Giornata in memoria di Angioletta Coradini

Sole e Sistema Solare: Progetti Spaziali Italiani

30 Ottobre 2012

Le missioni Cassini e Rosetta

Fabrizio Capaccioni

Istituto di Astrofisica e Planetologia Spaziali

Giornata in memoria di Angioletta Coradini

Sole e Sistema Solare: Progetti Spaziali Italiani

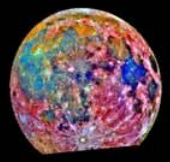
30 Ottobre 2012

TEN YEARS IN SPACE

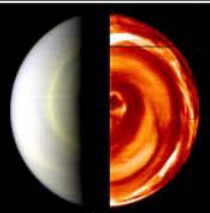
Planetary Missions and Instruments: 1997–2007


Saturn, Titan, Icy Moons and Rings


Mars


The Moon


Comet 67P/Churyumov-Gerasimenko


Venus


1 Ceres – 4 Vesta


15 october 1997


2 june 2003


27 september 2003

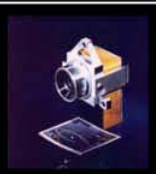

2 march 2004


9 november 2005


27 september 2007

-VIMS-V
-CASSINI-RADAR


-OMEGA
-PFS
-MARSIS

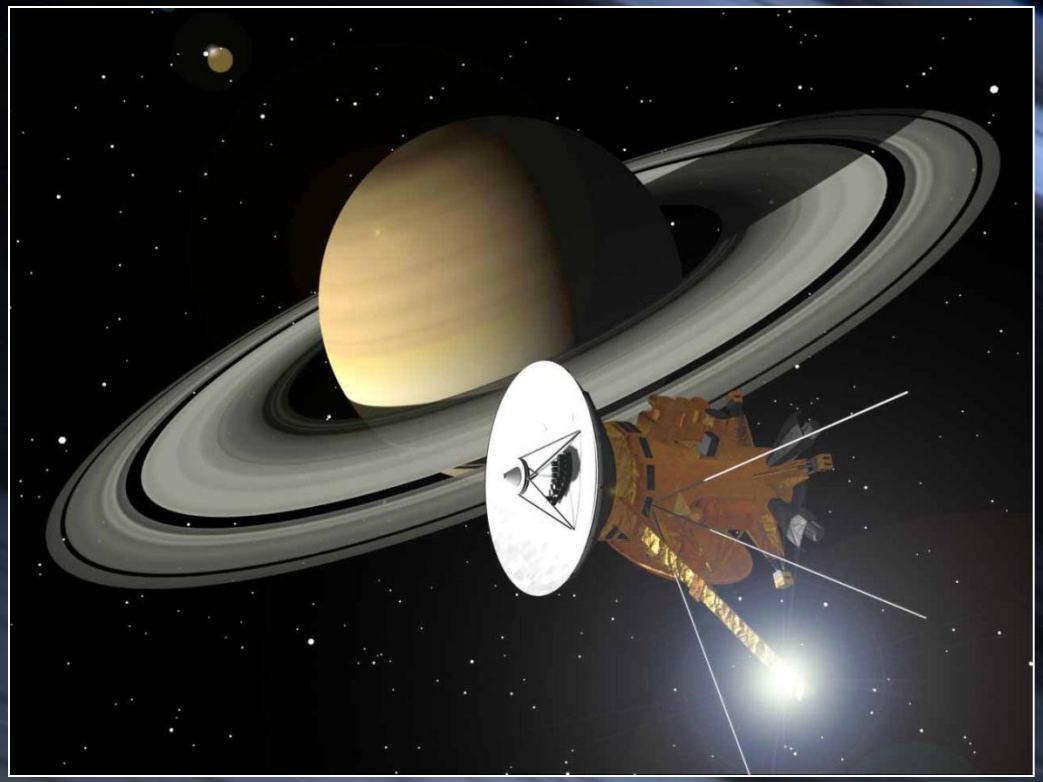

AMIE
Asteroid-Moon Micro-Imager Experiment

VIRTIS
Visible InfraRed Thermal Imaging Spectrometer

VIRTIS
Visible InfraRed Thermal Imaging Spectrometer


VIR-MS
Visible InfraRed Mapping Spectrometer

The CASSINI mission:
Scientific results after eight years around Saturn



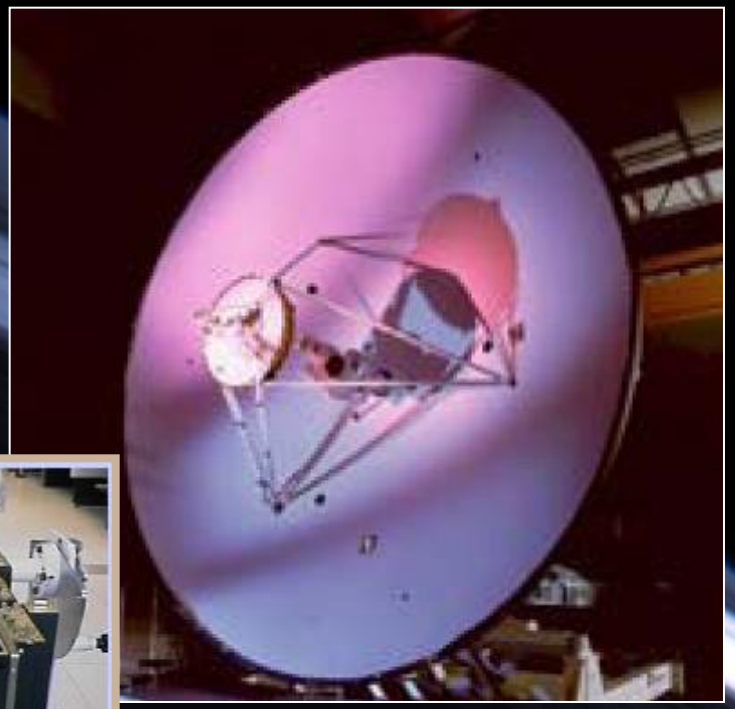
- La missione Cassini-Huygens, risultato della collaborazione tra NASA, ASI ed ESA è forse la più complessa ed ambiziosa missione mai tentata nel corso dell'esplorazione dei pianeti del Sistema Solare.

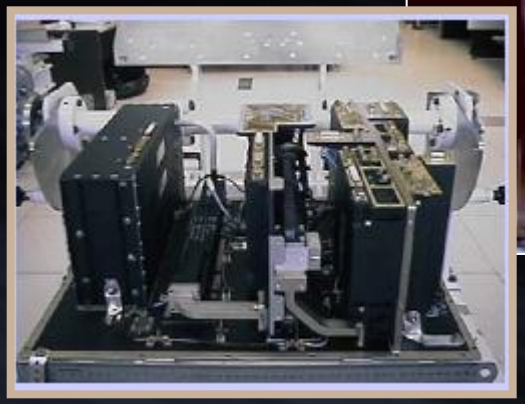
- I 12 strumenti del P/L coprono tutto lo spettro dall'UV alle microonde e gli esperimenti in-situ permettono di ottenere campioni di polveri, particelle energetiche e di misurare il campo magnetico locale.

- Lanciata nel 1996 è stata immessa nell'orbita di Saturno il 1 Luglio 2004

Italian Contribution to the orbiter

- S/C Sub Systems:
  - High Gain Antenna (4m carbon fiber reflector; 4 bands S,X,Ku,Ka)
  - Majority of the Radio System (RFES and RFIS)
  - Star Trackers





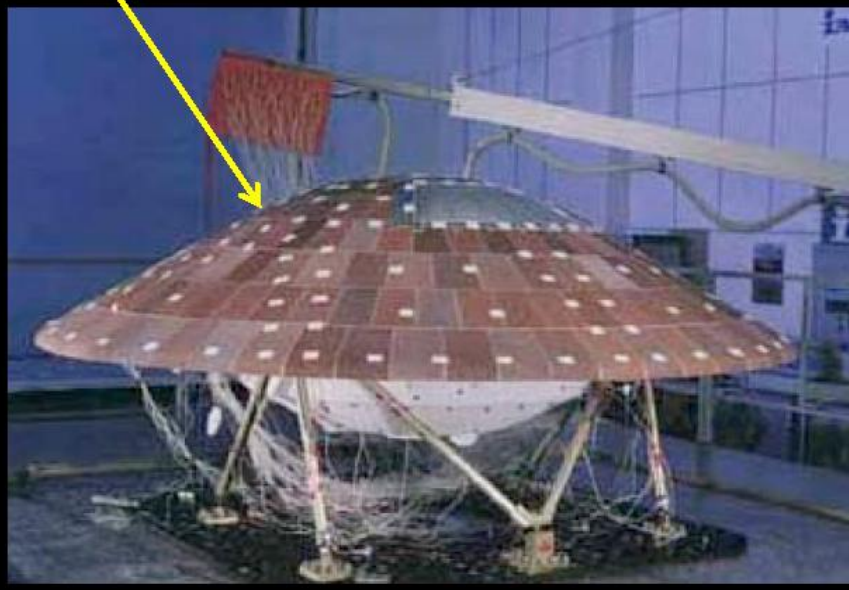
Scientific Payload

Visible and Infrared Mapping Spectrometer (VIMS)

Science Contribution

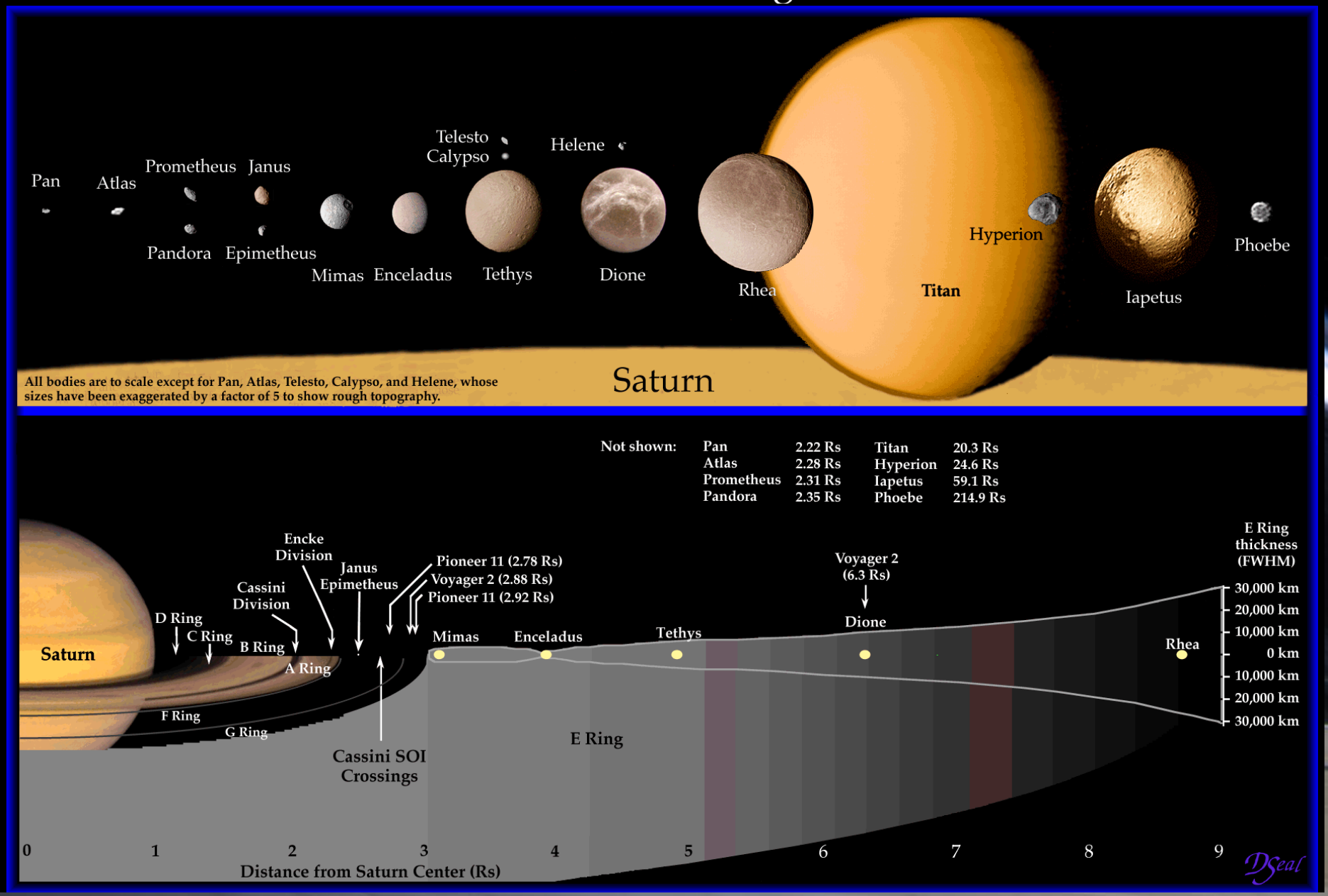
- Radio Science Experiment
- Radar Experiment
- Visible and Infrared Mapping Spectrometer (VIMS)
- 2 Participating Scientists from 2011

Cassini Orbiter & Huygens Probe



HASI
Huygens Atmospheric
Structure Instruments
led by Marcello Fulchignoni

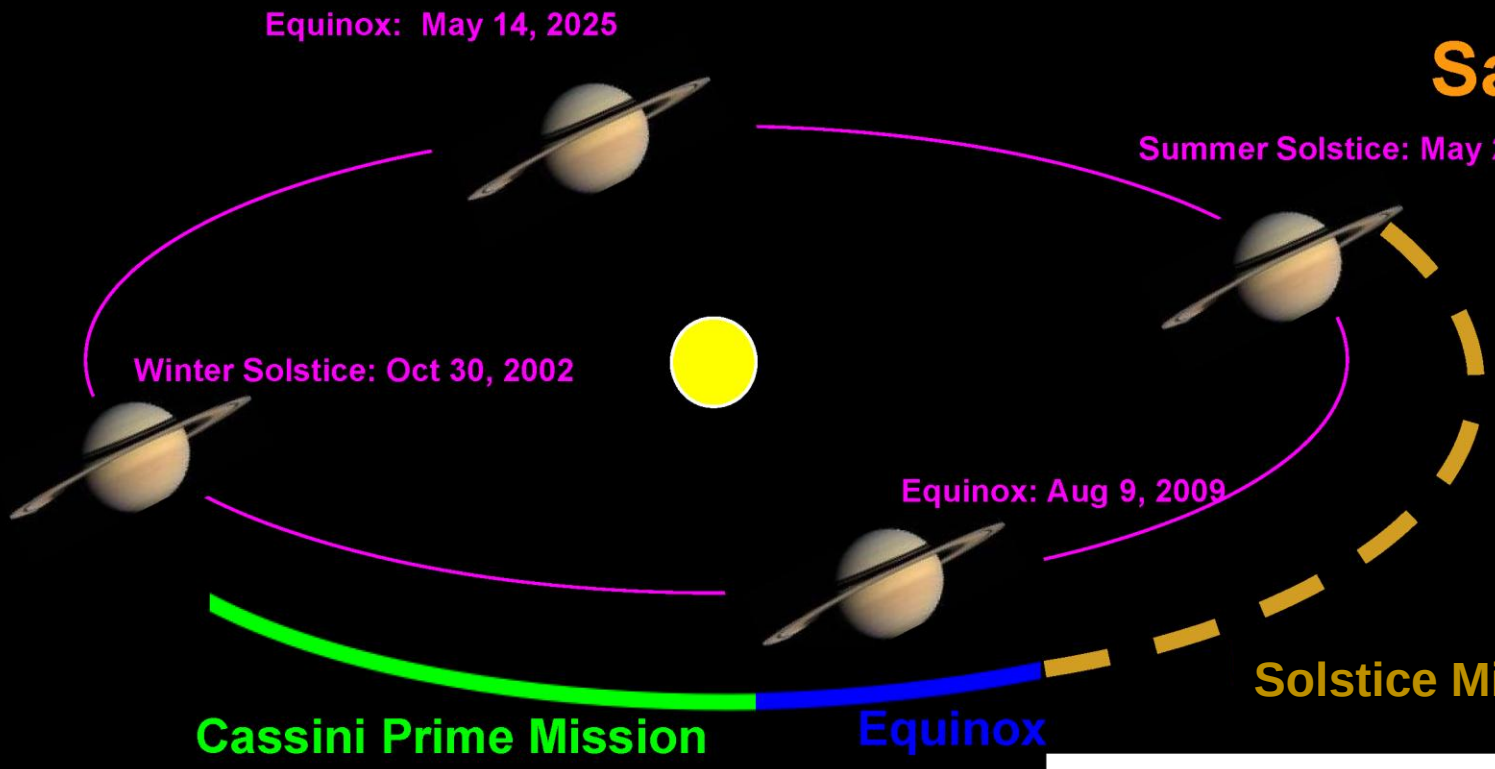
Saturn's rings and satellites system

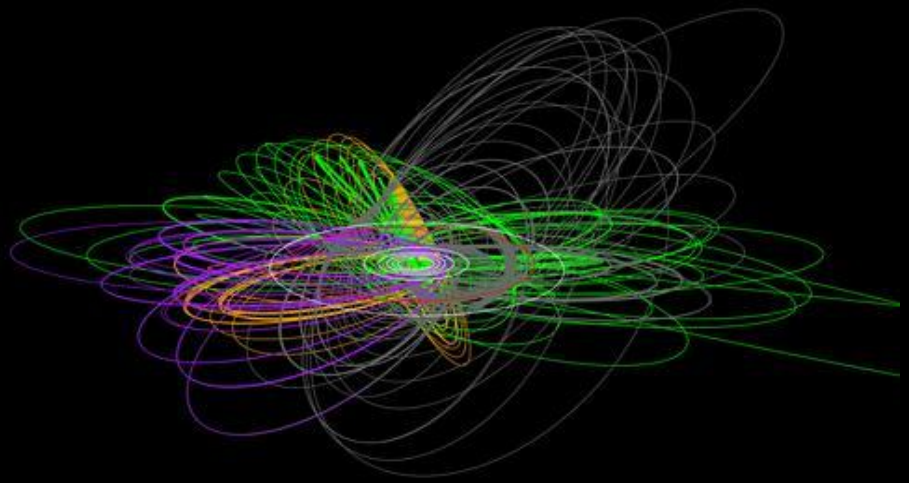


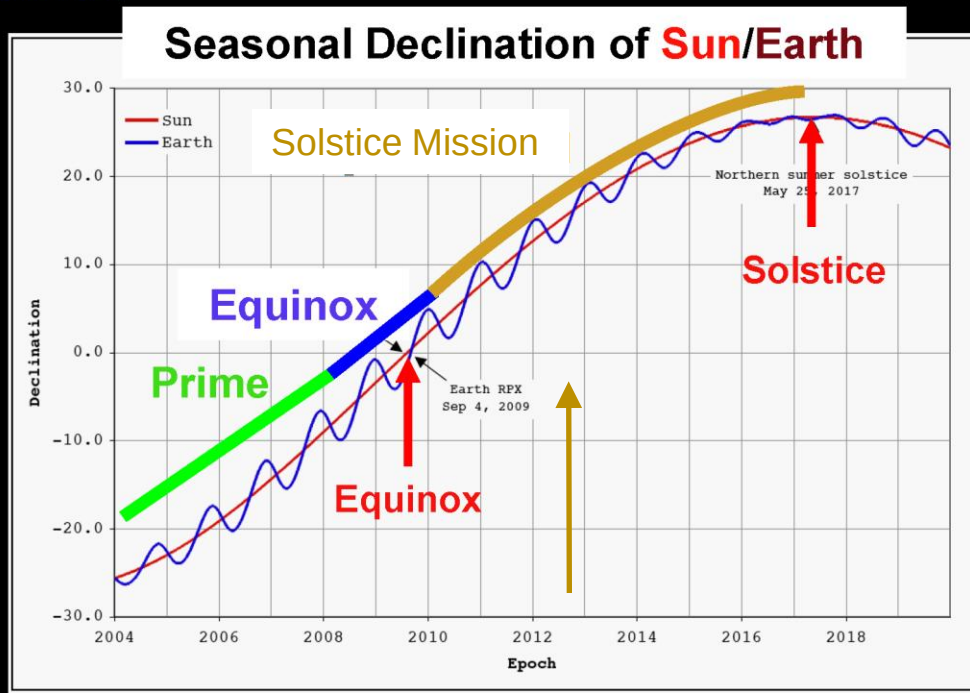
Why study the Saturn System?

