Origin and History of the Solar System

Lecture 1

Prof.Dr. Emad A. Al-Heety
Department of Applied Geology
University of Anbar
Ramadi – IRAQ
Email : emadsalah@ uoanbar.edu.iq

Planetary Orbits : the Titius – Bode Law

- -For many years theories of the origin of the solar system were based on rather little hard evidence.
- -Motions of the planets were well observed and orbital radii were seen to follow a regular, pattern.
- -This regularity was represented by an equation known as Titius – Bode Law or sometimes as Bode's Law.
- The law relates the mean distances of the planets from the sun to a simple mathematic progression of numbers.
- To find the mean distances of the planets, beginning with the following simple sequence of numbers:

Titius – Bode Law

0 3 6 12 24 48 96 192 384

With the exception of the first two, the others are simple twice the value of the preceding number.

Add 4 to each number:

4 7 10 14 28 52 100 196 388

Then divide by 10 :

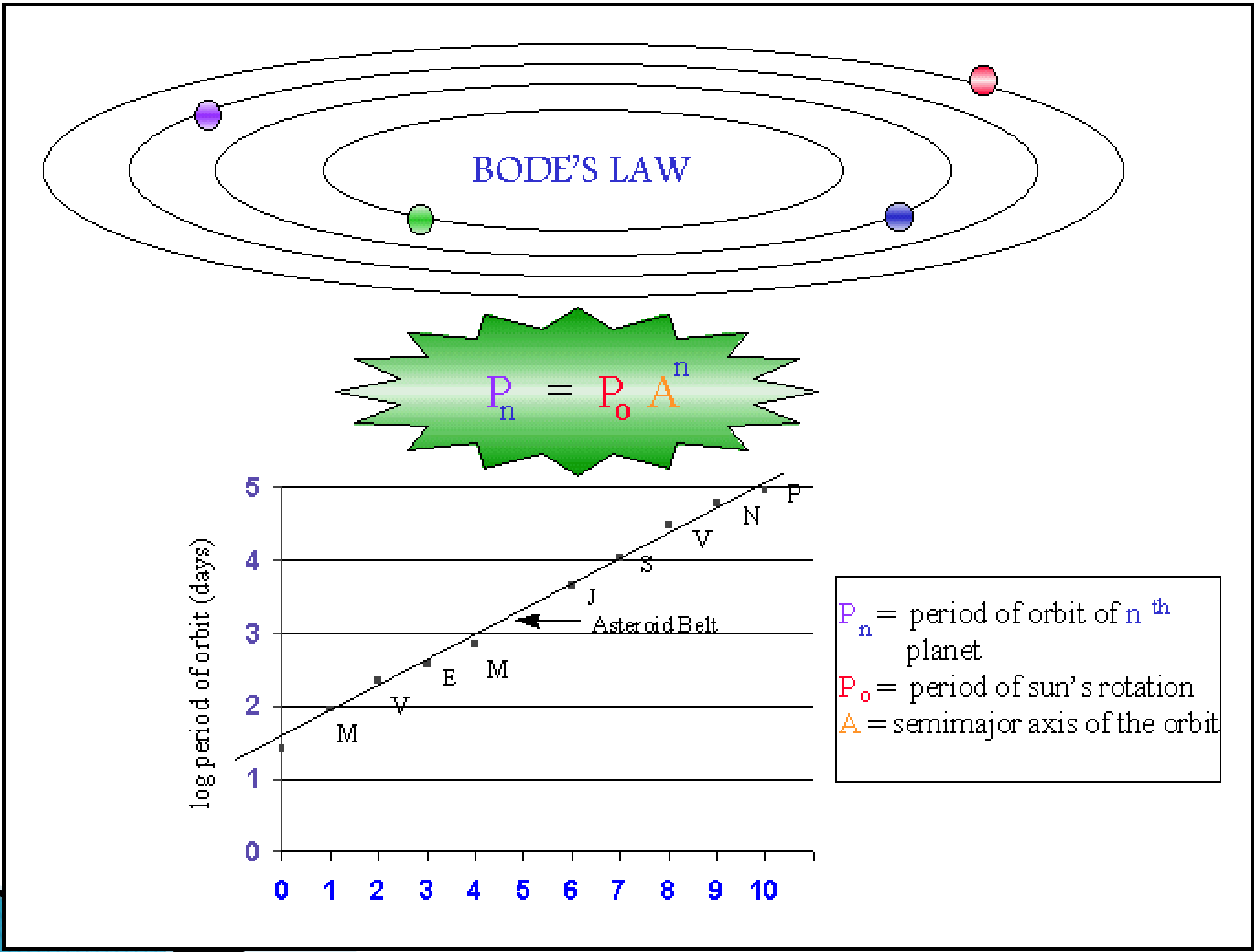
0.4 0.7 1 1.4 2.8 5.2 10 19.6 38.8

The resulting sequence is very close to the distribution of mean distances of the planets from the Sun :

Titius – Bode Law
Table 1.

