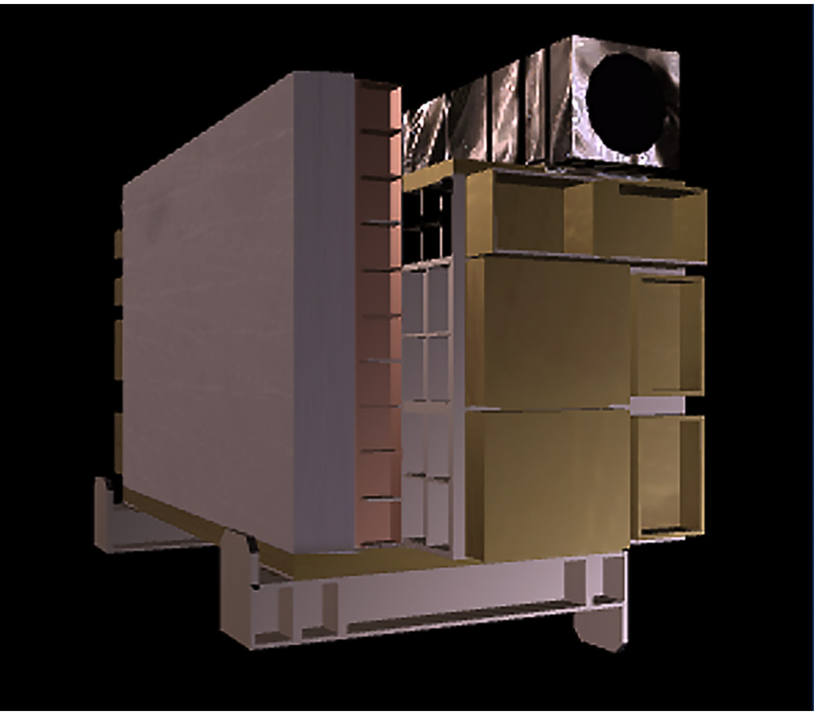

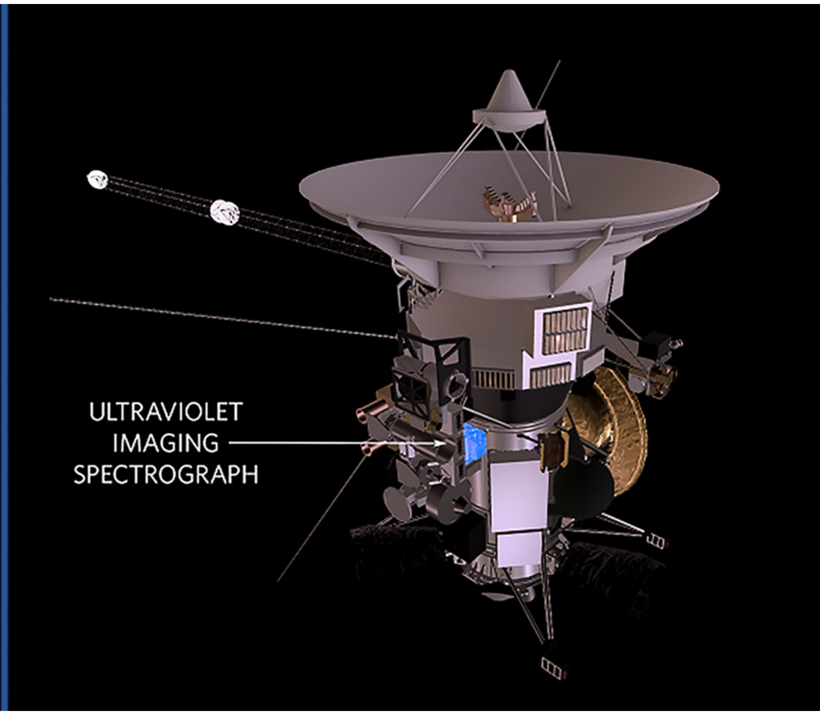

Ultraviolet Imaging Spectrograph

The Ultraviolet Imaging Spectrograph (UVIS) measured ultraviolet light (from 55.8 to 190 nanometers) invisible to the human eye from the Saturn system's atmospheres, rings, and surfaces. The science objectives of UVIS were to produce ultraviolet maps of Saturn's rings and many moons, to study the composition of atmospheres of the planet and its moon Titan, and also to look at how light from the Sun and the stars passed through atmospheres and rings in the Saturn system to determine their size characteristics and composition.

