**Overview**

The Titan Sections in Cassini Final Mission Report **(In preparation)** summarizes the status of Titan science, in 2018, as a result of Cassini exploration of the Saturn system. It also includes open questions that will be explored by future scientists.

Charm Talks is a series of talks given by the team that provides insight into discovery and development of understanding

**Mission Objectives**

* 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.
* 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.
* Measure winds and global temperatures; investigate cloud physics and general circulation and seasonal effects in Titan's atmosphere; search for lightning discharges.
* Determine physical state, topography and composition of surface; infer internal structure.
* Investigate upper atmosphere, its ionization and its role as a source of neutral and ionized material for the magnetosphere of Saturn.
* Determine seasonal changes in the methane-hydrocarbon hydrological cycle: of lakes, clouds, aerosols, and their seasonal transport.
* Determine seasonal changes in the high-latitude atmosphere, specifically the temperature structure and formation and breakup of the winter polar vortex.
* 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.
* Determine the types, composition, distribution, and ages, of surface units and materials, most notably lakes (i.e. filled vs. dry & depth; liquid vs. solid & composition; polar vs. other latitudes & lake basin origin).
* Determine internal and crustal structure: Liquid mantle, crustal mass distribution, rotational state of the surface with time, intrinsic and/or internal induced magnetic field.
* Measure aerosol and heavy molecule layers and properties.
* Resolve current inconsistencies in atmospheric density measurements (critical to a future Flagship mission).
* Determine icy shell topography and viscosity.
* Determine the surface temperature distribution, cloud distribution, and tropospheric winds.

A list of publications related to Titan can be found on the Cassini Titan Reference Page.

**Titan Data**

The science topics above include links to data sets related to each topic. This section includes a comprehensive list of all of the search tools and data archives related to Titan studies.

**Data Search Tools**

**Searching by parameters:**

OPUS is a search tool for CIRS, ISS, UVIS and VIMS data with a wide variety of search parameters including the target body, distance, and illumination conditions.

PDS Imaging Atlas is a search tool for ISS and RADAR data with a wide variety of search parameters including the target body, distance, and illumination conditions.

**Searching by surface map:**

Titan Trek **(in development)** is a Geographical Information System (GIS) tool to find, visualize and download data in the context of a map of Titan.

PILOT is a Geographical Information System (GIS) tool to find and download data in the context of a map of Titan (data through 2010).

**Searching by mission events:**

The Event Calendar helps search for Titan observations of icy satellites and related events such as ring-plane crossings.

**Documentation and Orientation**

**Narrative from the Cassini Titan mission reps (we have TOSTsummary\_v8 content complete, maybe nice to have a documentarian clean it up – or pay Kathleen?) (I’ve got this-needs editing –TOSTsummary\_v8.doc)** about how they planned the suite of observations made by different instruments. Includes observation tables, and helpful summary information on the variety and scope of Titan observations.

* Flyby Naming Scheme (T126 is the 127th flyby)
* **Templates (& Engine/Caboose Templates) Description (work not completed…will await 2019 funding, if it doesn’t get done then what is in the narrative will have to do)**

**One-page summary of all flybys**

**Legend for the one-page summary (Rudy has this close to done but is still working on it…Kathryn is it OK to charge in November for this? I would say end of November a good target)**

Titan Flyby Table, including: **This hidden table is not populated** **Trina - We need help on understanding your intent (OK Rob had a good start, maybe we should schedule a half hour to go over the concept…but will take some time to break out products – for example we have all the timelines done but they are on tab’s of a excel spreadsheet) This is the load that Trina is sending us**

Master Timelines **(content basically complete, but need to locate in such a way as they table gets populated, same with groundtrack phase and altitude plots)**

* Prime Mission Flybys (T0-T44)
* **Equinox (XM) Mission Flybys (T45-T70)**
* **Solstice (XXM) Mission Flybys (T71-T126)**
* Non-Targeted and Grand-Finale Flybys
* Master Timeline Legend

Tour Atlas

* **Groundtrack Phase and Altitude Plots** need to update tour atlas
* **Basic Data Plots (phase, distance, body plots, etc.)** need to update tour atlas

