Our Place in the Universe (Chapter 1)

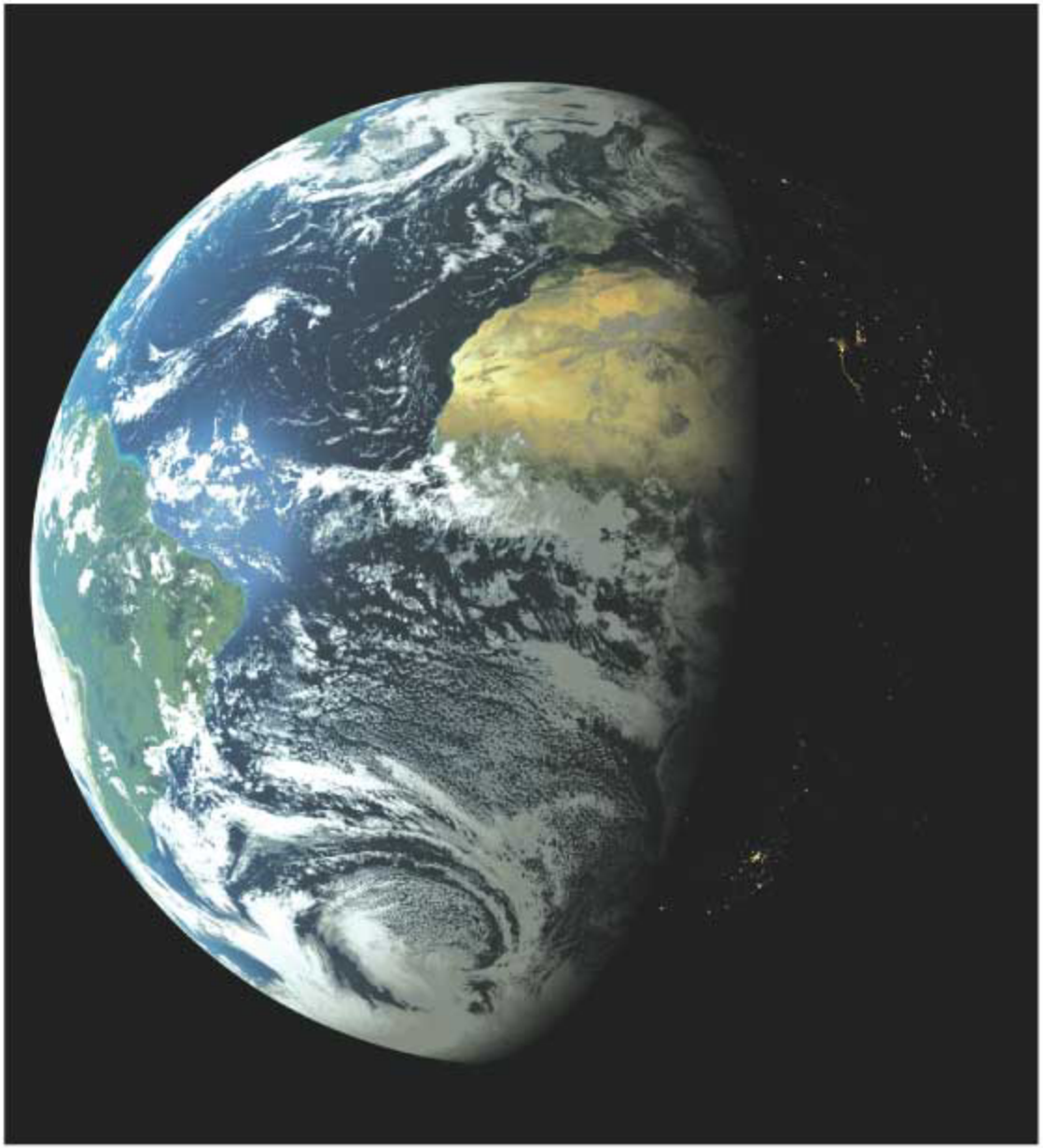
The Structure and Size of the Universe

Based on Chapter 1

- This material will be useful for understanding Chapters 2, 3, and 13 on “Years, Seasons, and Months”, “The Orbits of the Planets”, and “Extrasolar Planets”

Goals for Learning

- How are Earth, the solar system, and galaxies moving?
- How big are Earth, the solar system, and the Universe?
- How old is the Universe?

