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Christiaan Huygens

Facets of a genius

European Space Agency
Agence spatiale européenne

Foreword

At the 50th meeting of ESA's Science Programme Committee (SPC) meeting, that took place in November 1988, the European Participation in NASA's Cassini mission to Saturn was unanimously agreed. This European participation consists of a probe that will descend through the atmosphere of Saturn's largest moon, Titan, and land on its surface.

At the end of that particular meeting and in response to a request from Switzerland to find an appropriate name for the probe, my predecessor, Roger Bonnet, reminded the delegations that Titan was discovered in 1655 by the Dutch scientist Christiaan Huygens, recognised as a brilliant scientist in the Europe of those days. Professor Bonnet proposed that the European contribution to Cassini henceforth be known as 'Huygens'.

This proposal was accepted by acclamation, and, in particular, very much appreciated by the delegation from the Netherlands.

Following the successful launch in October 1997, and after a long journey, NASA's Cassini satellite with ESA's Huygens probe attached will arrive at Saturn in the summer of 2004. The Huygens probe will be released from the spacecraft during Christmas 2004, and will enter the atmosphere of Titan in January 2005.

In the context of this mission, ESA is organising a conference 'Titan, from Discovery to Encounter' in April 2004. Historians and scientists will convene in Noordwijk to discuss past and future investigations of Saturn and its moons. At the same time (April to May 2004), four museums in the region where Christiaan Huygens lived and made his observations are holding related exhibitions to visit under the umbrella title 'Christiaan Huygens, Facets of a genius'. This like-named publication contains four essays, each of which relates to one of the exhibitions. I would like to thank Huygensmuseum Hofwijck, Universiteitsbibliotheek Leiden, Museum Boerhaave and Space Expo for their kind and willing cooperation. I am very grateful to authors F Blom, J Yoder, A van Helden and N de Kort for their enlightening contributions.

Christiaan Huygens made his important discovery of Titan in the 17th century using the recently invented instrument, the telescope, with the best lenses available. With new observational techniques that became available in the 20th century, it was discovered that Titan has an atmosphere with a composition that is unique in our solar system. The present NASA/ESA/ASI Cassini/Huygens mission, a concerted effort combining the creativity and ingenuity of European and American scientists and engineers, will allow in-situ study of this fascinating and intriguing body into the 21st century.

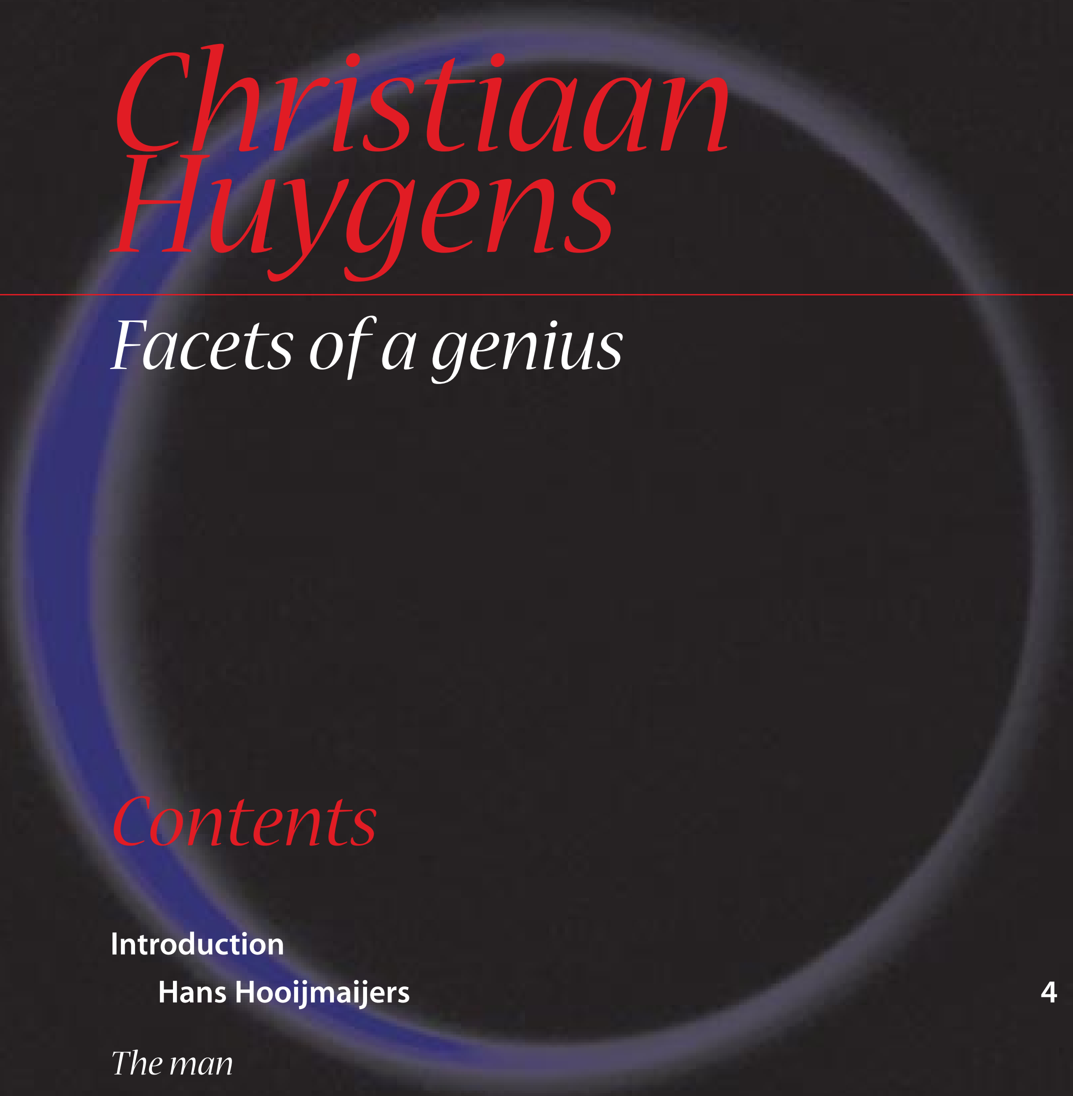
David Southwood

David Southwood
ESA Science Programme Director

Marble portrait medallion – Jean Jacques Clérion, Paris, 1679, Museum Boerhaave P2618

Christiaan Huygens

Facets of a genius



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Picture: NASA

Introduction

14 April 2004 is exactly 375 years after the birth of Christiaan Huygens (1629-1695). He was the world's greatest scientist in the period between Galileo and Newton. Christiaan was the second son of Constantijn Huygens, who was secretary to the house of Orange (the predecessors of the royal family), and a famous poet. The young Christiaan received an in-depth education in the arts and sciences from private tutors. He showed early signs of an extraordinary gift for mathematics, and when he went to study law and mathematics at Leiden University in 1645 there wasn't much they could teach him.

The oldest pendulum clock in the world, from a design by Christiaan Huygens. By Salomon Coster, Den Haag, 1657. Museum Boerhaave V9853

His father initially had a diplomatic career in mind for him. However, this wasn't Christiaan's calling, and with the financial support of his father he dedicated himself to maths and physical sciences instead. He became most famous for his invention of a clock with a hitherto impossible accuracy: the pendulum clock.

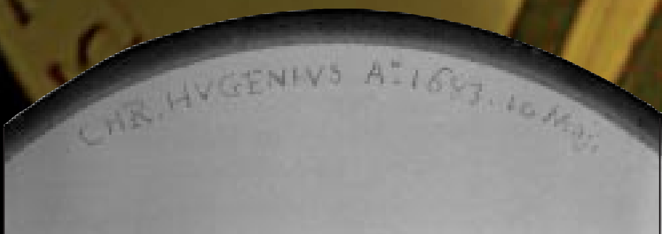
But Christiaan was at home in all fields: he came up with the wave theory of light; made mathematical descriptions of the cycloid; established laws of elastic collision; and even thought up a theory of music. Apart from being a theoretician, he was also a very practically-oriented scientist: among other things, he designed a microscope, a barometer, a spirit level, an air pump, and a tubeless telescope. Some of these inventions he even constructed himself, which was unusual for someone of his background.

His fame spread rapidly, and in 1665 he was invited by the prime minister of Louis XIV, Colbert, to be the head of scientific investigation in the soon-to-be-created *Académie Royale des Sciences* in Paris. Huygens was naturally very honoured, and remained attached to this institution for 15 years. It was the only paying job he ever had!

In his later years, new stars appeared in the scientific firmament. Although Huygens could understand Leibniz's differential theory and Newton's laws of mechanics, arguably his day was over. His last years were lonely, and when he died he was still famous but also rather undervalued. Huygens' most popular work *Cosmotheoros* ('spectator of the universe') was only published after his death.

The oldest astronomical clock in the world, From a design by Christiaan Huygens. Isaac Thuret, Paris, ca. 1670. Museum Boerhaave V9854

Christiaan Huygens died unmarried and childless. He left his scientific manuscripts to Leiden University. Hofwijck, the out-of-town retreat where Christiaan spent his last years, passed to his brother Lodewijk. Lodewijk's oldest son inherited the country estate, Zuylichem. Christiaan's books were auctioned and scattered across Europe; the rest of his legacy was divided among the children of his brothers and sister. But until 1754, the collection of Christiaan Huygens' artefacts was kept intact by Constantijn, the son of Christiaan's brother Lodewijk. That year, Constantijn's daughter Susanna Louise auctioned the whole collection, to settle the inheritance amongst the many relatives. She herself bought a number of pieces back again. These pieces were donated to Leiden University in 1809 by her heir, Alexander-Jerome Royer, together with a number of other pieces that he had acquired himself. In 1931 the university transferred the Huygens collection of artefacts, which had grown in the meantime, to the predecessor of Museum Boerhaave.



Lens ground by Christiaan Huygens, Den Haag, 10 May 1683 Museum Boerhaave V9108

In 1655, Christiaan Huygens discovered the first moon of Saturn, subsequently named Titan, using his own telescope with self-made lenses. Thereafter he also solved the puzzle of the strange attachments of Saturn: Huygens made the brilliant discovery that it must be a ring around the planet. At this very moment, the spacecraft Cassini/Huygens, a cooperation between NASA and ESA, is approaching Saturn. In honour of the genius Christiaan Huygens and his discovery of the moon Titan, a probe named Huygens will be ejected from this spacecraft on 25 December 2004, towards that moon.

As a run-up to this event, there will be an international conference in Noordwijk in April 2004. Around this conference there will be four exhibitions to visit, that illuminate the past and present of Christiaan Huygens. His last residence, now the Huygensmuseum Hofwijck, will be predominantly concerned with the life of Christiaan. Some of Huygens's manuscripts will be on show in the library of Leiden University, where attention will also be focussed on the restoration of these papers. The greater part of Huygens's remaining artefacts will be on public display in the Museum Boerhaave, and for this occasion attention will be focused on his efforts in astronomy. Finally, Space Expo will be displaying a model of the Huygens space probe, and information about the mission will be available.

The four essays in this booklet can be related to the four exhibitions. Frans Blom starts with the childhood of Christiaan Huygens and stories about his upbringing. Joella Yoder writes about how a large number of Christiaan's manuscripts came to be in Leiden University Library and what has happened with them since. Albert van Helden tells how the planet Saturn was viewed in Huygens's time, and which mysteries were associated with it. Finally, Niek de Kort gives an impression of events from the discovery of the first moon of Saturn up until the Huygens mission of 25 December 2004.

Hans Hooijmaijers, Museum Boerhaave

The man

The childhood of Christiaan Huygens

'Small in stature, but hugely enquiring and ambitious'

He was a shrimp of a child. With knobbly knees and pigeon toes. He was sometimes taken for his younger brother's twin, and praised for being such a sweet little girl. But when it came to learning, his talent was unmistakable and his diligence unrivalled. When he memorised the Lord's Prayer his mind did not stop working even at night, and he could be heard reciting the words in his sleep – when he wasn't singing.

Christiaan Huygens came from an extraordinary family. His father was a famous poet and composer, employed as secretary and adviser to Frederick Henry, Prince of Orange. His mother was an elegant creature, musical and artistic. She had five children. Christiaan was the second son in the family, after the one-year-older Constantijn, and ahead of his two other brothers, Lodewijk and Philips, and his little sister Susanna. The first-born boy was named after his father, the only girl after her mother, and Christiaan himself, at his birth on 14 April 1629, was given the name of his grandfather. The latter had been the highly-valued secretary of William of Orange, and after the assassination of the Father of the Fatherland had fulfilled the same office in the Council of State.

The five Huygens children surround their father.

Centre top the only daughter Susanna, top left Constantijn Jr., top right Christiaan, bottom left Lodewijk, and bottom right Philips. The mother is missing; she died shortly before, in 1639.

