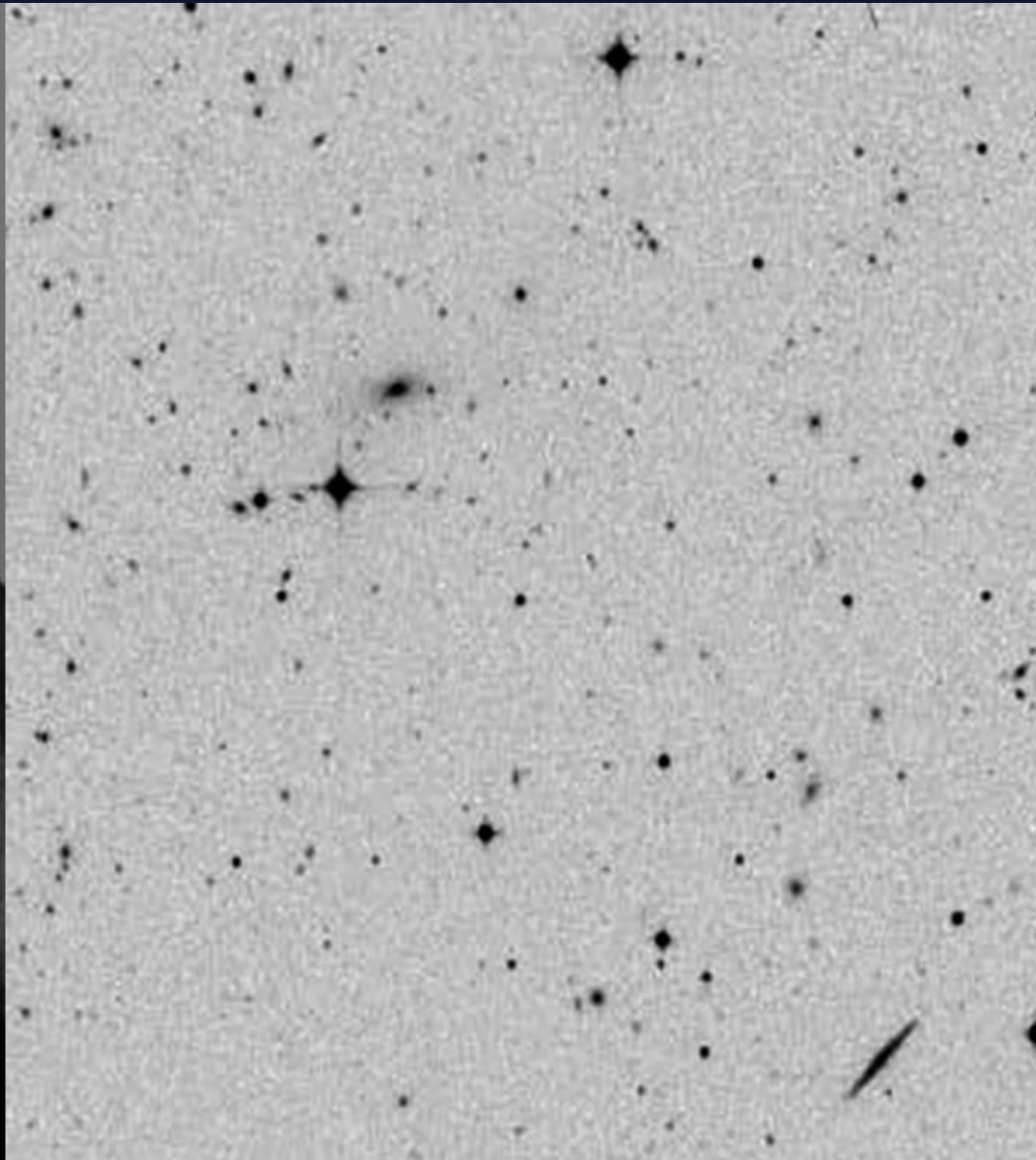


L13: The Universe and the Big Bang

The Great Debate



The Great Debate

Shapley vs. Curtis (1920)

In April 1920, two pioneering astronomers met at the Smithsonian Museum of Natural History to debate the nature of the cosmos.

The central question: Was the **Milky Way** the entire universe, or were spiral nebulae separate, distant "**Island Universes**"?

This pivotal moment set the stage for our modern understanding of the scale of the universe.

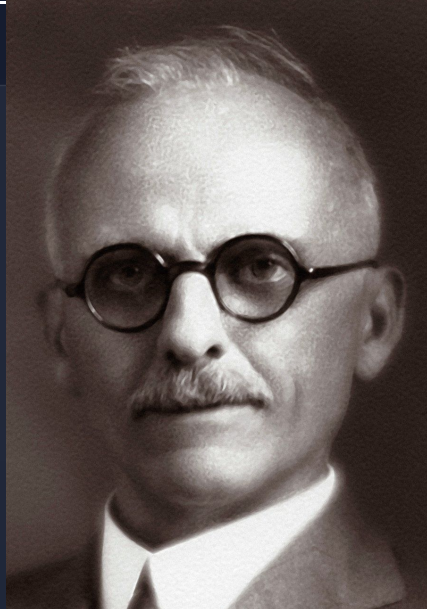


The Contenders & The Verdict



Harlow Shapley

Argued the **Milky Way** was **massive** (300,000 light-years) and constituted the entire universe. He believed spiral nebulae were merely local gas clouds within our galaxy.



