Discovering Titan

CHAPTER 1

The landscape seems alien. The few clouds that burned a garish red as the Sun set have flitted away and the sky is clear. Strange and unfamiliar life-forms, deprived of water, struggle to survive in the harsh conditions. This is no extraterrestrial scene though, but Tucson, Arizona. Arizona's commendably dark and clear skies are a magnetic attraction for astronomers.

High above, Jupiter gleams brilliantly. Through even a small telescope, an entourage of four moons circling this giant planet and its cloud bands alternating light and dark are obvious. A short distance to the east there is another planet, not as bright as Jupiter. It's Saturn. Through the telescope it is an altogether different object, with its rings tilted tastefully – as though a jeweller had set it there. A little to one side of the rings is a dim, unprepossessing dot, looking a little reddish maybe. This dot is the focus of our attention – Saturn's moon, Titan, a world as intriguing as any in the solar system.

On the 15th of October 1997, another Titan roared into the sky. To be precise, it was a Titan IVB/Centaur launch vehicle. Just before 5 o'clock in the morning local time the appropriately named rocket blasted off from Cape Canaveral Air Force Station, Florida, bearing a 5.8-tonne spacecraft bound for Saturn and Titan. It was the start of a seven-year journey for the *Cassini–Huygens* mission and of a tantalising seven-year wait for the anxious scientists on the ground. *Cassini* was destined to enter orbit around Saturn on the 1st of July 2004. Seven months later, if all goes according to plan, the *Huygens* probe will detach itself, cruise towards Titan for about three weeks, then parachute down onto Titan's surface. Instruments on board the *Cassini* orbiter will gather data about Saturn and its moons, espe-

Figure 1.1. The launch of the *Cassini–Huygens* mission on the 15th of October 1997 at 4.43 a.m. EDT, from Cape Canaveral Air Station in Florida. The launch vehicle was a Titan IVB/Centaur. NASA image. (In colour as Plate 1.)

cially Titan, over a four-year period. Then Titan will become the most distant world by far to have a human artefact land upon it. The enormous effort dedicated to achieving this feat is a testament to the growth in our fascination with Titan as world of unique significance in the quest to understand our own planet.

To see how Titan became the centre of such attention we must first turn the calendar back to the middle of the seventeenth century.

Galileo and the Saturn enigma

When Galileo Galilei turned a crude, low-powered telescope to the sky he opened a new era in astronomical discovery. News of the Dutch invention had spread through Europe like wildfire in the early part of 1609. Telescopes constructed from badly made spectacle lenses were being offered for sale at fabulous prices, even though the views through them were blurred. At the University of Padua, where he was professor, Galileo had set up a workshop for making scientific instruments and had acquired a deserved reputation for skilled craftsmanship. In the space of a few weeks, Galileo carefully ground lenses from the finest Venetian glass and built the best telescope in the world. It brought him instant international fame and was the first of many to be manufactured by his workshop.

Galileo began a survey of the heavens in 1609 using a telescope that gave him a magnification of 30 times. He was the first person to direct a telescope skywards and make a record of what he saw. Wherever he turned his gaze, new and amazing sights greeted him. A family of moons belonging to the planet Jupiter was one of the most significant. With a series of observations made between January and March 1610, Galileo demonstrated that four bright 'stars' near to Jupiter were not stars at all but moons orbiting around the planet. This discovery was not merely of scientific interest. It was political dynamite! It was a powerful piece of evidence in favour of a Sun-centred planetary system, which contradicted the religious dogma of the time. Nicolas Copernicus's heliocentric theory had been in circulation since 1543 but had not been generally accepted. Its lack of appeal was partly because it undermined the authority of the church and partly because it did not square with actual observations of the planets and the philosophical reasoning prevailing at the time. One of the arguments against Copernicus claimed that the Moon would be left behind if Earth moved. Newton's theory of gravity would not be published until 1684, so the concept of an attractive force to keep moons tied to their planets was some years off. Now here was Jupiter, indisputably going around the Sun, with moons that did not get left behind.

Galileo recorded his first observations of Saturn in July 1610. Having found four moons in orbit around Jupiter, he must surely have been on the lookout for satellites of Saturn. But either he failed to detect Titan, or he did not recognise it as a moon of Saturn. His telescopes may not have been good enough to discern the dim reddish

Figure 1.2. Three sketches of Saturn made by Galileo in 1612. He thought that the appendages he could see on either side of the planet might be stationary moons of some kind and never realised that Saturn was surrounded by a ring system.

speck, or he may have been led into a blind alley by the puzzling appearance of the ringed Saturn. Galileo thought that the appendages he detected on either side of Saturn were moons of some kind, though they were clearly different in character from Jupiter's moons. Galileo remained baffled throughout his life. He never realised that his apparently triple Saturn was in reality a planet surrounded by a set of rings. The privilege of discovering Saturn's largest moon was to fall to a gifted young Dutchman who would ultimately earn a reputation as one of the greatest scientists of the seventeenth century. His find was no quirk of chance but the reward for a major advance in telescope making.

