New Understanding of Venus from VEx VIRTIS

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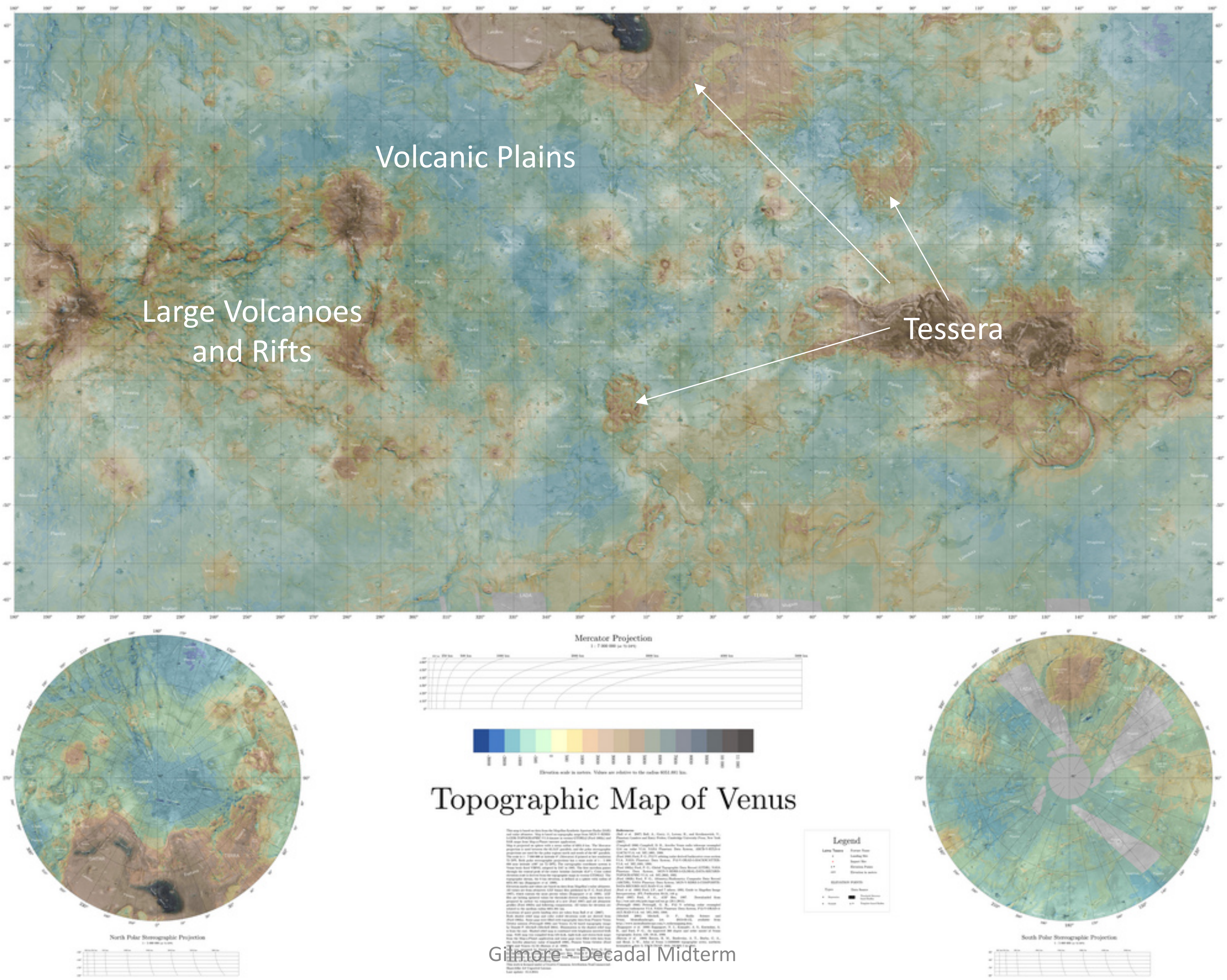
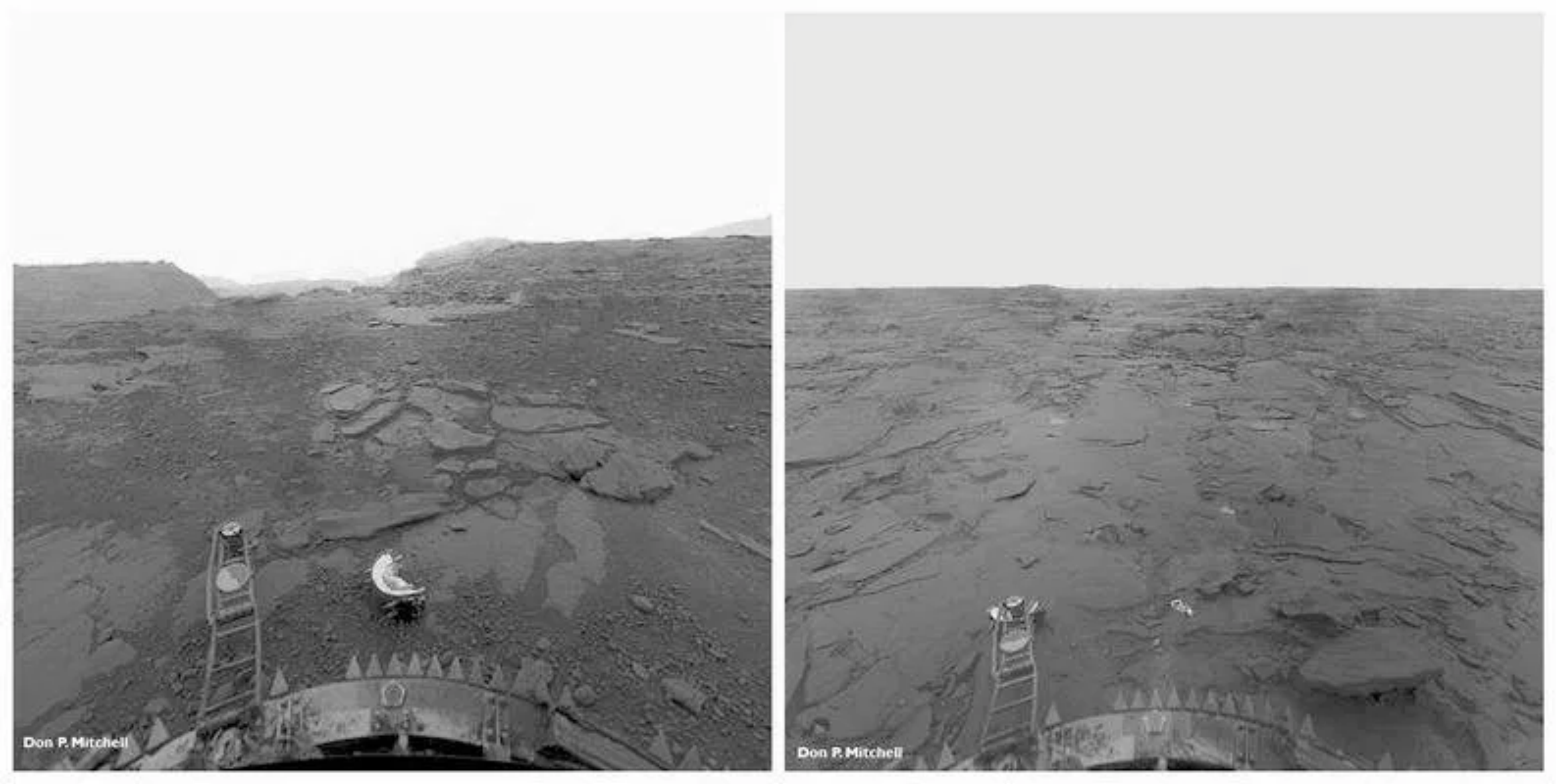
Presentation to the Decadal Midterm
July 12, 2017


Volcanic Plains
Large Volcanoes and Rifts
Tessera
Mercator Projection
Topographic Map of Venus
Legend
North Polar Stereographic Projection
South Polar Stereographic Projection


Don P. Mitchell
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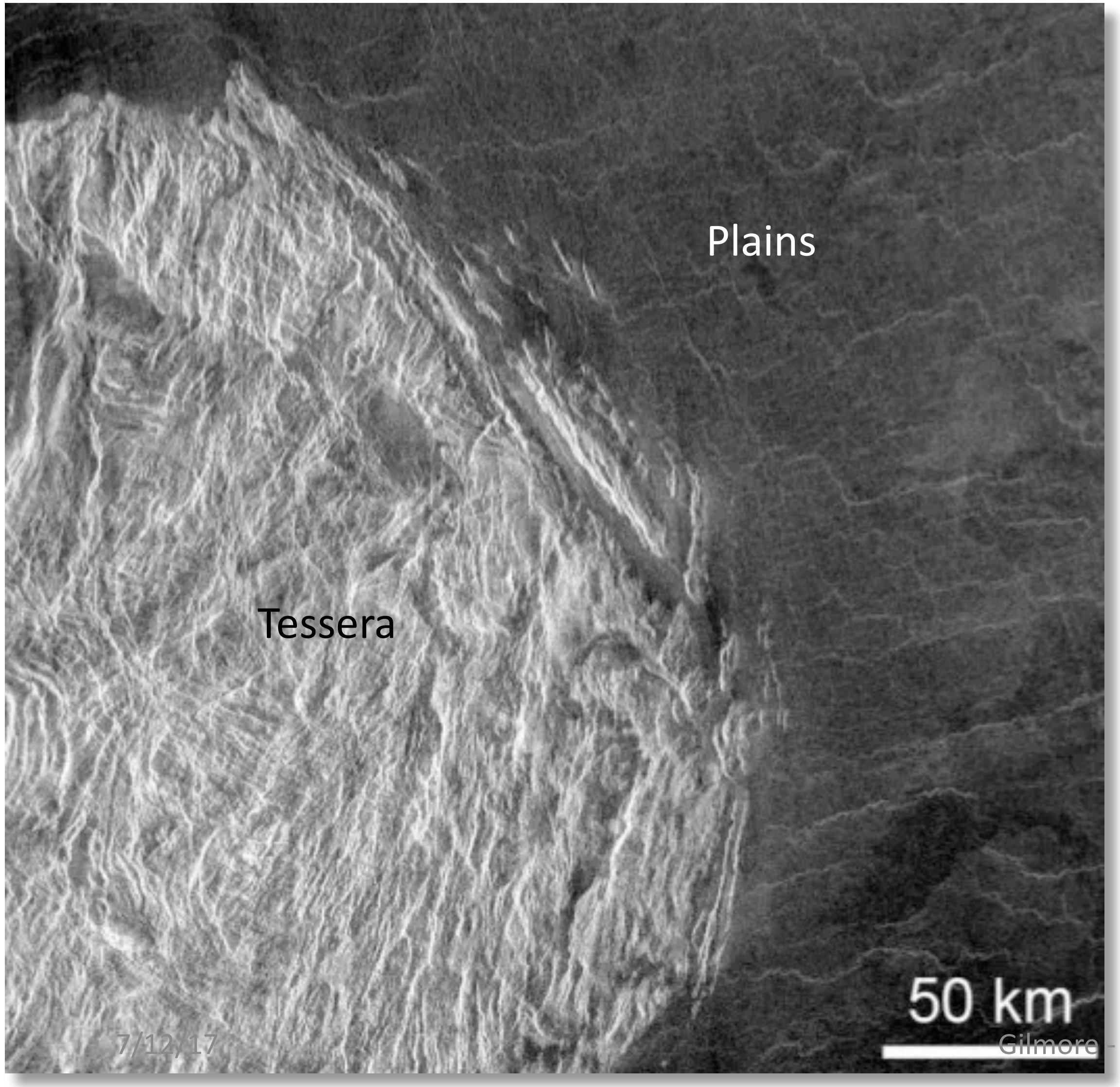
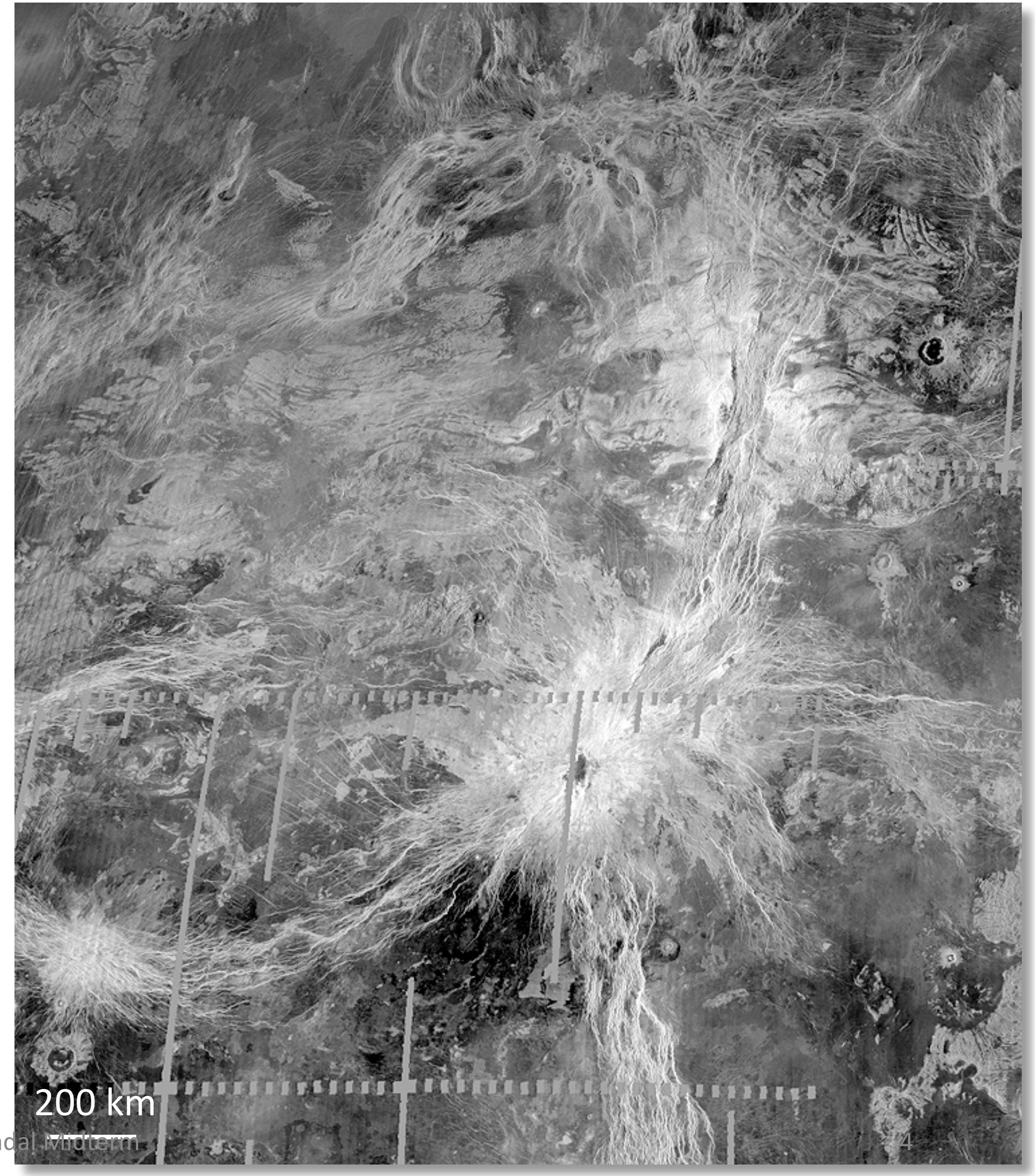
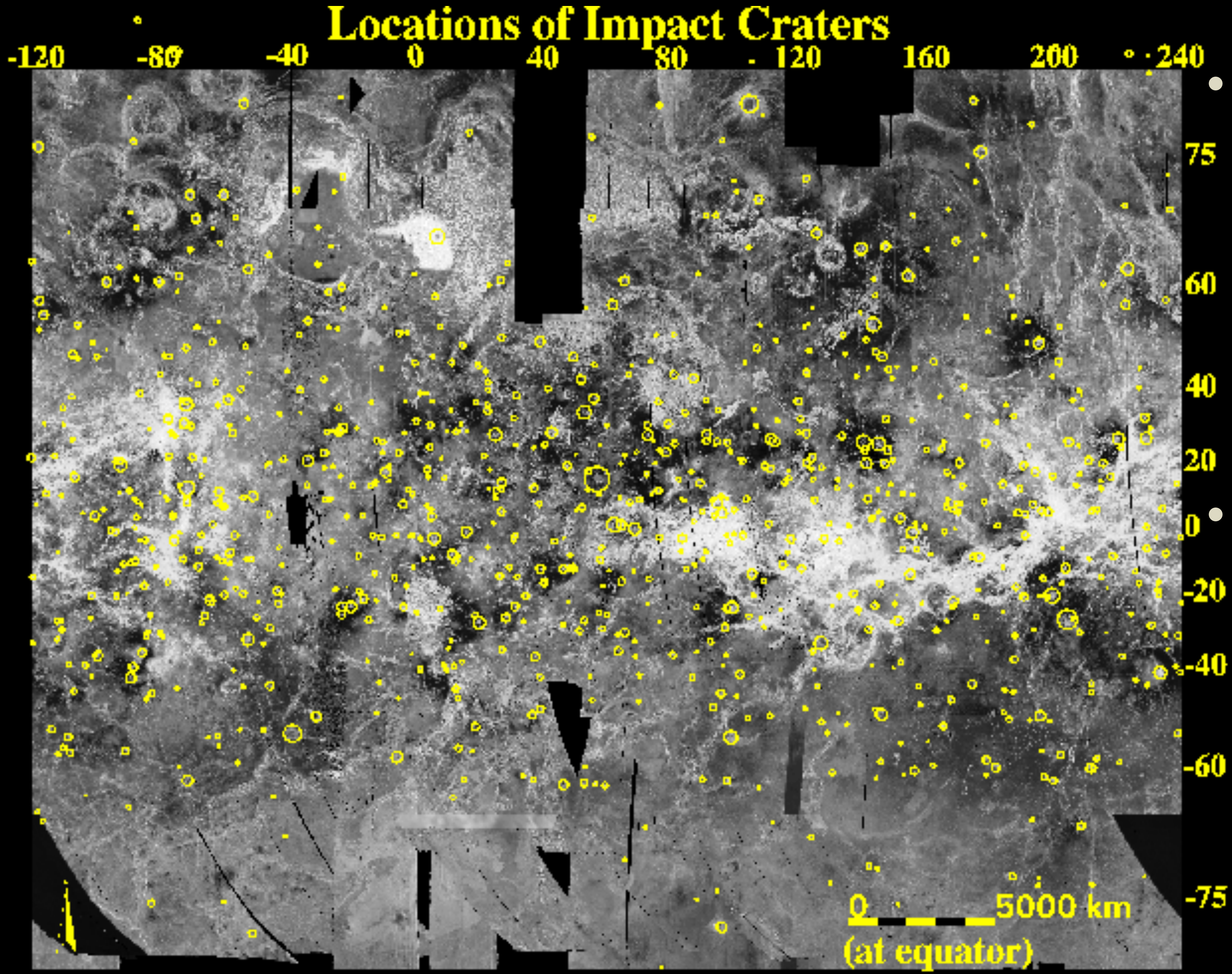
A General Stratigraphy

