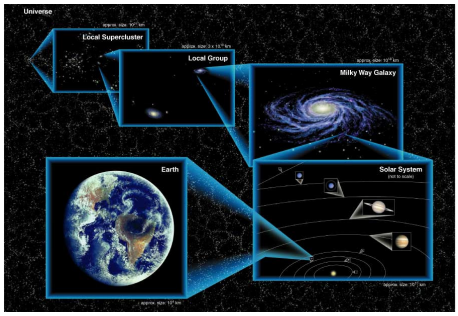
Chapter 1
Our Place in the Universe

1.1 A Modern View of the Universe

Our goals for learning:

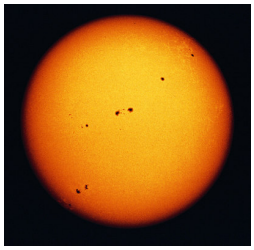
- What is our place in the universe?
- How did we come to be?
- How can we know what the universe was like in the past?
- Can we see the entire universe?

What is our place in the universe?

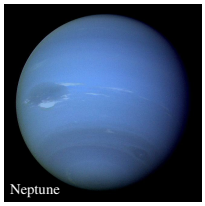


Star

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



Planet



A moderately large object that orbits a star; it shines by reflected light. Planets may be rocky, icy, or gaseous in composition.

- The IAU thereafter defined a planet in our solar system as **an object large enough to clear the smaller bodies from its orbit, a definition just murky enough to give teachers a considerable challenge to explain precisely what this means**. Taking the exclusive club approach for the heavyweights, the IAU went on to create a class of ``dwarf planets," including Pluto, that by definition are not planets. To me this is a linguistic absurdity, a contradiction that could have been avoided if they had chosen to define only the eight classical planets as the basic type of planets, allowing dwarf planets to be considered planets too, albeit of a different kind. But this cultural compromise was specifically rejected.

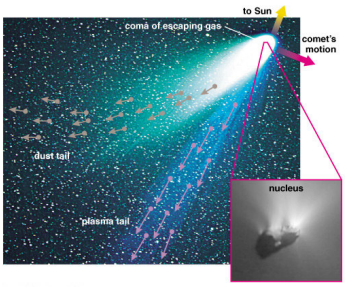
Moon (or satellite)

An object that orbits a planet.

Asteroid

A relatively small and rocky object that orbits a star.

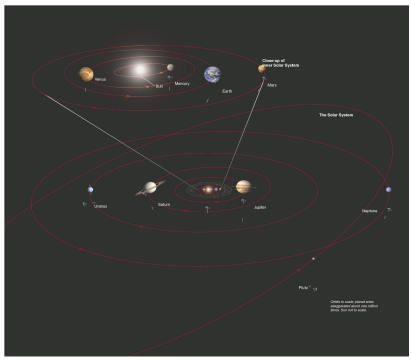
Comet



A relatively small and icy object that orbits a star.

Solar (Star) System

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

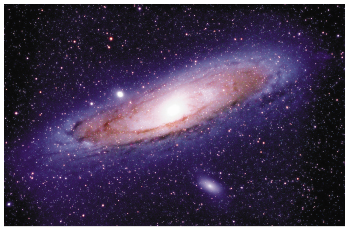


Nebula

An interstellar cloud of gas and/or dust

Galaxy

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

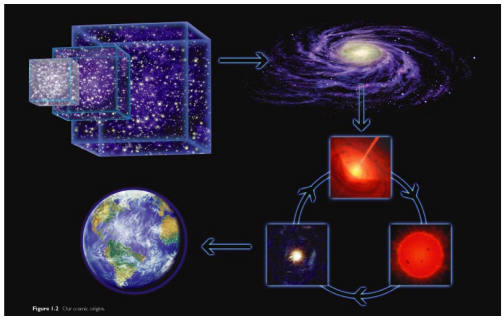


Universe

The sum total of all matter and energy; that is, everything within and between all galaxies

the sum total of all things which can be directly observed or whose physical effects on other things can be detected.

How did we come to be?



How can we know what the universe was like in the past?

