Astronomy 1 – Fall 2019

Announcements:

- Please read chapters 7, 8, and 10 this week. The homework webpage tells you which sections I am emphasizing on the homework.
- You are NOT responsible for chapter 9 (Living Earth).
- I will hold extra office hours today in Broida 2015D (3:20 – 3:50 pm); this is specifically to help students who have conflicts with my Wednesday 11am office hours.
- Please use Gaucho Space to check that your grades for HW 1 and 2 have been entered. Let your TA know if there is an error.
- Please check that you have participation grades (1 pt) for using your iClicker last Monday and Wednesday. See me during office hours if there is a problem.

Lecture 6: October 21, 2019

Previously on Astro 1

- Geometrical optics
  - Reflection & Refraction
  - Focus
- Telescopes
  - Reflectors vs. Refractors
  - Light gathering power
  - Magnification
  - Resolving power (diffraction limit)

Today on Astro1

- Our Solar System
  - Terrestrial vs. Jovian Planets
  - Why do some planets have atmospheres?
  - Smaller chunks of rocks and ice also orbit the Sun.
  - What do craters tell us about the geological history of planets?
  - What do magnetic fields tell us about planetary interiors?

- How did our solar system form?

- **Discussion Sections meet at night this week. Talk to your TA if you are uncertain where/when to meet**.
  - View Jupiter, the Galilean Satellites, and Saturn's Rings

Classification of Extrasolar Planets (iclickers Question)

Suppose that in the near future a series of extrasolar planets are discovered with the following characteristics: spherical solid surfaces; mean densities about four times that of water; radii about 4000 km; low density atmospheres. How would these planets be classified in terms of our solar system

A) Jovian Planets
B) Cometary nuclei
C) Asteroids
D) Terrestrial Planets

Classification of Extrasolar Planets (iclickers Question)

Suppose that in the near future a series of extrasolar planets are discovered with the following characteristics: spherical solid surfaces; mean densities about four times that of water; radii about 4000 km; low density atmospheres. How would these planets be classified in terms of our solar system

A) Jovian Planets
B) Cometary nuclei
C) Asteroids
D) **Terrestrial Planets**

Our Solar System Has Two Broad Categories of Planets

This Diversity Results From Its Origin and Evolution

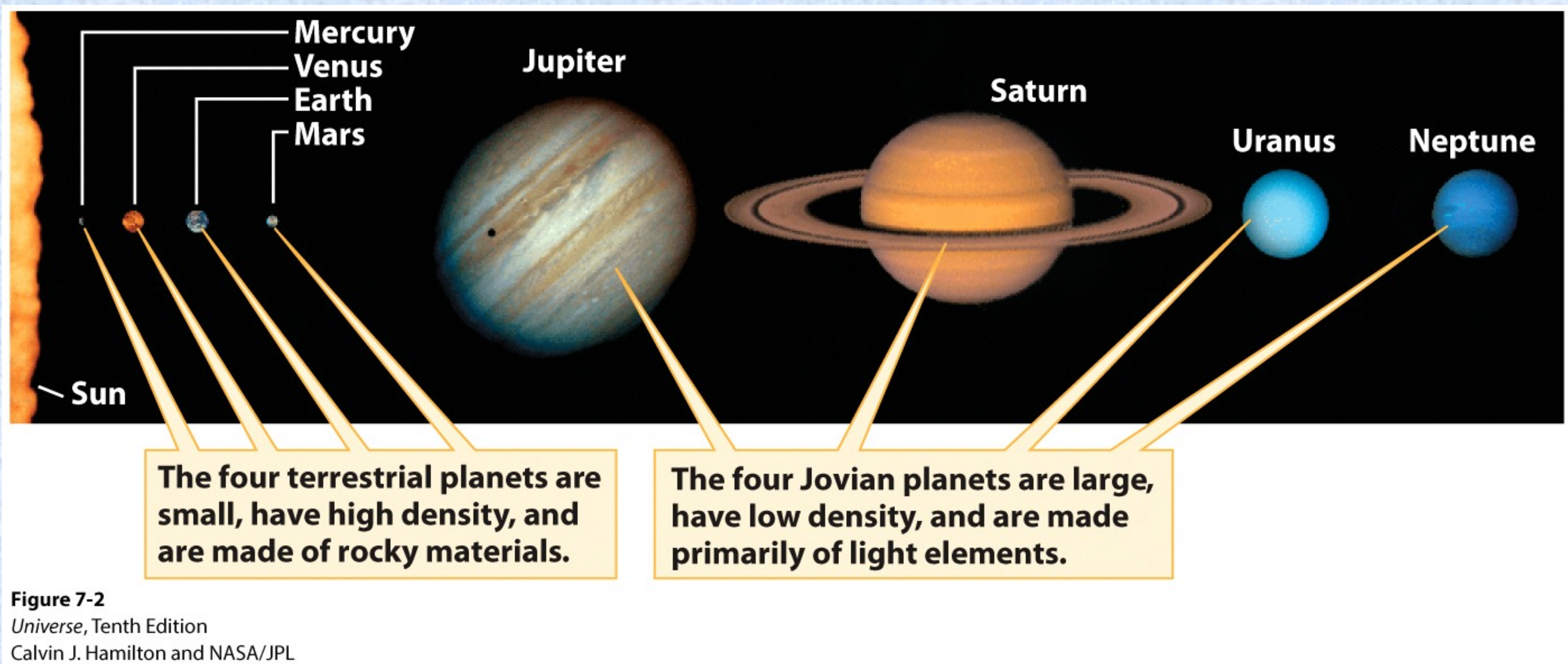


Figure 7-2
Universe, Tenth Edition
Calvin J. Hamilton and NASA/JPL

Terrestrial planets
- Closest to Sun
- Small, high density, rocky

Jovian planets
- Furthest from Sun
- Large, low density, gaseous

Orbital Radii of Terrestrial and Jovian Planets

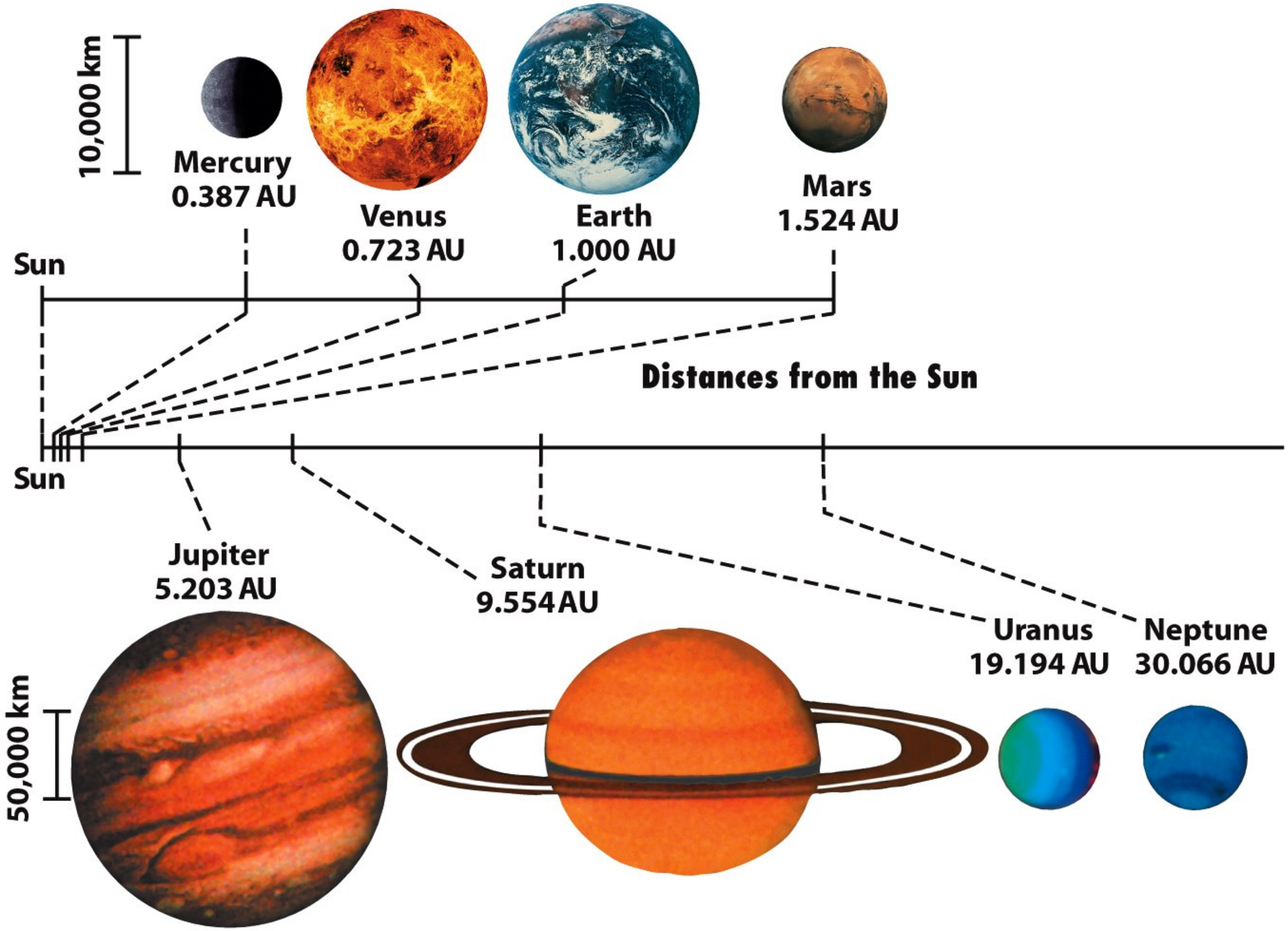


Table 7-1 illustration
Universe, Eighth Edition

Average Density of a Planet: A Clue About Its Composition

Measuring Density

- Distance: From period via Kepler's Third Law ($P^2 = a^3$)
- Size: Observed angular size and distance (small angle formula)
- Mass: satellite's period & Newton's Form of Kepler's Third Law
- Density: mass/volume ($\rho(H_2O)$ = 1000 kg/m3)

Table 7-1 Characteristics of the Planets

	The Inner (Terrestrial) Planets			
	Mercury	**Venus**	**Earth**	**Mars**
Average distance from Sun (10^6 km)	57.9	108.2	149.6	227.9
Average distance from Sun (AU)	0.387	0.723	1.000	1.524
Orbital period (years)	0.241	0.615	1.000	1.88
Orbital eccentricity	0.206	0.007	0.017	0.093
Inclination of orbit to the ecliptic	7.00°	3.39°	0.00°	1.85°
Equatorial diameter (km)	4880	12,104	12,756	6794
Equatorial diameter (Earth = 1)	0.383	0.949	1.000	0.533
Mass (kg)	3.302×10^{23}	4.868×10^{24}	5.974×10^{24}	6.418×10^{23}
Mass (Earth = 1)	0.0553	0.8150	1.0000	0.1074
Average density (kg/m^3)	5430	5243	5515	3934

Table 7-1 part 1
Universe, Eighth Edition

Rocky!

