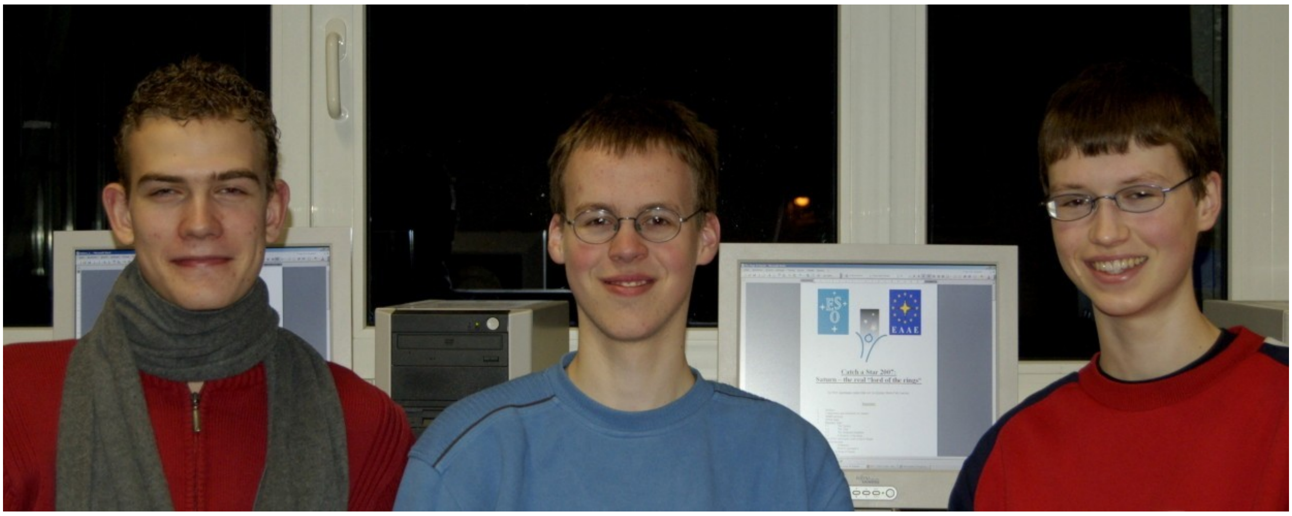
Catch a Star 2007:

Saturn – the real "Lord of the Rings"

by Mark Oppermann, Jannis Kühl and Jan Schotte; Martin Falk (teacher)

Structure

1. Abstract: Who we are and what the aim of our entry is



We, Jannis, Mark and Jan, chose astronomy as the subject we wanted to write our seminar paper in. Therefore having joined the astronomy group of our local high school under the supervision of our teacher Martin Falk, we were introduced to all the important aspects of astronomy.
Being fascinated by the mysteries of Saturn's rings and the latest findings of the Cassini orbiter, we decided to dive further into the world of the ring system for our seminar paper in the contest of '**Catch a Star 2007**'.
The main emphasis and aim of this work is to present and explain the difficult processes concerning the rings in a readily comprehensible way not omitting scientific detail. But before we go into the famous spokes, the numerous gaps, the formation of the rings, the Roche limit etc., let us quickly summarize Saturn's physical constitution and the most important orbital characteristics as well as the exploration of Saturn (history of observation, Saturn missions).
For being able to concentrate on the rings we virtually ignored the numerous satellites of Saturn on purpose and did not go into detail concerning their characteristics.
On the right you can see the three of us during the fine tuning of our entry.
At the end of this paper we will enclose our own pictures of the rings taken at our observation place about 40 km south of Hamburg.

2. Composition and Attributes of "Saturn"

Saturn is a planet of our solar system and belongs to the gas giants. It is constituted to great extend of light materials like hydrogen and helium. Because of that and because of his slight density, the Saturn rotates very fast and its weight is lower than Jupiter's, who is only slightly bigger than Saturn. The reason is the individual composition of Helium and Hydrogen. On the average, the weight of this mixture is smaller and the density is much lighter than the density of water. This is a special characteristic of Saturn and unique in our sun system. The temperatures inside Saturn are very low that's why a lot of Helium could condense into the outer space and the density became that low.

If you could walk inside Saturn you would notice that the compression gets higher the more you approach the nucleus. If a compression takes effect on a gas, the gas gets fluid at the "critical point". This effect takes place in Saturn, too. But this compression raises that permanently that the gas changes first into a status that is between gas and liquid and gets liquid when the compression is high enough. In the middle of the planet, there is the nucleus. The weight of this icy stone is 16 times the weight of the Earth. Because of the compression, the temperature of this stone is over 12 000 Kelvin. As a result of the gravitation, Saturn cools down and in consequence of that the compression gets higher and that leads to the fact that Saturn's core gets so hot.

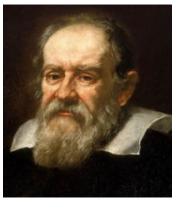
3. Saturn Missions

Already in the early 17th century Galileo Galilei observed Saturn and its moons.

I have seen the uppermost planet as three parts.

