July 29,2008

Cassini-Huygens Mission to Saturn
4th Anniversary CHARM, part 2

Dr. Claudia Alexander, Magnetosphere

Dr. Elizabeth Turtle, Titan

Saturn’s Magnetosphere at the end of the Prime Mission

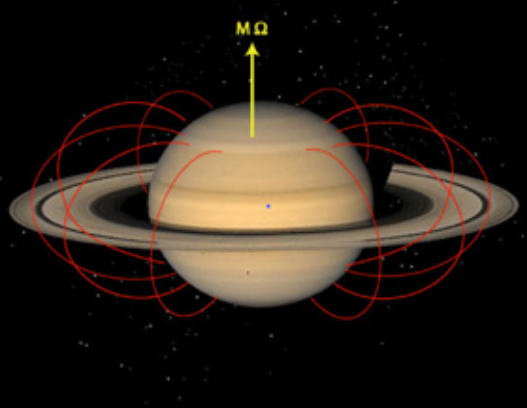
Dr. Claudia Alexander

Cassini Staff Scientist

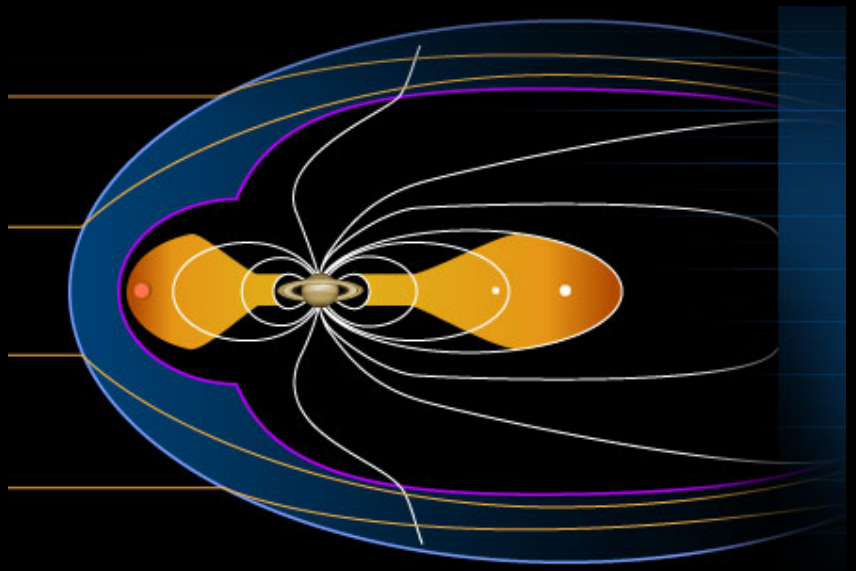
A. Completion of Primary MAPS Science Objectives (A)

- Magnetosphere:
  - Characterize this region of Saturn's environment:
    - the vector magnetic fields as a function of position and time.
    - the energy, composition and angular distribution of plasma (energetic charged particles) - including plasma wave phenomena - as a function of position and time.
- Status:
  - MAPS survey covered the inner magnetosphere for a 4-year period
  - Some major discoveries:
    - (A.1) Solar wind control is relatively weak compared to rotational and mass loading effects
    - (A.2) New radiation belt inside the D-ring
    - (A.3) Imaging of rotating dynamic ring current
    - (A.4 & B.1) Magnetosphere has time-varying rotation period

Global Morphology

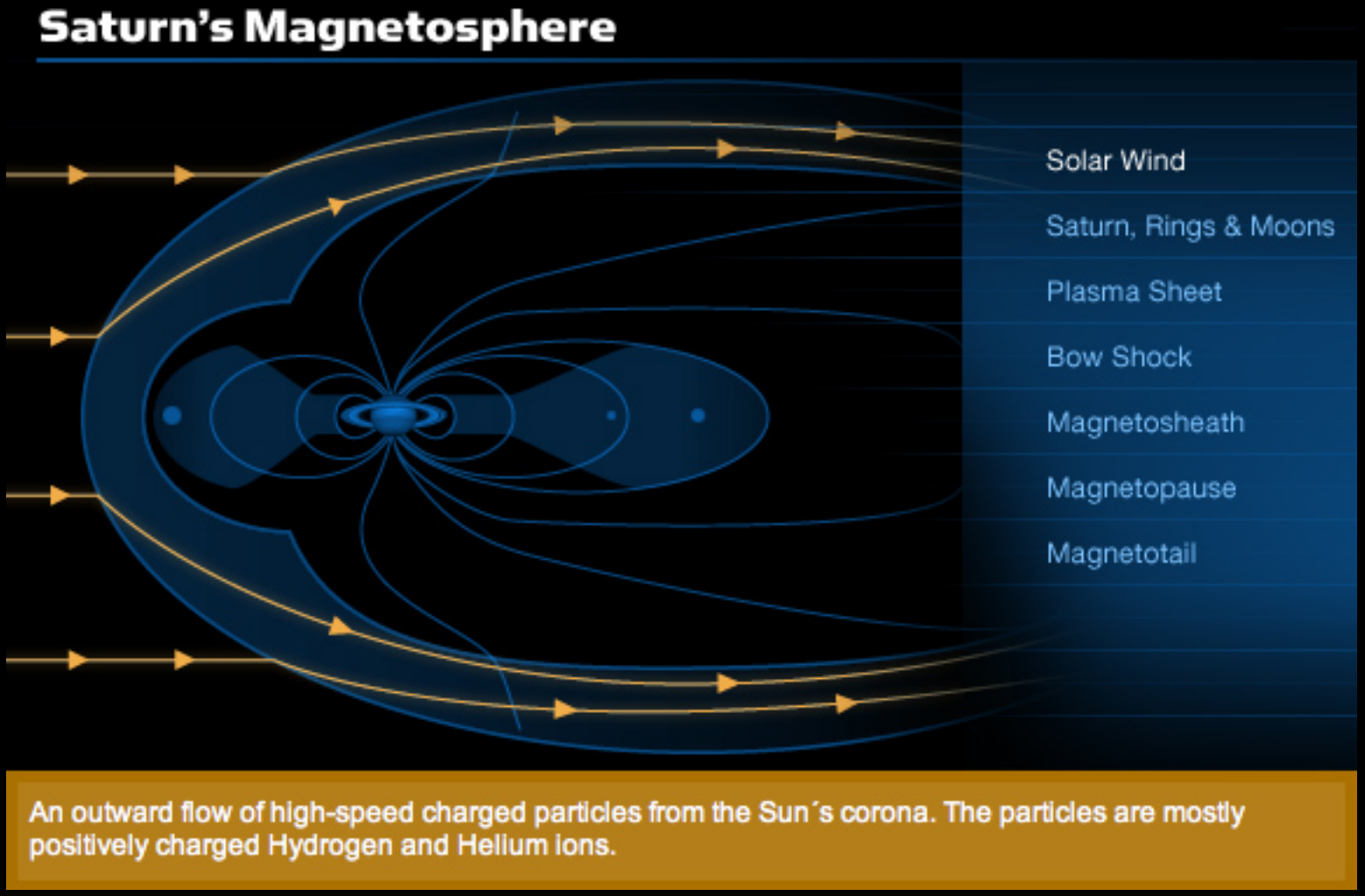


Very simple illustration

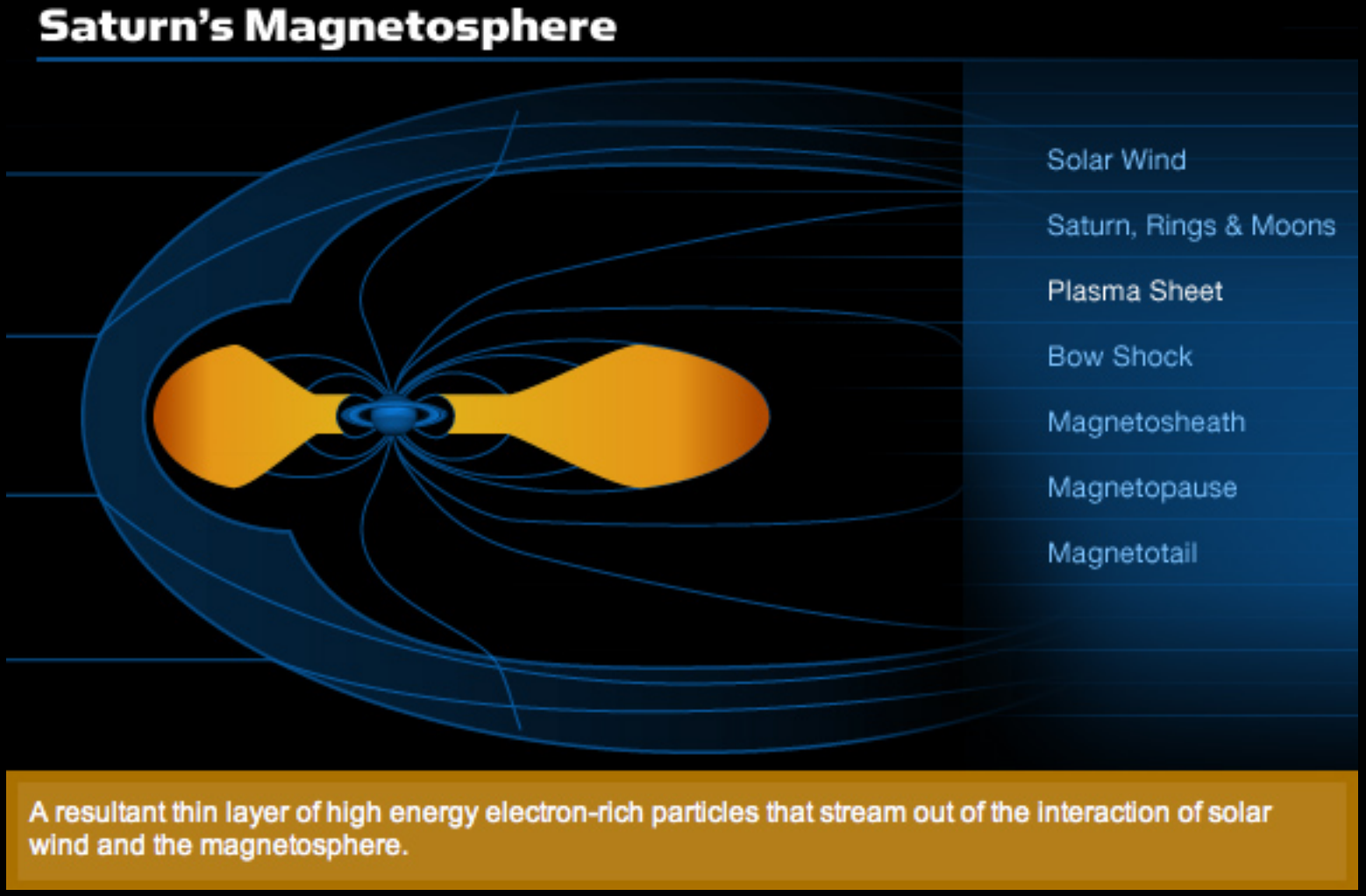


A more complex illustration, but what do the measurements tell us?

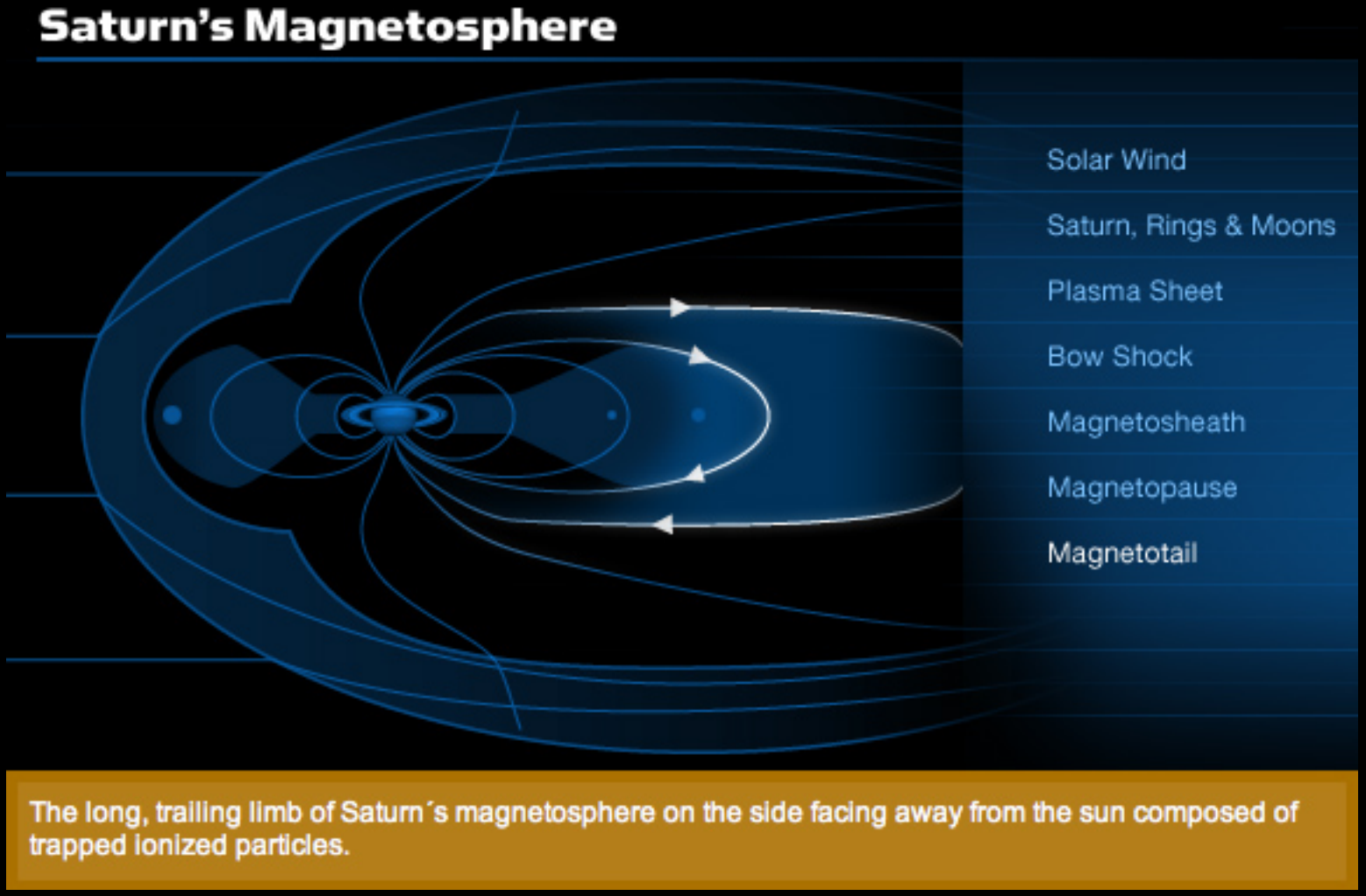
Generic Schematic: Solar Wind



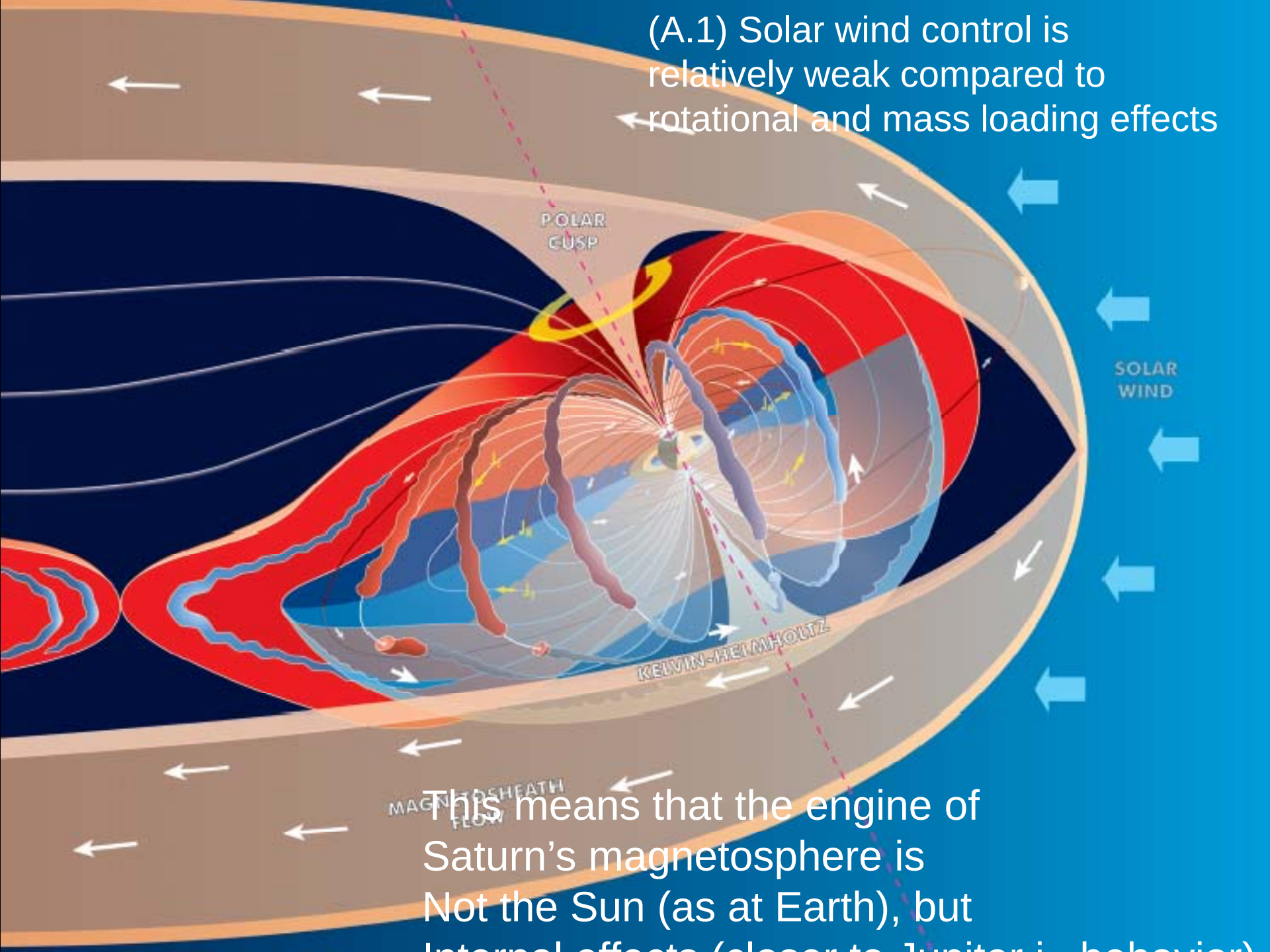
Generic Schematic: Plasma Sheet,& Neutral Cloud



Generic Schematic: Magnetotail



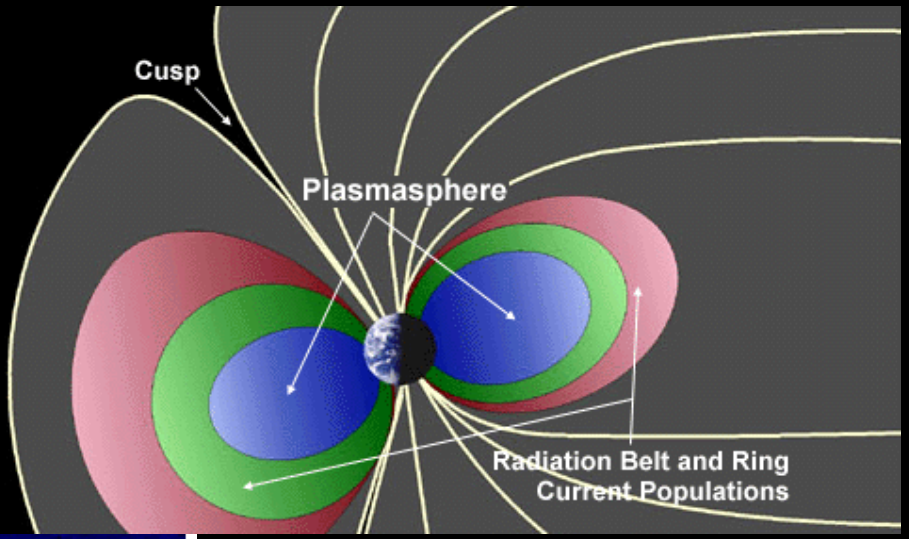
(A.1) Solar wind control is relatively weak compared to rotational and mass loading effects

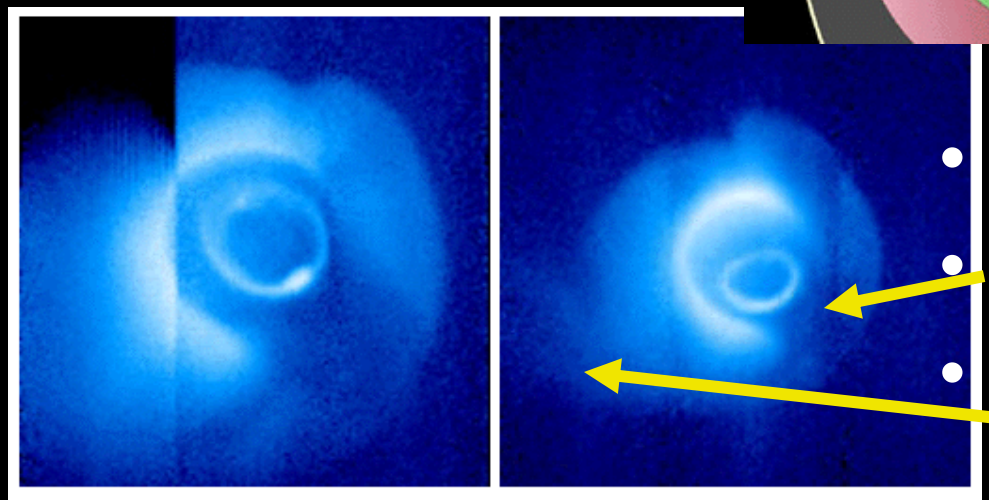


This means that the engine of Saturn's magnetosphere is Not the Sun (as at Earth), but

