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

• mathematician and physicist of the Netherlands

• (*1629, †1695)

• interpretation of Saturn’s ring

• discovery of the large moon Titan (1655)
GIOVANNI CASSINI

- French astronomer and mathematician
- (*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  Titan 20.3 Rs
Atlas 2.28 Rs  Hyperion 24.6 Rs
Prometheus 2.31 Rs  Iapetus 59.1 Rs
Pandora 2.35 Rs  Phoebe 214.9 Rs

This graphic is available in color if required.
SATURN!

1 Saturn year: 29.5 y
Rotation: 10 h, 40 min
Distance to Sun: 1400 Mkm
Diameter at equator: 120,000 km
Mass: 95 x Earth
Volume: 760 x Earth
Density: 0.7 g/cm^3 (Earth: 5.5)
Strong pole oblateness
Magnetic field: 4x10^-5 T at pole (Earth: 5x10^-5 T)
Dipole field axis = rotation axis!
Ring plane: 27° tilted towards orbit plane
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, $5 \times 10^{12}$ 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

- Pandora and Prometheus are shepahard moons for ring
- Dione and Tethys have own moons
- Janus and Epimetheus exchange their orbit
- Iapetus has a dark and bright side
- Mimas has a huge impact crater (1/4 of surface)
- Enceladus is active (ice geysers), highest albedo
- Phoebe has a retrograde orbit, KB object caught by Saturn (?)
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-tetraoxicd 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;
1MB 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
Cruise Science: Not Only Saturn ...

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
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

Krüger 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

Side View

Top View

A. Graps
Io as a Dust Source in the Jovian System

- 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: \( \sim 0.1 - 1 \text{ kg s}^{-1} \)
- Small compared to \( \sim 1 \text{ ton s}^{-1} \) of plasma ejected
- Peaks in dust emission coincide with largest surface changes
- Dust condensation in plumes
Electromagnetically Interacting Dust at Jupiter

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

Particle source: Io

Periodogram of Galileo data

Grün et al. 1998
Graps et al. 2000
Composition Of Io's Volcanic Matter

Time of Flight

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, compositional 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

Apr. 2007
SIMULATION OF ESCAPING DUST STREAMS FROM SATURN (M. HORANYI)
DUST STREAM MODELING

Time: 2004-155T00:00:00
Distance to Saturn: 252.3 Rs
Angle to the ring plane: -0.3 deg.
SATURN APPROACH

Enceladus

Mimas

Tethys
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 orbit insertion
2004-183

SOI Burn
01:12 - 02:49:54

Earth Occultation
03:33:58 - 04:09:35

Solar Occultation
03:36:51 - 04:08:40

DRPC
04:34:01

ARPC
00:47:01

Time ticks every 30 minutes
SATURN 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 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

200,000 km, 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

C ring

B ring

Cassini Division

A ring
RING PLANE CROSSING
F RING WITH SHEPHERD MOONS
PROMETHEUS AND PANDORA
F RING
SHEPHERD MOON PROMETHEUS (102 KM)
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
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
METHANE SOURCES?
PREDICTION AND MEASUREMENTS OF TITAN’S ATMOSPHERE: GOOD AGREEMENT
ACCELEROMETER AT LANDING

ACC-1 Mode 4

$g$ (Earth)

Sample (x2.0ms)
Mission time = 8869.7695s
HUYGENS LANDING SCENARIOS
TITAN SURFACE
PREDICTION AND REALITY
SCIENCE PLANNING!
EXAMPLE: CIRS
OBSERVATION PLANNING
ROCKING CASSINI: DUST DYNAMICS

Sensitive area (%)

Relative flux

Eccentricity vs. Semi-major axis (R$_S$)

Distance to Saturn (R$_S$)

Angle of CDA to Kepler RAM (°)

Impact rate on target: IID CA1 WALL

Doy 2006–056

7.93 8.00 8.25 8.50 8.75 9.00 9.06

21:00 22:00 23:00 24:00
DUST DENSITY
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 $\approx 4000$

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 $\sim 950 \text{ km}$

Escape Speed $\sim 207 \text{ m/s}$

Grain Size

$\sim 5\mu m$

$\sim 1\mu m$
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

\[(\text{H}_2\text{O})\text{H}^+\]

\[(\text{H}_2\text{O})_2\text{H}^+\]

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

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

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

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

Na$^+$

Mass (u)

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

< 6 km/s

Cluster length

16 km/s

H₂H₃⁺ (H₂O)ₓ⁺ H⁺ 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

H₂O

log Amplitude

Time of Flight

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, ...
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