Space Physics-Project
The moons of the planets

Christian Will 2007/10/22

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1 Introduction

Our solar system contains eight planets. Beginning with the closest one to the sun they are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune in order. Most of us also know Pluto, but since a redefinition of 'planet' in the year 2006 it is only called a dwarf planet (to be a planet, it must have cleared the neighborhood around its orbit which is not the case). There are at least 166 known moons in our solar system orbiting a planet. The amount of moons belonging to a planet varies intensely. Some planets don't have any moon; to Jupiter, which has the most moons, belongs 63 of them. Of course, it is not possible to mention every one of them in this project so I will try to talk about the most interesting ones.
The first known moon, of course, was Luna, the Earth's Moon. In 1610 Galileo Galilei discovered the first moons belonging to another planet (Juptier): Io and Ganymede. This observation of objects, which are not orbiting the Earth was an argument for the heliocentric and against the geocentric philosophy. While Galilei expected them as a planet, Christiaan Huygens was the first person, who discovered another moon (Titan, one of Saturn's moons) and called it a moon as well. So he understood that the relation between Saturn and Titan is the same like between Earth and Luna, the moon orbits its planet.

2 Overview of the planets and their moons

Below are the planets in our solar system, the amount of their moons and some names of them.

Planet	**Number of moons**	**some moons**
Mercury	0	-
Venus	0	-
Earth	1	Luna
Mars	2	Phobos, Deimos
Jupiter	63	Io, Europa, Ganymede, Callisto
Saturn	60	Titan, Hyperion, Enceladus, Epimetheus, Janus
Uranus	27	Miranda, Ariel, Umbriel, Titania, Oberon
Neptune	13	Proteus, Triton

Table 1: planets and their moons

3 Definition of a moon

A moon is a natural satellite in a solar system. The definition of a natural satellite says, that it is a celestial body or a galaxy, which revolves around a planet, a dwarf planet or

other smaller objects like an asteroid for example. The satellite follows the other object on its orbit around the central star of a solar system. In this project I will only talk about the first case.

Here are some important facts you should know when talking about moons:

inclination The inclination is the angular distance of the orbital plane of a moon relative to the equatorial plane of the planet that it orbits (see fig. 1, page 4). An inclination of 0° means an orbit in the equatorial plane, 90° means a polar orbit and 180° stands for a retrograde motion.

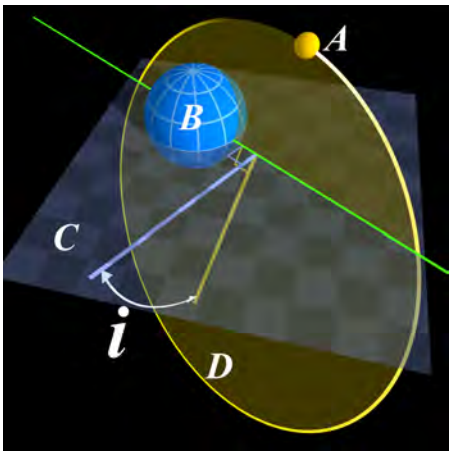


Figure 1: A=moon, B=planet, C=equatorial plane, D=orbital plane, i=inclination

direct (prograde) motion A direct motion corresponds to an inclination of 0° to 90°. This signifies a moon orbiting its planet in the same direction as the planet orbits the sun.

retrograde motion Retrograde motion corresponds to an inclination of 90° to 180°. So the moon orbits its planet in the contrary direction as the planet revolves around the sun.

regular satellite Regular satellites have a circular orbit and are all prograde. They are originated from the same collapsing region of the protoplanetary disk or results from a grand collision.

irregular satellite An irregular satellite does not have a circular orbit, it was probably an asteroid captured by its planet. It has to be far enough from the planet so that the precision of its orbit is mostly controlled by the sun (see figure 2, page 5. In general, they have a retrograde motion, but in some cases there are irregular moons with a direct motion.

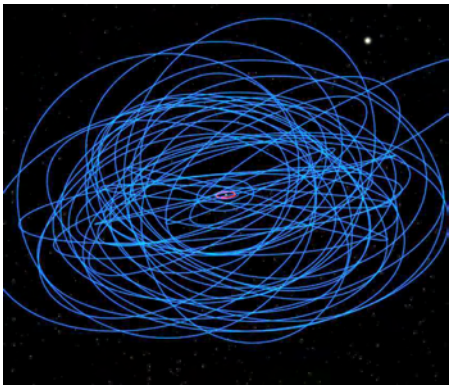


Figure 2: orbits of Saturn's irregular satellites

4 Some moons of the planets

4.1 Earth

4.1.1 Moon (Luna)

The Earth is the only planet in our solar system with only one natural satellite, so the Earth and its moon are the only double-planetary-system. Of course, the moon of the Earth was the first observed moon in space and is the best explored one until today. The interesting thing about it is, that it has no real name, the most common appellation except for 'Moon' is 'Luna', which is the Latin name of the goddess of the moon. Up to now it is the only celestial body where humans have landed. In the 1960s and 1970s it was the target of the space race between the United States of America and the Soviet Union. Nowadays it has become a prime destination for space projects of many nations.

