Astronomy 2202: 
“Our Home in the Solar System”

Fall 2015
TR 10:10 – 11:25 am, SS105

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Teaching Assistant: Michelle Vick
http://www.astro.cornell.edu/academics/courses/astro2202/

Familiar Physics in Unfamiliar Environments

Titan, Mars, and Venus are shaped by the same surface processes as Earth.

The Largest Moons and Smallest Planets

<table>
<thead>
<tr>
<th>Moon</th>
<th>Diameter (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Io</td>
<td>3642</td>
</tr>
<tr>
<td>Moon</td>
<td>3476</td>
</tr>
<tr>
<td>Europa</td>
<td>3138</td>
</tr>
<tr>
<td>Triton</td>
<td>2706</td>
</tr>
<tr>
<td>Pluto</td>
<td>2300</td>
</tr>
<tr>
<td>Titania</td>
<td>1580</td>
</tr>
<tr>
<td>Ganymede</td>
<td>5262</td>
</tr>
<tr>
<td>Titan</td>
<td>5150</td>
</tr>
<tr>
<td>Mercury</td>
<td>4880</td>
</tr>
<tr>
<td>Callisto</td>
<td>4806</td>
</tr>
</tbody>
</table>
Drawing of Titan by José Comas Solà, 1907 using 38cm Mailhat binocular telescope at Fabra observatory, Barcelona

Shows 'limb-darkening' – suggestive of an atmosphere

Spectrum of Titan taken by Kuiper shows absorption bands, prominent in near-IR, that are shared by the giant planets, but not by other satellites

This is the signature of methane.
'Titan: A Satellite with an Atmosphere' (Kuiper, 1944)
VIMS – IR
• Grating Spectrometer
  (0.84 - 5.1 \mu m n=264)

ISS
• VIS/NIR
  Telescope
  (0.2 – 1.1 \mu m)

RADAR
• 13.78 GHz  (2.16 cm)
  [Ku Band]
• SAR Resolution:
  300 m – 1.7 km

VIMS – IR
• Grating Spectrometer
  (0.84 - 5.1 \mu m n=264)

ISS
• VIS/NIR
  Telescope
  (0.2 – 1.1 \mu m)
Titan’s Complex Atmospheric Chemistry

- Chemistry driven by UV photons (~90%) and energetic particles (~10%)
- CH₄ is irreversibly destroyed (current abundance would be destroyed in ~10-100 Myr)
- Major net reaction is:
  \[ 2\text{CH}_4 + \text{hv} \rightarrow \text{C}_2\text{H}_6 + \text{H}_2 \]

• Escape
• Condensation
Photochemistry at the heart of Titan’s surface-atmosphere evolution.

\[ \lambda < 1450 \text{ Å} \]
\[ \lambda = 2000 \text{ Å} \]

Atmosphere  Surface  Seasons

Stratosphere

- Destruction of methane ~10^4-10^5 years

Troposphere

- Resulting of dune formation ~10^3-10^4 years

Surface

- Dunes
- Polar Dunes

Cratering

- Impact craters
- Surface/subsurface condensed methane/ethane

Impact Cratering
Radebaugh, Icarus 2008

Aeolian Processes

~50 km
~15 km

Dunes in Namib desert (L-band/SRL, 30 km wide)
Titan dunes at same scale

Lunine, Pappalardo, Matson

Radebaugh, Icarus 2008

~100 km

Narrow, sinuous, radar-bright channels on the western portion of Xanadu extend for many hundreds of km. They may be river networks of methane that carry photochemical debris as sediment (image is ~ 80 km wide)

Fluvial Processes

Networks of channels/valleys with high tortuosity near Memnon (T3) appear to drain > 10^4 km^2 into radar bright (rough?) regions (image is ~ 60 km wide)

This southern-hemisphere "coastline" resembles terrestrial embayments and wetlands (~ 100 km wide)
Lacustrine Processes

Turtle, Science 2011

Pluvial Processes

Turtle, Science 2011

Endogenic Processes?

