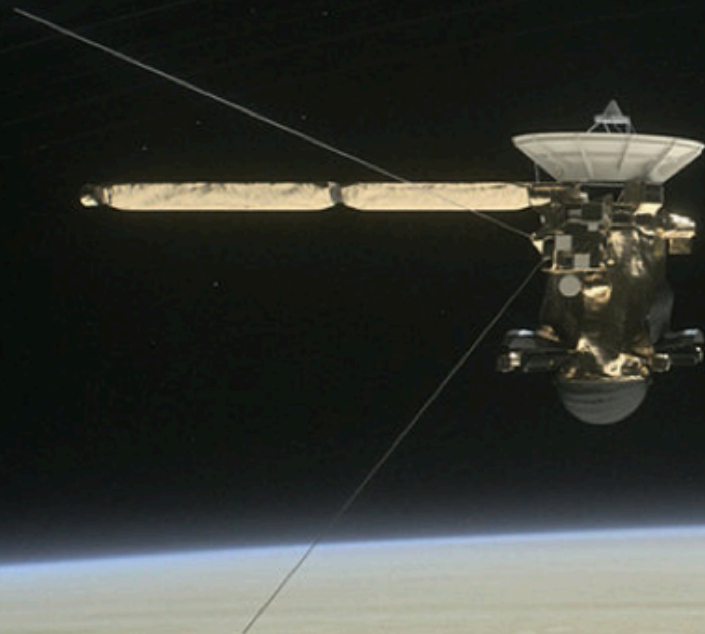


Cassini-Huygens:

A Journey to Saturn

A Journey to Saturn

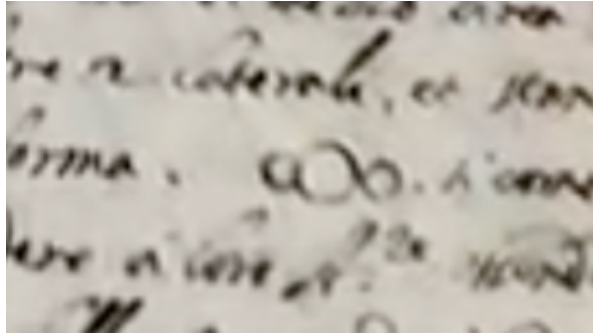


Speaker : Yu Zhou

Advisor : Prof. Xuening Bai

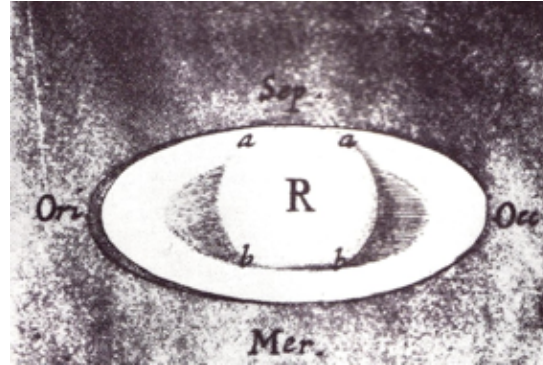
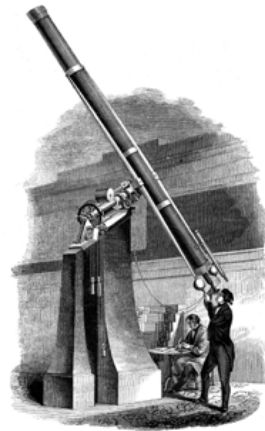
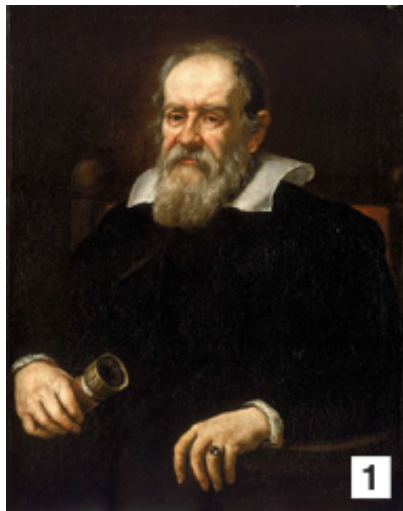
2019 - 01 - 04

Saturn Historical Gallery



First look : Saturn rings (1610)
Were thought as two moons on Saturn's sides.

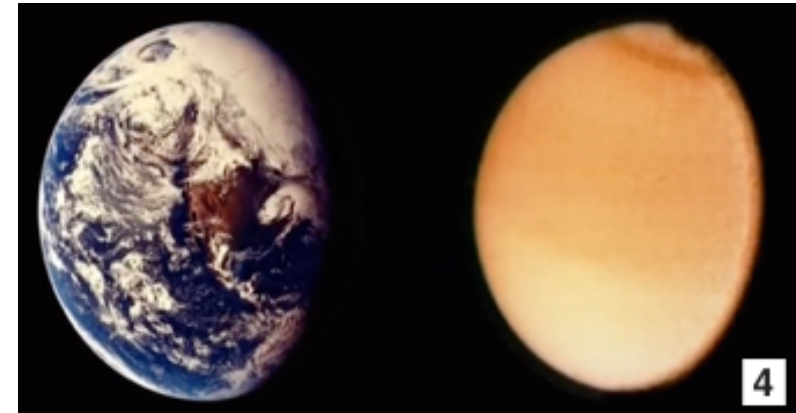
Galileo Galilei



Christiaan Huygens
Clarified the Rings
structure.
First discovered the
largest moon : Titan
(1655)



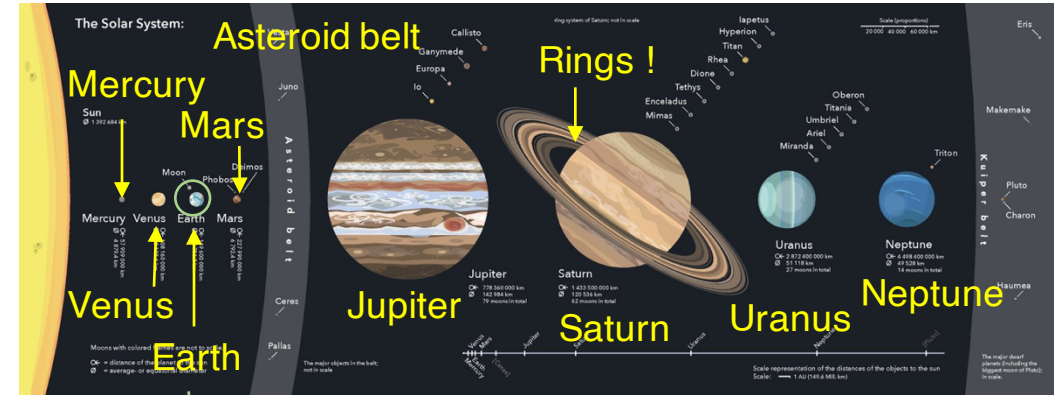
Giovanni Domenico Cassini
Other moons:
Lapetus, Rhea, Tethys, Dione
The gap : Cassini division (1675)



Voyager 1 : Titan's atmosphere
Is made of Nitrogen.
Just like the earth.

What is Cassini-Huygens and Why Saturn?

- Saturn : Extraordinary Ring System, 62 moons of great diversity
- Cassini : Wander all the way to Saturn
- Huygens : Sent to the land of unknown – Titan (a moon of Saturn)

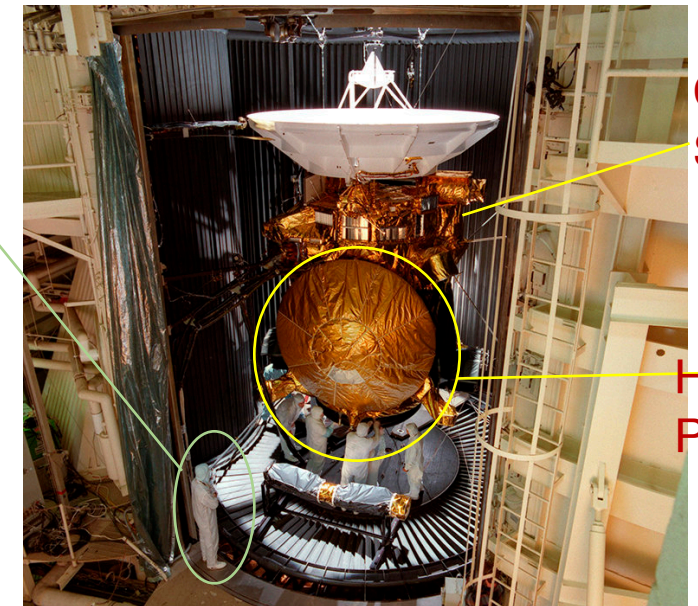
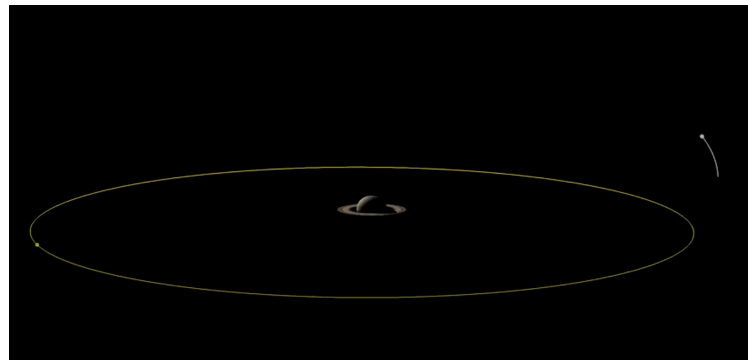


'You are here!'

'A planet floating on water'



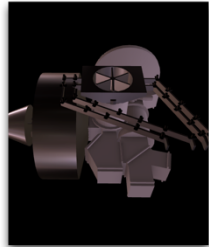
Cassini's dive to Saturn



Cassini Satellite

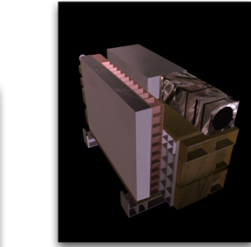
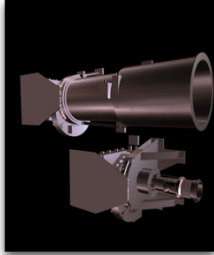
Huygens Probe

Satellite Overview and Mission Time Line



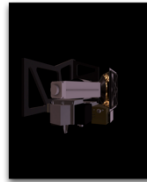
Composite Infrared Spectrometer (CIRS)

Imaging Science Subsystem (ISS)

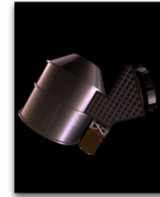


Ultraviolet Imaging Spectrograph (UVIS)

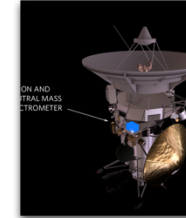
Visible and Infrared Mapping Spectrometer (VIMS)



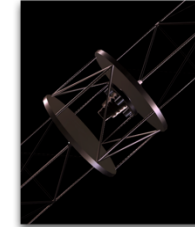
Cassini Plasma Spectrometer (CAPS)



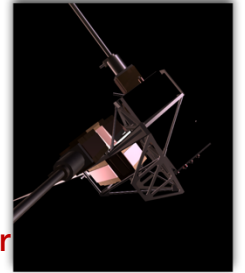
Cosmic Dust Analyzer (CDA)



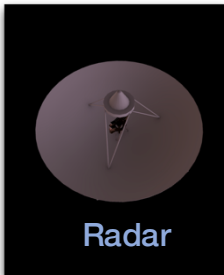
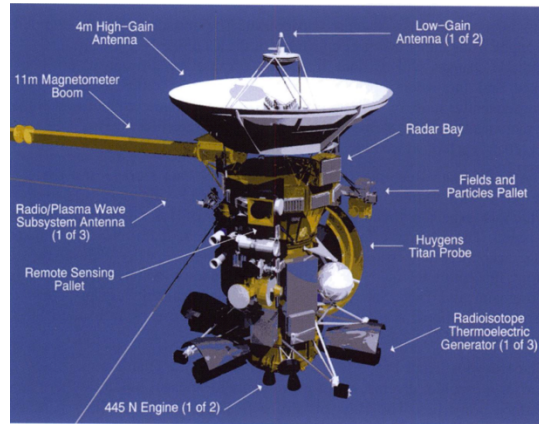
Ion and Neutral Mass Spectrometer (INMS)