Heber Curtis

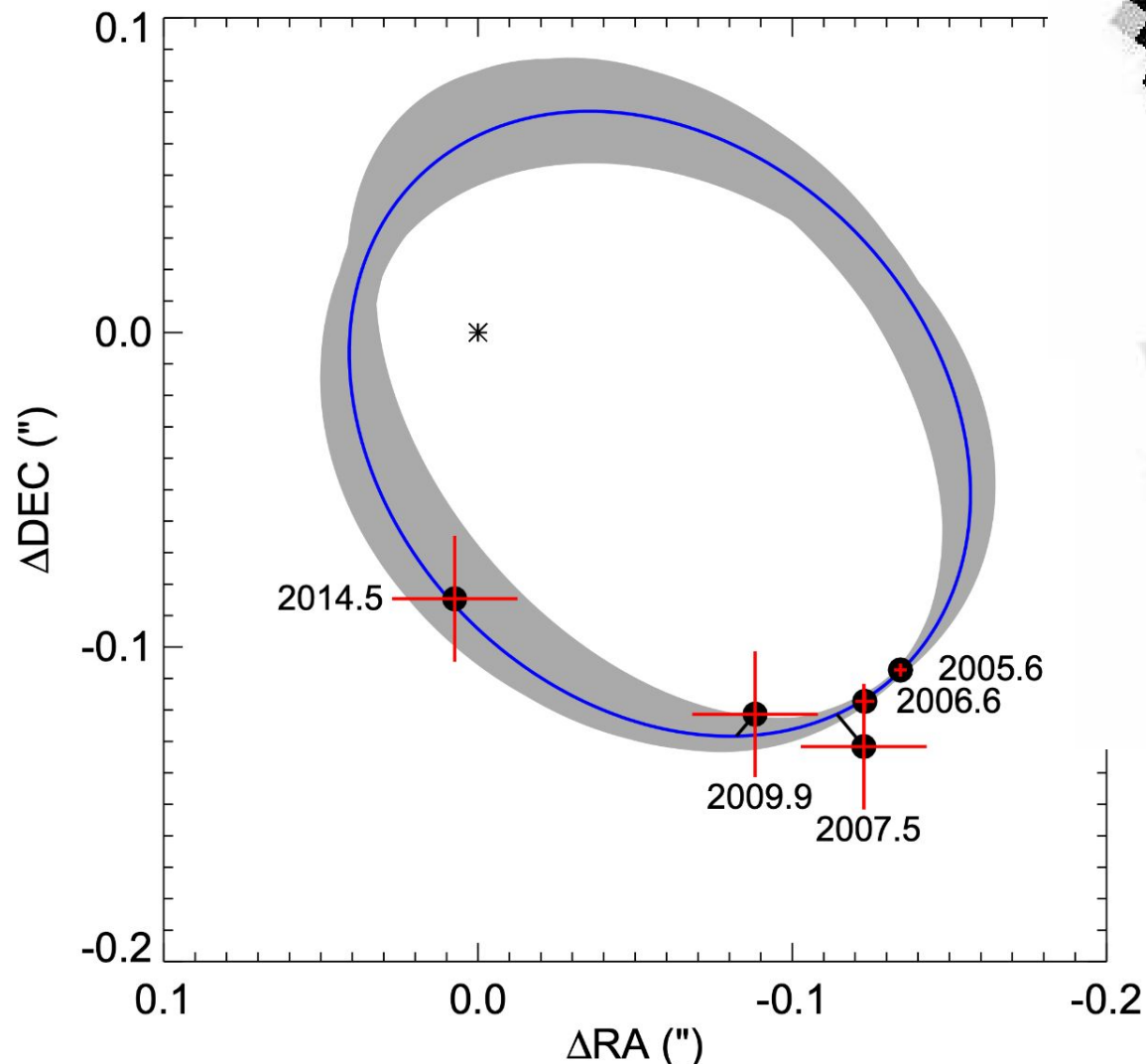
Contended the Milky Way was smaller (30,000 light-years) and that spiral nebulae were distinct, distant galaxies—independent **"Island Universes"** comparable to our own.



The Verdict (1924)

Edwin Hubble discovered a **Cepheid variable star** in Andromeda. His calculations proved it was far outside the Milky Way, confirming Curtis's view of separate galaxies.

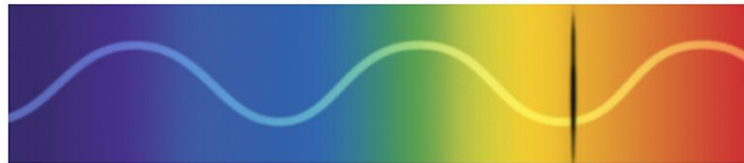
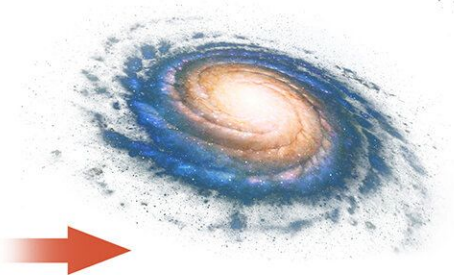
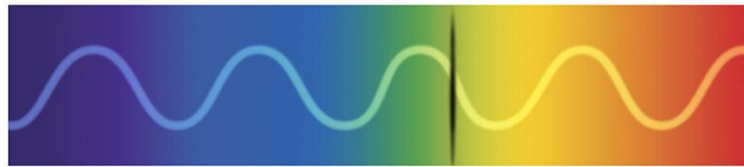
Polaris Aa and Ab (Evans et al, 2018)



Polaris is the Closest Cepheid to Earth (Accurate 445.5 light-years away)

Fig. 4.— Visual orbit of Polaris Ab relative to Aa, based on our *HST* measurements. Black

Hubble “Red Shift”