UVIS had two spectrographic channels: the extreme ultraviolet channel (EUV) and the far ultraviolet (FUV) channel, and also included a high-speed photometer (HSP) to perform stellar occultations, and a hydrogen-deuterium absorption cell (HDAC). The spectrograph could determine the atomic composition of those gases by splitting the light into its component wavelengths.

CONTENTS

Tables

Mission Objectives and Science Objectives and Results

The top ten discoveries from UVIS are listed here:

1. Enceladus icy jets spew 200 kg/sec of water, with no significant variations over the mission. The strongest jets are more variable, though.

2. Titan's airglow is primarily from sunlight and photoelectrons, but the weak night airglow is from magnetospheric particle impacts.

3. An atomic oxygen torus surrounds Saturn, peaking at its source, Enceladus.

4. The Europa atmosphere is dominated by atomic oxygen at low density, inconsistent with water plume activity at the time of the Cassini Jupiter flyby. The Enceladus plumes are significantly different from those found at Europa.

5. UVIS observations of propellers, gaps, ghosts, kittens, self-gravity wakes indicate ongoing aggregation in Saturn's rings; ring statistics, wavelet analysis, haloes, small particles show aggregation/disaggregation on an orbital time scale; we can understand this with an analogy to a predator-prey ecosystem.

6. UVIS and Visual and Infrared Imaging Spectrometer (VIMS) comparisons find small particles in the outer A-ring, and other regions that are strongly perturbed by moon resonances.

7. The ultraviolet (UV) spectrum of Saturn's rings can be matched by pure water ice polluted over the age of the solar system by material having the reflectance of Comet 67P (as measured by Rosetta's Alice). Using Cassini results for the ring mass from Radio Science Subsystem (RSS) and the polluting flux from Cosmic Dust Analyzer (CDA), we constrain the ring age to less than about 200 million years.

8. A solitary wave is excited by the Janus-Epimetheus swap, when Janus moves inward every eight years. This is evidence for non-linear dynamics, and may limit the application of previous conclusions based on a linear theory.

9. UVIS star and solar occultations quantify the profiles of aerosols, nitriles and organics in Titan's atmosphere; and show that Saturn's thermosphere breathes in and out. It was 'in' at the Grand Finale.

10. UVIS sees the auroral footprint of Enceladus and also time varying arcs and spots that indicate magnetospheric variations. Bombarding charged particle radiation may explain the dark color of the polar hexagon.

KEY OBJECTIVES

The UVIS science objectives include determination of the composition, structure and processes in the atmospheres of Saturn and Titan, composition of neutrals in the Saturn magnetosphere, morphology and active processes in the Saturn aurora, icy satellite surface and exosphere properties, the deuterium-to-hydrogen ratio in the atmospheres of Saturn and Titan, and the structure, dynamics and history of Saturn's rings.

SCIENCE ASSESSMENT, WITH TABLES

UVIS met or exceeded all science objectives with the exception of those related to D/H, which was due to a failure of the HDAC oxygen cell.

UVIS AO Mission Science Objectives

The UVIS instrument is designed to produce spatial UV maps, map ring radial structure, and to determine hydrogen/deuterium ratios. Specific science objectives for the Cassini mission are as follows.

1. Saturn System Scans
    a. EUV and FUV low resolution spectra of magnetosphere neutral and ion emissions.
    b. System scans at every apoapsis.
2. Satellites
    a. Latitude, longitude, and phase coverage coordinated through Satellite Surfaces Working Group (SSWG).
    b. Distant stellar occultations to determine satellite orbits and Saturn reference frame.
3. Atmosphere
    a. Vertical profiles of H, H_2, hydrocarbons, temp in exo, thermosphere.
    b. Long integrations map of hydrocarbons, airglow.
    c. Map emissions with highest resolution at the limb.
    d. Auroral Map: H and H_2 emissions over several rotations.

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4. Ring Stellar Occultation Objectives

   a. Highest Radial resolution (20 m) structure of rings

   b. Discovery and precise characterization of dynamical features generated by ring-satellite interactions.

      - Density waves and bending waves.
      - Edge waves and ring shepherding.
      - Embedded moonlets and discovery of new moons from dynamical response in rings.

   c. Discovery and precise characterization of azimuthal structure in rings.

      - Eccentric rings.
      - Density waves and edge waves.
      - Small-scale self-gravitational clumping in rings.

   d. Measure temporal variability in ring structure.

   e. Simultaneously measure UV reflectance spectrum of rings.

