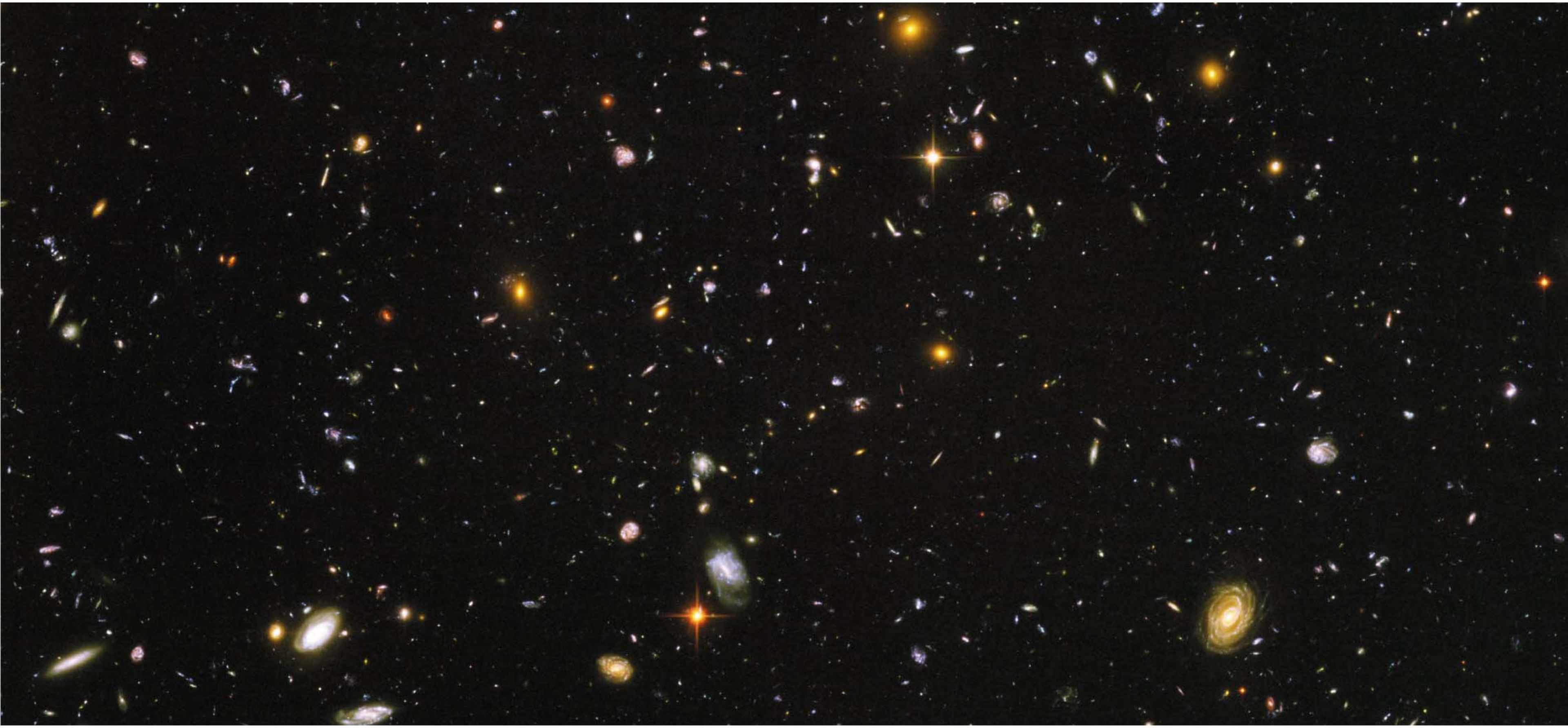
Chapter 1: Our Place in the Universe



Topics

- Our modern view of the universe
- The scale of the universe
- Cinema graphic tour of the local universe
- Spaceship earth

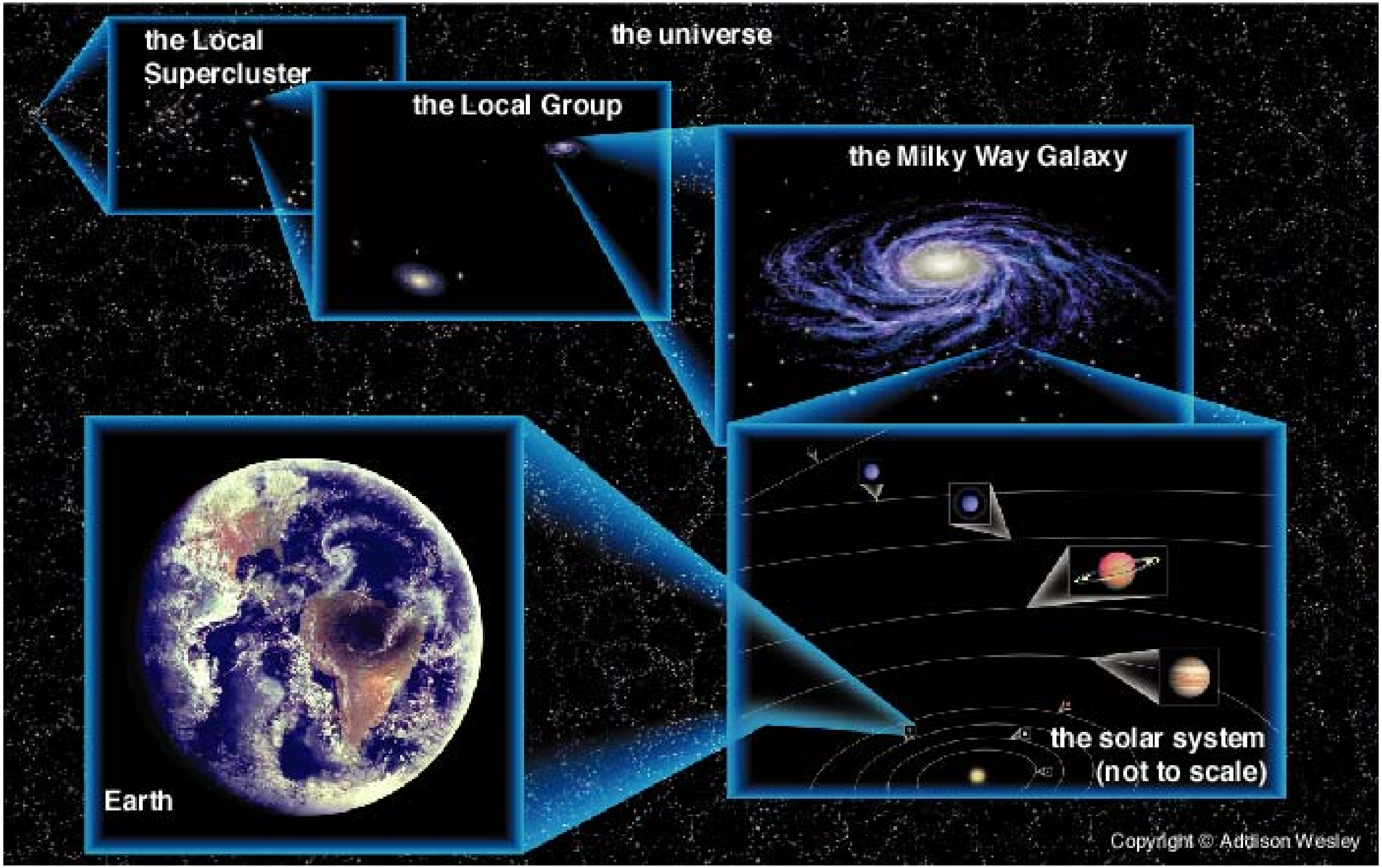
1.1 A Modern View of the Universe

Our goals for learning:

- What is our physical 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 physical place in the universe?

- Our "Cosmic Address"



