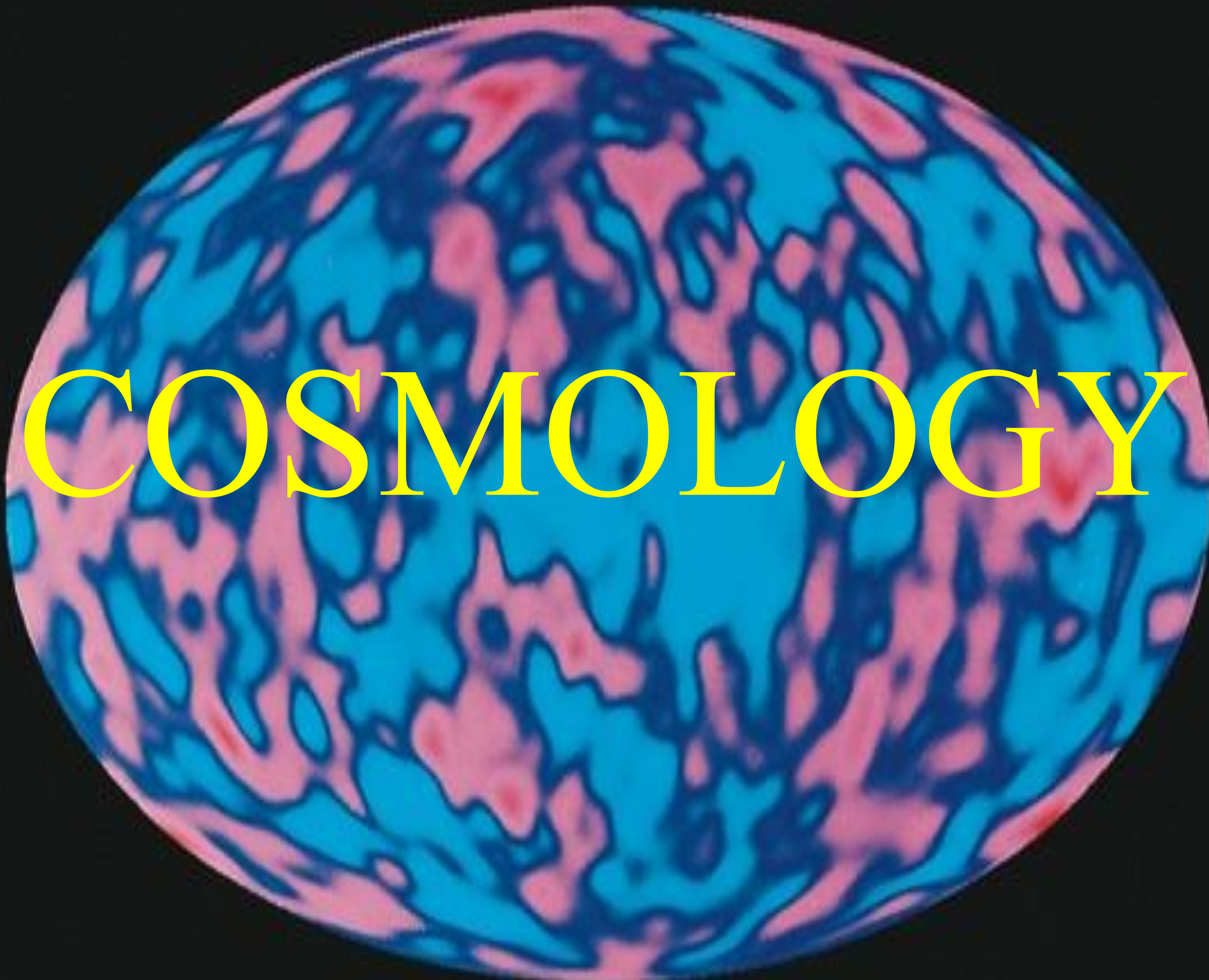

COSMOLOGY

COSMOLOGY

The study of the structure and evolution of the universe.

Questions?