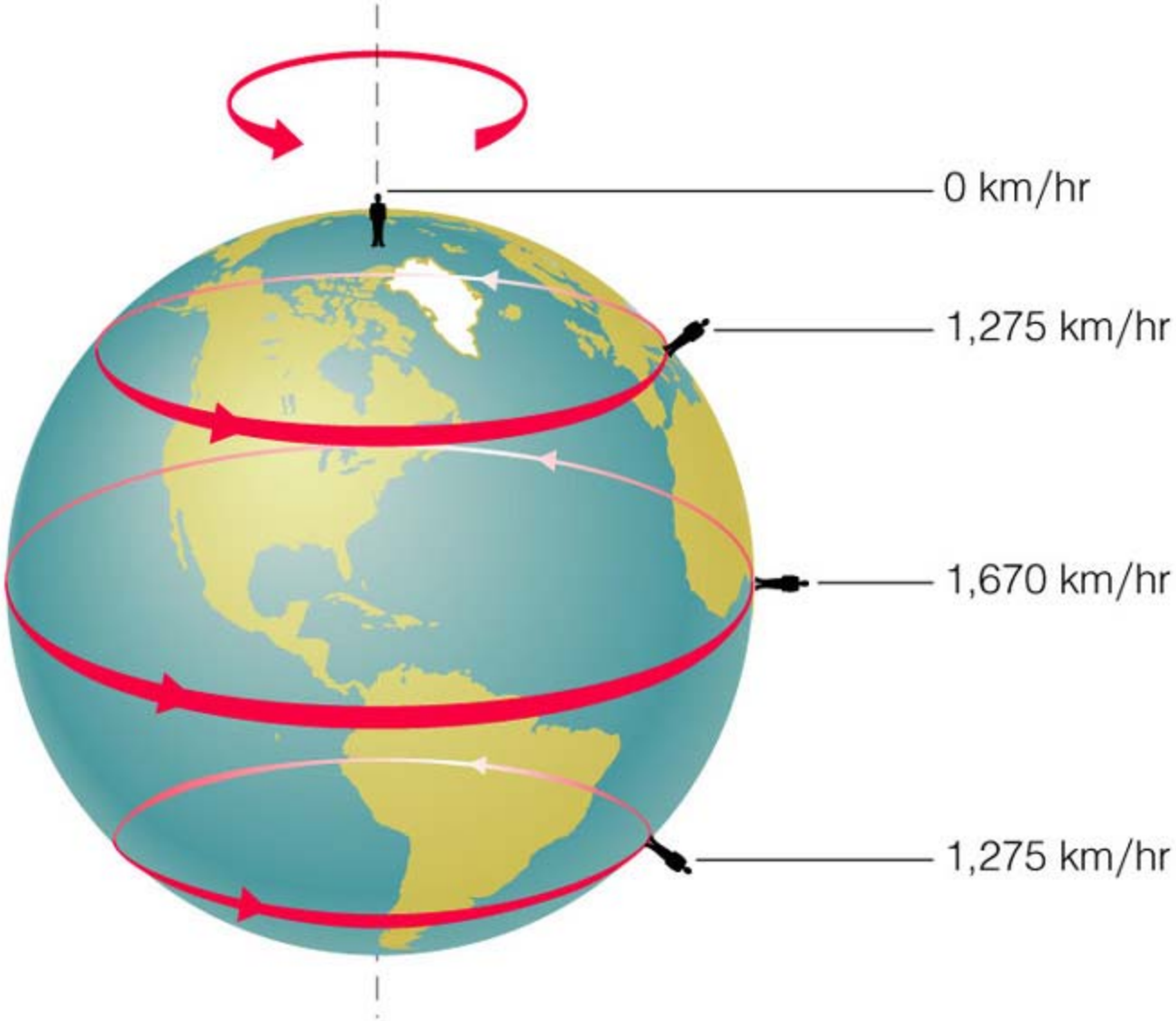


This is Earth

Earth moves

Earth rotates around its axis once per day

Earth also orbits around the Sun once per year

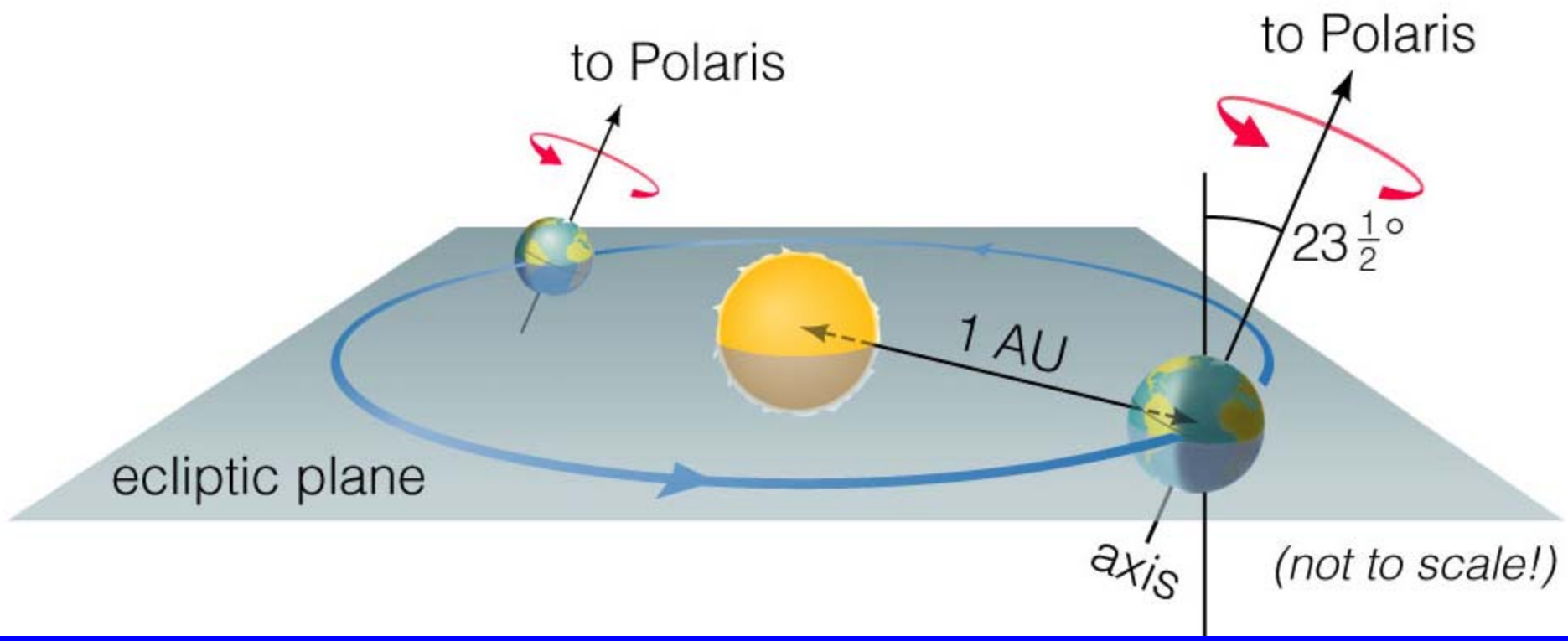


These speeds are faster than most airplanes

The speed varies with latitude

We don't feel the effects of the Earth's rotation

