Astronomy 9
Concepts of the Cosmos

Monday/Wednesday, 1:30-2:45 pm, Cabot Auditorium

LECTURE 2:

I. Our Place in the Universe

Lecture on Mon., Feb. 1st

Pre-course Test - REQUIRED! (if you want the attendance bonus - worth 2%…)

BRING A PENCIL #2

Assignment for Wed, Feb. 3rd

- Read Ch. 3 of the textbook
- Take the Reading Quiz #2 before 10 am on Feb. 3rd

DON’T FORGET YOUR LECTURE TUTORIAL AND FLASHCARD!!!

Science is not...

- A list of previously known facts about nature
- A list of equations handed down from Ancient times
- A set of laws that were discovered by Dead White Guys a long time ago and are kept from the general public

Science is...

- a continuing process that
  - seeks to understand the rules and laws of nature
  - uses systematic observations
  - uses mathematical models
  - experimentally tests ideas

- subject to independent verification

These are the components of the scientific method (observe, theorize, predict, test, and modify) used to comprehend the universe

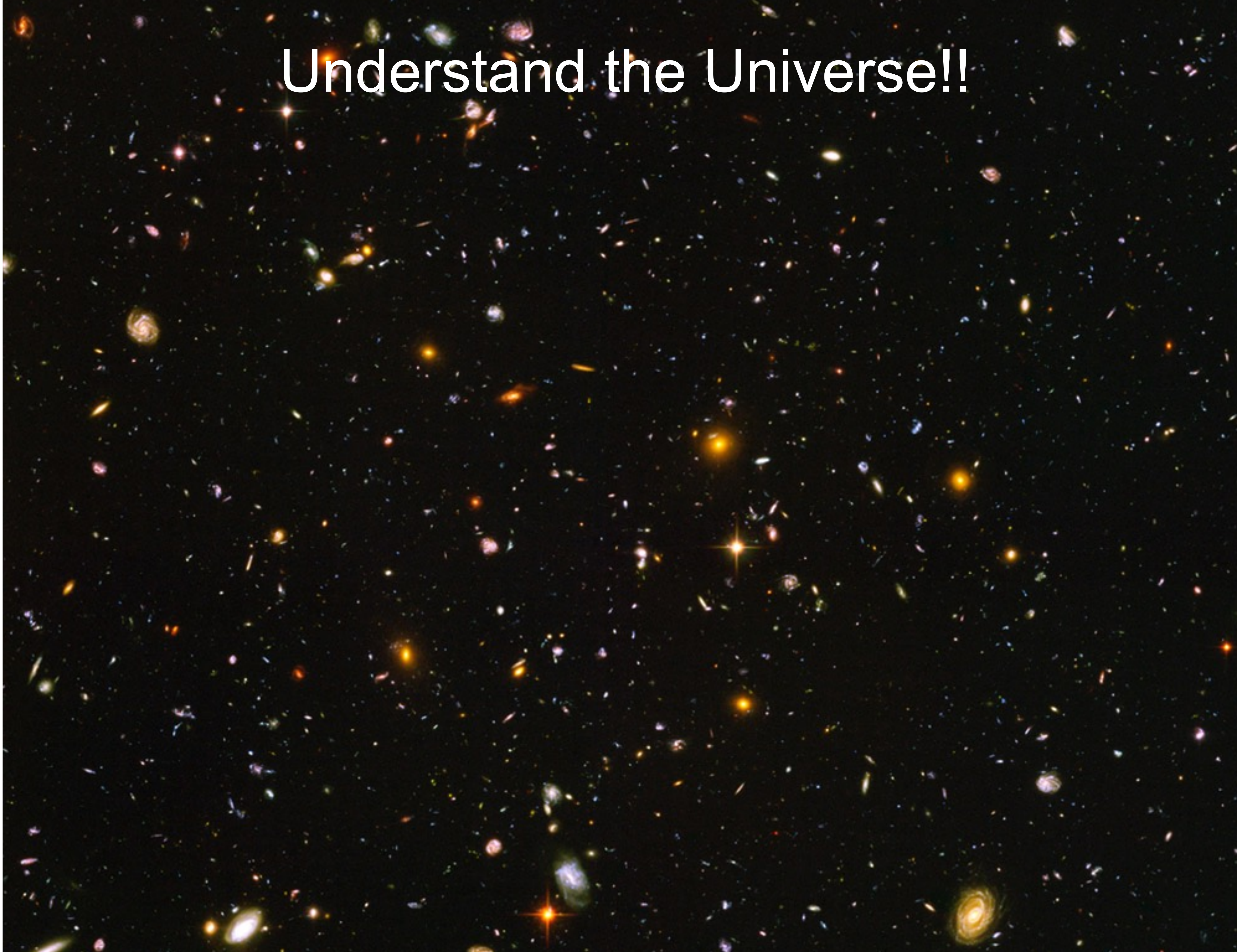
What do Astronomers do?

- make observations using telescopes
- analyze data/results of observations
- create theories about what is seen and what might exist yet unseen
- create computer models that simulate what occurs in the universe
- invent, design, and build instruments that let us see beyond the Earth!

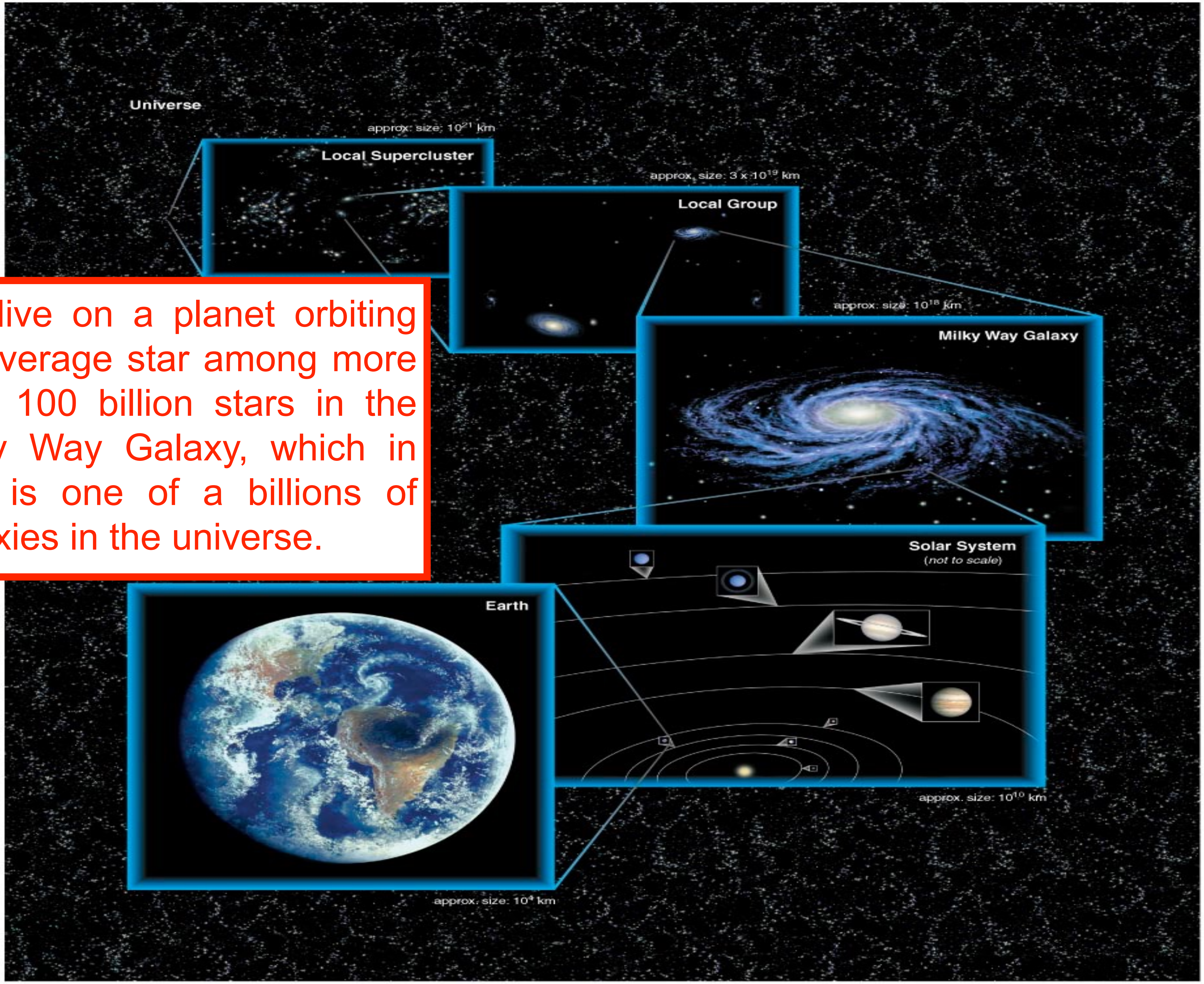
BUT, most astronomers do NOT spend much time looking through telescopes

