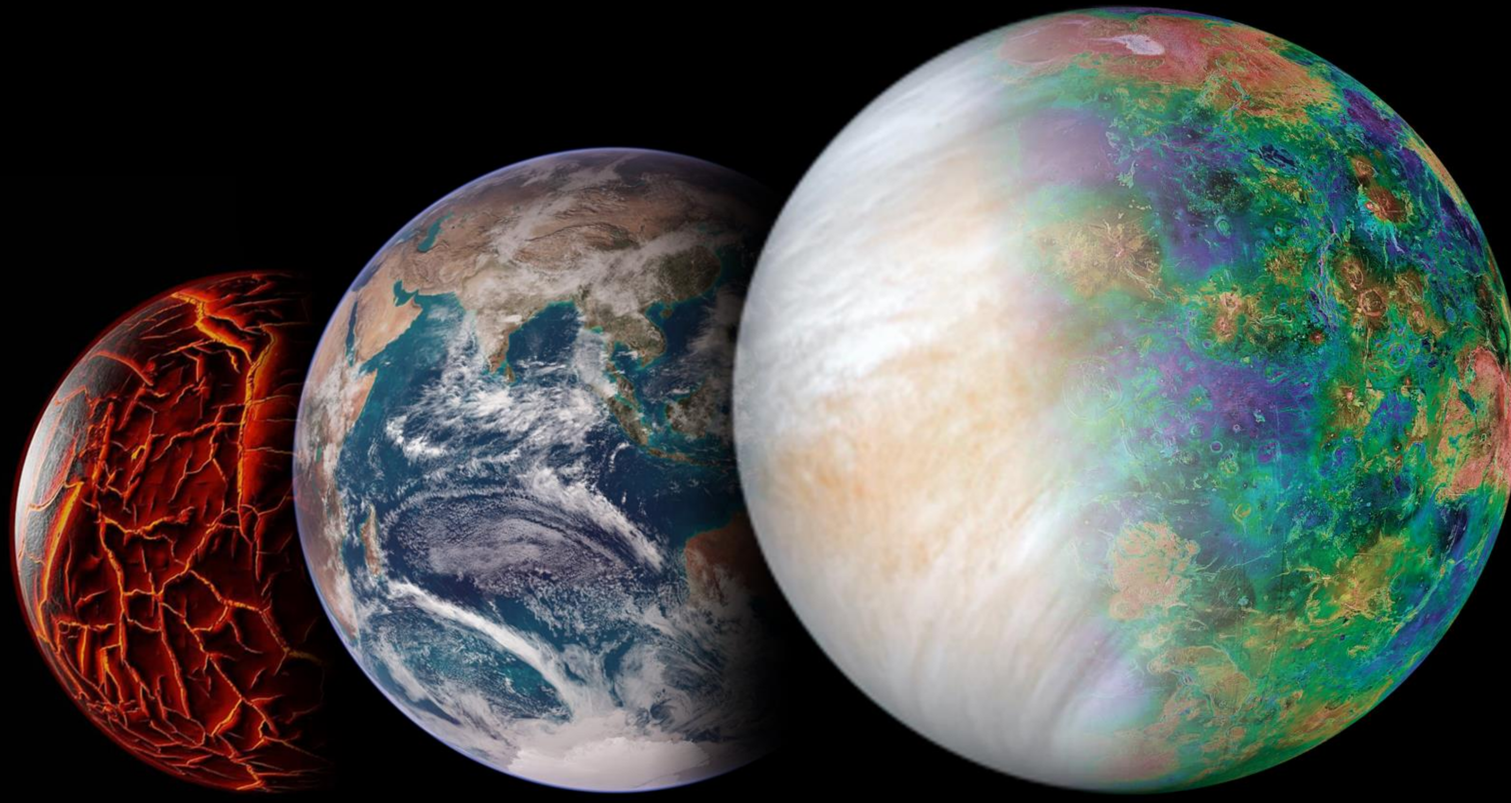
Venus – Comparative Planetology: perspectives from atmospheric science



Colin Wilson
Oxford University / SSI

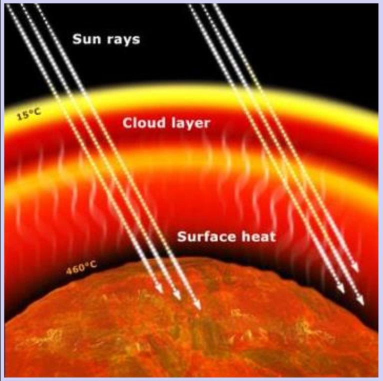
Planetary Science Decadal Survey / Venus panel / 22 April 2021

Outline

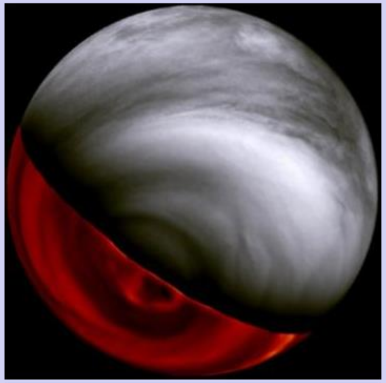
1. *Comparative processes*
2. *Comparative planetary evolution*
3. *Needed measurements*

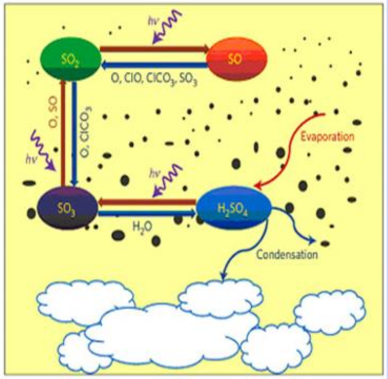
Motivation 1: Comparative processes

- Compare planetary processes to deepen our understanding of fundamental geophysics.



Radiative Balance, Greenhouse effect


Atmospheric dynamics, weather, turbulence

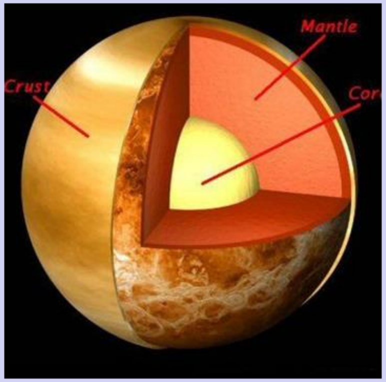


Atmospheric chemistry, clouds

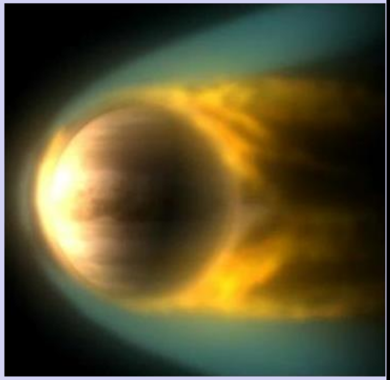

Atmospheric electricity, lightning


Sand and dust transport, weathering


Volcanism, tectonism, exchange with atmosphere

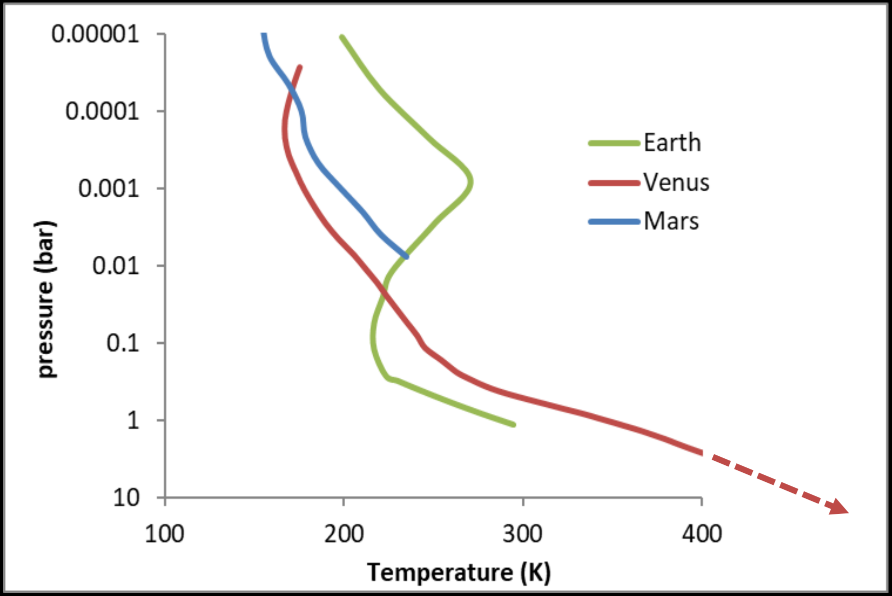


Interior structure and its evolution


Exchanges with space Solar wind & magnetosphere

Atmospheric dynamics

- *Thermal structure*
- *Super-rotation*
- *Meridional circulation*
- *Atmospheric waves*
- *Cloud-level convection*
- *Near-surface meteorology*
- *Measurements: winds, temperatures, densities at all altitudes*