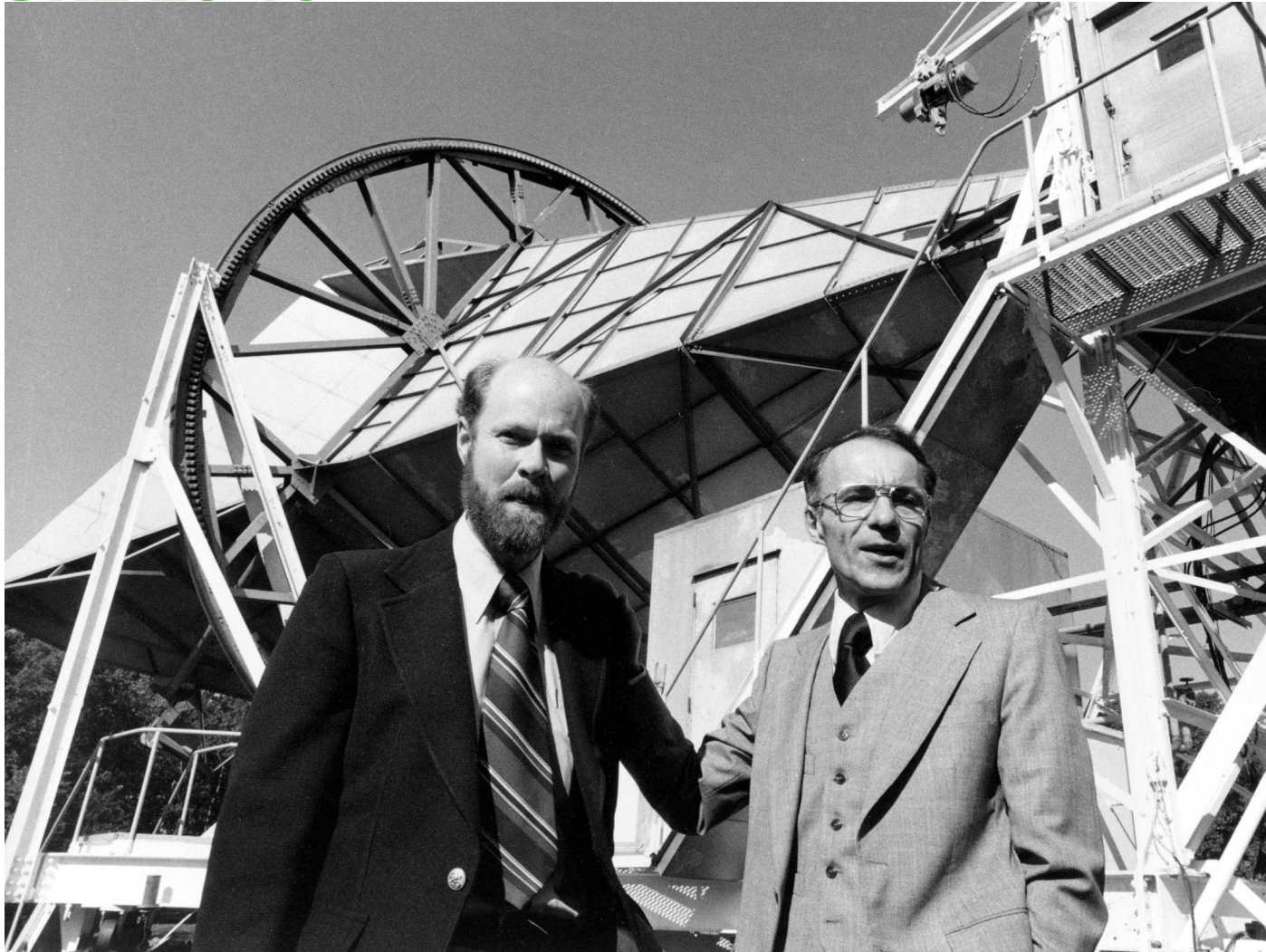
Project Echo (Bell Labs Holmdel, NJ)



Project Echo (Bell Labs Holmdel, NJ)