Magnetometer (MAG)



Radio and Plasma Wave Science (RPWS)

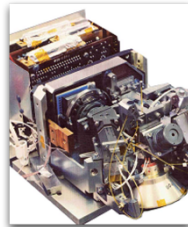


Radar



Radio Science Subsystem (RSS)

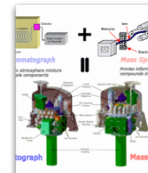
Descent Imager/Spectral Radiometer (DISR)



Doppler Wind Experiment (DWE)



Gas Chromatograph And Mass Spectrometer (GCMS)



Huygens Atmosphere Structure Instrument (HASI)



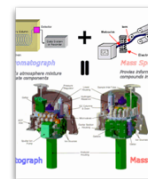
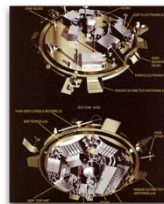
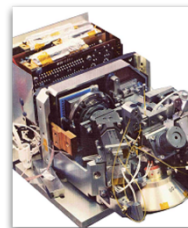
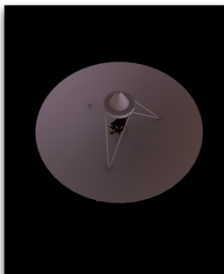
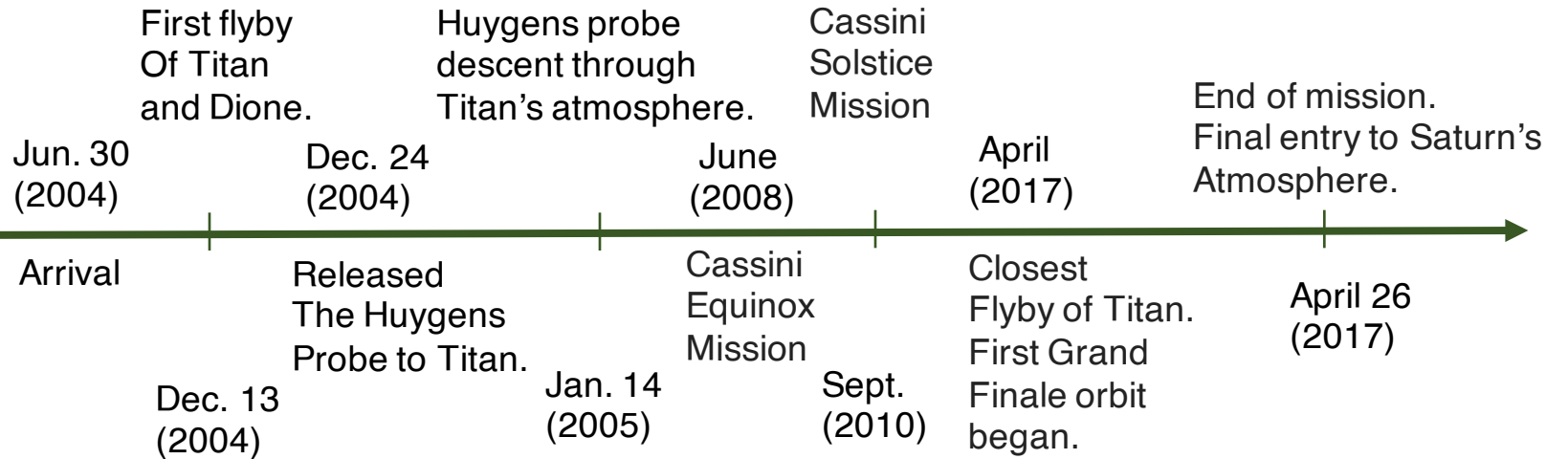
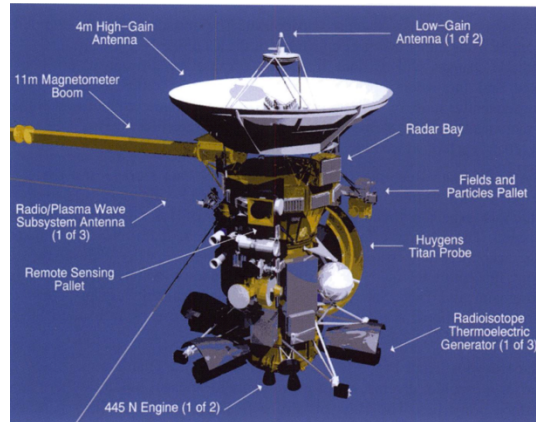
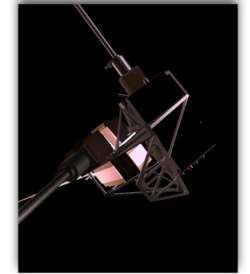
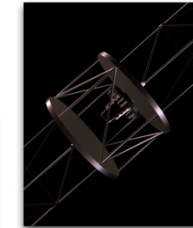
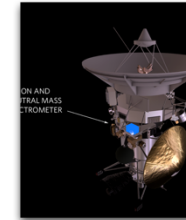
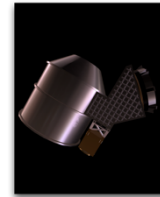
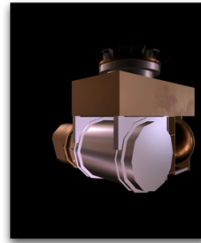
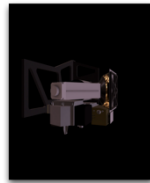
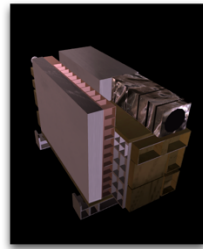
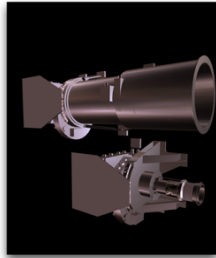
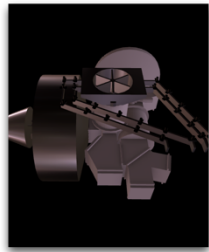
Surface Science Package (SSP)



NASA, ESA, the Italian Space Agency

Cassini :
 Electromagnetic spectrum
 Dust, plasma and magnetic fields
 Radio waves
 Huygens Instruments

Satellite Overview and Mission Time Line



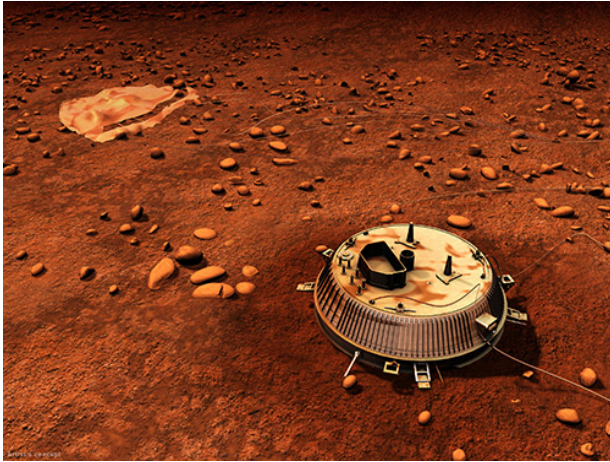
**NASA, ESA,
the Italian Space Agency**

Cassini :
Electromagnetic spectrum
Dust, plasma and magnetic fields
Radio waves
Huygens Instruments

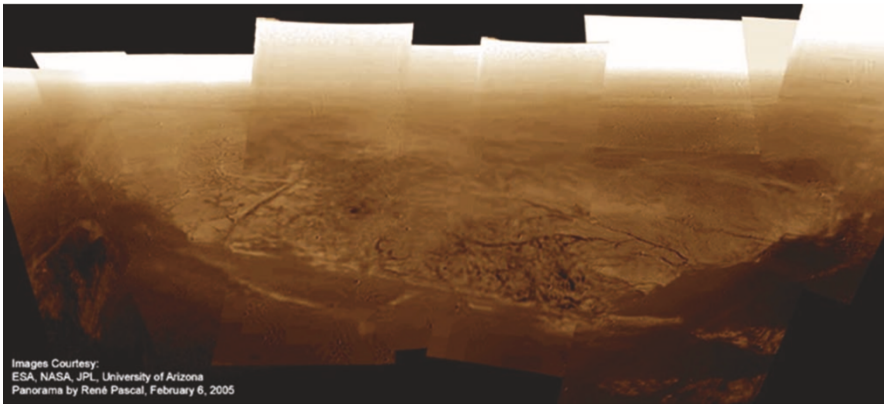
Outline

- **Titan (moon)** : Geology and Surface Processes on Titan.
- **Enceladus (moon)** : Surprising observation of hydrothermal vents and ocean underneath the crust.
- **Rings** : Substructure and its relation to proto-planetary disk.
- **Magnetosphere** : Shape and orientation of the magnetic field and its relationship to planet field origin.
- **Saturn** : Many 'firsts' on another planet and Cassini's grant finale.

Arriving at Titan



Huygens Probe Landing and First Glance of Titan

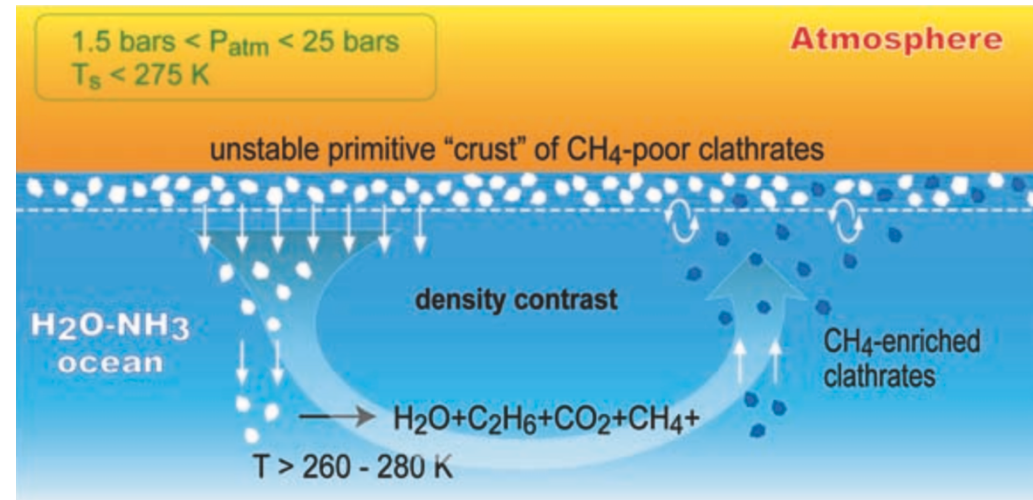


Panorama view taken by the DISR cameras during descent. Viewing direction is towards the north.

