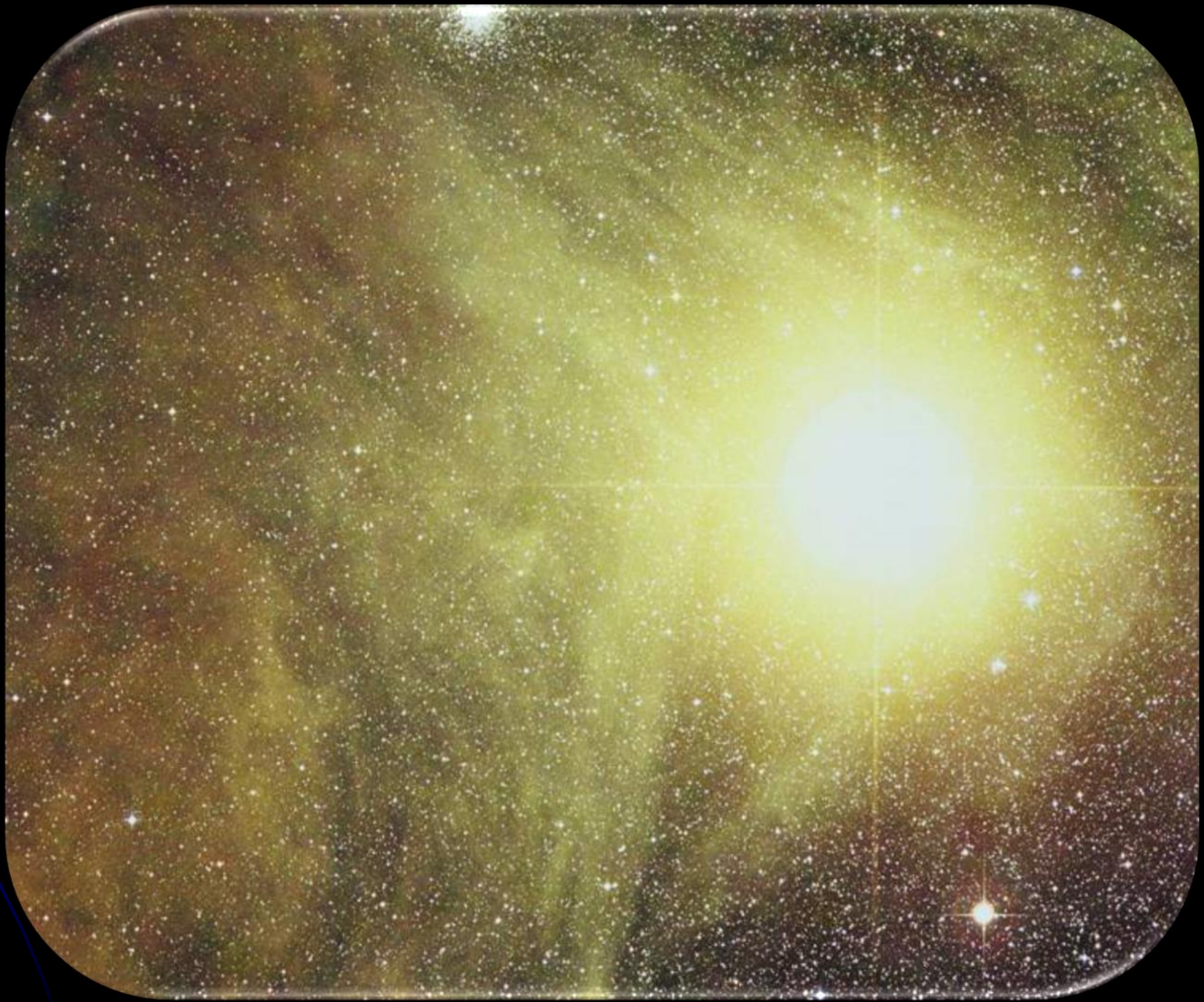
4.2 – The Formation of the Solar System and Other Planetary Systems



Earth/Space Science
Mr. Webber

WHAT DO YOU THINK?

- How many stars are there in the solar system?
- Was the solar system created as a direct result of the formation of the universe?
- How long has the Earth existed?
- Is Pluto always the farthest planet (dwarf planet) from the Sun?
- What typical shapes do moons have?
- Have any Earth-like planets been discovered orbiting Sun-like stars?

Our goals…

•How the solar system formed.

•Titius-Bode Law.

•Why the environment of the early solar system was much more violent than it is today.

•How astronomers characterize each planet's "personality."

•How the moons throughout the solar system formed.

•What the debris of the solar system is made of.

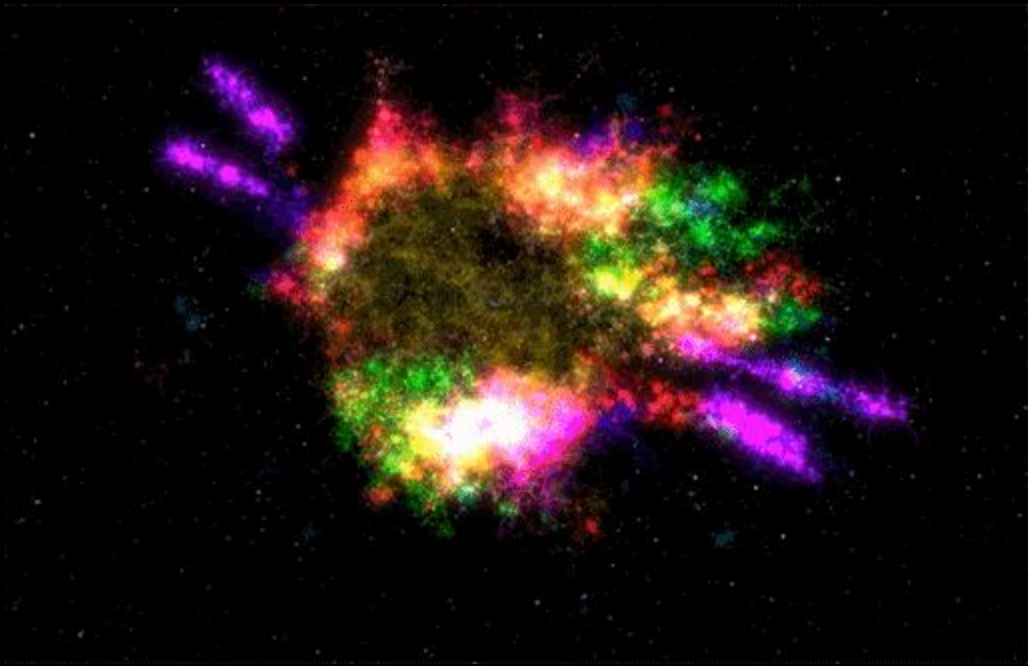
•That planets have been observed around a growing number of stars.

•That newly forming star and planet systems are being observed.

Recall: The lightest and simplest elements, hydrogen and helium, are abundant in the universe. Heavier elements, such as iron and silicon, are created by thermonuclear reactions in the interiors of stars, and then ejected into space by those stars.