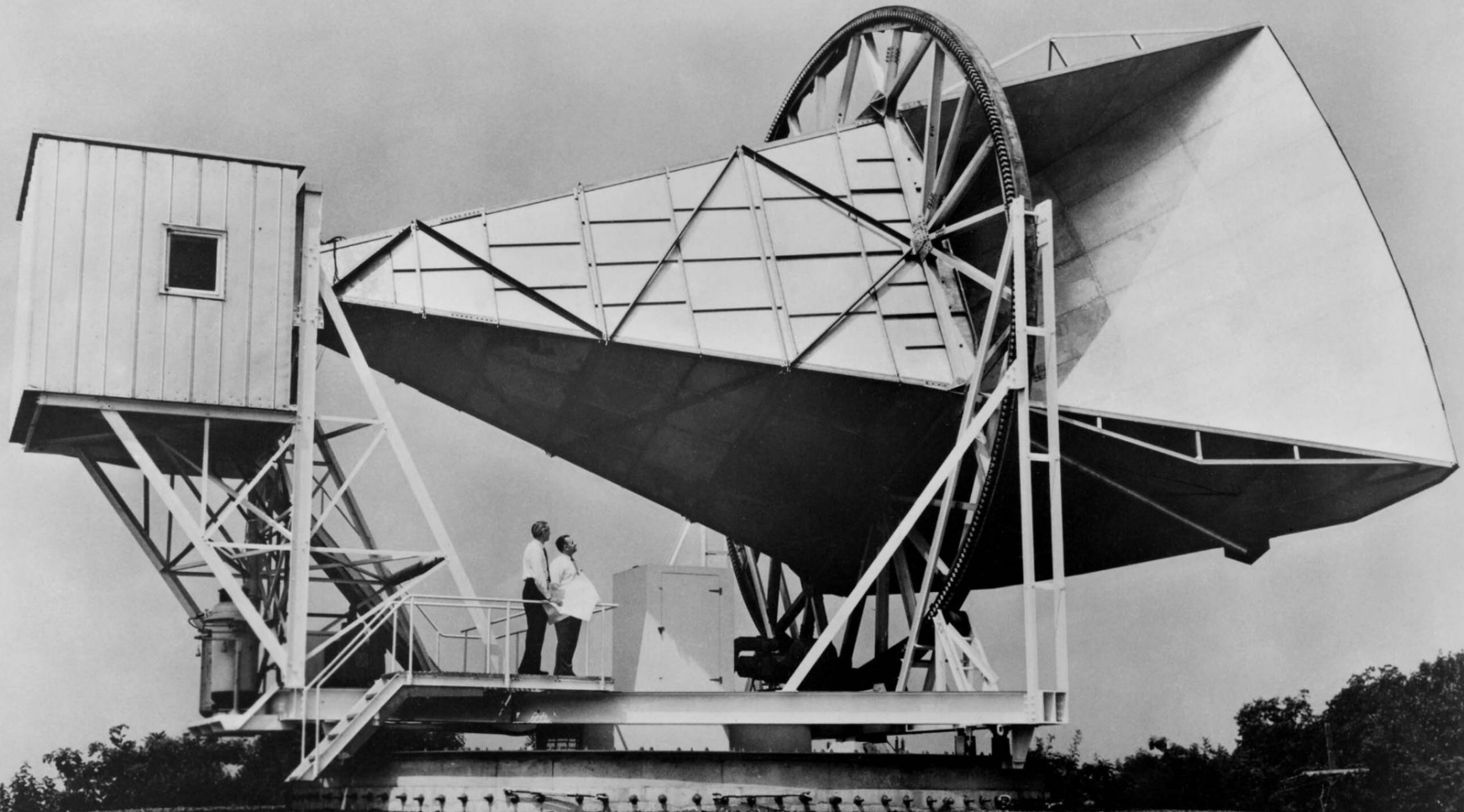


FIGURE 29.16

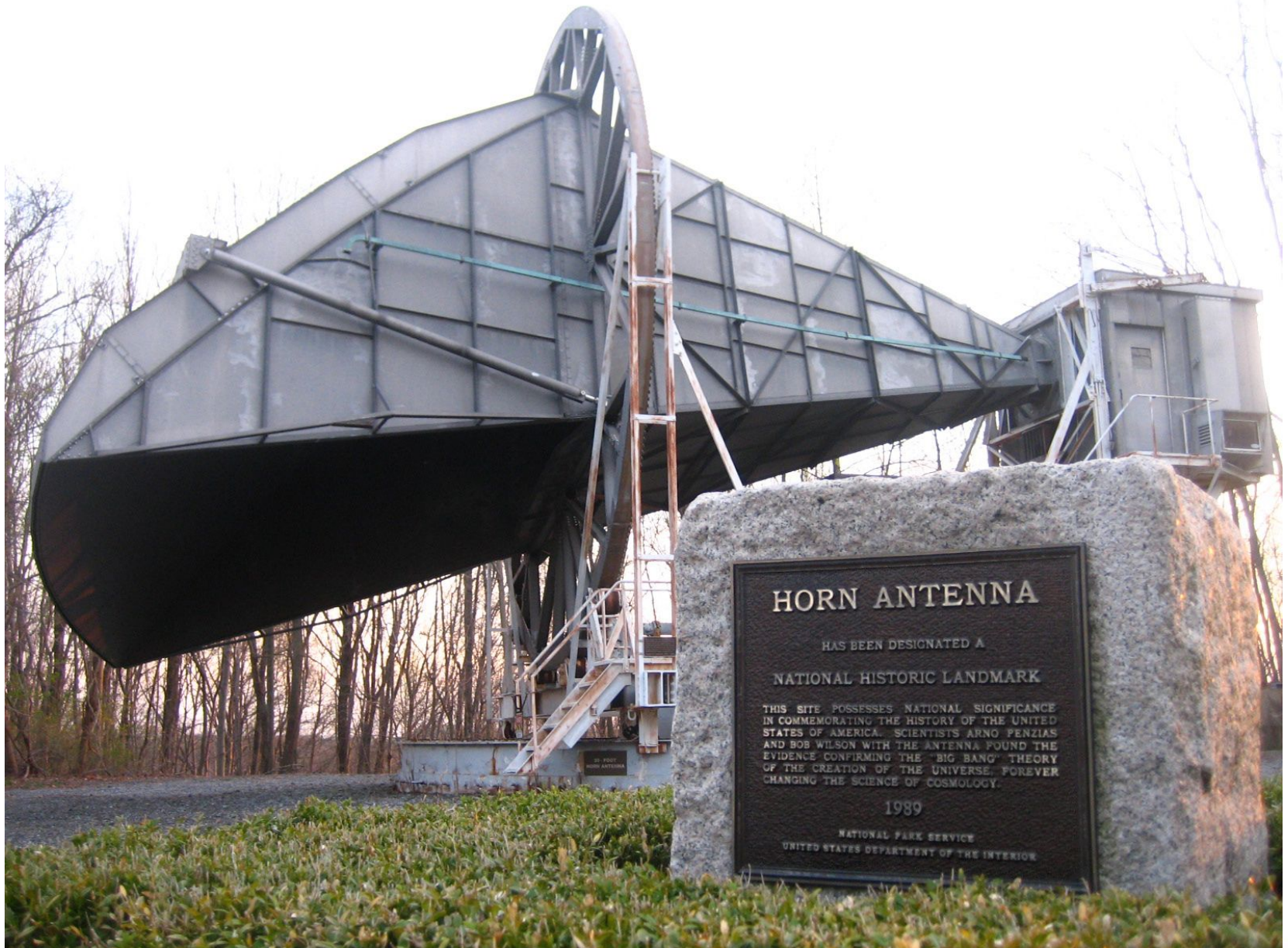


Robert Wilson (left) and Arno Penzias (right). These two scientists are standing in front of the horn-shaped antenna with which they discovered the cosmic background radiation. The photo was taken in 1978, just after they received the Nobel Prize in physics.

Horn Antenna-in Holmdel, New Jersey



Horn Antenna-in Holmdel, New Jersey



HORN ANTENNA

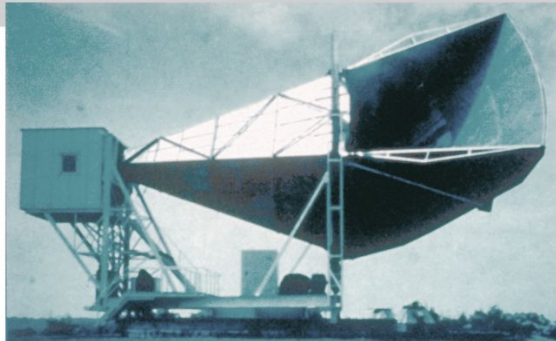
HAS BEEN DESIGNATED A
NATIONAL HISTORIC LANDMARK

THIS SITE POSSESSES NATIONAL SIGNIFICANCE
IN COMMEMORATING THE HISTORY OF THE UNITED
STATES OF AMERICA. SCIENTISTS ARNO PENZIAS
AND BOB WILSON WITH THE ANTENNA FOUND THE
EVIDENCE CONFIRMING THE "BIG BANG" THEORY
OF THE CREATION OF THE UNIVERSE, FOREVER
CHANGING THE SCIENCE OF COSMOLOGY.