By Adriaen Hanneman. Royal Cabinet of Paintings, Mauritshuis, The Hague

This meant that the name of Huygens, and that of Christiaan in particular, was intimately associated with the young Dutch Republic, which had fought as the United Provinces against the rule of Catholic Spain. Grandfather, a refugee from the Southern Low Countries, had settled in the liberated, Protestant region of Holland. In The Hague, the administrative centre, he had become the progenitor of an extremely ambitious family, which had thrown in its lot with the court and the governing councils. In the end, three successive generations were to provide senior secretarial officials for four generations of Princes of Orange.

Grandfather Christiaan Huygens (1551-1624), secretary of William of Orange, and later of the Council of State.

By A. Blooteling. Mezzotint, copy of a portrait from ca. 1580. Huygensmuseum Hofwijck, Voorburg

The Huygenses were thus newcomers in society in Holland, and had to cultivate the family's honour with care. A great deal was consequently invested in maintaining the vital connection with the house of Orange, the court, and the higher governing councils. This started with their education.

None of the Huygens children went to school: it would have wasted too much time, there was not enough individual attention, and the syllabus was too restrictive. Instead, they all followed a special curriculum at home, with efficient, varied and child-friendly teaching. This was something that had been thought out in the first generation. During his time at court, Christiaan Huygens Sr. had made a study of the knowledge, skills and manners required by young people of rank, in order to teach them to his children at home. His son Constantijn, the most multi-faceted figure in the seventeenth-century Republic, was proof of the success of this approach: a fluent speaker and writer in several languages, a connoisseur and an elegant practitioner of literature, music, painting and architecture, at home to some degree in natural philosophy and physics, a dignified presence and a noted correspondent.
The special programme of study was so successful that the third generation, that of Christiaan Jr., was also given the education devised by his grandfather. In a few cases – Latin, for instance – they even used the lesson notes he had written (see next page).

So it came about, according to Constantijn, that he and his sons were as alike as two drops of water. And elsewhere, with the pride of a father and teacher, he wrote that his five 'copies' surpassed their original:

Five heirs to my heritage, five 'Me's, five copies
Of the humble original, that they – praise God – surpassed
And infinitely surpassed in value;
Four boys, whom my care has made into men,
One girl, as much beautiful as obliging in looks,
Who strikingly reflects her mother's virtue. [i]

Just how highly education was regarded by the family can be seen from a whole series of pedagogic and biographical writings that were noted down in successive generations as if for a sort of family archive. Emulating Christiaan Huygens Sr., Constantijn, in particular, kept a close eye on the development of his children, and committed his account to paper from the days of their births [ii]. These notes, written in unpolished, everyday seventeenth-century Dutch, provide a unique insight into the life of the family, into the characters of the children and into their own individual development (see overleaf).

For although they all largely followed the same lessons, it became clear very early on where each child's strengths lay and which areas were not their particular forte. That applied equally – and perhaps particularly – to the budding physicist.

Music

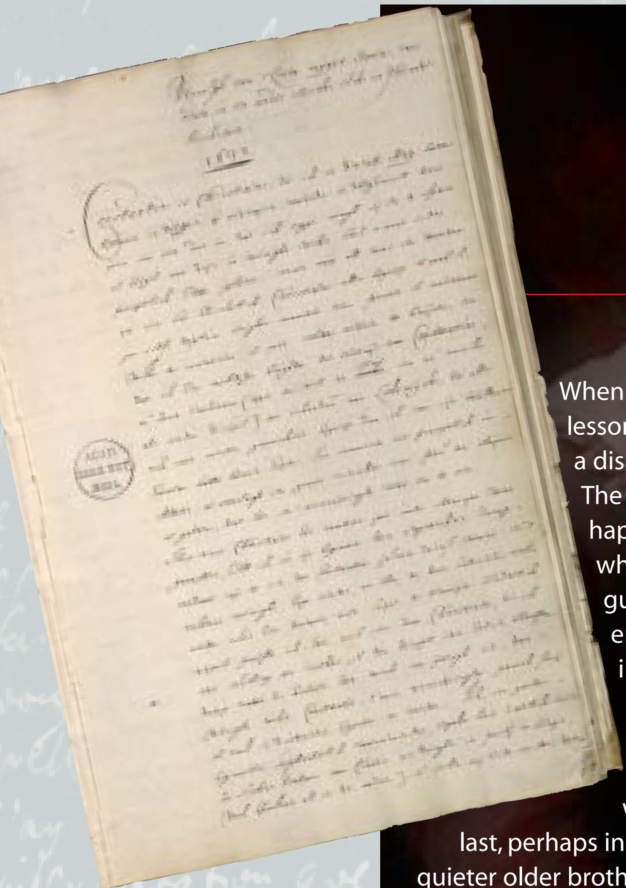
One of Christiaan's most evident characteristics was his height, or rather lack of it. This fact recurs again and again in the notes in observations like 'very small for his age', 'delicate of limb', 'little grown', 'still very undergrown' and 'remaining much shorter of stature'. In a society where outward appearance was more important than it is today, this may have been a matter of mild concern to his father.

Father Constantijn Huygens making music with his wife Susanna Huygens-Van Baerle. 1635.

By Jacob van Campen. Royal Cabinet of Paintings, Mauritshuis, The Hague

[i] Translated from 'Hofwijck', the Dutch poem Constantijn Huygens wrote about his house outside The Hague

[ii] The quotations by Constantijn Huygens about his children may be found in ms. Leiden UB, Hug. 30, II. The text was published in integral form for the first time by A.R.E. de Heer and A. Eyffinger (with paragraph numbering) in the collection 'Huygens herdacht' (pp. 75-166) in 1987. Most sources for this article are based on this text.



A page from the Dutch-language notes made by Constantijn Huygens about his children. Shown are the comments from 1638.

Universiteitsbibliotheek Leiden

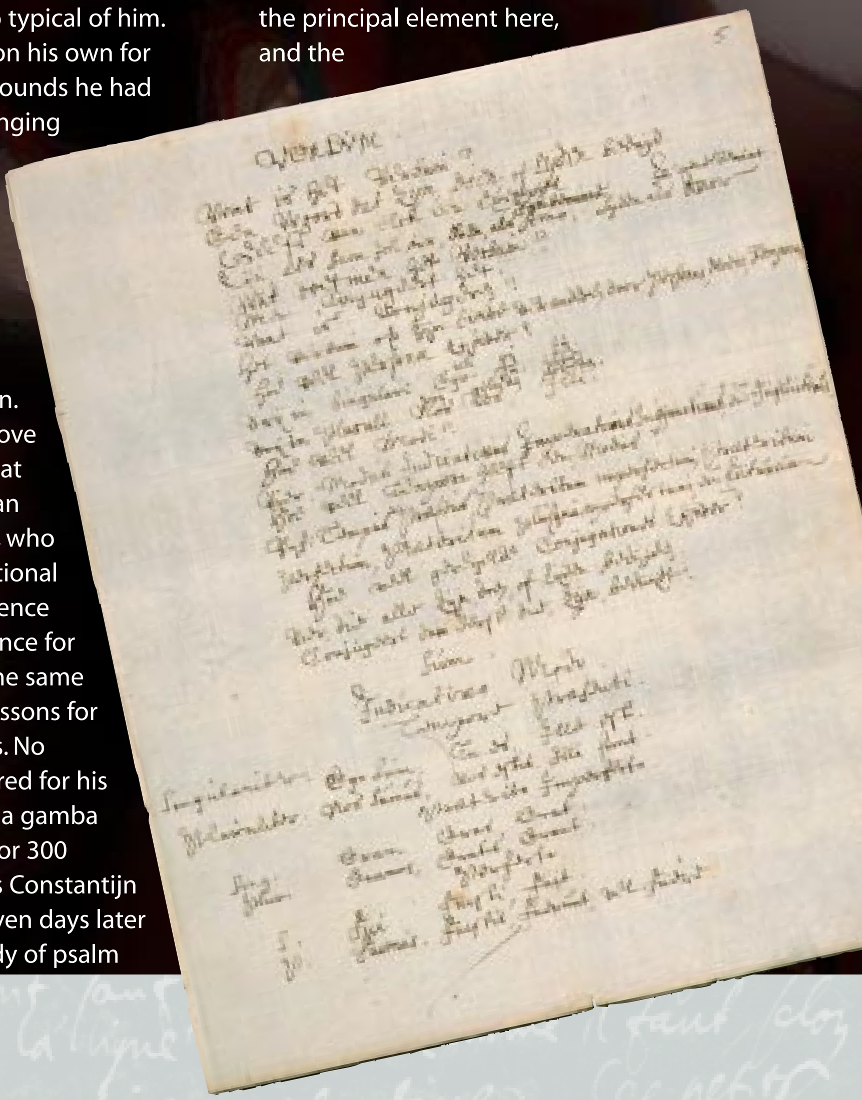
Hug. 30 II, f. 1r

When it came to dancing lessons, in any event, it meant a disappointing lack of grace. The little chap was, however, happy and sociable. Even when his eyes were gummed shut for days on end because of an infection, he continued to go about cheerfully, 'most of the time not ceasing to sing and talk, with his eyes closed'. This last, perhaps in contrast to his rather quieter older brother, is also typical of him. Sometimes the toddler lay on his own for hours, rhyming words and sounds he had heard, and he was always singing or humming as he played.

Thus, at a very early age, he exhibited a strong affinity for sound and music, much to the delight of his father, whose great musicality had also been expressed early on. The second son proved 'to love singing' and was very good at his singing lessons. Christiaan even gave his older brother, who found it more difficult, additional lessons, on payment of sixpence for the teacher and threepence for the pupil. Later, he played the same paid role again in singing lessons for his youngest brother Philips. No trouble or expense was spared for his musical education. A viola da gamba was purchased in England for 300 guilders (almost three times Constantijn Sr.'s monthly salary), and seven days later Christiaan played the melody of psalm 117 'perfectly'. A year later – by then he was ten – this was followed by the lute, the instrument that was popular in eminent circles and so skilfully played by his father. Here, too, 'Christiaan clearly outshone his brother'. It is unsurprising that during the lessons on the harpsichord it was once again observed that the second child 'had a much more skilful hand, as well as ear'.

Very creative, but not with verse

Would this ability also manifest itself when it came to learning languages? Latin was the principal element here, and the



Elementary Latin: The verb. Huygens and his older brother Constantijn Jr. learned their first Latin from from the grammar lesson notes designed by their grandfather.

Universiteitsbibliotheek Leiden

Hug. F 49,f. 5r.

children started lessons in it at the age of eight. The subject commenced with grammar and syntax on the basis of father's short summaries, and then fairly rapidly made the step to the easier authors. What was learnt was always actively applied. So the children learnt to write the language, for instance in letters in Latin to their father, and of course to speak it. The rules of rhetoric and the memorising of classical orations led to their producing and delivering short discourses themselves, and naturally their father, who was himself a celebrated poet, thought it important for them to compose their own verses after the example of the classical poets. The two older brothers attended the same lessons, but one was much more taken with them than the other. Now it was Constantijn who took after his father, and it seems that Christiaan was only able to keep up with the talent of his older brother through hard work and a natural competitive urge. 'It was impossible to get verses from Christiaan', wrote his father in some surprise. No, poetry was not his strong suit, nor did exercises in Latin prose flow readily from his pen: 'I could not drag any compositions out of Christiaan'. He was thirteen by the time his father finally accepted that Latin-style exercises were not to be expected from this boy, 'not with commands, nor with promises, nor with reproaches'. He did, though, identify a very different interest:

> In contrast, he grasped with exceptional alacrity anything and everything to do with Mechanics or any other area of Mathematics.

Christiaan preferred to devote the energy his older brother put into verses and prose to his own special interest. The following observation is telling. Whereas the older of the two was compiling a chronological overview of world history, the second spent his free time engrossed in technical questions:

> Christiaan devoted all such spare time to making little windmills and other models, even down to a lathe.

His father did not put the slightest obstacle in his second son's way in this regard, and never tried to steer him in a direction he did not want to go. This was highly unusual, for the object of the education, the *honnête homme* who would move in high official and court circles, was not, after all, served by this attitude. It was for this reason that Christiaan's grandfather, Christiaan Sr., had forbidden his own son, after a brief course in elementary mathematics, to waste any more time on it. But within a single generation, with lions like Stevin, Bacon, Drebbel and Descartes, the discipline had acquired so much prestige that in his turn Constantijn Sr. expressed no objections to the passion that his second son actually shared with him. He had even been his first teacher, spending an hour after supper every evening teaching the eight-year-old boy arithmetic. He noticed then how 'readily' Christiaan understood everything and, as in the case of music, paid him to teach his older brother. Later, too, when the boys were being taught by their tutor, Stampioen, all the praise in this area went to the younger of the two brothers 'who not only understood everything easily and

Father Constantijn Huygens (1596-1687) and his clerk, surrounded by attributes that illustrate his various interests.