(A.3) EUV "Images" of the Earth's Plasmasphere

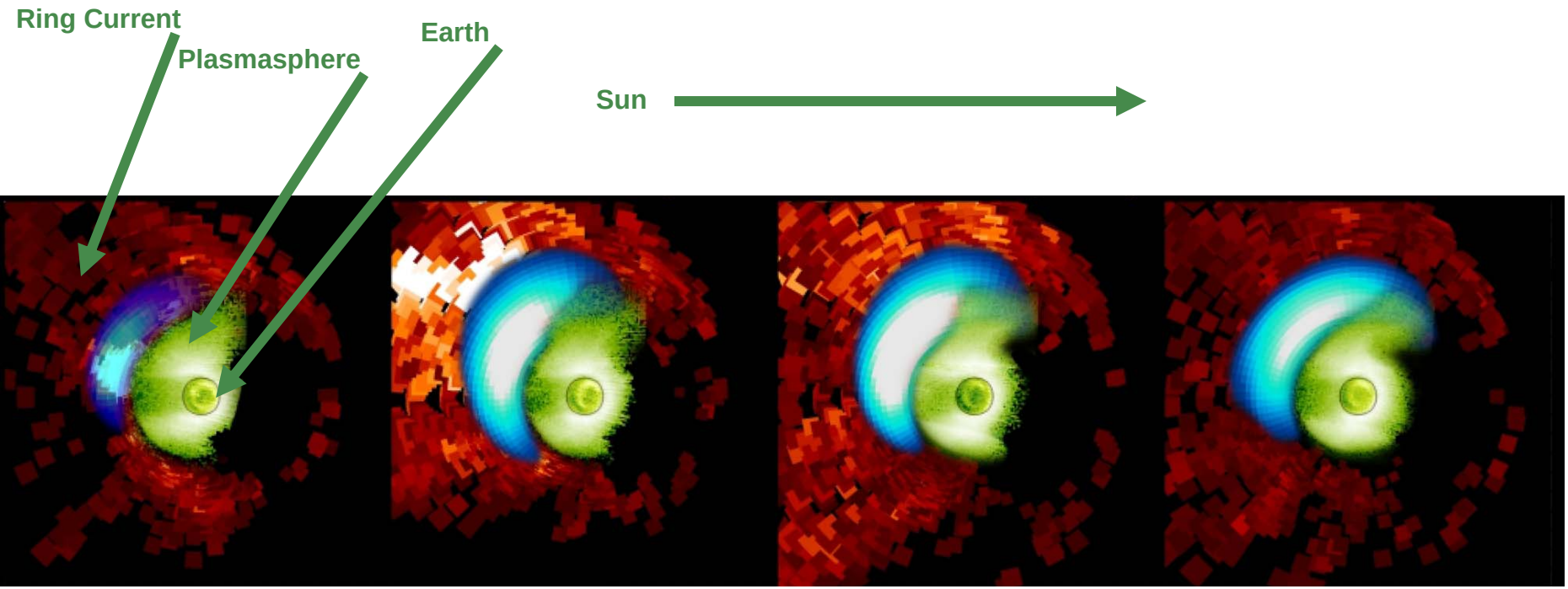
- Right: a schematic
- Left: actual images of the Earth; the surrounding particles; aurora at the pole.





- Sun at upper left.
- Earth's shadow
- Plasmaspheric particles middle left.

From the IMAGE s/c



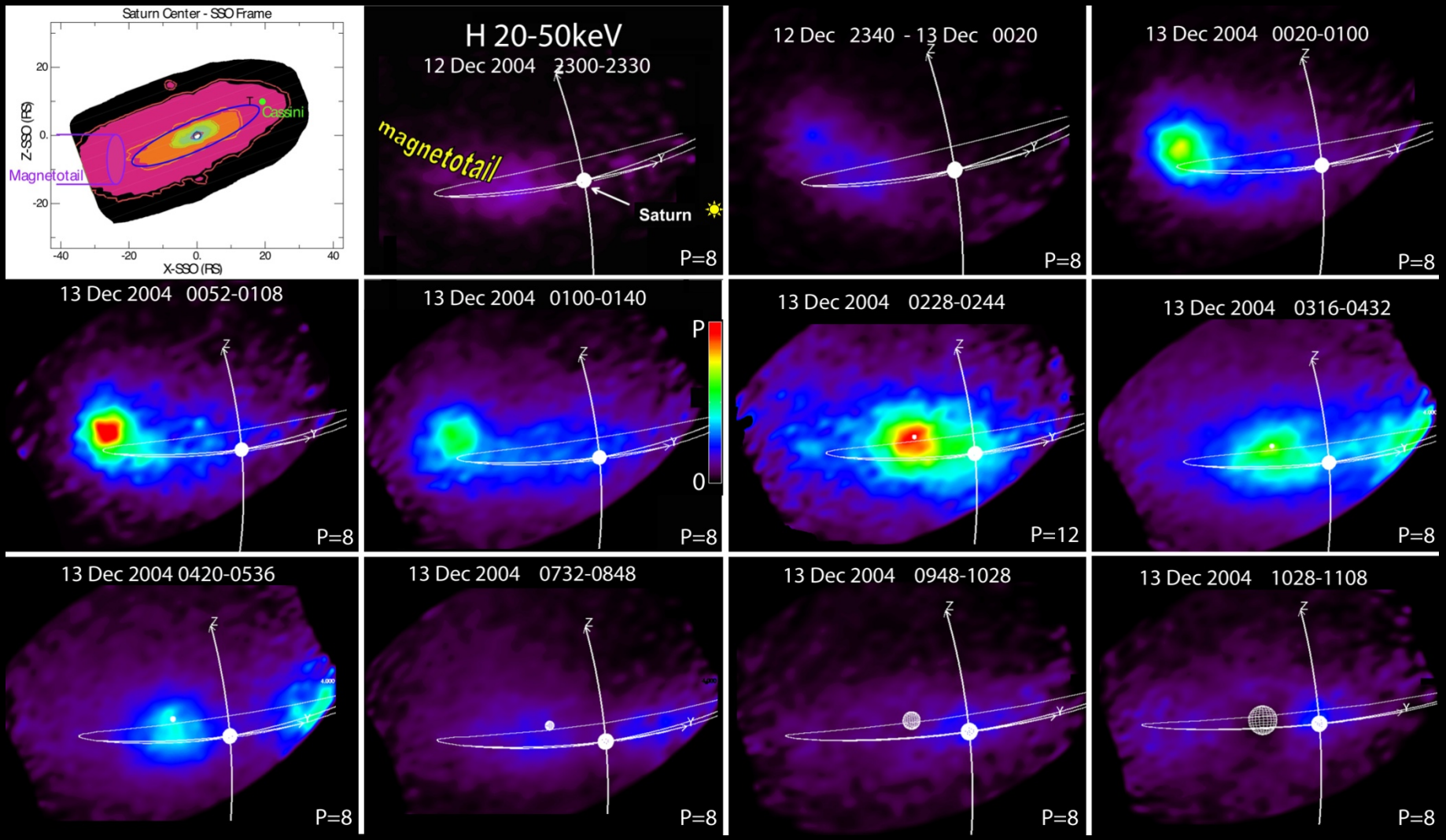
Panel 1:
nominal plasmasphere

Panel 2:
Ring current brightening as energetic particles from the tail impinge on the nightside of the Earth.

Panel 3:
Plasmasphere grows as the ring current particles are injected into it

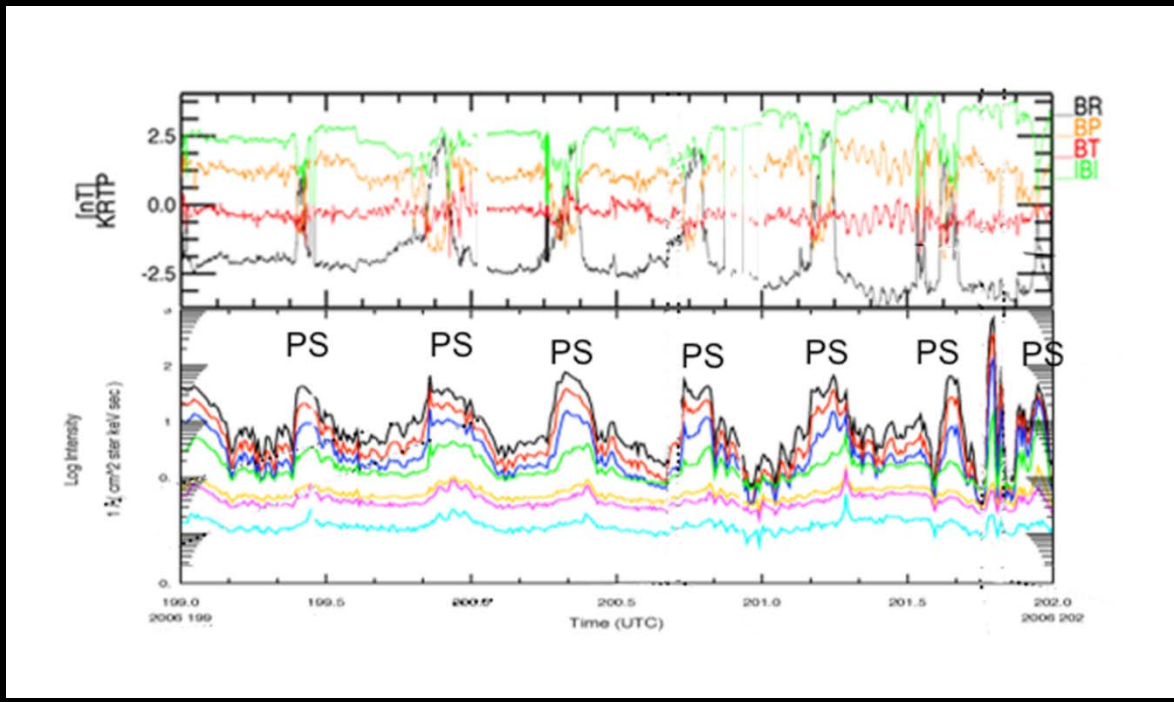
Panel 4:
Plasmaspheric loss occurs as particles precipitate and rain out through the auroral zone.

(A.3) MIMI evidence of plasma injection from the tail (imaging the ring current)

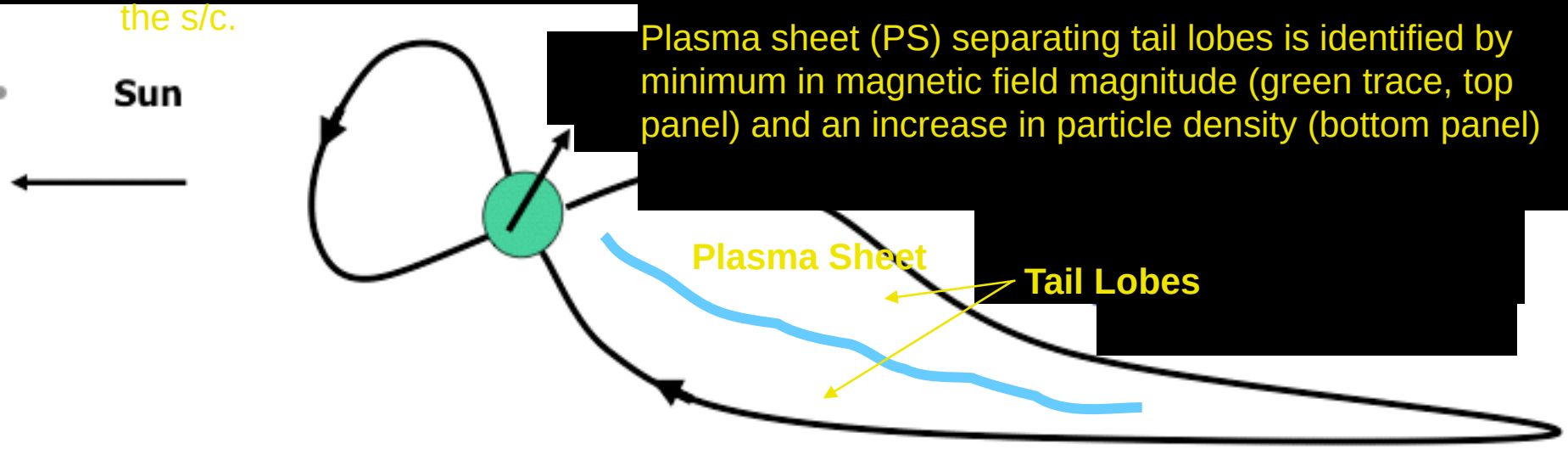


A.4) Saturn has an (unexpected) time-varying component

- Though the rotational axis and the dipole axis are aligned, Saturn's rotational axis is tiled with respect to the ecliptic.
- Figure shows an example of MAG and MIMI data from a recent tail pass
- Spacecraft (s/c) will be above then below the plasma sheet (PS). So the plasma sheet will 'beat' past the s/c.



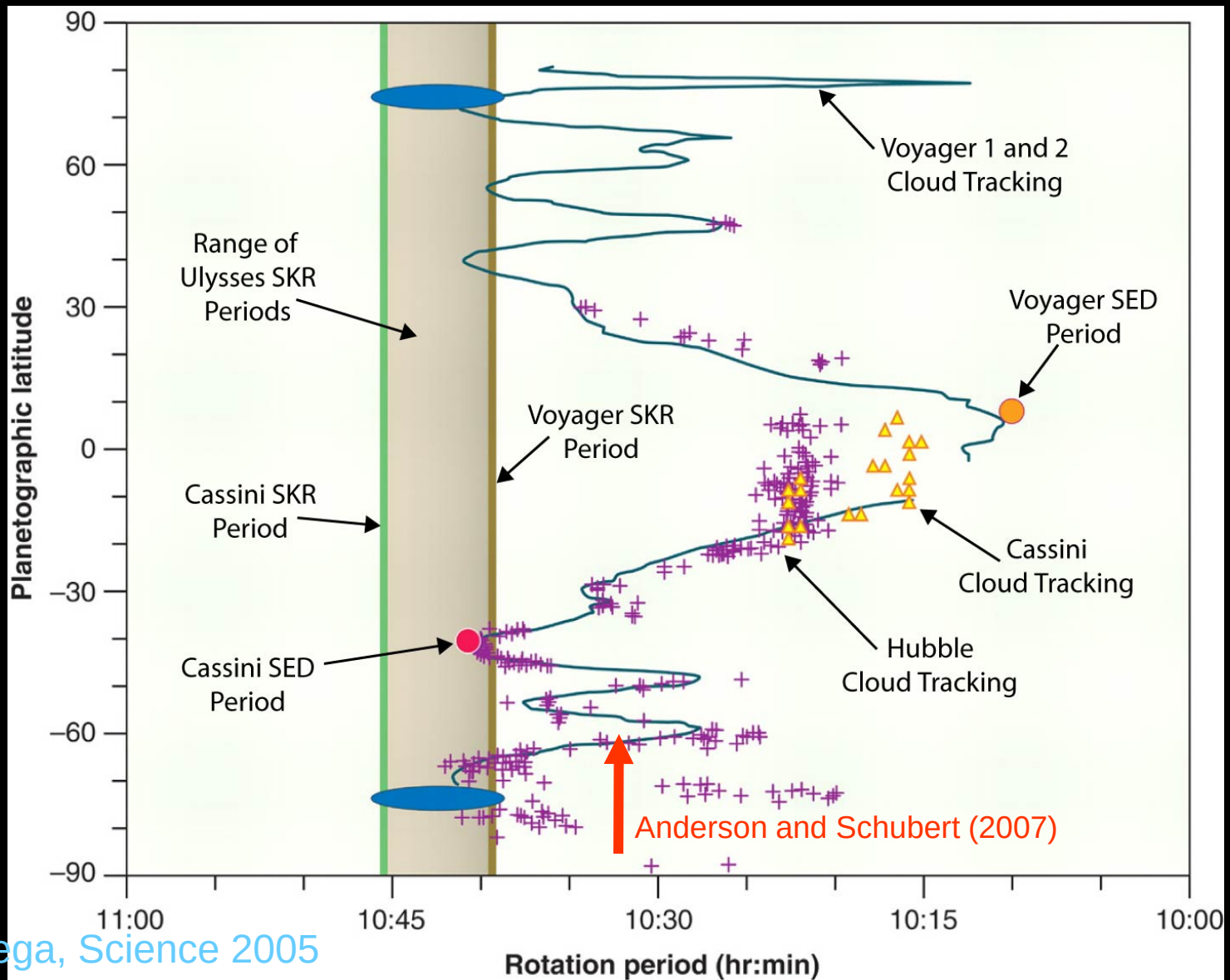
Plasma sheet (PS) separating tail lobes is identified by minimum in magnetic field magnitude (green trace, top panel) and an increase in particle density (bottom panel)



B. Completion of Primary MAPS Science Objectives (B)

- Saturn's Kilometric Radiation (SKR):
  - Objective: Determine the relationship of the magnetic field orientation to SKR.
- Status:
  - Some major discoveries:
    - (B.1) It was determined that the SKR period does not represent the internal rotation period of the planet.
    - (B.2) The variable period of SKR has been confirmed; it continues to evolve.
    - (B.3) Many magnetospheric phenomena have a period similar to the SKR period.

SKR Period is Different than the Internal Rotation



Sanchez-Lavega, Science 2005

What is Kilometric Radiation?

- **SKR is the Saturn analog of terrestrial AKR - at frequencies appropriate for Saturn.**
- **Auroral kilometric radiation** (AKR) is the intense radio emission in the acceleration zone (at a height of three times the radius of the Earth) of the aurora. The radiation mainly comes from cyclotron emission from electrons orbiting around the magnetic field lines of the Earth. The radiation has a frequency of between 50 and 500 kHz and a total power of between about 1 million and 10 million watts. The radiation is absorbed by the ionosphere. The sound produced by playing AKR over an audio device has been described as "whistles", "chirps", and even "screams". From Wikipedia.
- Earth's Auroral 'Radio Chatter' from Scientific American, June 30 2008.
- http://www.windows.ucar.edu/tour/link=/earth/Magnetosphere/tour/tour_earth_magnetosphere_08.html

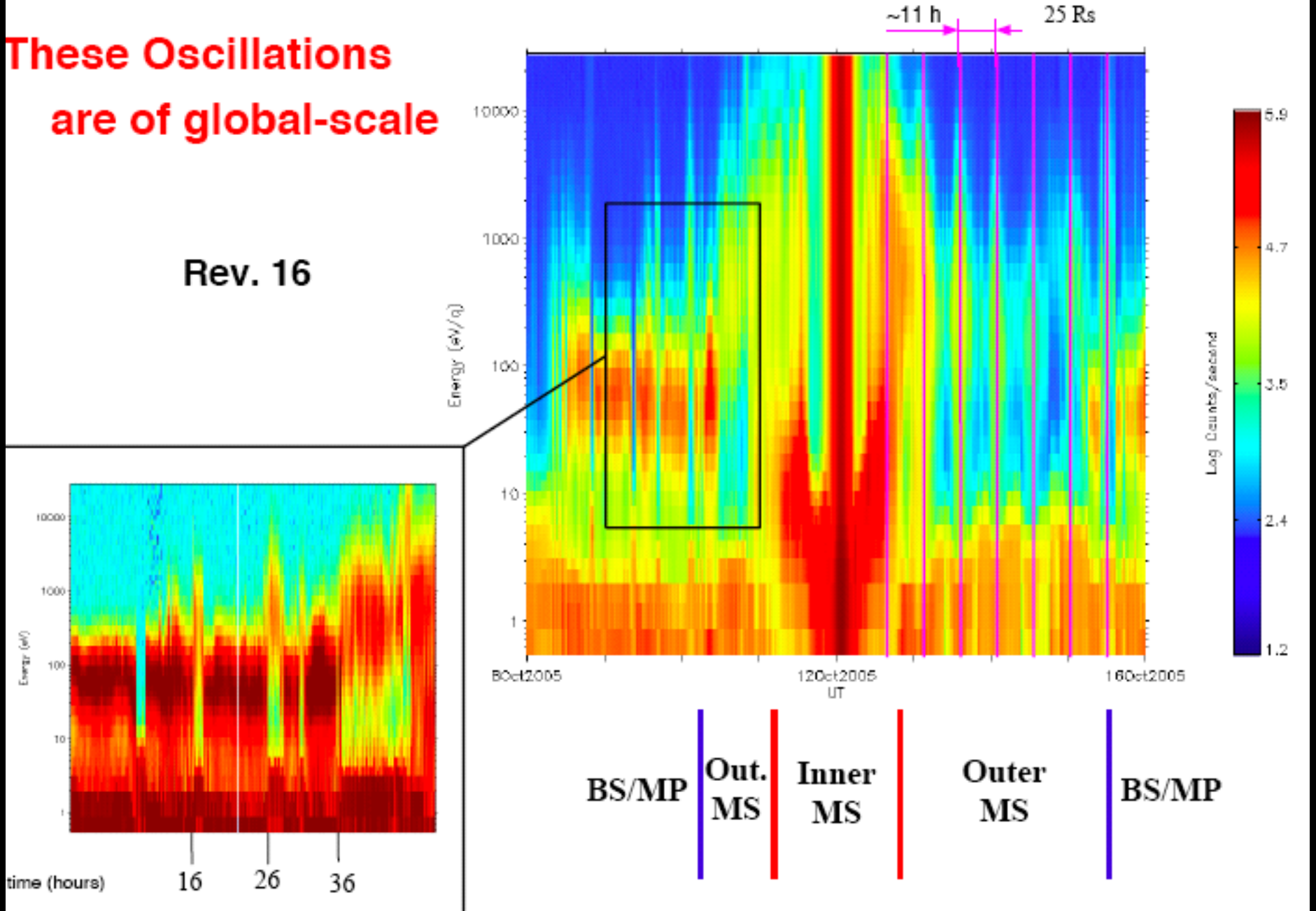
Planetary Period Oscillations in Saturn's Magnetosphere (MIMI)