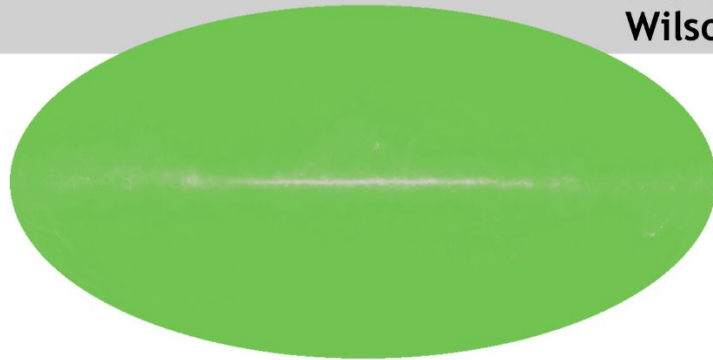
1989

NATIONAL PARK SERVICE
UNITED STATES DEPARTMENT OF THE INTERIOR

1965



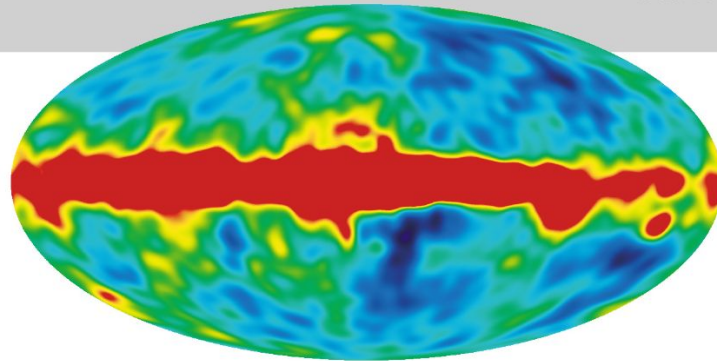
Penzias and
Wilson



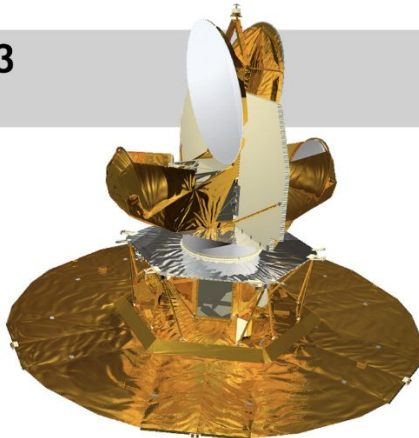
1992



COBE



2003



WMAP

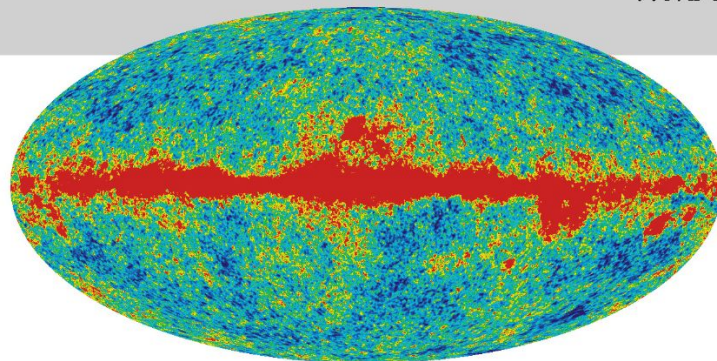
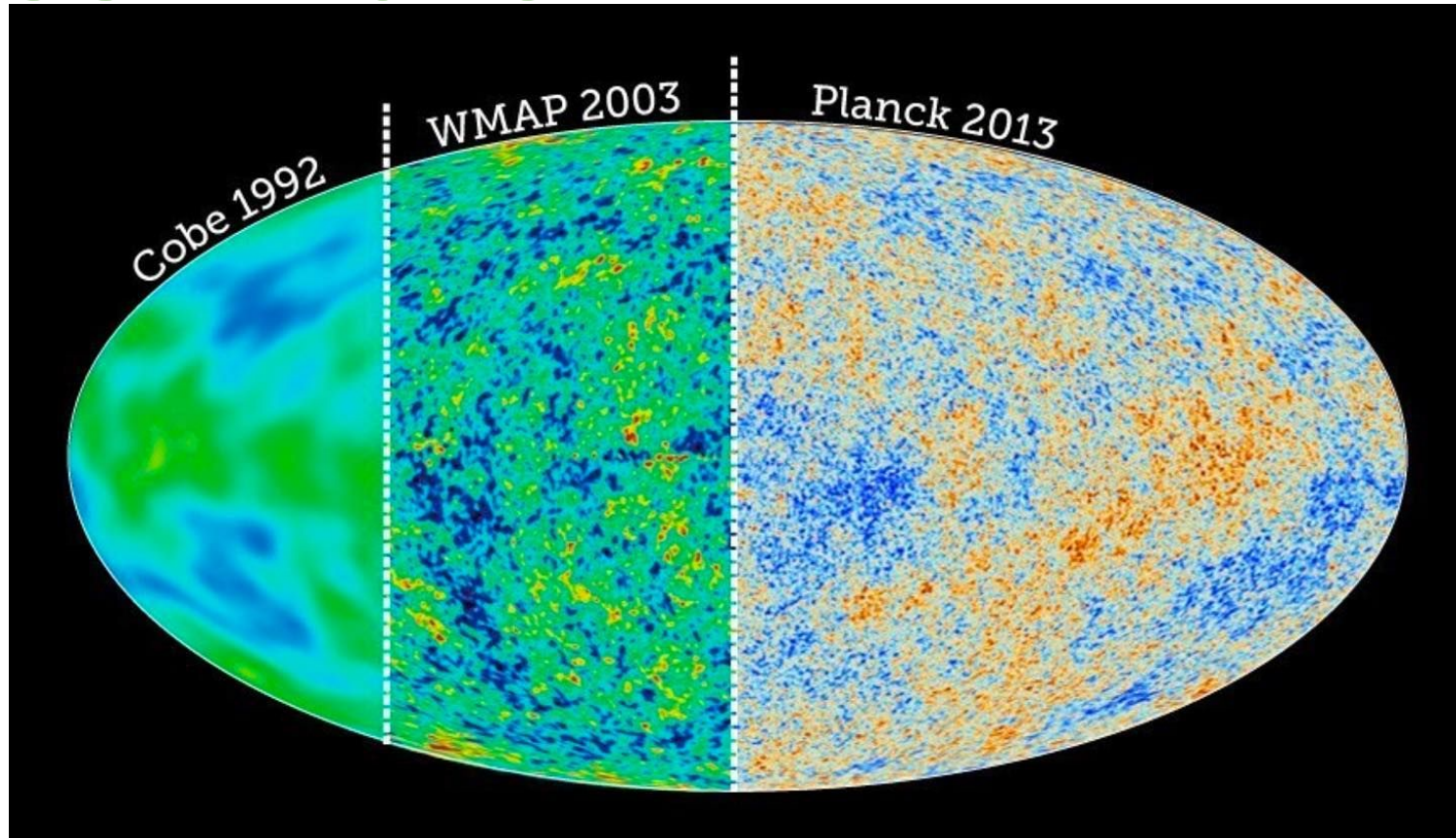


