Air and Space this Week

Item of the Week

THE CASSINI-HUYGENS MISSION TO SATUN AND TITAN

Originally appeared October 10, 2022

KEY WORDS: Saturn Titan Pioneer 11 Voyager 1 Voyager 2 Cassini Huygens

Saturn was flown by three spacecraft: Pioneer 11*, and* Voyagers 1 *and* 2*. Their instruments revealed a lot of details about Saturn, its amazing ring system, and its diverse moons. But a great step forward in our understanding of Saturn came later, with the* Cassini *orbiter and the probe it dropped onto Saturn's moon, Titan***.** **Cassini** ***launched twenty-five years ago this week, on October 15.***

SATURN

The Ancients were astute observers of the skies. They believed, with good cause, that the stars were "fixed" in their locations. But they noticed that seven other objects in the sky moved relative to the background stars, in ways that could be predicted. The Sun and Moon were special, but the other five looked like moving stars from which little could be deduced, apart from their brightness, color, and speed of movement.

Have you ever wondered why there are seven days in a week? The week reflects the importance of the seven objects in the sky that move, and in most cultures, those objects bear the names of deities. English is no exception. We have a Sun-day, a Mo(o)n-Day, and four that are named after gods in Norse mythology: Týr's Day, Woden's Day, Thor's Day, and Freyja's Day. The planets were named for Roman gods at Olympus: Mercury, Venus, Mars, and Jupiter. The names were lifted directly from the Greeks, with their characteristics but not their names intact: Hermes, Aphrodite, Ares, and Zeus. Saturn (Greek's Kronos) was a different case; the two gods were not alike. To the Romans, Saturnus was a minor harvest god; to the Greeks, Kronos was one of the Titans, the children of Uranus (The Sky) and Gaia (Mother Earth), who, with sister Titan Rhea, begat the Olympians.

Little was known of any of the planets until the invention of the telescope in 1608 CE. Galileo used his to find four moons circling Jupiter and spots on the Sun, but his telescope wasn't good enough to reveal the surface features of the others. But he did notice something was odd about the shape of Saturn …

GIOVANNI DOMENICO CASSINI

Jean-Dominique Cassini was born in Perinaldo (now in France) on June 8, 1625. At age 23, he took a position at an astronomical observatory in Panzano, near Bologna, where he trained under famed astronomers Riccioli and Grimaldi. Two years later, he became the principal chair of astronomy at the University of Bologna. There he enjoyed a string of professional accomplishments in both astronomy and engineering. He was not only the lead astronomer at U of B, he was also appointed by the city to serve as a hydraulic engineer, which led to a Papal appointment as inspector of fortifications for Bologna, and director of waterways for the Papal States. He was also responsible for the installation of a camera obscura in Bologna's San Petronio Basilica, with which he observed small changes in the apparent size of the Sun over the year, which supported Johannes Kepler's model of the Solar System's prediction of Earth having a slightly elliptical orbit. He also made determinations of the rotational period of Jupiter and Mars.

Cassini's successes in what would become Italy led to his being recruited to help set up an observatory in Paris. The Pope didn't want to let him go, but a generous grant from Louis XIV paved the way. He left Bologna on February 25, 1669. The Paris Observatory opened in 1671, with Cassini as its Director, a position he would hold until his death in 1712.

Cassini went to work with the new observatory immediately, and quickly discovered Iapetus, a moon of Saturn, which he would correctly deduce was darker on one side than the other. He would discover a total of four moons of Saturn: Iapetus (1671), Rhea (1672), Tethys (1684) and Dione (1684). He also discovered a division in Saturn's ring system that now bears his name (1675), and made other important astronomical observations, including deducing the nature of the Zodiacal Light. He also pioneered the technique of using simultaneous observations of Mars and using parallax to determine its distance, a version of which was attempted for Venus during the transit of 1769 and data collected by Captain Cook from Tahiti.

CHRISTIAAN HUYGENS

Christiaan Huygens, a Dutch scientist, was similarly multi-talented. He was born in The Hague on April 14, 1629. His father was a diplomat and advisor to the House of Orange, a friend to a wide range of European intellectuals. He was rigorously educated at home, first under his father's tutelage and then under a famed tutor. At 16, Christiaan enrolled at the Leiden University where he took an even-heavier academic workload, finishing his education in 1649.

Huygen's mathematical skills quickly began gathering attention. He tackled the mathematics of the catenary ("hanging chain" – not a trivial work!), and refined the mathematical understanding of the ellipse, ballistics, and the vibrating string. He also made advances in pre-Newtonian physics, including elastic collisions and the concept of system center of gravity.