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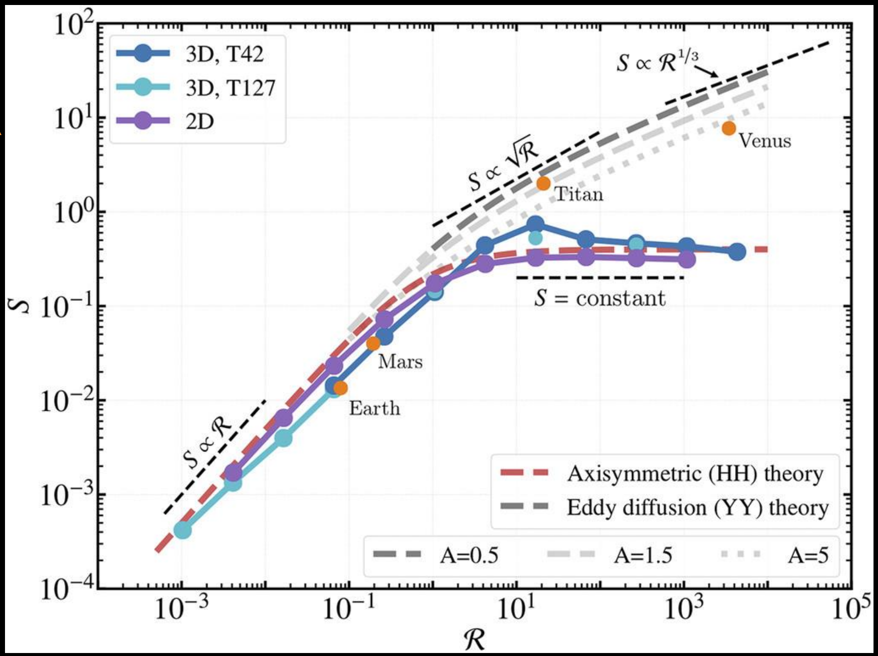
Super-rotation



Increasing planetary rotation rate

Lewis et al., JAS, 2021

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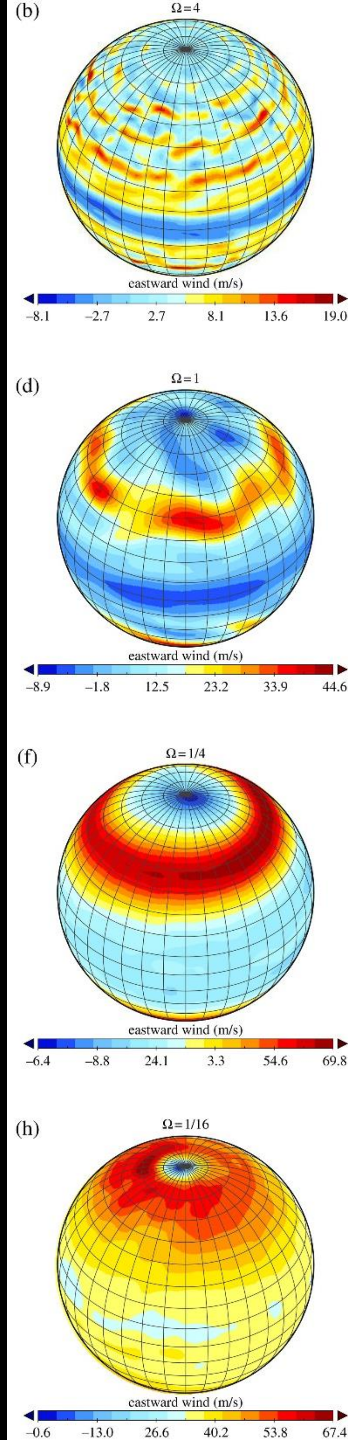
Increasing planetary rotation rate

Colours show Eastward wind speed (Wang et al., 2018)



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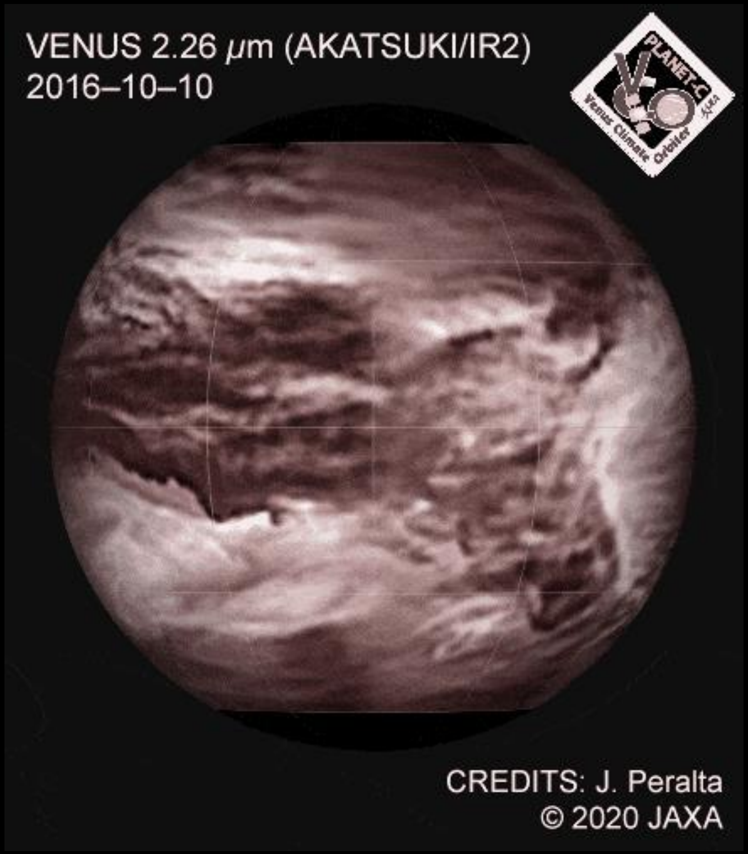

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Could such clouds occur on Venus? *Credit. M.T. Rader*

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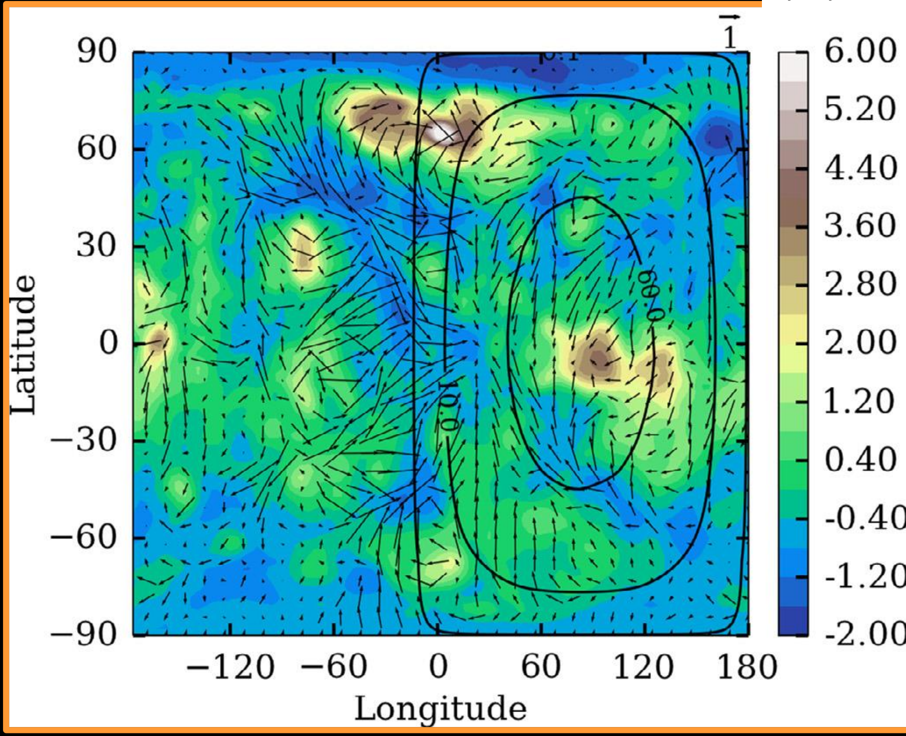
surf elev. (km)