Other flyby information

* RADAR SAR Flyby Summaries for Each RADAR Flyby

As flown SPASS for Titan Observations What is SPASS? **(All CIMS timelines with collected…so this is the “as uplinked” product – and would go in the table as such)**

**Instruments Used to Study Titan with Links to Data**

VIMS Powerpoints (e.g. T126\_VIMSobservations.pdf, Whole Set (130 MB))

ISS Data Processing Strategies and surface-study idiosyncrasies

CIRS Instrument and Titan-specific Guidebook

CIRS Sequence Notes (S59-S101, other sequences if time available)

CIRS Titan Target Notebook

UVIS Titan EUV/FUV Book

UVIS Saturn and Titan Occultation Atlas and Data Book

**Reference Tables to Help Find and Understand Data**

**Titan geometry (these are part of the Tour Atlas and shouldn’t be down in this area…they should be up above)**

Close flyby Times, Details, and Summary Plots **These all start at orbit 199**

Sun-Cassini-Titan Angle of less than 15 Degrees or 12 Degrees **These start at orbit 198**

Full Titan Tour Geometry in 5 Minutes or 1 Hour intervals **starts Oct 17 2013**

**Titan Interior**

Cassini measured Titan's gravity field and dynamic tidal response, indicating (together with Huygens electric field data) the presence of a deep subsurface water ocean—one denser than liquid water and thus possibly salty. A relatively low density, possibly hydrated, core was detected.

Cassini measured the shape of Titan's gravity field, including the tidal response and firmly established no intrinsic magnetic field.

**Key Publications**

In Titan from Cassini-Huygens (Brown, R. H., J-P. Lebreton, and J. H. Waite, Jr., Eds). Springer, 535 pp., 2009 (DOI: 10.1007/978-1-4020-9215-2)

The Origin and Evolution of Titan. J Lunine, M Choukroun, D Stevenson, G Tobie

In Titan: Interior, Surface, Atmosphere, and Space Environment (Ingo Müller-Wodarg , Caitlin A. Griffith , Emmanuel Lellouch, Thomas E. Cravens, Eds). Cambridge University Press (2014) (DOI: 10.1017/CBO9780511667398)

The Origin and Evolution of Titan. Tobie, G., J.I. Lunine, J. Monteux, O. Mousis And F. Nimmo

**Individual publications:**

Stiles et al.: Determining Titan's spin state from Cassini RADAR images. The Astronomical Journal, Volume 135, Number 5 (2008). (DOI: 10.1088/0004-6256/135/5/1669)

Iess, L. et al., (2010). Gravity field, shape, and moment of inertia of Titan. Science 327, 1367. (DOI: 10.1126/science.1182583)

Iess, L. et al., (2012). The tides of Titan. Science 337, 457. (DOI: 10.1126/science.1219631)

Use ADS to help find more publications

**Titan Interior Data**

From RSS (Radio Science Subsystem):

**Final Global Products (hmmm I think this is an “In preparation” until the publication comes out)**

Preliminary RSS Flyby Summary (plus supplementary information) [PDF]

From RADAR:

Titan Global Shape Model contains a variety of different models for the global shape of Titan obtained by interpolation or by least-squares fitting to RADAR altimetry and SARTopo data.

From MAG (Magnetometer): Should be linked to Magnetospheric Science page

TBD

**Titan Surface**

By the conclusion of the mission Cassini-Huygens had revealed a complex Titan surface with a striking resemblance to the total geomorphology of the Earth. Dunes, rivers, gullies, lakes, seas, volcanic constructs, mountains, are all present. Titan’s methane cycle, analogous to the Earth’s hydrologic cycle, drives processes including sedimentary transport that lead to the most geologically diverse surface after that of the Earth. Most spectacular was the discovery of several polar seas and hundreds of lakes, covering multiple hundreds of thousands of square kilometers. Some of the coastlines appear very Earth-like, with bays, cliffs, coves and river estuaries, while other boundaries are puzzling and may reflect a tectonic origin of the sea basins. Bathymetry and compositional measurements by Cassini lead to a liquid hydrocarbon inventory of about 70,000 square kilometers, mostly methane.