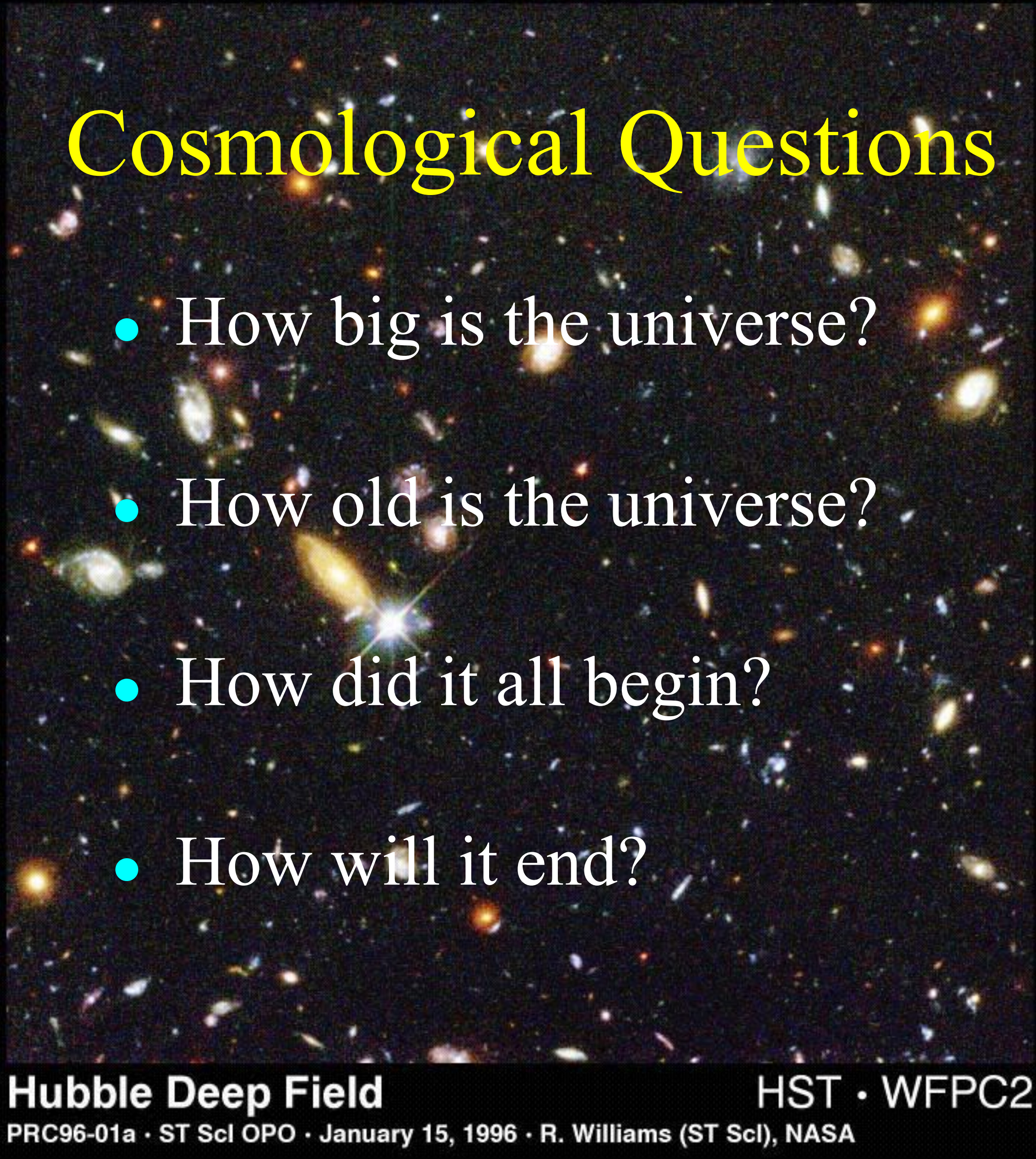
- What?
- When?
- Where?
- How?
- Who?
- Why?

The questions for science!

The questions for religion!

Cosmological Questions

- How big is the universe?
- How old is the universe?
- How did it all begin?
- How will it end?



Edwin Hubble

Hubble working the 100 inch telescope at Mt. Wilson.

- His discovery of Cepheid variables in the Andromeda galaxy expanded the known universe.
- Hubble and his assistant Milton Humason located Cepheids in other galaxies and calculated their distances.

Hubble's Galaxy Observations

- During the 1920's Edwin Hubble and Milton Humason photographed the spectra of many galaxies with the 100 inch telescope at Mount Wilson.
- They found that most of the spectra contained absorption lines with a large redshifts.

Hubble at Palomar Observatory

Galaxy Observations

- Using the Doppler effect, Hubble calculated the velocity at which each galaxy is receding from us.
- Using the period and brightness of Cepheid variables in distant galaxies, Hubble estimated the distances to each of the galaxies.

