Historian Corner

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Program Profile

This issue commemorates the 25th anniversary Cassini/Huygens mission to Saturn, which launched on a Titan TIVB/Centaur on October 15, 1997. The profile includes highlights from the discussion that I facilitated in a Zoom roundtable held in May, 2022 on the challenges for supporting and launching this major planetary mission. Several participants in the roundtable were kind enough to send written summaries of their efforts for this mission; those summaries and my notes from the roundtable are used for this profile.

Cassini/Huygens Major Mission Milestones

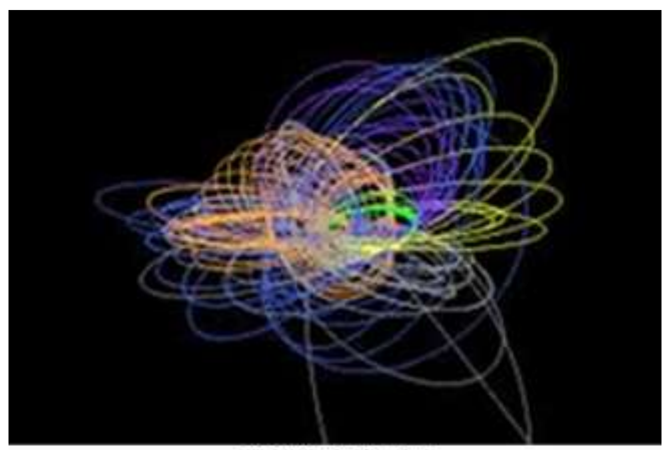
- Launched: October 10, 1997 08:43:00 UTC LC-40, CCAFS (now Space Force Station)
- Launch Vehicle: Titan TIVB-33 (401B) with Centaur upper stage (TC-20)
- Saturn Orbital Insertion: July 1, 2004 02:48 UTC (after a Venus-Venus-Earth-Jupiter Gravity Assist Trajectory)
- European Space Agency Huygens Probe landing on the moon Titan: January 14, 2005
- Number of Orbits of Saturn: 294
- End of Mission: Controlled entry into the atmosphere of Saturn, September 15, 2017 (Cassini had three mission extensions after its primary mission)

One of the Last Photos from Cassini
Enceladus Rises over Saturn
September 13, 2017
Photo Credit: NASA/JPL/ESA

The End of a Triumphant Planetary Mission

On Friday, September 15, 2017, the extraordinary Cassini spacecraft ended its final extended mission to Saturn by diving into the atmosphere of the giant ringed planet. This occurred on orbit number 294, after it had completed a risky last "Grand Tour" of the Saturnian system requiring several passes between the rings and the planet itself. Many mission controllers at JPL shed tears for the planned end of this mission, even though data will still be analyzed for years. I cried that day, too, as I consider this mission to be a career highlight (I retired after 37 years at Martin Marietta/Lockheed Martin exactly two months after the demise of Cassini).

I was on the launch team for the Titan Mission Success group at the Cape for the launch (see roundtable highlights) and I taught school groups and other organizations about the findings of the mission as a JPL Solar System Ambassador for quite a few years (my husband Steve also was a Solar System Ambassador for a few years and we did many presentations together). I followed the mission closely during the 13 years Cassini was at Saturn because of personal interest and to understand the discoveries that were made when doing this volunteer outreach work. The Solar System Ambassador program is a wonderful way to get the word out to the public about what the NASA/JPL programs are doing; the application for acceptance was longer and more intensive than a classified program clearance that I received.



The Yarn Pattern
Map of the Cassini Orbits of Saturn/Titan
during the Missions
Photo Credit: NASA/JPL/ESA

During the nearly 20 years the Cassini mission was in space and the 13 years at Saturn, nearly 2.5 million commands were issued, 635 gigabytes of data were collected, it traveled 4.9 billion miles, had 294 total orbits of Saturn, had 360 engine burns, took 453,048 images, and flew by the moon of Titan 127 times

(Titan was a "pivot point" of the many orbital paths up to the final Grand Tour). Cassini had close flybys of most of the other major moons of Saturn, many smaller moons and, of course, the rings of Saturn, including increasingly risky dives between the rings and the planet during the final "Grand Tour." Cassini also discovered seven new moons and unveiled the unique characteristics of the moon Enceladus, which has a likely internal ocean and is venting material onto its surface and into space. The European Space Agency provided the Huygens probe, which separated from Cassini and landed on the moon of Titan early in the mission and survived over 90 minutes on the surface of that large moon. Cassini mapped nearly 50% of the surface of Titan and determined that it also has a subsurface ocean of water and ammonia, along with seas of methane and ethane.

