

Exploring Saturn with Cassini/Huygens

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How do stellar systems and planets form?
How do they evolve over time?
How are the building blocks of life made?
How can simple physics be applied to these big
questions?

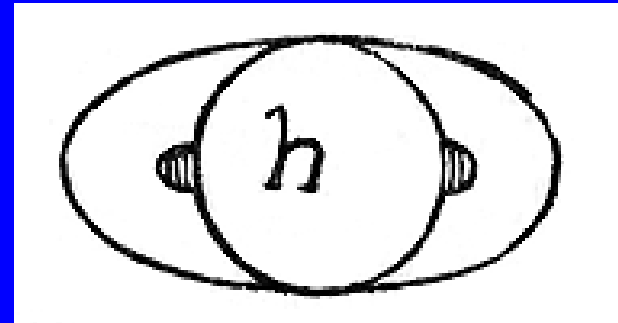
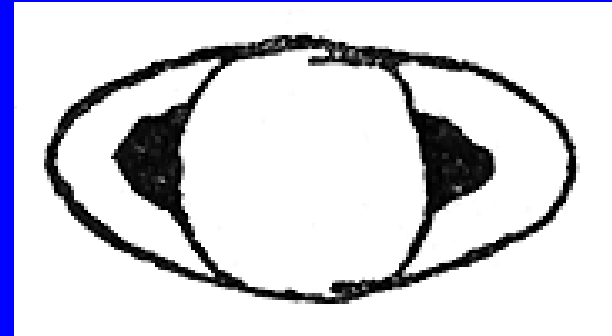
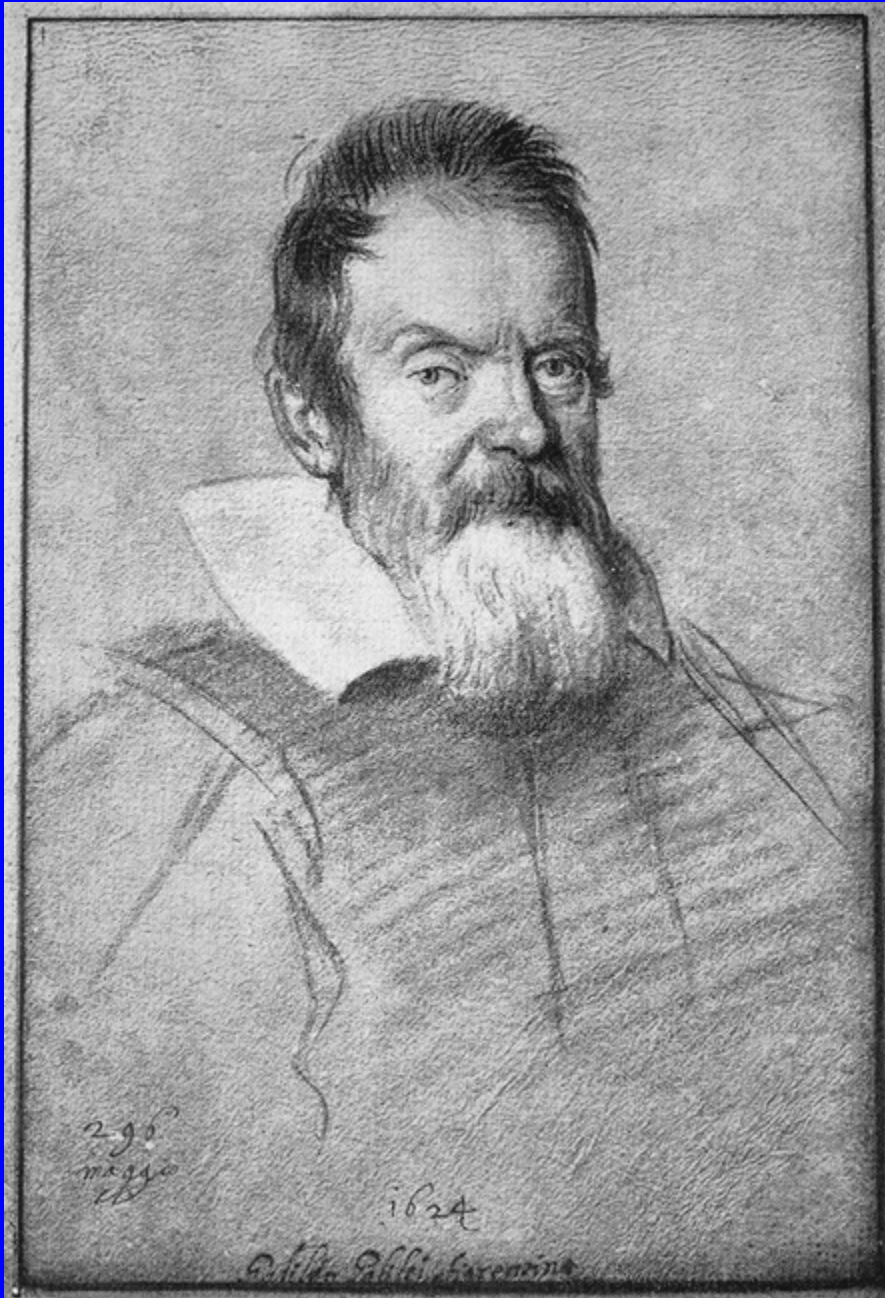
Tufts Physics Department Seminar 2004.11.05



M. Cassini

Overview

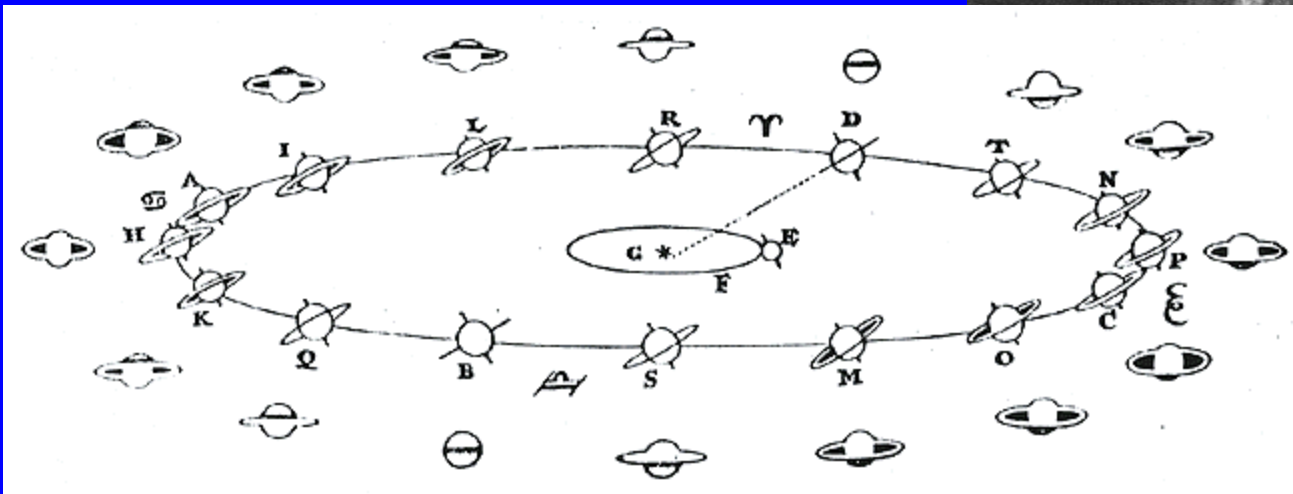
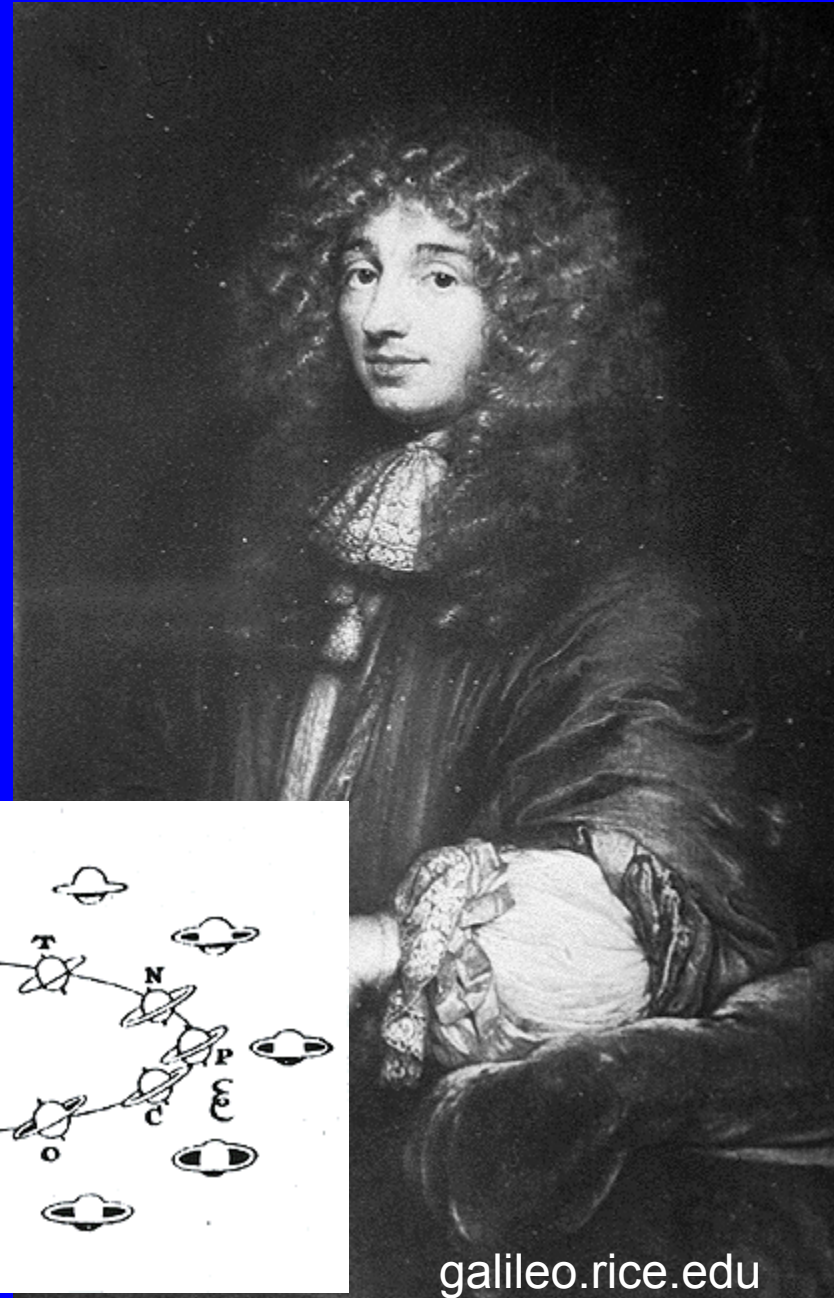
- Before Cassini
- Main Research Areas
 - Saturn
 - Rings
 - Icy Satellites
 - Magnetosphere
 - Titan
- Cassini Mission
- First Cassini observations at Saturn
- Huygens Mission



1610, Galileo Galilei
discovers that Saturn
changes shape

1655, Christaan Huygens discovers that Saturn has a satellite, Titan

1659, Huygens proposes that Saturn is surrounded by a thin, flat ring





1670-1675,
Giovanni Domenico
Cassini discovers
four more satellites
and a division within
the rings

Saturn

- 10 AU, 27° obliquity, circular orbit, 10hr day
- $10 \times R_E$, 0.7 g/cc, 10% flattening
- Metal/rock core of $\sim 10 M_E$, metallic H/He layer, molecular H/He, internal He rain
- Radiates internal heat
- Clouds of NH_3 , NH_4SH , H_2O
- Dynamics in belts/zones, with ovals/spots

Saturn
March 7, 2003



Ultraviolet



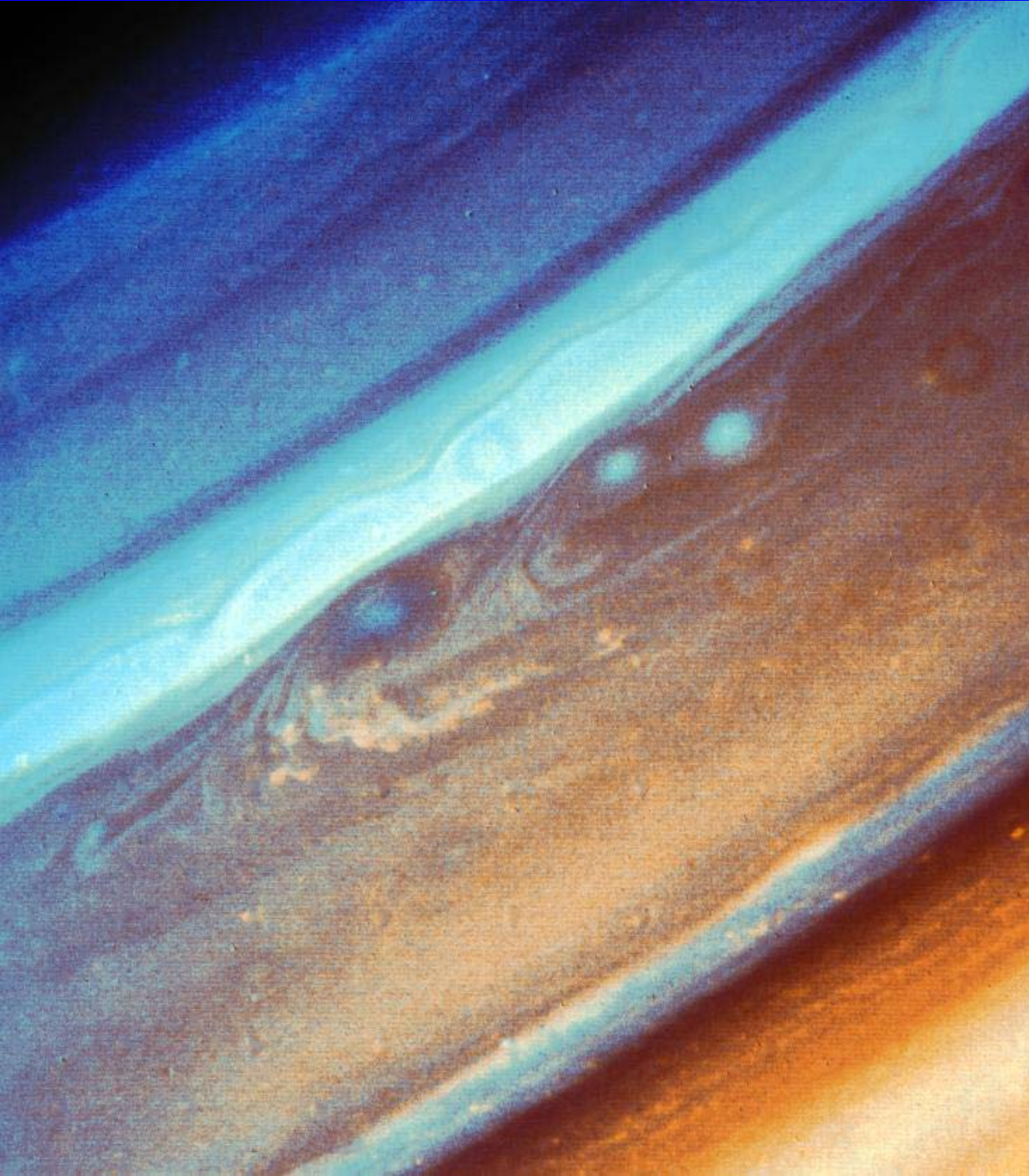
Visible



Infrared

Hubble Space Telescope
Wide Field Planetary Camera 2
NASA and E. Karkoschka (University of Arizona)
STScI-PRC03-23

imgsrc.hubblesite.org



Latitudinal banding
(belts/zones) are regions
of upwelling/downwelling
How deep do they go?

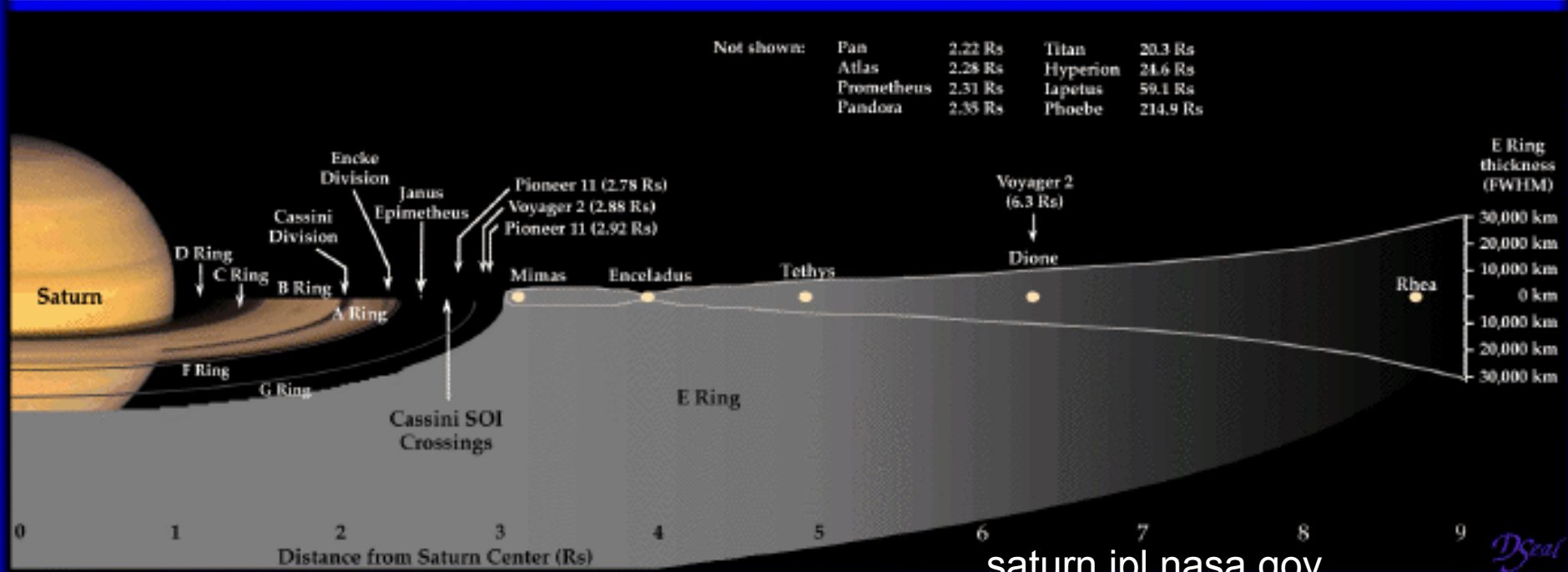
Few 100 m/s zonal winds

Less colorful than Jupiter
due to lower T – we think

Ovals are storm systems
that interact, merge

Polar winds?