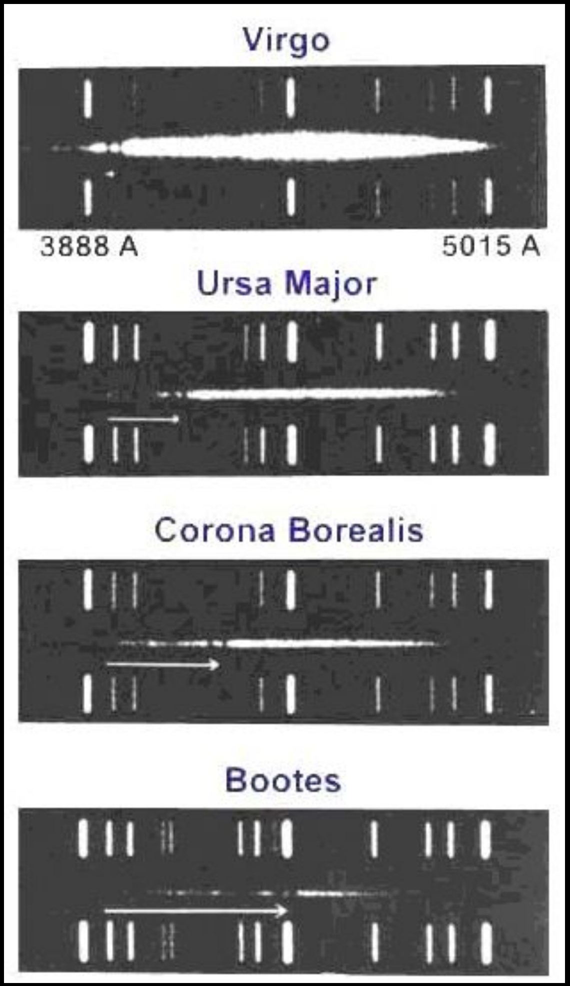
Red Shift and Distance

24 Mpc 1200 km/s

300 Mpc 15,000 km/s

780 Mpc 39,000 km/s

1220 Mpc 61,000 km/s



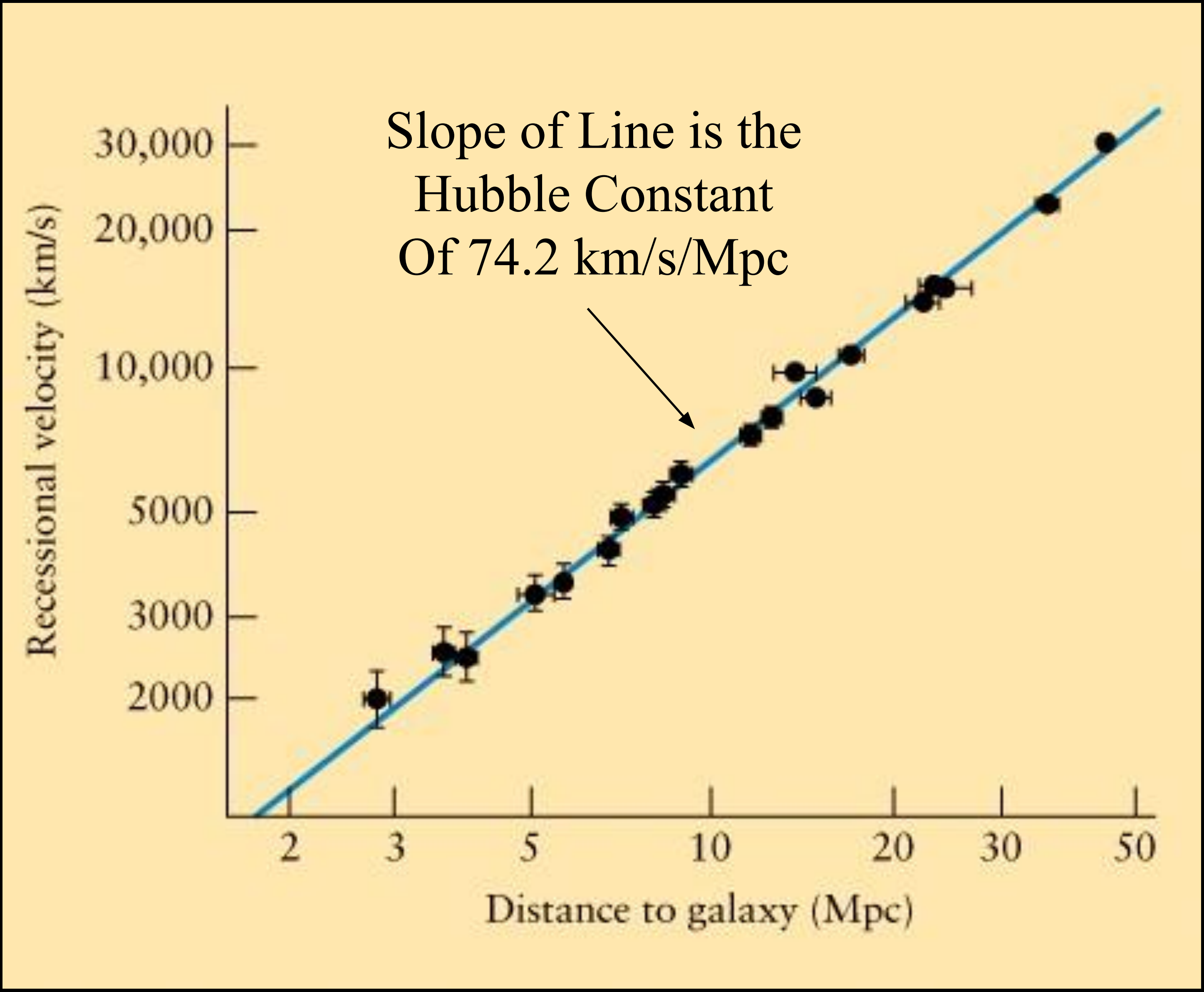
Hubble's Law

- Hubble noticed that there was a linear relationship between the recessional velocity and the distance to the galaxies.

- This relationship is know as Hubble's Law:

$$V = H D$$

recessional velocity = Hubble's Constant × Distance


Slope of Line is the
Hubble Constant
Of 74.2 km/s/Mpc
Recessional velocity (km/s)
30,000
20,000
10,000
5000
3000
2000
2
3
5
10
20
30
50
Distance to galaxy (Mpc)

The Hubble Constant

- H is known as the Hubble constant and is about 74.2 $\pm$ 3.6 (km/s)/Mpc.
  - *HST data (May 2009).*

- This number has been refined by using a variety of distance measurement techniques.

- These techniques are known as “standard candles”.

Standard Candles

- Standard Candles provide measurements of the absolute magnitude.
  - Remember! If you know the absolute magnitude (M) and the apparent magnitude (m) for a star, you can find the distance to that star.
- Inside the Milky Way Galaxy – Methods that are "direct".
  - Parallax: 0 - 150 pcs
  - Spectroscopic Parallax: 40 pcs - 10 kpcs
- Outside of the Milky Way Galaxy – Methods that are 'indirect' and yield an approximate value for absolute magnitude.
  - RR Lyrae Variables: 5 kpcs - 100 kpcs
  - Cepheid Variables: 1 kpcs – 30 Mpcs
  - Tully-Fisher Relation: 700 kpcs – 150 Mpcs
    - *Broad 21-cm H line means bright galaxy.*
  - Type Ia Supernovae: 1Mpc – 1000+Mpcs

The Age of the Universe

- Hubble's constant can tell us the age of the universe.
  - Age of the Universe = 1/H
  - Referred to as "Hubble Time"

- Today, the age of the universe is considered to be 13.75 $\pm$ 0.17 billion years.

