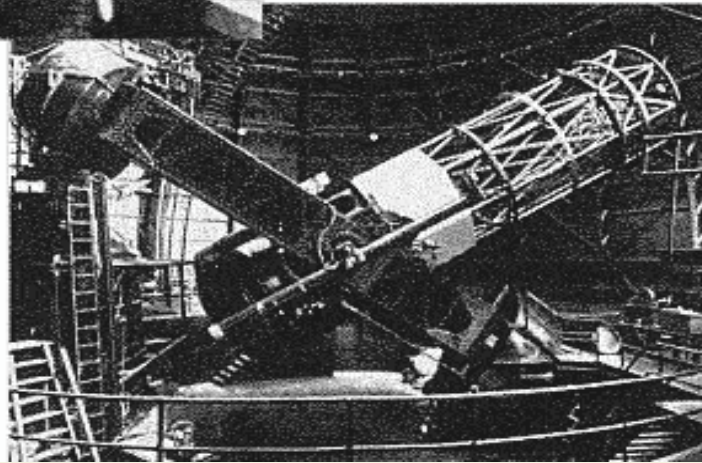
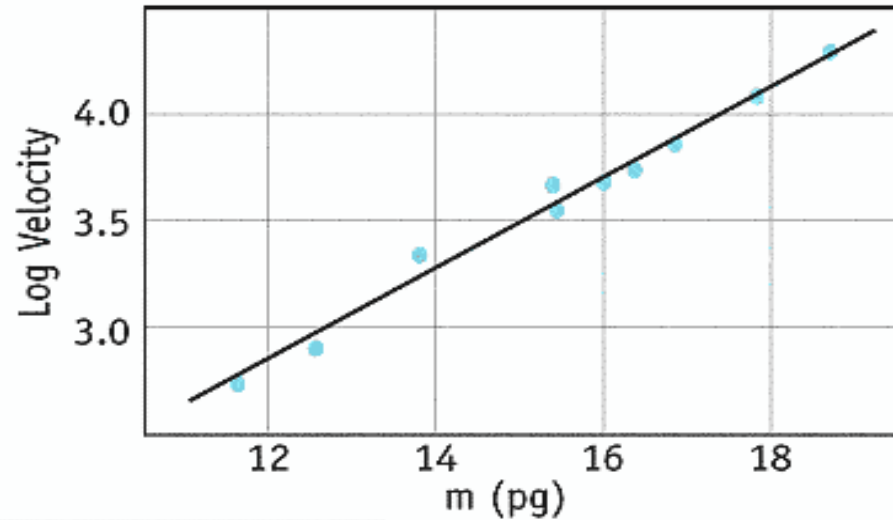