Saturn Result

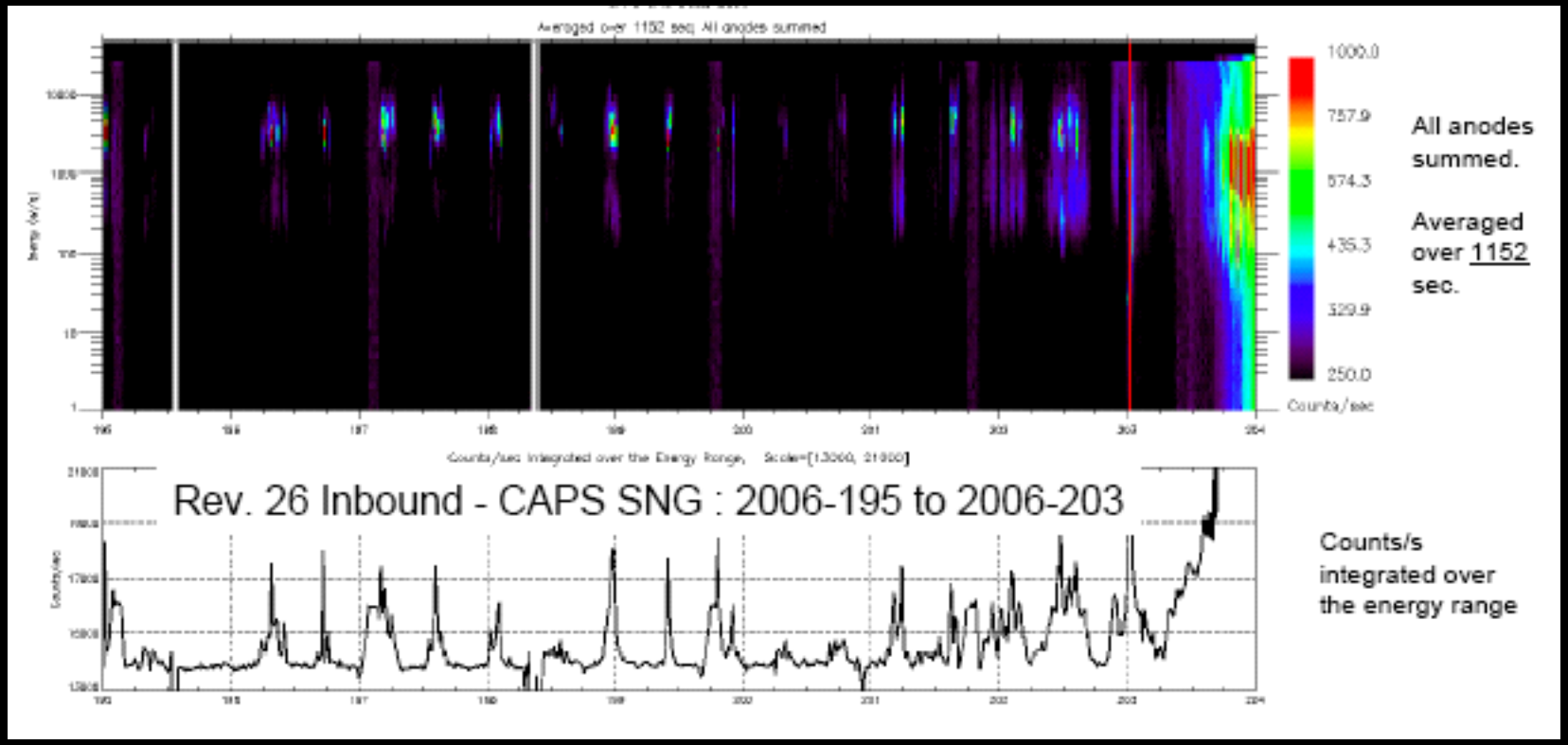
Clarke, et al., GRL, in press

These Oscillations are of global-scale

Rev. 16



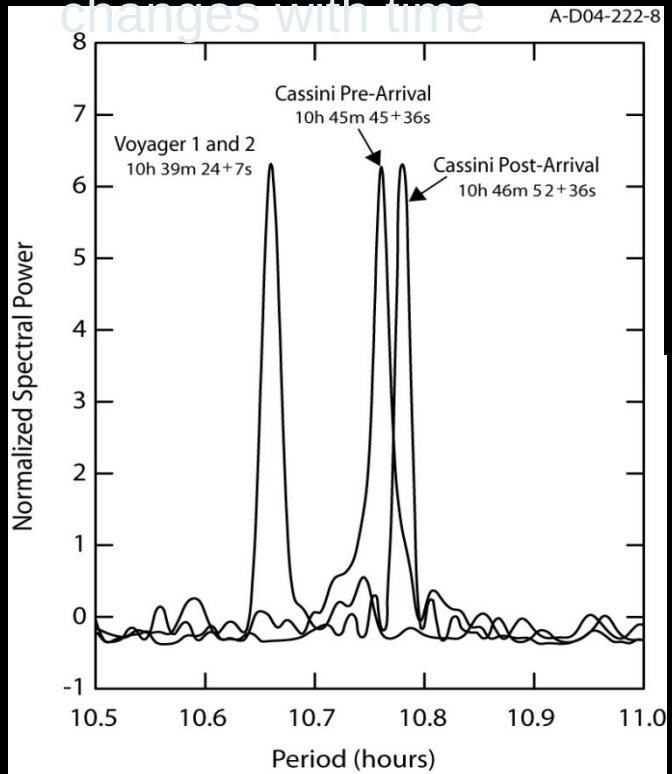
CAPS - Rotational Modulation of Ion Fluxes

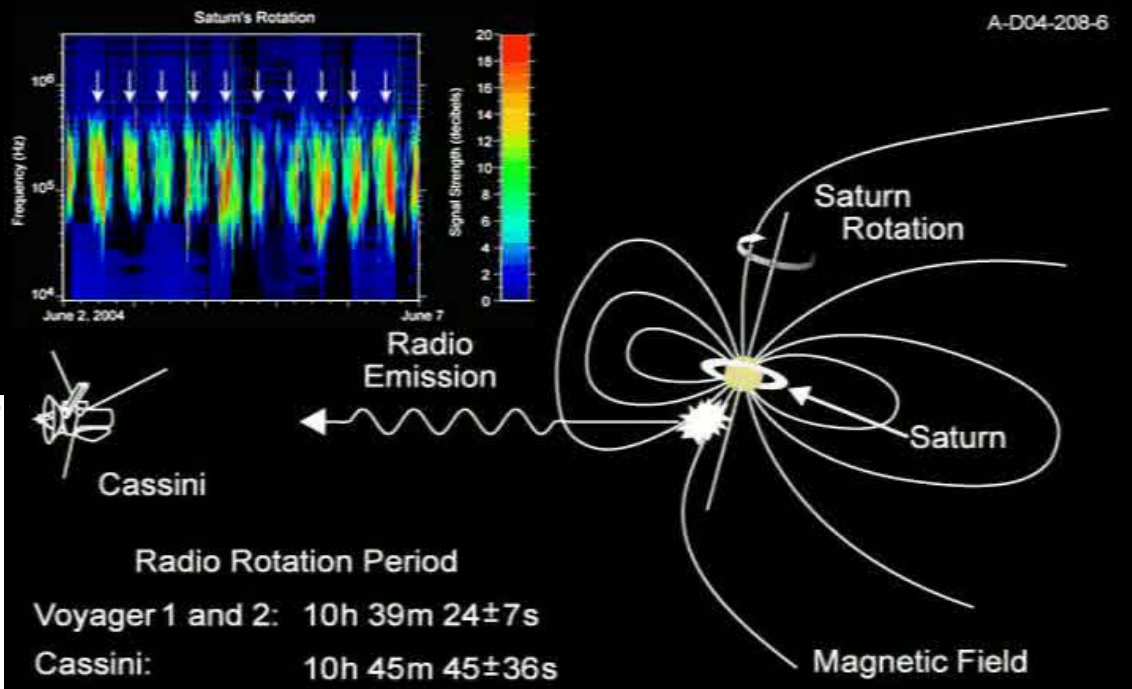


- Spectrograms (upper panet) show the modulation in ion fluxes in the magnetosphere at Saturn's rotational period of 10h 40m. Summation of ion energies (lower panel) also show the periodicity. Radial distance in the figure ranges from 48 Rs to 12 Rs

These modulations are not explained by the periodicity that RPWS measures

- IAU longitude system cannot be used to organize the data
- SKR drifts in longitude and time and the rate of drift changes with time





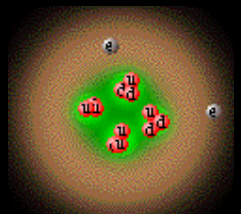
Cassini has found a different radio period than Voyager. The radio period is usually used to determine the rotation period of gas giant planets. A major mystery for Cassini to solve is the reason for the variation of the radio period. Once this mystery is solved, it will be possible to accurately determine the rotation period of the deep interior of Saturn.

C) Completion of Primary MAPS Science Objectives (c.

- Titan:
  - Investigate the upper atmosphere and ionosphere.
  - Investigate Titan-magnetosphere interactions.
- Status:
  - Some major discoveries:
    - (C.1) Heavy negative ions were detected in the ionosphere
    - (C.2) Nitrogen escaping from Titan's atmosphere is only a trace ion in the Saturnian magnetosphere

What are Negative Ions?

- Electrons are negatively charged particles
- Ions are generally positively charged particles, an atom stripped of one or more electrons.
- What CAPS and INMS seem to have discovered are very heavy - > 2000 AMU particles, probably aggregates of Polycyclinc Aromatic Hydrocarbons (PAH's), that drop down into the lower atmosphere after being created higher up.

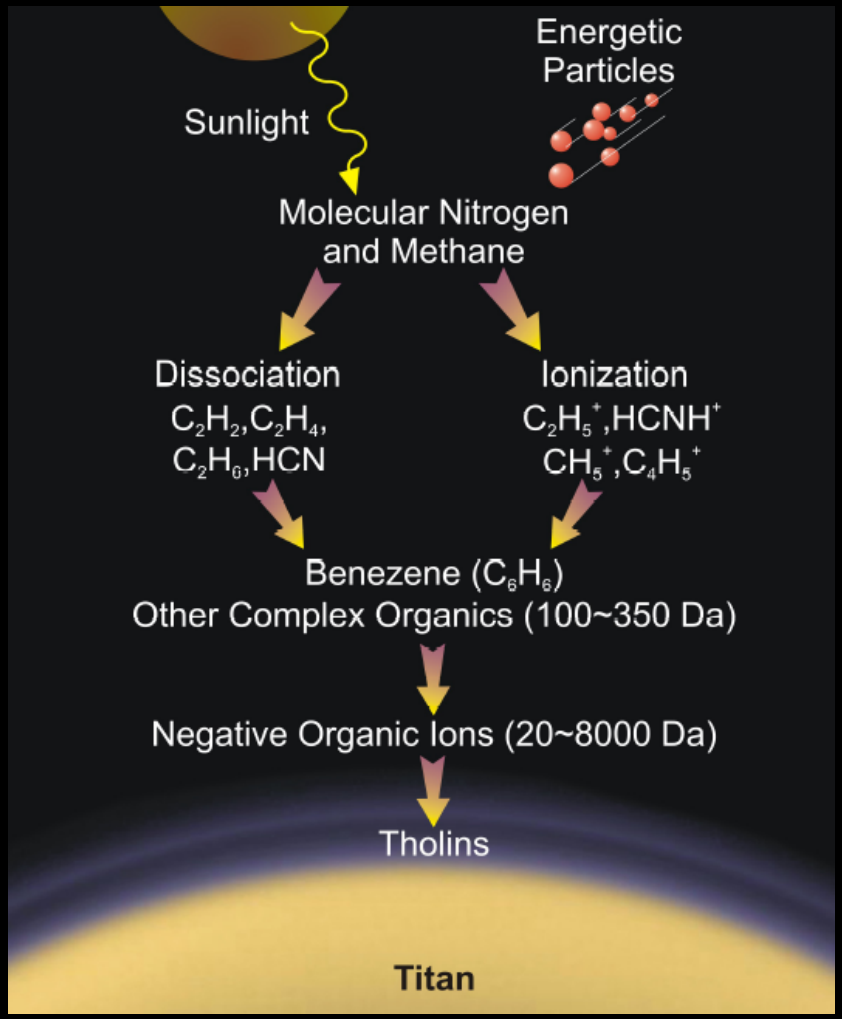


Model of an atom. The nucleus in green is made of protons (positive electric charge) and neutrons (electrically neutral). Protons and neutrons are made of smaller particles called quarks (shown in red).The white particles are electrons which have a negative electric charge. They orbit the nucleus at a considerable distance. Courtesy Windows to the Universe.

Heavy Negative Ions Discovered in Titan's Ionosphere

A joint CAPS and INMS discovery

… massive negative ions no longer in the gas phase, as compounds heavier than about 2,000 Da become aerosols in Titan's atmosphere then likely lose altitude, becoming condensation nuclei for supersaturated benzene and other components of Titan's atmosphere. As the particles grow and react, eventually they might become tholins, large hydrocarbon-nitrile particles thought to produce Titan's orange haze.



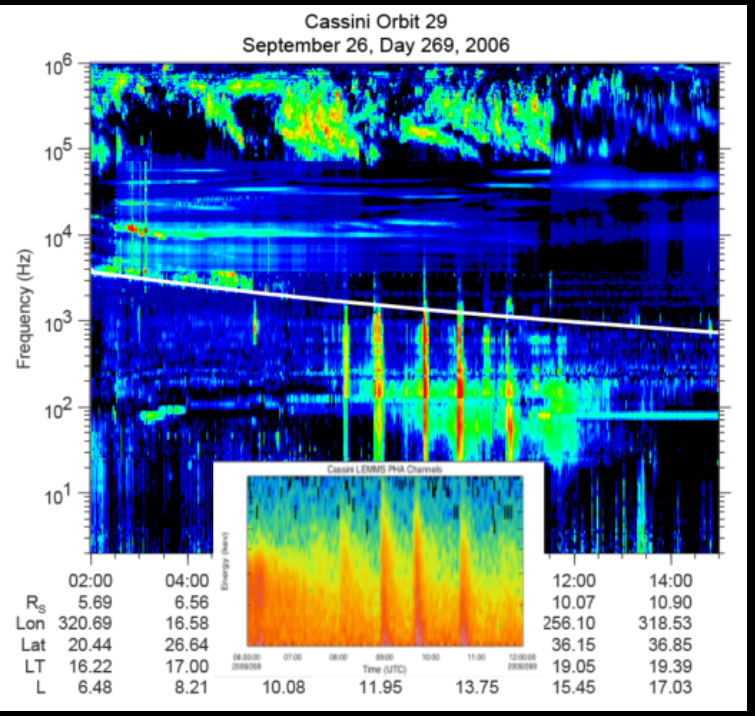
Waite et al, Science, 2007

(D) Completion of Primary MAPS Science Objectives (D)

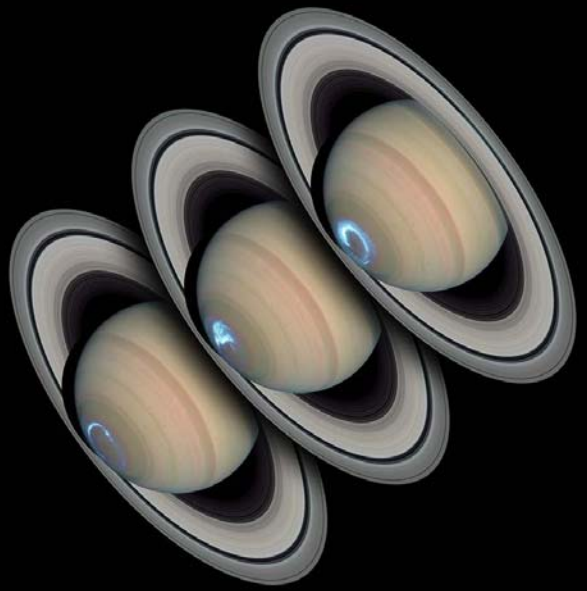
- Saturn:
  - Investigate the upper atmosphere and ionosphere.
  - Investigate sources of lightning and Saturn electrostatic discharge (SED).
- Status:
  - Some major discoveries:
    - (D.1) A 2-cell convection pattern develops in Saturn's high latitude ionosphere, controlled by mass loading from Enceladus' geysers.
    - (D.2) Variable mass loading rates from Enceladus and perhaps seasonal ionospheric conductivity variations change the rotation rate of the ionosphere.
    - (D.3) HST-Cassini campaign during Cassini's approach demonstrated the strong influence of solar wind pressure on auroral UV and radio emissions.
    - (D.4) The detection of Saturn electrostatic discharges (SEDs) from lightning is tightly coupled with observations of convective storms
    - (D.5) The propagation and polarization of SEDs provide information on Saturn's ionosphere (e.g. density).

D.3 Auroral Electrons

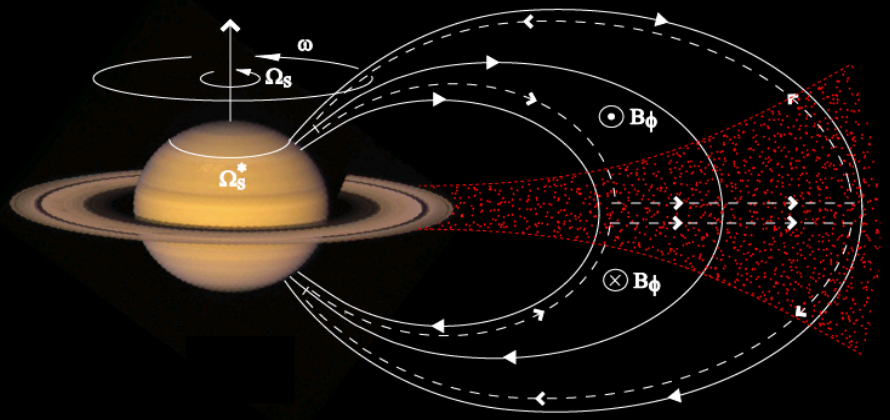
Field-aligned currents associated with precipitating particle fluxes are responsible for the aurora.
The MAPS instruments (CAPS, MAG, MIMI, RPWS) did find these precipitating beams and associated effects.



RPWS & MIMI



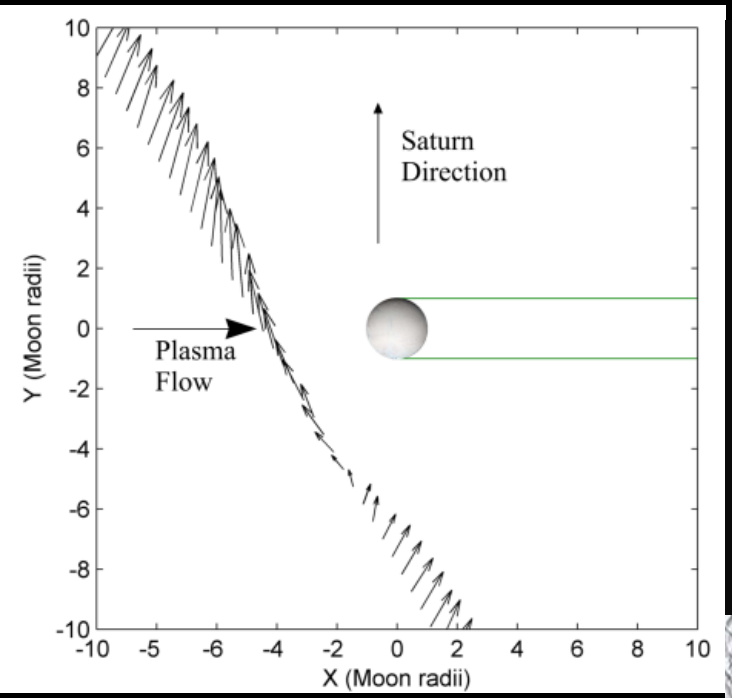
Clarke et al.