Atmosphere : N_2 , CH_4 , C_2H_6

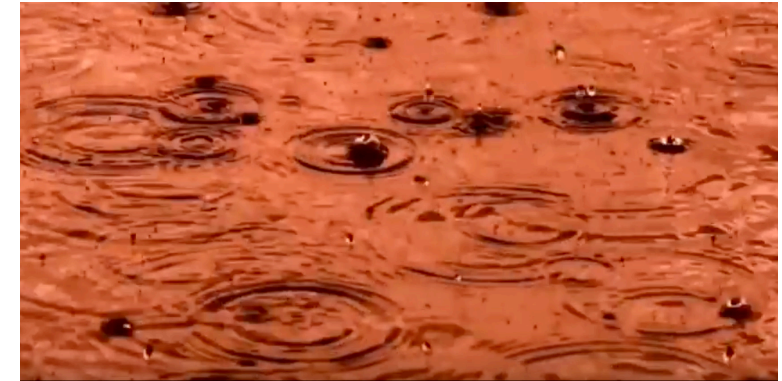
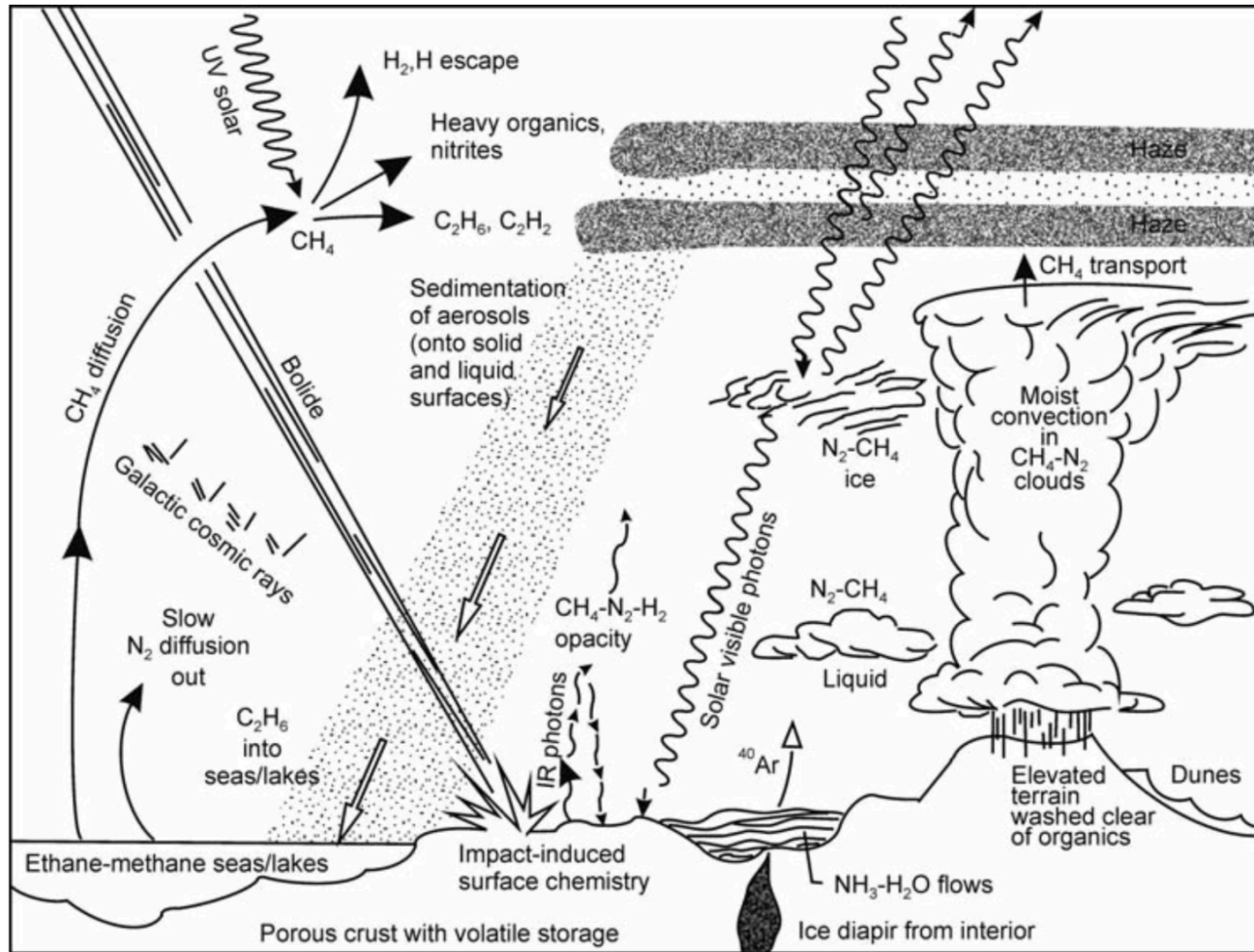
How is the CH_4 formed ?

Gravity measurements : NH_3 - H_2O ocean



(Choukroun 2007)

Raining Titan



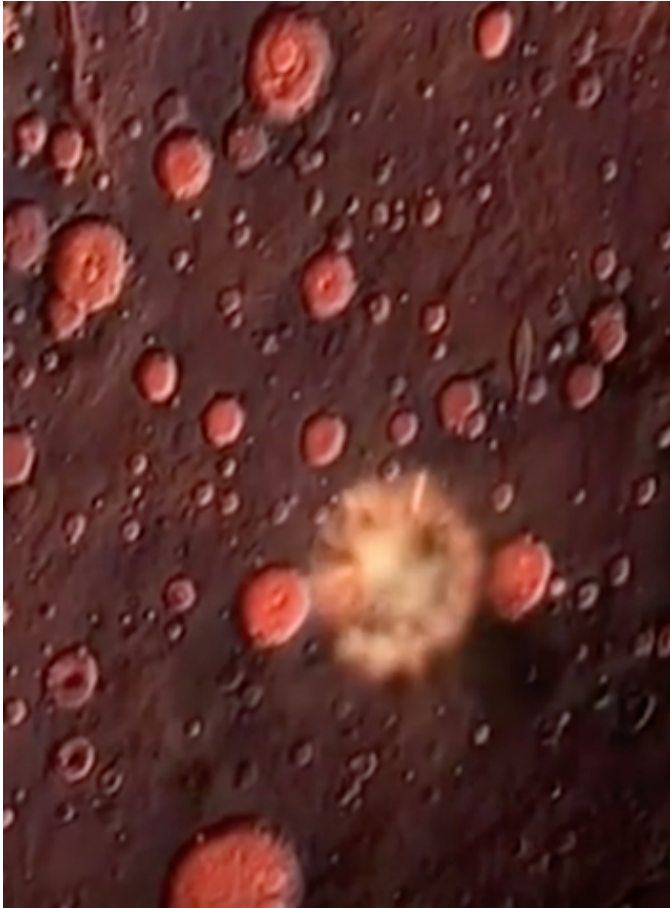
Rainfall : cleansing mechanism that might render elevated terrain optically brighter than lowlands

(Griffith et al. 1991;
Smith et al. 1996)

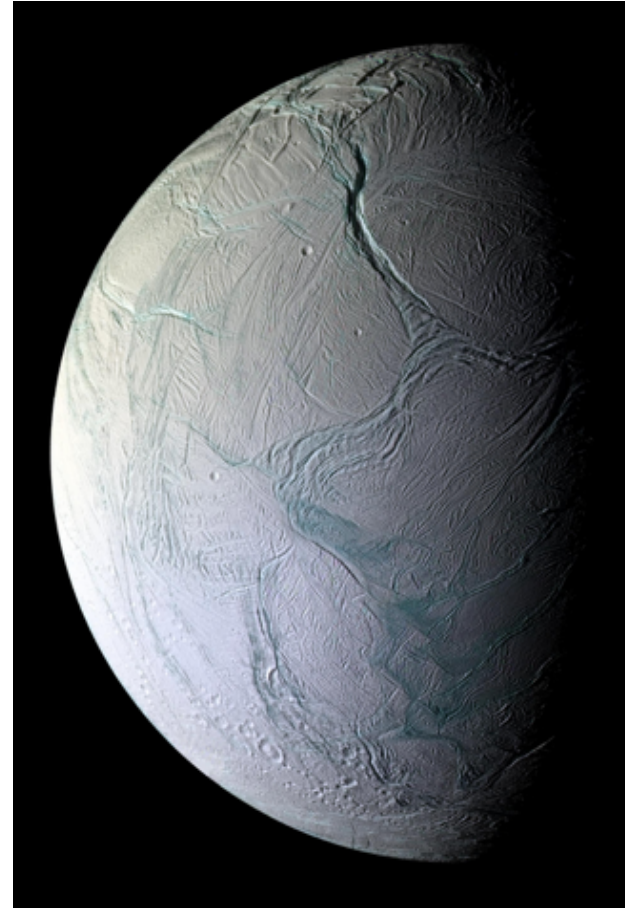
Methane raindrops on Titan would fall slowly (Lorenz 1993)

Sketch of Titan surface processes from Lunine (1990)

Enceladus :

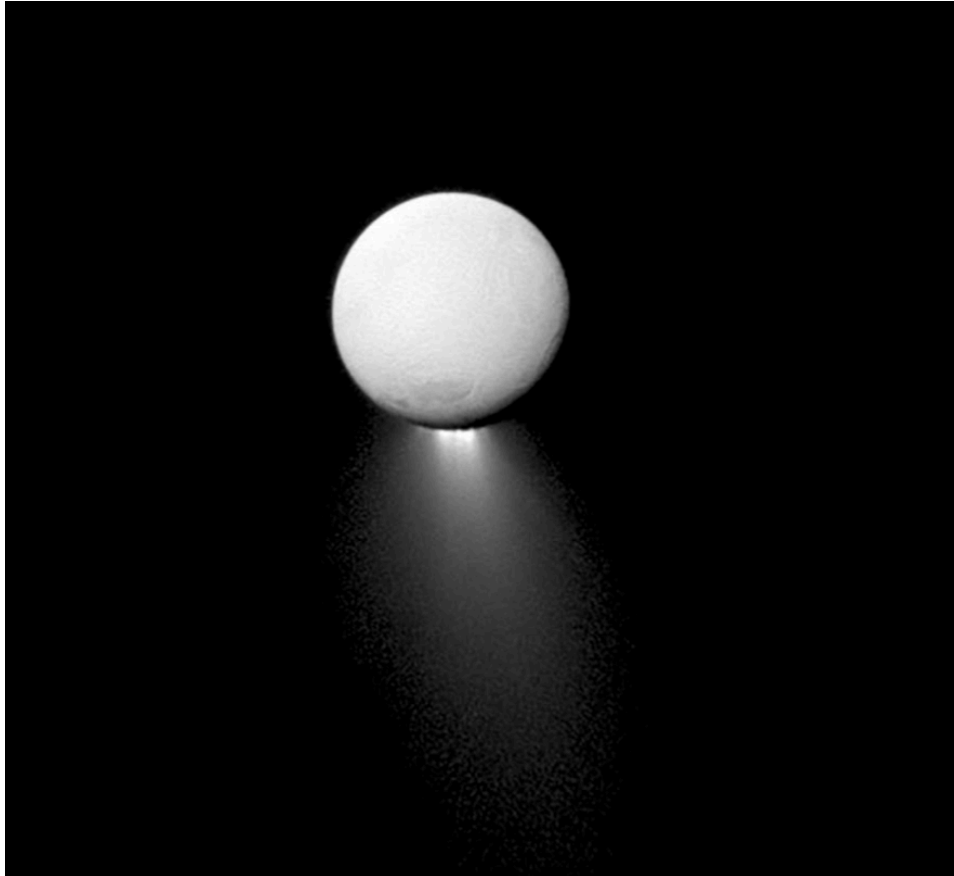


North Pole : Craters



South Pole : Smooth

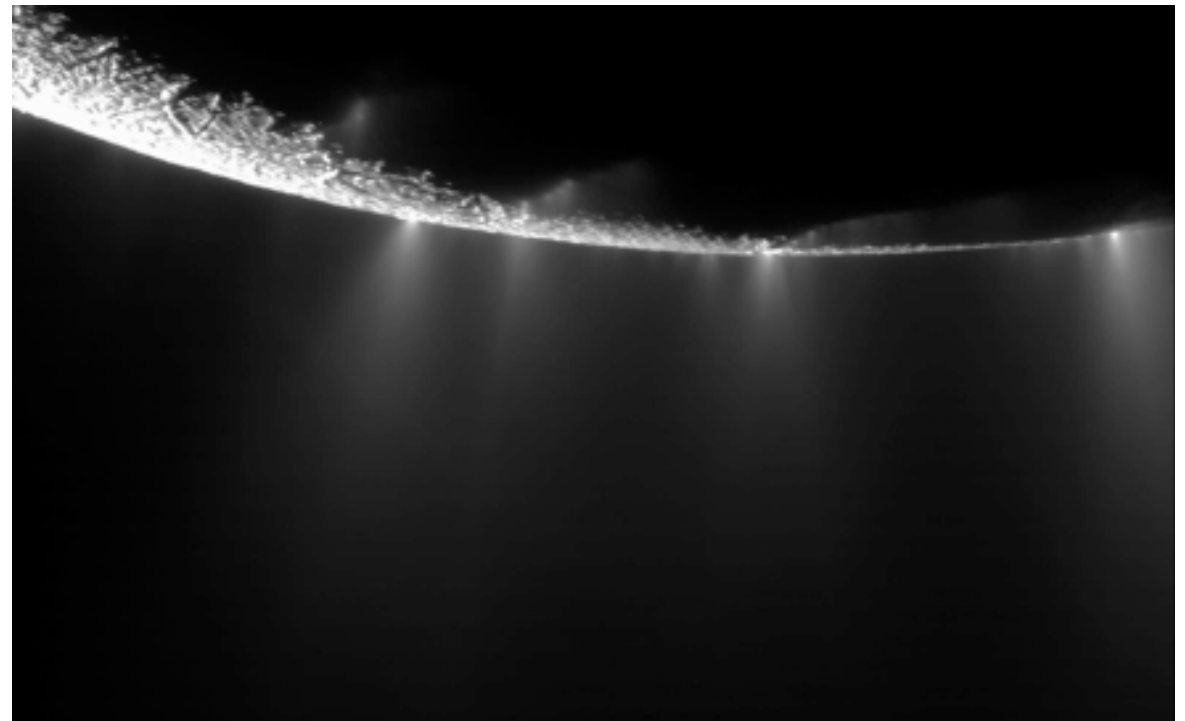
Enceladus : A Big Surprise



'Water Plume'
<Magnetometer>

Feb 2005
Cassini flyby

Jul 2005 confirmed by
Cassini camera team
(CIRS):