Ejection of Matter from Stars

FORMATION OF PLANETARY NEBULA



SUPERNOVA EXPLOSIONS

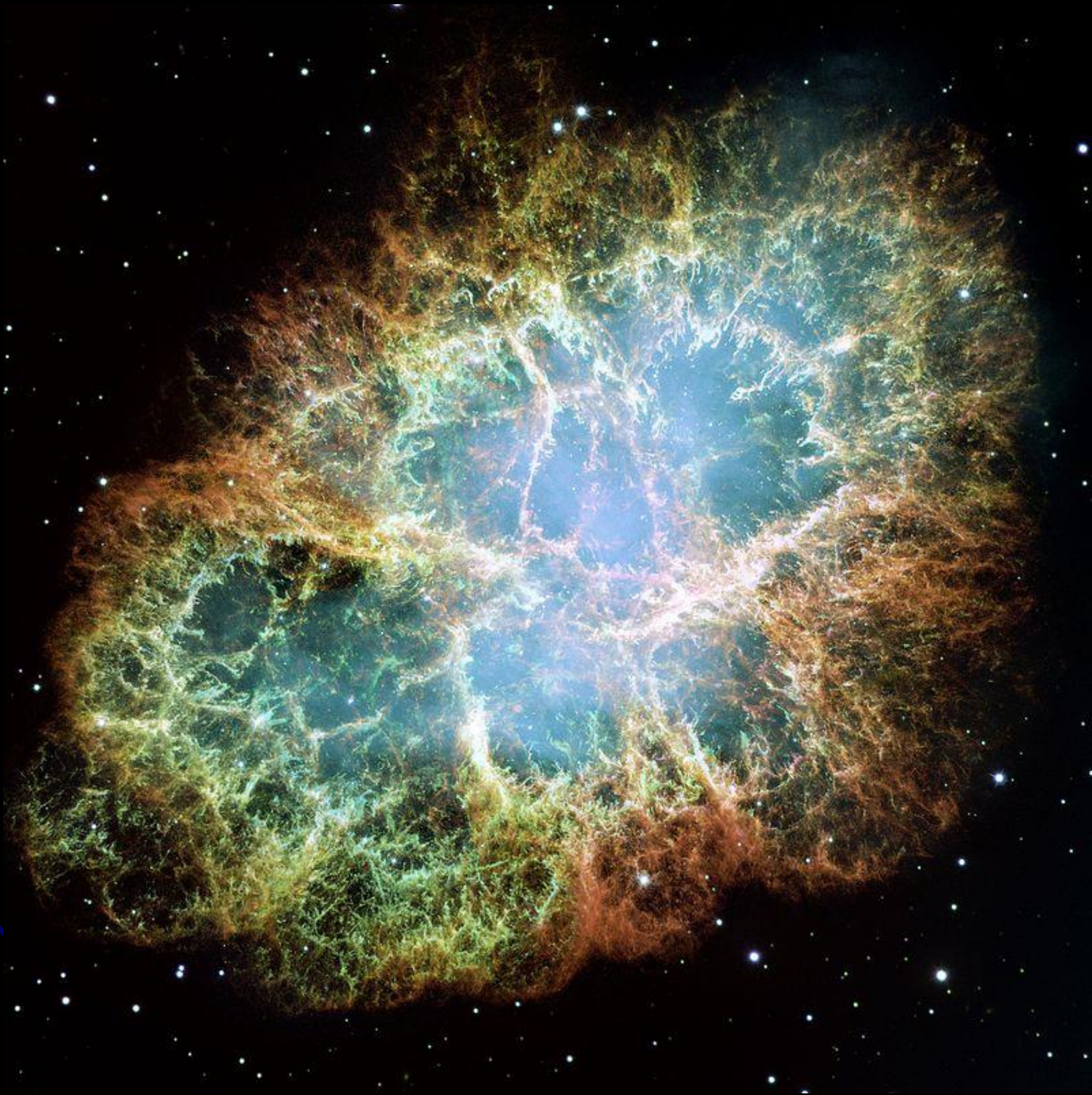
Planetary Nebula: The Ring Nebula

Planetary Nebula: The Cat's Eye Nebula

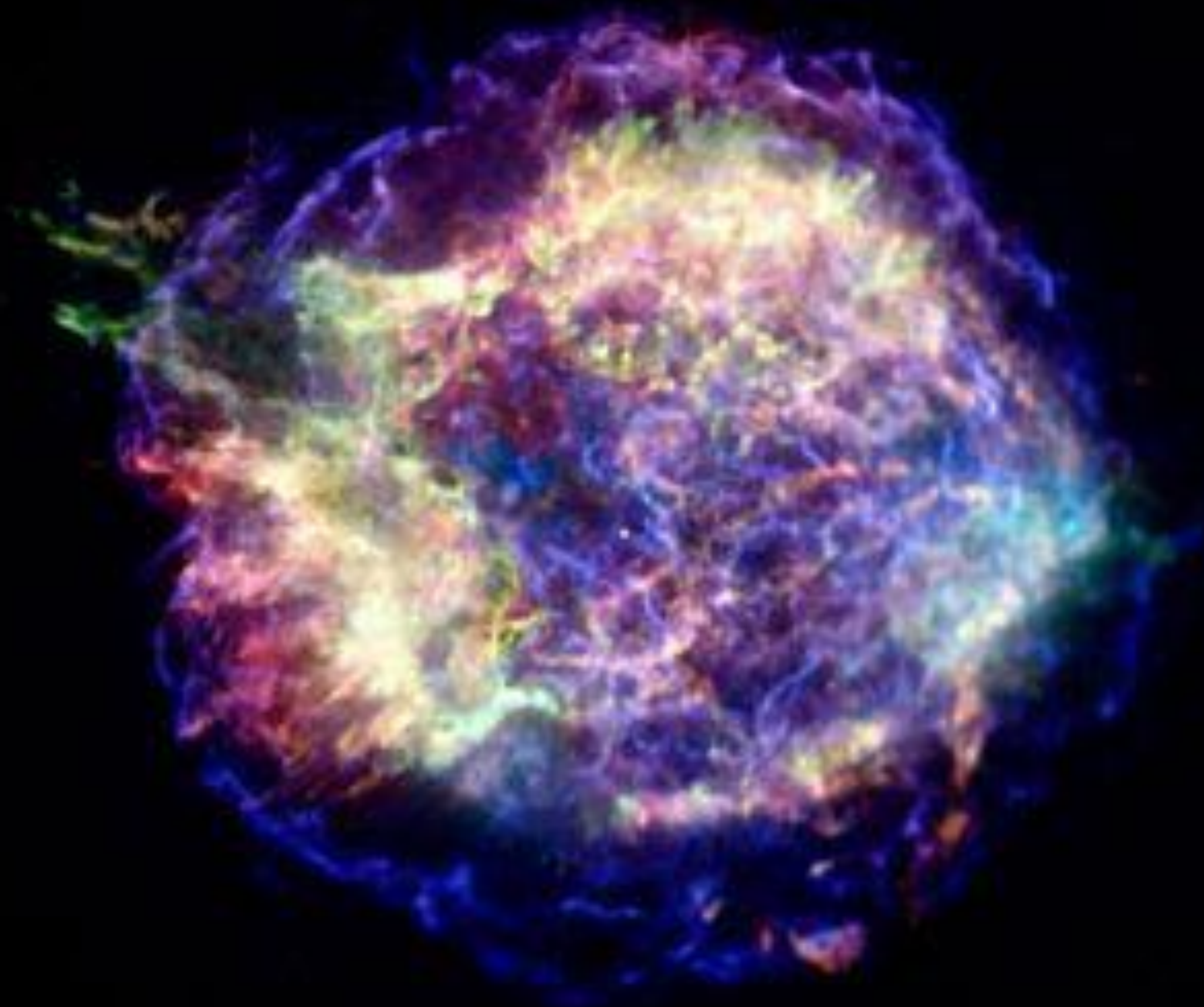
Planetary Nebula: ESO577-24

Planetary Nebula: Kronberger 61

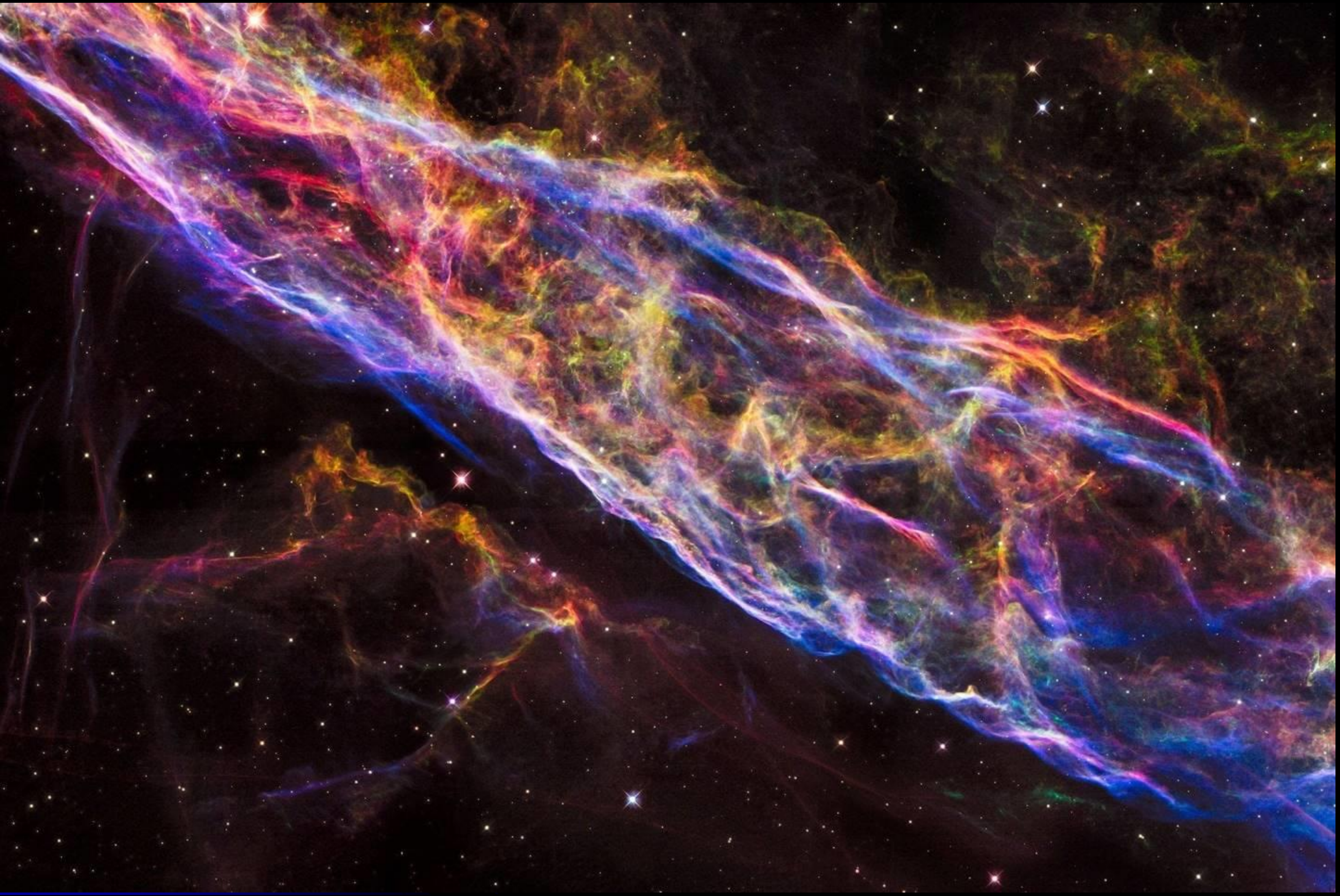
Supernova Remnant: Crab Nebula



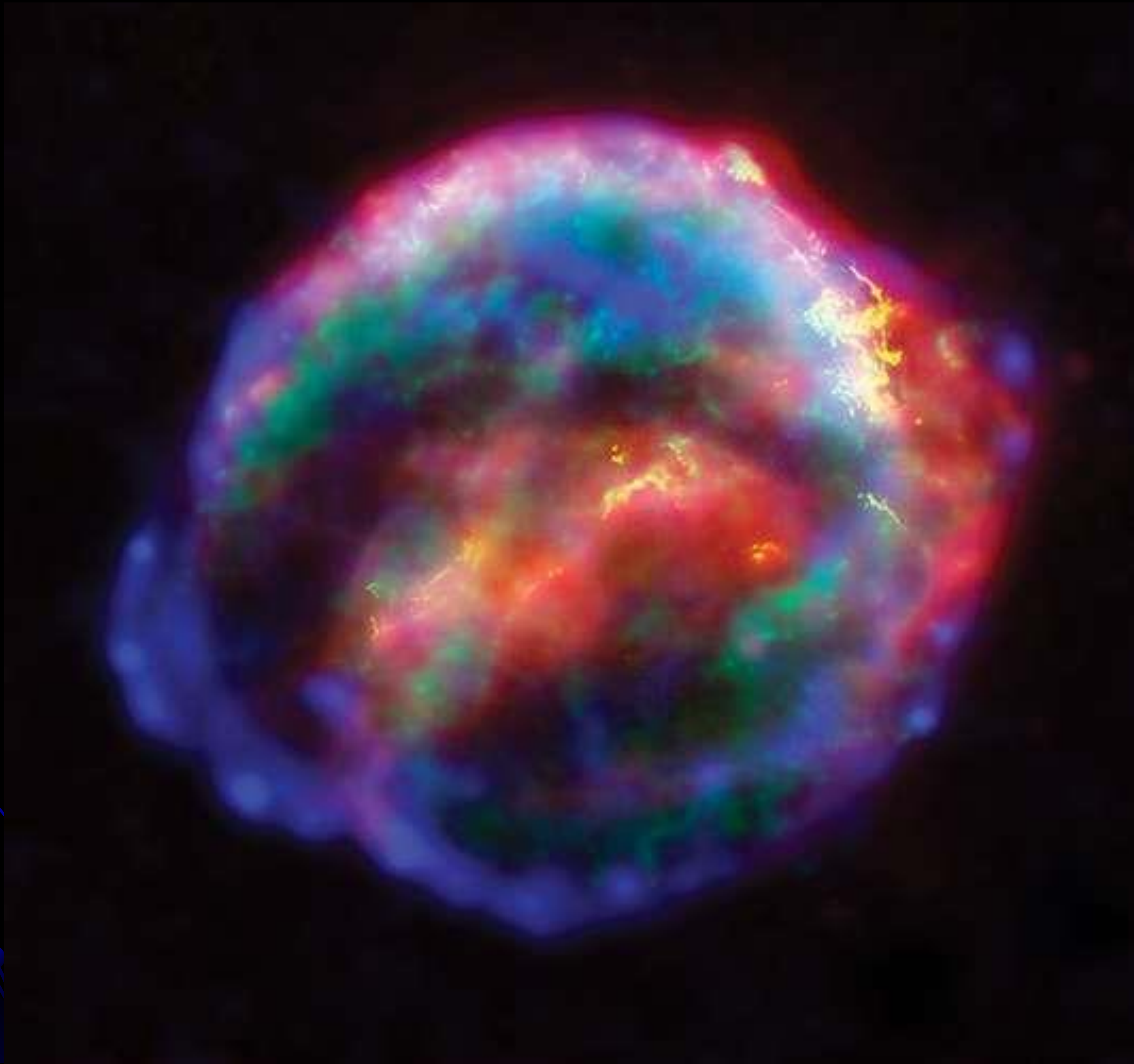
Supernova Remnant: Cassiopeia A



Supernova Remnant: Veil Nebula



Supernova Remnant: Kepler's Nebula

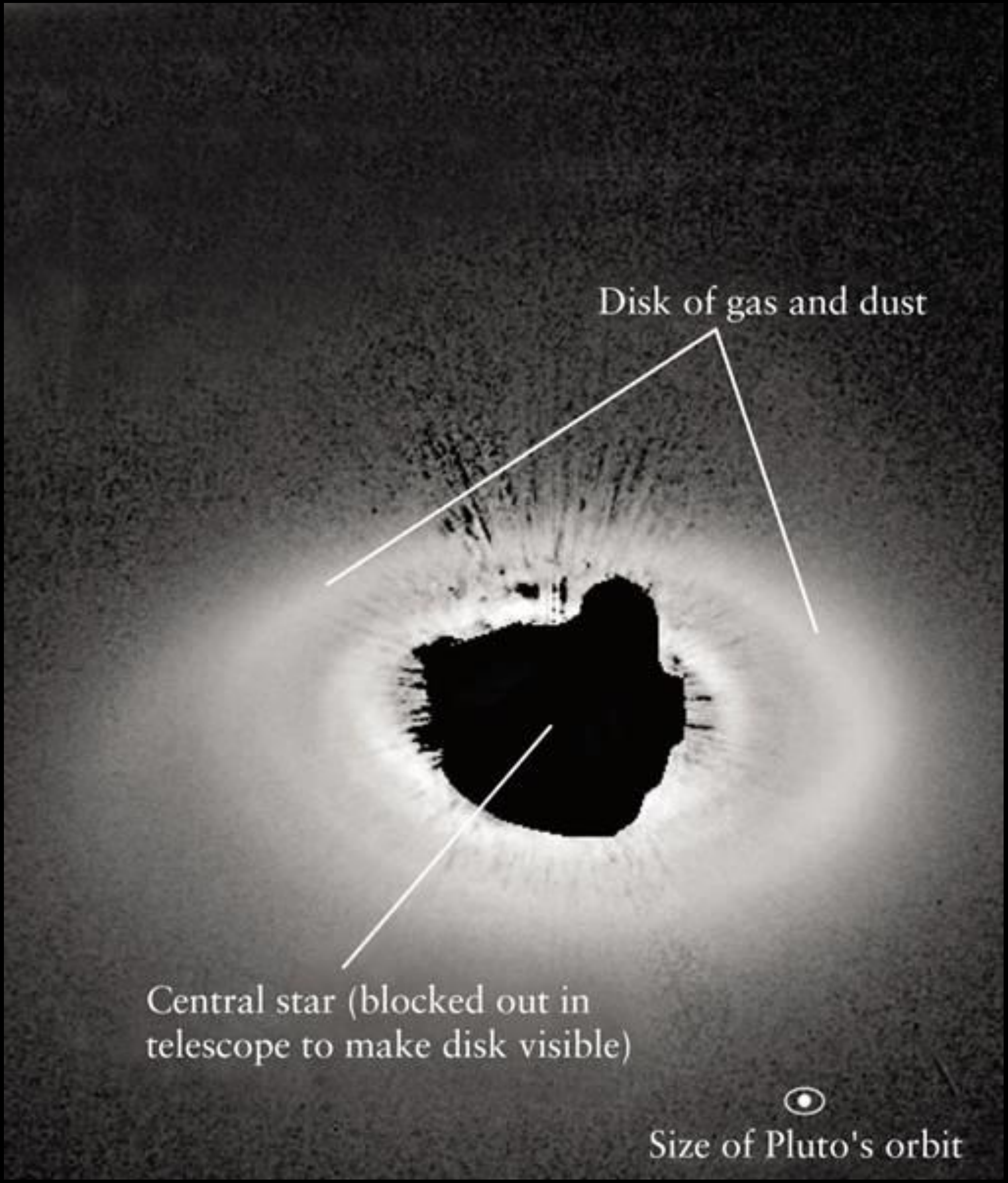


Great clouds of gas and dust ejected from old stars are gathered into regions from which new stars can be made.

This region in the constellation of Orion shows new stars still surrounded by the nebula from which they were formed.

Other Star Systems Forming

We can look at young star systems developing today. The planets orbiting these stars are formed from the surrounding disks of gas and dust, called protoplanetary disks or proplyds.



