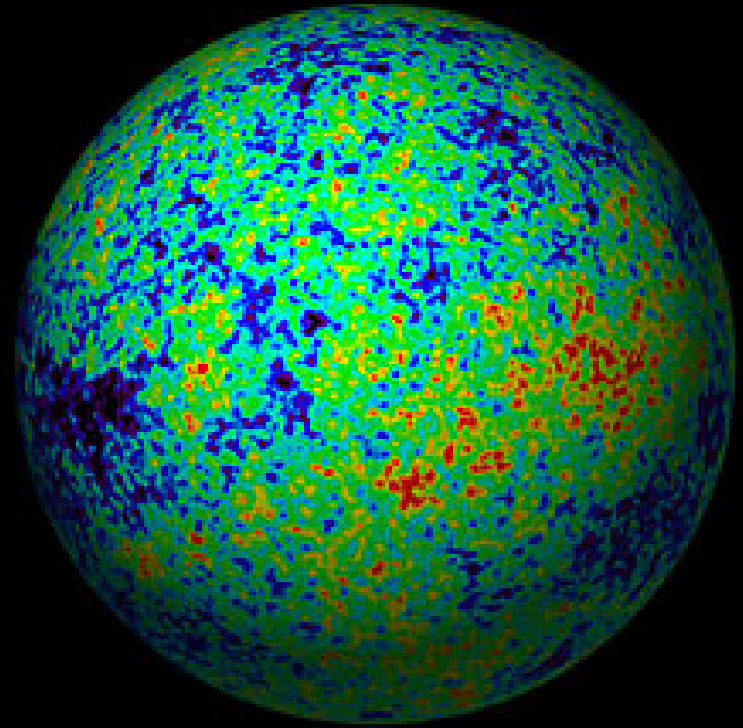


Galaxy Forum Canada  
July 26, 2008

# Our universe today

&



# tomorrow

Levon Pogossian

Simon Fraser University



# the universe

experienced a period of **Inflation**

which left it nearly **flat and uniform**

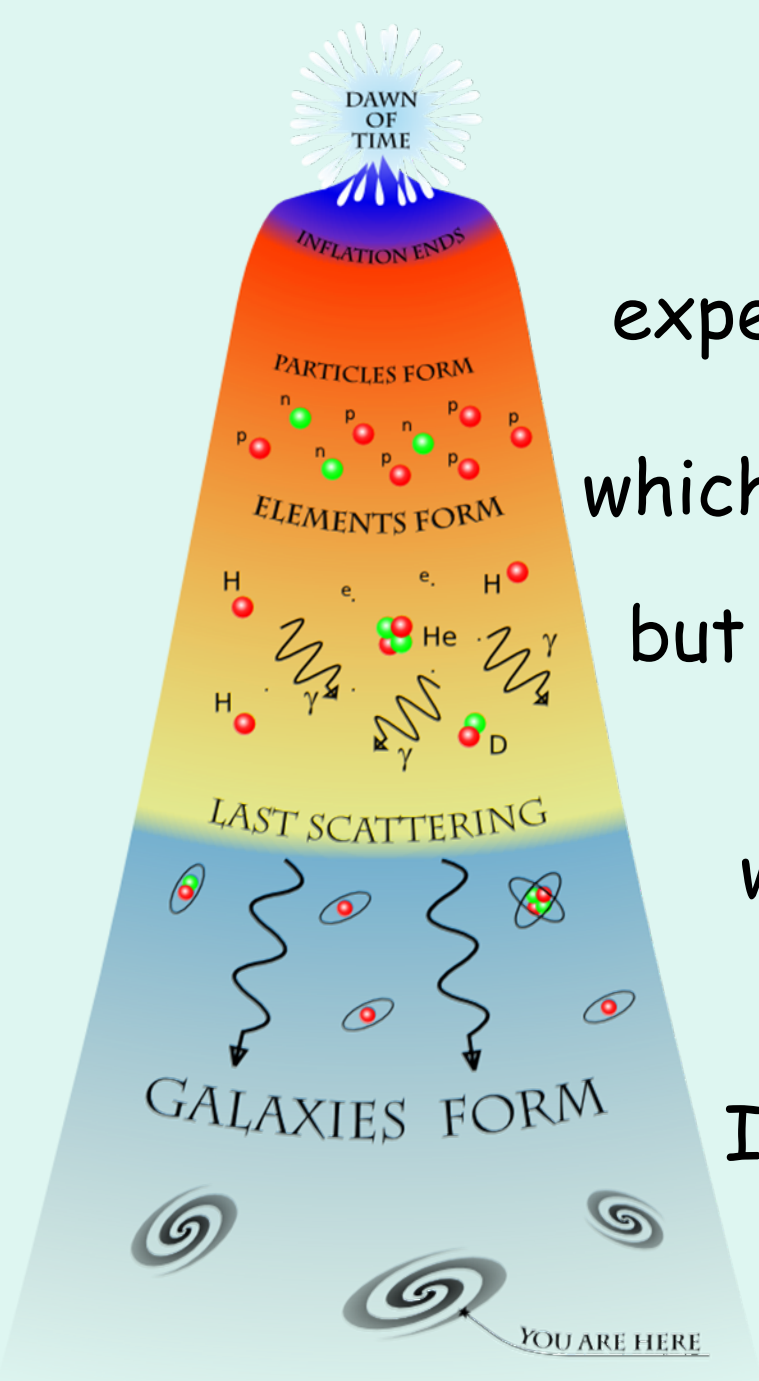
but with **tiny ripples**

that later **seeded galaxies**

which works if **most** of  
the **matter is Dark.**

It recently began **accelerating**

because of **Dark Energy**



# Expansion

QuickTime™ and a  
YUV420 codec decompressor  
are needed to see this picture.

