Exploring the Universe

- Explorer: all of us
- Guide of the tour: Houjun Mo
- In order to be in the team, please:
  - Sign “Student Contract”
  - Read requirements and the schedule
  - Have a copy of the text book
    (Stars and Galaxies, by Michael Seeds, available from Textbook Annex and Jeffery Amherst Bookshop)

Course WEB page:
http://www.astro.umass.edu/~hjmo/astro100/
The goal of our exploration

- To learn what are in the Universe
- To understand why the Universe is as it is

The Universe: all existing things
The difference between exploring Amherst and the Universe

- What are there in A? (Houses, colleges, Antonio......)
- How does it come to what it is?
- The tools for the exploration: car, two legs, and books

- What are there in U? (stars, galaxies, black holes, Aliens......)
- What was the origin of the Universe, and how does it evolve
- The tools of exploration: Telescopes; satellites, and books
You will learn among other things – if you stay to the end

- Why are there seasons?
- Why is my zodiac Scorpio?
- Why are there eclipses? Can I predict them?
- What is the expected LONG term climate change?
- Can all stars host planets that can support life?
- How many stars are there that can potentially support life?
- How big is the universe, does it have edge?
- What are black holes? Can we go to another universe through a black hole?
- What is the material content of the Universe: normal matter, dark matter, dark energy?
- How science works? Are all these science fiction or believable?
In order to describe and understand what you see, you need numbers and units

- Amherst:
  - UMass is about 1.5 miles from the center;
  - Antonio’s pizza is about 1 pound a slice
  - The town was founded about 200 years ago

- The Universe:
  - The nearest star is 4 light years away;
  - The mass of a massive black hole is about $10^8$ solar mass (1 solar mass is about $2\times10^{30}$ Kg)
  - The age of the Universe is about 14 billion years

The scales we meet in exploring the Universe are very big, we must learn how to deal with them
Scales of the Universe

(and a little math primer!)
Goals

- to understand and start to use scientific notations
- to remember how to convert units!
- to see the levels of structure in the Universe
- to comprehend the vastness of scales in the Universe
# How to say big numbers

<table>
<thead>
<tr>
<th></th>
<th>Giga (G)</th>
<th>10^9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Billion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Million</td>
<td>Mega (M)</td>
<td>10^6</td>
</tr>
<tr>
<td>Thousand</td>
<td>Kilo (K)</td>
<td>10^3</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>thousandth</td>
<td>milli (m)</td>
<td>10^-3</td>
</tr>
<tr>
<td>millionth</td>
<td>micro (mu)</td>
<td>10^-6</td>
</tr>
<tr>
<td>billionth</td>
<td>nano (n)</td>
<td>10^-9</td>
</tr>
</tbody>
</table>
Powers of 10

\[ 10^e = 10 \times 10 \times 10 \times \ldots \times 10 \]

- \( e \) factors of 10
- \( e = \) exponent

\[
\begin{align*}
10^0 &= 1 & 10^0 &= 1 \\
10^1 &= 10 & 10^{-1} &= 0.1 \\
10^2 &= 100 & 10^{-2} &= 0.01 \\
10^3 &= 1000 & 10^{-3} &= 0.001 
\end{align*}
\]
Scientific Notation

Every number can be expressed as a number between 1 and 10 x power of 10

Example: $206,265 = 2.06265 \times 10^5$
Positive exponent

\[ 2.73 \times 10^5 = 273,000 \]

Negative exponent

\[ 2.73 \times 10^{-5} = 0.0000273 \]
Multiplying and dividing factors of 10 is easy!

\[(x \times 10^a) \times (y \times 10^b) = (x \cdot y) \times 10^{a+b}\]

Similarly,

\[(x \times 10^a) \div (y \times 10^b) = \left(\frac{x}{y}\right) \times 10^{a-b}\]

For Example:

\[(6 \times 10^8) \div (2 \times 10^4) = 3 \times 10^4\]
This year, the budget deficit is estimated to be about $500 billion. If there are roughly 100 million households in the U.S., how much debt would each household acquire if the deficit were split evenly among them?

