

# Lecture 23

23 April 2009



**HOMEWORK 09:**  
**out now. Due next**  
***Thursday, 30th April***  
**2009, 11:59pm**

- **SCIENCE TOPICS:**  
Galaxies, Hubble's Law and the Expanding Universe
- **READING**  
Ch. 15, sec 15.3  
Ch. 17, sec 17.1 and 17.2
- **PRACTICE: Ch 15**  
Review: 1, 2, 5, 6  
Self-test: 1, 2, 5, 6, 10,  
Problems: 4, 5

# **Hubble's Law and the Expansion of the Universe**

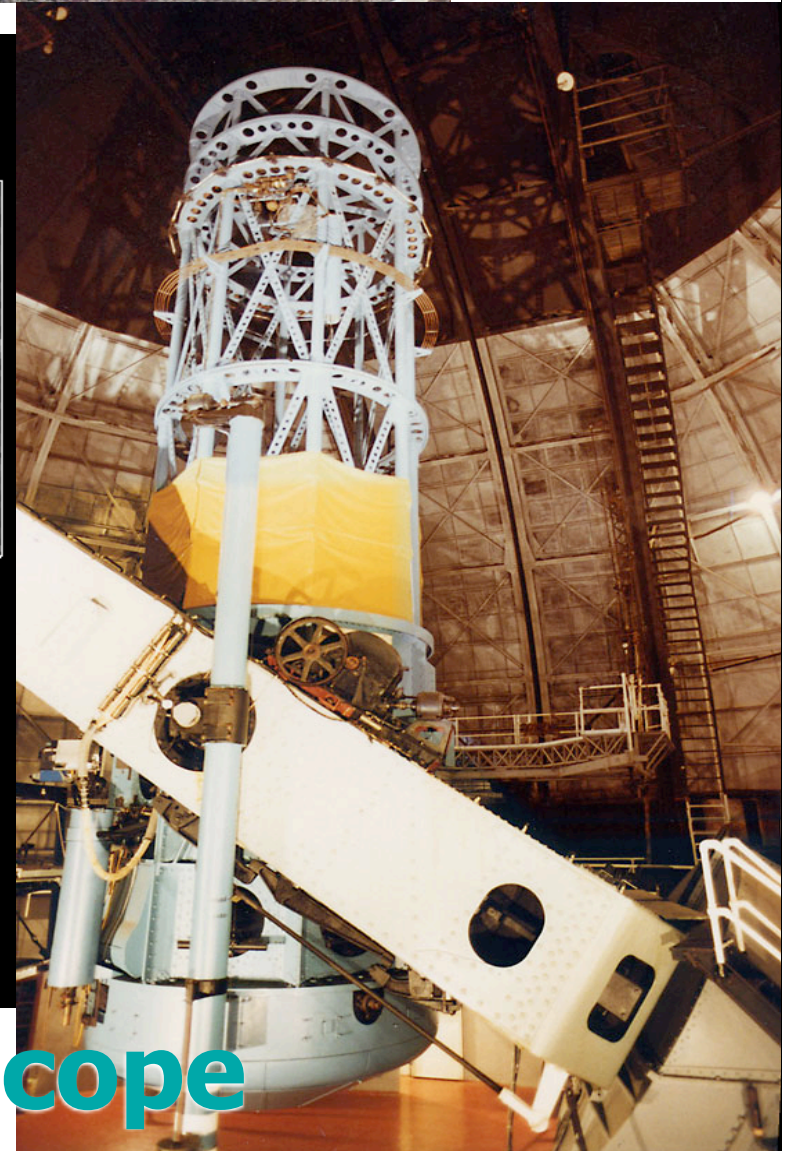
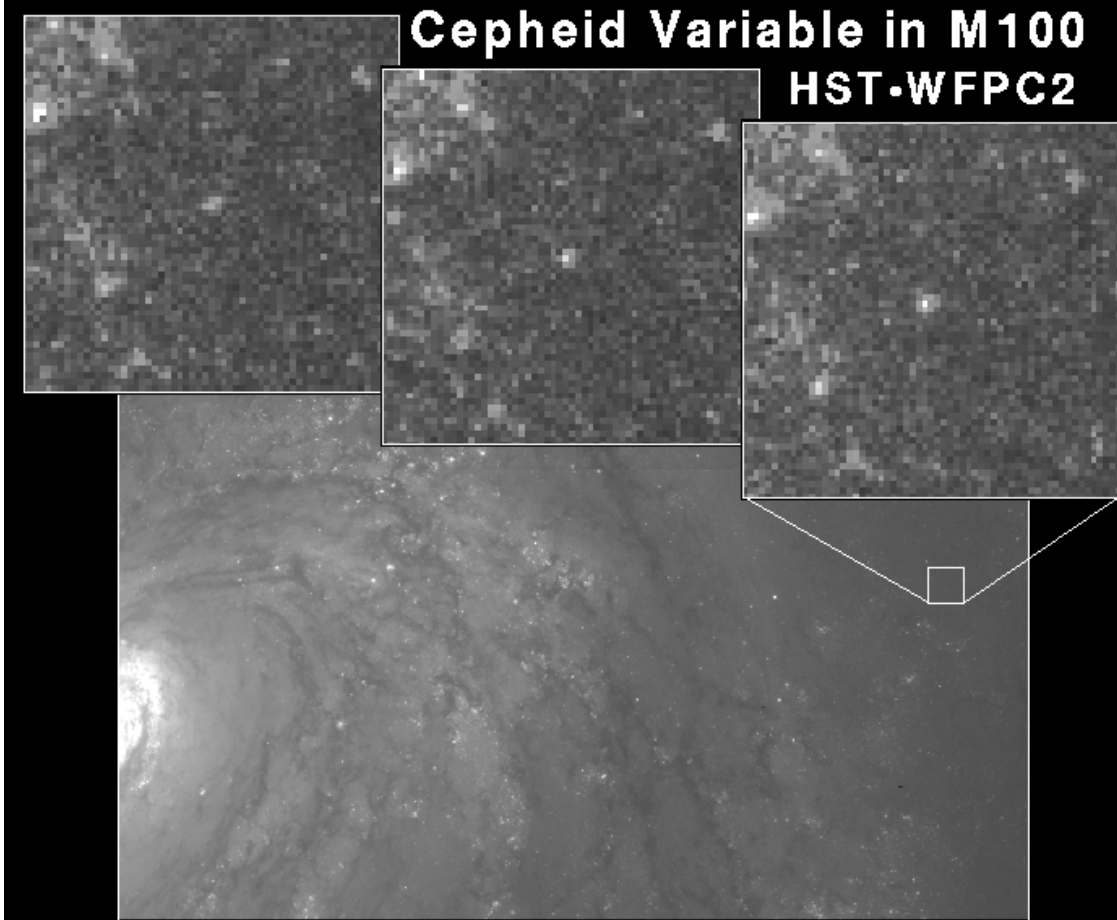
# The 1920's “The Great Debate”

- Harlow Shapley *et al.*
  - The Milky Way was the entirety of the Universe
- Heber Curtis *et al.*
  - The ‘nebula’ in Andromeda (what we now know as the Andromeda galaxy, a.k.a. M31) is another galaxy, much like our own Milky Way: an “Island Universe”.

Also, the first proper big telescopes are getting built.  
e.g. the 100 inch (2.5m) Hooker Telescope at Mt.  
Wilson, CA.