(Galileo Galilei in a letter to his friend Giuliano de Medici)

At that time, his observations could not be proven, although, today, they seem to have been quite obvious. A couple of years later, in 1656, the Dutch astronomer Huygens explained the phenomenon Galilei had observed. With a telescope much stronger than that of Galilei, Huygens discovered two new Saturn moons and that Galilei obviously had seen the Saturn rings – instead of moons. At that time, Huygens already had been a well known astronomer who, a year earlier, discovered Titan, the largest moon of Saturn. In the same century, another astronomer, the Italian Giovanni Domenico Cassini, concentrated on Saturn and discovered the moons Iapetus (1671), Rhea (1672) and Tethys and Dione (1684). But his most important observation was the determination of the ring system, which was finally named after him. In the years to come, several other minor discoveries were made concerning the moons orbiting Saturn. Among the most important astronomers are father and son Bond, William Henry Pickering and Seth Barnes Nicholson. However, despite of improved observation equipment, many questions remained unanswered. NASA tried to find answers to these questions by launching space probes to explore Saturn.

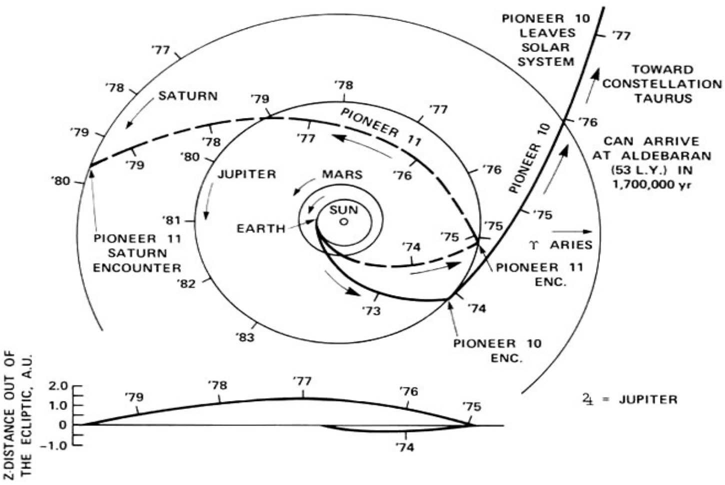


(Galileo Galilei)

Christiaan Huygens

The first ideas were developed in the 1980s. The Moon had been researched and the first space probe, Pioneer 10, had been launched into space in 1972. Only one year later, NASA started its next space probe project – Pioneer 11. On April 6, 1973, Pioneer was launched by an Atlas-Centaur carrier rocket with its first destination being Jupiter. Before reaching Jupiter, Pioneer 11 passed Saturn on September 1, 1979. At a distance of approx. 21,000 km, Pioneer took 400 photos and sent them back to Earth, providing additional information on Saturn, its moons and rings. Among the most important findings were the discovery of another moon and details about the rings.

Saturn and moon Titan in the Pioneer 11 photo

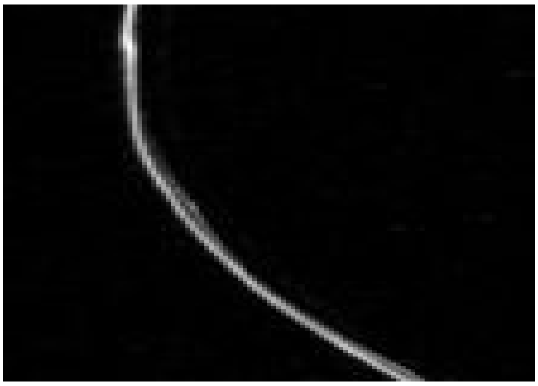


The paths of Pioneer 11and 12 through the solar system

After having passed Saturn, the space probe continued its journey towards the end of our solar system. After passing Neptune on February 23, 1990, Pioneer 11 entered interstellar space – as the fourth space vehicle made on Earth. On September 30, 1995, Pioneer 11 was pronounced to be “dead” due to lack of fuel. The last data from Pioneer 11 were received on November 24, 1995.

However, the results obtained about Saturn became obsolete quite soon. On August 20, 1977, and September 5, 1977 another two missions were started: Voyager 1 and Voyager 2. In reverse order, they were launched from the American spaceport Cape Canaveral.

Voyager 1 provided the first photographs in 1979, still 300,000 km away from Jupiter. On November 12, 1980, Voyager 1 passed Saturn. The most important findings were the discovery of the complex ring system and data on the atmosphere around Saturn and its moon Titan. Further accelerated by the gravitational force of the planet – a “swing-by”-, Voyager 1 travelled into interstellar space. And on February 17, 1998, at 23.10 h. Voyager 1 set a new record: It was 10.4 billion km away from the sun, and thus much further away from the sun than all other probes before. According to NASA, Voyager 1 will have reached interstellar space in about 10 years. Based on recent information, NASA expects to keep in touch with Voyager 1 up to the year 2020.



(Voyager 1 image of Saturn's F ring)

(Voyager 1 image of Saturn from 5.3 million km)

A year later, c ached Saturn passing by on July 9, 1979. As far as Saturn is concerned, the mission of Voyager 2 was the same as the one of Voyager 1. Various informative photos of the moons and the rings of Saturn were taken. Together with the results of Voyager 1, the missions were found to be very successful and informative.