The Formation of a Solar System: Star

A solar system begins as a gas cloud that collapses toward the center under the influence of *gravity*.

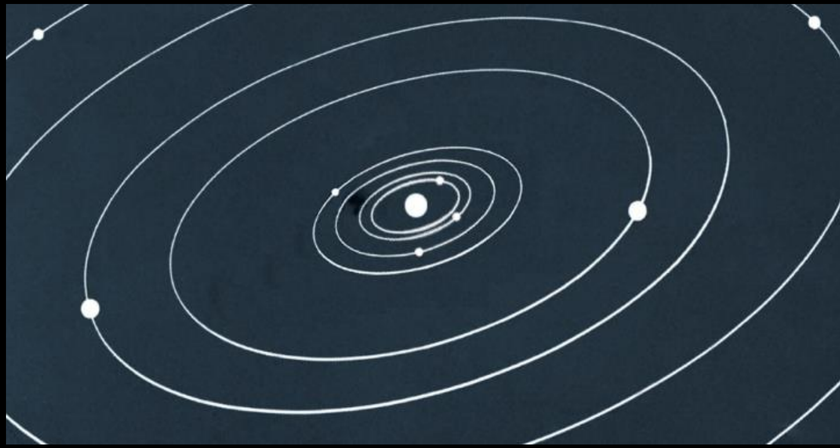
A condensation forms at the center, which is called a *protostar*.

A flattened disk of matter surrounds the protostar, which begins to shine. Our sun began to shine 4.71 billion years ago.

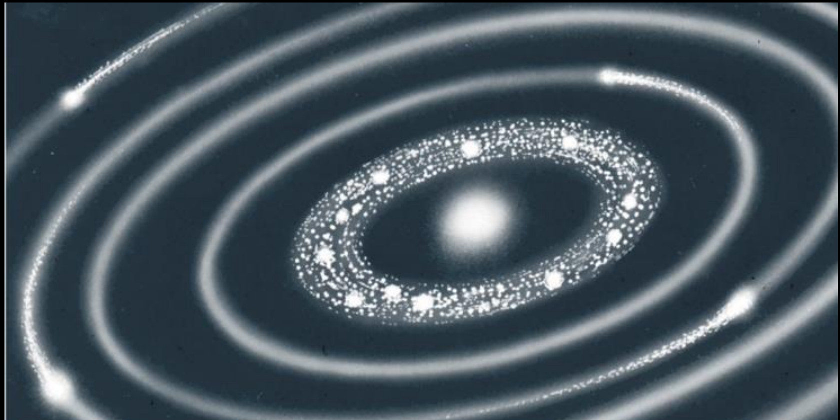
The Formation of a Solar System: Planets

The rising temperature from the sun removes the gas from the inner regions, leaving dust and larger debris.

The planets establish gravitation dominance in their regions of the solar system. Angular momentum is conserved.



After almost all of the remaining gas, dust, and small debris has been collected by the larger objects, the solar system takes on the form we recognize today.