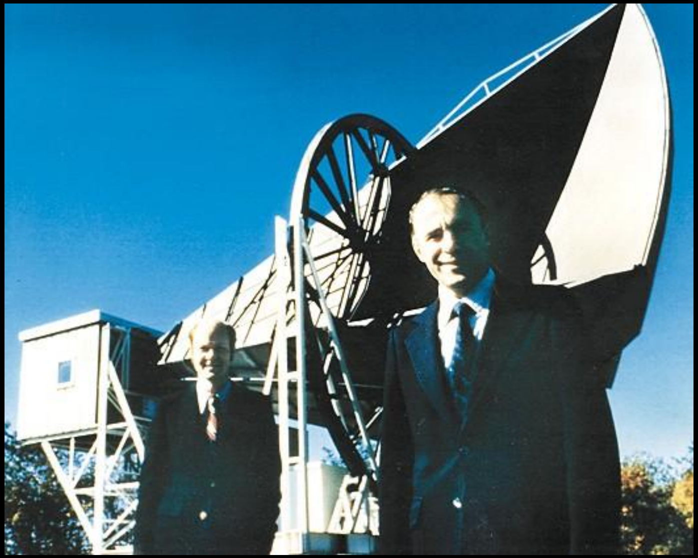
Update - The Value of H is being contested again!

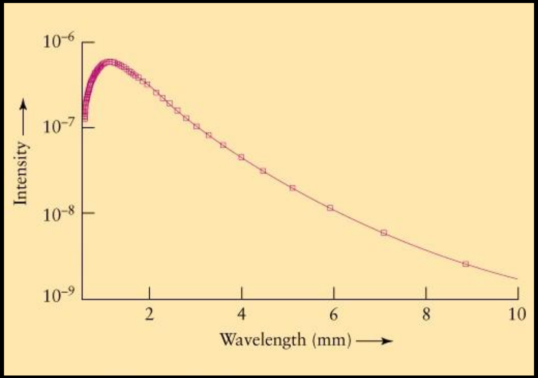
The Expansion of the Universe

The Big Bang Theory

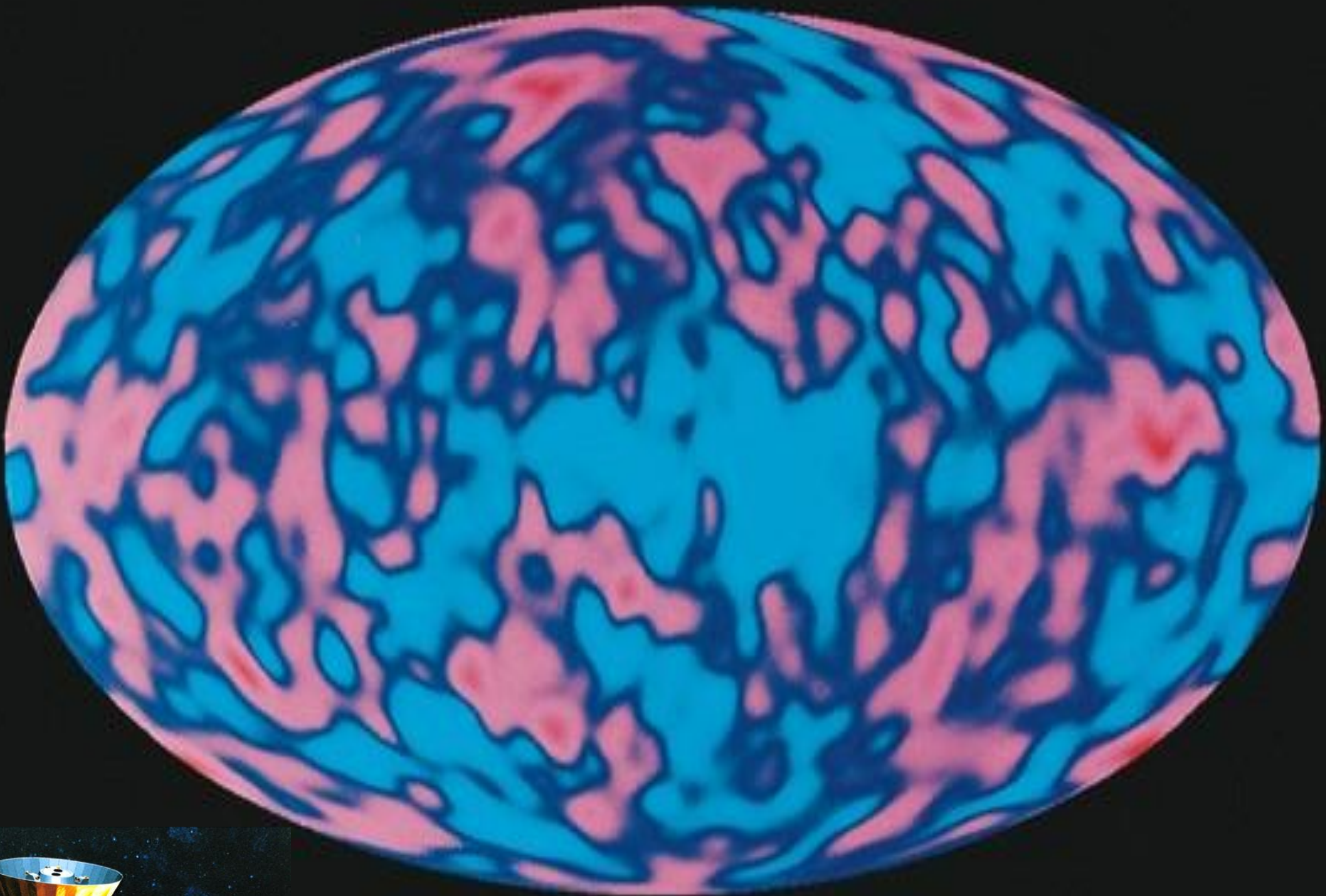
- The cosmological red-shift of the galaxies tells us that the universe is expanding.
- The expanding universe probably originated in an event now called the Big Bang.
- Evidence…
  - Red-shift of receding galaxies.
  - 3K (actually 2.7K) cosmic background radiation
    - Leftover radiation (microwave) from the formation of the universe.

