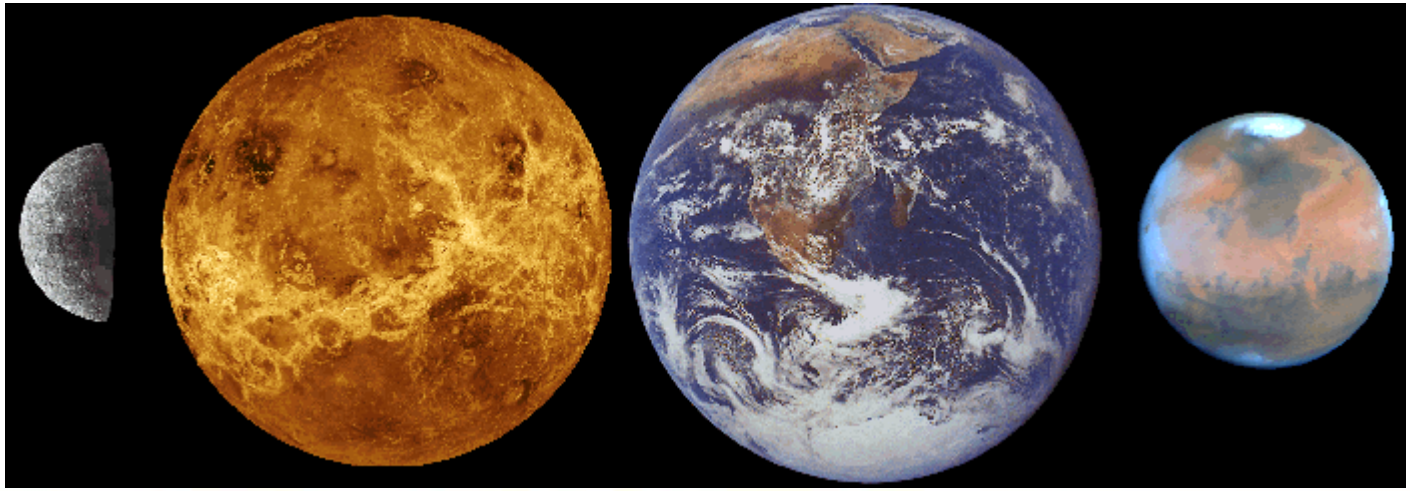
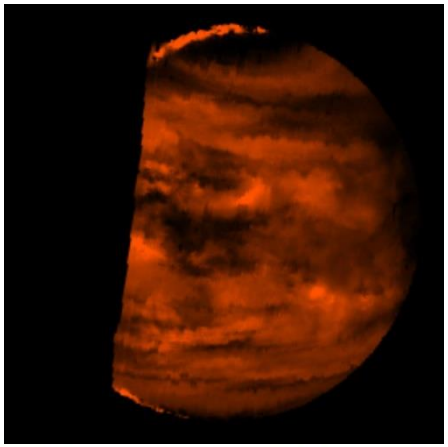
The Exploration of Mars and Venus

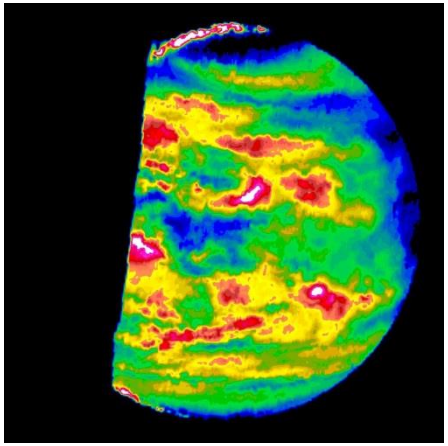
Ann C. Vandaele

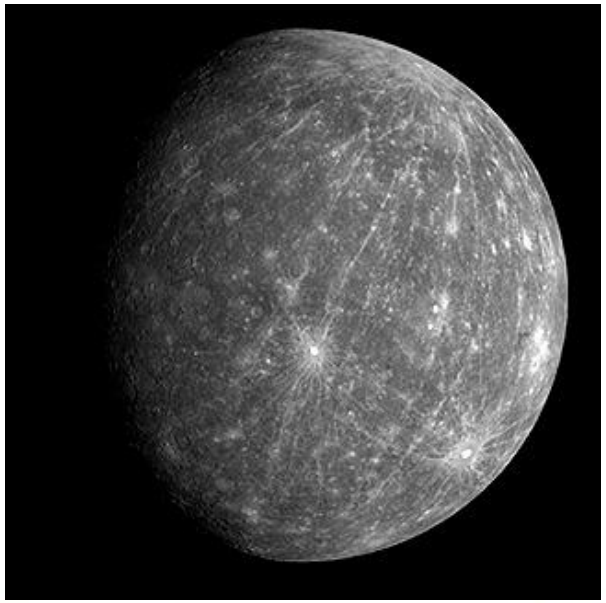


Outline

- What are telluric planets ?
- What is comparative planetology ?
- Structures of planetary atmospheres
- Energetic balance of planetary atmospheres







Telluric planets

- Solid surface
- Small, not massive but dense
- In our Solar System: 4 – the internal planets (Mercury, Venus, Earth, Mars)

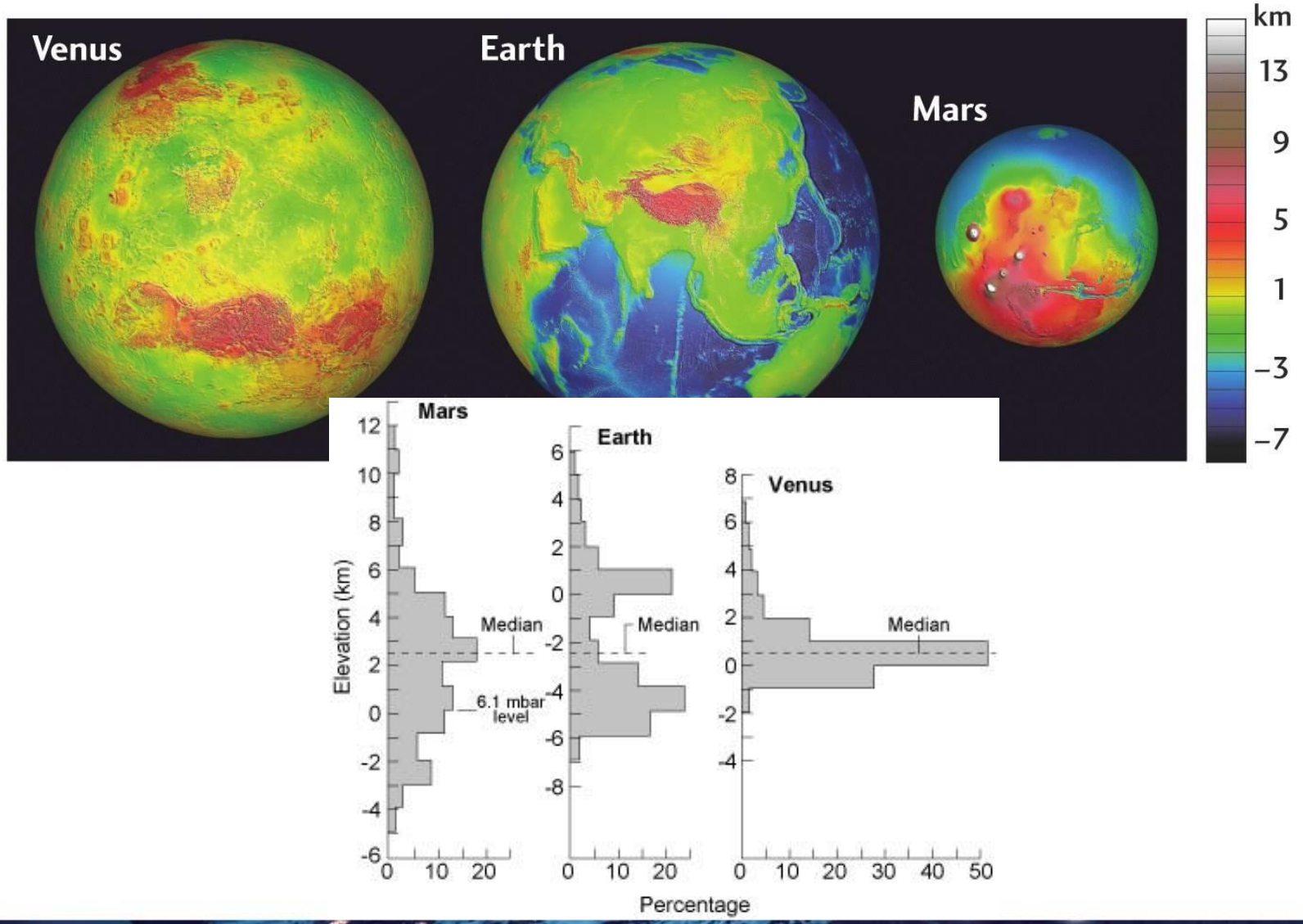
	Orbital Distance (UA)	Orbital period (yrs)	Rotation period (h)	Equ. Radius (km)	Obliquity (°)	Mass (rel. To Earth)	Gravity (m/s^2)	Density (kg/m^3)
Mercury	0,4	0,25	59 jours	2440	0,01	0,06	3,7	4879
Venus	0,7	0,62	243 jours	6051	177	0,82	8,8	5243
Earth	1,0	1,00	23,93	6378	23,5	1,00	9,8	5515
Mars	1,5	1,88	24,63	3397	25,2	0,11	3,7	3933
Jupiter	5,2	11,86	9,92	71492	3,1	317,9	23,1	1326
Saturnus	9,6	29,46	10,66	60271	26,7	95,15	9,1	687
Uranus	19,2	84,01	17,24	25559	97,9	14,54	8,7	1270
Neptunus	30,11	164,79	16,11	24766	28,8	17,23	10,9	1638

Comparative planetology

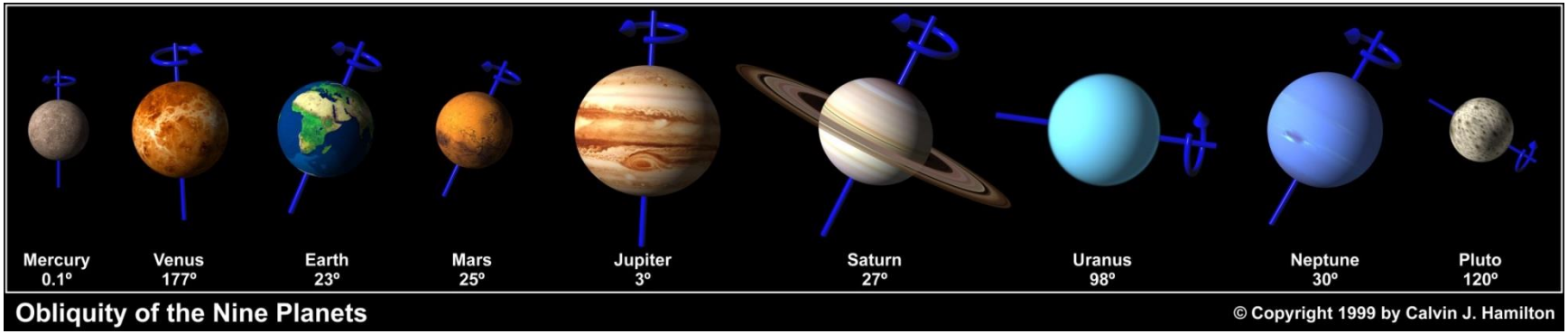
- Compare the different properties of the planets
- Search for similarities/differences

- Why ?
  - Understand the physical, chemical, dynamical processes
  - Trace the history and evolution of the other planets
  - Better understand the origins of our own planet, its evolution and future

Example : relief



Example: obliquity and rotation direction



- Give information on
  - Seasons
    - Varying distance to Sun (eccentricity of the orbit)
    - Inclination of the rotation axis

Quasi-circular orbits

	Eccentricity	Inclination of the axis of Rotation (°)
Venus	0.01	3
Earth	0.02	23.5
Mars	0,09	25.2

Too small !

  - Formation processes

Composition of the atmospheres

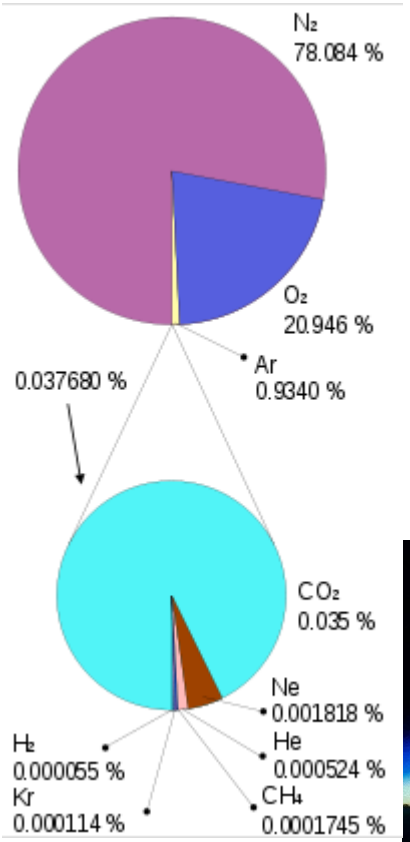
	Mercury		Venus		Earth		Mars	
Principal constituents	O2 Na H2	42% 29% 22%	CO2 N2	96,5% 3,5%	N2 O2 H2O	78,1% 20,9% <4%	CO2 N2 Ar	95,3% 2,7% 1,6%
	He K	6 % 0,5%	SO2 Ar H2O OCS He HCl Kr HF	150 ppm 70 ppm 30 ppm 15 ppm 12 ppm 0,6 ppm 25 ppb 5 ppb	Ar CO2 Ne He CH4 Kr N2O Xe HCl	0,93% 350 ppm 18 ppm 5 ppm 1,7 ppm 1,1 ppm 0,3 ppm 87 ppb 1 ppb	H2O Ne Kr Xe	0,03% 2,5 ppm 0,3 ppm 0,08 ppm
Photochemical products			CO, H2SO4, SO, O2		H2, CO, O3		O2, CO, NO, O3	

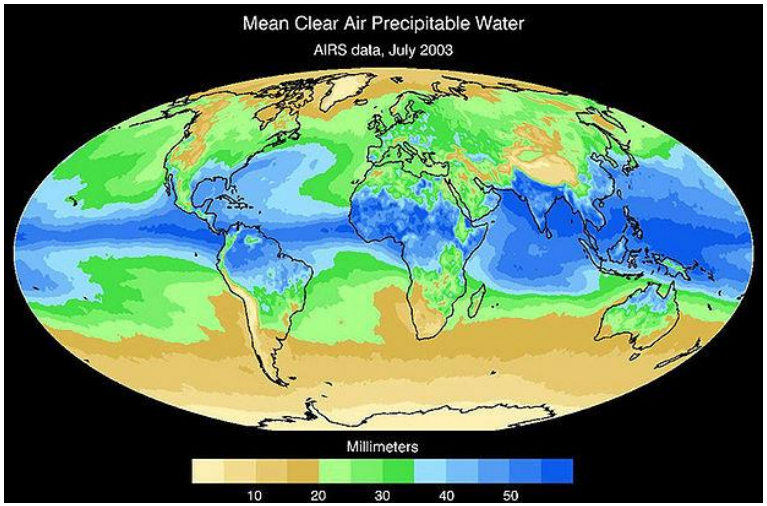
1 ppm = part per million = 10^{-6}

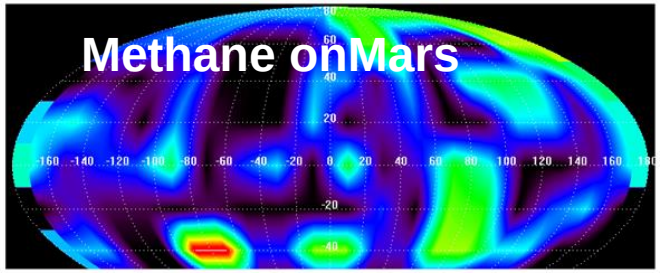
1 ppb = part per billion = 10^{-9}

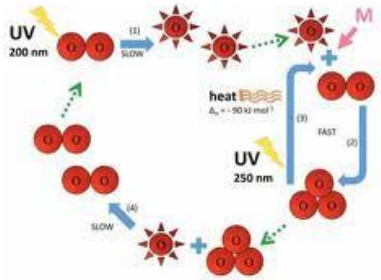
What is an atmosphere ?

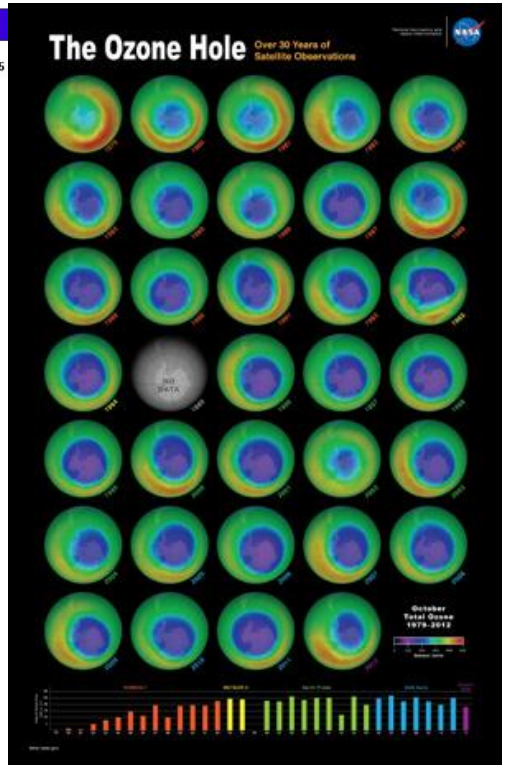
- **Atmospheric Composition**





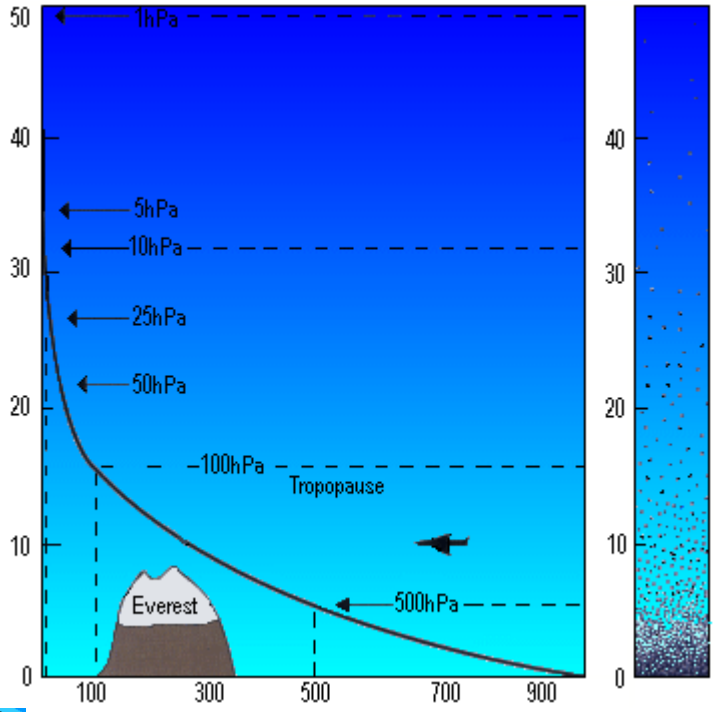


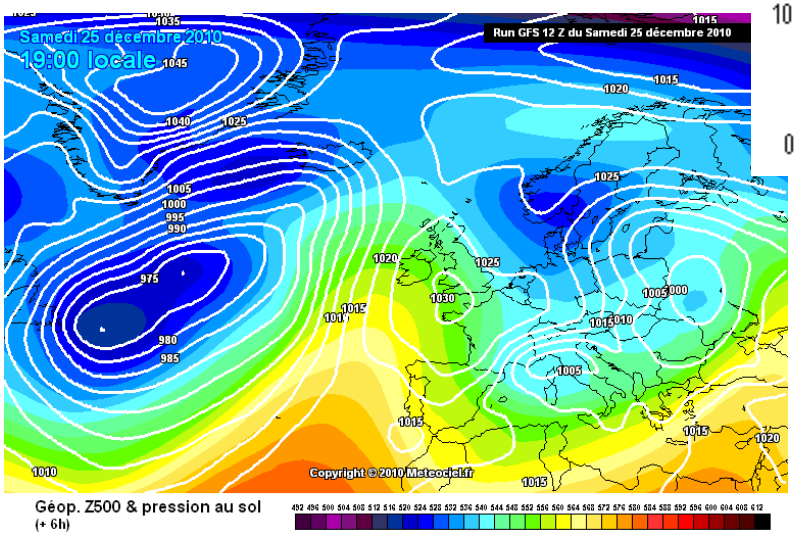




What is an atmosphere ?

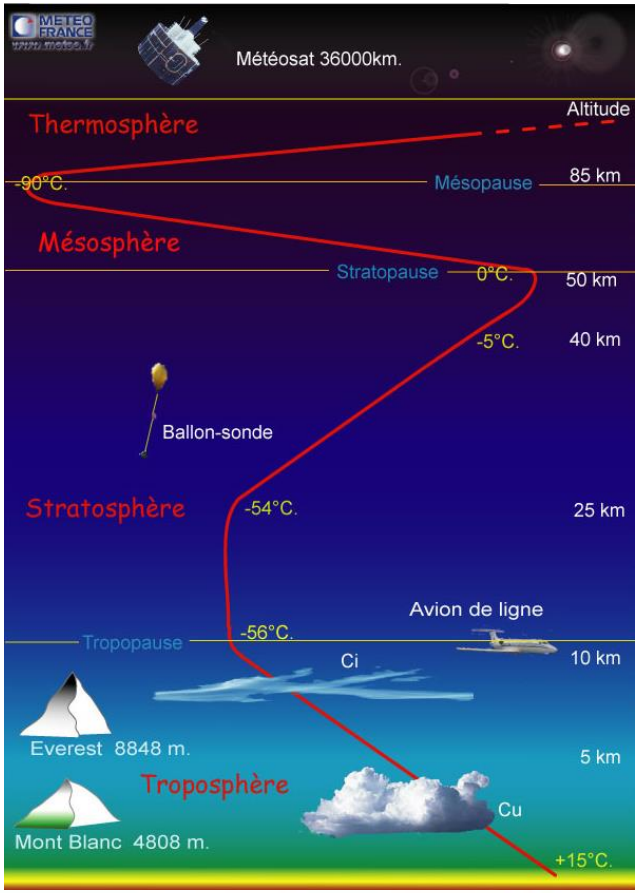
- **Pressure**
  - Decreasing pressure with altitude
  - Horizontal variations: depends on latitude/longitude, meteorological conditions, seasons

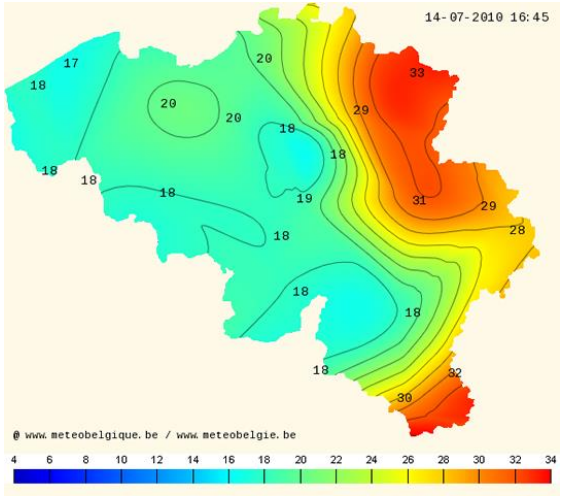


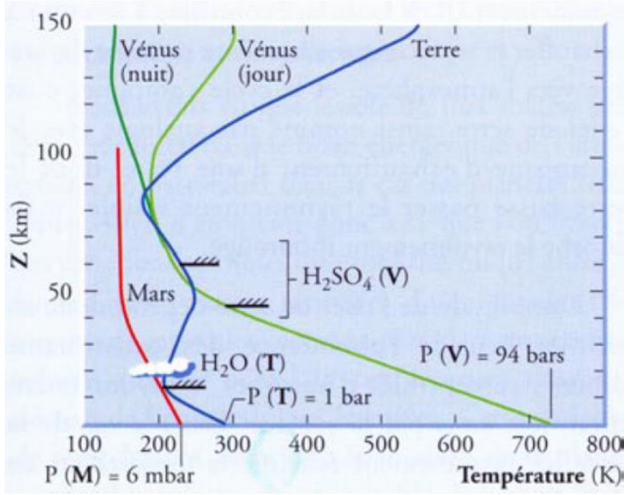


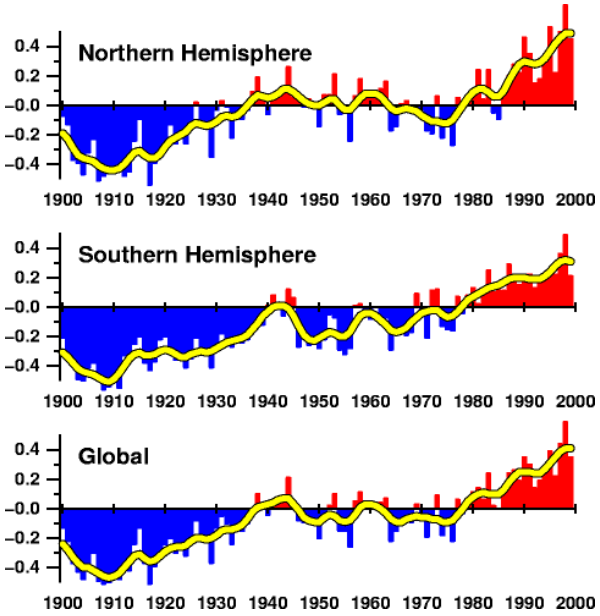
What is an atmosphere ?