# The universe is expanding



*Edwin Hubble 1889-1953*

PETER

1.21

4b) Expand

~~$x^2 + x - 2$~~

$$(a+b)^n$$

*Very  
young, Peter.*

$$= (a + b)^n$$

$$= (a + b)^n$$

$$= (a + b)^n$$

~~etc...~~

# Consequences of expansion

The universe was denser

which means hotter

which means high energy collisions

which destroy galaxies

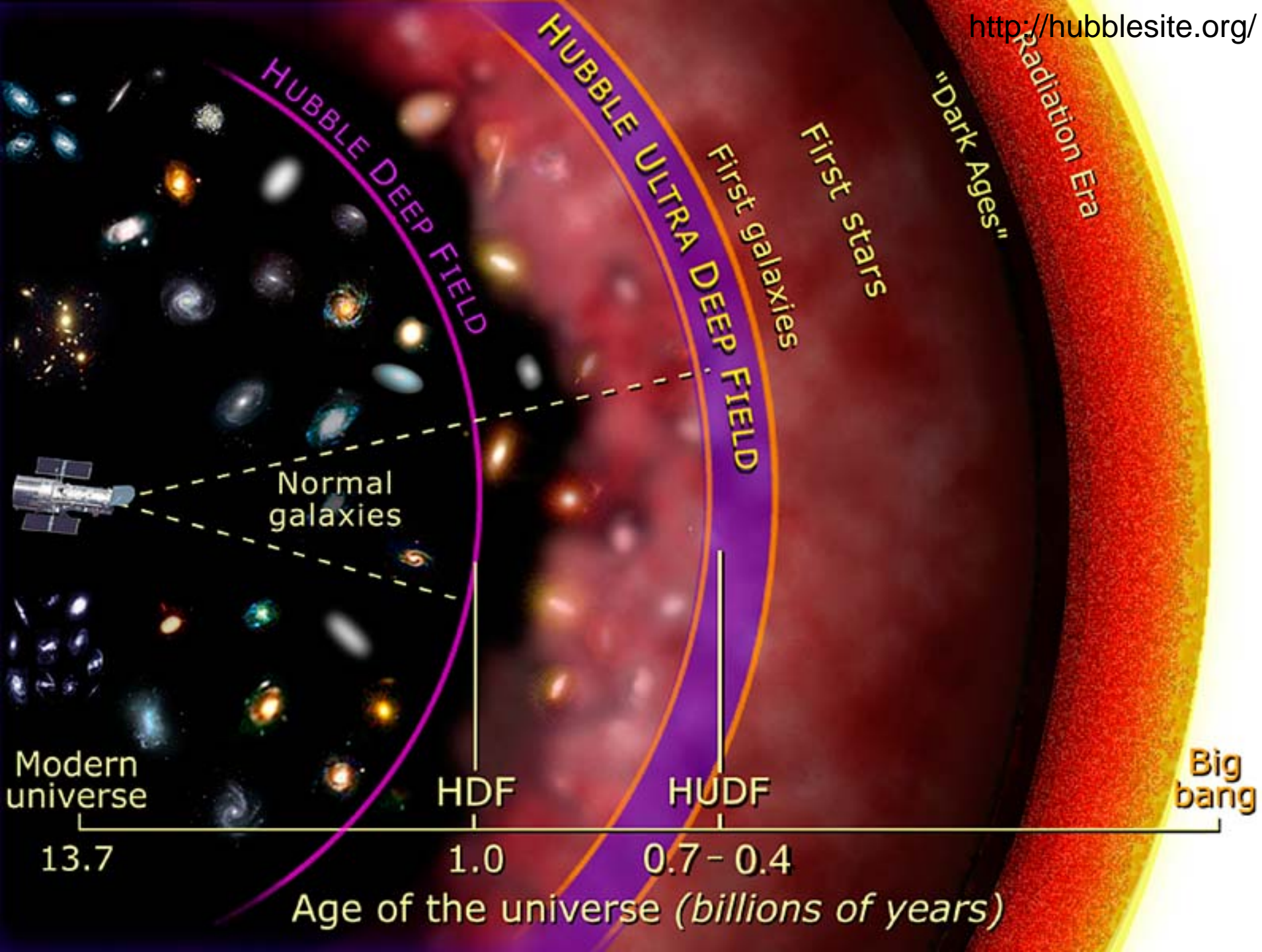
and stars

then atoms...

then nuclei...

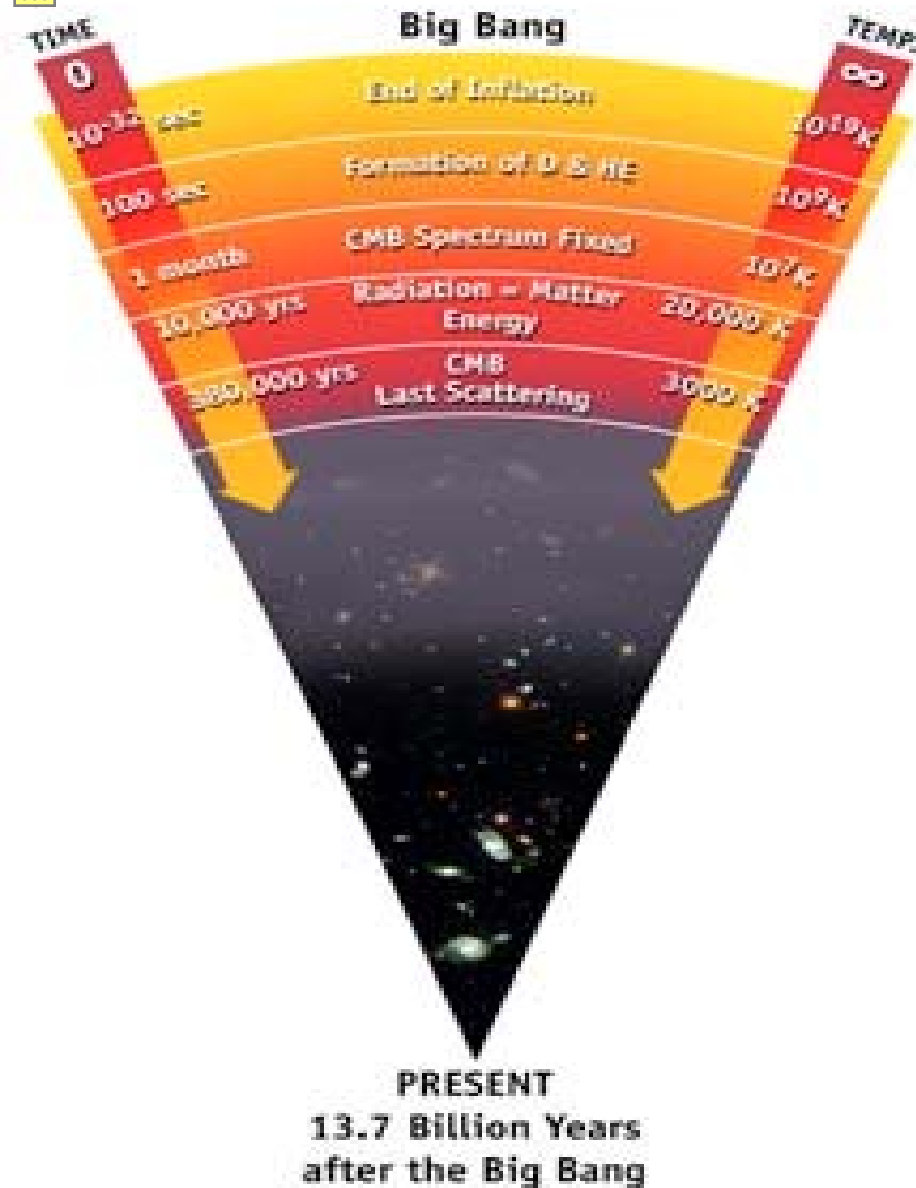
Is it possible to see?