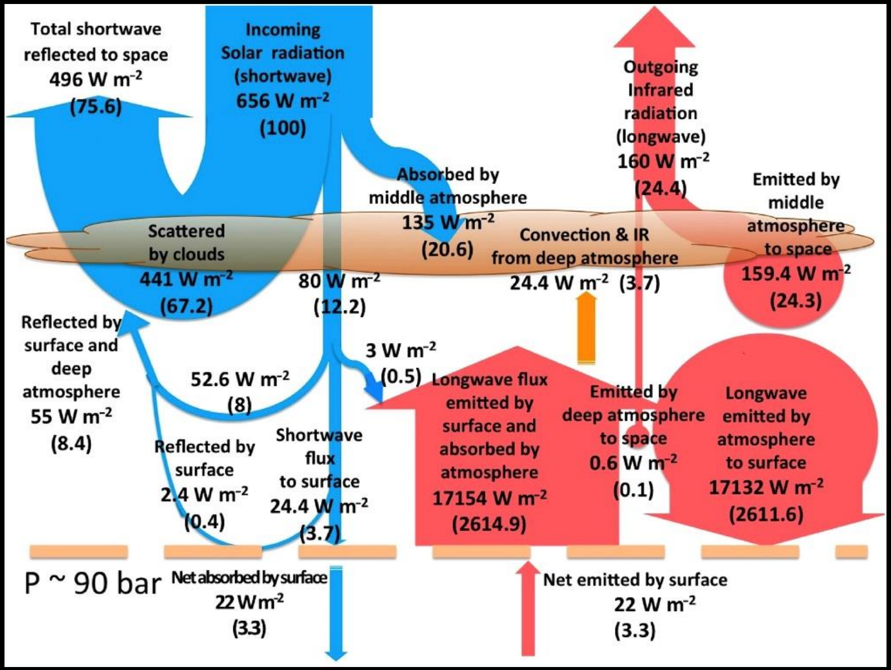


Arrows show wind vectors 150 m above surface

Lebonnois et al 2018

Radiative Transfer

- *Greenhouse effect*
- *Role of clouds*
- *Non-LTE (airglows etc)*
- *Measurements: radiative fluxes from orbit and within atmosphere*



"Trenberth diagram" showing net energy flows in Venus atmosphere. Read et al QJRMS 2016

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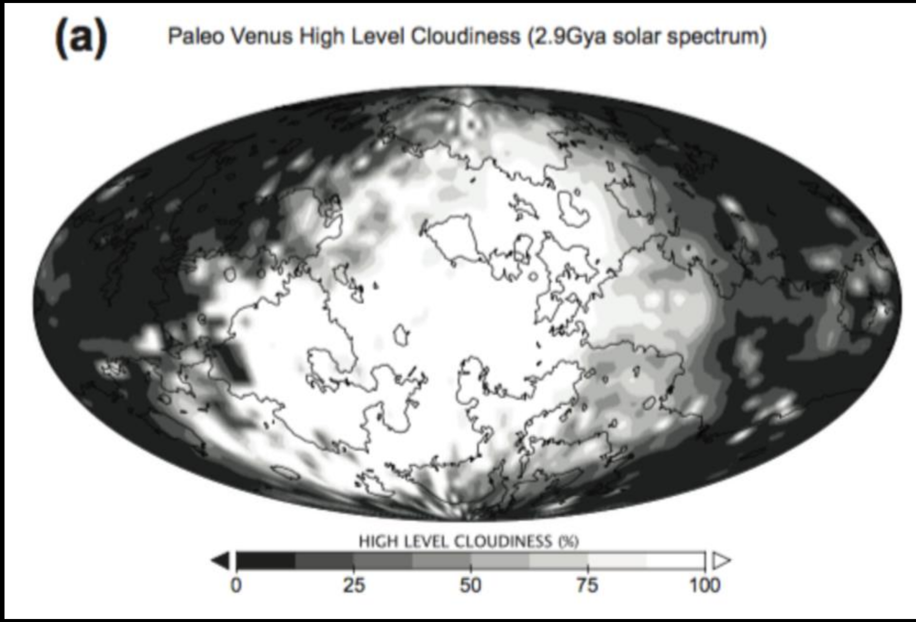

Way et al, GRL, 2016

Radiative

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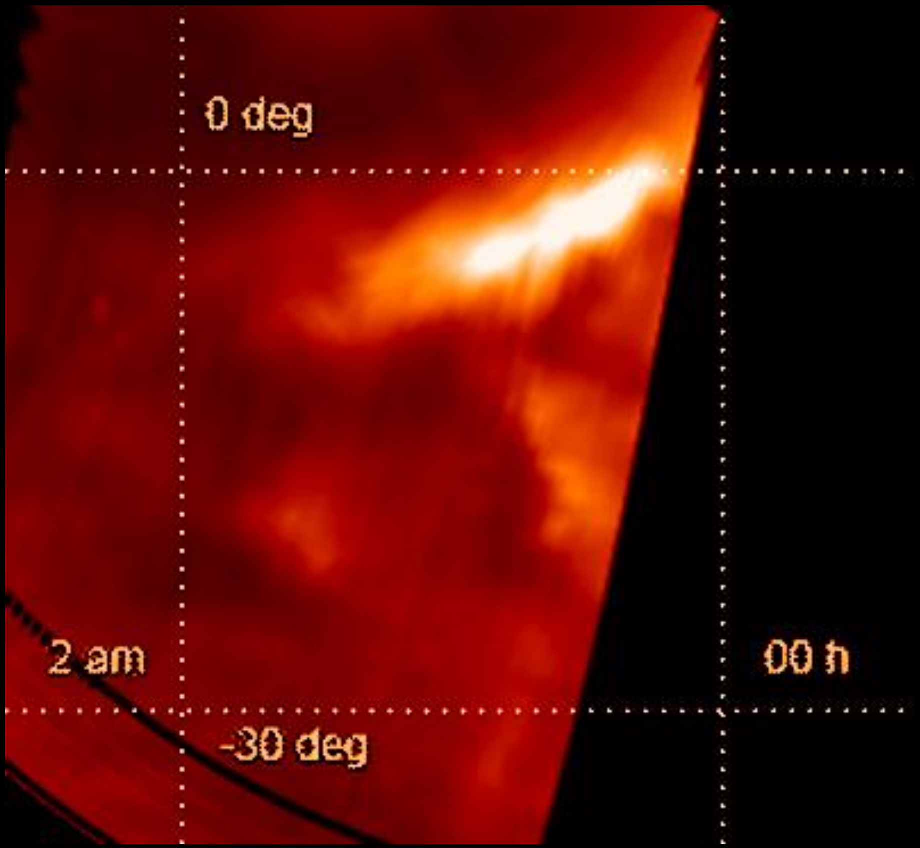
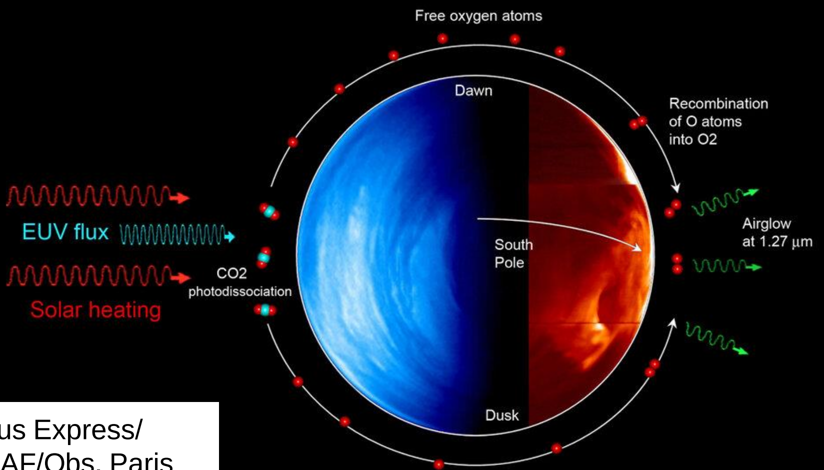
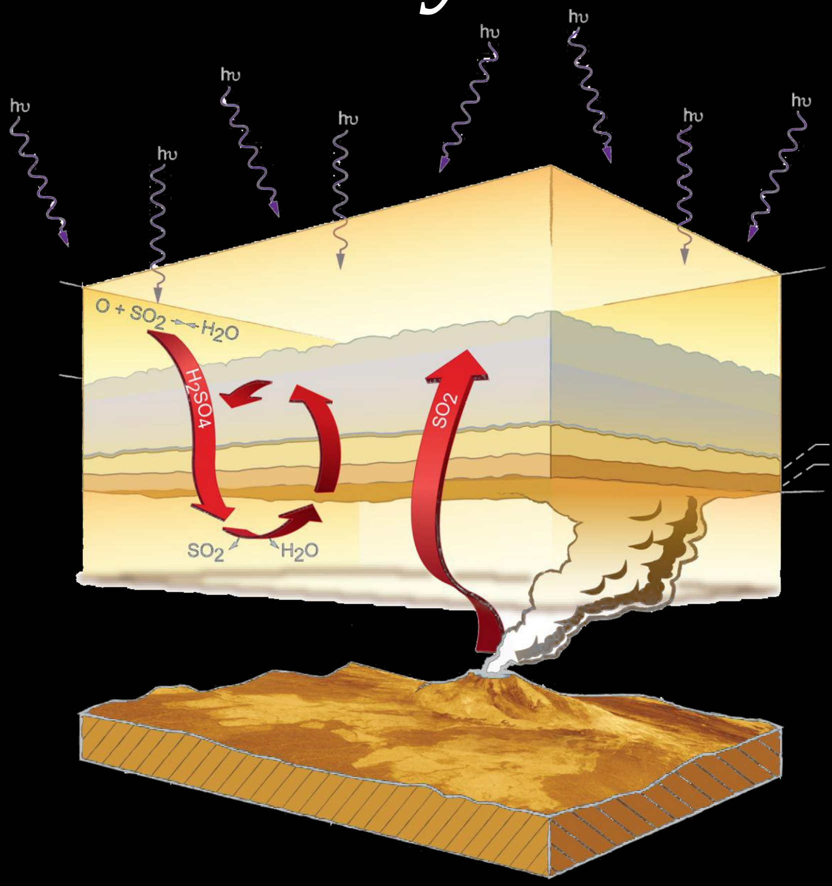




