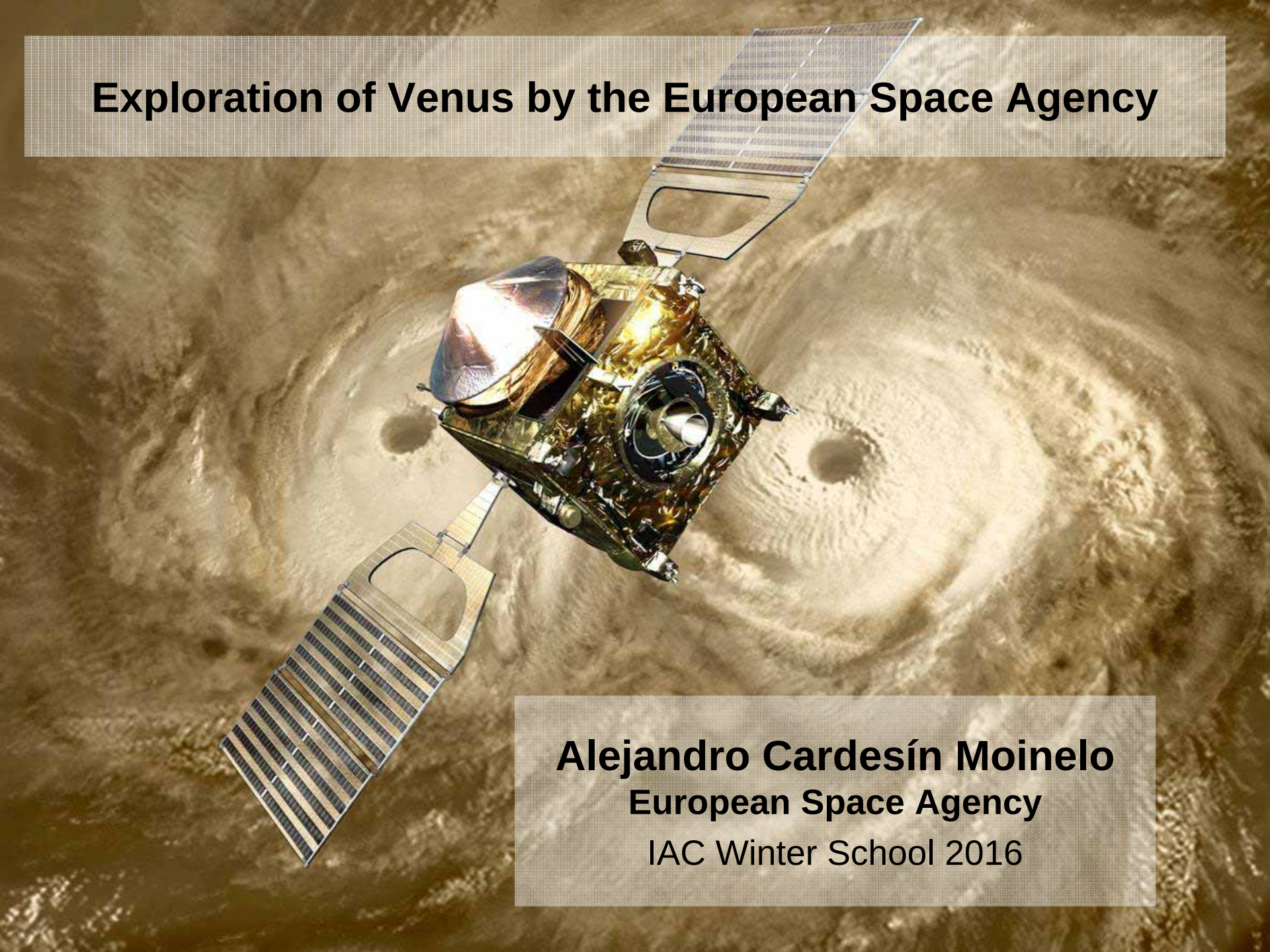
Exploration of Venus by the European Space Agency

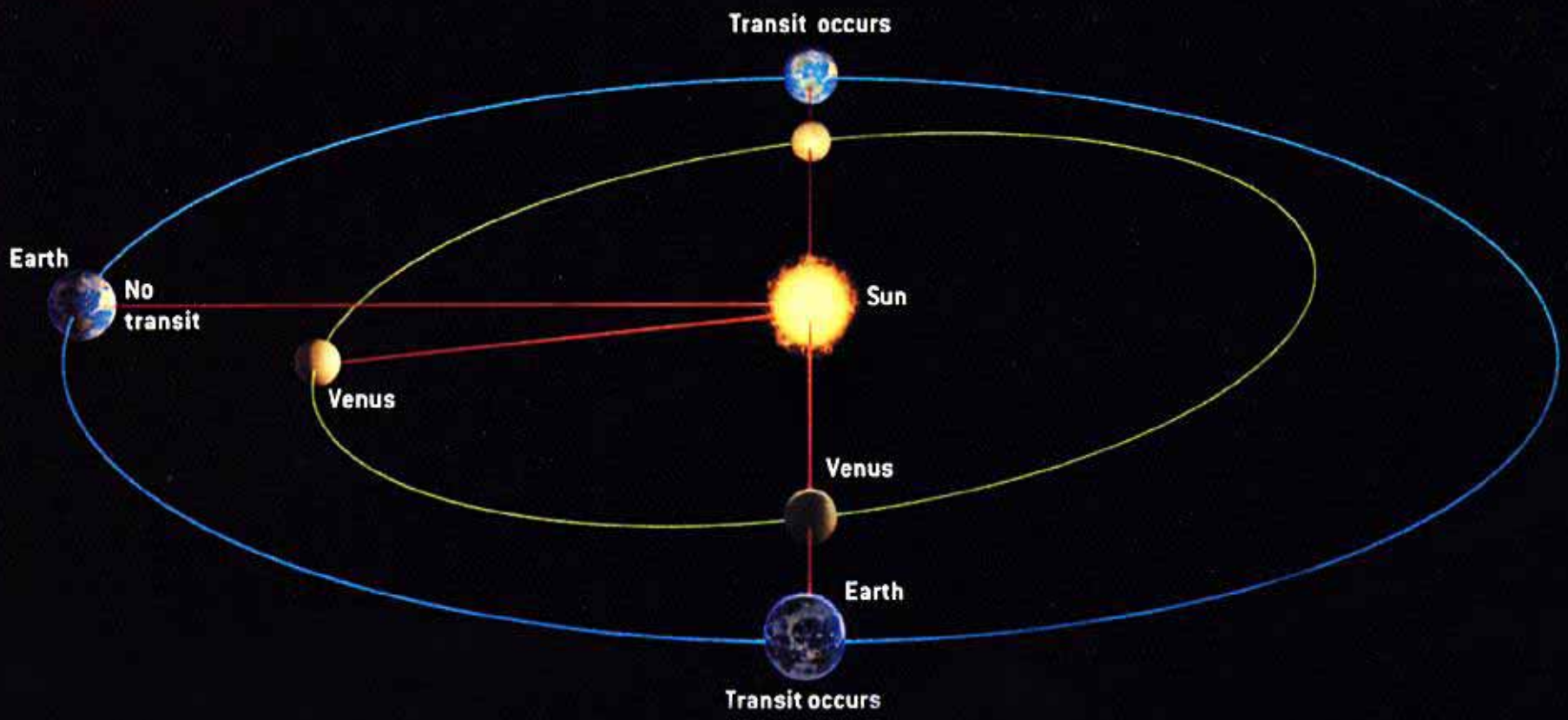


Alejandro Cardesín Moinelo
European Space Agency
IAC Winter School 2016

Venus, the “morning star”

or “evening star” …

Venus and Earth Orbits

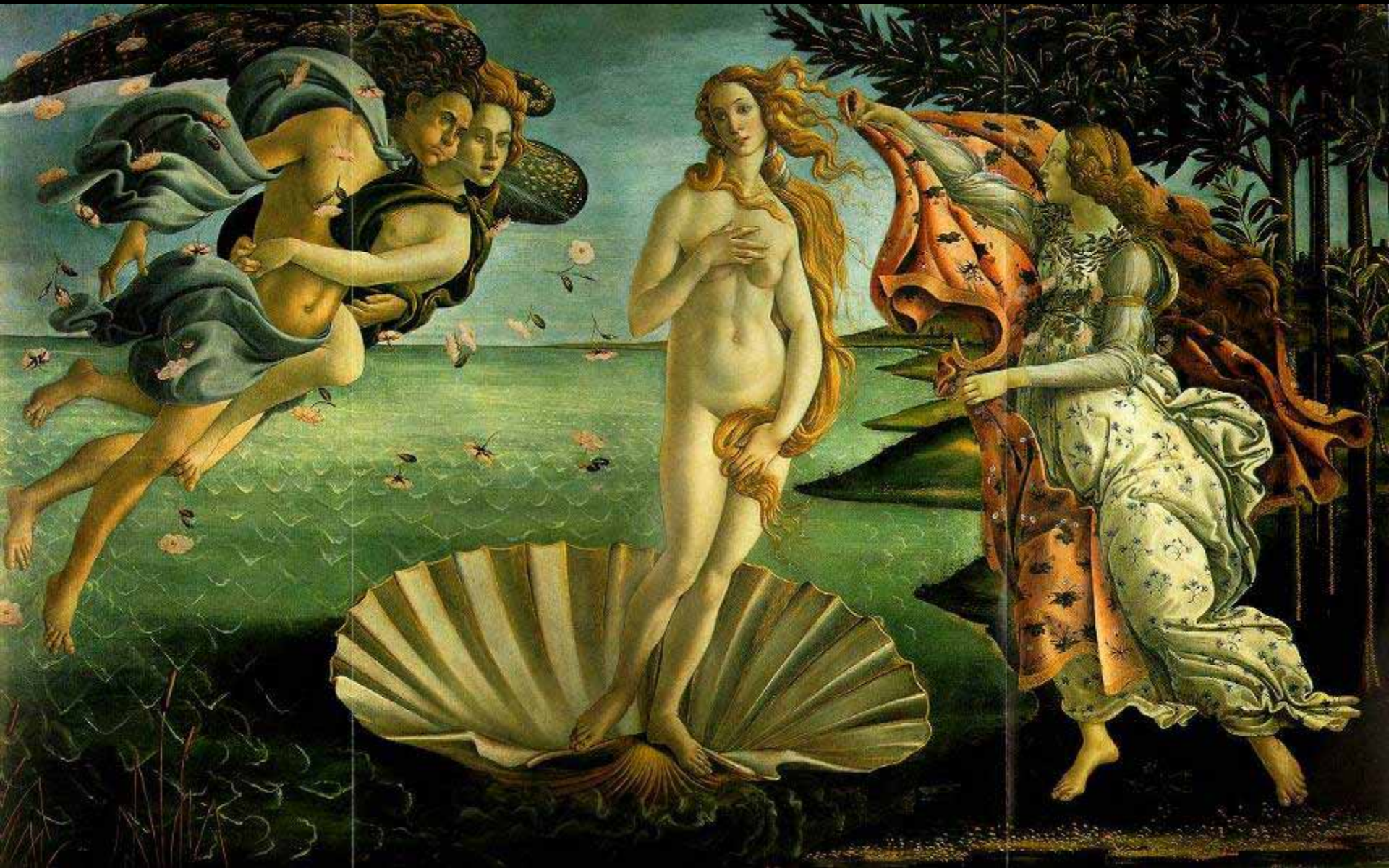


Orbital Inclination Exaggerated

when we get lucky…

(unfortunately not for the next 100 years… until Dec 2117)

Venus-Aphrodita
goddess of beauty and love



Venus has been followed by all civilizations

“Lespugue” 25000 BC

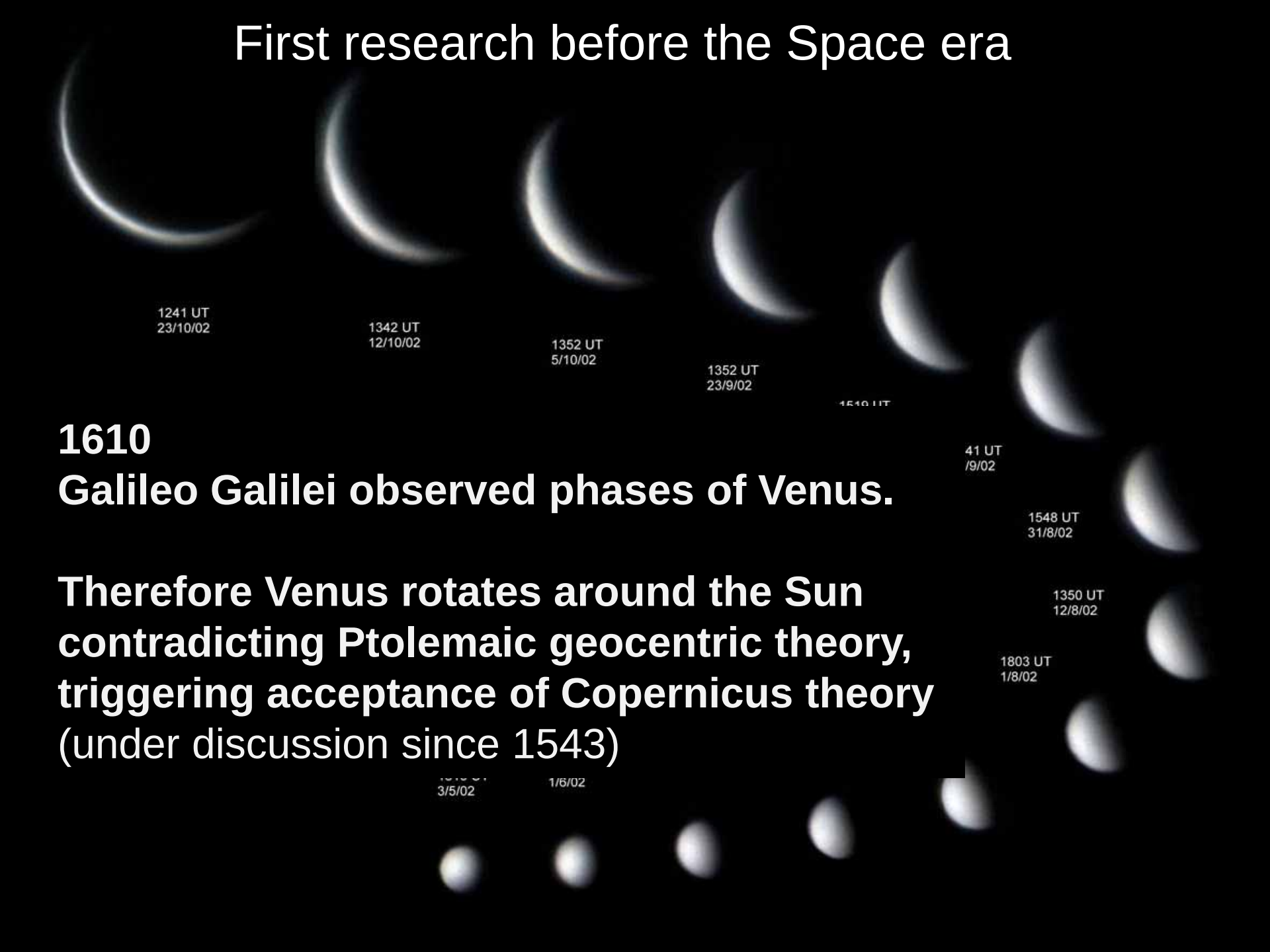
Willendorf 23000 BC

Babilon: *Ishtar*

Maya/Aztec/Inca:
Kukulkan / Quetzalcoatl

Early
Christians:
Lucifer

First research before the Space era



1610
Galileo Galilei observed phases of Venus.

Therefore Venus rotates around the Sun contradicting Ptolemaic geocentric theory, triggering acceptance of Copernicus theory
(under discussion since 1543)

Early research before the Space era

1639
Venus transit first predicted and used to measure Earth distance to the Sun using parallax from various observing points

1761
discovery of the atmosphere by Lomonosov

Venus just before the Space era

20th century
birth of spectroscopy

1920s
cloud top temperature
~240K

1930s
CO2 composition, low H2O

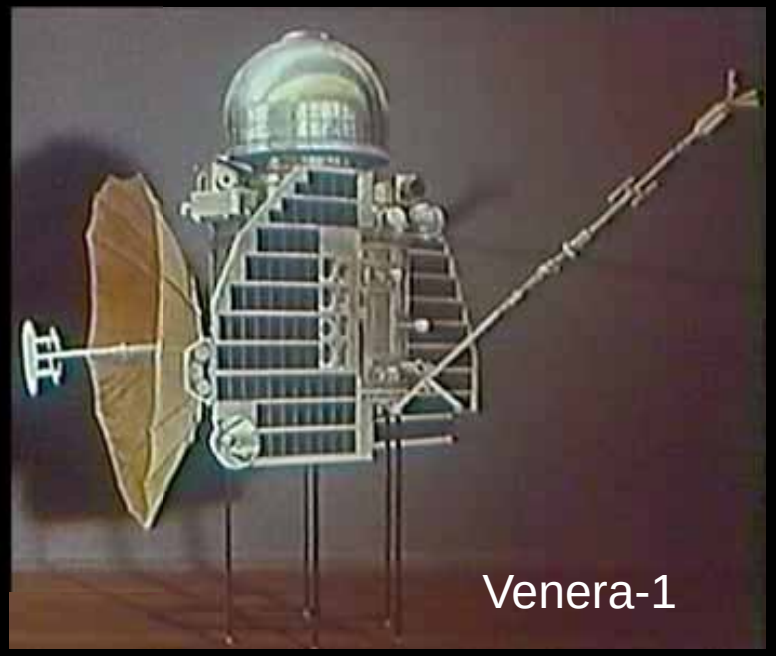
1950s
radio investigations:
planet rotation, hot surface

Just before space era, Venus still seemed a nice place to be …

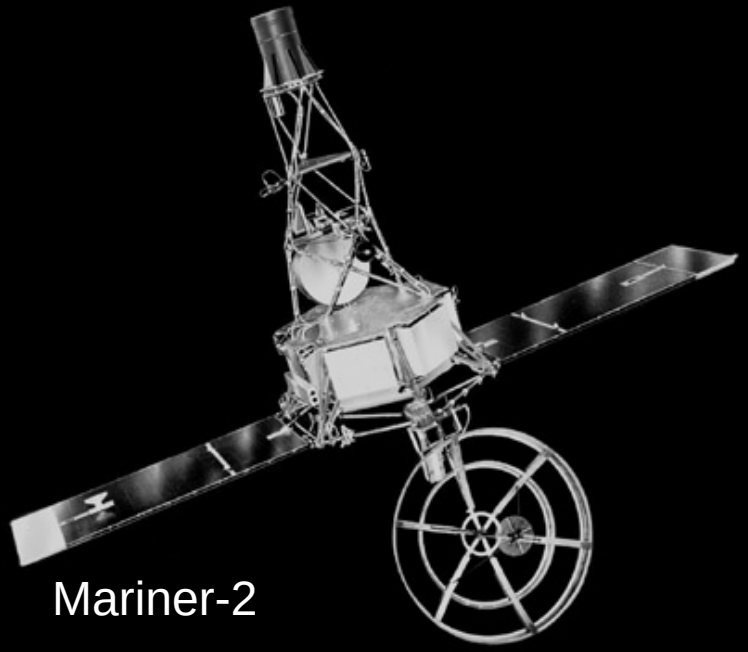
Venus surface according to S. Arrhenius in 1950s

The Space Race: Who will be the first to reach Venus?

1957: Sputnik
First ever earth satellite



1960-1961
Sovietic Veneras 1-2 both failed.
First launch failed,
second one succeeded but
communication was lost.



1962
USA Mariner-2
Venus fly-by and first data returned

First succesful planetary mission flyby!

Venus surface temperature ~400ºC!!!

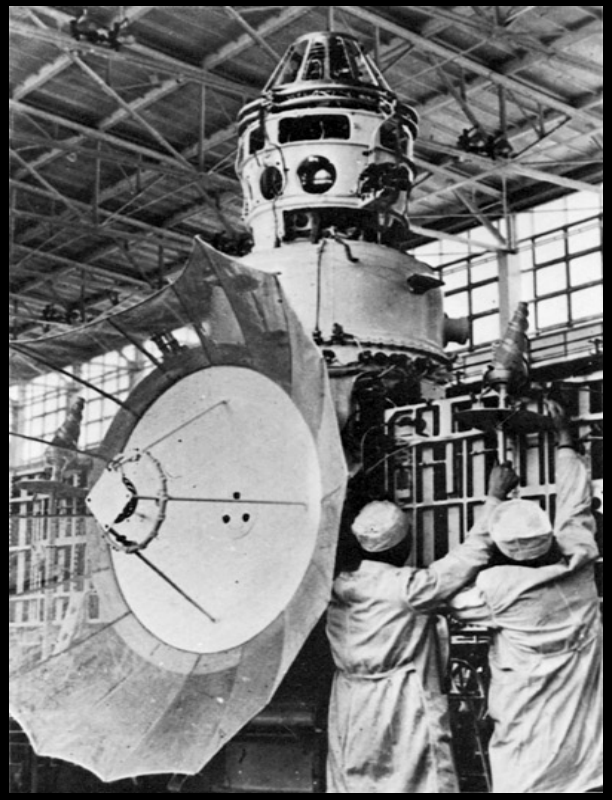
Next Goal: reach the surface!

1960s : Venera-4, 5, 6 reached ~20 km

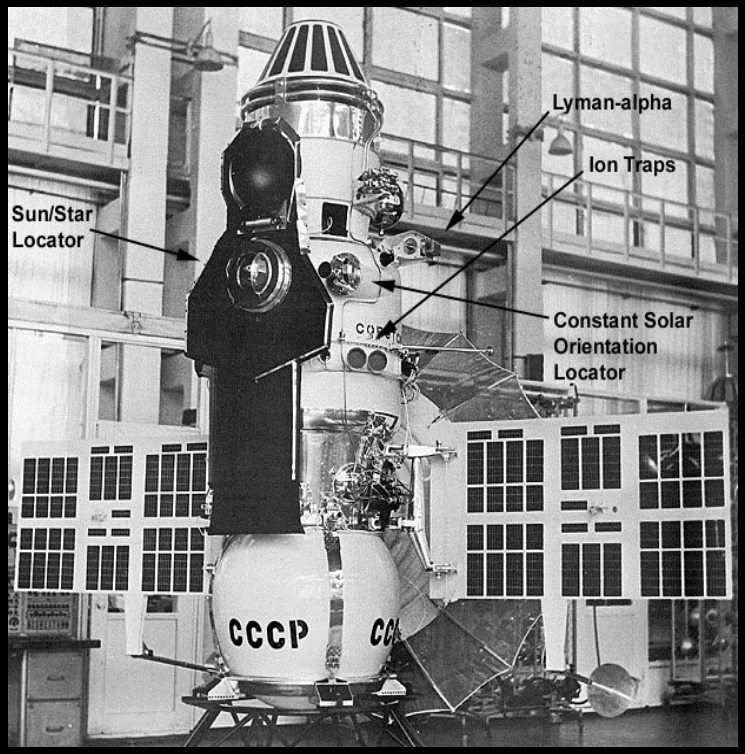
1970: Venera-7 : “soft” landing

First data from surface of another planet

Temperature ~475ºC!!! Pressure 90bar!!!



Venera-7

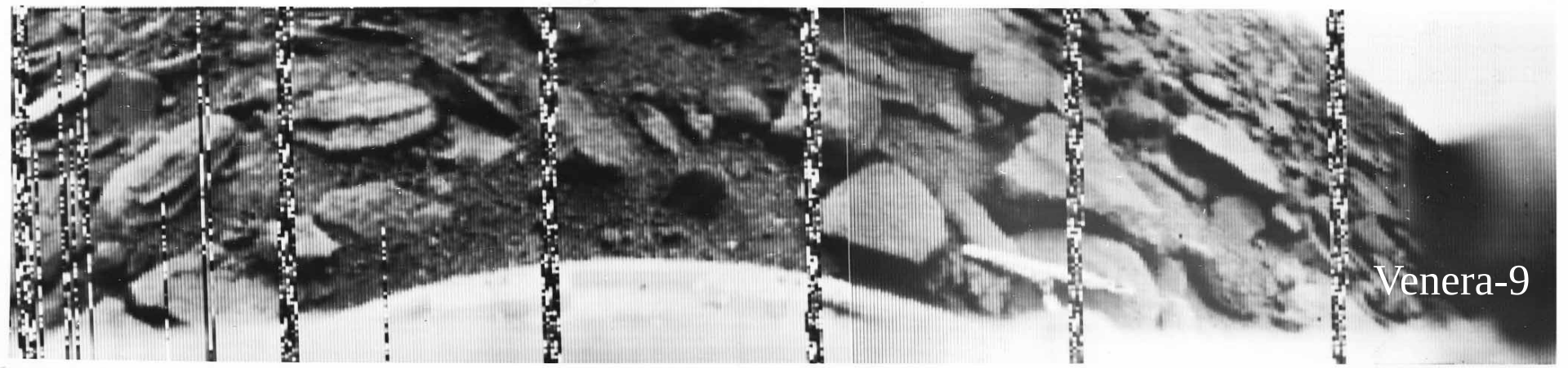


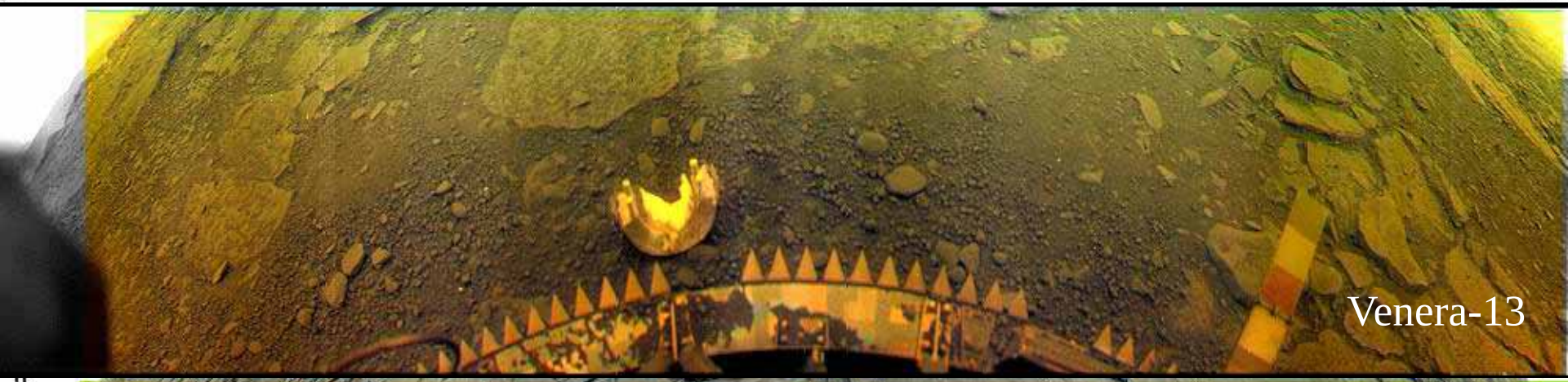
Venera-4

Russia rules Venus!

Second generation of the Venera spacecraft (70s)

1975-1982 First views of the surface!



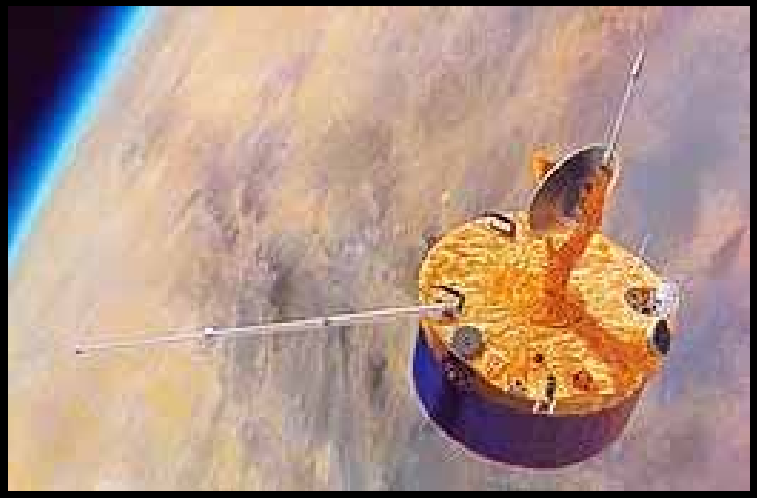


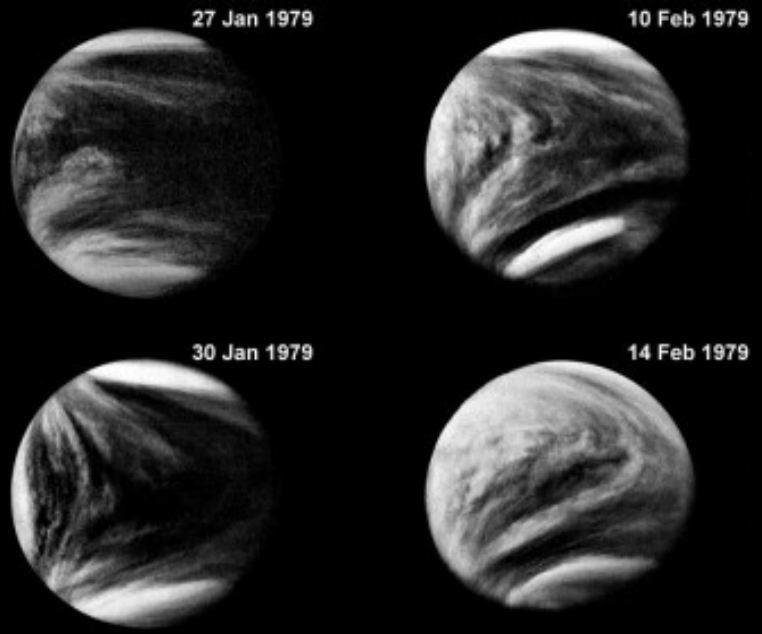
Pioneer Venus multiprobe (1978)

Carrier and 4 descent probes
- 1 big probe with parachute
- 3 small probes without parachute

All probes got to the surface
Only 1 small probe survived for 1h
Carrier also down to 110km height

Pioneer Venus orbiter (1978-1992!!!)



