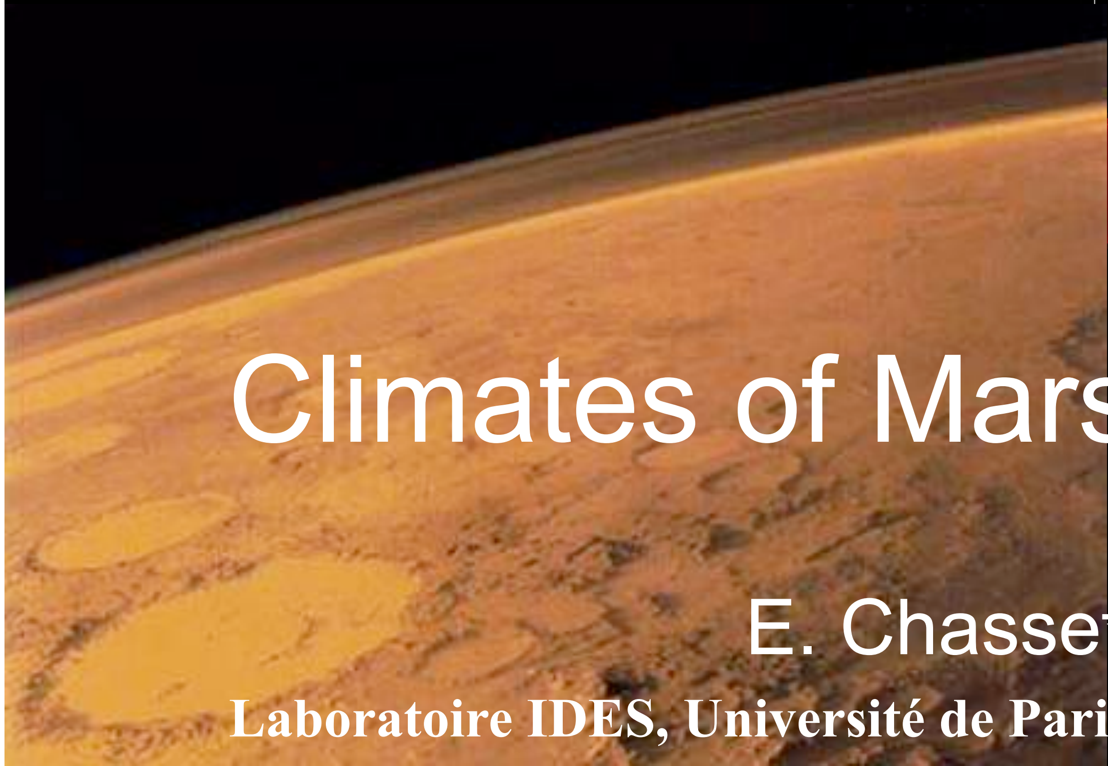

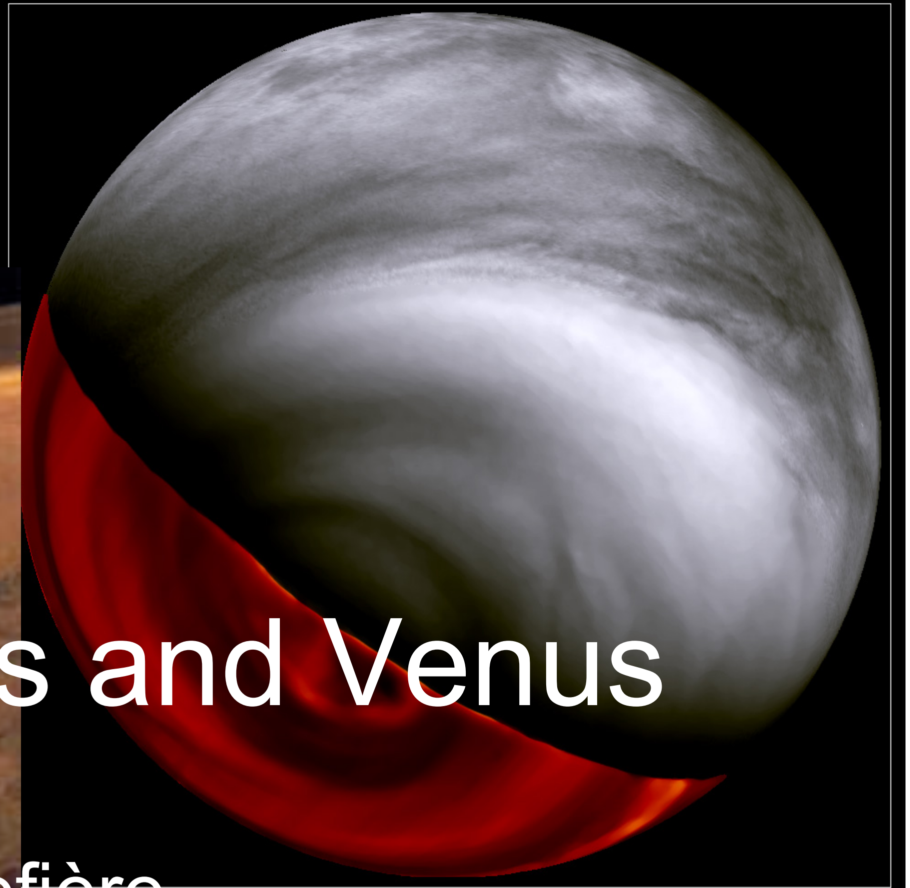

# Climates of Mars and Venus

E. Chassefière

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Interactions et Dynamique des Environnements de Surface

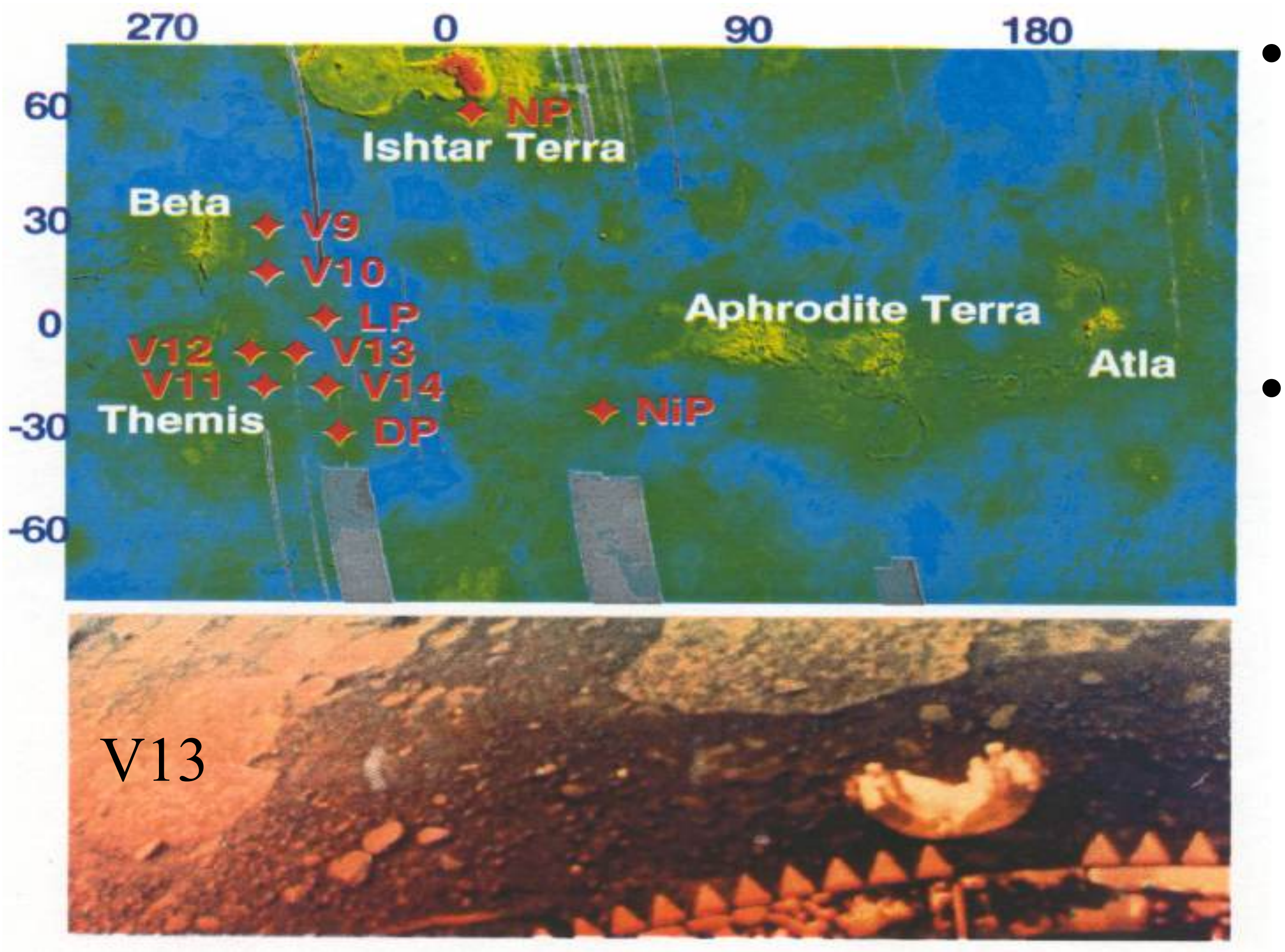
UNIVERSITÉ PARIS-SUD 11

CNRS

**Second ESA-CAS Mars Advanced School in China, 12-22 September 2011, Weihai, Shandong, China**

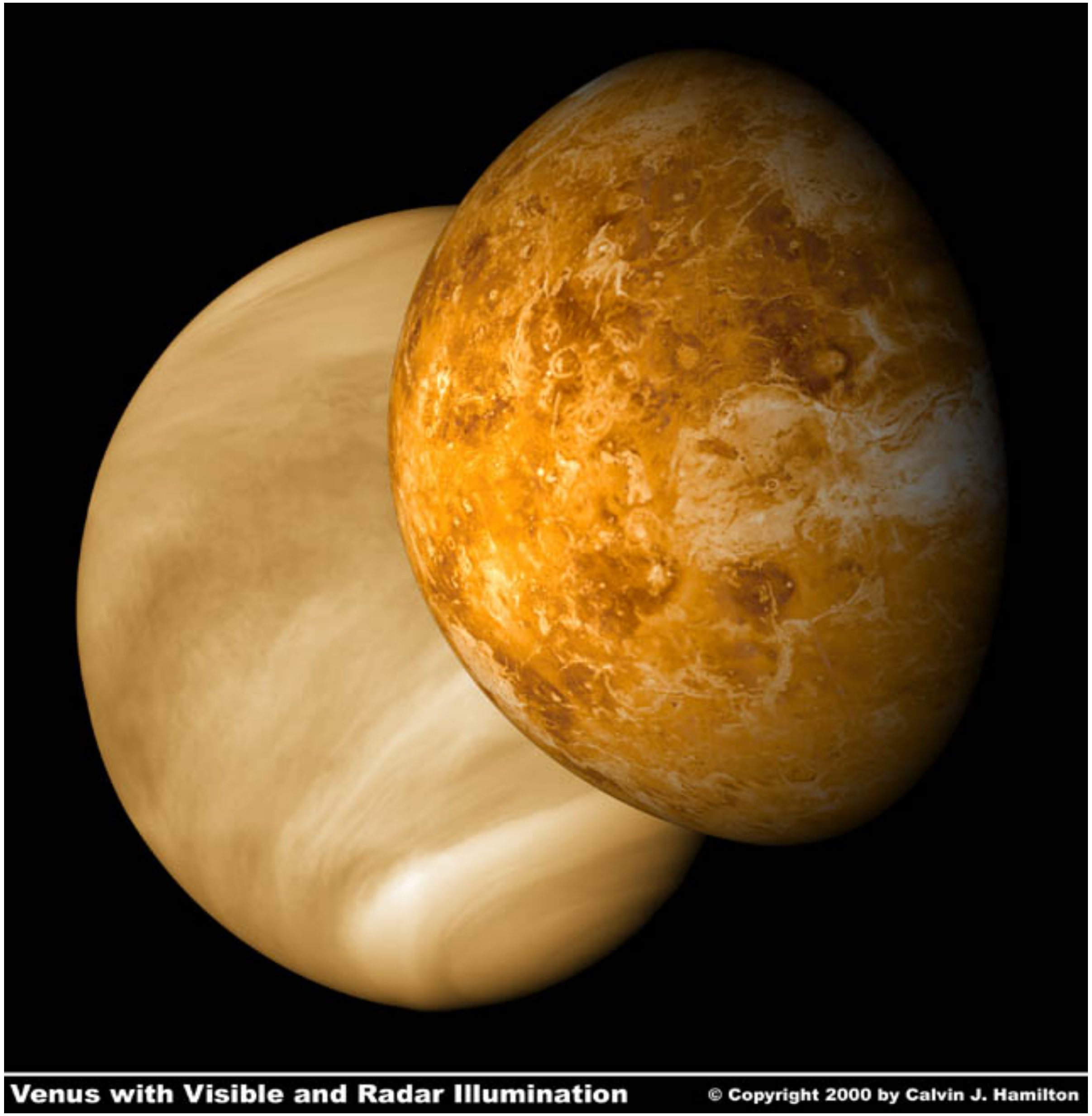
|  | Venus | Earth | Mars |
|---|---|---|---|
| Distance Sun-planet | 0,7 | 1 | 1,5 |
| Radius | 0,95 | 1 | 0,54 |
| Mass | 0,815 | 1 | 0,107 |
| Volumic mass (kg/m$^3$) | 5250 | 5515 | 3940 |
| Uncompressed volumic mass (kg/m$^3$) | 4000 | 4100 | 3800 |
| Core radius | 0,55 | 0,546 | 0,5 |

# Space exploration of Venus

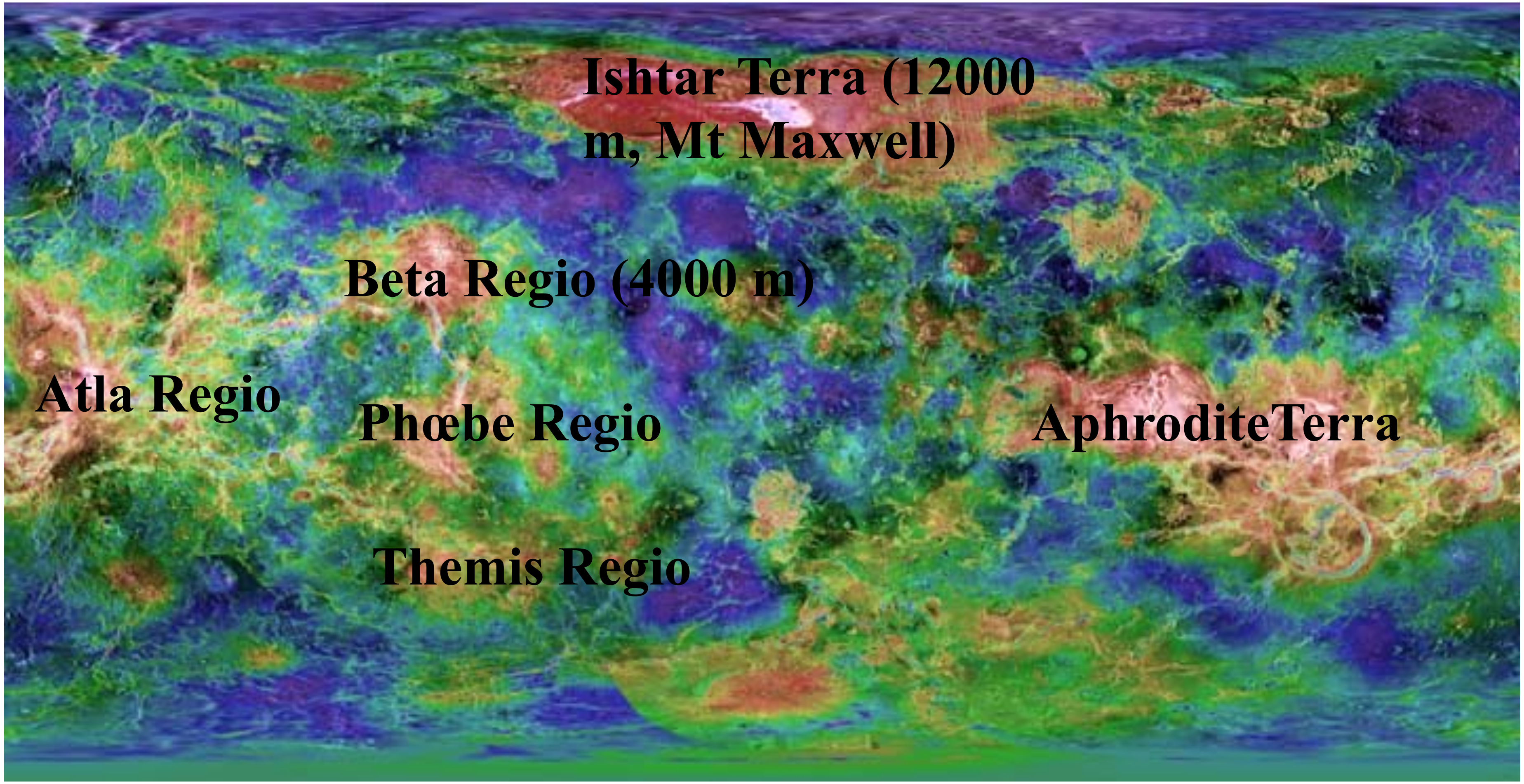



- 1974 : landing of 3 soviet probes : $T_s$=470°C, $p_s$ = 90 bars ($CO_2$).
- Photography of the surface, then radar mapping(V15/16 , Magellan at the beginning of nineties)

