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

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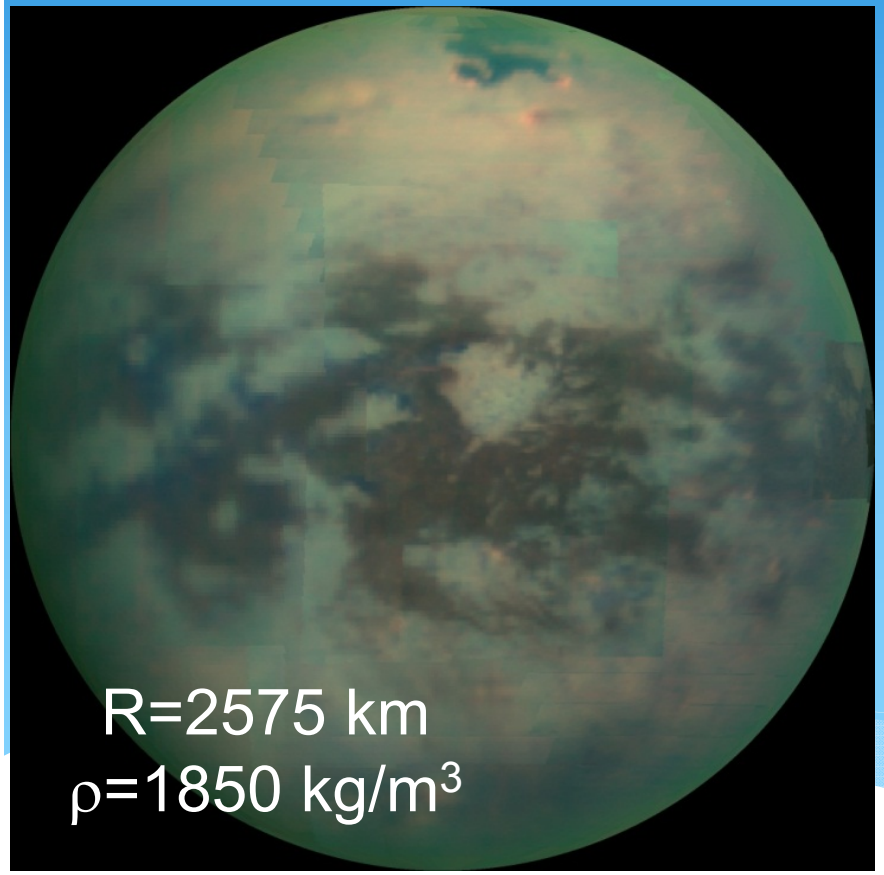
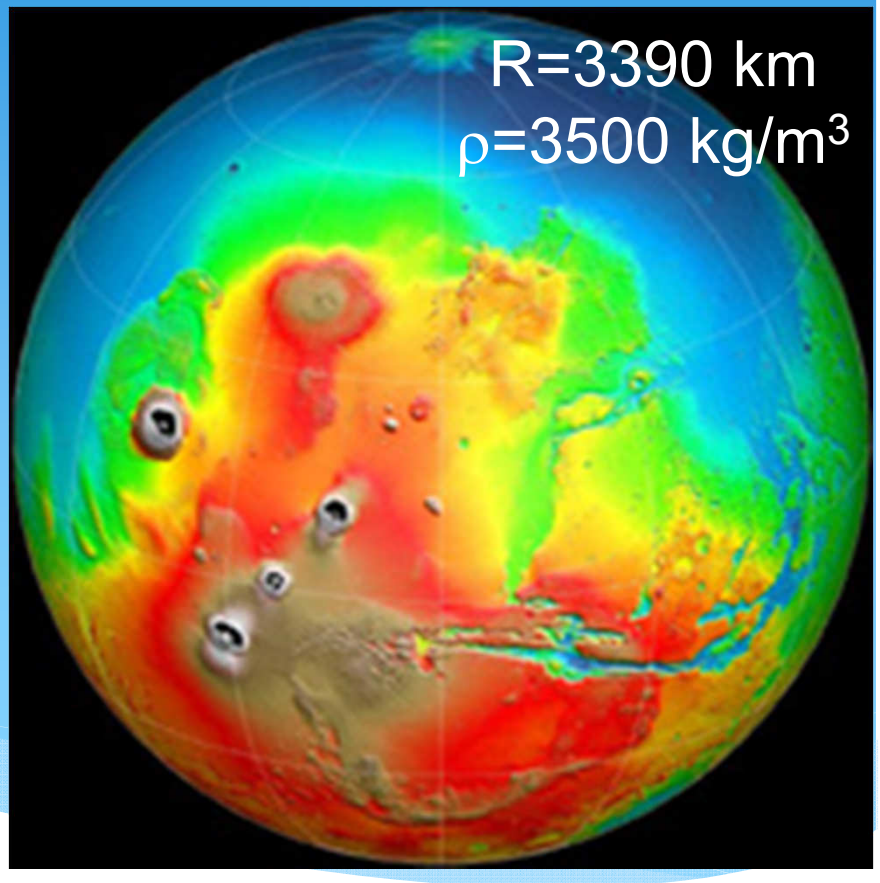