- A giant planet surrounded by a complex system of moons, ring and particles
- Understanding Saturn system formation will help understanding the formation of the Solar System
- A laboratory where phenomena that were present at the beginning of the Solar System are still acting (planet differentiation, accumulation and destructions in the rings, tidal interactions, collisional processes,…)
- A satellite (Titan) surrounded by a primordial atmosphere
- Captured objects possibly telling an history of far regions…

Saturn Year


Equinox: May 14, 2025
Summer Solstice: May 23, 2017
Winter Solstice: Oct 30, 2002
Equinox: Aug 9, 2009
Solstice Mission
Cassini Prime Mission
Equinox




Seasonal Declination of Sun/Earth
Sun
Earth
Solstice Mission
Northern summer solstice
May 23, 2017
Solstice
Equinox
Prime
Earth RPX
Sep 4, 2009
Equinox
Declination
Epoch
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
2004
2006
2008
2010
2012
2014
2016
2018

Cassini Mission Overview

Four-Year Prime Tour, Equinox Mission, and Solstice Mission (Proposed), May 2004 - September 2017

	Prime Mission				Equinox Mission		Solstice Mission						
Year of Tour	1	2	3	4	5	6	7	8	9	10	11	12	13
	'04-'05	'05-'06	'06-'07	'07-'08	'08-'09	'09-'10	'10-'11	'11-'12	'12-'13	'13-'14	'14-'15	'15-'16	'16-'17
Orbits	11	15	22	27	39	21	16	19	25	12	12	20	56
Titan													
Enceladus													
Other Icy Satellites (under 10,000 km)	Phoebe	Tethys, Hyperion, Dione, Telesto, Rhea		Rhea, Iapetus, Epimetheus		Mimas, Rhea, Helene, Dione, G arc	Rhea, Helene	Dione, Dione, Tethys, Methone, Telesto	Rhea		Dione, Tethys	Dione, Epimetheus, G arc	

*Huygens

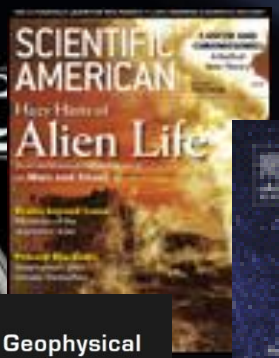
Proximal Orbits

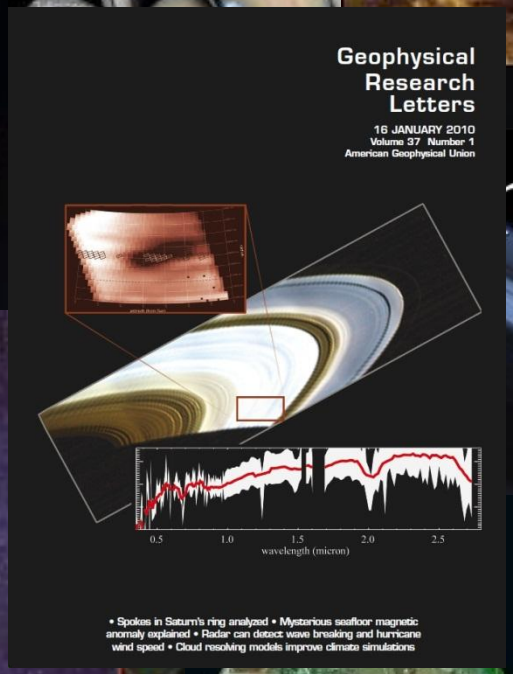
EOM Sep 15, 2017

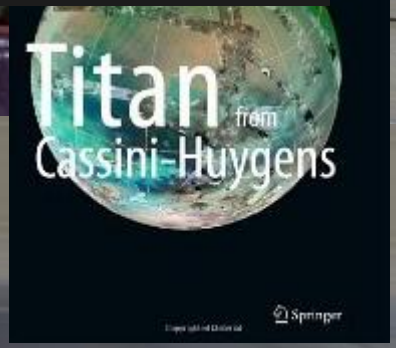
Saturn (seen from Sun)

29 June 2010

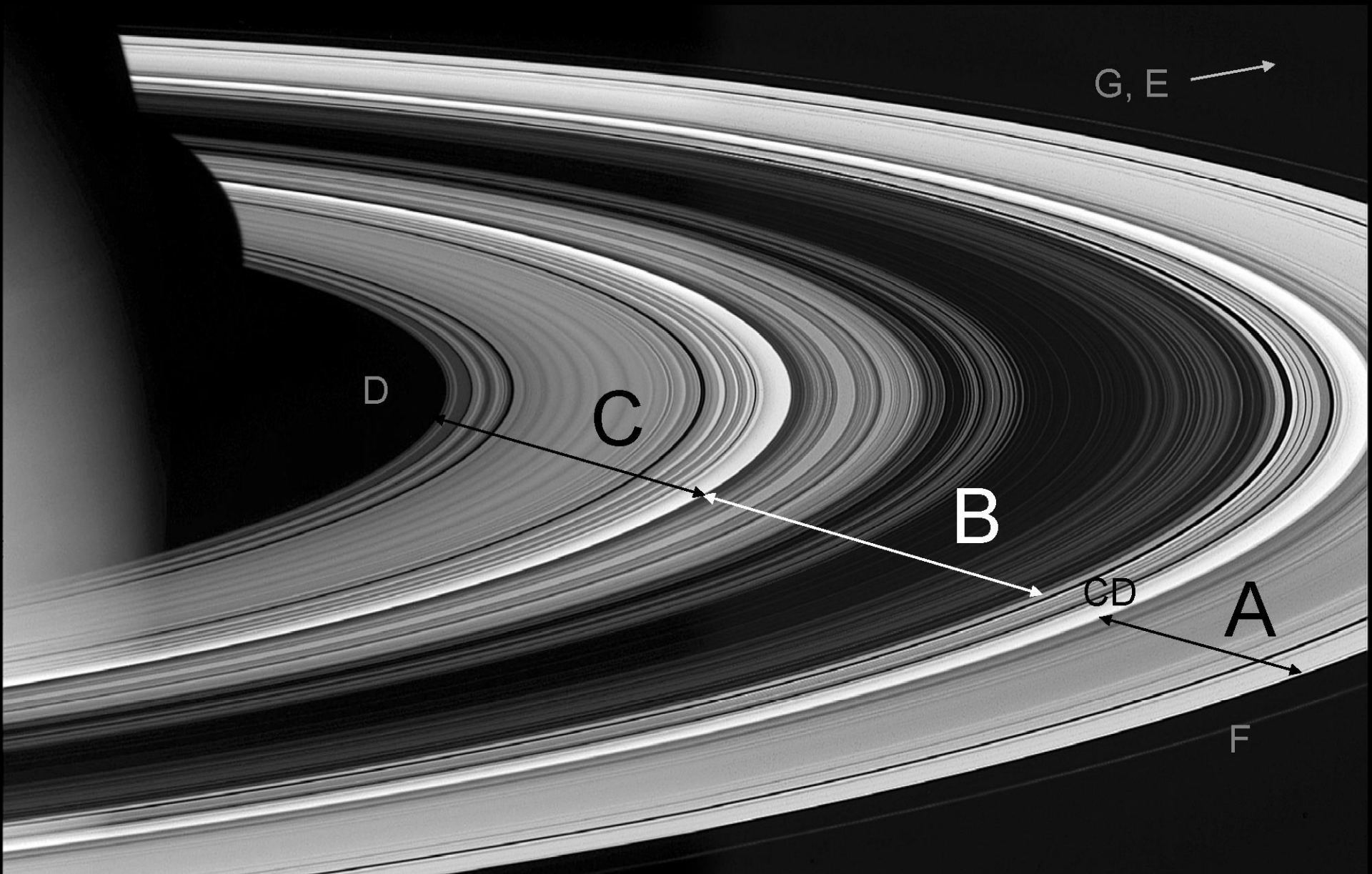
Overwhelming Scientific Production.....