Compared images in the visible (Mariner 10) and obtained by radar sounding(Magellan)



# Magellan topographic map of Venus



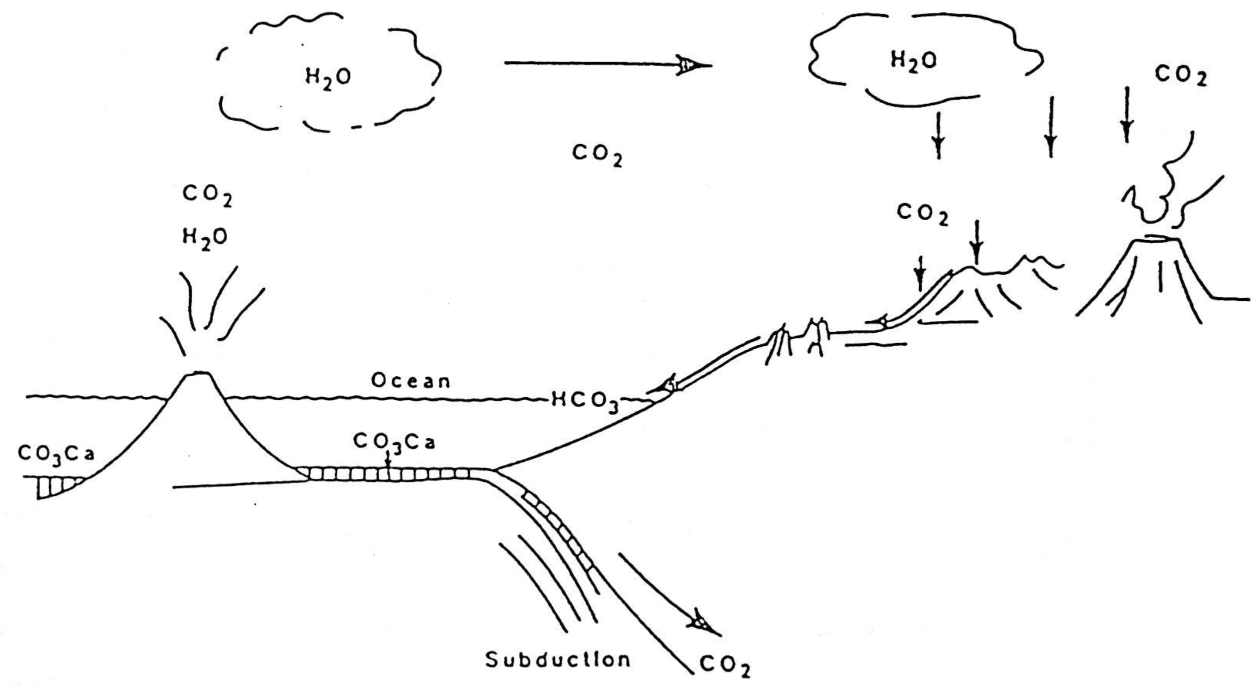
# Compared composition of the atmospheres of terrestrial planets

| Gaz | PLANÈTE | | | |
|---|---|---|---|---|
| | *Vénus* | *Terre sans vie* | *Mars* | *Terre actuelle* |
| Gaz carbonique | 96,5 % | 98 % | 95 % | 0,03 % |
| Azote | 3,5 % | 1,9 % | 2,7 % | 79 % |
| Oxygène | traces | 0,0 | 0,13 % | 21 % |
| Argon | 70 ppm * | 0,1 % | 1,6 % | 1 % |
| Méthane | 0,0 | 0,0 | 0,0 | 1,7 ppm * |
| Températures en surface (°C) | 459 | 240-340 | – 53 | 13 |
| Pression totale (bars) | 90 | 60 | 0,0064 | 1,0 |

* ppm : parties par million.

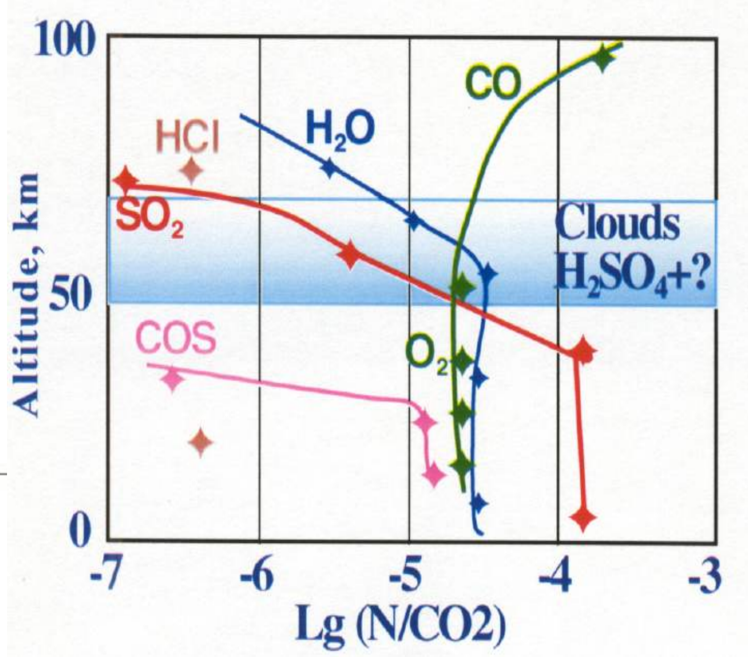
VENUS AND EARTH ARE SISTER PLANETS

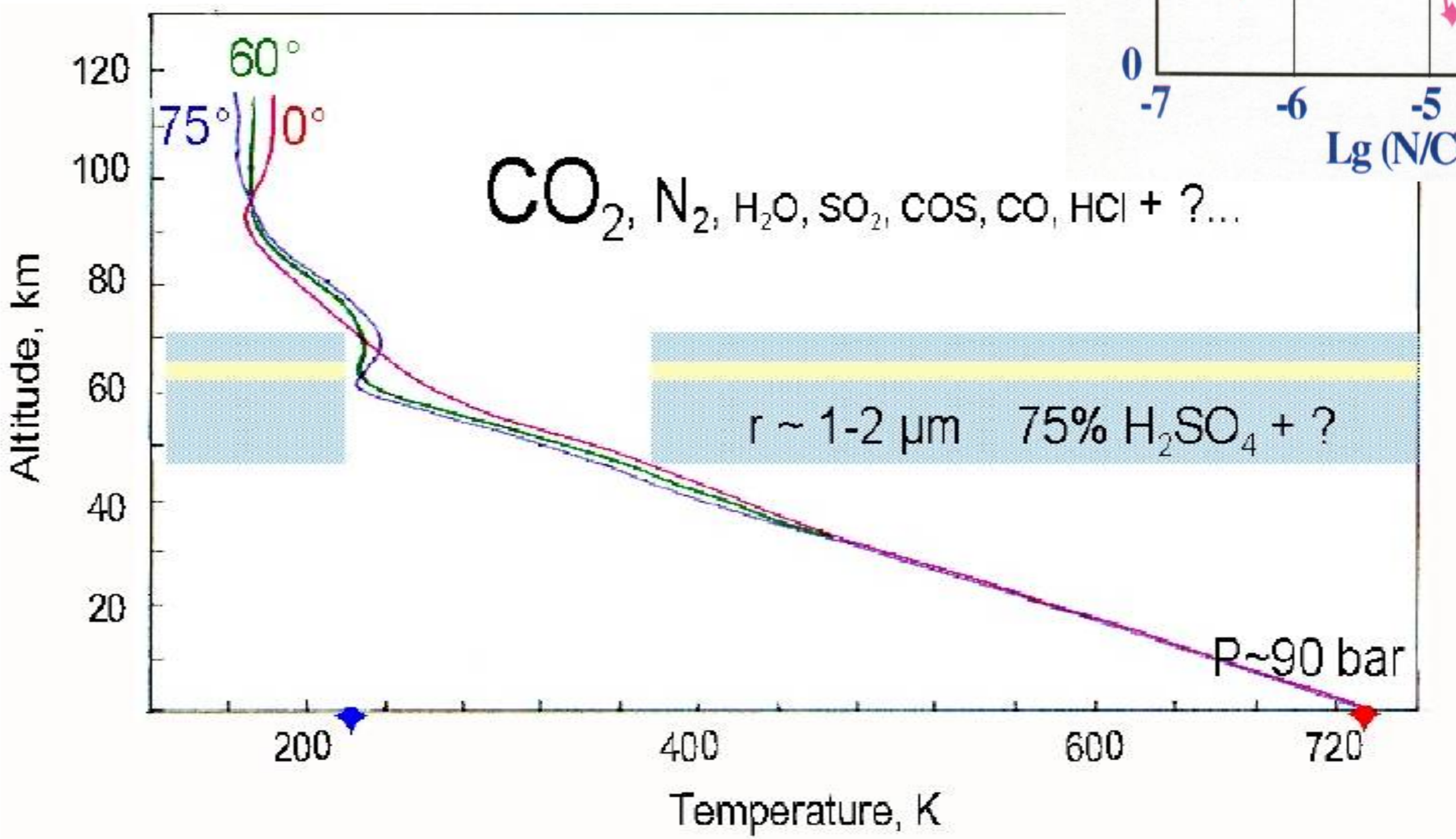
# Global scale carbon cycle on Earth



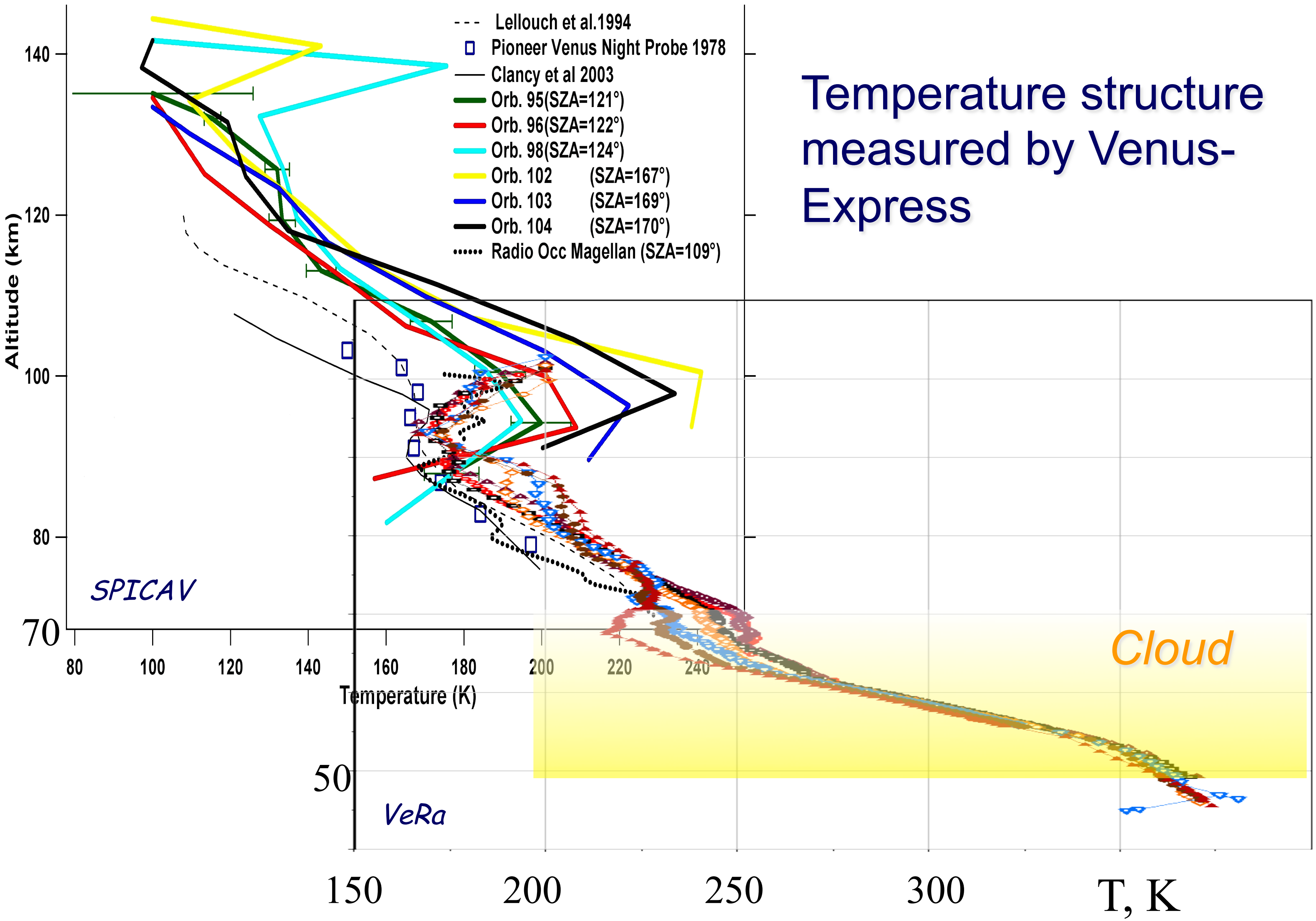

- Most of Earth's carbon dioxide is sequestrated in limestone
- Mars : $CO_2$ partly escaped to space, but mostly trapped in the subsurface (carbonates?).
- Vénus : Most $CO_2$ presently in the atmosphere (?) due to hot atmosphere and subsurface.