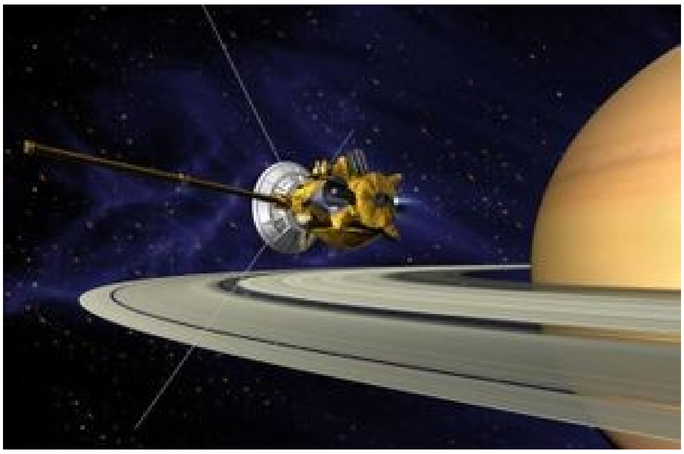
Although the space probes were produced to last only a couple of years and only the exploration of Saturn had been planned, NASA gave the go-ahead to explore Uranus and, later, Neptune. Thus, Voyager 2 passed Uranus on January 24, 1986 and Neptune on August 25, 1989. In the course of its journey, the probe collected many data helping us to understand our solar system. A total of 22 new moons and another two rings of Uranus were discovered during the mission. Meanwhile, Voyager 2 is also on its way to interstellar space expected to reach it in the year 2020.

(Color image of Enceladus taken by Voyager 2)

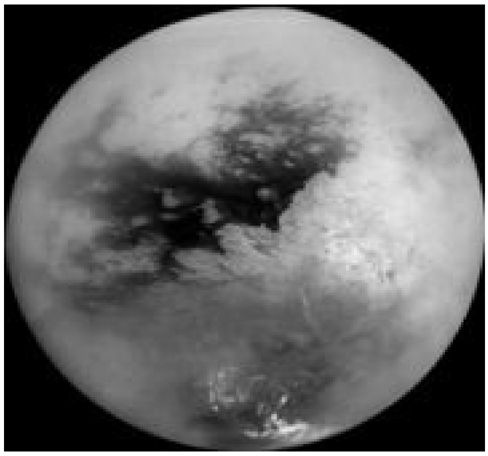
(Iapetus taken by Voyager 2)

After 2, no further effort had been made to explore Saturn until October 15, 1997, when the Cassini-Huygens mission was started. Employing the latest state-of-the-art equipment, more precise results about Venus, Jupiter and finally Saturn (which is the primary target of the mission) are expected to be obtained by a landing capsule (Huygens) and an orbiter (Cassini). The mission is financed by 17 countries and costs more than 3 billion US-dollars.

In the course of its approach, the Cassini-Huygens propbe has provided various interesting photos of our solar system and provided the latest proof of Einstein's theory of relativity. The observation of the 7th planet started on February 6, 2004, approx. 70 million km away from Saturn. The first close-by photos of the still undivided probe were taken from the Saturn moon Phoebe, which was passed on June 11, 2004 at a distance of about 2000 km. Only a few days later, on June 30, 2004, the Cassini-Huygens probe reached its target.



(An artist's concept of Cassini)



(Titan´s surface taken by Cassini)

As already mentioned, the next most important target of the mission was a detailed exploration of Titan culminating with the landing of Huygens. To achieve this, the two individual components of the probe had to be separated in a quite complicated way to make sure that both probes continued its further journey as planned.

The probe was separated on December 25, 2004 and Huygens landed on Titan on January 14, 2005 without problems. Since that time, Huygens provided breath-taking data from the surface and its magnetic fields and the "geology" of Titan. The other mission targets, mainly comprising the exploration of the other moons and the planet itself, were accomplished by the other part of the probe – Cassini.

A total of 74 orbits around Saturn are scheduled and Titan will be passed 45 times - also to change course, so that the moons Iapetus (January 1, 2005 and September 10, 2007), Enceladus (February 17, March 9 and July 14, 2005 and March 12, 2008), Mimas (August 2, 2005), Tethys (September 24, 2005 and June 27, 2007) Hyperion (September 26, 2005), Dione (October 11, 2005) and Rhea (November 26, 2005) can be watched at close range.

The exact date the Cassini-Huygens mission will end as well as the exact route of the orbiter after 2008 are unknown.

For more information about the path of the Cassini probe please click here:

http://www.esa.int/SPECIALS/Cassini-Huygens/SEMD6E2VQUD_0.html

The scientists say it shows the path, the key events and the current position of the NASA/ESA/ASI Cassini probe.