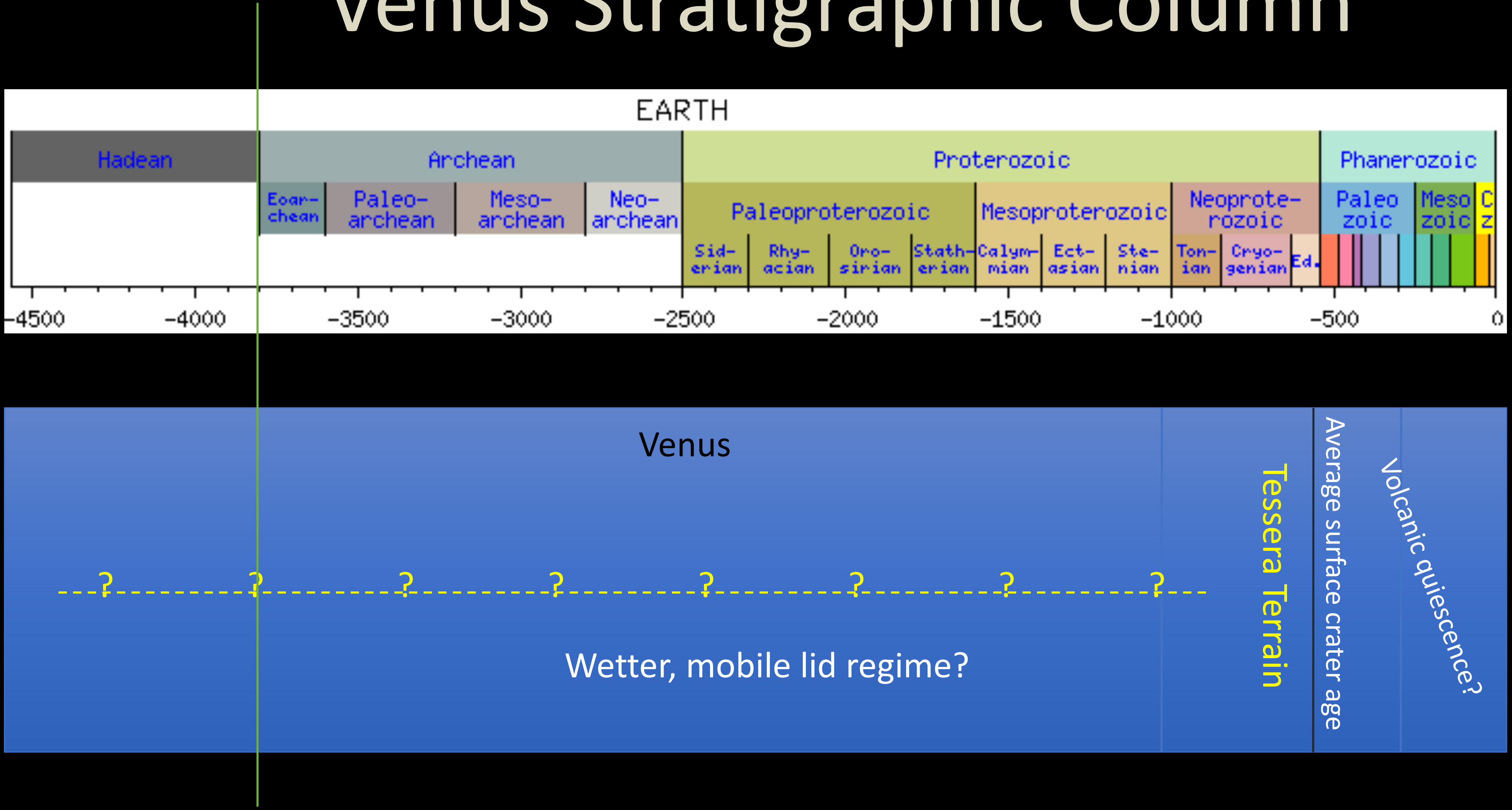






- ~900 craters apparent spatially random, **if** only 4% embayed, consistent with rapid emplacement of surface (Phillips et al., 1992; Schaber et al., 1992, Herrich and Rumpf, 2011)
- yields average age of 500 – 800 Ma
  - Periodic catastrophic overturn of lithosphere? (Parmentier and Hess, 1992)
  - Periodic plate tectonics? (e.g., Turcotte, 1993)
  - Steady state processes? (e.g., Solomon 1993; Solomatov & Moresi, 1996)

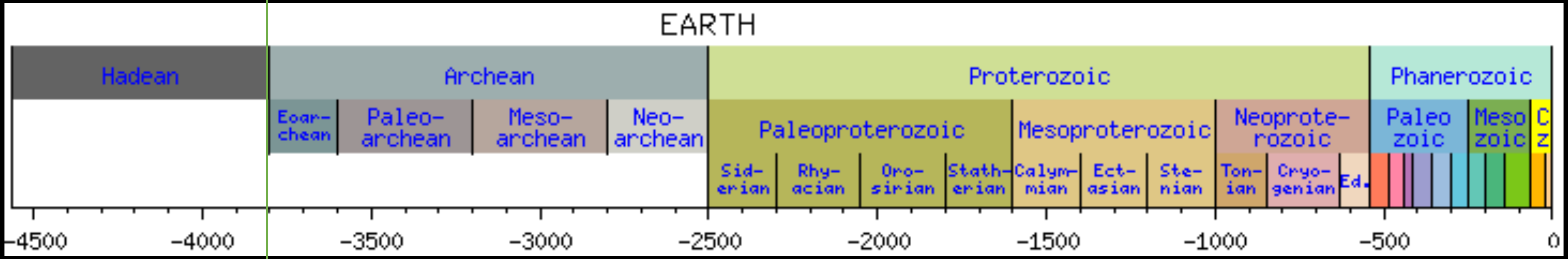
Venus Stratigraphic Column

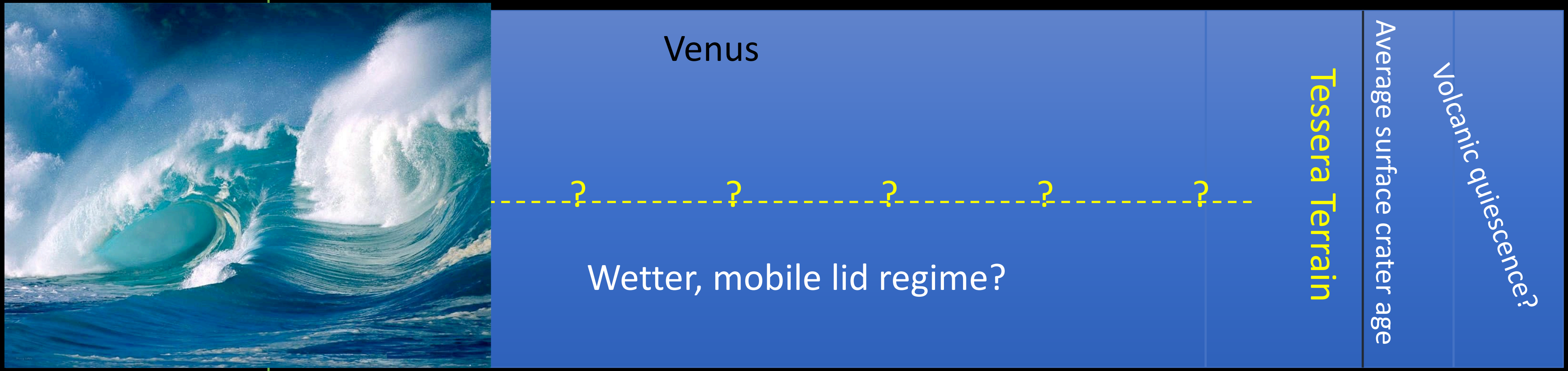


Dry? Strong? basaltic crust Stagnant Lid regime

3.8 Ga - Oldest evidence of life on Earth (Mojzsis et al., 1996)

Venus Stratigraphic Column





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~0.6 – 16% Earth ocean's worth of water (Donahue et al., 1997)

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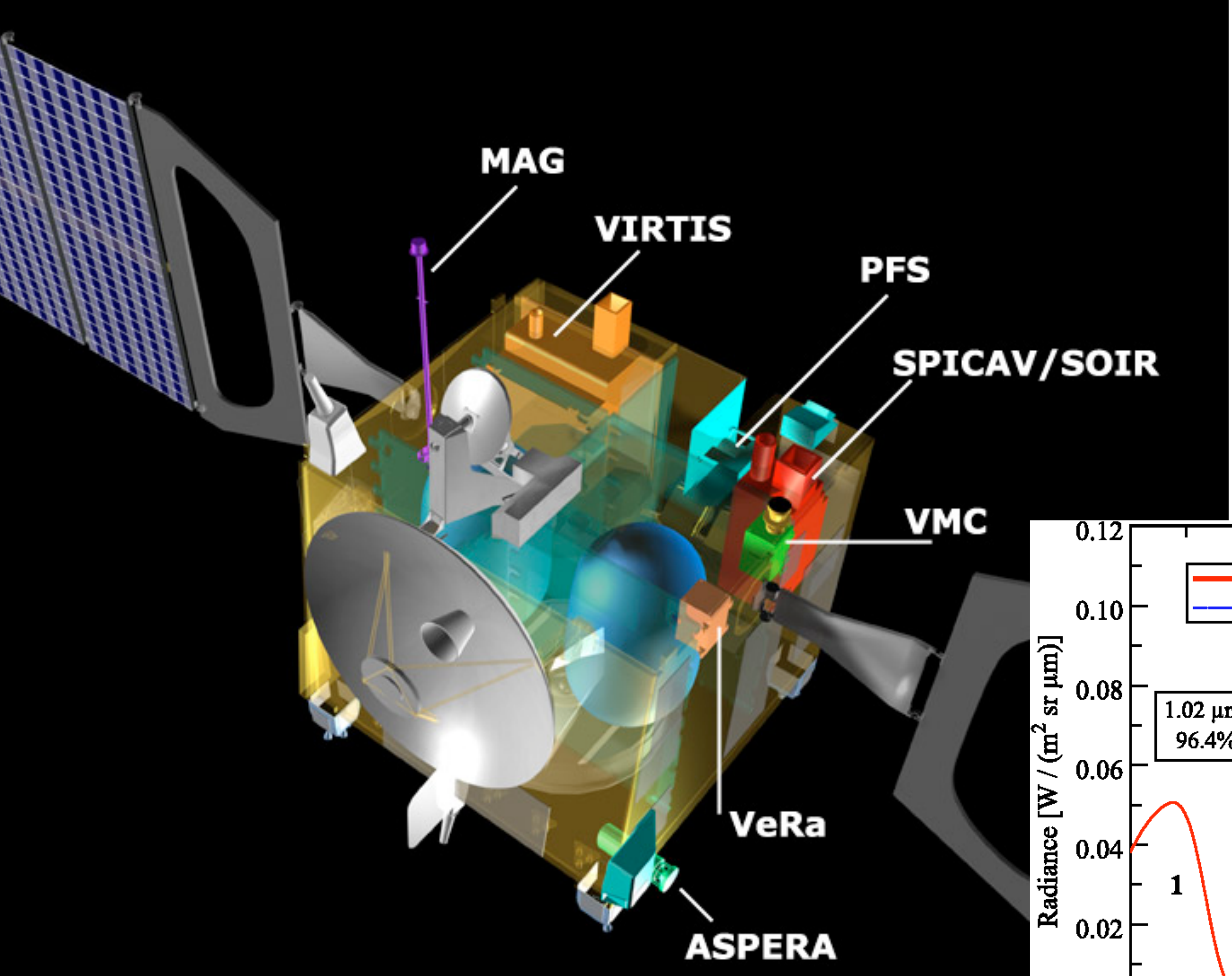
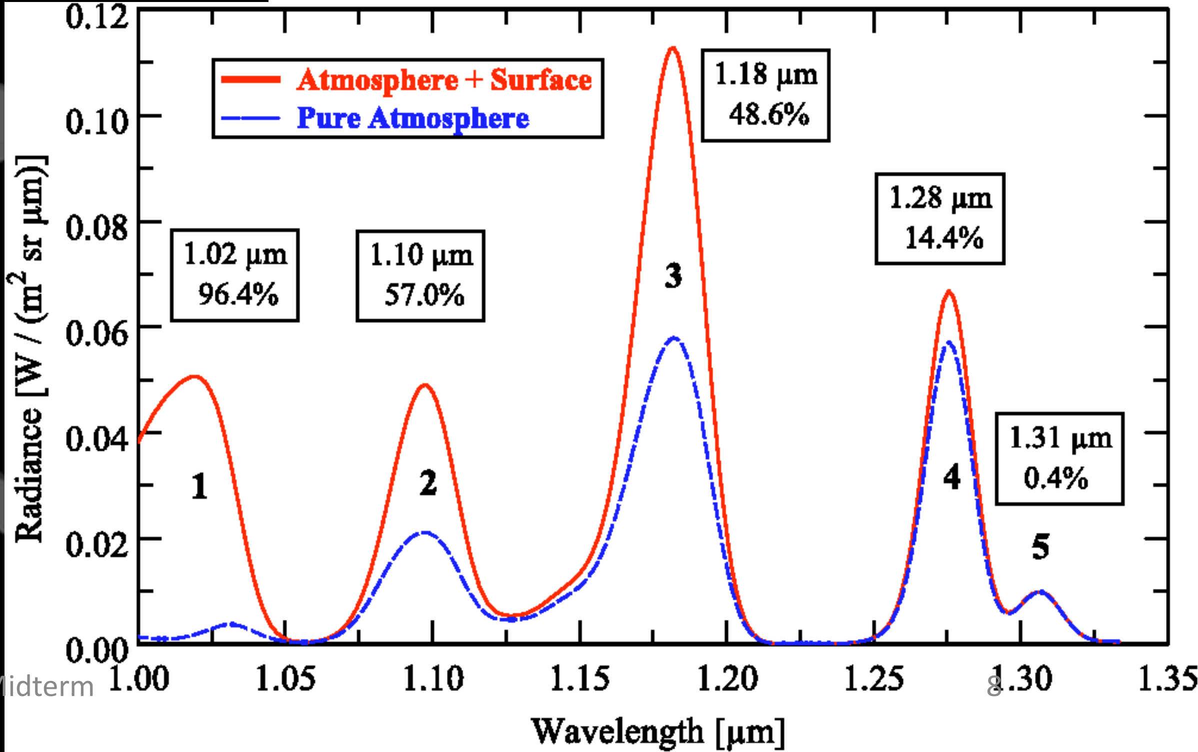
Recent model (Way et al., 2016) predicts ocean for 2-3 Ga.