Enceladus : An Active World

March 2008:

Water vapor, carbon dioxide, carbon monoxide, organic materials

June 2009:

Salty Evidence for Hidden Water

March 2011:

Heat output

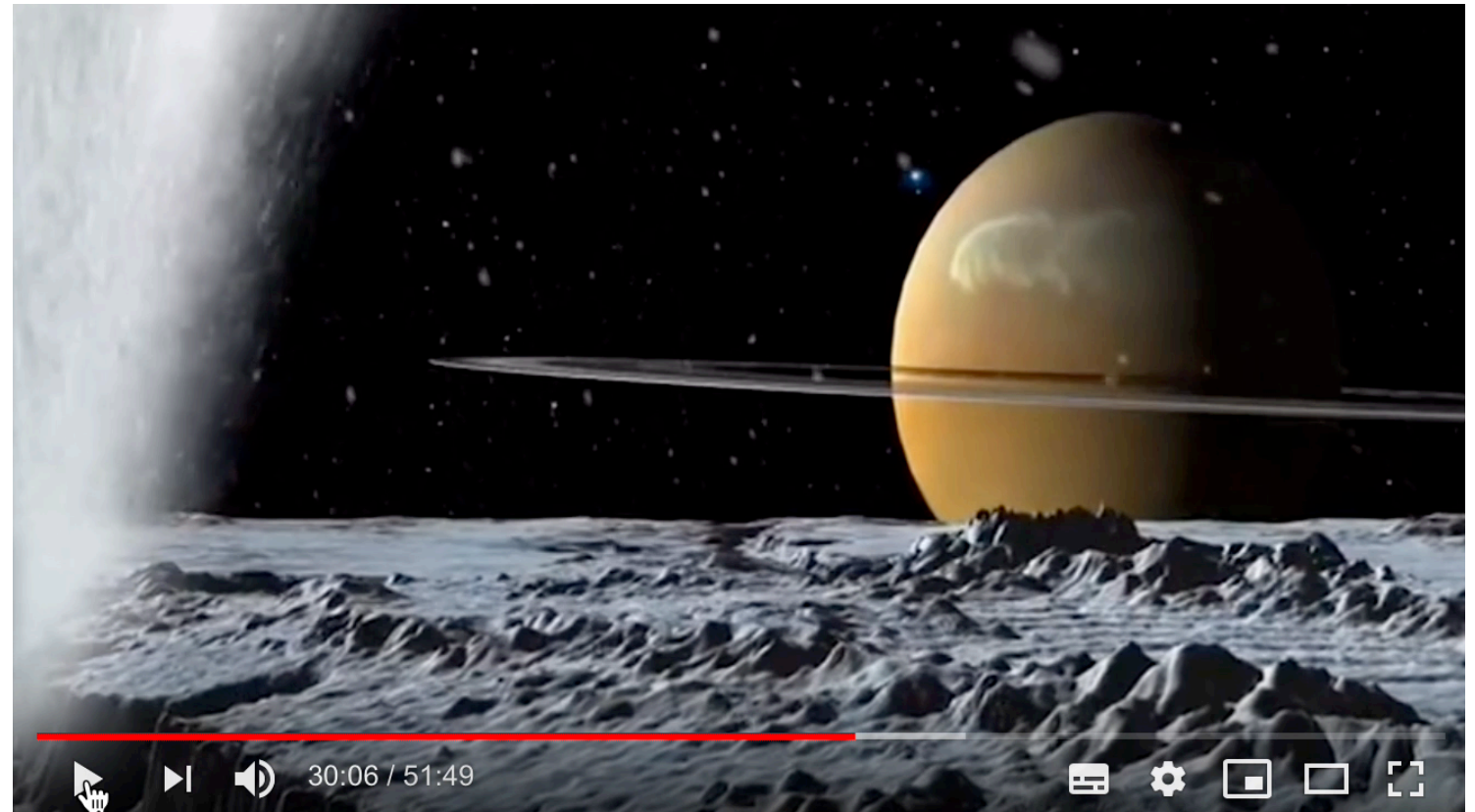
March 2015:

Rock particles rich in silicon

April 2017:

Hydrothermal hydrogen and Potential Habitability

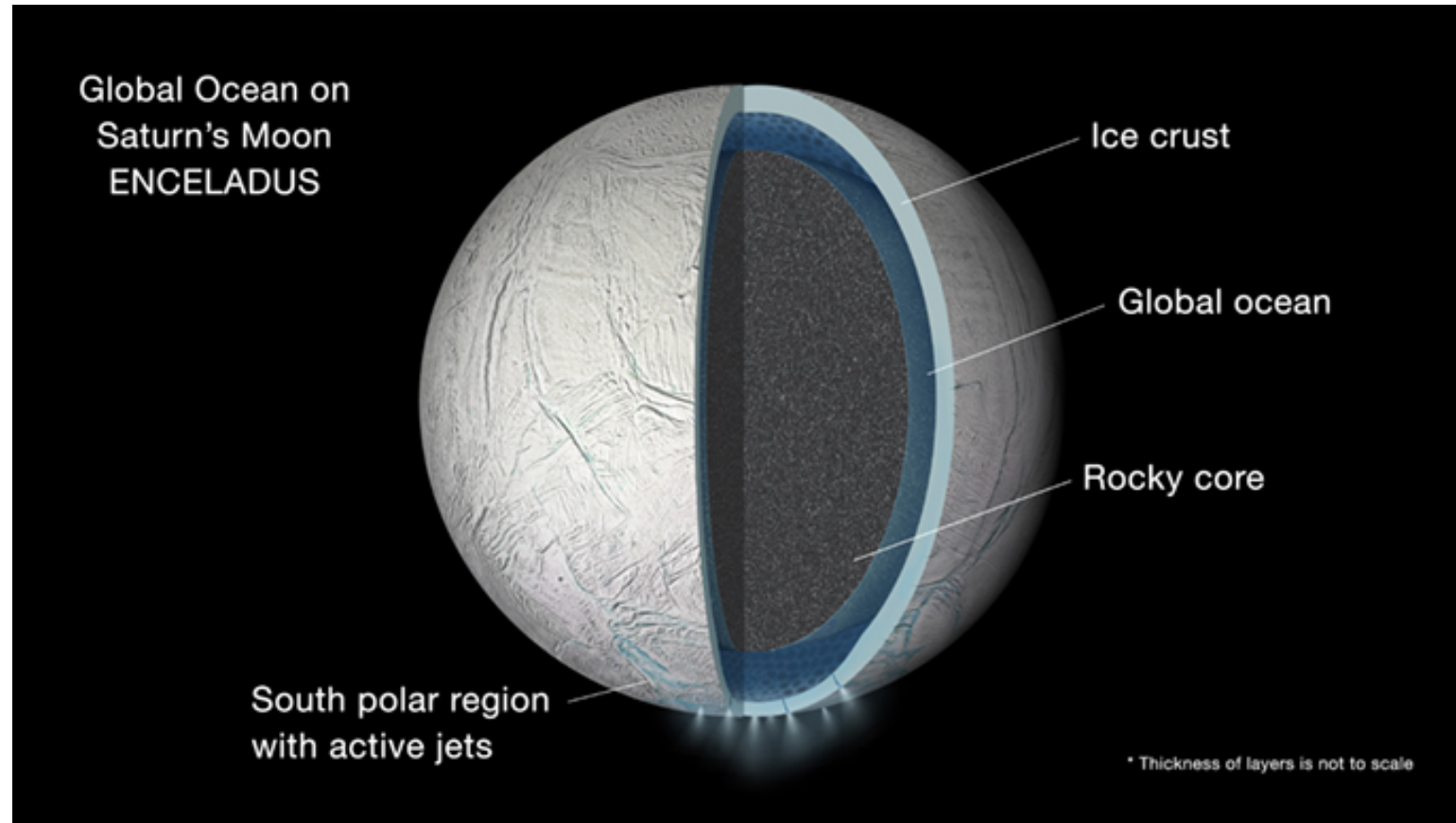
Geysers (间歇喷泉) erupt from the warm fractures.



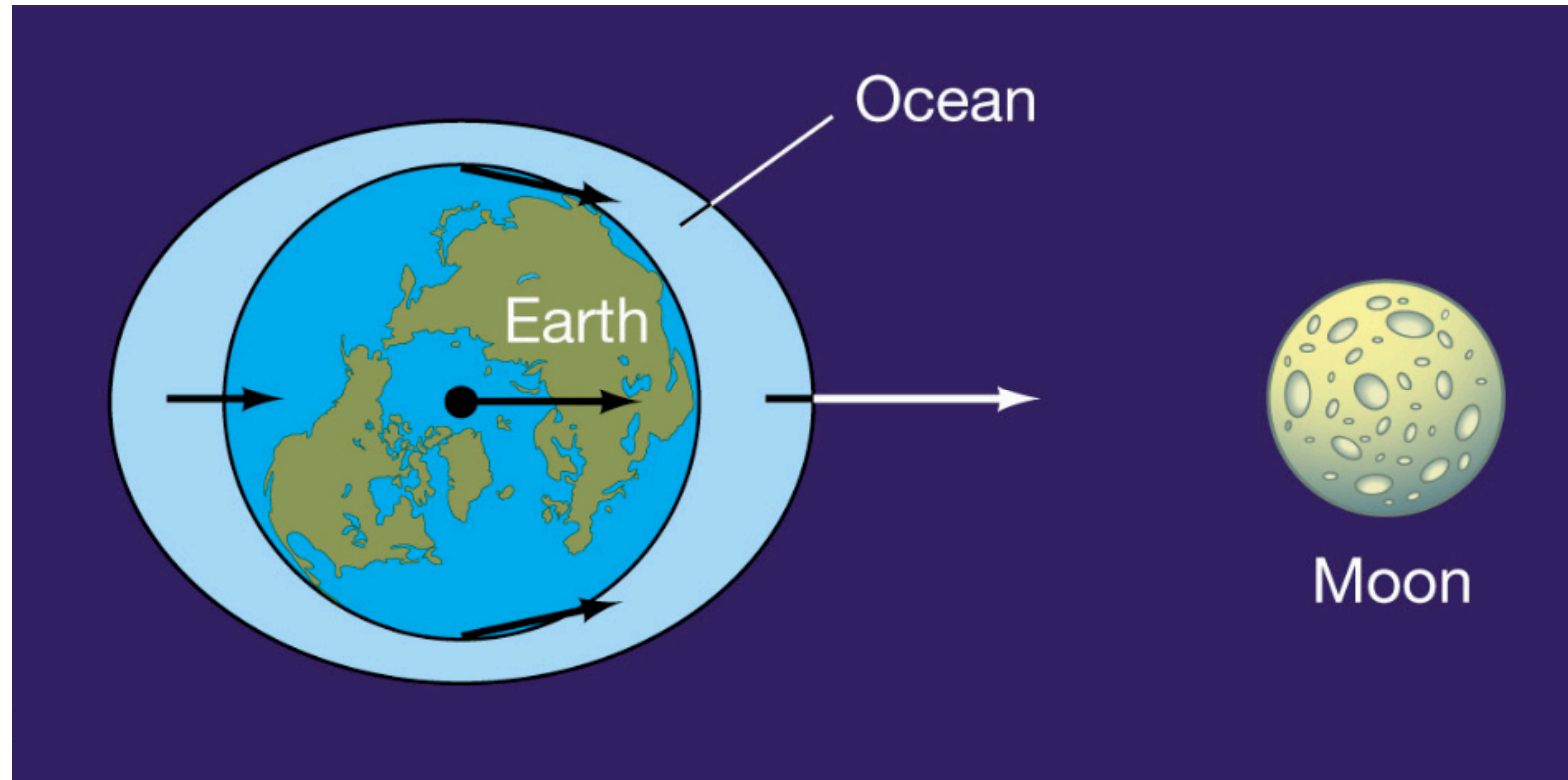
Enceladus : An Ocean Moon

September 2015: A Global Ocean

Slight wobble that can only be accounted for if its outer ice shell is not frozen solid to its interior.