Huygens really hit his professional stride in 1655, with the discovery of Saturn's large moon, Titan, which got him elected as a Fellow to the Royal Society of London. He also was the first person to accurately describe Saturn as having a ring that nowhere touched the planet. He was only 36 years old. His fame grew a year later with his invention of the pendulum clock.

Like Cassini, Huygens was recruited for a position at the Paris Observatory, in 1666. His time there was marred by politics and the Franco-Dutch War (1672-1678); the latter also got him cross-wise with the Royal Society.

Huygens met a young Gottfried Leibniz in 1672, who was working on a calculating machine. Huygens tutored Leibniz on analytical geometry, and corresponded with him extensively as Leibniz developed his version of calculus, independent of Newton.

EARLY FLY-BYS

Pioneers 10* and *11

NASA was riding a great wave of success in the latter half of the 1960s, achieving JFK's goal of landing a person on the Moon and returning them safely to the Earth.

But NASA was also interested in the broader exploration of the Solar System, too, sending primitive spacecraft to fly-by Venus (1962) and Mars (1964), and then progressively more-capable spacecraft in the ensuing years. Getting to Mars and Venus with Mariner-class spacecraft was relatively easy. Exploring the outer Solar System was more difficult, especially because sunlight there was not sufficient to power spacecraft past Mars with the prevailing state of solar cell technology. Radio-isotope Thermal Generators (RTGs) would be required, as would a more capable spacecraft bus!

Two spacecraft from the Pioneer series got the call. *Pioneer 10* would be sent to fly by Jupiter, the first time NASA tried to explore beyond Mars. Its twin, *Pioneer 11*, would be sent first to Jupiter, then use its gravity to slingshot on to Saturn.

Pioneer 10 was launched on March 3, 1972, before the Apollo program concluded. It carried a suite of 15 scientific instruments designed to study Jupiter and the interplanetary environment. It was the first spacecraft launched on a solar-escape trajectory, so it carried a Sagan-inspired plaque that depicted two humans and a digital code that indicated its point of origin – a "calling card" to the stars. *Pioneer 10* gave us our first up-close look at Jupiter, measured Jupiter's intense radiation belts and magnetic field, determined that Jupiter is largely liquid, and proved the concept behind the gravity slingshot. After flying by Jupiter, it continued to monitor the solar wind and cosmic rays until is scientific mission ended in March, 1997. NASA was able to keep in contact with *Pioneer 10* until February 25, 2003, decades beyond its design lifetime!

Pioneer 11 was launched on April 6, 1973. Its instrumentation was similar to that of *Pioneer 10*, and it, too, was on a solar-escape trajectory and carried the Sagan plaque. It passed closely by Jupiter on December 3, 1974, and flew by Saturn on September 1, 1975. It lasted much longer than expected, too, and was turned off on September 30, 1995. Pioneer 11 discovered two small moons and a new ring at Saturn, measured its magnetic field, charted its magnetosphere and provided data that allowed the basics of Saturn's interior structure to be determined.

Pioneer 11 also got a semi-good look at Saturn's large moon, Titan. It was somewhat of an enigma, for it is the only moon in the Solar System with an appreciable atmosphere. It couldn't image the Titan surface directly because Titan's atmosphere is cloudy, but it did determine that the surface temperature of Titan was far below the freezing point of water and therefore unlikely to support life.

The measurements of the radiation environments at both giant planets by both Pioneers proved to be of vital importance in designing the next round of outer Solar System explorers!

Voyagers 1* and *2

The orbital mechanics wizards of NASA determined that the mid-1970's provided a rare opportunity to explore the outermost Solar System with the technology of the day. The outer four gas giants were aligned in such a way that it would be possible to visit each in succession, using gravitational slingshots at each to send it more quickly to the next. A journey to Neptune, which would normally take over 40 years, would be possible in only 12! NASA jumped all over this news, but Congress didn't. The next pair of spacecraft authorized to visit Jupiter and Saturn, *Voyagers 1* and *2*, were only funded to go to Saturn. But NASA kept the idea of a "Grand Tour" mission in the back of their collective minds …

The Voyagers were much larger, more complicated, and more capable spacecraft than the Pioneer twins.

Voyager 2 was actually launched first, on August 20, 1977, but its trajectory was longer than that followed by *Voyager 1*. Both spacecraft were aimed at Jupiter and Saturn, with an emphasis on learning more about Titan. *Voyager 1* was launched on September 5, 1977. The nature of its trajectory was such that its mission would end at Saturn; having it go on the Uranus and Neptune was just not possible, Congressional support or no. *Voyager 2* had a trajectory that would allow visits to Uranus and Neptune, but only if it could take a path by Saturn that would not allow a close look at Titan. Since such a look was a primary mission objective, *Voyager 1* had to make it, so that *Voyager 2* could possibly go further.

