Next - Saturn’s moon
Cassini Mission - July 1, 2004

- 74 Orbits of Saturn
- 44 close flybys of Titan
- 8 close targeted flybys of other satellites
- 30 additional satellite flybys at distances less than 62,100 mi
- Many Saturn & Ring Occultation opportunities
4 year path of Cassini
Saturn’s Moons

- Moons show less variation in properties than Jupiter’s moons, & Saturn’s ring system is more extensive: smaller mass of Saturn? Lower temperature of sub-nebula?? Something else?
- Moons are half ice, half rock, but most have density range ~ 1.1 - 1.4 g cm\(^{-3}\). The moons are smaller - less compression of ice than previously discussed icy moons
- Many moons have high lunar-like crater counts
Pandora
Mimas - the “Deathstar” moon

- **Density** = 1.2 g cm\(^{-3}\)
- **Crater size** = 80mi x 6 mi
- **Moon Diameter** = 247 mi
- **Rotation period** = 0.94 days
- **Orbital period** = 0.94 days
Mimas Occulting Janus
Mimas & Saturn’s Rings
Enceladus

- **Density** = 1.1 g cm$^{-3}$
- **Rotation period** = 1.4 days
- **Orbital period** = 1.4 days
- **Surface**: a mixture of soft craters & complex fracture terrains
  - terrains ~ few hundred million yr old
• **Cryovolcanism**: flow of partially melted ice that mimics lava flows on silicate planets
• Spray of \( \text{H}_2\text{O} \) + ice particles observed emanating from Enceladus
• Looks like Io, but Enceladus isn’t forced into non-circular orbit by companion moons like Io. What is causing this activity??
Blue Streaks

- Are warmer than surrounding regions, clearly indicating heat-leak
- It’s not clear how the heat reaches the surface
Close Approach

- Boulders of ice are visible in geologically active region
- Sizes ~ 30 - 330 ft in diameter
Atmosphere of Enceladus

- Has been detected via an occultation of a star.
- Note the asymmetry in the light curve
Saturn’s Magnetic Field & Enceladus

- Saturn’s B-field is bent around Enceladus due to the interaction between particles in the moon’s atmosphere & the B-field.
Tethys

- **Density** = 1.2 g cm$^{-3}$
- **Orbital period** = 1.9 days
- Two major craters: Odysseus & Melanthius
- Melanthius has an elongated mountain range instead of a central peak
Structure on its Surface

- Icy land of steep cliffs
- Ithaca Chasma: heavily cratered regions. Thus, cliffs are very old
Dione

- **Density** = 1.4 g cm$^{-3}$
- **Orbital period** = 2.73 days
- Streaks on surface: caused by impacts or tectonic in nature
Dione & Saturn
Rhea

- **Density** = 1.3 g cm$^{-3}$
- **Orbital period** = 4.5 days
- Heavily cratered. Craters are similar in appearance to those on Moon, despite the fact that the surface is icy. Cold ice is brittle & thus less plastic in nature.
- **Reflectivity** = 60%
- The high reflectivity is due to the fact that the moon has an brittle, icy surface.
Hyperion - the “Sponge” Moon

- **Density** = 1.4 g cm\(^{-3}\)
- **Orbital period** = 21.3 days
- **Rotational period** = chaotic
- May have had a collision, which ripped away part of the moon & left it tumbling around Saturn
- Thin layer of dark material may be covering lighter material below
- Evidence of landslides?
Titan

- **Density** = 1.9 g cm\(^{-3}\) (½ ice, ½ rock)
- **Surface** is not visible through thick clouds (thus, the need for Cassini-Huygens mission)
- **Pressure** at Surface ~ 1.5 bars
- **Atmosphere** is 10 times more massive than Earth’s, and 10 times more extended

**Atmosphere** is 90% Nitrogen + Argon, Methane & Various Hydrogen compounds (Ethane, …)
Atmosphere of Titan

- Similar to the Earth in being mostly Nitrogen
- Different from the Earth in having Methane instead of Oxygen
- Low temperature keeps water frozen → no water vapor in atmosphere
- On terrestrial planets, water + carbon → carbon compounds (e.g. CO$_2$)
Atmosphere of Titan

- **Origin** of Atmosphere
  1) Outgassing from icy methane & ammonia surface
  2) Comets
  - \(\text{NH}_3 + \text{UV Sunlight} \rightarrow \text{N} + \text{H}\)
  - Hydrogen escaped, nitrogen accumulated
Spectroscopy of Titan Atmosphere