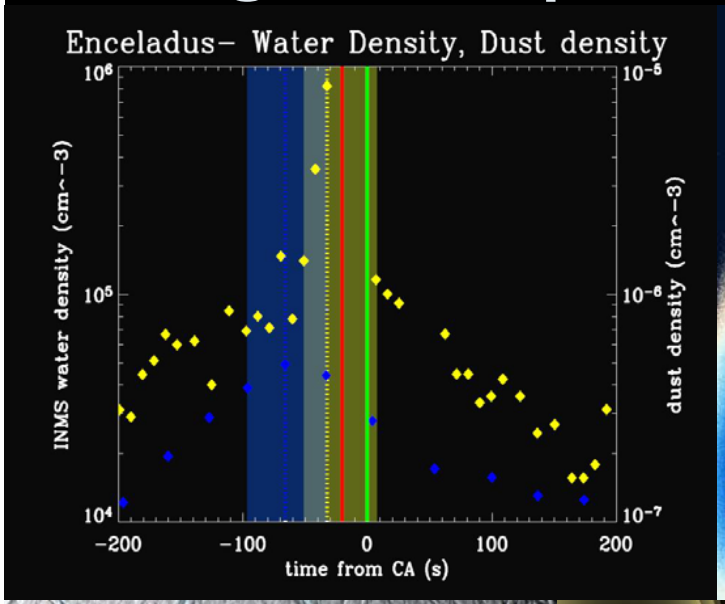


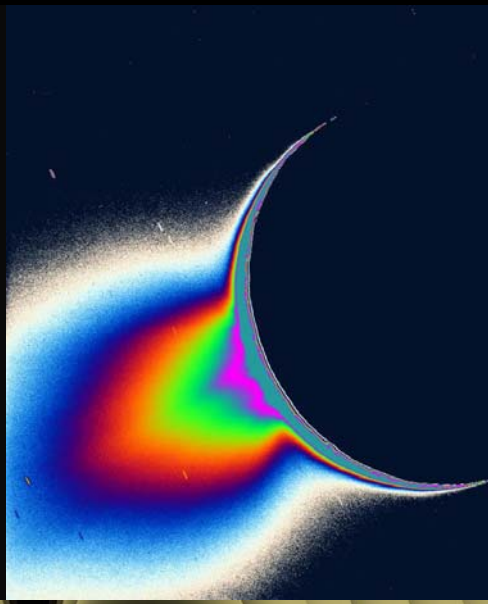
(E) Completion of Primary MAPS Science Objectives (E)

- Major icy satellites:
  - Determine the gravitational & magnetic fields, and their dynamic properties.
  - Study satellite atmospheres and ionospheres, any extended gas clouds; their interactions with the magnetosphere and rings.
- Status:
  - Some major discoveries:
    - (E.1) Enceladus is the ‘engine’ of the Saturnian magnetosphere
    - (E.2) Interesting, unique charged particle interaction with Rhea may be due to cloud of dust particles trapped within the Hill sphere.

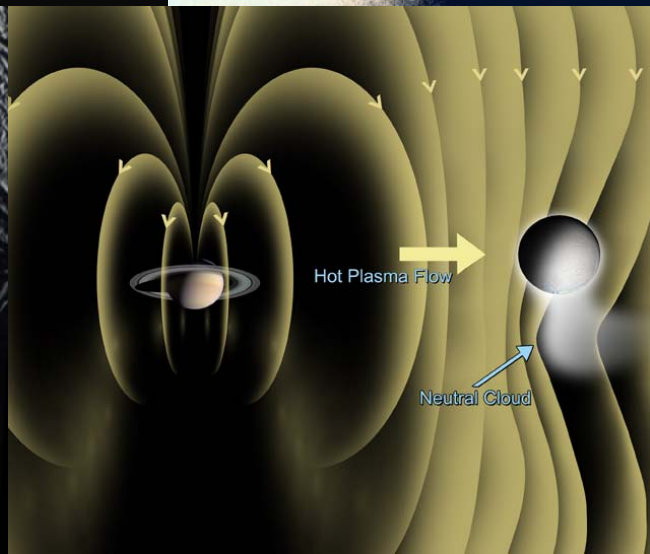
E.1 & D.2) Enceladus is the Engine of Saturn's Magnetosphere





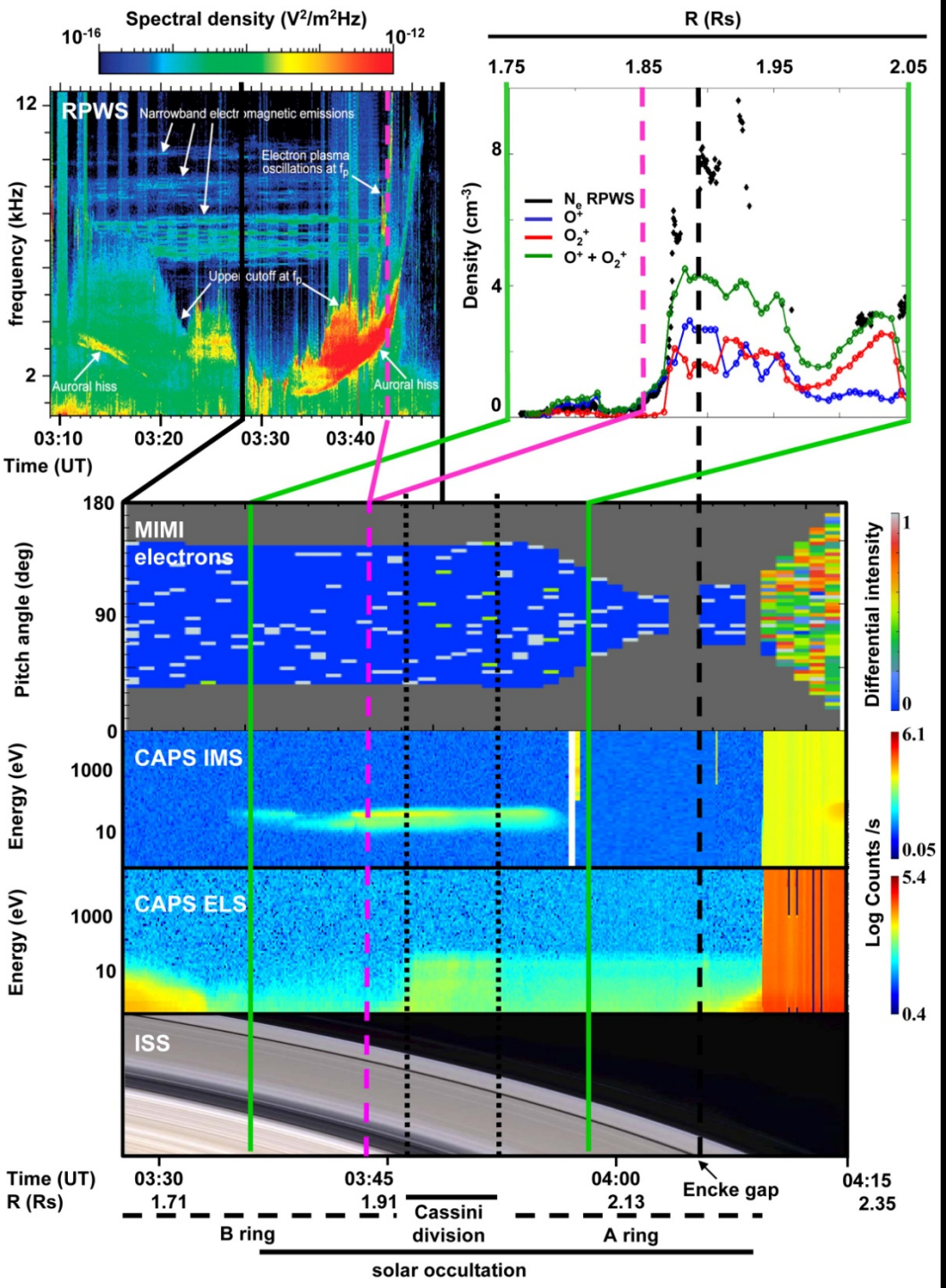


During the E1 flyby the magnetometer observed magnetic field draping that is characteristic of magnetospheric plasma interaction with a neutral gas cloud. This led to the discovery of the plumes of Enceladus.



(F) Completion of Primary MAPS Science Objectives (F).

- Saturnian rings:
  - Investigate ring-magnetosphere, ring-ionosphere, and ring-atmosphere interactions.
  - Investigate electromagnetic processes responsible for ring structure.
  - Determine the dust and meteoroid distribution.
- Status:
  - Some major discoveries:
    - (F.1) Discovery of ring-ionospheres
    - (F.2) Identification of particle fluxes, mass distributions and composition of grains in the E ring
    - (F.3) Interactions between rings and magnetosphere.



F..1) Ring Ionosphere

The main rings create a cavity inside Saturn's radiation belts in which production of neutrals and plasma are due to UV and low-energy particle irradiation, and to micrometeorite bombardment of the ring particles.

This production is important enough to maintain an exosphere and a tenuous ionosphere, which have been probed by the MAPS instruments and display specific chemical and dynamical features.

More to Do …

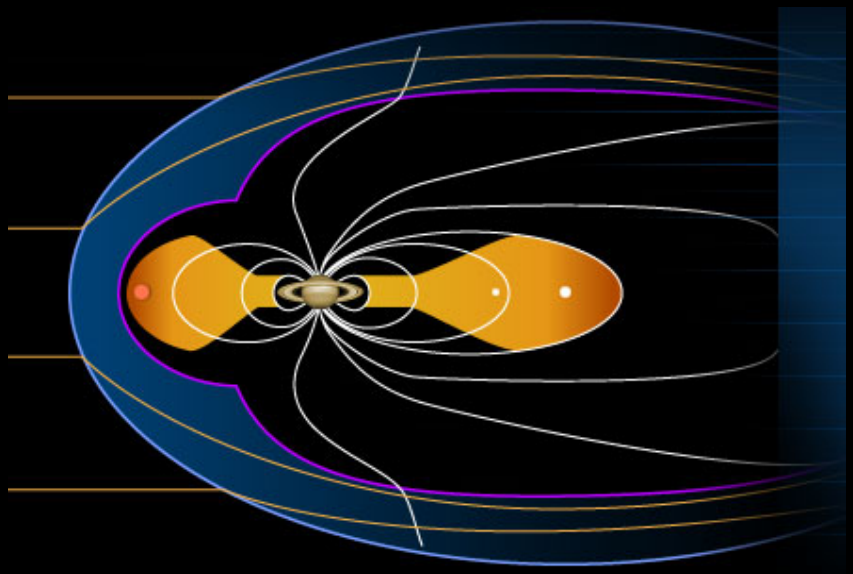
- Magnetosphere Objectives:
  - Cassini's orbit did not reach the magnetotail reconnection region and the neutral sheet. These will be covered during Equinox and Cassini Solstice Mission.
  - Cassini's orbit allowed *in-situ* observation of the auroral zones only late in the prime mission. These will be covered further during the Equinox Mission.
  - Temporal variations are observed only for 4 years. More complete coverage will be accomplished during the Equinox and Solstice Missions.
  - To accurately determine the planetary magnetic field of Saturn, complete spatial coverage at a wide range of latitudes and longitudes and close distances is required.
- Saturn - both SKR & SED Objectives:
  - Cassini's orbit allowed only very limited observations in the 3-5 R_S region
  - The 4 year prime mission did not allow enough time to distinguish between competing theories of why the SKR period varies and why it does not reflect the internal period of the planet.
  - Internal period is still not determined.

More to Do …

- Icy Satellite Objectives
  - We need additional close fly-bys (both upstream and downstream) with unexplored icy satellites (Mimas, Dione, Thetys, Rhea).
  - We need to explore the details of Enceladus' plume and its interaction with the magnetosphere.
- Titan Objectives
  - There was only one distant wake crossing, T9, that provided an excellent, but confusing data set of the distant interaction.
  - Only 2 dusk sector flybys were in the prime mission. In this geometry the magnetospheric flow is into the sunlit hemisphere of Titan, likely to produce strong ionospheric effects.
- MAPS Ring Objectives:
  - SOI demonstrated the unique and highly interesting nature of the region just above the main ring system. However, some instruments were not configured for optimum (or any) science observations during SOI because of the critical nature of SOI and the main engine burn, itself. Returning to this very interesting region would enable proper configuration of MIMI, CAPS, INMS, and RPWS to properly measure the ring ionosphere and would provide an additional very close periapsis for MAG to observe the internal field of Saturn.

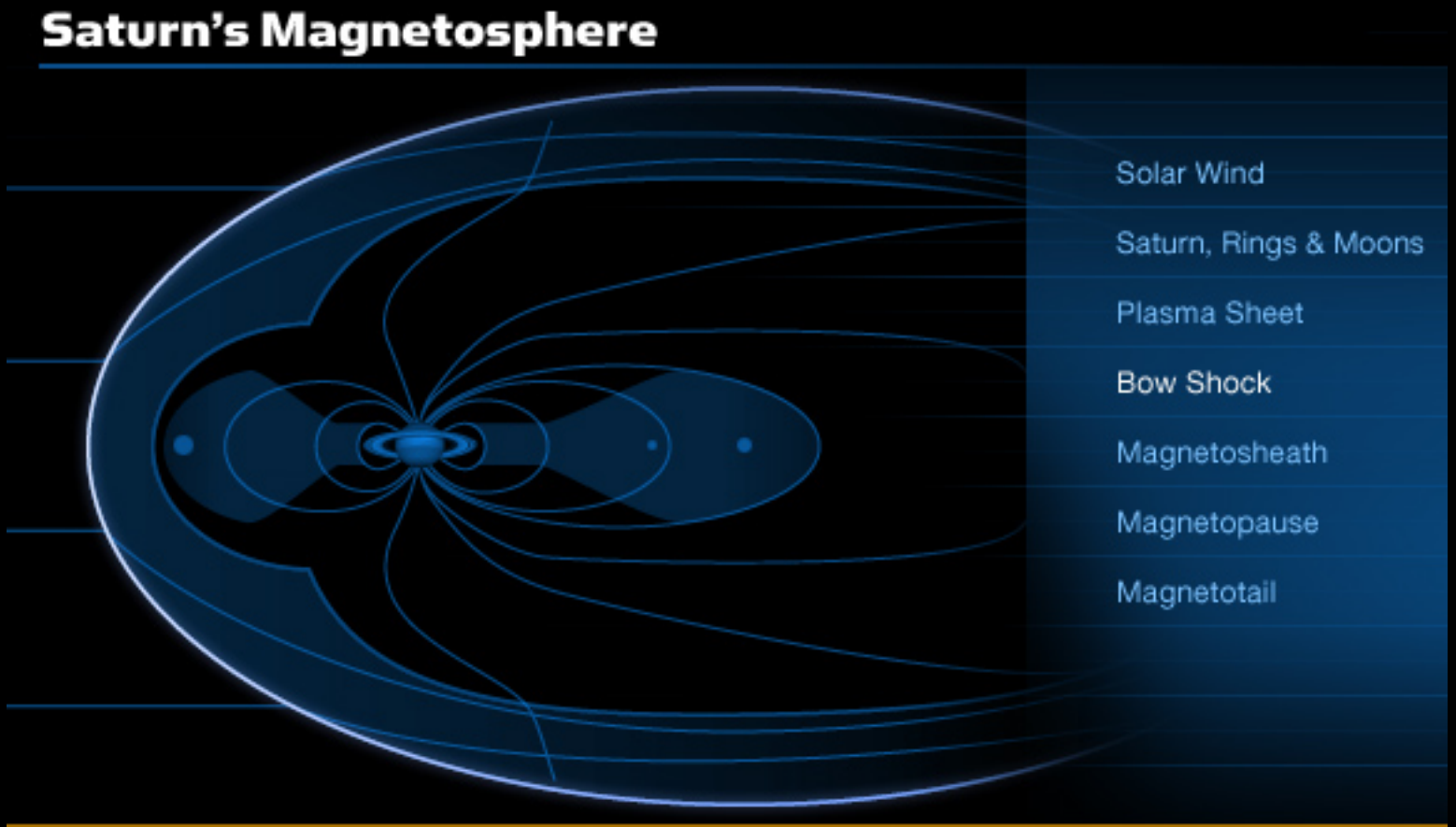
Basic Elements of the Magnetosphere

- Bow Shock
- Magnetosheath
- Magnetopause
- Moons & Rings
- Plasma Sheet/ magneto-disc
- Neutral Cloud
- Magnetotail

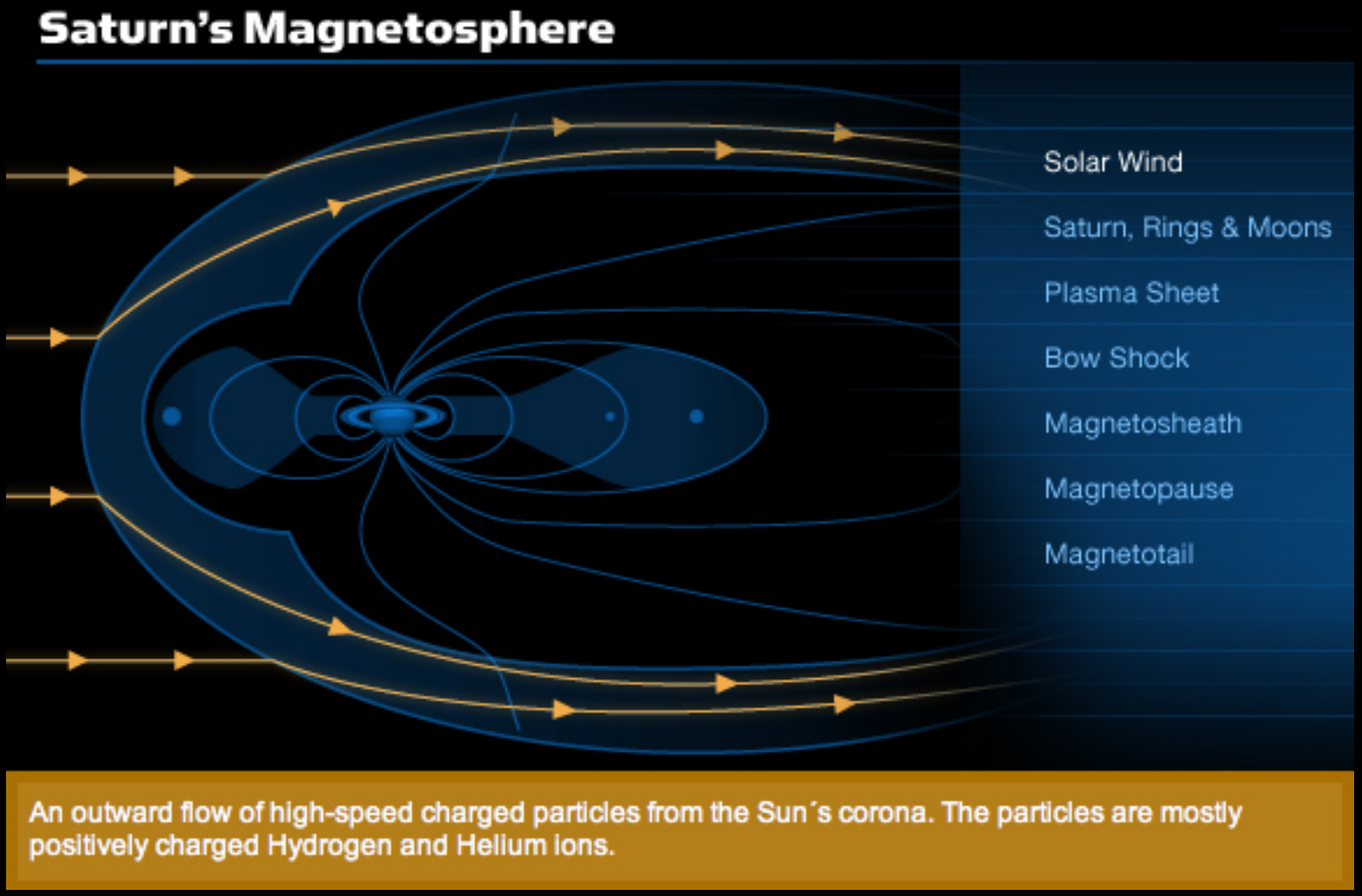


All of these parts
ARE IN MOTION!