Saturn's Satellites and Ring Structure



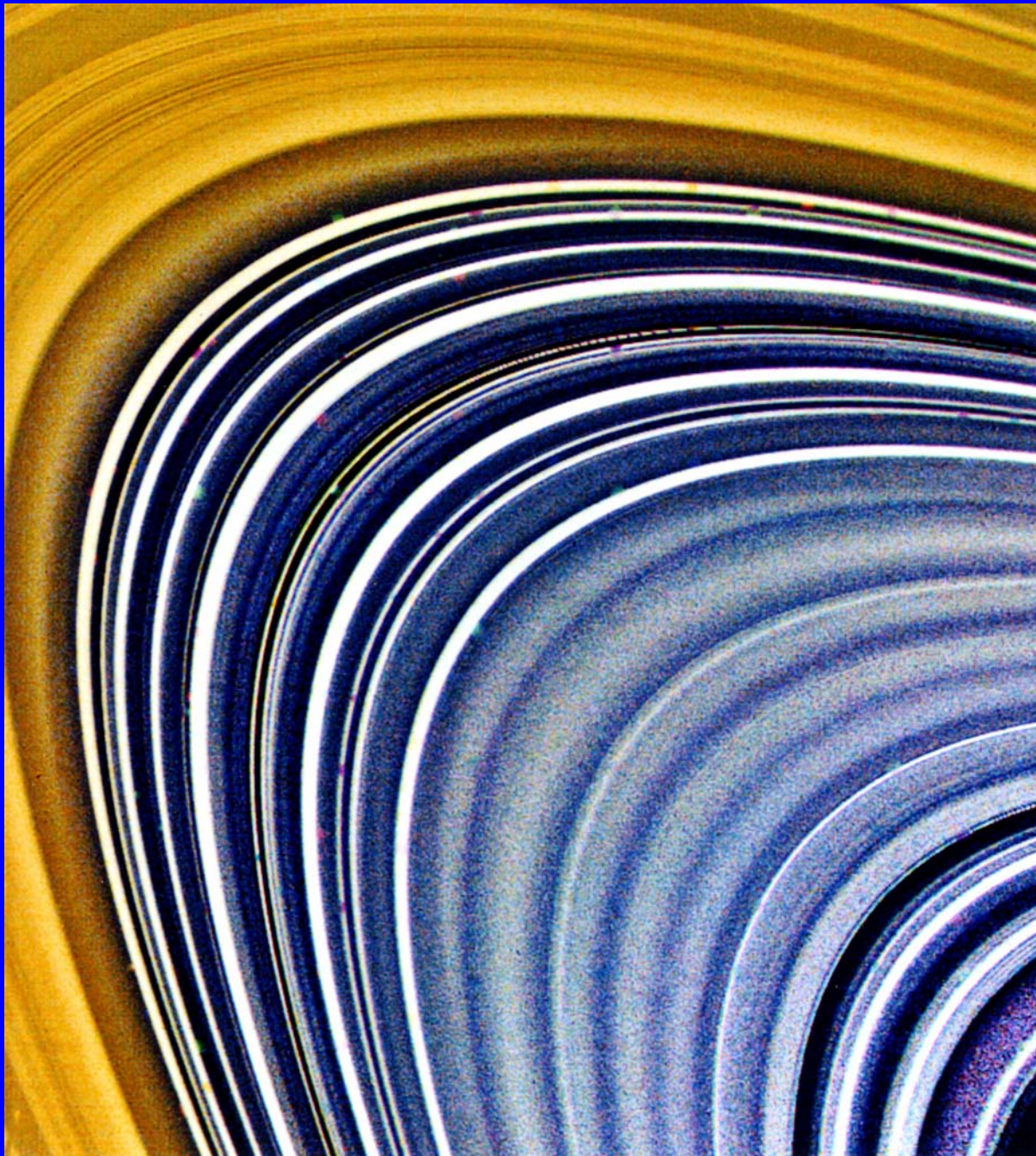
saturn.jpl.nasa.gov

D Seal

This graphic is available in color if required.

Rings

- 1.1 – 8.0 R_S , mostly ice, some rock
- Range of sizes, microns to metres
- Less than 1 km thick
- Organized by shepherd moons and additional resonances
- Lots of fine structure
- How old? (500 My???)



What do variations in size, shape, and composition of ring particles reveal?

Analogies to formation of galaxies, stars, and planets

What is origin and fate of ring system?

What structures are long-term? Short-term?

Icy Satellites

- 33 satellites known, more will be found
- Not all prograde with orbits in equatorial plane, some captured?
- Partial source of ring particles, shepherds
- Rock/ice mixtures
- Internal oceans and magnetic fields?
- Varied cratering and tectonic histories



Mimas



Enceladus



Tethys



Dione

saturn.jpl.nasa.gov



Rhea



Hyperion



Iapetus



To scale
Phoebe

Magnetosphere

- Field strength at surface same as Earth
- Dipole component aligned with spin axis
- Large non-dipole components
- 10MA ring current flows within magnetosphere
- Dynamics are partly driven by rotation, partly by solar wind
- Bright, variable aurora are common at poles

HST/STIS - Saturn's UV Aurora (Clarke et al. 2004):

10 Jan. 2004



26 Jan. 2004



28 Jan. 2004



30 Jan. 2004



Time variation in aurora

How is brightness and position of auroral oval related to solar wind properties?

Are there “footprints” of satellites?

Do internal (satellites, rings) processes or solar processes control aurora?

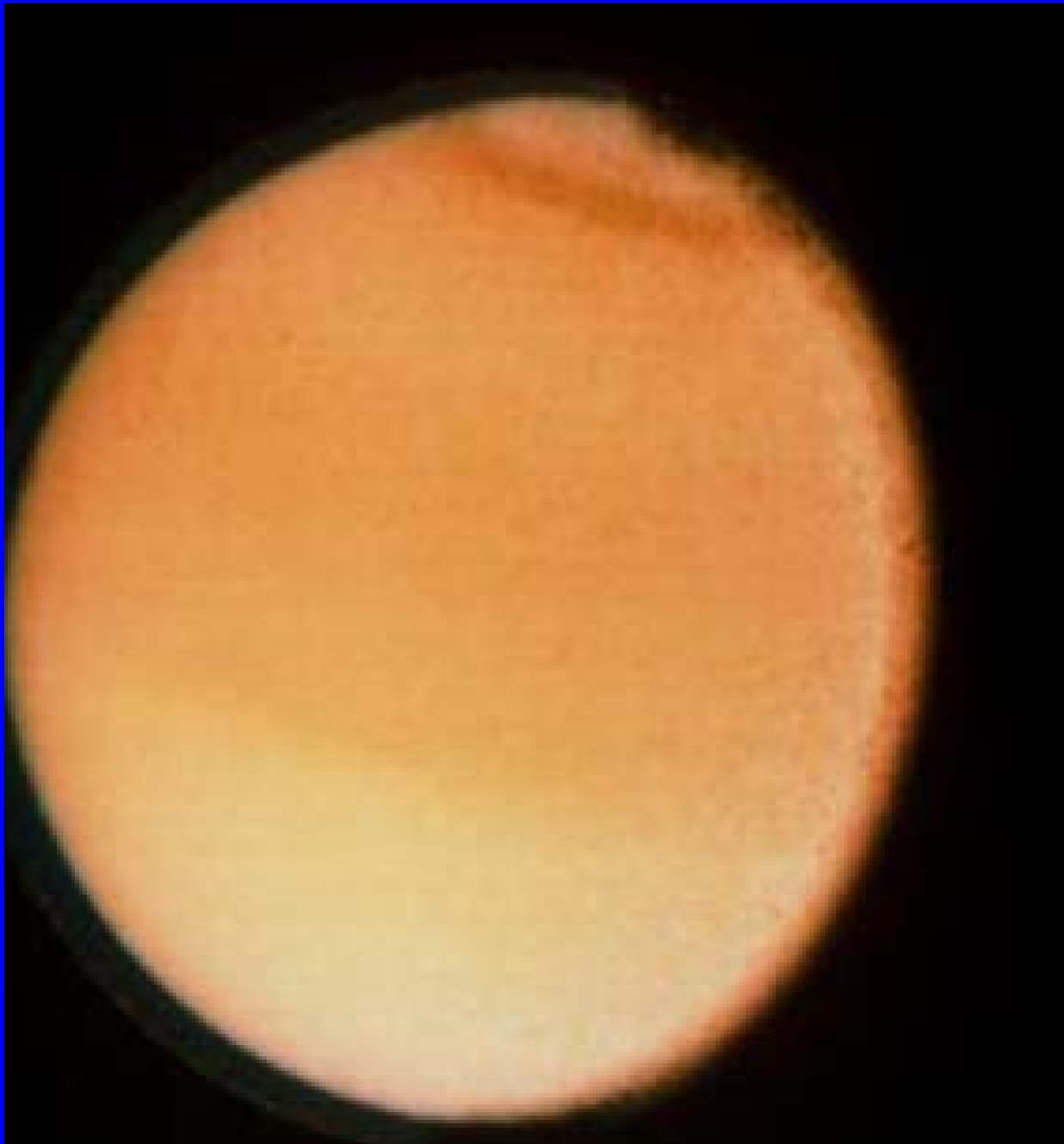
How does magnetosphere strip matter from surfaces and atmospheres of satellites and rings?

These pictures may appear in a high-profile journal soon, with Cassini particles and fields data

Image from John Clarke

Titan

- $\sim 0.5R_E$, orbits at $20 R_S$, made of ice/rock
- 1.5 bar N_2/CH_4 atmosphere, 1000 km thick
- Atmospheric hazes and clouds
- Liquid hydrocarbons stable on surface (100K)
- Internal H_2O ocean?
- Life?



What is thermal structure of atmosphere?

What are compositions of haze layers and clouds?

What energy sources drive the atmospheric chemistry?

How much atmospheric escape has there been?

How does magnetosphere affect atmospheric escape processes?



CH_4 is photochemically destroyed in 10 My, so why is it still in Titan's atmosphere? Surface is too warm for it to liquify

Loss of H leads to C_2H_6 , which can condense. CH_4 then dissolves in reservoirs of liquid C_2H_6 .

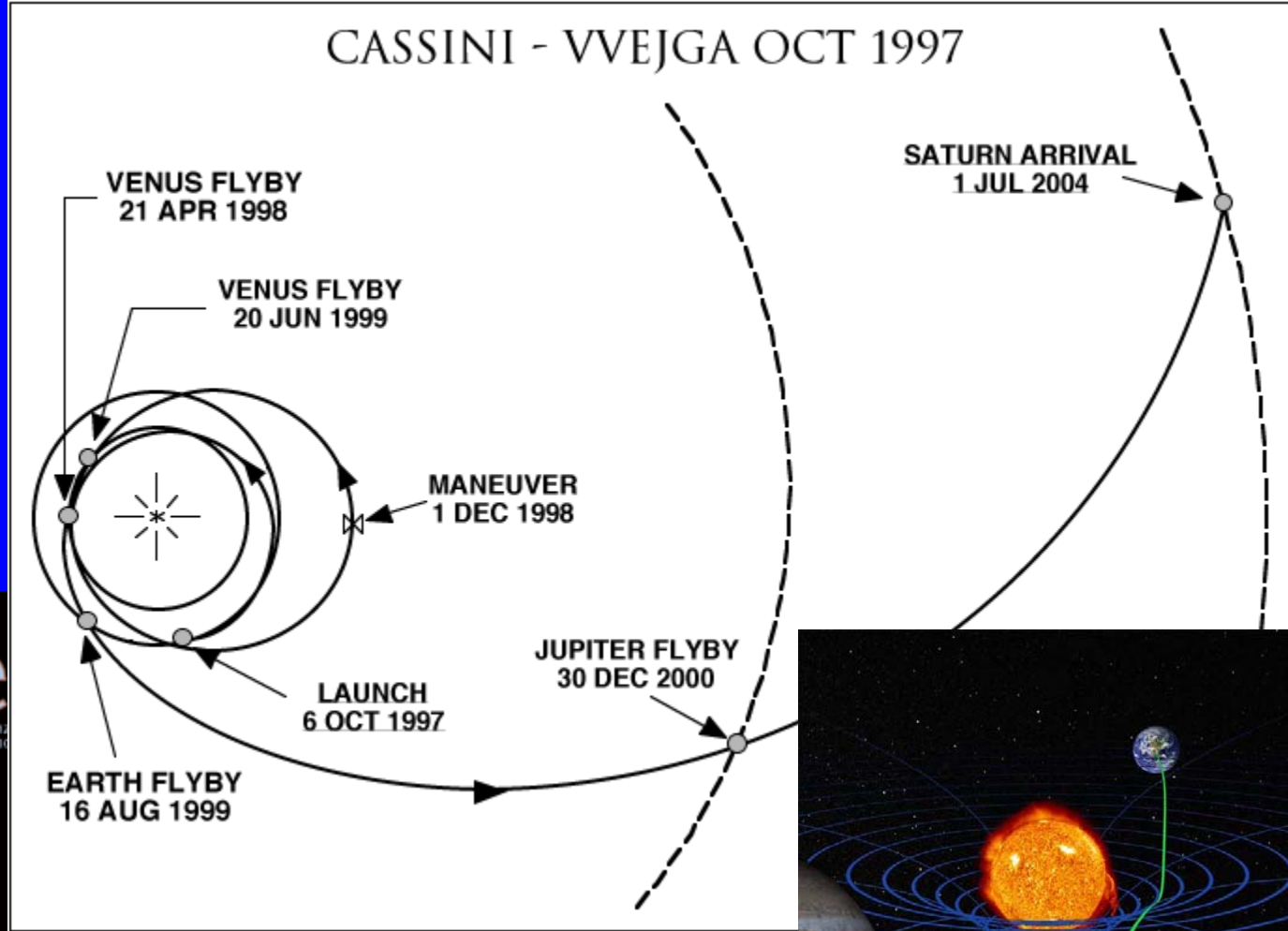
Heavier hydrocarbons at bottom of any such ocean/lake/pond/puddle.

This idea may be totally wrong in a few weeks.

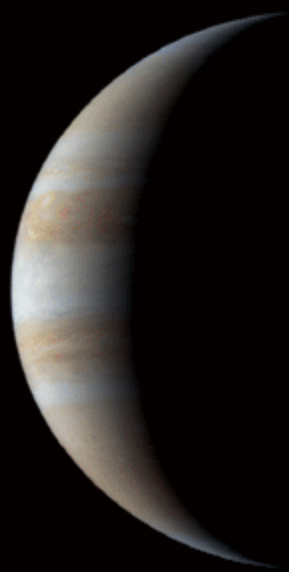
Getting Cassini off the ground

- 1982: Proposed to ESA
- 1983: NASA committee recommends Titan mission
- 1986: Challenger fails, plans change
- ~1988: Approval
- 1992: Near-cancellation, descope
- 15 Oct 1997: Launch

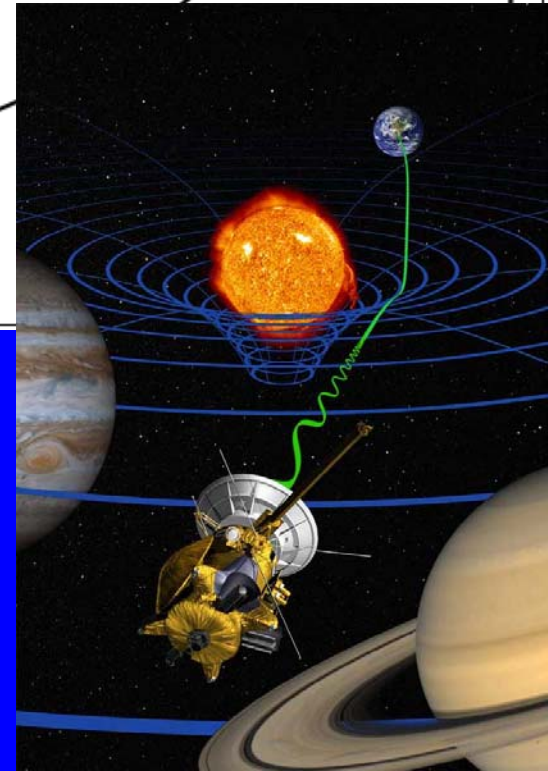
CASSINI - VVEJGA OCT 1997



7 March 2003
Science
Vol. 299 No. 5612
Pages 1469-1608 510



www.ssd.rl.ac.uk,
www.science.com,
www.jpl.nasa.gov



CASSINI SPACECRAFT



Remote Sensing

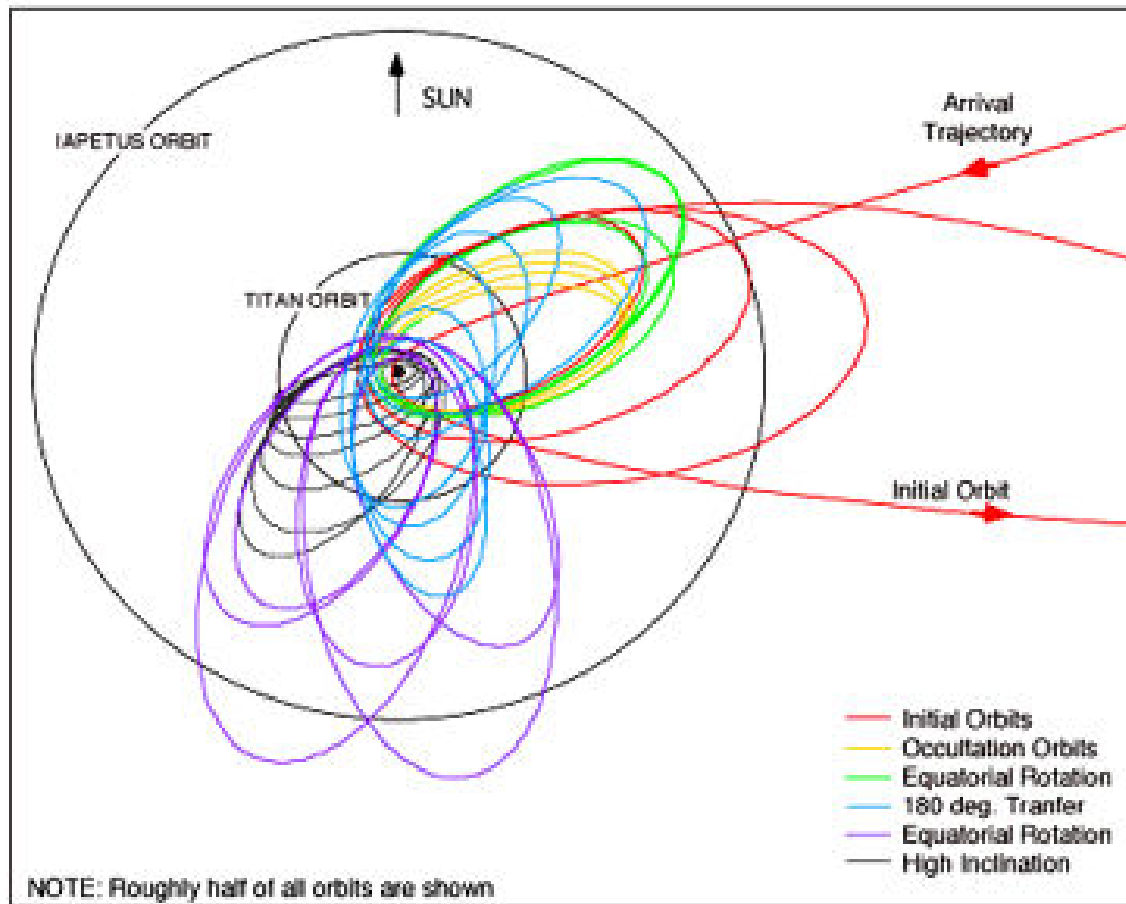
- Visible: Clouds and aerosols, geomorphology, ring dynamics
- IR: Surface, ring, and atmospheric composition, atmospheric $T(p)$
- UV: Aurora, atmospheric $T(p)$ and composition, ring/satellite atmospheres
- Radio: Satellite interiors, atmospheric $T(p)$, ionospheres, ring particle properties
- Radar: Topography, surface T , SAR image

