Exploring Saturn with Cassini/Huygens

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How do stellar systems and planets form?
How do they evolve over time?
How are the building blocks of life made?
How can simple physics be applied to these big questions?

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Overview

• Before Cassini
• Main Research Areas
  – Saturn
  – Rings
  – Icy Satellites
  – Magnetosphere
  – Titan
• Cassini Mission
• First Cassini observations at Saturn
• Huygens Mission
1610, Galileo Galilei discovers that Saturn changes shape.
1655, Christiaan Huygens discovers that Saturn has a satellite, Titan

1659, Huygens proposes that Saturn is surrounded by a thin, flat ring
1670-1675, Giovanni Domenico Cassini discovers four more satellites and a division within the rings.
Saturn

- 10 AU, 27° obliquity, circular orbit, 10hr day
- 10 x $R_E$, 0.7 g/cc, 10% flattening
- Metal/rock core of $\sim$10 $M_E$, metallic H/He layer, molecular H/He, internal He rain
- Radiates internal heat
- Clouds of NH$_3$, NH$_4$SH, H$_2$O
- Dynamics in belts/zones, with ovals/spots
Latitudinal banding (belts/zones) are regions of upwelling/downwelling. How deep do they go?

Few 100 m/s zonal winds

Less colorful than Jupiter due to lower T – we think

Ovals are storm systems that interact, merge

Polar winds?

photojournal.jpl.nasa.gov
Rings

- 1.1 – 8.0 $R_S$, mostly ice, some rock
- Range of sizes, microns to metres
- Less than 1 km thick
- Organized by shepherd moons and additional resonances
- Lots of fine structure
- How old? (500 My???)
What do variations in size, shape, and composition of ring particles reveal?

Analogies to formation of galaxies, stars, and planets

What is origin and fate of ring system?

What structures are long-term? Short-term?

voyager.jpl.nasa.gov
Icy Satellites

- 33 satellites known, more will be found
- Not all prograde with orbits in equatorial plane, some captured?
- Partial source of ring particles, shepherds
- Rock/ice mixtures
- Internal oceans and magnetic fields?
- Varied cratering and tectonic histories
Magnetosphere

- Field strength at surface same as Earth
- Dipole component aligned with spin axis
- Large non-dipole components
- 10MA ring current flows within magnetosphere
- Dynamics are partly driven by rotation, partly by solar wind
- Bright, variable aurora are common at poles
Time variation in aurora

How is brightness and position of auroral oval related to solar wind properties?

Are there “footprints” of satellites?

Do internal (satellites, rings) processes or solar processes control aurora?

How does magnetosphere strip matter from surfaces and atmospheres of satellites and rings?

These pictures may appear in a high-profile journal soon, with Cassini particles and fields data

Image from John Clarke
Titan

- \( \sim 0.5R_E \), orbits at 20 \( R_S \), made of ice/rock
- 1.5 bar \( N_2/CH_4 \) atmosphere, 1000 km thick
- Atmospheric hazes and clouds
- Liquid hydrocarbons stable on surface (100K)
- Internal \( H_2O \) ocean?
- Life?
What is thermal structure of atmosphere?

What are compositions of haze layers and clouds?

What energy sources drive the atmospheric chemistry?

How much atmospheric escape has there been?

How does magnetosphere affect atmospheric escape processes?
CH$_4$ is photochemically destroyed in 10 My, so why is it still in Titan’s atmosphere? Surface is too warm for it to liquify.

Loss of H leads to C$_2$H$_6$, which can condense. CH$_4$ then dissolves in reservoirs of liquid C$_2$H$_6$.

Heavier hydrocarbons at bottom of any such ocean/lake/pond/puddle.