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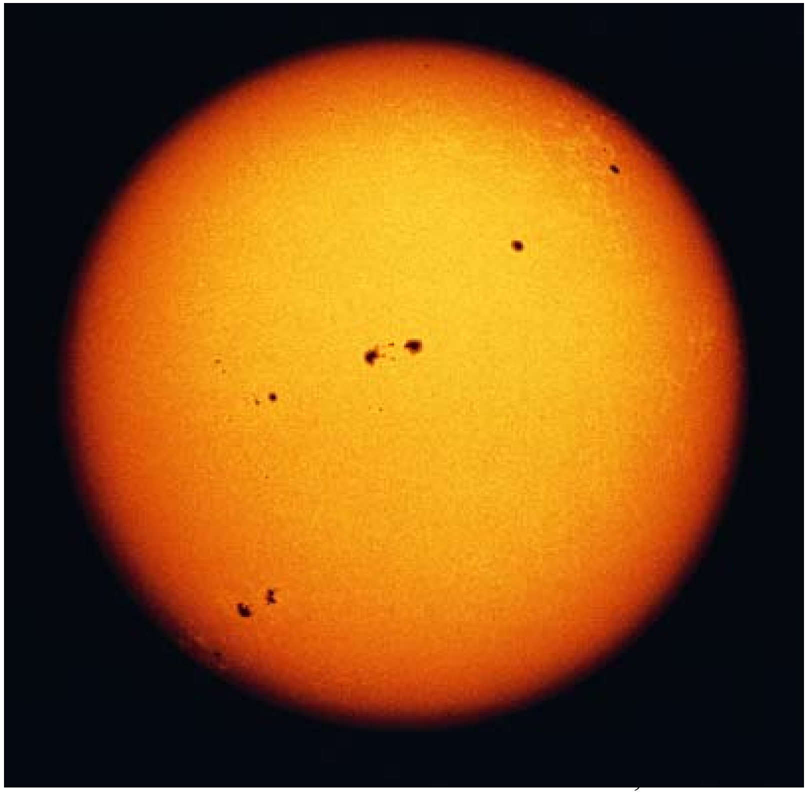
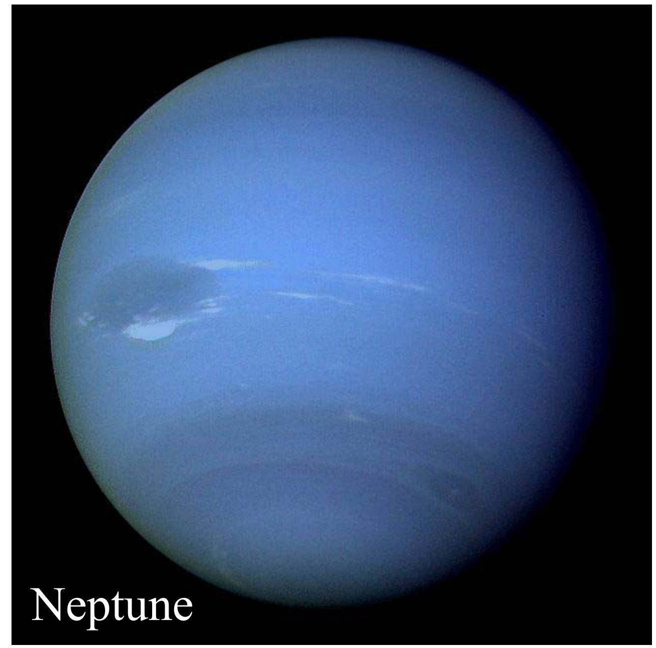
Star

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

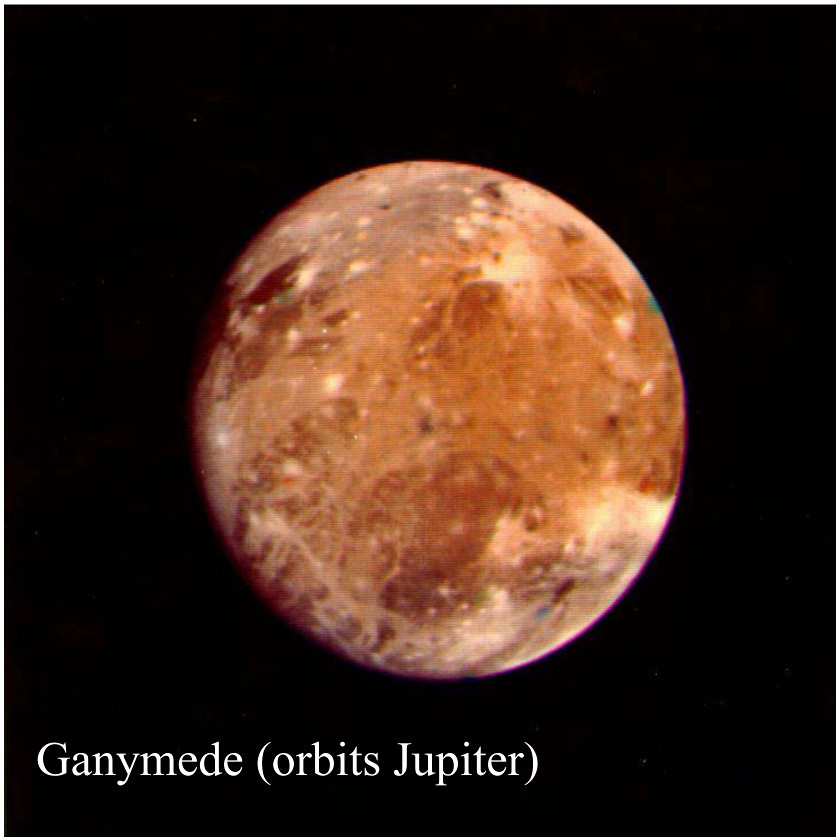


Planet



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

Moon (or satellite)

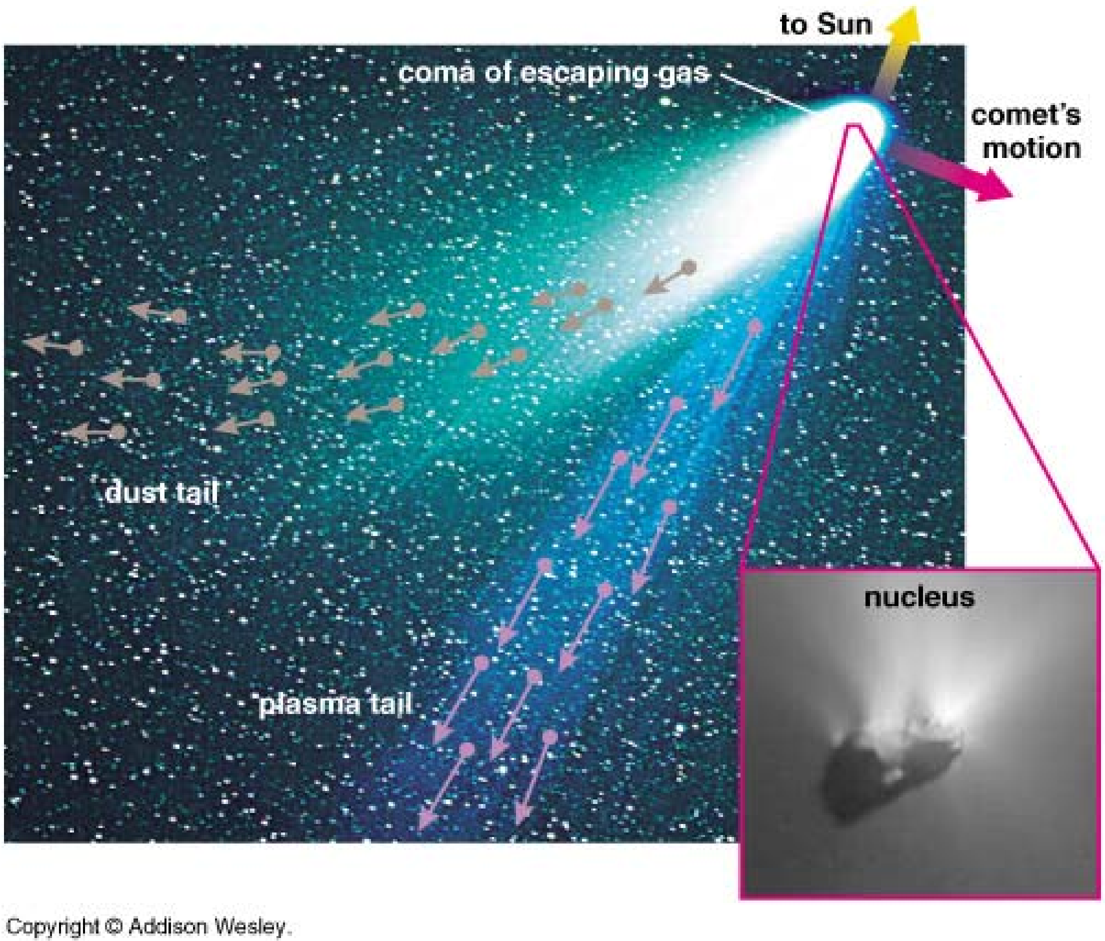

Ganymede (orbits Jupiter)

An object that orbits a planet.

Asteroid

A relatively small and rocky object that orbits a star.