In Situ

- Ions: Titan atmosphere, solar wind, ions escaping from Titan, satellites, rings
- Neutrals: Same
- Dust/Ice particles: satellite/ring interactions, chemical compositions
- Magnetic fields: Magnetosphere, interiors of Saturn, Titan, satellites
- Radio: EM fields, lightning, magnetosphere

CASSINI - SATURN ORBITAL SAMPLE TOUR

Saturn North Pole View



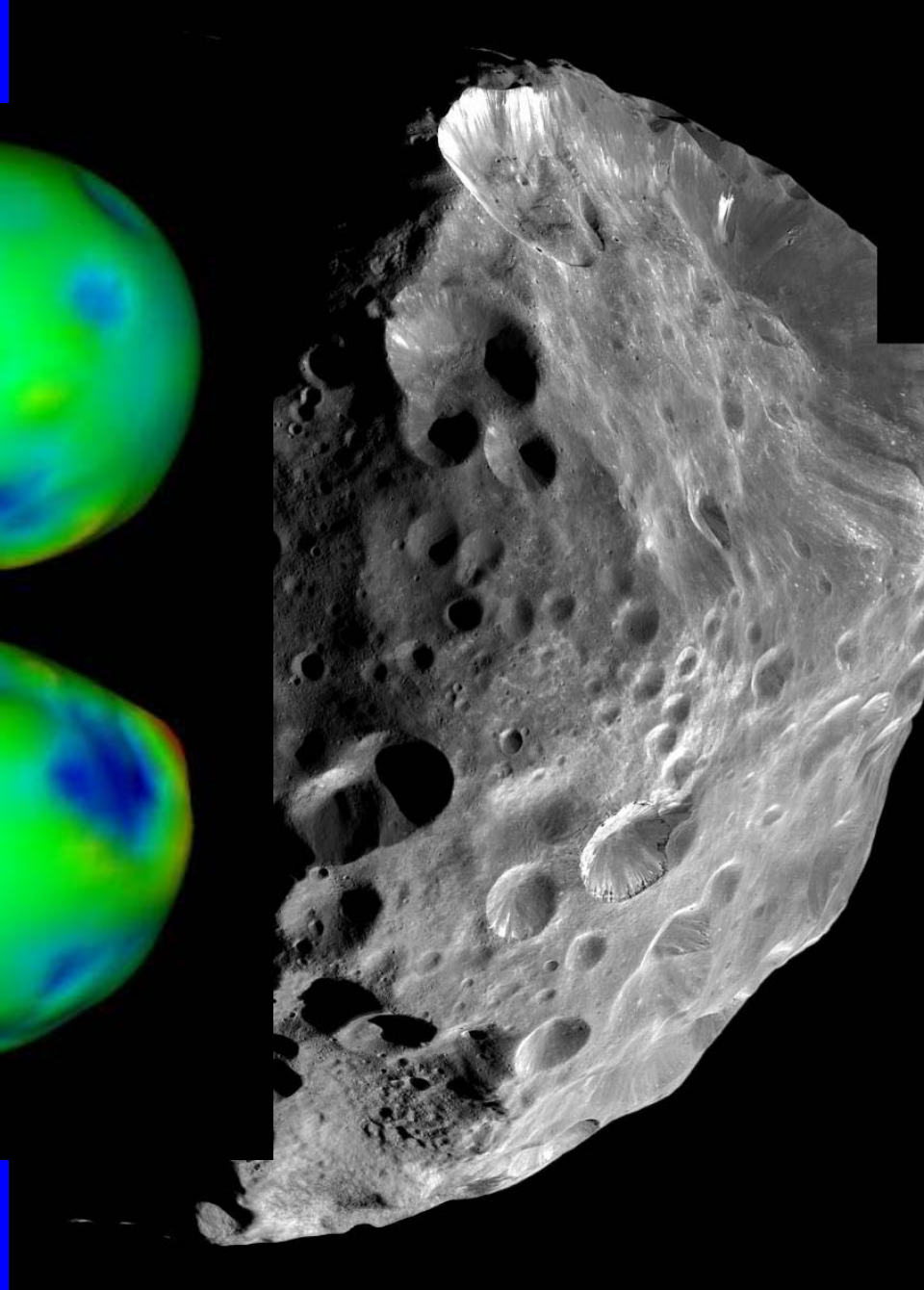
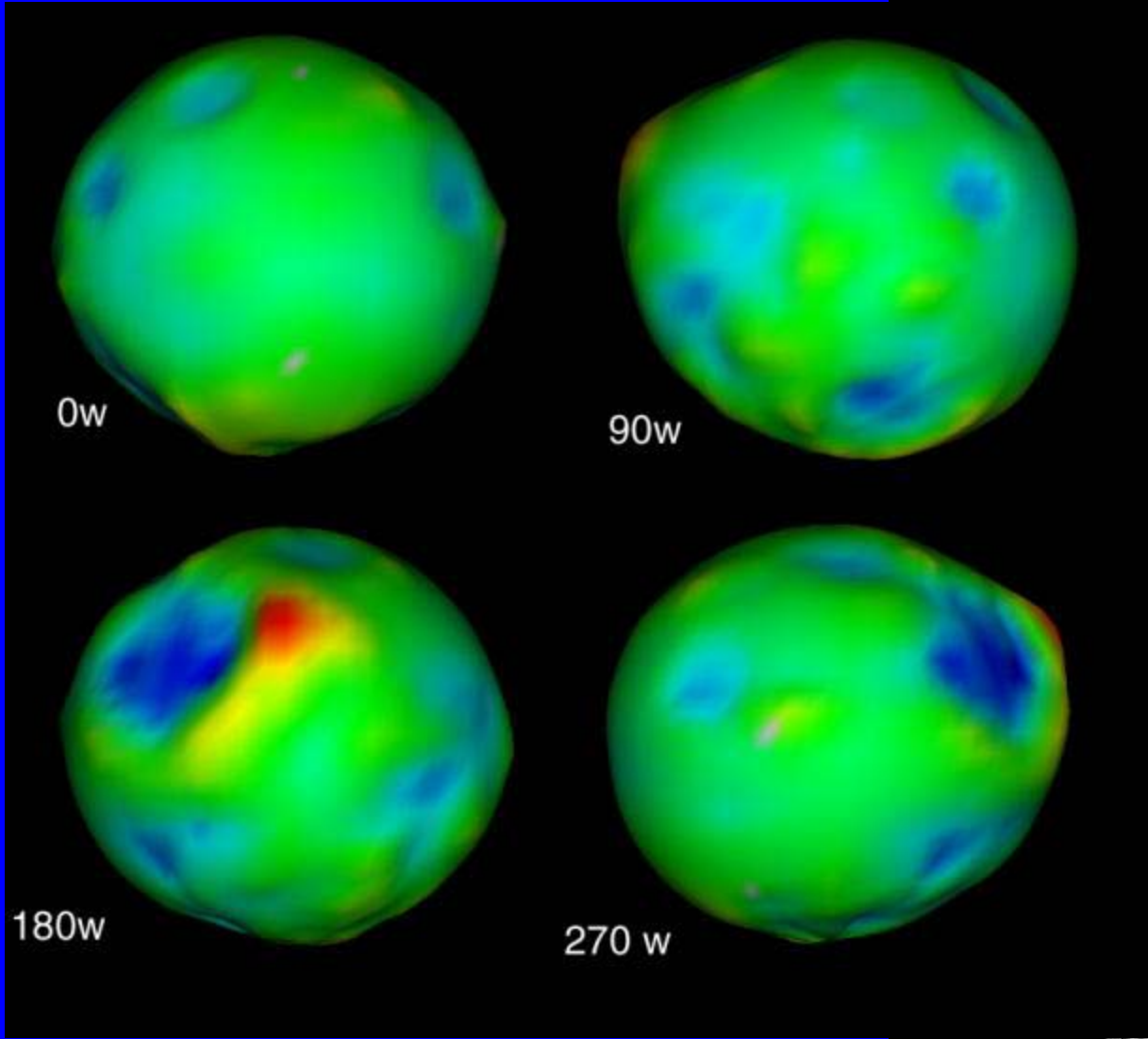
~70 orbits over
4 years

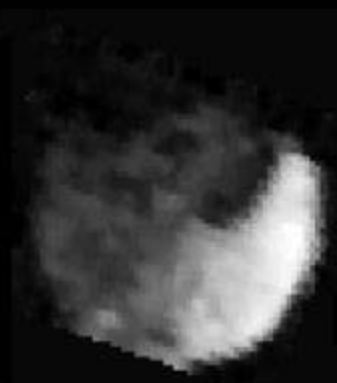
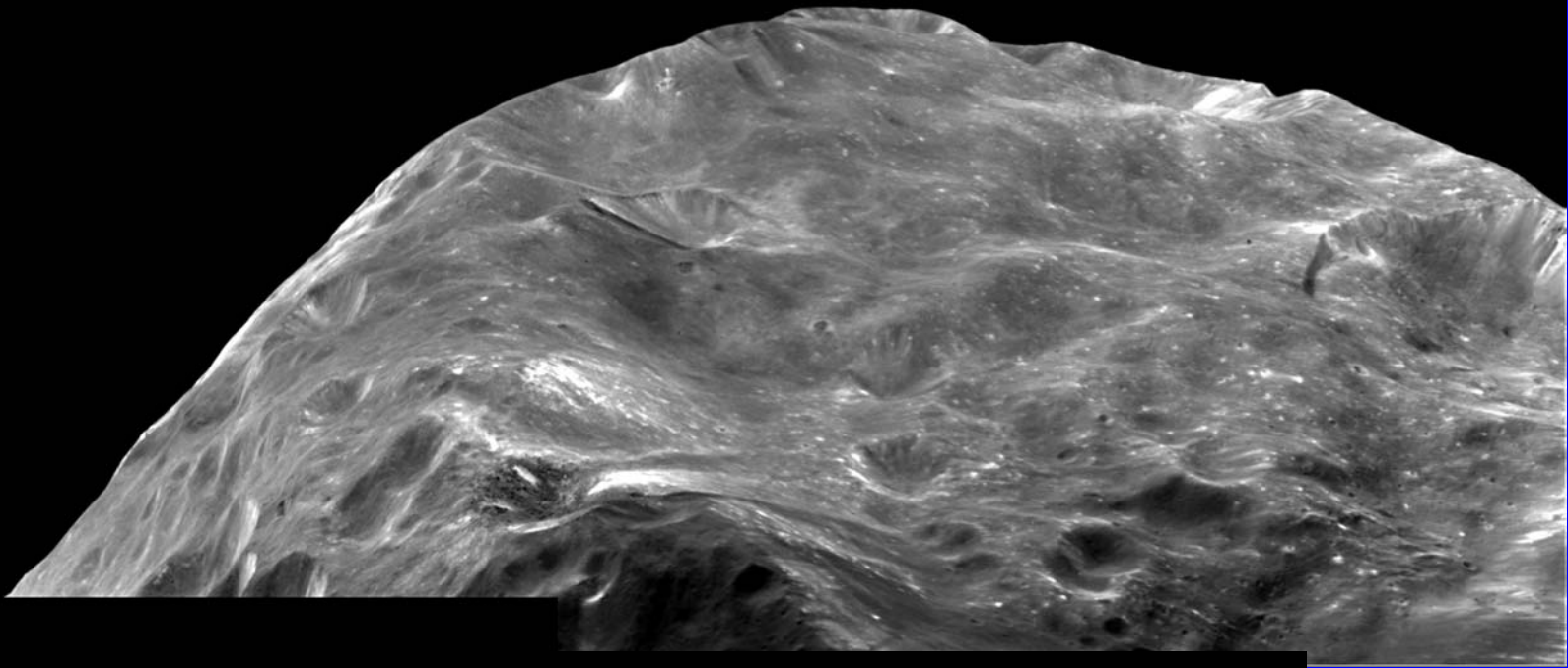
~40 flybys of
Titan

Some close
flybys of the
other satellites

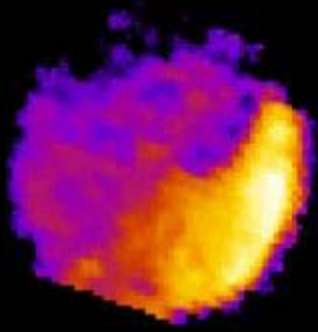
Negotiations
between each
instrument and
between the
scientists and
the engineers

Deluge of data

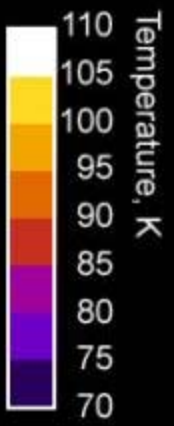




Observed
15-17 micron
Brightness

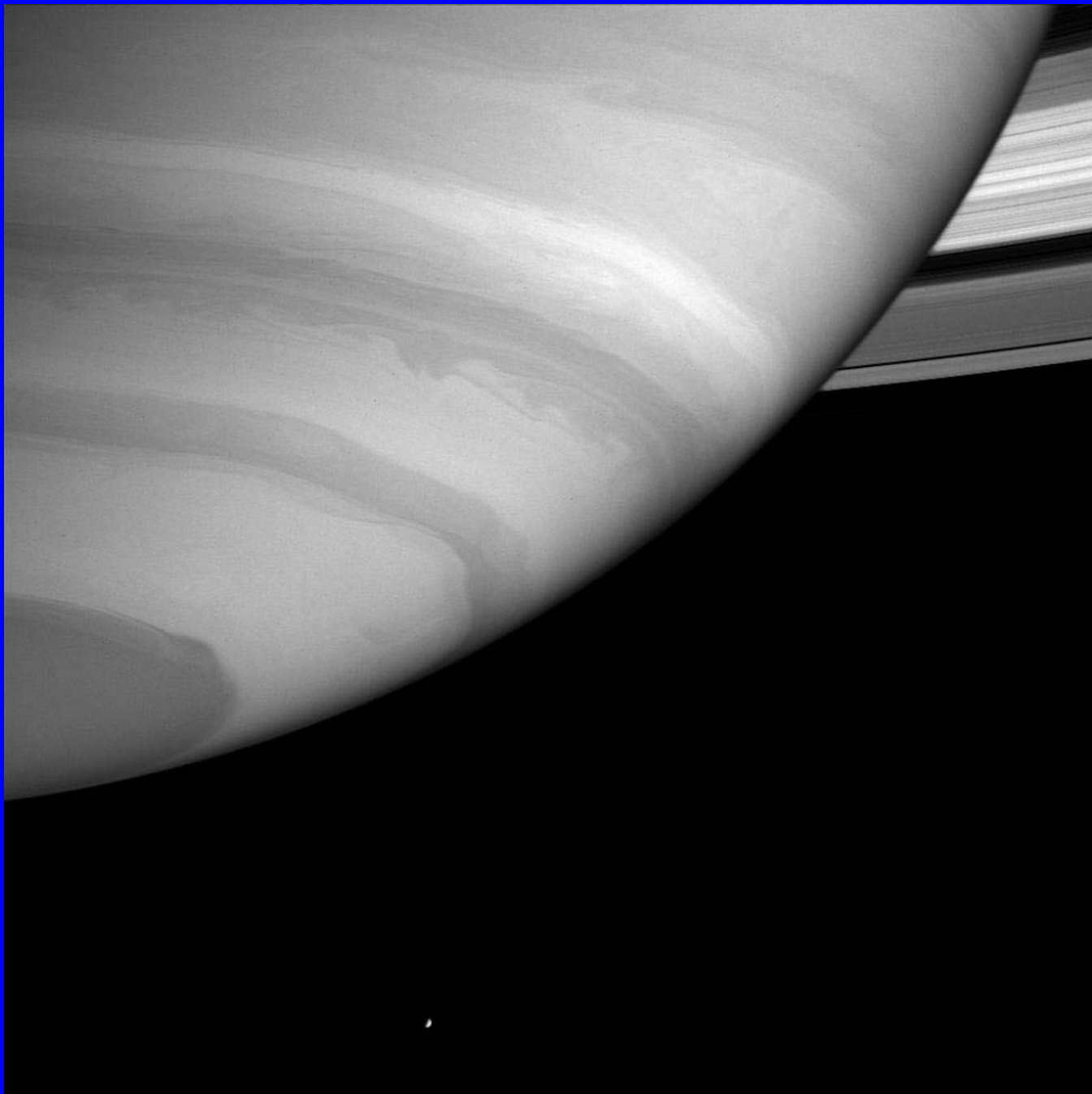


Derived
Surface
Temperature



Visible Image
Cassini
ISS Camera



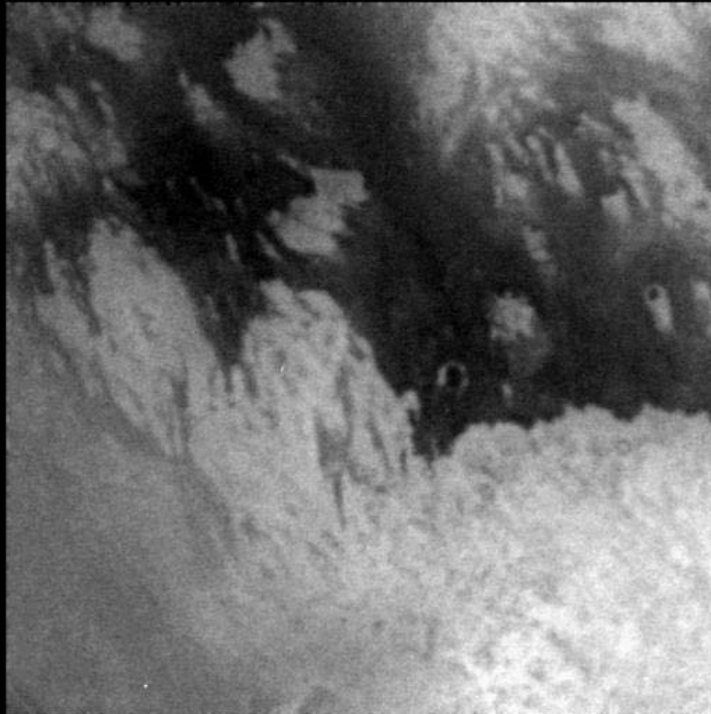
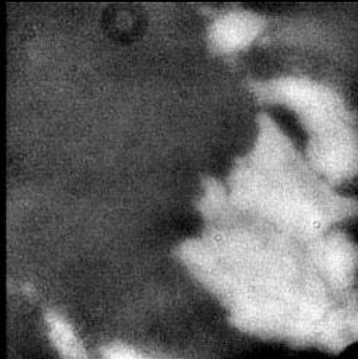
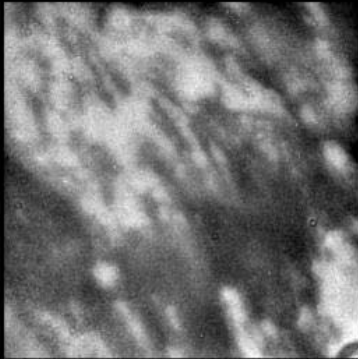