# Edwin Hubble

## DISCOVERY OF EXPANDING UNIVERSE

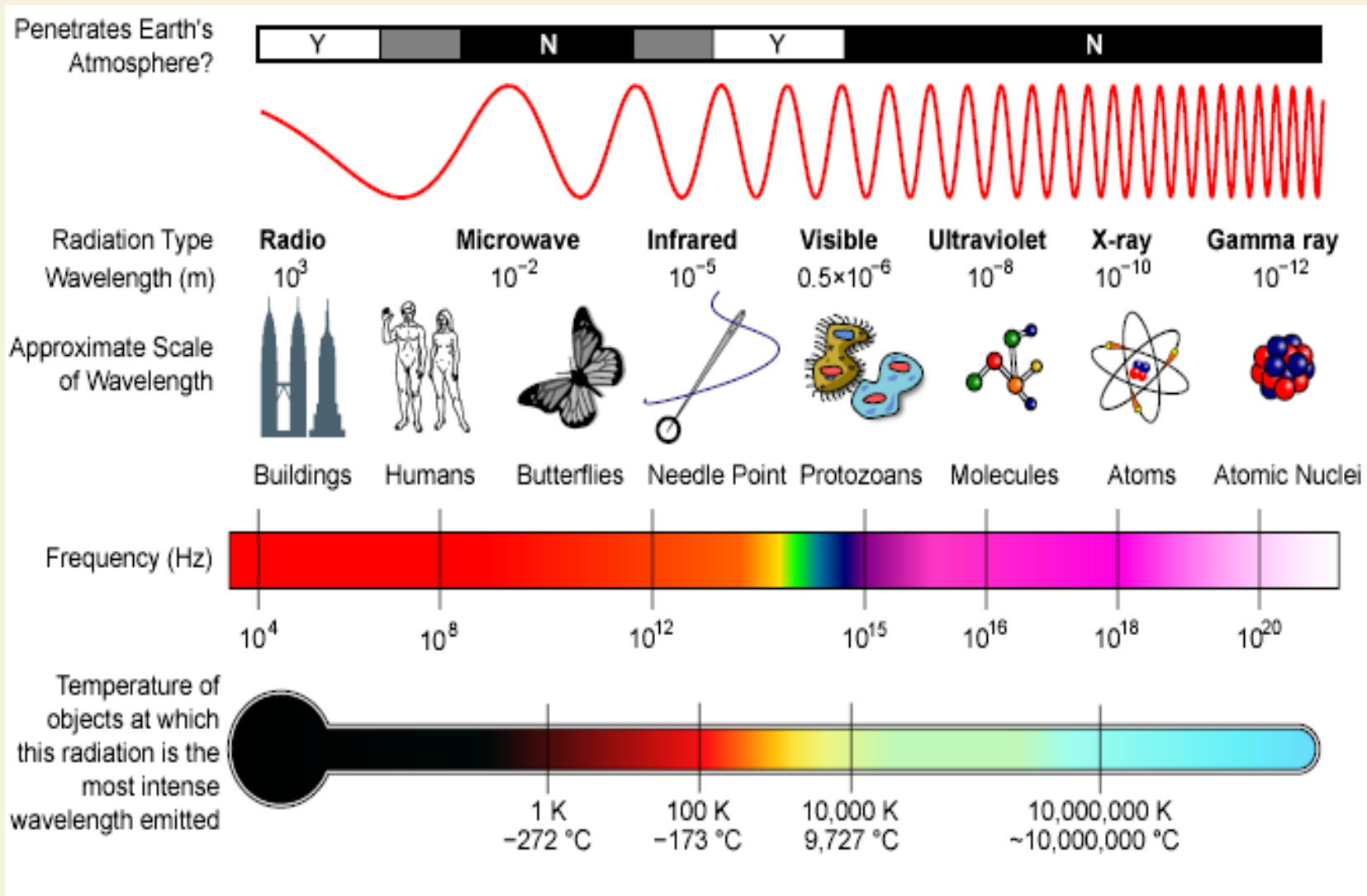


Edwin Hubble



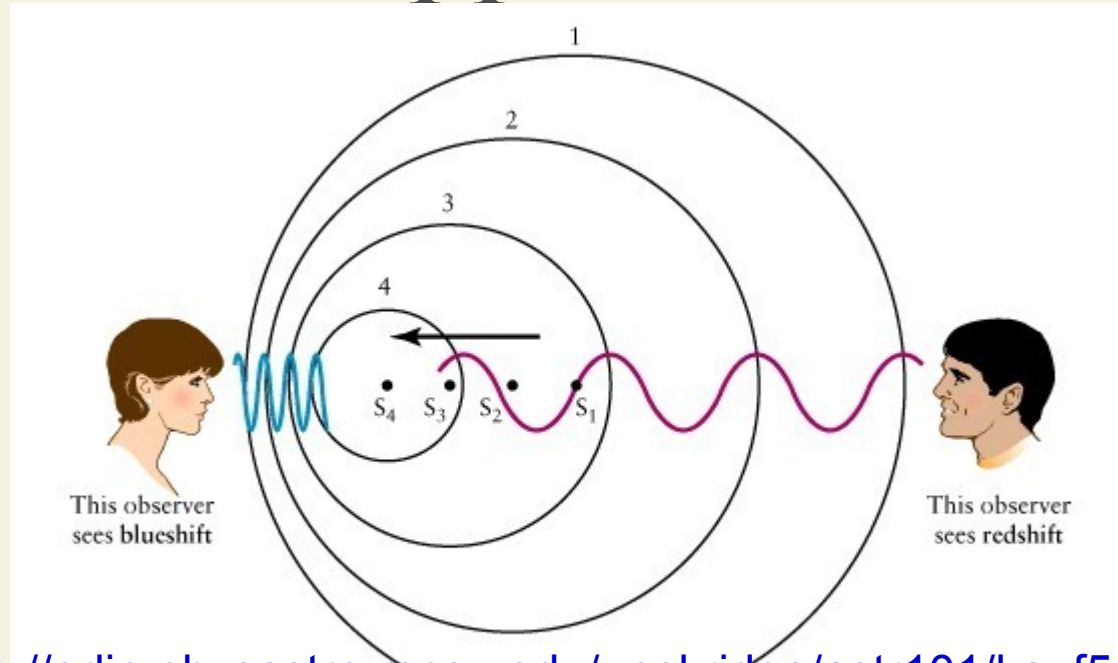
Mt. Wilson  
100 Inch  
Telescope

# EM Spectrum

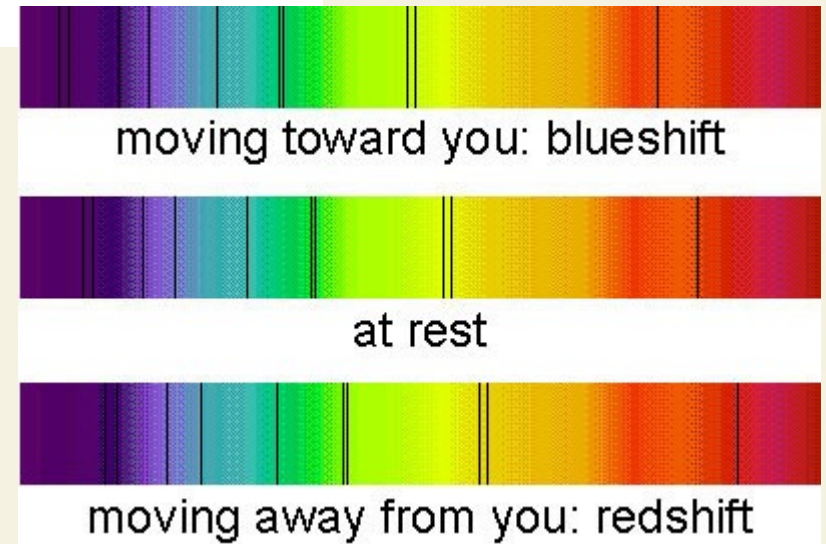
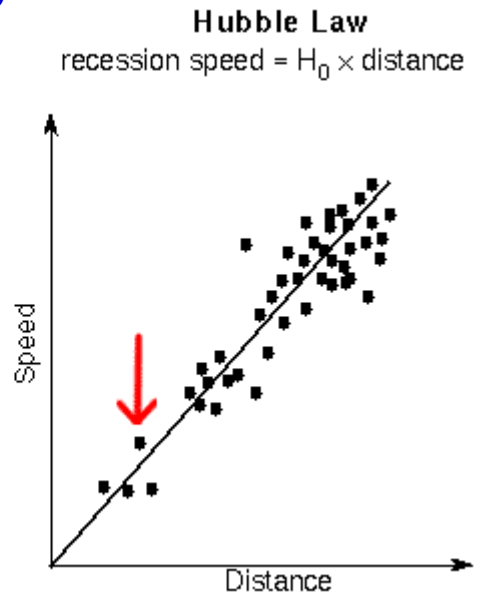
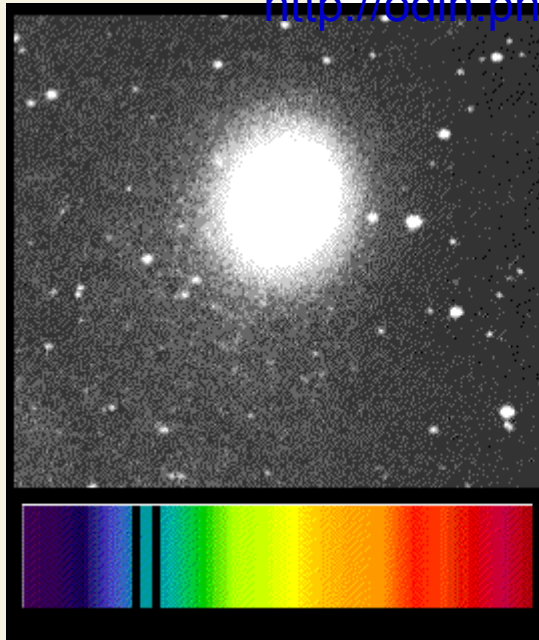