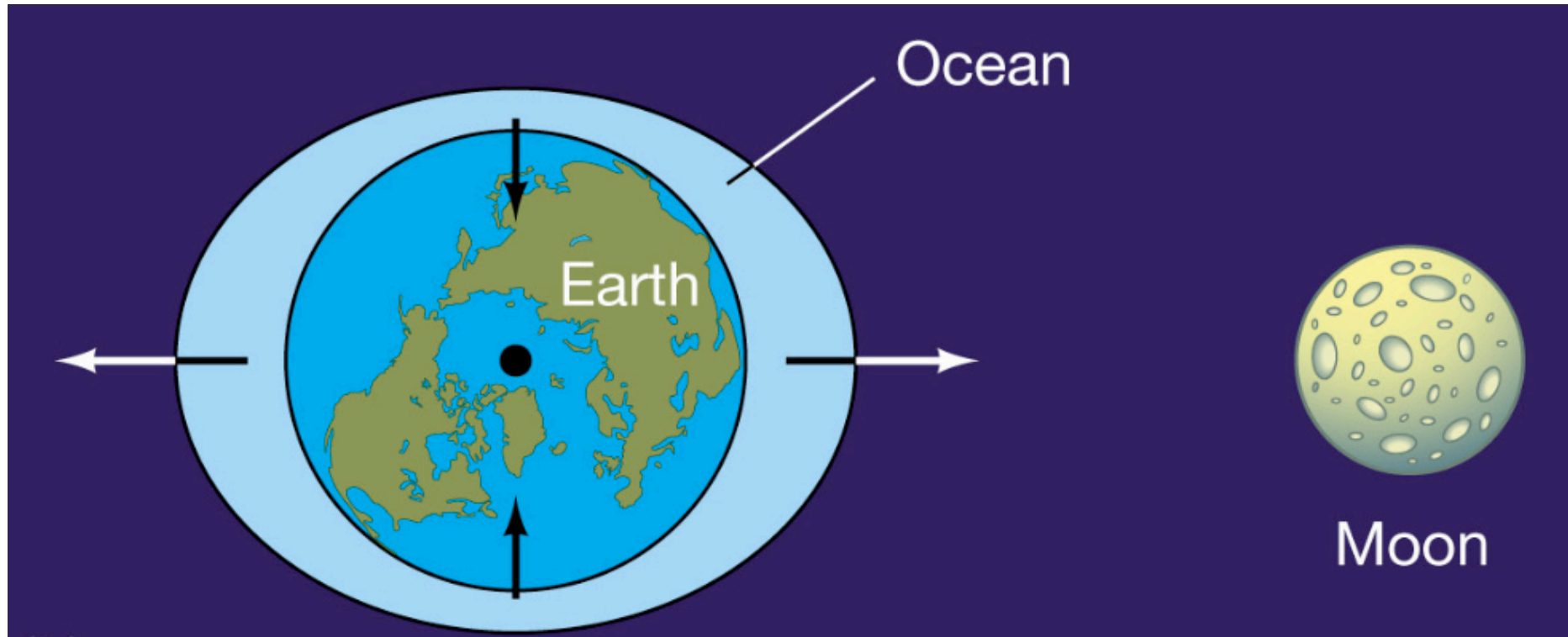


Enceladus : Tidal Friction to Heat



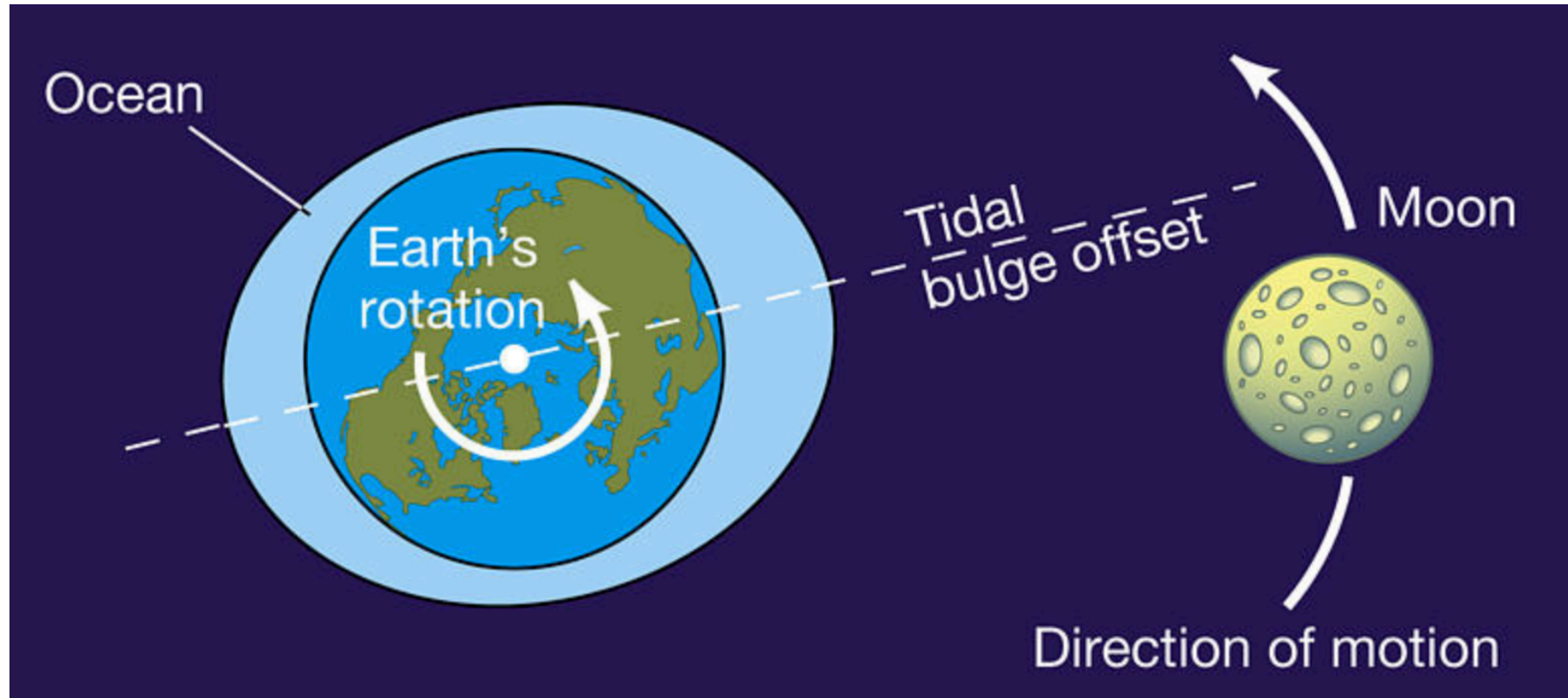
Tidal Force = Differential Gravitational Force

Enceladus : Tidal Friction to Heat



Relative to Earth Center

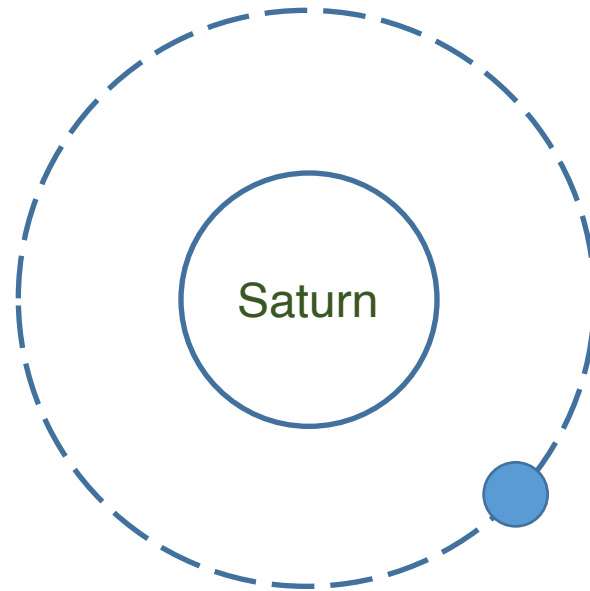
Enceladus : Tidal Friction to Heat



Tidal Friction : torque to lock Earth's rotation to the moon's orbiting period
Moon is migrating due to the tidal torque from the Earth.

Enceladus : Tidal Friction to Heat

● Enceladus

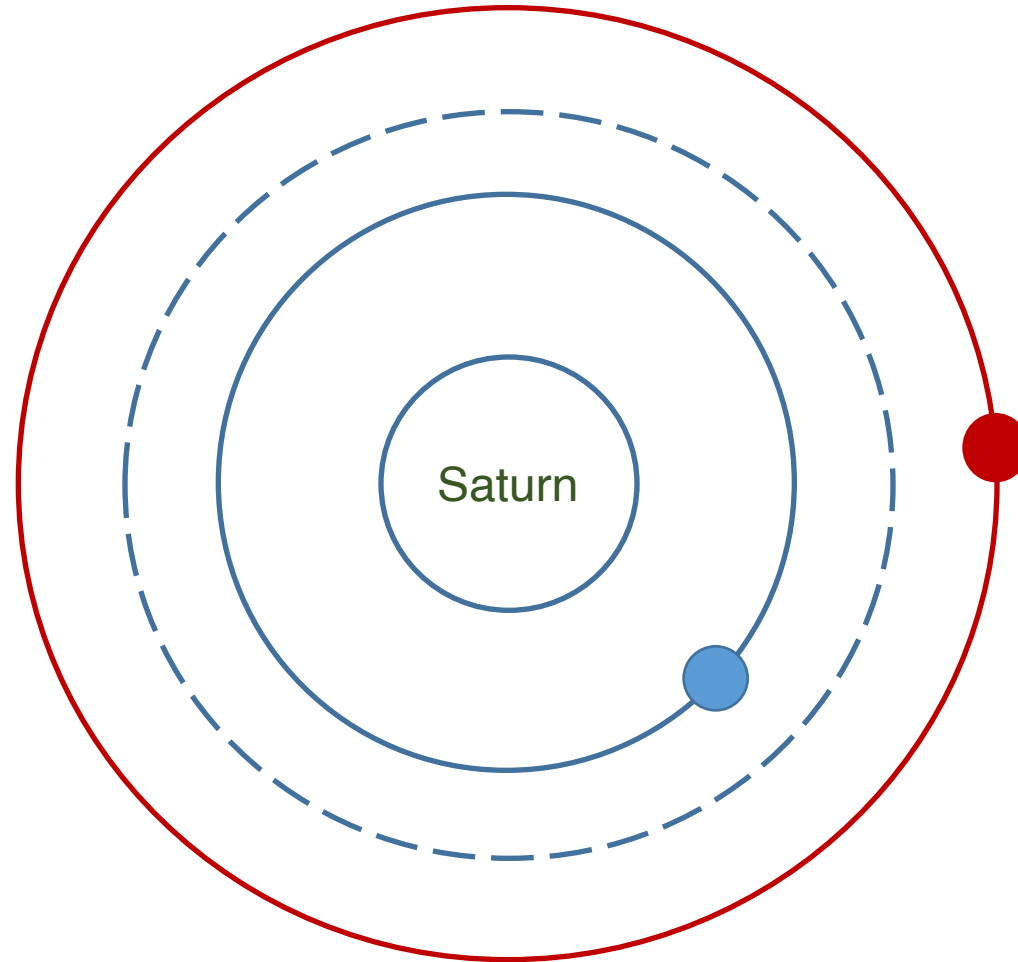


Enceladus is migrating due to the tidal torque from the **Saturn**.