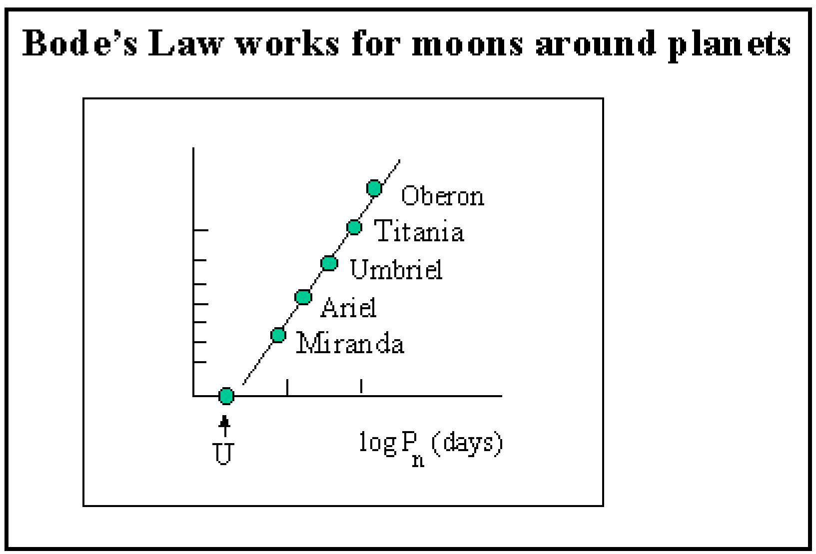
N planet	Actual Distance (AU)	Bode's Law
1Mercury	0.378	0.40
2Venus	0.723	0.70
3Earth	1.00	1.00
4Mars	1.524	1.60
5Asteroids	~2.8	2.8
6Jupiter	5.2013	5.20
7Saturn	9.538	10.0
8Uranus	19.18	19.6
9 Neptune	30.06	38.8