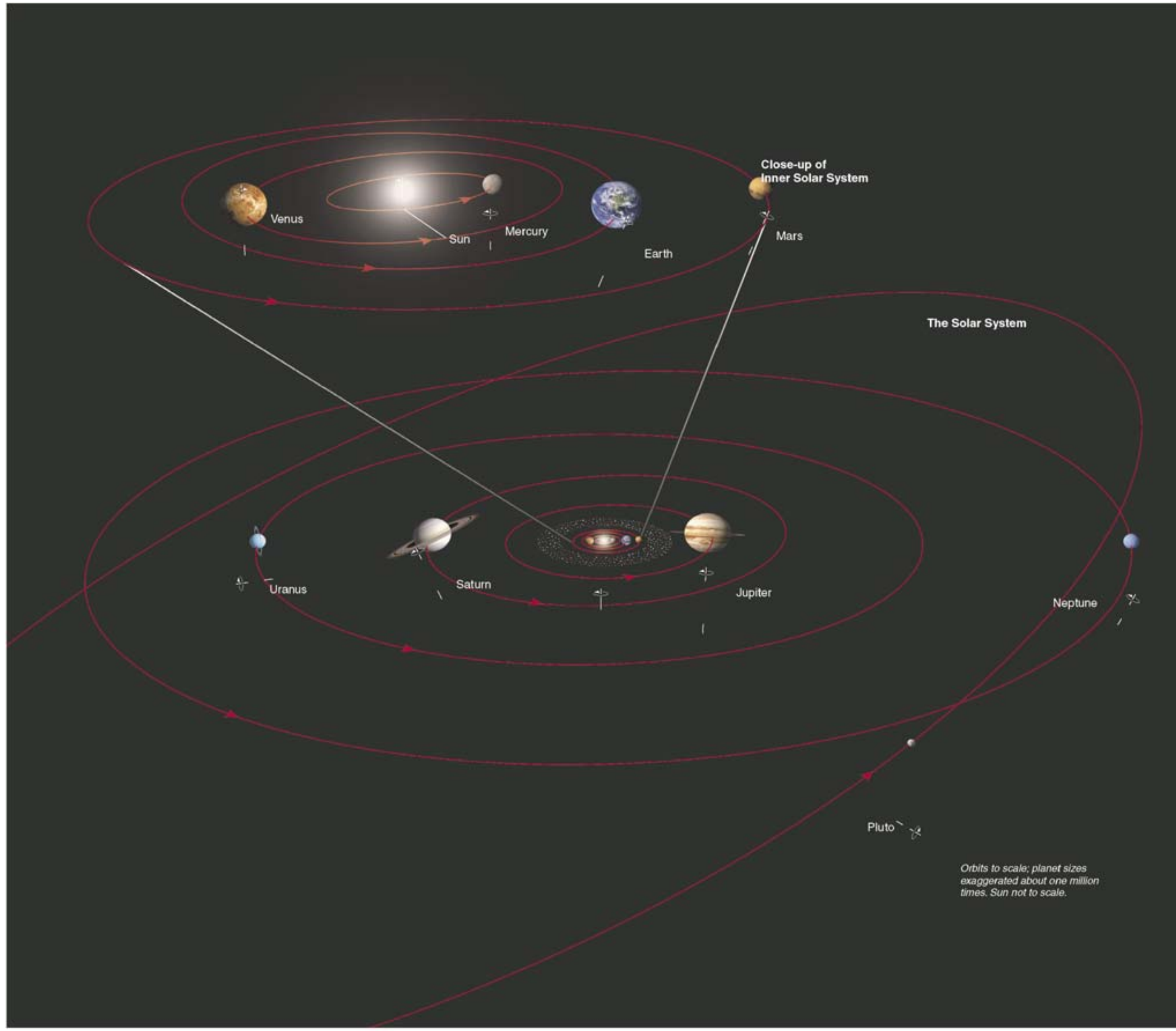
Comet



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

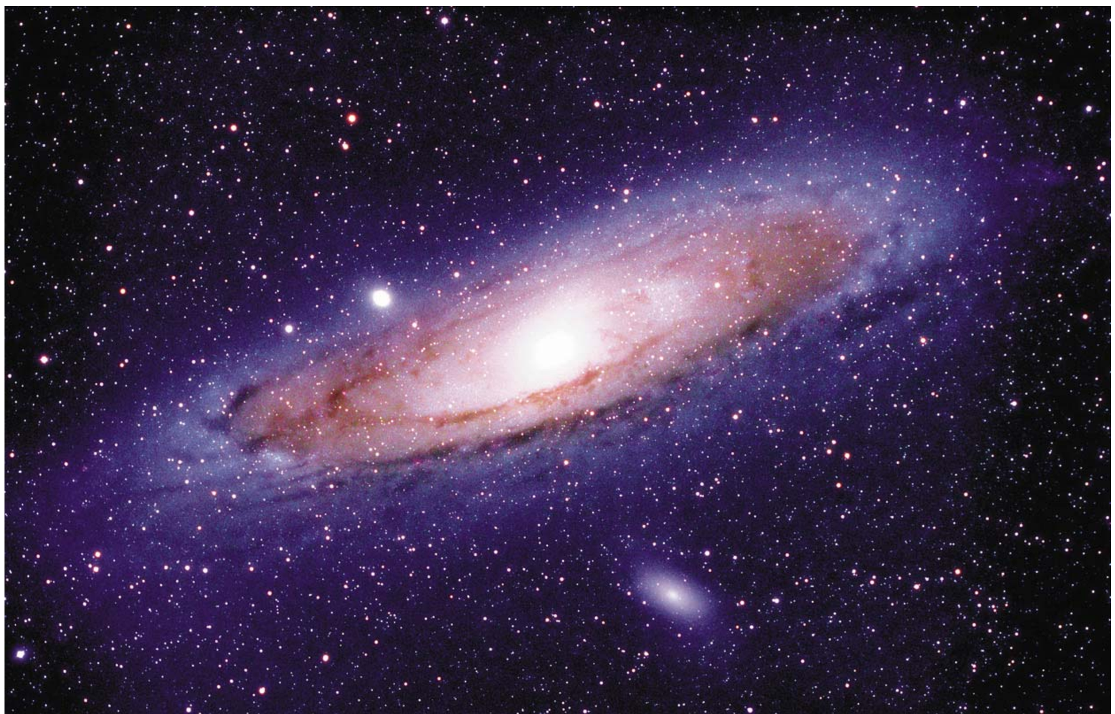


Nebula

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

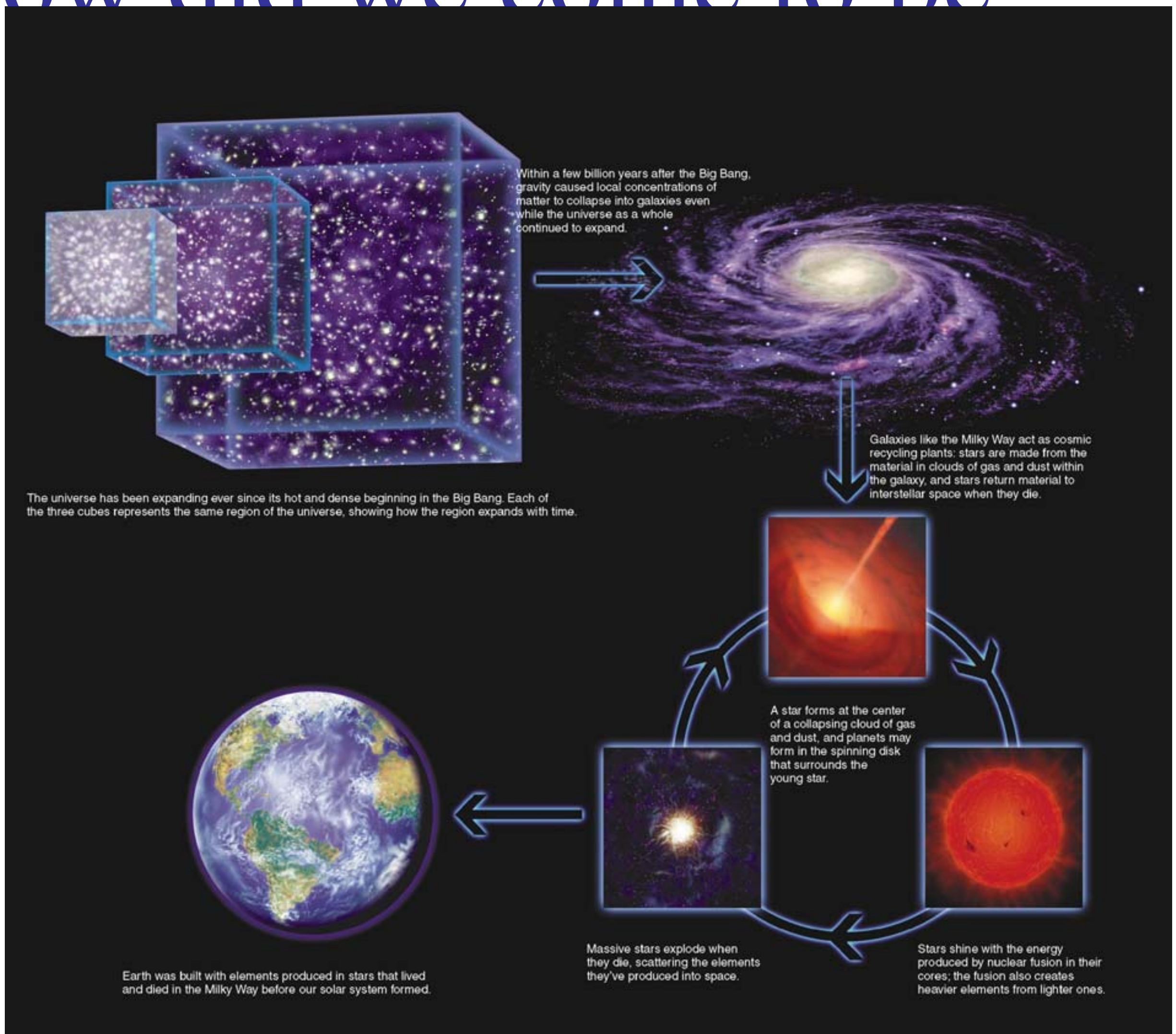
The sum total of all matter and energy; that is, everything within and between all galaxies

- Our Cosmic Origins

How did we come to be?

