SOLAR SYSTEMS

Astronomy

Introduction

Sections:

- Components of the Solar System
- Formation of Planetary Systems
- Other Planetary Systems

Components of the Solar System

The Sun

- The Sun is a star
- Star – ball of incandescent gas whose light and heat are generated by nuclear reactions in its core
- It's the largest body in the solar system
    - More than 700x the mass of the other objects put together
    - Its gravitational force holds the other planets in place
- Solar System – the gravitational domination of the planets by the Sun

Components of the Solar System

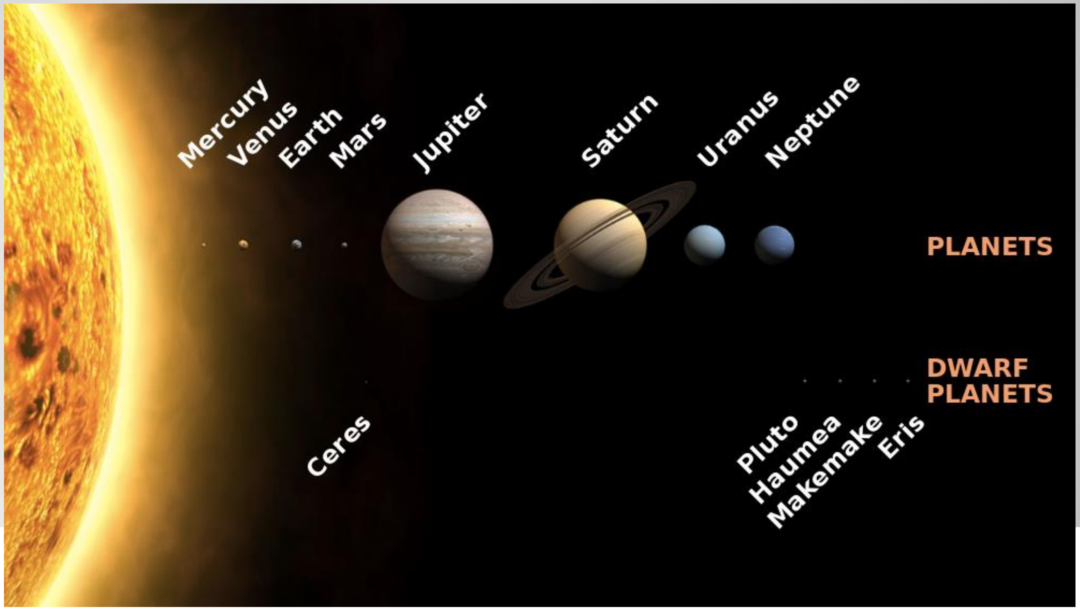
The Sun

- Mostly hydrogen and helium
  - About 71% H
  - About 27% He
- Contains small components of:
  - Carbon
  - Iron
  - Uranium
    - All in a vaporized form!
    - We can tell based off of the spectrum of light it emits

Components of the Solar System

The Orbits and Rotations of the Planets

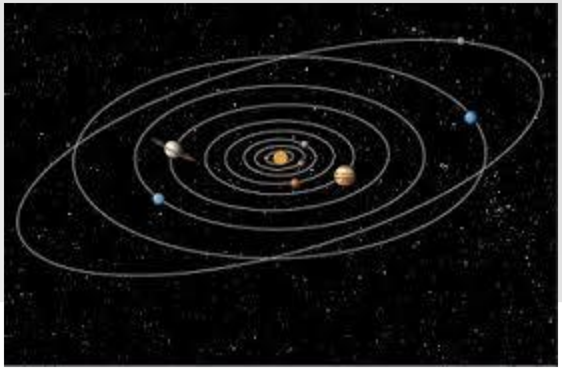
- Planets are much smaller than the Sun
- They emit no visible light of their own
  - They do shine by reflecting the Sun's light
- Planets in order:
  - Mercury
  - Venus
  - Earth
  - Mars
  - Jupiter
  - Saturn
  - Uranus
  - Neptune



Components of the Solar System

The Orbits and Rotations of the Planets

- The orbits of all of the planets around the Sun are mostly circular and almost about the same plane, horizontally
  - It almost looks like a spinning pancake with the planets traveling around the Sun in the same direction
- The planets' rotation around the sun is *counterclockwise*



Components of the Solar System

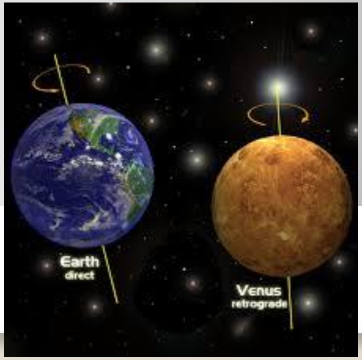
The Orbits and Rotations of the Planets

- As the planets orbit, each “spins” on its rotation axis
  - The angle of the tilt has to do with how far off of the horizontal plane it is
- Generally, this rotation is in the same direction as the orbit around the Sun
- 2 exceptions to this:
  - Venus
  - Uranus

Components of the Solar System

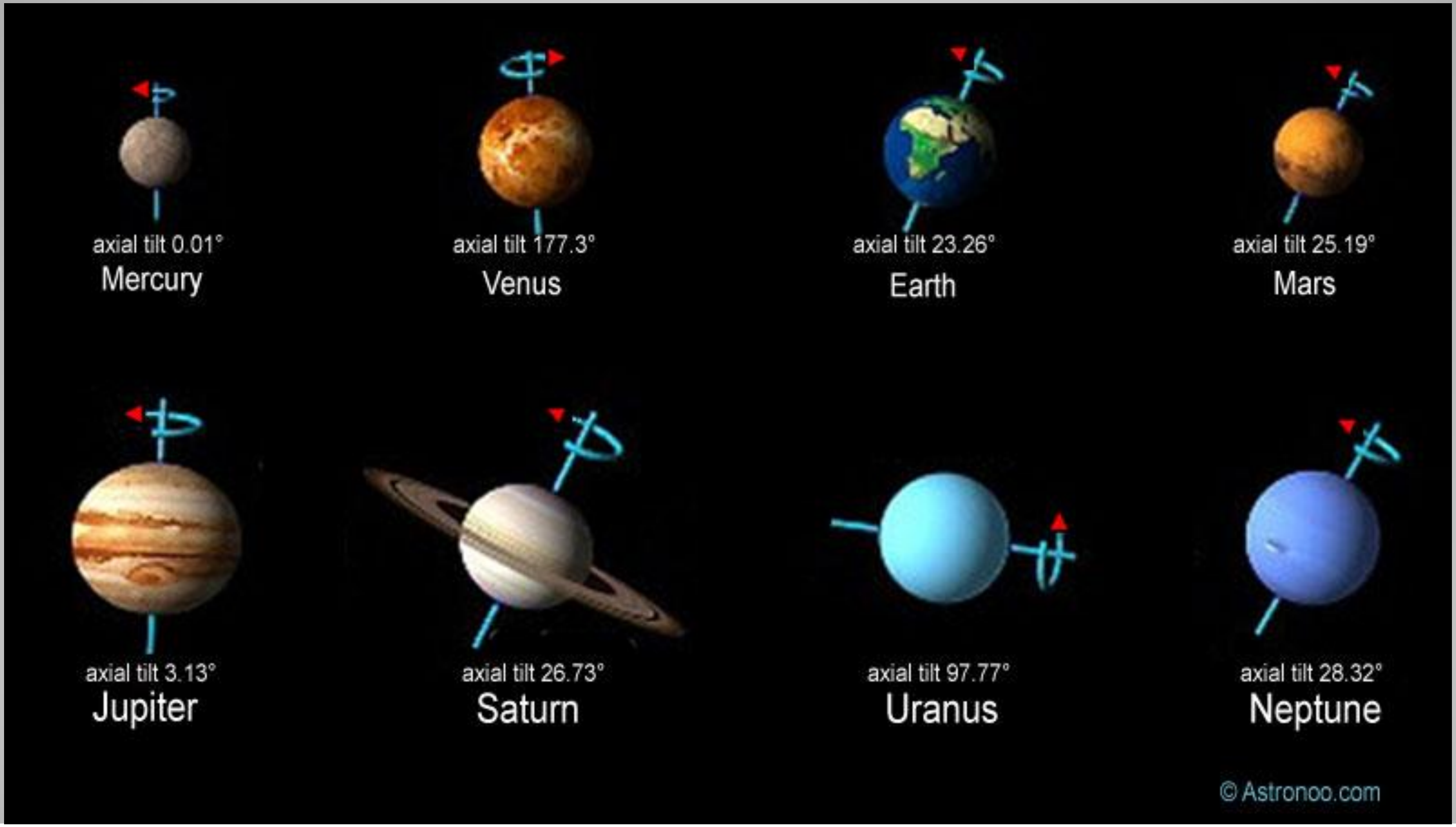
The Orbits and Rotations of the Planets

- Uranus has an extremely large tilt to its rotation axis (97.9˚)
- Venus's rotation axis has such a large tilt that it actually spins backwards (177. 4˚)
    - Still orbits in the same direction as the others around the Sun
- Retrograde rotation – when a planet's rotation axis is so steep that it spins backwards



