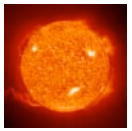
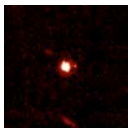
Lecture 2: Cosmic Evolution
A2020
Prof. Tom Megeath

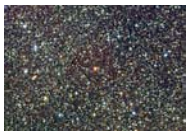
The Hubble Space Telescope Ultra Deep Field

Review
Light Travel Times


Start

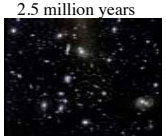

Sun: 8 minutes

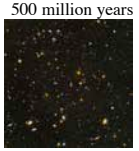

Eris: 12 hours


Proxima Centauri: 4.2 years


Center of our Galaxy: 25500 years


Nearest Galaxy: 2.5 million years


Nearest Galaxy Cluster: 500 million years


Most distant known galaxies:12.5 billion years

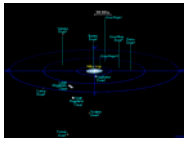
Your Cosmic Address

Earth

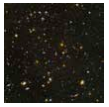
The Solar System

The Milky Way Galaxy

The Local Group



The Universe



Flight to the Virgo Cluster

The dynamic events occur over millions and billions of years?

How do we study the dynamic universe when things change so slowly?

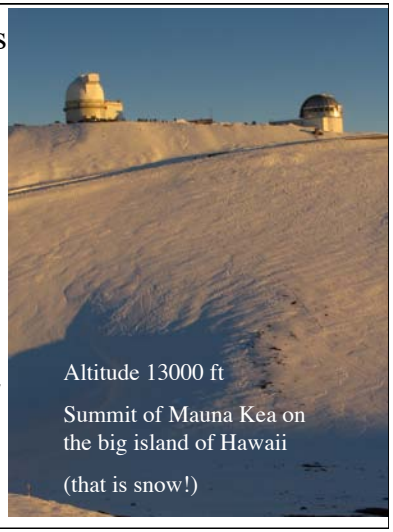
Answer 1: Telescopes are Time Machines

When you look at an object 1 light away, you are looking at what it looked like 1 year ago.

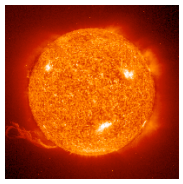
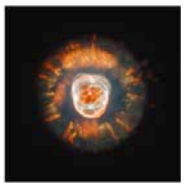
When you look at an object 1 million light years away, you are looking at it 1 million years ago.

The universe is thought to be 13.66 billion years old, so when you look back 12.7 billion years - are you looking back to a time when the universe was "young".

Cosmic evolution can be studied by looking at more and more distant objects.



Answer 2: study objects in different evolutionary stages

Answer 3: Use laws of physics to understand and simulate how things move.

Answer 4: Directly measure motions (proper motions in lecture 3, Doppler shift in lecture 5)

Answer 5: Measure ages of objects (this lecture)

Journey Back in Time

Astronomy, Physics, Geology and Biology have extended the history of our planet and universe back to the beginning time.

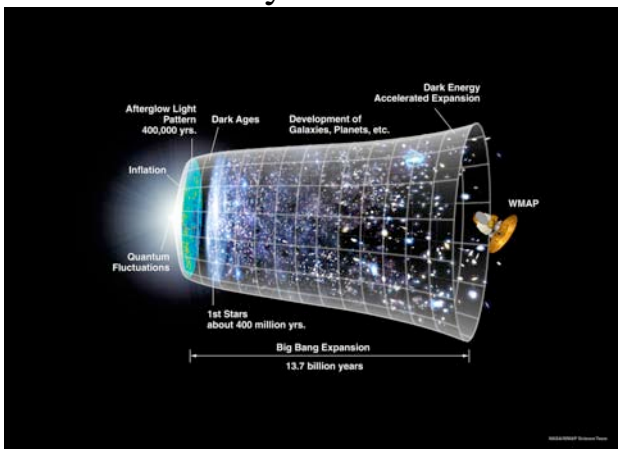
The cosmic calender:

Midnight January 1st - the beginning of the universe.