4. Orbital characteristics

Orbital characteristics	
Weight (10^{24} kg)	568,46
Volume (10^{10} km^3)	82713
Radius (km)	58232
Flattening	0,09796
Gravitation on the ground (m/s^2)	8,96
Density (kg/m^3)	687
Natural satellites	30
Planetary ring-system	yes

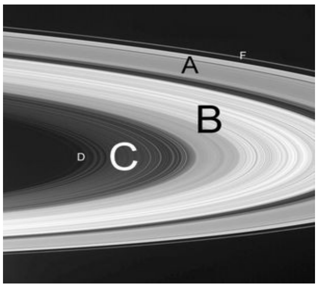
5. Planetary rings

The magnificent rings of Saturn have baffled astronomers for four centuries. Although the knowledge of the very complicated architecture of

by the Cassini orbiter

the ring system and the difficult processes taking place in it has grown steadily, some questions concerning the fine scale structure still need to be solved.

The ring system – as a whole only having the weight of a small moon like Mimas – largely comprises ice chunks as well as gas and dust particles. Some of these particles are as large as a house, others as tiny as a speck of dust. Within the ring system there are hundreds of gaps and divisions caused by the interaction of different ring particles and moons (of which many have presumably not been discovered yet). As the telescope technology improved, more and more details have been found out. The number of rings, for instance, rocketed over time: While Cassini was only able to differentiate the A and B Ring, today we distinguish seven main rings. From the inside to the outside these are the D, C, B, A, F, G, and E Ring. But as pictures taken by the three probes have shown the seven main rings themselves are subdivided into some 100,000 (!) separate rings. Note that each particle circles Saturn on its own on a virtually circular orbit, i.e. the particles in one ring are not joint together.



Overview of Saturn's main rings, note the Cassini division

In our table[1] below you can see the most important features of each single ring:

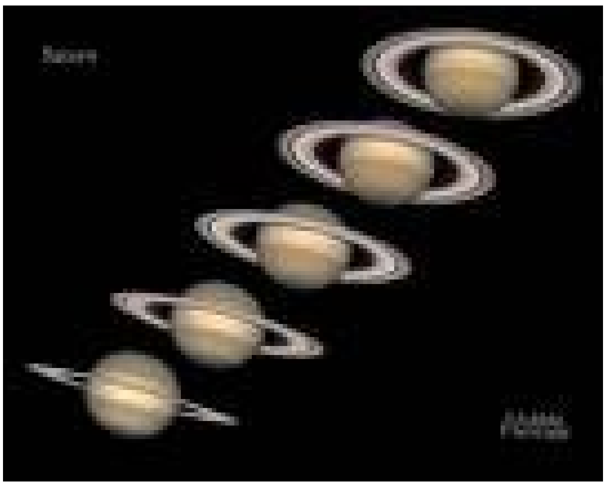
Name	Characteristics	radius, orbital period etc.
D Ring	the innermost ring, only 7,000 km away from Saturn's surface, not visible from Earth	67,000-74,510 km 4,91 hours
C Ring	vertical expansion amounts to less than 10 metres	also called Crepe Ring
B Ring	the brightest, thickest and densest ring of Saturn, contains the largest particles	together with the A Ring the best reflecting ring, 8-11 hours

[1] cf www.wikipedia.org, "rings of Saturn"

Cassini Division	discovered by and named after the 17th-century Italian astronomer (as the last probe), separates the B and A Ring	not completely swept, it rather contains some hundred tiny rings
A Ring	contains the Encke Division	about 130,000 km, rather opaque
F Ring	confined by the two famous shepherd satellites Prometheus and Pandora	width of only 500 km, its brims show various interweavings and distortions
G Ring	along with the E and F Ring this ring only contains microscopic particles	18-21 hours
E Ring	the outermost and widest ring, its material has its source in the cyrovulcanism of the moon Enceladus	width of 302,000 km, and a diameter of nearly one million km; 4 days

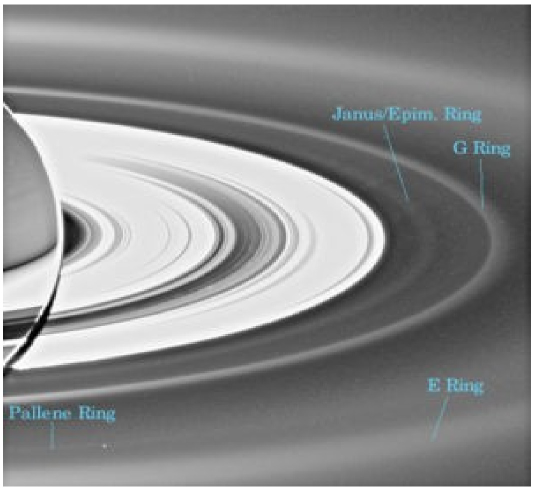
Lying in the equatorial plane of Saturn the ring system has got an inclination of 27° towards the orbital plane of Saturn. Since the position of it does not change and owing to the relative movement to the line of sight to Saturn, we can sometimes see the rings from above, sometimes from below. Every 15 years when the Earth passes the ring plane we look at the edge of the ring disc. Owing to the very small vertical expansion in contrast to the immense horizontal scale (see above) the rings then seem to vanish, a fact that has already puzzled Galilei.[2]