Venus Express 2005-2014





Venus at 1 µm

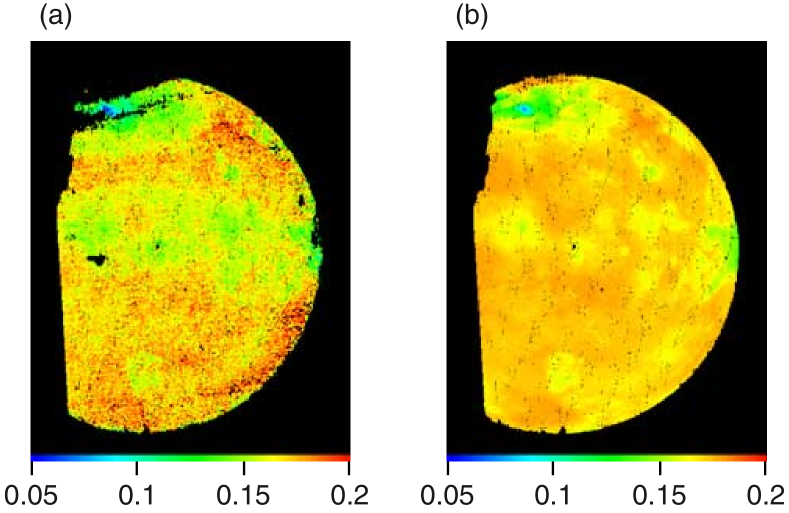
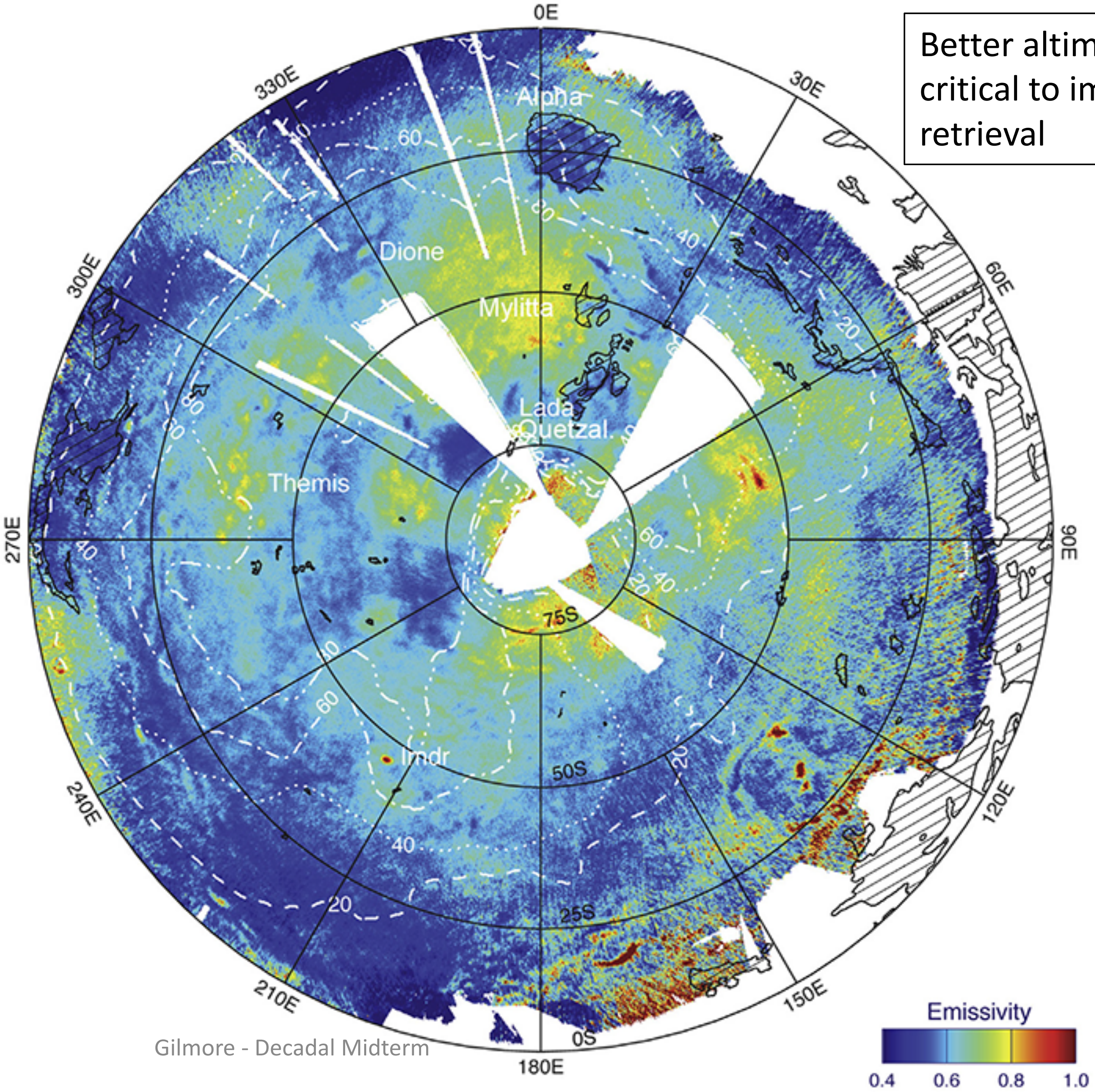


Figure 7. Thermal emission at 1.18 μm window wavelength from the surface and the lower atmosphere. (a) A de-clouded image that is corrected the cloud-induced contrast. (b) A synthesized image based on the Magellan topographic map.

Galileo NIMS
Hashimoto et al. 2008

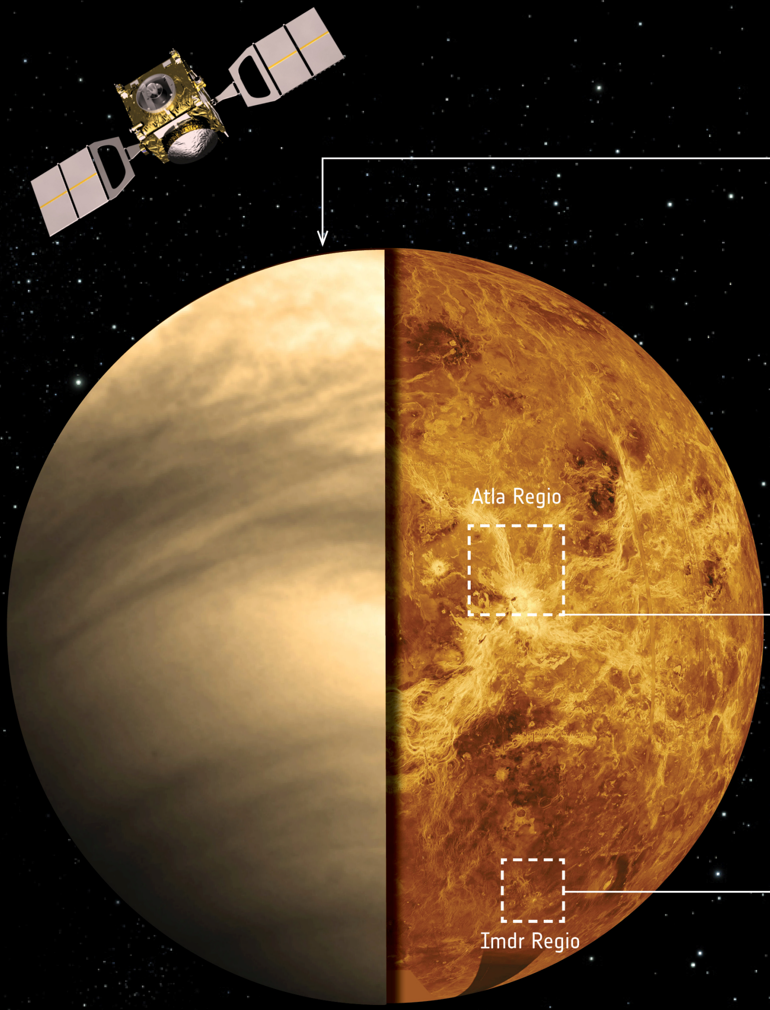
See also:
Basilevsky et al (2012) VMC data



Better altimetry data critical to improve this retrieval

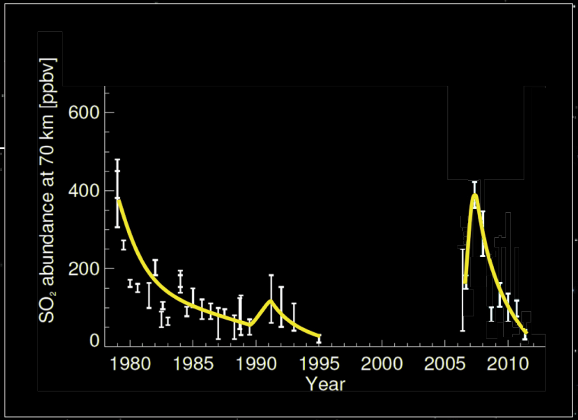
→ EVIDENCE FOR ACTIVE VOLCANOES ON VENUS

esa



Left: False-colour image of Venus cloud tops (credits: ESA/MPS/DLR/IDA); right: Magellan radar map of Venus (credits: NASA/JPL)
The cloud tops image is a local view over high southern latitudes whereas the radar image is a global view centred on the equator.

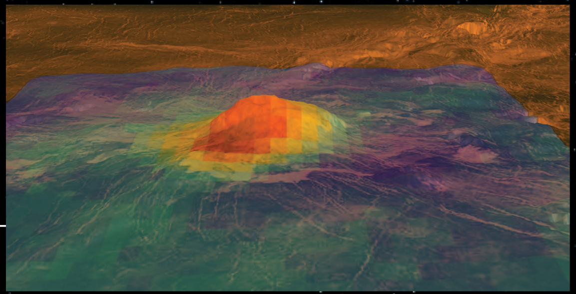
ATMOSPHERIC CHANGES



The rise and fall of sulphur dioxide (SO_2) in the upper atmosphere of Venus over the last 40 years, seen by NASA's Pioneer Venus and other spacecraft between 1978 and 1995, and ESA's Venus Express between 2006 and 2012. A possible explanation is the injection of SO_2 into the atmosphere by volcanic eruptions.

Credits: E. Marcq et al (2012)

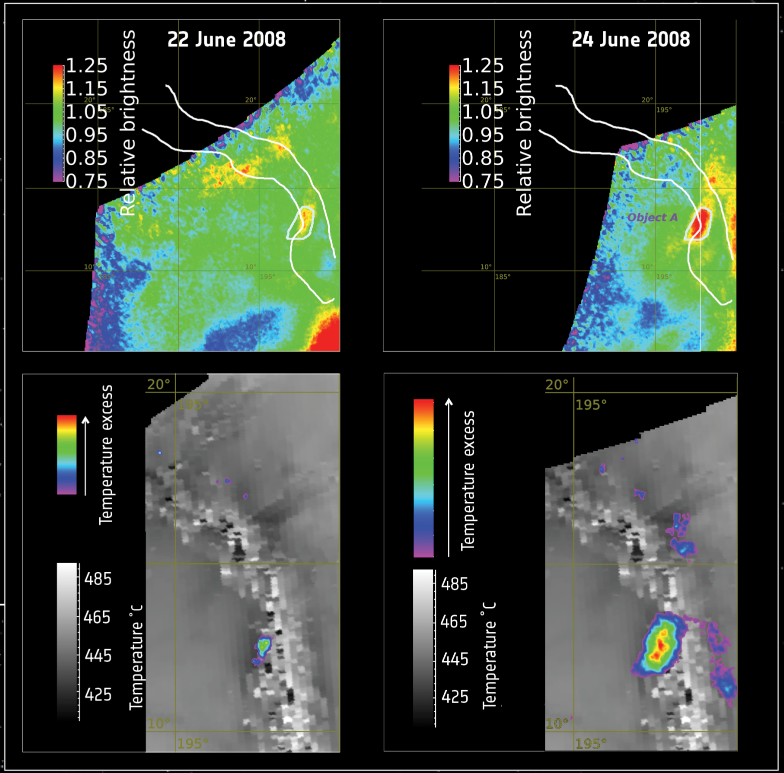
YOUNG LAVA



Venus Express found that the area around Idunn Mons in Imdr Regio was unusually dark compared with its surrounds, suggesting a different, younger, composition, pointing to lava flows within the last 2.5 million years. The map shows near-infrared emissivity; red–orange is high emissivity (darkest), purple is the lowest emissivity.

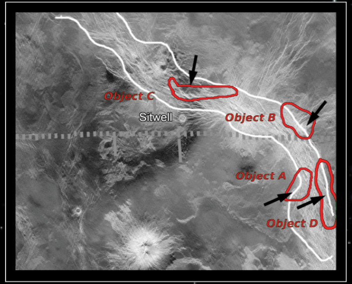
Credits: ESA/NASA/JPL/S. Smrekar et al (2010)

TRANSIENT HOT SPOTS

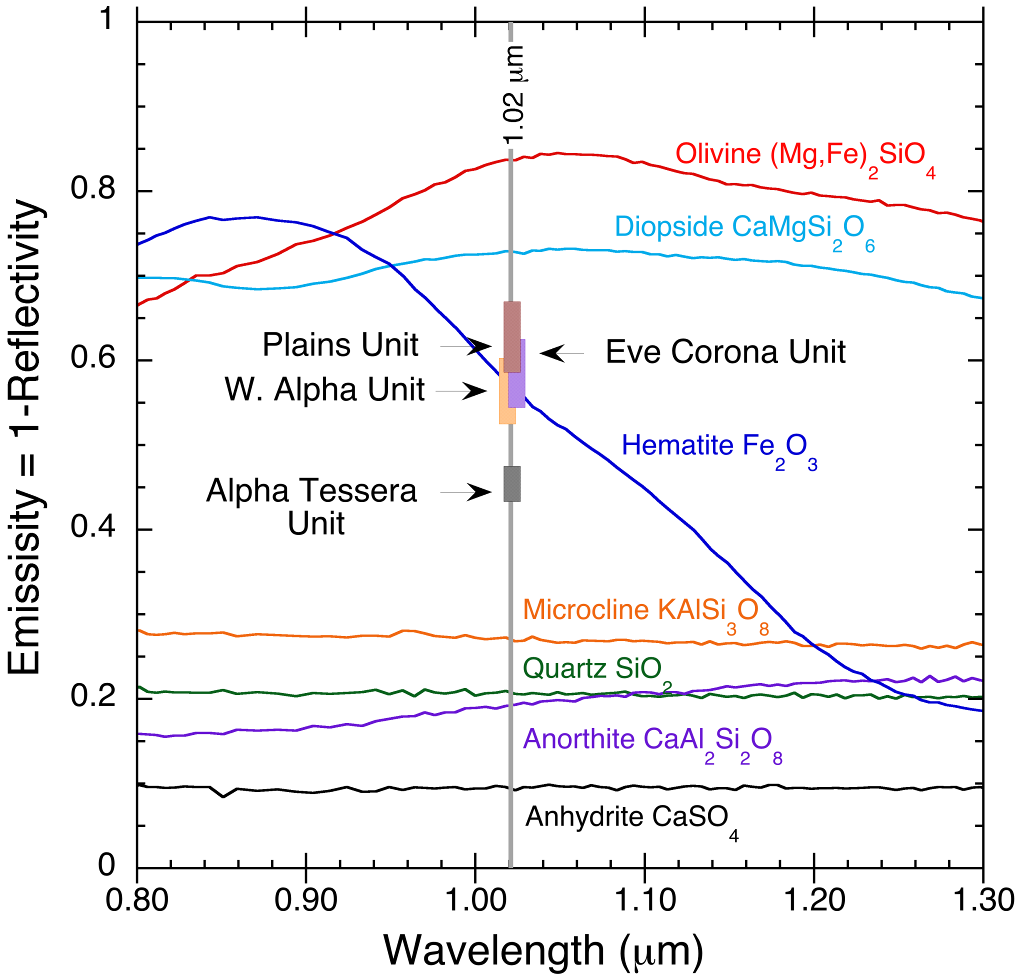


Four transient hotspots were detected by Venus Express in the Ganiki Chasma rift zone in Atla Regio (labelled Objects A–D in the radar map, right). Changes in relative brightness (top row) and temperature (bottom row) are shown for Object A. Some changes due to clouds are also visible in the top row. The bottom row shows the temperature excess compared with the average surface background temperature. Taking into account atmospheric effects, hotspot A is likely only 1 square km with a temperature of 830°C.