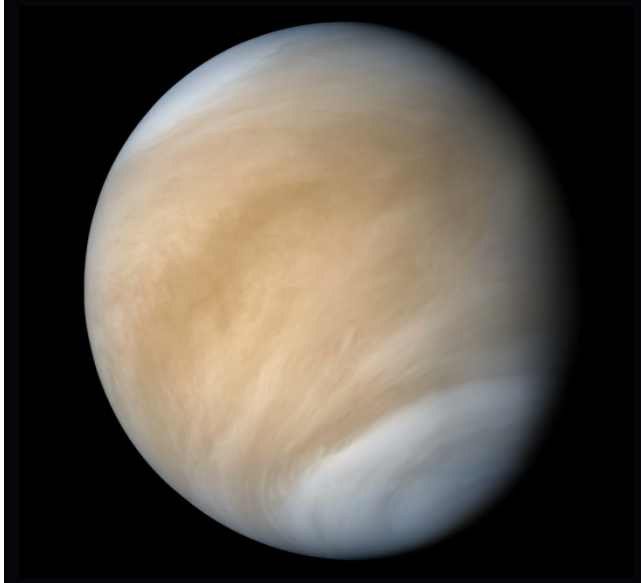




Contributions de Sue Smrekar, Mathieu Choukroun, Ashley Davies, Gabriel Tobie

# 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

# Our next door neighbor: Venus vs. Earth



Twin!

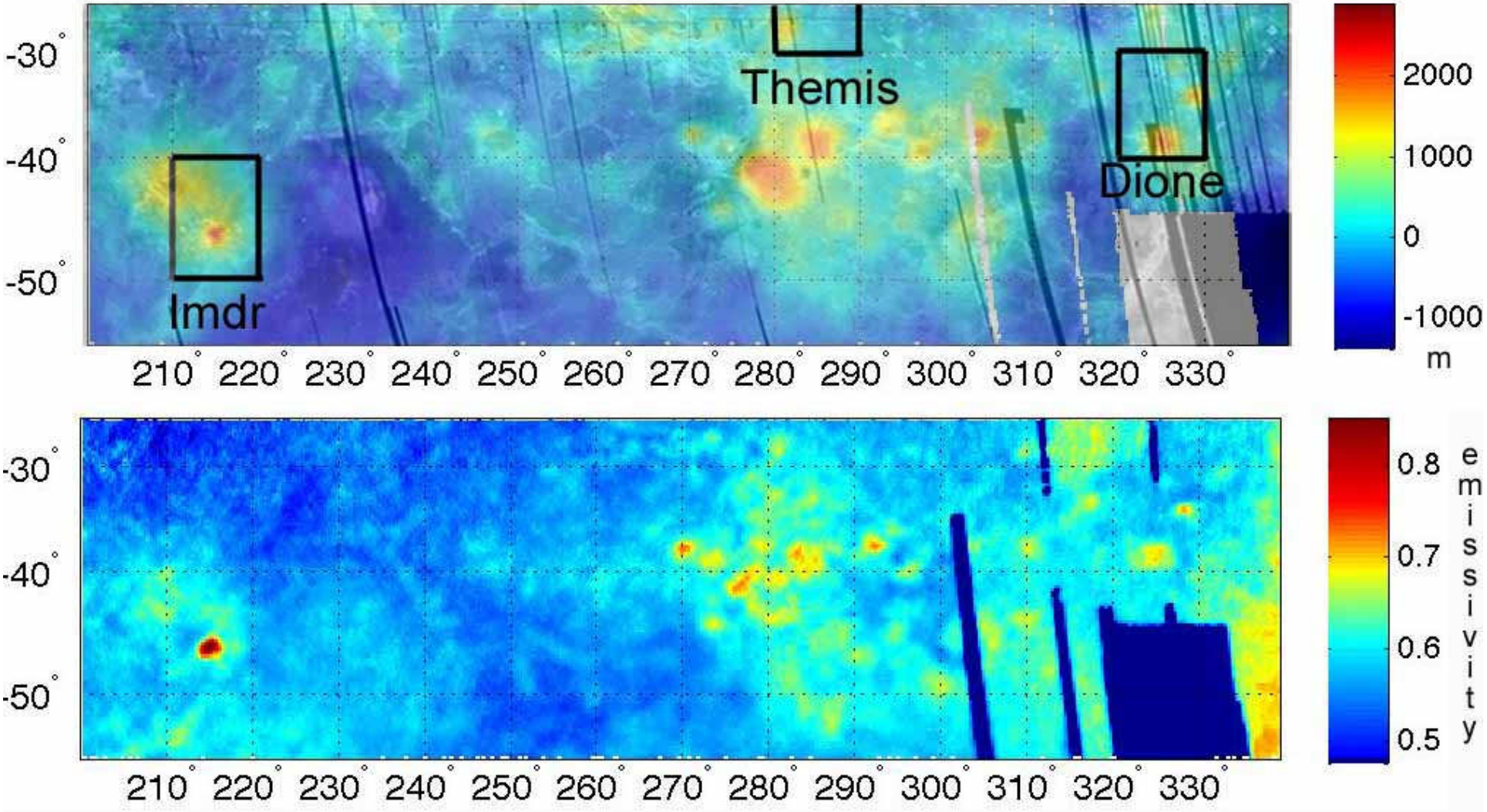
Evil!

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

Earth has 100,000 times as much water as Venus!