Cassini-Huygens observed dynamic meteorology in cloud behavior and rainstorms, changes in the lakes and seas, and evaporation of liquids from the surface. Cassini and the close-up images provided by Huygens establish fluvial erosion and rainfall as important processes tying together Titan's surface and atmosphere. A variety of cloud and weather patterns, including those generating rain, occur in the lower atmosphere, and comparison of cloud patterns with general circulation models supports the presence of a substantial amount of liquid methane in Titan’s crust.

An average surface age of ~ 0.5–1 billion years is derived from a variety of Cassini-Huygens data.

**Key Publications**

In Titan from Cassini-Huygens (Brown, R. H., J-P. Lebreton, and J. H. Waite, Jr., Eds). Springer, 535 pp., 2009 (DOI: 10.1007/978-1-4020-9215-2)

Geology and Surface Processes on Titan. R Jaumann, R. L. Kirk, R. D. Lorenz, R. M.C. Lopes, E Stofan, E. P. Turtle et al.

Composition of Titan's Surface. L. A. Soderblom, J. W. Barnes, R. H. Brown, R. N. Clark, M. A. Janssen, T. B. McCord et al.

In Titan: Interior, Surface, Atmosphere, and Space Environment (Ingo Müller-Wodarg , Caitlin A. Griffith , Emmanuel Lellouch, Thomas E. Cravens, Eds). Cambridge University Press (2014) (DOI: 10.1017/CBO9780511667398)

Titan's Surface Geology. By O. Aharonson, A. G. Hayes, P. O. Hayne, R. M. Lopes, A. Lucas, J. T. Perron

**Individual publications:**

Hayes et al., A post-Cassini view of Titan's methane-based hydrologic cycle, Nature Geosciencevolume 11, pages306–313 (2018) (DOI: 10.1038/s41561-018-0103-y)

**Titan Surface Data**

**Search tools**

Titan Trek (in development) allows geospatial search for RADAR, VIMS, and ISS data, as well as downloadable map mosaics.

PILOT to find ISS and VIMS data in the context of Titan's surface map (data through 2010).

PDS Imaging Atlas to find ISS, VIMS and RADAR data, based on search parameters.

OPUS is another parameter-based search tool to find CIRS, UVIS, ISS and VIMS data on Titan.

Cassini VIMS Data Portal at the Université de Nantes, organized by flyby.

**Derived data products**

From VIMS (Visual and Infrared Mapping Spectrometer):

**VIMS Map Mosaic (hmmmm Rob and I should look around on the VIMS page and see if they have a mosaic to link here)**

**Titan Atmosphere Data**

From ISS (Imaging Science Subsystem):

ISS Map Mosaic

Another ISS Map Mosaic

**ISS Map Mosaic with Latitude and Longitude lines This link doesn’ t show lat & long (OK…Rob and I will find something and get you the proper link)**

From RADAR:

Geologic Maps (a.k.a Geomorphologic Maps) of Titan are derived from SAR and HiSAR swath mosaics, and where these are not available, from global radiometry and ISS global mosaics. The maps show the major geomorphologic classes of Titan (Craters, Mountains, Labyrinths, Plains, Dunes, and Lakes) as described in Malaska et al., (2016) (DOI: 10.1016/j.icarus.2016.02.021). These maps are available as registered GeoTIFFs ready for installation in GIS programs.

Radiometer Maps include data from pole-to-pole scans and are tabulated in time ordered tables of point-by-point of brightness temperature and other parameters. Residual maps interpolated on a regular grid in cylindrical coordinate are also included.

**RADAR – SAR (hmmm I have a giant large file transfer from Karl but we should likely find what they delivered in the RADAR and just link to that)** Images from each flyby are derived from Cassini RADAR Basic Image Data Records at 256 pixels/degree. These versions have had systematic biases due to thermal and quantization noise, and systematic variation due to incidence angle have been removed. For more information on this process, see the User's Guide.

From RSS (Radio Science Subsystem):

**TBD**

RSS Bistatic surface information

**Other Derived data products**

**Titan Surface Nomenclature Map,** showing positions of named features **(OK, Rob and I can find something for you)**

**Huygens Lander on Titan**

"On 14 January 2005, at 13:34 CET (12:34 UTC), ESA's Huygens probe entered the history books by descending to the surface of Titan, Saturn's largest moon. This was humanity's first successful attempt to land a probe on another world in the outer Solar System.