By Thomas de Keyser, 1627. National Gallery, London.

View of Plein in The Hague; in the distance the Mauritshuis, and on the left (where nowadays is the side entrance of the Second Chamber of parliament) the self-designed home of the Huygens family. From this house, Christiaan Huygens discovered Saturn's ring.

Drawing by Jan van Call. Haags Gemeentearchief.

remembered it, but even invented all sorts of ingenious things every day, and collected them in a book, so that one could admire them mightily'.

Drawing

The two eldest brothers in the Huygens family thus each had his own strengths, and they seem to have been almost complementary in their aptitude for all the disciplines that were united in their father. There was one talent that they both shared with him. Or, more accurately, with their father and their mother – for in the field of the visual arts, one was only a celebrity in a passive sense, as a connoisseur and adviser on art to the Oranges, whereas the other had earned a reputation as an artist. Certainly Constantijn Sr. believed that his firstborn son had inherited his talent from his mother, because she had been passionately engaged in drawing during her pregnancy. Be this as it may, the two brothers were a match for each other and both made numerous 'outstanding drawings' during their childhood. Aside from his many technical sketches, there are drawings of The Hague and environs by Christiaan, the head of an old man after a work by Rembrandt, the magnificent drawing of Hofwijck in his sketchbook (right), and the portrait of his father, an engraving of which adorns Constantijn's volume of poetry, *Korenbloemen*.

'Small in stature, but hugely ambitious and enquiring' was the concluding observation about the young Christiaan. He was unlike his brothers in looks, talent or ambition. They all went through the same educational process in the parental home, but the second son in the family developed in an entirely individual way. He was never to get an appointment at court or an official position in the councils of state. The carefully cherished pedagogic tradition in the family, the healthy competition with his older brother and, perhaps above all, the parental empathy with his special aptitude, ensured that at an early age, while he was still living in the house in The Hague (above), he was able to develop precisely those talents that were to lead to world renown. And they continued to grow during his years studying at Leiden.

Even at university, where he originally read law, the young 'Archimedes' was unable to deny his first love: 'there he pursued his studies with enthusiasm, but especially in Mathematics, Drawing and Music'. Later again, when Christiaan was at the *Académie des Sciences* in Paris, his father thought back nostalgically to the time when he had had the privilege of being the first person to recognise his son's talents. In his autobiography, he wrote verses that looked back at the past with as keen a gaze as they looked into the future:

"After the first follows the son whose name does not fit in the stiff hexameter, and fame scarcely in the whole world. All that he has achieved and may be expected yet to achieve is recognised by France, that source of Charity and mother of nurtured talents, who now keeps my precious pledge under her wing. My beloved boy, were fate to grant it, I should so much want to share life and spend my old age together with you, wherever we might be. But much more I wish that all will go well for you, wherever and whenever I have to let you go. I do not want to remind you of much, for that is child's play from your youth that even I consider beneath your dignity, however great it may be for me and people like me, who creep insignificantly on the ground compared with your flight into the highest spheres of heaven. I shall not tell you how you excelled in head and hand as a musician and fathomed everything that nature concealed in the secret of her sounds. I shall also keep silent as to how you outdistanced your masters while still very young, soon growing from pupil to teacher of pupils, and acquired the name of Sicily's wise thinker. And I shall not speak either of the beauty that early graced your drawings in red or black chalk, and how skillfully you wield a pen. (For you, after all, these are trifles and qualities on which you look down, although someone who discovered them in himself by chance or mastered them through practice would not exchange them for any price.) As long as the wheel of heaven and the stars revolve, as long as time ticks with the regularity of the pendulum, as long as the planet Saturn is purged of the ignominious lugs that you have consigned to the realm of fable, and remains adorned with the stately ring that you discovered to its glory, that long will you endure and your name will not dim until the stars go out." [iii]

Frans R.E. Blom,
University of Amsterdam

[iii] *The autobiography in Latin verse was published by F.R.E. Blom in 2003 with an introduction, translation and commentary: 'Constantijn Huygens, Mijn leven verteld aan mijn kinderen in twee boeken'. For the quotations here, my translation into Dutch has been rendered into English.*

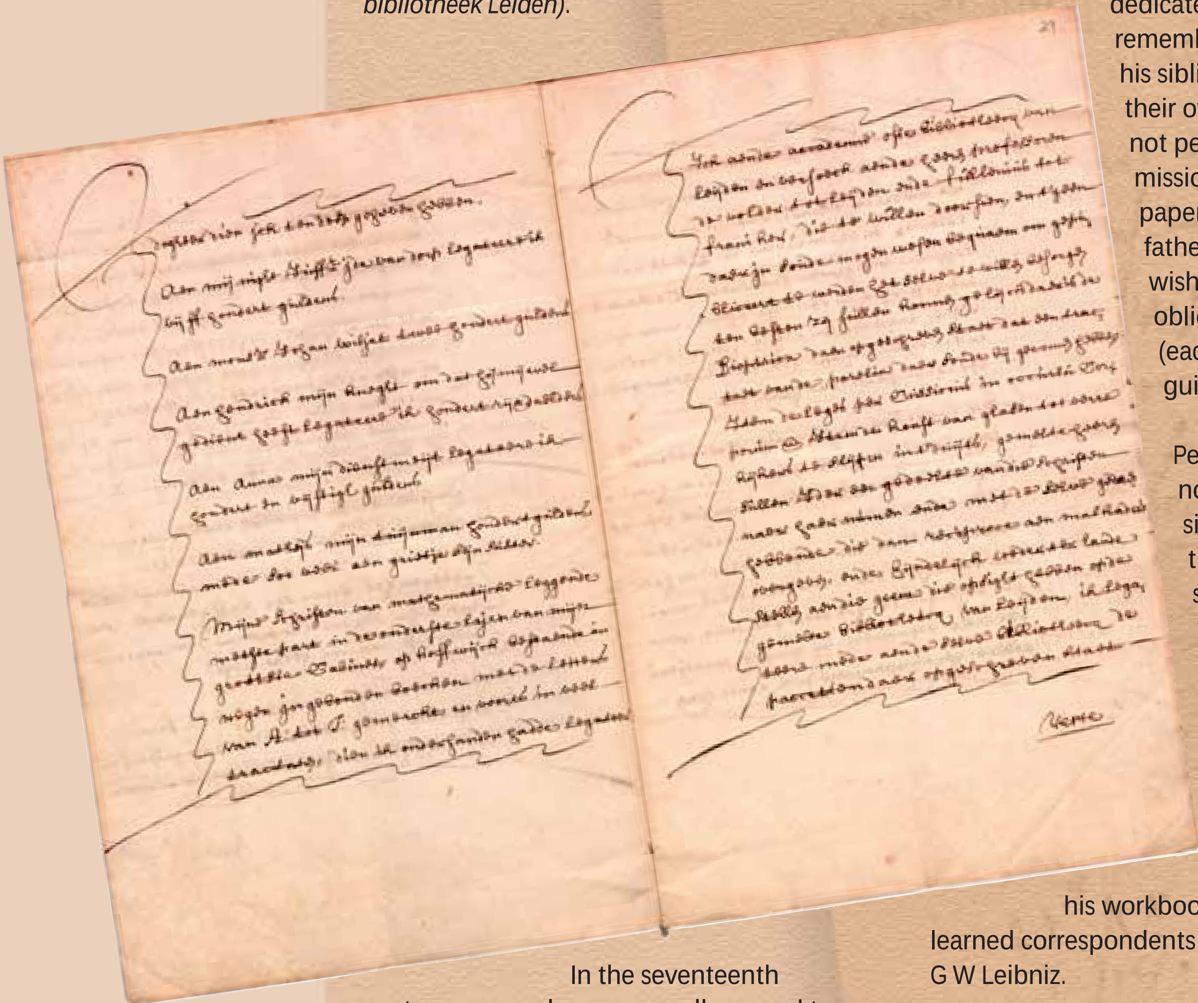
The Huygens family's out-of-town retreat, Hofwijck. Drawn in colour by Christiaan Huygens in 1658, in his sketchbook.

Universiteitsbibliotheek Leiden Hug. 14, f. 5r.

The manuscripts

Christiaan Huygens and his written legacy

In 1695, as death approached, Christiaan Huygens performed one last brilliant, uncommon act: he bequeathed his manuscripts and correspondence to the Leiden University Library *(Universiteits-bibliotheek Leiden)*.

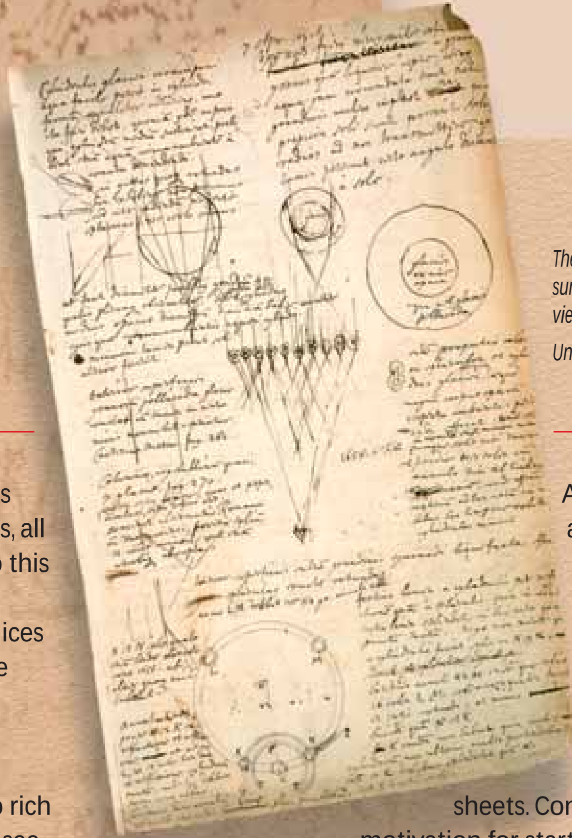


Copy of Christiaan Huygens's will, validated on 23 March 1695. Universiteitsbibliotheek Leiden Hug. 46, f. 28v/29r.

In the seventeenth century, personal papers usually passed to the next of kin, not to a public institution, and often vanished soon after because they had little monetary value. Huygens' unusual bequest shows that he had a very strong sense of his place in history and of the importance of his scientific papers as support for his reputation. Moreover, in his will he arranged for two famous Dutch professors to prepare for printing four major treatises that he had never published during his lifetime, and only entrusted the publication of his *Cosmotheoros* to his brother, to whom it was dedicated. Perhaps he was remembering that he and his siblings, caught up in their own busy lives, had not persevered in their mission to publish the papers of their famous father, Constantijn, and wished to have editors obliged to the task (each was paid 1000 guilders).

Perhaps he was right not to rely on his siblings. Although the spirit of his will suggested that he wanted the library to have all his papers, the library only received the items that he specifically mentioned: his scientific papers, his workbooks, and letters *from* learned correspondents such as G W Leibniz.

Missing from the list, and thus not given to Leiden, were his scientific instruments, and letters that passed between him and his family. Even the drafts of the replies that he wrote *to* his learned correspondents were held back! Yet, even without those items, some of which eventually did join the collection, the original bequest included



The first page of the workbook, A. Huygens draws how parallel light rays from the sun bend as they pass through a row of cylindrical ice crystals (middle) and are viewed by an eye (bottom).

Universiteitsbibliotheek Leiden, Hug. 10, f. 1r

thousands of pages written by Huygens, all safely preserved to this day under the collective title 'Codices Hugeniorum' of the Leiden University Library.