This idea may be totally wrong in a few weeks.
Getting Cassini off the ground

• 1982: Proposed to ESA
• 1983: NASA committee recommends Titan mission
• 1986: Challenger fails, plans change
• ~1988: Approval
• 1992: Near-cancellation, descope
• 15 Oct 1997: Launch
Remote Sensing

- Visible: Clouds and aerosols, geomorphology, ring dynamics
- IR: Surface, ring, and atmospheric composition, atmospheric T(p)
- UV: Aurora, atmospheric T(p) and composition, ring/satellite atmospheres
- Radio: Satellite interiors, atmospheric T(p), ionospheres, ring particle properties
- Radar: Topography, surface T, SAR image
In Situ

- **Ions:** Titan atmosphere, solar wind, ions escaping from Titan, satellites, rings
- **Neutrals:** Same
- **Dust/Ice particles:** satellite/ring interactions, chemical compositions
- **Magnetic fields:** Magnetosphere, interiors of Saturn, Titan, satellites
- **Radio:** EM fields, lightning, magnetosphere
~70 orbits over 4 years

~40 flybys of Titan

Some close flybys of the other satellites

Negotiations between each instrument and between the scientists and the engineers

Deluge of data

saturn.jpl.nasa.gov
Fine structure in the rings

Swirls and bands in the atmosphere

Enceladus

727 nm image, CH₄ absorption
Near-IR image
2000 km across
Overhead sun, so no shadows
Please speculate
Other Early Results from Titan

- High $^{15}\text{N}/^{14}\text{N}$ ratio, atmospheric loss
- Complex hydrocarbons sampled in situ
- Visible, IR, radar images – interpretations wildly speculative
- 150m topography along 400 km track, flat
- Optically bright, dark at 2cm, vice versa
Thermal structure
Composition of atmosphere and aerosols
Winds
Physical properties of surface
Descent images
Radiative transfer within atmosphere, aerosol shape/size

25 Dec: Release from Cassini
14 Jan: Arrival at Titan
<3 hours of data from 20 year mission
Major redesign to fix error in communications system

nssdc.gsfc.nasa.gov
Entry
1270 km above surface
Mach 20 300 - 250 km
Peak deceleration Heat-flux peak

Pilot-chute deployment
Mach 1.5 170 - 190 km
T₀

Front-shield separation
80 m/s 155 - 175 km
T₂ = T₀ + 30s

Main-parachute jettison Stabiliser-parachute deployment
80 m/s 152 - 172 km
T₃ = T₀ + 40s
40 m/s 110 - 140 km
T₄ = T₀ + 15min

Stabiliser-parachute inflated
100 m/s 109 - 139 km
T₅ = T₄ + 1s

Back-cover release Main-parachute deployment
100 m/s 160 - 180 km
T₁ = T₀ + 1s

Instrument configuration for descent

5 - 6 m/s 5 - 6 m/s
T₆ = T₀ + 150min (maximum)

Surface Impact
Surface mission phase duration > 3 min

saturn.jpl.nasa.gov
Conclusions

• The Saturn system is full of interesting physics
• Cassini/Huygens are going to revolutionize our understanding of rings and Titan
• You can work with all of the data from these spacecraft, and even get funding
The Purpose of Planetary Exploration (according to NASA)

• “Discover how the universe began and evolved, how we got here, where we are going, and whether we are alone” – NASA Space Science Enterprise

• Learn how the Sun’s family of planets and minor bodies originated
• Determine how the solar system evolved to its current diverse state
• Determine the characteristics of the solar system that led to the origin of life
• Understand how life begins and evolves
The Purpose of Planetary Science (according to me)

- Astronomy ... Geology

- How does vapour evolve into huge chunks of condensed matter?
- How do matter and radiation behave under conditions unlike terrestrial laboratories?
- Life – what is it, how does it start, how does it end?
- How special is our home, Earth?
Saturn Today
(Actually tomorrow)

View from Boston

2004.11.06
6am

www.heavens-above.com
Saturn before the Telescope

- Easily visible, -0.4 magnitude
- Slightly orange (or yellow) colour
- One of the five “wanderers” known to the Greeks

http://www.skynewsmagazine.com/media/everies/planetlabels.jpg
Other discoveries before the Space Age