[2] Keller, Hans-Ullrich: Von Ringplaneten und Schwarzen Löchern. p. 46



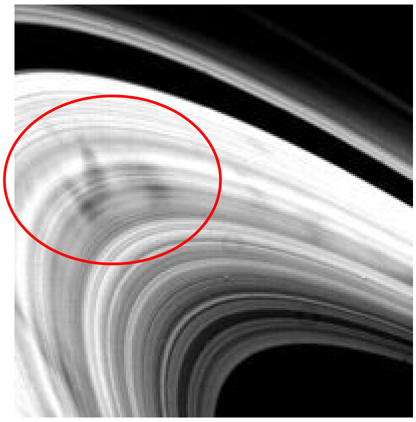
Different perspectives of the ring system

The outer rings



5.1. The spokes

This phenomenon mainly occuring in the B-ring is a mystery to astronomers since it was firstly photographed during NASA's Voyager mission in the 1980's. The spokes, dark radial structures up to 10, 000 km long, come into being in a few minutes and then gradually disappear during several hours/days.



Owing to the differential rotation this very long pattern actually should soon distort itself. But actually the spokes show quite a rigid rotation, i.e. they become diffuse only very slowly due to differential rotation.

For a long time the prevalent hypothesis explaining the development of these short-living mysterious structures has been as follows:

A cloud of plasma – being the result of the impact of a little meteorite on some ring particles – drifts radially to the outer regions of the ring system. Meanwhile the cloud consisting of ionized atoms charges tiny dust particles which therefore interact with the magnetic field of Saturn and are lifted out of the ring plane (so that they levitate above it). Since these radial dust patterns orbit Saturn at the same rate as Saturn's magnetosphere, that is, synchronously with it, it is assumed that they are influenced by electromagnetic forces.

While initially being easily and clearly visible the spokes then slowly disintegrate in virtue of differential rotation.

Colliding with other particles the charge of the particles slowly gets lost, so that the particles by and by sink to the ring plane again.

But after the Cassini probe had entered Saturn's orbit and sent its first impressions to the Earth, doubts about the verity of this hypothesis arose.
New theories[3] were proposed: As in the period from about 1998 to 2004 no ring spokes could be spotted, it is assumed that the appearance of this phenomenon depends on the sun angle. Standing edge-on to the sun more spokes seem to appear. Latest models say that the ring spokes seem to appear eight years in a row, followed by an absence of up to seven years.

Another assumption supposes that the spokes might be an effect of massive thunderstorms taking place in Saturn's atmosphere. Energetic lightning is said to charge ring particles that afterwards create the radial spokes.

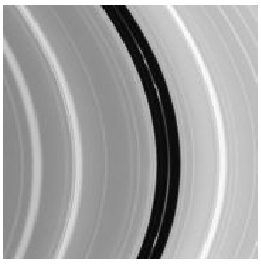
Be that as it may, if something can contribute to solve the riddle, then it is the Cassini spacecraft. And a watertight solution in the future might help to understand the planet's magnetosphere and its interaction with the ring system.

[3] http://www.space.com/saturn/

5.2. The gaps

The large divisions probably have developed due to orbital resonance with the outer moons whereas most of the smaller gaps seem to be swept by mini-satellites embedded in the rings.[4] Whenever such a small moon overtakes a ring particle orbiting Saturn further outside, the particle is accelerated and gains energy. Thus, it reaches a higher orbit. In contrast to this, particles passing the satellite in the inside lane experience a braking force so

[4] Monde und Ringe. Time Life Books. pp. 106 f. 122-125



The Encke Division in close-up

that they are forced onto a lower orbit. Hence, such a mini-moon is able to cut an aisle into the ring disc. This hypothesis was proven by the discovery of Pan, a moon only 20 km long, which cleared the Encke Division over time, a gap sixteen times its size.

The animation below is to illustrate this principle:

http://www.relativegal.de/saturn/saturn.rar

The greater gaps, e.g. the Cassini Division, are supposed to be caused by orbital resonance with outer moons. Whenever the orbital period of such a moon is in a ratio of two small integers with the orbital period of a ring particle (like 2:1 or 7:6), the respective particles experience a strong extra gravitational pull, so that they are driven out of their original orbit. The Cassini Division, for example, is in a 2:1 resonance with Mimas. All the same this huge gap is not completely empty (cf table). This stems from the gravitational disturbances of other bigger ring particles and inner moons. So the case of the mini-satellites sweeping gaps can be seen as a special case of orbital resonance: Between such bodies with a similar radius there is a 1:1 resonance.

5.3. The shepherd satellites

The small F Ring and the two shepherd satellites

Being embedded in the ring system and stabilizing the small F Ring, Pandora and Prometheus certainly are the most famous sample of shepherd satellites. Prometheus orbiting inside the F Ring steadily overtakes the F Ring's particles. Meanwhile, it forces them onto a higher orbit. As opposed to Prometheus, Pandora orbits Saturn outside the F Ring curbing the ring particles. Thus, the latter cannot escape the F Ring but are forced into a clearly defined area.