Luna Saturni

Christiaan Huygens discovered the moon we now know as Titan on the 25th of March 1655. He announced the find publicly a year later, in a pamphlet called *De Saturni luna observatio nova*. The telescope he used was cumbersome by modern standards but in 1655 it was a technical breakthrough. In collaboration with his brother Constantyn, Christiaan Huygens developed a machine for grinding and polishing lenses that made use of gears. Until the Huygens' invention, lenses were all ground and polished by hand. The process was laborious and it had proved very difficult to make the gently curved long-focus lenses that gave the least distortion in a telescope. Using their new machine, the Huygens brothers experienced little difficulty in producing long-focus lenses. The first to be incorporated as the main lens of a telescope had a focal length of about 3.6 m. This meant the telescope had to be almost 4 m long. A closed tube was out of the question and the main lens was mounted high up on a pole (Figure 1.4). A lens giving a magnification of 50 times served as an eyepiece. When Huygens turned his lanky telescope on Saturn, he noted a small point of light close enough to the planet to raise suspicions of an association

Figure 1.3. Christiaan Huygens (1629–1695), who discovered Titan in 1655.

between the two. Observing on subsequent nights, he saw the speck of light complete a circuit around Saturn over a period of 16 days. Innovation had paid off.

Englishman Christopher Wren, better known as an architect than for his early research in astronomy, and the German Johannes Hevelius both testified later that they had observed Titan through their telescopes before Huygens did but had never suspected it was anything other than a background star. The history of astronomy is full of such sorry tales of 'pre-discovery' observations by individuals who have lived to regret their lack of perception, or died without ever knowing what they missed. Indeed, Galileo never knew he had seen the planet Neptune.

Huygens had a rare combination of talents. Like Galileo, he was a practical inventor and skilled craftsman as well as being a brilliant mathematician and prolific writer. One of his greatest achievements was developing the wave theory of light but, in the late 1650s, between observations of Saturn, he was busy inventing and perfecting the pendulum clock. All the same, he found time to write *Systema Saturnium*, which was published in 1659. Saturn's mysterious appendages had remained unexplained since Galileo first reported them in 1610.

