Recent Discoveries from the Analysis of Cassini Spacecraft Data in Saturn's Orbit

Part 2 : Recent discoveries by Cassini, and further expectations

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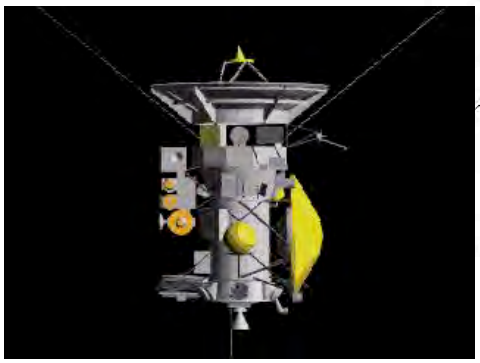
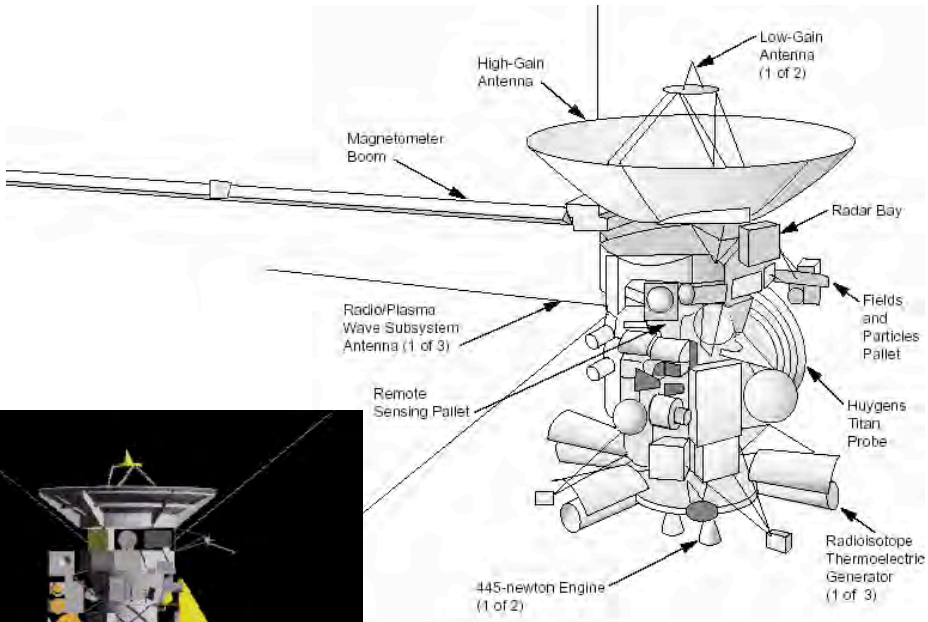
• How was Cassini-Huygens mission prepared ?

- Initial idea in 1980 after first Titan spectra revealing HCN
- Intense promotion by scientists to CNES, ESA, NASA
- 1982 : Assessment Study
- 1984-5 : Phase A
- 1986 : Explosion of Challenger Shuttle on Titan IV
- 1988 : Decision to go by ESA
- 1989 : Decision to go by NASA
- 1989 : Announcement of Opportunity for Experiment proposal
- 1990 : Selection of Scientific experiments

• The spacecraft





Cassini spacecraft

• The Huygens probe

Huygens probe

Cassini Quick Facts

Spacecraft

Spacecraft dimensions: 6.7 meters (22 feet) high; 4 meters (13.1 feet) wide

Weight: 5,712 kilograms (12,593 pounds) with fuel, Huygens probe and adapter. Unfueled orbiter alone weighs 2,125 kilograms (4,685 pounds)

Science instruments: camera; magnetic field studies; dust and ice grain analysis; infrared energy measurement; chemical composition of Saturn, its moons and rings; neutral and charged particle measurement; radar mapping; and gravitational wave searches

Power: 885 watts (at launch) from radioisotope thermoelectric generators

Huygens Probe

Probe dimensions: 2.7 meters (8.9 feet) in diameter

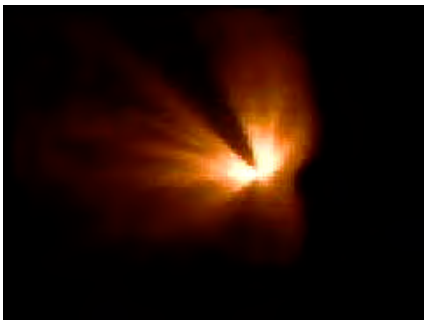
Weight: 320 kilograms (705 pounds)

Science instruments: spectrometer to identify atmospheric makeup; aerosol collector for chemical analysis; imager; sensors to measure atmospheric structure; wind speed measurements; sensors to measure conditions at impact site

Launch

Launch vehicle: Titan IVB/ Centaur Upper Stage

• Launch : 15 october 1997



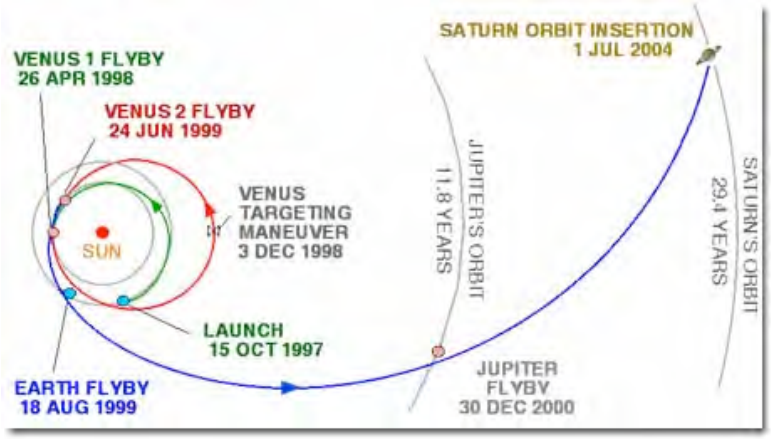
• Interplanetary billiard

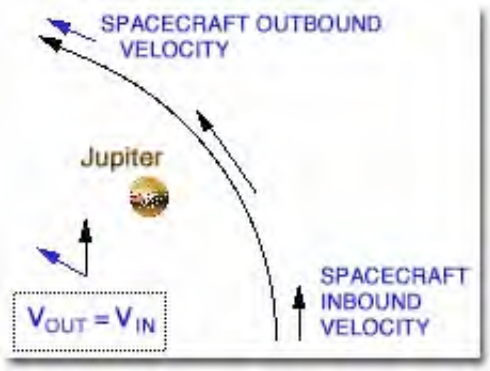
➢ Voyager : 800 kgs, ~4 year trip to Saturn (fly-by)

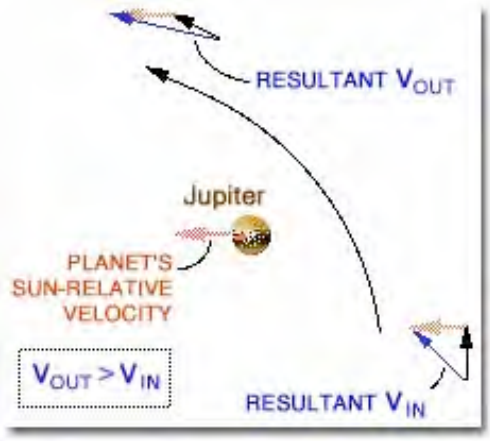
➢ Cassini : 6 tons + orbit insertion (deceleration)

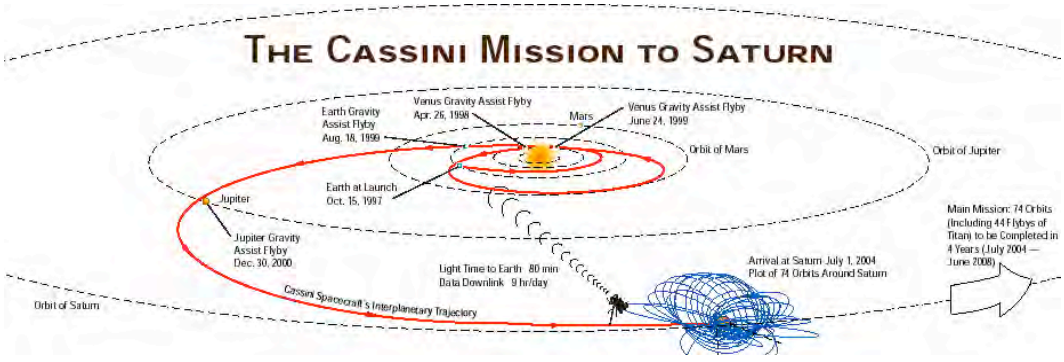
→ how to make the trip in < 20-30 years ?

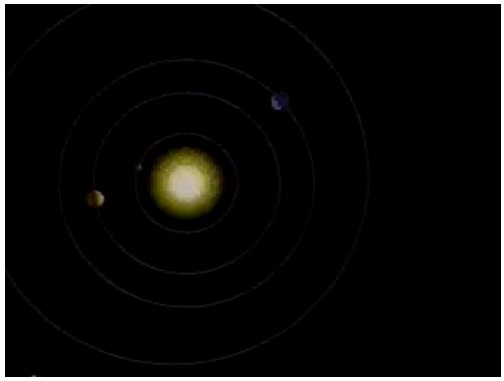
VVEJGA




SPACECRAFT OUTBOUND VELOCITY
Jupiter
SPACECRAFT INBOUND VELOCITY
$V_{OUT} = V_{IN}$

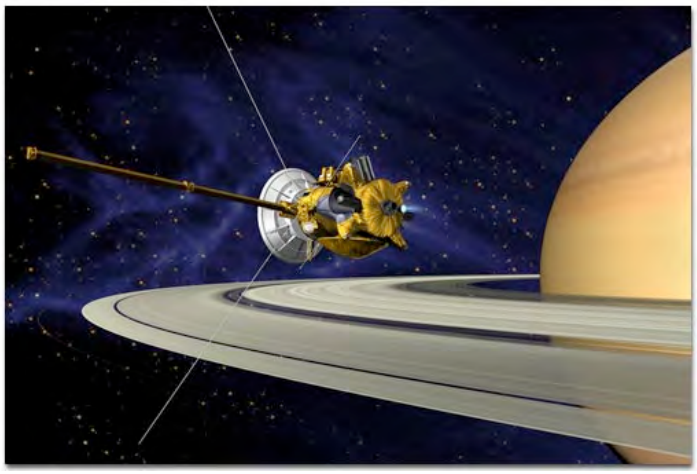

RESULTANT V_{OUT}
Jupiter
PLANET'S SUN-RELATIVE VELOCITY
$V_{OUT} > V_{IN}$
RESULTANT V_{IN}


THE CASSINI MISSION TO SATURN
Earth Gravity Assist Flyby Aug. 18, 1999
Venus Gravity Assist Flyby Apr. 26, 1998
Mars
Venus Gravity Assist Flyby June 24, 1999
Orbit of Mars
Orbit of Jupiter
Earth at Launch Oct. 15, 1997
Jupiter
Jupiter Gravity Assist Flyby Dec. 30, 2000
Main Mission: 74 Orbits (Including 44 Flybys of Titan) to be Completed in 4 Years (July 2004 — June 2008)
Light Time to Earth 80 min
Data Downlink 9 hr/day
Arrival at Saturn July 1, 2004
Plot of 74 Orbits Around Saturn
Cassini Spacecraft's Interplanetary Trajectory
Orbit of Saturn

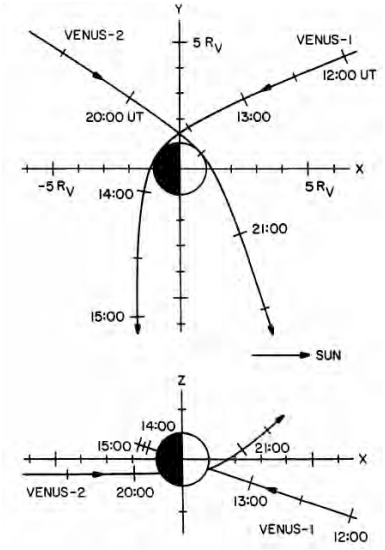


• Tracking Cassini : → DSN

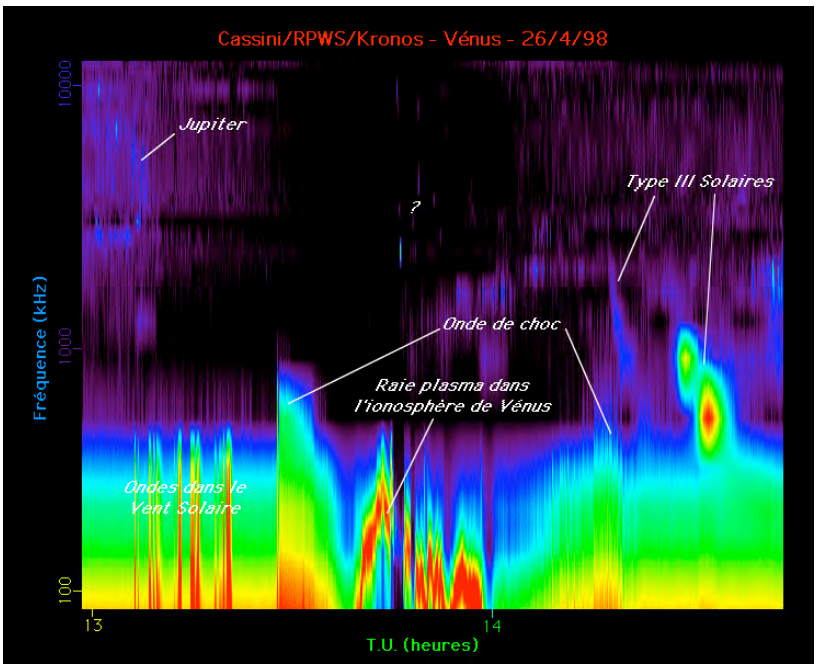
• Venus fly-by #1 : 26 april 1998 (at 300 km)
• Venus fly-by #2 : 24 june 1999 (at 600 km)
• Earth fly-by : 18 august 1999 (at 7000 km)
• Jupiter fly-by : 30 december 2000 (at 135 $R_J = 10^7$ km)
• Insertion in Saturn orbit : 1 july 2004 (at 1.3 R_S = 80000 km, 24 years after initial idea)



