National Aeronautics and Space Administration

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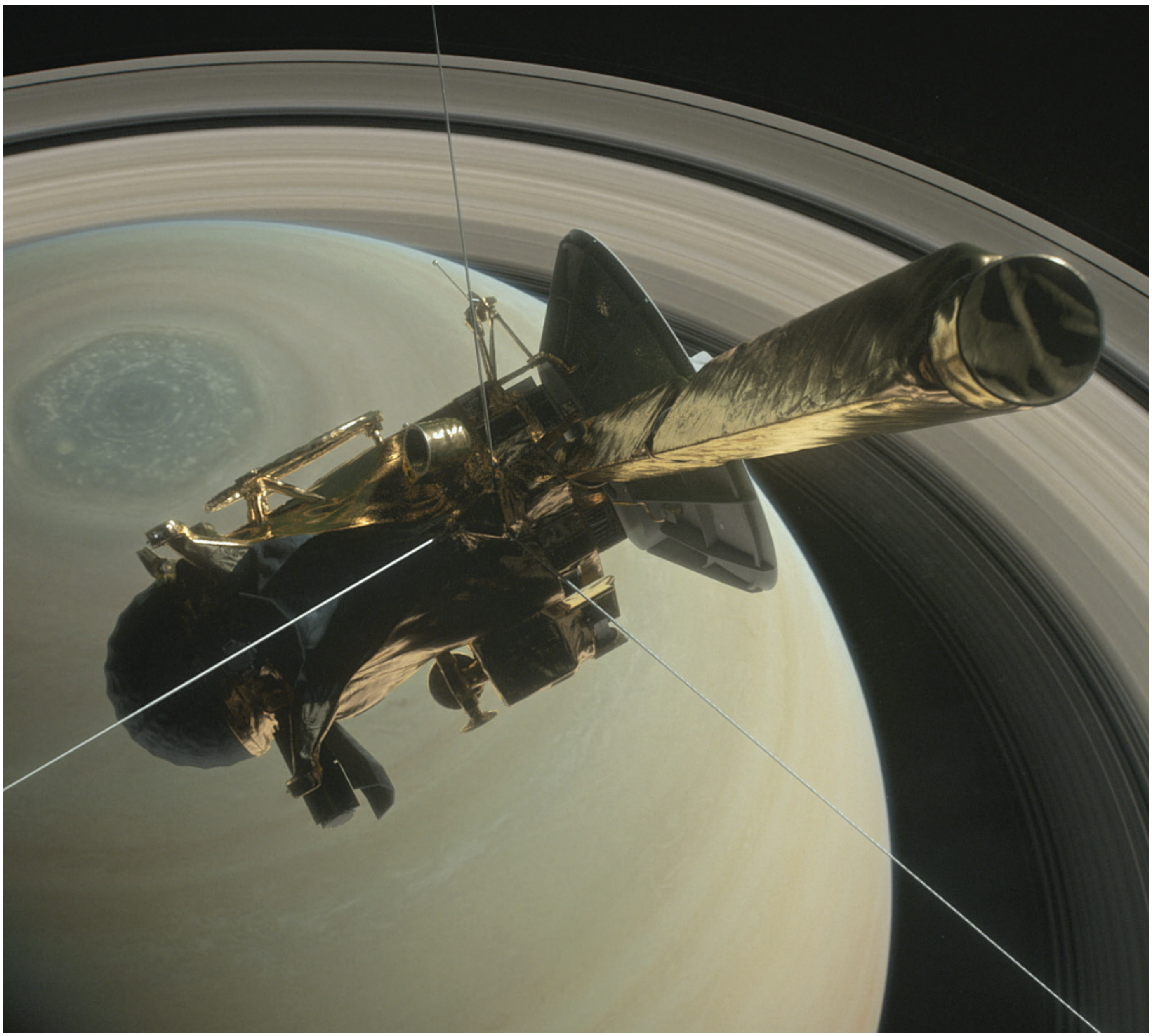
Cassini: End of Mission



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Contents

Introduction

After two decades in space, NASA's Cassini spacecraft is nearing the end of its remarkable journey of exploration. Having expended almost every bit of the rocket propellant it carried to Saturn, operators are deliberately plunging Cassini into the planet to ensure Saturn's moons will remain pristine for future exploration — in particular, the ice-covered, ocean-bearing moon Enceladus, but also Titan, with its intriguing pre-biotic chemistry.

Beginning in 2010, Cassini began a seven-year mission extension in which it completed many moon flybys while observing seasonal changes on Saturn and Titan. The plan for this phase of the mission was to expend all of the spacecraft's propellant while exploring Saturn, ending with a plunge into the planet's atmosphere. In April 2017, Cassini was placed on an impact course that unfolded over five months of daring dives — a series of 22 orbits that each pass between the planet and its rings. Called the Grand Finale, this final phase of the mission has brought unparalleled observations of the planet and its rings from closer than ever before.

On Sept. 15, 2017, the spacecraft will make its final approach to the giant planet Saturn. But this encounter will be like no other. This time, Cassini will dive into the planet's atmosphere, sending science data for as long as its small thrusters can keep the spacecraft's antenna pointed at Earth. Soon after, Cassini will burn up and disintegrate like a meteor.

To its very end, Cassini is a mission of thrilling exploration. Launched on Oct. 15, 1997, the mission entered orbit around Saturn on June 30, 2004 (PDT), carrying the European Huygens probe. After its four-year prime mission, Cassini's tour was extended twice. Its key discoveries have included the global ocean with indications of hydrothermal activity within Enceladus, and liquid methane seas on Titan.

And although the spacecraft may be gone after the finale, its enormous collection of data about Saturn – the giant planet itself, its magnetosphere, rings and moons — will continue to yield new discoveries for decades.

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Media Services Information

News and Status Reports

NASA and the Cassini team will issue periodic status reports on mission activities and make them available online at https://www.nasa.gov/cassini, and https://saturn.jpl.nasa.gov. NASA has released several media advisories in advance of Cassini's end of mission with details about press accreditation, media briefings, special media opportunities, on-site logistics at the Jet Propulsion Laboratory, and NASA TV and Web coverage.

Video and Images

Video and images related to the Cassini mission are available at the following websites:
https://vimeo.com/album/4649677 and https://photojournal.jpl.nasa.gov/mission/Cassini-Huygens. (See also: Appendix – Video and images)

NASA Television

NASA Television Channels are digital C-band signals, carried by QPSK/DVB-S modulation on satellite Galaxy-13, transponder 11, at 127 degrees west longitude, with a downlink frequency of 3920 MHz, vertical polarization, data rate of 38.80 MHz, symbol rate of 28.0681 Mbps, and 3/4 FEC. A Digital Video Broadcast (DVB) compliant Integrated Receiver Decoder (IRD) is needed for reception. For NASA TV information and schedules on the Web, visit www.nasa.gov/ntv.

Live NASA TV programming on NASA's public channel is available on the Web at nasa.gov/live. The NASA TV media channel is available live at https://www.ustream.tv/channel/nasa-media-channel. Archived NASA TV pro-gramming is available soon after it airs at youtube.com/nasatelevision.

Additional Live Video Streams

Additional live streaming video will be available at youtube.com/nasajpl/live, ustream.tv/nasajpl, and ustream.tv/nasajpl2. Schedule details for these channels will be available at saturn.jpl.nasa.gov/mission/grand-finale/for-media.

On-Site Media Logistics

News media representatives covering Cassini end-of-mission activities in person must be accredited through the Jet Propulsion Laboratory Media Relations Office. Registration for media has already ended. Journalists may call (818) 354-5011 for further information and to request interviews.

Cassini on the Web

Cassini information -- including this press kit, news releases, fact sheets, mission details and background, status reports and images — is available on the web at https://saturn.jpl.nasa.gov/grandfinale and https://www.nasa.gov/cassini.

Mission updates are also available on Twitter (@CassiniSaturn), Facebook (https://www.facebook.com/NASACassini).

Quick Facts

MILESTONES

Launch: Oct. 15, 1997, from Cape Canaveral Air Force Station, Florida

Launch vehicle: Titan IVB/ Centaur

Venus flybys: April 26, 1998, at 176 miles (234 km); June 24, 1999, at 370 miles (600 kilometers)

Earth flyby: Aug. 18, 1999, at 727 miles (1,171 kilometers)

Jupiter flyby: Dec. 30, 2000, at 6 million miles (10 million kilometers); closest approach at 5:12 a.m. EST

Saturn arrival: July 1, 2004, UTC (June 30, 2004 PDT)

Huygens Probe: Titan Release Dec. 24, 2004; Titan Descent Jan. 14, 2005

CASSINI ORBITER

Dimensions: 22 feet (6.7 meters) high; 13.1 feet (4 meters) wide

Weight at launch: 12,593 pounds (5,712 kilograms) with fuel, Huygens probe, adapter, etc.

Weight at end of mission: 4,685 pounds (2,125 kilograms)

Propellant used: 6504 pounds out of 6565 pounds (2950 kilograms out of 2978 kilograms)

Power: 885 watts (633 watts at end of mission) from radioisotope thermoelectric generators

Orbiter science instruments (12 total): composite infrared spectrometer (CIRS), imaging system (ISS), ultraviolet imaging spectrograph (UVIS), visual and infrared mapping spectrometer (VIMS), imaging radar (Radar), radio science (RSS), plasma spectrometer (CAPS), cosmic dust analyzer (CDA), ion and neutral mass spectrometer (INMS), magnetometer (MAG), magnetospheric imaging instrument (MIMI), radio and plasma wave science (RPWS).