Play Earth rotation movie



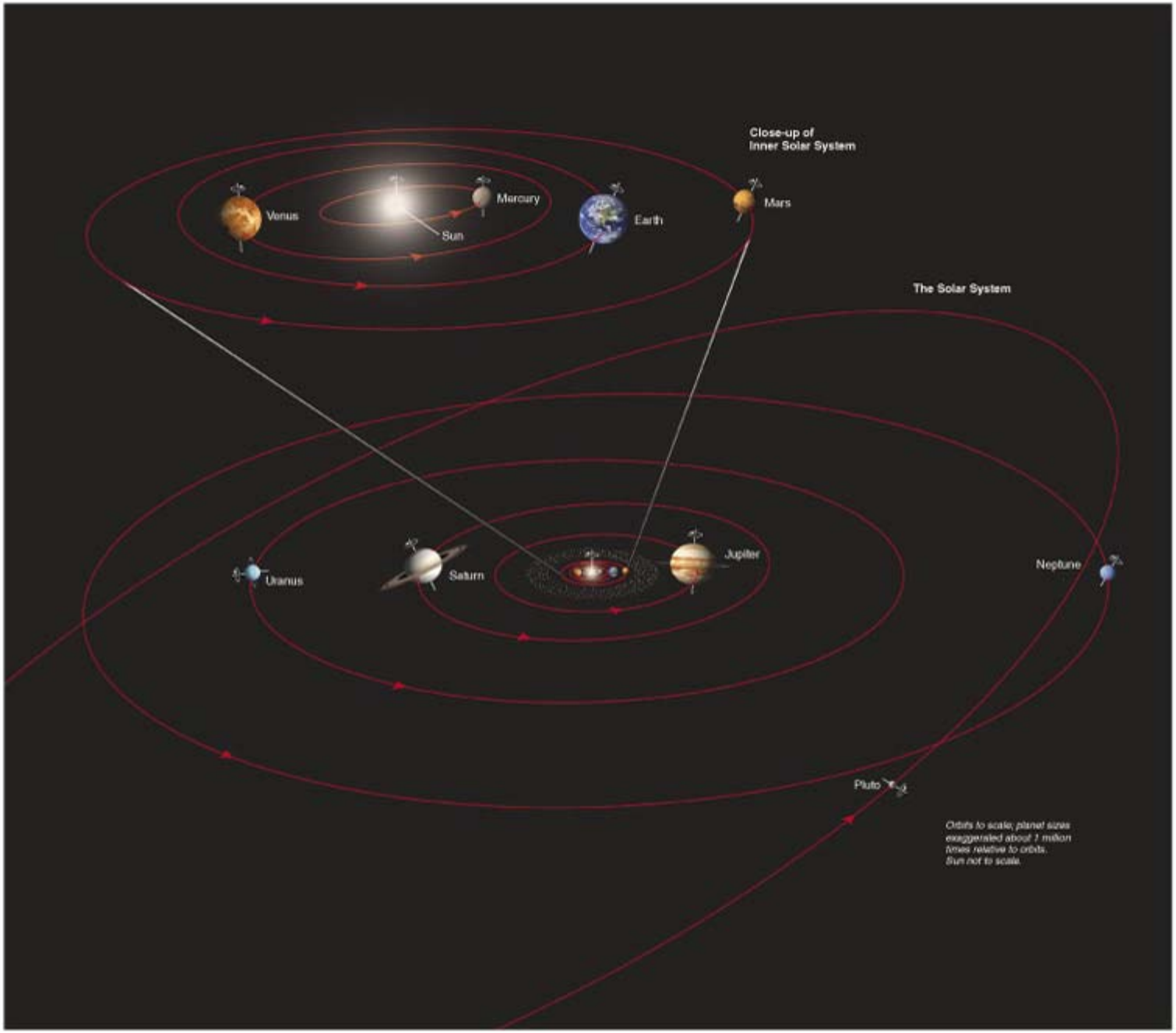
The Earth orbits round and round the Sun at the same time that it rotates around its axis.

The Earth's axis keeps pointing at the same star in the sky as the Earth orbits the Sun.

We are orbiting the Sun at 100,000 km per hour

STOP!