CASSINI AT VENUS



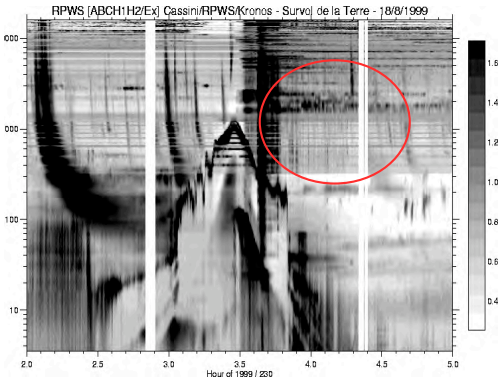
• no lightning

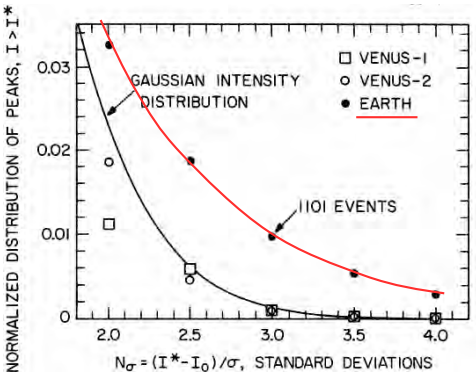


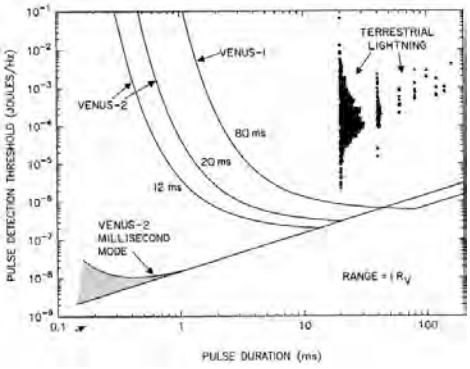
CASSINI AT EARTH

- >1000 lightning discharges

→ upper limit on Venus lightning

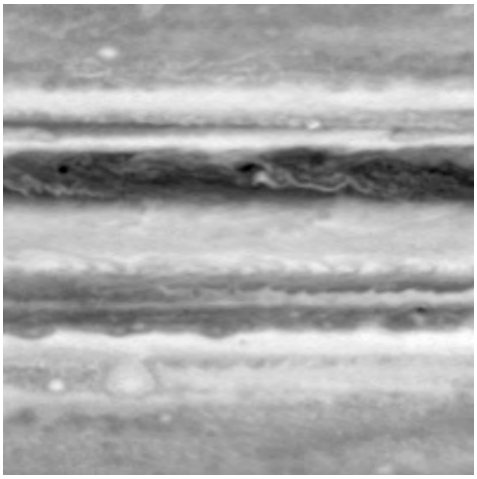




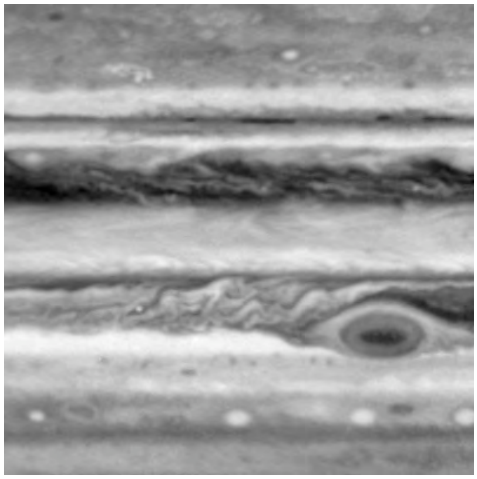


CASSINI AT JUPITER

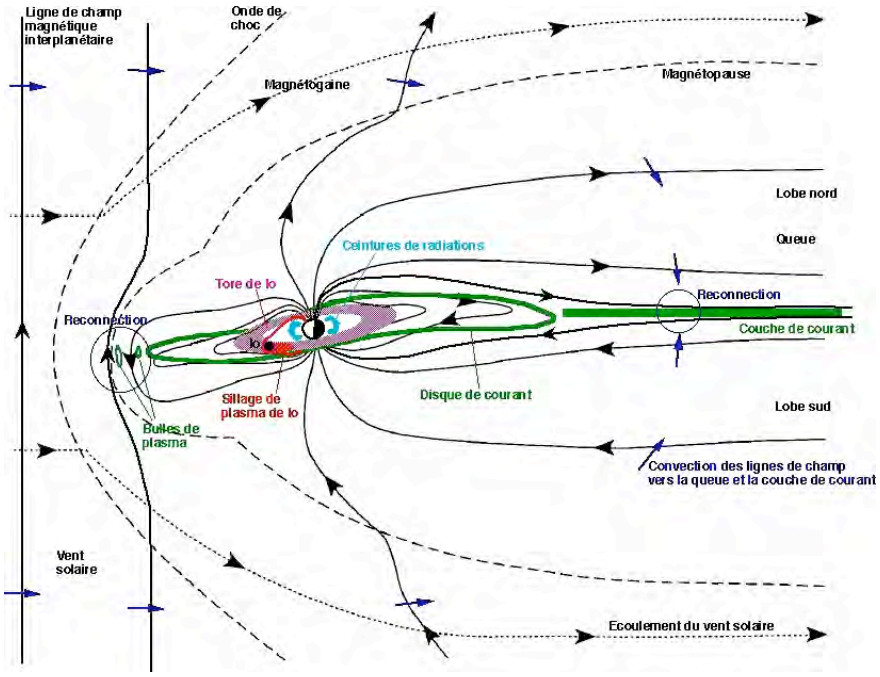
- Clouds



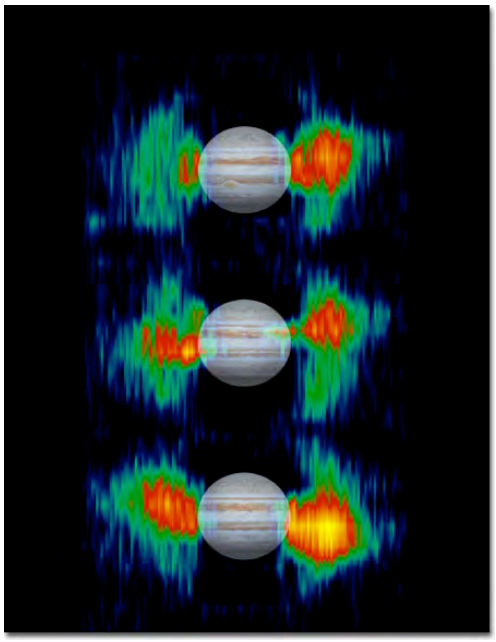
- Great Red Spot

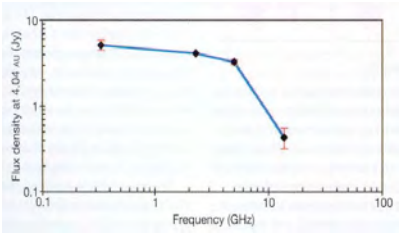


• Magnetosphere

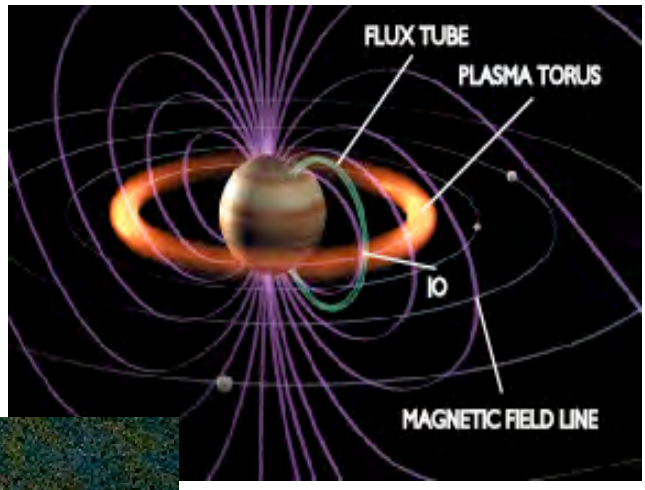


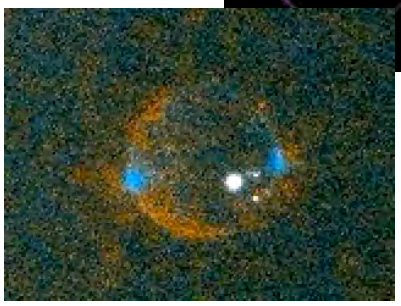
• probing radiation belts at 13.8 GHz (2.2 cm) → 50 MeV electrons

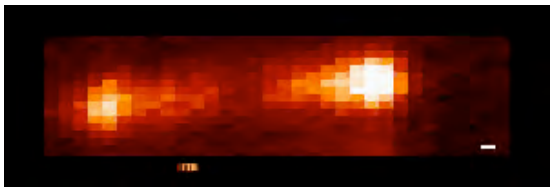




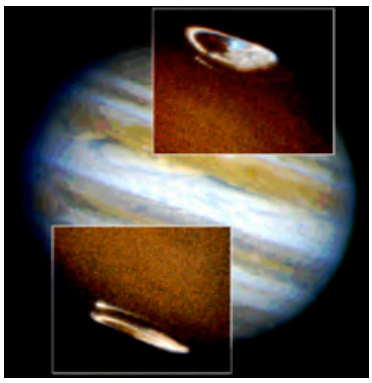
• Io torus and satellite-magnetic field interaction

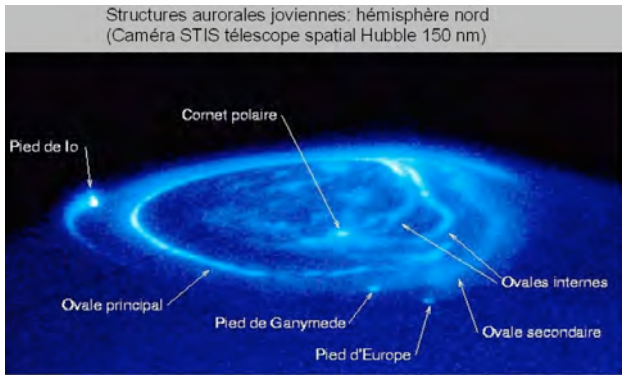




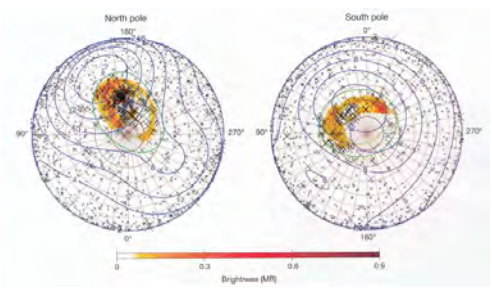


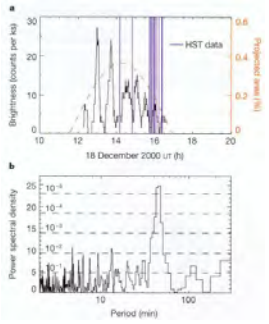
• Simultaneous UV observations by Hubble Space Telescope …



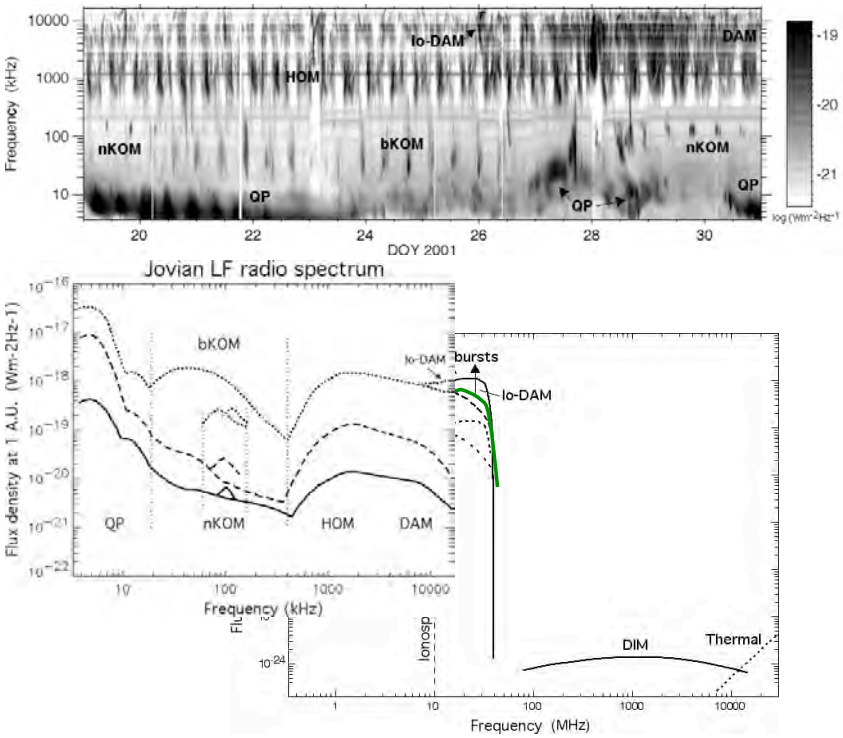


… and X-rays by Chandra

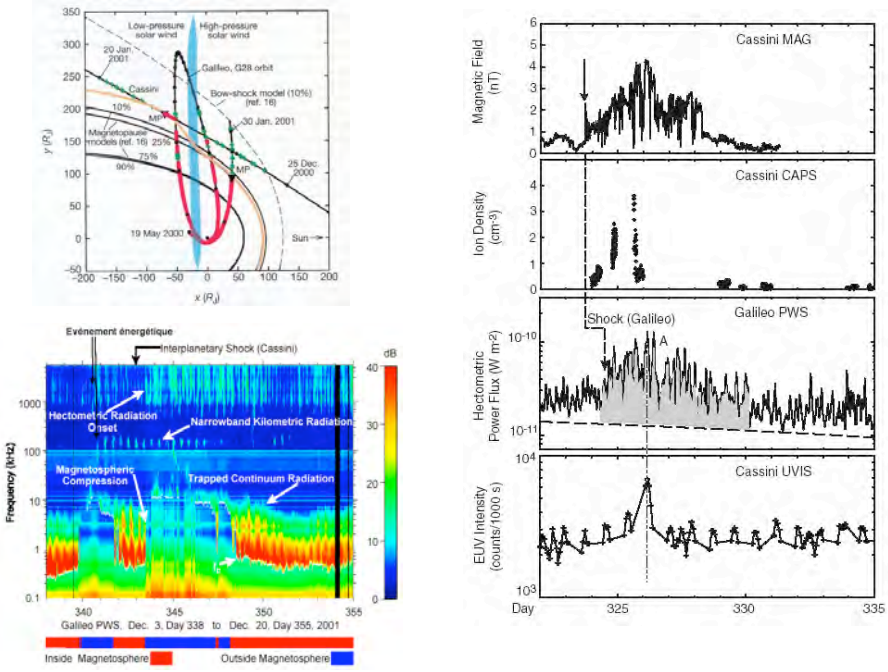


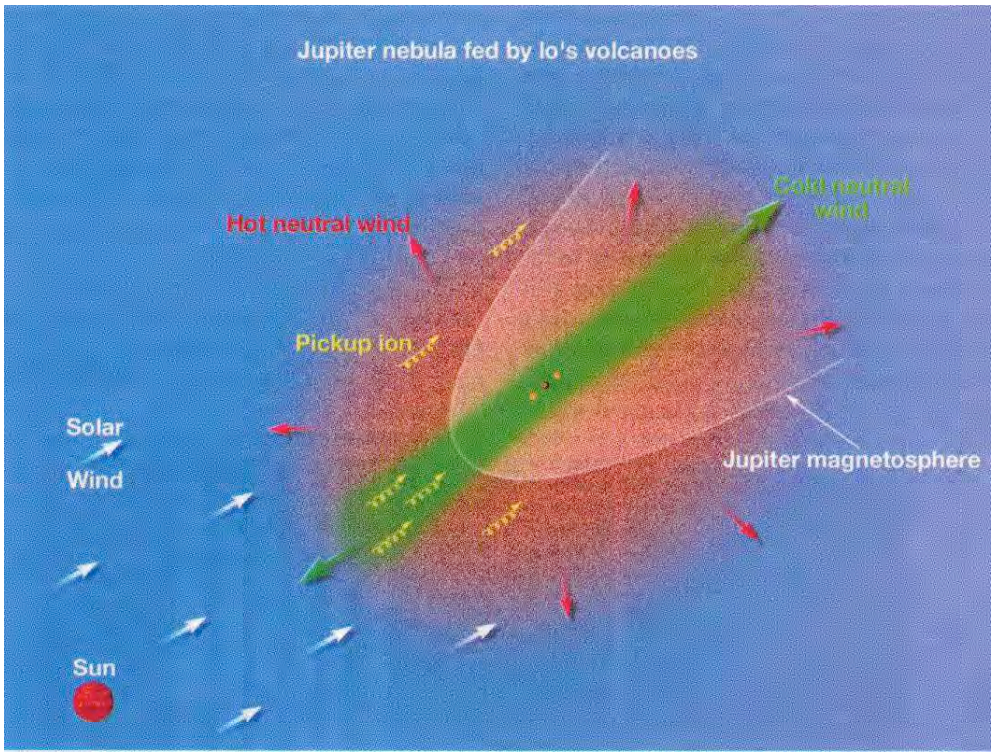


• Spectrum of Low-Frequency radio emissions (KOM-DAM)