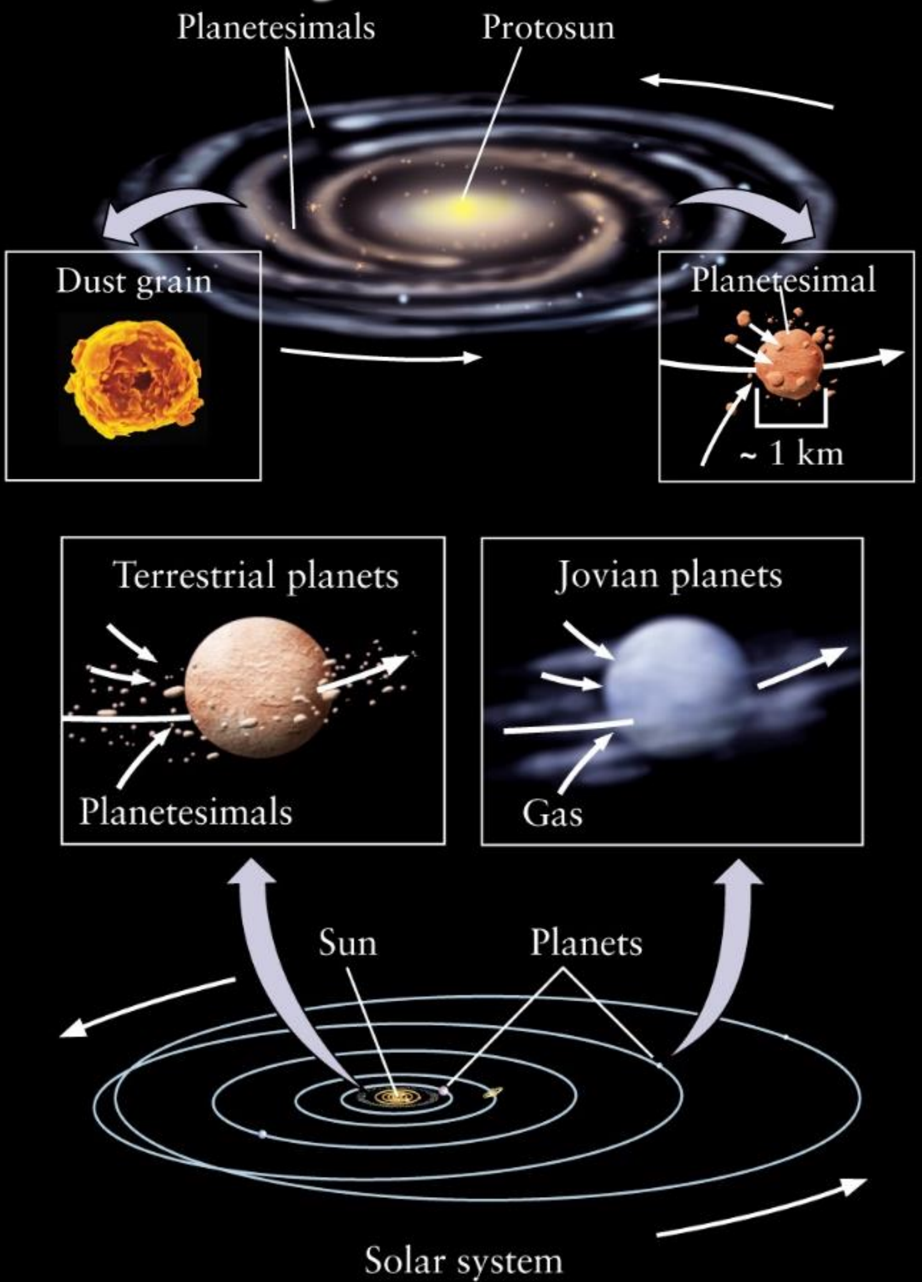


The Formation of a Solar System: Planets

Within the disk that surrounds the protosun, solid grains collide and clump together into *planetesimals*.

The terrestrial planets are built up by collisions and the *accretion* of planetesimals by gravitational attraction.

The jovian planets are formed by gas accretion, also due to gravity.



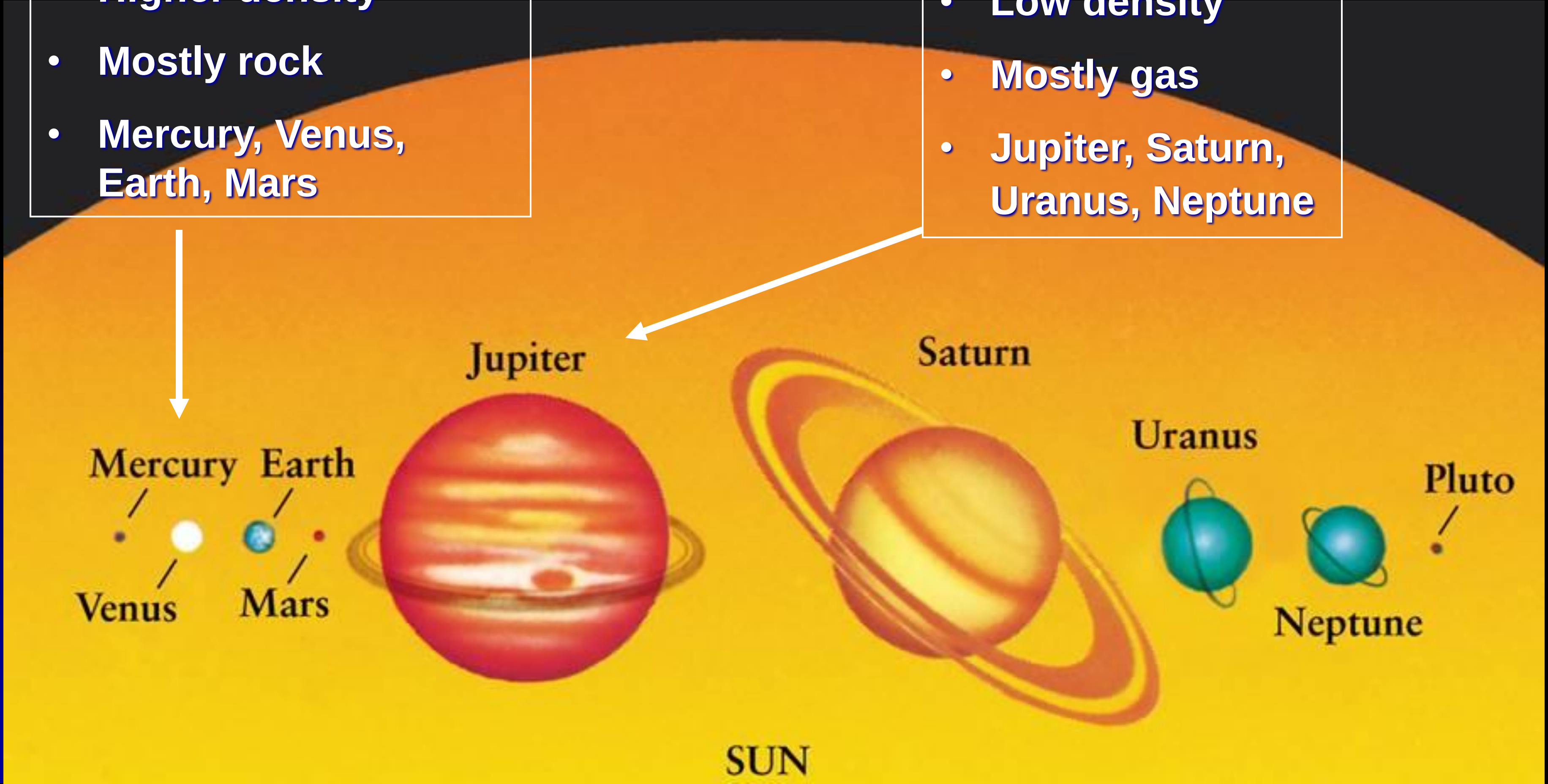
Two Basic Groups of Planets

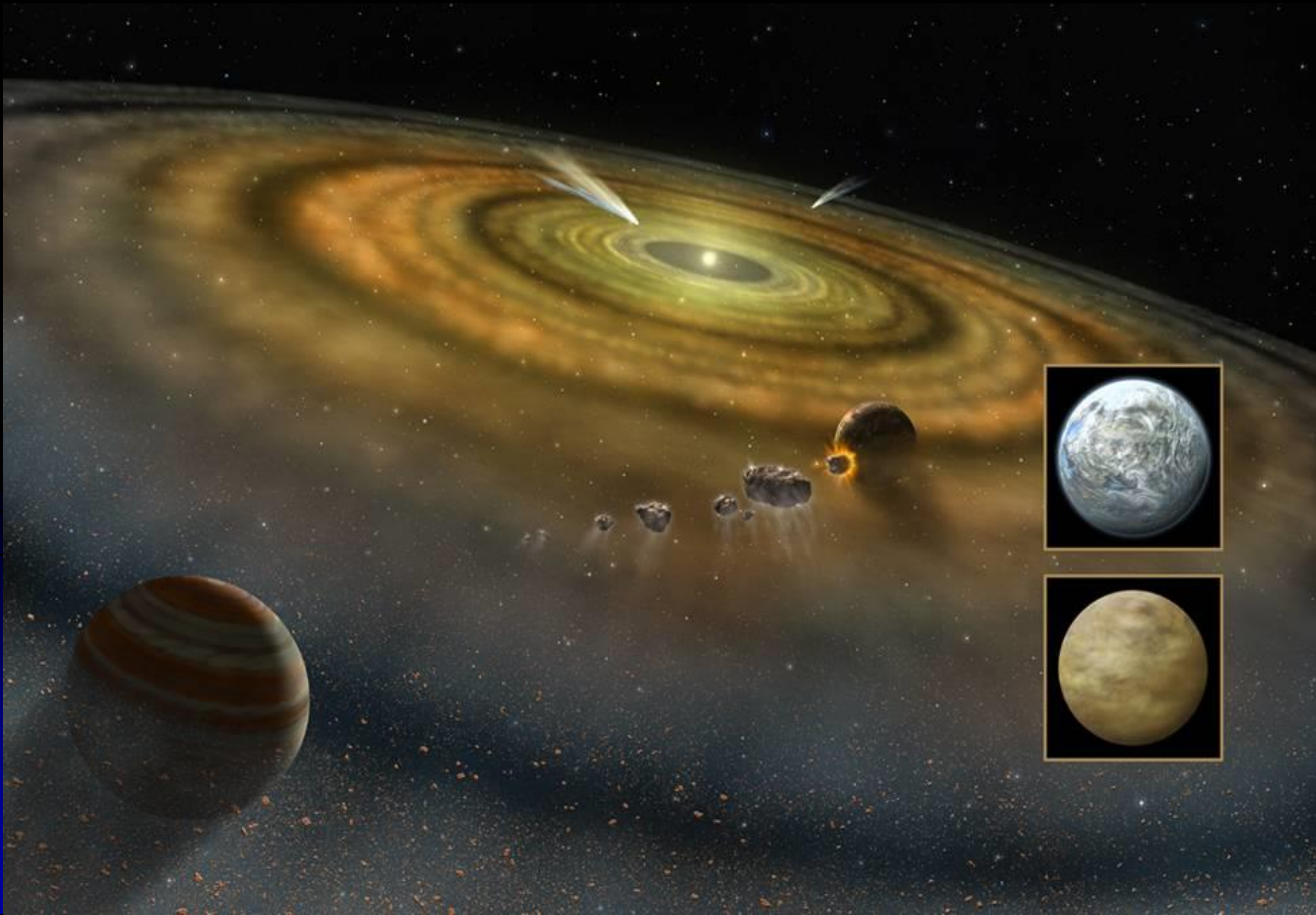
TERRESTRIAL

- Small size
- Low Mass
- Higher density
- Mostly rock
- Mercury, Venus, Earth, Mars

JOVIAN

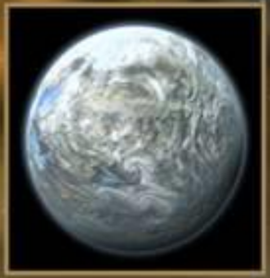
- Large size
- Massive
- Low density
- Mostly gas
- Jupiter, Saturn, Uranus, Neptune

