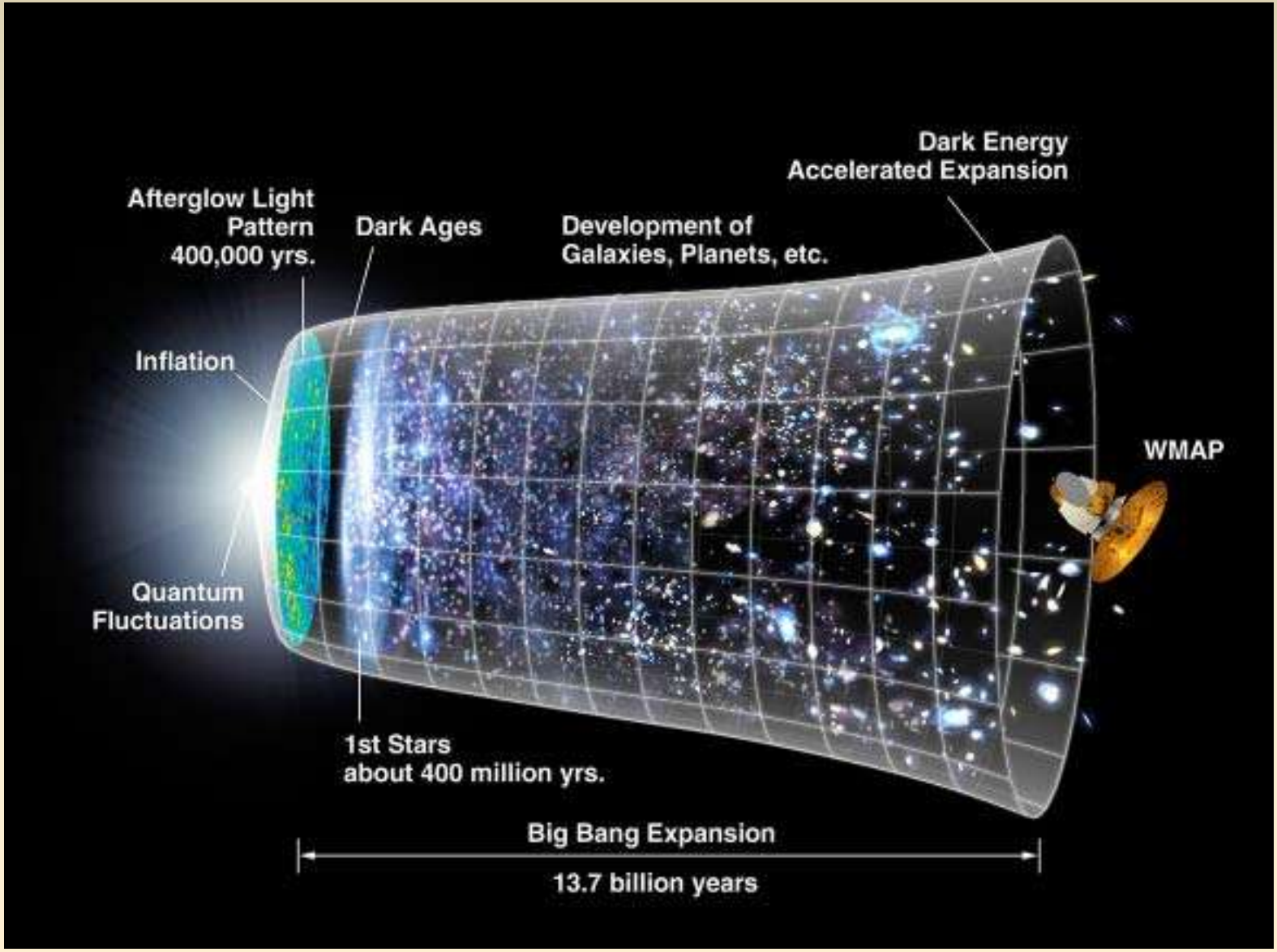
Origin of the Universe



What is Cosmology?

The Study of the Universe: its structure, origin, evolution, and destiny

Our universal “world view”

Our cosmological model

Like any field of science, cosmology involves the **formation of theories or hypotheses** about the universe which make specific **predictions** for phenomena that can be tested with observations. Depending on the outcome of the observations, the **theories will need to be abandoned, revised or extended** to accommodate the data. The prevailing theory about the origin and evolution of our Universe is the so-called Big Bang theory

Cosmology through the ages…

Universe models formed in many cultures

Our View of the Cosmos - the story of scientific models

Astronomy has seen 3 scientific revolutions in cosmology

2nd Century: Claudius Ptolemy **(Physics of Aristotle)**

Model: Earth-centered Cosmology

Big Idea: Different laws for Earth and the cosmos

16th Century: Nicolas Copernicus **(Physics of Newton)**

Model: Sun-centered Cosmology

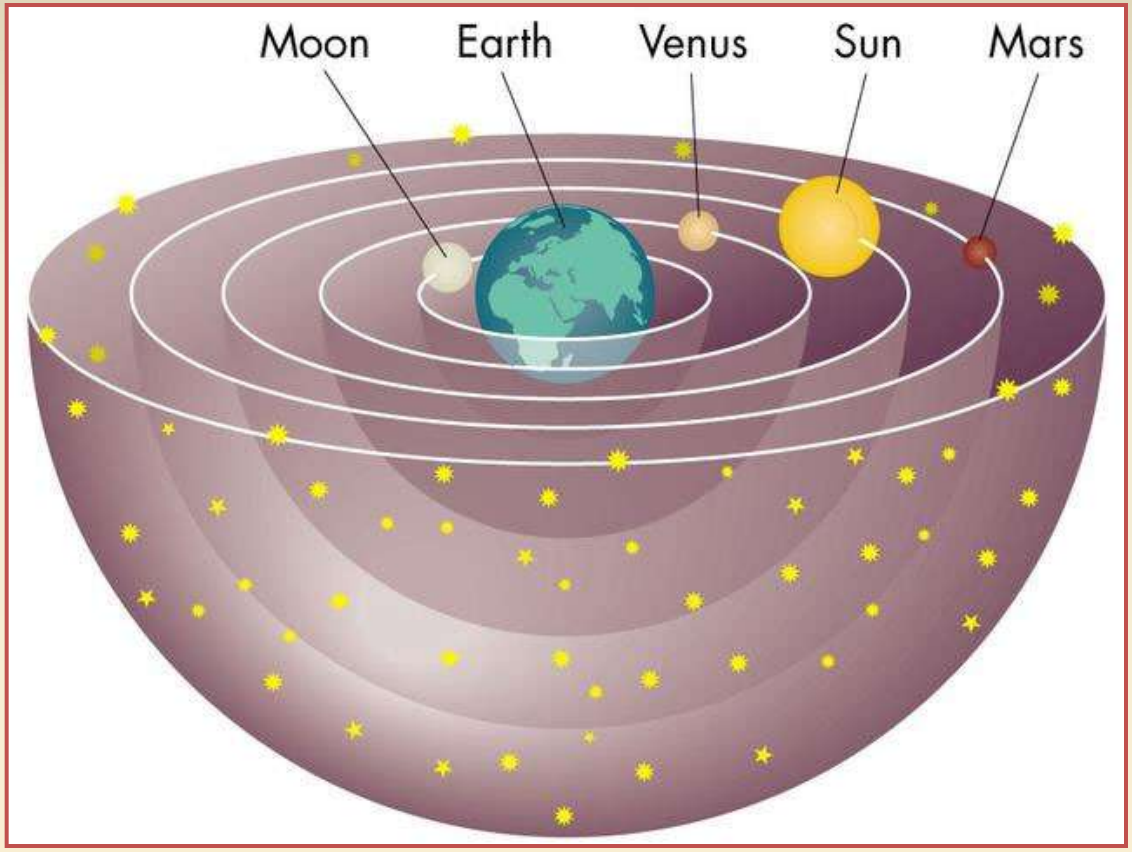
Big Idea: Universal physics; same laws everywhere

20th Century: Edwin Hubble **(Physics of Einstein)**

Model: Big Bang Cosmology

Big Idea: Universe is changing, evolving

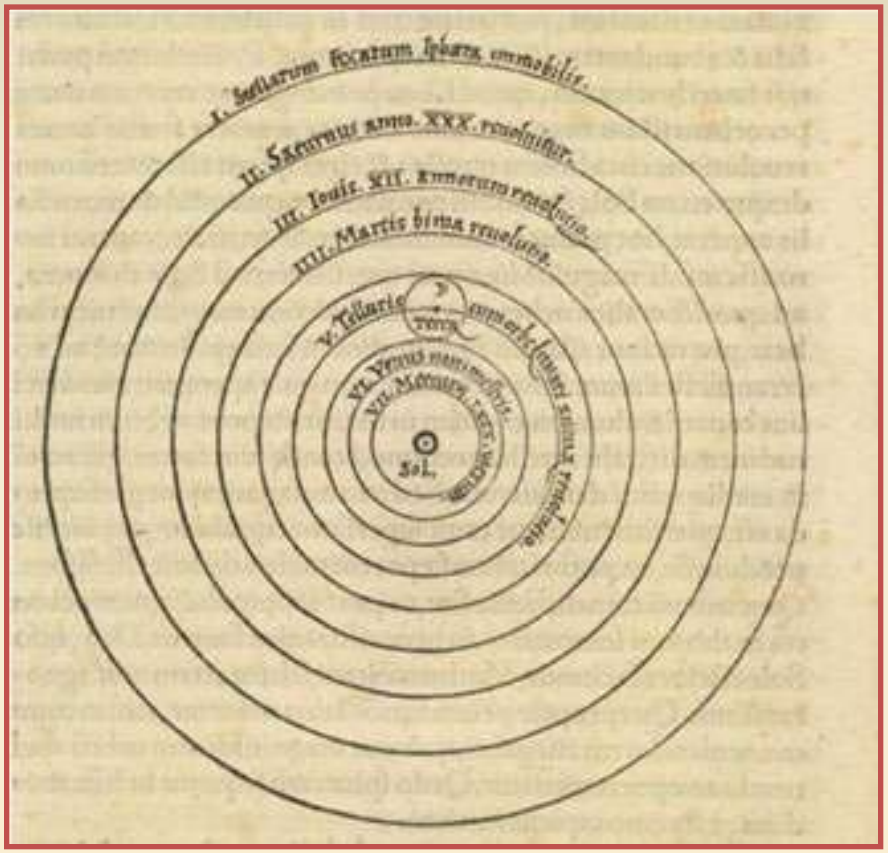
Earth-centered Cosmology: Claudius Ptolemy, 100-170 AD



…“the natural motion of the Earth ….is towards the center of the universe; that is the reason it is now lying at the center.”

Aristotle, On the Heavens

Sun-centered Cosmology: Nicolaus Copernicus 1473-1543



"At rest, however, in the middle of everything is the Sun."

Nicholaus Copernicus, de Revolutionibus

How old is Earth?

- Biblical scholars of 19th century (Bishop Ussher) – 6000 years (started at 4004 BC)
- Classical Greeks – infinite – history endlessly repeats itself
- Mayans believed earth recycled on a 3000 year time scale
- Han Chinese thought earth was recreated every 23,639,040 years
- The age we now except may change but is consistent with current theory

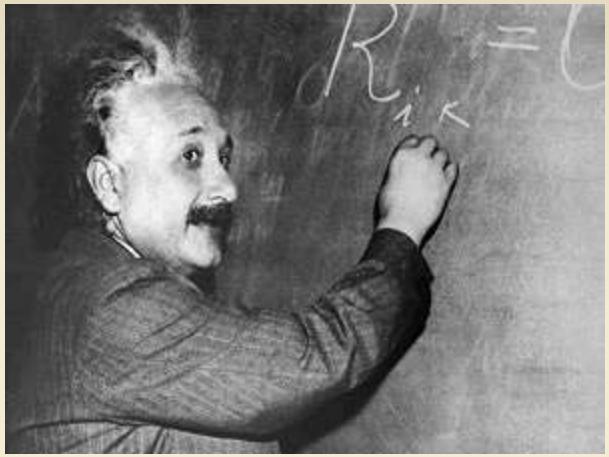
More recent efforts

- Lord Kelvin - 80 million years old – based on cooling of molten Earth
- Darwin - really old based on time for natural selection (biological argument)
- Hutton – really old based on uniformitarianism (processes in the past taking place at rates comparable to today) (geological argument)

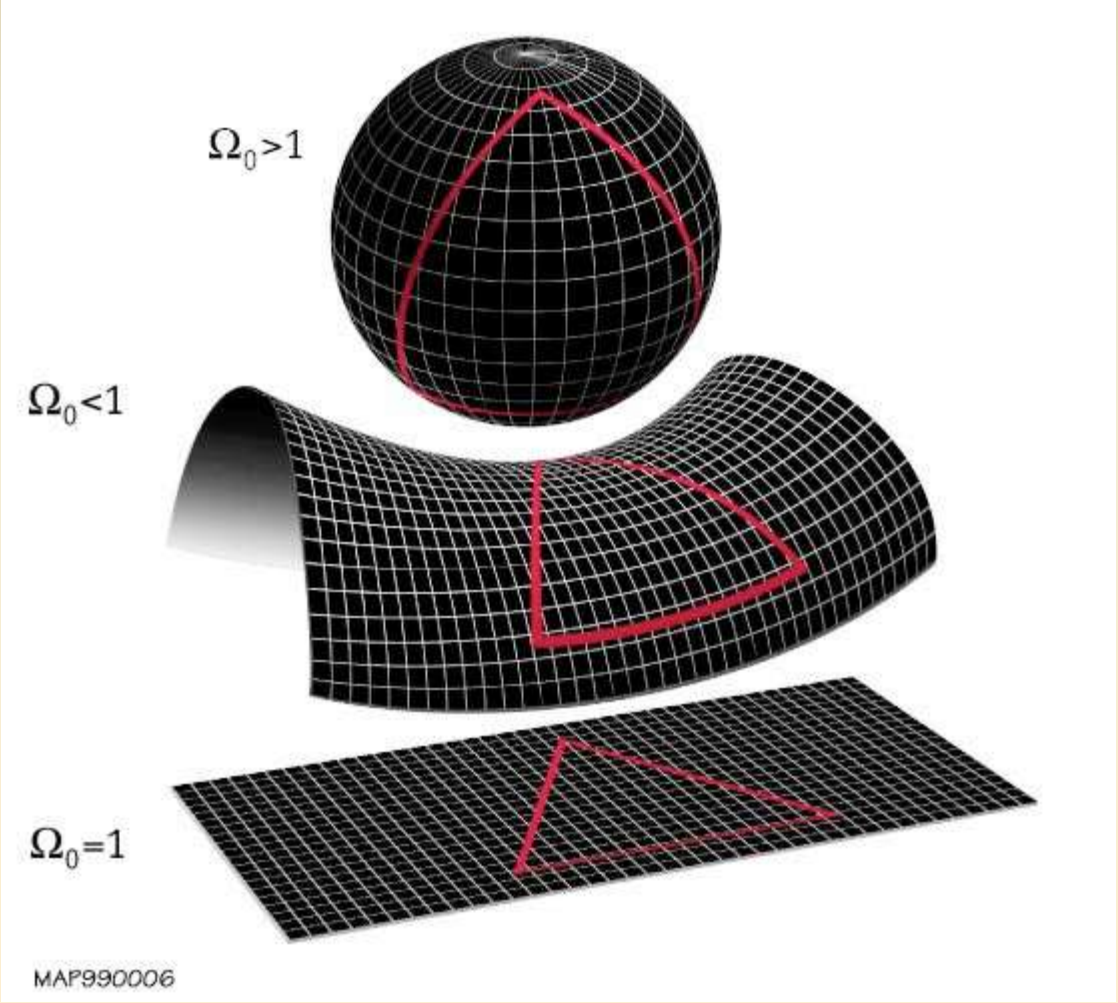
Earth's age

- Earth is about 4.5 (or 4.6) BY old
- First 700 MY Earth was a spinning cloud of gas, dust and planetoids
- These condensed and settled to solidify into a series of planets
- Since that time, geological history and evolution commenced.

