Awaited unfolding of Saturn – the ringed world

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Saturn is the second largest planet in our solar system. With a colourful ring system surrounding the planet, it is highly attractive. Only brief observations, using telescopes, Pioneer-11, Voyager-1, and Voyager-2 in situ recorders have been made. Comparatively impressive details of Saturn have already been obtained. A space mission named Cassini–Huygens is on its way to explore Saturn's biggest moon, Titan, which is slightly smaller than our earth. This mission is well planned to study Saturn and explore various details of its atmosphere. It is also expected to spend four out of fifteen years to go round Titan. With the on-board payloads, it is hoped that we will be able to get valuable details for updating current knowledge of Saturn and Titan. Cassini has already sent the first colour picture postcards of Saturn taken from a distance of 285 million kilometres.

SATURN is known to be the most beautiful object in our solar system and it may also be the most beautiful in the entire universe. It was known from ancient times. The understanding of planets came with the invention and use of instruments that could measure celestial positions that could catalogue the positions of the planets. Galileo, who invented the telescope, used it for observing the heavens and to locate different planets in the solar system. Better known are the inner planets. Saturn is attractive because of its ring system. Ionospheric details of Saturn were studied and discussed by Kaiser *et al.*[1,2]. Saturnian ionospheric physical processes and formation of Saturnian rings were discussed by many workers[3–5]. However, details of physical mechanisms forming the rings of varying colours are not yet known. The Cassini–Huygens mission[6] is expected to provide detailed information of various *in situ* processes taking place on Saturn and its moon. Titan, the largest moon of Saturn was discovered by Christiaan Huygens in the year 1655. After quite sometime, Jean-Dominique Cassini discovered the next four largest satellites of Saturn. This fact led the planners to name it as Cassini–Huygens mission. Here, we discuss some of the details of Saturn that we know so far and also the plans to explore Saturn using 'The Cassini Huygens Missions to Saturn and Titan'. The physical parameters of Saturn[4,7] are given in Table 1. Cassini–Huygens is an international mission in which three space agencies and seventeen countries are involved. Cassini is the main spacecraft that is carrying an atmospheric probe known as Huygens to explore detailed features of Titan.

The flybys of Voyager spacecraft have enhanced the list of icy satellites considerably, and newer satellites are being added to this list.

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Rings around Saturn

Galileo located the system of rings around Saturn with the help of a tiny telescope in July 1610. Since then, the rings of the giant planet have become one of the enduring mysteries of our solar system. The mystery of their existence has challenged the explanations of astronomers since their discovery, i.e. for four centuries. In fact during early observations, the nature of the rings was masked by the inadequate quality of the telescopes.

Christiaan Huygens' close friend, Jean Chapelain posed an important question in 1660: Are the rings solid or are they a swarm of tiny satellites in orbit around Saturn? This was an important question for a long time. During the 19th century, as the quality of telescopes improved, detailed observations of Saturn's rings were made. Most of the observations about Saturn and the associated ring system remained in dispute for a long time. In 1857, James Clerk Maxwell studied the nature of the Saturn rings. The dynamical features of Saturnian atmosphere and the associated ring system were studied by Stevenson[8], who discussed Saturn's atmospheric evolution and its associated ring system in detail[9].

The first robotic probes–Pioneer-11, Voyager-1 and Voyager-2 flew close to the planet. Observations made

Table 1. Physical parameters of Saturn

Physical parameter	Value
Mean distance from sun	9.54 AU
Orbital period	29.5 yrs
Inclination of equator	29°
Equatorial radius	60,000 km
Polar radius	49,000 km
Mass	5.69×10^{26} kg
Mean density	0.69 g cm^{-3}
Period of rotation	10 h 40 min 30 s