Fine structure in
the rings

Swirls and bands
in the atmosphere

Enceladus

727 nm image,
CH₄ absorption



Near-IR image

2000 km across

Overhead sun,
so no shadows

Please speculate

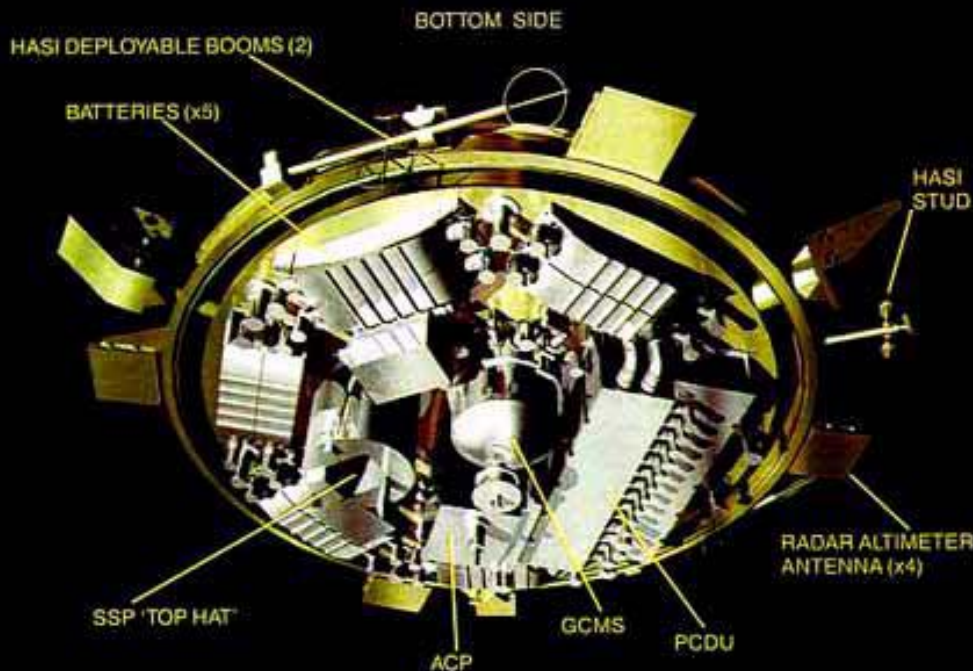
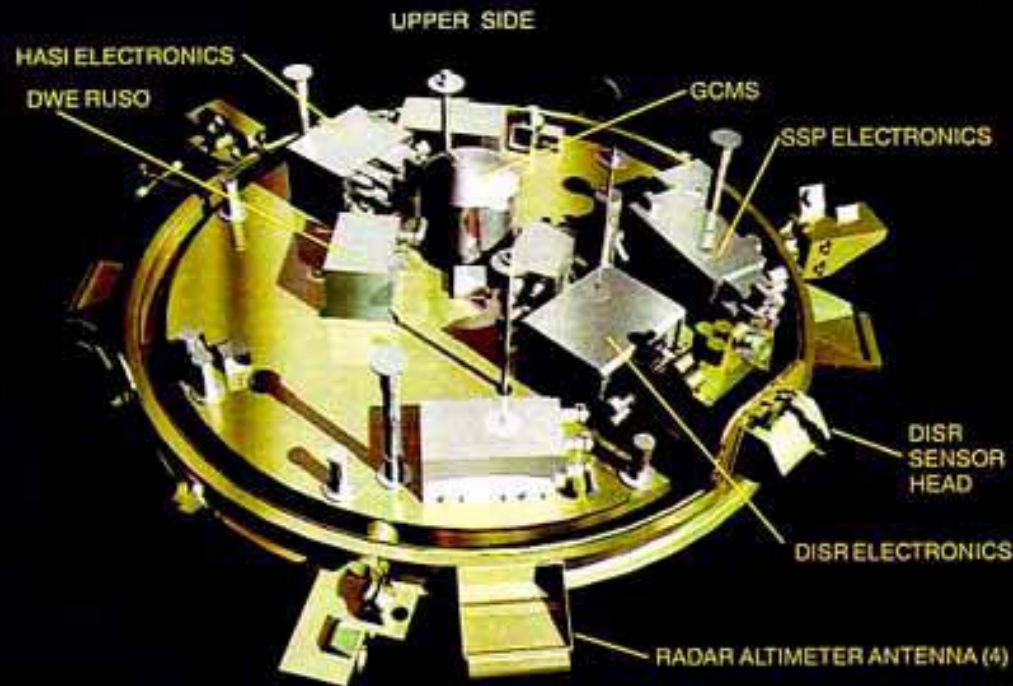
saturn.jpl.nasa.gov

Other Early Results from Titan

- High $^{15}\text{N}/^{14}\text{N}$ ratio, atmospheric loss
- Complex hydrocarbons sampled in situ
- Visible, IR, radar images – interpretations wildly speculative
- 150m topography along 400 km track, flat
- Optically bright, dark at 2cm, vice versa



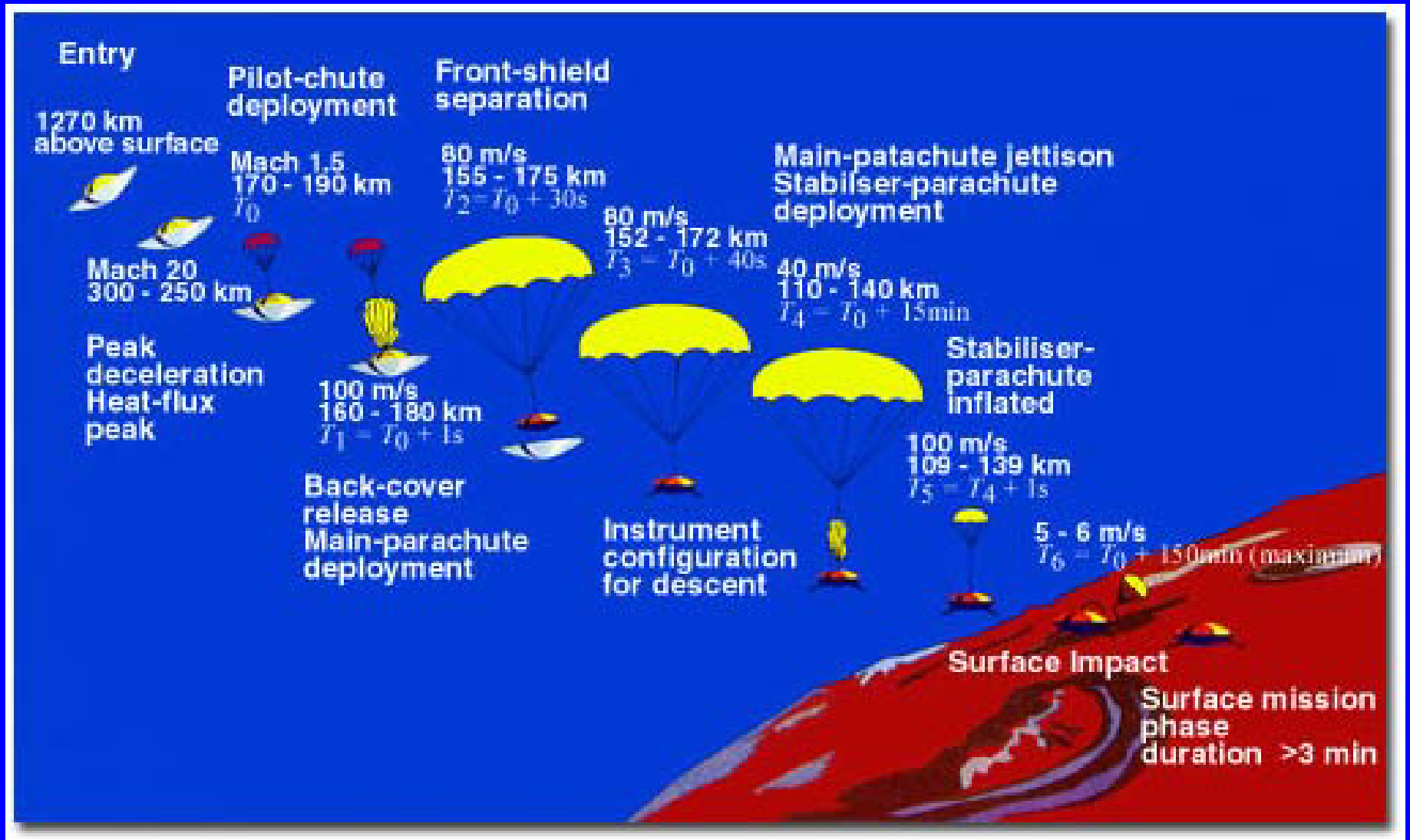
Thermal structure
Composition of atmosphere
and aerosols
Winds
Physical properties of surface
Descent images
Radiative transfer within
atmosphere, aerosol shape/size



25 Dec: Release from Cassini
14 Jan: Arrival at Titan

<3 hours of data from 20 year
mission

Major redesign to fix error
in communications system



Conclusions

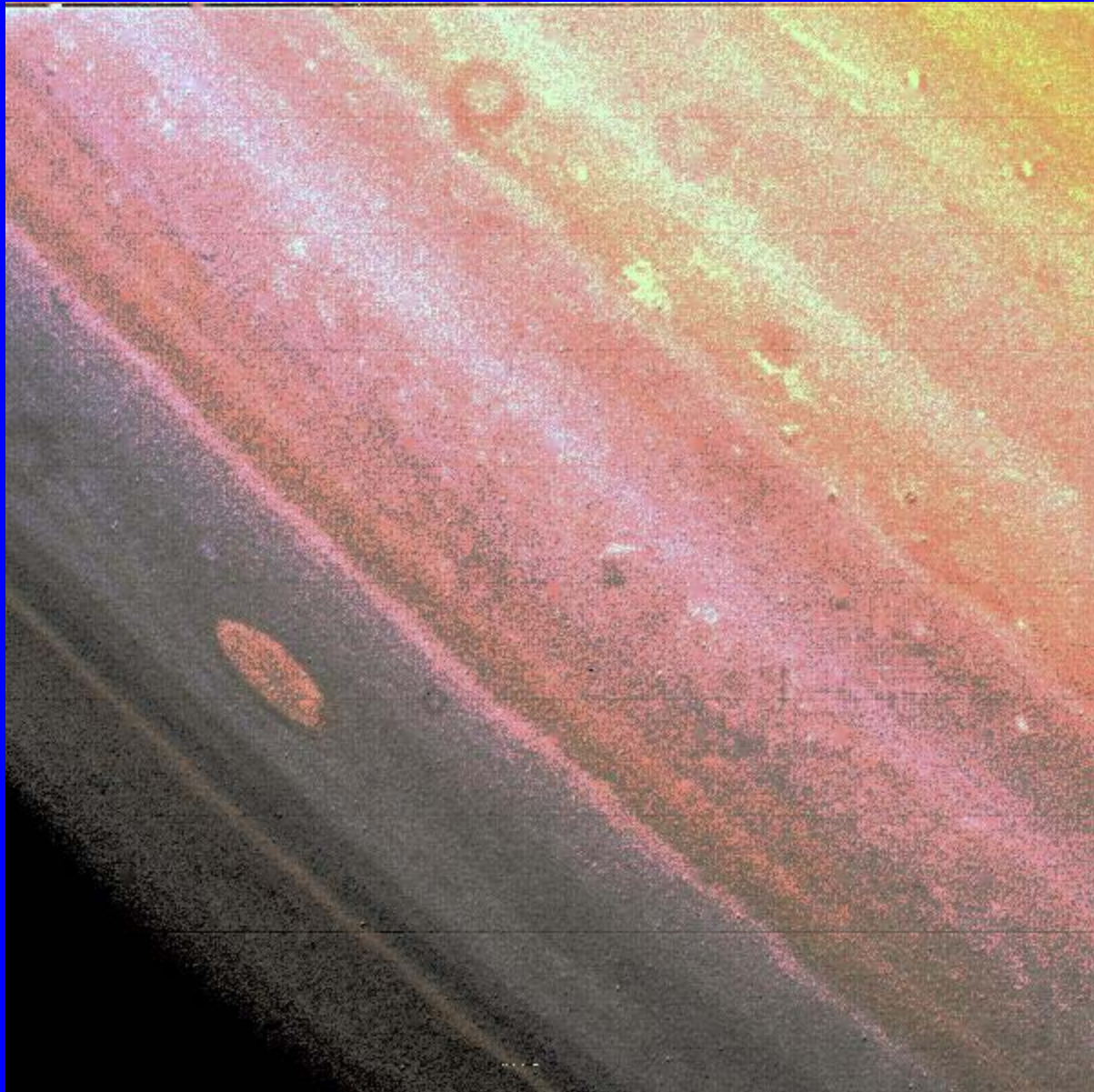
- The Saturn system is full of interesting physics
- Cassini/Huygens are going to revolutionize our understanding of rings and Titan
- You can work with all of the data from these spacecraft, and even get funding

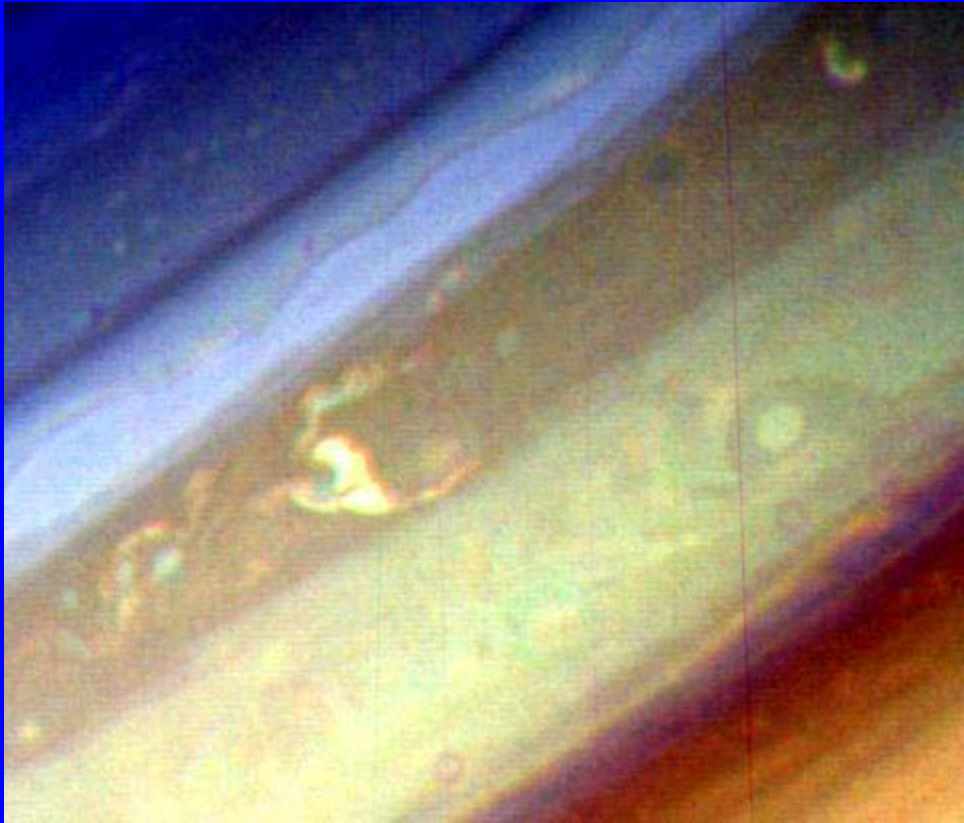
The Purpose of Planetary Exploration (according to NASA)

- “Discover how the universe began and evolved, how we got here, where we are going, and whether we are alone” – NASA Space Science Enterprise
- Learn how the Sun’s family of planets and minor bodies originated
- Determine how the solar system evolved to its current diverse state
- Determine the characteristics of the solar system that led to the origin of life
- Understand how life begins and evolves

The Purpose of Planetary Science (according to me)

- Astronomy ... Geology
- How does vapour evolve into huge chunks of condensed matter?
- How do matter and radiation behave under conditions unlike terrestrial laboratories?
- Life – what is it, how does it start, how does it end?
- How special is our home, Earth?

