The Cassini/Huygens Mission to SATURN

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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

- (*1629, †1695)
- interpretation of Saturn’s ring
- discovery of the large moon titan (1655)
GIOVANNI CASSINI

- (*1625, †1712)

- discovery of 4 Saturn moons and the ring division
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.

Not shown:
- Pan: 2.22 Rs
- Atlas: 2.28 Rs
- Prometheus: 2.31 Rs
- Pandora: 2.35 Rs
- Hyperion: 20.3 Rs
- Hyperion: 24.6 Rs
- Iapetus: 59.1 Rs
- Phoebe: 214.9 Rs

E Ring
- Thickness (FWHM) 30,000 km
- Ring
- Mimas
- Enceladus
- Tethys
- Dione
- Rhea

This graphic is available in color if required.
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, 5\times 10^{12} \text{ 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

• 비행대회 모나항방대회 다녀와서니야래시 • 방책비 • 오메파合法性대도파 • 파당해 • 사마타리페상

• 중 이야기 비행대 대자비모 • 음영피비 • 홍배파 • 뽀리

• 대방대비 • 방대가니라자애 • 사매지고방대신 • 오나하나가지

• 나방대비 • 음병 • 방지방대항방대대 • 조호 • 오다

• 비아방 • 음병 • 방고리 • 나방대신 • 방방바 • 미치바 • 방바 • 나방대신

• 나방대방대신 • 오 방대 • 방자비 • 오대 • 사매고 • 나방대신 • 방자바 • 나방대신

• 비로나비 • 음병 • 방대비 • 방대기 • 방대비 • 방대비 • 방대비
CASSINI/HUYGENS

- High Gain Antenna
- Magnetometer-boom
- Plasma wave antenna
- Camera platform
- RTG (Power)
- Main engine
CASSINI SPACECRAFT

COSMIC DUST ANALYSER

HUYGENS PROBE
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;
1 MB 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 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

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

frequency shift after corrections

![Graph showing frequency shift over time](image)
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

Kru¨ger et al., GRL, 2003
Speed of nano-dust: > 100 km/s

Are the grains fast enough for a detection? YES.

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
• 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 2\textsuperscript{nd} Jupiter flyby in 2004 (Krüger et al. 2006)

• Stream formation due to CIR and CME interaction (Flandes & Krüger, 2007)
**Dust Streams: A Monitor of Io's Volcanism**

- 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
Electromagnetically Interacting Dust at Jupiter

Particle source: Io

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

Periodogram of Galileo data
Composition Of Io’s Volcanic Matter

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 m²
- 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 km³
CDA Science Highlights I (Cruise)

- Streams of nano-dust from Saturn: Discovery, composition 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)
Time: 2004-155T00:00:00
Distance to Saturn: 252.3 Rs
Angle to the ring plane: -0.3 deg.
PHOEBE

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

190 m/pixel
PHOEBE CRATER
80 M/PIXEL
A COMET LIKE OBJECT

CO2 indicator for Kuiper Belt origin

retrograde orbit
ORBIT INSERTION
Saturn System Tour Trajectory

Titan Orbit

Iapetus Orbit
Saturn’s Atmosphere

ISS team
near IR, 890nm
Distance:
595,000 km
Pixel: 32 km
SIZE DISTRIBUTION OF RING PARTICLES

Cassini Visual and Infrared Mapping Spectrometer

grain-size composite

small colorbar large
DIRTY RINGS

inside

Infrared Reflectance  Water Ice Strength  "Dirt"  Color Composite

Cassini Division  A-Ring  Encke Gap
RINGS IN THE UV

more transparency

more water ice
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

\[ \lambda = 3\pi \Delta a_0 \]

(Julian & Toomre 1966, Lin & Papaloizou 1979)
DENSITY WAVES IN THE RING
WAVES IN THE UV
UV STAR OCCULTATION
F RING WITH SHEPHERD MOONS
PROMETHEUS 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)

1500 m tall = 150xthickness
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

Earth:
- Nitrogen
- Oxygen
- Argon
- Ozone
- Water

Titan:
- Nitrogen Methane Argon (?)
- Thin Haze Layer
- Thick Photochemical Haz
- Particulate Rain?
- Methane
MODEL OF TITAN'S ATMOSPHERE
HUYGENS PROBE (ESA)

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

Separation - 25. dec 2004
entry angle : 65° (+/- 3°)
entry speed : 6.1 km/s
peak deceleration : 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
SCIENCE PLANNING!
EXAMPLE: CIRS
OBSERVATION PLANNING
ROCKING CASSINI: DUST DYNAMICS

[Sensitive area (%) plot with semi-major axis (R_s) on the x-axis and eccentricity on the y-axis.]

[Relative flux plot with semi-major axis (R_s) on the x-axis and eccentricity on the y-axis.]

[Graph showing distance to Saturn (R_s) with corresponding semi-major axes and angles.]

[Plot of impact rate on target with DOY 2006-056 timeline.]
Comparison: Optical measurements

The E-Ring
Enceladus: Source of ice grains (E ring)

- Size: 499 km
- Density: 1600 kg/m³
- 70 km Ice Crust on Rocky Core
ENCELADUS FLYBY PLANNING
Ejecta Production

Meteoroid Impacts Splash up Ejecta

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

Mass Yield $\sim 4000$

Sremcevic et al., Icarus, 2005

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

Grain Size

~5 µm
~1 µm
Snow on Enceladus!

Kempf et al., 2009
Salty icy grains: Direct Evidence for Subsurface Liquid Water Reservoir

Water + Rocky Core

Water Dissolves Akali Salts

Ice Grains Should be Salty!
Dust Composition

Cassini Dust Detector CDA

Geyser Water Ice Grain

\[(\text{H}_2\text{O})\text{H}^+\]
\[(\text{H}_2\text{O})_2\text{H}^+\]
\[(\text{H}_2\text{O})_3\text{H}^+\]
\[(\text{H}_2\text{O})_4\text{H}^+\]
\[(\text{H}_2\text{O})_5\text{H}^+\]
\[(\text{H}_2\text{O})_6\text{H}^+\]

Mass (u)

Na$^+$

19 37 55 73 91 109
TOF Mass spectra (Cassini-CDA)

< 6 km/s

Cluster length

16 km/s

log Amplitude

Time of Flight

TOF Mass spectra

Cluster length

H, H2H3

(H2O)Rh+ 1 2 3 4 5 6 7 8 9

a: 6.4 km/s

b: 10.3 km/s

c: 14.3 km/s

d: 14.6 km/s

e: 16.2 km/s

(Cassini-CDA)
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
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