Rings, Moons and Water-Worlds

Cassini investigates Saturn‘s spectacular moon Enceladus

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Pictures: NASA / JPL

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Our Analytical Lab at Saturn: Cassini-Huygens

The Cassini-Huygens space craft:

- size: 6.7m x 4 m
- mass: 5700 kg (2500 kg dry)
- launch → arrival Saturn: Okt 1997 → Jun 2004
- mission end: ~ Sept. 2017
- 11 scientific instruments
- 3-axis stabilized
Our Analytical Lab at Saturn: Cassini-Huygens
Saturn's Satellites and Ring Structure

All bodies are to scale except for Pan, Atlas, Telesto, Calypso, and Helene, whose sizes have been exaggerated by a factor of 5 to show rough topography.
Enceladus
Icy Jets of Enceladus
Cassini Flyby 14 July 2005
closest approach: 270 km
Enceladus properties

- **Diameter:** \( D = 502 \text{ km} \)
- **Density:** \( \rho = 1610 \text{ kg/m}^3 \)
- **Rocky core:** \( D \sim 330 - 400 \text{ km} \)
- **Temperature:**
  - \( T_{\text{Aequator}} \approx 75 \text{ K} \)
  - \( T_{\text{Tiger Str.}} \approx 190 \text{ K} \)
- **South polar emission:** \( > 15 \text{ GW} \)
- **Energy sources:**
  - **Radio activity:** \( < 0.5 \text{ GW} \)
  - **Tidal forces:** \( \sim 1.0 \text{ GW} \)

\( \rightarrow \) no steady state possible!
Plume properties

- gas emission: 150 - 250 kg/s
- gas speed: ~ 400 – 1500 m/s
- ratio: gas/icy dust: ~ 2 - 5
- dust particel size: 0.001 – 10 μm
- dust particle speed: 10 - 300 m/s
- escape speed: ≈ 230 m/s

⇒ gas- and dust flux are decoupled
⇒ 0.5% - 5 % escapes and forms Saturn’s E-ring (~1 kg/s)

- relatively steady emission over years
- matter emitted by Enceladus dominates Saturn’s environment even beyond Titan!
Composition

- **Gas phase:**
  - H$_2$O: $> 92\%$
  - CO$_2$: $\sim 0.5 - 5\%$
  - volatile organics: $\sim 1 - 3\%$
  - NH$_3$: $\sim 1\%$
  - CO: $< 3\%$
  - N$_2$: $< 0.5\%$
  - Na: $< 0.0001\%$

- **Surface (from IR-spektroscopy):**
  - almost the entire surface is pure water ice
  - exception: CO$_2$ inclusions and traces of organic material at the Tiger Stripes
Since when is Enceladus active?

Estimate:

- from E ring profile
- active since > 1000 Jahren
- from „depth of snow“

Kempf et al., Icarus 2009
Since when is Enceladus active?

- snow layer > 100 m more than 100 km away from sources
- requires activity of > 10,000,000 years
clathrate decomposition

- volatile gases are suddenly “set free” and drag along ice particles
- H₂O forms from sublimation of entrained ice particles

sublimation of warm ice

- H₂O gas
- icy particles from through recondensation from vapour

water reservoir(s)

- slow evaporation
- ice particles from frozen spray (aerosols)
- … and vapor condensation

“boiling” water

- fracture exposes liquid suddenly to vacuum
- explosive boiling produces H₂O gas, liquid, and particles
Chemical and Dynamic Characterisation of Saturn’s Dust Environment: Cosmic Dust Analyser (CDA)
CDA measurements of E-Ring populations
Postberg et al. (2008, 2009)

- ~ 90% of E ring spectra show almost pure water ice
- \((H_2O)_nH^+\) cluster from defining pattern \(\rightarrow\) pattern strongly varies with impact velocity
CDA measurements of E-Ring populations
Postberg et al. (2008, 2009)

- \( \sim 6\% \) of all E ring Spectra

**Type III - Spectrum**

- \((\text{NaOH})_n\text{Na}^+\) cluster indicate strongly enhanced Na abundance \((\text{Na}/\text{H}_2\text{O} > 10^{-3})\)
- \((\text{NaCl})_n\text{Na}^+ + \text{Na(}\text{Na}_2\text{CO}_3\text{)} \text{ Na}^+\) cluster:
  - \(\text{NaCl} + \text{NaHCO}_3 / \text{Na}_2\text{CO}_3\) are the Na bearing compounds
- K-salts at much lower concentration
Reproduction of CDA spectra in the laboratory

- Simulation of impact-ionisation:
  - IR-Laser on μm water droplets
  - High-res TOF mass spectra
  - Test with different salty solutions

**Best Fit:**

- NaCl: 0.1 - 0.2 M/L
- NaHCO₃: 0.05 - 0.1 M/L
- pH: ~ 8.5
- Na/K: ~ 100
98% ice, 1 - 2% salts

- NaCl, NaHCO₃ / Na₂CO₃, KCl

- Saltwater with alkaline pH (8 – 9)

- Exactly these components were predicted for an Enceladus Ocean! (Zolotov, GRL 2007)
CDA measurements at close encounters

Postberg et al. (2011)
before closest approach: increase of percentage of salt rich particles

Maximum ~5 s after closest approach

salt rich fraction goes down again

CDA measurements at close encounters

Postberg et al. (2011)
CDA measurements at close encounters
Postberg et al. (2011)

- salt-rich particles are larger and heavier than salt-poor particles
- heavy particles \( \rightarrow \) lower ejection speed \( \rightarrow \) populate plumes preferably closer to the surface
A compositionally stratified plume

Enceladus preferably produce salt-rich grains

liquid water (not ice) must be the main source
How salt-rich particles form?

**Vapor**
- $H_2O$

**Liquid**
- $H_2O + NaCl$

**Aerosol water droplets**
- Gas bubbles

**Ice**
- Na$^+$, Cl$^-$, HCO$_3^-$, CO$_3^{2-}$, K$^+$

**Water**
Bursting Bubbles
(Lhuissier and Villermaux, PHYSICS OF FLUIDS 21, 091111 (2009))
How salt-rich particles form?