A scientific theory is a collection of ideas that explain a phenomenon in a way that is consistent with laws, observations, and experiments.

Understand the Universe!!

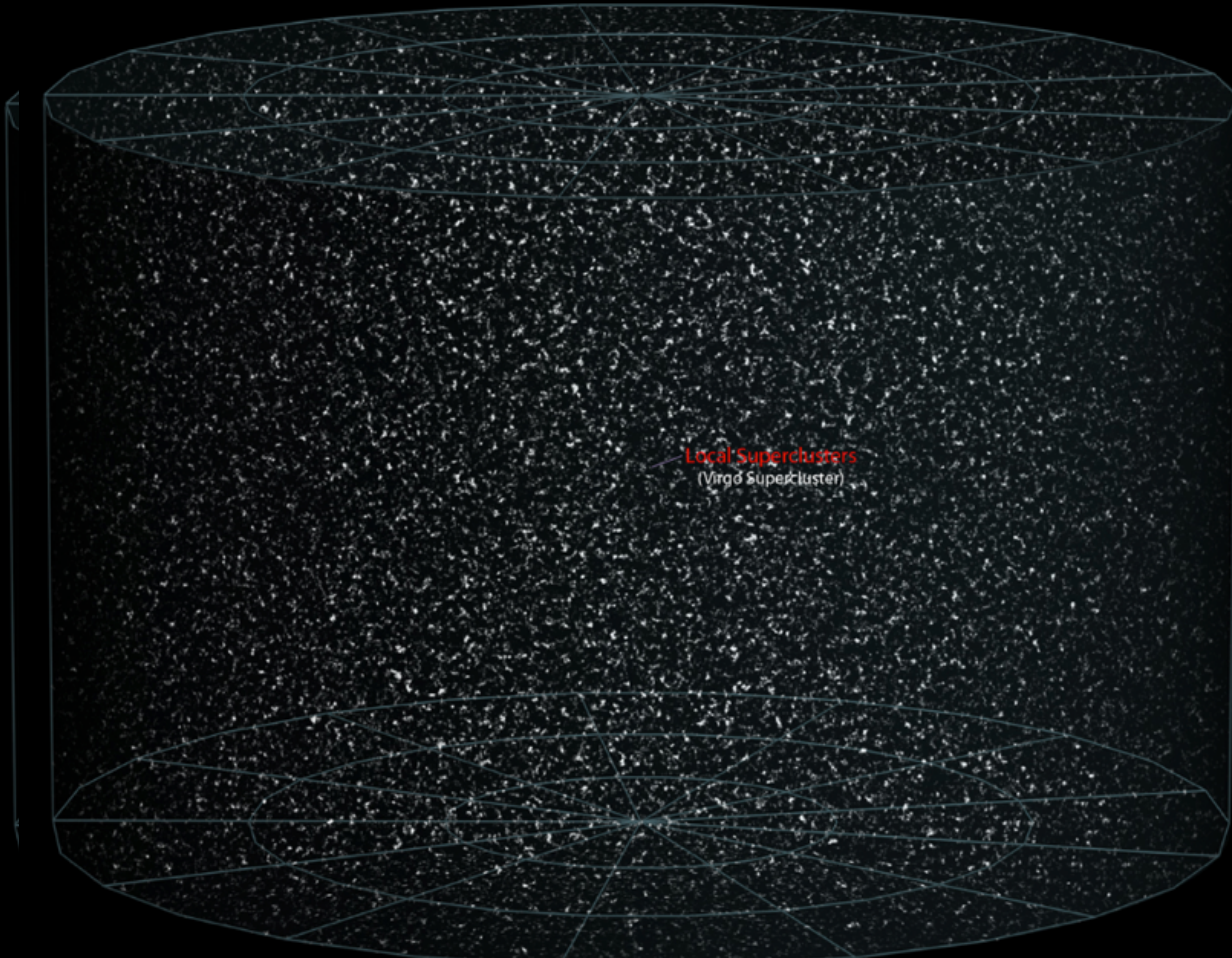


What is our place in the Universe?