# Southern Hemisphere Hotspots

## Topography + SAR

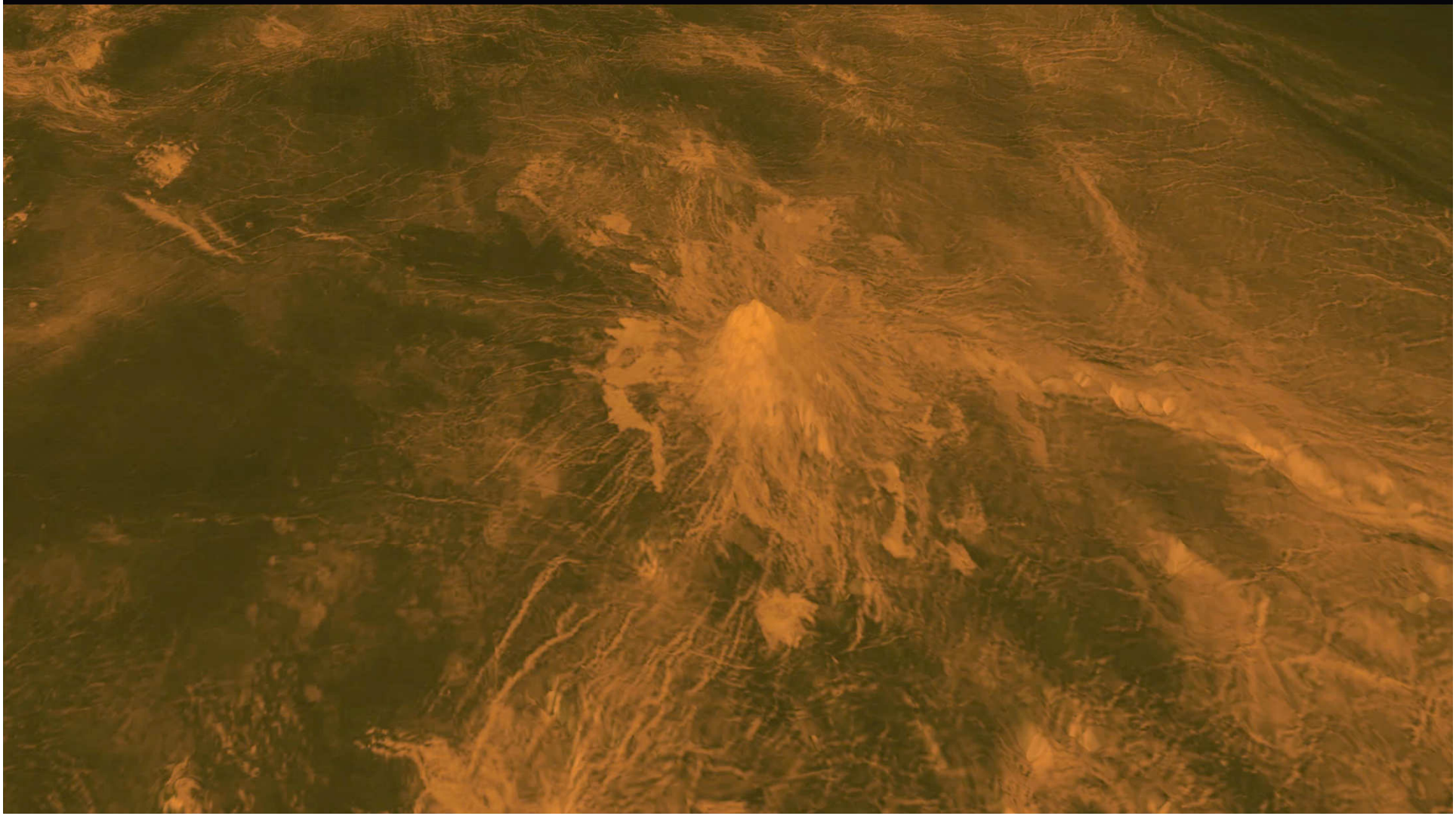



Emissivity (topo from Rappaport et al., 1999; mean emissivity set to 0.58)