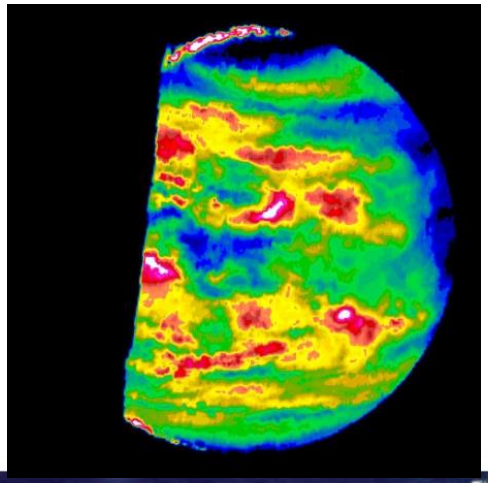
- **Temperature**





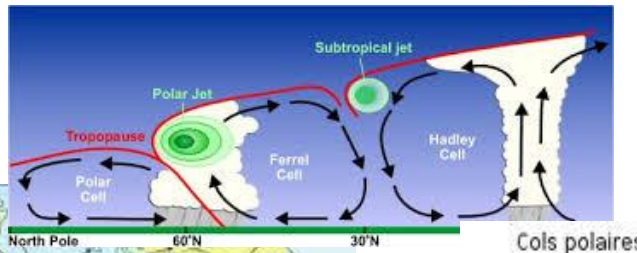


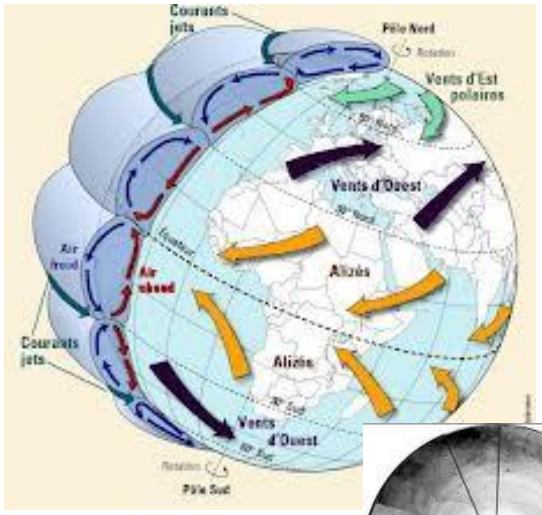


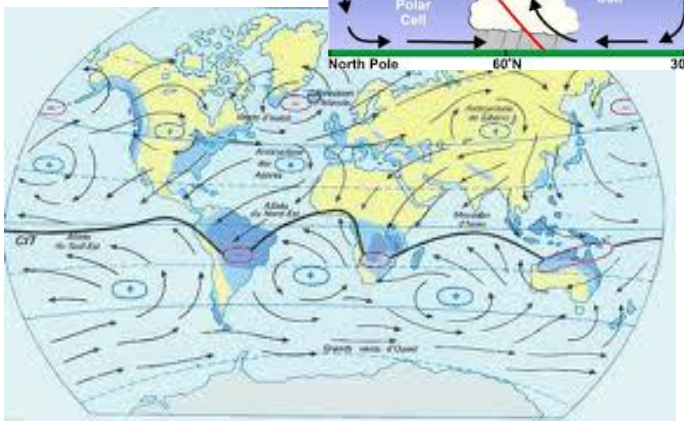


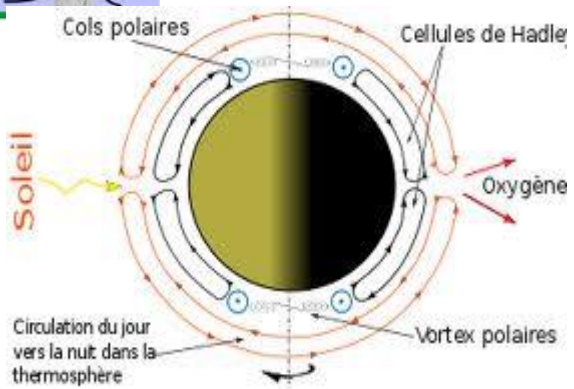
What is an atmosphere ?

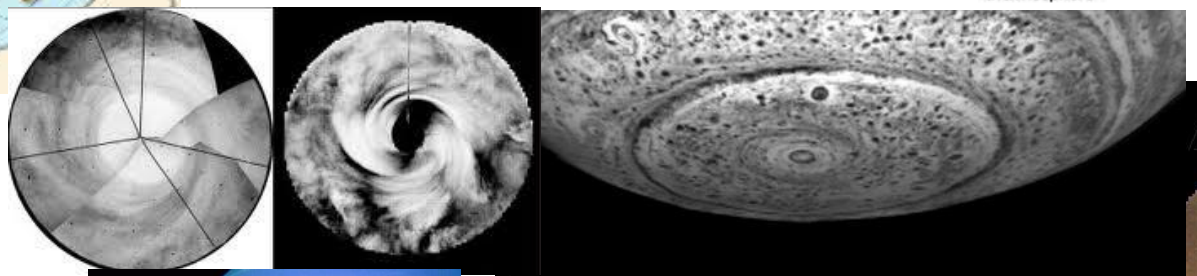
- **Winds - circulation**

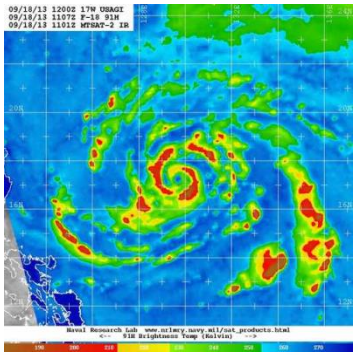


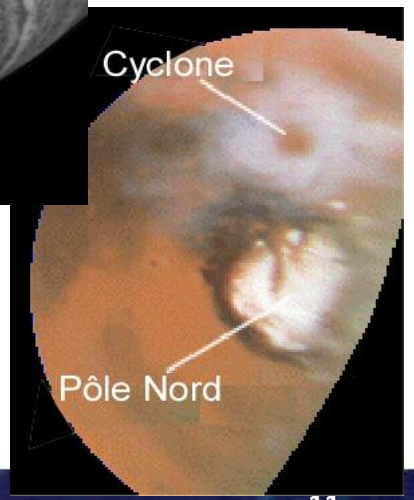






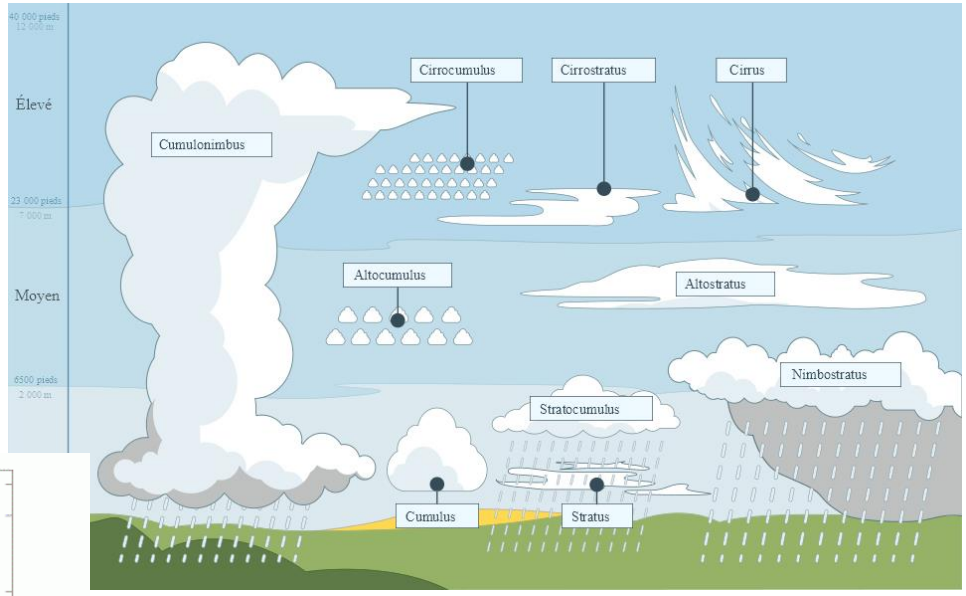


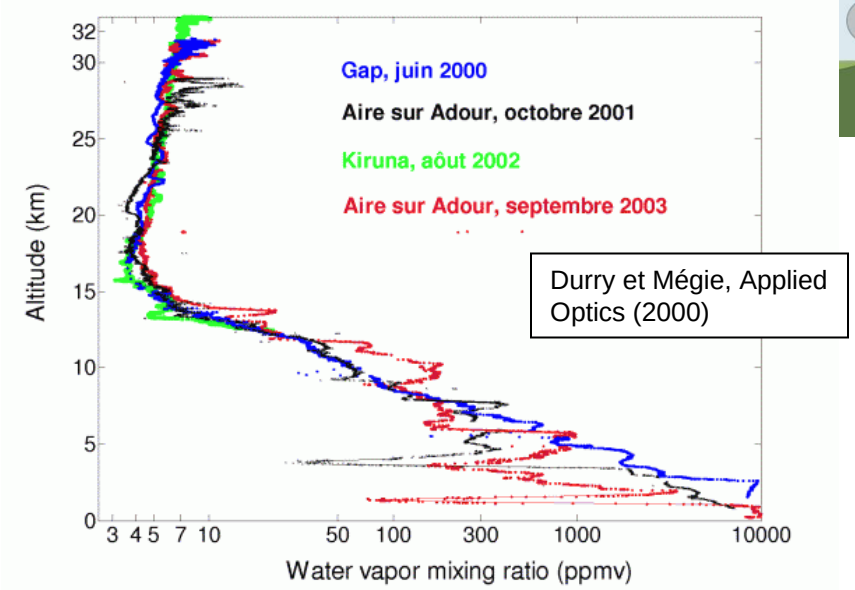




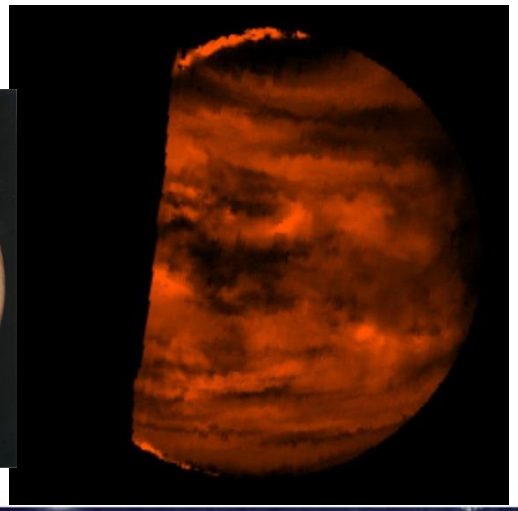
What is an atmosphere ?

- **Clouds – water vapour**

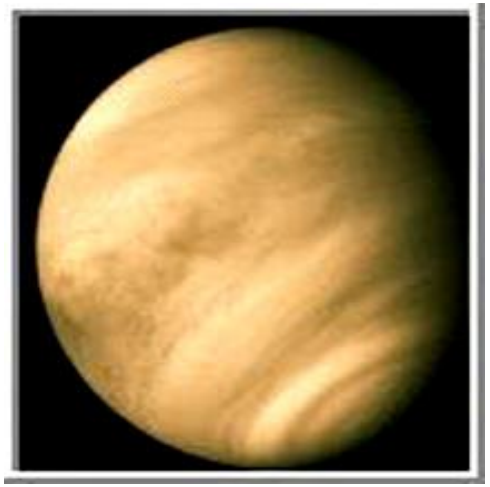




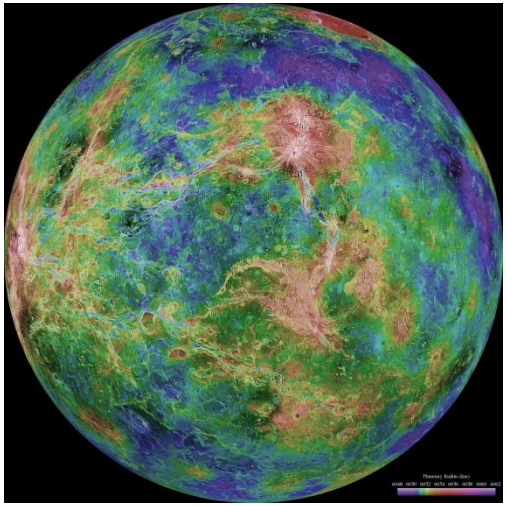
Durry et Mégie, Applied Optics (2000)



Venus

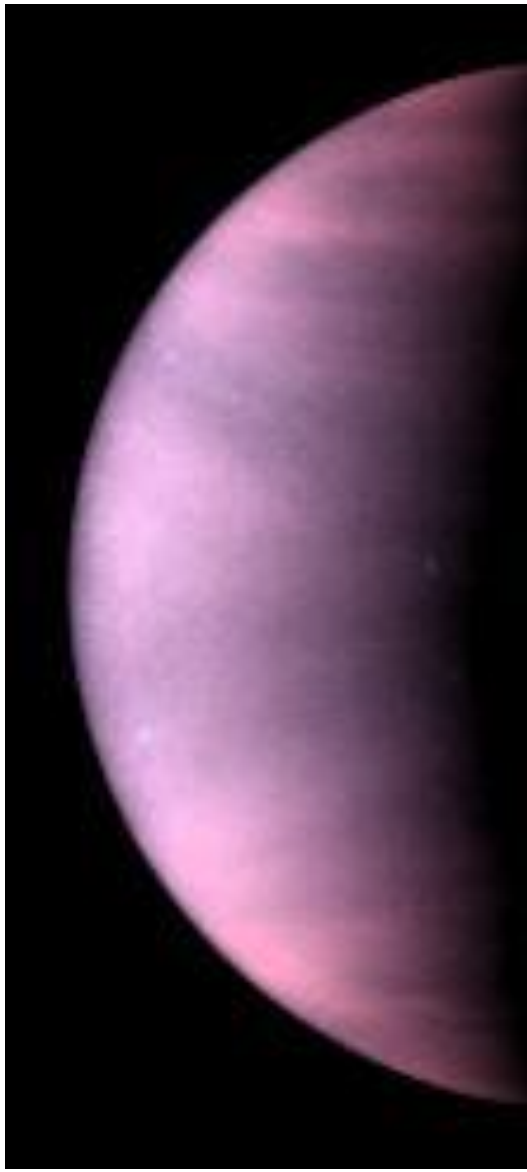


- At the surface
  - T= 737 K, p=91 atm
- Global cloud deck
- Super-rotation
  - Venus rotates slowly on itself, but
  - Winds > 500 km/h at cloud top

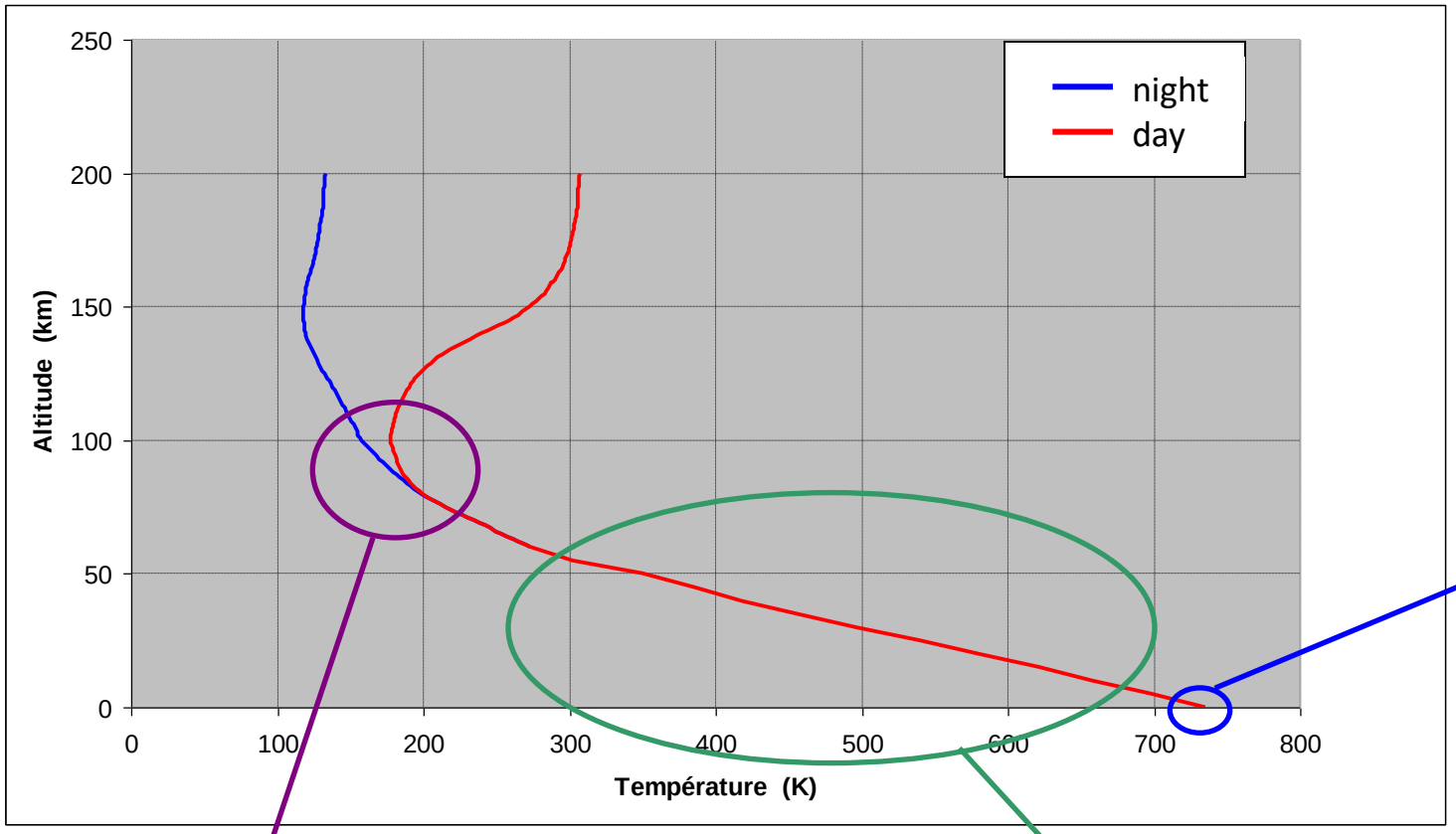


- CO_2 rich atmosphere
  - Trace gases: HCl, H_2O, ….
  - Sulfur cycle : OCS, SO_2, H_2SO_3

Earth		Venus
$5,9x10^{21}$ t	Mass	$4,8x10^{21}$ t
12 756 km	Diameter	12 104 km
15 °C	Surface temperature	480 °C
1 atm	Surface pressure	91 atm
365 jours	Rotation around Sun	225 jours
1 jour	Rotation on itself	243 jours
Azote, Oxygène	Main gases	Dioxyde de carbone
0,75	Albedo	0,3



