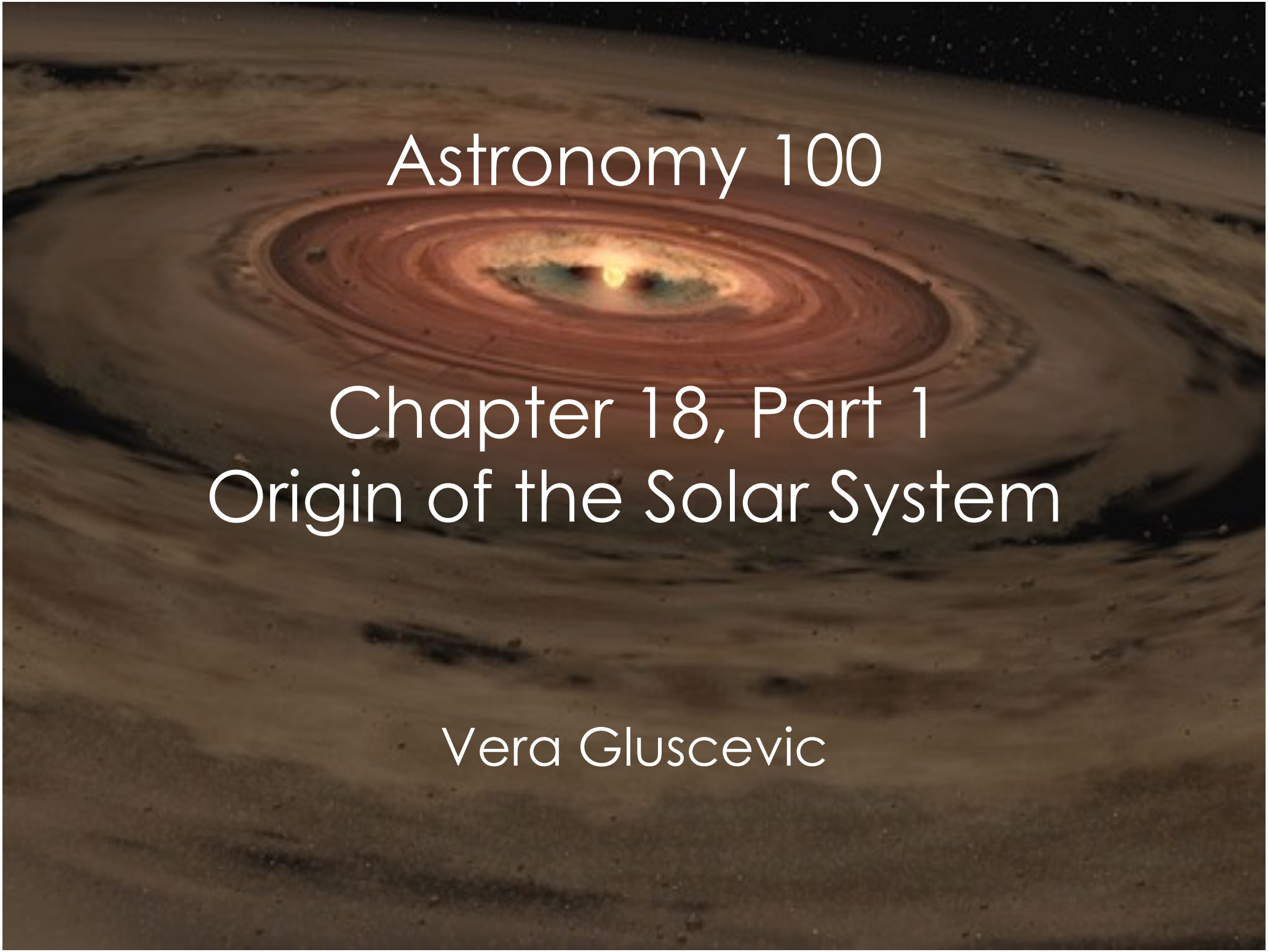


# Astronomy 100

# Chapter 18, Part 1
# Origin of the Solar System

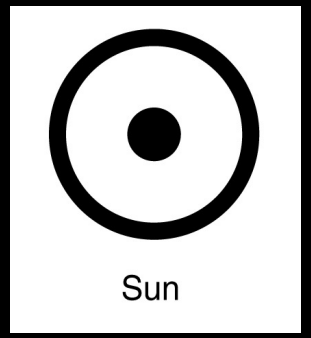
Vera Gluscevic

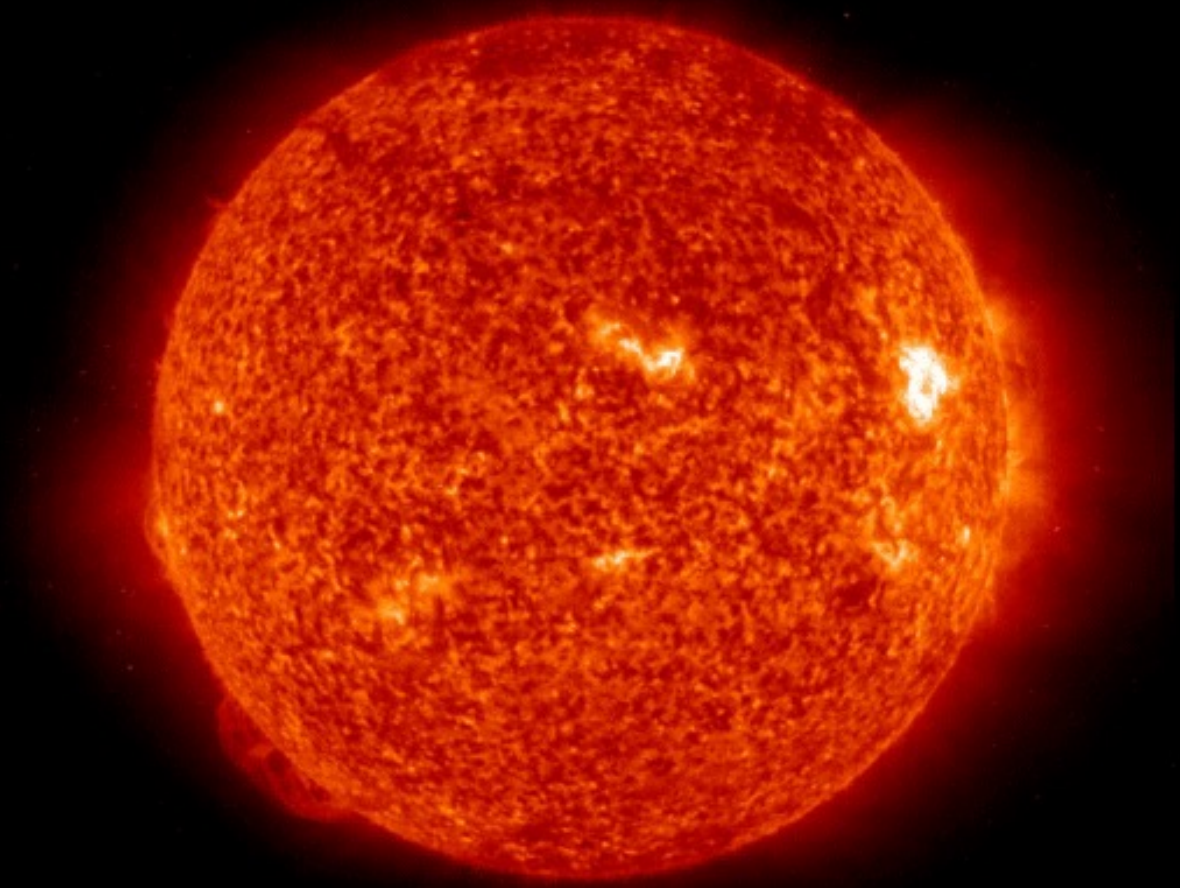
## Plan for this lesson:

Overview of the Solar System
Discoveries of planets
Formation of the Solar System
Measuring ages of planets

# Overview of our Solar System

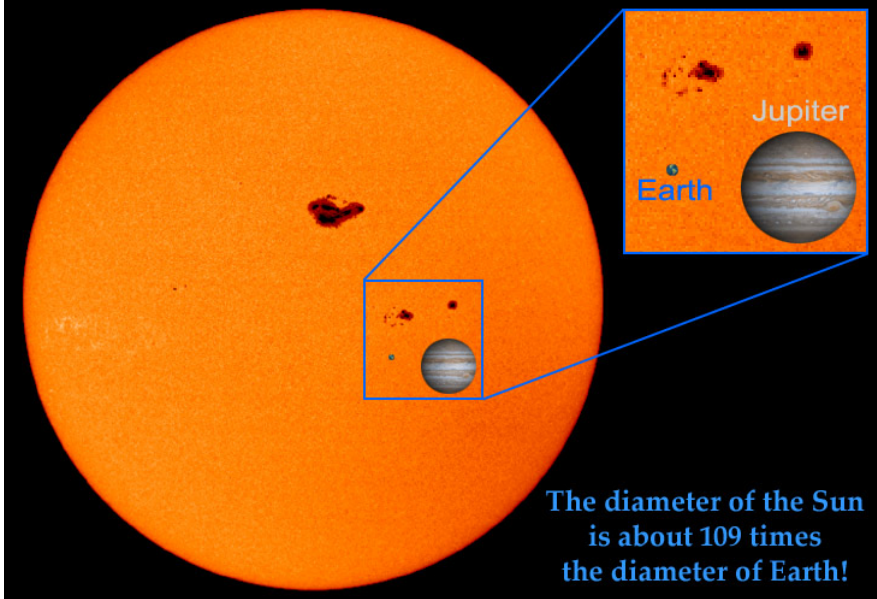
# The Sun



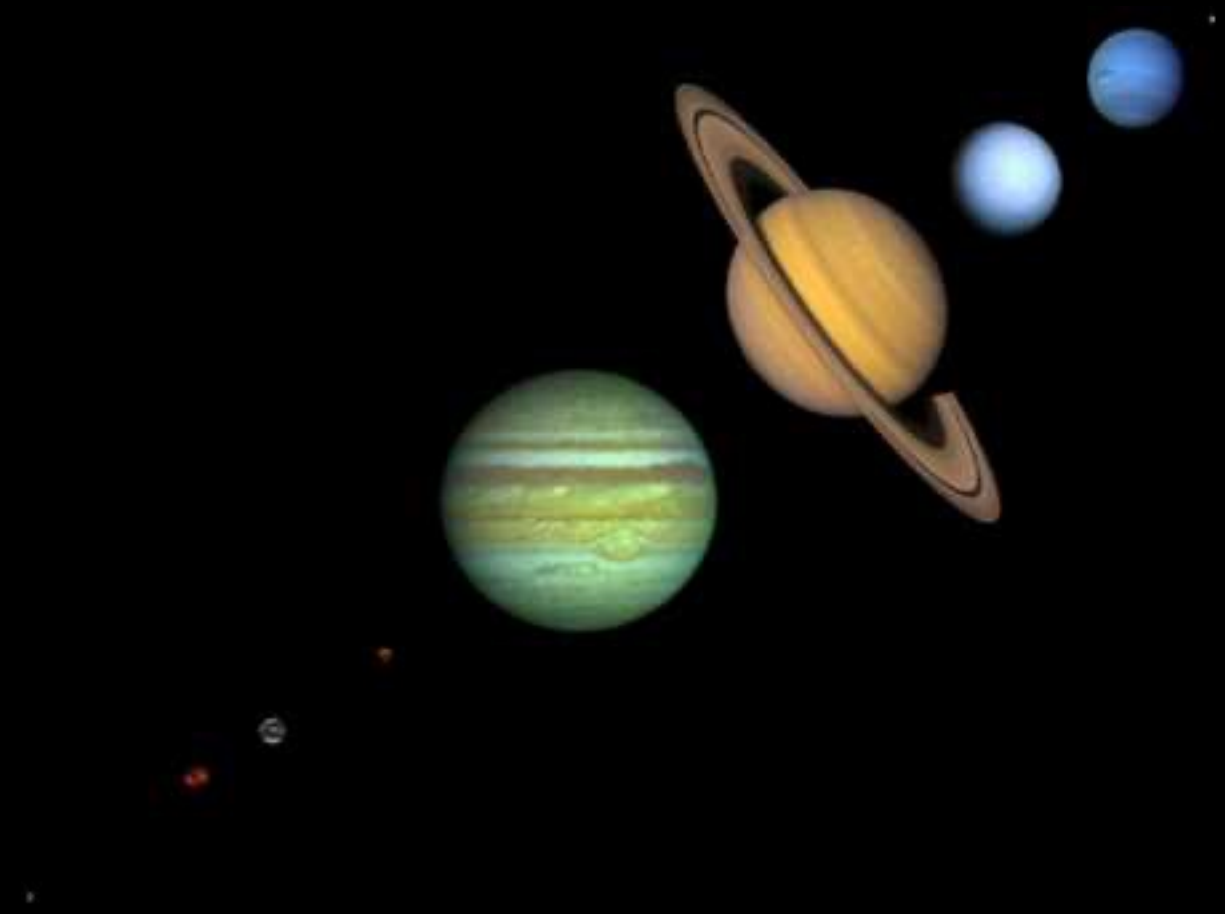



# The Sun

- The Sun is a star with a surface temperature of 9,941 °F or about **5800 K**.
- Mass is 330,000 times the mass of the Earth, volume is more than a million times Earth's.
- Accounts for **99.86% of the total mass of the Solar System** (1000 times more mass than all planets combined).
- The Sun formed **4.5 billion years ago**…