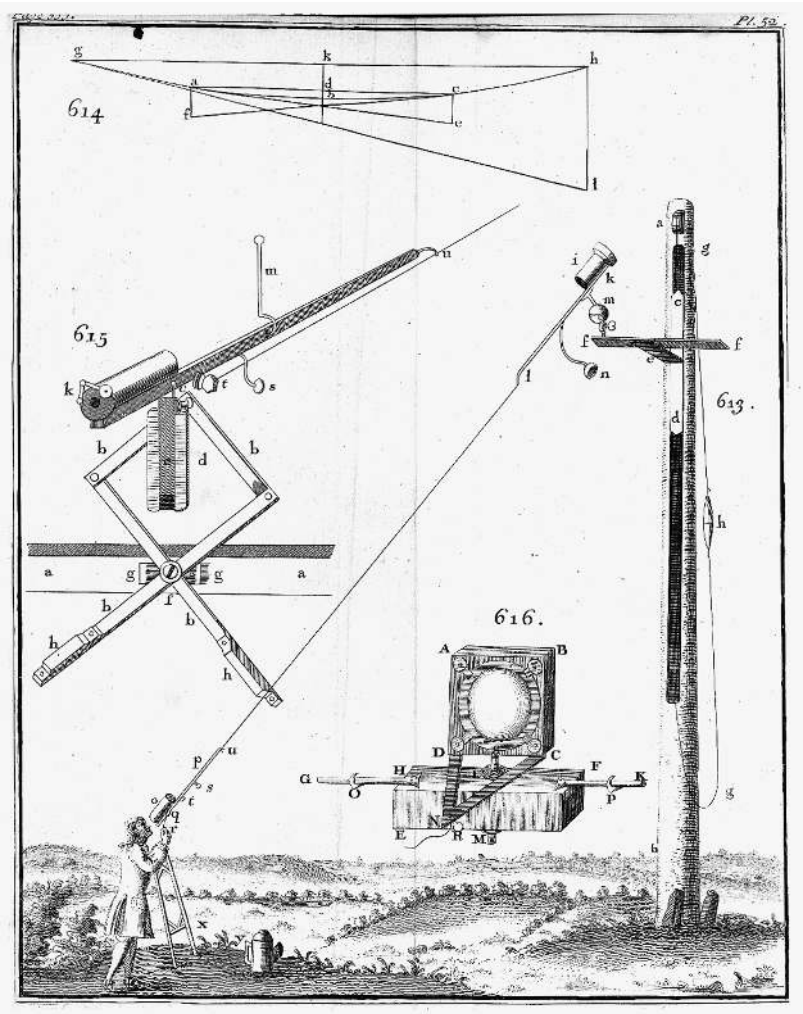

Figure 1.4. The 'aerial' telescope that Huygens was using when he discovered Titan, as illustrated in a treatise of 1738, *Compleat System of Optics* by R. Smith. Photograph courtesy of the Royal Astronomical Society.

Struggling with telescopes that were not up to the job, the handful of observers who tried simply could not make sense of what they were seeing. With the advantage of the superior telescopes he made for himself, and a brilliant mind, Huygens resolved the mystery once and for all. A thin flat ring around Saturn's equator could explain every feature of the telescopic observations recorded in the previous 39 years. The discovery of Titan orbiting Saturn in line with the 'appendages', Huygens said, was the key that led him to his correct

conclusion. It was to be 198 years before another great physicist, James Clerk Maxwell, proved that the rings must themselves consist of countless miniature moonlets.

To Huygens, the world he discovered was both faceless and nameless. His seventeenth century telescopes were not remotely capable of seeing Titan as a disk and the idea of giving moons individual names didn't catch on until the middle of the nineteenth century. Huygens referred to the moving point of light simply as Luna Saturni – Latin for 'Saturn's moon'.

Over the next 30 years, the tally of moons was raised to Jupiter 4, Saturn 5. But for a long time that was it. No more moons were discovered anywhere in the solar system until 1787 and the question of names never arose. For over 100 years, the four moons of Jupiter and the five moons of Saturn were designated by Roman numerals, in order of distance from their parent planet. The system was practical enough, if unimaginative. Then in 1787, William Herschel spotted the satellites of Uranus we now call Oberon and Titania. Two years later he followed them up with two more moons of Saturn. Inconveniently, they were nearer to Saturn then the other five. What was to be done? Numbering them VI and VII would play havoc with the ordering system but re-numbering all the moons would lead to worse confusion. Not surprisingly, confusion reigned.

William Herschel's son John came up with the solution. Give moons names. Then whatever numbering system is finally adopted, at least each world is individually identified. The discovery in 1848 of Saturn's eighth moon, also out of keeping with the original order, clinched the matter. The astronomical world gratefully accepted John Herschel's names. Drawing on Greek mythology for names connected with the god Saturn – or Cronus as his equivalent deity was known in Greek – Herschel gave us Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Hyperion and Iapetus. In some ways, Titan was a strange choice. Unlike the others, it was not the name of an individual but the collective name for six of the male offspring of Uranus and Gaia. Cronus, Hyperion and Iapetus were Titans. Mimas and Enceladus were two of 24 giants who were also brothers to Cronus. The female deities Tethys, Dione and Rhea were his sisters.

Dark ages

Titan's existence was known and its period of revolution around Saturn roughly determined but that was virtually the state of

knowledge about Titan for more than 200 years. While increasingly powerful telescopes opened up unimagined vistas on the universe at large, the moons circling the planets of the solar system – Titan included – remained as diminutive points of light, stubbornly beyond reach. Astronomers largely turned their attention to other things, while research on moons was forced to endure long dark ages. Enlightenment would not really arrive until the space era.

Even building the list of saturnian moons proved to be a tedious process. Huygens discontinued his search after finding Titan in 1655. A quaint belief in numerology apparently led him to conclude that the inventory of the solar system must be complete. Unscientific reasoning of that kind by someone of such ability seems extraordinary from our perspective in the twenty-first century but this was an era when people ardently looked for divine harmony in the construction of the heavens. In the event, Huygens' subsequent lack of interest left the way clear for Giovanni Domenico Cassini.

Cassini came from Italy but in 1669 he was lured to Paris by King Louis XIV to direct the first observatory there. He became a French citizen in 1673 and was known afterwards as Jean-Dominique Cassini. With a relatively modest telescope he discovered Iapetus in 1671 and

Figure 1.5. Giovanni Domenico Cassini (1625–1712). He discovered the moons of Saturn now known as Iapetus, Rhea, Dione and Tethys, and the Cassini division in the ring system. After becoming a French citizen in 1673 he was known as Jean-Dominique Cassini.