Oxygen airglow observed from Venus Express/
VIRTIS at 1.27 µm. Credits: ESA/INAF/Obs. Paris

Atmospheric chemistry

- *Sulphur & water cycles*
- *Mesospheric chemistry*
- *Cloud-level chemistry*
- *Near-surface chemistry*
- *Magmatic volatiles*
- *Measurements: atmospheric composition at all altitudes*



After Emmet Carter

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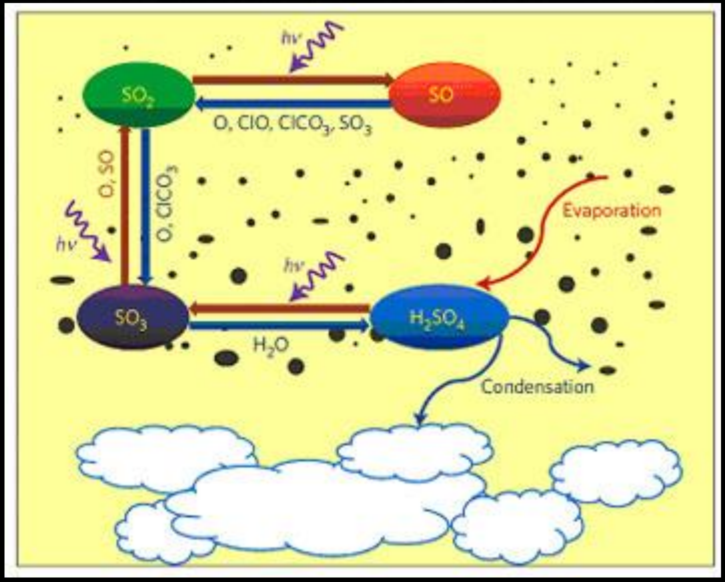

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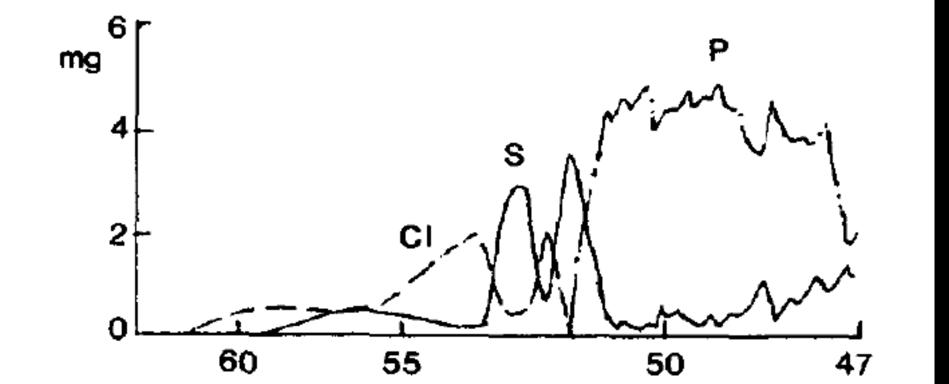

FIG. 1. Accumulation of chlorine, sulfur, and phosphorus on the filter of the Vega 2 X-ray radiometer (Andreychikov *et al.* 1987).

See also:

- *UV absorber*
- *"Mode 3" lower cloud particles*
- *Near-surface particulates*
- *Phosphine …*

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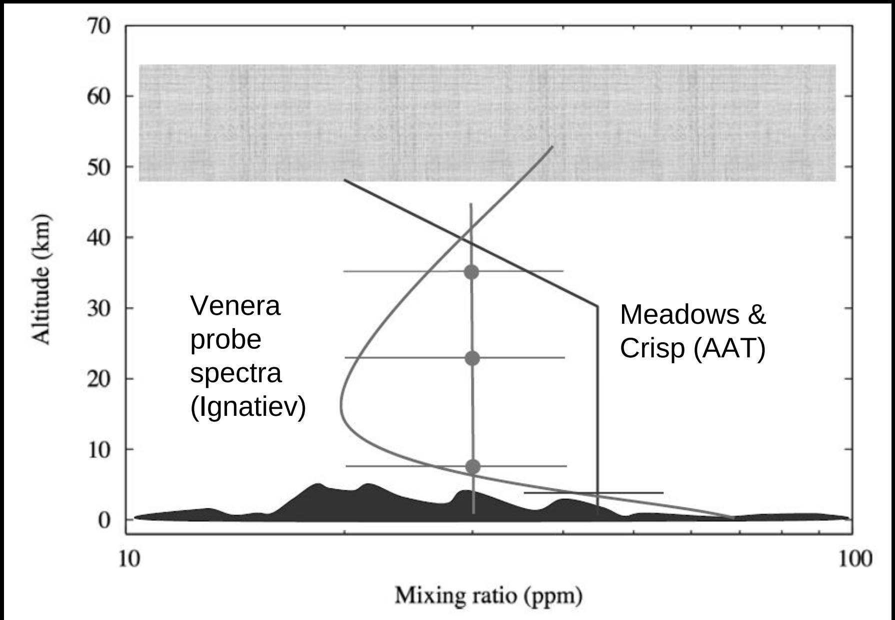

For example: this plot shows different possible profiles of H_2O abundance near the surface. Vertical distribution is very unconstrained.