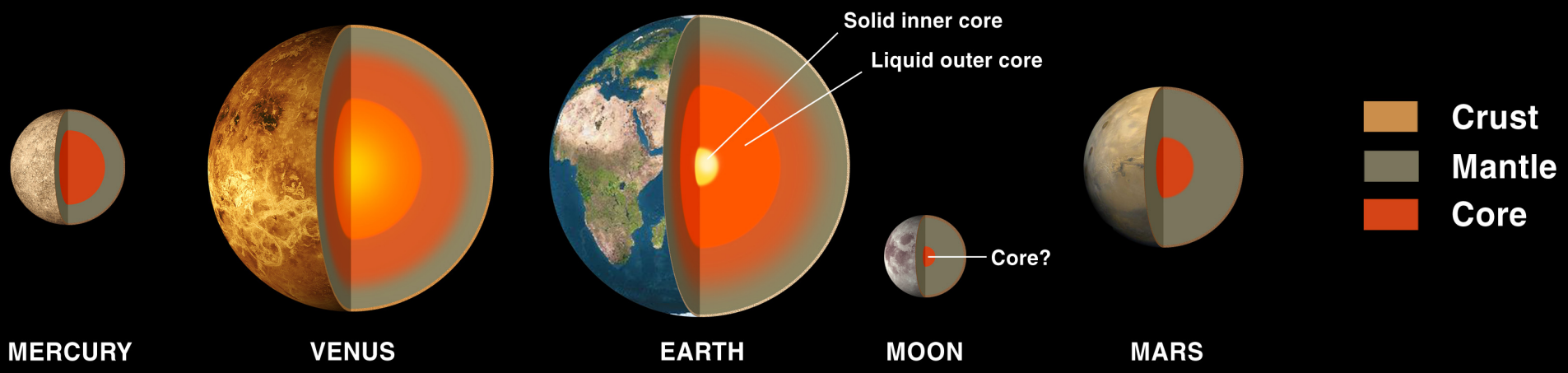


# The planets



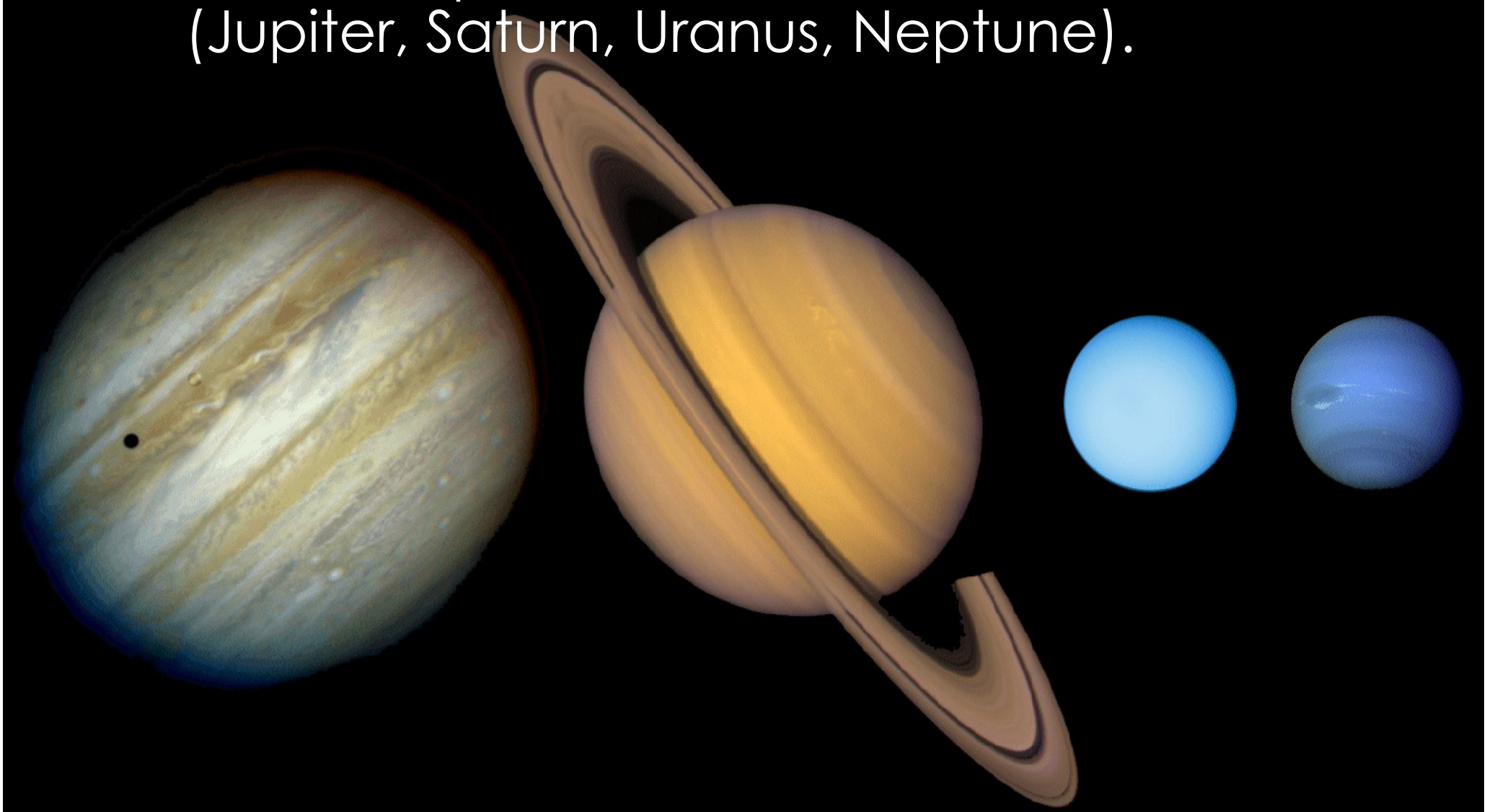
# Terrestrial planets

- Four planets closest to Sun are terrestrial (Mercury, Venus, Earth, Mars).

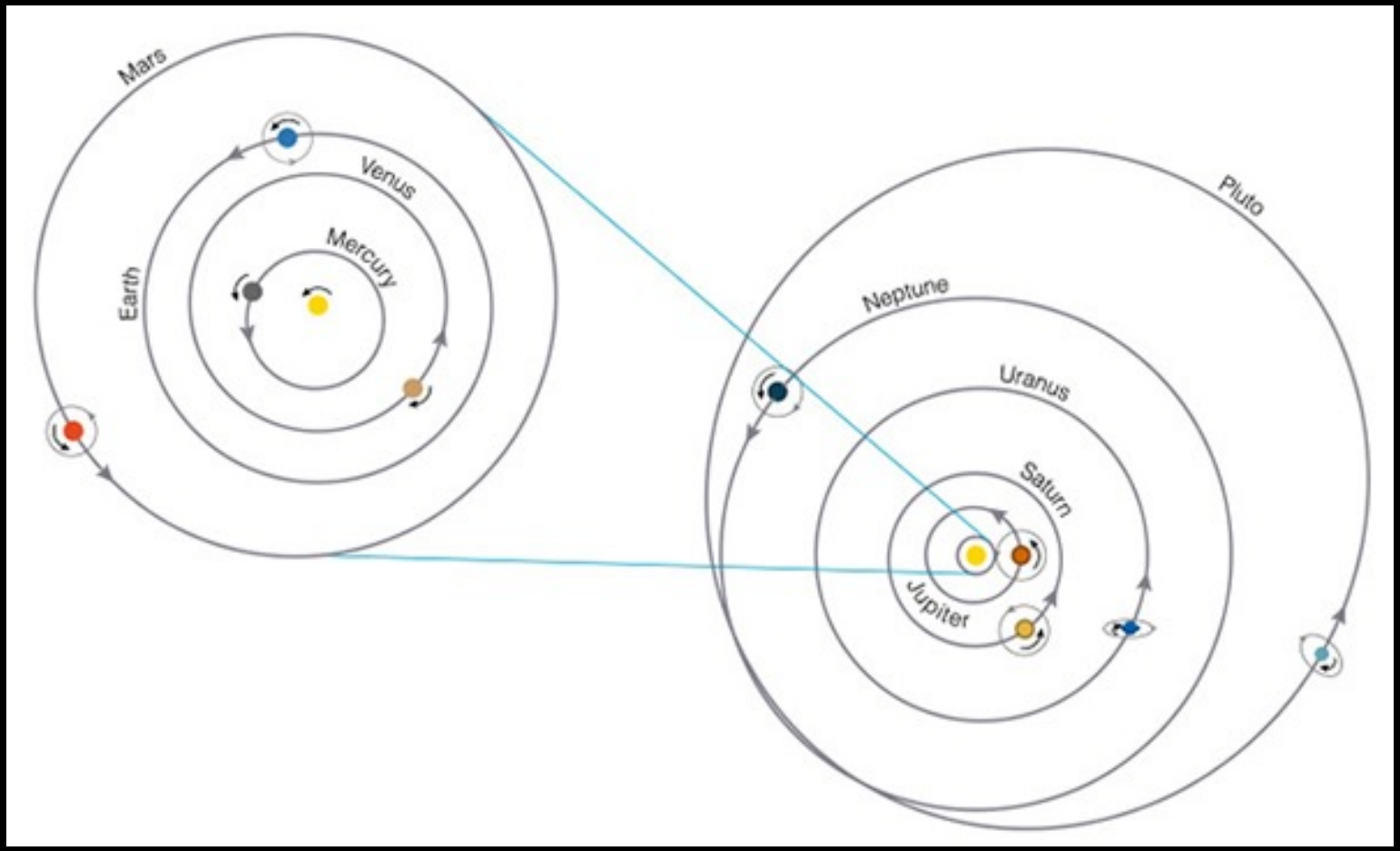


# Jovian planets

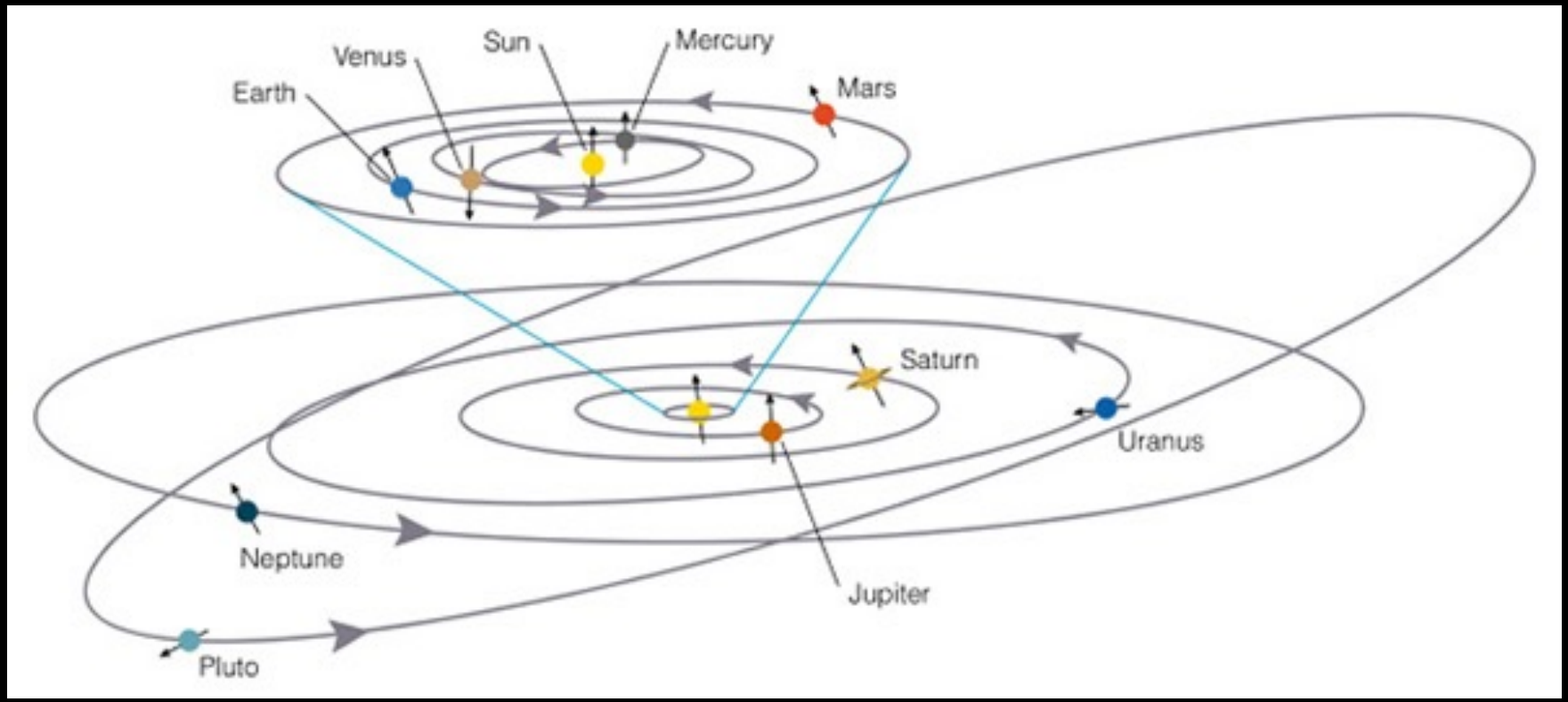
- Next four planets are “Gas Giants” (Jupiter, Saturn, Uranus, Neptune).



