The Saturn System as seen from the Cassini Mission

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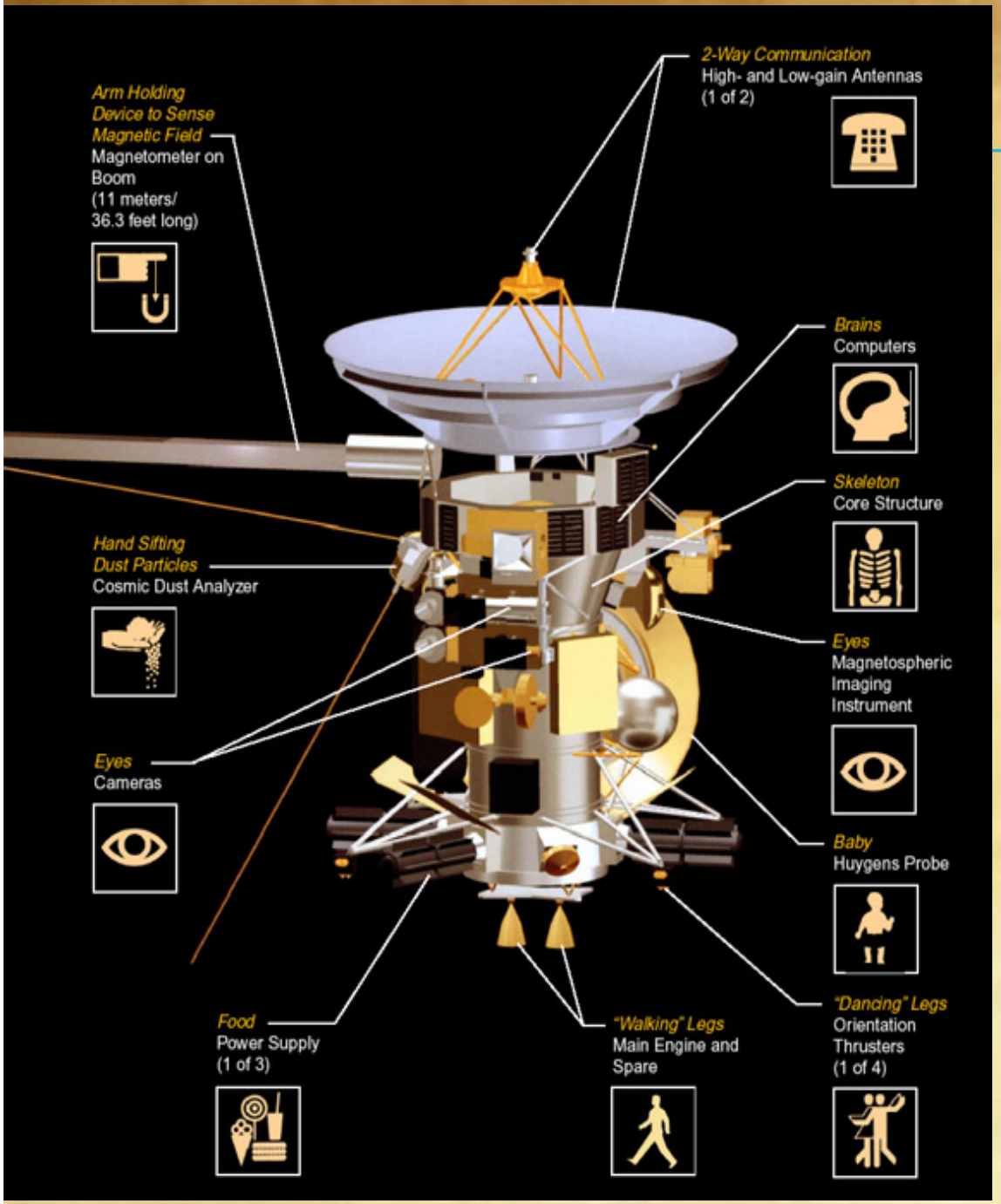
OUTLINE OF THE TALK

- Cassini Mission
  - The payload
  - How to use it
- Icy Satellites : why they are so important
- Selected bodies
  - Enceladus
  - Iapetus
  - The captured bodies
- Titan

THE PAYLOAD


2-Way Communication
High- and Low-gain Antennas
(1 of 2)
Arm Holding Device to Sense Magnetic Field
Magnetometer on Boom
(11 meters/ 36.3 feet long)
Brains
Computers
Skeleton
Core Structure
Hand Sifting Dust Particles
Cosmic Dust Analyzer
Eyes
Magnetospheric Imaging Instrument
Eyes
Cameras
Baby
Huygens Probe
Food
Power Supply
(1 of 3)
"Walking" Legs
Main Engine and Spare
"Dancing" Legs
Orientation Thrusters
(1 of 4)

PAYLOAD

Planets

- **Imaging science subsystem**: Imaging in visible, near-ultraviolet, and NIR
- **Visual and infrared mapping spectrometer**: Identifies the chemical composition of the the surfaces, atmospheres, and rings of Saturn
- **Composite infrared spectrometer**: Measures infrared energy from the surfaces, atmospheres, and rings
- **Ultraviolet imaging spectrograph**: Measures ultraviolet energy from atmospheres and rings to study their structure, chemistry, and composition.
- **Cassini radar**: Maps surface of Titan
- **Radio science subsystem**: Searches for gravitational waves; studies the atmosphere, rings, and gravity fields of Saturn and its moons.

Fields

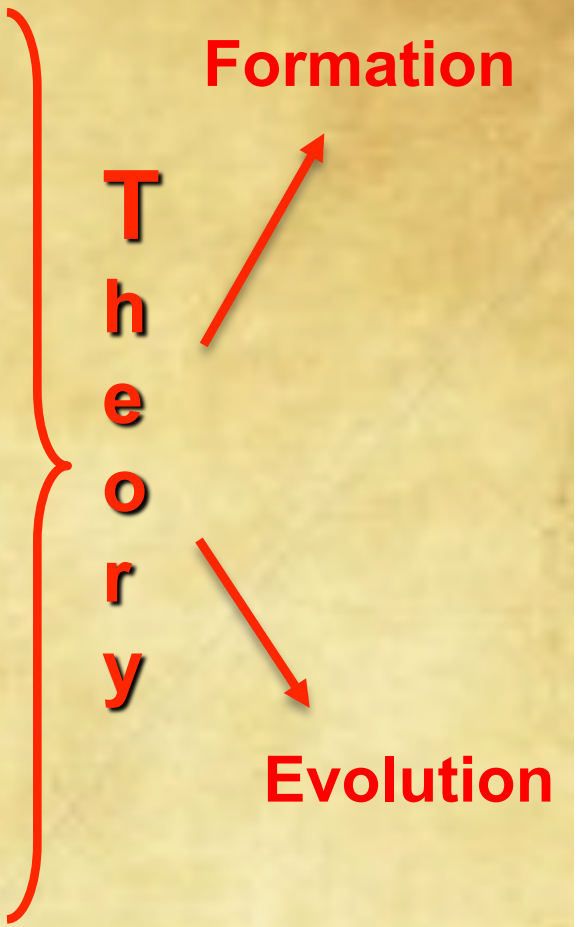
- **Magnetospheric imaging instrument**: Images Saturn's magnetosphere and measures interactions between the magnetosphere and the solar wind
- **Cassini plasma spectrometer**: Explores plasma within and near Saturn's magnetic field.
- **Ion and neutral mass spectrometer**: Examines neutral and charged particles
- **Radio and plasma wave science:** Investigates plasma waves natural emissions of radio energy, and dust.

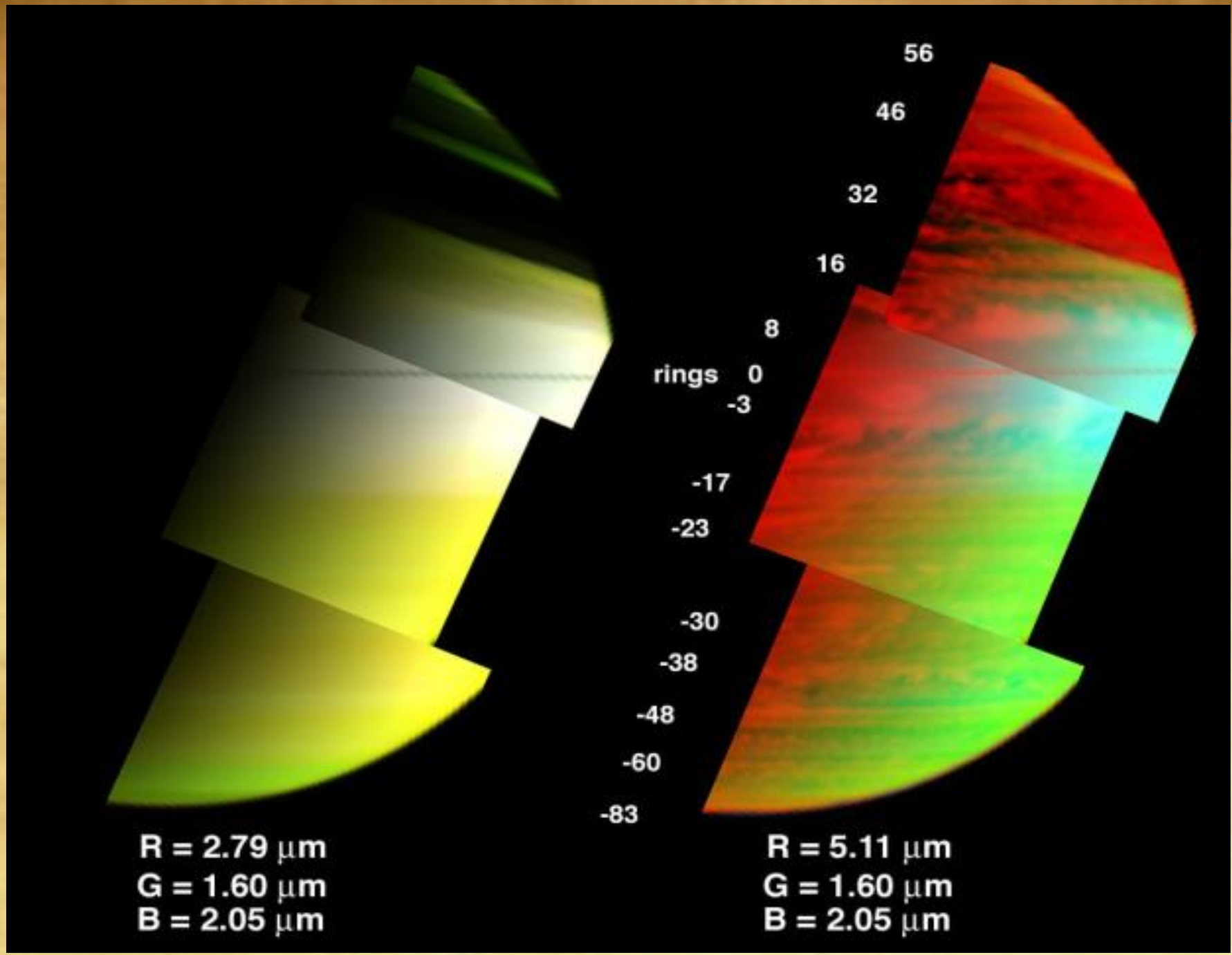
Env.

- **Cosmic dust analyzer:** Studies ice and dust grains in and near the Saturn system.