3K Cosmic Background Radiation



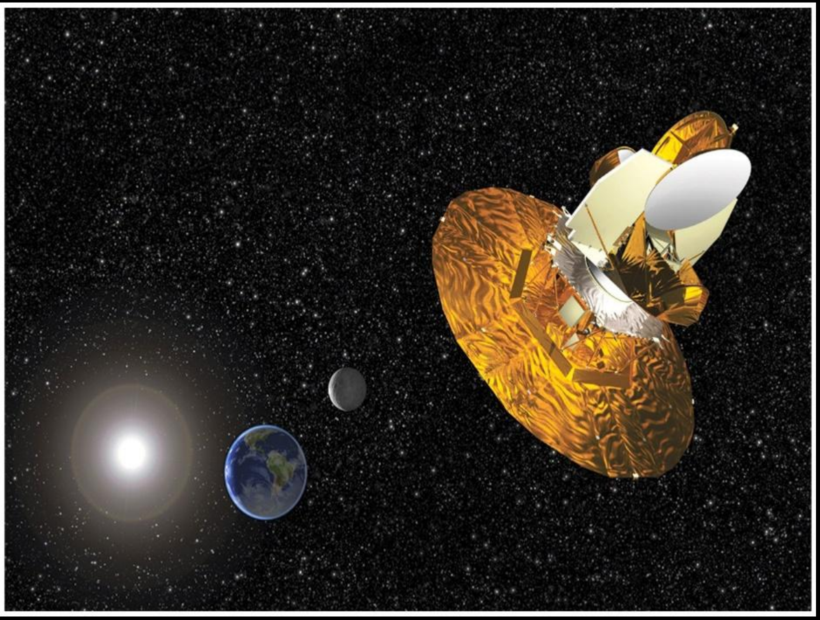


- Discovered by Penzias and Wilson while testing a microwave horn antenna designed to relay telephone calls to satellites (1965).
- They accidentally detected the theoretically predicted 3K cosmic background radiation.
- This radiation seems to come from all directions in the universe.
- Detailed observations were made by COBE (Cosmic Background Explorer) from 1989-1994.



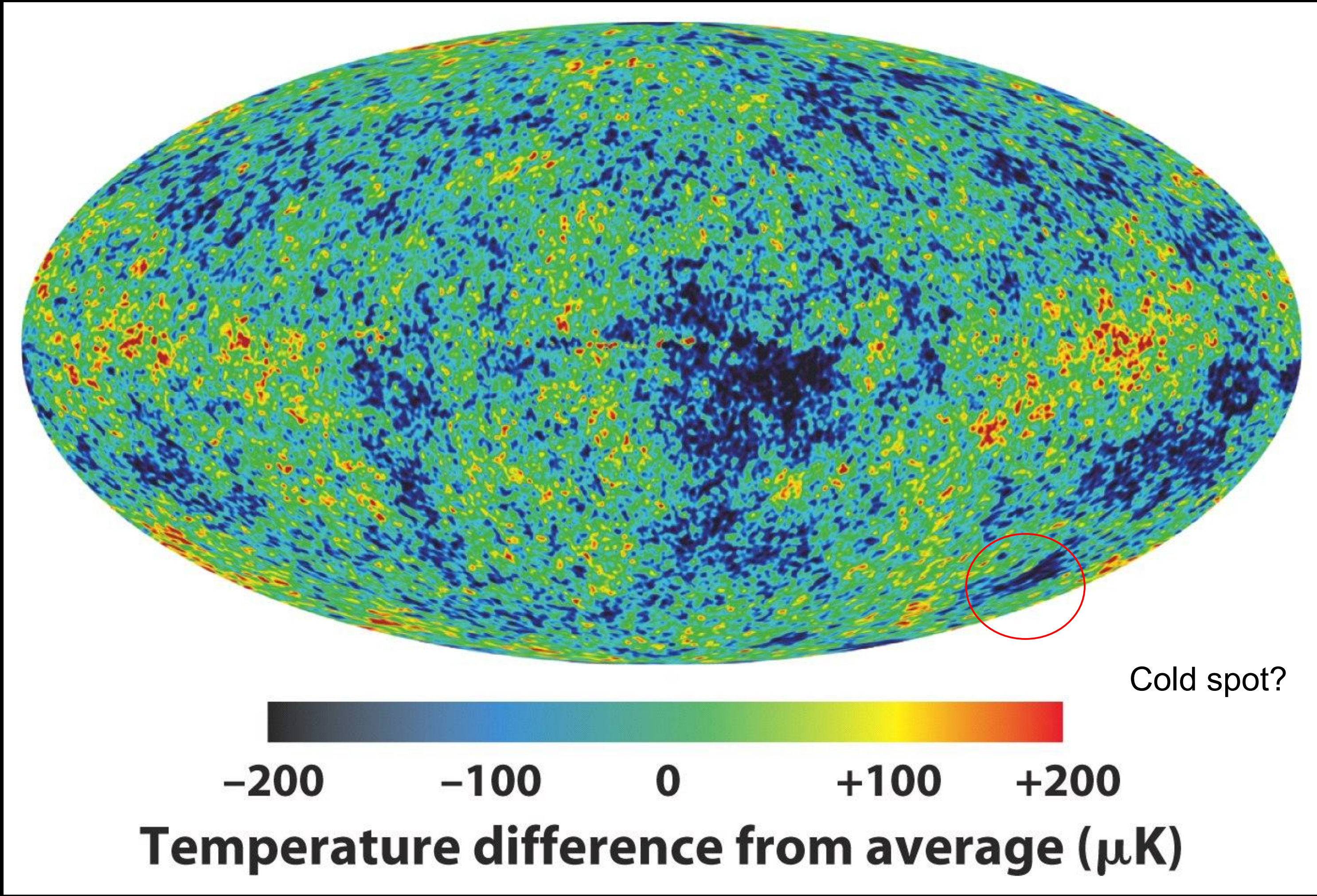
COBE's map of the cosmic background radiation at 2.73 ± 0.001K. The peak wavelength is 1.9mm. Small variations in temperature (~0.0033 K) are due to the Earth's motion through the CBR.