# Architecture of the Solar System



# The Solar System: side view

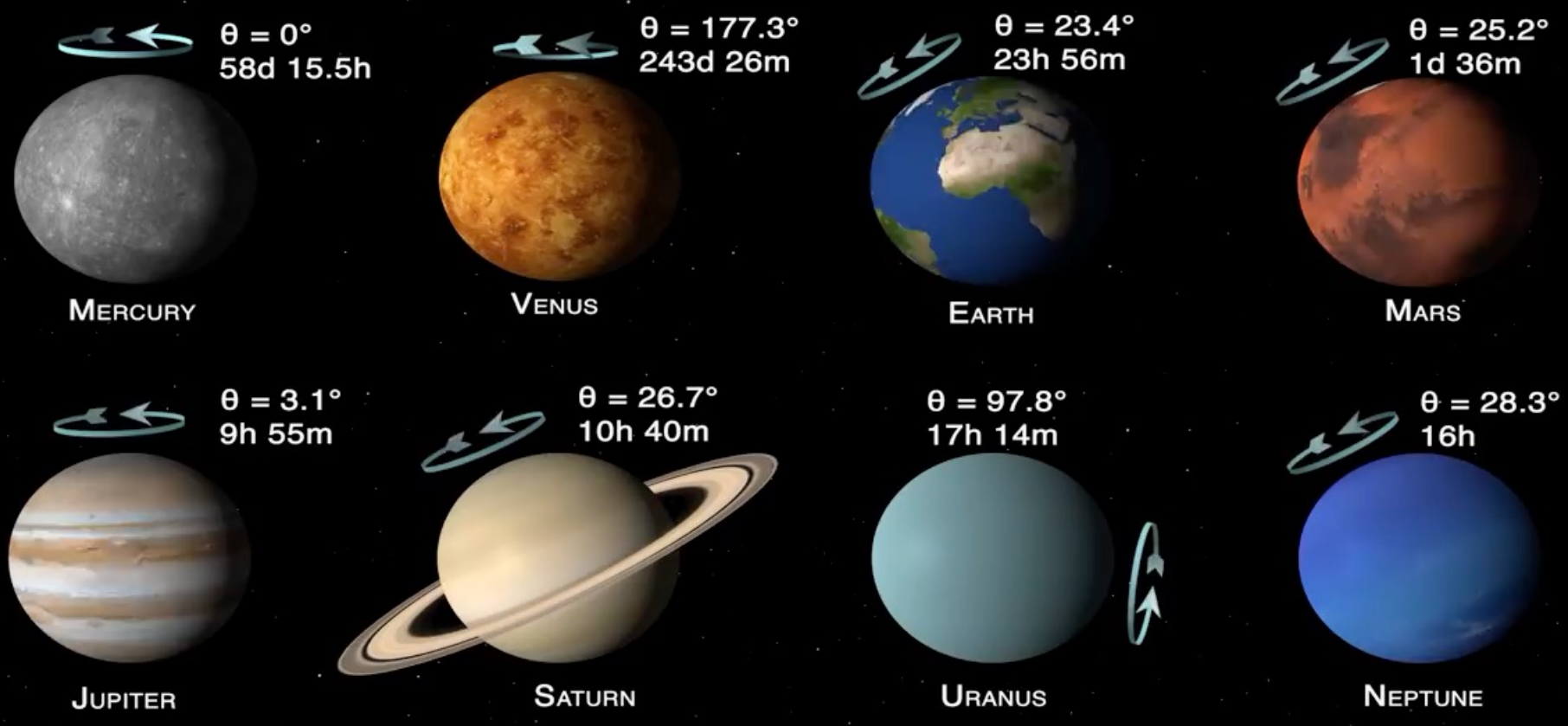



Explore also: https://solarsystem.nasa.gov/

# Terrestrial vs. Jovian Planets

- Terrestrial planets have smaller size and mass.
- Terrestrial planets have higher density.
- Terrestrial planets are made up of rocks and metals, Jovian planets are made up of hydrogen, helium, and hydrogen compounds.
- Terrestrial planets have a solid surface, Jovian planets do not.
- Terrestrial planets have very few (if any) moons, and no rings. Jovian planets have lots of moons, and all have rings.

# Rotation Rates of the Planets

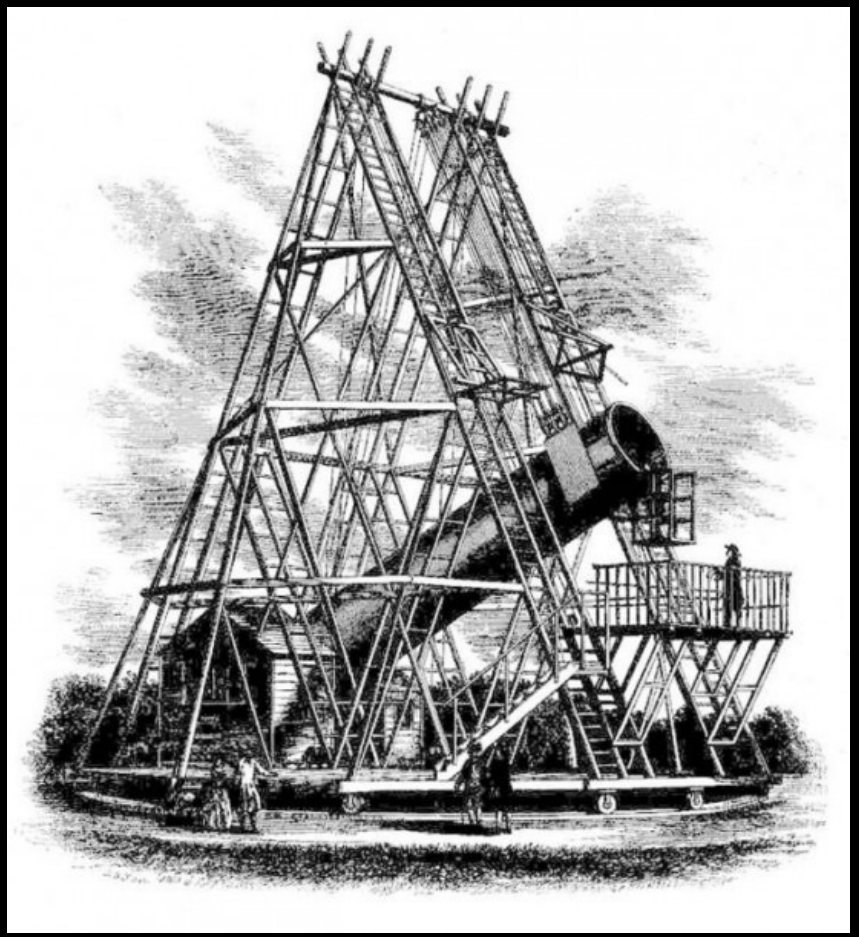



James O'Donoghue / NASA -- T: @physicsJ IG: jameslikesspace

Discoveries of new planets

# The Discovery of Uranus

- In 1781, **William and Caroline Herschel** were searching for comets (objects that moved among stars), and reported a "comet" Greenwich observatory.
- Herschels constructed the largest telescope in the world at Observatory House in England (48 in mirror).
- William was knighted and appointed court Astronomer by King George III.



# The Discovery of Neptune

- Since discovery, Uranus was nearing the completion of one orbit (84 years), but showed irregularities in its orbital path, that couldn't be due to Jupiter and Saturn.
- **Le Verrier** computed the location of a possible planet that would cause those additional irregularities, and based on these predictions, Neptune was found in 1846 by **Galle** at the Berlin Observatory.

# The Discovery of Pluto

- Early calculations showed that the orbits of Uranus and Neptune were both perturbed by an unseen planet.
- Percival **Lowell** constructed the Lowell Observatory in Arizona, in 1906, to search for "Planet X."
- Pluto was discovered in 1930 by Clyde **Tombaugh**.

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GRANDMA TRYING TO SAVE BABY IS KILLED BY TRAIN

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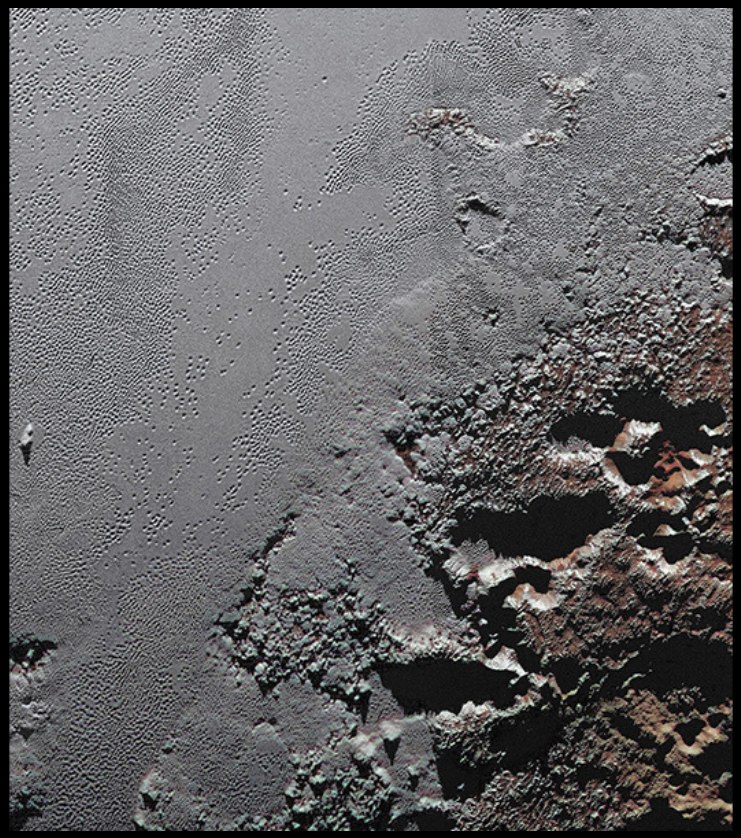
LOVE TRIUMPHS; COMPANIONATE COUPLE REUNITED

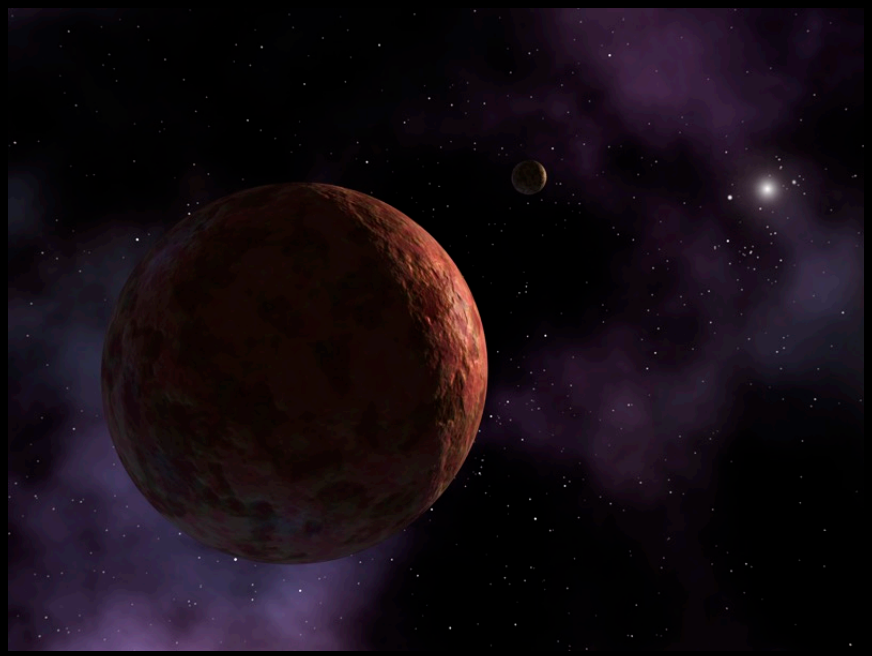
# Pluto

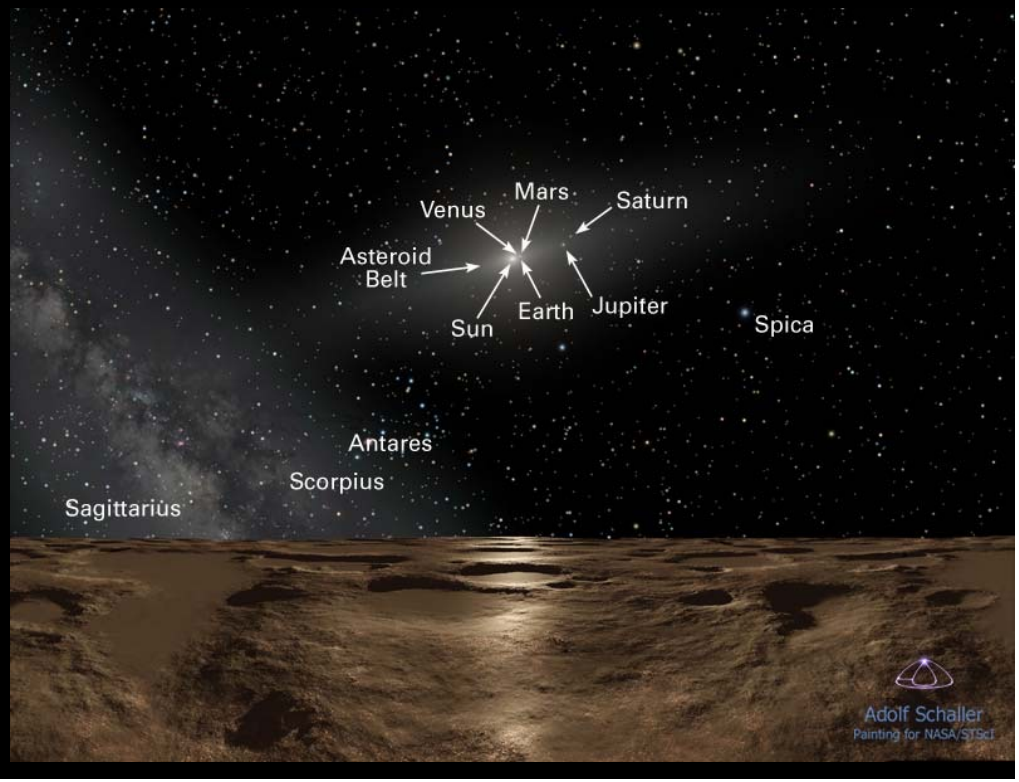
- Diameter: ~2,400 km.
- Orbit:  perihelion 29.7 AU, aphelion 49.3 AU, semimajor axis 39.5 AU.
- 1 year = 248 years, 1 day = 6 Earth days.
- Orbital Eccentricity: 0.25
- Orbital inclination 17°
- Moon Charon very large compared to Pluto itself (half the diameter), so they orbit each other like a double planet; 5 moons total.
- Had not been visited by Earth spacecraft till July 2015: **New Horizons**.