- Many organic (i.e., carbon-rich) compounds were detected by Voyager 1
- Atmosphere + Charged Particles $\rightarrow$ Organic Solid (Tholin)
- Tholin + Water $\rightarrow$ Amino Acid (chief component of proteins)
Pre-Cassini/Huygens Model of Titan

**Ethane sea** may result from

1) Methane + UV Sunlight $\rightarrow H + C$

2) $CO_2 +$ hydrocarbons sink to surface

3) Ethane + Methane + propane
Titan’s surface from Cassini

- Narrowband infrared to see through clouds
- Light & dark surfaces visible
- Dark spots → deposition of methane
- Problem: methane in the atmosphere would be depleted in 10-20 million years. What process is replenishing methane?
Cloud Motion in Titan’s Atmosphere
Cassini spacecraft: radar mapping of Titan (2004: Video)
Huygens Probe: a journey to the surface of Titan

- Cloud layers make it difficult to study the surface in detail. The solution → Huygens probe
- After ejection from Cassini (Dec 25 2004), the probe went dormant except for timers set to end 4 hrs 23 min before atmospheric entry (January 14, 2005)
- Mission: 2.5 hours during descent + several minutes on surface
- Due to unknown wind speeds, the uncertainty in landing spot ~ several hundred km
Huygens Probe Descent: Animation

Descent Imager & Spectral Radiometer Lamp on during descent

1270 km
21600 km/h

Descent Imager & Spectral Radiometer Lamp on during descent
Huygens probe descending to Titan - Actual Images from Descent Imager

Haze affects some of the images in this sequence

Haze observed all the way to the ground
Descent

- Bright spots → icy, roughed
- Dark spots → flat, lowlands
- Huygens landing spot → dark
Dendritic structures & a “shoreline”

- “River channels” in highlands leading to the lowland shoreline
- Channels → carved by methane rain + subsurface springs
- Dark regions too extended to have been caused by river channels
  → Made by larger river systems?
  → Catastrophic event??
Winds & Surface Temperature

- ~ 430 km hr\(^{-1}\) at 120 km (peak measured speed)
- < 3.6 km hr\(^{-1}\) at surface. Are these winds sufficient to form wind-induced features on surface, or are strong gusts required??
- Surface temperature ~ 94 K. Sufficient for methane & ethane to be in liquid form
Huygens Landing Site

- Lowlands → “Lake bed” region
- Dirty water ice
- Vapors from landing produced methane (CH₄)
  + C₆H₆, C₂N₂, CO₂, which are not detected in atmosphere → produced by surface chemistry?
- No ethane (C₂H₆)
Huygens Landing Site: Rocks

- Rock sizes: 3mm - 15 cm (0.1 - 5 inches)
- No meter-size (3.3 ft) rocks seen within 40x35m of landing site during descent
- Most rocks 5 cm
  → Large rocks can’t be transported in lake bed
  → Small pebbles removed from surface
## Earth - Titan Surface Comparison

<table>
<thead>
<tr>
<th>Earth</th>
<th>Titan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid water</td>
<td>Liquid methane</td>
</tr>
<tr>
<td>Silicate rocks</td>
<td>Frozen water ice</td>
</tr>
<tr>
<td>dirt</td>
<td>Hydrocarbon particles settling out of atmosphere</td>
</tr>
</tbody>
</table>

![Earth](image1.png)  ![Titan](image2.png)
Sky from the Surface of Titan

- Orange in color due to the attenuation of blue light by haze relative to red
- Noon Sun → 10 times smaller in size than the Sun as seen from Earth. Brightness & size are similar to car headlight seen from 160 yards away
- When the Sun is low in the sky, it is not visible.
Triton – a satellite of Neptune

- **Density** = 2.0 g cm$^{-3}$

- **Orbit**: moves in direction opposite Neptune’s rotation
  - i.e., irregular satellite
  - It is likely a captured Kuiper belt object
Triton Surface

- Methane ice + Nitrogen (& CO, CO$_2$)
- **Pinkish color**: organic compounds produced via chemical reactions of surface
- Very small impact crater density = young surface
Triton Terrains

1) **Southern hemisphere**: flat plains covered with dark spots

2) **Latitudes above equator**: smooth, uniform material with uniform tint

3) **Higher latitudes**: rough terrain crossed by long grooves ("Cantaloupe Terrain")
Triton Atmosphere: Nitrogen + some Methane