Circular orbit + Synchronous rotation : No tidal heating !

Enceladus : Tidal Friction to Heat

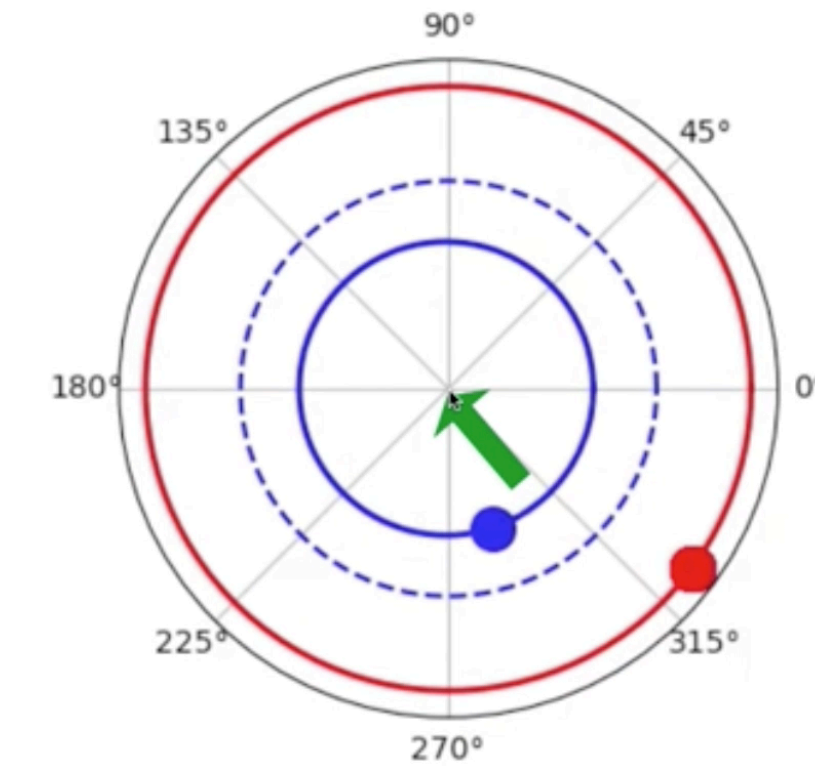
- Enceladus
- Dione



Dione's driving Enceladus orbit eccentric via mean motion resonance interaction.

Enceladus : Tidal Friction to Heat

- Enceladus
- Dione



- Time varying tides ($\sim e$)
- Internal friction tidal heating
- e damping

e : eccentricity

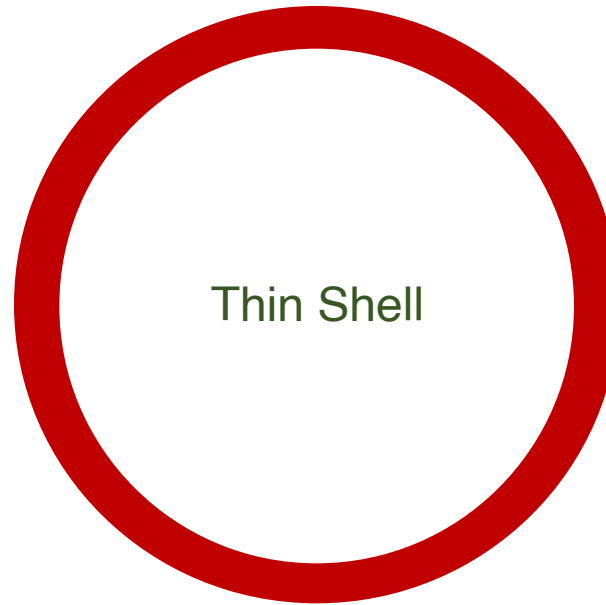
Dione's driving Enceladus orbit eccentric via mean motion resonance interaction.

Enceladus : Tidal Friction to Heat



Thick Shell

Small deformation
Weak heating
Slow e damping



Thin Shell

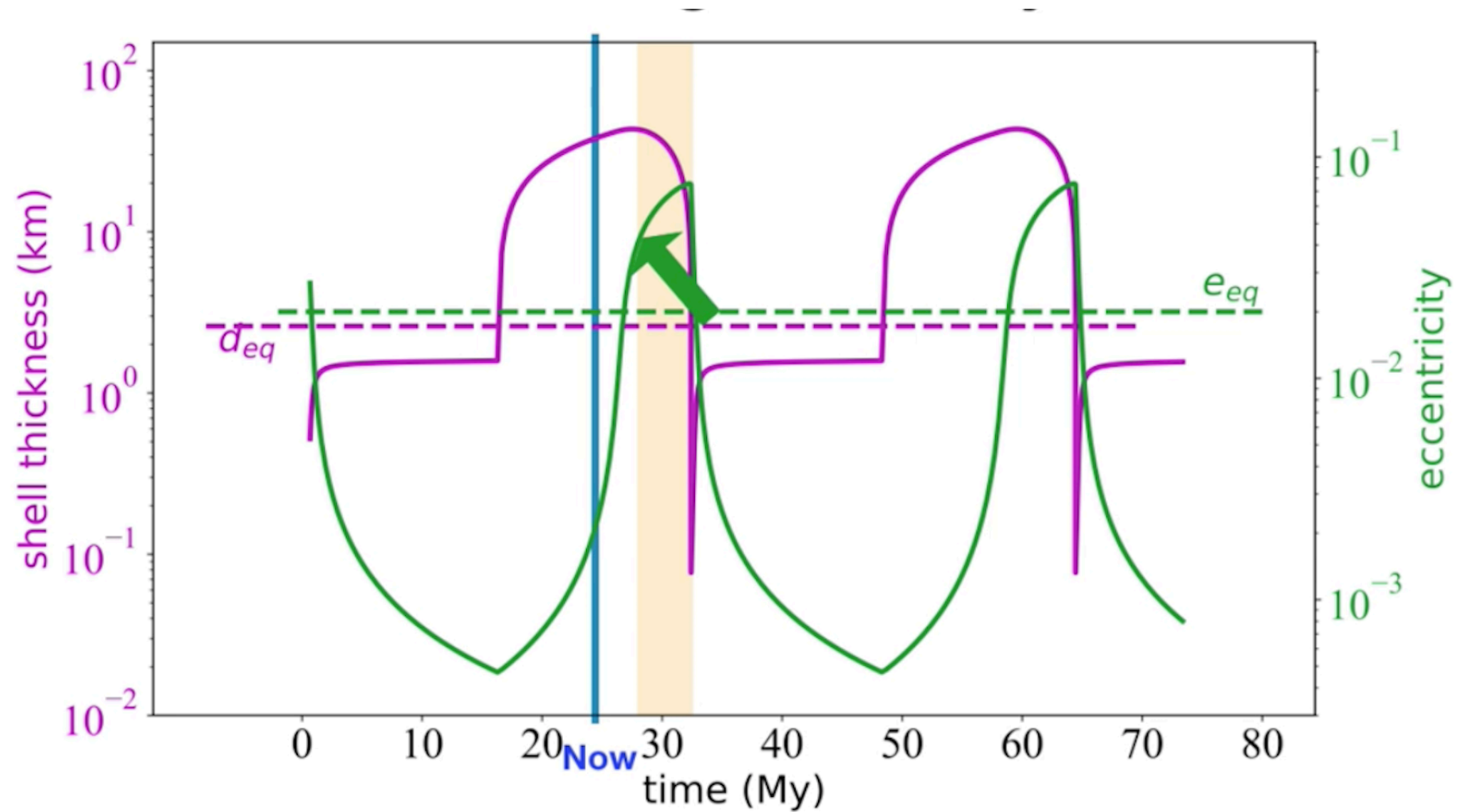
Large deformation
Strong heating
Fast e damping

→ Tidal heating melt the shell, d decreases

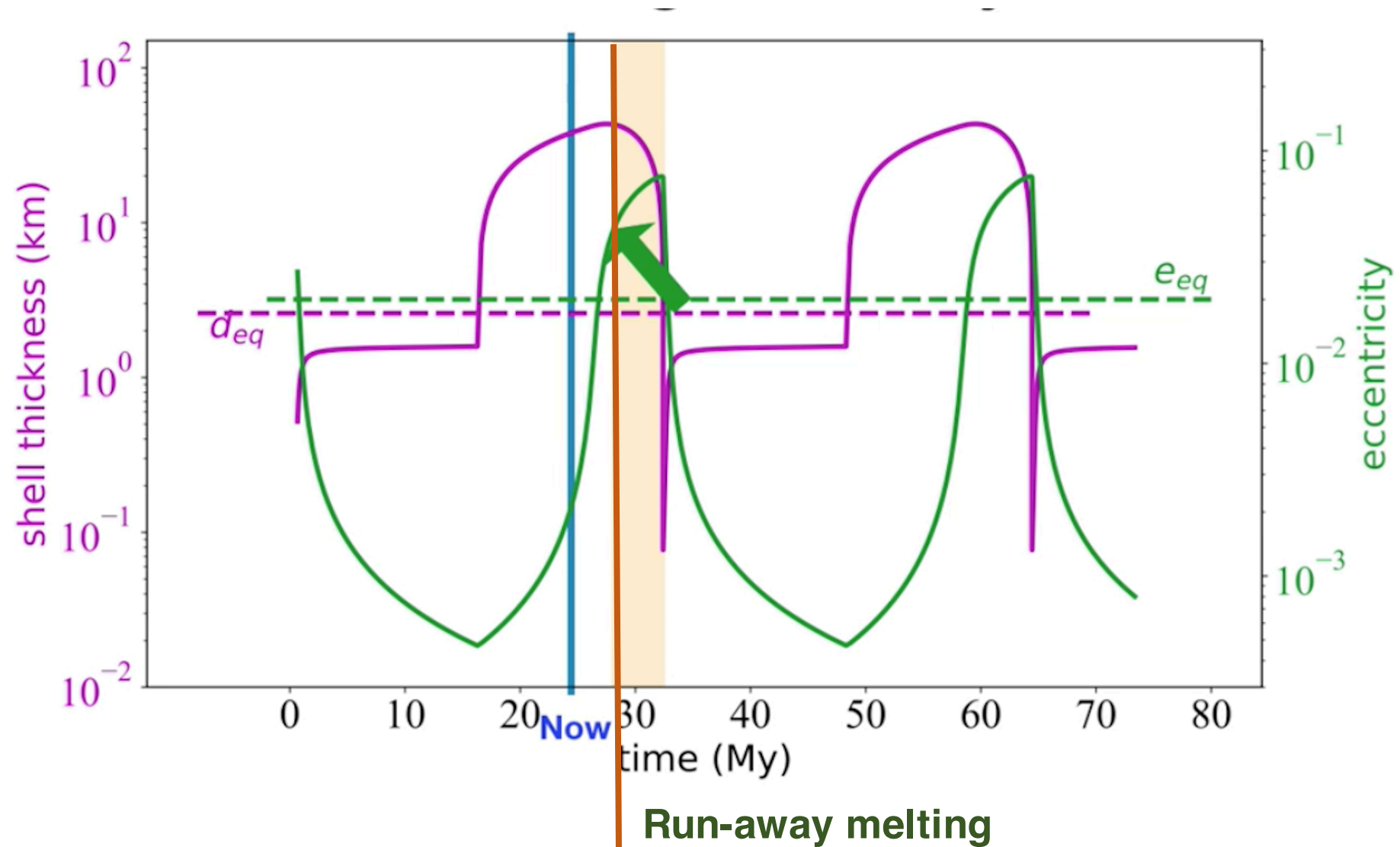
→ Conductive heat loss freeze the shell, d increases

