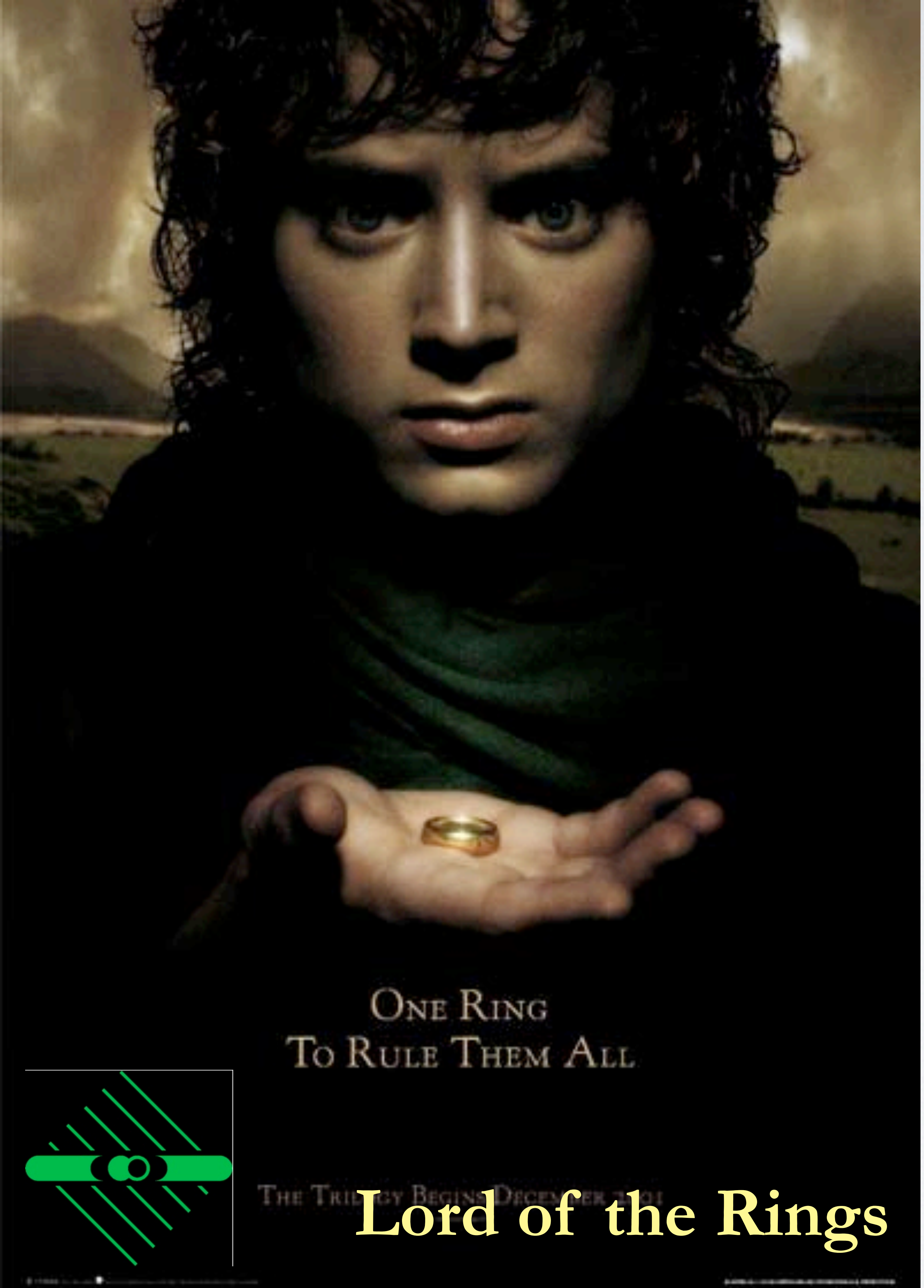


The **Cassini/Huygens Mission** to **SATURN**

Dr. R. Srama
MPI Nuclear Physics, Heidelberg, Germany
University Stuttgart

Kobe, March 2010

GALILEO TO KEPLER 1610

ALTISSIMUM PLANETAM TERGEMINUM OBSERVAVI

„The most distant planet has a three-fold shape !“

„Der entfernteste Planet hat eine dreifache Form“

(discovery of Saturn‘s ring)

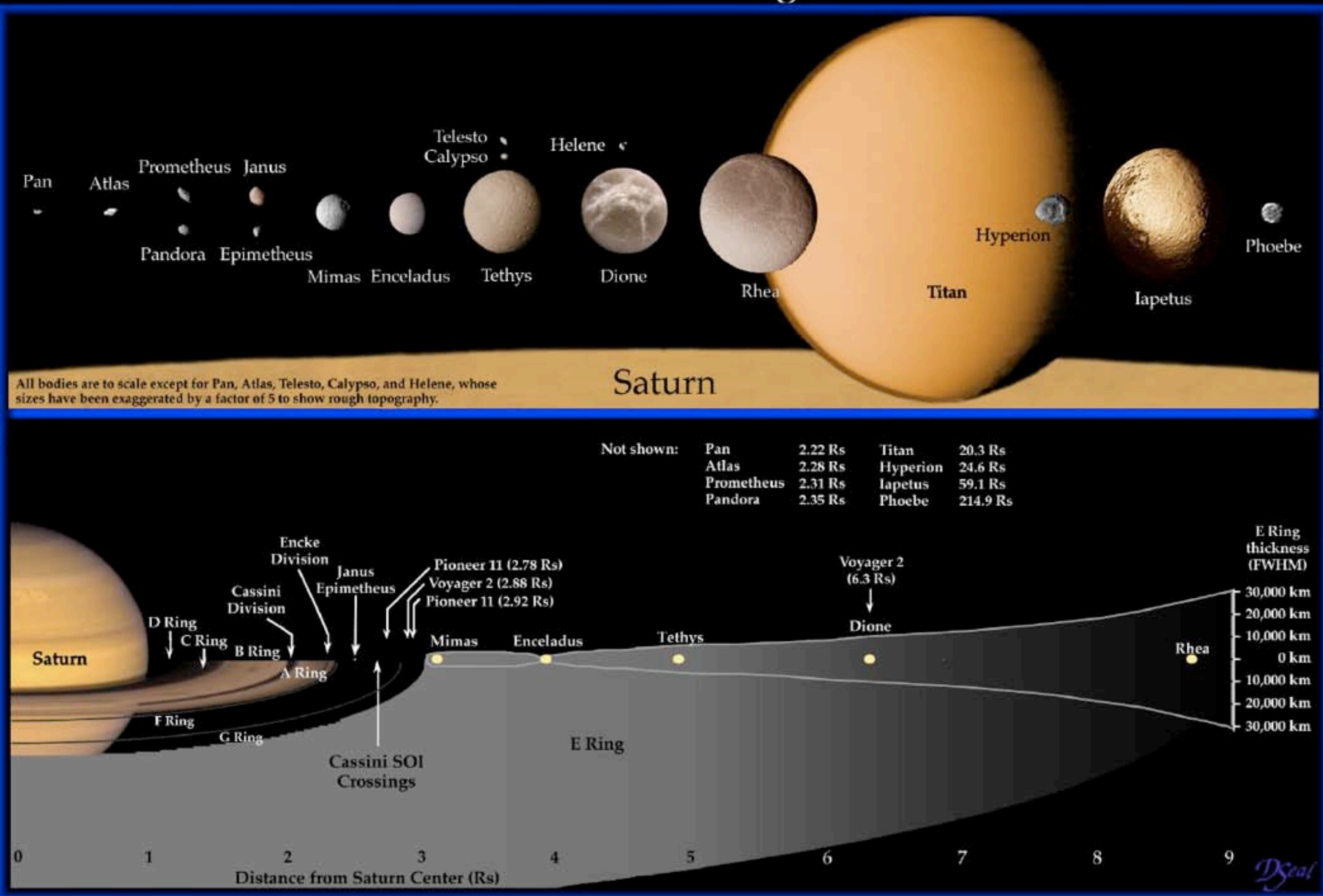
CHRISTIAAN HUYGENS

- mathematician and physicist of the netherlands
- (*1629, †1695)
- interpretation of Saturn‘s ring
- discovery of the large moon titan (1655)

GIOVANNI CASSINI

- french astronomer and mathematician
- (*1625, †1712)
- discovery of 4 Saturn moons and the ring division

Saturn's Satellites and Ring Structure



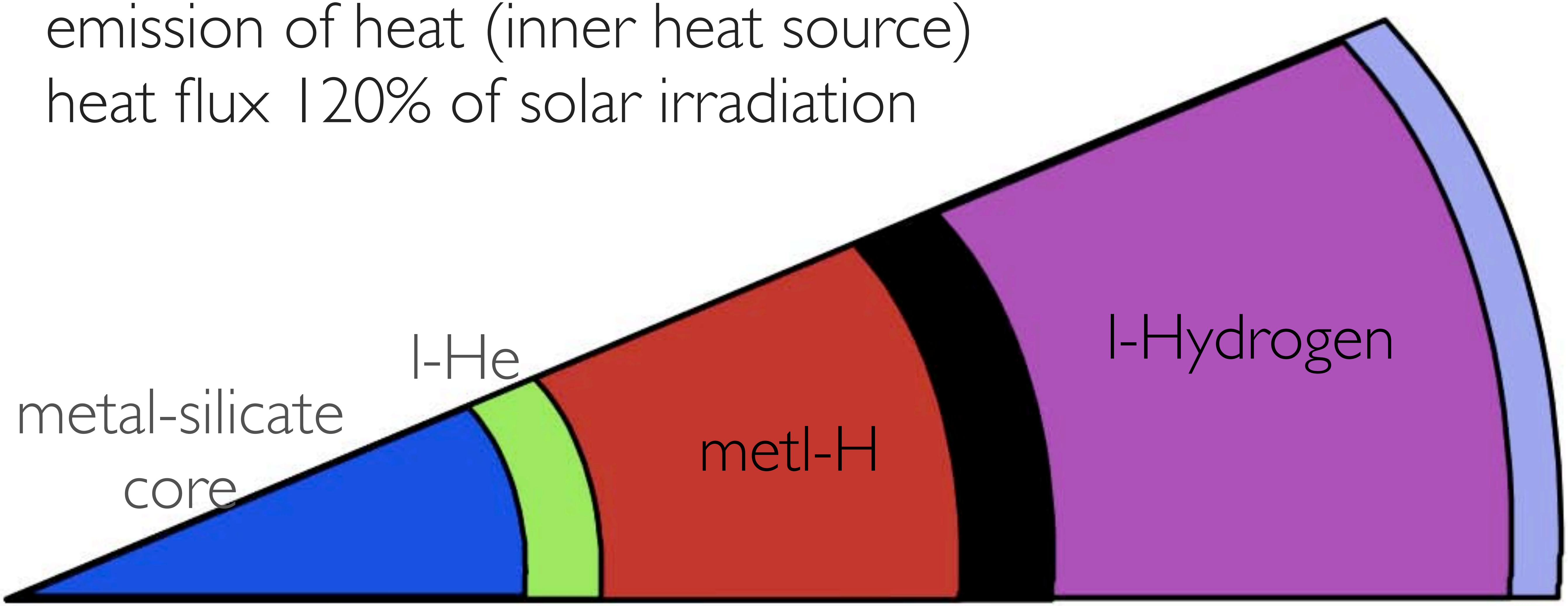
This graphic is available in color if required.

SATURN !

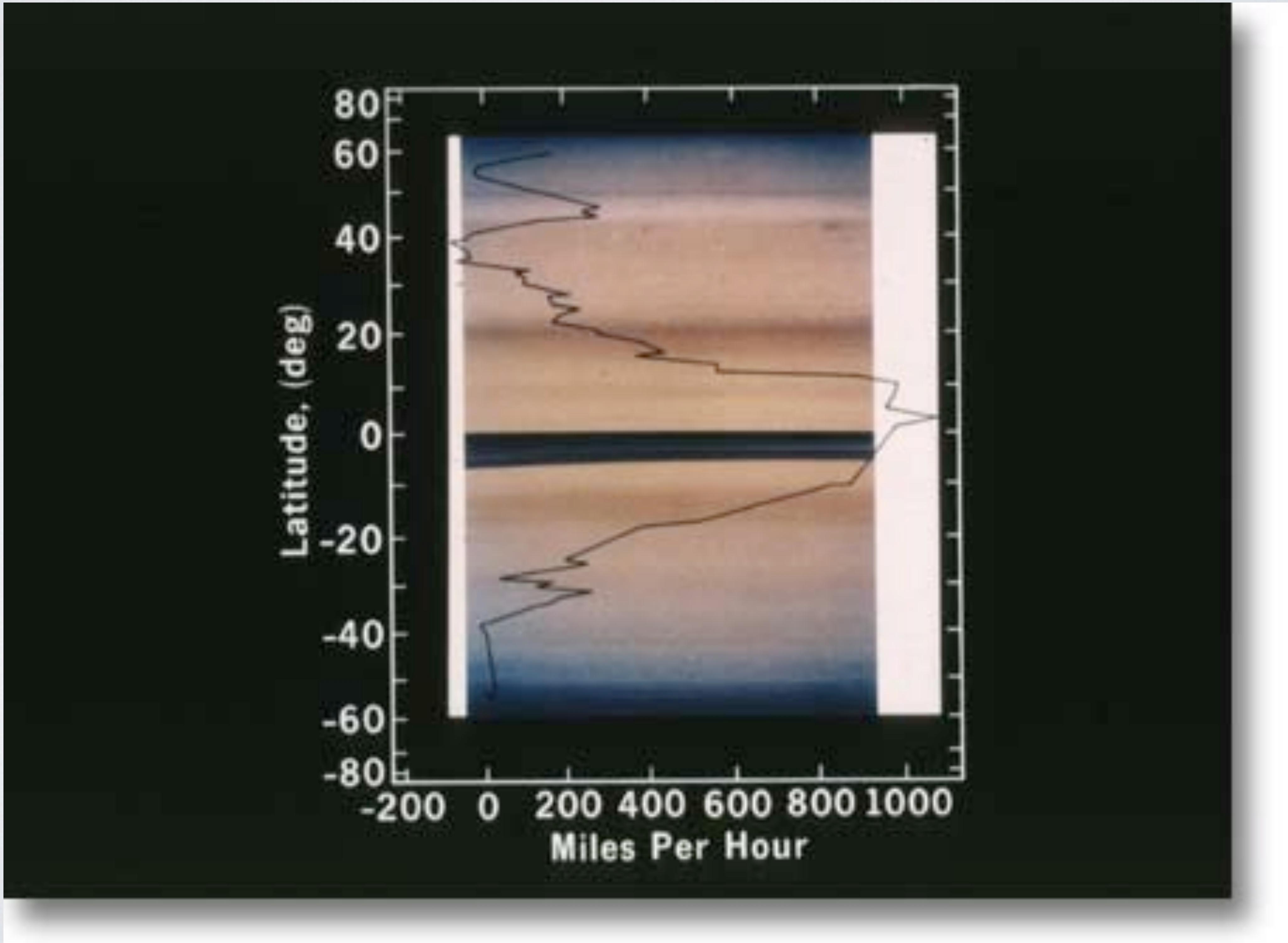
1 Saturn year :	29.5 y
Rotation :	10 h, 40 min
Distance to Sun :	1400 Mkm
Diameter at equator :	120.000 km
Mass :	95 x Earth
Volume :	760 x Earth
Density :	0.7 g/cm^3 (Earth 5.5)
Strong pole oblateness	
Magnetic field :	4x10-5 T at pole (Earth : 5x10-5 T)
Dipole field axis = rotation axis !	
ring plane :	27° tilted towards orbit plane

SATURN'S INTERIOR

Atmosphere : 94 % H, 6% He
T at upper cloud boundary : 150 K
T at cloud lower boundary : 80 K
T in center : 20.000 K, 5x10^12 P (Earth: 3800 K)
emission of heat (inner heat source)
heat flux 120% of solar irradiation



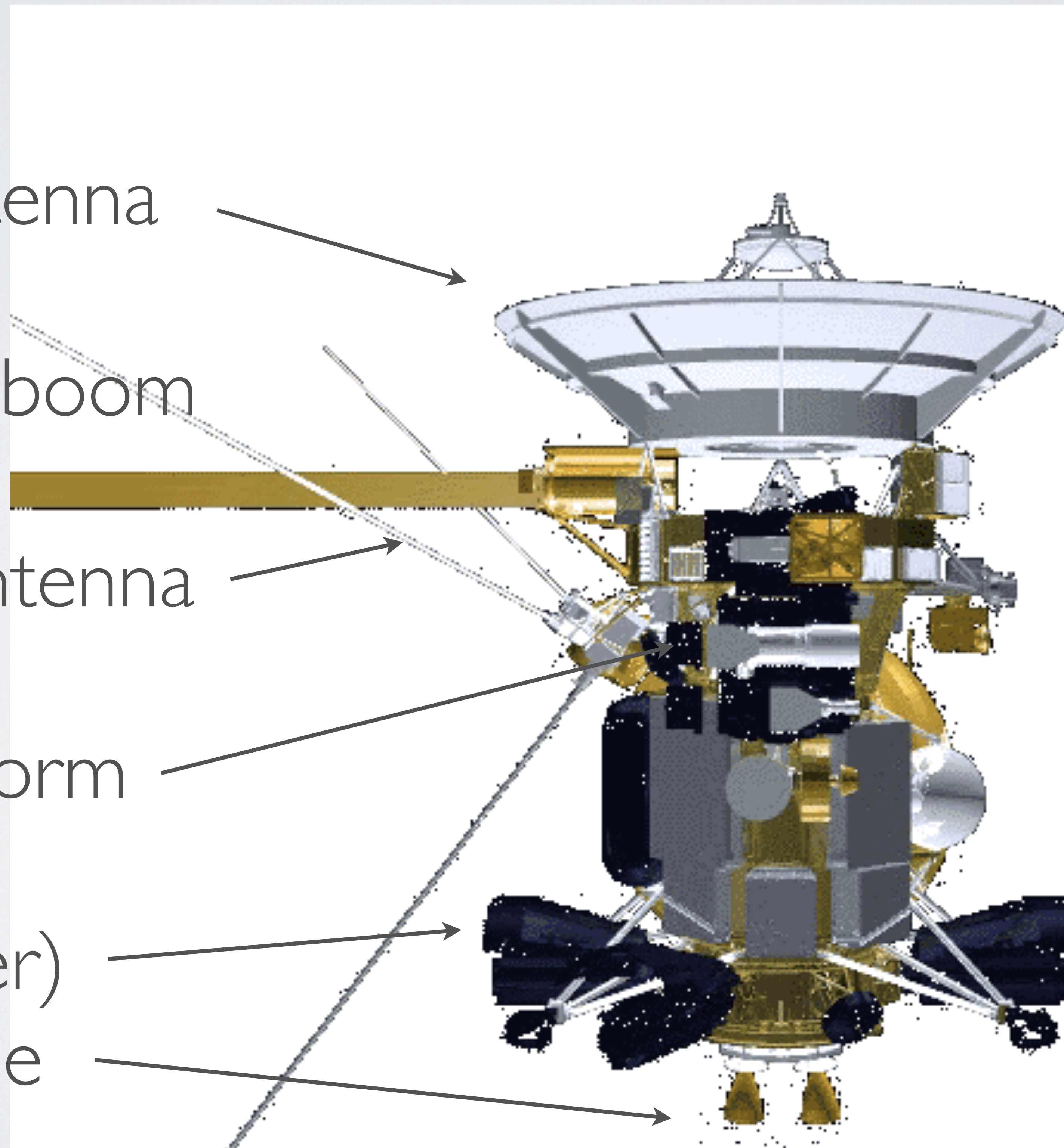
WINDS OF SATURN
(UP TO 500 M/S)

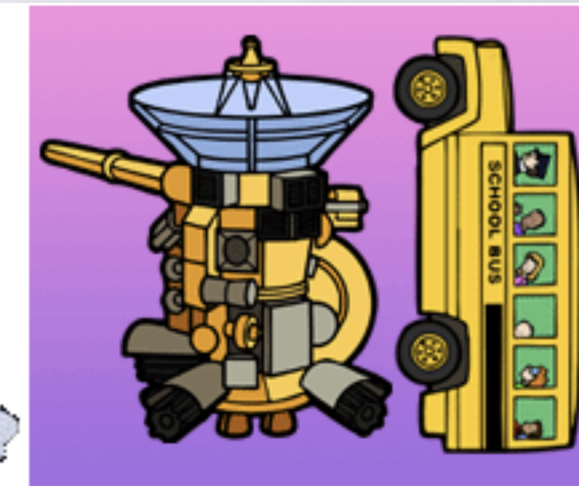


MOON MYSTERIES

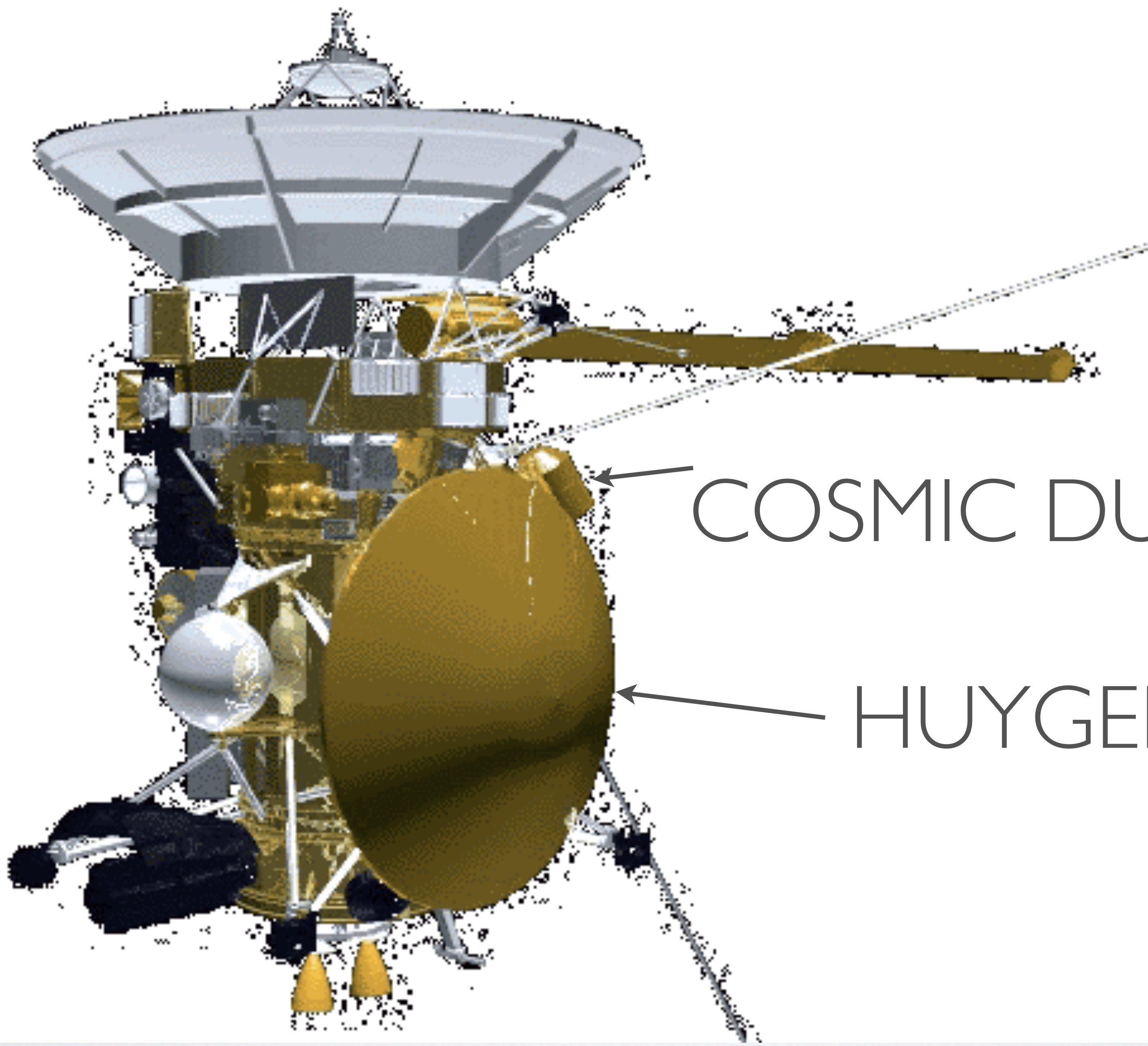
- Pandora and Prometheus are shephard moons for ring
- Dione and Tethys have own moons
- Janus and Epimetheus exchange their orbit
- Iapetus has a dark and bright side
- Mimas has a huge impact crater (1/4 of surface)
- Enceladus is active (ice geysers), highest albedo
- Phoebe has a retrograde orbit, KB object caught by Saturn (?)

CASSINI/HUYGENS





CASSINI SPACECRAFT



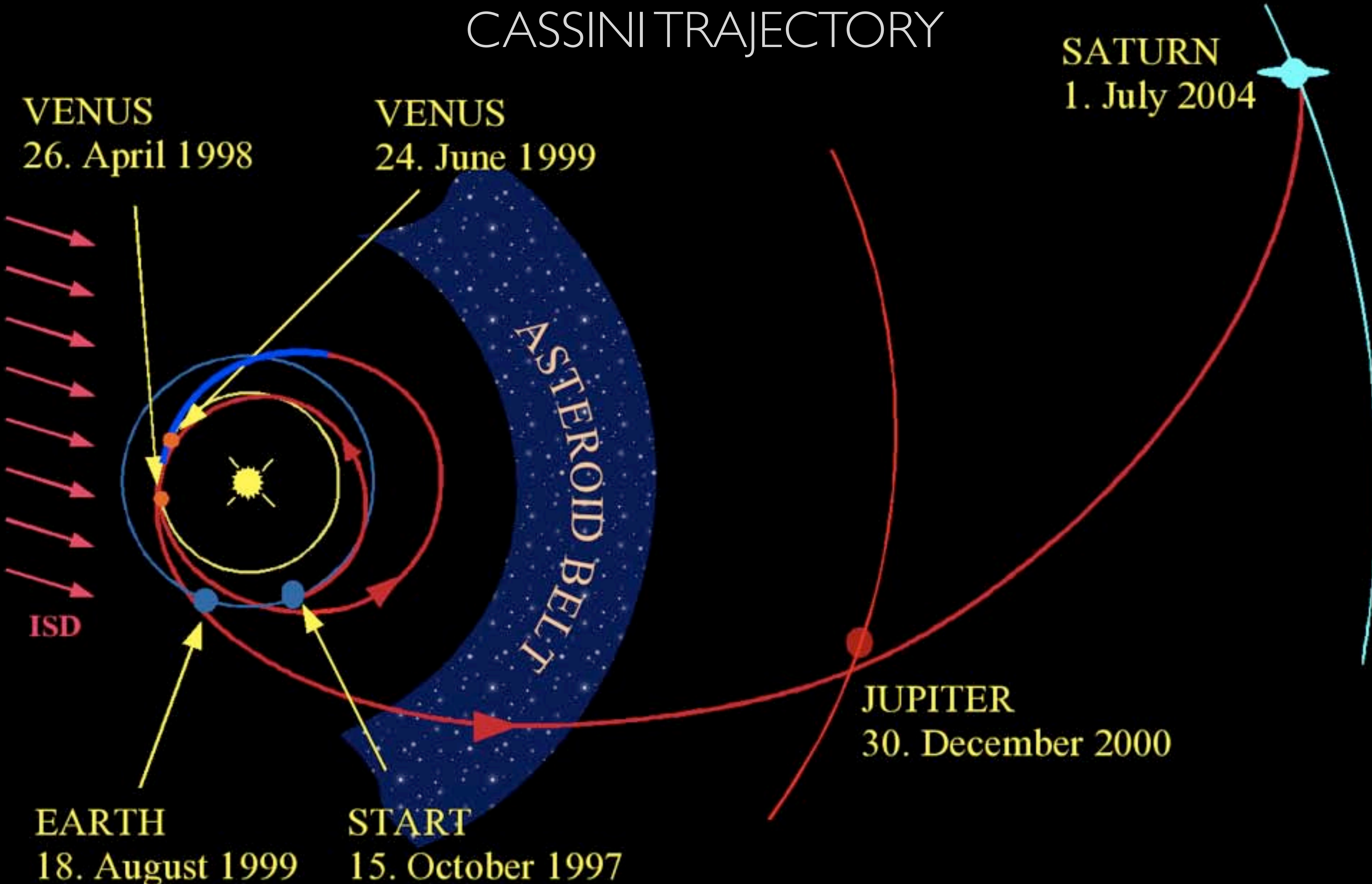
CASSINI FACTS

Program partners : NASA, ESA, ASI
17 countries
international engineers and scientists: 5000
costs : 1.4 billion (pre-launch development)
$ 710 M mission operations
$ 54 M tracking
$ 422 M launch vehicle
$ 500 M ESA (Huygens)
$ 160 M ASI
$ 3.27 billion, U.S. $2.6, Europe $ 660 M

CASSINI BUS

dry mass 2.11 + 320 kg Huygens probe + 3.1 t propellent = 5.7 t
height : 6.8 m, 4m antenna, boom 11 m
22.000 wire connections, 12 km cabling
largest interplanetary S/C ever launched
3 RTGs, 750 W + small radio-isotope heaters everywhere
Main Engine : Mono-methyl-hydrazin, N-tetraoxid oxidator
16 small thrusters (Hydrazin)
Inertial Reference Unit - perform turns/firings while retain knowledge of own position
X Band, 20 W, Ka, S, Ku
ADA software, 2x2 Gbit Solid State Recorder,
1MB memory for command subsystem, 16 kB PROM
redundant computers
4 Gyros, cover for main engine
Main engine : 445 Newton, gimbaled to maintain vector if CoM changes

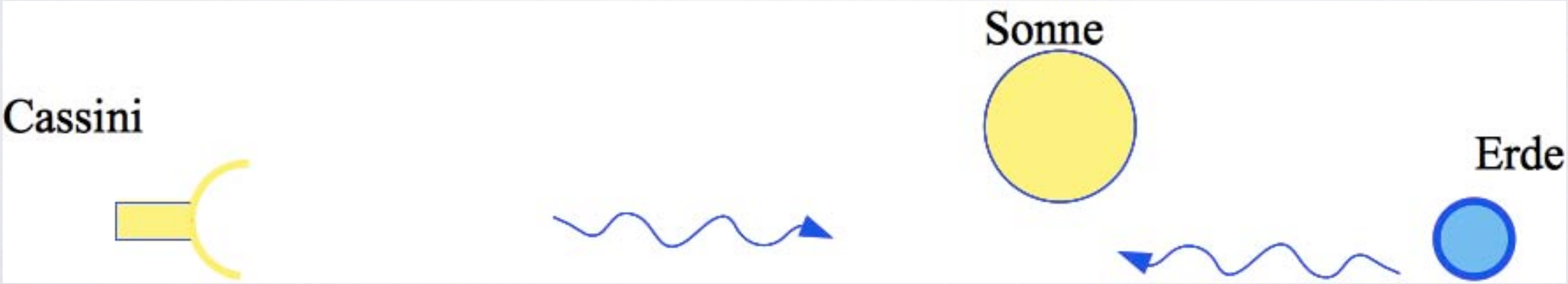
CASSINI TRAJECTORY



CRUISE SCIENCE: NOT ONLY SATURN ...

Cassini searches for gravity waves with radio science subsystem

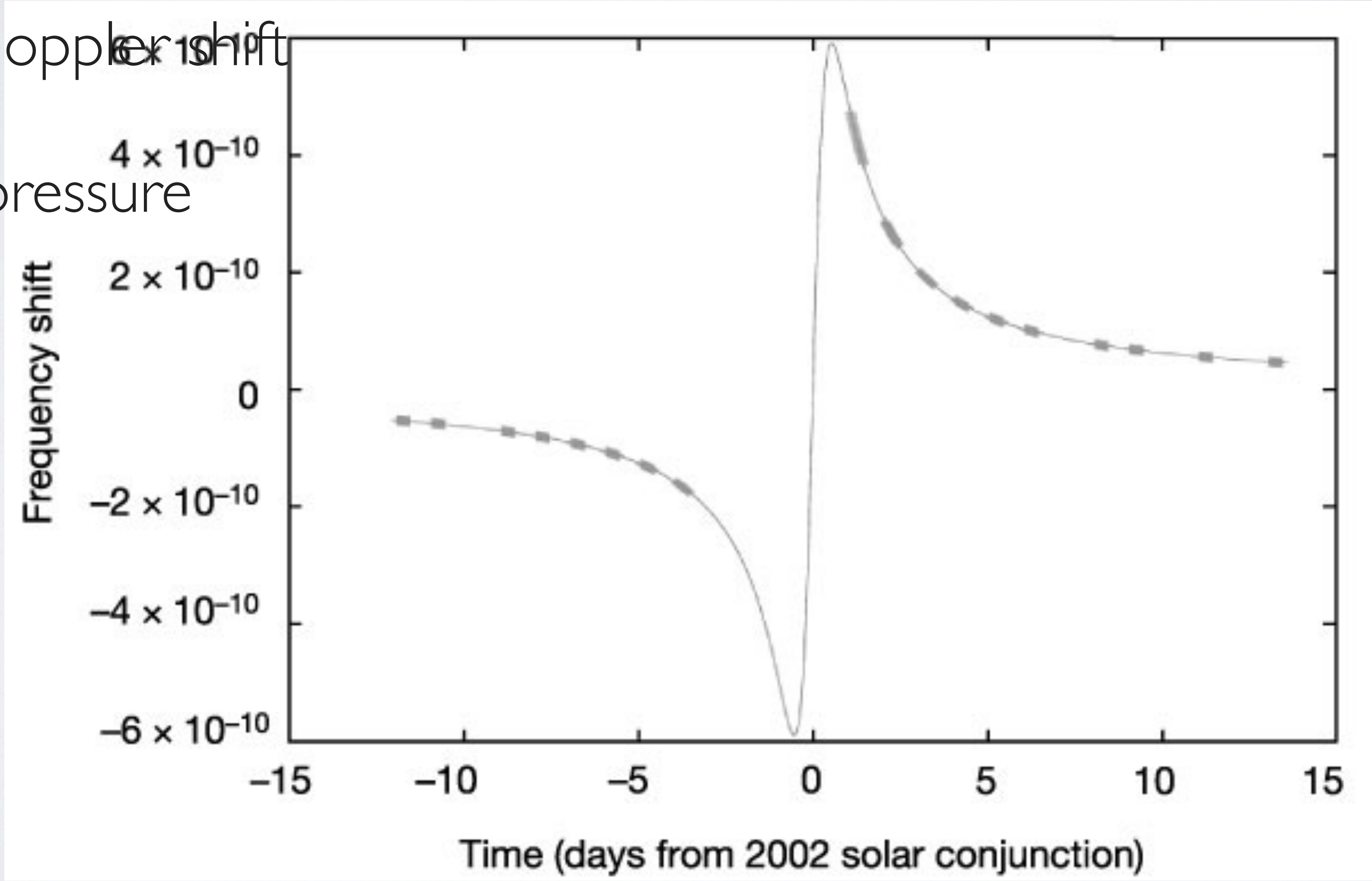
Cassini confirms general relativity theory during conjunction (Cassini - Sun - Earth) in June 2002 , Nature 2003



EINSTEIN WAS RIGHT

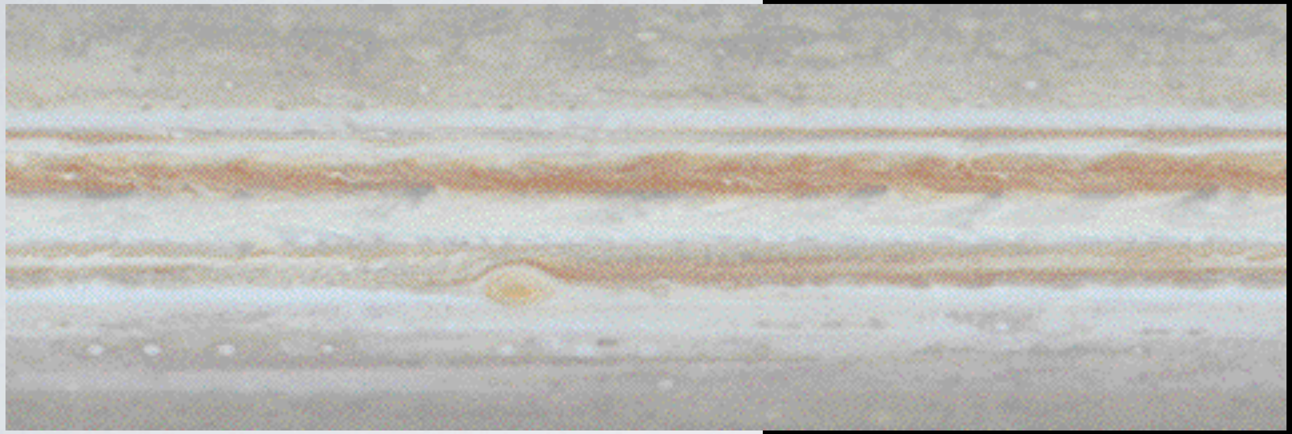
frequency shift after corrections

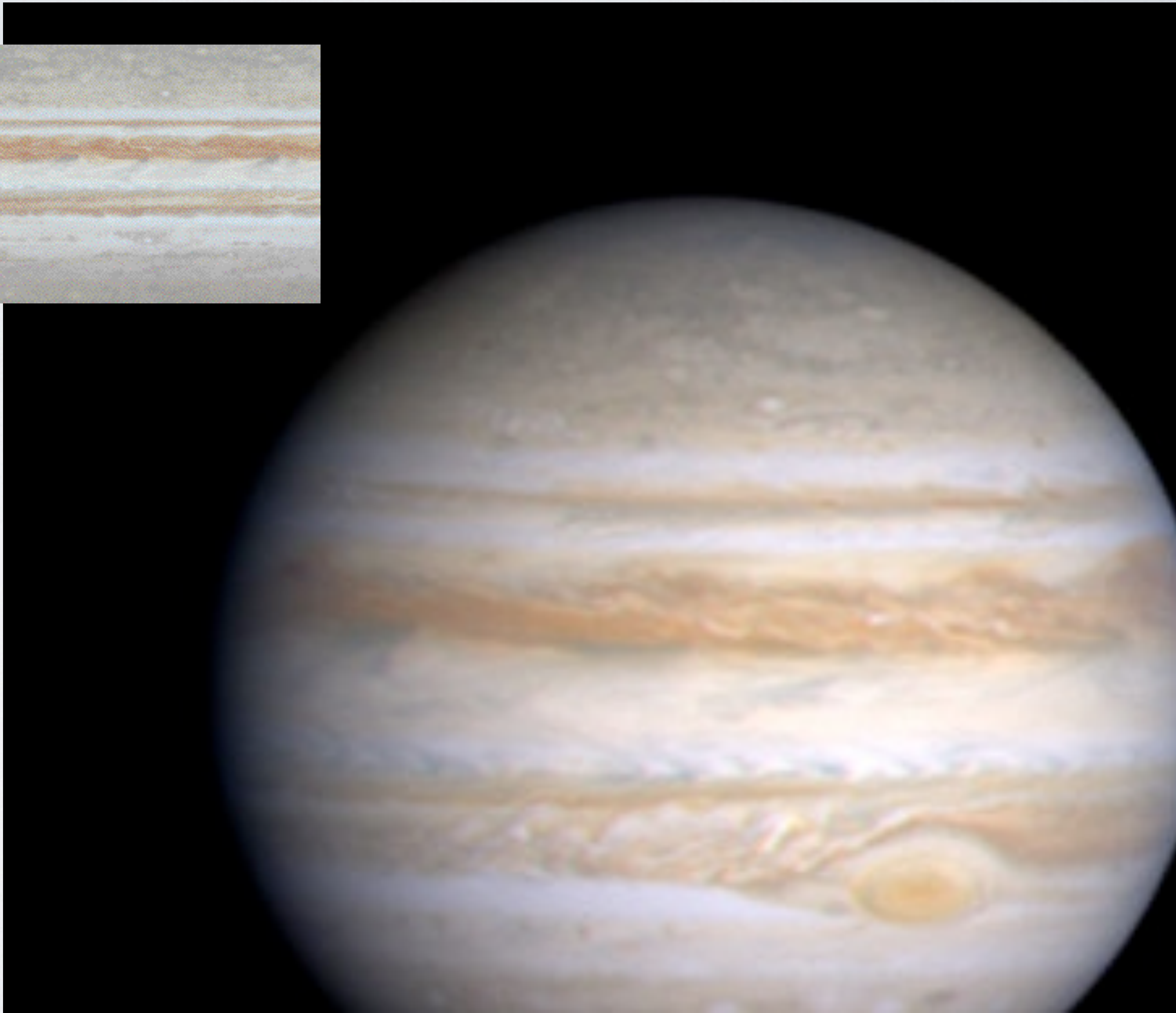
correction for doppler shift
due to
solar radiation pressure
non-isotrope
heat emission
of RTGs, ...