High pressure and temperature

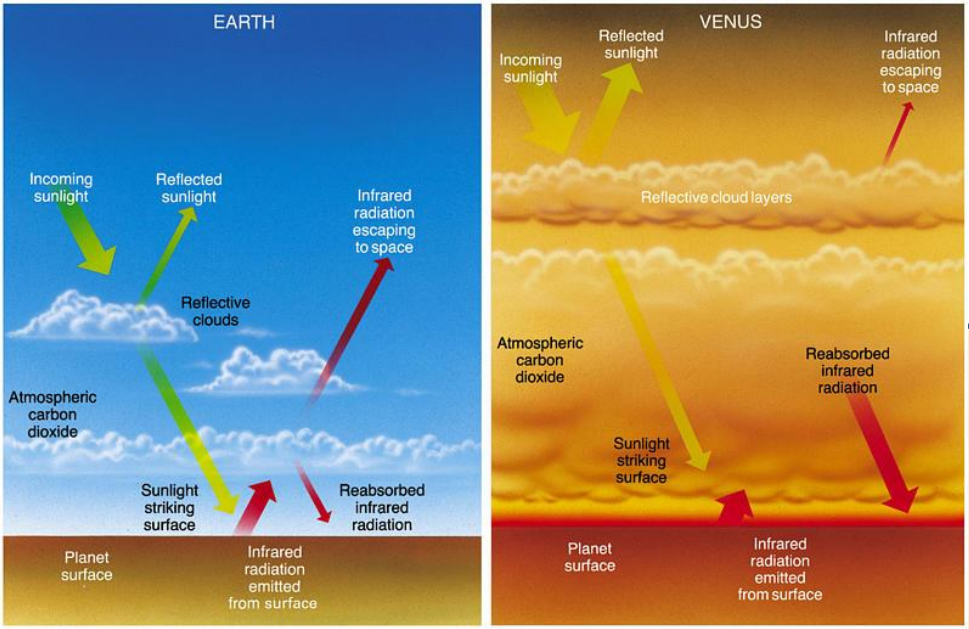


$T_{surface}$ = 737 K

Clouds

No diurnal variation

Green house gas effect



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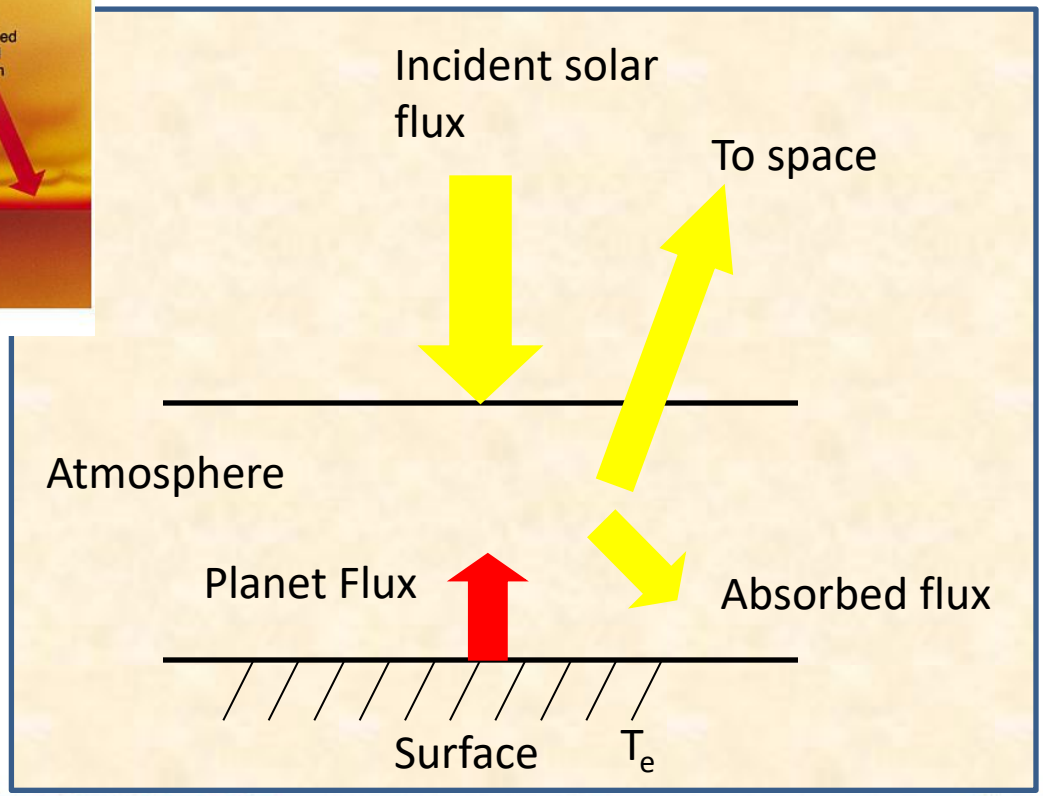
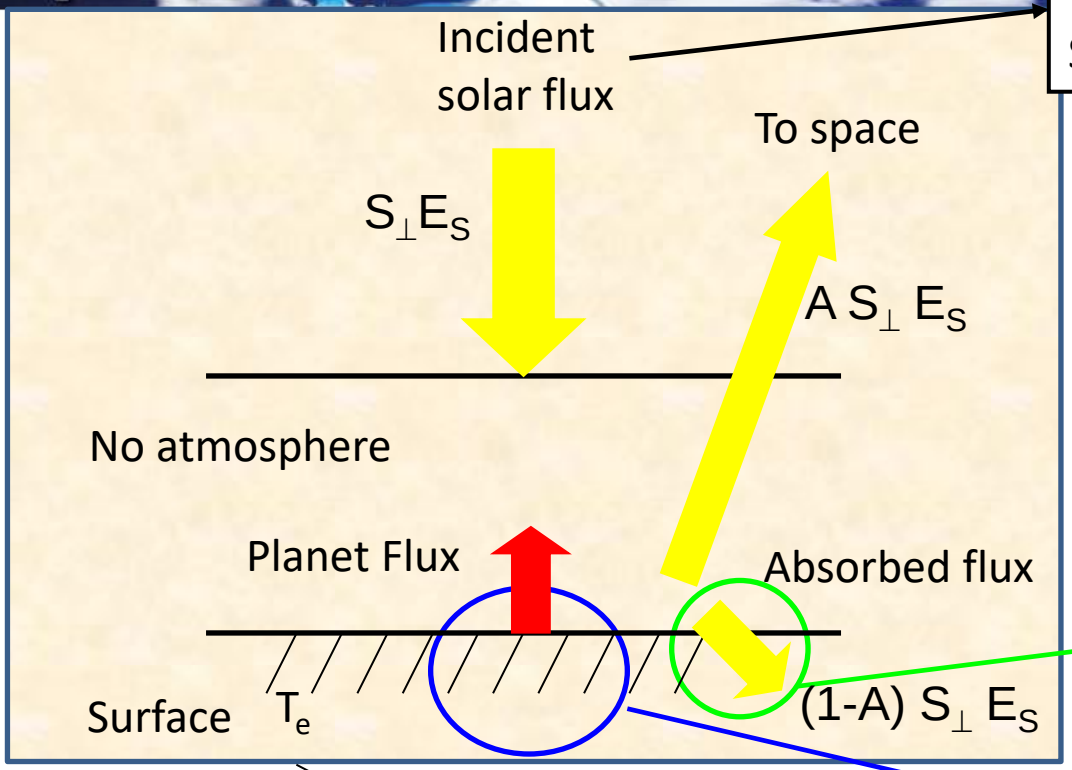




E_S = Solar flux at Venus

Solar constant = 1370 W/m^2 at 1 AU

For a planet at distance r from the Sun:

$$E_S = S_0 \left(\frac{r}{r_{Terre}} \right)^{-2}$$

Ex. for Venus E_S=2620 W/m^2

Albedo = % reflected flux

Absorbed flux = $S_\perp\, (1\text{-}A)\, E_S$

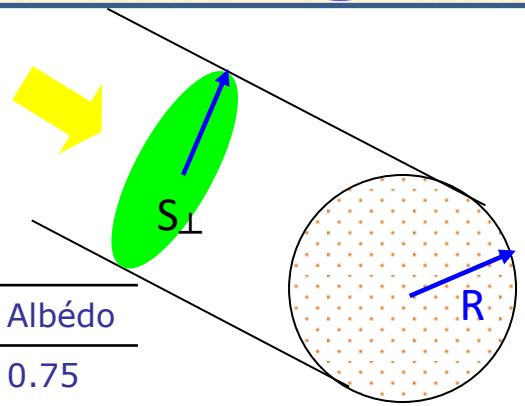
With $S_\perp = \pi R^2$

<u>Hyp</u>: the planet is a blackbody at T_e

Emitted flux = $S_{planet}\, \sigma\, T_e^4$

With $S_{planet} = 4\pi R^2$

σ Stefan- Boltzmann cst

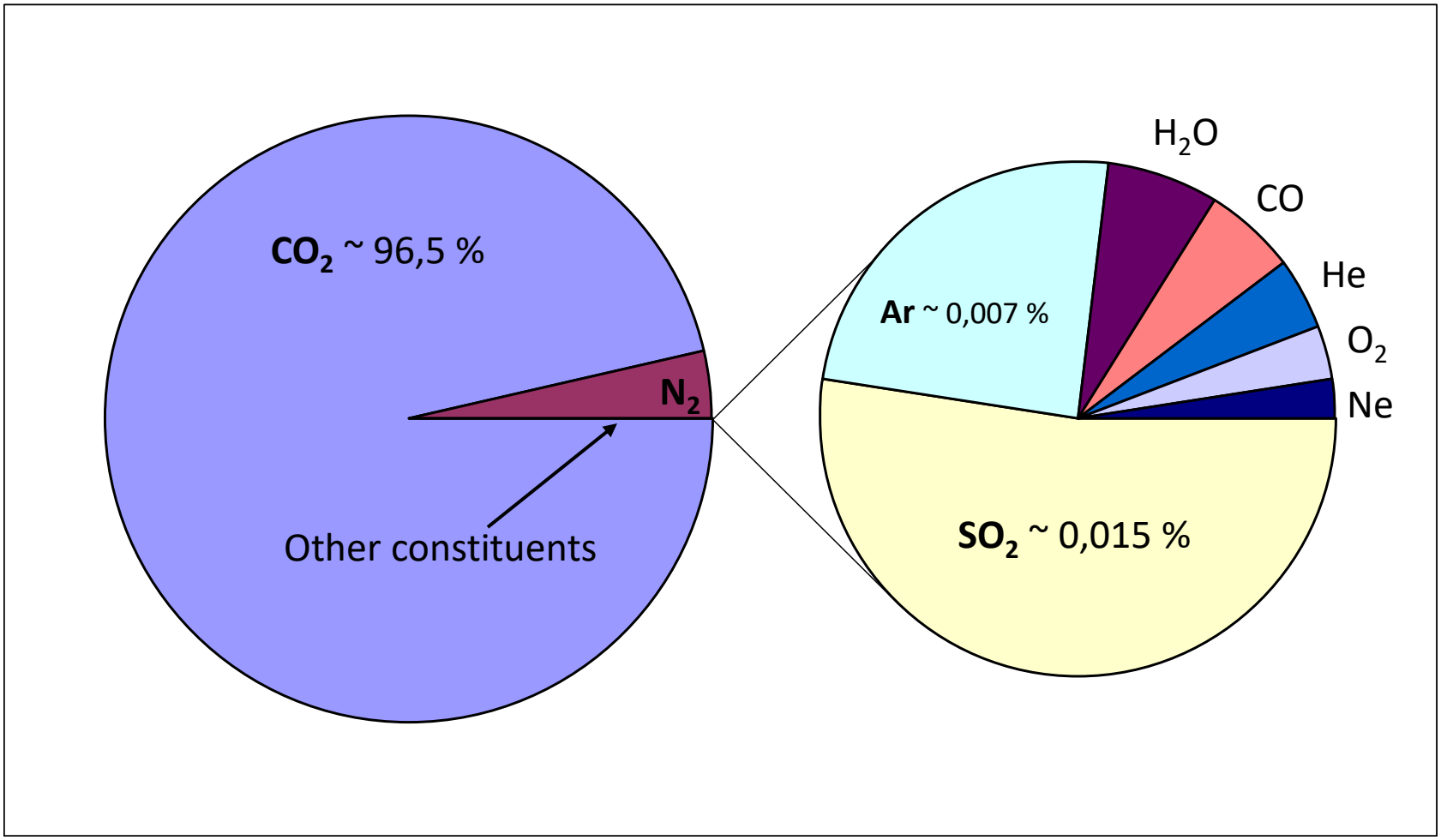


	Albédo
Vénus	0.75
Terre	0.31
Mars	0.25

Absorbed flux = Emitted flux → T_e

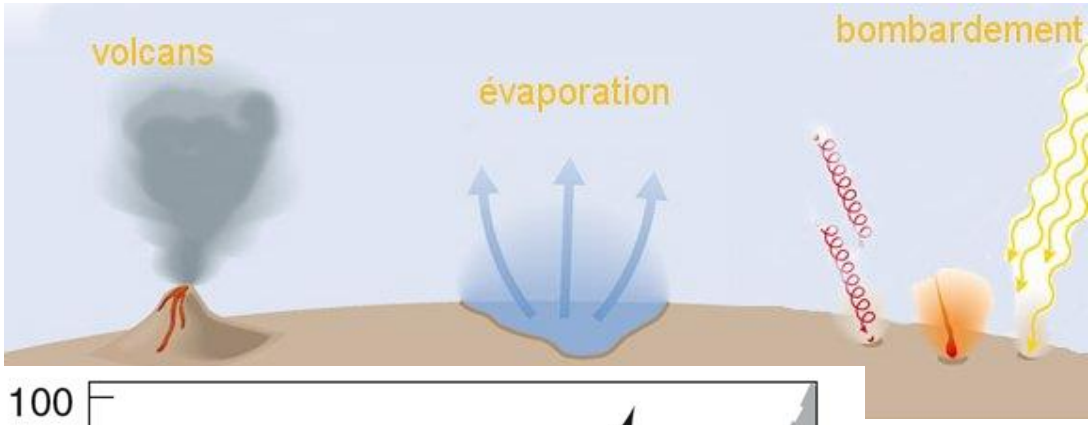
	Venus	Earth
Effective temperature = Apparent radiative temperature (from space)	232 K	254 K
Mean surface temperature	737 K	288 K
Increase of temperature due to greenhouse effect	+ 505 K	+ 34 K
Solar constante (W/m^2)	2614	1367
Net flux of solr energy at the surface (W/m^2)	367	842

Venus: Composition (under the clouds)

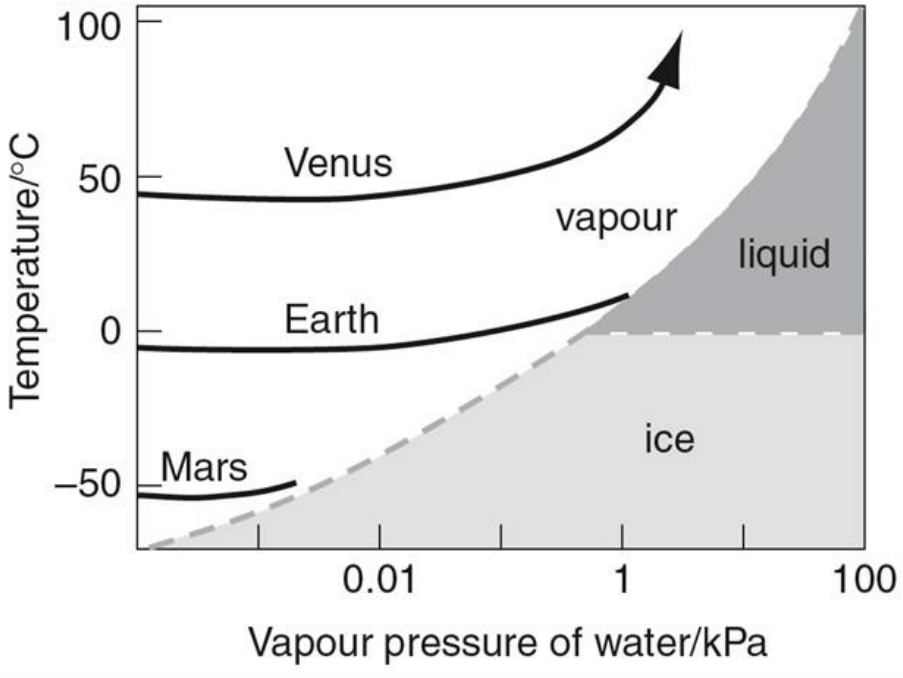


Water on Venus

- Sources : volcanism, evaporation



- No condensation



Water on Venus

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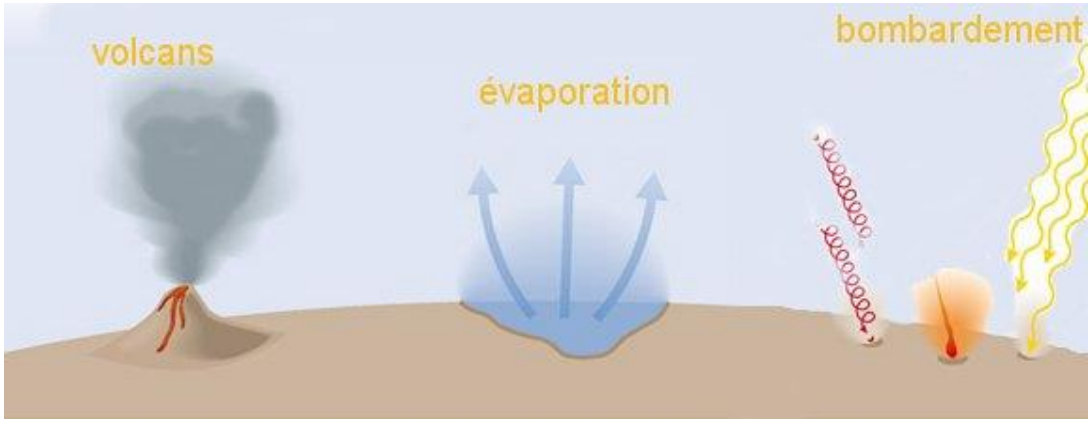
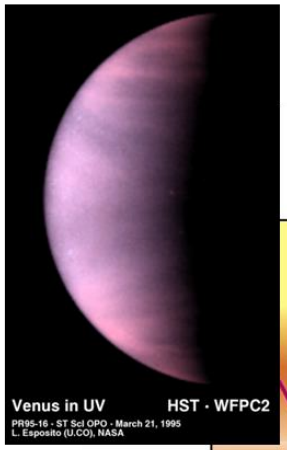


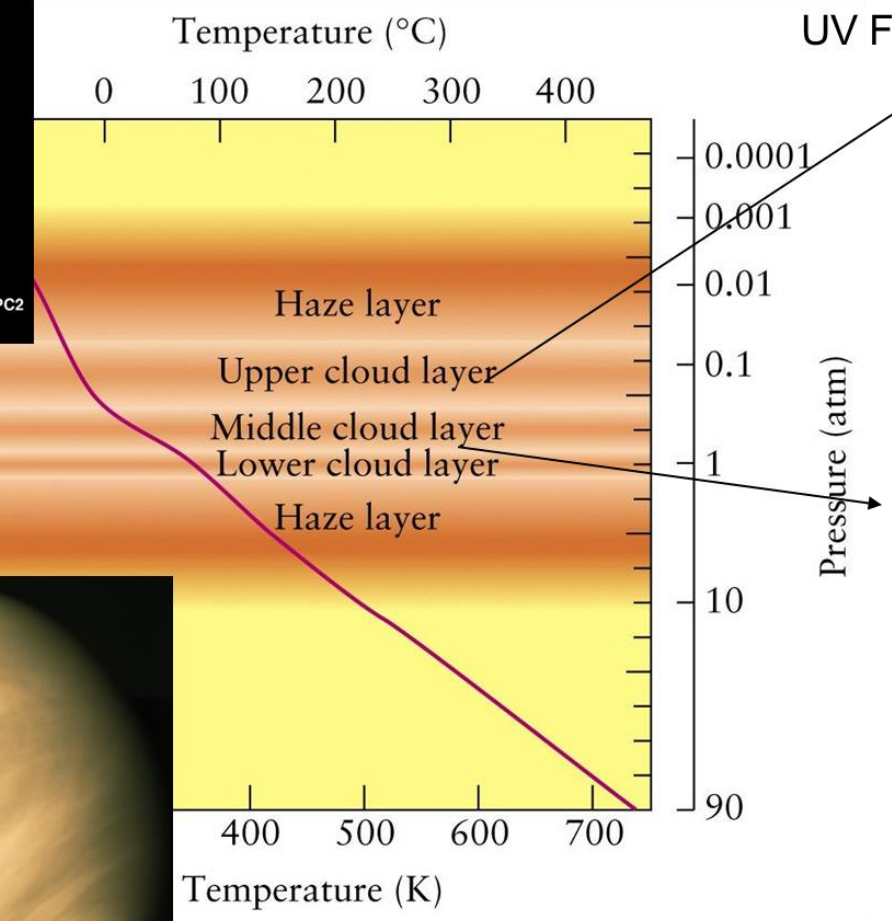
- No condensation

- UV radiation $H + O_2$
- H escapes : no cycle of water
- Proof : D/H ratio (D heavier, does not escape)

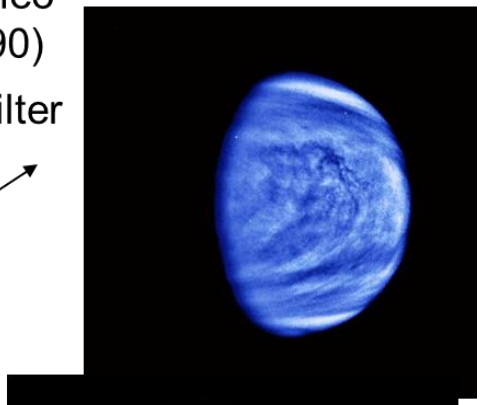
$D/H_{Venus} \sim 120 \times D/H_{Earth}$

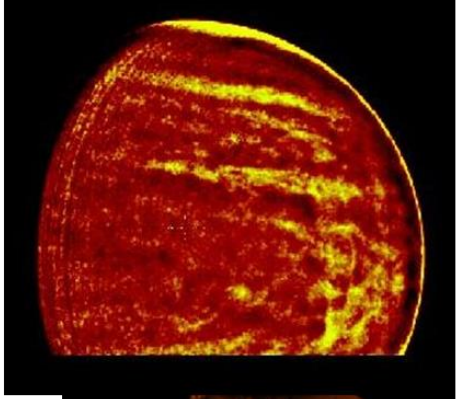
Clouds on Venus

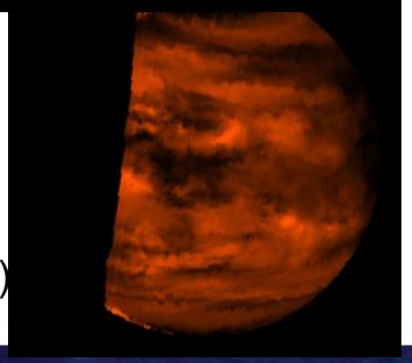




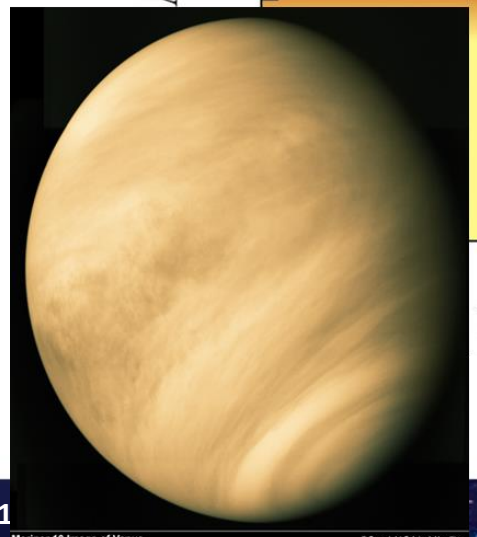
Galileo (1990)
UV Filter







Galileo (1990)
NIR

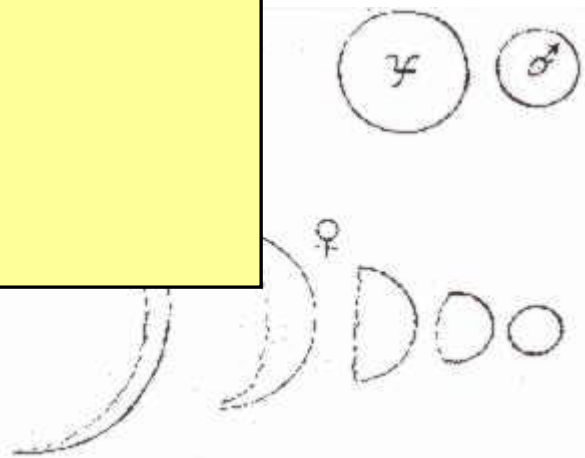


Galilée and the phases of Venus

Haec immatura a me iam frustra leguntur o y
Cynthiae figuras aemulatur mater amorum.