Components of the Solar System

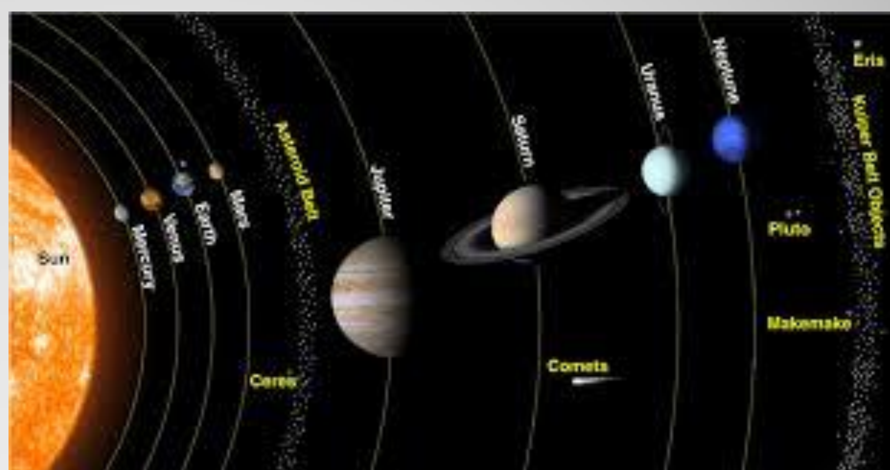
The Orbits and Rotations of the Planets



Components of the Solar System

The Orbits and Rotations of the Planets

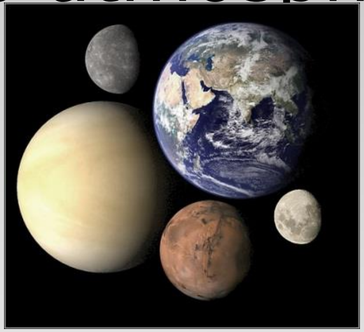
- These two factors (same direction orbit and flat plane) are the most fundamental features of the Solar System
- A third factor is that there are two different types of planets:
  - Inner
  - Outer
- Based on :
  - Size
  - Composition
  - Location in the Solar System



Components of the Solar System

Two Types of Planets

- Inner Planets – small, rocky bodies with relatively thin or no atmospheres
  - Mercury
  - Venus
  - Earth
  - Mars

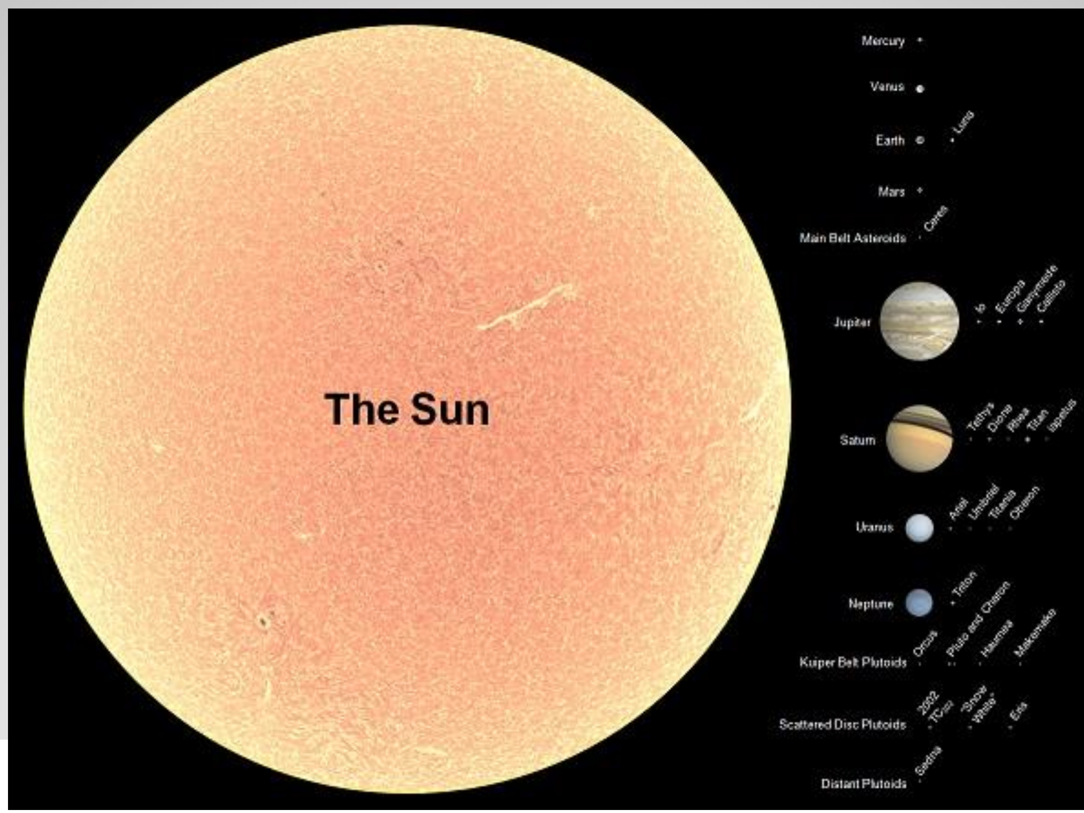


- Outer Planets – gaseous and liquid planets that are much larger and have deep, hydrogen-rich atmospheres
  - Jupiter
  - Saturn
  - Uranus
  - Neptune

Components of the Solar System

Two Types of Planets

- Jupiter is more than 10x larger in diameter than the Earth and has 318x its mass



Components of the Solar System

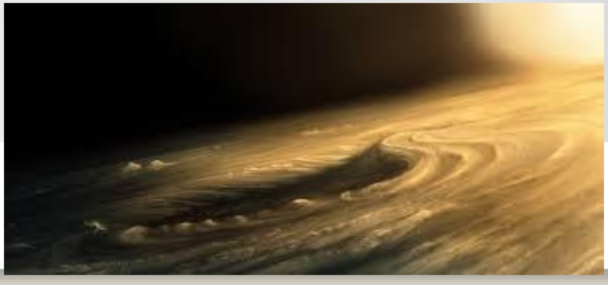
Two Types of Planets

- *Rock* and *ice* are how we describe the planets
- Rock – material composed of silicates
  - Silicates – composed of Si, O, and other heavier elements like Al, Mg, S, and Fe
- Ice – frozen liquids and gases
  - Such as:
    - Regular ice (H_2O)
    - Frozen carbon dioxide (CO_2)
    - Frozen ammonia (NH_3)
    - Frozen methane (CH_4)

Components of the Solar System

Two Types of Planets

- Looking at the entire solar system, rock is rare because of the amount of hydrogen
  - Because of the heat near the sun, the carbon dioxide, methane, water, and ammonia can't condense to mingle with it
- The outer planets have no "surface"
  - Their atmospheres thicken with depth and eventually convert to liquid
  - Therefore we can't "land" on Jupiter or the other outer planets



Components of the Solar System

Two Types of Planets

- Terrestrial Planets – Mercury and Mars
  - Because they resemble Earth
- Jovian Planets – Jupiter and Neptune
  - Because they resemble Jupiter

Components of the Solar System

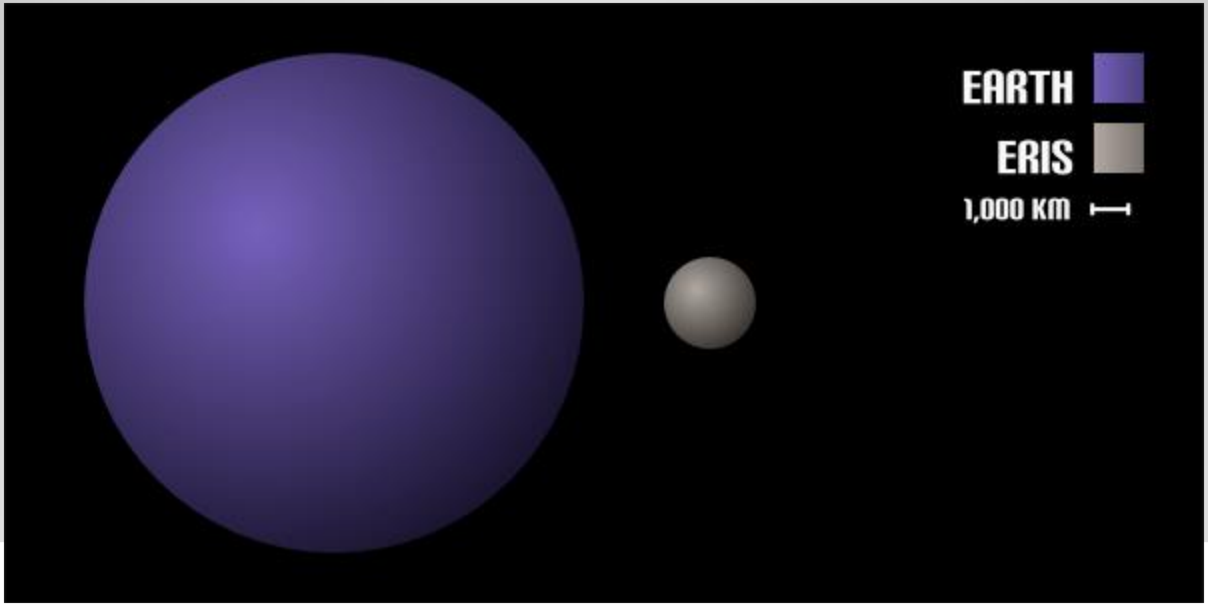
Two Types of Planets

- Why no Pluto?
  - Made if ice and rock
  - Odd orbit
  - Super small in comparison
- Astronomers found others similar to it
- Dwarf Planets – objects that orbit the Sun, are massive enough that their gravity compresses them into an approximately spherical shape, but have not swept their orbital region clear of other objects that add up to a comparable mass as the planet