[http://en.wikipedia.org/wiki/Electromagnetic\\_spectrum](http://en.wikipedia.org/wiki/Electromagnetic_spectrum)

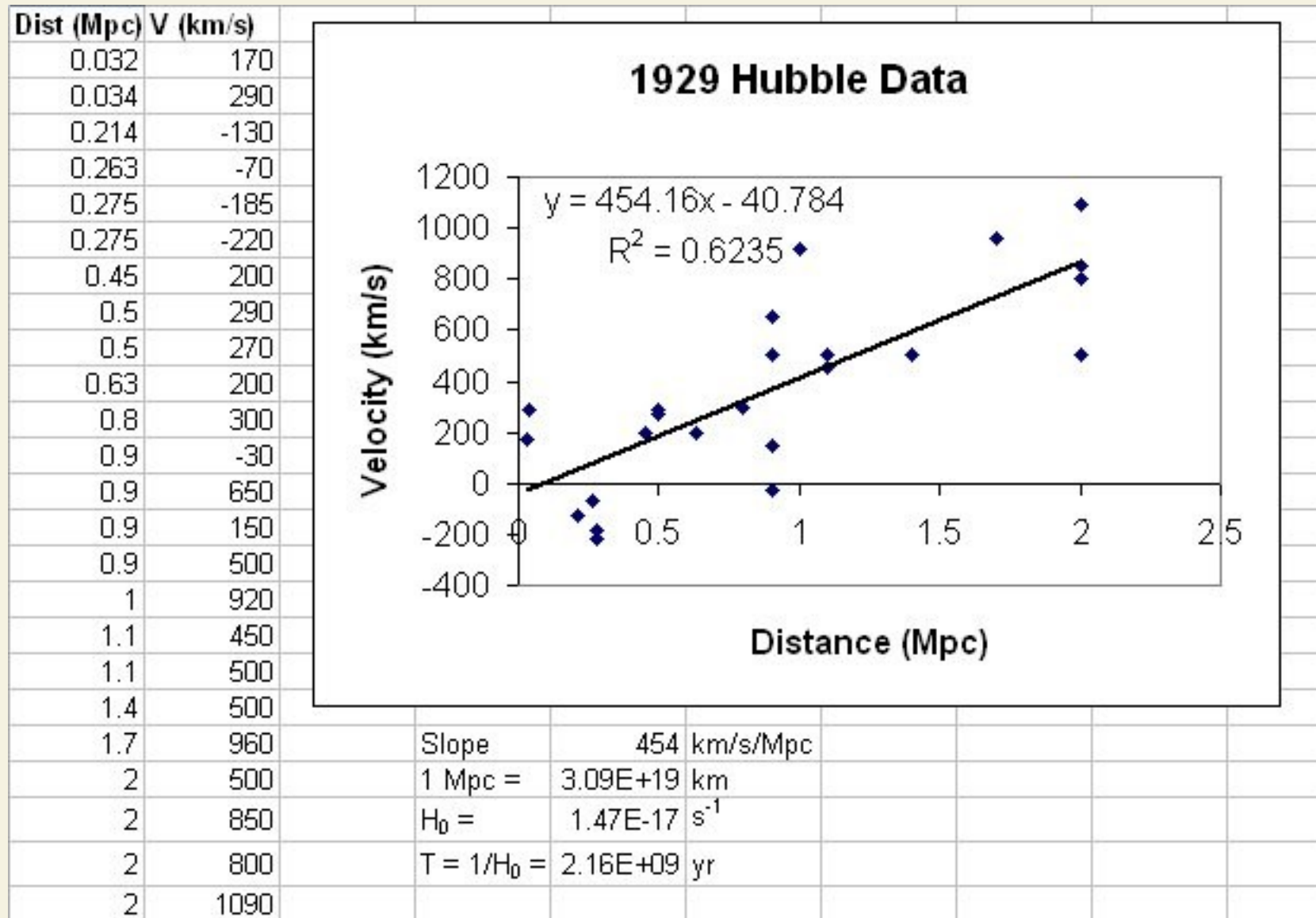
# Doppler Effect



[http://odin.physastro.mnsu.edu/~eskridge/astr101/kauf5\\_23.JPG](http://odin.physastro.mnsu.edu/~eskridge/astr101/kauf5_23.JPG)