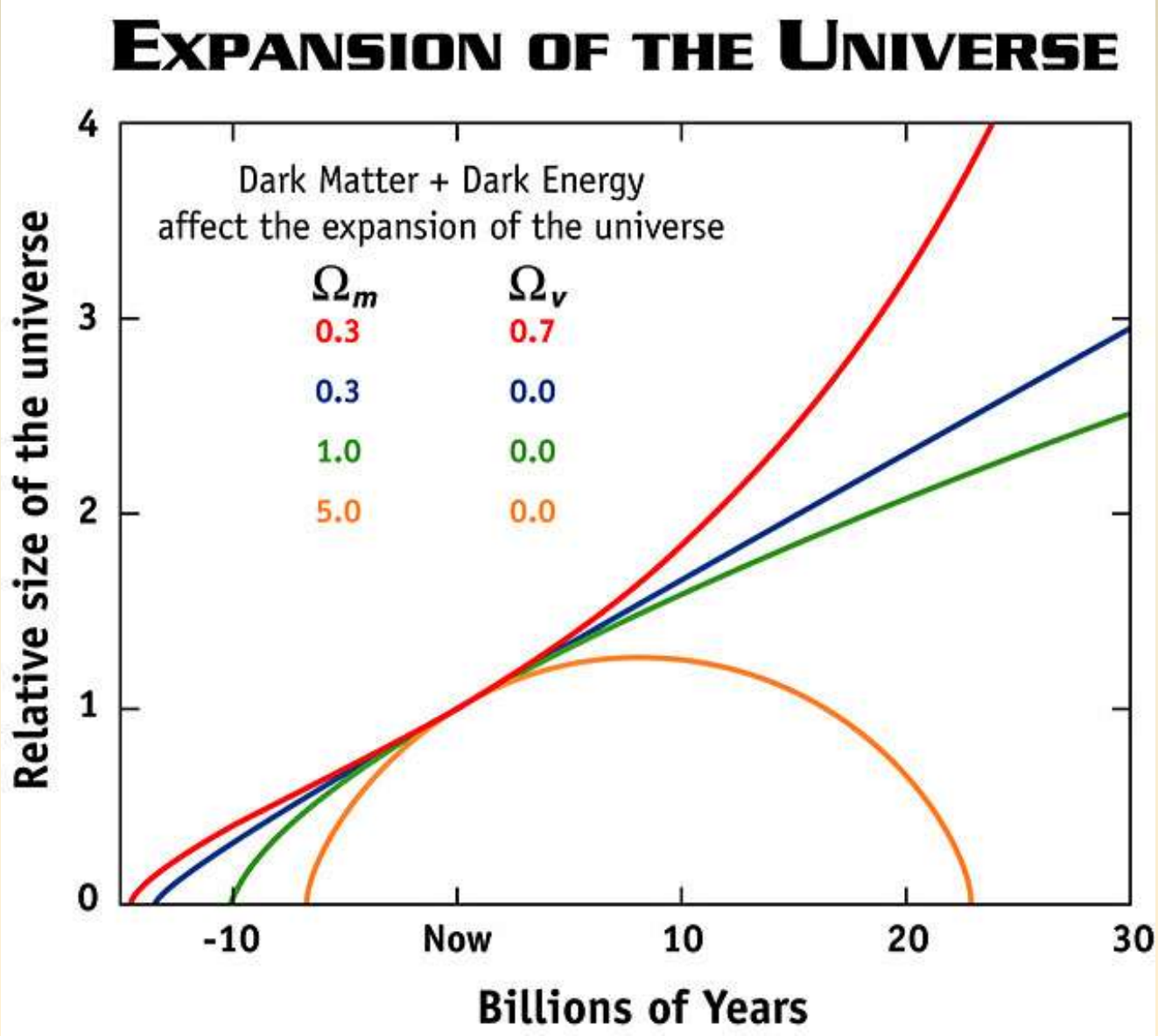
Distortion of space-time
Structure of the Universe



Albert Einstein
General Relativity



Dynamics of the universe - how space and the matter in it evolves with time

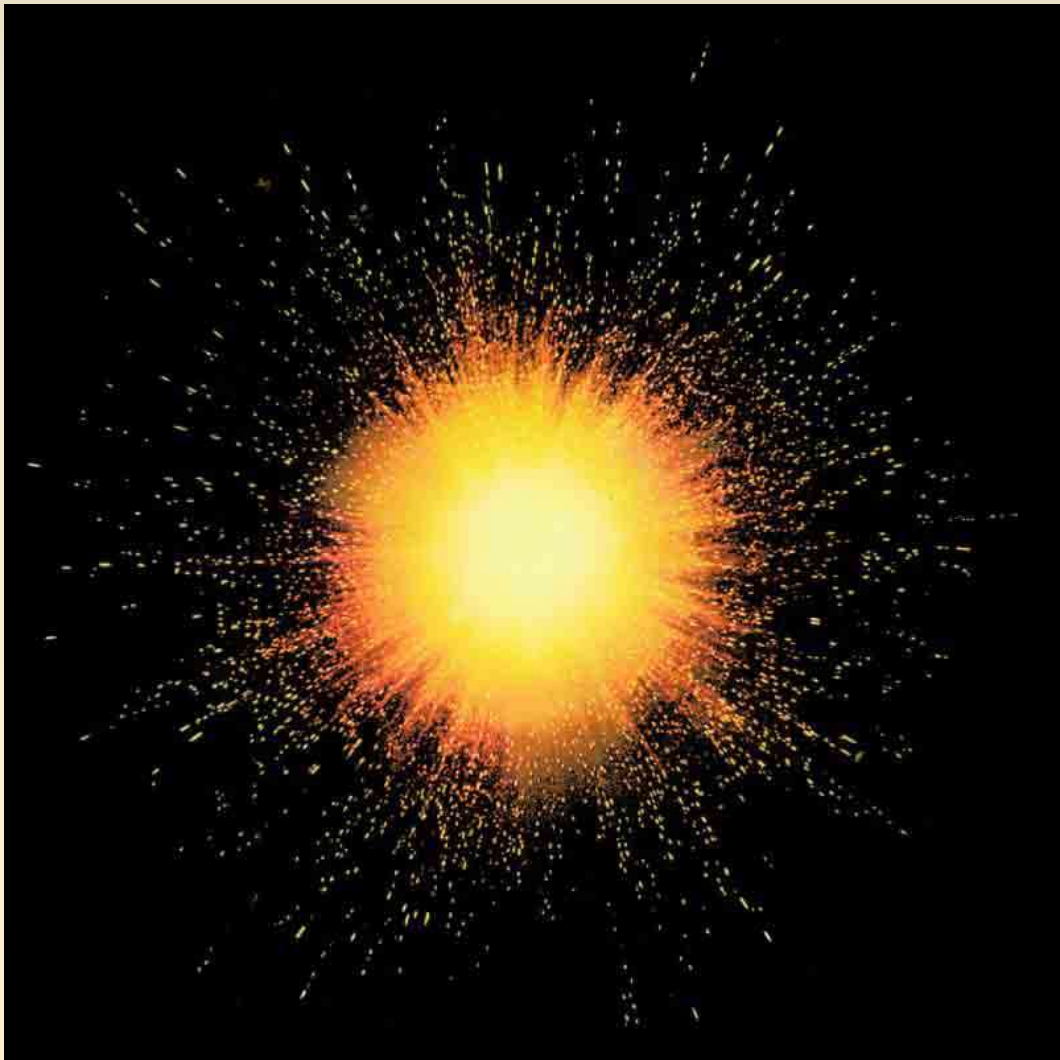


The universe started from a very small volume, an event dubbed the Big Bang, with an initial expansion rate.

A key question for the fate of the universe is whether or not the pull of gravity is strong enough to ultimately reverse the expansion and cause the universe to collapse back on itself.

Big Bang - Time begins

- The universe begins ~13.7 Billion years ago
- The universe begins as the size of a single atom (**singularity**)
- The universe began as a violent expansion
  - All matter and space were created from a single point of pure energy in an instant

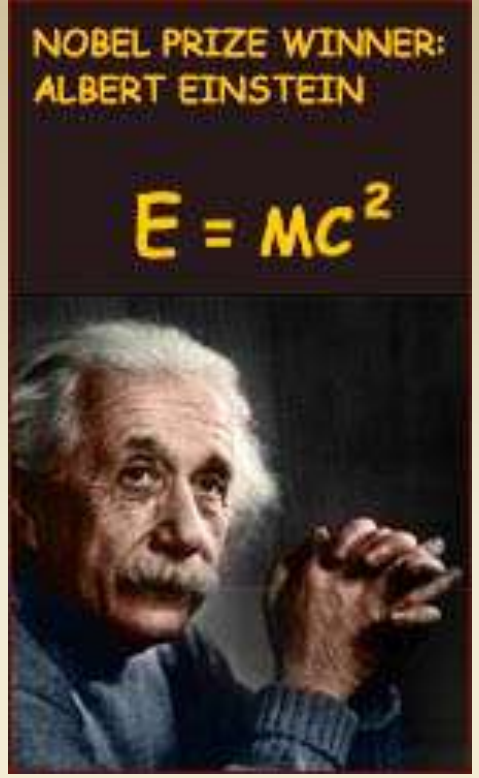


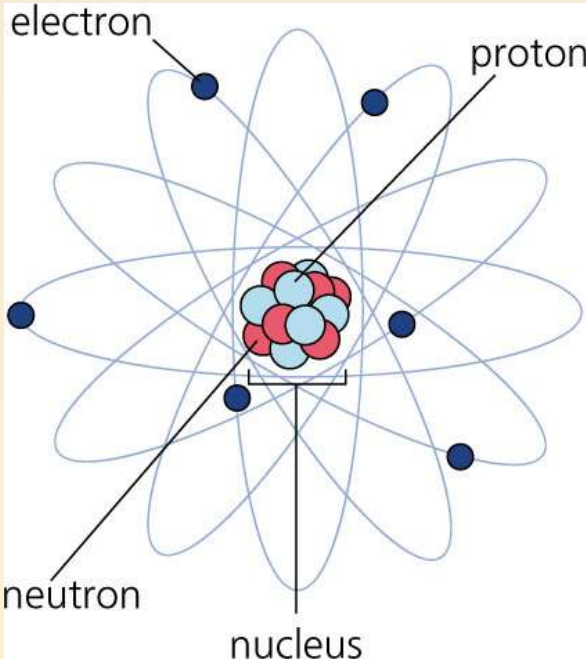
Misconceptions about the Big Bang

- there was no explosion; there was (and continues to be) an expansion
  - Rather than imagining a balloon popping and releasing its contents, imagine a balloon expanding: an infinitesimally small balloon expanding to the size of our current universe
- we tend to image the singularity as a little fireball appearing somewhere in space
  - space began inside of the singularity. Prior to the singularity, *nothing* existed, not space, time, matter, or energy - nothing.

~ 3 minutes after big bang

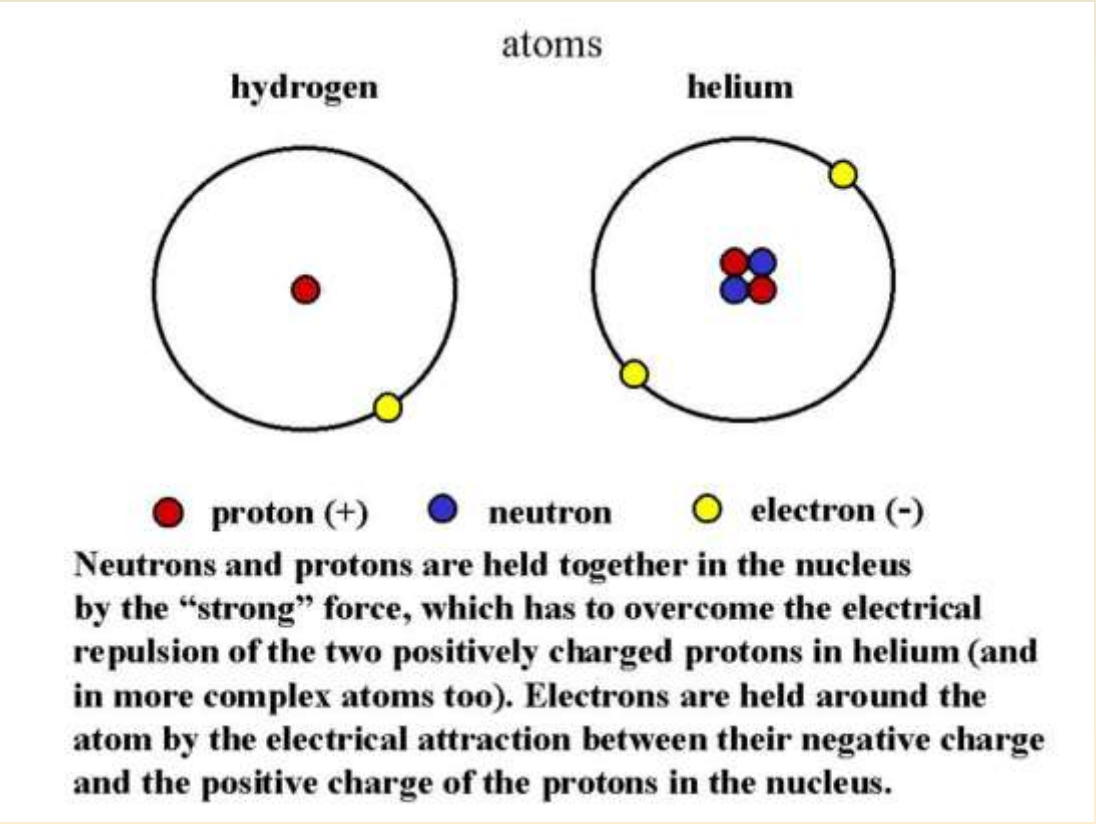
- The universe has grown from the size of an atom to larger than the size a grapefruit
- $E=mc^2$
- energy froze into matter according to Albert Einstein's equation.
- This basically says that like snowflakes freezing, energy forms matter into clumps that today we call protons, neutrons and electrons.
- These parts later form into atoms





Several hundred thousand years

after Big Bang



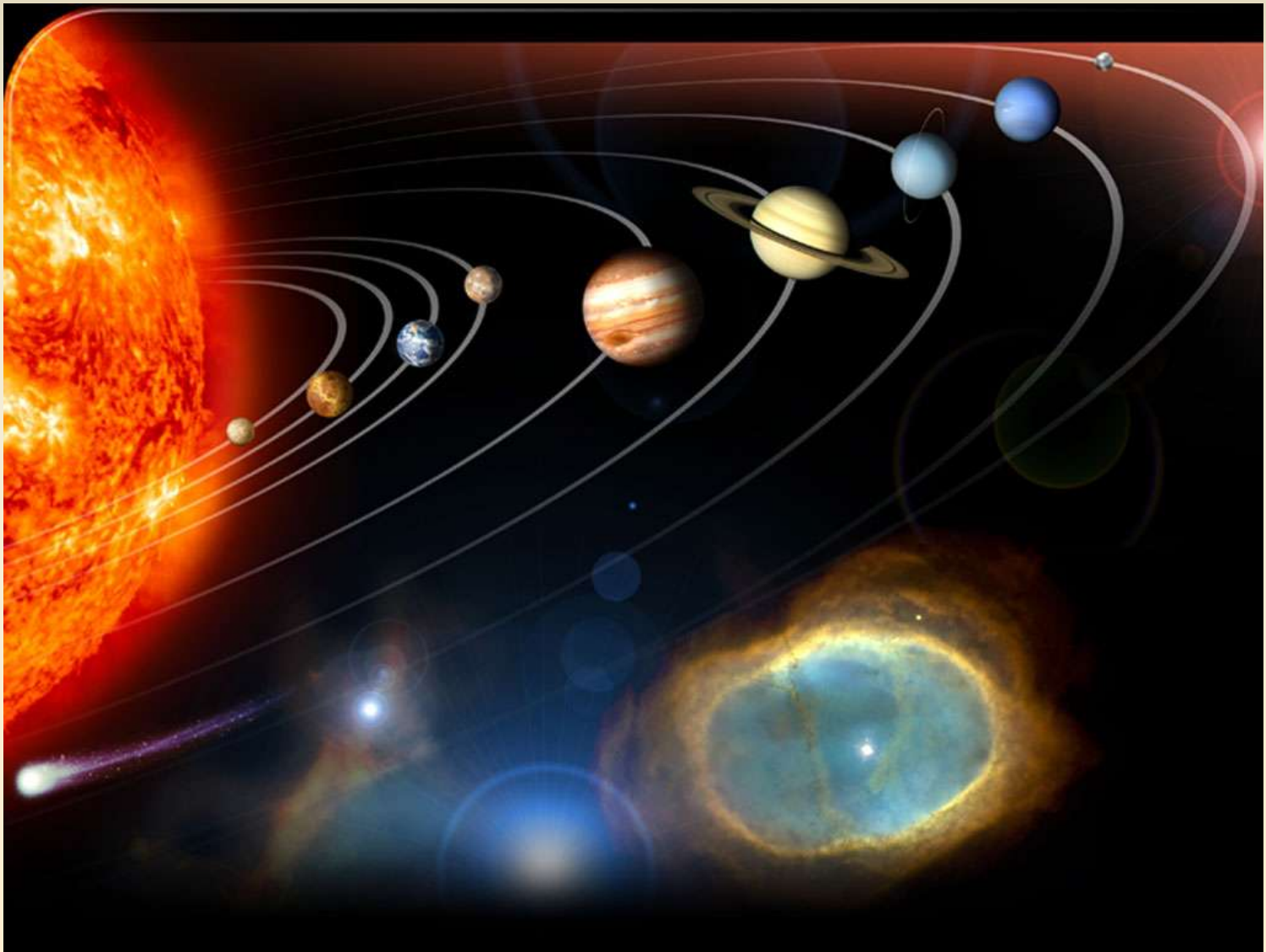
- ATOMS form (specifically Hydrogen and its isotopes with a small amount of Helium.)
- The early Universe was about 75% Hydrogen and 25% Helium. It is still almost the same today.