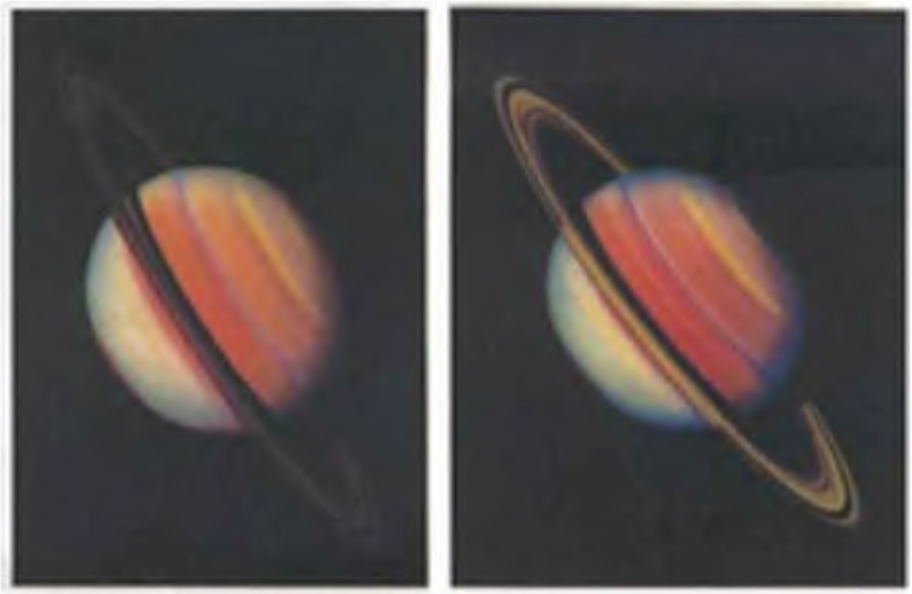

Figure 1 ***a*** **and** ***b*.** Two pictures of Saturn taken nine months apart by Voyager-1 and Voyager-2. The major change in these pictures is the brightness of the rings because of more tilt towards the sun for Voyager-2. The presence of varying clouds changes the quality of the pictures. The colourful clouds and systematic rings of varying colour combinations make Saturn the most attractive planet[4].

Table 2. The rings of Saturn[6]

Saturn ring	Distance (km)	Width of ring (km)
D	66,970	7500
C	74,500	17,500
B	92,000	25,400
A	122,170	14,610
F	140,180	50
G	170,180	8000
E	180,000	300,000

from these probes sorted out facts from on-going fiction – just as the Mariner flybys shattered the myths of Martian canals and civilizations of the planet. Saturn was found to have several distinct rings detected using images from the Pioneer and Voyager probes. Table 2 provides some features of these rings that would be confirmed and updated by measurements using Cassini–Huygen Explorer.

Figure 1 *a* and *b* shows pictures of Saturn as seen from a distance[4]. The pictures were taken by Voyager-2 using ultraviolet, violet and green bands of light. The three observations were combined to create the false-colour images of Saturn for illustrative purposes. Details of various Saturn rings as observed by many of the space missions are shown in Figure 2. Note carefully the positions of rings D, C, B, A, F, G and E and the orbital distances of various experiments among which Pioneer-11 inbound and Voyager-2 were the most successful and provided a major part of the information. High-resolution pictures of the Saturn ring system are also recorded and used for detailed study of ring structure and composition of these rings. Space scientists are not satisfied with the details obtained so far and they eagerly look forward to the results of Cassini–Huygens Mission that is on its way to study the details of Titan and provide indepth observations of the rings around Saturn.

Magnetic field of Saturn

One of the most important features of Saturn's magnetic field is its polarity and inclination of the magnetic dipole. Saturn has no measurable tilt between its axis of rotation and magnetic dipole axis. Nearly perfect alignment of the two axes is considered to be a unique feature among all the planets[6,9]. Another important feature of Saturn is that the polarity of its magnetic dipole is opposite that of Jupiter. Exact processes of magnetic-field generation in Saturn are not yet known. The nature of the magnetic field is thought to be dipolar like the earth's magnetic field, except for its change of polarity[10,11]. The solar wind interaction with the planet will have identical features and may not affect the ring system associated with the planet, as we understand it at present. The close interaction studies using Cassini–Huygens results would be more revealing. Most of the solar wind interaction features are customarily studied and interpreted in terms of our knowledge and experience with earth and its interaction with the incident solar wind. Figure 3 is a schematic illustration of probing Saturn's dipolar magnetic field using Voyager-1, Voyager-2 and Pioneer-11 systems, with the location of various moons and shaded square showing the region of ring current. The charge particle dynamics along the dipolar