Density of Jovian Planets

Table 7-1 Characteristics of the Planets

	The Outer (Jovian) Planets			
	Jupiter	Saturn	Uranus	Neptune
Average distance from Sun (10^6 km)	778.3	1429	2871	4498
Average distance from Sun (AU)	5.203	9.554	19.194	30.066
Orbital period (years)	11.86	29.46	84.10	164.86
Orbital eccentricity	0.048	0.053	0.043	0.010
Inclination of orbit to the ecliptic	1.30°	2.48°	0.77°	1.77°
Equatorial diameter (km)	142,984	120,536	51,118	49,528
Equatorial diameter (Earth = 1)	11.209	9.449	4.007	3.883
Mass (kg)	1.899×10^{27}	5.685×10^{26}	8.682×10^{25}	1.024×10^{26}
Mass (Earth = 1)	317.8	95.16	14.53	17.15
Average density (kg/m^3)	1326	687	1318	1638

Table 7-1 part 2
Universe, Eighth Edition

- Gaseous
- Visible surfaces show cloud formations

What are ices?

- Hydrogen and Helium are gaseous except at extremely low temperature and high pressure.
- Rock forming substances such as iron and silicon are solids except at temperatures well above 1000 K.
- Between these two extremes are substances which solidify at low temperatures (from below 100 to 300 K) to solids called ices.
  - H_20, CO_2, CH_4, NH_3
  - They are liquids or gases at somewhat higher T.

What Determines Whether a Planet Has an Atmosphere?

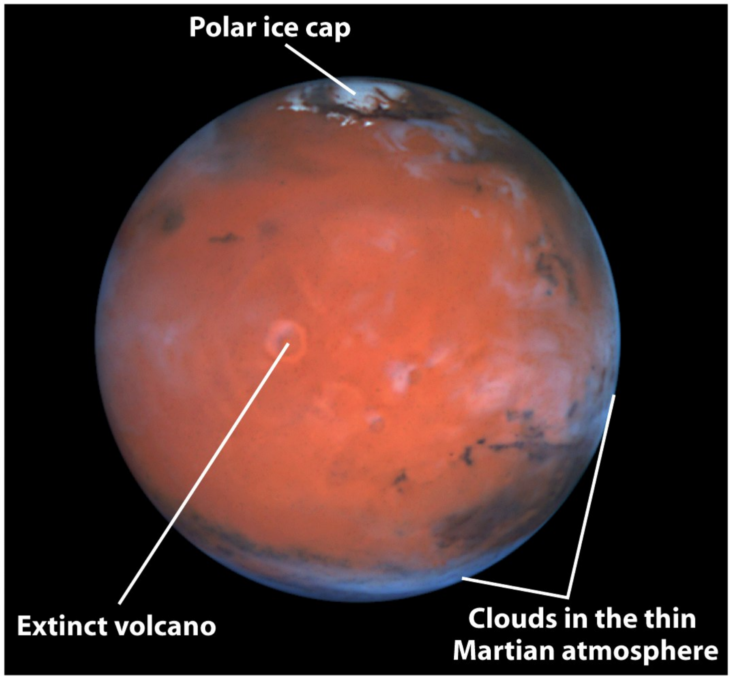


Figure 7-6
Universe, Eighth Edition

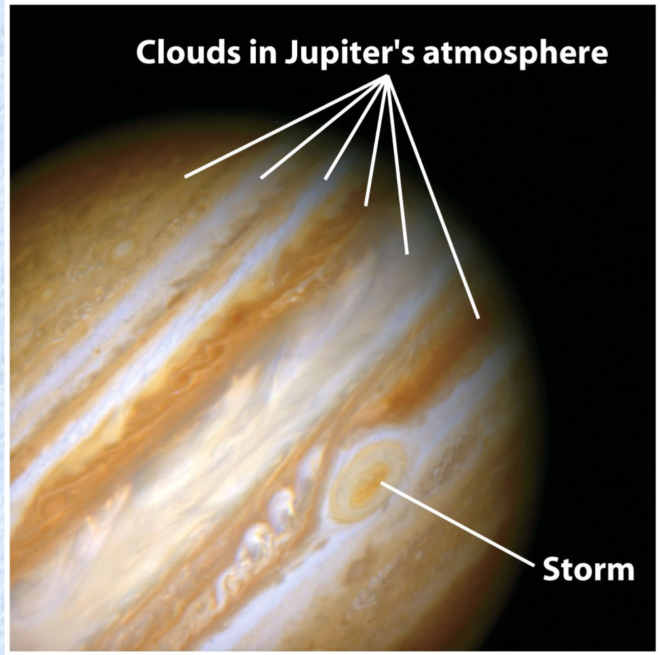
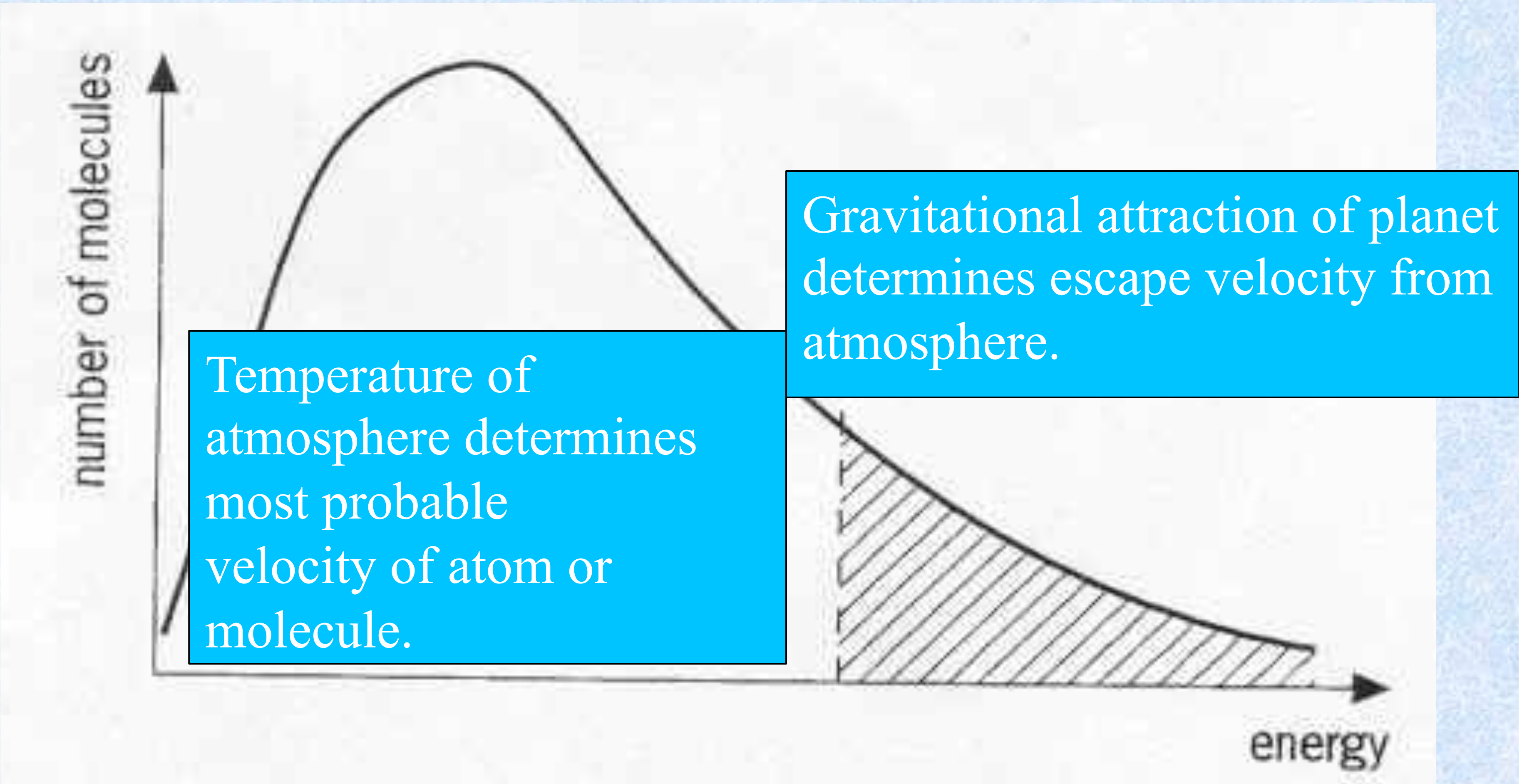


Figure 7-5
Universe, Eighth Edition

- Mars has a thin, nearly cloudless atmosphere.
- Jupiter does not have a solid surface. It’s atmosphere is composed mostly of lightest elements (hydrogen, helium); but there are trace amounts of other elements and molecules.

Particle Velocities in an Atmosphere



- A planet can retain a gas if the escape speed is at least 6 times greater than the average speed of the molecules in the gas.

The higher surface temperature of terrestrial planets explains the absence of light elements.

Escape speed from a planet of mass M and radius R:

- $V_{esc} = (2 G M / R)^{1/2}$
  - The escape velocity from the earth is 11.2 km /s
  - Jupiter is roughly 300 times more massive than the Earth
  - But Jupiter is also bigger than the Earth; R_J is 11 earth radii.
  - Jupiter's escape velocity is about 5.3 times that on Earth!
  - HW4-problem 1: What speed must a spacecraft on Europa obtain in order to escape?

Average speed of a gas atom or molecule:

- $V = (3 k T/ m)^{1/2}$ where k is Boltzmann's constant
  - $k = 1.3807 \times 10^{-23}$ J / K
  - m = mass of particle ($m_H = 1.67 \times 10^{-27}$ kg)

Average Speed of Molecules in an Atmosphere (iclicker Question)

The temperature of Earth's atmosphere is roughly 20^o C. Jupiter's atmosphere is colder at -148^o C. Compare the speed of nitrogen molecules in Earth's atmosphere to that of He atoms in Jupiter's atmosphere.

A. Nitrogen molecules move faster because Earth's atmosphere is hotter.

B. Nitrogen molecules move slower because Earth's atmosphere is colder on the Kelvin temperature scale.

C. Nitrogen molecules move slower because Nitrogen (atomic number 7, 14 m_H) is heavier than Helium (atomic number 2, 4 m_H).

D. They move at roughly the same speed.

E. Both B & C

Average Speed of Molecules in an Atmosphere (iclicker Question)

The temperature of Earth's atmosphere is roughly 20^o C. Jupiter's atmosphere is colder at -148^o C. Compare the speed of nitrogen molecules in Earth's atmosphere to that of He atoms in Jupiter's atmosphere.

