Let's start by familiarizing ourselves with some common astronomical objects and distance scales in the Universe....

**Star**
A large, glowing ball of gas that generates heat and light through nuclear fusion

**Planet**
A moderately large object that orbits a star. Planets may be rocky, icy, or gaseous in composition.
**Moon (or satellite)**
An object that orbits a planet.

**Asteroid**
A relatively small and rocky object that orbits a star.

**Comet**
A relatively small and rocky/icy object that orbits a star.

**Solar System**
A star and all the material that orbits it, including planets and moons, asteroids and comets, etc.
**Galaxy**
A great collection 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 galaxies

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**Scales in the Universe:**
our Cosmic Address

- Earth
- Sun/Solar System
- Milky Way Galaxy
- Local Group
- Local Supercluster

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**Scale models of the Universe**
- Scale Sun as a grapefruit (1:10,000,000,000)
What about distances from the Sun on the same scale?

- Earth = tip of ball point pen, 15 meters (49 feet)
  - Moon = 4 cm away from earth
- Mars = tip of ball point pen, 23 meters (75 feet)
- Jupiter = marble, 78 meters (255 feet)

Moving out of the solar system

- On this scale, the nearest stars would be a system formed by a cantaloupe, a small apple and a kiwi fruit, located in the middle of Alaska (with solar system in middle of Colorado)
- There is essentially nothing in between!!

New Scale for the Galaxy:

- Stars are microscopic - located a few mm apart
- Milky Way galaxy is 100 meters in diameter, contains 100,000,000,000’s (100’s of billions) of stars

Yet Another Scale for Everything Else

- Galaxies are 10” paper plates
- Milky Way and nearest neighbor Andromeda are 5 meters apart
- Galaxy groups and clusters contain 10’s to 1000’s of galaxies
• Superclusters 50 meters across (size of buildings in our scale model) are the largest structures we see
• Observable universe is about size of our county on this scale

In this image, each dot is an entire galaxy

Sample Clicker Question

Which of these are the most likely?

A. Two planets colliding  
B. Two stars colliding  
C. Two galaxies colliding  
D. None of the above… there’s too much space!

Sample Clicker Question

Milky way and Andromeda Galaxy in local group predicted to collide in about 4 billions years
Sizes are going to be large!

Powers of Ten

- Zooming through the Universe

Quick Scientific Notation Reminder

1. \((3 \times 10^{10}) \times (2 \times 10^3) = ?\)
   - When you multiply exponents, you ADD them
   \[= (3\times2) \times (10^{10+3}) = 6 \times 10^{13}\]

2. \((8 \times 10^{12}) \div (2 \times 10^5) = ?\)
   - When you divide exponents, you SUBTRACT them
   \[= (8 \div 2) \times (10^{12-5}) = 4 \times 10^7\]

3. \((6 \times 10^8) \div (3 \times 10^{-3}) = ?\)
   - Negative exponents? You still SUBTRACT them
   \[= (6 \div 3) \times (10^{8-(-3)}) = 2 \times 10^{11}\]

Powers of 10:

- **BIG NUMBERS**
  - \(10^0 = 1\)
  - \(10^3 = 1,000\) kilo- (aka thousand)
  - \(10^6 = 1,000,000\) mega- (aka million)
  - \(10^9 = 1,000,000,000\) giga- (aka billion)
  - \(10^{12} = 1,000,000,000,000\) tera- (aka trillion)
  - \(10^{15} = 1,000,000,000,000,000\)
  - \(10^{18} = 1,000,000,000,000,000,000\)
  - \(10^{21} = 1,000,000,000,000,000,000,000\)

- **LITTLE NUMBERS**
  - \(10^{-1} = 1/10 = 0.1\)
  - \(10^{-2} = 1/100 = 0.01\) centi-
  - \(10^{-3} = 1/1000 = 0.001\) milli-
  - \(10^{-4} = 1/10000 = 0.0001\)
Order of Magnitude
Astronomy

- Astronomy frequently deals with very BIG numbers
- When dealing with really big quantities, the small details become trivial
  - For example, when we say that the nearest galaxy is 2 million (2,000,000) light-years away, does it really matter if it's actually 2,000,001 or 2,000,100?
  - How far is it to drive from here to Los Angeles? (centimeters won’t matter…)

What’s a factor of π between friends?

More on order of magnitude
Astronomy

How many piano tuners are there in Boulder County?

A. 2
B. 20
C. 200
D. 2000
E. Too many to count!

Start with known facts and reasonable guesses

Population of Boulder County?
- ~300,000 people

How many people have a piano?
- 1 in 30?
  - Could be off but probably not by much!