      - Determine microstructure on particle surfaces.
      - Compositional information on ring particles.

   f. Measure size distribution of large particles through occultation statistics.

   g. Measure dust abundance in diffraction aureole.

   h. Simultaneously search for flashes from 0.1 m–1.0 m meteoroid impacts.

Science Assessment Table

This table is an Assessment of Data collected to satisfy an objective. It is not an assessment of the status of data analysis/publications.

Table UVIS-1. Assessment of data collected to satisfy an objective.

Fully/Mostly Accomplished: **Partially Accomplished:** **Not Accomplished:**

UVIS Science Objectives	AO and TM Science Objectives	Science Assessment	Comments—if yellow (partially fulfilled)
1) Saturn System Scans			
EUV and FUV low resolution spectra of magnetosphere neutral and ion emissions.	S_AO4		
System scans at every apoapsis.	S_AO4, S_AO5, T_AO2, TN1c		Not every apo
2) Satellites			
Latitude, longitude and phase coverage coordinated through SSWG.	I_AO3		
Distant stellar occultations to determine satellite orbits and Saturn reference frame.			Not done
3) Atmosphere			
Vertical profiles of H, H2, hydrocarbons, temp in exo, thermosphere.	S_AO1		
Long integrations map of hydrocarbons, airglow.	S_AO1		
Map emissions with highest resolution at the limb.	S_AO1		
Auroral Map: H and H2 emissions over several rotations.	S_AO1		
4) Ring Stellar Occultation Objectives			
Highest Radial resolution (20 m) structure of rings.	R_AO1, R_AO3, R_AO4, RC1a, RC1b, RC2a, RN1c, RN2a, RN2b		
Discovery and precise characterization of dynamical features generated by ring-satellite interactions.	R_AO1, RC1a, b		
Density waves and bending waves.	R_AO1, RC1a, b		
Edge waves and ring shepherding.	R_AO1, RC1a, b		
Embedded moonlets and discovery of new moons from dynamical response in rings.	R_AO1, RC1a, b		
Discovery and precise characterization of azimuthal structure in rings.	R_AO1, RC1a, b		
Eccentric rings.	R_AO1, RN1c		
Measure temporal variability in ring structure.	R_AO1, RC1b		
Simultaneously measure UV reflectance structure.	R_AO1, R_AO2, RC1a		
Measure size distribution of large particles through occultation statistics.	R_AO1, R_AO2, RC1a		
Measure dust abundance in diffraction aureole.	R_AO2		
Simultaneously search for flashes from 0.1 m—1.0 m meteoroid impacts.	R_AO4		

Saturn System Results, including synergistic science and open questions

Saturn Atmosphere

Koskinen et al. [2015]; West et al. [2009]; Shemansky et al. [2012] give details of some of the UVIS results, which show the variability of Saturn's thermosphere; clouds and hazes in Saturn's atmosphere; and the structure of Saturn's upper atmosphere. Saturn's thermosphere was cooler at the time of the Grand Finale.

Titan Atmosphere

Solar and stellar occultations provide a probe of the Titan atmosphere [Shemansky et al. 2005]. Hazes [West et al. 2014] are created by photochemical processes [Liang et al. 2007a; Kammer et al. 2016]. The Titan airglow is primarily from sunlight and photo-electrons [Ajello et al. 2007, 2008b, 2012]. The weak nightside airglow is from magnetospheric particle impacts [Royer et al. 2017].

Saturn Magnetosphere

Contrary to pre-Cassini expectations, [Sittler et al. 2009], Saturn's magnetosphere is dominated by neutrals, unlike Jupiter [Shemansky et al. 2009; Melin et al. 2009]. This is the result of water vapor eruptions from Enceladus [Hansen et al. 2006].

Saturn Aurora

UVIS auroral observations have been correlated with those from Hubble Space Telescope (HST) [Gérard et al. 2005, 2013; Grodent et al. 2011, 2015; Gustin et al. 2010, 2012, 2013, 2017] to characterize the interactions with Saturn magnetosphere that give rise to these emissions [Radiotti et al. 2011, 2013a, 2013b, 2014a, 2014b, 2016a, 2016b, 2017a, 2017b].

Titan Airglow and Aurora

Stevens et al. [2011, 2015] and Lavvas et al. [2015] characterize the Titan airglow and compare the Nitrogen emissions to Earth's.