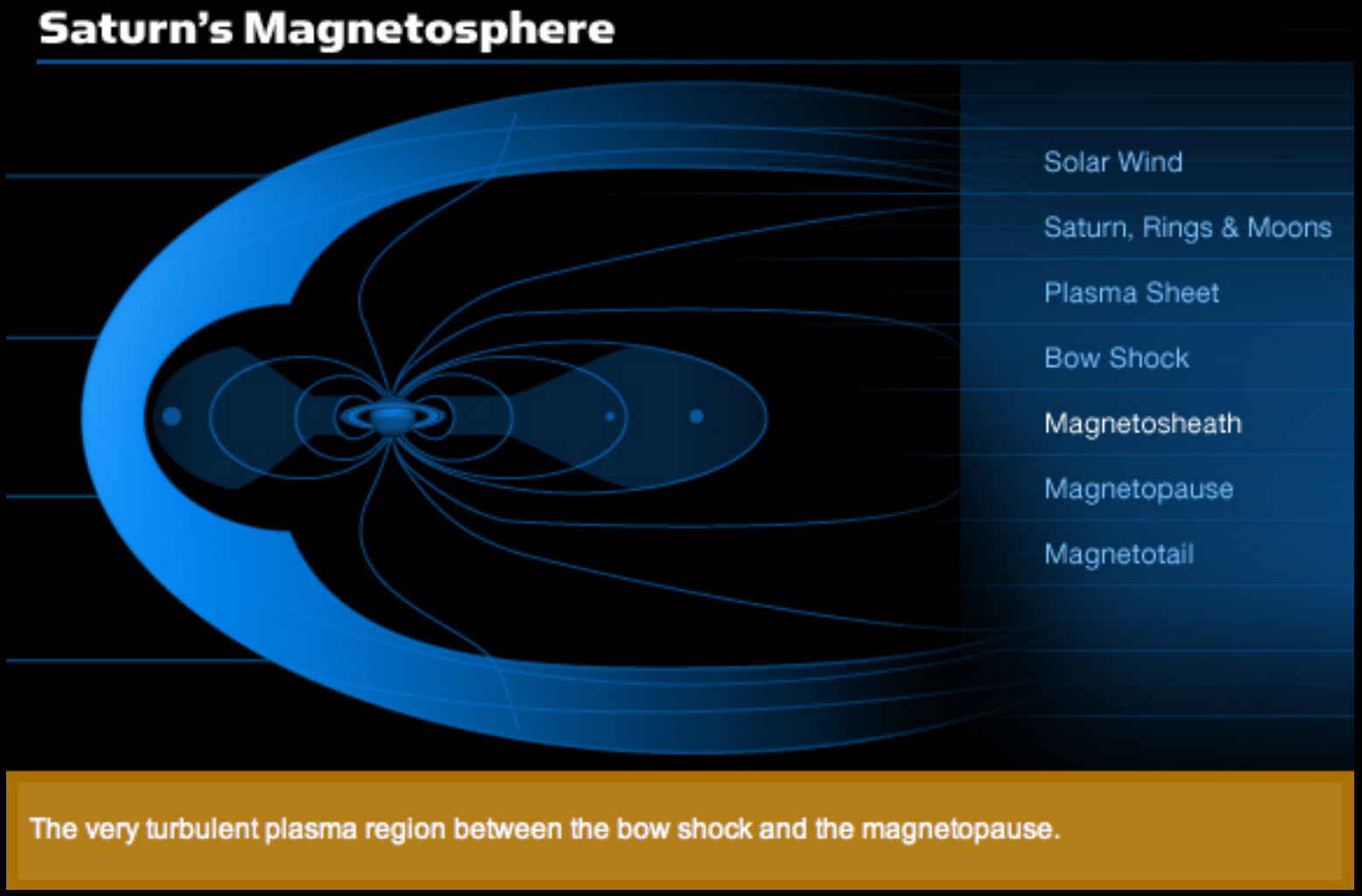
Bow Shock


Saturn's Magnetosphere
Solar Wind
Saturn, Rings & Moons
Plasma Sheet
Bow Shock
Magnetosheath
Magnetopause
Magnetotail
A supersonic shock wave that is formed as the solar wind interacts with the outermost layer of Saturn´s magnetosphere.

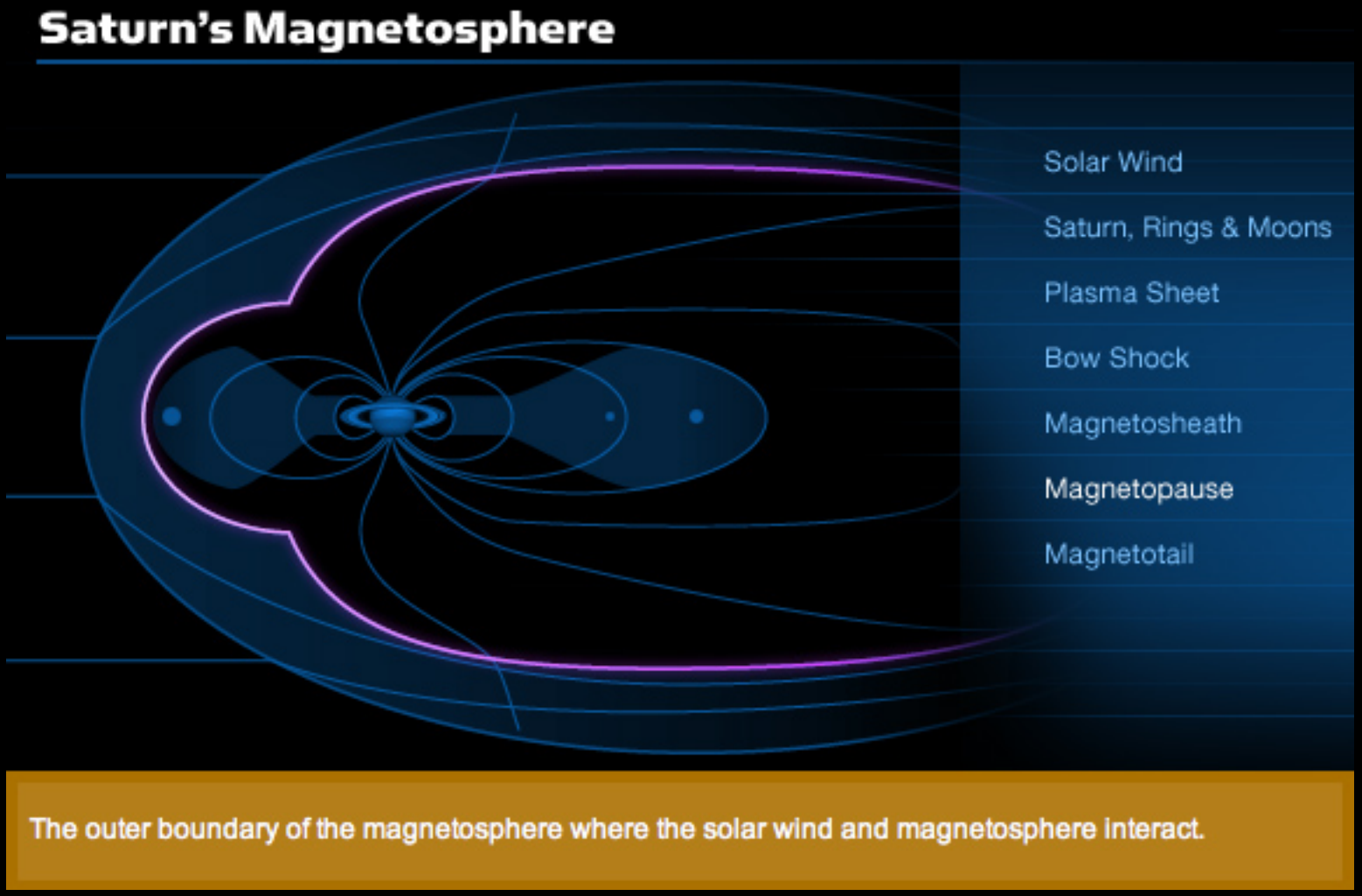
Solar Wind


Saturn's Magnetosphere
Solar Wind
Saturn, Rings & Moons
Plasma Sheet
Bow Shock
Magnetosheath
Magnetopause
Magnetotail
An outward flow of high-speed charged particles from the Sun´s corona. The particles are mostly positively charged Hydrogen and Helium ions.

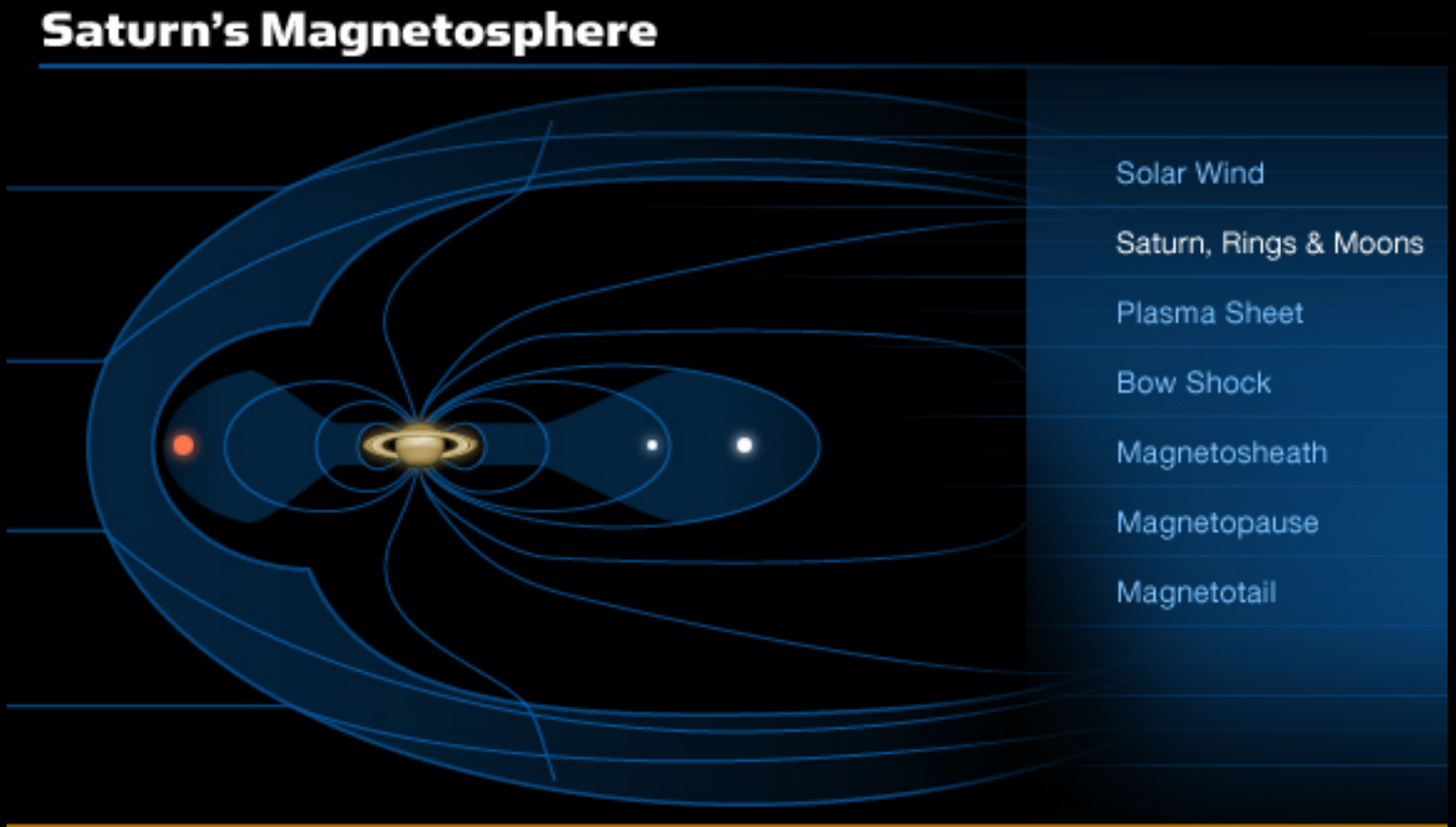
Magnetosheath



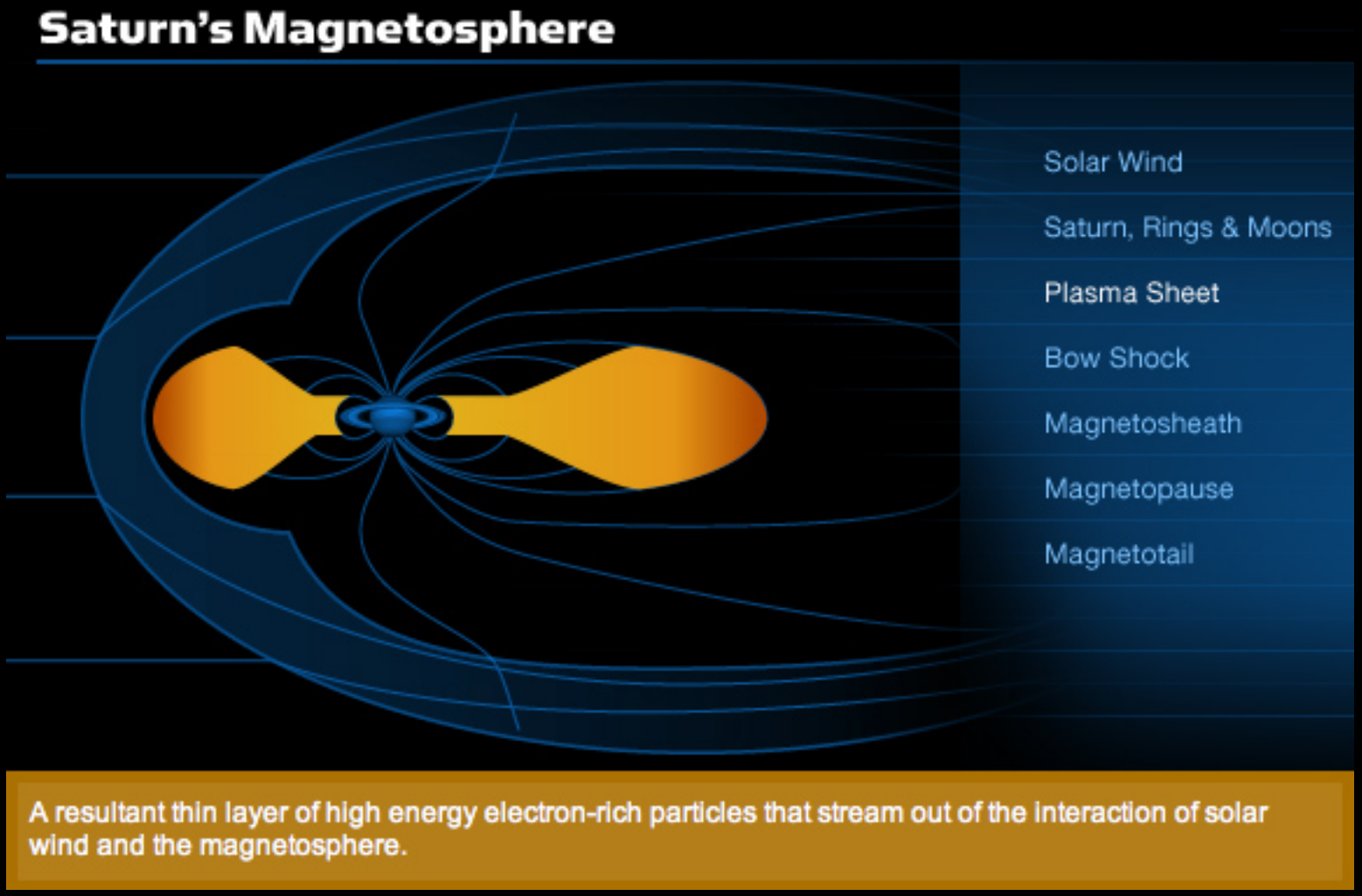
Magnetopause



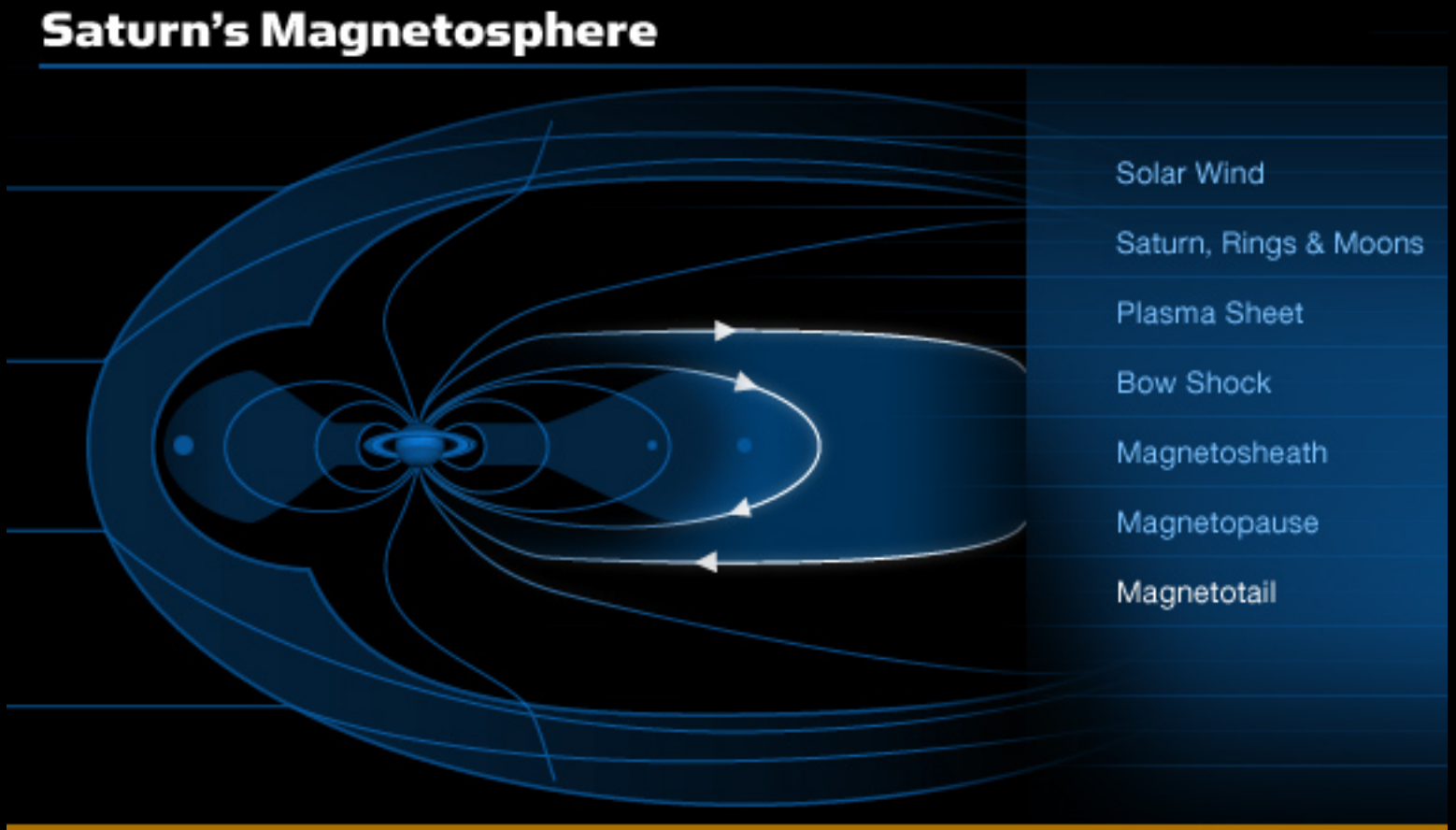
Rings & Moons


Saturn's Magnetosphere
Solar Wind
Saturn, Rings & Moons
Plasma Sheet
Bow Shock
Magnetosheath
Magnetopause
Magnetotail
Saturn´s metallic-rocky core creates a magnetosphere that forces the charged particles to stream around Saturn, its rings and most of the moons.

Plasma Sheet, Magnetodisc,& Neutral Cloud



Magnetotail



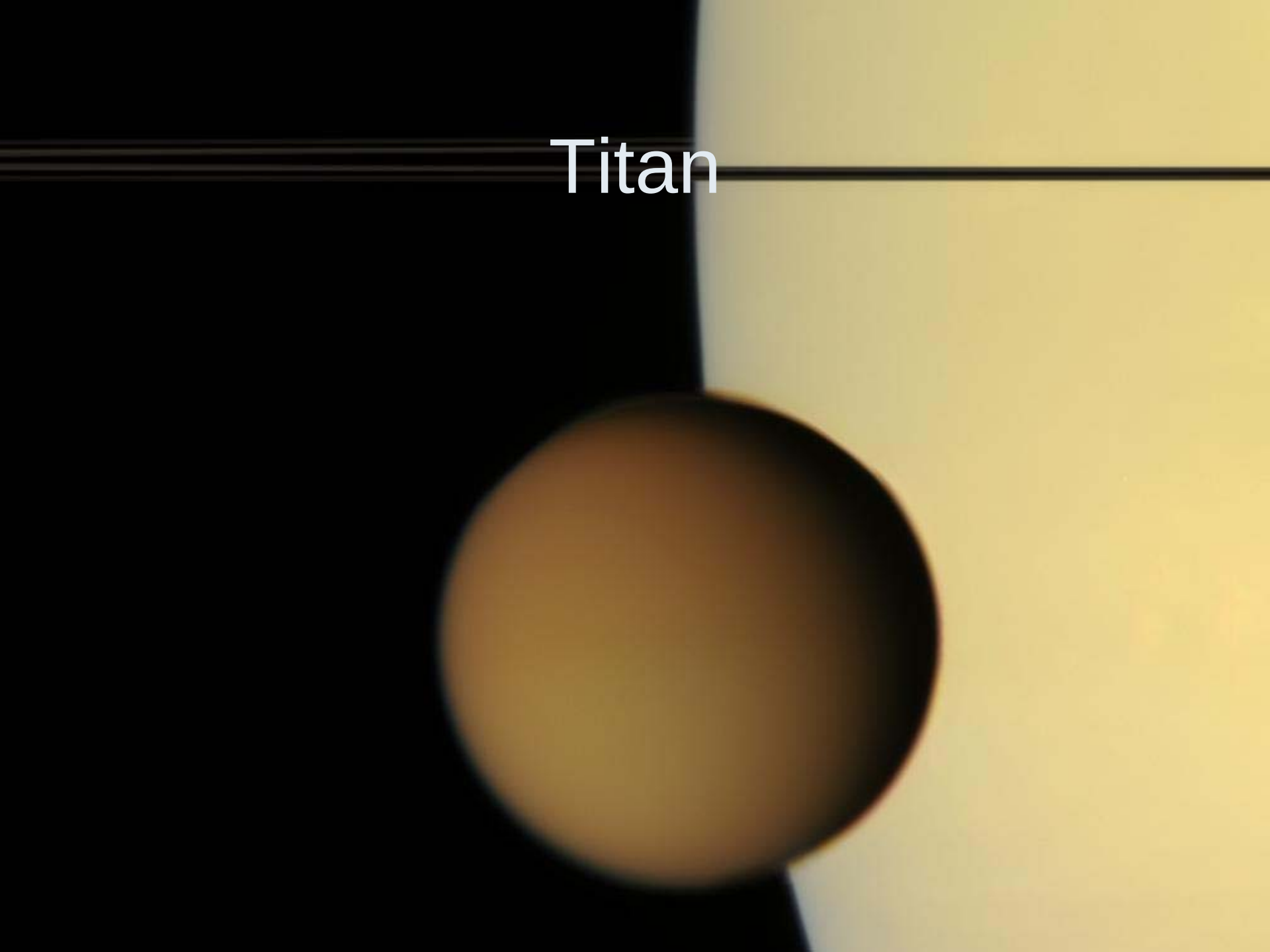
MAPS-Focused Instruments

- CAPS
  - Ion Mass Spectrometer
  - Ion Beam Spectrometer
  - Electron Spectrometer
- MAG
- MIMI
  - LEMMS: Suprathermal particles
  - CHEMS: Ion charge-state
  - INCA: Ion and Neutral Camera
- RPWS
  - Wave Electric Field Sensors
  - Wave Magnetic Field Sensors
  - Langmuir Probe
  - 1 Hz – 16 MHz receivers, including waveform capabilities

Multiple-Purpose Instruments

- INMS
  - Measures ion and neutral composition
    - in the upper atmosphere of Titan,
    - during ring plane crossings and
    - at icy satellites.
- CDA
  - Investigates dust as a source/sink of charged particles.
- RSS
  - Observes ion and neutral density profiles in the upper atmospheres of Saturn and Titan.
  - Measures the exospheres of icy satellites.
- ISS
  - Investigates lightning, aurora and airglow.
- UVIS
  - Observes the aurora and neutral tori.