# Sedna

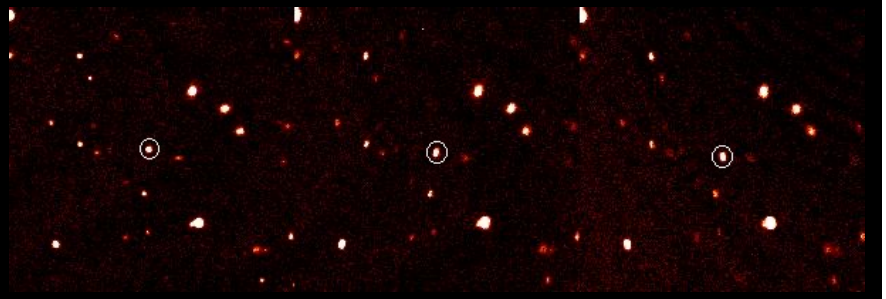
- No other large objects discovered until early 2000s.
- In 2003: Sedna discovered at 86 AU (twice the distance to Pluto), the size of Charon.
- It takes 10,500 years to orbit the Sun.



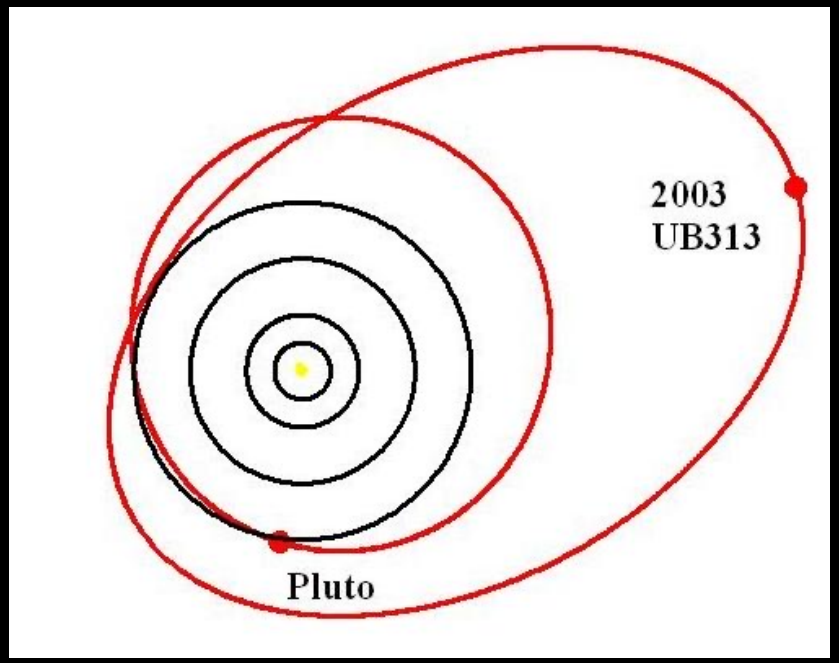


# Eris

- In 2005, a possible "tenth planet" was discovered.
- Originally designated Xena, then renamed to Eris.
- More massive (but slightly smaller) than Pluto and has a moon Dysomnia.
- Eris' orbit is very elongated, with aphelion at 97 AU.



The images that led to the discovery of Eris

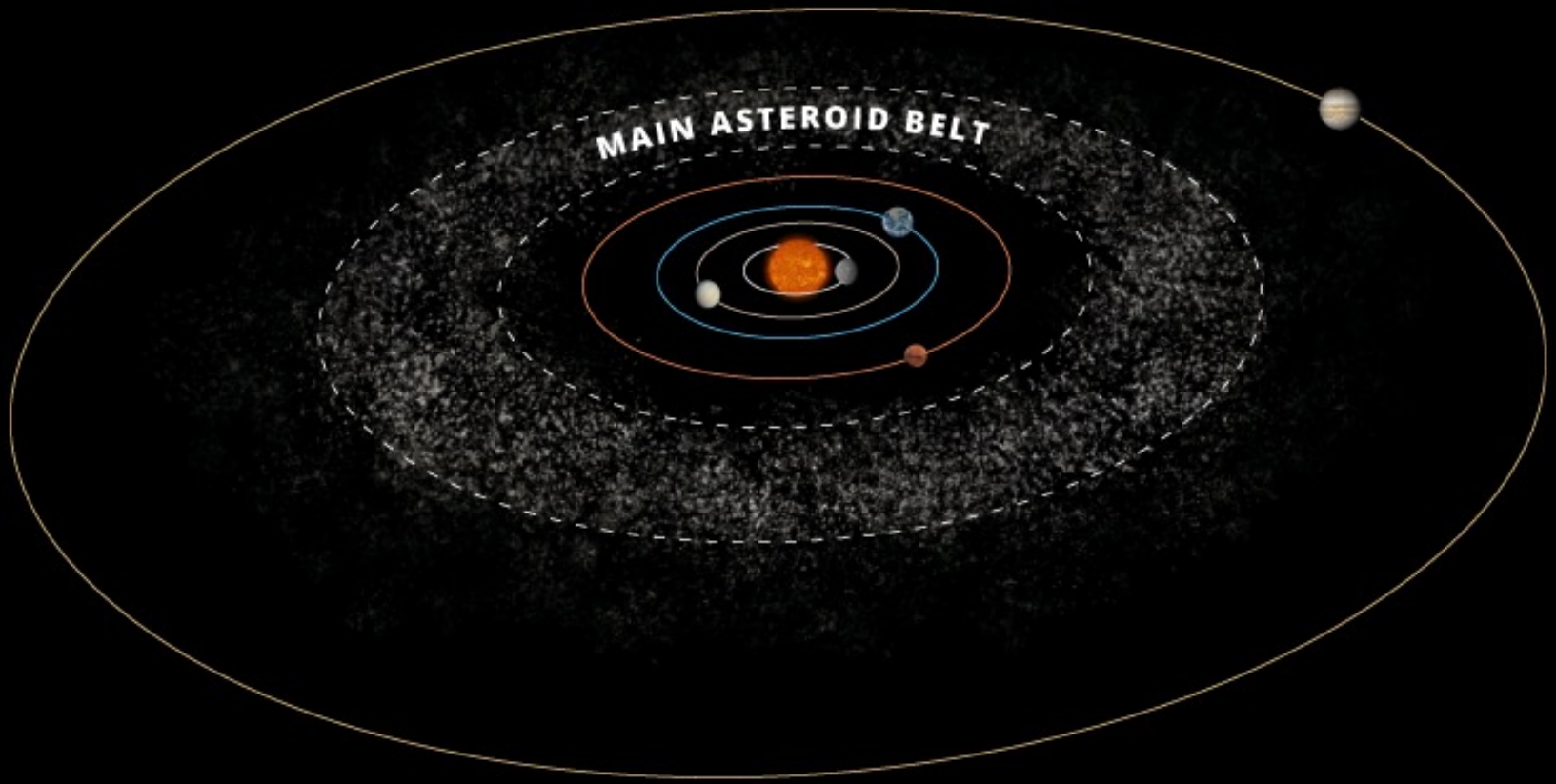



The orbit of Eris

# Largest known trans-Neptunian objects (TNOs)

# The Main Asteroid Belt

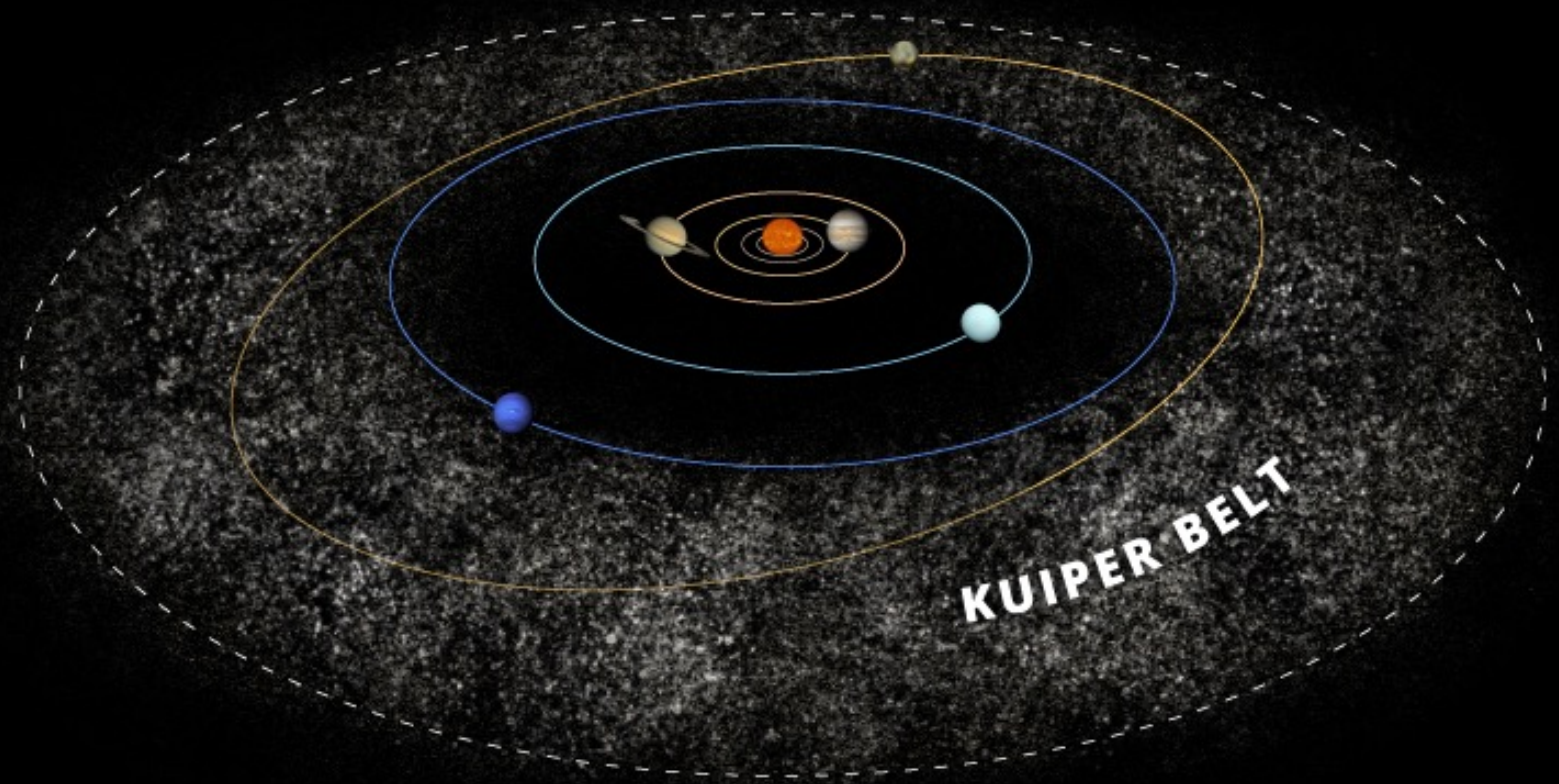
- Asteroids are rocky objects that are mostly located in the **asteroid belt** between Mars and Jupiter.
- Total mass ~ 3% of the mass of the Moon (Moon is 1/80 of the mass of the Earth), millions of objects.