Details about all of Cassini's science instruments:
https://saturn.jpl.nasa.gov/mission/spacecraft/cassini-orbiter

MISSION

Commands Executed: 2.5 million

GB of Science Data Collected: 635 GB

Saturn Orbits Completed: 293 at end of mission

Targeted moon flybys: 162

Targeted Titan Flybys: 127

Targeted Enceladus Flybys: 23

Images Taken: 453,048

Main Engine Burns: 183

Oceans Discovered: 2 (Titan, Enceladus)

Titan Seas and Lakes Discovered: 3 seas, hundreds of small lakes

Named Moons Discovered: 6

Science Papers Published: 3,948

Primary mission: 4 years

Two extended missions: Equinox (2008-2010) and Solstice (2010-2017)

Total distance traveled: At Cassini's end of mission, the spacecraft will have traveled about 4.9 billion miles (7.8 billion kilometers) with respect to the Sun; this distance includes its 2.1 billion-mile (3.4-billion kilometer) interplanetary trajectory from Earth to Saturn. With respect to Saturn, Cassini traveled a total of 1.2 billion miles (1.9 billion kilometers) from arrival to end of mission.

Saturn's average distance from Earth: 890 million miles (1.43 billion kilometers)

One-way speed-of-light time from Saturn to Earth during orbital tour: Varies between 67 and 85 minutes

One-way speed-of-light time from Saturn to Earth at end of mission: 83 minutes

Spacecraft speed at loss of signal (relative to Saturn): 69,368 mph (111,637 kph)

PROGRAM

Partners: NASA, European Space Agency (ESA), Italian Space Agency (Agenzia Spaziale Italiana or ASI)

Number of people who worked on some portion of Cassini-Huygens: More than 5,000

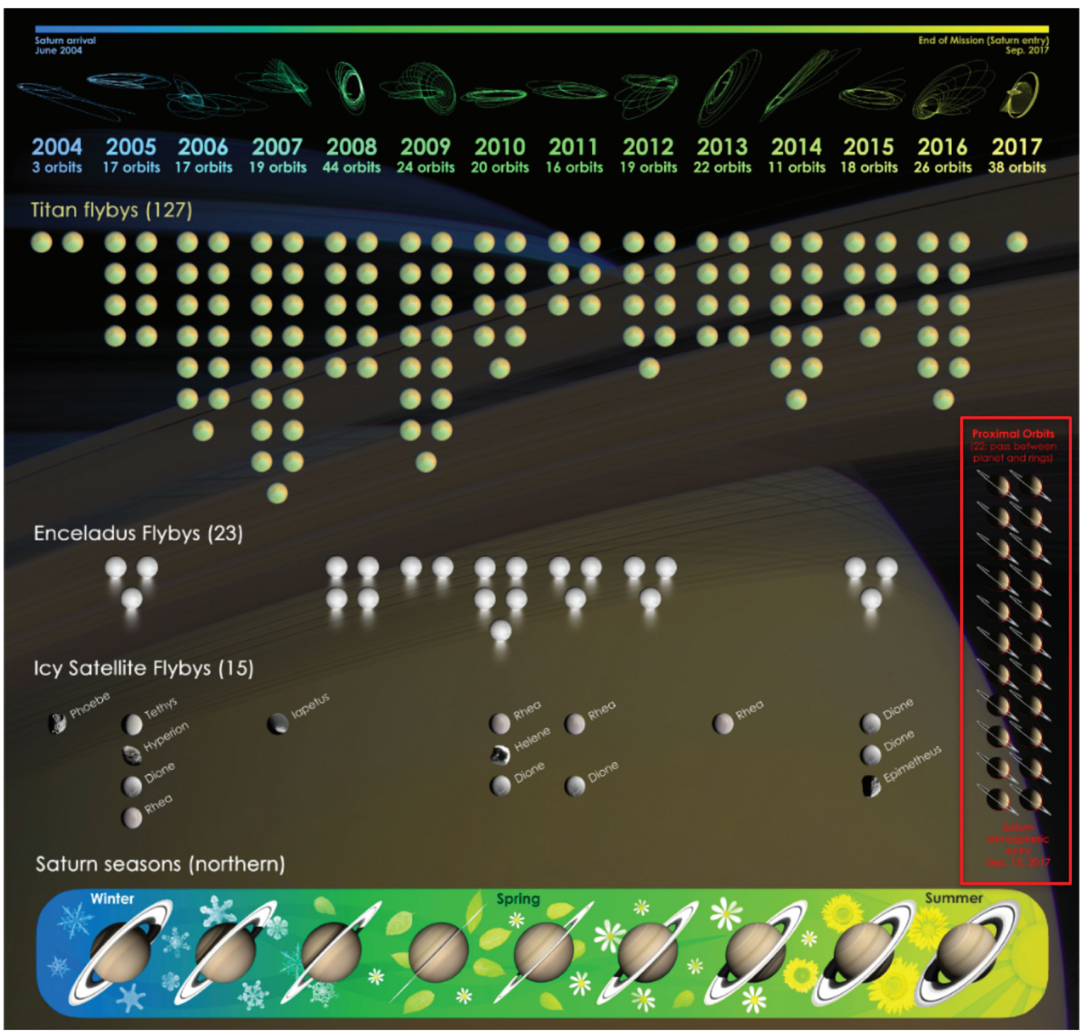
Cost of mission: $3.9 billion. This figure includes $2.5 billion in pre-launch costs (including launch vehicle and contributions from ESA and the Italian Space Agency), and $1.4 billion in post-launch costs (including operations and tracking for 20 years in flight).

The Cassini-Huygens Mission and Why It Matters

The Cassini-Huygens mission — a joint endeavor of NASA, ESA (the European Space Agency), and the Italian Space Agency — is the first mission to orbit Saturn and explore its environs in detail. The mission was conceived from the beginning as an international endeavor, in 1982, just after the two NASA Voyager spacecraft flew past Saturn. The Voyager flybys whetted the appetites of planetary scientists for more in-depth exploration, particularly with regard to the mysterious moon Titan. Launched in 1997, Cassini has been touring the Saturn system since arriving there in 2004, performing a detailed, up-close study of the planet, its rings and moons.

The mission delivered ESA's Huygens probe to Titan in 2005, where it performed the first descent and landing on a world in the outer solar system. In complement to Huygens' dazzling revelations about Titan, the Cassini orbiter performed 127 of its own close flybys of Titan (with many more distant encounters).

By the end of its mission, the Cassini spacecraft will have observed almost half of a Saturn year, which is 29 Earth years long. The four seasons of Saturn's year last about seven Earth years apiece, and upon Cassini's arrival at Saturn, the planet's northern hemisphere was just beginning to emerge from winter. Following its initial,



This graphic summarizes Cassini's 13 years orbiting Saturn, with moon flybys grouped into columns for each phase of the mission. The Grand Finale orbits appear as Saturn flybys in 2017. This list of icy satellite flybys includes three additional close encounters (Phoebe, Helene and Epimetheus) not included in the official tally of 12 "targeted" flybys. At bottom, Saturn's northern hemisphere seasons are indicated from 2004 to 2017. Credit: NASA/JPL-Caltech. Click to view this image online.

four-year tour, Cassini's mission was extended two more years, to enable the spacecraft to observe changes — particularly in the rings — as Saturn reached equinox and the Sun shone edge-on to the rings. After equinox, Cassini was granted an additional seven-year extension. This enabled scientists to follow up on their earlier discoveries at Enceladus and Titan, and watch as summer sunlight came to the northern hemisphere of Saturn and its moons, while winter darkness embraced the south.

The findings of the Cassini mission have revolutionized our understanding of Saturn, its complex rings, the amazing assortment of moons and the planet's dynamic magnetic environment. The most distant planetary orbiter ever launched, Cassini started making astonishing discoveries immediately upon arrival and continues today. Icy jets shoot from the tiny moon Enceladus. Titan's hydrocarbon lakes and seas are dominated by liquid ethane and methane, and complex pre-biotic chemicals form in the atmosphere and rain to the surface. Three-dimensional structures tower above Saturn's rings, and a giant Saturn storm circled the entire planet for most of a year. Cassini's findings at Saturn have also fundamentally altered many of our concepts of how planets form around stars.

When Cassini ends, it will leave a rich scientific and engineering legacy.

Mission Achievements

— NASA's Cassini spacecraft and ESA's Huygens probe expanded our understanding of the kinds of worlds where life might exist.

With discoveries at Saturn's moons Enceladus and Titan, Cassini and Huygens made exploring "ocean worlds" a major focus of planetary science. Insights from the mission also help us look for potentially habitable planets — and moons — beyond our solar system.

Life as we know it is thought to be possible in stable environments that offer liquid water, essential chemical elements, and a source of energy (from sunlight or chemical reactions). Before Cassini launched in 1997, it wasn't clear that any place in the icy outer solar system (that is, beyond Mars) might have this mix of ingredients. By the next year, NASA's Galileo mission revealed that Jupiter's moon Europa likely has a global ocean that could be habitable. Since its 2004 arrival at Saturn, Cassini has shown that Europa isn't an oddball: Potentially habitable ocean worlds exist even in the Saturn system — 10 times farther from the Sun than where Earth sits.

