Interior structure and dynamics: exchanges between the interior and the surface

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Contributions de Sue Smrekar, Mathieu Choukroun, Ashley Davies, Gabriel Tobie
The interior structure
- Mars and Venus
- Titan

Interior dynamics and volcanism (exchange mechanisms)
- Venus: Is there active volcanism?
- Titan: origin of atmospheric methane and Argon?

Conclusions
Our next door neighbor: Venus vs. Earth

<table>
<thead>
<tr>
<th></th>
<th>Venus</th>
<th>Earth</th>
</tr>
</thead>
<tbody>
<tr>
<td>D (km)</td>
<td>12,104</td>
<td>12,756</td>
</tr>
<tr>
<td>M (10^{24}) kg</td>
<td>4.86</td>
<td>5.97</td>
</tr>
<tr>
<td>(V_e) (km/s)</td>
<td>10.4</td>
<td>11.2</td>
</tr>
<tr>
<td>P (bars)</td>
<td>92</td>
<td>1</td>
</tr>
<tr>
<td>(T_s) (C)</td>
<td>477</td>
<td>20</td>
</tr>
<tr>
<td>(H_2O) (kg)</td>
<td>(5.9 \times 10^{16})</td>
<td>(1.4 \times 10^{21})</td>
</tr>
<tr>
<td>Magnetic Field</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Plate Tectonic</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Earth has 100,000 times as much water as Venus!
Southern Hemisphere Hotspots
Topography + SAR

Emissivity (topo from Rappaport et al., 1999; mean emissivity set to 0.58)
Evidence for recent activity:
1. Gravity data indicates a hot plume at depth
2. Emissivity associated with youngest flows, and interpreted as fresh unweathered flows
Titan is Saturn’s largest moon. It is composed of a mixture of ice and rocks. It is the only moon with a dense atmosphere.
There are two observations that strongly suggest exchange processes between the interior and the atmosphere:

- The age of methane in Titan’s atmosphere is less than 940 Myr (Mandt et al., 2012) - It is less than 470 Myr if there has been no replenishment since the outgassing event

- The presence of $^{40}\text{Ar}$ in the atmosphere because $^{40}\text{Ar}$ comes from the decay of $^{40}\text{K}$ which is present in the deep layers
Seas and lakes of Titan
### Some characteristics compared to Earth

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Earth</th>
<th>Other World 1</th>
<th>Other World 2</th>
<th>Other World 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius (km)</td>
<td>6371</td>
<td>1822</td>
<td>2575</td>
<td>252.3</td>
</tr>
<tr>
<td>Mass ($10^{24}$ kg)</td>
<td>6</td>
<td>0.0894</td>
<td>0.1345</td>
<td>0.000108</td>
</tr>
<tr>
<td>Density ($kg/m^3$)</td>
<td>5525</td>
<td>3528</td>
<td>1881</td>
<td>1608</td>
</tr>
<tr>
<td>Composition</td>
<td>Silicates and 1/3 iron</td>
<td>Silicates</td>
<td>Ice and silicates</td>
<td>Ice and silicates</td>
</tr>
<tr>
<td>Heat Flux (TW)</td>
<td>42</td>
<td>105 (&gt;2 W/m^2)</td>
<td>750 (estimate)</td>
<td>6 in the South Pole area</td>
</tr>
</tbody>
</table>

Radioactive energy is proportional to the mass of silicates
Other sources include tidal heating, accretional heat (cooling and latent heat)
Outline

* The interior structure
  * Mars and Venus
  * Titan

* Interior dynamics and volcanism (exchange mechanisms)
  * Venus: Is there active volcanism?
  * Titan: origin of atmospheric methane and Argon?

* Conclusions
Venus Interior: Hotspots, coronae, drips...