Space Facts / Laurine Moreau

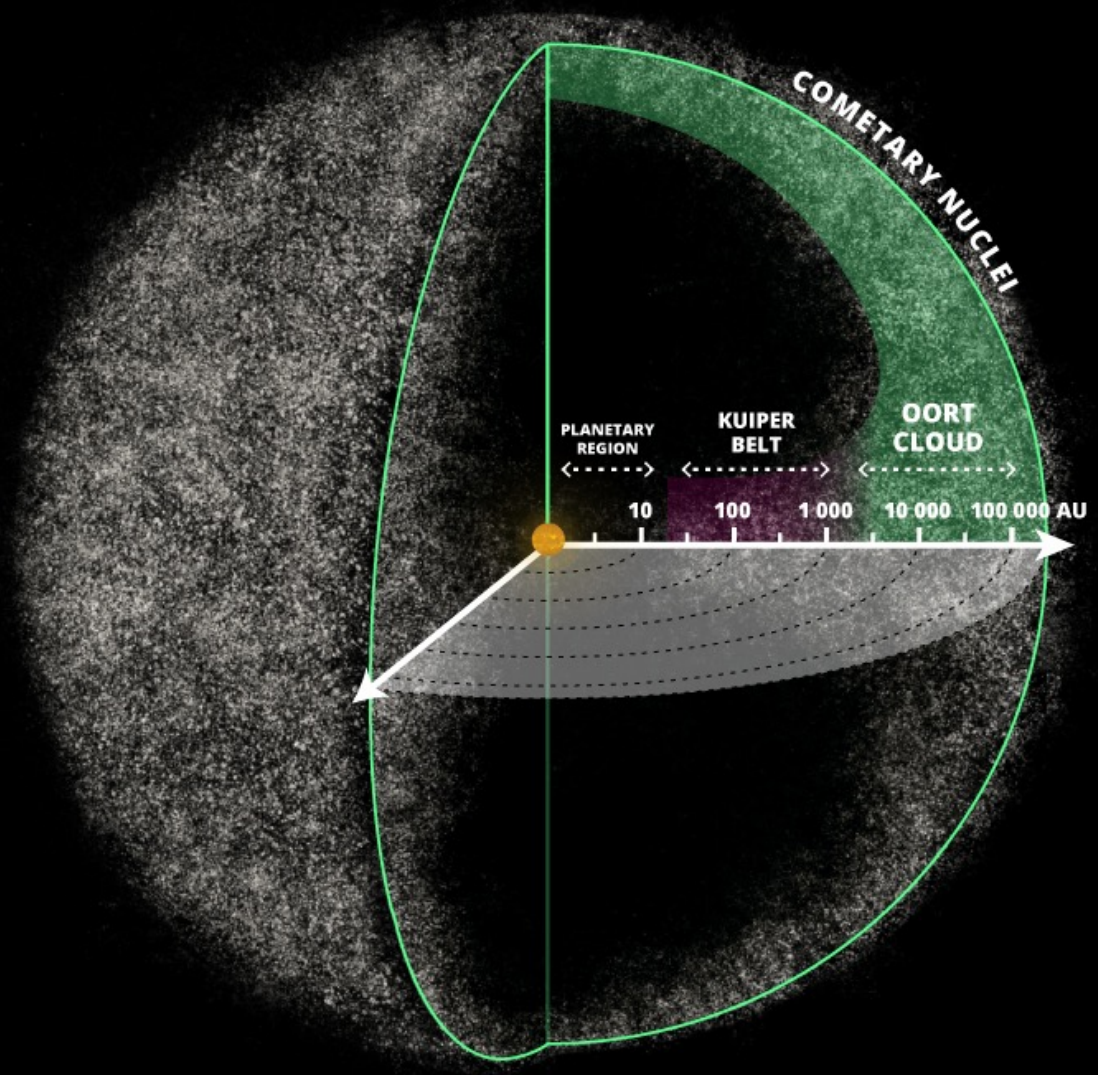
# The Kuiper Belt

- The **Kuiper Belt** extends beyond the orbit of Neptune and includes a number of dwarf planets, including Pluto.
- Total mass: about 10 times the mass of the Moon.



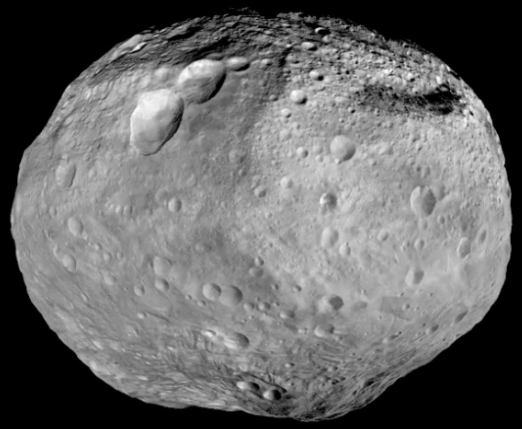
# Is that all there is?

- The **Oort Cloud** is a distant cloud of comets.



# **Planetesimals**: leftovers from planet formation

- Rocky/Metallic planetesimals formed close to the Sun, remaining ones are **asteroids**.



- Icy planetesimals formed outer planets, and remaining are **comets** of the Kuiper Belt and Oort Cloud.

# What Happened to Pluto?

# The IAU decision in 2006

Definition of a planet:

1. An object that orbits the Sun (thousands of objects qualify).
2. Has sufficient mass to assume a round shape (every object larger than 800 km in diameter qualifies).
3. Has cleared the neighborhood around its orbit (only 8 objects qualify!).

# "Clearing the Neighborhood" Quantified

- In an effort to quantify what it means to clear the neighborhood, some astronomers have come up with the planetary discriminant, which is the ratio of the mass of the planet to the combined mass of all other objects sharing its orbit.
- You could put together 13 Pluto sized objects from all the "stuff" sharing an orbit with Pluto.

| Object | Planetary Discriminant |
|---|---|
| Earth | 1,700,000 |
| Venus | 1,350,000 |
| Jupiter | 625,000 |
| Saturn | 190,000 |
| Mars | 180,000 |
| Mercury | 91,000 |
| Uranus | 29,000 |
| Neptune | 24,000 |
| Ceres | 0.33 |
| Eris | 0.1 |
| Pluto | 0.077 |
| Haumea | 0.02 |
| Makemake | 0.02 |

# Why is the universe full of spheres and disks?

# Formation of the Solar System

# Solar System in a nutshell

- ✓ The Sun rotates in counter-clockwise direction.
- ✓ All planets orbit the Sun in counter-clockwise direction.
- ✓ Planetary orbits are nearly circular and coplanar.
- ✓ The largest moons revolve around their planets in same direction as planet' s motion.
- ✓ Spacing between planetary orbits increases outward from the Sun.
- ✓ Gas giants are on the outside, rocky planets on the inside.

## Solar Nebula Theory

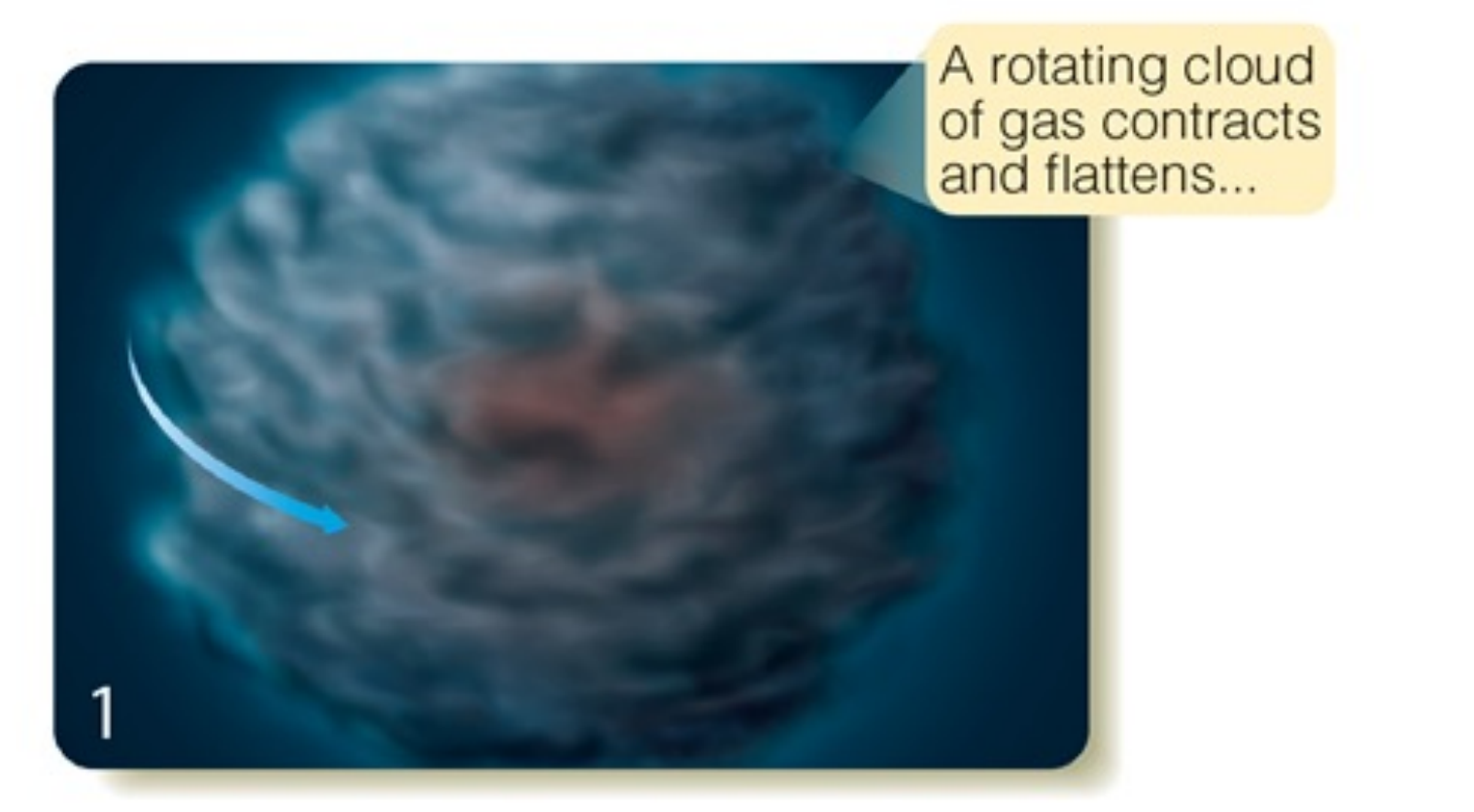
- Solar system formed from the collapse of an interstellar nebula (a cloud of gas).
- Proposed by Kant and Laplace (18th century).

# Solar System Formation

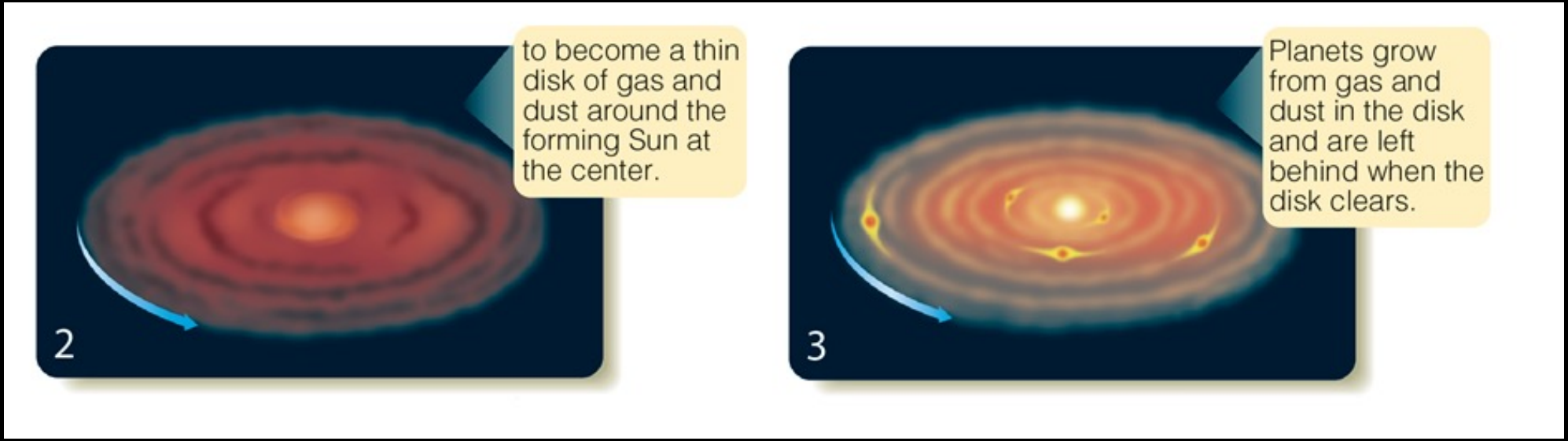
# Start with a Molecular Cloud (a Nebula)

# Cloud begins to Collapse

- The collapse is triggered by a disturbance, often the explosion of a nearby star (a supernova)