Big bang

14 billion years ago



Evolution of the Universe: Large Scale Structure and Galaxy Formation

Grand Challenge Cosmology Consortium

Michael Norman, NCSA
Brian O'Shea, NCSA
Greg Bryan, Princeton

HDTV Visual Excerpt from "Runaway Universe"

Courtesty NOVA/WGBH, PBS
Thomas Lucas Productions

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

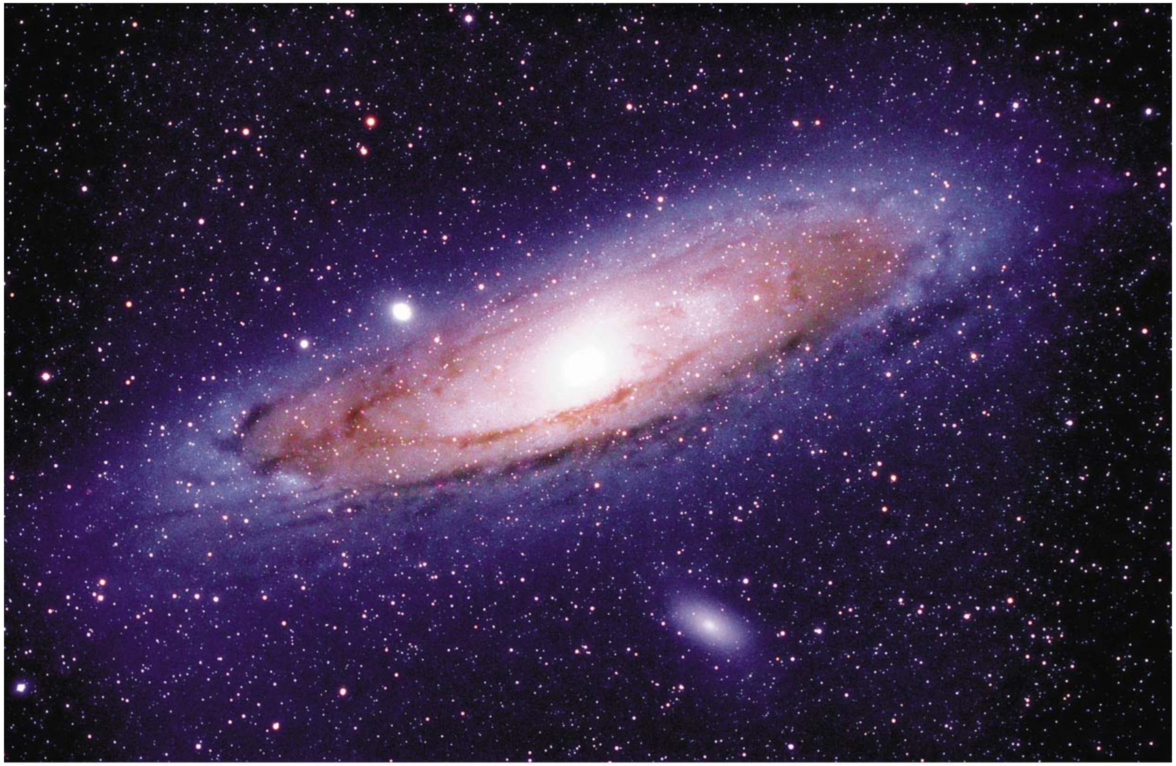
- Thus, we see objects as they were in the past:

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

Example:

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

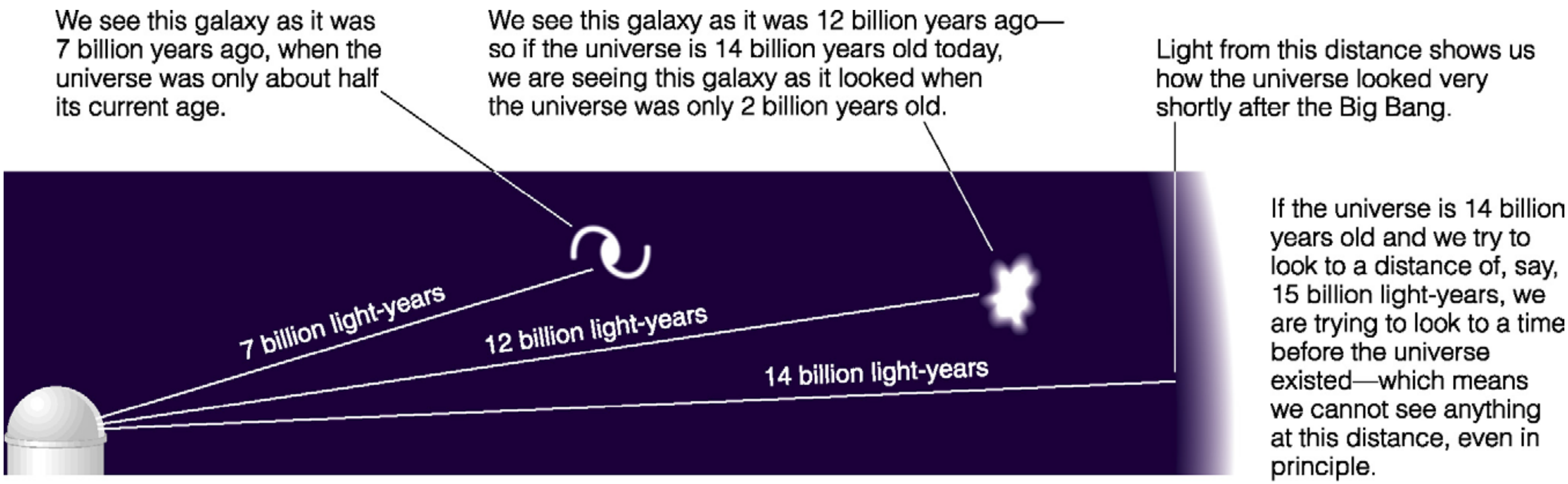
Question: When will be able to see what it looks like now?



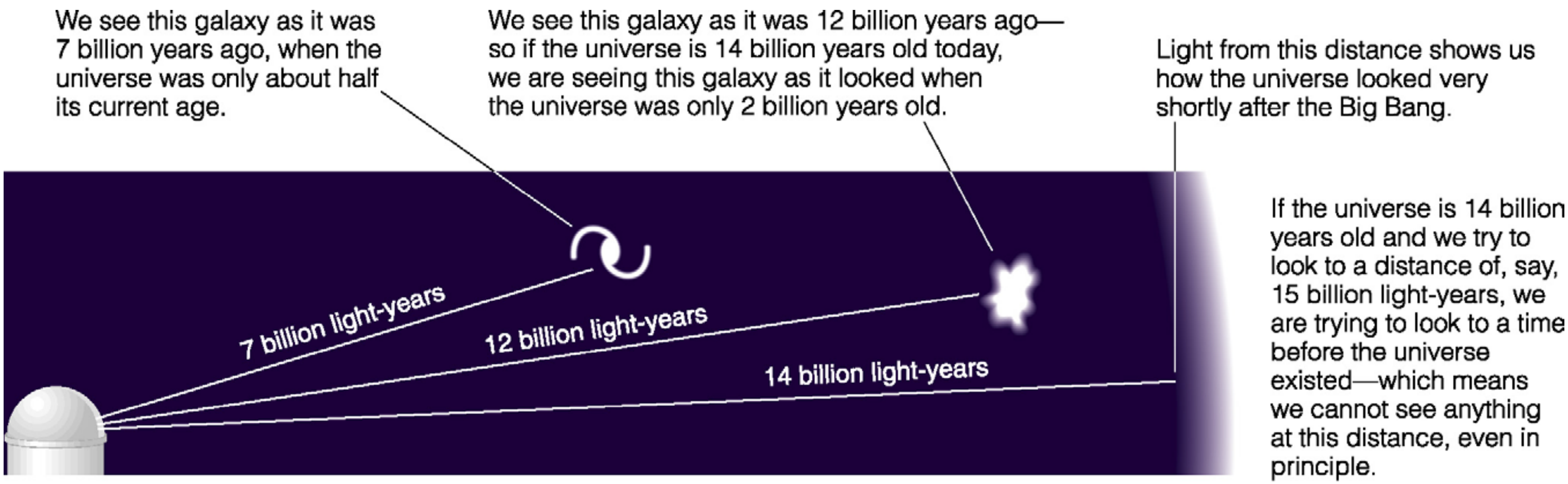
Definition: a **light-year**

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

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



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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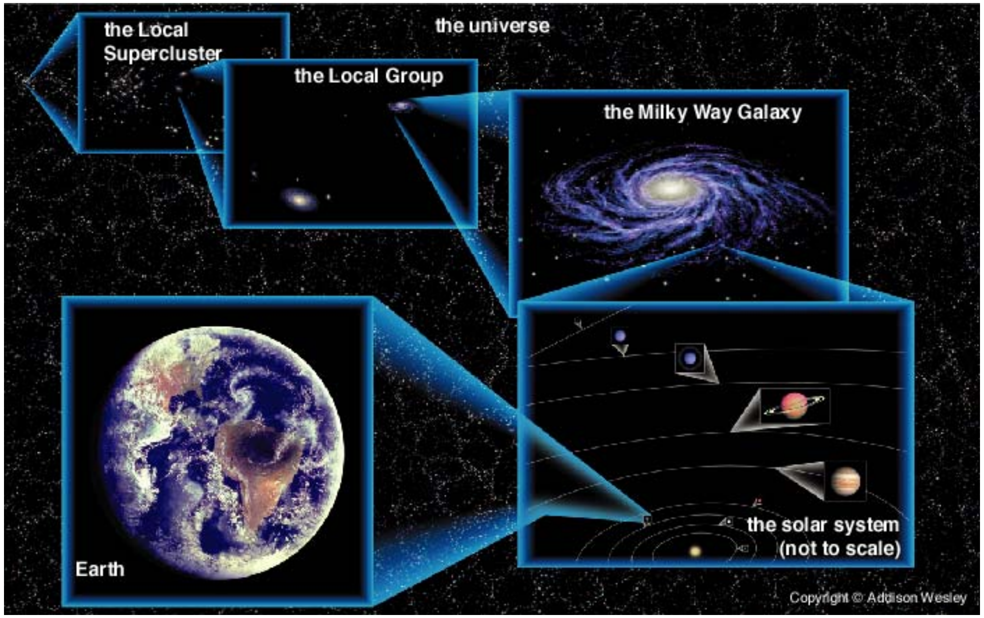
What have we learned?