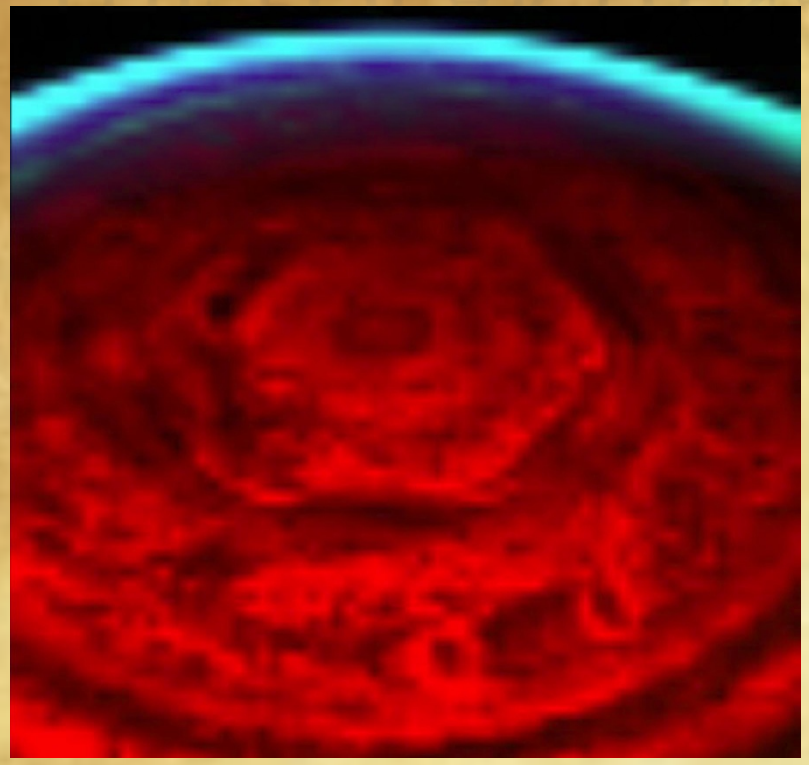
THE KIND OF OBSERVATIONS

- Imaging
  - **Overall geological/geophysical history**
  - **Large Scale processes characterizing the surface**
  - **Figure**
- Spectroscopy
  - **Composition**
  - **Mineralogy**
  - **Gas emission – interaction with ionized particles**
- Magnetometer/Plasma analyzers
  - **Internal and external magnetic fields**
- Radio Science
  - **Internal structure**
- Radar
  - **Surface structure and dielectric properties**

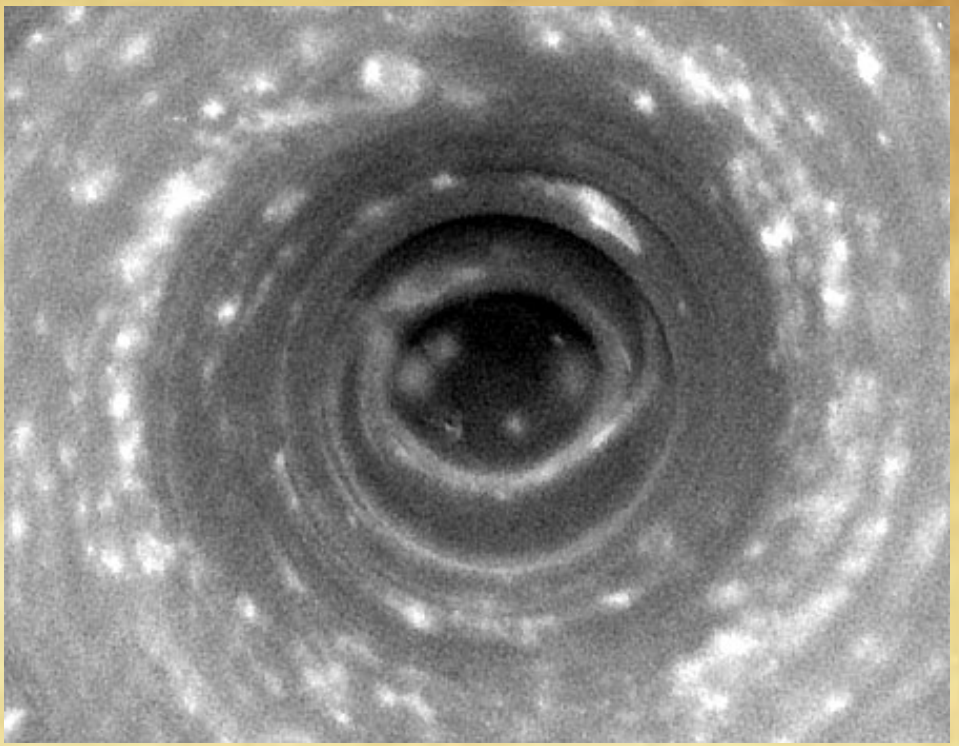



56
46
32
16
8
rings 0
-3
-17
-23
-30
-38
-48
-60
-83
R = 2.79 μm
G = 1.60 μm
B = 2.05 μm
R = 5.11 μm
G = 1.60 μm
B = 2.05 μm

THE POLAR DYNAMICS



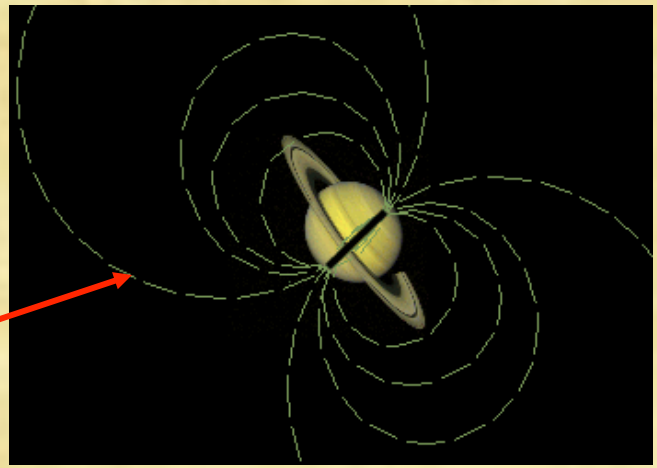
Saturn's northern Polar Hexagon, discovered in Voyager is a prominent feature, extending downward at least several bars of pressure. 5-µm-bright hexagon at speeds of 100 m/s



At the south pole, a hurricane-like vortex feature is observed with a deep "eye" of cloud-free ~1 bar deeper than the surrounding ring of clouds. Clouds whip around the pole at speeds approaching 200 m/s

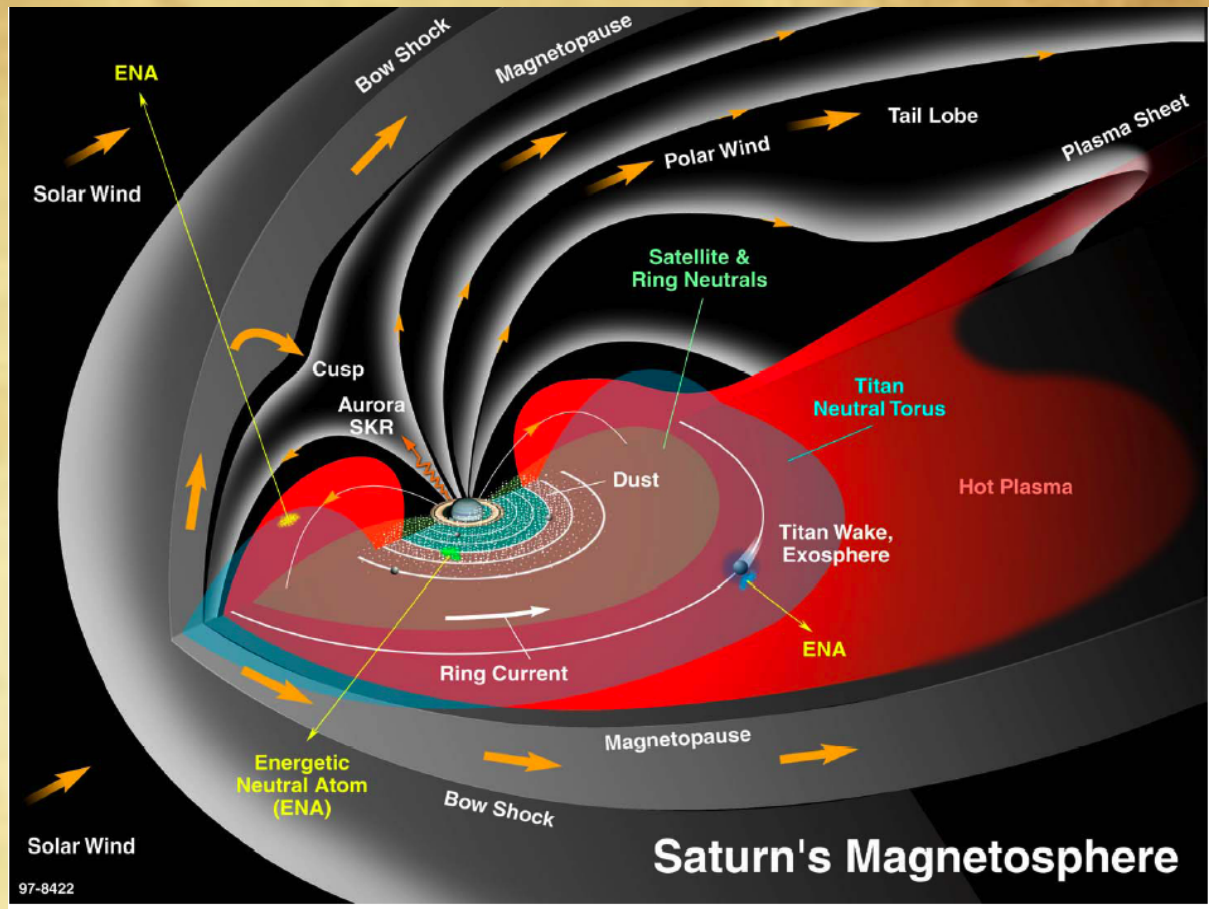
SATURN INTERIOR

- Results from estimates indicate that Saturn has a hard core made of ***rock and ice of 6-20 Earth Masses*** (Schubert et al 2008).
- The next layer up, surrounding the core, is a layer of metallic hydrogen.
- Above this is a layer composed of hydrogen molecules that are in a form of a liquid but at a greater height become gas.
- The helium mixes with the hydrogen gas and then condenses with the metallic hydrogen and then falls, which gives off heat in the process.
- ***During this process, a magnetic field is also produced throughout the planet.***
- The magnetic moment, was also somewhat smaller than expected at
- ***4.6×10^{18} T m^3***



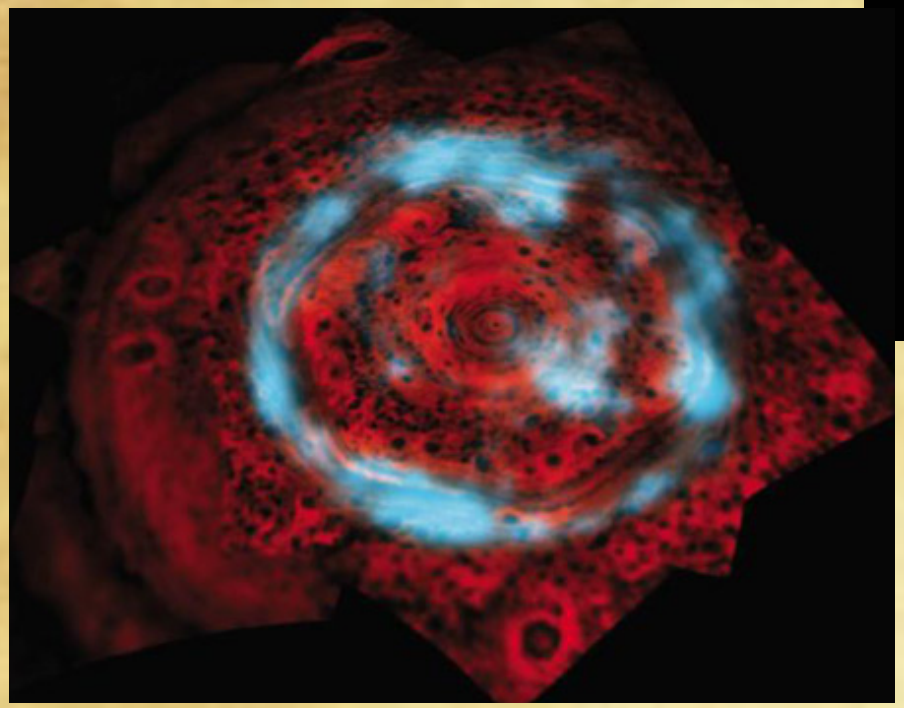
SATURN MAGNETOSPHERE

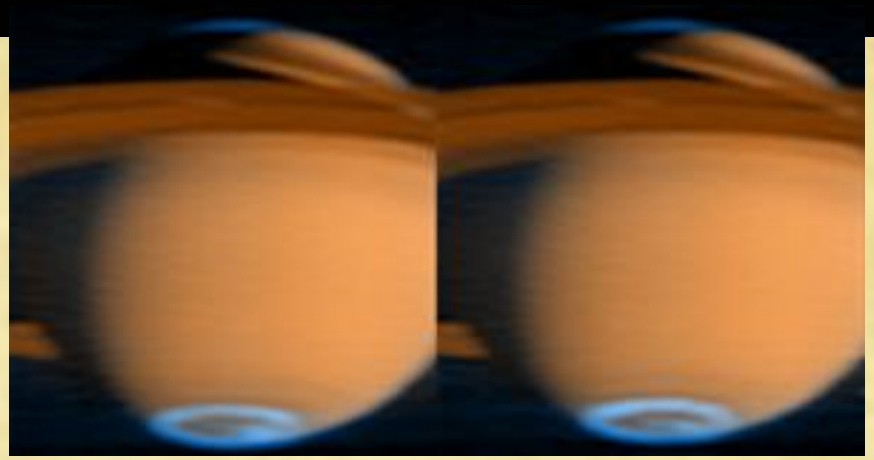
- Saturn has an large **magnetosphere** (one-fifth that of the Jupiter one).
- **On their inner edge** the radiation belts are terminated by the main (A, B and C) rings of Saturn, which absorb any particles that encounter them.
- **The radiation belt** particles are absorbed if they collide with the moons where are present ***local minima*** are reached.