d : thickness of the ice shell

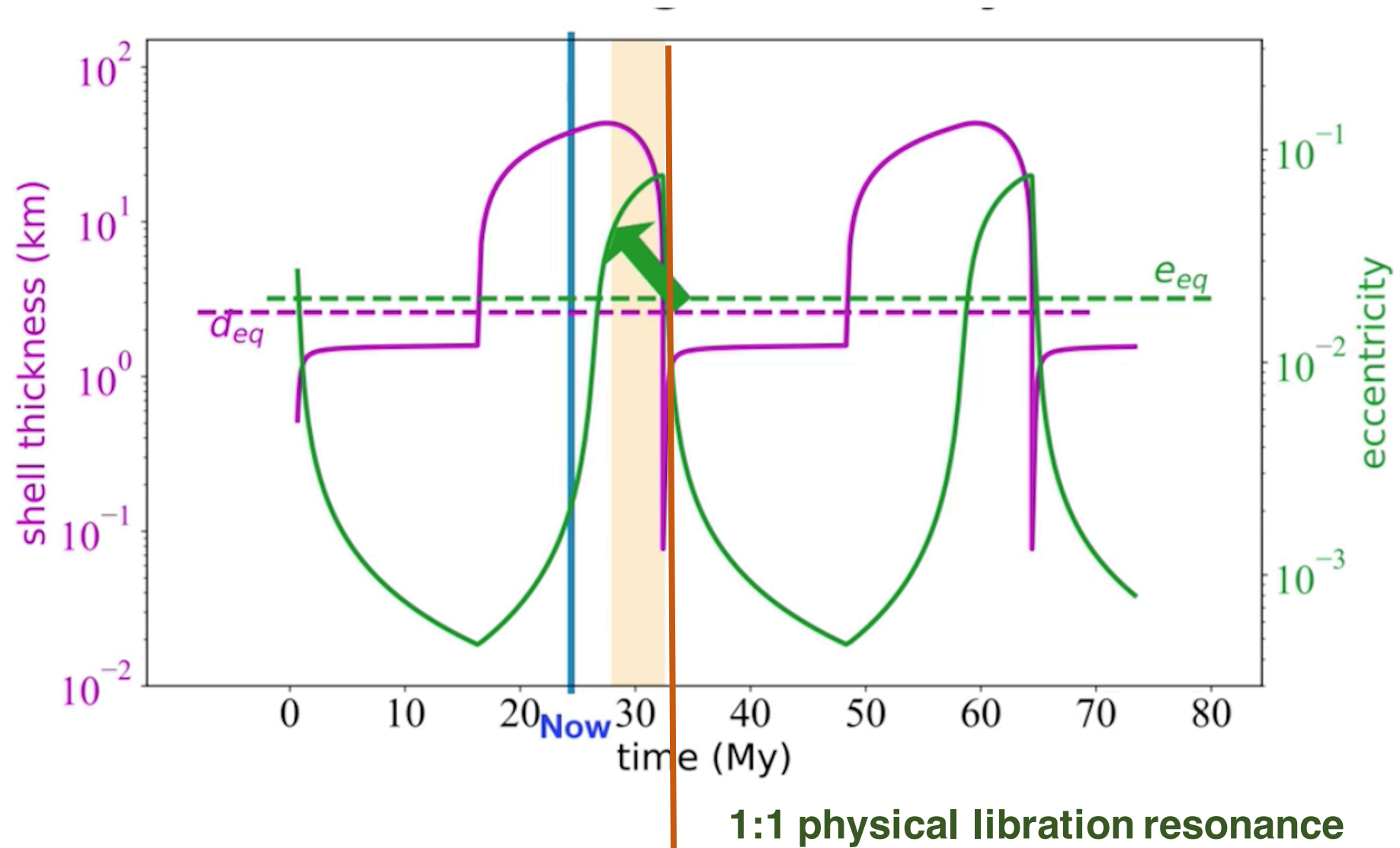
Enceladus : Limit Cycle



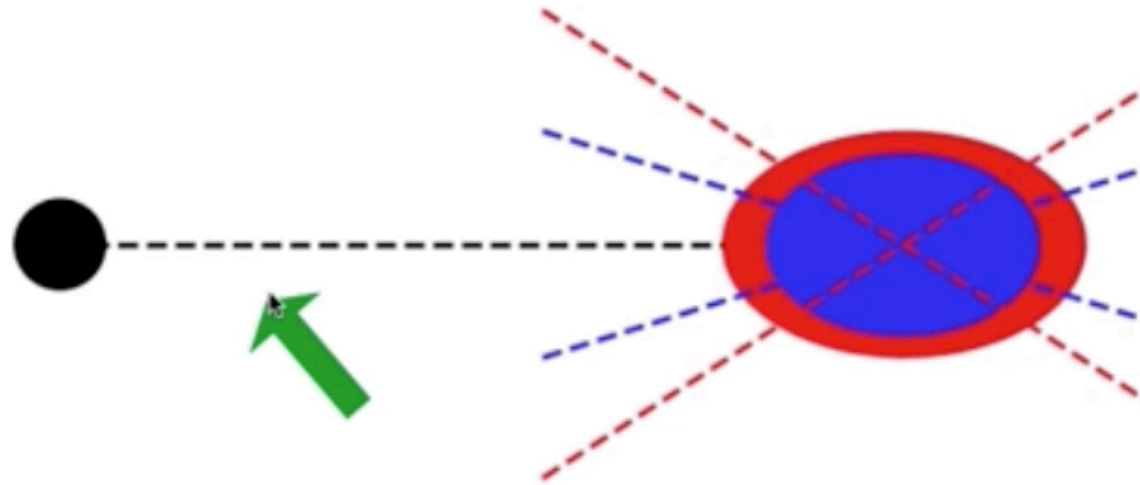
Enceladus : Limit Cycle



Enceladus : Limit Cycle



Enceladus : 1:1 physical libration resonance



Physical libration resonance

Enhanced with interior ocean

More tidal heating and e damping

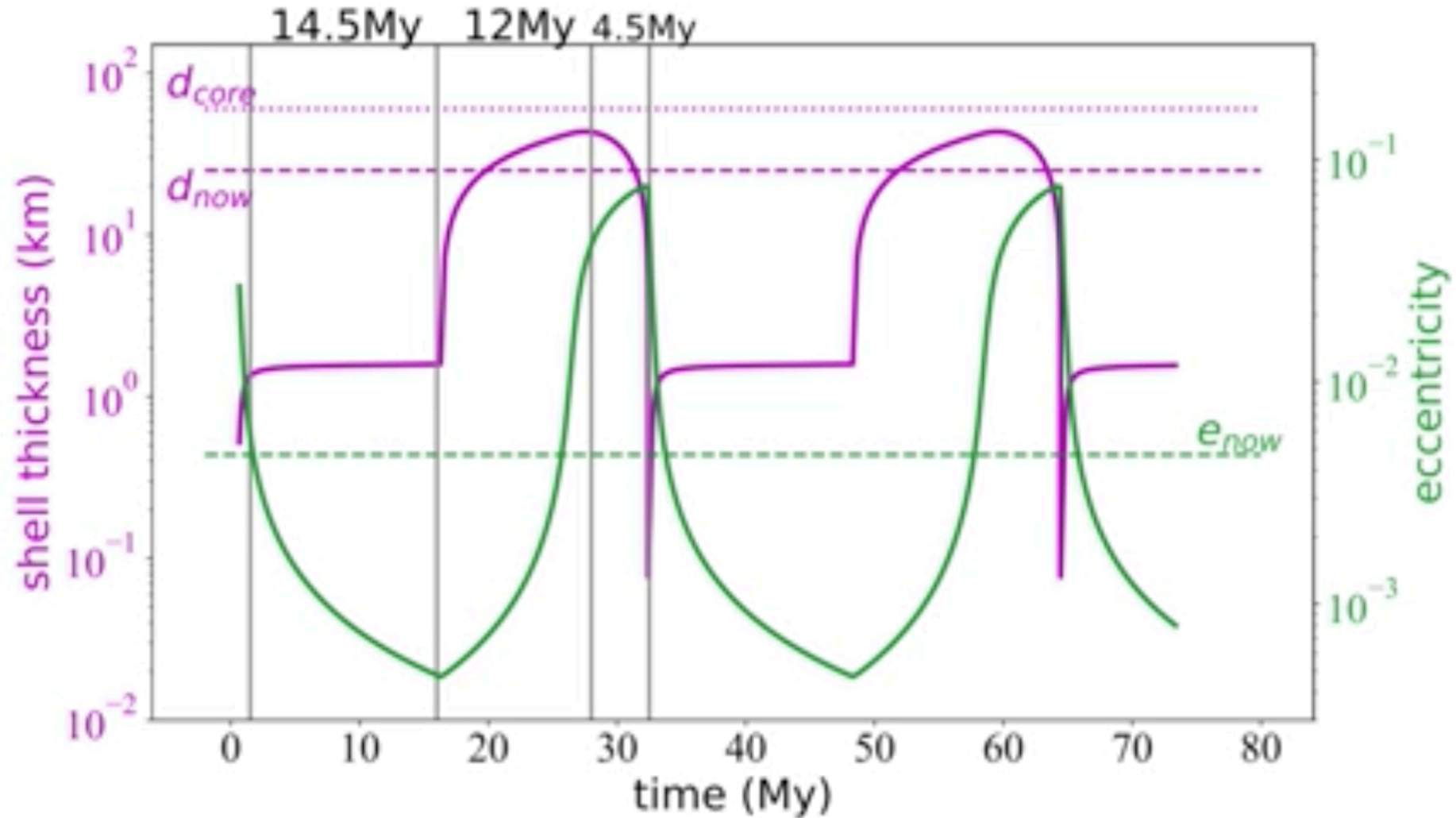
Especially for Enceladus

When $d = 1.5 \text{ km}$

$$\omega_{\text{libration}} = n_{\text{orbit}}$$

1:1 physical libration resonance

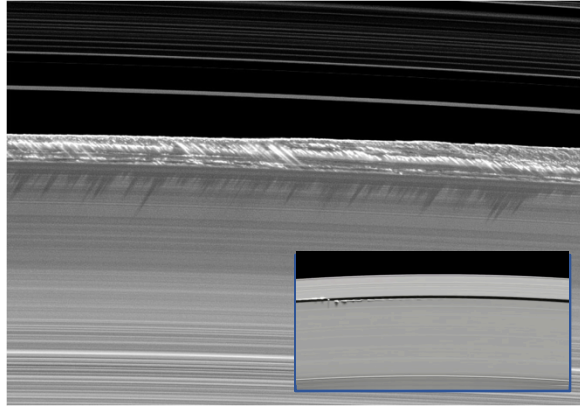
Enceladus : Limit Cycle



Enceladus : E-ring

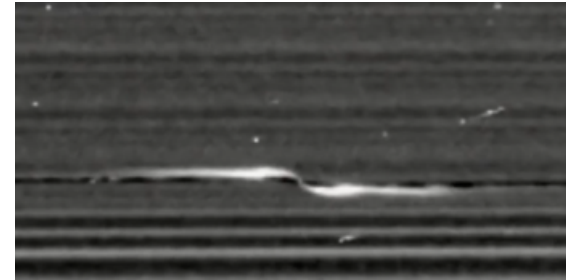


Rings : Astonishing Sub-Structures



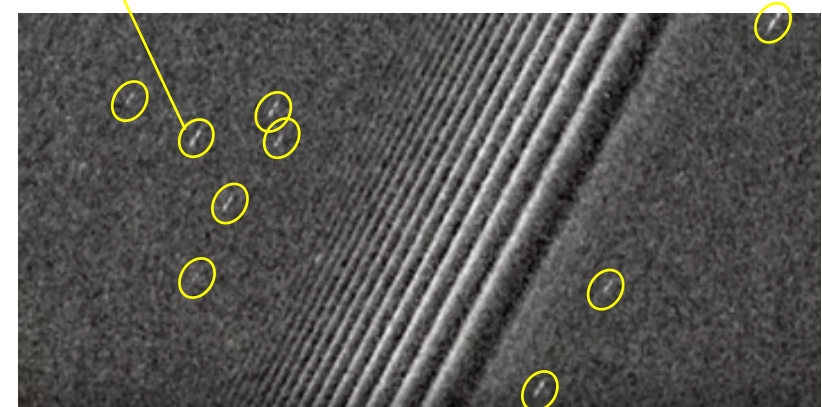
Ring Chunks

Measured miles (kilometers) in size when the sun shadows edge-on.



