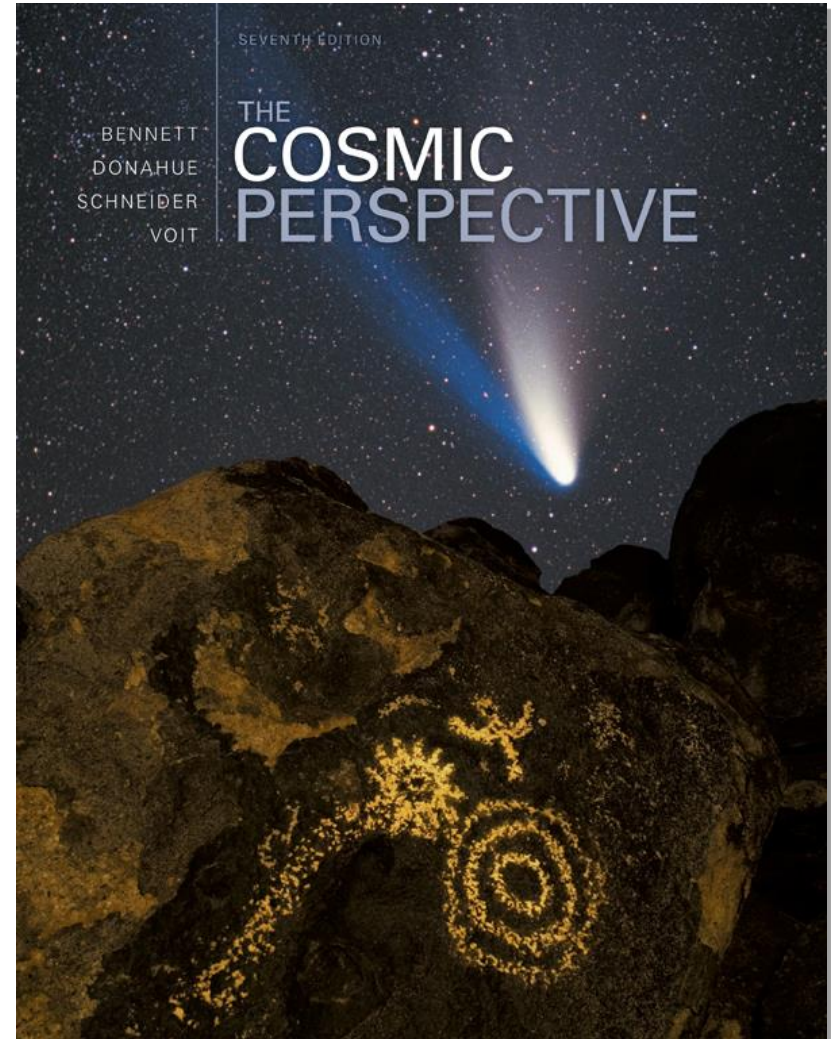


The Cosmic Perspective

A Modern View of the Universe



The Distant Universe



Course Introduction

Professor: George Chartas

Office: 307 RITA

Office Phone: 843 953 3609

Email: chartasg@cofc.edu

Office Hours: TR 3:00-4:00 pm

Textbook: Bennett, The Cosmic Perspective 8th, 9th or 10th Edition

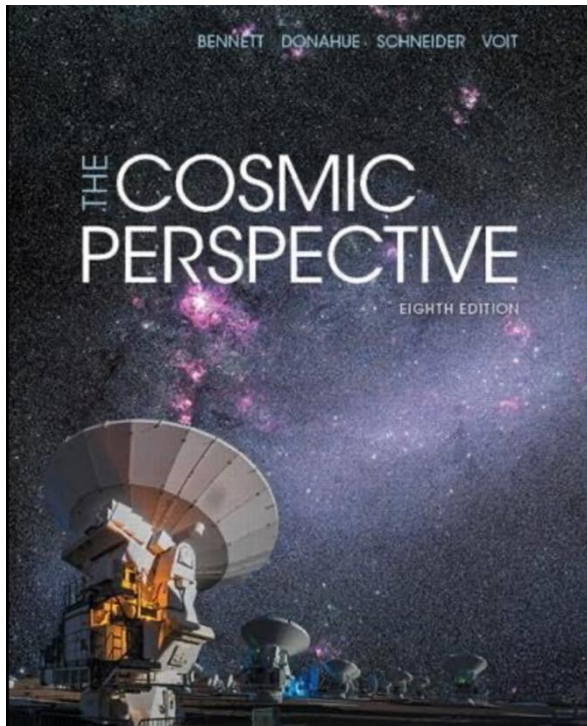
Lecture website: <http://chartasg.people.cofc.edu/chartas/Teaching.html>

Lectures: Tuesday and Thursday

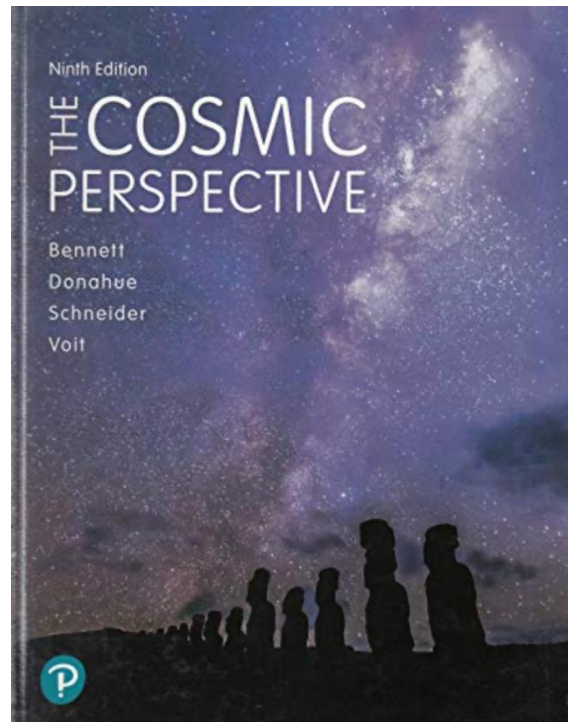
Time: 12:15-1:30pm

Lecture Room: RITA room 387

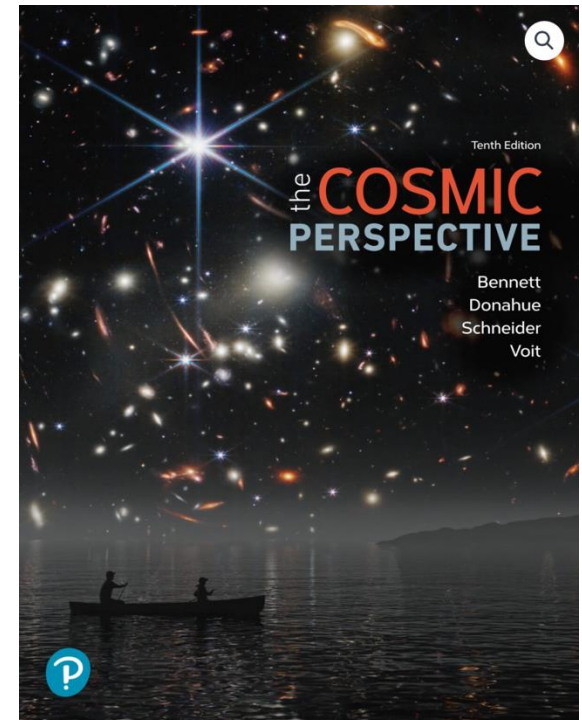
8th Edition



9th Edition



10th Edition



Course Requirements

- Read text before course
- Attend lectures
- Astro News Presentation
- Participate in discussions during lecture, ask questions
- Quizzes in class (5% of your grade)
- Astro-News (10% of grade)
- THREE MIDTERM EXAMS (45% of your grade)
- FINAL EXAM (40% of grade)

ASTRO-NEWS

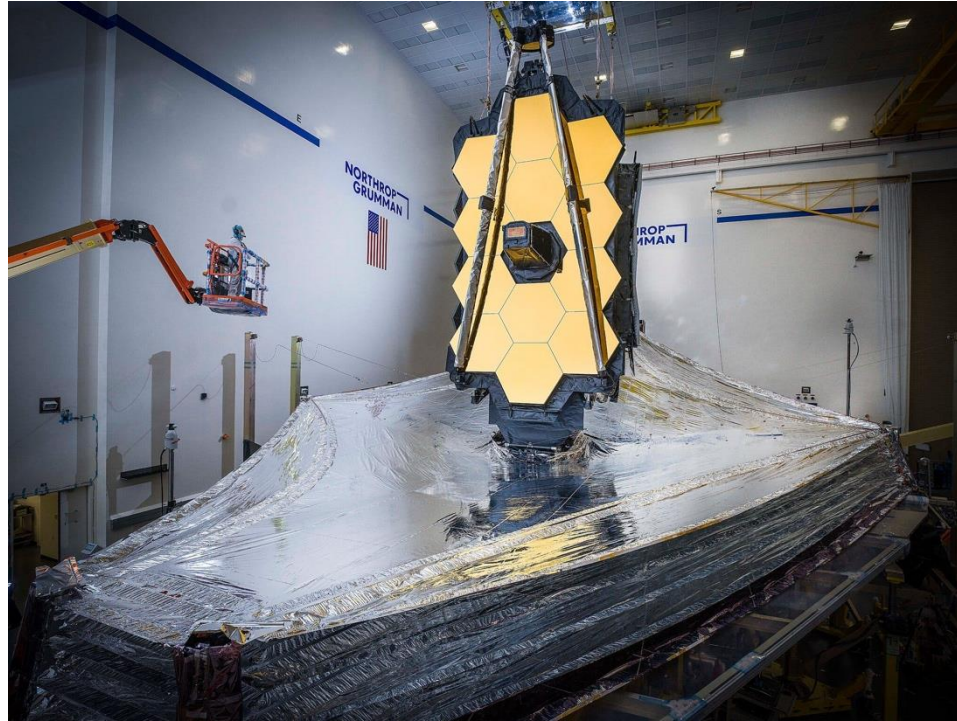
Astro-News:

Each class will contain a segment called Astro-News. Every student will be expected to give a ~3-minute presentation during Astro-News (only one presentation per student over the entire course). The presentation may be in PowerPoint, keynote, or PDF. Astro-News will cover events that have been recently presented in a recognized astronomy media source. Presentations must be emailed to me at least 1 hour prior to lecture.