FIGURE 29.18



CMB Observations. This comparison shows how much detail can be seen in the observations of three satellites used to measure the CMB. The CMB is a snapshot of the oldest light in our universe, imprinted on the sky when the universe was just about 380,000 years old. The first spacecraft, launched in 1989, is NASA's Cosmic Background Explorer, or COBE. WMAP was launched in 2001, and Planck was launched in 2009. The three panels show 10-square-degree patches of all-sky maps. This cosmic background radiation image (bottom) is an all-sky map of the CMB as observed by the Planck mission. The colors in the map represent different temperatures: red for warmer and blue for cooler. These tiny temperature fluctuations correspond to regions of slightly different densities, representing the seeds of all future structures: the stars, galaxies, and galaxy clusters of today. (credit top: modification of work by NASA/JPL-Caltech/ESA; credit bottom: modification of work by ESA and the Planck Collaboration)





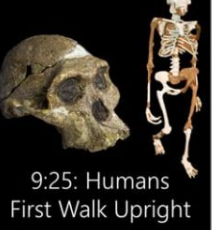



1.15

The Cosmic Calendar


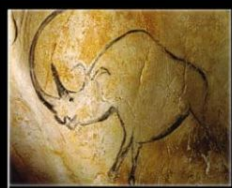
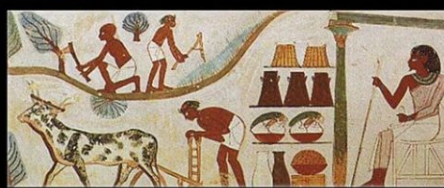
The 13.8 billion year history of the universe scaled down to a single year, where the Big Bang is January 1st at midnight, and right now is midnight 1 year later

January	February	March	April	May	June	July	August	September	October	November	December
<p><i>Known from telescopes looking back in time, physical models</i></p>								<p><i>Known from geologic record, fossils, genetic drift</i></p>			
<p>The Big Bang, Stars First Appear</p>				<p>Thin Disk of the Milky Way</p>				<p>The Solar System, Life</p>	<p>Oxygen from Photosynthesis</p>	<p>Eukaryotic Cells</p>	<p>Multicellular Life</p>

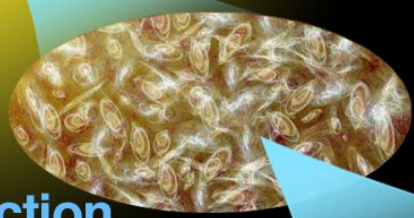
The Month of December...

1	2	3	4	5	6	7	8	9	10	11	12	13	14		
15 Trace Fossils Only		16		17 Bones and Shells		18 Vertebrates		19 Land Plants		20 Fish with Jaws		21 Insects			
22 Amphibians		23 Reptiles		24 Pangaëa Forms		25 Dinosaurs		26 Mammals		27 Birds		28 Flowers			
29 Tyrannosaurids		30 Dinosaurs Extinct, Mammals Take Over on Land and in Sea		31 The Final Day...											
				 <p>Dawn: Apes and Monkeys Split</p>		 <p>8 PM: Humans and Chimpanzees Split</p>		 <p>9:25: Humans First Walk Upright</p>		 <p>10:30: Human Brain Size Begins Tripling</p>		 <p>11:52: Modern Humans Evolve</p>		 <p>11:56 to 11:59: Human Migration</p>	

The Final Minute... A human life only lasts for the blink of an eye on the Cosmic Calendar: $100 \text{ years} * 365 * 24 * 60 * 60 / 13,800,000,000 = 0.23 \text{ Cosmic Seconds}$

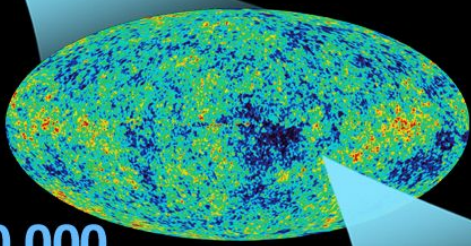
<p><i>Known from artifacts, radiocarbon dating, DNA extraction from remains</i></p>					<p><i>Written records</i></p>							
	 <p>End of Last Ice Age, Sea Level 400 Feet Lower Than Now</p>		<p>Agriculture Leads to Permanent Settlements</p>	<p>Columbus Arrives in America (1.2 Seconds Ago)</p>	<p>Christ Born</p>	<p>Mohammed Born</p>	<p>Old Testament, Buddha</p>	<p>Dynastic China Begins</p>	<p>0</p>			
60	55	50	45	40	35	30	25	20	15	10	5	0