Titius – Bode Law



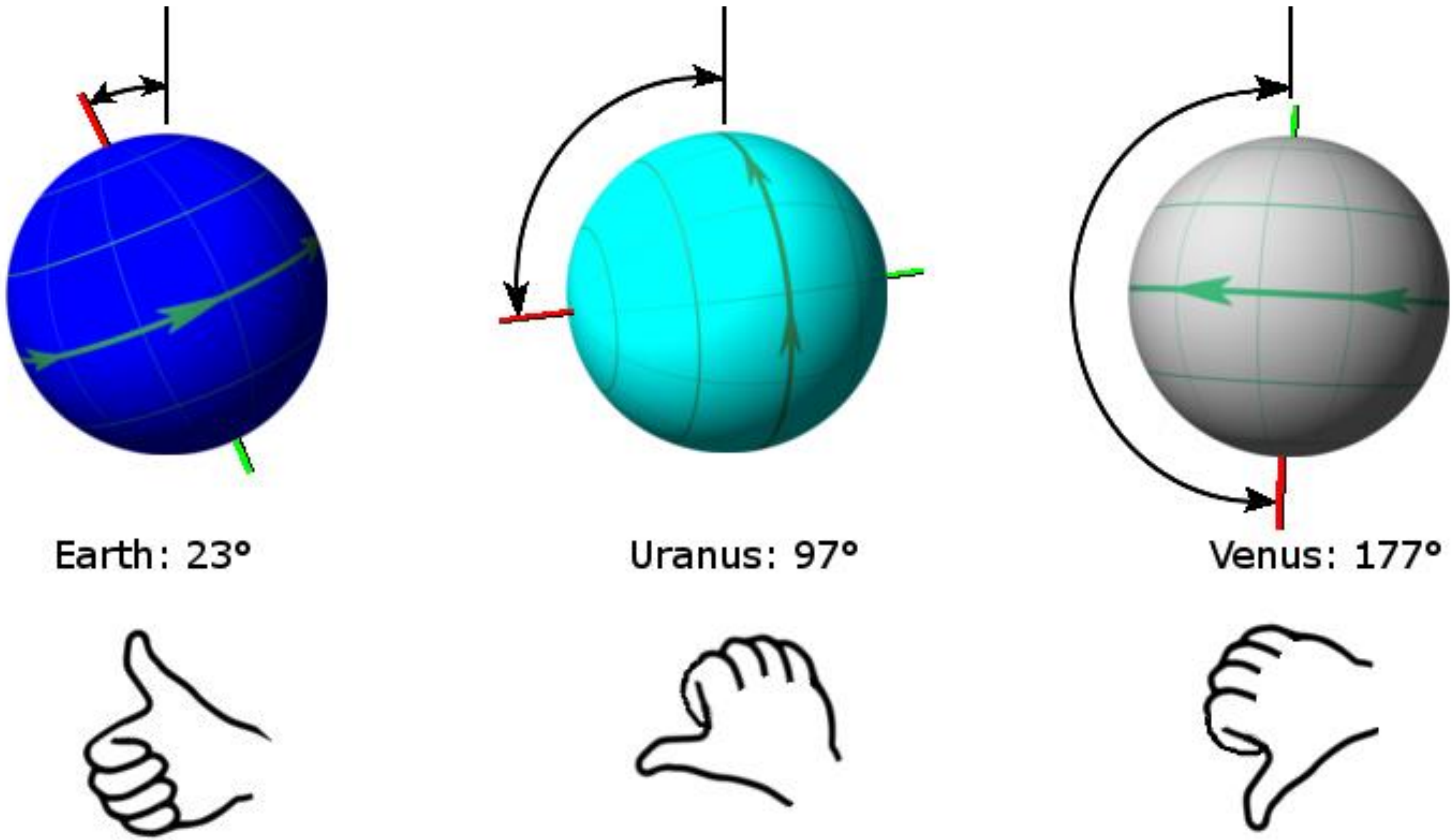
Titius - Bode Law

As evidence of the generality of the Titius - Bode law , we note that the orbital radii of the major satellites of the giant planets also fit (Fig.)



Axial rotations

- The rotations of the planets differ greatly from one to another in both speed and axial orientation.
- Rotation in the sense of the orbital motion predominates , but Uranus , whose axis is almost in the orbital plane , Venus , whose very slow rotation retrograde , are exceptions.



Comparison of the tilt of the rotation axis to the plane of the orbit for three planets: Earth, Uranus, Venus. Includes a right-hand-rule demonstration

Axial rotations

- The terrestrial planets are rotating slowly compared with both the giant planets and asteroids.
- In the cases of Mercury , Venuse , and the Earth, the slower rotations are due to the dissipation of rotational energy by tidal friction .
- **Tidal friction,** in astronomy, strain produced in a celestial body (such as the Earth or Moon) that undergoes cyclic variations in gravitational attraction as it orbits, or is orbited by, a second body.

Distribution of Angular momentum

–Definitions:

Ordinary momentum is a measure of an object's tendency to move at constant speed along a straight path. Momentum depends on **speed** and **mass**. A train moving at 20 mph has more momentum than a bicyclist moving at the same speed. A car colliding at 5 mph does not cause as much damage as that same car colliding at 60 mph.

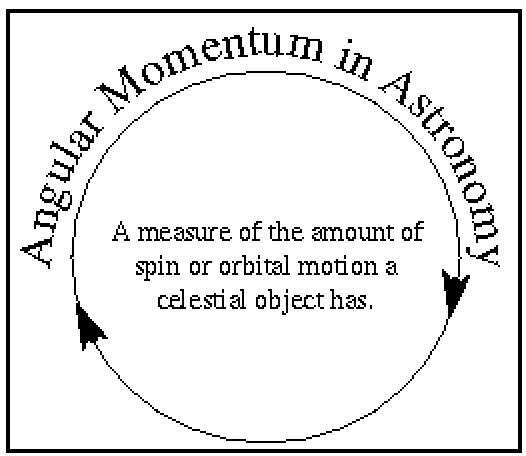
– For things moving in straight lines

$$\textbf{momentum} = \textbf{mass} \times \textbf{speed}$$

Distribution of Angular momentum

–**Angular momentum** measures an object's tendency to continue to spin. An ``object'' can be either a single body or two or more bodies acting together as a single group.

–**angular momentum = mass × velocity × distance** (from point object is spinning or orbiting around).



Distribution of Angular momentum

- The total orbital angular momentum of the solar system = 3.137×10^{43} **Kg m^2 s^{-1}.**