• Galileo - Cassini observations :
→ magnetospheric activity triggered by interplanetary shocks





RECENT DISCOVERIES BY CASSINI AT SATURN

(1) Saturn's interior

(2) Saturn's atmosphere

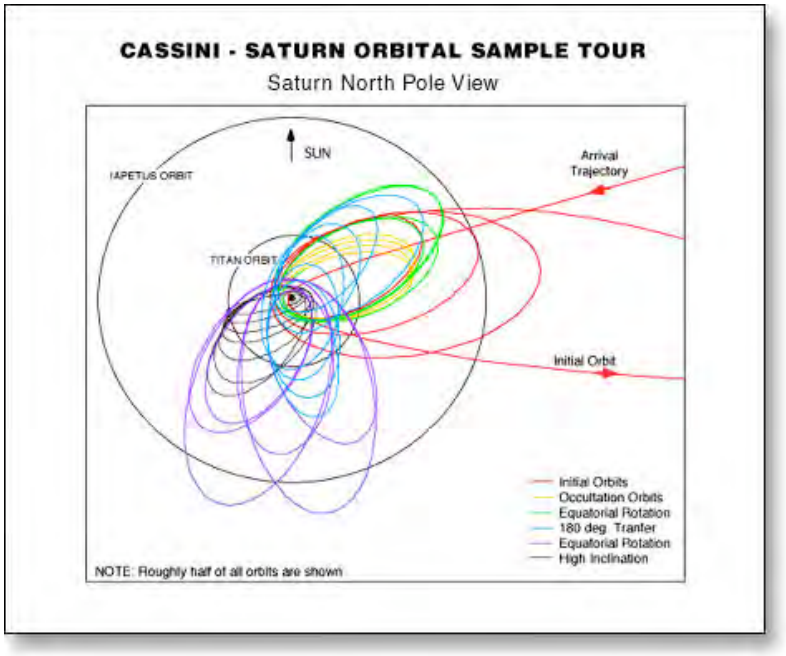
(3) Rings

(4) Titan

(5) Icy satellites

(6) Magnetosphere

• The Saturn-Titan Tour : 2004-2008 (baselline, 76 orbits)



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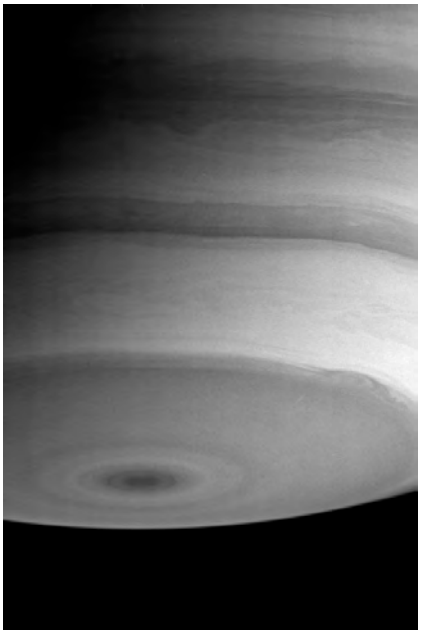
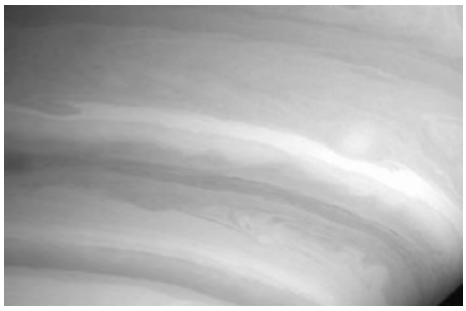
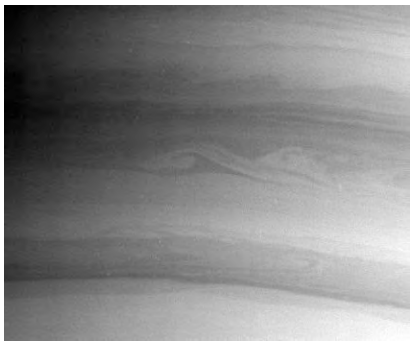
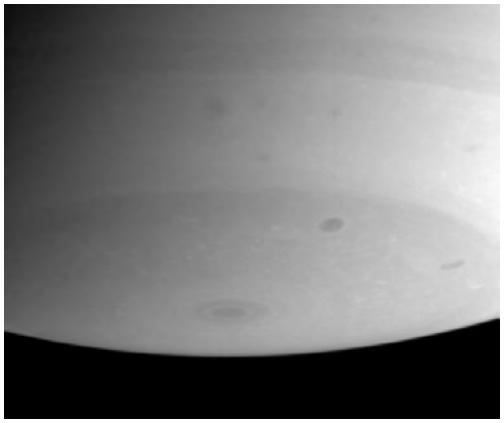
• Polar atmosphere : disturbed band boundaries (≠wind speeds)
• High-resolution images with IR filter, 50-100 km resolution

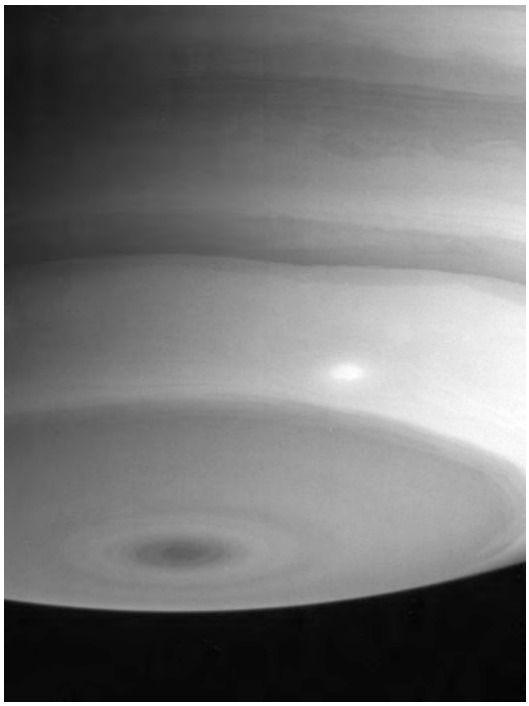




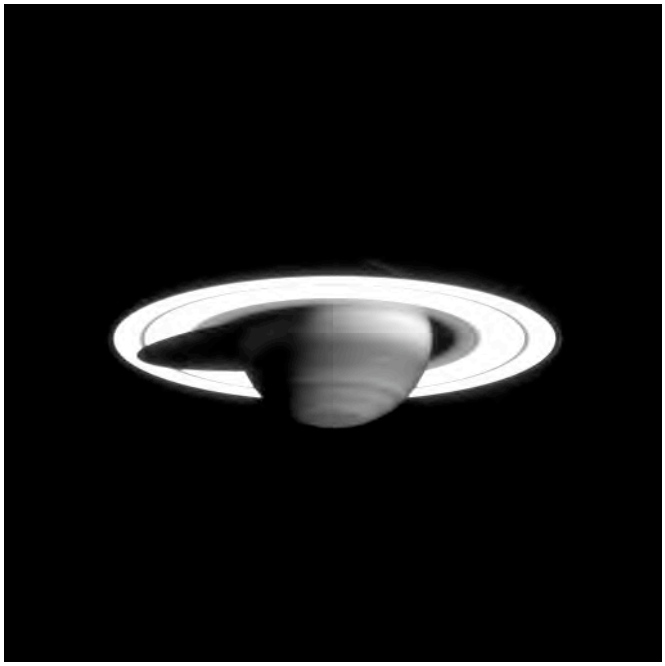


• Dark and Bright storms



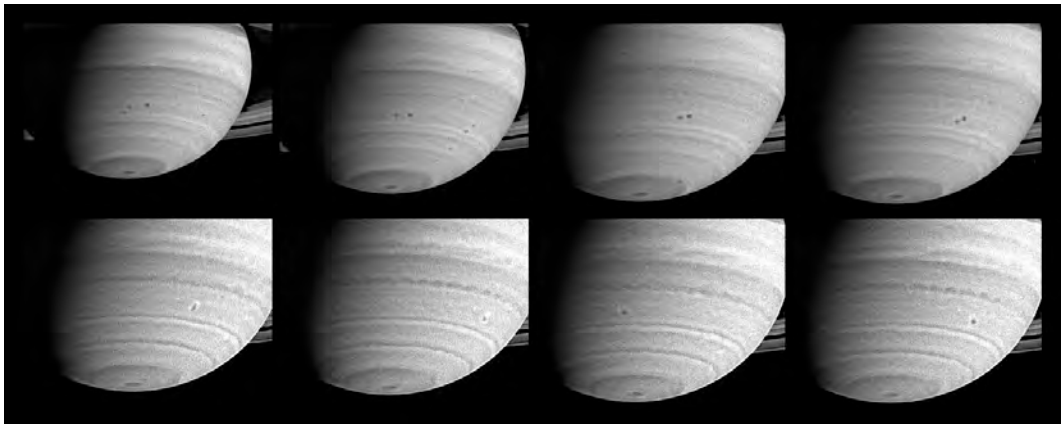


• High altitude / high speed winds (up to 500 m/s, 1800 km/h at equator)



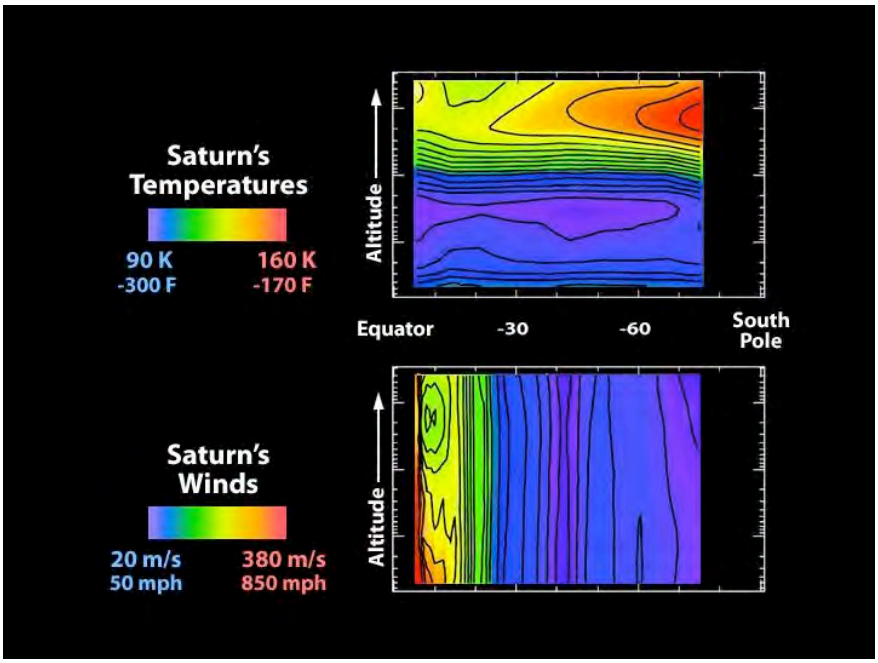
• Merging of 2 storms (19-20/3/2004, ∅=1000 km, long lived)

February 22

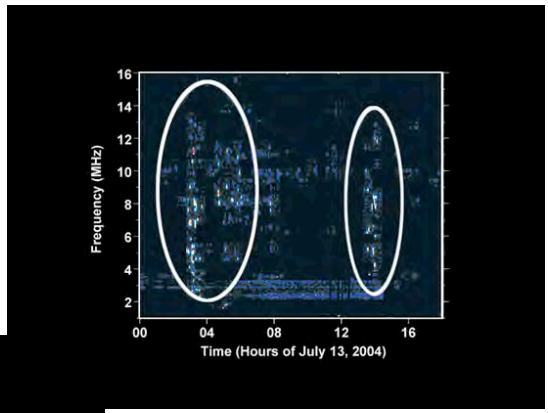


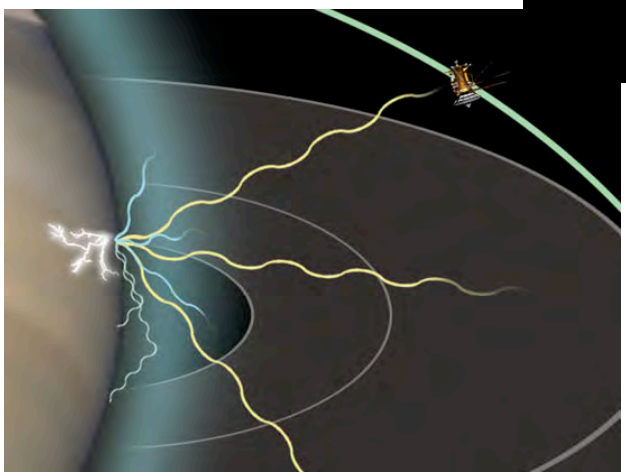
March 22

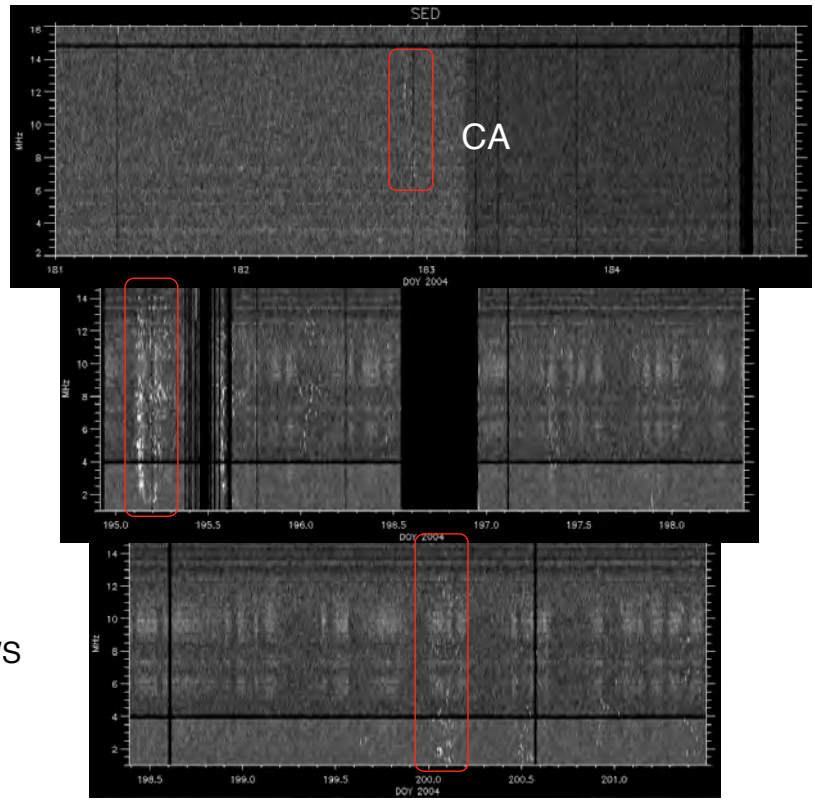
• Atmospheric temperatures and wind maps (CIRS)