Components of the Solar System

Two Types of Planets

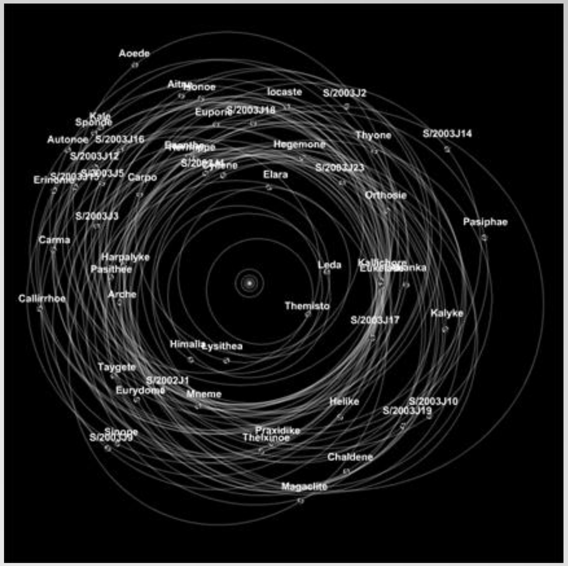
- The discovery of Eris in 2005 is what set the demotion of Pluto
  - Its closer than Pluto and also larger in size, but still fits the *dwarf* planet criteria



Components of the Solar System

Moons

- As the planets orbit the Sun, most are orbited by other objects
- Moons:
  - Jupiter: 67
  - Saturn: 62
  - Uranus: 27
  - Neptune: 14
  - Mars: 2
  - Earth: 1



- Even dwarf planets can have moons
  - Ex: Eris has 1

Components of the Solar System

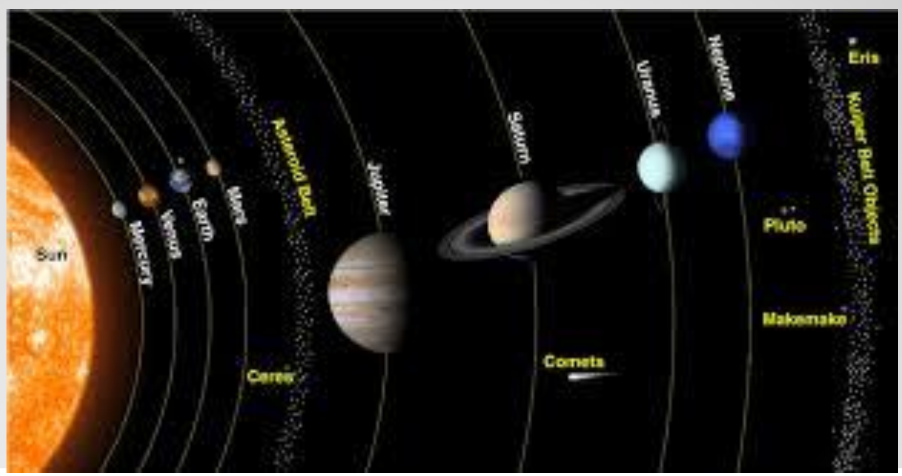
Asteroids and Comets

- Asteroids and comets are far smaller than planetary objects
- Asteroids – rocky or metallic objects with diameters that range from few meters up to about 1000 km
- Comets – icy objects about 10 km or less in diameter that grow huge tails of gas and dust as they near the Sun and are partially vaporized by heat

Components of the Solar System

Asteroids and Comets

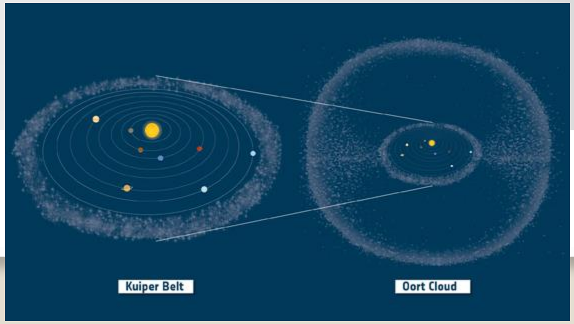
- These two are not only different in composition but also their location in the solar system
- Asteroid Belt – large gap between the orbits of Mars and Jupiter where asteroids orbit the Sun



Components of the Solar System

Asteroids and Comets

- Most comets orbit far beyond Neptune
- Oort Cloud – spherical region that completely surrounds the solar system
  - Extends from about 40,000 to 100,000 AU from the Sun
  - Some can come Kuiper
- Kuiper Belt - the disk-like swarm of icy objects that lies just beyond the orbit of Neptune and extends to be about 50 AU from the Sun



Components of the Solar System

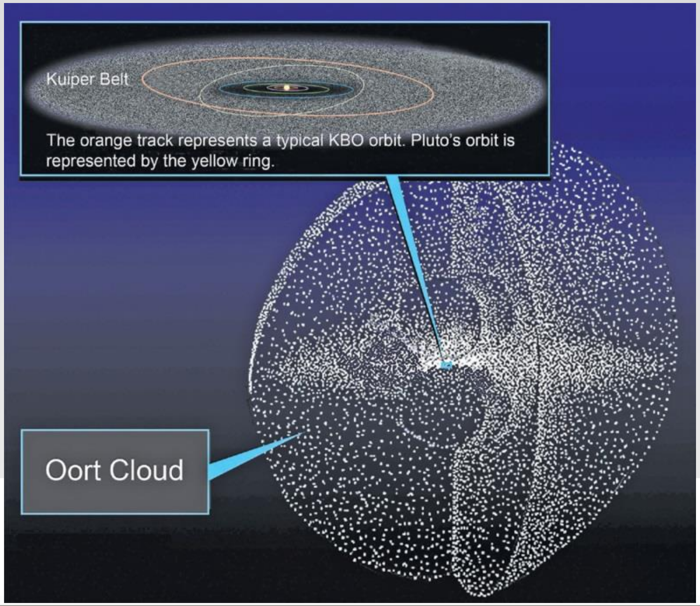
Composition – Inner and Outer Planets

- We can detect a planet's composition a couple different ways
- Using its spectrum, we can measure its atmospheric composition and get some info about its surface rocks (if they're there)
- We use earthquake waves to tell us about Earth's interior and even though we haven't been able to do that with the other rock planets yet, it would tell us a lot of information

Components of the Solar System

Asteroids and Comets

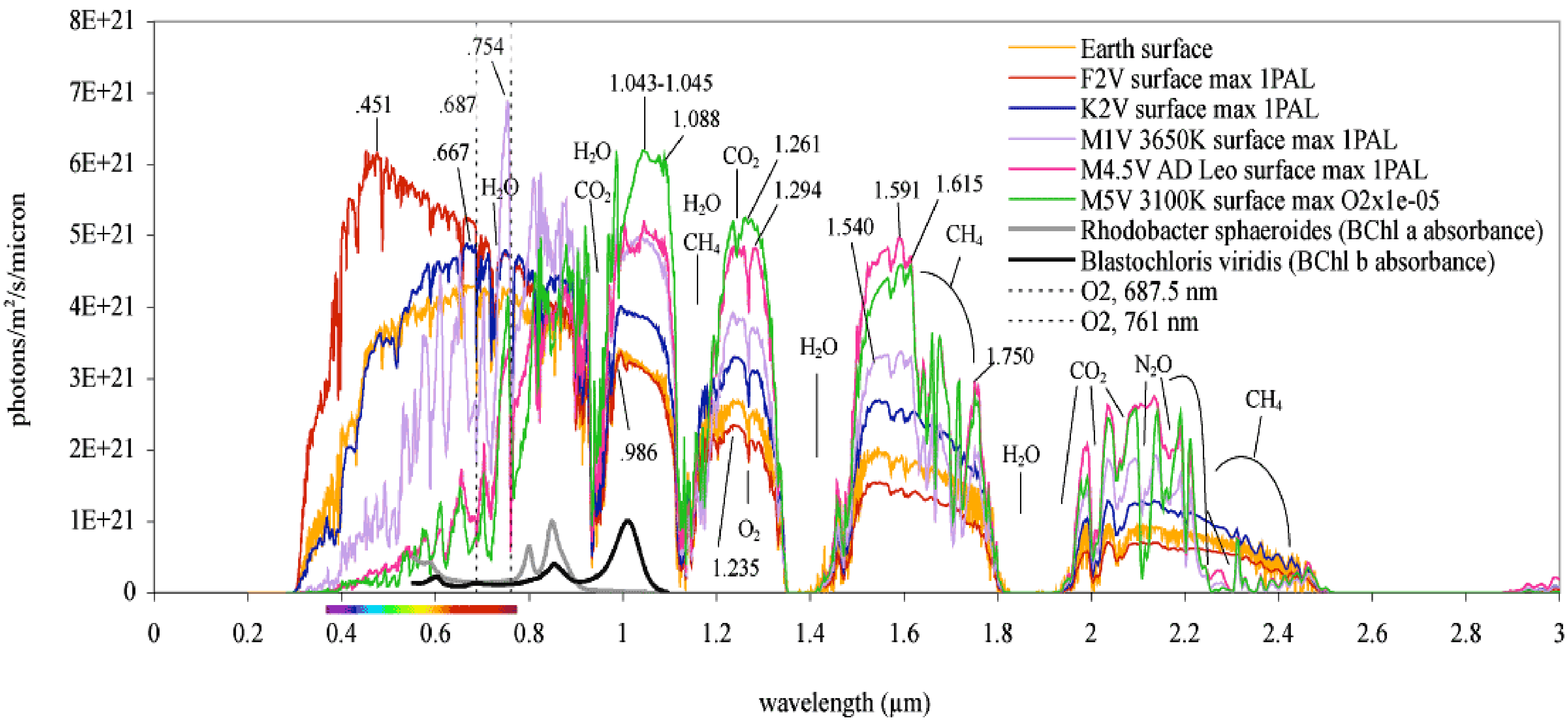
- The Oort cloud and Kuiper put together can hold:
  - more than 1 trillion ($1x10^{12}$) comets
  - thousands of larger objects
  - Several dozen dwarf planets – including Pluto