AURORAE

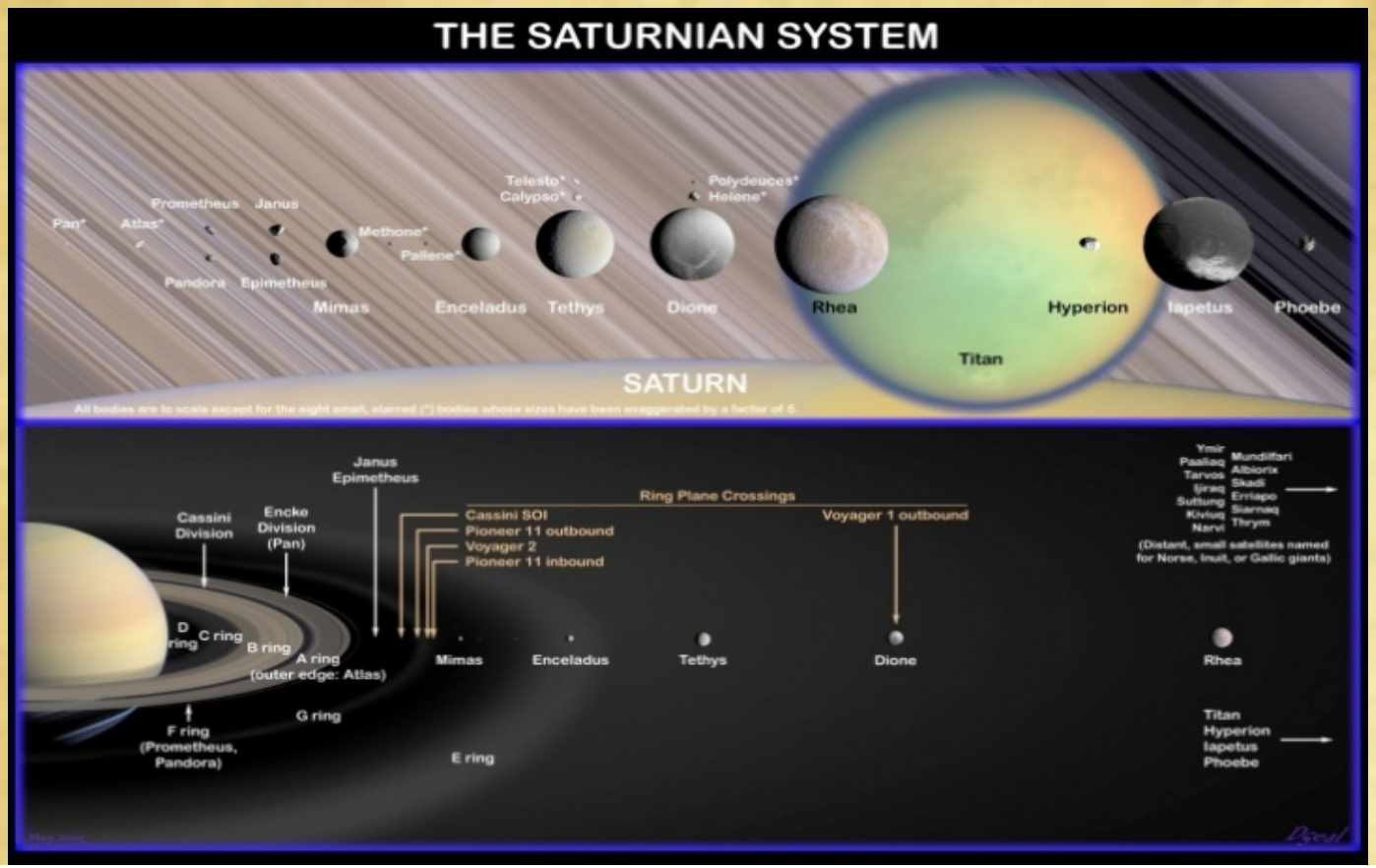
In the images**, blue** represents aurora emissions from hydrogen gas excited by electron bombardment, while **red-orang**e represents reflected sunlight.





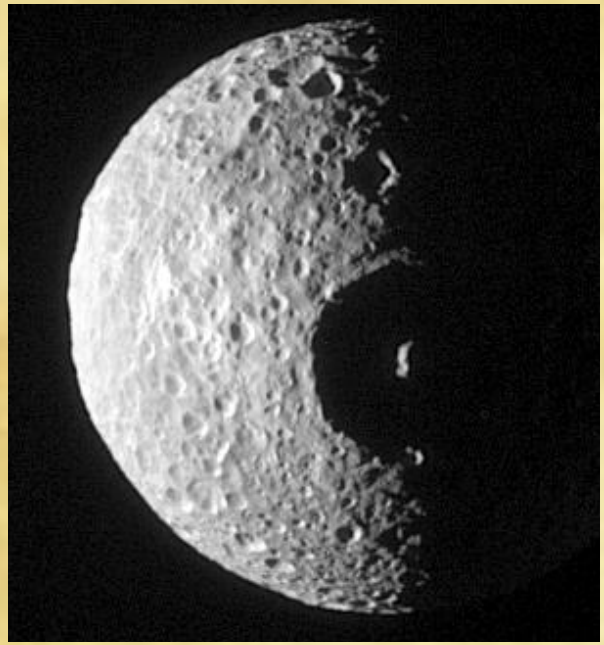
THE SATURN SYSTEM

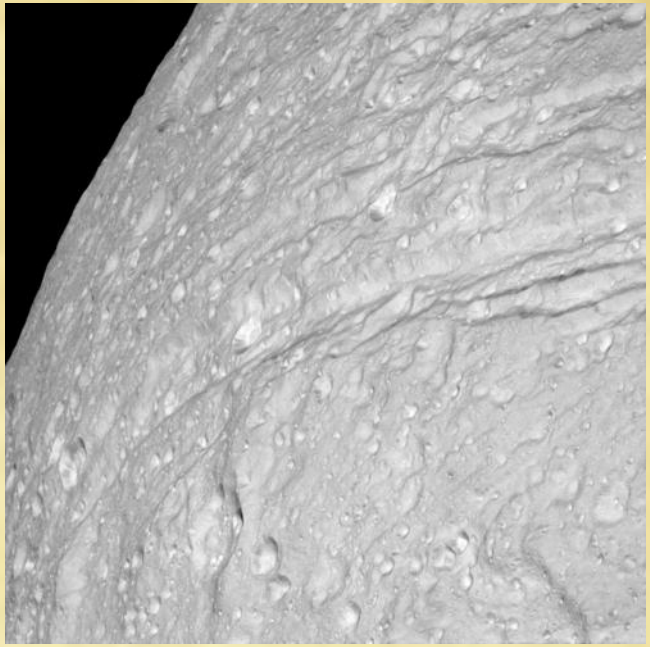
- Saturn has at least 60 moons.
- They range up to 2,575 km (1,600 mi) in radius.
- They consist mostly of the lighter, icy substances
- A number of the moons are retrogrades, suggesting that were captured by Saturn's gravitational field.

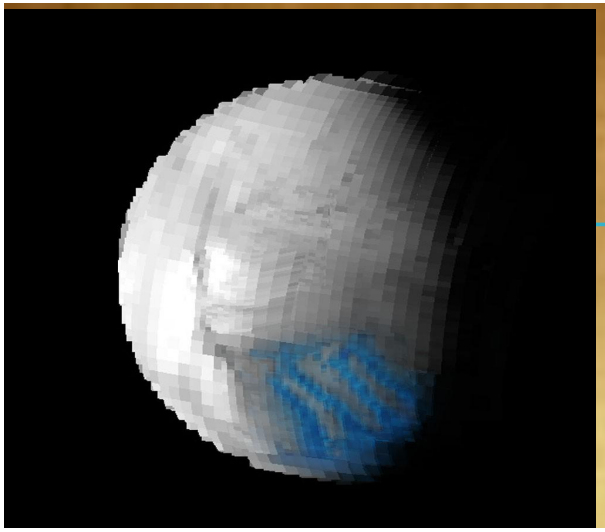


THE SATURN ICY SATELLITES

- Mimas and Thetis have impact craters caused that their were very close to the destruction limit

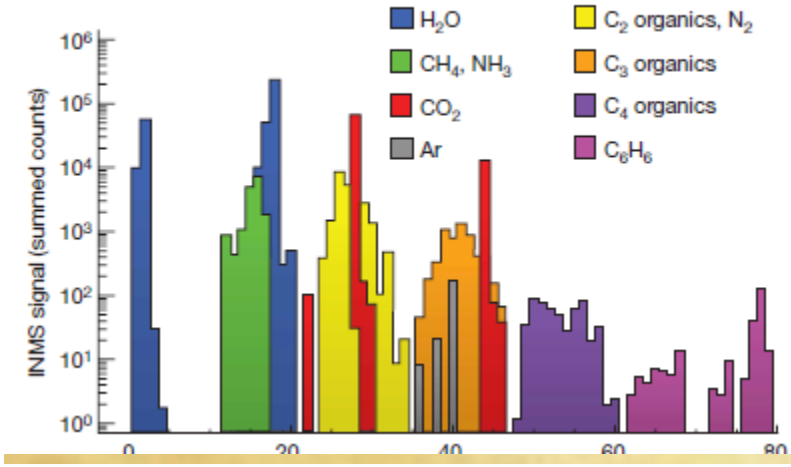


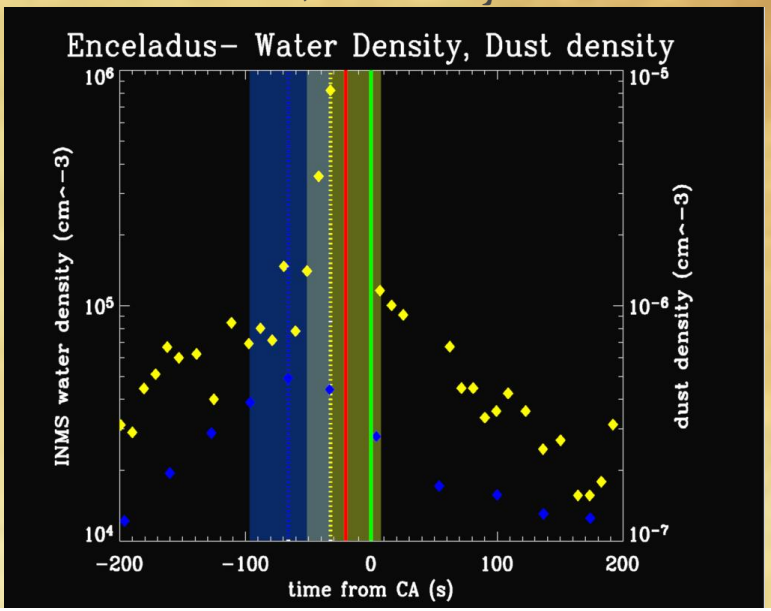




- Enceladus seen by VIMS (in the 2 micron-wavelength)
- The dark cracks at the south pole dubbed "tiger stripes" for their distinct stripe-like appearance.
- Superimposed on top of the map is a "crystallinity" map that shows the freshest, most crystal ice as blue.