200 to 400 million years after Big Bang

- 1st stars and galaxies form

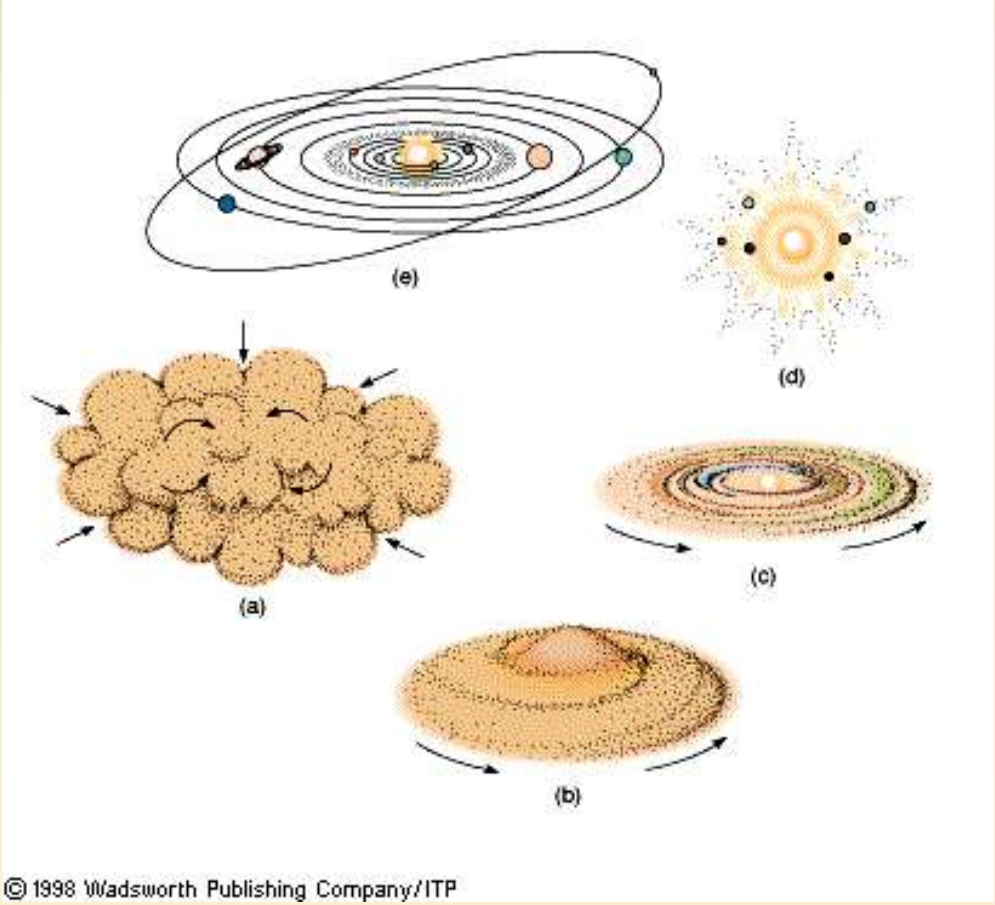
~ 4.6 billion years ago

- Our Solar system forms



The Solar System - Its Origin and Early Development

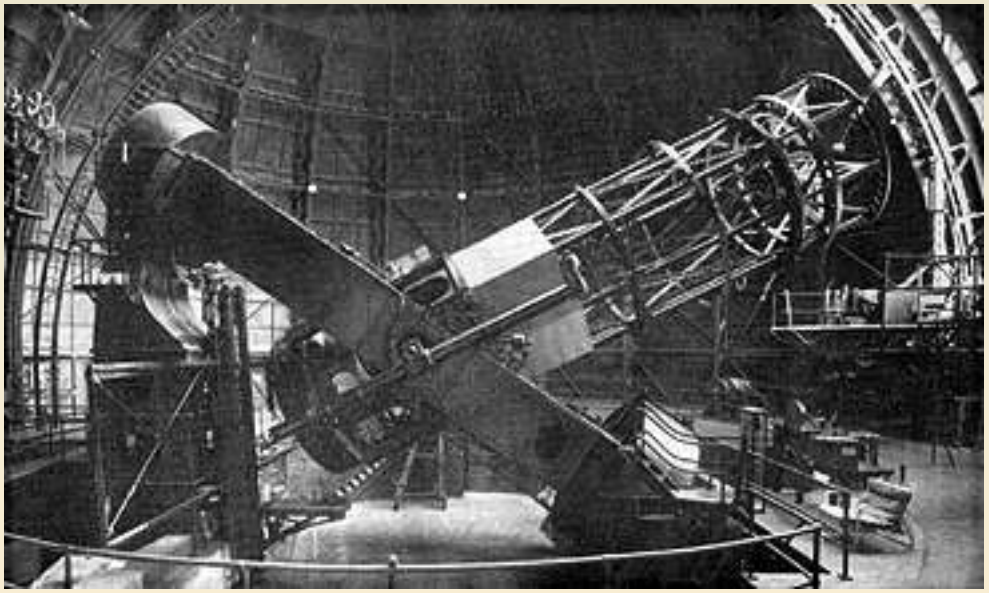
- Our solar system, part of the Milky Way galaxy, consists of the Sun, nine planets, 64 known moons, many asteroids, millions of comets and meteorites, as well as interplanetary dust and gases



Edwin Hubble at Mt. Wilson

Hubble's observations at the 100 inch during the 1920's led him to the conclusion that the universe is expanding, and that an object's recession velocity is proportional to its distance from the observer.

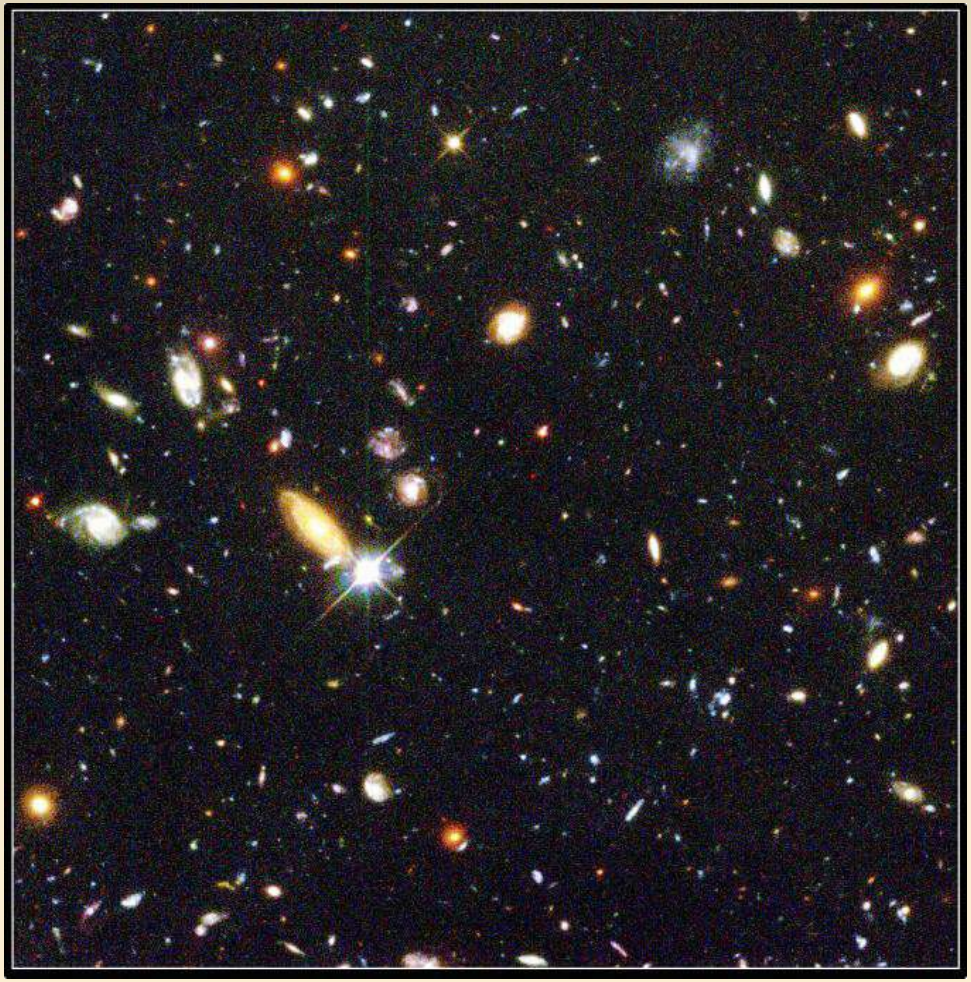
Hubble guiding the Hooker 100 inch telescope in 1923.



The Hooker 100 inch telescope atop Mt. Wilson near Pasadena, CA. It was the largest telescope in the world from 1917-1947.

Hubble Telescope

Deep Hubble Space Telescope Image

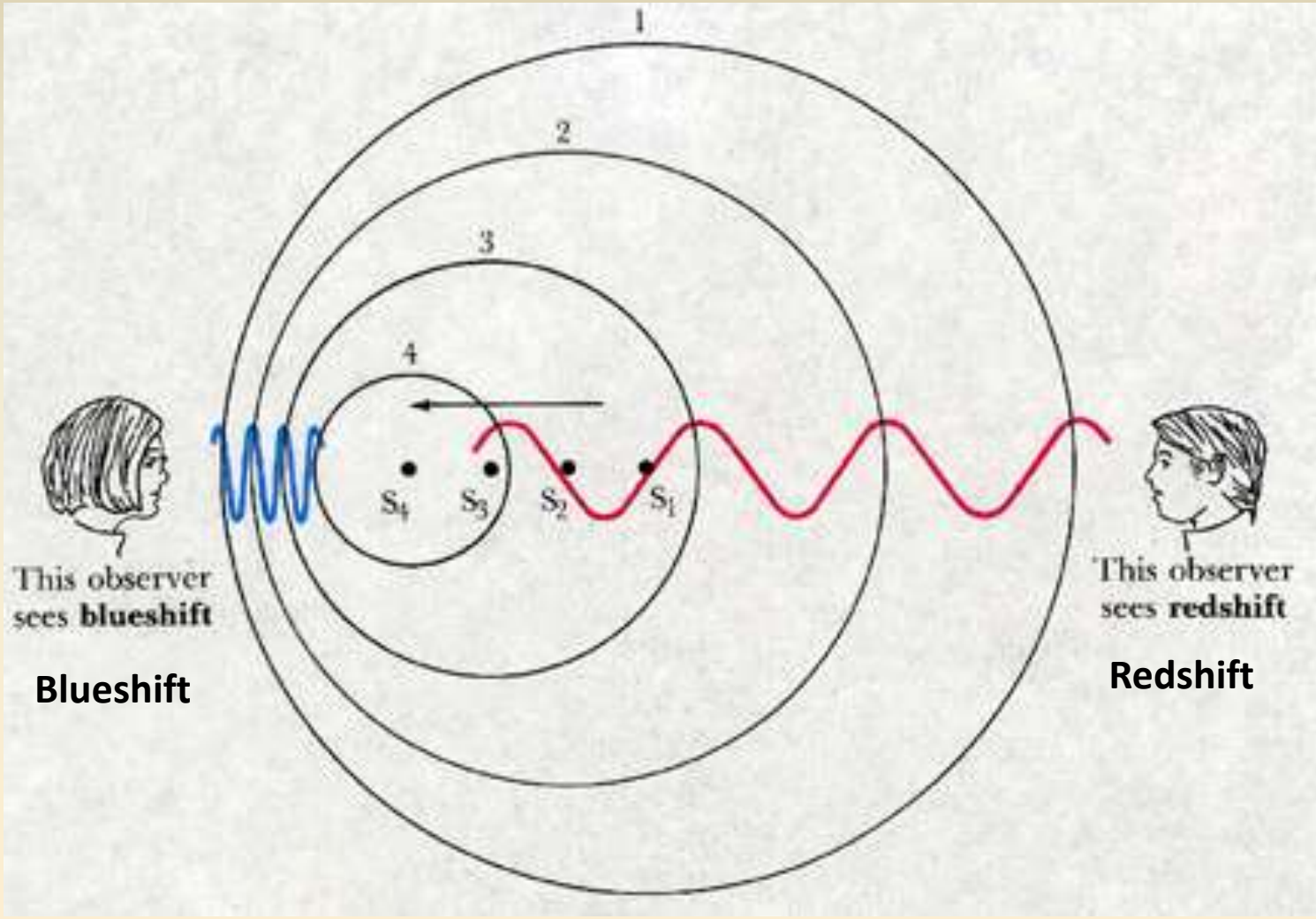


A deep image of an "empty" portion of the sky with the Hubble Space Telescope reveals that the universe is filled with galaxies- many just like our own. The light we see from the most distant galaxies has traveled approximately 10 billion years to reach us.