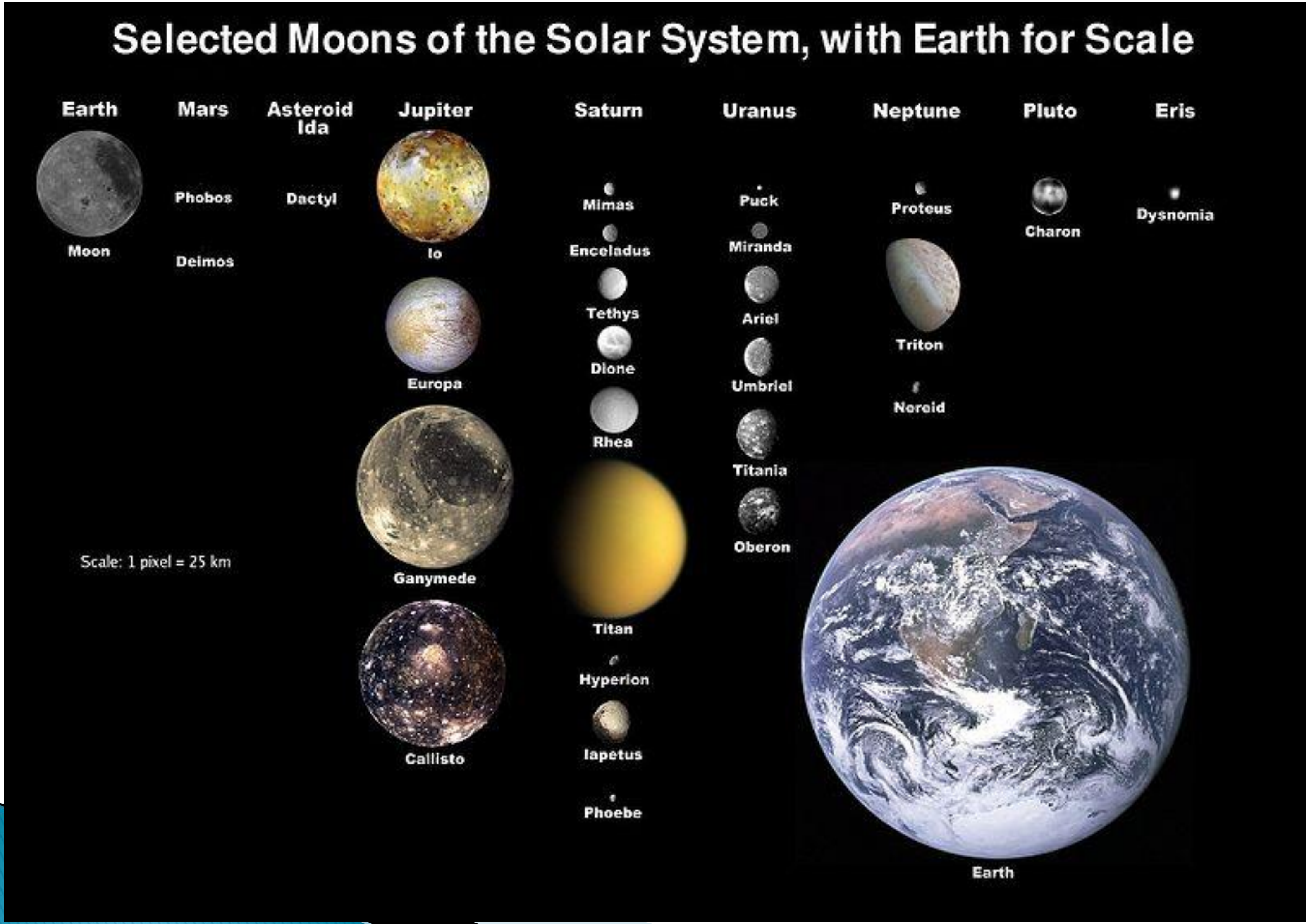
Jupiter accounts for more than *60%* of this total.

- **The angular momentum of planetary rotations are very much smaller than the orbital angular momentum. The rotational angular momentum of the Earth is 2.2 parts in ten millions .**
- **The sun has only a small fraction (0.5%) of the total orbital angular momentum of the Solar System , although the planets have little more than 0.1% of the mass.**

Satellites

- The giants planets have numerous satellites, but the terrestrial planets have only three , Moon , satellite of the Earth ,Phobos and Deimos , satellites of Mars (Figure 1).
- Phobos and Deimos, are small, irregularly shaped close satellites of Mars that give the impression of being captured asteroids.