Bézard et al 2007

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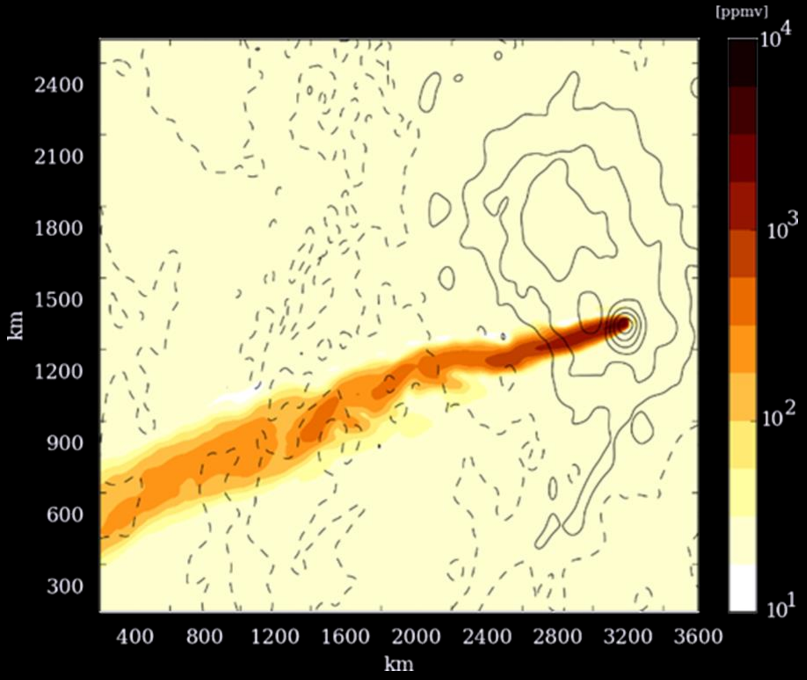
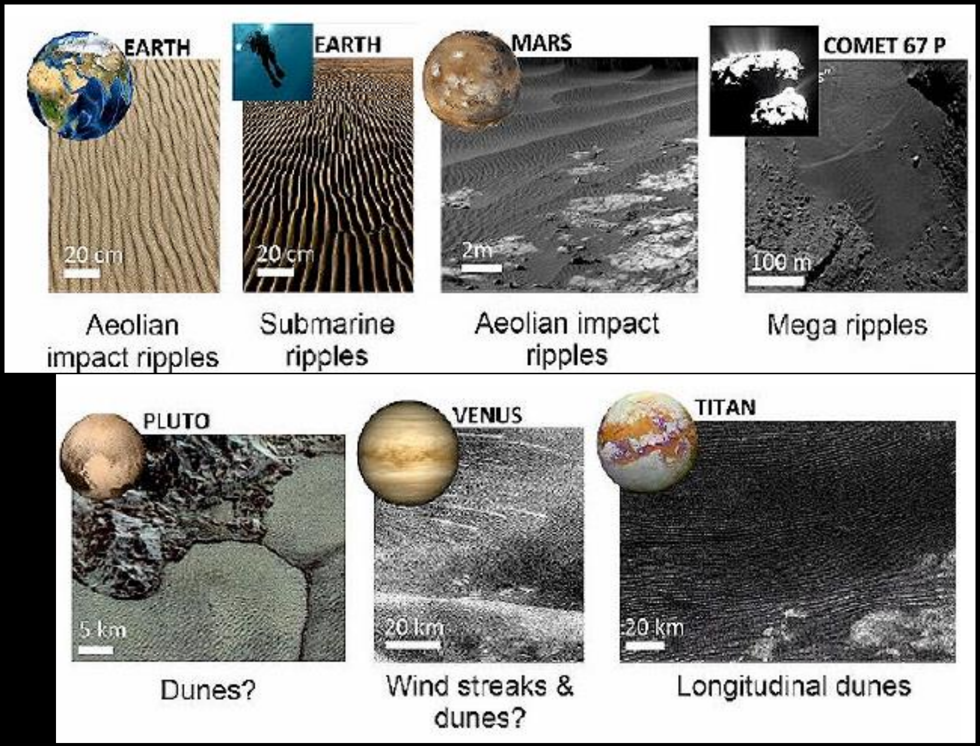


Simulated volcanic gas release. Credit: M. Lefevre

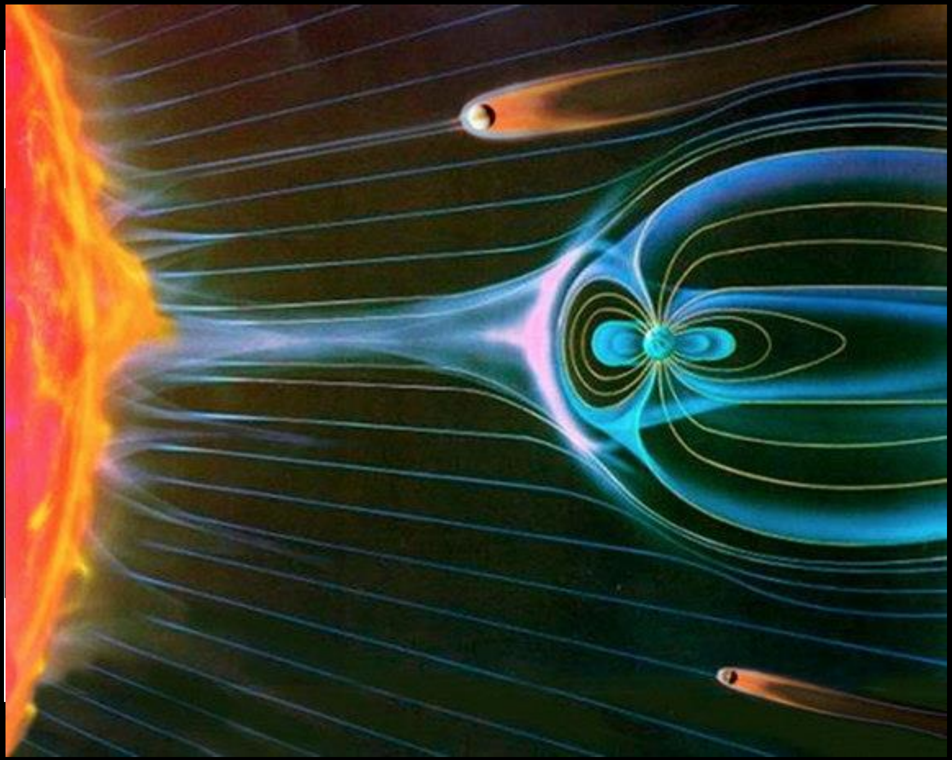
Surface-atmosphere interactions

- Dunes & ripples
- Ejecta & other deposits
- High altitude anomalies
- Measurements: high-resolution radar; surface meteorology



Atmospheric escape

- *Escape rates now and through time*
- *Effect of magnetic field on escape*
- *Effect of solar activity*
- Measurements: ion & neutral abundances & escape flows; magnetosphere / ionosphere / thermosphere structures



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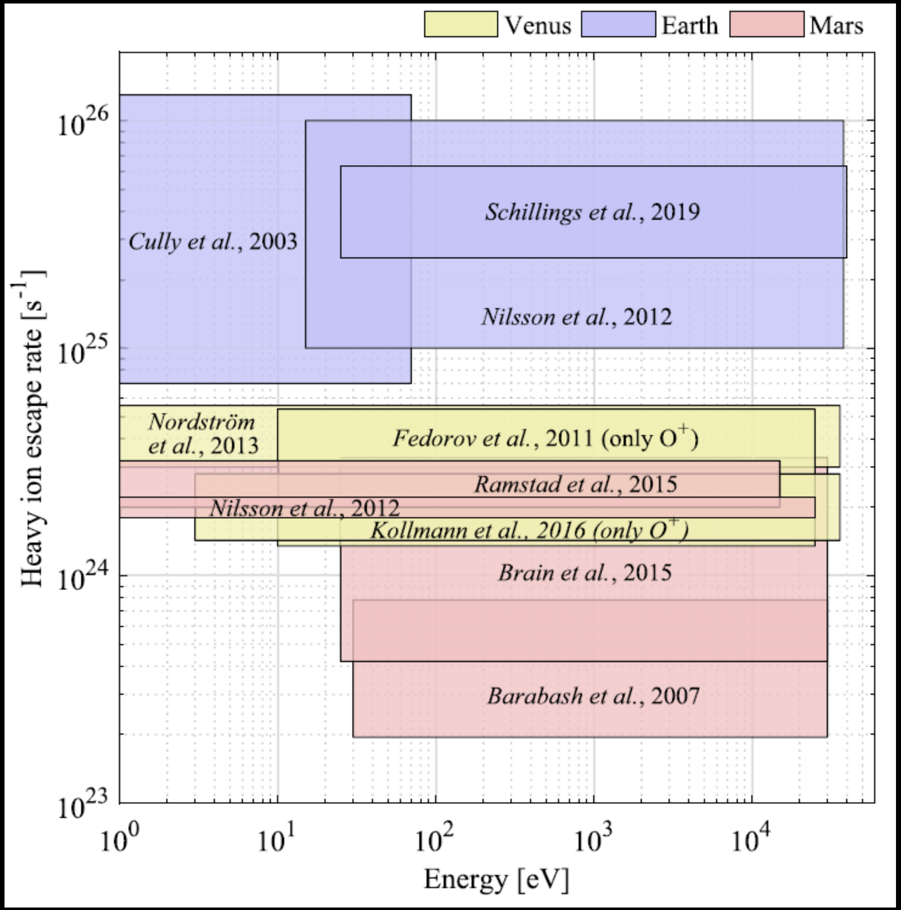

Ramstad et al Spa Sci Rev 2021

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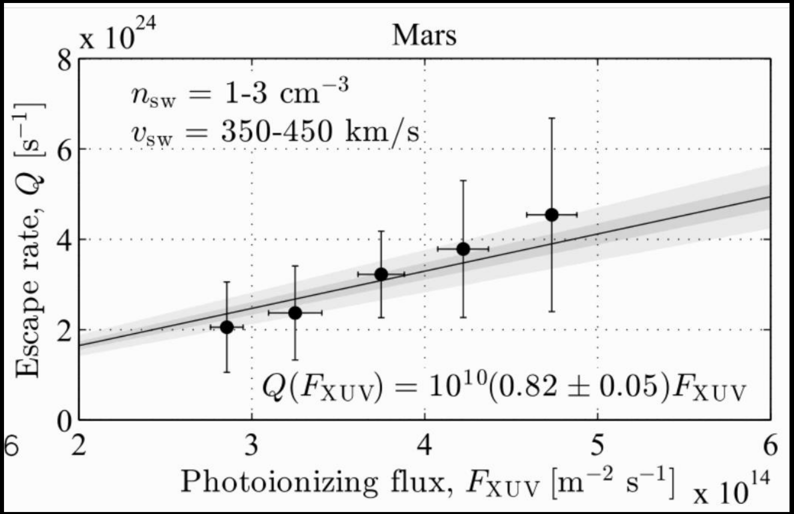