Hubble's Discovery

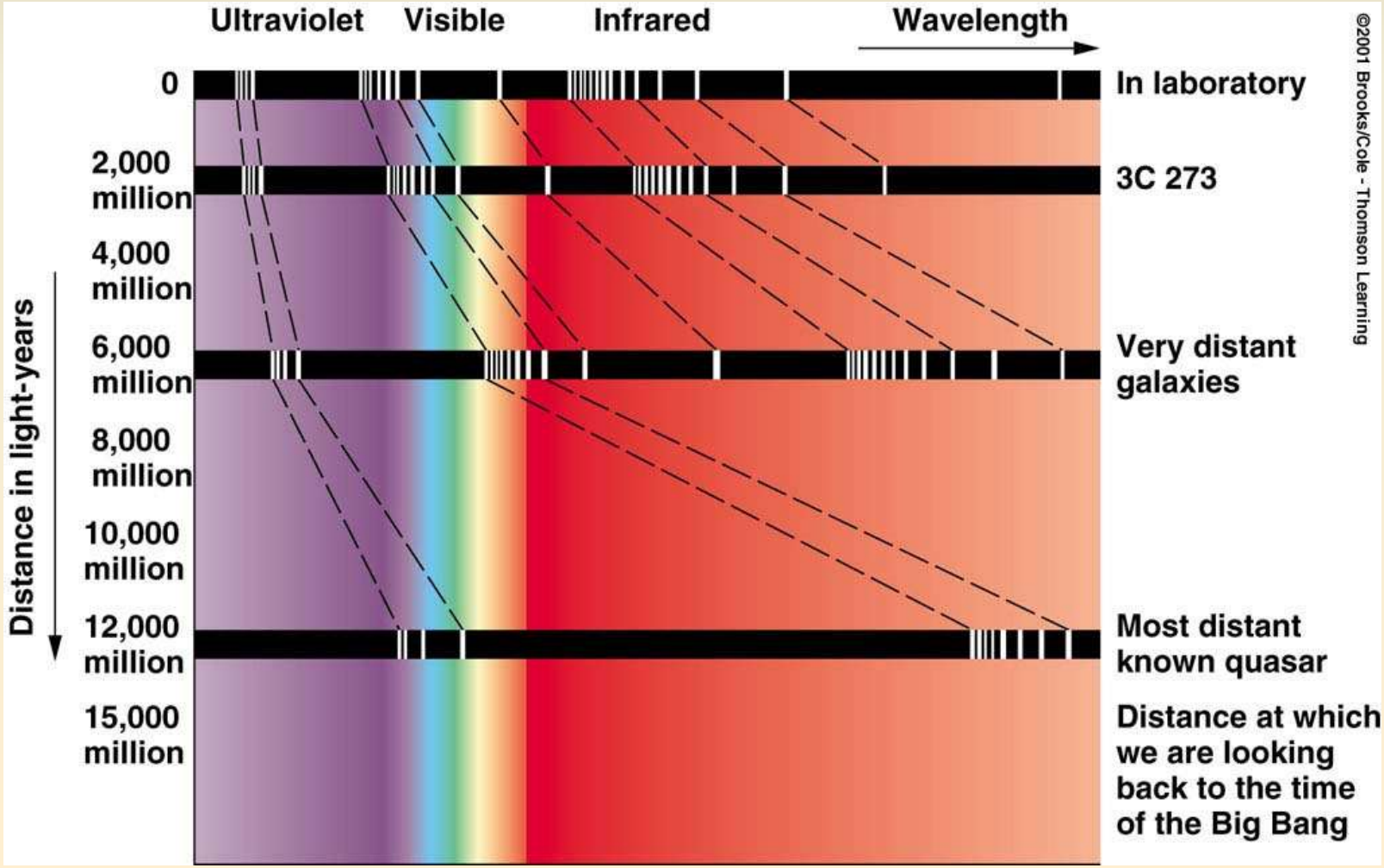
- Edwin Hubble's observations of remote galaxies, and the redshift of their spectral lines (1924).
- Hubble noticed that the further away the galaxy, the greater the redshift of its spectral lines.
- This linear relationship is called Hubble's Law.

Using the Doppler Effect to Measure Velocity

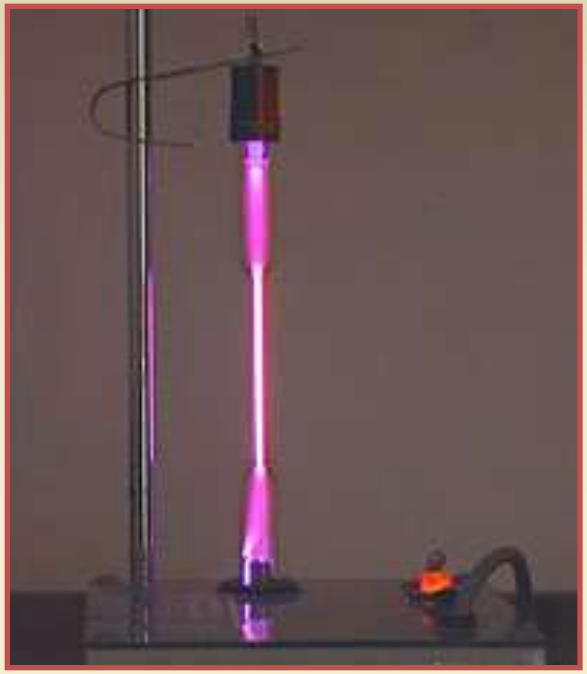


Redshift

- The wavelengths of the light emitted by distant objects is elongated as it travels to earth.
- Longer the light travels, the more it gets redshifted.

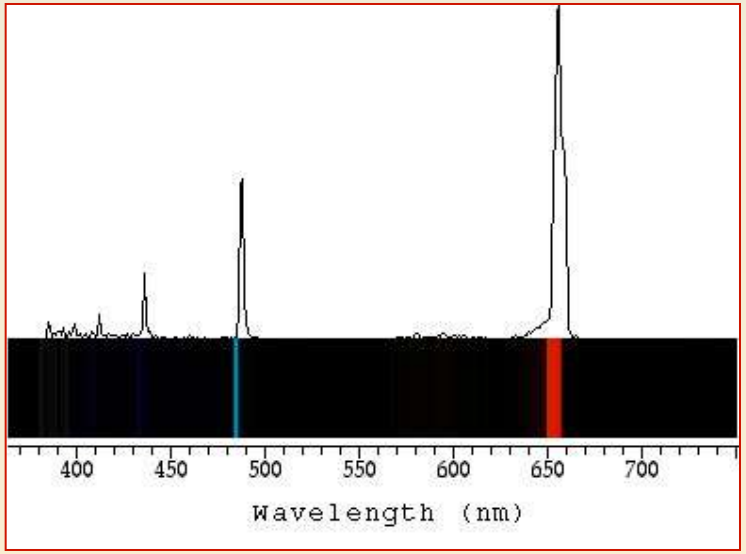


Evidence for an expanding universe



Hydrogen lamp

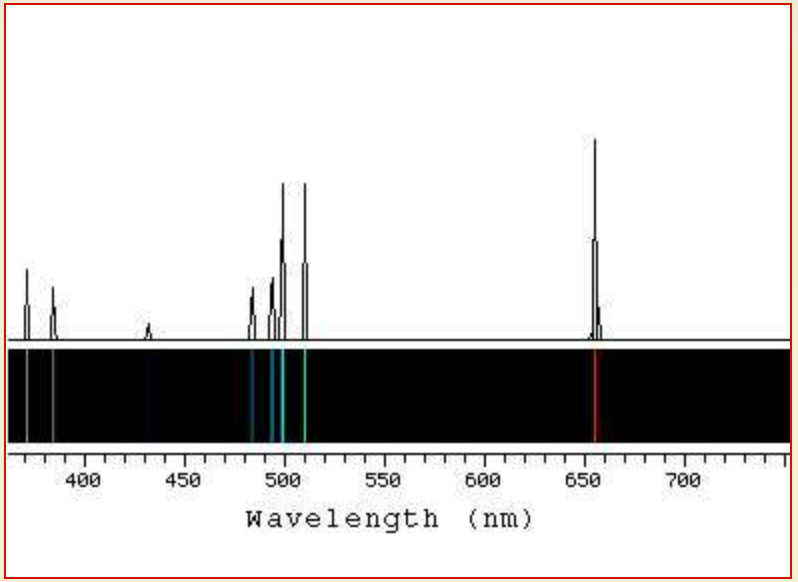
The spectrum of hydrogen gas is the unique fingerprint of that element



Evidence for an expanding universe

Orion Nebula

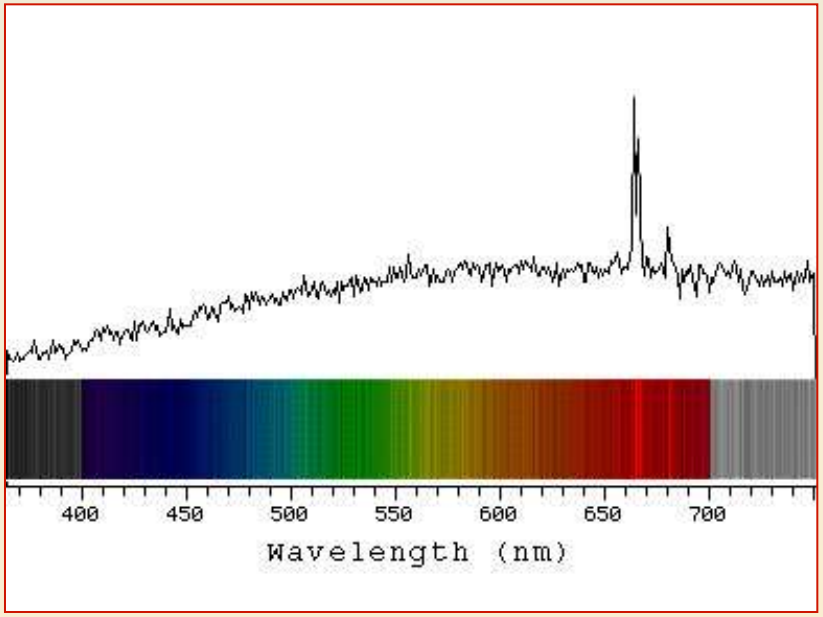
When we see a repeat of the pattern we saw in the lab, we know hydrogen is present



Evidence for an expanding universe

Galaxy UGC 12915

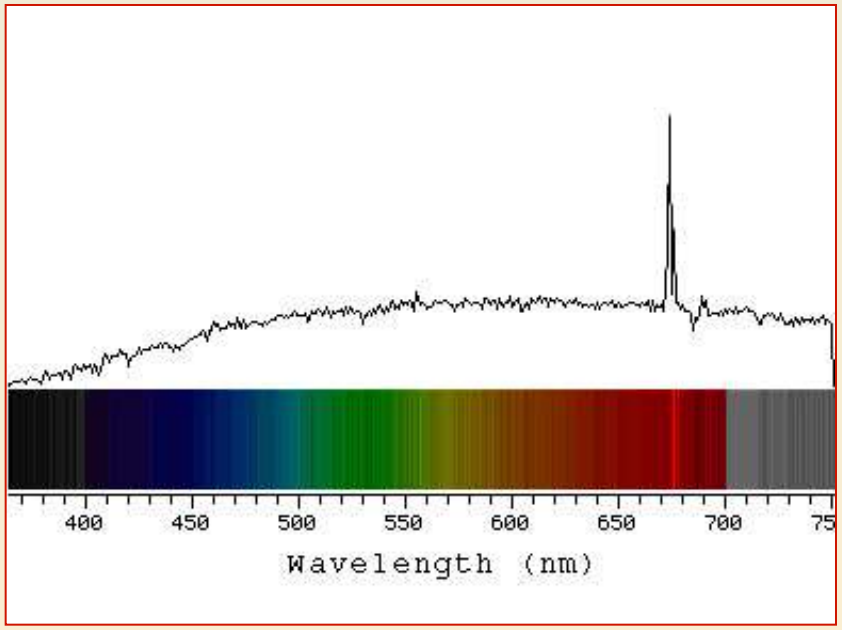
We see the same repeating pattern of lines in a galaxy, but displaced to the red