•VIMS image taken during Cassini's close flyby of Enceladus on July 14, 2005.





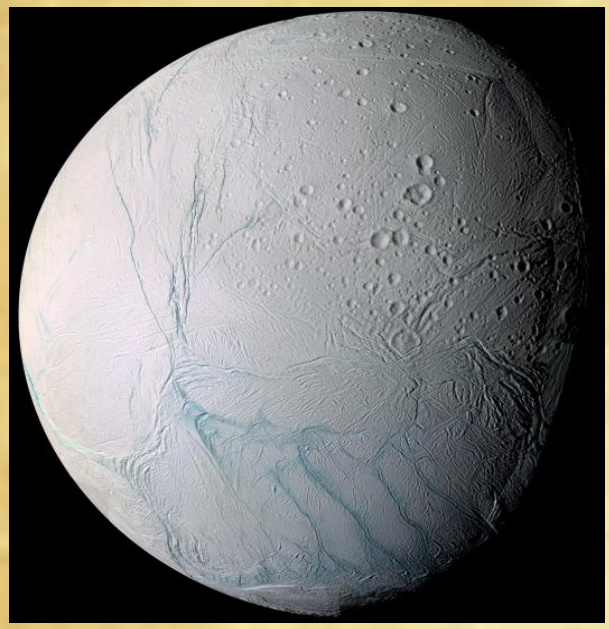
Dust analyser data 35 seconds before closest approach to Enceladus, as it flew over the south polar region at an altitude of 270 kilometers.

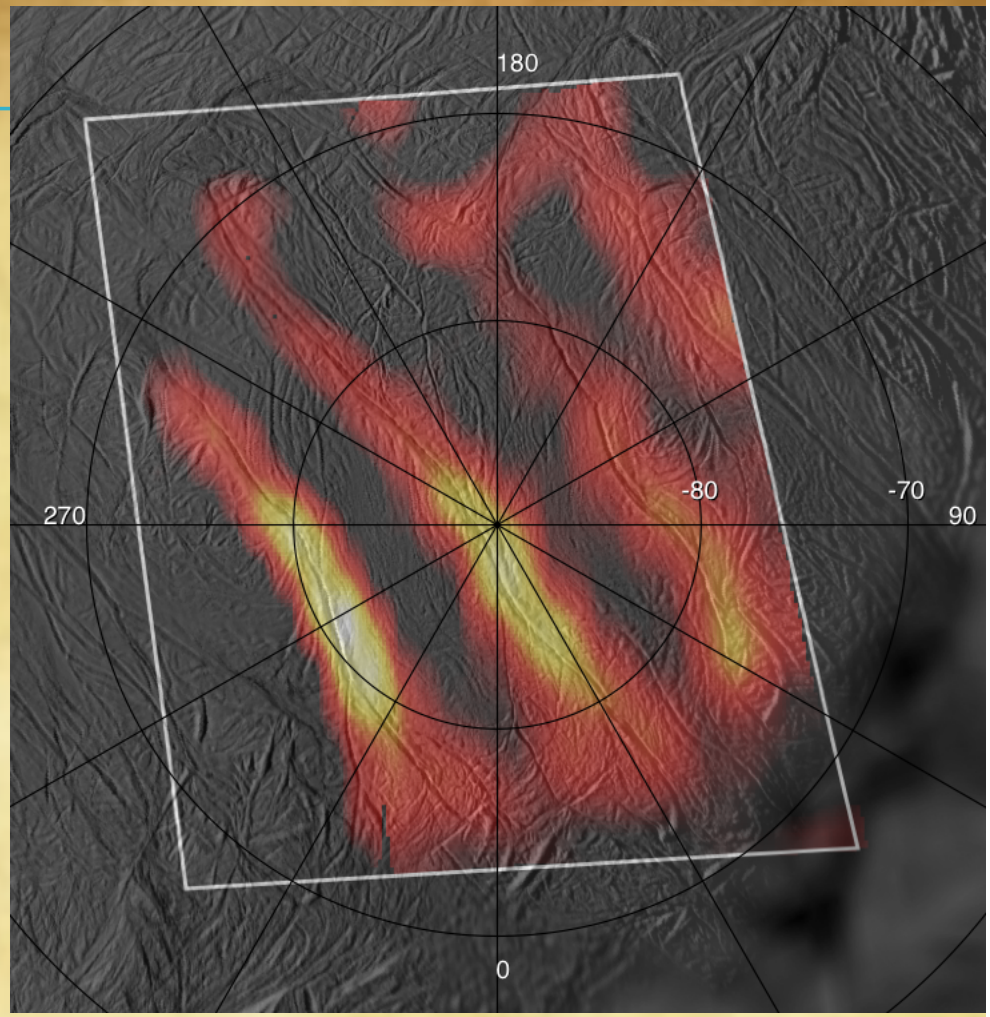
•Water production rate = 0.5 to 1.2 x 10^{28} H_2O molecules / sec= 150 to 360 kg / sec
•Ammonia is present in the plume with a mixing ratio of 0.8% → Lubricant of the interior
•Detection of grains in the E-Ring that are rich in Na→ direct proof of the ocean?

TIGER STRIPES

- **Average Earth 87 mW/m^2**

- **Enceladus South Pole 250 mW/m^2**

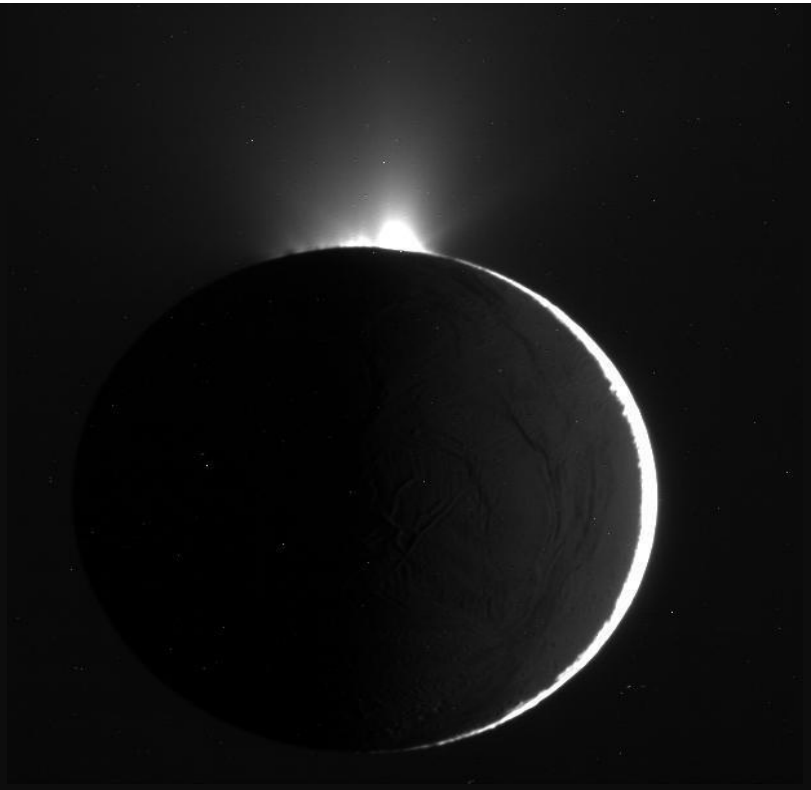




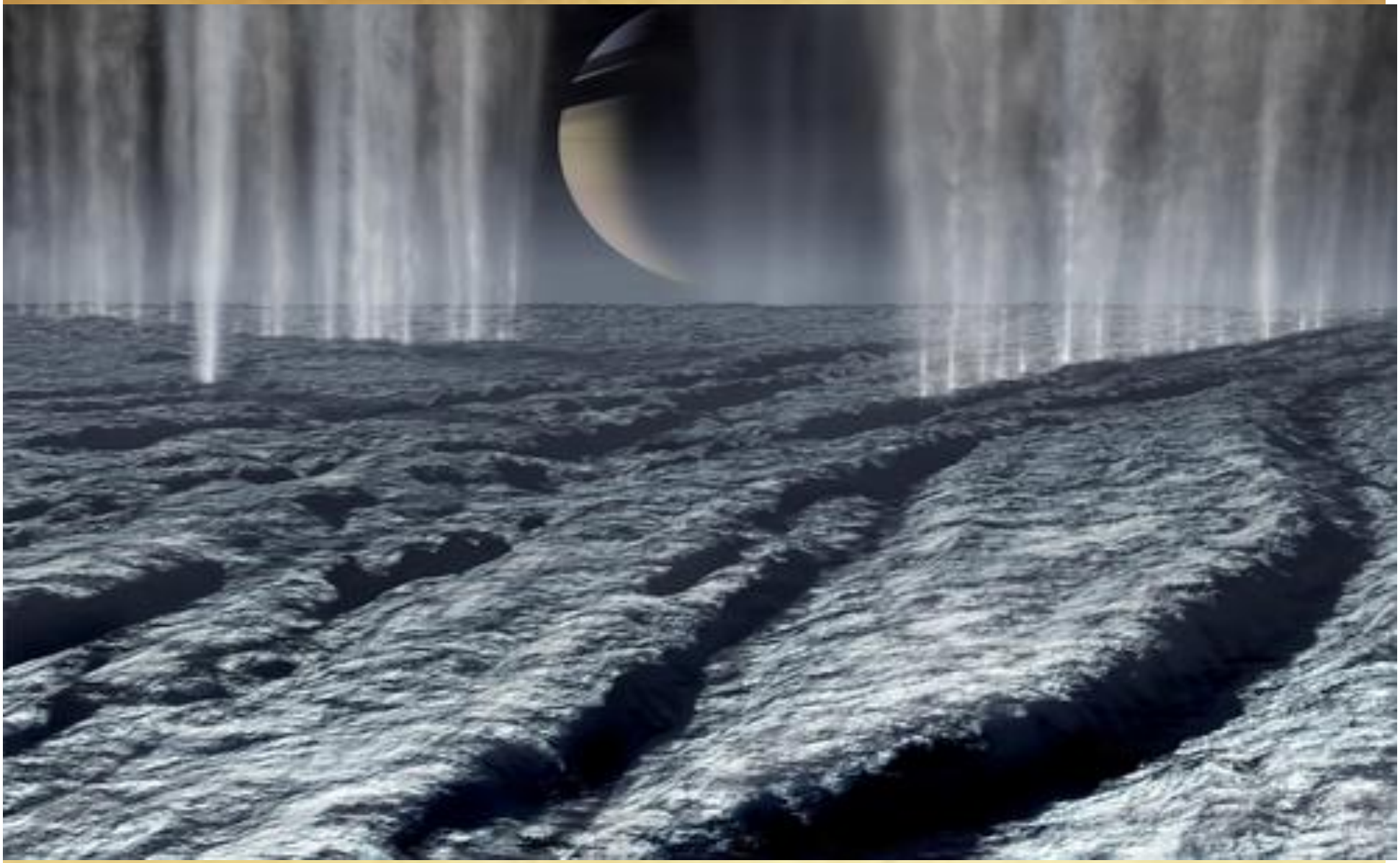
Tiger Stripes are warm along entire length

