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Cassini: One Year Later

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Abstract

Cassini, the most distant planetary orbiter ever launched, arrived at Saturn in 2004. For the next 13 years, through its prime and two extended missions, and over almost half a Saturnian year, this spacecraft made astonishing discoveries, reshaping and fundamentally changing our understanding of this unique planetary system. Cassini sent back its final bits of unique science data on 15 September 2017, as it plunged into Saturn's atmosphere, vaporizing and satisfying planetary protection requirements.

During its last year of exploration, Cassini completed its investigations of the Saturn system, probed as-yet unsolved mysteries, observed seasonal and temporal changes, and addressed new questions that arose during the mission, some of which could only be answered during the final, unique orbits plunging between the rings and planet. Science highlights and new mysteries gleaned from the Ring Grazing and Grand Finale orbits will be discussed.

1. Key Mission Highlights

Titan, Earth-like world: Less than a year after arrival, Cassini released Huygens, the European Space Agency's parachuted probe built to study the atmosphere and surface of Titan. The Huygens probe became the first human-made object to land on an outer solar system moon. The probe's descent provided the first in situ measurements of atmospheric temperature, pressure and composition, and provided the first detailed images of the surface. Huygens revealed Titan's surface to be remarkably Earth-like and other Cassini instruments also found that Titan has many geologic processes reminiscent of those on Earth. These processes generate methane clouds and rain, build river channels, form lakes and seas containing liquid methane and ethane, form complex atmospheric hydrocarbons, and generate dunes of hydrocarbon particles. Cassini also detected a subsurface ocean on Titan.

Enceladus, an ocean world: Cassini's revolutionary findings at tiny Enceladus included icy jets of material shooting from Enceladus' four south polar fractures, or "tiger stripes", and a subsurface, global, salty ocean containing organics, ammonia, hydrogen, and silicates, with active hydrothermal vents on its seafloor. Cassini revealed an ocean world that is potentially habitable. These discoveries have fundamentally altered many of our concepts of where life may be found in our solar system. Enceladus is also the source of the E Ring and water from its jets dominates the Saturnian magnetosphere.

Dynamic Rings: Cassini's 13 years in orbit made it possible to observe temporal changes in Saturn's dynamic ring system. The orbiter discovered migrating propeller-like objects and unexpected ring particle clumping, imaged the possible birth of a new moon at the edge of the A ring, and observed one of the most active, chaotic rings in our solar system, Saturn's F ring. Ring processes provide a laboratory for how planets might form.

Saturn's storms: Cassini discovered hurricane-like storms centered at each pole. Around the north polar hurricane is a long-lived hexagonal-shaped jet stream that is two Earth diameters across. The source of this six-sided jet stream still remains a mystery. Cassini also provided multiwavelength coverage of a great northern storm that began in 2010, the first of its kind on Saturn since 1990. Within months, this storm completely encircled the planet with a swirling band of clouds and vortices, fading away nine months later, shortly after the main vortex in its head collided with one in its tail.

Saturn's Internal Rotation Rate: Saturn's Kilometric Radiation (SKR) was first observed by Voyager in the 1980's and used to make an initial calculation of Saturn's internal rotation period. However, when Cassini arrived at Saturn and measured the SKR period, data from the radio and plasma wave instrument showed that the variation in radio waves was different in the northern and southern hemispheres. Clearly the observations of SKR were not coming from the interior but are an atmospheric signal. It remained for magnetic field measurements taken during the Grand Finale orbits to attempt to solve this puzzle.

Many other fascinating discoveries were made by the Cassini orbiter and Huygens probe that are the subjects of numerous papers and books.

2. Cassini's Final Orbits

Cassini's ocean world discoveries required a mission end that would not allow the spacecraft to impact and potentially contaminate Saturn's ocean worlds once Cassini was out of fuel and could no longer navigate the Saturn system.

Ring Grazing Orbits. In late 2016, a close flyby of Titan changed Cassini's trajectory to a series of 20 Ring Grazing orbits with peripases located within 10,000 km of Saturn's F ring (Figure 1, gray orbits). These orbits provided some of the mission's highest-resolution views of Saturn's F ring, and A and B rings, and prime viewing conditions for fine scale ring structures such as propellers and wispy clumps in the rings. They also included the closest flybys of tiny ring moons, including Pan, Daphnis and Atlas, and remarkable views of the Daphnis-created wave on the edge of the Keeler gap. Plasma and dust composition measurements were also conducted in this region.

Grand Finale Orbits. In late April 2017, a final close flyby of Titan propelled Cassini across Saturn's main rings and into its Grand Finale orbits. The spacecraft repeatedly dove between Saturn's innermost rings and upper atmosphere for 22 orbits (Figure 1, blue orbits) attempting to answer fundamental questions unattainable earlier in the mission. The Grand Finale represented a brand-new mission, exploring a region of the Saturn system that was unexplored by any previous outer planet spacecraft.

Saturn's gravitational field was measured to unprecedented accuracy, providing information from which constraints on the interior structure of the planet, winds in the deep atmosphere, and mass distribution in the rings could be derived. Probing the magnetic field provided insight into the physics of the magnetic dynamo, the structure of the internal magnetic field, the location of the metallic hydrogen transition region and Saturn's internal rotation period.

The Grand Finale orbits provided the highest resolution observations ever of both Saturn's C and D rings and Saturn's atmospheric weather layer. Direct in-situ sampling of the ring particle composition and the innermost radiation belts was also achieved. The ion and neutral mass spectrometer sampled the exosphere and upper atmosphere for molecules entering and escaping from the atmosphere and water-based molecules originating from the rings. The cosmic dust analyzer directly sampled the composition of ring particles from different regions of the main rings for the first time.

Cassini's Final Half-orbit. The last orbit turned the spacecraft into the first Saturn atmosphere probe with all of fields and particle instruments gathering data as long as the spacecraft remained stable. Approximately one additional scale height of atmosphere was probed prior to loss of the radio signal from the spacecraft.

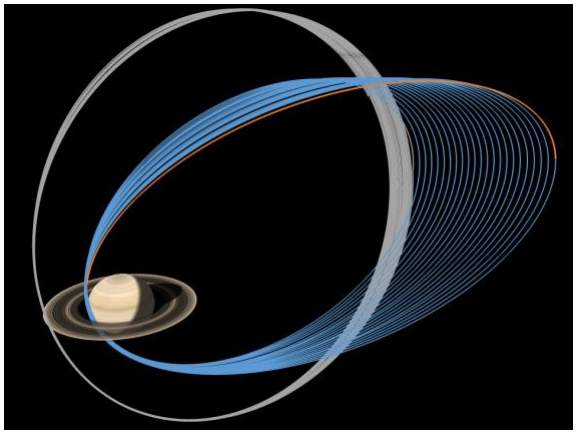

Figure 1: Cassini's 20 Ring Grazing (gray) and Grand Finale (blue) orbits. The last orbit (orange) plunged Cassini into Saturn's atmosphere.

3. Summary

Cassini-Huygens exploration of Saturn has yielded 13 years of unprecedented discoveries and answers to many scientific mysteries, in addition to revealing potentially habitable ocean worlds. The final phase of the mission ended with the first in-situ exploration of the region between the rings and planet.

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