Icy Satellite Surfaces

The long Cassini mission provided full longitudinal and phase angle coverage of the icy satellites. The strong UV water absorption band is diagnostic of water ice, a major component of all the icy surfaces. This allows significant constraints on the surface composition and the processes that control the evolution of their surfaces [Hendrix et al. 2008a, 2008b, 2010a, 2012, 2017, 2018a, 2018b; Royer et al. 2014].

Icy Satellite Atmospheres

UVIS used stellar occultations and remote sensing to search for thin atmospheres. This was spectacularly successful for Enceladus [Hansen et al. 2006], see section entitled Enceladus Plumes and Jets. Searches at Tethys, Rhea and Dione showed no detectable atmosphere [Hansen et al. 2018].

Enceladus Plumes and Jets

The search for an atmosphere around Enceladus was successful when a stellar occultation probed the region above the south pole [Hansen et al. 2006]. Subsequent stellar and solar occultations mapped the structure and variability of the Enceladus plume and jets [Hansen et al. 2008, 2011, 2017]. Enceladus eruptions are mostly water vapor, with a variable amount of ice grains [Hedman et al. 2018]. No significant variations in the amount of water vapor is seen over the course of the mission, although the strongest jets, which lift the most icy grains, are more variable [Hansen et al. 2017].

Saturn's Rings

UVIS star, sun occultations and remote sensing of UV reflectance provide clues to the structure and composition of Saturn's rings. In turn, these results constrain the dynamics, history and origin of the rings, and parallels to other flattened systems, like proto-planetary disks. UVIS observations of propellers [Sremcevic et al. 2007], gaps, ghosts [Baillié et al. 2013], kittens [Esposito et al. 2008; Meinke et al. 2012], self-gravity wakes [Colwell et al. 2006, 2007] indicate ongoing aggregation in Saturn's rings; ring statistics [Colwell et al. 2017b], wavelet analysis [Esposito et al. 2012], haloes [Madhusudhanan et al. 2018], small particles [Colwell et al. 2009a, 2018b; Becker et al. 2016, 2018; Jerousek et al. 2016] show aggregation/disaggregation on an orbital time scale; we can understand this with an analogy to a predator-prey ecosystem [Esposito et al. 2012].

UVIS star, sun occultations and remote sensing of UV reflectance provide clues to the structure and composition of Saturn's rings.

UVIS and VIMS comparisons find small particles in the outer A-ring, and other regions that are strongly perturbed by moon resonances [Colwell et al. 2018b].

The UV spectrum of Saturn's rings can be matched by pure water ice polluted over the age of the solar system by material having the reflectance of Comet 67P (as measured by Rosetta's

Alice). Using Cassini results for the ring mass from RSS and the polluting flux from CDA, we constrain the ring age to less than about 200 million years [Esposito 2018].

A solitary wave is excited by the Janus-Epimetheus swap, when Janus moves inward every eight years [Rehnberg et al. 2017]. This is evidence for non-linear dynamics, and may limit the application of previous conclusions based on a linear theory.

Key Open Questions

1. What is the mechanism that creates the Enceladus plume, giving rise to its stability over the Cassini mission and the variability of its individual jets? How does it re-supply the E-ring?
2. How do magnetospheric processes mediate Titan's airglow emissions?
3. How do the possible plumes on Europa compare to Enceladus?
4. What is the basic mechanism for creation of aggregates in Saturn's rings and their subsequent dis-aggregation? What does this say about planet formation?
5. What is the origin of Saturn's rings, consistent with Cassini data?
6. How do chemical processes in Titan's haze layers give them seasonal variability?
7. What is the cause of the variability of Saturn's thermosphere?
8. How do magnetospheric phenomena produce the Saturn auroral variations?

Non-Saturn Results, including heliosphere, Venus, Moon, and Jupiter system

Heliosphere

Background

IPHSurvey (Interplanetary Hydrogen Survey) data were taken by the Cassini UVIS instrument with the EUV, FUV, and HDAC instruments throughout the mission, generally when not looking at a planet or moon. The objectives were to:

1. Monitor interstellar hydrogen and helium and their brightness variations in response to changing solar illumination at the H Lyman-alpha 121.6 nm and He 58.4 nm lines, changing solar EUV photoionization, and changing solar wind flows. In the case of H,

solar wind charge exchange of protons with neutral H is a dominant loss process for slow interstellar H passing through the solar system.

2. Monitor changes in instrumental flat-fields and spectral response because the emissions are spatially extended and always available.