5.4. Formation of the rings

Among scientists it is still hotly disputed how t
we will present the two most common theories:

According to the accretion theory[5] the entire system comprising the planet itself as well as the rings and the moons emerged simultaneously from the pre-planetary cloud of gas and dust. Consequently, the rings of Saturn would be nearly 4,5 billion years old.

While in the centre of this cloud the matter was compressed into the planet, the material near the surface of Saturn, but still inside the Roche limit, was inhibited from coalescing to a moon (see Roche limit) and formed the ring system.

Nevertheless, this hypothesis has got a blemish:

In the course of time the particles' kinetic energy would have declined due to crashes of the particles with each other and collisions with photons (the so-called 'Poynting-Robertson effect'). As a result the ring particles eventually would have plunged into the atmosphere of Saturn and burnt up there. The solution to this problem – provided that the theory is true – might either be a matter source such as Enceladus' cyrovulcanism or some meteorites which – having collided with the ring – deliver the necessary substance.

This objection might also be a hint that the rings are not as old as they are considered to be according to the accretion theory. Perhaps they are less than one hundred million years old, a supposition that is supported by the remarkable brightness of the ring system. Being exposed to cosmic bombardment the rings sooner or later should become dark because they absorb particles darkened by solar radiation. The brightness of the rings hence suggests a much younger age of the rings of Saturn.

The second hypothesis puts the evolution of the ring system down to the crash of a meteorite with one of the moons of Saturn within the Roche limit. The remnants of this collision, not able to build a new satellite because of the strong tidal forces, formed the ring. Dynamic and gravitational processes then led to the characteristic disc of the ring system. But also this "debris theory" does not give a watertight explanation for the ring formation. Some astrophysicists object that it would be quite a chain of accidents that all gas giants of all planets do have rings even if these are not as distinct as the rings of Saturn.

6. How ESO-telescopes could observe Saturn

[5] Monde und Ringe. Time Life Books. p. 99-105

As the Cassini probe in the orbit of Saturn is in a unique position to study the planet, any operation carried out with one of the ESO-telescopes actually would be a waste of observation time.

Nevertheless, the Very Large Telescope (VLT) can try to record the reflected light of the very faint D Ring. Due to adaptive optics or interferometry and only little disturbances in the earth's atmosphere in the clear sky of the Atacama desert, the VLT can supply high-resolution pictures of even very remote astronomic objects. For that reason it's worth an attempt to spot the very faint D Ring as the first ground-based observatory in the world.
Another possible application refers to the 'lightning theory' of the spokes' emergence provided that it is true. Assuming that a great thunderstorm occurs in Saturn's atmosphere but the Cassini probe is just on the opposite side of the planet and therefore not able to photograph the spokes, then the VLT could stand in to spot the ring spokes and thus prove the relation between the thunderstorms and the emergence of the spokes. Since such a thunderstorm can be active for several hours, there is enough time to prepare the telescope for observation.

7. The Roche limit

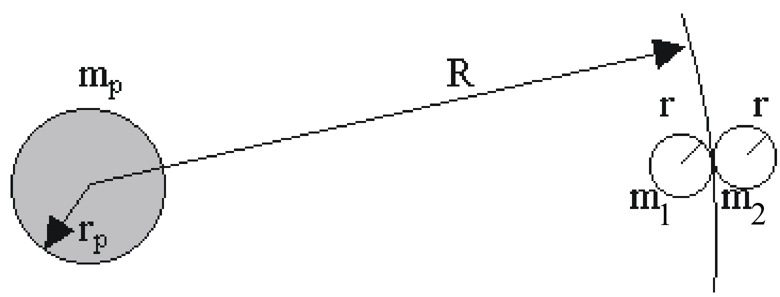
7.1. Definition of the Roche limit

As we have heard before the ring phenomenon has fascinated people ever since Saturn's discovery by Galilei in 1610. In 1848, the French astronomer Edouard Roche (1820-1883) was able to calculate the distance *within* which a satellite orbiting a planet would be torn into pieces because of the influence of tidal forces caused by the planet.
These tidal forces arise since the side of the satellite facing its planet experiences a stronger gravitational pull by the planet than the opposite side due to its shorter distance from the planet. The difference between these gravitational forces, i.e. the

tidal forces, causes a distortion of the satellite. The shorter the distance between both celestial bodies and the bigger the radii and masses of both the moon and the planet, the higher the tidal forces, that is, the higher the deformation.
The distance within which these tidal forces exceed the gravitational self-attraction of the satellite and therefore within which the satellite will be smashed into pieces is called "Roche limit", named after the French astronomer.
Roche deduced that outside the Roche limit particles from clouds of gas or dust will be able to coalesce, to form a moon by accretion whereas inside the Roche limit material orbiting the planet will not due to friction and distortion.
Note that the Roche limit is not just mere speculation but sometimes has a very serious effect on comets/moons. Take the case of the comet 'Shoemaker-Levy 9' which – having passed Jupiter's Roche limit – was torn to pieces.