# Idunn 3D

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



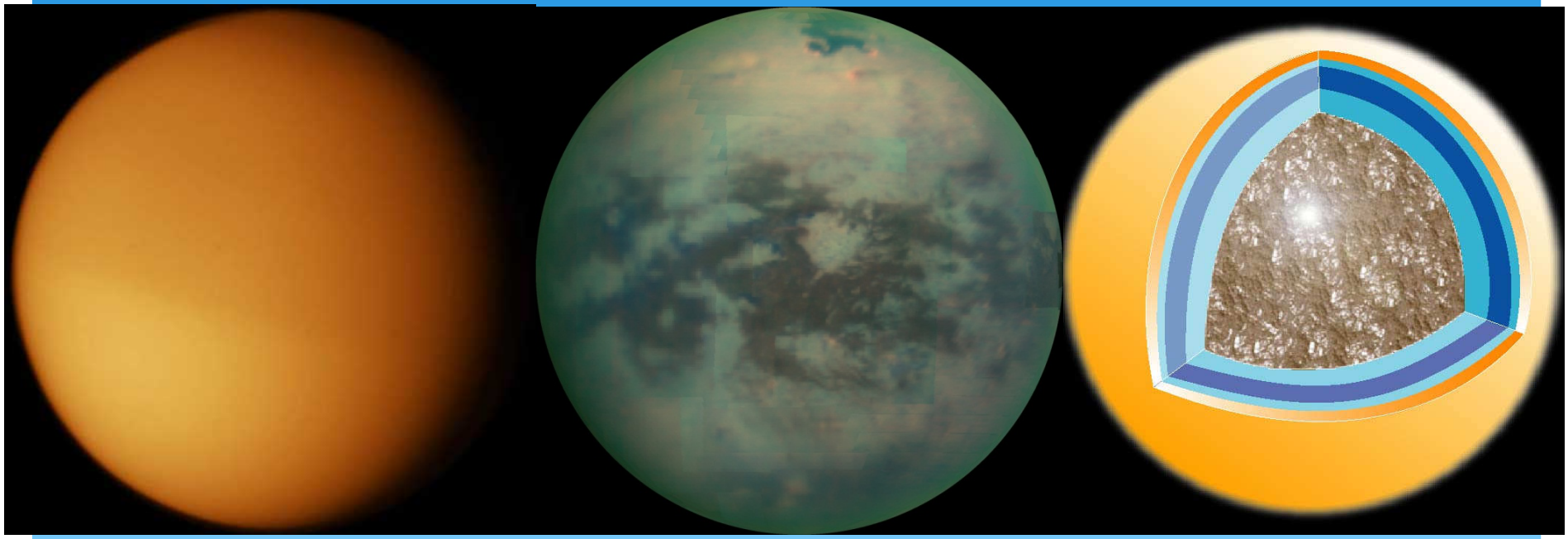
# Titan

**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**

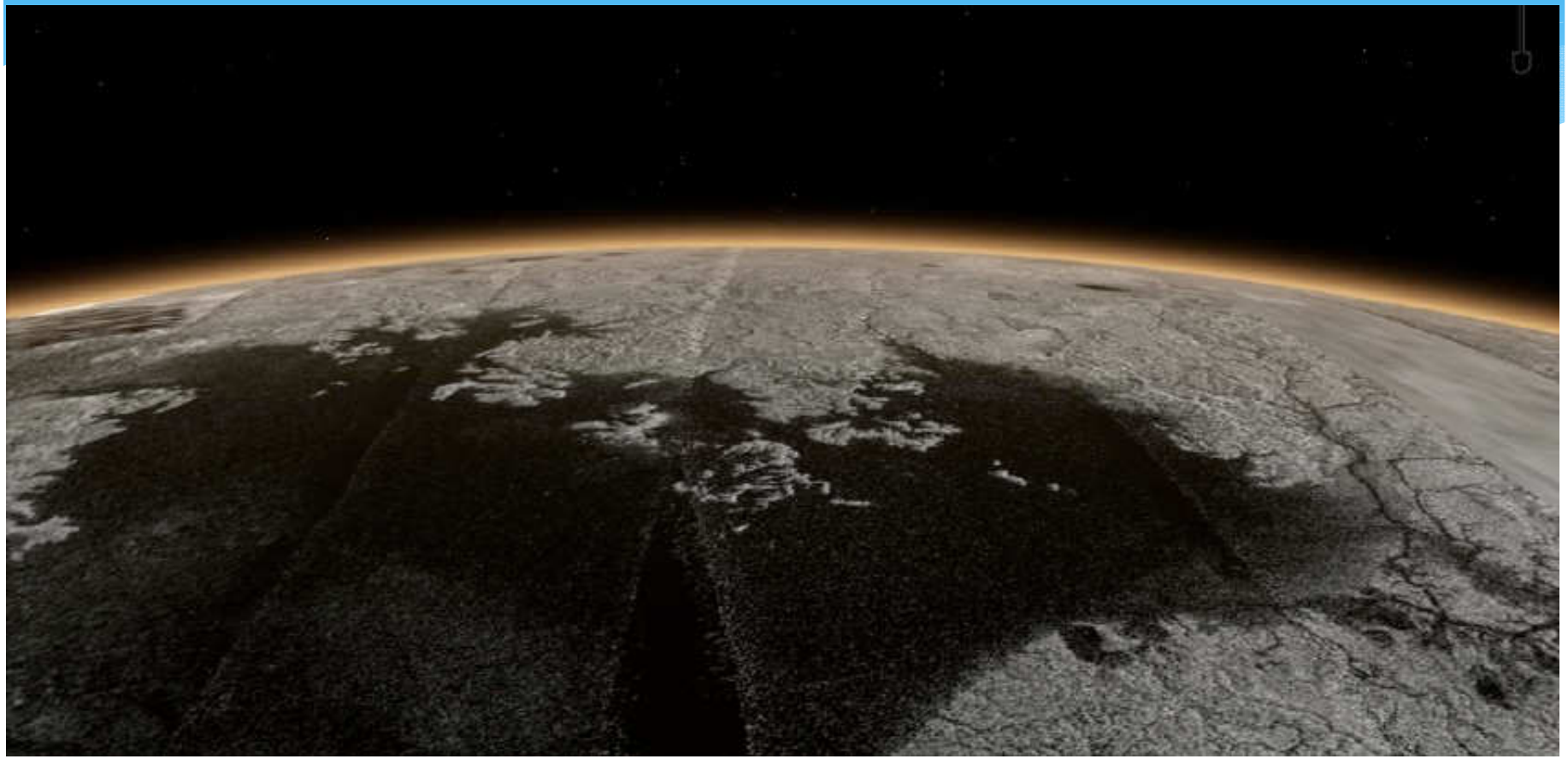
# Echanges entre l' intérieur de Titan et son atmosphère



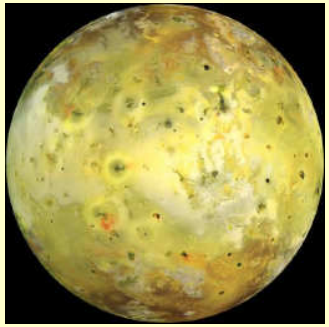
There are two observations that strongly suggest exchange processes between the interior and the atmosphere:

- 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 $^{40}Ar$ in the atmosphere because $^{40}Ar$ comes from the decay of $^{40}K$ which is present in the deep layers