# Vertical structure and composition

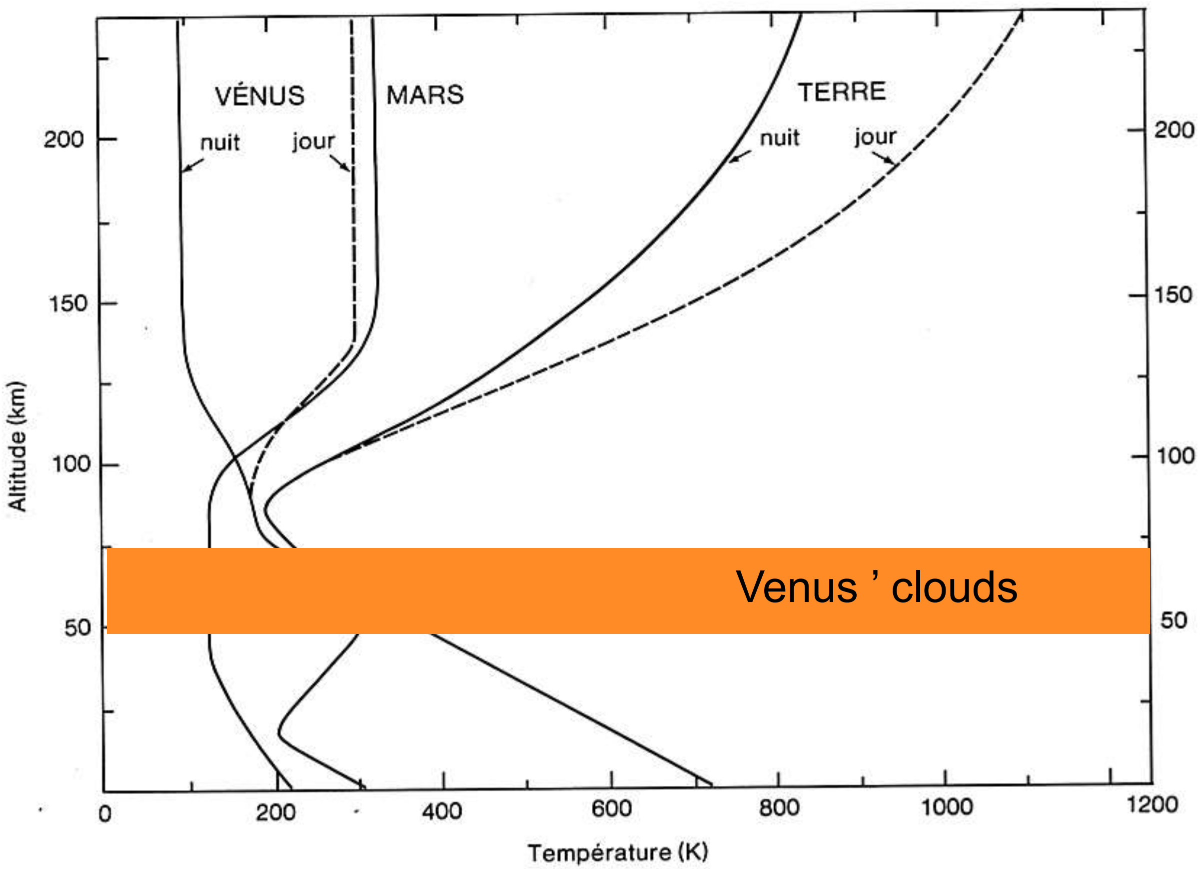


# Temperature structure measured by Venus-Express

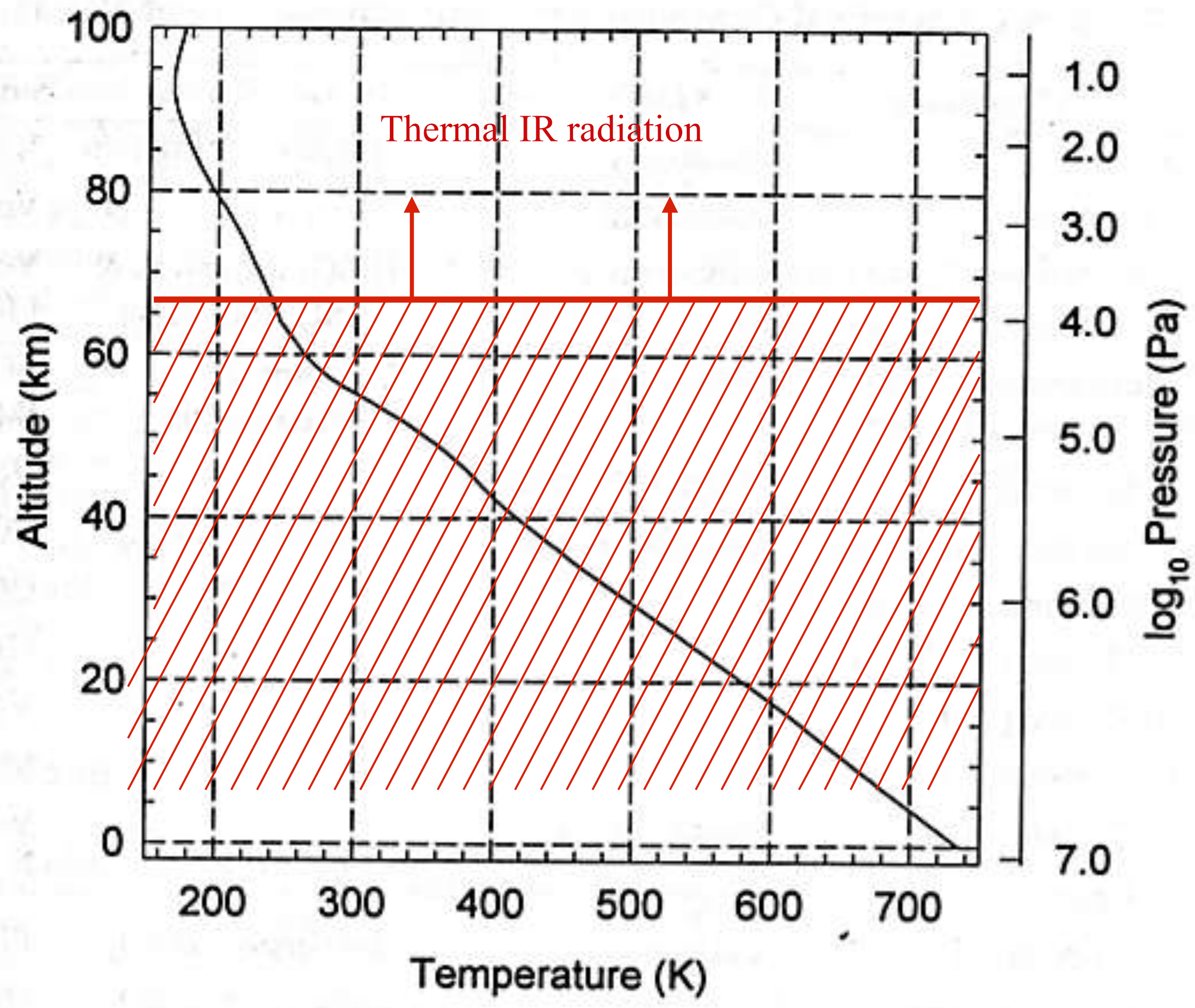


# Compared thermal structures of the atmospheres of the three terrestrial planets



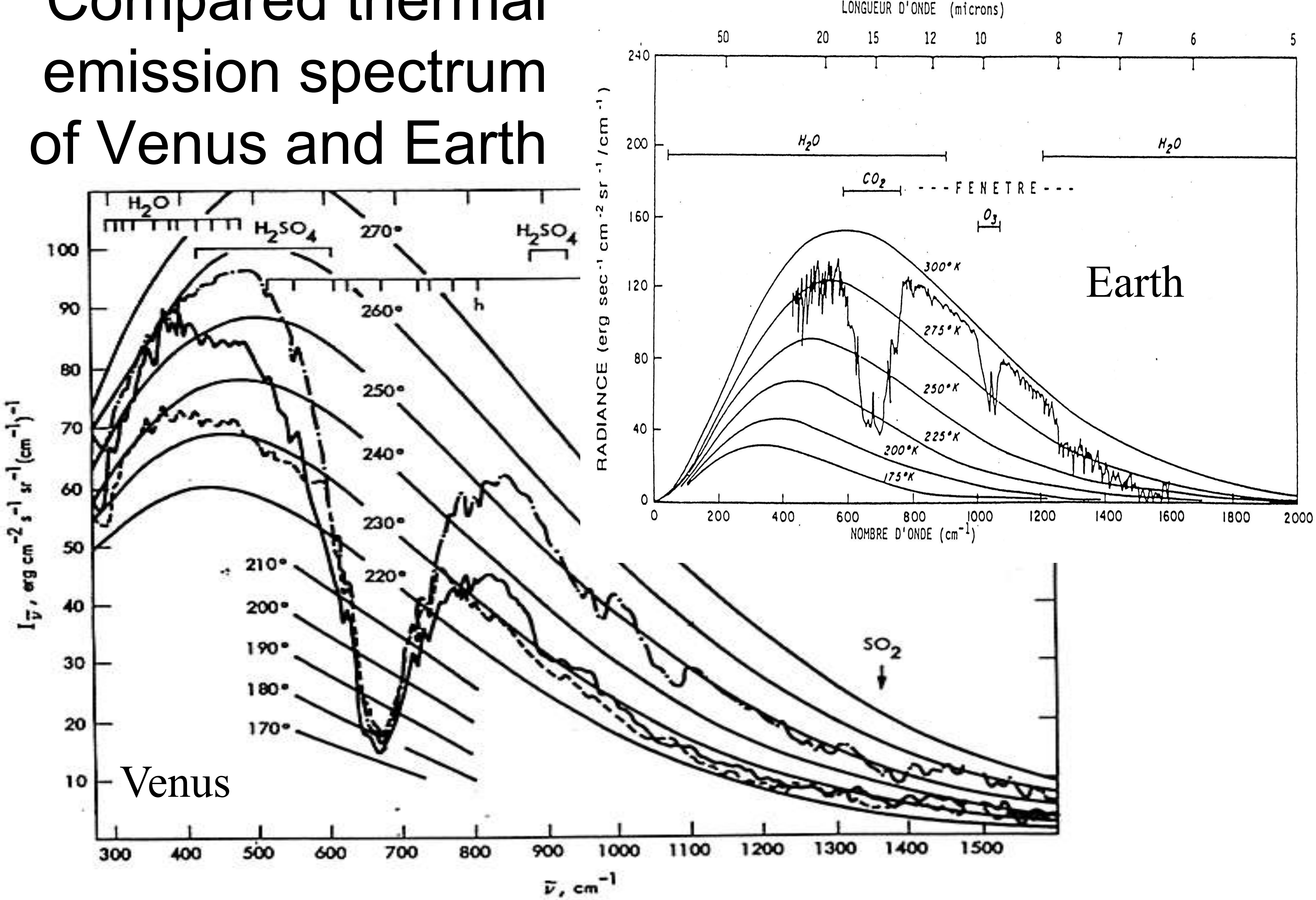

- P, T conditions at the top of Venus' clouds similar to conditions on Earth and Mars.
- No stratosphere on Venus and Mars (due to $O_3$ on Earth)

# Atmospheric thermal structure and IR radiation




- The radiative temperature of Venus (230 K) is the atmospheric temperature at 100 mbar (65 km) at cloud top.

# Compared thermal emission spectrum of Venus and Earth

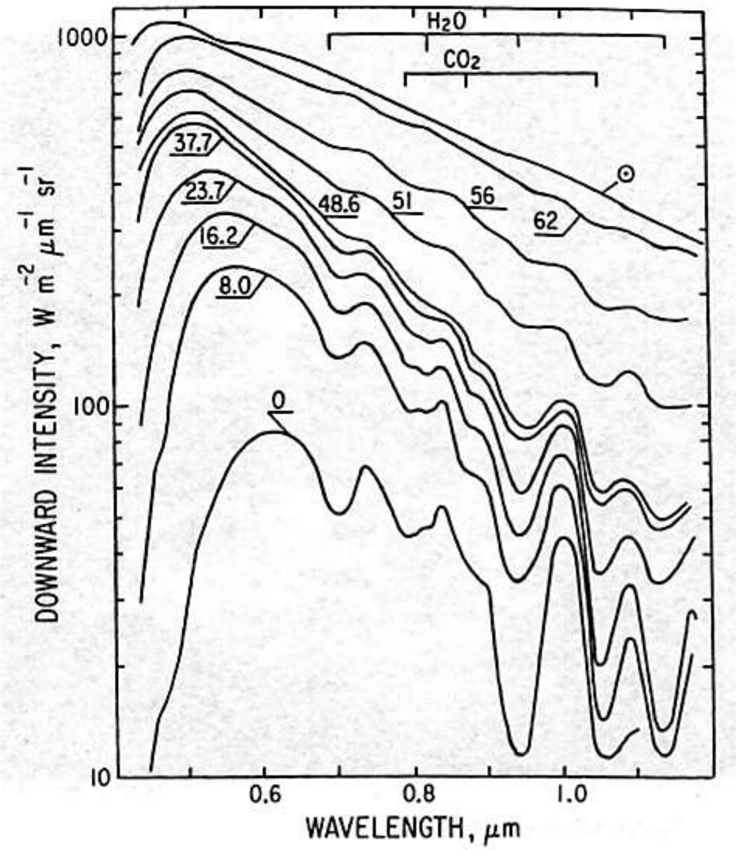


# Greenhouse effect on the 3 terrestrial planets

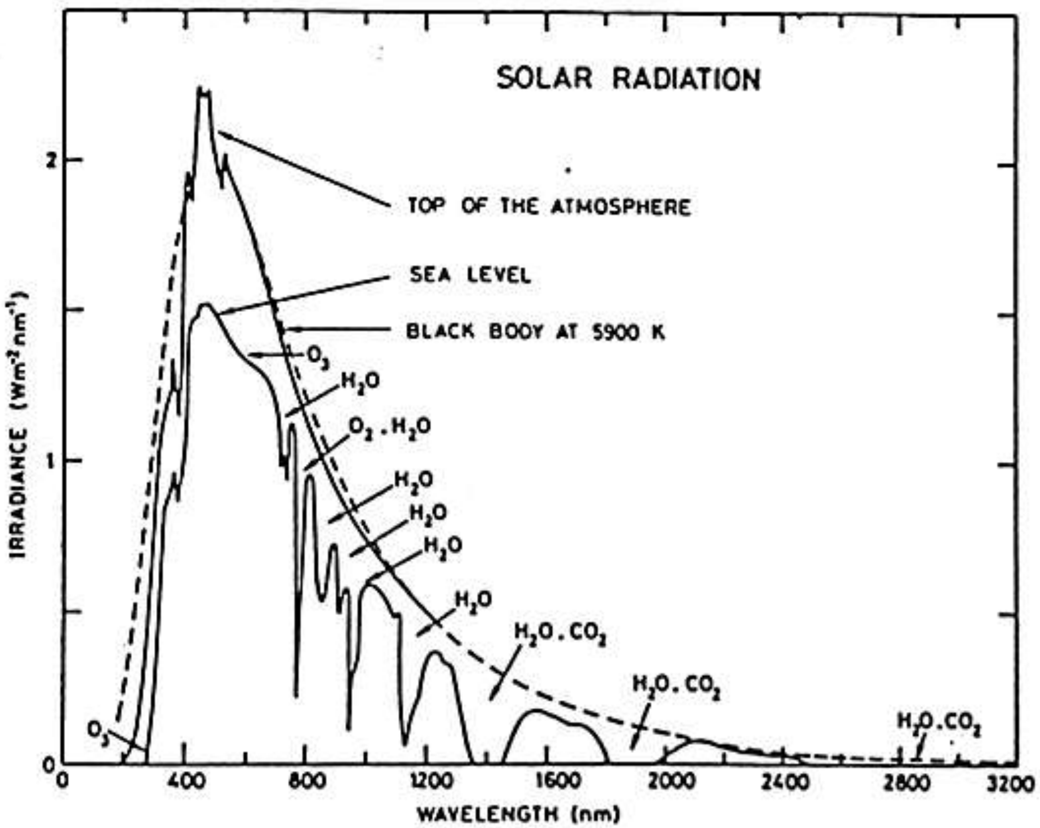
| | Venus | Earth | Mars |
|---|---|---|---|
| Surface temperature | 735 K | 288 K | 218 K |
| Effective temperature | 230 K | 255 K | 215 K |
| Involved greenhouse gases | $CO_2$, $H_2O$, $SO_2$, CO and clouds $H_2SO_4$ | $H_2O$, $CO_2$, $O_3$, … | $CO_2$ |
| $\Delta T$ | +505 K | +33 K | +3 K |

# Attenuation of solar radiation by Venus' atmosphere

Venus' case




Earth's case



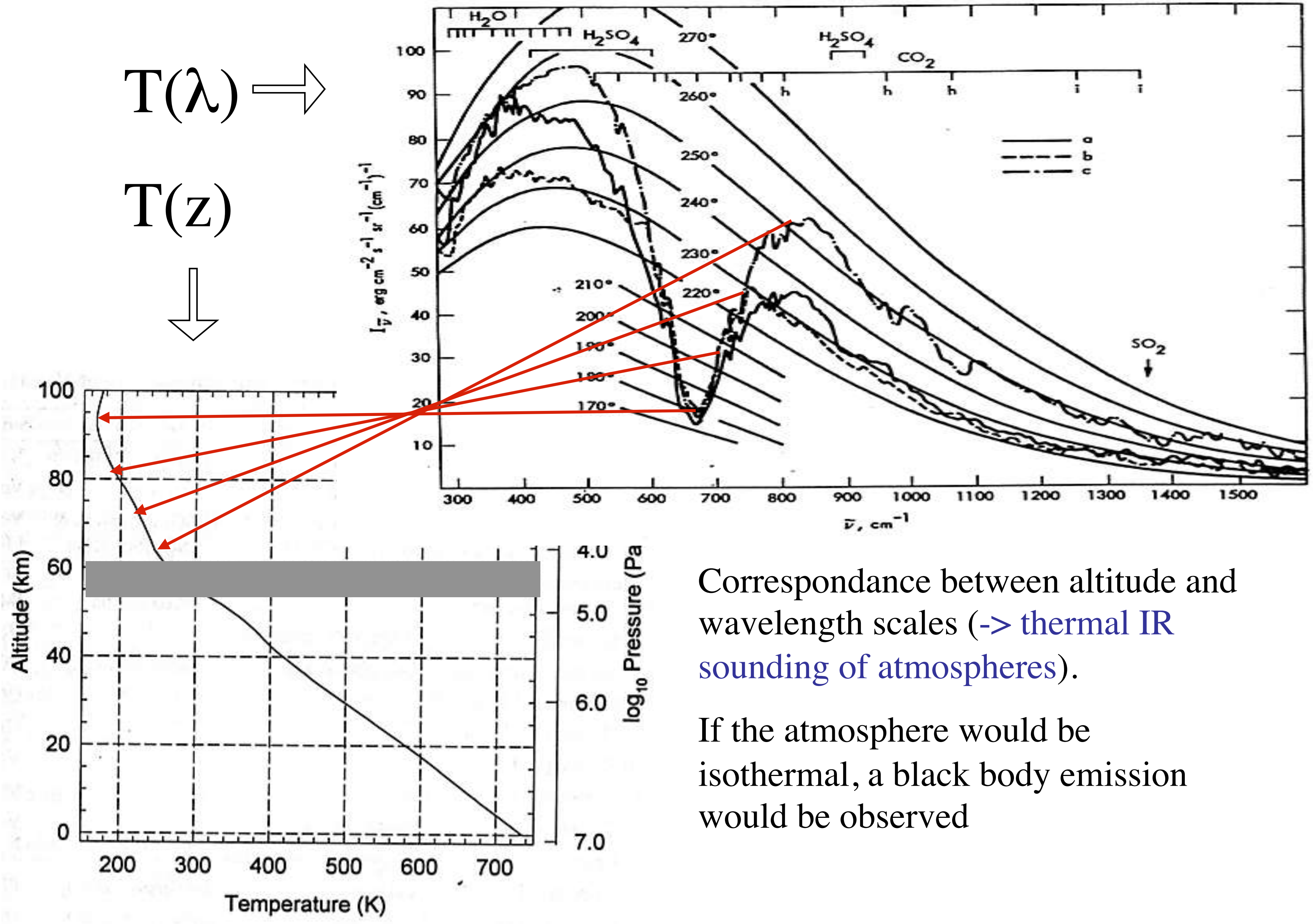

Less than 10% of solar radiation can reach Venus' surface

# Principle of atmospheric IR sounding

T(λ) ⇒

T(z)