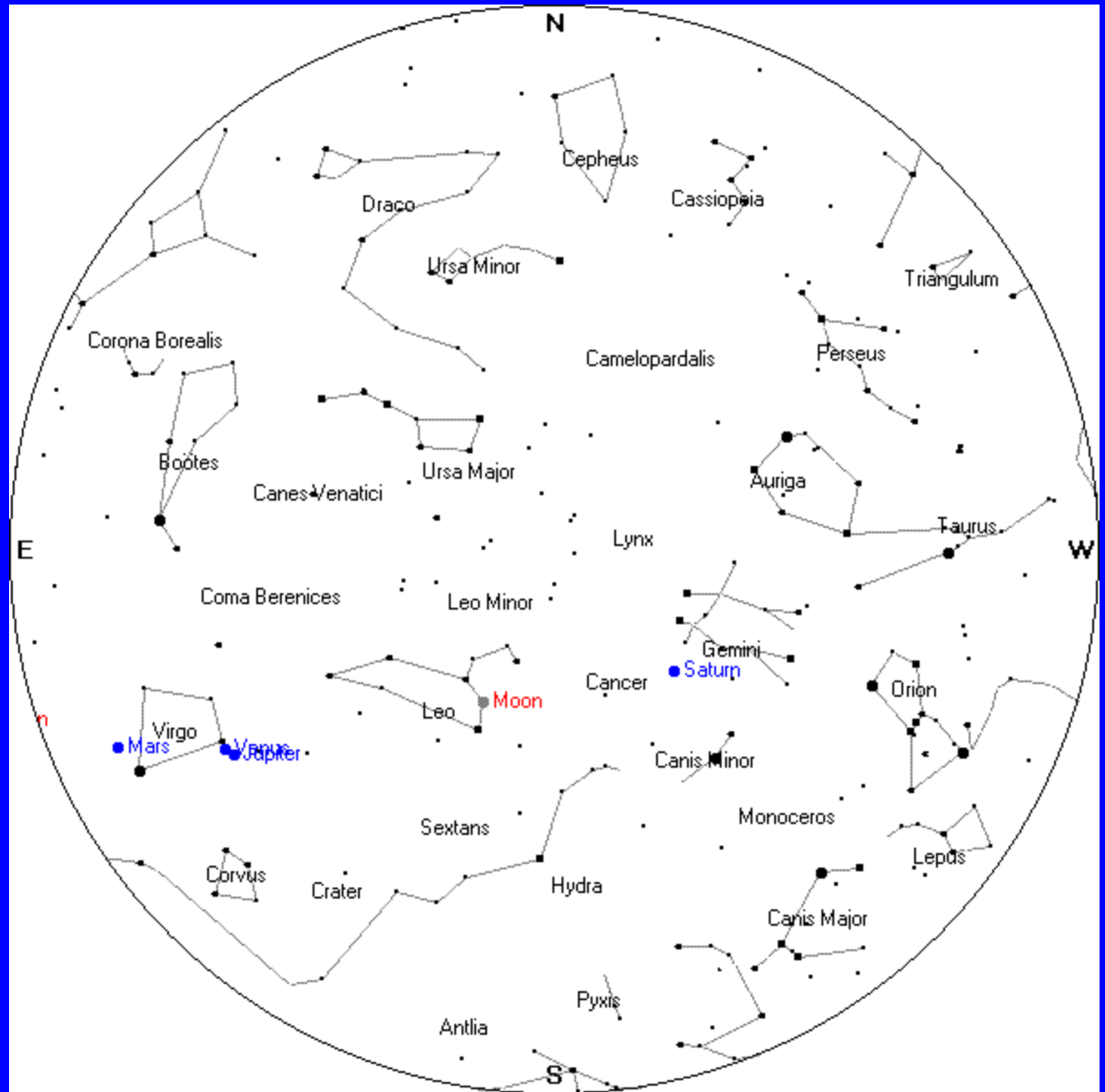




Saturn Today
(Actually tomorrow)

View from Boston

2004.11.06
6am



Saturn before the Telescope

- Easily visible, -0.4 magnitude
- Slightly orange (or yellow) colour
- One of the five “wanderers” known to the Greeks

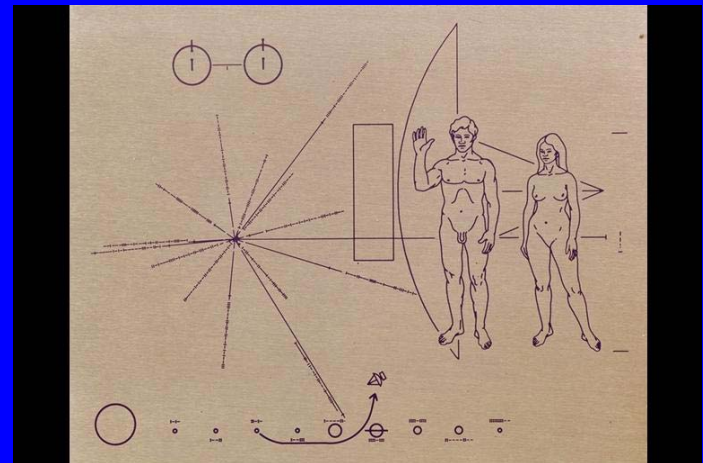
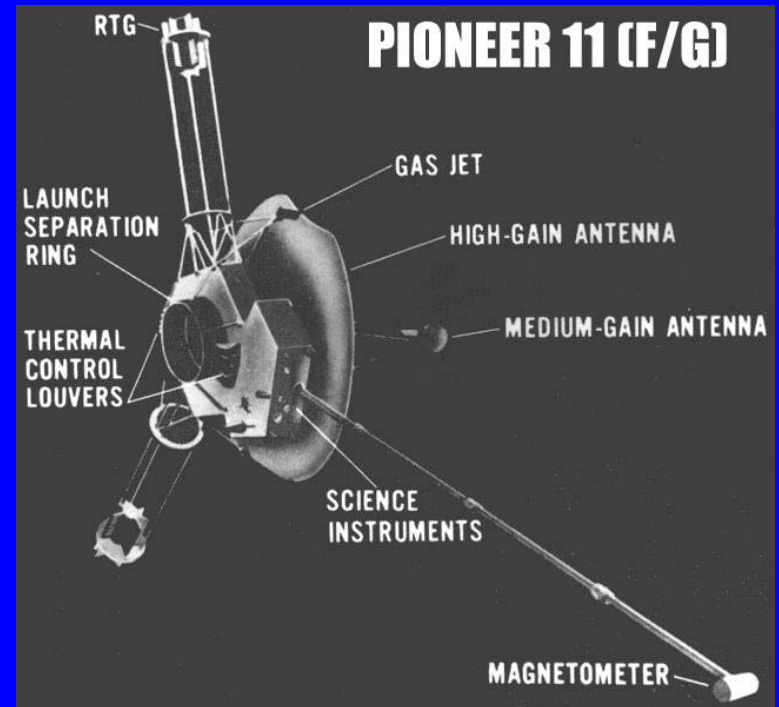


Other discoveries before the Space Age

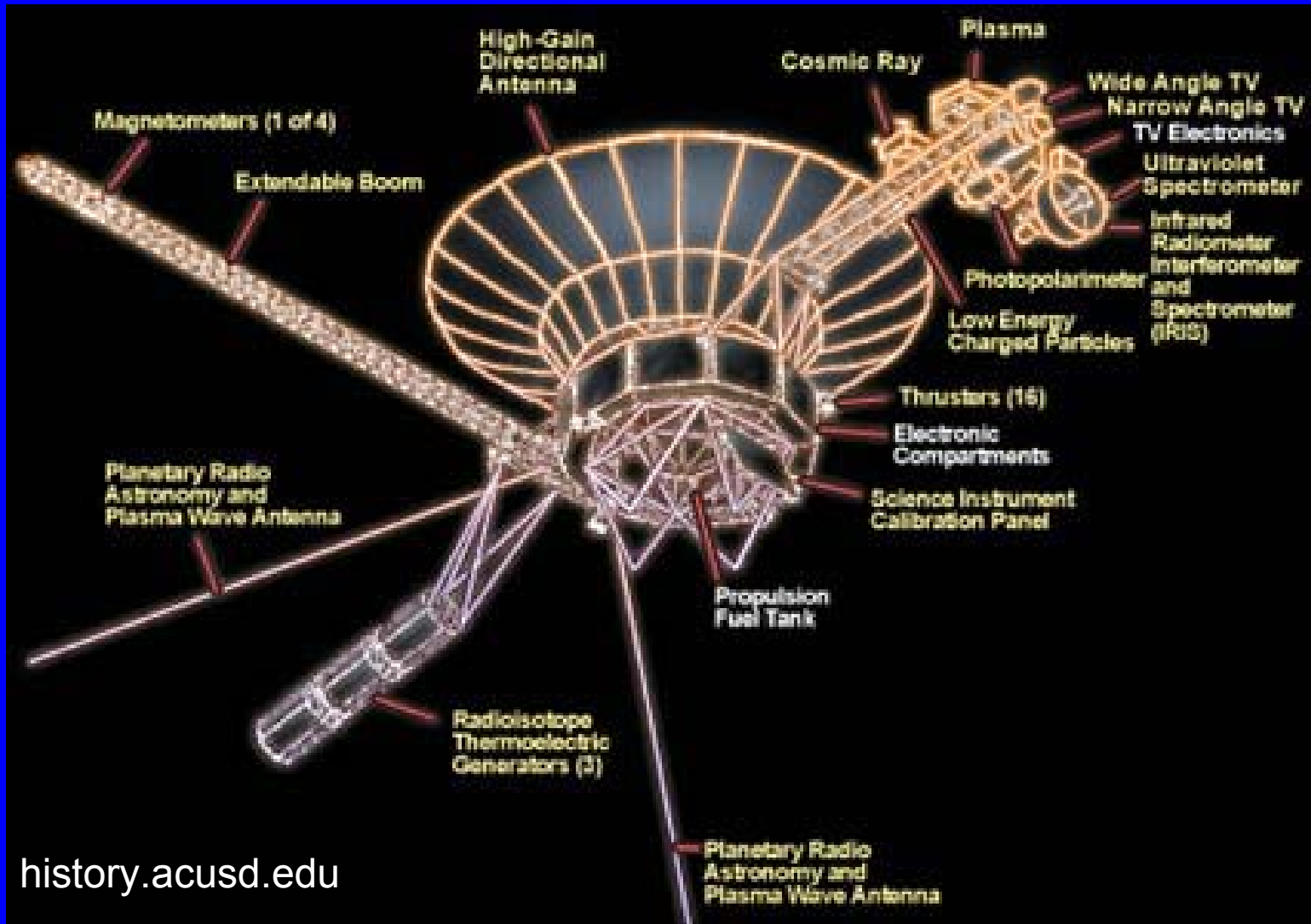
- More satellites
- More structure within the rings
- Maxwell (yes, that Maxwell) proves that the rings are made up of many tiny fragments
- Titan has an atmosphere

Pioneer 11 - 1979

- Mostly “particles and fields” experiments
- Trail-blazing for Voyager spacecraft
- Camera took images one pixel at a time

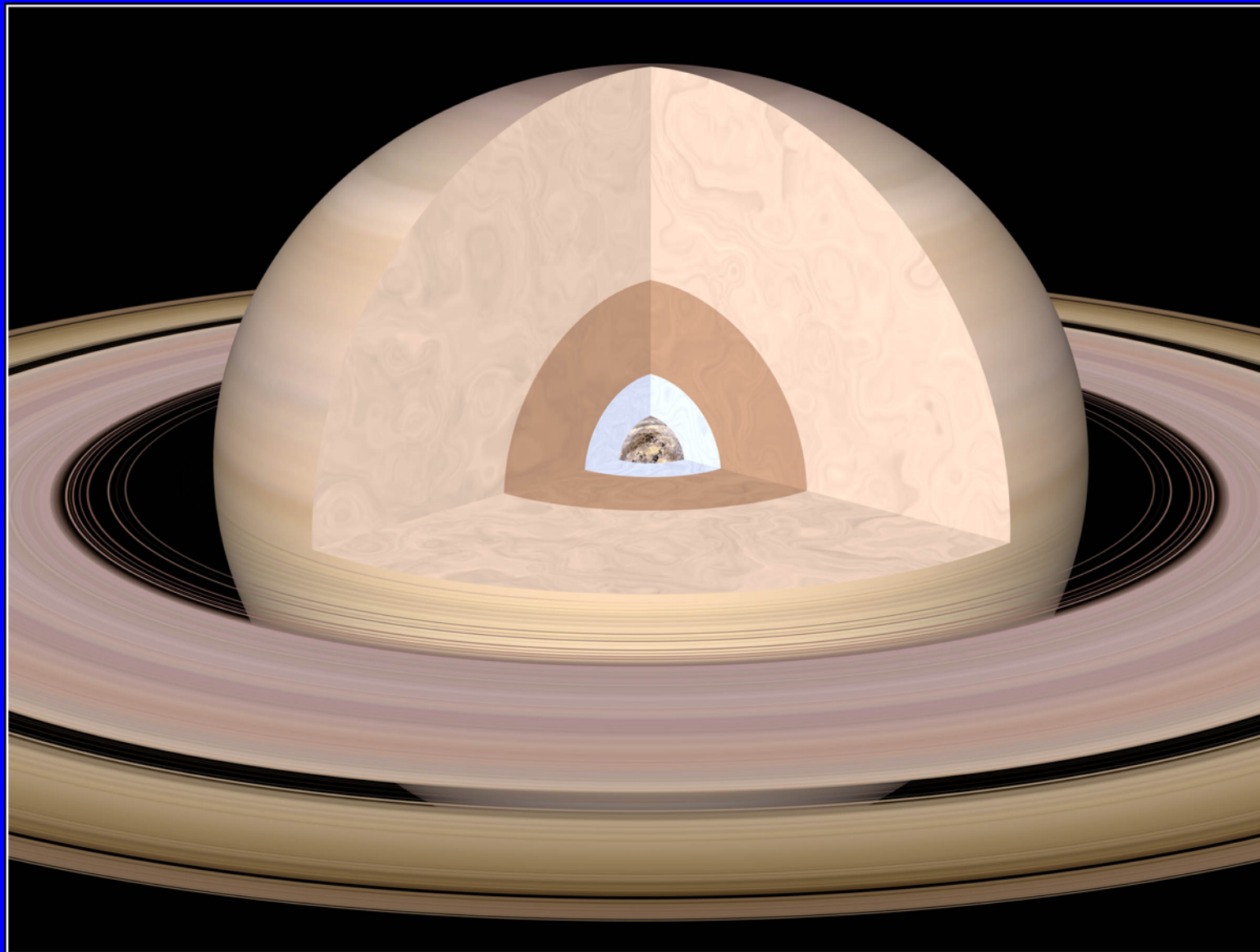


Voyager 1 and 2 – 1980 and 1981



Main Research Areas

- Saturn
- Rings
- Magnetosphere
- Icy moons
- Titan



$H_2(g)$
 $H_2(l)$

$H_2(\text{metal})$

$H_2O/NH_3/$
 CH_4 ice

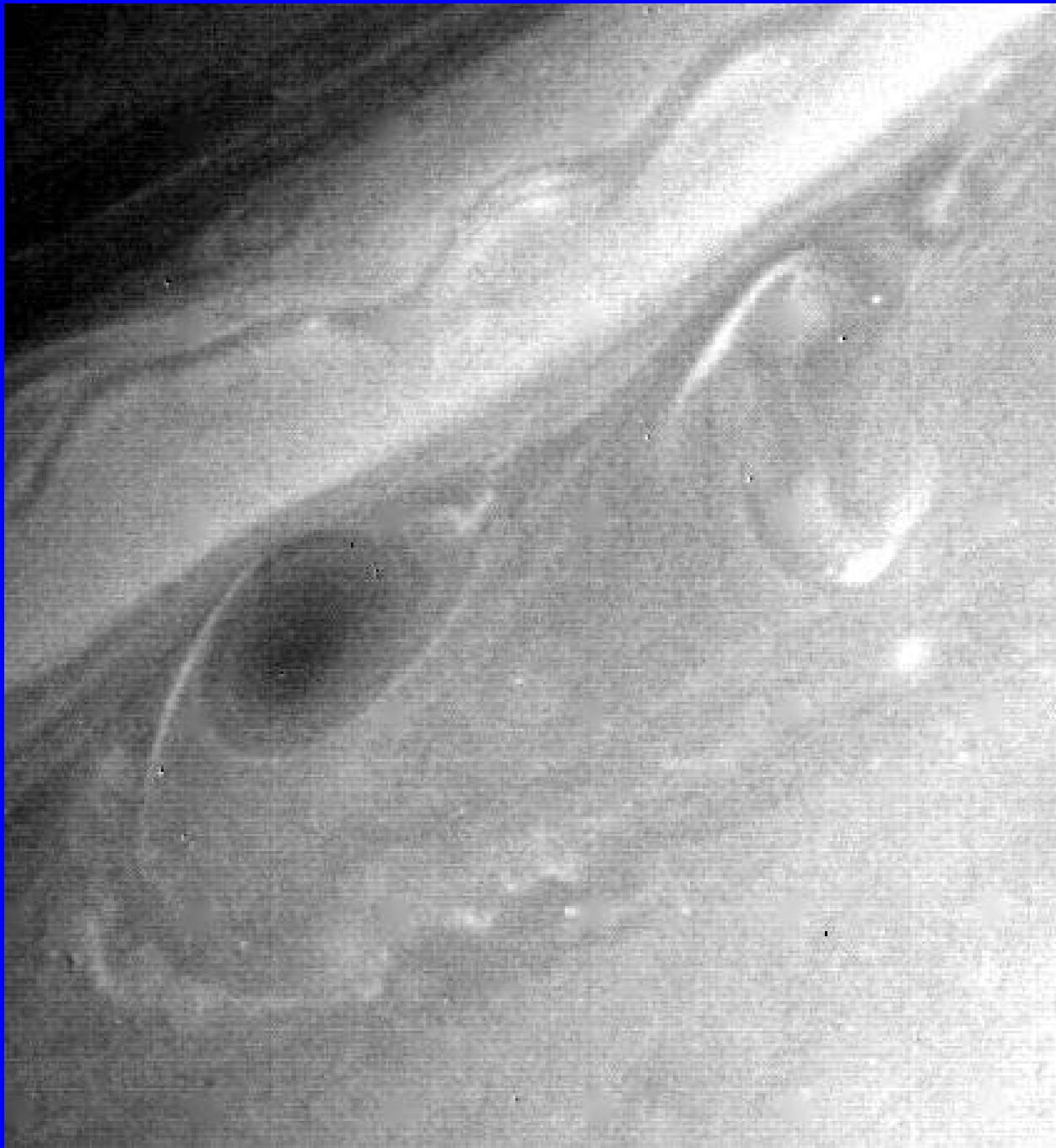
iron/silicate
core

Models are
critically
dependent on
the high
pressure
equation of
state of H and
He mixtures,
core might not
exist