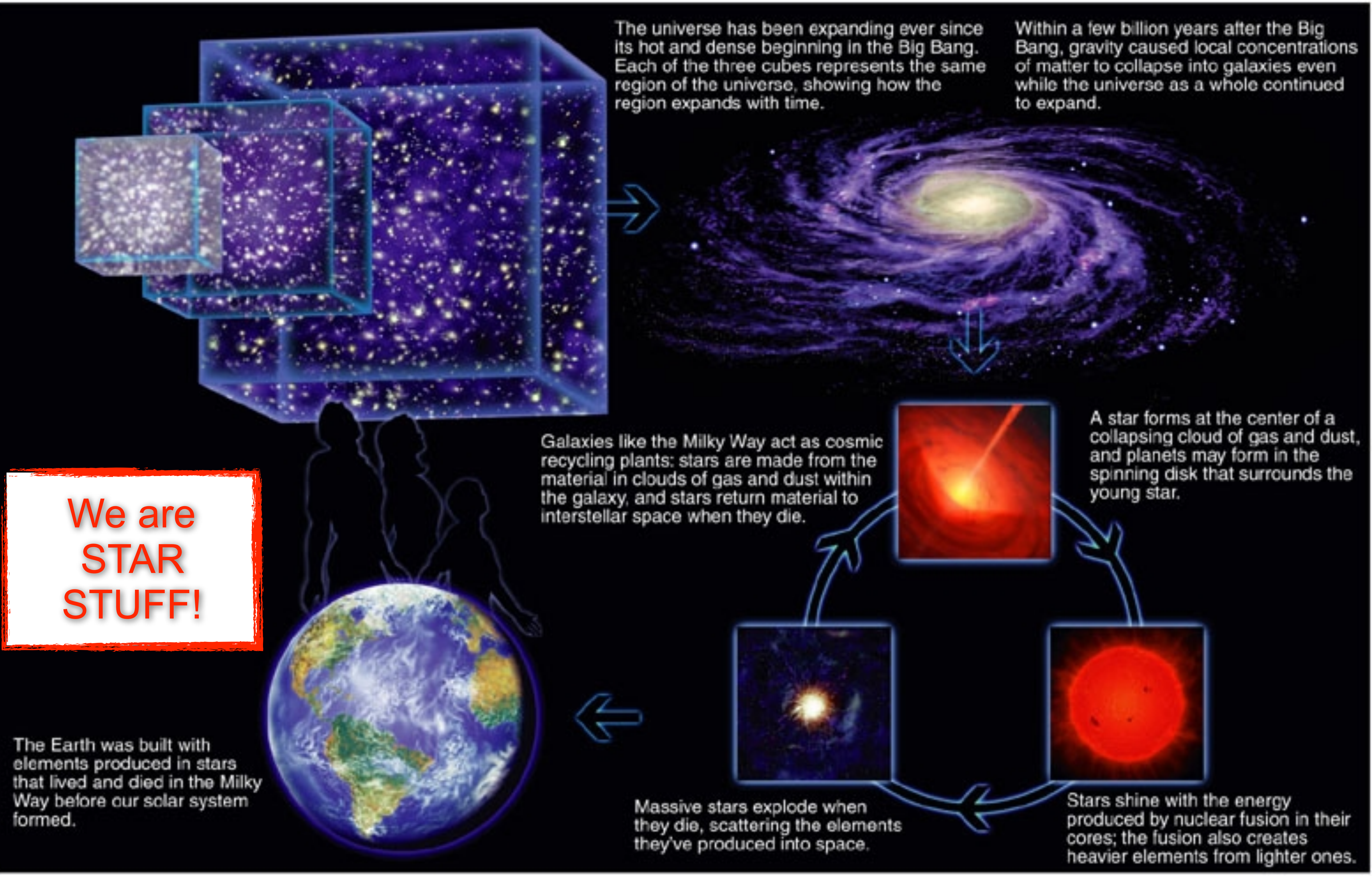


We live on a planet orbiting an average star among more than 100 billion stars in the Milky Way Galaxy, which in turn is one of a billions of galaxies in the universe.

Observable Universe



How did we come to be?



www.eso.org

The numbers in astronomy are so large, and small, that astronomers use scientific notation

AN ASTRONOMER'S TOOLBOX 1-1

Powers-of-Ten Notation

Astronomy is a science of extremes. As we examine various cosmic environments, we find an astonishing range of conditions, from the incredibly hot, dense centers of stars to the frigid, near-perfect vacuum of interstellar space. To describe such divergent conditions accurately, we need a wide range of both large and small numbers. Astronomers avoid such confusing terms as "a million billion billion" (1,000,000,000,000,000,000,000,000) by using a standard shorthand system. All the cumbersome zeros that accompany such a large number are consolidated into one term consisting of 10 followed by an *exponent*, which is written as a superscript and called the **power of ten.** The exponent merely indicates how many zeros you would need to write out the long form of the number. Thus,

$$10^0 = 1$$
$$10^1 = 10$$
$$10^2 = 100$$
$$10^3 = 1000$$
$$10^4 = 10{,}000$$

and so forth. The exponent tells you how many tens must be multiplied together to yield the desired number. For example, ten thousand can be written as 10^4 ("ten to the fourth") because $10^4 = 10 \times 10 \times 10 \times 10 = 10{,}000$. Similarly, 273,000 can be written 2.73×10^5.

In scientific notation, numbers are written as a figure between 1 and 10 multiplied by the appropriate power of 10. The distance between the Earth and the Sun, for example, can be written as 1.5×10^8 km. Once you get used to it, you will find this notation more convenient than writing "150,000,000 kilometers" or "one hundred and fifty million kilometers."

This powers-of-ten system can also be applied to numbers that are less than 1 by using a minus sign in front of the exponent. A negative exponent tells you that the location of the decimal point is as follows:

$$10^0 = 1$$
$$10^{-1} = 0.1$$
$$10^{-2} = 0.01$$
$$10^{-3} = 0.001$$
$$10^{-4} = 0.0001$$

and so forth. For example, the diameter of a hydrogen atom is 1.1×10^{-8} cm. That is more convenient than saying "0.000000011 centimeter" or "11 billionths of a centimeter." Similarly, .000728 equals 7.28×10^{-4}.

Using the powers-of-ten shorthand, one can write large or small numbers like these compactly:

$$3{,}416{,}000 = 3.416 \times 10^6$$
$$0.000000807 = 8.07 \times 10^{-7}$$

Because powers-of-ten notation bypasses all the awkward zeros, a wide range of circumstances can be numerically described conveniently:

one thousand $= 10^3$
one million $= 10^6$
one billion $= 10^9$
one trillion $= 10^{12}$

and also

one thousandth $= 10^{-3} = 0.001$
one millionth $= 10^{-6} = 0.000001$
one billionth $= 10^{-9} = 0.000000001$
one trillionth $= 10^{-12} = 0.000000000001$

The accompanying figure shows how clearly the powers-of-ten notation expresses the scale of objects, ranging from subatomic particles like the proton to the size of the observable universe.

$10^0 = 1$

$10^1 = 10$

$10^2 = 100$

$10^3 = 1000$ $\quad$ $5.3 \times 10^3 = 5{,}300$

$10^4 = 10{,}000$ $\quad$ $8.9 \times 10^4 = 89{,}000$

and, for small numbers

$10^{-1} = 0.1$

$10^{-2} = 0.01$ $\quad$ $2.1 \times 10^{-2} = 0.021$

$10^{-3} = 0.001$ $\quad$ $6.6 \times 10^{-3} = 0.0066$

Astronomical distances and sizes are very very large, so astronomers use different units

AN ASTRONOMER'S TOOLBOX 1-2

Astronomical Distances

Throughout this book we will find that some of our traditional units of measure become cumbersome. It is fine to use kilometers to measure the diameters of craters on the Moon or the heights of volcanoes on Mars. However, it is as awkward to use kilometers to express distances to planets, stars, or galaxies as it is talk about the distance from New York City to San Francisco in millimeters. Astronomers have therefore devised new units of measure.

When discussing distances across the solar system, astronomers use a unit of length called the **astronomical unit** (AU), which is the average distance between the Earth and the Sun:

$$1 \text{ AU} = 1.5 \times 10^8 \text{ km} = 9.3 \times 10^7 \text{ miles}$$

Jupiter, for example, is an average of 5.2 times farther from the Sun than is the Earth. Thus, the distance between the Sun and Jupiter can be conveniently stated as 5.2 AU. This can be converted into kilometers or miles using the relationship above.

When talking about distances to the stars, astronomers choose between two different units of length. One is the **light-year** (ly), which is the distance that light travels in a vacuum (in the absence of air) in one year:

$$1 \text{ ly} = 9.46 \times 10^{12} \text{ km} = 63{,}000 \text{ AU}$$

One light-year is roughly equal to six trillion miles. Proxima Centauri, the star nearest to our solar system, is just over 4.2 ly from Earth.

