Scales of Space and Time
Solar (Star) System

A star and all the material that orbits it, including its planets and moons
Galaxy

A great island of stars in space, all held together by gravity and orbiting a common center
Universe

The sum total of all matter and energy; that is, everything within and between all the galaxies. Most of space is empty.
When we look up at the moon, we are looking into the past… it takes 1 second for light to travel from the Moon to the Earth.
How can we know what the universe was like in the past?

- Light travels at a finite speed (300,000 km/s).

<table>
<thead>
<tr>
<th>Destination</th>
<th>Light travel time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moon</td>
<td>1 second</td>
</tr>
<tr>
<td>Sun</td>
<td>8 minutes</td>
</tr>
<tr>
<td>Sirius</td>
<td>8 years</td>
</tr>
<tr>
<td>Andromeda Galaxy</td>
<td>2.5 million years</td>
</tr>
</tbody>
</table>

- Thus, we see objects as they were in the past: 
  
  *The farther away we look in distance, the further back we look in time.*
Example:

This photo shows the Andromeda Galaxy as it looked about 2 1/2 million years ago.

Question: When will be able to see what it looks like now?
Definition: a **light-year**

- The **distance** light can travel in one year
- About 10 trillion km (6 trillion miles)
- At great distances, we see objects as they **were**
A Scale Model

Set the Earth to a 6cm ball, or a 1:200,000,000 scale model

- The Moon is a marble at your arm span
- The Sun is a 7 m ball (about the height of Old Main) 700 m away (about the length of the UofA mall)
- The Solar System is the size of Tucson
- The nearest star is 1/2 distance to the moon!
And at this scale, light is reduced to slow walking speed. There’s no way information in the universe can travel any faster.

- The Moon is a seconds walk away
- The Sun is 8 minutes walk away
- 10 hours to walk the Solar System
- 4 years to walk to the nearest stars
Definition: Astronomical Unit

- The mean **distance** between the Earth and the Sun
- About 150 million km (93 million miles)
- Denoted as 1 “AU”
Definition:
Astronomical Unit
• The Voyager spacecraft – the farthest human craft from the Earth has taken almost 25 years to reach the edge of the Solar System.

> 38,000 mph at 120 AU!
Solar flares take about 1 day to reach the Earth.
The orange track represents a typical KBO orbit. Pluto’s orbit is represented by the yellow ring.
Comet

A relatively small and icy object that orbits a star.
Relative Sizes of the Planets
Reduce the scale by a factor of 50,000,000

- The Solar System is a grain of sand
- The distance between stars is 10 m
- The Milky Way is the size of the U.S.
- The MW has 100,000,000,000 stars
Sun takes 250 million years to orbit the Galaxy
Now reduce by another factor of 100,000,000

- The Milky Way is the size of a frisbee
- The nearest galaxy is 10 m away
- The visible universe is the size of the U.S.
- Billions of galaxies within this space
The Milky Way is not alone … Satellite Galaxies
Magellanic Clouds are visible from Southern Hemisphere
Large Magellanic Cloud – “Irregular Galaxy”

Distance $\sim 150,000$ ly

$1/10^{th}$ size of Milky Way

$1/100^{th}$ mass of Milky Way
Sagittarius Dwarf Galaxy is being cannibalized!
Zooming Out by factor of 10 … “Local Group”
Andromeda Galaxy

Distance ~ 2.5 million ly

Slightly more massive than Milky Way
Andromeda Galaxy

Today

View from Earth

+2 billion years

+3.75 billion yr

+3.85 billion yr

+3.9 billion yr

+4 billion yr
Triangulum Galaxy

Distance ~ 3 million ly
Zooming out by factor of 20 … Galaxy Clusters
Virgo Cluster of Galaxies

Distance ~ 50 million ly
Fornax Cluster of Galaxies

Distance ~ 60 million ly
Zooming out by factor of 10 ... SuperClusters
Coma Supercluster of Galaxies

Distance ~ 300 million ly
On largest scales Gravity has organized clusters into Filaments 100s of millions light years long.
• Number of galaxies in the observable universe: ~ 60 billion
• Number of stars in the observable universe: ~ $10^{22}$

90% of the volume or look-back time is probed by deep field
90% of the galaxies in the volume are counted
How many stars is that?

- The Milky Way is one of about 60 billion galaxies.
- \(10^{11} \text{ stars/galaxy} \times 10^{11} \text{ galaxies} = 10^{22} \text{ stars}\)

As many stars as grains of (dry) sand on all Earth’s beaches…
Counting galaxies at one/second, \(~2000\) years
At this rate, it would take longer than the lifetime of universe to count all the stars
Cosmic Microwave Background

Radiation signature from 300,000 years after the Big Bang
What is our physical place in the universe?

• Our “Cosmic Address”
How do our lifetimes compare to the age of the Universe?

- The Cosmic Calendar: a scale on which we compress the history of the universe into 1 year.
- This is a time scale model where 14 billion years equals 1 year, i.e. 14,000,000,000:1.
- Our lives would scale similarly, so 80 years goes down by a factor of 14 billion too.
- In the scale model, a human life is about 2 tenths of a second!
The Cosmic Calendar: January - November

- **January 1 (15 bya)**: Big Bang
- **March 20 (12 bya)**: Galaxies form
- **October 6 (3.6 bya)**: Life established, first fossils, photosynthesis (?)
- **September 2 (5 bya)**: Formation of our solar system
- **September 14 (4.5 bya)**: Earth formed
- **November 14 (2 bya)**: Complex single cells
- **November 19 (1.8 bya)**: Free oxygen
- **November 21 (1.7 bya)**: Evidence of multicellular organisms (?)
Now home in on the more recent span of the history of life and of humans and civilization.
The Raw Material for Astrobiology

- **Space:** the potential habitable worlds around ten thousand billion billion billion stars; ours is just one.

- **Time:** a cosmic history of nearly 14 billion years; life took less than $\frac{1}{2}$ billion years to start here.

“A sad spectacle. If they be inhabited, what a scope for misery and folly. If they not be inhabited, what a waste of space.”

Thomas Carlyle, Scottish Essayist (1795-1881)