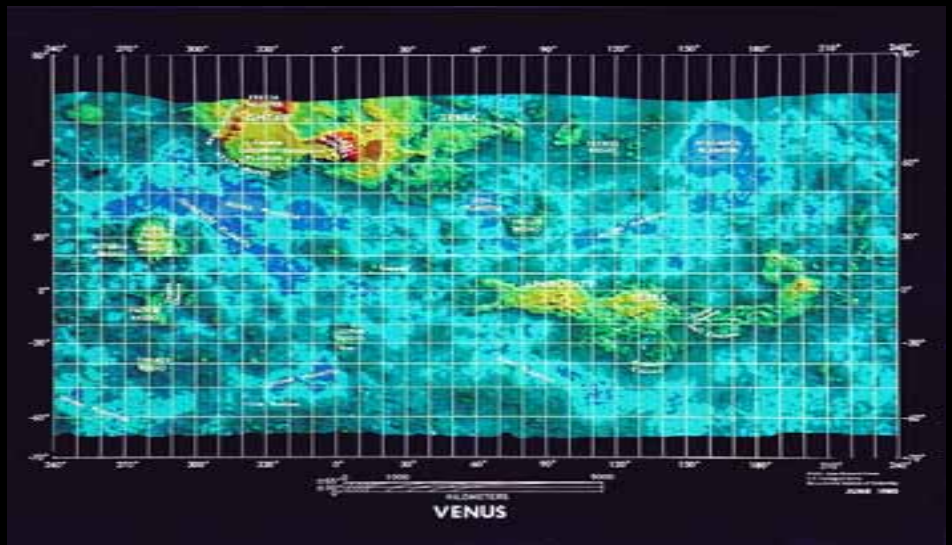


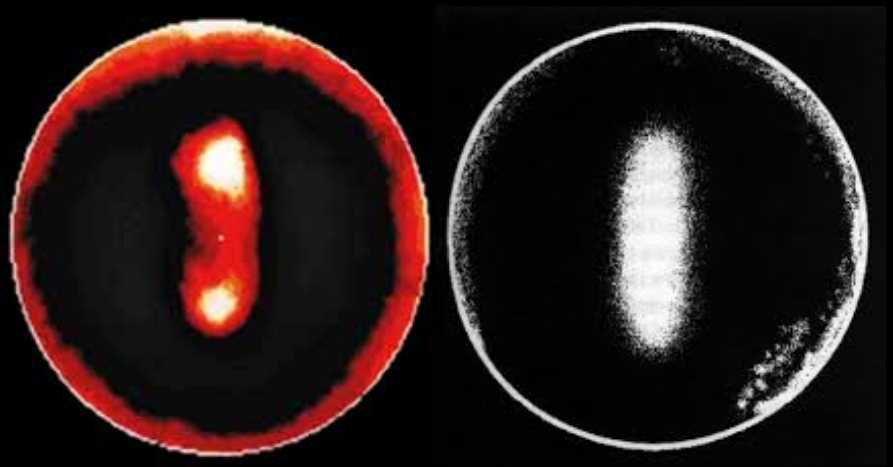
Atmospheric studies from orbit

In-situ plasma investigations

First surface radar mapping

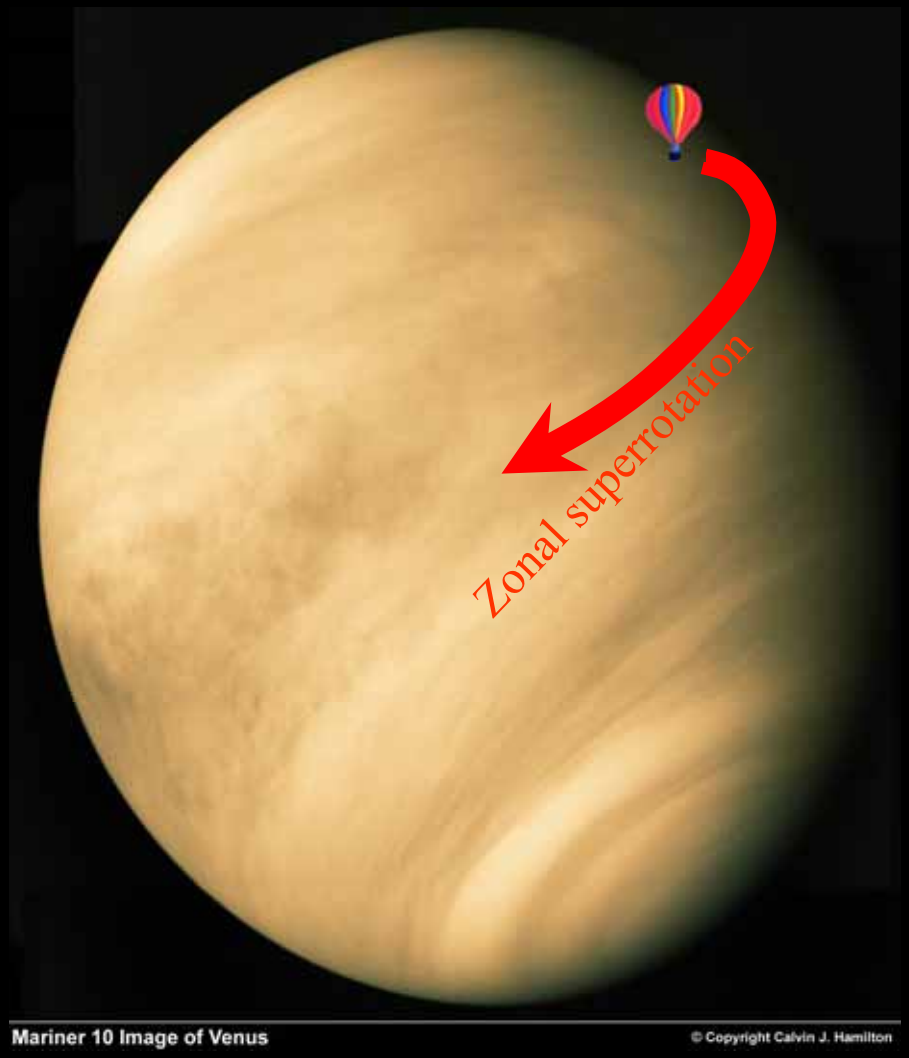
dipole in the north pole???





1984 Russian VEGA balloons 1,2

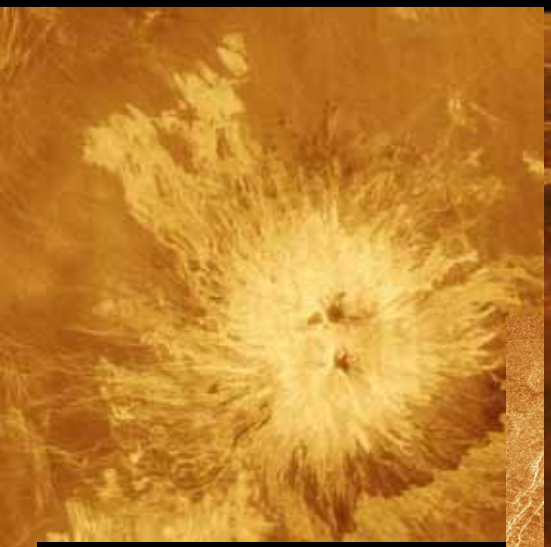
2 earth days flying over venus clouds ~54km

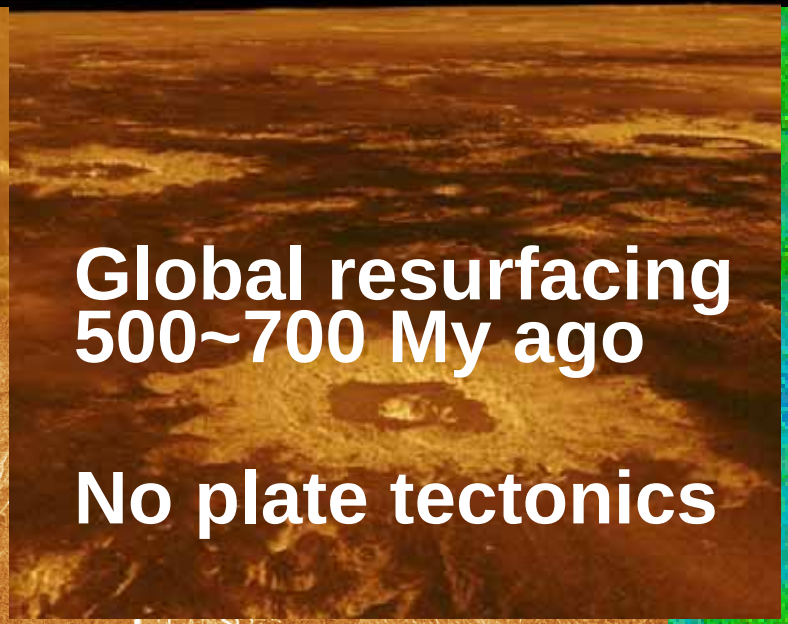


1990s: Venus unveiled…

Magellan, US, 1990, SAR images (100-200 m), radioph. properties, gravity

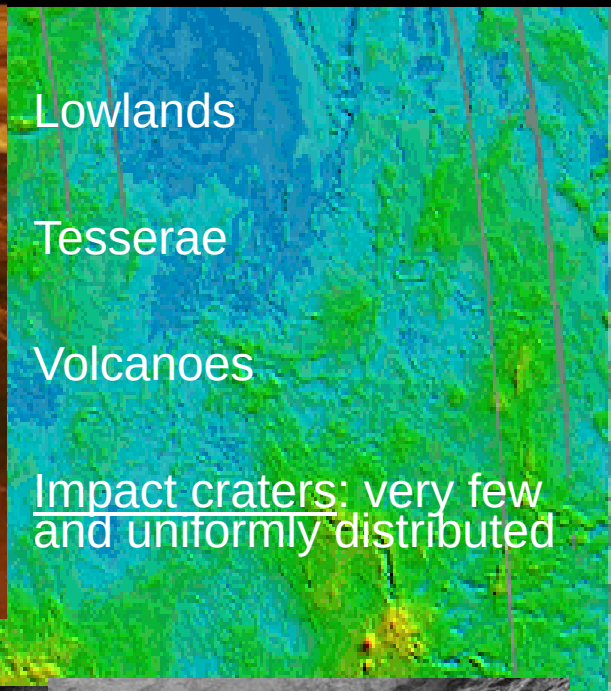
Venus Surface





Global resurfacing 500~700 My ago

No plate tectonics

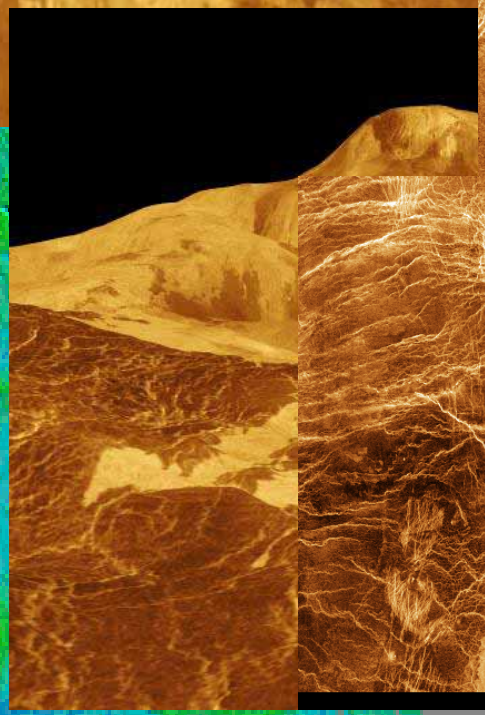


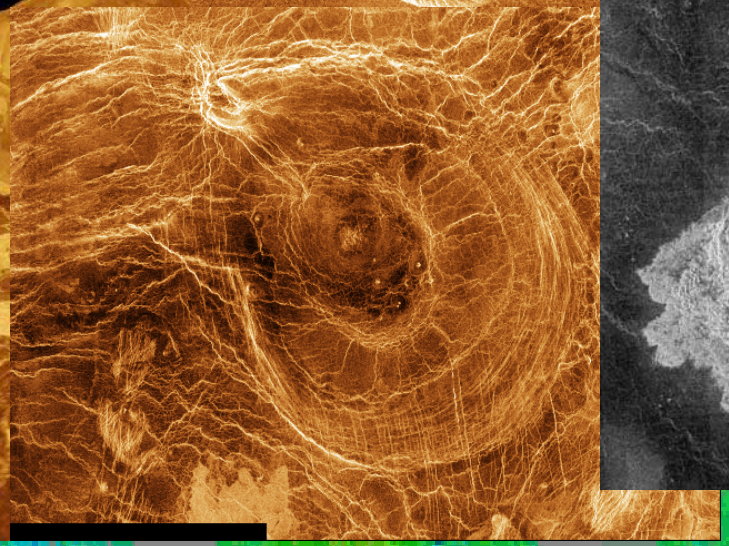
Lowlands

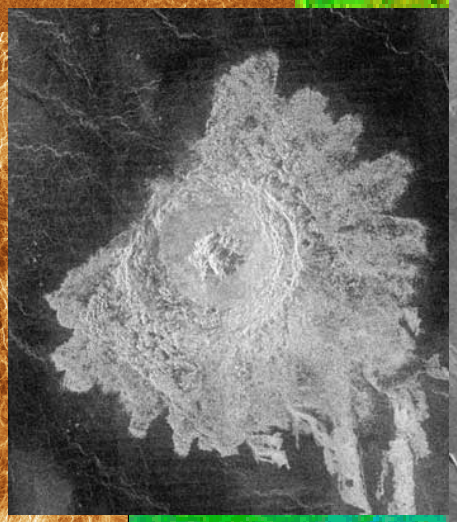
Tesserae

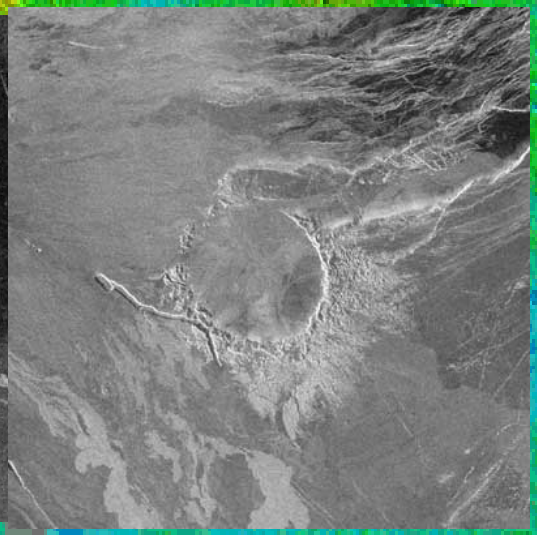
Volcanoes

Impact craters: very few and uniformly distributed

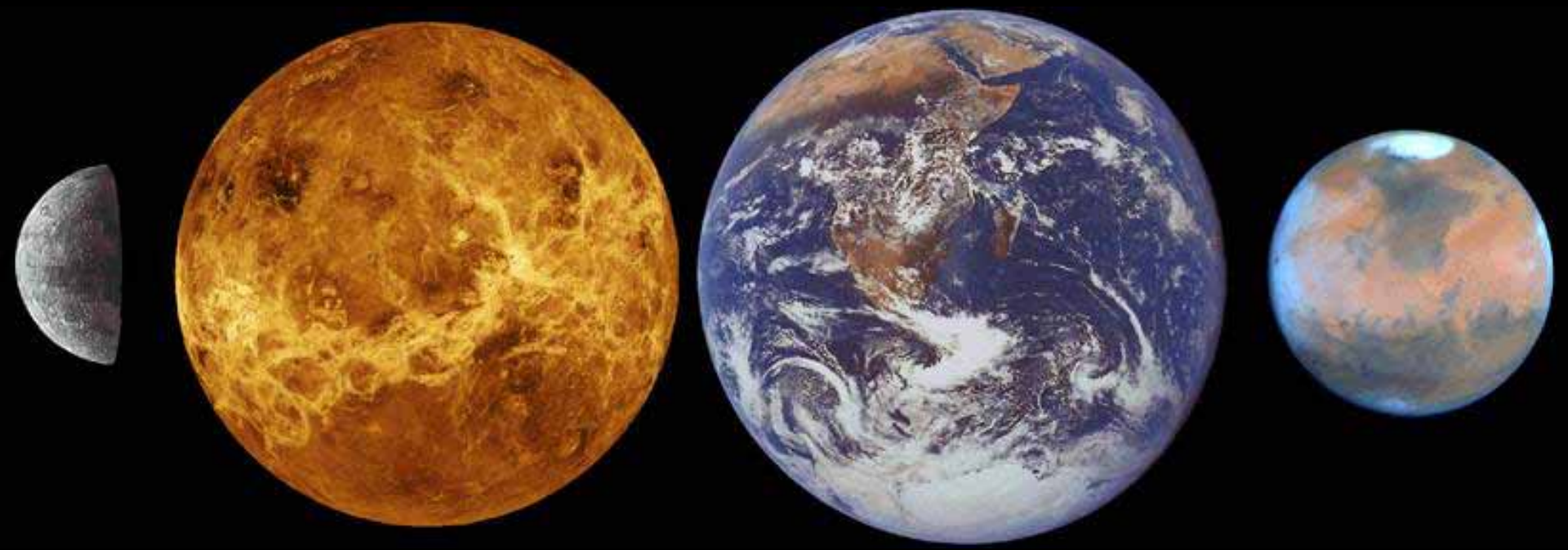






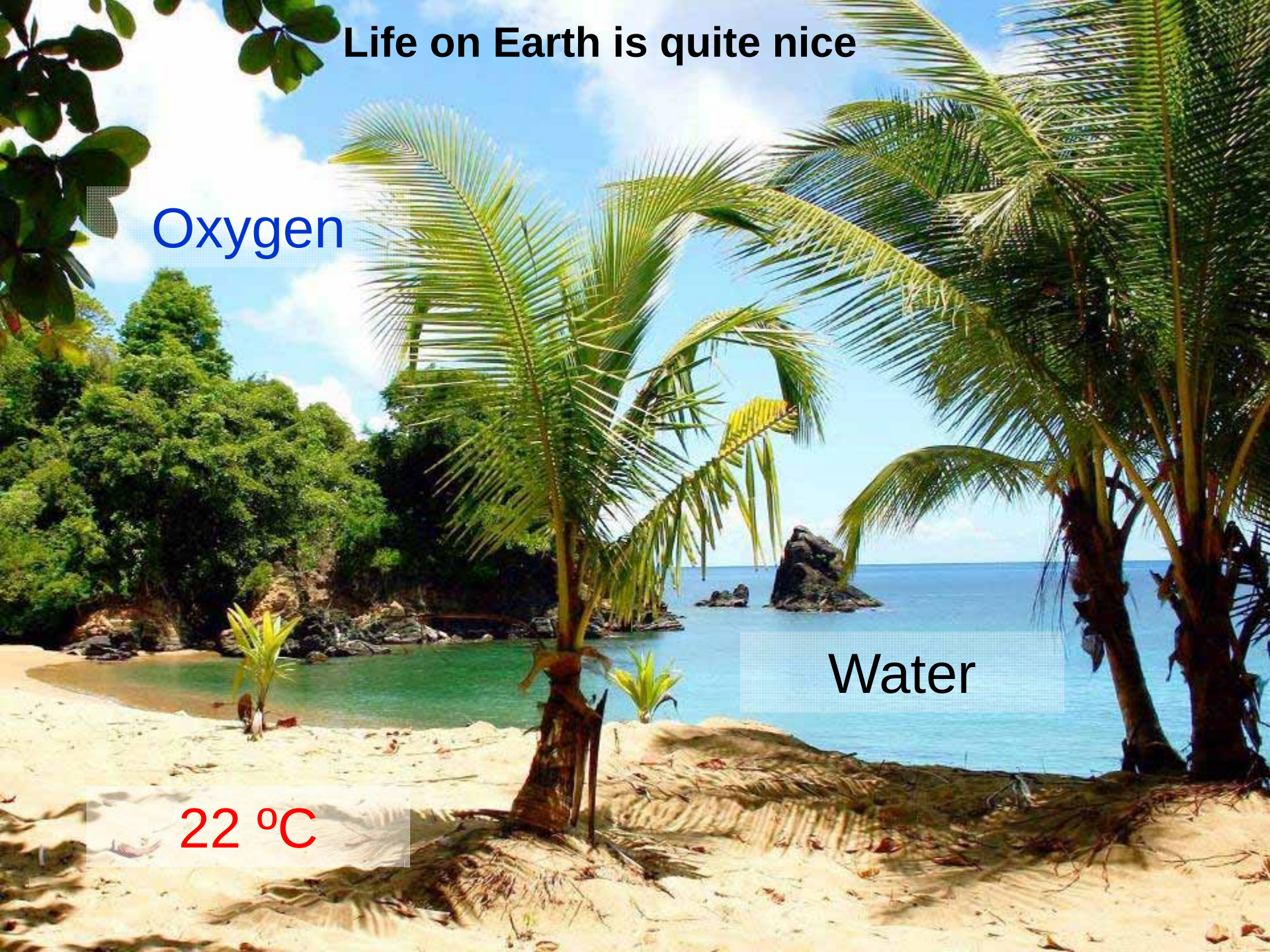


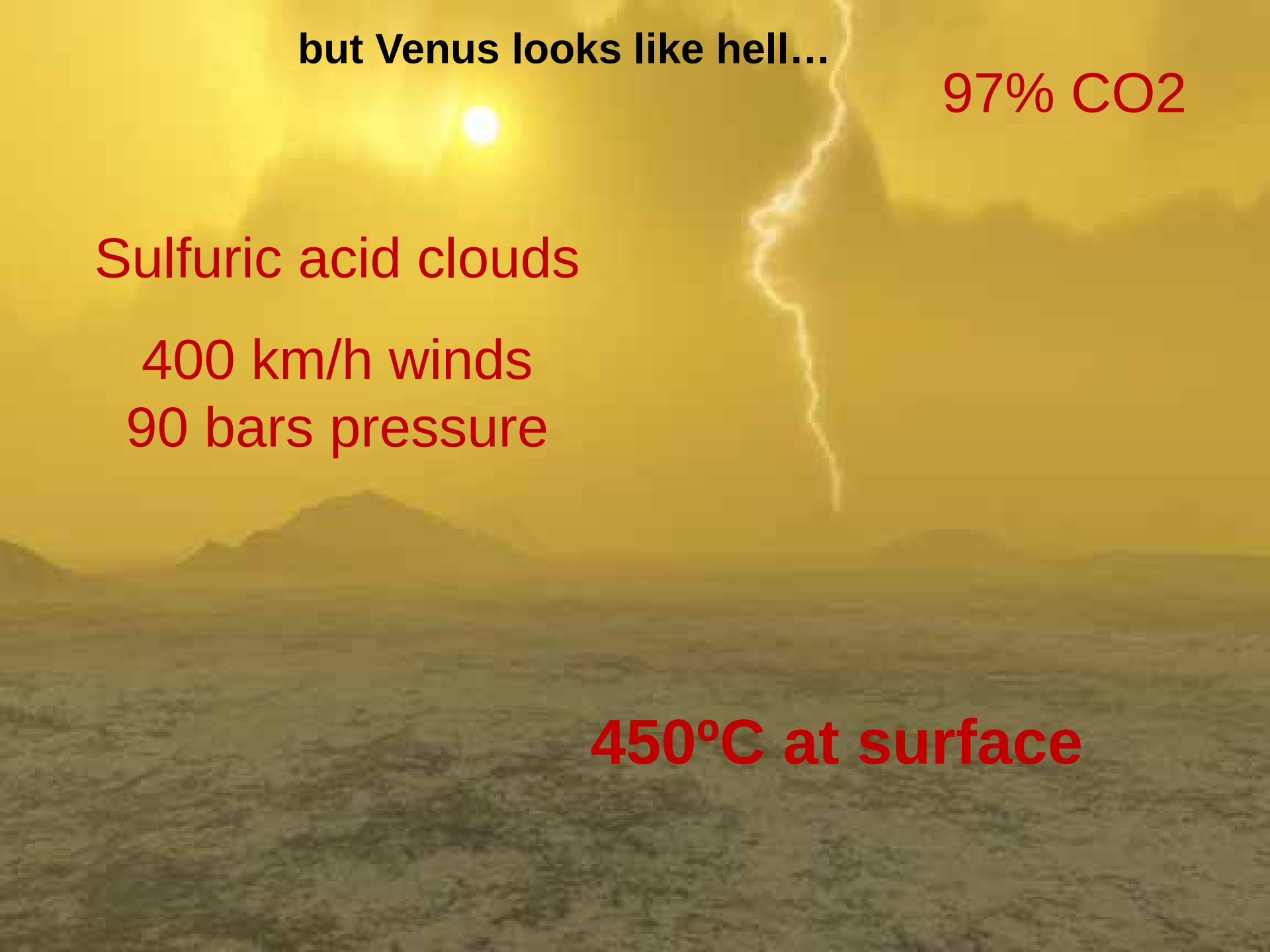
Earth and Venus



“Twin” Planets

(separated at birth, with a very different fait…)

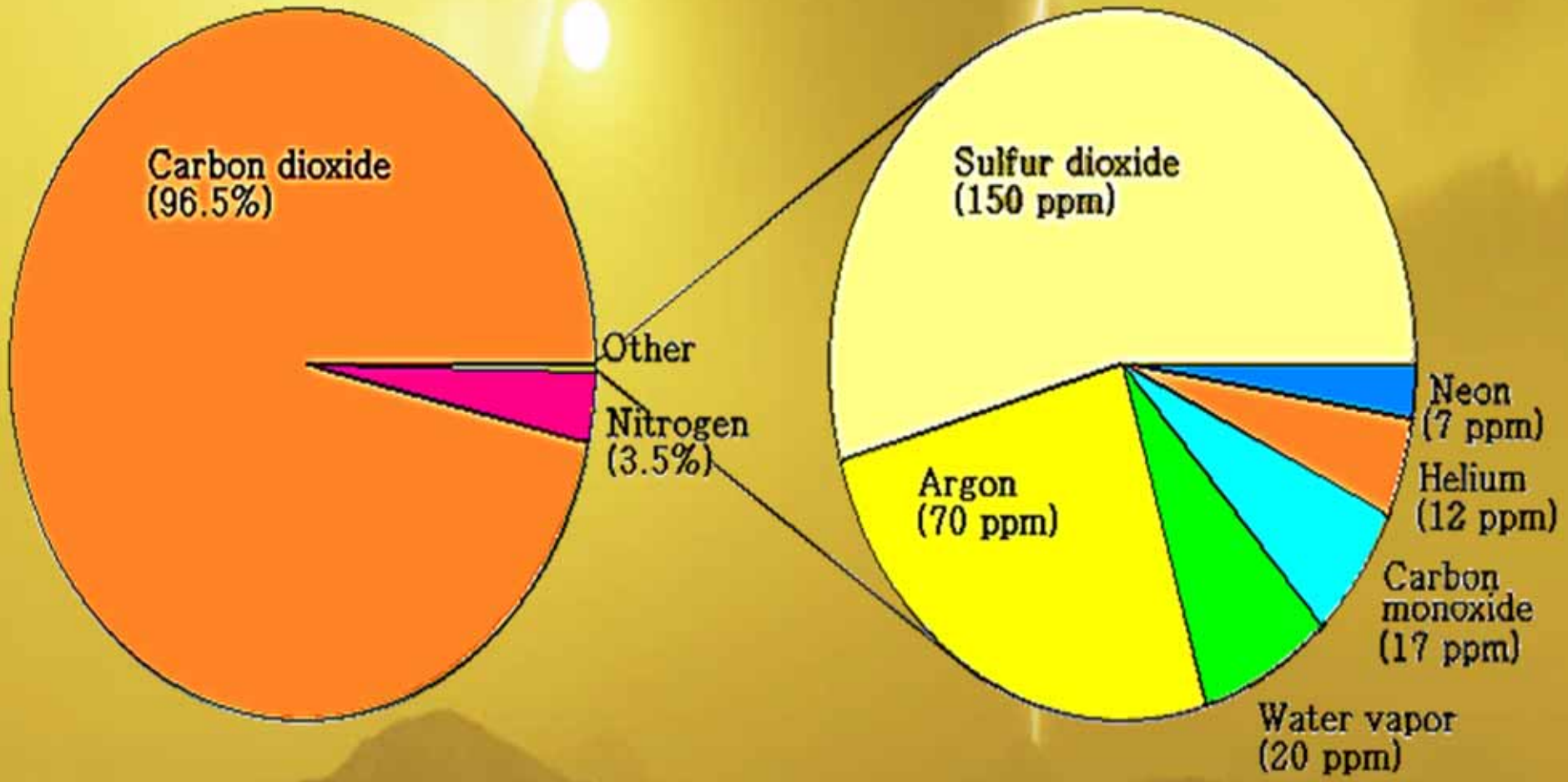

Life on Earth is quite nice
Oxygen
Water
22 ºC


but Venus looks like hell…
97% CO2
Sulfuric acid clouds
400 km/h winds
90 bars pressure
450ºC at surface