• More satellites
• More structure within the rings
• Maxwell (yes, that Maxwell) proves that the rings are made up of many tiny fragments
• Titan has an atmosphere
Pioneer 11 - 1979

- Mostly “particles and fields” experiments
- Trail-blazing for Voyager spacecraft
- Camera took images one pixel at a time

www.racine.ra.it, spaceprojects.arc.nasa.gov, ails.arc.nasa.gov
Voyager 1 and 2 – 1980 and 1981

history.acusd.edu
Main Research Areas

- Saturn
- Rings
- Magnetosphere
- Icy moons
- Titan
Models are critically dependent on the high pressure equation of state of H and He mixtures, core might not exist.
Sinuous structure

Large, dark storm

Fluid dynamics on a grand scale

How do abundances of condensable species vary with latitude, altitude, and season?

What is bulk isotopic and elemental composition?

photojournal.jpl.nasa.gov
Spokes rotate with Saturn, not with orbital speeds

What are they?

How long-lived?

Where do they come from?

How do rings and satellites interact?

How do shadows of the rings affect Saturn’s weather?

Brightness of rings suggests youth

photojournal.jpl.nasa.gov
What is the cause of this braiding in the outermost F ring?

What causes azimuthal asymmetries in some of the rings?

How do the dynamics of Saturn’s rings relate to those of Jupiter, Uranus, and Neptune?

A neutral cloud of H and OH envelopes the rings: how does it behave?

voyager.jpl.nasa.gov
How similar are Titan’s torus and the Io plasma torus at Jupiter?

What are the sources and sinks of ions?

What causes powerful radio emissions from Saturn?

How does the composition and temperature of the plasma vary?
Mimas (Death Star)
200 km radius

Diameter of crater Herschel is 1/3 that of Mimas, 15 km of topography

Why is it so much bigger than all other craters?

How did Mimas survive impact?

Mostly ice, same total mass as rings

Responsible for one edge of the Cassini Division

photojournal.jpl.nasa.gov
Tethys 500 km radius

Mimas would fit inside crater Odysseus

15 km radius Telesto and Calypso orbit at Lagrange points of Tethys, +/- 60 deg

Mostly ice

Some regions have been resurfaced

Ithaca Chasma – trench girdles satellite, 100 km wide, <3 km deep, equatorial to Odysseus

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Iapetus – 700 km radius

Like most satellites, it rotates synchronously. Hyperion has chaotic rotational state, weird

Leading hemisphere has albedo of 0.05, trailing one has albedo of 0.5

Cassini (1670) was confused

Dark stuff is a big mystery, dark usually means carbon/organics

(Where the monolith was in the book version of “2001”…)

photojournal.jpl.nasa.gov
Enceladus – 250 km
Same size and orbit as Mimas but…

Brightest body known

Absence of craters means that surface is very young – 100 My

What was source of heating - $\text{H}_2\text{O}/\text{NH}_3$ volcanism, tides, impact?

Collocated with E ring, which has very fine ice particles – are they emitted by geysers?

photojournal.jpl.nasa.gov
Haze absorbs visible light, Voyager didn’t see any surface features.

Solar UV and charged particles generate soup of hydrocarbons – haze.

Is atmosphere similar to early Earth?

Clouds occasionally seen – clouds of what?

Is atmosphere old or young?
What is thermal structure of atmosphere?

What are compositions of haze layers and clouds?

What energy sources drive the atmospheric chemistry?

How much atmospheric escape has there been?

How does magnetosphere affect atmospheric escape processes?
Atmosphere is optically thin in near-IR

Bright region known as Xanadu, but its nature is unknown

Are there volcanoes, tectonics, craters, liquids, life?

Is surface icy or oily?

Is there a subsurface ocean of H$_2$O, like Europa?

Image from HST

photojournal.jpl.nasa.gov
Arecibo/Green Bank radar saw specular reflection from parts of Titan

13 cm wavelength

Interpreted as lakes ~ 80 km across – or smooth solid surfaces