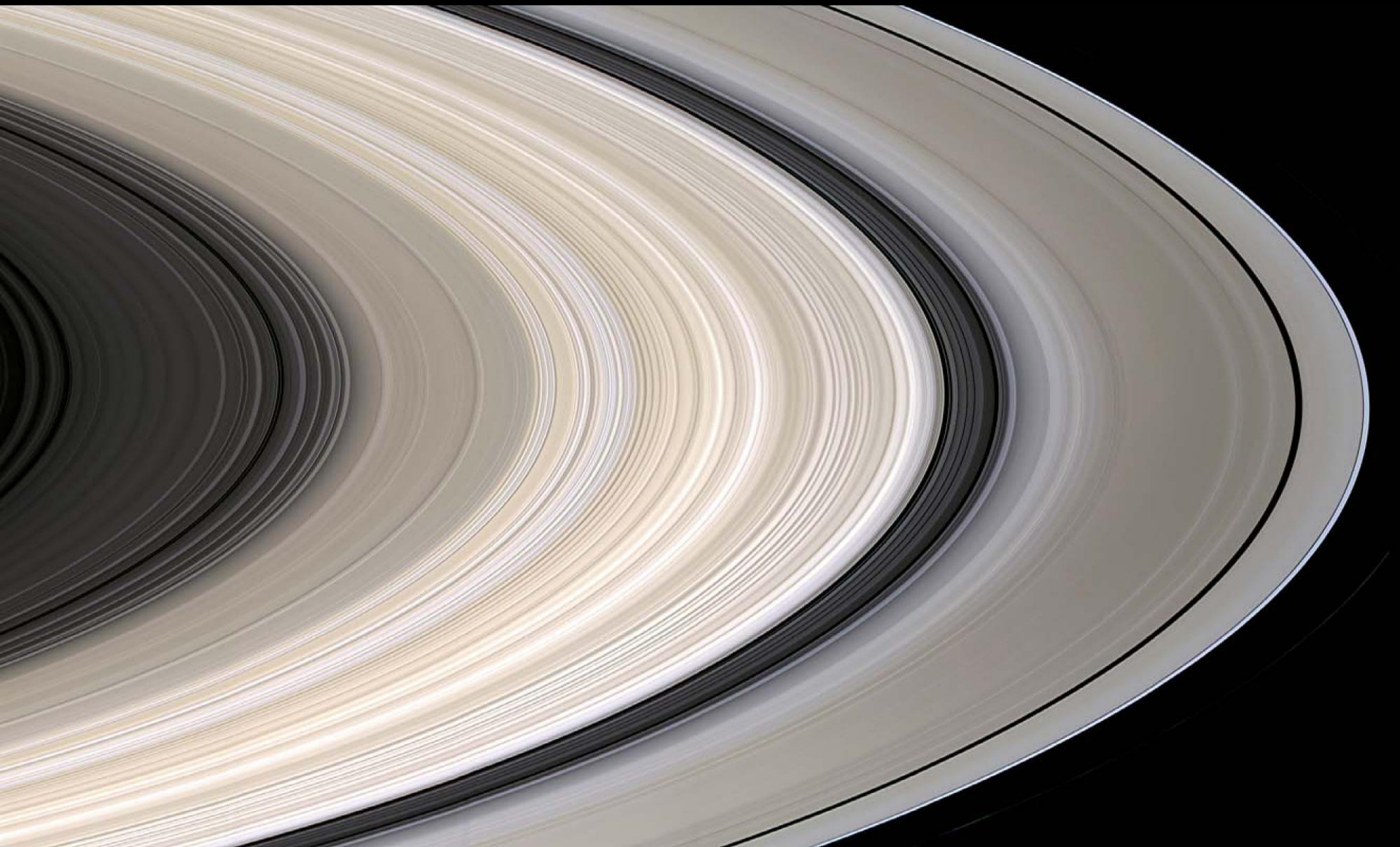


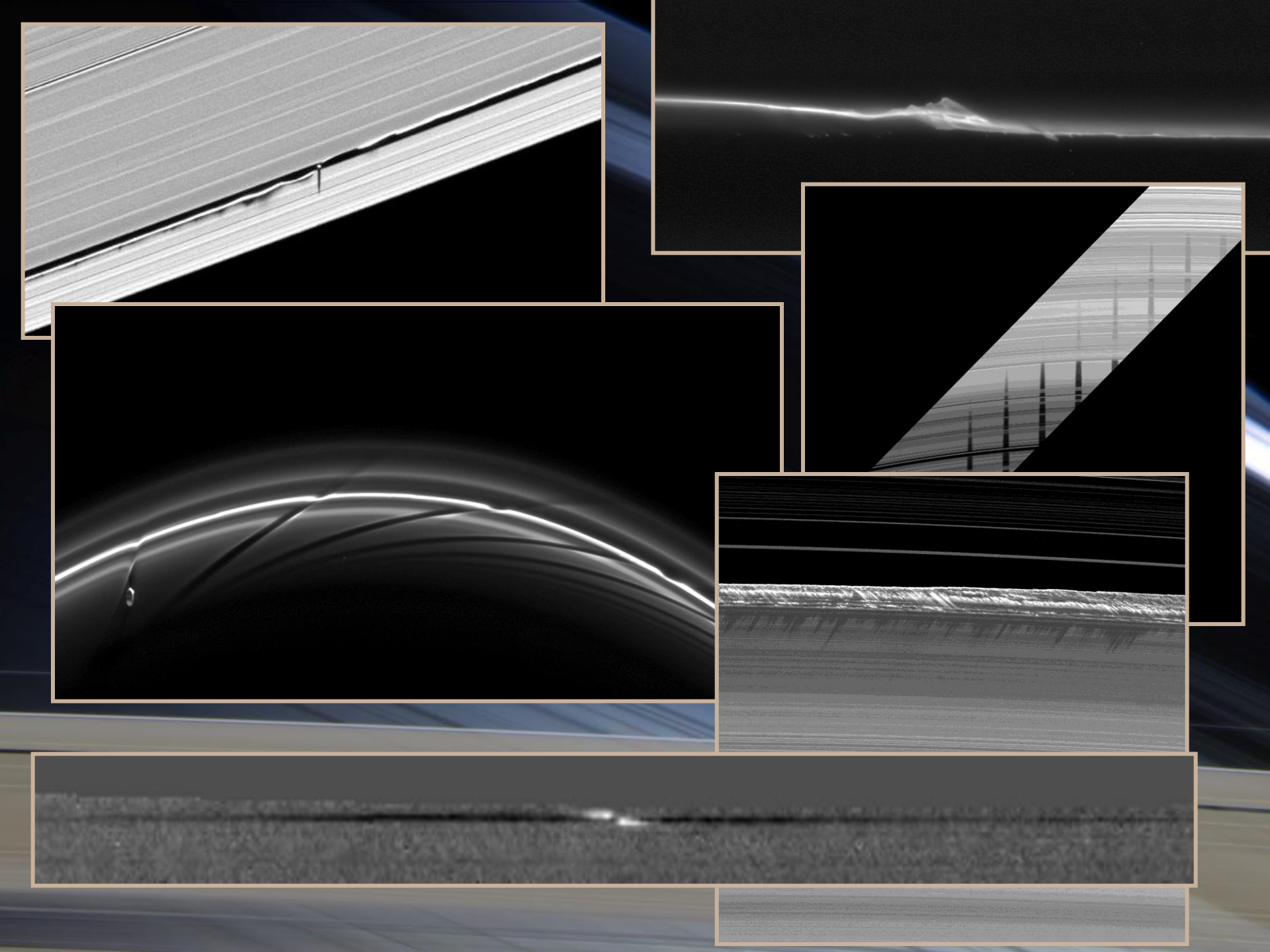


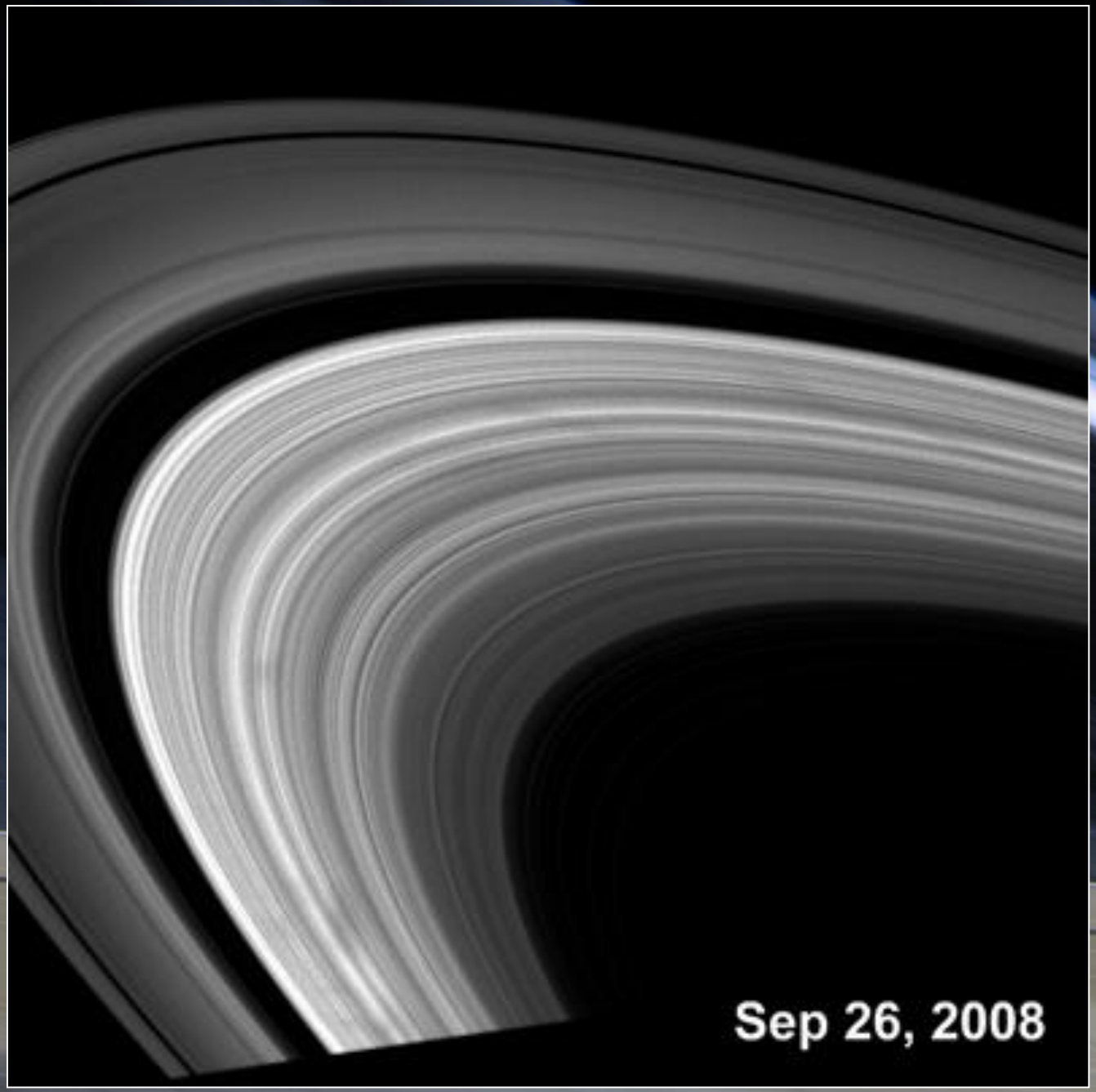
RINGS



Away from the Dark Side

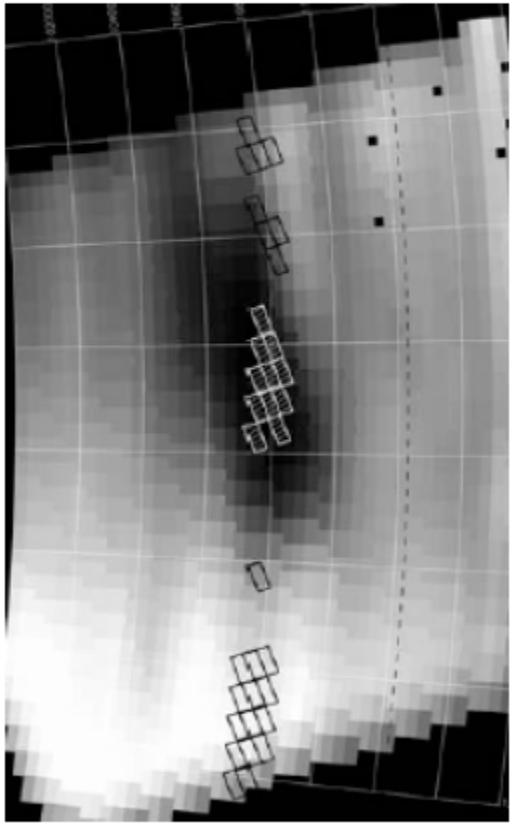


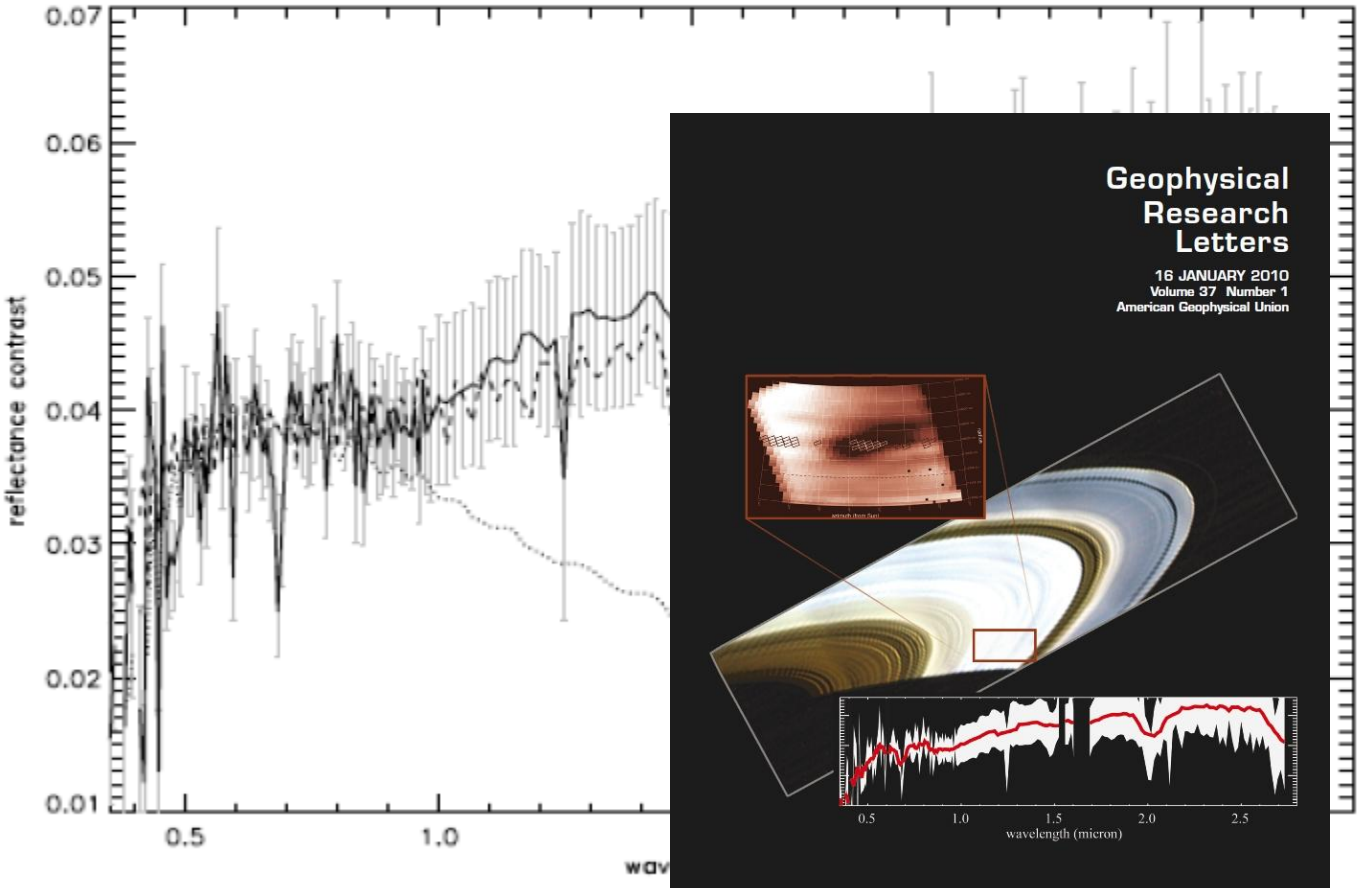



Sep 26, 2008

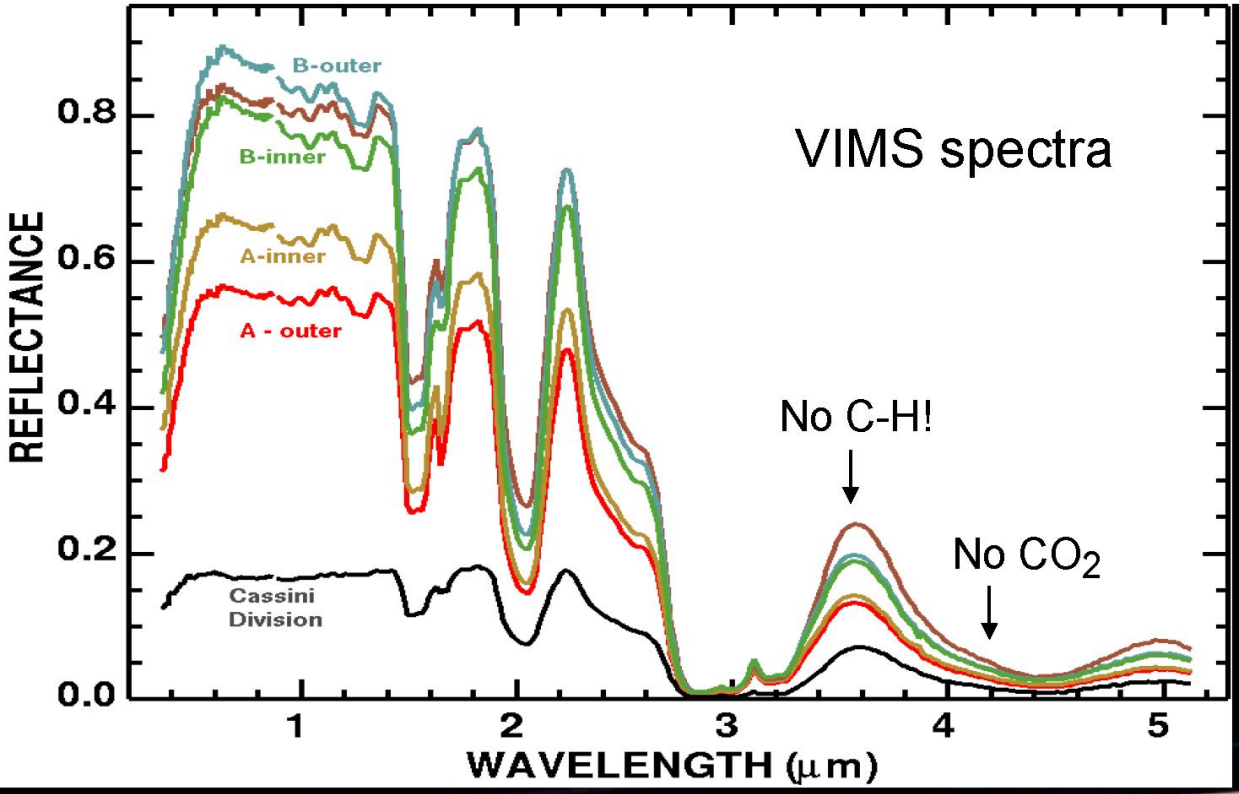
The “color” of spokes, and the spoke particle size distribution (VIMS)

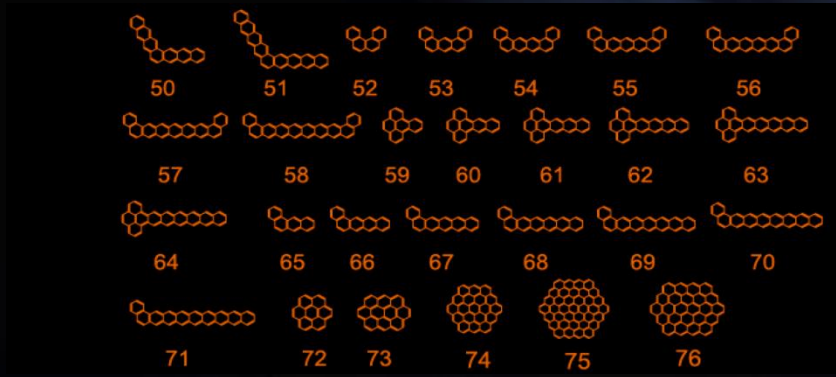
D’Aversa et al (2010) used VIMS multispectral data to measure the contrast of a spoke (left) from surrounding regions. This spectrum (right) shows strongly increasing contrast from 0.35 - 0.6 microns - indicative of a particle size in the micron size range - but the high contrast continues to much longer wavelengths - suggesting a broader size distribution than previously believed.



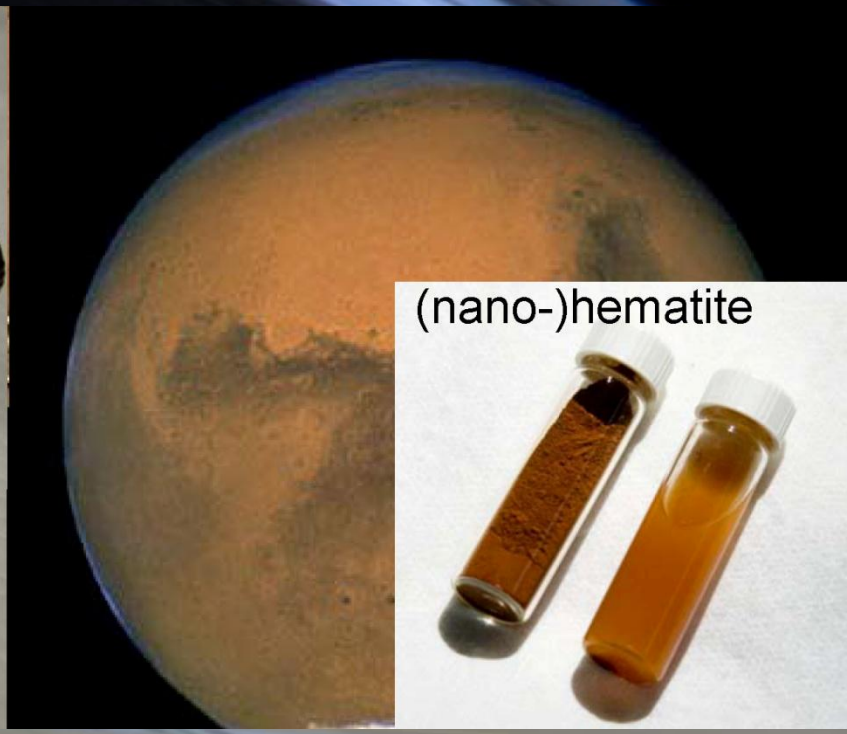


Chemical composition and size distribution of ring material

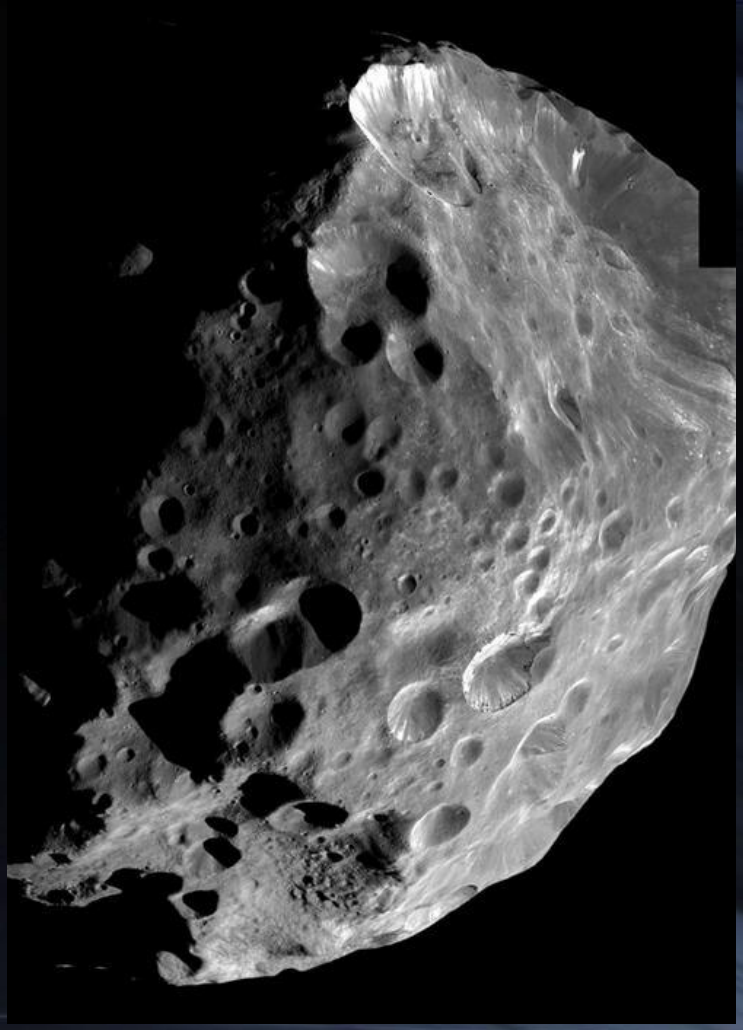




Why are the rings reddish?
"organic" or inorganic origin?
Lack of spectral features
Suggests nano-inclusions



Cuzzi et al., 2012



Phoebe

Phoebe is the farthest Saturn satellite orbiting at a distance of 13 million km (215 Rs);

is on a 550 days retrograde orbit and has a radius of about 110km

Orbit inclination is 27°

Its albedo is below 6% and its spectrum is considerably different from the other Saturn satellites.

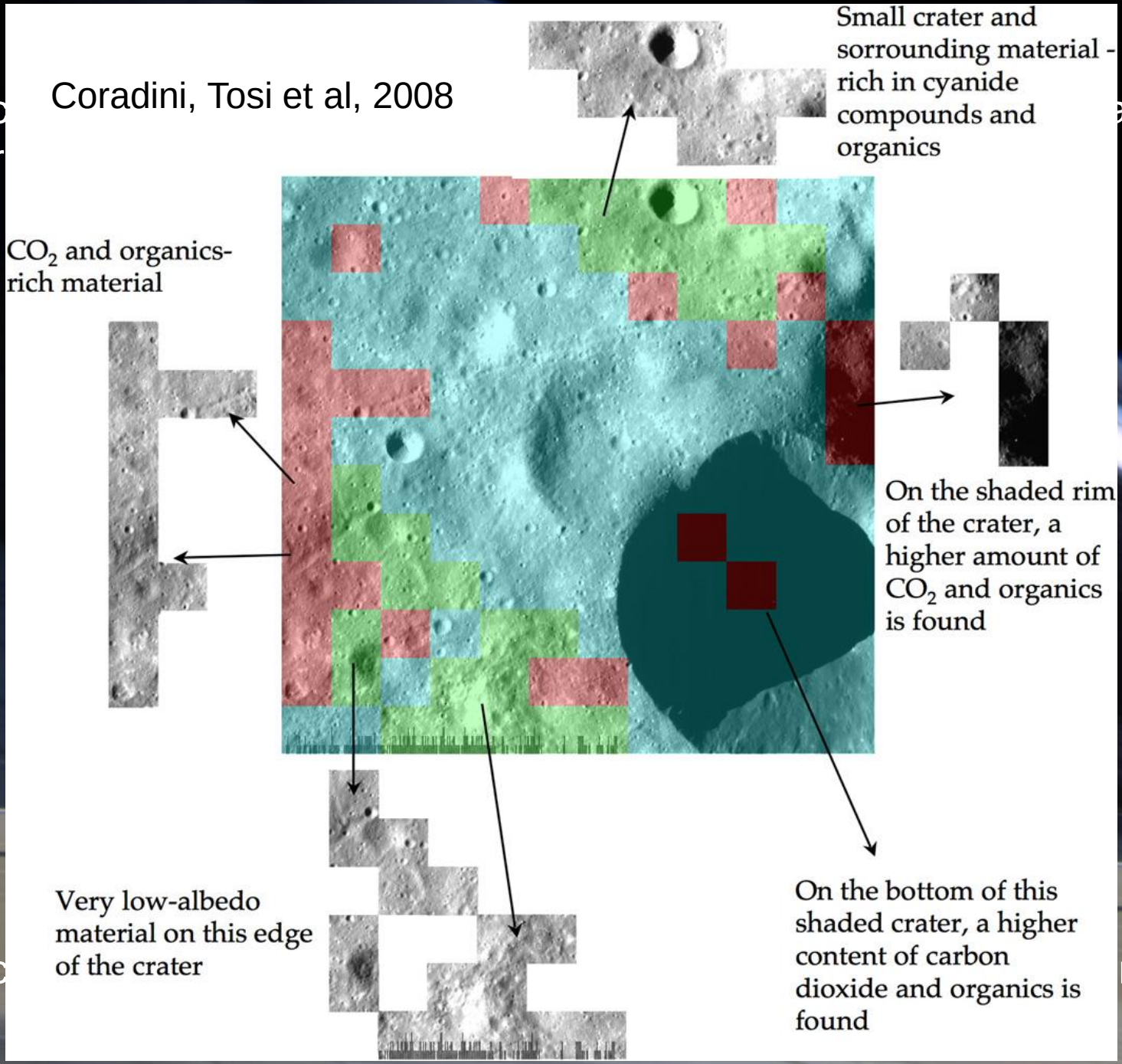
Most closely resembles that of C-type asteroids and small outer SS bodies such as Chiron and Pholus thought to have originated in the Kuiper Belt.