Components of the Solar System

Composition – Inner and Outer Planets

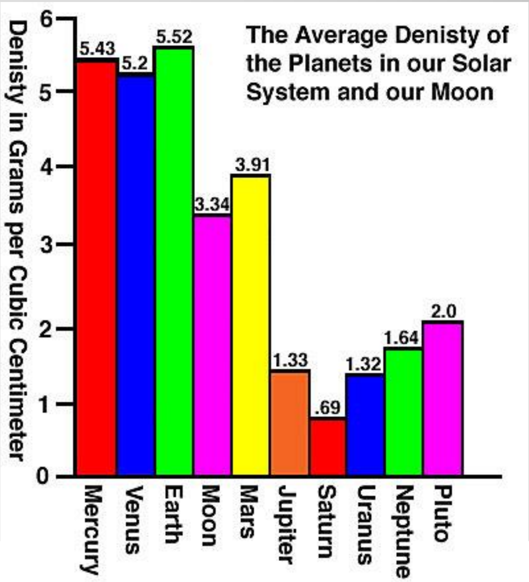
- Earth – detected by satellites and simplified by NASA



Components of the Solar System

Composition – Inner and Outer Planets

- For gas planets, we can't use any type of rock work and the spectrum only takes care of the surface and atmosphere
- The simplest technique to use is planetary density



Components of the Solar System

Planetary Density

- The average density of a planet is its mass divided by its volume
  - We can calculate a planet's mass by observing the orbital motion of one of its moons or a passing spacecraft
  - Then we can calculate the volume of the planet using one of Kepler's formulas from his third law

$$V = \frac{4\pi R^3}{3} \qquad M = \frac{4\pi^2 d^3}{GP^2}$$

Components of the Solar System

Planetary Density

- Volume
  - Variable:
    - R – radius of the planet

$$V = \frac{4\pi R^3}{3}$$

- Mass
  - Variables:
    - d – distance of object from the planet
    - G – gravitational constant
    - P – orbital period

$$M = \frac{4\pi^2 d^3}{GP^2}$$

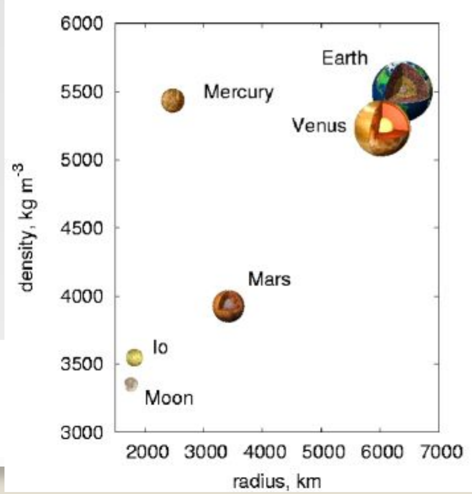
- Density

$$D = \frac{M}{V}$$

Components of the Solar System

Planetary Density

- Once the planet's average density is known, we can compare it with the density of the abundant, candidate materials to find what would mathematically match up!
  - We figured this out using Earth's density, calculating the silicate and iron densities and cross comparing them with the earthquake waves… it worked!



Components of the Solar System

Planetary Density

- Drawbacks of this strategy:
  - Several different substances that will produce an equally good match to the observed density
  - The density of a given material can be affected by the planet's gravitational force
- Conclusion:
  - All of the terrestrial planets have a similar density to Earth (about 3.9 to 5.5 g/cm^3)
    - Largely rock with iron core

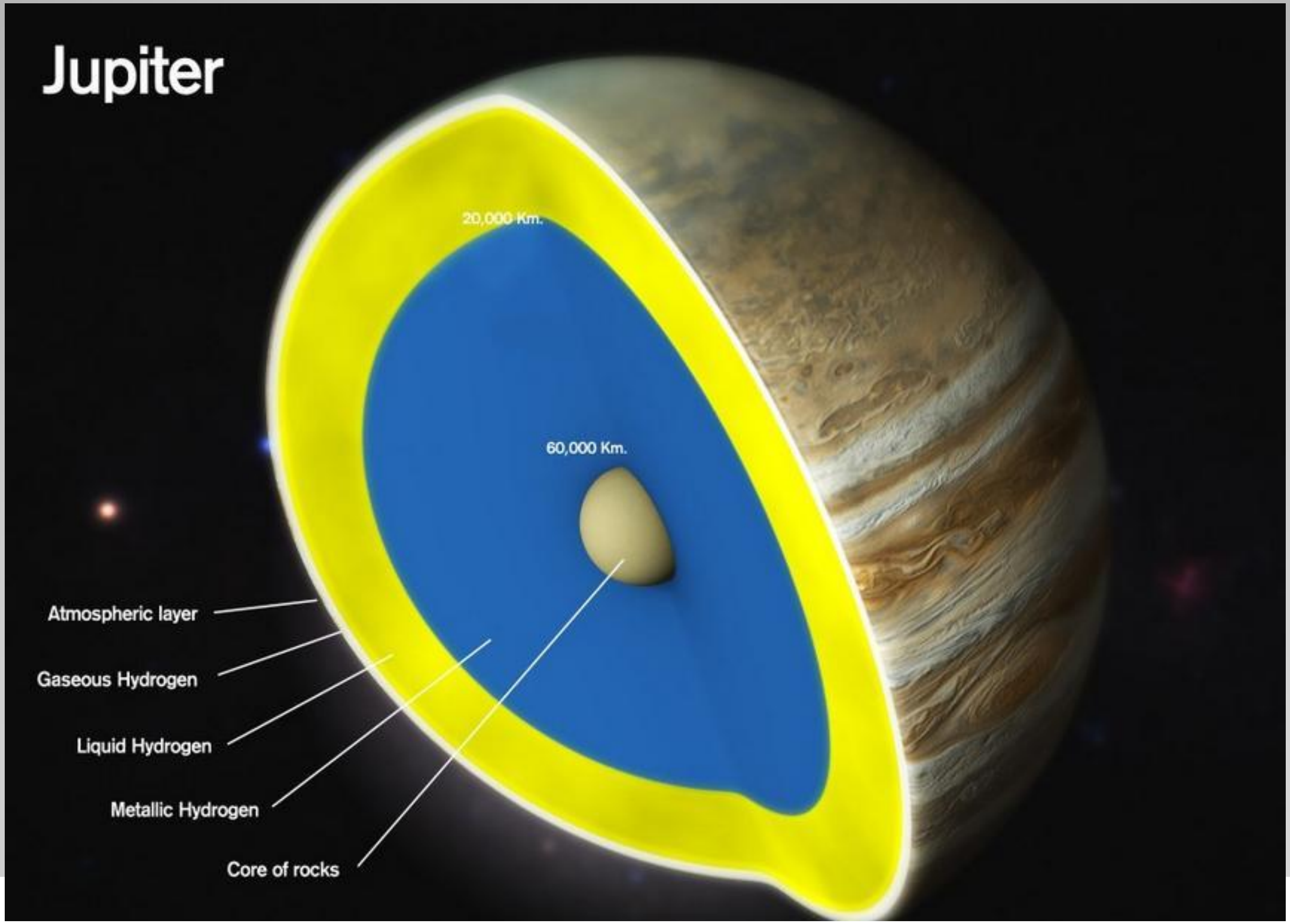
Components of the Solar System

Planetary Density

- Conclusion
  - All of the Jovian planets have a much smaller density (.7 to 1.7 g/cm^3) – similar to ice
    - Contain mainly methane, ammonia, and ice (H_2O)
  - Probably have an iron core and rock base the size of Earth on the inside
    - This was figured out based on the mass calculations and the effects of gravitational pull that these planets can create
    - Jupiter – estimated core 7x the mass of Earth… something solid has to be there…