Cassini Mission Roundtable

On May 12, 2022, I facilitated a Zoom roundtable discussion about the Cassini mission (see link at the end of the article). Invitations were sent out earlier this year to round up some folks who were actively involved in that mission and the MARS members were invited to call in and hear the stories and ask questions. The audience participation was disappointing, but the panel was fantastic, full of fun anecdotes and shared memories. I thank the panel members for their participation! The final panel included the following members:

- Bob Jaquess: Mission Manager from the beginning of formal integration until retirement in 1994
- Leo Johnson: Titan IV Mission Manager for the Cassini mission after Bob's retirement
- Monte Kopke: Electrical Systems Manager (also Hydraulics)
- Jason Cowley: Avionics Mission Design/Payload Integration for Cassini mission
- Becky Bramlage: LM Payload Integration and Ground Mechanical (Becky had to leave the roundtable before she could participate in the discussion)
- Keith Hamlyn: Propulsion Module Systems Engineering for Cassini (Spacecraft Main Engine Assembly)
- Mark Edson: Booster Vehicle Harness Integrity Testing and Single Point Ground
- Tom Sayuk: Ground Mechanical Payload Integration (participated via notes shared with Jason Cowley)
- Barb Sande: Titan Systems Mission Success

The comments for each participant come from the panel discussion and/or notes that several of them provided before or after the Roundtable event.

Commentary by Bob Jaquess Mission Manager until 1994 (from the mission summary document he created):

The Cassini Spacecraft and Huygens planetary mission to Saturn was an extremely ambitious undertaking at the time. A follow on to the Voyager 1, 2 and Pioneer 11, the science objectives would take full advantage of the technologies at the time. It was hoped that this $3.3 billion mission (cost at launch) would provide answers to the many questions that the Voyager and Pioneer Spacecrafts had left unanswered in their very brief flyby of Saturn. Cassini and Huygens were loaded with science instruments and sensors for gathering as much data as possible.

The Mission Plan called for orbiting Saturn and exploring Saturn's Moons. It was a joint endeavor that would involve NASA, Jet Propulsion Lab (JPL), European Space Agency (ESA), Martin Marietta (now Lockheed Martin), General Dynamics who would provide the Centaur Upper Stage, and the Air Force. NASA and JPL would provide the Cassini Space Craft, ESA would provide the Huygens Probe, the Air Force would provide the Titan IV Launch Vehicle, and Lockheed Martin would provide the Payload Integration Process. The Cassini Mission consisted of three major parts. There was the Payload integration phase, the Hardware Building Phase and the Mission Phase. The integration phase began at Lockheed Martin in the early 1990's.

Early in the program Cassini became characterized by the progression of special studies. A primary objective was to accomplish the program in such a way that the primary mission would achieve 100% of the science objectives by launching on the primary launch date. Delaying to the backup launch date would yield only 80% of the science objectives. Delaying to the second backup launch date would yield only 50% of the science objectives, any further delays would result in such a small amount of science objectives being achieved the program would be terminated.

Three of the major concerns that could jeopardize the primary launch date was the availability of the Air Force-provided Titan IV Launch Vehicle, an injunction obtained by some 26 Environmental Activist Groups, and the weather. The primary mission for the Titan IV Launch Vehicles was national security. Any new security concern could result in the Air Force exercising priority either on the launch vehicle assigned to the Cassini Mission and or the launch date. Weather was another concern of which very little could be done to mitigate any adverse conditions.

A special project was initiated by Lockheed Martin Payload Integration Team to identify mitigations for the possible injunctions to stop the launch. The Environmental Activist Groups had become aware that the Cassini Spacecraft would be using nuclear power source in the form of plutonium power sources. They were concerned about the pollution that could occur if there was an accident. A special team was assembled in Payload Integration that was comprised of Roy Adams, Dr. Kevin Rudolf, Dr. Robert Lee and Lynn Zoller. This team were the primary authors of what became known as the Radioisotope Thermoelectric Generator (RTG) Safety Data Book. The book addressed the possible risk that could occur and the mitigations to these risks. Lockheed Martin's cost for the preparation of the RTG Book was $7,000,000! The book was successful in convincing Federal Judges to deny the numerous injunctions.