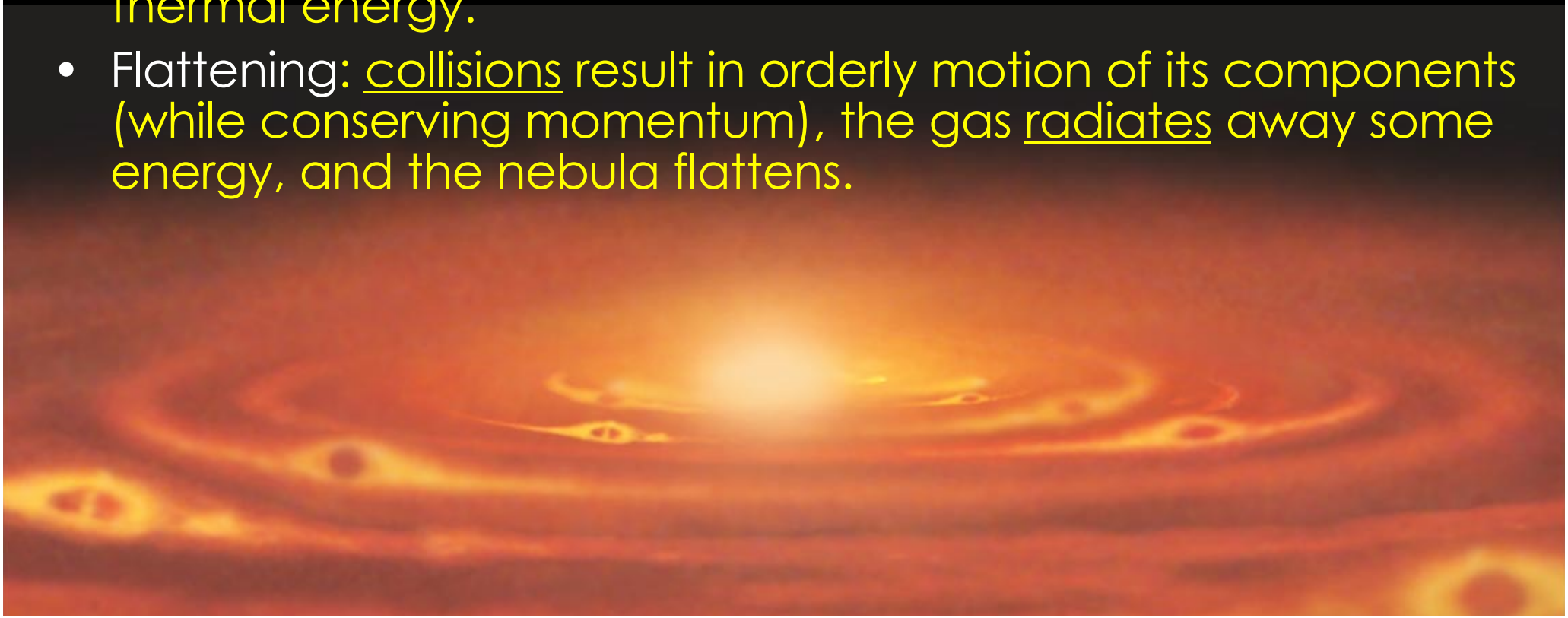


# Collapse leads to rotation and flattening



# What Happens to the Solar Nebula as it Collapses?

- Spinning: Solar nebula contracts and spins up – conservation of angular momentum.
- Heating: temperature of solar nebula increases as it collapses – gravitational potential energy converted into thermal energy.
- Flattening: collisions result in orderly motion of its components (while conserving momentum), the gas radiates away some energy, and the nebula flattens.



# The Composition of the Solar Nebula

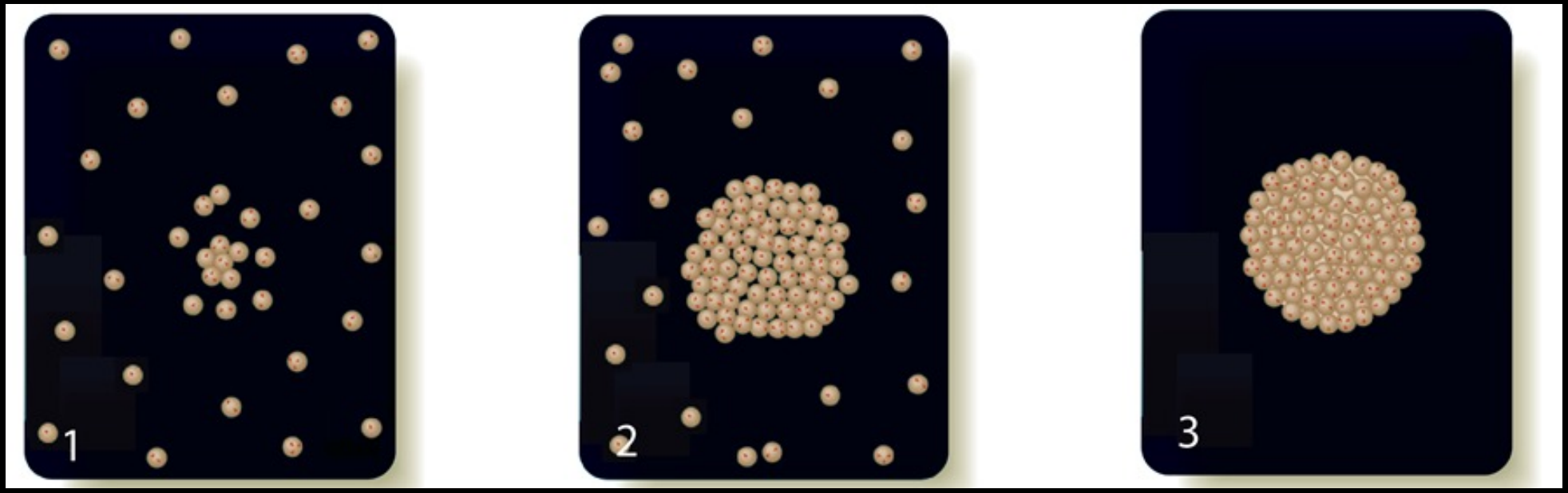
- The composition of the solar nebula was very similar to what we see in the Sun's photosphere: 73% hydrogen, 25% helium, 2% heavier elements (by mass).
- Density of solar nebula was highest near the Sun.

Table 18-1 Observed and Uncompressed Densities

| Planet | Observed Density ($g/cm^3$) | Uncompressed Density ($g/cm^3$) |
|---|---|---|
| Mercury | 5.43 | 5.3 |
| Venus | 5.24 | 4.4 |
| Earth | 5.51 | 4.4 |
| Mars | 3.93 | 3.8 |

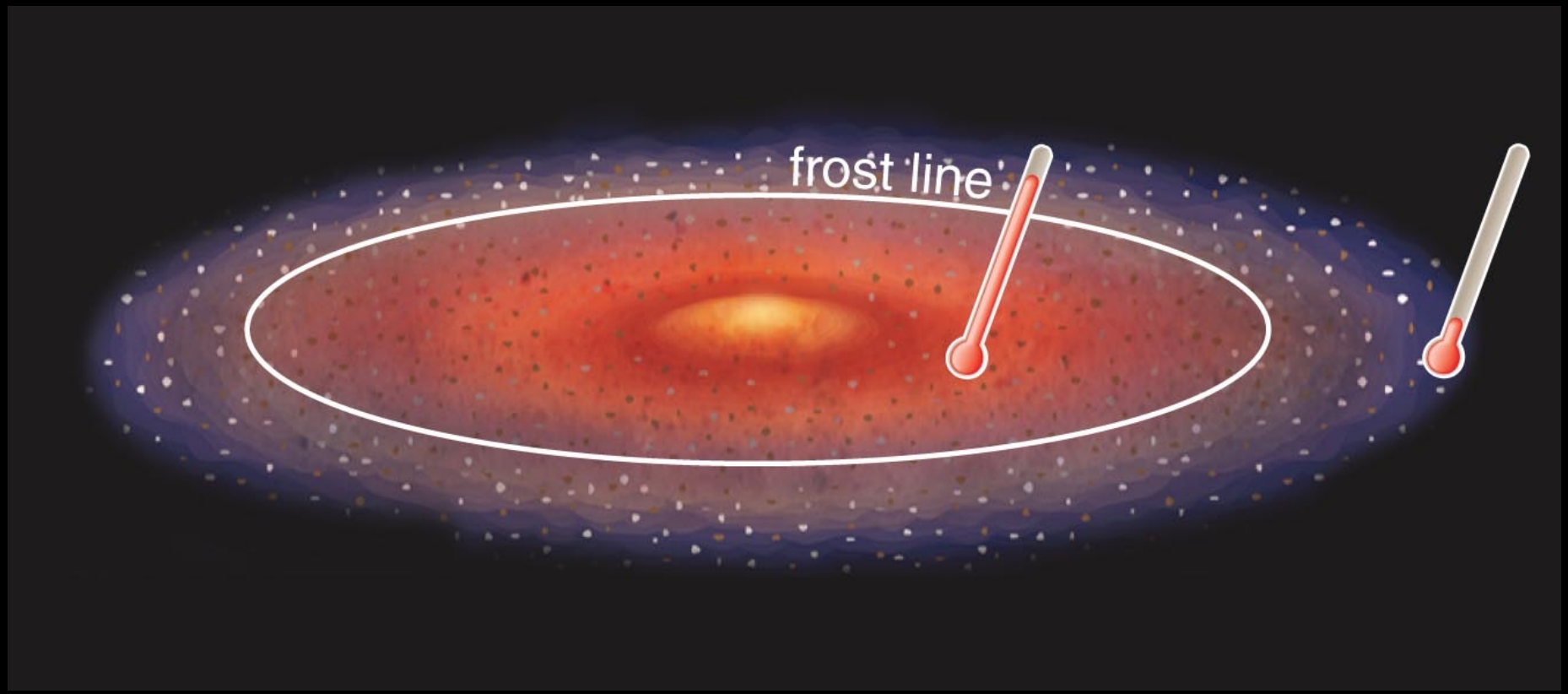
# Condensation and Accretion

- Condensation is the formation of solids from the cooling gas of the solar nebula.
- Accretion is the sticking together of solid particles to make bigger particles.



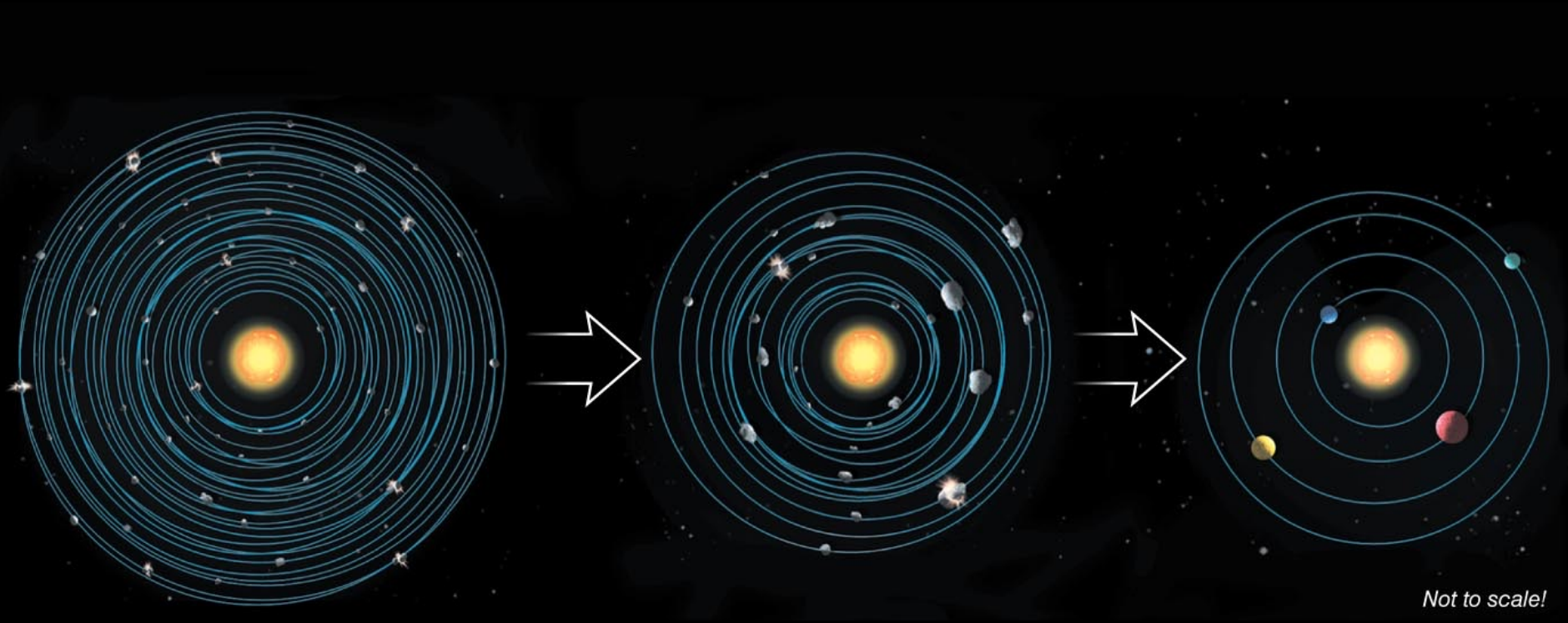
# Riddles answered: Two types of planets

- Beyond the "**frost line**," it was cold enough for icy planetesimals to form, and for planets to hold on to gases.
- Inside the frost line, only rocky and metallic planetesimals formed.