• Lightning : weaker / more variable activity than at Voyager time (RPWS)





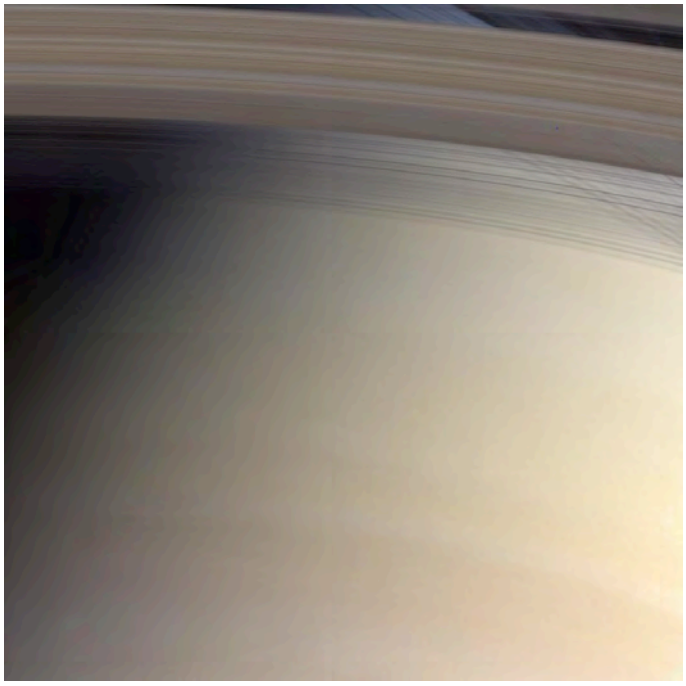


RPWS data

- due to fainter ring shadow, hence smaller grad(T) ?

Voyager 1/11/1980

Sketch of Voyager 1's equatorial storm system



Cassini 10/5/2004

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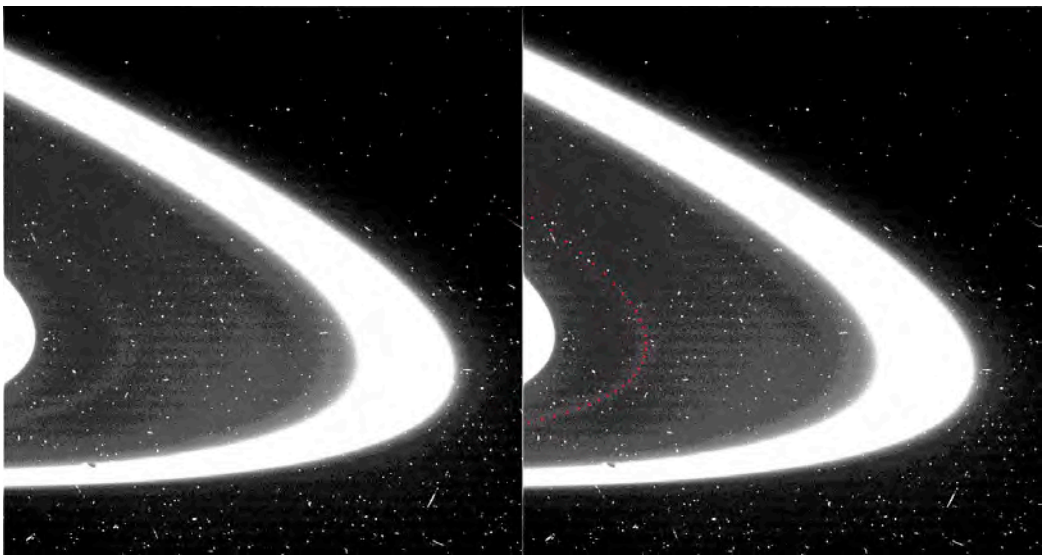
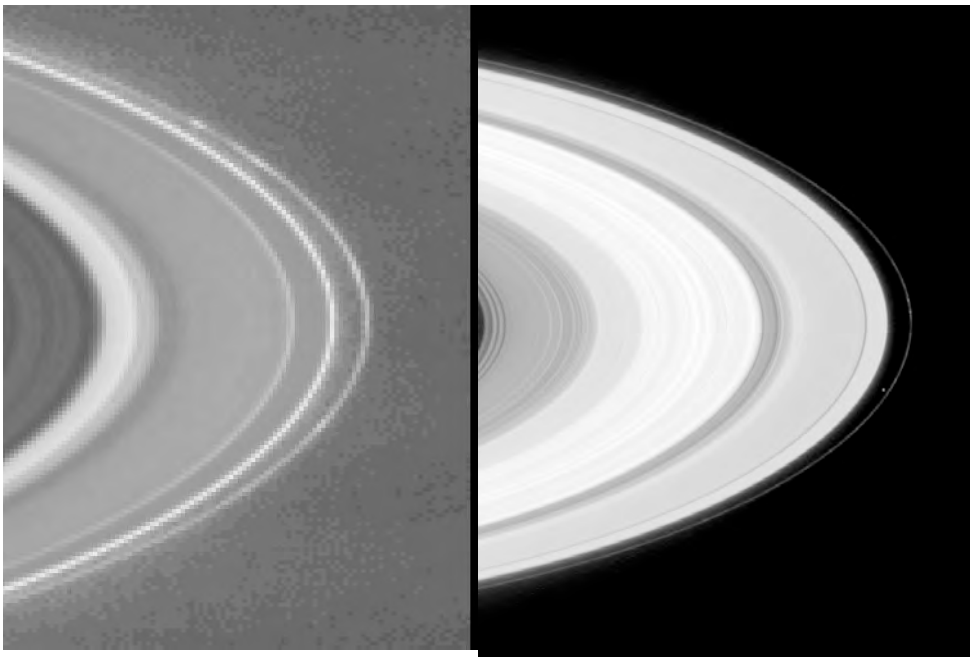
• Real-color images

• Discovery of a new faint ring S/2004 1 R in Atlas orbit, between A & F rings (7 km/pixel)

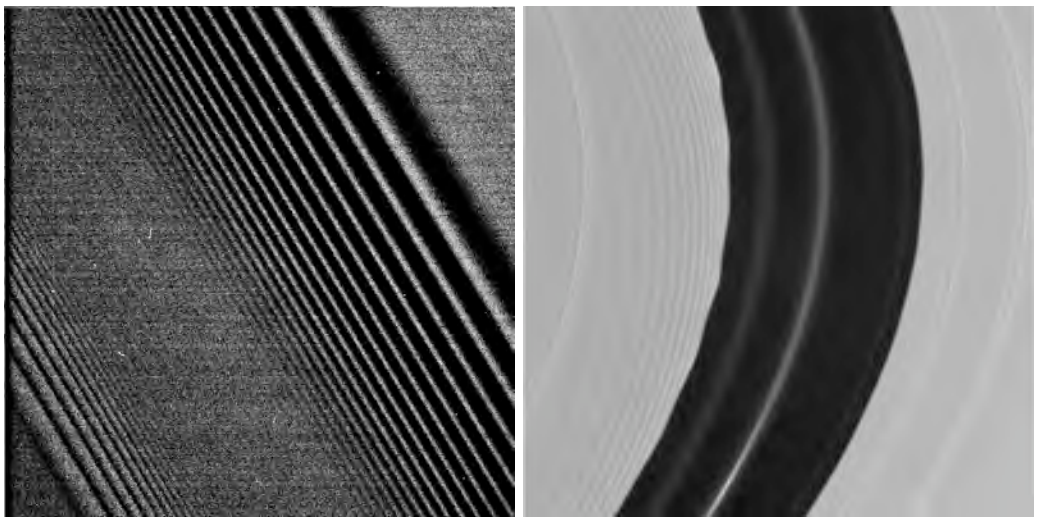


• Azimuthal clumps in F-ring (meteoroid bombardment ?
Internal collision ?)

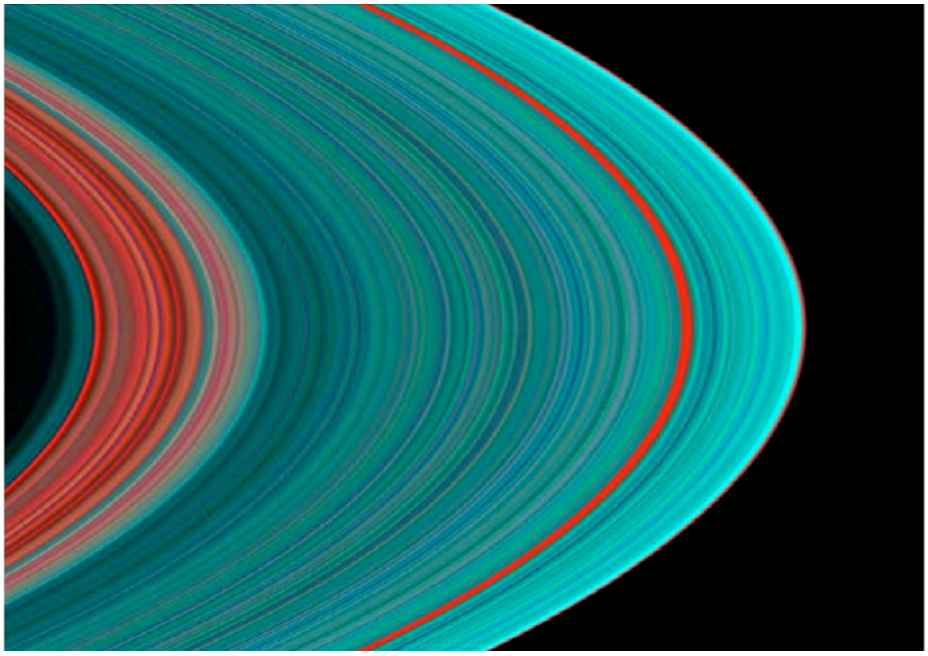


←2 hours→

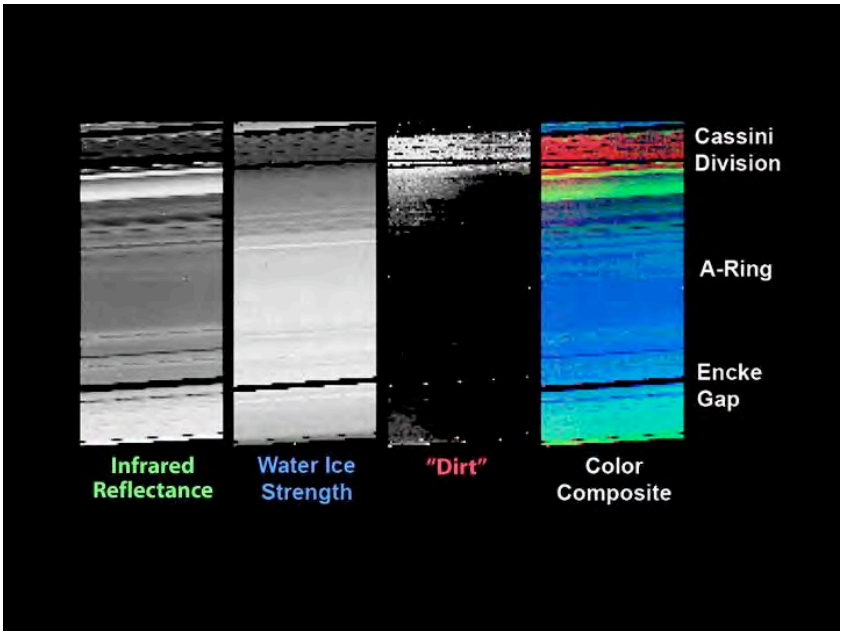
• Density waves in A ring (inside Encke gap, in unlit side of rings)
and wavy ring edges



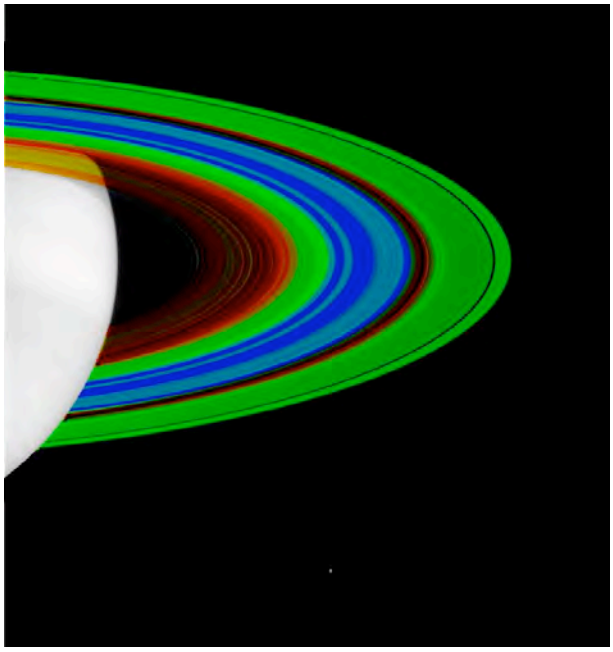
• Rings in UV → ice (blue) / dirt (red) concentration (UVIS)



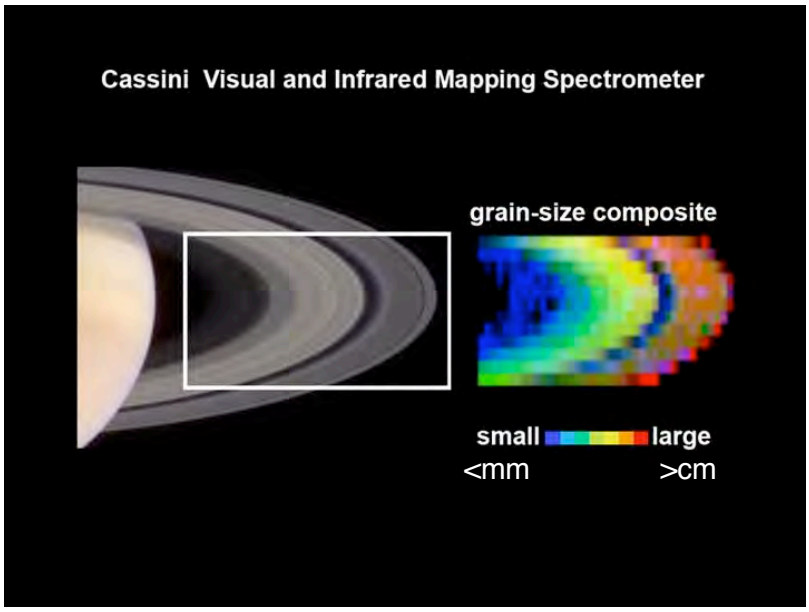
• Rings composition with VIMS
→ mechanism to sort ring material versus distance ?
→ « Dirt » origin = Phoebe ?