3. Obtain information on H, He, O and other gases that may be present in the Saturn system.

Additional detail on the IPHSurveys can be found in Chapter 11 of the Cassini UVIS Users Guide written by Wayne Pryor.

Operational lessons

There was intense competition for observation time throughout the mission, except during downlink periods when the Cassini spacecraft was pointed to Earth. For this reason, we requested IPHSurveys for most downlink periods, and were usually granted these requests. In some later orbits, additional IPHSurveys were requested in non-downlink periods.

IPHSurveys were usually at low data rates, such as 74 bits per second, or 76 bits per second, but proved adequate for our purposes. The HDAC instrument participated in these IPHSurveys, and has obtained partial maps of the sky at Lyman-alpha.

Careful attention to Lyman-alpha degradation is necessary before analyzing UVIS IPHSurvey FUV data. The standard calibration pipeline degradation corrections may not be adequate and future work to improve corrections is needed.

Science lessons

Interplanetary hydrogen has been extensively studied on other missions and is fairly well understood. Pryor et al. [2008] explored how varying solar brightness (27-day variations as seen from Earth) varied going from solar observations at Earth to observations of hydrogen at Cassini and on out to observations of hydrogen at Voyager. As discussed previously by Quemerais et al. [1996], the initial 27-day brightness wave becomes increasingly damped with distance in the outer heliosphere due to multiple scattering effects, constraining the still poorly-known absolute H density values.

There is interest in the heliospheric community in future studies of the Cassini IPHSurvey data. For example, mutual observations—e.g., Hall [1992] obtained by two spacecraft looking towards and away from each other are useful for determining their relative calibrations. Future proposers to data analysis programs should be aware that there is a tremendous amount of data

There is interest in the heliospheric community in future studies of the Cassini IPHSurvey data.

available obtained with varying geometries. H and He brightness data is available throughout the mission. We have recently applied interstellar wind He models developed for Mariner 10 [Ajello 1978] to Lunar Reconnaissance Orbiter (LRO) Lyman-Alpha Mapping Project (LAMP) heliospheric observations [Grava et al. 2018]; these models may be adapted for future Cassini studies. IPHSurvey Observations obtained near Saturn especially merit further study as they may contain magnetospheric H and O, as was found by Melin et al. [2009] in Cassini UVIS system scan observations.

Venus

Cassini observed the Venus airglow during the Cassini Venus flyby [Gérard et al. 2011a, 2011b]

Moon

Cassini observed the lunar reflectance during the Cassini Earth flyby [Hendrix 2005].

Jupiter System

UVIS observed the Io plasma torus for a period of six months surrounding the Cassini Jupiter flyby [Steffl et al. 2004a, 2006] showing radial and temporal variations that extend the Voyager and Galileo measurements.

Europa's oxygen atmosphere and torus were also characterized by these data [Hansen et al. 2004, 2005]. These results place an upper limit on eruptive activity on Europa at the time of the Cassini Jupiter flyby [Shemansky et al. 2014].

Key Open Questions for Non-Saturn Science

1. How do the different eruptive styles of Europa and Enceladus lead to the remarkably different effects in the Jovian and Saturnian magnetospheres?

UVIS INVESTIGATIONS

Planned UVIS Science Investigations with Saturn AO and Solstice Mission Objectives

The UVIS instrument is designed to produce spatial UV maps, map ring radial structure, and determine hydrogen/deuterium ratios. Specific Announcement of Opportunity (AO) science objectives for the Cassini mission are:

1. Saturn System Scans
    a. EUV and FUV low resolution spectra of magnetosphere neutral and ion emissions.
    b. System scans at every apoapsis.
2. Satellites
    a. Latitude, longitude and phase coverage coordinated through SSWG.
    b. Distant stellar occultations to determine satellite orbits and Saturn reference frame.
3. Atmosphere
    a. Vertical profiles of H, H2, hydrocarbons, temp in exo, thermosphere.
    b. Long integrations map of hydrocarbons, airglow.
    c. Map emissions with highest resolution at the limb.
    d. Auroral Map: H and H2 emissions over several rotations.
4. Ring Stellar Occultation Objectives
    a. Highest Radial resolution (20 m) structure of rings
    b. Discovery and precise characterization of dynamical features generated by ring-satellite interactions.
        - Density waves and bending waves.
        - Edge waves and ring shepherding.
        - Embedded moonlets and discovery of new moons from dynamical response in rings.
    c. Discovery and precise characterization of azimuthal structure in rings.
        - Eccentric rings.
        - Density waves and edge waves.
        - Small-scale self-gravitational clumping in rings.
    d. Measure temporal variability in ring structure.
    e. Simultaneously measure UV reflectance spectrum of rings.