Another study consisted of trying to determine what problems that could occur that would jeopardize the launch. A team was assembled to brainstorm things that could impact the mission. This very extensive list was subject to prioritization in terms of likelihood of occurrence. Some items were eliminated due to the very low likelihood of occurrence. Remaining items were assigned a probability of occurrence. Those that had a high probability of occurrence were subject to mitigation plans that could be enabled in the event of an issue. The mitigations included steps that could be implemented in the event the problem occurred. Fortunately, none of the problems occurred and the Cassini Mission proceeded essentially trouble free to a launch on the primary date [the launch was initially scheduled for October 13, 1997 and was delayed 48 hours to October 15 due to a ground problem for Centaur that occurred after Centaur propellant loading].

The original plan called for the mission to last 3-1/2 years after completing the 7-year journey to Saturn. As it happened Cassini flight was so perfectly nominal that there were no mid-course corrections needed. The maneuvering propellant was saved and was available to use on the mission together with spare propellant. This enabled the mission to be extended for three more years. The mission was subsequently extended again so the total time was 20 years including the time to reach Saturn. Also, the original mission called for Cassini to use the last of the maneuvering propellent to escape Saturn's gravitational field and head for outer space. The plan was subsequently changed so that Cassini would descend through Saturn's atmosphere and burn up. This occurred on September 15, 2017.

Lockheed Martin performed the Cassini Payload Integration. Bob Jaquess was the Payload Integration Mission Manager for NASA Missions including the Cassini Mission. He assembled a Payload Integration Team that had the responsibility to prepare an Integration Control Document (ICD). This document defined the specifications and requirements needed for assuring that the launch vehicle, upper stage and Cassini Spacecraft would be able to interface successfully. The ICD was coordinated and developed with all the primary agencies participating. In addition to the Payload Integration Team there were various Lockheed Martin support groups that became involved. Examples are Loads and Dynamics, Mass Properties, Avionics, and Ground Operations. Members of the integration team interfaced with the various support groups. The Lockheed Martin Payload Integration Team was comprised of Roy Adams-RTG Safety Data Book, Jayson Cowley-Avionics, Chris Garcia-Planner/Scheduler, Pam Lavergne--Budget/Finances, Dr. Robert Lee-RTG Safety Data Book, Dr. Kevin Rudolf-RTG Safety Data Book, Tom Sayuk-Ground Operations, Lynn Zoller-RTG Safety Data Book, and Michael Summerlin who performed oversight at General Dynamics who provided the Centaur Upper Stage at San Diego.

Commentary by Leo Johnson, Mission Manager after the retirement of Bob Jaquess in 1994 (notes taken from the Roundtable discussion):

I had just finished launching a couple of USAF missions and knew what was required and assembled the team. The team worked in the "swamp", as we called it (named after the MASH team) and was extremely close-knit. Becky Bramlage worked ground operations. Conflicting rules from JPL, ESA, USAF, LM were a problem that we dealt with. We had team meetings all day long with LM, NASA, JPL and ESA sorting through the constantly changing rules. At the end near launch, protestors climbed into the pad area. Tough struggle with herding the cats. Technical crew did an outstanding job. We did speak unkindly about the protestors. Also, there were too many press people looking for stories.

Commentary by Monte Kopke, Electrical Systems Manager, Titan Program (notes taken from the Roundtable discussion):

This was the second TIVB vehicle after TIVB-24 [February, 1997, a non-Centaur mission]. We would have received new environments from that flight and were scurrying around to assess those environments. Lots of stuff in was in production. A funny story: Gene Pickett, who did cabling design, always had to get breakfast. There were three or four identical blue Pontiacs at the restaurant, and I picked the wrong one when we came out; guess that was the popular model at the rental car agency. Oh, and there was a lot of concern about the radiation environments, and I re-looked at the assessment. I'm also pretty sure that was the last vehicle with a full-blown sneak circuit analysis. JPL was concerned because the launch was during a Van Allen belt radiation maximum period and asked for the analysis.

Commentary by Jayson Cowley, Avionics Design & Payload Integration. Jason provided written notes *summarizing Avionics, Mission Design, Ground Mechanical, and Ground Operations with inputs from Tom Sayuk:*

Tom Sayuk:
Avionics:

- Electromagnetic Interference/Contamination was a significant concern due to the spacecraft instrument sensitivity. Mapping of permanent magnetic fields within the site processing facility were mapped and all tools had to be de-gaussed before being used within 5 meters of the spacecraft.
- Titan IV had very limited spacecraft data pass-through capability during ascent. Tailoring of data pages was used to optimize options.
- The capability to pass commands to the spacecraft was even more limited, essentially via 4 discrete (0 versus 28 volt) commands normally used for powering payload functions.
- These discrete commands were used, among other things, to send the "Bad News" command. This alerted the spacecraft flight software in the event that separation from Centaur had not been detected as planned. This was to be used by the spacecraft for contingency actions since uplink commands under these conditions could not be guaranteed.