Looking **deep** into space  
=  
looking **back** in time





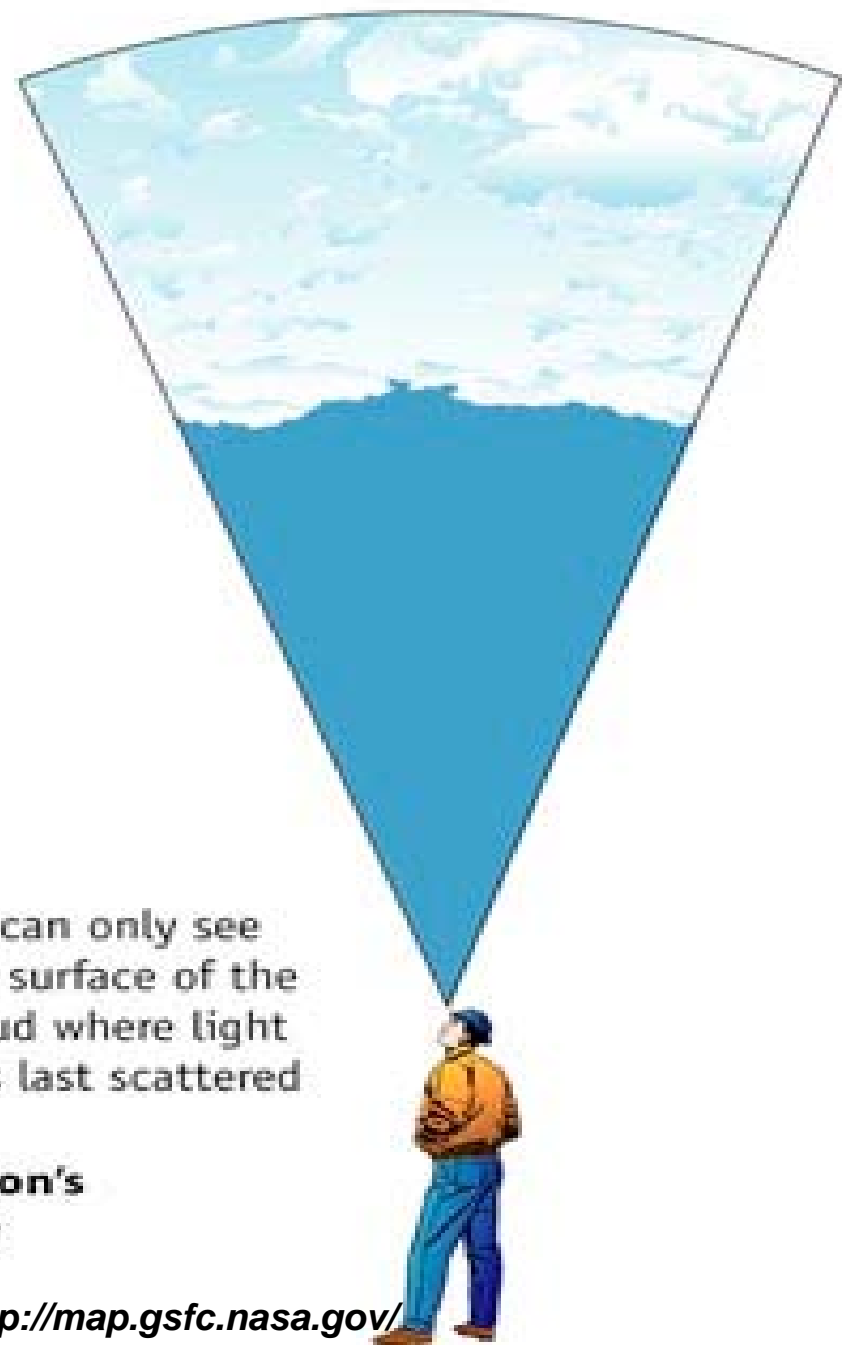
# How far back can we see?



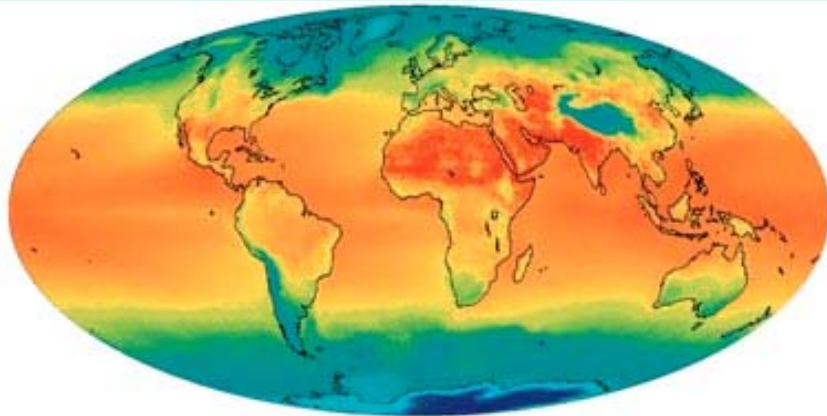
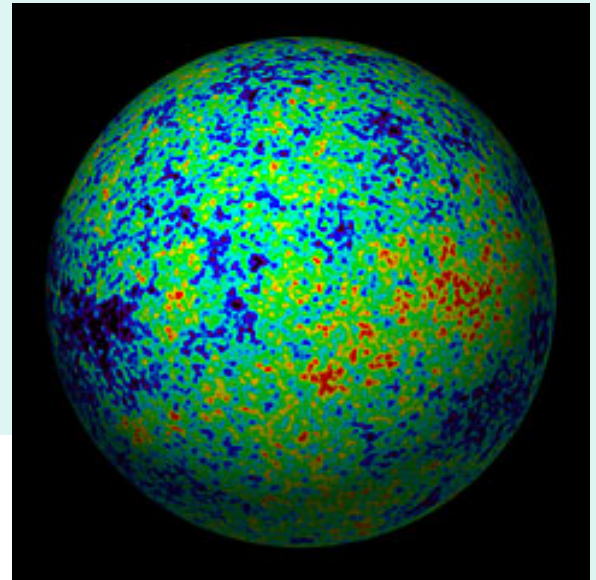
The cosmic microwave background Radiation's "surface of last scatter" is analogous to the light coming through the clouds to our eye on a cloudy day.