The WMAP Mission



- Wilkensen Microwave Anistropy Probe (WMAP).
- Shows small fluctuations in the cosmic background radiation.
- Results from WMAP set the age of the universe at 13.73 billion years.
- Results have shed light on the overall composition of the universe (more later).

WMAP showing small variations in the cosmic background radiation. Temperature differences in this image are no more than 200μK.



TOPICS THAT NEED TO BE INCLUDED

ISOTROPY = the concept that the direction of observation does not matter overall

HOMOGENEITY = the concept that on the grandest of scales, the universe is similar in appearance everywhere ???

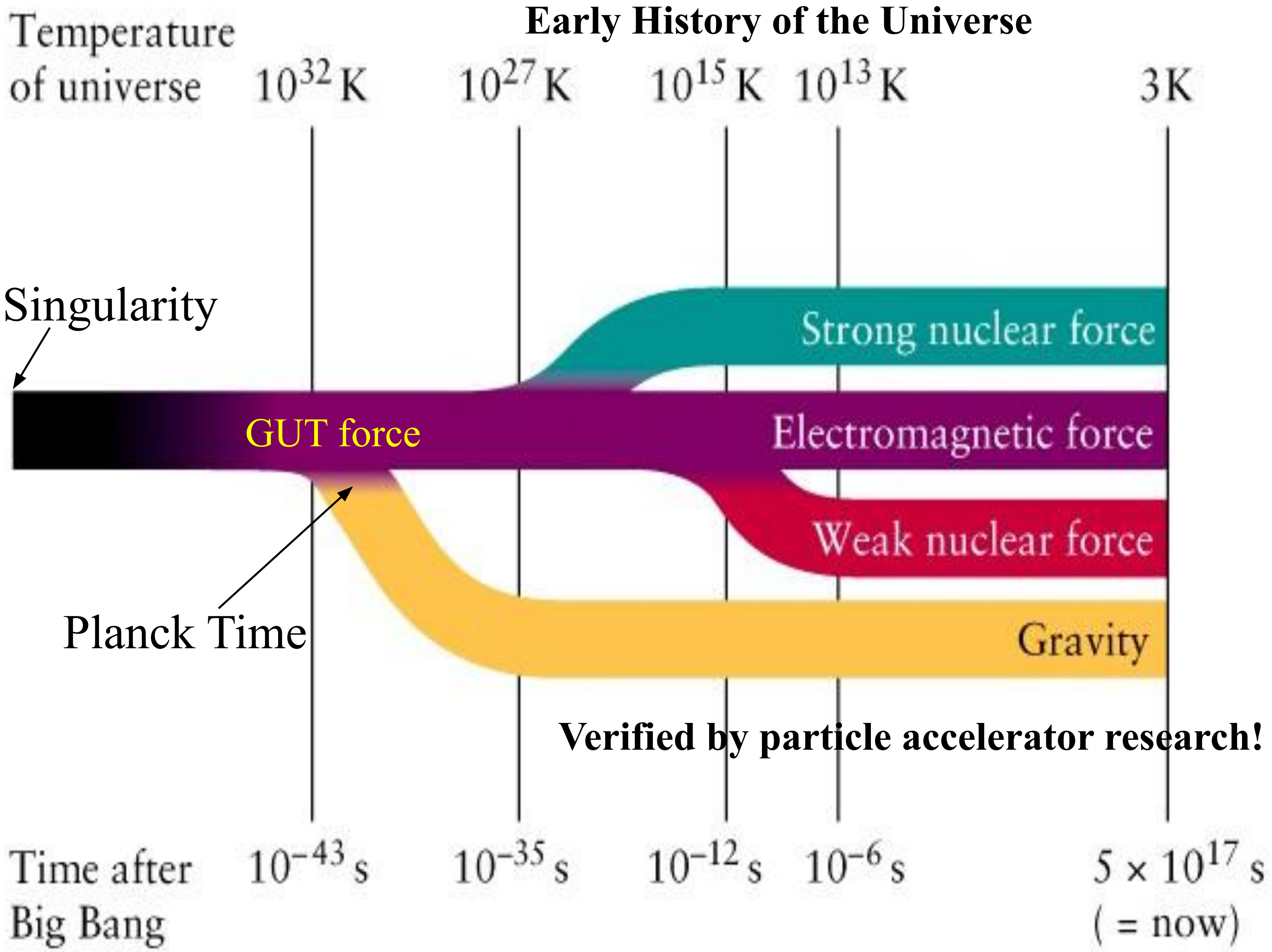
THE COSMOLOGICAL PRINCIPLE

Brief History of the Universe

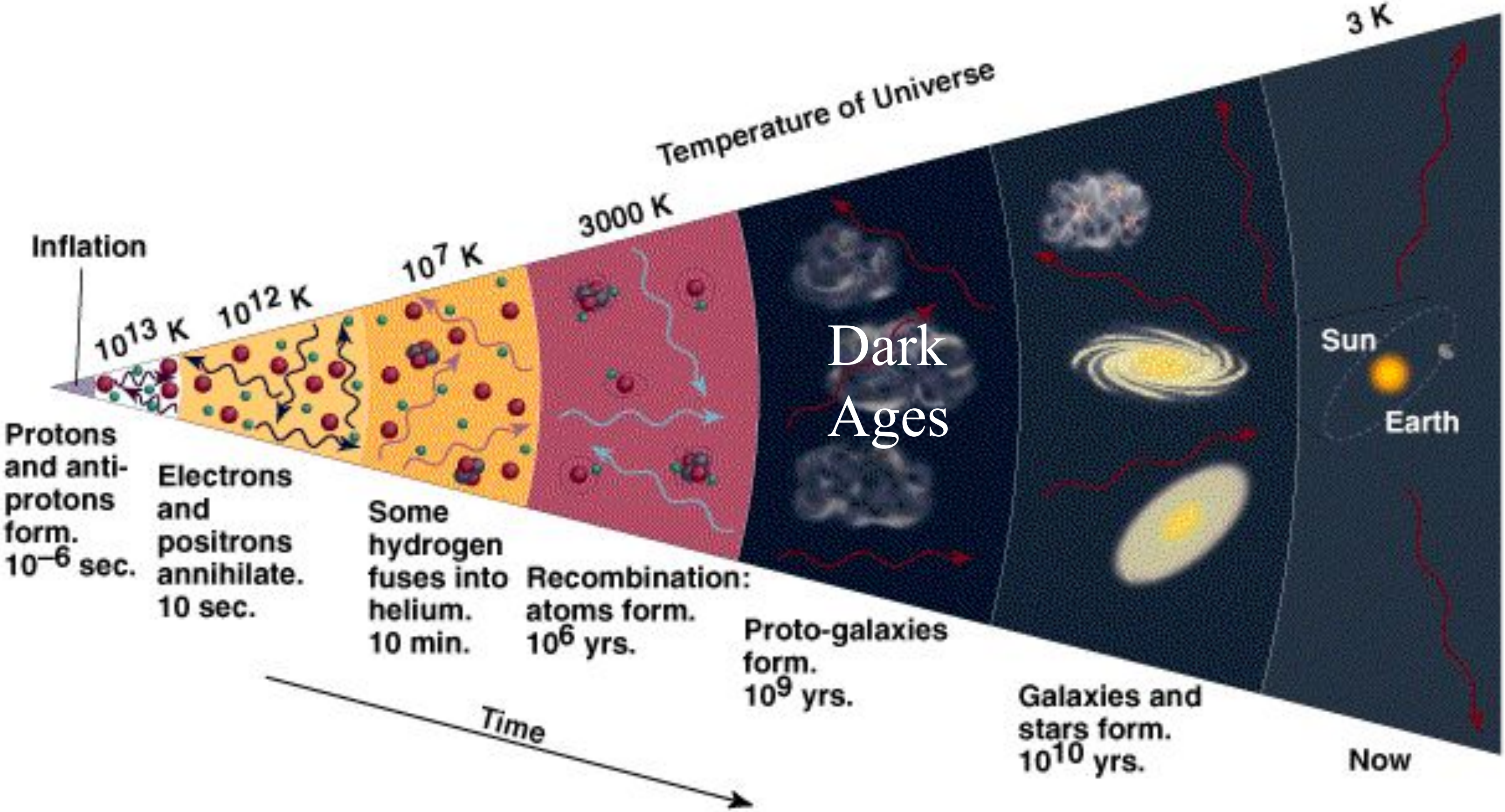
- T = 0
  - The Ylem - All energy, time, and space was confined to an infinitesimally small space.
    - The four forces of nature were combined into one.
    - This was a universe dominated by radiation.
    - Abundance of photons.

  - The expansion began (why? how?). … This is what we call the “Big Bang” and it was immediately followed by a Primeval Fireball period.

- $10^{-43} < T < 10^{-6}$ seconds
  - Expansion causes universe to cool.
  - Forces of nature ‘freeze’ out of the mix making possible the formation of matter along the way.
    - Gravity
    - Strong Nuclear Force (holds protons and neutrons together in the atom’s nucleus)
    - Weak Nuclear Force (governs radioactive decay; the changes in quarks)
    - Electromagnetic Force


Early History of the Universe
Temperature of universe
10^{32} K
10^{27} K
10^{15} K
10^{13} K
3K
Singularity
Strong nuclear force
GUT force
Electromagnetic force
Weak nuclear force
Planck Time
Gravity
Verified by particle accelerator research!
Time after Big Bang
10^{-43} s
10^{-35} s
10^{-12} s
10^{-6} s
5×10^{17} s
(= now)