The second commonly used unit of length is the **parsec** (pc) (the distance at which two objects separated by 1 AU make an angle of 1 arcsecond). Imagine taking a journey far into space, beyond the orbits of the outer planets. Watching the solar system as you move away, the angle between the Sun and the Earth becomes smaller and smaller. When the Sun and Earth are side by side and you measure the angle between them as 1/3600° (called 1 arcsecond), you have reached a distance astronomers call 1 parsec, as shown in the figure below. The parsec turns out to be longer than the light-year. Specifically,

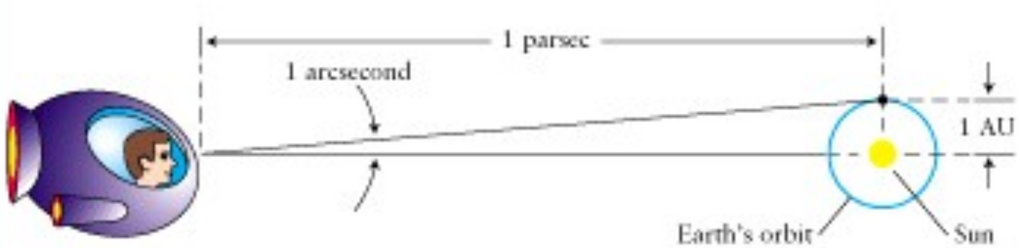
$$1 \text{ pc} = 3.09 \times 10^{13} \text{ km} = 3.26 \text{ ly}$$

Thus, the distance to the nearest star can be stated as 1.3 pc as well as 4.2 ly. Whether one uses light-years or parsecs is a matter of personal taste.

For even greater distances, astronomers commonly use *kiloparsecs* (kpc) and *megaparsecs* (Mpc), in which the prefixes simply mean "thousand" and "million," respectively:

$$1 \text{ kpc} = 10^3 \text{ pc}$$
$$1 \text{ Mpc} = 10^6 \text{ pc}$$

For example, the distance from Earth to the center of our Milky Way Galaxy is about 8.6 kpc, and the rich cluster of galaxies in the direction of the constellation Virgo is 20 Mpc away.



A Parsec The parsec, a unit of length commonly used by astronomers, is equal to 3.26 ly. The parsec is defined as the distance at which 1 AU perpendicular to the observer's line of sight makes an angle of 1 arcsecond.

One "Astronomical Unit" (AU)

average distance between Sun and Earth

- 93,000,000 miles
- 150,000,000 km
- 1.5×10^8 km

Distance Light Travels in One Year is a "Light-year" (LY)

- 9.46×10^{12} km
- 63,000 AU or 6.3×10^4 AU
- 0.307 parsecs (pc)

The nearest star to our solar system, alpha centauri is 4.0×10^{16} m (4.3 light-years) away. The diameter of the sun is 1.4×10^{9} m. How many suns would have to be lined up adjacent to each other to reach alpha centauri?