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

Destination	Light travel time
Moon	1 second
Sun	8 minutes
Sirius	8 years
Andromeda Galaxy	2.5 million years

- Thus, we see objects as they were in the past:

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

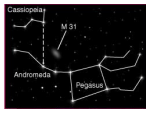
Example:

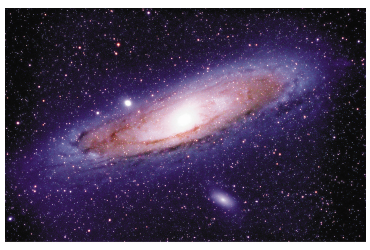
We see the Orion Nebula as it looked 1,500 years ago.

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?

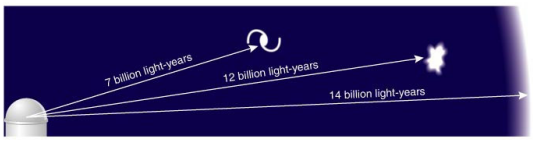




Light-year

- The **distance** light can travel in one year.
- About 10 trillion km (6 trillion miles).

- At great distances, we see objects as they were when the universe was much younger.



How far is a light-year?

$$1\text{ light - year} = (\text{speed of light}) \times (1\text{ year})$$
$$= \left(300{,}000\frac{\text{km}}{\text{s}}\right) \times \left(\frac{365\text{ days}}{1\text{ yr}} \times \frac{24\text{ hr}}{1\text{ day}} \times \frac{60\text{ min}}{1\text{ hr}} \times \frac{60\text{ s}}{1\text{ min}}\right)$$

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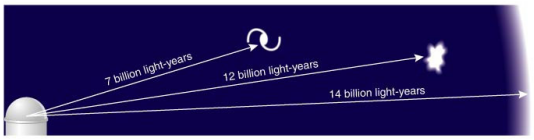
$$= 9{,}460{,}000{,}000{,}000\text{ km}$$

Can we see the entire universe?



Thought Question
Why can't we see a galaxy 15 billion light-years away?
(Assume universe is 14 billion years old.)

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. Because looking 15 billion light-years away means looking to a time before the universe existed.

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What have we learned?

- What is our physical place in the universe?
  - Earth is part of the Solar System, which is the Milky Way galaxy, which is a member of the Local Group of galaxies in the Local Supercluster
- How did we come to be?
  - The matter in our bodies came from the Big Bang, which produced hydrogen and helium
  - All other elements were constructed from H and He in star and then recycled into new star systems, including our solar system

What have we learned?

- How can we know that the universe was like in the past?
  - When we look to great distances we are seeing events that happened long ago because light travels at a finite speed
- Can we see the entire universe?
  - No, the observable portion of the universe is about 14 billion light-years in radius because the universe is about 14 billion years old

1.2 The Scale of the Universe

Our goals for learning:

- How big is Earth compared to our solar system?
- How far away are the stars?
- How big is the Milky Way Galaxy?
- How big is the universe?
- How do our lifetimes compare to the age of the universe?

How big is Earth compared to our solar system?

Let's reduce the size of the solar system by a factor of 10 billion; the Sun is now the size of a large grapefruit (14 cm diameter).

How big is Earth on this scale?

A. an atom
B. a ball point
C. a marble
D. a golf ball

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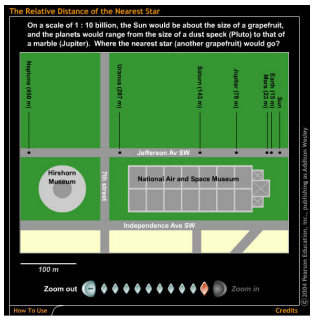
The scale of the solar system

- On a 1-to-10 billion scale:
  - Sun is the size of a large grapefruit (14 cm)
  - Earth is the size of a ball point, 15 meters away.



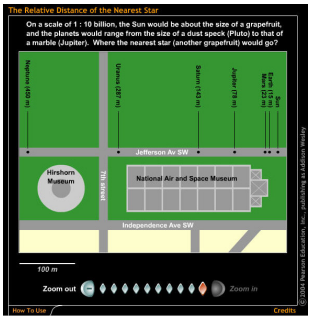
How far away are the stars?

On our 1-to-10 billion scale, it's just a few minutes walk to Pluto.

How far would you have to walk to reach Alpha Centauri?