1) $50
2) $500
3) $5,000
4) $50,000
Scale is important in Math too!

\[10^6 + 3 \times 10^6 = 4 \times 10^6\]

But …

\[10^8 + 10^4 \approx 10^8\]
Survey Question

For which of the following are $x$, $y$, and $z$ most nearly the same?

1) \( x = 10^9 + 10^9, \ y = 10^5 \times 2 \times 10^4, \ z = 3 \times 10^{11} / 10^2 \)

2) \( x = 10^2 + 10^6, \ y = 10^2 \times 2 \div 10^8, \ z = 10^{11} / 10^9 \)

3) \( x = 10^3 - 10^3, \ y = \frac{5 \times 10^4}{10^2 \times 10^2}, \ z = 10^{11} / 10^{11} \)
Units Conversion

First of all – Units are good things!
You can say the distance to Boston in miles (or km) instead of inches (or cm)!
Translating to useful units is a very handy skill.

The key to changing units is remembering to replace a unit by something equivalent
Converting Units

How many quarters are there in 1000 dollars?
1000 dollars = 1000 \times 1 \text{ dollar}
= 1000 \times 4 \text{ quarters}
= 4000 \text{ quarters}

Question: How many cm are there in 3 km?
3 \text{ km} = 3 \times 1 \text{ km}
= 3 \times 1000 \text{ m} = 3000 \text{ m}
= 3000 \times 1 \text{ m}
= 3000 \times 100 \text{ cm}
= 300000 \text{ cm}
How much does 1 billion dollar bills weigh?
(guess that $1000 weighs about 1kg)

1) one million kg
2) one hundred thousand kg
3) one thousand kg
4) one hundred kg
Survey Question

How much does 1 billion dollar bills weigh?
(guess that $1000 weighs about 1kg)

1) one million kg
2) one hundred thousand kg
3) one thousand kg
4) one hundred kg

1 billion dollar=$10^9$ dollar=$10^6 \times 1000$ dollar=$10^6 \times 1\text{ kg}=1\text{ million kg}
Light-time=Light traveling time=distance

Car-traveling time as distance: Boston is about 1.5 hours away (assuming the speed of a car is 60 miles per hour).

The speed of light: \( c = 3 \times 10^5 \text{ km/s} \).

<table>
<thead>
<tr>
<th>Source</th>
<th>Distance (km)</th>
<th>Light Travel time</th>
</tr>
</thead>
<tbody>
<tr>
<td>London</td>
<td>6,000</td>
<td>0.02 s</td>
</tr>
<tr>
<td>Moon</td>
<td>385,000</td>
<td>1.3 s</td>
</tr>
<tr>
<td>Sun</td>
<td>( 1.5 \times 10^8 )</td>
<td>500 s (8.3 min)</td>
</tr>
<tr>
<td>Jupiter</td>
<td>( 7.8 \times 10^8 )</td>
<td>43 min</td>
</tr>
<tr>
<td>Nearest Star</td>
<td>( 4 \times 10^{13} )</td>
<td>4.3 years</td>
</tr>
<tr>
<td>Most Distant Galaxy</td>
<td>( 1.4 \times 10^{23} )</td>
<td>14 billion years</td>
</tr>
</tbody>
</table>

Whenever you see "light-(time)", that means we are talking about distance, not time.
Examples

1 yr = 3.15 x 10^7 s (Earth revolves around the Sun once)

1 l.y. = (3 x 10^5 km/s) x 3.15 x 10^7 s = 9.45 x 10^{12} km
=10 thousand billion km!
Now... on to some Astronomy.
52 feet across
1 mile across.
160 kilometers across
1 mile = 1.61 kilometers
1,600,000 km
= $1.6 \times 10^6$ km
1.6x10^8 \text{ km} = 1.6x10^{11} \text{ m}

1 \text{ AU} = 1.5x10^{11} \text{ m}

AU is a distance unit
$1.6 \times 10^{10}$ km, or a trillion ($10^{12}$) times wider than the first picture!