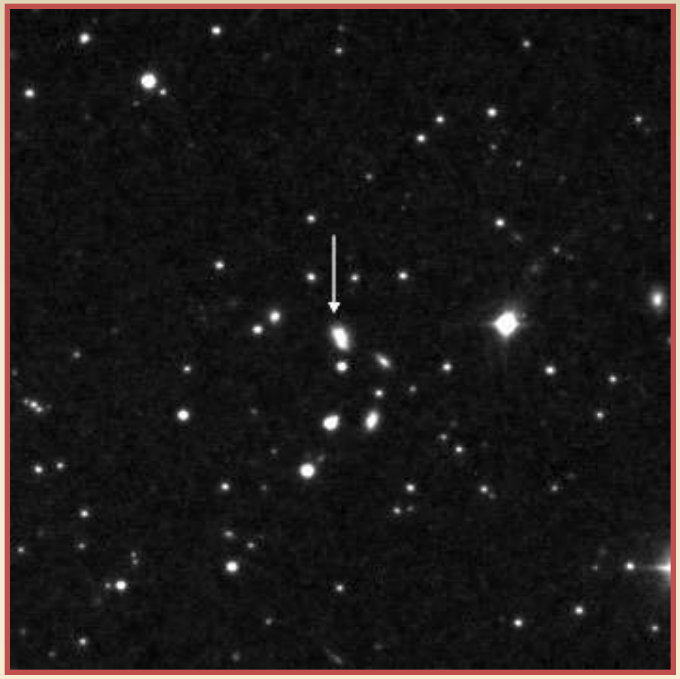
Evidence for an expanding universe

Galaxy UGC 12508

The further the galaxy,
the more the shift to the red

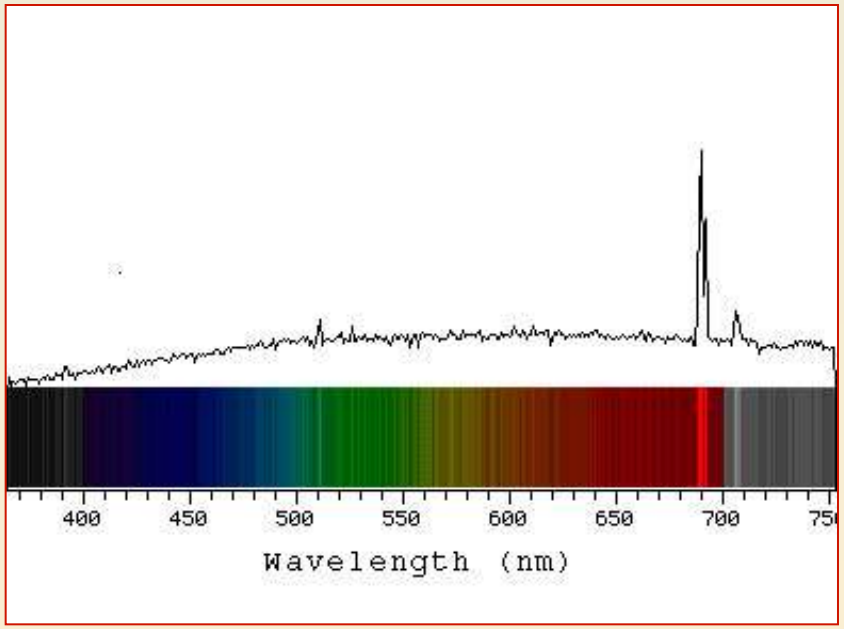


Evidence for an expanding universe

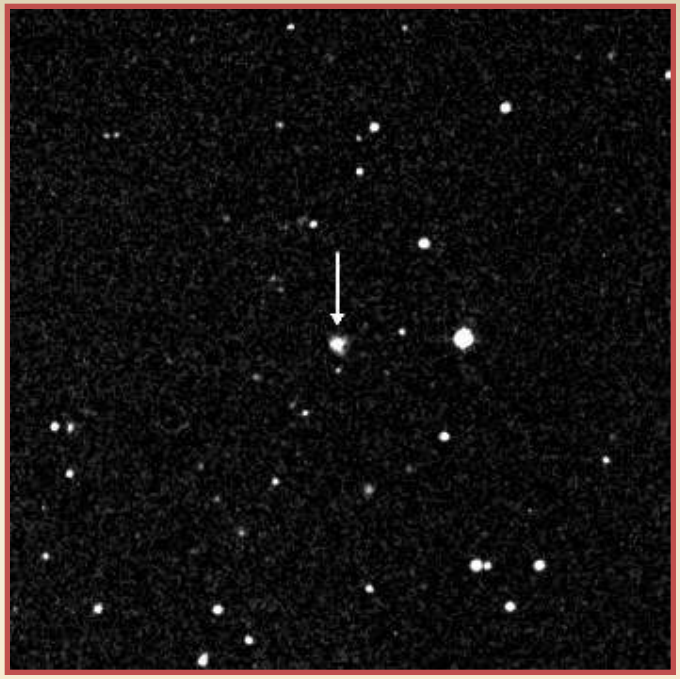


Galaxy KUG 1750

The greater the red shift,
the faster the galaxy is receding

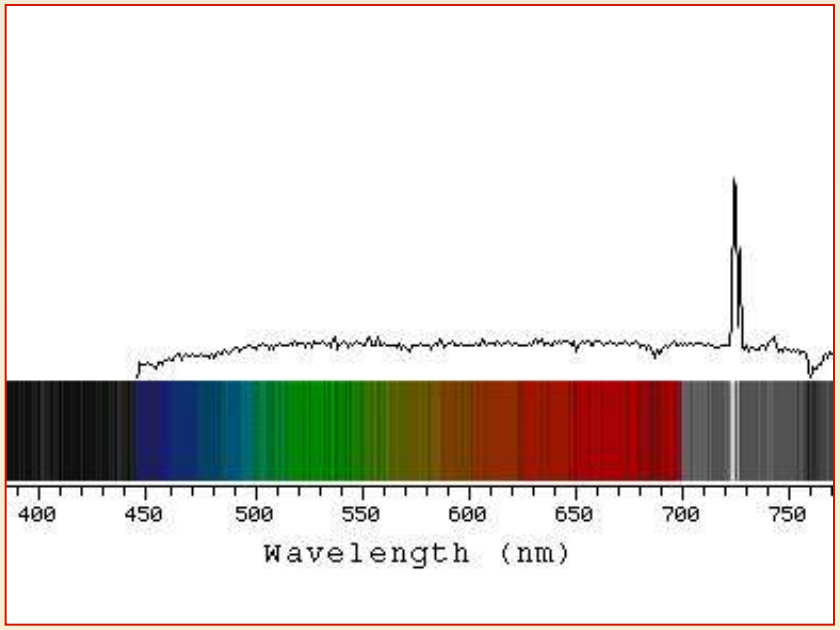


Evidence for an expanding universe



Galaxy KUG 1217

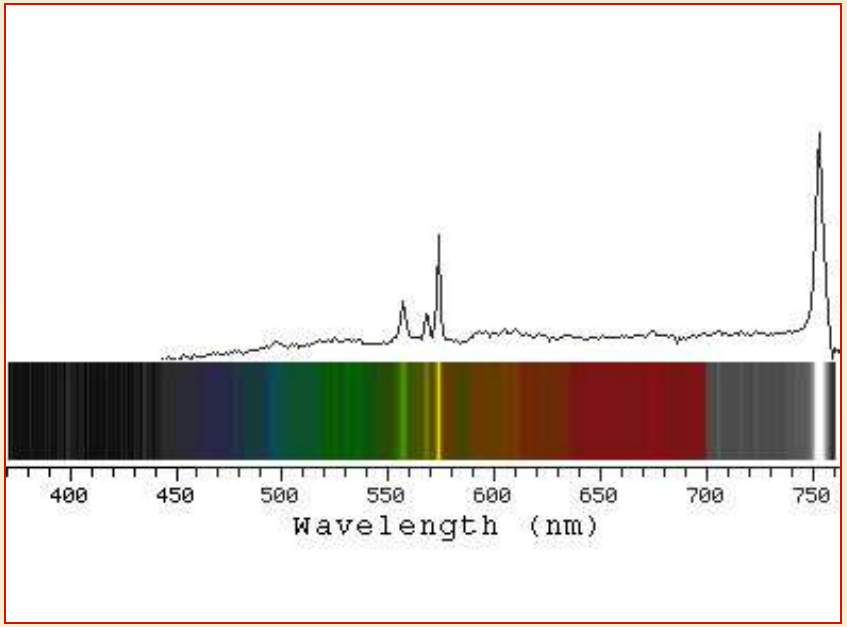
The red shift is caused
by the expansion of space.



Evidence for an expanding universe

Galaxy IRAS F09159

The red shift is evidence
for an expanding universe

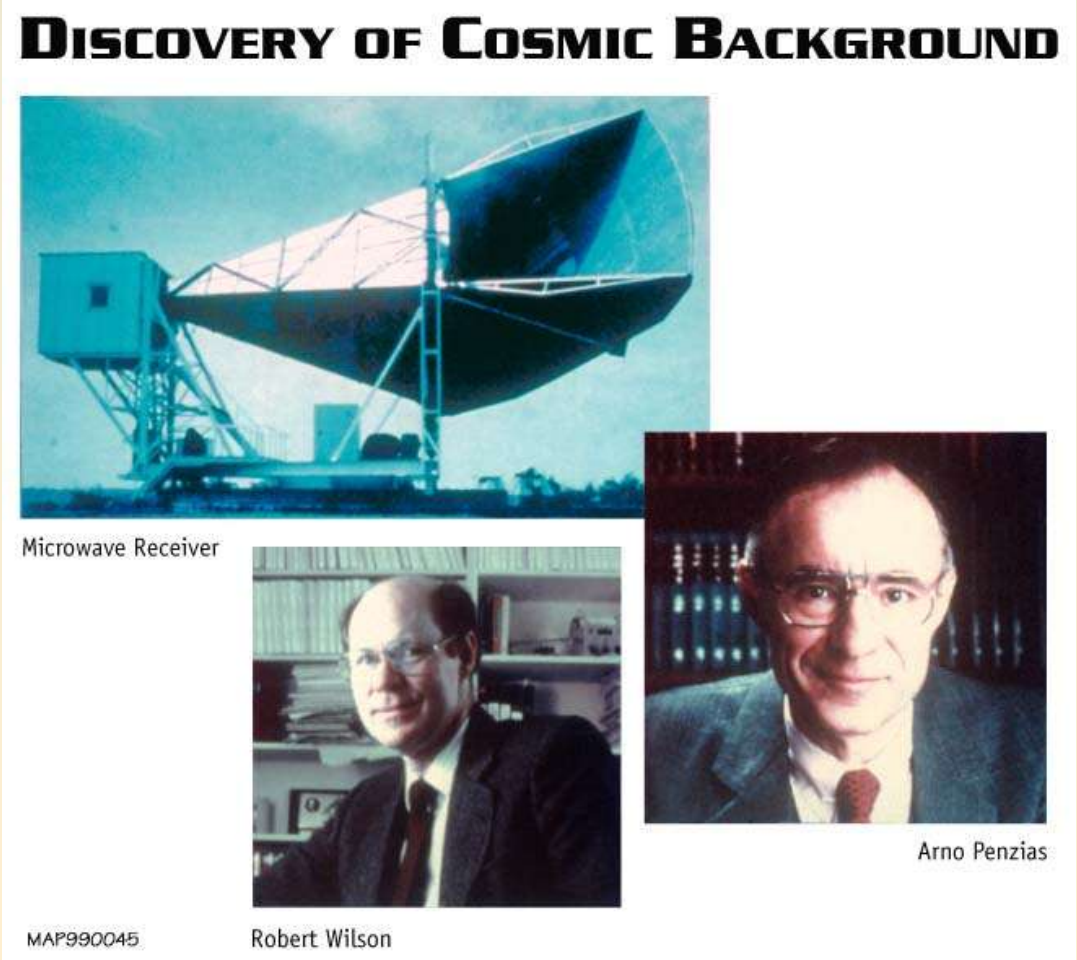


Discovery of the Background Radiation from initial Big Bang

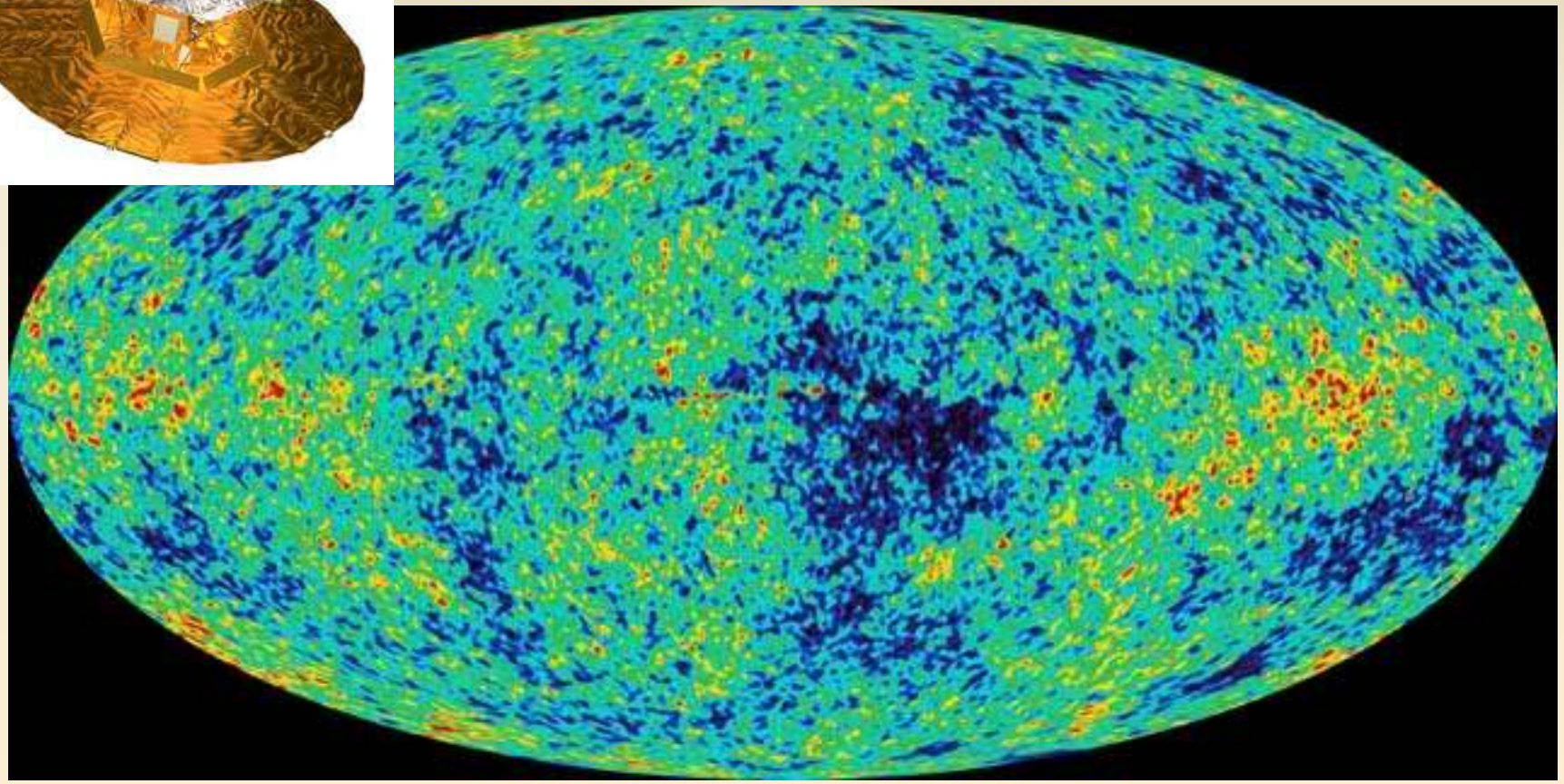
-Long wavelength

-came from all directions

Penzias and Wilson, 1965



Cosmic Microwave Background WMAP Satellite

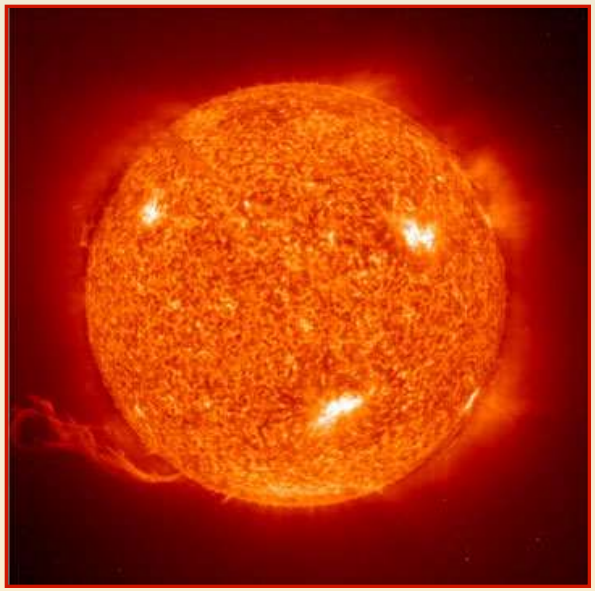


The CMB radiation was emitted 13.7 billion years ago, only a few hundred thousand years after the Big Bang, long before stars or galaxies ever existed

Testing the Big Bang model

Prediction: A hot, dense expanding universe, should be predominantly hydrogen, helium.

Observation: Universe is ~75% hydrogen, ~25% helium by mass



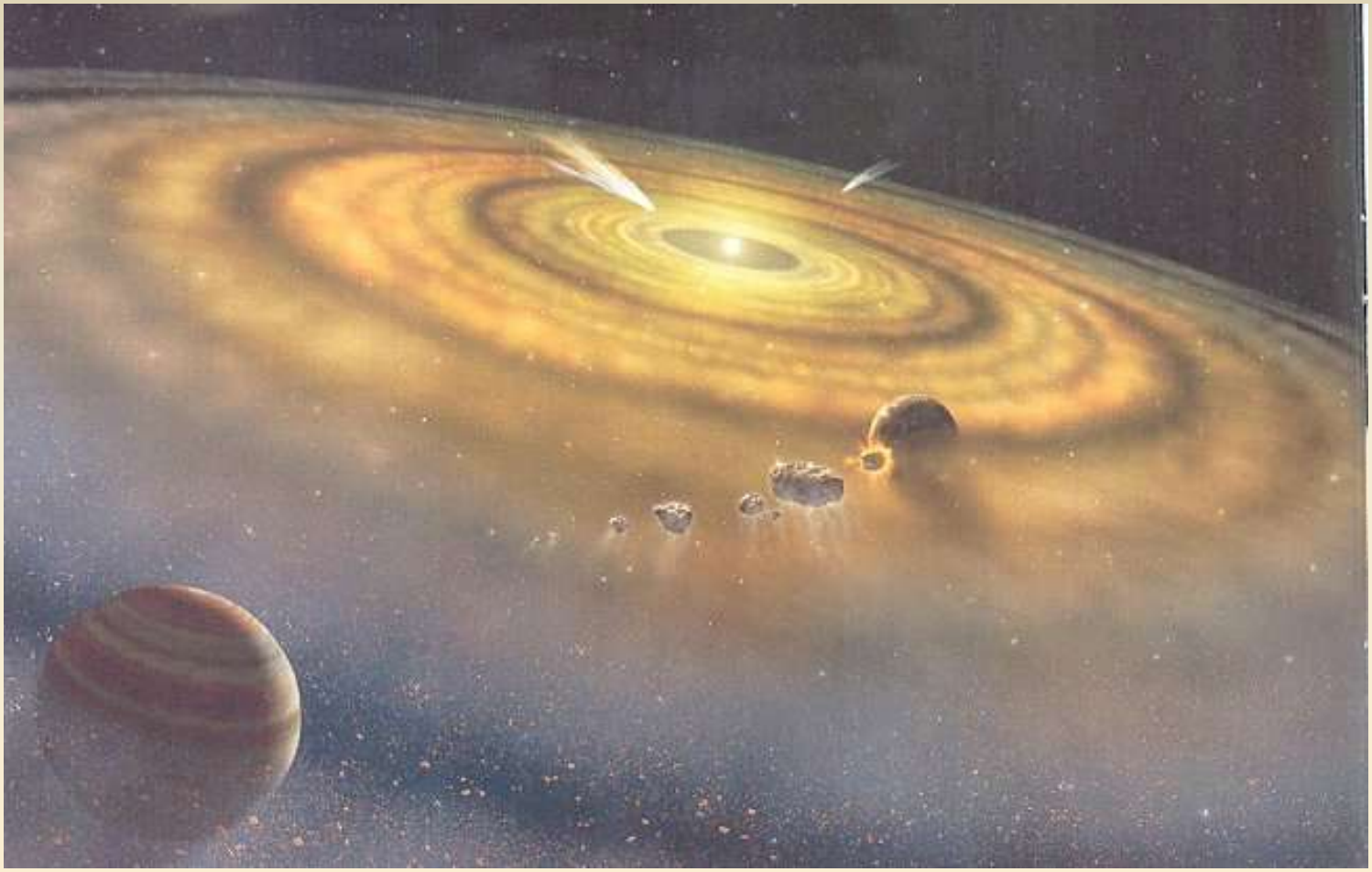
The Sun: 74.5% H, 24% He by mass

The heavy elements are made later, in stars.