When the Cassini mission started, scientists presumed Enceladus was too small to generate and hold onto the heat required to maintain subsurface reservoirs of liquid water. Cassini's discovery of intense geologic activity near the moon's unexpectedly warm south pole — complete with towering jets of icy spray — sent shockwaves through the space science community. After more than a decade of investigation, the mission eventually determined that Enceladus hosts a global liquid water ocean, with salts and simple organic molecules, and likely even hydrothermal vents on its seafloor. Thanks to Cassini, Enceladus is now one of the most promising places in our solar system to search for present-day life beyond Earth.

Saturn's largest moon, Titan, offered tantalizing hints that it, too, could help us understand whether life could have evolved elsewhere. Cassini and ESA's Huygens probe (which landed on Titan's surface) found clear evidence for a global ocean of water beneath Titan's thick, icy crust and an atmosphere teeming with prebiotic chemicals. Based on modeling studies, some researchers think Titan, too, may have hydrothermal chemistry in its ocean that could provide energy for life. On its frigid surface, which hosts vast seas of liquid hydrocarbons, scientists wonder, could Titan be home to exotic forms of life "as we don't know it"?

— At Saturn's largest moon, Titan, Cassini and Huygens showed us one of the most Earth-like worlds we've ever encountered, with weather, climate and geology that provide new ways to understand our home planet.

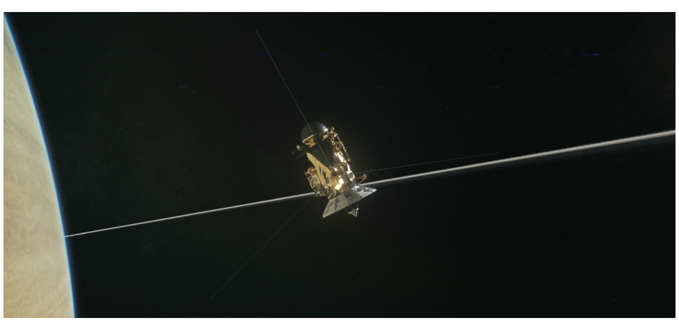
Titan is 10 times farther from the Sun than Earth's orbit, and much colder, but Cassini showed it to be the only other place in our solar system with stable liquid on its surface and a kind of "hydrological" cycle involving methane rather than water.

Flowing liquid hydrocarbons at Titan make for eerily Earthlike landscapes -- they carve branching channels and steep canyons into rock-hard ice; they settle into lakes and seas with gently sloping shorelines and sheltered bays; they tumble water-ice "rocks" into rounded pebble shapes like those in earthly rivers.

Titan's landscape also shares other similarities with Earth. Large, arid swaths of dunes gird the moon's equatorial regions. Composed of organic materials that settle out of Titan's thick, hazy atmosphere, these dunelands are sculpted by winds in ways similar to dunes in places like Namibia and the Sahara. Scientists have also spotted volcano-like mounds that, if indeed volcanic in nature, would erupt slushy lavas made of water rather than molten rock.

From its perch in space, Cassini has been watching Titan's climate cycle play out over the years, with seasonal changes bringing bright, feathery methane rain clouds that dump precipitation on the landscape. Huygens saw clear evidence of a landscape that experiences intermittent but heavy floods, not unlike places in the American desert Southwest.

Titan's smoggy atmosphere resembles an extreme version of the skies above Los Angeles or other major cities on a day with poor air quality. And, more importantly, Titan's atmosphere is thought to be similar to early Earth's before life developed here. Titan provides perhaps the best stage in the solar system to watch the organic chemistry that led to the origin of life on Earth billions of years ago. Titan can also be considered a possible analog for the future Earth. Its methane cycle hints at what Earth's water cycle might look like in the far future as the increasingly brighter-burning Sun changes the stability of water in our oceans and atmosphere. The seas at Titan's poles might be remnants of larger bodies of liquid that once covered much more of the moon's surface.



— Cassini is, in a sense, a time machine. It has given us a portal to see the physical processes that likely shaped the development of our solar system, as well as planetary systems around other stars.

Cassini has provided a brief glimpse into deep time in the Saturn system. The rings, for example, are a natural laboratory for processes that form planets — a mini solar system, if you will. They show us how objects clump together and break apart. And in the ripples we can read the history of impacts into the rings. We also see "propeller" features that obey the same physical processes that form planets.

Moons in the Saturn system are also time capsules preserving histories of bombardment and other forces at play over time. At Titan, in particular, we have access to the kinds of complex carbon chemistry that might have taken place on Earth in its "prebiotic" days. During the Cassini mission's finale, data about the planet's interior and the mass of the rings will provide powerful insights about their formation and evolution.

— The longevity of the Cassini mission has enabled us to observe weather and seasonal changes, improving our understanding of similar processes at Earth, and potentially those at planets around other stars.

While other missions flew past Saturn or trained telescopes periodically from afar, Cassini has had a front-row seat for approximately 13 years -- nearly half a Saturn year (northern winter to the start of northern summer) — to epic changes unfolding before its very eyes.

This long-lived robotic observing platform, bristling with science instruments, provided an unparalleled glimpse into what happens as weather and climate conditions on the planet and Titan respond to the seasons — sometimes rather abruptly. Among the most amazing changes Cassini has captured: the eruption of a once-every-30-years storm (one of the most powerful ever seen in the solar system), methane rainstorms at Titan and the appearance and disappearance of features called "magic islands" in Titan's seas, whose nature scientists are still working to understand.

Over a longer span of years, the color of Saturn's northern hemisphere shifted as the ring shadows retreated southward — changing from the surprisingly bluish tones seen upon arrival to the hazy, golden hues most observers are familiar with. On Titan, Cassini witnessed a vortex filled with complex organic chemicals forming over its south pole, and saw sunlight glinting off of the lakes in its northern hemisphere as the Sun rose over them.

The spacecraft's patient eyes also were rewarded with new views of Saturn's north pole as winter ended there and the Sun rose once more. Cassini's infrared sensors measured temperatures across the rings as the Sun set on one side and rose on the other, revealing new details about the structure of ring particles. It used the onset of wintry darkness at the south pole of Enceladus to obtain an unambiguous reading of the amount of heat coming out of the moon's interior. And it saw the mysterious ring features called spokes (wedge-shaped features in the rings that rotate along with the rings like the spokes in a wheel) appear and disappear — apparently a seasonal phenomenon.

— Cassini revealed Saturn's moons to be unique worlds with their own stories to tell.

Planet-size Titan and diminutive Enceladus stood out in Cassini's in-depth survey of Saturn's moons. But the mission showed that every moon in the Saturn system is a unique character with its own mysteries, and many of Saturn's satellites are related in surprising ways.

For example, Cassini data enabled scientists to confirm earlier suspicions that Phoebe is likely an object from the outer solar system beyond Neptune, captured by Saturn's gravity long ago. Phoebe also turns out to be key to the two-toned appearance of the moon Iapetus: As Phoebe sheds its dark dust, it coats the leading side of Iapetus and causes ice to heat up and migrate to the moon's opposite side.

Cassini also gave scientists a better understanding of why Hyperion looks like a giant sponge or wasp's nest tumbling through space. Researchers determined the moon's density is so low impacts tend to compress its surface rather than blasting it out, and the material that is launched into space tends to escape for good, thanks to Hyperion's low gravity.

Cassini found that Enceladus is not only active, but its geologic activity is creating Saturn's E ring and spray-painting the surfaces of several of the other moons with its highly reflective ice particles.

The mission also followed up on a mystery from the early 1980s when NASA's Voyager spacecraft flew by the Saturn system and saw bright wispy terrains on Dione. Cassini found that the features were in fact a vast network of canyons. Cassini also detected hints of a faint atmosphere that might have been outgassed from the moon's interior.

And Cassini watched closely over many years how Prometheus interacts with Saturn's F ring to create features like "streamers," "plumes" and "drapes."

— Cassini showed us the complexity of Saturn's rings and the dramatic processes operating within them.

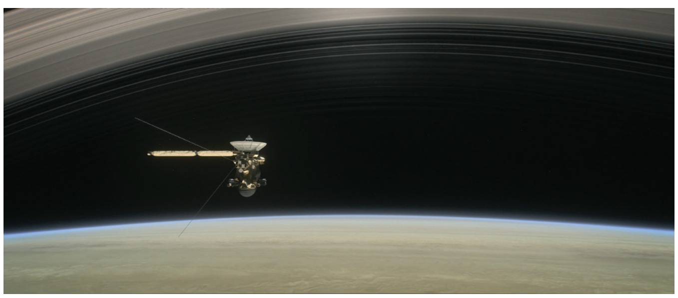
Although Cassini scientists are still working on determining the exact origin of Saturn's main system of rings — and hope to collect data that will answer this question as its mission draws to a close — they have learned along the way that there are in fact, many ways to form rings around a planet.

A diffuse ring is created out of the bits of water ice jetted out by the moon Enceladus (the E ring). Other rings were created because of the material thrown off when meteorites hit moons (such as the G ring and the two rings discovered by Cassini in images from 2006 — the Janus-Epimetheus ring and the Pallene ring). There are rings controlled by interactions with moons, like the F ring, which is regularly perturbed by Prometheus, and the narrow ringlets that share the Encke Gap with Pan.

In addition to the rings' origins, Cassini's close-up examination has revealed propeller-shaped features that mark the locations of hidden moonlets. The processes involved in the formation of such objects are thought to be similar to how planets form in disks around young stars.

Cassini also helped explain features in the main rings called spokes, which were first spotted during the Voyager flybys of the early 1980s. Cassini scientists figured out that spokes are made of tiny ice particles lifted above the surface of the rings by an electrostatic charge, the way a statically-charged balloon held over a person's head will lift hairs. Their charge appears to be related to the angle of sunlight striking the rings — a seasonal effect.