A. Nitrogen molecules move faster because Earth's atmosphere is hotter.

B. Nitrogen molecules move slower because Earth's atmosphere is colder on the Kelvin temperature scale.

C. Nitrogen molecules move slower because Nitrogen (atomic number 7, 14 m_H) is heavier than Helium (atomic number 2, 4 m_H).

D. They move at roughly the same speed.

E. Both B & C

All the planets orbit the Sun in the same direction, in nearly the same plane, and most also rotate in the direction of the orbit.

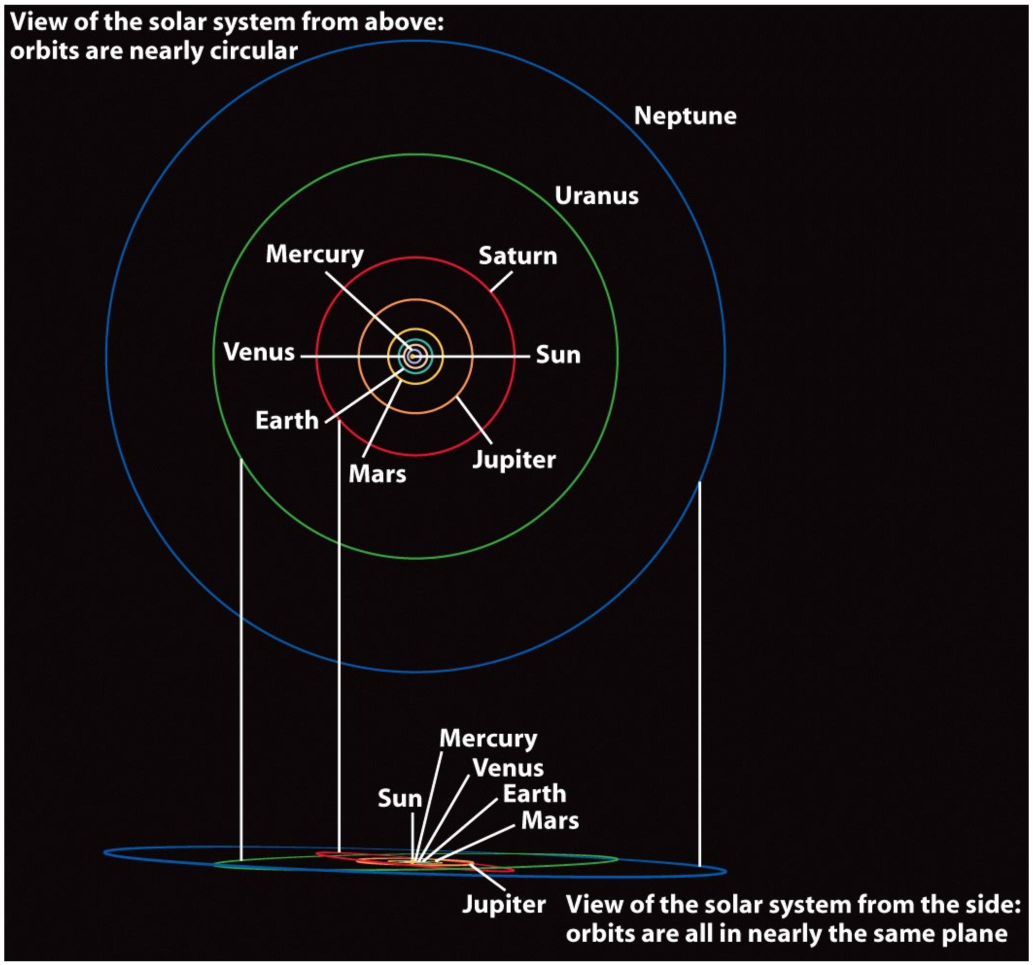


Figure 7-1
Universe, Eighth Edition

- Any model for the origin of the solar system must explain this!

Small Chunks of Rock & Ice Also Orbit the Sun

- Asteroids
  - An extension of planets to lower masses
  - Found in asteroid belt between Mars and Jupiter
- Trans-Neptunian Objects
  - Pluto and Eris are the most massive
  - Over 900 identified at much lower masses
  - Orbits cross Neptune’s orbit
- Comets

Asteroids

Figure 7-7
Universe, Eighth Edition

- Rocky objects between Mars and Jupiter in “asteroid belt”
- Left-overs that did not form a planet
- Combined mass < Moon

Asteroids

Figure 7-7
Universe, Eighth Edition

433 Eros:
- 33 km (21 mi) long and 13 km (8 mi) wide
- Gravity too weak to have pulled it into a spherical shape
- Image taken March 2000 by *NEAR Shoemaker,* first spacecraft to orbit around and land on an asteroid.

Trans-Neptunian Objects (TNOs) = Kuiper Belt Objects (KBOs)

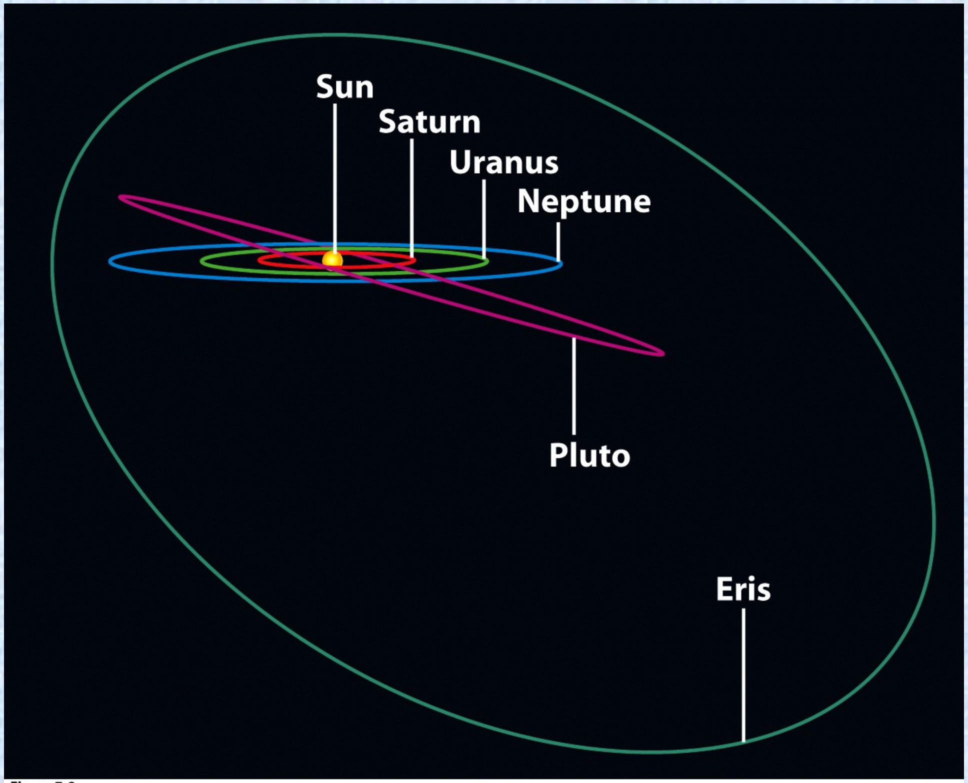


Figure 7-8
Universe, Eighth Edition

Pluto and Eris (2003 UB313):
- Two largest Trans-Neptunian Objects
- Orbits steeply inclined to the ecliptic

Trans-Neptunian Objects (TNOs) = Kuiper Belt Objects (KBOs)