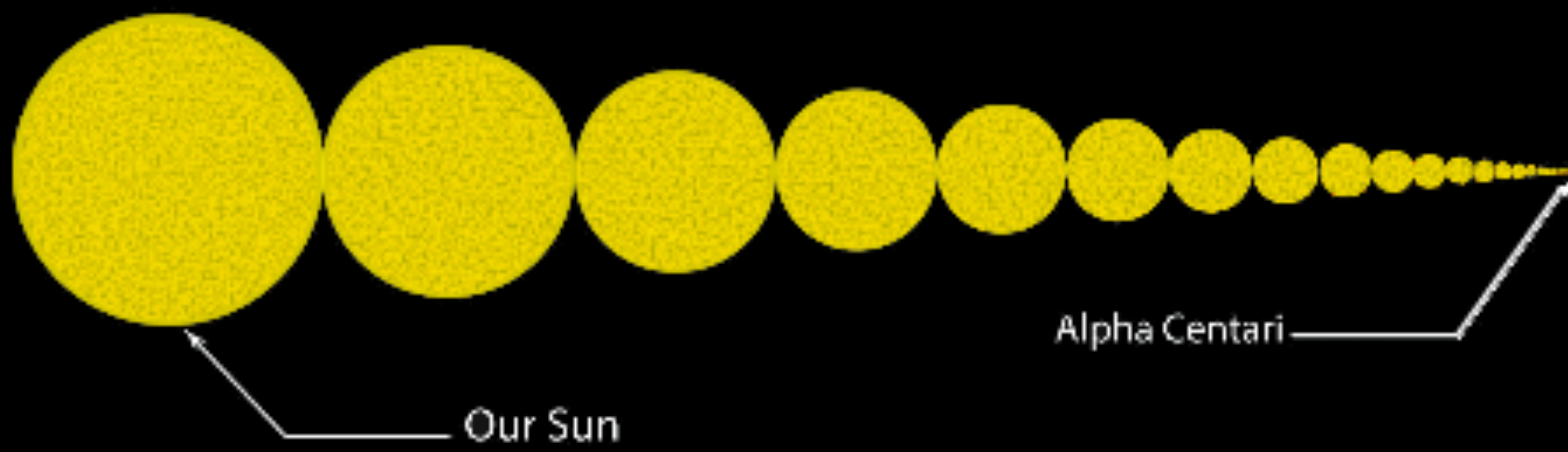
(A) 5.60×10^{6}

(B) 5.60×10^{7}

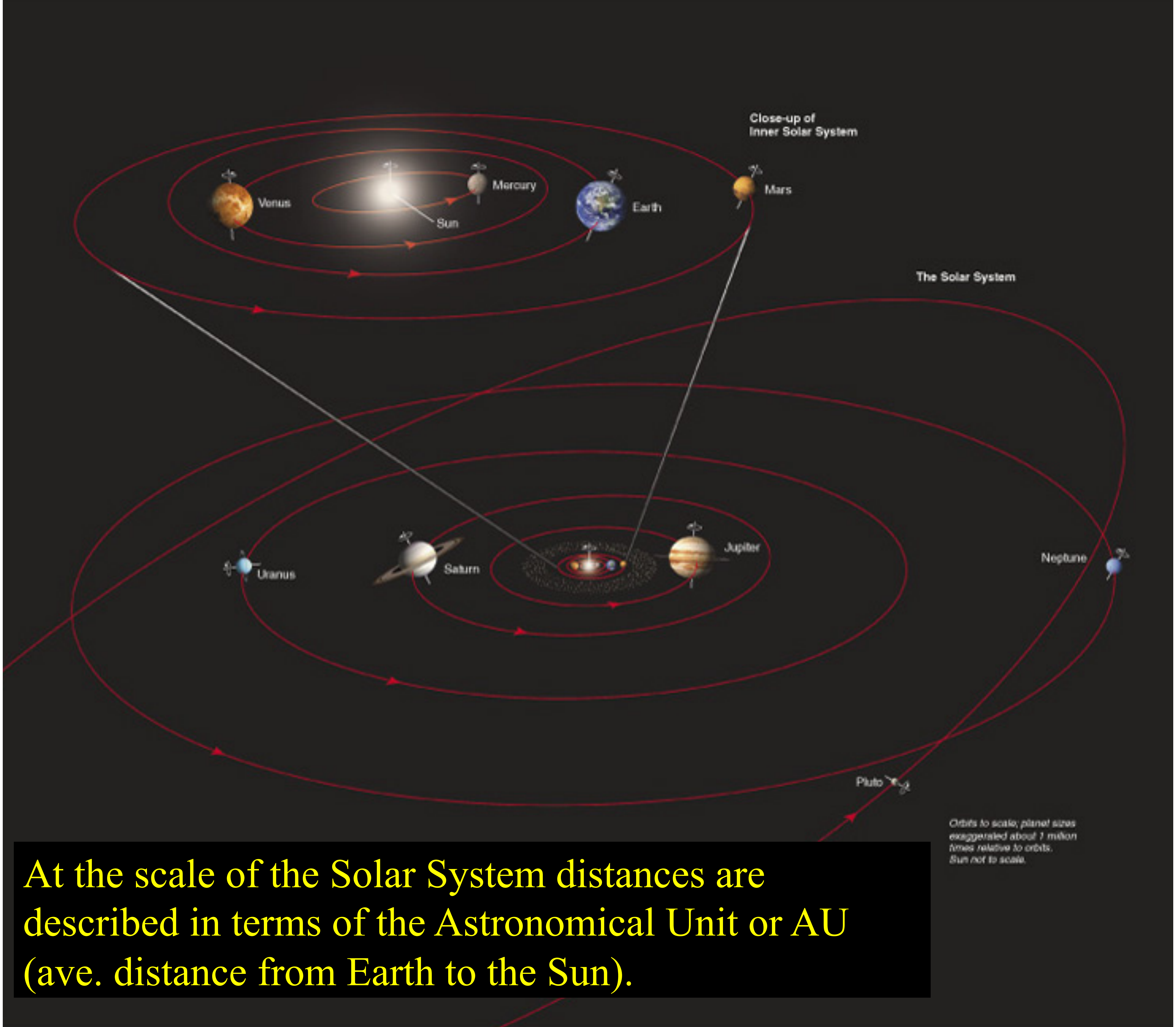
(C) 5.60×10^{25}

(D) 2.80×10^{7}

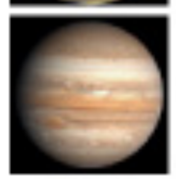
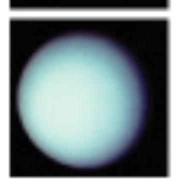
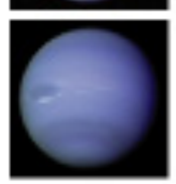
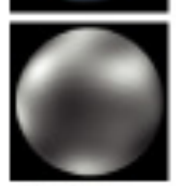
(E) 2.80×10^{25}



At the scale of the size of a planet or moon we describe things in terms of kilometers (km)

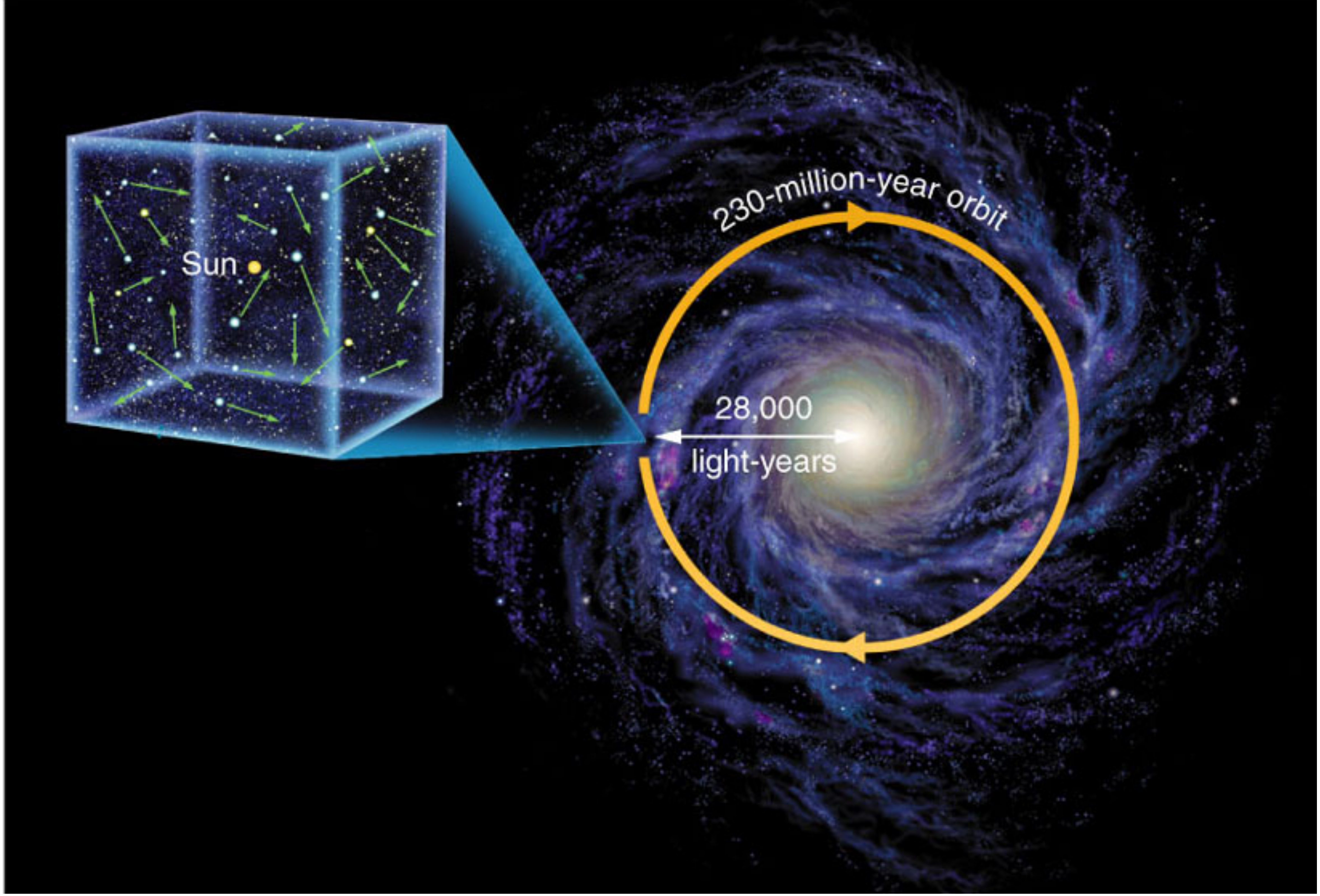


At the scale of the Solar System distances are described in terms of the Astronomical Unit or AU (ave. distance from Earth to the Sun).