- Determine microstructure on particle surfaces.
- Compositional information on ring particles.

f. Measure size distribution of large particles through occultation statistics.

g. Measure dust abundance in diffraction aureole.

h. Simultaneously search for flashes from 0.1 m–1.0 m meteoroid impacts.

Implementation Challenges and Achievements

a. Distributed operations was a challenge, but gave the science team control.

b. Data limitations forced binning and windowing of the UVIS spectral images.

c. Evil pixels limited photometric accuracy and the spectral/spatial resolution.

d. UVIS calibration involved disparate approaches by different team members: Investigators used the approach most suited to their science.

e. Loss of the near ultraviolet (NUV) channel during mission de-scoping limited science for Saturn and icy satellites.

f. New scientific discoveries motivated new observational strategies to address them: Tracking occultations, shorter occultation integration periods, Enceladus star and solar occultations, Dione, Tethys and Rhea plume searches.

g. The multiplicity of ring occultations allowed investigations and discoveries not expected from our original proposal: Self-gravity wakes, gaps and ghosts, kittens and clumps, solitary waves.

Summary and Suggestions

The broad capability of UVIS allowed us to address our prime objectives and many new science questions that arose during the long mission. We were able to corroborate and/or extend findings from other instruments by riding along whenever possible.

AO Objectives

Table UVIS-2 shows the prioritized summary of the Cassini Solstice Mission Science Objectives.

Table UVIS-2. Prime Mission AO Science Objectives.

Saturn	Rings	MAPS	Icy Satellites	Titan
Cassini				
Determine temperature field, cloud properties, and composition of the atmosphere of Saturn.	Study configuration of the rings and dynamical processes (gravitational, viscous, erosional, and electromagnetic) responsible for ring structure.	Determine the configuration of the nearly axially symmetric magnetic field and its relation to the modulation of Saturn Kilometric Radiation (SKR).	Determine the general characteristics and geological histories of the satellites.	Determine abundance of atmospheric constituents (including any noble gases), establish isotope ratios for abundant elements, constrain scenarios of formation and evolution of Titan and its atmosphere.
Measure the global wind field, including wave and eddy components; observe synoptic cloud features and processes.	Map composition and size distribution of ring material.	Determine current systems, composition, sources, and sinks of magnetosphere charged particles.	Define the mechanisms of crustal and surface modifications, both external and internal.	Observe vertical and horizontal distributions of trace gases, search for more complex organic molecules, investigate energy sources for atmospheric chemistry, model the photochemistry of the stratosphere, study formation and composition of aerosols.
Infer the internal structure and rotation of the deep atmosphere.	Investigate interrelation of rings and satellites, including embedded satellites.	Investigate wave-particle interactions and dynamics of the dayside magnetosphere and the magnetotail of Saturn and their interactions with the solar wind, the satellites, and rings.	Investigate the compositions and distributions of surface materials, particularly dark, organic rich materials and low melting point condensed volatiles.	Measure winds and global temperatures; investigate cloud physics, general circulation, and seasonal effects in Titan's atmosphere; search for lightning discharges.
Study the diurnal variations and magnetic control of the ionosphere of Saturn.	Determine dust and meteoroid distribution both in the vicinity of the rings and in interplanetary space.	Study the effect of Titan's interaction with the solar wind and magnetospheric plasma.	Investigate interactions with the magnetosphere and ring systems and possible gas injections into the magnetosphere.	Determine the physical state, topography, and composition of the surface; infer the internal structure of the satellite.
Provide observational constraints (gas composition, isotope ratios, heat flux, …) on scenarios for the formation and evolution of Saturn.	Study interactions between the rings and Saturn's magnetosphere, ionosphere, and atmosphere.	Investigate interactions of Titan's atmosphere and exosphere with the surrounding plasma.		Investigate the upper atmosphere, its ionization, and its role as a source of neutral and ionized material for the magnetosphere of Saturn.
Investigate the sources and the morphology of Saturn lightning (Saturn Electrostatic Discharges (SED), lightning whistlers).				

Table UVIS-2. Prime Mission AO Science Objectives.