There was one more joker in the deck. *Voyager 1*'s booster underperformed somewhat. It wasn't enough to mess up its mission, but if it had been *Voyager 2*'s booster, the underperformance would have prevented a visit to Uranus and Neptune!

Voyager 1 and *2* were complete successes, the latter became our only close look at Uranus and Neptune to date, and NASA is still in contact with both as they cross the heliopause. As for the Sagan plaque, both Voyagers carry a "golden record" with sounds and images of Earth and digital instructions on how to replay them.

Voyager 2 was the star of the *Al Hibbs Show*, a real-time program where you, the viewer, would see images of never-before-seen-up-close bodies in the outer Solar System at the same time as the mission scientists, as described in the very first A+StW Item of the Week, here.

CASSINI MISSION

The Pioneers and Voyagers were like old-time scouts; their mission was to get a good look and basic physical data at Jupiter and Saturn. The next step would be a far more in-depth exploration by orbiting spacecraft and atmospheric probes. A spacecraft was sent to Jupiter to orbit and explore its atmosphere in detail, both from an orbiter and an atmospheric probe, and its four large satellites, discovered by Galileo, the namesake of this particular mission. Another spacecraft and probe were planned for Saturn, also and orbiter but with the probe that was provided by ESAA targeted on its unique moon, Titan.

I hope it is no surprise to you that NASA chose the name of its Saturn mission to be "Cassini," in honor of the Italian/French scientist whose accomplishments in understanding Saturn and its moons were described above. And likewise, it should be no surprise that the name selected for the atmospheric probe of Titan was "Huygens," the name of the person who discovered Titan!

Cassini was launched on **October 15, 1997, 25 years ago** this week.

Cassini had to take a roundabout way to Saturn, because it needed a total of four gravity "slingshot' assists to get there, Venus twice, then Earth, and finally Jupiter. As it flew by Jupiter, it made a series of observations that were coordinated with those by *Galileo*, already there, and the *Hubble Space Telescope*.

Several other spacecraft transiting the "asteroid belt" have made fly-bys of asteroids, and *Cassini* was no exception. It wasn't a close pass and the asteroid is not very large, but it does carry an interesting name: 2685 Masursky, honoring an early planetologist at USGS Flagstaff. It was a chance encounter; *Cassini* was already in flight when it was determined that it would pass near 2685. *Cassini* had been equipped with automated object-targeting capabilities, so the encounter proved a good test for it, and it passed with flying colors. I find it satisfying that Hal Masursky found one last way to contribute to the field long after his illustrious career!

Cassini flew closely past Saturn's moon, Phoebe, and then was inserted into a highly-elliptical initial orbit. The spacecraft was then maneuvered to be in position to release the Huygens probe, which it did on December 25, 2004. It took over two weeks before *Huygens* entered Titan's atmosphere; meanwhile, the *Cassini* spacecraft was positioned to observe Titan during *Huygen*'s descent and act as a communications relay. *Huygens* not only probed the atmosphere, it actually landed on Titan on January 14, 2005. It took images and data during its passage through Titan's atmosphere and from Titan's surface.

CASSINI SCIENCE

Titan was found to have features akin to those on Earth due the hydrologic cycle. The Titan equivalent involves methane, not water, however. *Huygens* imaged lakes and rivers of liquid methane, made by methane rain. Detailed measurements show that Titan's is the most chemically complex atmosphere in the Solar System. Sunlight and methane make complex molecules that make the atmosphere opaque to visible light.

Voyager 2 had shown that Saturn's moon, Enceladus, appeared to be similar to Jupiter's moon, Europa. Both are covered with a global ocean, with a thick crust of ice that shows fractures from internal forces. Neither moon has many impact craters, therefore some mechanism must cause resurfacing. *Cassini* showed that water is actually geysering from some of the fractures on Enceladus, and it even flew through and sampled one of the plumes in the final stage of the mission. The water showed chemistry similar to that of Earth's deep-ocean "hot smokers," which are local abodes of abundant life …

Saturn has another odd moon, Iapetus, that was a focus of attention by both *Voyagers* and *Cassini*. Early astronomers thought they were seeing two separate moons, because Iapetus appears brighter when it is on one side of Saturn than when it is on the other. Better telescopes showed that it was one object. Like many moons in the Solar System, ours included, Iapetus' rotation is "tidally-locked," meaning it makes one rotation each revolution, thus keeping the same face pointed at Saturn. This makes one hemisphere the "leading hemisphere," which is darker than Iapetus' trailing hemisphere. There were two possible mechanisms in play here, one I call "bugs on the windshield" and the other the "eroded candy-coated chocolate." In the former, dark material is swept up on the leading side, darkening its surface. In the latter, the more intense impacting on the leading hemisphere blasts away a light-colored crust, revealing darker material beneath. *Cassini* data give the victory to the bugs!