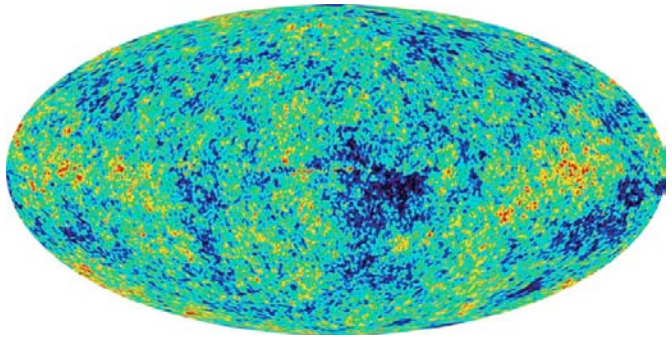
11:59:59 PM December 31st - today

Compresses all of cosmic evolution into a single year

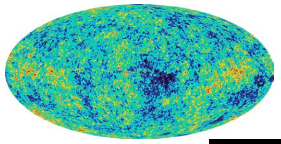
January-December



A real image of January 1st 400,000 Years after the Beginning of the Universe

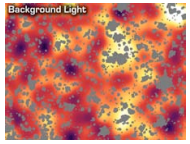


January

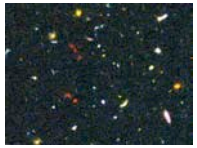


January 1st: The Big Bang 13.7 billion years ago.

Early January: Dark ages - no stars just gas (first 400,000 years)

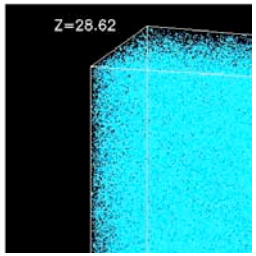


Mid January: The first stars (400 million years)



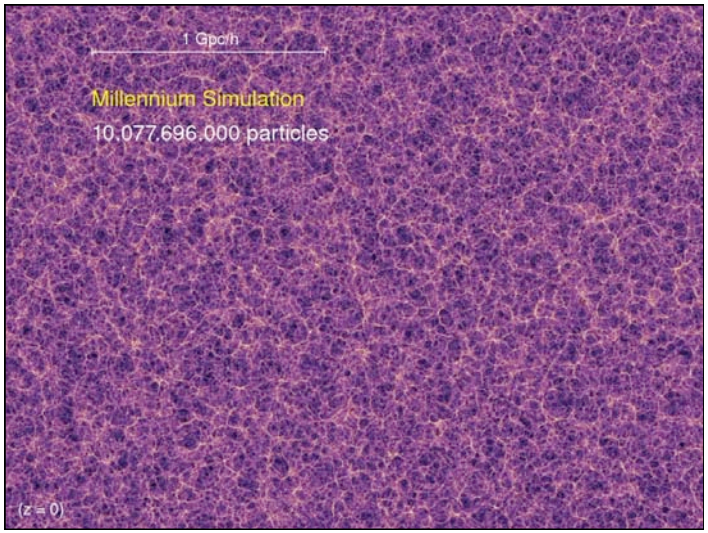
By end of January: The first galaxies formed (< 1 billion years)

How Gravity Organized the Universe (January - December)



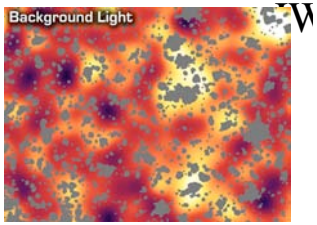
The Universe in a box - a computer simulation of a "chunk" of the Universe showing how the hydrogen gas left over from the big bang was pulled together by gravity into filaments.

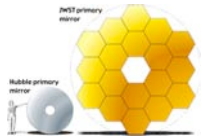
http://cosmicweb.uchicago.edu/filaments.html



2013: the James Webb Space Telescope

Detecting the First Stars with W





Why is a bigger telescope better?

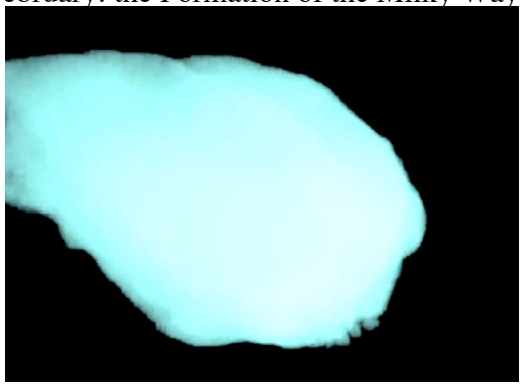
- It collects more light (higher sensitivity)
- Can obtain higher resolution (sharper) images

February: The Age of the Quasar Begins

Quasars are unusually bright objects which are only found in the early universe. They are galaxies in which massive black holes have formed. The energy released as gas and stars fall into the black hole are what we see.