- Do activity on Earth’s rotation and orbit



Everything that orbits the Sun is part of the Solar System

Planets
Moons
Asteroids
Comets
Some dust
You and me

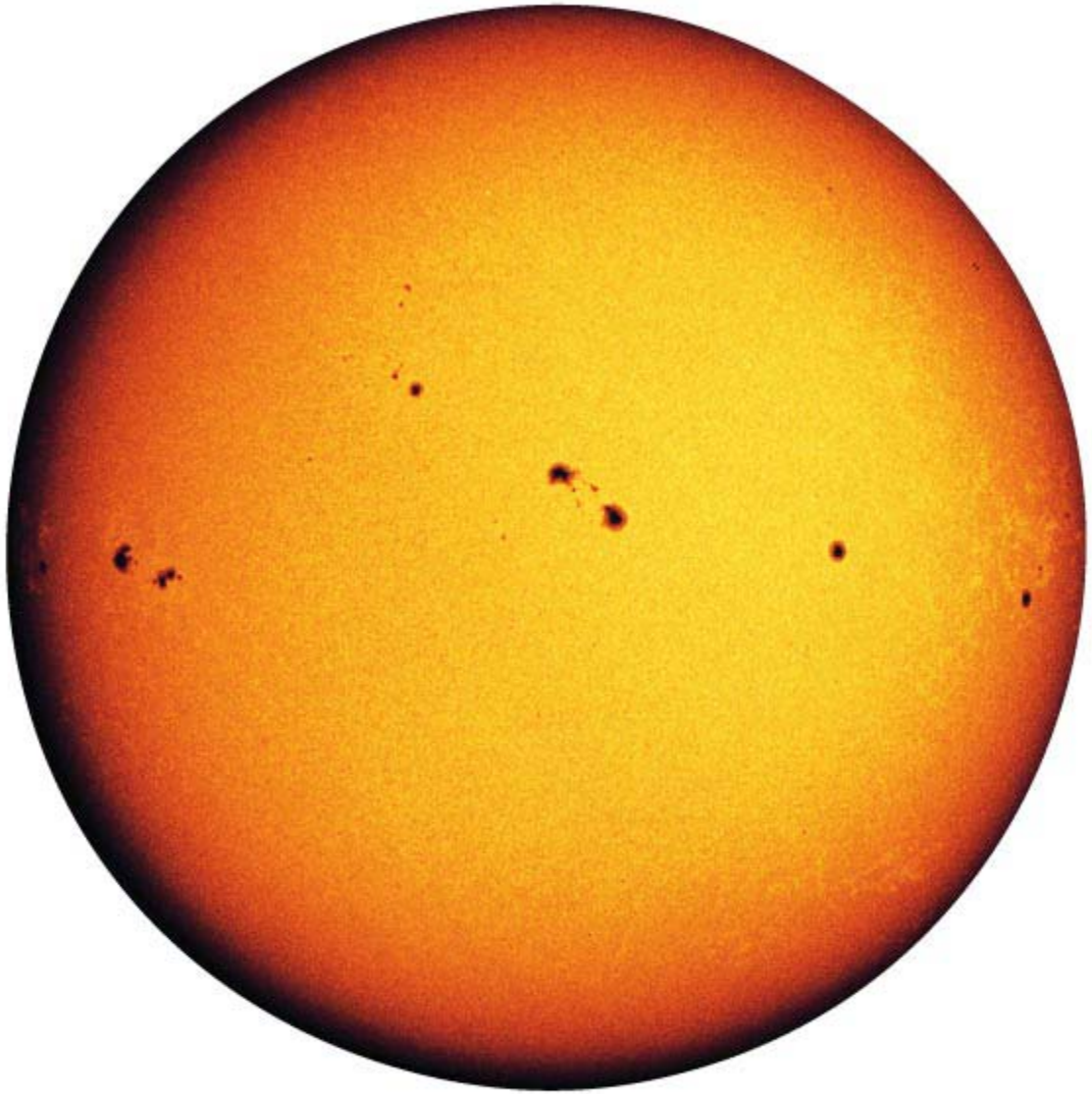
Plus the Sun Itself

This is Figure 7.1 in the book

Figure 7.2 is shows a view from above

Orbits and Rotations of Planets

- Interactive figure on “A more accurate model of the solar system”
- The orbits and rotations of the planets will reappear in Chapter 7.
- They are hard to display on a screen or projector
- Today: Orbits of planets are very close to being in the same plane



A star shines with its own light.

The Sun is a star.

The Moon only reflects light from the Sun, so it is not a star.

Stars are large balls of hot gas, mostly hydrogen and helium

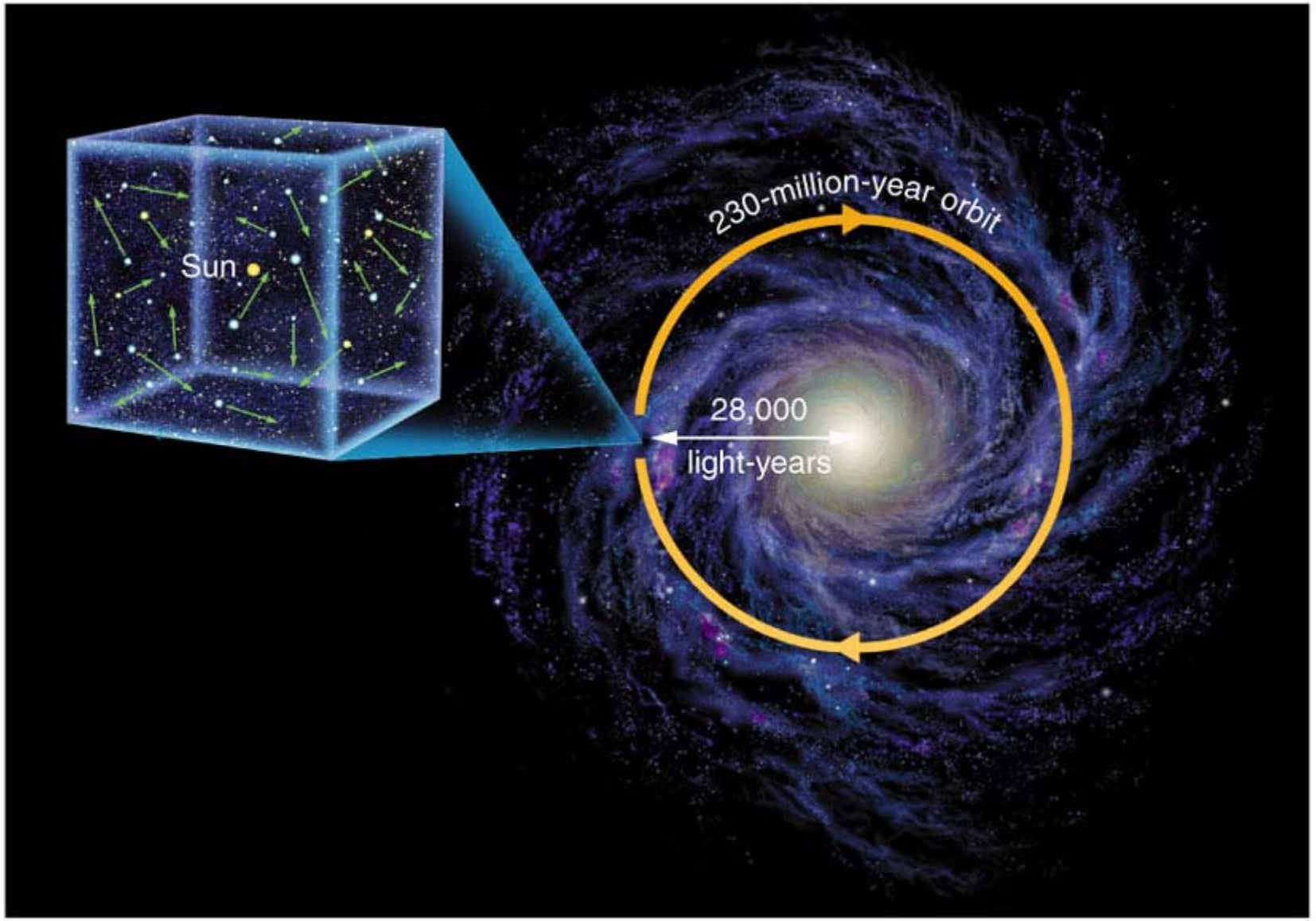
The Sun generates heat and light by a process called nuclear fusion