We can only see the surface of the cloud where light was last scattered

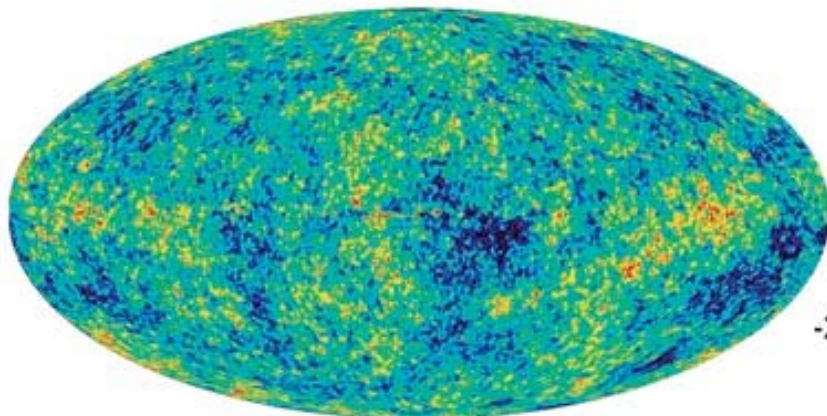
<http://map.gsfc.nasa.gov/>



# The map



Earth  
Temperatures



Microwave Sky  
Temperatures

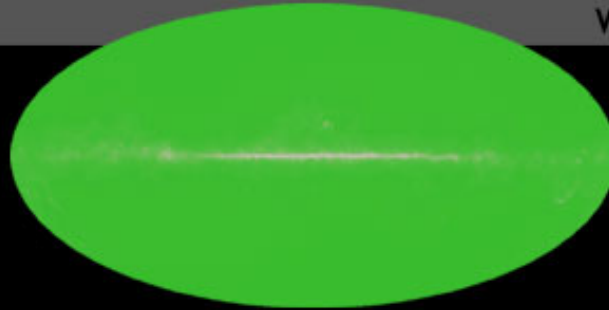


# Evolution of the map

1965



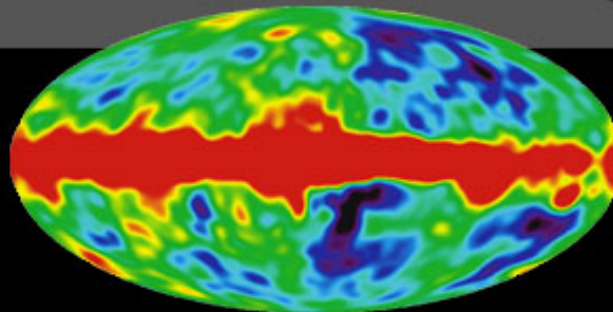
Penzias and  
Wilson



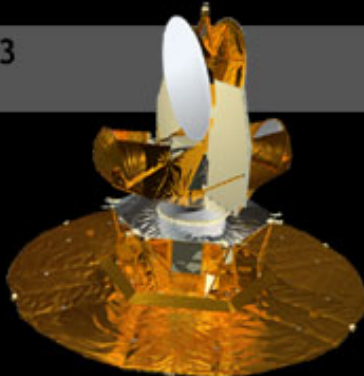
1992



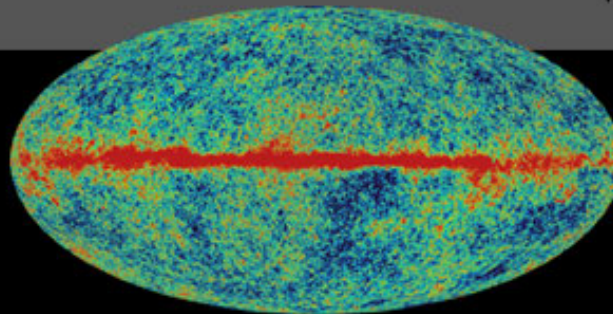
COBE



2003

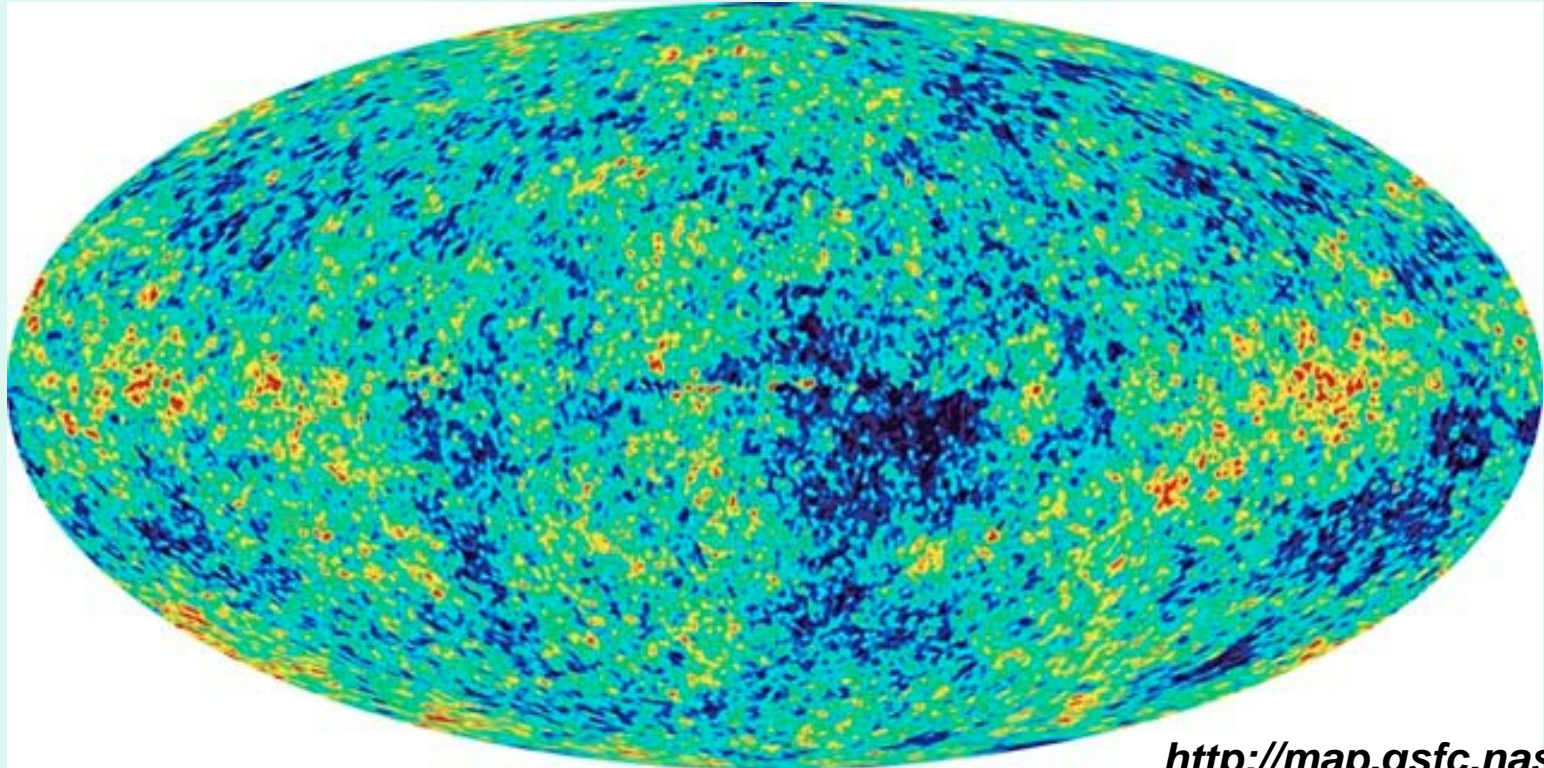


WMAP



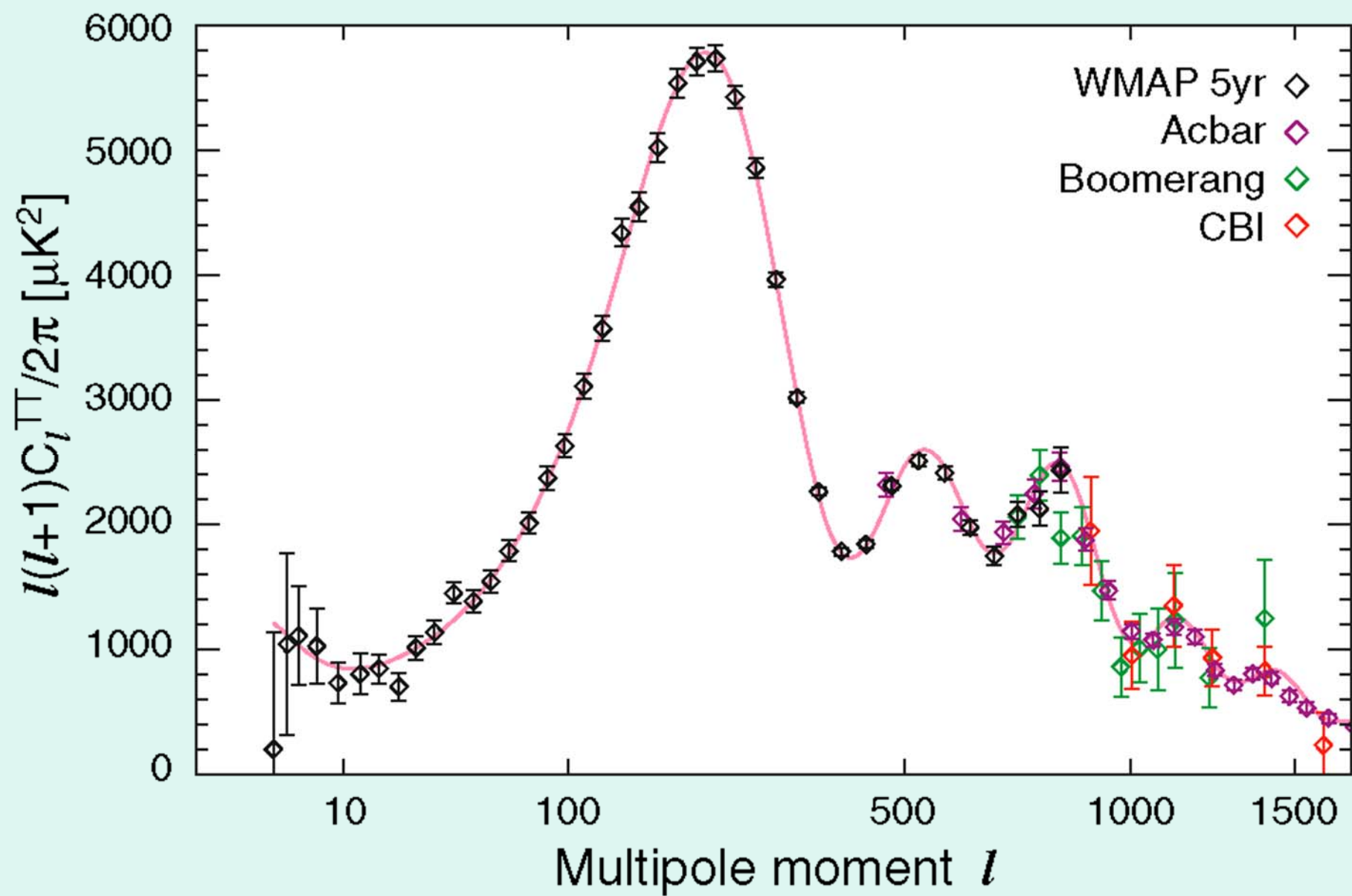