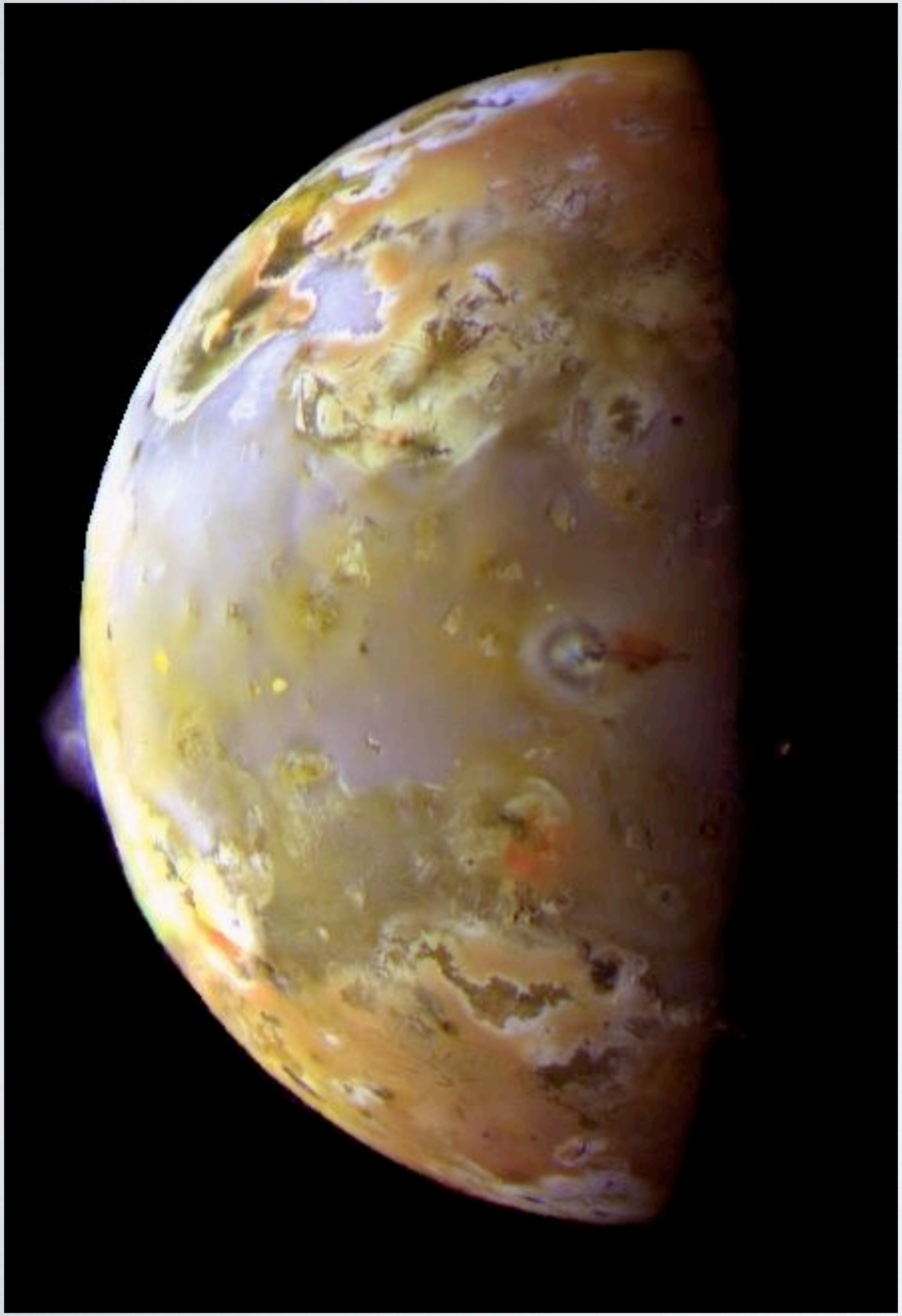
JUPITER SCIENCE

2000

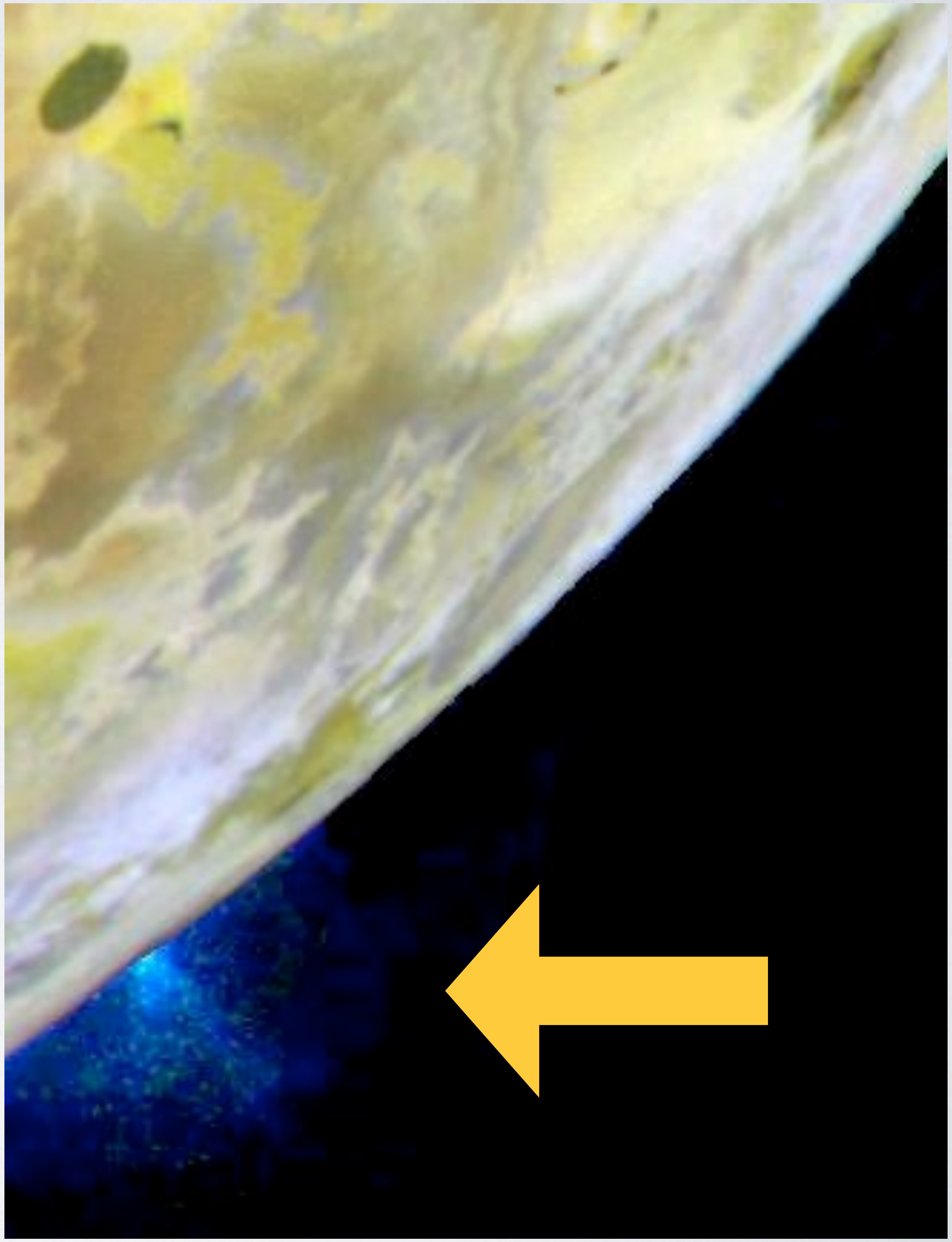




DUST FROM JUPITER

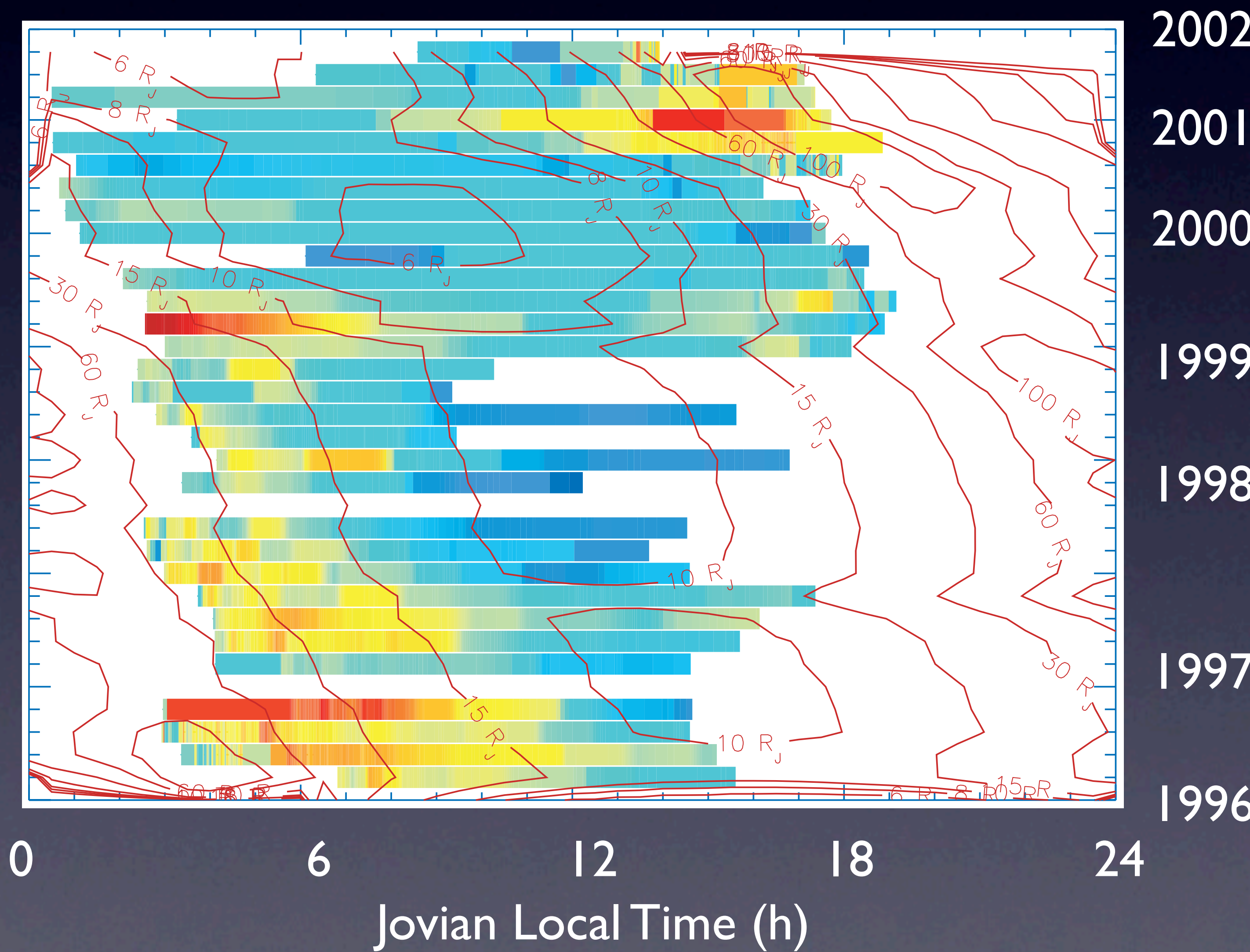


„Io Ashes"



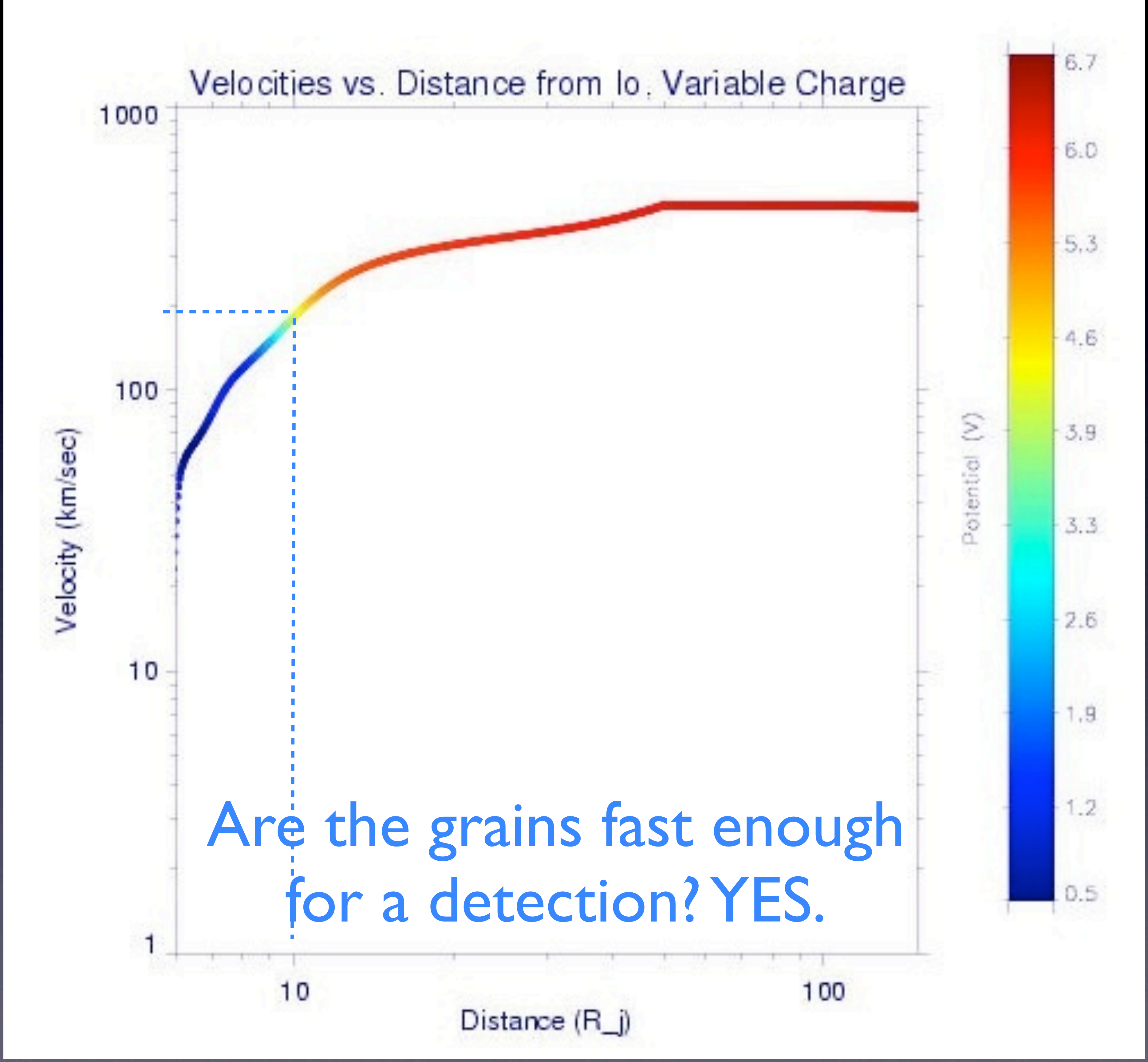
„Io Ashes“ - Stream Particles

- Origin: Io Volcanoes
- Size: 5 ... 40 nm
- Dynamics Dominated by EM Forces
- Fast Enough to Escape From Jovian System
- Allow to Monitor Io Activity



Krüger et al., GRL, 2003

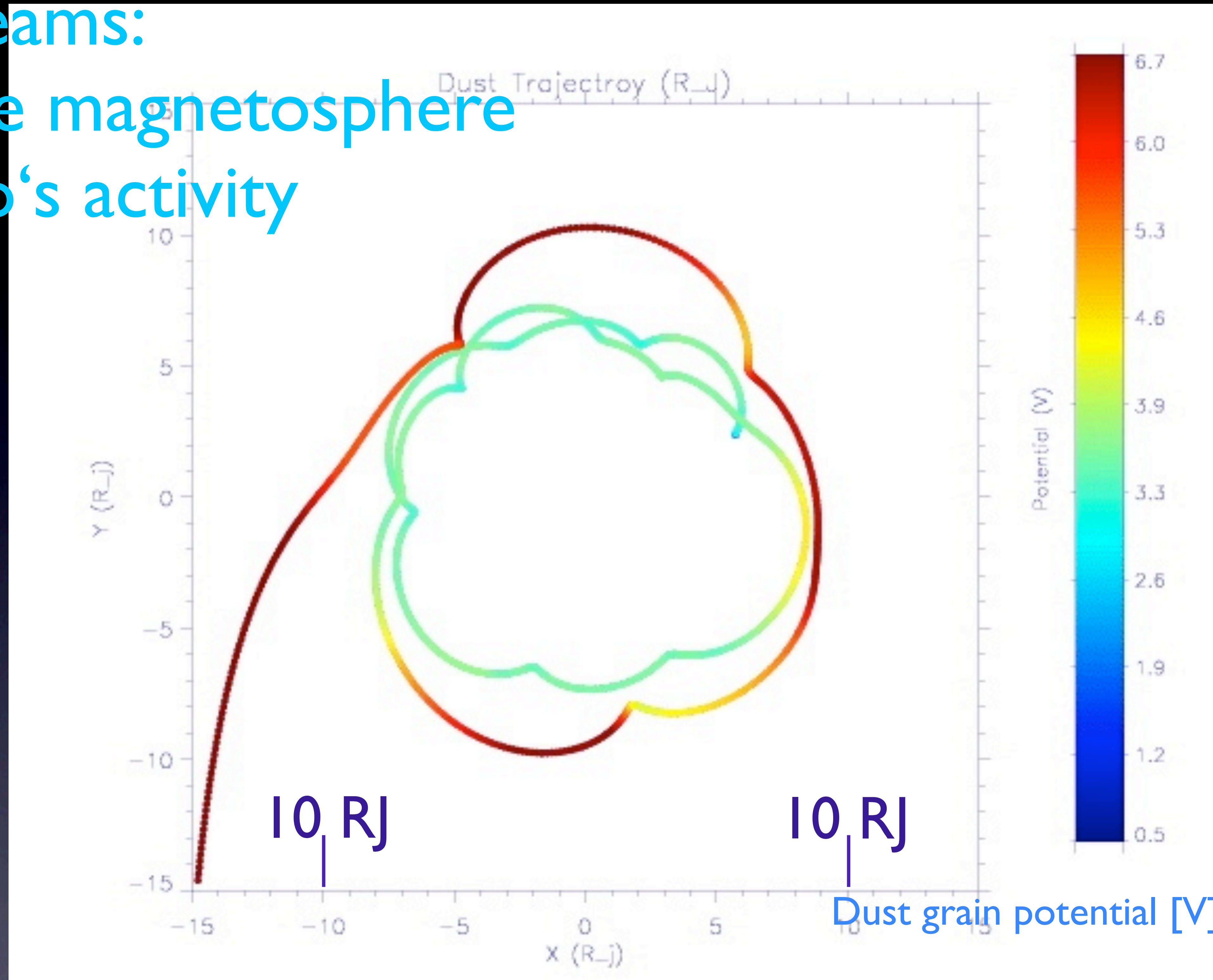
Speed of nano-dust : > 100 km/s



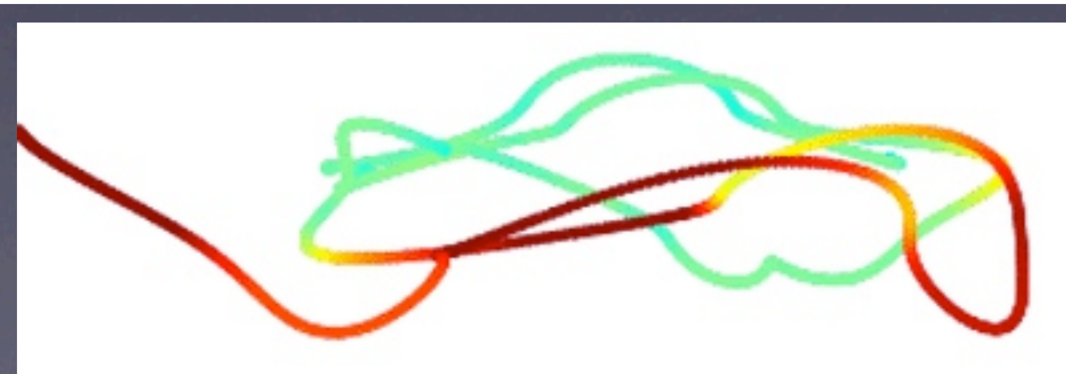
6 nm grains

A. Graps

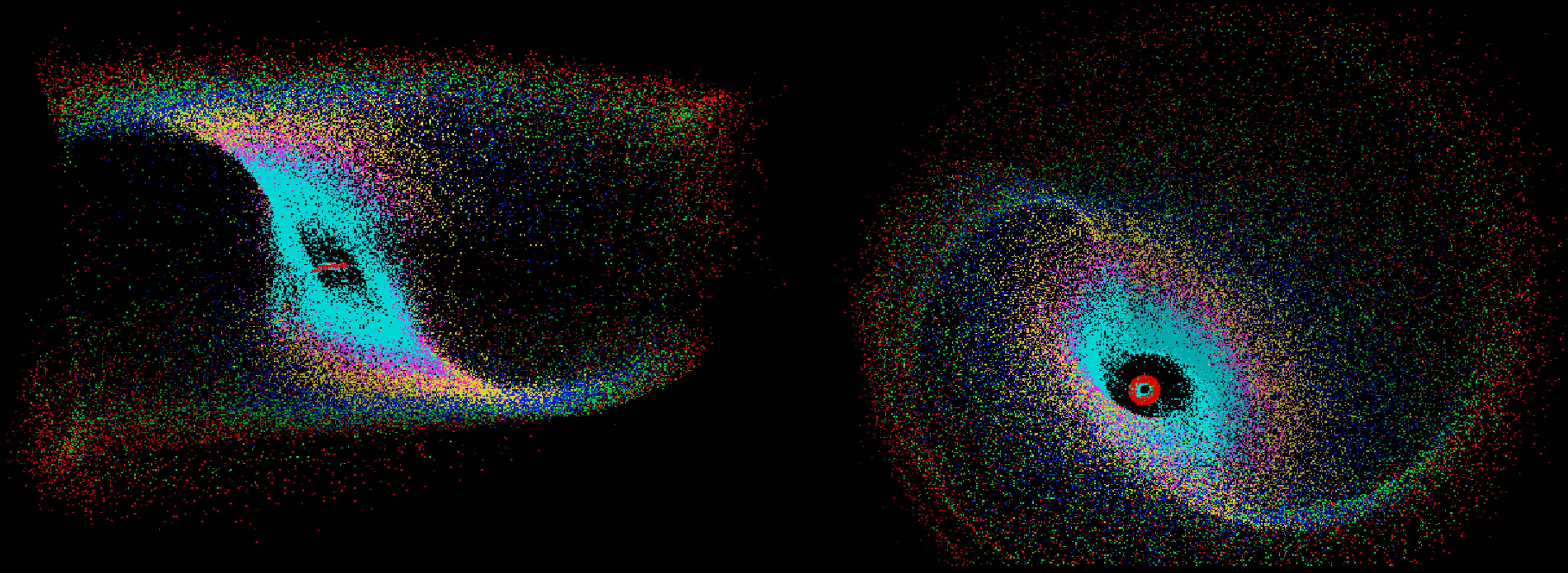
Io‘s dust streams:
Probes of the magnetosphere
Probes for Io‘s activity



5 nm grain (silicate)

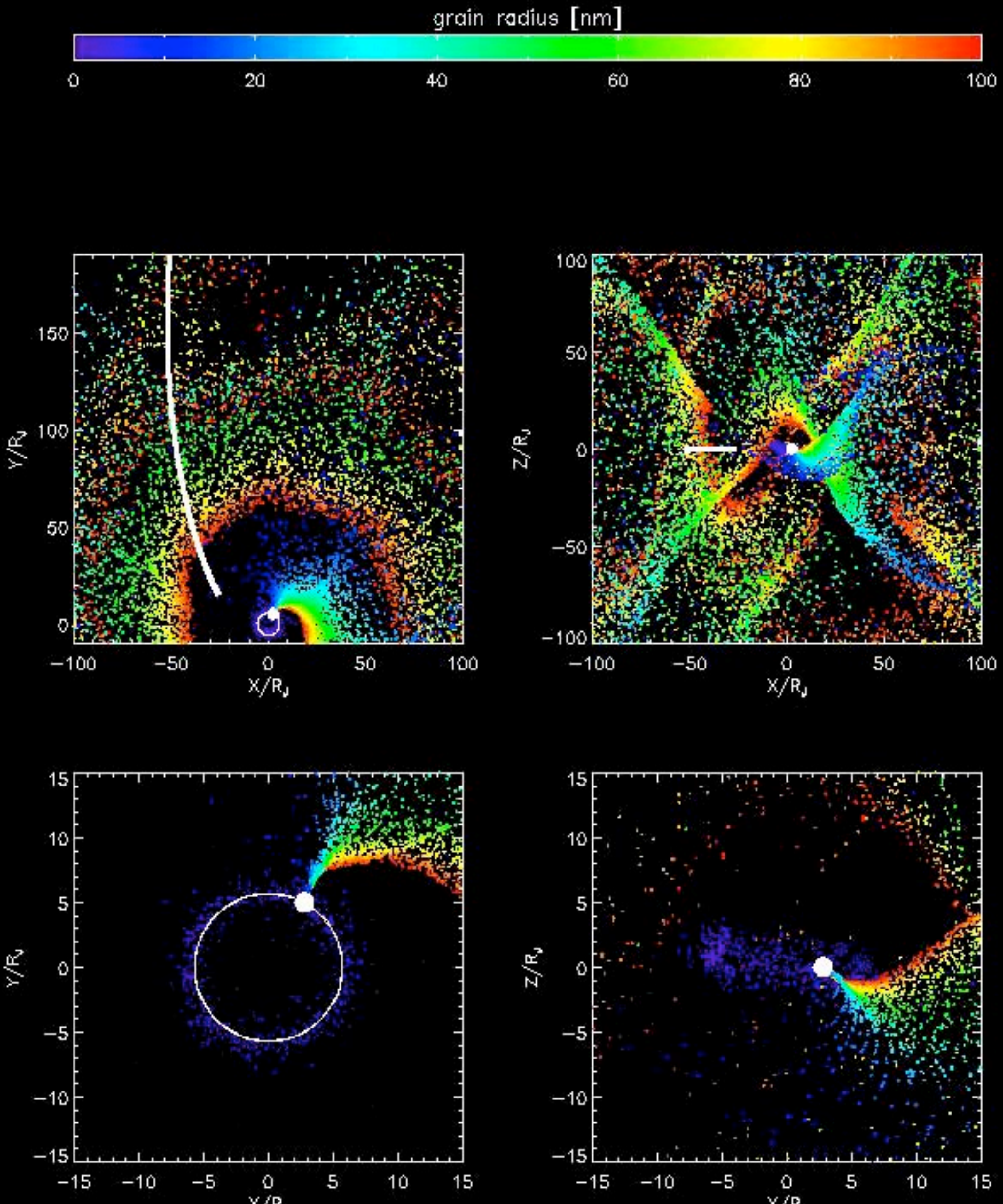


Io as a Dust Source: Nano-Dust Coupling to Magnetosphere



Side View   Top View

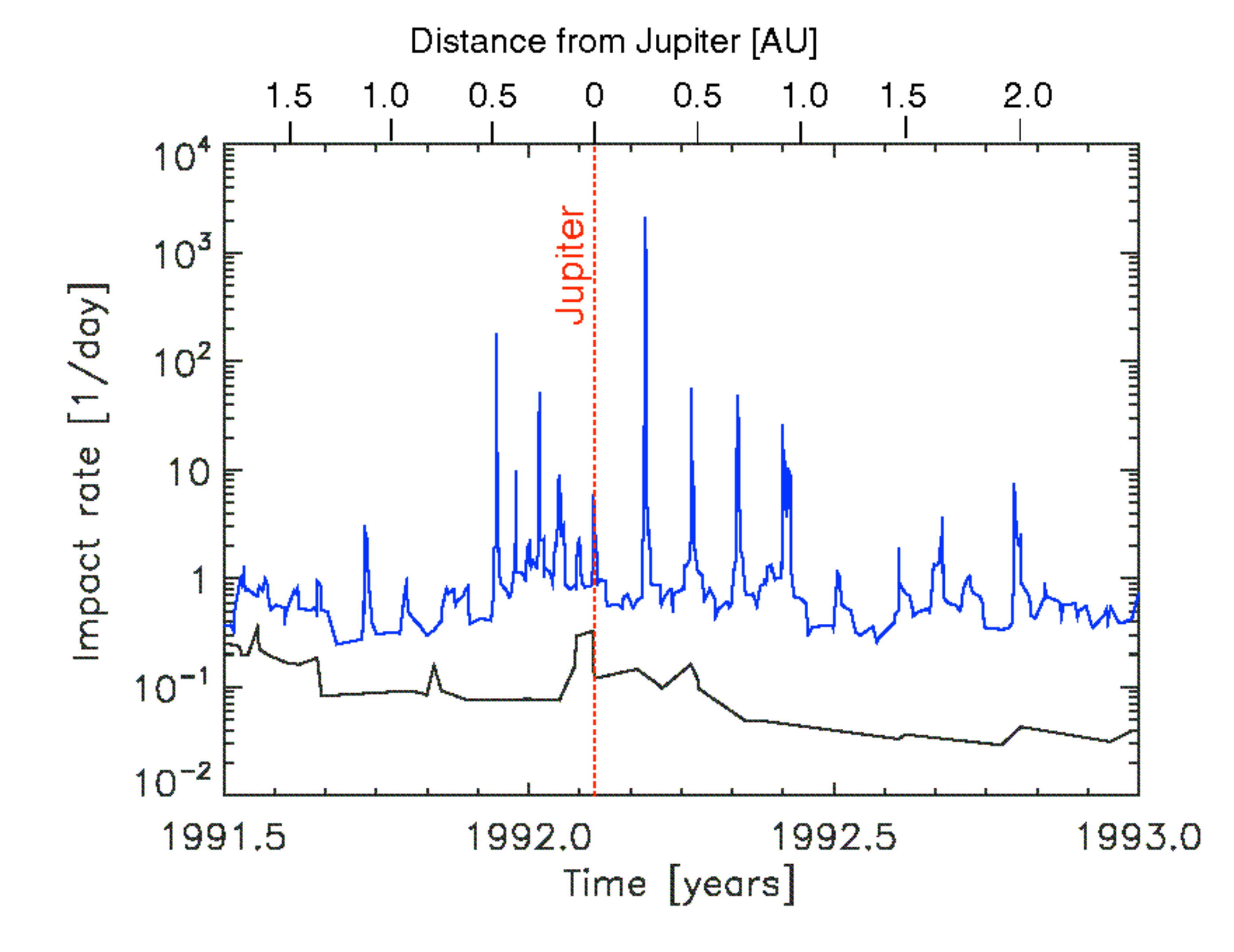
A. Graps


grain radius [nm]
0
20
40
60
80
100
Y/R_J
X/R_J
Z/R_J
−100
−50
0
50
100
150
−15
−10
−5
5
10
15

M. Horanyi

Io as a Dust Source in the Jovian System

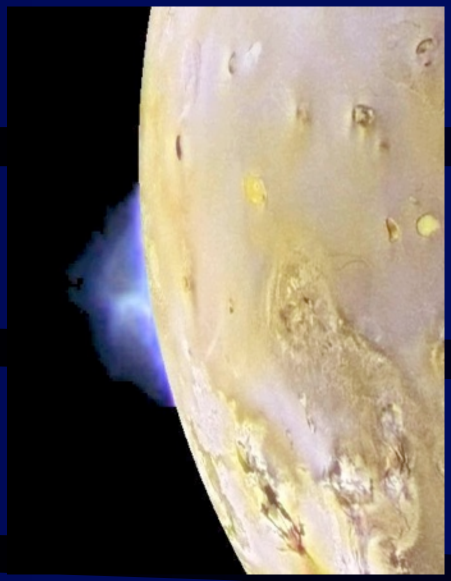
- Streams of electrically charged dust grains emanating from the jovian system (Grün et al., 1993)
- 26 day periodicity (Krüger et al., 2006)
- Interaction with interplanetary magnetic field
- Grain radii: ~ 10 nm, speeds > 300 km/sec (Zook et al., 1996)
- Jupiter's magnetosphere: giant dust accelerator
- Source: Io (Graps et al., 2000)
- Confirmed during 2nd Jupiter flyby in 2004 (Krüger et al. 2006)
- Stream formation due to CIR and CME interaction (Flandes & Krüger, 2007)



H. Krüger

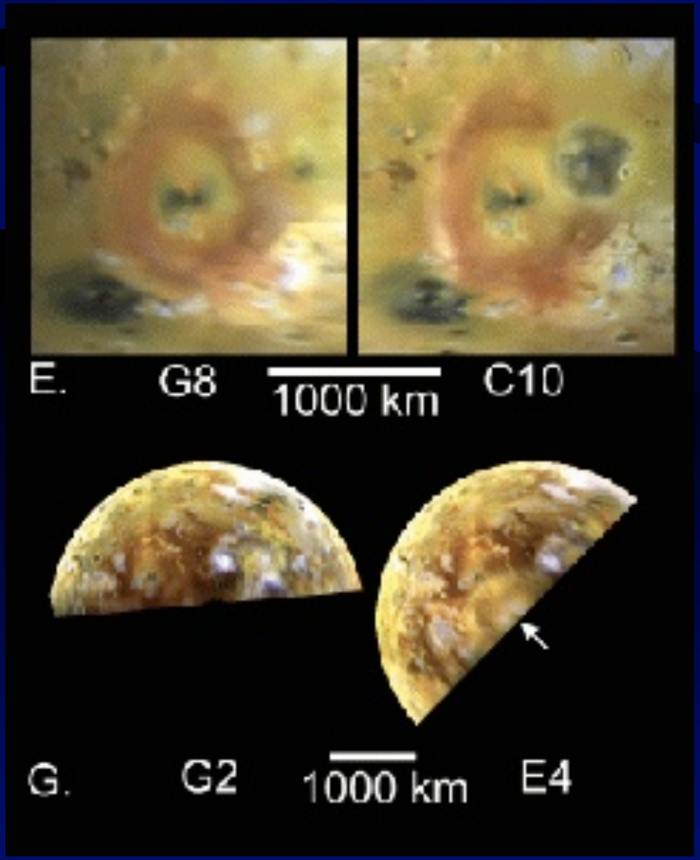
Ulysses

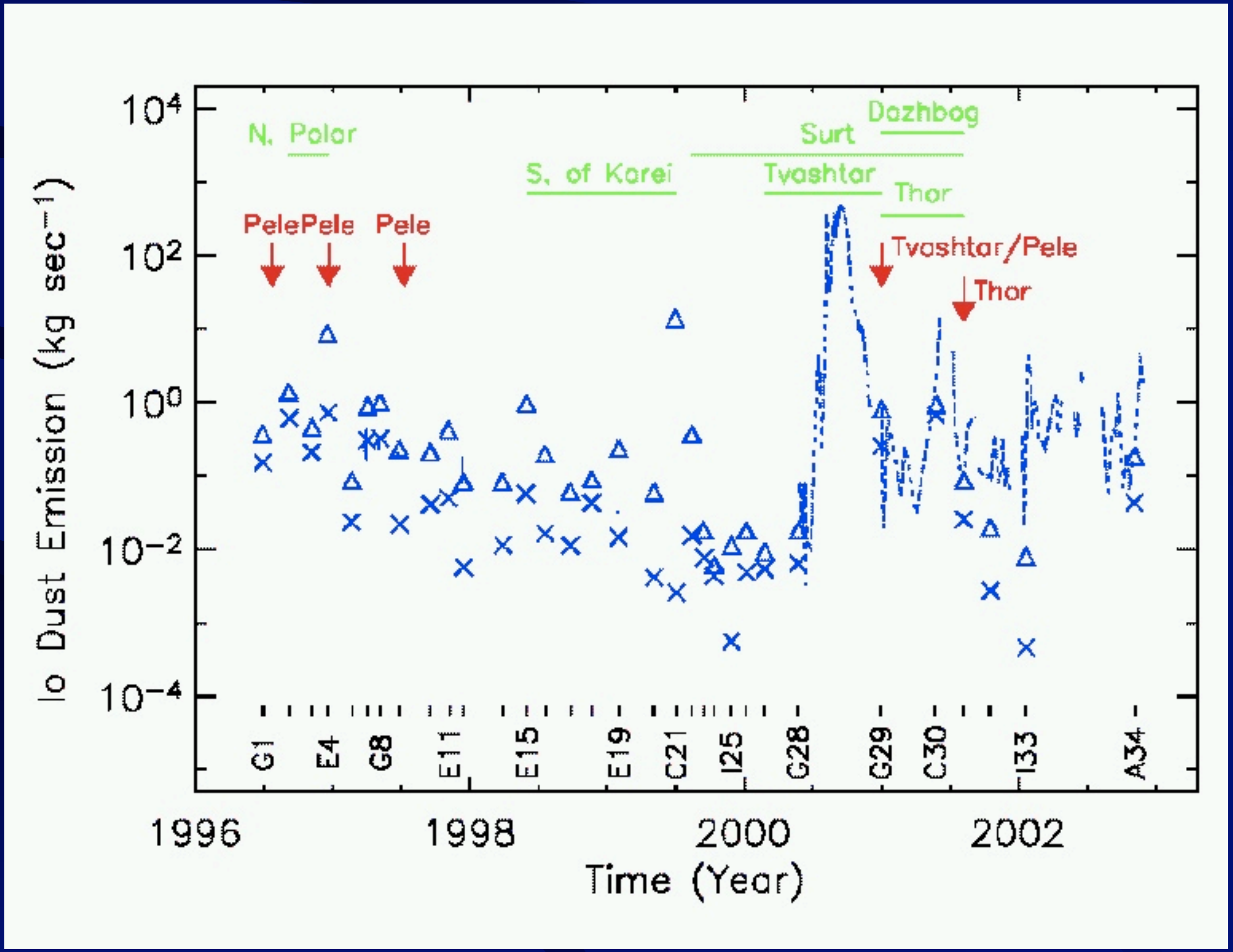
Dust Streams: A Monitor of Io's Volcanism



Io, Galileo

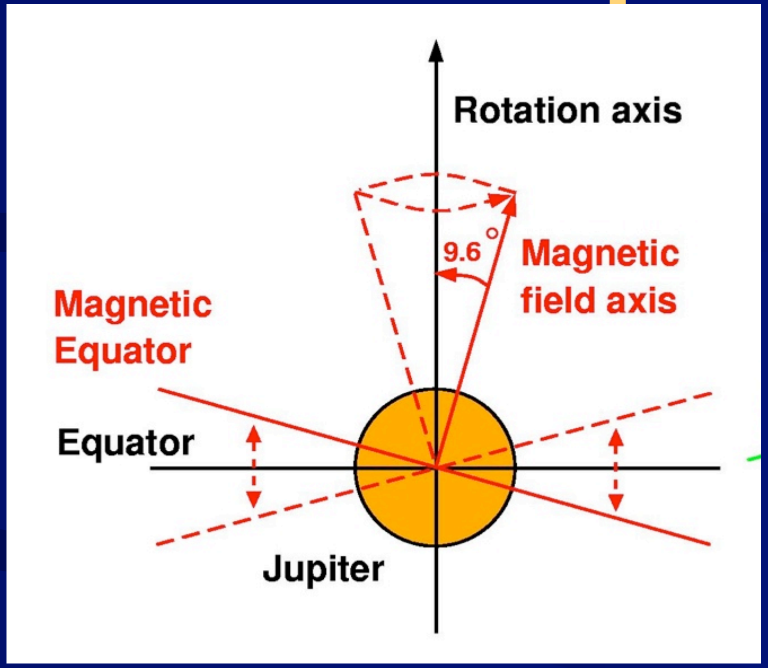
- Average Io dust emission: ~0.1 - 1 kg s^{-1}
- Small compared to ~1 ton s^{-1} of plasma ejected
- Peaks in dust emission coincide with largest surface changes
- Dust condensation in plumes