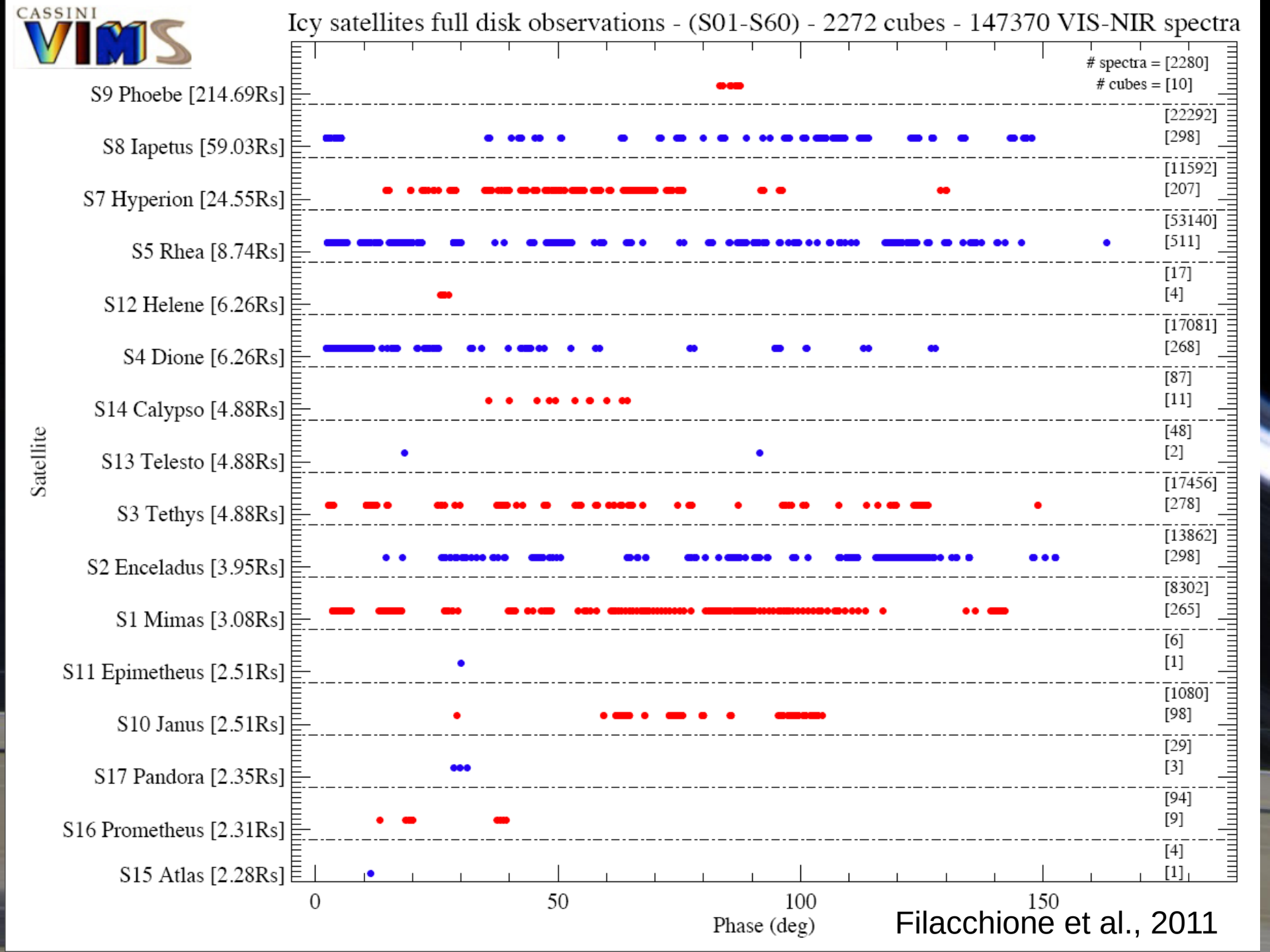
Every clue points to a captured origin of a body that could represent a sample of a very primitive class of objects, possibly originated in the Kuiper Belt

VIMS spec ace.
The spectr

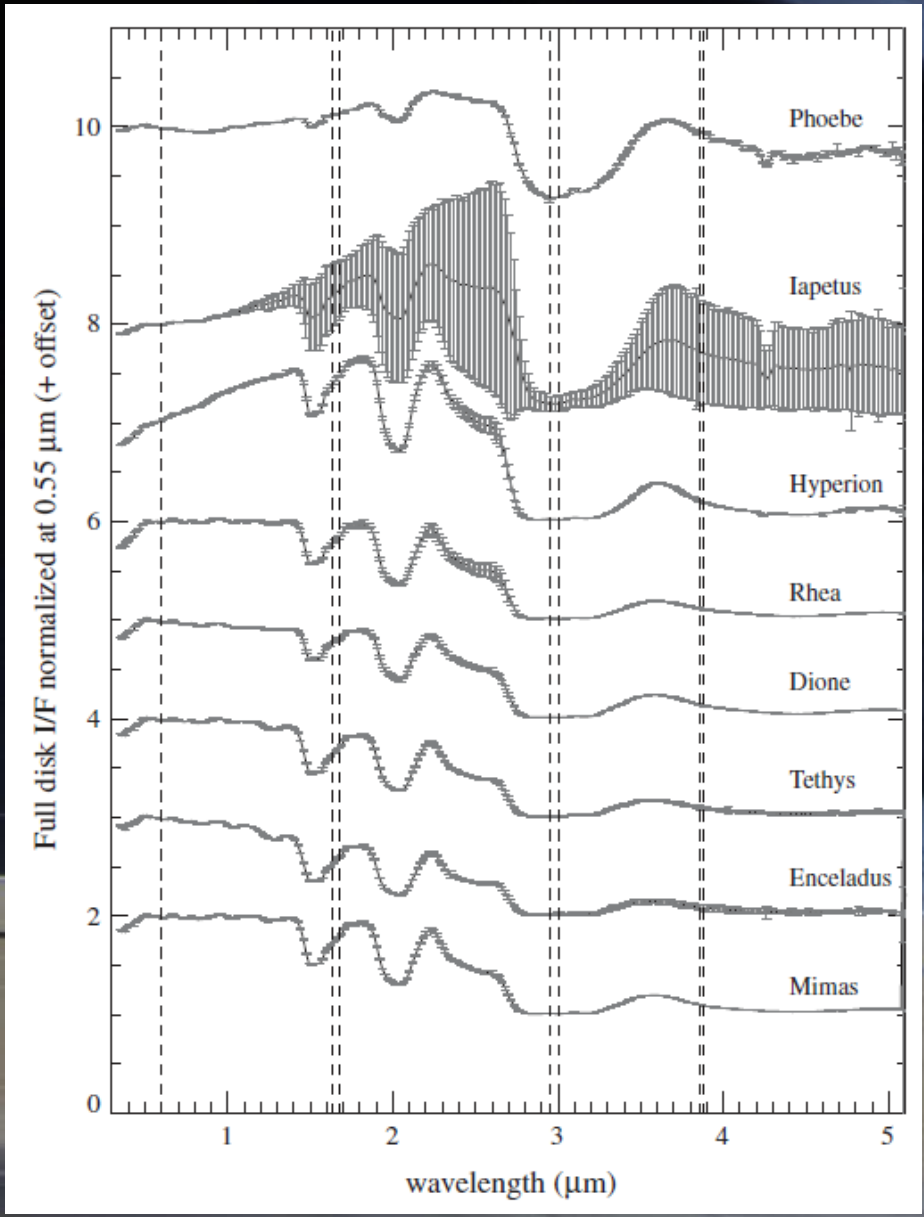
VIMS spec ng
method to

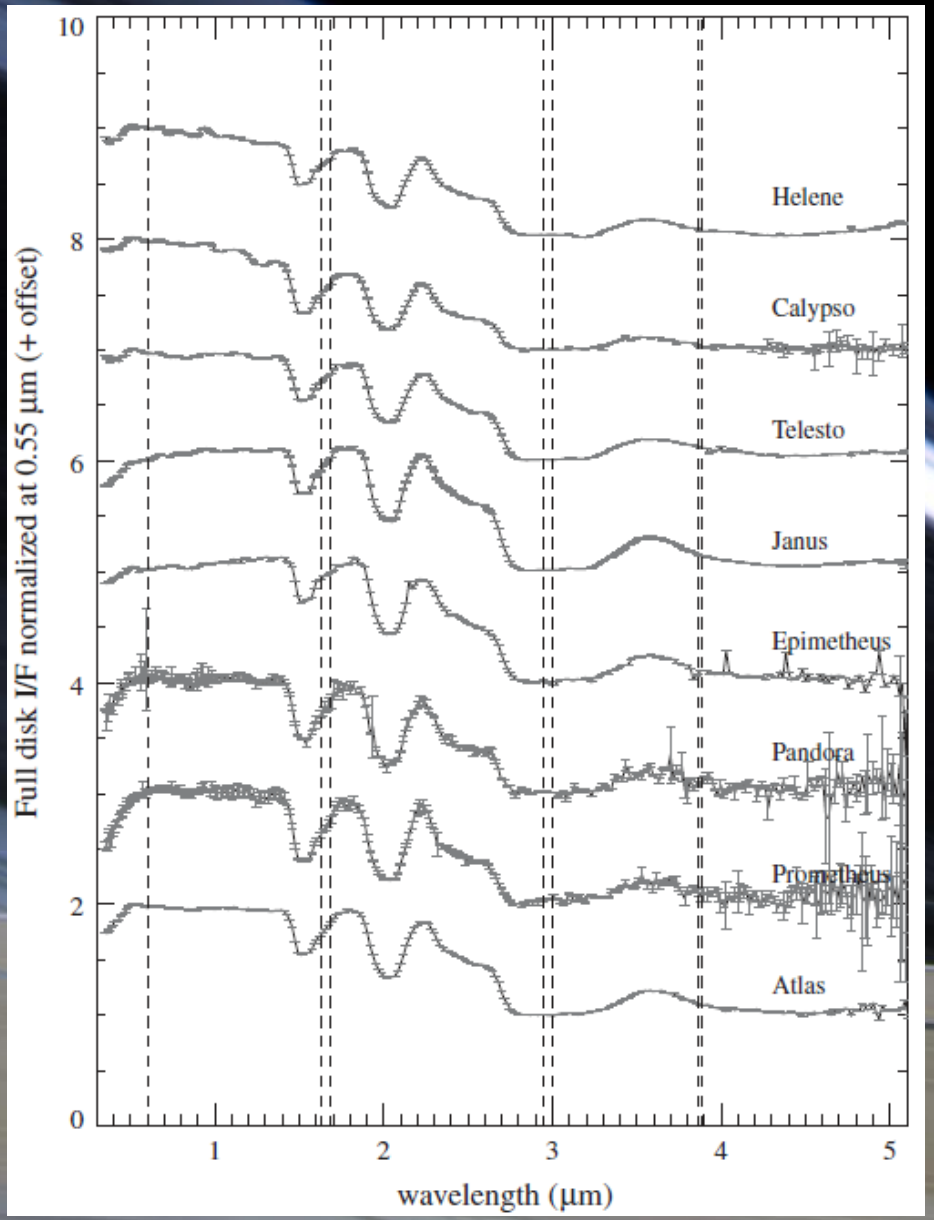
Coradini, Tosi et al, 2008



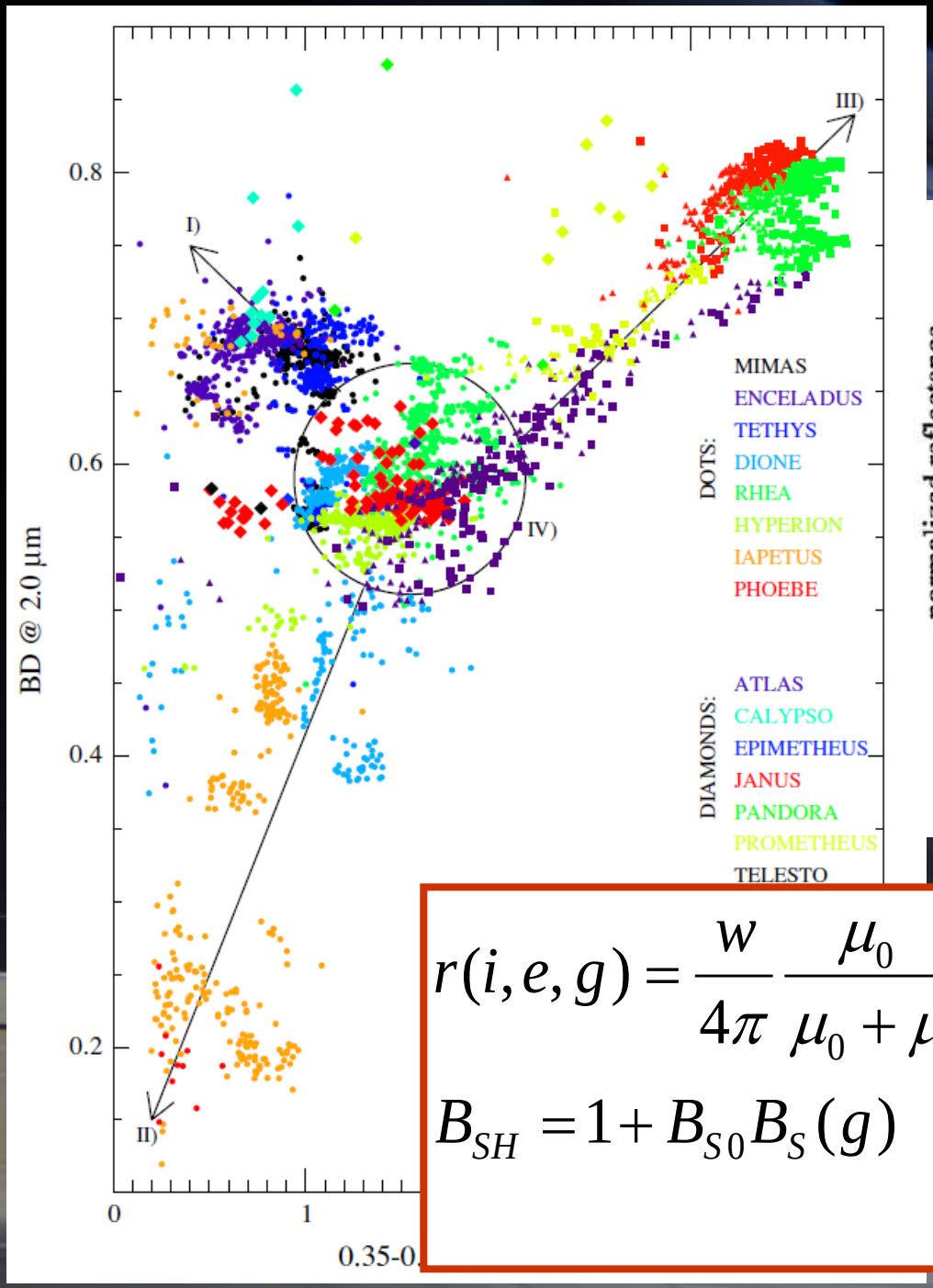

CASSINI VIMS
Icy satellites full disk observations - (S01-S60) - 2272 cubes - 147370 VIS-NIR spectra
spectra = [2280]
cubes = [10]
S9 Phoebe [214.69Rs]
S8 Iapetus [59.03Rs]
S7 Hyperion [24.55Rs]
S5 Rhea [8.74Rs]
S12 Helene [6.26Rs]
S4 Dione [6.26Rs]
S14 Calypso [4.88Rs]
S13 Telesto [4.88Rs]
S3 Tethys [4.88Rs]
S2 Enceladus [3.95Rs]
S1 Mimas [3.08Rs]
S11 Epimetheus [2.51Rs]
S10 Janus [2.51Rs]
S17 Pandora [2.35Rs]
S16 Prometheus [2.31Rs]
S15 Atlas [2.28Rs]
[22292] [298]
[11592] [207]
[53140] [511]
[17] [4]
[17081] [268]
[87] [11]
[48] [2]
[17456] [278]
[13862] [298]
[8302] [265]
[6] [1]
[1080] [98]
[29] [3]
[94] [9]
[4] [1]
Satellite
0
50
100
150
Phase (deg)
Filacchione et al., 2011