# Universe, baby album, page 1: ( 400,000 years of age)



<http://map.gsfc.nasa.gov/>

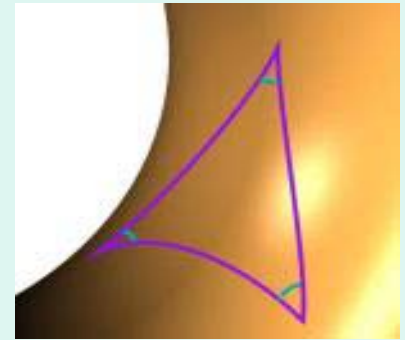
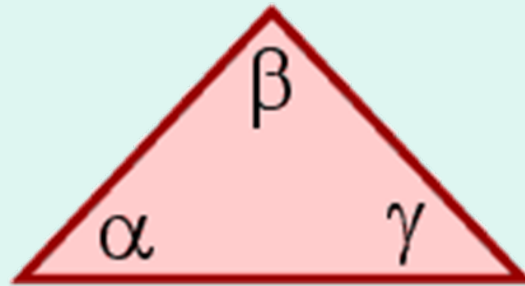
Contains imprints of what happened before and after



# Predictions of Inflation

✓ 1. Nearly uniform density

✓ 2. Flat space-time



✓ 3. “Adiabatic”, scale-invariant ripples

4. Gravitational wave background

the tiny ripples grow to form galaxies  
onal Instability

QuickTime™ and a  
Sorenson Video decompressor  
are needed to see this picture.

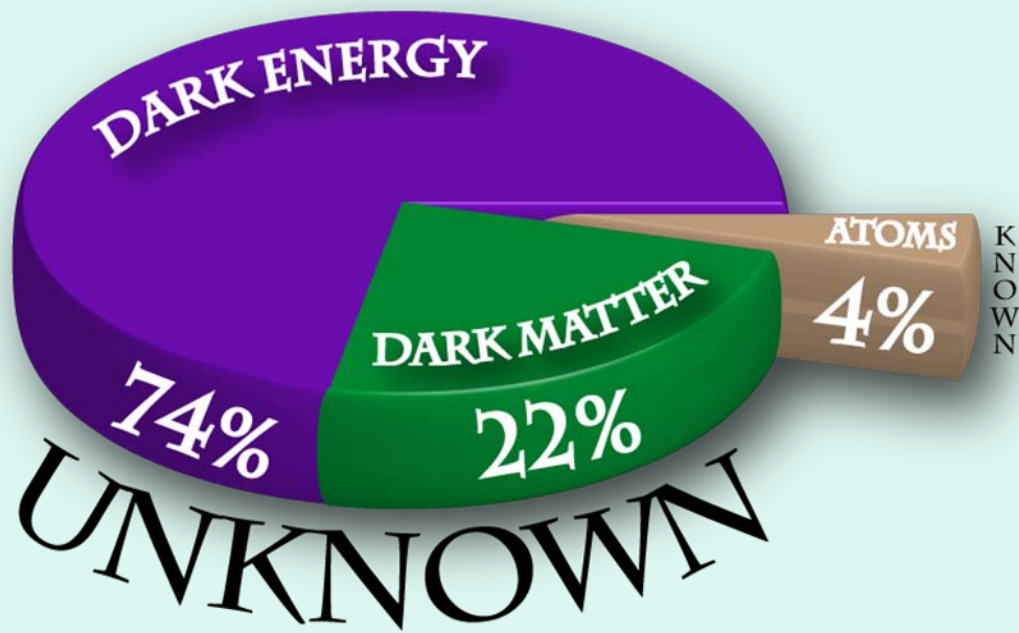
Need dark matter

But does it **really** exist?