How many pianos?
- ~10,000 pianos in Boulder County

How often do you need to tune a piano?
- Once a year??
  - 10,000 piano tunings/year

Other needed estimates

- How long does it take to tune a piano?
  - 3-4 hours?
  - = 2 tunings per day

\[
\begin{align*}
2 \text{ piano tunings} & \times \frac{5 \text{ days}}{\text{week}} \times \frac{50 \text{ weeks}}{\text{year}} = \frac{500 \text{ piano tunings}}{\text{tuner}} \\

\frac{10,000 \text{ piano tunings}}{\text{year}} & = 20 \text{ tuners}
\end{align*}
\]
Navigating the Universe: Sizes and Scales

“I don’t pretend to understand the Universe. It’s a great deal bigger than I am.”

- Thomas Carlyle (1795-1881)

How do we measure distances to things in space?

- Kilometers (km)
- Astronomical Units (AU)
- Light-years
- Parsecs*
  * We won’t deal with parsecs in AST 105

Measuring cosmic distances

- One of the most useful measures is based on the speed of light = \(300,000 \text{ km/sec}\)
- Nothing travels faster through space
- All light travels at a constant speed in space.

Convert SPEED to DISTANCE

You know that

\[
\text{SPEED} = \frac{\text{DISTANCE}}{\text{TIME}}
\]

meters/sec = meters / sec (or think mph)

Multiplying both sides by TIME we can get

\[
\text{SPEED} \times \text{TIME} = \text{DISTANCE}
\]

\((m/s) \times (s) = \text{meters}\)
Measuring cosmic distances

- Most useful measure is based on the speed of light = 300,000 km/sec
  - Nothing travels faster through space
  - All light travels at a constant speed in space.

- Light-year = the distance light travels in a year
  \[ \text{Light-year} = 300,000 \text{ km/sec} \times 60 \text{ sec/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} \times 365 \text{ days/year} \times 1 \text{ year} \]
  \[ \approx 10 \text{ trillion kilometers} = 10^{16} \text{ m} = 6 \times 10^{12} \text{ miles} \]

- Like saying “I live 30 min from Stony Brook”
  - You are giving a time... but are implying traveling at a certain velocity

Sample Clicker Question

How much time does it take light to travel 1 Astronomical Unit (1 AU)?

A. Speed of light \times 1 \text{ AU}
B. Speed of light / 1 \text{AU}
C. 1 \text{AU} / Speed of light
D. 1 light-year

How much time does it take light to travel 1 Astronomical Unit (1 AU)?

\[ \text{Speed} = \frac{\text{Distance}}{\text{Time}} \]
\[ \Rightarrow \text{Time} = \frac{\text{Distance}}{\text{Speed}} \]
\[ \text{Time} = \frac{1 \text{ AU}}{\text{Speed of light}} \]
\[ = 1.5 \times 10^{11} \text{ meters} \]
\[ 3 \times 10^8 \text{ meters/sec} \]
\[ = 0.5 \times 10^3 \text{ sec} \]
\[ = 5.0 \times 10^2 \text{ sec} \]
\[ = 500 \text{ seconds} \approx 8 \text{ minutes} \]
Over astronomical distances, even light takes a lot of time to travel between the stars

- This means that what we SEE in the distant universe is light that has traveled a long time.

- Our image of the universe is a delayed image. In looking out into space, we are looking back in time!

  - The farther away we look in distance, the further back we look in time.

Lookback Time

- What we SEE is always delayed by the speed of light.
- In the classroom, our view of each other is only about $10^{-7}$ seconds old, so we barely notice.
  \[ 10^{-7} \text{ sec} = 0.0000001 \text{ sec} \]
- The image of the Sun is \[8 \text{ min}\] old

Lookback Time

- The image of a galaxy spreads across 100,000 years of time.

- Try to think of what we SEE NOW as different from what may EXIST now.
Astronomers see a bright supernova explode in the Andromeda galaxy (the nearest big galaxy in the local group; located 2.6 million ly away). The remnants from such explosions disperse in about 10,000 years.

A. The supernova remnant still exists now, and we will watch it disperse over the next 10,000 Earth years.
B. In reality, the supernova remnant has already dispersed, but we will watch it disperse over the next 10,000 Earth years.
C. The image of the supernova dispersing will not reach us for another 2.6 million years.
D. We will never see the supernova remnant because it has already dispersed.

Over astronomical distances, even light takes a lot of time to travel

- What is the furthest away we could in principle see in the Universe?
  Age of Universe = 13.7 billion years

13.7 billion light years! [reality more complicated though..]

Sample Clicker Question

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Sample Clicker Question

Why can’t we see a galaxy 20 billion light-years away?

A. Because no galaxies exist at such a great distance.
B. Galaxies may exist at that distance, but their light would be too faint for our telescopes to see.
C. Galaxies may exist at that distance, but due to their distance would be too small for our telescopes to see
D. Because looking 20 billion light-years away means looking to a time before the universe existed.
E. Galaxies 20 billion light-years away emit at a wavelength we can’t detect yet.
Clicker Question

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