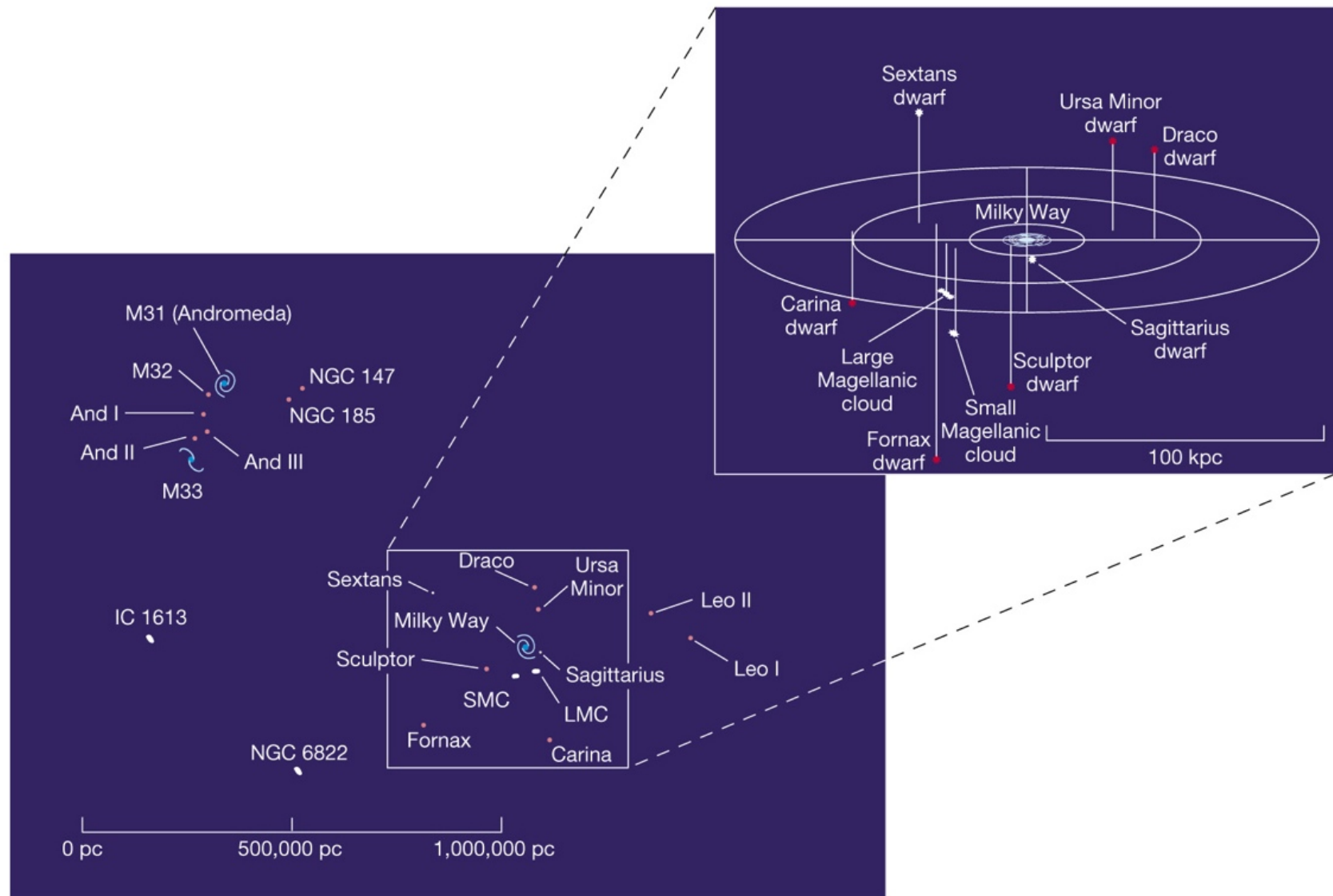
# MOUNT WILSON OBSERVATORY

1929



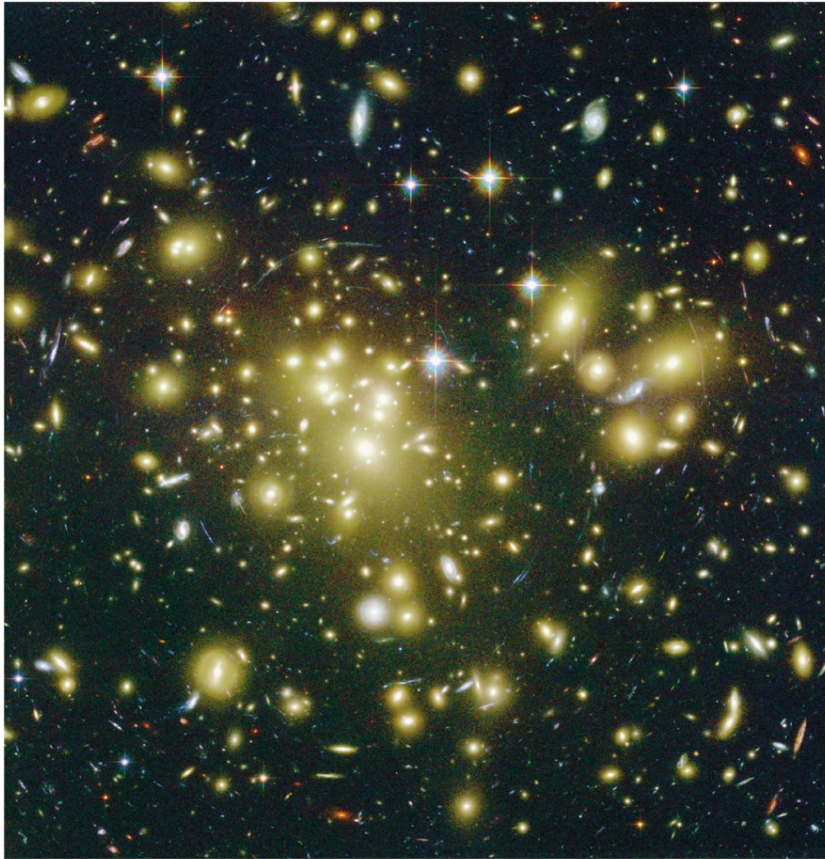
**100-inch** Hooker **telescope**

# The “Local