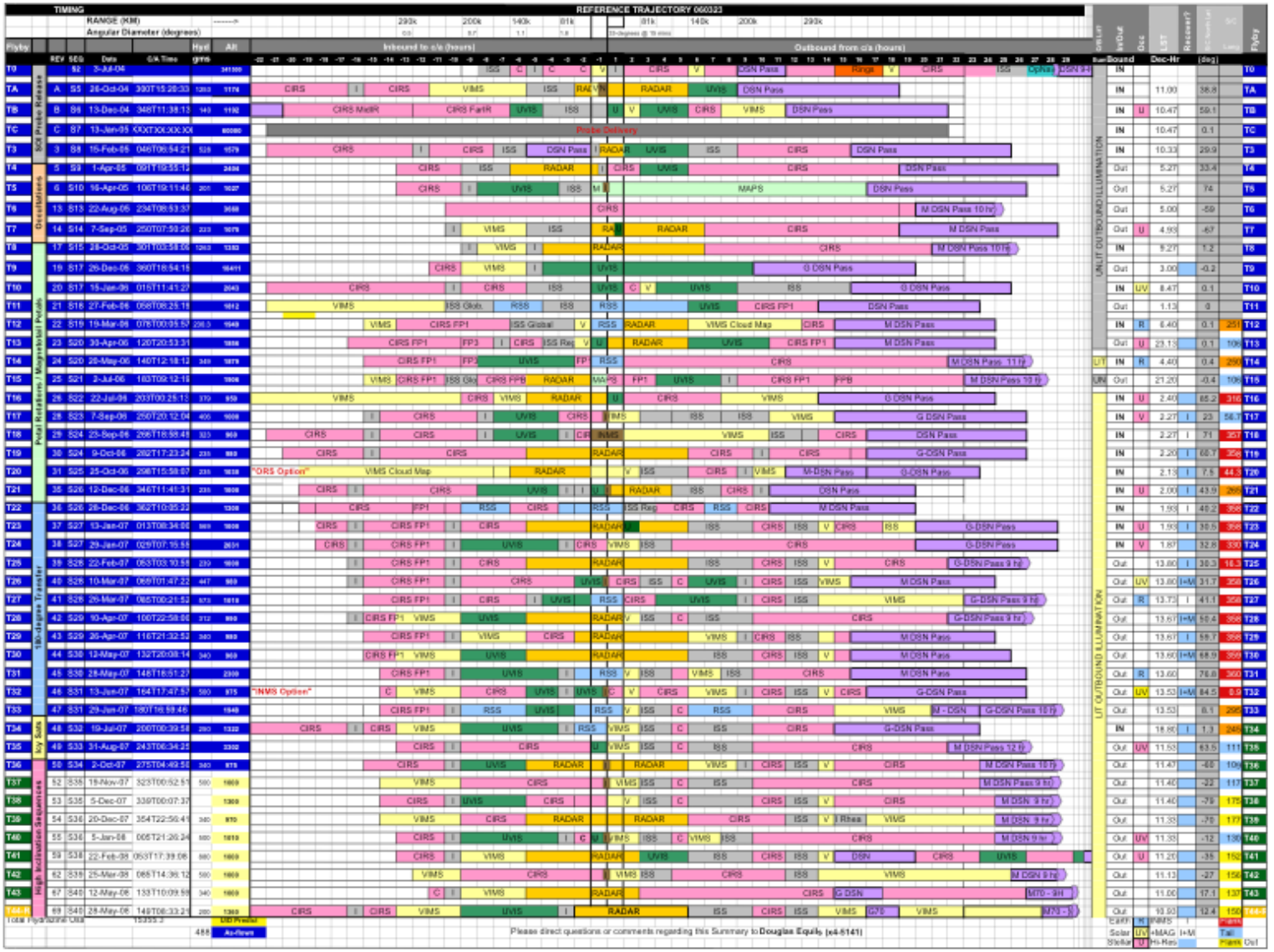
Titan



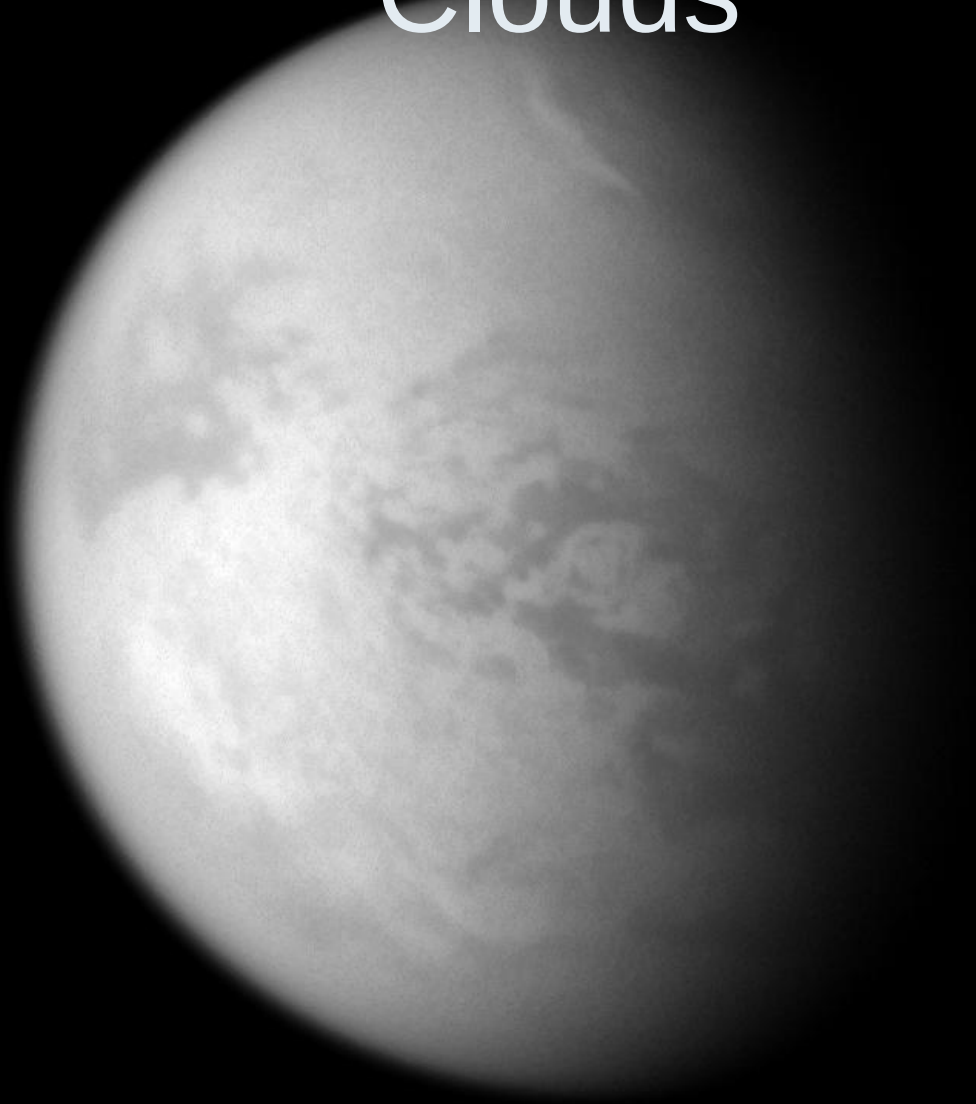
Titan Flybys in 4th year

T34	19 Jul 2007	VIMS high-res mapping
T35	31 Aug 2007	VIMS stellar occultation, high-res mapping
T36	2 Oct 2007	INMS; RADAR SAR, HiSAR, altimetry
T37	19 Nov 2007	INMS; VIMS high-res mapping
T38	5 Dec 2007	VIMS high-res of Ontario Lacus
T39	20 Dec 2007	First RADAR SAR of South Pole
T40	5 Jan 2008	INMS; VIMS high-res of Huygens LS
T41	22 Feb 2008	RADAR SAR of Hotei Arcus, Huygens LS
T42	25 Mar 2008	INMS; VIMS high- to medium-res mapping
T43	12 May 2008	RADAR SAR of Xanadu, Tortola Facula
T44	28 May 2008	RADAR SAR of Xanadu, Tui Regio

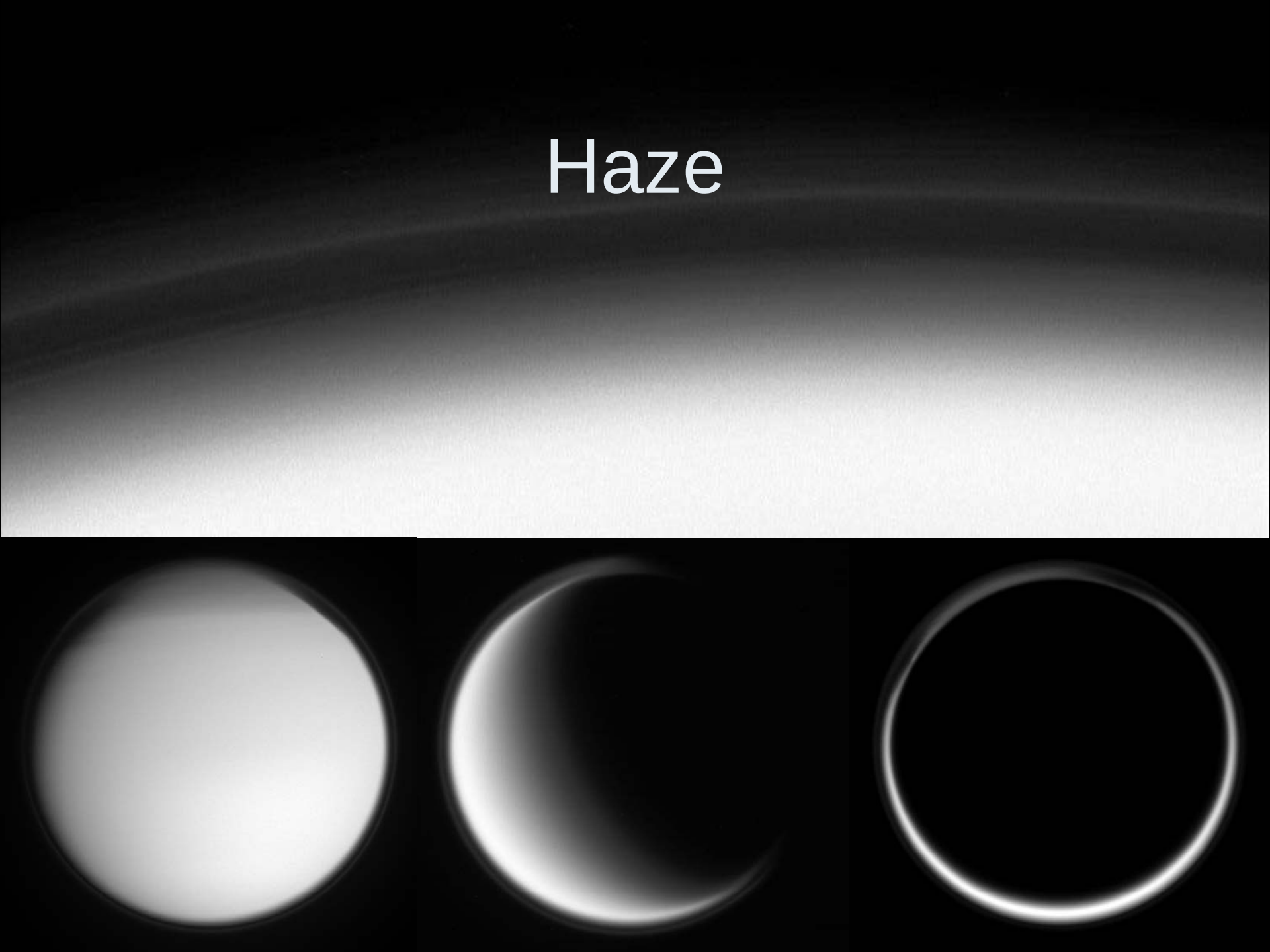
Titan Flybys



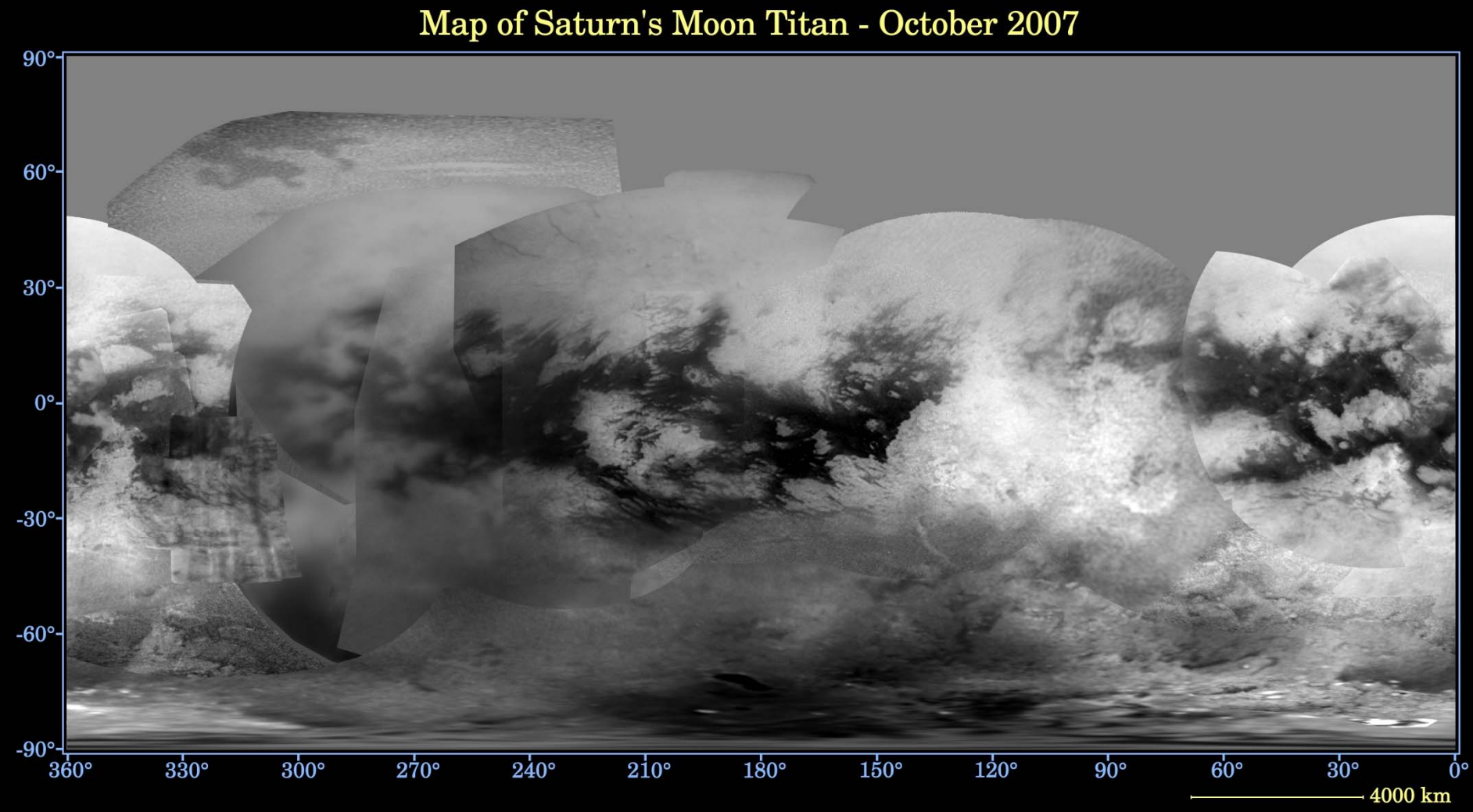
Clouds



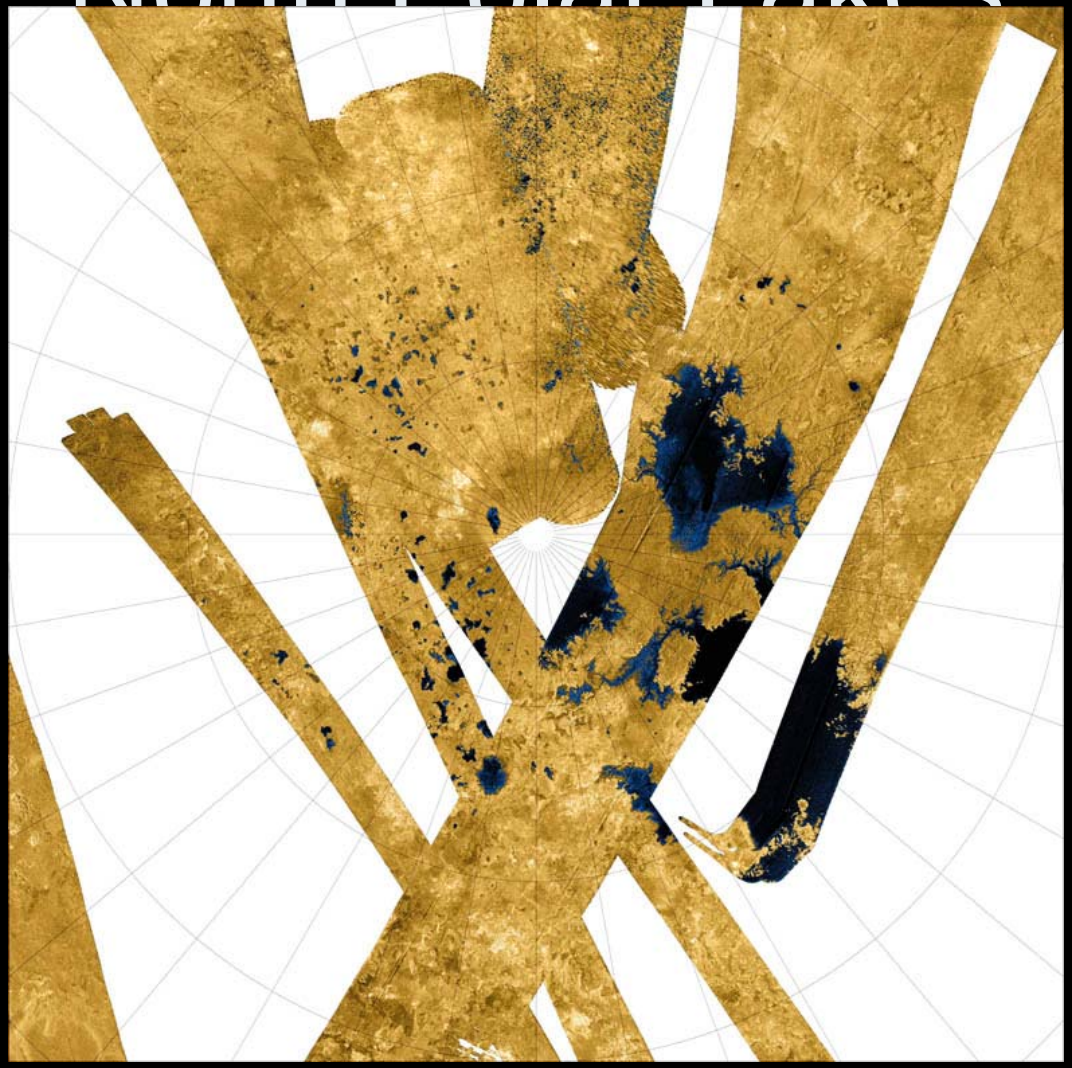
Haze



Titan Surface Map (Oct. 2007)