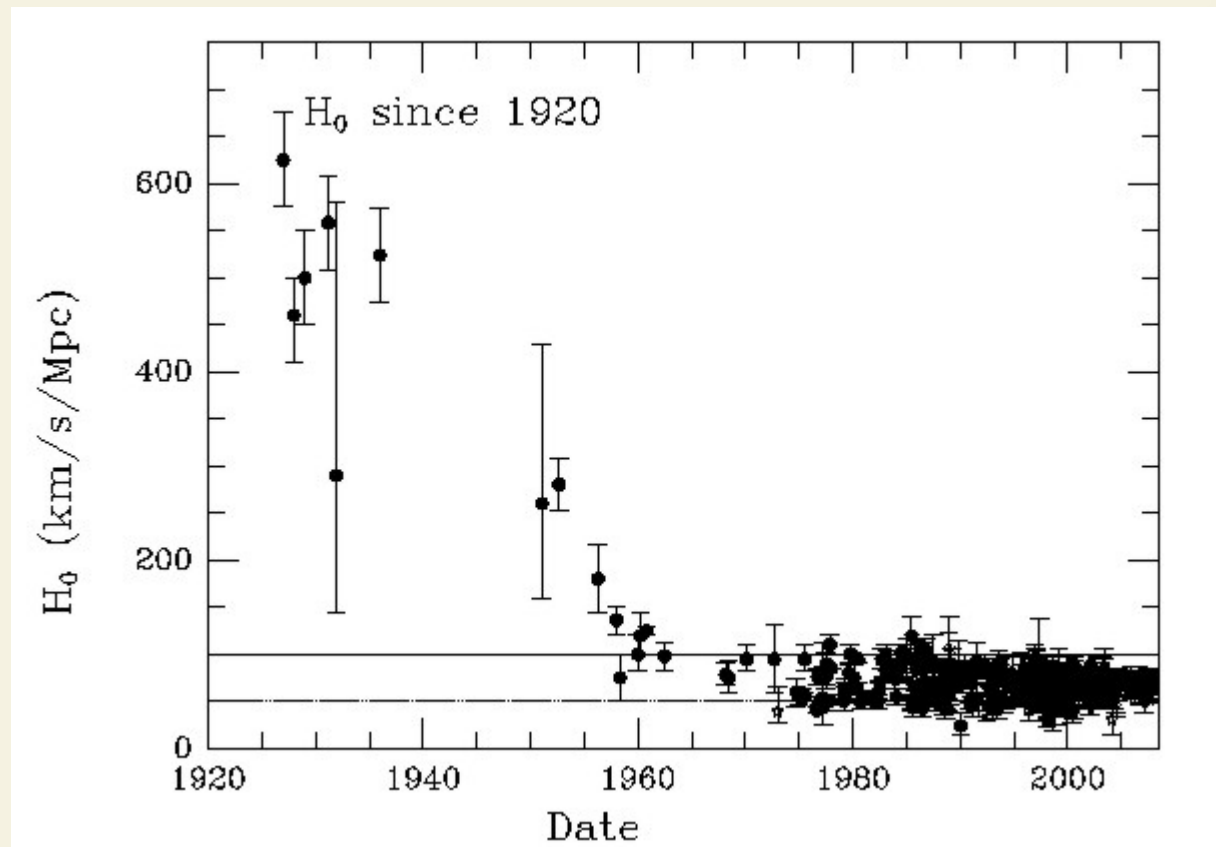
# Hubble's Constant: $v = H_0 d$





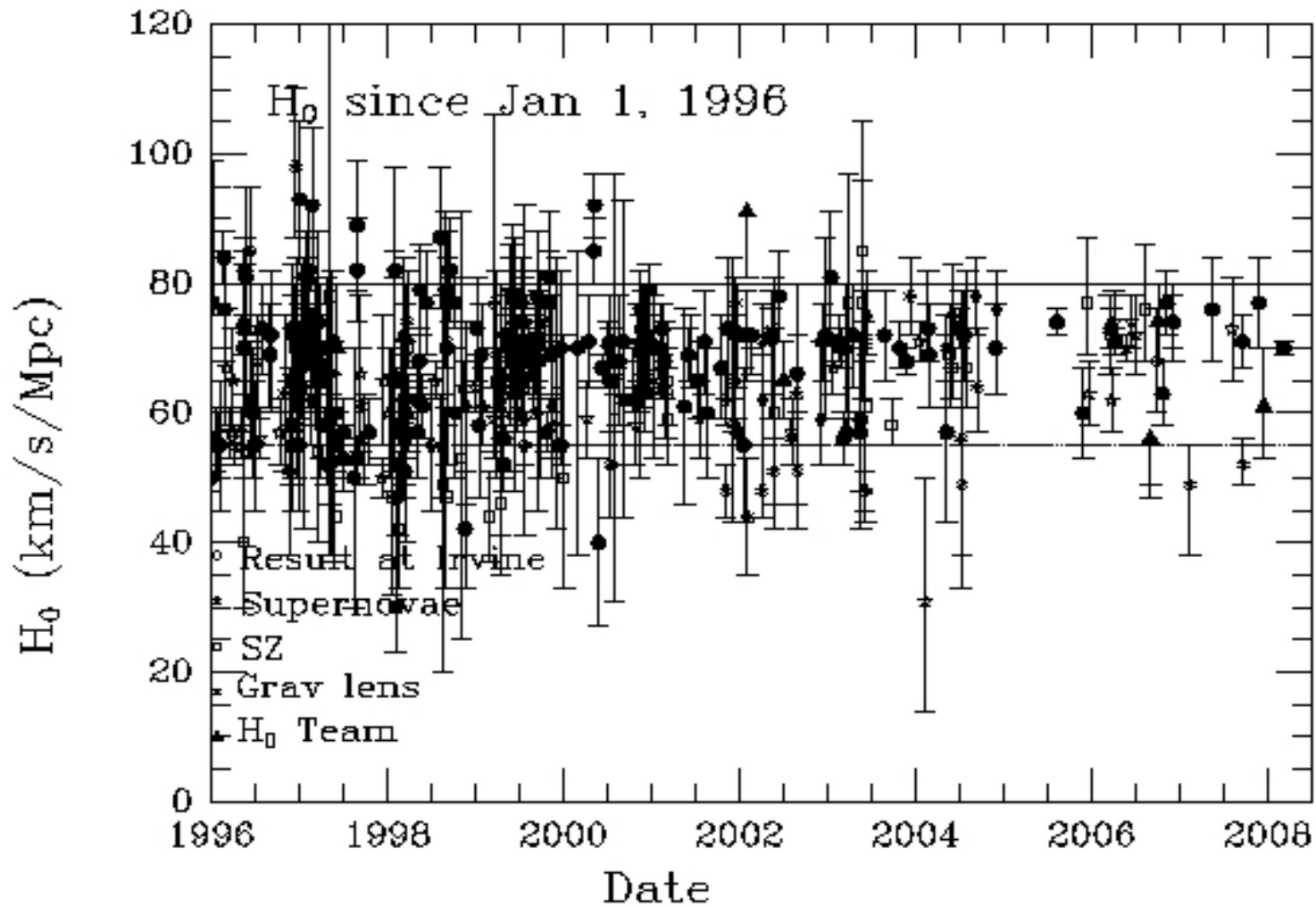
# Hubble's Constant and the Age of the Universe