Great sources of astronomy news include:

- (a) the Science Section of the New York Times (see <http://www.nytimes.com/pages/science/index.html>),
- (b) the NASA News Website (see <http://www.nasa.gov/news/index.html>),
- (c) the Hubble Space Station News website (see <http://hubblesite.org/newscenter/>),
- (d) the Sky and Telescope news site (see <http://www.skyandtelescope.com/news>), and
- (e) the spaceweather website (see <http://www.spaceweather.com/>).

ASTRO-NEWS: Webb Telescope Reveals a New Vision of an Ancient Universe



Launch: Webb successfully launched from ESA's spaceport in French Guiana on December 25, 2021 07:20am EST.

Wavelength Coverage: 0.6 - 28.5 microns (this is the Infrared Band)

Diameter of primary mirror: 6.5 meters

Webb's launch put in on a trajectory into an orbit around the second Lagrange point (L2). It is an approximately million-mile journey that takes ~1 month.



Webb Telescope Observation of Gravitationally Lensed Galaxies

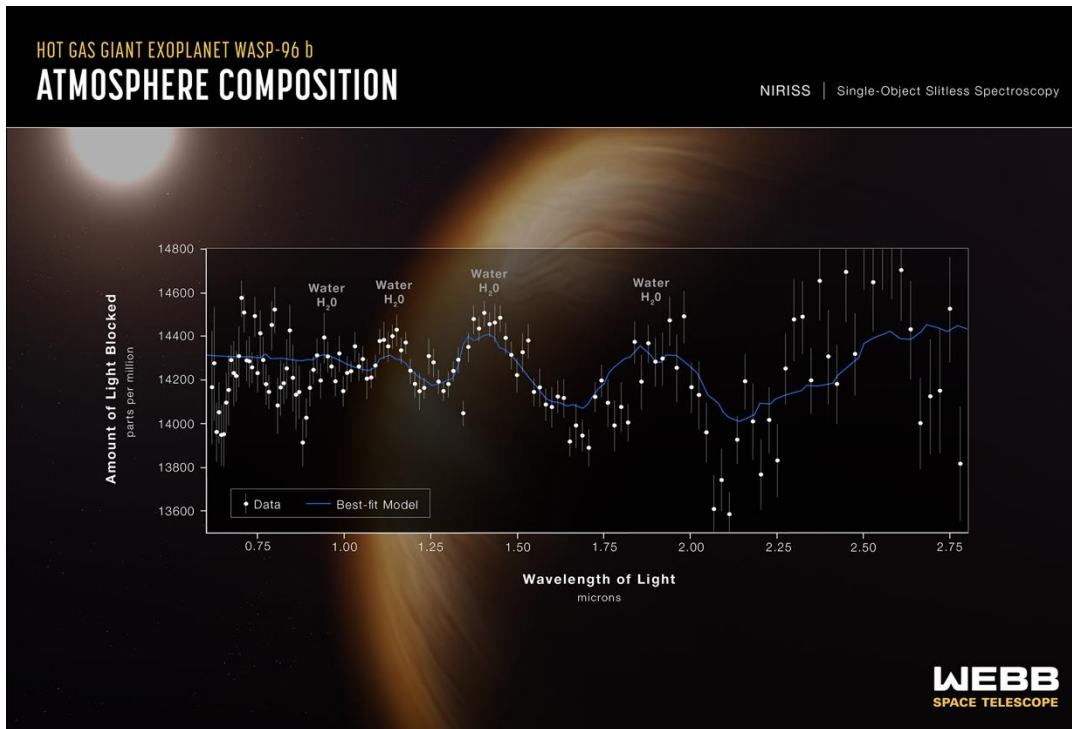


The image of a distant cluster called SMACS 0723, revealed the presence of still more-distant galaxies spilled across the sky.

The light from those galaxies, magnified into visibility by the gravitational field of the cluster, originated more than 13 billion years ago.

To look outward into space is to peer into the past.

Webb Telescope observation of water vapor in the atmosphere of a remote exoplanet.



Webb's measured starlight filtered through the atmosphere of an exoplanet.

The spectrum of the exoplanet located 1,150 light-years away reveals distinct signatures of water.

Webb's powerful new view also shows evidence of haze and clouds that previous studies of this planet did not detect.

Webb Telescope Reveals a New Vision of an Ancient Universe

References:

<https://www.nytimes.com/2022/07/12/science/james-webb-telescope-images-nasa.html>

<https://www.nasa.gov/image-feature/goddard/2022/nasa-s-webb-reveals-steamy-atmosphere-of-distant-planet-in-detail>

Midterm Exams Homework and Quizzes:

There will be 3 midterm exams over the semester. Short online quizzes will be given during lectures. The quizzes will be based on material already presented in lectures. There will be a final exam that will cover most of the material presented in the lectures. **Midterms and final are open notes.**

Grades

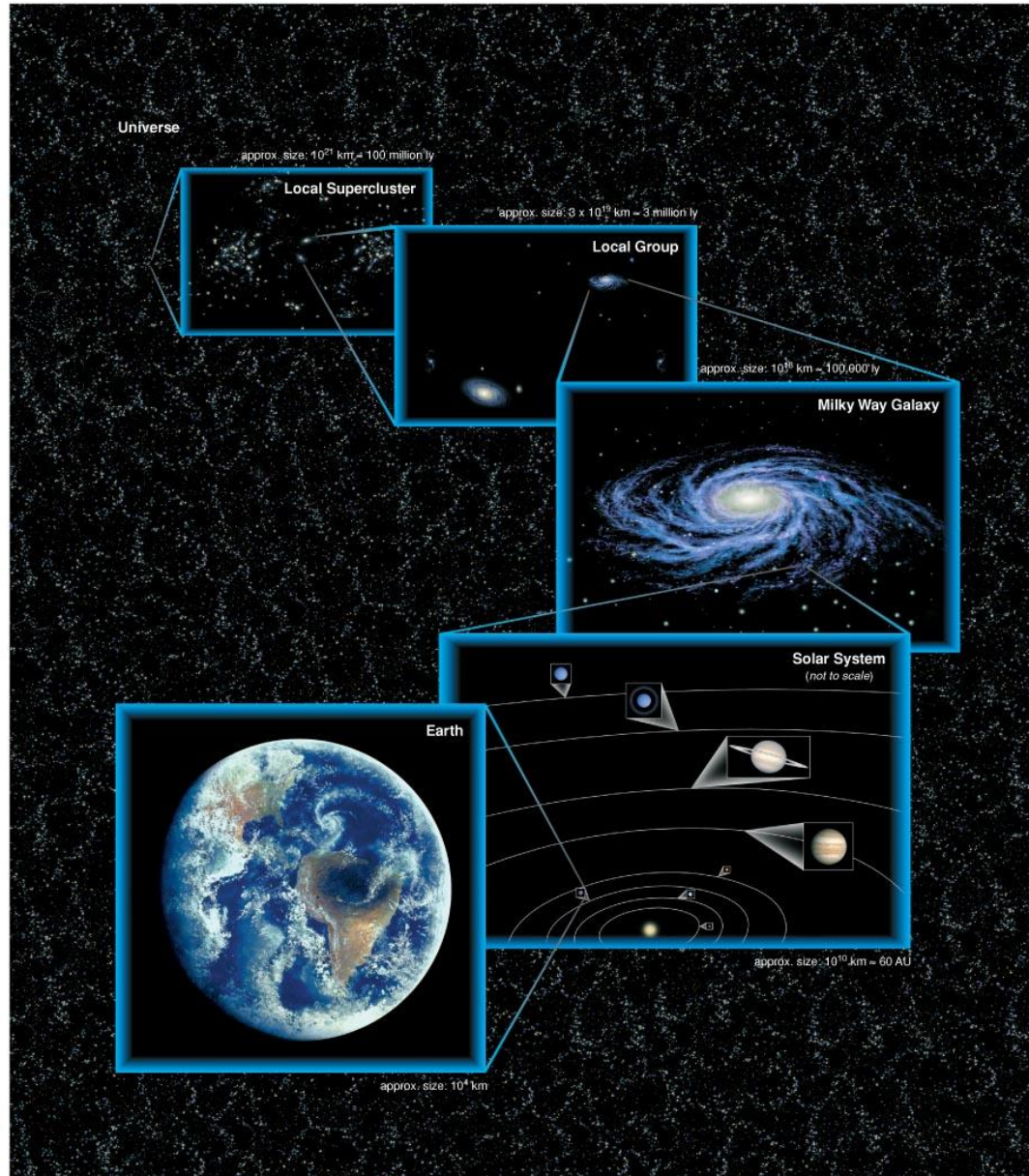
Your final grade will be calculated as follows:

- Quizzes in class (5% of your grade)
- Astro-News (10% of grade)
- THREE MIDTERM EXAMS (45% of your grade)
- FINAL EXAM (40% of grade)

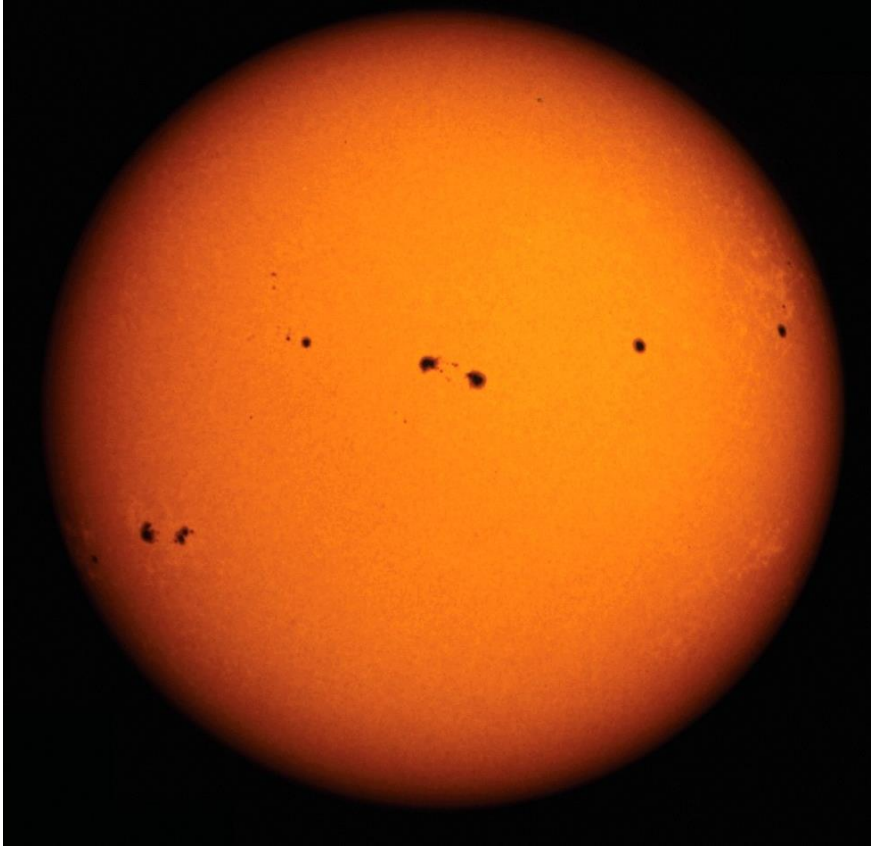
1.1 The Scale of the Universe

- Our goals for learning:
 - **What is our place in the universe?**
 - **How big is the universe?**

What is our place in the universe?



The Nearest Star to Earth



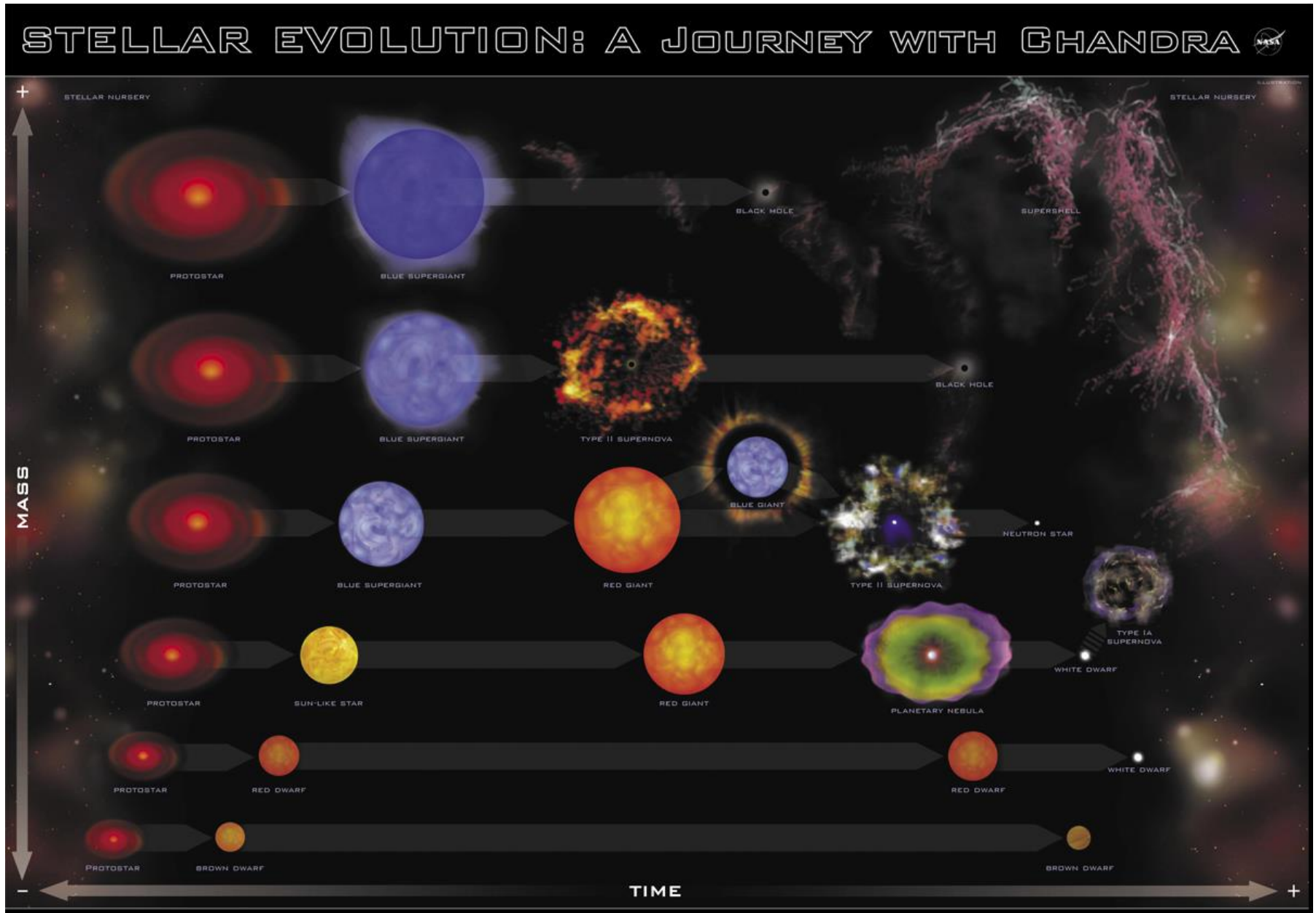
- A large ball of gas that generates heat, light and energetic particles through nuclear fusion.
- The Sun is the nearest star to Earth at an average distance of

1 AU $\sim$ 150,000,000,000 m
(= 1.5×10^{11} m)

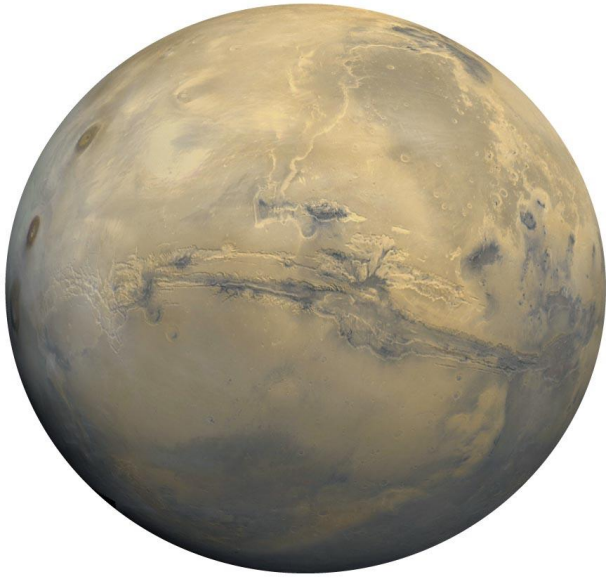
AU = Astronomical Unit

The next nearest star is about 100,000
(= 1×10^5) times further away.

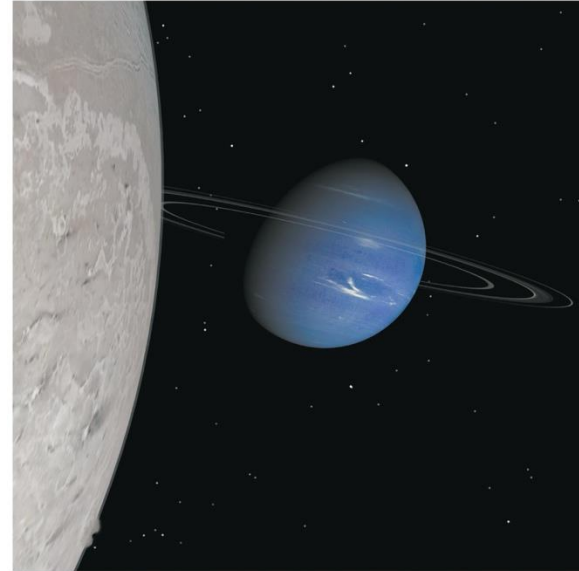
Why Study Stars?