"La mère de l'amour [Vénus] imite les figures de Cynthia [la Lune]

"The mother of Love [Venus] mimics the faces of Cynthia [the Moon]



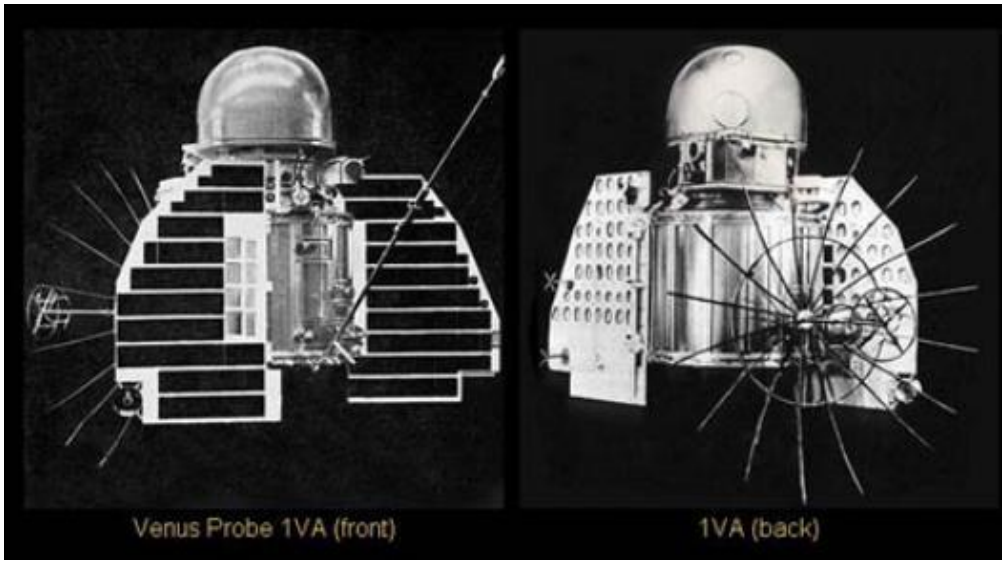
Sidereus Nuncius
(Messager céleste, 1610)

History of the exploration of Venus

- Venus transit in 1761 : the Russian astronome M. V. Lomonossov reports the presence of a halo
  - = atmosphere around Venus
- 1932 : CO_2 is identified for the first time using absorption spectroscopy (near IR)
- 1958 : measurement of the temperature at the surface (radio observations)
- 1970 : Sulfuric acid clouds are discovered

The 60's : 4 « success » on 18 missions

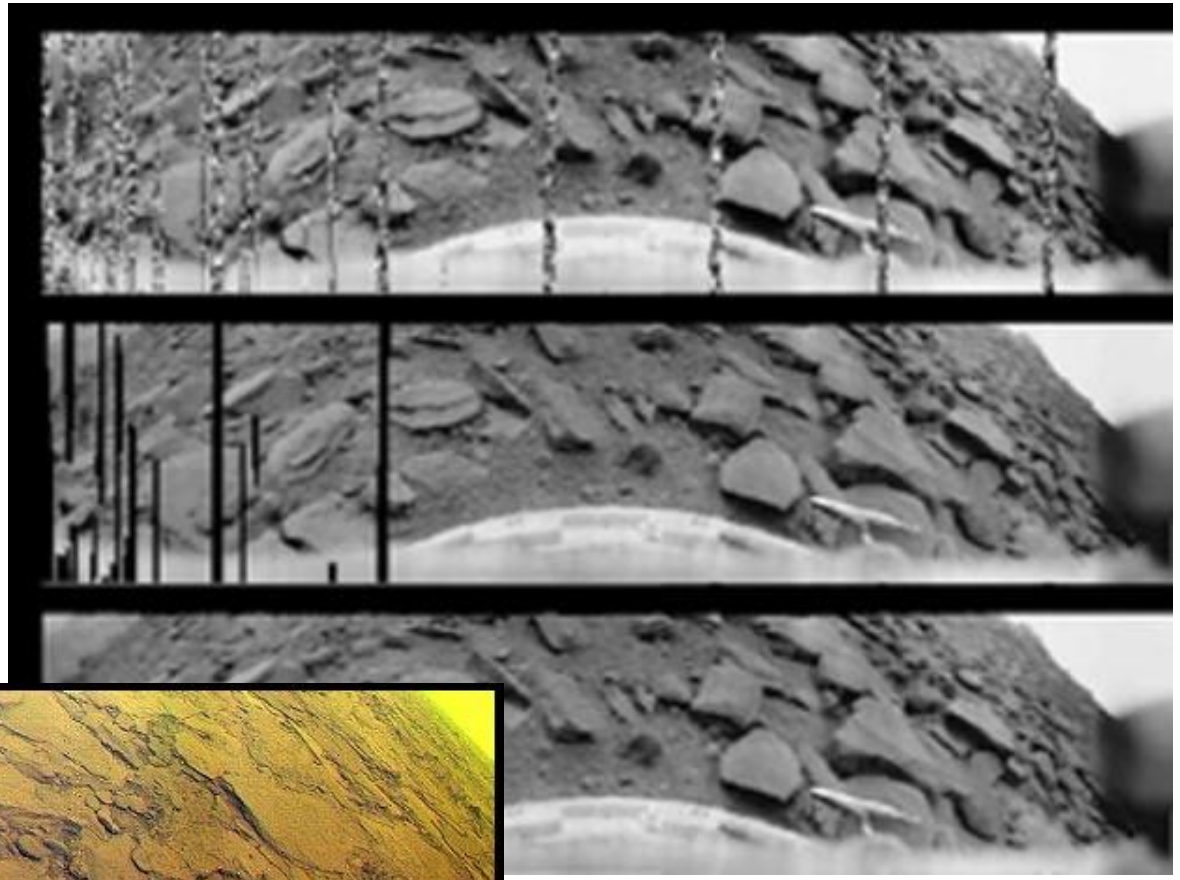
- Mariner 2 (USA): 1st flyby, dense atmosphere, high T, no magnetic field – 15 days of missions
- Venera 3 (URSS): successful entry but no transmition
- Venera 4 (URSS): successful entry, data down to 24 km
  - Composition: at least 90% CO2
- Mariner 5 (USA): flyby

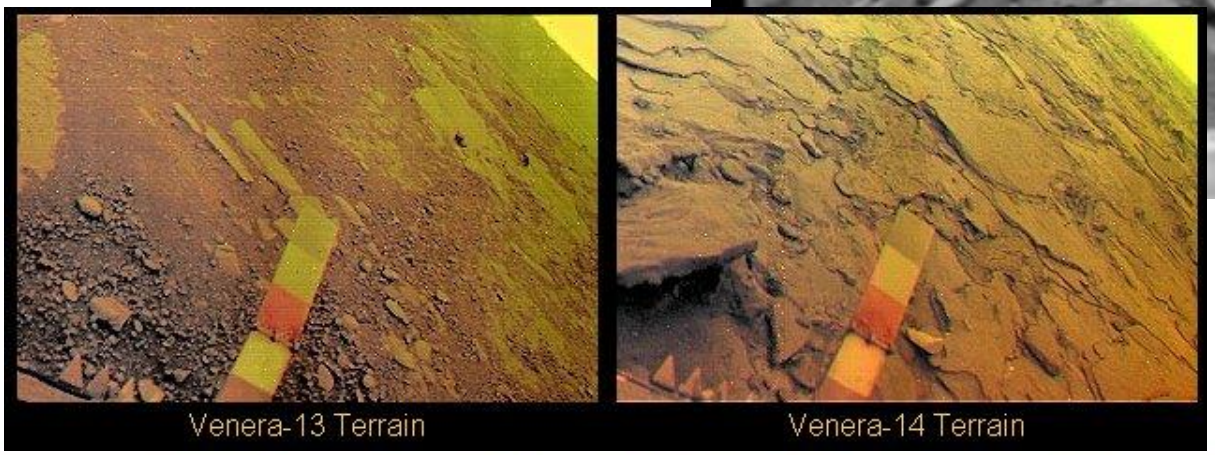


Venera 4

Exploration of Venus: the first pictures

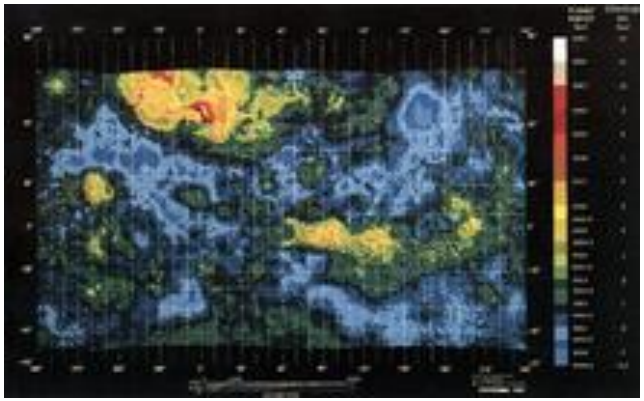
- 1975 – Venera 9 & 10: the first pictures of another planet !
- Venera 13 & 14: with colors





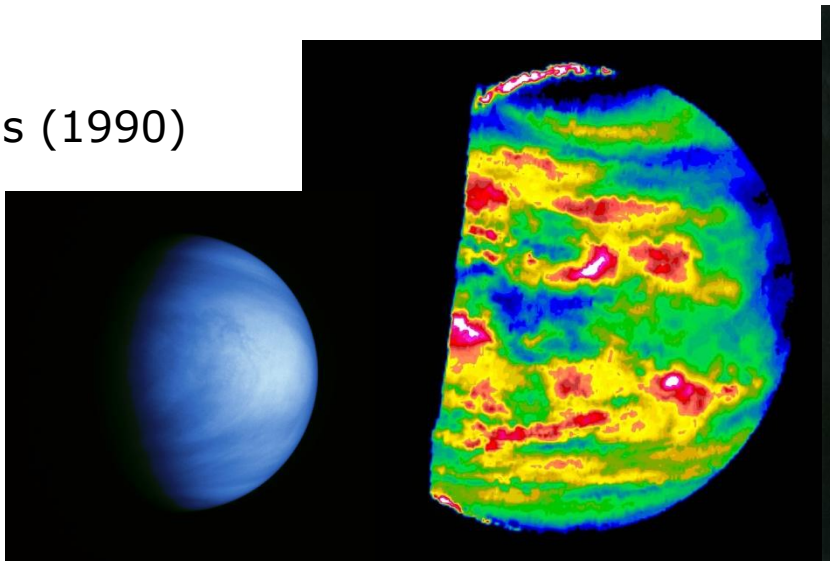
Exploration of Venus: the 80's & 90's

- Pioneer Venus : 2 satellites (1978):
  - 1 orbiter– 4 descent modules



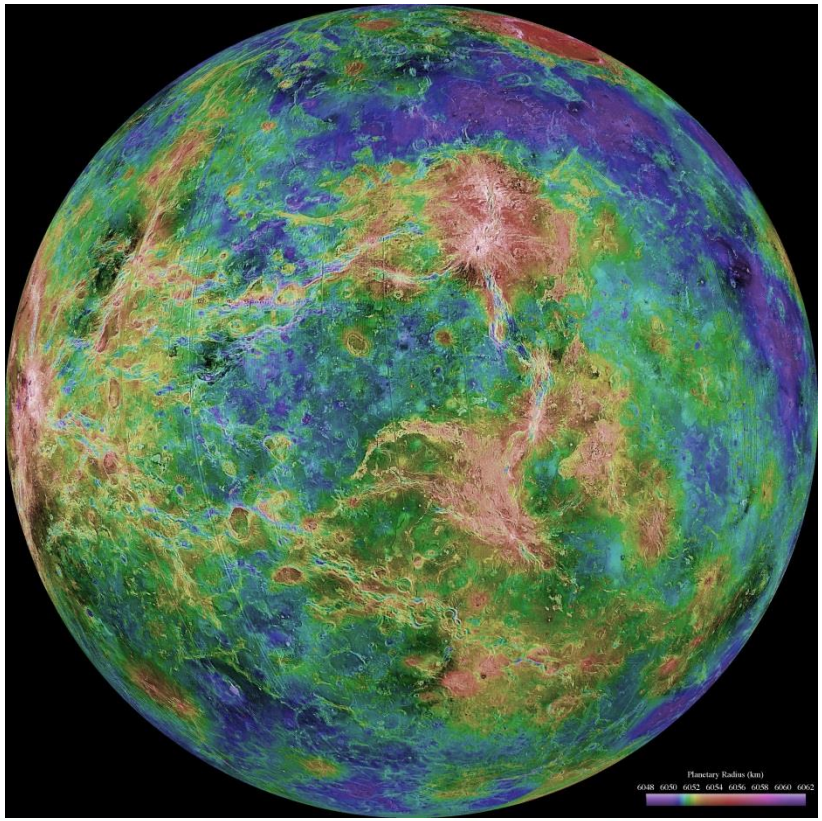
Map from Pioneer Venus Orbiter (1pixel=20km)

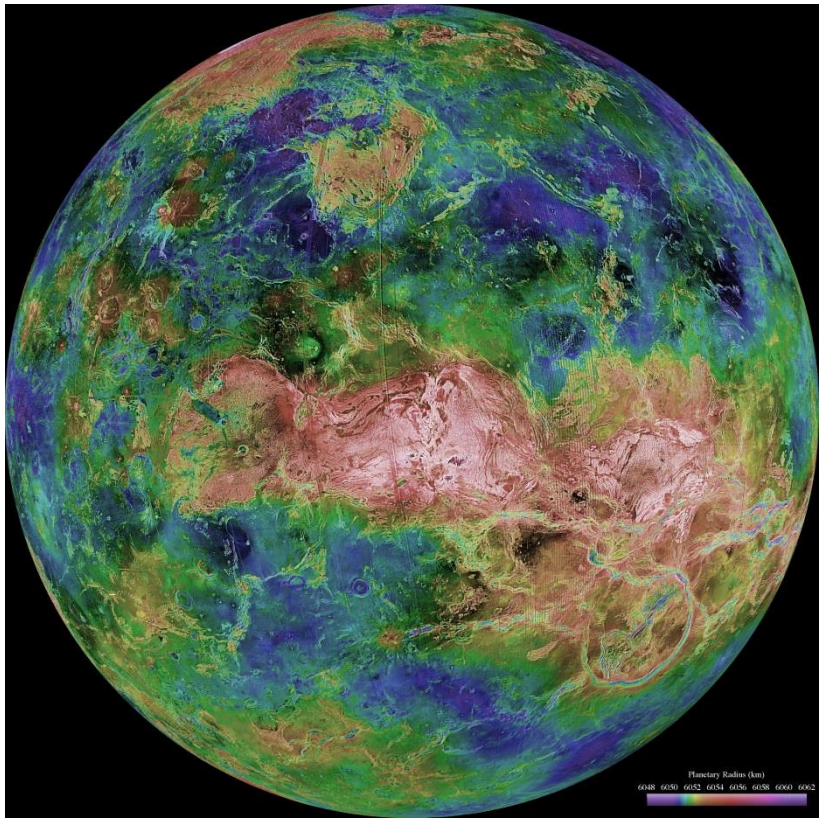
- Galileo
  - Flyby of Venus (1990)



1990 - 1994 : Magellan

- Cartography of 98 % of the surface
- Resolution = 120 m (Equ.) – 250 m (Poles)

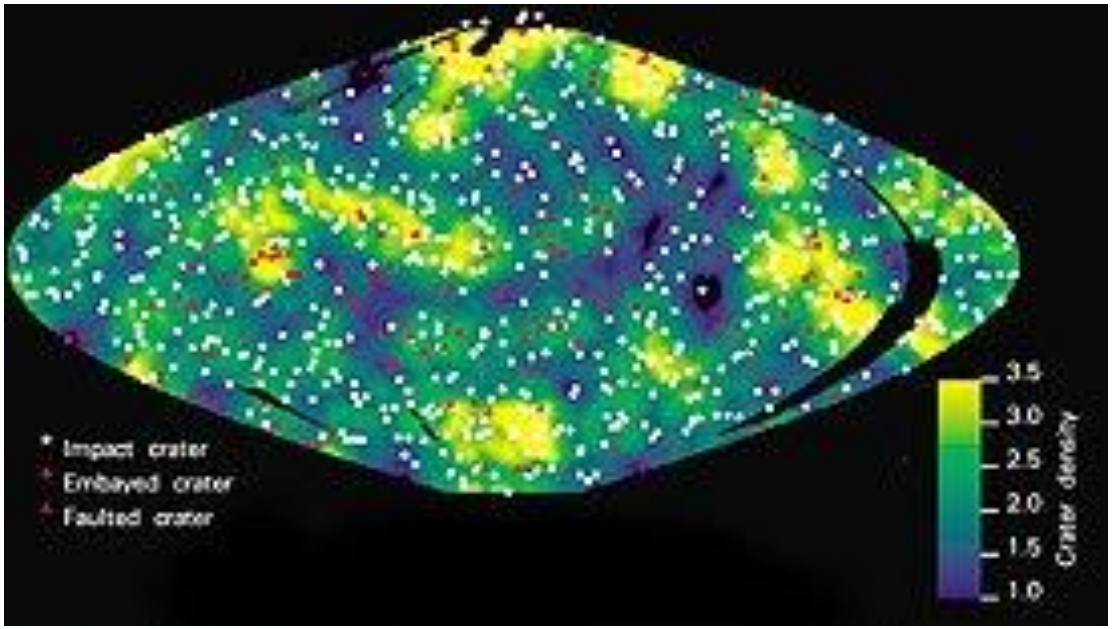




Craters at the surface

- Less than 1000 craters => 500 millions yrs.

- Random distribution
  - Since then no activity anymore
  - No plate tectonics



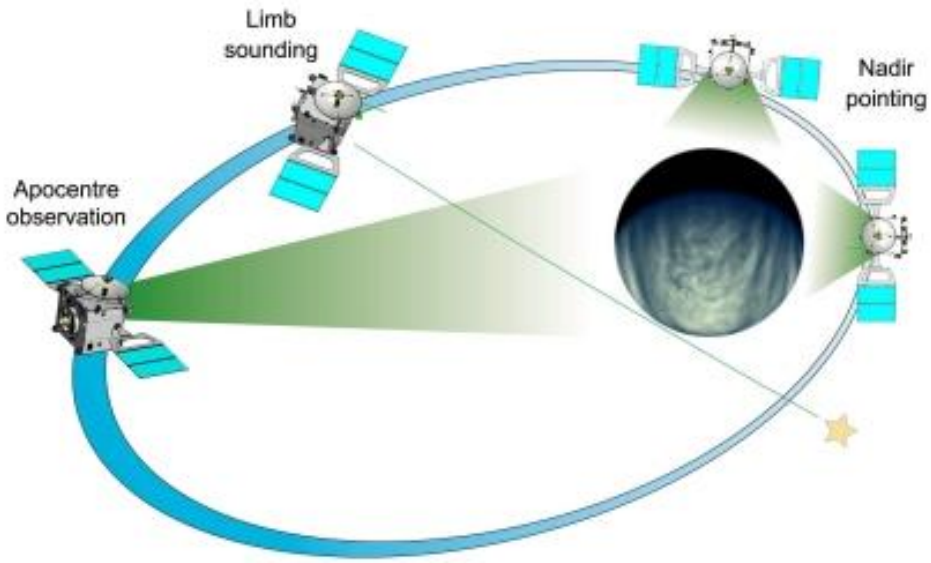
esa
NEXT STOP VENUS
VENUS
EXPRESS

Venus Express

- Launch from Baïkonour (Nov 2005)
- Arrival in April 2006

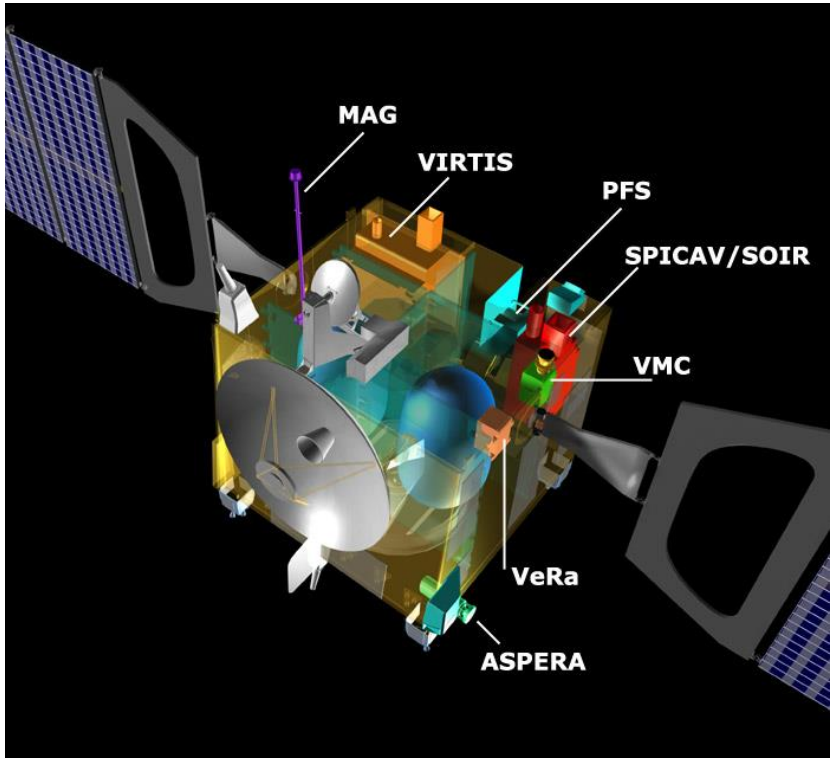
- Orbit :

- 24 hours period
- 250-400 km pericentre altitude
- 66000 km apocentre altitude
- 90 deg inclination
- Pericentre latitude ~80 deg N
- 7-10 hours communication link per orbit

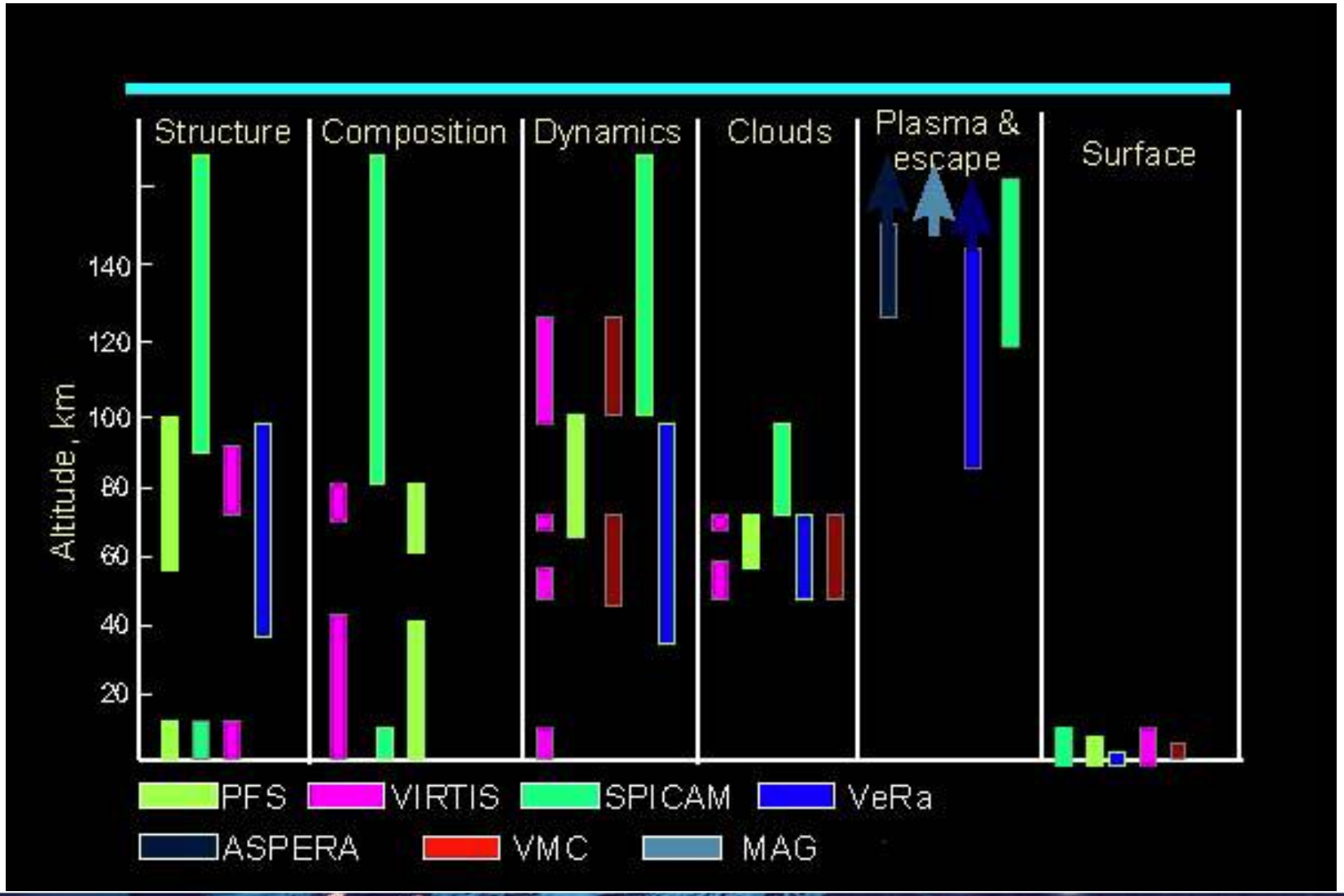


Scientific payload

- **ASPERA** – Space plasma and energetic ions
- **MAG** - magnetometer
- **PFS** – high resolution IR Fourier spectrometer
- **SPICAV/SOIR** – UV & IR spectrometer for solar/stellar occultations and nadir observations
- **VeRA** – radio science experiment
- **VIRTIS** – UV-vis-NIR imaging spectrometer
- **VMC** – Venus Monitoring Camera