This is different from what happens in nuclear power stations

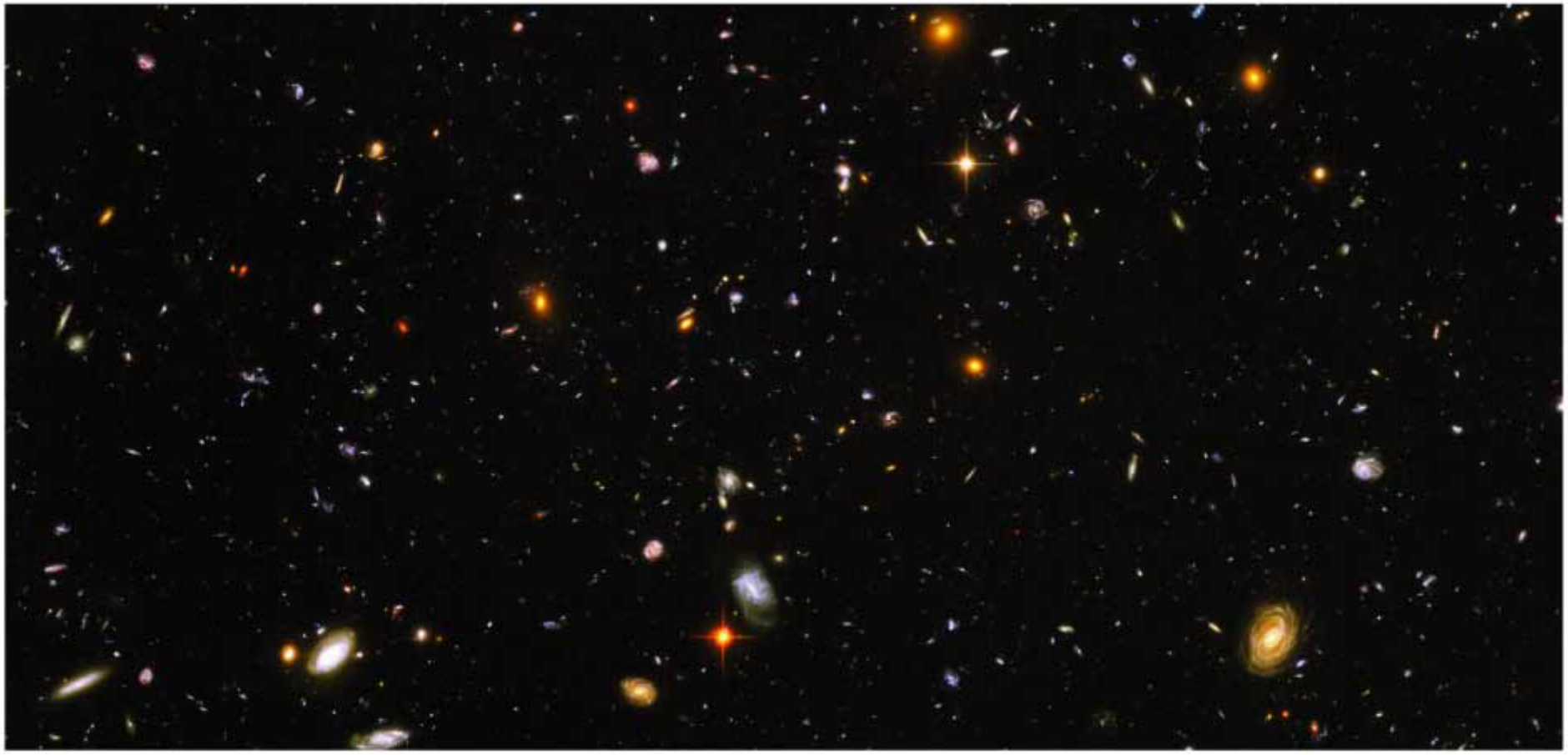
Stars form groups called galaxies

This is a fake picture of our galaxy, the Milky Way

It contains 100 billion stars

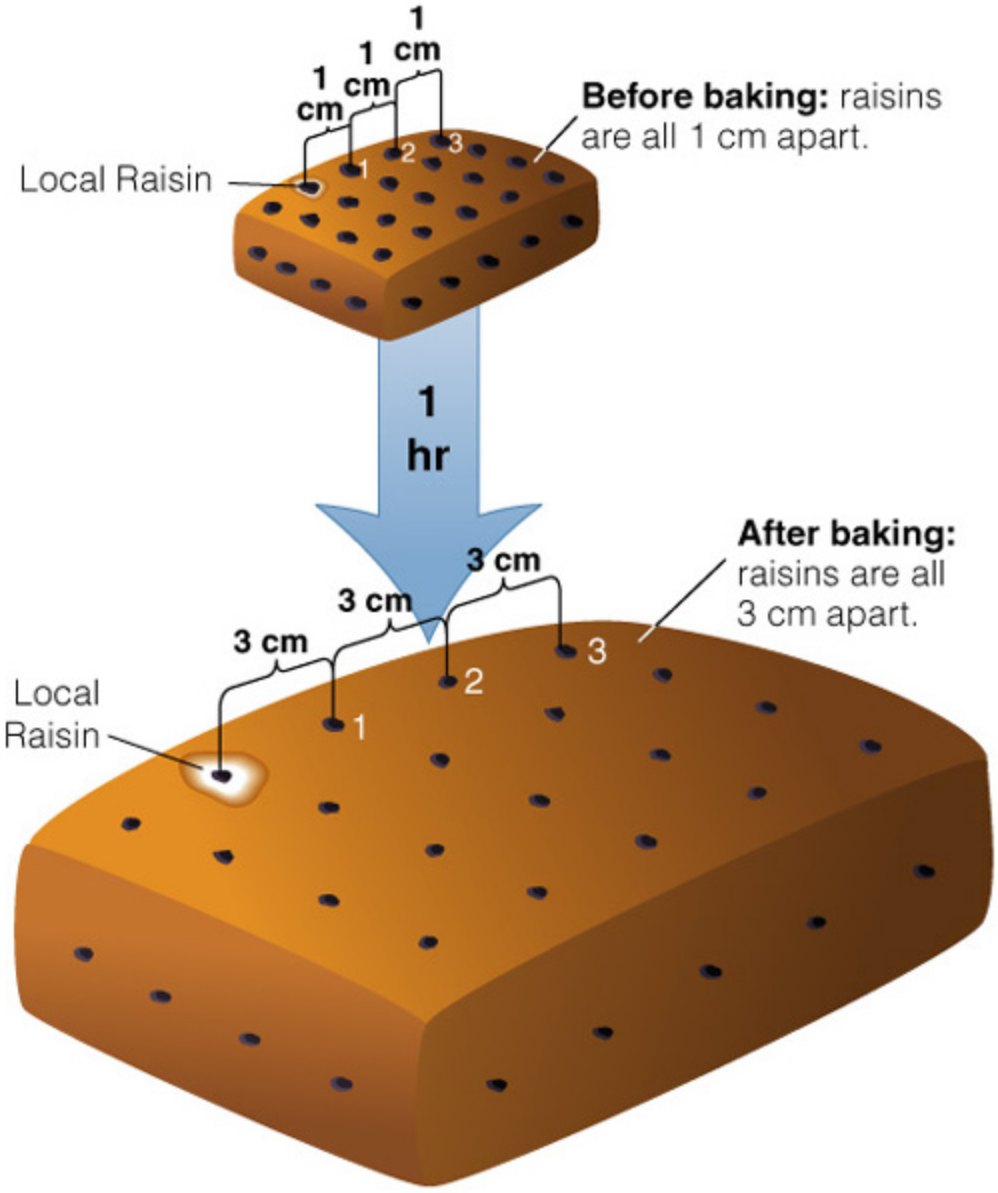


The Solar System orbits the centre of the Milky Way Galaxy every 230 million years



Every object in this picture is a galaxy that contains billions of stars.

The Universe contains at least 100 billion galaxies



Do raisin loaf demo (fig 1.16)

Astronomers can measure how far away galaxies are and how fast they are moving

All the galaxies in the Universe, including our Milky Way, are spreading apart and moving away from each other.

Galaxies that are close together are moving apart slowly, but galaxies that are far apart are moving apart more quickly.

How can this happen? The entire Universe is, for some reason, expanding.

Galaxies themselves are not getting larger, but the distances between galaxies are increasing

Summary

- Earth rotates around its axis
- Earth also orbits around the Sun
- The Sun is one of many stars in our galaxy, the Milky Way
- The Milky Way is one of many galaxies in the Universe
- All galaxies in the Universe are moving away from each other – the Universe is expanding