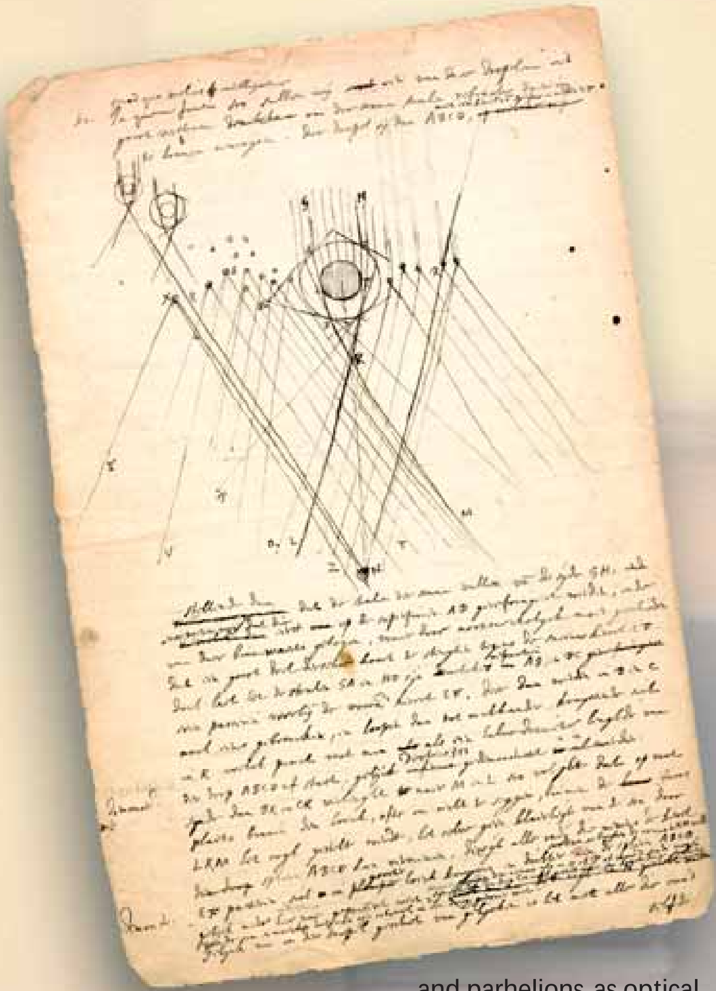
The collection is so rich that it allows us to see Huygens at work, so to speak. Although he had already made important scientific discoveries by the age of seventeen, published three mathematics treatises during his twenties, and begun the research into motion and light that would dominate his later work, a new sense of seriousness seemed to announce itself in 1658, when he began recording his daily research in large bound volumes that he lettered alphabetically, ending with 'I' in 1695. These workbooks contain the first sketches of many future projects, derivations of theorems, notes on books that he was reading, calculations, and even doodles. Some pages are neat, while others are a sloppy jumble of overlapping work. The very first page in Book A, which deals with his early attempts to analyse the halos and false suns that sometimes surround the sun on a cold day (called coronas and parhelions), is a good example of the juxtaposition of neatly written comments and rough sketches.

Indeed, once his ideas had formed, Huygens often abandoned the confines of the books and wrote on loose paper. Sometimes he began with a list of topics to be covered and references to other researchers' work; for example, he compiled notes on previous observations of coronas. A set of underlying assumptions, or hypotheses, might follow. Finally, a neatly written, precisely argued, first draft emerged. Further refinements were also written on loose sheets. Consequently, whatever his motivation for starting them, the workbooks ended up constituting only a third of the total number of pages in Huygens' working papers. Indeed, he sometimes even resorted to using strange substitutes, such as two almanacs in which he wrote on the pages not covered with monthly prognostications. Moreover, when he arranged his papers for the editors of his posthumous works, he actually cut important passages from the workbooks and saved them together under one cover.

His two editors, Bernard Fullenius (professor of mathematics at Franeker) and Burchard de Volder (professor of physics and mathematics at Leiden), were the first of many people who safeguarded Huygens' scientific achievements by drawing attention to previously unpublished documents in the manuscript collection. It was in their edition that Huygens' explanation of coronas

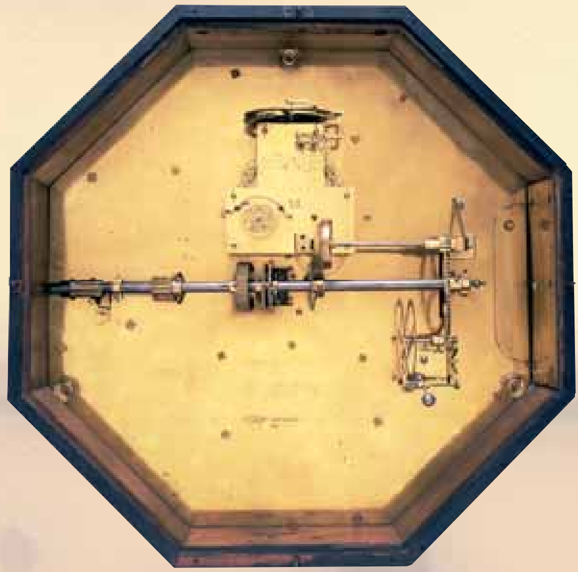
Letter from Huygens to J Hudde, dated 14 December 1690. Huygens talks about his latest attempt to use his clocks at sea in order to determine longitudinal position.

Universiteitsbibliotheek Leiden, Hug. 45



A more refined version of the drawing from workbook A , with the central region blown up to demonstrate how the light passes through a single crystal.

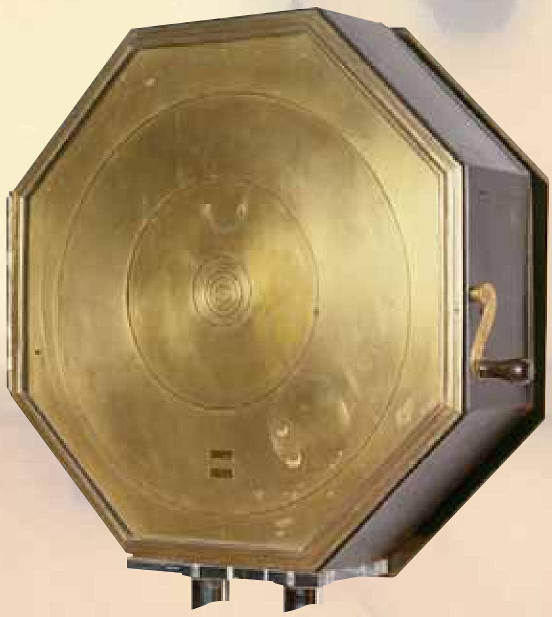
Universiteitsbibliotheek Leiden, Hug. 31, f. 96r



and parhelions, as optical phenomena that occur when ice crystals in the atmosphere refract light, finally appeared in print. Likewise, Huygens had worked on his great treatise on the refraction of light by lenses for most of his adult life, yet *Dioptrica* was only published in the posthumous edition. Furthermore, although his reputation rests on his early studies of colliding bodies, particularly his use of relative frameworks, only portions of *De motu corporum* had appeared during his lifetime. A treatise on how to grind lenses for telescopes, co-written with his brother Constantijn Jr., completed the set of four items that Huygens specified in his will for publication.

But his enthusiastic editors added two more that they felt were sufficiently finished. One was a description of a precision clockwork device that showed the motion of the planets on its face and had originally been commissioned for Louis XIV when Huygens was still in his service. (This planetarium is now in Museum Boerhaave.) The theorems of the other, *De vi centrifuga*, were reordered by Fullenius and De Volder to conform to a list that Huygens did publish. Done with their editing, the two professors returned the manuscripts to Leiden, where they were finally catalogued in 1716.

Another person mentioned in Christiaan's will, his nephew Constantijn Lodewijkszoon, also figures prominently in the preservation and dissemination of his papers. Through a combination of early deaths and intermarriage, Constantijn Lz became the sole possessor of most of the family property and papers, including those of his grandfather Constantijn, and those of his uncle Christiaan that had not already passed to the Leiden University Library. This nephew made neat copies of Christiaan's drafts and synopsised letters between his two uncles that dealt with their work on lenses, plus he wrote a biographical sketch of Christiaan. Much of this material he made available to Willem 's Gravesande, the great Newtonian physicist, who prepared the second edition of Huygens' work. This 1724 collection included reprints of some of the major works that Huygens did publish in his lifetime, such as *Horologium Oscillatorium* and *Systema Saturnium*, as well as excerpts from his letters. In 1728, 's Gravesande published another collection that included a complete reprint of the Fullenius and De Volder edition, plus Latin translations of Huygens' treatise on light and discourse on the cause of gravity, both of which had originally appeared in French. Background material for these editions, including 's Gravesande's draft of a biography and letters from Constantijn Lz to him, were



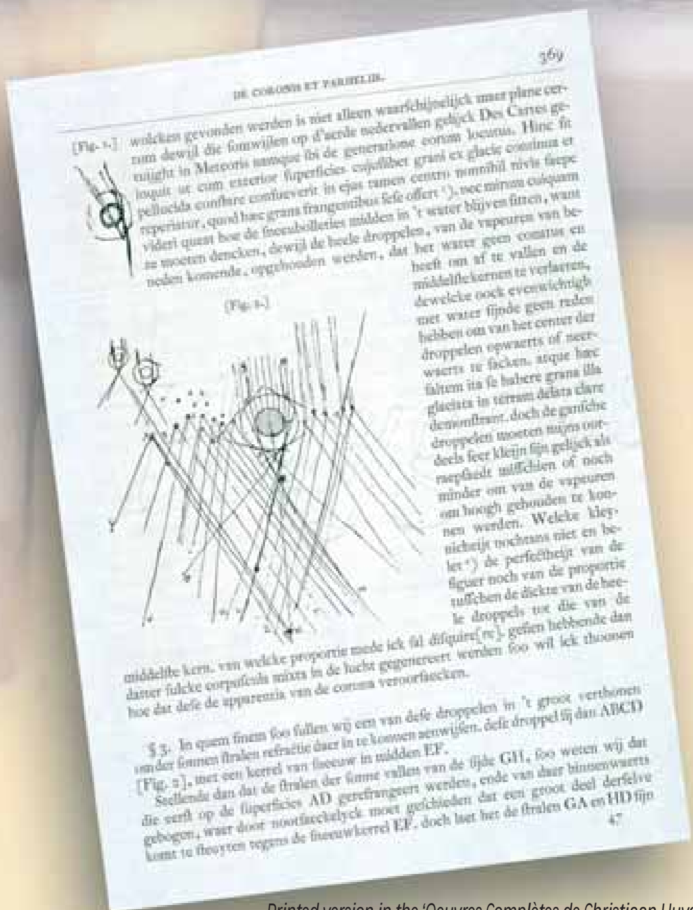
Planetarium designed by Christiaan Huygens.
The clockwork and the orbits are so precise that over twenty years the orbits will be accurate to within 3.5 degrees. The planetarium can be manually adjusted to show every configuration of the planets between 1580 and 1880.

Johannes van Ceulen, Den Haag, 1682, Museum Boerhaave V9997

willed to the Leiden University Library in 1809 by A J Royer, a great-nephew who had subsequently inherited part of the family collection. Royer also donated other items, including Christiaan's planetarium.

Unfortunately, not all the heirs were so generous. When Constantijn Lz died, the vast collection passed to the only surviving child of his marriage to his cousin Philippina Doublet, Susanna Louise. Upon her death, the lot was inherited by 14 various cousins, including Royer. The collection of papers remained together under the care of Royer's older brother for almost three decades, but eventually it was divided up. One large set of papers went up for auction in 1823. Samuel Iperuszoon Wiselius, royal archivist, argued that the cultural heritage of the Netherlands should not be sold away, perhaps to foreigners, and convinced King Willem I to buy the entire set. After purchase, however, the set was divided among various Dutch institutions. Leiden's Codices Hugeniorum received over 2,000 letters written to Constantijn Huygens, letters that passed between his sons, as well as all manuscript material in Christiaan's hand, including the autograph of *Cosmotheoros* and his draft letters.

Another large number of family papers, including nearly a thousand letters to Constantijn Huygens, was auctioned off in 1825. The owner attempted to sell the collection to the royal family, but asked for substantially more money than they had paid for the previous set. Turned down, he then put the collection up for auction outside the Netherlands. With no single buyer to preserve the collection, the individual items met different fates, some now unknown, and nothing came directly to Leiden from that sale. Family papers from still another auction did eventually join the Codices Hugeniorum, some having first been owned and published by A D Schinkel, although many other pieces known to have existed have simply disappeared. All these added items now total nearly half the papers in the Codices Hugeniorum, and although most are not in

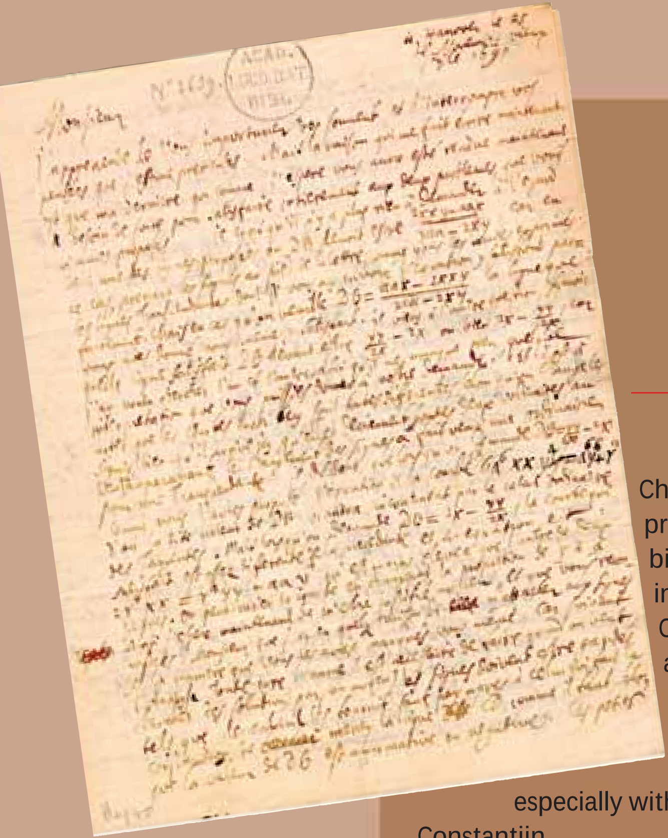

DE CORONIS ET PARHELIIS. 369

[Fig. 1.]