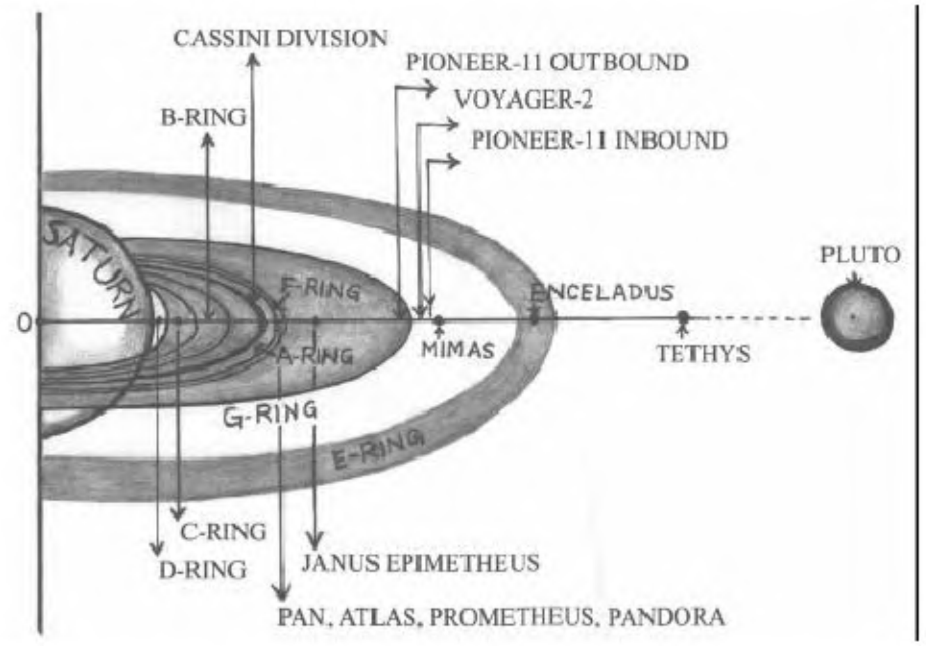

Figure 2. Illustration of Saturn's rings from the planet outwards. The rings are named D, C, B, A, F, G and E. Pioneer-11 inbound and outbound along with Voyager-2 orbits are shown. Most of the measurements are in the vicinity of Mimas, which is a small moon close to the planet. High-resolution measurements are expected to enhance the number of moons and rings considerably[6].

