# CASSINI-HUYGENS 2004-2017

Organic-rich atmosphere and surface

De-coupled icy shell Global subsurface ocean High-pressure ice

Hydrous silicate con

#### N. Altobelli, SSW 10, Aranjuez, 2017

#### 15 September 2017 ~ 5 am Pacific Time



- CASSINI worked 91 s as first Saturn atmospheric entry probe!
- 8.6 deg latitude entry point
- Altitude reached: 1231 km above 1 bar level



#### Cassini in the broader context...

Credit N. Powell, Imperial College

3

2012

Xtra-Si Ierwor

Future Landings

2030

characterisation

JUICE

2004

Exploration

1995

1985

Deep habitats

1974

Insight

1610

Discovery





![](_page_4_Picture_0.jpeg)

# TITAN EXPLORATION HIGHLIGTS

# ICY MOONS AND RINGS

# • THE MYSTERIES BEHIND THE SCIENCE OF THE GRAND FINALE

![](_page_6_Figure_0.jpeg)

## TITAN: Cassini-Huygens has lifted the 'veil'

# How Cassini-Huygens lifted Titan's veil : Huygens, first lander on an outer-planet moon

![](_page_8_Figure_1.jpeg)

# Atmospheric seasonal variations

![](_page_9_Picture_1.jpeg)

ESA/C. Carreau

Equinox

Southern winter

![](_page_10_Picture_0.jpeg)

#### Witnessing a season change...

Large cloud/vortex at South Pole

## Complex atmospheric organic chemistry Nitrogen (~98%), Methane(~2%)

![](_page_11_Picture_1.jpeg)

![](_page_11_Picture_2.jpeg)

# Titan's lakes and 'hydrological' cycle

![](_page_13_Picture_0.jpeg)

![](_page_14_Figure_0.jpeg)

![](_page_15_Figure_0.jpeg)

Evaporation process during Northern Spring – Observations during the Solstice Mission

# Methane rainfalls at equator

![](_page_17_Picture_1.jpeg)

NIEMANN ET AL.: TITAN'S ATMOSPHERE AND SURFACE VOLATILES

![](_page_17_Figure_3.jpeg)

![](_page_17_Picture_4.jpeg)

![](_page_18_Picture_0.jpeg)

## Source of methane: Ice Volcanoes ?

![](_page_19_Figure_0.jpeg)

![](_page_20_Figure_0.jpeg)

# Icy Moons

![](_page_21_Picture_1.jpeg)

![](_page_22_Picture_0.jpeg)

![](_page_23_Picture_0.jpeg)

# "IRREGULAR MOONS"

# Hyperion

# Phoebe

![](_page_24_Figure_3.jpeg)

Ering

![](_page_25_Figure_0.jpeg)

isolated, closed systems  $\rightarrow$  Examples of magnetospheric interactions

![](_page_25_Picture_2.jpeg)

#### ICY MOONS, SATURN AND RINGS ALSO INTERACT DYNAMICALLY

$$\frac{\mathrm{d}a_{\mathrm{s}}}{\mathrm{d}t} = \frac{3k_{2\mathrm{p}}m_{\mathrm{s}}G^{1/2}R_{\mathrm{p}}^{5}}{Q_{\mathrm{p}}M^{1/2}a_{\mathrm{s}}^{11/2}} + \frac{2a_{\mathrm{s}}^{1/2}\Gamma_{\mathrm{s}}}{m_{\mathrm{s}}(GM)^{1/2}}$$

Keeler Gap

Encke Gap

Colombo Gap

DC

Maxwell Gap

Creation of waves and gaps in the rings

 $\bigcirc$ 

Saturn's and rings rotational energy is transferred via tidal torques to the moons in the form of orbital energy (moons' orbits expand) and heat (internal friction)

#### TN FACT, MANY OF THE ICY MOONS MAY BE BORN FROM THE RINGS...

Highest spatial resolution obtained during the Ring Orbits – Summer 2017

RING VISCOUS SPREADING MEETS ROCHE DISTANCE → RING LOOSES MATERIAL→ FORMATION OF MOONS

![](_page_27_Figure_4.jpeg)

![](_page_28_Figure_0.jpeg)

RINGS AND ICY MOONS (UP TO RHEA )- MAY BE GENETICALLY LINKED-MOONS THEN MIGRATE OUTWARD AND CONFINE THE RING WITHIN ITS ROCHE LIMIT