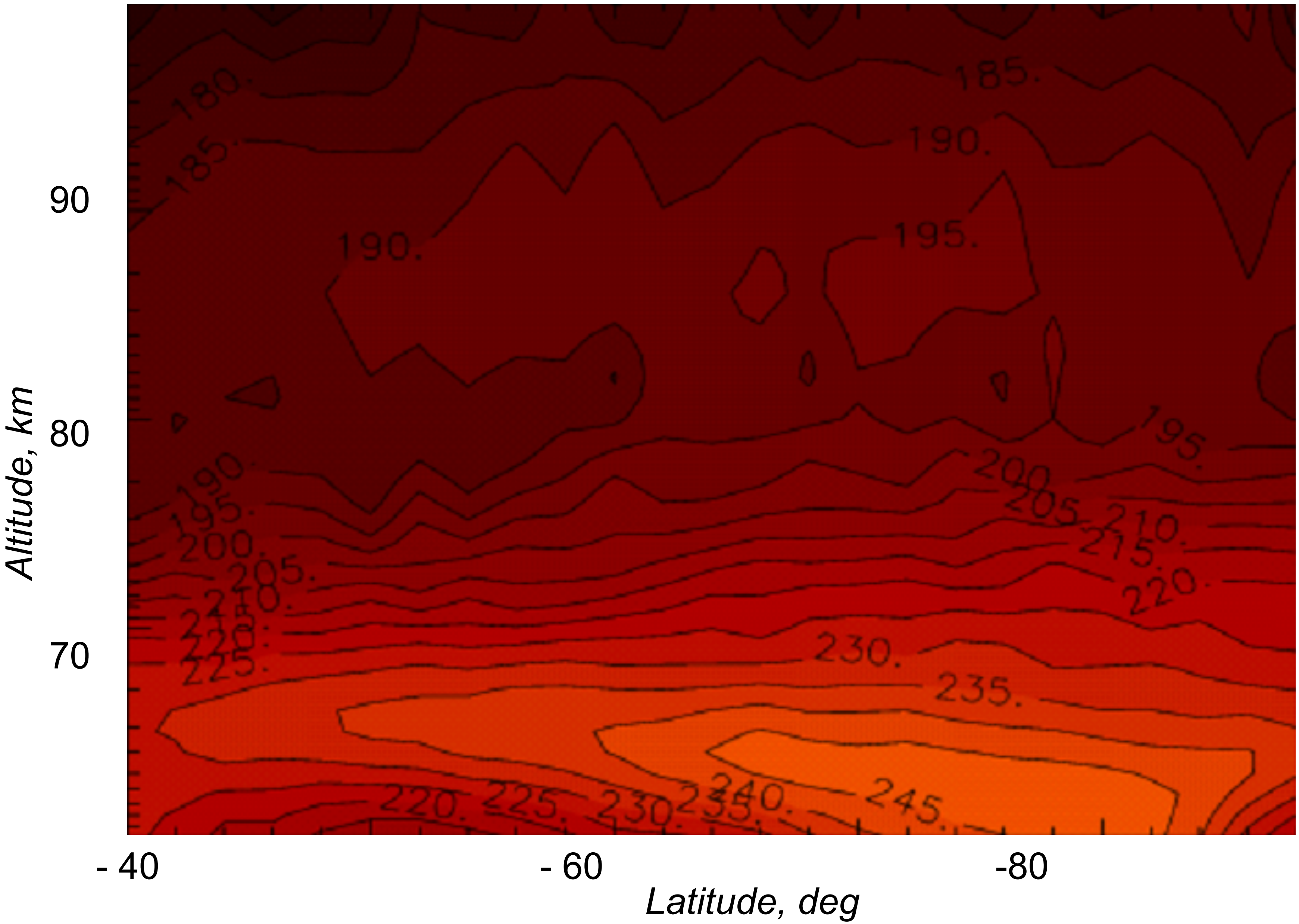
⇓




Correspondance between altitude and wavelength scales (-> thermal IR sounding of atmospheres).

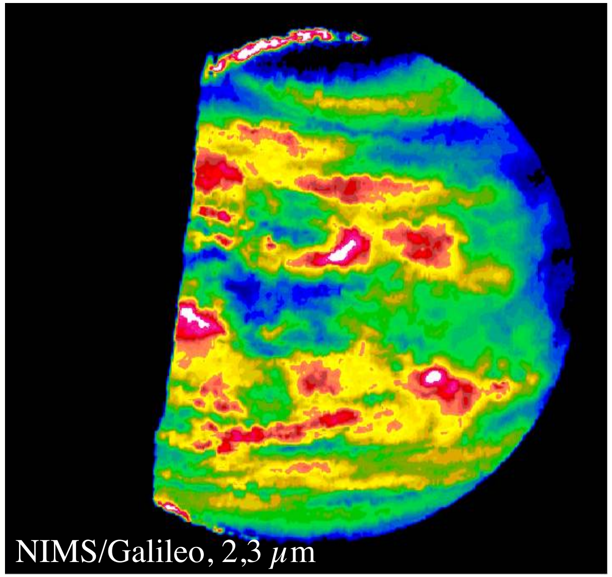
If the atmosphere would be isothermal, a black body emission would be observed

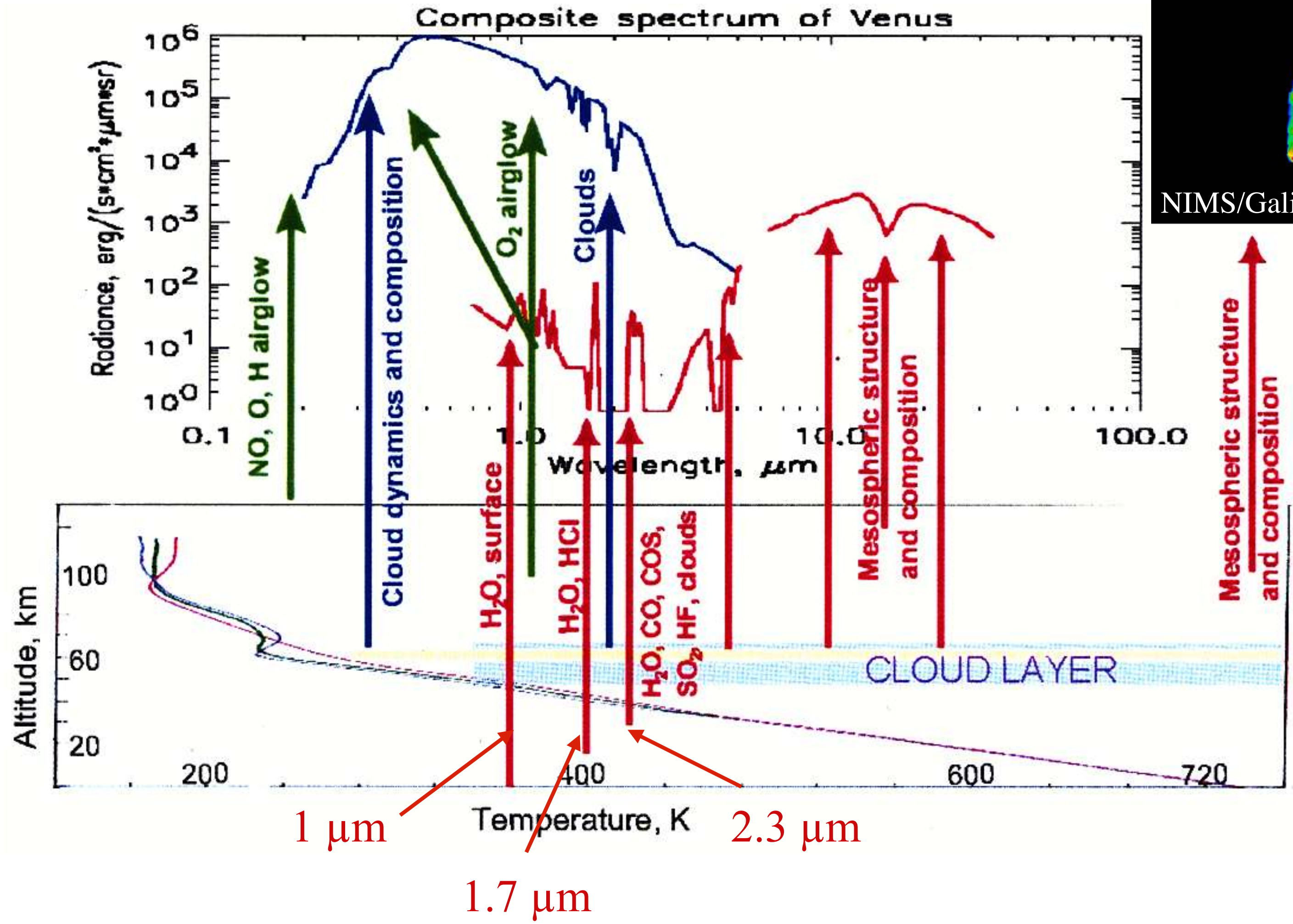
# Temperature sounding in the 4.3 μm $CO_2$ band by VIRTIS



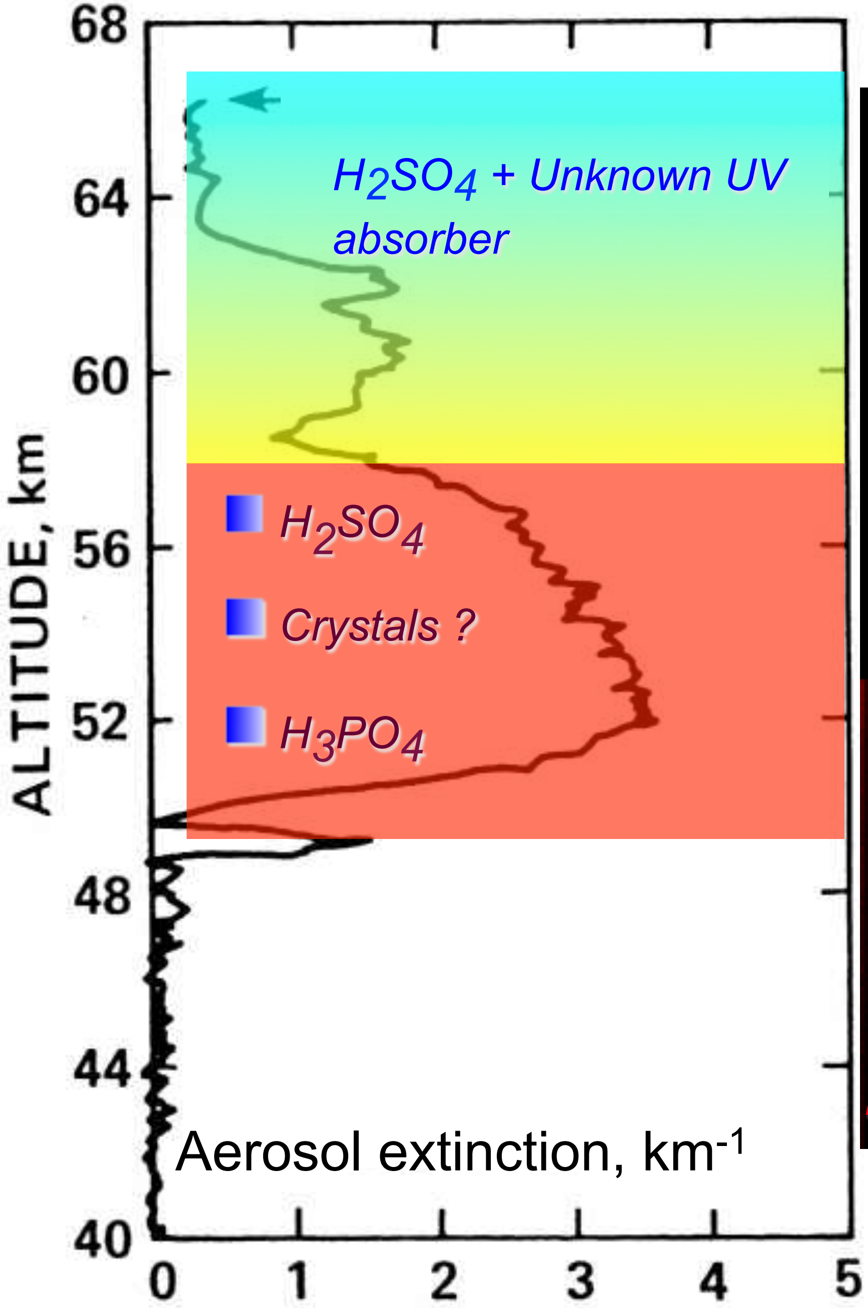

*Grassi and the VIRTIS Team*

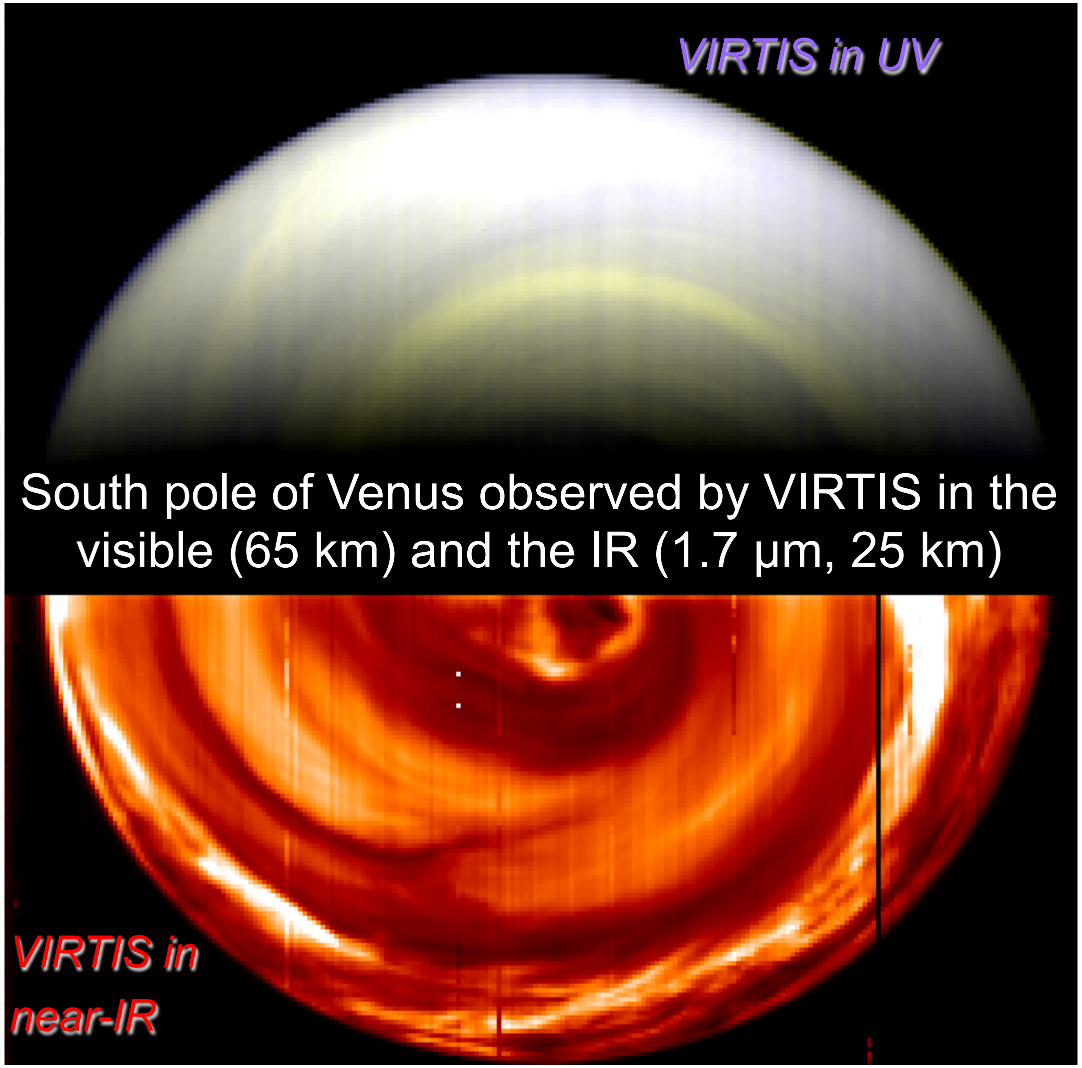
# Outgoing thermal radiation : transparency windows