Group”

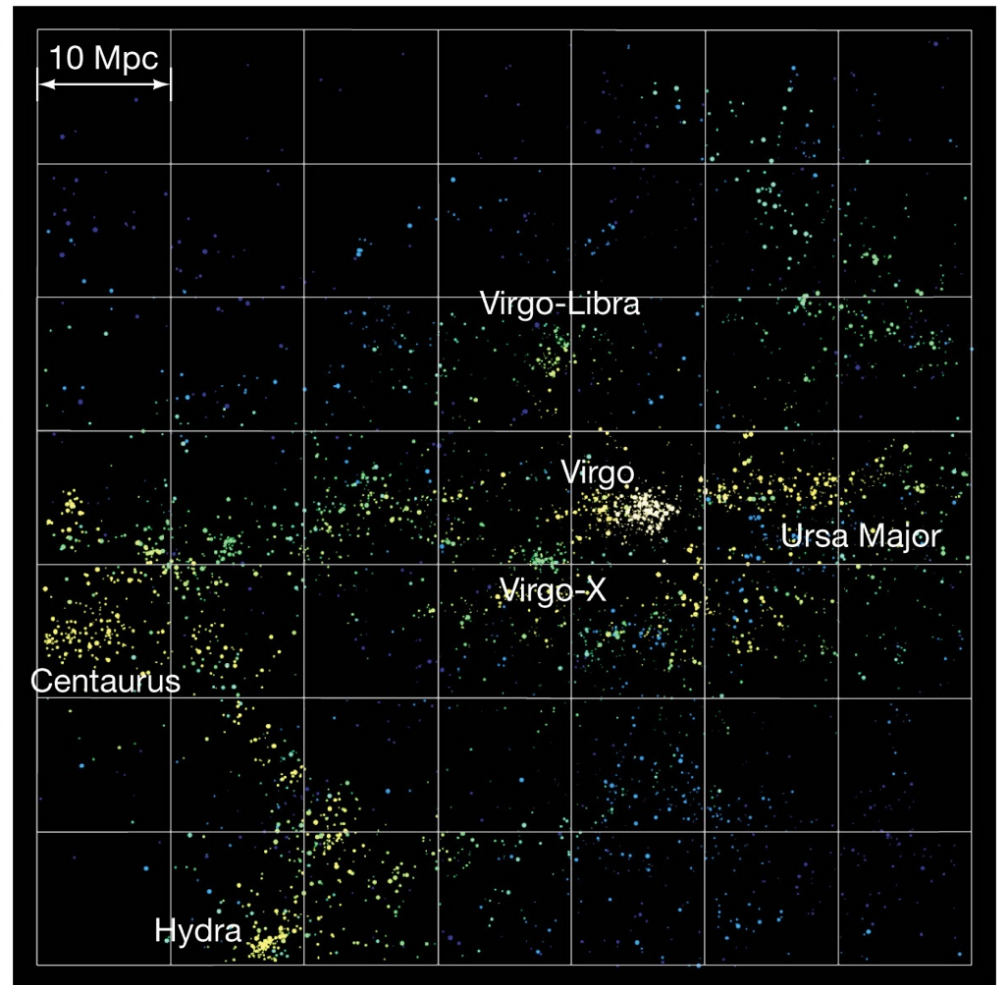




# Clusters and Superclusters

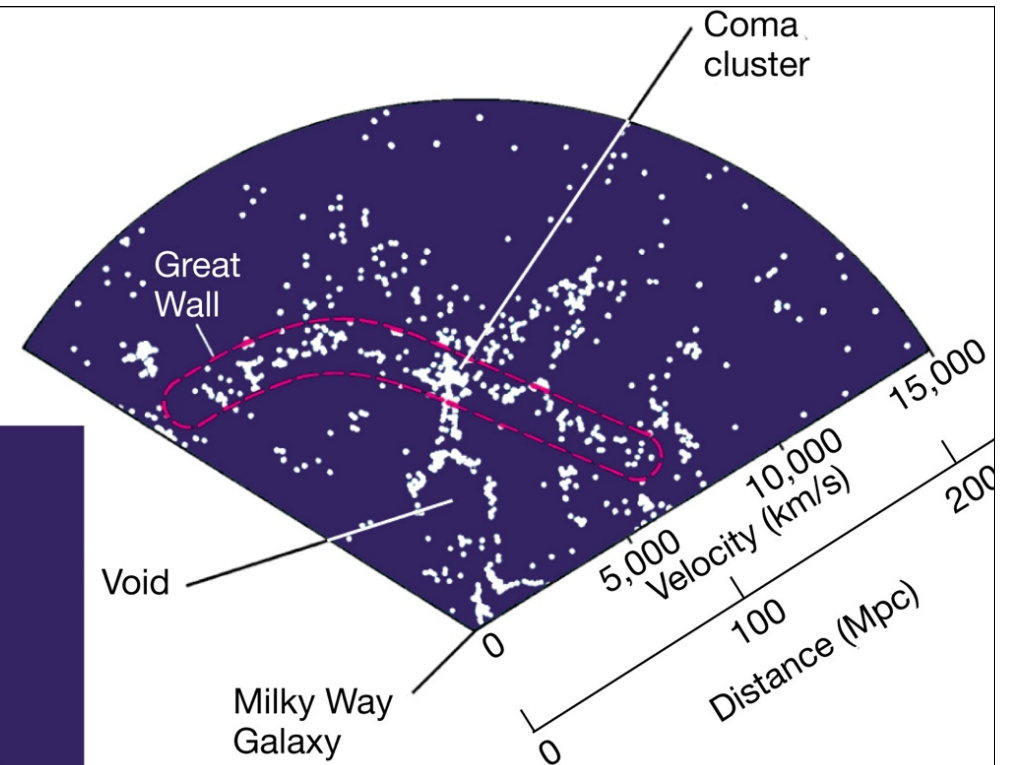
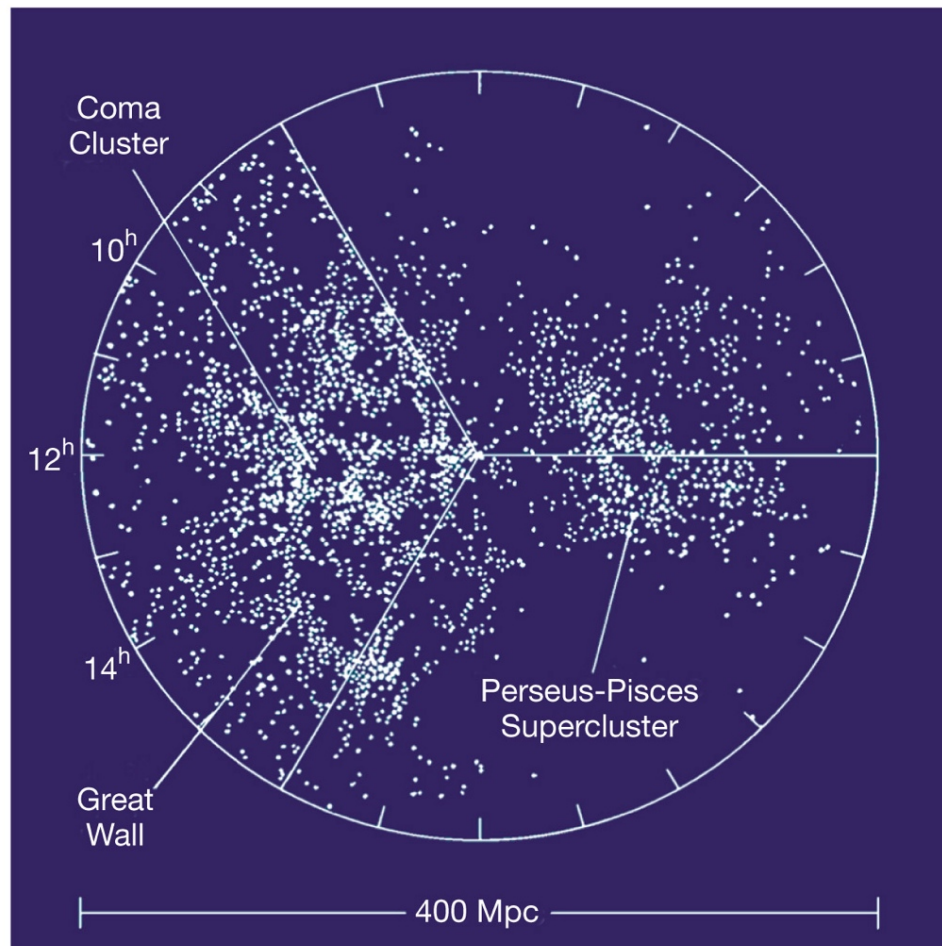