Mission Design:

- As the first NASA flight of the upgraded SRMU, adequate and accurate performance estimates were a significant concern. This resulted in recurring test data deliveries as well as an extensive (and sometimes contentious) series of trajectory simulation shootouts between the NASA Lewis and Lockheed analysis teams.
- The interplanetary trajectory required that the spacecraft be placed into a static, heliocentric, and very narrow window of position and velocity regardless of the launch day or launch time. To meet the high energy and stringent target, a continuously-variable flight azimuth design was proposed. Ultimately, this proved too complex to design and verify in conjunction with the normal wind loads reduction steering. A compromise was to build separate trajectories for the open, middle, and close of the launch window for each day of the launch period. While a normal, earth-orbiting mission would design and verify two or three trajectories for a launch, Cassini required hundreds. This meant that each day the wind balloon data would be used to shape the trajectory for the appropriate window segment, be test-run in a ground simulation for verification, and then uploaded to the vehicle in a time-critical sequence.

Ground Mechanical:

- Cassini was a small spacecraft relative to the minimum size TIV-B payload fairing, which increases the severity of acoustic loads. To characterize and minimize the ascent vibro-acoustic environment, a series of tests at the Lockheed-Martin chamber were conducted. This provided empirical model information to design the fairing blanket thickness and coverage (see photo).

Acoustic Test of Cassini Model
Photo Credit: Provided by Jason Cowley

Ground Operations:

- The Cassini RTGs generated a lot of heat inside the insulated payload fairing that needed to be balanced to keep the rest of the instruments cool until exposed in space. A triple-redundant cooling system with independent cooling controls had to be designed to cut-over within 5 seconds of a failure.
- A major launch timeline driver was the installation of 3 RTGs late in launch site integration flow. Design of ground mechanical systems minimized the processing time and worker radiation exposure while meeting all safety requirements. Multiple installation rehearsals were conducted to ensure team members were trained properly.
- Once Cassini was stacked on the Titan IV and the HVAC connected, a significant design flaw was revealed. The spot-cooling flow intended for the RTGs was too high and resulted in tears in the spacecraft insulation. Repair and replacement of these one-of-a-kind blankets had to be completed on a short timeline to prevent delay of the mission.

One additional observation I can make was about the team "*esprit de corps.*" Over the many years of development, the JPL, Centaur and Titan TIV teams developed a wonderful working relationship. When meetings were held at the Cape, we would set up potluck dinners at the Cape Winds and have a fantastic time. Many of us look back and consider Cassini the highlight of our careers for this reason.

Commentary by Keith Hamlyn, Propulsion Module Systems Engineer, Cassini Main Engine Assembly. Keith provided an informative presentation about the Cassini propulsion system, which was used in an AIAA conference, with additional comments from the Roundtable notes:

Originally, the spacecraft propulsion system was going to be provided by the ESA. It came back to JPL and Martin Marietta was in competition with Lockheed and RCA and won the proposal. The Main Engine Assembly (MEA) is described as follows:

- The MEA function was to provide directed thrust for the delta-V maneuvers and for Saturn Orbit Insertion (SOI)
- The MEA consisted for two gimbaled "block redundant" Rocket Engine Assembly (REA) platforms that are pointed by a pair of Engine Gimbal Actuators
    - REAs can be moved in a 11.5-degree half-angle cone to ensure their thrust vector is pointed through spacecraft center of mass
    - Kaiser-Marquardt build the R-4D 100 lbf REA (now part of Aerojet-Redmond)
    - Titanium flex lines were required to feed MMH (Monomethyhydrazine) and NTO (Nitrogen Tetroxide) into the REAs
- REAs included pressure transducers and filters in each propellant leg
- Qualification temperature limits were -5 to 55 degrees C
- Tank pressures varied between 170 to 330 psia