Planetologist already knew that the Saturn ring system was complex, but images from *Cassini* showed how small moonlets shepherd ring fragments to make finely-divided rings and gaps. Much was learned about orbital mechanics and ring dynamics. Detailed examination showed that the rings were shedding ("raining") material to the upper atmosphere below, affecting its composition, but the data were too sparse to be sure.

In general, Saturn's rings are extremely thin relative to their large size. But *Cassini* images taken at Saturn's equinox, when the rings are illuminated edge-on, showed some unusual vertical structure.

Saturn's "surface" appears much less turbulent than Jupiter's, but storms do occasionally occur. *Cassini* was in position to observe one such in late 2010. A giant storm was brewed up, and smeared into a global best of roiled gases. The surface temperature increased greatly, and molecules never seen in Saturn's upper atmosphere were observed.

Saturn's atmosphere in its polar regions was found to be very turbulent, too, with a hurricane-like storm at each pole. The north polar region has a persistent hexagonal-shaped jet stream that makes a striking picture, but the mechanisms that form the hexagon and make it stable have yet to be fully worked out.

Determination of the exact rotation rate for Jupiter and Saturn is difficult, since both atmospheres have differential rotation – the rotation rate is higher at low latitudes than at higher ones. *Cassini* data showed that Saturn's differential rotation is even odder. The rotation rate in the northern hemisphere is different from that in the southern hemisphere. These differences appear to be seasonal, with the hemispheres shifting as to which is moving faster.

All good things must come to an end. After 13 years in orbit, *Cassini* was nearing the end of its highly-successful mission. Mission controllers began to take more risks with the spacecraft to get additional data. One example was mentioned previously, diving *Cassini* into the plume of one of Enceladus' giant geysers. *Cassini* was set to go out in style, diving into the upper atmosphere, with its Neutral Mass Spectrometer in full operation, its antenna still pointing at Earth and relaying the NMS data. *Cassini* lasted almost a full minute before its destruction, and in that minute the NMS confirmed that "ring rain" was a thing. A fitting end for a gallant spacecraft, indeed!

REFERENCES

A good general audience read on the Cassini-Huygens mission was published in *National Geographic* magazine's December, 2006 issue. *Beautiful Stranger: Saturn's Mysteries Come to Light* has some wonderful images of both Saturn and Titan.

NASA Summary of Key Results of the Cassini-Huygens mission: https://solarsystem.nasa.gov/news/12892/cassini-10-years-at-saturn-top-10-discoveries

NSSDC Cassini: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1997-061A

NSSDC Huygens: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1997-061C

NASA Saturn overview: https://solarsystem.nasa.gov/planets/saturn/overview/#!

NASA Saturn In-depth: https://solarsystem.nasa.gov/planets/saturn/in-depth

NASA Saturn Gallery: here

CNN Summaries: https://www.cnn.com/2018/10/04/world/cassini-saturn-death-dive-results/index.html and https://www.cnn.com/2017/10/24/us/cassini-saturn-atmosphere-rings/index.html

NASA SpacePlace (for the younger scientist): https://spaceplace.nasa.gov/all-about-saturn/en

The *Journal of Geophysical Research* devoted a special issue to the presentation of the Voyager 1 and 2 fly-bys of Saturn: Volume 88, Number A11, November 1, 1983.

A great overview of the Cassini mission and its results is *Passage to a Ringed World: The Cassini-Huygens Mission to Saturn and Titan*, NASA SP-533, edited by Linda J. Spilker. It's available at: https://history.nasa.gov/SP-533.pdf

Robert Brown and others edited a two-volume text about the Cassini-Huygens mission: *Saturn from Cassini-Huygens* and *Titan from Cassini-Huygens*, published by Springer in 2009. The former: ISBN 978-1-4020-9216-9; the latter: ASIN B008BB7N8W

Be sure to check out the e-book from the Cassini mission, "The Saturn System: Through the Eyes of *Cassini*," here: https://www.nasa.gov/connect/ebooks/the-saturn-system.html.

Last Edited on 9 October 2022