THE NEW FLY-BY

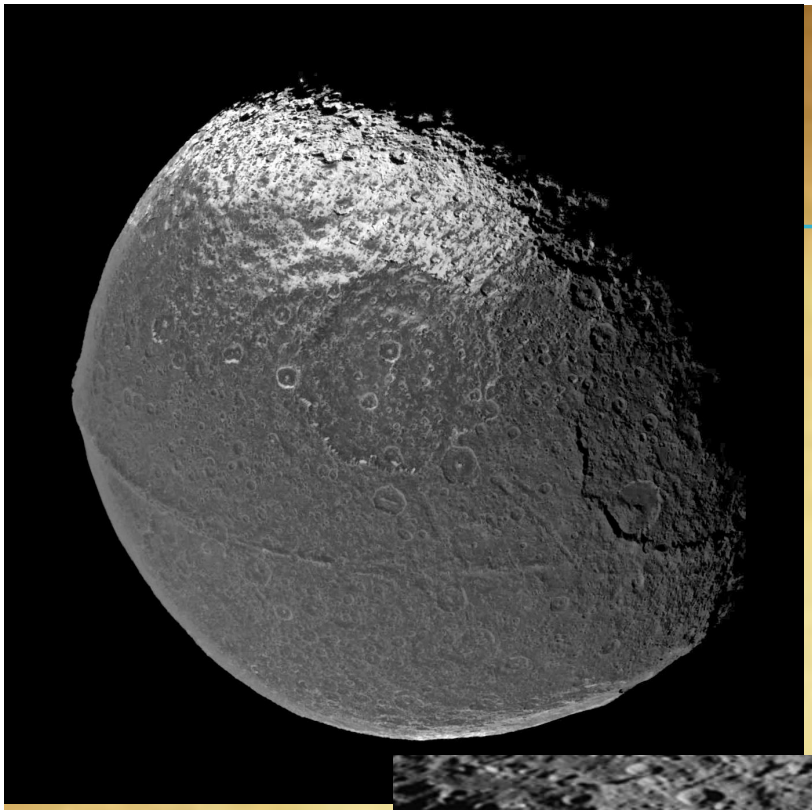
- **H_2O 91 ± 3 %mol**
- **CO_2 3.2 ± 0.6 %mol**
- **N_2 4 ± 1 %mol**
- **CH_4 1.6 ± 0.4 %mol**
- **CO < 0.9 %mol**
- **NH_3, HCN, C_2H_2, C_3H_8 < 0.5 % mol (*i.e.*, detected)**
- Inferred from a combination of INMS and UVIS data
- Data need to be confirmed

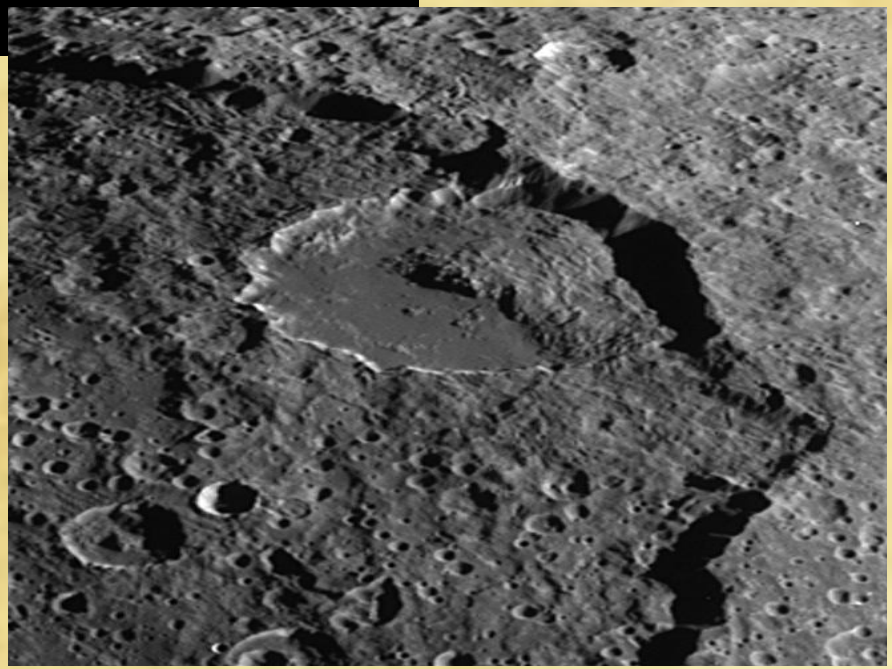


ENCELADUS



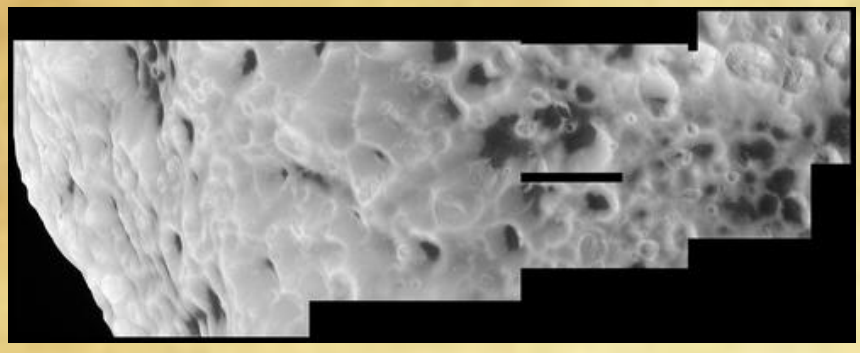
IAPETUS

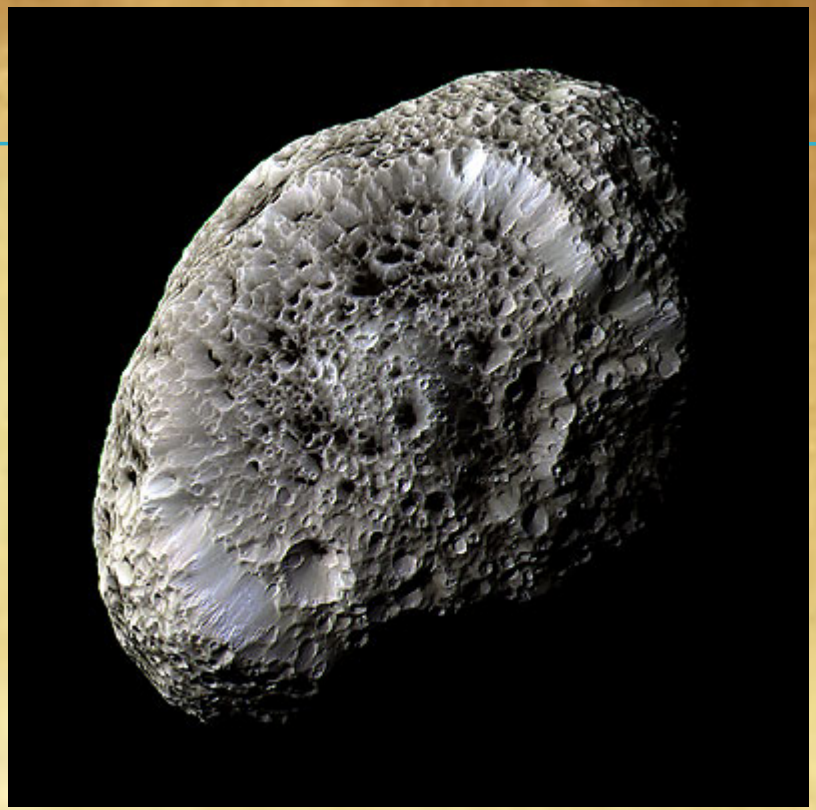




- The equatorial ridge may be associated with despinning 200 to 900 My after formation – some basins post-date ridge
- Iapetus' dark hemisphere has been likened to tar or asphalt and is so dark that no details within this terrain were visible to Voyager 2.

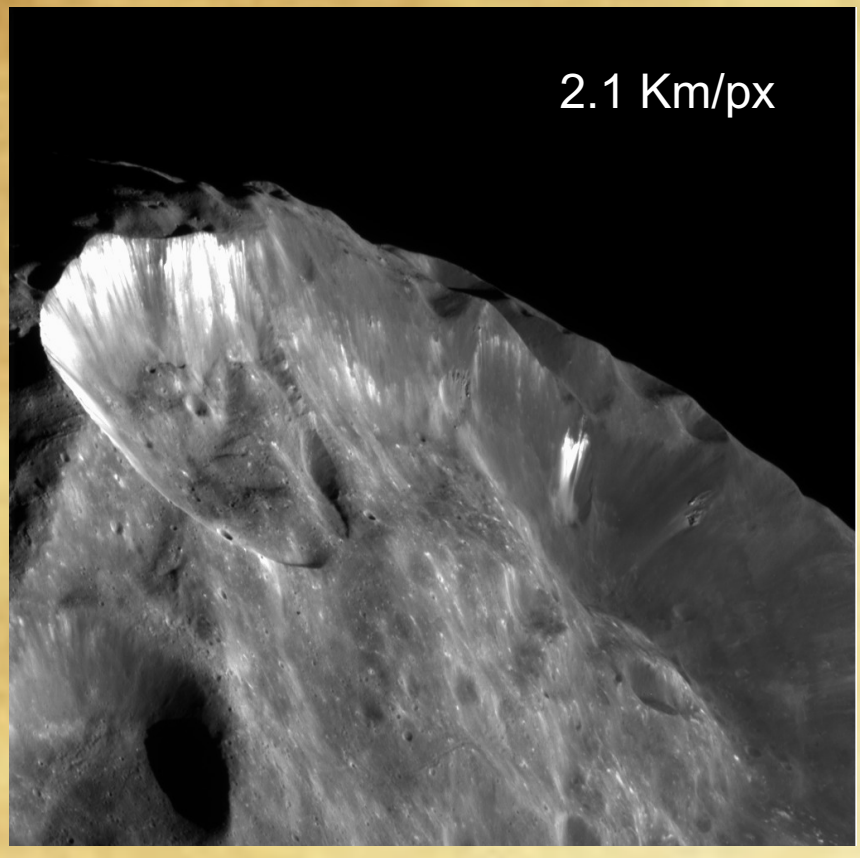
HYPERION

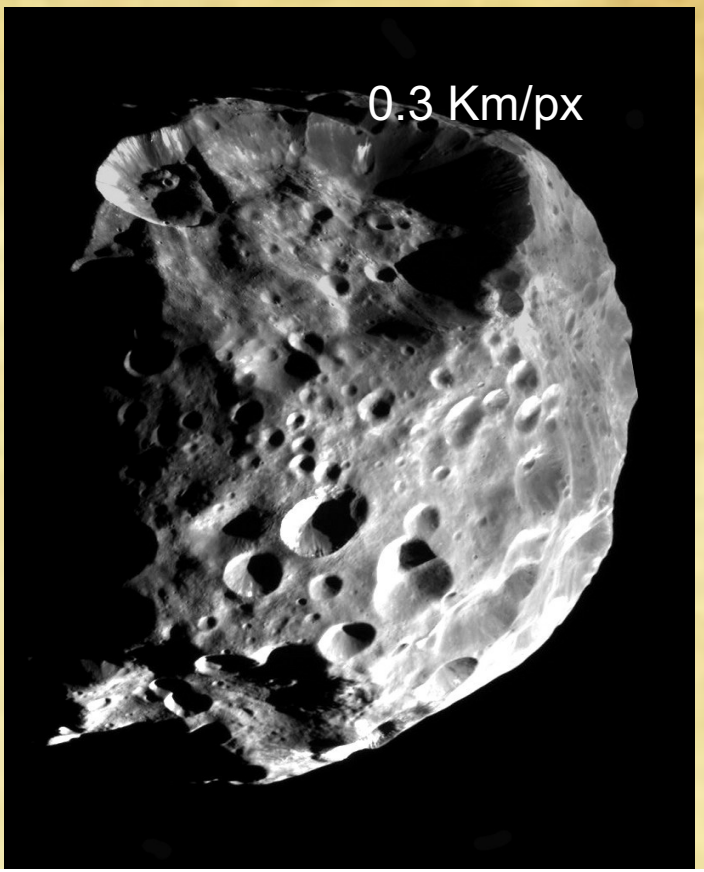




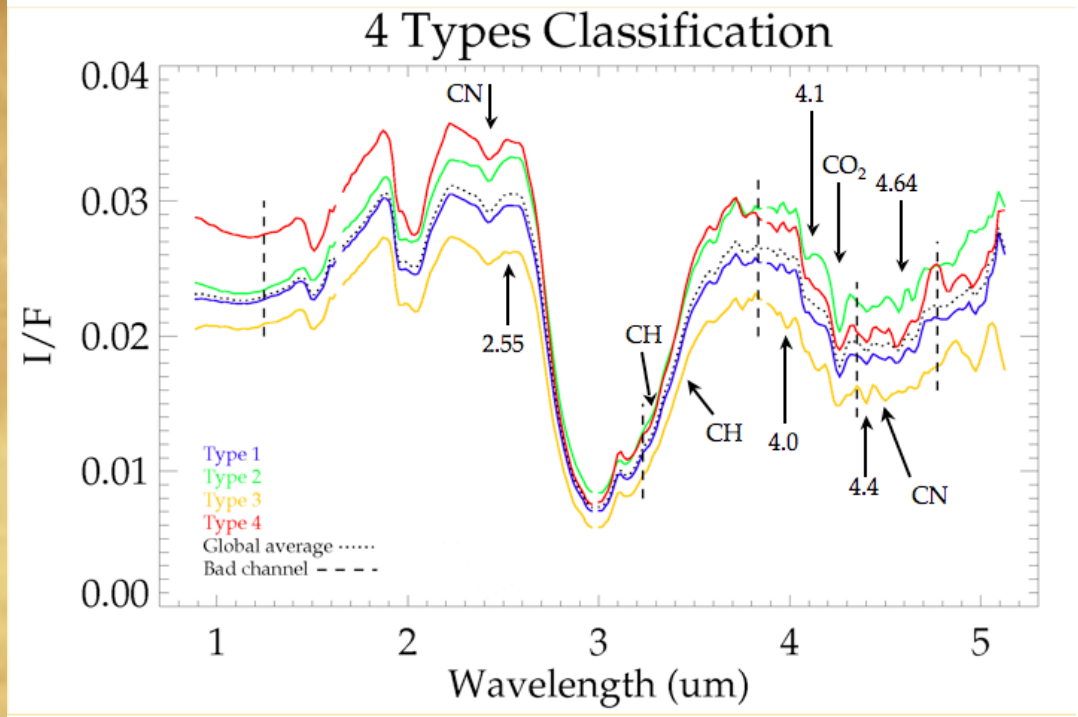
26 September 2005 by the NASA/ESA/ASI Cassini spacecraft, reveals crisp details and variations in colour across the strange surface that might represent differences in the composition of materials.