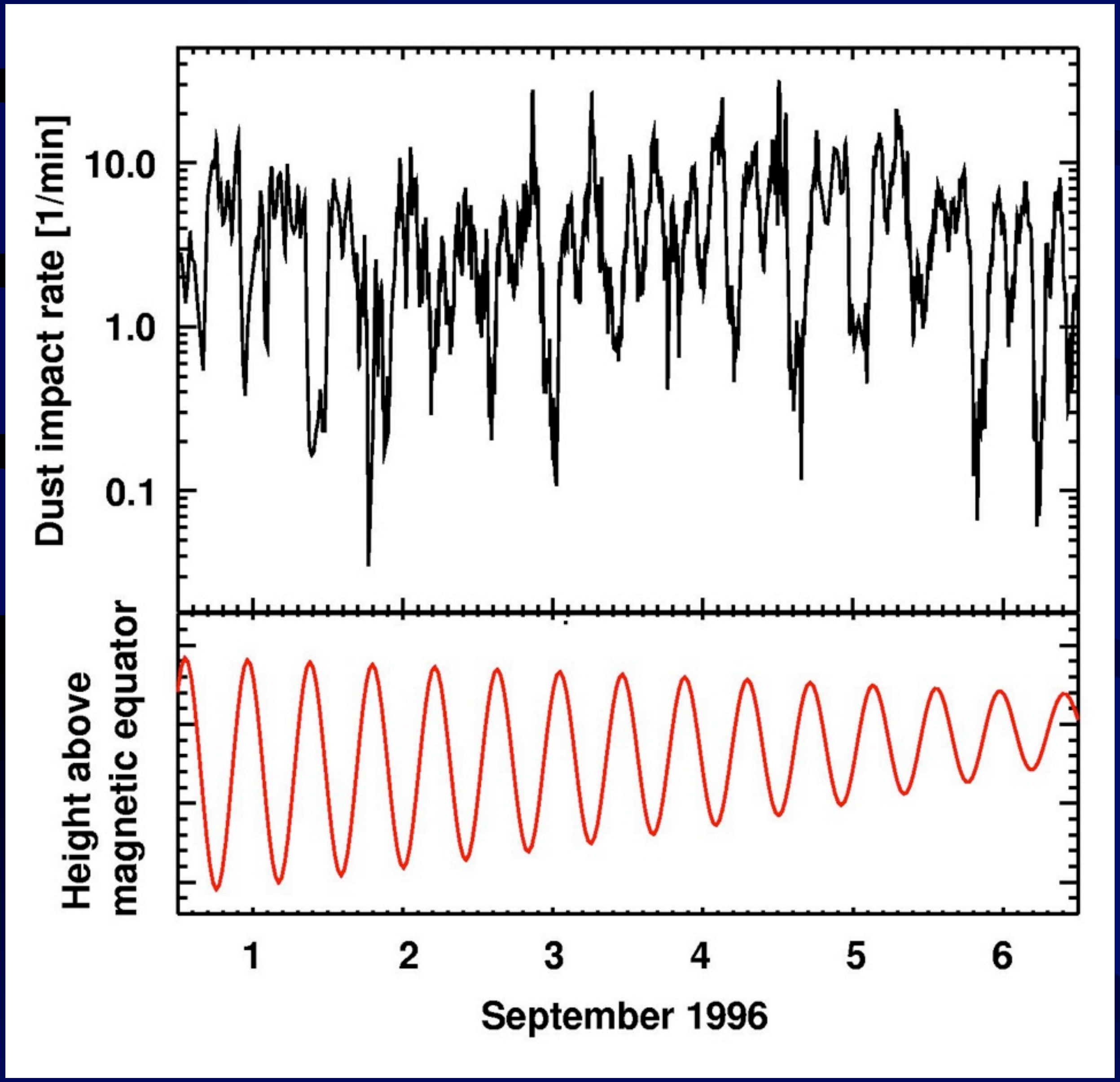


Krüger et al., 2003

Electromagnetically Interacting Dust at Jupiter



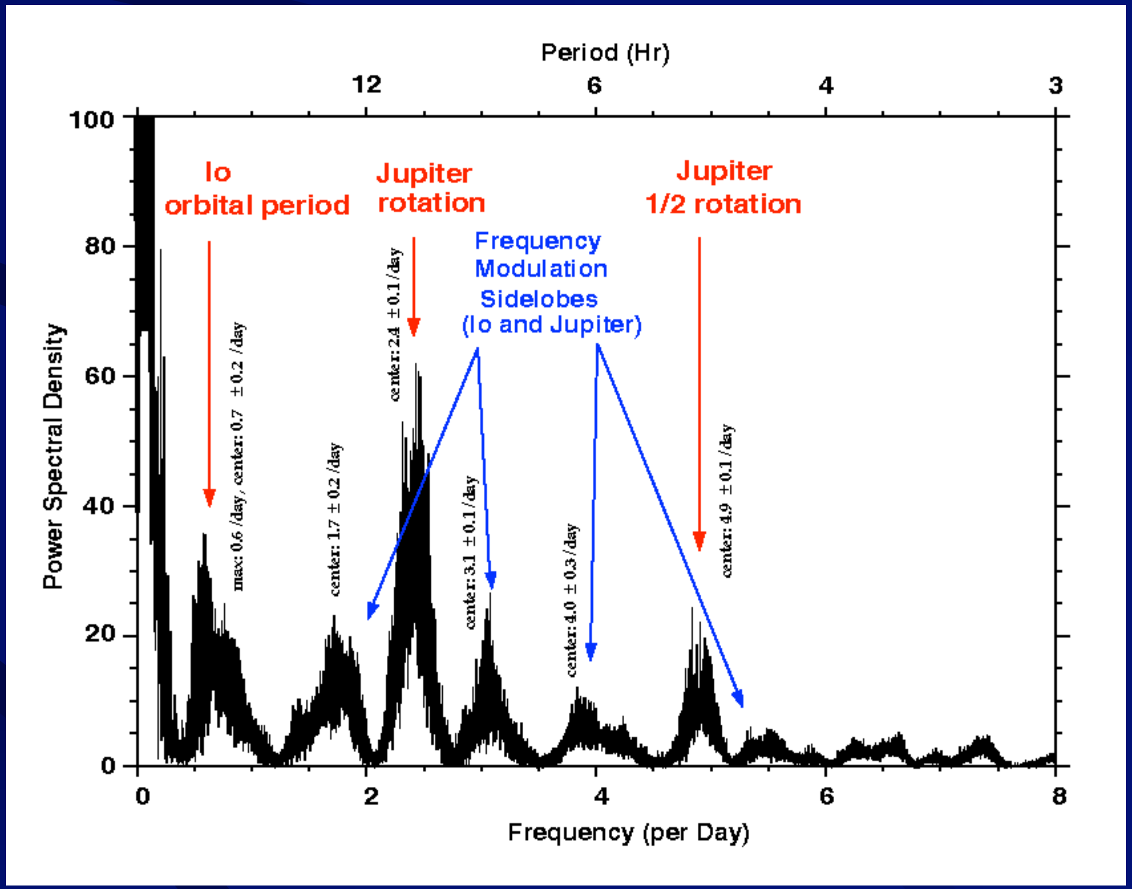
Dust impact rate correlated with Jupiter's 10h rotation period



Grün et al. 1998

Galileo

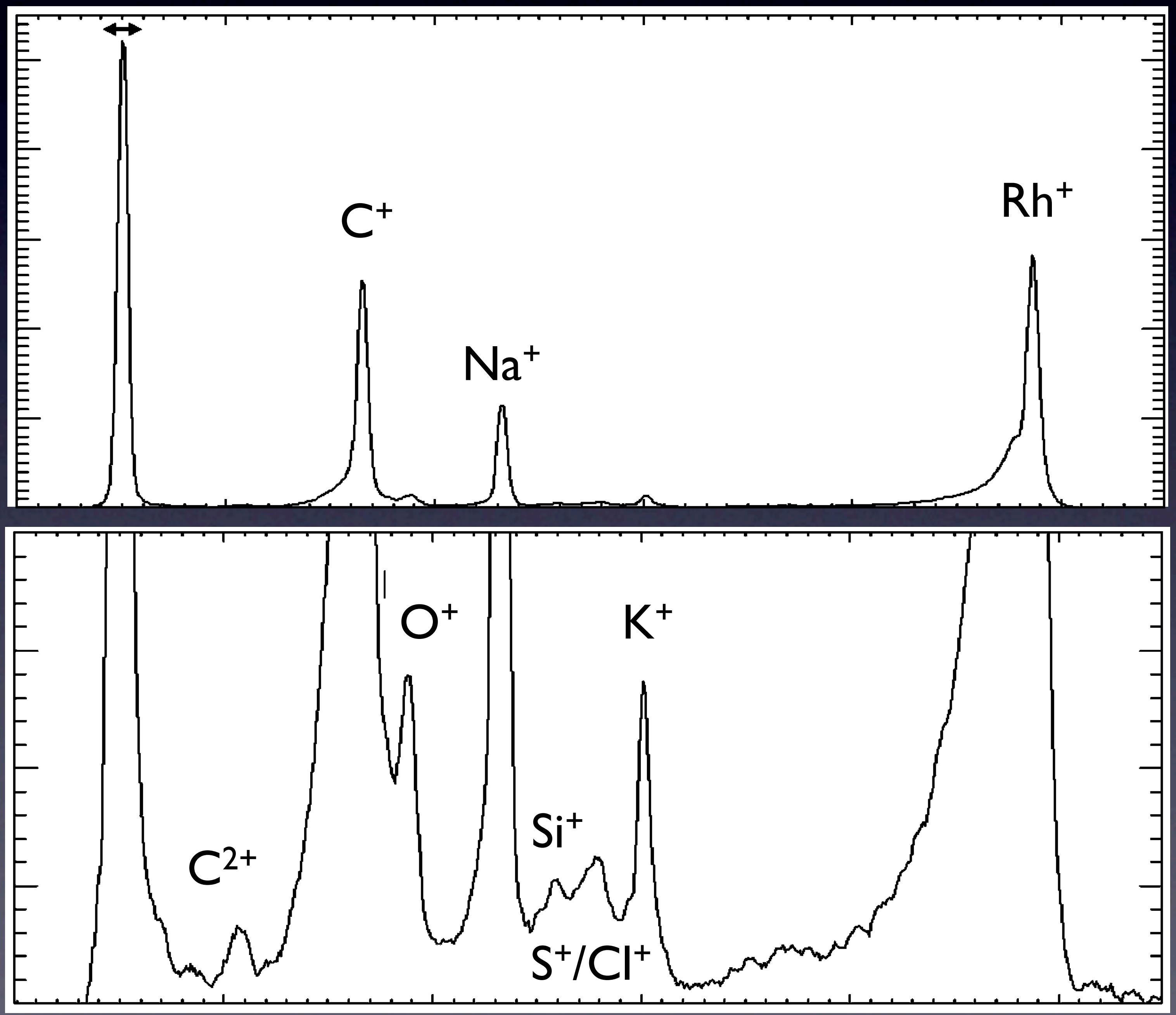
Periodogram of Galileo data



Graps et al. 2000

Particle source: Io

Composition Of Io's Volcanic Matter



Time of Flight

Io Ashes Mostly NaCl Crystals

Postberg et al., Icarus, 2006

Cosmic Dust Analyser (CDA)

Dust detector on Cassini spacecraft:

- dust mass/velocity: impact ionisation detector
- chemical composition: time of flight mass spectrometer
- dust charge/velocity/impact angle: charge sensitive entrance grids
- high rate detector (HRD)

CDA measurement range

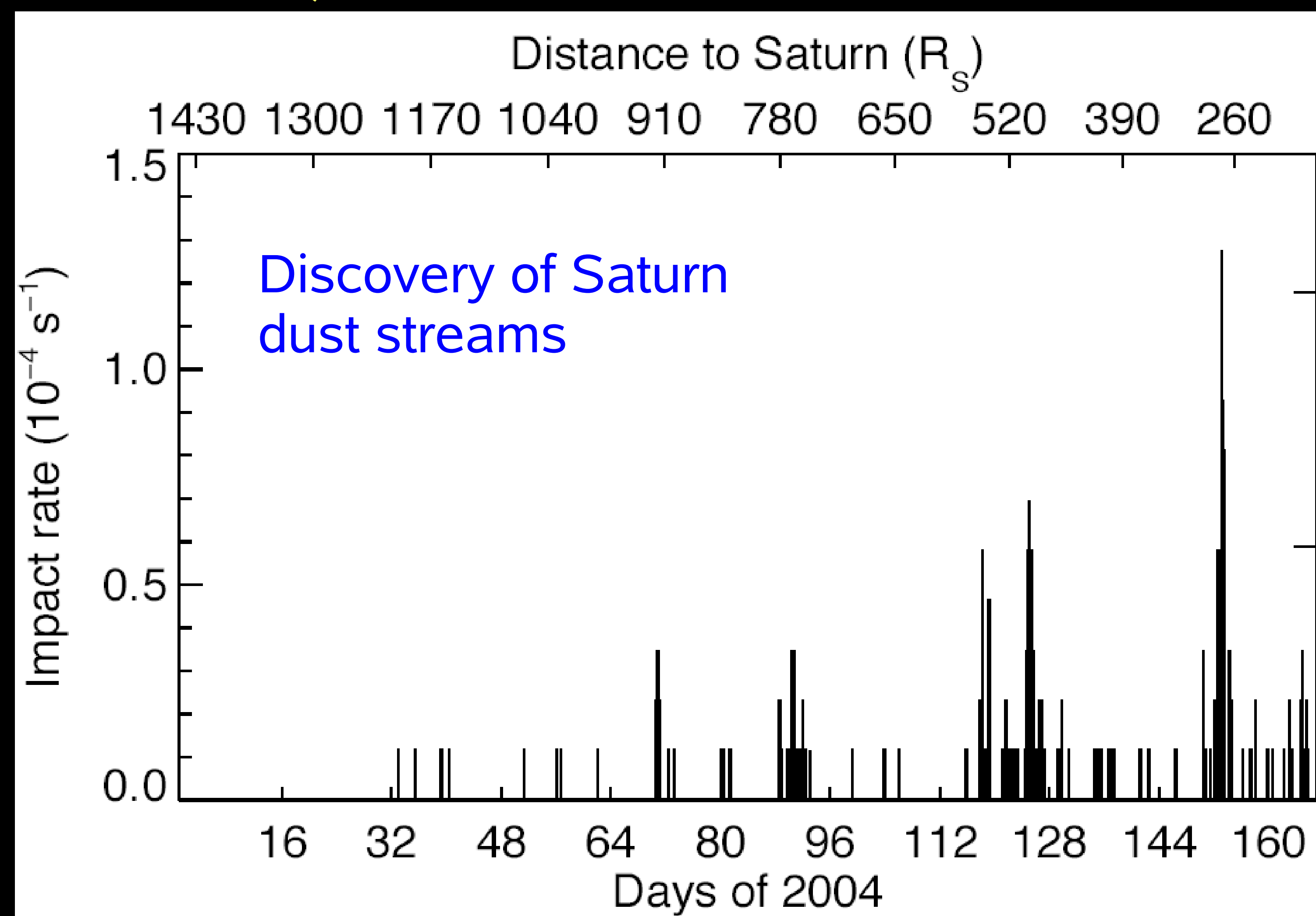
- Sensitive area: 0.1 m^2
- Dust speed: 1-100 km s^{-1}
- Dust mass: 10^{-15}-10^{-9} g (@20 km s^{-1})
- Dust charge: 10^{-15} - 10^{-13} C
- Dust composition: 20-50 mass resolution
- Impact counting rate: 1/week-10000/s

1000 times more sensitive than optical measurements

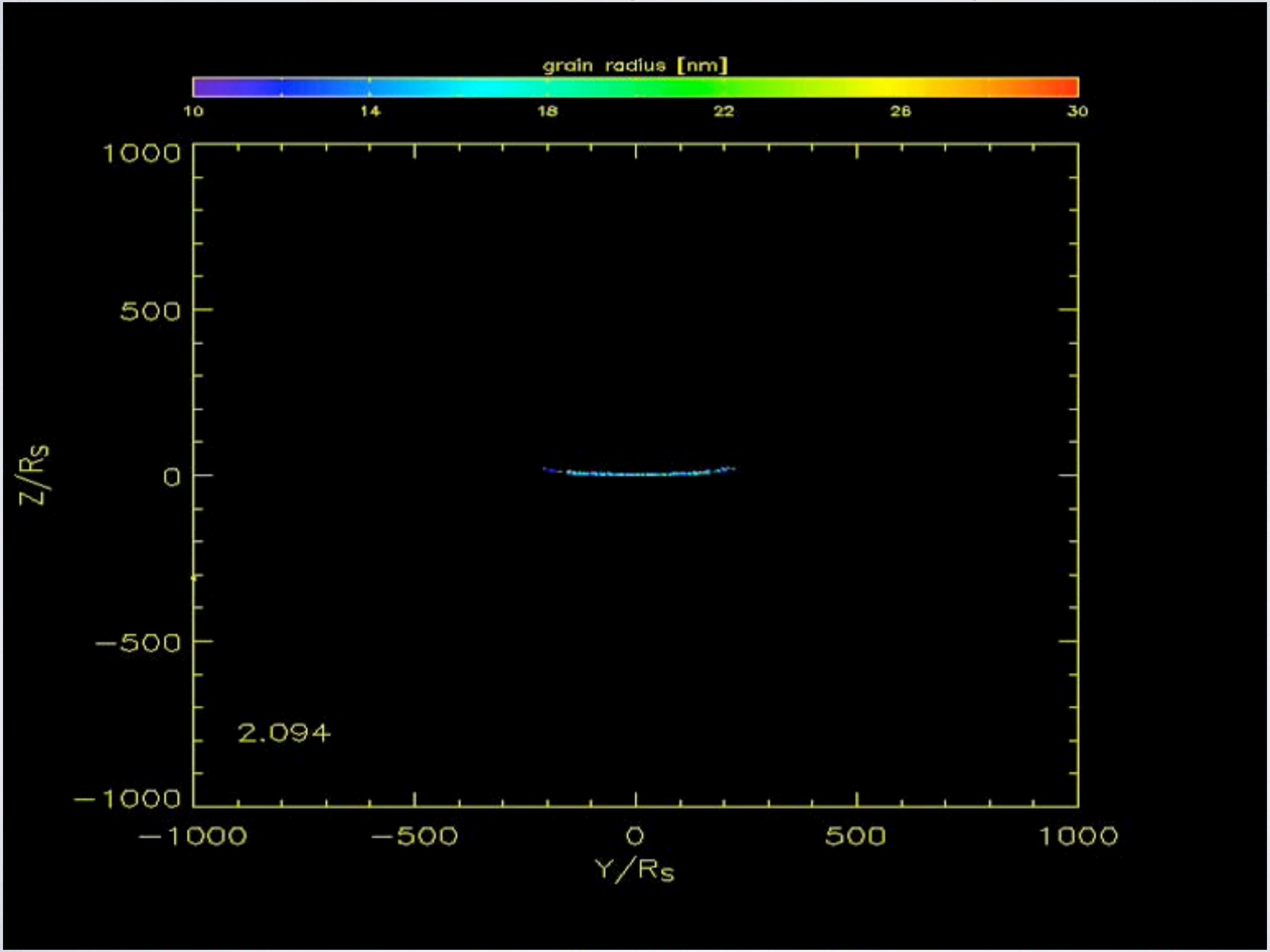
CDA finds one particle within one km^3

CDA Science Highlights I (Cruise)

- Streams of nano-dust from Saturn :
  Discovery, compositon and dynamics,
  coupling between CIRs/CMEs and dust stream dynamics (S. Kempf, Nature)
- Origin of particles detected during the approach to Saturn is the A ring
- Composition of these particles: silicates

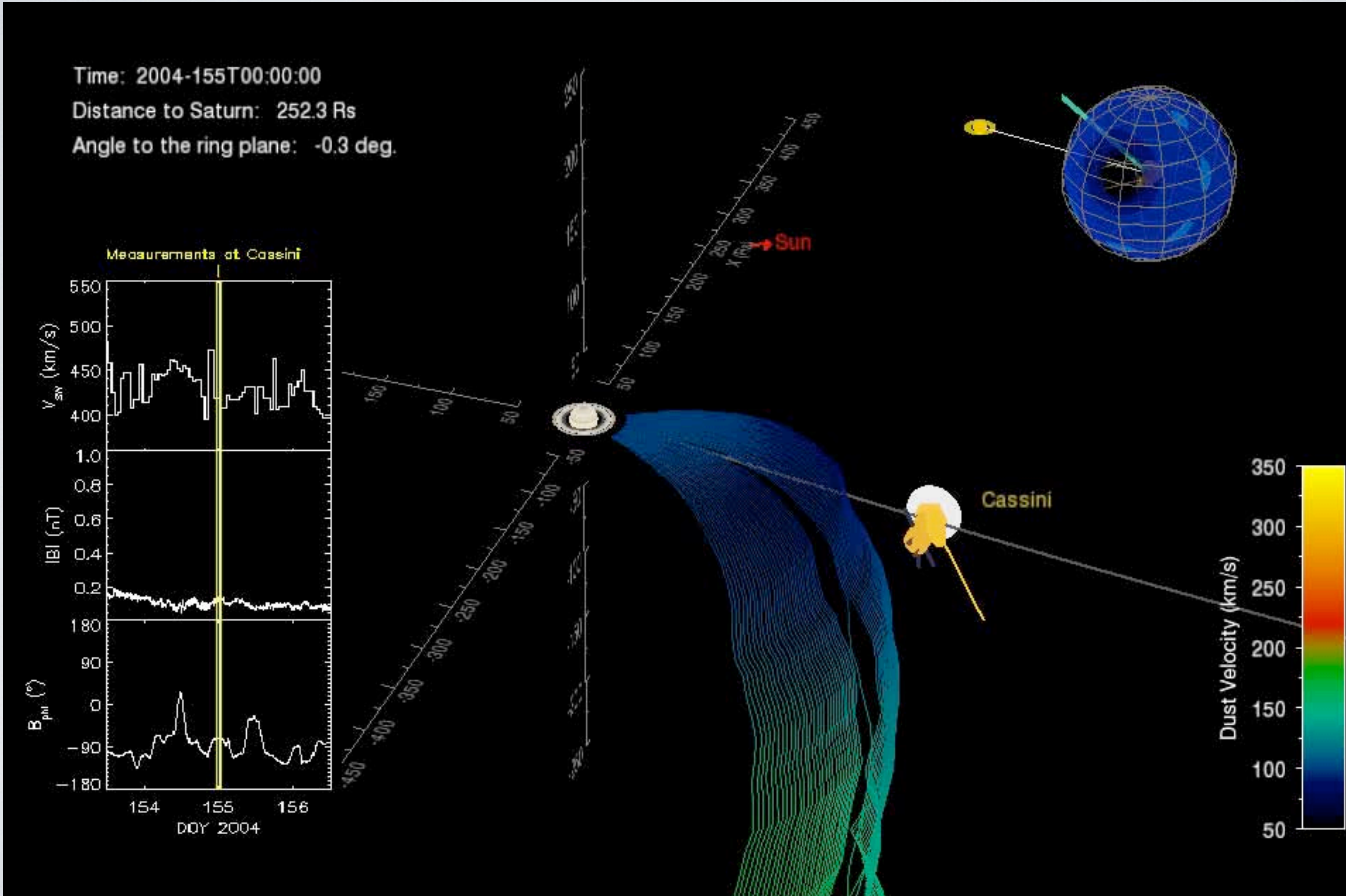


SIMULATION OF ESCAPING DUST STREAMS FROM SATURN (M. HORANYI)

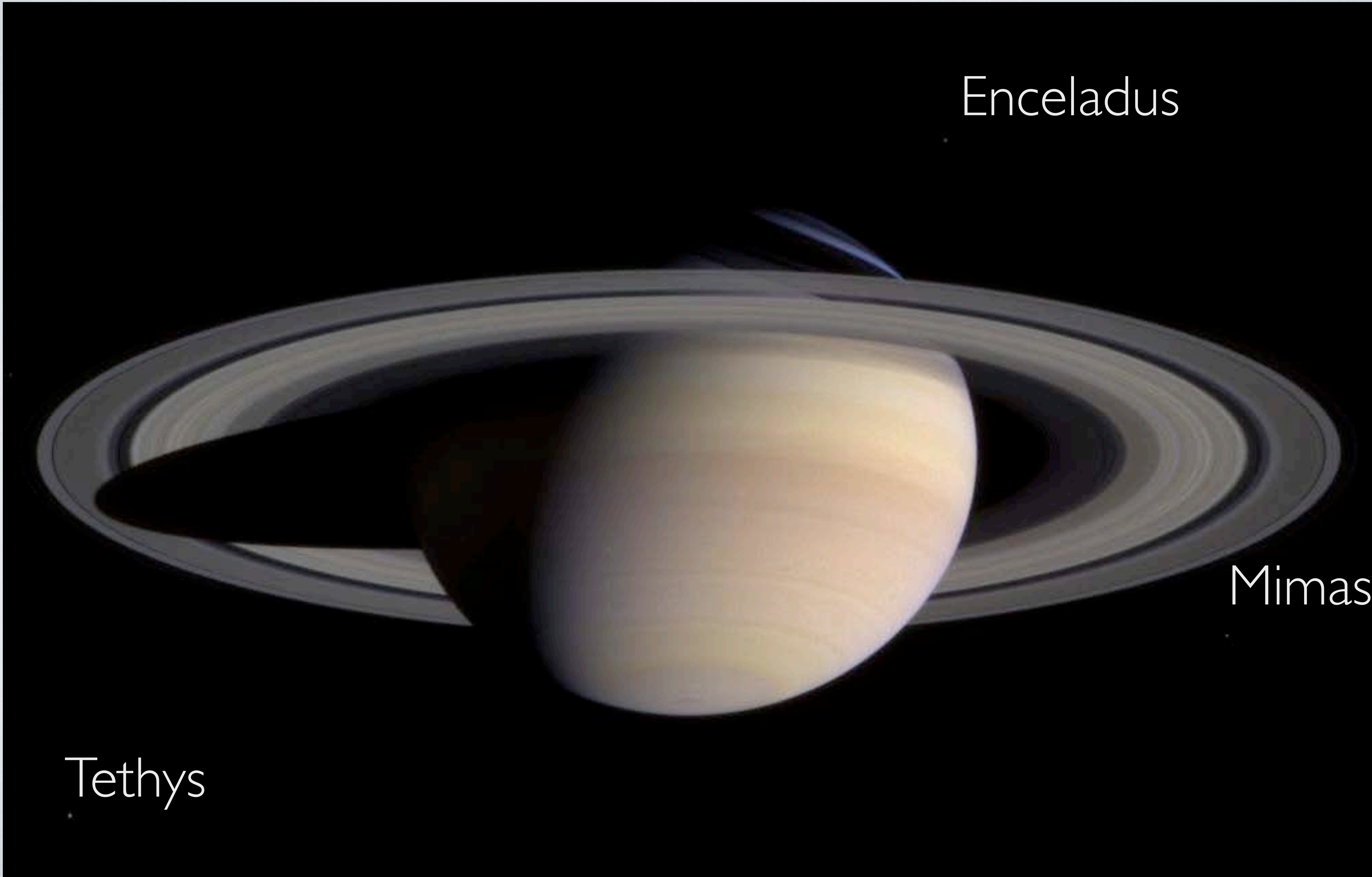


DUST STREAM MODELING

S. Hsu



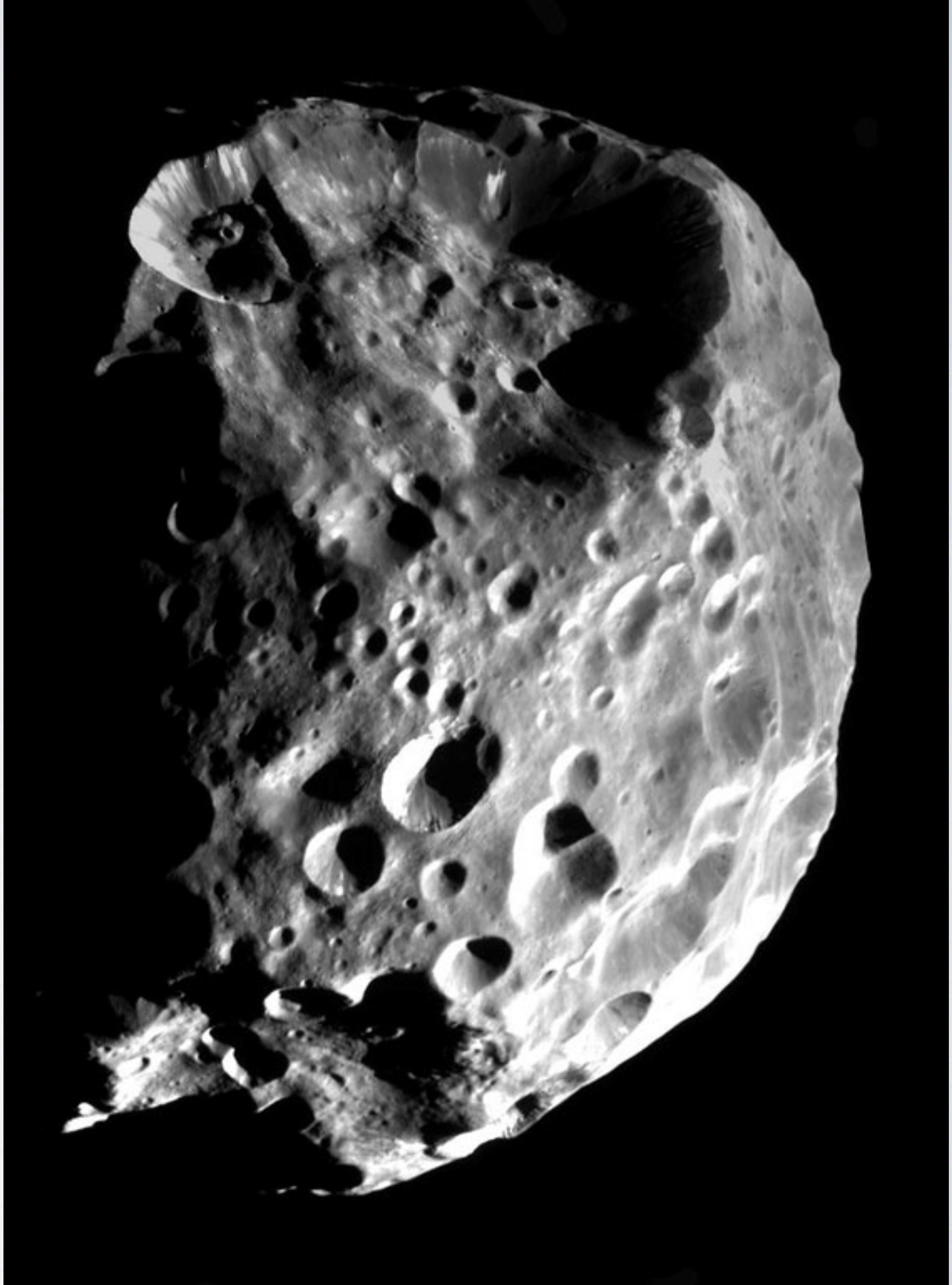
SATURN APPROACH



PHOEBE

Flyby : 2004, June 11
ice-rich moon coverd
with dark material
bright crater edges

