Introduction

The Cassini-Huygens spacecraft was a joint space research mission with the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA). The Cassini-Huygens spacecraft was launched on October 15th, 1997. It aimed to study Saturn, its rings, its magnetosphere and its icy satellites [1]. The Cassini-Huygens mission accomplished many discoveries during its seven-year journey. It discovered icy plumes that sprayed from Enceladus, acquired high resolution images of Saturn's polar hexagonal jet stream and found lakes of liquid methane on Titan. Additionally, Cassini carried a probe called Huygens on its journey to the Saturnian system. Huygens developed by ESA, was tasked to explore Saturn's largest moon Titan. Huygens was the first spacecraft to land on a world in the outer solar system. Cassini began the final phase of its mission in April 2017 with a "Grand Finale" manoeuvre where it dove in between the 2000 km wide gap between Saturn and its rings every week before finally plunging deep into Saturn's atmosphere on September 15th, 2017 [2].

Mission trajectory and journey timeline

Cassini began its interplanetary journey in 1997. The rocket that launched Cassini was the most powerful rocket that was available to NASA at the time however, it was not powerful enough to send a nearly 6,000 kg spacecraft on a direct course to Saturn [3]. For this reason, flyby gravity assists were needed for Cassini to reach its target destination. This would also be beneficial to save propellant (heat emitted from the decay of Plutonium) on board the spacecraft. It first performed a flyby of Venus on the 26th of April 1998 and again on the 24th of June 1999. The gravitational pull of Venus gave Cassini a 7 km/s boost in speed. No opportunity was missed to study the characteristics of Venus during these flybys. Cassini searched for lightning in Venus's atmosphere and the radar instruments carried on board was used to bounce signals off the surface of Venus [4]. Leaving Venus, Cassini was moving more than 141,000 km relative to the Sun [4]. Cassini performed two other similar gravity assists using the gravity of Earth and Jupiter on the way to Saturn. It made its closest approach to Jupiter at 10 million km and joined forces with the Galileo spacecraft which was already in orbit around Jupiter. It captured 26,000 images of Jupiter and its moons [5]. Cassini spent 6 months orbiting the Jovian system with its closest approach being within 9.7 million km of Jupiter's cloud tops [5].

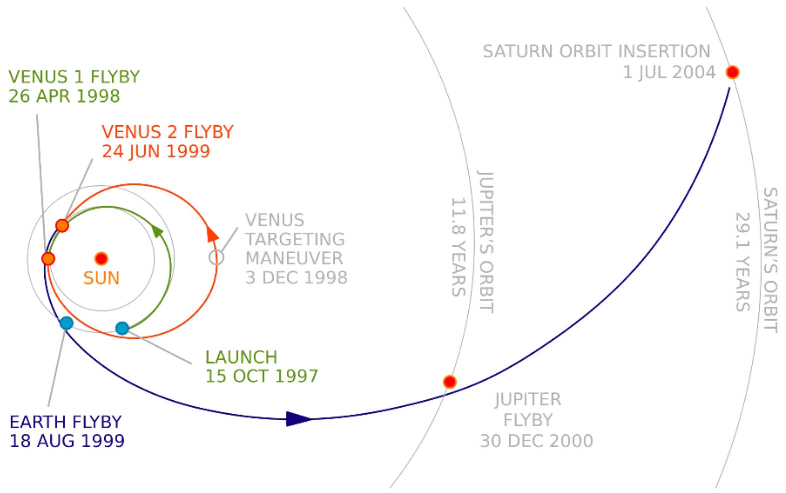

Fig 1. This graphic depicts Cassini's mission trajectory since the launch date. It includes positions and dates of flybys relative to the sun. Graphic acquired from https://science.nasa.gov/resource/cassini-trajectory/.

Cassini reached Saturn on July 1st, 2004, and later ejected the probe Huygens which was sent to orbit and land on Titan.

Cassini's mission planned to last four years however, at the end of its four-year orbit, NASA made the decision to extend the mission for another two years. This extension was known as the "Equinox Phase" because it marked the springtime period in the northern hemisphere of Saturn. This allowed for convenient imaging of the northern hemisphere and the northern latitudes of its moons [6]. Another mission extension was approved in 2010 for the operation of Cassini to last another seven years since the equipment onboard was still functional. This was known as the "Solstice Phase" to mark the phenomenon occurring in the hemisphere. During this time, the Sun's favourable position allowed for imaging of Saturn's north pole region [6].

After a remarkable two decades in space, it was time for Cassini to meet its end. The Solstice Phase aimed to expend the entirety of the spacecraft's Plutonium propellent because scientists feared that an uncontrolled spacecraft might collide with one of Saturn's icy moons that could be harbouring life. To enforce this, it was decided that Cassini would be plunged into Saturn's atmosphere. In total, Cassini orbited Saturn 294 times which included 113 Titan flybys, 24 trips past the icy moon Enceladus and 22 other trajectories around other moons [7]. Over the course of five months, Cassini set on a trajectory of 22 orbits which passed in between the planet and its rings. This was dubbed as Cassini's "Grand Finale" manoeuvre. This phase of the mission allowed scientists to observe Saturn from closer than ever before [7].