The Interior of Saturn

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www.solarviews.com



Same region as previous picture

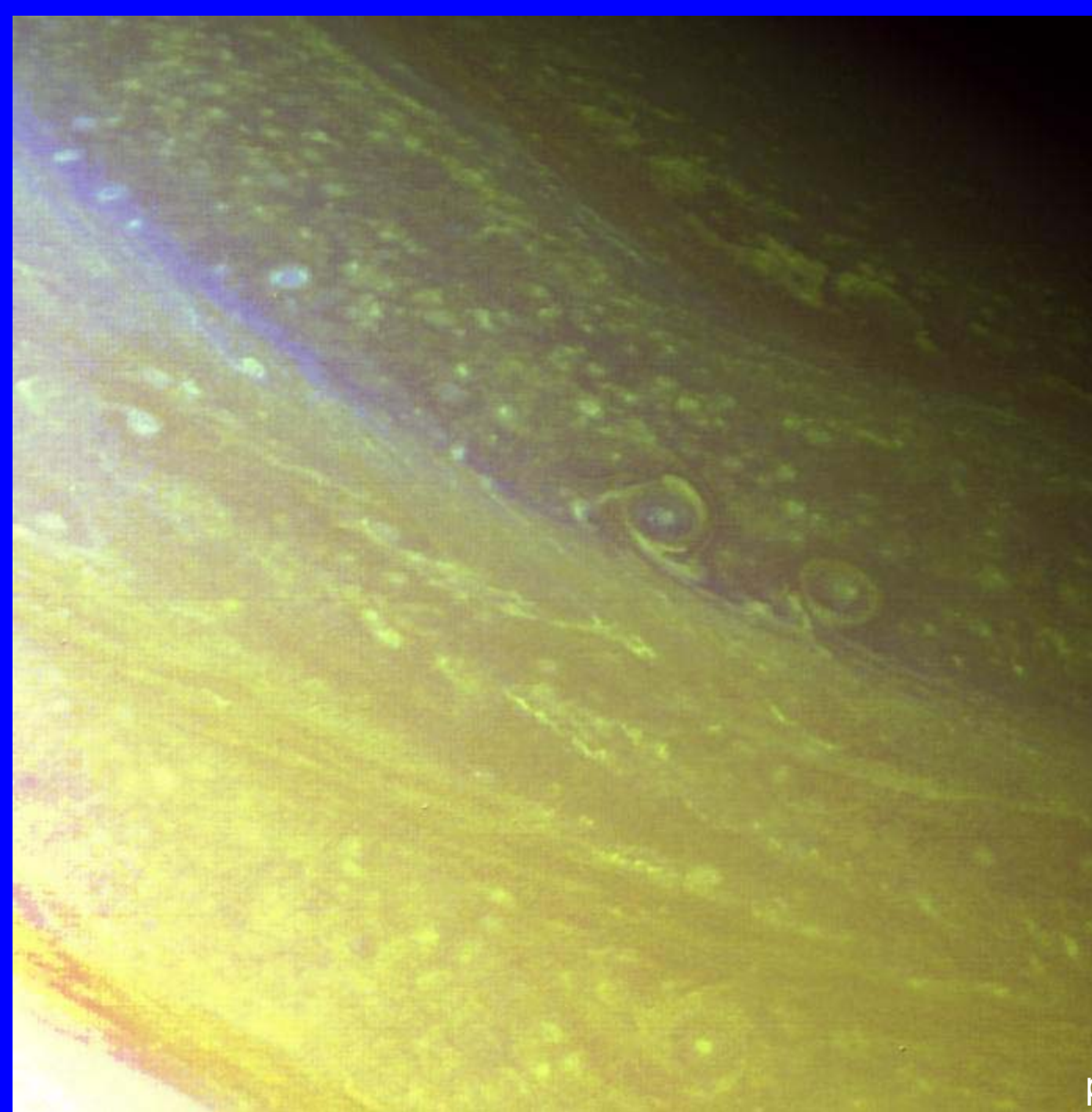
Sinuuous structure

Large, dark storm

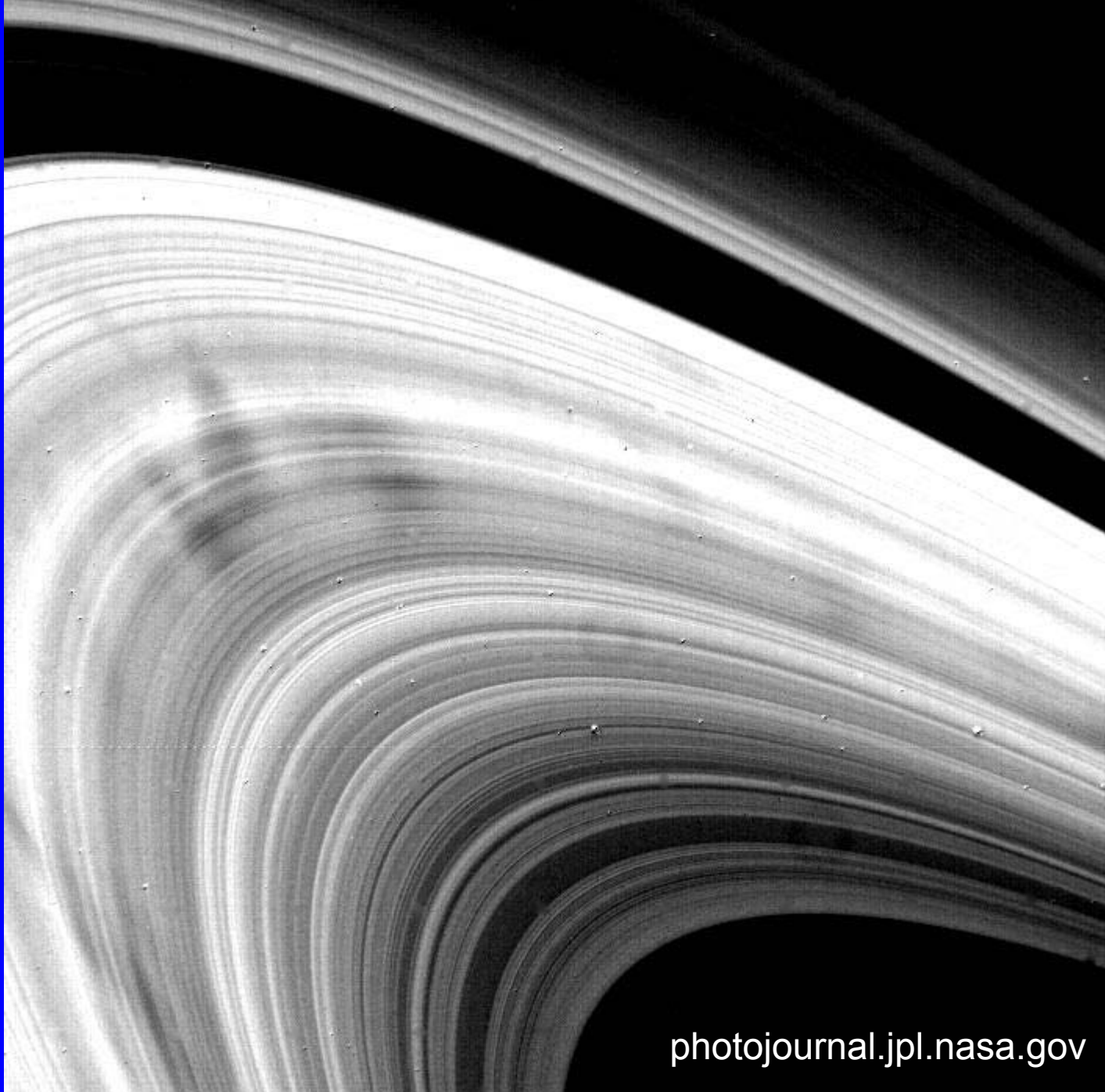
Fluid dynamics on a grand scale

How do abundances of condensable species vary with latitude, altitude, and season?

What is bulk isotopic and elemental composition?







Spokes rotate with Saturn, not with orbital speeds

What are they?

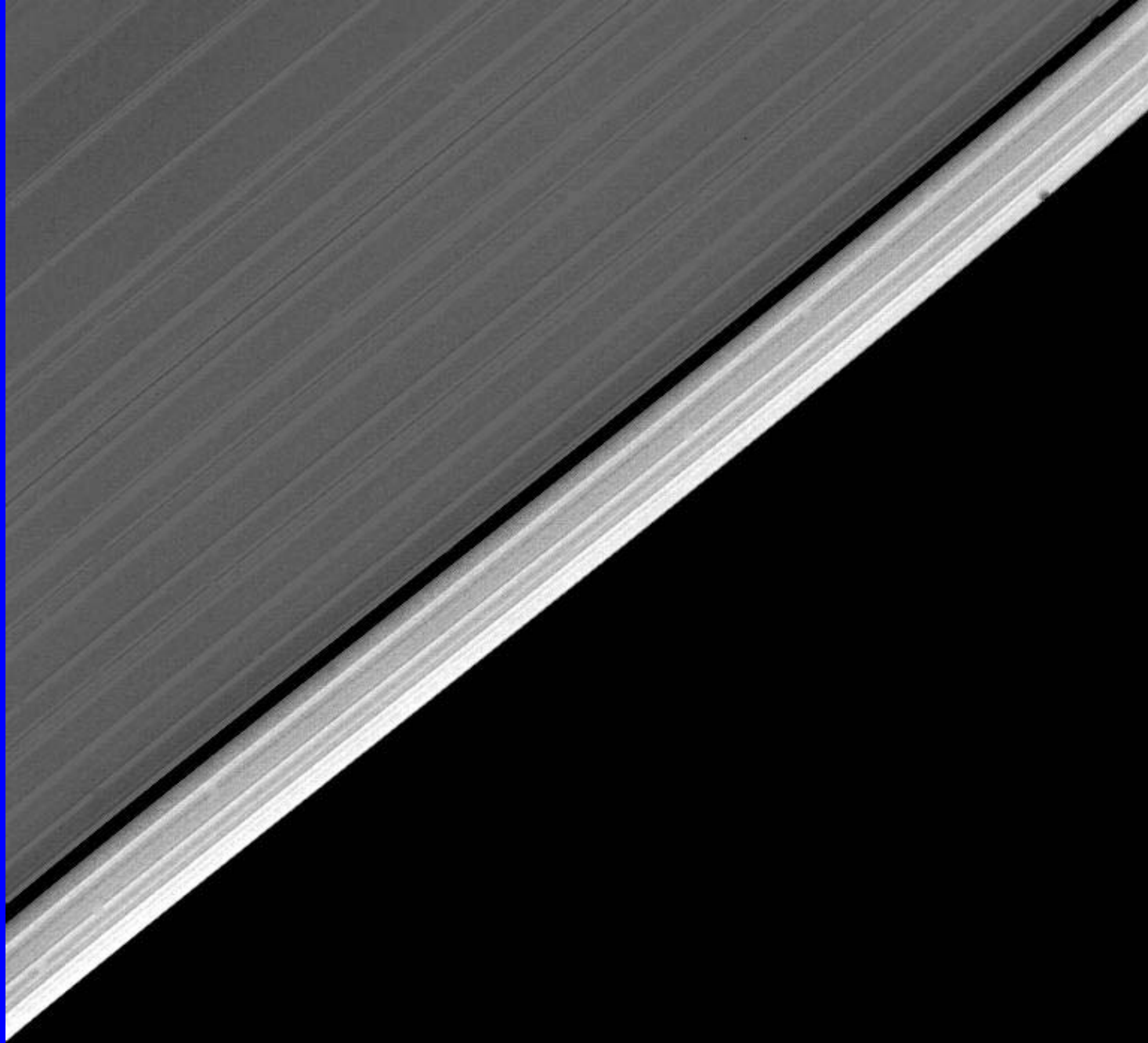
How long-lived?

Where do they come from?

How do rings and satellites interact?

How do shadows of the rings affect Saturn's weather

Brightness of rings suggests youth



ringmaster.arc.nasa.gov

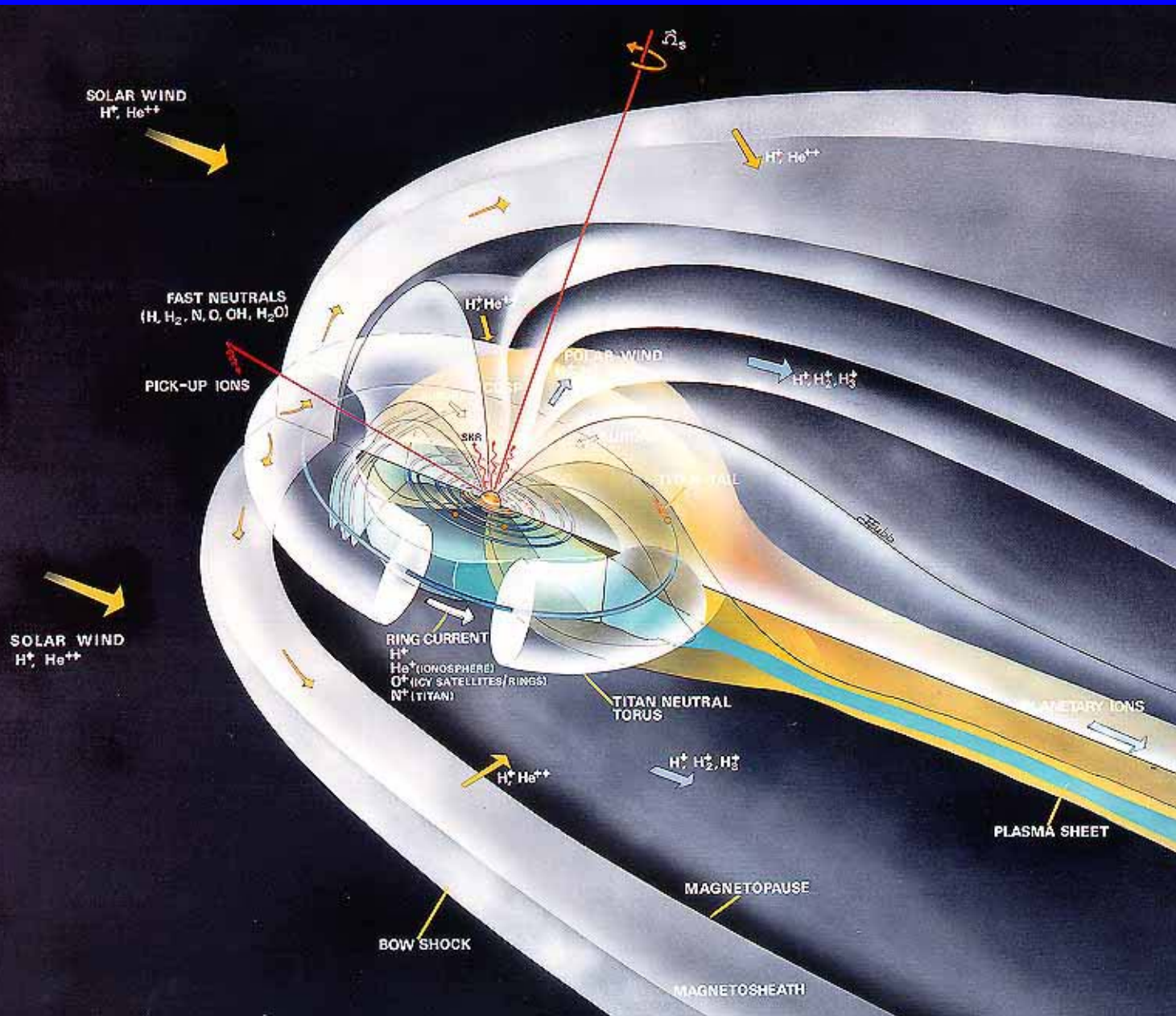


What is the cause of this braiding in the outermost F ring?

What causes azimuthal asymmetries in some of the rings?

How do the dynamics of Saturn's rings relate to those of Jupiter, Uranus, and Neptune?

A neutral cloud of H and OH envelopes the rings: how does it behave?

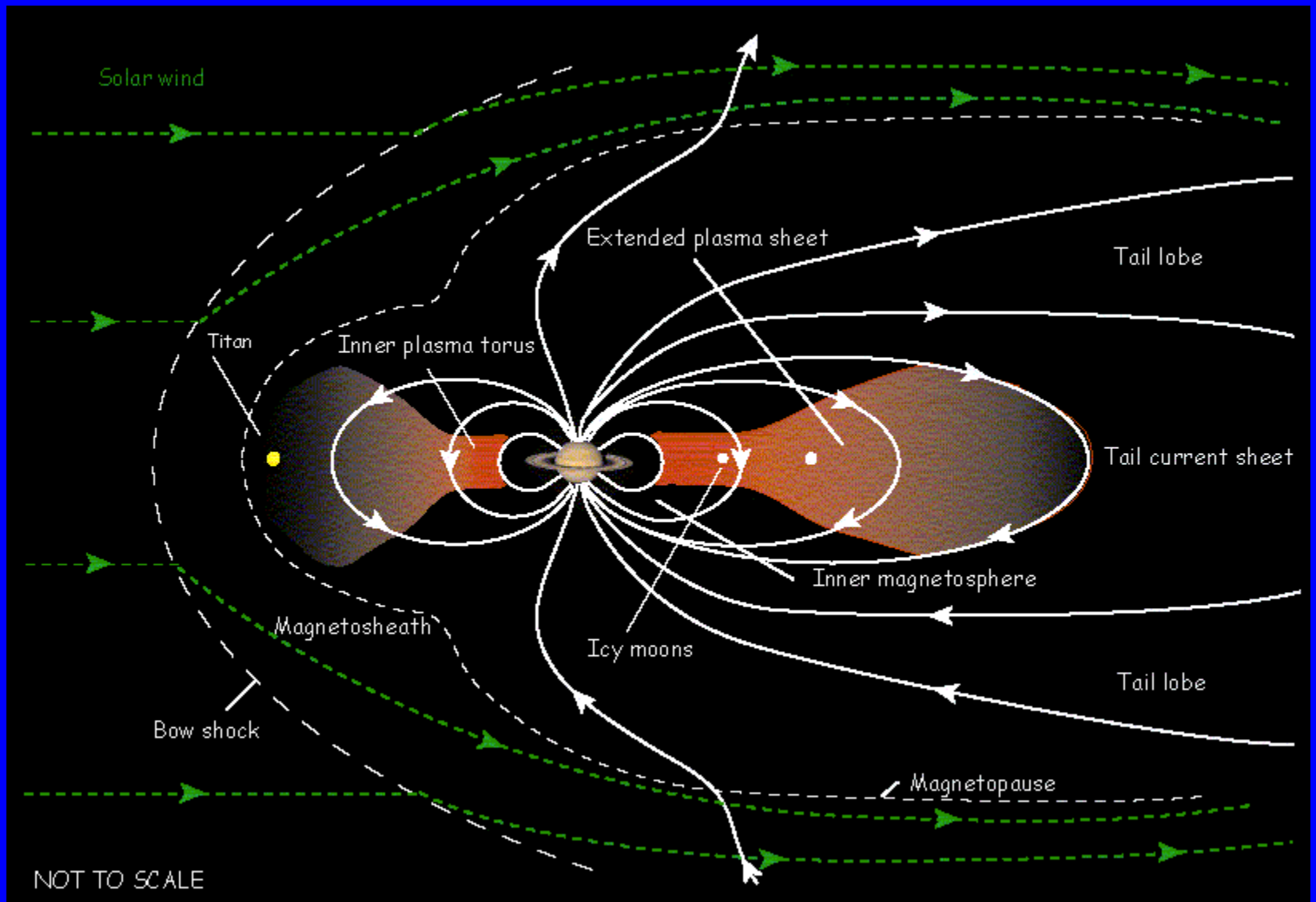


How similar are Titan's torus and the Io plasma torus at Jupiter?

What are the sources and sinks of ions?

What causes powerful radio emissions from Saturn?

How does the composition and temperature of the plasma vary?