# Seas and lakes of Titan



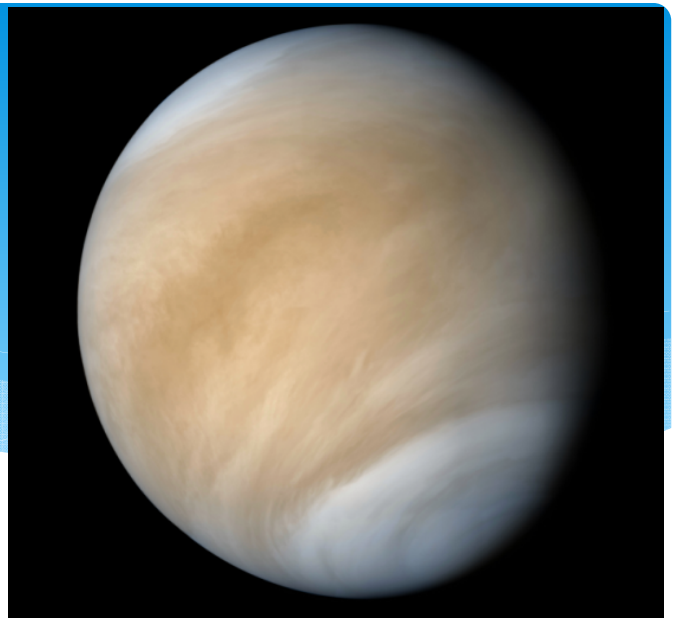
# Some characteristics compared to Earth



| 6371 km | 1822 km | 2575 km | 252.3 km |
|---|---|---|---|
| 6 $10^{24}$ kg | 0.0894 $10^{24}$ kg | 0.1345 $10^{24}$ kg | 0.000108 $10^{24}$ kg |
| 5525 kg/m$^3$ | 3528 kg/m$^3$ | 1881 kg/m$^3$ | 1608 kg/m$^3$ |
| 2/3 Silicates and 1/3 iron | Silicates | Ice and silicates | Ice and silicates |
| **42 TW** | **105 TW (>2 W/m$^2$)** | **750 GW (estimate)** | **6 GW in the South Pole area** |

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

# Outline



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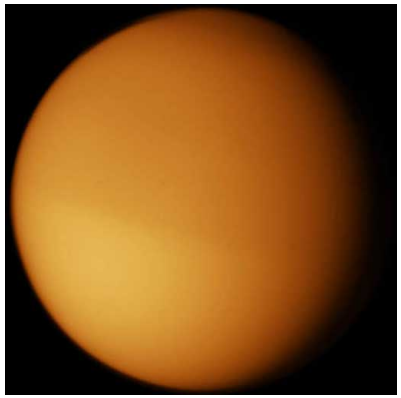
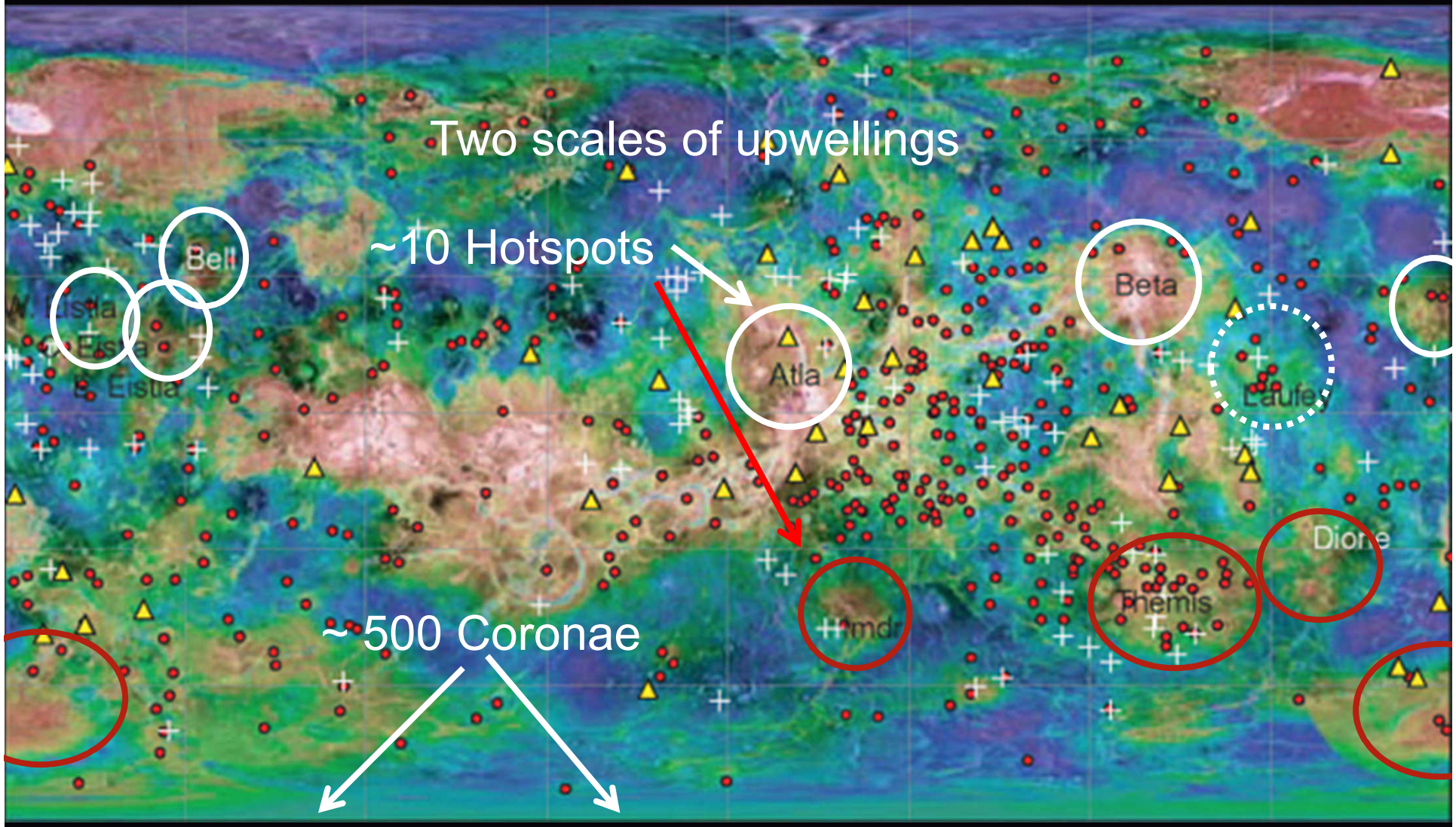
* **Interior dynamics and volcanism (exchange mechanisms)**
  * Venus: Is there active volcanism ?
  * Titan: origin of atmospheric methane and Argon?