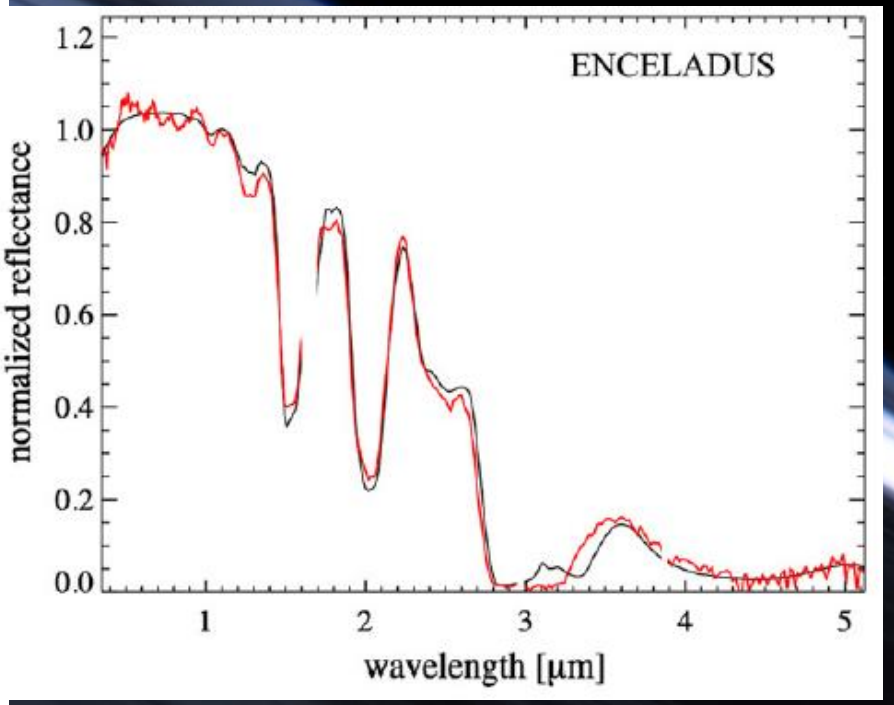
Icy Satellites Spectral Variability





Spectra interpretation and modelling



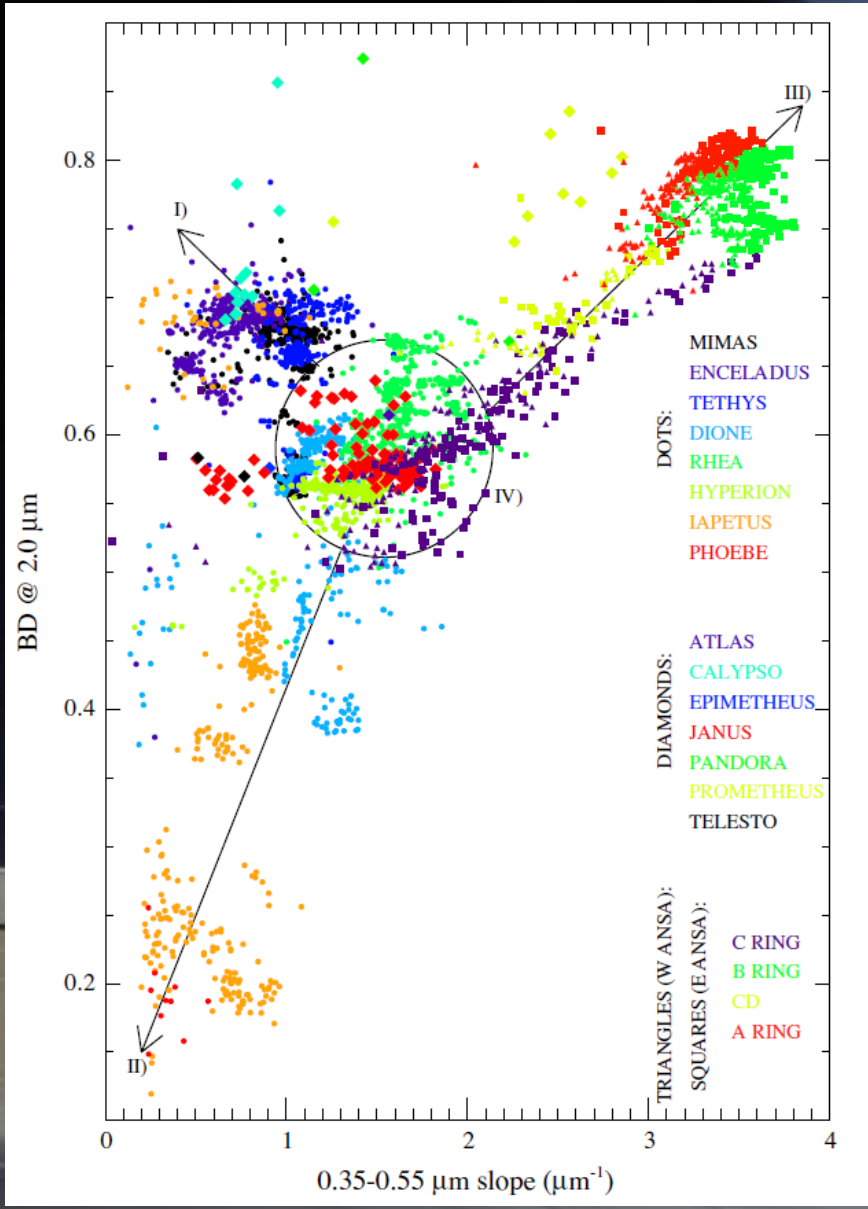


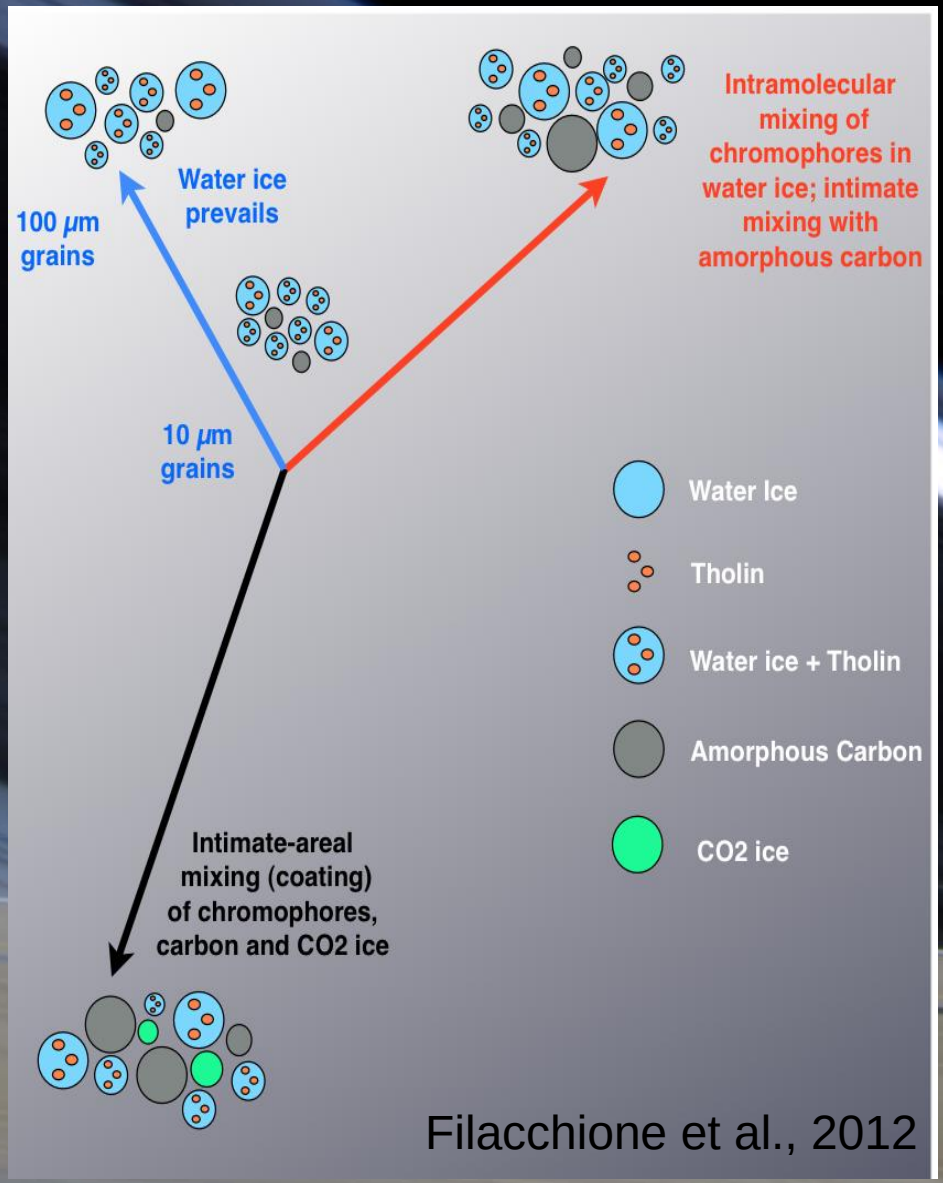
$$r(i,e,g) = \frac{w}{4\pi}\frac{\mu_0}{\mu_0+\mu}\left[p(g)B_{SH}(g) + H(\mu_0)H(\mu) - 1\right]$$

$$B_{SH} = 1 + B_{S0}B_S(g)$$

Ciarniello et al, 2011

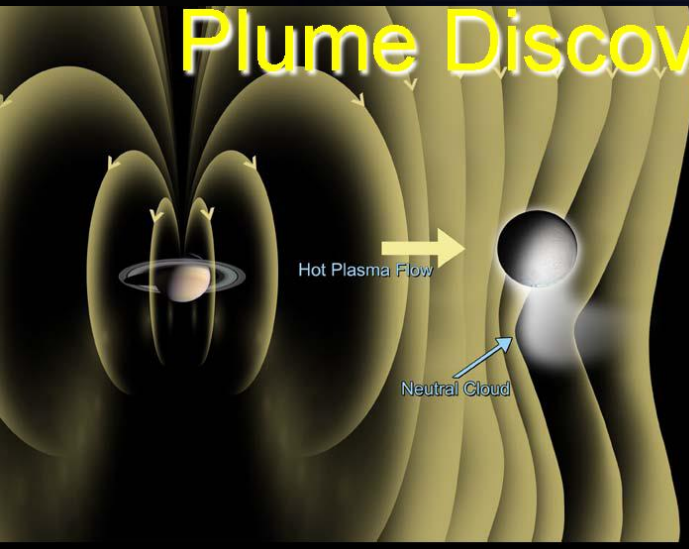
Spectra interpretation and modelling

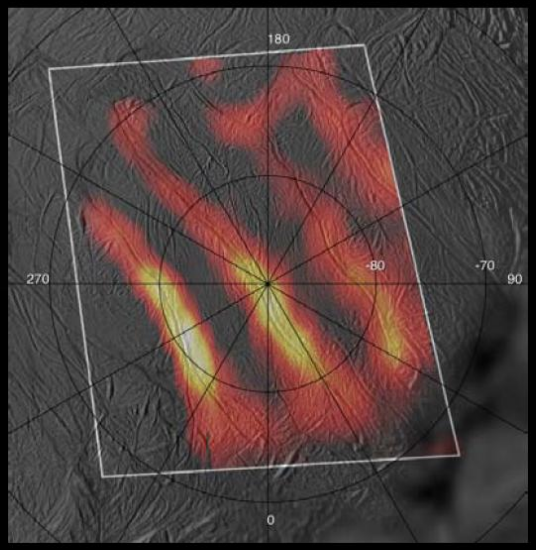


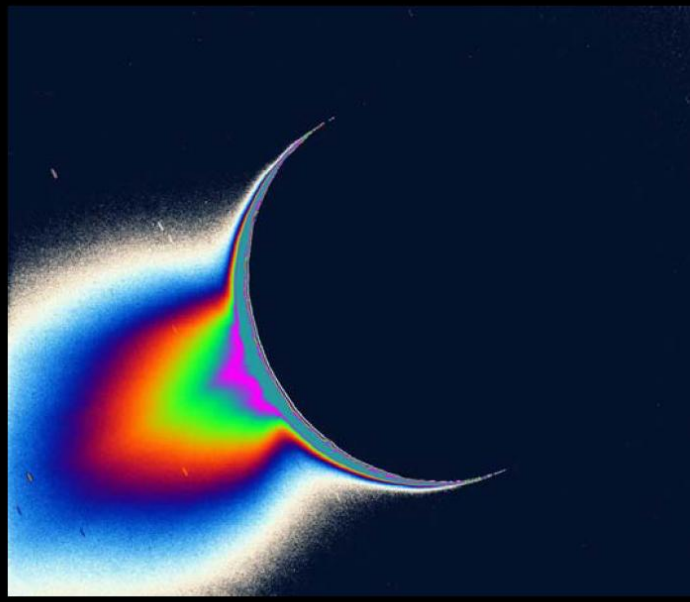


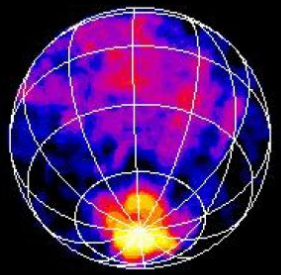
Filacchione et al., 2012

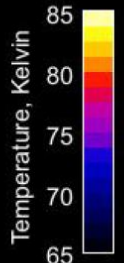
Plume Discovery through Interdisciplinary Science

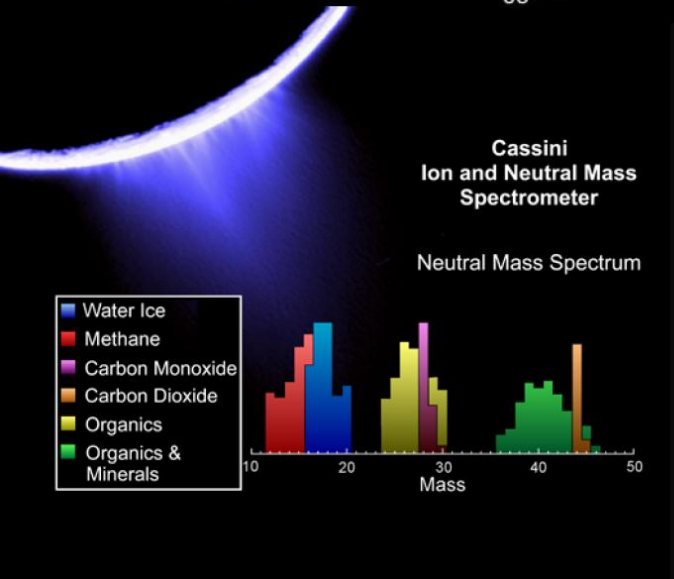


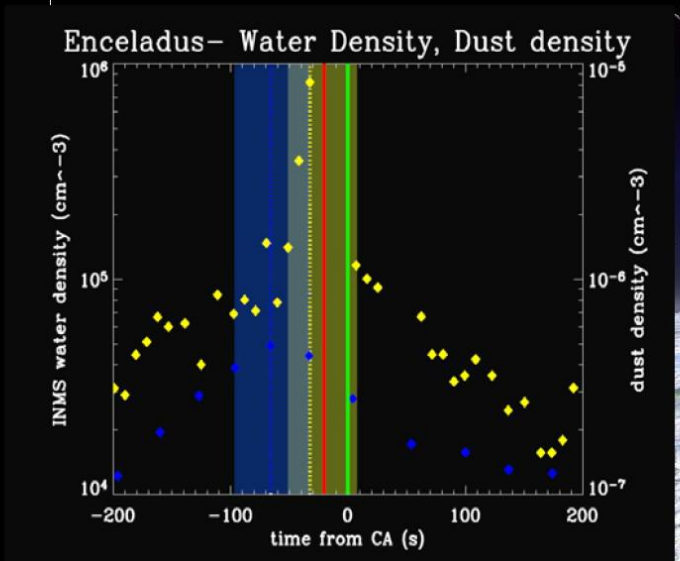


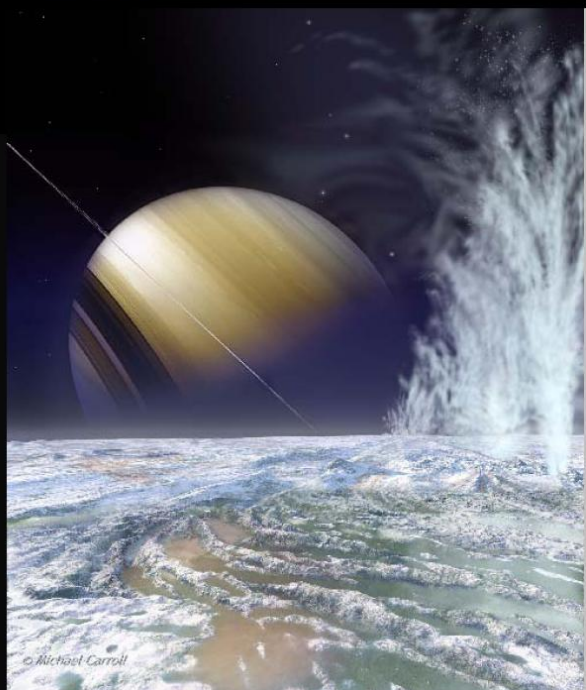




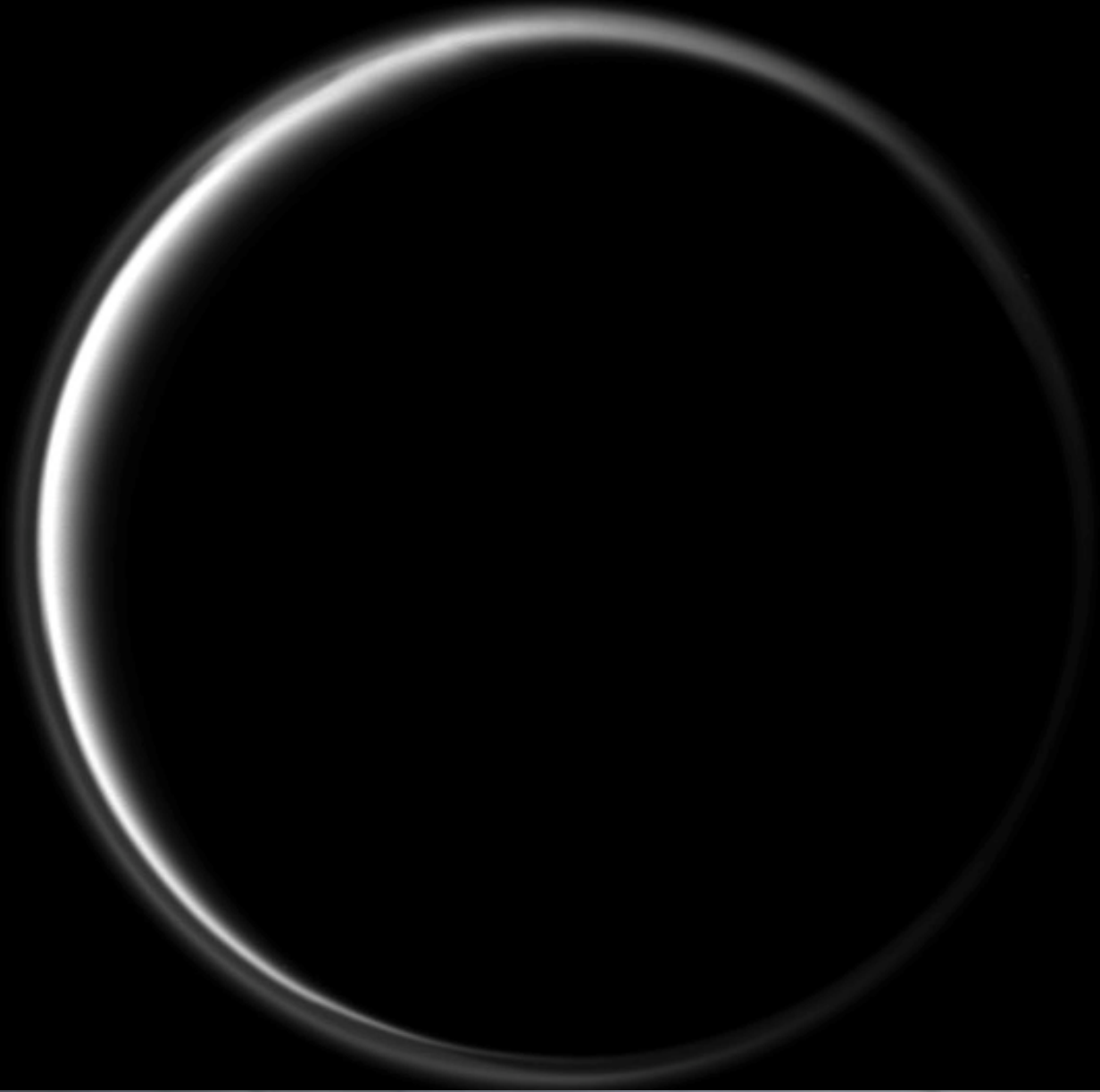








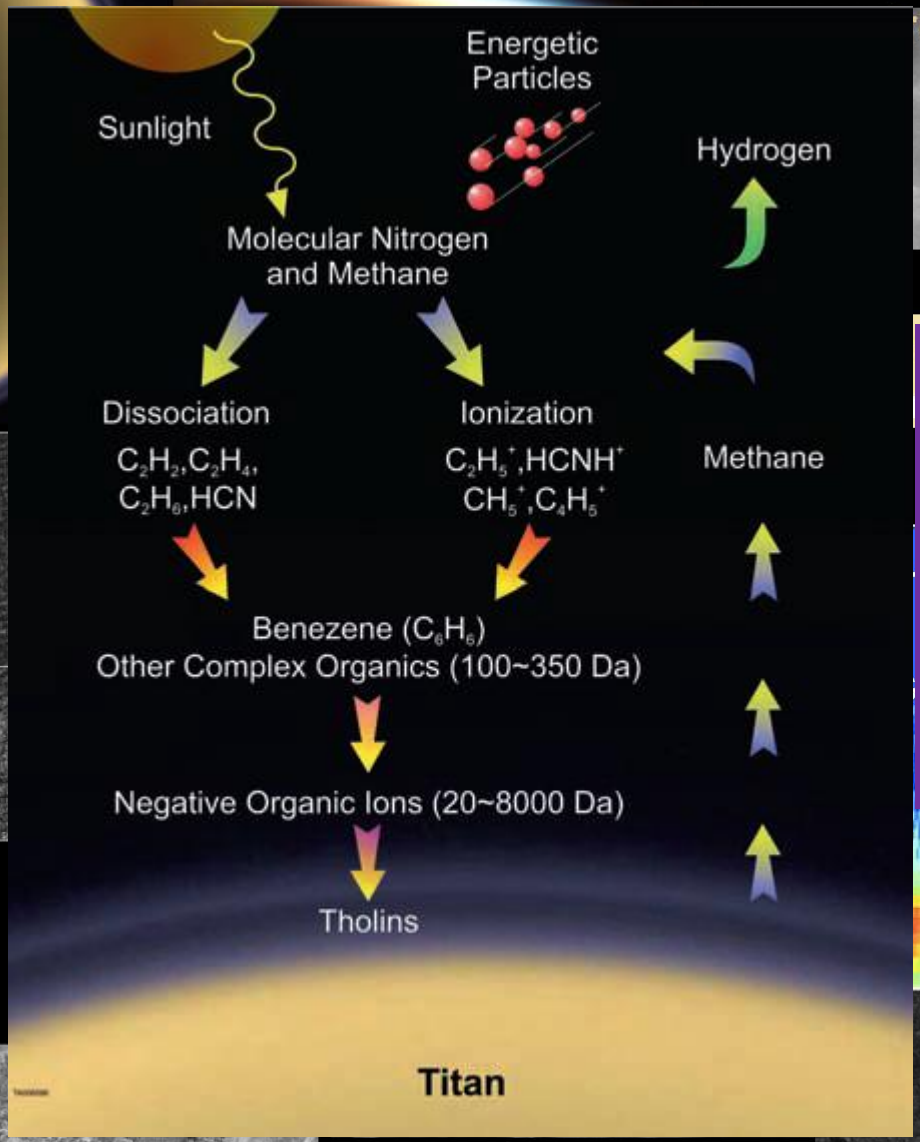
Titan Highlights



Titan: Complex surface, atmosphere and organics

detached haze

mid-latitude



drainage channels

wind driven dunes

Observation of HCN spectral features at 800-1100km altitudes correlated to Solar Zenith Angle
Adriani et al 2011

Very few craters

aeolian patterns

lakes

Specular reflection from Kraken Mare

The Cassini spacecraft captured the first flash of sunlight reflected off a lake on Saturn's moon Titan, confirming the presence of liquid on the part of the moon dotted with many large, lake-shaped basins.