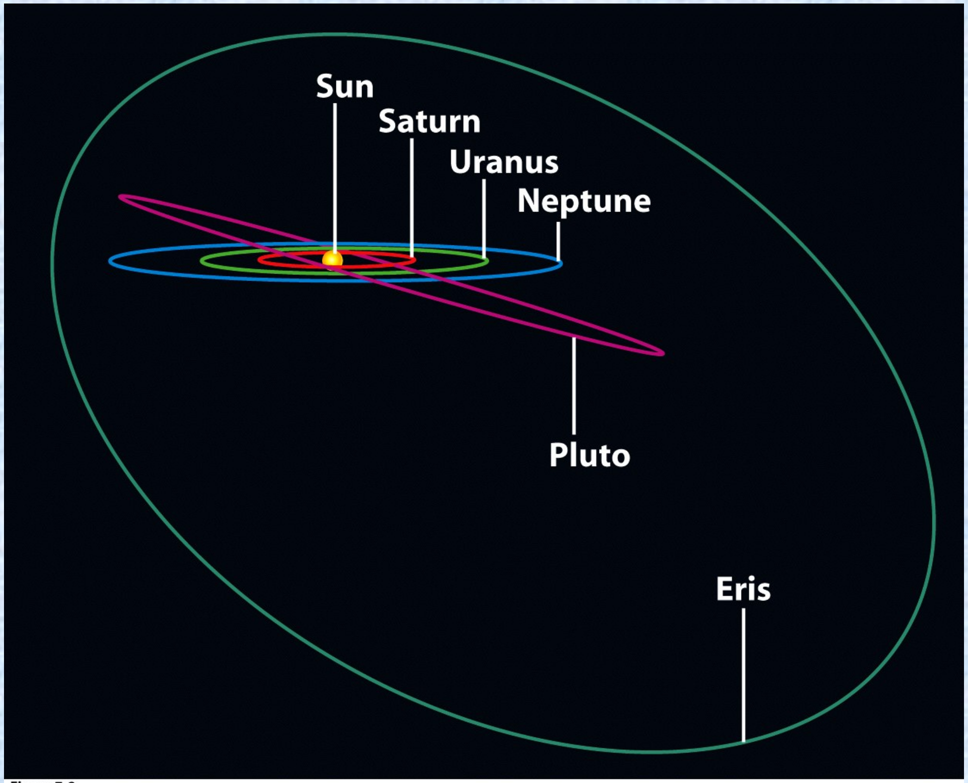


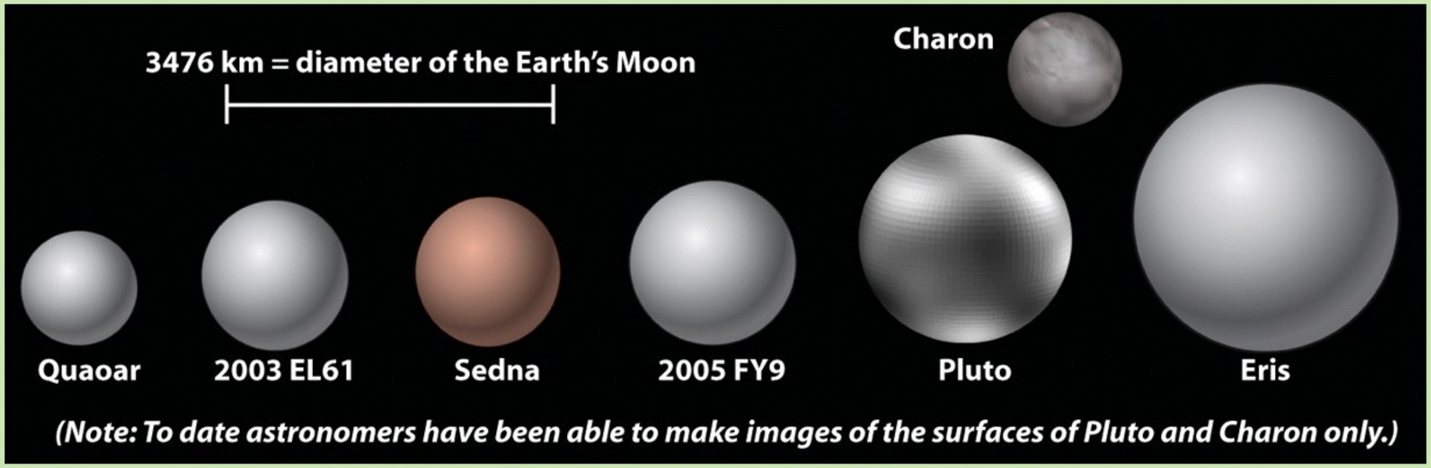
Figure 7-8
Universe, Eighth Edition

- Rocky & icy objects beyond Neptune (> 900 known; maybe up to 35,000?)
- High eccentricities
- Pluto is first discovered TNO (1930) and second biggest
- Reside in Kuiper belt (30-50 AU from sun)
- Debris left over from formation of solar system

Large Trans-Neptunian Objects (TNOs)

Table 7-4 Seven Large Trans-Neptunian Objects

	Quaoar	2003 EL61	Sedna	2005 FY9	Pluto	Charon (satellite of Pluto)	Eris
Average distance from Sun (AU)	43.54	43.34	489	45.71	39.54	39.54	67.67
Orbital period (years)	287	285	10,800	309	248.6	248.6	557
Orbital eccentricity	0.035	0.189	0.844	0.155	0.250	0.250	0.442
Inclination of orbit to the ecliptic	8.0°	28.2°	11.9°	29.0°	17.15°	17.15°	44.2°
Approximate diameter (km)	1250	1500	1600	1800	2274	1190	2900



R I V U X G

(Images of Pluto and Charon: Alan Stern, Southwest Research Institute; Marc Buie, Lowell Observatory; NASA; and ESA)

Table 7-4
Universe, Eighth Edition

***HW#4 − problem 2** - calculate how long it takes a TNO to move 1 arcminute on the sky; enough that you could see it move with your eye.*

Comets ("Dirty Snowballs in Space")

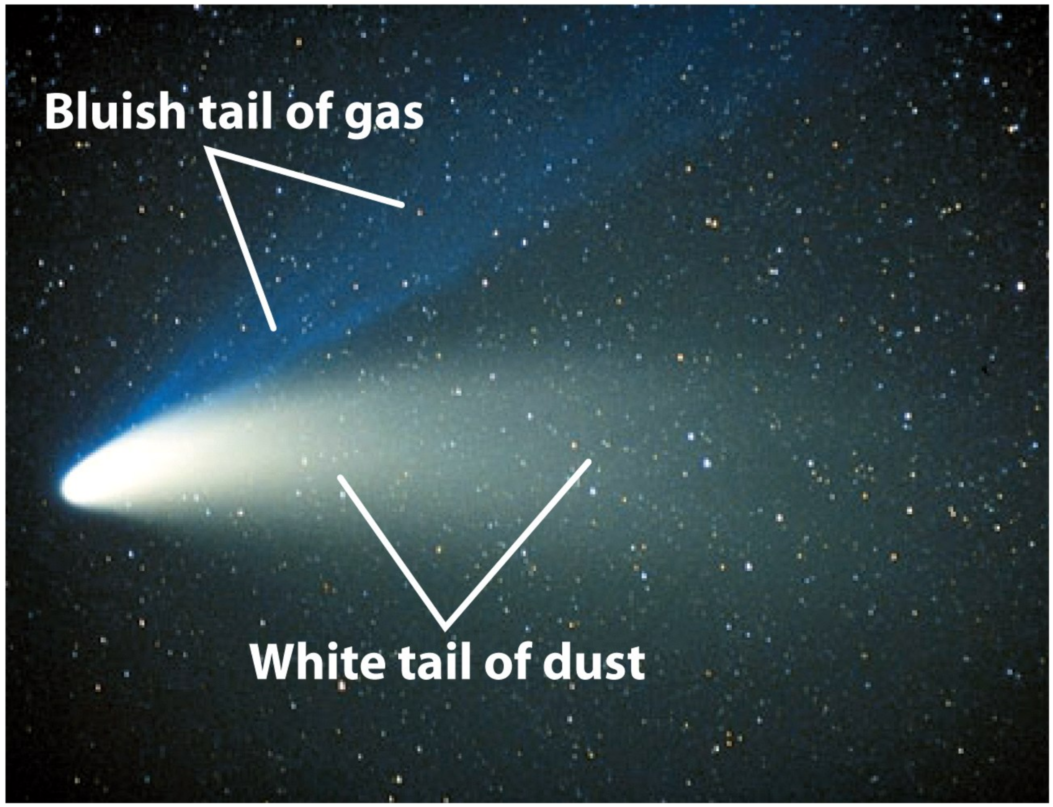


Figure 7-9
Universe, Eighth Edition

- Rocky & icy objects on eccentric orbits that come close to sun.
- Few tens of km in diameter
- From Kuiper Belt or even further out (Oort Cloud; 50,000 AU)
- e.g. if collision of two KBOs, a fragment can be knocked off and diverted into elongated object, brings it close to sun

Comets

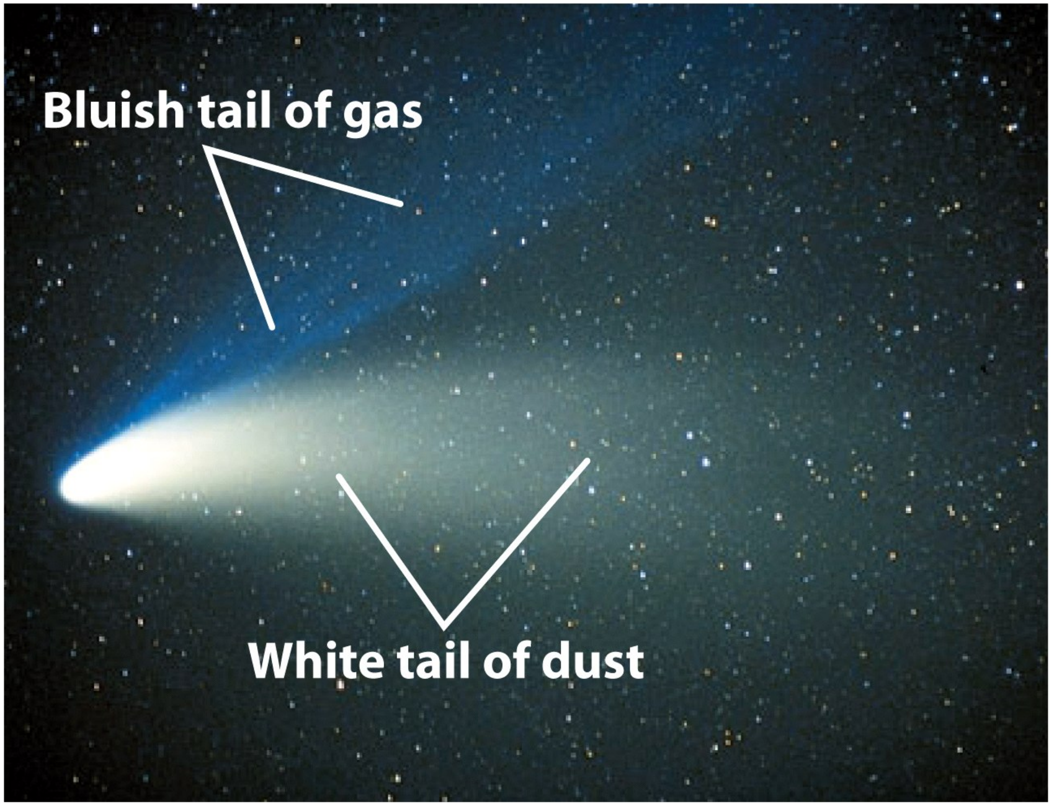


Figure 7-9
Universe, Eighth Edition

Hale-Bopp: (April 1997)
- Near Sun: solar radiation vaporizes some icy material
- Bluish tail of gas, white tail of dust
- Tails can extend for tens of millions of kilometers

Do All Planets Have a Magnetic Field?

Consider how Earth's magnetic field is generated.
Measure planetary magnetic fields with spacecraft.

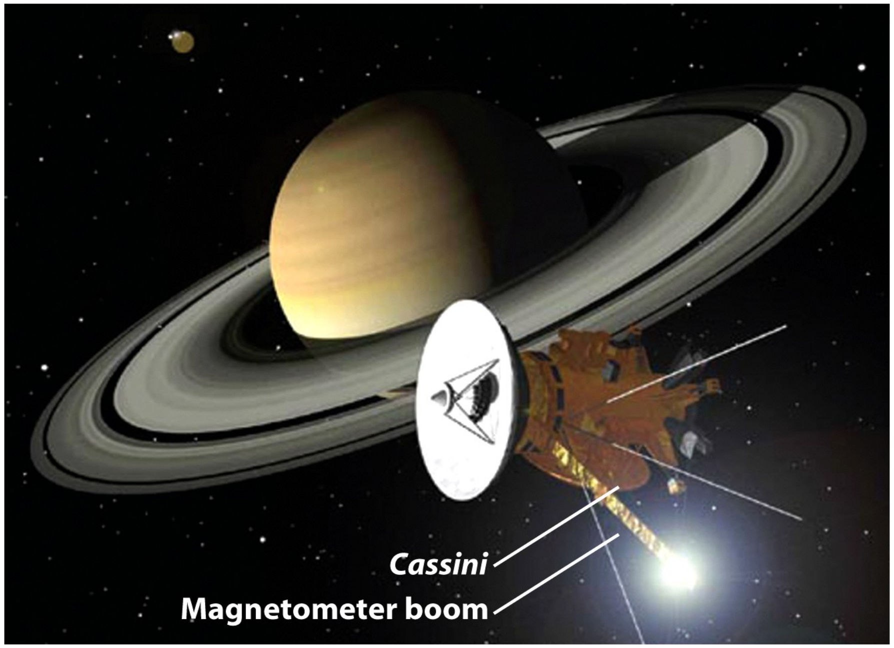


Figure 7-14
Universe, Eighth Edition

Earth's Magnetic Field Is Generated by the Motion of Electrically Conducting Liquid Iron in Its Core