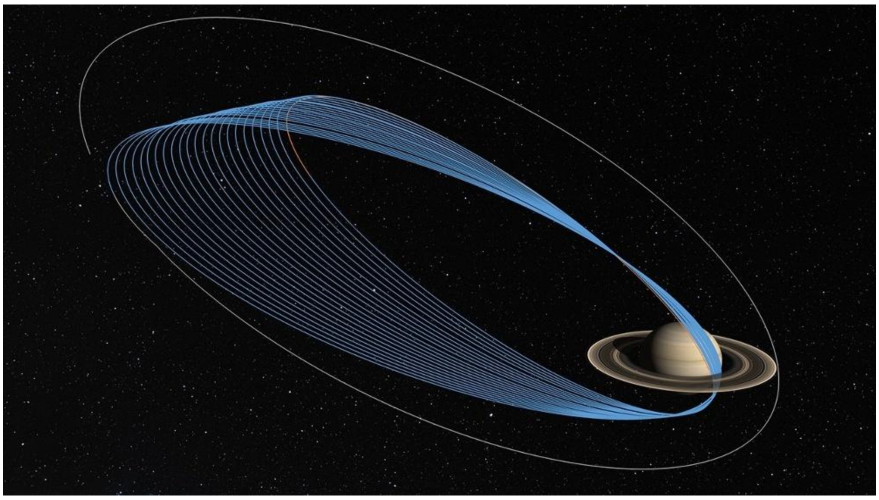

Fig 2. Artist's rendition of the orbit plot of Cassini's Grand Finale with the final orbit in orange. Image credit: Erick Sturm https://science.nasa.gov/resource/orbit-plot-cassini-grand-finale-artists-concept/

Main discoveries

Cassini began studying Enceladus in 2005. The equator of Enceladus receives the most sunlight with average temperatures around -193°C [8]. One would assume the south pole to be colder since it receives less sunlight, however, the temperature was found to be slightly warmer than the equator with a temperature of -188°C and the surface fractures located there were found to be as warm as -163°C [8]. Scientists had also observed water clouds above Enceladus but the heat source that allowed for the evaporation was unknown. By 2006, the images showed material gushing out from the moon's south pole, these were concluded to be icy water jets that erupted from the surface fractures. Scientists discovered that the composition of the material ejected mainly consisted of water and other molecular constituents such as CO_2, NH_3, H_2, and CH_4 [9]. This makes Enceladus a prime candidate for microbial life.

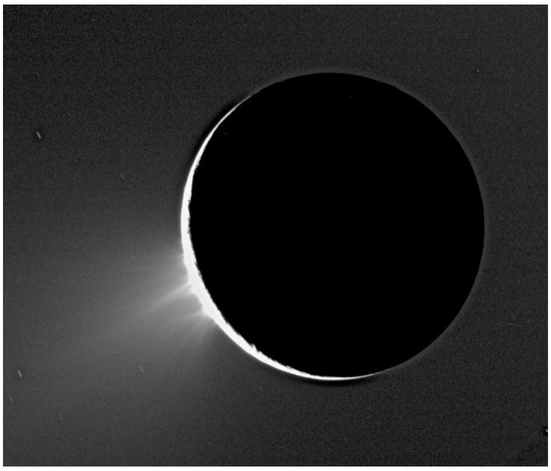

Fig 3. Image of Enceladus erupting icy plumes with sunlight scattering. Image taken from https://www.esa.int/Science_Exploration/Space_Science/Cassini-Huygens/Cassini_samples_the_icy_spray_of_Enceladus_water_plumes

Cassini also revealed the high-speed cyclonic vortex round Saturn's northern pole (76°N. lat.) with winds exceeding 135 m/s [10]. The hexagonal vortex was first discovered by Voyager in 1981, and the images Cassini took confirmed that it has remained unchanged since. The source of the hexagonal shape is not well understood however a possible "Rossby wave mechanism" (RW's), also known as a planetary wave mechanism, is a proposed explanation [10]. RW's develop in rotating fluids (in this case, planets) and form due to the Coriolis effect. When air moves towards the poles, it experiences an increase in the Coriolis force and is deflected eastwards. When it moves towards the equator, it experiences a decrease in force and is deflected westwards. This latitudinal motion may be a cause for the hexagonal shape, along with possible influences of other smaller vortexes that surround the polar region.