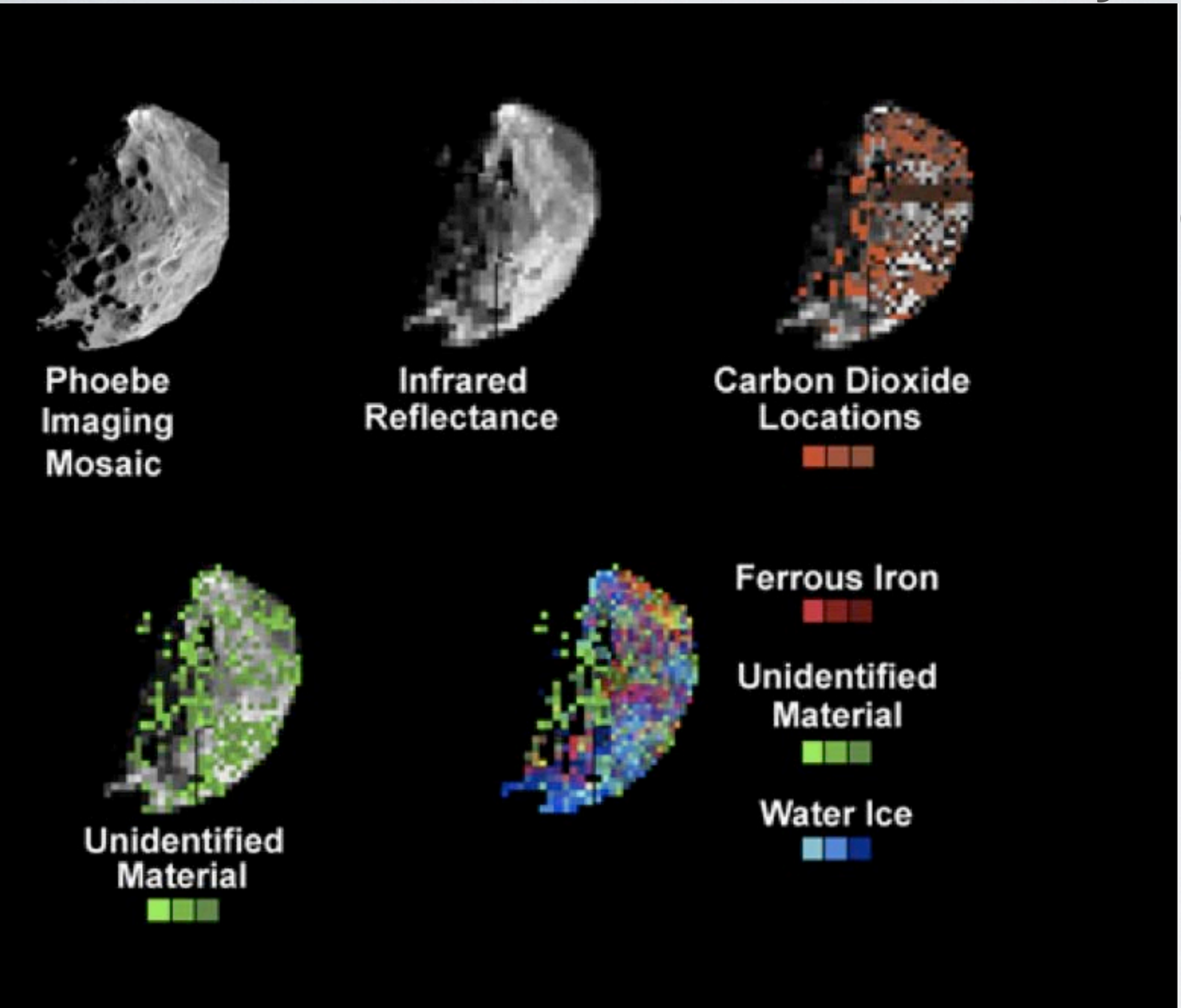
190 m/pixel



PHOEBE CRATER

80 M/PIXEL

A COMET LIKE OBJECT

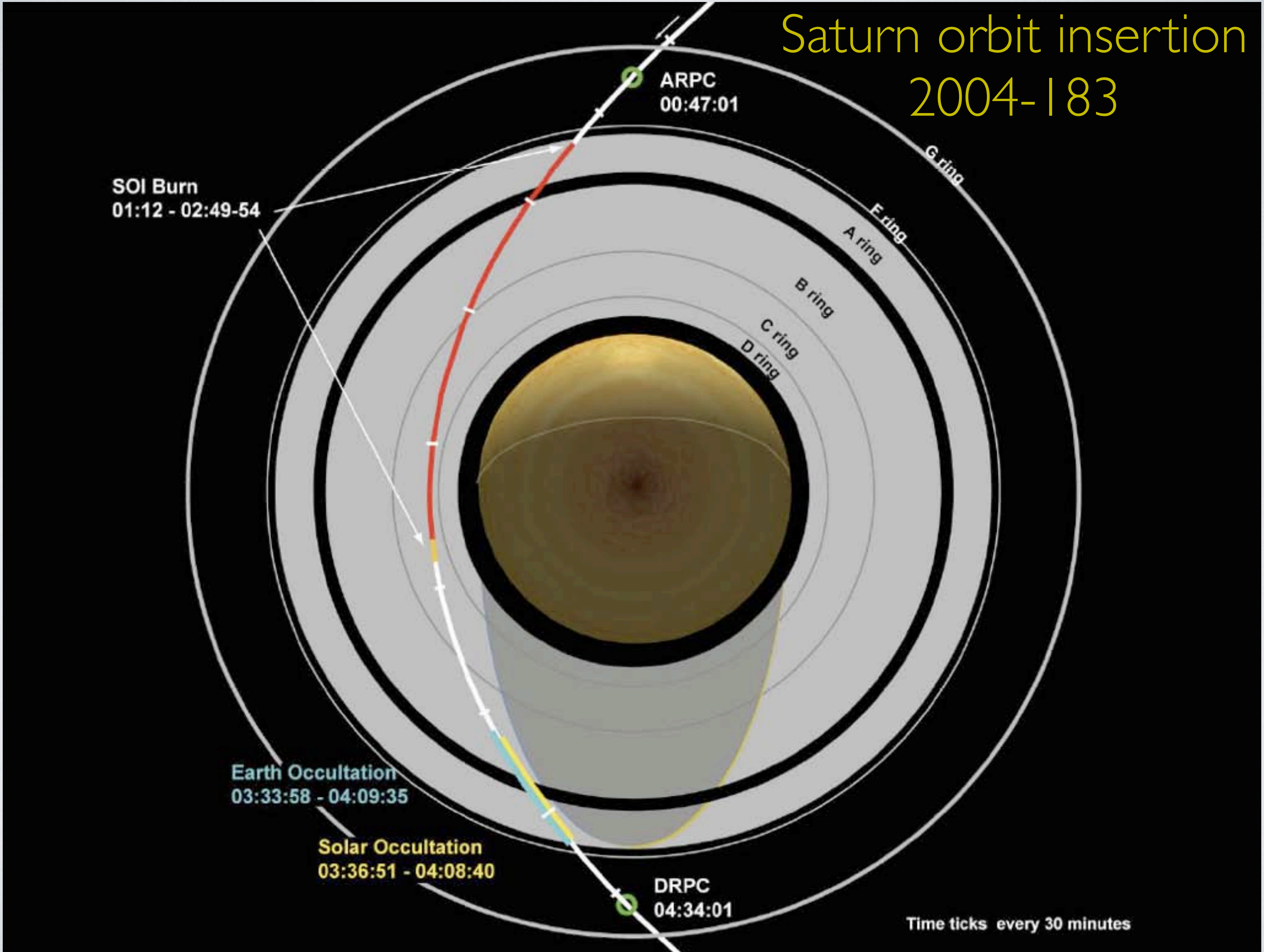


CO2 indicator for KuiperBelt origin

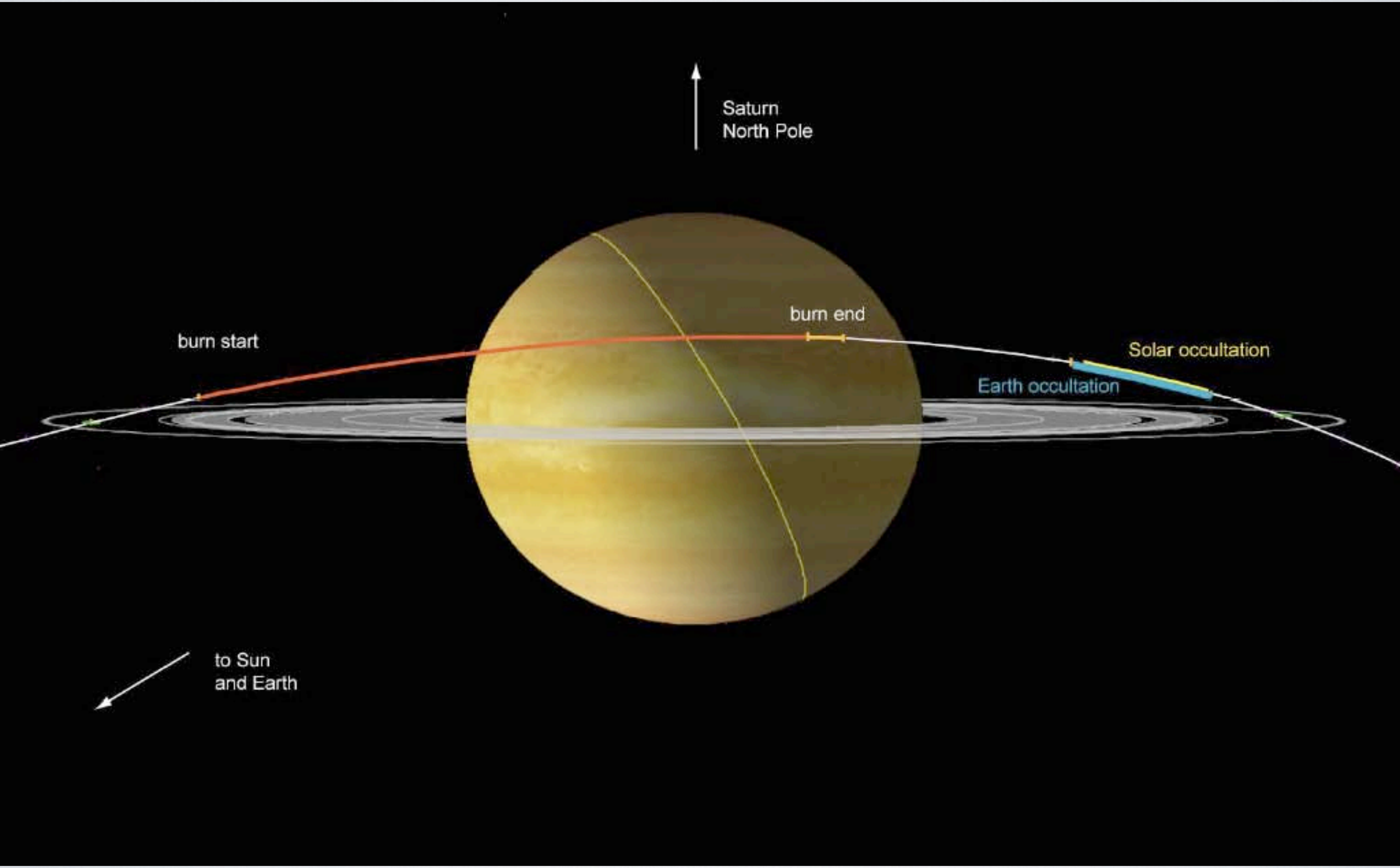
retrograde orbit

ORBIT INSERTION

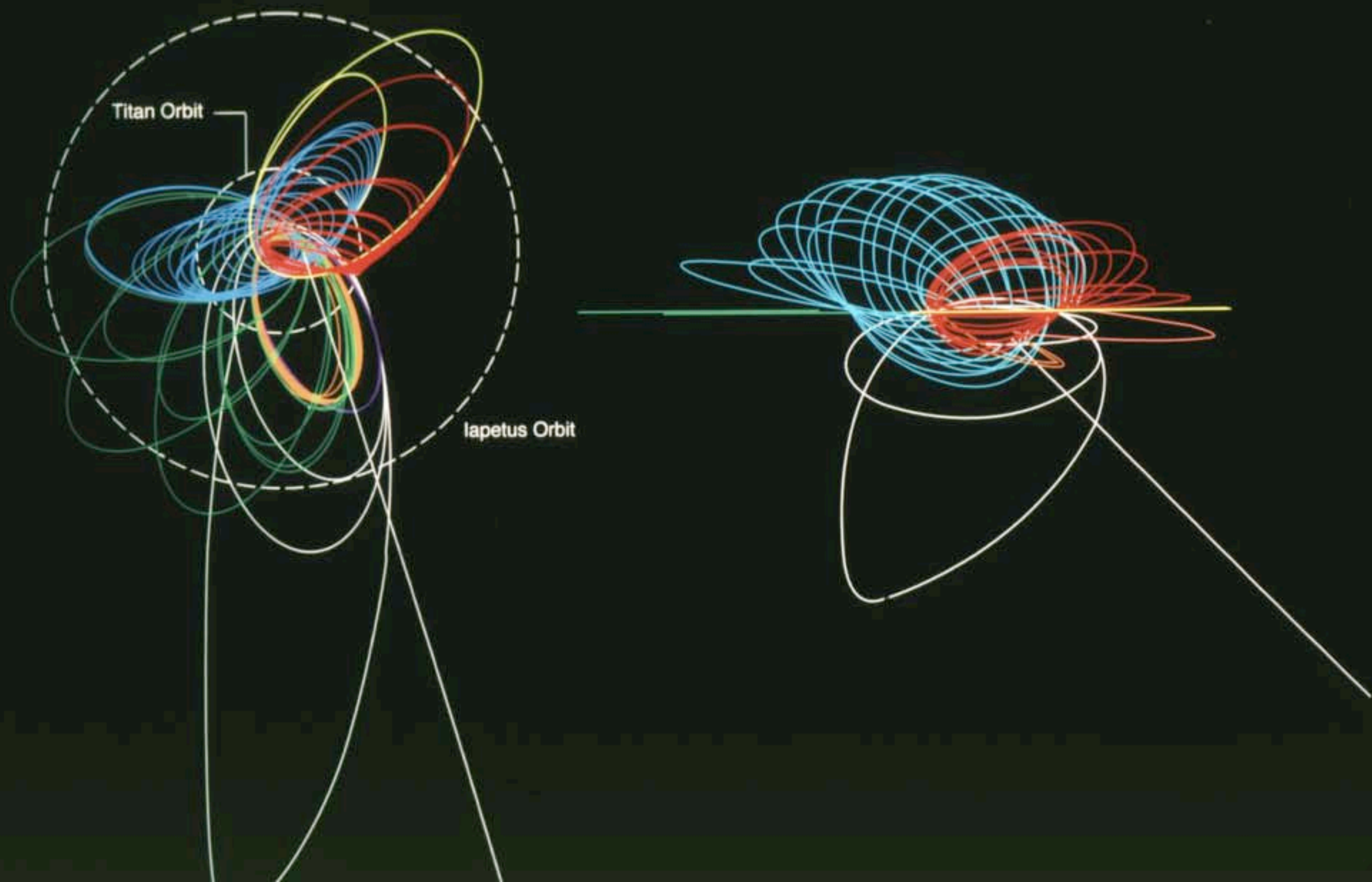
Saturn orbit insertion 2004-183



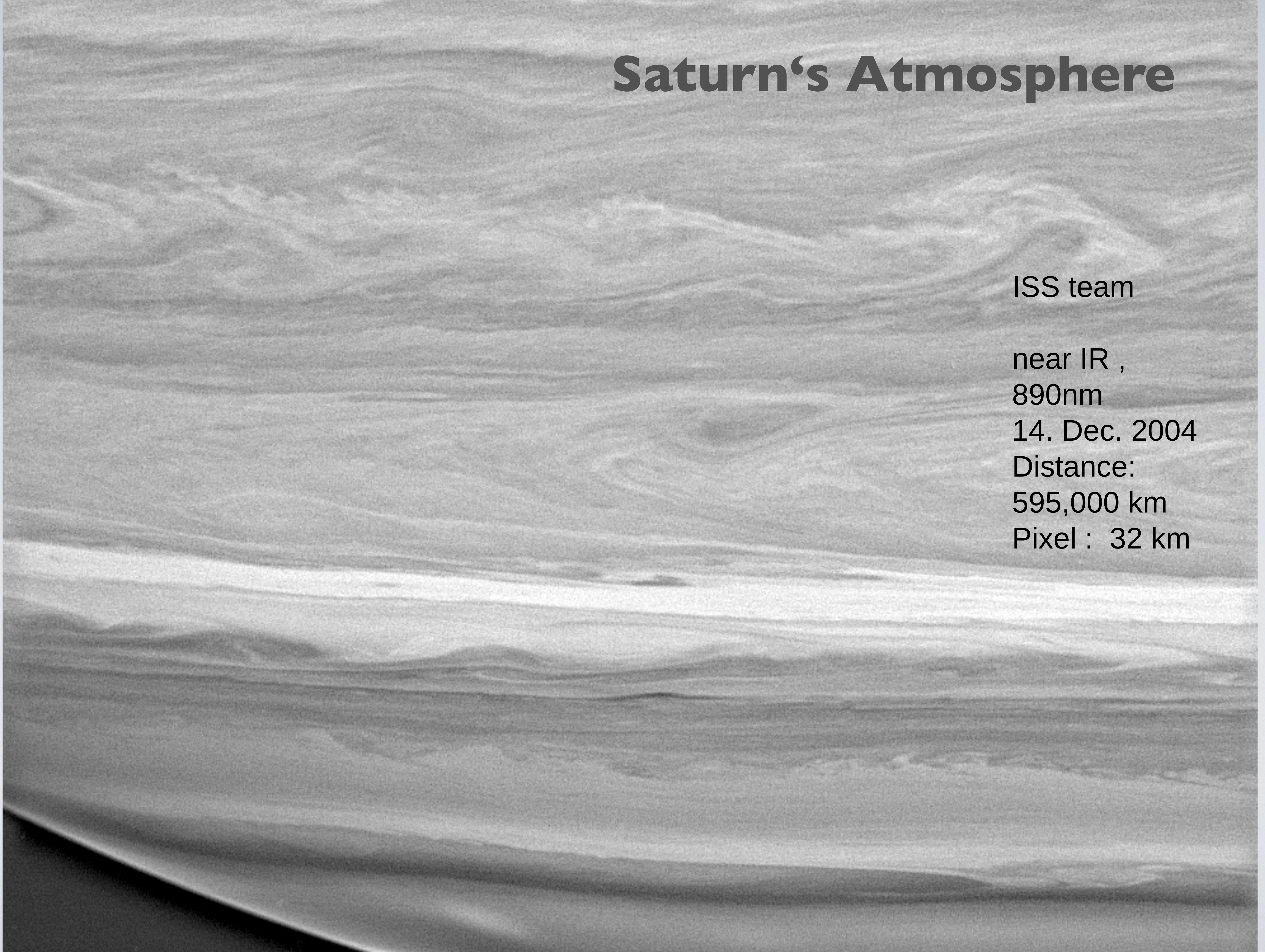
SATURN ORBIT INSERTION



Saturn System Tour Trajectory



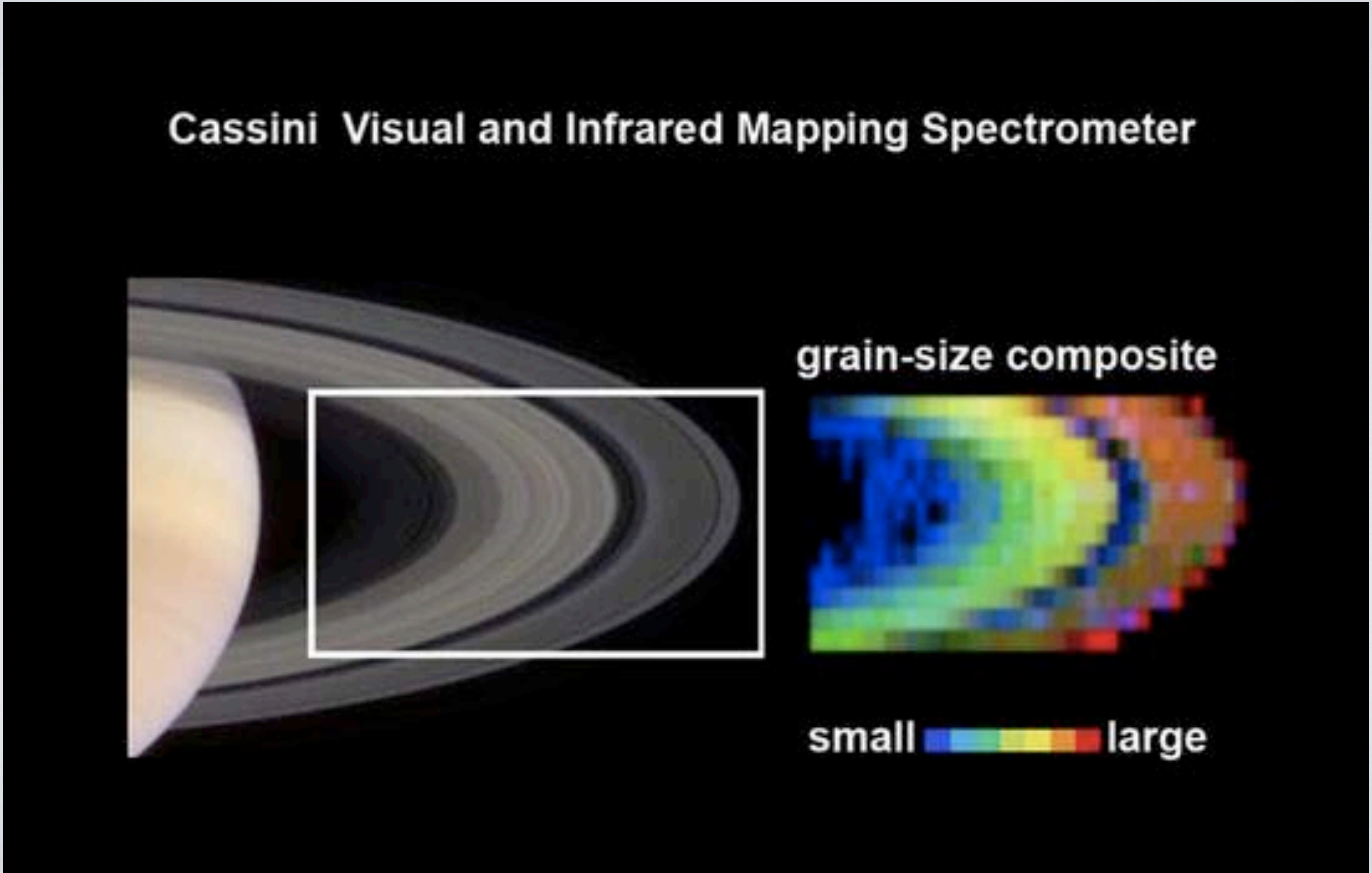
Saturn‘s Atmosphere



ISS team

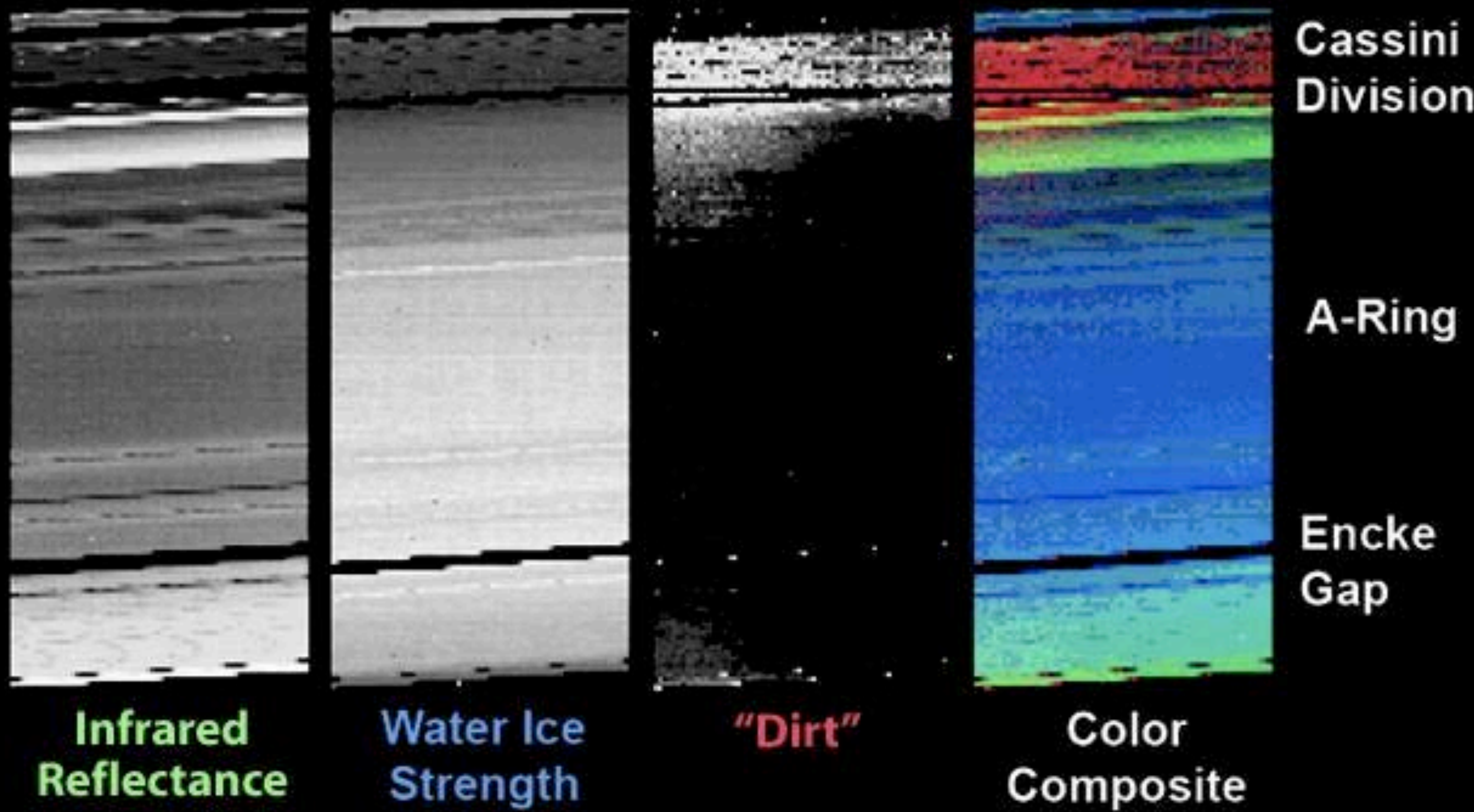
near IR ,
890nm
14. Dec. 2004
Distance:
595,000 km
Pixel : 32 km

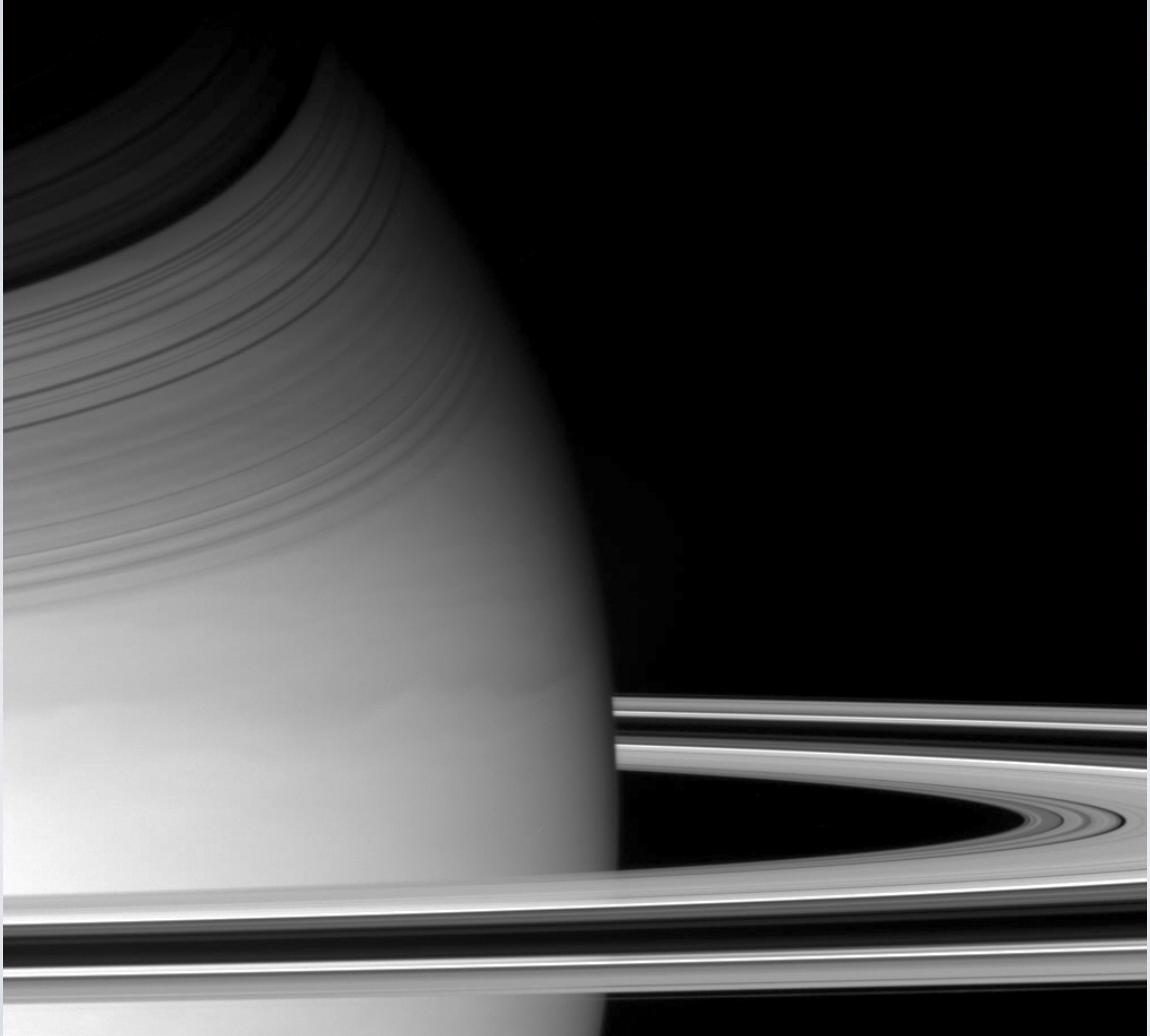
SIZE DISTRIBUTION OF RING PARTICLES



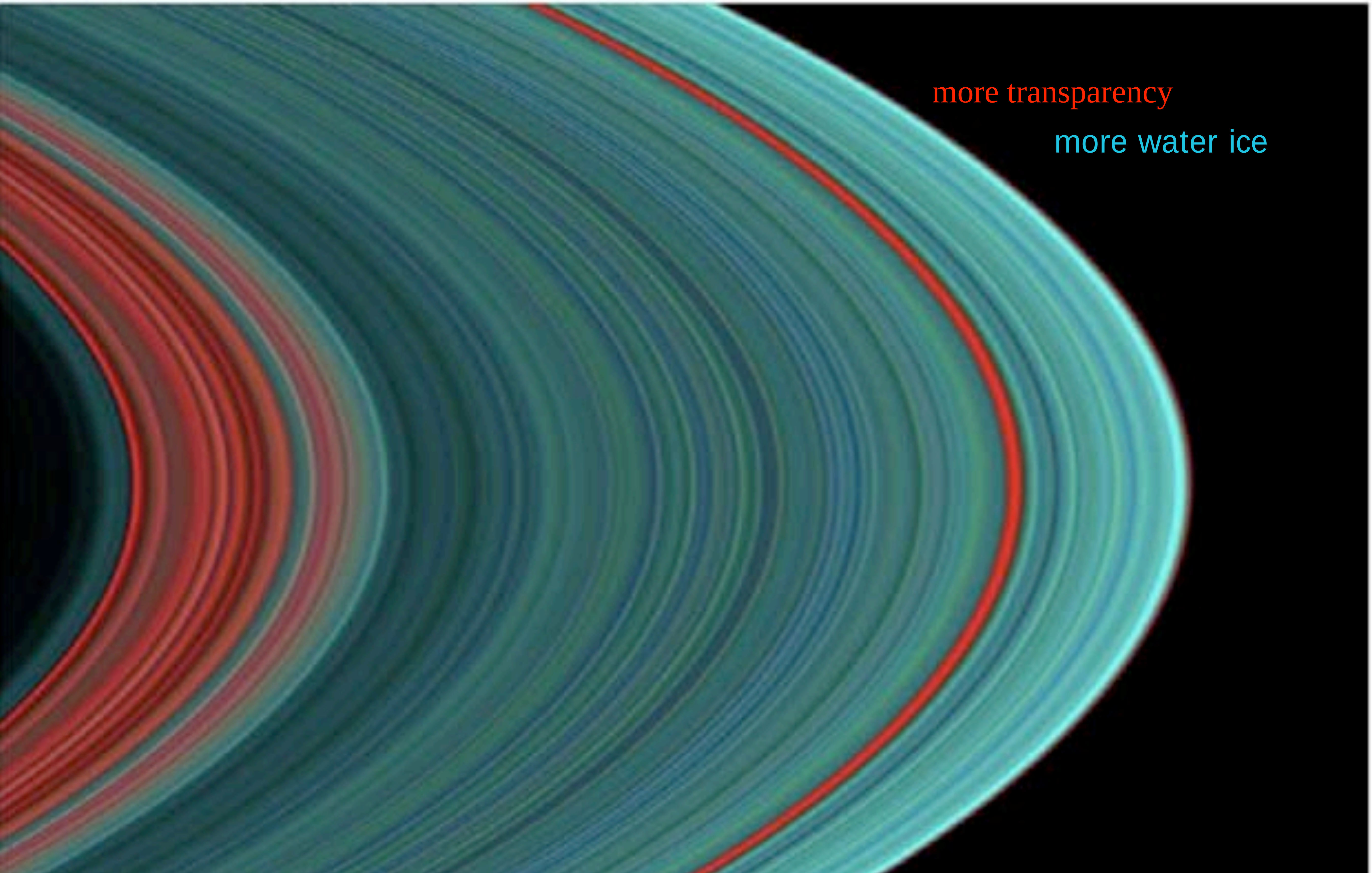
DIRTY RINGS

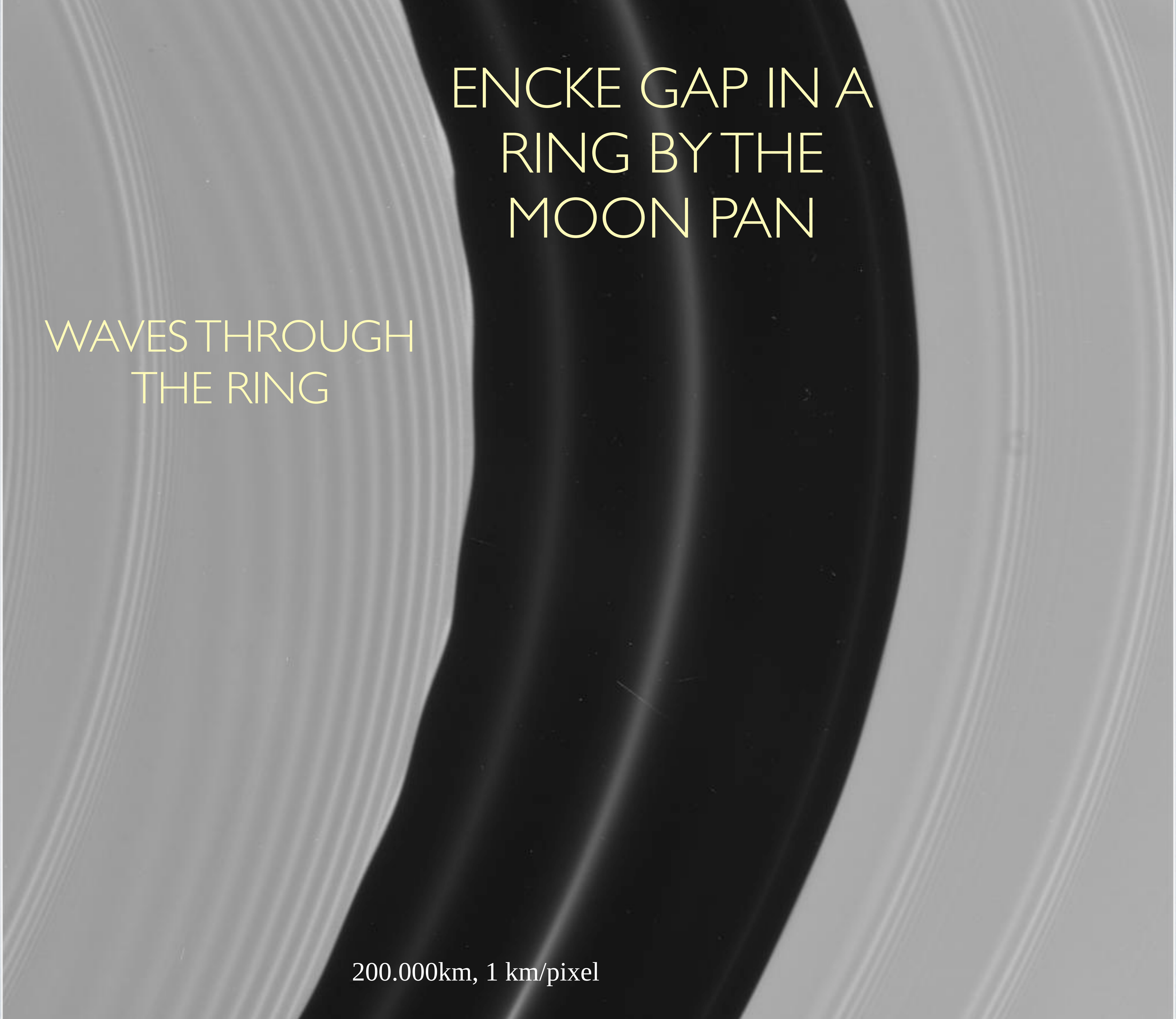
inside





RINGS IN THE UV

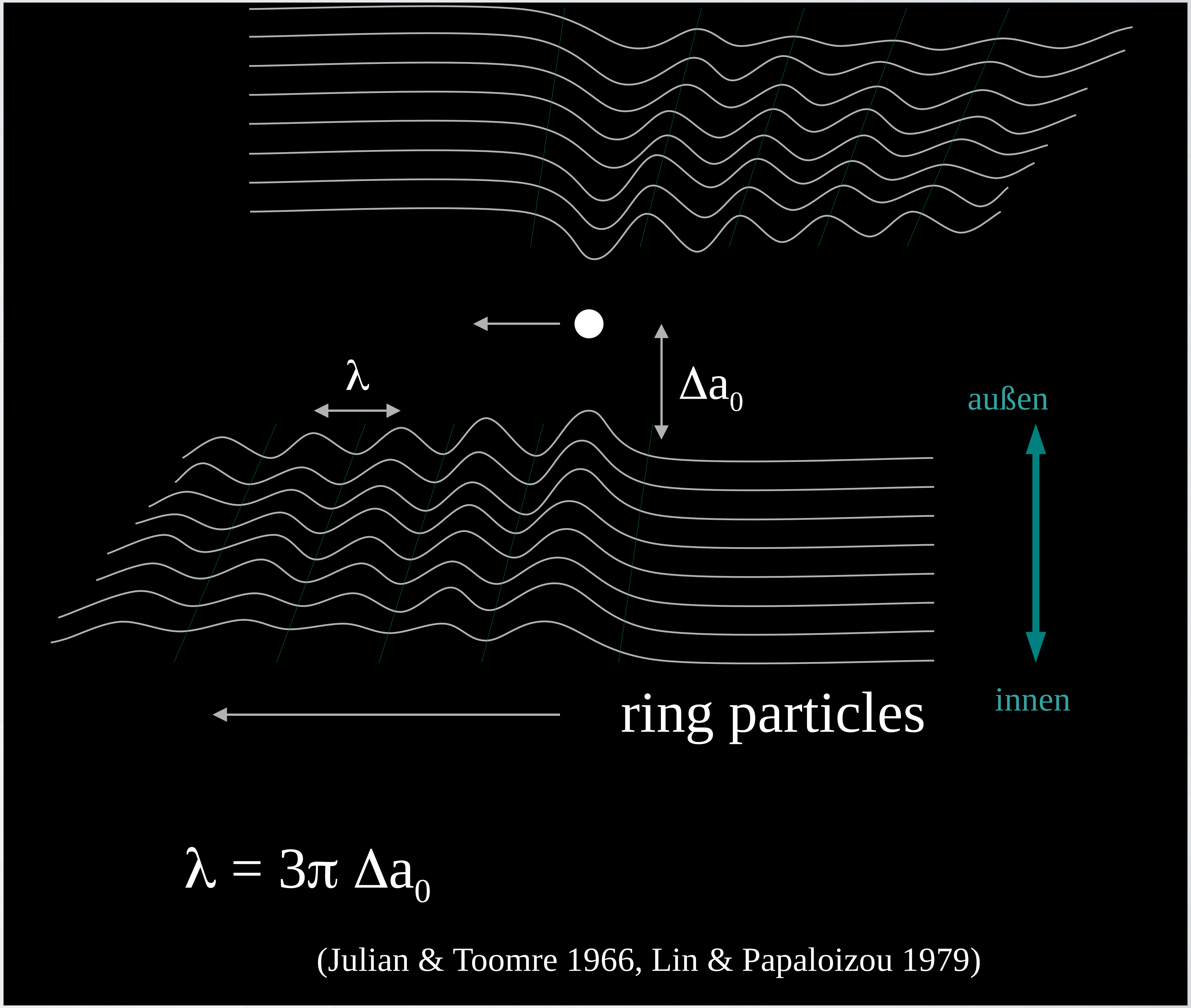



ENCKE GAP IN A RING BY THE MOON PAN
WAVES THROUGH THE RING
200.000km, 1 km/pixel

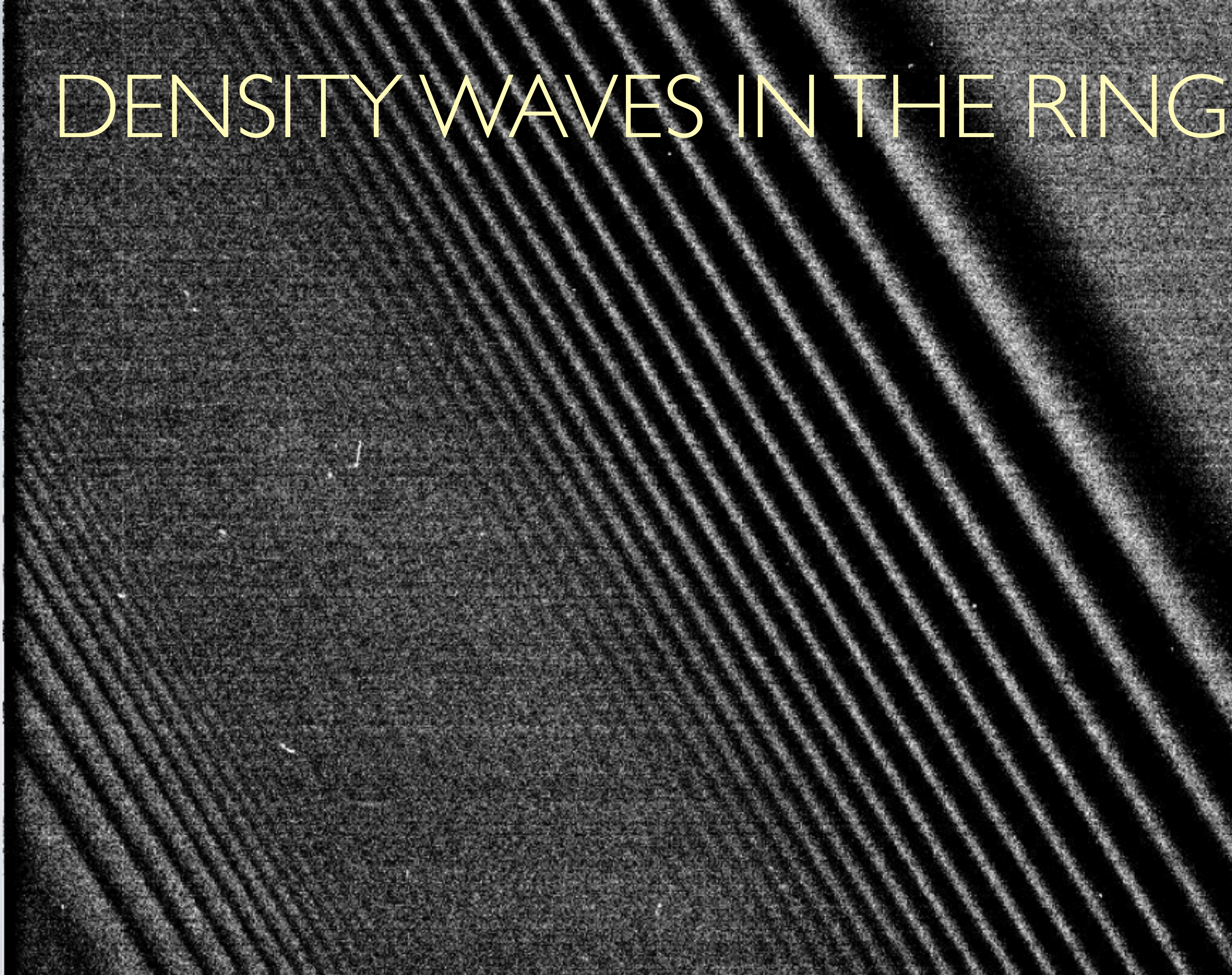
MOON - RING INTERACTION

moon causes gap and changes eccentricity of ring particles

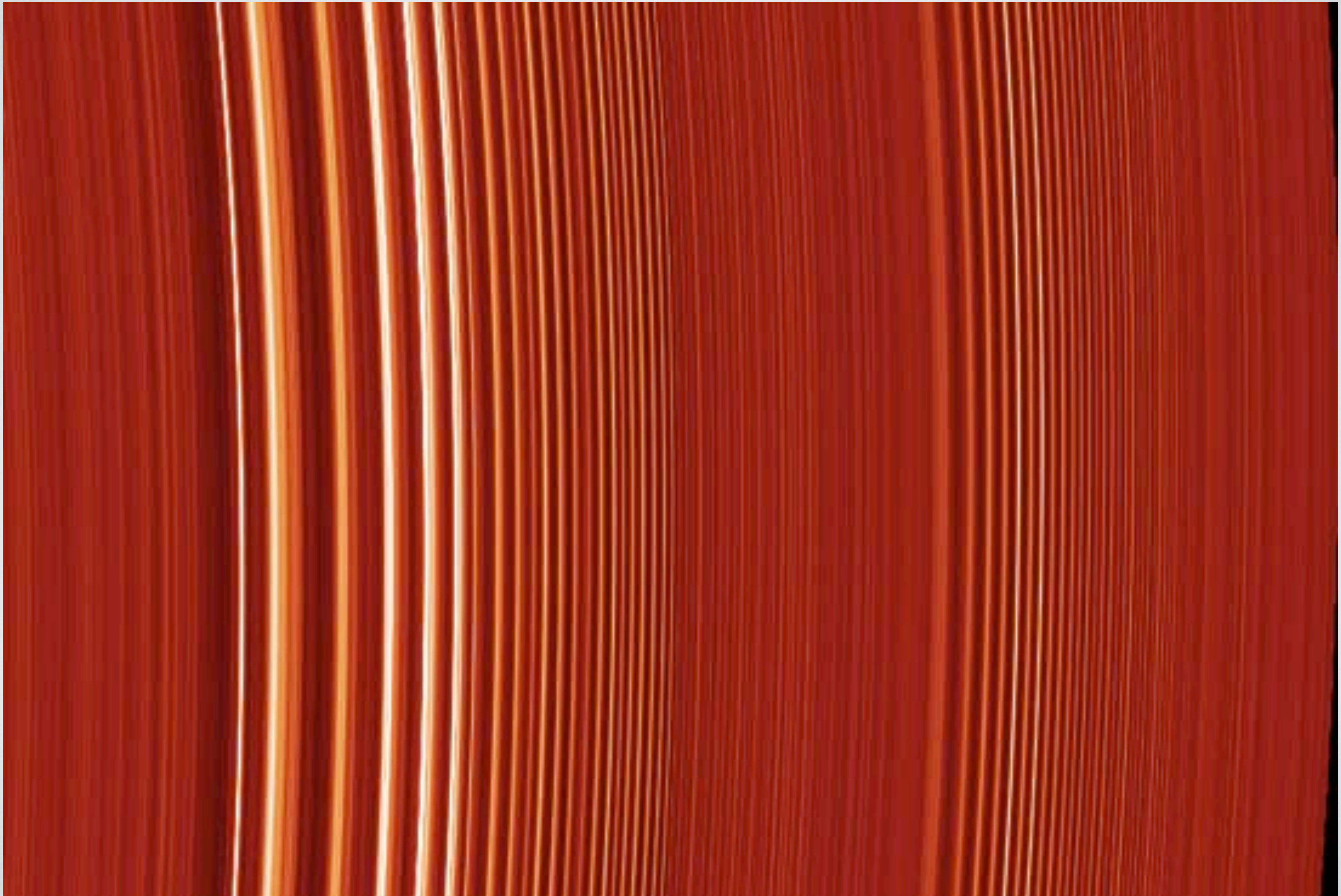
calculation/ discovery of small embedded moons by analysing ring waves