- What is our place in the Universe?
  - Earth orbits the Sun
  - There are 100 billion other stars in the Milky Way
  - There are about 40 other galaxies in the Local Group.



- The Local Group is part of the Local Supercluster.
- The Local Supercluster is one small piece of the Universe.

What have we learned?

- How did we come to be?
  - Big Bang starts the expansion of the universe.
  - Early universe contained only the elements hydrogen and helium.
  - All other elements were made in stars and recycled into new generations of stars within galaxies.
  - We are “star stuff”

What have we learned?

- How can we know what the universe was like in the past?
  - Light takes time to travel through space (the speed of light = c = 300,000 km/s). Thus, when we look farther away, we see light that has taken a longer time to reach us.
- Can we see the entire universe?
  - No - age limits the size of the observable universe. For a 14 billion year old universe, our observable universe is 14 billion light-years in radius.

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.

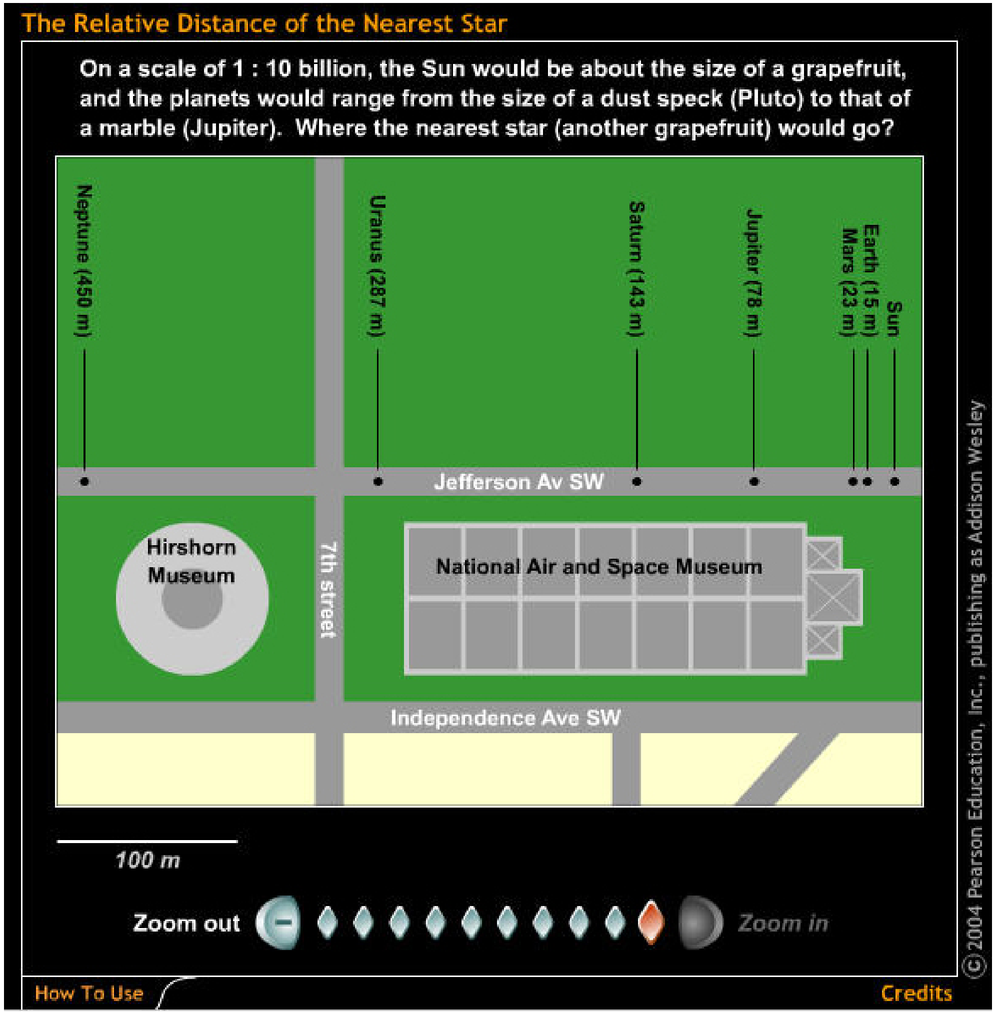
How far away are the stars?

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)

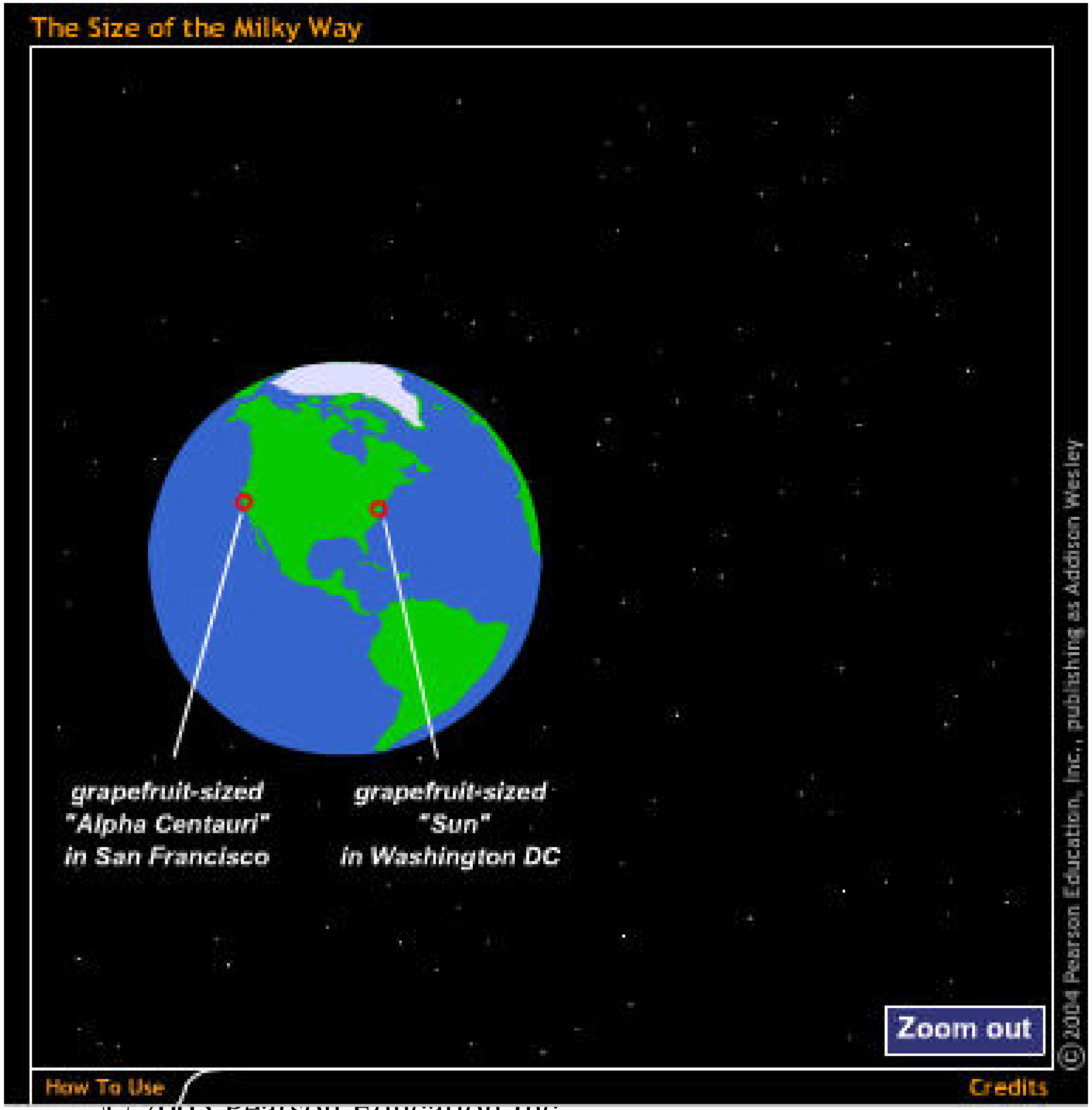
Answer: D, the distance across the U.S.



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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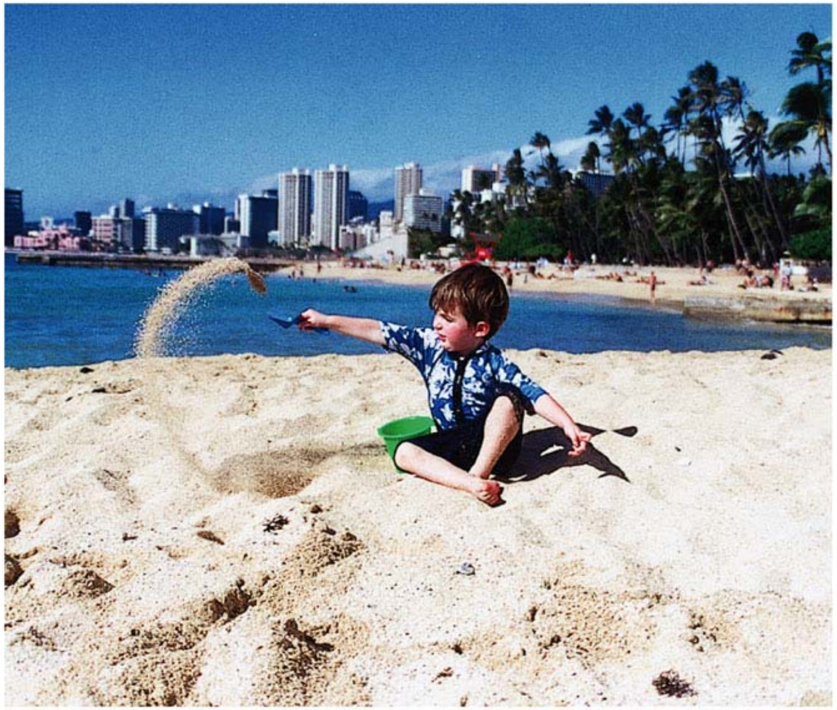
How big is the Universe?