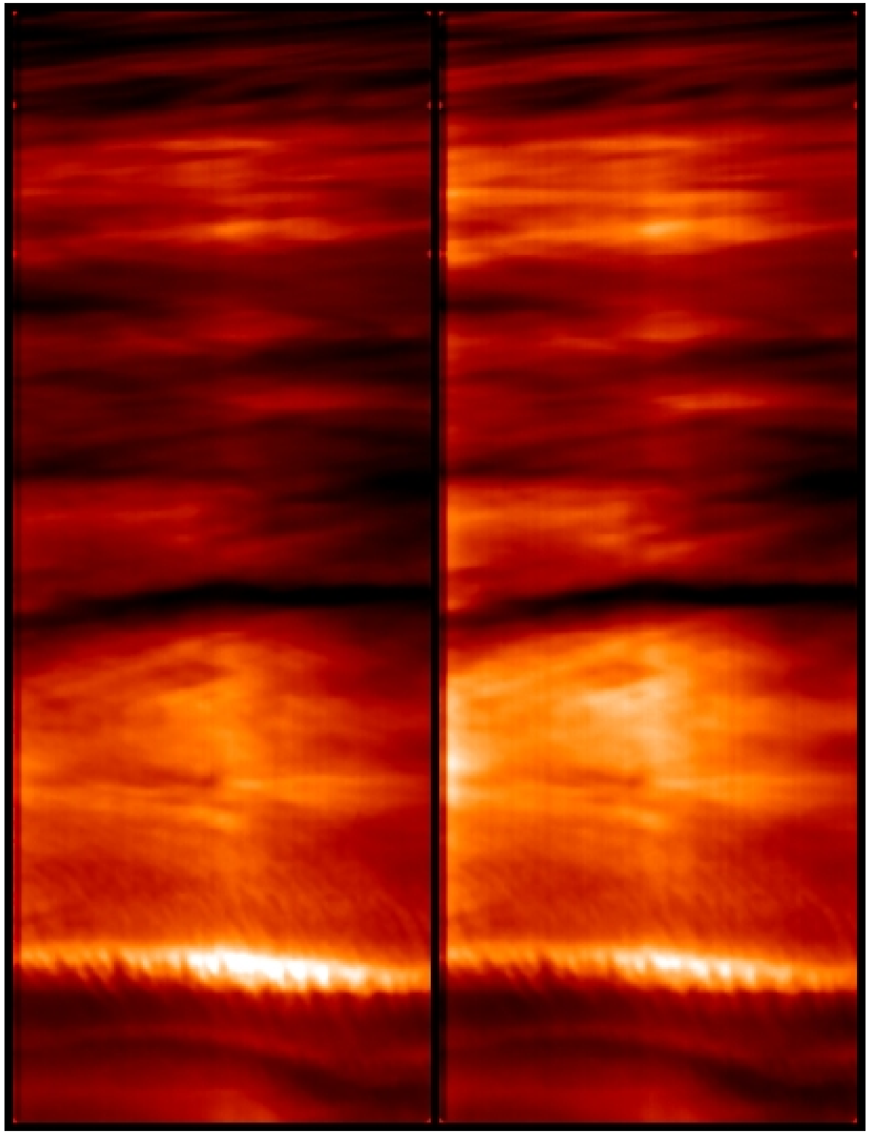



# Cloud investigations

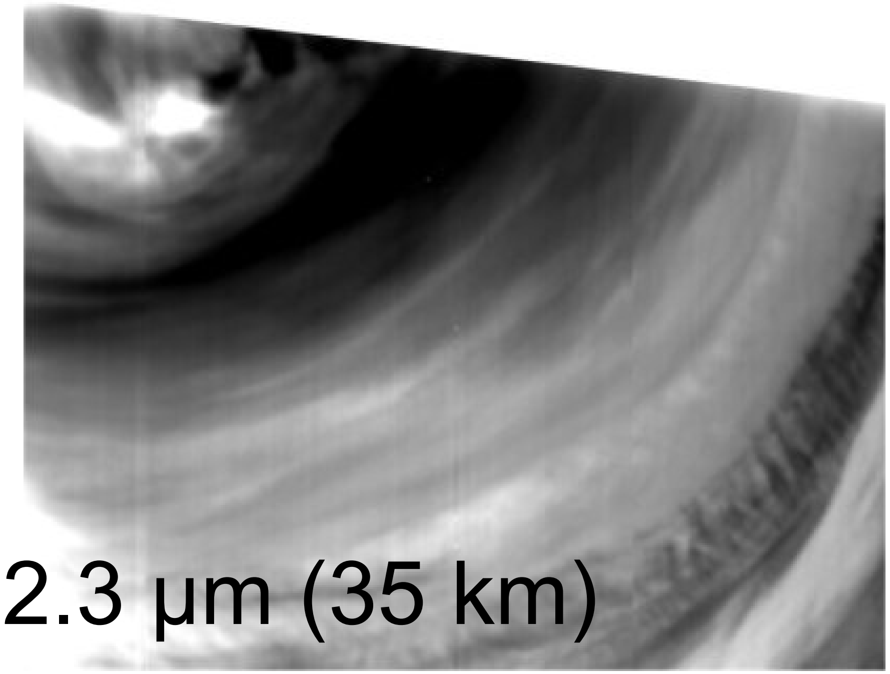



*Markiewicz, Piccioni & VMC/VIRTIS Teams*



Venus clouds in the IR at 2.3 µm -left- (35 km) and 1.7 µm -right- (25 km)



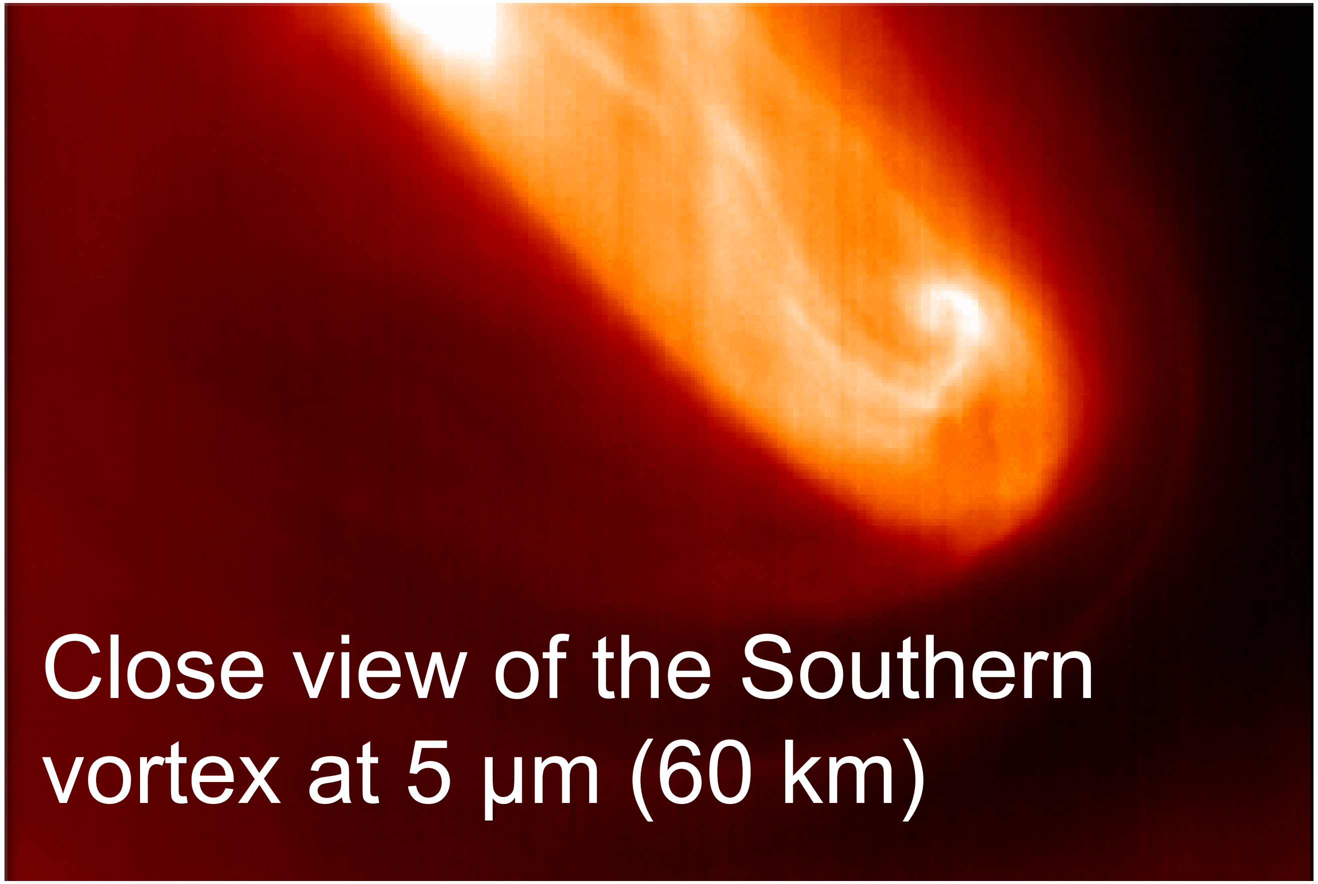
Cloud wave structure at 2.3 µm (35 km)

# Cloud wave structure on Mars

Wave Clouds (Viking)