Huygens hitched a ride to the Saturn system during an epic, seven-year voyage attached to NASA's Cassini spacecraft. The final chapter of the interplanetary trek was a 21-day solo cruise toward the haze-shrouded moon. Plunging into Titan's atmosphere, the probe survived the hazardous 2 hour 27 minute descent to touch down safely on Titan's frozen surface."

* From Huygens: The Top 10 Discoveries at Titan

**Huygens Data and Related Cassini Orbiter Data**

Search for Huygens data at the ESA planetary science archive by selecting Huygens from the MISSIONS menu on the left and then pressing the magnifying glass icon at the bottom left

Search at the PDS Atmospheres Node Mirror Site

Huygens Data Gazeteer [PDF] is a guide to the Huygens datasets and the literature in which they are discussed.

Cassini Data Relevant for Comparison with the Huygens Probe [PDF] summarizes the Cassini data most relevant for comparison or context-setting of the Huygens probe.

**Data Files and Information [ZIP]** I think I incorporated all of these into the above PDF and Ralph Lorenz reviewed it. which support the above PDF

**Key Publications**

Lebreton, J. P., A.Coustenis, J. I. Lunine, F. Raulin, T. Owen, D. F. Strobel, Results from the Huygens probe on Titan, Astro & Astrophys. Rev., 17, 149-179, doi 10.1007/s00159-009-0021-5, 2009.

Huygens, Science, Payload and Mission, ESA SP-1177, ed. Wilson, A., European Space Agency, Noordwijk, The Netherlands, 1997.

**Titan Atmosphere**

To understand the structure of Titan's atmosphere one must keep in mind certain basic facts from solar system dynamics. First, the axial tilt of Saturn and Titan is 26.73°, second, Saturn's orbital eccentricity is 0.05415, which yield variations in the distance from the Sun from 9.04 to 10.07 AU and in the total solar flux of ~ 20 %. Titan's atmospheric seasonal evolution is driven by three mechanisms: the seasonal change in solar declination, the orbital eccentricity of Saturn with Titan receding from the Sun since 2002, and the solar cycle variation of the Sun with activity increasing from its minimum in late 2009 to peak solar activity for cycle 24 in April 2014. Perihelion last occurred in 25 February 2003. Summer solstice in Titan's southern hemisphere was 17 March 2002; summer solstice in the northern hemisphere was on 24 May 2017 after spring equinox on 11 August 2009. The measurement of isotopic argon in the atmosphere supports significant outgassing over Titan's history, while the low abundance of primordial argon along with other isotopic measurements support ammonia as the original parent molecule of Titan's atmospheric nitrogen.

At the end of the Cassini-Huygens Prime Mission, we had a good first order knowledge of the density and thermal structure of the atmosphere with the exception of the ~ 500-950 km region, variously called the ignorosphere, agnostosphere, etc. Although HASI inferred the thermal structure at equatorial latitudes through this region, it did not yield a pronounced mesopause as was widely expected from theory. CIRS data provided detailed altitudinal and latitudinal composition and temperature measurements of the stratosphere. The latter allowed the derivation of stratospheric zonal winds at substantial super-rotation speeds.

The Cassini Equinox and Solstice Missions enabled the study of seasonal variations of composition, temperatures and inferred zonal winds to understand the transition from summer in the southern hemisphere to equinoctial conditions to summer in the northern hemisphere, especially as the northern polar region emerges out of the polar winter night and its strong circumpolar vortex breaking up. The entire duration of the Cassini Mission exceeded 13 years, permitting observations over close to half of a seasonal cycle (almost half of Saturnian year) on Titan and revealed that seasonal variations are not symmetrical. The eccentricity of Saturn's orbit and the obliquity of its rotational pole is sufficient to produce the observed asymmetry in Titan's seasonal response. But its entire stratosphere is tilted by several degrees from the rotational pole. Seasonal variations in composition, density, and thermal structure of Titan's upper atmosphere were characterized in particular by INMS with complementary data from UVIS measurements. Cassini-Huygens observed dynamic meteorology in cloud behavior and rainstorms, changes in the lakes and seas, and evaporation of liquids from the surface.