Credits: E. Shalygin et al (2015)



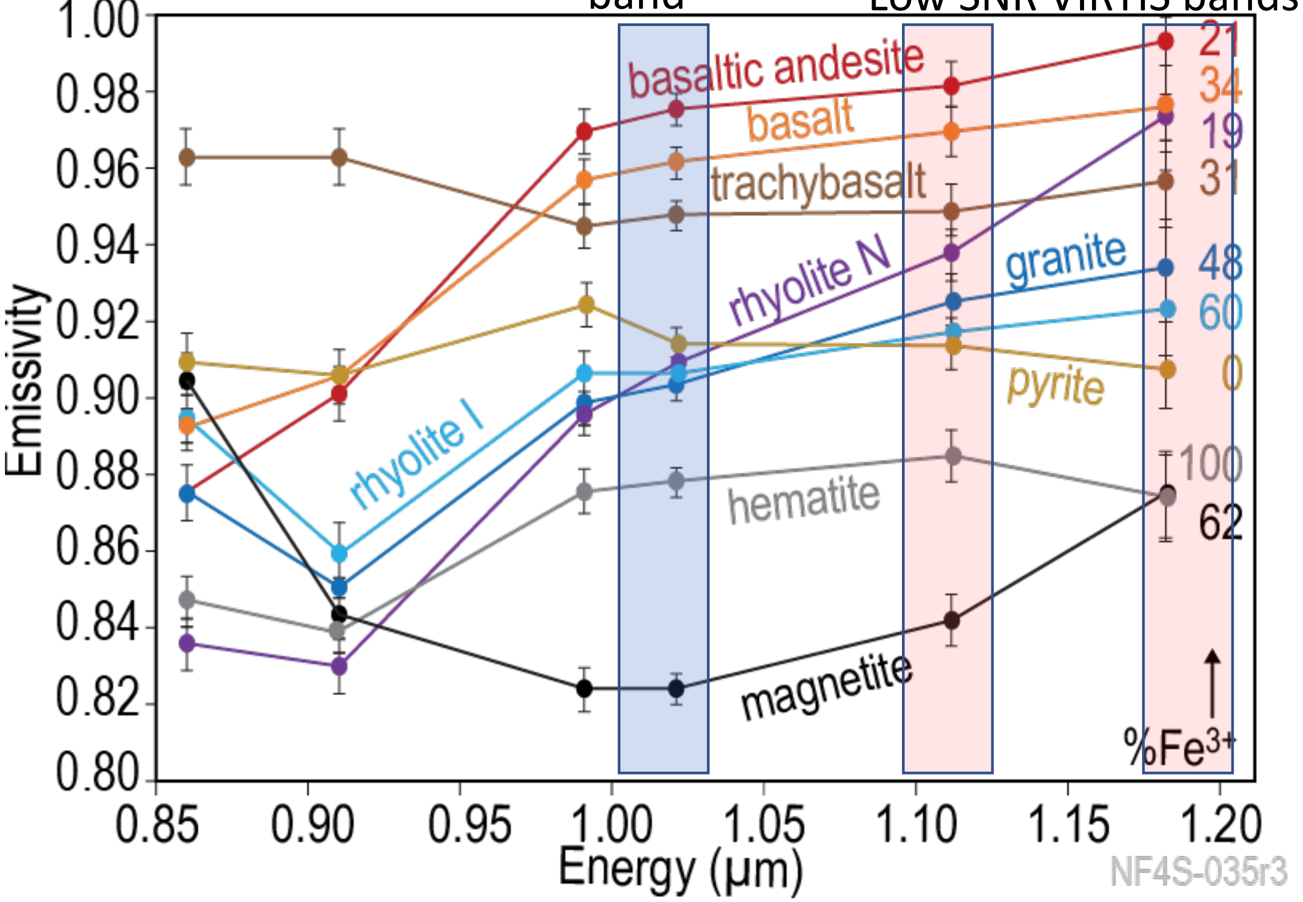
Atmospheric Windows vs. Lab Spectra



Room Temperature

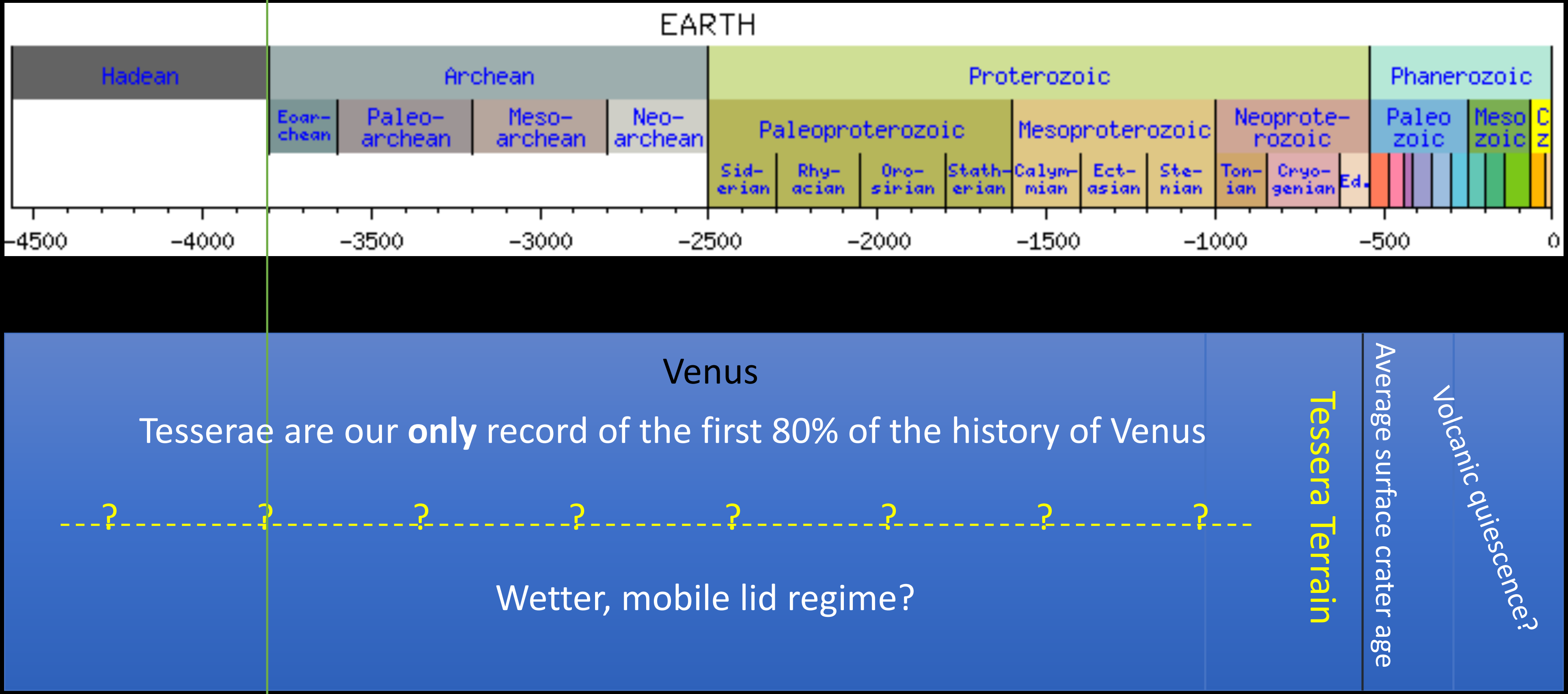
Moderate SNR VIRTIS band

Low SNR VIRTIS bands



Venus Temperature (DLR lab)

Venus Stratigraphic Column



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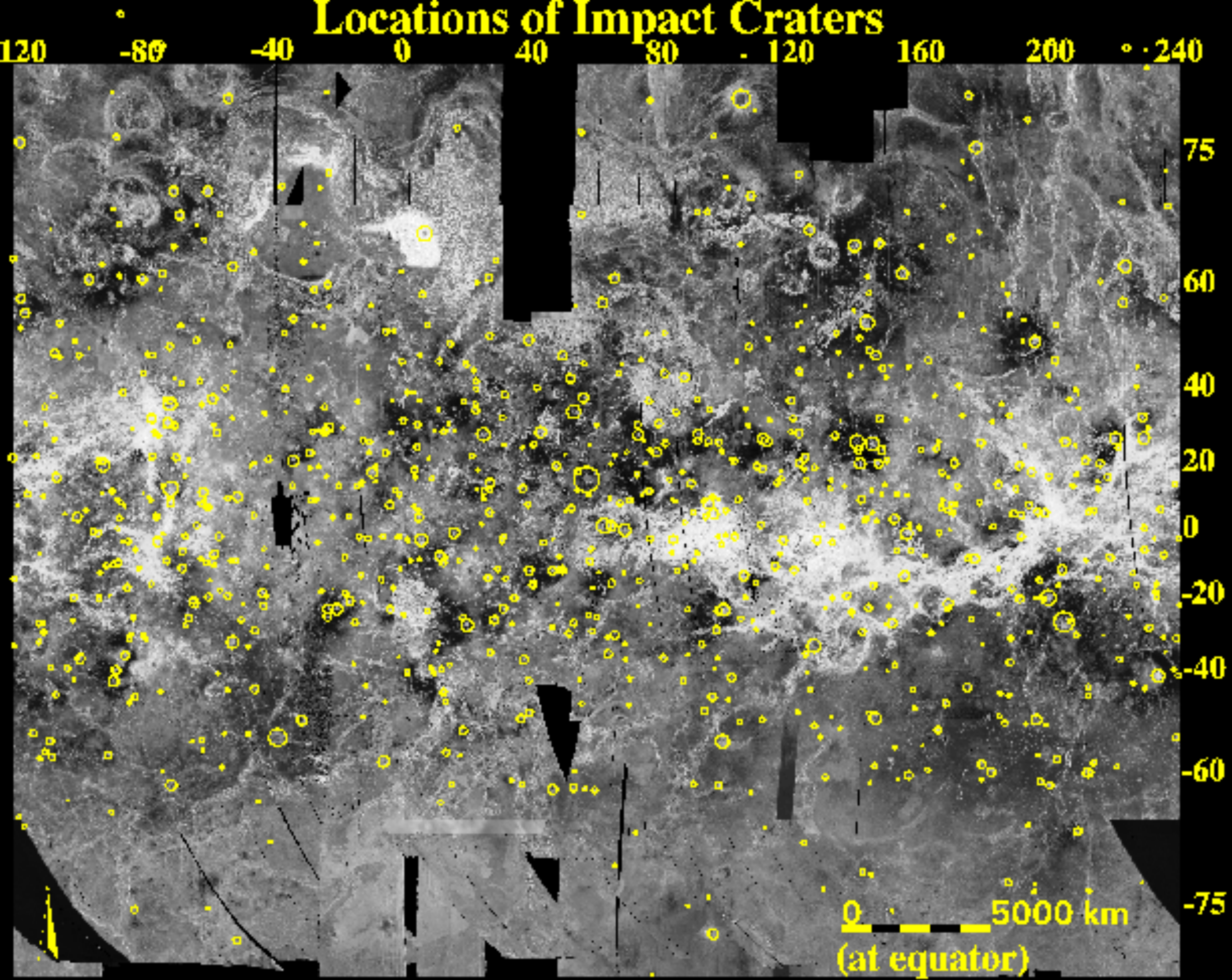
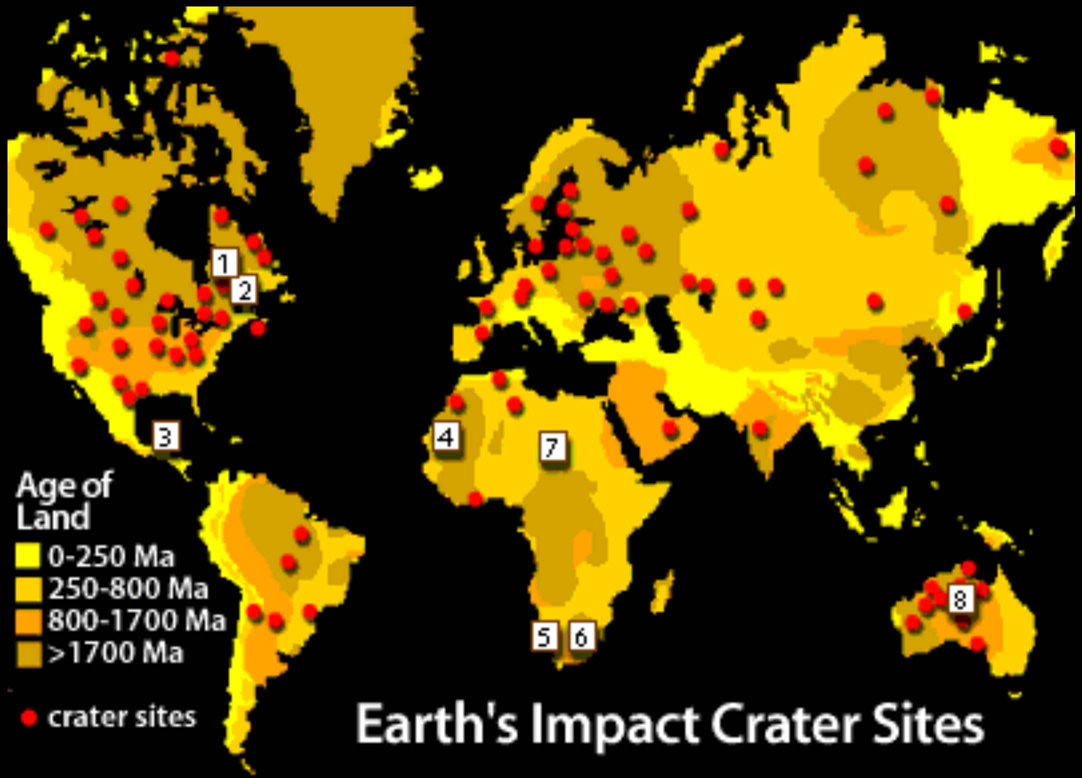