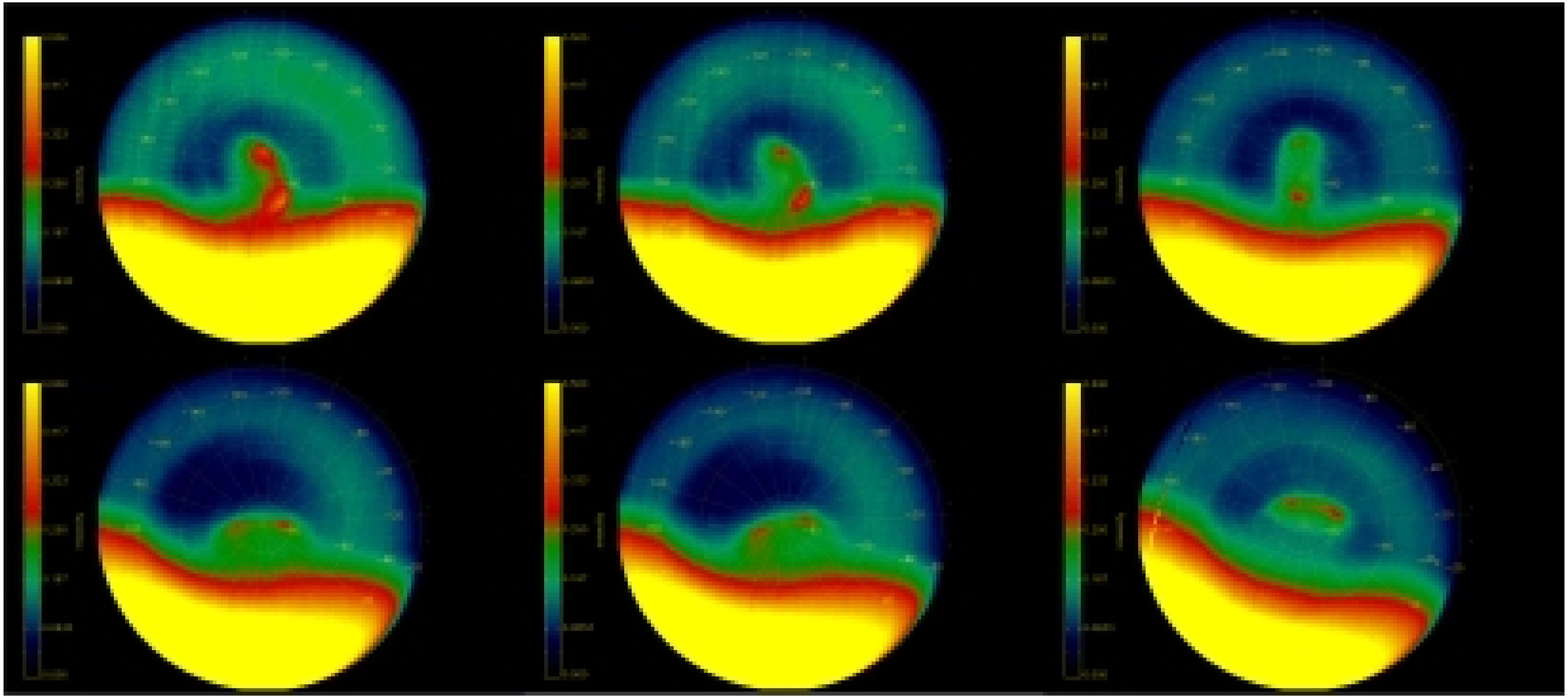
Lee Wave Cloud
Crater with Wavy Fog

# Double eyed vortex

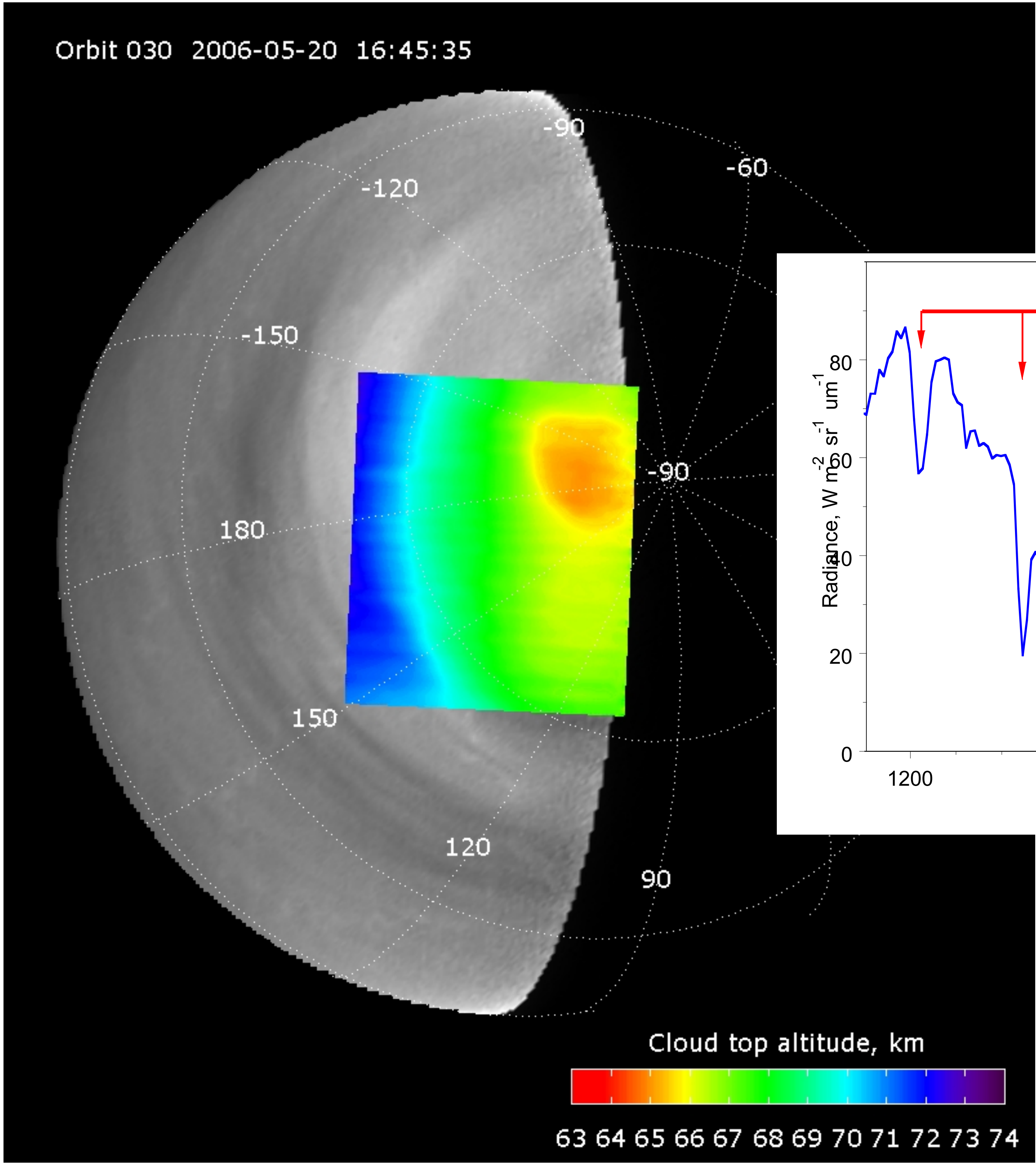


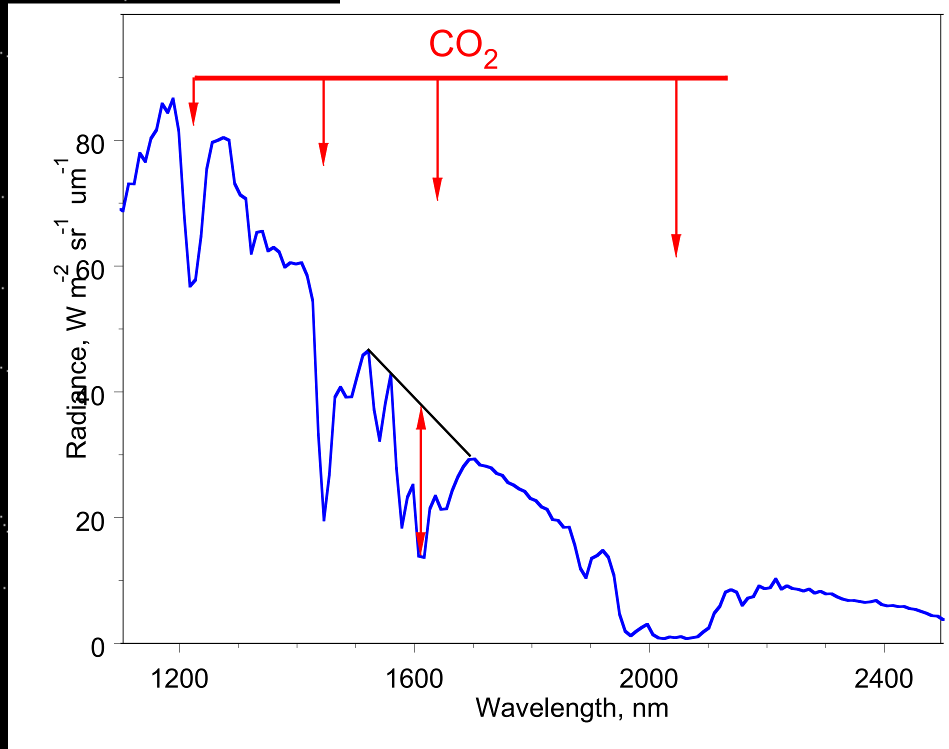

- Brightest spot : centre of the vortex where radiation from the deeper layers becomes clearly visible.
- Dark circular structures surrounding the brighter area belonging to the big vortex structure - 2500 km across.

# Double vortex structure at South Pole at 5 μm (59 km)



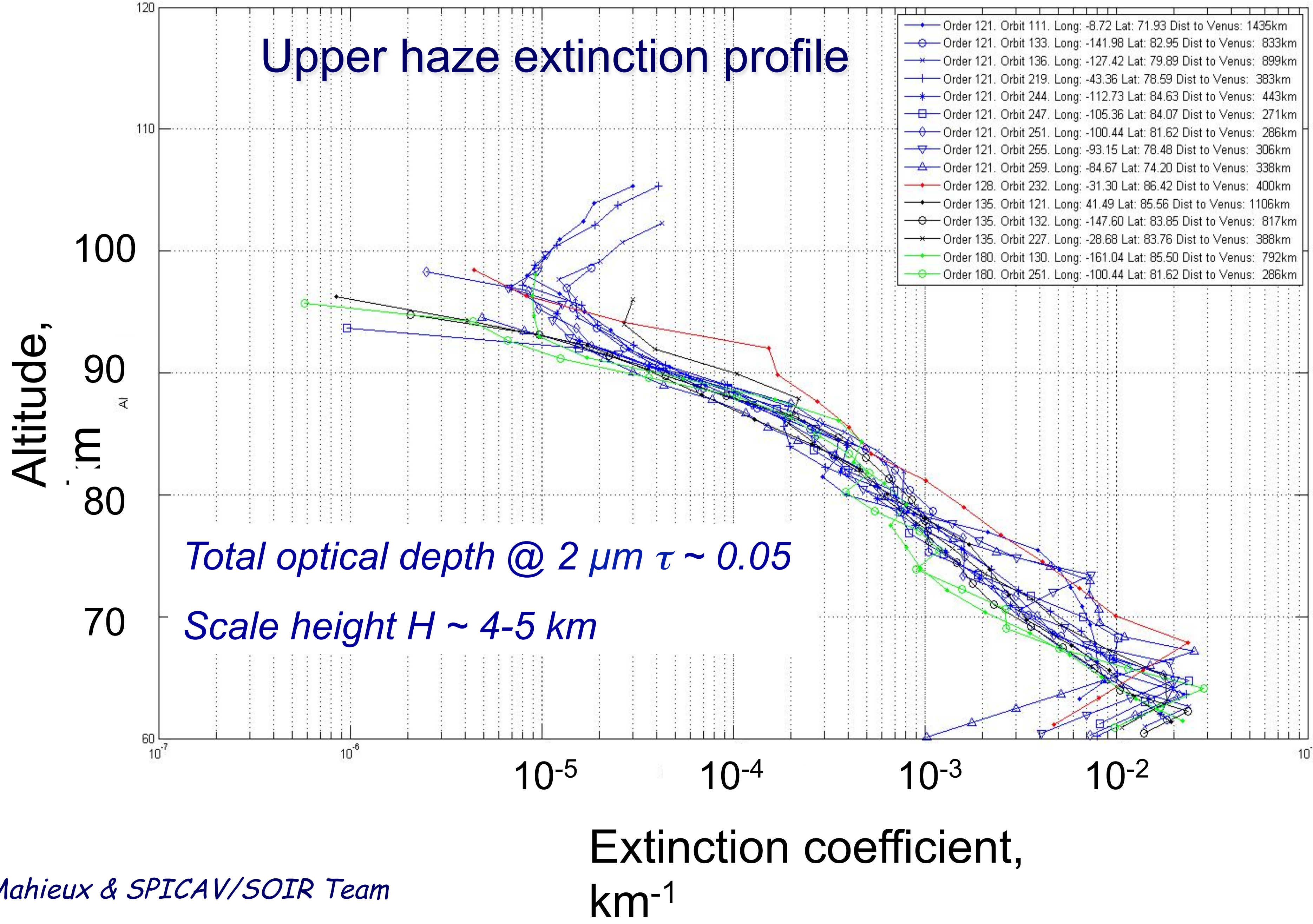
# Altimetry of the cloud tops



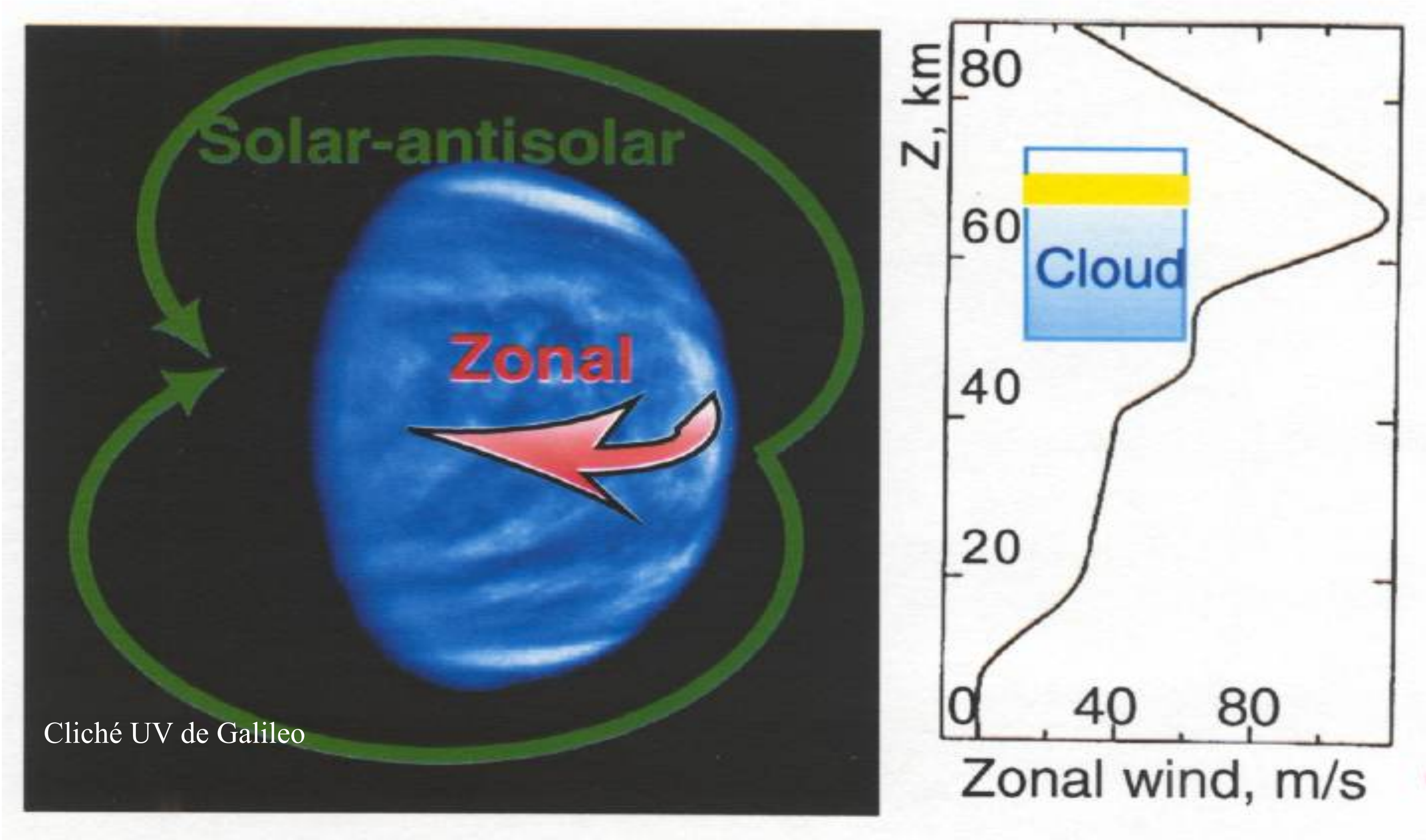

*Ignatiev & VIRTIS/VMC Teams*

# Clouds and hazes



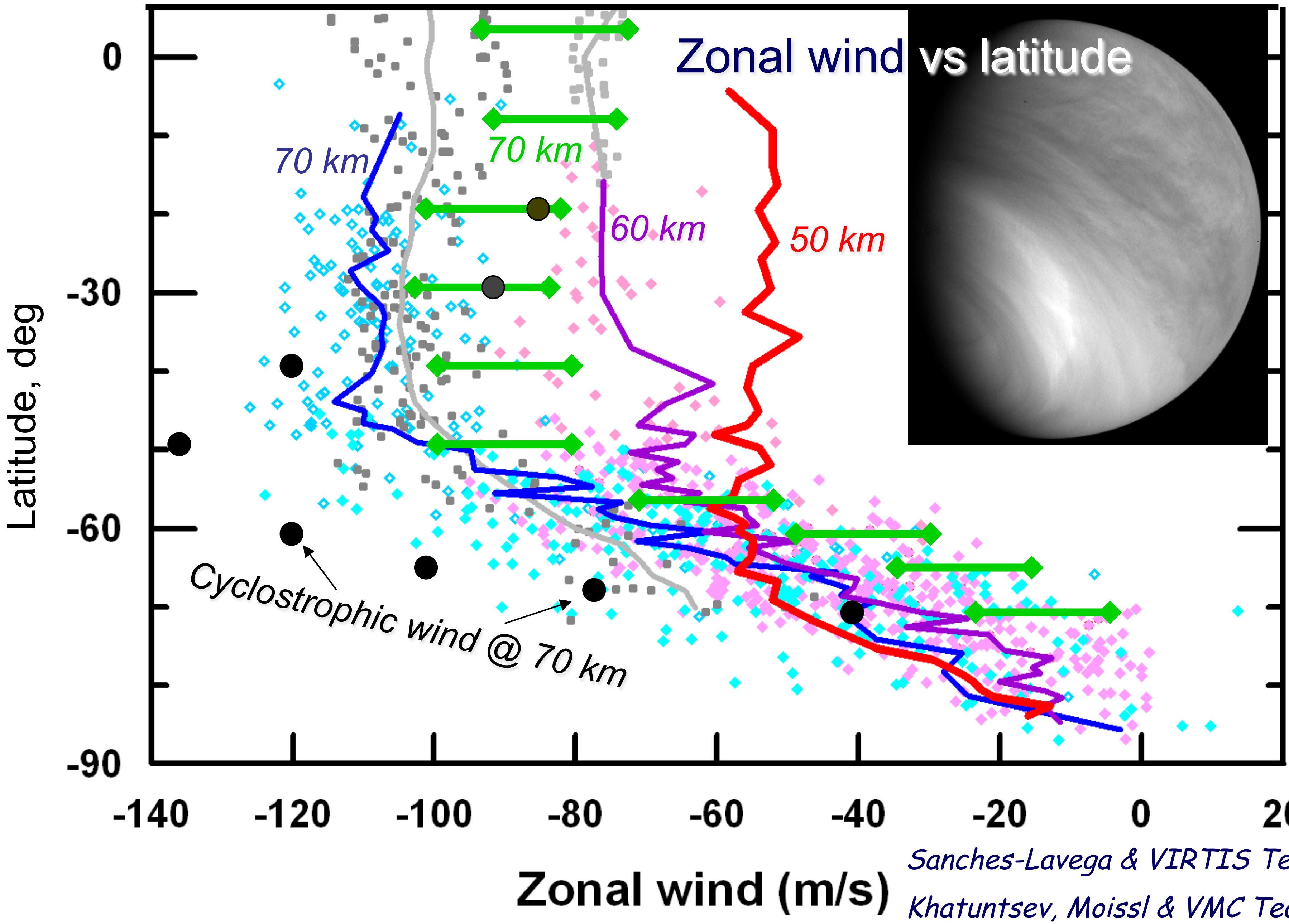

*Mahieux & SPICAV/SOIR Team*

# Atmospheric super-rotation




- Venusian day duration: 243 days (slow retrograde rotation)
- At 60 km altitude, rotation in 4 days (60 times faster than solid planet).
- Winds of 100 m/s at 60 km.
- Origin of super-rotation : the principle is understood (angular momentum conservation), but difficult to model.