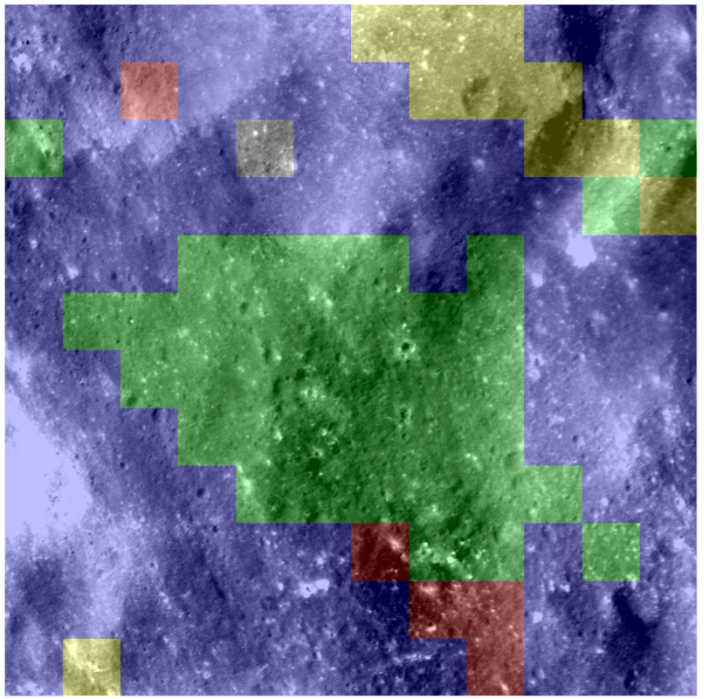
SATELLITES: PHOEBE

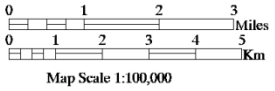




Closer view→ more complex chemistry→ apparently incompatible with Saturn sub-nebula



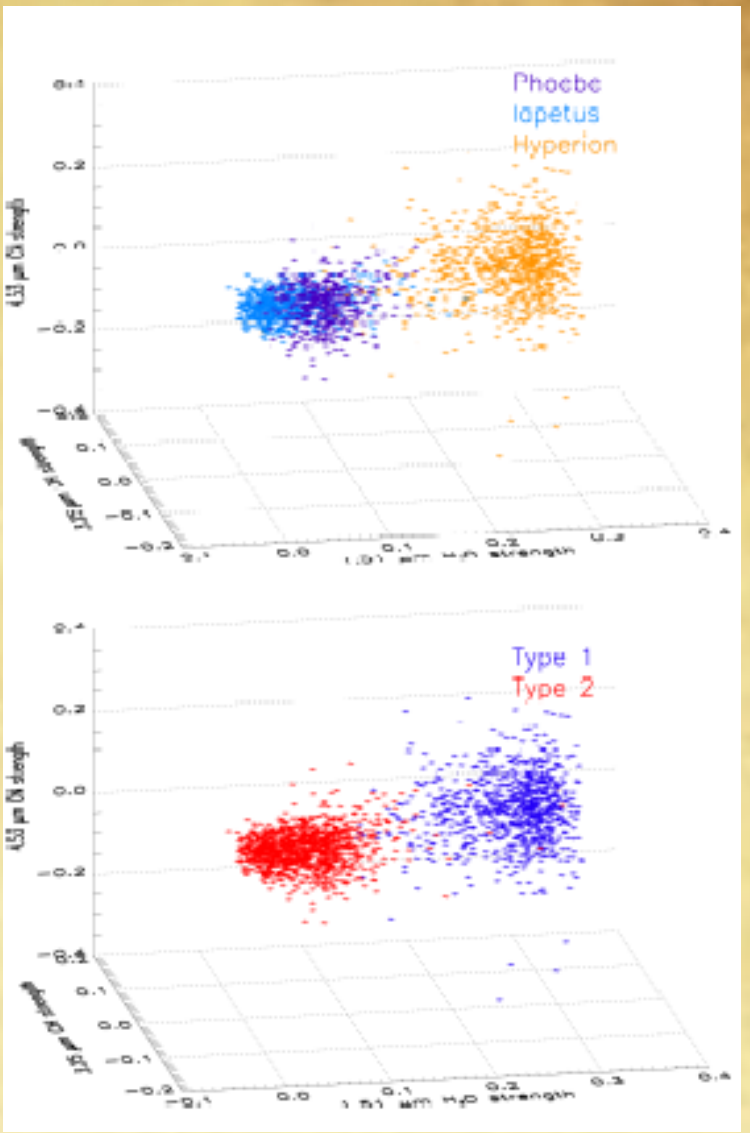




Coradini et. al Icarus 2007

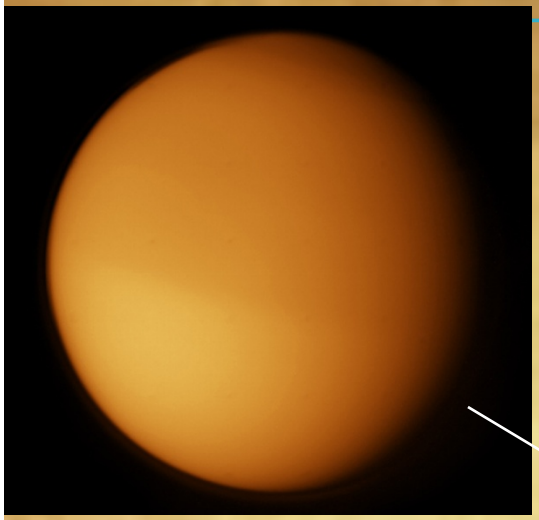
CONTAMINATION

- Dark material is present on the leading hemisphere of Iapetus
- Two issues –
  - Sources (Phoebe, Hyperion)
  - Dynamical evolution
- The collisional history of Phoebe and the irregular satellites supplies a natural scenario for the dark material
- Cassini IR data can help in understanding the dark material origin



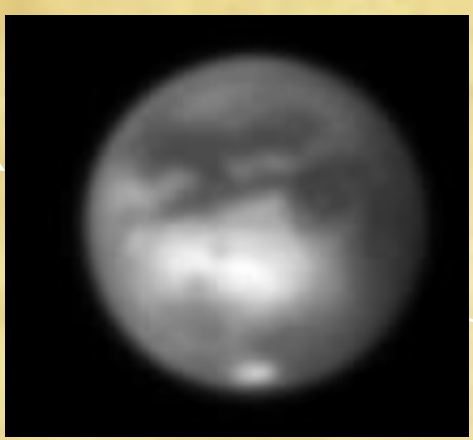
Tosi et al. Monthly Notices, 2009

TITAN



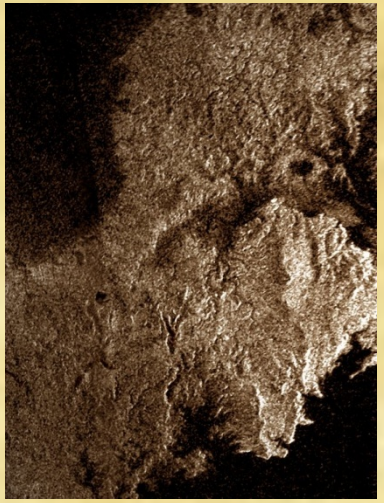
1980-1981

Voyager



1990's

HST and Keck

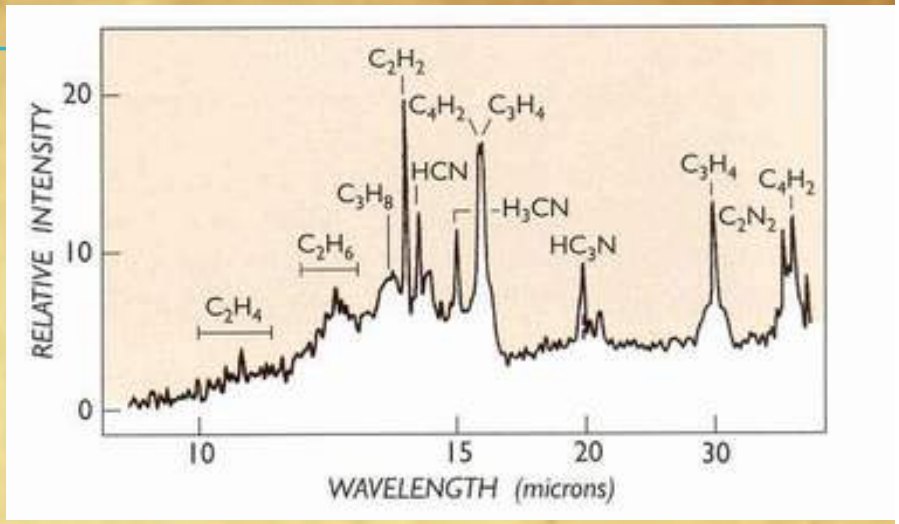


2004-2010

Cassini-Huygens

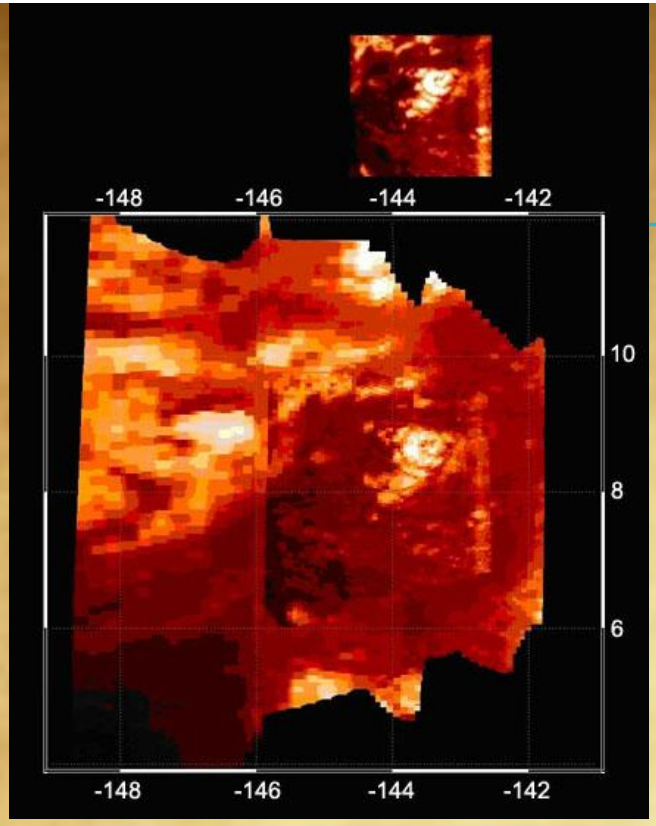
ATMOSPHERIC COMPOSITION

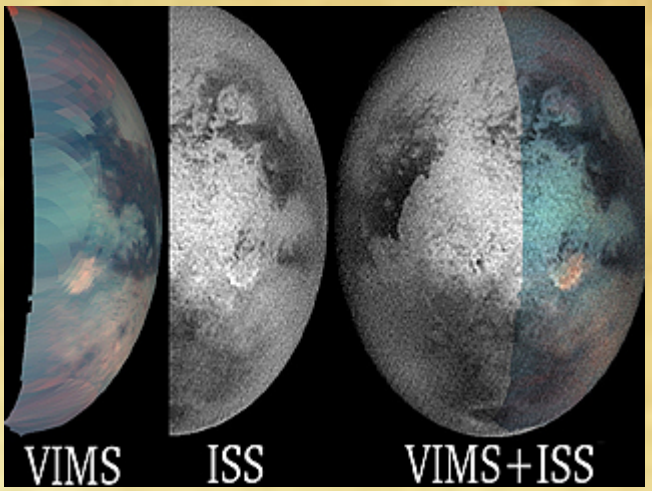
	Titan	Earth
N_2	82-99 %	78%
CH_4	2-10 %	2 ppm
O_2	-	21%
CO_2	0.01 ppm	350 ppm
Ar	< 1-6 % ?	0.9%