[Fig. 2.]

47

Printed version in the 'Oeuvres Complètes de Christiaan Huygens' vol. 17, p. 369



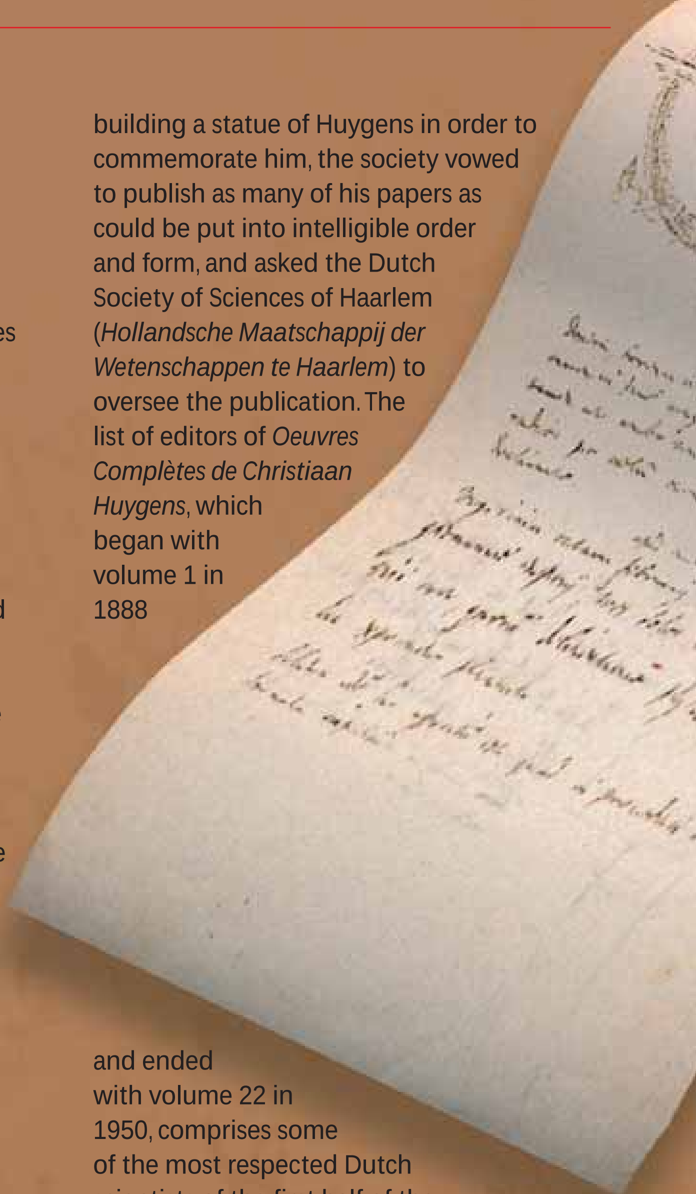
Letter from GW Leibniz to Huygens, dated 5 December 1690, in which he demonstrates the power of his new calculation method (calculus).

Universiteitsbibliotheek Leiden, Hug. 45

Christiaan's hand, they provide important biographical information, such as Constantijn's notes about the education of his children, copies of Christiaan's will, and family history, especially with regard to Constantijn.

At the very time that the collection at Leiden was being expanded by the Royer and Royal donations, it was being surveyed by P J Uylenbroek as part of a general appraisal of the library's holdings. J H van Swinden had already begun working more extensively with unpublished manuscripts in the collection, but most researchers had been content to rely on the existing editions. Uylenbroek was astounded by the richness of the unedited material, and argued that the very rough drafts allowed us to see the paths that led Huygens to his remarkable discoveries. Chiding earlier editors for not pointing out papers that proved Huygens' priority, especially with regard to his work on motion, Uylenbroek drafted a prospectus for a subscription list that would fund an edition of these more obscure pieces. Alas, the only part of his ambitious plan that ever materialised was his 1833 edition of the correspondence between Huygens and Leibniz (and others) regarding the foundations of calculus.

A few decades later, however, Uylenbroek's vision was taken up by the Royal Academy of Sciences of Amsterdam (*Koninklijke Akademie van Wetenschappen*). Instead of building a statue of Huygens in order to commemorate him, the society vowed to publish as many of his papers as could be put into intelligible order and form, and asked the Dutch Society of Sciences of Haarlem (*Hollandsche Maatschappij der Wetenschappen te Haarlem*) to oversee the publication. The list of editors of *Oeuvres Complètes de Christiaan Huygens*, which began with volume 1 in 1888



and ended with volume 22 in 1950, comprises some of the most respected Dutch scientists of the first half of the twentieth century, including DJ Korteweg, HA Lorentz, and P Zeeman, thus continuing a tradition in which the leading Dutch scientists of their day edited the papers of this most famous Dutch savant.

Since then, many scholars have made use of *Oeuvres Complètes* to do precisely what Uylenbroek envisioned: to situate Huygens in his milieu. And as the questions have

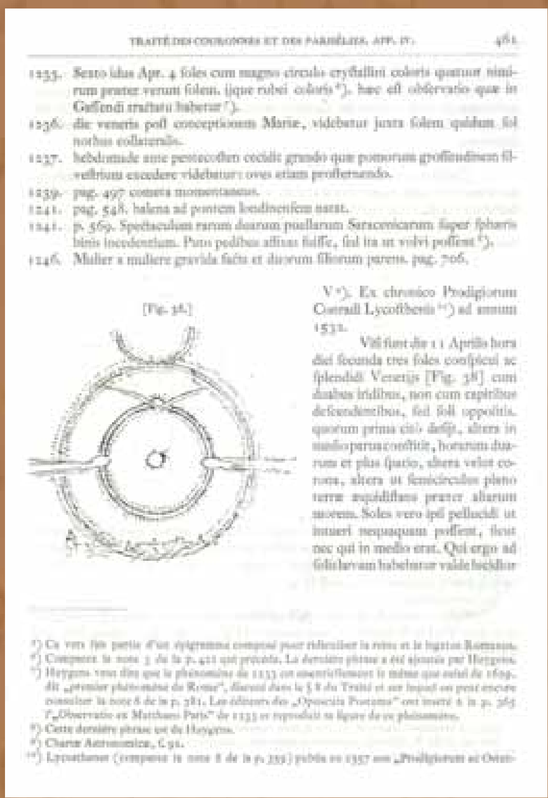
Huygens's notes from reading about an observation of a solar phenomenon involving three false suns and two complete circular rainbows. Similar notes at the bottom of the first page of workbook A.

Universiteitsbibliotheek Leiden, Hug. 31, f. 91r

become more detailed, the need to return to the manuscripts themselves has reappeared. Marginal calculations hitherto unedited suddenly take on significance. In response to the needs of scholars, a very detailed catalogue that cross-references the manuscripts with the edition is now being prepared. Thus each generation returns to the manuscripts of Christiaan Huygens to see a great mind at work and to answer the historical questions of its time.

Today, more than 300 years after the original bequest, Leiden University Library continues its stewardship of Huygens' papers. Although the collection has been preserved in accordance with high standards, the papers are showing the ravages of time and handling. Indeed, in some cases, passages written in the margins that the editors of *Oeuvres Complètes* could read are now missing, having in the meantime literally turned to dust. That is why the library is in the process of restoring the manuscripts under a grant from the Dutch Academic Heritage Foundation (*Stichting Academisch Erfgoed*), with a completion date of autumn 2005. The goals of the restoration project are to clean and repair damaged pages (primarily the loose papers and letters), stop paper degradation caused by iron-gall ink corrosion, and conserve the original parchment bindings of the workbooks and other codices. Thus catalogued and preserved, the legacy of Christiaan Huygens will continue to be available for many more generations.

Joella Yoder, Independent Scholar



TRAITÉ DES COURONNES ET DES PARHÉLIES. APP. IV. 461

1233. Sexto idus Apr. 4 soles cum magno circulo crystallini coloris quatuor similes praeter verum solem, (que rubei coloris *), haec est observatio quae in Gassendi tractatu habetur ²).

1236. die veneris post conceptionem Mariae, videbatur juxta solem quidam sol nothus collateralis.

1237. hebdomade ante pentecosten cecidit grando quae pomorum grossitudinem silvestrium excedere videbatur: oves etiam prosternendo.

1239. pag. 497 cometa momentaneus.

1241. pag. 548. balena ad pontem londinensem natat.

1241. p. 569. Spectaculum rarum duarum puellarum Saracenicarum super sphaeris binis incedentium. Puris pedibus afixas fuisse, sed ita ut volvi possent ³).

1246. Mulier a muliere gravida facta et duorum filiorum parens. pag. 706.

[Fig. 38]

V *). Ex chronico Prodigiorum Conradi Lycosthenis **) ad annum 1532.

Visi sunt die 11 Aprilis hora diei secunda tres soles conspicui ac splendidi Venetijs [Fig. 38] cum duabus iridibus, non cum capitibus descendentibus, sed soli oppositis, quorum prima caelo defixa, altera in medio partim constitit, horarum duarum et plus spacio, altera velut corona, altera ut semicirculus plano terrae aequidistans praeter aliarum morem. Soles vero ipsi pellucidi ut intueri nequaquam possent, sicut nec qui in medio erat. Qui ergo ad solis laevam habebatur valde lucidior

*) Ce vers fait partie d'un épigramme composé pour ridiculiser la reine et le légat Romanus.
²) Comparez la note 3 de la p. 422 qui précède. La dernière phrase a été ajoutée par Huygens.
³) Huygens veut dire que le phénomène de 1233 est essentiellement le même que celui de 1629, dit „premier phénomène de Rome", discuté dans le § 8 du Traité et sur lequel on peut encore consulter la note 8 de la p. 381. Les éditeurs des „Opuscula Posthuma" ont inséré à la p. 365 l'„Observatio ex Matthaeo Paris" de 1233 et reproduit la figure de ce phénomène.
⁴) Cette dernière phrase est de Huygens.
⁵) Chartae Astronomicae, f. 91.
¹⁰) Lycosthenes (comparez la note 8 de la p. 355) publia en 1557 son „Prodigiorum ac Osten- [illegible]

Printed version in Oeuvres Complètes, vol 17, p. 461

Universiteitsbibliotheek Leiden

The moon and ring

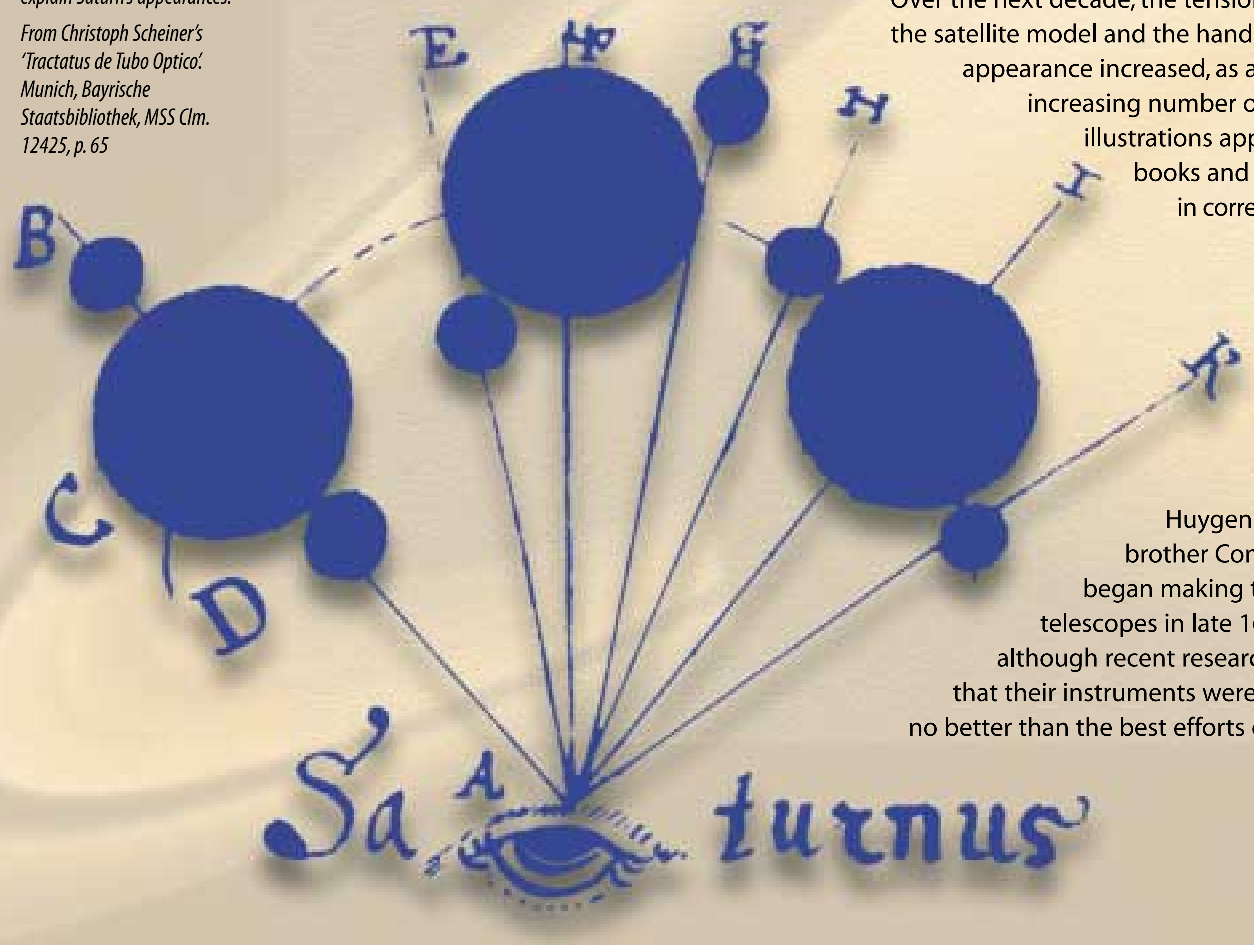
Christiaan Huygens and Saturn

Annulo cingitur, tenui, plano, nusquam cohærente, ad eclipticam inclinato

('It is surrounded by a thin flat ring, touching it nowhere, and inclined to the ecliptic')
Systema Saturnium, 1659