~ 1930 Earth 3 billion yrs old!



<http://cfa-www.harvard.edu/~huchra/hubble/>

# And the winner is ...



72 +/- 8 km/s/Mpc

~ 1 Mpc =  $3.086 \times 10^{22}$  m – try Google!

~ 1 km/s/Mpc =  $3.24 \times 10^{-20}$  Hz

~  $1/H_0 = \dots$

~ Scale of Universe:

<http://www.krysstal.com/scale.html>

~ If flat and matter dominated –  $2/(3H_0) = 9$  Gyr

~ WMAP – 13.7 +/- 0.13 Gyr

# Gamow, Alpher, Herman The Big Bang 1948

- ~ Expansion and cooling of universe
  - ~ Initial state - infinite density and temperature.
  - ~ "Ylem" = protons, neutrons, and electrons in an ocean of high energy radiation.
  - ~ Computer calculation of nuclear processes
  - ~ Gave off radiation => the universe is now 5K
- ~ What determined the cosmic abundance of the elements?



# Hoyle, Bondi, Gold Steady State Model, 1950

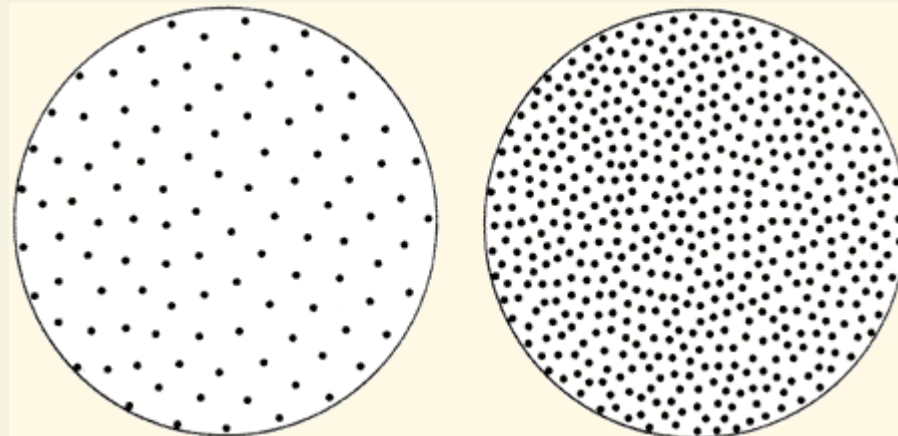
“[The Big Bang] is an irrational process that cannot be described in scientific terms ... [nor] challenged by an appeal to observation.” Hoyle

~ Test 1 – Age of Universe

~ Test 2 - the rate of expansion of the universe.

~ In a big bang the expansion rate would slow;

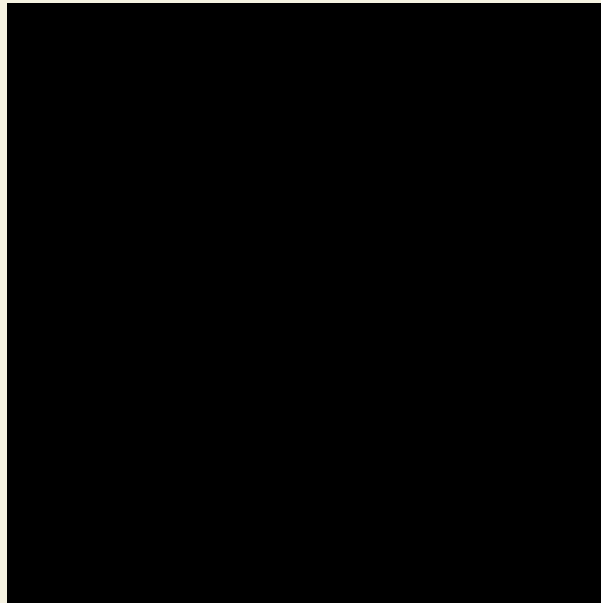
~ In a steady state universe it would remain constant.