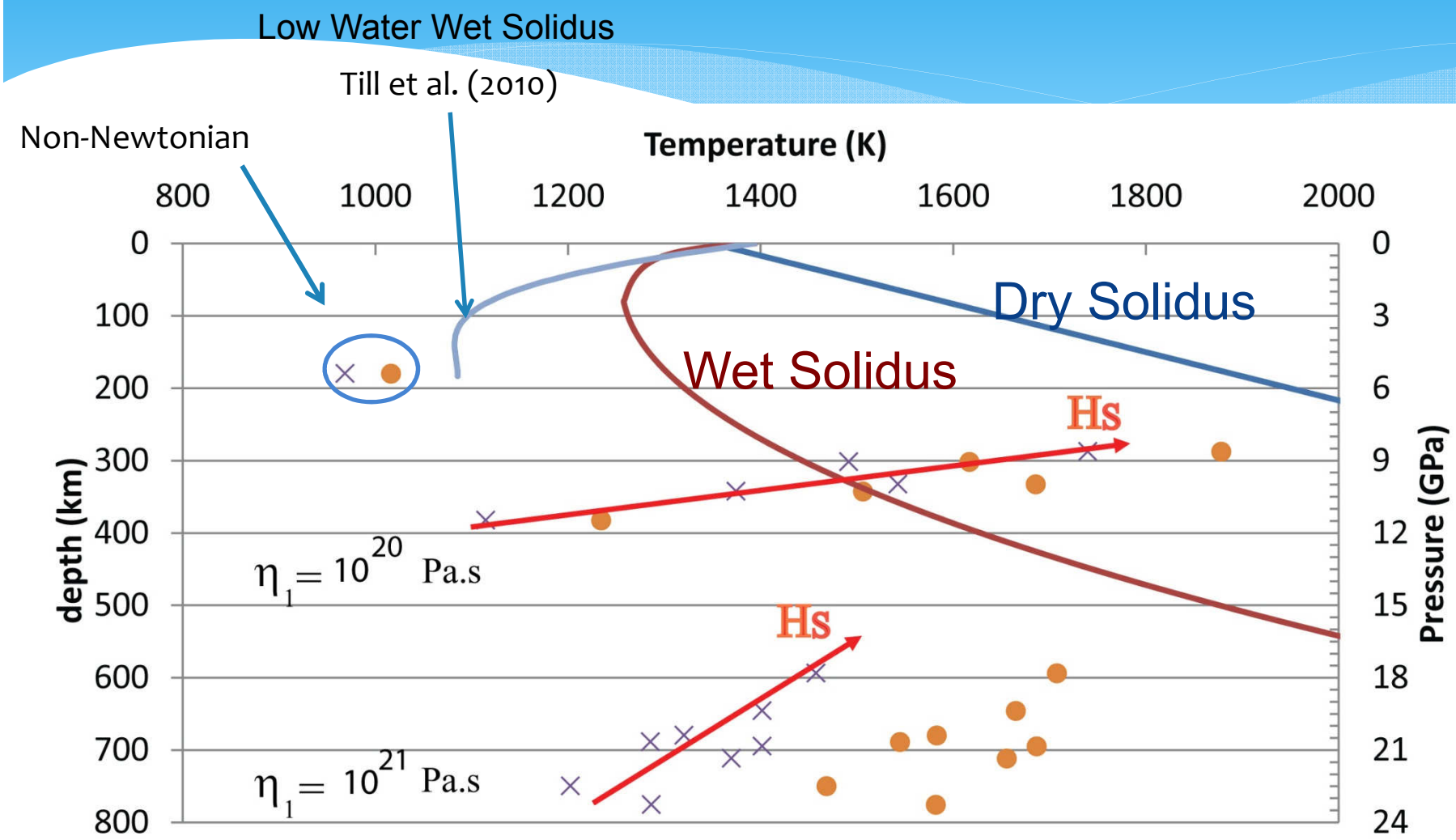


* Conclusions

# Venus Interior: Hotspots, coronae, drips…



# Volcanisme – fusion partielle en profondeur - convection




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

# Amount of outgassing

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

| | Venus | Earth | Mars |
|---|---|---|---|
| $^{40}Ar$ in atm (kg) | 1.6 (±0.5) $10^{16}$ | 6.6 $10^{16}$ | 5 $10^{14}$ |
| $^{40}Ar$ (kg/kg planet) | 3.3 $10^{-9}$ | 1.11 $10^{-8}$ | 7.9 $10^{-10}$ |
| $^{40}Ar$/Si | 1.7 $10^{-8}$ | 5.2 $10^{-8}$ | 4.1 $10^{-9}$ |
| potential $^{40}Ar$(kg) | 6.8 $10^{16}$ | 1.4 – 1.56 $10^{17}$ | 1.6 $10^{16}$ |
| $^{40}Ar$ atm / potential | 24 (±10)% | 42-56 % | 3% |