Components of the Solar System

Planetary Density

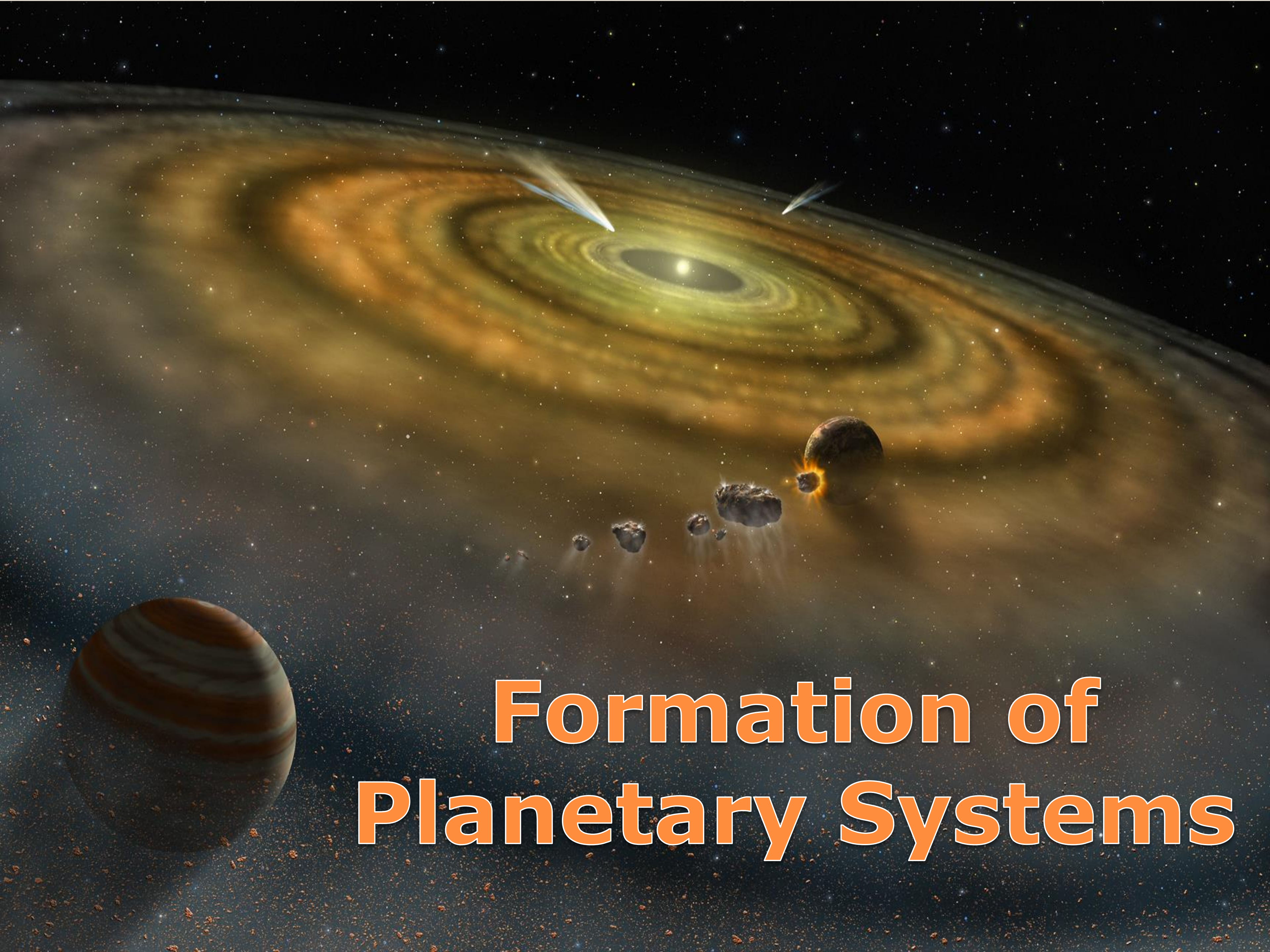


Components of the Solar System

Age of the Solar System

- Outside of their differences in size, composition, and structure, it seems as though almost everything in the solar system formed at nearly the same time
- We can directly measure that date for the Earth, moon, and some asteroids
  - Thanks to radioactivity of their rocks
  - None are more than 4.6 billion years old
- The Sun is our age, too
  - Based off of its current brightness, temp., and rate of nuclear fuel consumption

Formation of Planetary Systems



Formation of the Solar Systems

Introduction

- Not easy to figure out…
  - Why? We weren't there to witness it
- Whatever we come up with has to support these properties of the solar system:
  - The system is flat, with all of the planets orbiting the same direction
  - There are two types of planets, inner and outer
    - With the inner being rock and outer being ice and gas
  - The composition of the outer planets isn't too far off of the sun's, and the same is true for the inners (minus the gas)
  - All of the bodies whose ages have so far been determined are younger than 4.6×10^9 years old

Formation of the Solar Systems

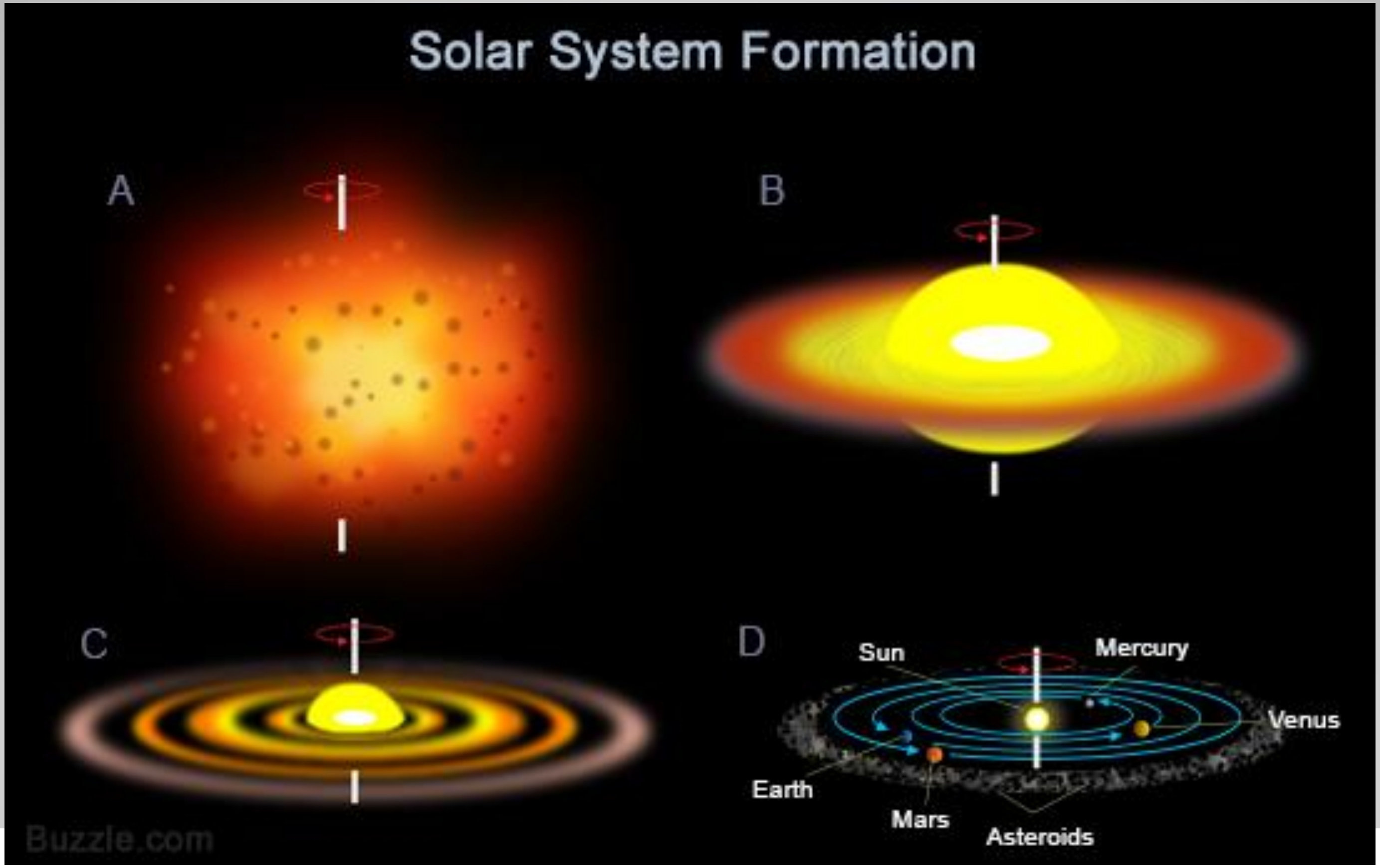
Introduction

- Top theory: Solar Nebula Theory
  - States that the solar system originated from a rotating, flattened disk of gas and dust, with the outer part of the disk becoming the planets and the center becoming the Sun
    - Supports: the horizontal plane and the counterclockwise orbit of all of the planets
- We assume that if there are other solar systems out there that could be similar to ours, their properties must be similar