Planet



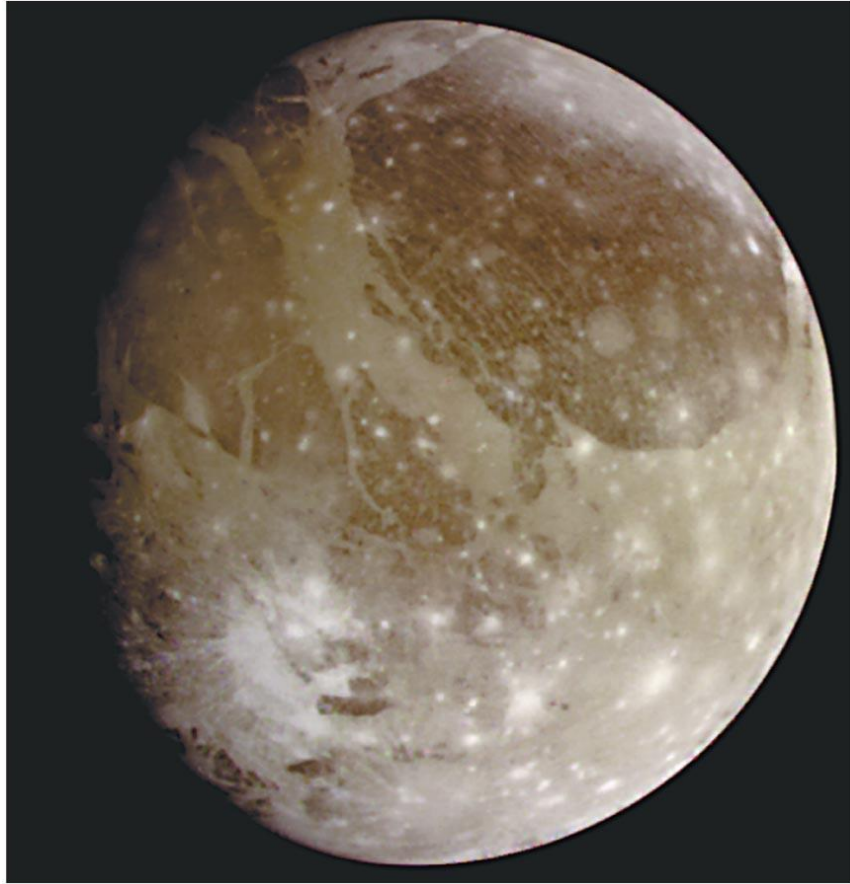
Mars



Neptune

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

Moon (or Satellite)

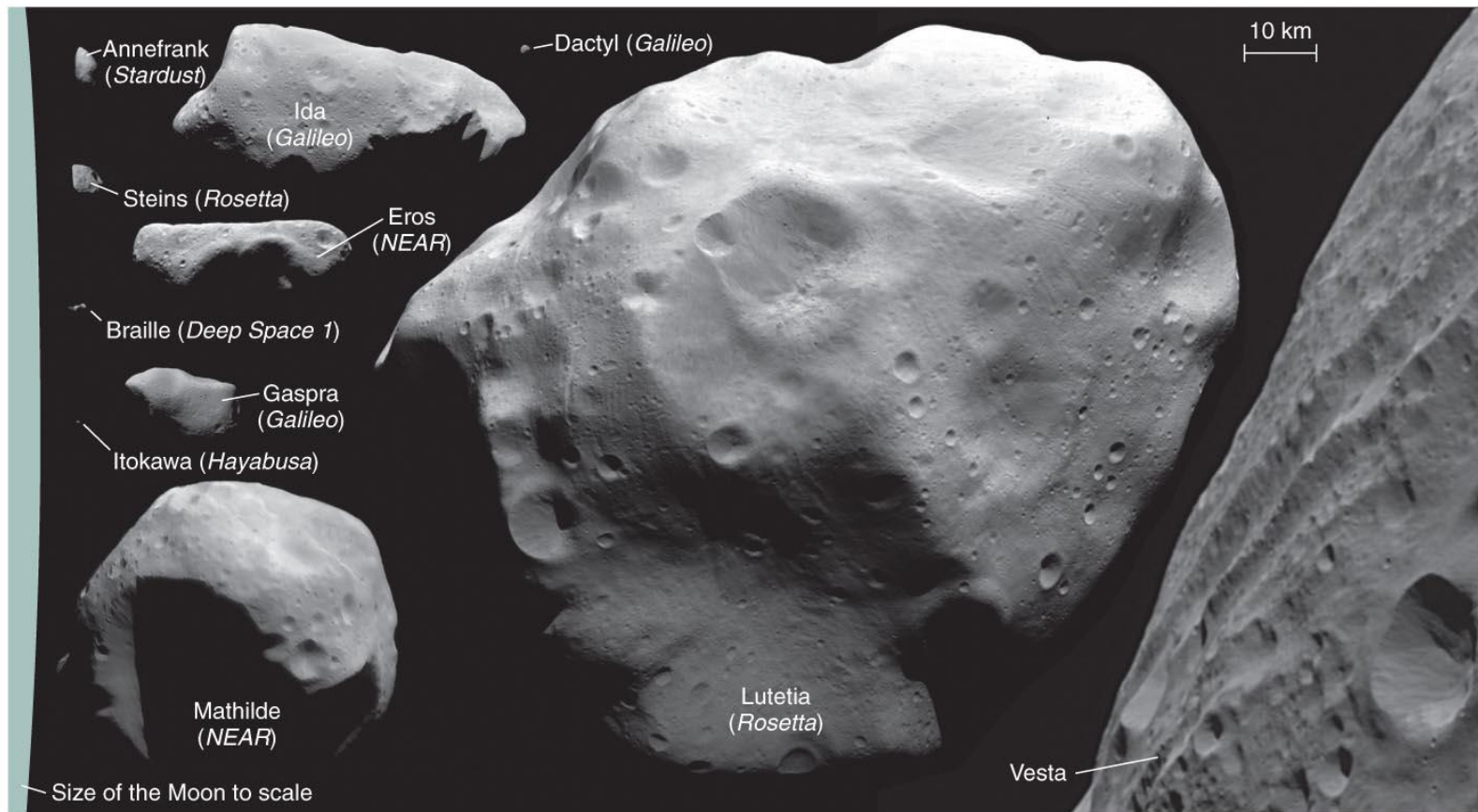


Ganymede (orbits Jupiter)