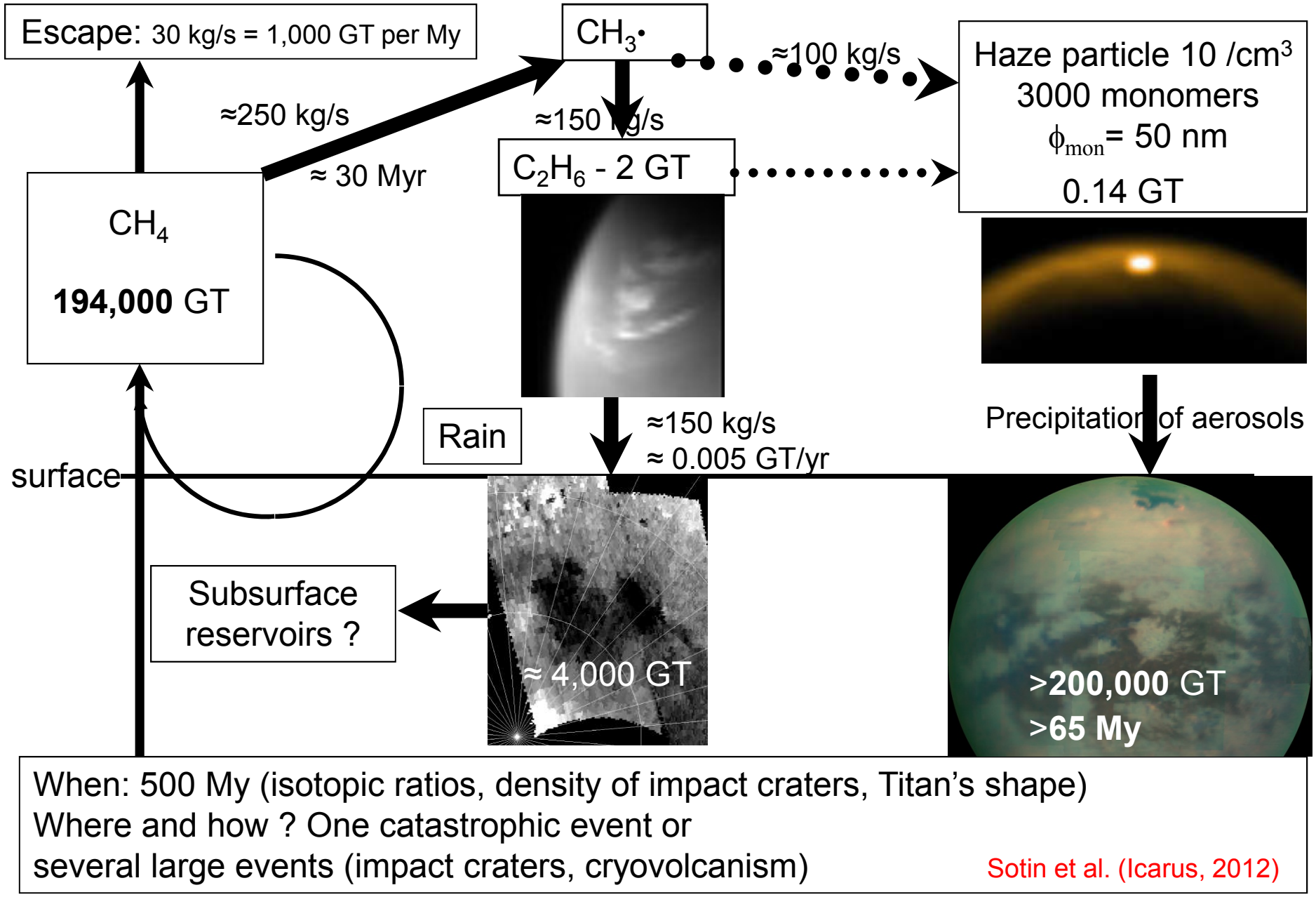
**Is the recent resurfacing due to plumes raising from the Core/Mantle boundary (CMB) ?**

# Amount of water in the atmosphere

* 0.3-1.0 ppmv $H_2O$ 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 $10^{15}$ 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)