A. 1 mile
B. 10 miles
C. 100 miles
D. the distance across the U.S. (2500 miles)

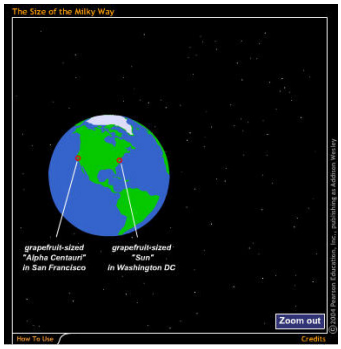
Answer: D, the distance across the U.S.



How big is the Milky Way Galaxy?

The Milky Way has about 100 billion stars.

On the same ten billion-to-one scale….



Thought Question

Suppose you tried to count the more than 100 billion stars in our galaxy, at a rate of one per second…

How long would it take you?

A. a few weeks
B. a few months
C. a few years
D. a few thousand years

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How big is the Universe?

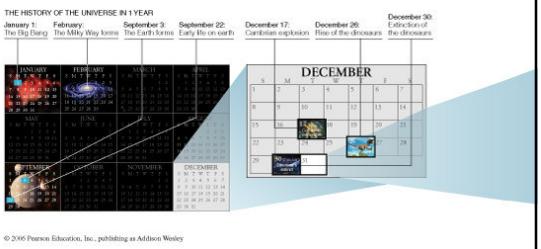
- The Milky Way is one of about 100 billion galaxies.
- 10^{11} stars/galaxy x 10^{11} galaxies = 10^{22} stars

As many stars as grains of (dry) sand on *all* Earth's beaches…

- Now let's step through the Universe in powers of 10:

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.



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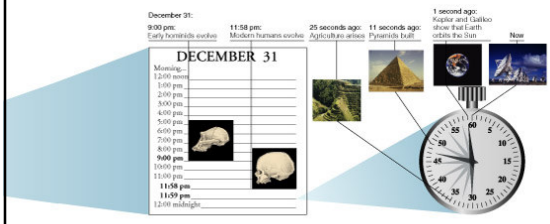


What have we learned?

- How big is Earth compared to our solar system?
  - The distances between planets are huge compared to their sizes—on a scale of 1-to-10 billion, Earth is the size of a ball point and the Sun is 15 meters away
- How far away are the stars?
  - On the same scale, the stars are thousands of km away
- How big is the Milky Way galaxy?
  - It would take more than 3,000 years to count the stars in the Milky Way Galaxy at a rate of one per second, and they are spread across 100,000 light-years

What have we learned?

- How big is the universe?
  - The observable universe is 14 billion light-years in radius and contains over 100 billion galaxies with a total number of stars comparable to the number of grains of sand on all of Earth's beaches
- How do our lifetimes compare to the age of the universe?
  - On a cosmic calendar that compresses the history of the Universe into one year, human civilization is just a few seconds old, and a human lifetime is a fraction of a second

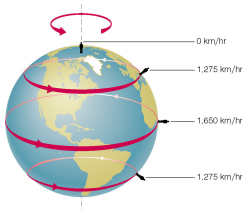
1.3 Spaceship Earth

Our goals for learning:

- How is Earth moving in our solar system?
- How is our solar system moving in the Galaxy?
- How do galaxies move within the Universe?
- Are we ever sitting still?

How is Earth moving in our solar system?

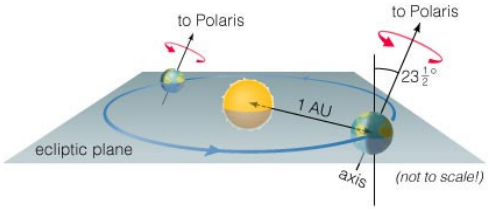
- Contrary to our perception, we are not "sitting still."
- We are moving with the Earth in several ways, and at surprisingly fast speeds…



The Earth **rotates** around its axis once every day.

Earth **orbits** the Sun (revolves) once every year:

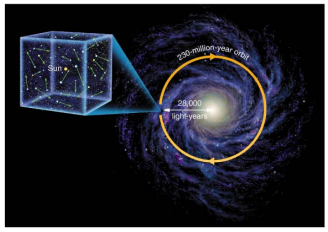
- at an average distance of 1 AU ≈ 150 million km.
- with Earth's axis tilted by 23.5º (pointing to Polaris)
- and rotating in the same direction it orbits, **counter-clockwise** as viewed from above the North Pole.