Climate and atmosphere composition

Properties	**Earth**	**Venus**
Surface P, bar	1	**90**
Surface T, °C	+15	**+ 450 (!)**
Composition		
N_2	**78%**	3.5%
O_2	**21%**	~ 0
Atmospheric H_2O	< 3%	40 ppm
Total H_2O	**~3 km**	~3 cm
SO_2	~0	~200 ppm
Clouds	H_2O	**H_2SO_4 + ?**
CO_2	300 ppm	**96.5%**

Venus Atmosphere Chemical Composition



Summary of Basic Atmospheric Elements

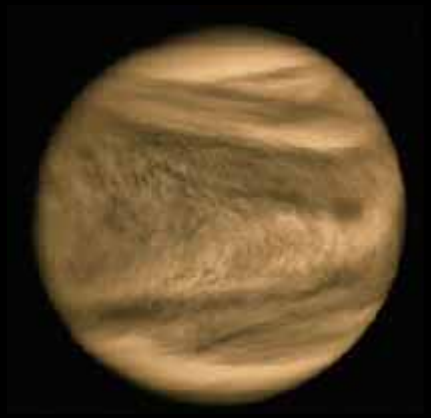
Habitability zone in the Solar System

MARS

1.52

EARTH

1 AU



VENUS

0.72

MERCURY

0.39

distance

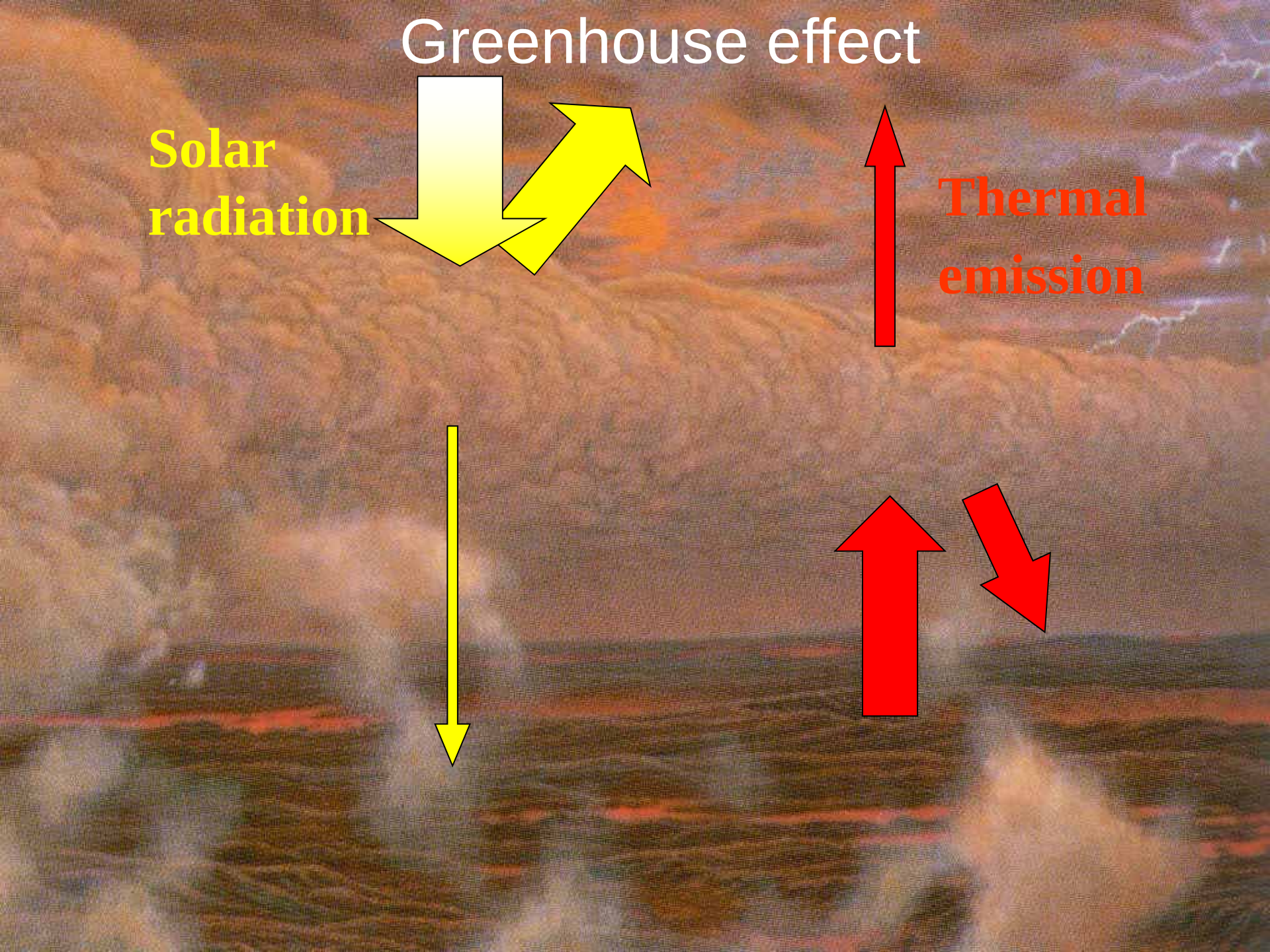
Global fridge

"Paradise"

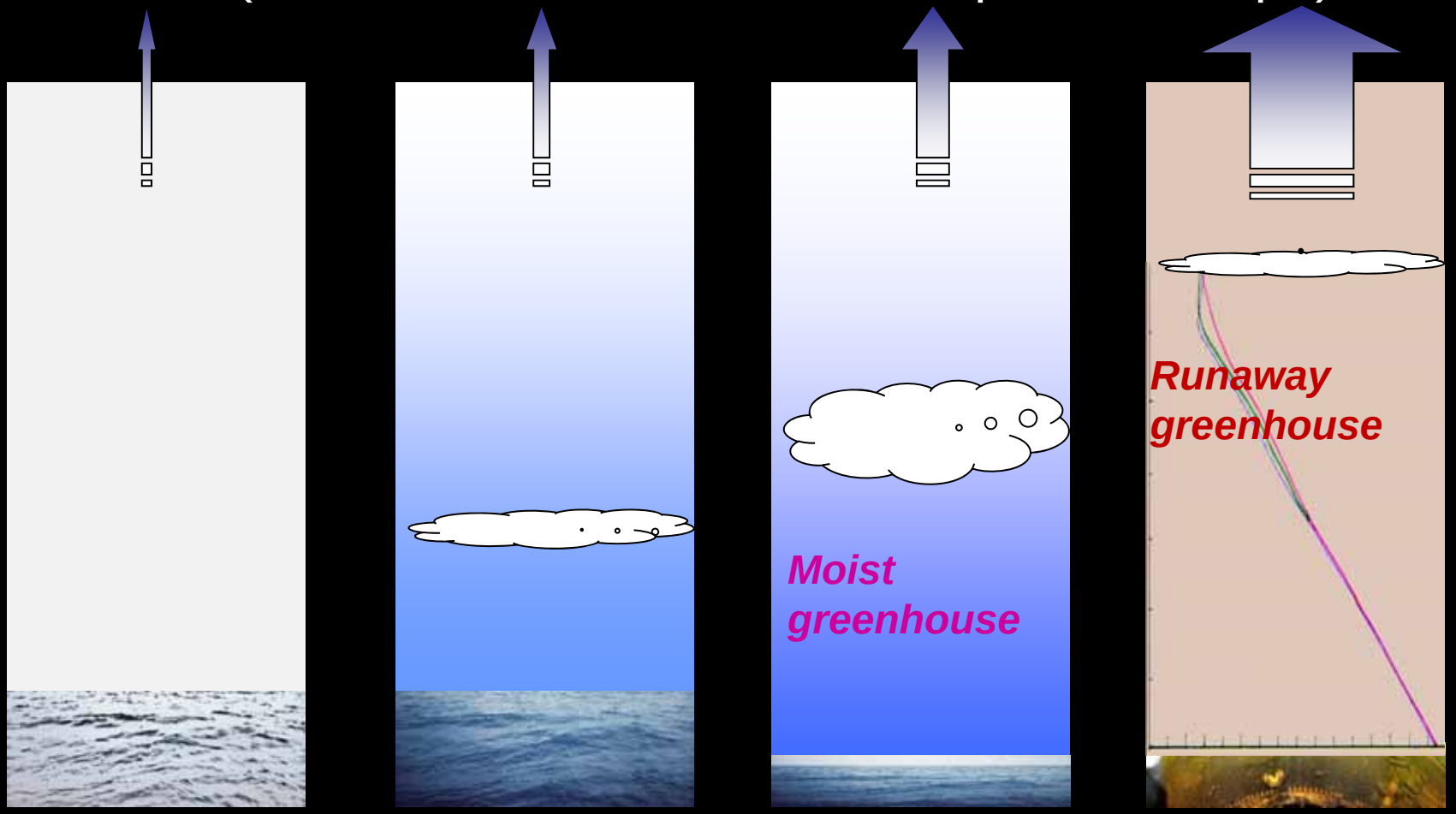
Greenhouse oven

Thin atmosphere frying pan

Greenhouse effect



Water balance on an Earth-like planet
(Greenhouse effect and atmospheric escape)



$T_s < 0$ C

$T_s \sim 22$ C

$T_s \sim 100$ C

$T_s >> 100$ C

Solar flux, W / m^2

Earth now

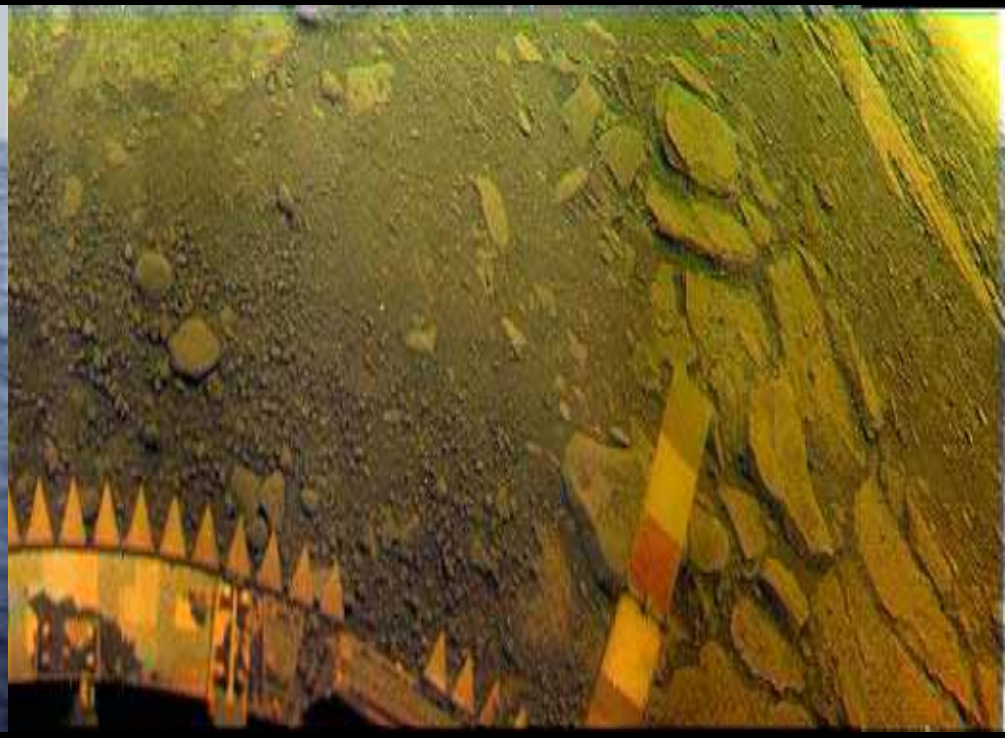
300

400

Venus now

625

Greenhouse effect and water loss



Earth and Venus: Similar volatile inventories at origin:

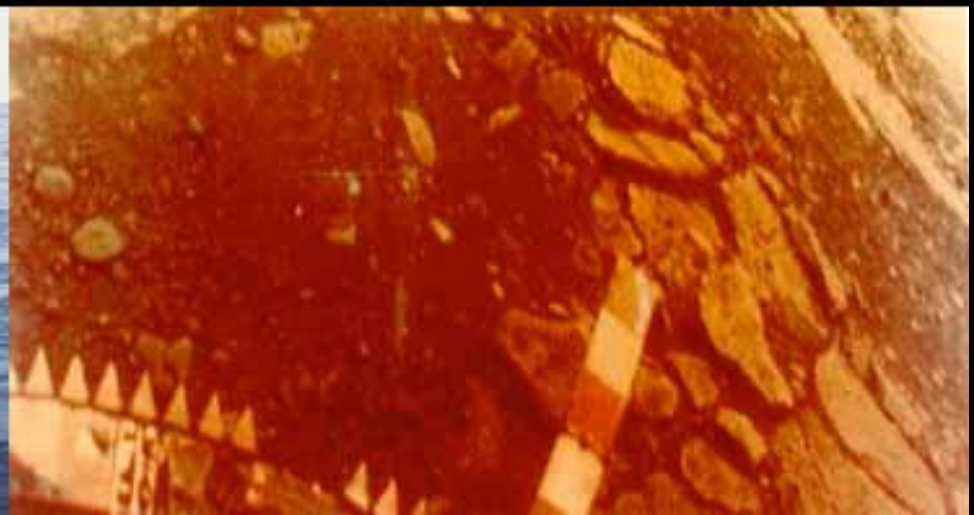
Present water amount: $H_2O_{VENUS} \sim 10^{-5}\ H_2O_{EARTH}$

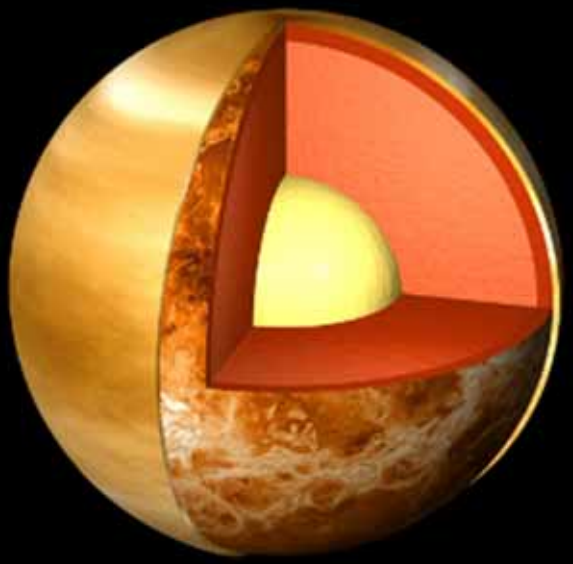
Deuterium enrichment: $(D/H)_{VENUS} \sim 150\ (D/H)_{EARTH}$

History of Venus: A Unified Scenario

- ≈ 2.5 -3 Gy (??) Loss of surface water. Subduction of hydrated sediments ceases.
- Mantle becomes desiccated.
- Lack of water makes lithosphere thicker & more difficult to break.
- Loss of asthenosphere -> lithosphere is tightly coupled to mantle.
- ≈ 1 Gy Plate tectonics ceases, Venus becomes a "1 plate planet"
- ≈ 700 My, global resurfacing rate declines precipitously.
- 700 My to present: localized volcanism and tectonism, conductive heat release, production population of craters.
- Venus may have been a habitable planet for a significant portion of Solar System history.

Courtesy of D. Grinspoon





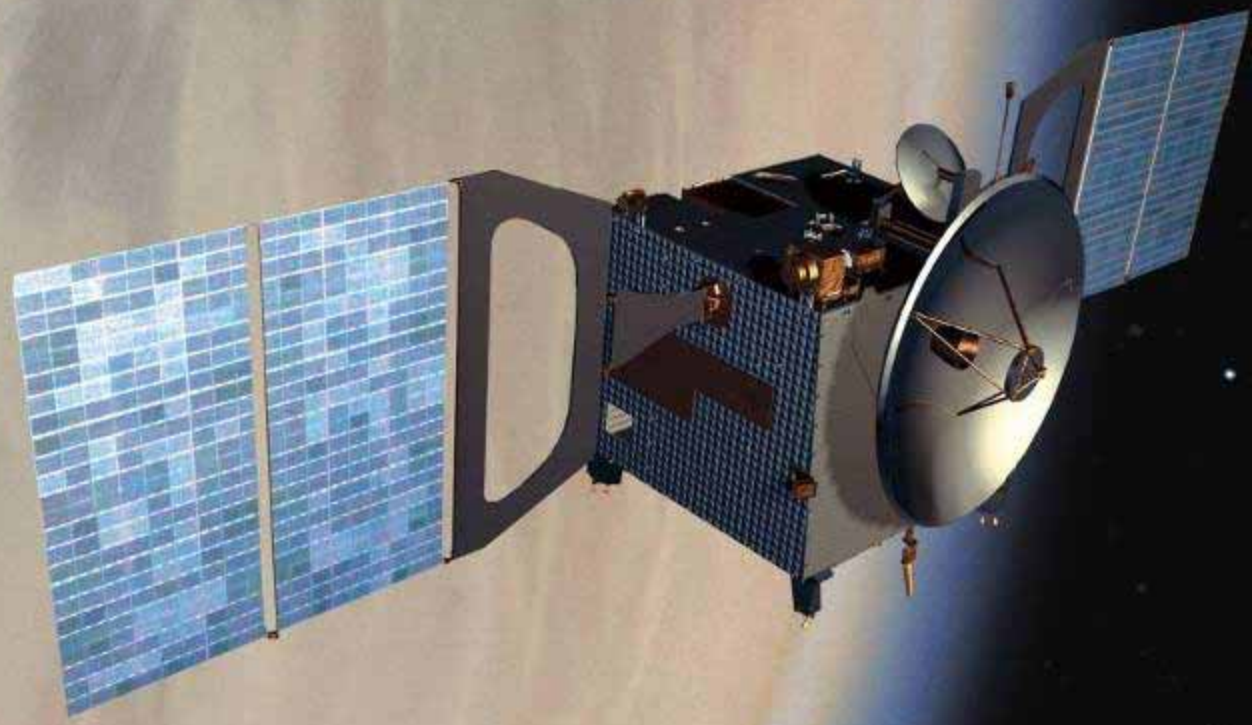
So if Earth and Venus were born similar, why did they end up so different??

Can Earth end up like Venus??