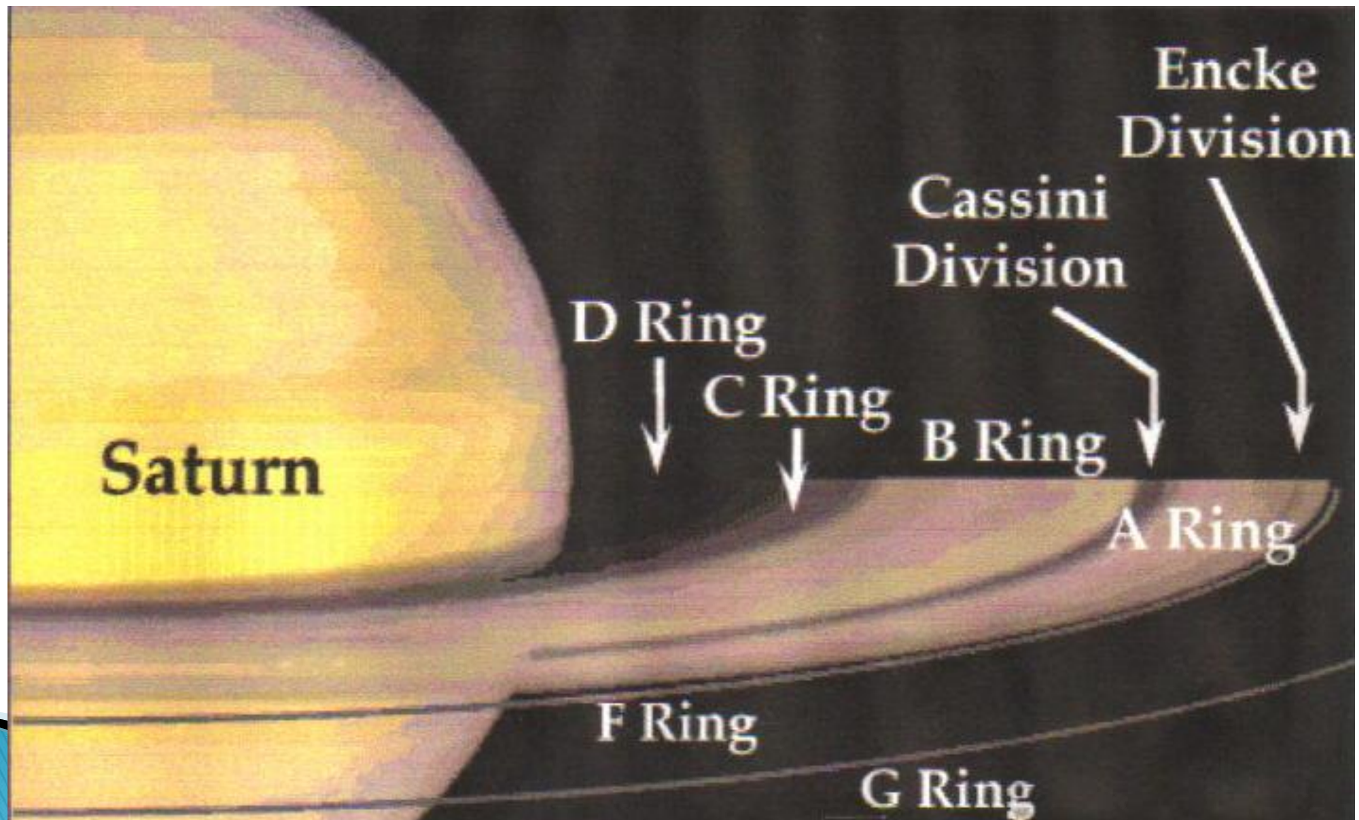
Figure 1



Selected Moons of the Solar System, with Earth for Scale
Earth
Mars
Asteroid Ida
Jupiter
Saturn
Uranus
Neptune
Pluto
Eris
Moon
Phobos
Deimos
Dactyl
Io
Europa
Ganymede
Callisto
Mimas
Enceladus
Tethys
Dione
Rhea
Titan
Hyperion
Iapetus
Phoebe
Puck
Miranda
Ariel
Umbriel
Titania
Oberon
Proteus
Triton
Nereid
Charon
Dysnomia
Scale: 1 pixel = 25 km
Earth

Satellites

- The giants planets all have rings of fine particles that are most clearly observed around Saturn (Figure 2.)



Satellites

- Most of satellites are presumed to have formed with their parent planets in the same manner as the planets were formed around the Sun.
- Other satellites are captured asteroids.
- Surfaces of the satellites of the giants planets are very different from one another.
- Several satellites show evidence of internal activity and even active volcanism (example the Jupiter's closest large satellite , Io,).
- The densities of the satellites of the giants planets are mostly less than 2000 kg/ cubic meter, much lower than the densities of terrestrial planets , indicating compositions rich in ices (condensed volatiles such as H_2O , CH_4).

Satellites

-Satellites are a normal feature of the Solar System, as evidenced by their large numbers for the giants planets.

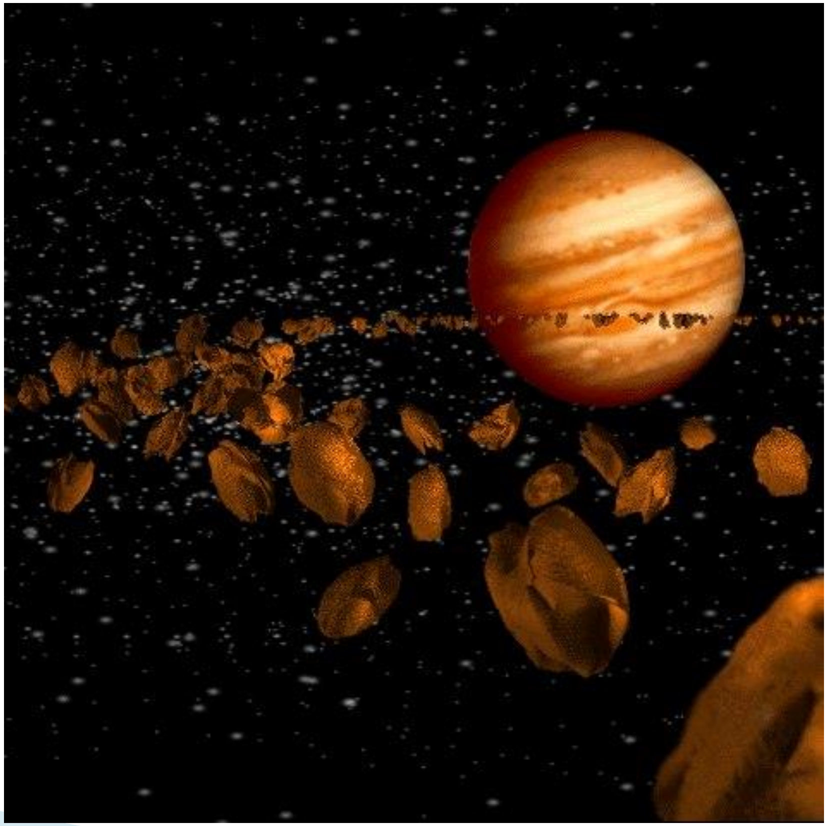
Asteroids

- *Asteroids* are the small bodies with orbits concentrated between Mars and Jupiter. The name *asteroids* means "star-like". In the night sky asteroids look like stars since they do not emit gases and dust like comets (Figure 3) .
- A few of them have elliptical orbits extending as far as the Earth and are referred to as near Earth asteroids

(NEAs) or as the Apollo group of asteroids. This group are of the best observed and because meteorites are (NEAs) intercepted by the Earth.