QuickTime™ and a  
YUV420 codec decompressor  
are needed to see this picture.



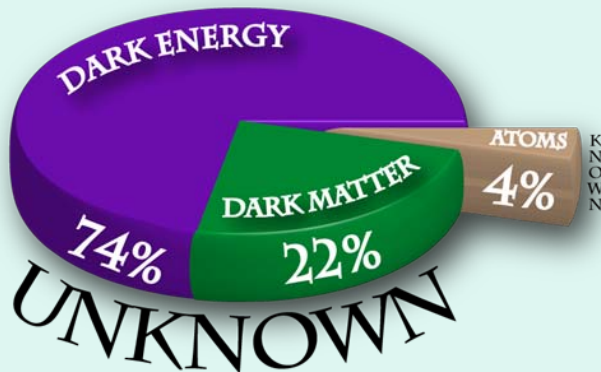
Chandra, VLT, Hubble, Magellan, 2006



**Who ordered this?**

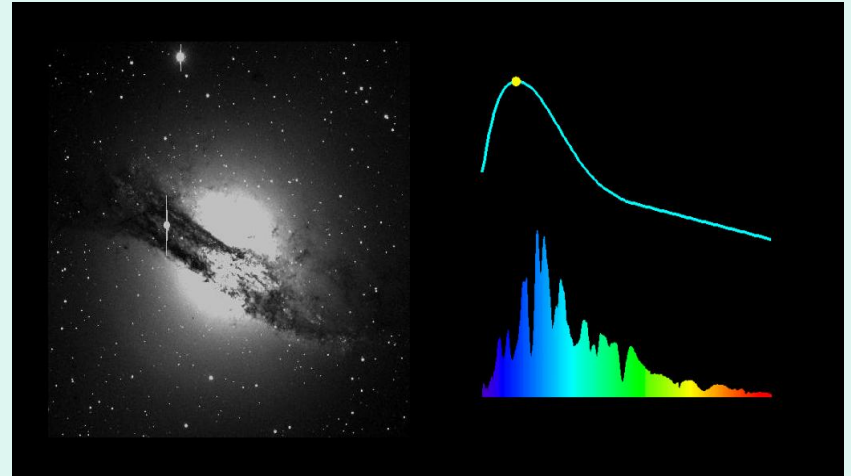
# Why Dark Energy?

Stars older than universe

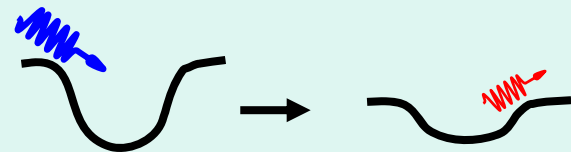


Budget deficit

## Supernovae



<http://www-supernova.lbl.gov>



The ISW effect

$\Lambda$  ?

Quintessence?

Modified gravity?

Extra dimensions?



## Cosmology today:

overwhelming evidence for  
Inflation, Dark Matter, Dark Energy

## Big questions for tomorrow:

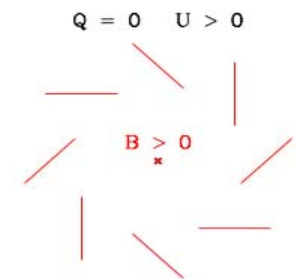
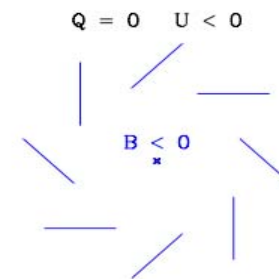
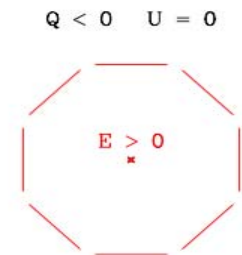
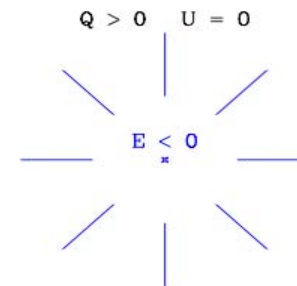
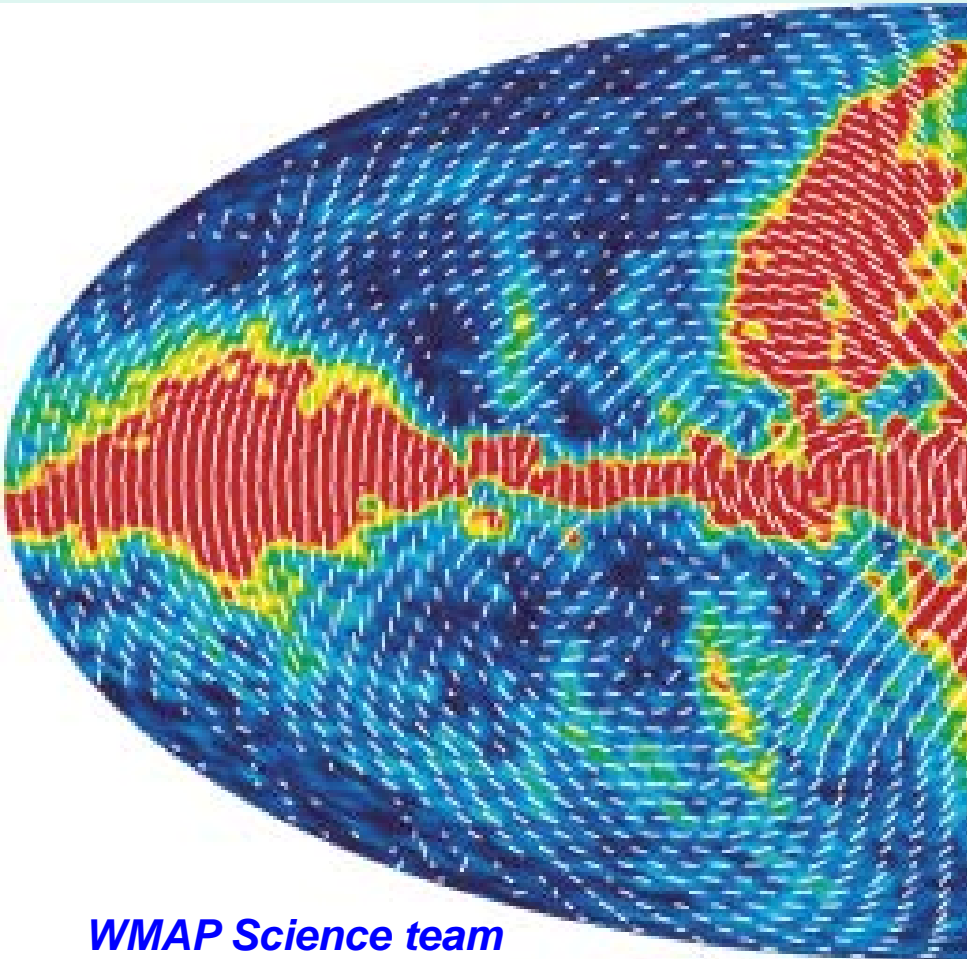
Which model of Inflation?