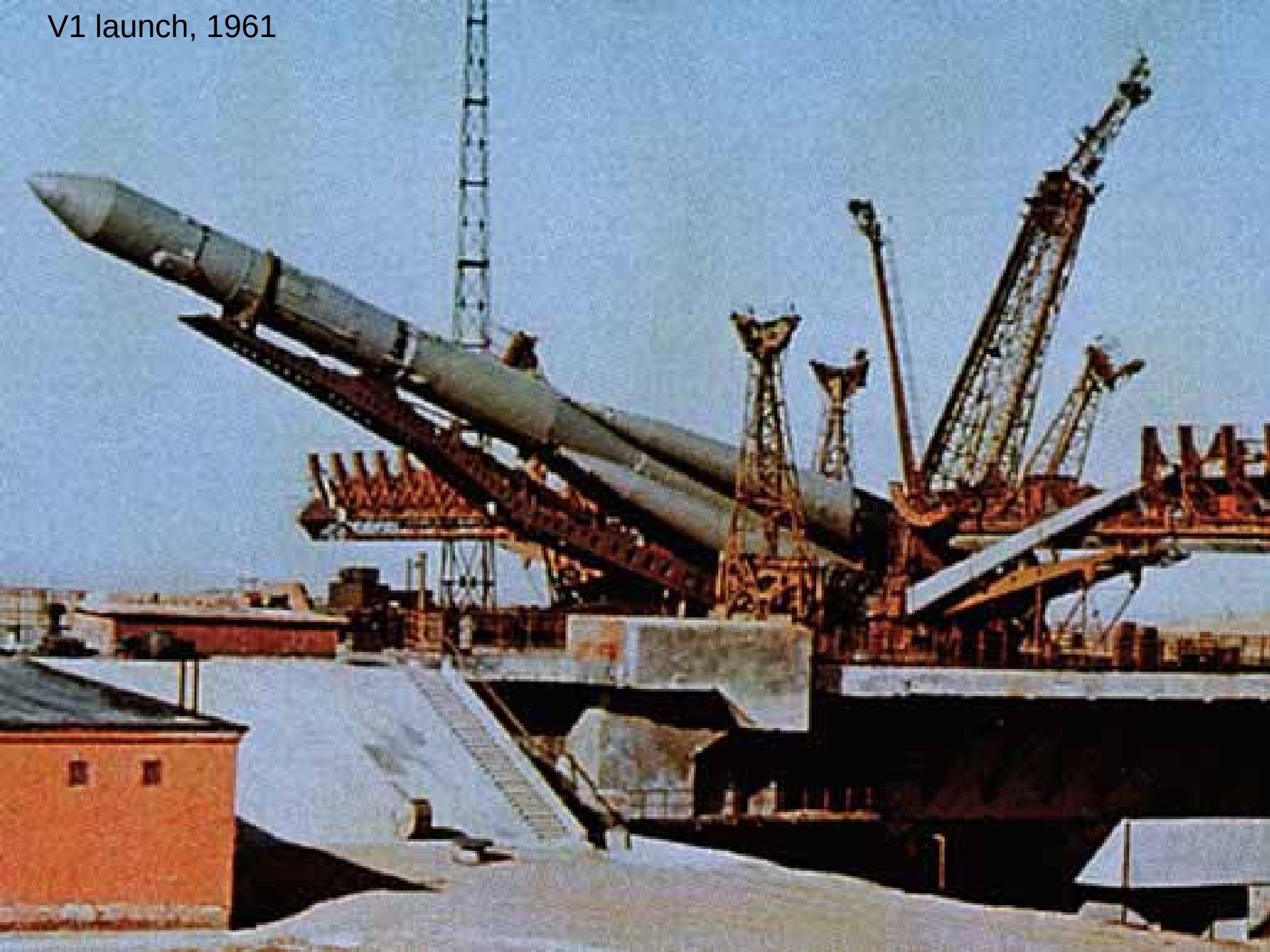
we need to know more…

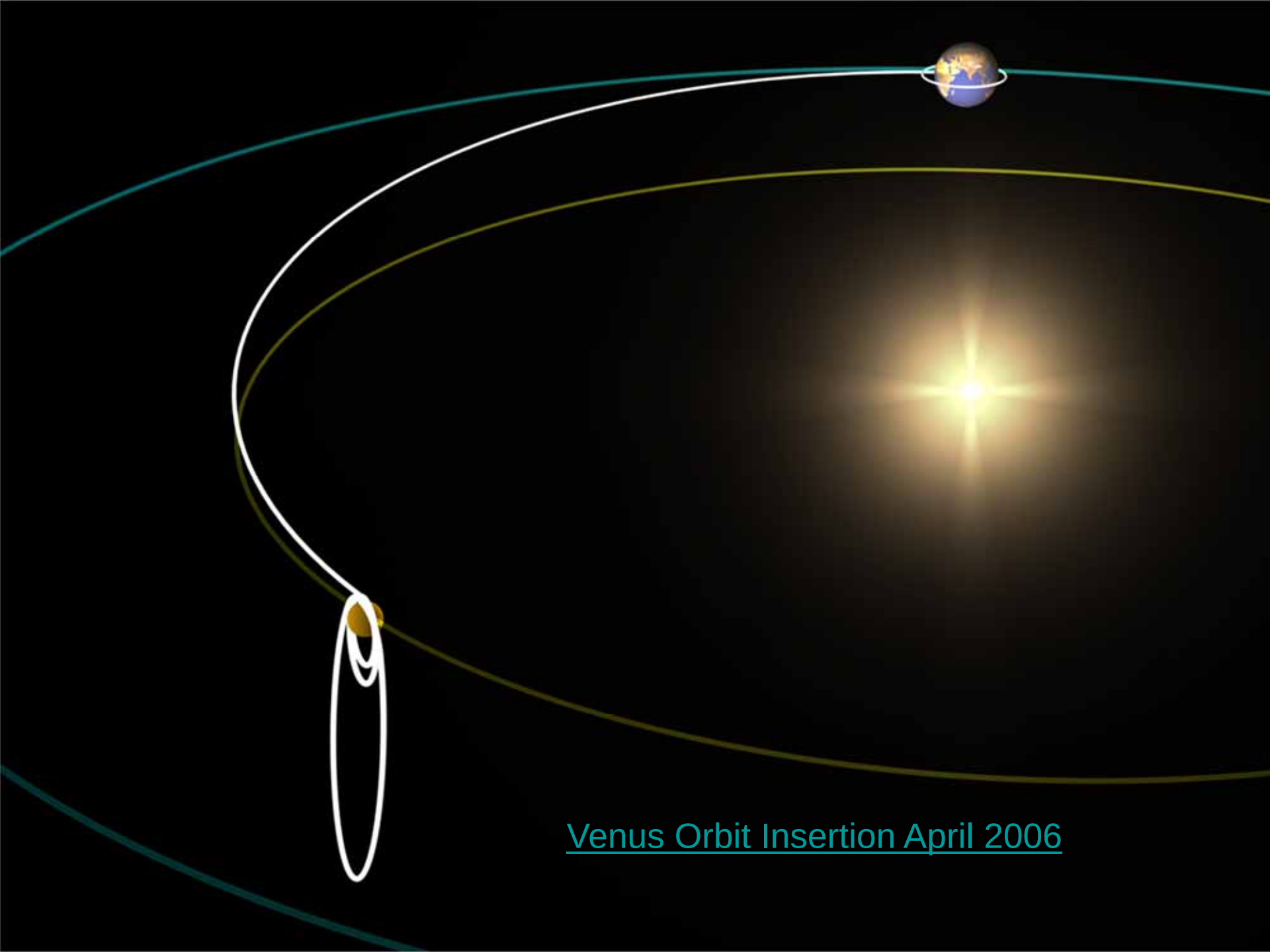
Venus Express

2005-2014

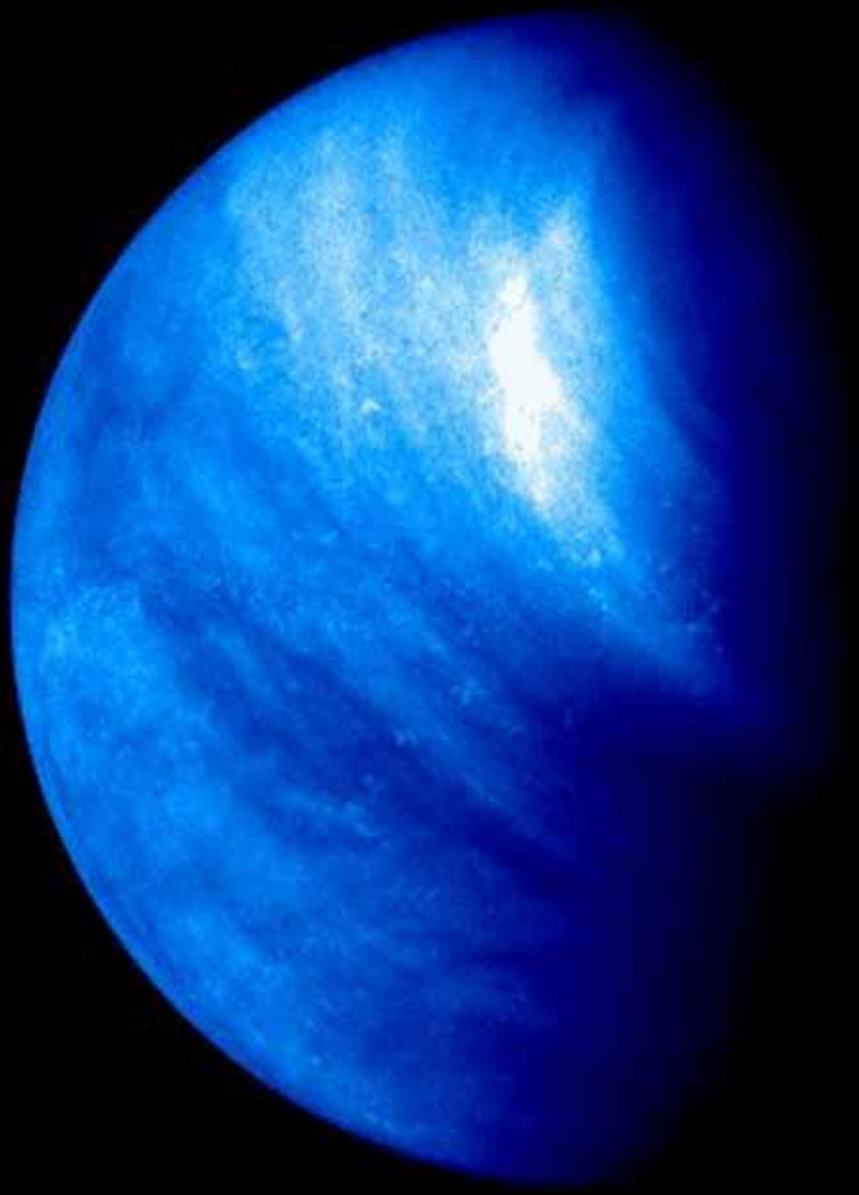



Venus Express launch, 09 Nov. 2005


V1 launch, 1961



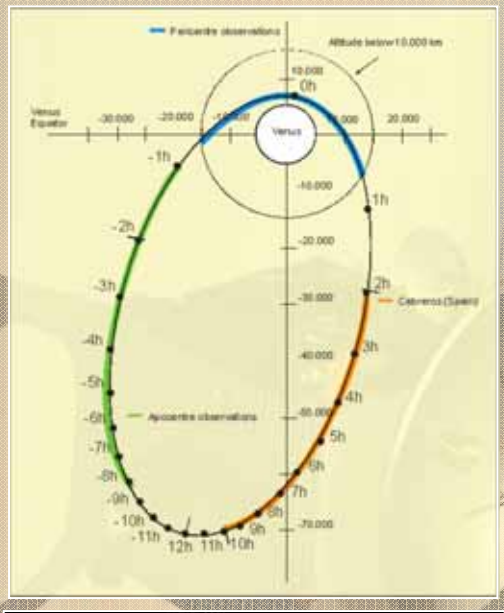
Venus Orbit Insertion April 2006

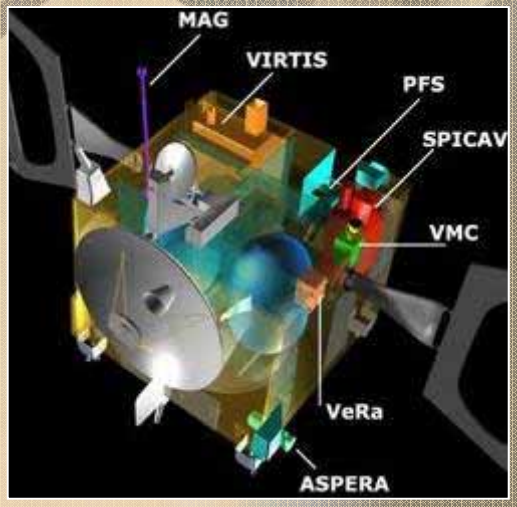


after 10 years, we're back at Venus

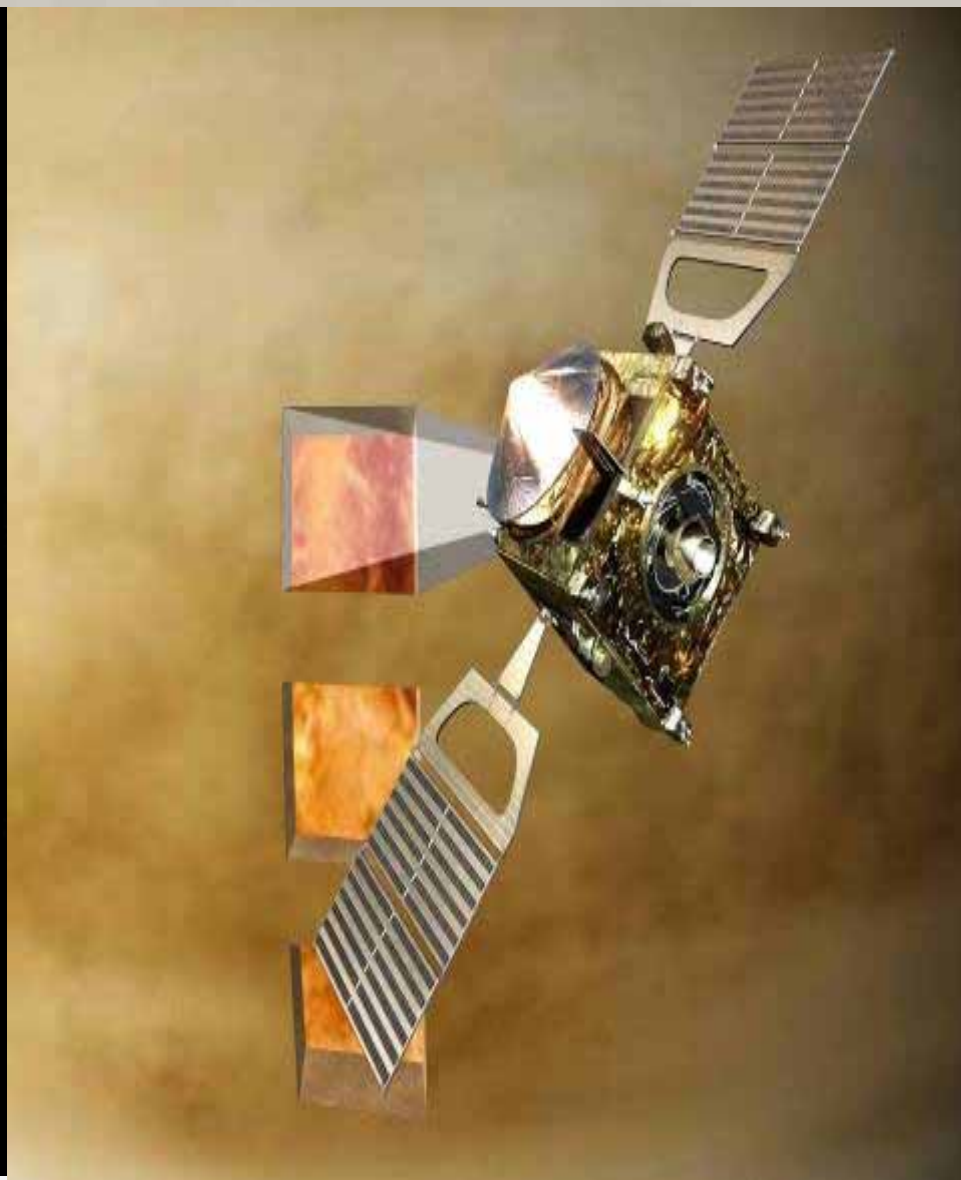
Venus Express

- Launch 09 November 2005 04:43 UTC
  - Venus Orbit Insertion 11th April 2006
- Polar elliptical orbit
  - Pericentre ~250 km
  - Apocentre ~66.000 km
  - Period ~24 hours
- Scientific Objectives
  - Atmosphere composition
  - Cloud morphology and structure
  - Atmosphere/surface interaction
  - Thermal mapping (and vulcanism)
- Instrumentation
  - VIRTIS (Imaging Spectrometer IR-VIS)
  - PFS (IR Spectrometer)
  - SPICAV (UV Spectrometer)
  - VMC (VIS-UV Camera)
  - ASPERA (Plasma science)
  - MAG (Magnetometer)





Science operations focusing on the atmosphere



Radiation in the venus atmospheric layers

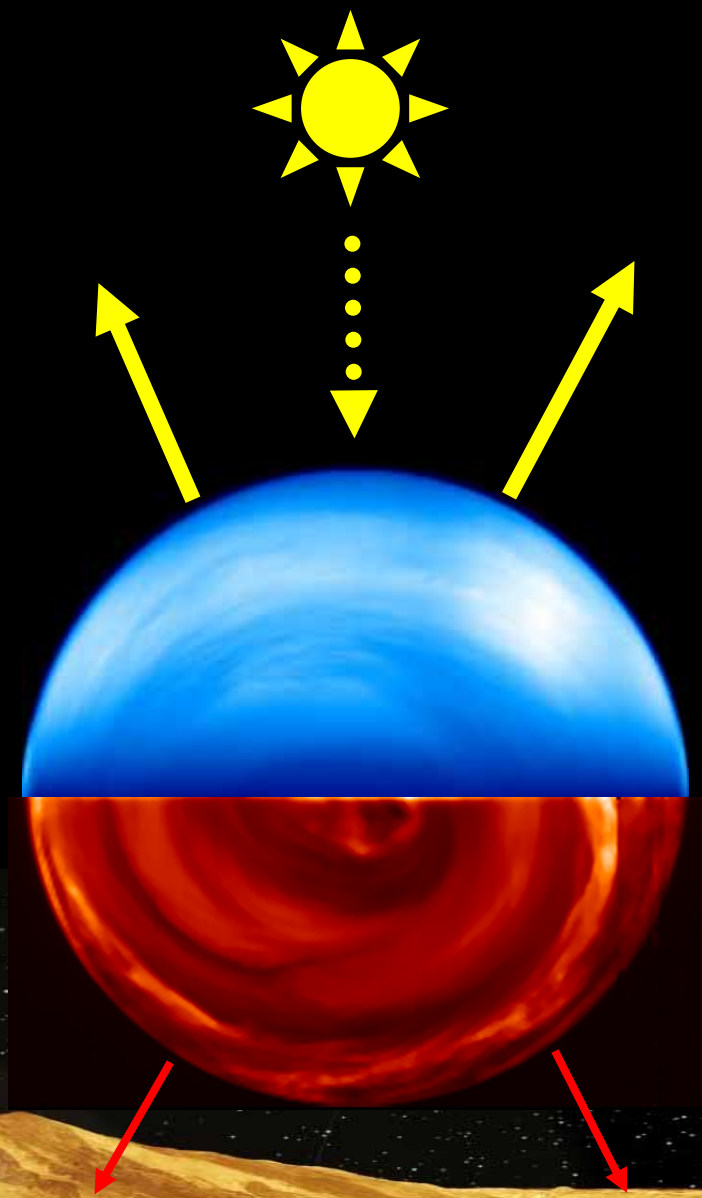
Night side, infrared (atmospheric windows)

Day side

This part is not accessible by visible light neither for day time nor for night time !

We need the infrared light and only in night time !

Surface is very hot >> unveils in the night

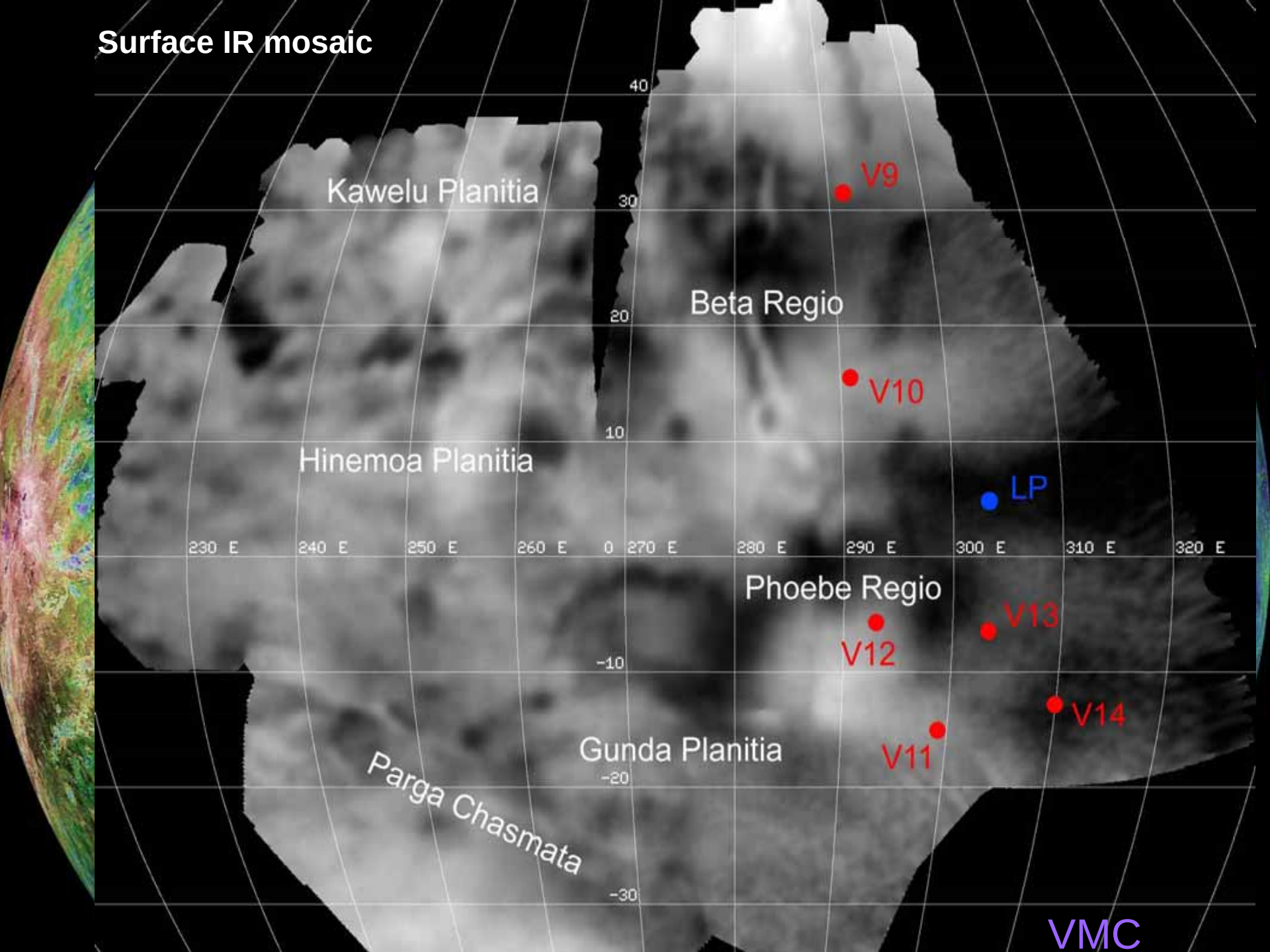


Surface

Surface thermal radiation

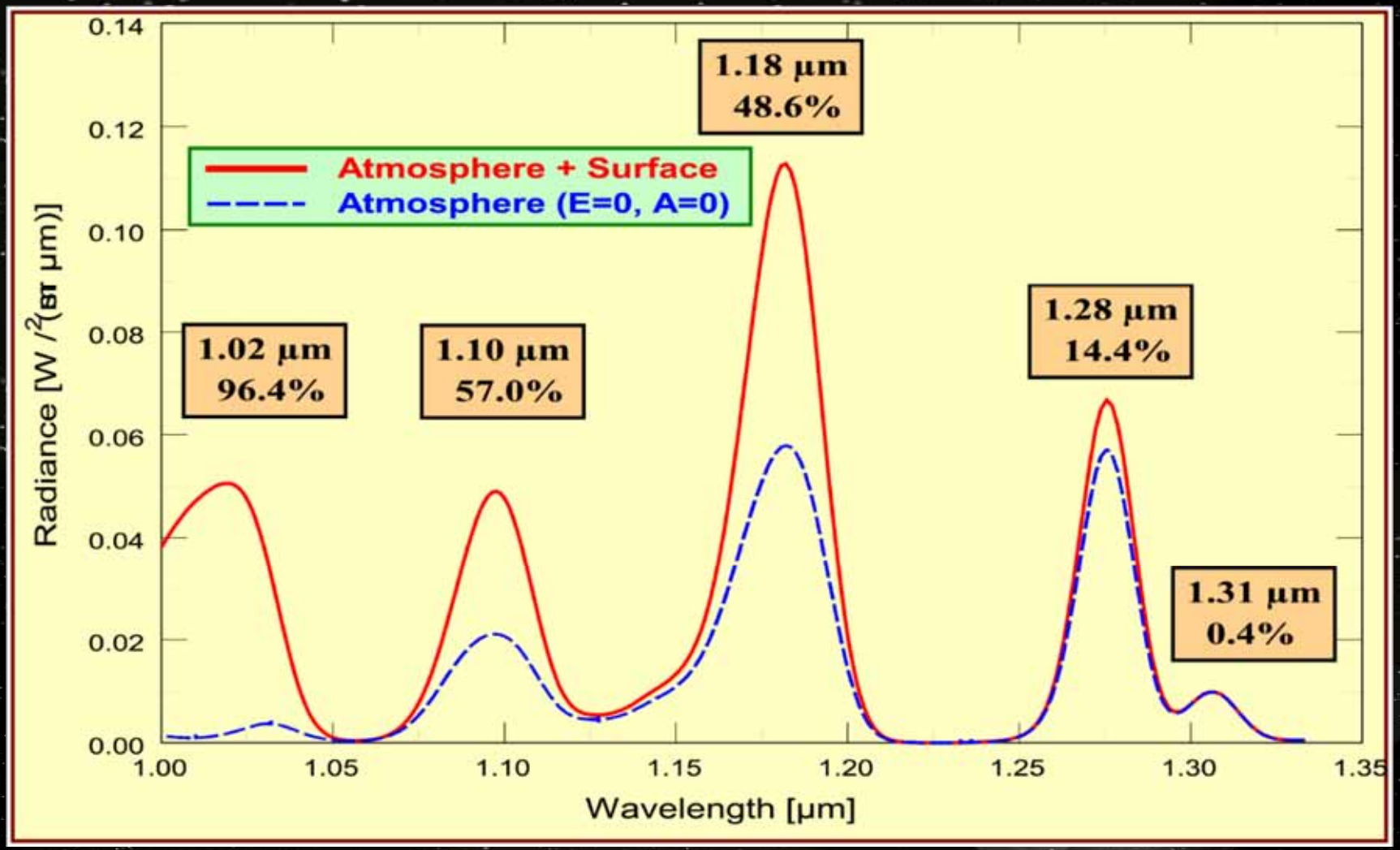
Video: http://www.lightcurvefilms.com/a-breath-of-venus/ **A Breath of Venus, 13:57**

Surface IR mosaic



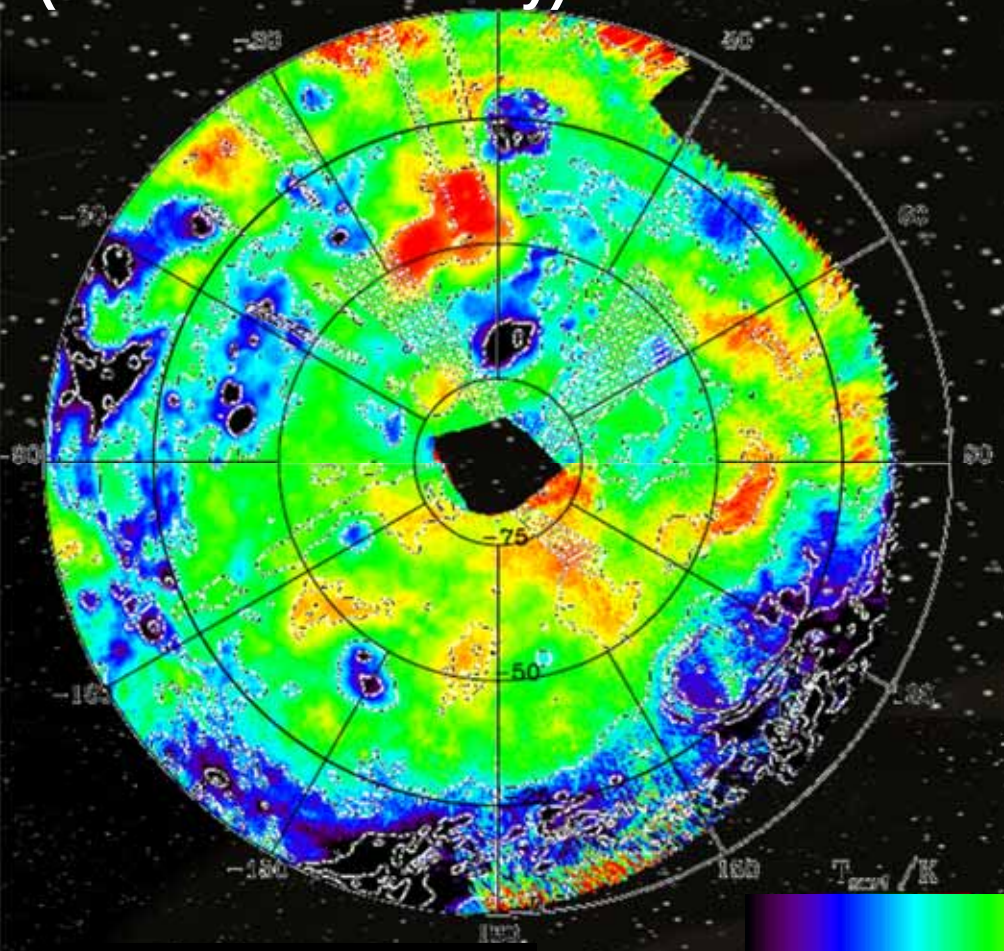
VMC

Surface study in the windows

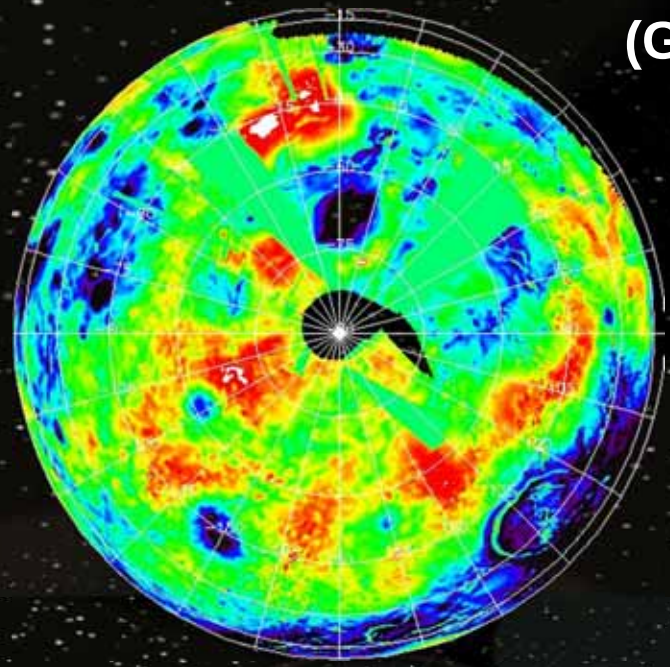


Mapping the surface of Venus
Surface brightness temperature

Thermal map of VIRTIS (constant emissivity)



Syntetic thermal map from MAGELLAN (GTDR)



725 K — 745 K

Müller, et al., JGR 2008

Science AAAS
nature International weekly journal of science
Full text access provided to Osservator

Idunn Mons

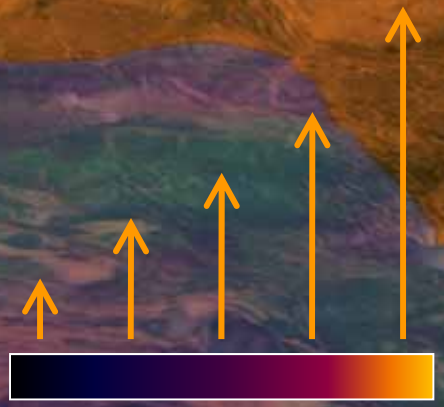
Lat -46 °

Long 214.5 °

Radar image

VIRTIS image

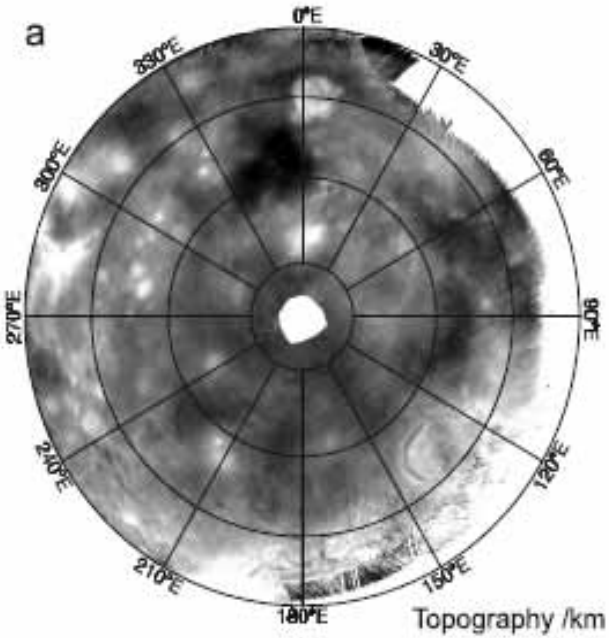
Thermal radiation

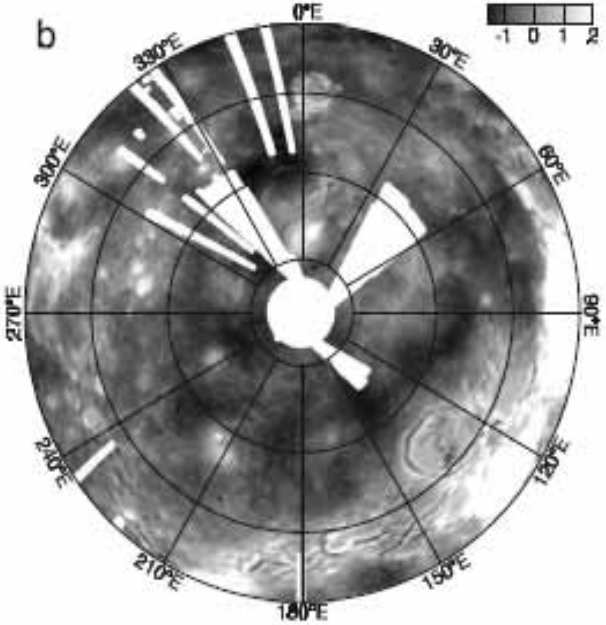


Lava flow more recent than **250ky**, perhaps much younger

"Fresh" lava, darker in IR, higher emissivity

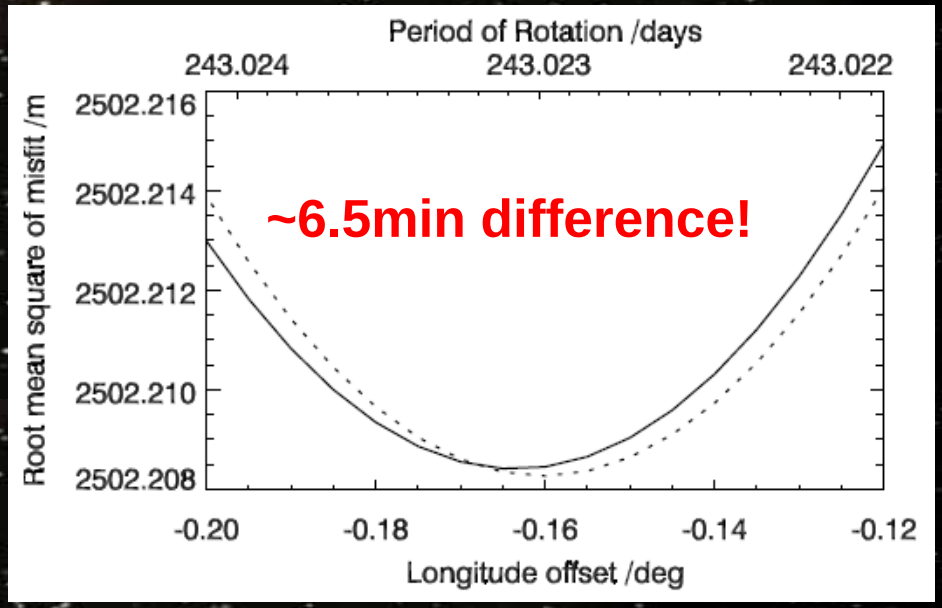
Smrekar et al., Science 2010





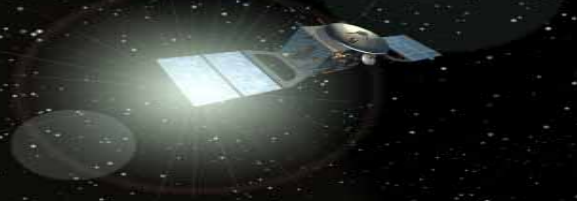
VIRTIS derived altimetry

Magellan altimetry



Comparison VIRTIS-MAGELLAN reveals a deviation in longitude indicating a rotation of the planet not fully described by the body fixed coordinate system

Revised period of rotation of Venus of **243.023 ± *0.001 days*** is significantly different from the value of **243.0185 ± *0.0001*** recommended by IAU



Mueller et al.

esa space science

European Space Agency

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Could Venus be shifting gear?

17-Apr-2012
VOI highlights and press conference

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A bad day on Venus gets even worse

Agence France-Presse

7:43 am | Thursday, March 1st, 2012

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February 2012

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Animation of Venus

10 February 2012
ESA's Venus Express spacecraft has discovered that our cloud-covered neighbour spins a little slower than previously measured. Peering through the dense atmosphere in the infrared, the orbiter found surface features were not quite where they should be.

Using the VIRTIS instrument at infrared wavelengths to penetrate the thick cloud cover, scientists studied surface features and discovered that some were displaced by up to 20 km from where they should be given the accepted rotation rate as measured by NASA's Magellan orbiter in the early 1990s.

These detailed measurements from orbit are helping scientists determine whether Venus has a solid or liquid core, which will help our understanding of the planet's creation and how it evolved.