7.2. How to calculate the Roche limit

For deriving a formula to calculate the Roche limit let us consider the following example:
Assuming that two spherical celestial bodies m_1 and m_2 of the same mass m – staying in contact with each other – move straight towards the center of a very large planet m_p one behind the other.
The question is in which distance R the influence of the tidal forces will not allow the two bodies any more to touch one another.
Let the Roche limit be R, the radii of the two masses be r and the radius of the planet be r_p, then the distance between the centres of the planet and m_1 is 'R-r' and the distance between the centres of the planet and m_2 'R+r' as one can easily see from the picture below.



According to Newton's law of gravity the gravitational self-attraction of the two masses can be expressed as

$$F_G = \frac{G \cdot m \cdot m}{(2r)^2} \qquad (1)$$

As we have seen before both masses will stay in contact with each other until the tidal forces, i.e. the difference between the gravitational forces on m_1 and m_2, exceed the gravitational self-attraction of m_1 and m_2, that is, until the two masses have *passed* the Roche limit. In other words: The Roche limit is reached when the tidal forces are equal to the two masses' gravity:

$$F_{tidal} = F_G \qquad (2)$$

Since the tidal forces can be expressed as the difference between the gravitational forces on m_1 and m_2 we can write (2) as

$$\frac{G \cdot m_p \cdot m}{(R-r)^2} - \frac{G \cdot m_p \cdot m}{(R+r)^2} = \frac{G \cdot m \cdot m}{4r^2} \qquad (3)$$

Putting '$G \cdot m_p \cdot m$' outside the brackets we find

$$G \cdot m_p \cdot m \cdot \left(\frac{1}{(R-r)^2} - \frac{1}{(R+r)^2} \right) = \frac{G \cdot m \cdot m}{4r^2} \qquad (4)$$

After reducing the content of the brackets to a common denominator we can write

$$G \cdot m_p \cdot m \cdot \left(\frac{(R+r)^2 - (R-r)^2}{(R-r)^2 \cdot (R+r)^2} \right) = G \cdot m_p \cdot m \cdot \left(\frac{R^2 + 2Rr + r^2 - r^2 + 2Rr - r^2}{(R-r)^2 \cdot (R+r)^2} \right) = \frac{G \cdot m \cdot m}{4r^2} \qquad (5)$$

Since 'R^2' and '-R^2' and 'r^2' and '-r^2' respectively cancel each other out, (5) can be simplified to

$$G \cdot m_p \cdot m \cdot \left(\frac{4Rr}{(R-r)^2 \cdot (R+r)^2} \right) = \frac{G \cdot m \cdot m}{4r^2} \qquad (6)$$

As R>>r we can conclude that both 'R+r' and 'R-r' approximately equal 'R'.

$$G \cdot m_p \cdot m \cdot \left(\frac{4Rr}{R^4} \right) = G \cdot m_p \cdot m \cdot \frac{4r}{R^3} = \frac{G \cdot m \cdot m}{4r^2} \qquad | \div m^2 \cdot 4r^2 \cdot R^3 \div G \quad (7)$$

$$\Rightarrow \quad R^3 = \frac{m_p}{m} \cdot 16 \cdot r^3 \Leftrightarrow R = \sqrt[3]{\frac{m_p}{m} \cdot 16 \cdot r^3} \qquad (8)$$

We know that density is defined by mass/volume $\delta = \frac{m}{V} \Leftrightarrow m = \delta \cdot v$ and that the volume of a sphere can be expressed as $V_{sphere} = \frac{4}{3} \cdot \pi \cdot r^3$.

Therefore we can rewrite (8) as

$$R = \sqrt[3]{16 \cdot r^3 \cdot \frac{\frac{4}{3} \cdot r_p{}^3 \cdot \pi \cdot \delta_p}{\frac{4}{3} \cdot r^3 \cdot \pi \cdot \delta_m}} \qquad (9)$$

which can be simplified to

$$R = \sqrt[3]{16 \cdot \frac{r_p{}^3 \cdot \delta_p}{\delta_m}} \approx 2.519 \cdot r_p \cdot \sqrt[3]{\frac{\delta_p}{\delta_m}} \,. \qquad (10)$$

Let us assume that the densities of the planet and the moon equal each other, then the distance 2,5 r_p is known as the Roche limit. As far as Saturn is concerned these are 151 866 kilometres.[6]

Of course it strikes us immediately that large parts of the ring system, especially the E-ring, are situated outside the Roche limit. But why don't they coalesce to a satellite then? Is there a contradiction to what we have said before? No, it is not.

Being very small the E-ring particles disperse because of electromagnetic forces and the influence of the solar wind. Thus, they are dispersed throughout the Saturn system. They simply do not stay long enough in the E-ring to build larger objects by accretion. But if the E-ring particles vanish sooner or later, where do the supplies of material come from? They have their origin in the moon Enceladus: A giant ice volcano spews out matter forming the E-ring. If this cyrovulcanism stopped, the E-ring would also end to exist. One therefore can conclude that only the inner and quite easily visible rings exist owing to the importance of the Roche limit.

Note that the calculation above for the Roche limit totally omits atomic and molecular forces like adhesion or cohesion. Therefore it is also possible for a little satellite or spaceship to orbit a planet within the planet's Roche limit provided that it is not only held together by its gravity but also by chemical bonds, e.g. Saturn's two shepherd satellites Prometheus and Pandora which we have already referred to earlier.