Rhea in 1672. Using a more powerful instrument, he brought the total of known saturnian moons to five with his 1684 discovery of Dione and Tethys. Cassini was also the first to draw attention to the dark gap in Saturn's rings now universally known as the Cassini Division.

Next to add to the slowly growing catalogue of Saturn's satellites was William Herschel. Few celestial targets escaped the attention of this eagle-eyed musician-turned-astronomer from Hanover, who became internationally famous after discovering Uranus in 1781. In 1789, Saturn's rings appeared edge-on as viewed from Earth. In effect, they virtually disappear from view for several weeks. This made it easier for Herschel to detect for the first time two faint inner satellites that would be known as Mimas and Enceladus. But that was not all. Herschel made numerous observations of all seven of the moons he was aware of, computing the time each one took to make a revolution around Saturn. With further refinements from other observers, Titan's period of revolution was pretty well determined by the 1840s. The German astronomer Friedrich Wilhelm Bessell quoted 15 days 22 hours 41 minutes 24.86 seconds, only about half a second out from the modern accepted time.

In the nineteenth century, the study of how heavenly bodies move – the science of celestial mechanics – became highly sophisticated. Minute variations in the courses of the planets and their moons could be explained when the small gravitational tugs they each give the others were taken into account. John Couch Adams in England and Urbain J. J. Leverrier in France predicted that there was a planet beyond Uranus by assuming that its gravitational influence was responsible for pulling the errant Uranus off course. Not only that, they pinpointed where the unknown planet would be found. The discovery of Neptune in 1846, just as predicted, was a triumph for the mathematicians. In similar fashion, there were data to be gleaned about Titan's mass from the way it pulled its fellow moons around.

Saturn's eighth moon, Hyperion, proved to be the vital key in this ingenious exercise. Hyperion was discovered independently by William C. Bond at Harvard University and the noted English amateur, William Lassell, in September 1848. By an amazing coincidence, both became satisfied that they had found a new saturnian satellite on the night of the 19th. Hyperion turned out to be Titan's nearest neighbour in the saturnian family and it soon materialised that the pair interact in a remarkable way. To explain how, we should take a closer look at their orbits.

The orbits of all planets and moons are elliptical but some are a great deal more elliptical than others. Although Titan's orbit is close to being circular, Hyperion's is noticeably elongated. Saturn sits off centre, so Hyperion's distance constantly changes, swinging between 1.33 million km at one end of its orbit and 1.64 million km at the other. Titan meanwhile ranges between 1.11 and 1.26 million km from Saturn. The two orbits are not tilted to each other. Titan's is nested inside Hyperion's, like rings on a target.

Now imagine lining up Titan and Hyperion on the same side of Saturn. We put them where Hyperion is at its greatest distance from Saturn, so they are both on the long axis of Hyperion's orbit. The starting gun fires and the two take off like athletes racing around a track, except that this is an unfair competition. According to the laws of planetary motion, the more distant a moon lies from its planet the slower it's forced to go. Titan will lap Hyperion sooner or later. In fact, Titan catches Hyperion when it's made exactly four circuits, about 64 days later. What's particularly interesting is the fact that the pair are virtually back at the starting blocks, because Hyperion has done three laps in the same interval of time. Astronomers have a technical expression for this phenomenon. Hyperion and Titan are said to be in a 3:4 resonance.

Real life situations are rarely simple. In the case of Hyperion and Titan, the catch-up position isn't exactly where the two started on the long ('major') axis of Hyperion's orbit. But it's a welcome complexity for astronomers who would like to estimate Titan's mass. Titan's pull on Hyperion wants to bring the line-up back to the starting position. Over time, the interaction between Titan and Hyperion causes the Saturn–Titan–Hyperion line to swing from one side of Hyperion's major axis to the other, like a pendulum. The most it deviates is 36° and the time for a complete swing is 640 days. Crucially, the time-scale of this pendulum-like action in the line-up of the two moons is set by the mass of Titan. Several mathematicians worked on the motion of Hyperion in the 1880s, including the American George W. Hill. Hill determined that Titan's mass was 1/4714 that of Saturn. The 'modern' value is 1/4262, so Hill was about 20% off – not bad at all.

The incident of the Spanish eyes

There is no doubt that some individuals are gifted with exceptionally acute eyesight. Their problem is convincing everyone else – ordinary