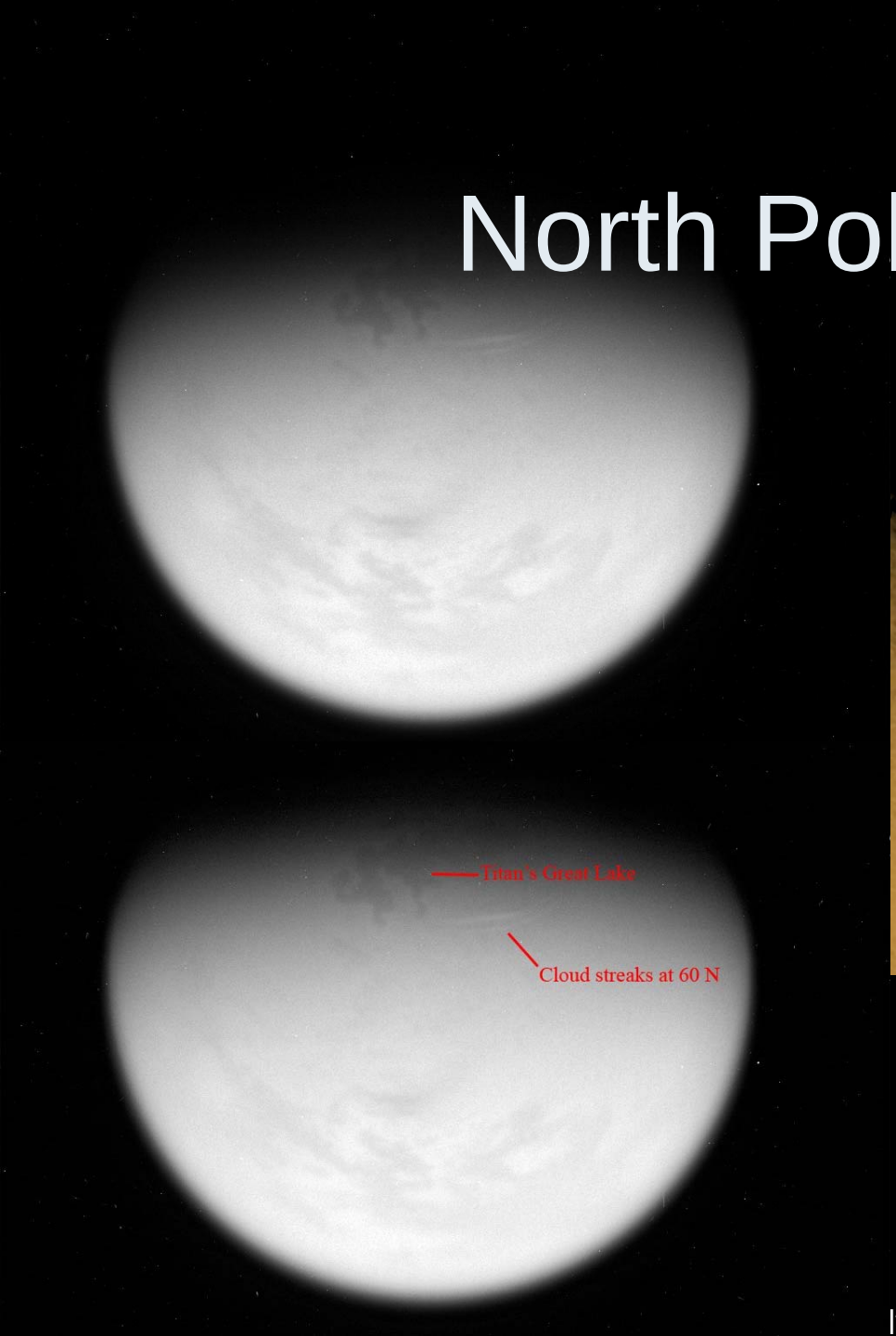


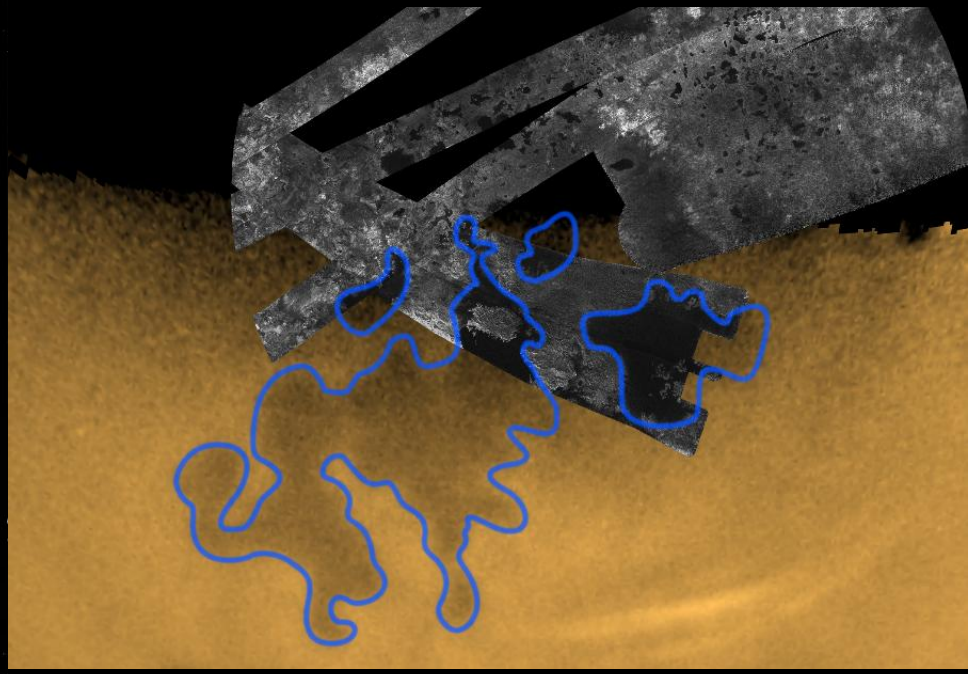
North Polar Lakes



http://photojournal.jpl.nasa.gov/archive/PIA10008.mov

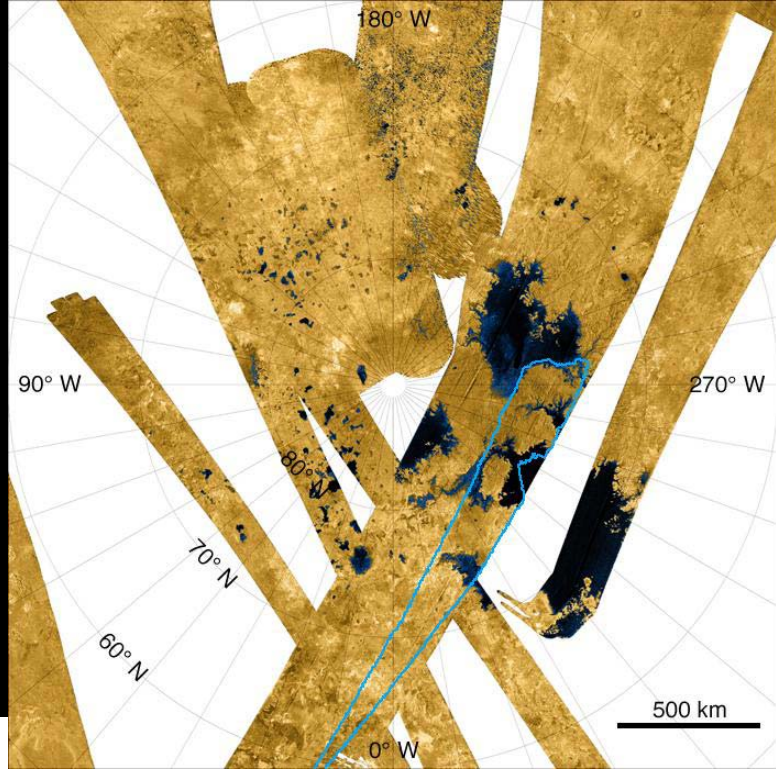
North Polar Lakes

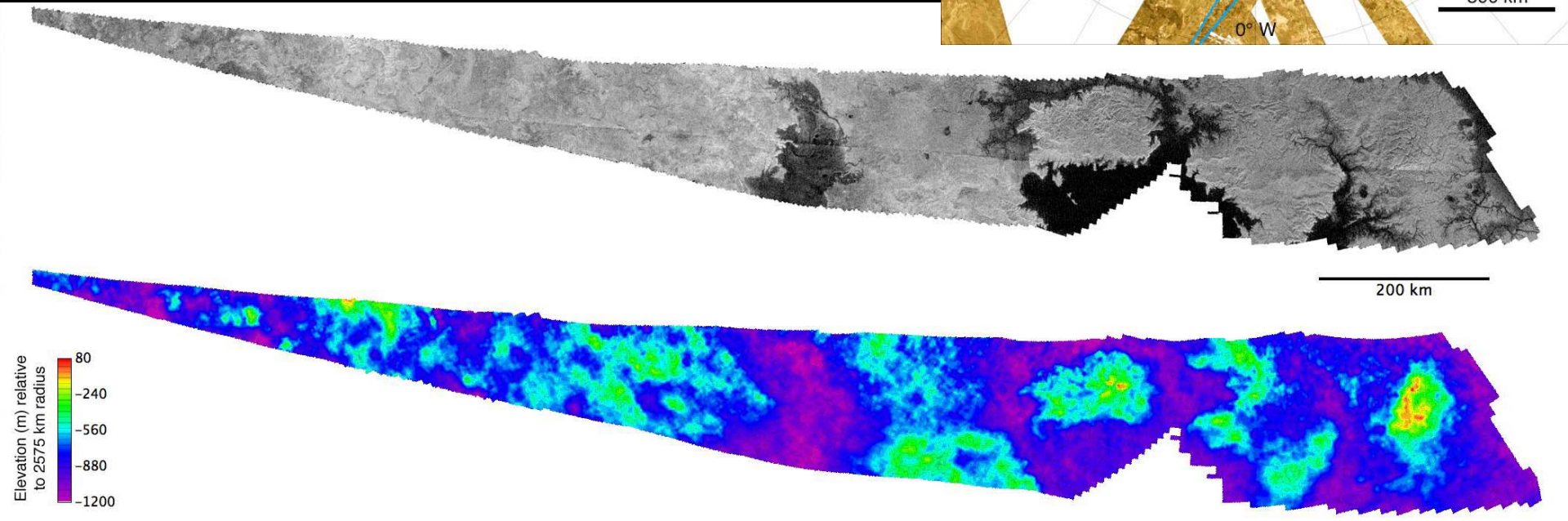




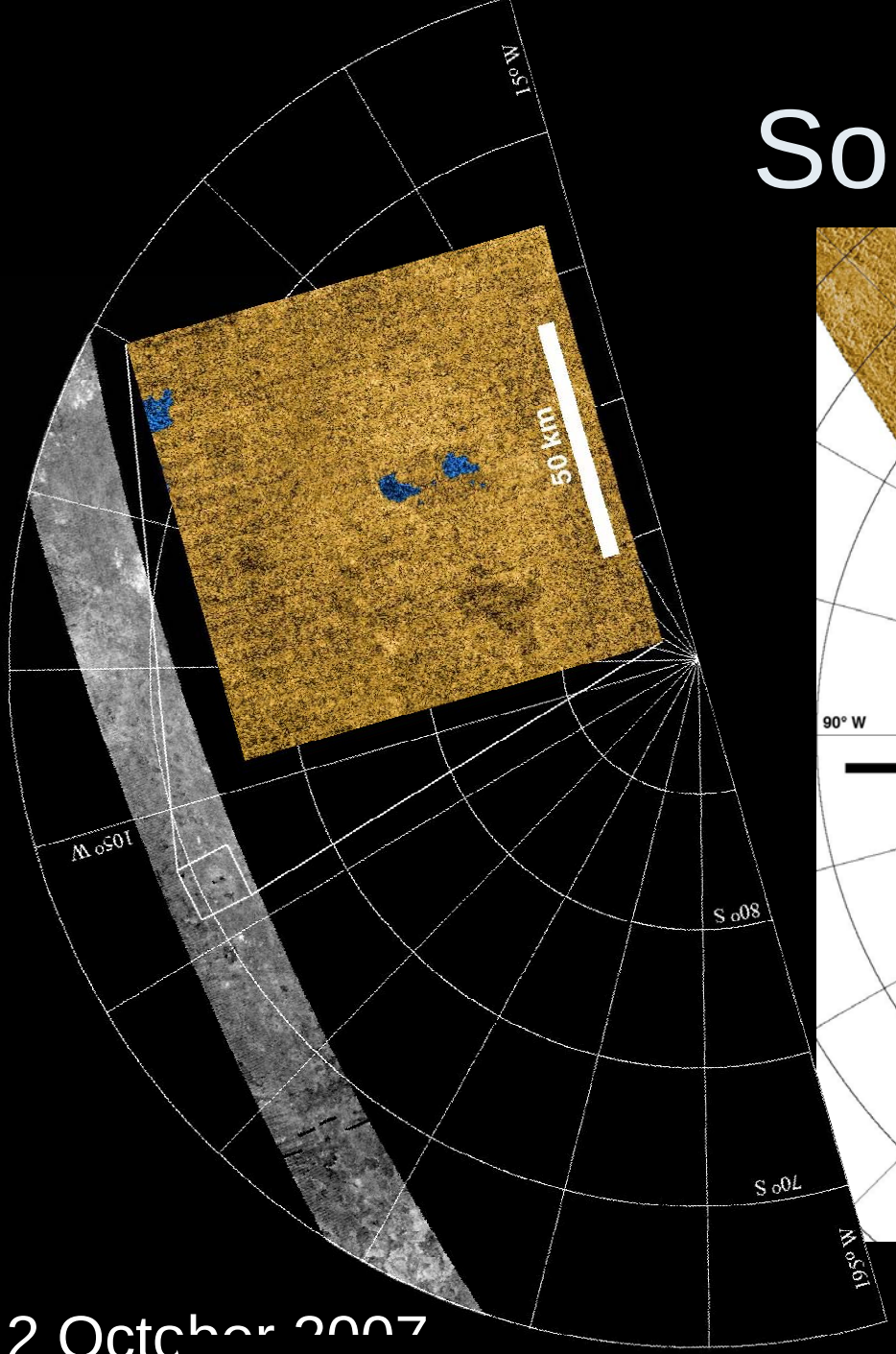
February 2007

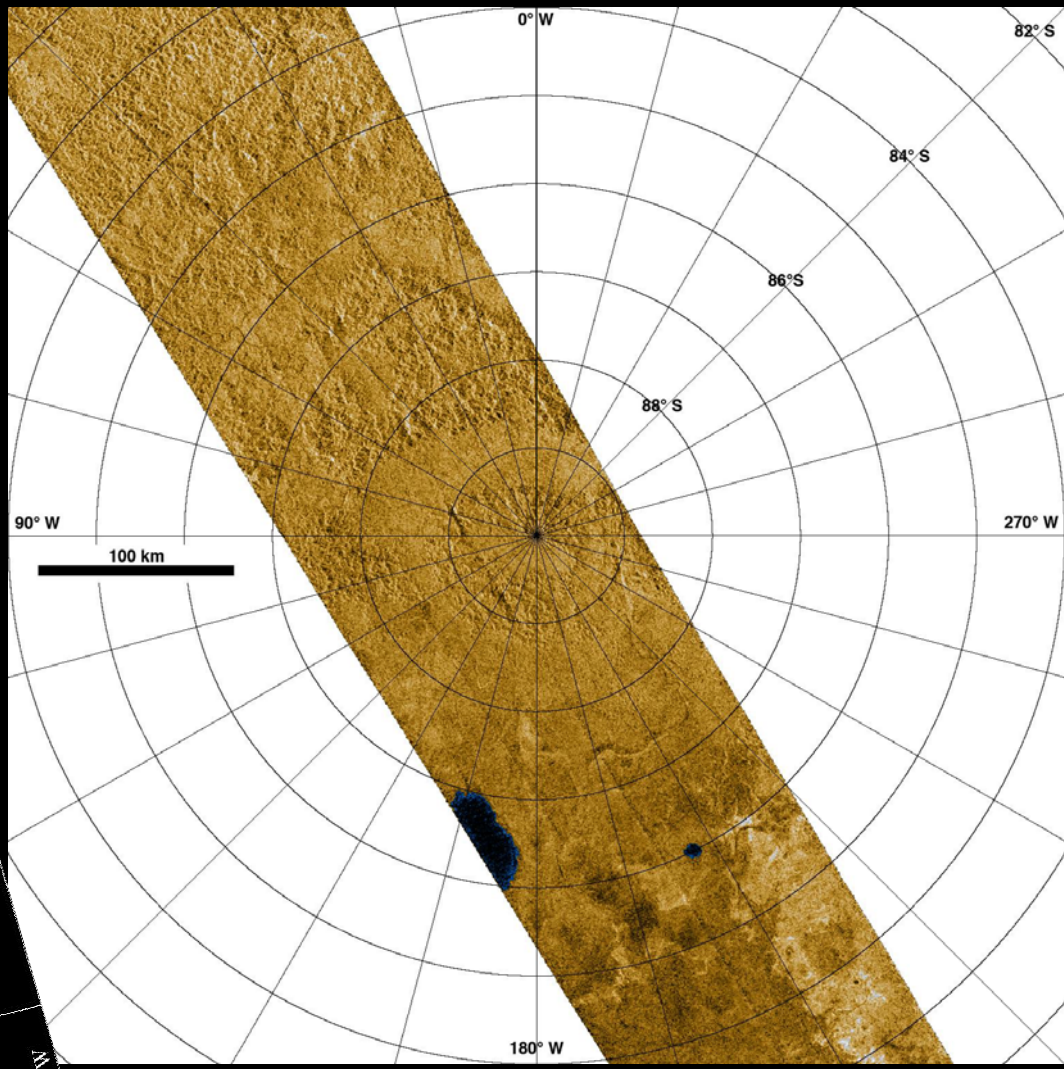
Topography


180° W
90° W
270° W
80° N
70° N
60° N
0° W
500 km


200 km
Elevation (m) relative to 2575 km radius
80
-240
-560
-880
-1200

South Polar Lakes

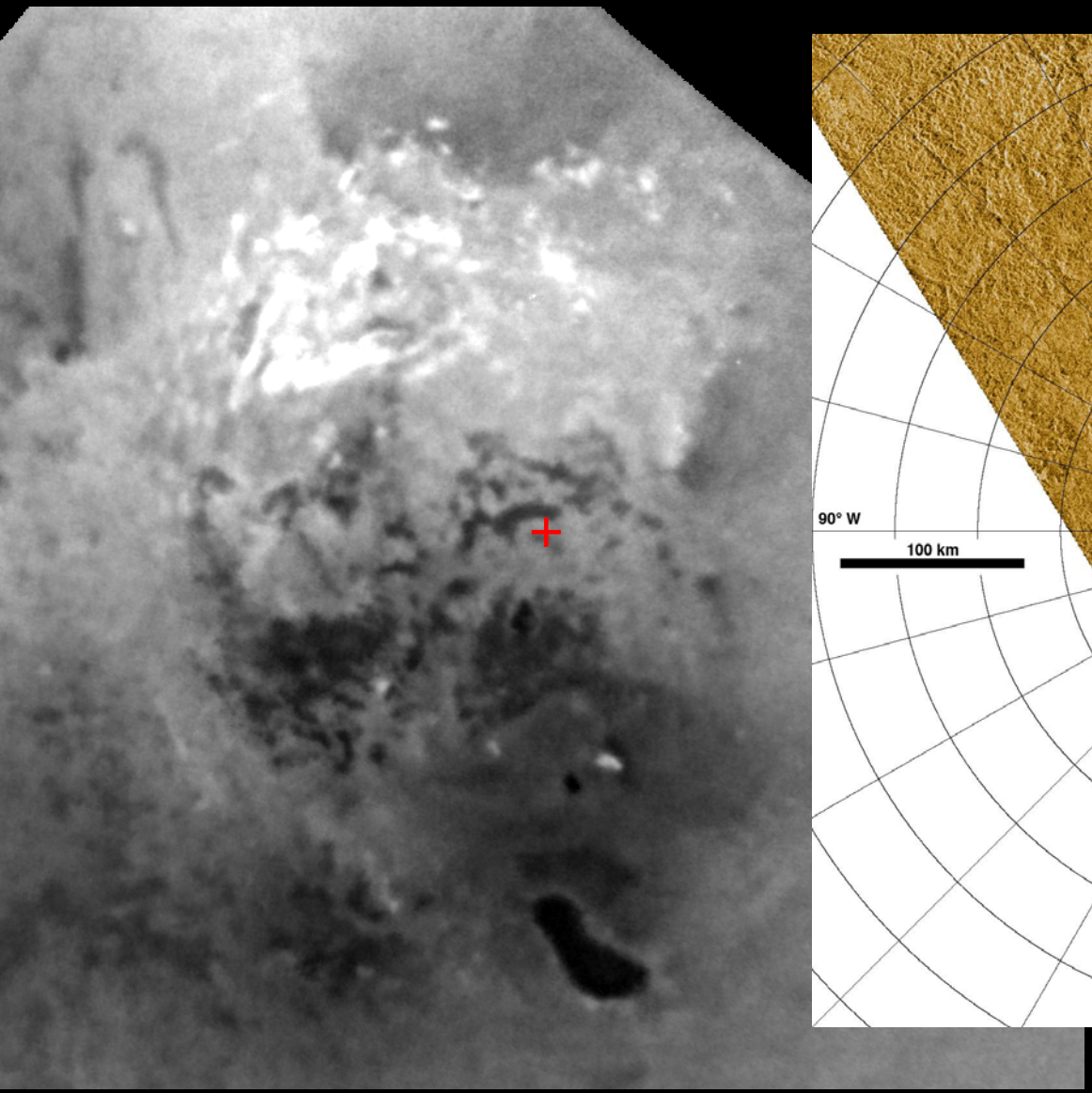


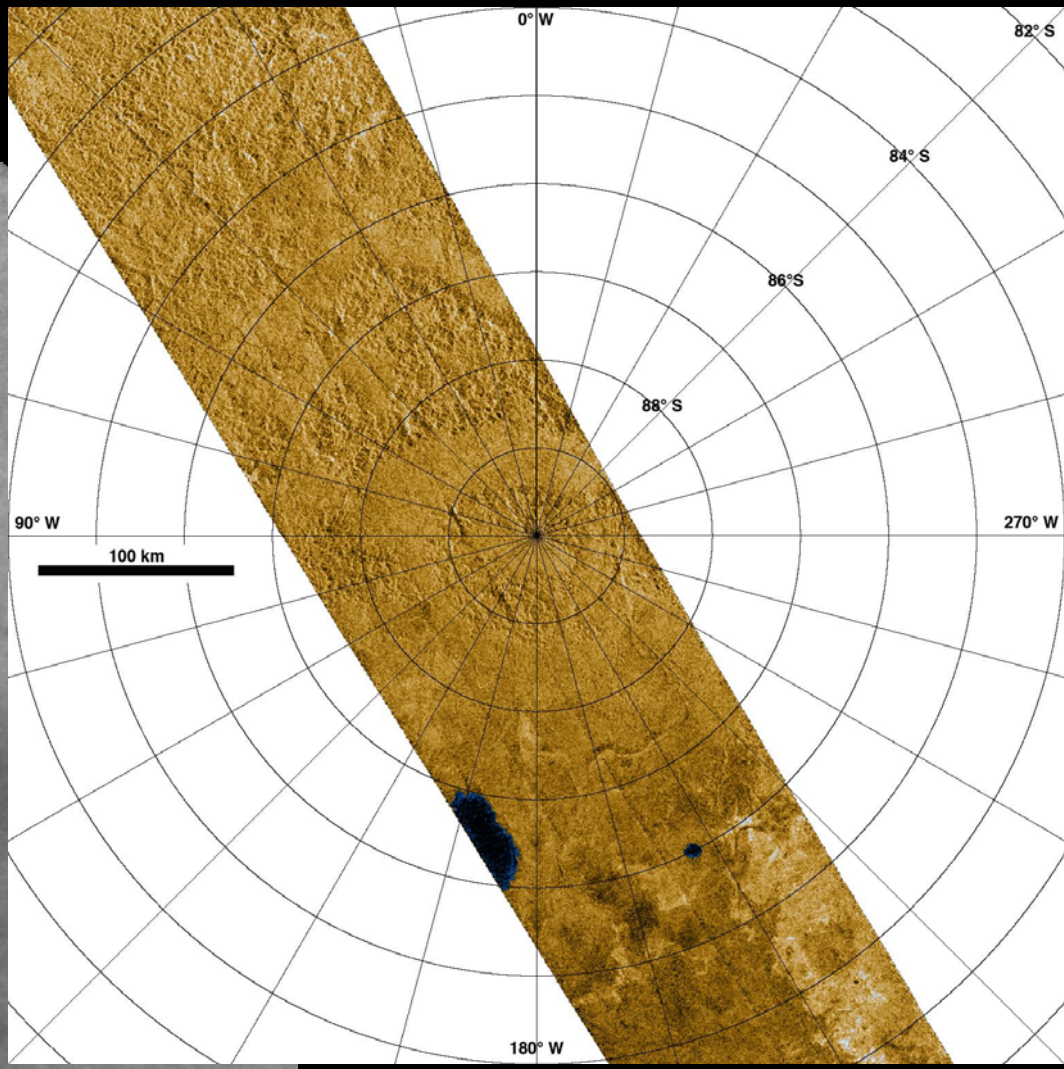


2 October 2007

20 December 2007