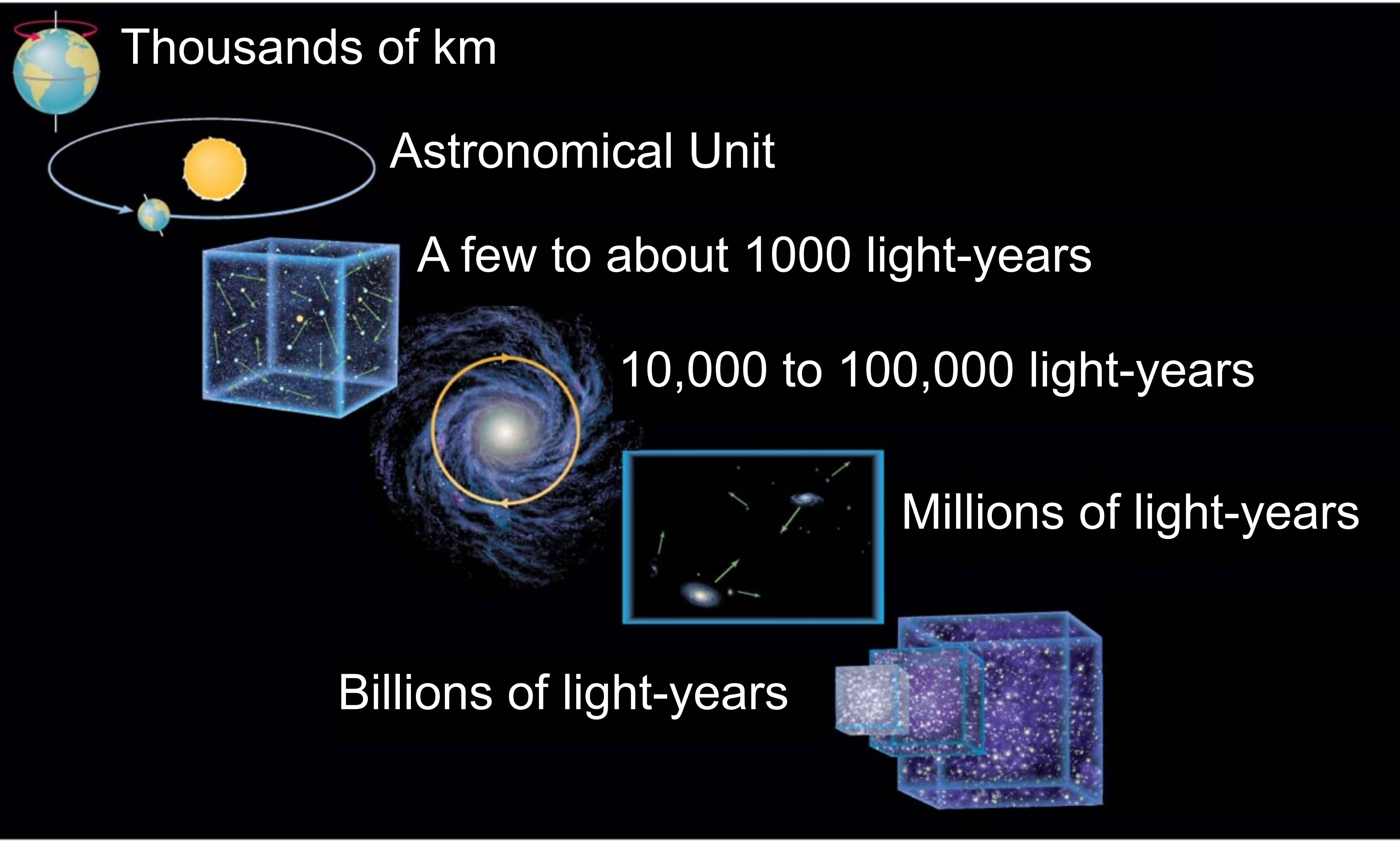
Photo	Planet	Relative Size	Average Distance from Sun (AU)	Average Equatorial Radius (km)
	Mercury		0.387	2,440
	Venus		0.723	6,051
	Earth		1.00	6,378
	Mars		1.52	3,397
	Jupiter		5.20	71,492
	Saturn		9.54	60,268
	Uranus		19.2	25,559
	Neptune		30.1	24,764
	Pluto		39.5	1,160
	Planet X‡		67.9	1,430

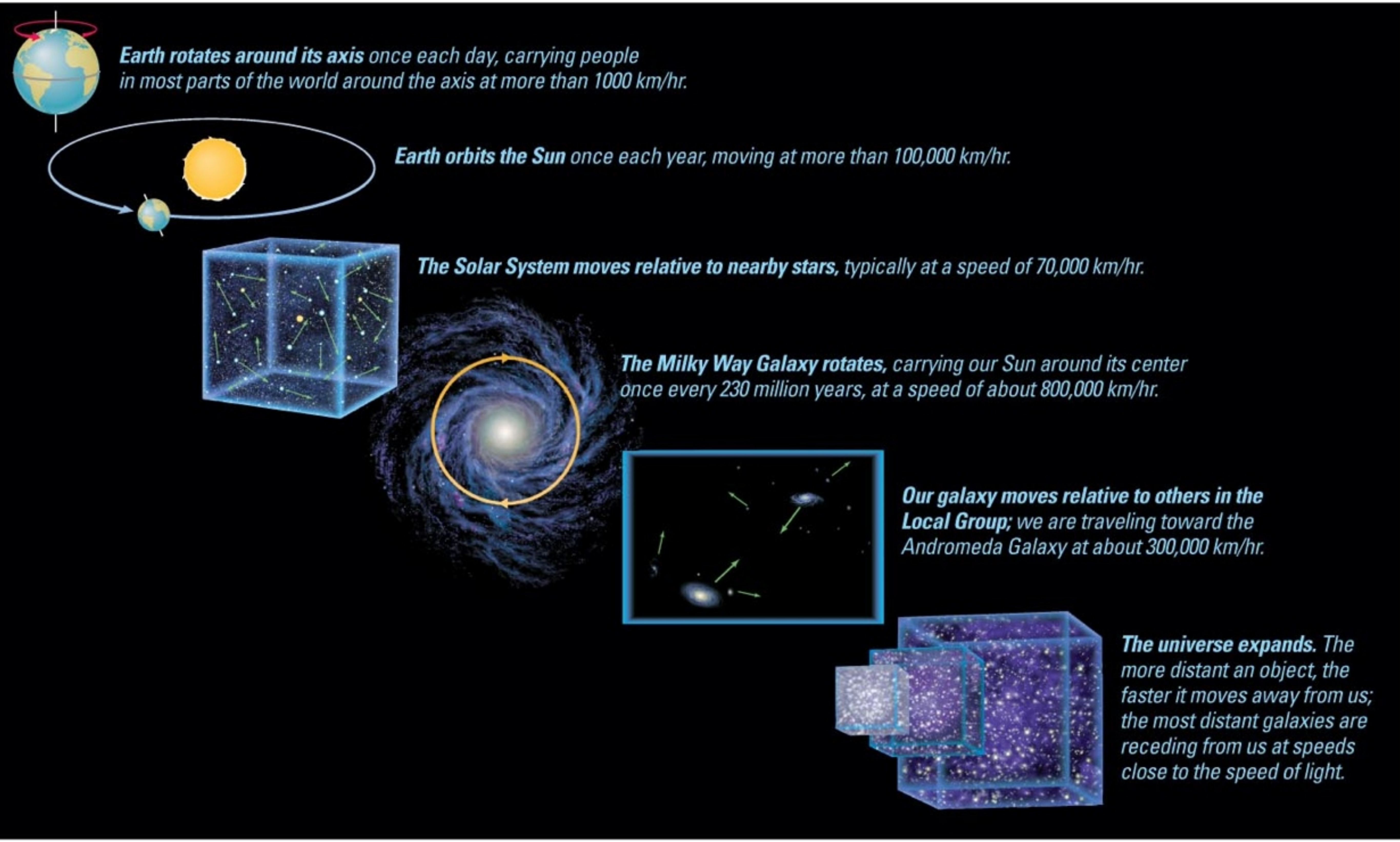
* Appendix E gives a more complete list of planetary properties. †Surface temperatures for all o

‡Little is known about this newly-discovered object, formally known as UB313.