Our Sun moves randomly relative to the other stars in the local Solar neighborhood…

- typical relative speeds of more than 70,000 km/hr
- but stars are so far away that we cannot easily notice their motion

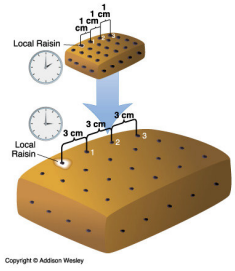
… And orbits the galaxy every 230 million years.



More detailed study of the Milky Way's rotation reveals one of the greatest mysteries in astronomy:

How do galaxies move within the universe?

Galaxies are carried along with the expansion of the Universe. But how did Hubble figure out that the universe is expanding?

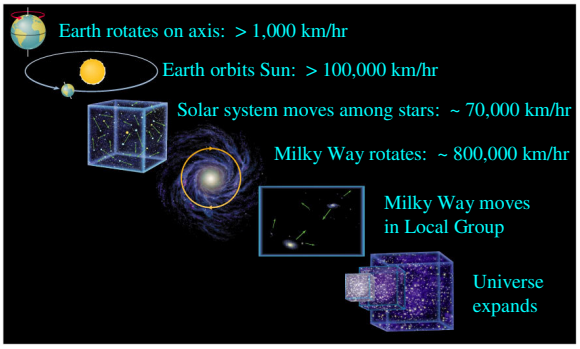


Hubble discovered that:

- All galaxies outside our Local Group are moving away from us.
- The more distant the galaxy, the faster it is racing away.

Conclusion: We live in an expanding universe.

Are we ever sitting still?



What have we learned?

- How is Earth moving in our solar system?
  - It rotates on its axis once a day and orbit the Sun at a distance of 1 A.U. = 150 million km
- How is our solar system moving in the Milky Way galaxy?
  - Stars in the Local Neighborhood move randomly relative to one another and orbit the center of the Milky Way in about 230 million years

What have we learned?

- How do galaxies move within the universe?
  - All galaxies beyond the Local Group are moving away from us with expansion of the Universe: the more distant they are, the faster they're moving
- Are we ever sitting still?
  - No!

1.4 The Human Adventure of Astronomy

Our goals for learning:

- How has the study of astronomy affected human history?

How has the study of astronomy affected human history?

- Copernican Revolution showed that Earth was not the center of the universe (Chapter 3)
- Study of planetary motion led to Newton's Laws of motion and gravity (Chapter 4)
- Newton's laws laid the foundation of the industrial revolution
- Modern discoveries are continuing to expand our "cosmic perspective"

What have we learned?

- How has the study of astronomy affected human history?
  - Throughout history, astronomy has provided an expanded perspective on Earth that has grown hand in hand with social and technological developments

Put these objects in the correct order, from nearest to farthest from Earth:

- The Sun, the Milky Way, Alpha Centauri, Pluto, the Andromeda galaxy
- The Sun, Alpha Centauri, Pluto, the Andromeda galaxy, the Milky Way
- The Sun, Pluto, Alpha Centauri, the Milky Way, the Andromeda galaxy
- Pluto, the Sun, Alpha Centauri, the Milky Way, the Andromeda galaxy

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What does it mean to say that the universe is expanding?

- The galaxies are getting farther apart from each other
- Each galaxy is getting larger
- The solar system is getting larger
- All of the above

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Does the expansion of the universe cause you to expand?

- Yes
- No

Does the expansion of the universe cause you to expand?

- Yes
- **No**

In a scale model solar system that used a grapefruit to represent the Sun, how far away would the Earth be?

- 6 inches
- 1 foot
- 5 feet
- 50 feet
- 1 mile

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In a scale model solar system that used a grapefruit to represent the Sun, how far away should you put another grapefruit to represent Alpha Centauri, the next nearest star?

- 10 feet
- 1,000 feet
- 1 mile
- 10 miles
- 2,000 miles

In a scale model solar system that used a grapefruit to represent the Sun, how far away should you put another grapefruit to represent Alpha Centauri, the next nearest star?