Kirk, LPSC 2011
Titan: A New World

Titan Interior Castillo and Lunine, 2010
C/MR² = 0.342

Water-ammonia ocean with dissolved potassium

Titan Interior Tobie et al., 2006
C/MR² = 0.32-0.33

Comparison of "fully differentiated" Titan models.

Methane clathrate hydrate + Ice I
anhydrous silicates

Titan Interior Castillo and Lunine, 2010
C/MR² = 0.342

Titan: Life’s origins; life today?

Can a form of life exist in ethane-methane instead of water?:
–Local alien biology
–Strict test of life’s cosmic commonality

Traces of the chemistry leading to life:
Comet/asteroid impacts melt the icy crust for hundreds to thousands of years.
–Organics evolve in water then freeze
–Experiments in origin of life preserved for study

Base of the liquid water ocean:
Does life as we know exist in hydrothermal vents?
Together RADAR, VIMS, and ISS provide a complete picture of the lake / sea distribution

<table>
<thead>
<tr>
<th>Lake Feature</th>
<th>Global</th>
<th>North (55°N-90°N)</th>
<th>South (55°S-90°S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swath Coverage</td>
<td>59%</td>
<td>81%</td>
<td>67%</td>
</tr>
<tr>
<td>Filled / Partially Filled / Empty</td>
<td>1.1% / 0.1% / 0.3%</td>
<td>12% / 0.9% / 1.3%</td>
<td>0.3% / 0.1% / 1.2%</td>
</tr>
</tbody>
</table>

Lacustrine, fluvial, and hillslope morphologies express a range of characteristics that suggest a rich history operating over seasonal, millennial, and geologic timescales.

Aharonson et al., Nature Geosciences 2009

Winds on Titan Lakes: North 10 km

Stephan et al., GRL 20

10 km North

Wye et al., GRL 2009

Stephan et al., GRL 2010
Growth Rate:

\[
\left( \frac{\beta}{\omega} \right)_{Donelan} = 0.194 \frac{\rho_a}{\rho_f} \left[ \frac{U_{\chi/2}}{c} \cos(\chi - \chi_0) - 1 \right]^2
\]

\[\beta_{\infty} / \omega = 4 \nu k / c \quad \text{(Viscous Dissipation)}\]

\[c^2 \approx \gamma k / \rho_f + g / k \quad \text{(Dispersion Relation)}\]

Hayes et al., Icarus 2013
Titan’s Dynamic Methane Cycle

**Southern Summer:**
- Formation of dendrites due to condensation

**Vernal Equinox:**
- Equatorial precipitation akin to April showers

<table>
<thead>
<tr>
<th>Date</th>
<th>Incidence</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feb. 22, 2007</td>
<td>20°</td>
<td>T25 SAR</td>
</tr>
<tr>
<td>Apr. 28, 2007</td>
<td>19°</td>
<td>T29 SAR</td>
</tr>
<tr>
<td>Dec. 27, 2009</td>
<td>36°</td>
<td>T64 SAR</td>
</tr>
<tr>
<td>July 10, 2013</td>
<td>6°</td>
<td>T92 SAR</td>
</tr>
</tbody>
</table>

**Northern Spring/Summer:**
- Onset of dynamic phenomena is gradual in northern latitudes
Anomalou s Features
“Magic Island”

Hofgartner et al., NatGeo 2014
VIMS also detected the Kraken Magic Islands!
All-invisibility observations of Ligeia Mare unexpectedly showed a second peak arising from reflection off the seafloor, providing an unambiguous measurement of depth (~150 m).

The secondary reflection can only be observed in radar-transparent liquid, constraining liquid composition to be nearly pure methane/water with little to no suspended particles.

Similar measurement of Kraken Mare, Titan's largest sea, are possible in fall 2015.

Mastrogiuseppe et al., GRL 2014
114: August 2014
Altimetry across North Kraken
• wave detection
• depth sounding
Low-Incidence SAR of transient ‘island’ feature in Ligeia.
VIMS heating
• 3.1 K -> 5.9 K

Eastern Kraken Mare
(Mouth of Drowned River Valley)