• Ring Temperature (CIRS)
blue = 70K, green = 90K, red = 100K → opaque rings colder ?

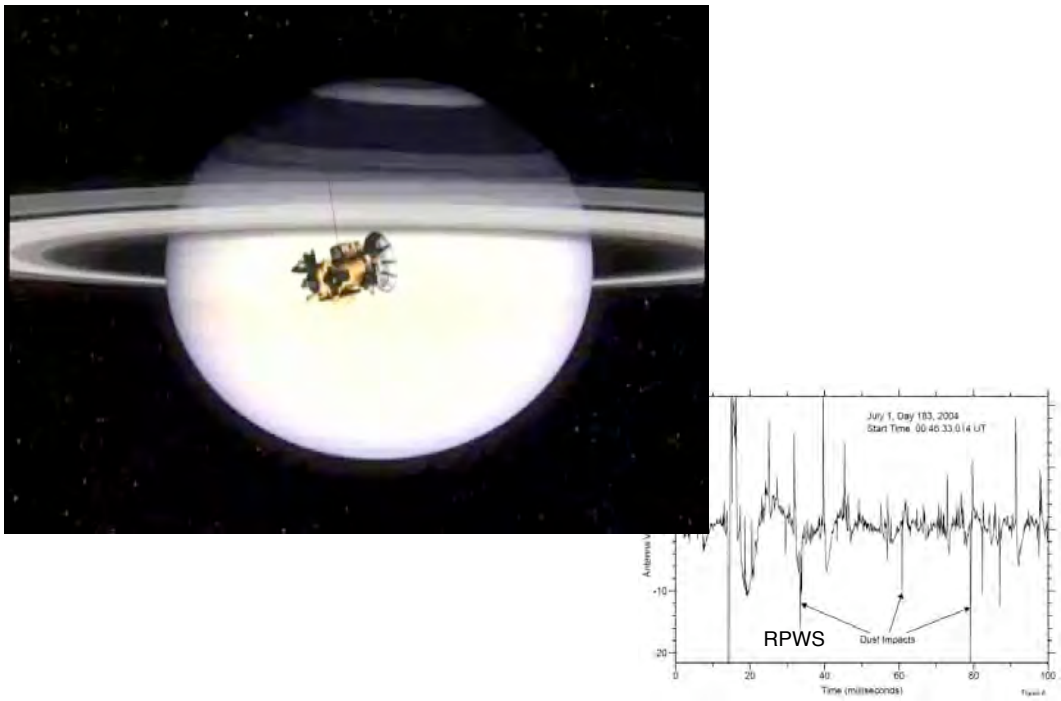


• Grain size from Visible/IR scattered light

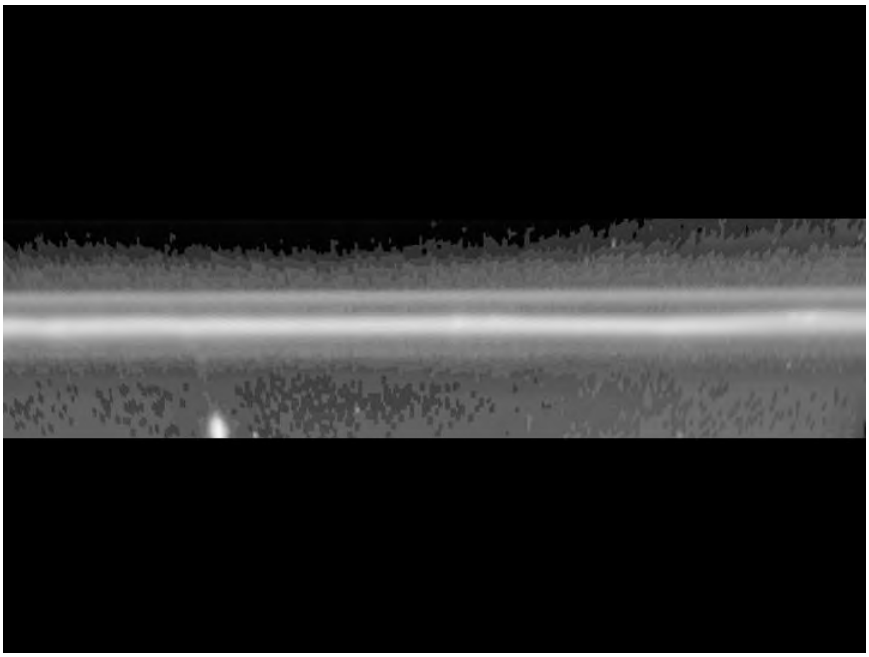


⇒ (small-hot-dirt) & (thick-cold-ice) ? → origin, evolution ?

• Rings-flyby → spatial distribution of particles



• Material appears to connect Prometheus and F ring



RECENT DISCOVERIES BY CASSINI AT SATURN

(1) Saturn's interior

(2) Saturn's atmosphere

(3) Rings

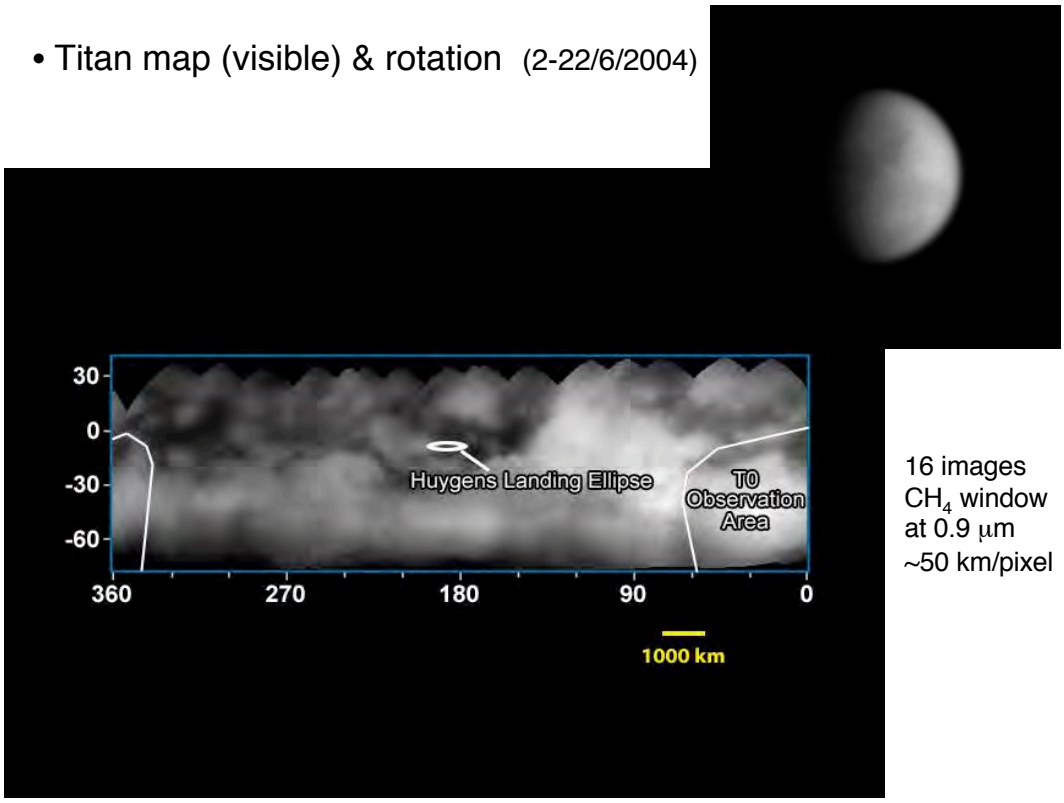
(4) Titan

(5) Icy satellites

(6) Magnetosphere

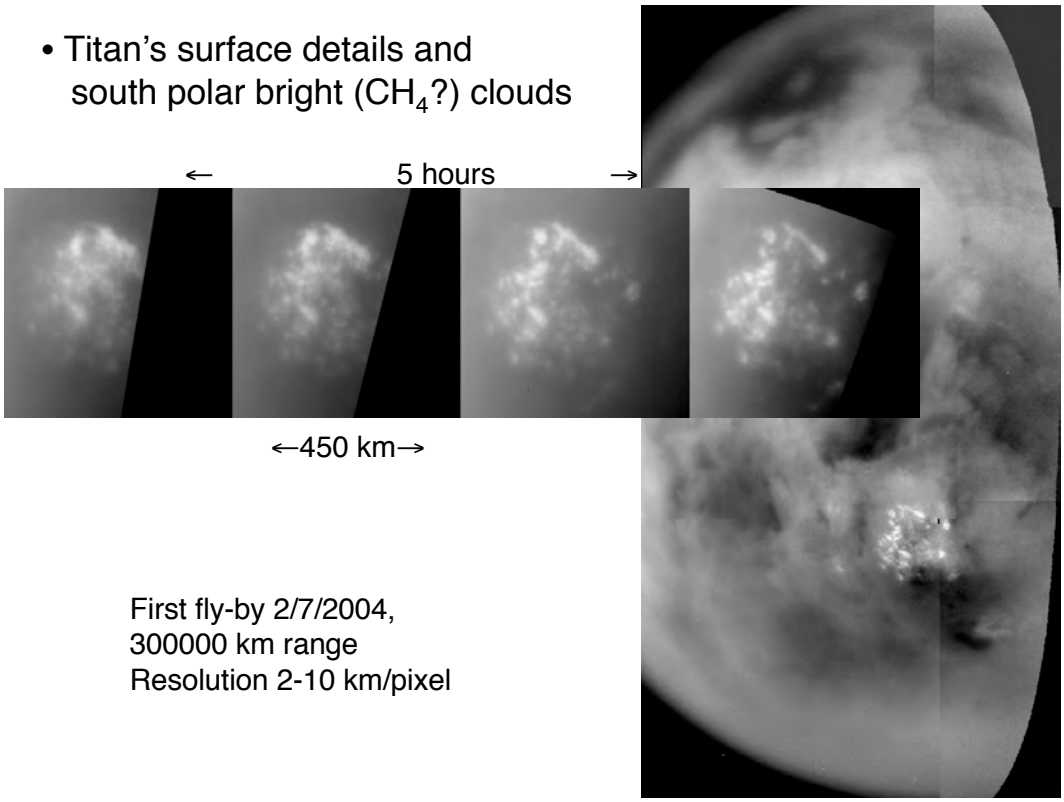
- Titan hazes (blueish limb due to scattering)

• Titan map (visible) & rotation (2-22/6/2004)



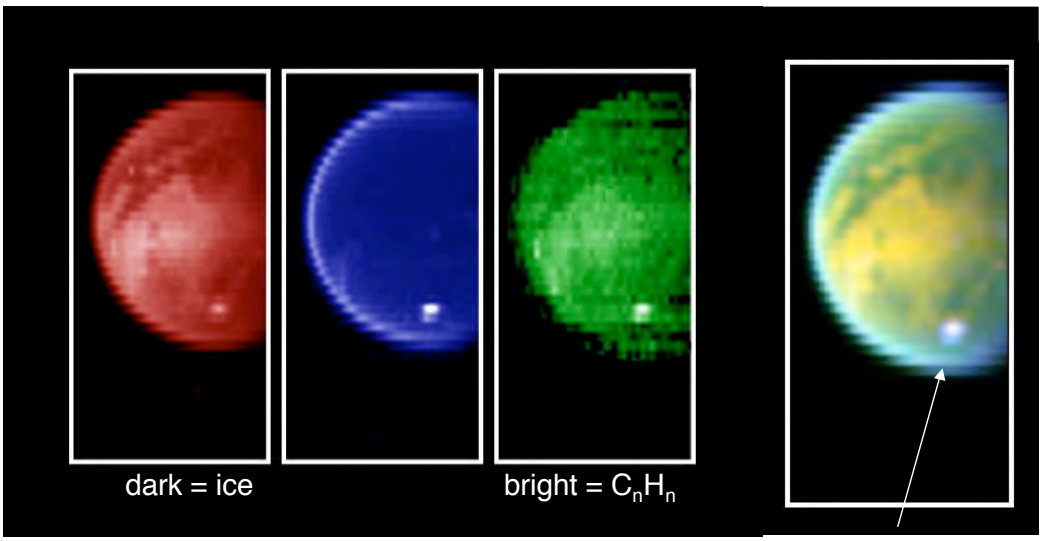
16 images
CH_4 window
at 0.9 μm
~50 km/pixel

• Titan's surface details and
south polar bright (CH_4?) clouds

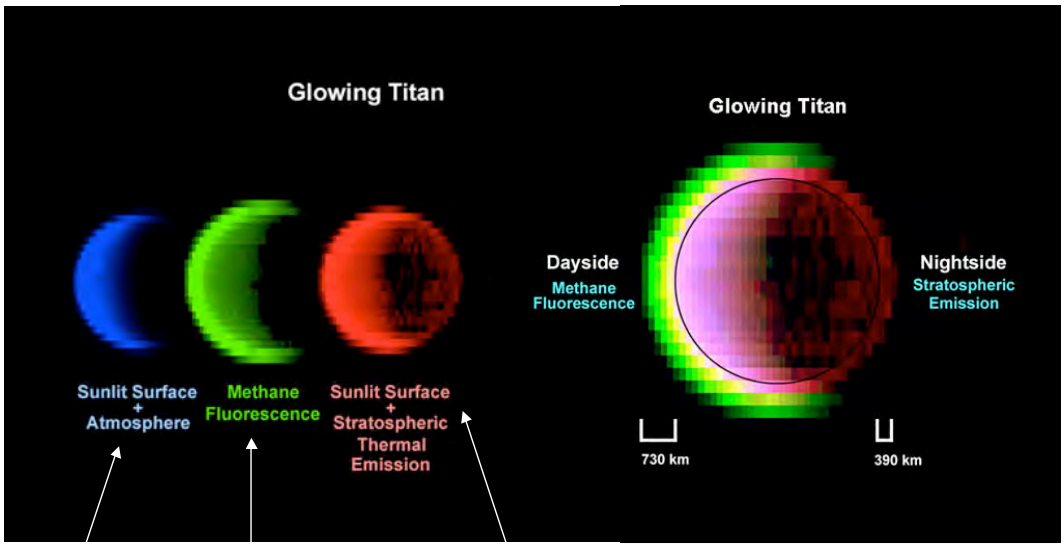


First fly-by 2/7/2004,
300000 km range
Resolution 2-10 km/pixel

• Titan surface at 3 wavelengths (VIMS)
2., 2.8 and 5. μm + false color combination



• Titan atmospheric glow at 3 wavelengths (VIMS)