Formation of the Solar Systems

Introduction

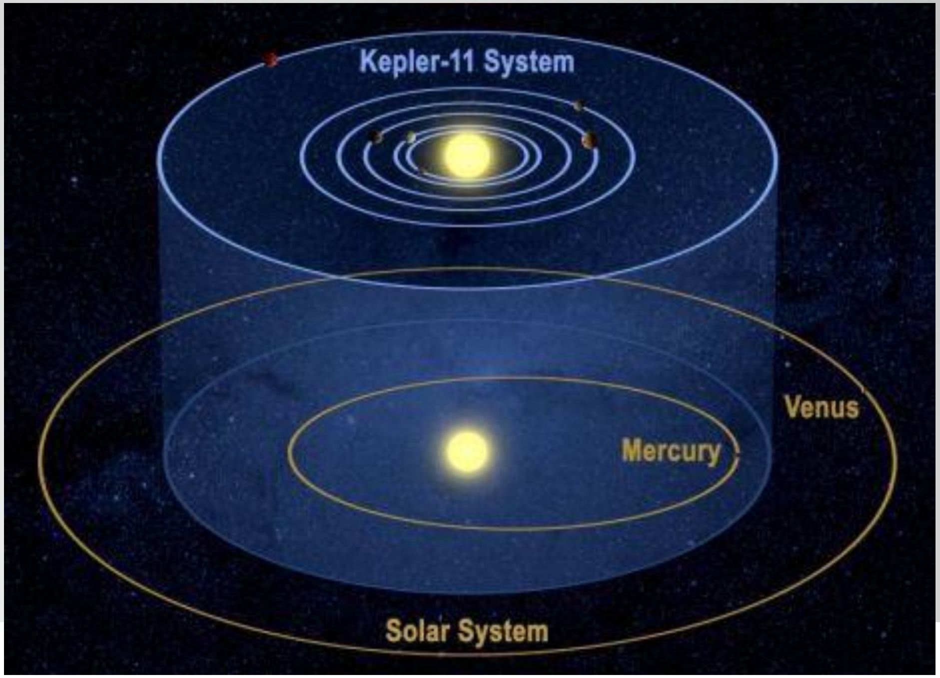
- Top theory: Solar Nebula Theory



Formation of the Solar Systems

Introduction

- Top theory: Solar Nebula Theory
- We are searching for and studying other stars in various stages to see if these stages are similar



Formation of the Solar Systems

Interstellar Clouds

- Interstellar Cloud – enormous rotating aggregate (whole combo) of gas and dust
  - Common between stars and astronomers believe these are what developed into each of the stars
  - Right now, *MOST* stars could have planets orbiting them… we have no way to know for sure right now
    - Both the stars and the planets would have developed from that dust and gas

Formation of the Solar Systems

Interstellar Clouds

- The cloud that developed into the Sun was probably every bit of a couple light years in diameter and twice the present mass of the sun
- Interstellar Grains – tiny dust particles found amongst the gases in interstellar clouds
  - Combo of: silicates, iron, carbon, and frozen water
  - These elements have been shown in the same proportions of the Sun according to the Sun's spectra

Formation of the Solar Systems

Interstellar Clouds

- The cloud began converting into the Sun and planets when the gravitational attraction between the particles in the densest parts of the cloud caused it to collapse inward
  - Could've been triggered by a star exploding nearby or hitting into another cloud
  - Because the cloud was rotating, it became flat rather than fully collapsing in the middle

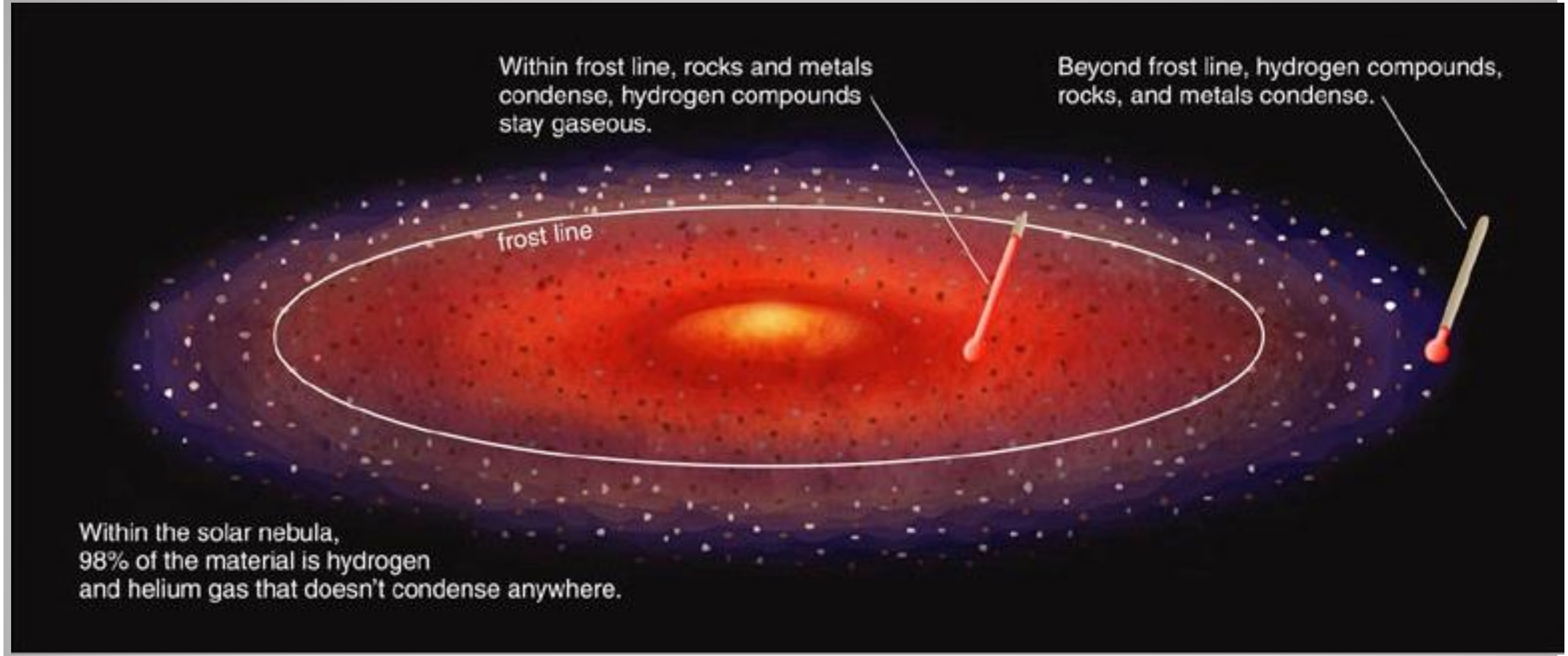
Formation of the Solar Systems

Formation of the Solar Nebula

- Solar Nebula – rotating disk with a bulge at the center from a collapsing interstellar cloud
  - Took a few million years to occur
  - Condensed into the planets while the bulge became the sun
  - This supports the disk-like structure and the orbit pattern of the planets
  - Probably about 200 AU in diameter and *possibly* 10 AU thick
  - Some areas were really hot (especially the center) while others were well below the freezing point
  - We have been able to figure this out thanks to the Hubble and seeing the same set-up with other stars

Formation of the Solar Systems

Formation of the Solar Nebula



Formation of the Solar Systems

Condensation in the Solar Nebula

- Condensation – occurs when a gas cools and its molecules stick together to form a liquid or solid
  - There was an entire condensation sequence in the solar nebula as it cooled after collapsing
  - The Sun's heat could only reach so far and that division in condensation created the inner and outer planets
    - The silicate-iron particles in the inner part
    - Similar outer part but with ice

Formation of the Solar Systems

Accretion and Planetesimals

- Accretion – when tiny particles that condensed from the nebula must have begun to stick together into bigger pieces
  - This eventually created the planetesimals
- Planetesimals – small planet-like bodies
  - Perhaps held together by electrical forces like static electricity
  - Collisions (that weren't too crazy) allowed particles to stick together, too
  - Range in size from a few mm to km