- Two scales of upwellings
- ~10 Hotspots
- ~500 Coronae

Legend:
- Red circle: Type 1 Coronae
- Blue diamond: Type 2 Coronae
- Yellow triangle: Flow fields
- Red circle: N. Hemisphere Hotspots
- Black circle: S. Hemisphere Hotspots
Volcanisme – fusion partielle en profondeur - convection

Till et al. (2010)

Low Water Wet Solidus

Non-Newtonian

Dry Solidus

Wet Solidus

Temperature (K)

Pressure (GPa)

depth (km)

\[ \eta_1 = 10^{20} \text{ Pa.s} \]

\[ \eta_1 = 10^{21} \text{ Pa.s} \]

X – temp. at base of conductive lid; • W/adiabatic correction
**Amount of outgassing**

- $^{40}\text{Ar}$ is a good tracer of the amount of outgassing since it comes from the decay of $^{40}\text{K}$ and it does not escape on Earth and Venus.
- 25% of the interior has been outgassed based on $^{40}\text{Ar}$ (Kaula, 1999)
- The upper mantle is about 25% of the total mantle in mass

### Amount of outgassing

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<th>Mars</th>
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<tr>
<td>$^{40}\text{Ar}$ in atm (kg)</td>
<td>$1.6 (\pm 0.5) \times 10^{16}$</td>
<td>$6.6 \times 10^{16}$</td>
<td>$5 \times 10^{14}$</td>
</tr>
<tr>
<td>$^{40}\text{Ar}$ (kg/kg planet)</td>
<td>$3.3 \times 10^{-9}$</td>
<td>$1.11 \times 10^{-8}$</td>
<td>$7.9 \times 10^{-10}$</td>
</tr>
<tr>
<td>$^{40}\text{Ar}$/Si</td>
<td>$1.7 \times 10^{-8}$</td>
<td>$5.2 \times 10^{-8}$</td>
<td>$4.1 \times 10^{-9}$</td>
</tr>
<tr>
<td>potential $^{40}\text{Ar}$ (kg)</td>
<td>$6.8 \times 10^{16}$</td>
<td>$1.4 - 1.56 \times 10^{17}$</td>
<td>$1.6 \times 10^{16}$</td>
</tr>
<tr>
<td>$^{40}\text{Ar}$ atm / potential</td>
<td>$24 (\pm 10)%$</td>
<td>42-56 %</td>
<td>3 %</td>
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Is the recent resurfacing due to plumes raising from the Core/Mantle boundary (CMB)?
0.3-1.0 ppmv $\text{H}_2\text{O}$ in the upper atmosphere.

* but more in the lower atmosphere according to Venus Express data: 45 ppm / 30 ppm (Bezard et al., 2009 / 2011) ~ $6 / 4 \times 10^{15}$ kg ~ 3 cm total (upper and lower atmospheres).

* the D/H ratio in the upper atmosphere suggests an amount 300 times higher in the past ~ 10 m total.

* The water is still in the interior (Lécuyer et al., 2000).

How much water is released by hot spot volcanism?
Is dry melting possible in the stagnant lid regime?
When: 500 My (isotopic ratios, density of impact craters, Titan’s shape)
Where and how? One catastrophic event or several large events (impact craters, cryovolcanism)

Sotin et al. (Icarus, 2012)
Outgassing of Argon

- The major uncertainty is the initial amount of K. Is K/U = 12,000 or 60,000? (Atreya et al. (2006) used a terrestrial ratio)
- Models must be coherent: if K/U = 60,000, then internal heating is 3 times higher during the first Gyr (2 times larger at present time).

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When was $^{40}$Ar released in the atmosphere? At the same time CH$_4$ was released?
Internal dynamics and evolution

(Tobie et al. 2006)
- atmospheric composition
- models of subsolidus convection
- different considerations (high eccentricity = tidal dissipation is minimum)

3 periods during which volatiles (methane) can be present
- During accretion
- Onset of convection in the silicate core
- Onset of convection in the outer ice layer
Volcanoes are surface features resulting from the internal processes.

Volcanic activity may still be going on at Venus’ surface but only future missions will tell us.

Volcanic eruptions provide information on the interior composition, the degree of differentiation, and the evolution of the planet/satellite.

Atmospheric composition provides information on the interior processes.
Active Volcanism

Radioactive energy / convection

Tidal dissipation

Terrestrial planets

Icy moons

• Europa: volcanism on the sea-floor and ice volcanism at the surface?
• Volcanic activity existed in the past on Mars and on large icy moons such as Ganymede – Case for Titan
• Geysers on Charon and Enceladus