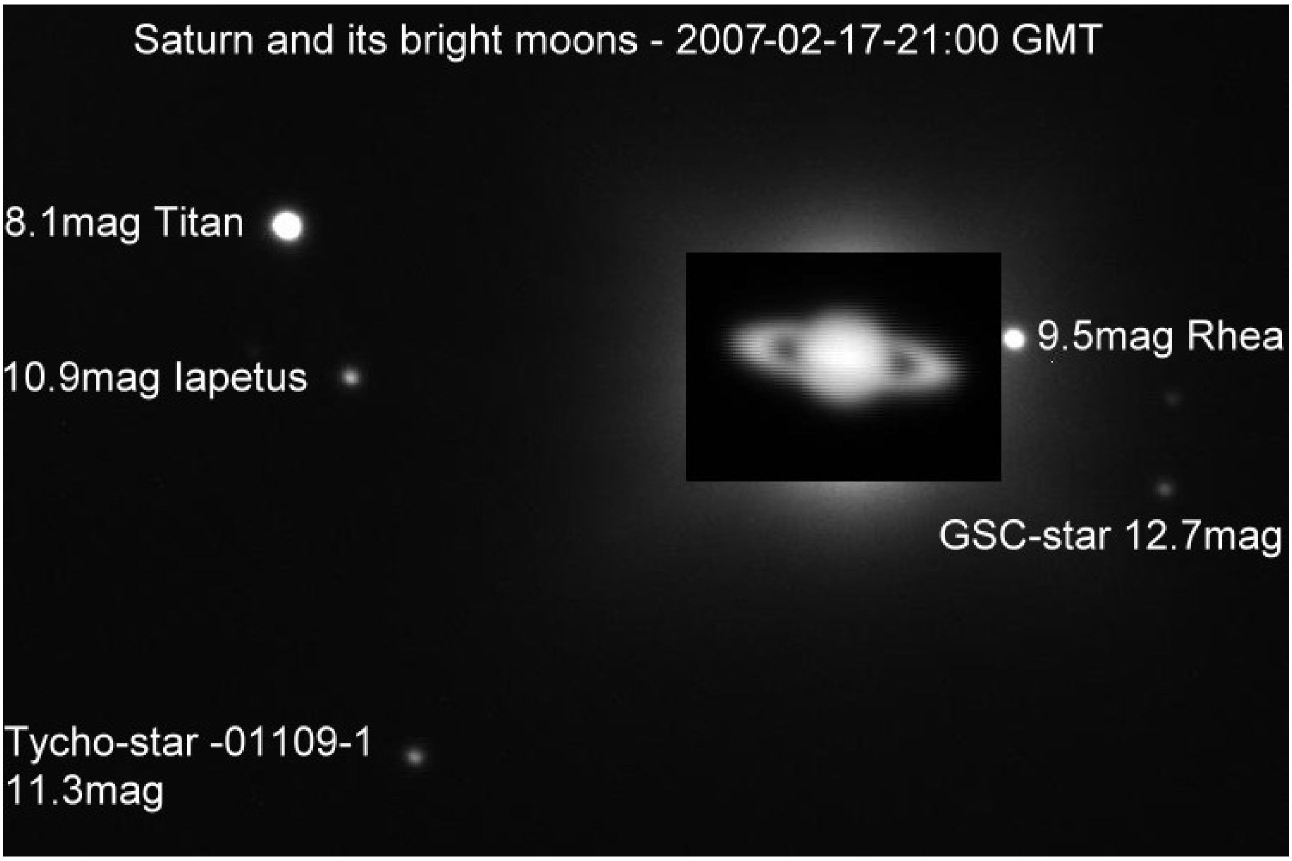
[6] For the derivation of the formula see http://leifi.physik.uni-muenchen.de/web_ph12/grundwissen/12gezeiten/saturnringe.htm

To put the whole work into a nutshell,

We have to realize that many aspects (like the formation of the rings and inner-ring phenomena) are not completely clear yet. Consequently, it is necessary to continue the great efforts made to throw a light on Saturn's unsolved mysteries.

8. Our own pictures

Our attempts of letting Saturn throw its light into our astronomy-group's telescope have been spoiled by the wet winter in Northern Germany. Within the last two months there was only one fairly clear night when we positioned the f/12.5 10-inch-Maksutov on Saturn. The telescope is equipped with a MEADE-CCD-camera (DSI Pro II with 8.5 micron pixels) which allows images in the focal plane of 12 arc-minutes (measured diagonally). We chose the infra-red filter for a 20 sec image of Saturn's moons:



The insert was taken by means of a 20mm-eyepiece projection, but due to a hazelayer in the medium atmosphere we were not able to get any short-exposure image showing the Cassini seperation as clearly as possible. We therefore looked through our group's gallery to find an older image, also taken by eyepiece projection with a conventional digicam. The image shows Saturn's rings with the greater inclination of 2003 and a fairly well separated Cassini gap:

9. Bibliography

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