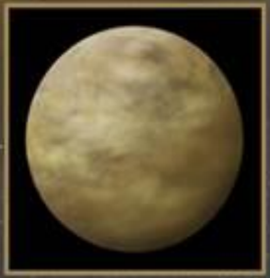




The Age of Our Solar System

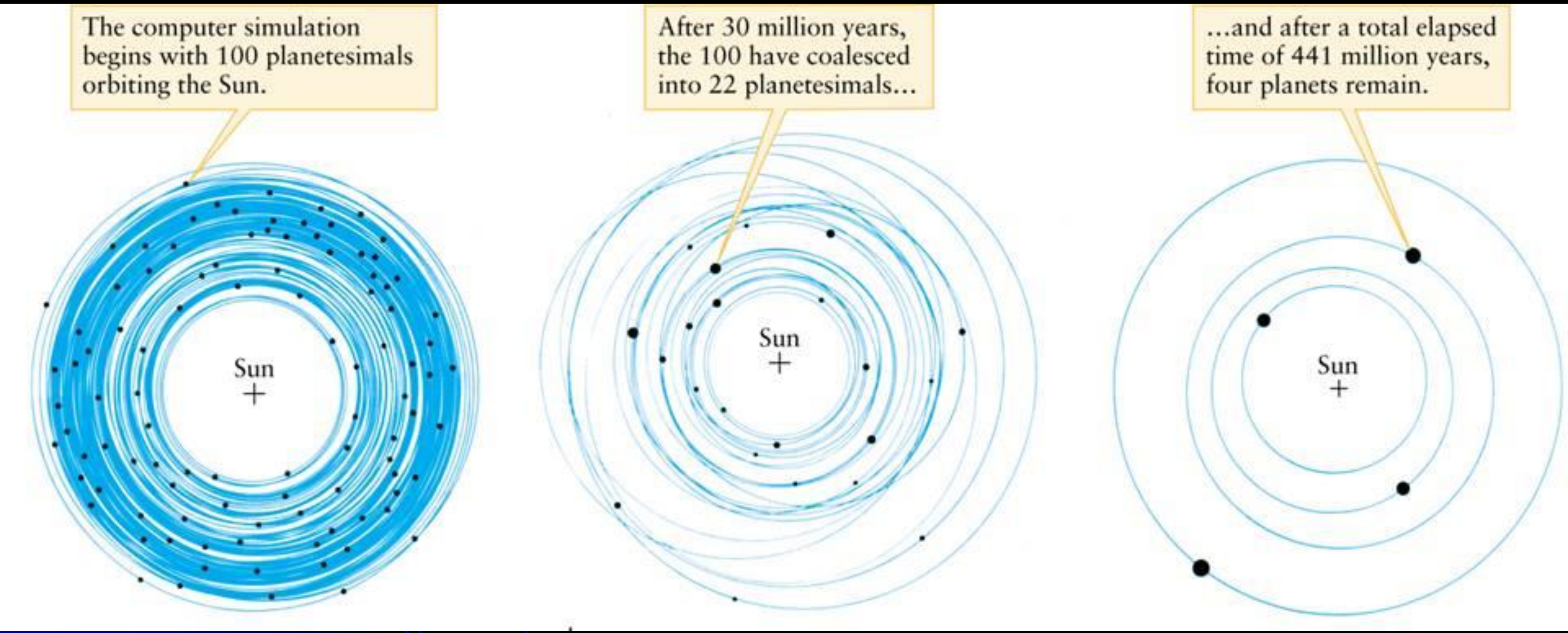
The Universe:	13.77 Billion Years*
The Milky Way Galaxy:	13.51 Billion Years*
The Sun (Sol):	4.603 Billion Years
The Solar System:	4.571 Billion Years
Earth:	4.543 Billion Years
Mercury:	4.503 Billion Years
Venus:	4.503 Billion Years
Mars:	4.603 Billion Years
The Gas Giants:	4.503 Billion Years





*± 200 Million Years

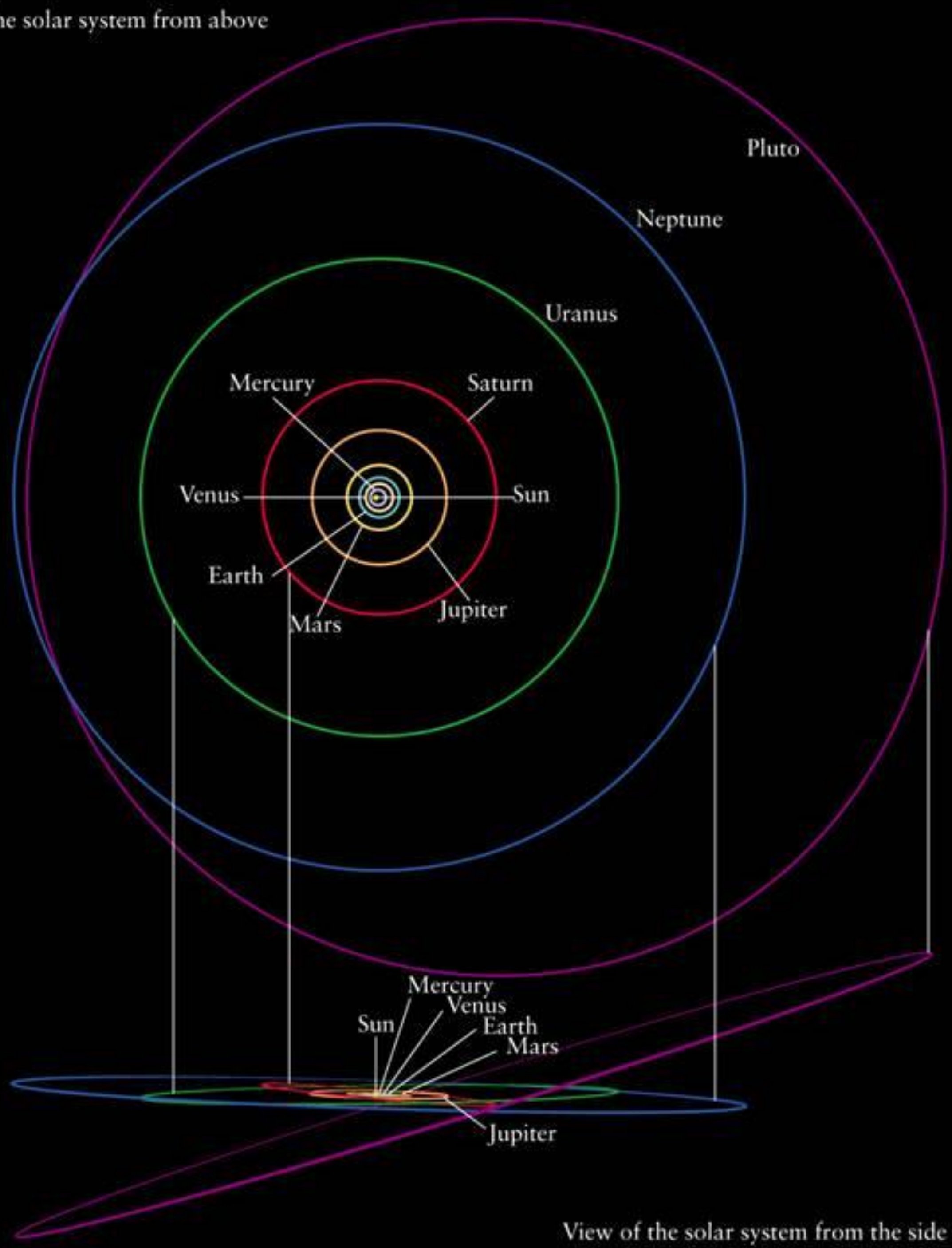
COMPUTER SIMULATION OF THE FORMATION OF THE SOLAR SYSTEM



Common Properties of Planet Orbits in Our Solar System

As viewed from above, all of the planets orbit the Sun in a counter-clockwise direction.

The planets orbit in nearly the same plane. All planets except Pluto have an orbital inclination of less than 7°.



Comparative Planetology

ORBITS

•The planets nearest to the Sun (Mercury, Venus, Earth, and Mars) are relatively close together, while those farther away (Jupiter, Saturn, Uranus, Neptune, and Pluto) are more spread out.

•Most of the planets are in nearly circular orbits.

TABLE 5-1 Orbital Characteristics of the Planets

	Average distance from Sun		Orbital period
	(AU)	(10^6 km)	(yr)
Mercury	0.39	58	0.24
Venus	0.72	108	0.62
Earth	1.00	150	1.00
Mars	1.52	228	1.88
Jupiter	5.20	778	11.86
Saturn	9.54	1427	29.46
Uranus	19.19	2871	84.01
Neptune	30.06	4497	164.79
Pluto	39.53	5914	248.54

The Titius-Bode Law

- The Titius-Bode Law, often just Bode's Law, is a mathematical model that gives the approximate position of the planets.
- Therefore, this model also tells us where planet's are not!
- Named after Johann Daniel Titius, who first presented it in 1766, and Johann Elert Bode, who refined and popularized it in 1772.

The Titius-Bode Law

$$a = 0.4 + (0.3 \times 2^n)$$

Where:

a is the average distance from the sun (the semimajor axis of the ellipse)

$n = -\infty, 0, 1, 2, \ldots$

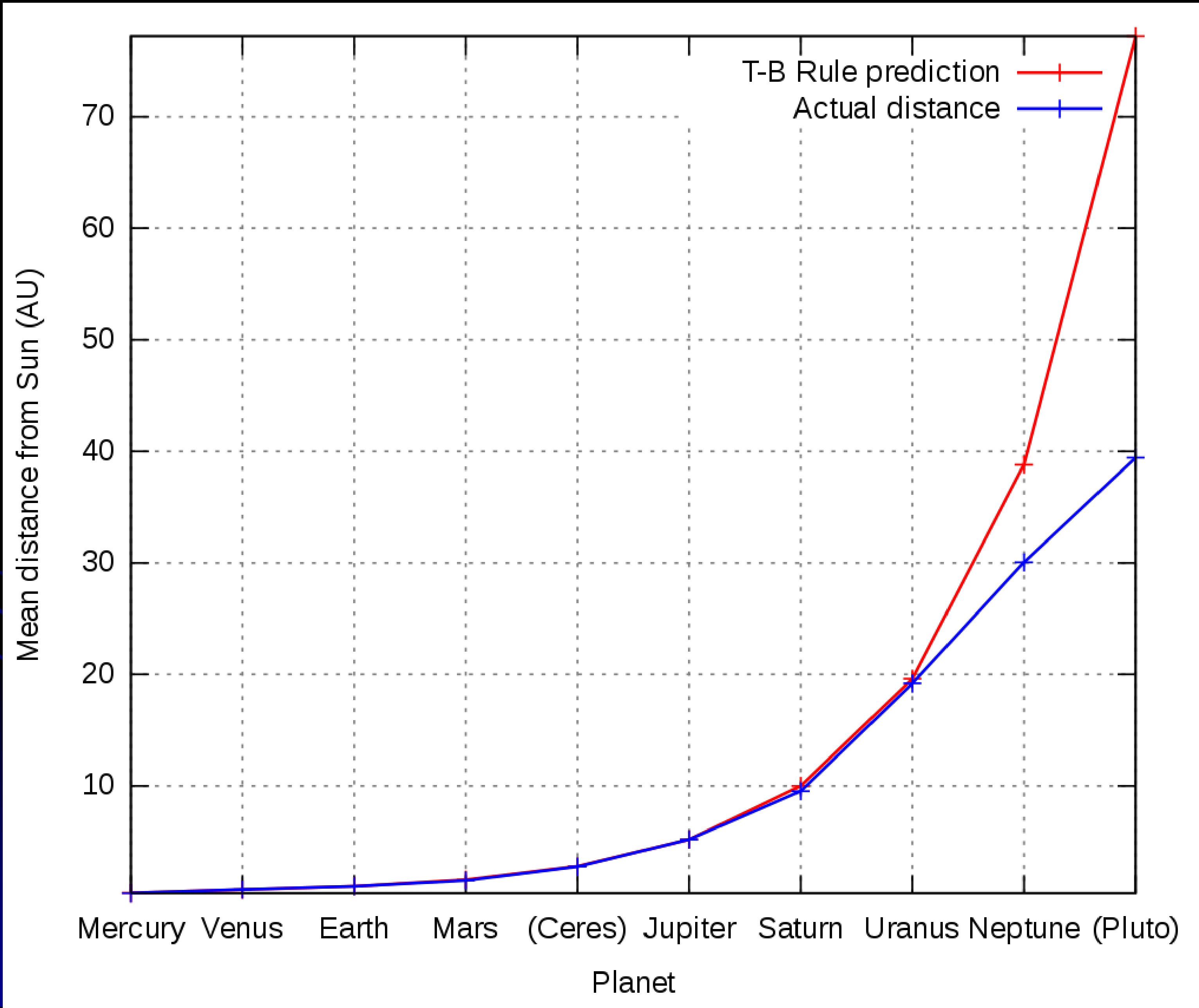
Note:

- The form given above only works for Astronomical Units.
- Bode's Law is not rooted in theory; that is, there is no theoretical construct in mechanics or gravitational physics from which it can be derived. It is purely an observational model.
- Does not work with Moons or in other planetary systems.

The Bode's Law -- Results

	n	Mean Distance from Sun in AU (Earth = 1AU) a	Mean Distance from Sun by Bode's Law: ($a = 0.4 + 0.3[2^n]$)
Mercury	-∞	0.39	0.4
Venus	0	0.72	0.7
Earth	1	1.00	1.0
Mars	2	1.52	1.6
????	3		2.8
Jupiter	4	5.20	5.2
Saturn	5	9.54	10.0
Uranus	6	19.18	19.6

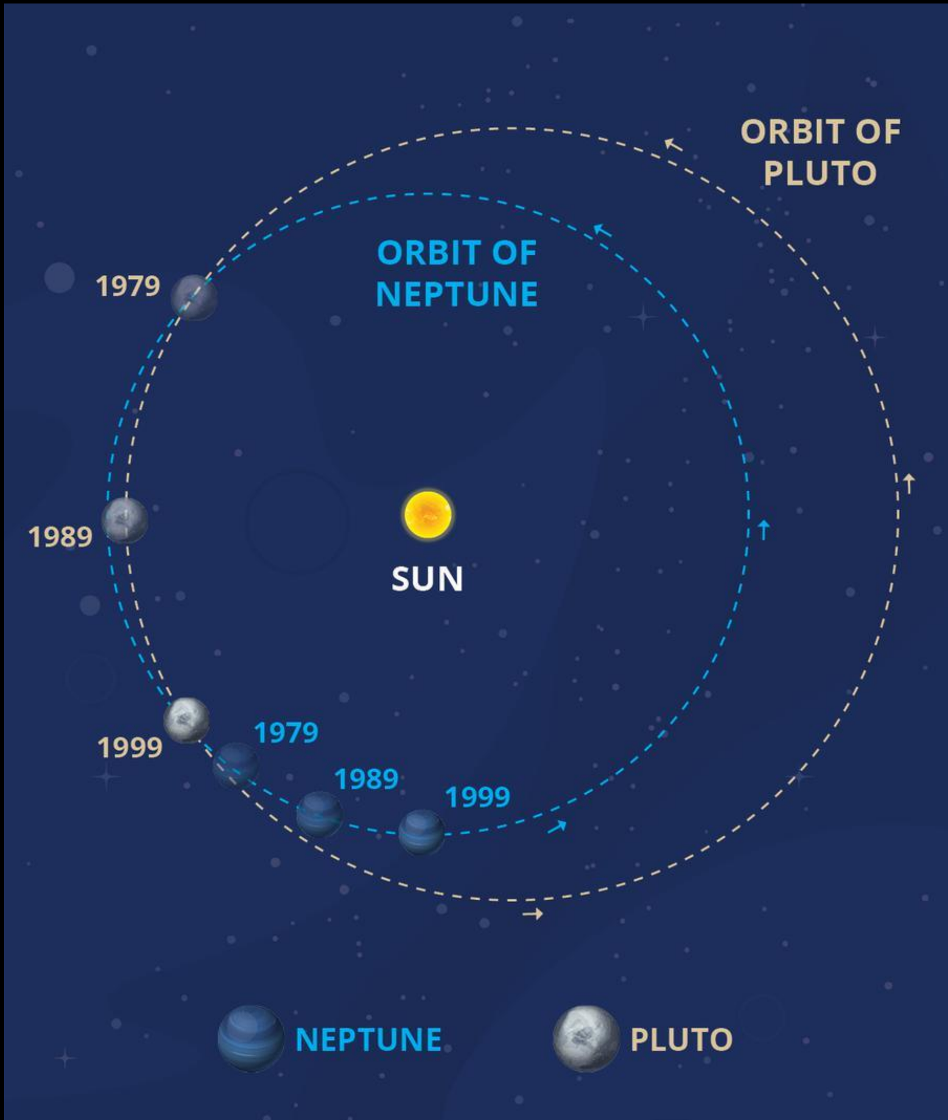
The Bode's Law -- Results



Peculiar Pluto

- Pluto, a Dwarf Planet, takes 248 years to orbit the Sun (that means a school year would be 186 Earth years!).
- It's orbital tilt is 17º.
- However…

Pluto's orbit crosses inside Neptune's orbit for 20 years every 248 years!



Moons

- Planets and moons which have no appreciable atmosphere will show scars from impacts with planetary debris, called craters.
- Our Moon still has numerous craters, providing evidence of many impacts in its history.

Debris in Our Solar System Today

Asteroids—rocky bodies several kilometers across which orbit the sun—are found mainly in the asteroid belt located between the orbits of Mars and Jupiter.

Even smaller rocky objects, called meteoroids, are scattered throughout the solar system.

Billions of chunks of rock and ice called **comets** are located beyond the orbit of Neptune. Occasionally, one of these will be pulled toward the inner solar system and form the familiar "tails" as it orbits close to the Sun.

•SIZE=the physical volume of the planet

•MASS=the amount of matter in an object

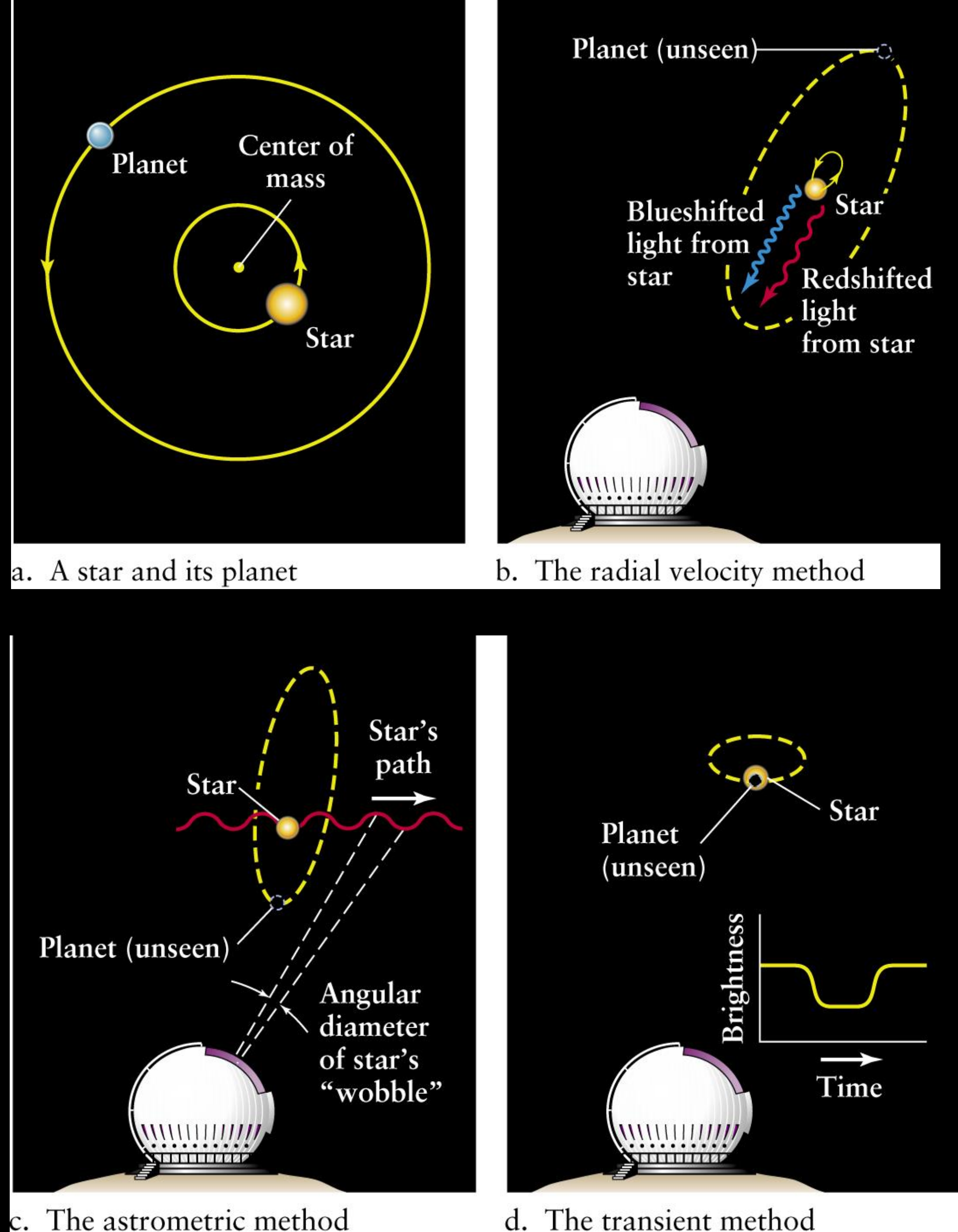
•DENSITY=the amount of mass per unit volume
Density depends on the composition of an object and not just the size. The objects shown here all have the same mass but different densities.