When Christiaan Huygens turned his attention to the planet Saturn, in 1655, he addressed himself to a celebrated problem in astronomy. When Galileo first observed Saturn, in 1610, he saw a central disc flanked by two smaller ones. And although some of his contemporaries saw the planet more as 'an elongated star in the shape of an olive', it was on the authority of Galileo that a 'satellite model' (below) of the planet's appearance predominated for a surprisingly long time, even when the 'lateral bodies' expanded into what became known as *ansae* or 'handles'.

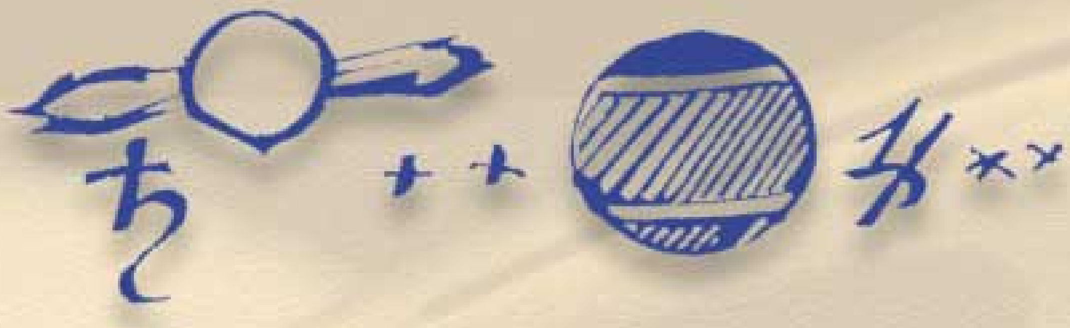
The 'solitary appearance' (i.e. when the ring was edge-on, and therefore invisible) of 1613 was observed by Galileo, who predicted the return of the lateral bodies on the basis of the satellite model. By 1630 there were a handful of published illustrations of Saturn of varying qualities, but because there were few observers with good telescopes there was no concerted attack on this problem; for the time being, Saturn's appearance was an anomaly and a wonder. Although the solitary appearance of 1626 was noted, it was not until the next solitary appearance, that of 1642, that the problem of Saturn became one of the central problems of telescopic astronomy. Over the next decade, the tension between the satellite model and the handled appearance increased, as an increasing number of illustrations appeared in books and circulated in correspondence.



Galileo's 'satellite model' to explain Saturn's appearances.

From Christoph Scheiner's 'Tractatus de Tubo Optico'. Munich, Bayrische Staatsbibliothek, MSS Clm. 12425, p. 65

Huygens and his brother Constantijn Jr. began making their own telescopes in late 1654, and although recent research shows that their instruments were certainly no better than the best efforts of Italian



Saturn and Jupiter as observed by Huygens in March 1655, the earliest surviving drawings of an observation by Huygens.

Oeuvres Complètes, vol. 1, p. 322.

telescope makers, luck was on their side. As the lateral bodies were slowly shrinking and observers all over Europe were anticipating the solitary appearance of that year, Huygens was the one to notice, on 25 March 1655, a little star on the extension of the *ansae* that proved to be a satellite. Although it appears that at least Johannes Hevelius in Poland, and perhaps Christopher Wren and Paul Neile in England, had observed this satellite before Huygens, they had taken it to be a fixed star. Huygens circulated an anagram about his discovery, as Galileo had done in 1610 when he first observed Saturn's anomalous appearance. In March 1656 Huygens published *De Saturni Luna Observatio Nova*, or 'A New Observation of a Moon of Saturn,' in which he gave a full account of his discovery and the satellite's period. He ended this publication with yet another anagram, which, he promised, contained the solution to the problem of the planet's appearance:

a a a a a a a c c c c c d e e e e e g h i i i i i i i l l l l m m n n n n n n n n n o o o o p p q r r s t t t t t u u u u u

In this way, he notified the scientific community that he had made an important discovery but protected himself from false priority claims. Three years later Huygens published the solution to the anagram in his *Systema Saturnium* (see the motto at the top).

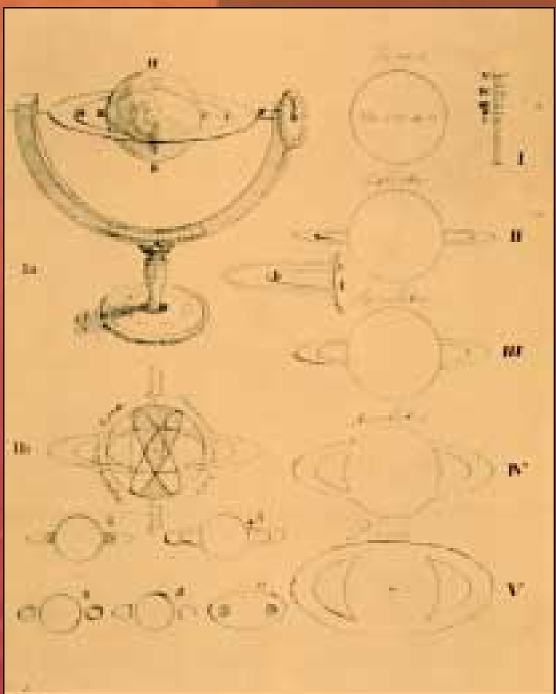
Because of his (later) achievements in optics, astronomers and historians have naturally assumed – and Huygens himself gave them cause to think – that he had made superior telescopes that revealed the true shape of the planet and its appendages. The facts, however, are different. Firstly, Huygens made the discovery when he still only had his first-generation telescopes available, telescopes that were of about the same quality as those of his competitors. Secondly, when he came up with the ring solution, in the winter of 1655-56, the planet was in conjunction with the Sun, and when it reappeared in January 1656 the *ansae* had disappeared. The key to his discovery was an observation in March 1655 that showed the lateral bodies not as globes but rather straight extensions from the planet. The fact that the *ansae* kept their length was an important clue.

Huygens was a follower of the vortex cosmology of Descartes, in which the solar system was seen as a vortex of matter revolving around the Sun. (This cosmology became more and more problematical for Huygens during his life but he never entirely abandoned it.) In this, like the Earth and its Moon, Saturn and its moon were part of a sub-vortex in the larger vortex of the solar system. Since the period of Saturn's moon was 16 days (the name *Titan* came into use only in the 19^{th} century), all matter between this moon and the central globe of Saturn rotated with a period of less than 16 days, in analogy to our Moon's period and the Earth's 24-hour rotation on its axis. But this meant that whatever the real shape of the *ansae* was, it had to be symmetrical about the axis perpendicular to the orbit of the satellite, and it kept its length. Moreover, it disappeared every fifteen years or so. Only a ring could satisfy these conditions.

Huygens's announcement of the new satellite, and the anagram hiding his

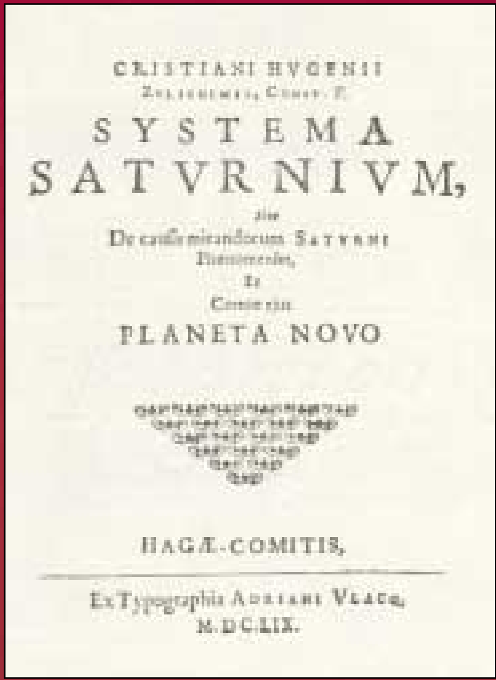
solution to the planet's strange appearances, spurred other observers on to publish their own ideas about the planet. In Gdansk, Johannes Hevelius had already been at work on his book, *De Nativa Saturni Facie* ('On the Real Appearance of Saturn', 1656), when he received a copy of Huygens's *De Saturni Luna*. Hevelius's theory, based on a mistaken observation that Saturn's central body was ovoid, was that this body and its attached handles rotated on an axis once every 30 years, but it gave no satisfactory explanation of how the *ansae* shrunk and disappeared periodically. That same year, Giovanni Battista Odierna in Sicily published *Protei Caelestis Vertigines seu Saturni Systema* ('The Changes of the Celestial Proteus, or System of Saturn'), in which he posited that the planet was one ovoid body with two large cavities or dark spots – a theory that suffered from the same shortcomings as Hevelius's theory. Others expressed less well-developed ideas about Saturn's appearances in response to Huygens's challenge. But by far the most interesting theory is an unpublished tract by Christopher Wren, written in 1658. Wren supposed that the handles were an elliptical 'corona' attached to the central body, and that the entire formation librated or rotated about an axis coinciding with the direction of the *ansae*, which thus kept their length (left).

Wren explained the periodic disappearance of this corona by supposing it to be so thin that 'it may be taken as a mere surface'. The corona could therefore not be a solid structure, but rather had to consist of vaporous emanations coming only from the equatorial zone of Saturn.



Christopher Wren's theory of Saturn's appearances in De Corpore Saturni (1658).

Oeuvres Complètes, vol. 3, p. 424-25.

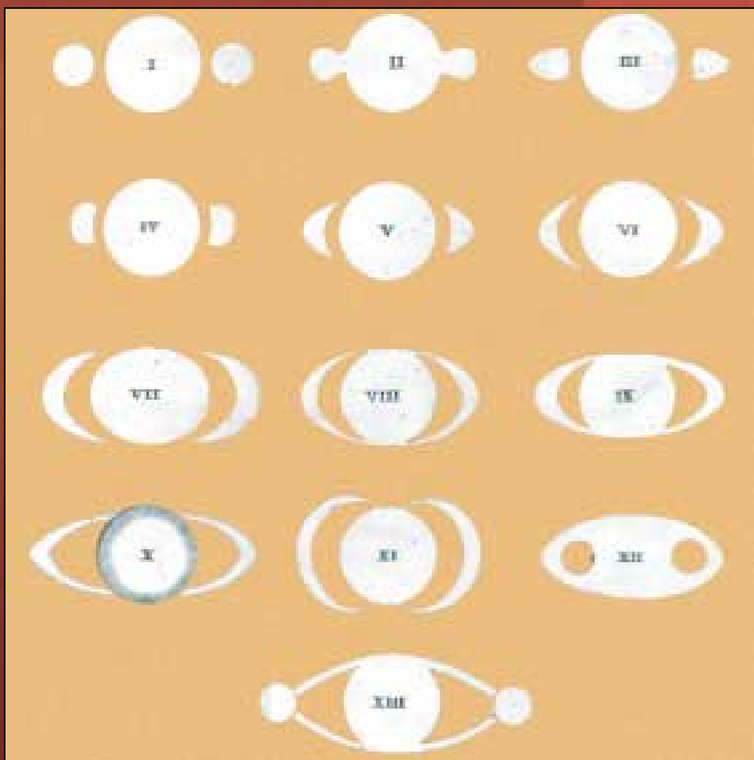


CRISTIANI HVGENII
Zulichemii, Const. F.
SYSTEMA
SATVRNIVM,
sive
De causis mirandorum Saturni
Phaenomenon,
Et
Comite ejus
PLANETA NOVO

HAGÆ-COMITIS,
Ex Typographia Adriani Vlacq,
M.DC.LIX.