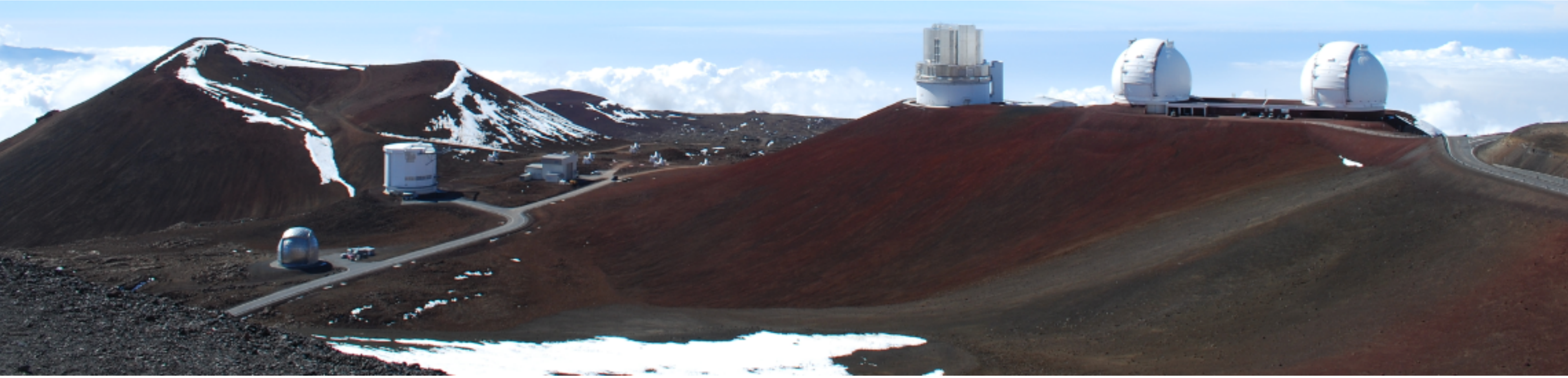


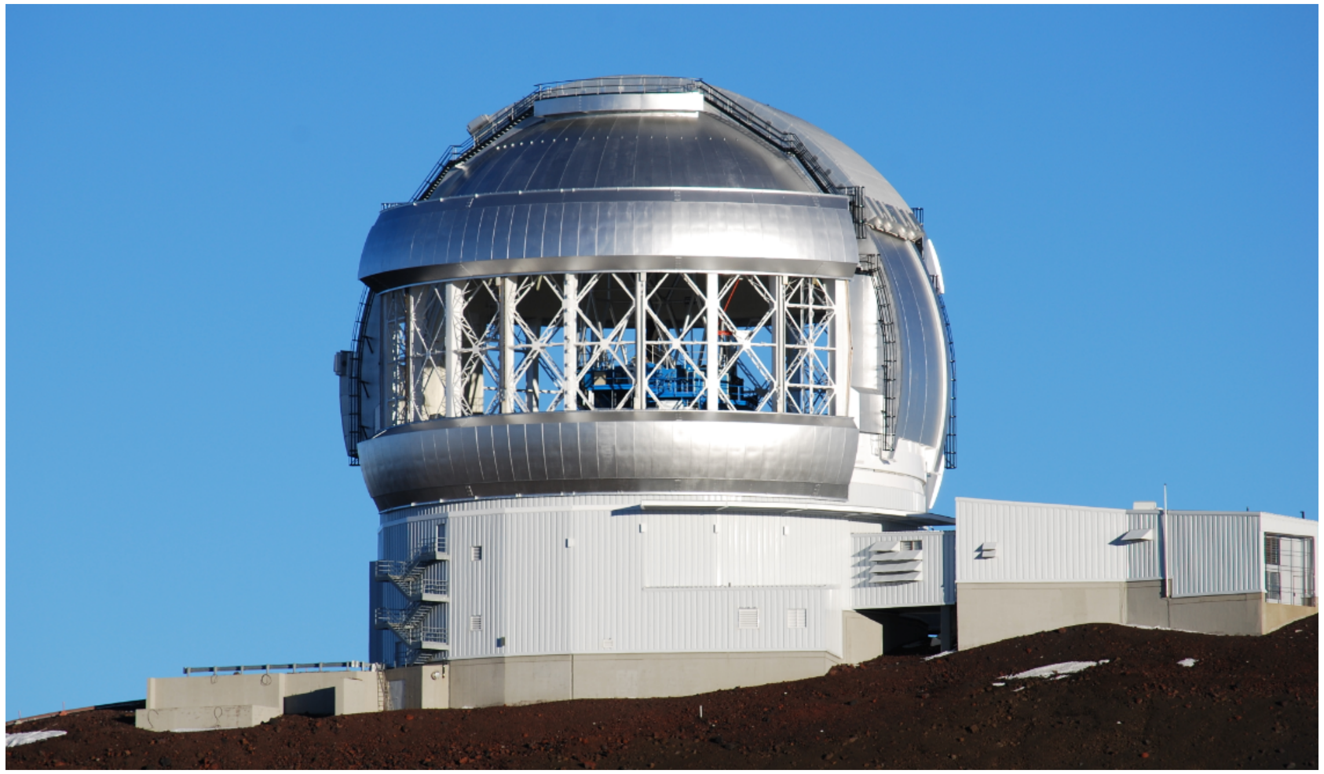
At the scale of the Milky Way Galaxy distances are described in terms of Light-years which is the distance light travels in one year.


Thousands of km
Astronomical Unit
A few to about 1000 light-years
10,000 to 100,000 light-years
Millions of light-years
Billions of light-years


Earth rotates around its axis once each day, carrying people in most parts of the world around the axis at more than 1000 km/hr.
Earth orbits the Sun once each year, moving at more than 100,000 km/hr.
The Solar System moves relative to nearby stars, typically at a speed of 70,000 km/hr.
The Milky Way Galaxy rotates, carrying our Sun around its center once every 230 million years, at a speed of about 800,000 km/hr.
Our galaxy moves relative to others in the Local Group; we are traveling toward the Andromeda Galaxy at about 300,000 km/hr.
The universe expands. The more distant an object, the faster it moves away from us; the most distant galaxies are receding from us at speeds close to the speed of light.

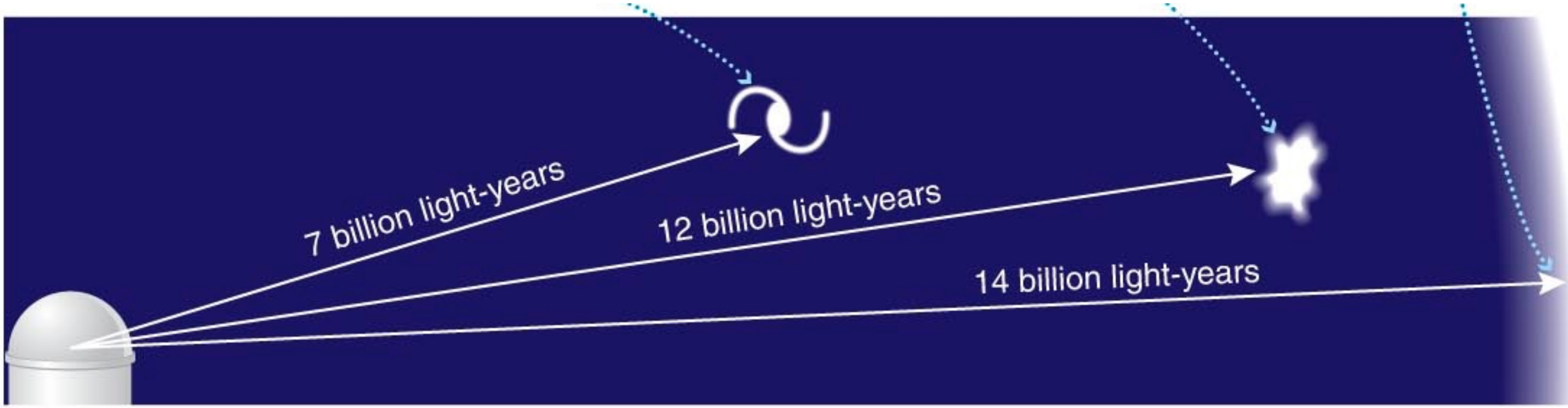
Telescopes gather light emitted from objects in the universe





The speed of light is finite, very large (300,000 km/s), but still finite!!