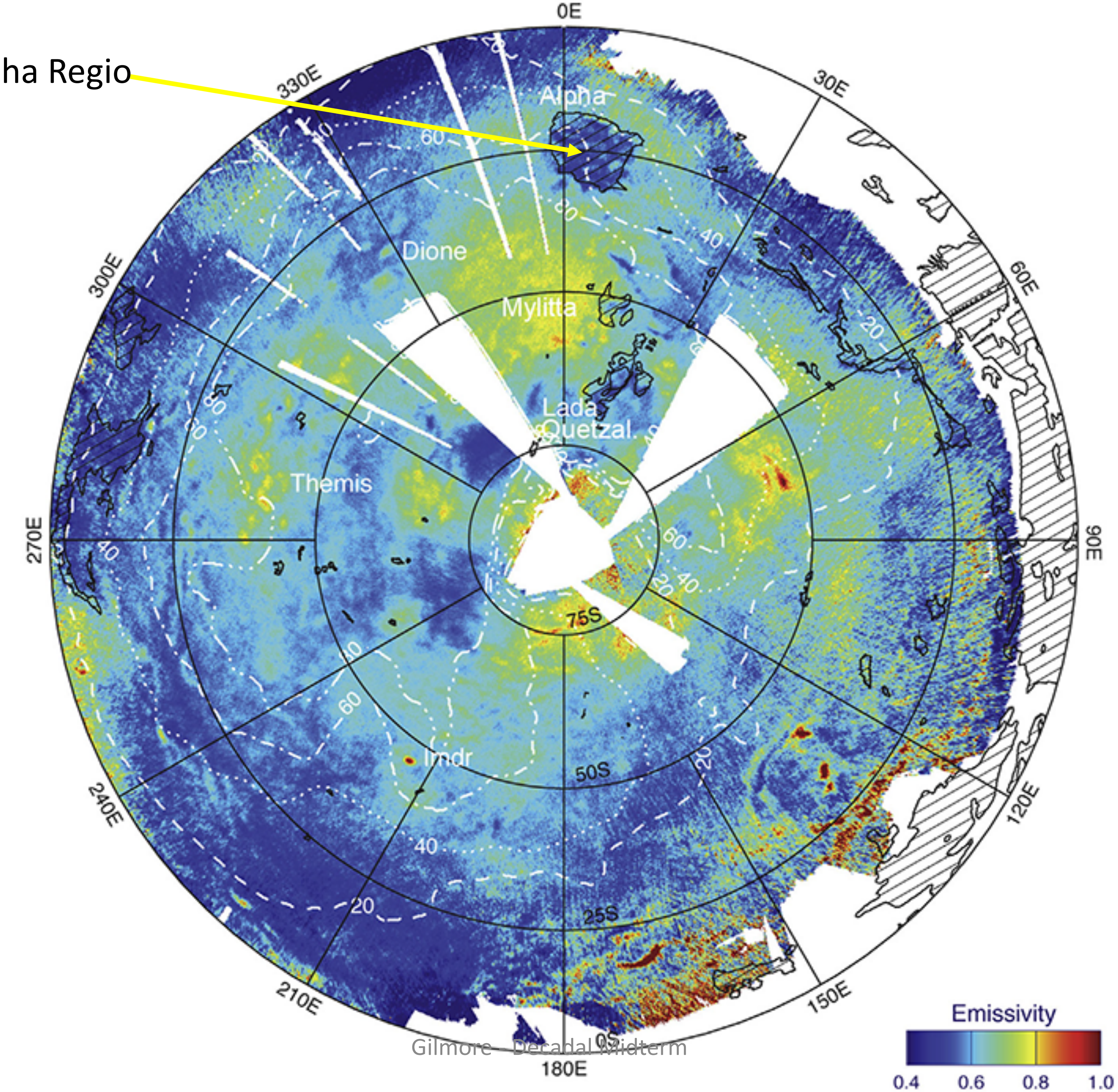


900 craters = crater age ~ 500 Ma

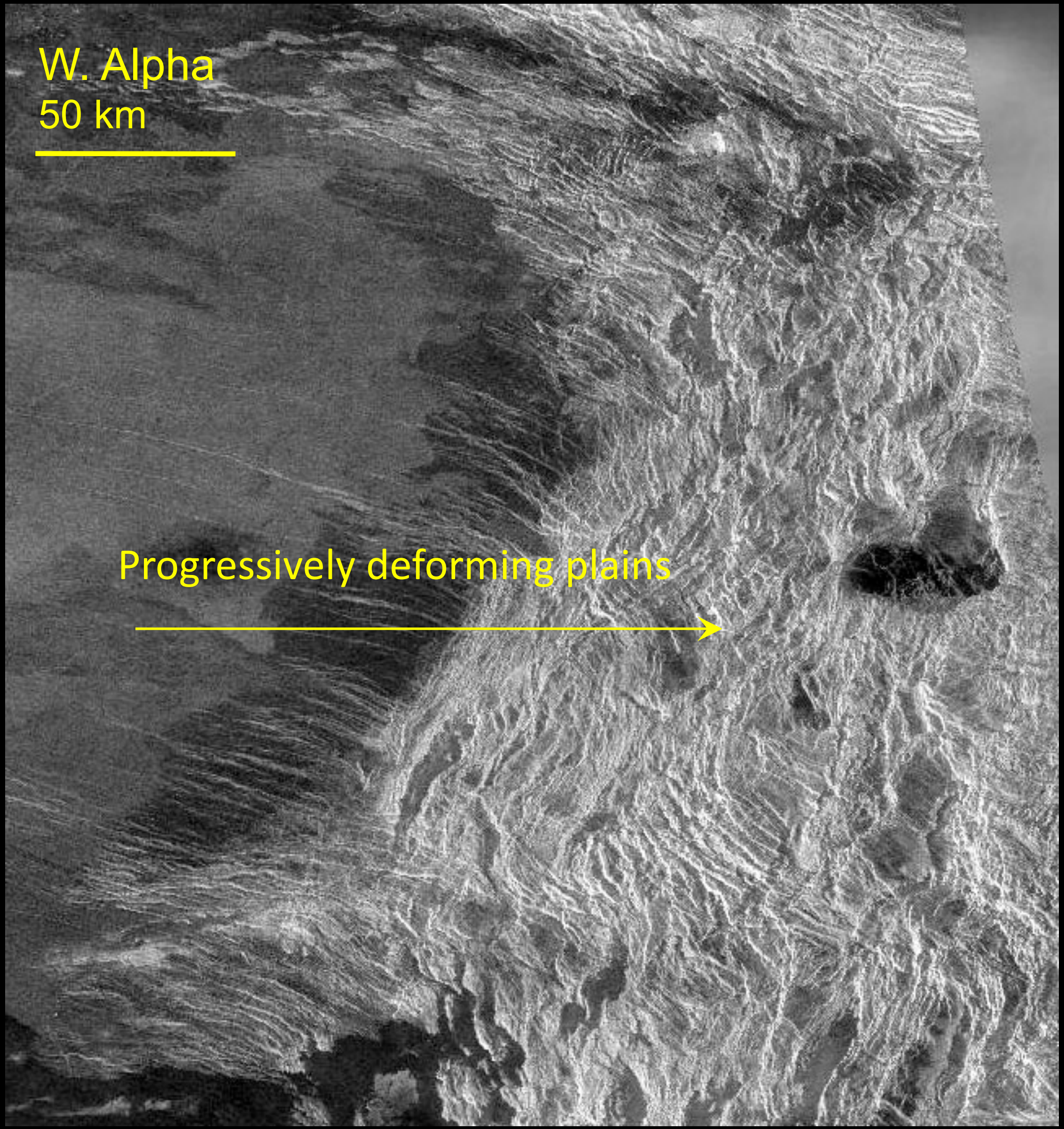
70 craters = crater age of 50 Ma?

Crater age is not formation age! (it's last deformation age)

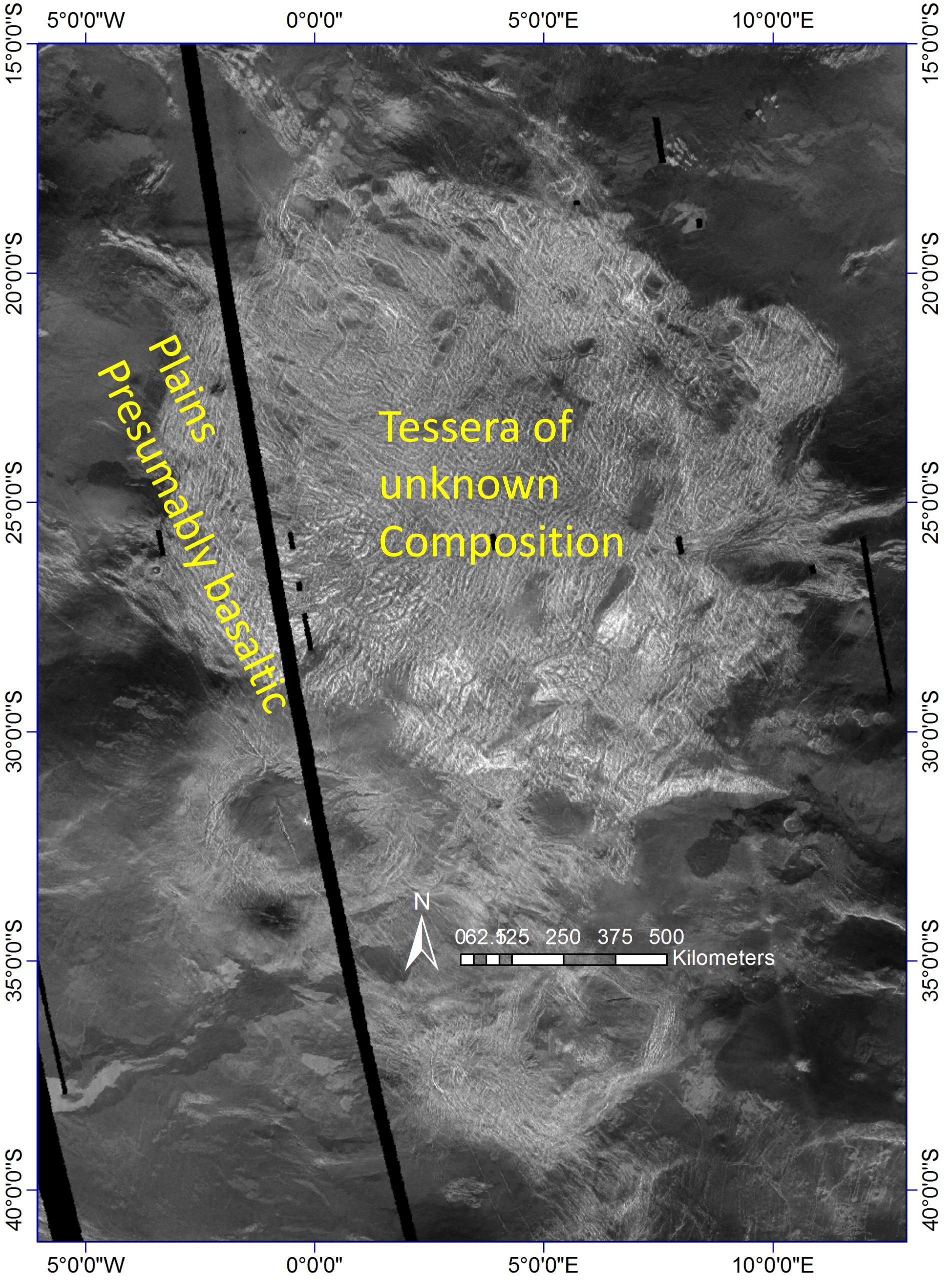
Alpha Regio



0E
30E
60E
90E
120E
150E
180E
210E
240E
270E
300E
330E
Alpha
Dione
Mylitta
Lada
Quetzal.
Themis
Imdr
75S
50S
25S
0S
Emissivity
0.4
0.6
0.8
1.0

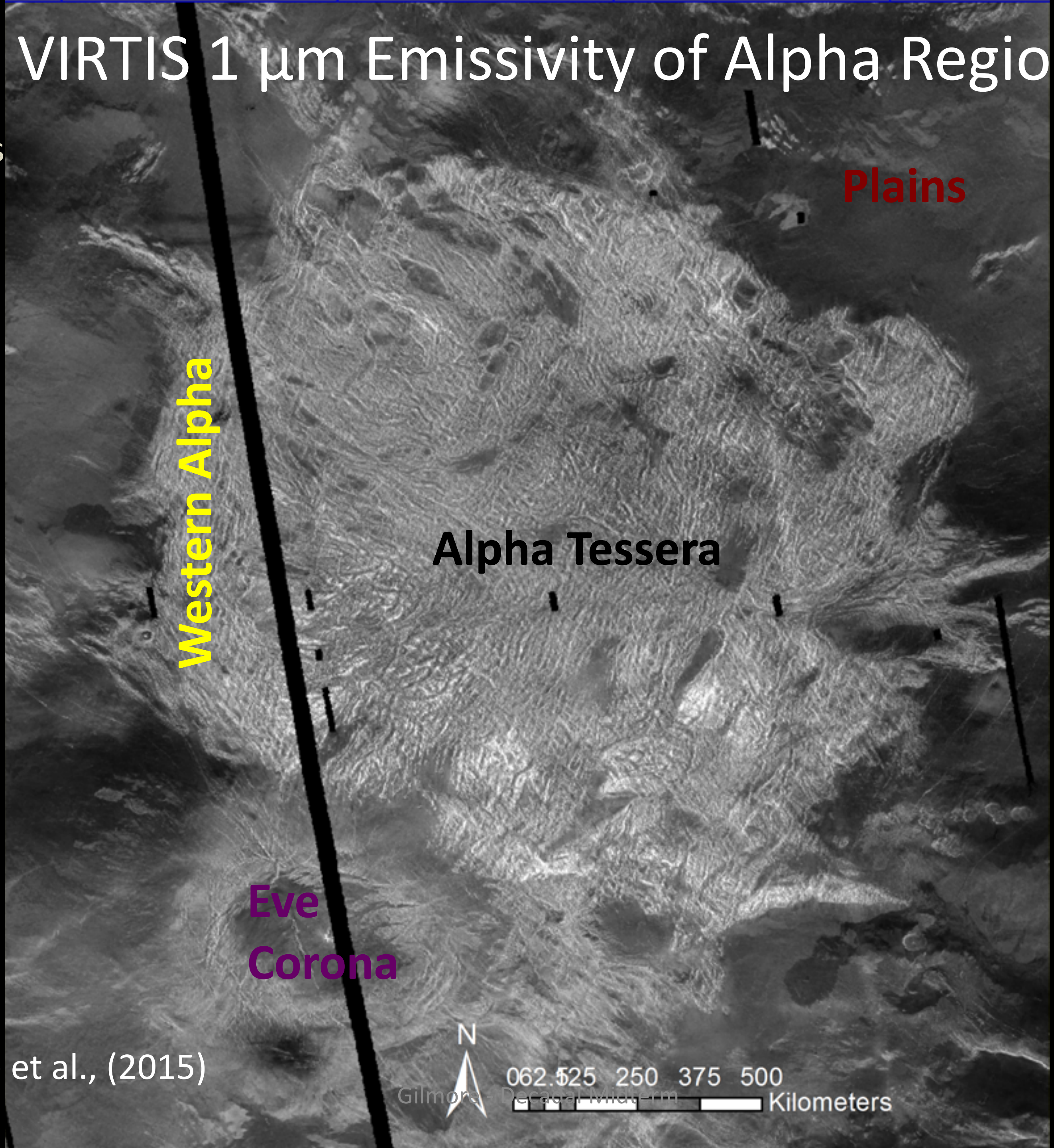


Gilmore and Head, 2000



VIRTIS 1 μm Emissivity of Alpha Regio

Alpha Regio
W. Alpha is deformed plains
(Gilmore & Head, 2000)
Can control for macroscale roughness, local effects



Gilmore et al., (2015)

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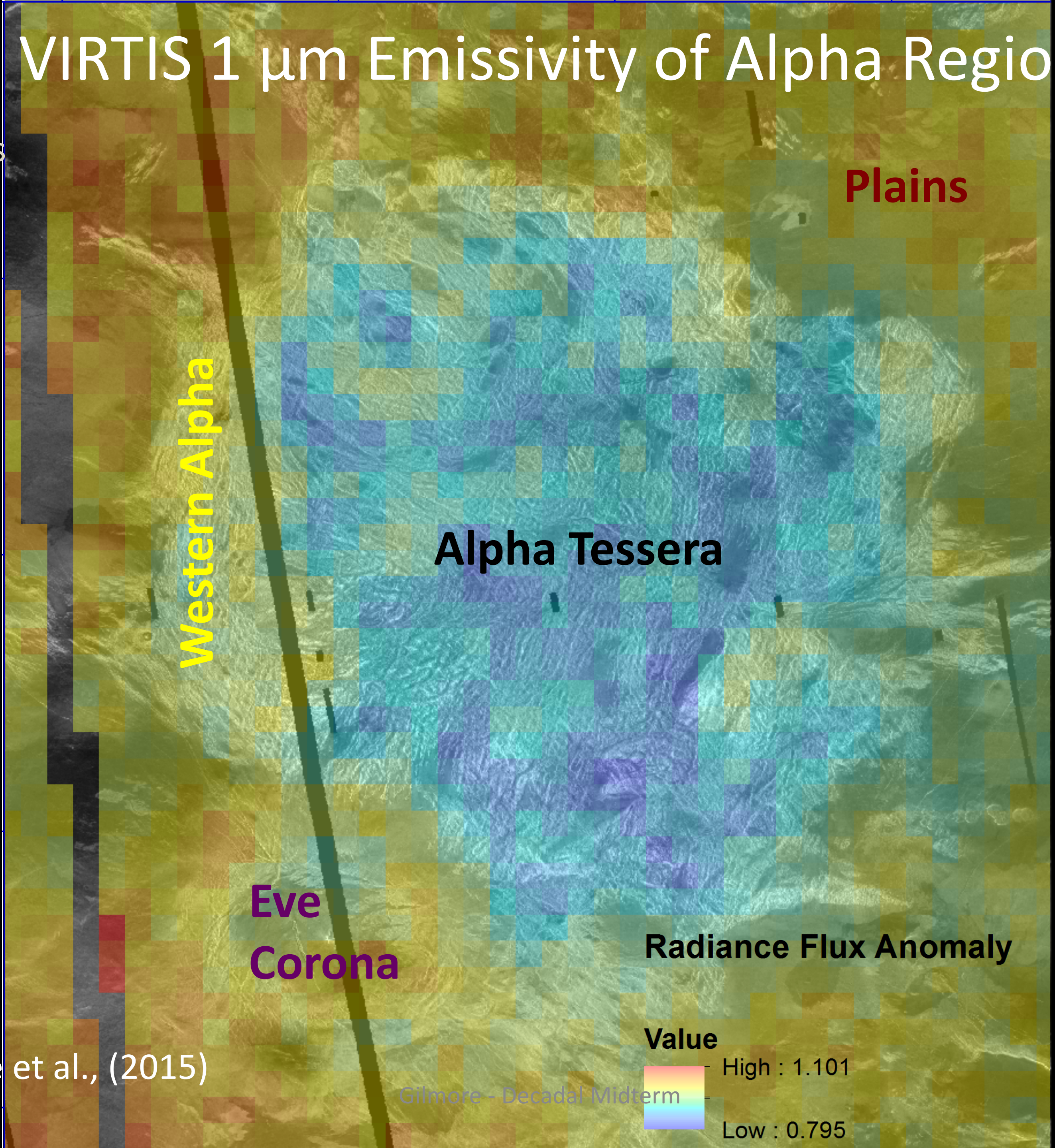