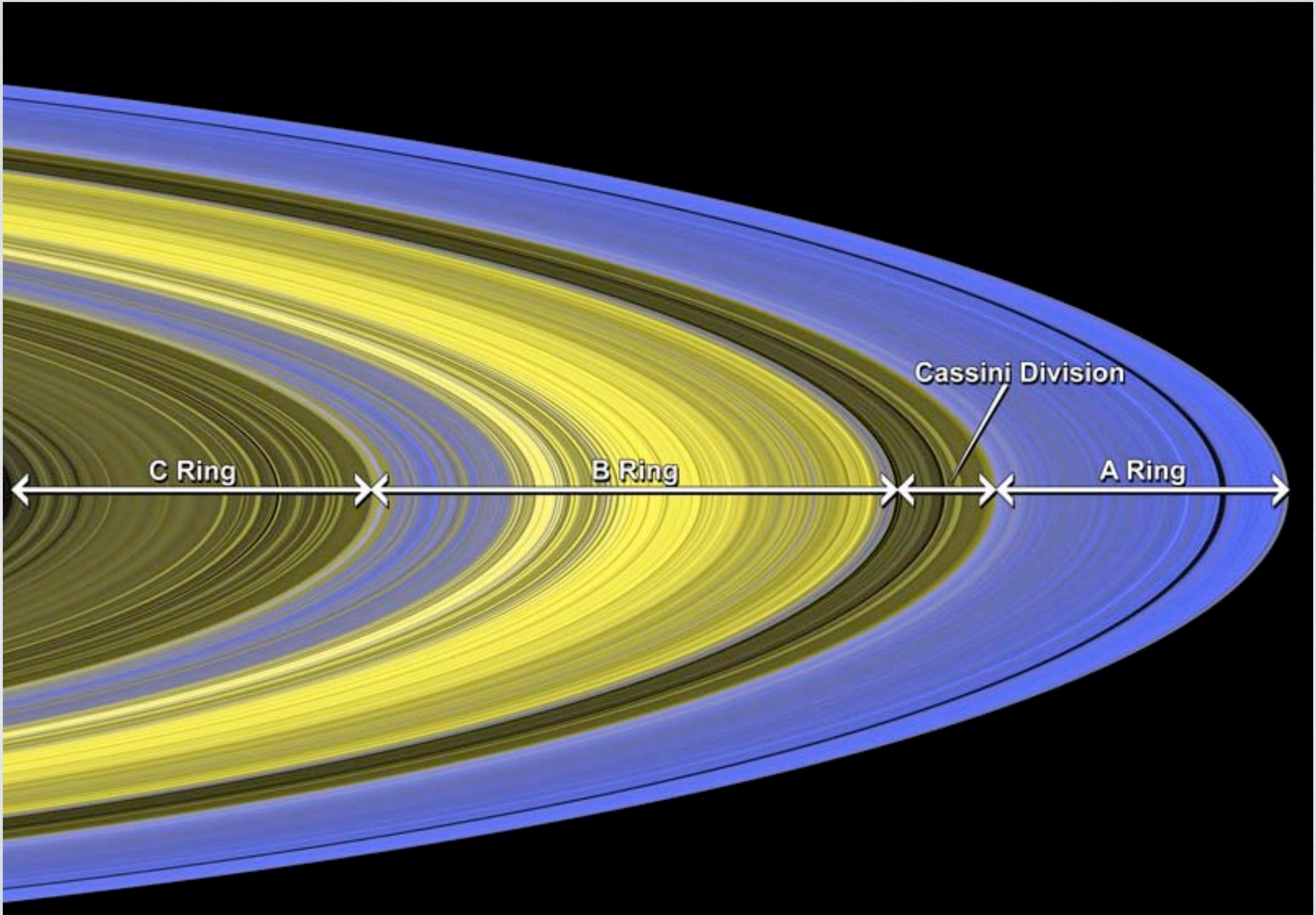
DENSITY WAVES IN THE RING



WAVES IN THE UV



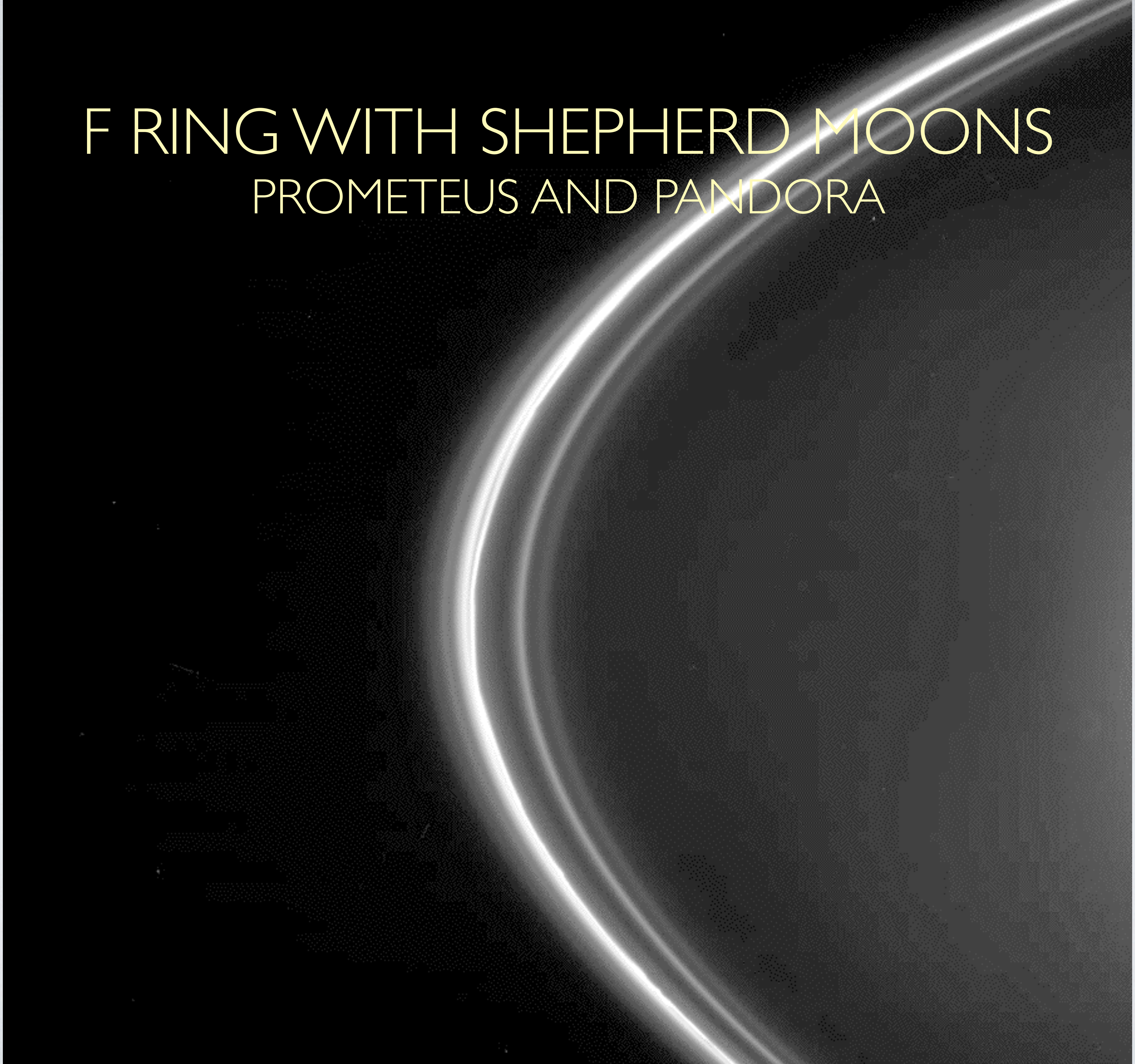
UV STAR OCCULTATION



RING PLANE CROSSING

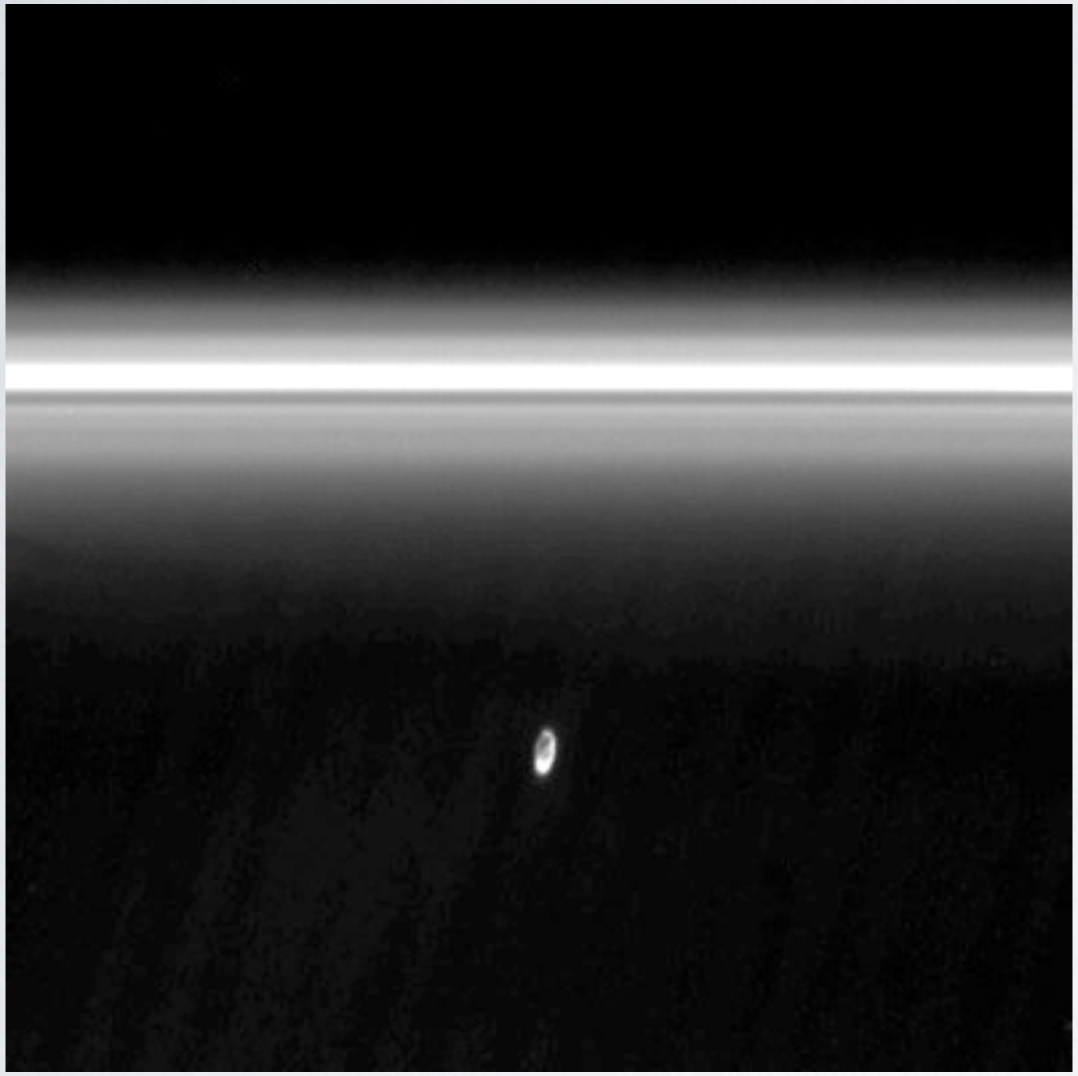
F RING WITH SHEPHERD MOONS

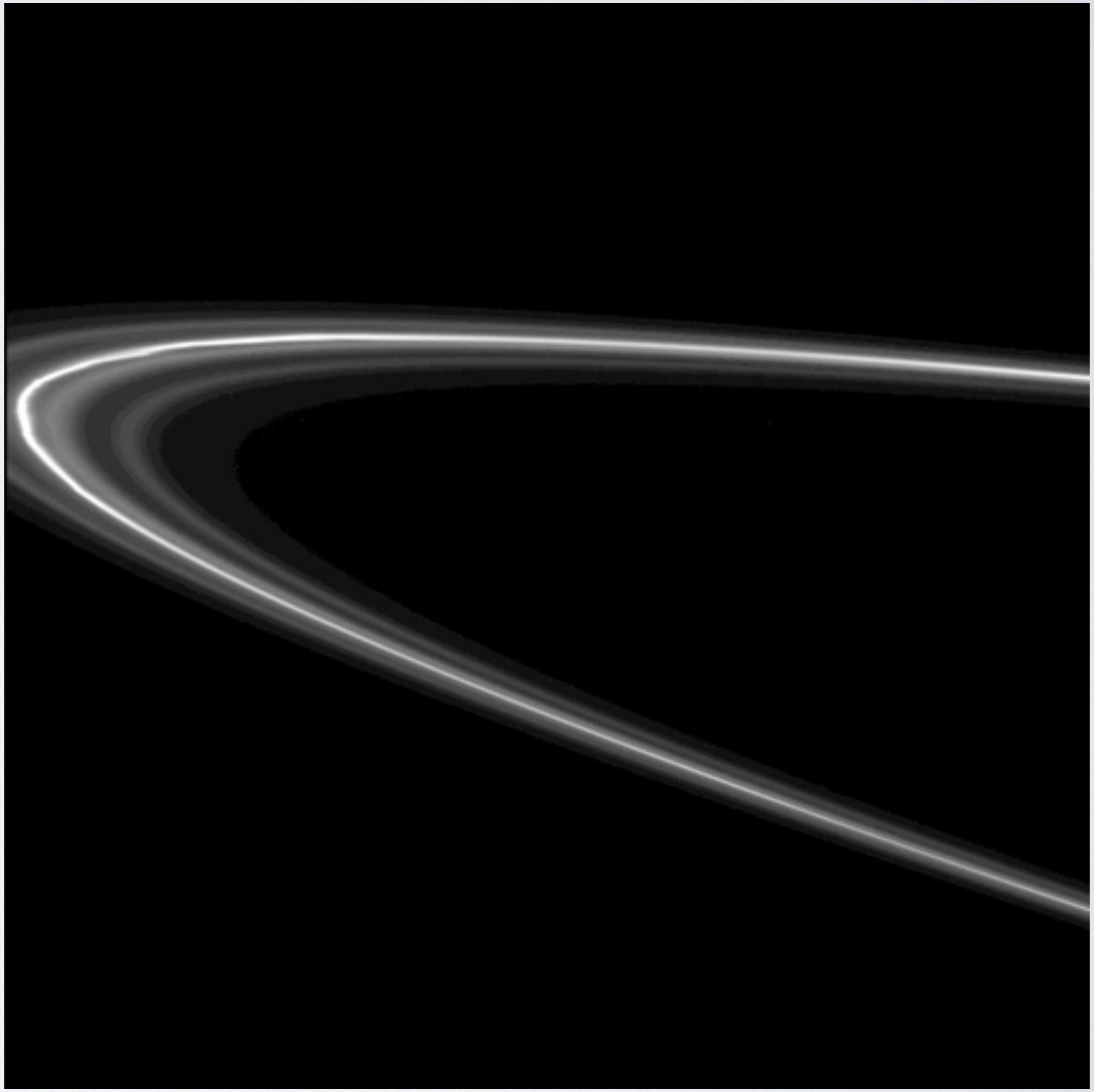
PROMETEUS AND PANDORA



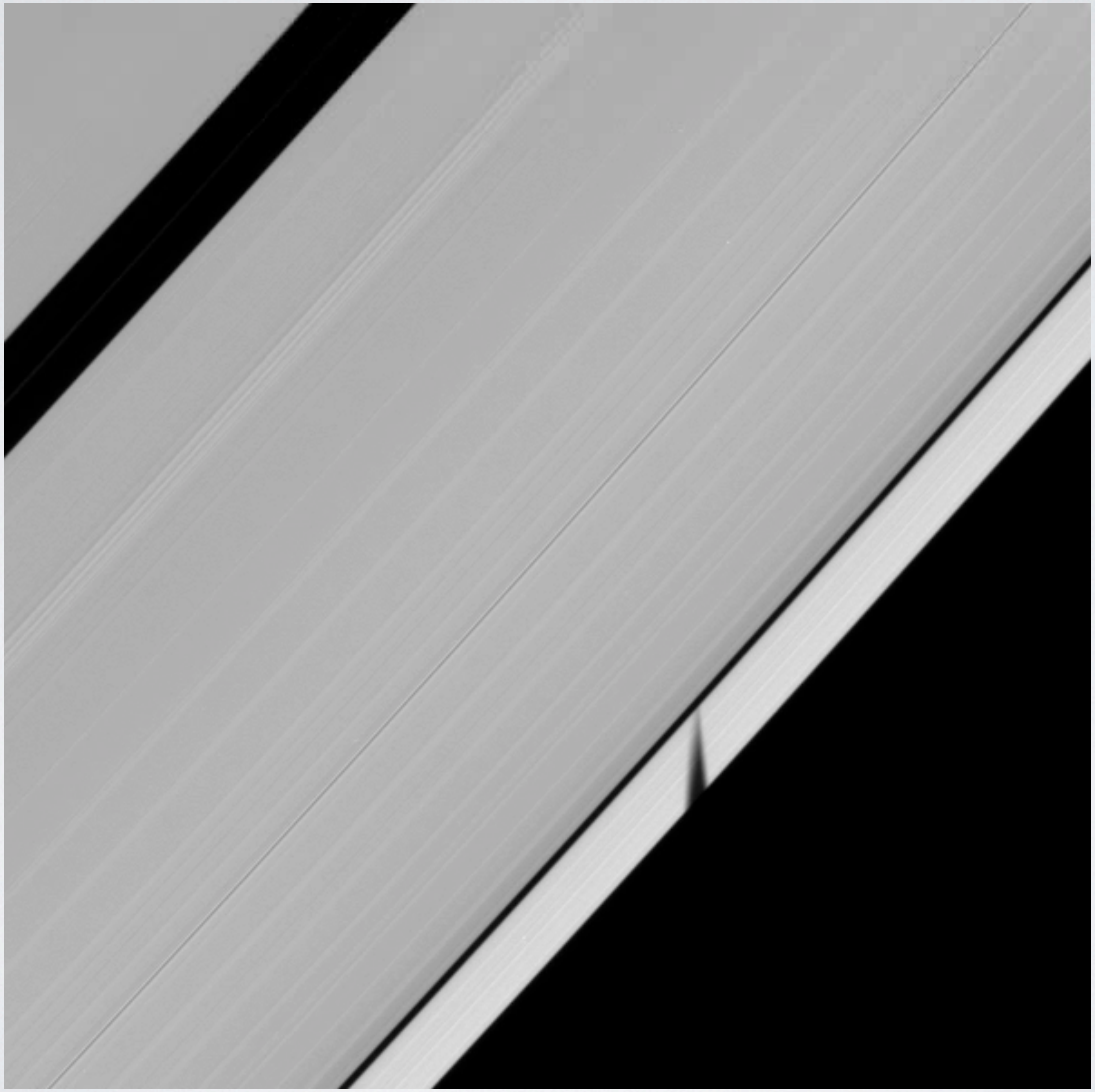
F RING

SHEPHERD MOON PROMETHEUS (102 KM)

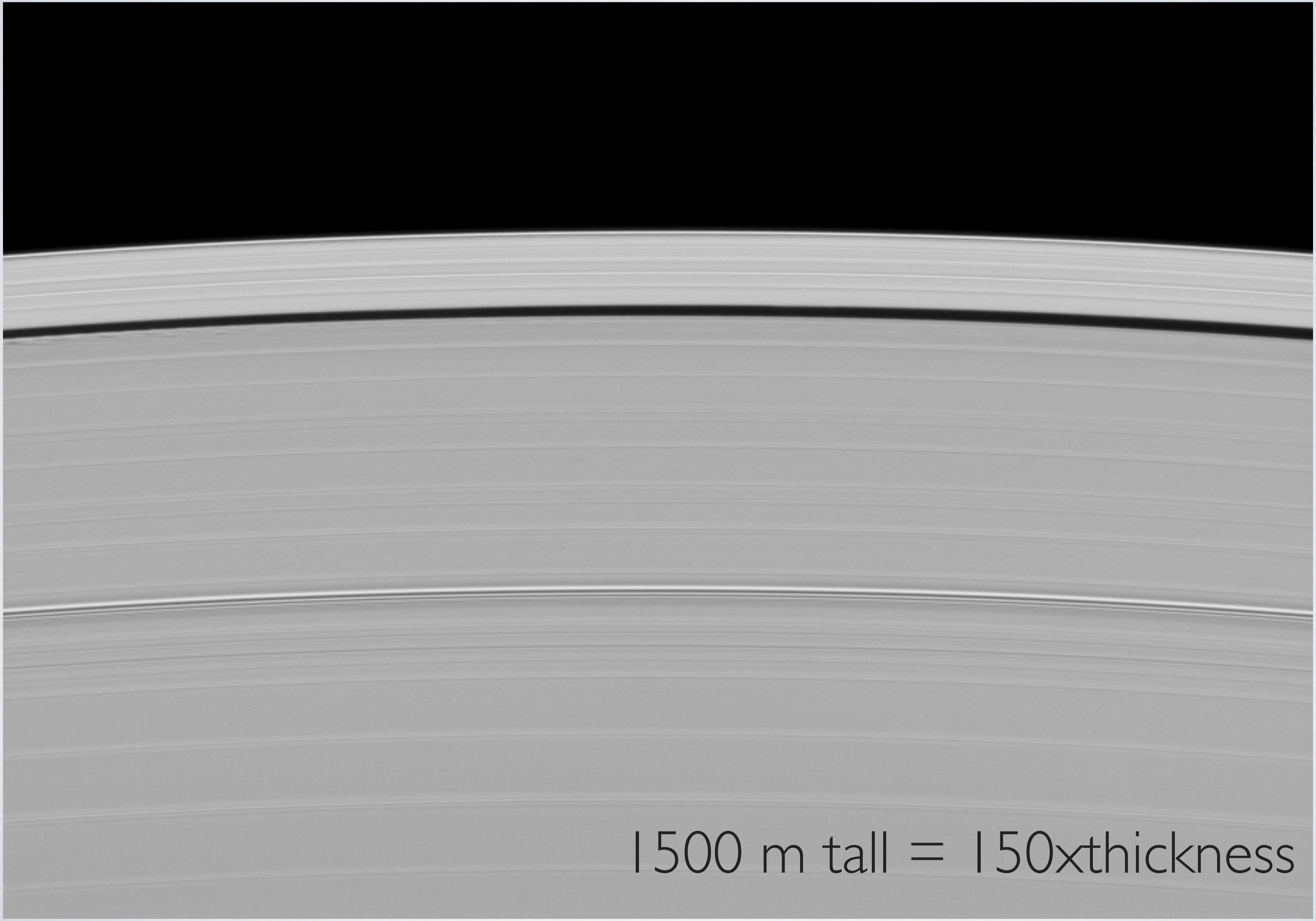


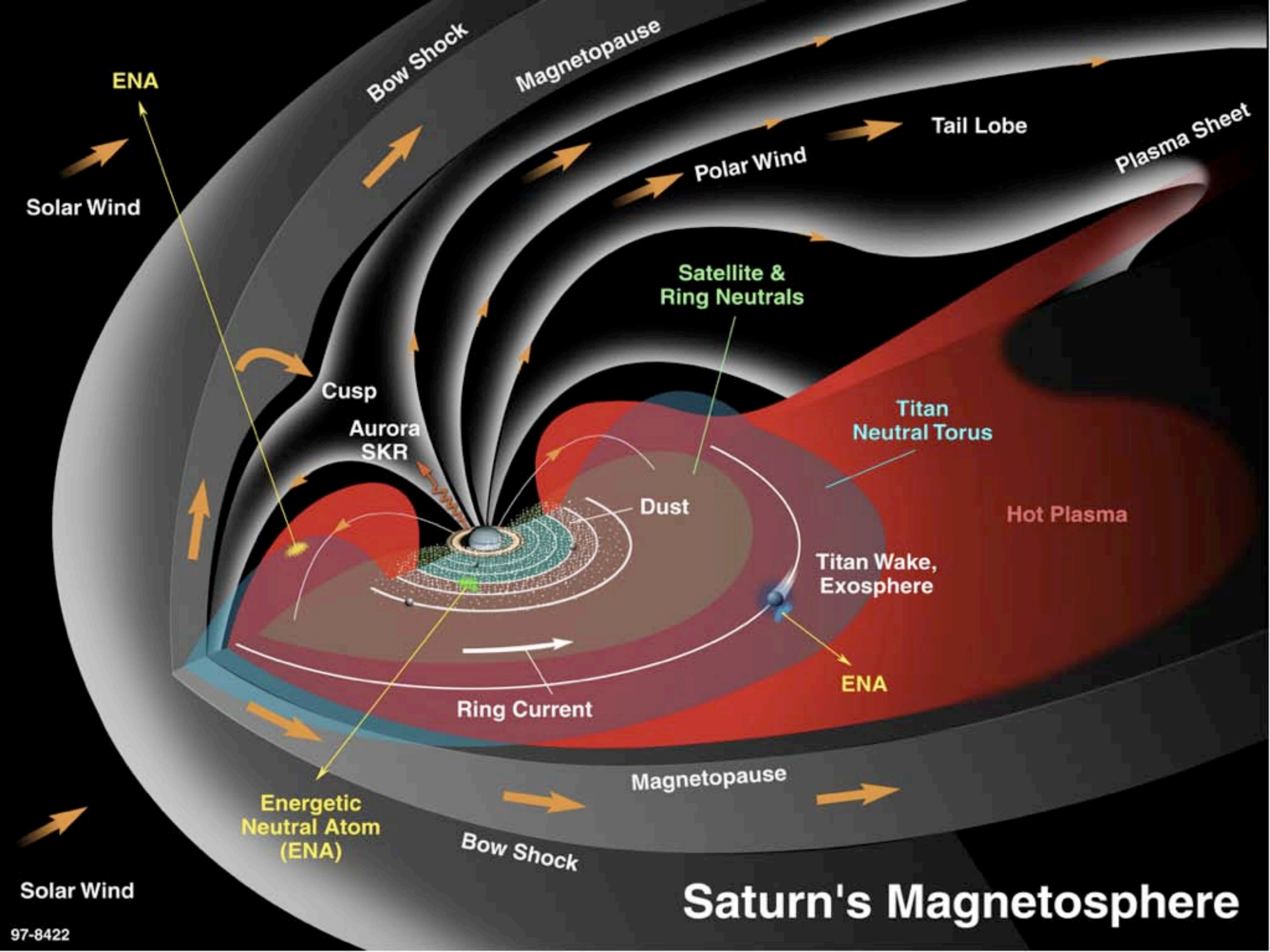


SHADOW OF EPIMETHEUS



MOON DAPHNIS (8 KM) ON INCLINED ORBIT WITHIN THE 42-KILOMETER WIDE KEELER GAP (A RING)

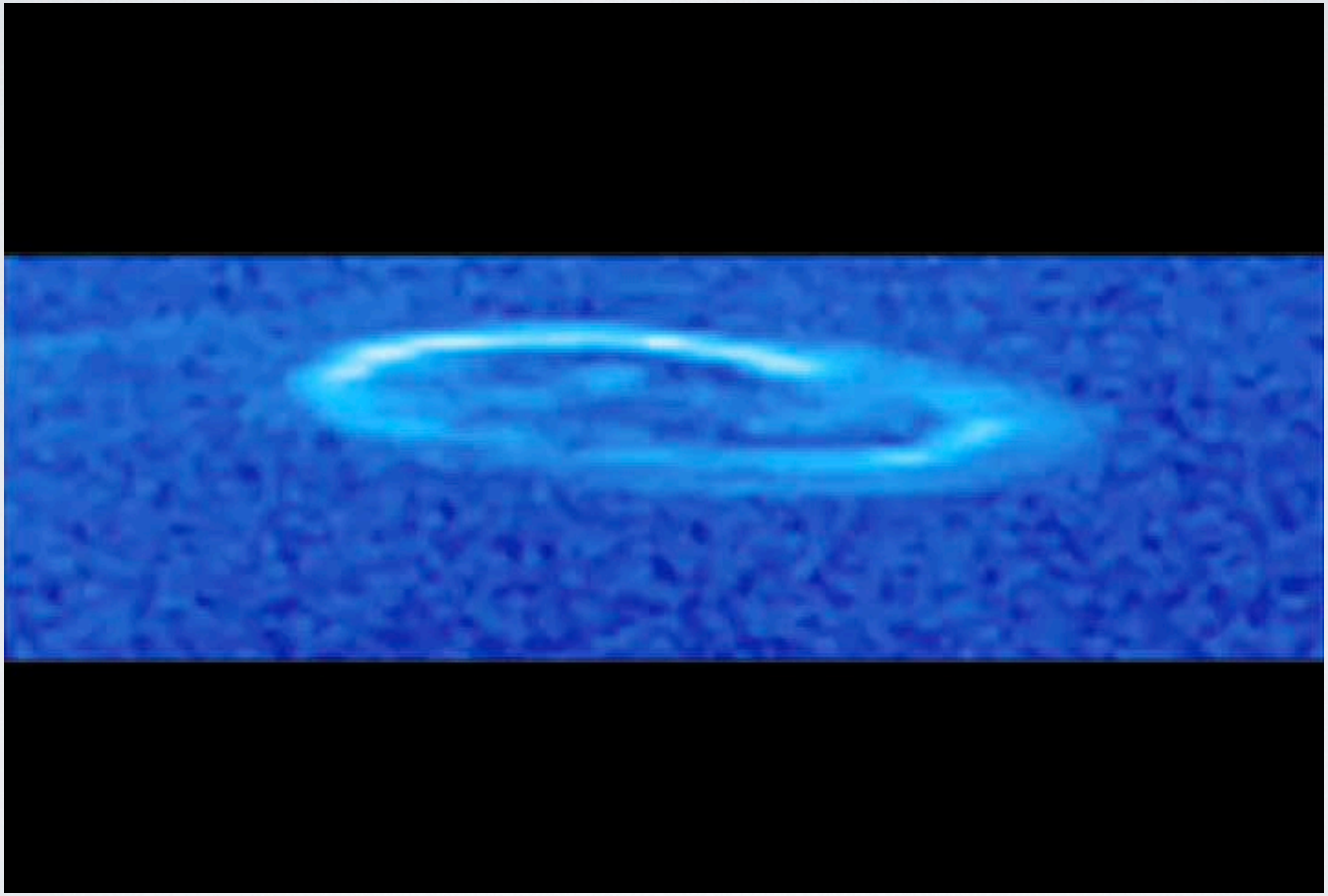




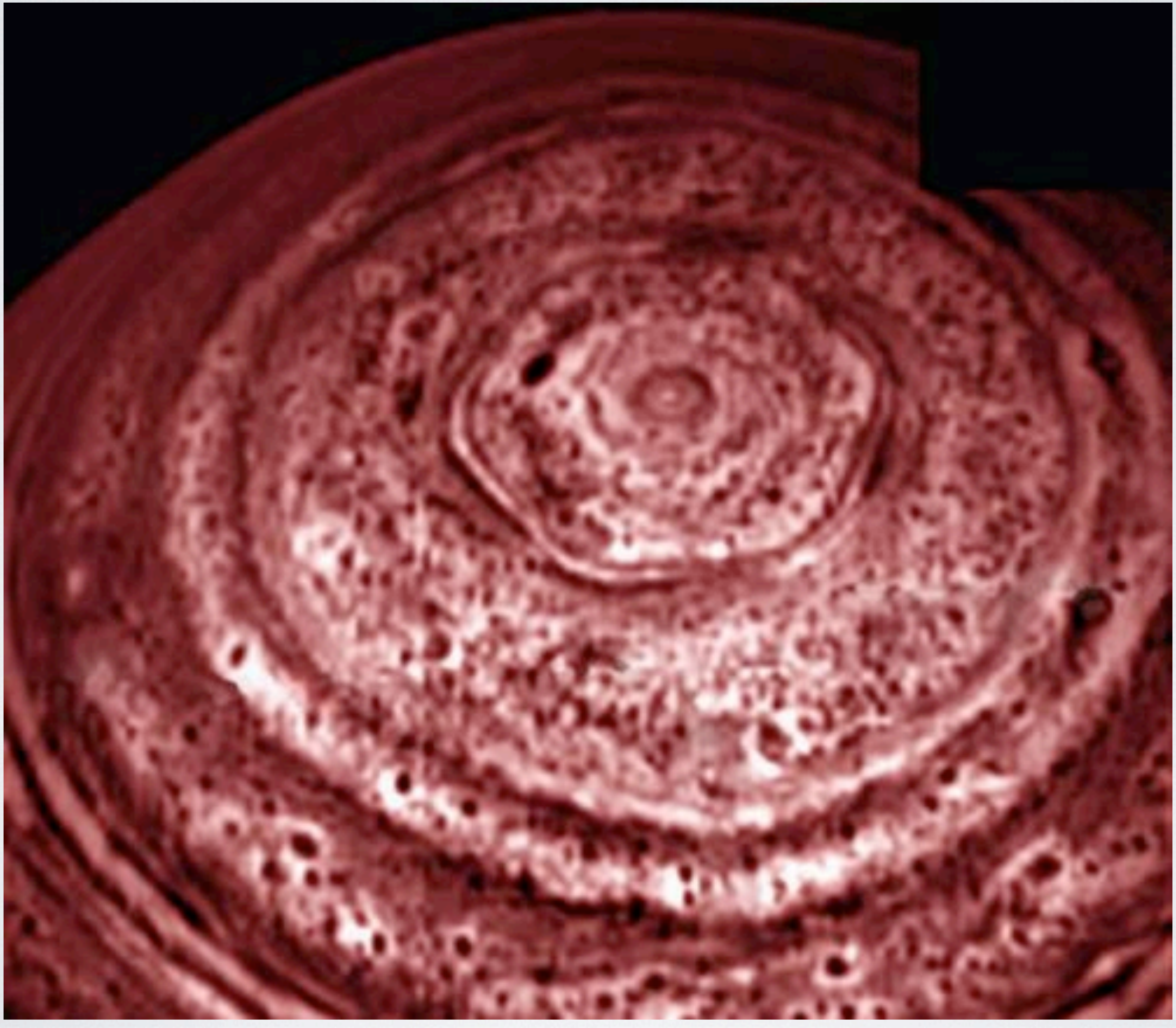
ENA
Bow Shock
Magnetopause
Solar Wind
Tail Lobe
Polar Wind
Plasma Sheet
Satellite &
Ring Neutrals
Cusp
Aurora
SKR
Titan
Neutral Torus
Dust
Hot Plasma
Titan Wake,
Exosphere
ENA
Ring Current
Magnetopause
Energetic
Neutral Atom
(ENA)
Bow Shock
Solar Wind
Saturn's Magnetosphere
97-8422

NEON LASSO

CHARGED PARTICLES STRIKE THE HYDROGEN ATMOSPHERE

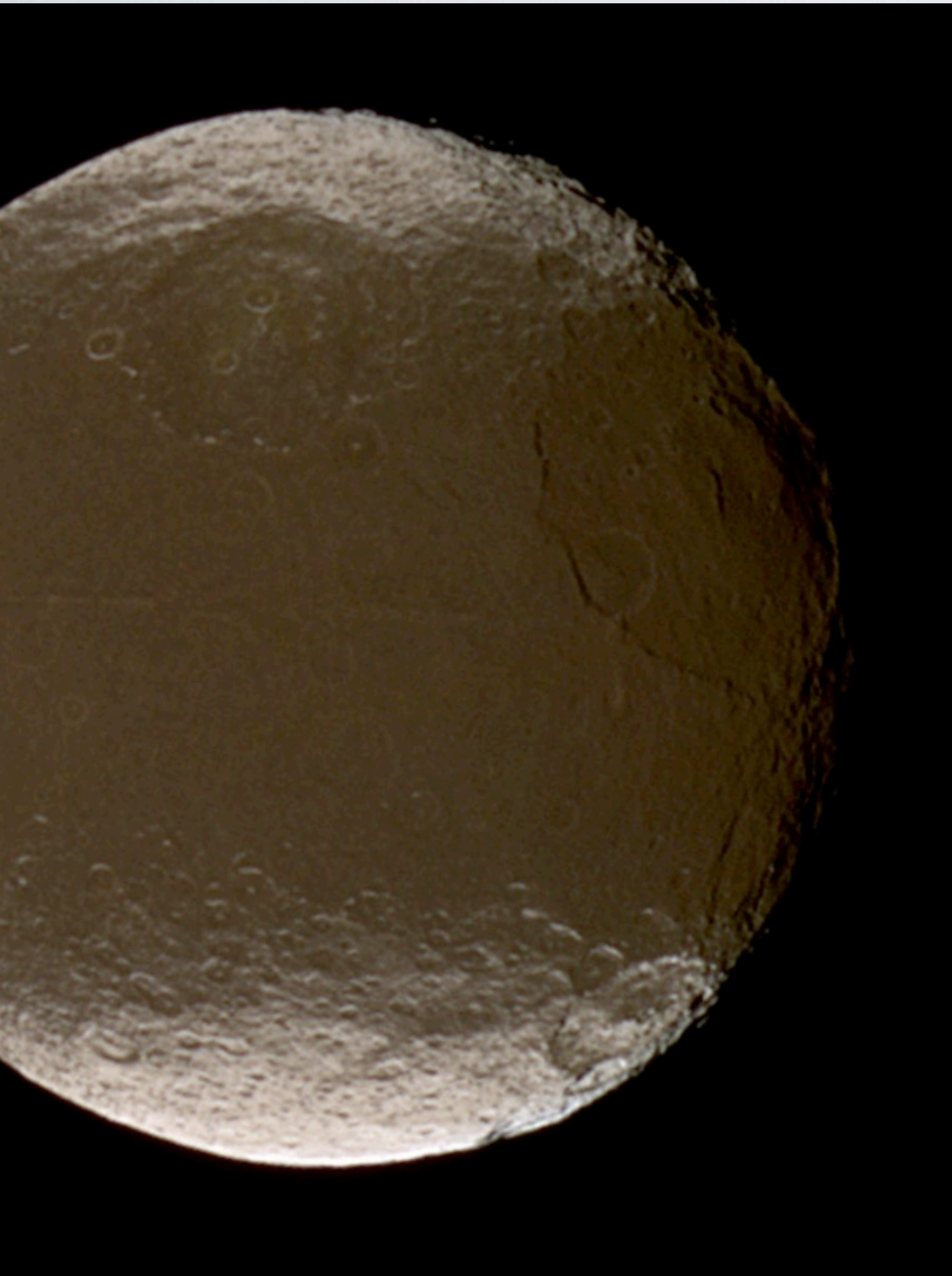


HEXAGON AT THE POLE

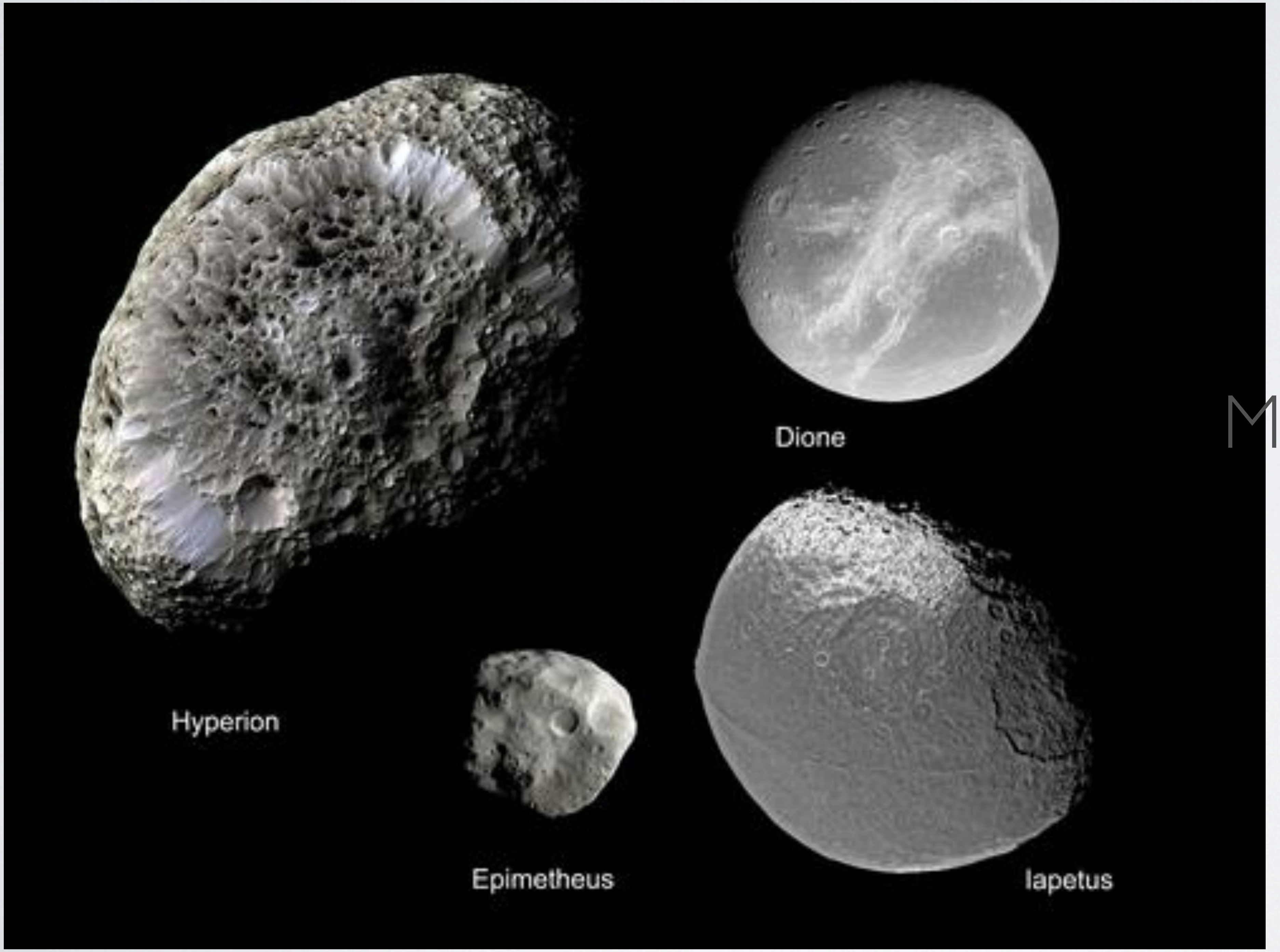


IAPETUS - DICHOTOMY

EVAPORATION OF WATER ICE ON LEADING SIDE (MICROMETEOROID IMPACTS)

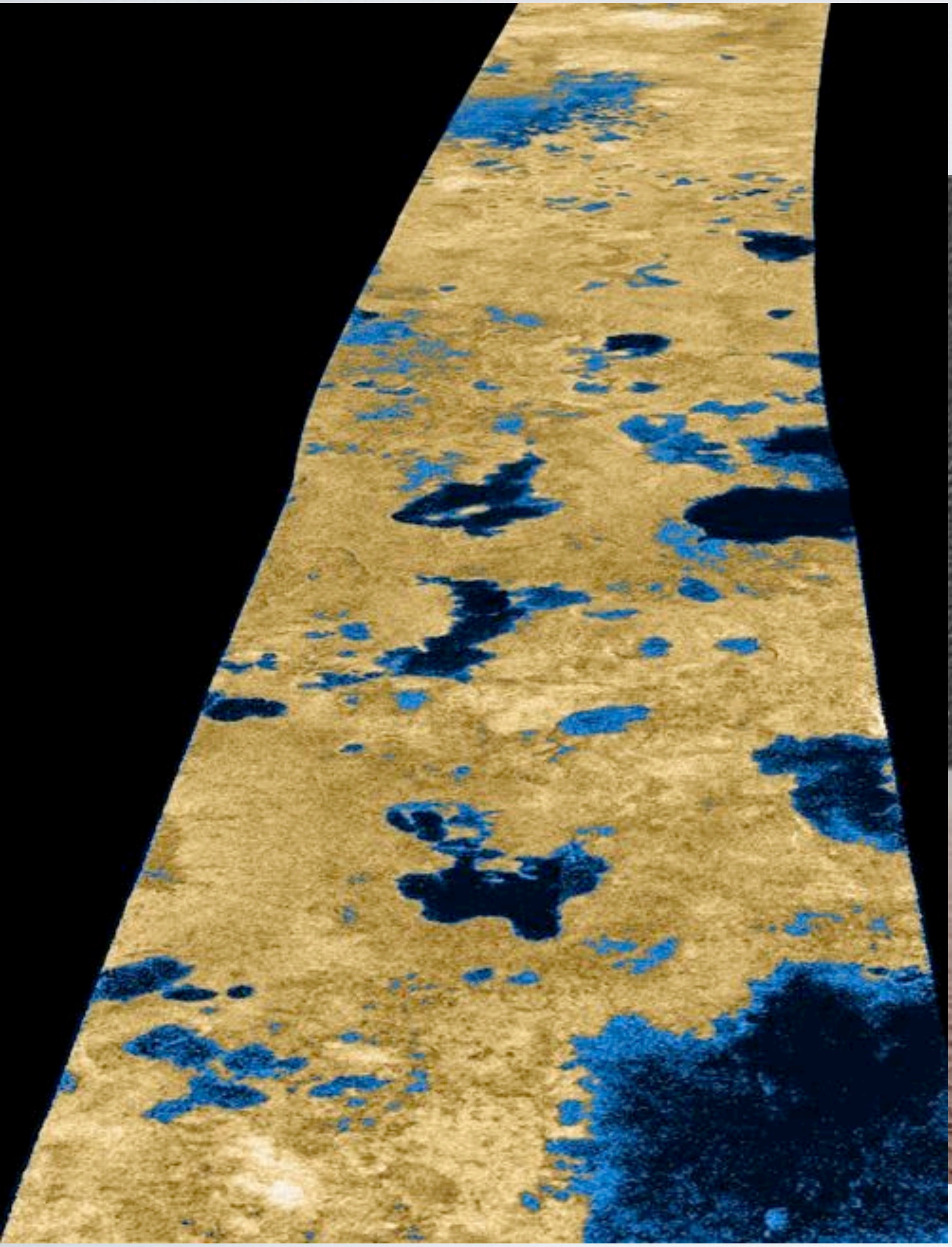


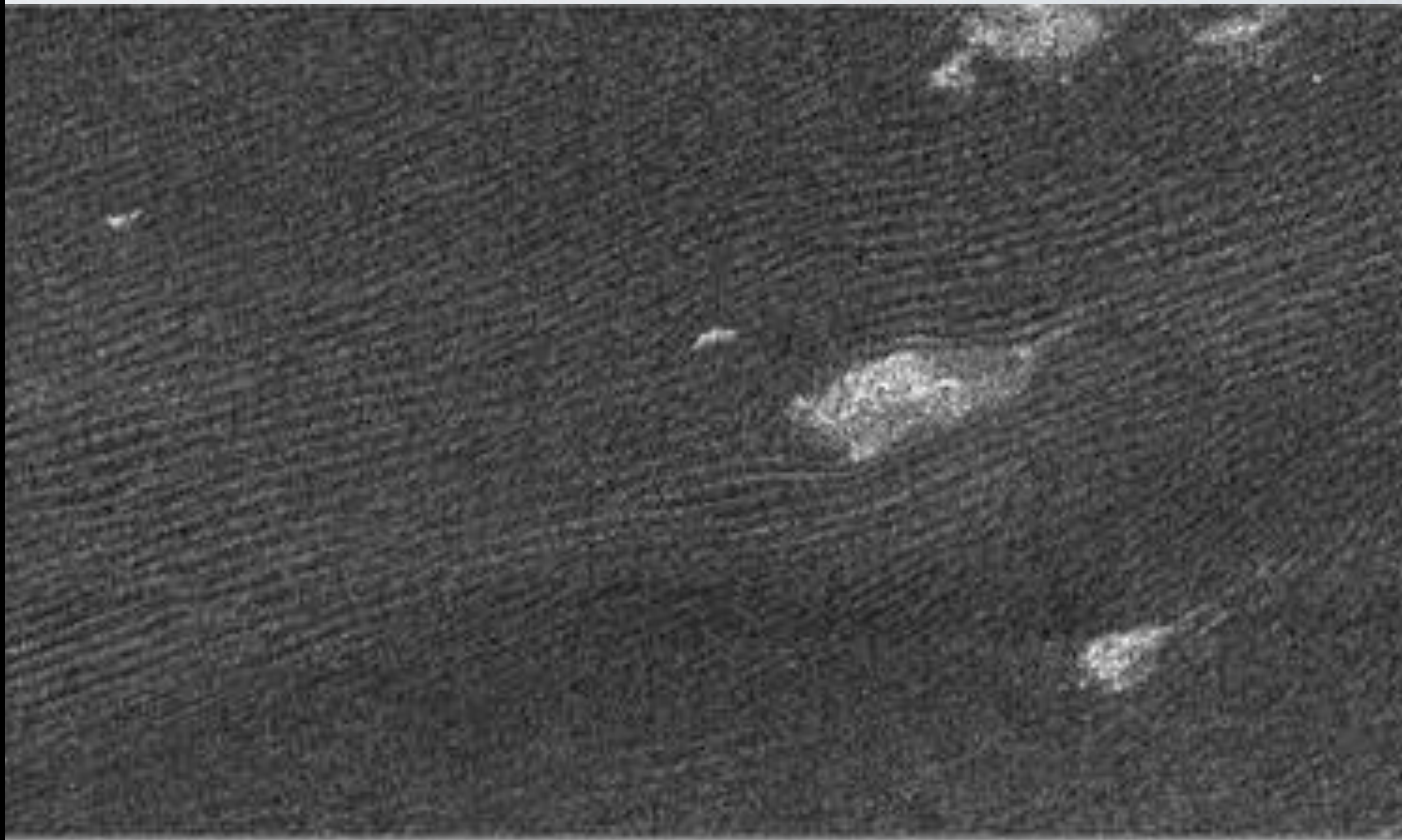
MANY MANY MORE ...