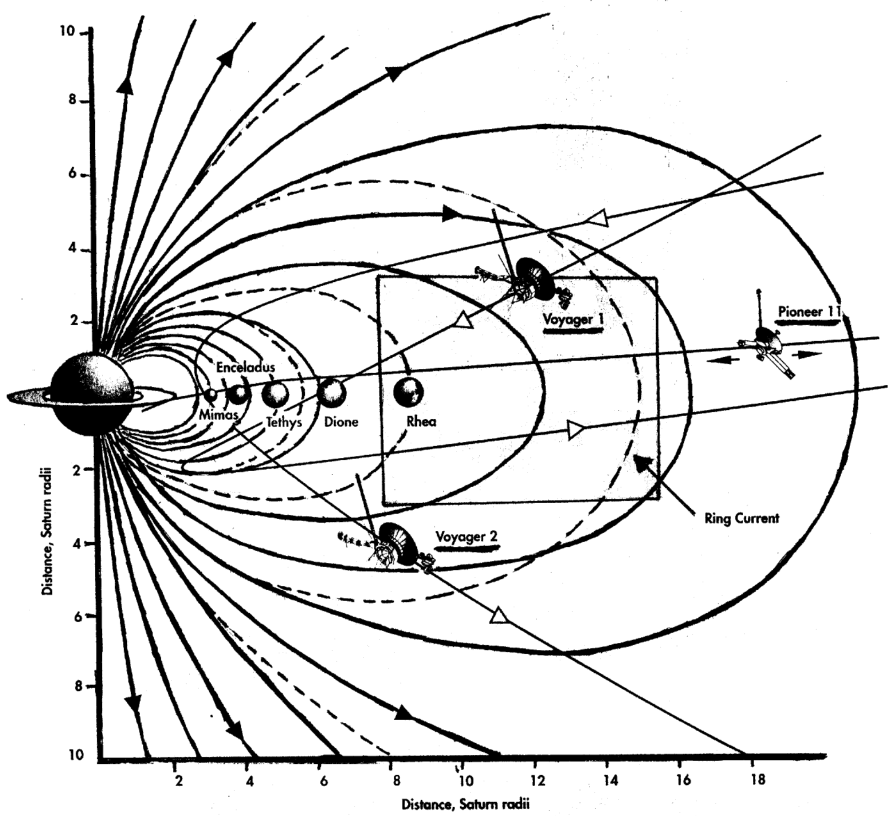

Figure 3. Schematic illustration of dipolar magnetic field of Saturn. The presence of ring current affects the dipolar magnetic field distribution that is shown by dotted lines. In the distant region, the magnetic field is seen to change significantly from the dipolar magnetic field. Stretching out of the magnetic field lines due to ring current flow is illustrated by the shaded region. Pioneer-11 follows the same inbound or outbound trajectory and is capable of depicting the temporal changes of the region[6].

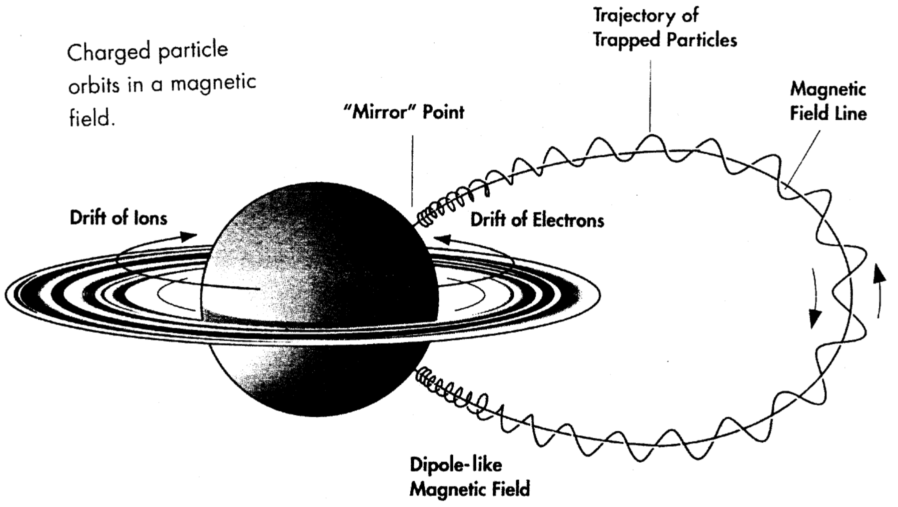

Figure 4. Charged particle motion along Saturn's dipolar magnetic field, similar to the well known motion of charged particles in the ionospheric and magnetospheric regions. Electrons and ions are seen to move in opposite directions in the lower atmospheric region of Saturn.

magnetic field lines is also similar to that of the earth, as shown in Figure 4. Drift of electrons and ions that are seen to move in the atmosphere as well as in the ring system associated with Saturn are also shown. It is well known that in a uniform magnetic field, charged particles move in a helical orbit with constant gyroradius. In the dipolar magnetic field, the charged particle trajectory is similar to that in the dipolar earth. The gyrating charges are either reflected back and forth or are precipitated into the dense atmosphere near the north and south poles. Formation of aurora and emission of radiation of broadband of electromagnetic waves are also envisaged. The most popular electromagnetic radiations from auroral regions are known as Saturn kilometric radiations (SKR), known much before the launch of Voyager. Lightning phenomenon is also thought to be taking place, which shows the formation and movements of clouds in Saturn's lower atmosphere[7]. The whistler-mode electromagnetic wave propagation in the radiation belt was reported by Coroniti *et al.*[12].