A full-scale qualification unit was brought to White Sands NASA Test Facility in New Mexico. The qualification test was intended to verify at least twice operating life for the REAs, gimbals and other components at simulated flight conditions. During the testing a rough combustion phenomena was noted at a 260-300 Hz resonance that created disturbances of up to 10g on the REA mounting plate. Low temperature and fully saturated propellants along with low fuel valve inlet pressures were contributors to this "chugging" phenomena. This occurs when the MEA feed system resonant frequencies couple with an engine frequency from a combustion delay. An extensive analysis led to the implementation of two modifications:

- Removal of the MEA filters
- Tuned-coupled feedlines (detune the resonance response)

A welded version of the modes was implemented on the Qual MEA and a series of tests were run to verity the performance. It should be noted that NO chugging was observed during any of the burns during actual operation of the MEA on Cassini. Two lessons learned from this experience:

1) With the complexity of large propulsion systems there is no substitute for a full-up firing test to confirm the system performance is as expected,
2) As always, there were many involved in the successful resolution of this test issue, particularly NASA WSTF and JPL.

Cassini Main Engine Assembly
Photo Credit: Provided by Keith Hamlyn

Commentary By Mark Edson, Booster Vehicle Integrity Testing:

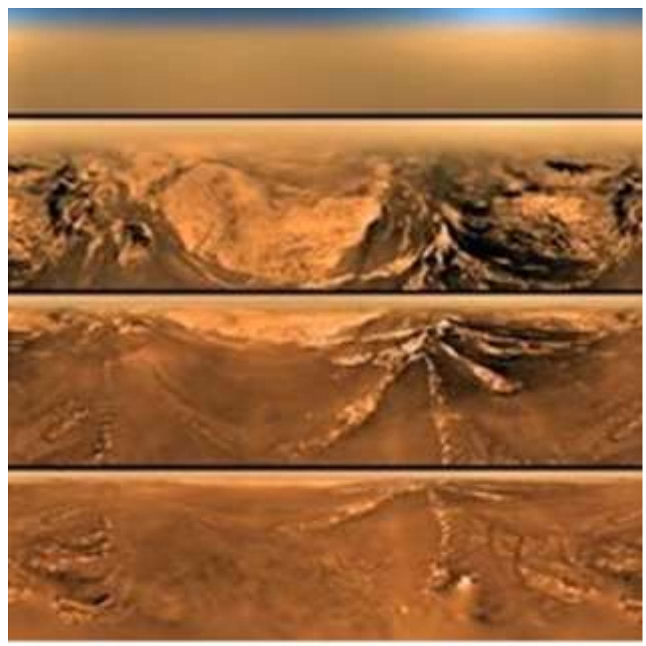
The booster vehicle, K-33, was late to the integrity testing process, putting pressure on the test team. Hook-up would take two weeks around the clock with over 400 connectors in Stage II alone. The Booster Integrity Test (BIT) used a Hughes Analyzer at 1500 VDC. There were concerns for shield integrity and retest was required after four weeks of fixing errors. The connectors were capped and stowed and there were no failures during single point ground test, a rarity. There were also no significant unverified failures that I recall. In light of successive vehicles with significant harness defects (TIVB-25 and TIVA-20, which was a flight failure due to a wiring short to structure), this was a clean vehicle, with minimal wiring errors.

Commentary by Barb Sande, Titan Systems Mission Success Lead:

I requested to be the launch support person for this vehicle, which was easily accommodated when my first boss, Todd Fenimore, was sent to VAFB to support the processing of TIVA-18 and Todd's boss, Larry Young, was asked to be an expert witness in a trial trying to the stop the launch in Hawaii. We talked a little bit about the protestors at the Roundtable, but they were significant nuisances hanging out at the gates and disrupting operations and yelling at people going in the gates. There were concerns on their part that the mission would fail and the RTGs would spread radioactivity all over Florida (or worse). They sued to stop the launch in the Ninth Circuit Court and requested the hearing be held in Hawaii. Larry was part of that hearing, and everyone was relieved when the court threw out the lawsuit. At the same time, we were trying to process a TIVA vehicle (TIVA-18) at VAFB, which was delayed from August, 1997, due to a problem with flow control valves on the Thrust Vector Control system on the SRMs (they actually released N2O4 on the pad). Another vehicle, TIVA-17, was also in work at the Cape. The three vehicles (TIVA-18, TIVB-33, TIVA-17) launched within 30 days of each other, becoming a "hat trick" that resulted in a great party when we got home.