1 - 9 billion years

February: the Formation of the Milky Way



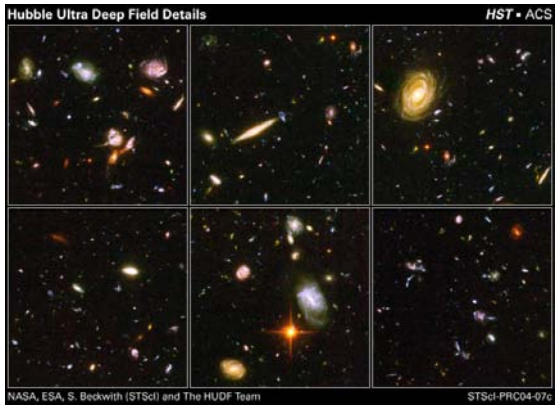
We can estimate when our galaxy formed by finding the oldest stars in the Galaxy, and measuring their ages. The Milky Way formed early, either in January or February

1 billion years

What force is responsible for creating galaxies?

Gravity

February - August (1-9 Billion Years)
Galaxies continue to form, stars continue to form and die in galaxies



We started with Hydrogen and Helium.

Where do the other elements come from?

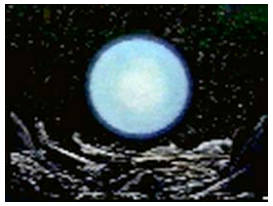
January to December

The Creation of the Elements

Elements heavier than hydrogen and helium created in the centers of stars (Carbon, Oxygen, Nitrogen, Iron, Aluminum)

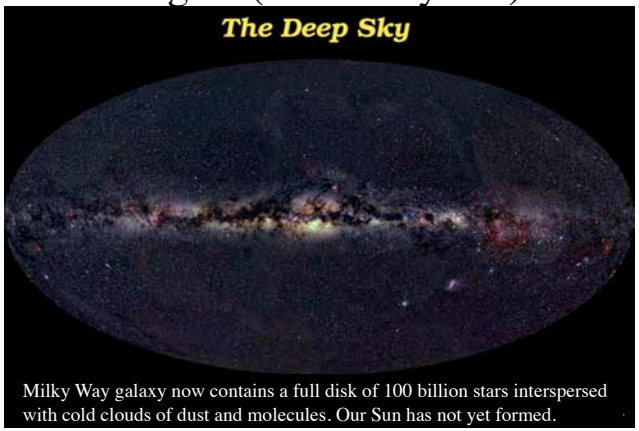
When stars die, they release some of these elements into the universe.

New stars form from the gas with the new elements.



Artist conception of supernovae explosion.

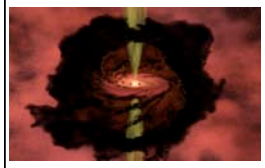
August (8 billion years)



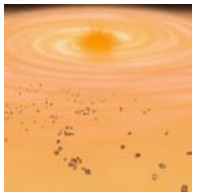
Milky Way galaxy now contains a full disk of 100 billion stars interspersed with cold clouds of dust and molecules. Our Sun has not yet formed.

Axel Mellinger

September 3rd (9 billion years): Our Solar System Forms



Protostar 300,000 years



Dust collects into planetesimals and eventually planets: 3 million years

Sun surrounded by disk of gas and dust: 1 million years

Young Earth covered in oceans of lava: 30 million years

September 22nd: 11billion years

First Single Cell Life - Bacteria

Layered rocks thought be mats of fossilized bacteria are found on the Canadian shores of Lake Superior

October - November (11.5-12.5 billion years)

Life Alters Earth's Atmosphere and produces Oxygen

Bacteria convert CO_2 in O_2 through photosynthesis

Bacteria may have lived in stromatolites

Shark's bay Australia

December: last billion years

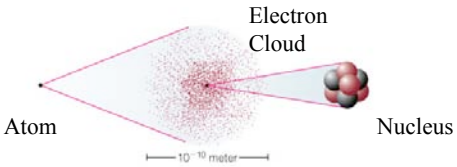
December 8 - single cell animals (Eukaryotes)
December 13 - Jellyfish
December 20 - Fish first appear
December 22 - Animals first take to land
December 26 to December 29 - Dinosaurs
December 31, 9 PM - early hominids
December 31,11:58 PM - modern Humans
December 31, 11:59:35 PM - Agriculture begins
December 31, 11:59:49 PM - Pyramids
December 31, 11:59:59 PM - Galileo, Copernicus and Kepler show how the planets go around the sun

How do we determine when something occurred?