- An object that orbits a planet

Asteroid

- A relatively small and rocky object that orbits a star



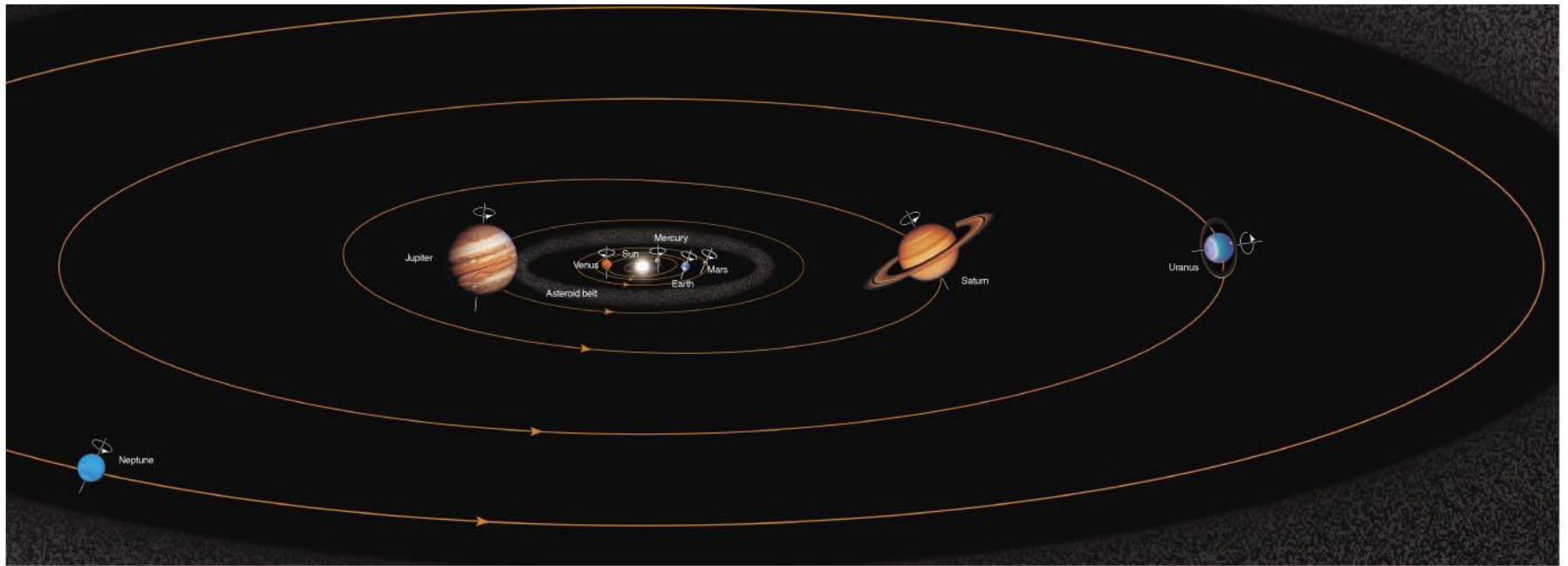
Comet



- 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



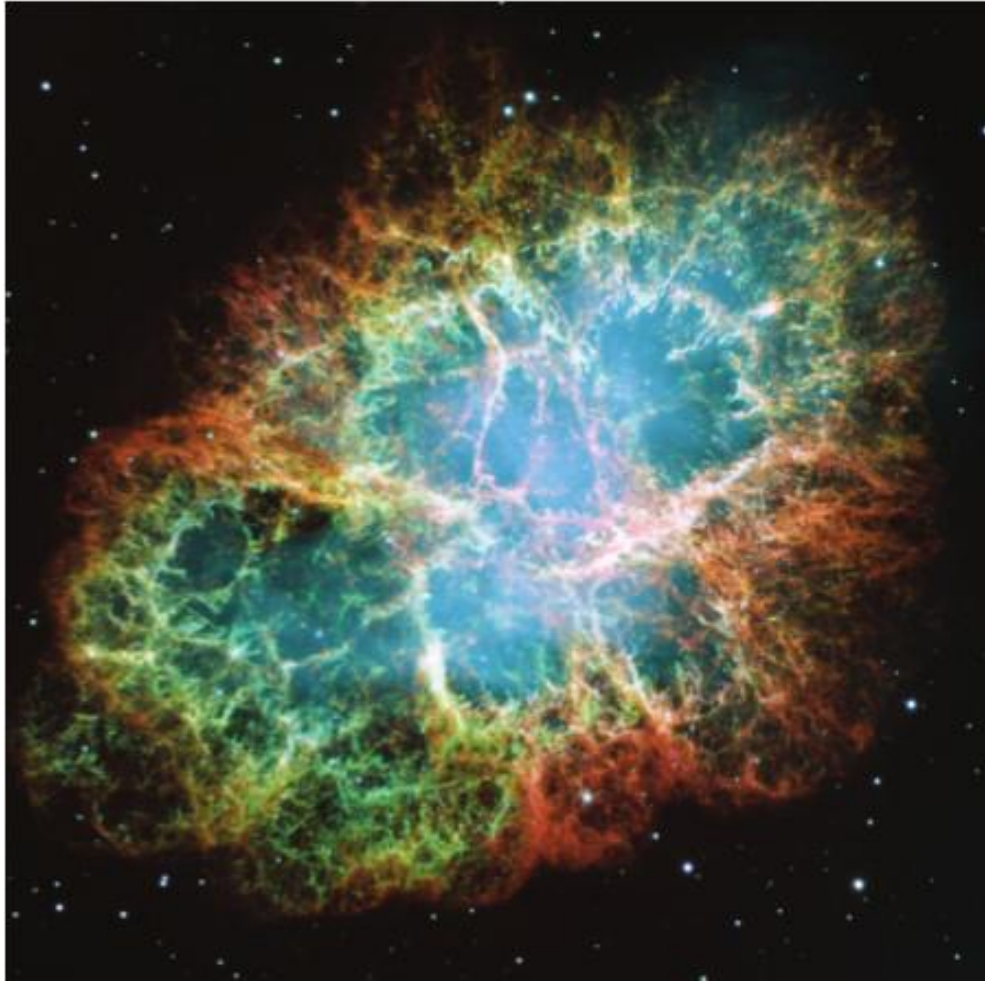
Nebula



- Nebulae are huge clouds of interstellar gas and are the birth places of stars.
- By studying many stars in nebulae we can learn about the life-cycles of stars.
- Intense ultraviolet light from newborn stars excites the surrounding gas and causes it to glow.

The Orion Nebula, Birthplace of Stars

Exploding Stars



- Exploding stars enrich their interstellar neighborhood with heavy elements
- The Sun and the planets were created from material ejected from a supernova.
- The carbon in our bodies was manufactured deep inside stars that exploded many many years ago.

The Crab Nebula, Core collapse supernova
Distance to Earth $\sim 6,500$ ly

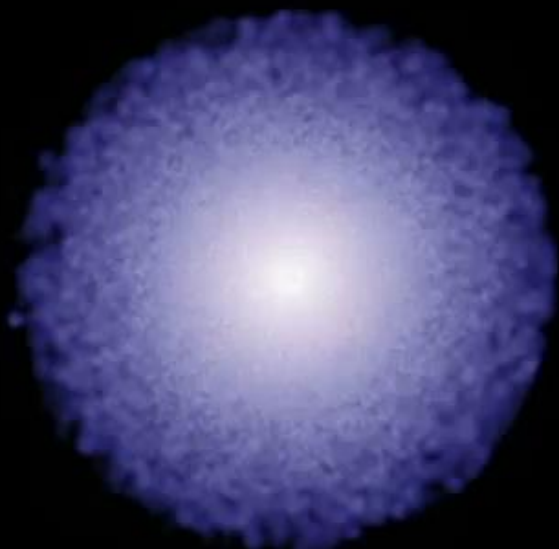
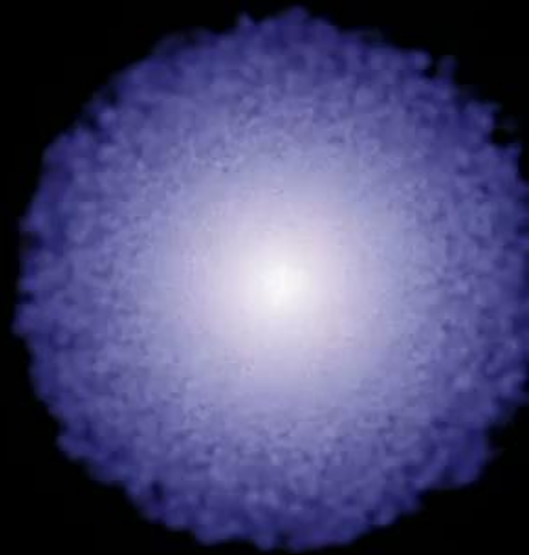
Galaxy

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



**M31 also known as Andromeda is about
2.5 million light years away**

$T = 0$ Myr



10 kpc/h



Universe

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

Far away means back in time?

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

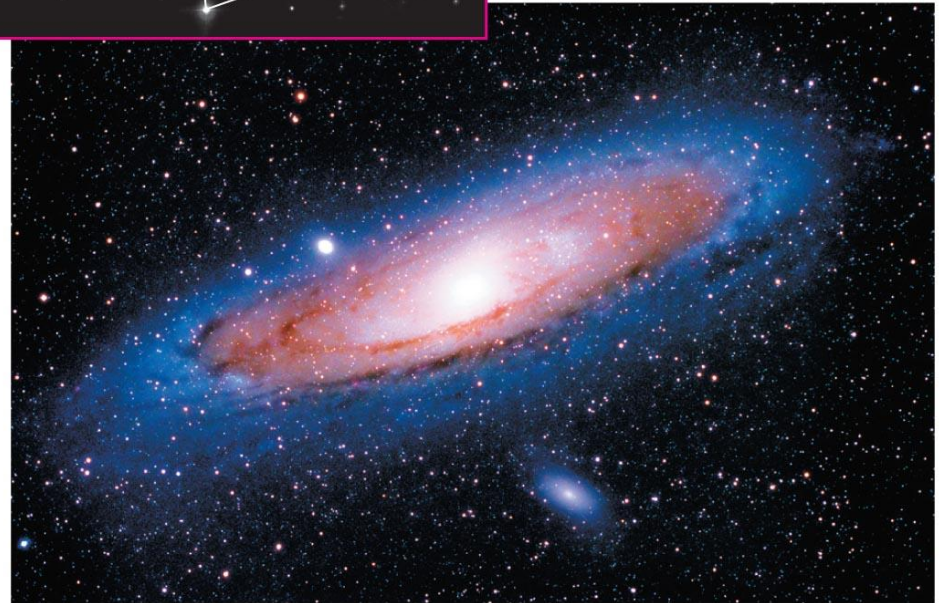
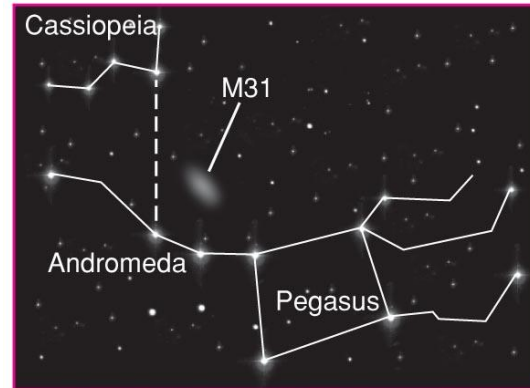
Destination	Light travel time
Moon	1 second
Sun	8 minutes
Sirius	8 years
Andromeda Galaxy	2.5 million years

- Thus, we see objects as they were in the past:
***The farther away we look in distance,
the further back we look in time.***

Far away means back in time?