Asteroids
Figure 3.

Asteroids of our Solar System.



Asteroids

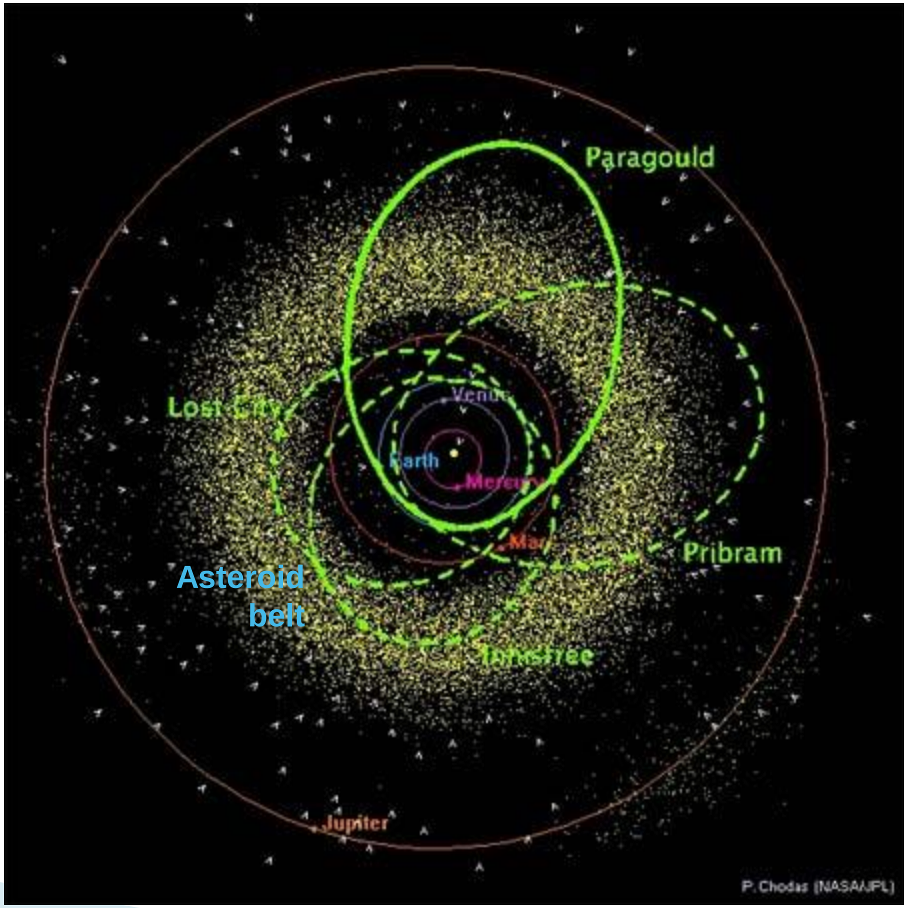
- More than *10000 asteroids* have been identified and new and new discoveries occur at a rate of about one per day.
- Orbits of asteroids do not form an uninterrupted continuum but have gaps , known as *Kirkwood gaps* after their discoverer.
- *Asteroids* on a collision course with Earth are called *meteoroids*. When a meteoroid burns up as it falls through our atmosphere, it is called a *meteor*, or "shooting star". If a meteoroid crashes into the Earth it is called a *meteorite.*

Meteorites: falls , finds, and orbits

- Meteorites are iron and stone bodies that arrive on the Earth in small numbers , on elliptical orbits that extends from the main asteroidal belt.
- Observed falls are signalled by fiery trails through the atmosphere. A few meteorites falls have been observed in sufficient detail to allow reliable calculations of their pre-terrestrial orbits.
- The first clear example was the chondritic meteorite , Pribram , that fell in Czechoslovakia in 1959 and this is one of the four with orbits plotted in (Figure 4.).

Meteorites

Figure 4. The calculated orbits of four recovered meteorites .



Meteorites

- An interesting statistical consequence arises from the orbits of meteoritic bodies : falls occur twice as frequently between noon and 6 pm local time as between 6 am and noon , when the opportunity for observation is similar.
- It is important to distinguish ***meteorites*** from ***meteors*** , they are briefly luminous trials in the upper atmosphere . Most meteors are produced by small particles , called ***meteoroids*** , that never get near to the ground. Most meteors are friable particles of low density , identified as debris from comet .

Meteorites
Classification of Meteorites

- *Meteorites* are usually divided into three major groups: *stones*, *stony-irons*, and *irons*, according to their main composition. The *stones* are sub-divided into *chondrites* and *achondrites*, depending on whether or not they contain small rounded grains called *chondrules.*

I. *Stones Meteorites* are meteorites that look like ordinary earth rocks.

Classification of Meteorites

II. Stony-Irons meteorites

They are meteorites that grade in composition from droplets of olivine imbedded in pure nickel-iron to droplets of nickel-iron in pure olivine.