Mimas (Death Star)
200 km radius

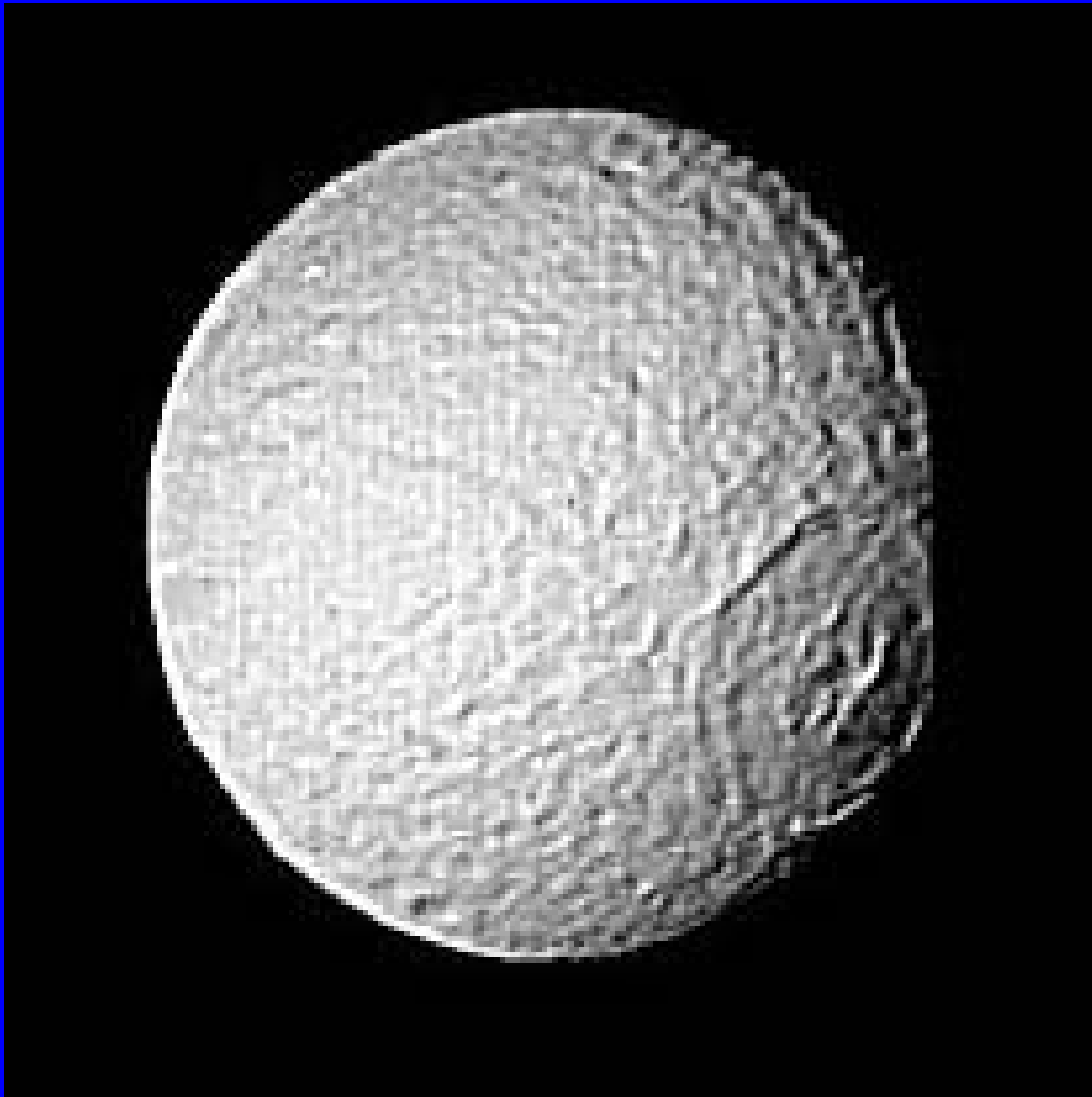
Diameter of crater
Herschel is 1/3 that
of Mimas, 15 km of
topography

Why is it so much
bigger than all
other craters?

How did Mimas
survive impact?

Mostly ice, same
total mass as rings

Responsible for
one edge of the
Cassini Division



Tethys 500 km radius

Mimas would fit inside
crater Odysseus

15 km radius Telesto
and Calypso orbit at
Lagrange points of
Tethys, +/- 60 deg

Mostly ice

Some regions have
been resurfaced

Ithaca Chasma – trench
girdles satellite, 100 km
wide, <3 km deep,
equatorial to Odysseus



Iapetus – 700 km radius

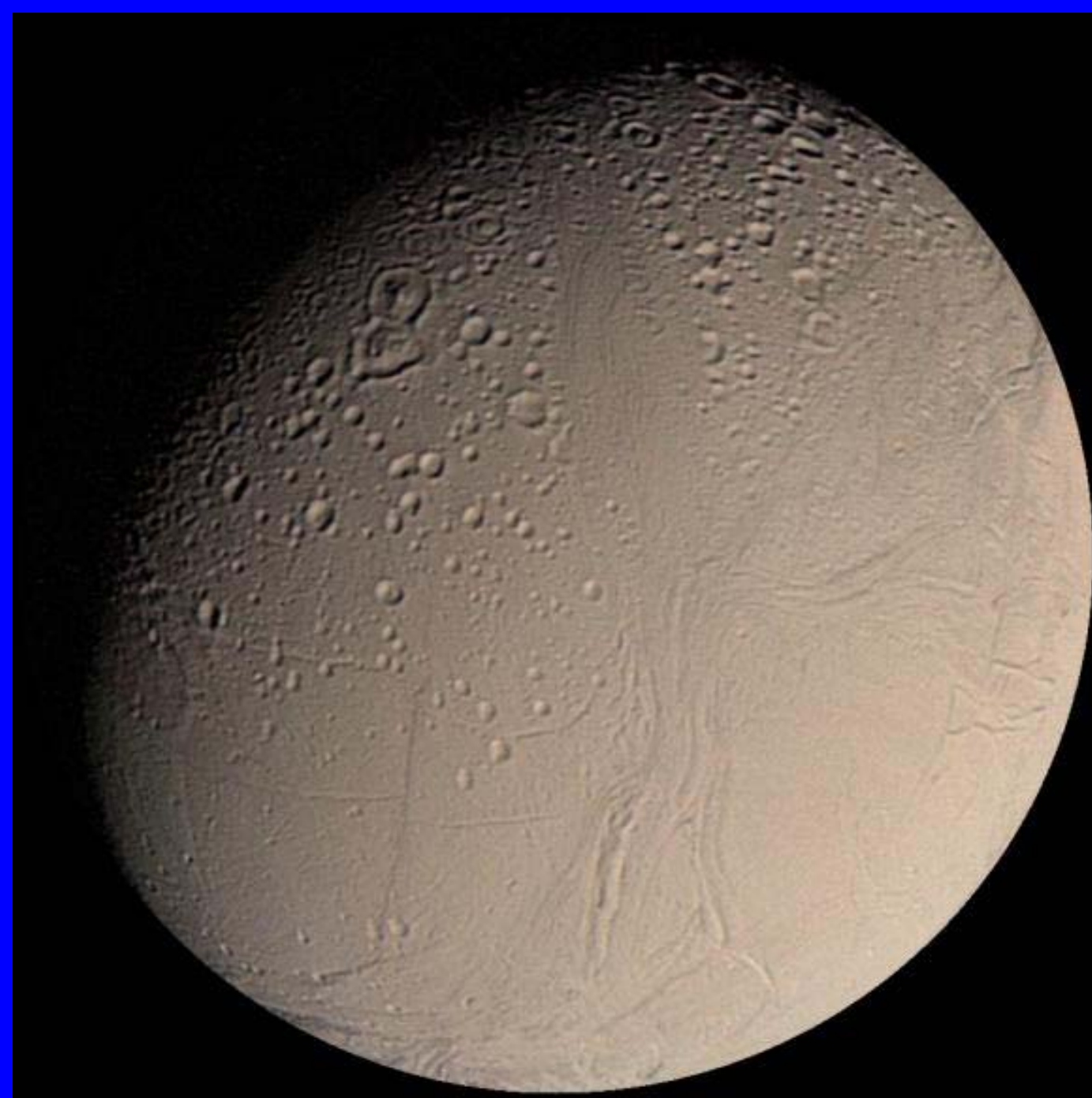
Like most satellites, it rotates synchronously. Hyperion has chaotic rotational state, weird

Leading hemisphere has albedo of 0.05, trailing one has albedo of 0.5

Cassini (1670) was confused

Dark stuff is a big mystery, dark usually means carbon/organics

(Where the monolith was in the book version of “2001”...)



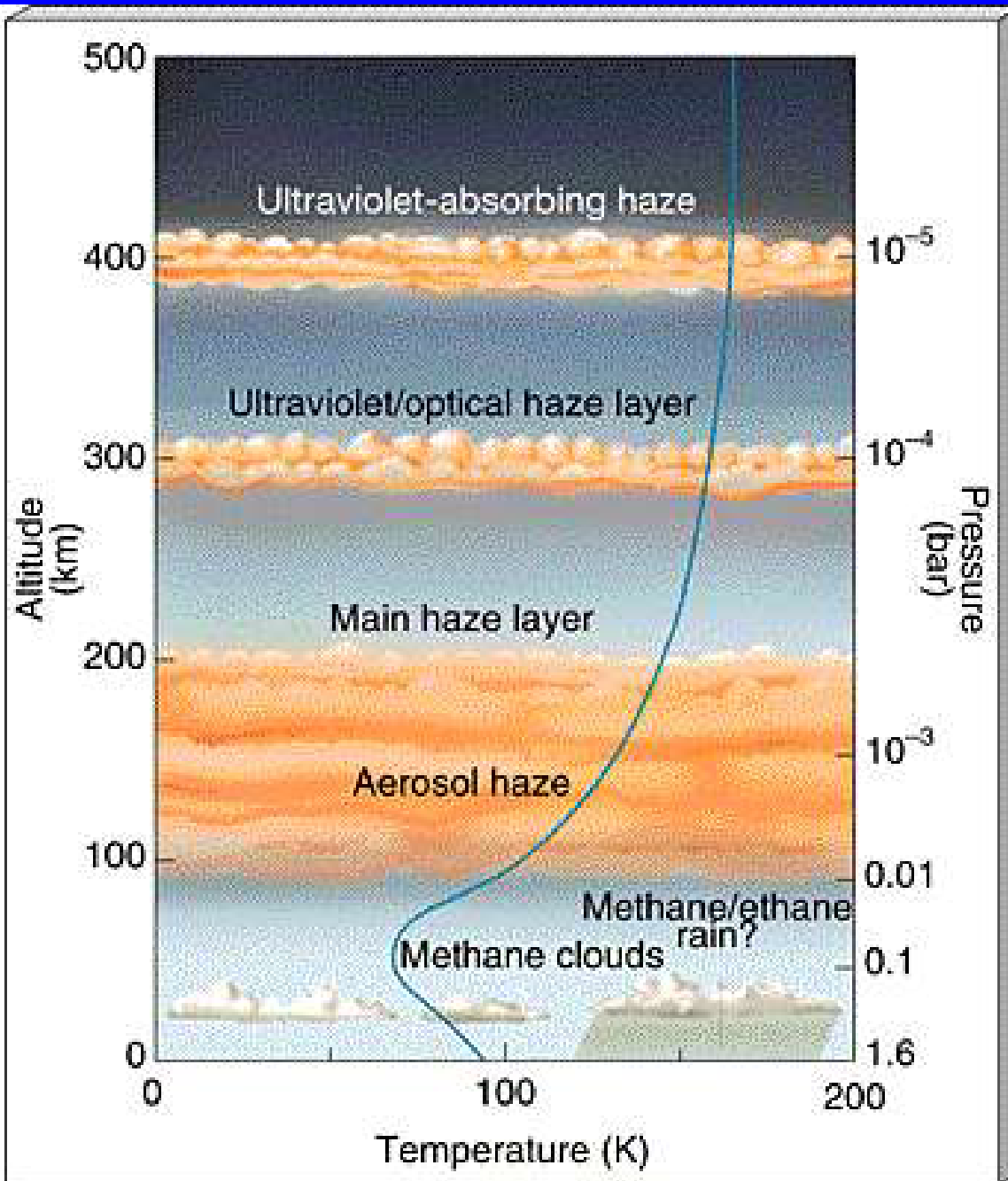
Enceladus – 250 km
Same size and orbit
as Mimas but...

Brightest body known

Absence of craters
means that surface is
very young – 100 My

What was source of
heating - H_2O/NH_3
volcanism, tides,
impact?

Collocated with E ring,
which has very fine ice
particles – are they
emitted by geysers?



Haze absorbs visible light, Voyager didn't see any surface features

Solar UV and charged particles generate soup of hydrocarbons – haze

Is atmosphere similar to early Earth?

Clouds occasionally seen – clouds of what?

Is atmosphere old or young?



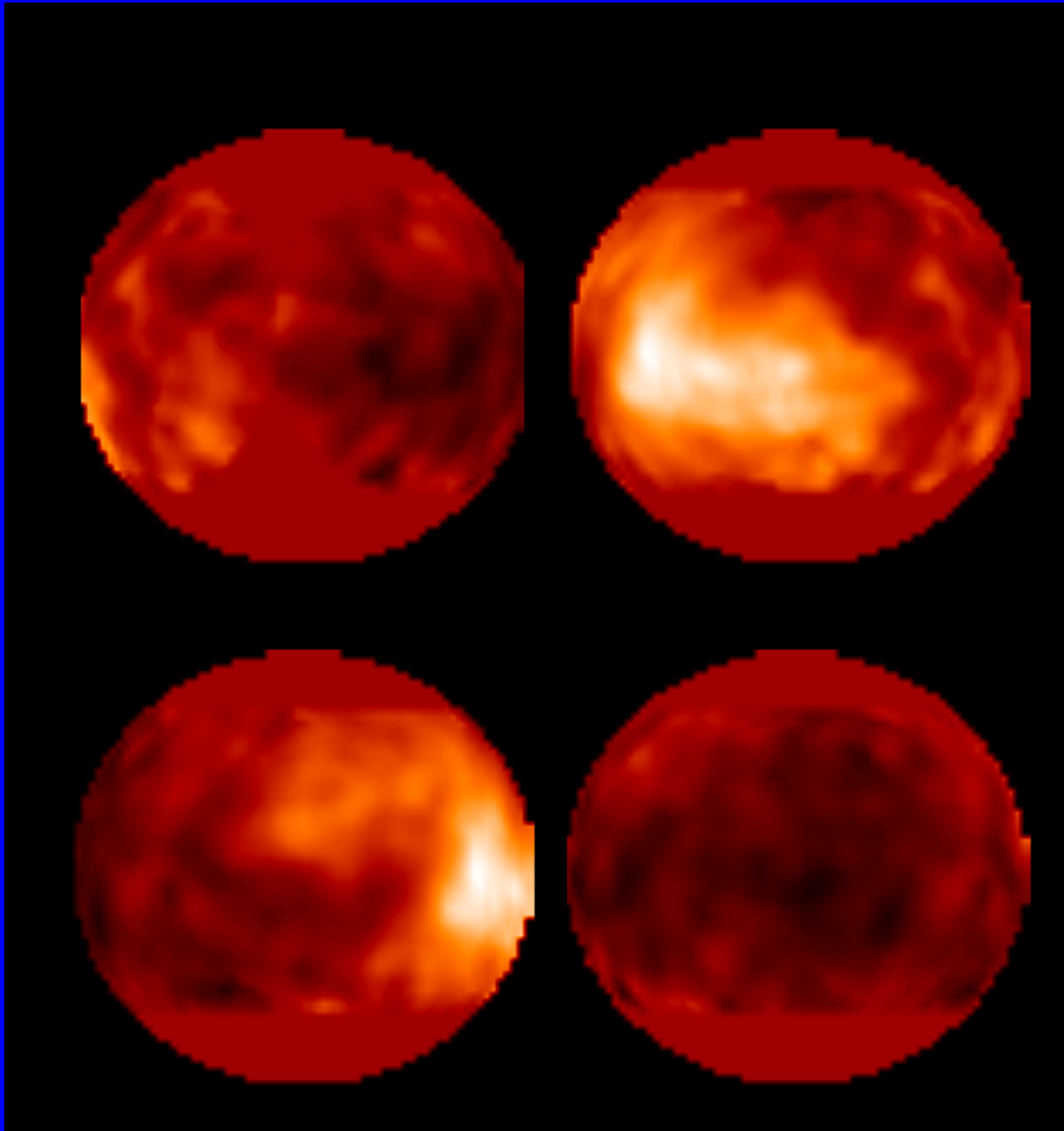
What is thermal structure of atmosphere?

What are compositions of haze layers and clouds?

What energy sources drive the atmospheric chemistry?

How much atmospheric escape has there been?

How does magnetosphere affect atmospheric escape processes?



Atmosphere is optically thin in near-IR

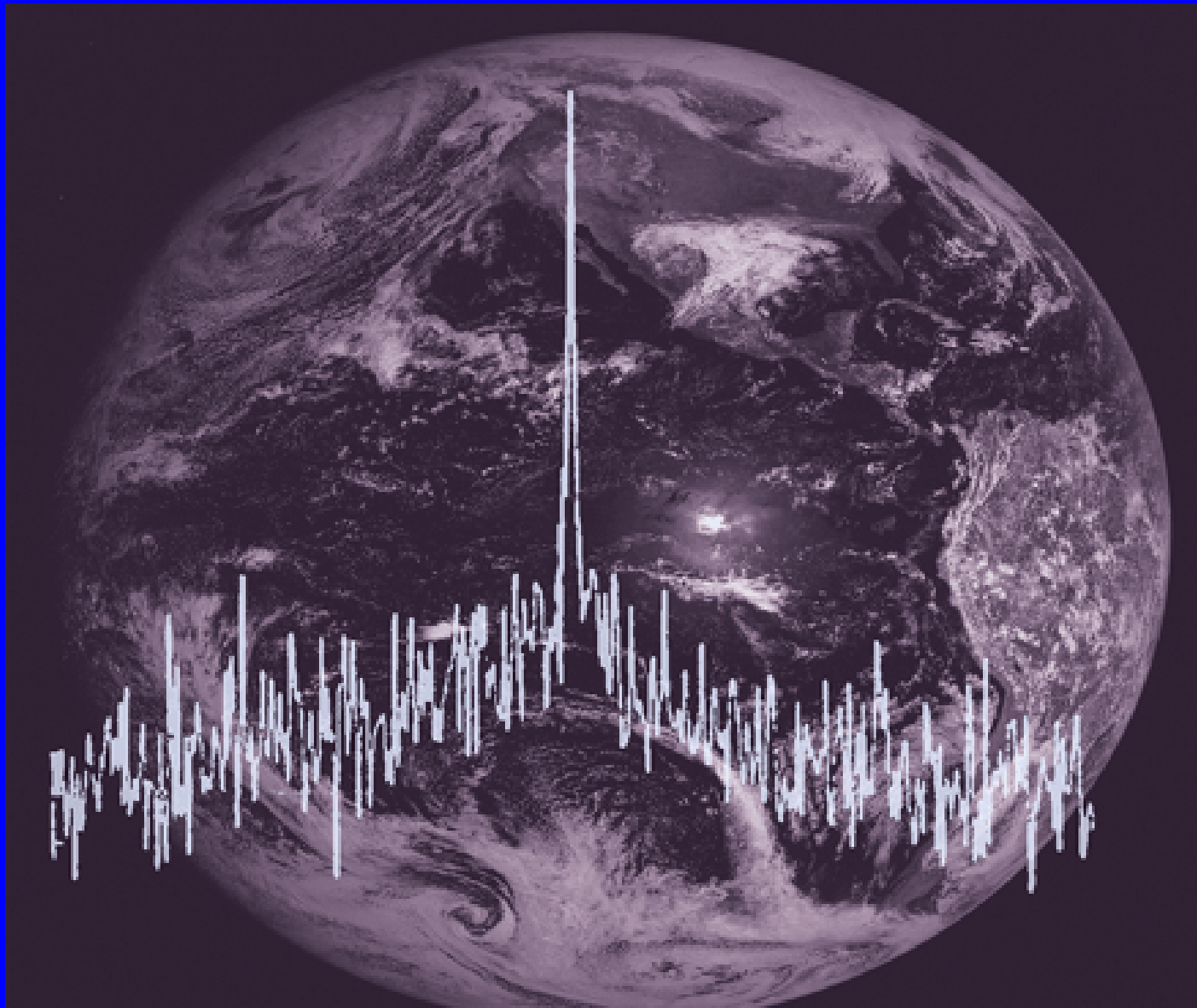
Bright region known as Xanadu, but its nature is unknown

Are there volcanoes, tectonics, craters, liquids, life?