The changing angle of the Sun also showed scientists an array of vertical structures in the rings, including fluffy peaks of material as high as the Rocky Mountains at the outer edges of the A and B rings. The vertical structures and the shadows they cast also revealed wavy patterns in the parts of the rings that resemble a miniature Milky Way, giving scientists insight into the way galaxies form.



— Some of Cassini's best discoveries were serendipitous. What Cassini found at Saturn prompted scientists to rethink their understanding of the solar system.

You can only get to know a planet so well with remote and sporadic observations. To truly understand the dynamics of a place as complicated and interesting as Saturn, you have to go there and stay to explore.

Towering jets of ice and water vapor pouring out of a moon as tiny as Enceladus were a huge surprise (explaining why Voyager flybys in the early 1980s saw that the moon had a young surface), as was the later finding that the moon has an ocean under its icy crust. Scientists also had not expected to find Saturn's magnetosphere — the region around the planet strongly influenced by Saturn's magnetic field — to be filled with an electrically excited gas, or plasma, of oxygen. It turned out this was another surprise from Enceladus, as the water vapor from its plume is broken apart by sunlight and the liberated oxygen spreads out through Saturn's magnetic bubble. Cassini detected this oxygen on approach to Saturn, but its origin was perplexing at first.

No one knew for sure what kind of environment ESA's Huygens probe would find when it came to rest on Titan's surface, so Huygens was built either to land on hard ground or float, if need be. Cassini later showed scientists that most of the moon's lakes and seas were near the north pole, and most of the moon's landscape was more like the Arizona desert. Cassini also observed a surprisingly rich variety of complex, organic chemicals forming in Titan's atmosphere.

Another unexpected finding — which endures as a mystery — is the irregularity of Saturn's day (how long the planet takes to make one rotation on its axis). At Jupiter, a beacon-like burst of radio waves known as "kilometric radiation" beams out with clock-like regularity once a day. But Saturn's kilometric radiation isn't consistent. It's somewhere between 10.6 and 10.8 hours. That might not seem like a big discrepancy, but for such a fundamental property as the planet's rotation period, it's frustratingly imprecise for scientists. They hope to settle the score by the time the mission ends by flying Cassini close enough to the planet to tease out the true answer from the magnetic field.

— Cassini represents a staggering achievement of human and technical complexity, finding innovative ways to use the spacecraft and its instruments, and paving the way for future missions to explore our solar system.

The Cassini-Huygens mission is an international collaboration involving three space agencies, with 19 countries contributing hardware to the flight system. The Cassini spacecraft carries 12 instruments, Huygens carried six more, and scientists from 26 nations are participating in the investigations. Among the many pioneering technologies of the mission are new solid-state data recorders with no moving parts that have since replaced tape recorders, solid-state power switches (space-based versions of circuit breakers), and advanced solid-state electronics. The spacecraft has more than 9 miles (14 kilometers) of cabling and 22,000 connections.

Cassini was able to explore the entire Saturn system in a way inconceivable with conventional propulsion. Building on the techniques used by NASA's Galileo mission to Jupiter, Cassini mission planners designed flybys of the moon Titan to use the moon's gravity to navigate around the Saturn system and maximize the science return of the mission. Titan became, in a way, Cassini's virtual "gas station" since the spacecraft couldn't possibly have brought enough fuel for a tour this long and complex. Each of Cassini's 127 targeted Titan flybys changed the spacecraft's velocity (on average) by as much as the entire Saturn orbit insertion burn. The finely tuned orbit optimization techniques developed during Cassini will enable planning for future exploration that can use similar approaches. Chief among these opportunities is NASA's planned mission to explore Jupiter's moon Europa using multiple flybys, known as the Europa Clipper.

Cassini has required an extremely complex schedule for determining which instrument's observations can be made at any given moment. Cassini's intricate observation sequences, often timed to fractions of a second, are frequently planned many months or years before they are executed by the spacecraft. The collaboration between multiple teams with often differing objectives has become an exemplary model for future missions.

Over the course of almost 20 years in space, Cassini also showed that you can teach an old dog new tricks, as the mission team found new ways to use its instruments and engineering systems that their designers had not foreseen. These include using the radar instrument to plumb the depths of Titan's seas; tasting the plume of Enceladus with instruments meant to sample Titan's atmosphere; scanning the rings with a radar originally designed to bounce signals off Titan's surface; and having the Deep Space Network's highly accurate frequency reference fill in for the radio science instrument's lost ultra-stable onboard frequency reference unit (Cassini's Ultra Stable Oscillator, used for one type of radio science experiment, was turned off in 2013). In a unique collaboration, the attitude control and navigation teams joined with the instrument teams to develop a consolidated model of Titan's atmosphere. Cassini will finish its mission repurposing the instruments that sniffed Titan's atmosphere and Enceladus' plume once more, this time to sample the Saturn atmosphere itself.

The mission also has had some rather surprising earthly benefits. A Cassini resource exchange, created prior to launch to help team members trade and effectively share power, mass, data rates and budget, has become a model for how to manage other types of international collaboration, including carbon trading.

When Cassini plunges into Saturn's atmosphere, it will have spent nearly every last drop of fuel it's carrying, a fitting end to a spacecraft that pushed itself to the limit.

— Cassini revealed the beauty of Saturn, its rings and moons, inspiring our sense of wonder and enriching our sense of place in the cosmos.

Earthlings have cast their gaze upward at Saturn since ancient times, but Cassini's decade-plus odyssey in orbit there revealed the true splendor of what is arguably the most photogenic planet in our solar system.

The mission returned stunning views of complex, swirling features in Saturn's atmosphere, draped by the graceful ring shadows that slowly shift with the seasons.

The spacecraft also revealed the bewildering variety of Saturn's moons and helped us see each one as a unique world in its own right. One has a noticeable ridge around its equator and a two-toned color pattern (Iapetus); one looks like the "Death Star" from Star Wars (Mimas); one looks like a sponge (Hyperion); another looks like a flying saucer (Atlas); another looks like a potato (Prometheus); another looks like a ravioli (Pan).

Cassini has shown us icy ringscapes that are at once magnificent in their sheer physical extent and exquisitely delicate in their expression of the subtle harmonies of gravity. These ringscapes mesmerize with the myriad designs embossed in them — the changing pattern of thick and thin, ruffles that stand as high as the Rocky Mountains, icy waves generated by small moons interacting with the rings, and "streamers" and "mini-jets" created in the ribbon-thin F ring by interactions with Prometheus.

Perhaps the most awe-inspiring views have been the panoramic scenes that encompass the entire Saturn system, including those with the planet and rings backlit, and the tiny glow of our far-off, blue home planet visible far across the gulf of outer space.

Lists of Cassini's top discoveries by year:
https://saturn.jpl.nasa.gov/mission/top-tens/science-highlights

The Grand Finale

Since April 2017, NASA's Cassini spacecraft has been writing the final, thrilling chapter of its remarkable 20-year-long story of exploration: its Grand Finale.

Every week, Cassini has been diving through the approximately 1,200-mile-wide (2,000-kilometer-wide) gap between Saturn and its rings. No other spacecraft has ever explored this unique region.

A final close flyby of the moon Titan on April 22 used the moon's gravity to reshape Cassini's trajectory so that the spacecraft leapt over the planet's icy rings to pass between the rings and Saturn. During 22 such passes over about five months, the spacecraft's altitude above Saturn's clouds varied from about 1,000 to 2,500 miles (1,600 to 4,000 kilometers), thanks to occasional distant passes by Titan that shifted the closest approach distance. At times, Cassini skirts the very inner edge of the rings; at other times, it skimmed the outer edges of the atmosphere. During its final five orbits, its orbit passes through Saturn's uppermost atmosphere, before finally plunging directly into the planet on Sept. 15.

Six Things to Know about Cassini's Grand Finale

1. The Grand Finale preserves and protects potentially habitable moons of Saturn

Cassini has been operating for 20 years and is running out of fuel. The planned descent into Saturn prevents the spacecraft from colliding with the moons Enceladus and Titan, which might be targets for future exploration. This avoids any possible contamination from hardy Earth microbes that might have stowed away and survived the journey on Cassini intact. NASA has therefore chosen to safely dispose of the spacecraft in the atmosphere of Saturn.

2. This is an opportunity for unique science

As the spacecraft repeatedly dives through the gap between the rings and Saturn during the Grand Finale, it collects rich and valuable information that was too risky to obtain earlier in the mission:

- Detailed maps of Saturn's gravity and magnetic fields, revealing how the planet is arranged internally, and possibly helping to solve the irksome mystery of just how fast Saturn is rotating.
- Vastly improving our knowledge of how much material is in the rings, bringing us closer to understanding their origins.
- Sampling of icy ring particles being funneled into the atmosphere by Saturn's magnetic field, along with the first direct sampling of particles from the main rings (specifically, the D ring)
- Ultra-close images of Saturn's rings and clouds.

3. Cassini is doing science, right to the end

Even as the spacecraft makes its final plunge into the planet's atmosphere, it will be sending home new data in real time. Key measurements will come from its mass spectrometer, which will sniff the atmosphere, telling us its composition until contact is lost. (Cassini's final images are expected to be returned several hours before its final plunge.)

4. The Grand Finale is daring exploration

Cassini is diving repeatedly through an unexplored region between Saturn and its rings. At times, the spacecraft skirts the very inner edge of the rings; at other times, it skims the outer edges of the atmosphere. While the mission team is confident the risks are well understood, there could still be surprises. This kind of daring tour could only be undertaken at the end of the mission.