- 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:

Virtual Voyage:
Milky Way to the Virgo Cluster

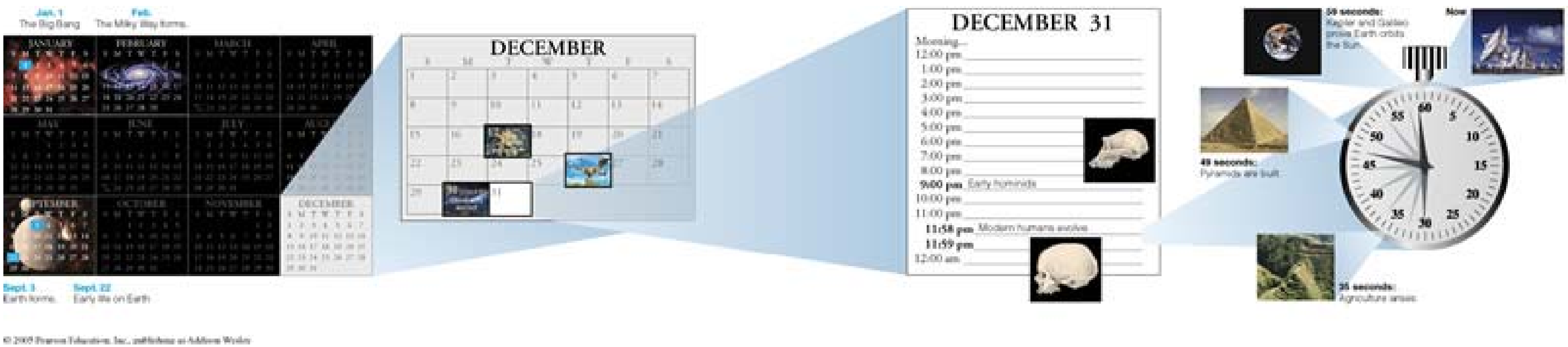
HDTV Visual Excerpt from "Runway Universe"

Courtesy NOVA/WGBH, PBS

Tom Lucas Productions

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.



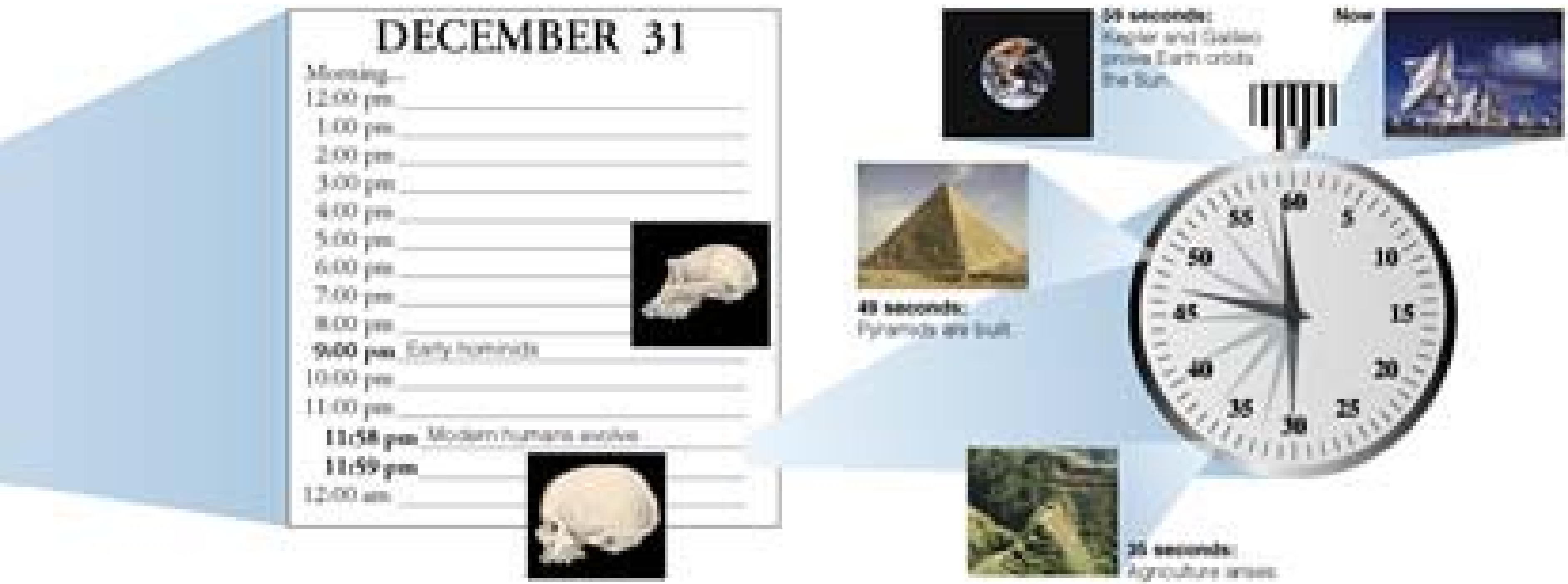
Cosmic Calendar

Dec. 17: Cambrian explosion

Dec. 16: rise of dinosaurs

Dec. 30: extinction of dinosaurs

Cosmic Calendar



What have we learned?

- How big is the Earth compared to our solar system?
  - On a scale of 1-to-10 billion, the Sun is about the size of a grapefruit. The Earth is the size of a ball point about 15 m away. The distance between planets are huge compared to their sizes.
- 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. The Milky Way Galaxy is about 100,000 light-years across.

What have we learned?

- How big is the universe?
  - 100 billion galaxies in the observable Universe.
  - 14 billion light-years in radius.
  - As many stars as grains of sand on 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.

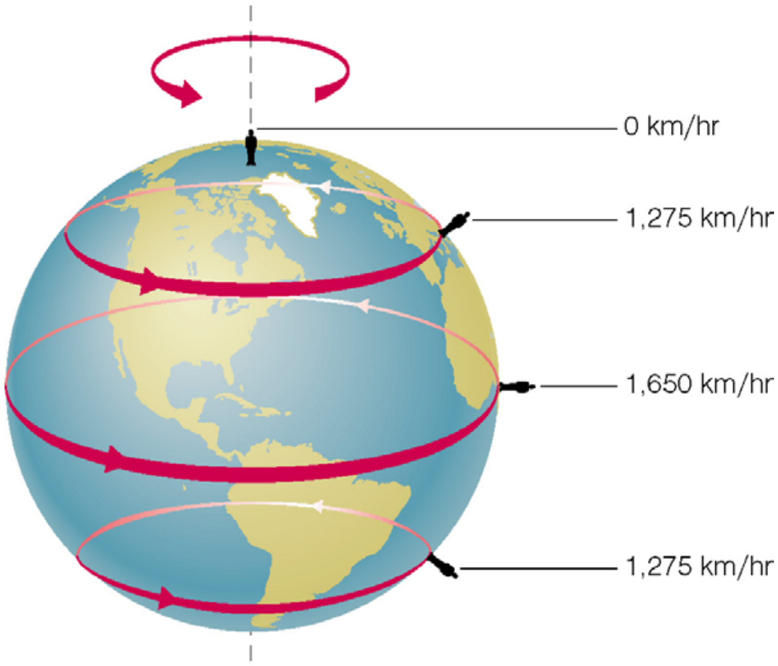
1.3 Spaceship Earth

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?

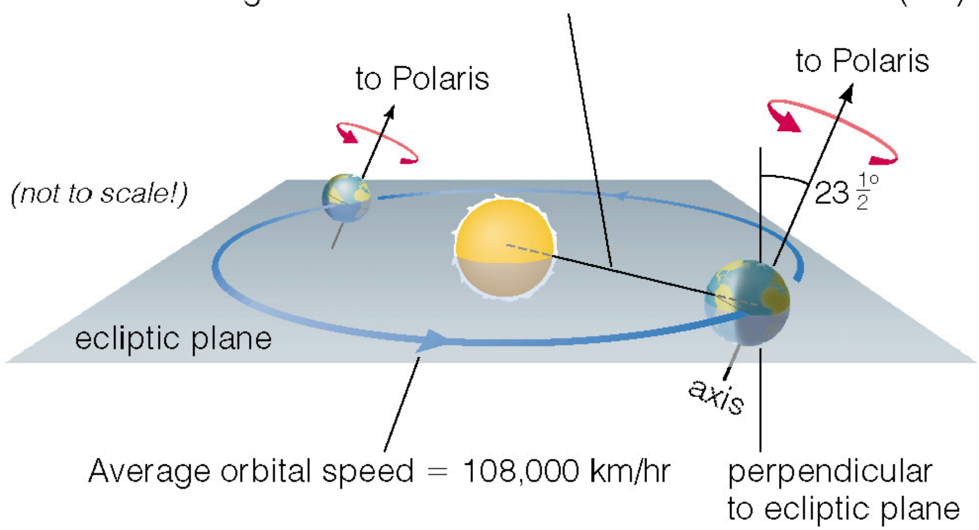
- Contrary to our perception, we are not "sitting still."
- We are moving with the Earth in several ways, and at surprisingly fast speeds…