Example:

- This photo shows the Andromeda Galaxy as it looked about 2 1/2 million years ago.
- **Question: When will we be able to see what it looks like now?**



Scientific Notation

$$10^0 = 1 \text{ (one)}$$

$$10^1 = 10 \text{ (ten)}$$

$$10^2 = 100 \text{ (one hundred)}$$

$$10^3 = 1000 \text{ (one thousand)}$$

$$10^4 = 10,000 \text{ (ten thousand)}$$

$$10^6 = 1,000,000 \text{ (one million)}$$

$$10^9 = 1,000,000,000 \text{ (one billion)}$$

$$10^{12} = 1,000,000,000,000 \text{ (one trillion)}$$

$$10^0 = 1 \text{ (one)}$$

$$10^{-1} = 1/10 = 0.1 \text{ (one tenth)}$$

$$10^{-2} = 1/10^2 = 0.01 \text{ (one hundredth)}$$

$$10^{-3} = 1/10^3 = 0.001 \text{ (one thousandth)}$$

Scientific Notation

Express Numbers in the form :

$$A \times 10^n$$

This is referred to as the powers-of-ten notation.

Some rules:

$$10^{-n} = 1/10^n$$

$$10^{a+b} = 10^a \times 10^b \quad \text{example: } 10^2 \times 10^3 = 10^{2+3}$$

$$(10^a)^b = 10^{ab} \quad \text{example: } (10^2)^3 = 10^{2 \times 3} = 10^6$$

Examples:

$$3500 = 3.5 \times 10^3, 0.0035 = 3.5 \times 10^{-3}$$

$$12900000. = ?, 0.000000129 = ?$$

$$10^6 \times 10^3 = ?, 10^2 \times 10^{-2} = ?, (10^2)^{-3} = ?$$

Scientific Numerical Prefixes

SI prefixes

10^n	Prefix	Symbol	Decimal
10^{12}	tera	T	1 000 000 000 000
10^9	giga	G	1 000 000 000
10^6	mega	M	1 000 000
10^3	kilo	k	1000
10^2	hecto	h	100
10^1	deca	da	10
10^0	<i>(none)</i>	<i>(none)</i>	1
10^{-1}	deci	d	0.1
10^{-2}	centi	c	0.01
10^{-3}	milli	m	0.001
10^{-6}	micro	μ	0.000001
10^{-9}	nano	n	0.000000001

International System Of Units

SI units:

length is measured in meters (m)

time is measured in seconds (s)

and mass is measured in kilograms (kg)

Light-year

The **light-year** (abbreviated ly) is the distance that light travels in one year.

The **speed of light** in empty space is $c = 3 \times 10^5 \text{ km/s}$

1 light-year = 1ly = $9.46 \times 10^{12} \text{ km}$ (derive this)

1 Astronomical Unit = 1 AU = Average distance between Sun and Earth = $149,598,000 \text{ km} \approx 1.5 \times 10^8 \text{ km}$

Light year

$$velocity = \frac{distance}{time}$$

$$1 \text{ light year} = (velocity) \times (time) = (speed \text{ of light}) \times (1 \text{ year}) = \\ (3 \times 10^5 km/s) \times (365.25 \times 24 \times 60 \times 60 s) = 9.46 \times 10^{12} km$$

Example: Estimate the time it takes for light to reach us from the sun

Example: Estimate the time it takes for light to reach us from the sun

$$velocity = \frac{distance}{time}$$

$$time = \frac{distance}{velocity} \rightarrow time \text{ from sun} = \frac{1 \text{ AU}}{3 \times 10^5 \text{ km/s}}$$

$$\rightarrow time \text{ from sun} = \frac{1.5 \times 10^8 \text{ km}}{3 \times 10^5 \text{ km/s}} = 500 \text{ s}$$

$$= 8.33 \text{ minutes}$$

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



- There are as many stars as grains of (dry) sand on *all* Earth's beaches.

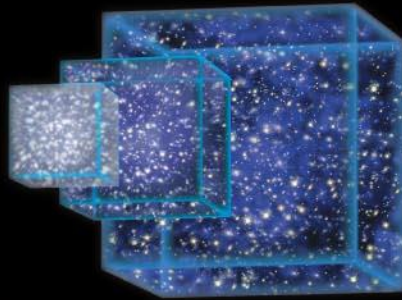
1.2 The History of the Universe

- Our goals for learning:
 - **How did we come to be?**
 - **How do our lifetimes compare to the age of the universe?**

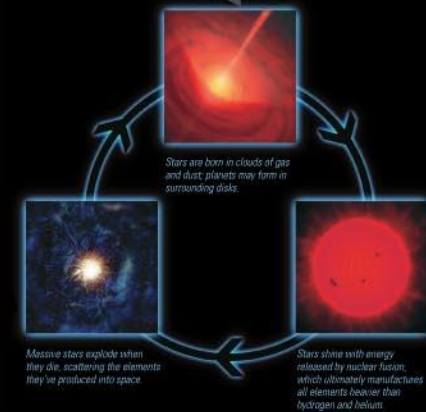
How did we come to be?

Throughout this book we will see that human life is intimately connected with the development of the universe as a whole. This illustration presents an overview of our cosmic origins, showing some of the crucial steps that made our existence possible.

- ① **Birth of the Universe:** The expansion of the universe began with the hot and dense Big Bang. The cubes show how one region of the universe has expanded with time. The universe continues to expand, but on smaller scales gravity has pulled matter together to make galaxies.



- ② **Galaxies as Cosmic Recycling Plants:** The early universe contained only two chemical elements: hydrogen and helium. All other elements were made by stars and recycled from one stellar generation to the next within galaxies like our Milky Way.



- ③ **Life Cycles of Stars:** Many generations of stars have lived and died in the Milky Way.

- ④ **Earth and Life:** By the time our solar system was born, 4½ billion years ago, about 2% of the original hydrogen and helium had been converted into heavier elements. We are therefore "star stuff," because we and our planet are made from elements manufactured in stars that lived and died long ago.



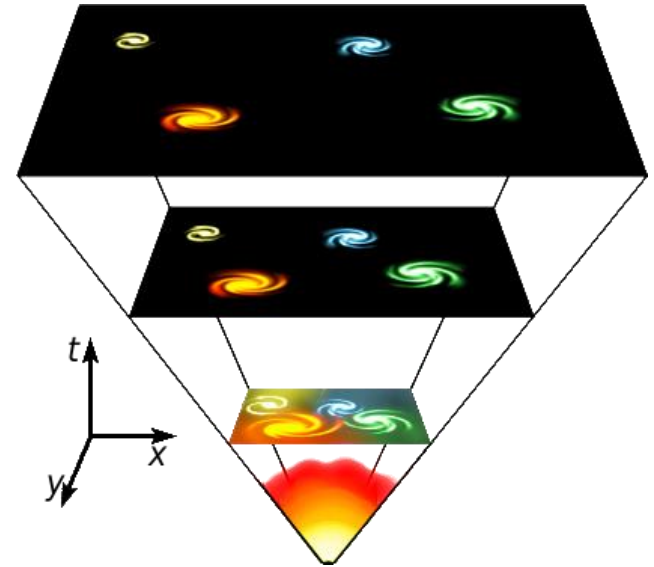
How do our lifetimes compare to the age of the universe?

Age of the Universe = 13.8 Billion years

- The age of the Universe is estimated from the Hubble–Lemaître Law:

$$v = H_0 d$$

v = recessional velocity of a galaxy,
 H_0 = Hubble constant, d = distance to the galaxy.



According to the Big Bang Model the Universe expanded from an extremely dense and hot state and continues to expand today.

What have we learned?

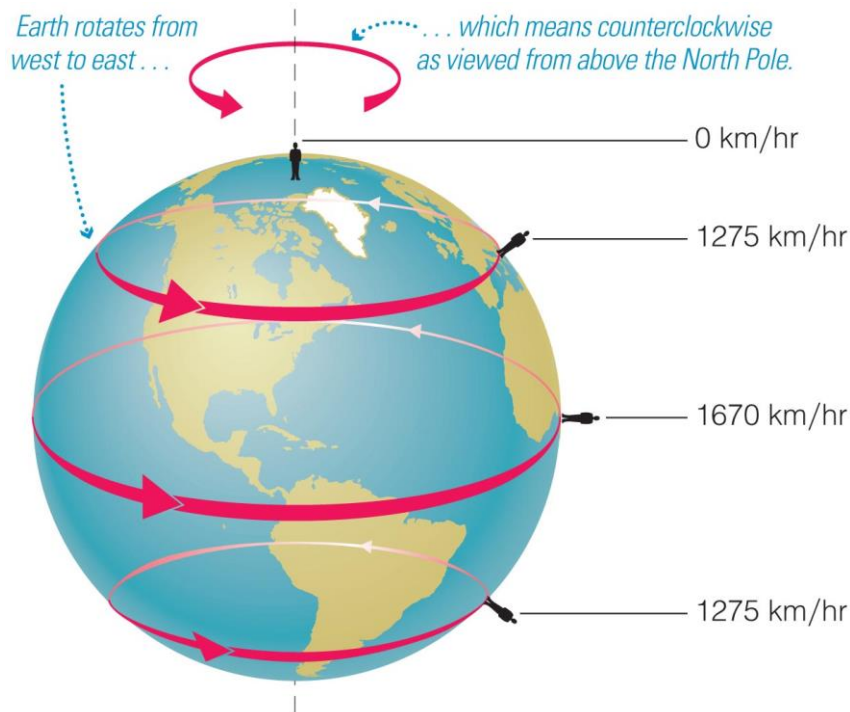
- **How did we come to be?**
 - The matter in our bodies came from the Big Bang, which produced hydrogen and helium.
 - All other elements were constructed from H and He in stars and then recycled into new star systems, including our solar system.
- **How do our lifetimes compare to the age of the universe?**
 - On a cosmic calendar that compresses the history of the universe into 1 year, human civilization is just a few seconds old, and a human lifetime is a fraction of a second.