VIMS, 8 July 2009

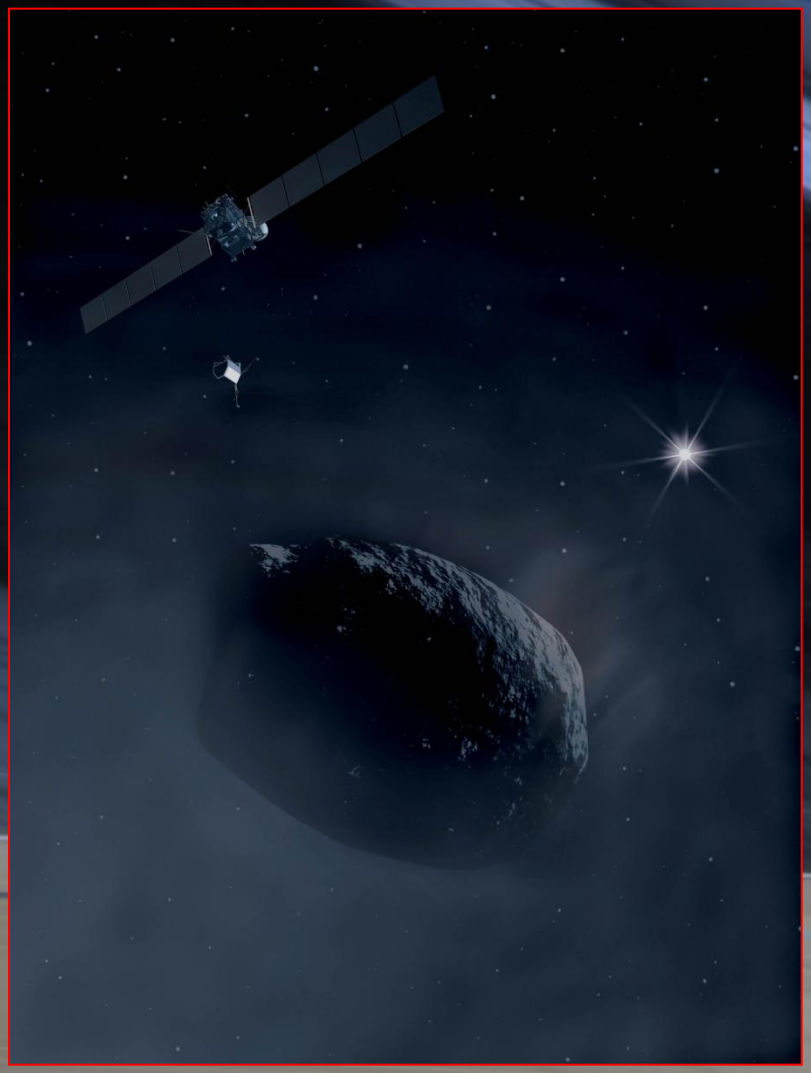
Titan Interior from the Radio science experiment

- Lacking a detectable internally generated magnetic field, constraints on the interior of Titan come from gravity, topography, and rotation measurements.
- The modulation of tidal forces due to the non-negligible eccentricity of Titan's orbit causes deformation of the shape and changes in the gravity field described by the Love number K_2
- K_2 It is an indication of the mass redistribution inside the body in response to the forcing potential (K_2 =0 for a rigid body, K_2 =3/2 for an incompressible fluid body)
- Results obtained by Iess et al, 2012 show K_2 value compatible with some global layer within Titan which is behaving like a fluid on orbital time scales

	k_2 (value $\pm$ 1σ)		
SOL1a	0.589	±	0.075
SOL1b	0.670	±	0.090
SOL2	0.637	±	0.112

Iess et al., 2012

The Rosetta mission: ESA’s comet chaser



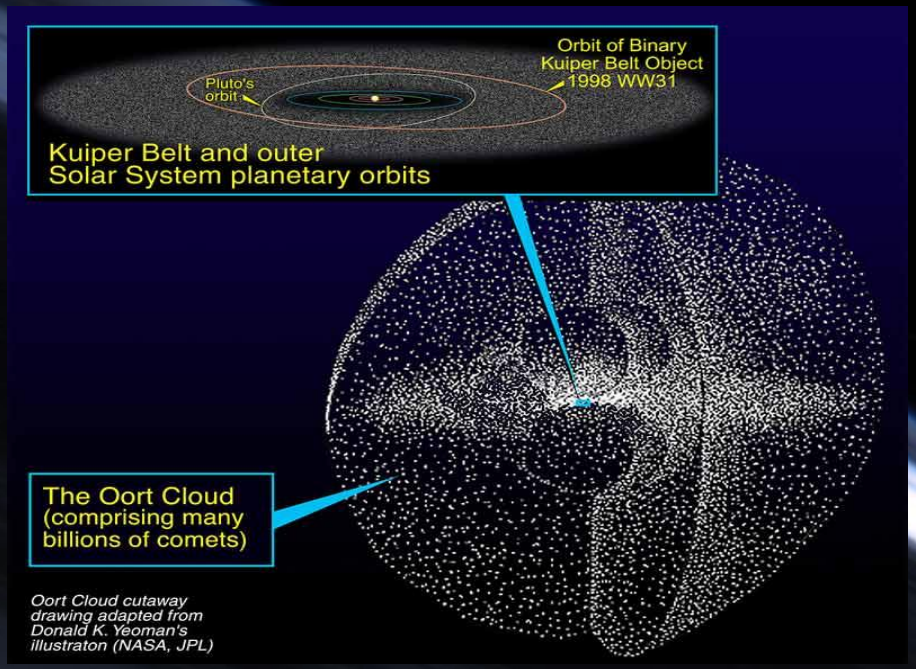
The Rosetta mission

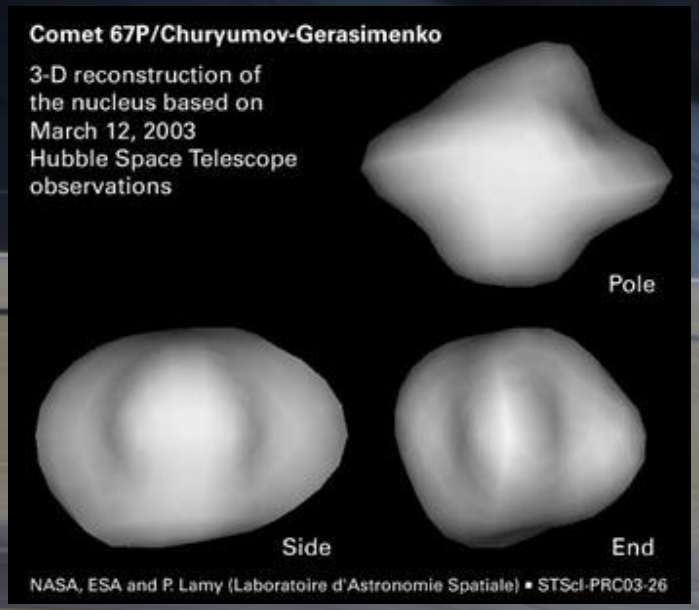
- ESA's Rosetta spacecraft will be the first to undertake the long-term exploration of a comet at close quarters.
- It comprises a large orbiter carrying 11 P/L instruments, which is designed to operate for a decade at large distances from the Sun, and a small lander (Philae).
- Rosetta was launched on 2nd March 2004.

- Is presently in hibernation (since June 2011); not even the 32 meters long solar panels can provide enough power for operations at distances larger than 4AU.
- It will be revived in February 2014 for an encounter with comet 67P/Churyumov-Gerasimenko in November 2014

Why study a Comet?

- Comets are believed to be the most primitive objects in the Solar System.
- They have spent most of their life in a cold environment and are unlikely to be deeply thermally altered.
- When a comet enters the inner Solar System a coma is formed by the sublimation of ices, followed by dust ejection and differentiation of the subsurface layers.

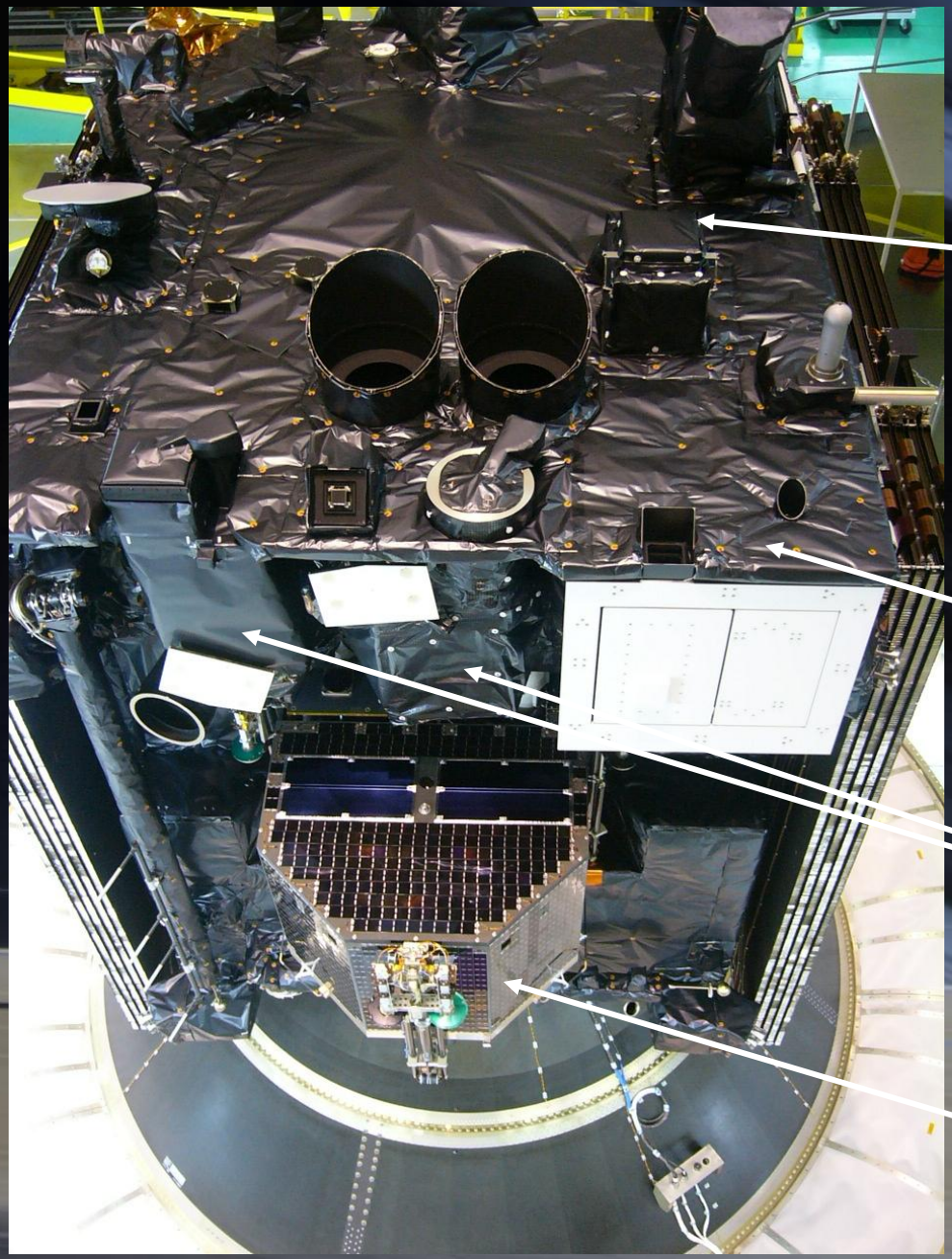




Comet 67P/Churyumov-Gerasimenko has a nucleus about 4 kilometres wide.

It orbits aroud the Sun with a period of 6.6 years on an elliptic orbit, between 186 million kilometres and 857 million kilometres from the Sun.

Italian Contribution



GIADA PI A. Rotundi
OAC +Università Pathenope

VIRTIS PI F. Capaccioni
IAPS-INAF

OSIRIS CoPI C. Barbieri
Università di Padova

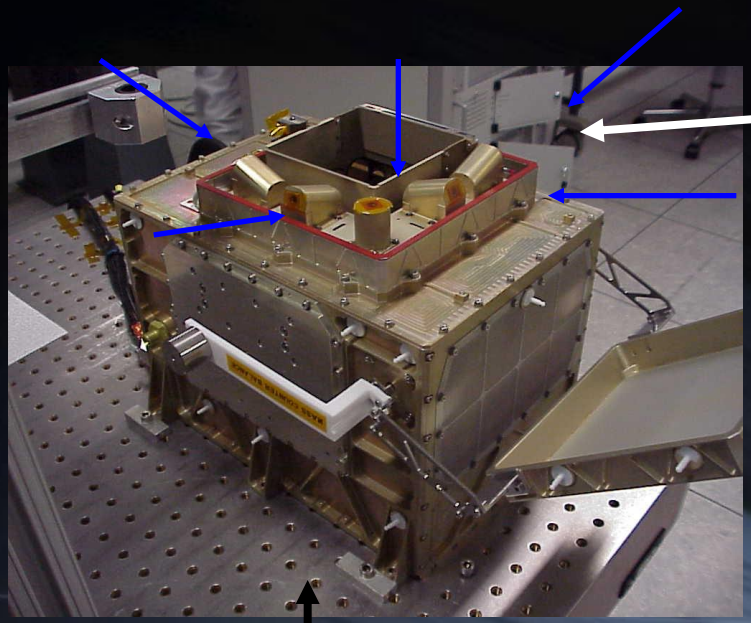
SD2 – Drill A. Ercoli Finzi
Politecnico di Milano

Grain Impact Analyzer and Dust Accumulator

- GIADA is designed to measure the **physical and dynamical properties** of grains emitted by the nucleus
- GIADA is an “event driven” instrument: continuous operation is required to accumulate statistically relevant amount of events during comet evolution
- GIADA has to be operative during **all the Rosetta rendezvous period at the comet**
- Measured quantities
  - Dust **flux** and **fluence** (different directions)
  - Dynamics of cometary dust
  - Single grain **momentum**
  - Single grain **velocity**
  - Dust velocity distribution
  - Single grain **mass**

GIADA working principle

- Quartz micro-balances for dust collection (MBS)
- Optical device for grain detection (GDS)
- Impact sensor (IS)

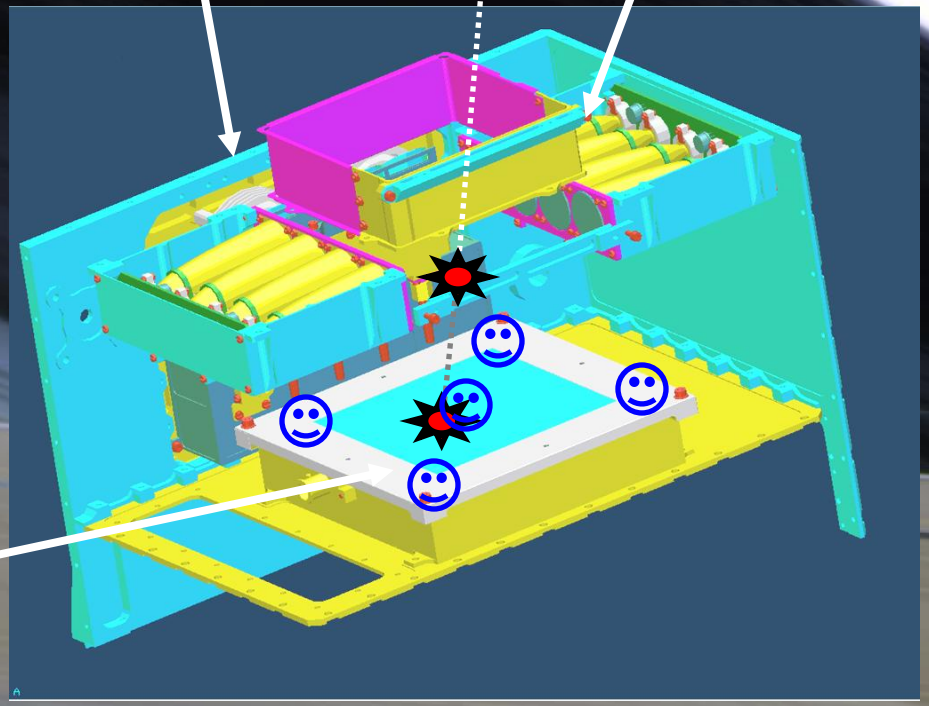


Grain

5 Micro-balances (MBS)

GDS lasers

GDS receivers



Electronics

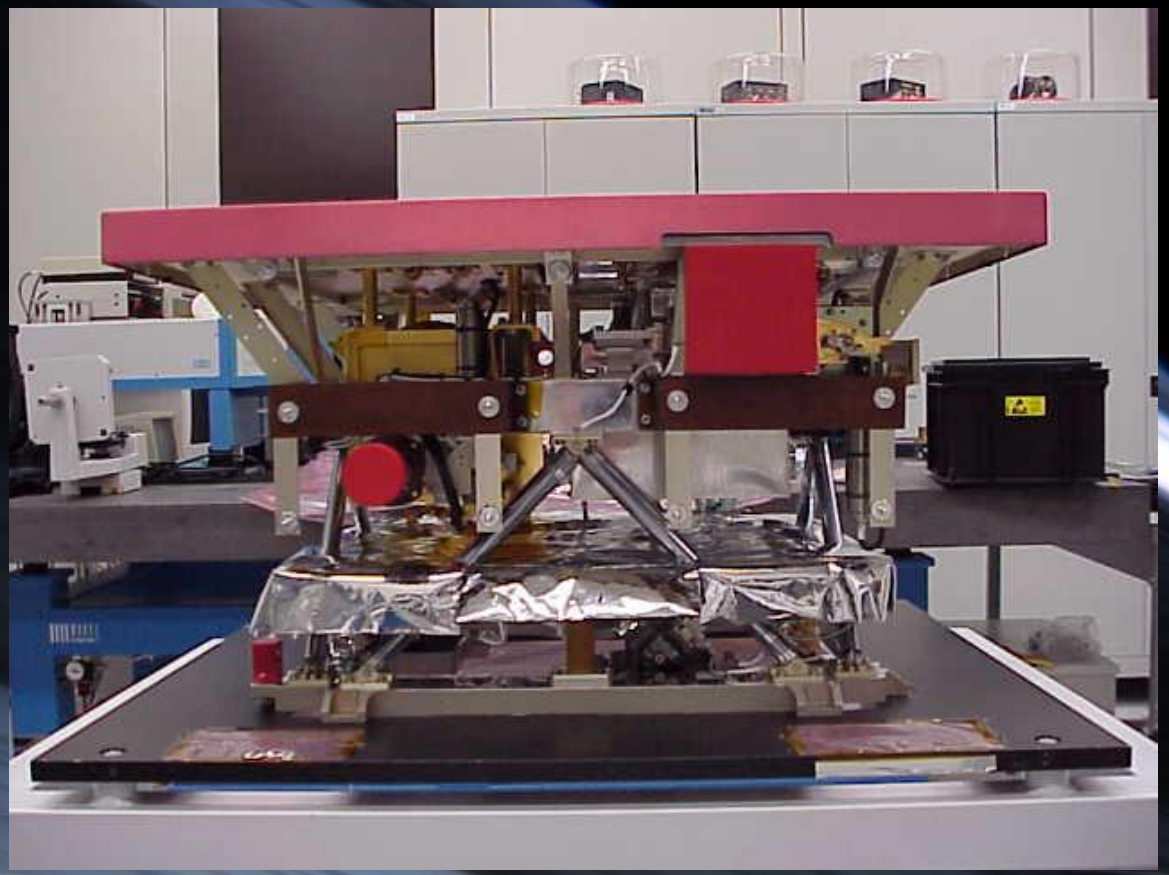
Impact sensor (IS)

VIRTIS

Visible, InfraRed and Thermal Imaging Spectrometer

VIRTIS is an imaging spectrometer and a high resolution spectrometer

VIRTIS–M is a slit spectrometer; acquires hyperspectral images with a max spatial resolution of 250μrad, using an internal scan mirror, in the spectral range 0.25-5 μm



VIRTIS –H is a high-resolution infrared spectrometer in the 2-5 μm range. It uses a prism and a grating to achieve a spectral resolution as high as 3000 on a matrix detector identical to the VIRTIS-M IR FPA.