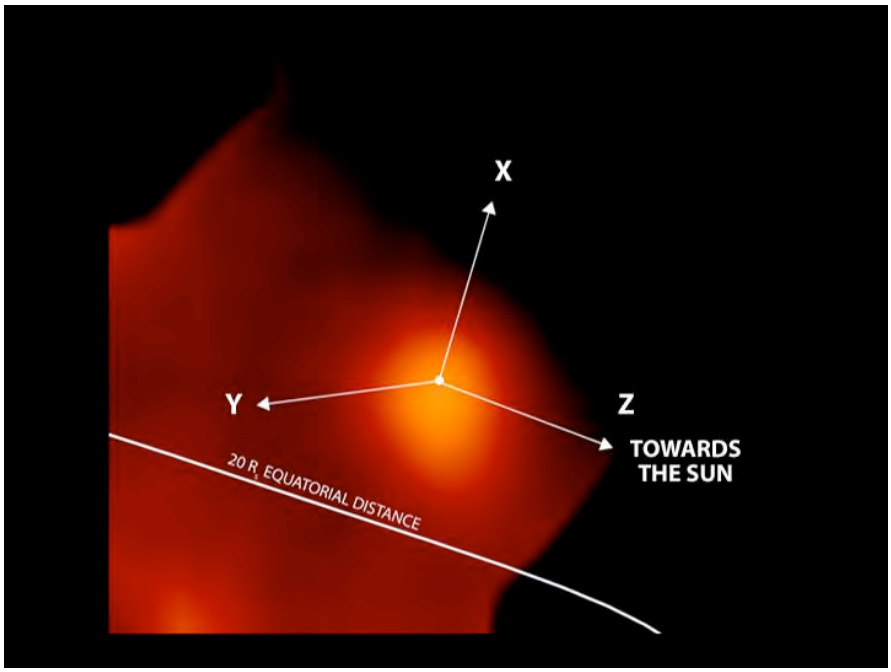


2 μm = CH_4 window

3.3 μm = thick CH_4 atm. (700 km)

4.7 μm = CO in warm stratosphere (200 km)

• Neutral Gas Cloud Around Titan (MIMI / INCA)



RECENT DISCOVERIES BY CASSINI AT SATURN

(1) Saturn's interior

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(3) Rings

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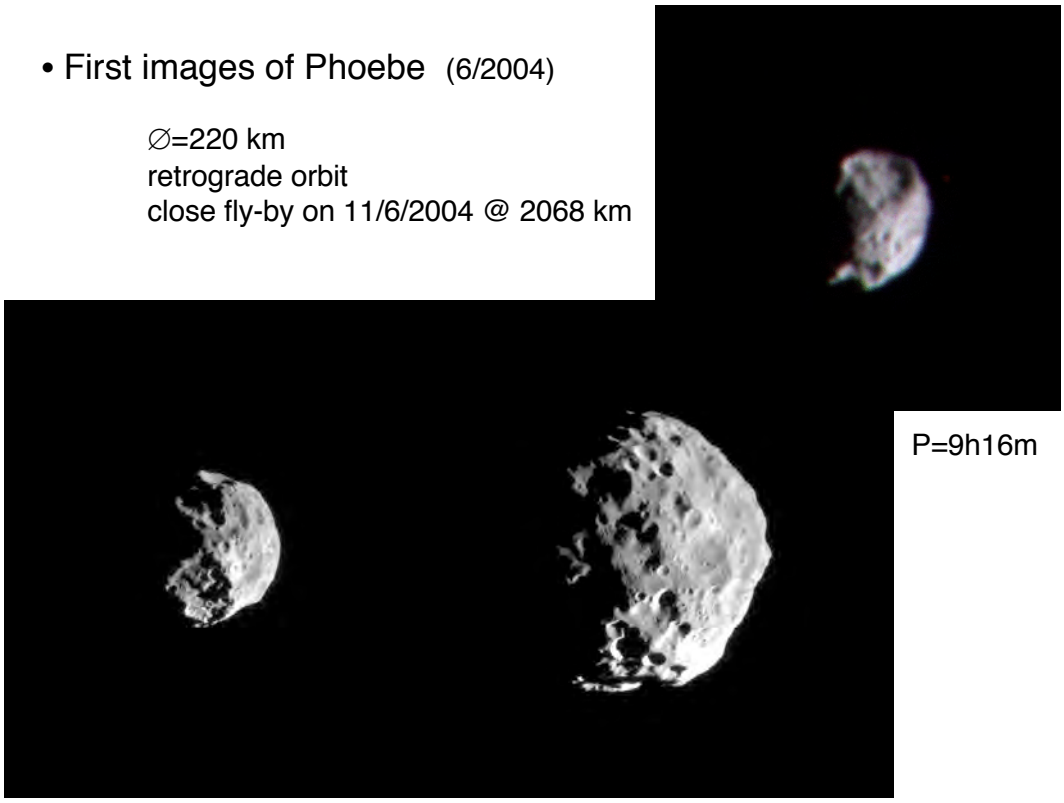
(5) Icy satellites

(6) Magnetosphere

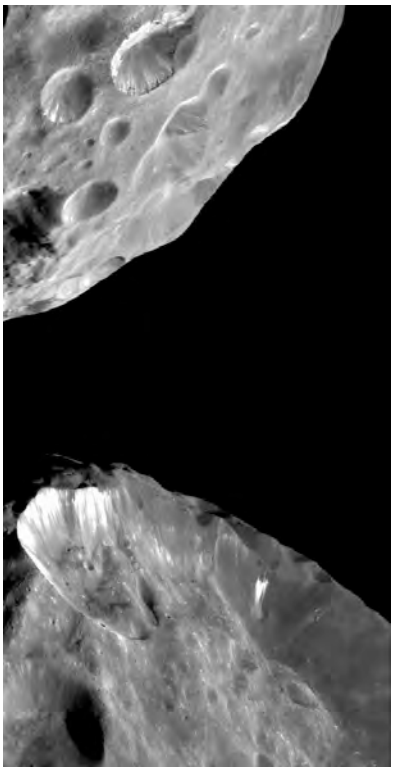
• First images of Phoebe (6/2004)

∅=220 km
retrograde orbit
close fly-by on 11/6/2004 @ 2068 km

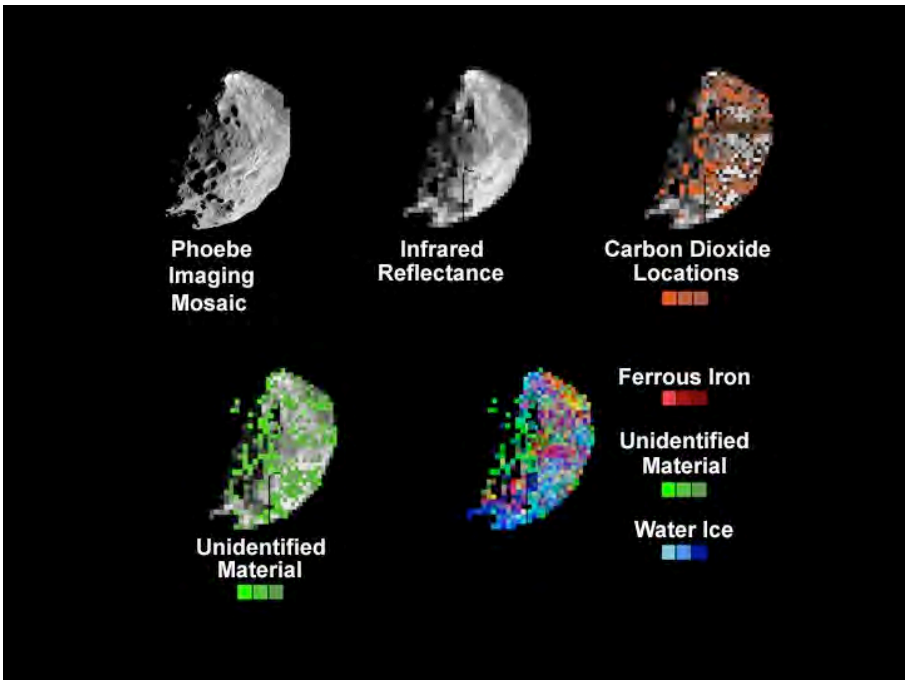


P=9h16m

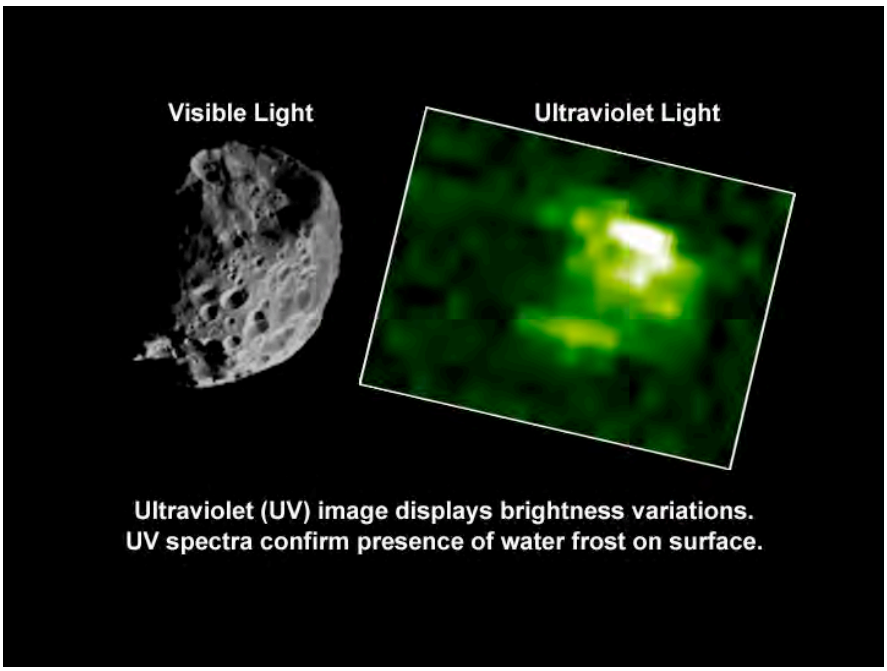
• Phoebe : not spherical, impact craters, ridges
resolution = 0.1-1 km



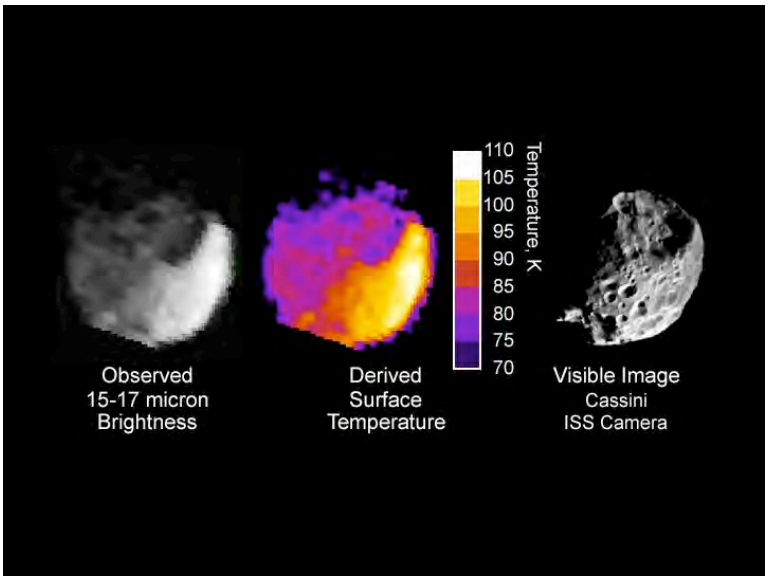
• Phoebe's Mineral Distribution (VIMS)



• Phoebe in Ultraviolet (UVIS)

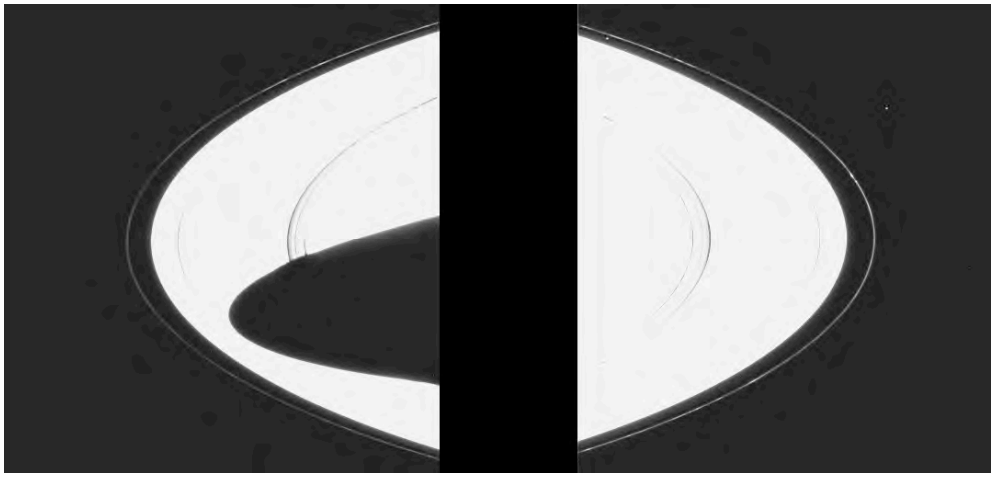


• Phoebe's thermal emission and Temperature (CIRS)



Þ CO_2, density = 1.6 (ice+rock/clays/organics), RADAR observations
Þ Kuiper Belt Object !

• Atlas rediscovered (ring A shepherd) and F-ring clumps

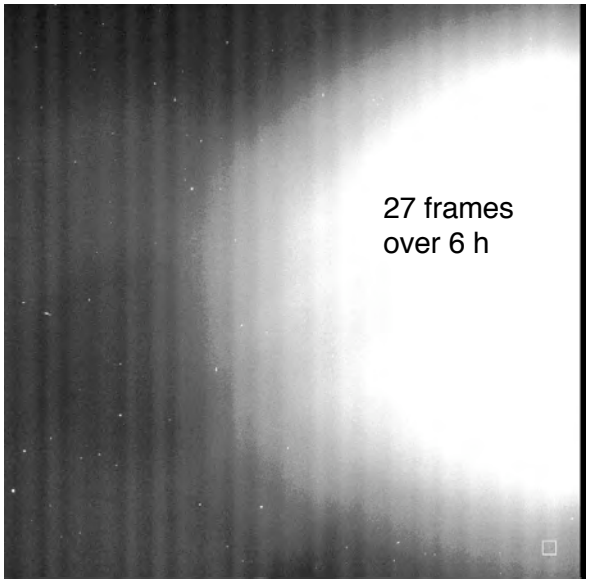


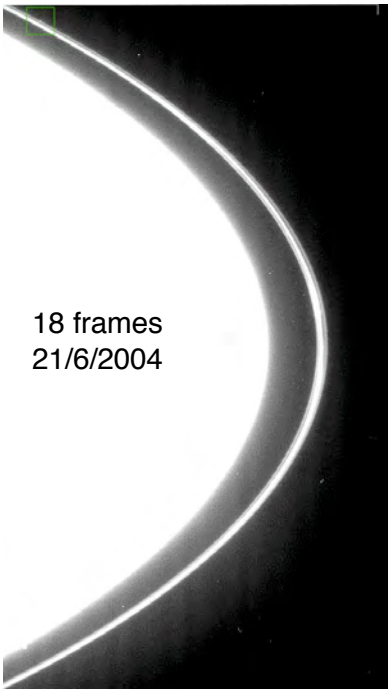
• New moons S/2004 S1 & S3 : now 33 satellites

S1 : orbit @ 194000 km, ∅=3 km

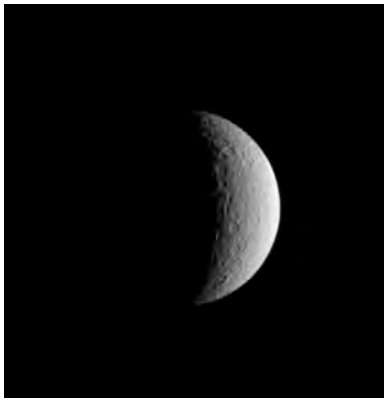
S2 : orbit @ 211000 km, ∅=4 km

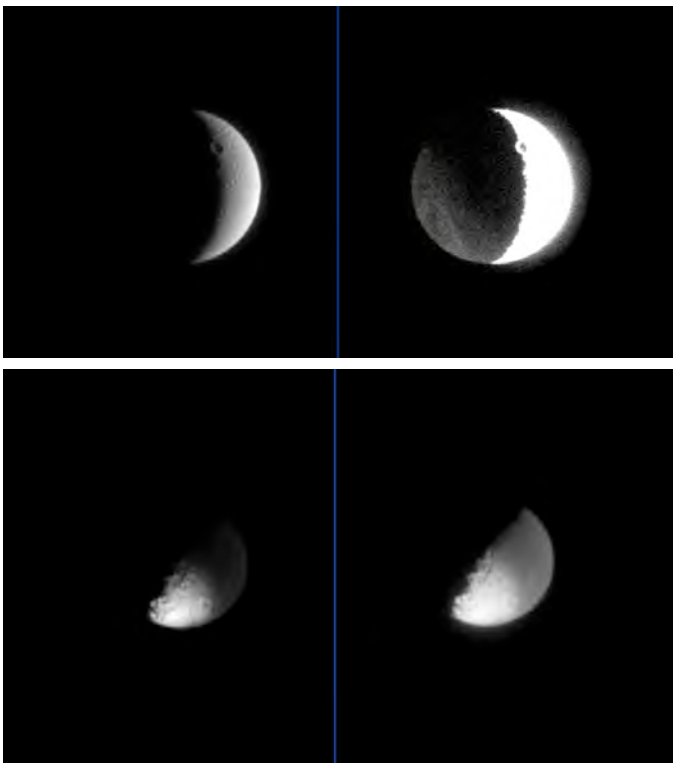
S1 : orbit @ 141000 km (F-ring), ∅=4-5 km ?