What is Dark Matter?

What is Dark Energy?

Does General Relativity work on cosmological scales?

# Gravity waves from Inflation: CMB polarization

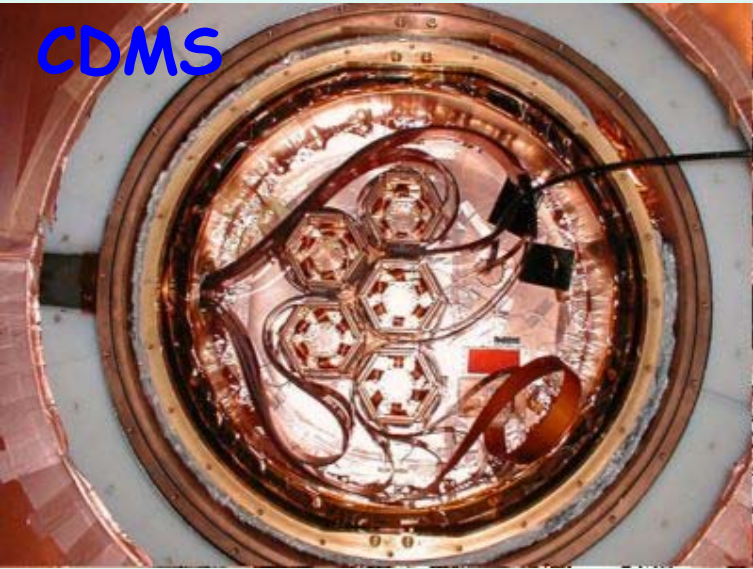


By M. Zaldarriaga

What is Dark Matter?

What is Dark Energy?