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

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

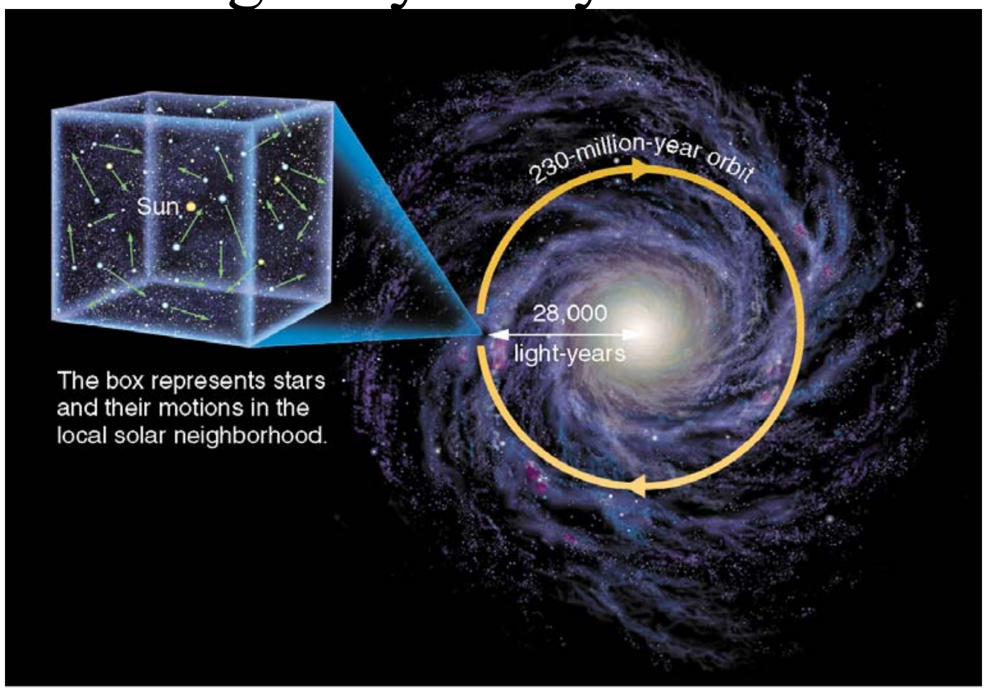
- at an average distance of 1 AU ≈ 150 million km.
- with Earth's axis tilted by 23.5º (pointing to Polaris)
- and rotating in the same direction it orbits, **counter-clockwise** as viewed from above the North Pole.



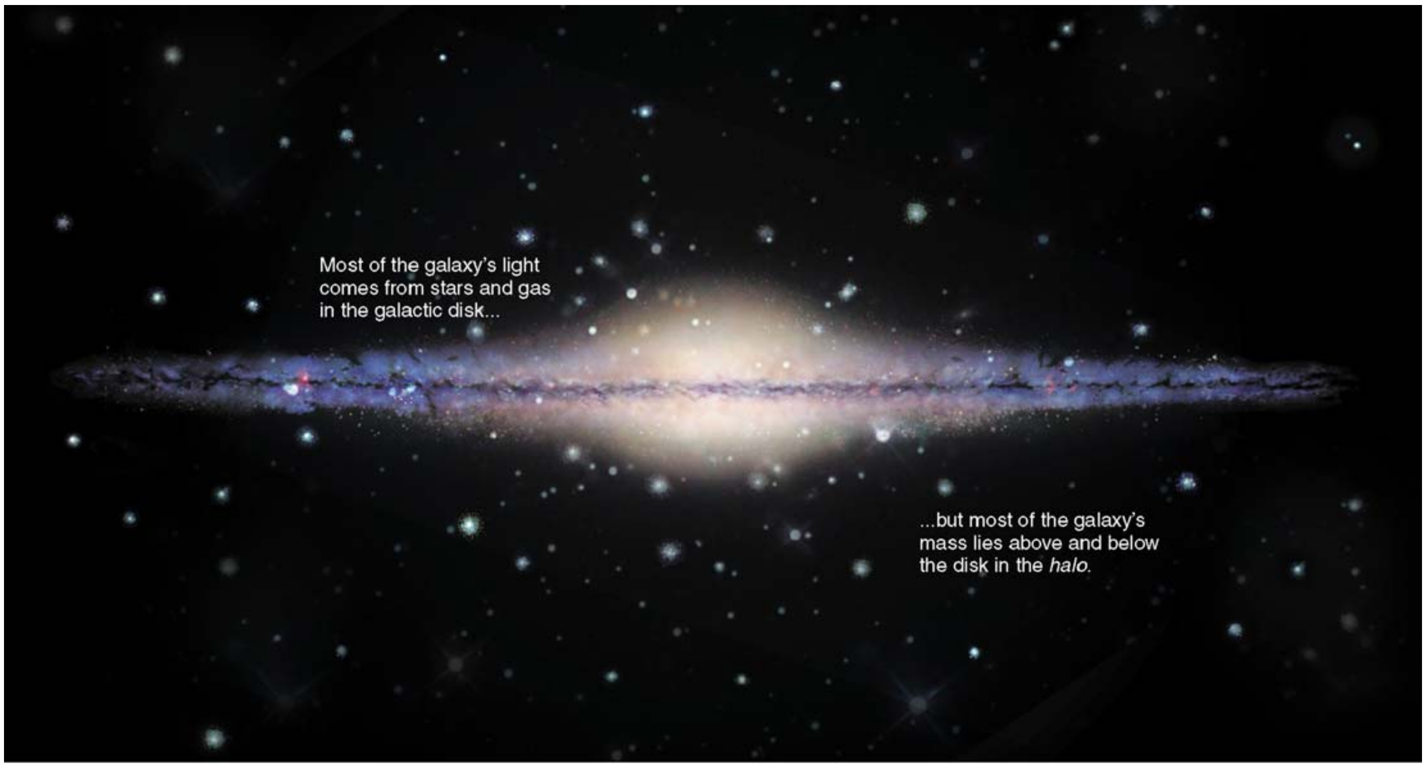
Our Sun moves randomly relative to the other stars in the local Solar neighborhood…

- 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.

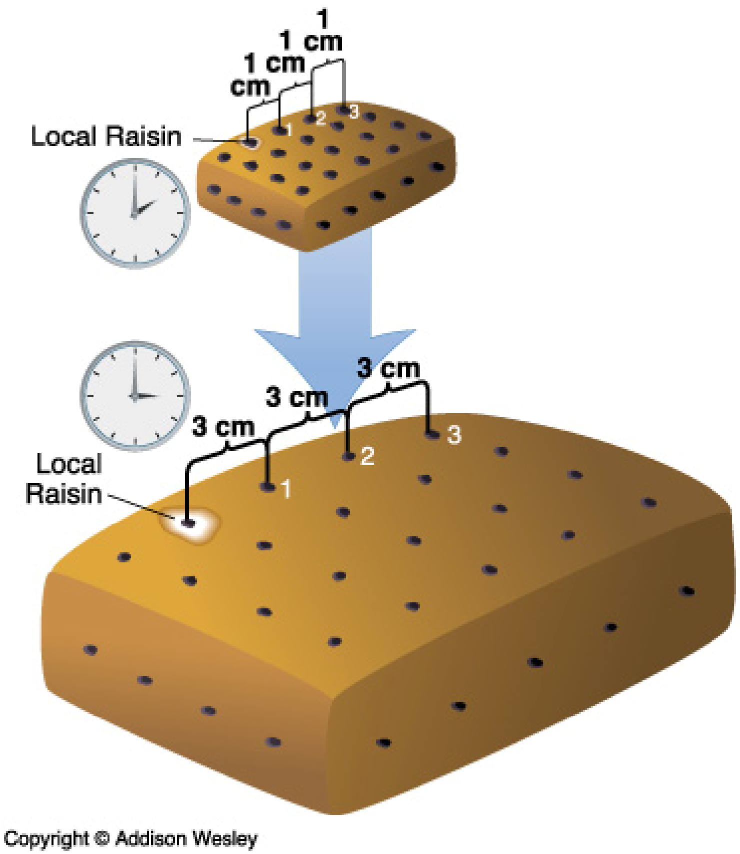


More detailed study of the Milky Way's rotation reveals one of the greatest mysteries in astronomy:



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?