VEX instruments summary

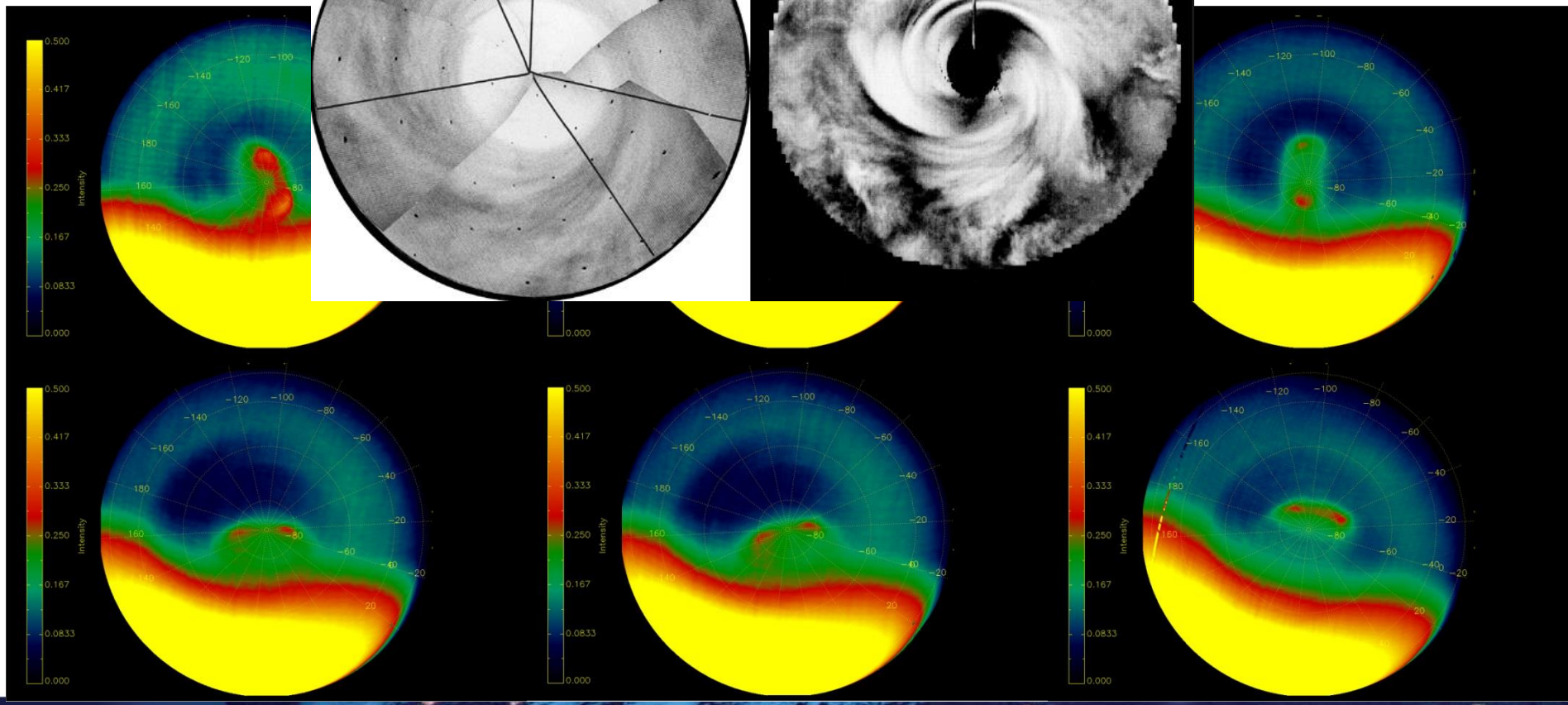


Vortex at South Pole

Mariner 10

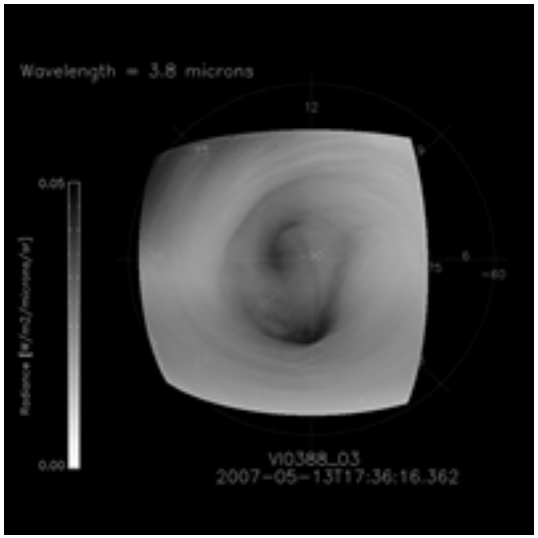
Pioneer Venus

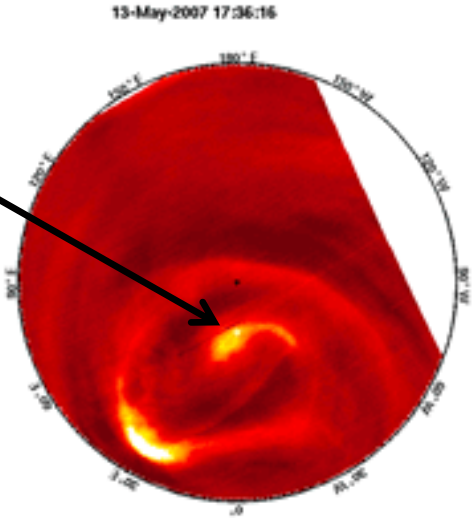
VIRTIS



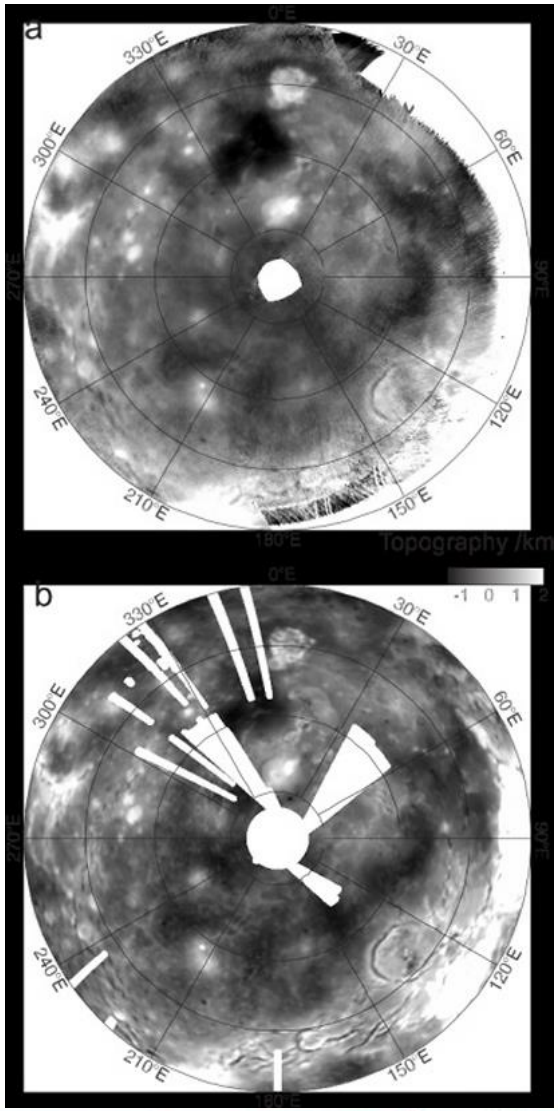
Atmospheric dynamics – Polar vortex

- VIRTIS has revealed that the southern vortex is far more complex than previously believed
- The centre of the vortex has a highly variable shape and internal structure, and its morphology is constantly changing on timescales of less than 24 hours
- The centre of rotation (white dot) is offset from the geographical South Pole + it drifts right around the pole over a period of 5-10 Earth days

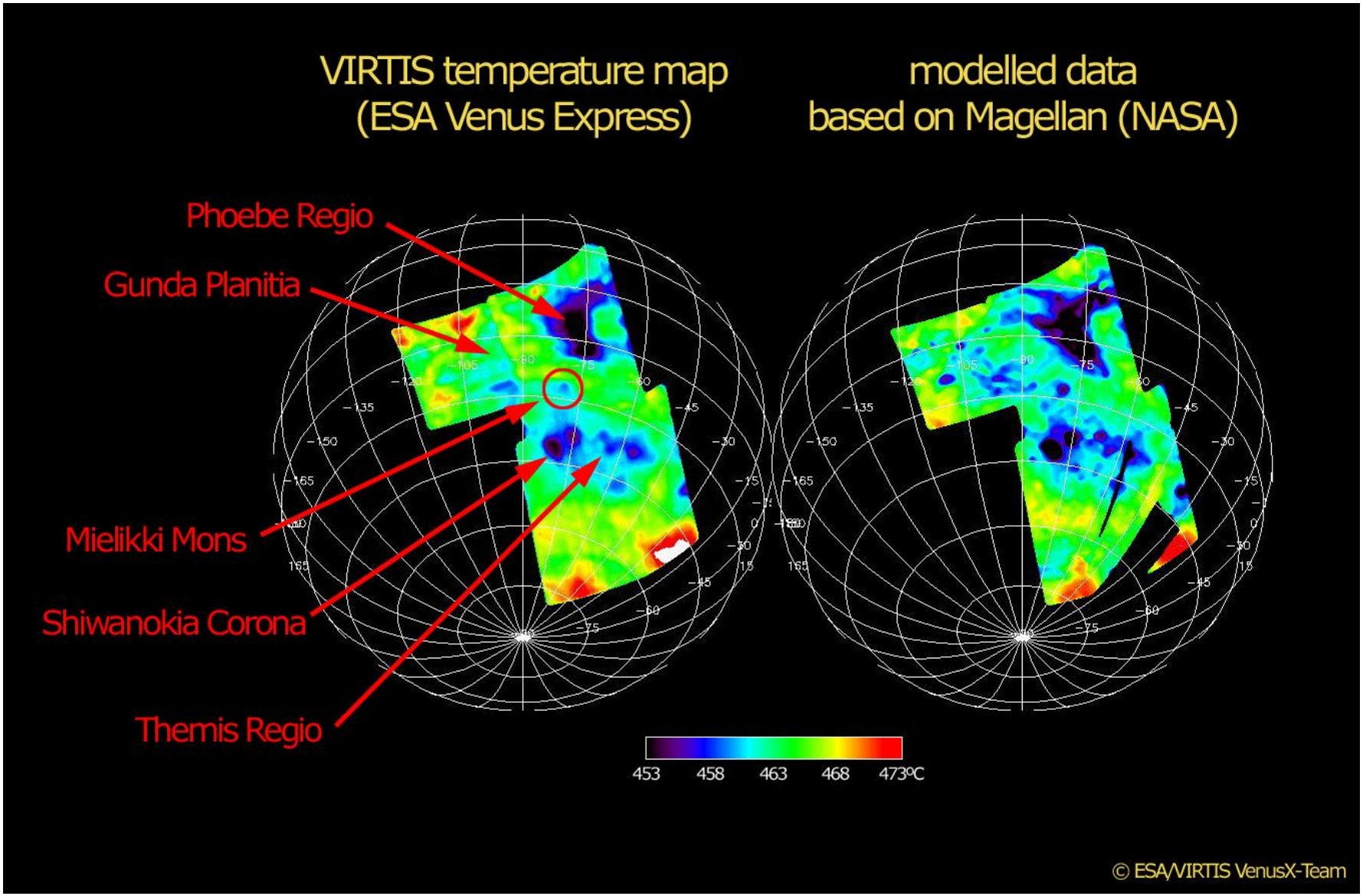




Venus is slowing down

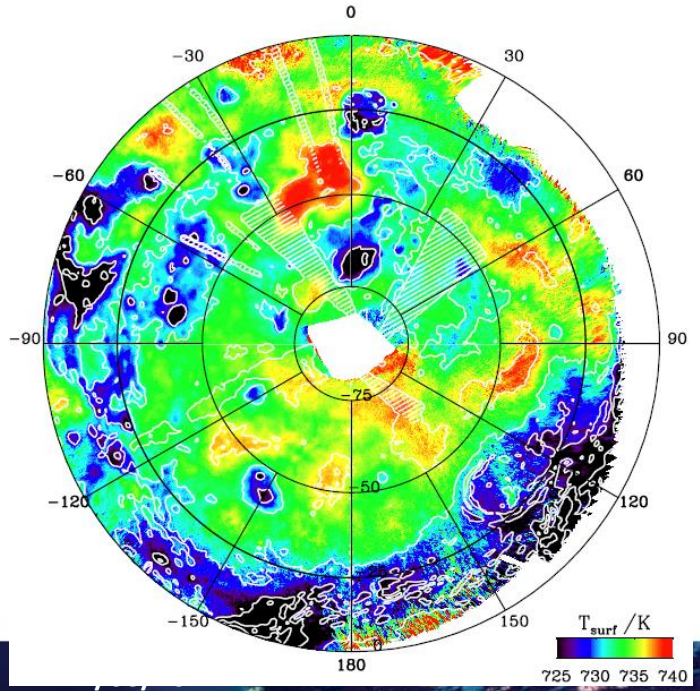


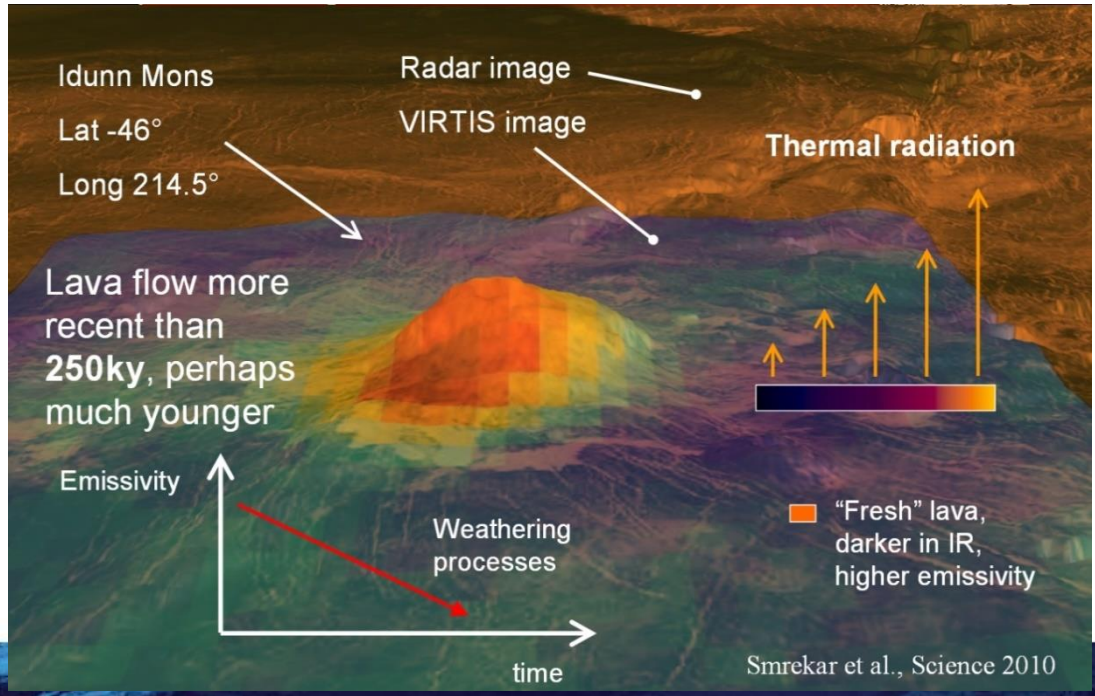
- Comparison between topographic maps from Magellan and Venus Express shows shifts in surface features up to **20 km** caused by a change in the rotation rate of the planet
  - The current Venus day is 6.5 minutes longer compared to Magellan era (16 years ago)


VIRTIS temperature map
(ESA Venus Express)
modelled data
based on Magellan (NASA)
Phoebe Regio
Gunda Planitia
Mielikki Mons
Shiwanokia Corona
Themis Regio
453
458
463
468
473ºC
© ESA/VIRTIS VenusX-Team

Surface mapping – Recent volcanism ?

- VIRTIS has measured the spectral emissivity of the surface to study the properties of likely Venusian hot spots. In particular, around volcanoes in three of the hot spots, VIRTIS data show anomalously high emissivity values
- These high emissivity regions are interpreted as fresh recent unweathered lava flows - perhaps a few thousands to a few tens of thousands of years in age



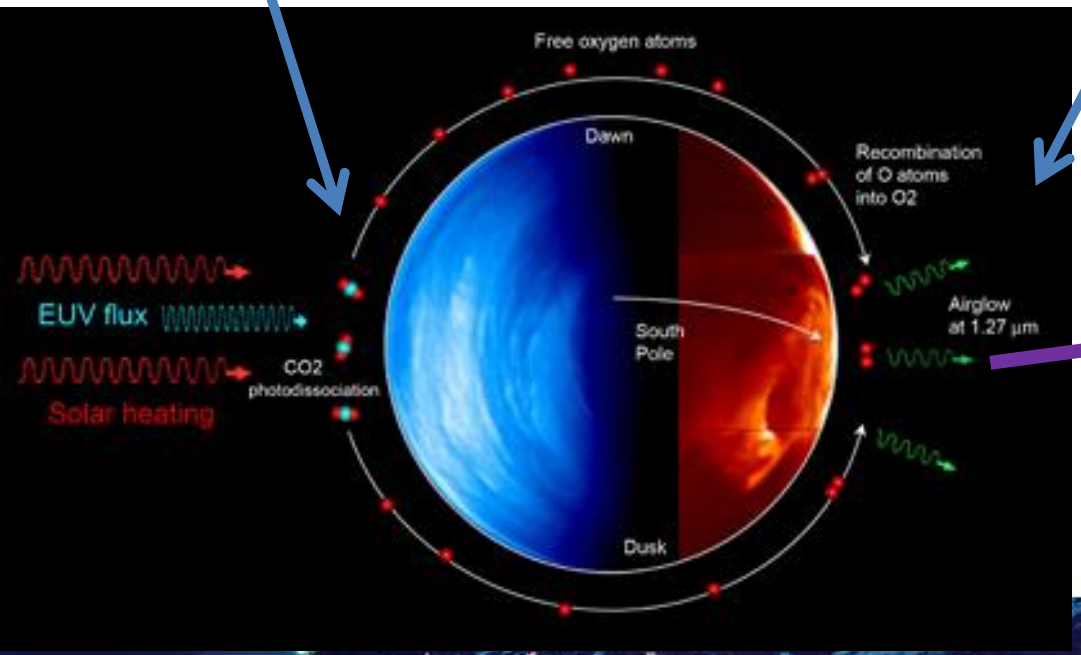


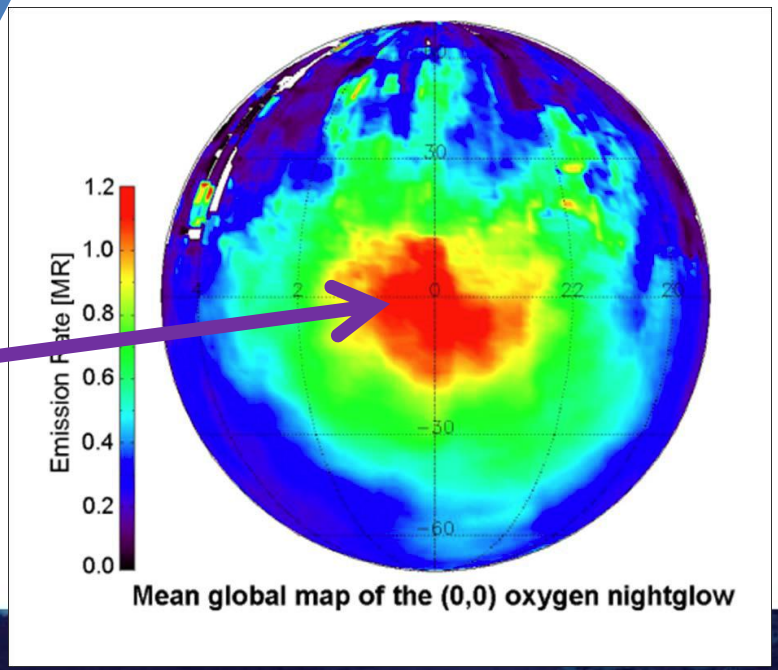
Upper atmosphere dynamics

- Analysis of the Oxygen airglow adds evidence to the Solar to anti-solar circulation

Day side
Photodissociation of CO_2

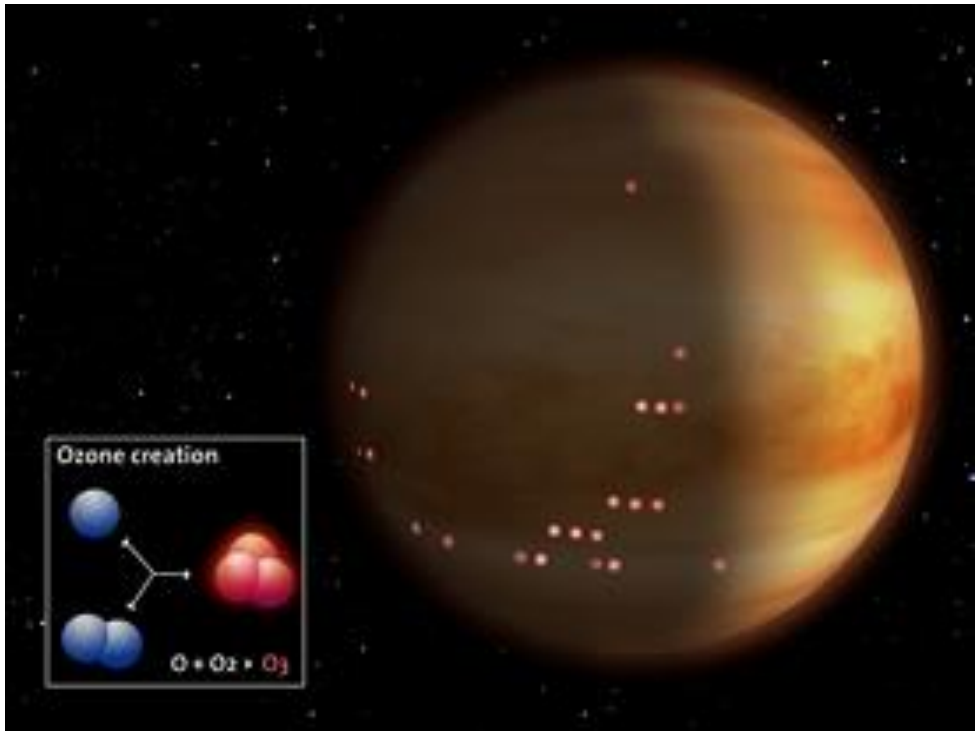
Nigth side
Recombinaison $O + O + CO_2 \rightarrow O_2^* + CO_2$
Emission $O_2^* \rightarrow O_2 + h\nu$
Quenching $O_2^* + M \rightarrow O_2 + M$



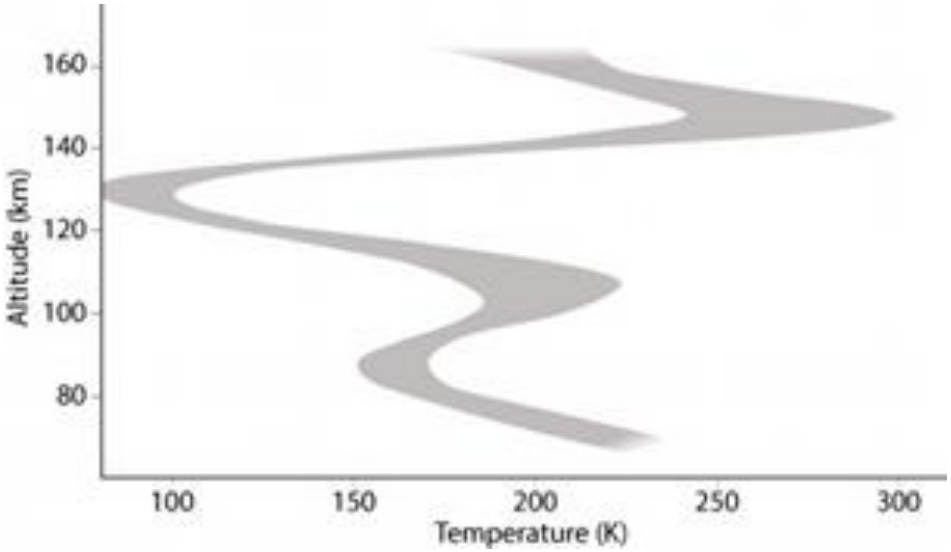


Discovery of ozone

- Discovered by SPICAV-UV stellar occultation observations
- O_3 is located at varying altitudes in the Venusian atmosphere, between 90 and 120 km
- The ozone layer on Venus is very tenuous – up to 1000 times less dense than that on Earth
- surprise : absence of O_3 at the anti-solar point, where molecular oxygen is highly concentrated
- Could be explained by catalytic destruction by chlorine-based compounds