- Postcards from Venus

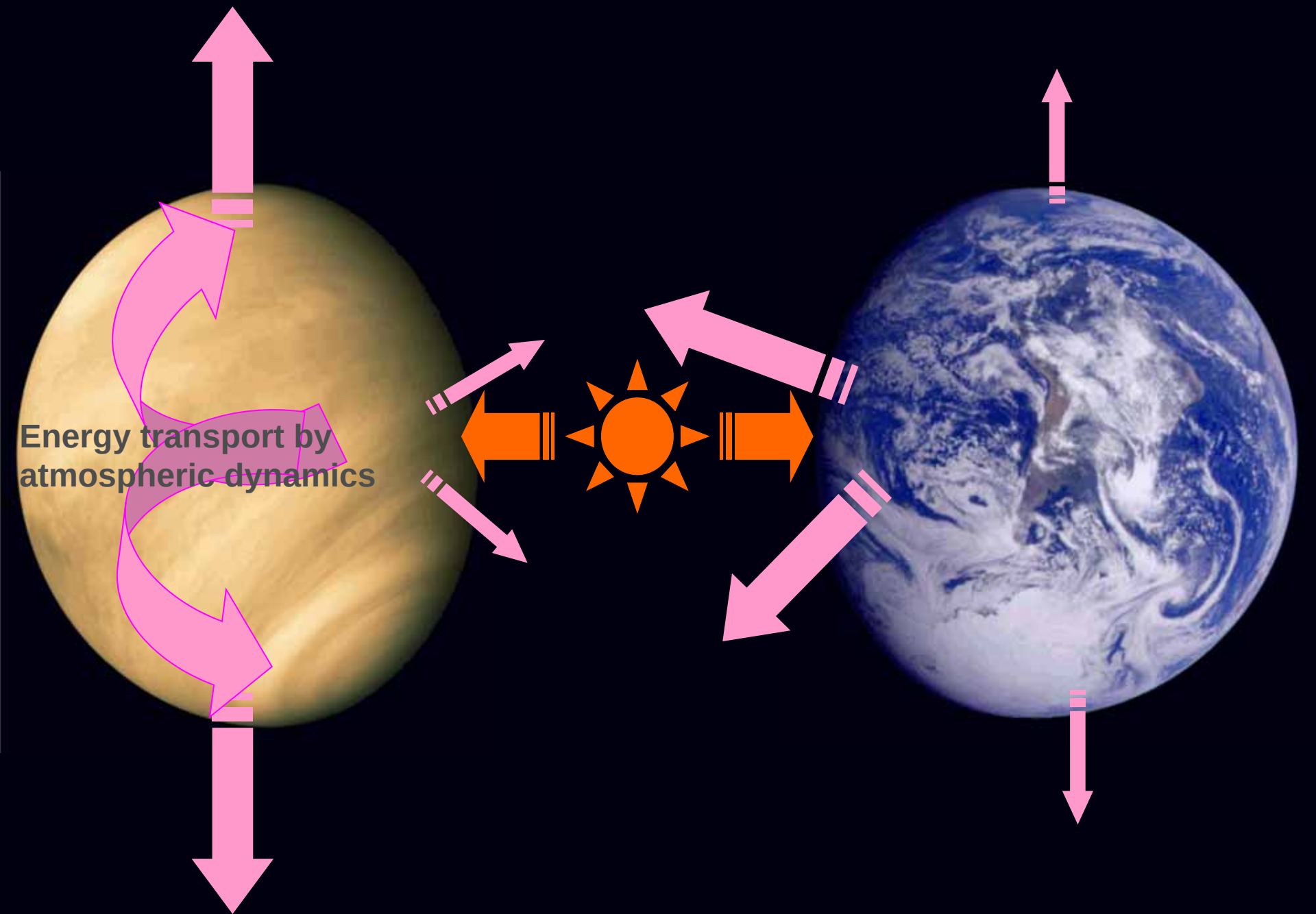
For the media
- Media Press Kit
- Venus Express brochure (pdf)

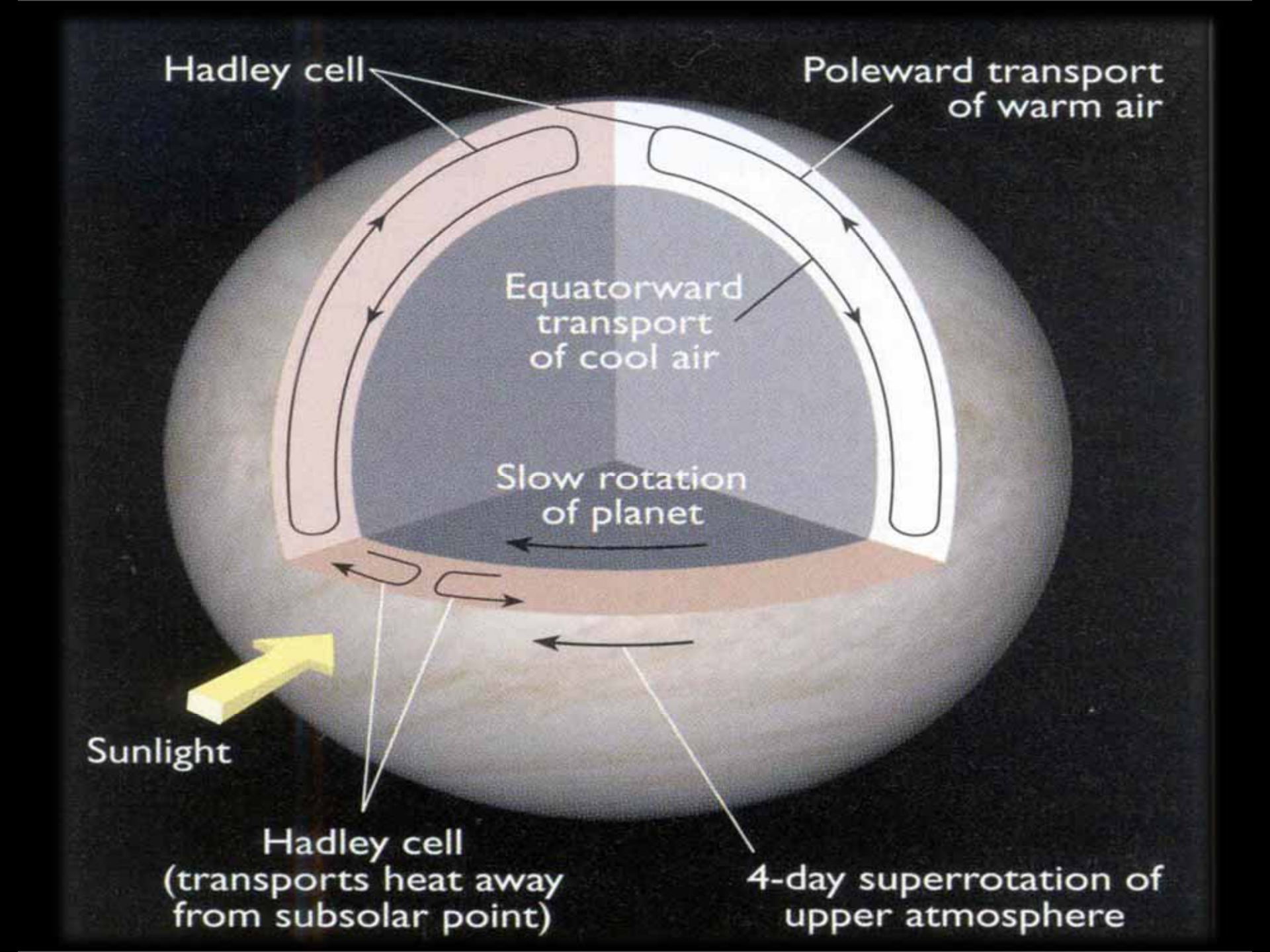
In depth
- Venus Express in-depth

Related links
- Submitting your pictures of Venus is now easier
- Venus Express operations
- Starsem - the Soyuz

Atmospheric Clouds morphology & dynamics

Radiation gets trapped forcing global circulation on Venus

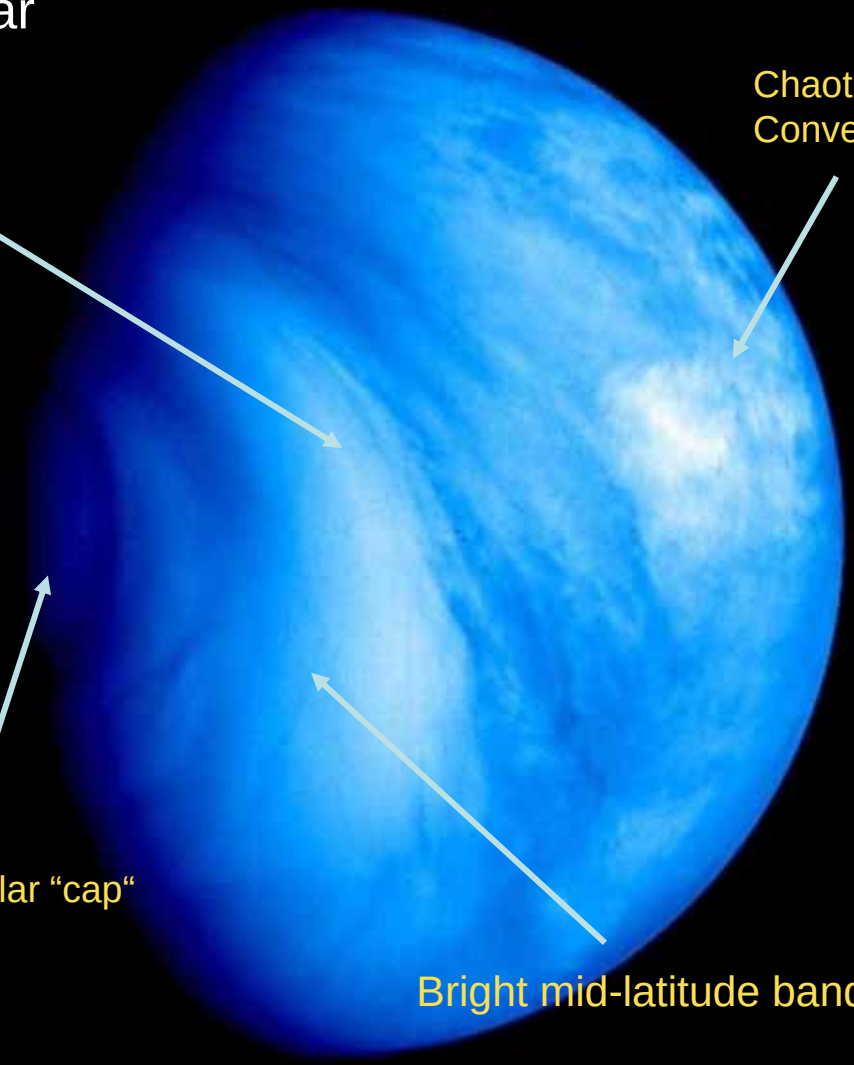



Hadley cell
Poleward transport of warm air
Equatorward transport of cool air
Slow rotation of planet
Sunlight
Hadley cell (transports heat away from subsolar point)
4-day superrotation of upper atmosphere

Main dynamic regimes:

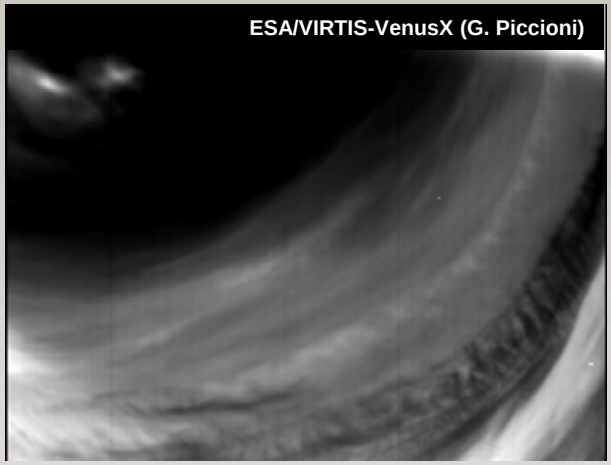
- Equator → chaotic
- Mid latitudes → laminar
- Polar → spiraling

General large scale features seen in UV



ESA/VMC (W. J. Markiewicz)

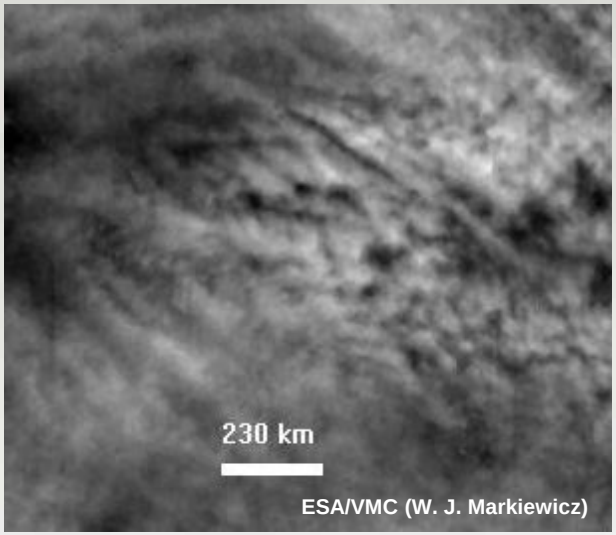
Waves and convection on a very dynamic planet

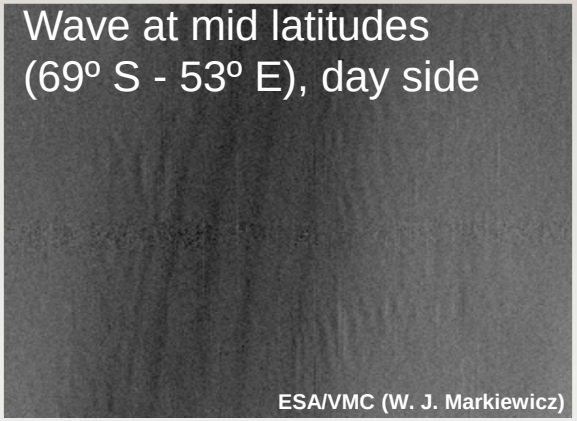


Gravity waves were discovered in the deep atmosphere at 55º S, 50 km altitude, in the night side

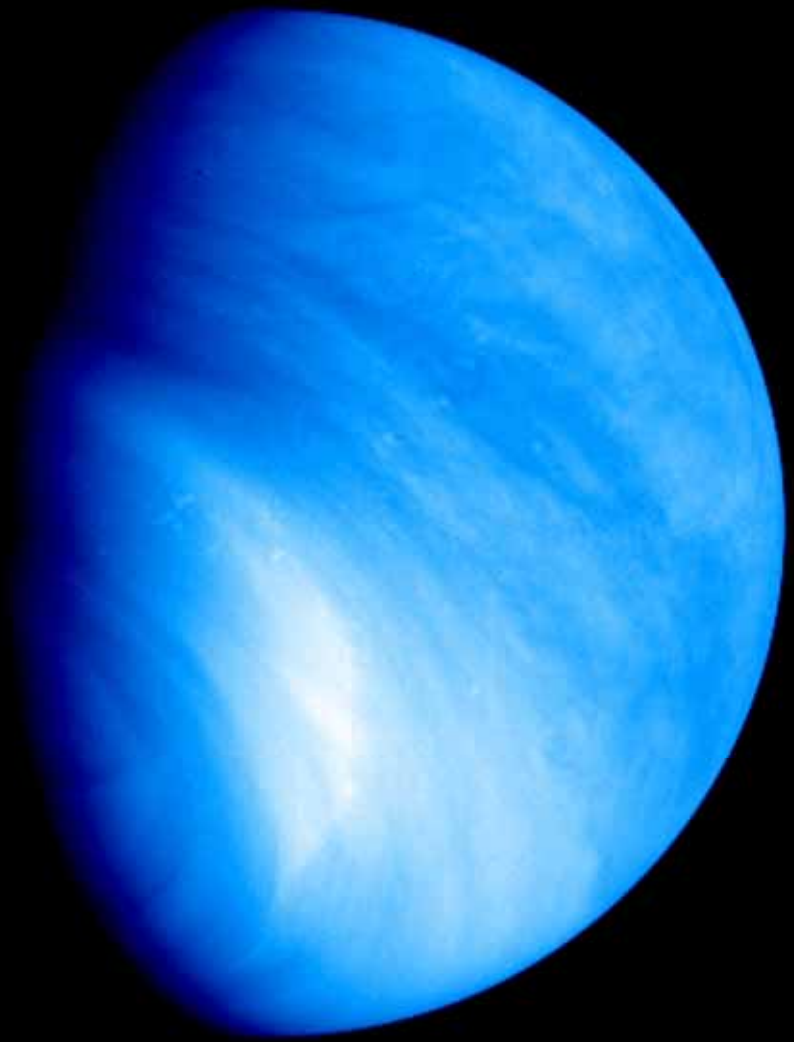
Convection cells at local midday were found to be **10 times** smaller than thought previously

→ These phenomena contribute to the global dynamics and energy re-distribution





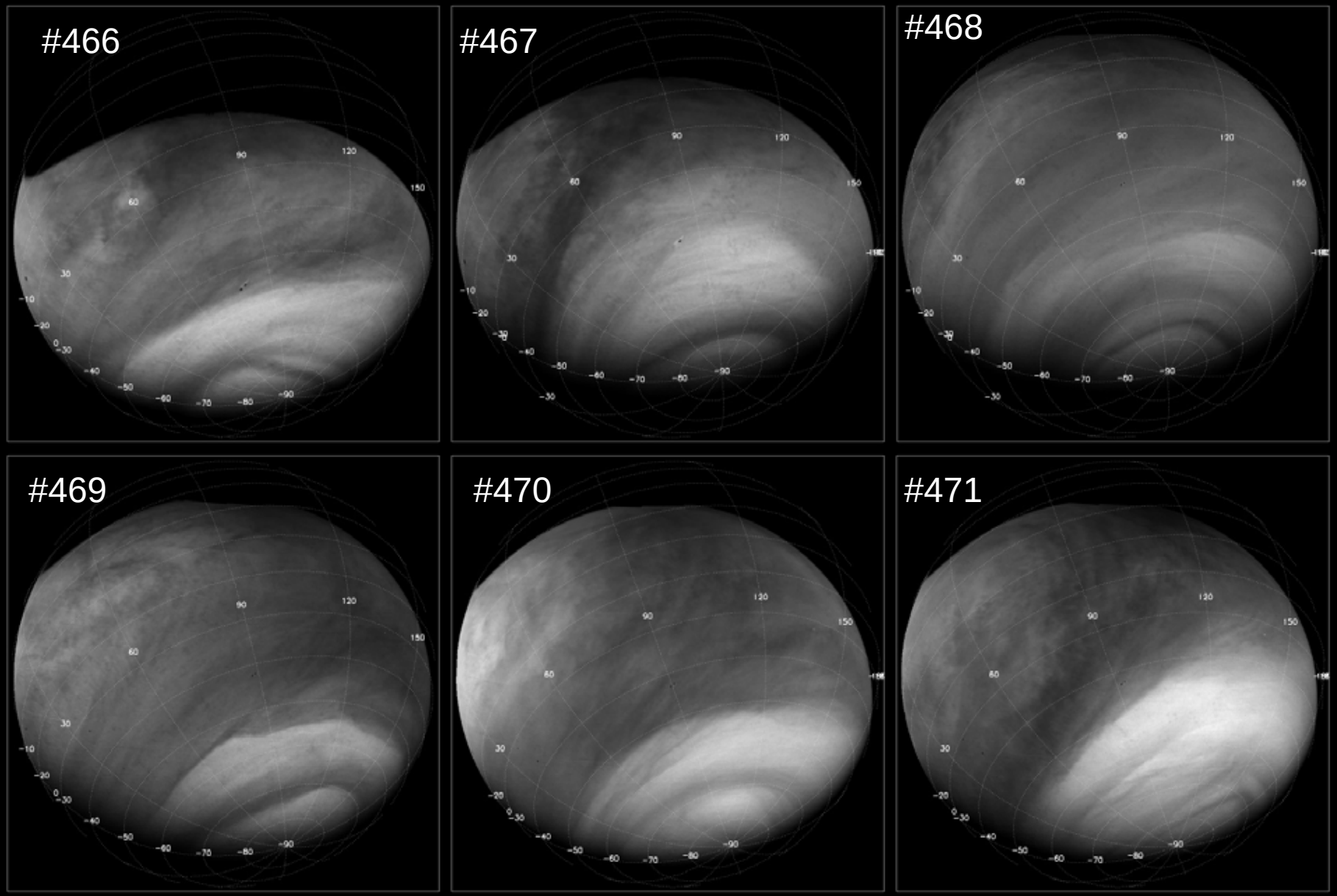
and we can study the dynamics …



ESA/VMC (W. J. Markiewicz)

Real time ~8 hours

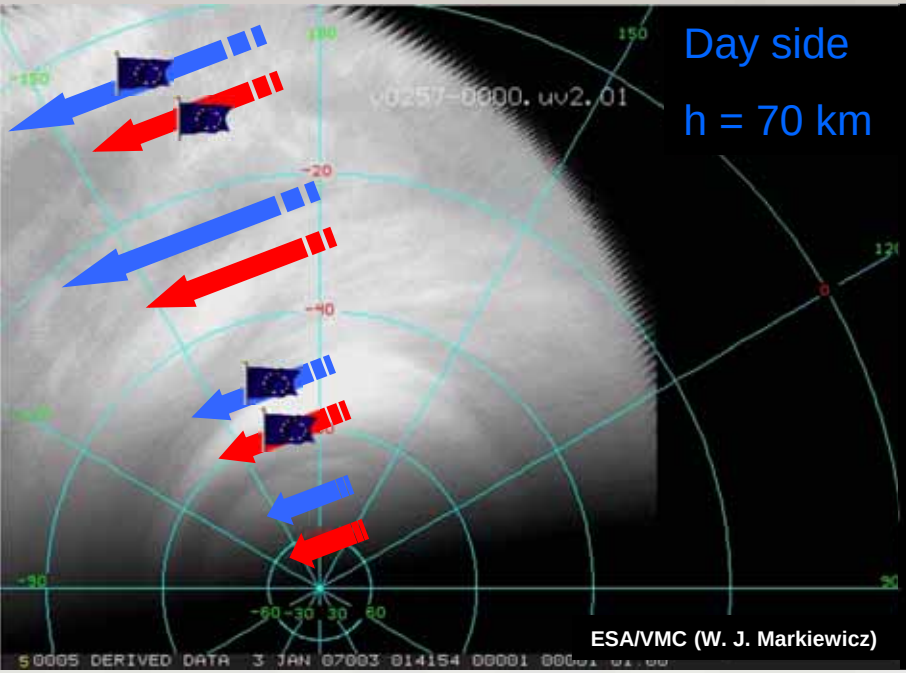
Great variability of Venus clouds

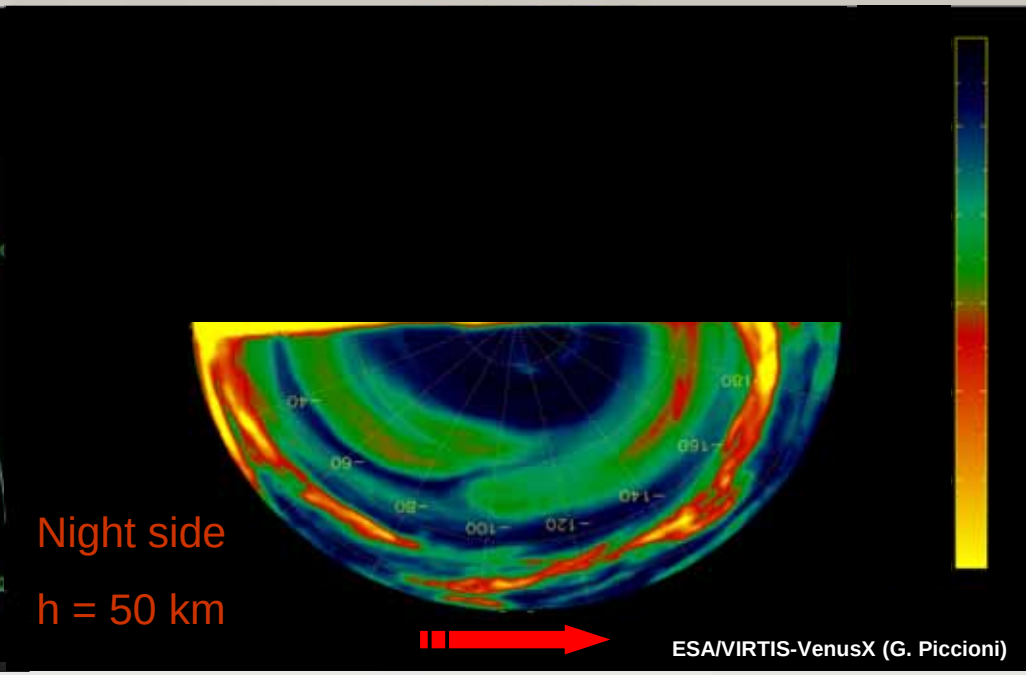


ESA/VMC (W. J. Markiewicz)

Clouds as probe for the wind speed

The atmosphere is up to **60 times** faster than the solid body rotation
Wind speeds can be as strong as 400 km/h)
how is this amazing powerful dynamics sustained?

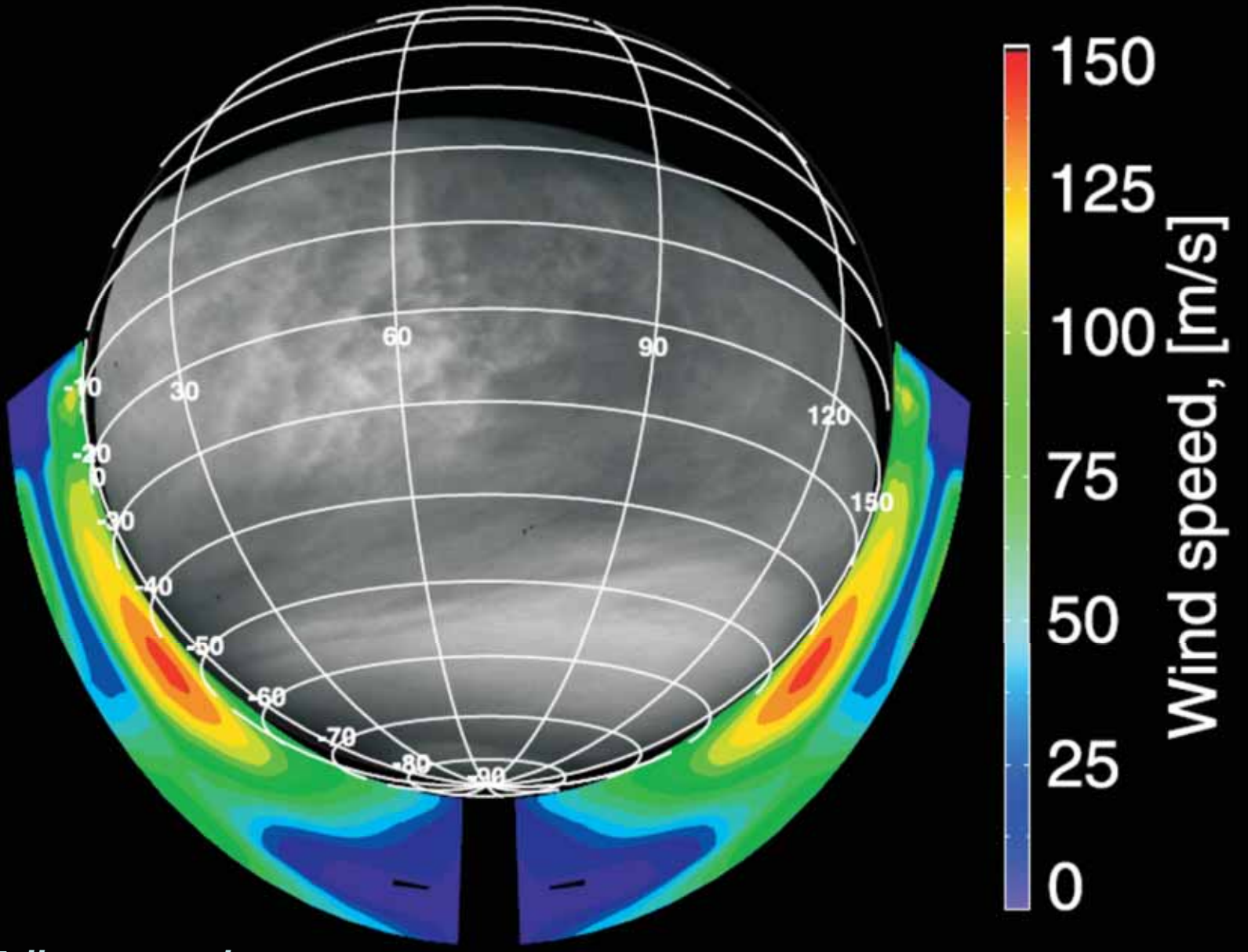




Examples of wind measurements in the equatorial region:

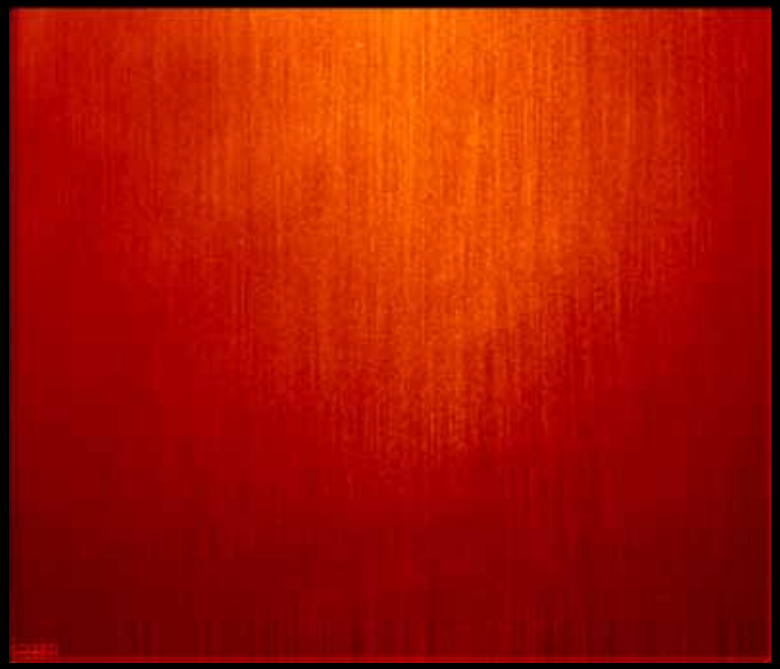
- about 400 km/h at 70 km altitude
- about 200 km/h at 50 km altitude

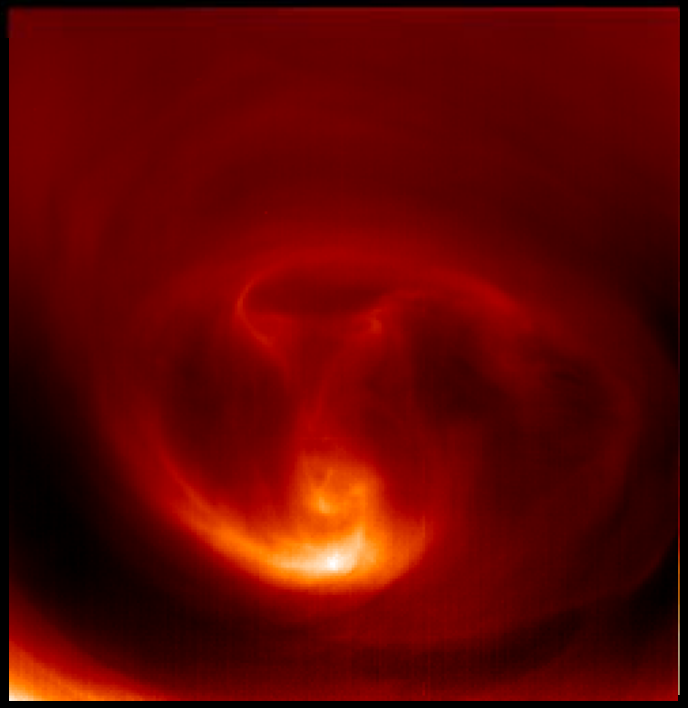
Cyclostrophic wind in the mesosphere

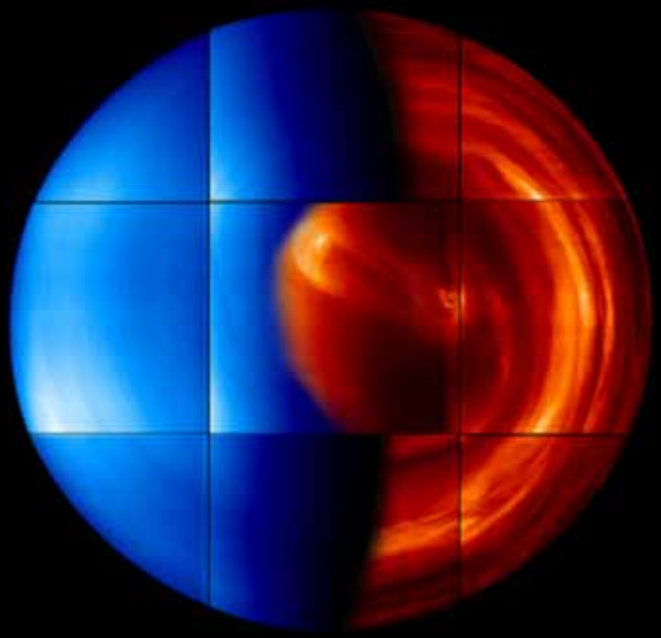


Piccialli, Tellmann et al

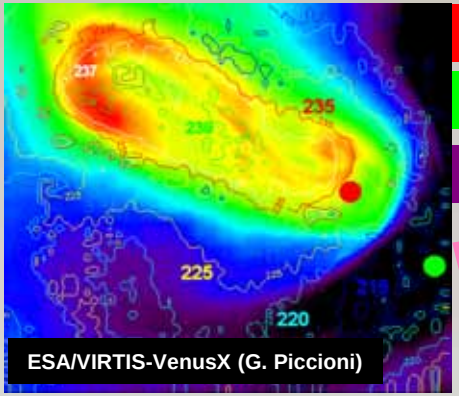
Venus Polar Vortex







Polar vortex in 3D and its temperature

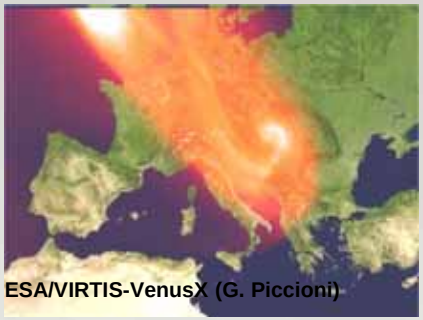


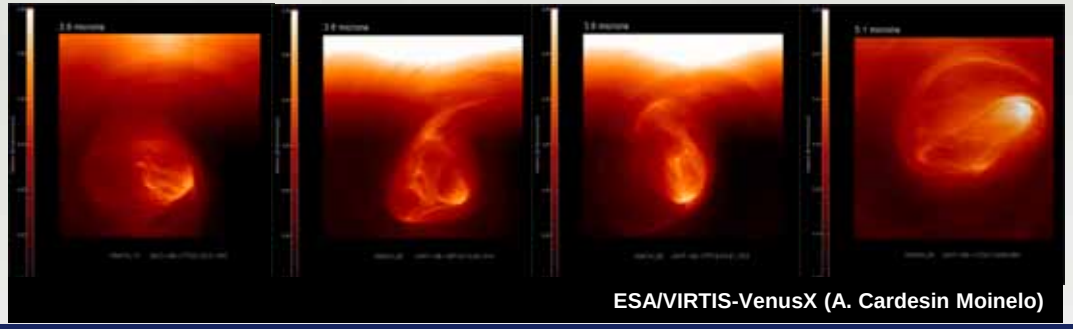
T = -30°C

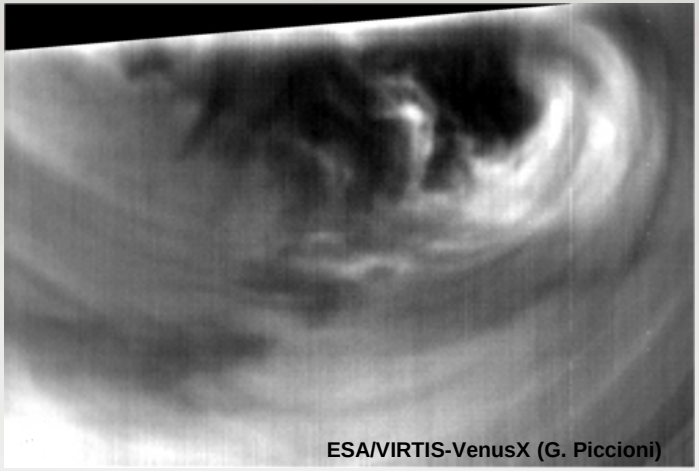
T = -45°C

T = -60°C

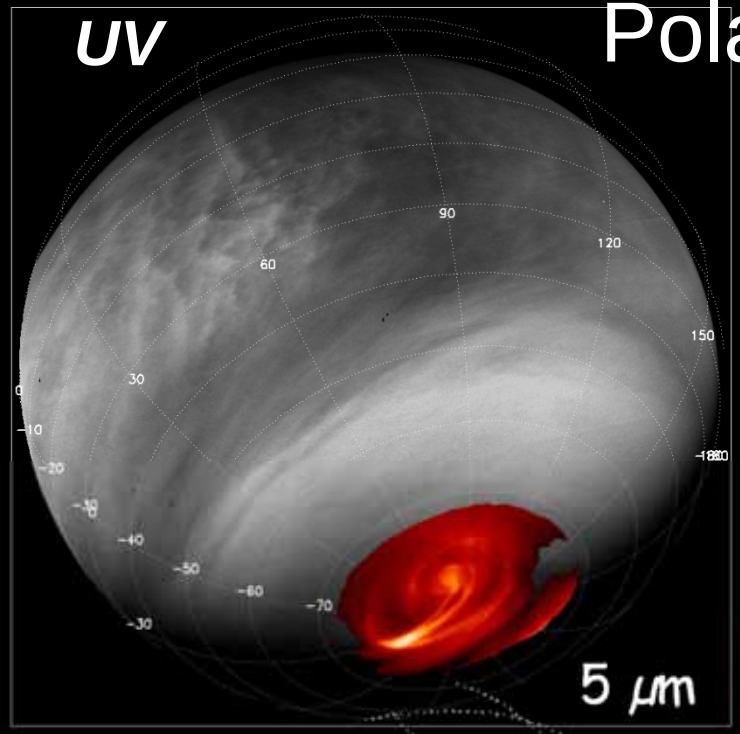
- The vortex sometimes displays an inverse S-shape, and it extends 2700 x 890 km
- The vortex shape varies with time
- The clouds temperature within the vortex is the highest found on the planet, in contrast with the much colder air-collar around it
- The cloud tops are much lower (45-50 km)

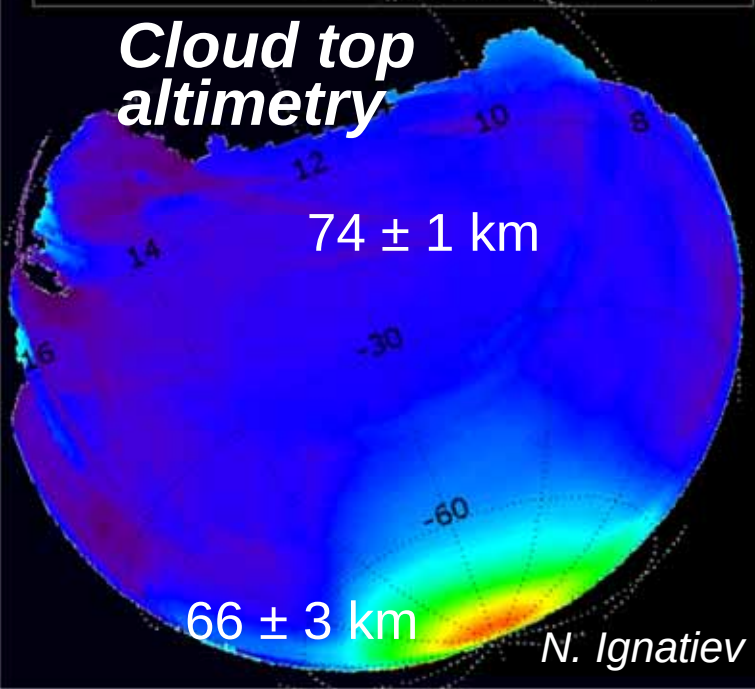




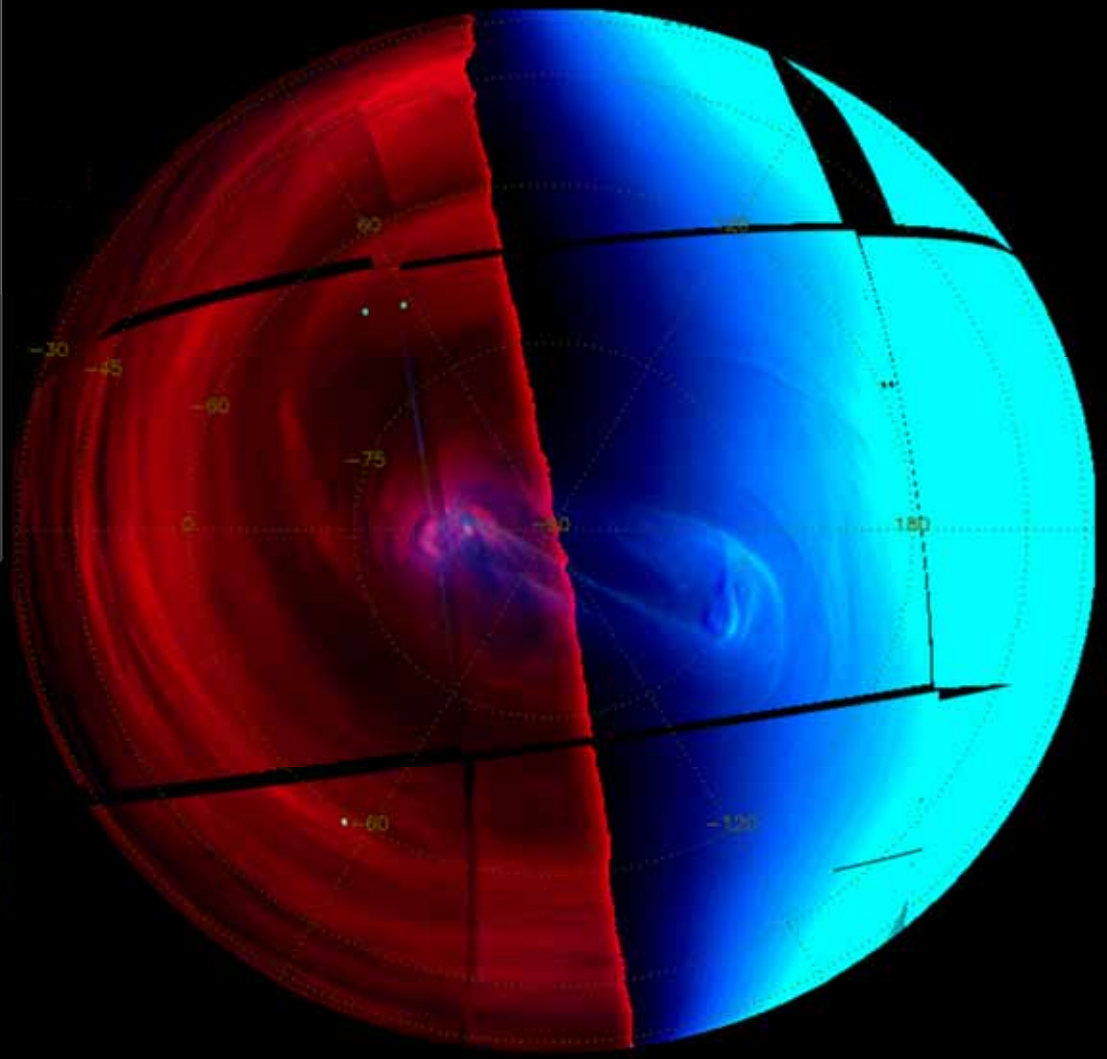


Polar depression and vortex “eye”

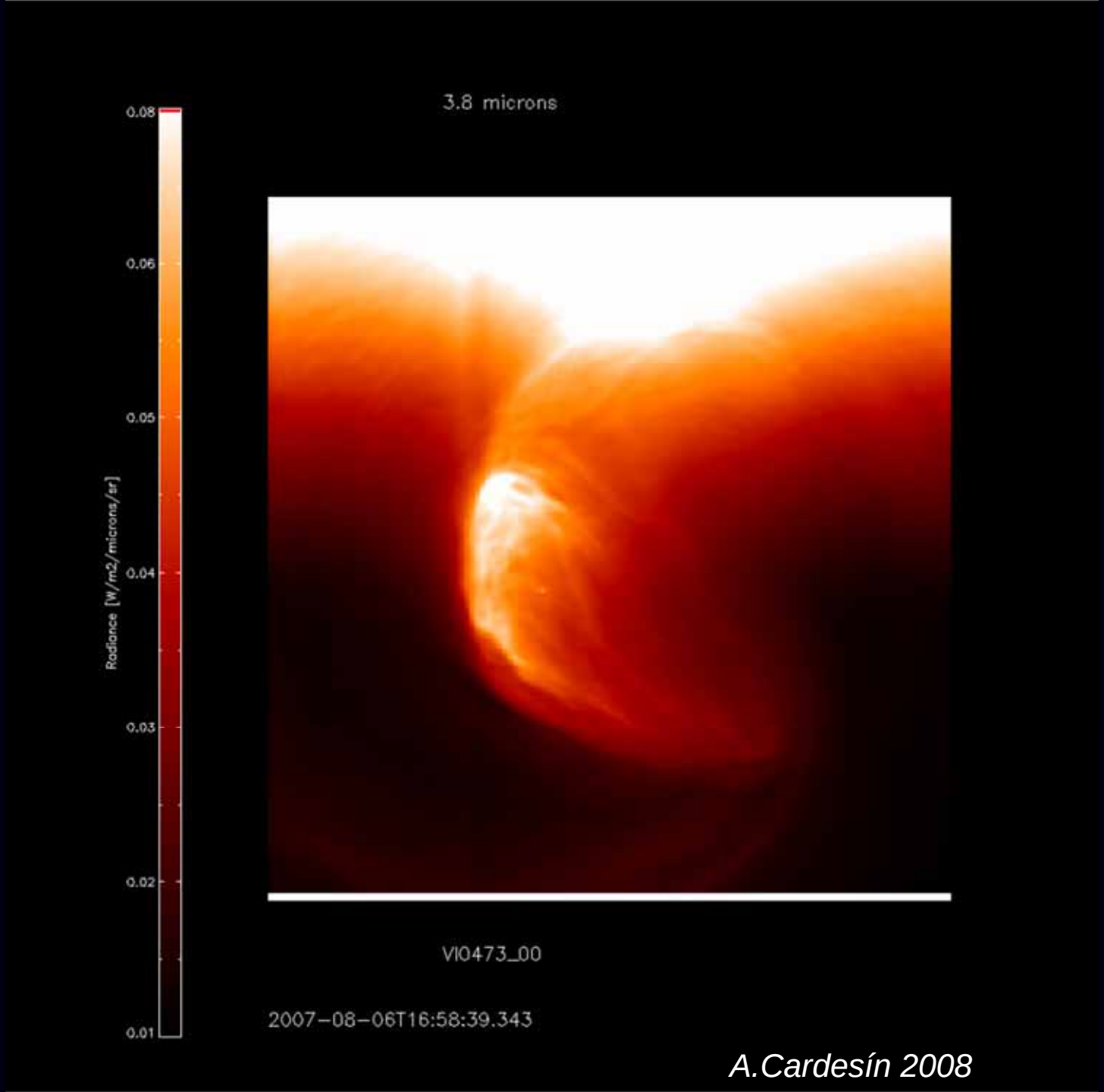




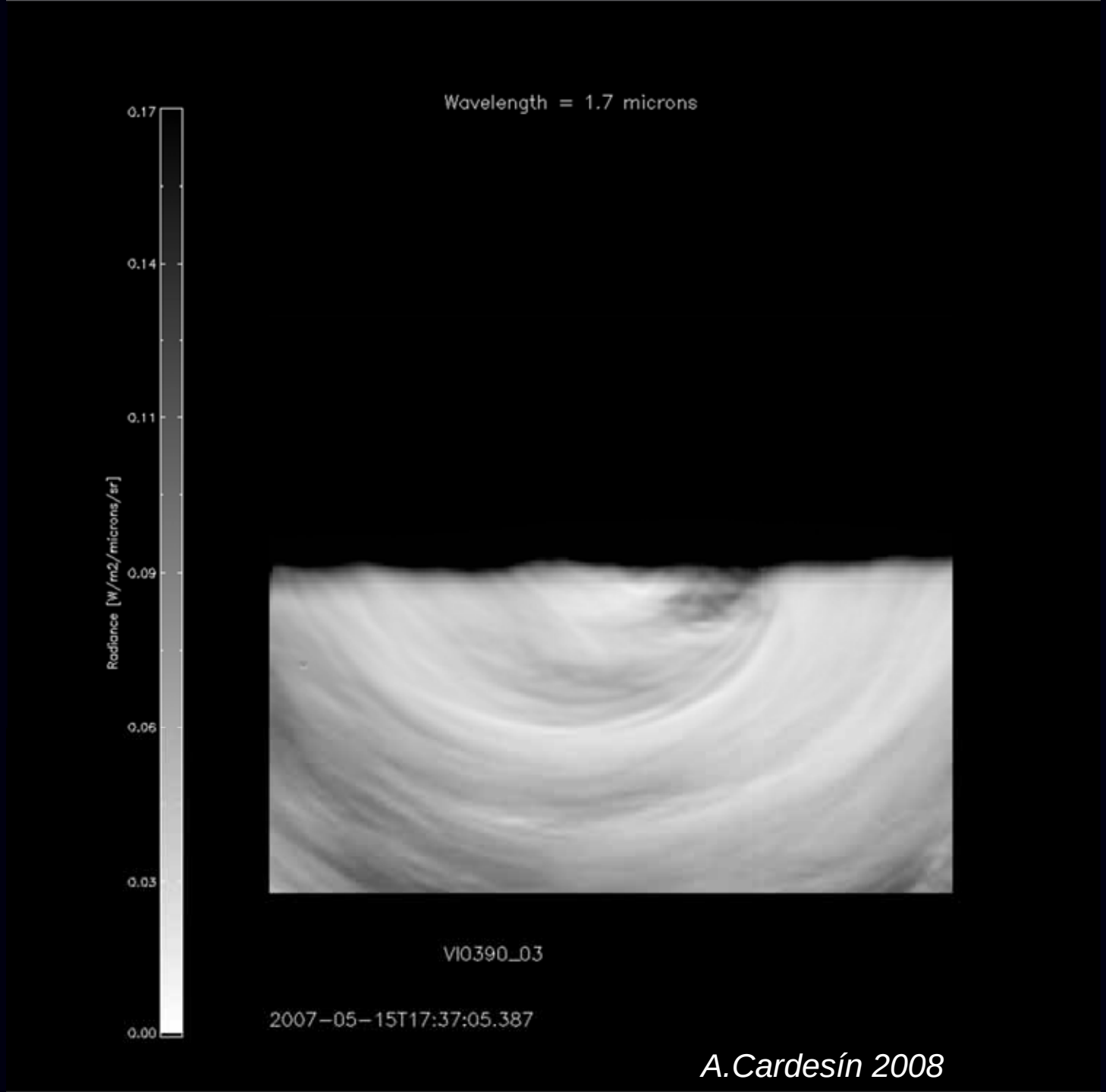
N. Ignatiev 2009



A.Cardesín 2007

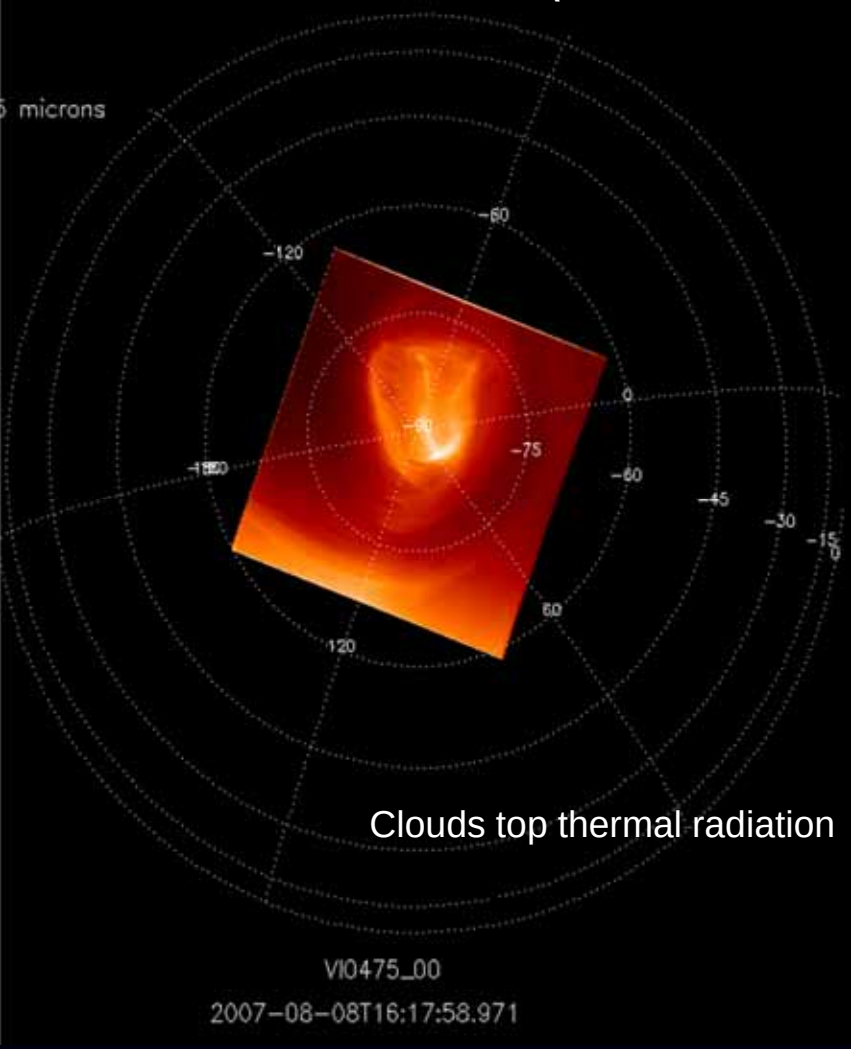


A.Cardesín 2008



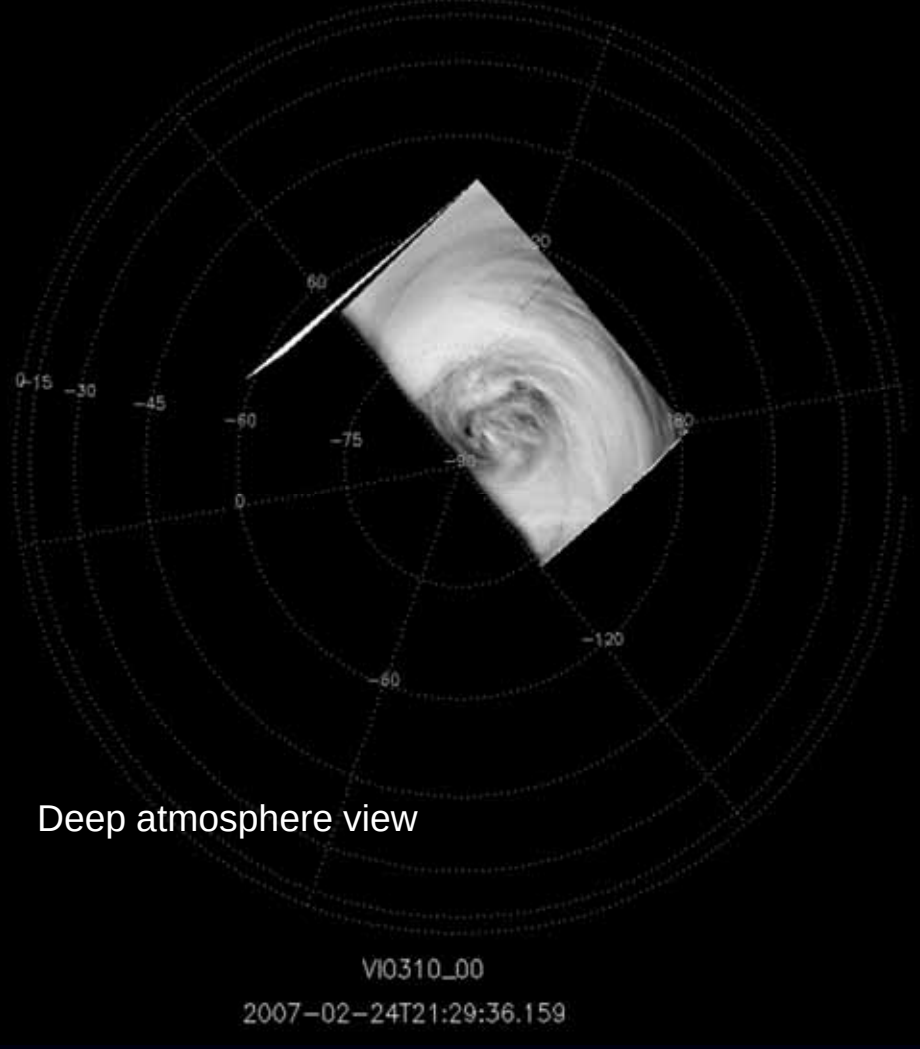
A.Cardesín 2008

ESA/VIRTIS-VenusX (A. Cardesin Moinelo)