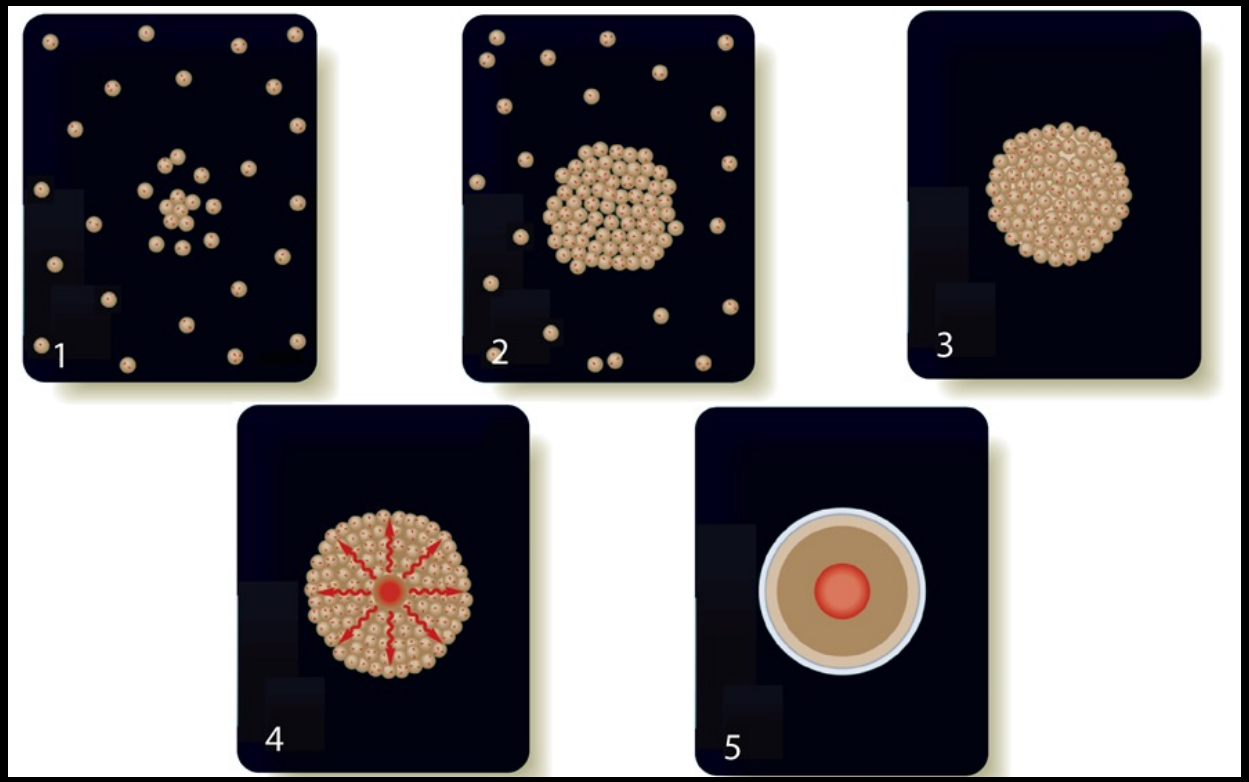
# How did the inner solar system form?

- Many large planetesimals coalesced at first, some with crisscrossing orbits.
- Collisions and gravitational interactions slowly reduced the number of planetesimals, and those surviving grew in size and became the four rocky planets.



# Differentiation

- **Differentiation** is the separation of material according to density.
- As protoplanets formed, the heat of formation due to repeated bombardment and radioactive decay caused the protoplanet to melt and differentiate.



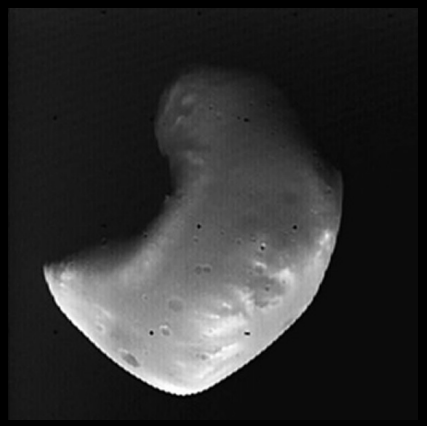
Where do the moons come from?

# Formation in-place

- Nebular theory: the gas giants formed their own accretion disks, forming their moons.
- These moons have regular orbits and are coplanar with the eight planets.


# Gravitational capture

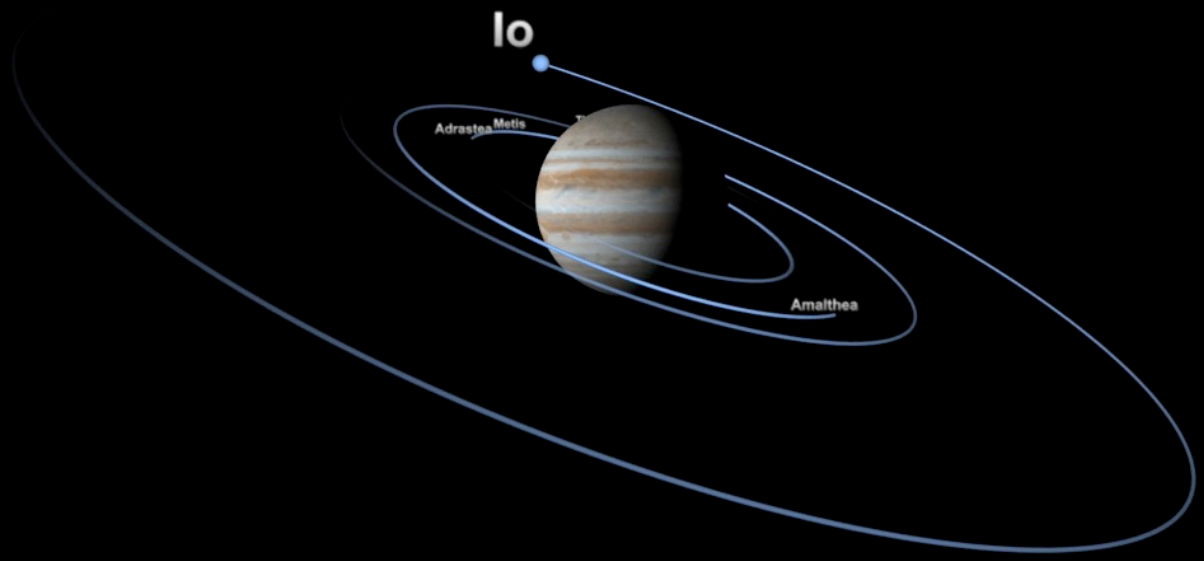
- Captured moons are usually smaller, and shaped more like asteroids and comets.
- These moons often have retrograde or very inclined orbits.
- Composition differs from that of nearby solar system.



Deimos

Phobos

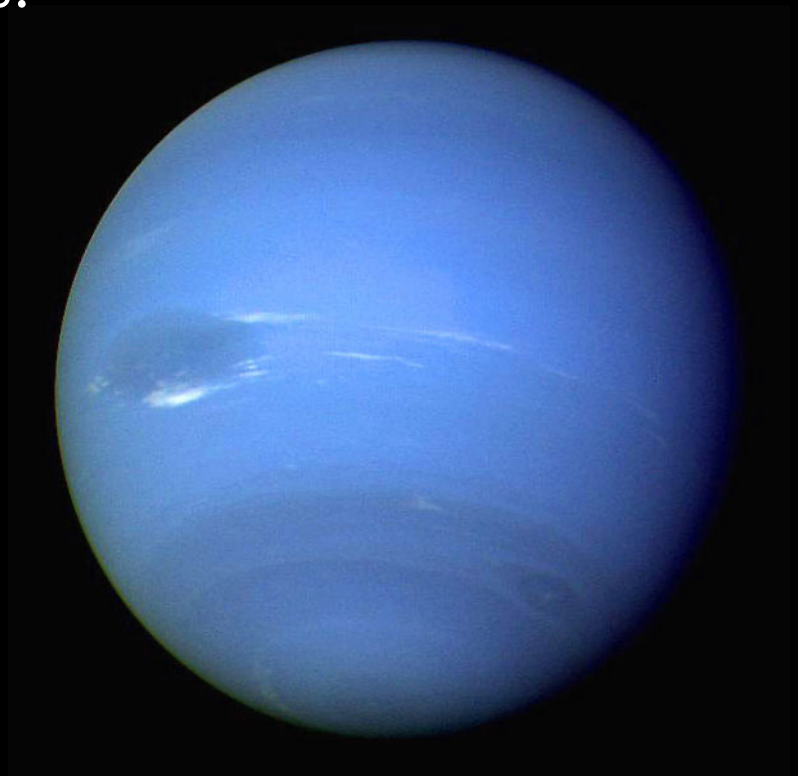
# Formation vs. Capture at Jupiter



How did Neptune and Uranus form?

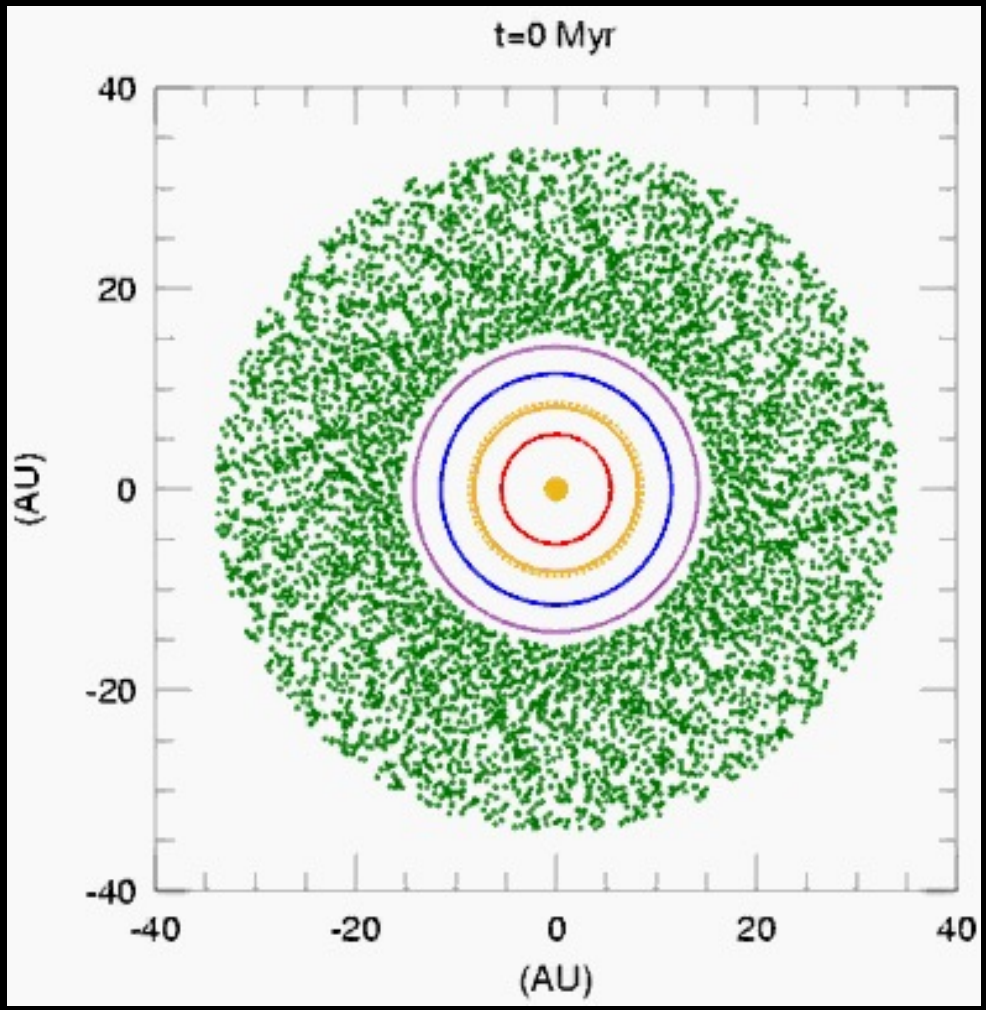
# The Neptune Mystery

- Neptune (and Uranus) is a very large planet in a region of the Solar System where there may not have been sufficient nebular material.
- **Nice model**: Neptune and Uranus formed closer in and migrated outward due to repeated interactions with the two gas giants.

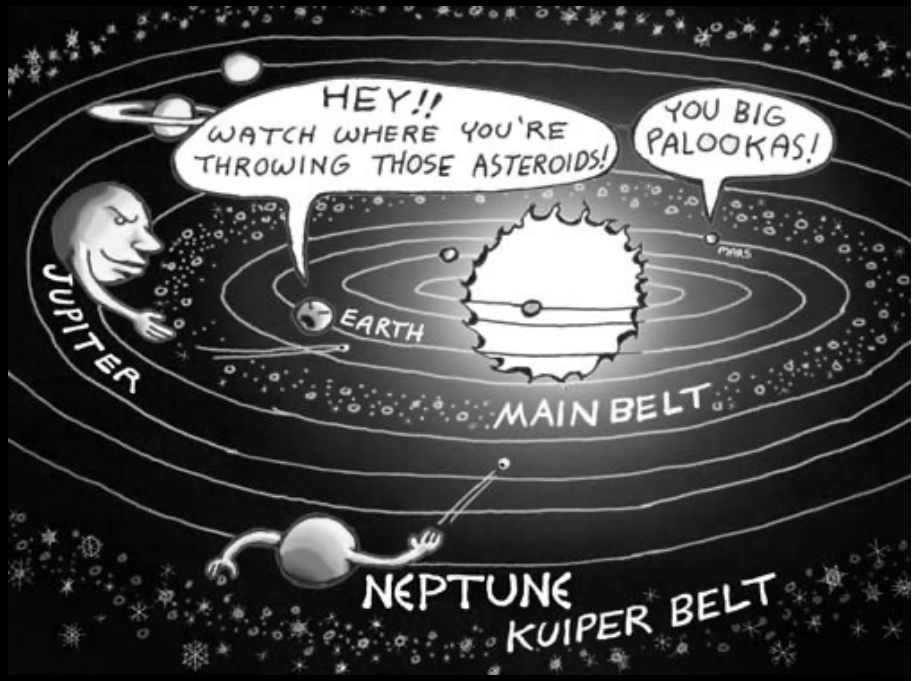


# The Nice Model

- Nice model successfully explains the distribution of objects in the Kuiper belt, the formation of the Oort cloud, the late heavy bombardment of the inner solar system, and the presence of water in the inner solar system.