Titan IVB-33/Titan Centaur TC-20 Launch
Payload: Cassini/Huygens to Saturn
October 15, 1997
Photo Credit: NASA/JPL/ESA

I was busy attending lots of worry meetings and status updates at the Cape and also helped with a 20 AH battery analysis after it failed activation. The machine shop room at the Cape was full of high-level NASA and USAF personnel watching some poor tech working on the battery breakdown (the usual foreign debris found between plates). Upper-level management didn't show up until the day before the first launch attempt on October 13 (delayed until October 15 because of a Centaur ground problem) because of the attempt to fly TIVA-18 at VAFB. We were told not to wear any of the Cassini souvenir clothing because of the protestors nor were we supposed to engage them. I recall having a late dinner at the bar at the Radisson and another person at the bar started screaming about how we were all going to die when Cassini launched. It took all of my self-control to get up and walk out; a veteran reporter with the BBC stayed and challenged this protestor's assertions. Needless to say, everything went great on a beautiful night for the launch and NASA and JPL were very happy with the booster and Centaur performance. It was fortunate that we launched when we did, because we lost three in a row starting the next year, in August, 1998.



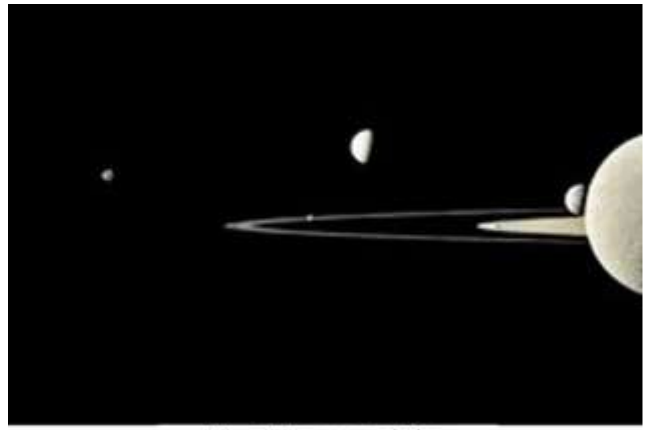
Descent Photos Taken from the Huygens
Probe of the Saturnian Moon Titan
Photo Credit: ESA

A Final Tribute to Cassini

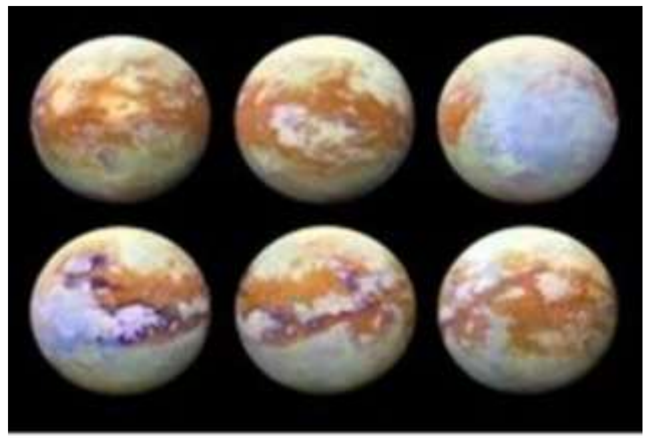
The Roundtable was a fun way to bring back memories of this fantastic event that happened to be a career highlight for many at LM. What better way to remember this mission than with a few stunning photos:

The Rings of Saturn
Photo Credit: NASA/JPL/ESA

Enceladus, A Mysterious Moon
with an Interior Ocean
Photo Credit: NASA/JPL/ESA



Five Moons and the
Rings of Saturn
Photo Credit: NASA/JPL/ESA



Infrared Imaging of Titan
Photo Credit: NASA/JPL/ESA

The Glorious Ringed Planet Saturn
Photo Credit: NASA/JPL/ESA

Resources and Links

Cassini at Saturn
https://www.nasa.gov/mission_pages/cassini/main/index.html

Cassini Overview
https://solarsystem.nasa.gov/missions/cassini/overview/

General and Supporting Information
https://en.wikipedia.org/wiki/Cassini–Huygens

Video: Last Look at Saturn
https://www.youtube.com/watch?v=_5ZrSKpbdSg

Last Fly-by of Titan
https://www.nasa.gov/feature/jpl/cassini-completes-final-and-fateful-titan-flyby

Link to Roundtable Discussion on YouTube
https://bit.ly/MARSCASSINI

Next Edition

In the next MARS STAR, I will profile the final Apollo lunar mission, Apollo 17. In 2023, look for articles about Skylab 1 (Skylab launch) & 2 (first lab crew), Mercury/Atlas 7-9 missions, and Skylab 3 & 4 (second and third crews).

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