The First Three Minutes, UNC Wilmington, 2008

# Olber's Paradox 1823

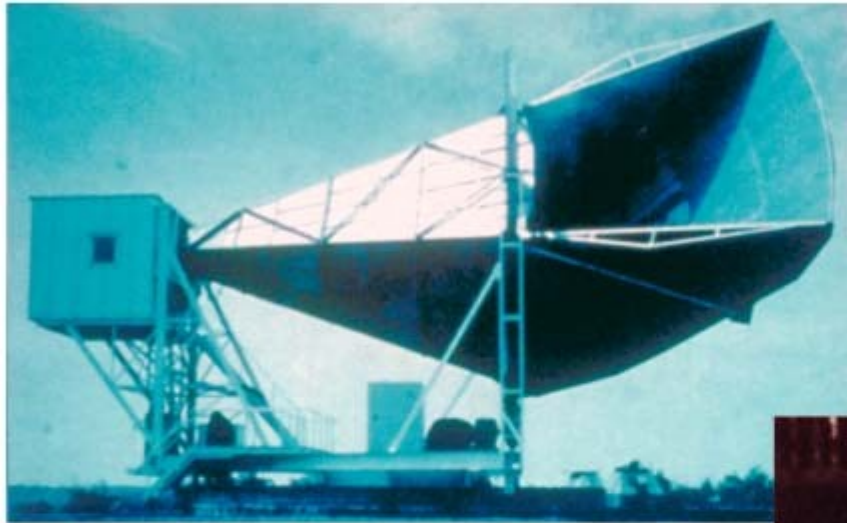
Why is the sky dark at night?



[http://en.wikipedia.org/wiki/Olbers'\\_paradox](http://en.wikipedia.org/wiki/Olbers'_paradox)

# Arno Penzias and Robert Wilson

## DISCOVERY OF COSMIC BACKGROUND

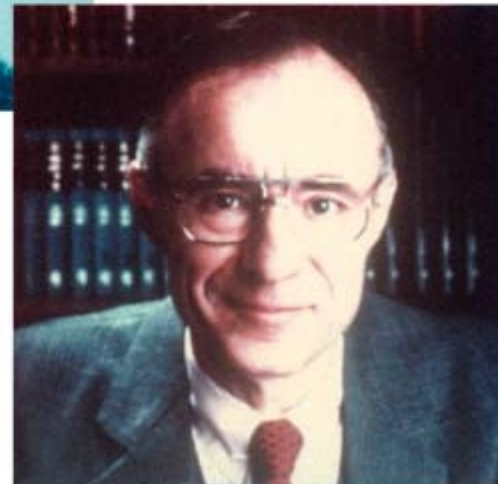


Microwave Receiver



MAP990045

Robert Wilson

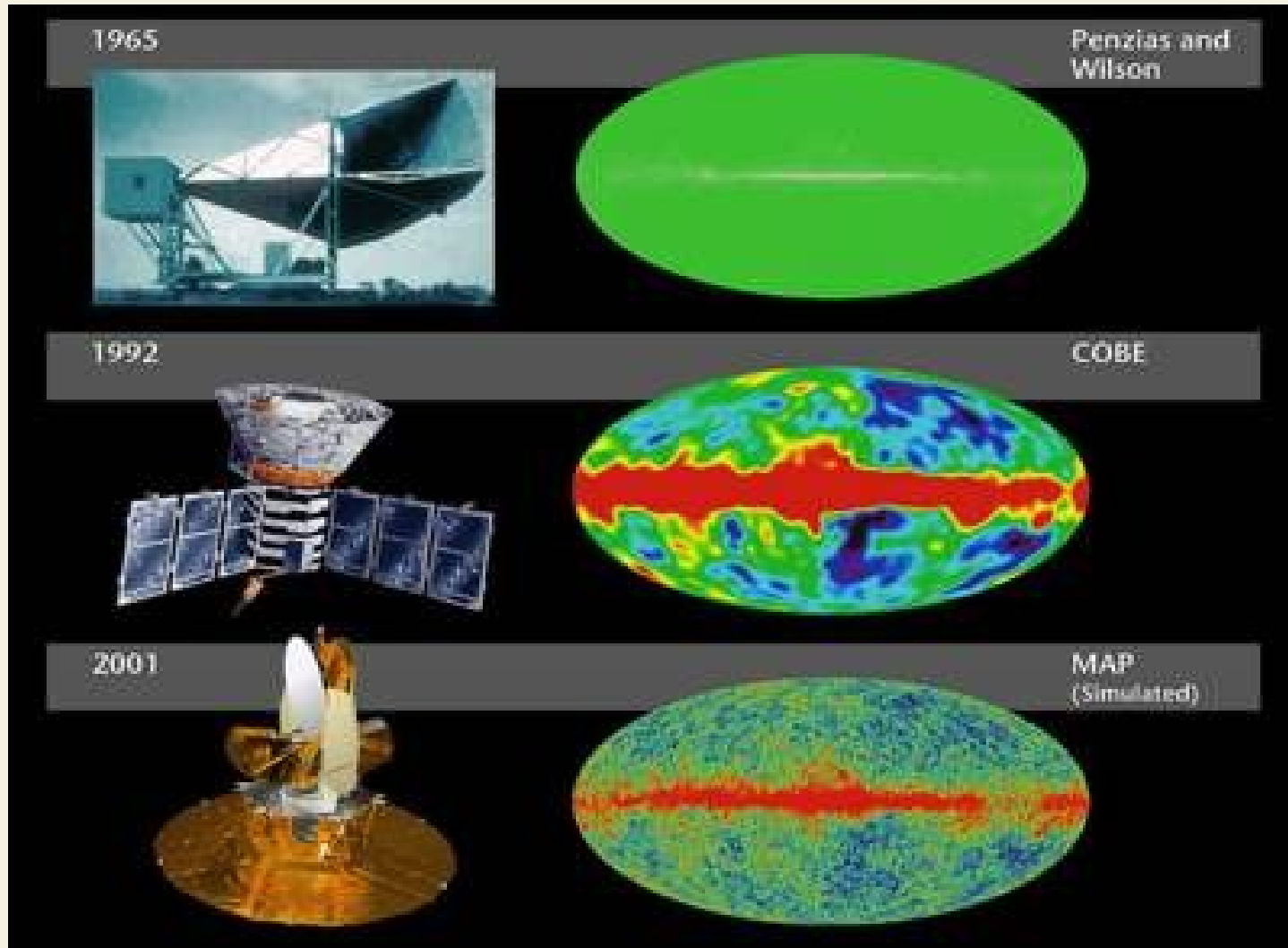


Arno Penzias

The First Three Minutes, UNC Wilmington, 2008

[http://www.jca.umbc.edu/~george/images/cosmology/penzias\\_wilson\\_pic.jpg](http://www.jca.umbc.edu/~george/images/cosmology/penzias_wilson_pic.jpg)