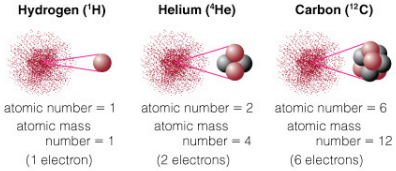
How do we study cosmic evolution:

1. Radioactive dating
2. Finding ages of clusters of stars
3. Looking back in time (telescopes are time machines)
4. Measuring the motions of the galaxies

Atomic Terminology

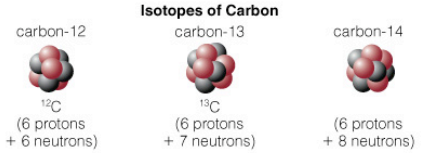


- Atomic Number = # of protons in nucleus
- Atomic Mass Number = # of protons + neutrons

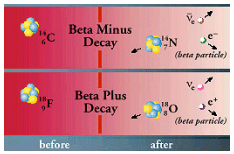


Atomic Terminology

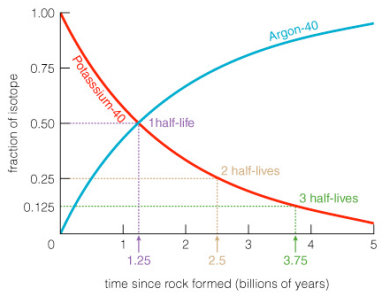
- Isotope: same # of protons but different # of neutrons. (^{4}He, ^{3}He)



Radioactive Decay



Determining the Age of the Solar System
Half Life of Radioactive Decay



A radioactive isotope of Potassium (40P) undergoes beta decay and changes into Argon

$^{40}P \rightarrow {}^{40}Ar + \beta$

Half life = 1.25 billion years ago

P is parent species
Ar is daughter species

The Ages of the Earth and Moon

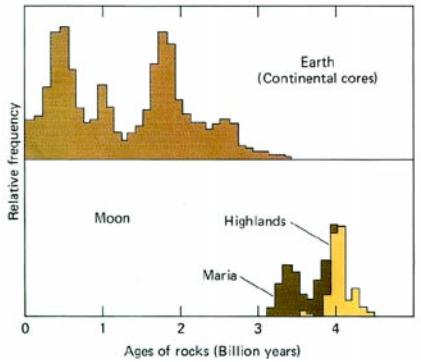
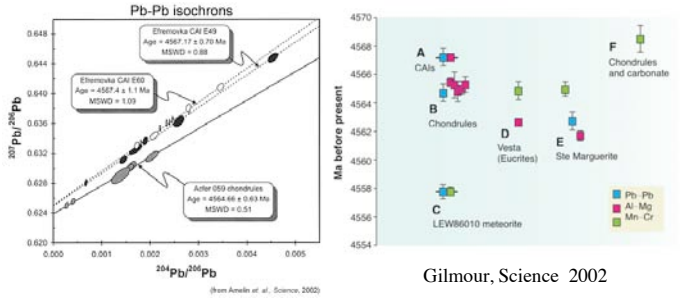


Figure from Jay Frogel.

The Ages of Meteorites



Gilmour, Science 2002

http://www.psrd.hawaii.edu/Sept02/isotopicAges.html

Amelin, Krot et al. 2002

When did our galaxy form?

Many stars are found in clusters of stars, all of which formed together at roughly the same time.