Title page of Systema Saturnium (1659)

When his *Systema Saturnium* finally appeared in 1659, it was a complete review of observations since Galileo, a catalogue of his observations of the new satellite, and an explanation of his theory. Huygens classified all the observations published since Galileo in one plate, and he now had to explain away the ones that could not be accounted for by his hypothesis.



Composite of previous observations in Systema Saturnium.
Oeuvres Complètes, vol. 15, p. end piece.

Huygens did not see Wren's tract until several years later, but he did read the efforts of Hevelius and Odierna, as well as the more speculative ideas of some of his correspondents. And while he was continuing his observations and amassing information for a complete treatise on Saturn, he also perfected a pendulum clock and published his *Horologium* (1657).

Observation of February 1658.
Oeuvres Complètes, vol. 15, p. 39.

Observation of 12 February 1659, as shown in Systema Saturnium.
Oeuvres Complètes, vol. 15, p. 252.

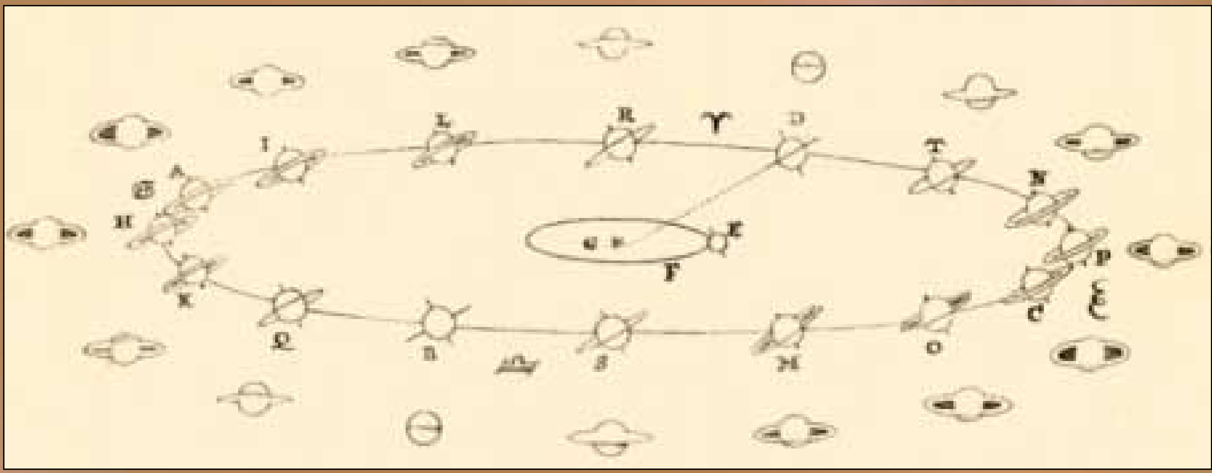


Diagram explaining how the ring theory accounts for Saturn's changing appearances, Systema Saturnium.

Oeuvres Complètes, vol. 15, p. 309.

He argued that since he had discovered the satellite, which others had not been able to see, his telescopes were better than anyone else's, and therefore he was justified in rejecting disparate observations as being due to inferior instruments. His ring theory he explained by means of a brilliant diagram.

But breathtaking as his solution might be, it had several flaws. First, Huygens insisted that the ring was a solid structure of appreciable thickness, adducing as evidence the shadow of the ring on the body, which he claimed was the light-absorbing edge of the ring. Second, in analogy to the Earth's axis of rotation, Huygens argued that the inclination of Saturn's axis of rotation to its orbital plane was 23.5°. But this inclination predicted a length-to-width ratio of the *ansae* at the ring's most open position that was significantly greater than what had been observed by previous observers. These were scientific problems that occupied Huygens and his contemporaries for some time to come.

The ring hypothesis initially had a mixed reception. Upon reading *Systema Saturnium*, Christopher Wren adopted the theory immediately, writing later about his own theory: '… I confesse I was so fond of the neatnesse of it, & the Naturall Simplicity of the contrivance agreeing soe well with the physical causes of the heavenly bodies, that I loved the invention beyond my own [,]' although he thought his own theory 'equipollent'. Hevelius, on the other hand, felt his reputation as a telescope maker and observer slighted and vented his rage in private letters to third parties, while he argued about the relative merits of their respective theories with Huygens in more measured tones. But while in Paris Huygens's pendulum clock and ring-theory were applauded by the learned community, in Rome an important challenge was launched.

In *Systema Saturnium,* Huygens had criticised the presentation of an observation published in 1649 by Eustachio Divini, generally considered the best telescope-maker in Europe, for incorrect shading. Moreover, Huygens had presented himself as an unapologetic follower of Copernicus, a position not acceptable in Rome. In 1660, therefore, Divini and the Jesuit scientist Honoré Fabri published *Brevis Annotatio in Systema Saturnium*, in which Divini attacked Huygens's observations and challenged him to a telescope duel, while Fabri rejected Huygens's Copernicanism and put forward a satellite hypothesis in which two bright and two dark satellites moved in orbits behind the planet, thus accounting for the various appearances. Now, Huygens had dedicated *Systema Saturnium* to Prince Leopold dei Medici, co-founder of the *Accademia del Cimento* in Florence, and Divini and Fabri did the same with their *Brevis Annotatio*. The Prince was thus cast in the role of referee, having to judge between a brilliant theory published by a Copernican and heretic on the one hand, and an inferior ad-hoc hypothesis by a protector of the Faith on the other. True to the motto of the Academy,

'*provando e riprovando*' (to experiment and to experiment again), its members had models of the two hypotheses built (Huygens's one is shown) and had them observed from a distance by various people with the naked eye and with telescopes of different magnifications.

Huygens's theory won handsomely, but not without some criticism: the academicians noted in their report that no matter how thin they made the ring, it never became entirely invisible.

Although the battle of the books continued for some time – Huygens writing a response, *Brevis Assertio* (1660), and Divini and Fabri publishing *Pro sua Annotatione* (1661) – the main argument of the ring-theory was quickly accepted. The details, however, remained a source of some controversy. As more detailed observations of the mutual shadow effects between ring and planet were published, the idea that the ring was a solid structure of appreciable thickness slowly became sidelined, although Huygens himself still clung to it in his posthumously published *Cosmotheoros* (1698), where he estimated the thickness at 600 German miles, or almost 4000 km.

The inclination of the ring to the ecliptic and Saturn's orbital plane was a question that occupied astronomers for a number of years. In 1668 Huygens observed the ring with Jean Picard in Paris and adjusted the inclination of the ring to the ecliptic and Saturn's orbital plane upward to 'about 31°.

In the meantime the 'System of Saturn' was undergoing changes. In 1664 Giuseppe Campani, the new telescope maker in Rome, published remarkable observations of Saturn's ring that showed the outside part less bright than the inside part. This observation was further elaborated by Giovanni Domenico Cassini who, working with Campani instruments, discovered the division (since named after him) between these two parts of the ring. It was Cassini, too, who discovered two new satellites of the planet in 1671-72, and then two more in 1684, all during edgewise positions of the ring.

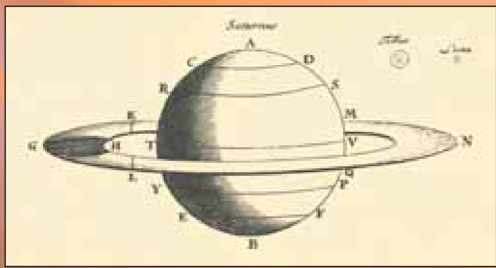


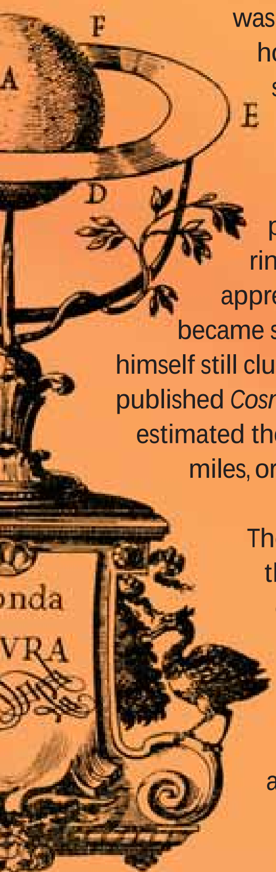
Diagram of Saturn and its ring, showing the ring's appreciable thickness as well as the relative sizes of Saturn, the Earth (Tellus), and the Moon (Luna), in Cosmotheoros (1698).

Oeuvres Complètes, vol. 21, p. 788.

At the end of the 17th century, Saturn with its rings plus its five moons was, along with the satellites of Jupiter, sunspots, and the phases of Venus, a showcase example of the new Copernican cosmology: new, spectacular, and entirely unanticipated by the sages of Antiquity. What remained was the question of the exact nature of the rings. Were they solid structures as Huygens maintained, or were they swarms of many small satellites as others were beginning to think?

The solution to that question had to wait until the 19th century, when both observations and mathematical models confirmed that the ring system consists of a huge number of small bodies orbiting the planet.

Albert van Helden, University of Utrecht



Test model of Saturn and its ring built by the Accademia del Cimento in 1660.

Oeuvres Complètes, vol. 3, pp. 154-55.

The mission

Saturn and its moons rediscovered through space exploration

Ask any astronomer at random which planet is the most beautiful, and ten to one the answer will be 'Saturn' – the planet with the rings. Because even with a small telescope, it is a spectacular sight: a golden ball encircled by a beautiful set of rings.

Telescope photo of Saturn - NASA

The beauty of this sight is in contrast to the nature of the Roman god the planet is named after. Saturn (like his Greek counterpart Kronos) was the father of Jupiter and was one of the old generation of gods, the Titans. His slow motion in the heavens made him the personification of the god of time. Like many gods, Saturn married his sister, Rhea. Saturn's malevolent nature is apparent from the fact that he devoured his children. For how else could he prevent the prediction that he would be dethroned by a son from coming true? Miraculously, Jupiter escaped and later became the chief god. Saturn was relegated to a lower level.

Telescopes and theories

Coincidentally, in terms of dimensions and mass, the planet Saturn is also the second planet in the solar system after Jupiter. This knowledge is the result of scientific research into the planet, which actually began in 1610 when Galileo Galilei was the first person to look at this heavenly body through a telescope. Galileo believed that he could see two large moons on opposite sides of the planet, in a similar fashion to the four moons that he had earlier discovered around Jupiter. But somewhere, something wasn't quite right. The moons didn't change position, and were, at a third of the size of Saturn, actually very large indeed. 'It looks as though the outer planet is a triplet', declared Galileo, in the form of an anagram. But two years later, Galileo looked again at Saturn. The moons had disappeared. Had Saturn really devoured his 'children'?

The Dutch scientist Christiaan Huygens solved the riddle in 1655. He was able to grind good quality lenses himself and he used them to construct a telescope that he claimed was superior to Galileo's. In March of that year, he discovered a real moon near Saturn, later called Titan. About Galileo's 'moons' he wrote – once again in an anagram – that the planet is surrounded by a thin flat ring, touching it nowhere, and inclined to the ecliptic.

Huygens realised that as a result of the movements of the Earth and Saturn, we sometimes look precisely at the edge of the rings: they then appear to have disappeared. At other times, we look at them at an angle from above or below and then see the ringed planet in its full glory.

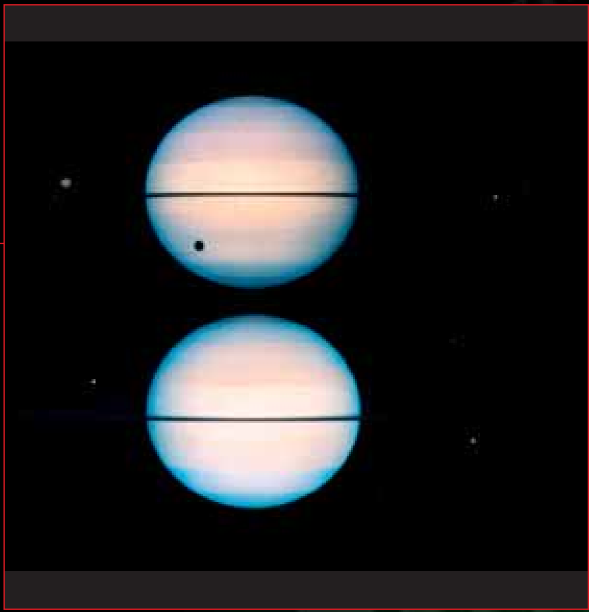
In 1675, Giovanni Cassini was the first to observe that the ring was really a system of rings. By now famous for his discovery of the Great Red Spot on Jupiter, he observed that 'the ring' consisted of an outer ring and an inner ring, separated by a darker band. This is now known as the 'Cassini division'. He also discovered four new moons.