Cassini data determined that the thermosphere is highly variable, contradicting model predictions. It is also a chemical factory that initiates the formation of complex positive and negative ions in the high thermosphere as a consequence of magnetospheric-ionospheric-atmospheric interaction involving solar EUV and UV radiation, energetic ions and electrons. This factory produces very heavy positive and negative ions and large molecules, which condense out and are detectable in solar and stellar UV occultations at ~ 1000 km, and initiate the haze formation process. As these particles fall through the 500-950 km region and grow, they become detectable by remote sensing: UVIS at ~ 1000 km, ISS at ~ 500 km and eventually become ubiquitous throughout the stratosphere. These haze particles are strong absorbers of solar UV and visible radiation, play a fundamental role in heating Titan's stratosphere and mesosphere and provide a surface for heterogeneous reactions. The differential heating with latitude drives wind systems in Titan's middle atmosphere, much as ozone does in the Earth's middle atmosphere.

* Cassini-Huygens discovered a variety of weather patterns, including rainstorms, in Titan's lower atmosphere and documented seasonal changes therein.
* Cassini further explored the evolution and composition of the winter circumpolar vortex that switches hemispheres seasonally. Titan has strong parallels to the Earth with strong winter polar vortices.
* Cassini-Huygens discovered Enceladus as one possible source for oxygen compounds in Titan's atmosphere.
* Cassini-Huygens came up with the surprising result that lightning is absent despite observed methane moist convection.

**Key Publications**

In Titan from Cassini-Huygens (Brown, R. H., J-P. Lebreton, and J. H. Waite, Jr., Eds). Springer, 535 pp., 2009 (DOI: 10.1007/978-1-4020-9215-2)

Volatile Origin and Cycles: Nitrogen and Methane. R Jaumann, R. L. Kirk, R. D. Lorenz, R. M.C. Lopes, E Stofan, E. P. Turtle et al.

High-Altitude Production of Titan's Aerosols. J. H. Waite Jr., D. T. Young, J. H. Westlake, J. I. Lunine, C. P. McKay, W. S. Lewis

Atmospheric Structure and Composition. Darrell F. Strobel, Sushil K. Atreya, Bruno Bézard, Francesca Ferri, F. Michael Flasar, Marcello Fulchignoni et al.

Composition and Structure of the Ionosphere and Thermosphere. T. E. Cravens, R. V. Yelle, J. -E. Wahlund, D. E. Shemansky, A. F. Nagy

Aerosols in Titan's Atmosphere. Martin G. Tomasko, Robert A. West

Atmospheric Dynamics and Meteorology. F. M. Flasar, K. H. Baines, M. K. Bird, T. Tokano, R. A. West

Seasonal Change on Titan. Ralph D. Lorenz, Michael E. Brown, F. Michael Flasar

Mass Loss Processes in Titan's Upper Atmosphere. R. E. Johnson, O. J. Tucker, M. Michael, E. C. Sittler, H. T. Smith, D. T. Young et al.

Energy Deposition Processes in Titan's Upper Atmosphere and Its Induced Magnetosphere. Edward C. Sittler, R. E. Hartle, Cesar Bertucci, Andrew Coates, Thomas Cravens, Iannis Dandouras et al.

In Titan: Interior, Surface, Atmosphere, and Space Environment (Ingo Müller-Wodarg , Caitlin A. Griffith, Emmanuel Lellouch, Thomas E. Cravens, Eds). Cambridge University Press (2014) (DOI: 10.1017/CBO9780511667398)

Thermal structure of Titan's troposphere and middle atmosphere pp 102-121. F. M. Flasar, R. K. Achterberg, P. J. Schinder

The general circulation of Titan's lower and middle atmosphere pp 122-157. S. Lebonnois, F. M. Flasar, T. Tokano, C. E. Newman

The composition of Titan's atmosphere pp 158-189. B. Bézard, R. V. Yelle, C. A. Nixon

Storms, clouds, and weather pp 190-223. C. A. Griffith, S. Rafkin, P. Rannou, C. P. McKay