# Tital energy transfer from Saturn fuels Enceladus activity

![](_page_29_Picture_1.jpeg)

![](_page_29_Picture_2.jpeg)

80

atomic mass

150

H<sub>2</sub>O CO<sub>2</sub> N<sub>2</sub> CH<sub>4</sub> CO 91 ± 3 % wt. 3.2 ± 0.6 % wt. 4 ± 1 % wt.\* 1.6 ± 0.4 % wt. < 0.9 % wt

 $NH_3$ , HCN,  $C_2H_2$ ,  $C_3H_8 < 0.5$  % wt. (*i.e.*, detected)

10

+ Nano-silicates + H2

Hydrothermal activity at the Ocean-Core interface of ENCELADUS potentially on-going for billions of years...

![](_page_30_Picture_1.jpeg)

#### Choblet et al, 2017

(Porous) core dissipation simulated for the first time

![](_page_30_Picture_4.jpeg)

#### ENCELADUS

![](_page_30_Picture_6.jpeg)

# The Science of the Grand Finale Mission

**RINGS AND UPPER ATMOSPHERE** 

SATURN'S INTERIOR, AND MAGNETIC FIELD

#### How did the ring form ?

#### What is the mass of the ring ?

Cassini Division

Α

#### What is the ring composition ?

D

Is the ring material flowing into Saturn's atmosphere?

# SATURN GRAND FINALE OBJECTIVES (MAG)

![](_page_33_Picture_1.jpeg)

Determine magnetic field moments to:

- Get Saturn's internal rotation rate from tilt of the magnetic field
- determine how deep the magnetic dynamo region lies

# SATURN GRAND FINALE OBJECTIVES (RADIO SCIENCE GRAVITY)

- Determine gravity field moments (up to J10) to:
  - estimate size of Saturn's rocky core (the seed that attracted all the gas as Saturn was forming)
  - measure the depth of Saturn's winds
  - Ring Mass

![](_page_34_Picture_5.jpeg)

# THE PROBLEM WITH SATURN'S PERIOD OF ROTATION AND MAGNETIC FIELD

![](_page_35_Figure_1.jpeg)

## Saturn's Kilometric Radio Emission...

![](_page_36_Figure_2.jpeg)

## ...not a good proxy to infer Saturn's interior rotation!

![](_page_37_Figure_1.jpeg)

# **NEW RESULTS from Grand Finale Orbits**

- The magnetic B field appears still perfectly aligned with the rotation axis (within 0.06 deg) → We still cannot determine Saturn's interior rotation rate
- The inner core mass of Saturn was measured to be 15 Earth masses
- The interior of Saturn appears to be made of multiple layers with different rotation rates, extending deeper than expected

# THE PROBLEM WITH THE RING AGE , ITS MASS AND COMPOSITION

![](_page_39_Picture_1.jpeg)

# **RING EVOLUTION...**

Non-elastic collisions remove orbital energy but conserve angular momentum

- → Precursor debris 'cloud' **flattens** and **spreads** toward lowest energy level
- → Spreading time and initial mass are linked the current mass was UNKNOWN (before Grand Finale)
- → Erosion + pollution by micro-meteoroids the current flux was UNKNOWN (before Cassini)

![](_page_40_Figure_5.jpeg)

![](_page_41_Picture_0.jpeg)

![](_page_41_Picture_1.jpeg)

IR thermique

#### **RING COMPOSITION**

(Before Grand Finale) –Rings appeared to be made of nearly pure water ice...

![](_page_41_Picture_5.jpeg)

# ➡ So, possible old ring scenario ? (Canup, Nature, 2010)

![](_page_42_Figure_1.jpeg)

micro-meteoroids

# **NEW RESULTS including Grand Finale Orbits**

 The mass of the ring was found to be about ¼ Mimas mass

- The ring composition shows a significant silicate fraction
  (Passive radar data and in-situ sampling)
- The current micro-meteoroid flux erodes the rings within a short timescale preventing the old ring scenario
- Methane found in the upper atmosphere of Saturn, originating from the ring!

→ All new data are consistent with young ring scenario (captured massive body, tidal break-up)

![](_page_43_Figure_6.jpeg)

![](_page_44_Picture_0.jpeg)

# QUESTIONS ?

![](_page_44_Picture_2.jpeg)