Cecilia Payne

The chemical composition of stars (and the fact that they were predominantly hydrogen) was determined by Cecilia Payne (1925)

Formation of the Solar System



Aging the Earth & Solar System

- Oldest rocks on earth about 4.1 bybp (zircons)
- Material in solar system appears older (~4.55 bybp)
- Dating meteorites, chunks of rock and metal, formed about the same time as the sun and planets and from the same cloud.
  - Carbonaceous chondrites are a class of meteorites believed to be the most primitive in the solar system (silicate minerals, water and carbon)
- Dating moon rocks and oldest rocks found on Earth (about 3.8 BY old)
- Rate of expansion (astronomers had very accurate measurements and calculated backwards to an age of 13-14 BY old).

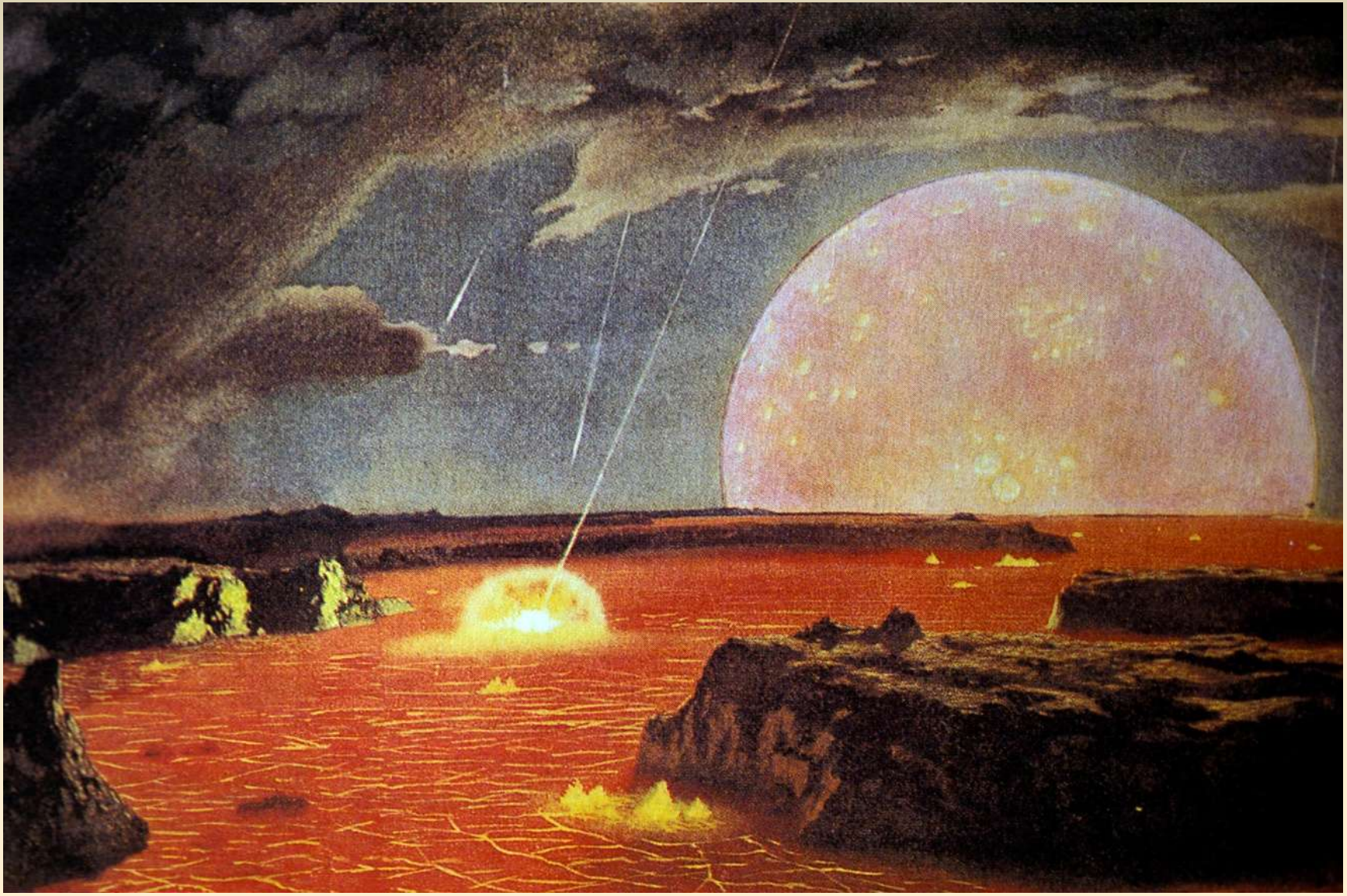
How do we age things?

- Isotopic decay
- Radioisotopes are unstable and decay to form daughter products which form next to parent nuclide.
- Know the ratio of daughter to parent in undisturbed sample and the rate of conversion (e.g., decay rate or half-life) allows computation of age
- This has been done with several isotope pairs to arrive at age of solar system

Conclusions

- Big Bang model describes our current understanding of the universe.
- New discoveries, such as dark matter and accelerating expansion (Dark Energy), lead us to refine our model, but there is no crisis in our understanding (yet).
- Science is an ongoing process - forcing us to test our model through prediction and observation. The more tests it passes, the greater is our confidence in it.

Hadean -Era of Large Impacts



End

Big Bang

- ~14 or 15 BY ago
- Beginning of space and time
- Expansion/cooling of universe began
- Protons and neutrons form
- Cooling initiated the formation of atoms – first mostly H (the most abundant form of matter in the universe) and He (two lightest elements)

The universe

- H_2 and He gas are still the dominant elements in the universe
  - Still about 99% of all material
- Giant gas and dust clouds form
  - Clouds begin to break into megaclouds
  - Megaclouds organized into spiral and elliptical shapes due to rotational forces
  - Galaxies or nebulae are the gases and dust in the disk
- Some of the gas in these galaxies broke up into smaller clusters to form stars
  - Gravitational collapse of stars produces heat
  - Initiates fusion reactions that make other elements

T = 0 seconds to 10^{-43} seconds

- BIG BANG occurs.
- Something causes infinitely dense point to expand (into Nothing).
- Density of universe is so high that time and space are curled up and the laws of physics that we know today do not apply.
- All four forces in nature were unified.
- This is time is called the Planck Time.

Separation of Forces

After the Planck time, the temperature had decreased 10^{32} K and gravity was the first force to separate.

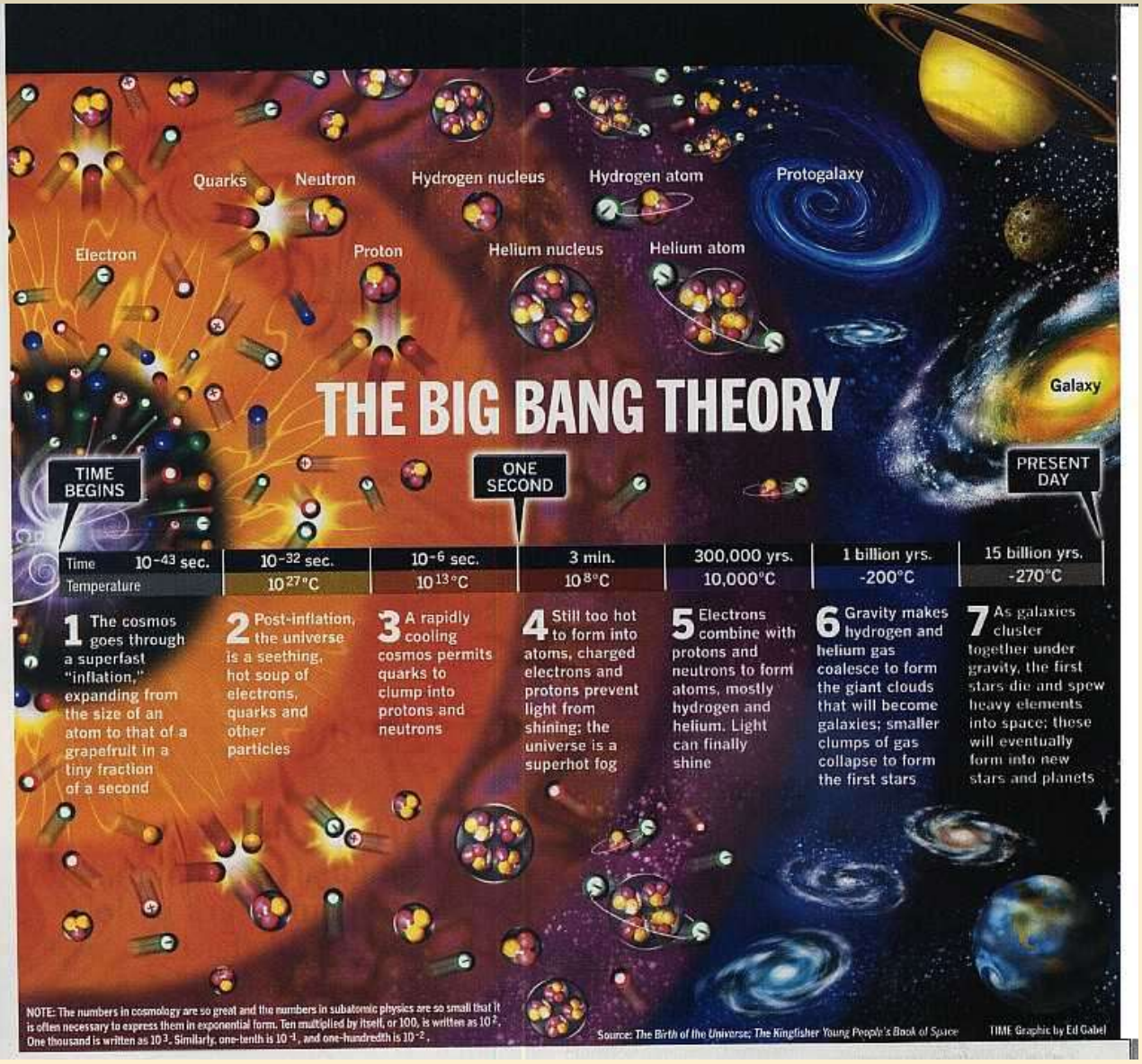
The remaining three forces were still united - these are the conditions that particle physicists today try to replicate.

$T = 10^{-35}$ to 10^{-32} seconds

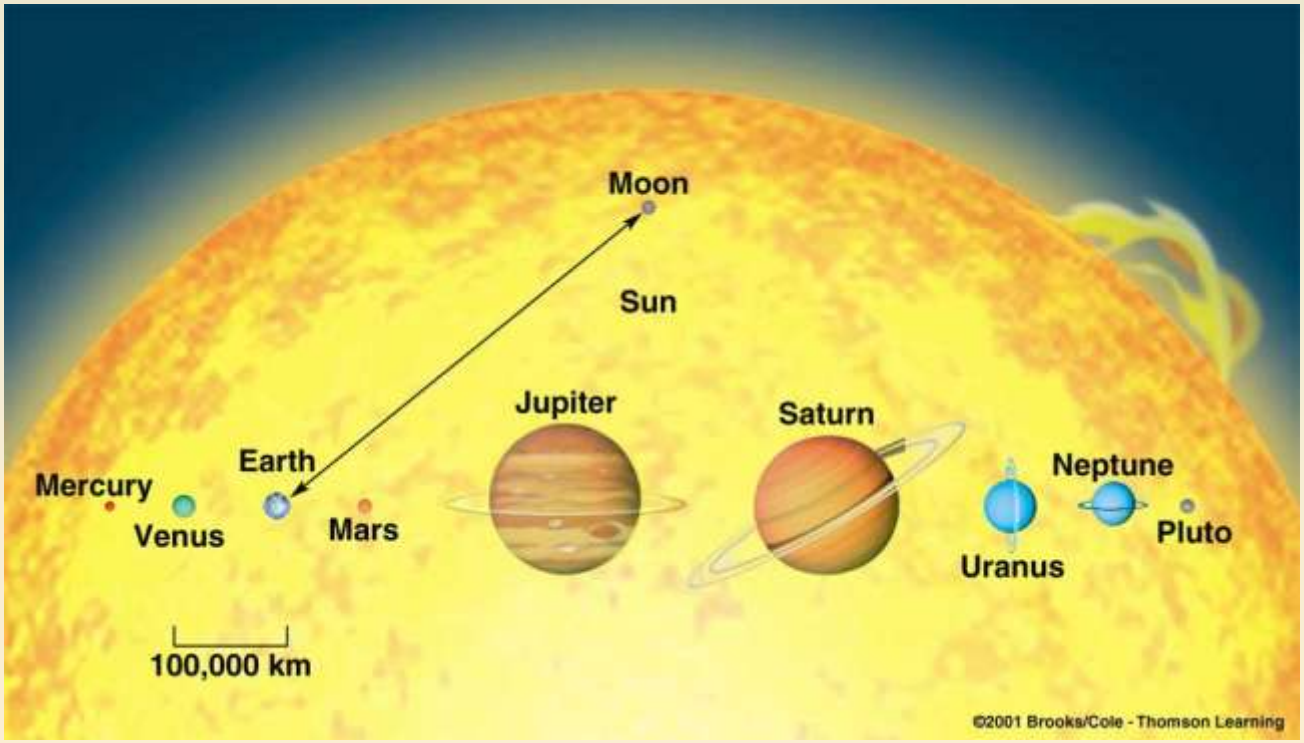
- Inflation caused the size to the universe to increase exponentially by a factor of 10^{50}.
- This time is called the inflationary epoch.