Propellers

(Tiscareno 2006)



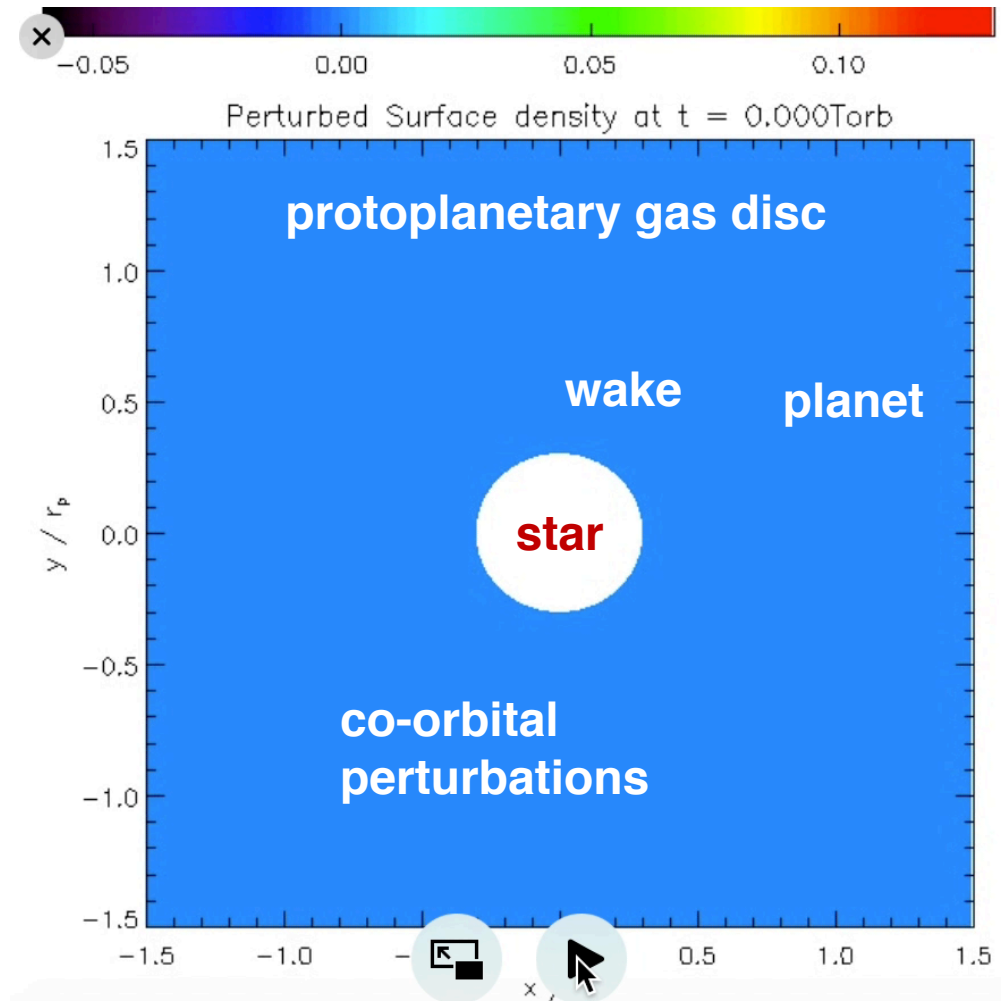
Ring: Very flat instead of being warped, only 10 meters thick.

Rings : Propellers

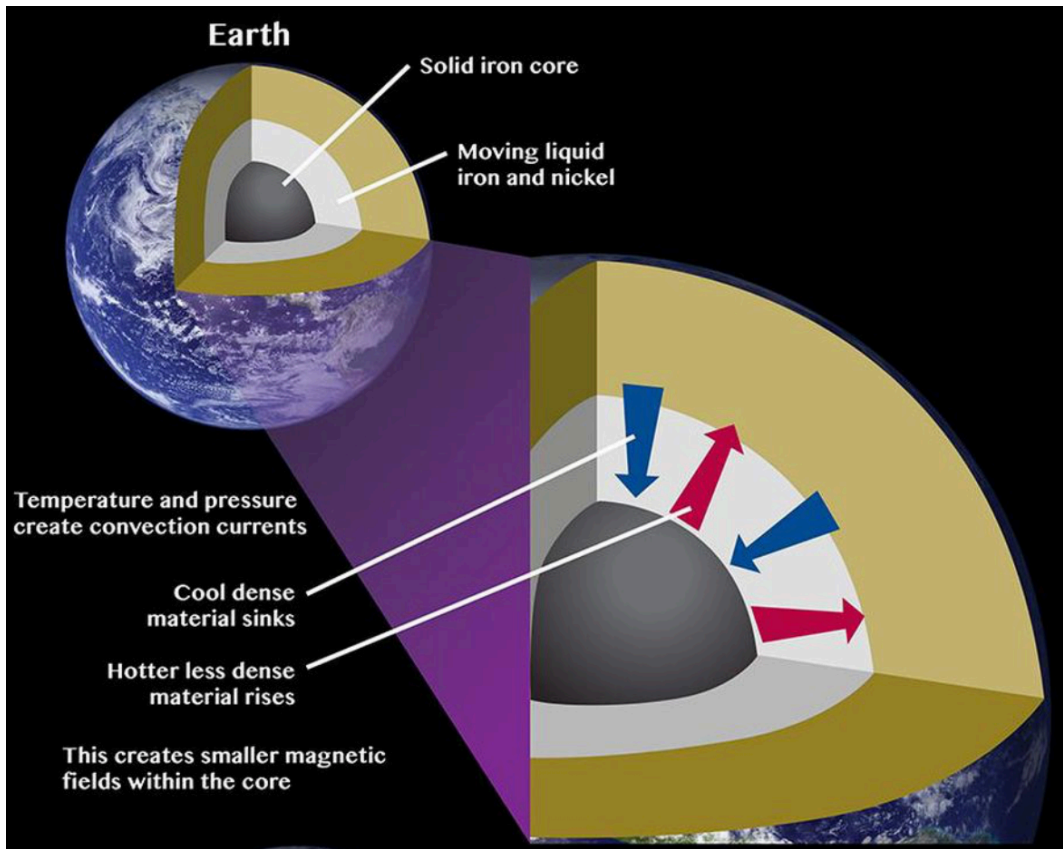
Ring-Moonlet Interaction



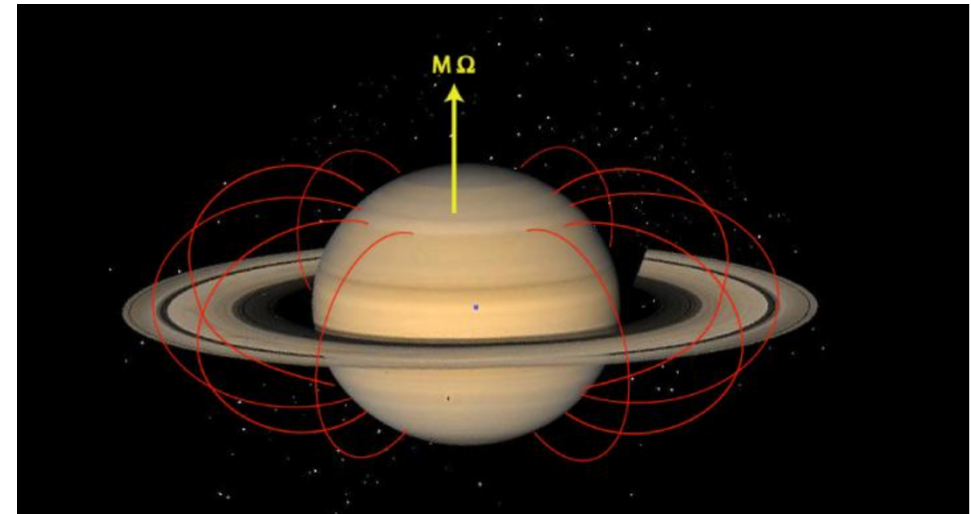
In Analogy with Protoplanetary Disk



Magnetosphere



A tilt of **11.5 degree** between the **Earth field** and its **rotation axis**.

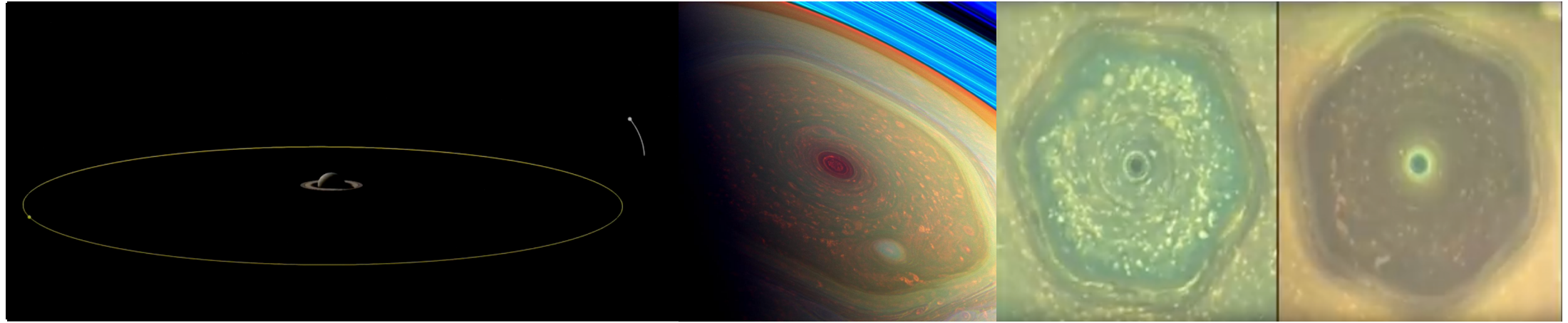


The Saturn field:

Only a **0.06 degree** difference from the rotational axis.

Dying magnetic field ?

Saturn and Cassini's Grant Finale



Cassini dive to Saturn

Royal Crown : Hexagon

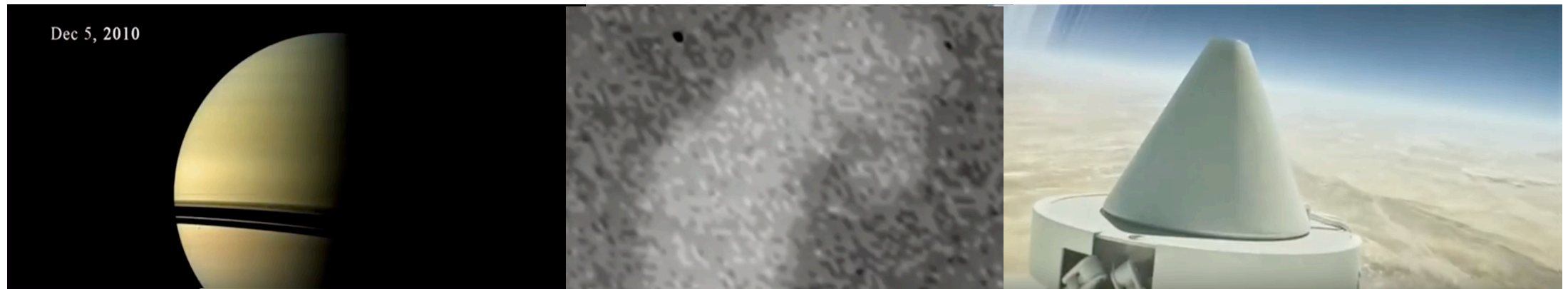
Winter

Summer

Giant Storms

First movie of Lightning
on another planet

Cassini's Grant Finale



Summary

- **Titan (moon)** : Geology and Surface Processes on Titan.
- **Enceladus (moon)** : Surprising observation of hydrothermal vents and ocean underneath the crust.
- **Rings** : Substructure and its relation to proto-planetary disk.
- **Magnetosphere** : Shape and orientation of the magnetic field and its relationship to planet field origin.
- **Saturn** : Many 'firsts' on another planet and Cassini's grant finale.