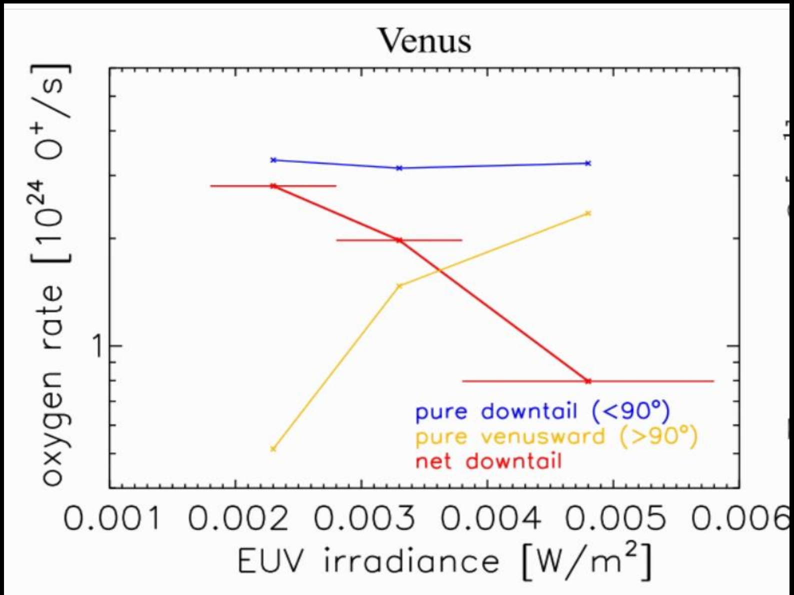

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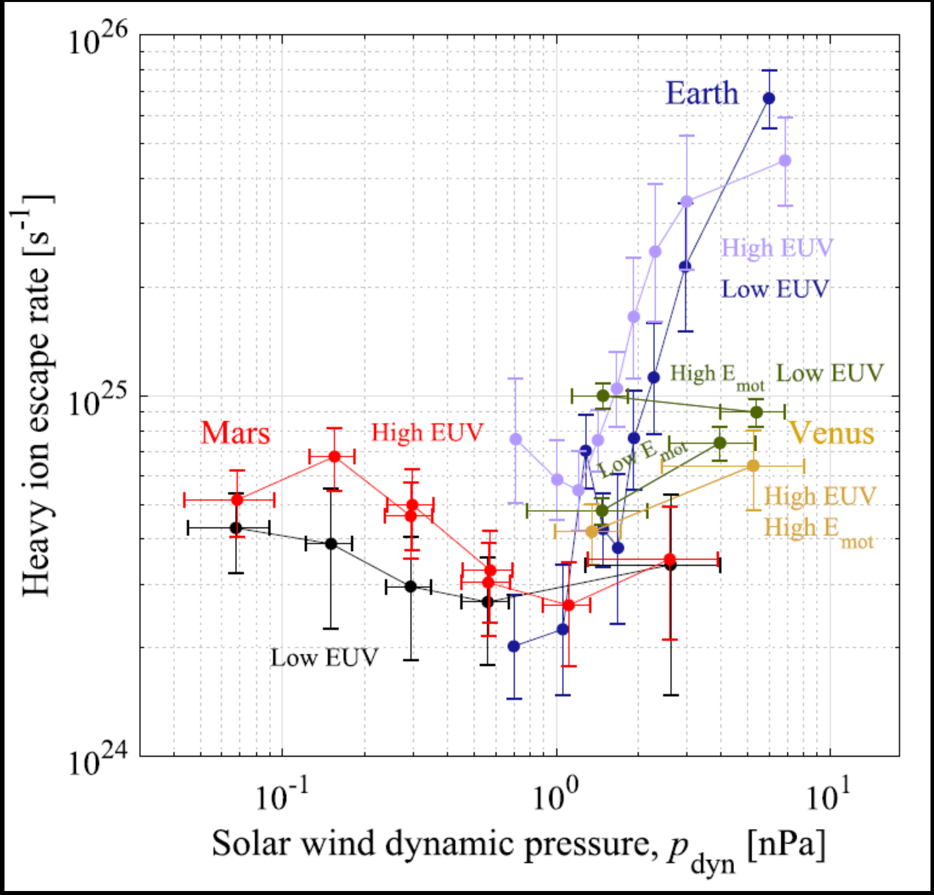
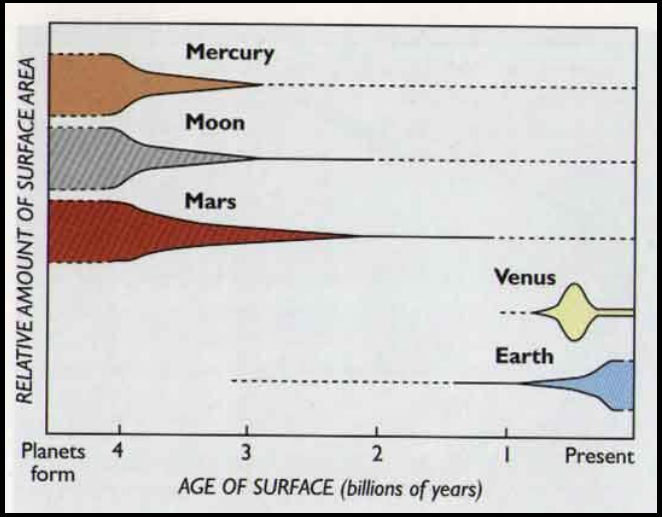


Ramstad et al Spa Sci Rev 2021

Motivation 2: Planetary evolution



- Early Venus was probably much like early Earth

  Hot dense atmosphere rich in CO_2 and water

  Similar initial inventory of volatiles and noble gas isotopes

  Did Venus ever harbor liquid water? Could life have evolved there?

- Venus also illustrates the probable fate of the Earth.

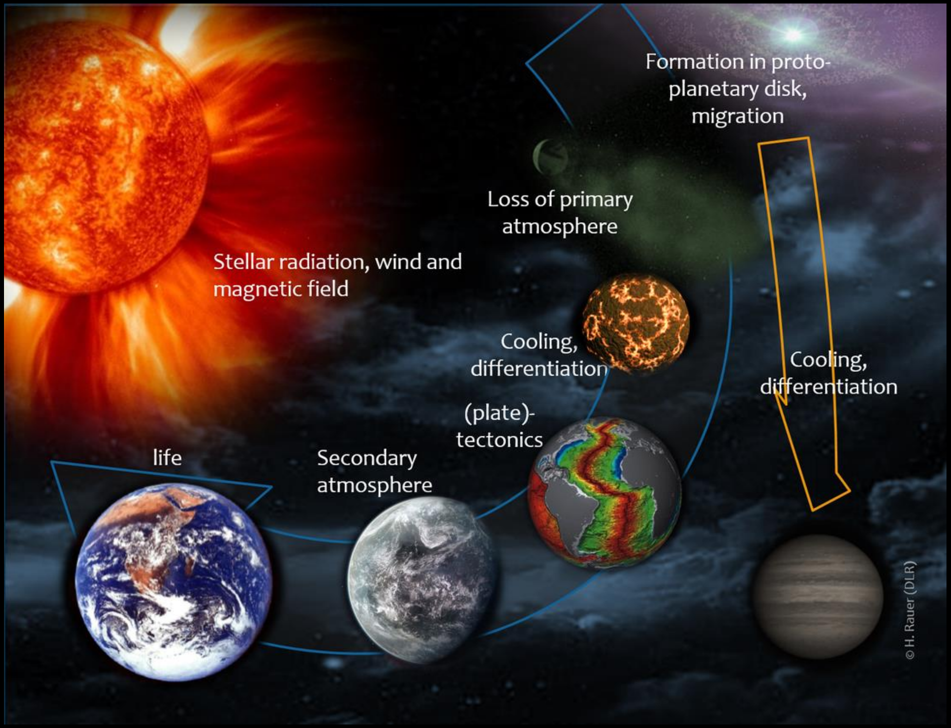
  In ~ 1 billion years, with a brighter sun, the insolation at Earth will be similar to that at Venus today.