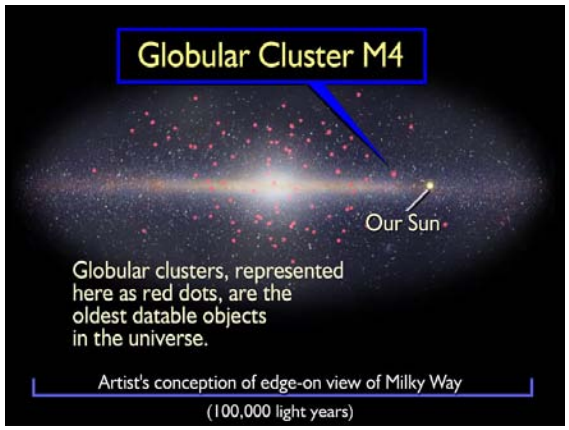
The richest clusters are globular clusters, which can contain 1 million stars

In the distance between the Sun and the nearest star, a globular cluster would contain 100,000 stars.

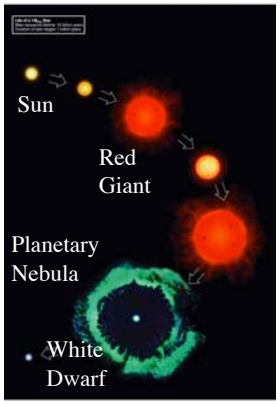
The Formation of the Milky Way Galaxy

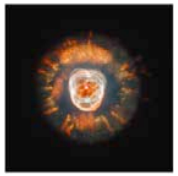
The first stars forming in our galaxy formed in globular clusters. Thus the ages of stars in globular clusters give us an estimate for the age of the Milky Way

When did our galaxy form?

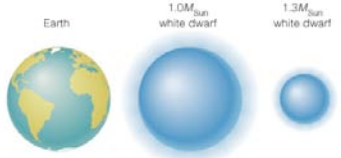


Lifecycle of stars: White Dwarfs





Planetary Nebula with White Dwarf



300,000 times the mass in the same volume

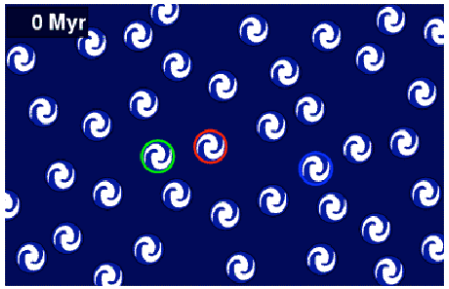
When did our galaxy form?

In this globular cluster, stars with similar masses to our Sun, have turned into white dwarfs.

Measured Ages of white dwarfs: 12.7 billion years

Within 1 billion years of the formation of the Universe, the first stars in our Galaxy formed.

When did the universe form?

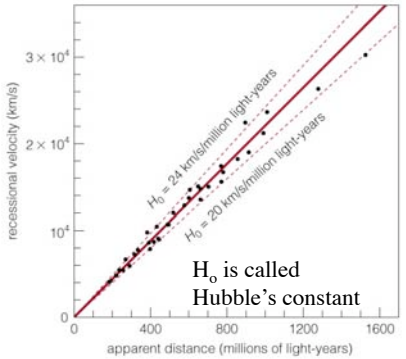


The Universe is expanding by following the Hubble law.

The more distant the object, the faster it is moving away from us.

http://www.einstein-online.info/en/elementary/cosmology/expansion/index.html

When did the universe form?



H_o is called Hubble's constant

Hubble's law, first discovered by Edwin Hubble in 1929

Edwin Hubble: (1889-1953)

When did the universe form?

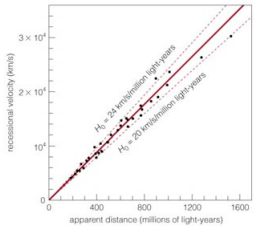
The age of the universe is given by Hubble's constant.

Age = $1/H_0$ x speed of light (km/s) x length of million year (s)

= 1/22(km/s/million light years) x $3x10^5$ (km/s) x π x 10^{13} (s)

= 13.6 billion years

(best estimate is 13.7 +/- 0.2 billion)



By using Hubble's law, we can measure the distance to a galaxy, and thus how far back in time we are looking. Thus, by looking at more distant galaxies which are moving away faster and faster, we can study cosmic evolution from the comfort of the Earth

Summary

Things to know:

I. How do we study an evolving universe.

II. The cosmic calendar big events:

1.the formation of the Solar System
2.the formation of the Milky Way
3.the big bang

III. How do we measure the age of the Earth, Milky Way and Universe