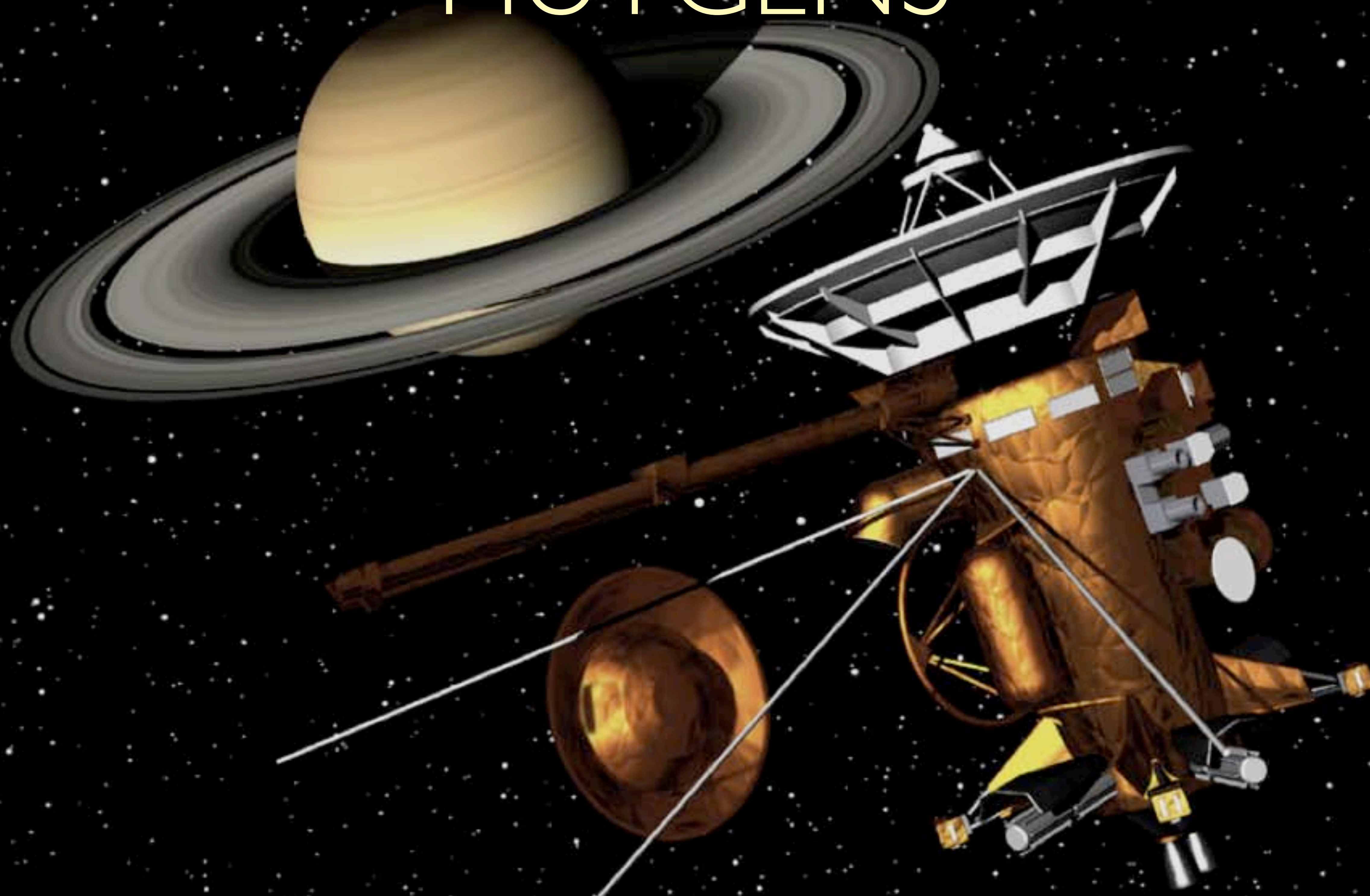
Titan lakes
Titan dunes
Rhea ring
Radiation belts
MAPS in-situ results

LAKES AND DUNES - TITAN

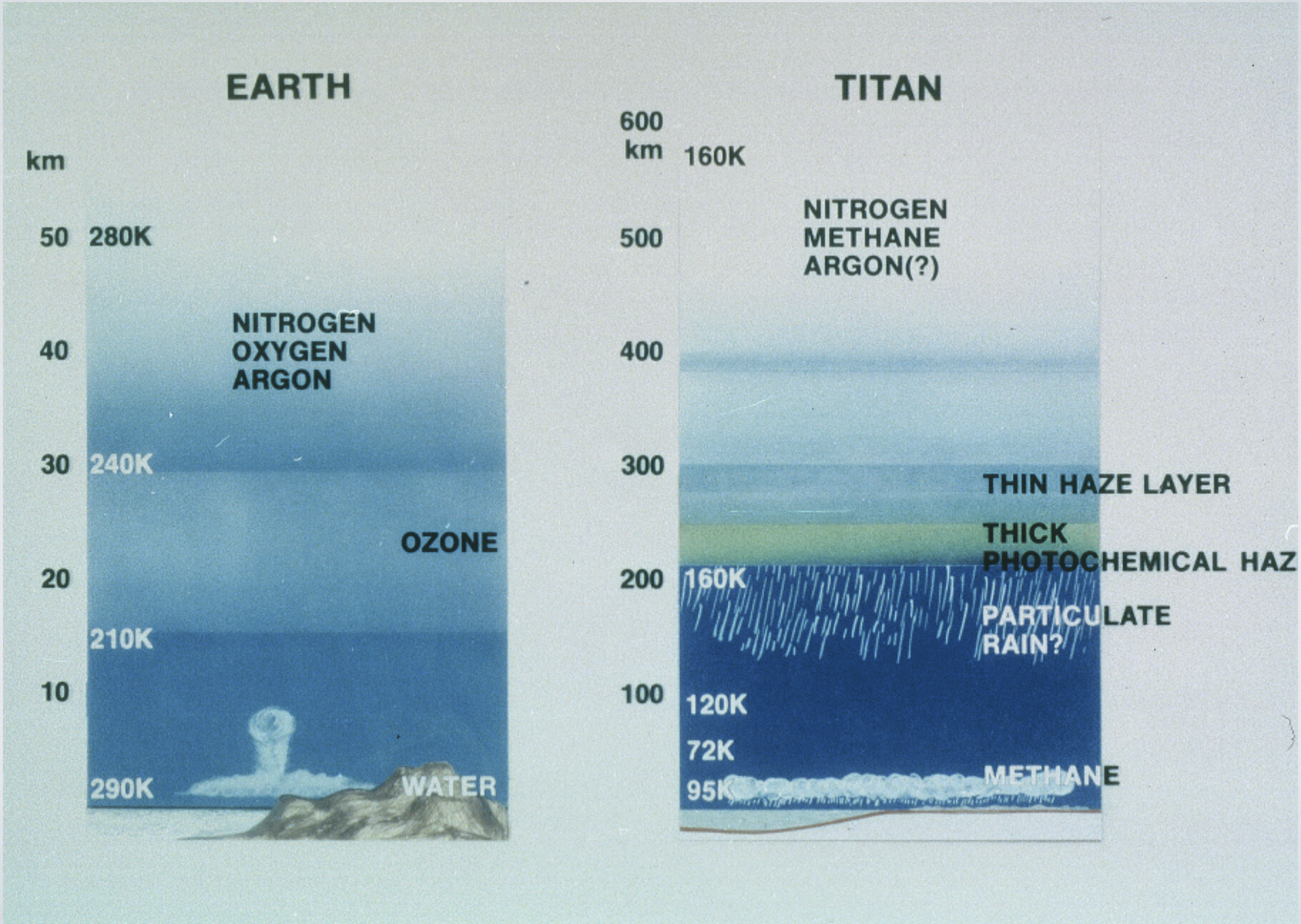




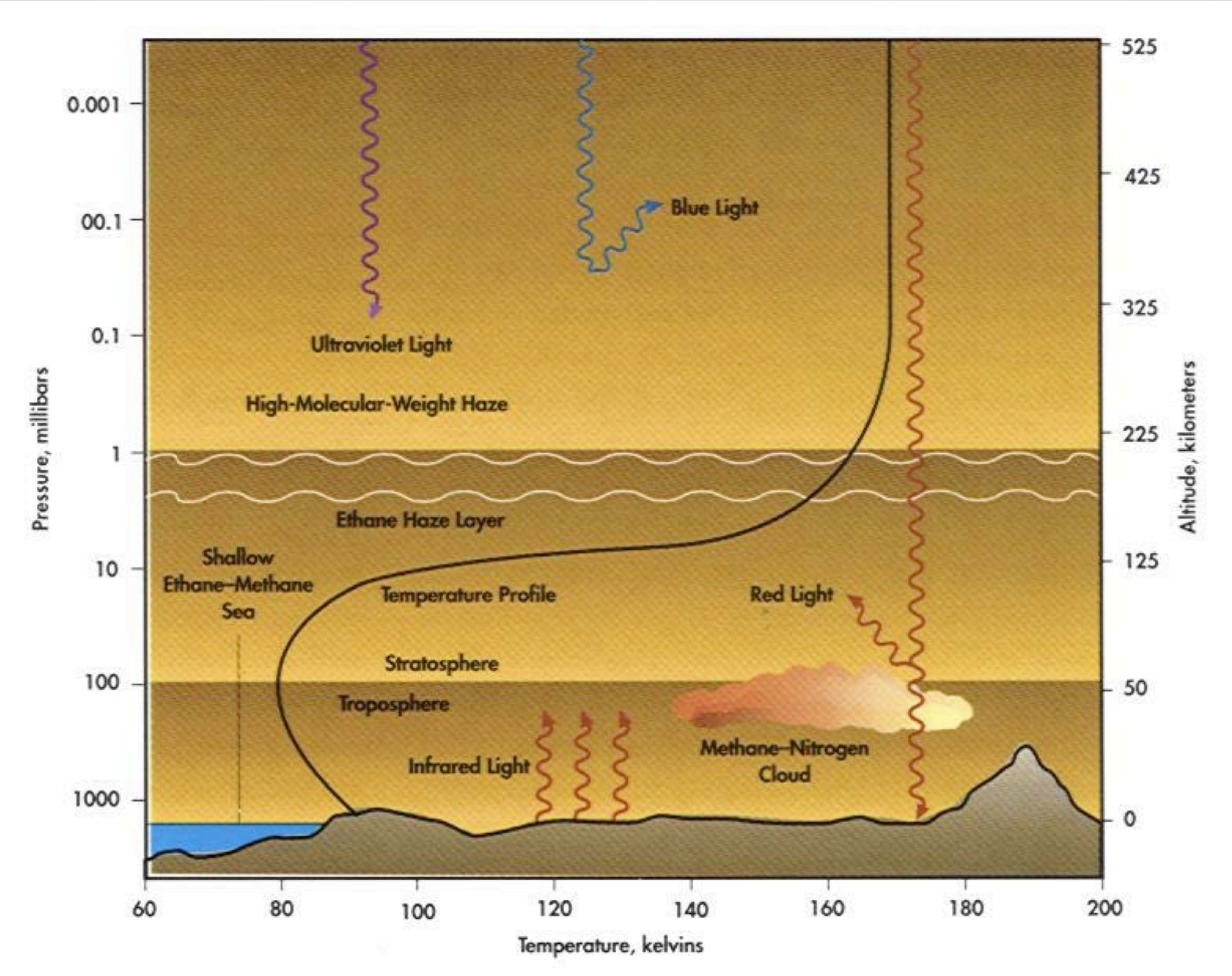
HUYGENS



COMPARE EARTH - TITAN



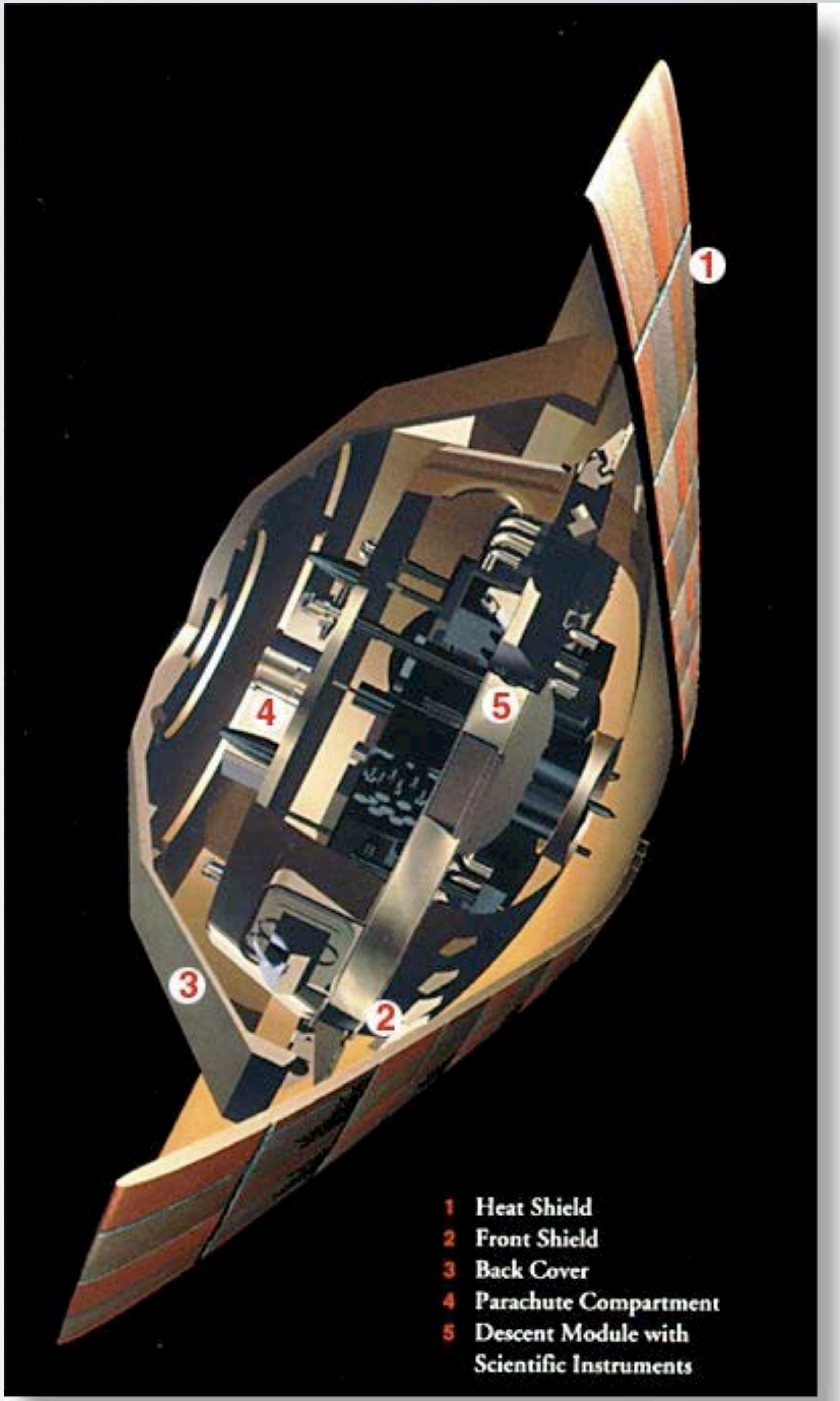
MODEL OF TITAN'S ATMOSPHERE

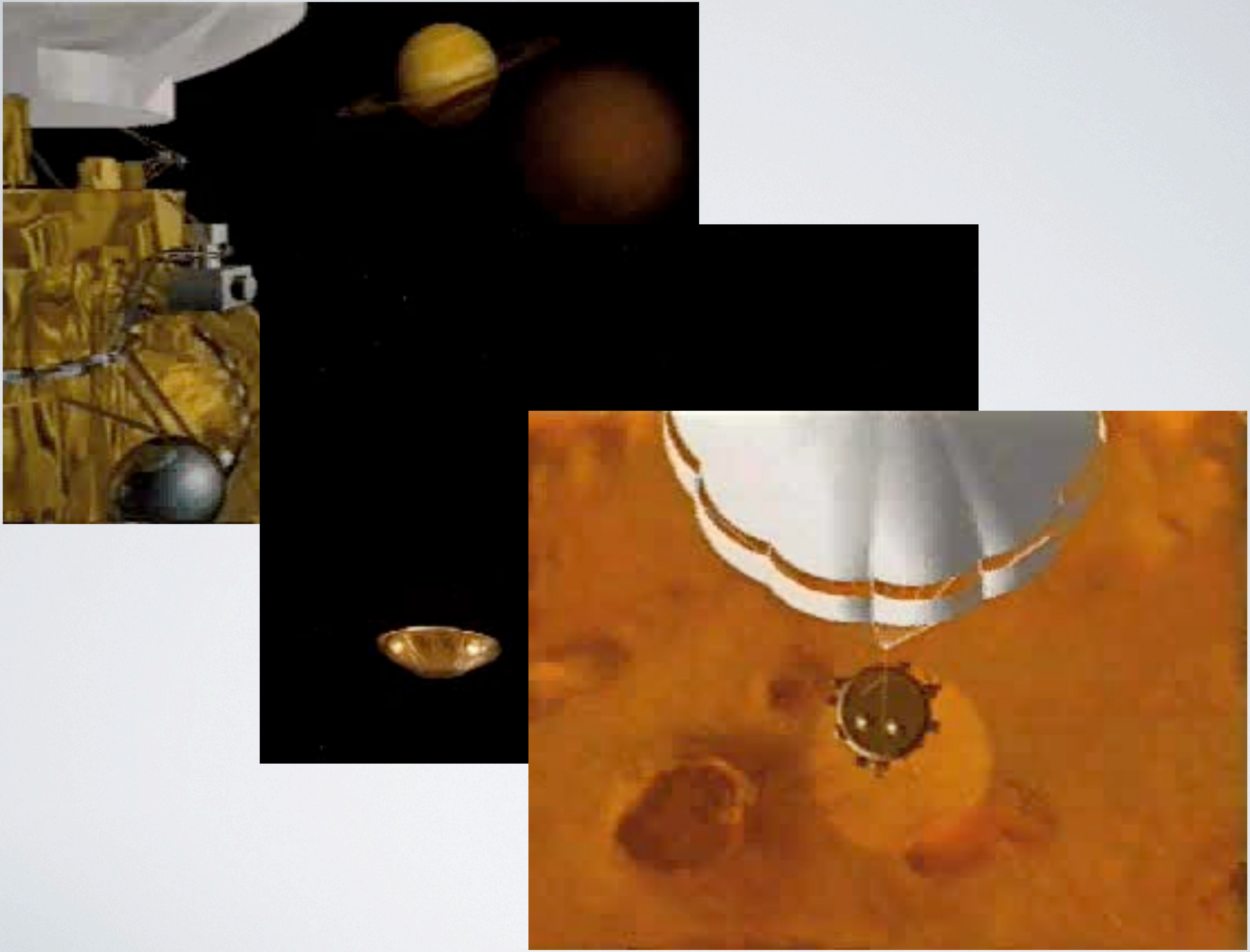


HUYGENS PROBE (ESA)

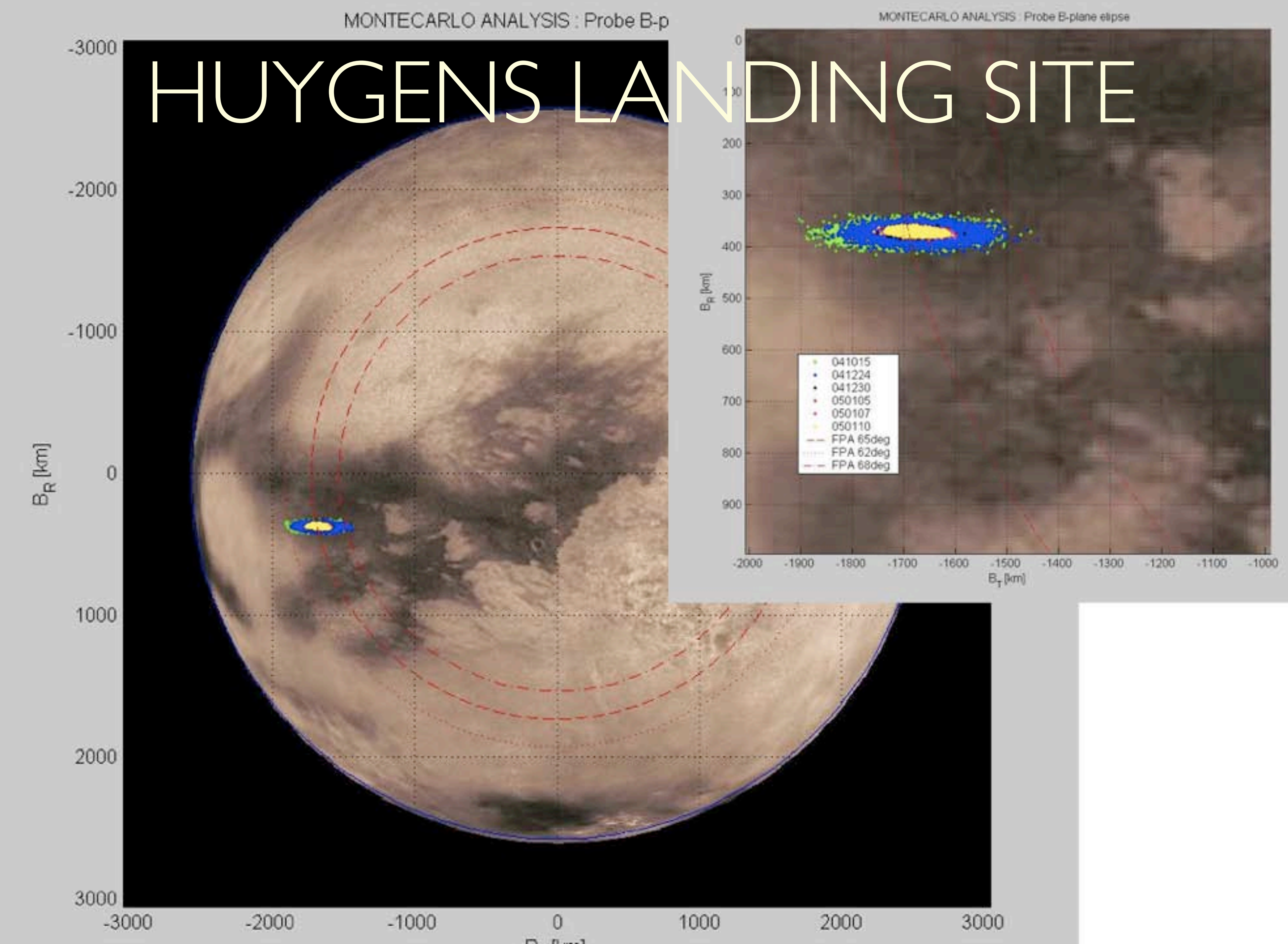
Titan atmosphere, winds, composition, temp., pressures,...

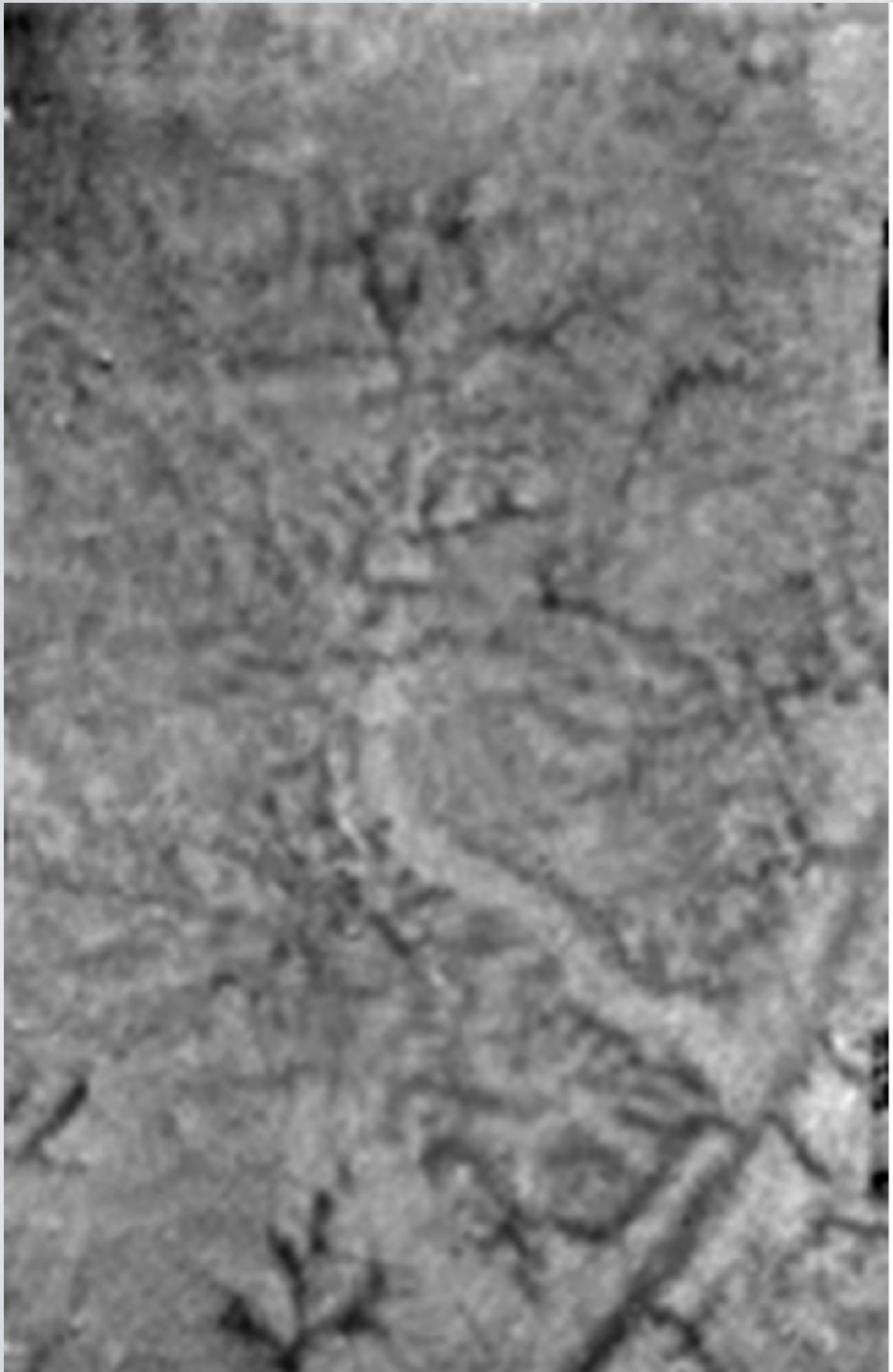
Separation - 25. dec 2004
Titan atms entry: 14. Jan 2005
entry angle : 65° (+/- 3°)
entry speed : 6.1 km/s
peak decceleration : 10-19 g
peak heating : 500-1500 kW/m^2
decent time : 2:30 h

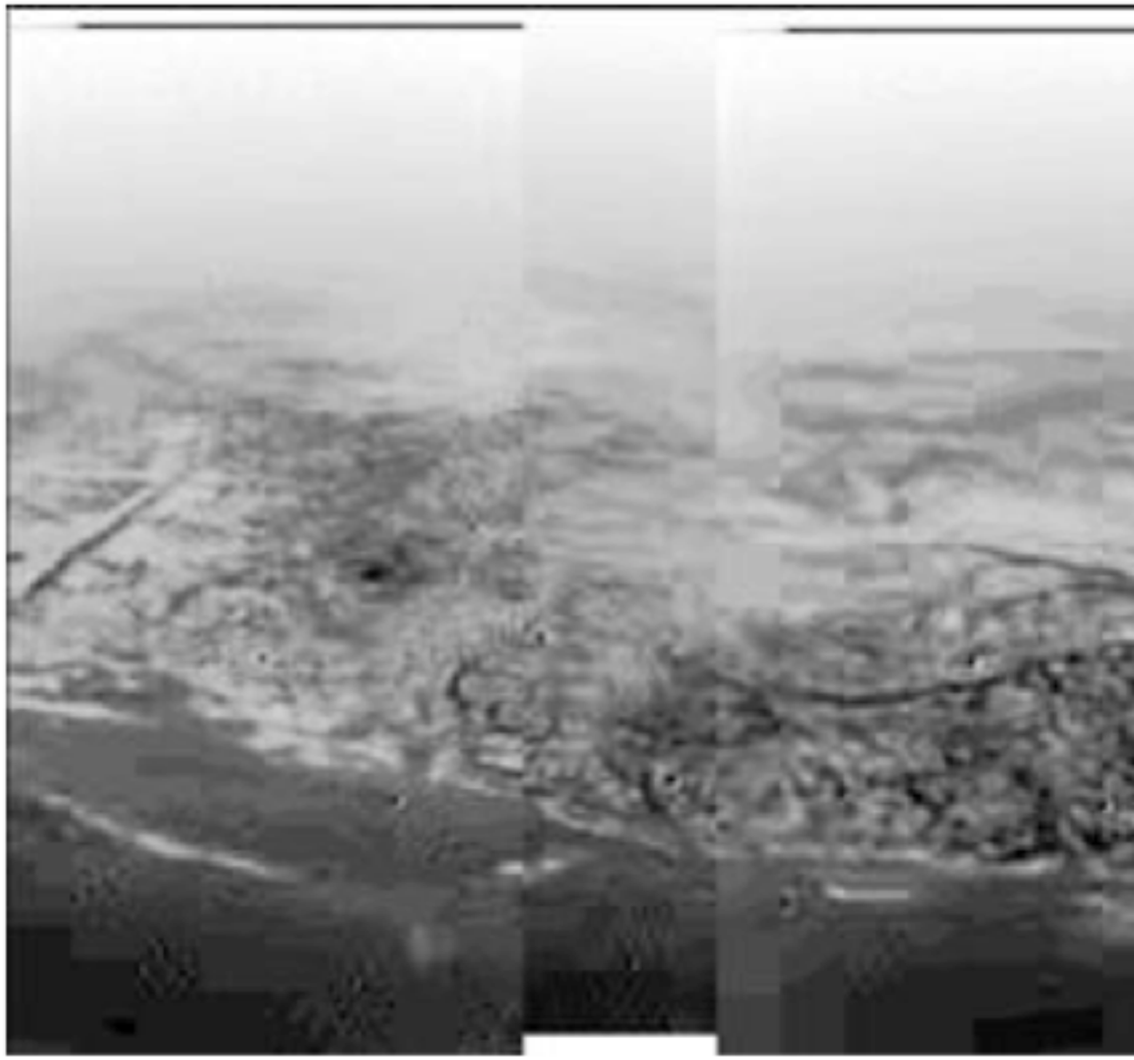




HUYGENS LANDING SITE

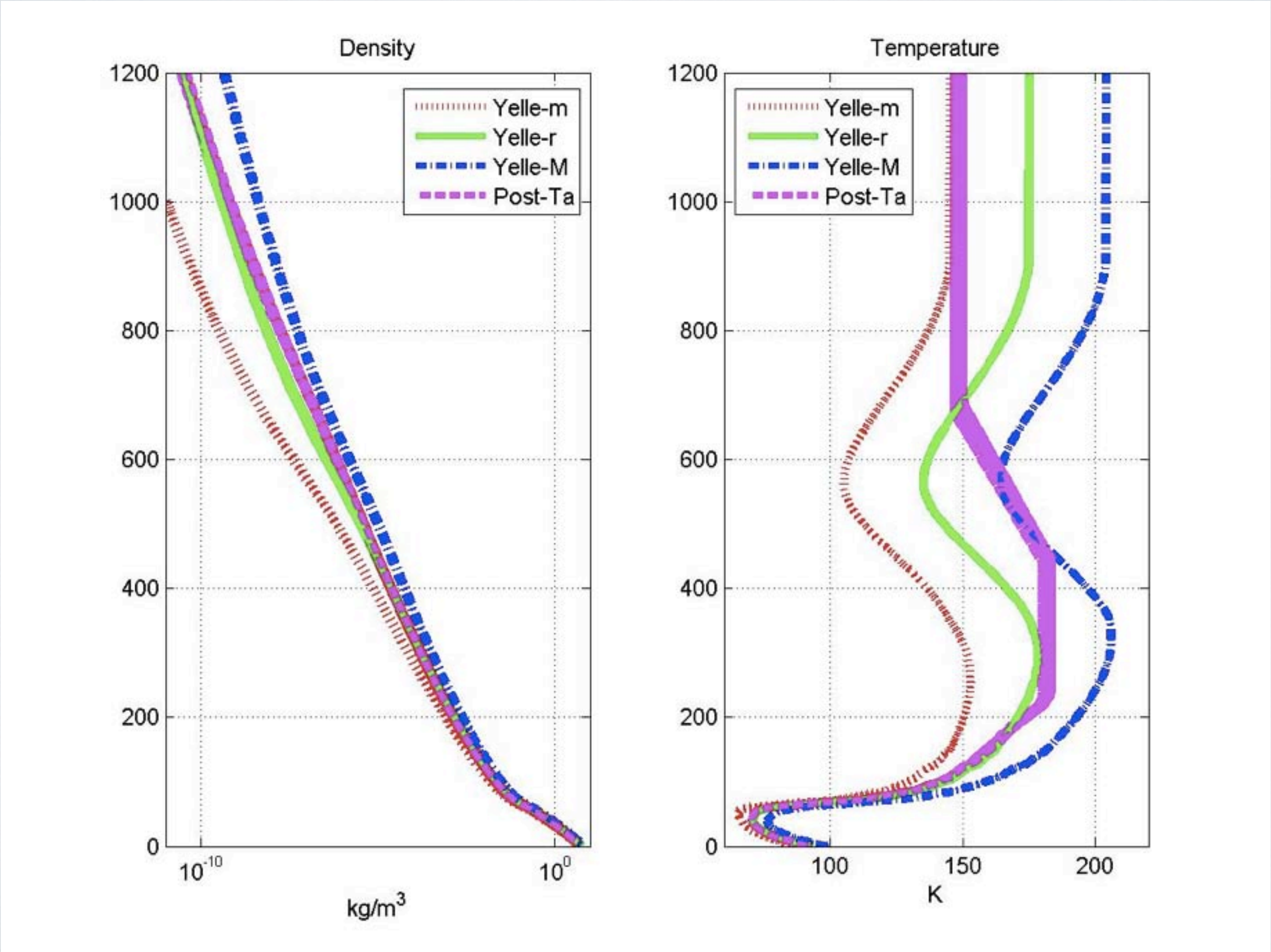




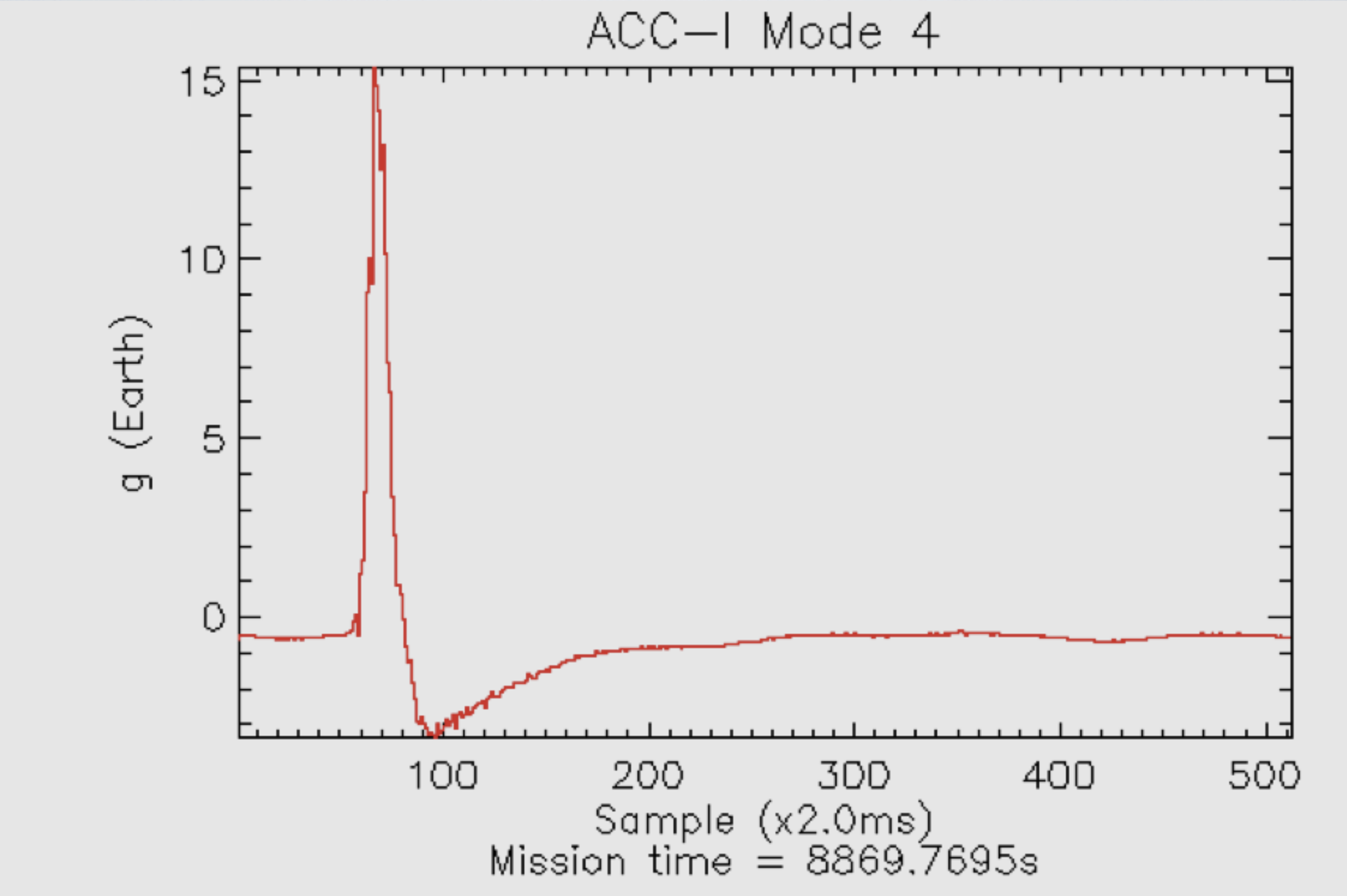


METHANE SOURCES?