# Cosmic Microwave Background



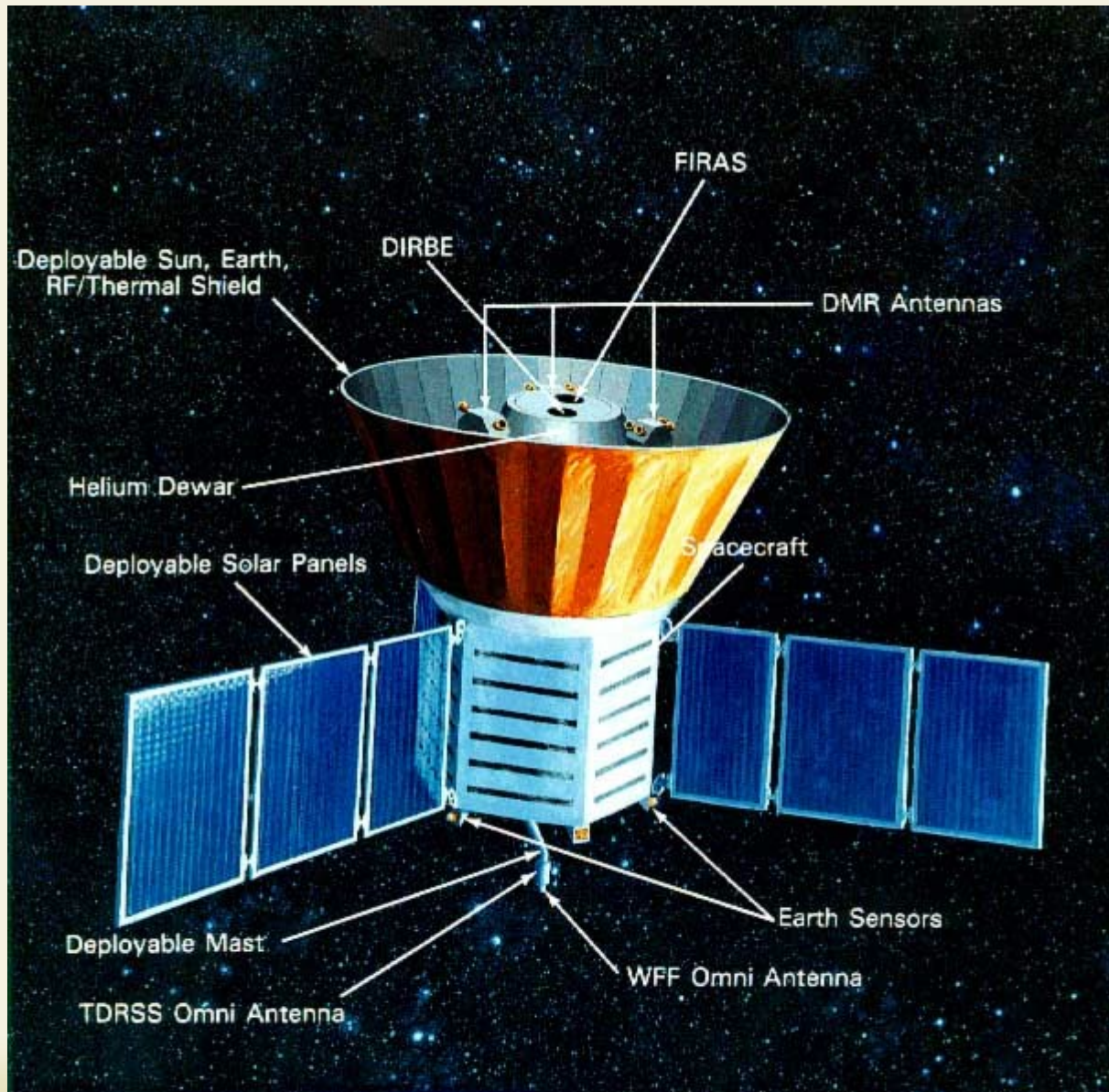
[http://www.space.com/scienceastronomy/map\\_mission\\_basics\\_030211.html](http://www.space.com/scienceastronomy/map_mission_basics_030211.html)