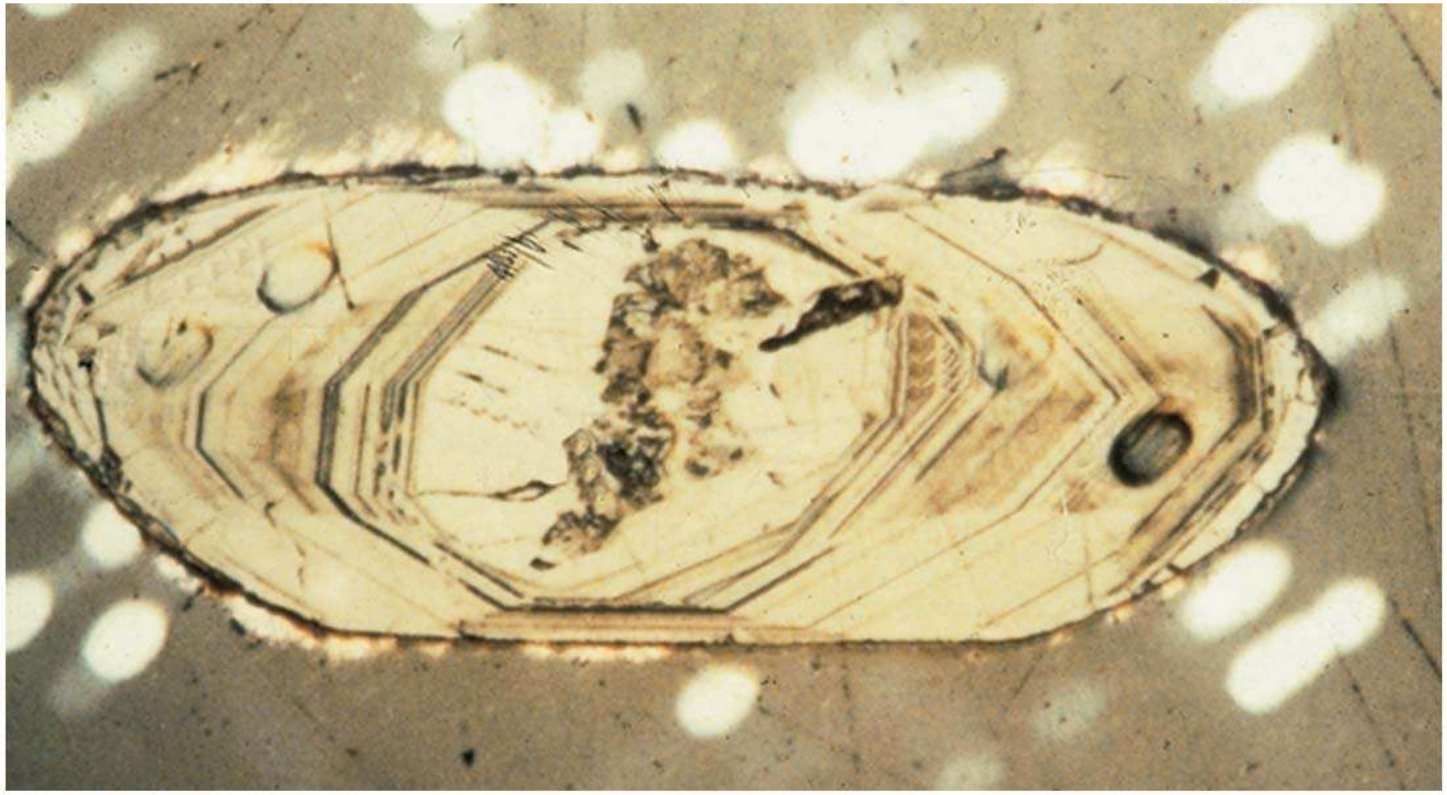
After Inflation Stops

- Matter is created:
  - Photons collide and produce pairs of elementary particles such as electrons and positrons, and quarks and antiquarks.
  - Pair production continues until one of particle could no longer be produced - pair annihilation happens - result: symmetry breaking.
  - Reason for slight excess of matter over antimatter is because of an unknown reaction known as baryogenesis, in which conservation of baryon number is violated.
  - Pair Production occurred until T = 6E9K, but pair annihilation happens independent of temperature.

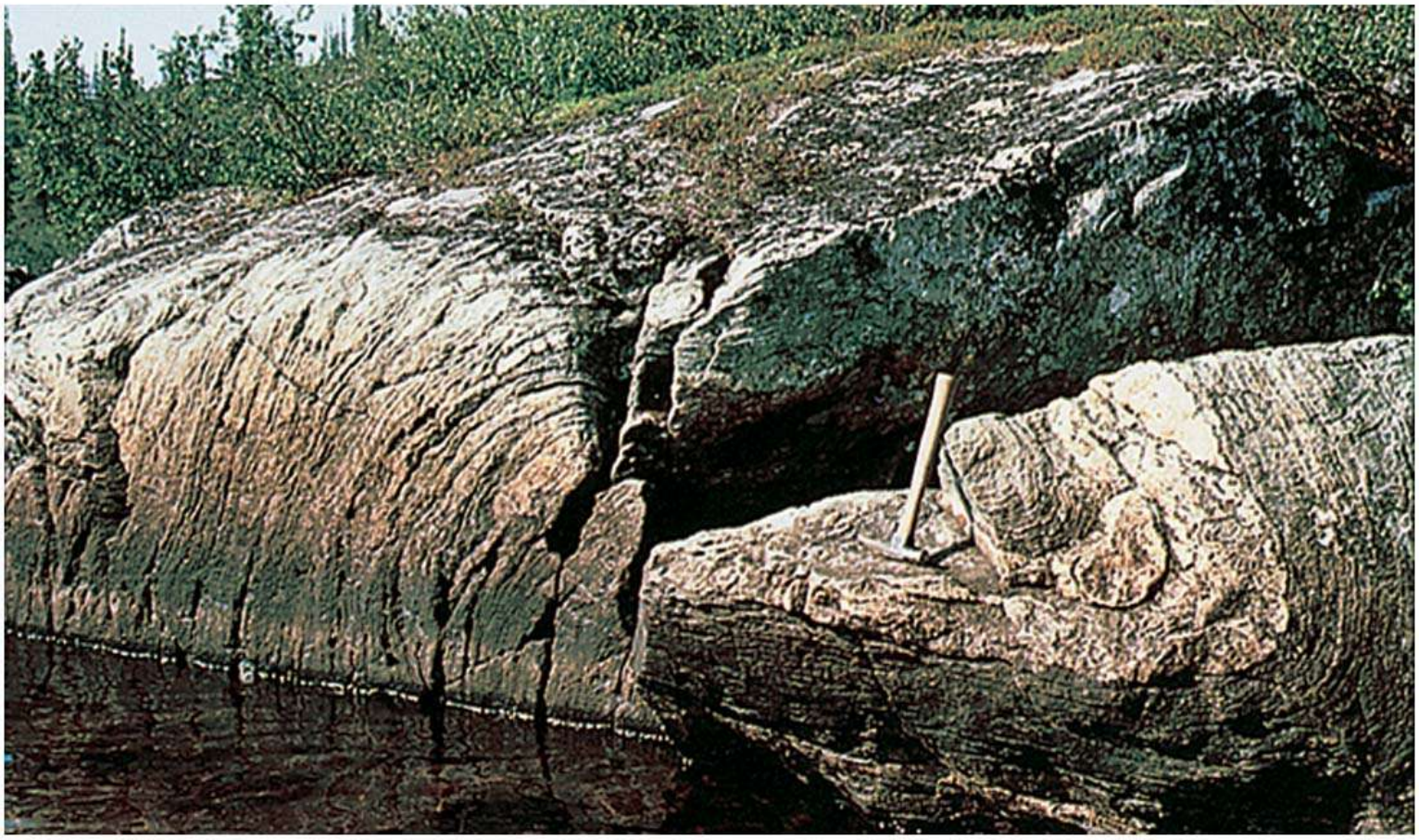

Quarks
Neutron
Hydrogen nucleus
Hydrogen atom
Protogalaxy
Electron
Proton
Helium nucleus
Helium atom
Galaxy
THE BIG BANG THEORY
TIME BEGINS
ONE SECOND
PRESENT DAY
Time 10-43 sec. | 10-32 sec. | 10-6 sec. | 3 min. | 300,000 yrs. | 1 billion yrs. | 15 billion yrs.
Temperature | 1027°C | 1013°C | 108°C | 10,000°C | -200°C | -270°C
1 The cosmos goes through a superfast "inflation," expanding from the size of an atom to that of a grapefruit in a tiny fraction of a second
2 Post-inflation, the universe is a seething, hot soup of electrons, quarks and other particles
3 A rapidly cooling cosmos permits quarks to clump into protons and neutrons
4 Still too hot to form into atoms, charged electrons and protons prevent light from shining; the universe is a superhot fog
5 Electrons combine with protons and neutrons to form atoms, mostly hydrogen and helium. Light can finally shine
6 Gravity makes hydrogen and helium gas coalesce to form the giant clouds that will become galaxies; smaller clumps of gas collapse to form the first stars
7 As galaxies cluster together under gravity, the first stars die and spew heavy elements into space; these will eventually form into new stars and planets
NOTE: The numbers in cosmology are so great and the numbers in subatomic physics are so small that it is often necessary to express them in exponential form. Ten multiplied by itself, or 100, is written as 10 2. One thousand is written as 10 3. Similarly, one-tenth is 10 -1, and one-hundredth is 10 -2.
Source: The Birth of the Universe; The Kingfisher Young People's Book of Space
TIME Graphic by Ed Gabel

The Solar System - Its Origin and Early Development



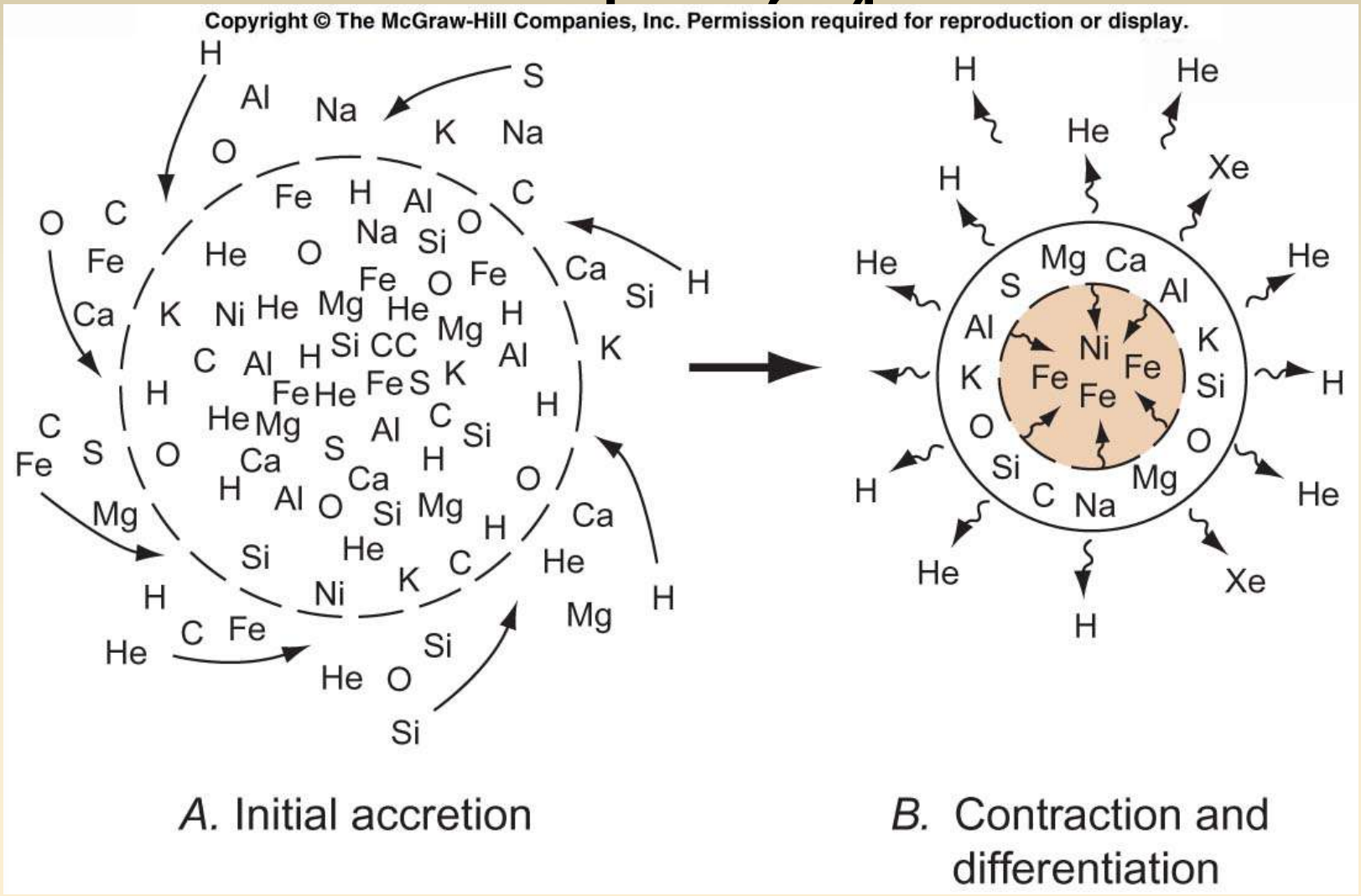


Zircon grain from the Acasta Gneiss, Slave Province, NW Territories, Canada. The crystal has been etched with acid to highlight the growth zones. These zircons have been dated to 4.03 By.

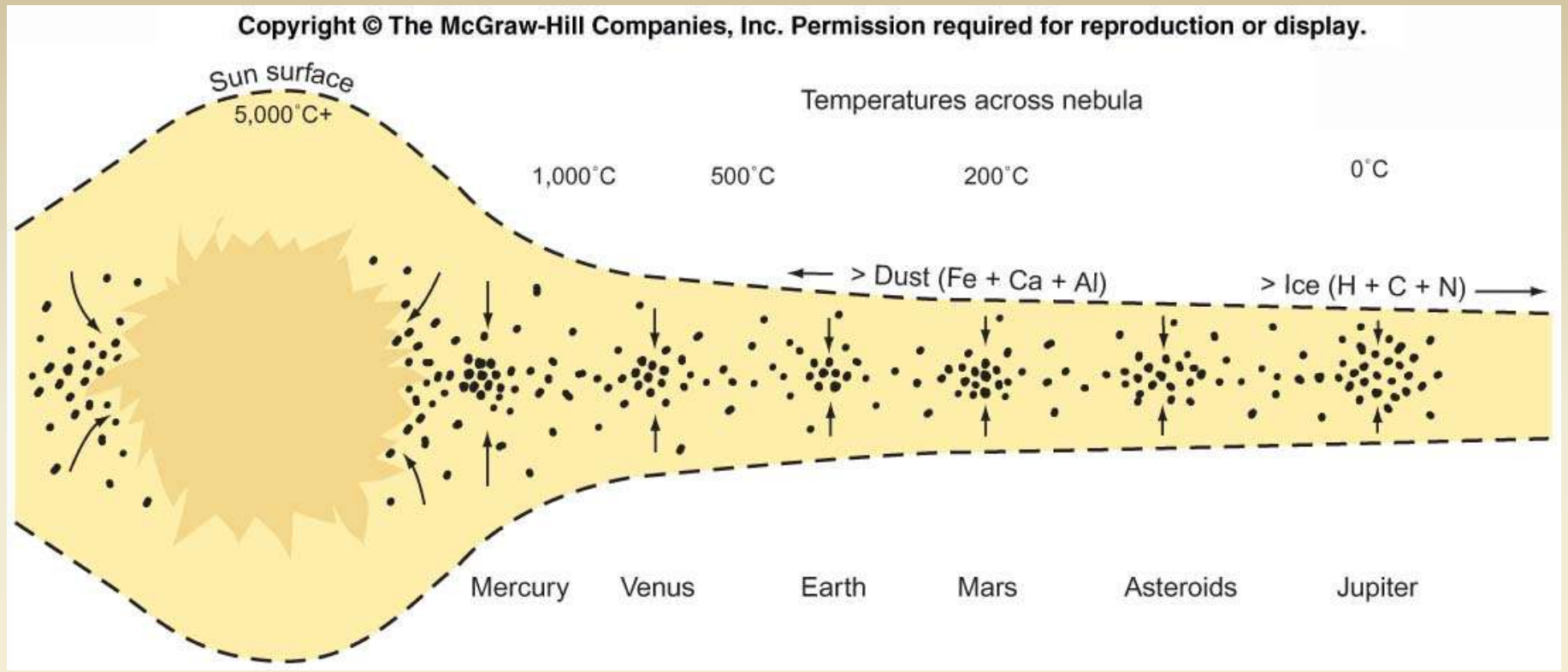


The Acasta Gneiss. Great Slave Province, NW Territories, Canada. One of the oldest (4.03 Bya) dated rocks on Earth. This must have been one of the first crustal rocks to form either at Late Hadean or shortly thereafter.

Stages in Formation of Early Earth



. From (A) a homogeneous, low-density protoplanet to (B) a dense, differentiated planet



Cross section through a spinning disk-shaped nebular cloud illustrating formation of planets by condensation of planetesimals. Temperatures refer to conditions at initial condensation.