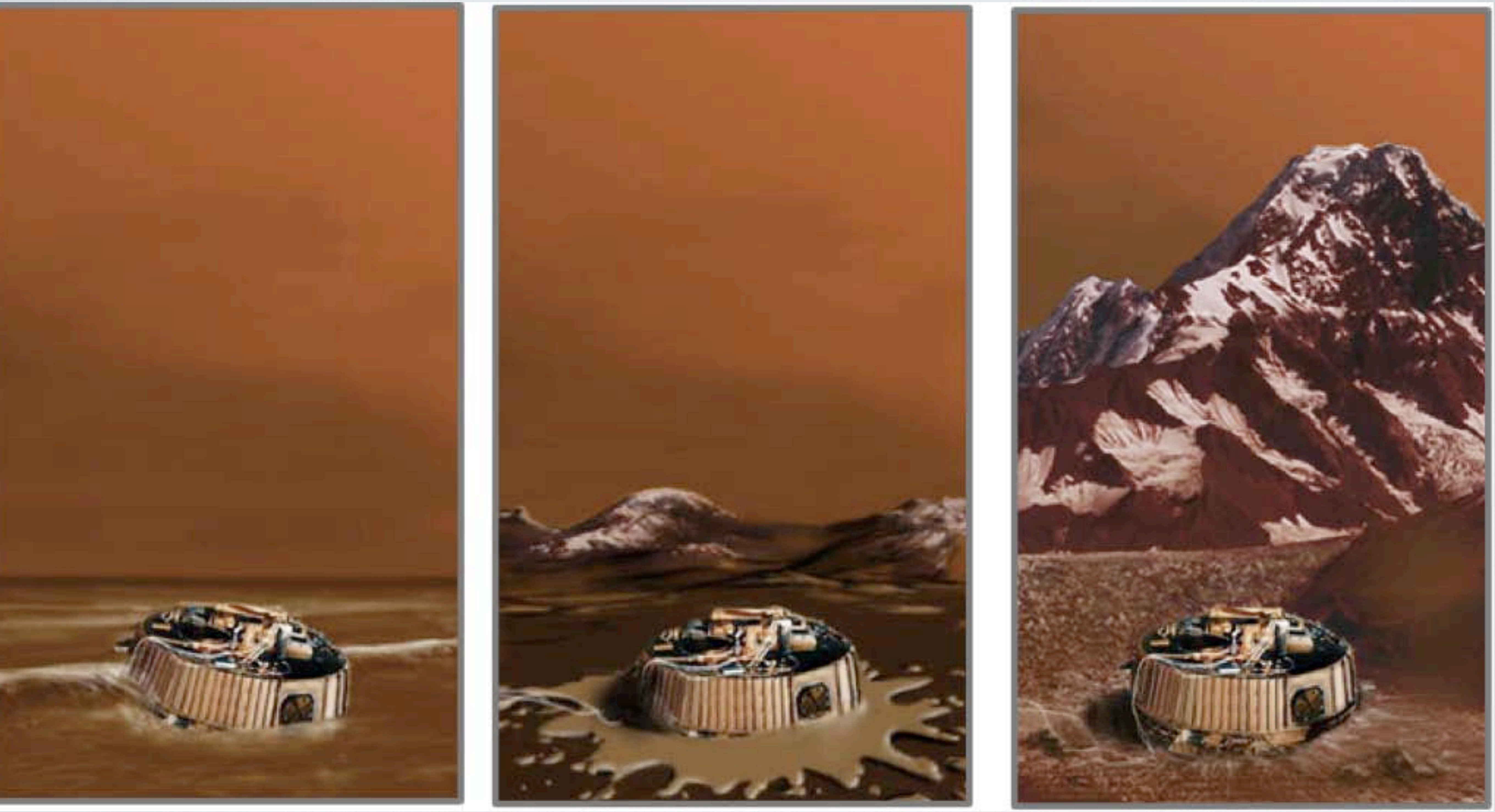
PREDICTION AND MEASUREMENTS OF TITAN'S ATMOSPHERE : GOOD AGREEMENT



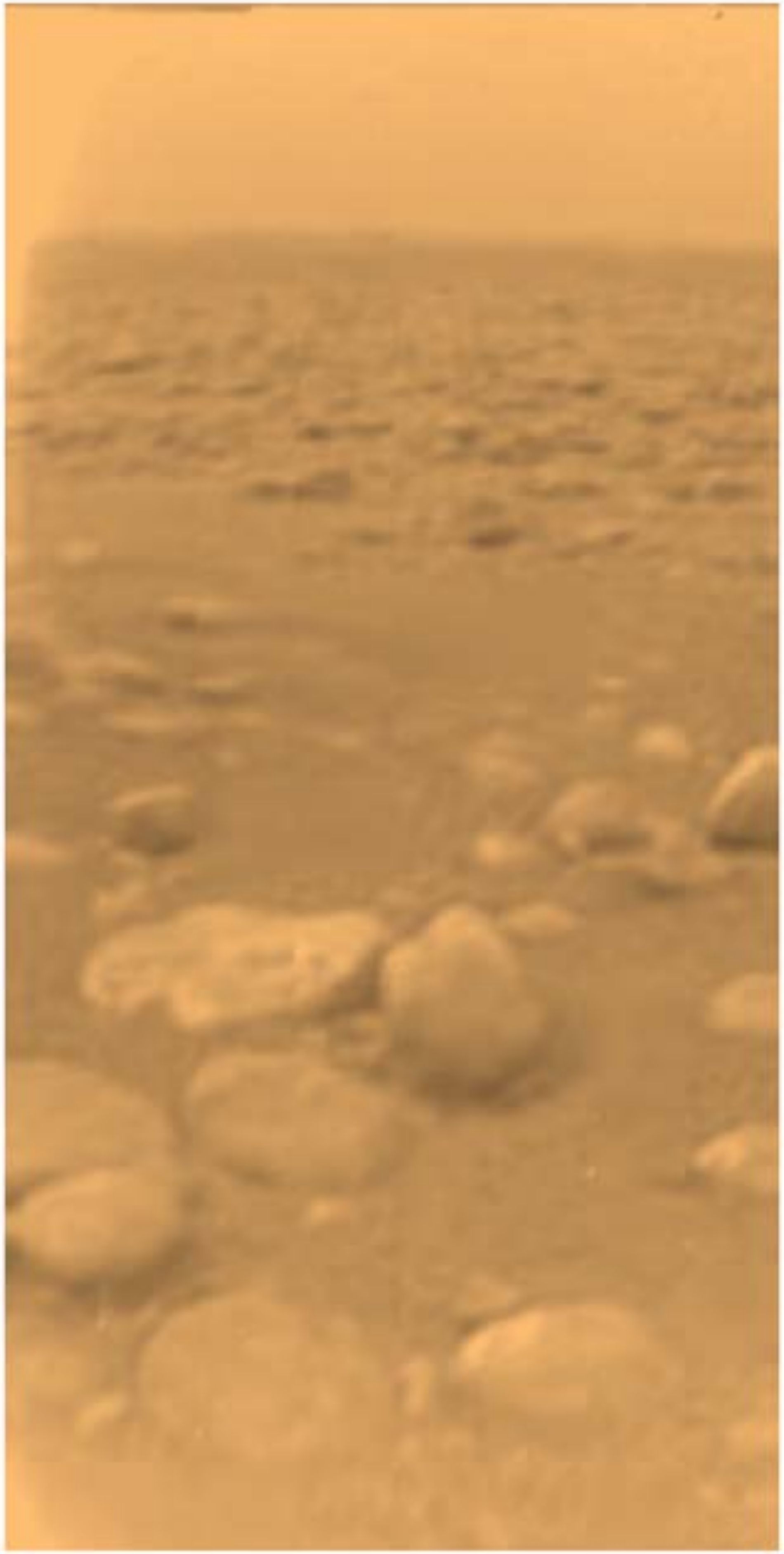
ACCELEROMETER AT LANDING



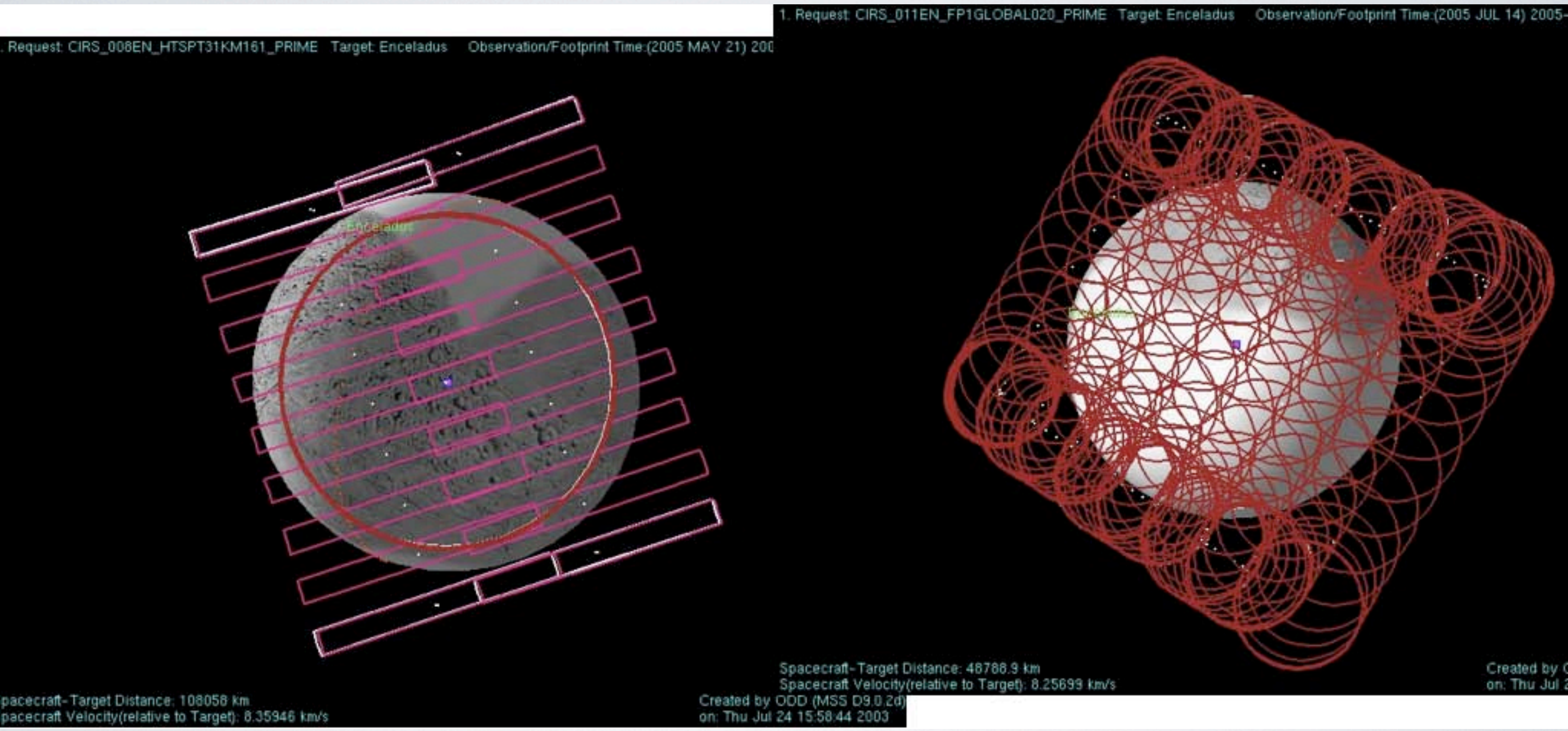
HUYGENS LANDING SCENARIOS



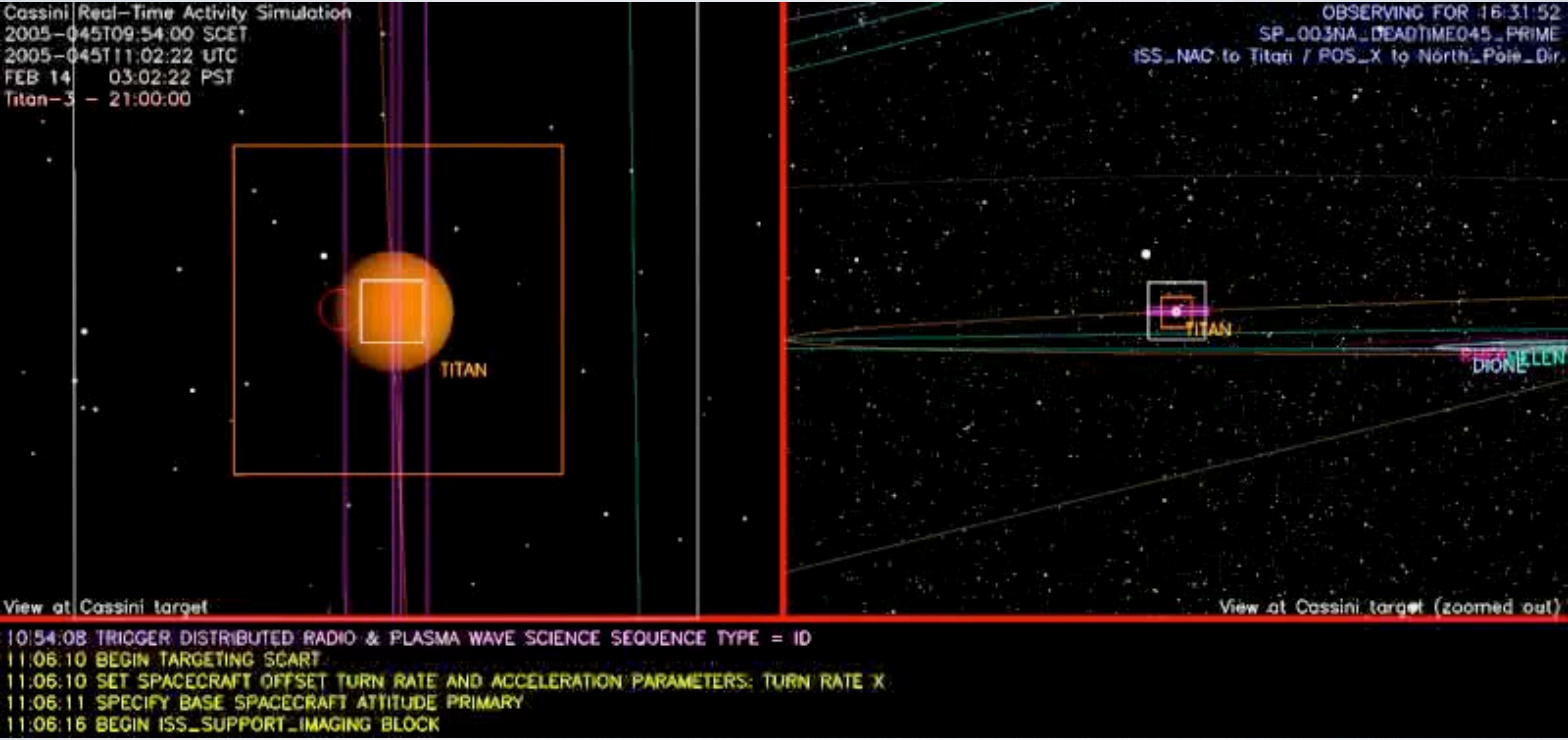
TITAN SURFACE
PREDICTION AND REALITY



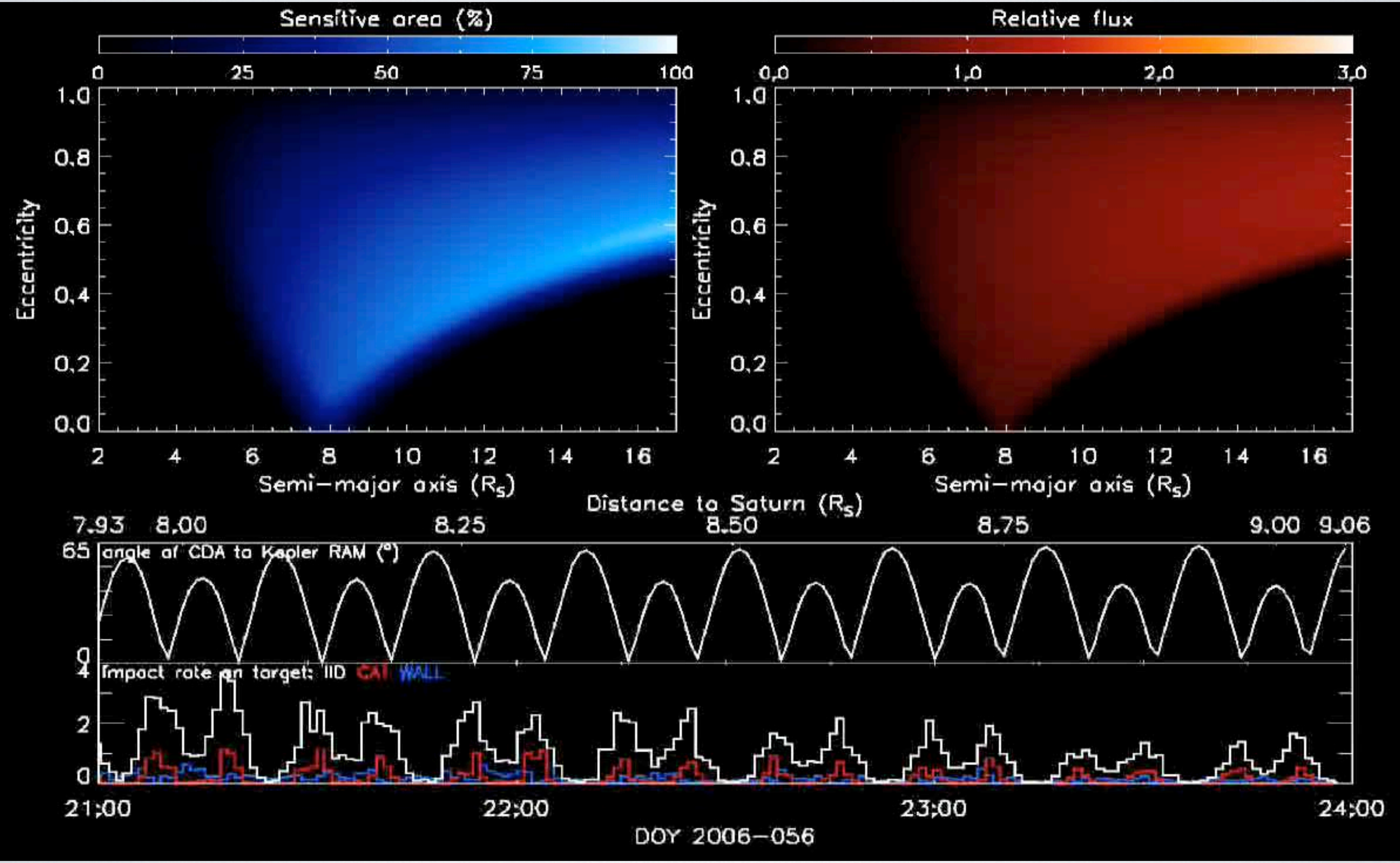
SCIENCE PLANNING ! EXAMPLE : CIRS



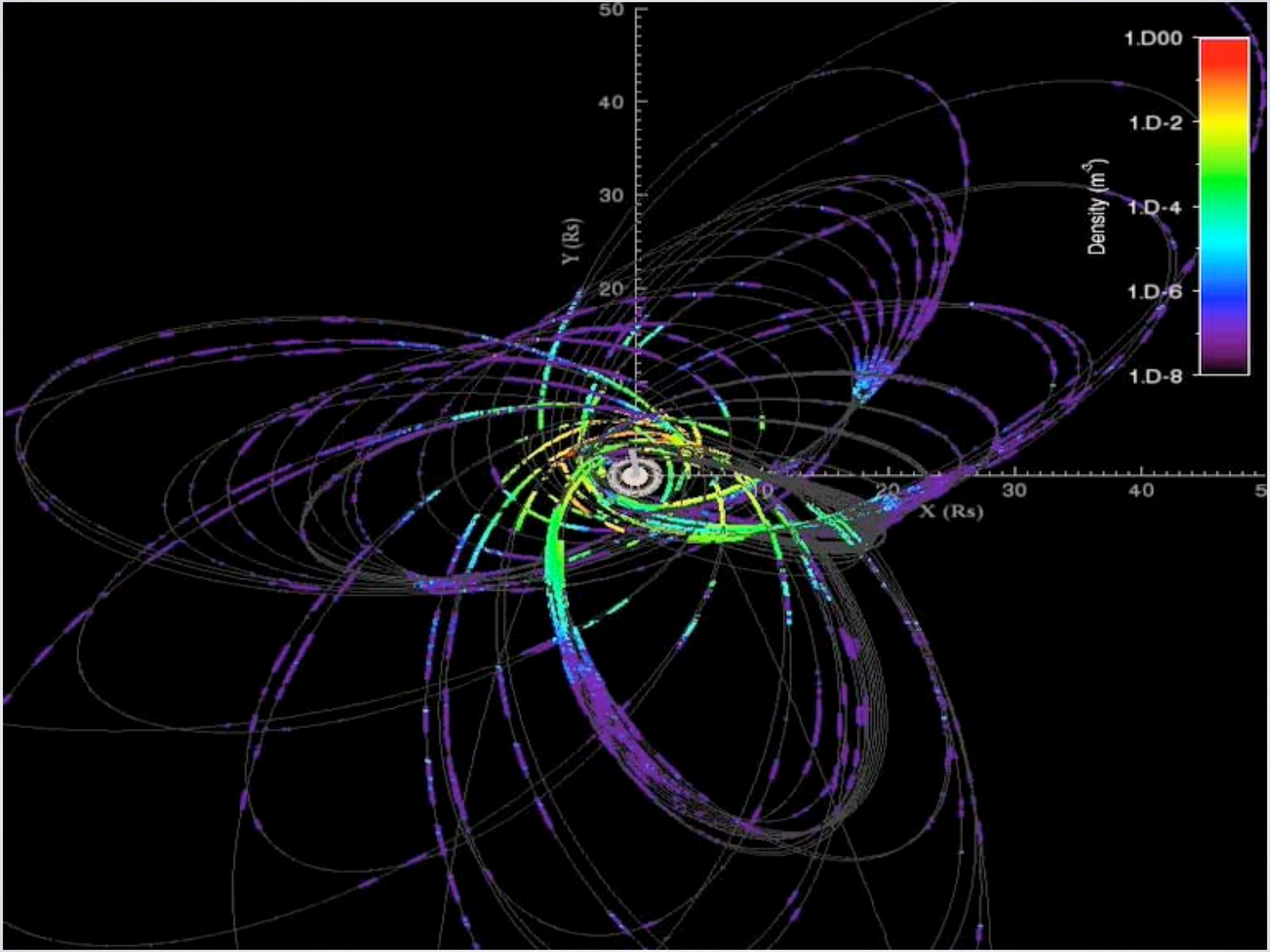
OBSERVATION PLANNING



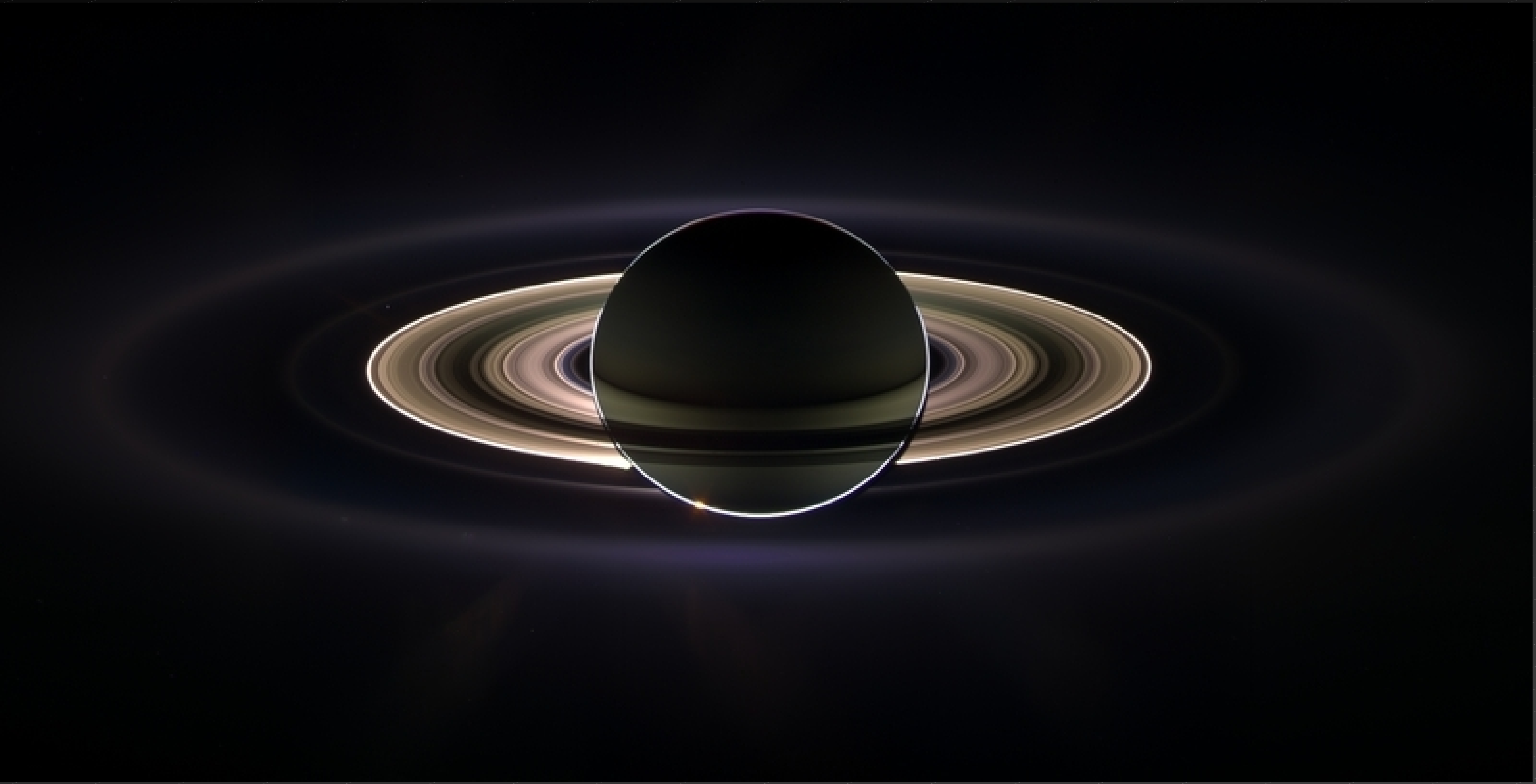
ROCKING CASSINI: DUST DYNAMICS



DUST DENSITY

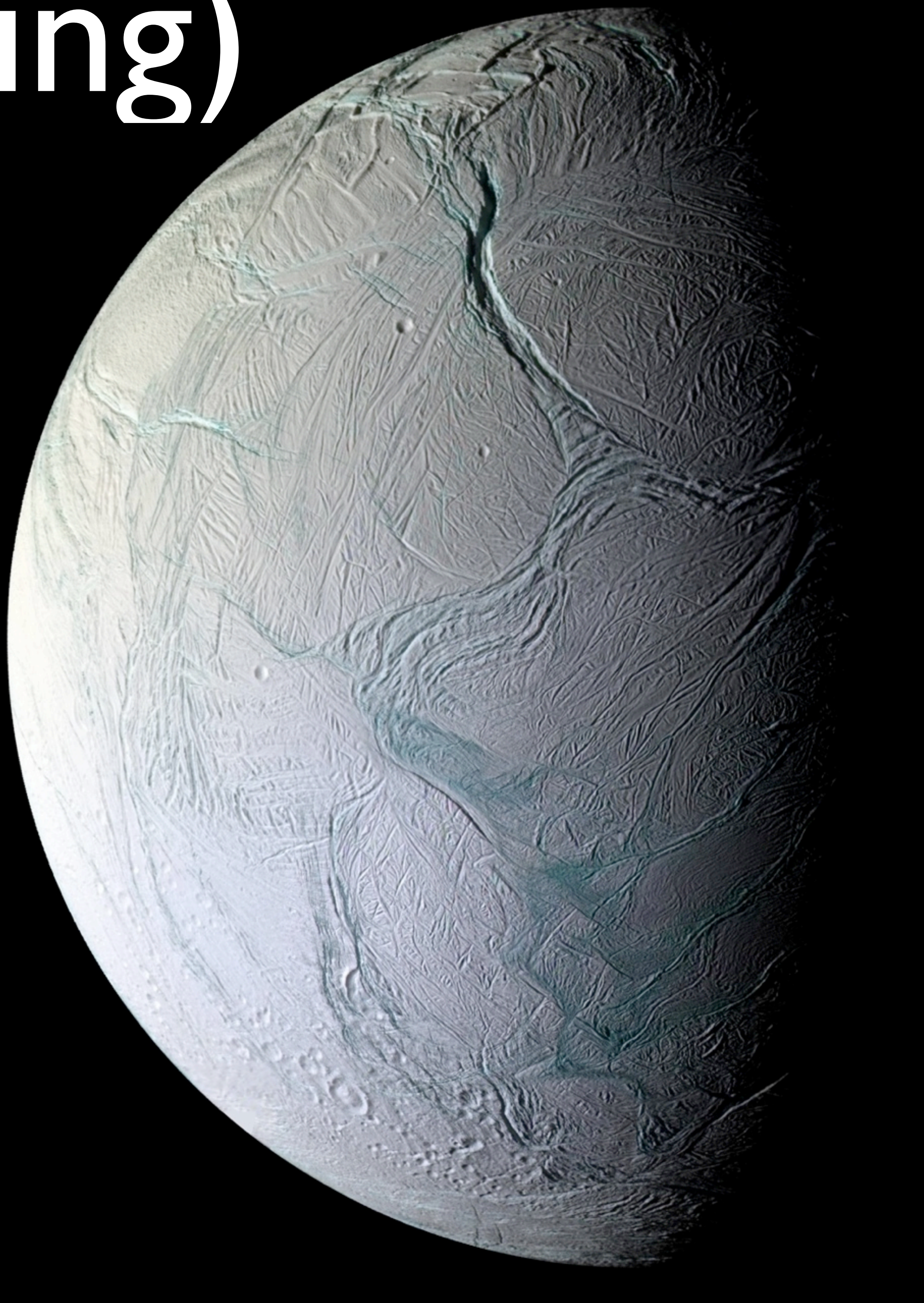


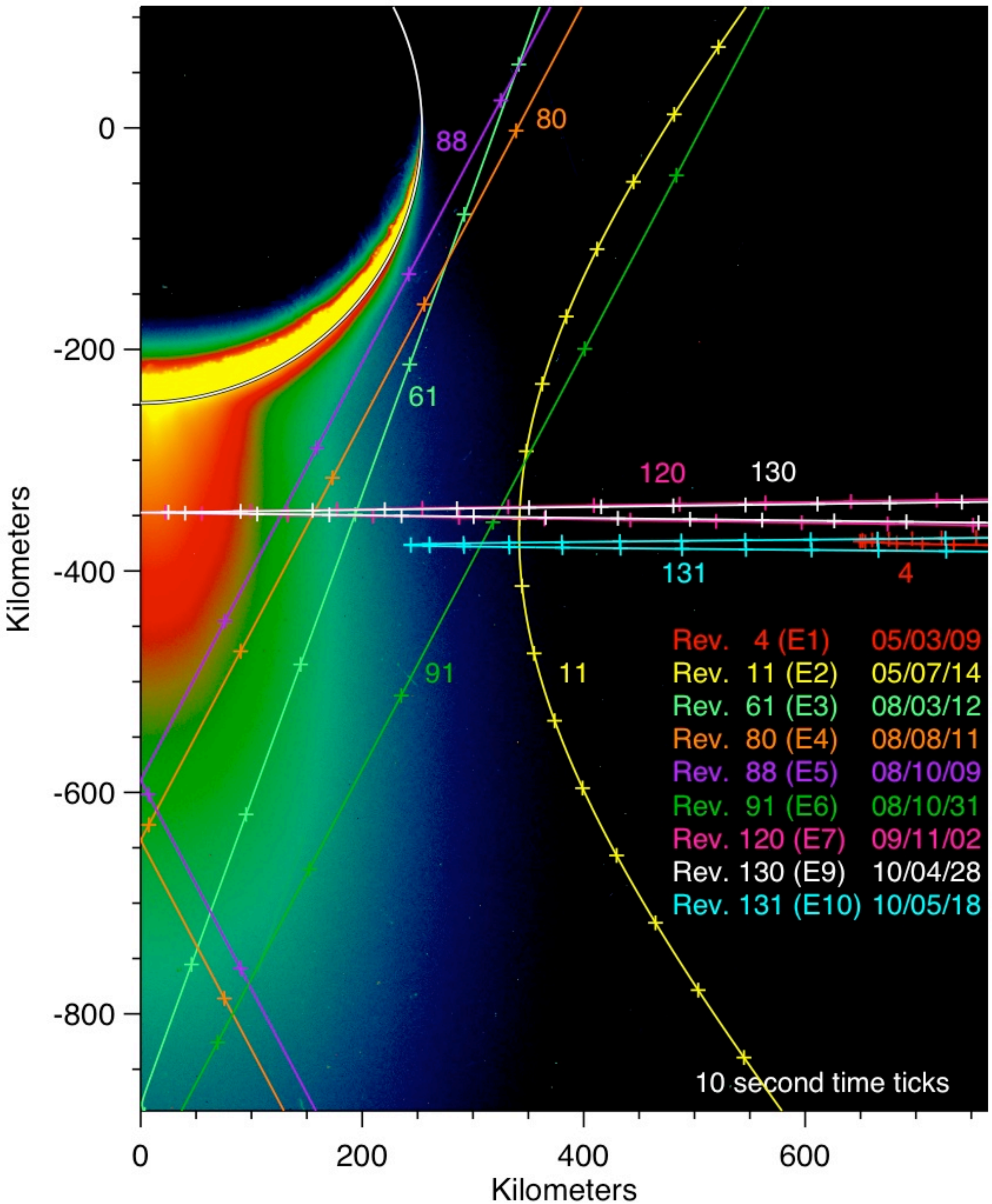
The E-Ring



Enceladus : Source of ice grains (E ring)

- Size: 499 km
- Density: 1600 kg/m^3
- 70 km Ice Crust on Rocky Core

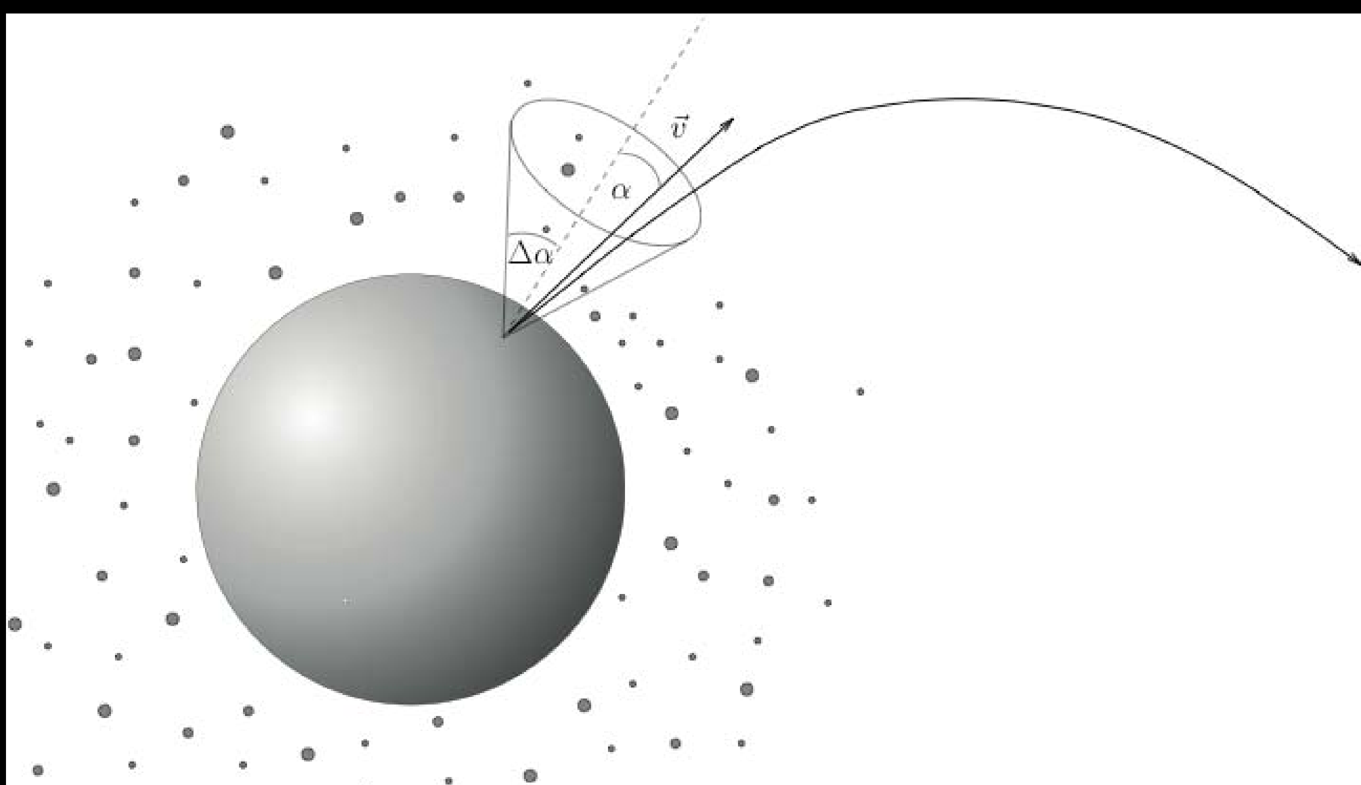




ENCELADUS FLYBY PLANNING

Ejecta Production

Meteoroid Impacts Splash up Ejecta



Sremcevic et al., Icarus, 2005

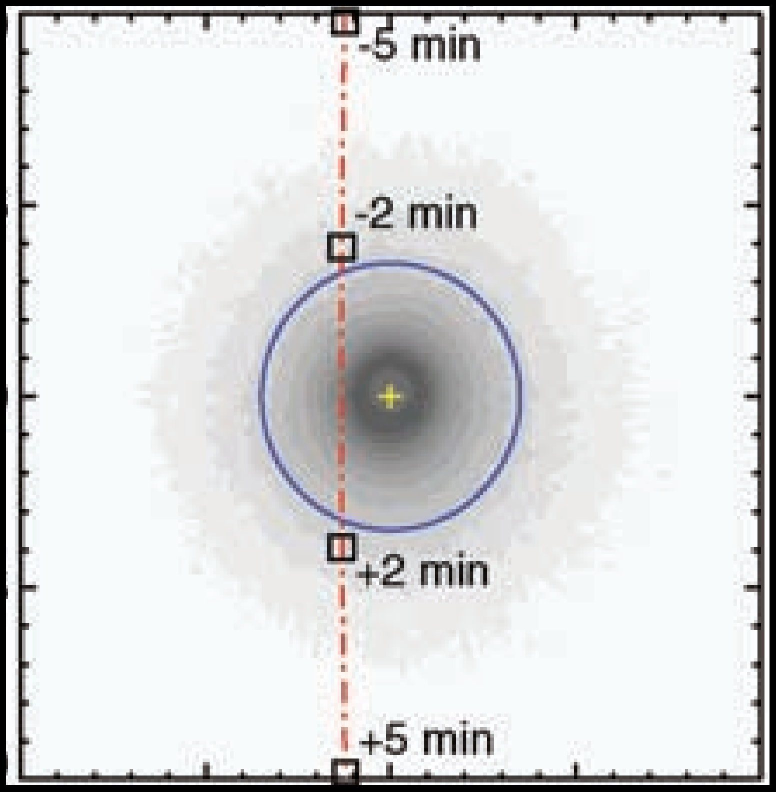
Mass Yield ~ 4000

Koschny & Grün, Icarus, 2001; Krivov et al., Icarus, 2003

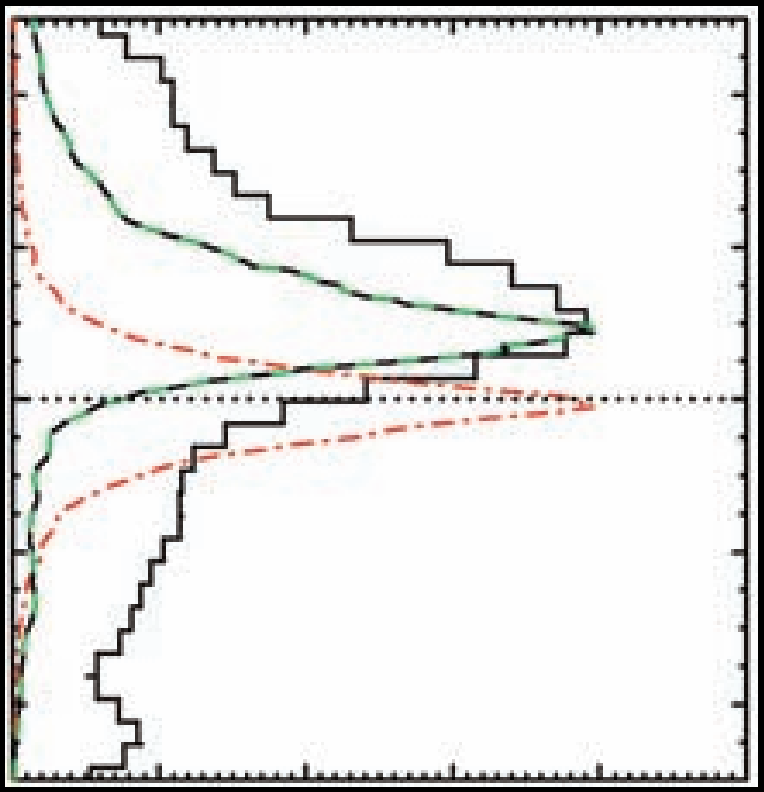
- Gravitationally Bound Ejecta Populate Cloud
- Some Ejecta Escape:
  - Feed Rings
  - Mass Loss Mechanism