Formation of the Solar Systems

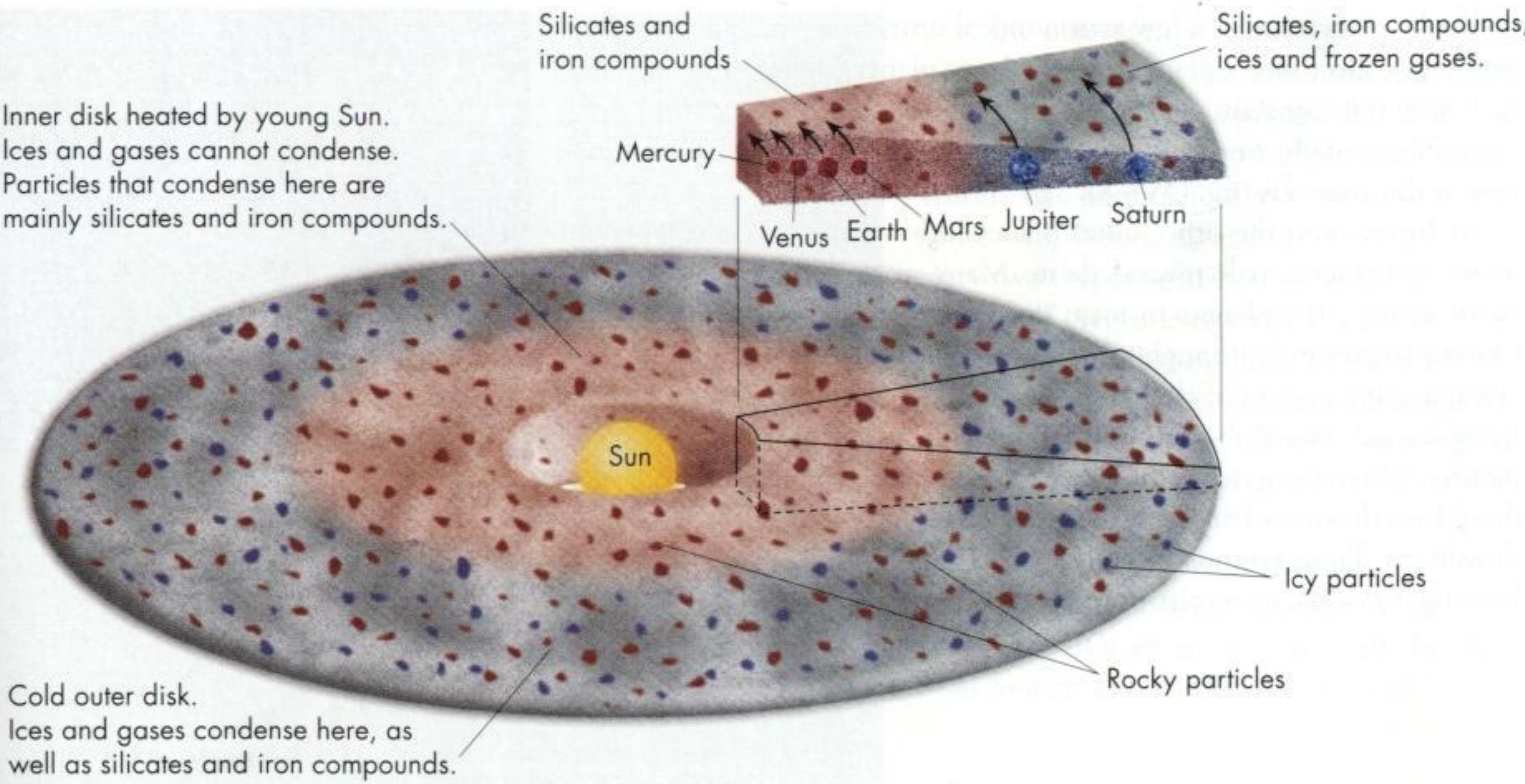


FIGURE OV4.6

Heat from the young Sun prevented ice from condensing in the inner parts of the Solar Nebula. The planetesimals—and ultimately the planets—that formed there are therefore composed mainly of rock and iron.

Formation of the Solar Systems

Formation of the Planets

- As the planetesimals moved within the disk and collided, planets began to form
  - Some hit and shattered while others that collided more gently stuck together
  - Due to gravity, substances found in certain areas of the nebula, and other chemical factors (like density) it has been concluded that these collisions are what lead the outer planets to be so much larger than the inner ones
  - Almost all of the planets accumulated like Earth, but the inner planets couldn’t hold the gas layers like the outers and therefore they became much larger in volume

Formation of the Solar Systems

Formation of Satellite Systems

- The satellite systems include the moons and other materials that orbit planets
  - This developed once the planet was able to develop a larger mass, strong enough to begin attracting other objects to itself
  - Many of the satellites (moons) are about as large as Mercury and would be considered planets if they orbited the sun rather than another planet

Formation of the Solar Systems

Formation of the Atmospheres

- Last part of the development
- Inner and outer planets are thought to have formed atmospheres differently
  - Outer: captured the gases from the nebula
  - Inner: not massive enough and too hot to capture the gas from the nebula
    - Likely created their own from volcanoes and by retaining gases from infalling comets and icy planetesimals that vaporized on contact

Other Planetary Systems

Other Planetary Systems

Introduction

- Exoplanets – planets orbiting stars other than the Sun
  - Studying other planets helps us better understand how our solar system developed
  - Most present evidence fro exoplanets comes from their effect on the star they orbit
    - The planet exerts a gravitational force back on the star as a result of Newton's third law (action-reaction)
    - This causes the star to wobble which creates a Doppler shift in the spectra that we can measure

Other Planetary Systems

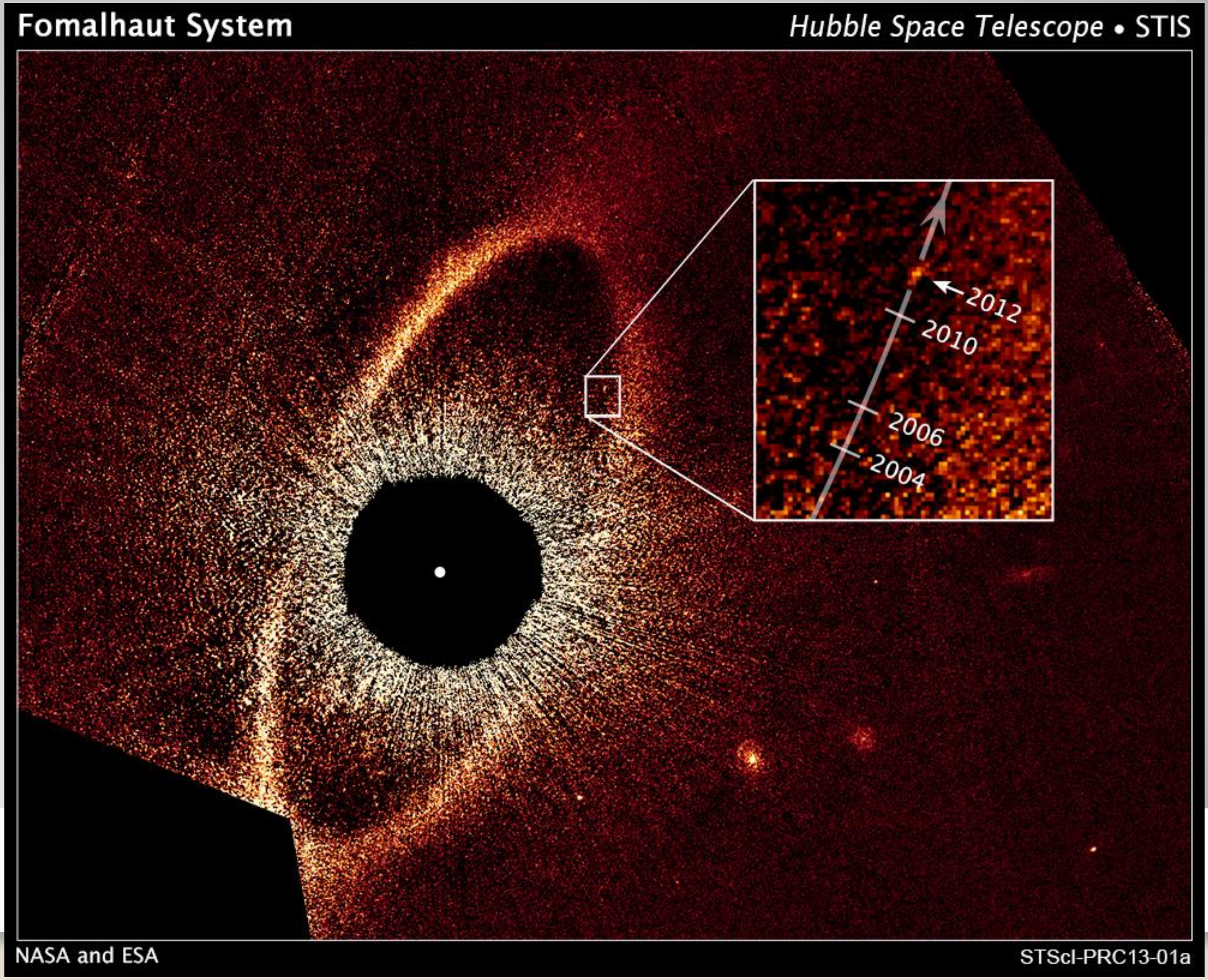
Introduction

- Fomalhaut – a star with a detected exoplanet
  - Estimated to be a 200 million year old star
  - Has an ice ring around it (similar to Kuiper's belt)
  - The planet is assumed to have been growing by accreting that frozen material
  - The exoplanet is really faint and hard to see against the star's light, but the evidence from the star, itself, tells us a lot about that exoplanet

Other Planetary Systems

Introduction

- Fomalhaut – a star with a detected exoplanet

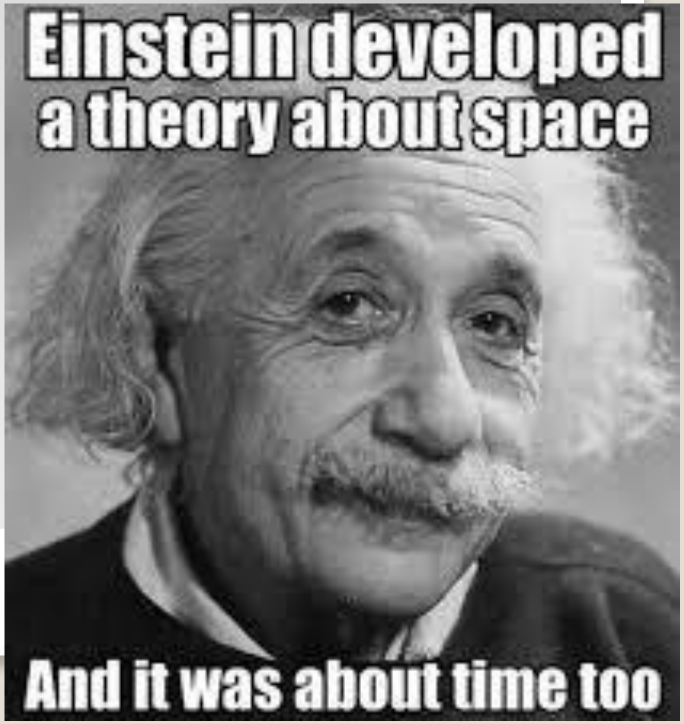


Other Planetary Systems

Finding Exoplanets

- Many of the objects we pick up on are large in size and close to their star
- This allows us to pick up on that Doppler signal since most are hardly visible, even being large in size
- Another idea…