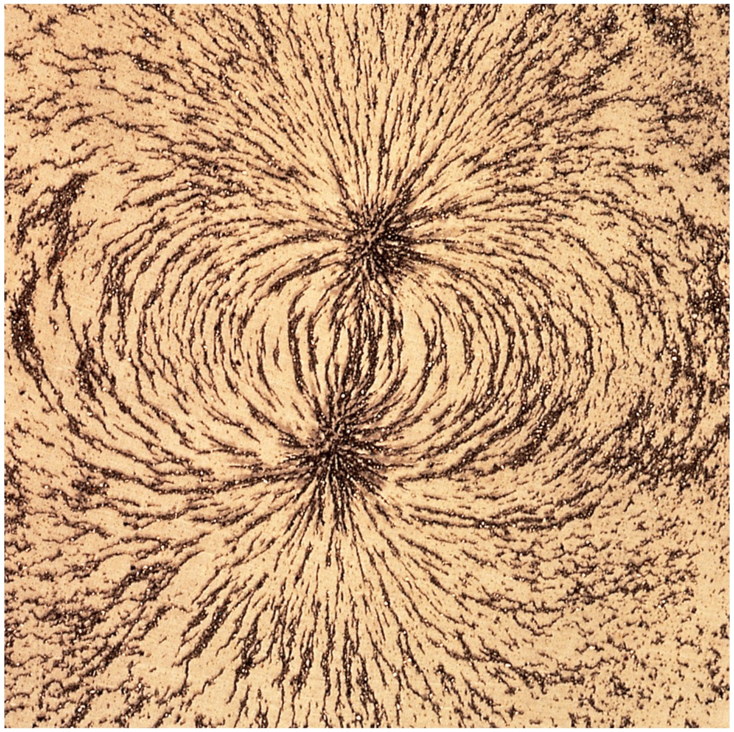


Figure 7-13a
Universe, Tenth Edition
Jules Bucher/Photo Researchers

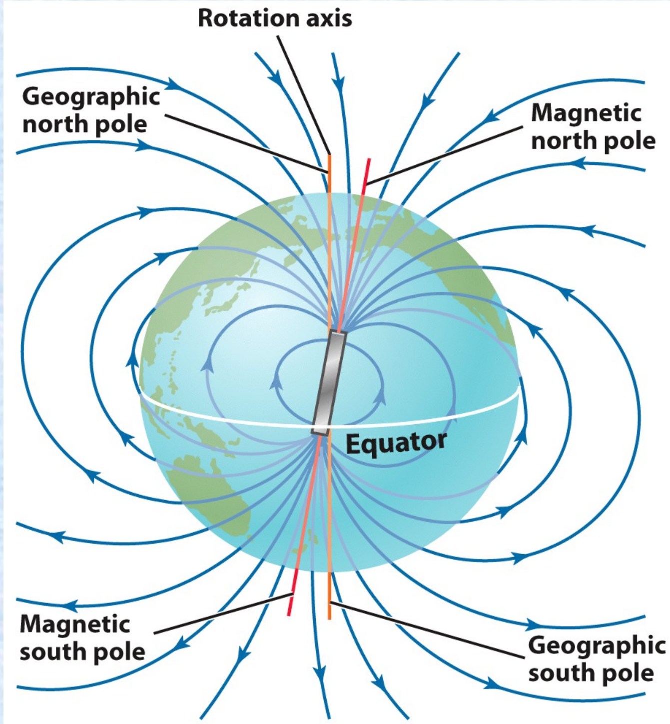


Figure 7-13b
Universe, Tenth Edition
© 2014 W. H. Freeman and Company

This dynamo action requires:

1. rotation. Venus hardly rotates so it lacks a magnetic field.
2. molten core.
   a. Mercury's weak field ➔ some of the interior is molten
   b. Martian rocks ➔ Mars had molten core in the past

Measure Magnetic Fields with Spacecraft

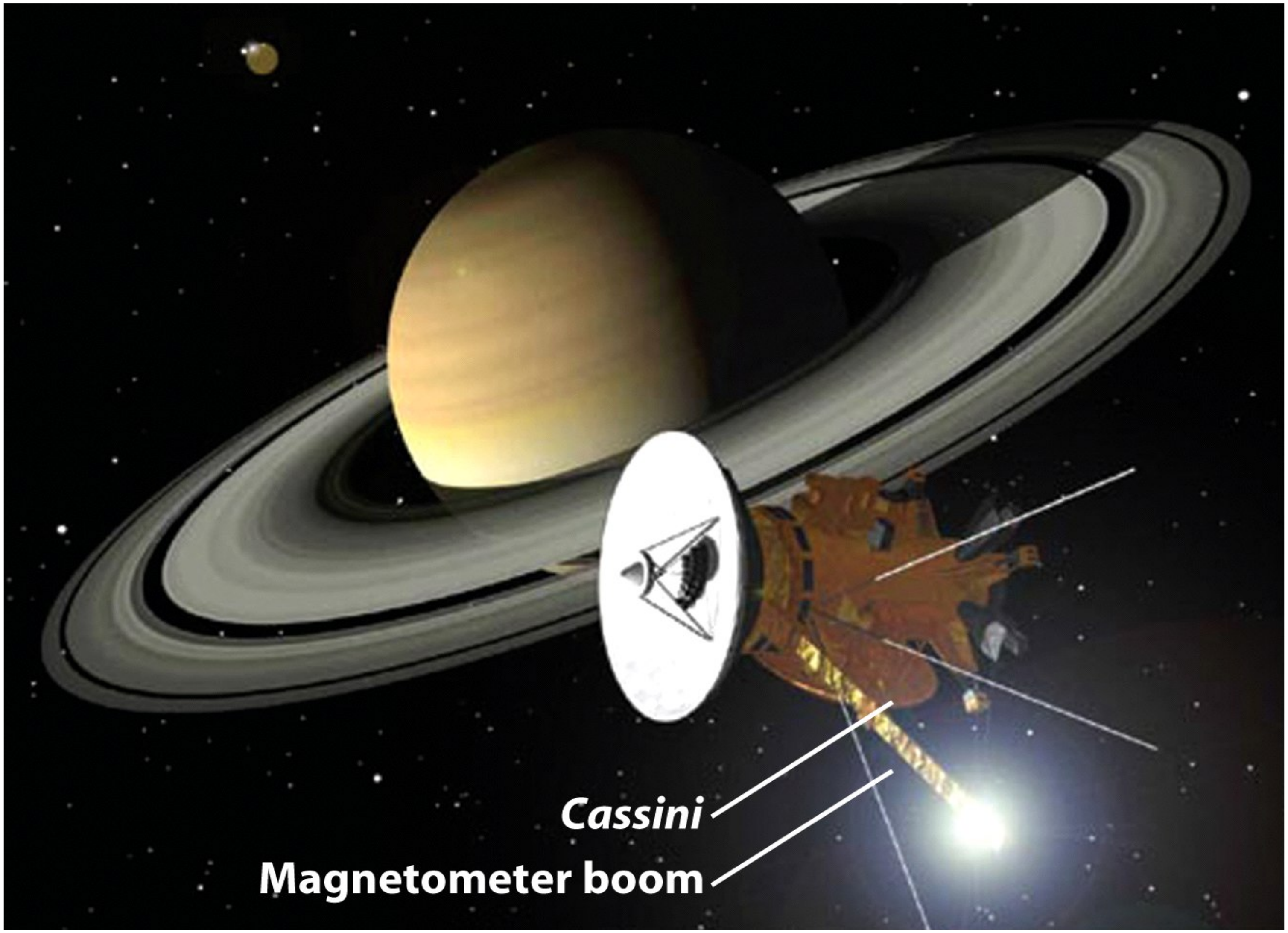


Figure 7-14
Universe, Eighth Edition

Planets are Heated Internally & Smaller Planets Lose Their Heat Faster

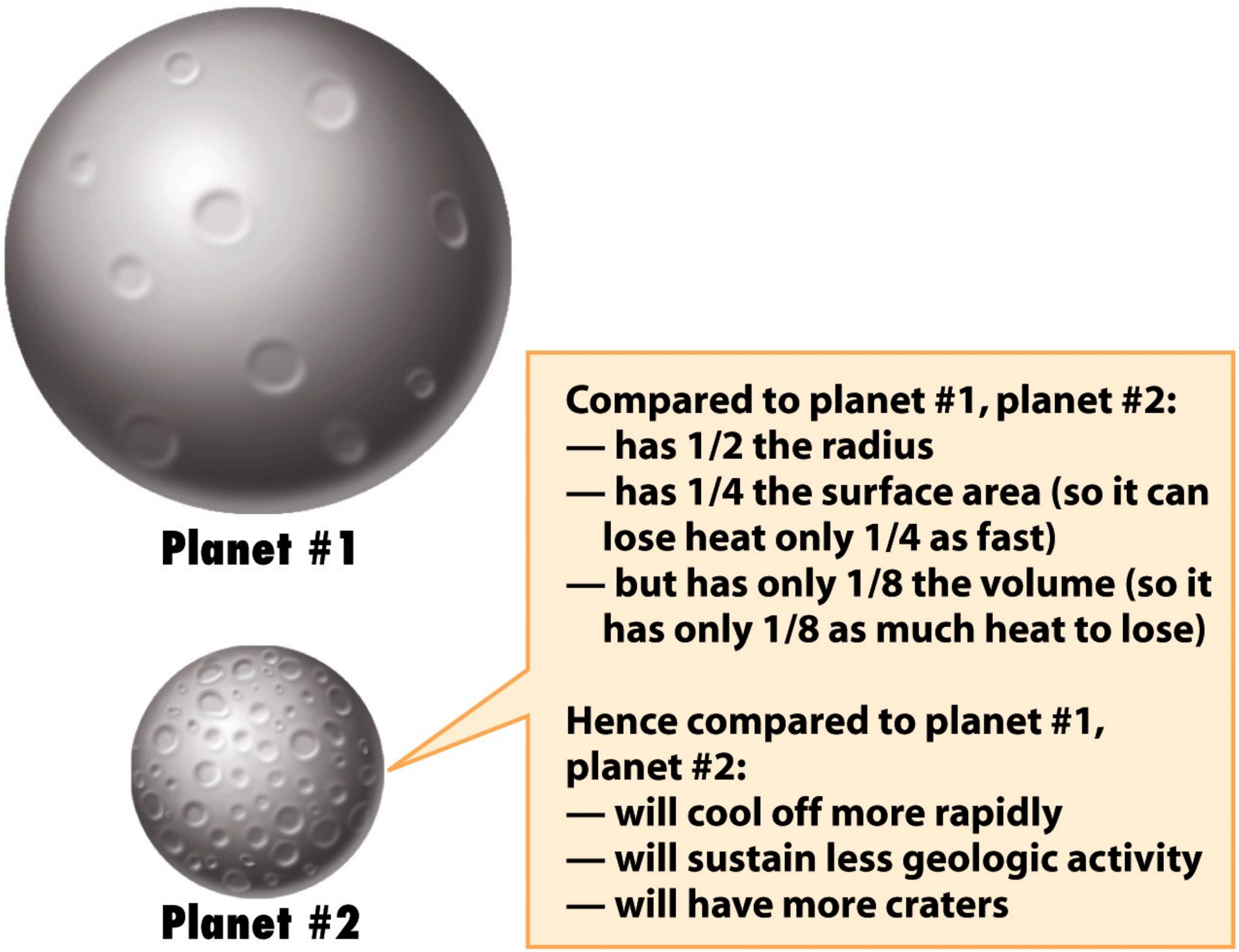


Figure 7-11
Universe, Eighth Edition

Magnetism of Small Bodies (iclickers Question)

In general small bodies in the solar system are less likely than large bodies to possess a planet-wide magnetic field. Why should we expect size and magnetism to be correlated?