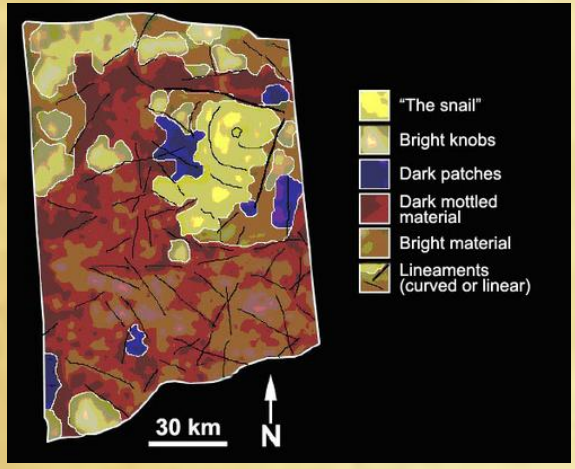


- Surface pressure 1.5 bar, temperature 94 K
- Obtained from UV/IR spectra and radio occultation data
- Various organic molecules at the few ppm level
- Haze consists of ~1 μm particles, methane condensates plus other hydrocarbons (generated by photodissociation and recombination of methane;)

LOCALIZED VOLCANOES





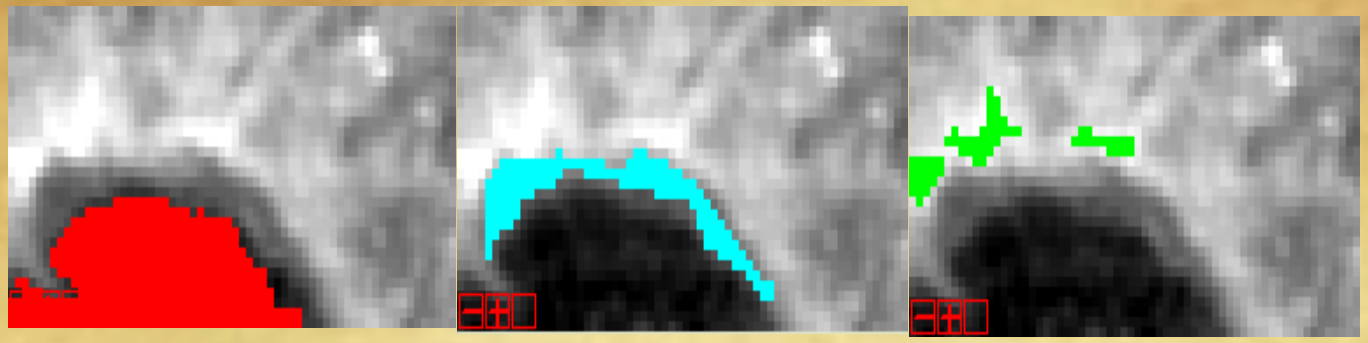


- High resolution image collected by VIMS-Cassini on Titan, October 26th 2004. Image resolution 2.6 - 1.8 Km per pixel.

SOUTH POLE LAKES!

•An overlapping between the ISS observation (June 2005) of the Ontario lacus and the VIMS observation at 5 mm, map in satellite projection, has been tried.
•The South Pole position in the ISS image is indicated by a black cross.

FIRST GUESS ON LAKE COMPOSITION



A liquid reservoir, looks darker because of the solar radiation extinguishes entering into the lake (red) ; a ramp with variable gradient, looking as the dark grey region surrounding the reservoir (cian); an irregular ridge, suggesting a not uniform elevation and morphology, looking as the brighter area in the image (green)**. From Moriconi et al. 2009**.

Similarities between a glacial basin's typology (Miage, Italy, Earth) (8a) and the Titan's Ontario Lacus (8b). The red circles indicate a possible similar characteristic in the basin morphology.

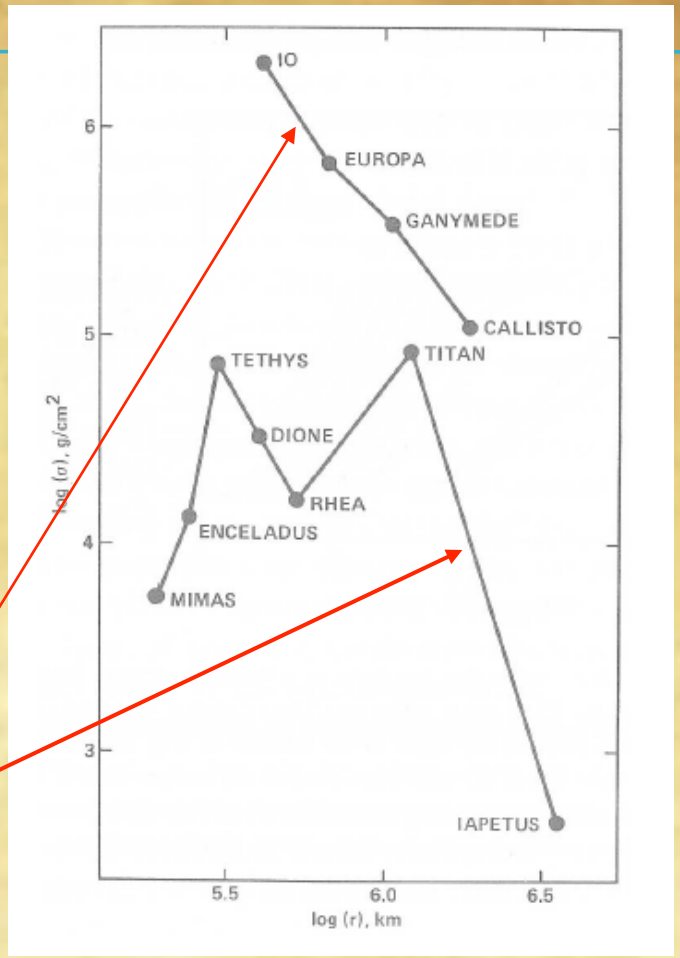
WHAT SATELLITES TELL?

- Ice becomes *a new important component* of the satellites in Jupiter system and is dominating the Saturn System
- There may have been *initial variations in composition* and structure due to radial gradients in the protosolar nebula → "snow-line"
- *New heating mechanism* are dominating these satellites → *High volatility* materials can reduce the ice melting point → Enceladus
- However the quantity and quality of radiogenic element shall be carefully assumed
- *Organic chemistry* have surely played an important role

How this information can be used in a general scheme of formation?

WORKING HYPOTHESIS: CO-FORMATION

- We consider a scenario in which the regular satellites form within circumplanetary accretion disks produced during the final stages of gas accretion (e.g.,Coradini et al1981, Magni and Coradini, 2003, Lubow et al. 1999; D'Angelo et al. 2002).
- For a given inflow rate M of gas and solids, a quasi steady-state circumplanetary gas disk is produced through a balance of the inflow supply and the disk's internal viscous evolution, assuming that the disk viscous spreading time is short compared to the timescale over which the inflow changes.



Minimum mass subnebulae for the Jupiter and Saturn satellite systems (from Pollack & Consolmagno 1984).

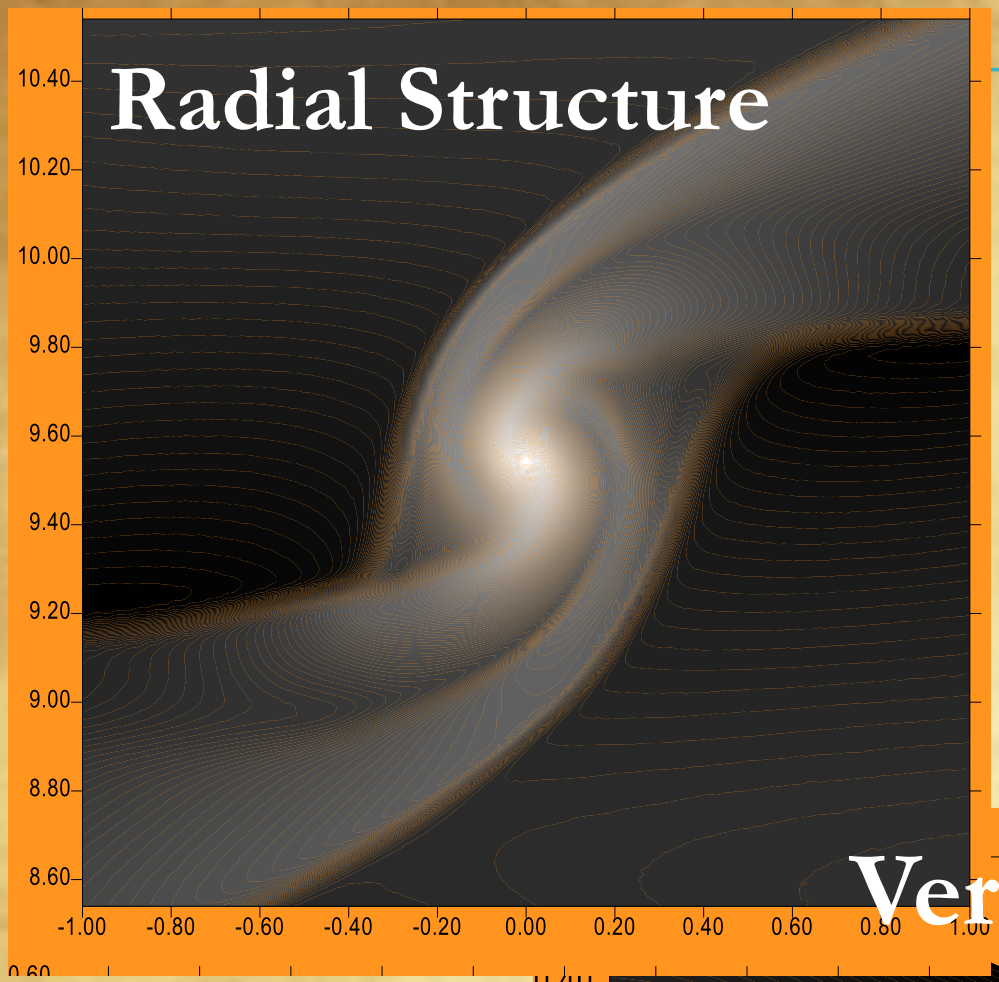
TIMESCALES: A POSSIBLE SCENARIO

- Core formation: 10^6 – 10^7 years by planetesimals collisional evolution → compatible with the new gravity measurements
- Gas accretion: 10^3 – 10^4 years by gradual input of gas inside the enlarging Hill lobe
- Feedback mechanism: the accretion heats the atmospheric envelope, the enhancement of the pressure gradient slows the accretion, that should be driven by the radiative KH cooling time,