- 10 feet
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At the *speed of light*, how long would it take to go from Earth to the Sun?

1. About a second
2. About a minute
3. About 8 minutes
4. About a day
5. About a year

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1. About a month
2. About a year
3. About 4 years
4. About 1,000 years
5. About 1,000,000 years

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About how old is the Earth?

- 6,000 years
- 1 million years
- 1 billion years
- 5 billion years
- 14 billion years

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The Earth rotates on its axis:

- Once a day
- Once a week
- Once a month
- Once a year
- Once every 250,000 years

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The Earth revolves around the Sun:

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The Earth revolves around the Milky Way galaxy:

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Why do we not feel or sense the various motions of the Earth in the universe?

1. They are not real, they are just models
2. They are too slow to sense
3. They are nearly uniform, and you can not sense uniform velocity, only acceleration, which is a change of velocity or direction

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Considering the size and scale of the universe makes me:

- Feel very small
- Think it is remarkable that we can discover anything about the universe at all
- Think it is remarkable that all of this was created for us
- Think that the Earth is less important than I used to think
- Appreciate how fragile and unique the Earth is

Suppose that, at this very moment, students are studying astronomy on planets in Andromeda. Could they know that we exist here on Earth?

1. Yes, because we can see stars in Andromeda, so they can see us in the Milky Way.
2. No, the light from the solar system has not yet reached Andromeda.
3. No, the light from the solar system that has reached Andromeda came from a time before the Earth had formed.
4. No, radio signals from terrestrial civilizations have not yet reached Andromeda.
5. Yes, in principle. With sufficiently powerful telescopes, they should be able to see man-made features such as the Great Wall of China on the surface of the Earth.

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1. A light-year is a unit of distance, not time.
2. A light-year is much greater than a century.
3. The Earth is only one light-year old.
4. The Red Sox won the World Series in 2003.

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Which of the following can be used as an argument <u>against</u> the existence of other civilizations in the Universe?

1. The lack of potential habitats for other civilizations.
2. Most organisms on Earth are microscopic and relatively primitive.
3. The relatively short lifetime of intelligent life on Earth.
4. The immense distance to other stars in the galaxy and our lack of convenient interstellar travel.
5. The relatively young age of the Universe.

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You hear that NASA plans to launch a spacecraft that will leave the Milky Way Galaxy to take a photograph of the galaxy from the outside. Do you think this is true?

1. Yes, the spacecraft will be able to tell us the size and shape of the Milky Way.
2. No, but it would be a good idea to do so.
3. No, even a spacecraft that moved close to the speed of light would take tens of thousands of years to get to a good vantage point.
4. No, as the Sun and Earth move through the galaxy, we will be able to take a photograph from a different perspective.
5. No, several NASA spacecrafts have already left the solar system on their way out of the galaxy.

You hear that NASA plans to launch a spacecraft that will leave the Milky Way Galaxy to take a photograph of the galaxy from the outside. Do you think this is true?

1. Yes, the spacecraft will be able to tell us the size and shape of the Milky Way.
2. No, but it would be a good idea to do so.
3. **No, even a spacecraft that moved close to the speed of light would take tens of thousands of years to get to a good vantage point**.
4. No, as the Sun and Earth move through the galaxy, we will be able to take a photograph from a different perspective.
5. No, several NASA spacecrafts have already left the solar system on their way out of the galaxy.

Yes/No? The observable Universe is the same size today as it was a few billion years ago.

1. Yes, the Universe does not gain or lose mass or energy.
2. Yes, although the Universe continues to expand, what we can see - the observable Universe - stays the same size.
3. No, we can see light from more distant parts of the Universe today than we could have seen a few billion years ago.
4. No, the observable Universe is smaller today than it was a few billion years ago.
5. This question doesn't make sense because the Big Bang only happened about 1.4 billion years ago.

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Because nearly all galaxies are moving away from us, we must be located at the center of the Universe.

1. Yes, it is impossible not to be at the center and have everything else move away from us.
2. Yes, this was the astonishing discovery made by Hubble in the 1920s.
3. Yes, if we were not at the center, our solar system would not survive the gravitational tug from other galaxies.
4. No, the center of the Universe is at the center of our galaxy.
5. No, everything moves away from everything else in an expanding Universe and there is no unique center.

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