Powers of Ten

- 0.00000000000000000001 is a very small number
- 100000000000000000000 is a very large number
- We will discuss very big things, like the Universe, and very small things, like atoms
- We need a way to write these kinds of numbers more compactly

Powers of Ten

- Rule 1: $10^1 = 10$
- Rule 2: $10^A \times 10^B = 10^{(A+B)}$

- $10 \times 10 = 100$
- $10 \times 10 = ?$

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Powers of Ten

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- Rule 2: $10^A \times 10^B = 10^{(A+B)}$

- $10 \times 10 = 100$
- $10 \times 10 = 10^1 \times 10^1 = 10^{(1+1)} = 10^2$
- So $10^2 = 100$

Some Exercises

- $10^3 = ?$
- $10000 = ?$ (Give answer as Power of Ten)
- $100 \times 10^2 = ?$ (Give answer as Power of Ten)
- $10^4 \times 10^4 \times 10^{19} = ?$ (Give answer as Power of Ten)

Division

- $10^4 / 10^3 = ?$
- $10^4 / 10^2 = ?$
- $10^4 / 10^1 = ?$

- $10^A / 10^B = 10^?$

Division

- $10^4 / 10^3 = 10 = 10^1$
- $10^4 / 10^2 = 100 = 10^2$
- $10^4 / 10^1 = 1000 = 10^3$

- $10^A / 10^B = 10^{(A-B)}$

What is 10^0 ?

- $10^A \times 10^B = 10^{(A+B)}$
- $10^1 \times 10^0 = 10^{(1+0)} = 10^1$
- $10^1 \times ? = 10^1$
- $10 \times ? = 10$

What is 10^{-1}?