III. Irons Meteorites

They consist of iron with small amounts of nickel and sulfur. These meteorites were once completely molten and, as indicated by sizes as large as several meters for some individual crystal, cooled slowly over millions of years.

Meteorites

Like earth rocks, meteorites have experienced different amounts of ***heating***, ***metamorphism***, and ***melting***. They are the result of geologic processes similar to the processes making different kinds of rocks on Earth. Since they come from the asteroids, an understanding of the processes that made the meteorites will tell us what geologic processes operated on the asteroids.

Comets

-*Comets* are small, fragile, irregularly shaped bodies composed of a mixture of non-volatile grains and frozen gases. They have highly elliptical orbits that bring them very close to the Sun and swing them deeply into space, often beyond the orbit of Pluto.

- Some comets follow elliptical orbits about the Sun , but most approach on orbits that are indistinguishable from parabolas.

- The volatile ices of the comets evaporate in the vicinity of the Sun ,producing luminous halos and often tails (Figure 6). Without the halos comets are small, very dark and virtually invisible.

Comets

-Ablation of the ices by the Sun releases the small , friable grains that become meteoroids .

Figure 6. Comets Halos and Trials

Terrestrial Planets
Some Comparisons

- The mean densities of the terrestrial planets and the Moon are listed in Table 2.

Table 2. Mean densities of the terrestrial planets and Moon.

Planet	Mean Density (Kg/m3)
Mercury	5427
Venus	5204
earth	5515
Moon	3345
Mars	3933

Terrestrial Planets
Some Comparisons

Table 3.Decompressed densities of terrestrial planets and Moon.

Planet	Decompressed density (km/m3)
Mercury	5017
Venus	3868
Earth	3995
Moon	3269
Mars	3697

Terrestrial Planets
Some Comparisons

- *Venus* is similar to the Earth in size and mean density (Table 2.) and is presumed to similar internally.
- The estimated zero pressure density (Table 3.) is only slightly less than that of the Earth .
- *Venus* has a core comparable to that of the Earth and it is at least partly liquid , but generate no magnetic field.
- It is probable that *Venus* has no weak asthenospheric layer, which we can explain by arguing that water is essential to the weakness of the Earth’s asthenosphere ,and that *Venus* has no surface water to cycle through an asthenosphere by subduction and volcanism.

Terrestrial Planets
Some Comparisons

- *Mars* is less dense than the Earth and its moment of inertia coefficient is high ,indicating that the core is relatively small.
- *Mars* has a composition comparable to that of the Earth , but that it is more oxidized and has a smaller total fraction of Fe.
- The magnetic field is weak enough to be explained by remnant magnetism in the thick and highly magnetizable crust, but this required an earlier core-generated field.

Terrestrial Planets
Some Comparisons

- *Mercury* has by far the highest uncompressed density of all the terrestrial planets.
- *Mercury* is the smallest , excluding the Moon ,so that self-compression is slight.
- With respect to oxidation, *Mercury* is evidently at the opposite end of the scale from *Mars*.
- The magnetic field of *Mercury* is of particular interest . Although much weaker than the fields of the *Earth* or giant planets , it is more than 100 times stronger than the fields of *Venus* , *Mars* or the *Moon*.

Terrestrial Planets
Some Comparisons

- **The *Moon* is** less dense than the terrestrial planets and it is small enough to have only 2.3% difference between compressed and uncompressed densities.
- A core with 2.5% of the mass of the ***Moon*** and 22% of its radius.
- The records of the lunar seismometers did not establish the presence or absence of a core , but the evidence of an early lunar magnetic field demands one.
- The core of the Moon is still at least partly fluid.

Early History of the Moon

- **The origin of the Moon has been a fertile source of conjecture.**
- **Several mechanisms have been proposed for the Moon's formation .**

These include the ***fission of the Moon from the Earth's crust*** through centrifugal forces, which would require too great an initial spin of the Earth, ***the gravitational capture of a pre-formed Moon***, which would require extended atmosphere of the Earth to dissipate the energy of the passing Moon, and ***the co-formation of the Earth and the Moon together in the primordial accretion disk***, which does not explain the depletion of metallic iron in the Moon. These hypotheses also cannot account for the high angular momentum of the Earth-Moon system .

Early History of the Moon
Giant Impact Hypothesis

- The giant impact hypothesis (big whack) is the now dominant scientific hypothesis for the formation of the Moon , which is thought to have formed as a result of a collision between the young Earth and the Mars -sized body sometimes called Theia.
- 4.533 Ga ago, shortly after the formation of the Earth,a Mars - sized planetesimal hit the Earth at an oblique angle, destroying the impactor and ejecting most of that body a long with a significant portion of the Earth's felsic - rich mantle out into space.

Early History of the Moon
Giant Impact Hypothesis

- Some of this material then accreted into the Moon from an orbiting ring of debris (Figure 8).
- Current estimates based on computer simulation of such an event suggests the spherical shape of the Moon was attained between only one and one hundred years after the impact.