Discovery (MAG, INMS, CDA):
South Pole Ice Geysers

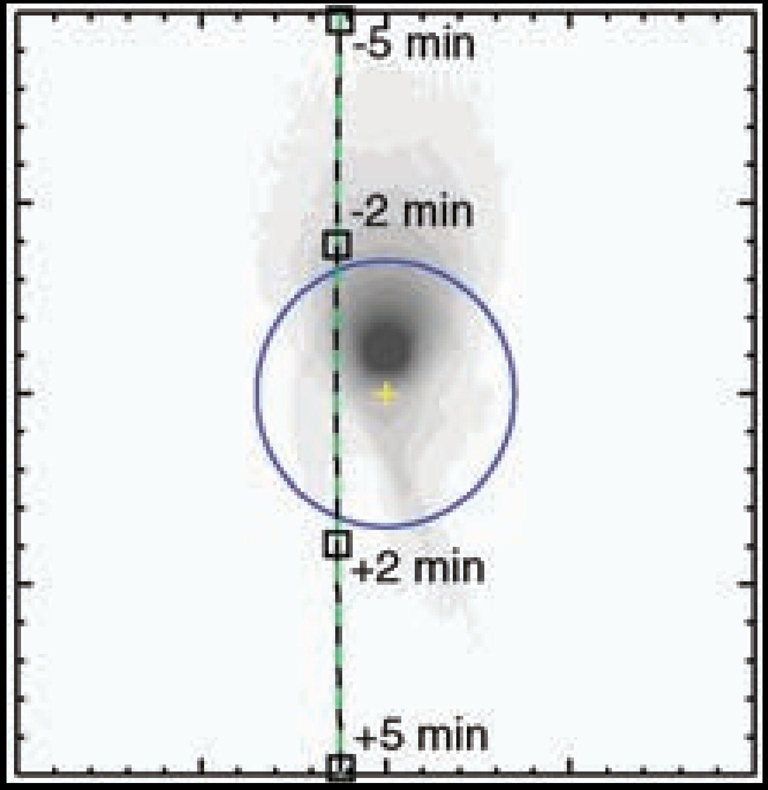
Dust Cloud



Dust Data



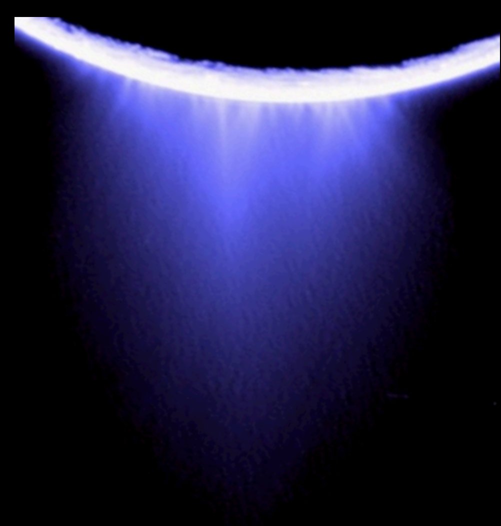
Dust Plume

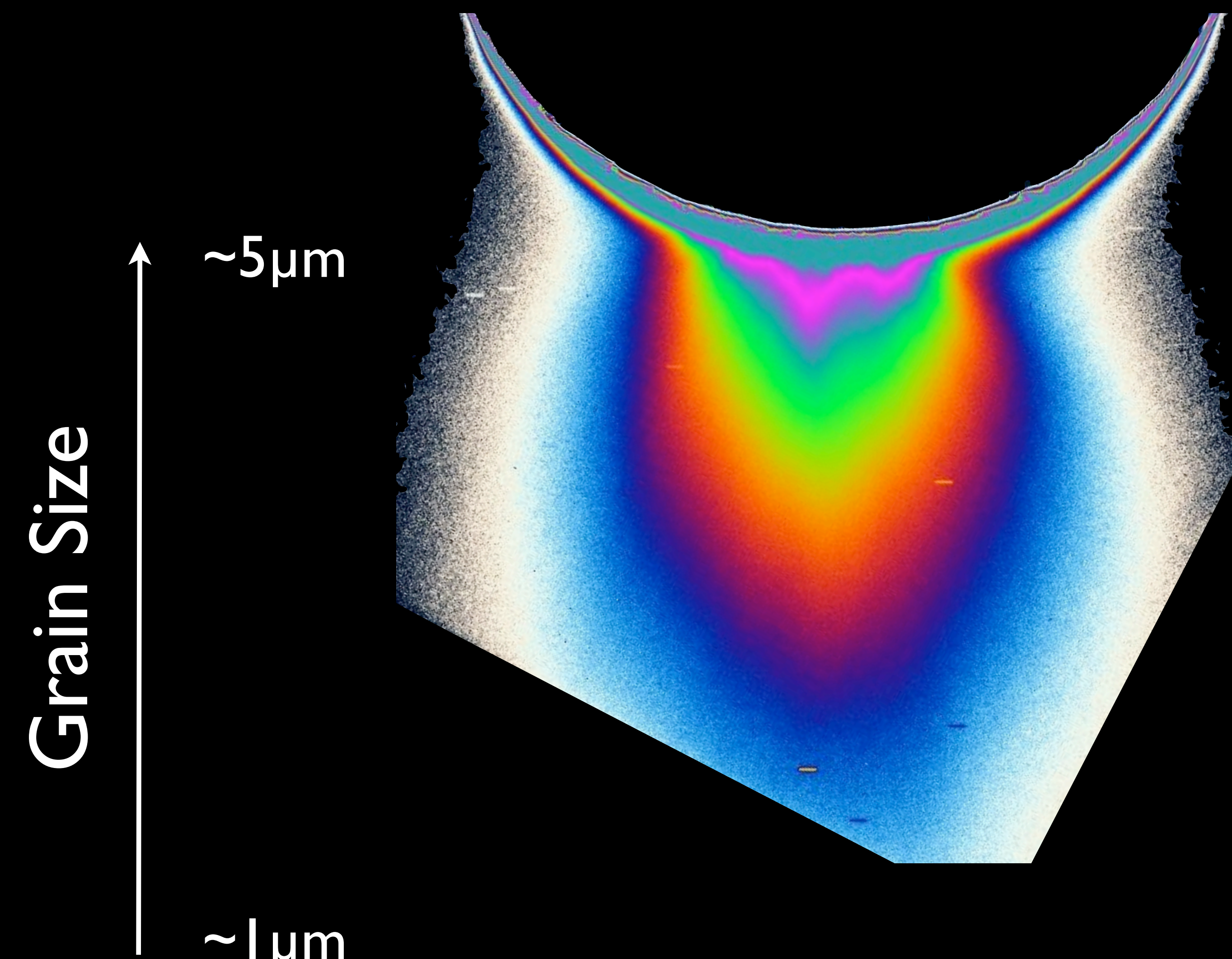


Spahn et al., Science, 311, 2006

peak rate not at closest approach

Geyser Grains Slower Than Escape Speed

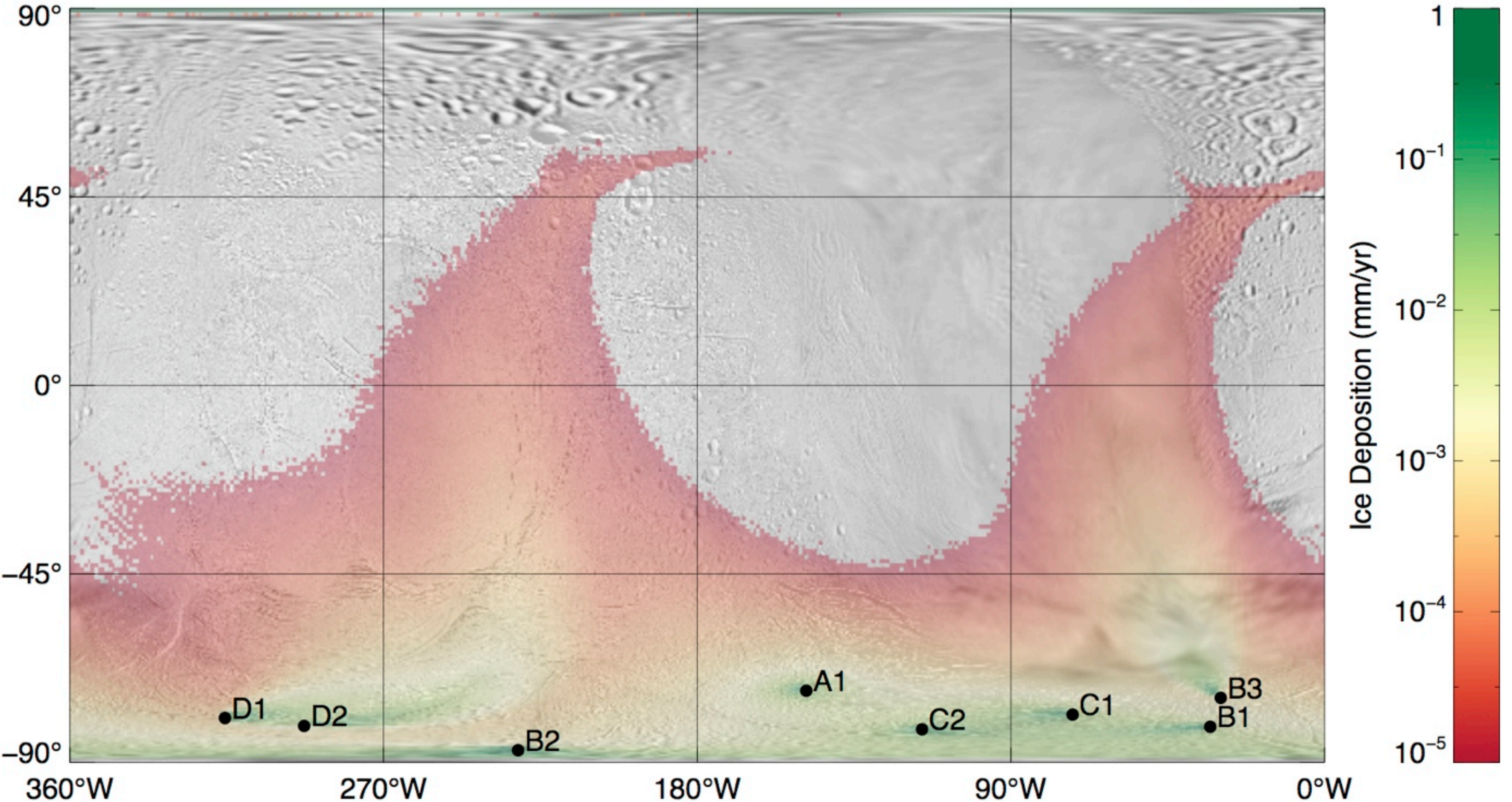




Hill Radius ~ 950 km

Escape Speed ~ 207 m/s

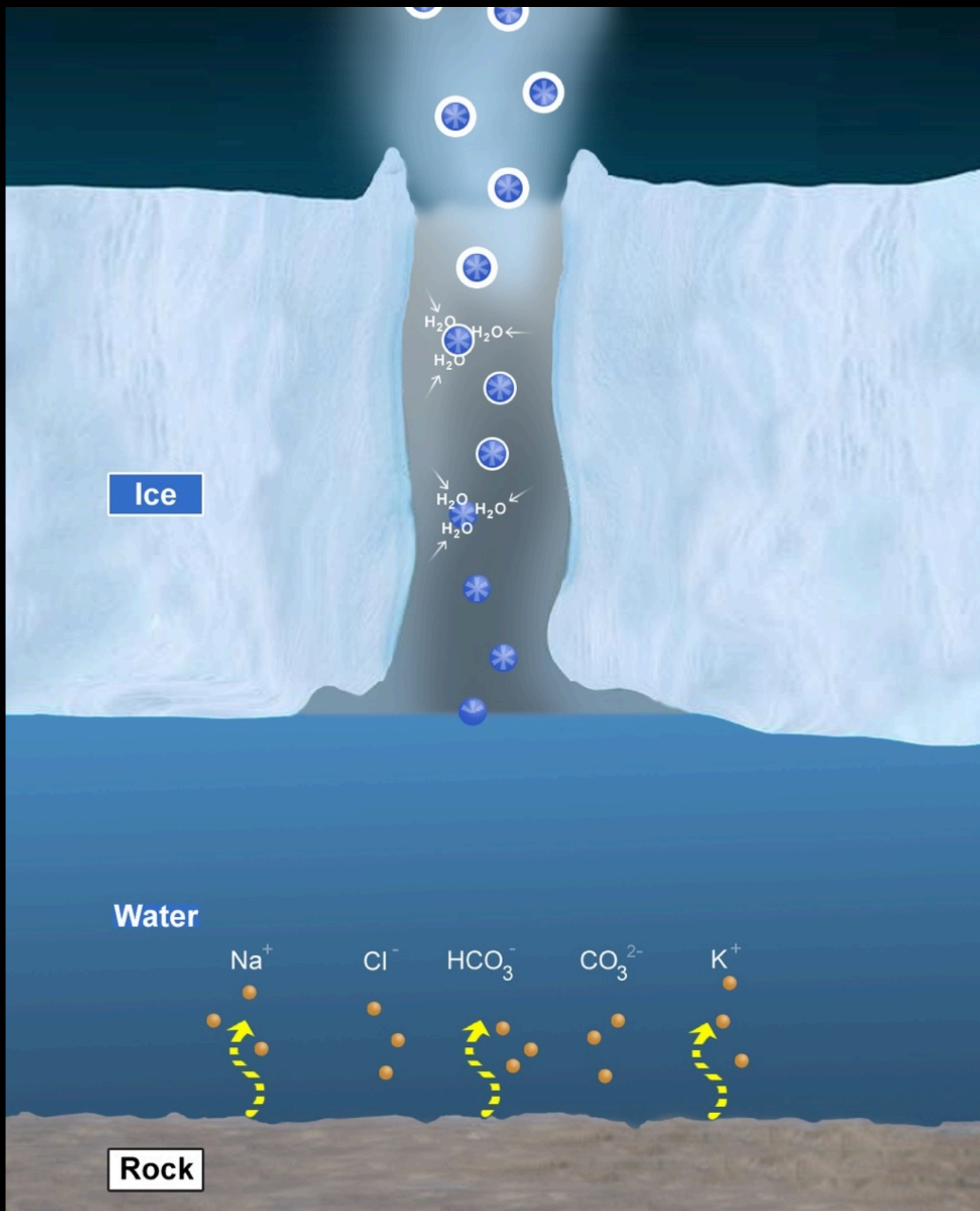
Snow on Enceladus !



Kempf et al., 2009

Salty icy grains : Direct Evidence for Subsurface Liquid Water Reservoir

Water + Rocky Core



Water Dissolves Akali Salts

Zolotov, Geophys. Res. Lett., 34, 2007

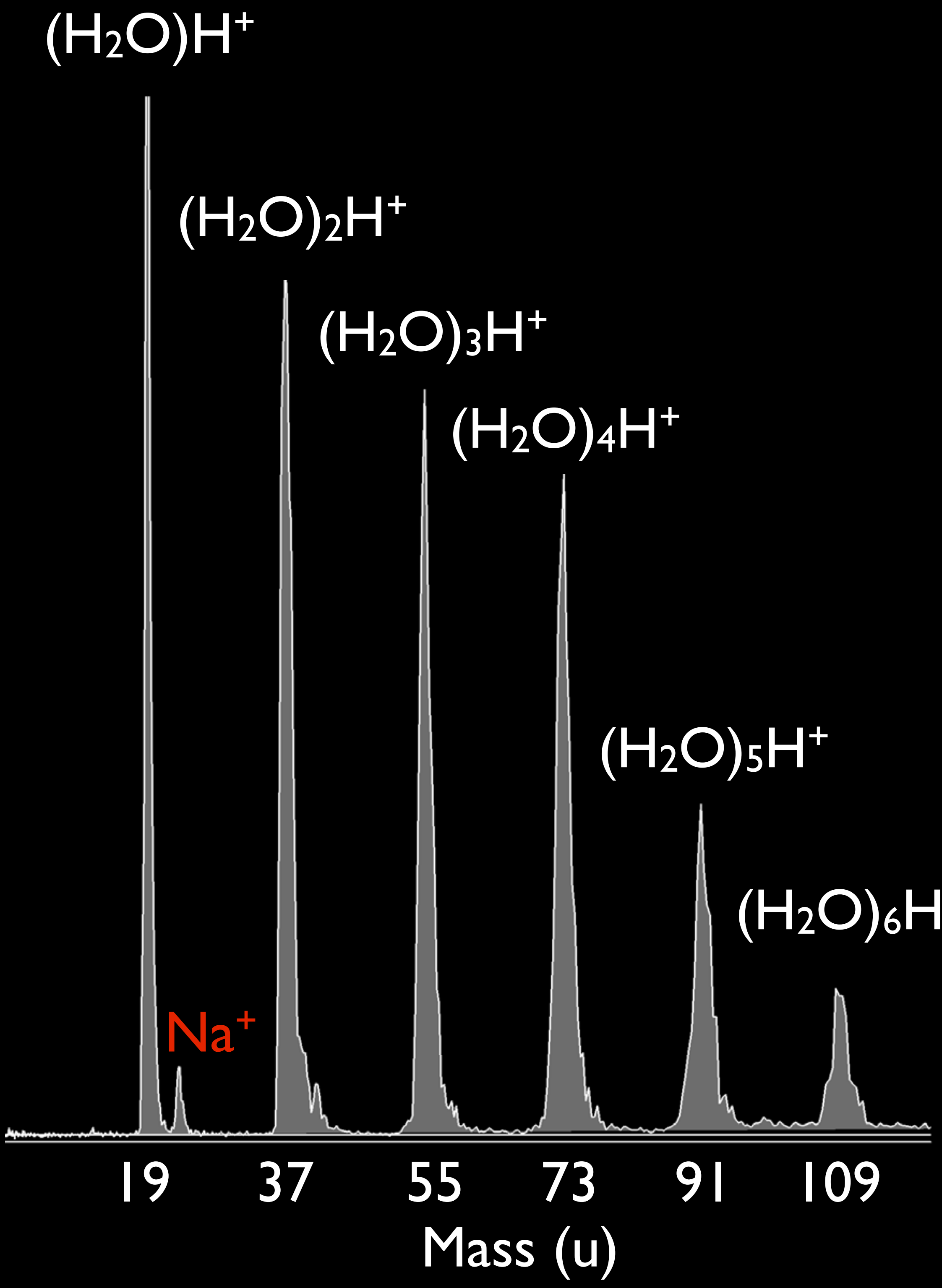
↓

Ice Grains Should be Salty!

Dust Composition

Cassini Dust Detector CDA

Geyser Water Ice Grain

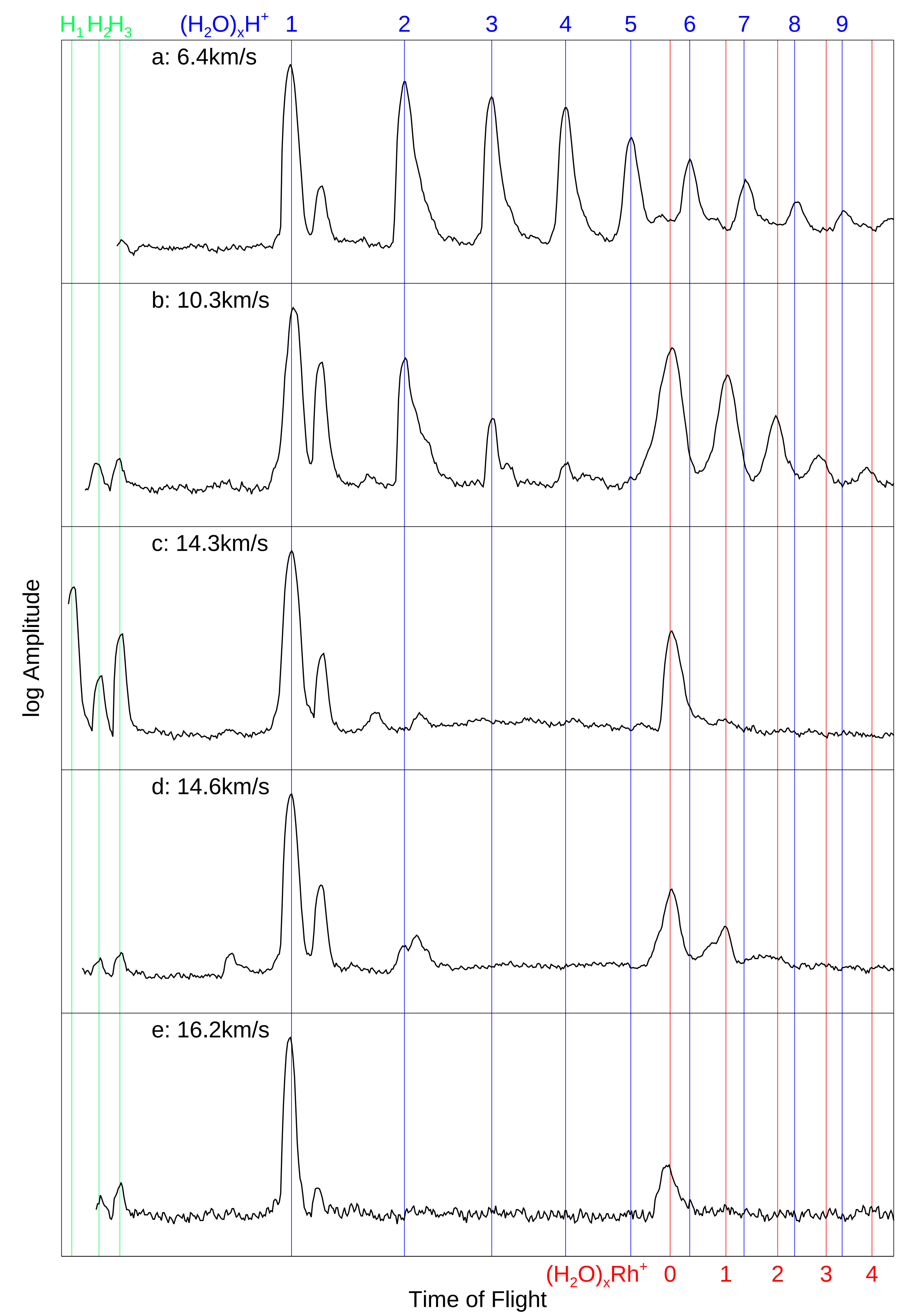


TOF Mass spectra (Cassini-CDA)

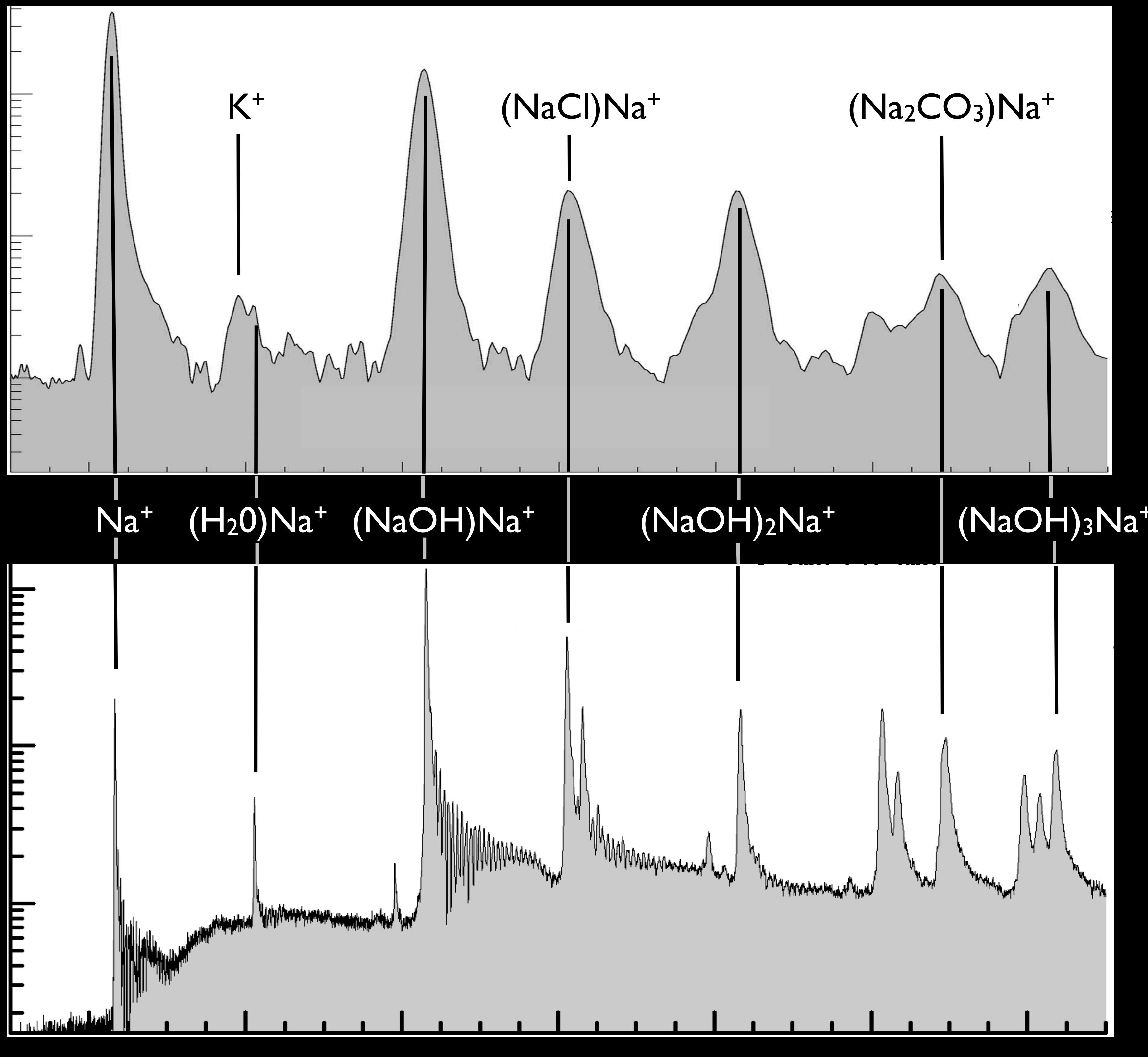
< 6 km/s

Cluster length

16 km/s



Salty Ice Grains - measured in E ring



Co-Added CDA Spectrum:

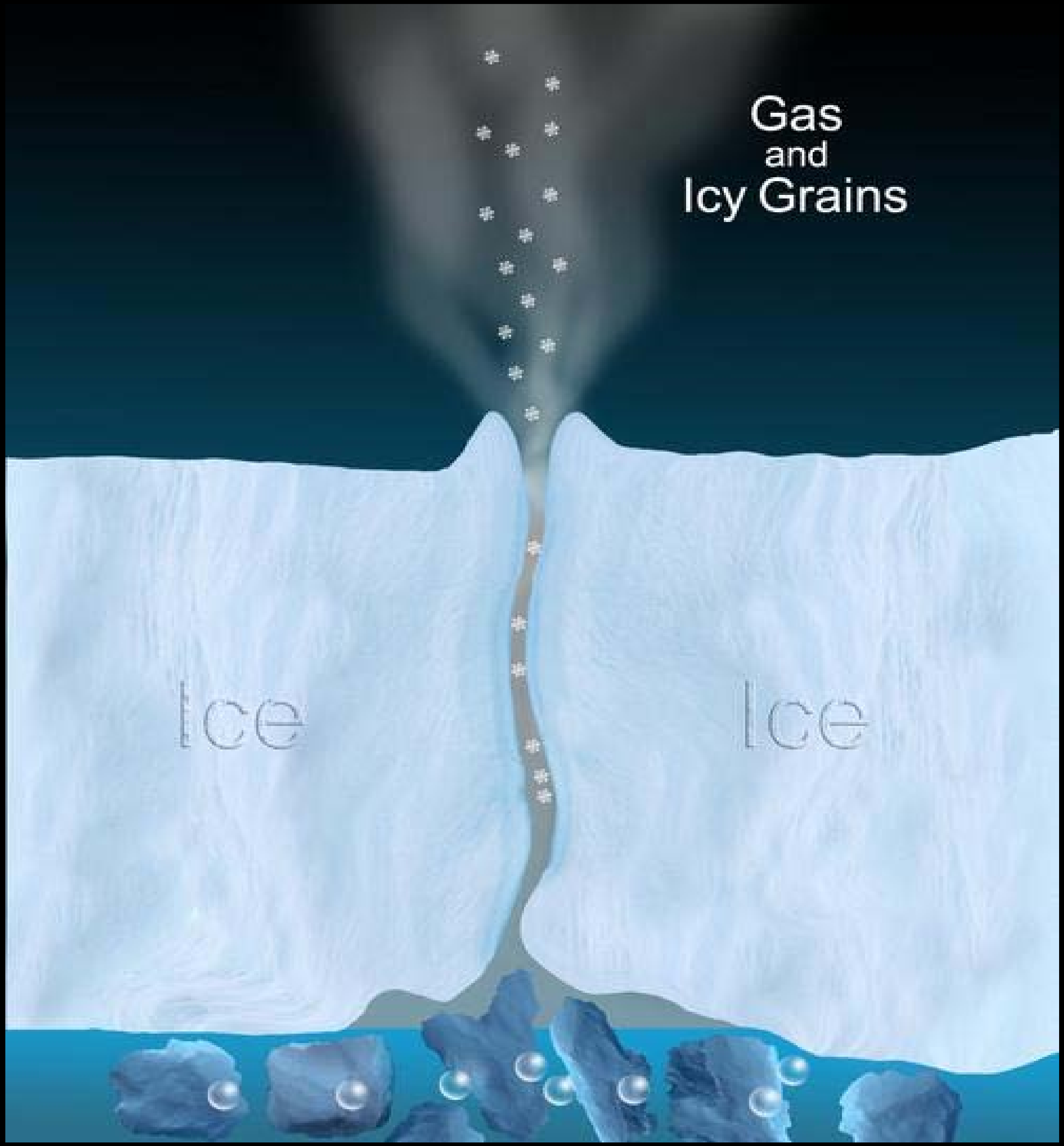
Salt-rich Geyser Ice Grains (6%)

Lab Spectrum:

Laser Dispersion of Salt Water

Postberg et al., Nature, 2009

Results from Dust Measurements: Enceladus Ocean



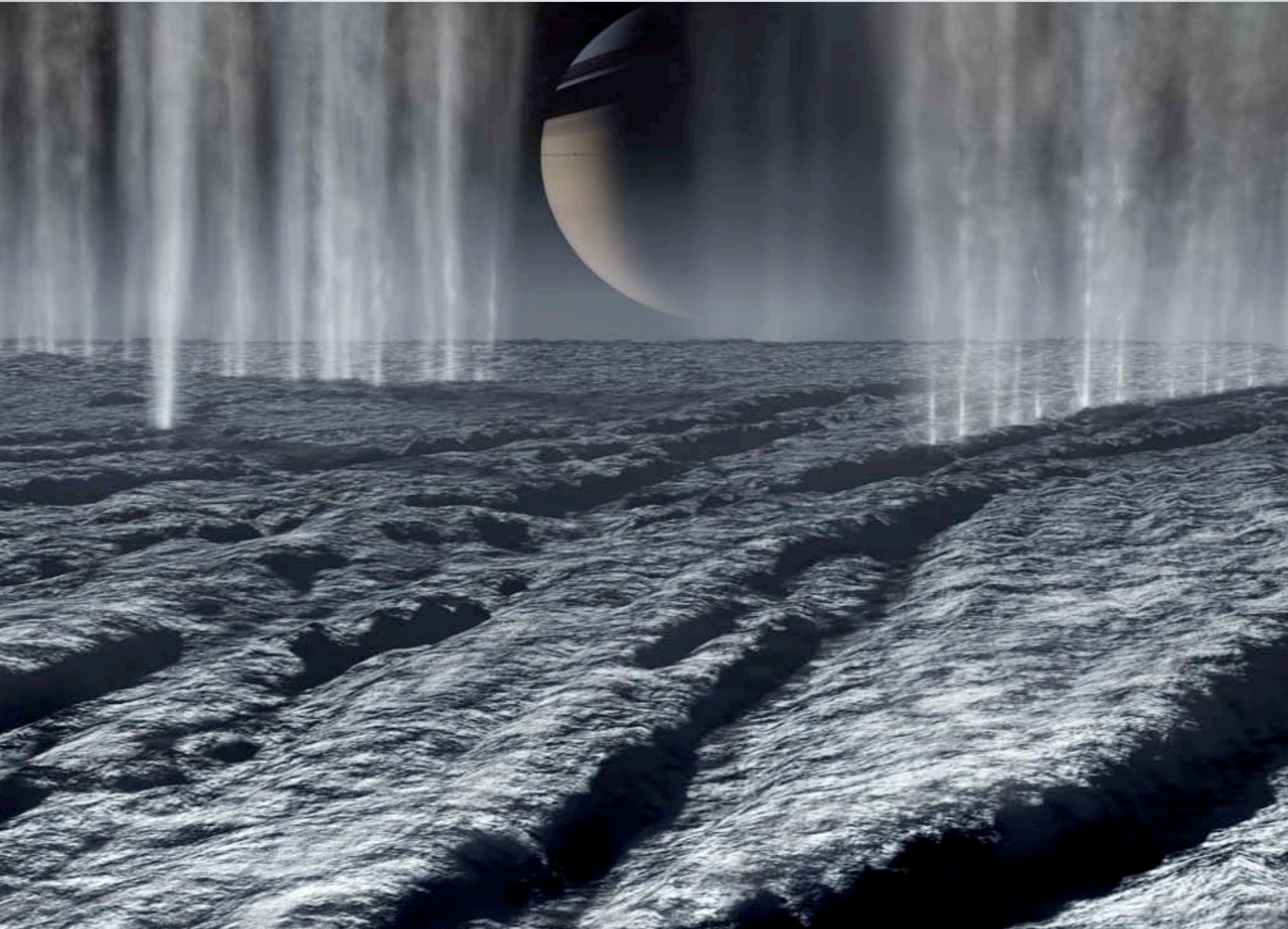
„Soda“ Ocean

Rich in Carbonates

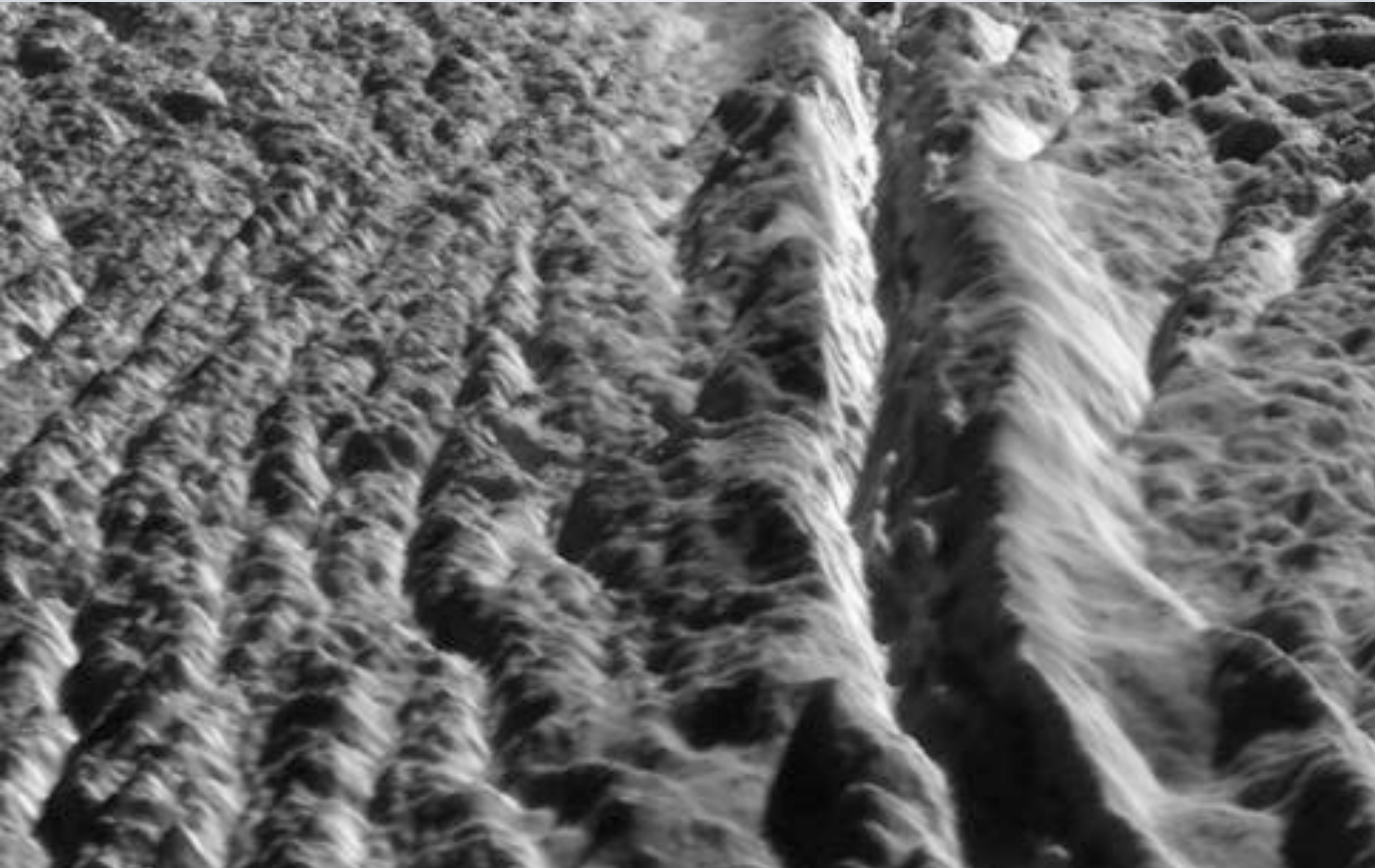
pH ~ 9

Salinity ~1% (Earth 1...4%)

Postberg et al., Nature, 2009



ARTISTS WERE ALMOST RIGHT



ENCELADUS REALITY

thanks to: NASA/JPL
S. Kempf, G. Moragas-Klostermeyer
F. Postberg, E. Grün, M. Burton, M. Roy
S. Hsu, H. Krüger, M. Horanyi, U. Beckmann, P. Strub,
N. Altobelli, V. Sterken, J. Schmidt, F. Spahn, ...
Cassini-CDA project grant by DLR