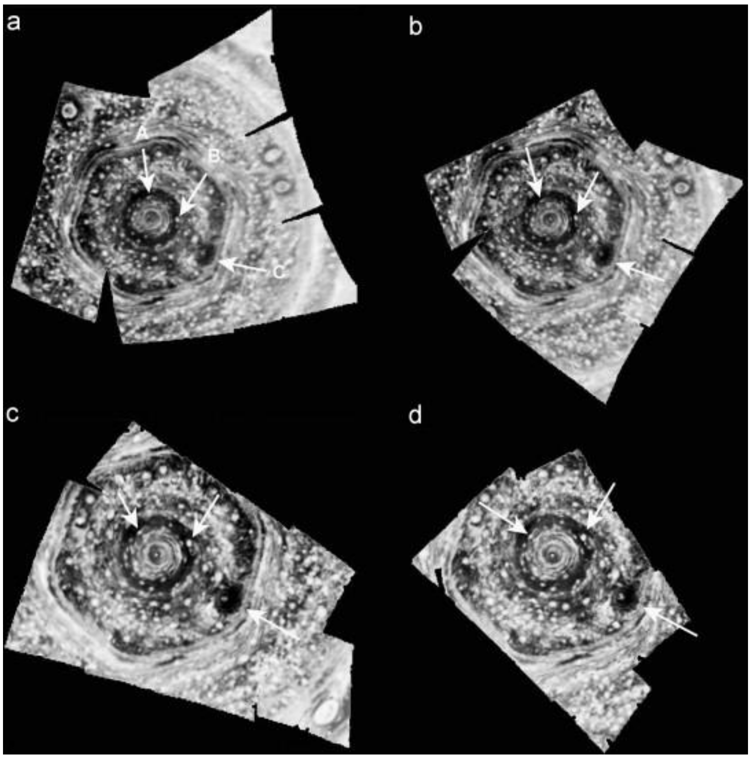

Fig 4. Set of 5.1μm mosaics of Saturn's polar hexagonal vortex. Brighter regions are clouds features. Image from Shttps://www.sciencedirect.com/science/article/pii/S0032063309001937

Cassini also carried with it the Huygen's probes developed by ESA and the ASI. The aim of the Huygens probe was to land on Titan and conduct a study of the moon's atmosphere and surface. Huygens landed on Titan on January 14th, 2005, over a boundary between bright icy terrain that had eroded by fluvial activity [11]. The surface of Titan seen through Cassini's camera show bright and dark regions scattered along the surface. These are hypothesised to be hydrocarbon lakes. During its 2.5 hours on Titan, Huygens returned the first images of Titan revealing its thick atmosphere to be rich in methane and organic compounds which was observed to be constantly reacting. If found on a planet with earth-like conditions, it would be a possible sign of life [12].

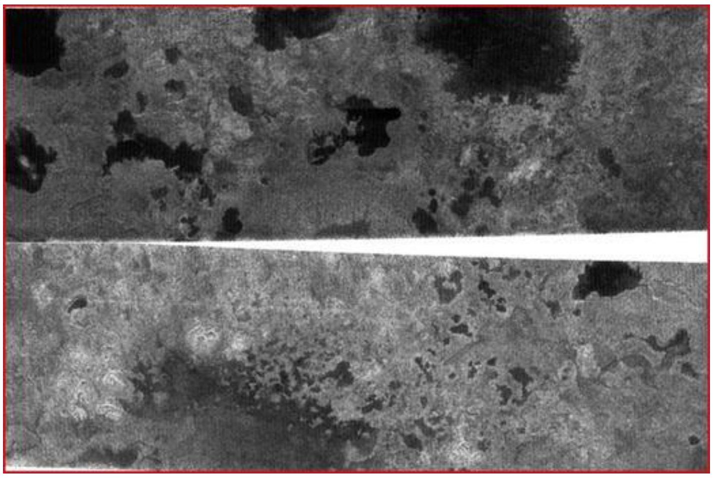 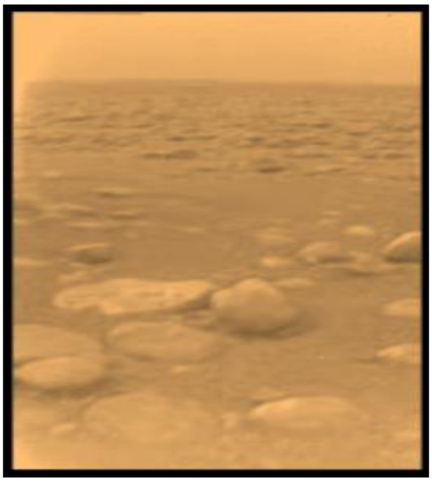

Fig 5. (Left) Picture of the surface of Titan taken from the Cassini orbiter. Image taken from NASA/JPL/Space Science Institute. Fig 6. (Right) Colourised version of the surface of Titan taken from the Huygens DISR camera after it landed. Image taken from https://nssdc.gsfc.nasa.gov/planetary/titan_images.html

Knowledge gained from the Cassini mission is now being applied to the NASA Europa Clipper mission. It aims to flyby Jupiter's ocean moons to investigate possible habitability and will follow the orbital tour design that was derived from the way Cassini explored Saturn.

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