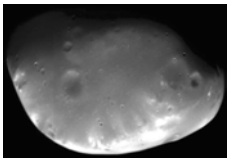
Luna is the fifth biggest moon in our solar system with an average diameter of 3476km (which is about $\frac{1}{4}$ that of the Earth). The gravitational acceleration is much lower than on Earth, it is $1.62\frac{m}{s^2}$. The average surface temperature is 274K. Luna orbits the Earth in about 27 days, so once a month which is the origin of the name 'month'. It rotates at the same rate than it orbits, so we see only one side of the Moon. The surface is heavily cratered because of bombardments by asteroids and comets in the dawn of the Moon 3 to 4.5 billion years ago. The largest impact crater on the Moon, the Aitken basin, is also the largest known one in the entire solar system with a diameter of 2240km and a depth of 13km.

4.2 Mars

4.2.1 Phobos

Phobos is the larger one of the two tiny moons of Mars. It is irregular shaped with diameters of 27 x 21.6 x 18.8km and for this reason expected as a captured asteroid with a very low density. Its surface shows a lot of craters. It is a retrograde moon, so from Mars' surface you will see it rise in the West and set in the East. The orbit of Phobos is so close to Mars that it moves faster than Mars spins and rises two times a day. Concerning its close orbit it is not visible at high latitudes from the surface of Mars because it moves below the horizon. Another fact resulting from this is that you can see a solar eclipse every time Phobos orbits Mars.

4.2.2 Deimos

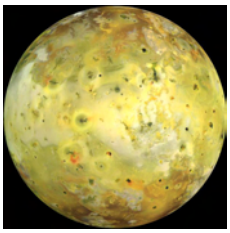


Deimos is the smaller moon of Mars. It is also irregular shaped and expected as a captured asteroid and possesses many craters. The diameters are 15 x 12.2 x 11 km. Its orbital period is not much longer than the rotation rate of Mars so it lasts 2.7 days from rise to set. Deimos is one of the most gloomy celestial bodies in our solar system and it is so small that it seems not brighter to an observer on Mars than Venus does to one on the Earth.

4.3 Jupiter

Jupiter is the biggest planet with the most moons in our solar system so it is not possible to comment to each of them. It has 63 moons whereof 50 are named. Now I will illustrate the four biggest ones which were discovered by Galileo Galilei.

4.3.1 Io



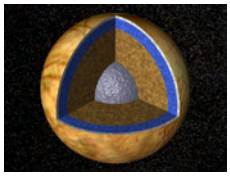
Io is the 13th biggest solar system body and the most inner moon of Jupiter. Its diameter is 3643km, the density is relatively high and the inclination is 0.04° which means that the orbit is nearly in the equatorial plane of Jupiter. Io is the most volcanically active body in our solar system. It is predominant made up of silicate stones and has a core with a diameter of 900km which consists completely of iron. Unlike the other three Galilean moons Io has practically no water.

Io has a very young surface which shows no craters caused by impacts. Instead of that there are many calderas which have diameters up to 400km and a depth of several kilometers. The surface is caused by at least 300 discovered active volcanoes that raises clouds of dust, consisting mainly of sulfur, up to 300km. This sulfur compounds cover

nearly the completely moon and cause its colorful surface. The average surface temperature on Io is 130K, but it can reach temporary up to 1700K during a volcanic eruption. This is the highest temperature ever measured on a planet or a moon. In addition there are many lakes of liquid sulfur, high mountains up to 9km that do not have a volcanic origin and lava rivers that range several hundred kilometers.

The energy for the eruptions is caused by tidal forces between Jupiter and Io (which is 1000 times bigger than the tidal force between Earth and Moon) as well as between Io, Europa and Ganymede. The periods of these moons have a resonance so that Io is oscillating and producing heat.

4.3.2 Europa



Europa is the second nearest moon of Jupiter and one of the brightest solar system bodies. Its diameter is 3122km. It is also predominant made up of silicate stones and has a small iron core. The interesting fact is that Europa is the most water holding body in our solar system. The outer layer is a crust of ice, approximately 10-15 km thick. The temperature of the surface is between 50K and 110K. Beneath this ice crust is expected a 90km deep ocean of fluid water that is heated by the tidal forces. Europa has a thin atmosphere which contains also oxygen. Because of the radiation of the sun, water is splitted to hydrogen and oxygen and by reason of its low density the hydrogen will disappear out to space.

There are some speculations about the existence of life on Europa, but there is no evidence. Future missions are supposed to resolve this question. However, a NASA research in 2004 resulted in the assumption that Europa could be more hostile than expected due to the fact that there could be hydrogen peroxide and sulfuric acid.

4.3.3 Ganymede

Ganymede, the third moon of Jupiter, is the biggest moon in our solar system, with a diameter of 5262km even larger than Mercury and Titan, a moon of Saturn which was supposed to be the biggest one in our solar system until 1980. The surface of Ganymede can be separated in two disparated terrains, a very old and dark one which contains many impacts and a younger and lighter one with rifts and faults. There are two tectonic discs that move independent from each other. This movement causes long mountain ranges. Beneath the thick mantle of ice Ganymede could contain a liquid ocean layer like Europa, but there is no evidence. The tectonic activities are similar to the Earth but they came to a standstill.