5. The Grand Finale is so much more than the final minutes

Although Cassini will plunge into Saturn at the very end, that dramatic event is the capstone of months of daring exploration and scientific discovery. Those 22 orbits are the thrilling final chapter in a historic 20-year journey.

6. The end of Cassini's mission is sad, yes, but also a time for celebration

While NASA and the Cassini team are saddened that the mission is coming to an end, it is truly a spectacular end for one of the most scientifically rich voyages yet undertaken in our solar system. From Cassini's launch in 1997 to the unique Grand Finale science of 2017, the mission has racked up a remarkable list of achievements.

Dates, times and other info for all of the Grand Finale Orbits: https://saturn.jpl.nasa.gov/mission/grand-finale/grand-finale-orbit-guide

The End of Cassini's Mission

On Sept. 15, 2017, the Cassini spacecraft will make a fateful plunge into Saturn's atmosphere, ending the mission just one month shy of its 20th launch anniversary.

End of Mission Timeline

All times are estimates as of late-August 2017 and may change by a few minutes based on the density of Saturn's atmosphere as encountered by the spacecraft in its final five orbits (more info here). For the updated times, see https://go.nasa.gov/2wbaCBT.

Times in left column are spacecraft event time, i.e., when the events happen at Saturn. "ERT" (in right column for some entries) refers to Earth received time, which is the time when the spacecraft's signal relaying the event arrives on Earth. After events happen at Saturn, it takes 83 minutes for Cassini's radio signal to reach Earth.

Event happens at Saturn		Signal received on Earth
Sept 8		
8:08 pm EDT 5:08 pm PDT	Final dive through the gap between Saturn and the rings (closest approach to Saturn is 1,044 miles, 1,680 kilometers above the cloud tops)	
Sept 9		
9:07 am EDT 6:07 am PDT	Downlink of data from last Grand Finale dive begins	10:29 am EDT 7:29 am PDT
Sept 11		
3:04 pm EDT 12:04 pm PDT	Final, distant Titan flyby (aka, the "goodbye kiss") closest approach (altitude 73,974 miles, 119,049 kilometers above Titan's surface)	
Sept 12		
1:27 am EDT 10:27 pm PDT (Sept. 11)	Apoapse, or farthest point from Saturn in the orbit (800,000 miles, 1.3 million kilometers from Saturn)	
7:56 pm EDT 4:56 pm PDT	Downlink of final Titan data begins	9:19 pm EDT 6:19 pm PDT

Event happens at Saturn		Signal received on Earth
Sept 14		
3:58 pm EDT 12:58 pm PDT	Scheduled time when the final image will be taken by Cassini's cameras	
4:22 pm EDT 1:22 pm PDT	Spacecraft turns antenna to Earth; communications pass begins for final playback from Cassini's data recorder, including final images. Communications link is continuous from now to end of mission (~14.5 hours).	5:45 pm EDT 2:45 pm PDT
	Deep Space Network station in Canberra, Australia, takes over tracking Cassini to end of mission	11:15 pm EDT 8:15 pm PDT
Sept 15		
1:08 am EDT 10:08 pm PDT (Sept. 14)	High above Saturn, Cassini crosses the orbital distance of Enceladus for the last time	
3:14 am EDT 12:14 am PDT	Spacecraft begins a 5-minute roll to point instrument (INMS) that will sample Saturn's atmosphere and reconfigures systems for real-time data transmission at 27 kilobits per second (3.4 kilobytes per second). Final, real-time relay of data begins	4:37 am EDT 1:37 am PDT
3:22 am EDT 12:22 am PDT	High above Saturn, Cassini crosses the orbital distance of the F ring (outermost of the main rings) for the last time	
6:30 am EDT 3:30 am PDT	Atmospheric entry begins about 1,190 miles (1,920 kilometers) above the cloud tops; thrusters firing at 10% of capacity	7:53 am EDT 4:53 am PDT
6:31 am EDT 3:31 am PDT	Thrusters at 100% of capacity about 940 miles (1,510 kilometers) above the cloud tops; high-gain antenna begins to point away from Earth, leading to loss of signal	7:54 am EDT 4:54 am PDT

Collision Course

A final, distant flyby of the giant moon Titan on Sept. 11, 2017, provides the gravitational assist that puts Cassini on an impact course with Saturn. The spacecraft will pass 73,974 miles (119,049 kilometers) above Titan's surface during the encounter. The geometry of the flyby causes Cassini to slow down slightly in its orbit around Saturn. This lowers the altitude of its flight over the planet so that the spacecraft goes too deep into Saturn's atmosphere to survive.

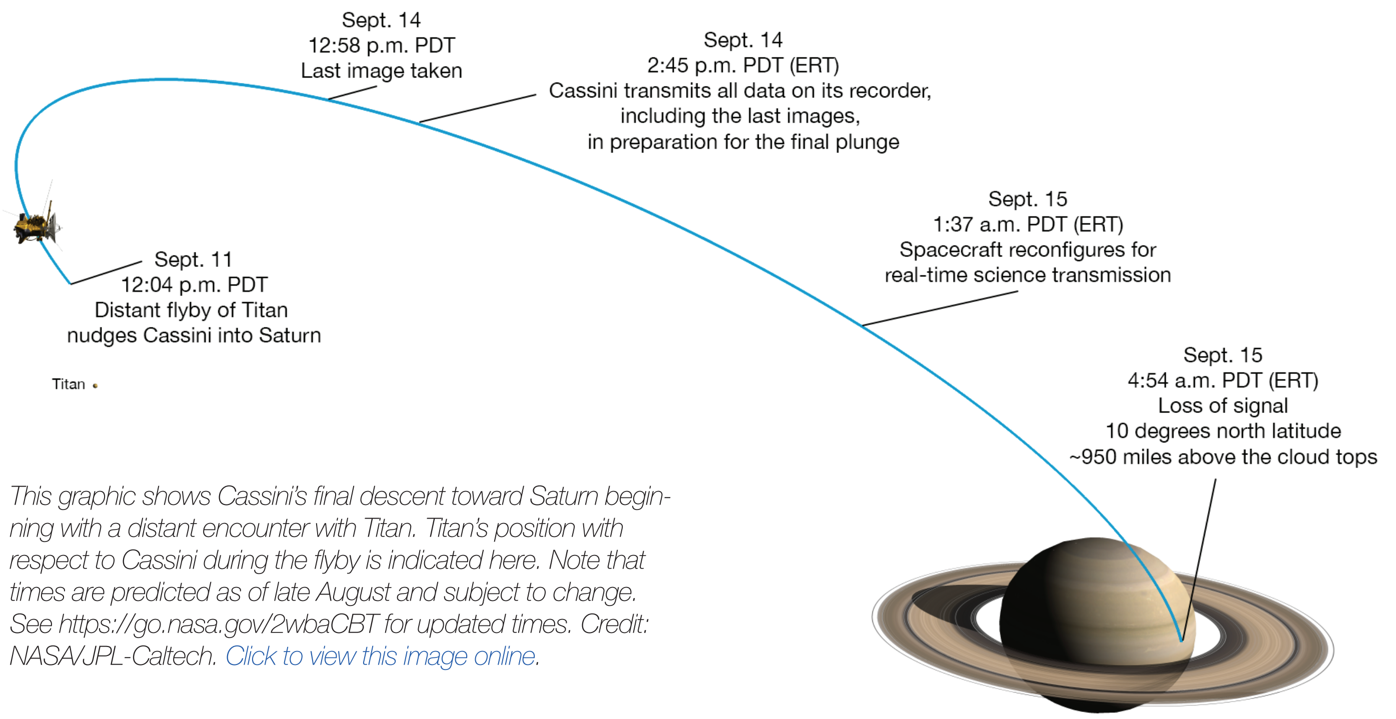
Last Look

On Sept. 13 and 14, Cassini will acquire its final imaging observations. This set of planned observations is a "final look" around the Saturn system, encompassing many subjects of interest, including a color mosaic image of Saturn and the rings, a movie sequence of Enceladus setting behind the planet, views of Titan, the tiny moonlets in the rings called propellers, and a final look at the mysterious possible moonlet nicknamed "Peggy." No images will be taken during the final plunge into Saturn, as the data transmission rate required to send images is too high and would prevent other high-value science data from being returned.

