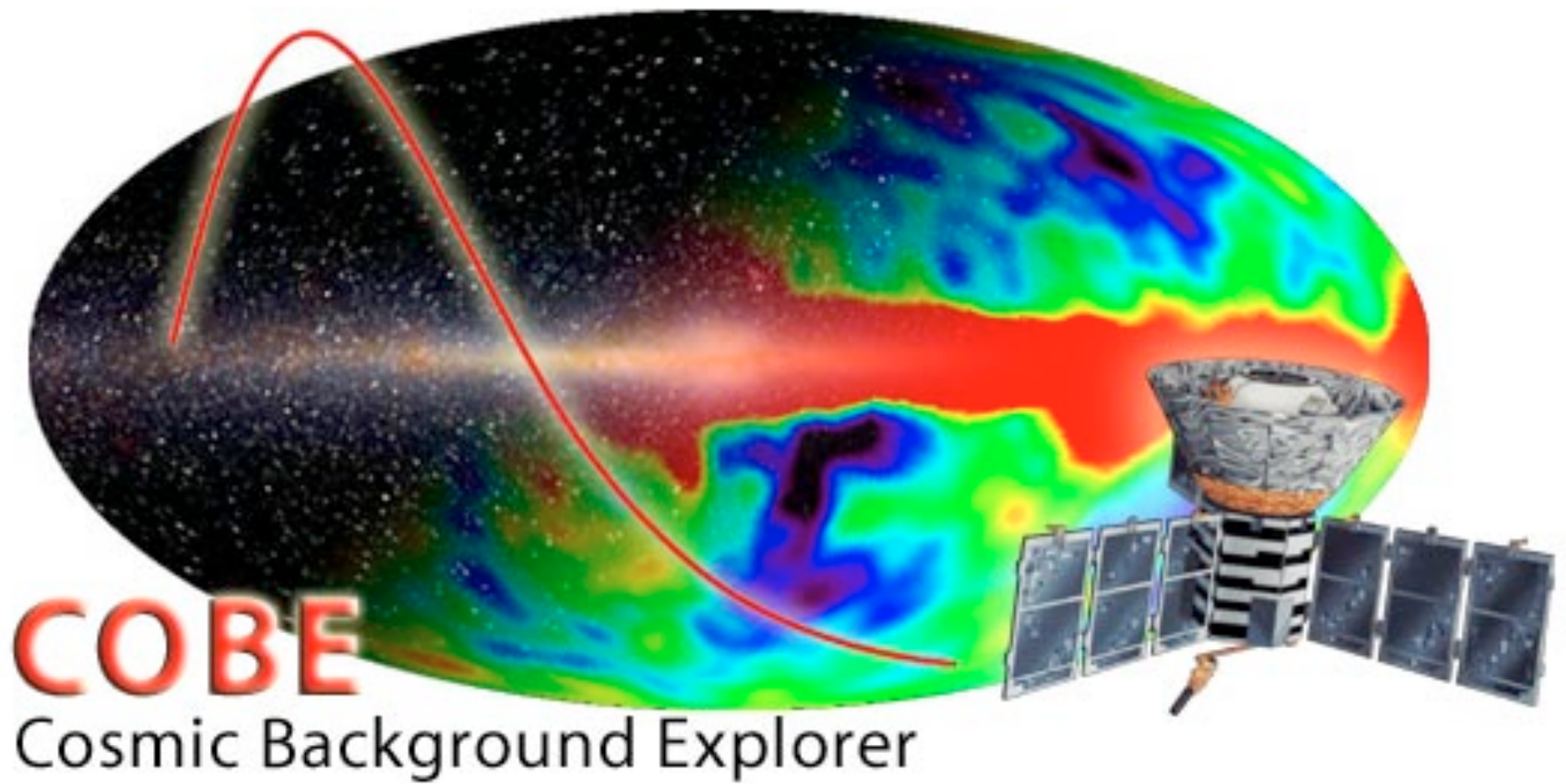
Tegmark, Jr., 2001

COBE



Max Tegmark  
Dept. of Physics, MIT  
tegmark@mit.edu  
Bright Horizons Cruise  
May 30, 2010





Other people associated with MIT who worked on COBE:  
**Chuck Bennett, Ed Cheng, Steve Meyer, Rai Weiss & Ned Wright**