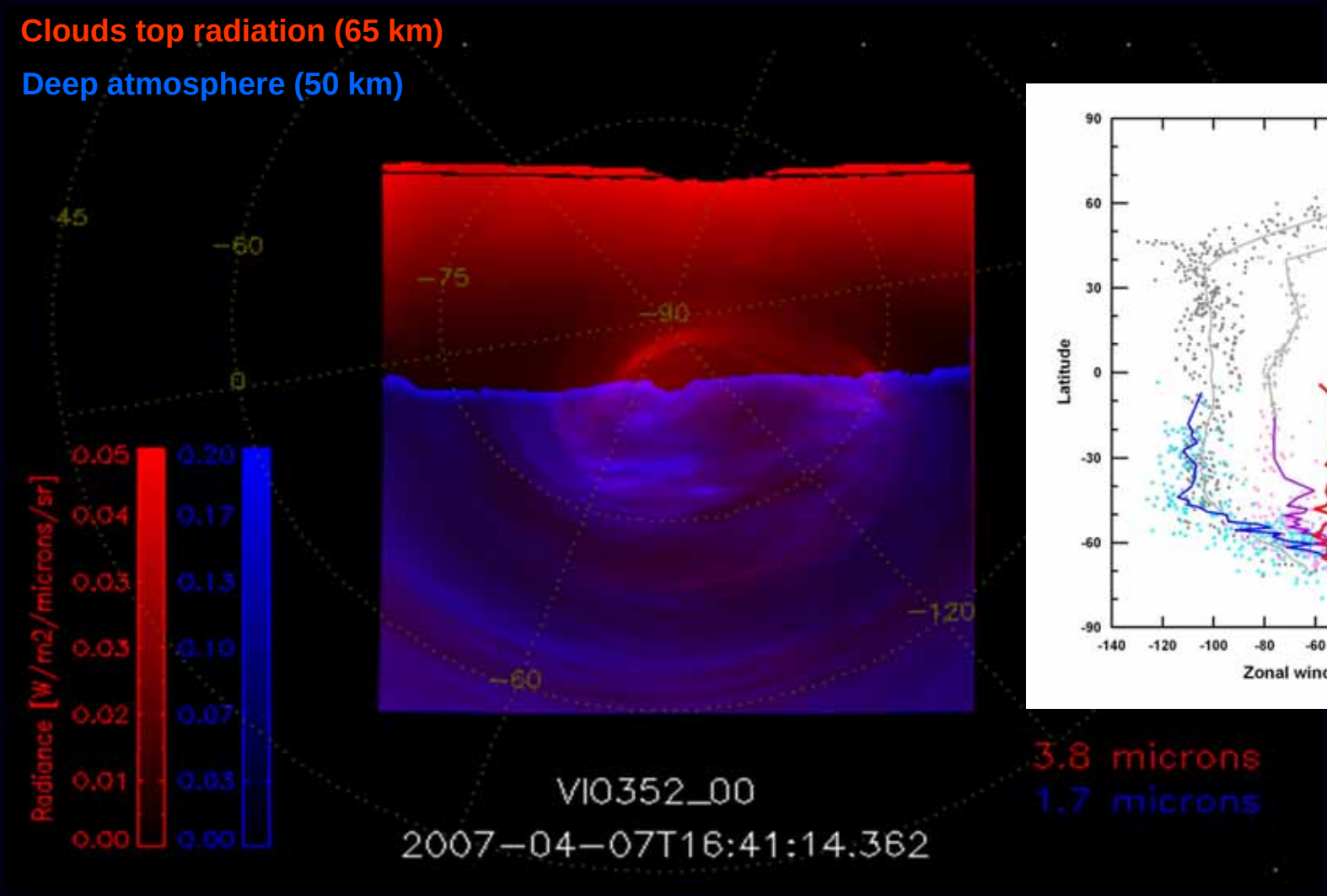
Clouds top thermal radiation

ESA/VIRTIS-VenusX (A. Cardesin Moinelo)

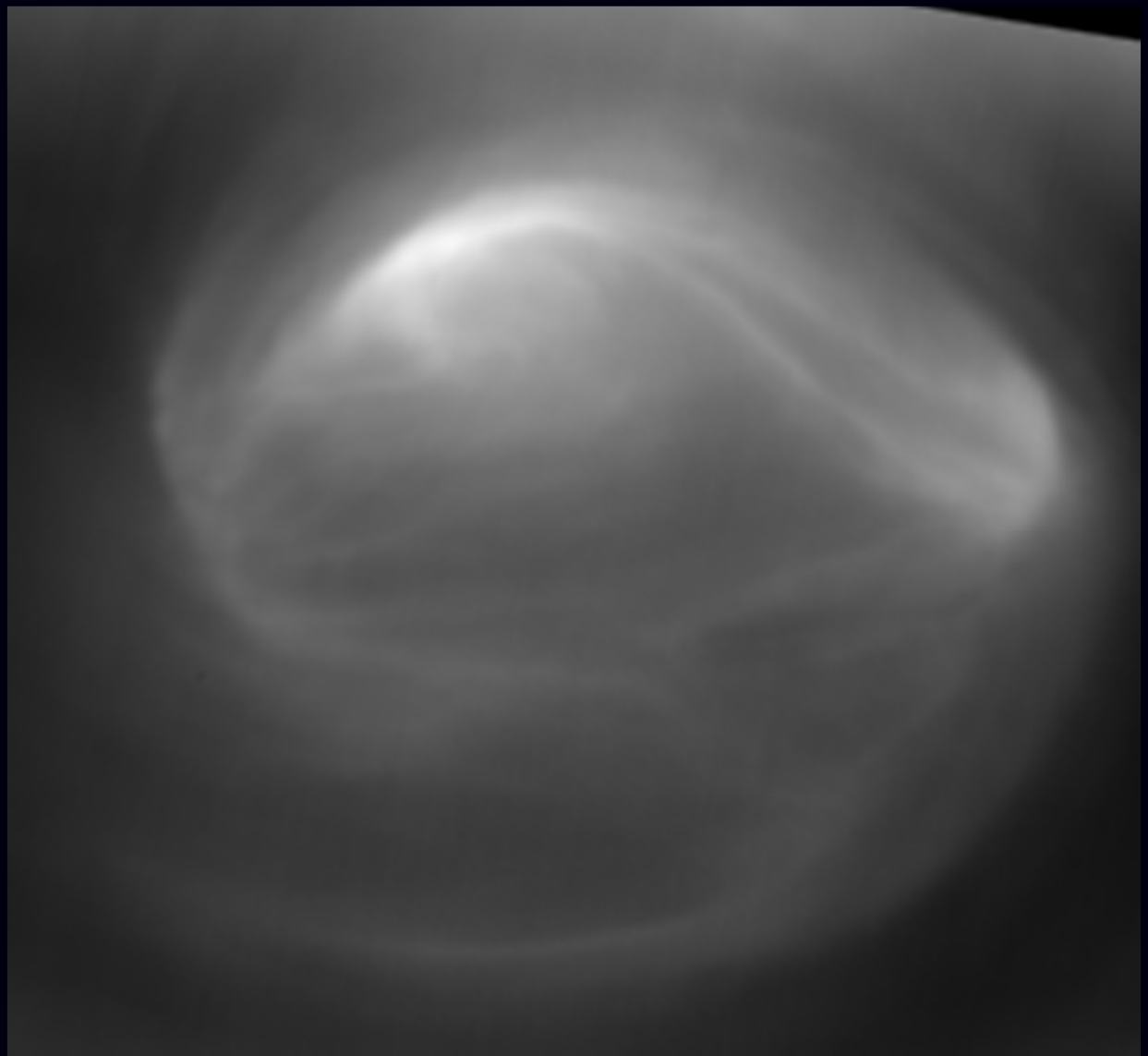


Deep atmosphere view

Polar vortex 3D solid body rotation



Detailed unexpected complexity of the dynamics in the polar vortex



C.Wilson 2008

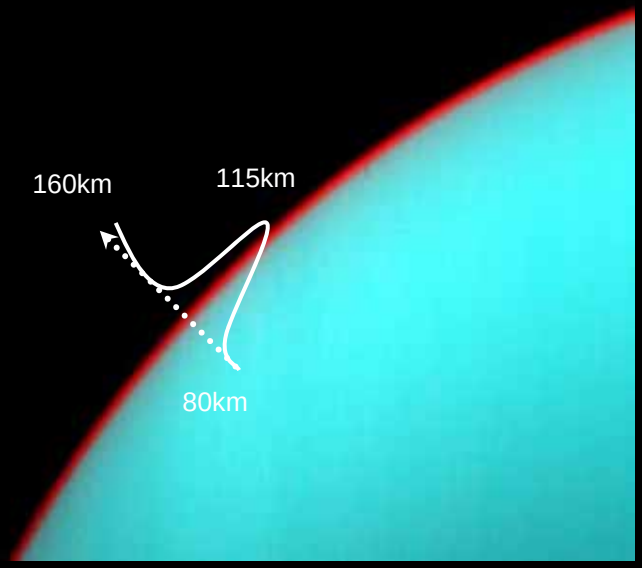
Upper atmosphere

ESA/VIRTIS-VenusX (A. Cardesin Moinelo)

First direct measurements of CO_2 fluorescence (day) and O_2 nightglow (night)

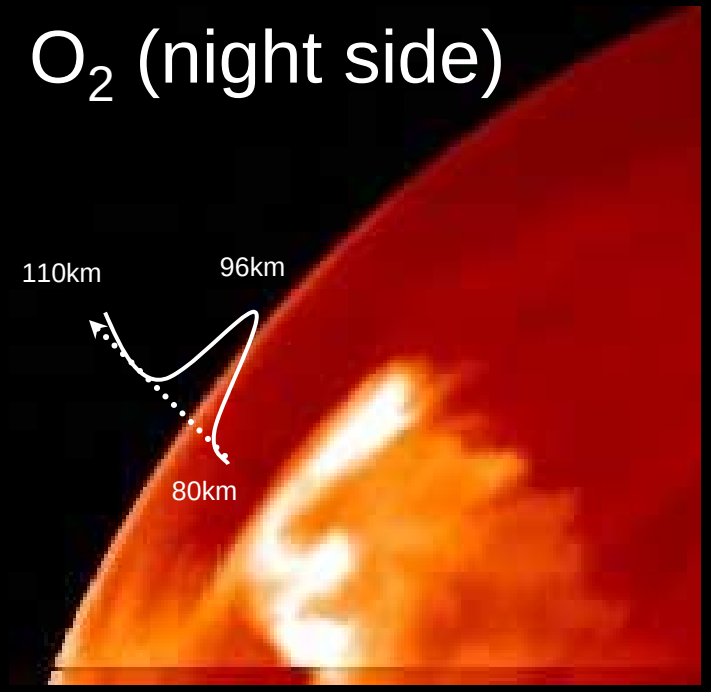
Side looking (limb) to explore the skin of a planet!

CO_2 (day side)



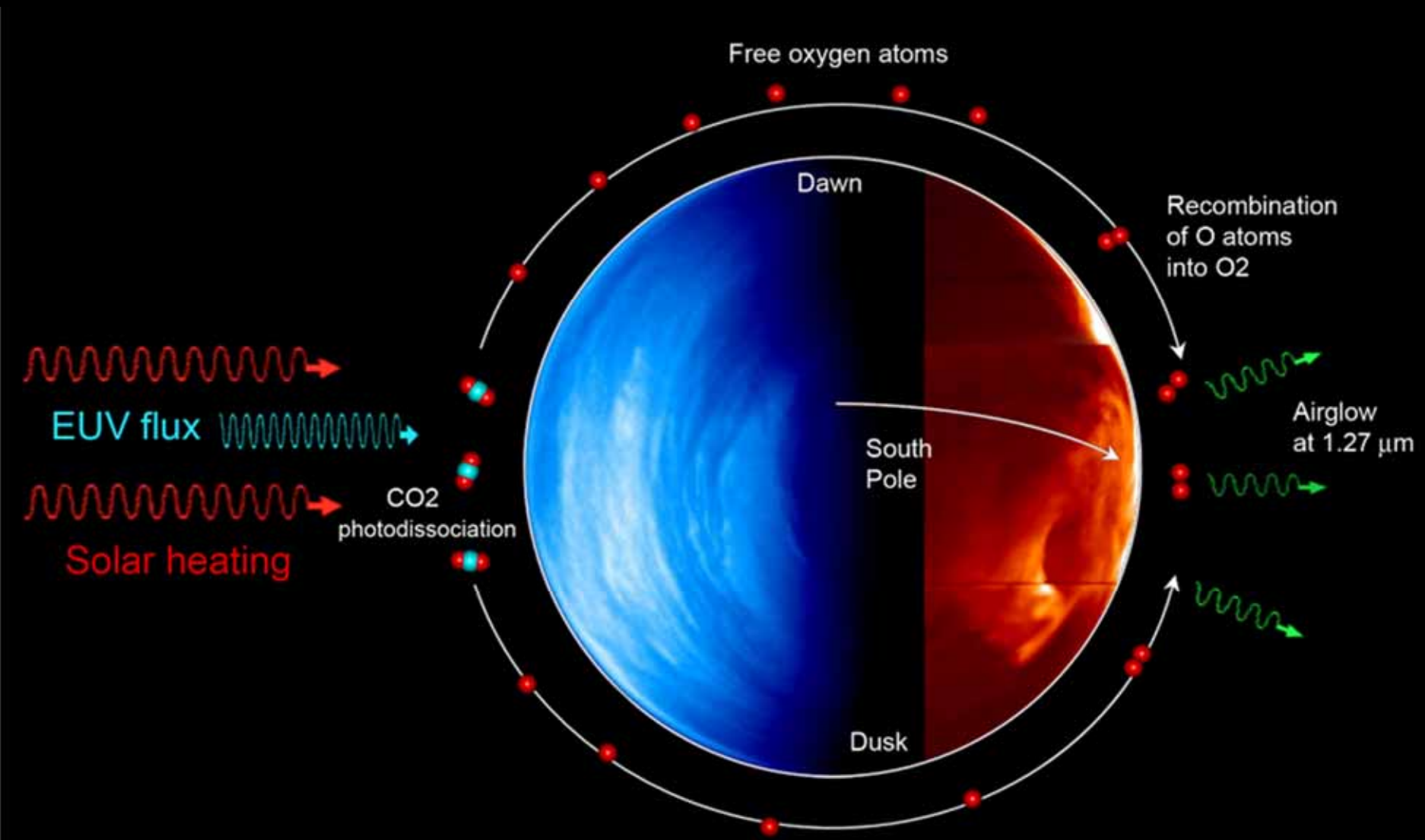
- CO_2 emission at limb (4.3 μm) peaks at 115 km

O_2 (night side)

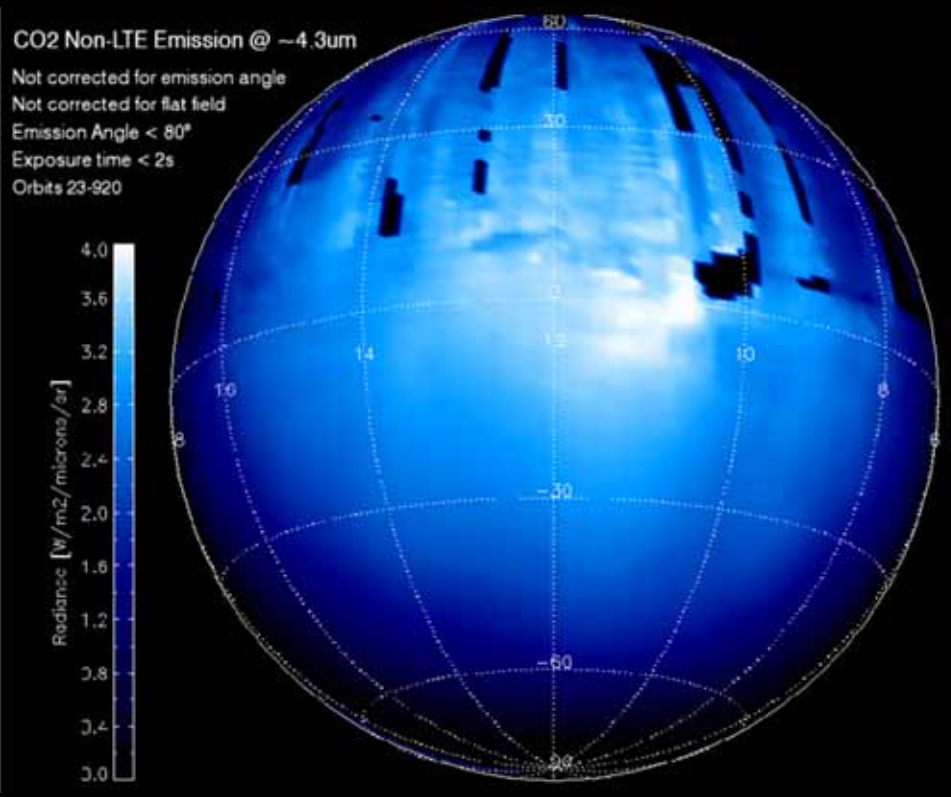


O_2 emission at limb (1.27 μm) peaks at 96 km

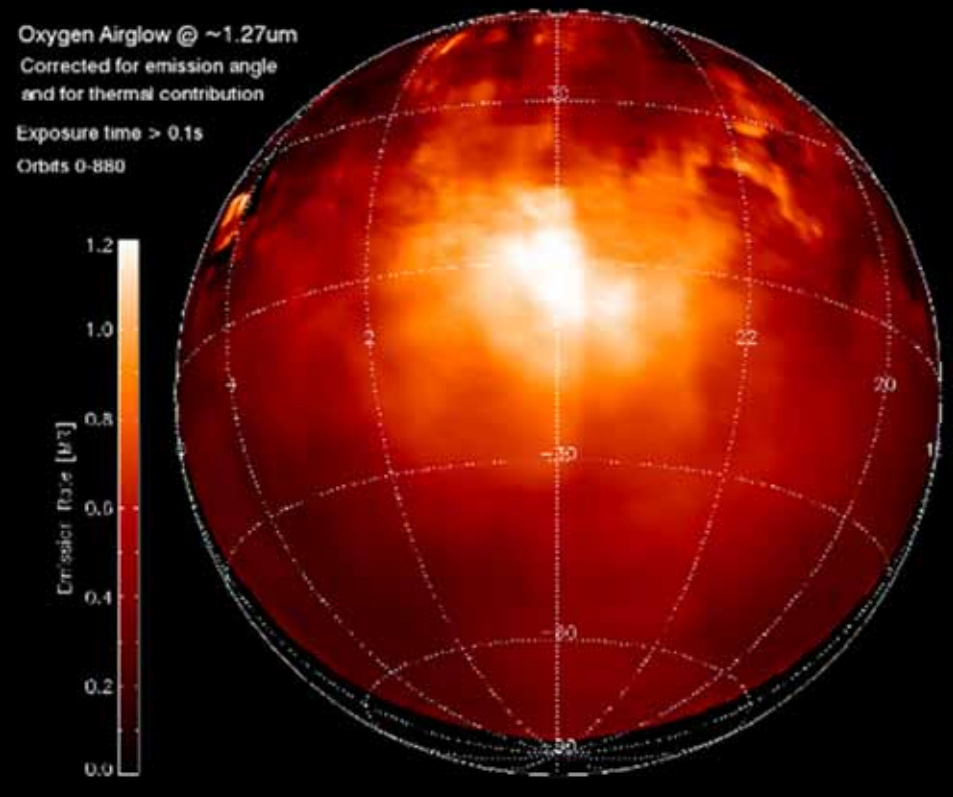
Oxygen Circulation on Venus



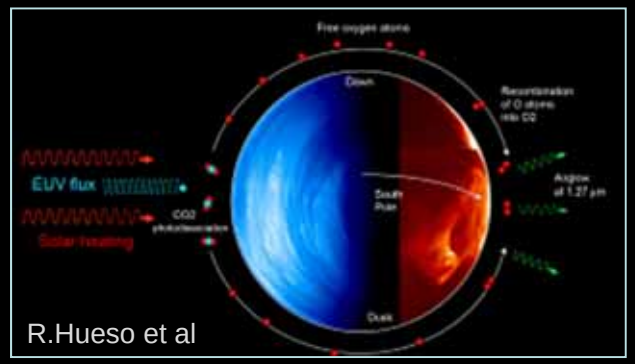
R.Hueso et al



A. Cardesin et al

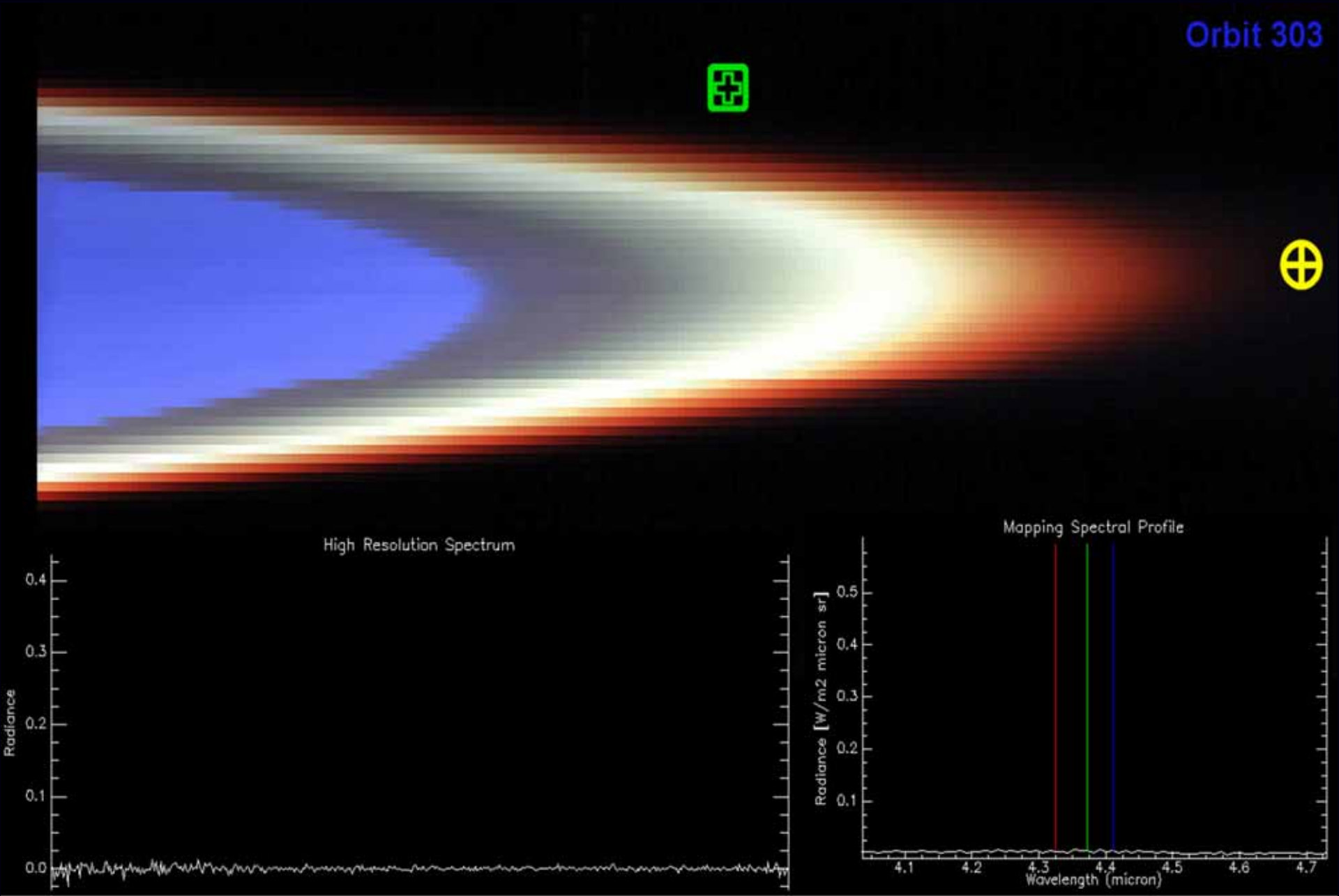


A. Cardesin et al

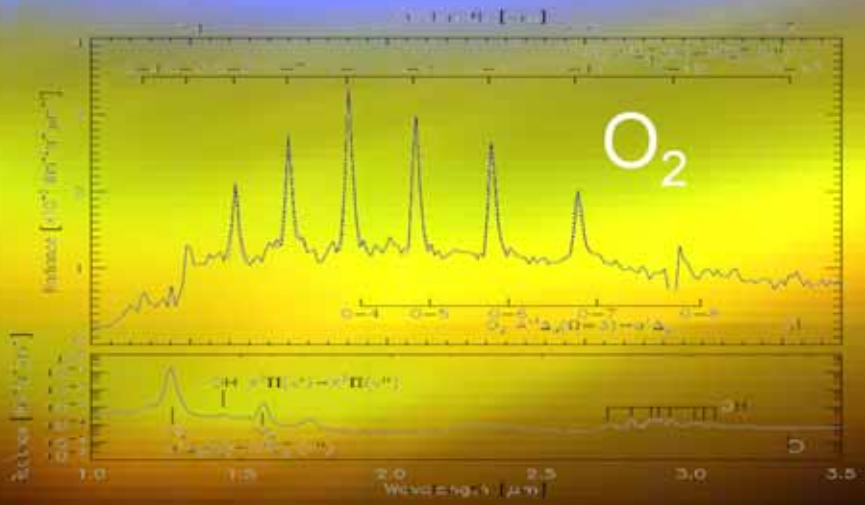


R.Hueso et al

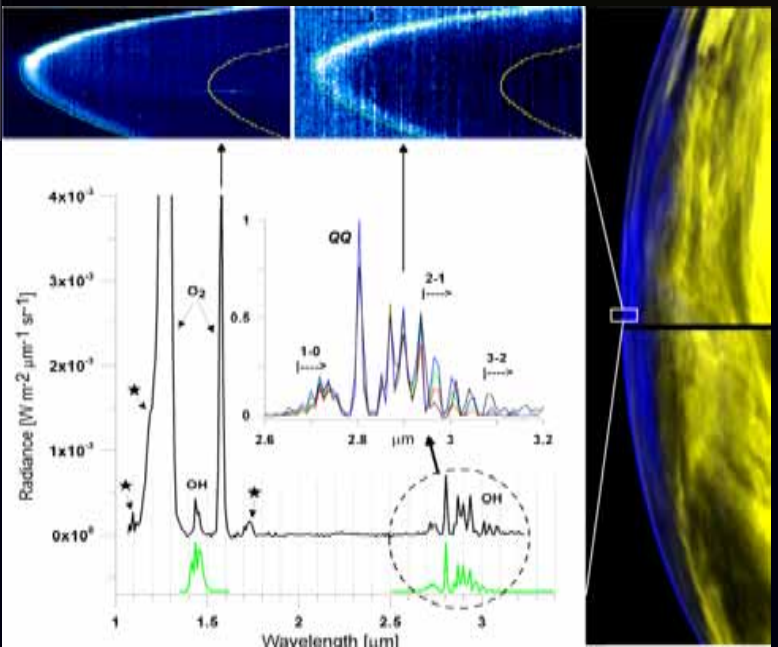
Dayside CO_2 non-LTE emission



Nightglow emissions at different altitudes



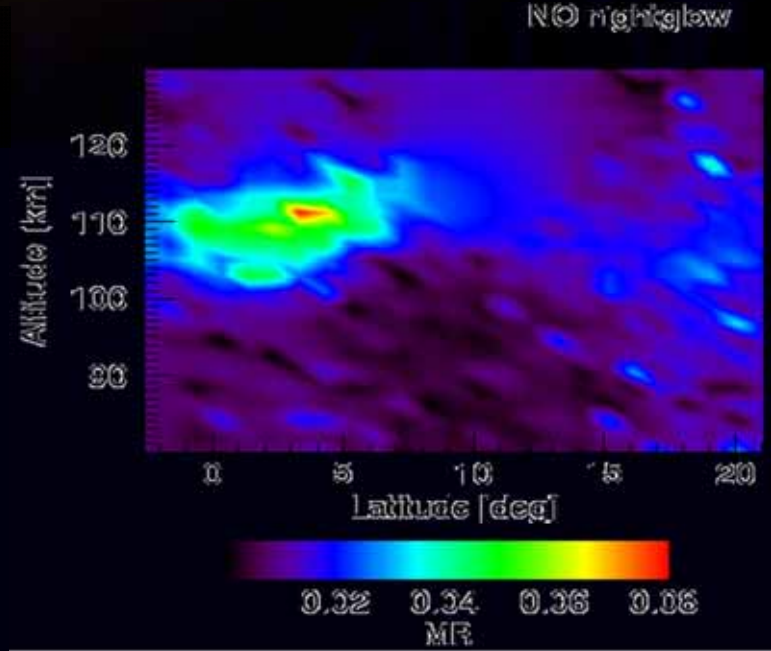
García Muñoz et al.