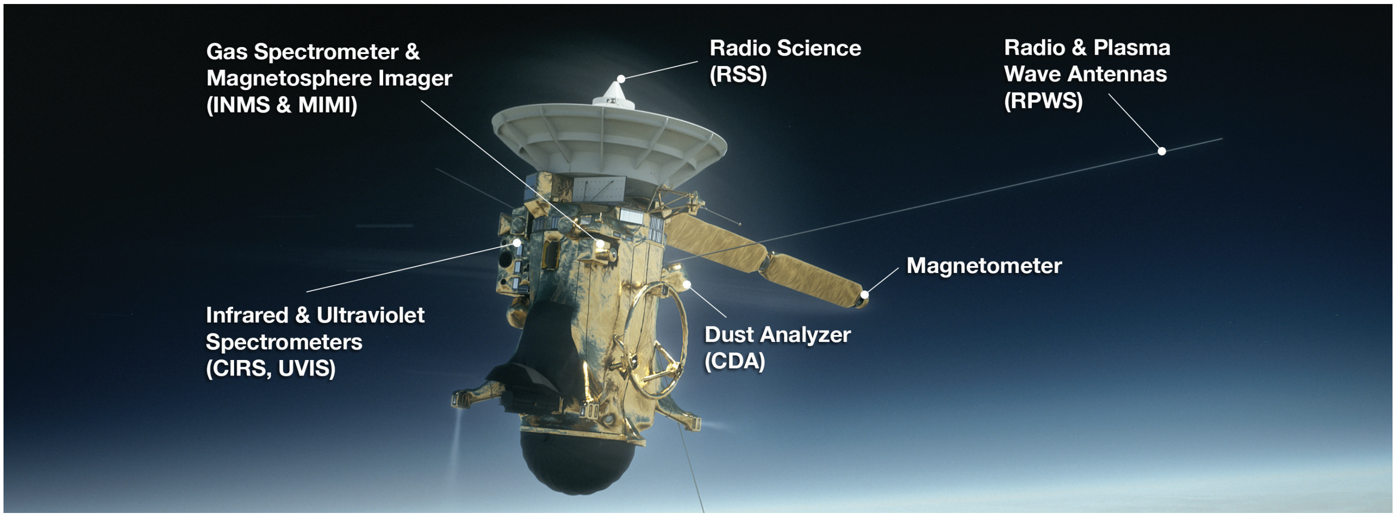
The Final Plunge

The final plunge begins about 3.5 hours prior to atmospheric entry. At this time, the spacecraft reconfigures itself to allow science and engineering data to be sent back to Earth with a delay of only a few seconds, rather than storing the data on the spacecraft's data recorder for transmission later. This novel approach allows the Cassini team to turn the Saturn orbiter into, essentially, an atmospheric probe for the last few hours of the mission. Eight of Cassini's 12 instruments – all the magnetosphere and plasma science instruments (CDA, INMS, MAG, MIMI, and RPWS), plus the spacecraft's radio science (RSS), and infrared and ultraviolet spectrometers (CIRS and UVIS) — will collect data during the final plunge.

Chief among the observations being made as Cassini dives into Saturn are those of the Ion and Neutral Mass Spectrometer, or INMS. The instrument will directly sample the composition and structure of the atmosphere, which cannot be done from orbit. The spacecraft will be oriented so that INMS is pointed in the direction of motion, to allow it the best possible access to oncoming atmospheric gases. (INMS is located on the side of the spacecraft where Huygens was attached) INMS is sampling the uppermost atmosphere during the five preceding orbits as well, but the spacecraft is expected to reach an atmospheric density about twice as high during the final plunge, prior to loss of contact.

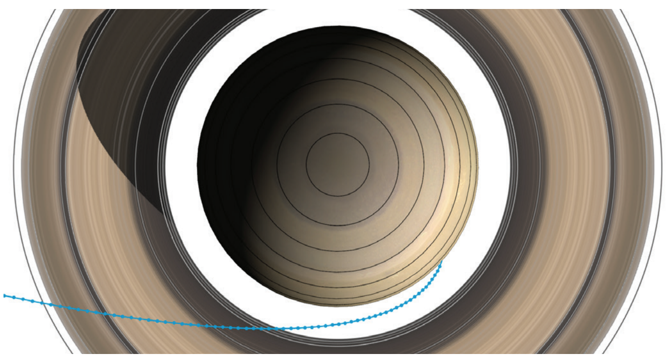


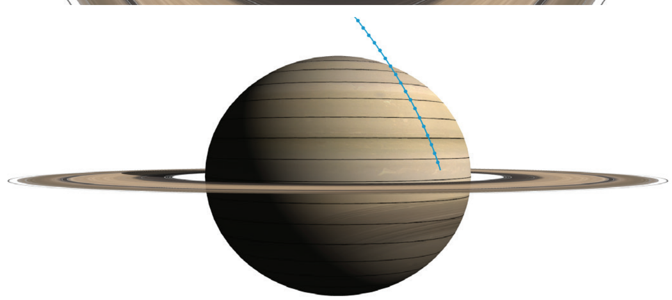
This graphic shows Cassini's final descent toward Saturn beginning with a distant encounter with Titan. Titan's position with respect to Cassini during the flyby is indicated here. Note that times are predicted as of late August and subject to change. See https://go.nasa.gov/2wbaCBT for updated times. Credit: NASA/JPL-Caltech. Click to view this image online.



Eight of Cassini's science instruments are planned to be turned on during the final plunge, including the Ion and neutral Mass Spectrometer (INMS). Credit: NASA/JPL-Caltech

Other first-ever observations include measurements of the temperatures, magnetic field, and plasma density in Saturn's ionosphere and thermosphere.





These graphics show Cassini's final plunge toward Saturn, with tick marks representing time intervals of 2 minutes, leading to the spacecraft's entry into the atmosphere. Credit: NASA/JPL-Caltech. Click to view the top-down image online. Click to view the side-view image online.

Cassini's Final Minutes

Cassini will enter Saturn's atmosphere approximately 10 degrees north of the equator. During the final plunge, the spacecraft will begin to encounter atmosphere much denser than any of the preceding five orbits (during which the spacecraft transits through Saturn's upper atmosphere at closest approach). Cassini's thrusters will begin firing to counter atmospheric torques in order to keep the high-gain antenna (HGA) accurately pointed at Earth with stability as it relays science data and spacecraft health data (telemetry) in near-real time.

Within one to two minutes after the thrusters begin to fire, increasing torque caused by atmospheric drag will push past their capacity to keep Cassini in a stable orientation. Once the HGA, which has a very narrow beam, turns away from Earth, our connection with the spacecraft will be permanently severed. This is predicted to take place at approximately 930 miles (1,500 kilometers) above Saturn's cloud tops (which lie around the 1 bar pressure level). When the signal is lost, the spacecraft's mission will be considered complete from the perspective of mission controllers on Earth.

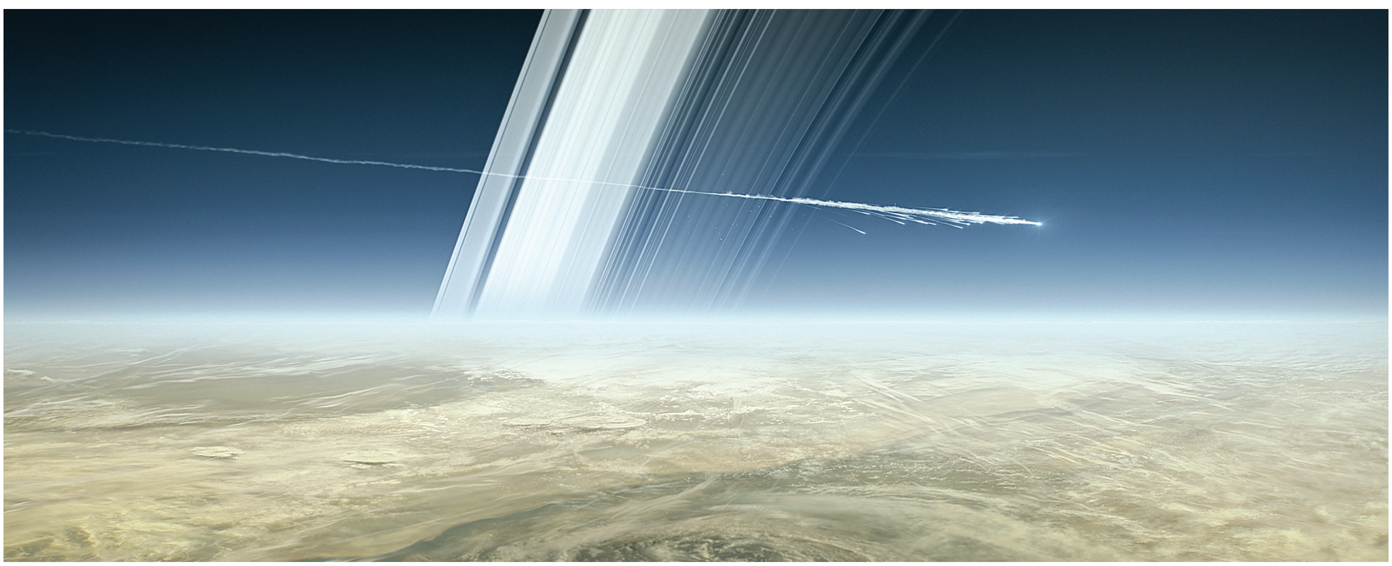
In the following seconds, Cassini will begin to run through its fault protection procedures as it attempts to stabilize itself, but it will soon begin to tumble -- slowly at first, and then quite rapidly, around multiple axes. Atmospheric friction, combined with the tumbling, will place extremely high loads on Cassini's structural components, causing some of them to break apart. The spacecraft is expected to burn up and break up like a meteor by the time it reaches the 1 bar atmosphere pressure level, around the height of the cloud tops. The remaining debris will sink into Saturn's deep atmosphere, where intense heat and pressure will cause all of its materials to melt and completely dissociate, eventually becoming completely diluted in the planet's interior.

Why End the Mission?

Cassini's finale plunge is a fitting and truly spectacular end for one of the most scientifically rich voyages yet undertaken in our solar system. This end was planned for Cassini in 2010, at the beginning of its second extended mission phase, known as the Solstice Mission. The seven-year Solstice Mission was designed to use Cassini's propellant in a way that would optimize the science return of the mission and satisfy planetary protection requirements. After a seven-year journey to Saturn and 13 years in orbit around the planet, the propellant used for adjusting Cassini's course is almost depleted. If left unchecked, this situation would eventually prevent mission operators from controlling the course of the spacecraft.