TABLE 5-2 Physical Characteristics of the Planets

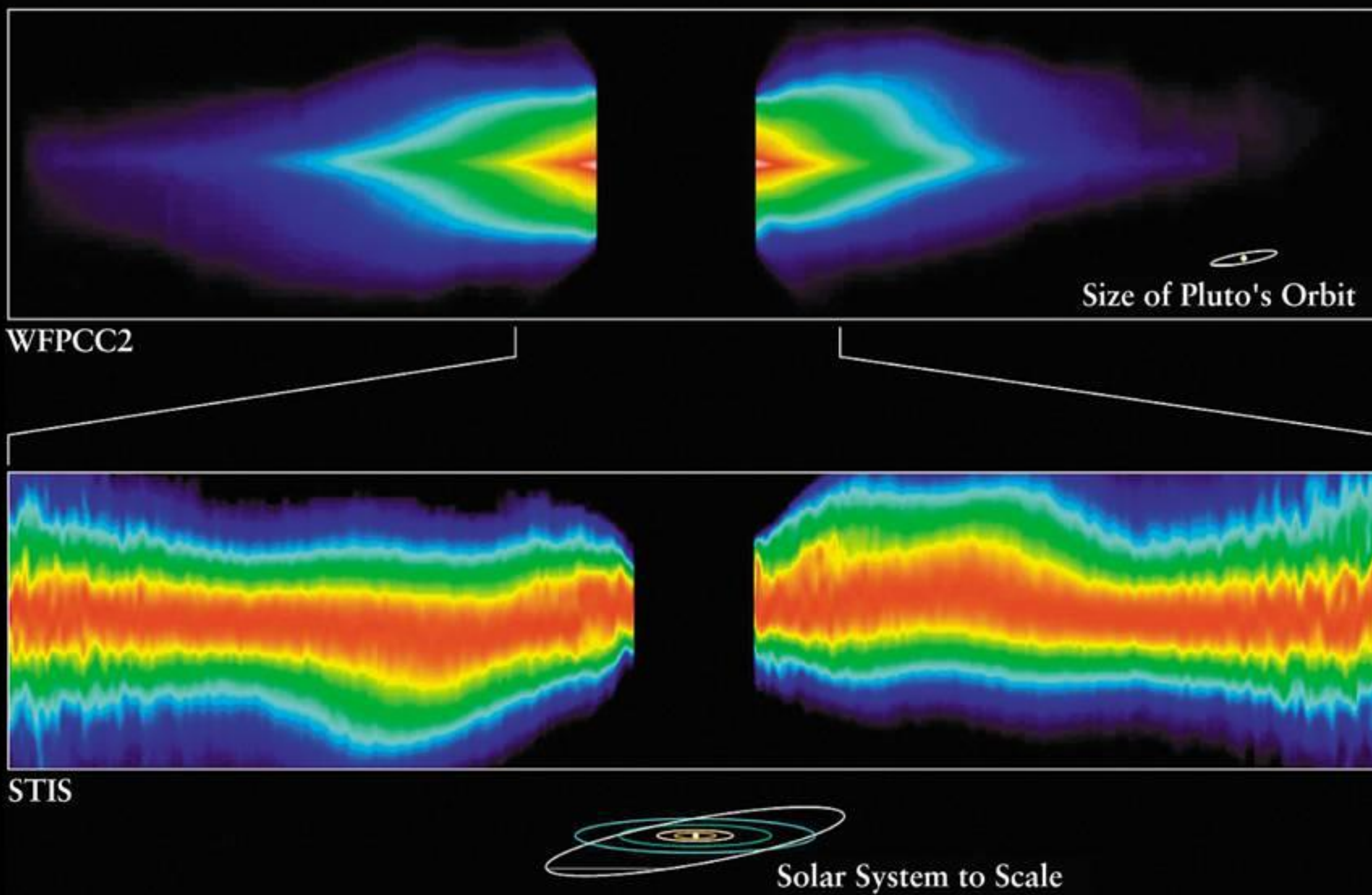
	Diameter (km)	Diameter (Earth = 1)	Mass (kg)	Mass (Earth = 1)	Average density (kg/m^3)
Mercury	4,878	0.38	3.3×10^{23}	0.06	5430
Venus	12,100	0.95	4.9×10^{24}	0.81	5250
Earth	12,756	1.00	6.0×10^{24}	1.00	5520
Mars	6,786	0.53	6.4×10^{23}	0.11	3950
Jupiter	142,984	11.21	1.9×10^{27}	317.94	1330
Saturn	120,536	9.45	5.7×10^{26}	95.18	690
Uranus	51,118	4.01	8.7×10^{25}	14.53	1290
Neptune	49,528	3.88	1.0×10^{26}	17.14	1640
Pluto	2,300	0.18	1.3×10^{22}	0.002	2030

Extrasolar planets are either too dim or too close to the stars they orbit to observe directly.

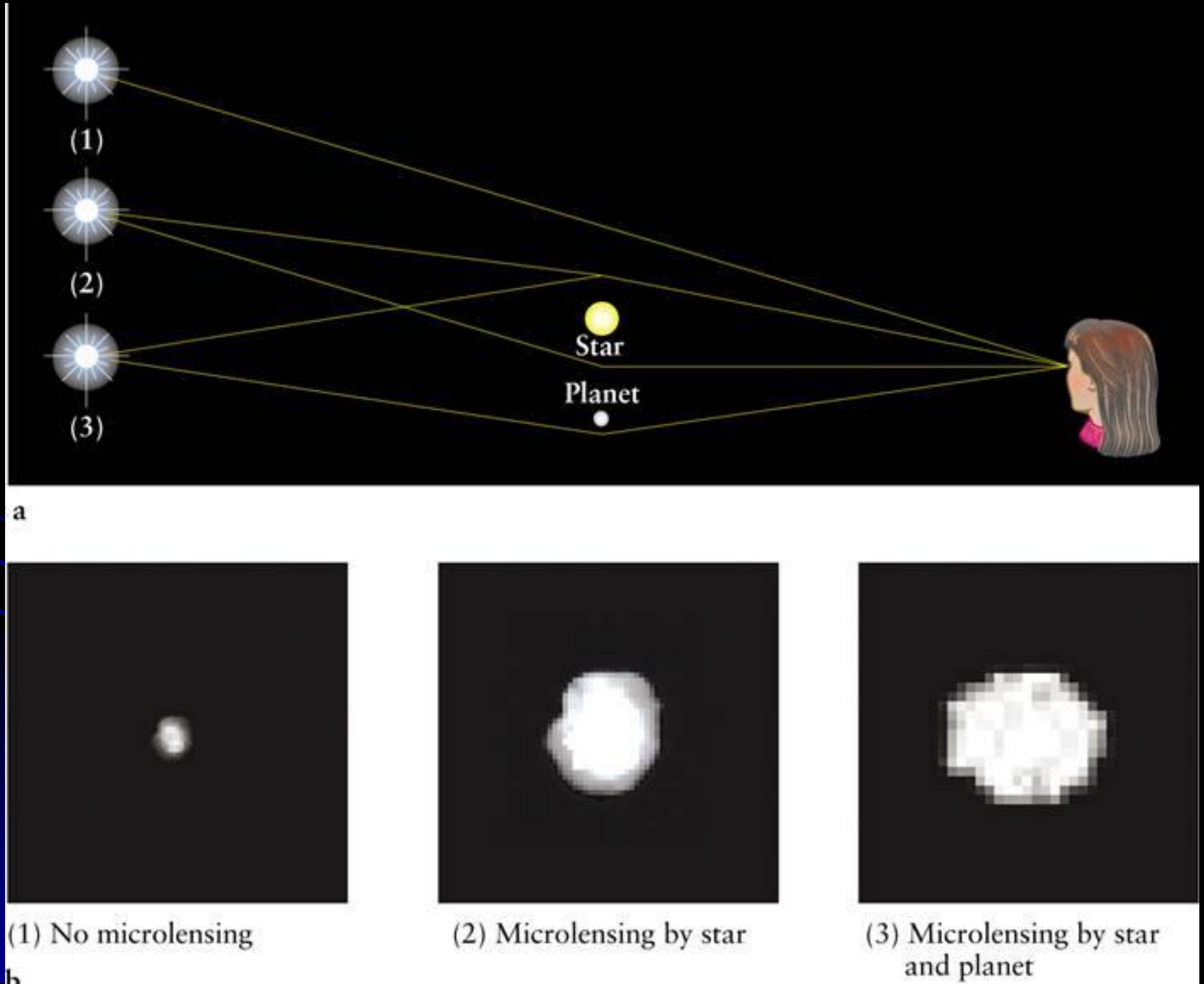
However, we can detect the effect they have on the spectra from their star to confirm their existence.



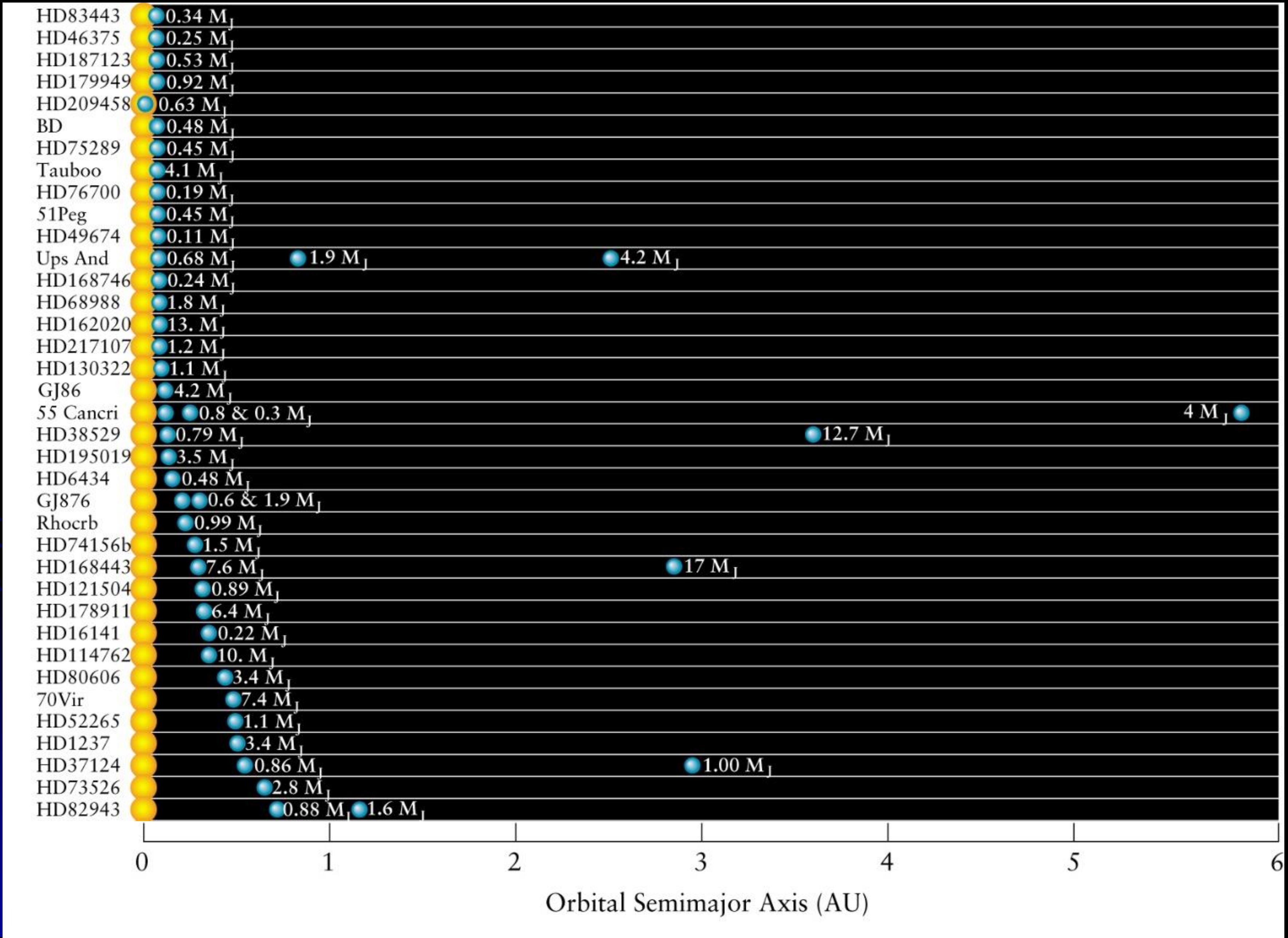
Evidence of Planets Orbiting Other Stars