A) A small body cools more rapidly and is less likely to possess a molten liquid interior.

B) Small bodies are more likely to be heavily cratered and such impacts can destroy the mechanism that produces the magnetic field

C) Magnetic fields are produced by the entire volume of a body. Smaller bodies have smaller volumes and therefore smaller magnetic fields

D) Small bodies necessarily rotate more slowly and a rapid rotation rate is one requirement for a planet wide magnetic field

Magnetism of Small Bodies (iclickers Question)

In general small bodies in the solar system are less likely than large bodies to possess a planet-wide magnetic field. Why should we expect size and magnetism to be correlated?

A**) A small body cools more rapidly and is less likely to possess a molten liquid interior.**

B) Small bodies are more likely to be heavily cratered and such impacts can destroy the mechanism that produces the magnetic field

C) Magnetic fields are produced by the entire volume of a body. Smaller bodies have smaller volumes and therefore smaller magnetic fields

D) Small bodies necessarily rotate more slowly and a rapid rotation rate is one requirement for a planet wide magnetic field

Insight from other worlds

Methods
- Direct imaging
- Radial velocity
- Transit photometry (light curves)
- Astrometric wobble

Direct Imaging Presents a Contrast Problem

First Extrasolar Planet Visible in a Telescope Image

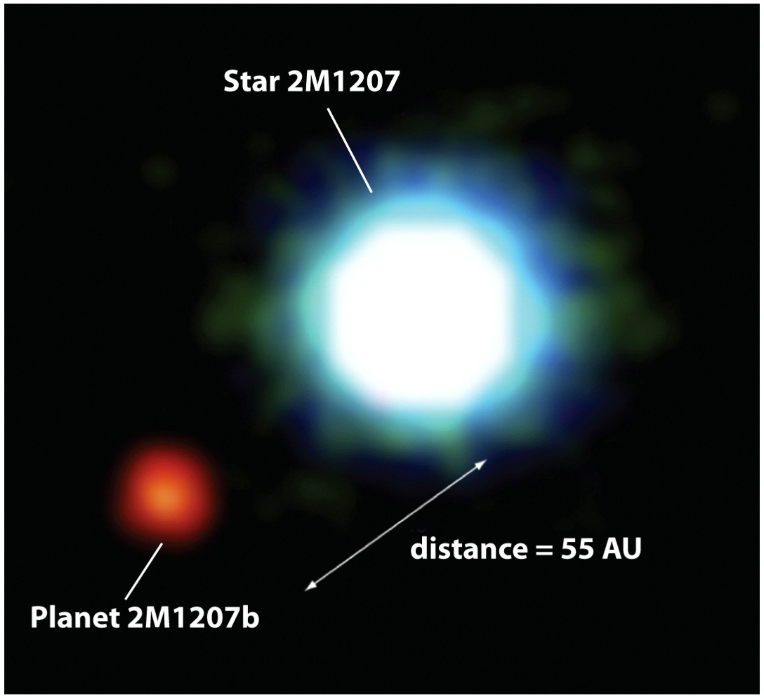


Figure 8-15b
Universe, Tenth Edition
ESO/VLT/NACO

- Direct imaging of a planet is a contrast problem because the star is so much brighter.
- HW#4 – problem 3 – will help you understand why astronomers designed JWST to observe at infrared wavelengths.
- HW#4 – problem 4 –will complete an orbit of the star in your lifetime?

A Few Planetary Systems Have Been Imaged

Four Planets Orbit the Star HR 8799

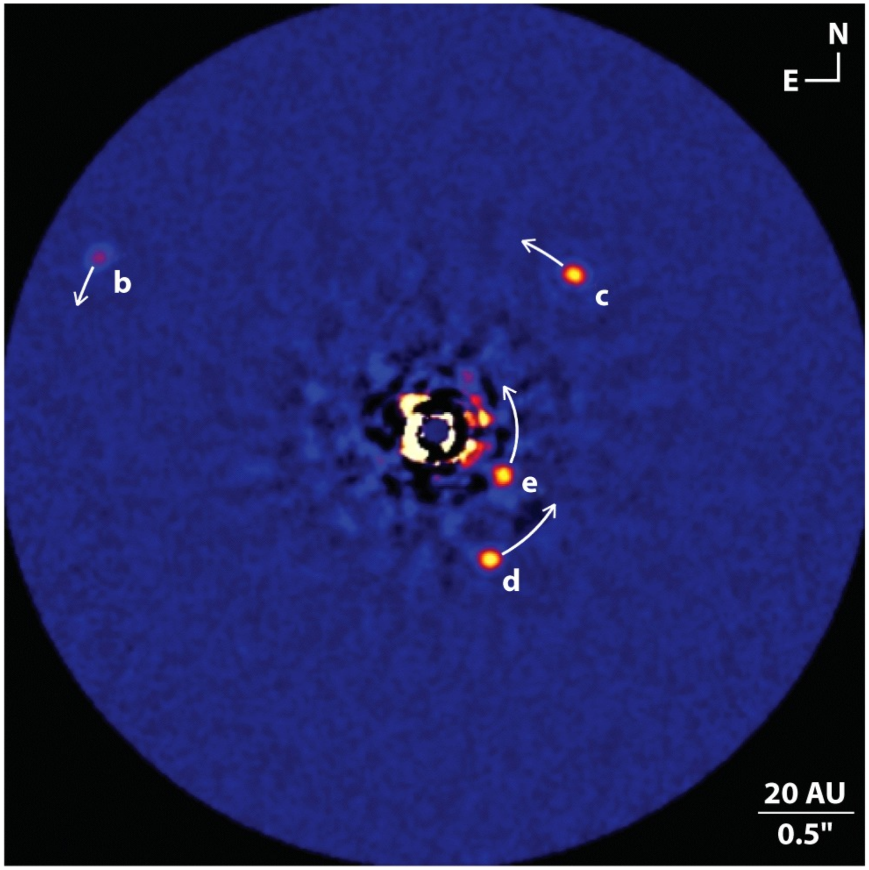


Figure 8-15a
Universe, Tenth Edition
NASA/W. M. Keck Observatory

Detecting a Planet by Measuring Its Parent Star's Motion

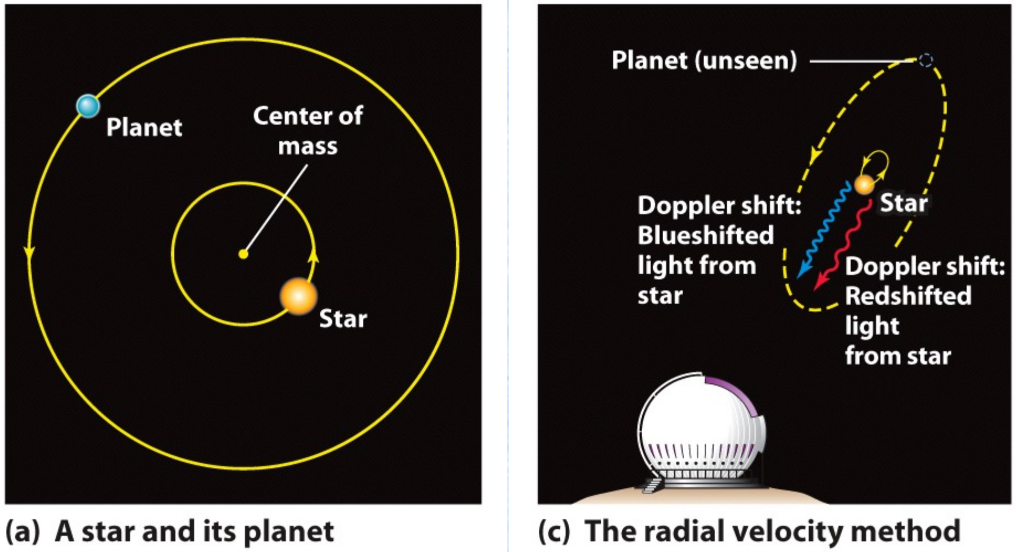


Figure 8-16
Universe, Tenth Edition

Early studies subject to selection biases

- Massive planets
- Short periods

Provides a lower limit on planet's mass. Why?