Over the past decade, Cassini data have revealed the potential of two moons of Saturn, Enceladus and Titan, to contain habitable — or at least "prebiotic" — environments. It is unlikely but possible that Cassini could someday collide with one of these moons if it were left in orbit around Saturn. Based upon exposure experiments on the International Space Station, it is known that some microbes and microbial spores from Earth are able to survive many years in the space environment — even with no air or water, and minimal protection from radiation.

Therefore, NASA has chosen to dispose of the spacecraft in Saturn's atmosphere to avoid the possibility that viable microbes from Cassini could potentially contaminate Saturn's moons — principally Enceladus, and to a lesser extent, Titan. This will ensure that Cassini cannot spoil future studies of habitability and potential life on those moons.



What's Next

As the Cassini spacecraft nears the end of a long journey rich with scientific and technical accomplishments, its legacy is an already powerful influence on future exploration. In revealing that Enceladus has essentially all the ingredients needed for life, the mission energized a pivot to the exploration of "ocean worlds" that has been sweeping planetary science over the past couple of decades.

Jupiter's moon Europa has been a prime target for future exploration since NASA's Galileo mission, in the late 1990s, found strong evidence for a salty global ocean of liquid water beneath its icy crust. But the revelation that a much smaller moon like Enceladus could also have not only liquid water, but chemical energy that could potentially power biology, was staggering.

Many lessons learned during Cassini's mission are being applied in planning NASA's Europa Clipper mission, planned for launch in the 2020s. Europa Clipper will make dozens of flybys of Jupiter's ocean moon to investigate its possible habitability, using an orbital tour design derived from the way Cassini has explored Saturn. The mission will orbit the giant planet (Jupiter in this case) using gravitational assists from large moons to maneuver the spacecraft into repeated close encounters, much as Cassini has used the gravity of Titan to continually shape the spacecraft's course.

In addition, many engineers and scientists from Cassini are serving on Europa Clipper and helping to shape its science investigations. For example, several members of the Cassini Ion and Neutral Mass Spectrometer team are developing an extremely sensitive, next-generation version of their instrument for flight on Europa Clipper. What Cassini has learned about flying through the plume of material spraying from Enceladus will be invaluable to Europa Clipper, should plume activity be confirmed on Europa.

By pulling back the veil on Titan, Cassini has ushered in a new era of extraterrestrial oceanography — plumbing the depths of alien seas — and delivered a fascinating example of earthlike processes occurring with chemistry and temperatures very different from our home planet.

In the decades following Cassini, scientists hope to return to the Saturn system to follow up on the mission's many discoveries. Mission concepts under consideration include spacecraft to drift on the methane seas of Titan and fly through the Enceladus plume to collect and analyze samples for signs of biology.

Atmospheric probes to all four of the outer planets have long been a priority for the science community, and the most recent Planetary Science Decadal Survey continues to support interest in sending such a mission to Saturn. By directly sampling Saturn's upper atmosphere during its last orbits and final plunge, Cassini is laying the groundwork for an eventual Saturn atmosphere probe.

Farther out in the solar system, scientists have long had their eyes set on exploring Uranus and Neptune. So far, each of these worlds has been visited by only one brief spacecraft flyby (Voyager 2, in 1986 and 1989, respectively). Collectively, Uranus and Neptune are referred to as ice giant planets. In spite of that name, relatively little solid ice is thought to be in them today, but it is believed there is a massive liquid ocean beneath their clouds, which accounts for about two-thirds of their total mass. This makes them fundamentally different from the gas giant planets, Jupiter and Saturn (which are approximately 85 percent gas by mass), and terrestrial planets like Earth or Mars, which are basically 100 percent rock. It's not clear how or where ice giant planets form, why their magnetic fields are strangely oriented, and what drives geologic activity on some of their moons. These mysteries make them scientifically important, and this importance is enhanced by the discovery that many planets around other stars appear to be similar to our own ice giants.

A variety of potential mission concepts are discussed in a recently completed study, delivered to NASA in preparation for the next Decadal Survey — including orbiters, flybys and probes that would dive into Uranus' atmosphere to study its composition. Future missions to the ice giants might explore those worlds using an approach similar to Cassini's mission.

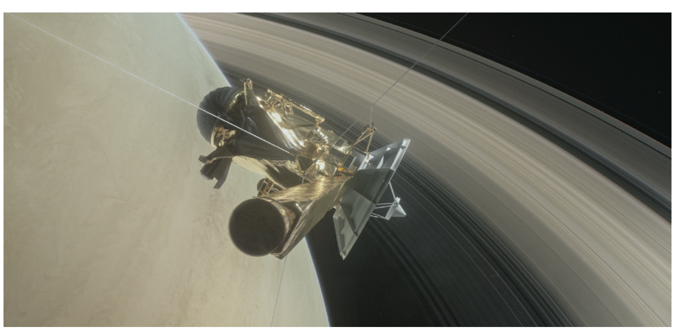
Frequently Asked Questions about Cassini's End of Mission

Q: Was it always planned that Cassini would end its mission by plunging into Saturn, or did this decision come about recently?

A: The preferred end-of-mission plan for Cassini has always been to safely dispose of the spacecraft in the upper atmosphere of Saturn. The exact "when" and "how" of the mission's conclusion has evolved over the years as the scientifically productive mission has been granted three extensions by NASA. The current "Grand Finale" scenario — to send the spacecraft on a series of orbits between the planet and its rings — has been part of the mission plan since 2010 and was developed in detail over the past four years.

Q: How much longer would Cassini have lasted if it had been allowed to remain in orbit?

A: The propellant remaining could be used for a few additional years of operations, but the scientific value of the observations during that time is much smaller than the scientific value of the mission's currently planned Grand Finale. The Grand Finale orbits represent a completely new mission for Cassini that pursues compelling and completely new science investigations. That, along with the planetary protection requirement to ensure Enceladus is not contaminated, make the Grand Finale orbits very attractive.



Q: Why dispose of the spacecraft in Saturn's atmosphere instead of using other possible ends for the mission (for example, send Cassini somewhere else in the solar system, attempt a landing on one of the moons, crash into the rings and watch the impact with telescopes)?

A: Concepts were evaluated for parking Cassini in an orbit around Saturn that would have been stable for a long time, along with a variety of other mission scenarios. However, the Grand Finale of close dives past the outer and inner edges of the rings, and ultra-close brushes with the planet and its small, inner moons, offered such enormous scientific value that this scenario was chosen for the mission's conclusion.

Q: Why is it safe to dispose of a spacecraft by burning it up in Saturn's atmosphere? Are we polluting Saturn? What about the possibility of life there?

A: Disposing of Cassini in Saturn's atmosphere is safe. The spacecraft will enter Saturn's atmosphere at high speed and will burn up like a meteor. Any spacecraft material that survives atmospheric entry, potentially including its radioisotope fuel, will sink deep into the planet where it will melt and become completely diluted as it mixes with the hot, high-pressure atmosphere of the giant planet.

Saturn's atmosphere does not have conditions that would be favorable to life as we know it, according to evaluations by the Committee on Space Research of the International Council for Science.

Program and Project Management

The Cassini program is an international cooperative effort involving NASA, the European Space Agency (ESA) and the Italian Space Agency, Agenzia Spaziale Italiana (ASI), as well as several separate European academic and industrial contributors. The Cassini partnership represents an undertaking whose scope and cost could not likely be borne by any single nation. The mission was made possible through shared investment and participation.

In the United States, the mission is managed for NASA's Science Mission Directorate by the Jet Propulsion Laboratory (JPL), Pasadena, California. JPL is a division of Caltech. At JPL, Earl H. Maize is the Cassini program manager. Linda J. Spilker is the Cassini project scientist, and Scott G. Edgington is the deputy project scientist.

At NASA Headquarters, Bill Knopf is Cassini program executive and Curt Niebur is Cassini program scientist.

Development of the Huygens Titan probe was managed by the European Space Technology and Research Center. The center's prime contractor, Aerospatiale (now Alcatel) in Cannes, France, assembled the probe with equipment supplied by many European countries. Huygens' batteries and two scientific instruments came from the United States.

ASI contributions were major components of the Radio Subsystem and the Radar and Visible and Infrared Spectrometer instruments.

At ESA, Nicolas Altobelli is the project scientist. Enrico Flamini, the ASI contract manager during the development phase, is the ASI project representative.

The U.S. Department of Energy provided Cassini's radioisotope thermoelectric generators. The U.S. Air Force supplied the Titan IVB/Centaur launch vehicle. These components, as well as the spacecraft propulsion module, were built by the mission's major U.S. contractor, Lockheed Martin.

Full list of Cassini team members and roles:
https://saturn.jpl.nasa.gov/mission/team

Follow Cassini in Real Time with NASA's Eyes on the Solar System

3-D Interactive lets you fly alongside Cassini at any point in its journey, including end of mission

It's the next best thing to being at the Jet Propulsion Laboratory as NASA's Cassini mission reaches its dramatic conclusion: NASA's Eyes on the Solar System app.

Eyes on The Solar System has developed a module dedicated to Cassini and its Grand Finale. In this online, interactive visualization, you can ride along with the Cassini spacecraft in realtime as it makes its last approaches to Saturn and its rings, or travel backward or forward to any point in the mission, from its launch in 1997 to any of its hundreds of icy moon flybys, to its fateful final plunge into Saturn's atmosphere on Sept. 15, 2017.