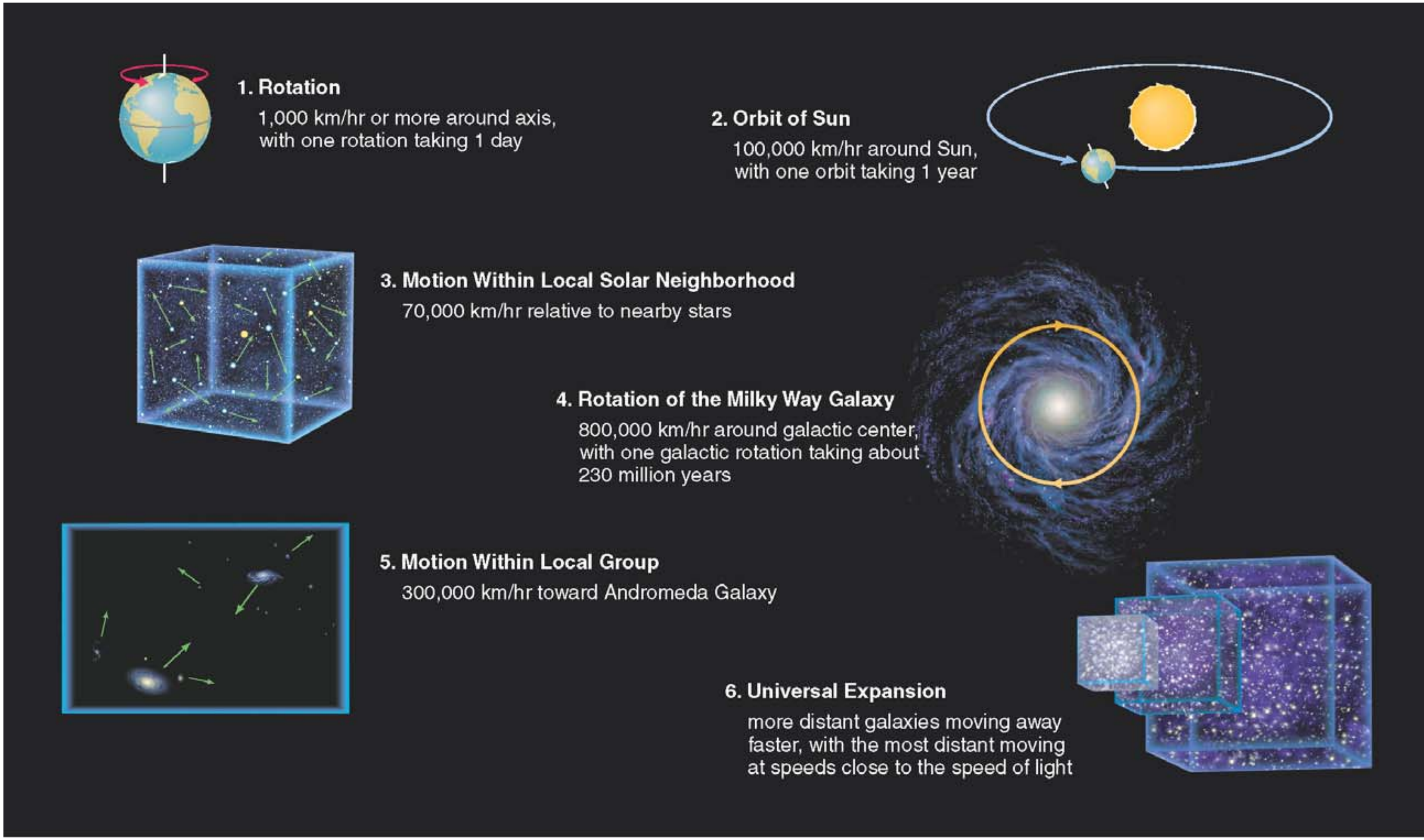


Hubble discovered that:

- 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?



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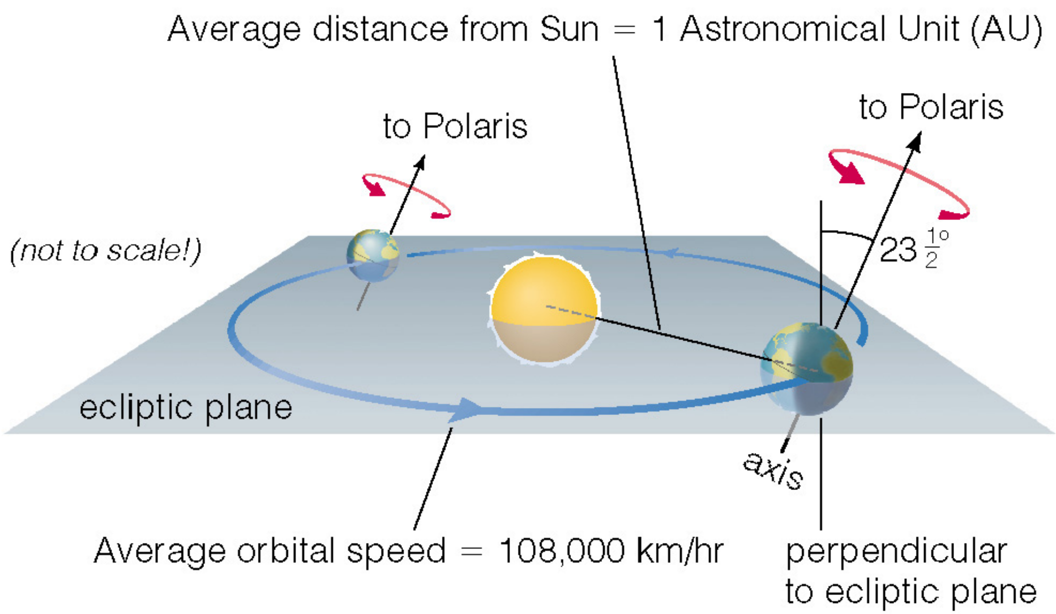
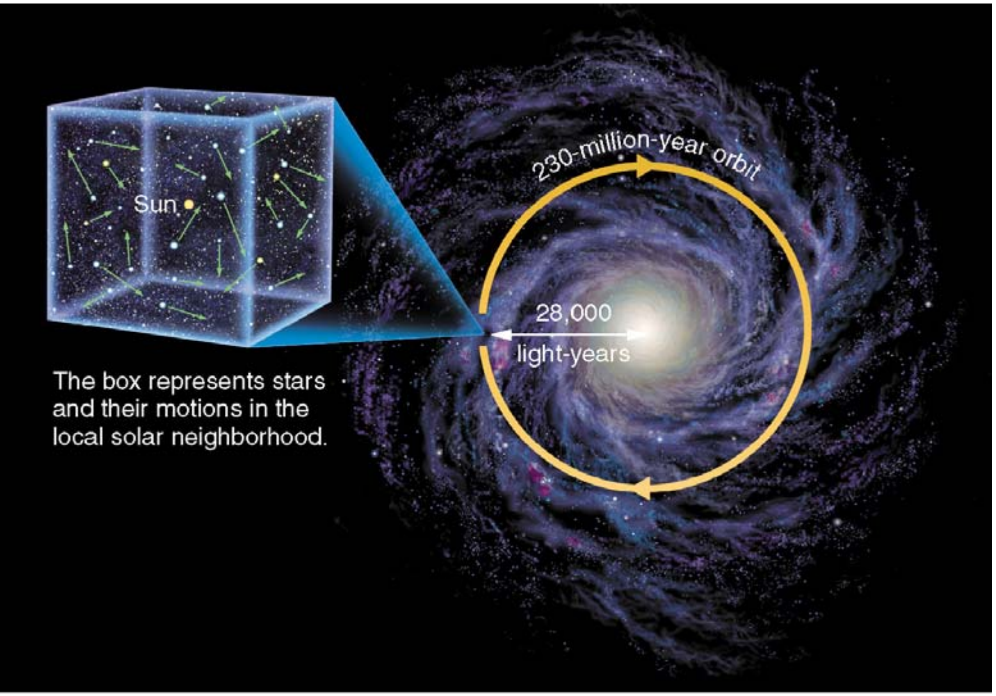
What have we learned?

- How is Earth moving in our solar system?
  - Earth rotates on its axis once each day and orbits around the Sun once each year at an average distance of 1 A.U. (≈150 million km).



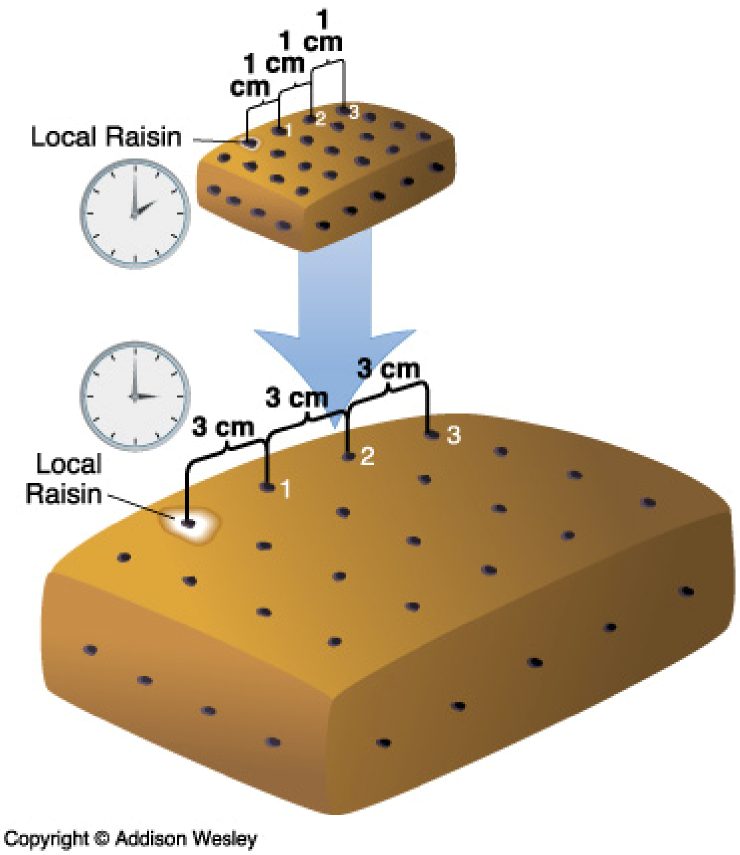
What have we learned?



- How is our solar system moving in the Milky Way Galaxy?
  - Stars in the Local Neighborhood move randomly relative to each other.
  - Our Solar System orbits the center of the Milky Way Galaxy about every 230 million years: the entire Galaxy rotates.

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.



What have we learned?

- Are we ever sitting still?
  - No!