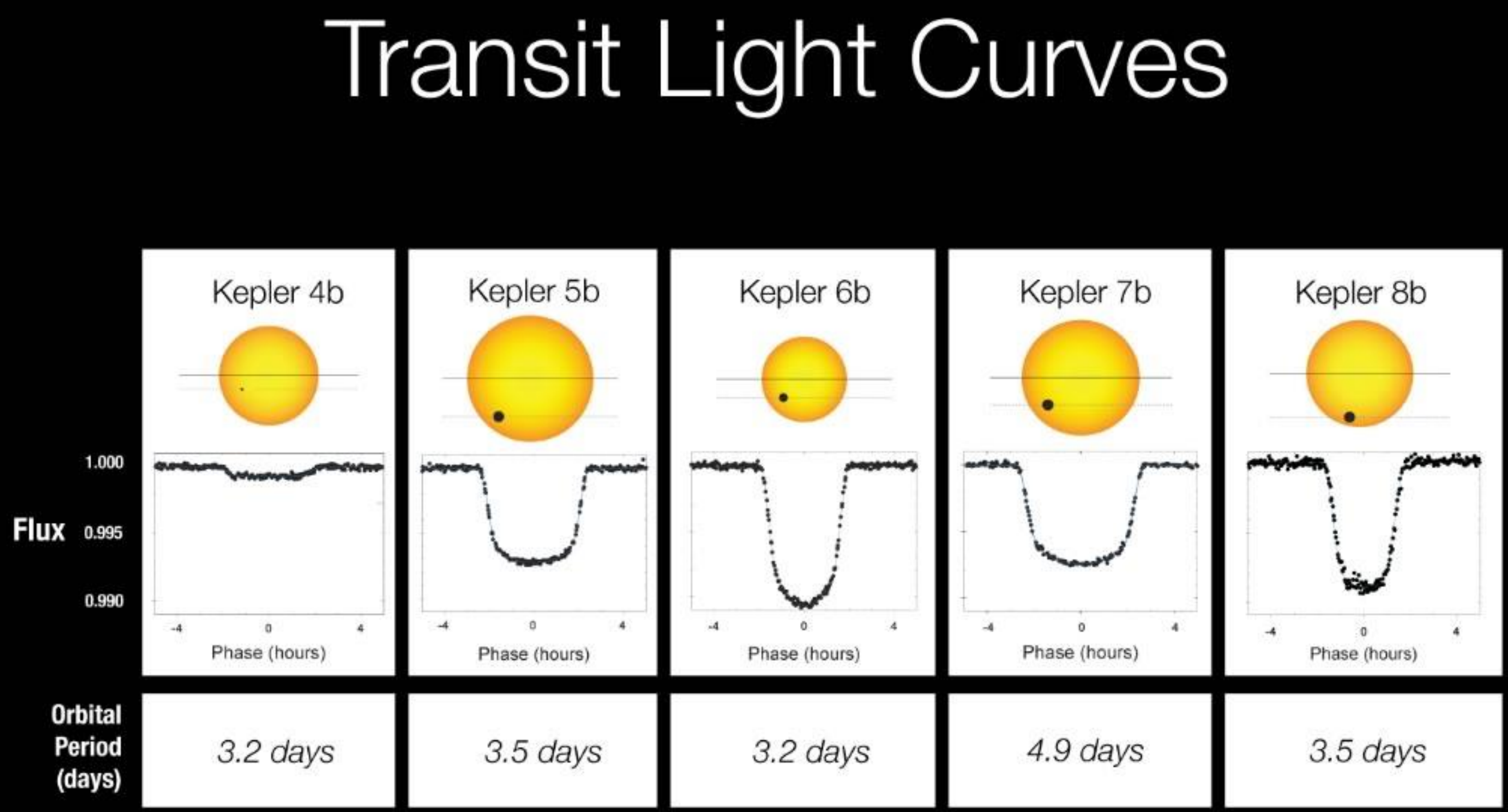
The gravitational fields of a star and its planet will cause passing light to change direction. The focusing of light by gravity is called microlensing or gravitational lensing.



Separation between Extrasolar Planets and Their Stars

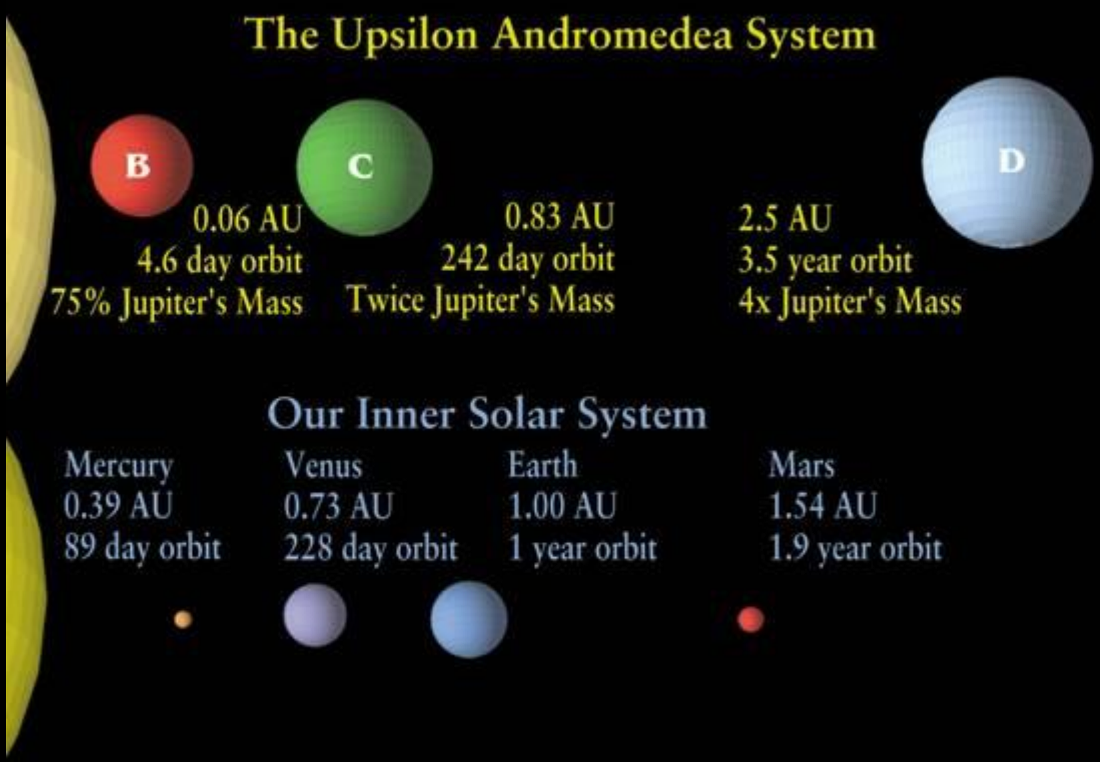


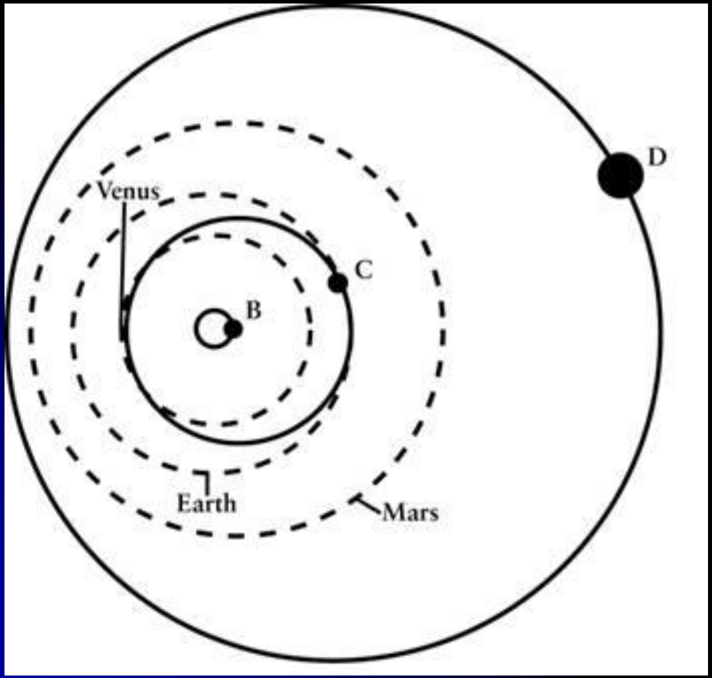
Discovering Extrasolar Planets by Examing their Transits



AN EXTRASOLAR SYSTEM

Unlike our solar system, the Upsilon Andromedea System has large planets orbiting close to the star.





The orbits of the inner planets in our solar system compared to those of the Upsilon Andromedea System

*Thousands* of exoplanets have been discovered, with some having the conditions for life!

Video