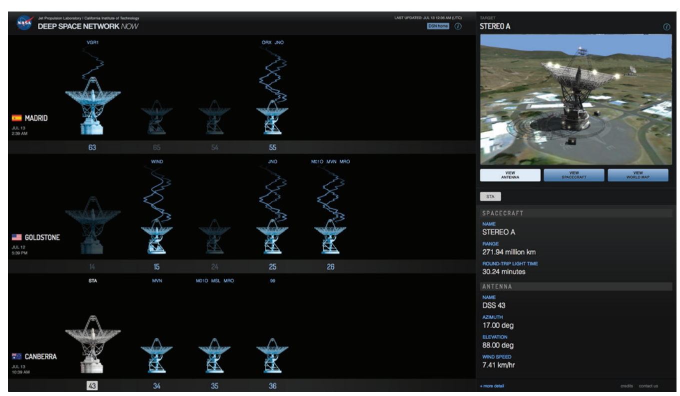
The module provides accurate speed, distance and time info based on the same navigation data used by NASA engineers to fly the spacecraft.

NASA's live commentary, to be broadcast on NASA TV and webcast online, will also use Eyes on the Solar System to help visualize Cassini's end of mission.

Try it for yourself!

Go to https://eyes.nasa.gov
and click "Cassini's Tour"

Also available is DSN Now, an interactive online resource showing real-time status of communications with spacecraft exploring deep space. DSN Now shows Cassini's signal during every communications pass, including end of mission.



Go to https://eyes.nasa.gov/dsn

Appendix

Digital Media and Assets

VIDEO

Cassini video reels for download
(animations, interviews and mission b-roll):

https://vimeo.com/album/4649677

Animations: Grand Finale and end of mission

https://vimeo.com/album/4649677/video/211408631

Other Cassini Web videos

https://www.jpl.nasa.gov/video/?search=cassini

Cassini's Grand Finale:

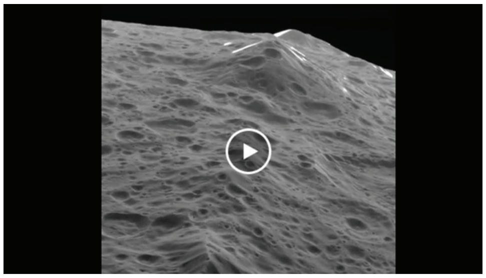
https://saturn.jpl.nasa.gov/resources/7628/?category=videos

Cassini's Greatest Hits ("The Wonder of Saturn"):

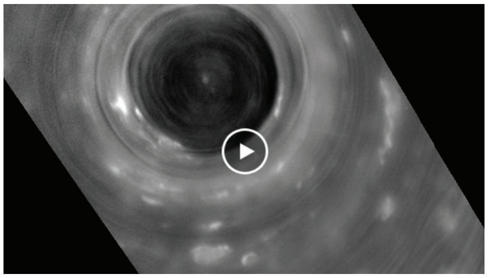
https://saturn.jpl.nasa.gov/resources/7747/?category=videos

Cassini's Grand Finale

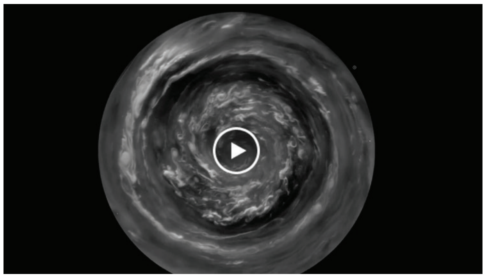
Flight Over Iapetus



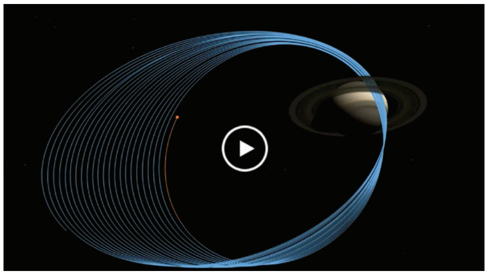
Cassini Noodle Mosaic of Saturn



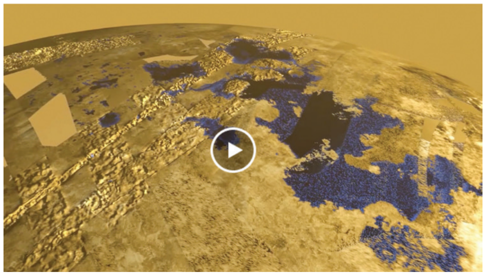
Saturn Hurricane



Grand Finale Orbits: Petal Plot

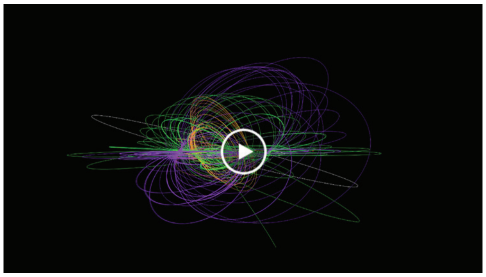


Flying Over an Extraterrestrial Land of Lakes



Cassini: The Wonder Of Saturn

The Ball of Yarn: Cassini's Orbits



IMAGES

Top Cassini images
(“Hall of Fame”)

https://saturn.jpl.nasa.gov/galleries/hall-of-fame

Photos of the Cassini spacecraft

https://saturn.jpl.nasa.gov/resources/?topic=153&type=51

Images processed by members of the public

https://saturn.jpl.nasa.gov/galleries/amateur-images

Mission graphics (diagrams, orbit info)

https://saturn.jpl.nasa.gov/resources/?topic=170&type=168

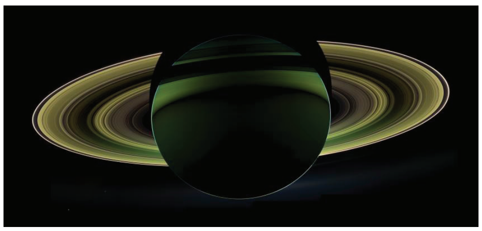
Raw (unprocessed) images gallery

https://saturn.jpl.nasa.gov/galleries/raw-images

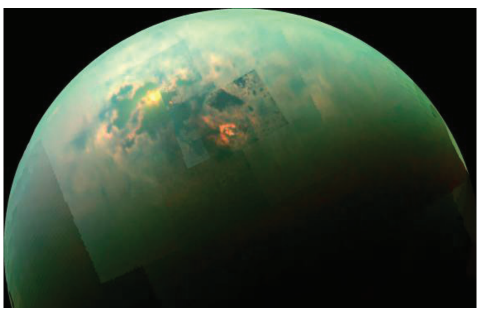
Additional top images, by year

https://saturn.jpl.nasa.gov/mission/top-tens/images

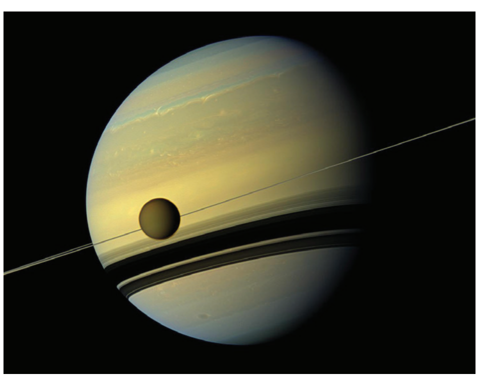
Backlit Saturn



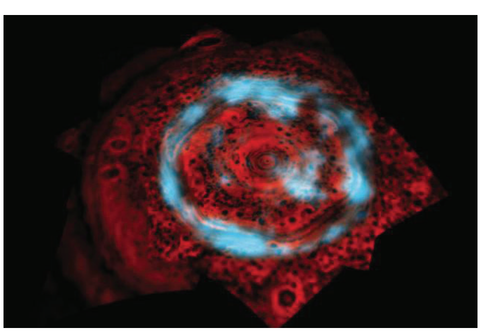
Through Titan’s Haze



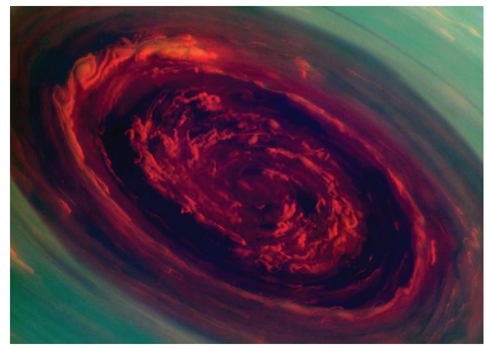
Titan and Saturn



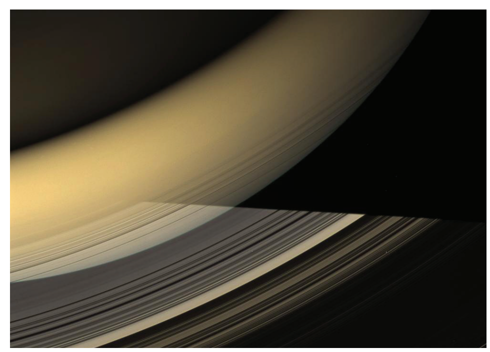
Saturn’s Auroras



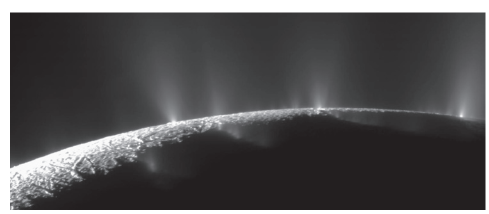
North Pole Vortex



Shadowed Rings



Enceladus Jets



Above Saturn