South Polar Lakes

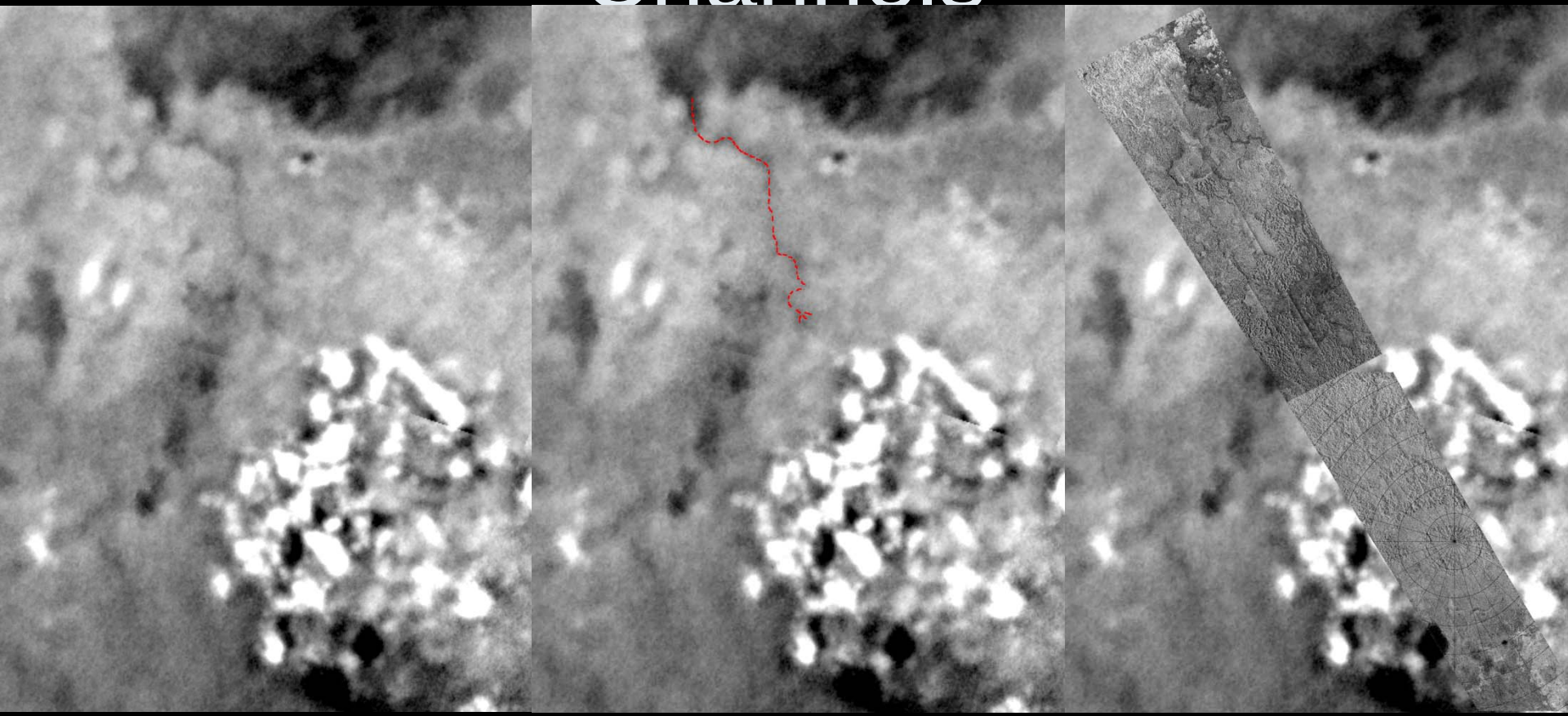




6 June 2005

20 December 2007

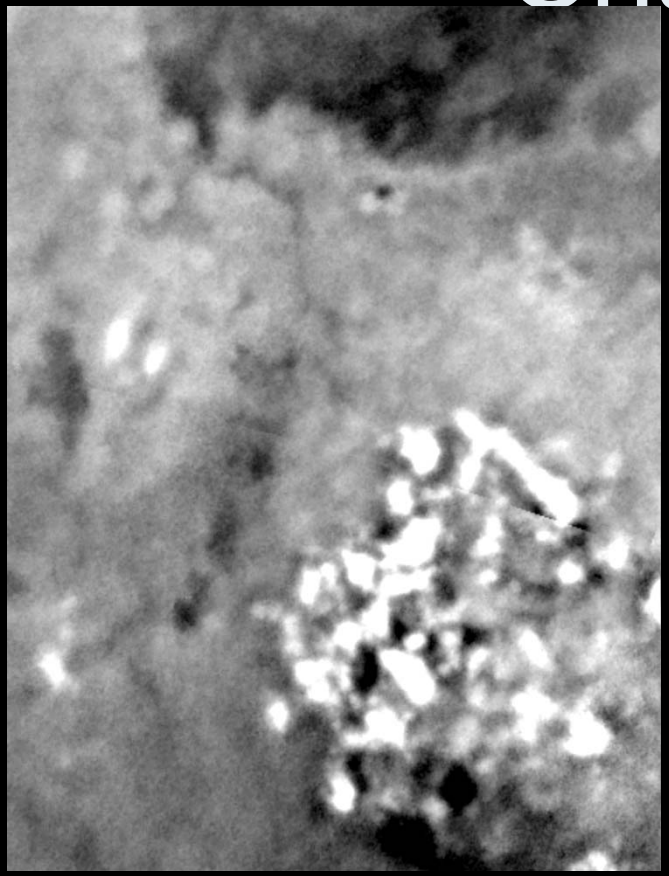
Channels



3 July 2004

20 December 2007

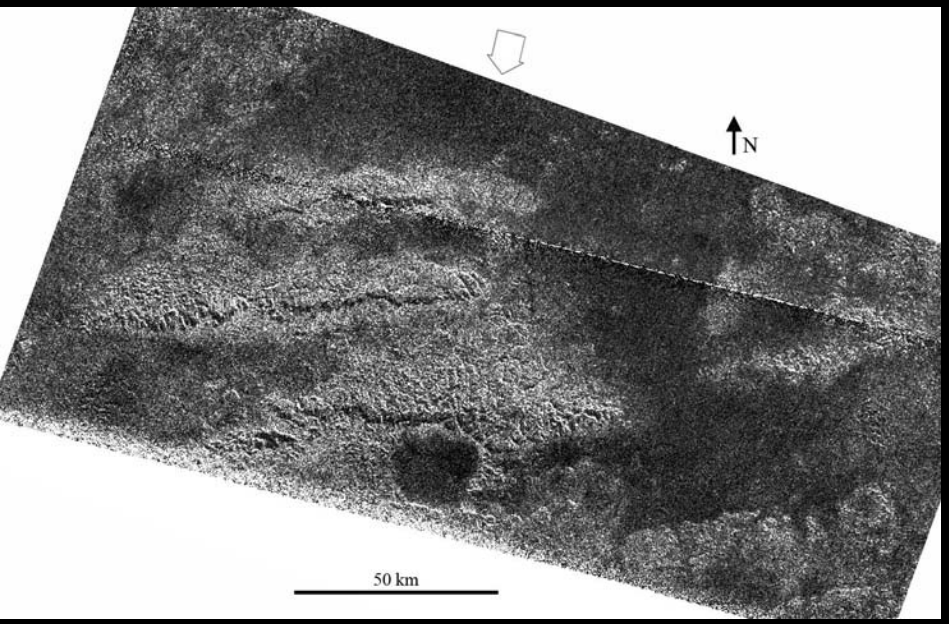
Channels

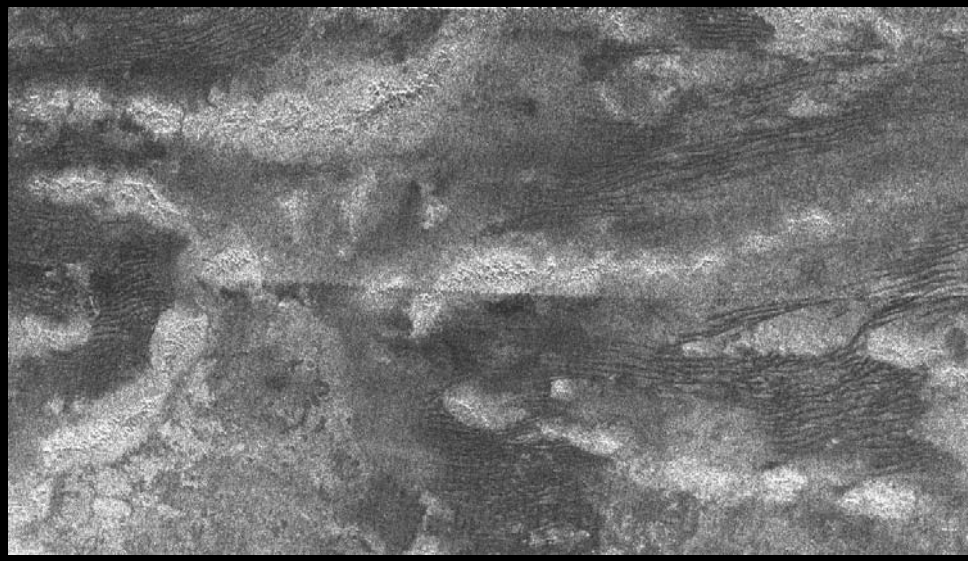


3 July 2004

20 December 2007

Tectonics

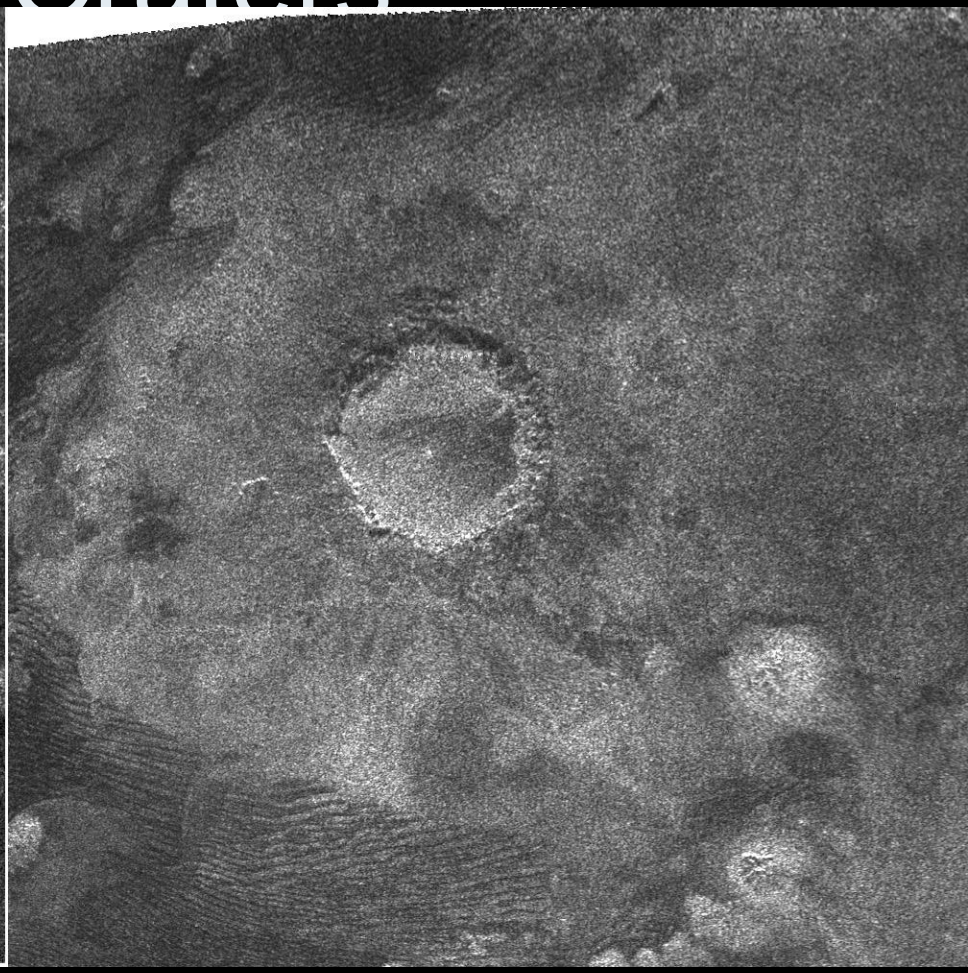




12 May 2008

28 October 2005

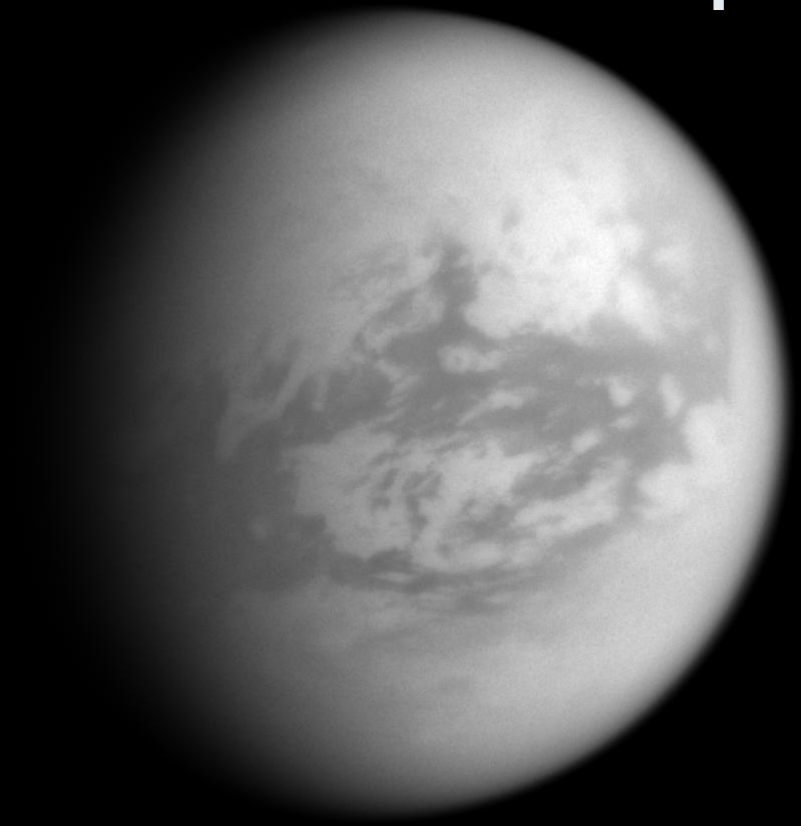
Impact Craters



12 May 2008

15 February 2005

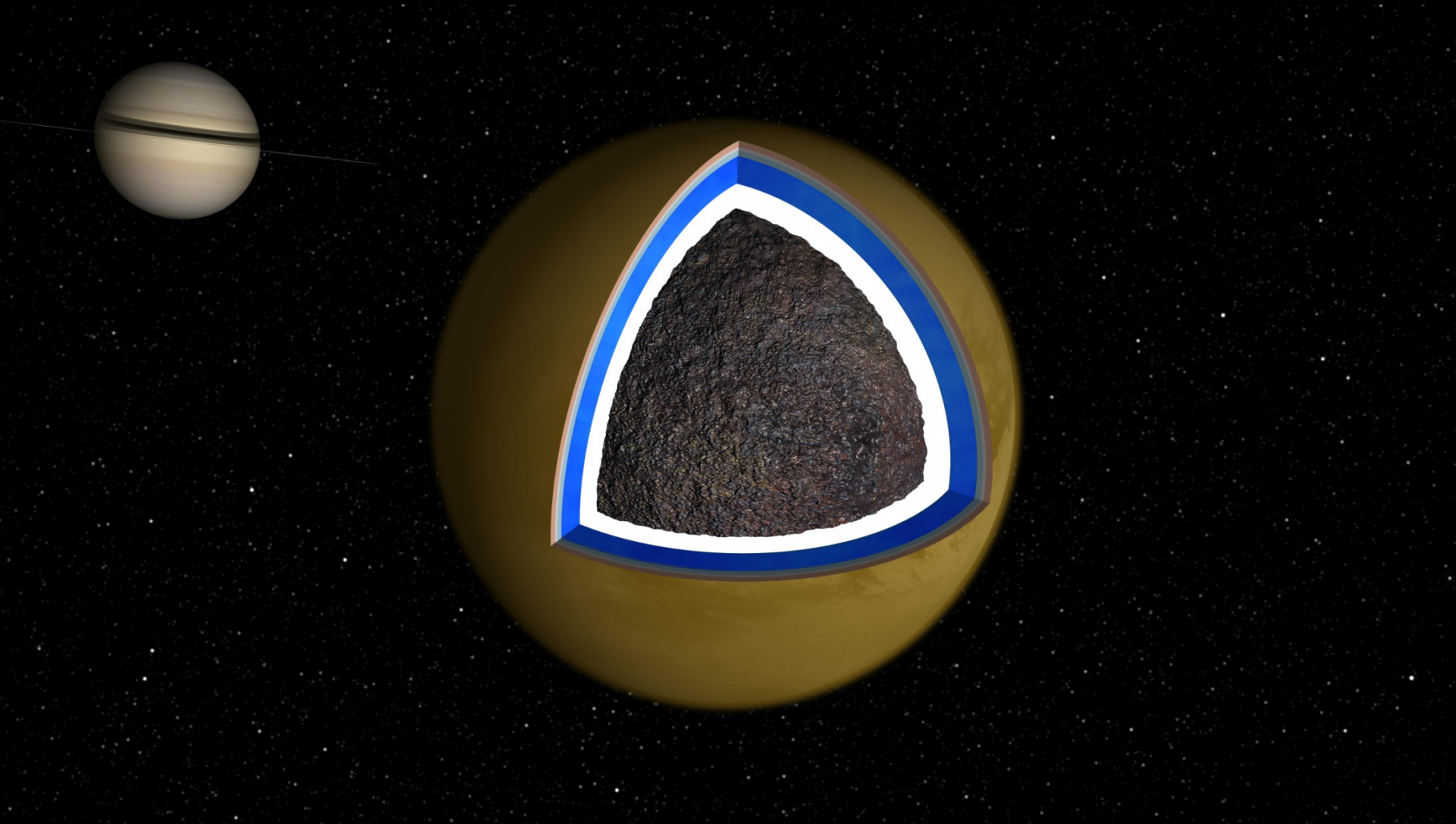
Impact Craters



19 November 2007

13 May 2007

Interior Ocean Revealed



Year 5 = T45 through T57!