The Wobble of 51 Pegasi

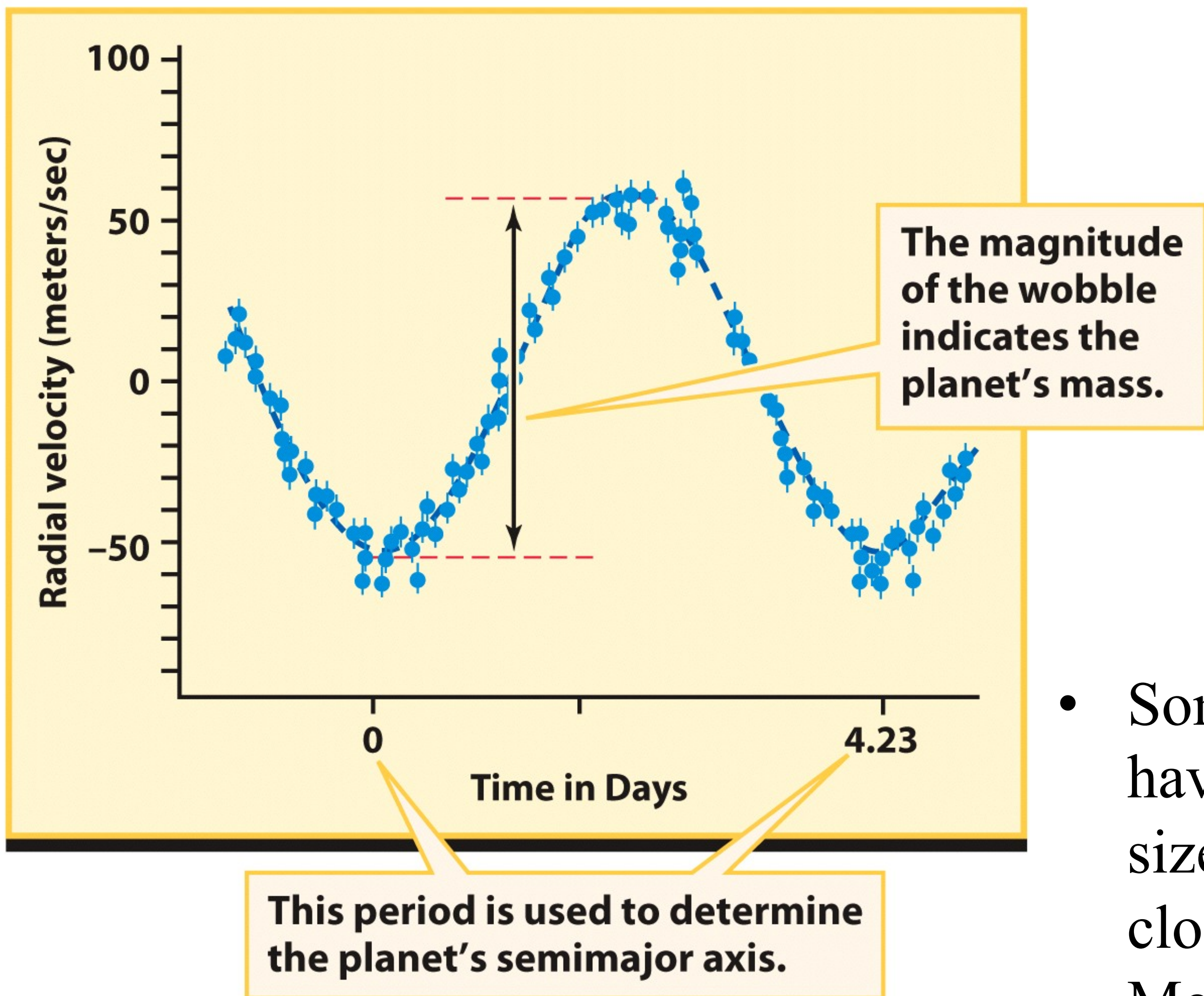


Figure 8-17
Universe, Tenth Edition

- Some planetary systems have a planet about the size of Jupiter orbiting closer to their star than Mercury does to our Sun!

Transit Method of Planet Detection

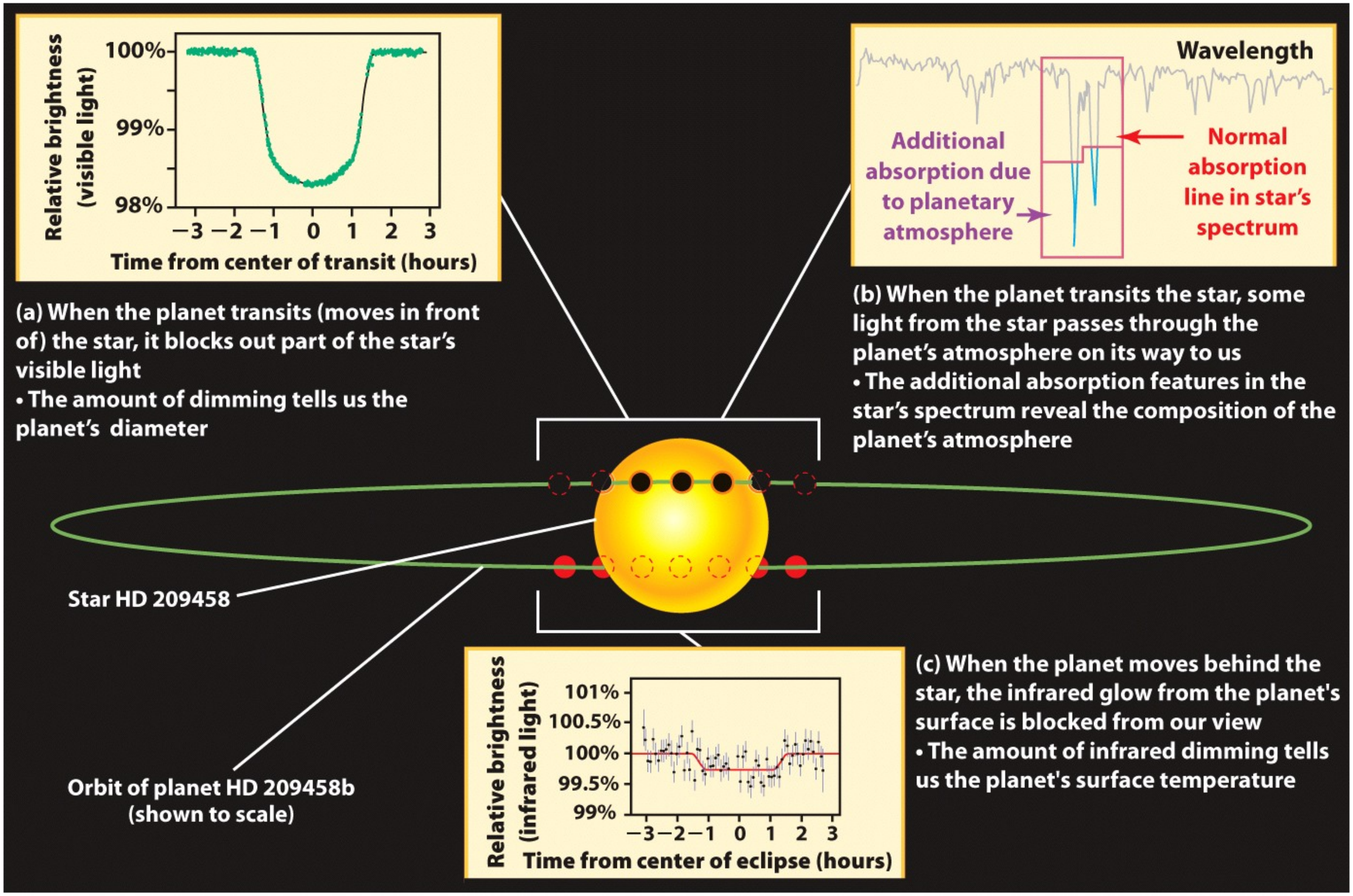
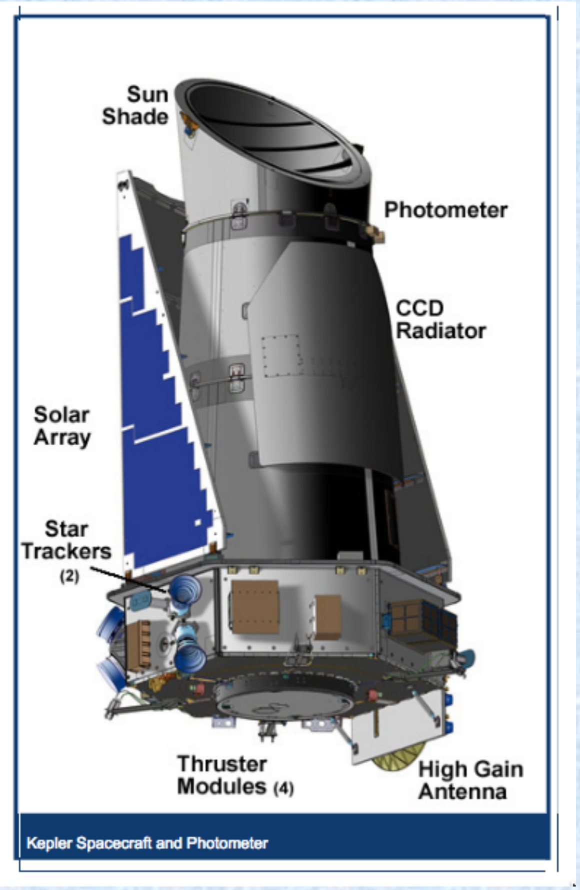
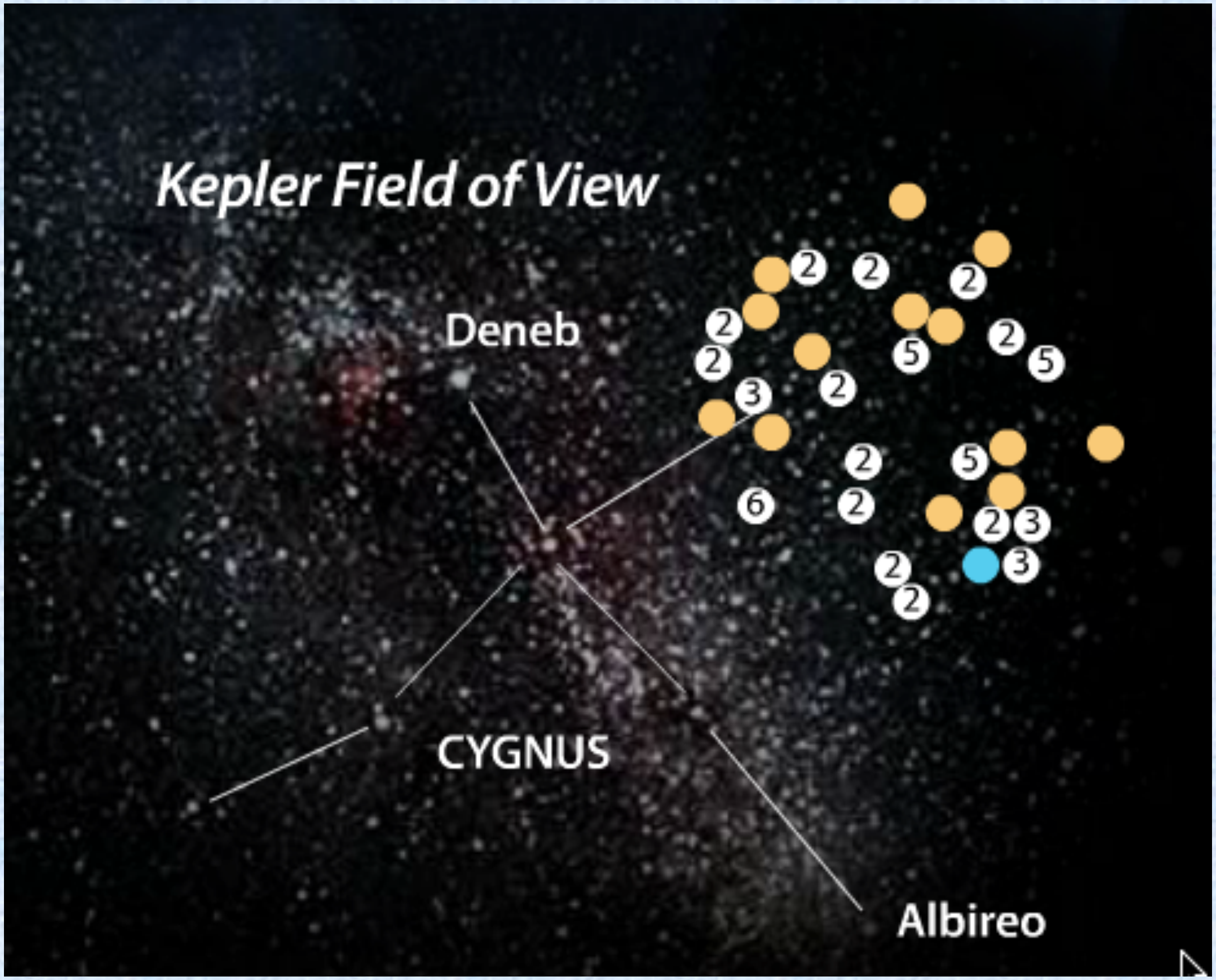