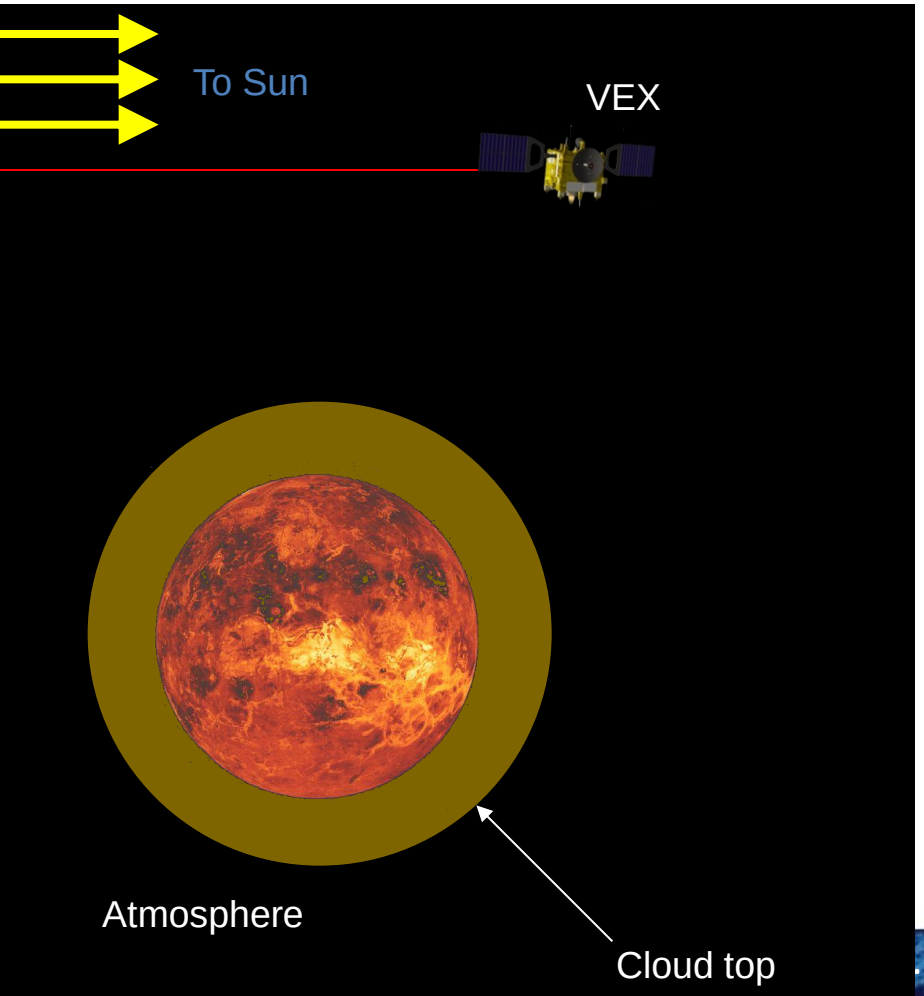
Structure : unexpected temperature vertical profile



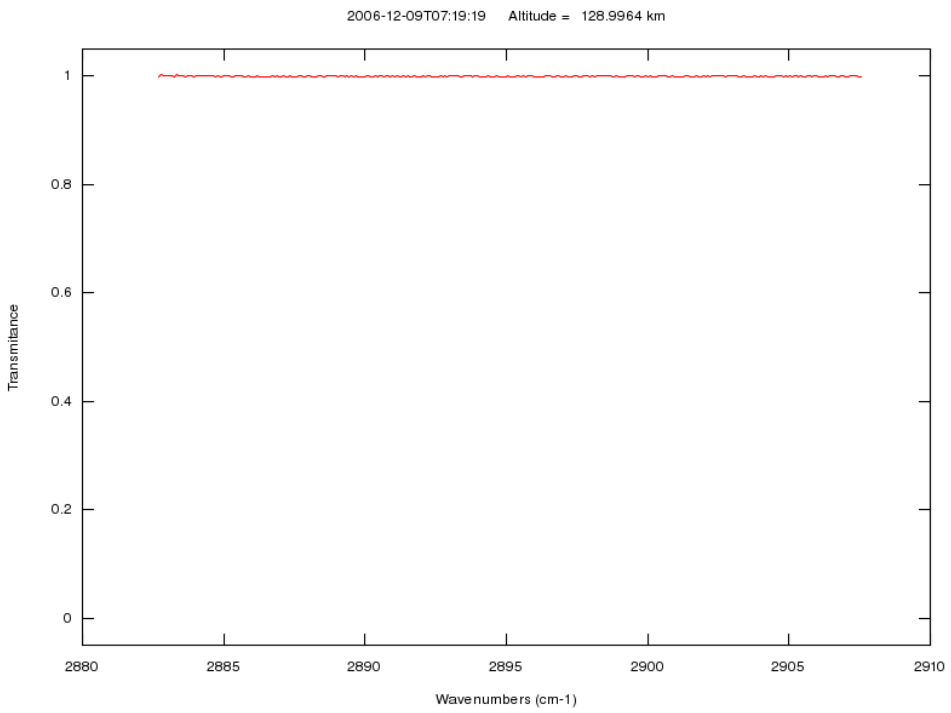
Venus Express discovered a surprisingly cold region high in the planet's atmosphere, where conditions may be frigid enough for carbon dioxide to freeze out as ice or snow

- SOIR obtained vertical profiles of temperature at the terminator
  - The temperature profiles on the hot dayside and cool night side at altitudes above 120 km are extremely different, so the terminator is affected by conditions on both sides.

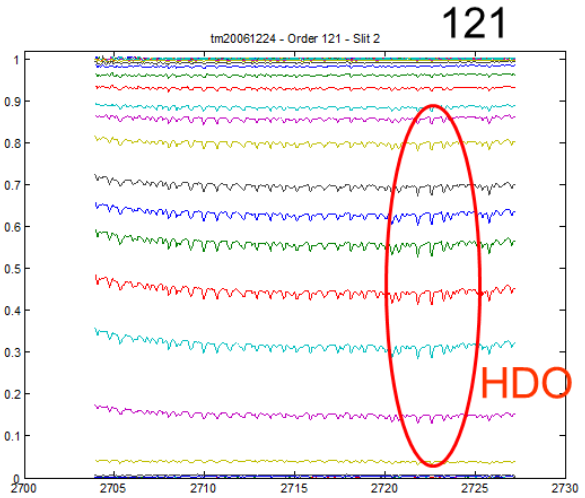
SOIR observation: solar occultation

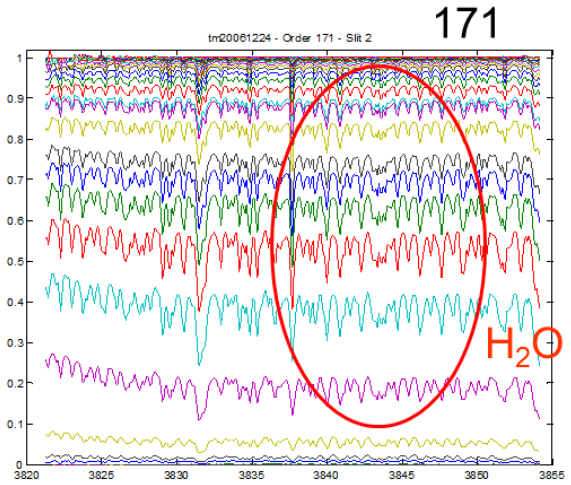


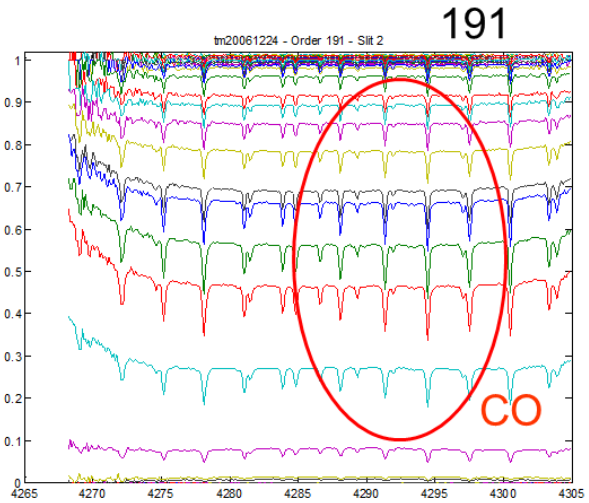
Orbit 232 – Order 129

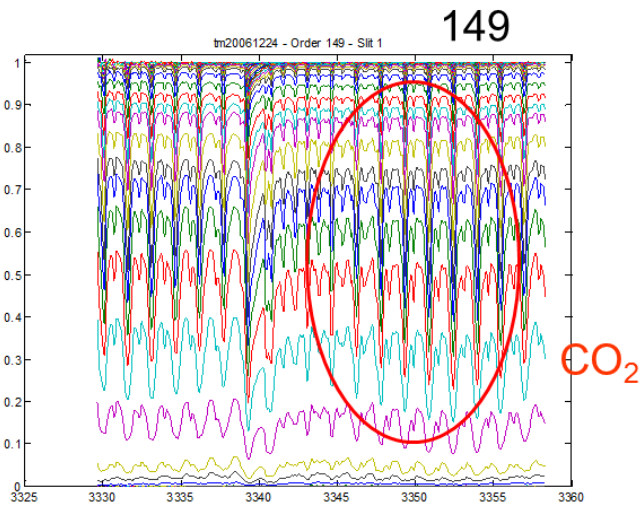


Example of set of SOIR spectra









The end ?

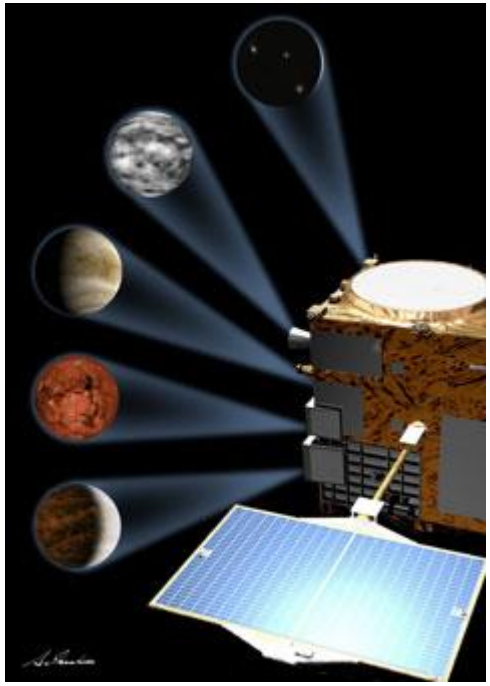
- In June 2014 : Venus Express gets ready to take the plunge ; 'experimental aerobraking'
  - for 18 June – 11 July @ 130 km
  - limited science measurements with the spacecraft's magnetic field, solar wind and atom analysing instruments will be possible

- The s/c has survived:
  - However during the manœuvres to rise again the altitude of the s/c, the communication with the s/c was lost
  - Antenna could not point to Earth

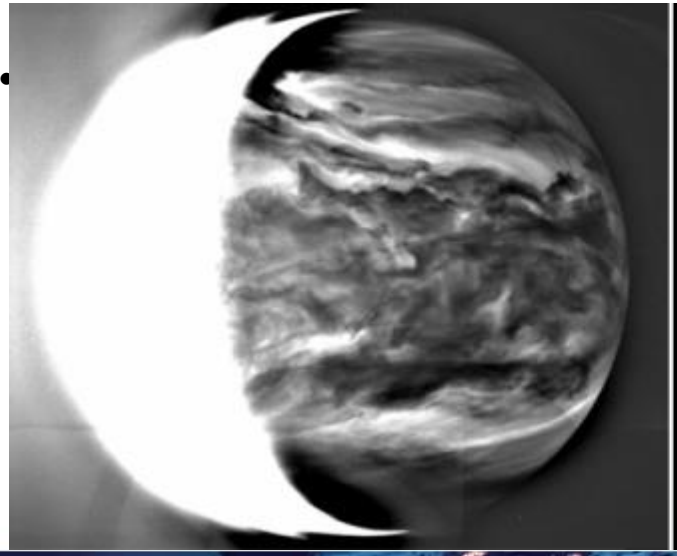
  - Cause : end of fuel !

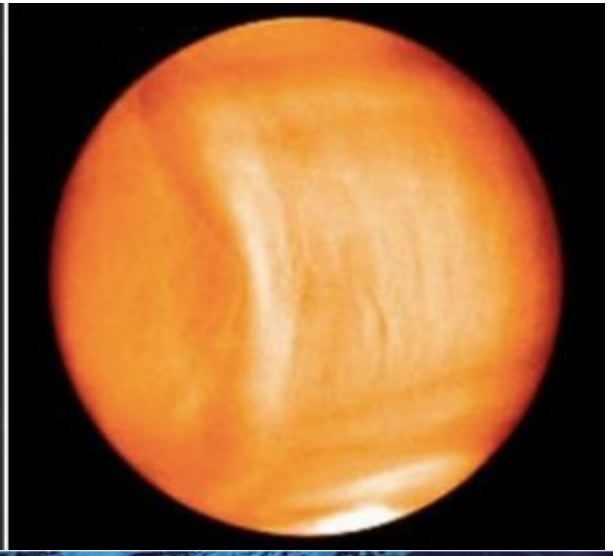
- End of mission declared on Dec 18 2014

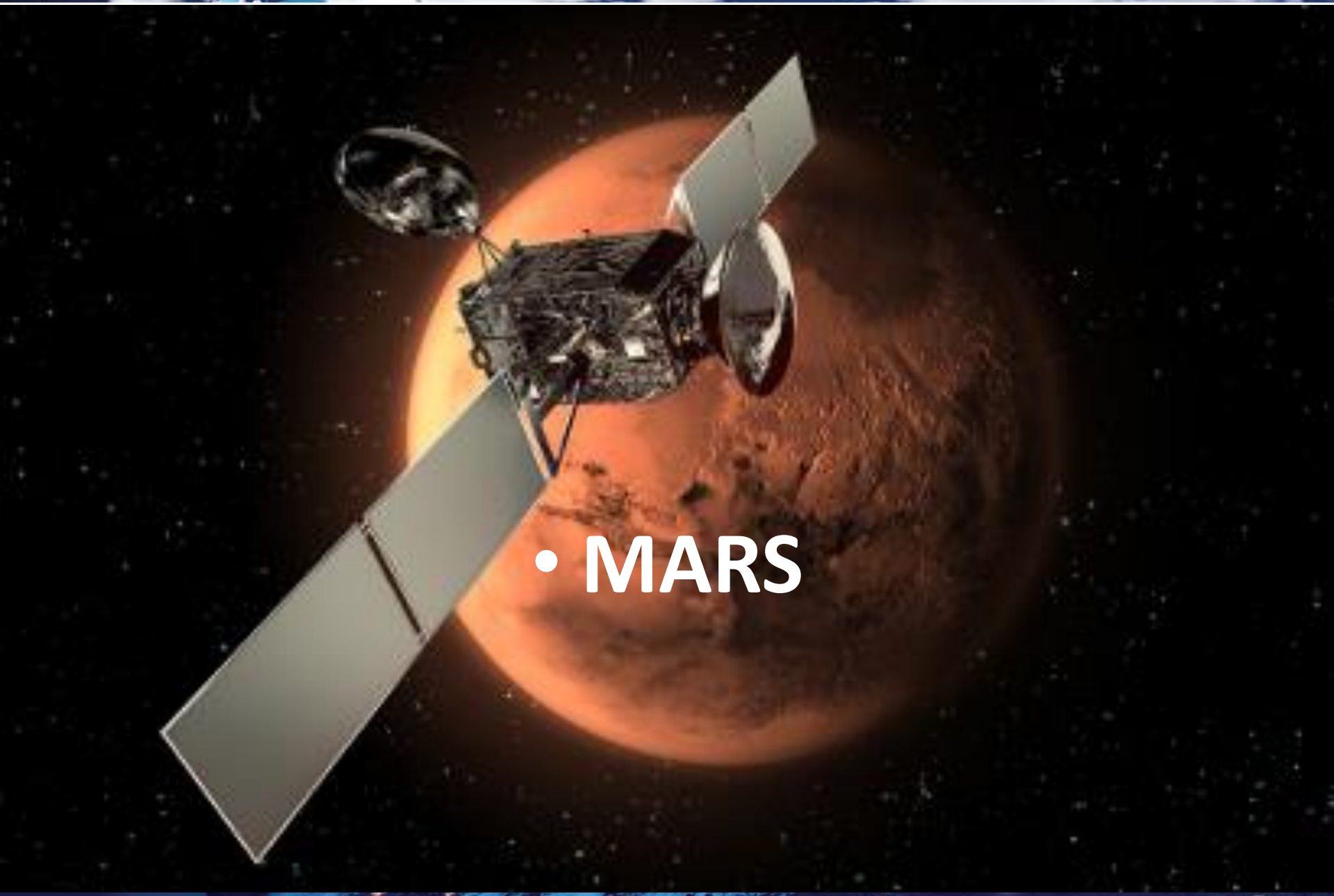
Akatsuki



- ou Planet-C – Akatsuki=aube
  - Caméras IR et UV : étude des nuages
  - Caméra spécifique pour observer les éclairs et la foudre
  - Radio-occultation : p, T < 90 km
  - ~~Synergie avec Venus Express~~
- Lancée en 2010 – aurait dû arriver à Vénus en déc
- Mais, manœuvre d'insertion en orbite a échoué
- …. Retour en 2016
-

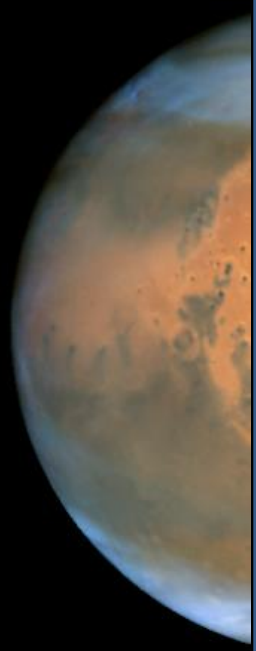




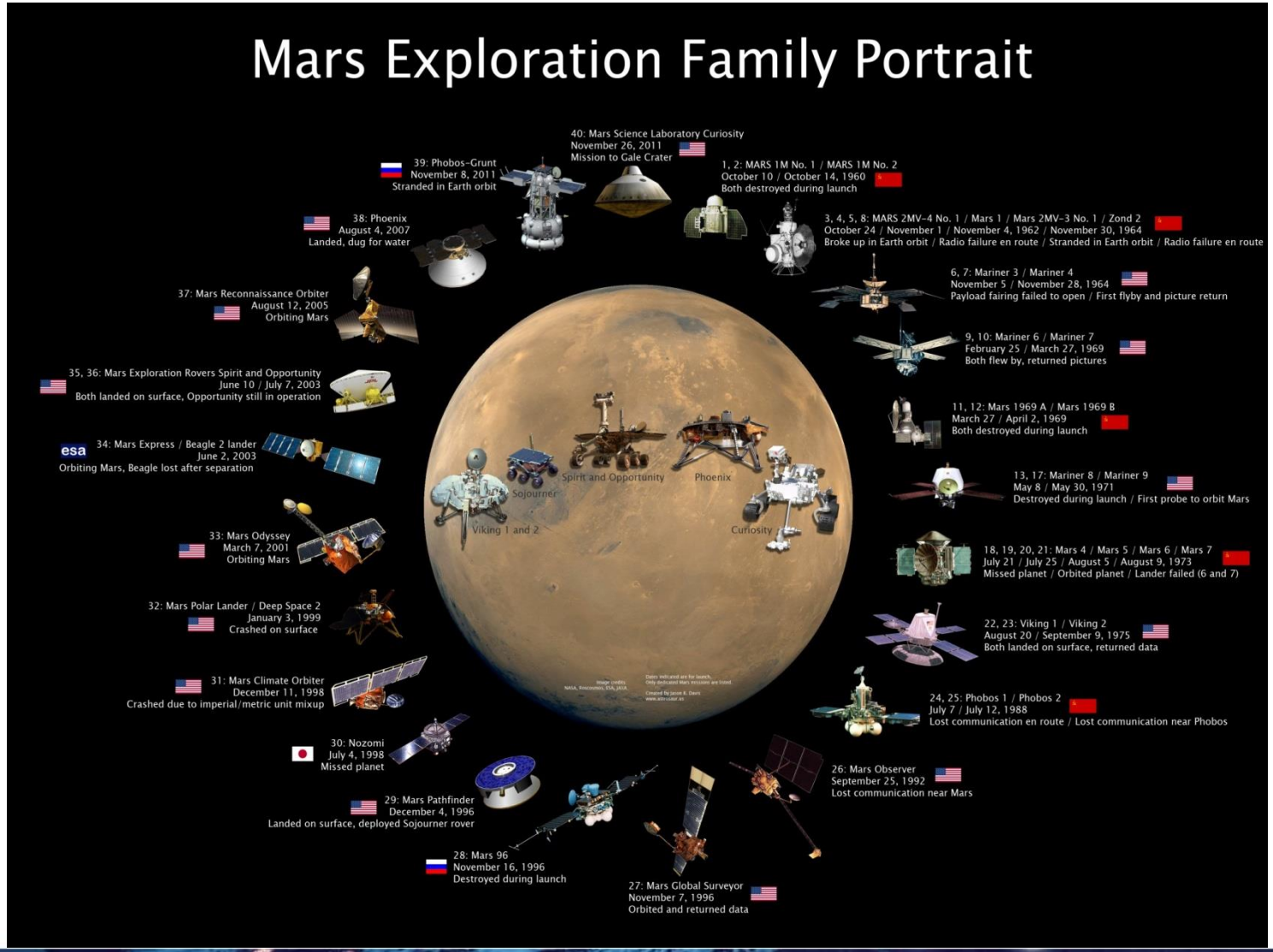


- MARS

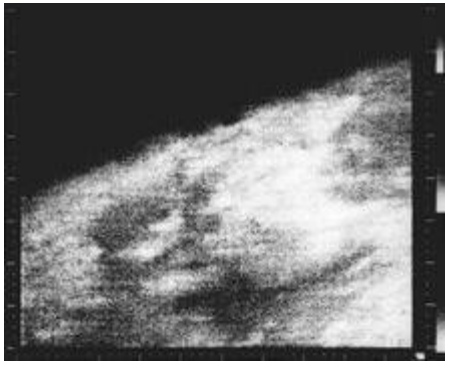
Earth		Mars
$5{,}9 \times 10^{24}$	Mass (kg)	$6{,}4 \times 10^{23}$
12 756 km	Diameter	6794 km
15 °C	Temperature (surface)	-55 °C
1 atm	Pressure (surface)	0,006 atm
365 days	Revolution around the Sun	687 days
1 dag	Rotation	24u 37 min
N_2, O_2	Main gasses	CO_2