Saturn has not been observed directly by *in situ* probes, extensively. Many features of Saturn's rings have been deciphered from ground-based observations. Saturn's ring plane crossing was studied using ground-based telescopic observation on 10 August 1995 by Scharringhausen *et al.*[13]. Saturn's ring-system is ornamental in many respects and is saturated with an ever-increasing system of newer satellites. Gladman *et al.*[14] reported the discovery of 12 more satellites of Saturn that exhibited orbital clustering and similar features that were discussed in detail. Ever-changing colour shades of Saturnian rings are observed using ground-based telescopes under suitable observing conditions. The number of moons are known to vary and their number is governed by the observing conditions. The dust dynamics at Saturn is found to be invariably non-Keplerian, as discussed by Howard and Horanyi[15]. Nonlinear dust acoustic wave propagation in Saturn's F, G and E rings has been discussed using unattenuated ring distribution and dynamical constraints[16]. Whatever is known regarding solar wind interaction with earth is being attributed to other planets in the vicinity, namely Venus, Jupiter and Saturn. Viscous overstability of Saturn's rings using computer simulations and measurements of transport coefficients has been studied in detail. Results of hydromagnetic theory and simulation codes have been found to be compatible, as revealed by Salo *et al.*[17] and Schmidt *et al.*[18]. Saturn's atmosphere and surrounding ring system are found to be a source of microwave emission. These waves, recorded and studied in detail, provide interesting features regarding Saturn's rings and the associated magnetic field[19]. Further, the flux of dust particles is known to control the size of Mach cones[20,21]. The system of Saturn rings is stable to a large extent, but these rings are known to be influenced by disturbances in the giant planet, namely Jupiter by its side. A kinetic theory of quasi-linear stability of Saturn's rings has been put forward by Griv *et al.*[22].

Launch of the interplanetary mission

Whatever we know today about Saturn, its rings and a large number of moons are largely the outcome of devoted and dedicated observations and thought processes of two astronomers. The Cassinni spacecraft orbiter weighting 5630 kg is named after Jean-Dominique Cassinni, who discovered the satellites Lapetus, Rhea, Dione and Tethys as well as the ring system during the period 1671–84. The Titan probe is named after Christiaan Huygens, who discovered Saturn's largest satellite, Titan in 1655. The orbiter was launched about six years ago on 15 October 1997. This mission is a joint undertaking by NASA, USA and European Space Agency (ESA). The Italian Space Agency (ISA) is providing the hardware system through a bilateral agreement with NASA. The mission is planned to orbit Saturn for over 15 years.

The number of moons may increase further as results of this mission start coming up. Many of the 27 experiments on-board are meant to make measurements around Saturn and six of them are meant to make measurements on and around Titan. The detailed features of solar wind interaction with Saturn will also be studied and results will be compared with measurements around other planets. The study of Titan and its interaction with the solar wind would enable us to ascertain additional features that are different from results known in the case of other planets with intrinsic magnetic field. The Cassini–Huygens mission is approaching Saturn and has sent the first colour picture postcard from a distance of 285 million kilometres, as reported in *Nature* in November 2001. The Huygens probe is scheduled to descend into Titan's atmosphere in January 2005.

Conclusion

In the past, with the help of short-duration space missions, Saturn's rings and its extended atmosphere have been studied. Titan is one of the outer moons of Saturn; it is the fifteenth moon from the centre of the planet among the 18 moons known so far. As mentioned, 12 more moons were reported recently[14]. The smallest moon of Saturn is Pan, at a distance of 133,580 km. This is the closest to Saturn and its size is only 20 km. It appears that there could be many more moons of this size that have escaped attention, as reported recently. The Cassini–Huygens mission will be able to add many more to this list of moons in the near future. The detailed study of Titan is planned mainly because it resembles our own planet earth in many respects, and is slightly smaller in size. It is hoped that the planned mission would enrich us with new and interesting information in the near future.

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