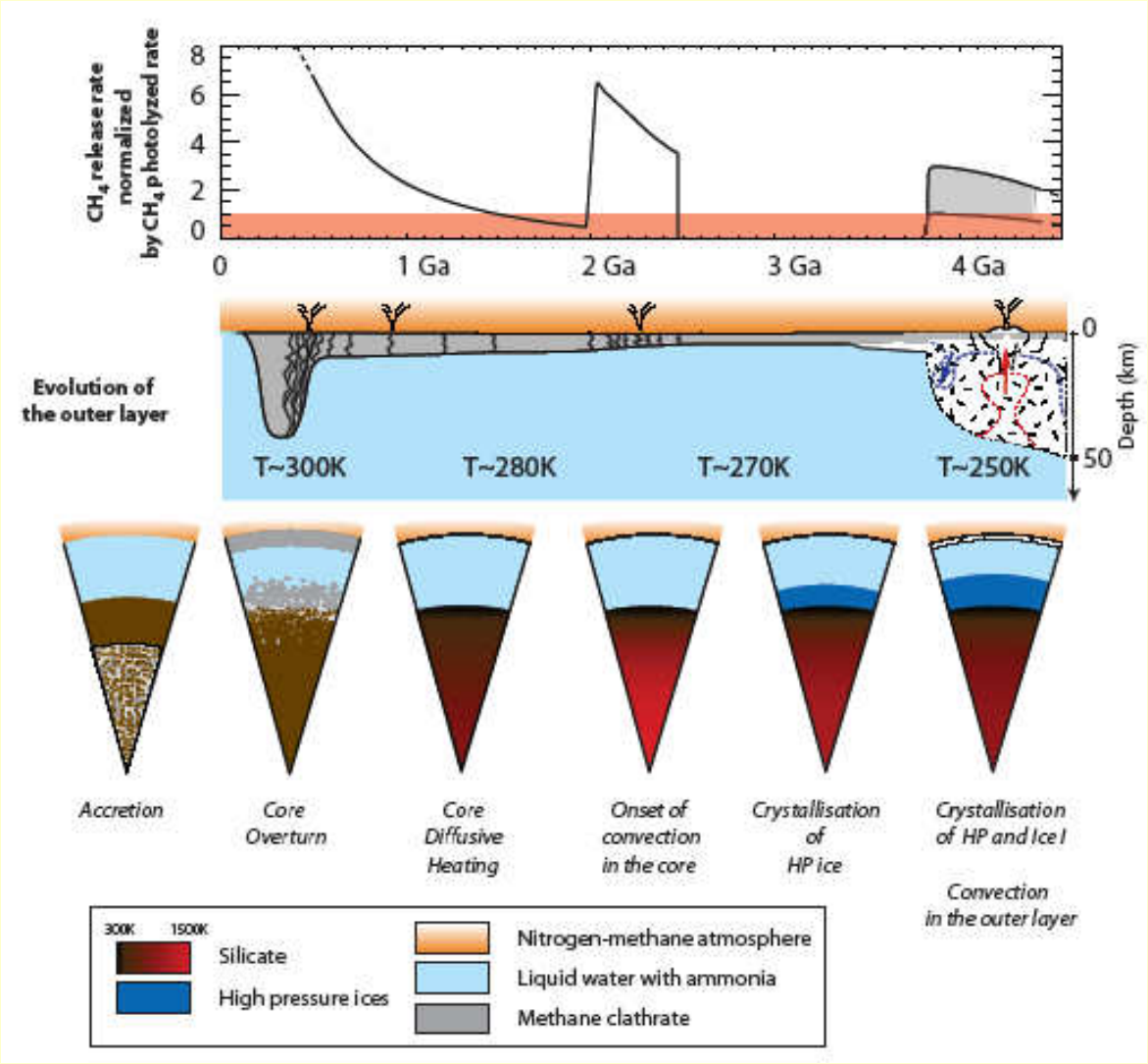
# Outgassing of Argon

- 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).

| | Venus | Earth | Mars | Titan |
|---|---|---|---|---|
| $^{40}$Ar in atm (kg) | 1.6 (±0.5) $10^{16}$ | 6.6 $10^{16}$ | 5 $10^{14}$ | 5.4 $10^{14}$ |
| $^{40}$Ar (kg/kg planet) | 3.3 $10^{-9}$ | 1.11 $10^{-8}$ | 7.9 $10^{-10}$ | 4.95 $10^{-9}$ |
| $^{40}$Ar/Si | 1.7 $10^{-8}$ | 5.2 $10^{-8}$ | 4.1 $10^{-9}$ | 3.43 $10^{-8}$ |
| potential $^{40}$Ar(kg) | 6.8 $10^{16}$ | 1.4 – 1.56 $10^{17}$ | 1.6 $10^{16}$ | 2.0 $10^{15}$ |
| $^{40}$Ar atm / potential | 24 (±10)% | 42-56 % | 3% | 27% |

**When was 40Ar released in the atmosphere ? At the same time CH4 was released?**

# Internal dynamics and evolution




(Tobie et al. 2006)

- atmospheric composition
- models of subsolidus convection
- different considerations (high eccentricity = tidal dissipation is minimum)

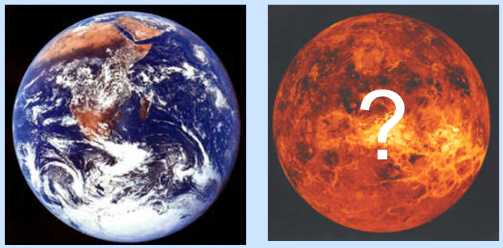
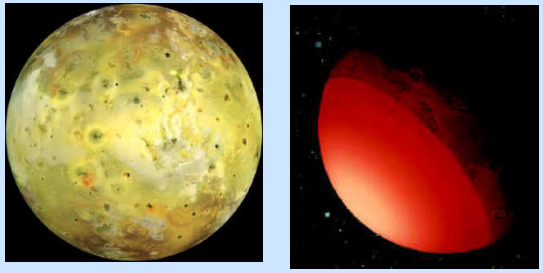
3 periods during which volatiles (methane) can be present

- During accretion
- Onset of onvection in the silicate core
- Onset of convection in the outer ice layer

# Conclusions (1/2)

* 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

# Conclusions (2/2)

| 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