OH

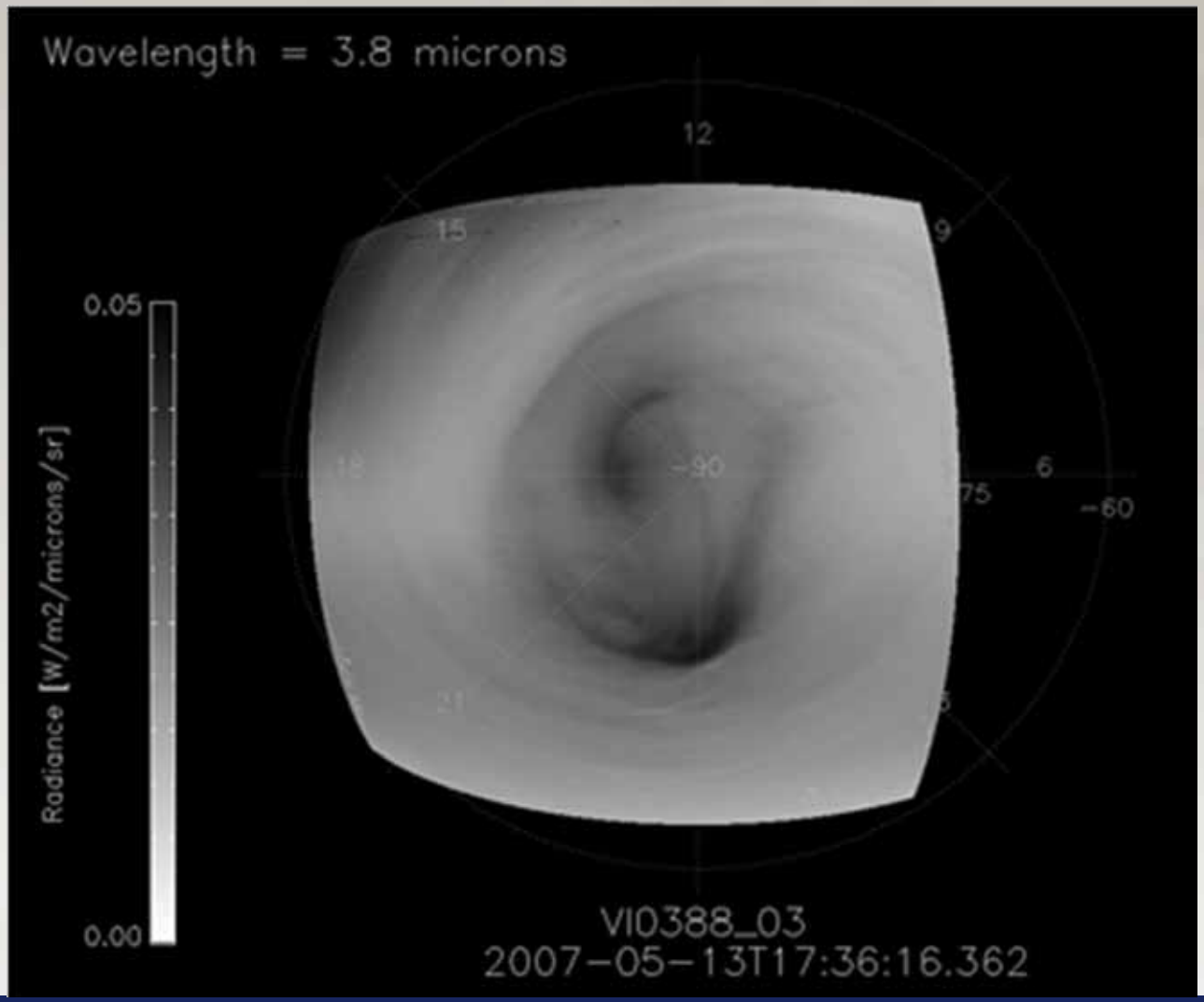
NO

Migliorini et al.

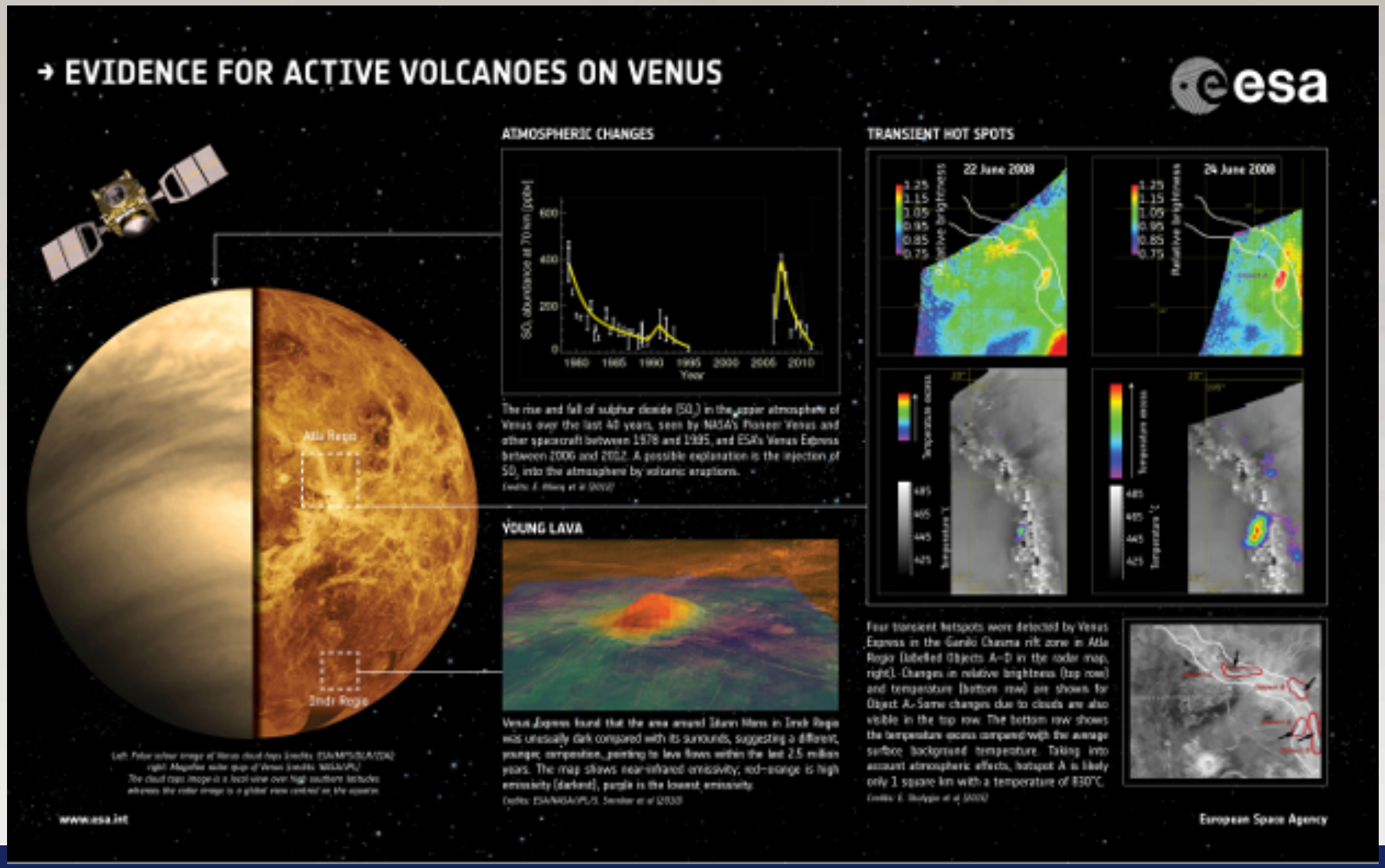


VENUS EXPRESS SCIENCE HIGHLIGHTS

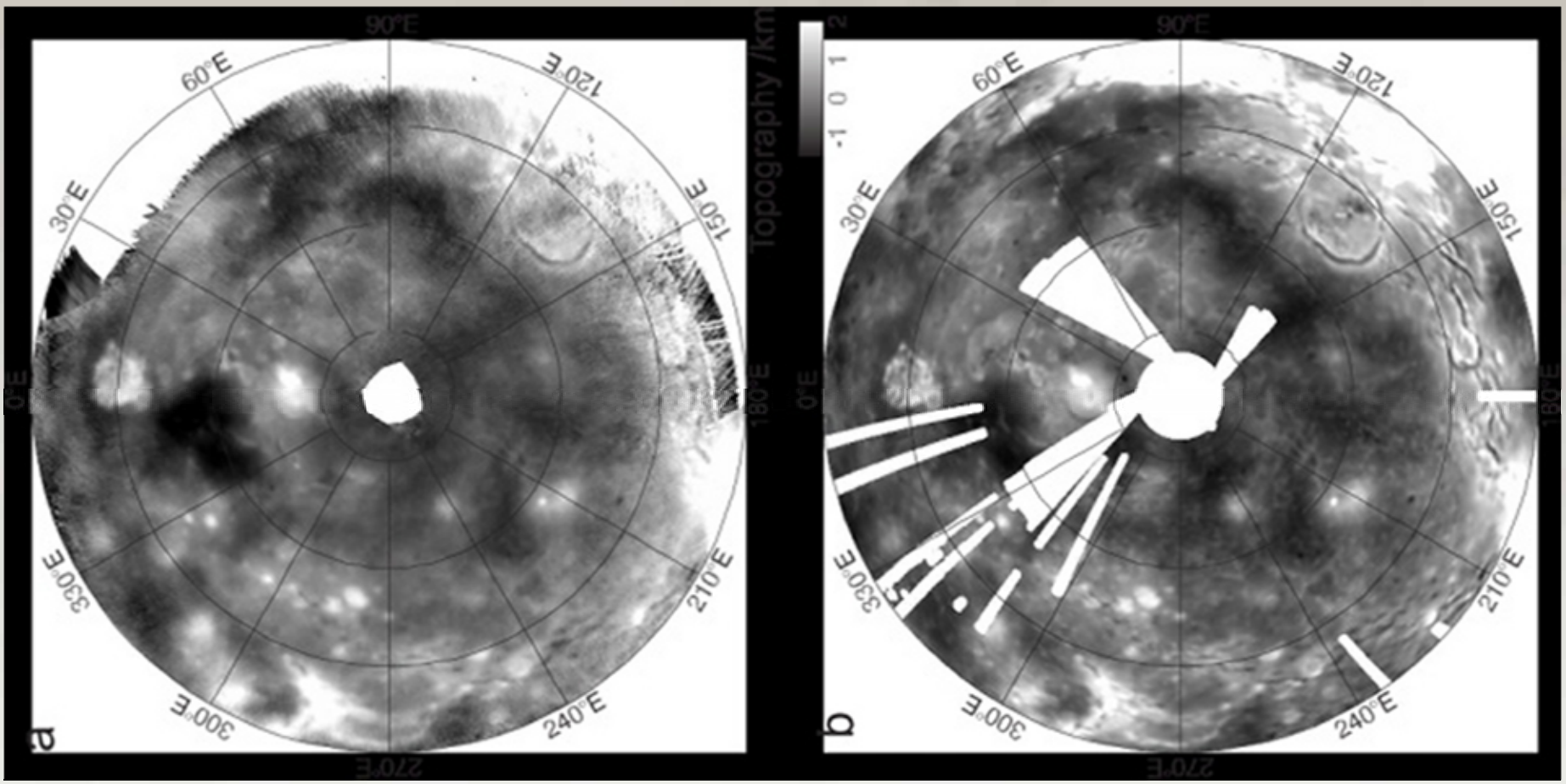
Science Highlight 1: Dynamic polar vortex



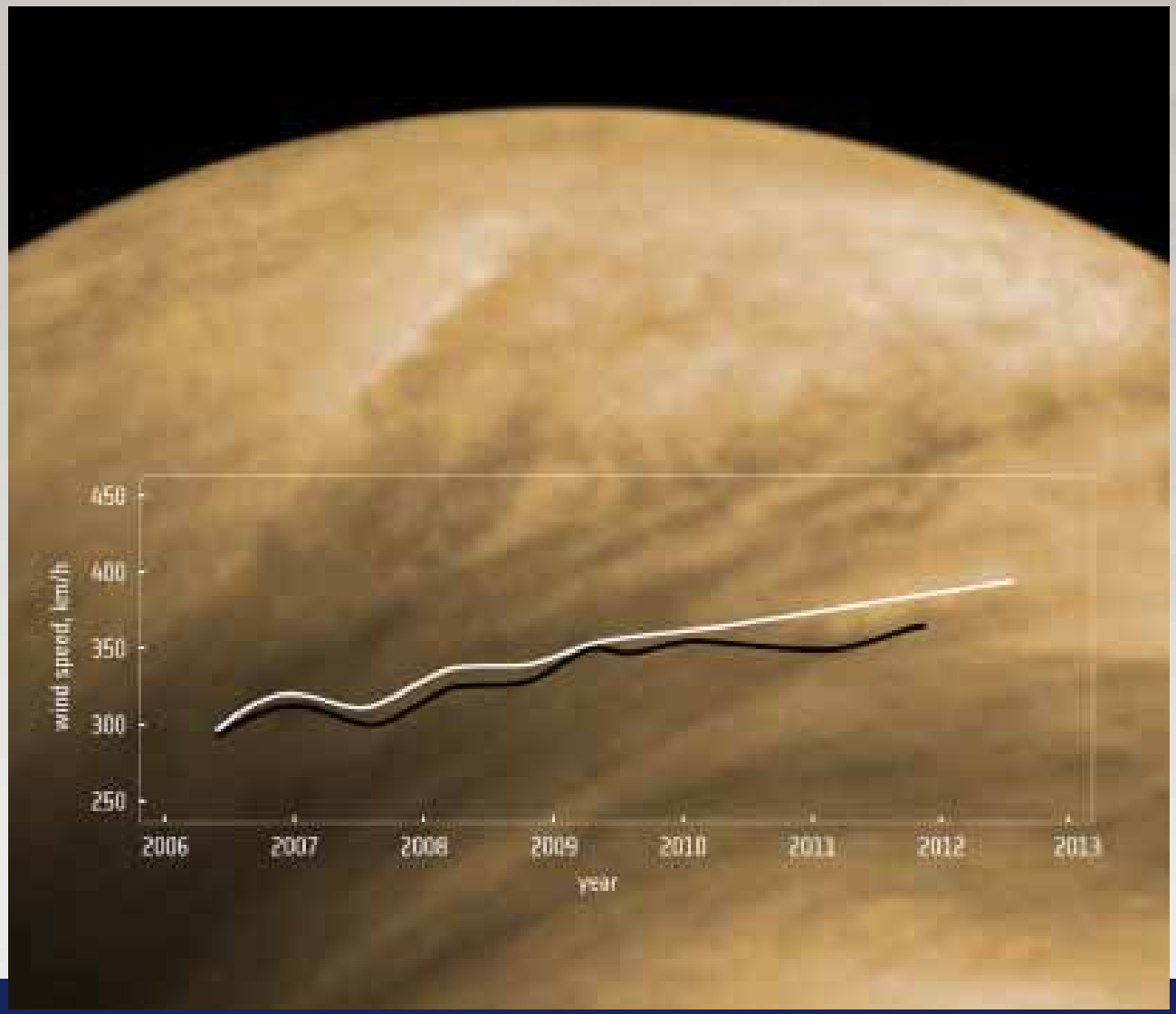
Science Highlight 2: Volcanic lava flows



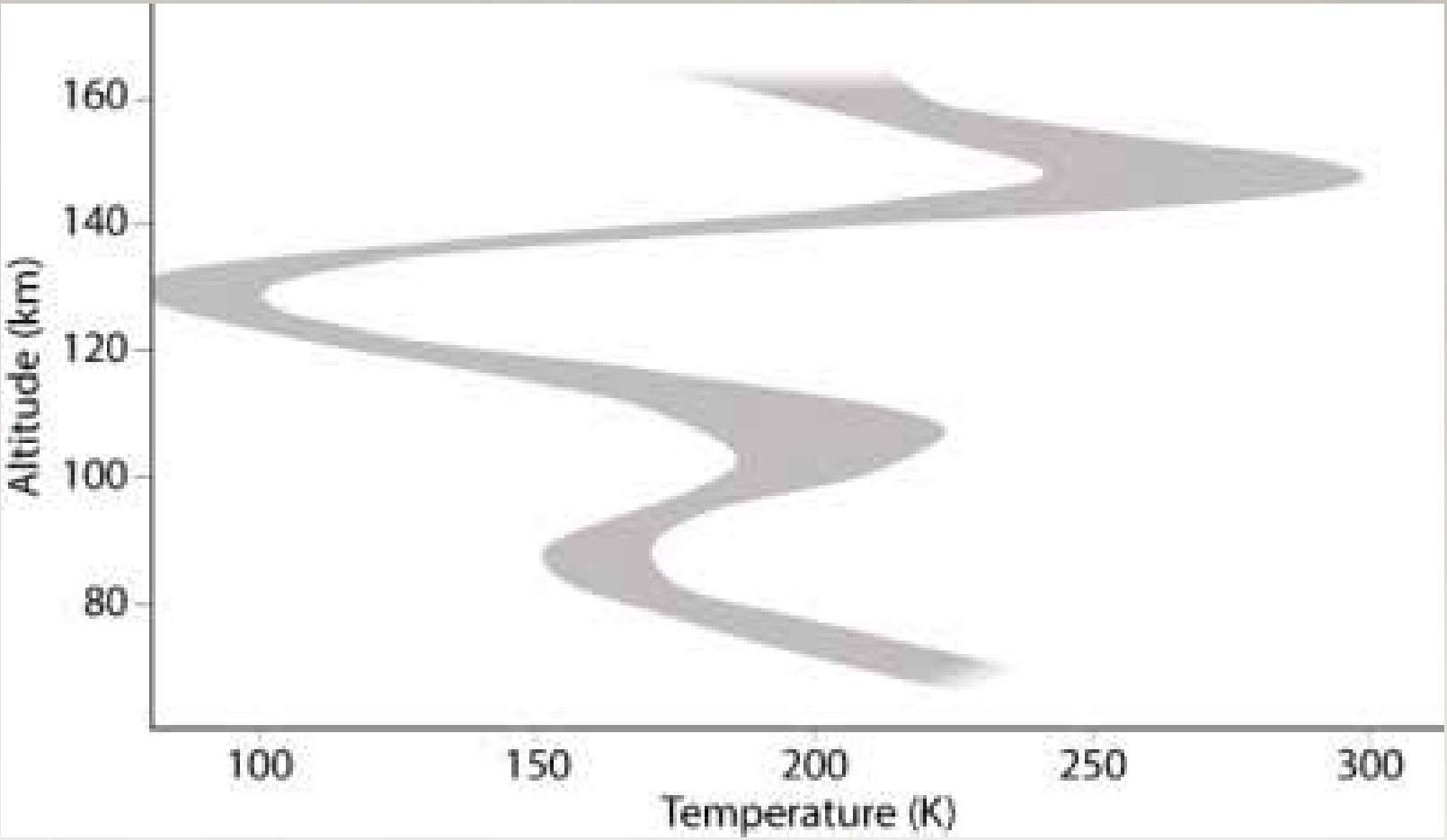
Science Highlight 3: Venus Spin slowing down



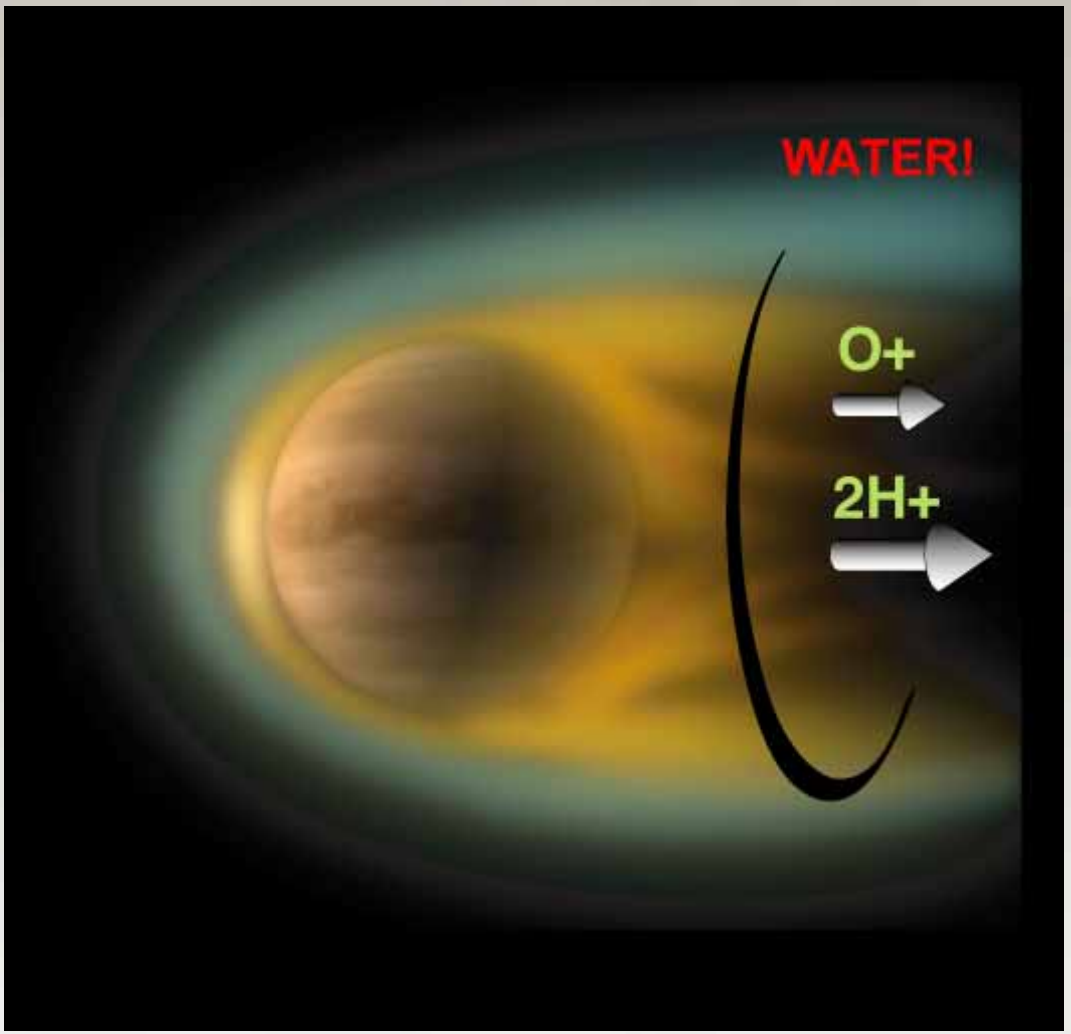
Science Highlight 4: Increasing super-rotation



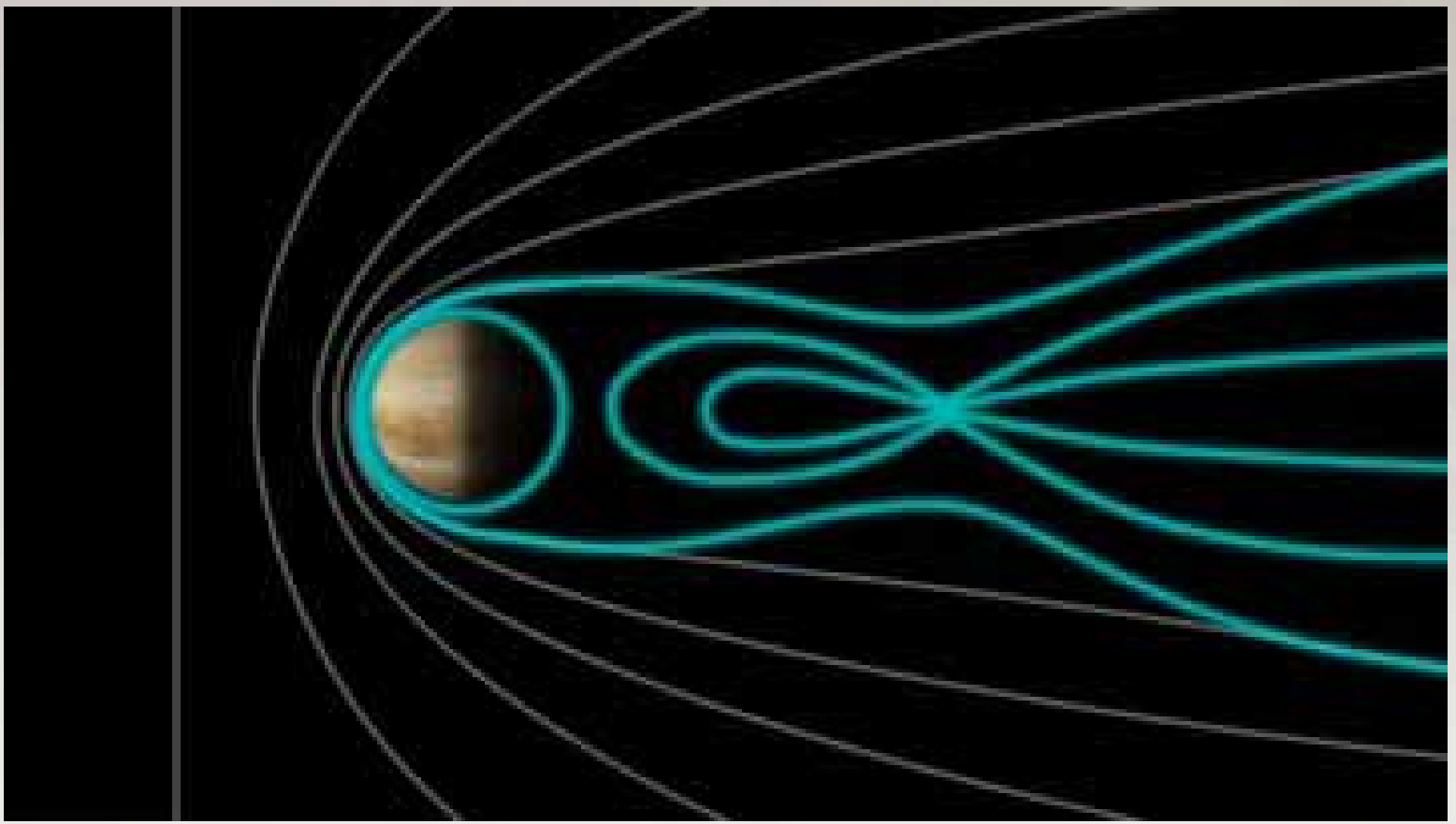
Science Highlight 5: Venus CO2 snow ?



Science Highlight 6: Water escape

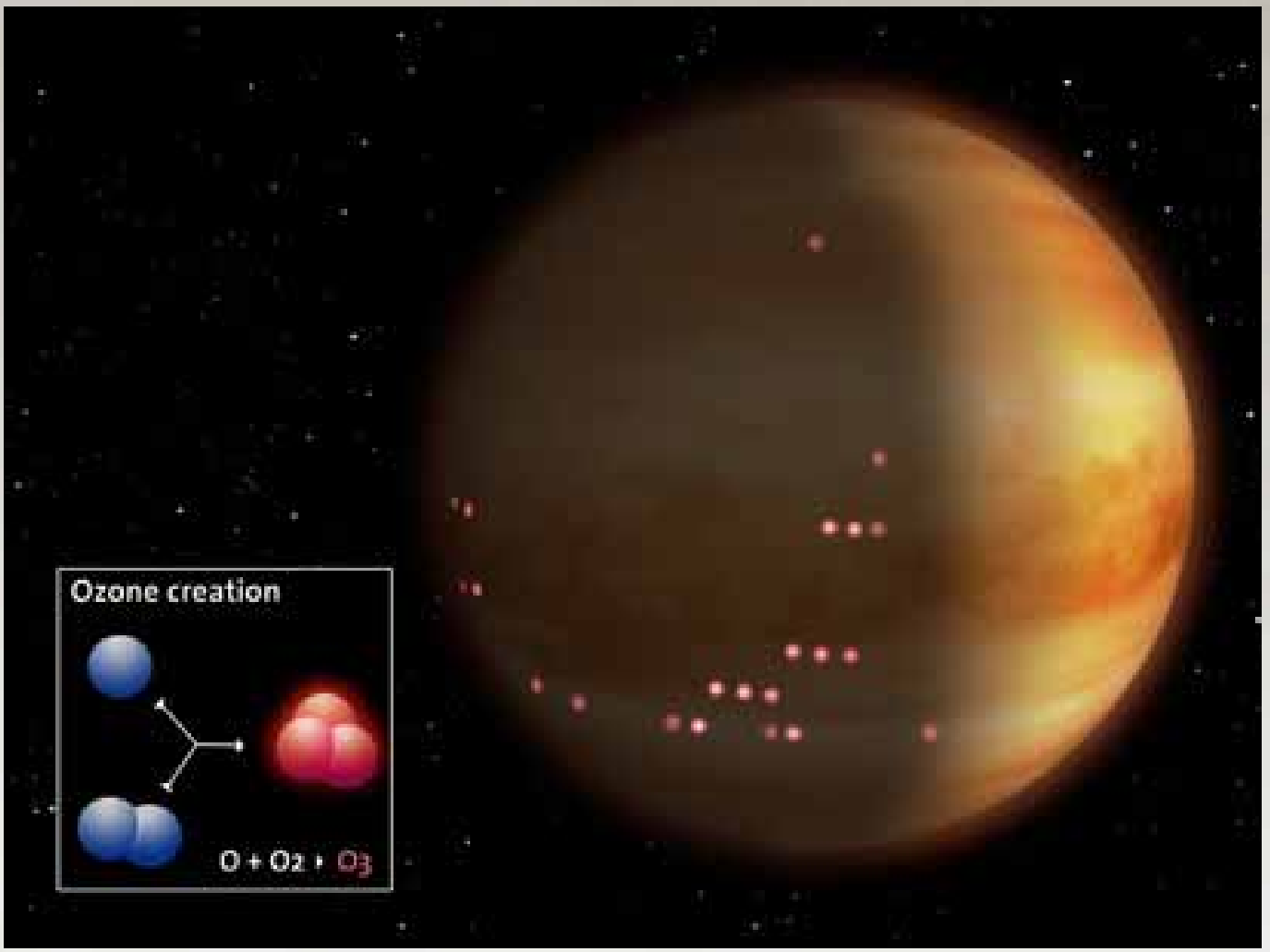


Science Highlight 7: Magnetic reconnection



Science Highlight 8: Lightning detected by magnetometer

Science Highlight 9: Venus Ozone layer



Venus Express

dissapeared in the atmosphere in Dec 2014
after a series of aerobraking experiments
probing down to 130km

Let's hope we don't have to wait 10 years for the next mission to Venus


Venus vortex
Earth Hurricane
THANKS
S. Limaye et al.