  Will we be able to avoid the runaway greenhouse warming that is found at Venus?

How long does a planet stay in the habitable zone?

Atmospheric evolution

- *Origin of atmosphere*
- *Exchange with mantle throughout time*
- *Atmospheric loss throughout time*
- *An ageing sun*
- *Measurements: noble gas and light element isotopic abundances*
- *Models: coupled interior & atmosphere evolution*



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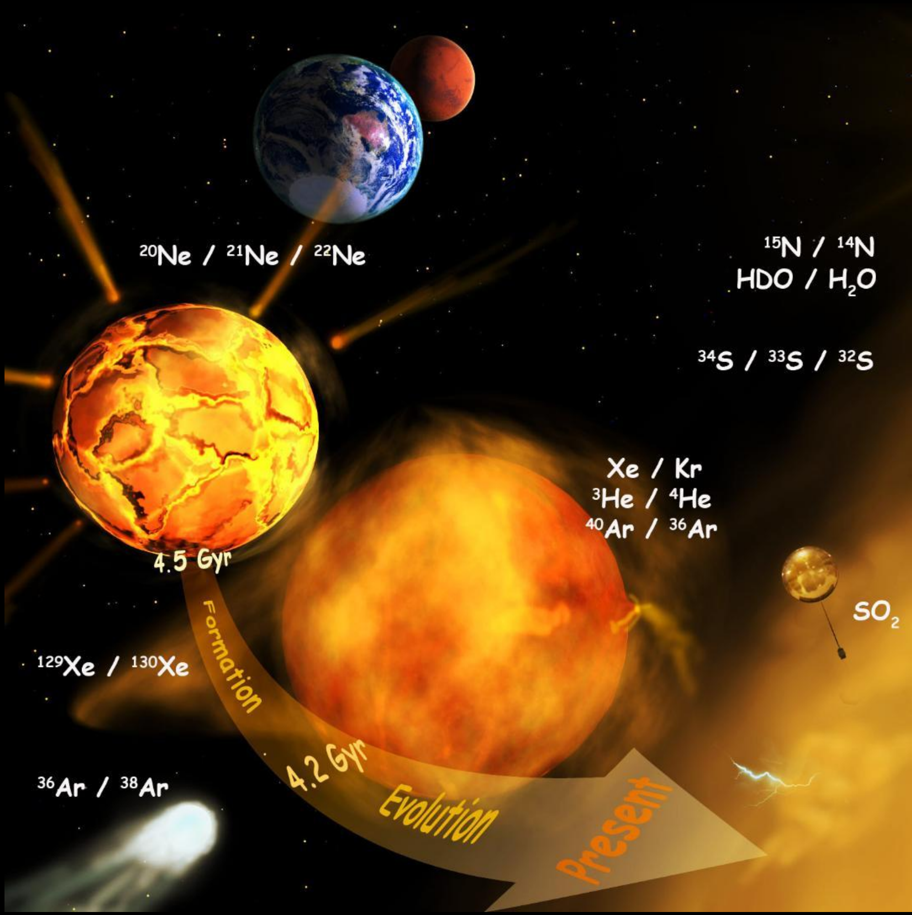


Modified after Baines et al (2007)

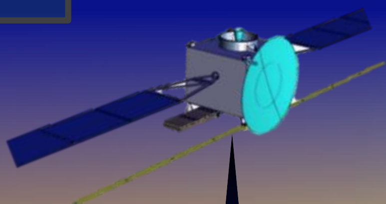
The next decade…

(to enable atmospheric science comparative planetology)

Orbital

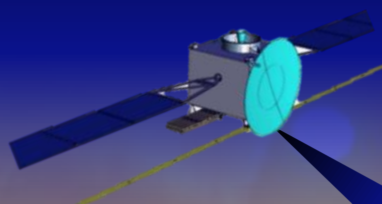
Geophysics orbiters

e.g. EnVision M5 orbiter
Radar imagery, topography, polarimetry, radiometry.
Science goal: current & past geological activity



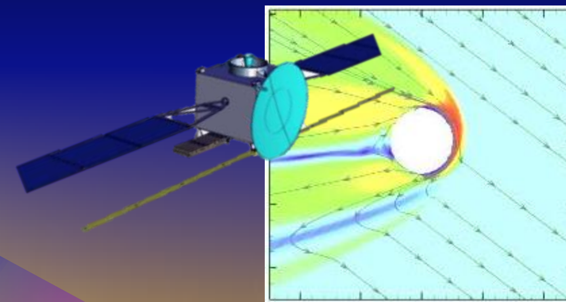
Atmospheric remote sensing

Direct measurement of winds & trace chemistry; airglows.
Science Goal: atmospheric dynamics & chemistry, aeronomy



In situ orbital sensing

Magnetometry, ions & neutral particles
Science goals: Study solar wind response & escape processes; aeronomy'; thermosphere composition



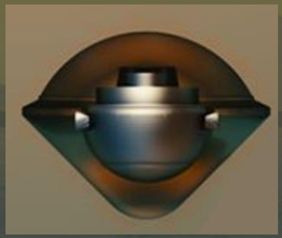
Thermosphere Skim

Sample noble gas isotopes l
homopause (<125 km)
Science goal: constrain form
evolution scenarios

Aerial

Descent probes

e.g. Venera probes
Atmospheric composition & structure; noble gas isotopes.
Science goals: Atmospheric dynamics & chemistry; geochemistry



Cloud-level platforms

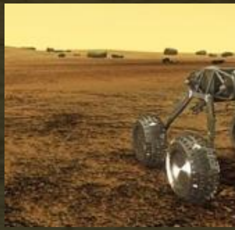
e.g. EVE M3 proposal
Balloons (constant- or variable-altitude), or lifting wing aircraft.
Science goals: Atmospheric dynamics & chemistry