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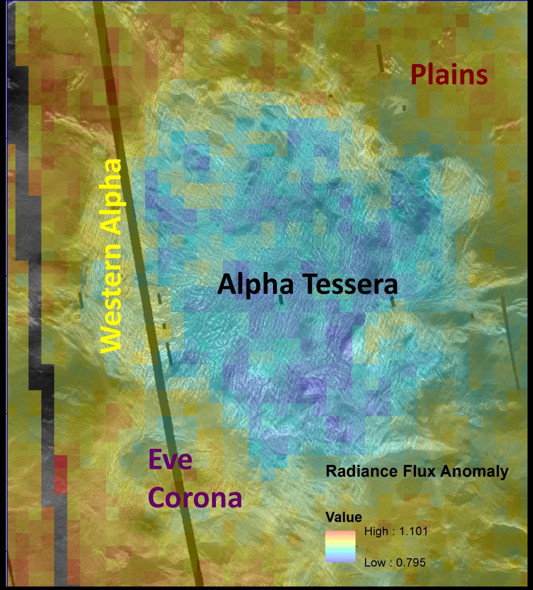
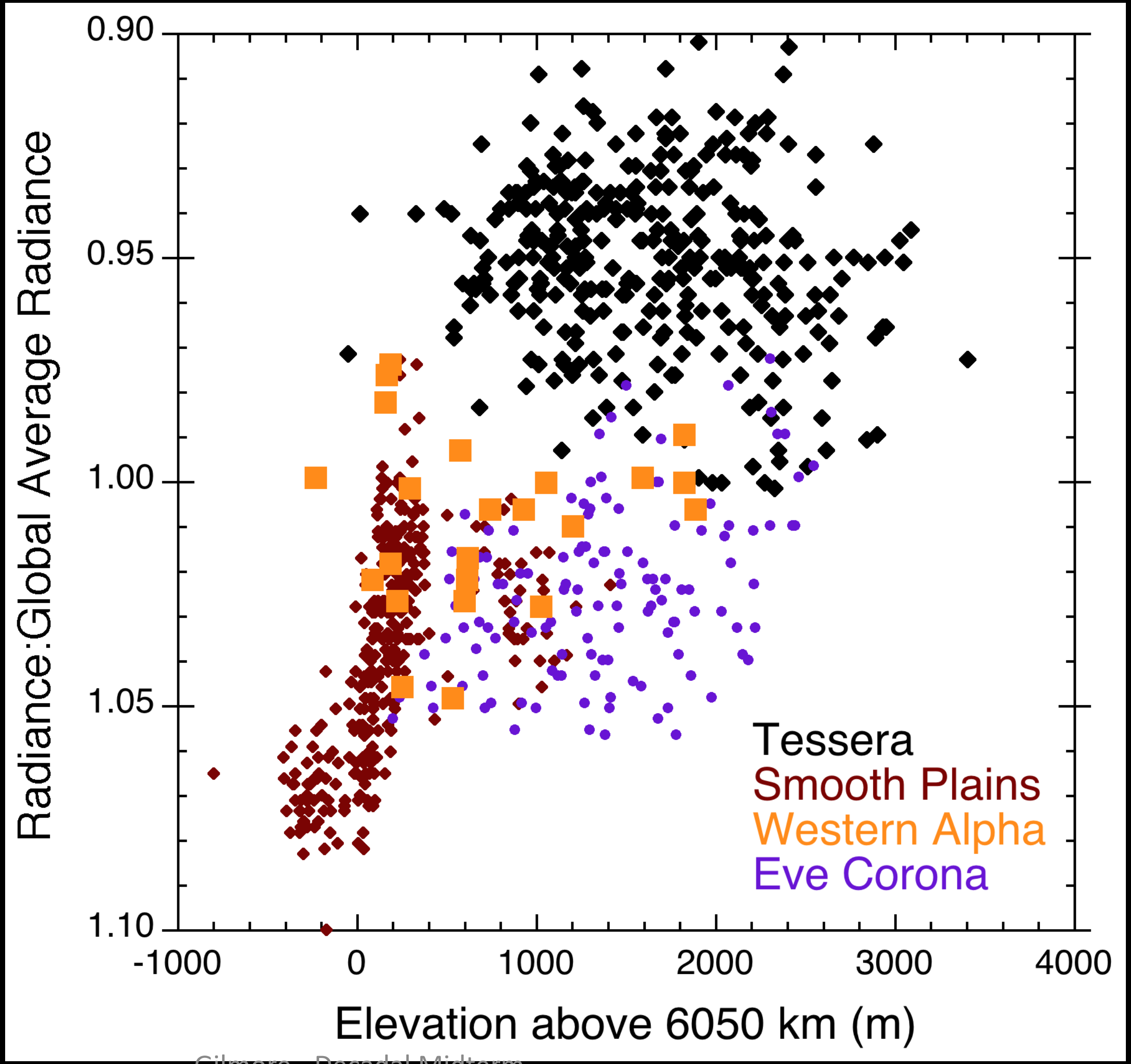
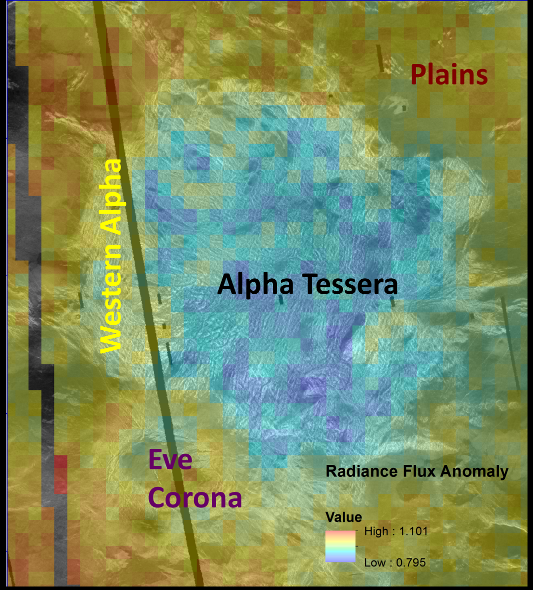


VEx VIRTIS radiance for Alpha Regio Region



Gilmore et al. 2015



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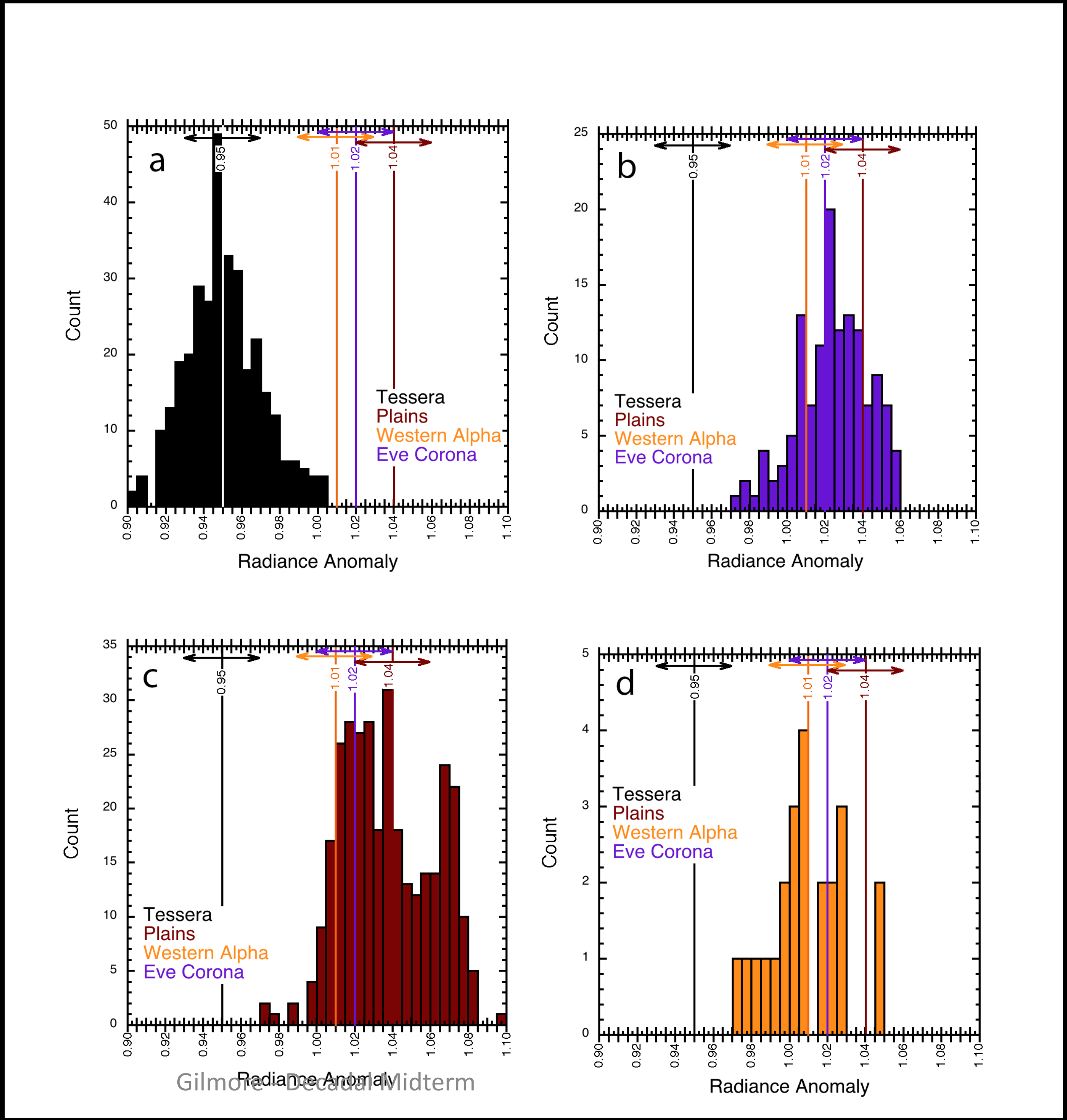

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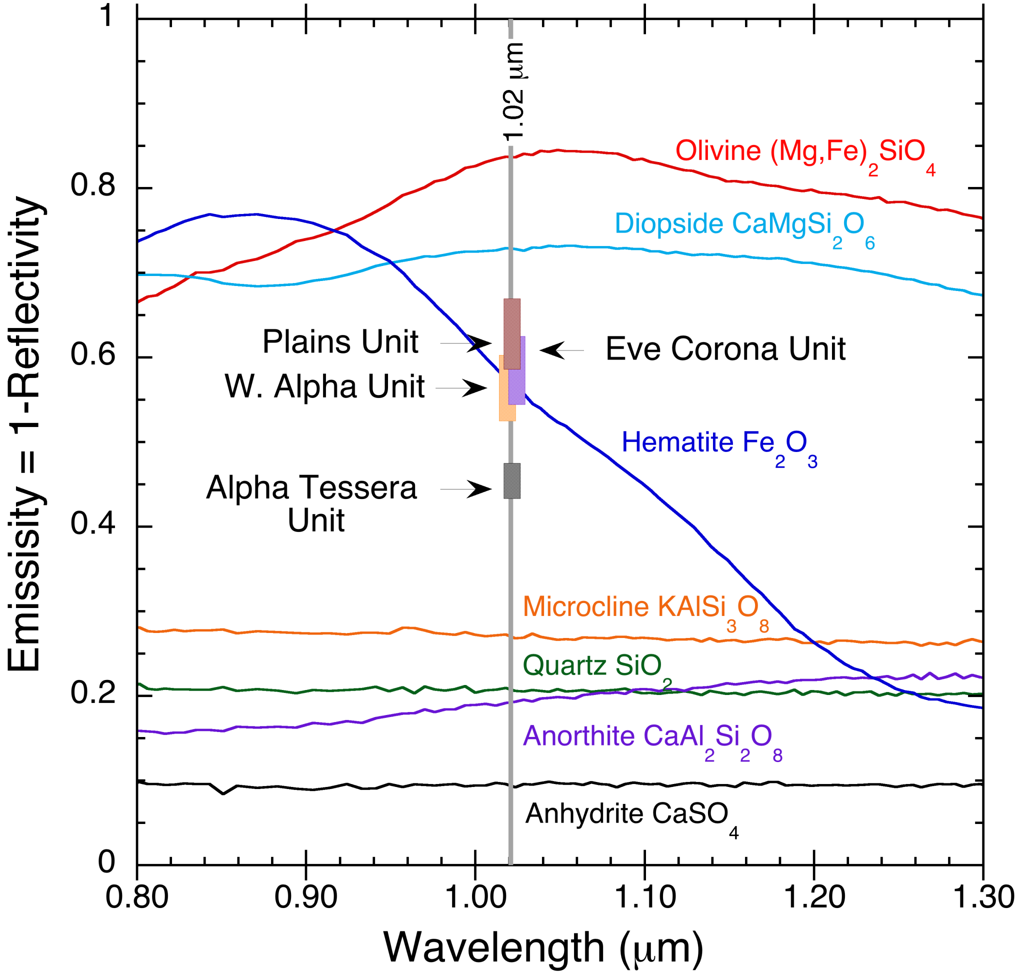
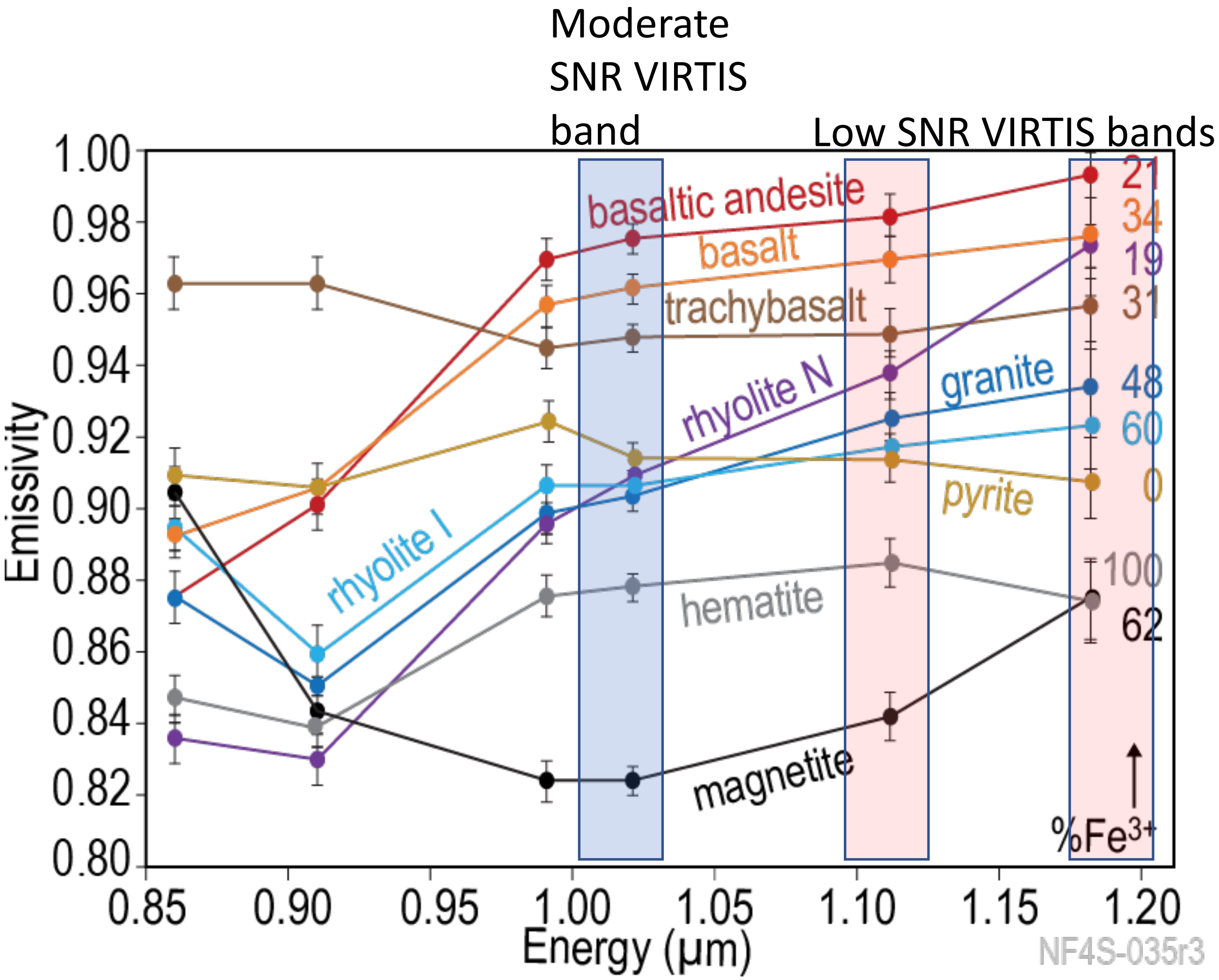


Room Temperature



Venus Temperature (DLR lab)

GEOPHYSICAL RESEARCH LETTERS, VOL. 10, NO. 11, PAGES 1061-1064, NOVEMBER 1983

NO WATER, NO GRANITES - NO OCEANS, NO CONTINENTS

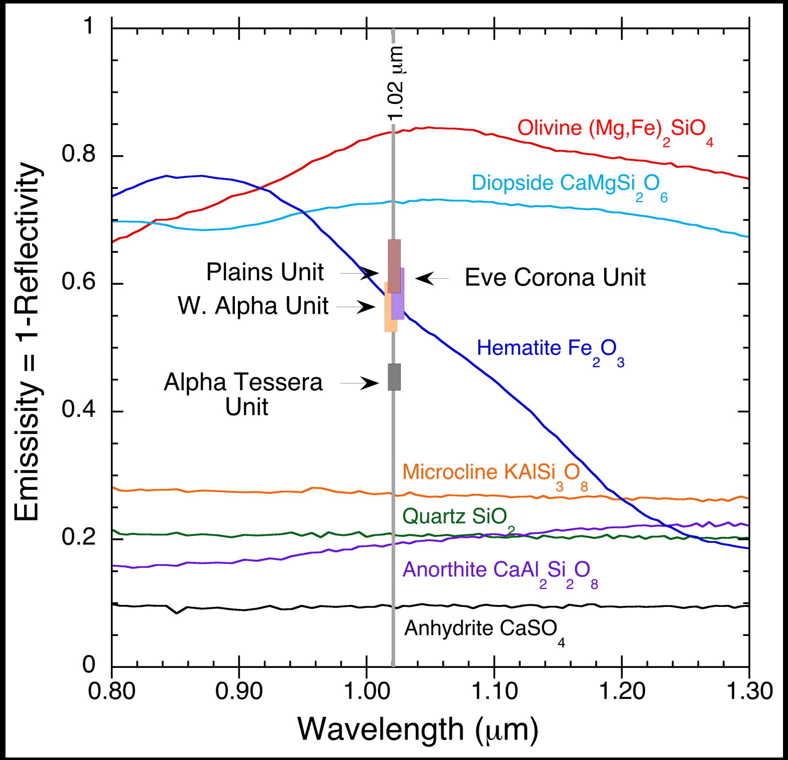
I.H. Campbell* and S.R. Taylor

"Our main thesis is simple. Water is essential for the formation of granites, and granite, in turn, is essential for the formation of stable continents. The Earth is the only planet with granite and continents because it is the only planet with abundant water."