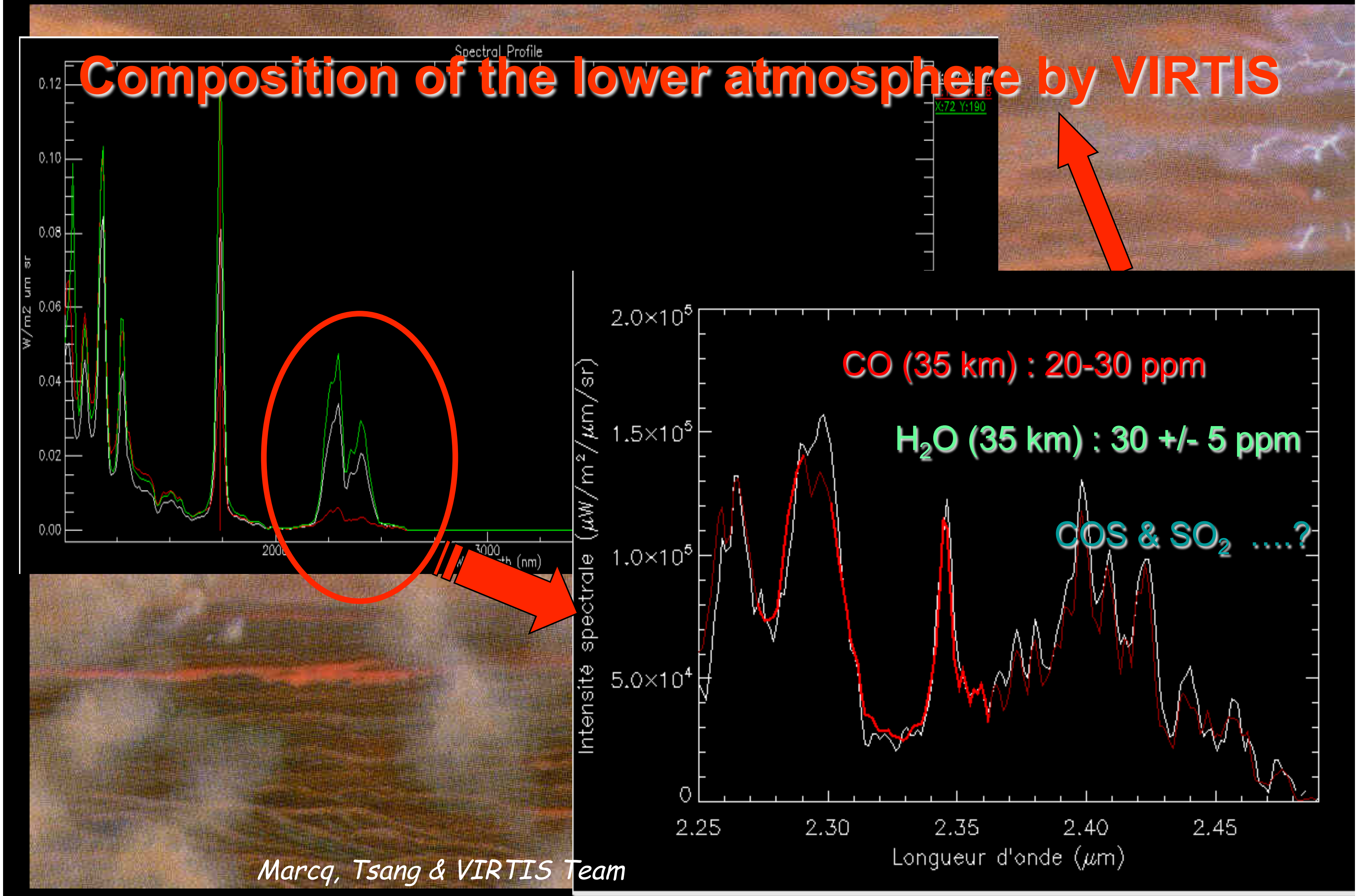
# Atmospheric dynamics



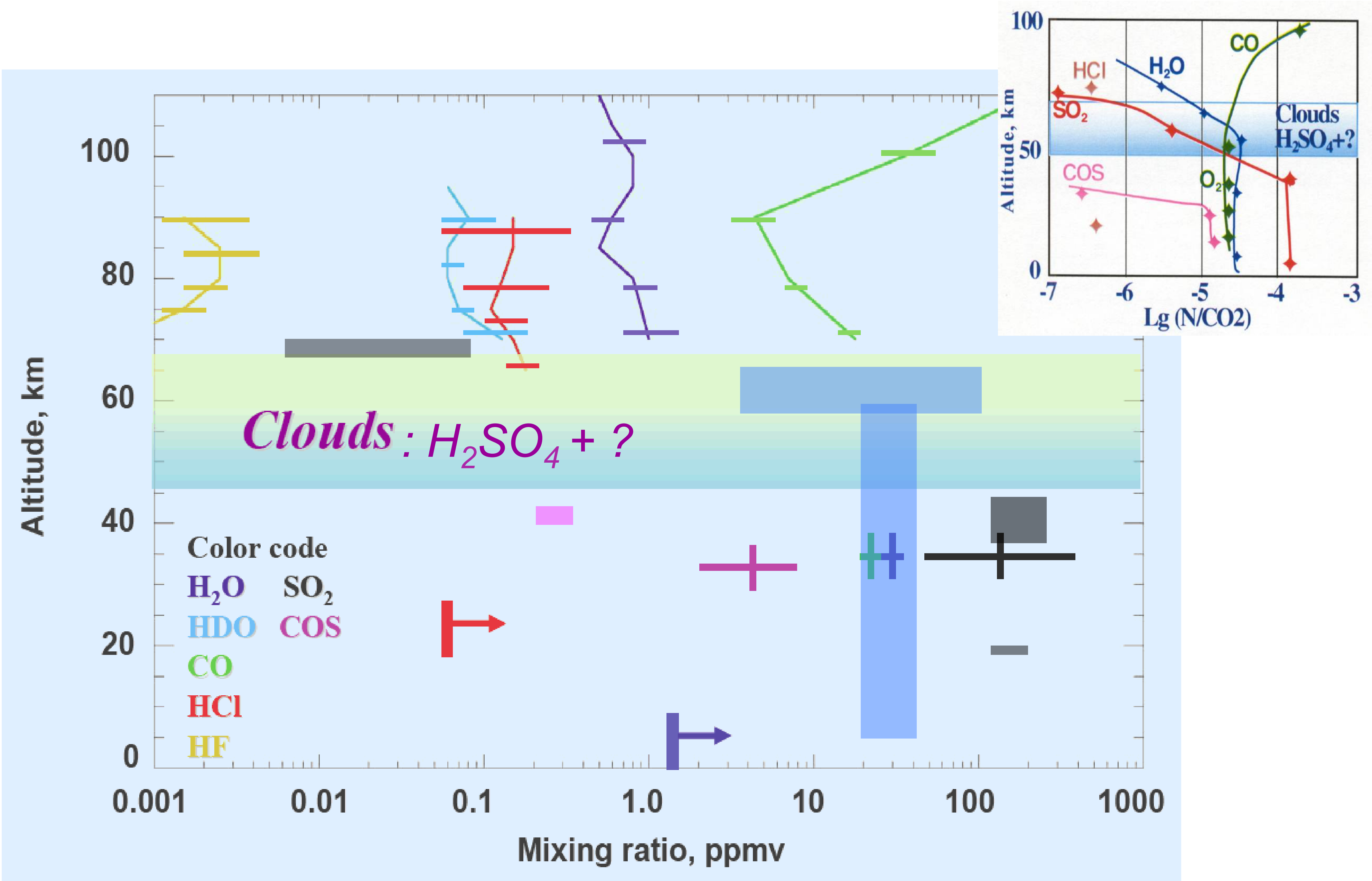

Sanches-Lavega & VIRTIS Team

Khatuntsev, Moissl & VMC Team

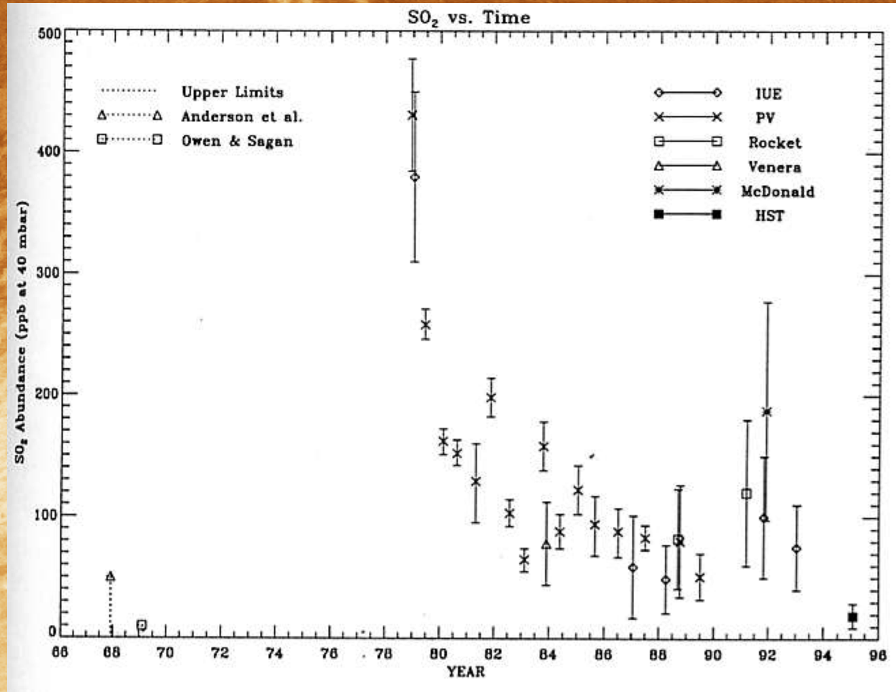
# Atmospheric composition



# Synthesis of the composition measurements

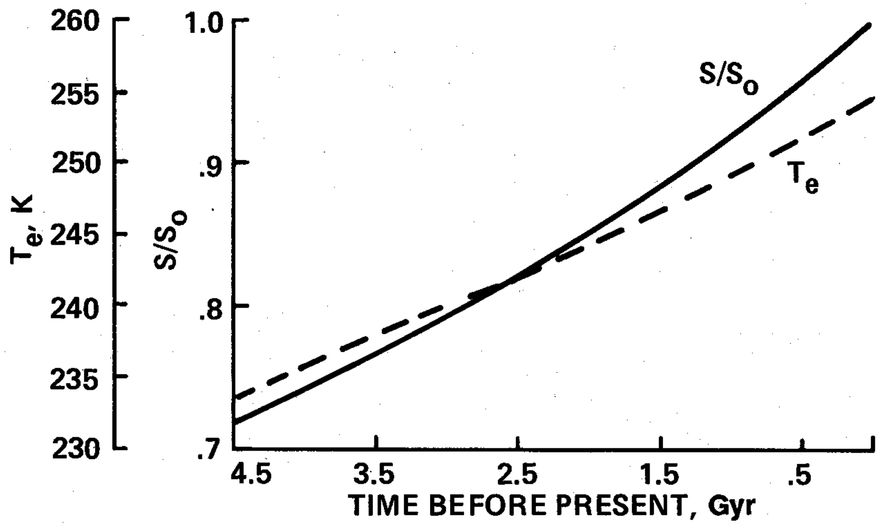


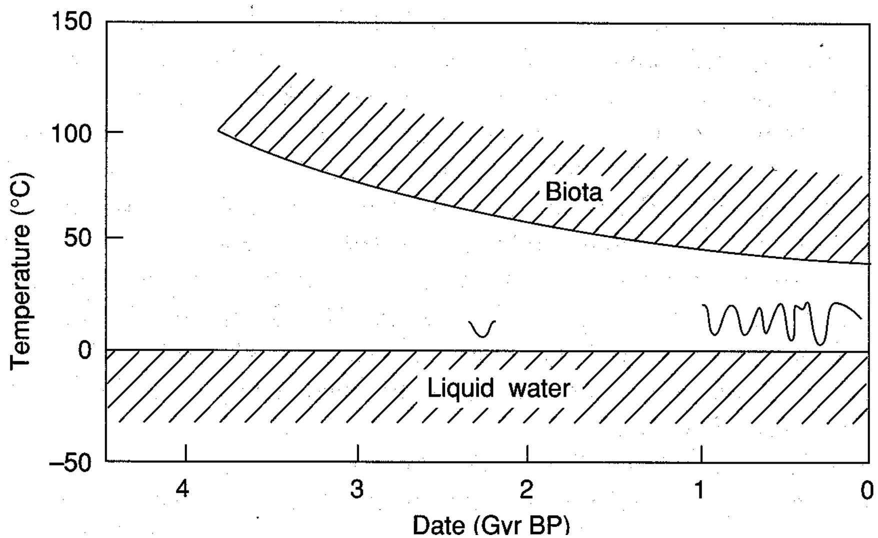
# Is volcanism still active on Venus?




- Global resurfacing ≈600 Myr ago.
- Great volcanoes like Sepas Mons (Φ 400 km, H 1500 m).
- Some variability of $SO_2$ measured above clouds.

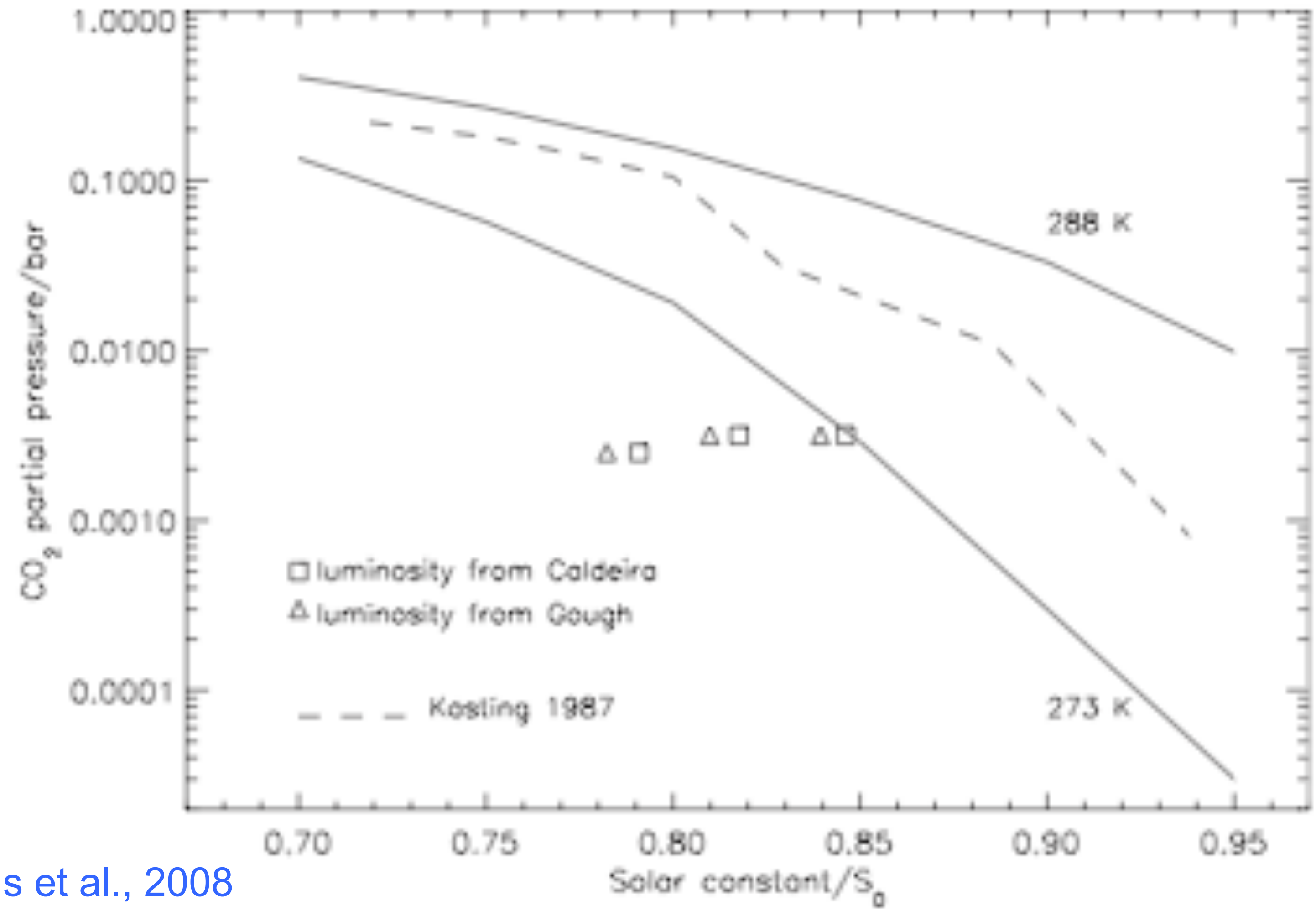
# Evolution of the solar luminosity




- The luminosity of the early Sun was about 70-80% of its present value (see e.g. Graedel and Crutzen, 1993).
- Continuous presence of liquid water requires Earth temperature has ever been above 0°C (ref. id.).
- **How was such a mild temperature maintained?**

# A solution for the faint young sun paradox




Von Paris et al., 2008

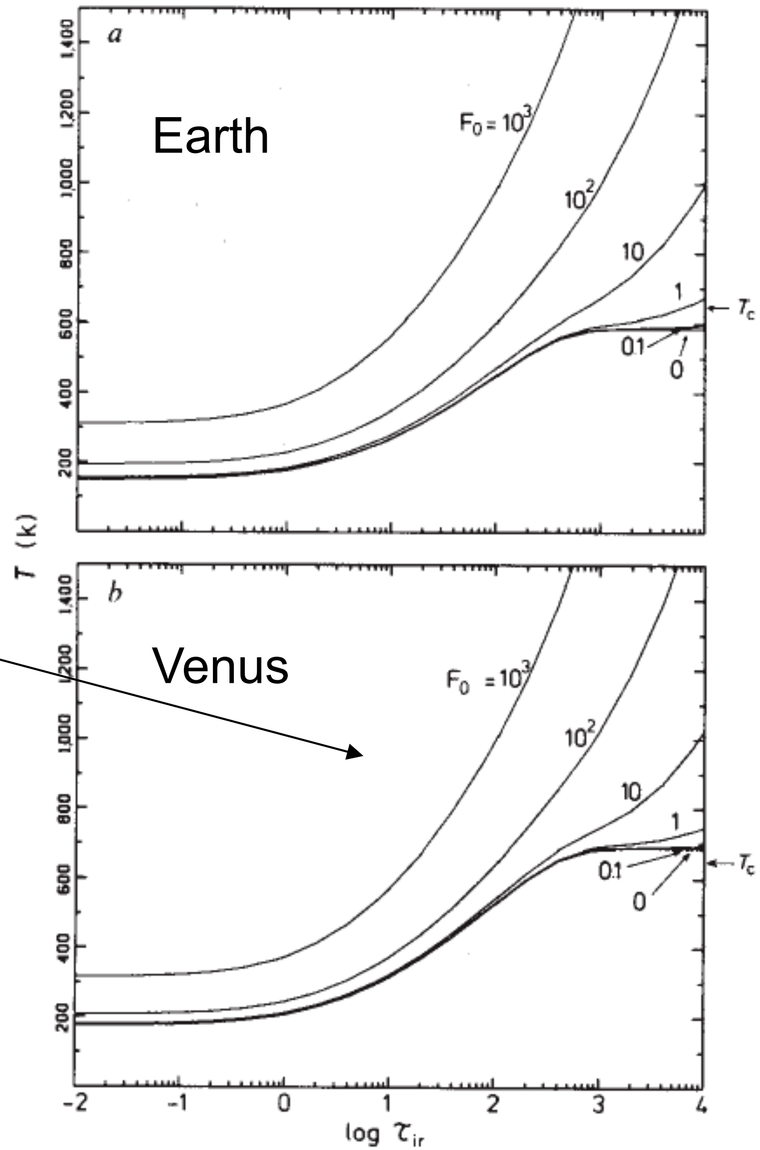
Minimal values of CO2 partial pressure required to obtain chosen surface temperatures of 273 and 288 K at a fixed N2 partial pressure for different solar constants. Symbols are included which represent the upper CO2 limits derived from the sediment record).