Early History of the Moon
Giant Impact Hypothesis
Evidences

1. Evidence for this impact comes from rocks collected during the Apollo Moon Landings , which show an oxygen isotope composition that is nearly identical to the Earth's mantle .
2. Chemical inspection of those rocks found them to be nearly devoid of volatile and lighter elements, leading to the speculation that they formed from an unusually extreme amount of heating that boiled them off.
3. Sesimometers on the Moon have measured the size of its nickel – iron core and have found that it is much smaller than predicted under other formation scenarios, such as tandem formation with the Earth.

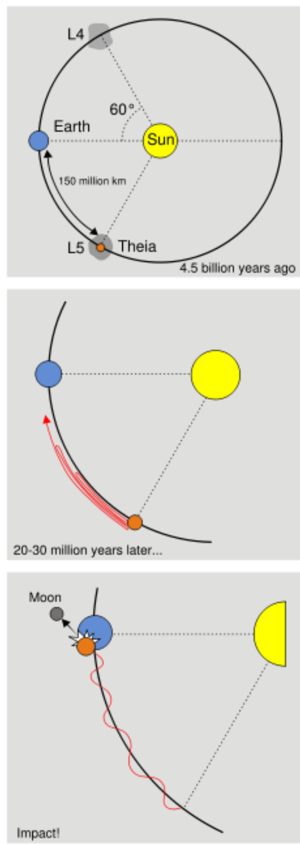
Early History of the Moon
Giant Impact Hypothesis
((Evidences

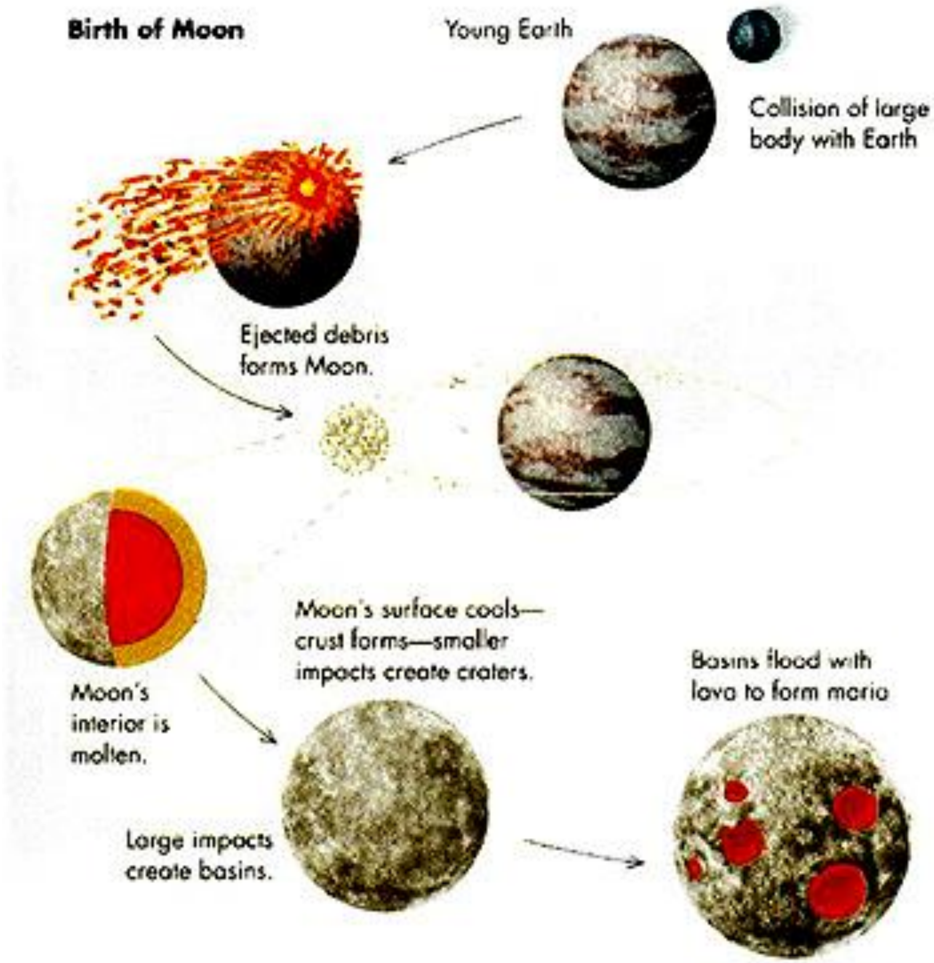
4. A smaller core is consistent with the impact theory because this theory predicts that the moon was formed mostly from the mantle of the Earth and partly from the mantle of the impacting body and not from the core of the impacting body (it is thought that the core of the impactor sank and merged with the Earth's core).
5. Impact conditions satisfy the high angular momentum constraints of the Earth-Moon system. The orbital angular momentum per unit mass of satellites is necessarily very much greater than the rotational angular momentum of their parent planets .

. For the Moon the Ratio is 400.

Early History of the Moon
((Giant Impact Hypothesis))

Figure 8.





References

- Stacey F. and Davis P., Physics of the Earth, Cambridge University Press, 2008.
- Lowrie, W., Fundamentals of Geophysics, Cambridge University Press, 2007.