Interpretation 1: the Tesserae are granitoids formed the common way

- Most Earth granitoids formed via melting of continental crust, sediments and/or peridotitic mantle in the presence of H_2O [e.g., Campbell and Taylor, 1983; Brown, 2013]. Settings:
  - Fractionation of hydrous mantle above subducting plate
  - Remelt older continental crust or seds by basaltic underplating or collision (e.g., Hubbert and Sparks, 1988, Thompson and Connolly, 1985)
  - Archean TTGs partial melting of hydrated basalts/eclogites (e.g., Martin et al., 2005)
  - Rare (~10^4 km^3) felsic eruptions on Earth associated with continental breakup (plumes) - such volumes requires the partial melting of hydrous lower continental crust materials [e.g., Bryan et al., 2002].
- To get continents' worth of granitic magma – need **water** and **recycling**. Recycling invoked in Venus's past (Parmentier and Hess, 1992; Turcotte et al, 1999) and present (Elkins-Tanton et al., 2007). Therefore, likely limited to lifetime of water on Venus.

Interpretation 2: the Tesserae are mafic…..but weathered differently



Treiman and Schwenzer (2009)

diopside + atmospheric S ↔ anhydrite + enstatite + quartz

$CaMgSi_2O_6 + SO_3 \leftrightarrow CaSO_4 + MgSiO_3 + SiO_2$

plagioclase + atmospheric S ↔ anhydrite + andalusite + quartz

$CaAl_2Si_2O_8 + SO_3 \leftrightarrow CaSO_4 + Al_2SiO_5 + SiO_2$

Zolotov (2007)

Fe silicates + atmospheric (S,CO_2,H_2O)? -> magnetite -> atmospheric (S,CO_2,H_2O)? -> hematite

Elevate pH_2O get everything to completion and more

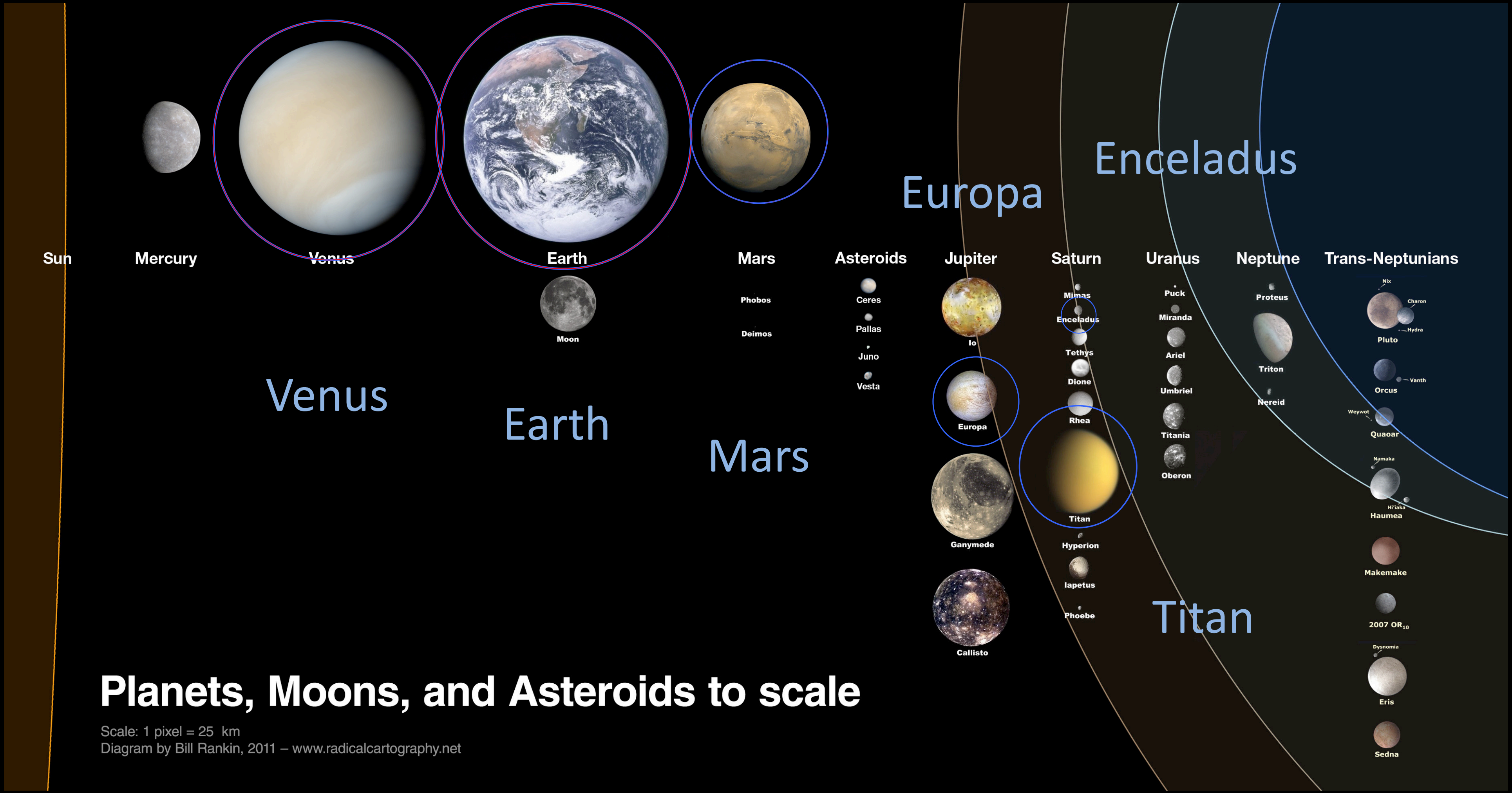
Weathering during plains emplacement? On ancient Venus?

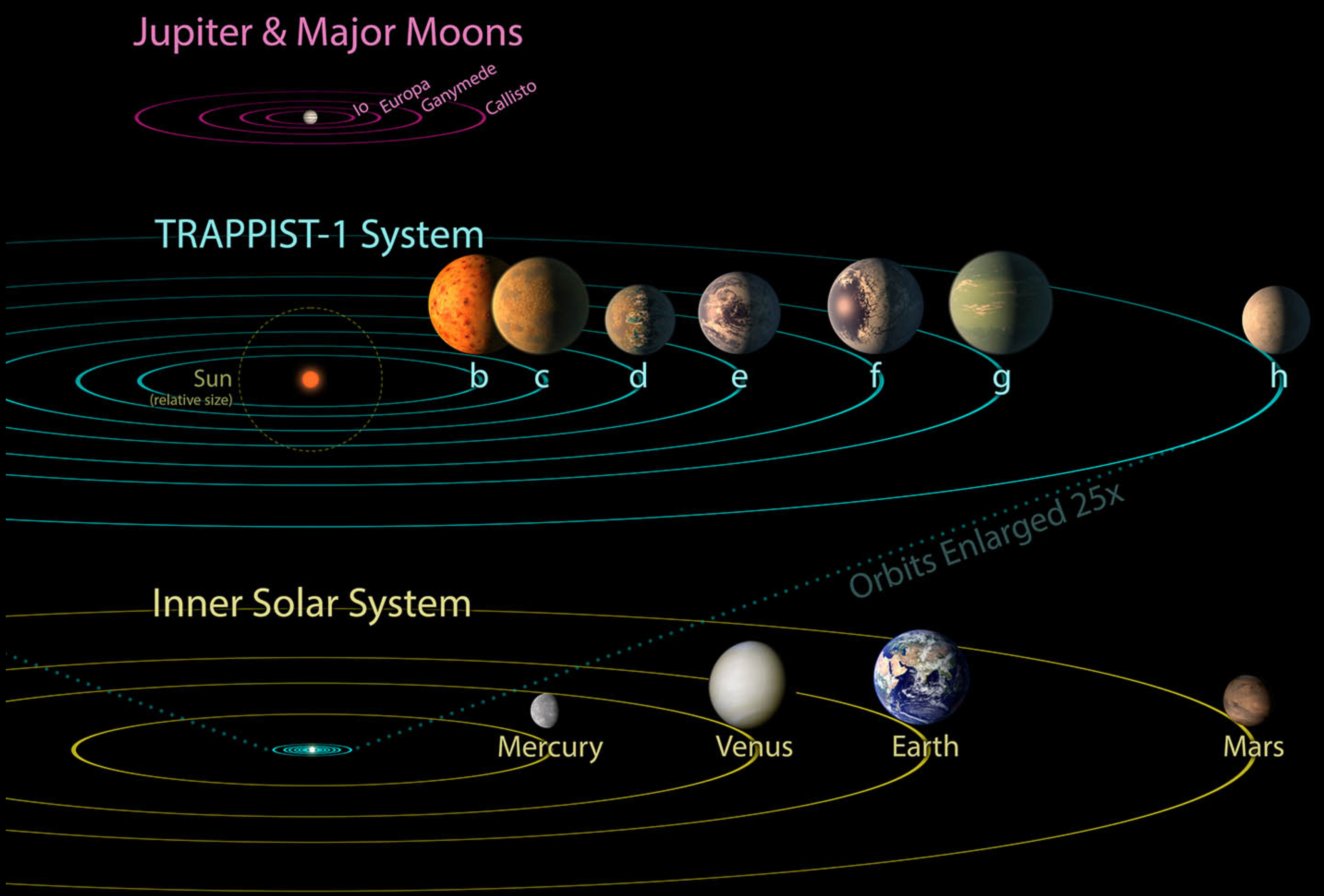
The tesserae are not igneous?

Conclusions so far

- The tesserae are the oldest rock on Venus. They represent of period of high strain immediately prior to the global emplacement of presumably basaltic plains.
- The emissivity of the tesserae is different than the plains.
- Subject to verification with improved spectral libraries and topography, this signature corresponds to felsic mineralogy or weathered basalts.
- The tesserae experienced a different history than the plains and likely to each other.
- There is no age constraint on the tesserae, yet.
- **Critical need for higher resolution imaging, topography and surface mineralogy as has been proposed in Discovery and New Frontiers**

Habitable Worlds in a Habitable Solar System




Jupiter & Major Moons
Io
Europa
Ganymede
Callisto
TRAPPIST-1 System
Sun
(relative size)
b
c
d
e
f
g
h
Orbits Enlarged 25x
Inner Solar System
Mercury
Venus
Earth
Mars

THE ASTROPHYSICAL JOURNAL

ATMOSPHERIC CHEMISTRY OF VENUS-LIKE EXOPLANETS

Laura Schaefer and Bruce Fegley Jr

Published 2011 February 4 •

The Astrophysical Journal, Volume 729, Number 1

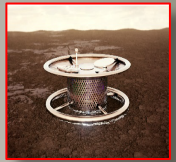
6. CONCLUSIONS

Based on our surface–atmosphere equilibrium model, we can say that planets similar to Venus (i.e., thick CO_2 atmospheres with only trace water) are more likely to be colder than Venus rather than hotter. Hotter planets should have significantly more water in their atmospheres and generally will have higher total pressures. Hot felsic planets will have relatively large pressures and HF abundances, with less water and HCl than similar mafic planets. Planets colder than Venus are more geochemically plausible. These planets will generally have lower total pressures than Venus and may have water vapor abundances similar or larger than Venus. Cold felsic planets will have higher total pressures, HCl, and HF abundances, but lower H_2O abundances than similar mafic planets.

40 years

NASA
Magellan
1989-1994

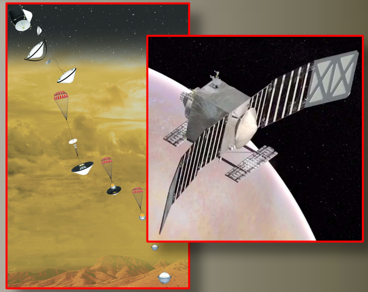
US Missions



SmallSats?

Venus Bridge?

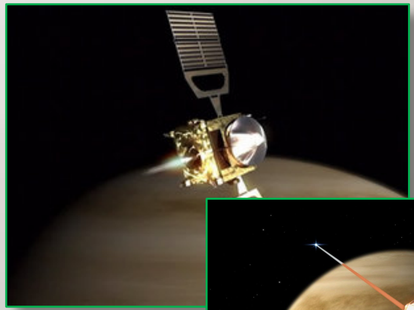
New Frontiers?
Discovery?



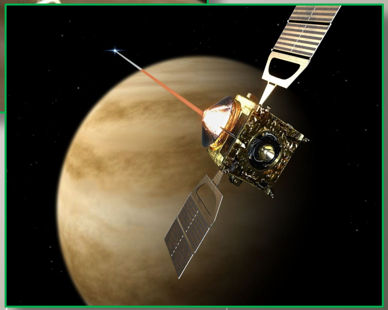
Venus Flagship?

International Missions

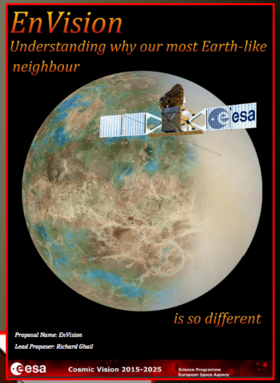
ESA
Venus Express
2005-2014



JAXA
Akatsuki
2010-present



RSA
Venera D
2026+?



ESA
Envision
2031?

1990 1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045

Venus Bridge Charter

- VEXAG has been directed by NASA's Science Mission Directorate Associate Administrator to determine if useful Venus exploration can be performed within a $200M cost cap.