Can we see the entire universe?



★ The fact that looking deep into space means looking far back in time allows us to observe how the universe has changed through time

★ By looking to great distances, we can see what the universe looked like when it was younger

★ Our observable universe consists only of objects lying within 14 billion light-years of Earth

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

Question

15 years ago, a quasar was observed that was found to be located 8 billion light years away. If our universe is approximately 15 billion years old, when did the quasar emit the light that we observe?

(A) 15 years ago

(B) 7 billion years ago

(C) 8 billion years ago

(D) 15 billion years ago

LECTURE TUTORIAL:
Looking to distant objects (pg. 149-150)

★ Work with a partner!
★ Read the instructions and questions carefully
★ Discuss the concepts and your answers with one another. <u>TAKE TIME TO UNDERSTAND IT NOW!!!</u>
★ Come to a consensus answer you both agree on
★ If you get stuck or are not sure of your answer, ask another group.

Question

15 years ago, a quasar was observed that was found to be located 8 billion light years away. If our universe is approximately 15 billion years old, when did the quasar emit the light that we observe?

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(C) 8 billion years ago

(D) 15 billion years ago

A lot to comprehend!

Eta Carina is a southern hemisphere object located about 10,000 ly away. It is a massive star expected to die in a violent explosion known as a supernova. Suppose that this star went supernova in the year 2000 BC. How long would it be (from today) until we would know about it ?

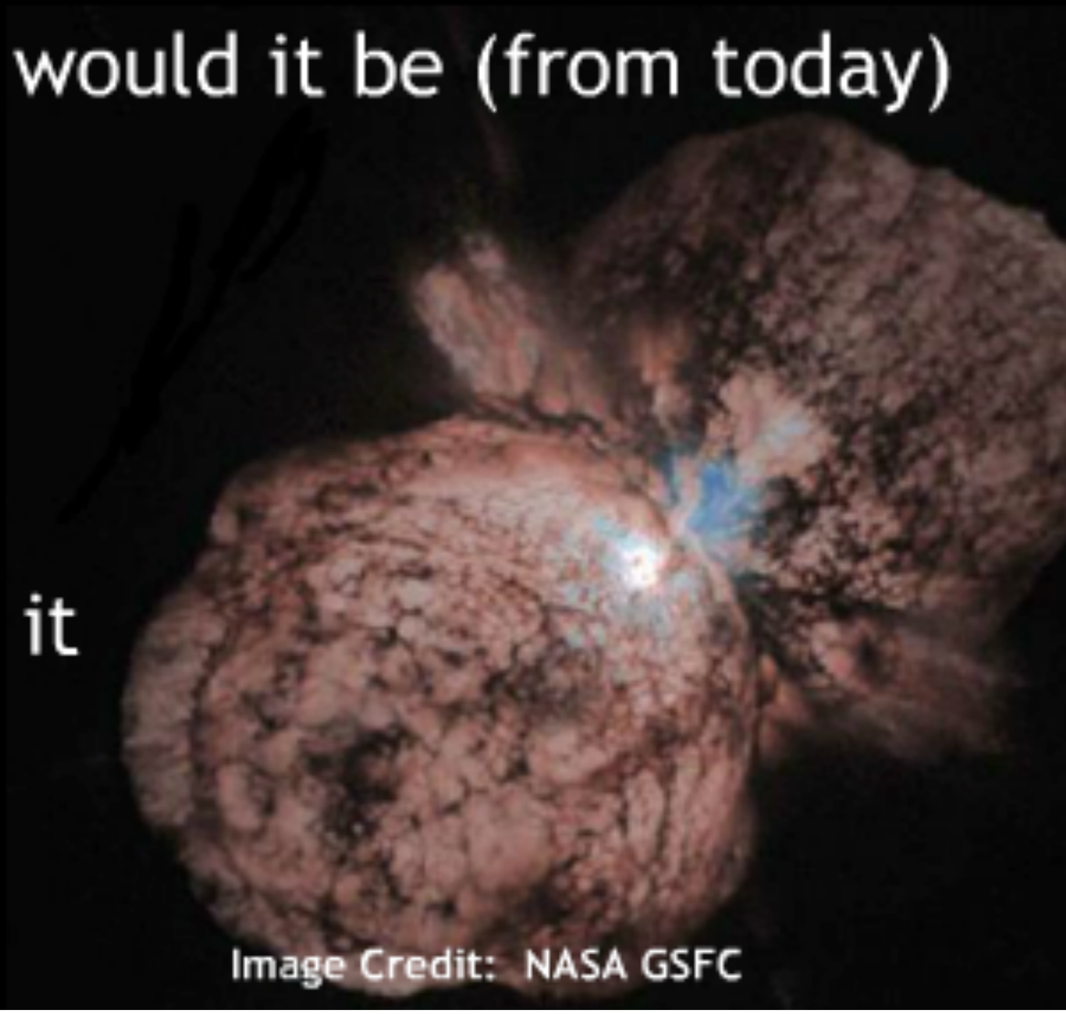
(A) 8000 years

(B) 4000 years

(C) We would already know about it

(D) 2000 years

(E) 6000 years



The Andromeda Galaxy is about two-thirds of a Mpc (or 2,000,000 light-years) away. Thus, the light that we observe from Andromeda was emitted...

(A) 2/3 of a year ago

(B) Just a second ago

(C) Can't be determined

(D) A year ago

(E) 2,000,000 years ago

Image Credit: NASA GSFC

How big is the universe?

The Milky Way is one of about 100 billion galaxies

10^{11} stars in each galaxy x 10^{11} galaxies = 10^{22} stars!!!

How big is the universe?

The scale of the numbers associated with the economy can be larger than those relevant to astrophysics:

1. Moon-Earth distance: 384,000 km = 3.84×10^5 - it take US government exactly 8 sec to generate $384,000 of debt

2. Mars-Earth distance: 55 million km = 5.5×10^7 - in $$, this is as large as the two highest paid NFL yearly contracts for 2008!

3. Age of Sun: 5 billion yrs = 5×10^9 yrs - #87 in the list of the world's billionaires has 5 billion $... There are 86 human beings richer than this!!

4. Age of Universe: 13.7 billion yrs = 1.37×10^9 yrs - In the world, there are at least 14 people who have more money in $$ that years in the history of the Universe!!!

Debt of USA = 17.3 trillions = 1.73×10^{13}: people should stop talking about these numbers as being ASTRONOMICAL, and start calling them ECONOMICAL...

Question

Which of the following sequences of objects is in the correct order of increasing distance?

(A) Large Magellanic Cloud, Sirius, Virgo Supercluster, Moon, Jupiter

(B) Moon, Jupiter, Sirius, Large Magellanic Cloud, Virgo Supercluster

(C) Virgo Supercluster, Large Magellanic Cloud, Sirius, Moon, Jupiter

(D) Large Magellanic Cloud, Moon, Virgo Supercluster, Sirius, Jupiter

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