Abel 1689 cluster

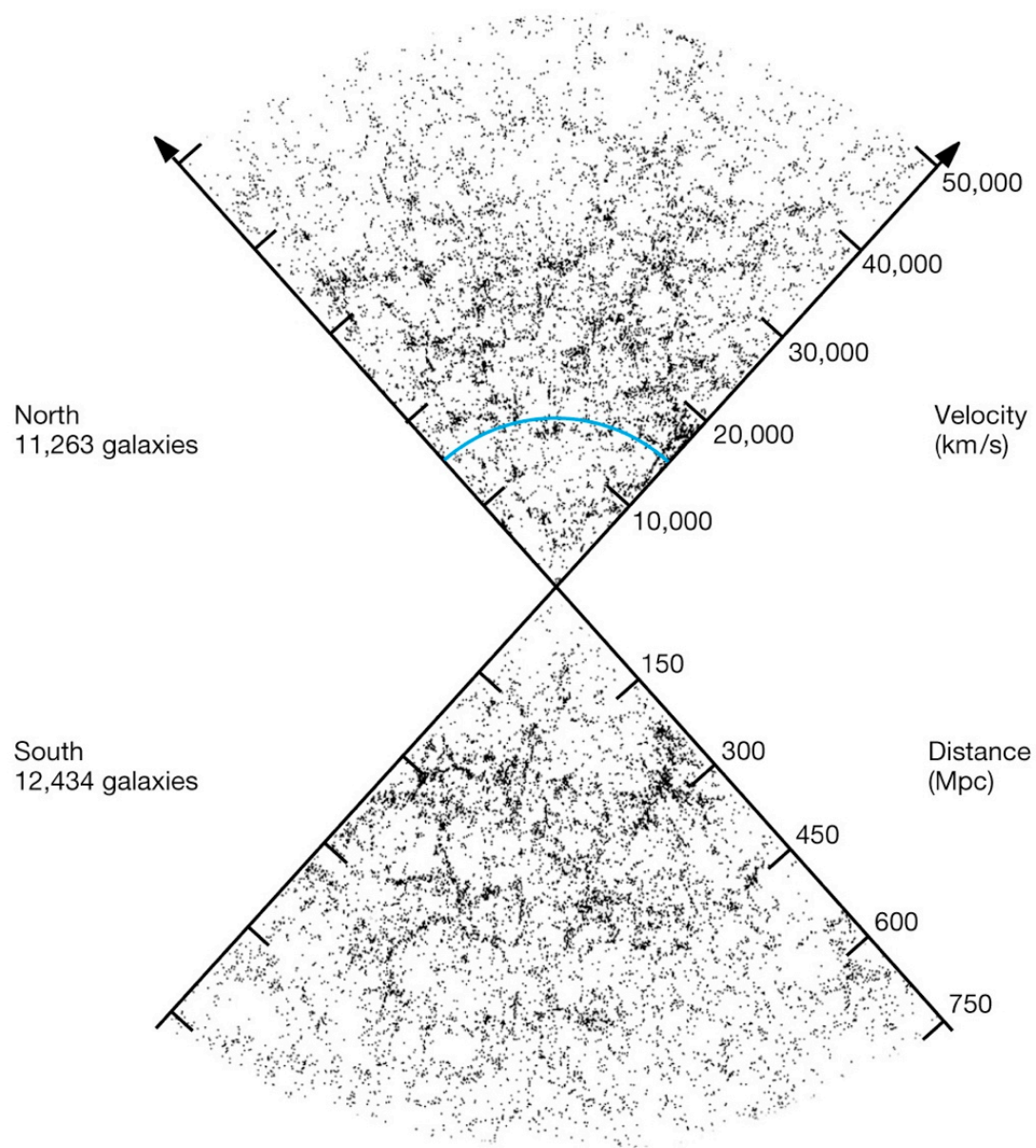


The “local supercluster”

# Filaments and Voids









**How do we measure the  
distance to galaxies?**

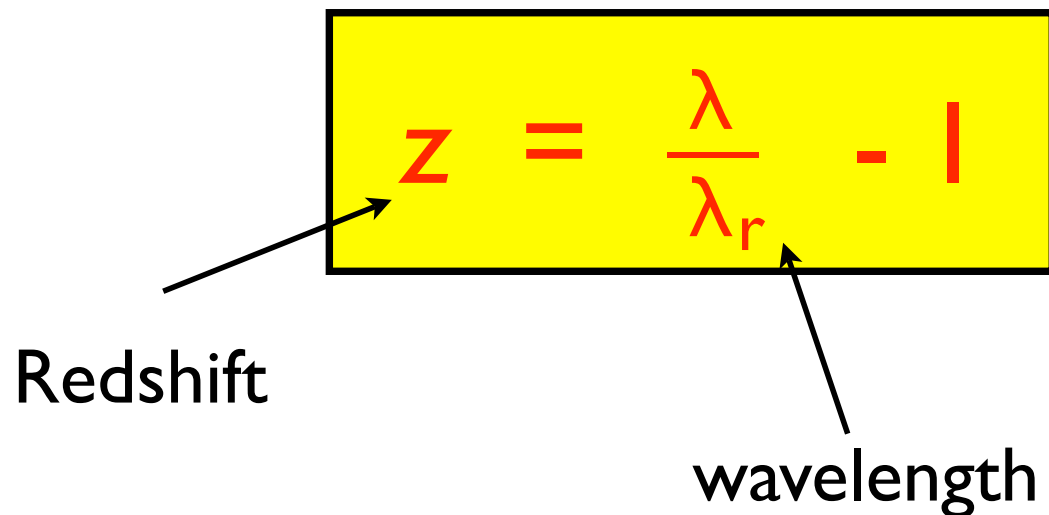
# Redshift

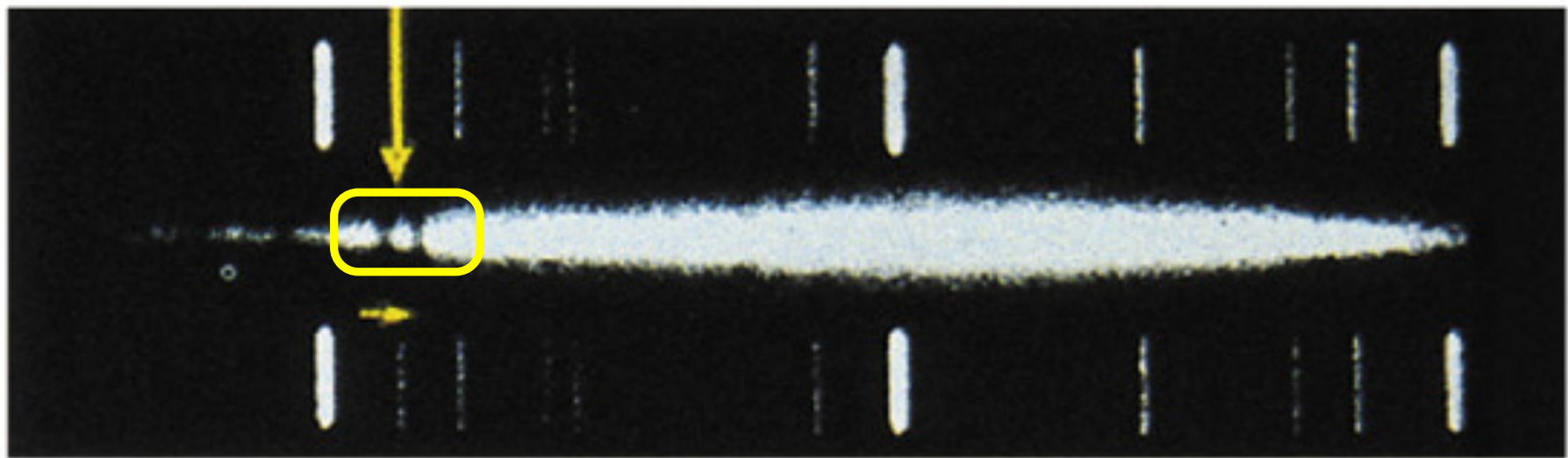
- Essentially, the DOPPLER EFFECT for galaxies.
- Measure the wavelength (from the spectrum) from a galaxy
- Compare it to a “rest” wavelength here on Earth