- Specifically, VEXAG will determine if one or more small missions can perform important science investigations, as defined in VEXAG Goals, Objectives, and Investigations (GOI: www.lpi.usra.edu/vexag/reports/GOI-2016.pdf) with launch dates in the early-to-mid 2020s

- The VEXAG Venus Bridge Focus Group was established to develop the Venus Bridge concept and determine if it is feasible. The members are
  - Jim Cutts, Lead, Jet Propulsion Laboratory
  - Robert Herrick, University of Alaska
  - Gary Hunter, NASA Glenn Research Center
  - Kandis Lea Jessup, South West Research Institute
  - Martha Gilmore, Wesleyan University
  - Robert Grimm, South West Research Institute
  - Robert Lillis, UC Berkeley
  - Noam Izenberg, Applied Physics Laboratory
  - Thomas W. Thompson, Jet Propulsion Laboratory

Venus Bridge Focus Group - Status

- Conducted a series of telecons to identify potential mission ideas between late March and early May
- Conducted a Venus Bridge A-Team Study, May 19, 2017
  - Presented science concepts developed by the Focus Group
  - Worked with engineering experts on
    - Feasibility of different options for getting to Venus
    - Deep space telecommunications for smallsats and cubesats
    - Relay telecommunications for cubesats, probes, aerial platforms and landers
    - Cost issues for cubesat and smallsat missions
- Venus Focus Group is now directed towards
  - Defining mission concepts for Team X/Compass studies
  - Planning a briefing to VEXAG at the November meeting
  - Completing a report by January 2018

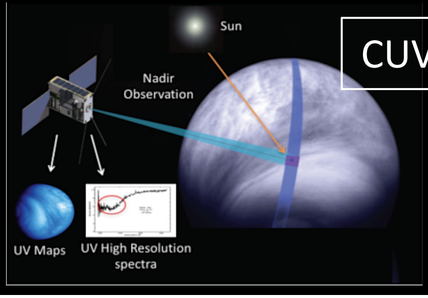
Mission Study Needs, Plans and Gaps

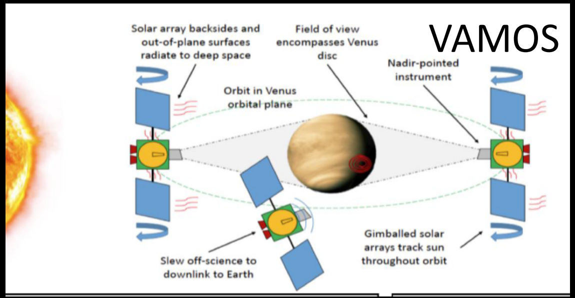
Observational Vantage Points identified by Focus Group

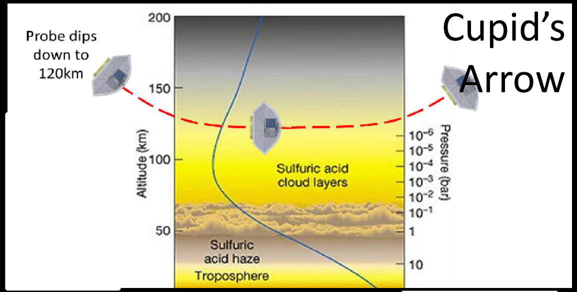
- Orbital – Elliptical
- Orbital – Circular
- High Atmosphere - >100Km
- Mid Atmosphere ~55 km
- Lower atmosphere and surface

PSDS3 Funded Venus studies 2017-18

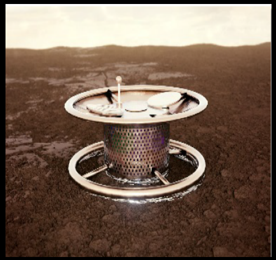
CUVE







SAEVE



Candidates for Team X COMPASS Studies

- Telecom relay orbiter
- Deep small probe
- Balloon cubesat class
- Cubesat aerocapture

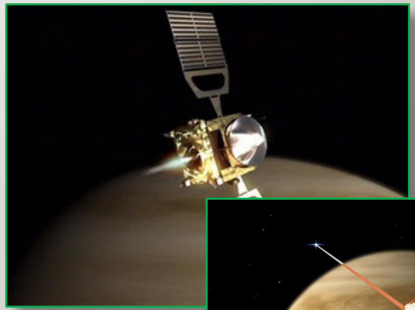
PSDS3=Planetary Science Deep Space Smallsat Studies

Backup slides

NASA
Magellan
1989-1994

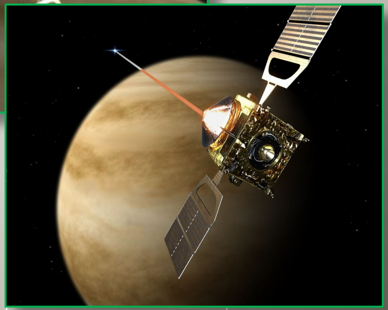
US Missions

ESA
Venus Express
2005-2014



International Missions

JAXA
Akatsuki
2010-present



1990 1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045

92 bars, 735 K

Venus now

Way et al predict a clement Venus as a function of composition, irregardless of the mechanism or timing of D:H loss. It’s Venus’ birthright!

1 bar, 287 K

Earth Now,
Venus maybe for ~3 Ga
Snow! Sediments! Rivers!

0.006 bar, 250 K

Mars, now

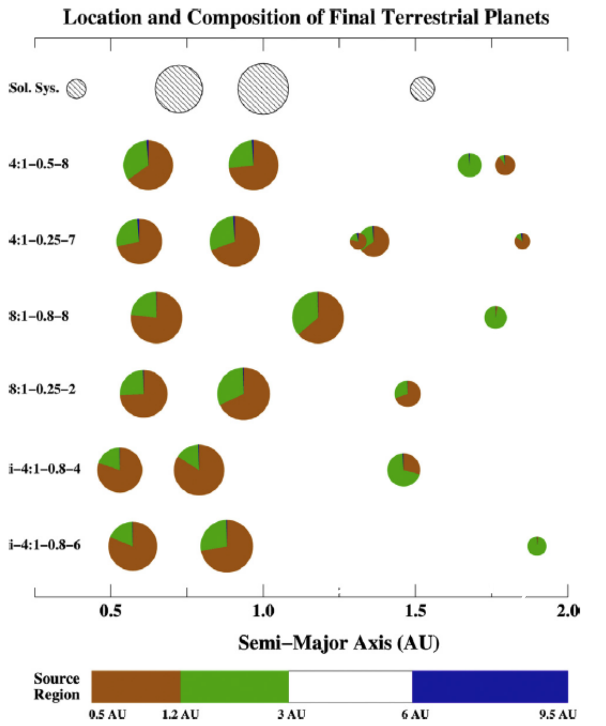
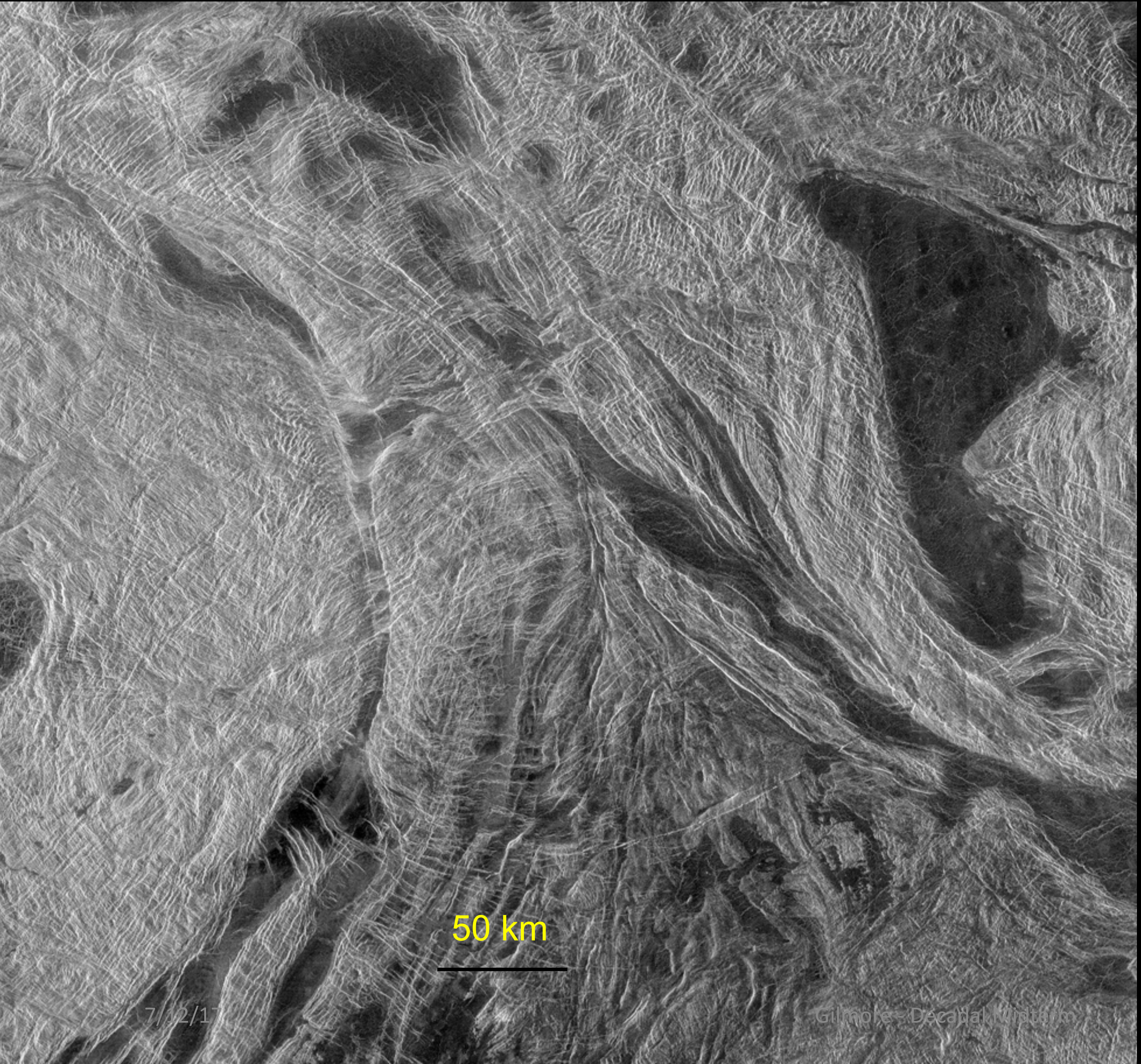
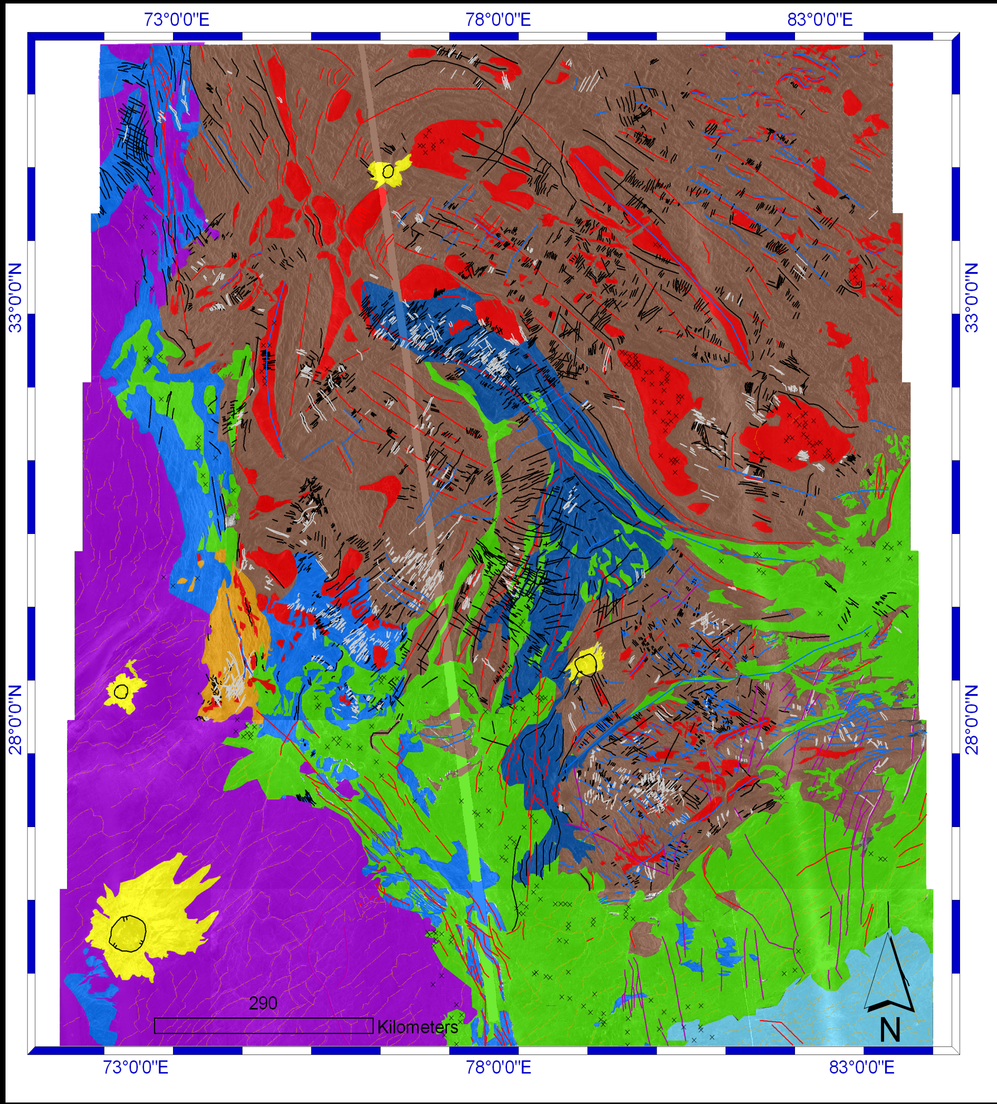


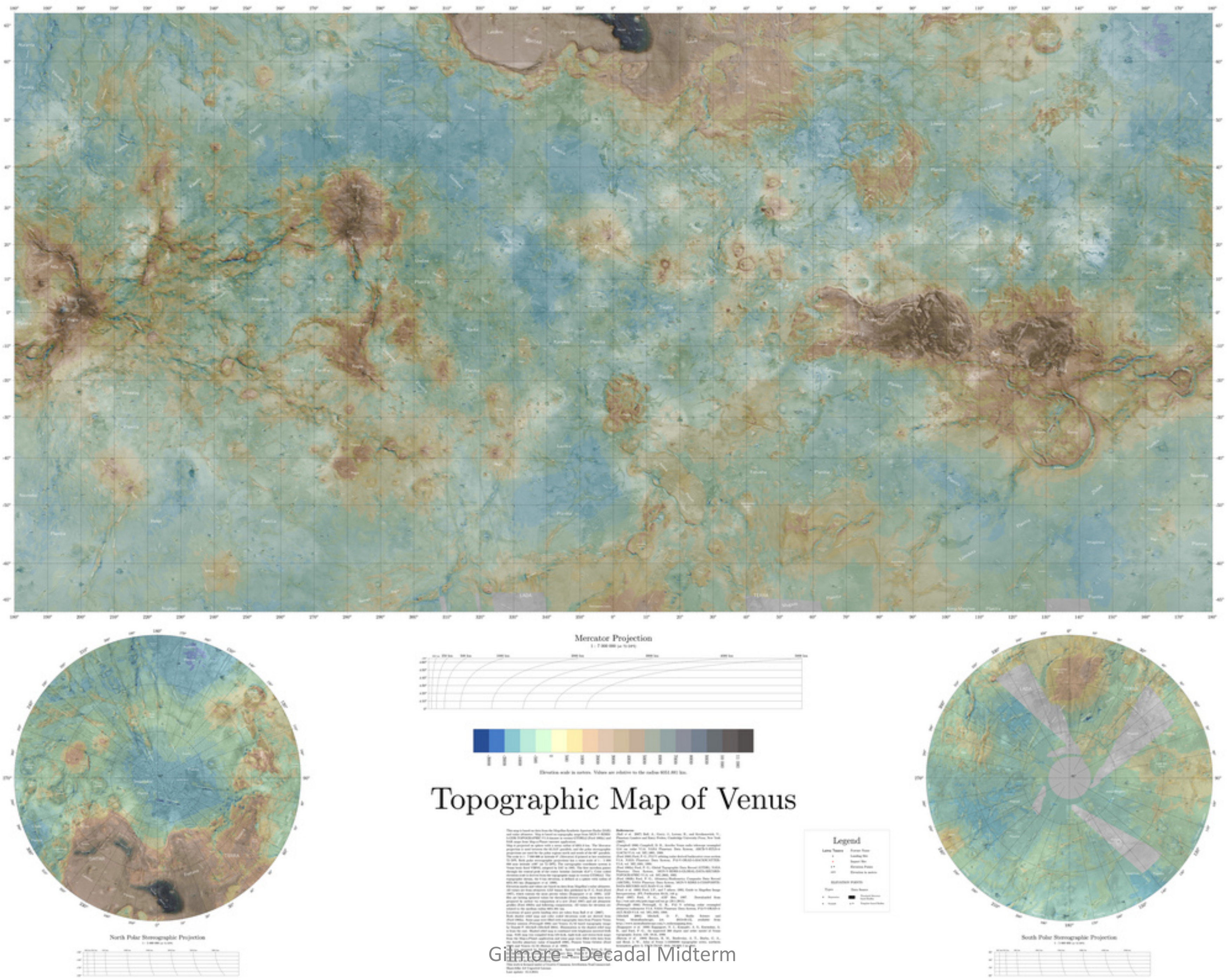
Fig. 1. Mass and location of the final planets in the six Grand Tack simulations of this study. The actual planets of the Solar System are shown at the top for comparison. The colored segments show the proportions of accreted material that originates from 0.5 to 1.2 AU (brown), 1.2 to 3 AU (green) and 6 to 9.5 AU (blue), respectively. Note that no material originates between 3 and 6 AU because the formation of Jupiter and Saturn cleared all bodies from this region. (For interpre-

SW Tellus Regio





Straley & Gilmore, 2007


Mercator Projection
Topographic Map of Venus
Legend
North Polar Stereographic Projection
South Polar Stereographic Projection