Saturn	Rings	MAPS	Icy Satellites	Titan
Huygens				
				Huygens: Determine abundances of atmospheric constituents (including any noble gases); establish isotope ratios for abundant elements; constrain scenarios of formation and evolution of Titan and its atmosphere.
				Huygens: Observe vertical and horizontal distribution of trace gases; search for more complex organic molecules; investigate energy sources for atmospheric chemistry; model the photochemistry of the stratosphere; study formation and composition of aerosols.
				Huygens: Measure winds and global temperatures; investigate cloud physics, general circulation and seasonal effects in Titan's atmosphere; search for lightning discharges.
				Huygens: Determine the physical state, topography and the composition of the surface; infer the internal structure of the satellite.
				Huygens: Investigate the upper atmosphere, its ionization, and its role as a source of neutral and ionized material for the magnetosphere of Saturn.

UVIS Traceability Matrix (TM)

Table UVIS-3 shows the prioritized summary of the Cassini Solstice Mission Science Objectives, and the goals to observe seasonal change in the Saturn system to understand the underlying process and prepare for future missions.

Table UVIS-3. Seasonal-Temporal Change and New Questions. Source: 2014 Senior Review Traceability Matrix (Table) + N2e (Hyperion) and IN2f (Iapetus) from 2010 Senior Review Traceability Matrix.

Saturn	Rings	MAPS	Icy Satellites	Titan
Seasonal-Temporal Change				
Priority 1				
SC1a: Observe seasonal variation in temperature, clouds, and composition in three spatial dimensions.	**RC1a:** Determine the seasonal variation of key ring properties and the microscale properties of ring structure, by observing at the seasonally maximum opening angle of the rings near Solstice.	**MC1a:** Determine the temporal variability of Enceladus' plumes.	**IC1a:** Identify long-term secular and seasonal changes at Enceladus, through observations of the south polar region, jets, and plumes.	**TC1a:** Determine seasonal changes in the methane-hydrocarbon hydrological cycle: of lakes, clouds, aerosols, and their seasonal transport.
SC1b: Observe seasonal changes in the winds at all accessible altitudes coupled with simultaneous observations of clouds, temperatures, composition, and lightning.	**RC1b:** Determine the temporal variability of ring structure on all timescales up to decadal for regions including Encke gap, D-ring, F-ring, and ring edges by substantially increasing the cadence and time baseline of observations.	**MC1b:** Observe Saturn's magnetosphere over a solar cycle, from one solar minimum to the next.		**TC1b:** Determine seasonal changes in the high-latitude atmosphere, specifically the temperature structure and formation and breakup of the winter polar vortex.
Priority 2				
SC2a: Observe the magnetosphere, ionosphere, and aurora as they change on all time scales—minutes to years—and are affected by seasonal and solar cycle forcing.	**RC2a:** Focus on F-ring structure, and distribution of associated moonlets or clumps, as sparse observations show clumps, arcs, and possibly transient objects appearing and disappearing.	**MC2a:** Observe seasonal variation of Titan's ionosphere, from on Solstice to the next.		**TC2a:** Observe Titan's plasma interaction as it goes from south to north of Saturn's solar-wind-warped magnetodisk from one solstice to the next.
New Questions				
Priority 1				
SN1a: Determine Saturn's rotation rate and internal structure despite the planet's unexpected high degree of axisymmetry.	**RN1a:** Constrain the origin and age of the rings by direct determination of the ring mass, and of the composition of ring ejects trapped on field lines.	**MN1a:** Determine the dynamics of Saturn's magnetotail.	**IN1a:** Determine the presence of an ocean at Enceladus as inferred from induces magnetic field and plume composition, search for possible anomalies in the internal structure of Enceladus as associate with plume sources, and constrain the mechanisms driving the endogenic activity by in situ observations and remote sensing.	**TN1a:** Determine the types, composition, distribution, and ages, of surface units and materials, most notably lakes (i.e., filled versus dry and depth; liquid versus solid and composition; polar versus other latitudes and lake basin origin).

Table UVIS-3. Seasonal-Temporal Change and New Questions. Source: 2014 Senior Review Traceability Matrix (Table) + N2e (Hyperion) and IN2f (Iapetus) from 2010 Senior Review Traceability Matrix.