4.3.4 Callisto

Callisto has a diameter of 4821km and is the third biggest moon in the solar system. Its surface has the most impact craters so Callisto possesses the oldest surface which is supposed to be four billion years old. Its interior is very primitive, it consists mostly of ice and rocks which are jumbled together instead of being separated in layers. The craters are very smooth in fact of the thick crust of ice which relaxes the originally sharp-edged craters over geologic time. Some of them are brighter than other ones. This refers to a liquid ocean beneath the crust of ice. After an impact, clear water from this ocean could rise to the dusty surface and freeze so it will reflect more light than the surrounding surface of Callisto.

4.4 Saturn

4.4.1 Titan

Titan is the biggest moon of Saturn, the second biggest in the entire solar system and the only one with a dense atmosphere. Its diameter is 5150km and because of the high density of its atmosphere it was supposed to be larger until 1980. The average surface temperature is 93K. The atmosphere is denser than on Earth and the pressure near the surface is about 1.5bar, that is 50% higher than on Earth. The atmosphere consists mainly of nitrogen (at least 90%) and methane. In a height of about 300km they can be cracked by UV-radiation and electrons coming from the magnetosphere of Saturn and form more complex molecules like ethane and propane.

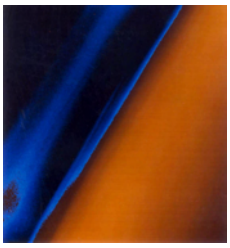


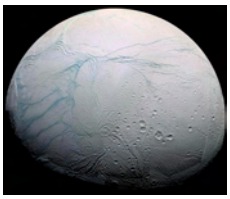
Figure 3: Atmosphere of Titan

The atmosphere rotates five times faster than Titan itself which is called 'super rotation' and causes winds that can reach velocities of $400\frac{km}{h}$ in a height of 50km. The weather processes are similar to that on Earth billions of years ago, there are clouds, rain of methane and ethane, rivers and lakes. But because of the small size and the slow rotation of Titan the processes are much slower than on Earth.

4.4.2 Hyperion

Hyperion has diameters of 360 x 280 x 225km. It is very porous, has a low density and unique properties. For its size it is the most irregular formed body in the solar system. It is supposed to be a fragment of an origin body caused by an impact. There are many craters, the biggest one has a diameter of 120km and a depth of 10km. It is the biggest non-spherical moon in our solar system with the most eccentric orbit of all regular moons. The axis of rotation fluctuates unpredictable so the rotation is totally chaotic. It is the only known moon with such an orbit. Furthermore the velocity of rotation changes continually.

4.4.3 Enceladus



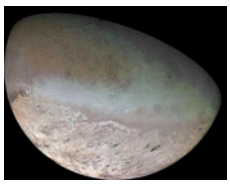
Enceladus has a diameter of 504km and is the smallest moon with an atmosphere. This atmosphere has a low density and consists mainly of water vapor. The interesting fact is that the gravitational forces are too small to conserve an atmosphere so there have to be everlasting sources of water vapor which are supposed to be water volcanoes or geysers. Like explained for Io, the energy for this volcanism have to be caused by the tidal forces of Jupiter and the neighboring moons.
Another interesting fact is the amount of reflected light. Because of the surface of clean ice, Enceladus reflects 99% of the incident light and is the moon with the highest albedo in the entire solar system. This causes a very low surface temperature of averaged 70K.

4.4.4 Epimetheus & Janus

A very interesting phenomena can be observed at this two moons. The distance of their orbits is is only about 50km and smaller than their diameters (Epimetheus: 117km, Janus: 181km). The moon on the inner orbit moves faster than the outer one so we should expect a collision. But before they collide, the inner and faster one will gain some angular momentum meanwhile the outer and slower one will loose some angular momentum. This results in a change of orbits because the inner one will slow down and achieve a bigger orbit meanwhile the outer one will speed up and achieve a smaller orbit. So they will not pass each other.

4.5 Neptune

4.5.1 Triton



Triton, that has a diameter of 2707km, is one of the few retrograde moons in our solar system, the inclination is 157°. This causes the assumption that Triton was a major object out of the Kuiper belt which was captured by the gravitational forces of Neptune. The distance of its orbit to Neptune is critical which causes high tidal forces. The distance is still decreasing so in about 100 million years Triton will get to close to Neptune and disrupt which directs to a ring of Neptune like the rings of Saturn.

Concerning to the axis of rotation and the orbit the poles will temporarily turn to the Sun with very long seasons. Meanwhile at one pole it is summer, at the other pole it is winter for this a long period of 40 years. This causes low temperatures at the farther pole of only 34K. This is the coldest place in the entire solar system! At this pole you can find frozen nitrogen and methane. When the seasons change they will evaporate and depose at the other pole.

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