# Scenario of a primitive wet Venus

- A **water ocean may have formed or not**, depending on thermodynamical conditions :

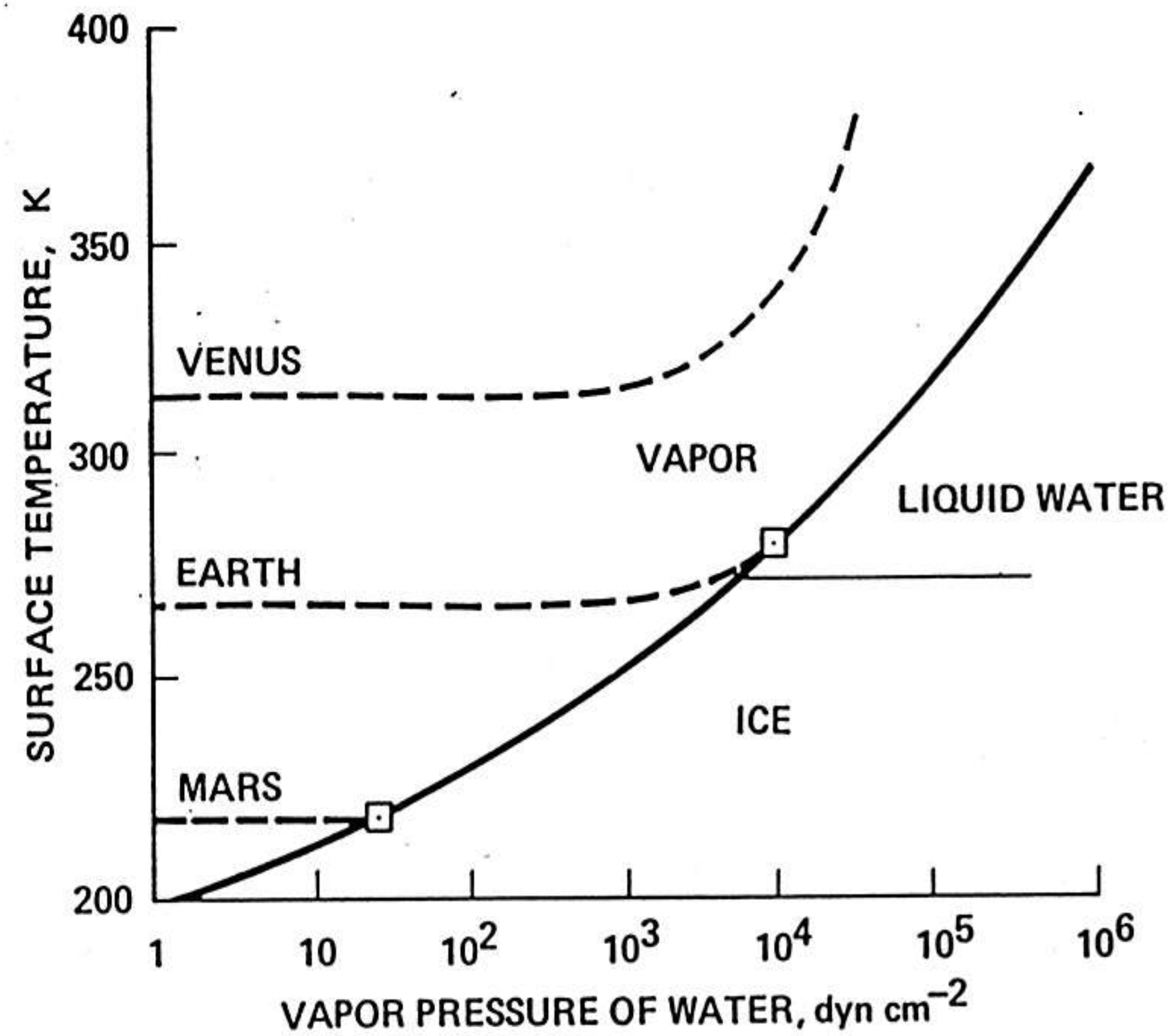
↳ Neglecting clouds, $T_s > T_c$ for Venus at the end of accretion : **water vapor doesn't condense to an ocean** (Matsui and Abe, 1986).

↳ But, in presence of clouds, **smaller surface temperature and formation of an ocean** (with further evaporation by runaway/moist greenhouse) (Kasting, 1988)



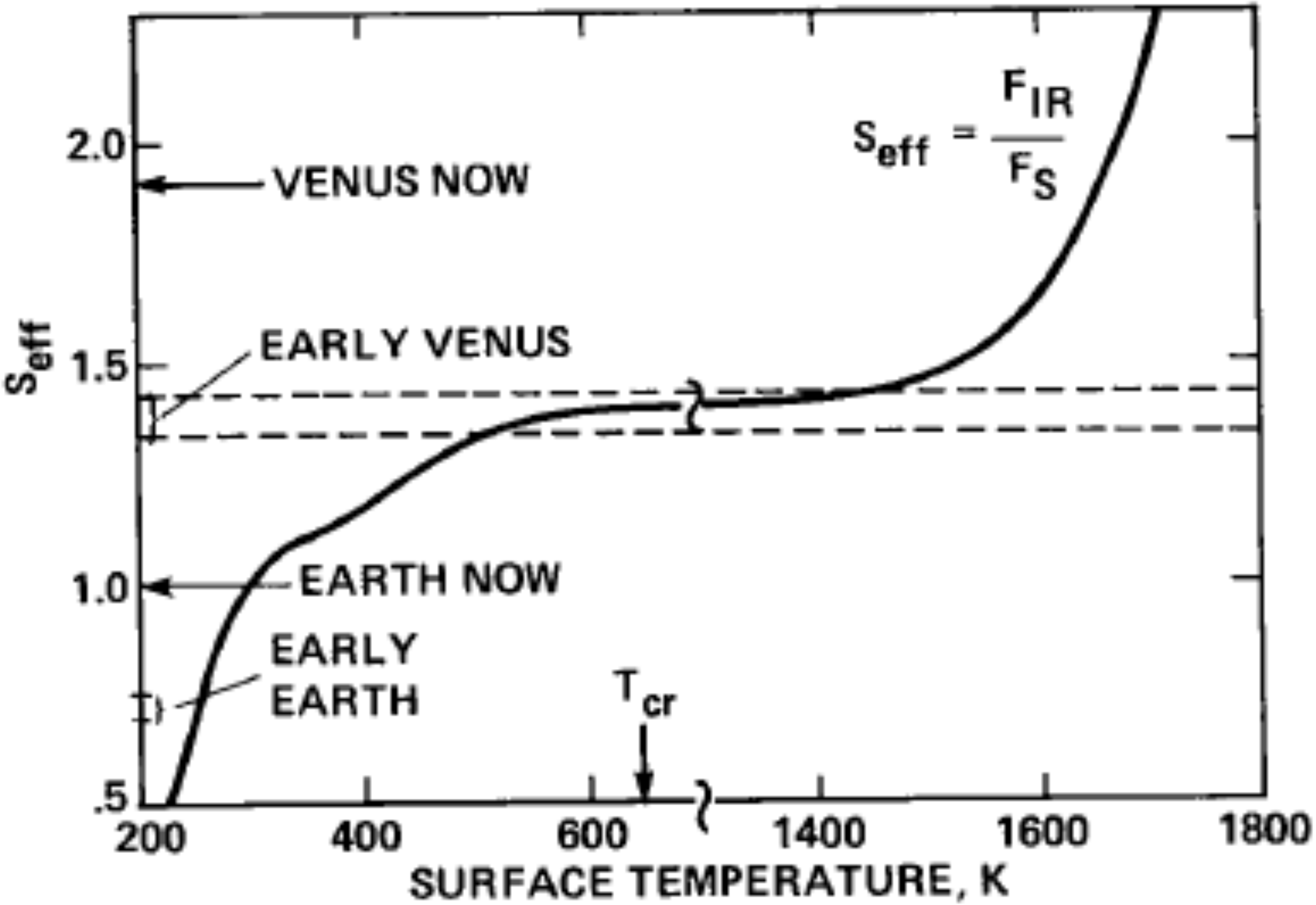

Matsui and Abe, 1986

# Principle of runaway greenhouse




Rasool and De Bergh, 1970

# Evaporation of the primitive ocean

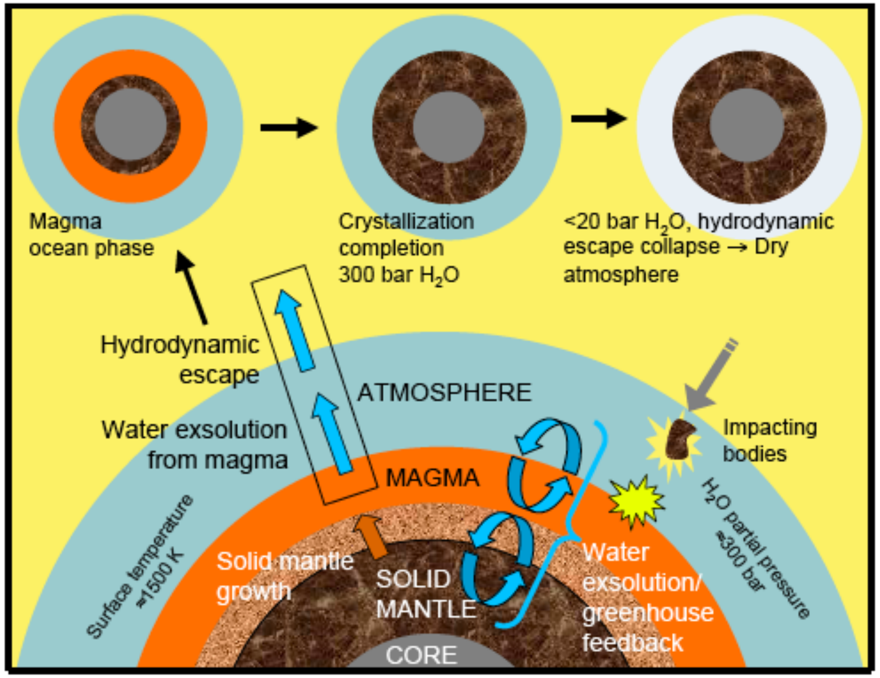



Kasting, 1988

# What happens following runaway greenhouse?

- Further photodissociation of $H_2O$ by solar UV radiation in the upper atmosphere.
- Hydrodynamic escape of H due to strong solar EUV energy depoisition at the top, yielding the present massive $CO_2$ atmosphere (Kasting and Pollack, 1983, Chassefière, 1997).
- Removal of the totality of H contained in 1 TO (Terrestrial Ocean) during the first billion years (Kasting and Pollack, 1983).
- Remaining 90 bar atmosphere of $CO_2$ maintaining strong greenhouse.

# Hypothesis of an early dessicated Venus




Gillmann et al, 2009

Comparison Venus wrt Earth :

→ Lower initial water endowment (likely).

→ Closer to the Sun/no magnetic field : more intense escape.

➥ Venus possibly « dried up » early (≈70-100 Myr)

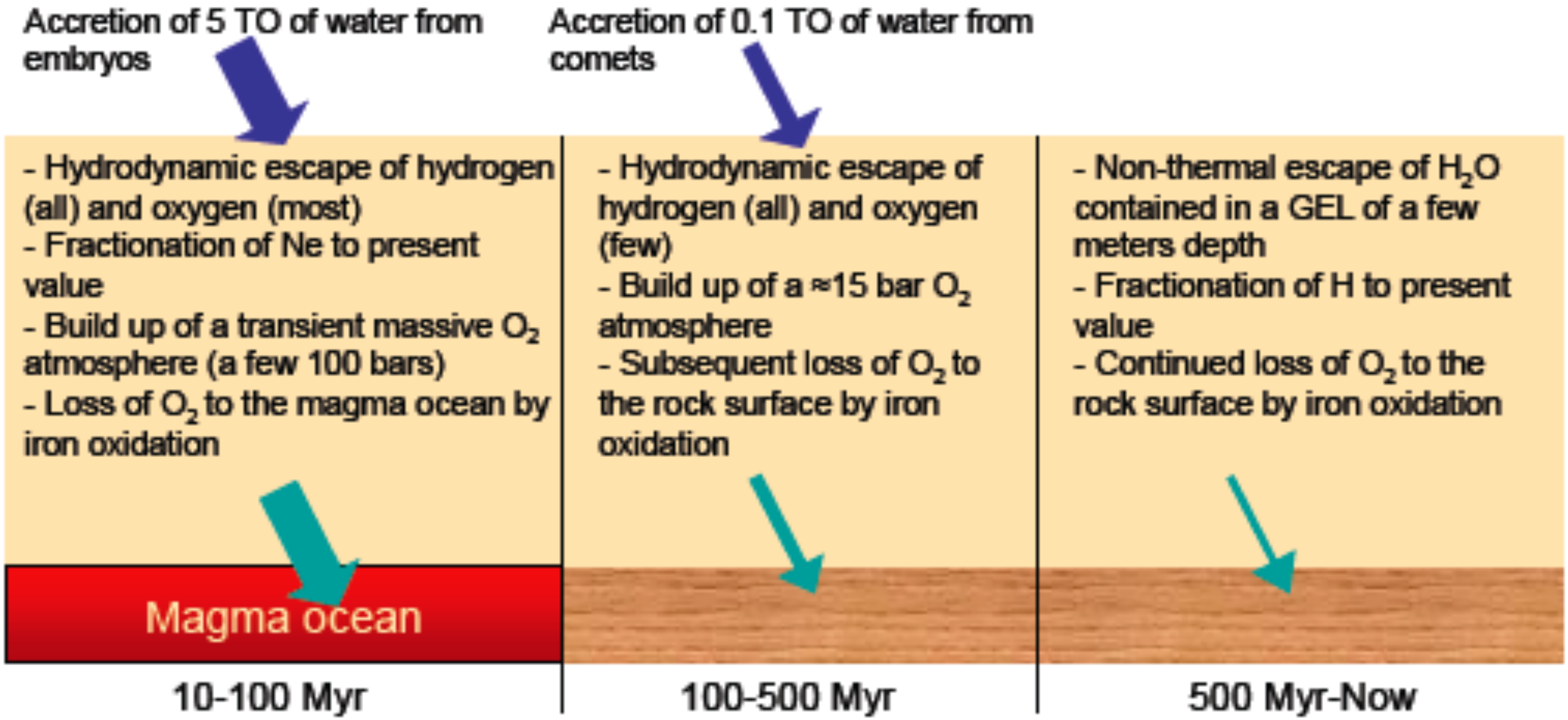
Potential implications :

➥ Early crystallization of the Venus magma ocean due to vanishing atmospheric greenhouse (**no water left** for an Earth-size ocean).

➥ **Late veneer of water** on Venus (comets), but **<0.1 TO**.

➥ Earth (endowed with more water) left with large amounts of water at 100-200 Myr : subsequent formation of the ocean.

# A possible evolution scenario of Venus




Gillmann et al, 2009