32 AU
100 AU

Sun
10,000 AU

Sun ->
$10^6 \text{ AU} = 17 \text{ ly}$

$1 \text{ ly} = 63,000 \text{ AU} = 10^{13} \text{ km}$
1700 ly
The local group of galaxies

1.7 x 10^7 ly

Milky Way Galaxy
A Sense of Space

1. The Sun would hold 1.3 million Earths. i.e. the radius of the Sun is about 100 times that of the Earth.

2. There are \(~100\) billion "Suns" in a galaxy like our own Milky Way Galaxy.

3. Astronomers can see billions of galaxies.
Basic classes of objects:

Planets: Earth as one
Stars: Sun as one
Galaxies: Milky Way as one

Their sizes

Earth: $10^4$ km poppy seed
Sun: $10^6$ km grape fruit
Milky Way $10^{18}$ km Earth-Sun distance
Universe $10^{23}$ km 100,000 Earth-Sun distance
So...How Big is the Observable Universe anyway?

...about 10 billion-billion-billion centimeters in diameter

or

10,000,000,000,000,000,000,000,000,000,000 cm

or

$10^{28}$ cm

or

10 billion l-y

or

6000 Mpc
The finite speed of light lets us “look” into the past!

Consider this:
If you had friends throughout the galaxy, how could you create a “live” TV show?
If the Sun were a grapefruit on one side of the room, what would be Earth?

1) A poppy seed on the other side.
2) Another grapefruit on the other side.
3) A poppy seed in my office.
4) An apple on the other side.
If the Sun were a grapefruit on one side of the room, what would be Earth?

1) A poppy seed on the other side.
   (Earth-Sun distance ~ 100x radius of Sun ~ 100 radius of Earth)

2) Another grapefruit on the other side.

3) A poppy seed in my office.

4) An apple on the other side.
What would then be the nearest star?

1) A poppy seed at the Amherst downtown.
2) A poppy seed on the west coast
3) A grapefruit at the Amherst downtown.
4) A grapefruit on the west coast.
What would then be the nearest star?

1) A poppy seed at the Amherst downtown.
2) A poppy seed on the west coast
3) A grapefruit at the Amherst downtown.

A grapefruit on the west coast.

(Nearest star is 4Ly ~ 300,000 AU)
A Sense of Time

If we were to compress the time since the Big Bang into one year, and make the time of the Big Bang January 1,

- The Earth was formed in mid-September.
- The mammals appeared on December 26.
- All human prehistory (from the first known stone tools) and history have occurred in the last $\frac{1}{2}$ hour of New Year's Eve.

All of human history is but a fleeting instant on the cosmic timescale.
14,000,000,000 yrs

1st stars

Solar System

1st life (single cell)

1st multi-cell life

Earth
If the Universe is infinite in size and 14 billion years old, the most distant object that we could ever hope to see is:

1) 100,000 light-years away
2) 14 billion light-years away
3) 14 billion years away
4) there is no limit – if we look hard enough, we will see all objects.
Sound travels at a speed of 300 meters per second. In analogy to the light-year, what does 1 sound-minute equal?

1) The time sound takes to travel 300 meters.
2) The time delay of a sound heard 300 meters away.
3) The distance traveled by sound in 1 minute.
4) The speed of sound 1 minute later.
Evolving Universe

Only in the last 50 years have we realized that the Universe is not static.

1. The entire Universe is expanding and is now accelerating.
2. The Universe is 14 billion years old.
3. Events of fantastic violence take place in the Universe.
Summary of concepts

- Various units and their conversion
- Order of magnitude
- Power of 10, exponent
- Scientific notation
- The speed of light
- Various scales of the Universe
- Our place in the Universe, both in space and time
What is our address in the Universe?

UMass, Amherst, Massachusetts
U.S.A., Earth, Solar System
Milky Way Galaxy, Local Group, Local
Supercluster
Our Universe