Chemistry of Titan's atmosphere pp 224-284. V. Vuitton, O. Dutuit, M. A. Smith, N. Balucani

Titan's haze pp 285-321. R. West, P. Lavvas, C. Anderson, H. Imanaka

Titan's upper atmosphere: thermal structure, dynamics, and energetics pp 322-354. R. V. Yelle, D. S. Snowden, I. C. F. Müller-Wodarg

Titan's upper atmosphere/exosphere, escape processes, and rates pp 355-375. D. F. Strobel, J. Cui

**Individual publications:**

Hayes et al., A post-Cassini view of Titan's methane-based hydrologic cycle, Nature Geoscience volume 11, pages306–313 (2018) (DOI: 10.1038/s41561-018-0103-y)

Hörst, S. M., Titan's atmosphere and climate, Journal of Geophysical Research: Planets, Volume 122, Issue 3, pp. 432–482 (2017) (DOI: 10.1002/2016JE005240)

**Titan Atmosphere Data**

**Search tools:**

Event Calendar can be used to find data related to flybys of Titan

OPUS is one way to find data

**The instruments used to study Titan's atmosphere, grouped by study topic, were:**

Atmosphere-Surface Interaction Layer

Planetary Boundary Layer (CIRS, ISS, RSS)

Surface-atmosphere interaction data (RADAR, CIRS, ISS, VIMS)

Methane humidity (GCMS)

Clouds and Haze (DISR, ISS, VIMS)

Troposphere

Density and Temperature (CIRS, RSS, HASI)

Clouds and Haze (DISR, ISS, VIMS)

Stratosphere (~ 45-450 km)

Density and Temperature (CIRS, RSS, HASI, VIMS)

Haze (CIRS, VIMS, ISS, DISR)

Mesosphere (~ 450-950 km)

Density and Temperature (UVIS, HASI)

Haze (UVIS, CDA)

Thermosphere (> 950 km)

Density and Temperature (INMS, UVIS, HASI, AACS, NAV)

Ionosphere/Plasma composition, density, temperature, conductivity,

magnetic field

(INMS, CAPS, RPWS+LP , RSS, MAG)

Exosphere (> 1500 km)

Density and Temperature (INMS, UVIS)

Plasma composition, density, temperature (INMS, CAPS, RPWS+LP)

Atmospheric Chemistry

Neutral Photochemistry (CIRS,VIMS, UVIS, INMS)

Ionospheric Chemistry (INMS, CAPS, RPWS+LP, RSS)

Aerosol and Haze Formation (ACP, UVIS, INMS, CAPS, RPWS+IP)

Atmospheric Dynamics

Troposphere and Stratosphere (DWE, CIRS, RSS, ISS)

Thermosphere (INMS, RPWS-LP, UVIS)

Atmospheric Radiation and Power Sources

Solar power - DISR measurements

Magnetospheric Power (CAPS, MIMI, INMS, UVIS)

Airglow (Dayglow: UVIS); (Nightglow: ISS, UVIS)

Thermal emission (CIRS)

**High-Level Data Products by Instrument**

Cross-instrument:

Composite Titan Occultation List [CSV] for RSS, UVIS, VIMS, both Stellar and Solar Occultations. More info may be provided in the instrument-specific occultation lists, below.

From INMS (Ion and Neutral Mass Spectrometer):

Download the Titan INMS Neutrals Guide [PDF]

From RSS (Radio Science Subsystem):

RSS Occultation List [PDF]

RSS Example Graphic [PDF]

RSS DSN Elevation Angle [PDF]

RSS Observation Book

**RSS Occultation Summary linked to same product as RSS Occultation list**

**From UVIS (Ultraviolet Imaging Spectrograph):**

**UVIS Solar & Stellar Occultation Summary**

From VIMS (Visible and Infrared Mapping Spectrometer):

VIMS Solar Occultation List

VIMS Stellar Occultation List

VIMS Occultation Summary

**VIMS Observation Book**

**Observation High-Level Data Products**

Cloud observation summaries performed by ISS (Visible Camera) and **VIMS (Visible and Infrared Spectrometer)**

TAMWG

**UVIS Titan EUV/FUV Book**

**Titan Hybrid Simulations (INMS)**

**Titan Magnetospheric Interactions**

Cassini magnetometer data was used to determine that the internal magnetic field of Titan was at the most very small, but the magnetometer data show that the moon's magnetic environment is strongly affected by its proximity to Saturn's warped and highly dynamic magnetodisk. Saturn's magnetodisc is in turn controlled by the solar wind pressure, Saturn seasons, and inner magnetospheric effects (periodicities and mass loading by rings and by Enceladus).