**DAWN
OF
TIME**



**tiny fraction
of a second**

inflation

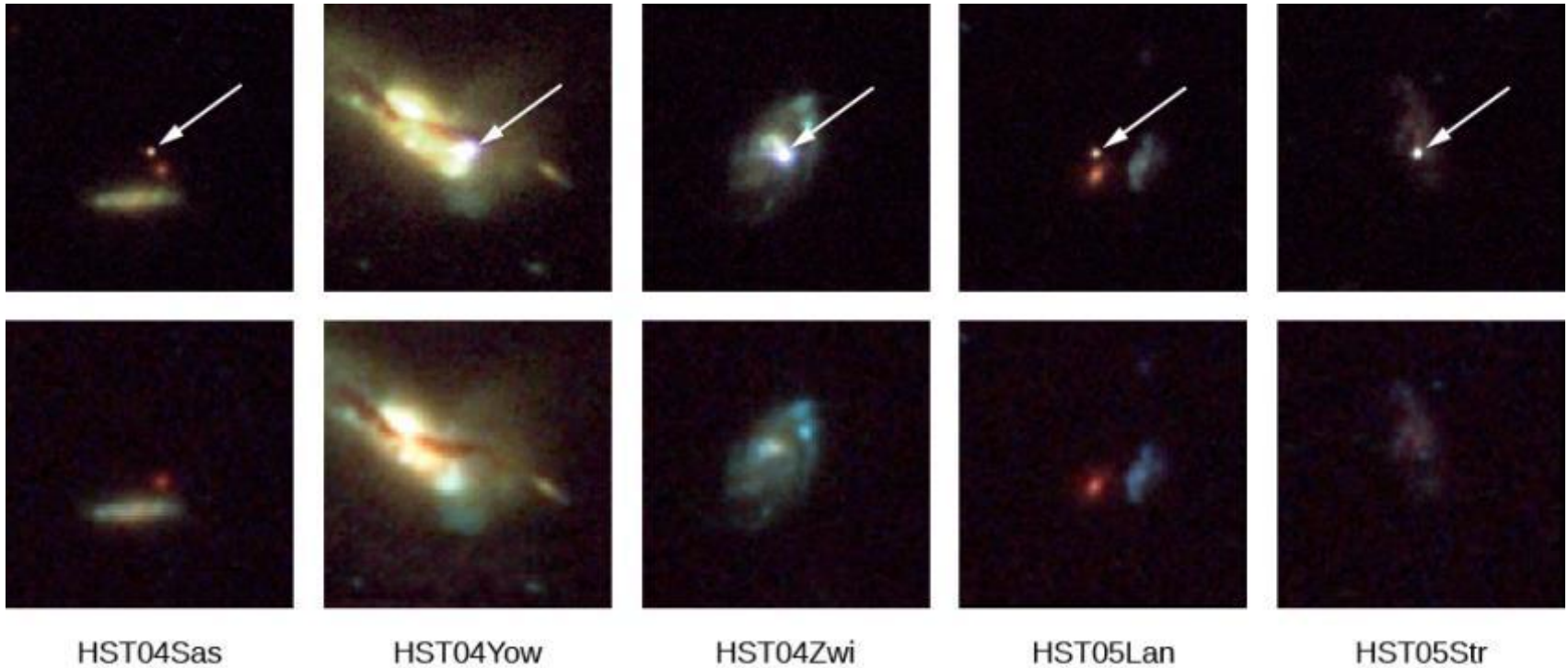


**380,000
years**



**13.7
billion
years**

FIGURE 29.3

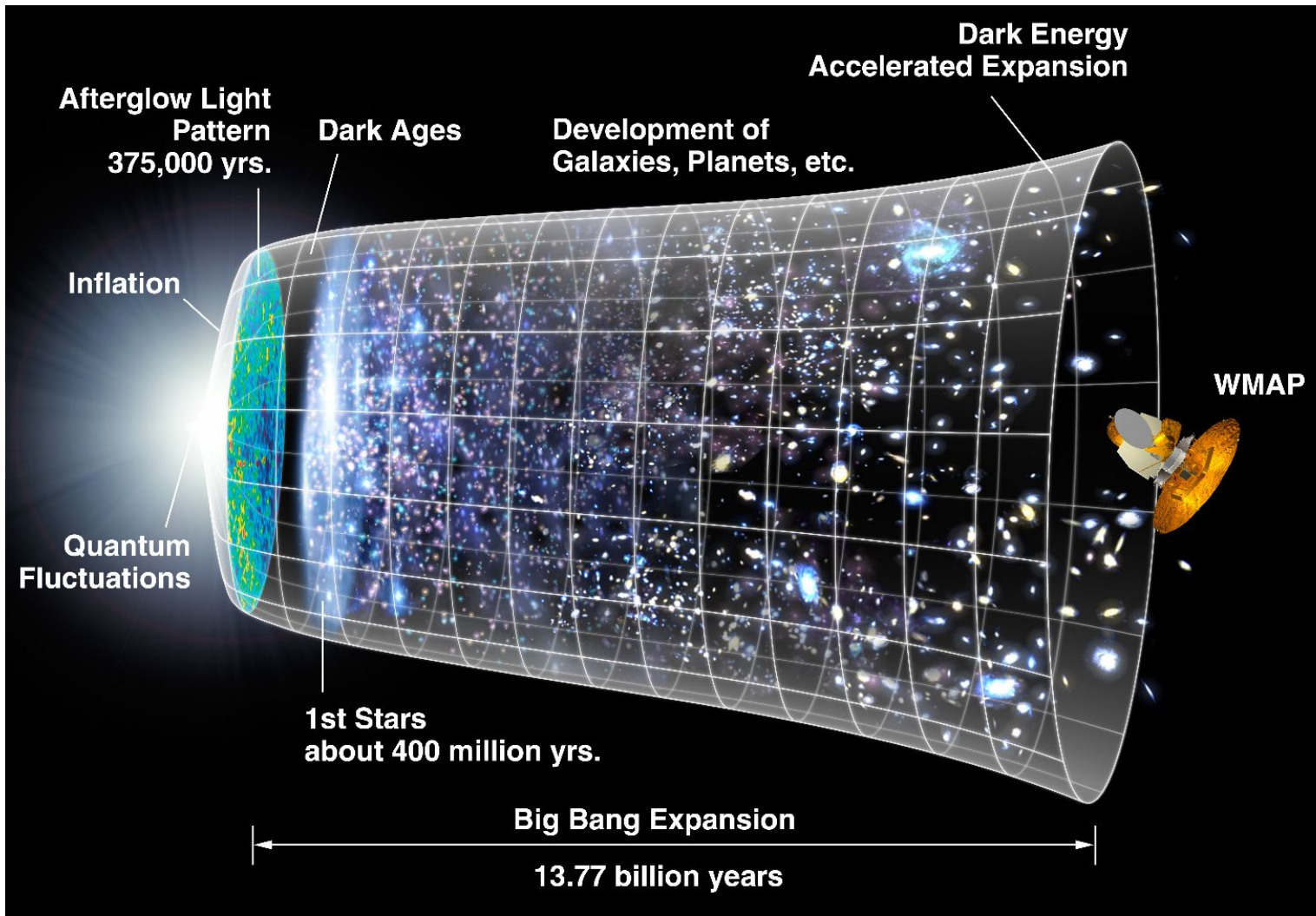


Five Supernovae and Their Host Galaxies. The top row shows each galaxy and its supernova (arrow).

Supernovae are a *standard bulb*, so can accurately calculate distance from Earth. The bottom row shows the same galaxies either before or after the supernovae exploded.

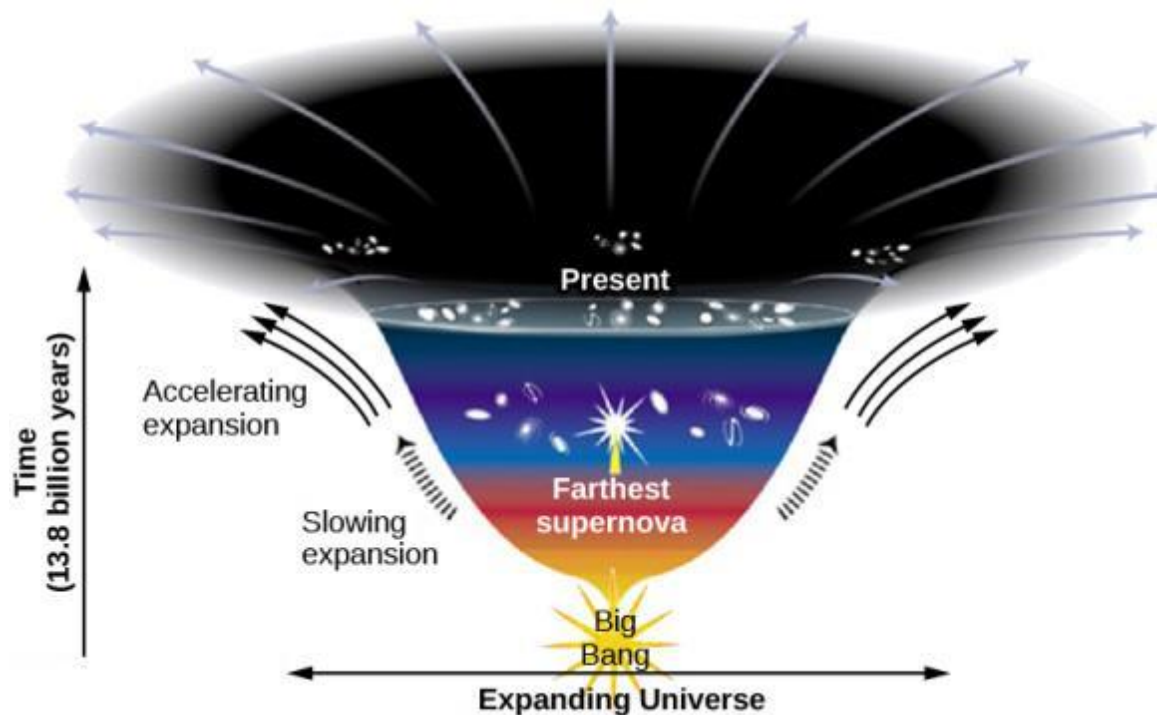
Hubble constant, and Hubble's Law predicts constant expansion, but not the case!
2011 Nobel Prize in Physics

FIGURE 29.24



History of the Universe. This image summarizes the changes that have occurred in the universe during the last 13.8 billion years. Protons, deuterium, helium, and some lithium were produced in the initial fireball. About 380,000 years after the Big Bang, the universe became transparent to electromagnetic radiation for the first time. COBE, WMAP, Planck, and other instruments have been used to study the radiation that was emitted at that time and that is still visible today (the CMB). The universe was then dark (except for this background radiation) until the first stars and galaxies began to form only a few hundred million years after the Big Bang. Existing space and ground-based telescopes have made substantial progress in studying the subsequent evolution of galaxies. (credit: modification of work by NASA/WMAP Science Team)

FIGURE 29.4



Changes in the Rate of Expansion of the Universe Since Its Beginning 13.8 Billion Years Ago. The more the diagram spreads out horizontally, the faster the change in the velocity of expansion. After a period of very rapid expansion at the beginning, which scientists call inflation and which we will discuss later in this chapter, the expansion began to decelerate. Galaxies were then close together, and their mutual gravitational attraction slowed the expansion. After a few billion years, when galaxies were farther apart, the influence of gravity began to weaken. Dark energy then took over and caused the expansion to accelerate. (credit: modification of work by Ann Feild (STScI))

Final Exam

- TUES, 12/16, 6 PM-8 PM in this room
- Multiple Choice Questions
- No Essay
- Covering Lectures 8-13:
 - 8: Gas Giants (Chs 11 and 12)
 - 9: Light (Ch 5)
 - 10: Stars (Chs 16, 17, 18, 19)
 - 11: Star Evolution (Ch 21)
 - 12: Galaxies (Chs 25, 26)
 - 13: The Big Bang (Ch 29)