Figure 8-19
Universe, Tenth Edition
S. Seager and C. Reed, Sky and Telescope; H. Knutson, D. Charbonneau, R. W. Noyes (Harvard-Smithsonian CfA), T. M. Brown (HAO/NCAR), and R. L. Gilliland (STScI); A. Feild (STScI); NASA/JPL-Caltech/D. Charbonneau, Harvard-Smithsonian CfA

NASA’s Kepler Mission





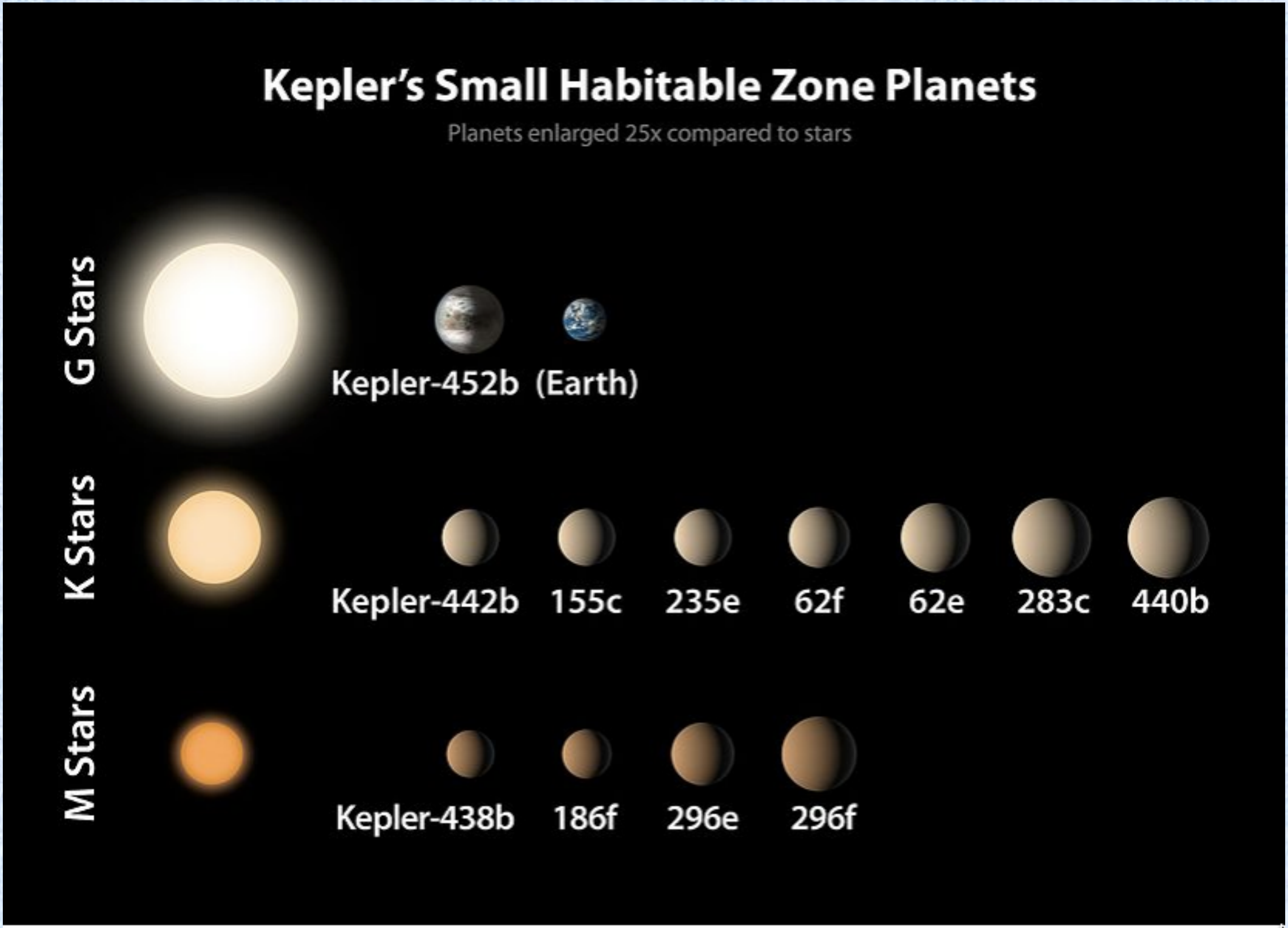
What is the Habitable Zone?

- We do not know what conditions might be required for some sort of alien life.

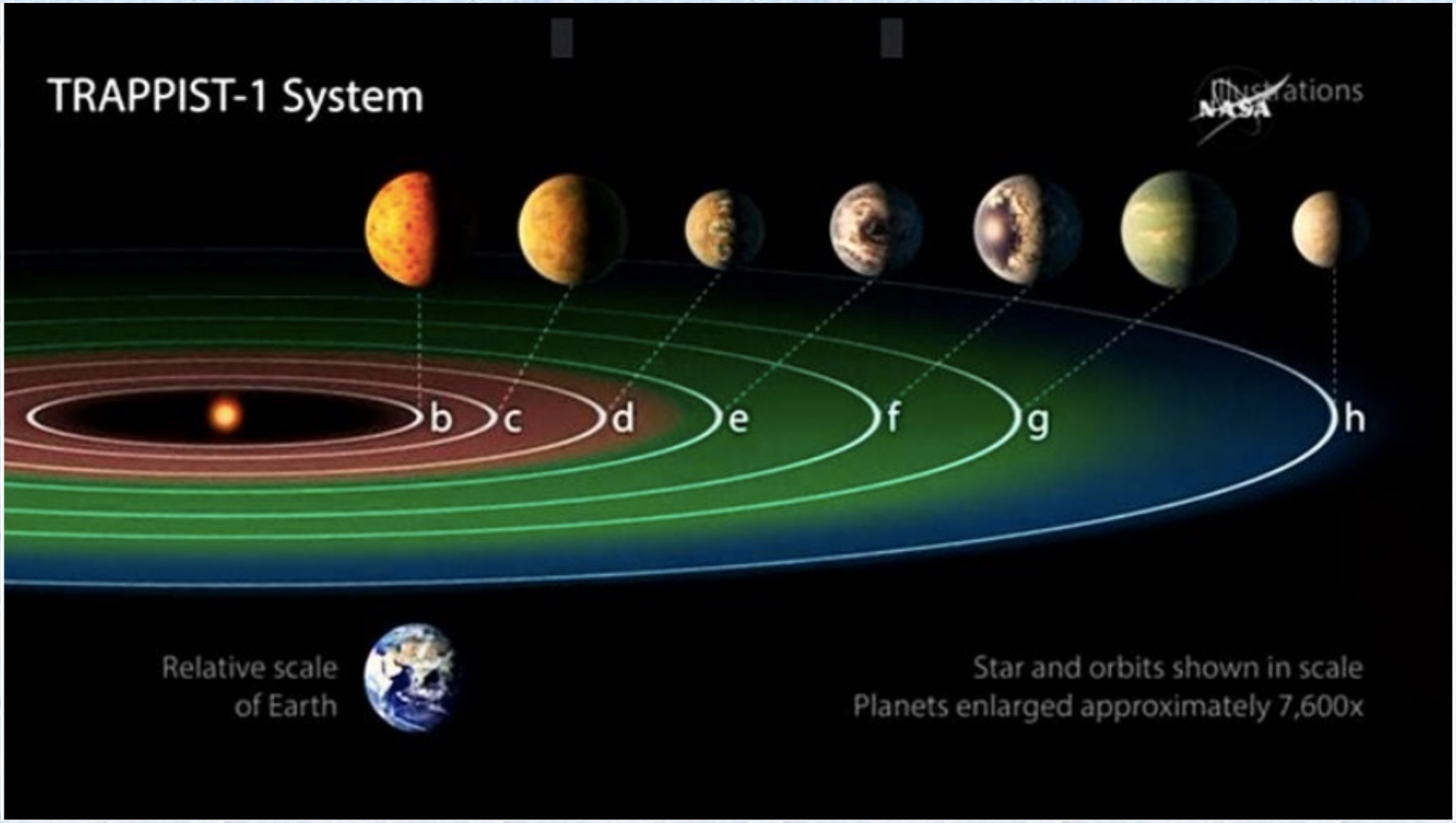
- What conditions might increase the chance of finding life?

1. Planet ‘s temperature could support the liquid phase of water.
    - Depends on temperature of star (hotter bodies emit more power)
    - And distance from that star (energy flux diluted by inverse square law)
2. Rocky planets that are Earth-size
    - Smaller planets would lose their atmosphere

- Astronomers estimate that there are roughly 1 to 10 billion exoplanets in the habitable zone of Galactic stars.


Kepler's Small Habitable Zone Planets
Planets enlarged 25x compared to stars
G Stars
Kepler-452b
(Earth)
K Stars
Kepler-442b
155c
235e
62f
62e
283c
440b
M Stars
Kepler-438b
186f
296e
296f

Planets in the Habitable Zone!



- The star Trappist-1 is only 39 light years away.
- Several stars in the habitable zone orbit it.
- It is a small star (only a little more massive than Jupiter).

Summary

- **Properties of the Planets:**
  - Orbits in the same plane and direction
  - Inner (terrestrial) planets are small and made of heavy elements
  - Outer (Jovian) planets are big and made of light elements
- **Other bodies in the Solar system**
  - Asteroids in Asteroid Belt between Mars and Jupiter
  - Outer solar system is populated by TNO and comets
  - Moon and satellites (next lecture)
- **Is Our Solar System Unique?**
  - There are billions of others with planets similar in mass to the Earth that could have liquid water.
  - NASA's JWST could detect oxygen in the atmospheres of the closest ones.