VIRTIS derived nucleus materials properties

- Surface Composition: Abundance of Ices, Opaques compounds, minerals and Organics (few % level in mixtures from modelling)
- Photometric properties; Phase function, Surface roughness and Grain Size for the different end-members in the overall spectral range (needs phase curve coverage over wide range of phase angles 0° -120 °).
- Global and High Resolution Surface distribution; of Ices, carbon-rich areas, etc. (global 20m, high res 5m).
- Identification of landmarks; these are derived from composition or thermal properties, and comprises active (or potentially active) areas, morphological features, hills, scarps, pits, craters.
- Temperature (min detectable T=170K-180K)
- Thermal Properties; Thermal Inertia; thermal conductivity, porosity, surface roughness and grain sizes (needs observations of same area at several local times).
- Coupled with MIRO data: characterise physical properties of the first 10-20cm layers.
- Surface dynamics: changes in surface composition and/or physical properties, both erratic (outburst) or periodic (diurnal and seasonal cycles).

VIRTIS derived coma properties

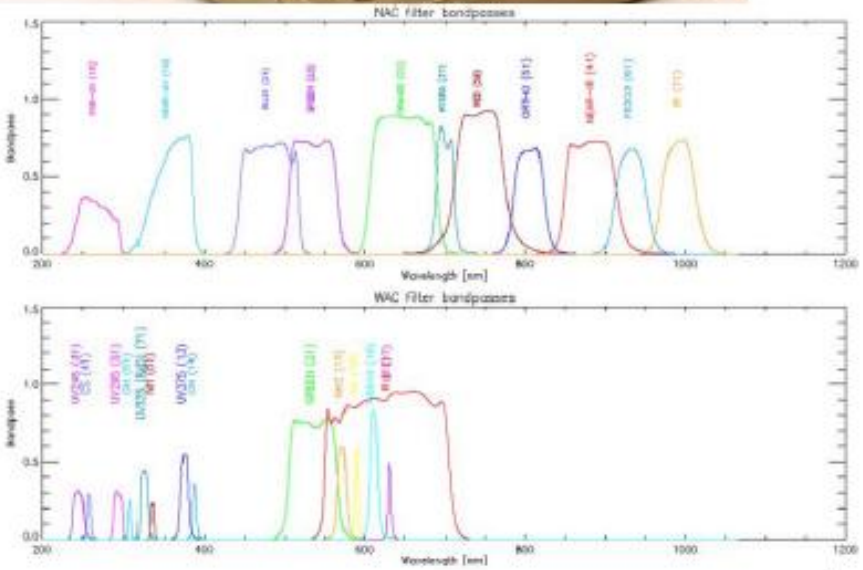
- Molecules column density in Coma/Jets. (Limb scan over jets; at 10km resolution of less than 5m)
  - Absolute column density can be retrieved where opacity is negligible;
  - Where opacity increases the measured radiance is used to study spatial distribution. This will allow shorter integration times (lower SNR required).
- CO2 detection (and possibly H2O) at distance > 3.0AU
- Thermodynamics of the inner coma ; Rotational Temperature of H2O;
- Ortho-H2O to Para-H2O Ratio; Formation temperature of comets. Requires long effective integration times (several hours), but is not spatially dependent.
- H2O and CO2 2D Maps (from surface to 5km)
- Minor species detection and production rate (Methane, Methanol, Formaldehyde)
- Surface-Coma Coupling; diurnal and seasonal variations for Jets; association between jet variation and surface composition
- Outburst: Compositional characteristics Vs Jets
- Icy grains abundance Vs distance from surface; Sublimation of icy grains
- Dust Scattering properties (needs observations at several phase angles with respect to the jet); grain size
- Dust to Gas ratio

OSIRIS - Scientific Camera System

NAC – Narrow Angle Camera
FOV 2.2°, IFOV 18.6 µrad/px
SiC, 2k x 2k BI E2V CCD, AB
3-mirror off-axis, f/8, 717mm

plus 3 **E-Boxes**
(35 kg total)

WAC – Wide Angle Camera
FOV 12°, IFOV 101 µrad/px
Al bench, 2k x 2k BI E2V CCD, AB
2-mirror off-axis, f/5.6, 140mm

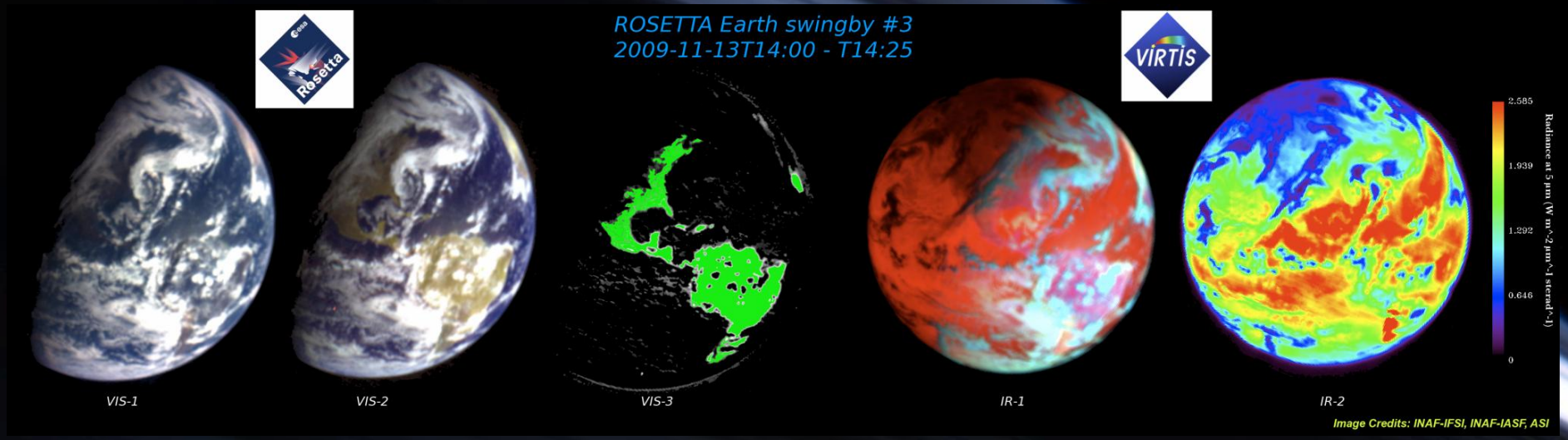


Scientific Objectives of OSIRIS

OSIRIS – Key scientific questions of cometary research (response to Orbiter Payload Scientific Objective, Remote Imaging System)

- What is the physical structure of the nucleus?
- What is the chemical composition of the comet and how does this relate to the interstellar medium?
- What were the prevailing conditions under which the comet formed?
- What distinguishes active and inactive regions?
- What causes outbursts of activity?
- What are the physical processes affecting the initial outflow of gas and dust?
- What processes will ultimately lead to the comet's "death"?

Earth Observation VIRTIS-M



- Fig1. VIS channel; spatial resolution of about 50 km. RGB imaging (0.44, 0.55, 0.7μm).
- Fig 2 VIS Channel; contrast enhanced image (0.474μm, 0.785μm, 1.0μm).
- Fig 3 VIS Channel; contrast enhancement of chlorophyll absorption feature.
- Fig 4 IR Channel; B @1.20μm, G@2.25μm and R@4.92μm. Radiation emitted from the night side clearly shows up in this image. The cyan spots are high altitude clouds, while Oceans appears in red having a thermal emission and inertia larger than the landforms (in pink).
- Fig 5. Thermal emission region at 5.0 μm; the Earth looks fairly uniform on the day and night side. The northern American continent (in the top-left quadrant of the image), mainly at night and during the winter season, appears as the coldest area of this image (in blue).

21 Lutetia Fly-by

- For about one year, until Dawn arrival at Vesta, 21 Lutetia was the largest asteroid observed by a S/C
- Size of 126×103×95 km (Sierks et al., 2011)
- Rosetta only observed northern hemisphere due to the inclination of only 6° from ecliptic
- C/A distance of 3170 km
- Fly-by speed 10Km/s

3 papers on Lutetia Fly-by published on 28 Oct 2011:

OSIRIS

VIRTIS

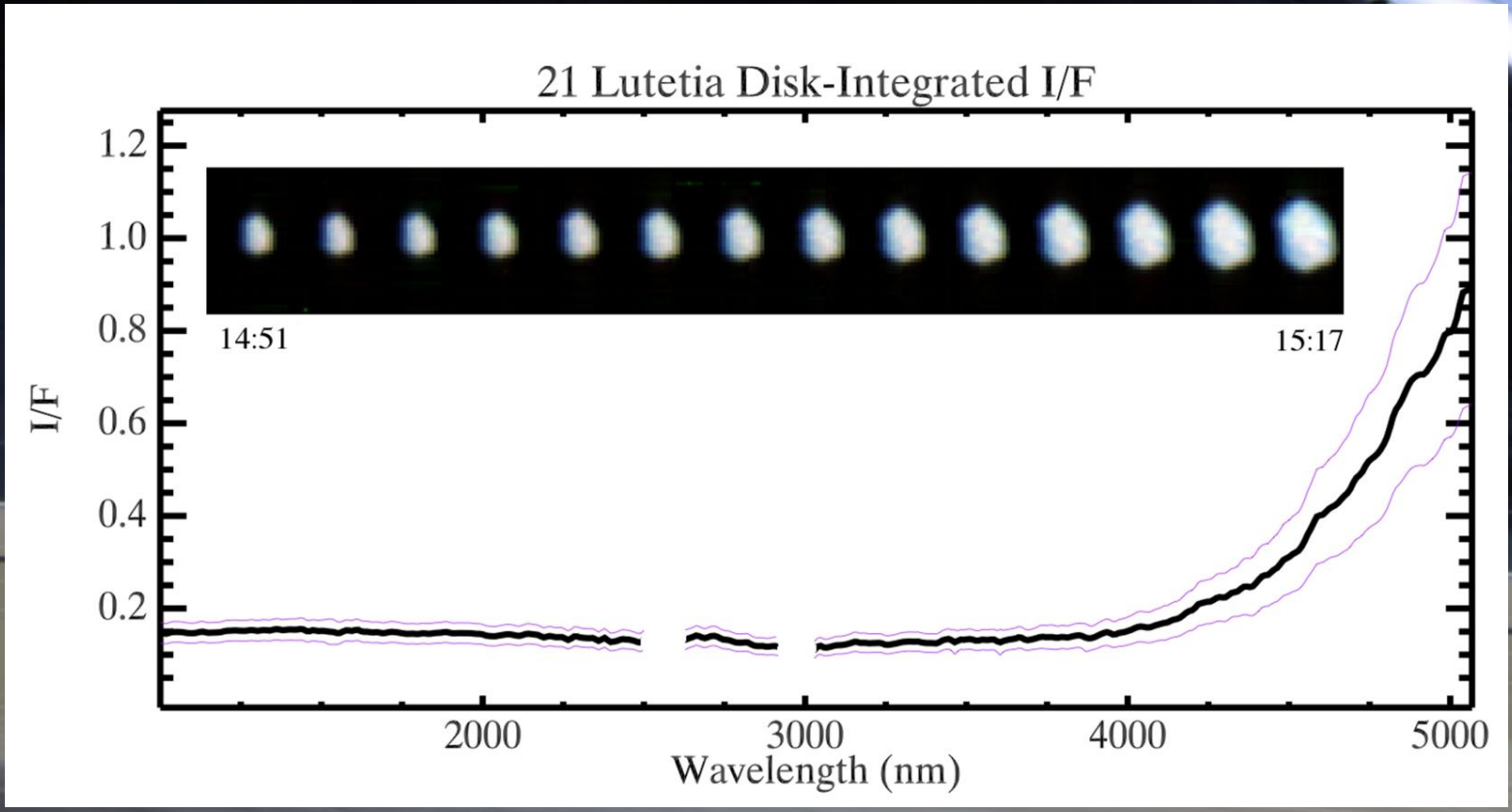
RSI

Rosetta got the Cover Page!

Huge resonance in the media.

Lutetia IR Spectra

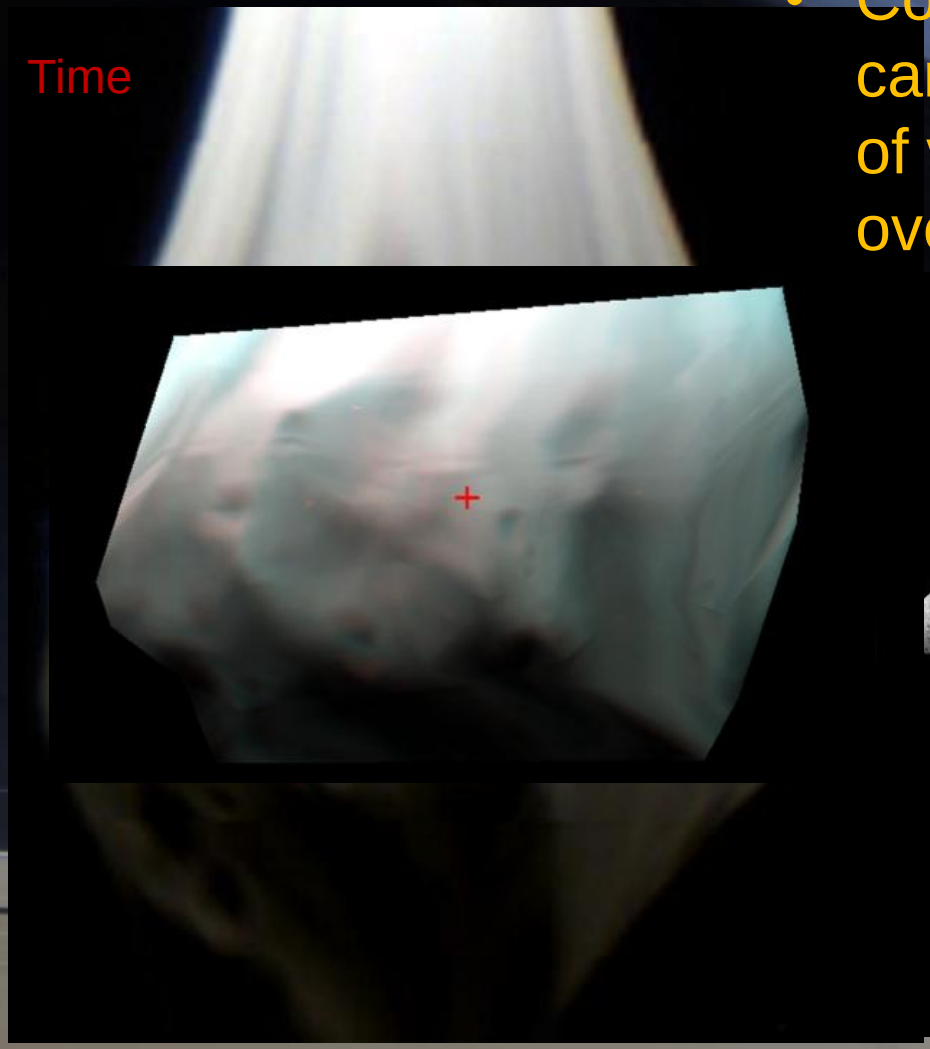
- 15 consecutive scans; total 27min
- Lutetia rotated by ~20°
- S/C distance 48 – 25 x10^3 km
- Pixel size 12km - 6.5km

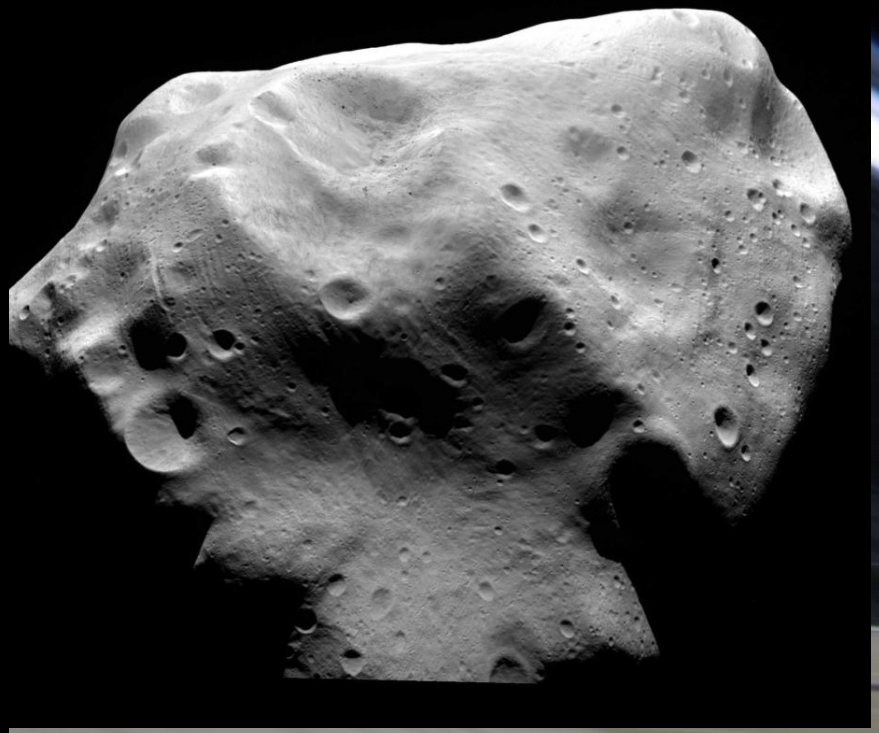


21 Lutetia highest resolution cube

- Comparison to a camera image can be misleading as the point of view changes continuously over the picture

Time





VIRTIS pixel sampling 2km to 0.75km at C/A

21 Lutetia highest resolution cube

- Comparison to a camera image can be misleading as the point of view changes continuously over the picture

Surface Temperature

VIRTIS pixel sampling 2km to 0.75km at C/A

28 OCTOBER 2011 VOL 334 SCIENCE

The Surface Composition and Temperature of Asteroid 21 Lutetia As Observed by Rosetta/VIRTIS

A. Coradini,[1] F. Capaccioni,[2*] S. Erard,[3] G. Arnold,[4] M. C. De Sanctis,[2] G. Filacchione,[2] F. Tosi,[1] M. A. Barucci,[3] M. T. Capria,[2] E. Ammannito,[1] D. Grassi,[1] G. Piccioni,[2] S. Giuppi,[1] G. Bellucci,[1] J. Benkhoff,[5] J. P. Bibring,[6] A. Blanco,[13] M. Blecka,[7] D. Bockelee-Morvan,[3] F. Carraro,[1] R. Carlson,[8] U. Carsenty,[9] P. Cerroni,[2] L. Colangeli,[5] M. Combes,[3] M. Combi,[10] J. Crovisier,[3] P. Drossart,[3] E. T. Encrenaz,[3] C. Federico,[11] U. Fink,[12] S. Fonti,[13] L. Giacomini,[1] W. H. Ip,[14] R. Jaumann,[9] E. Kuehrt,[9] Y. Langevin,[6] G. Magni,[2] T. McCord,[15] V. Mennella,[19] S. Mottola,[9] G. Neukum,[16] V. Orofino,[13] P. Palumbo,[21] U. Schade,[22] B. Schmitt,[17] F. Taylor,[20] D. Tiphene,[3] G. Tozzi[18]

The Visible, InfraRed, and Thermal Imaging Spectrometer (VIRTIS) on Rosetta obtained hyperspectral images, spectral reflectance maps, and temperature maps of the asteroid 21 Lutetia. No absorption features, of either silicates or hydrated minerals, have been detected across the observed area in the spectral range from 0.4 to 3.5 micrometers. The surface temperature reaches a maximum value of 245 kelvin and correlates well with topographic features. The thermal inertia is in the range from 20 to 30 joules meter^{-2} kelvin^{-1} second$^{-0.5}$, comparable to a lunarlike powdery regolith. Spectral signatures of surface alteration, resulting from space weathering, seem to be missing. Lutetia is likely a remnant of the primordial planetesimal population, unaltered by differentiation processes and composed of chondritic materials of enstatitic or carbonaceous origin, dominated by iron-poor minerals that have not suffered aqueous alteration.