Thanks to ever-better telescopes, even more moons were discovered later; by around the beginning of the twentieth century, nine Saturn moons were known.

In 1857 the famous English physicist James Clerk Maxwell proved that Saturn's rings could not be solid or liquid. They had to consist of myriad small particles that were orbiting Saturn like individual moons. Others tried to discover the nature of the Saturn moons. It was the Dutch-born astronomer Gerard Kuiper who discovered in 1944 that the largest moon, Titan, has its own atmosphere. A short time later, observations revealed that it had to be a dense atmosphere in which many clouds were drifting around. This made Titan unique in the solar system. A (relatively thin) atmosphere has only been found on two other large moons, Jupiter's Io and Neptune's Triton.

Pioneer 11

In fact, when the first space missions to this strange, faraway world started, in the middle of the seventies, our knowledge about the Saturn system was extremely limited. It was known that Saturn itself was a large ball of gas consisting mainly of hydrogen and helium. Thanks to its rapid rotation, taking just under 11 hours, the ball is significantly flattened. Only occasionally could temporary light and dark spots be seen in the vague structure of bands of cloud running parallel to the equator. Virtually nothing was known about the moons, except for their orbits, their orbital periods and rough estimates of their dimensions. The encounter of the American spacecraft Pioneer 11 in 1979, after its successful flyby of Jupiter, provided sensational discoveries. Cassini's 'division' turned out not to be empty but to consist of myriad small, thin dust rings. Outside the then outermost known ring, yet another ring was found.



[top] Hubble Space Telescope snapshot of Saturn with its rings barely visible. Saturn's largest moon, Titan, is casting a shadow on Saturn. Titan's atmosphere is a dark brown haze. The other moons appear white because of their bright, icy surfaces. Four moons - from left to right, Mimas, Tethys, Janus and Enceladus - are clustered around the edge of Saturn's rings on the right. Two other moons appear in front of the ring plane. Prometheus is on the right edge; Pandora on the left. the rings also are casting a shadow on Saturn because the Sun was above the ring plane.

[bottom] The planet with its rings slightly tilted. The moon Dione is on the lower right. The moon on Saturn's upper left is Tethys.

Erich Karkoschka (University of Arizona Lunar & Planetary Lab) and NASA

Saturn fact sheet

Type of planet:	Gas giant
Average distance from the Sun:	9.6 AU*
Orbit period round the Sun:	29 years and 5.5 months
Mass:	95.2 Earth masses
Diameter at the equator:	120,536 km (about 10 times the size of Earth)
Rotation period:	10 hours and 39 minutes
Average density:	0.7 g/cm^3**
Composition:	Mainly hydrogen and helium
Temperature near cloud surface:	-138 °C
Width of the ring system:	From about 200,000 to 67,000 km above the surface
Average thickness of ring system:	30 to less than 500 metres
Number of known moons:	About 40***

* *An Astronomical Unit (AU) is the average distance from Earth to the Sun, about 150 million kilometres*
** *Saturn could float on water! In comparison, the average density of the Earth is 5.4 g/cm^3*
*** *Situation on 15 December 2003*

The first mission to Saturn was Pioneer 11 in 1979. Its images were primitive, but even so, clearly superior to the best views from Earth, and they provided a lot of useful advance information for planning the Voyager missions. The rings are dark in this image because it is actually viewing the shaded side of the rings.

NASA

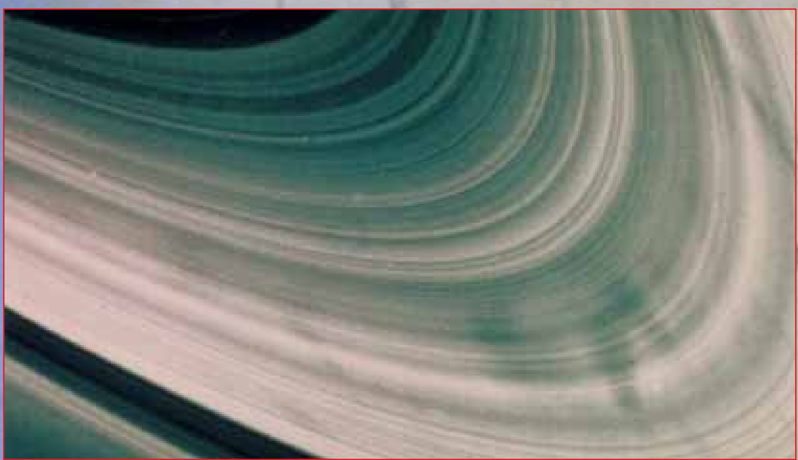
The probe also discovered that Saturn has a strong magnetic field, a thousand times more powerful than that of our own planet. This meant that Saturn, like Jupiter, had to have a core of liquid hydrogen and helium compressed so much that the mixture has the properties of a metal. Strangely enough, the axis of this magnetic field nearly coincides with the axis of rotation, and that occurs nowhere else in the solar system. A magnetic field in which the axis is tilted with respect to the axis of rotation, as on Earth, is much easier to explain.

Finally, Pioneer 11 discovered that Saturn radiates more heat than it receives from the Sun. Originally people thought that this, as in the case of Jupiter, was due to the slow shrinking of the planet. However, from detailed calculations it emerged that Saturn cannot shrink any further and had already reached its current size two billion years ago. Pioneer 11 answered old questions, but also left scientists on Earth with more new questions.

Voyagers 1 and 2

Shortly after the flyby of Pioneer 11, Saturn received a lightning visit from the American Voyagers 1 and 2 (1980 and 1981). When Voyager 1, as the first, approached the planet, Saturn's cloud cover looked rather boring at first sight. There were hardly any spots to be seen, unlike on Jupiter. It looked as though there were clouds of ammonia particles floating in the upper layers of the atmosphere, forming a sort of mist and hiding all sorts of eddies in the deep atmosphere. Fortunately the craft also had ultraviolet cameras on board. With the aid of the photos they took, the weather systems on Saturn could indeed be seen. To everyone's surprise, the clouds above the equator appeared to spin with the highest cloud velocity ever measured in the solar system – up to 1800 kilometres an hour! Cloud banks form in the direction of the poles, just as they do on Jupiter.

Both Voyagers succeeded in photographing all the moons known at that time, and in discovering some new moons. The moons consist mainly of ice and rock, and are strewn with craters that are sometimes so big that they cover a large proportion of the moon's surface. In other cases, cosmic



'Spokes' visible in the rings - NASA

Saturn's cloud structure - NASA

Titan Fact Sheet

Discovered:	1655
Distance from the centre of Saturn:	1 221 870 km
Orbit Period:	Approx. 16 days
Diameter:	5150 km

impacts – the cause of the craters – have thrown up dark material (ice?) from the interior of the moons.

The Voyagers also provided an intriguing view of the 'operation' of the rings. A subtle balance between the gravity of the planet and of moons that are rotating close by or in the rings ensures that the dust spins around Saturn in small bands – often no thicker than a few tens of metres. One of the outer rings, the F-ring, appeared not to obey the laws of gravity. It exhibited strange twists and kinks.

It later turned out that this is due to the interaction of two 'shepherd moons' that periodically disturb the orbit of the dust. On other pictures, 'spokes' could be seen in the rings. These appeared to be related to fine dust particles compressed into bundles by the planet's magnetic field.

Titan

Almost everything we currently know about Saturn's largest moon, Titan, comes from information obtained by the two Voyagers. The dimensions appear to be slightly smaller than Jupiter's moon Ganymede, but larger than the planet Mercury; the orbit period is approximately 16 days. At the surface, the pressure from the dense atmosphere is one and a half Earth atmospheres. This atmosphere consists mainly of nitrogen, just like Earth. But what makes it interesting is the presence of a few percent of methane.

Despite the similarities, Titan is a totally different world from our own planet because of the extremely low temperature of about -180°C. All the water has been frozen into ice. Nevertheless, lakes and oceans filled with liquid can still exist on Titan. It seems as though the pressure and temperature are sufficient to liquefy methane (natural gas).

F-ring. Two braided separate orbit rings - NASA

The rings are extremely thin

NASA

Whether or not this is really the case can't be seen directly. The atmosphere of Titan is completely filled with orange-coloured clouds and mist such that the surface can't be seen. With the aid of radar measurements from the Earth, indications have however been found that there may indeed be lakes on Titan. The orange colour is due to organic haze, caused by sunlight breaking down the methane in the atmosphere. All in all, this makes Titan an intriguing place that exhibits many similarities to conditions that may well once have prevailed on Earth. That is why ESA developed the Huygens probe!

Scientific instruments on the Huygens probe

Instrument	Purpose
Gas chromatograph and mass spectrometer	Measuring the chemical composition of the atmosphere
Aerosol collector and pyrolyser	Measuring the chemical composition of aerosols (dust)
Descent imager (panoramic camera) and spectral radiometer	Measuring the thermal properties of the atmosphere Distribution of aerosols (dust) and cloud droplets Determining the nature of the surface Measuring the composition of the atmosphere
Huygens atmosphere structure instrument	Measuring the electrical properties of the atmosphere Measuring the temperature and density profile of the atmosphere Research into lightning on Titan
Doppler wind experiment	Measuring the vertical wind profile Measuring horizontal winds
Surface science package	Measuring the (chemical) properties and composition of the surface

Titan's atmosphere - NASA

Cassini/Huygens mission

NASA's Cassini spacecraft, with ESA's Huygens probe hitching a lift on board, left Earth on 15 October 1997.

The 5.6-tonne colossus was too heavy to be launched straight to Saturn. The final destination will be reached 6.7 years later after a complicated journey past Venus, the Earth and Jupiter, during which the speed of the craft has been steadily increased by planetary swing-bys (also known as gravity assists). Cassini will go into orbit around Saturn in July 2004, and will release the Huygens probe on the third orbit. Cassini's mission will last for 75 orbits of Saturn, over a period of four years. The planet itself, its magnetic field and the cloud structures, as well as the rings and the moons, will be the subject of extensive measurements. The scientific experiments are primarily mounted on two platforms: one takes care of the photography, and the other is equipped for measuring magnetic and electrical fields and for detecting particles. In addition, there are several instruments that are body-mounted.

The mission of the Huygens probe is to investigate the unique atmosphere of Titan. It will be released on 25 December 2004 and will then carry on alone towards Titan for 22 days. No contact with the craft will be possible during this journey. On 14 January 2005, the probe will dive into Titan's atmosphere. A timer will ensure that Huygens wakes up' just before it reaches the atmosphere. From that moment, batteries will provide the electrical energy

Artist's impression of the Cassini/Huygens spacecraft - NASA

Artist's impression of Huygens leaving Cassini and descending towards Titan - ESA

for the instruments and the radio transmitter. During the descent, and until after the landing, the probe will transmit data to Cassini. This will relay the information on to the Earth.

The 2.75-metre heat shield will ensure that the probe is slowed down by atmospheric friction from 6 km/s to 400 m/s within two minutes. Somewhere between 180 and 150 kilometres from the surface, a small parachute will unfold and pull the 8.3-metre main parachute from its housing. After a quarter of an hour, this parachute will be released and replaced by a smaller three-metre version, with which the probe will descend at a constant speed of 5 m/s. A special lamp will be turned on for the final stage of the descent to illuminate the twilight landscape, in order to allow accurate measurement of the colour of the surface. The colour will give clues about the surface composition.

The total descent will take 2 to 2.5 hours, during which time Huygens will collect a wide variety of data about the atmosphere of Titan (see table on previous page). This is in fact the main goal of the mission.

It is hoped that the probe will survive the landing and continue to transmit data for some minutes after the landing. Given that the bottom part of the descent module is more or less watertight, it may even float for a few minutes if it lands in a sea of methane! However, it is largely unknown what sort of surface Huygens will face, and so there is no guarantee that it will survive. But even if the probe doesn't survive on the surface, its rich harvest of atmospheric data will still be considered a tremendous success.

In many respects, a journey to Saturn is a journey to the origins of the solar system. The moon Titan is similar to the primeval Earth in its frozen state. Perhaps the building blocks of life have been preserved there and the Huygens mission will provide insight into the way in which life began on Earth. The system of rings and moons is also a sort of model of the archetypal solar system, when fragments of rock and ice collided with each other and melted on a grand scale.

In short, Saturn and its environment is an intriguing place where time appears to have stood still for billions of years. A fascinating thought for this former god of time!

Niek de Kort,
Astronomer and space science publicist

Saturn photographed by Cassini on 9 November 2003, when it was about 111 million kilometres from the planet. The view offered by this photo is very different from the one from Earth: it shows Saturn's dark side!

NASA

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