$$z = \frac{\lambda}{\lambda_r} - 1$$

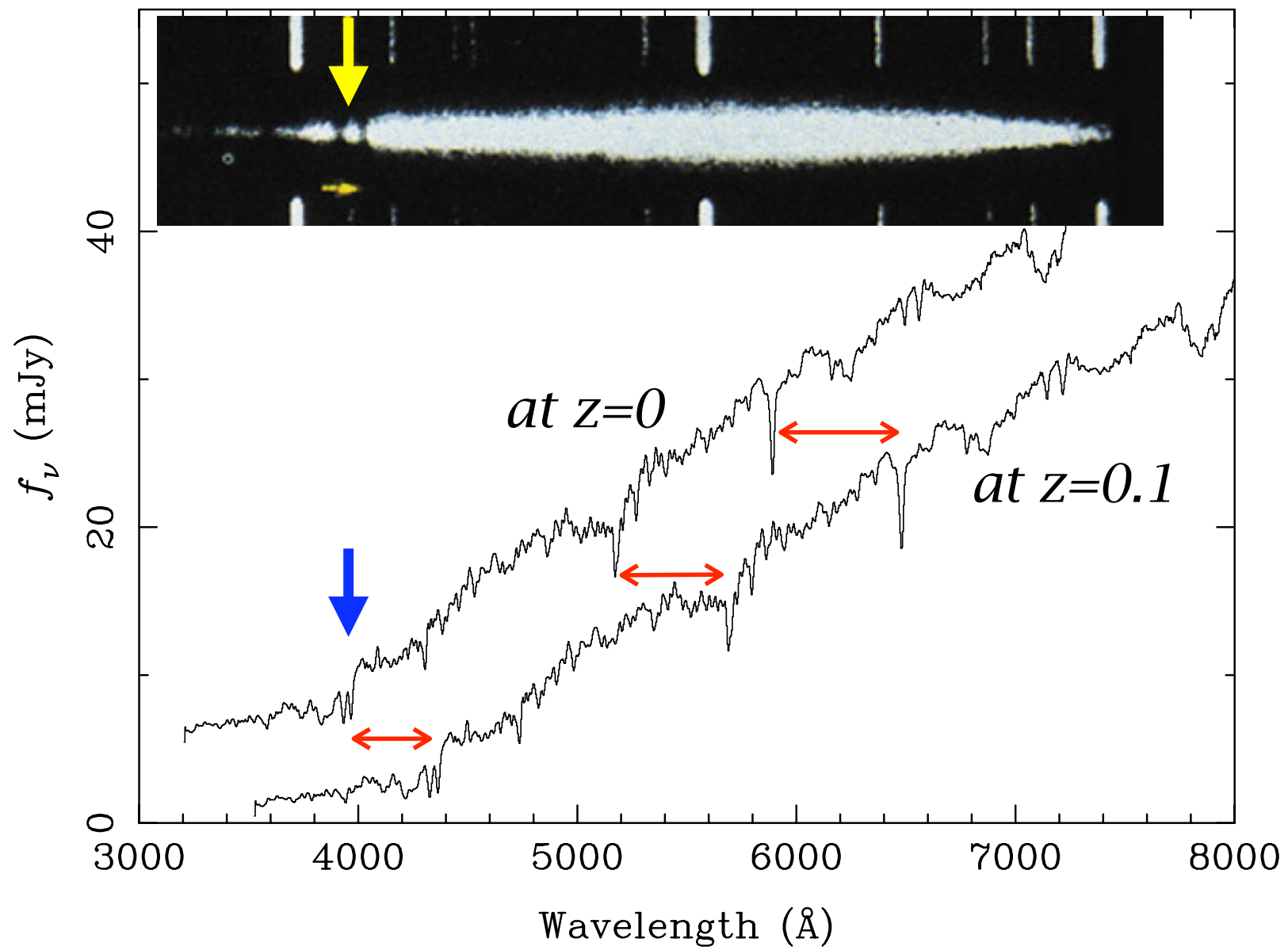
Redshift

wavelength

The diagram shows the redshift formula  $z = \frac{\lambda}{\lambda_r} - 1$  inside a yellow rectangular box with a black border. An arrow points from the label 'Redshift' to the variable 'z' on the left side of the equation. Another arrow points from the label 'wavelength' to the variable ' $\lambda_r$ ' in the denominator of the fraction.



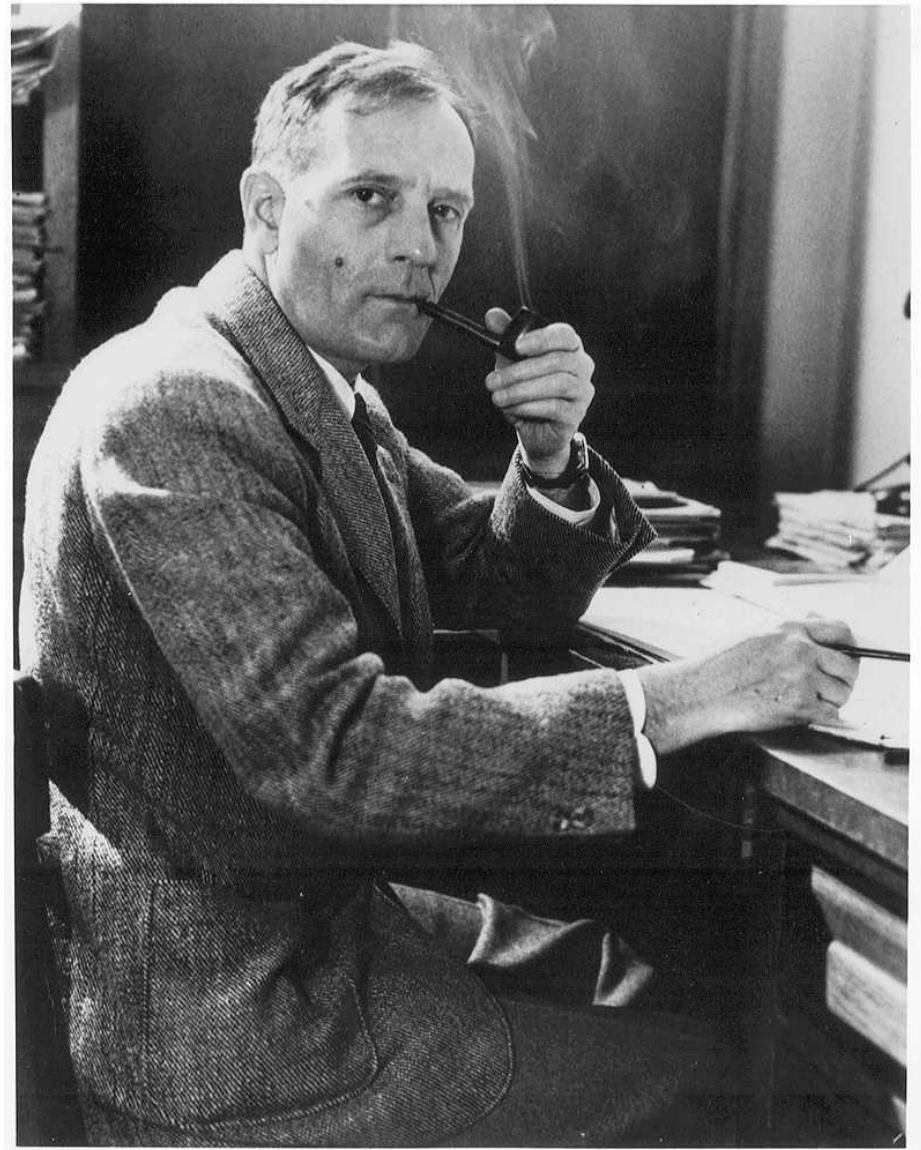
# NGC 3379





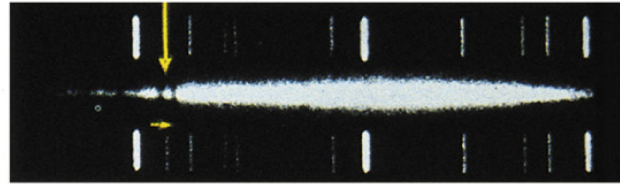
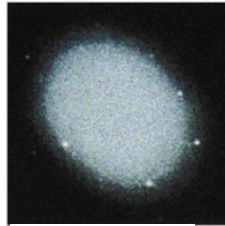
# Edwin Hubble

- 1889-1953
- American
- Originally studied law
- Served in the Army in WWI (Major) and in WWII (Legion of Merit)
- Ph.D. from U.Chicago
- Went to work at Mt. Wilson and Mt. Palomar observatories
- Has a space telescope...



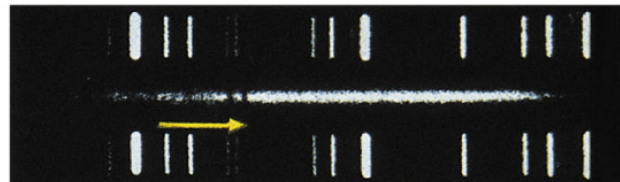
Radial Velocity (or wavelength)

Virgo  
17 Mpc



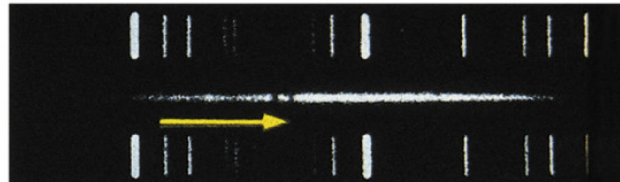
1,210 km/s

Ursa Major  
210 Mpc



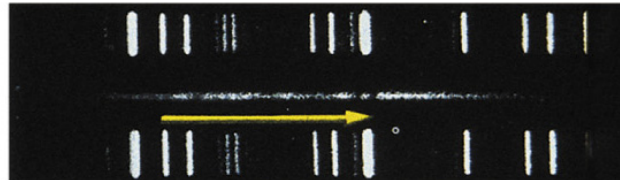
15,000 km/s

Corona Borealis  
310 Mpc



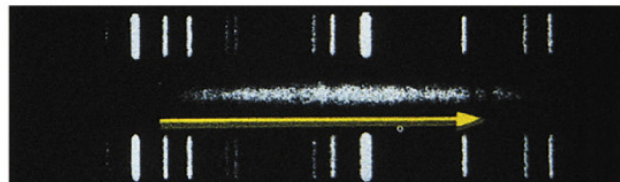
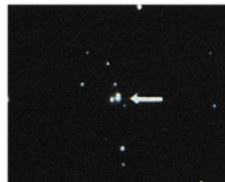
21,600 km/s

Bootes  
560 Mpc



39,300 km/s

Hydra  
870 Mpc



61,200 km/s

## What Hubble did...

- Looked at “Cepheid Variable” stars in our and nearby galaxies and linked *distance* to the **redshift** of light.  
GALAXIES ARE MOVING AWAY FROM US.
- AND!!!! Observed that the ***FURTHER*** away the galaxies were, the ***FASTER*** they were receding!