CDMS

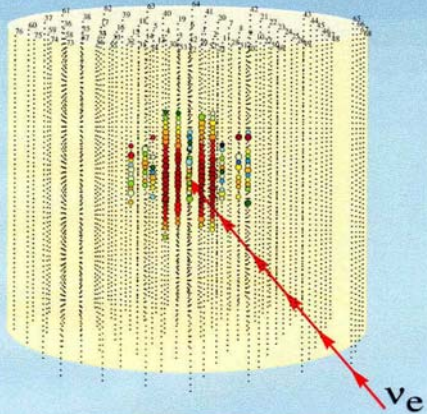


LHC



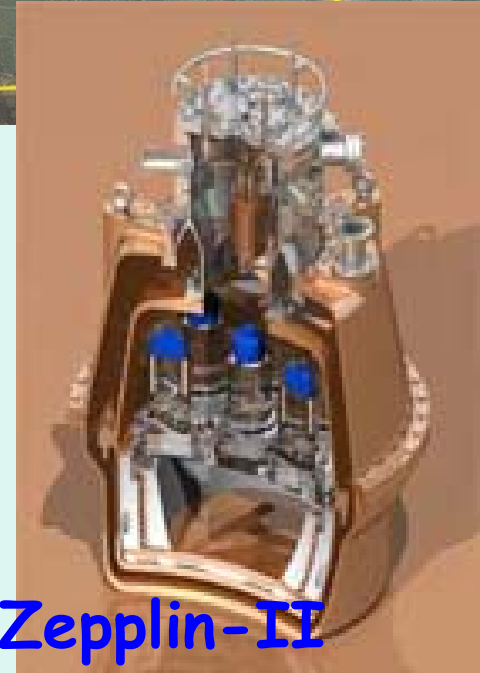
IceCube

1000m



Direct search for  
Dark Matter particles

Zepplin-II





# Tracking the evolution of cosmic structures



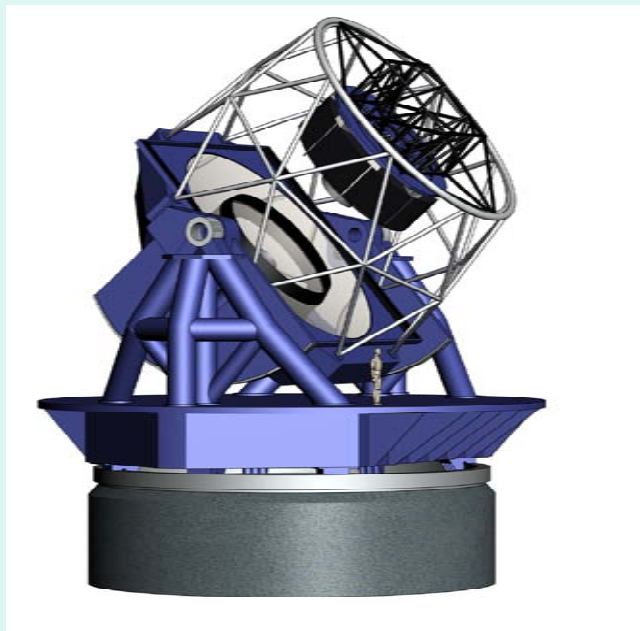
<http://snap.lbl.gov/>

**SNAP 2014 (?)**

16 redshift bins

~ 3000 S<sub>ne</sub>

$z_{\text{max}}=1.7$



**LSST, 2014 (?)**

10 photometric redshift bins

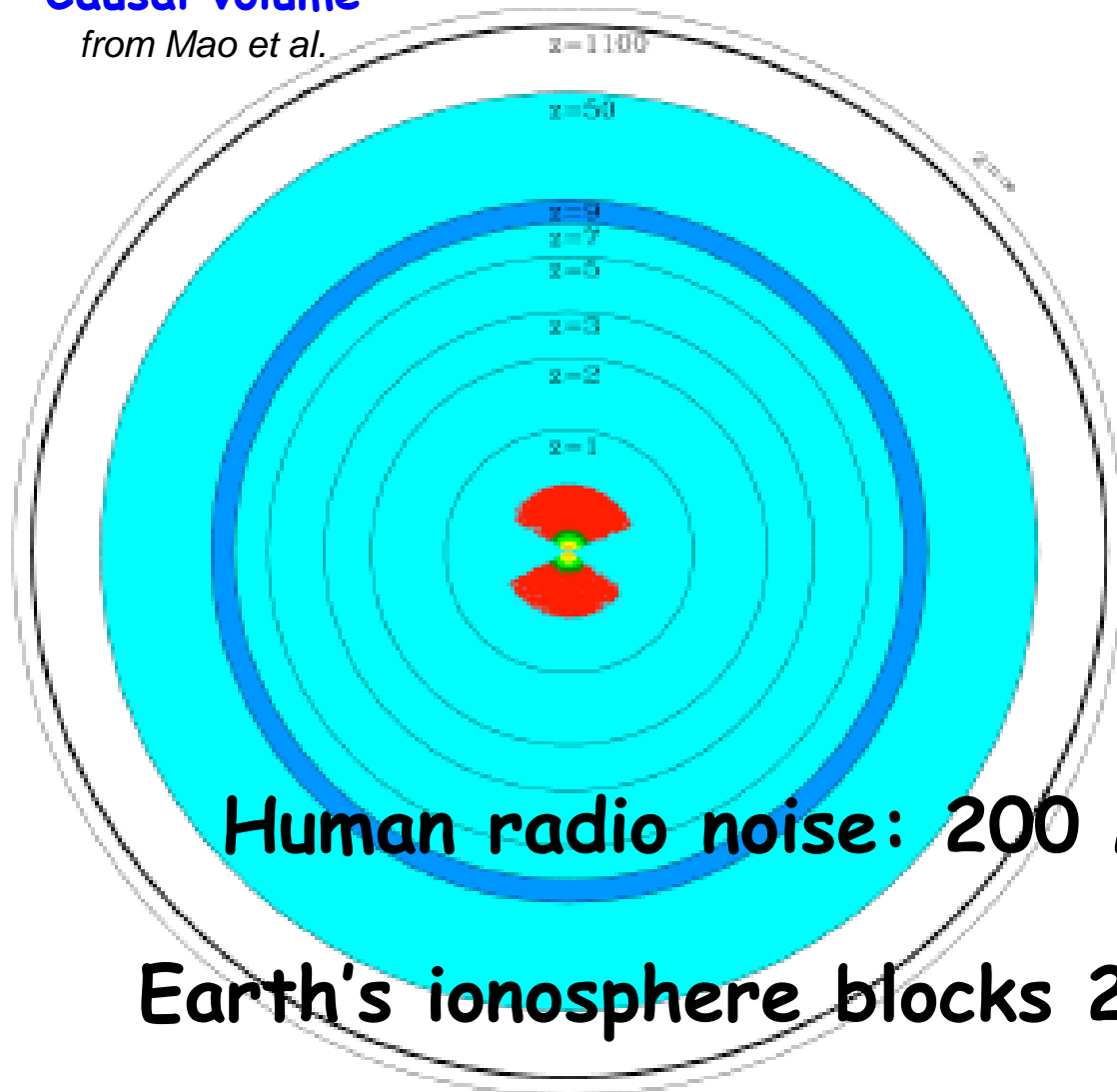
10 billion galaxies

$z_{\text{max}}=3$

# Mapping Dark Ages with 21 cm surveys

Causal volume

*from Mao et al.*



21cm: 1420 MHz

at  $z=10$ : 129 MHz

at  $z=100$ : 14 MHz

Human radio noise: 200 MHz and lower

Earth's ionosphere blocks 20 MHz and lower

# 宇宙第一缕曙光探测

## 21 Centimeter Array (21CMA): Search For The First Light Of The Universe

Detection of 21 cm emission/absorption signatures of neutral hydrogen at  $z=6-50$  against cosmic microwave background will provide a unique tool for study of formation of first stars/QSOs in the universe, for understanding of reionization histories and for mapping of 3D matter distribution at high redshifts. We are building huge array of 10160 2-meter log periodic antennas for measurement of the 21 cm mission from reionization epoch. The array, 21CMA, consisting of 80 pods with a baseline of 3 km, allows us to reach an angular resolution of 4 arcmin and a sensitivity of about 1 mK per day. 1/4 of the array has been set up in Xinjiang, west China and starts to collect the weak 21 cm background signals.



# MIT to lead development of new telescopes on moon

David Chandler, MIT News Office  
February 15, 2008

NASA has selected a proposal by an MIT-led team to develop plans for an array of radio telescopes on the far side of the moon that would probe the earliest formation of the basic structures of the universe. The agency announced the selection and 18 others related to future observatories on Friday, Feb. 15.

The new MIT telescopes would explore one of the greatest unknown realms of astronomy, the so-called "Dark Ages" near the beginning of the universe when stars, star clusters and galaxies first came into existence. This period of roughly a billion years, beginning shortly after the Big Bang, closely followed the time when cosmic background radiation, which has been mapped using satellites, filled all of space. Learning about this unobserved era is considered essential to filling in our understanding of how the earliest structures in the universe came into being.

The Lunar Array for Radio Cosmology (LARC) project is headed by Jacqueline Hewitt, a professor of physics and director of MIT's Kavli Institute for Astrophysics and Space Science. LARC includes nine other

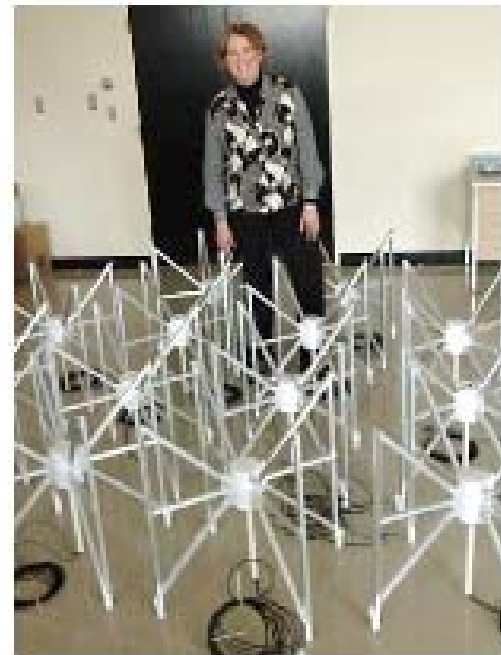


Photo / Donna Coveney

Physics professor Jacqueline Hewitt, director of MIT's Kavli Institute for Astrophysics and Space Science, stands behind a prototype of a radio telescope array. A team she leads has been chosen by NASA to develop plans for such an array on the far side of the moon. [Enlarge image](#)

# Summary

## Today:

a working cosmological model  
supported by precise data

several puzzles and strategies  
for addressing them with future experiments

## Tomorrow:

Gravitational wave studies

3D map of the entire universe

The moon?