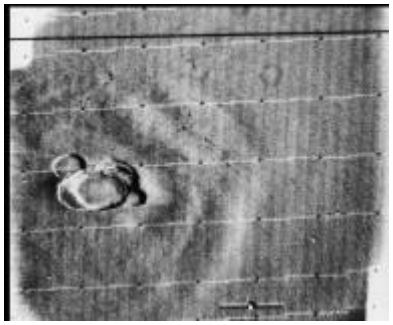
Exploration of Mars



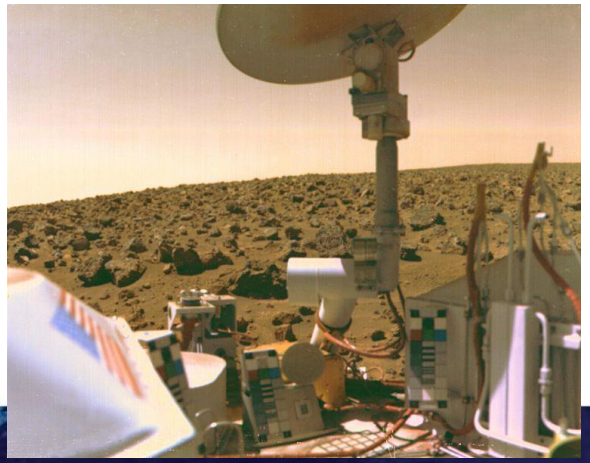
In the early years: Few successes – lots of failures



First image of Mars taken by Mariner4



- Russian probes 1960-1964 : 4 launched, none reached Mars
- American probes 1964-1971:
  - Mariner3-8 (failure), Mariner4 (flyby in 1965)
  - First real success: Mariner 9 (1971)
    - Cartography of the surface, volcanoes, Valles Marineris, polar caps
    - Storms observed
- American succes with Viking 1 & 2 (1975)
  - Cartography
  - Atmospheric composition (CO_2)
  - Detection of life: ambiguous results



Mars exploration : the 90s

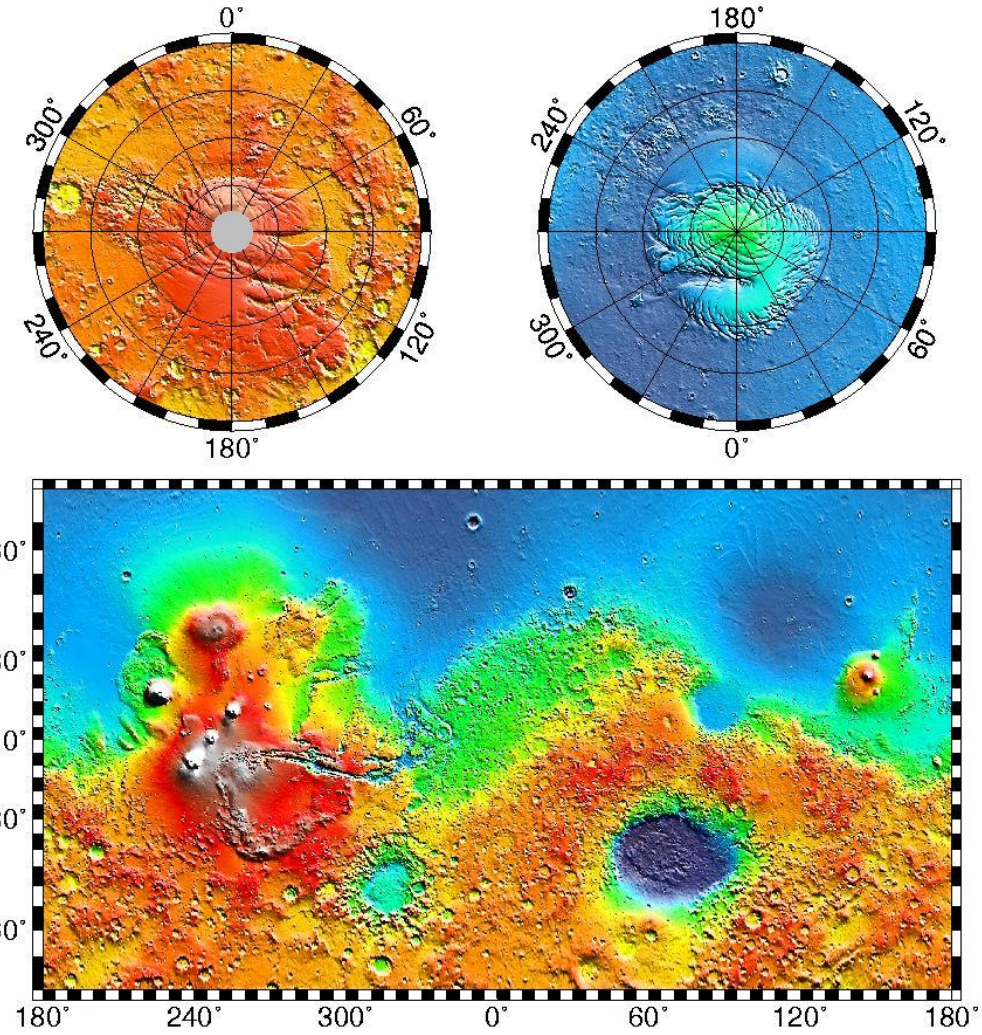
- Americain disaster : Mars Observer
  - The NASA more expensive mission ever
  - New approach« better, faster, cheaper »

- 1996 :
  - Mars Pathfinder

First mobile rover, Sojourner, on Martian surface

  - Mars Global Surveyor (MGS)
    - 9 years of mission
    - Detection of hematite and sedimentary deposit
    - Fossil magnetic field
    - Global topography map

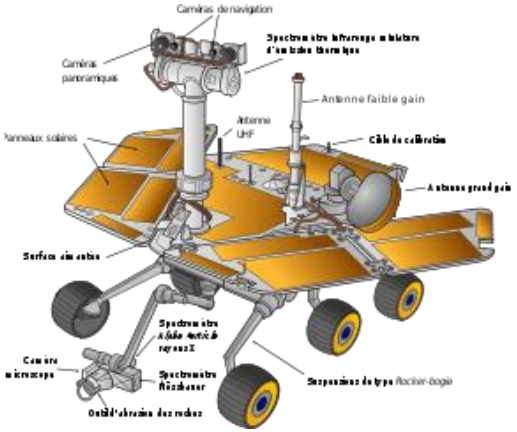
MOLA onboard MGS



Topography map from MOLA-Mars Global Surveyor, Mercator + polar projections

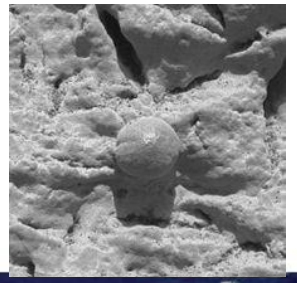
Mars exploration : recent missions

- Mars Exploration Rover (2003)
  - Spirit (MER-A): Gusev crater, † 2010
  - Opportunity (MER-B): Meridiani Platum
  - Study the rocks
  - Search for liquid water



360 deg view of the landing site of the *Spirit* rover taken on Jan 12 2004

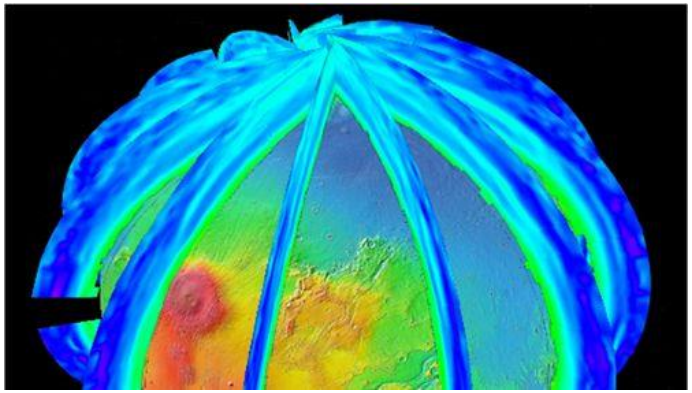
Spherule (blueberry)

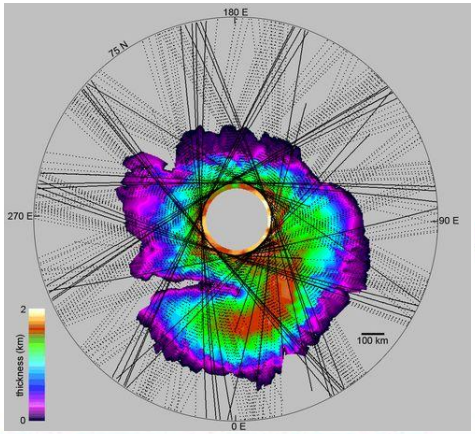


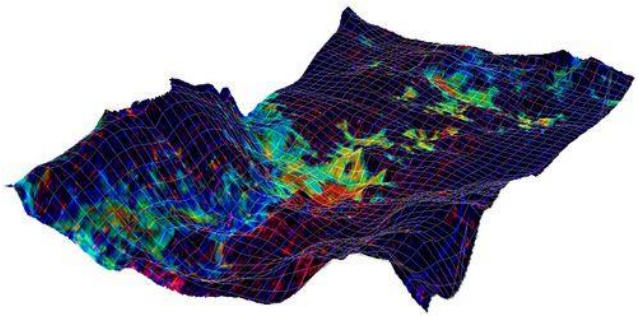
Mars exploration : recent missions

- Mars Reconnaisssance Orbiter (2005)
  - **HiRISE** : High-definition camera
  - **MCS** : 9 channels spectrometer IR-UV, global coverage (T, clouds, water), vertical profiles
  - **MARCI** : UV-vis imager, globale maps – daily, seasonal and yearly variations, **CRISM** : IR-vis spectrometer, surface (mineralogy)
  - **SHARAD** : sub-surface radar , search for water

HiRISE Camera



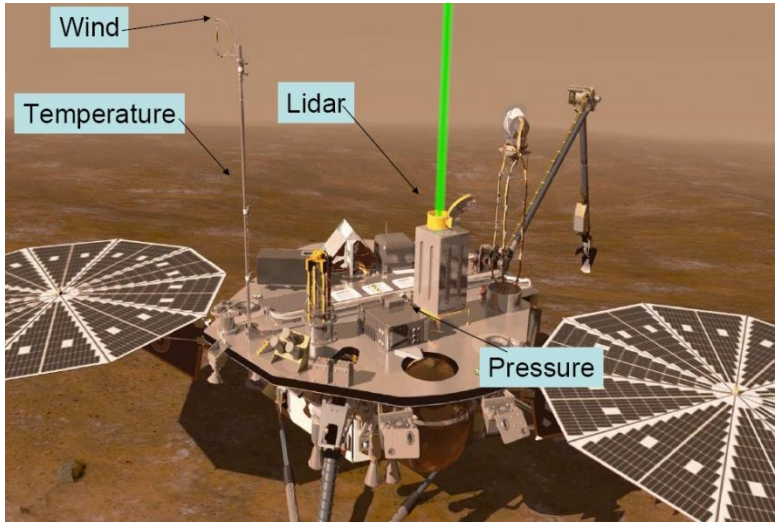


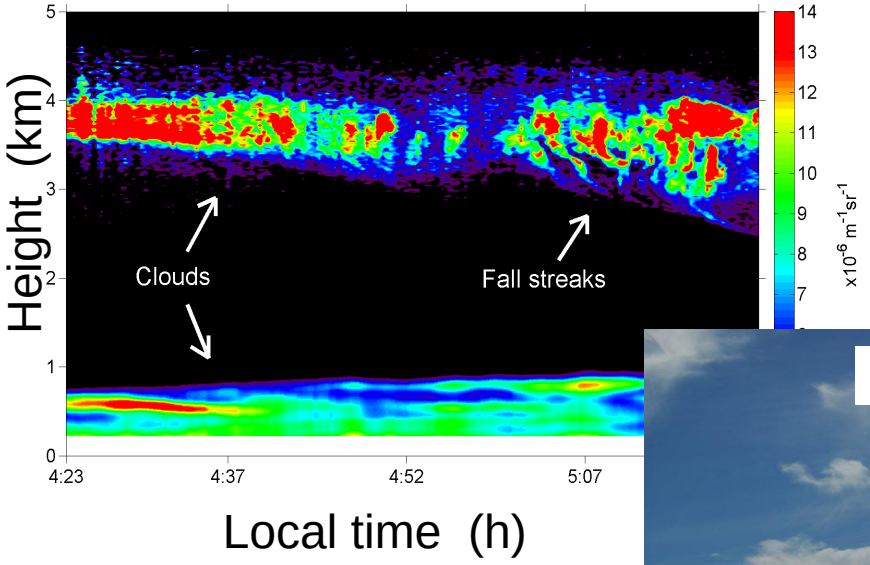


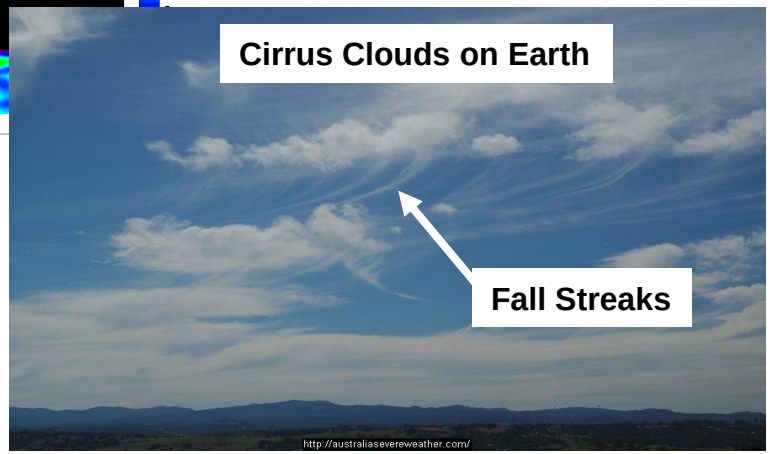
Mars exploration : recent missions

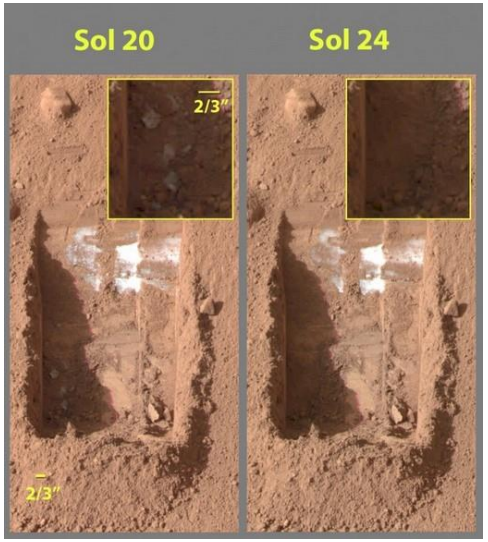
- Phoenix lander

Launch: 4 August 2007
Landing: 25 May 2008
Last contact: 2 November 2008



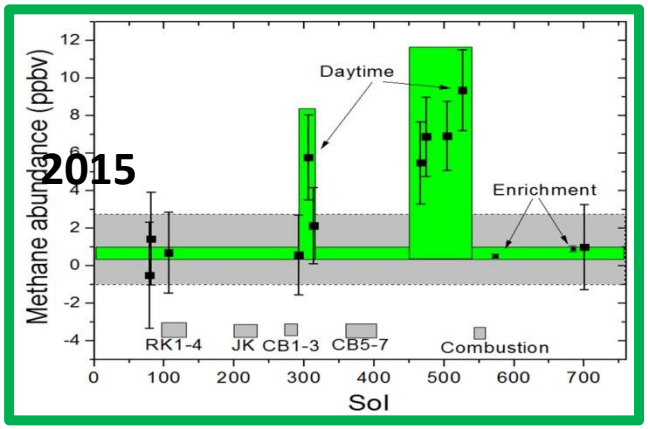


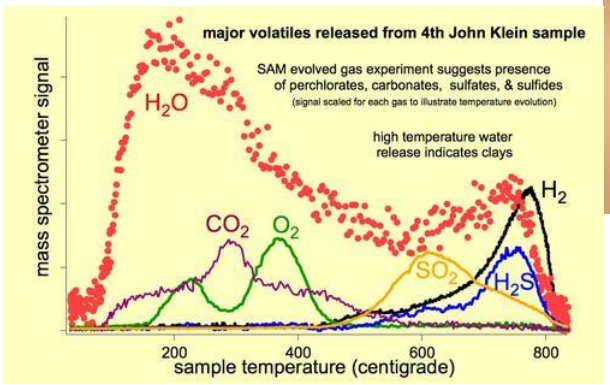




Mars exploration : recent missions

- Mars Science Laboratory (2011)

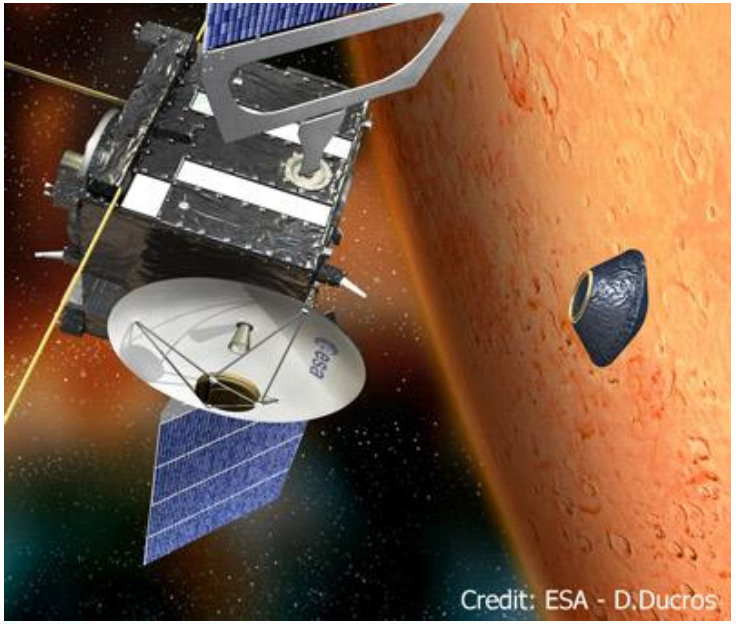




- Mars Atmosphere and Volatile EvolutioN (MAVEN)
  - Characterize the solar wind, Mars' ionosphere, and their interactions
  - global characteristics of the upper atmosphere and ionosphere
  - composition and isotopes of neutrals and ions
- MOM: Mars Orbiter mission
  - ISRO – launched from Southern India on Nov 5 – arrived at Mars in Sep 2014

European mission : Mars Express

- Launched in 2003 – still alive
- 7 instruments
  - **ASPERA** : analysis of charged particules (solar wind)
  - **HRSC** : high-resolution camera
  - **OMEGA** : near-IR spectrometer for the analysis of the surface
  - **PFS**: Fourier Transform spectrometer, study of the atmosphere
  - **MaRS**: radio science
  - **MARSIS**: radar, detection of water under the surface
  - **SPICAM**: IR & UV spectrometer study of the atmosphere
  - Beagle 2



The next European mission: ExoMars

- Long history …
- in 2009 NASA and ESA signed the Mars Joint Exploration Initiative
  - 2 misisons: TGO&EDM (2016) + rovers (2018)
- In 2012
  - NASA withdrawal
  - Agreement between ESA and ROSCOSMOS

Post NASA withdrawal

ExoMars Programme Mission Architecture

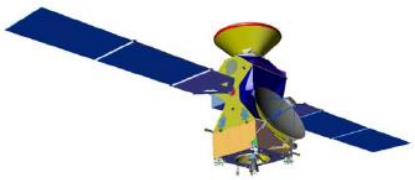
ExoMars Programme: *<u>two missions launched in 2016 and 2018.</u>*

- **The 2016 mission consists of a Trace Gas Orbiter (TGO) and an EDL Demonstrator Module (EDM)**
- **The 2018 mission consists of a Rover accommodated inside a Descent Module (DM) carried to Mars by a Carrier Module (CM)**
- **Large international cooperation with Roscosmos and some contributions from NASA**

esa 2016 Mission

Proton

<u>Trace Gas Orbiter (TGO)</u>



<u>EDL Demonstrator Module (EDM)</u>

+

Roscosmos DSN

ESA ESTRACK

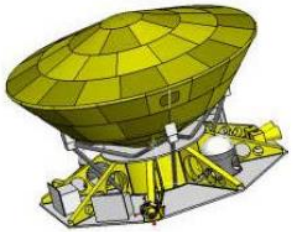
<u>MOCC @ ESOC Spacecraft Operations</u>

Science Operations Centre TBD

esa 2018 Mission

Proton

<u>Carrier Module & Descent Module</u>



<u>Rover +ROCC + Landed Platform Ops Centre</u>

ESA UNCLASSIFIED – For Official Use

Payload

NOMAD — High resolution occultation and nadir spectrometers
Atmospheric composition (CH_4, O_3, trace species, isotopes) dust, clouds, P&T profiles

UVIS (0.20 – 0.65 µm) λ/Δλ ~ 250	SO	Limb	Nadir
IR (2.3 – 3.8 µm) λ/Δλ ~ 10,000	SO	Limb	Nadir
IR (2.3 – 4.3 µm) λ/Δλ ~ 20,000			SO

CaSSIS — High-resolution camera
Mapping of sources; landing site selection

ACS — Suite of 3 high-resolution spectrometers
Atmospheric chemistry, aerosols, surface T, structure

Near IR (0.7 – 1.7 µm) λ/Δλ ~ 20,000	SO	Limb	Nadir
IR (Fourier, 2 – 25 µm) λ/Δλ ~ 4000 (so)/500	SO		Nadir
Mid IR (2.2 – 4.5 µm) λ/Δλ ~ 50,000			SO

FREND — Collimated neutron detector
Mapping of subsurface water

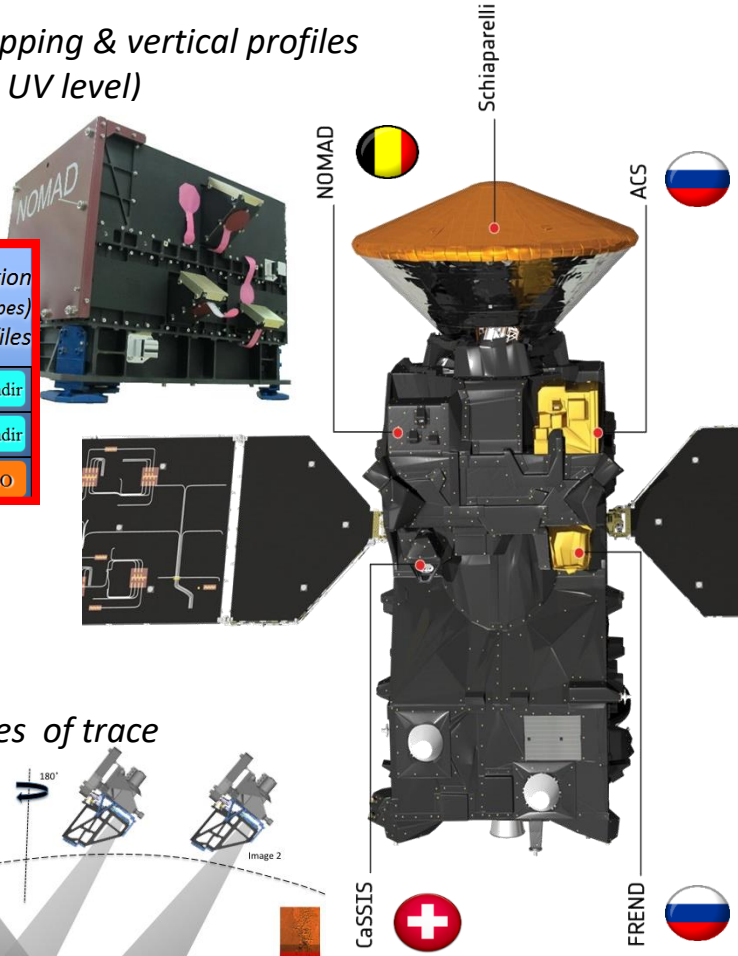
All Power Resolution λ/Δλ calculated at mid-range