Origin and Early Evolution of Earth

- Age of universe is ~ 14.5 By, about 10 By older than Earth
- Early universe had only protons & helium nuclei as condensed particles we are familiar with, rest was elementary particles & radiation
- First stars formed from hydrogen and helium, the rest of the elements formed in protostars by nucleosynthesis
- Stars of a certain critical size exploded as supernovae, scattering hydrogen, He & newly formed elements as intergalactic “dust”. Other stars became “black holes”, brown dwarfs, etc.
- Inhomogeneities in dust clouds led to formation of secondary stars, similar to our sun, but now could contain orbiting debris formed from elements in 1st generation stars.
- Inherited angular momentum caused debris to orbit main condensation center, and eventually gave rise to orbiting planets

"Hadean" is name given to Eon in which Earth formed by accretion and meteorite bombardment.

It was truly "hell on earth" as constant meteorite bombardment and high interior heat flow combined to keep early Earth surface in nearly constant molten state.

Atmosphere of early Earth likely reducing (i.e. no oxygen) and similar to present Jupiter atmosphere (?), mostly:

methane (CH_4),

ammonia (NH_3),

hydrogen (H_2) and

helium (He)

with some traces of noble gases like neon (Ne)

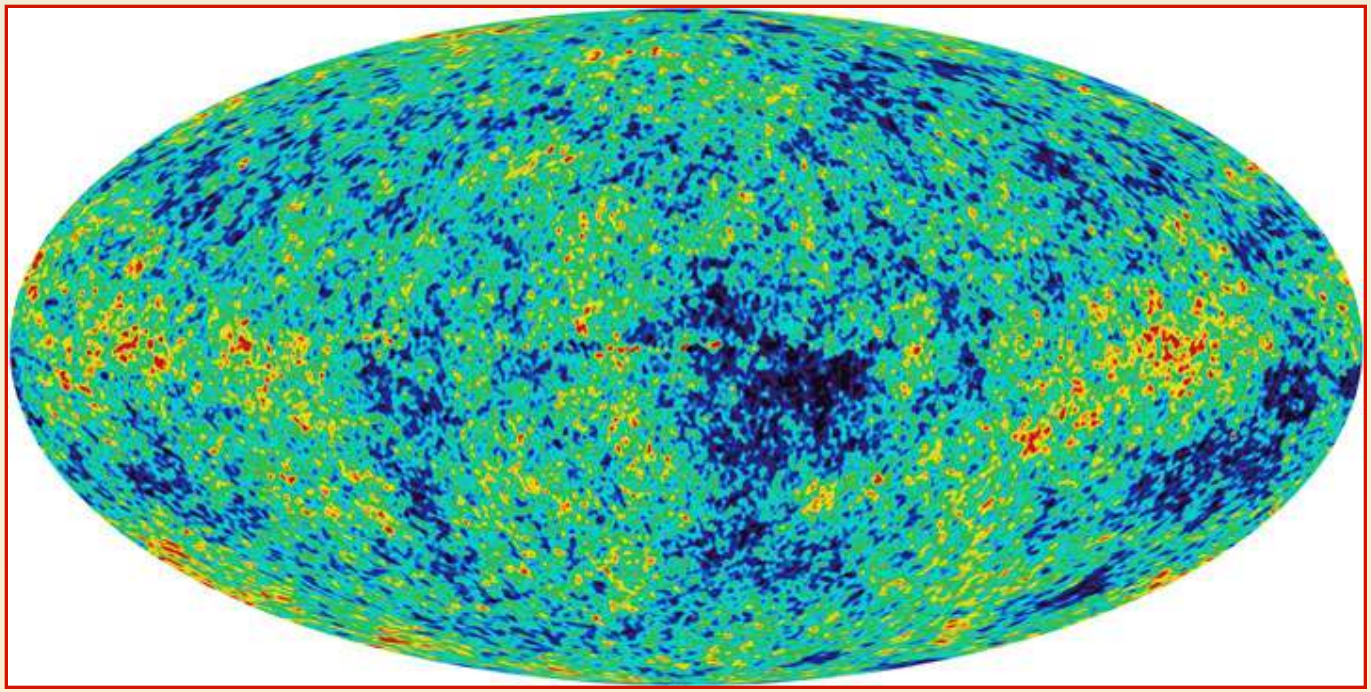
Eon	Era	Period		Epoch	Date (Millions of years before present)
Phanerozoic	Cenozoic	Quaternary		Holocene	
				Pleistocene	
		Tertiary	Neogene	Pliocene	
				Miocene	
			Paleogene	Oligocene	
				Eocene	
				Paleocene	
	Mesozoic	Cretaceous		End of Mesozoic 65 m.y.	
		Jurassic			
		Triassic			
	Paleozoic	Permian		End of Paleozoic 245 m.y.	
		Carboniferous	Pennsylvanian		
			Mississippian		
		Devonian			
		Silurian			
		Ordovician			
		Cambrian			
Proterozoic	Precambrian (87% of geologic time scale)	End of Precambrian 543 m.y.			
Archean					
Hadean					

http://www.carleton.ca/%7Etpatters/teaching/intro/intro.html

Testing the Big Bang model

Prediction: If the universe was denser, hotter, in past, we should see evidence of left-over heat from early universe.

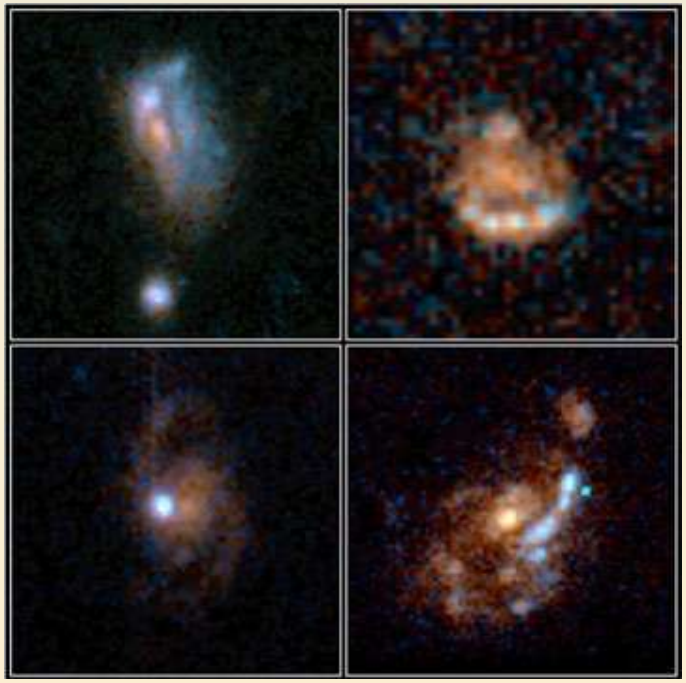
Observation: Left-over heat from the early universe. (Penzias and Wilson, 1965)



Testing the Big Bang model

Prediction: An expanding universe is evolving over time. If we look at the early universe, it should appear different.

Observation: Distant galaxies less evolved, physically and chemically.



Evidence for Expansion

- The light from remote galaxies and other objects is redshifted.
- This redshift is called **cosmological redshift** because it is caused by the expansion of the universe, not by the actual movement of the object (doppler redshift).

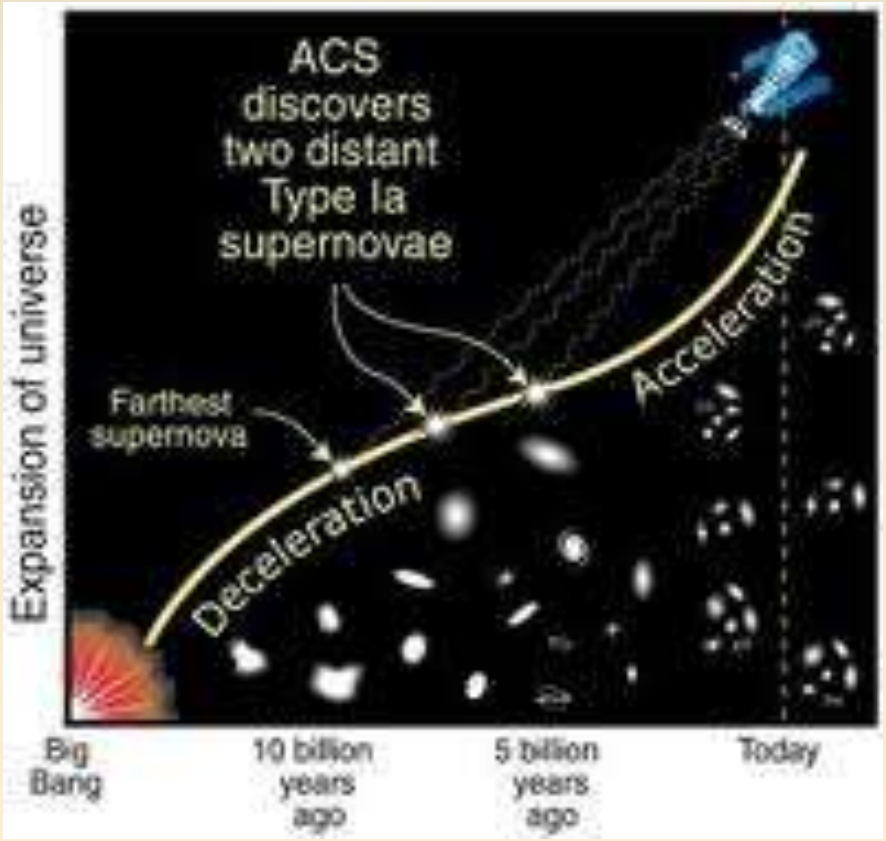
Matter in the Universe Today

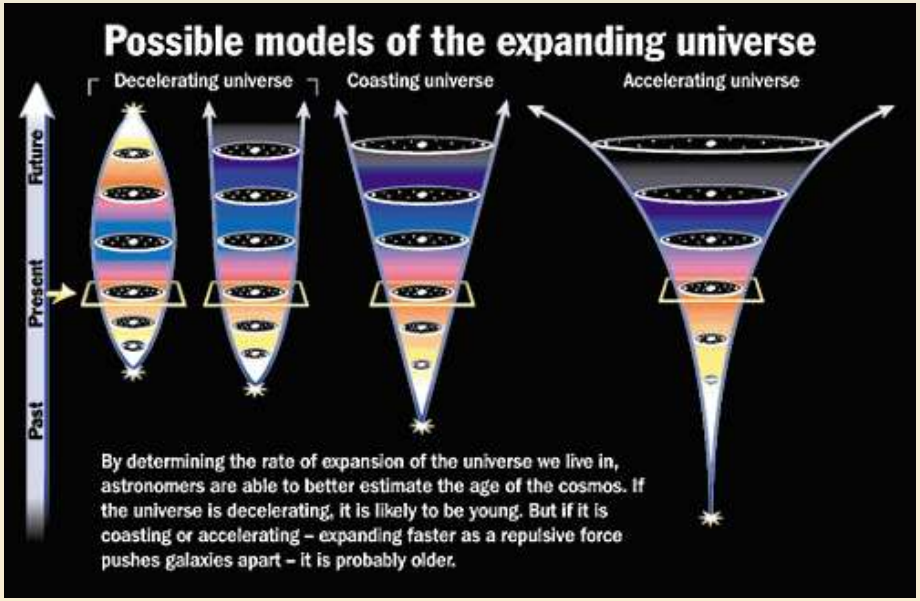
- Evidence gathered from WMAP shows that all of the matter in the universe is composed of three types of matter:
  - Cold dark matter
  - Hot dark matter
  - Baryonic matter
  - Cold dark matter accounts for ~82% of all matter and hot dark matter and baryonic matter combined account for the remaining ~18%.

Nature of Expansion Today

- Evidence of Type 1a supernovae and CMB radiation show that the expansion is accelerating, driven by dark energy.
- Dark energy comprises ~72% of all energy and permeates all space.
- It is likely that this dark energy has always been throughout the universe, but when the universe was younger and much smaller, gravity was stronger than dark energy.
- This acceleration could be described by Einstein's cosmological constant.
- Today, dark energy is still very misunderstood.

Expansion & Fate of Universe

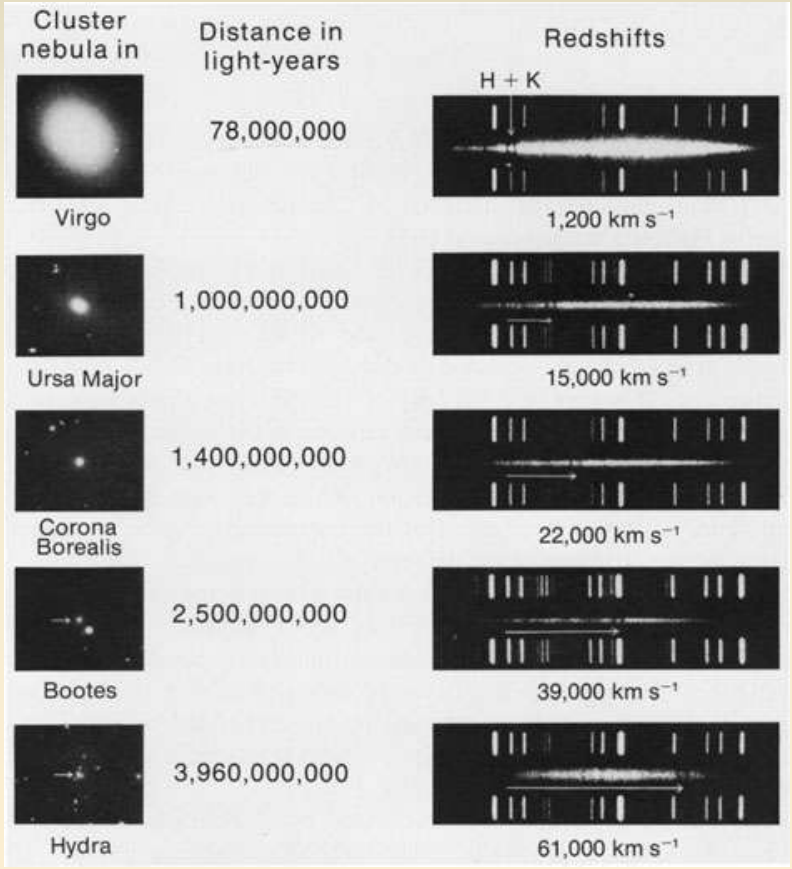




http://www.astronomy.com/asy/default.aspx?c=a&id=2103

http://startswithabang.com/?p=1724

Hubble's Discovery



- Edwin Hubble's observations of remote galaxies, and the redshift of their spectral lines (1924).
- Hubble noticed that the further away the galaxy, the greater the redshift of its spectral lines.
- This linear relationship is called Hubble's Law.

http://rst.gsfc.nasa.gov/Sect20/A9.html

Big Bang – what is it?

- Collapsing cloud of interstellar dust
- Cloud dense and cold so collapses under its own self-gravity (cold gas has less internal pressure to counteract gravity)
- Once collapsed, it immediately warms up because of release of gravitational energy during collapse
- All mass and energy concentrated at a geometric point

Big Bang

- ~14 or 15 BY ago
- Beginning of space and time
- Expansion/cooling of universe began
- Protons and neutrons form
- Cooling initiated the formation of atoms – first mostly H (the most abundant form of matter in the universe) and He (two lightest elements)

The universe

- H_2 and He gas are still the dominant elements in the universe
  - Still about 99% of all material
- Giant gas and dust clouds form
  - Clouds begin to break into megaclouds
  - Megaclouds organized into spiral and elliptical shapes due to rotational forces
  - Galaxies or nebulae are the gases and dust in the disk
- Some of the gas in these galaxies broke up into smaller clusters to form stars
  - Gravitational collapse of stars produces heat
  - Initiates fusion reactions that make other elements

Remaining Questions

- What is dark matter?
- What is dark energy?
- Can dark energy and matter be detected and studied in labs?
- What happened from the birth of the universe, at the instance of the Big Bang, until the end of the inflationary epoch?
- What caused the Big Bang?
- What is the ultimate fate of the universe?