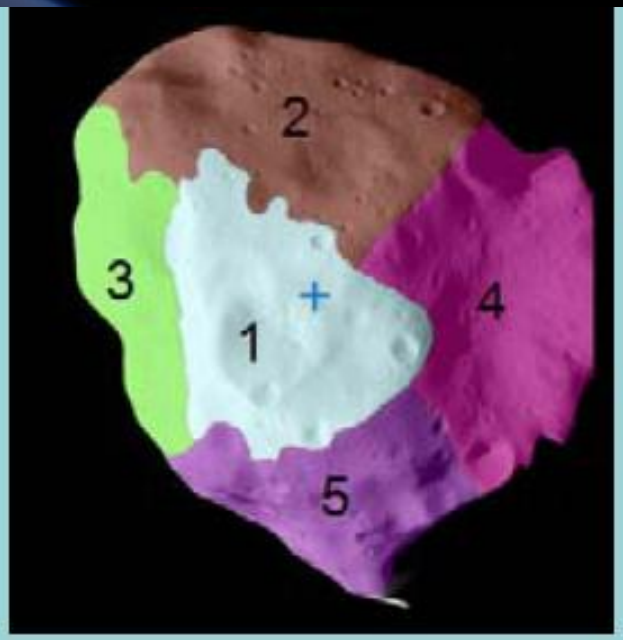
21 Lutetia flyby

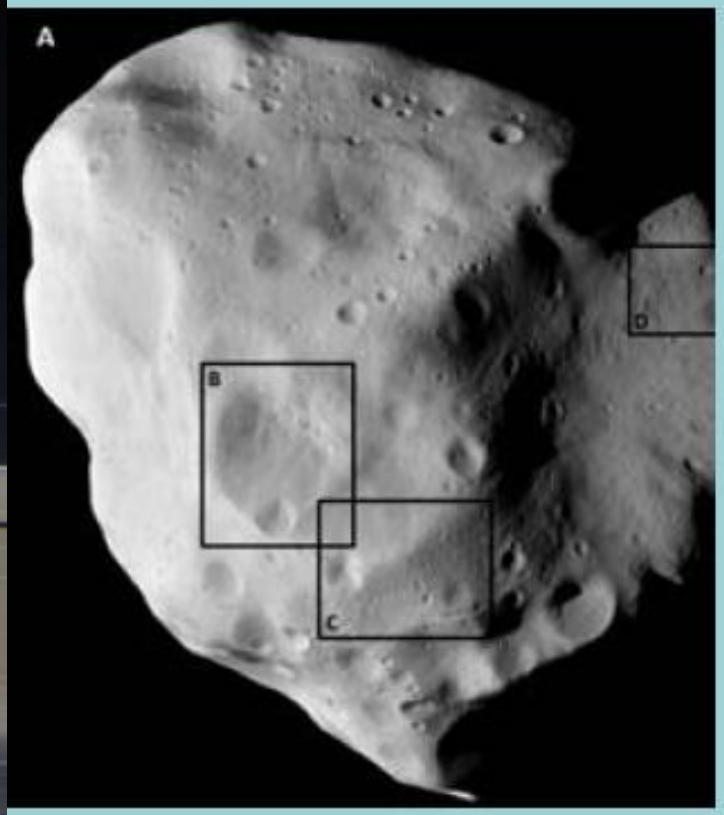
Main themes:

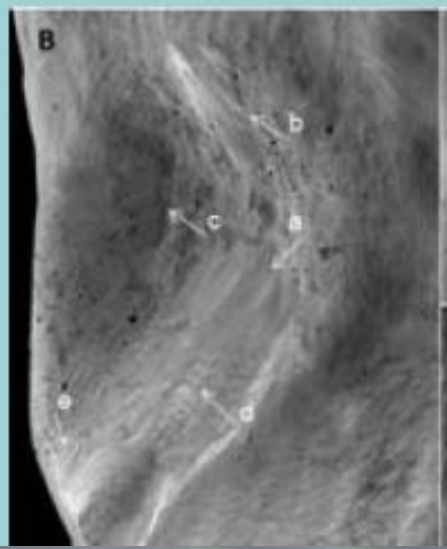
- Geomorphology
- Feature names (accepted by IAU)
- Cratering and age determination
- Geological maps
- Shape and stereo reconstruction
- Spectrophotometry

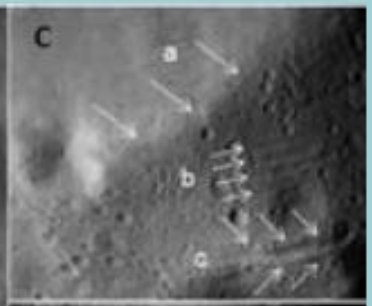
Surface Features

- crater of all sizes, from 55 km down to the resolution limit (100 m)
- landslides
- boulders & rocky outcrop
- scarps, graben, faults, grooves

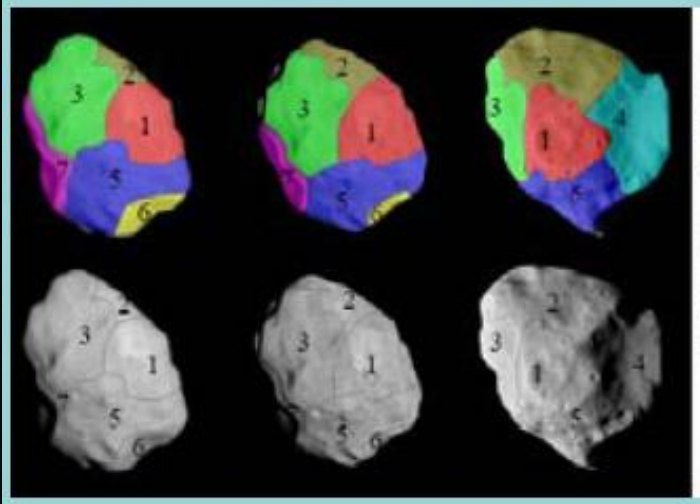




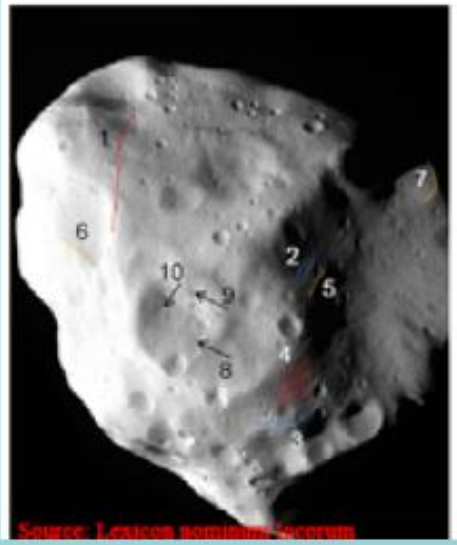




Geologic Map and Features names



1. Baetica
2. Achaia
3. Etruria
4. Narbonensis
5. Noricum
6. Pannonia
7. Raetia

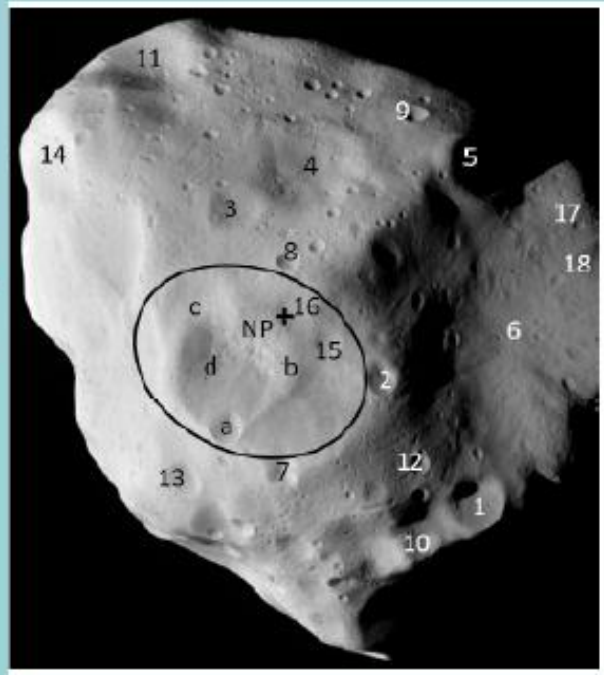


Curvilinear features:
rima, fossa, cavus, dorsum, rupes, labes

1. **Tiberis** rima system (p.309)
2. **Sequana** fossa (p.287)
3. **Hiberus** fossa (p. 107)
4. **Rhodanus** rimae(p.263)
5. **Ticinum** dorsum (p. 310)
6. **Rhenus** rupes (p. 257)
7. **Glana** rupes (p.130)
8. **Danuvius** labes (p. 97)
9. **Gallicum** labes (p. 124)
10. **Sarnus** labes (p. 281)

IAU approved feature types:
- Fault: rima
- Graben: fossa
- Groove: cavus
- Fracture: rima
- Ridge: dorsum
- Scarp: rupes
- Landslide: labes

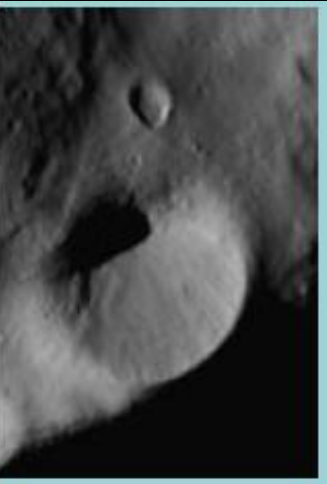
Source: Lexicon nominum locorum



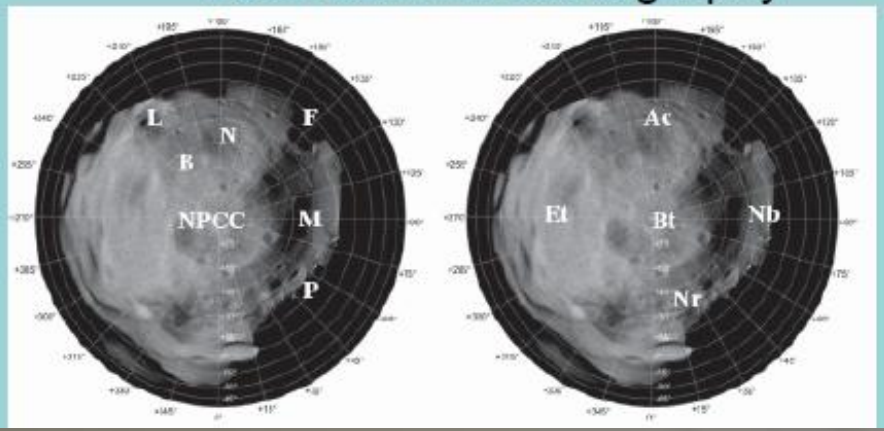
1: **Patavium**
2: **Bonna**
3: **Burdigala**
4: **Nicaea**
5: **Florentia**
6: **Massilia**
7: **Gaudiaco**
8: **Basilia**
9: **Turicum**
10: **Saloca**
11: **Lugdunum**
12: **Bagacum**
13: **Syracusae**
14: **Roma**
15 :**Gerunda**
16: **Toletum**
17: **Genua**
18: **Salomacus**

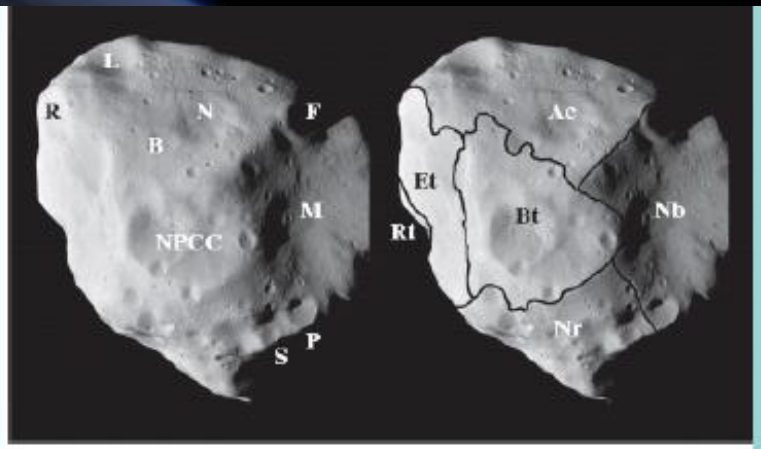
North Pole (NP) crater cluster with structures: a, b, c, d.

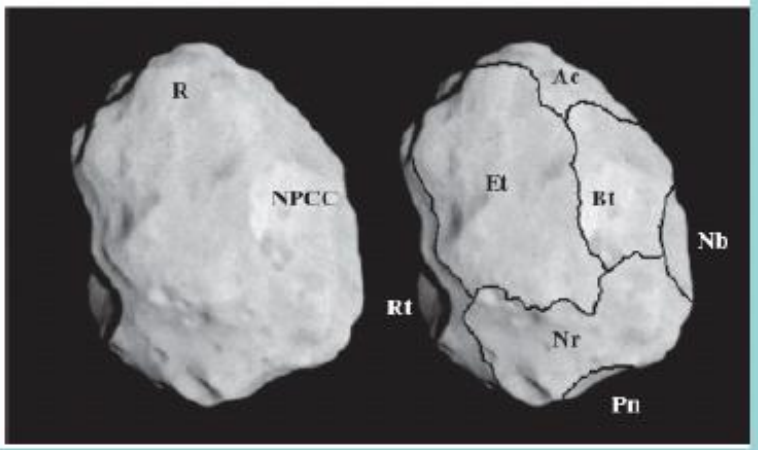
Geologic Map and stratigraphy



- High variated surface and geological units of disparate ages
- Geological history: a part from big cratering events generating Massilia and the North Polar Crater Cluster, only minor events are recorded in its stratigraphy







Surface age from cratering

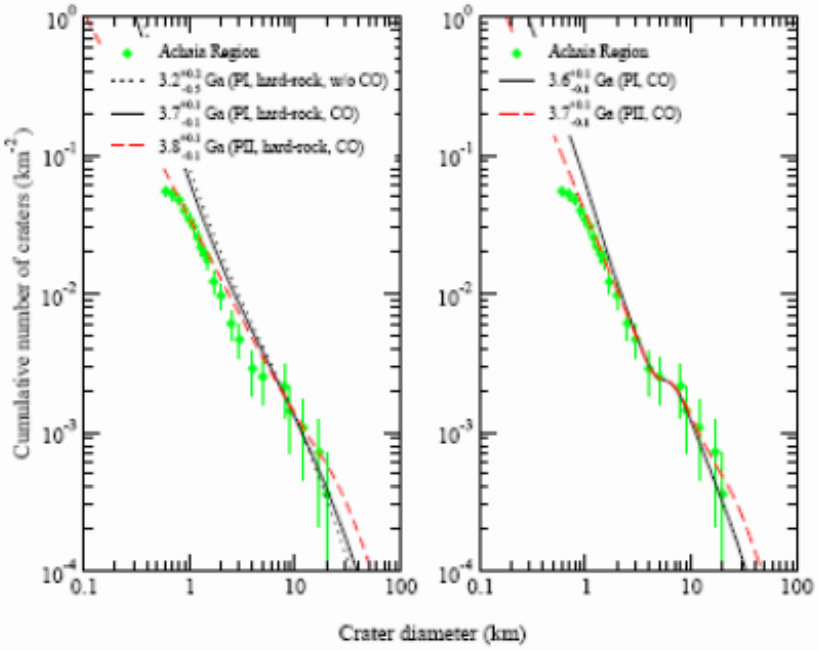


Figure 6: Achaia MPF best fit. Left panel: Best fits obtained using hard-rock scaling law, with and without crater obliteration (CO), and using the MBA population from Bottke et al. (2005) (PI) and Gladman et al. (2009) (PII). Right panel: Best fits obtained modeling a transition in the physical properties of Achaia region, namely adopting a fractured layer onto a more competent interior (see text for more details).

Lutetia underwent a complex collisional evolution, involving major local resurfacing events till recent times.

The difference in crater density between the youngest and oldest recognized units implies a difference in age of more than a factor of 10.

The youngest unit (Baetica) has an estimated age of 10s – 100s Ma, while the oldest one (Achaia) has an age of 3.6 Ga.

Surface Photometry

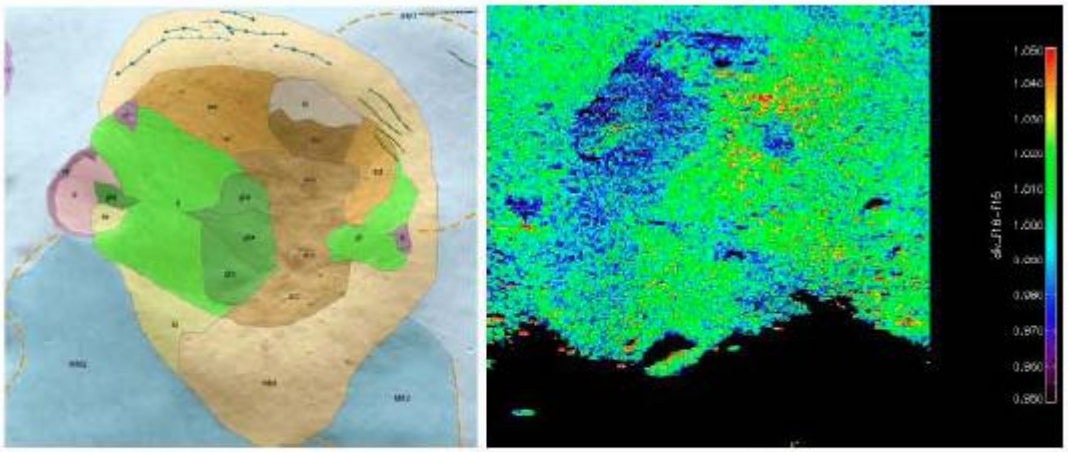


Figure 11: (a) Massironi et al. (2011) description of the Baetica region in geologic units. Green areas refer to Danuvius (left) and Gallicum (right) gravitational taluses, grey area is the Sarnus sliding surface. Other brown areas indicate landslide accumulation material. (b) NAC-F16/NAC-F15 normalized ratio.

- The spectrophotometry (consistent with ground based observations) does not show surface diversity above the data error bars.
- The blue and UV images may however indicate a variegation of the optical properties of the asteroid surface on the Baetica region.
- We also speculate on the contribution due to different illumination and to different ground properties (composition or grain size diversity). In particular a correlation with geologic units is evident, suggesting that the variegation of the ground optical properties is likely to be real

What next

- Rosetta is in hibernation but the preparatory activities for the operations at the comet are running at full speed.
- The ESA team and P/L instruments are working hard (almost daily teleconferences) to converge on an optimum plan for the almost 2 years of operations at the comet.
  - February – May 2014 Commissioning
  - May – November 2014 Pre-Landing Phase (Landing site selection)
  - November 2014 – December 2015 Science Mission Phase
  - 2016 Extended Mission?

“She was everything for us, she built our planetary community, she fought for us, she encouraged and led us.”

P. Cerroni

Backup Slides

Enceladus as the source of material for the E Ring