ExoMars 2016: Trace Gas Orbiter

NOMAD

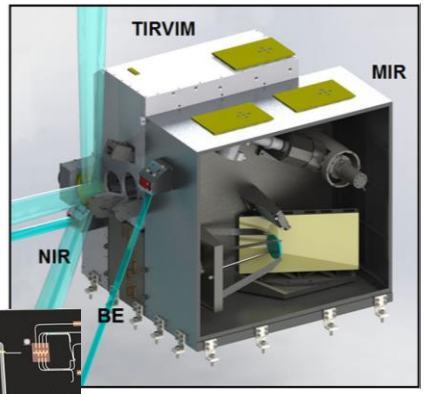
- *Atmospheric composition: mapping & vertical profiles*
- *Improve climatologies (ozone, UV level)*

NOMAD	High resolution occultation and nadir spectrometers	*Atmospheric composition (CH_4, O_3, trace species, isotopes) dust, clouds, P&T profiles*	
UVIS (0.20 – 0.65 µm)	$\lambda/\Delta\lambda$ ~ 250	SO Limb Nadir	
IR (2.3 – 3.8 µm)	$\lambda/\Delta\lambda$ ~ 10,000	SO Limb Nadir	
IR (2.3 – 4.3 µm)	$\lambda/\Delta\lambda$ ~ 20,000	SO	



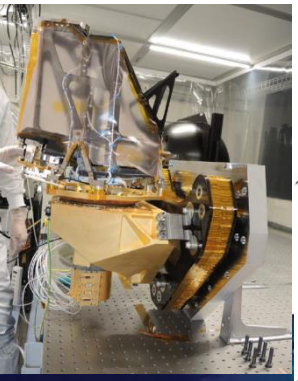
ACS

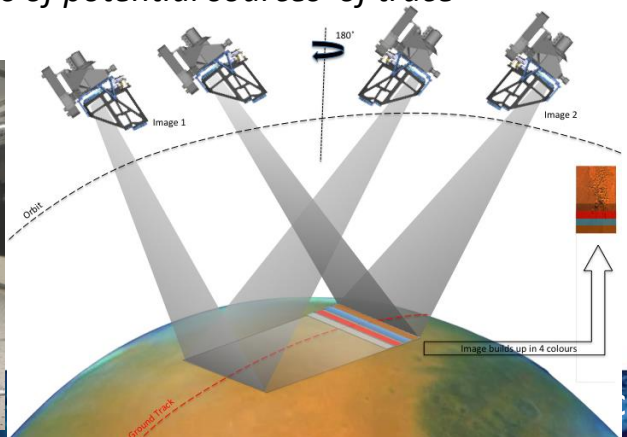
- *Atmospheric composition*



CaSSIS

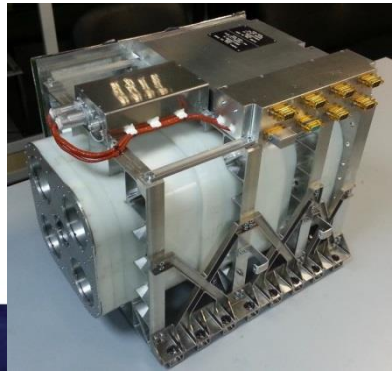
- *Images of surface features*
- *Map regions of potential sources of trace gases*





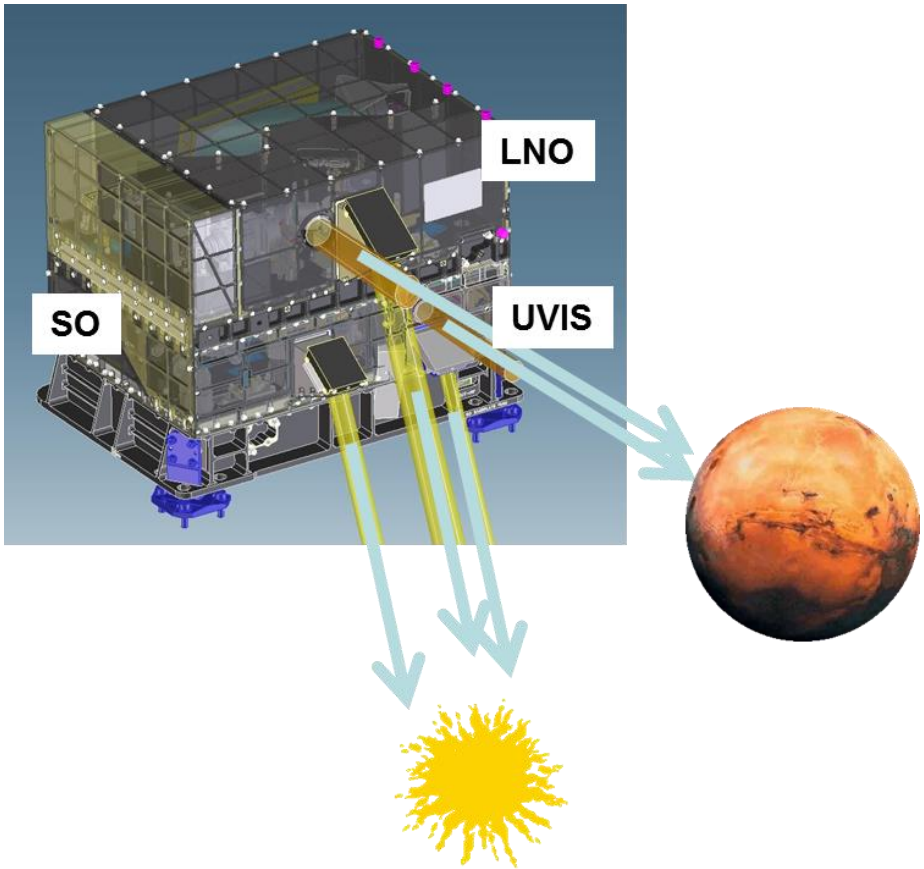
FREND

- *Maps of hydrogen in the soil*
- *Monitoring neutrons and charged particules*



. Vandaele

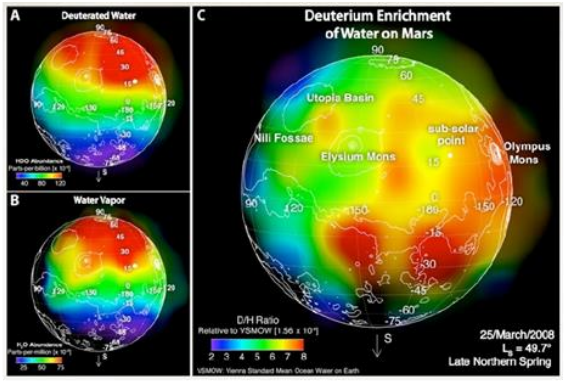
NOMAD : 3 channels



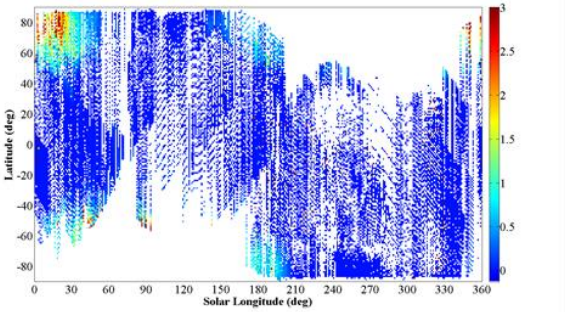
- SO **SOIR/ Venus Express**
  - Solar Occultation
  - IR : 2.2-4.3 μm
  - Resolution ~ 0.15 cm^{-1}
  - Resolving power = 22000
- LNO
  - Nadir, Limb, Solar Occultation
  - IR : 2.2-3.8 μm
  - Resolution ~ 0.3 cm^{-1}
  - Resolving power = 11000
- UVIS **Humbolt/ExoMars**
  - Nadir, Limb, Solar Occultation
  - UV-vis : 200-650 nm
  - Resolution ~ 1 - 2 nm

NOMAD : Science Objectives

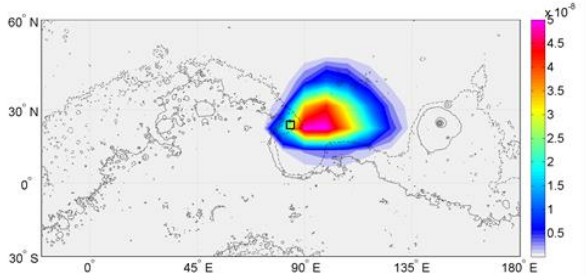
- Chemical composition
  - Detection of a broad suite of trace gases and key isotopes
    - CO_2, CO, O_3
    - CH_4 related : CH_4, $^{13}CH_4$, CH_3D, C_2H_2, C_2H_4, C_2H_6, H_2CO
    - Escape processes : H_2O, HDO -> D/H
    - Volcanism related : SO_2, H_2S, HCl
- Mars Climatology & Seasonal cycles
  - 3D spatial & temporal variability of trace gases and aerosols
  - Climatology of O_3 and UV radiation levels
- Sources & Sinks
  - Analyse correlation trace gases – dust – clouds – T&P
  - Use GCM for interpretation



Villanueva et al., 2008

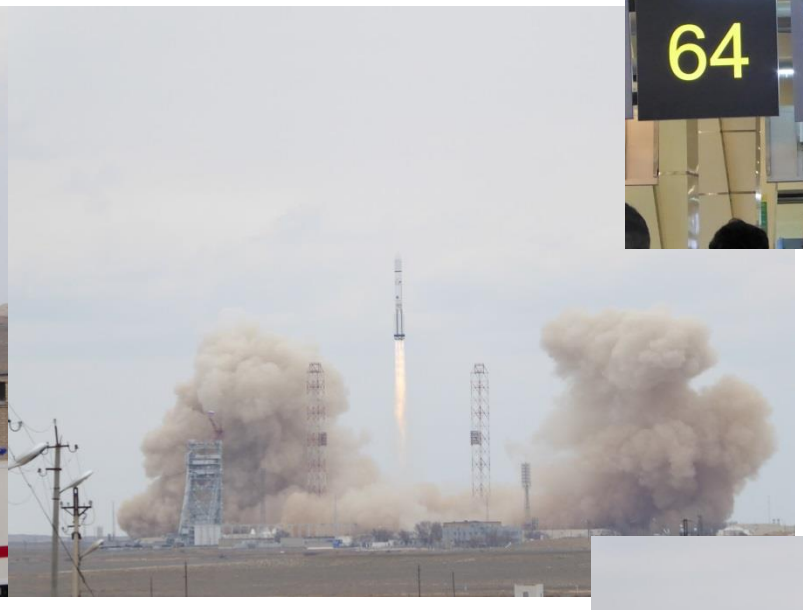


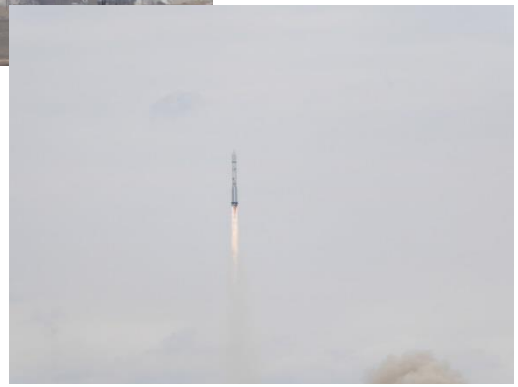
O_3- SPICAM-UV/Mars Express (Y. Willame)



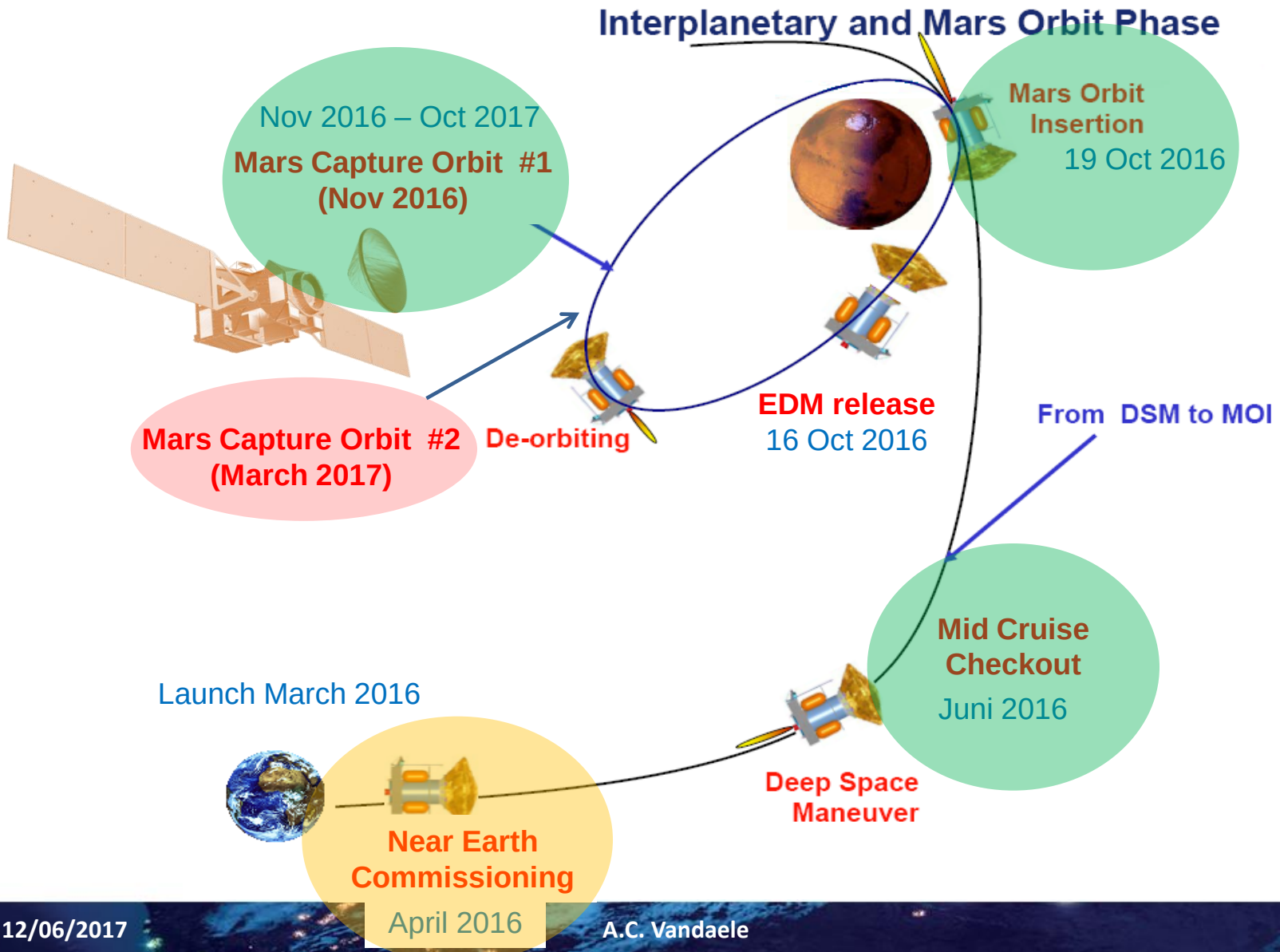
GCM simulation (F. Daerden)

Launch 14th March 2016



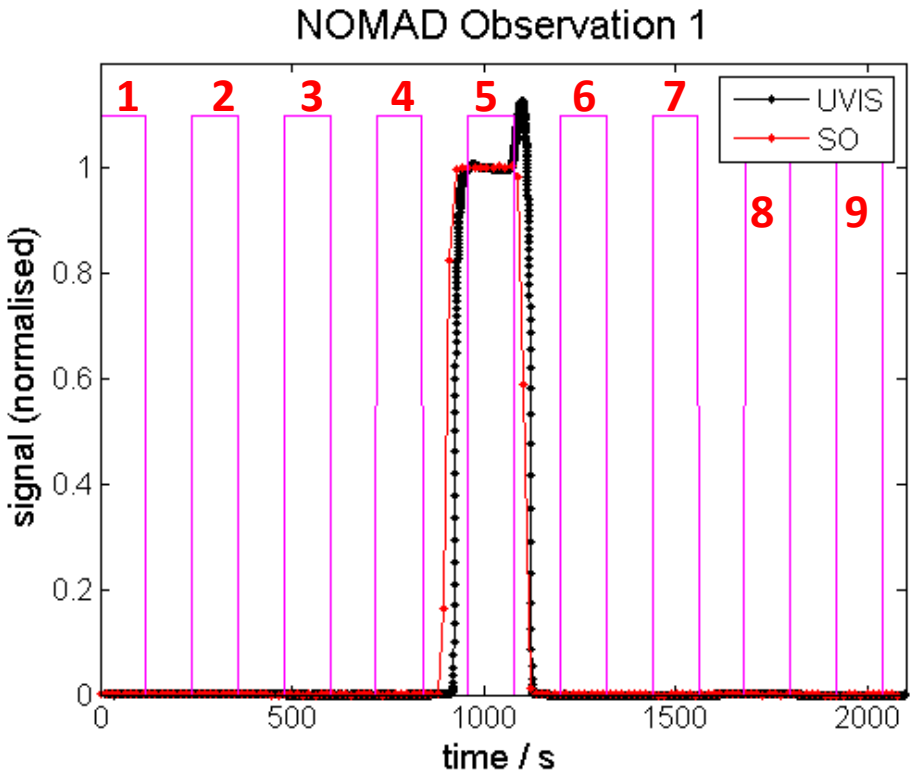


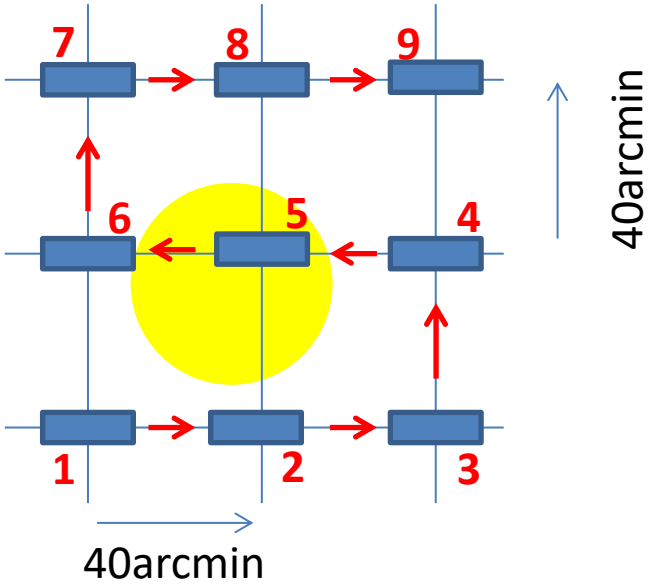
Where are we today ?



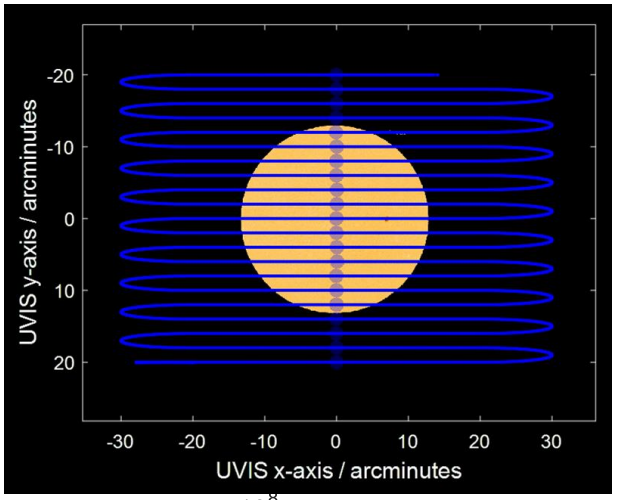
Some very preliminary results

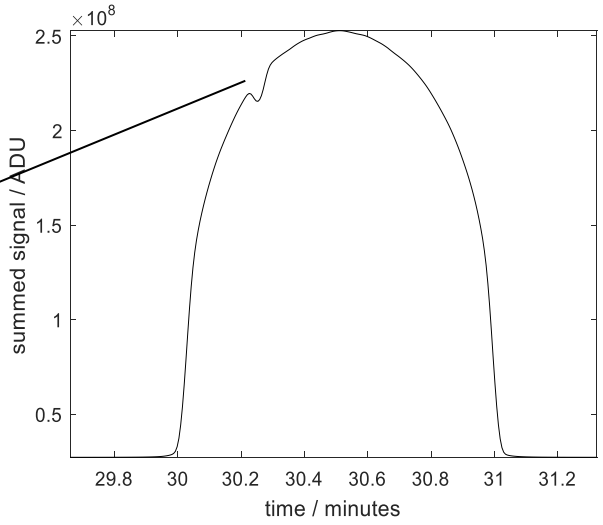
- Checking the pointing to the Sun

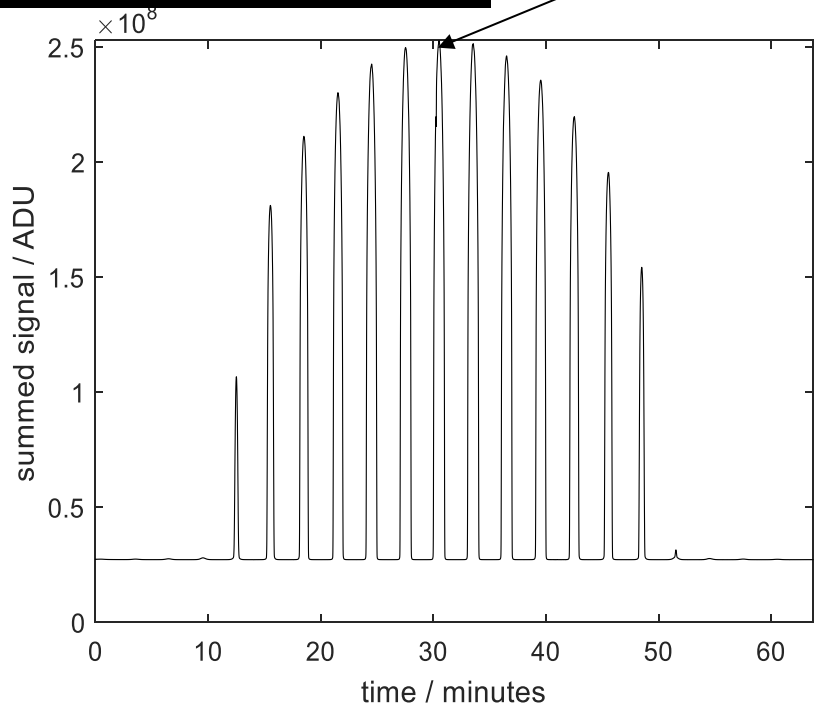


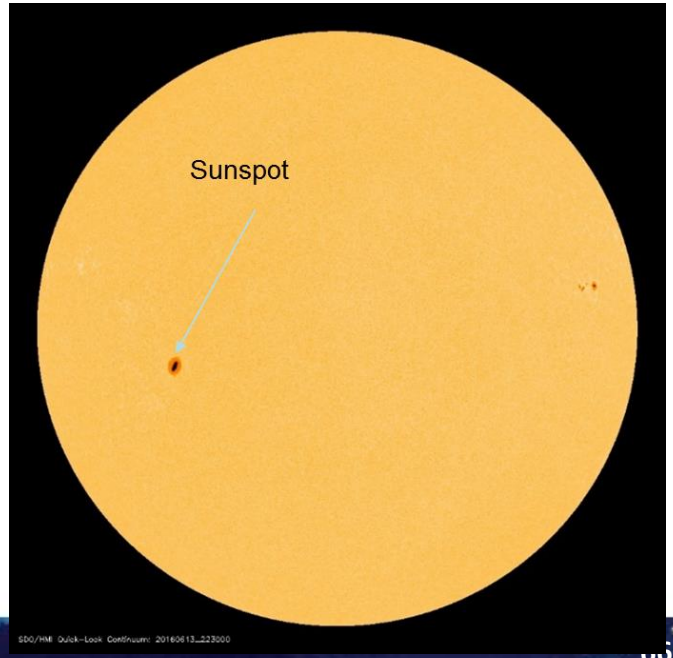


UVIS checkout









Thanks

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- Planetary.aeronomie.be