Cassini data determined that the thermosphere is a chemical factory that initiates the formation of complex positive and negative ions in the high thermosphere as a consequence of magnetospheric-ionospheric-atmospheric interaction involving solar EUV and UV radiation, energetic ions and electrons. It is very dynamic and temporally variable. Qualitatively, Cassini in situ measurements point to an important role for Saturn's magnetospheric interaction as a key driver of this observed variability as well as the solar EUV and UV input. It is likely that solar radiation mostly heats the upper atmosphere, whereas magnetospheric particle precipitation plays a more important role in the ionization of the atmosphere below the main ionosphere.

**Key Publications**

Several chapters from the Titan book published in 2009 provide useful background on Titan’s ionosphere and interaction with Saturn’s magnetosphere. They include chapters 8 (Waite), 11(Cravens) and 16 (Sittler).

Brown, R., Lebreton, J. P., & Waite, H. (Eds.). (2009). Titan from Cassini-Huygens. Springer Science & Business Media.

A number of key references attempted to categorize each Titan flyby according to the magnetospheric environment at the time of the flyby:

Rymer, A. M., Smith, H. T., Wellbrock, A., Coates, A. J., & Young, D. T. (2009). Discrete classification and electron energy spectra of Titan's varied magnetospheric environment. Geophysical Research Letters, 36(15).

Simon, S., Wennmacher, A., Neubauer, F. M., Bertucci, C. L., Kriegel, H., Saur, J., ... & Dougherty, M. K. (2010). Titan's highly dynamic magnetic environment: A systematic survey of Cassini magnetometer observations from flybys TA–T62. Planetary and Space Science, 58(10), 1230-1251.

Simon, S., van Treeck, S. C., Wennmacher, A., Saur, J., Neubauer, F. M., Bertucci, C. L., & Dougherty, M. K. (2013). Structure of Titan's induced magnetosphere under varying background magnetic field conditions: Survey of Cassini magnetometer data from flybys TA–T85. Journal of Geophysical Research: Space Physics, 118(4), 1679-1699.

Review papers

Coates, A. J. (2009). Interaction of Titan's ionosphere with Saturn's magnetosphere. Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences, 367(1889), 773-788.

Bertucci, C., Duru, F., Edberg, N., Fraenz, M., Martinecz, C., Szego, K., & Vaisberg, O. (2011). The induced magnetospheres of Mars, Venus, and Titan. Space science reviews, 162(1-4), 113-171.

**Titan Magnetosphere Data**

**Search tools**

WebGeoCalc

**Reference tables and charts**

Local times vs altitude plots for T1-T44 [PDF]

Local times vs altitude plots for T45-T70 [PDF]

Local times vs altitude plots for T71-T126 [PDF]

Titan Flybys Close Enough for Fields and Particles Experiments [TXT]

Titan Flybys Outside the Magnetosphere [TXT]

**High-Level Data Products by Instrument**

From CAPS (Cassini Plasma Spectrometer):

Summary Table of CAPS Observations of Titan [XLSX]

From INMS (Ion and Neutral Mass Spectrometer):

Summary Table of INMS Observations of Titan [XLS]

Download the Titan Ions Guide [PDF]

From MAG (Magnetometer):

MAG Data in Titan-Centered Coordinates

**Magnetosphere models and other high-level data products**

Magnetosphere models on the Magnetospheric Science page

**Analyzing Titan Data**

Software tools and publications related to the analysis of data on Titan. (TBD)

**Key Publications**

**TBD**

**Data Analysis Guides and Tools**

**Cassini ISS Titan Imaging Strategy and Surface Image Processing Guide (I have that document Cassini\_Titan\_Imaging\_Strategy\_180112.docx)**