- $10^{A} / 10^{B} = 10^{(A-B)}$
- $10^{0} / 10^{1} = 10^{-1}$
- $1 / 10 = 10^{-1}$
- $0.1 = 10^{-1}$

Some Exercises

- $0.1 \times 0.1 = ?$ (Give answer as Power of Ten)
- $0.1 \times 0.1 \times 0.1 = ?$ (Give answer as Power of Ten)
- $1 / 10^6 = ?$ (Give answer as Power of Ten)
- $10^2 / 10^4 = ?$ (Give answer as Power of Ten)

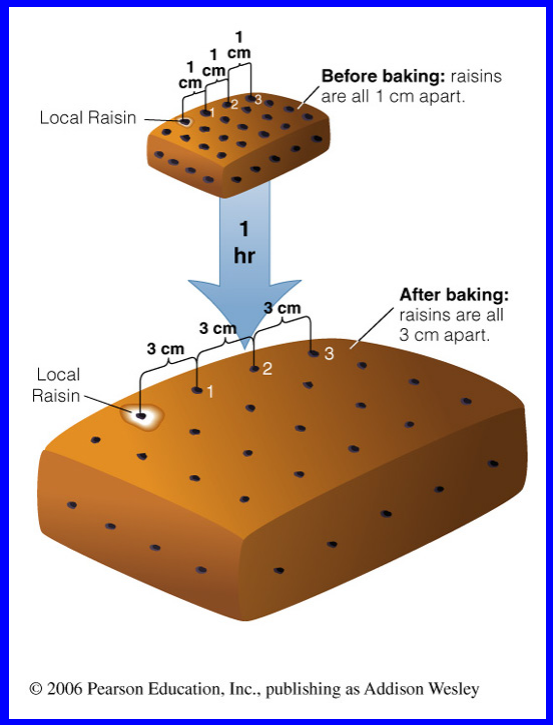
Summary

- Rule 1: $10^1 = 10$
- Rule 2: $10^A \times 10^B = 10^{(A+B)}$

- $10^2 = 10 \times 10 = 100$
- $10^1 = 10$
- $10^0 = 1$
- $10^{-1} = 0.1$
- $10^{-2} = 0.1 \times 0.1 = 0.01$

The Age of the Universe

- The Universe is very old



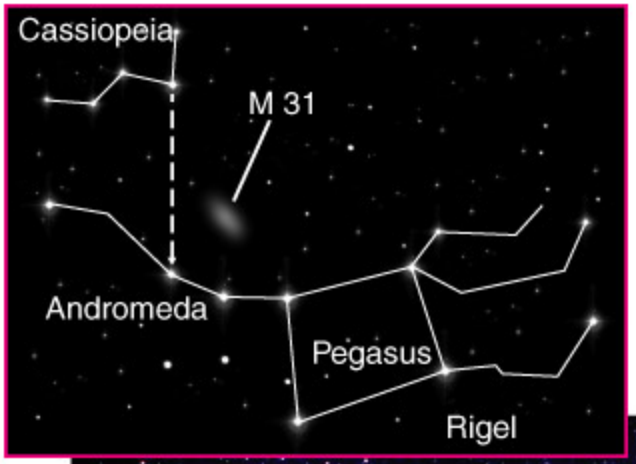
Interactive Raisin Loaf

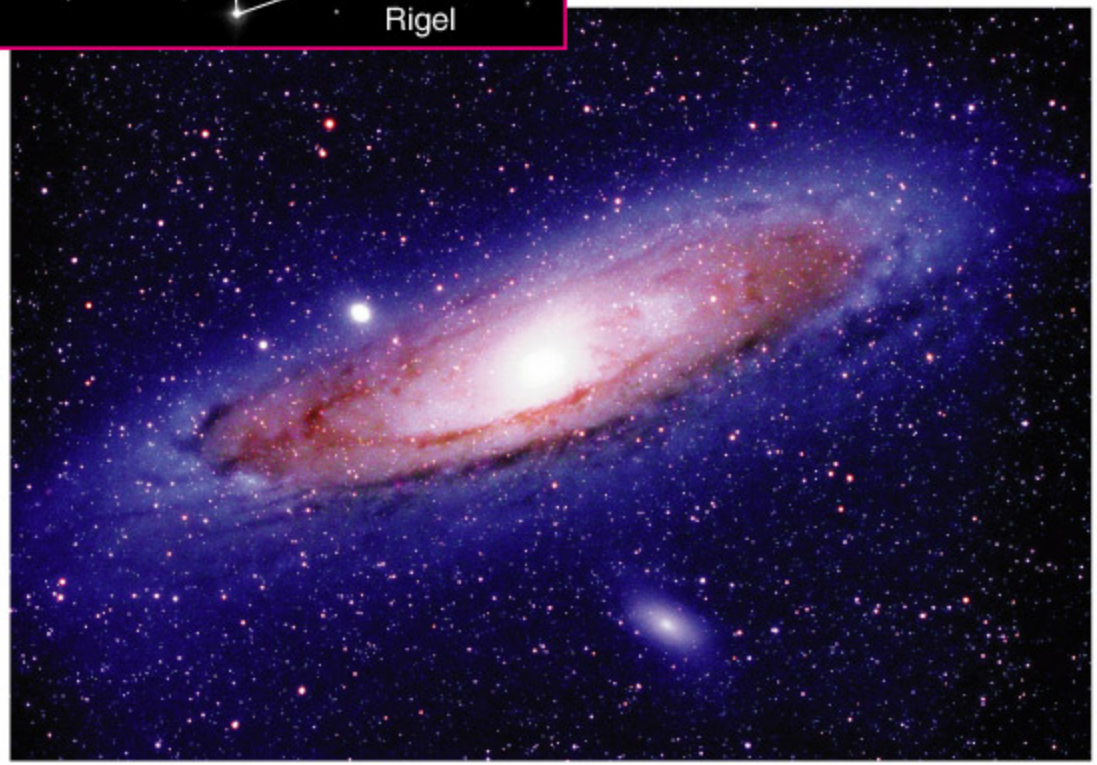
- Astronomers know how far away other galaxies are
- Astronomers know how quickly those galaxies are moving away from us
- By comparing those distances and speeds, they can estimate how long the Universe has been expanding for

- 14 billion years – The age of the Universe
- The Solar System is younger. It only formed 4.5 billion years ago

The Size of the Universe

- Astronomers don’t know the size of the Universe.
- We’ve never observed anything like the edge of the Universe
- Without any edges, there can’t be a “centre of the Universe”
- Astronomers do know that the Universe must be larger than a certain size…





The Speed of Light

Light travels very quickly, much faster than anything else in our everyday lives.