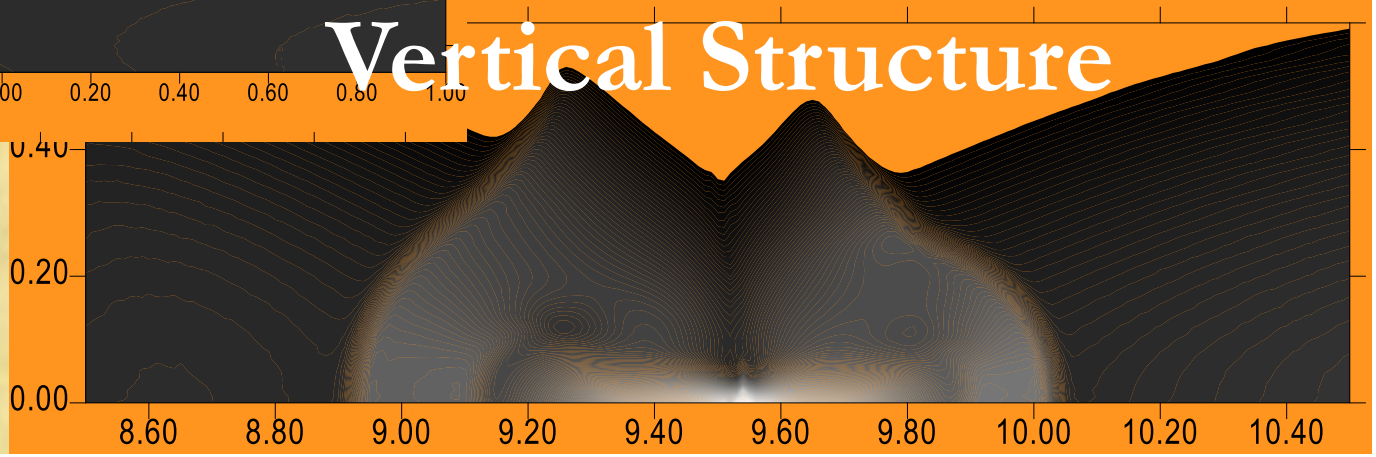
BUT

- Turbulent dissipation inside the accretion disk (dissip. timescales of tens of years) around the growing planet significantly fastens the gas infall process
- During the accretion, and after then le final mass has been reached, the atmospheric envelope nearly fills the Hill lobe (0.1 - 0.3 AU for Jupiter) for 10^3 – 10^5 years (large cross section for late planetesimals capture)

THE SATURN DISK



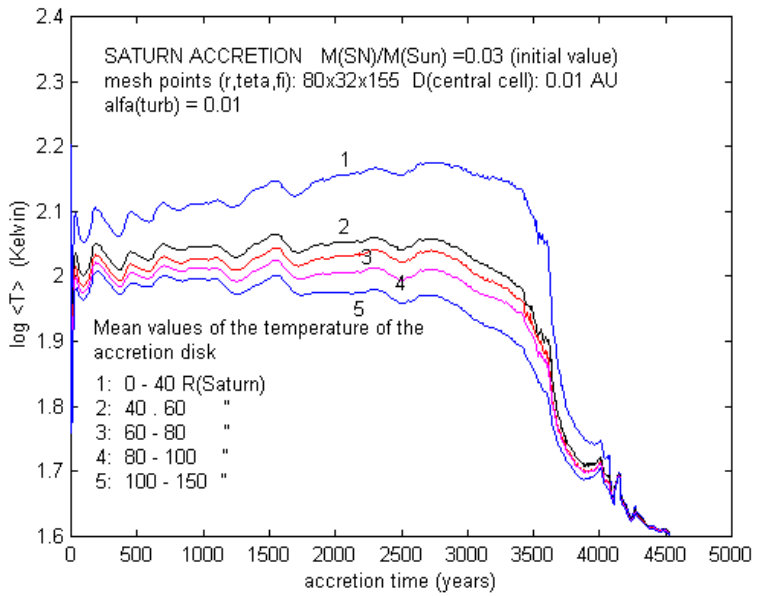
In this calculation, the accretion timescales for Jupiter and Saturn results between a few 10^3 and about 10^5 years, depending on the value of the alpha parameter



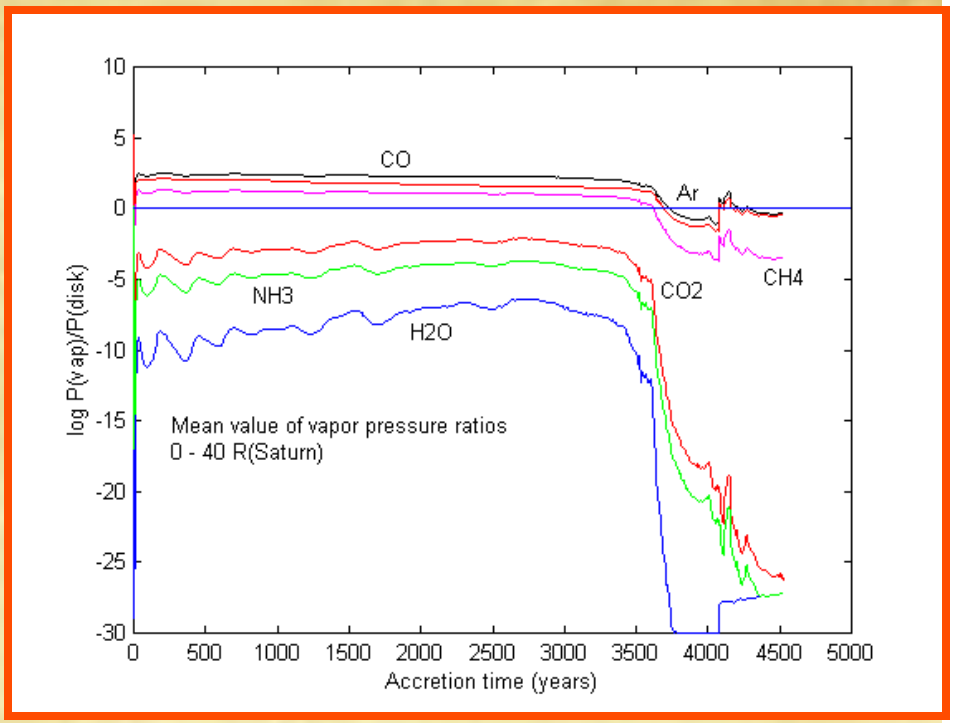
THE DISK CHARACTERISTICS

- The final phases of accretion are slow, and the gas is accreted gradually generating a disk
- The structure of the disk is very complex:
  - external region are strongly perturbed by the interactions with the gas of the protosolar nebula
  - Internal regions are more dominated by the interaction with the protoplanet
- The disk is mostly cold, only the internal regions have temperature allowing the sublimation of different ices, thus allowing a complex chemistry to evolve

DISK TEMPERATURE AND CHEMISTRY



Saturn → Maximum Temperature 125K



WHAT IS BEHIND THESE RESULTS ?

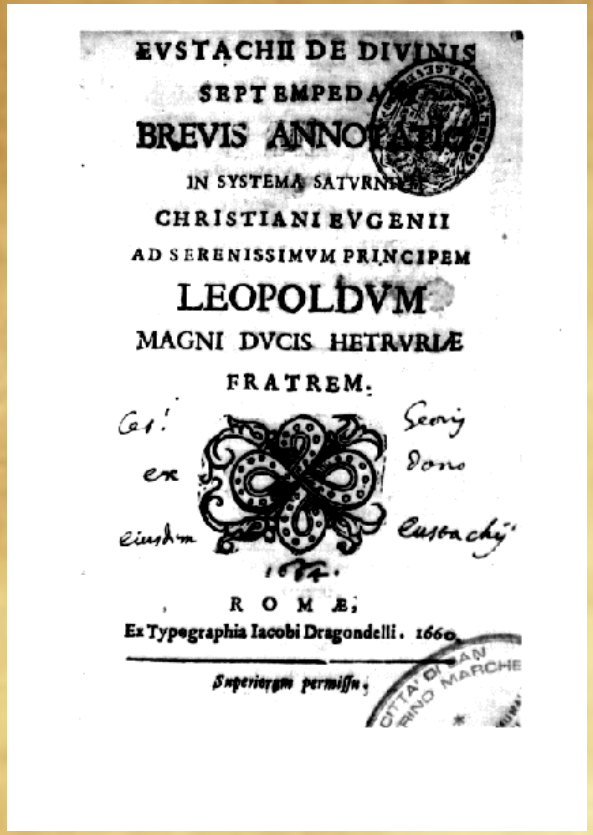
1. ISS – Imaging Subsystem *wide angle & narrow angle cameras*
2. CIRS – Composite Infrared Spectrometer *three spectrometers*
3. UVIS – Ultraviolet Imaging Spectrograph
4. VIMS – Visible and Infrared Mapping Spectrometer *visible and infrared*
5. *channels and solar port*
6. RADAR – Radar *radiometer, scatterometer, altimeter, synthetic aperture radar*
7. RSS – Radio Science Subsystem *three transmitters and DSN receivers; bistatic radar, radiometer, doppler, polarization, and transmittance*

SIDEREUS NUNCIUS

- *"Die itaque septima Ianuarii, instantis anni millesimi sexcentesimi decimi, hora sequentis noctis prima, cum cælestia sidera per Perspicillum spectarem, Iuppiter sese obviam fecit; cumque admodum excellens mihi parassem instrumentum (**quod antea ob alterius organi debilitatem minime contigerat),** tres illi adstare Stellulas, exiguas quidem, veruntamen clarissimas, cognovi; quæ, licet e numero inerrantium a me crederentur, nonnullam tamen intulerunt admirationem, eo quod secundum exactam lineam rectam atque Eclipticæ parallelam dispositæ videbantur, ac cæteris magnitudine paribus splendidiores."*

- Il giorno sette gennaio, dunque, dell'anno milleseicentodieci, a un'ora di notte, mentre col cannocchiale osservavo gli astri mi si presentò Giove; poiché mi ero preparato uno strumento eccellente, vidi (e ciò prima non mi era accaduto per la debolezza dell'altro strumento) che intorno gli stavano tre stelle piccole ma luminosissime; e quantunque le credessi del numero delle fisse, mi destarono una certa meraviglia, perché apparivano disposte esattamente secondo una linea retta e parallela all'eclittica, e più splendenti delle altre di grandezza uguale alla loro."

DIVINI E CAMPANI


EVSTACHII DE DIVINIS

SEPTEMPEDA

BREVIS ANNOTATIO

IN SYSTEMA SATVRNIVM

CHRISTIANI EVGENII

AD SERENISSIMVM PRINCIPEM

LEOPOLDVM

MAGNI DVCIS HETRVRIÆ

FRATREM.

ROMÆ,

Ex Typographia Iacobi Dragondelli. 1660.

Superiorum permissu.

CANNOCCHIALE OTTAGONALE

EVOLUTION OF THE LENS AND TELESCOPES IN ROMA


SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
vnicuique, præsertim verò
PHILOSOPHIS, atq; ASTRONOMIS, quæ à
GALILEO GALILEO
PATRITIO FLORENTINO
Patauini Gymnasij Publico Mathematico
PERSPICILLI
Nuper à se reperti beneficio sunt obseruata in IVNÆ FACIE, FIXIS IN-
NVMERIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS,
Apprime verò in
QVATVOR PLANETIS
Circa IOVIS Stellam disparibus interuallis, atque periodis, celeri-
tate mirabili circumuolutis; quos, nemini in hanc vsque
diem cognitos, nouissimè Author depræ-
hendit primus; atque
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.
VENETIIS, Apud Thomam Baglionum. M DC X.
Superiorum Permissu, & Priuilegio.

1610 Observations


IL SAGGIATORE
Nel quale
Con bilancia esquisita e giusta
si ponderano le cose contenute
nella
LIBRA ASTRONOMICA E FILOSOFICA
DI LOTARIO SARSI SIGENSANO
Scritto in forma di lettera
All'Illustre et Reuerendiss. Mons. D.
VIRGINIO CESARINI
Acc.co Linceo M.co di Camera di N.S.
Dal Sig.
GALILEO GALILEI
Acc.co Linceo Nobile Fiorentino
Filosofo e Matematico Primario
del
Ser.mo Gran Duca di Toscana.
FILOSOFIA NATVRALE
MATEMATICA
IN ROMA M D C XXIII
Appresso Giacomo Mascardi

1623
Testing and verifying

Piazza Navona

Avete voi forse dubbio che, quando Aristotele vedesse le novità scoperte in cielo, e' non fusse per mutar opinione e per emendar I suoi libri , e per accostarsi a più sensate dottine discaccaindo da se quei poveretti di cervello che troppo pusillanimemente s'inducono a voler sostenere ogni suo detto (Saggiatore, VII, 133)

Back up slides

The on Titan