  use Einstein's approach

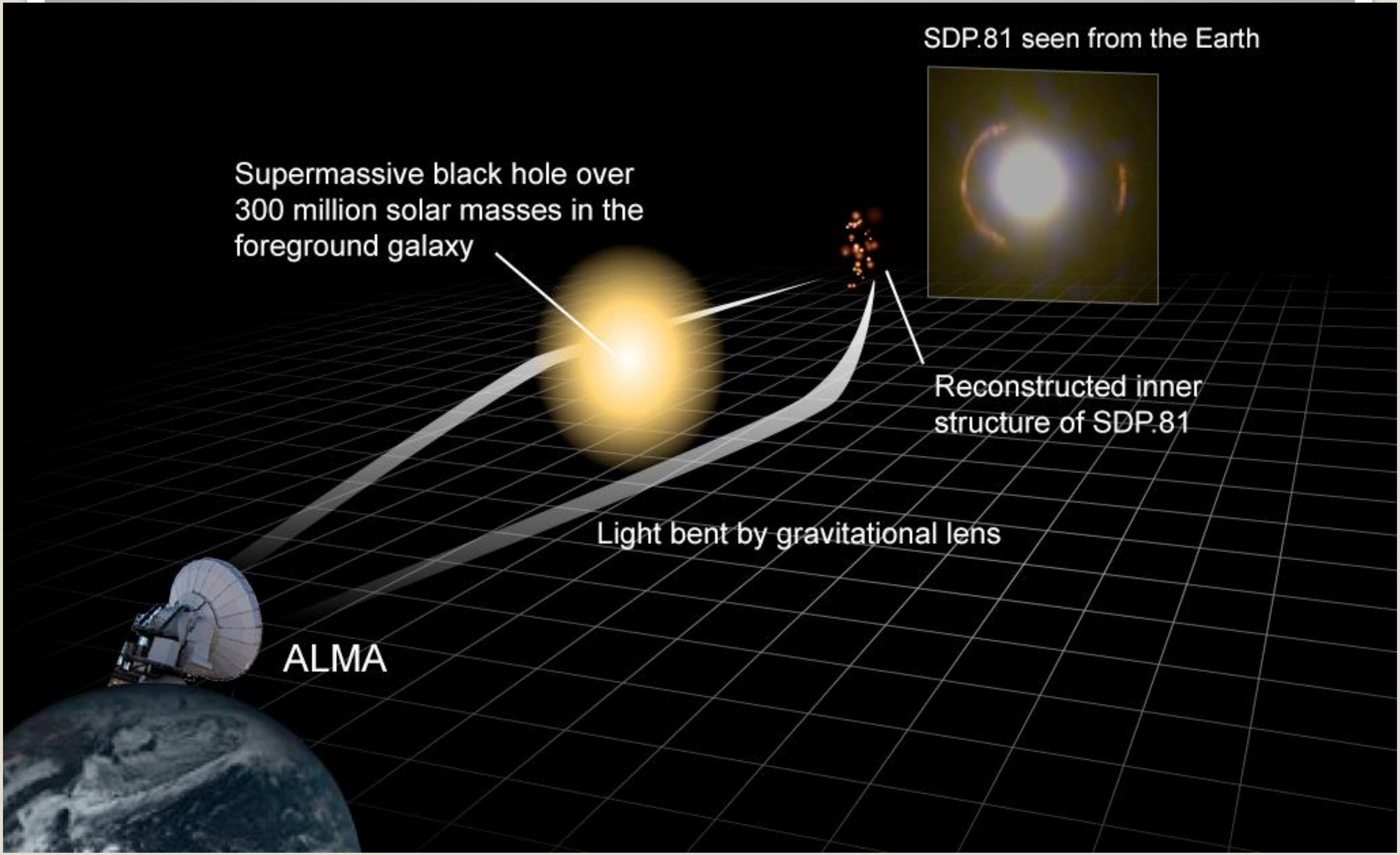


Other Planetary Systems

Einstein's Approach

- He showed that a mass bends space in its vicinity and that this bending creates the mass's gravity
  - Part of his general theory of relativity
- If a ray of light passes near a mass, the bent space around the mass deflects the light and can bring it to a focus

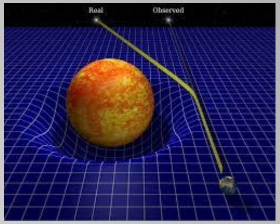
Other Planetary Systems



Other Planetary Systems

Einstein's Approach

- Gravitational Lensing – bending of light by gravity
  - Great tool for detecting low-mass planets
  - How it works:
    - Measure a star's brightness
    - If a planet crosses in between, its mass will bend the light and because of reflection actually focus more light our way (it's not much more, but hey, any little bit helps)



- Astronomers are running billions of data screens on millions of stars to detect any slight increase in that brightness level that might suggest a planet or big body that would be present

Other Planetary Systems

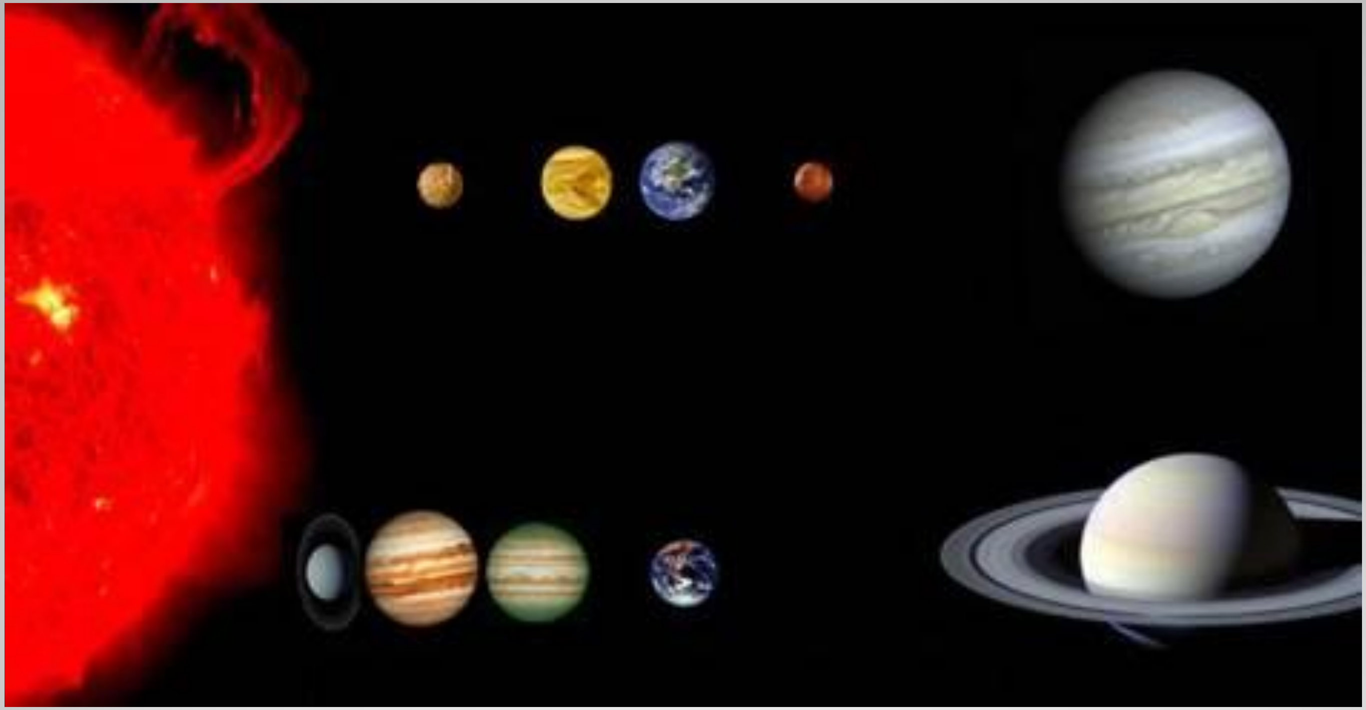
Exoplanet Systems

- As of what has been released to the public, astronomers haven't found a system that looks particularly like our own
- The nearest match so far is the system of planets orbiting the star *55 Cancri*
  - This sun-like star has five planets orbiting within 6 AU of the star just like ours
  - All of the planets are massive (10x Earth)
  - 3 of the planets orbit closer to the star than Mercury does from the Sun

Other Planetary Systems

Exoplanet Systems

- *55 Cancri*



Other Planetary Systems

Exoplanet Systems

- *55 Cancri* and its set up really challenges our understanding of how the solar system set itself up
  - having giant gas planets so close to the star
  - According to solar nebula, they should've formed much further back off of the star where the temperatures are much lower
  - Astronomers are working on understanding what's different in systems like that one that make this scenario possible in its solar system and not ours

Other Planetary Systems

Exoplanet Systems

- It is thought that planets in other systems might have the ability to "migrate" within the system
- Others are known to have elliptical orbits rather than circular ones which can damage or effect the orbits of smaller planets in that same system
  - This can either eject them out or cause them to crash into the star

The research continues….