However, the Universe is so big that it takes a long time for light to travel from one galaxy to another. It takes 2.5 million years for light from the nearby Andromeda Galaxy to reach us.

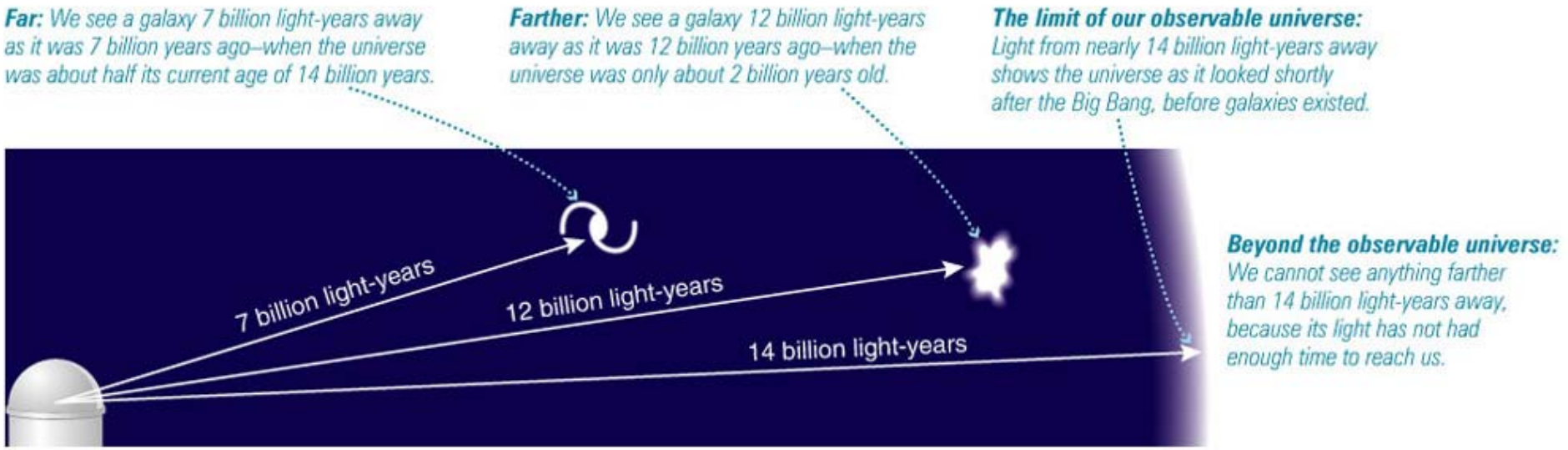
If you look at the Andromeda Galaxy today, you see it as it looked 2.5 million years ago.

Light-Years

- Light travels at 300,000 km per second
- Fast enough to circle Earth 8 times every second

- 1 Light-year = the distance that light can travel in 1 year
- 1 light-year is about 10,000,000,000,000 km or 10^{13} km

Looking Back in Time



When we look at the sky, we see nearby objects as they were a short time ago, but we see far-away objects as they were a long time ago

We can't see anything beyond 14 billion light years away from Earth, but that doesn't mean that nothing exists that far away

Sizes of Things

- Universe – 14 billion (14×10^9) light years or more
- Galaxy – 10^5 light years

- Distances between galaxies varies a lot, but can be around 100x the typical diameter of a galaxy
- There is plenty of empty space between galaxies

Sizes of Things

- Galaxy – 10^5 light years
- Closest star to the Sun – 4 light years or 4×10^{13} km
- Distance from the Sun to Pluto – 0.006 light years = 6×10^9 km
- Diameter of the Sun – 7×10^5 km

- You could fit 10^8 Suns in the distance between the Sun and its closest neighbour
- There is a lot of empty space between stars (or between stellar systems) in galaxies

Sizes of Things

- Distance from the Sun to Earth – 1.5×10^8 km = 1 Astronomical Unit or 1 AU
- Diameter of the Sun – 7×10^5 km
- Diameter of the Earth – 6400 km

- There is a lot of empty space in the Solar System between the Sun and its planets

Goals for Learning

- How are Earth, the solar system, and galaxies moving?
- How big are Earth, the solar system, and the Universe?
- How old is the Universe?

Goals for Learning

- How are Earth, the solar system, and galaxies moving?
  - Earth rotates on its axis once per day and orbits the Sun once each year. Earth's axis is tilted from its orbital plane
  - Everything in the solar system orbits the Sun. The Sun orbits the centre of the Milky Way
  - Galaxies are receding from each other, so the Universe is expanding

Goals for Learning

- How big are Earth, the solar system, and the Universe?
  - Earth is 6400 km radius and 1.5×10^8 km from the Sun
  - The solar system is about 100 AU radius
  - Typical galaxies contain 100 billion stars and the Universe contains 100 billion galaxies
  - The Universe is at least 14 billion light years across

Goals for Learning

- How old is the Universe?
  - The Universe formed 14 billion years ago in the Big Bang
  - The solar system formed 4.5 billion years ago

Compressed History

- The Universe is 14 billion years old. If the history of the Universe were compressed into 1 year, this is what the calendar would look like.

- 14 billion years -> 1 compressed year
- 1.2 billion years -> 1 compressed month
- 270 million years -> 1 compressed week
- 38 million years -> 1 compressed day
- 1.6 million years -> 1 compressed hour
- 27,000 years -> 1 compressed minute
- 440 years -> 1 compressed second

How far is a light-year?

- The Milky Way Galaxy is 100,000 light years across. The nearest star to the Sun, Alpha Centauri, is 4 light years away. 1 light-year equals 10^{13} km.
- If you had a ruler whose length was one of these distances, how many times would you need to lay the ruler end-to-end before you had measured out one light-year?

- Sun - Pluto distance = 6×10^{9} km
- Sun - Earth distance = 1.5×10^{8} km
- Sun's diameter = 1.4×10^{6} km
- Earth - Moon distance = 3.8×10^{5} km
- Earth's diameter = 1.2×10^{4} km