# The Nice Model




- Locations of Neptune and Uranus
- Distribution of objects in the Kuiper belt
- The formation of the Oort cloud
- Late heavy bombardment
- Water in the inner Solar System

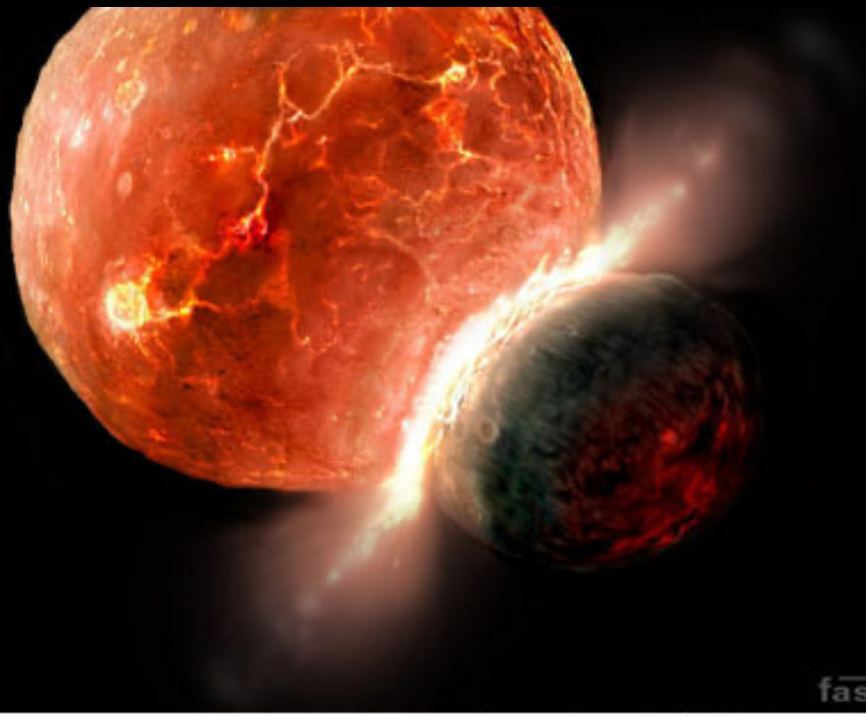
# The Solar System: A Simulation

https://www.youtube.com/watch?v=yXq1i3HlumA

What else was happening?

# Blame everything else on collisions!

- Earth's Moon was formed by the collision of a Mars-sized object with Earth.
- Pluto's moon Charon thought to have formed in the same manner.
- Venus' slow retrograde rotation also blamed on a giant collision.




James Garry, Fastlight Used with permission.

# Is Solar System formation unique?

- We see stars in every stage of their evolution, including birth.
- We now know that most Sun-like stars have a planetary system!

# Solar System in a nutshell

- ✓ The Sun rotates in counter-clockwise direction.
- ✓ All planets orbit the Sun in counter-clockwise direction.
- ✓ Planetary orbits are nearly circular and coplanar.
- ✓ The largest moons revolve around their planets in same direction as planet' s motion.
- ✓ Spacing between planetary orbits increases outward from the Sun.
- ✓ Gas giants are on the outside, rocky planets on the inside.

# question for you

Which of the following statements is/are true?

A. Captured moons tend to have orbits that are co-planar with the solar system.
B. Moons that formed together with a planet share its isotope composition, while those that were captured do not have to.
C. Moons that formed with the planet tend to have no iron cores, while captured moons always have cores.
D. All of the above.

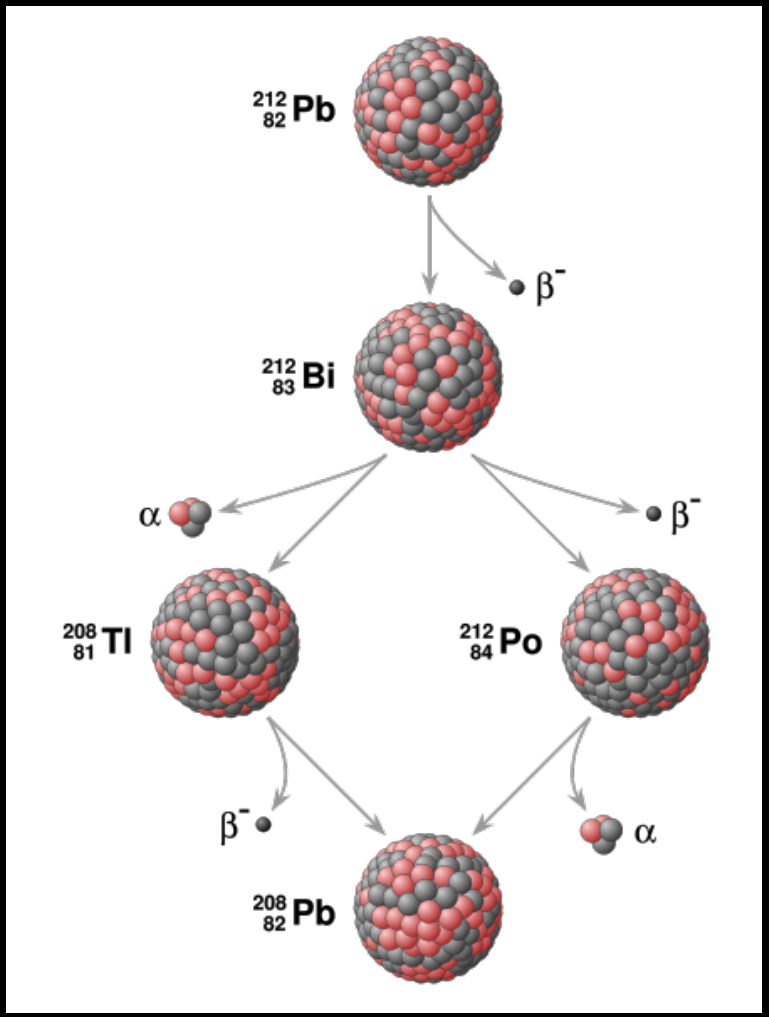
# The age of the Solar System

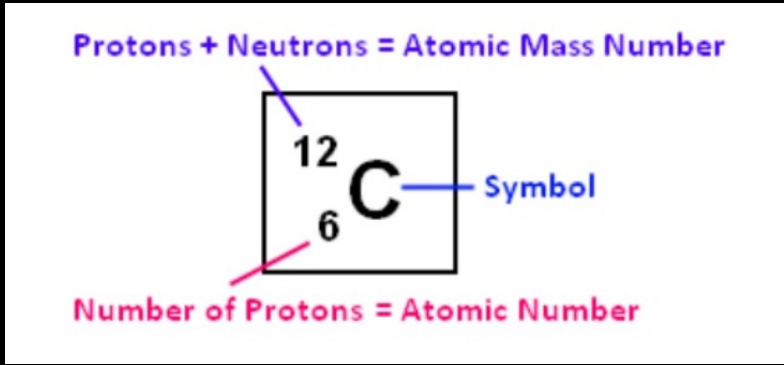
# The Age of the Solar System

- Our Solar System is about **4.5 billion years old**.
- Asteroids and Kuiper Belt Objects are left over from the formation of the Solar System, unchanged since that time.
- We can radiometrically date meteorites that come from those objects.

# "Alchemy" of radioactive isotopes

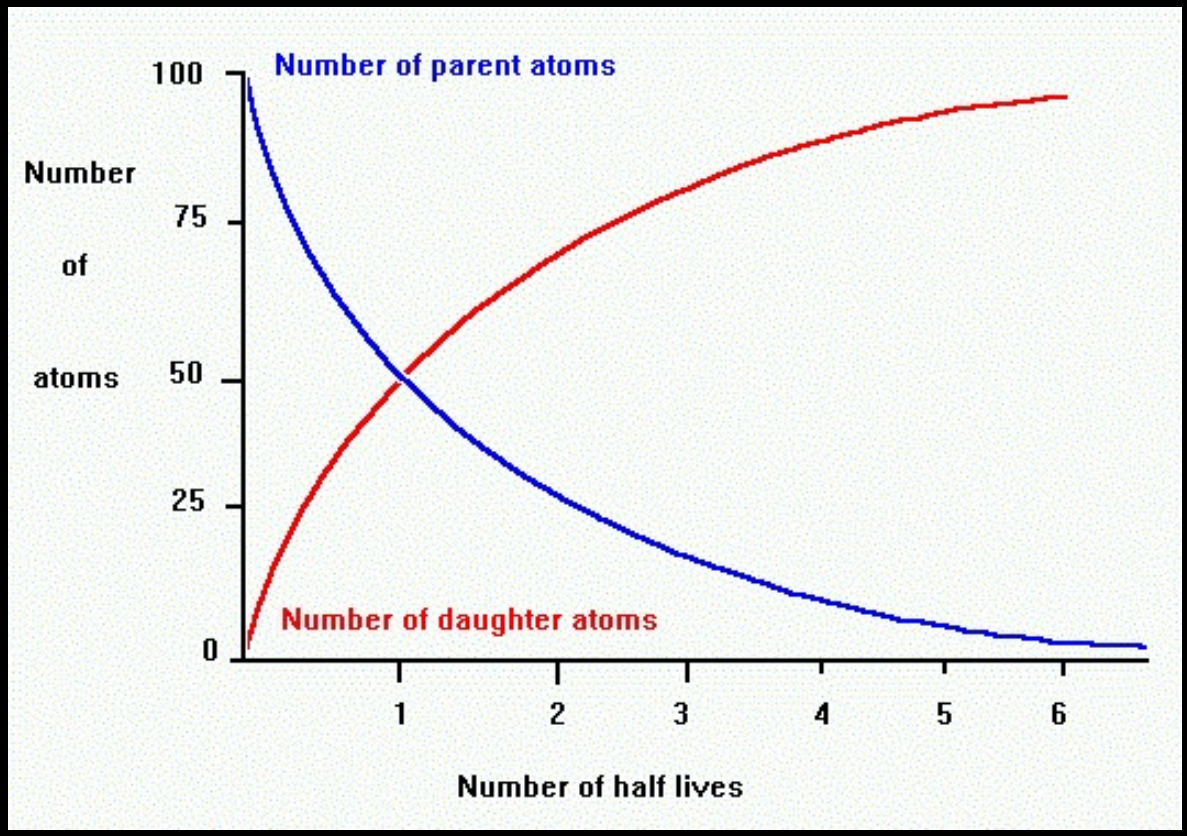
- Isotope Analysis
  - Measures the amounts of specific isotopes in rocks.
  - Radioactive isotopes decay over time, so that their abundace can be used to find the age of rocks and fossils.



# Radiometric Dating

- The decay of Potassium-40 into Argon-40 has a "half life" of 1.2 billion years, which means the amount of potassium decreases to 50% of its original amount in 1.2 billion years.
- By measuring the relative amounts of Potassium-40 and Argon-40 in a rock, we can determine its age.



# Carbon Dating

# question for you

Imagine that you start with a sample of 200 K-40 atoms. After 1.2 billion years, you end up with 100 K-40 atoms. After 2.4 billion years, you will have:

A. No atoms left.
B. No K-40 atoms, 200 Ar-40 atoms.
C. 100 K-40 atoms, 100 Ar-40 atoms.
D. 50 K-40 atoms, 150 Ar-40 atoms.
E. I have no idea.

# What did we learn in Chapter 18 Part 1?

- Although Mercury is the closest planet to the Sun, Venus has a higher average temperature because of a runaway greenhouse effect.
- Earth is the densest planet in the solar system, followed closely by Mercury.
- Mars is showing more and more evidence of surface liquid water now and in the past.
- All four of the giant planets have ring systems.
- Most of the asteroids are found in the Asteroid Belt, between the orbits of Mars and Jupiter.
- The Kuiper Belt consists of icy planetesimals beyond the orbit of Neptune.

# What did we learn in Chapter 18 Part 1?

- Our solar system formed from the collapse of a cloud of gas and dust (called a nebula), which was mostly hydrogen and helium.
- The pattern of motion in our solar system was determined during the collapse and rotation of the nebula.
- As the nebula shrank and collapsed, it grew hotter, denser at the center, began to rotate faster, and flattened out into a disk.
- The frost line is the distance from the Sun beyond which it was cold enough for ices could condense.

# What did we learn in Chapter 18 Part 1?

- Pluto was demoted from planethood in 2006 by the IAU since it did not fulfill the third criterion of "clearing its neighborhood."
- The age of the solar system is determined from the radiometric dating of primitive meteorites.
- In radiometric dating, the proportions of parent and daughter nuclei are compared, and, based on the half life of the radioactive nucleus, the age of the substance is determined.
- Radiometric dating indicates that the solar system formed 4.571 billion years ago.