History of Matter and Radiation in the Early Universe



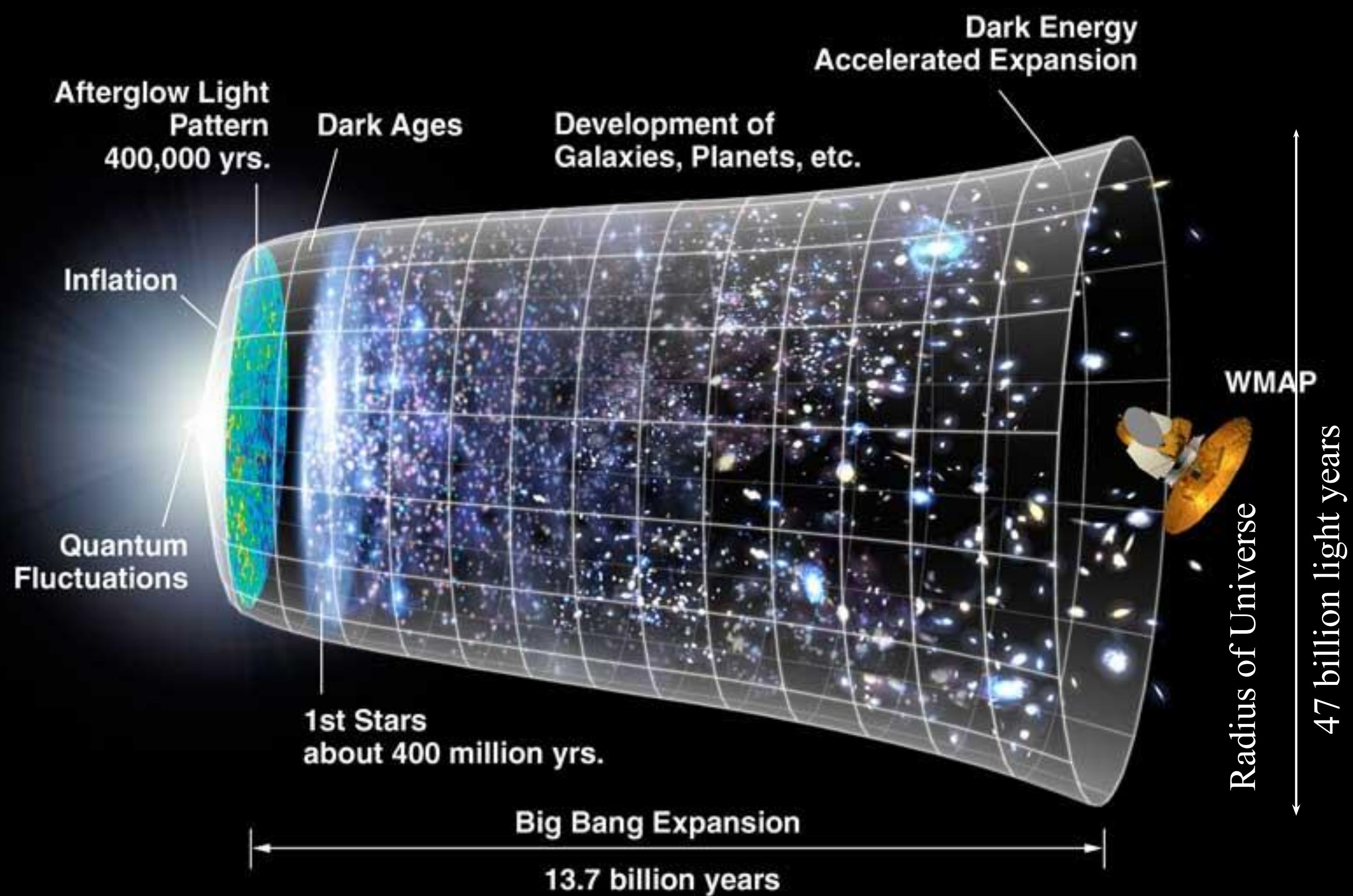
Brief History of the Universe

- 0 < T < 50,000 years
  - Photons were so energetic that they prevented neutral atoms of Hydrogen to form.
  - This era is often referred to as the 'primordial fireball' – this state is called a *plasma* and is opaque to all wavelengths.
- 50,000 < T < 100,000 years
  - Universe expanded to a point that red-shifts were causing photons to lose energy.
  - The event is called *decoupling*. Neutral atoms of hydrogen could now form.

Brief History of the Universe

- 400,000 < T < 200 million years
  - Universe stopped being hazy and became transparent. This period is call the ‘era of recombination’. *Telescopes can’t see beyond this point.*
    - IOK-1 Farthest known galaxy – 12.88 billion light years.
  - The universe was making the transition from being dominated by radiation to being dominated by matter.
    - Gravity slowly became the key force controlling the fate of the universe.
    - For most of this transition time, the universe was dark.
    - This time is often called the “Dark Ages.”

- 200 million < T < 2 billion years
  - Galaxies (filled with stars) began to form out of huge clouds of hydrogen gas.
  - Light once again was seen in the universe.


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
WMAP
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years
Radius of Universe
47 billion light years

Future of the Universe

- For much of the 20th century, two theories dominated…
  - Universe will expand forever (Big Chill)

  - Gravity will halt the expansion (Big Crunch)
    - In order for the Big Crunch to occur, we needed to find more matter in the universe.
    - The search was on for Dark Matter!

Future of the Universe

- Astronomers now know that only about 23% of the mass of the universe is Dark Matter. This isn't enough to halt the expansion.

- In 1998, astronomers (using Type 1 Supernovae observations) determined that the expansion of the universe is actually accelerating due to a repulsive force now called "dark energy". It appears that the expansion will go on forever.
  - Two ideas for Dark Energy
    - Vacuum energy predicted by Einstein's Cosmological Constant
      - Particles spring in/out of existence in the vacuum of space creating repulsive energy.
    - Quintessence ("fifth element")- Energy in the vacuum of space that has been accumulating since the expansion and eventually overpowers gravity.
  - Dark energy is currently becoming the dominant force in the universe.
    - Possible future = "The Big Rip!"

Composition of the Universe

- 5 % Ordinary Matter (called baryonic matter)
- 23 % Dark Matter
- 72 % Dark Energy

- This means that 95% of the universe is made up of stuff that we don’t know what it is!!!!!!!!!!!!