The First Three Minutes, UNC Wilmington, 2008



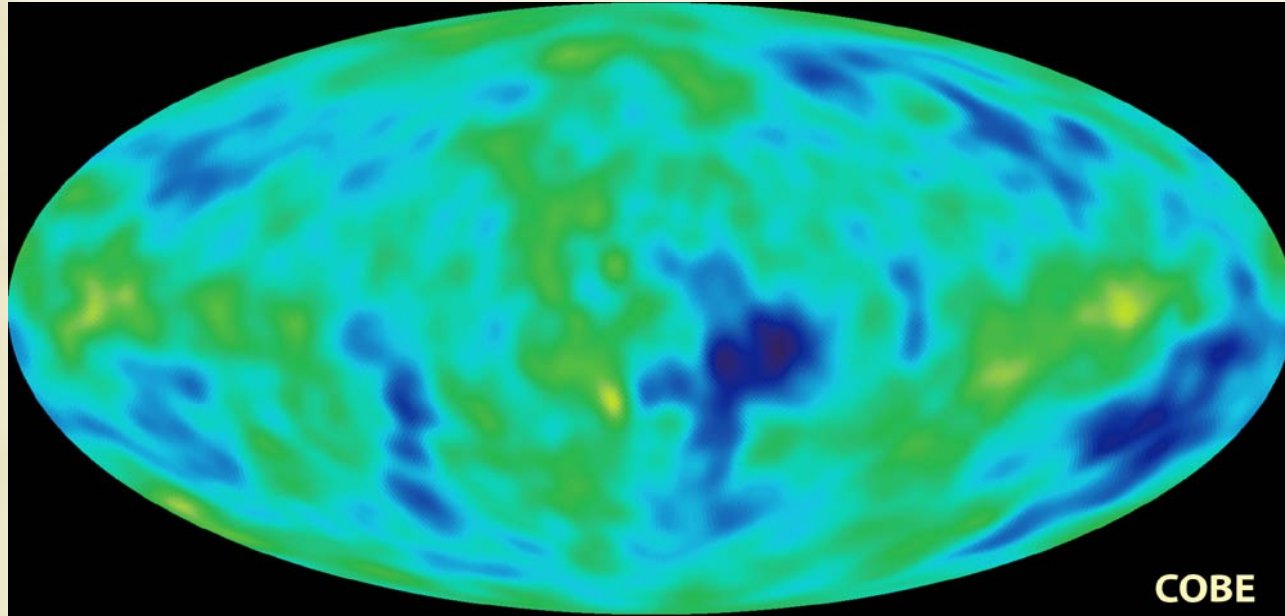
# COBE

<http://commons.wikimedia.org/wiki/Image:Cobe.jpg>

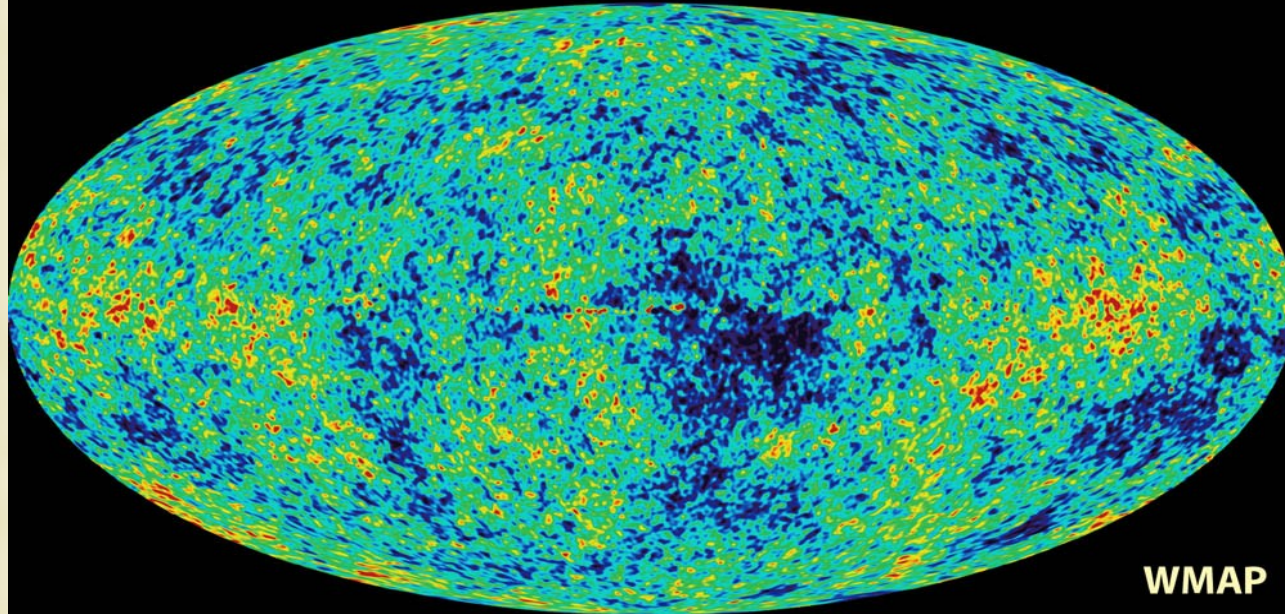




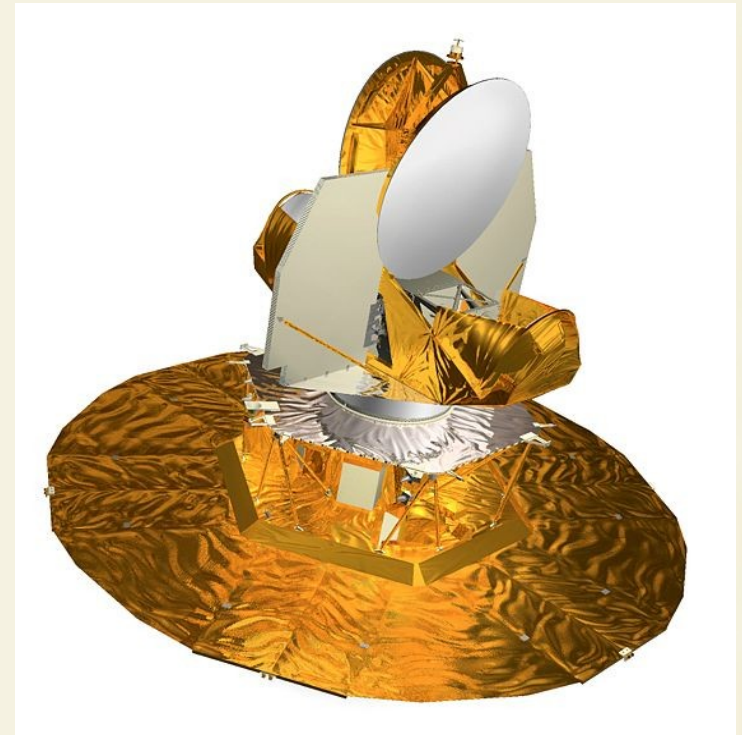
# WMAP



COBE



WMAP





# History of Universe