*This is BIG PROFOUND STUFF....*

# The Expansion of the Universe

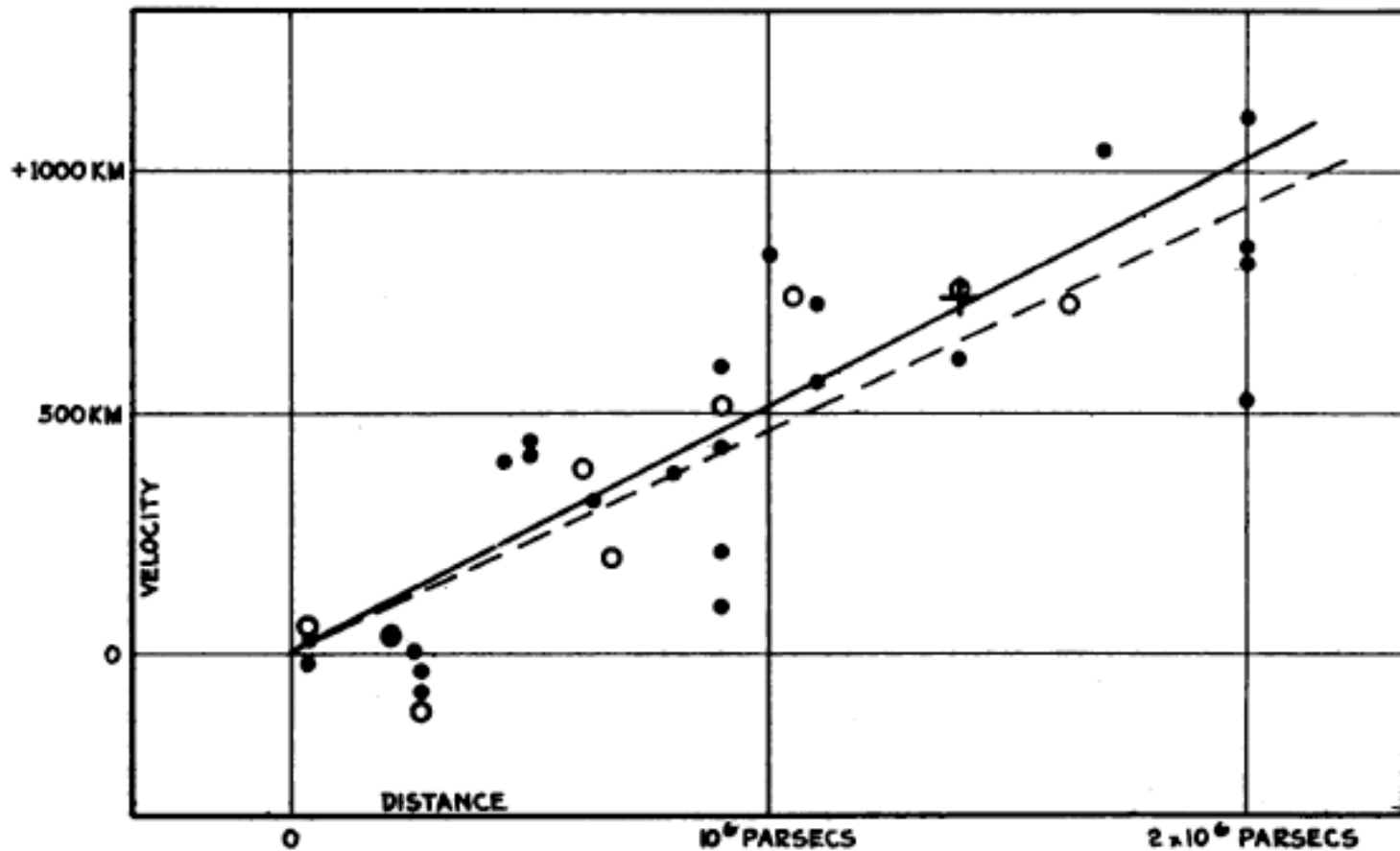


FIGURE 1

- E. P. Hubble (1929, Proc. of the NAS Vol.15, Issue 3, pp. 168-173)



# The Hubble Law

Relation between (recessional) velocity and distance:

The diagram shows the Hubble Law equation  $v = H_0 d$  inside a yellow rectangular box. Three arrows point from descriptive labels to the variables in the equation: one from 'velocity (km/s)' to  $v$ , one from 'Hubble Constant (km/s/Mpc)' to  $H_0$ , and one from 'distance (Mpc)' to  $d$ .

$$v = H_0 d$$

velocity (km/s)

Hubble Constant (km/s/Mpc)

distance (Mpc)

# The Expansion of the Universe

- Galaxies go with the “Hubble Flow”....
- **Velocity = constant x Distance**
- Hubble’s original estimate of constant had:  
 **$\sim 500 \pm 100 \text{ km/s/Mpc}$**
- Today’s best estimate:  
 **$\sim 70 \pm 1 \text{ km/s/Mpc}$**