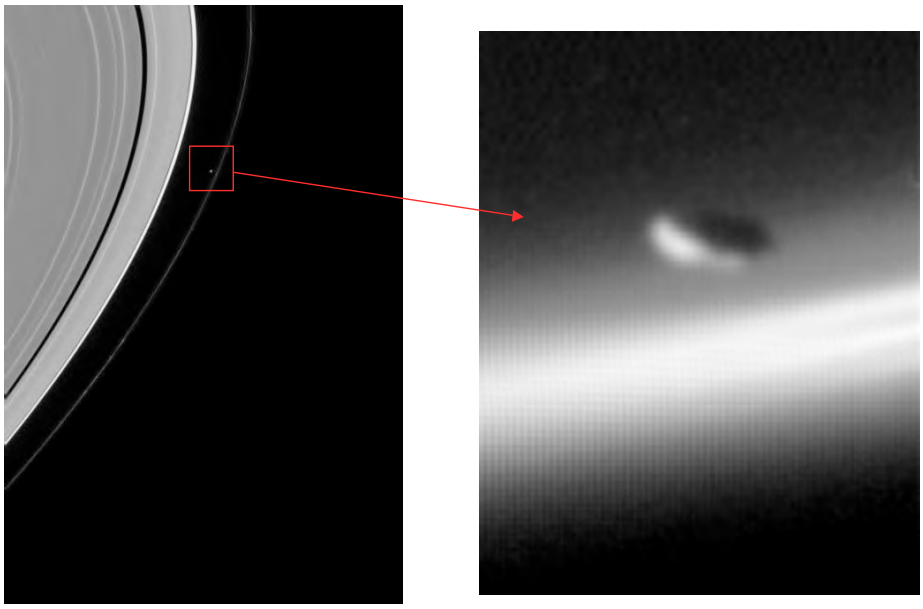


• Rhea, Iapetus, Dione





• Prometheus (102 km across, not spherical) = inner shepherd of F-ring



RECENT DISCOVERIES BY CASSINI AT SATURN

(1) Saturn's interior

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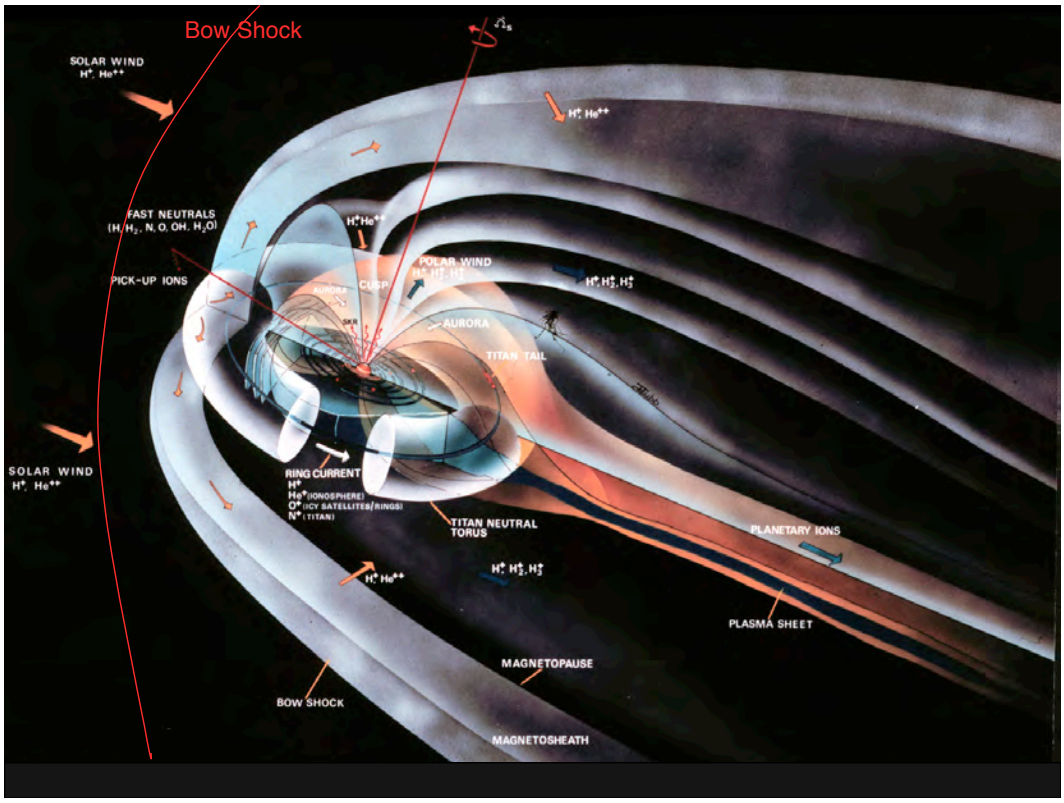
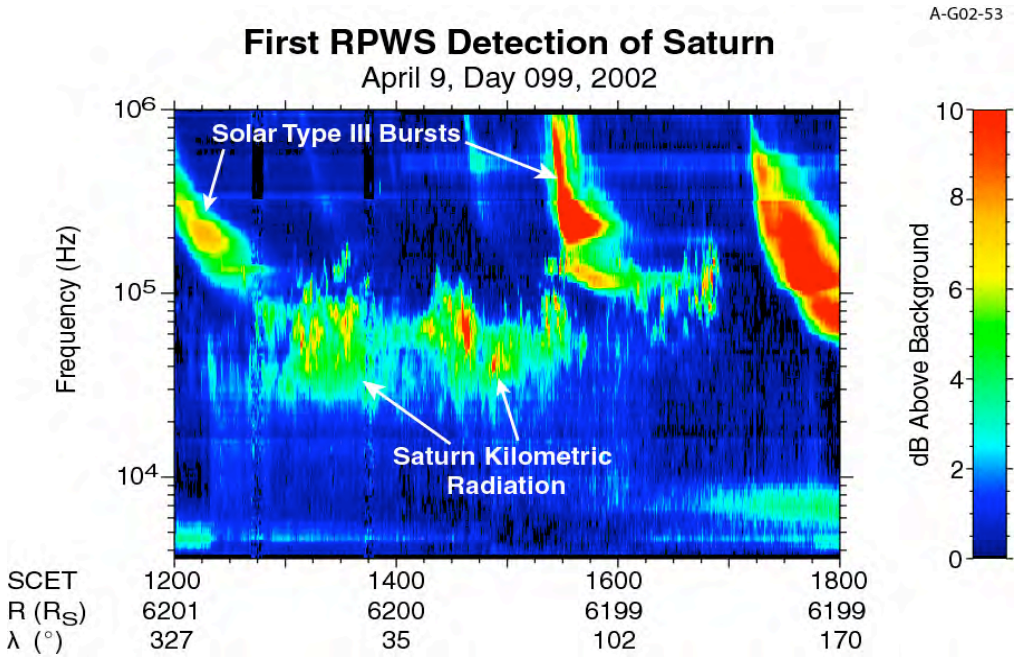
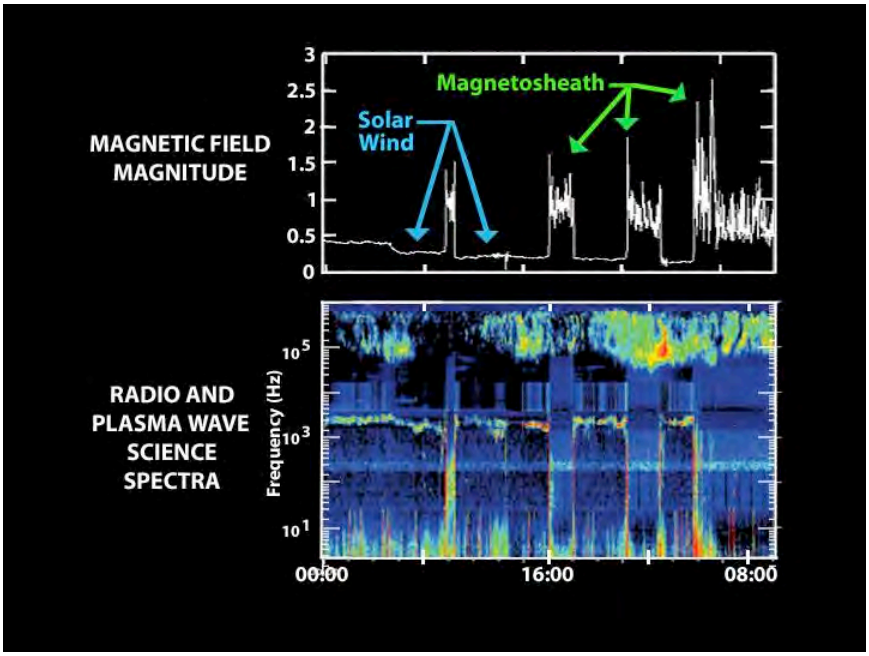
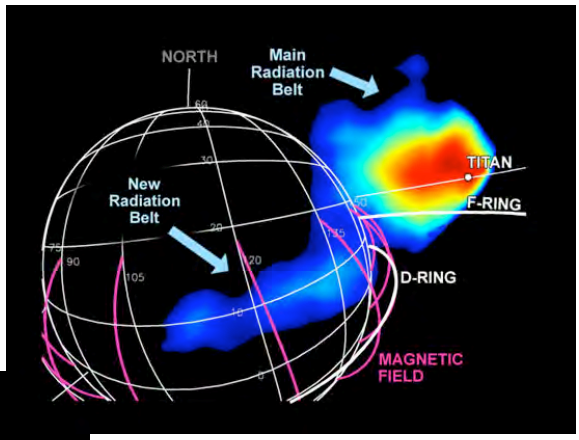

Bow Shock
SOLAR WIND
FAST NEUTRALS
PICK-UP IONS
POLAR WIND
AURORA
TITAN TAIL
SOLAR WIND
RING CURRENT
TITAN NEUTRAL TORUS
PLANETARY IONS
PLASMA SHEET
MAGNETOPAUSE
BOW SHOCK
MAGNETOSHEATH


A-G02-53
First RPWS Detection of Saturn
April 9, Day 099, 2002
Solar Type III Bursts
Saturn Kilometric Radiation
Frequency (Hz)
dB Above Background
SCET 1200 1400 1600 1800
R (RS) 6201 6200 6199 6199
λ (°) 327 35 102 170

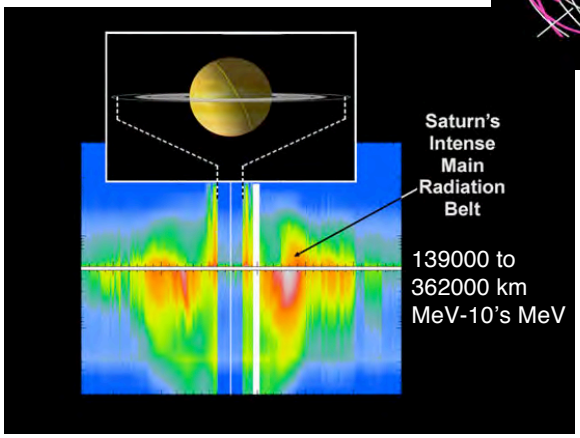
• Series of Bow Shock crossings at magnetosphere entry at 50 Rs ! (MAG & RPWS)



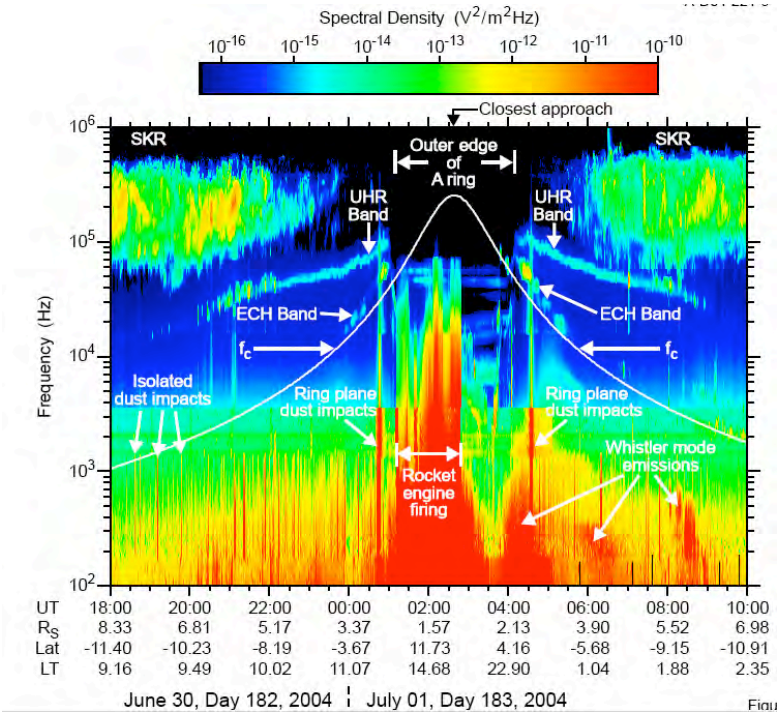
• Main & New radiation belts
(MIMI energetic ions & electrons, & ENA : 30 keV → MeVs)