1.3 Earth's motion through space

- Our goals for learning:
 - **How is Earth moving through space?**
 - **How do galaxies move within the universe?**

How is Earth moving through space?

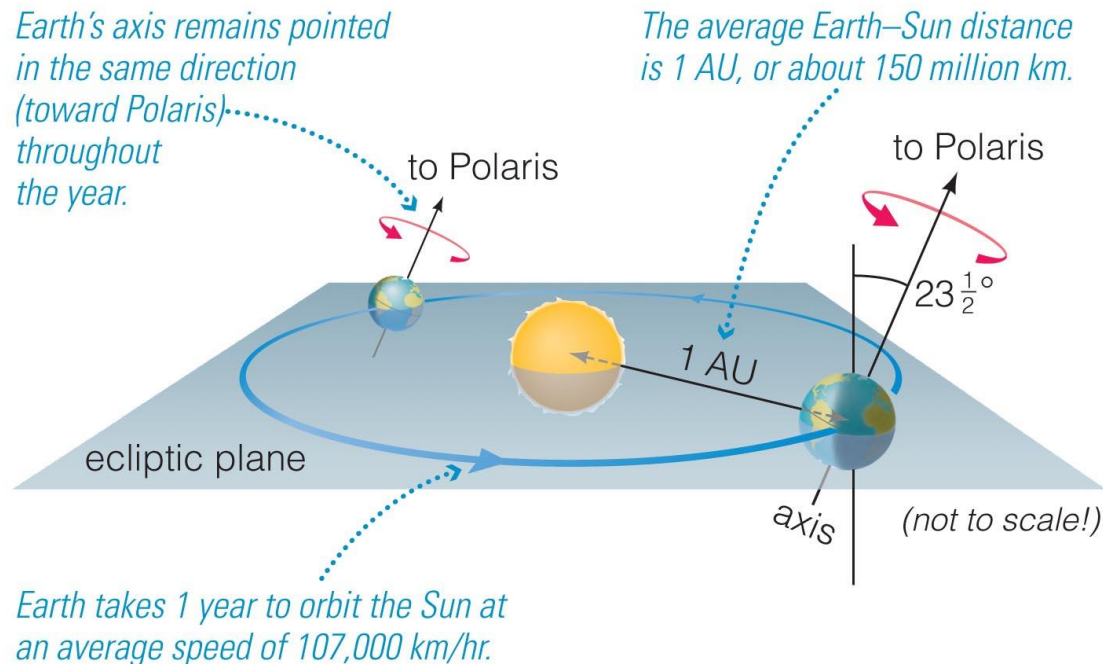
- Contrary to our perception, we are not "sitting still."
- We are moving with Earth in several ways, and at surprisingly fast speeds.



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

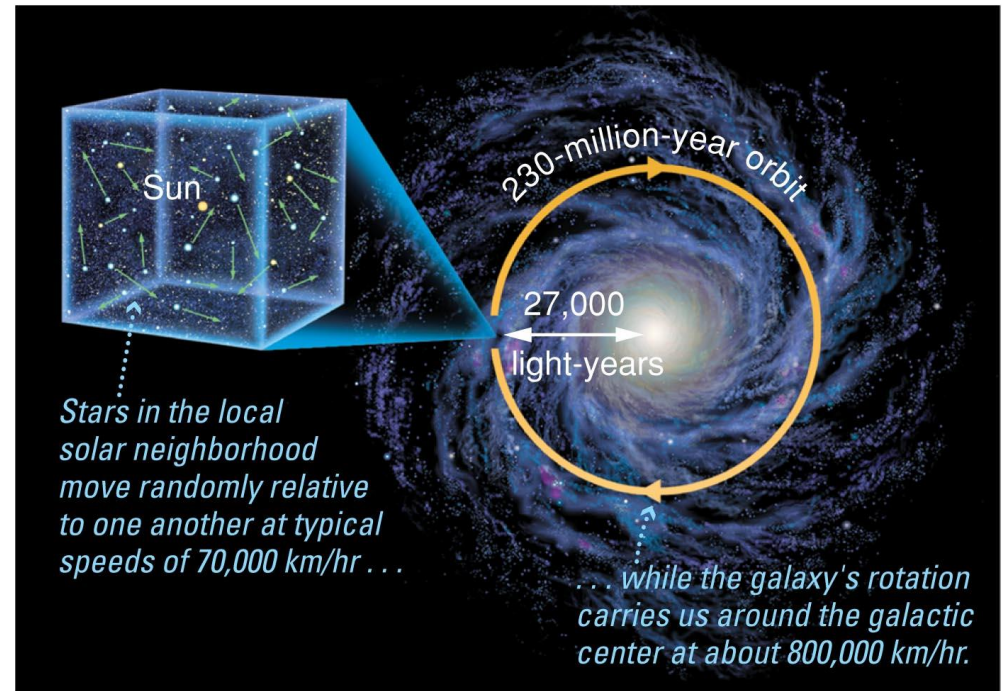
How is Earth moving through space?

- Earth **orbits** the Sun (revolves) once every year:
 - at an average distance of 1 AU $\approx$ 150 million kilometers.
 - with Earth's axis tilted by 23.5° (pointing to Polaris)
- It rotates in the same direction it orbits, **counterclockwise** as viewed from above the North Pole.



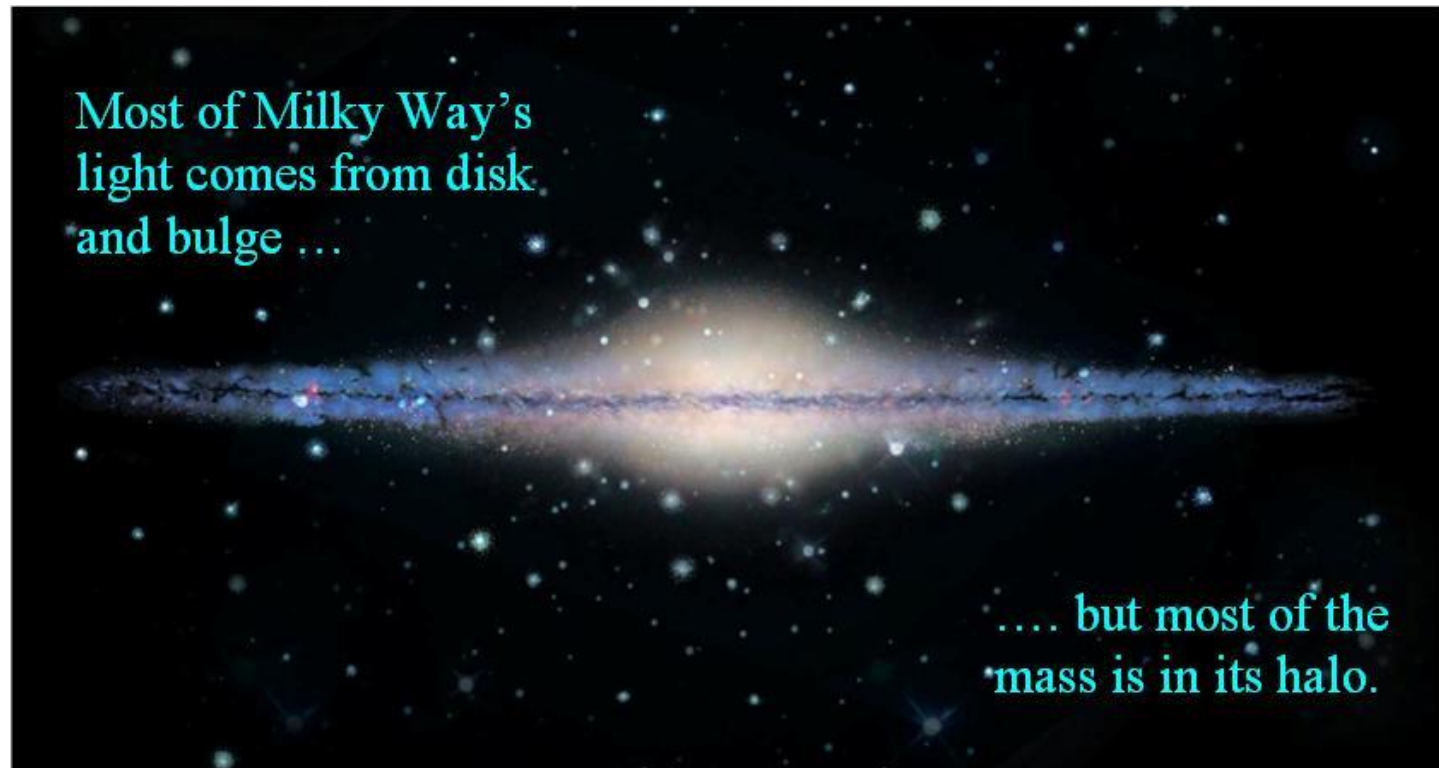
How is our Sun moving in the Milky Way Galaxy?

- 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.