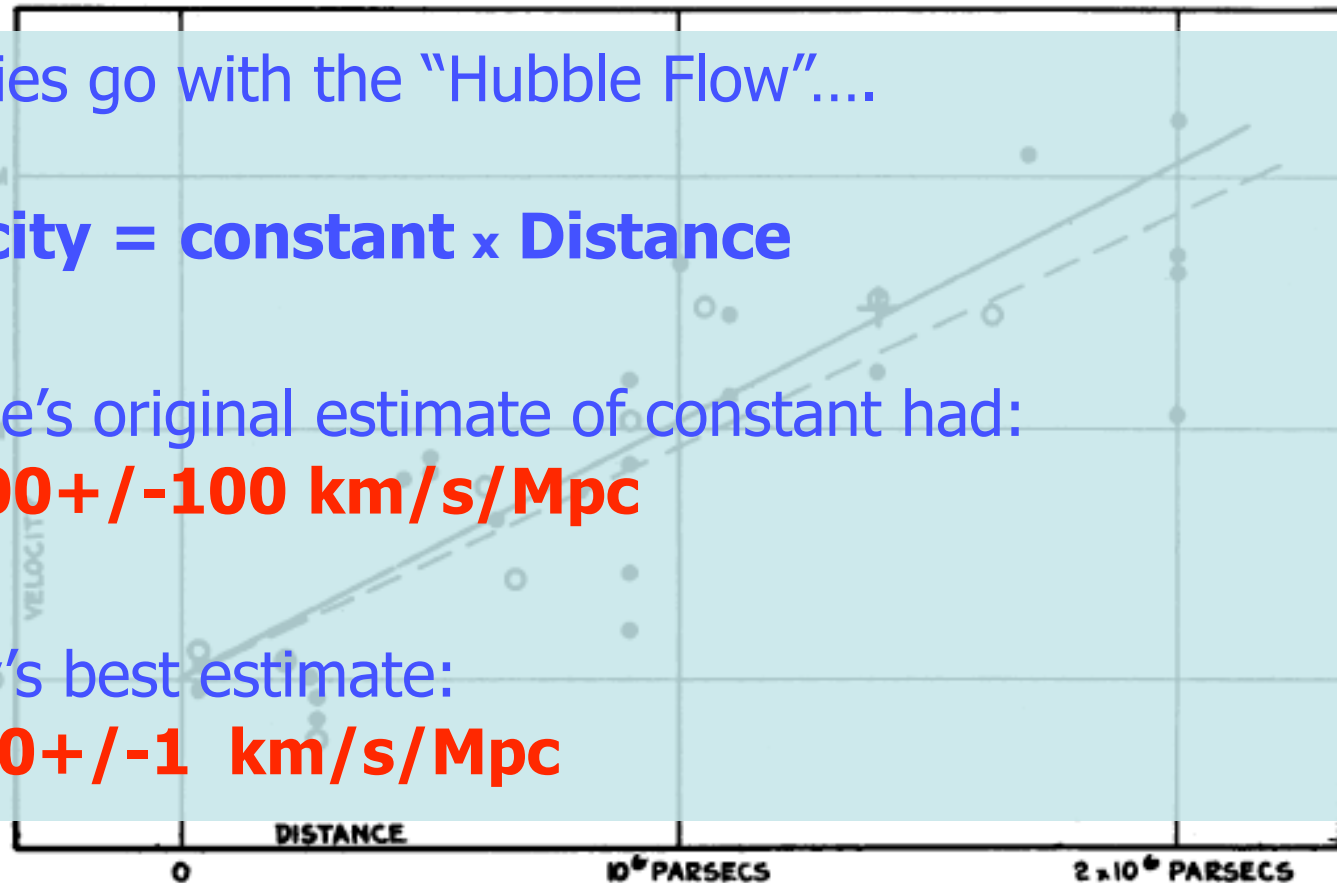
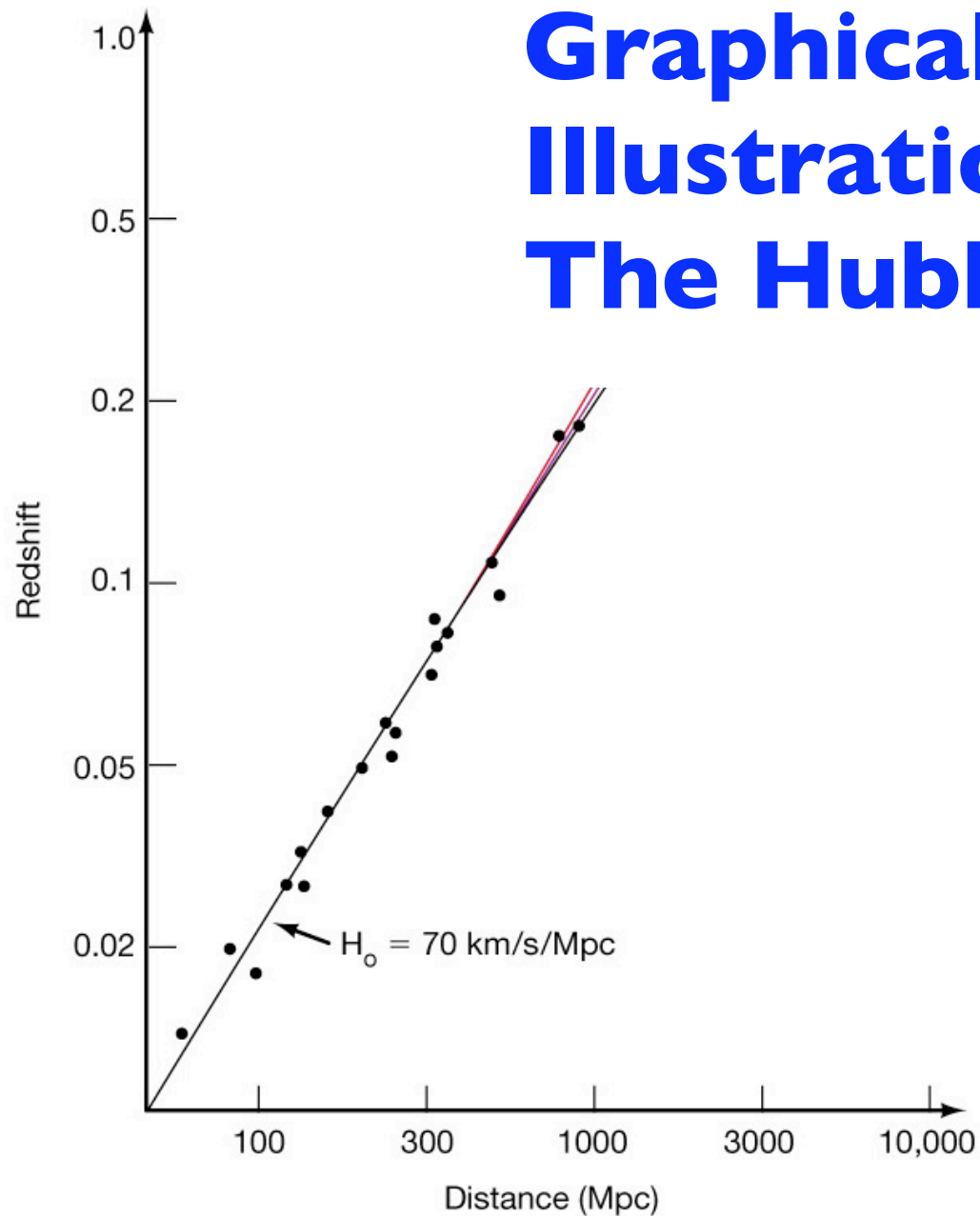
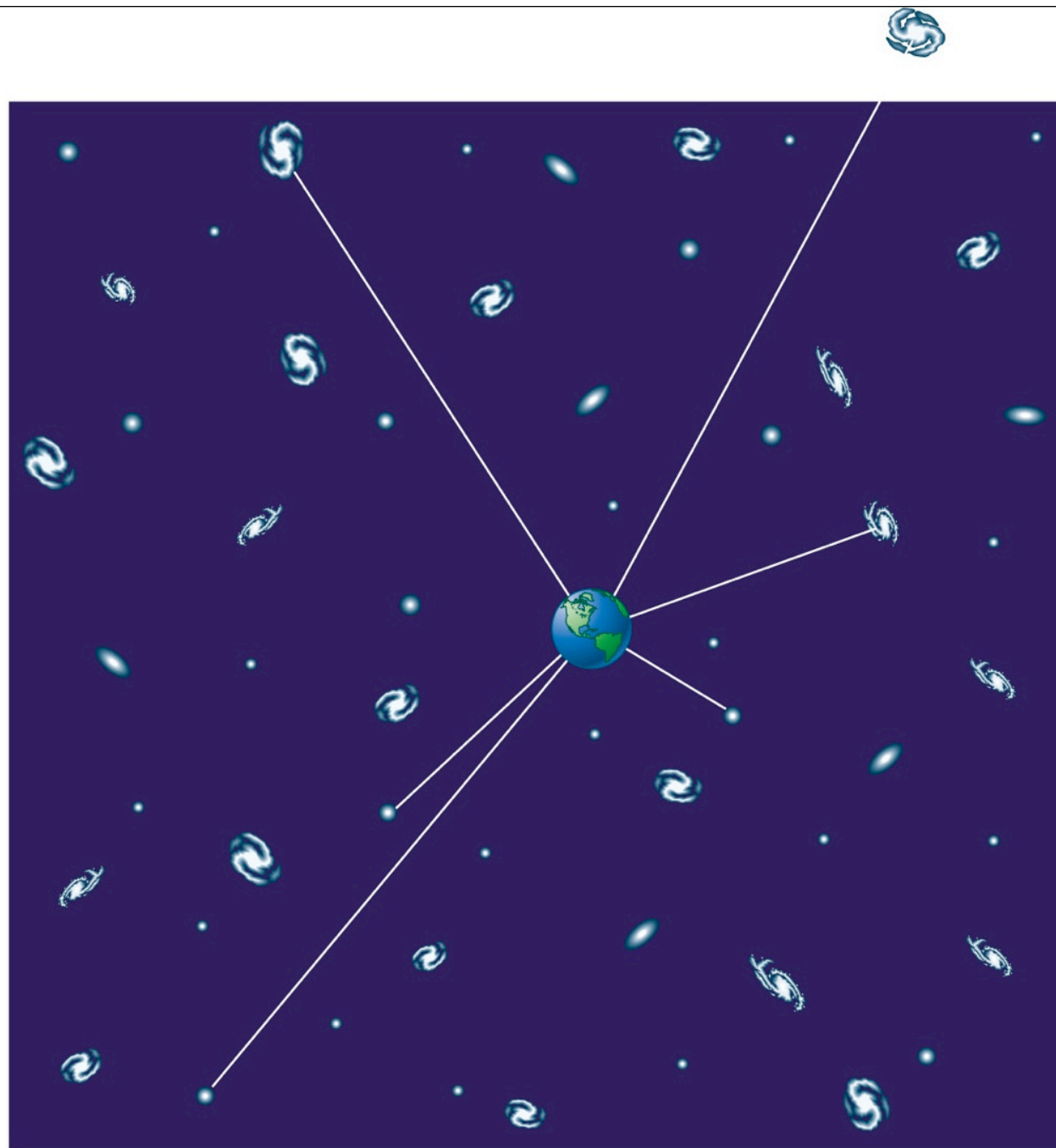