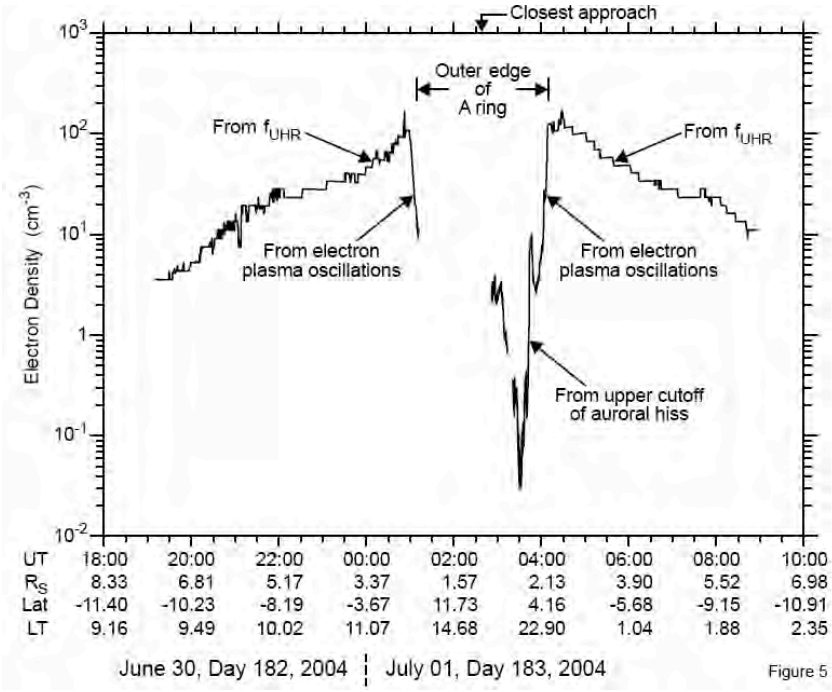
6000 km thick
< 150 keV particles



• First Saturn fly-by with RPWS

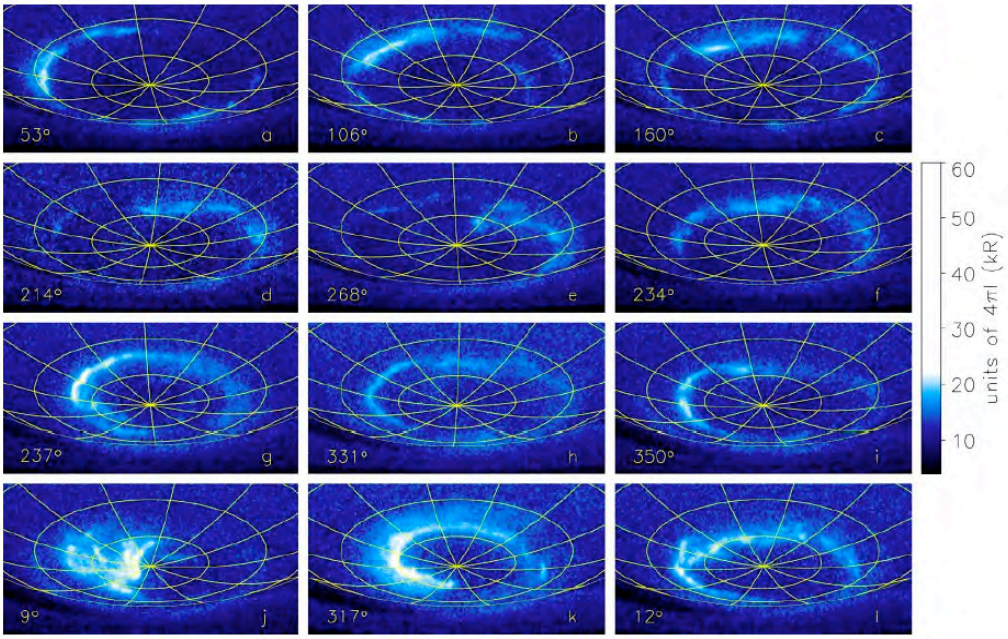


• Electron density drop at A ring (RPWS)

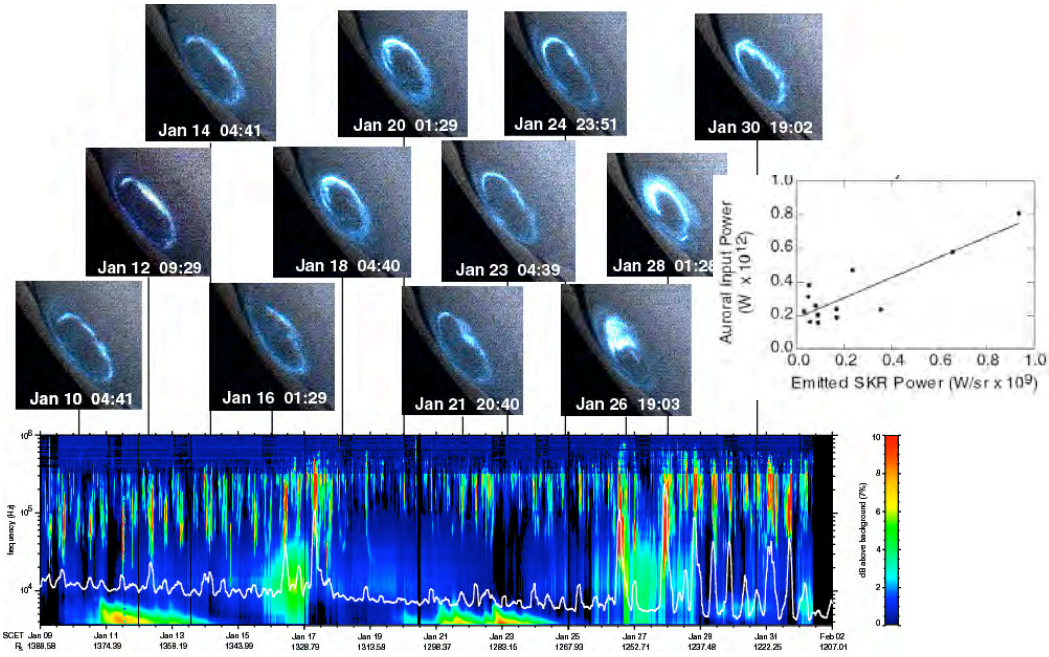


• UV observations by HST (26/01/2004, 19:03 UT)

• Variability of UV aurora

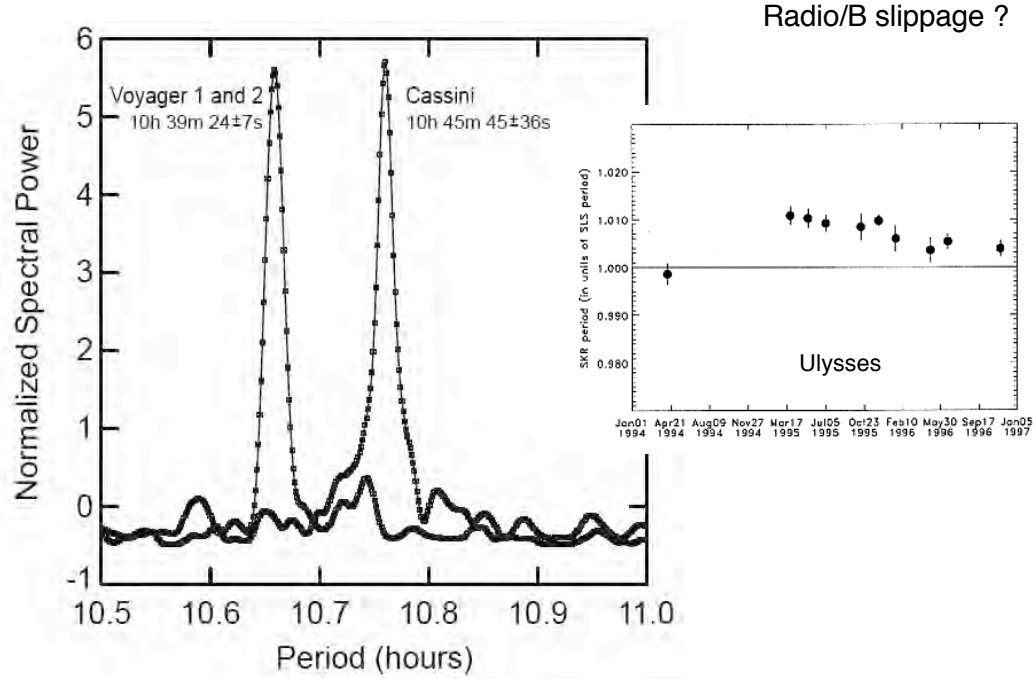


• UV / Radio aurora correlation



• Variability of Saturn's radio period

B/interior or
Radio/B slippage ?



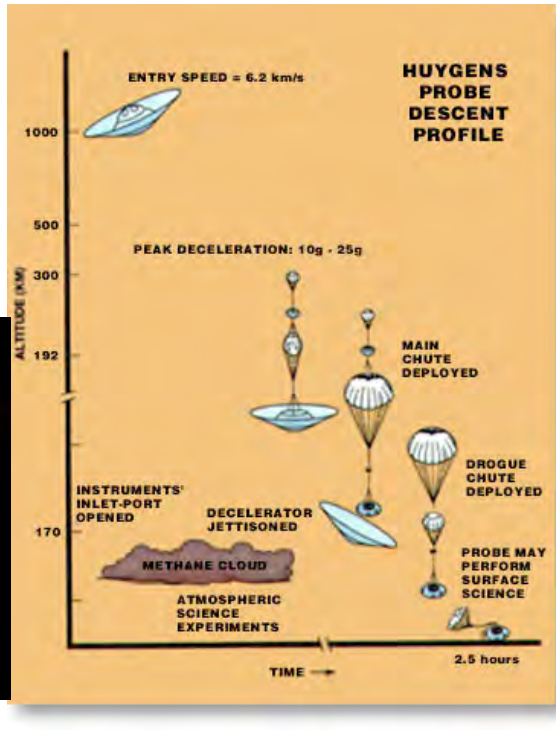
CASSINI EXPECTATIONS

TITAN EXPLORATION

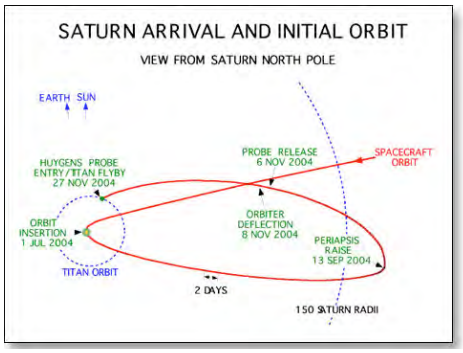
- Titan Imaging (45 close fly-bys)

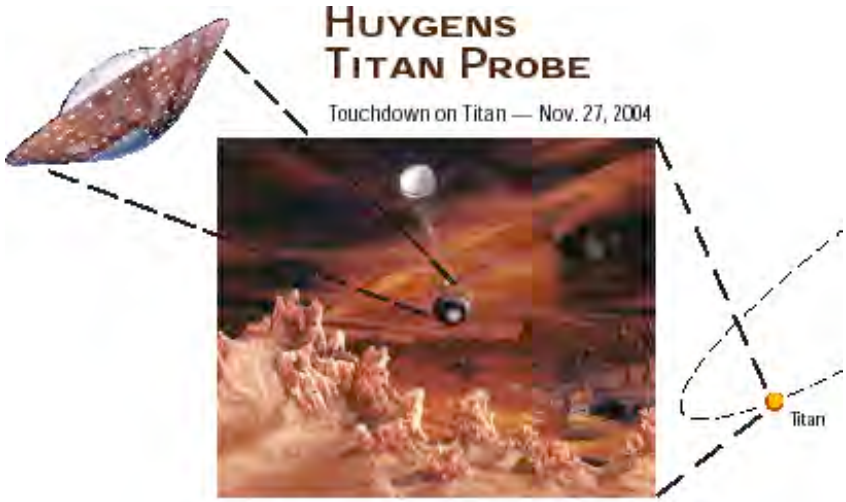
• Titan RADAR (45 close fly-bys)

• Huygens release
(25 december 2004)



- Huygens arrival
  (14 january 2005 …
  instead of 27 november 2004)

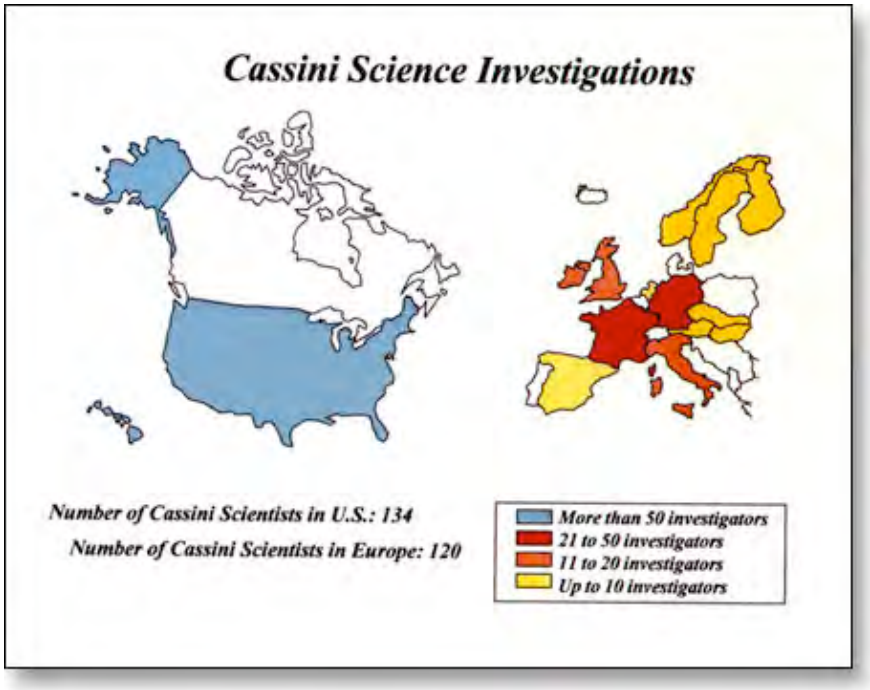




During 3 hours of science observation and measurements, the Huygens Probe instruments will:

- Collect aerosols for chemical analysis.
- Make spectral measurements and take pictures of Titan's surface and atmosphere.
- Measure wind speeds using the Doppler effect.
- Identify constituents in atmosphere.
- Measure physical and electrical properties of the atmosphere.
- Measure physical properties of the solid or liquid surface of Titan.

→ ~ 300 Co-Is of which ~150 Europeans (~50 french)
→ 1/3 P.I. Europeans
→ NASA/ESA : 75/25% of total cost (2 G$)



REFERENCES

• Passage to a ringed world, NASA SP 533, L. Spilker Ed., 1997, available at
http://saturn.jpl.nasa.gov/multimedia/products/references.cfm

• NASA/JPL site on Solar System
http://www.jpl.nasa.gov/solar_system/

• NASA site on Cassini
http://saturn.jpl.nasa.gov/home/index.cfm

• ESA site on Cassini
http://www.esa.int/SPECIALS/Cassini-Huygens/

• Details on historical background of Saturn's exploration
http://www.solarviews.com/eng/saturnbg.htm