Is surface icy or oily?

Is there a subsurface ocean of H₂O, like Europa?

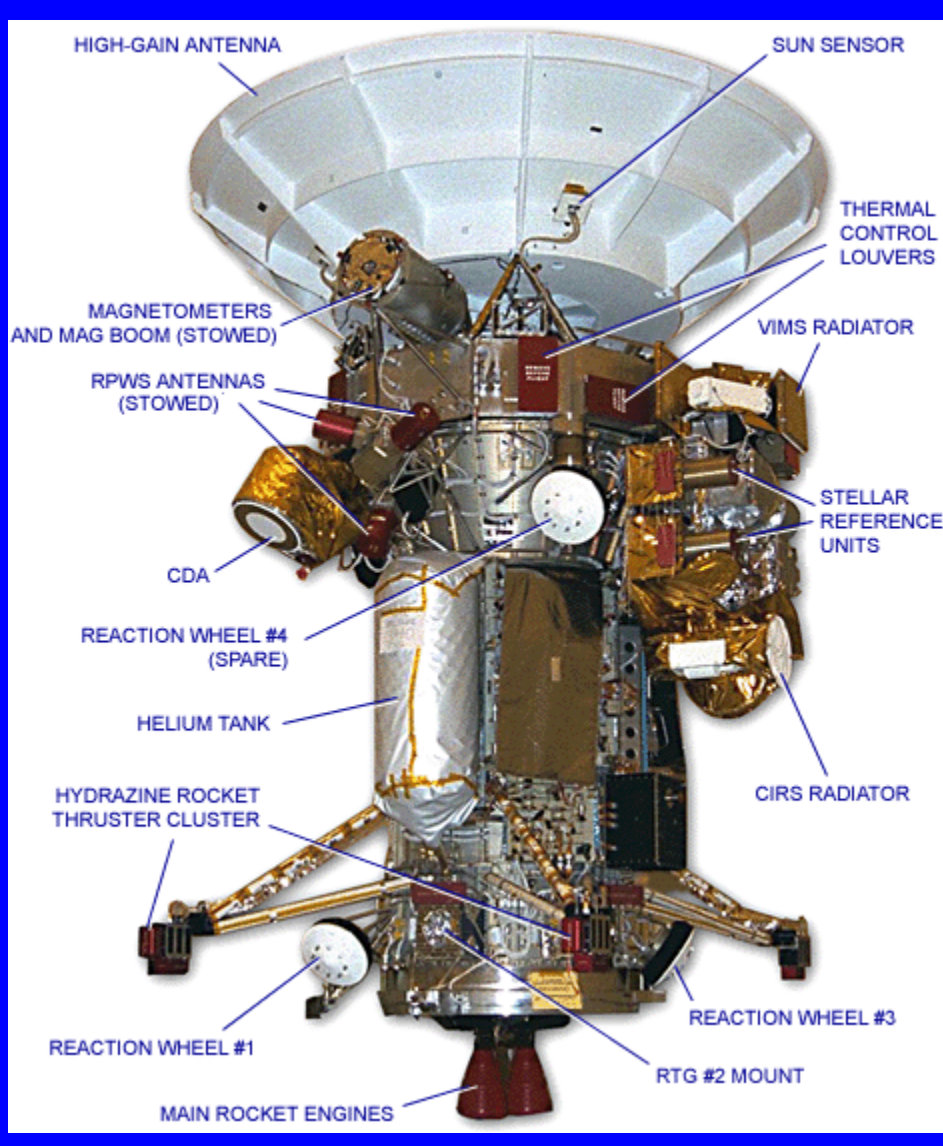
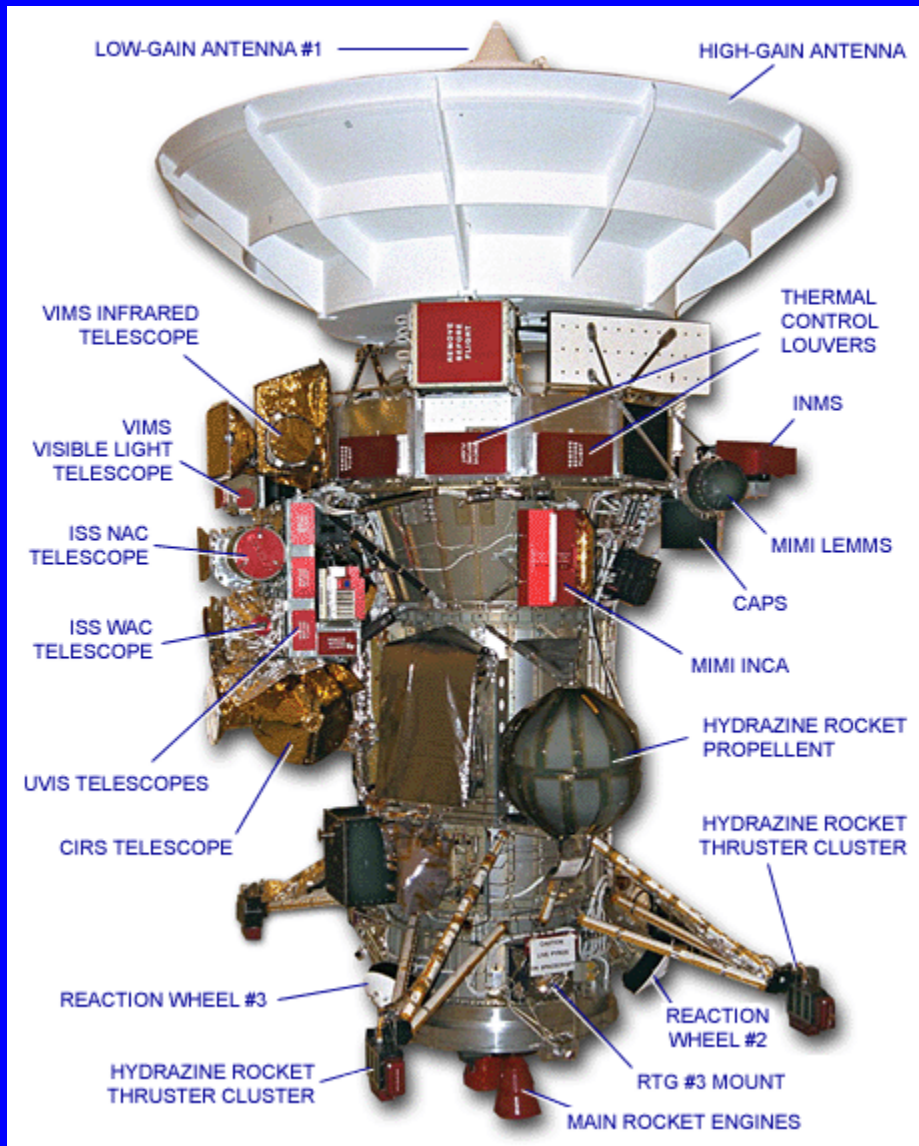
Image from HST

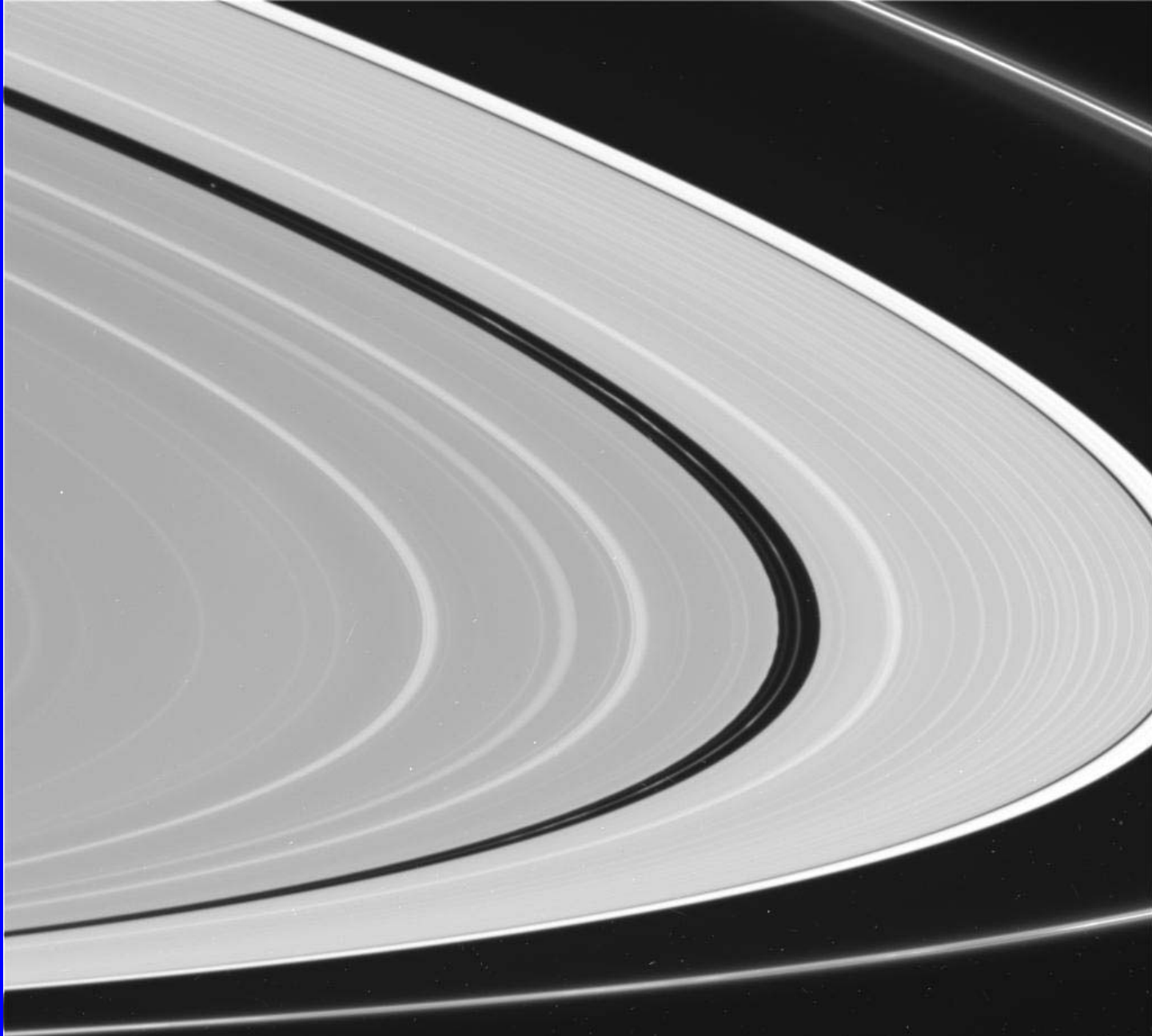


Arecibo/Green
Bank radar saw
specular reflection
from parts of Titan

13 cm wavelength

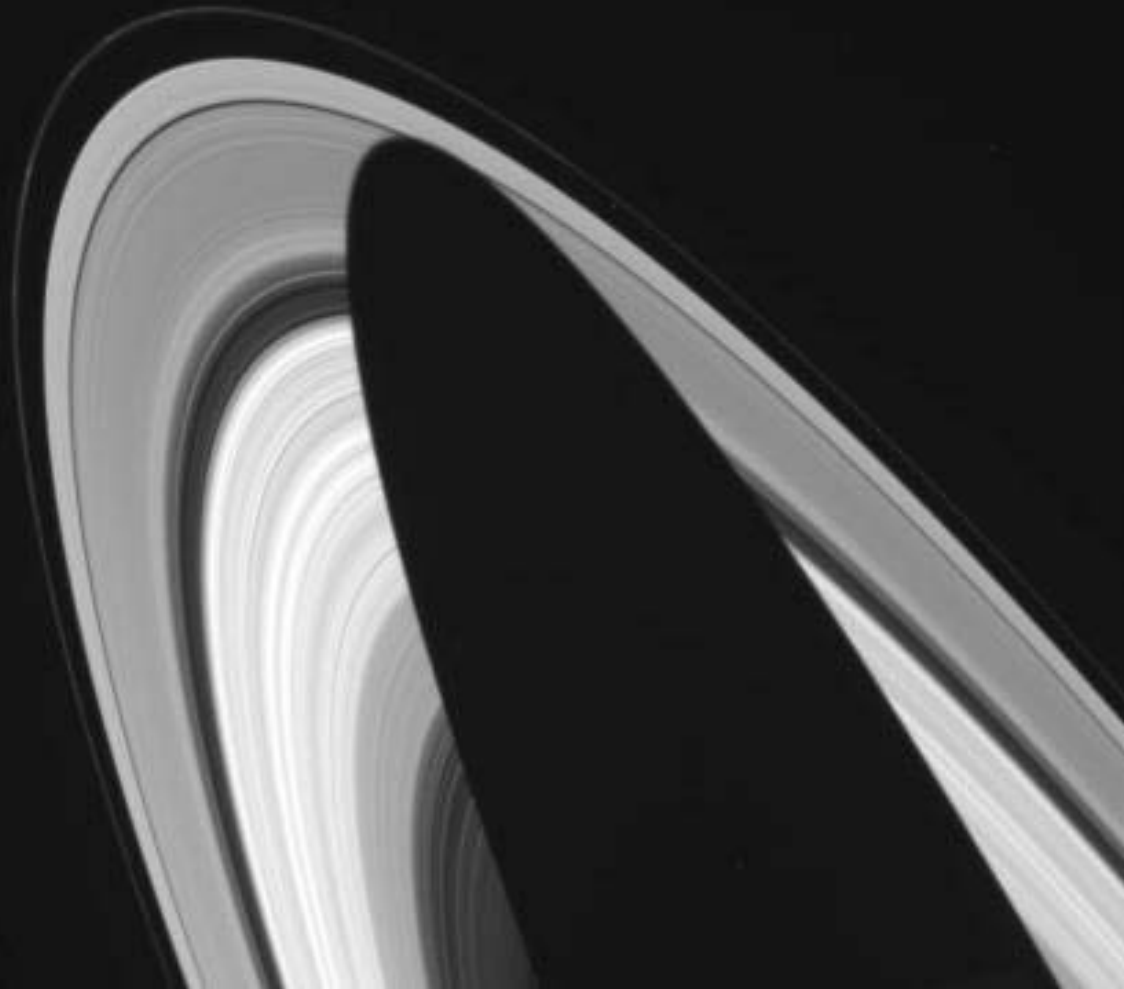
Interpreted as
lakes ~ 80 km
across – or smooth
solid surfaces

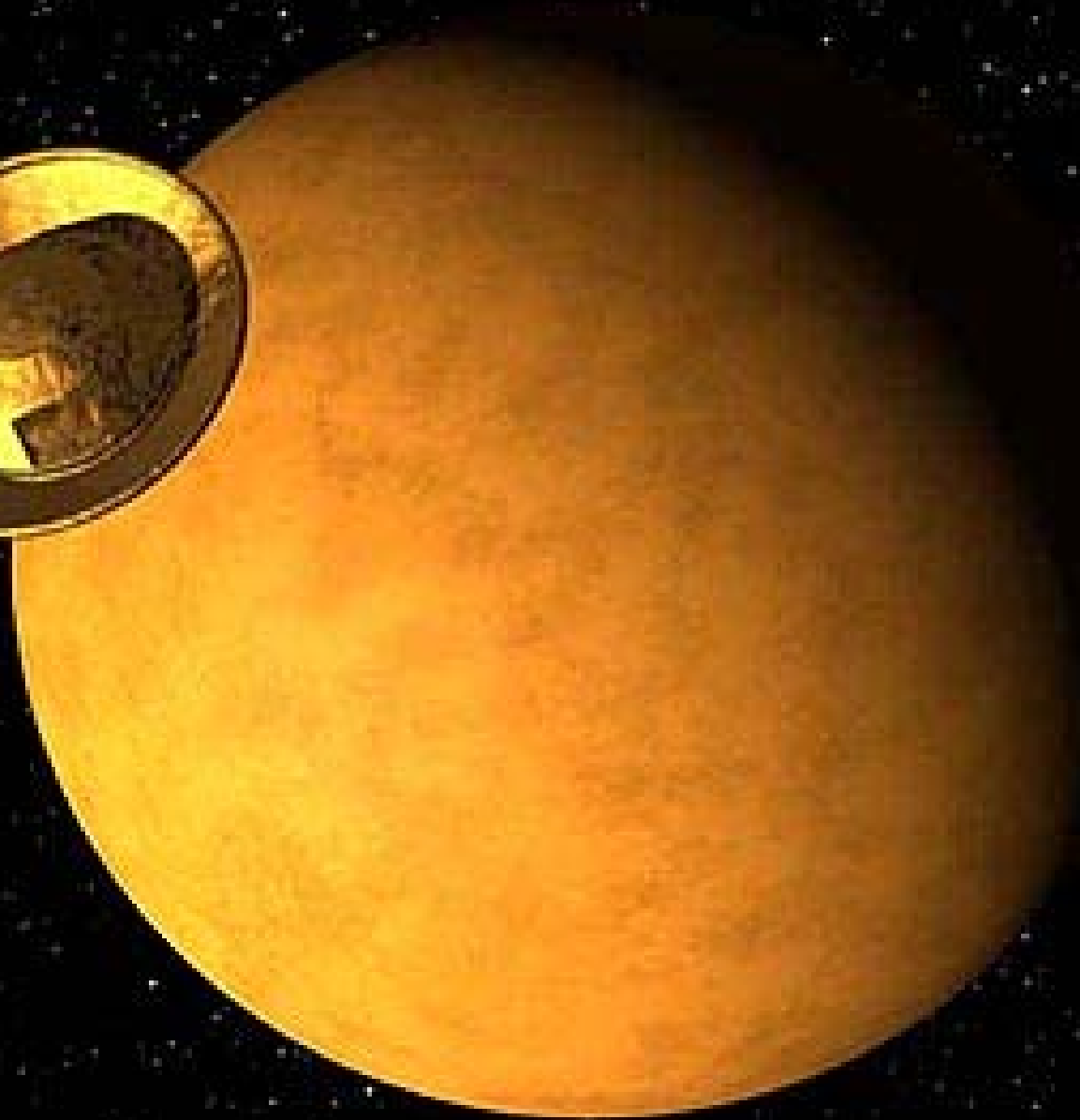




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