FIGURE 1

- E. P. Hubble (1929, Proc. of the NAS Vol.15, Issue 3, pp. 168-173)

# Graphical Illustration of the The Hubble Law

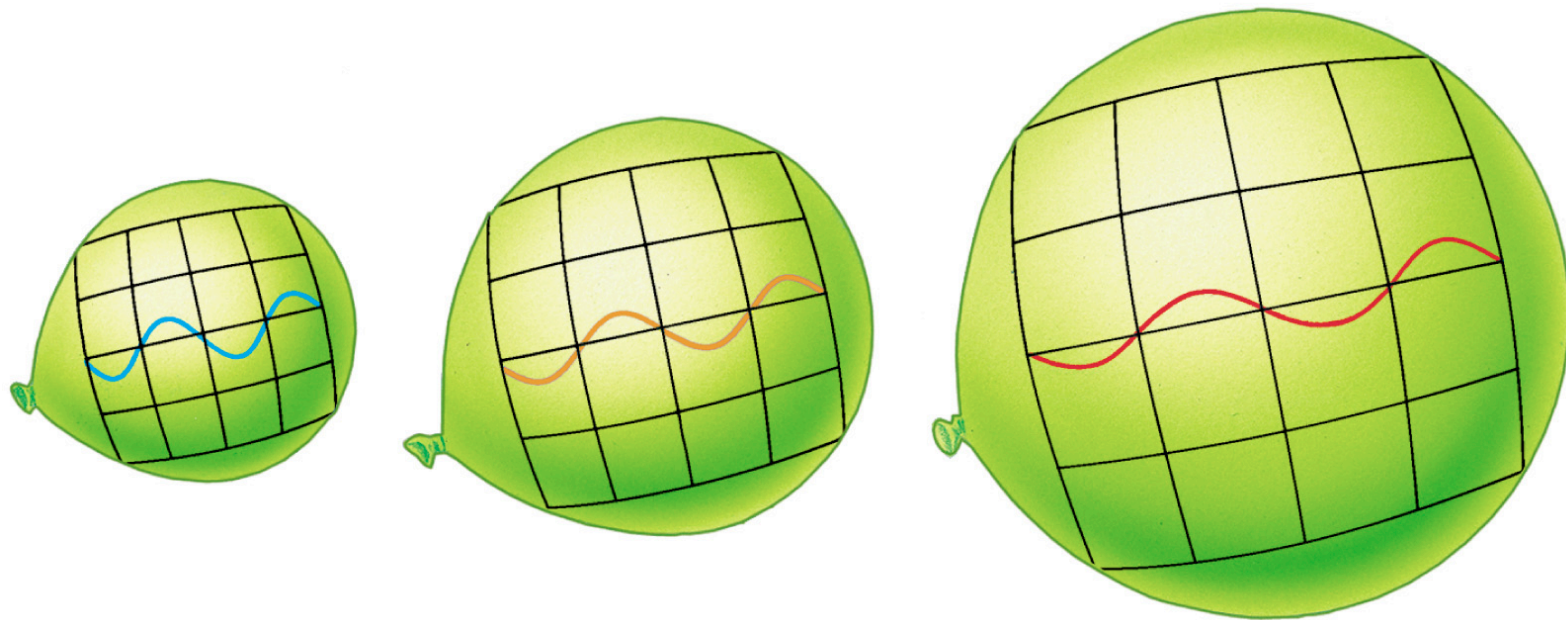
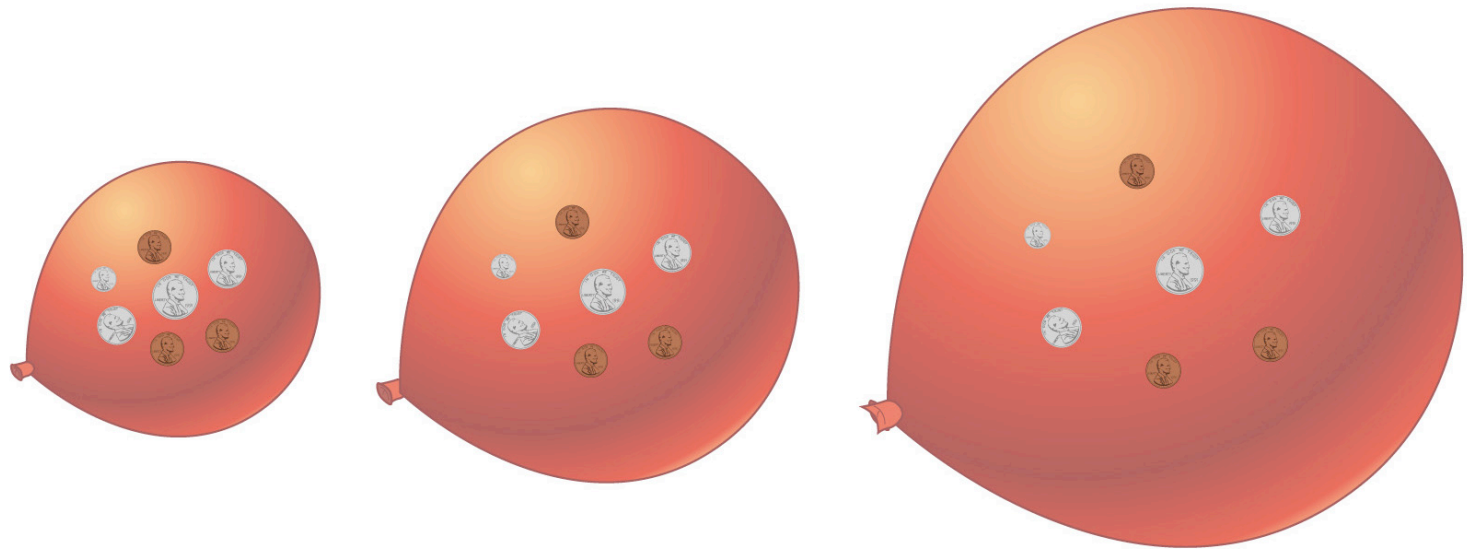






**Where's the “center” of  
expansion??**

**- Is it the Earth??!!**



# Implications of the Hubble Law

- Today, the Universe is expanding.
- Stop the tape.
- Press “Rewind”.
- Everything, space and time, starts coming together...

# The Big Bang Theory

- In the past, everything is closer together...
- The Universe is **YOUNGER**, **HOTTER** and **DENSER**
- Georges Lemaître suggested “primeval atom” in 1927
- Evidence:
  - Hubble’s Law
  - The Cosmic Microwave Background
  - Abundance of light elements (Nucleosynthesis)
  - [“Large Scale Structure” (distribution of galaxies)]



**How long ago was  
the Big Bang?**

***About 14 billion years ago.***