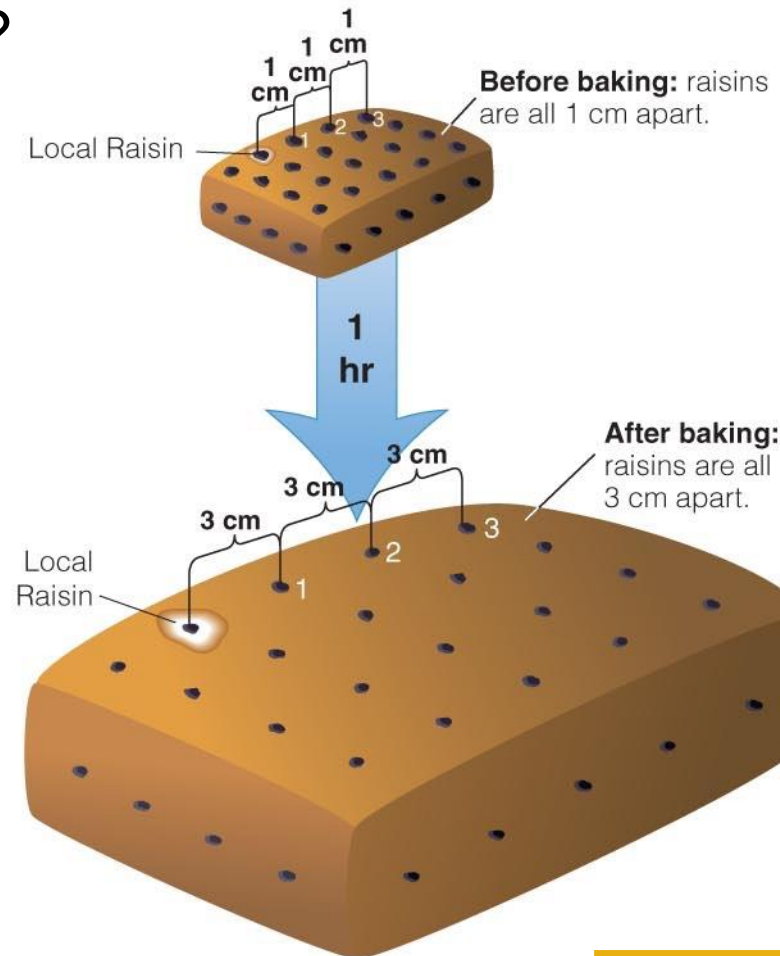
How is our Sun moving in the Milky Way Galaxy?

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



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.

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?

- The 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."

Multi-Wavelength Observations of the Universe



The Hubble Space Telescope
(near-infrared, ultraviolet and optical)



The Chandra X-ray Observatory (X-ray)



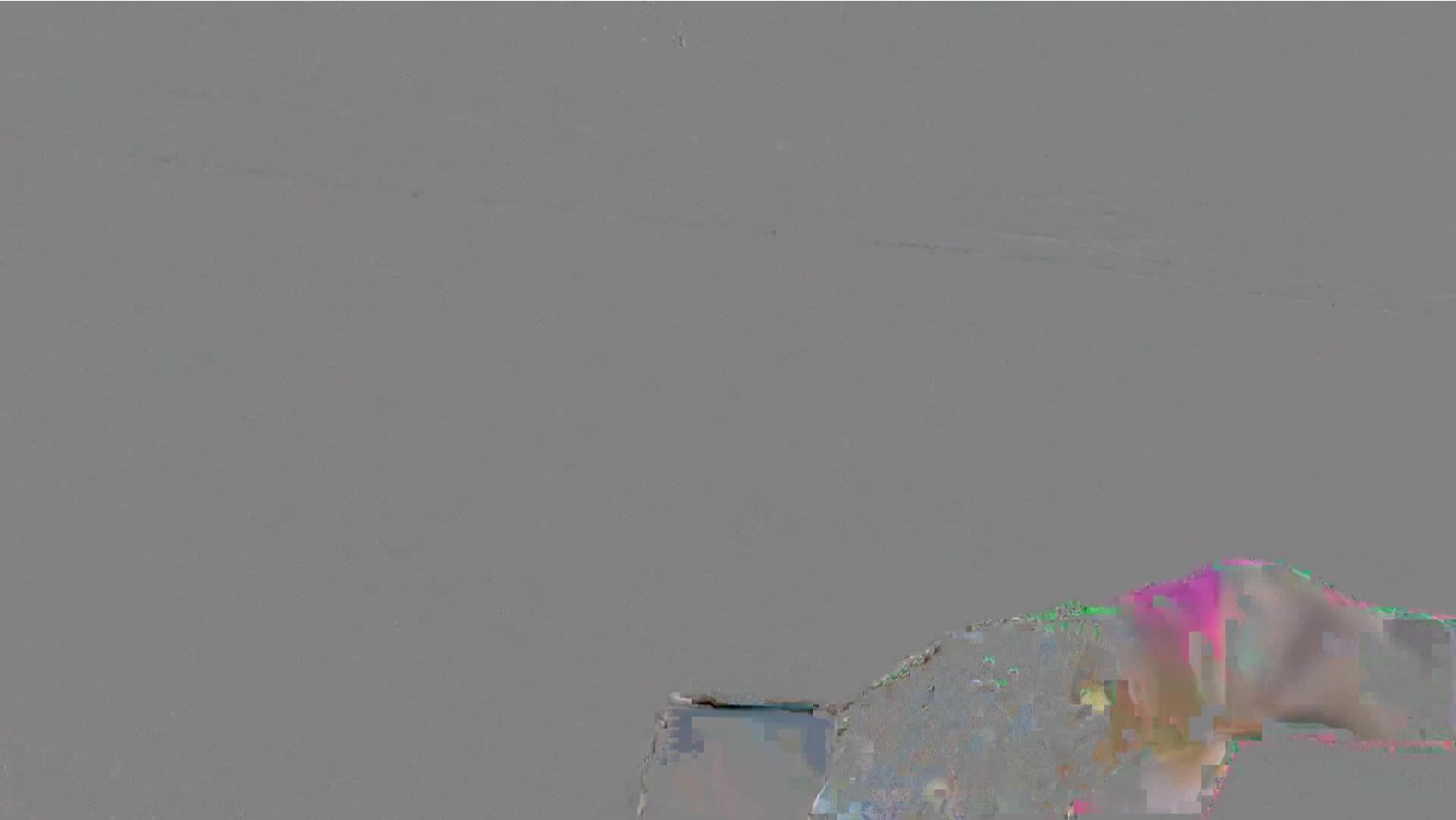
The Very Large Array (Radio)



**Gamma-ray Astronomy at the
Whipple Observatory**



Extra Slides



Are we ever sitting still?



Earth rotates on axis: > 1000 km/hr



Earth orbits Sun: $> 100,000$ km/hr



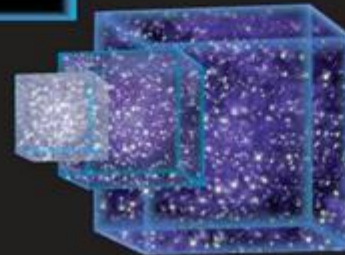
solar system moves among stars: $\sim 70,000$ km/hr



Milky Way rotates: $\sim 800,000$ km/hr



Milky Way moves
in Local Group



universe
expands

Webb Telescope Observation of Galaxy Interactions in Stephan's Quintet

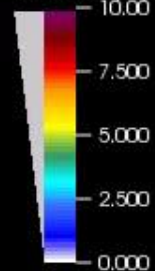


Webb's image of Stephan's Quintet, shows five galaxies packed tightly in the constellation Pegasus.

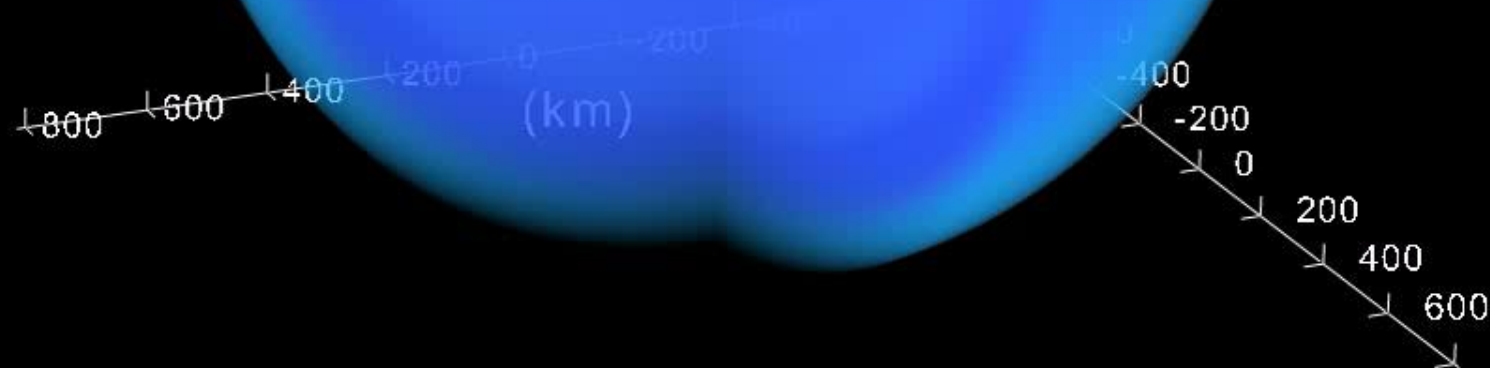
Four are so closely engaged in a gravitational dance that they will eventually merge.

Indeed, the image revealed a band of dust that was being heated up as two of the galaxies ripped stars from each other.

Volume
Var: entropy
Units: $\text{kJ} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$



Max: 5.069
Min: 1.246



time=0.0000 s