Saturn	Rings	MAPS	Icy Satellites	Titan
SN1b: Observe the aftermath of the 2010–2011 storm. Study the life cycles of Saturn's newly discovered atmospheric waves, south polar hurricane, and rediscovered north polar hexagon.	**RN1b:** Determine the composition of the close-in ring moons as targets of opportunity.	**MN1b:** Conduct in situ and remote sensing studies of Saturn's ionosphere and inner radiation belt.	**IN1b:** Complete the comparative study of Saturn's mid-sized satellites, their geological and cratering histories, and interactions with the Saturn system, with remote sensing of Mimas at the highest resolution possible in order to understand the mechanisms behind its unique thermal properties discovered by Cassini.	**TN1b:** Determine internal and crustal structure: Liquid mantle, crustal mass distribution, rotational state of the surface with time, intrinsic and/or internal induced magnetic field.
SN1c: Measure the spatial and temporal variability of trace gases and isotopes.	**RN1c:** Determine structural and compositional variations at high resolution across selected ring features of greatest interest, using remote and in situ observations.	**MN1c:** Investigate magnetospheric periodicities, their coupling to the ionosphere, and how the SKR periods are imposed from close to the planet (3–5 R_S) out to the deep tail.	**IN1c:** Determine whether Dione exhibits evidence for low-level activity, now or in recent geological time.	**TN1c:** Measure aerosol and heavy molecule layers and properties.
Priority 2				
SN2a: Monitor the planet for new storms and respond with new observations when the new storms occur.	**RN2a:** Conduct in-depth studies of ring microstructure such as self-gravity wakes, which permeate the rings.	**MN2a:** Determine the coupling between Saturn's rings and ionosphere.	**IN2a:** Determine whether there is ring material orbiting Rhea, and if so, what its spatial and particle size distribution is.	**TN2a:** Resolve current inconsistencies in atmospheric density measurements (critical to a future Flagship mission).
	RN2b: Perform focused studies of the evolution of newly discovered propeller objects.		**IN2b:** Determine whether Tethys contributes to the E-ring and the magnetospheric ion and neutral population.	**TN2b:** Determine icy shell topography and viscosity.
			IN2c: Determine the extent of differentiation and internal inhomogeneity within the icy satellites, especially Rhea and Dione.	**TN2c:** Determine the surface temperature distribution, cloud distribution, and tropospheric winds.

Table UVIS-3. Seasonal-Temporal Change and New Questions. Source: 2014 Senior Review Traceability Matrix (Table) + N2e (Hyperion) and IN2f (Iapetus) from 2010 Senior Review Traceability Matrix.

Saturn	Rings	MAPS	Icy Satellites	Titan
			IN2d: Observe selected small satellites to quantify the movement of Enceladus material through the system, the history of satellite collisions/breakup, interaction with ring material as indicated by surface properties/ composition, and cratering rates deep in the Saturnian system.	
			IN2e: Understand the unusual appearance of Hyperion with remote sensing observations of the highest resolution possible.	
			IN2f: Use remote sensing of Iapetus to test models for the albedo heterogeneity of the satellite. Quantify the effect of the newly-discovered Phoebe ring on the properties of Iapetus' surface.	

Cell Codes:

First Letter = Discipline (**S**aturn, **R**ings, **M**agnetospheric and Plasma Science (MAPS), **I**cy Satellites, **T**itan)

Second Letter = Objective Type (**C**hange related or **N**ew question)

Third number = Priority Level (**1**, **2**)

Fourth Letter = Distinction within Priority Level (**a**, **b**, **c**, etc.)

ACRONYMS

Note: For a complete list of Acronyms, refer to Cassini Acronyms – Attachment A.

AO	Announcement of Opportunity
CDA	Cosmic Dust Analyzer
EUV	extreme ultraviolet channel
FUV	far ultraviolet channel
HDAC	hydrogen-deuterium absorption cell
HSP	high-speed photometer
HST	Hubble Space Telescope
LAMP	Lyman-Alpha Mapping Project
LRO	Lunar Reconnaissance Orbiter
MAPS	Magnetospheres and Plasma Science
NUV	near ultraviolet
RSS	Radio Science Subsystem
SED	Saturn Electrostatic Discharges
SKR	Saturn Kilometric Radiation
SSWG	Satellite Surfaces Working Group
TM	Traceability Matrix
UV	ultraviolet
UVIS	Ultraviolet Imaging Spectrograph
VIMS	Visual and Infrared Imaging Spectrometer

References

__Disclaimer:__ The partial list of references below correspond with in-text references indicated in this report. For all other Cassini references, refer to Attachment B – References & Bibliographies; Attachment C – Cassini Science Bibliographies; the sections entitled References contributed by individual Cassini instrument and discipline teams located in Volume 1 Sections 3.1 and 3.2 Science Results; and other resources outside of the Cassini Final Mission Report.

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