Far-term (2

Surface exploratio

Science Goal: Geological explor
Low altitude balloons

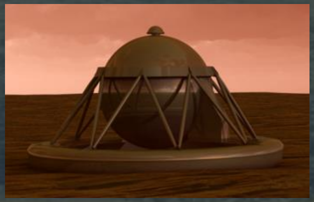
Surface Rovers



Surface

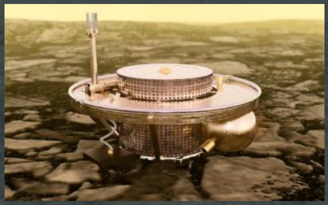
Short-lived lander

(~ 1 hr on surface)
Science goals: Local site characterization & composition

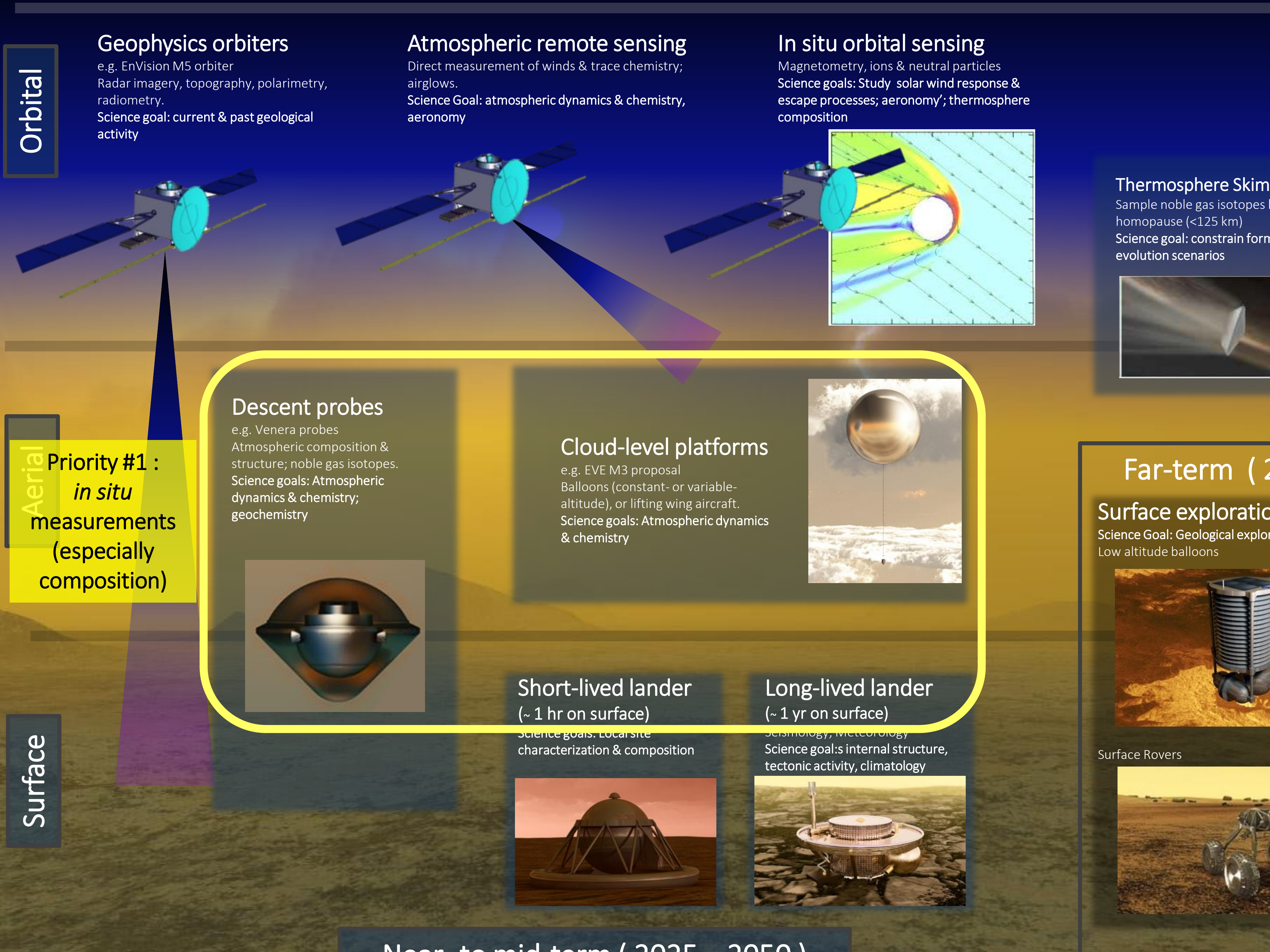


Long-lived lander

(~ 1 yr on surface)
Seismology, Meteorology
Science goal:s internal structure, tectonic activity, climatology



Near- to mid-term (2025 – 2050)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Sample noble gas isotopes l
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Aerial
Priority #1 : *in situ* measurements (especially composition)
Descent probes
e.g. Venera probes
Atmospheric composition & structure; noble gas isotopes.
Science goals: Atmospheric dynamics & chemistry; geochemistry
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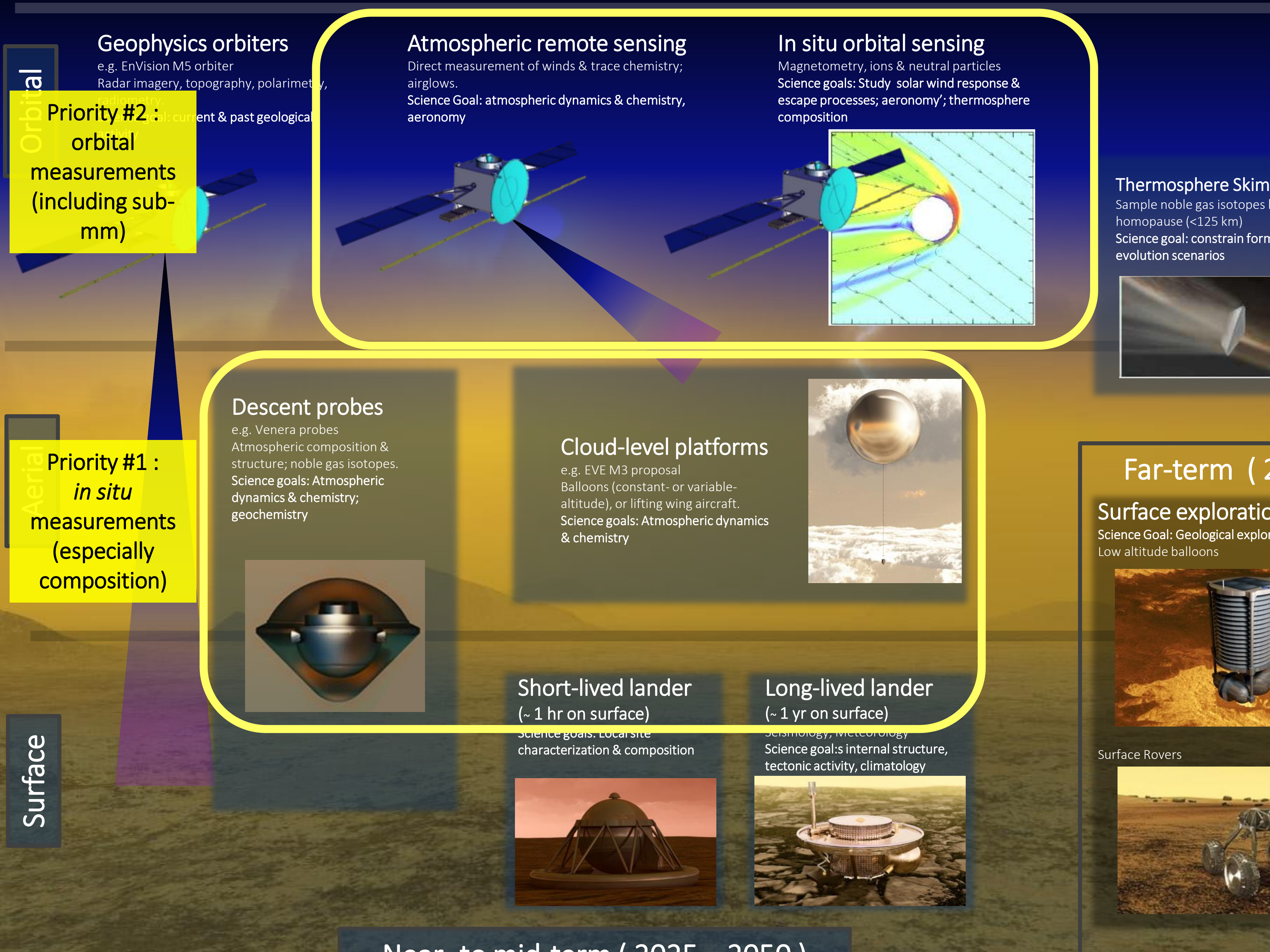
Orbital
Aerial
Surface
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Priority #2 : orbital measurements (including sub-mm)
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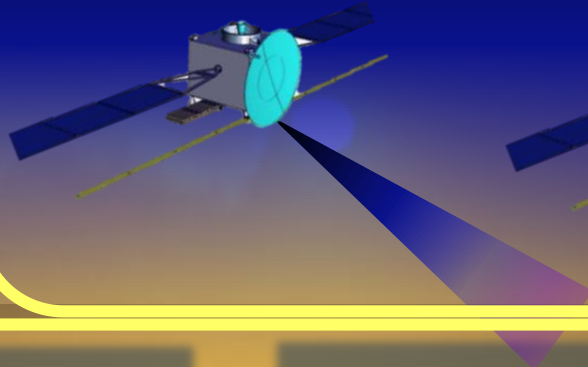

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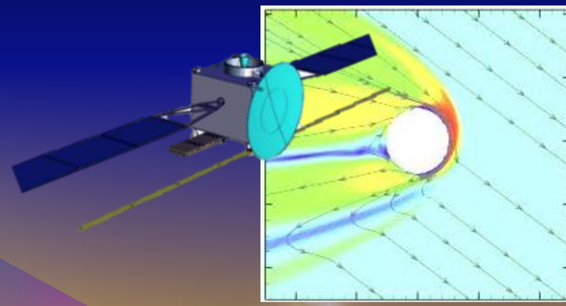

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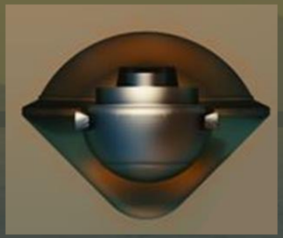

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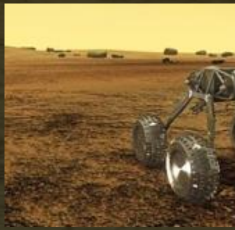
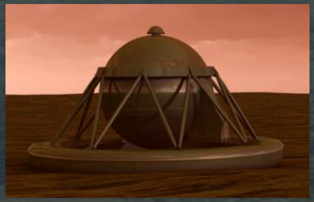


Surface

Priority #3 : *Tech development towards surface meteorology*

Short-lived lander

(~ 1 hr on surface)
Science goals: Local site characterization & composition



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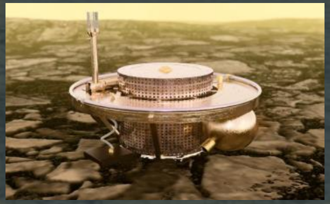

Near- to mid-term (2025 – 2050)