



Venus: The Forgotten, Mysterious Planet

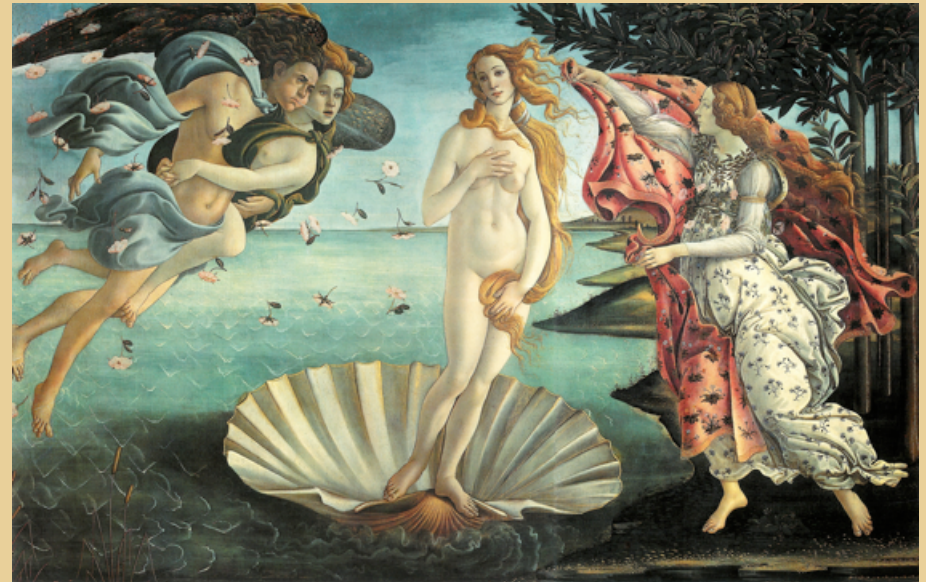
Dr. Lori S. Glaze

NASA's Goddard Space Flight Center

September 27, 2017

Why are we so fascinated by Venus?

- Venus was one of the first 'wanderers' identified by early astronomers; important in many early mythologies
- Venus is the brightest object in the night sky (other than the moon)
- Unique in the way she appears to jump from evening to morning sky and in how in sync she is with Earth: 13 Venus years = 8 Earth years



Botticelli's "Birth of Venus": born of the foam from the sea after Saturn castrated his father Uranus and his blood fell to the sea.

Venus today (at sunrise)!

Venus is currently the Morning Star

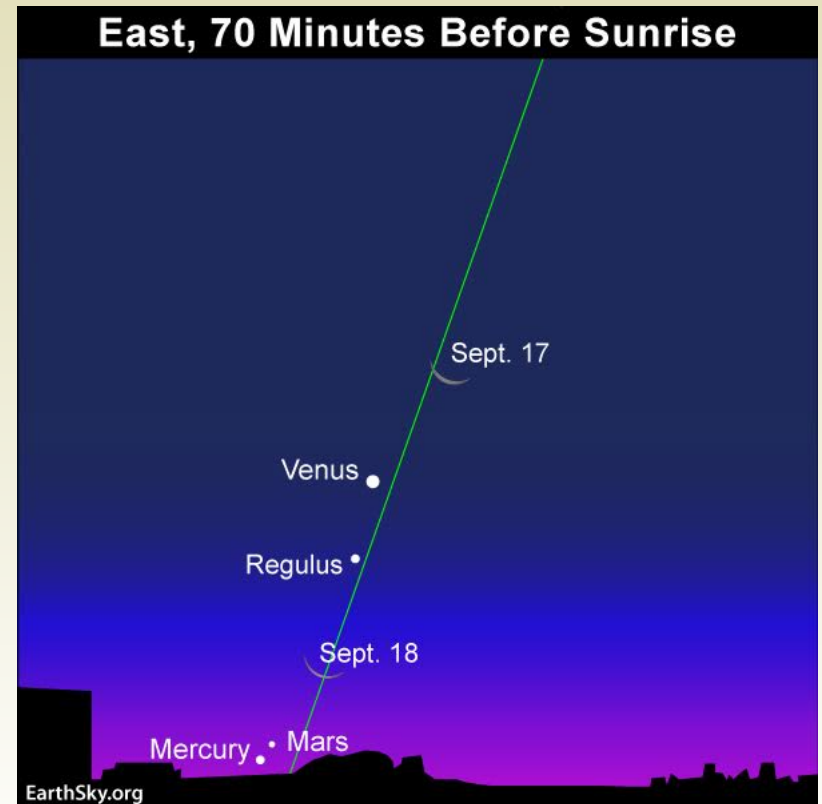
- August was pinnacle of current visit
- Venus rises a couple hours before sunrise

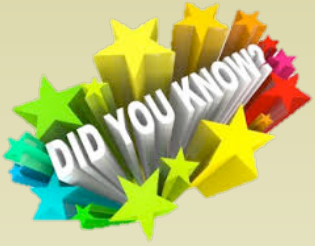
Venus disappears in December

- Not visible for 2 months while she passes behind the sun

Venus as the Evening Star

- Venus will reappear in February in the evening sky

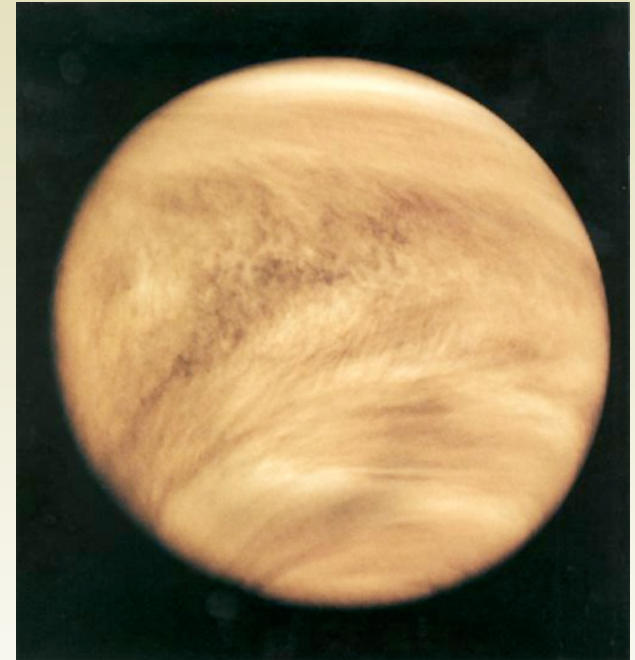




Venus fun facts

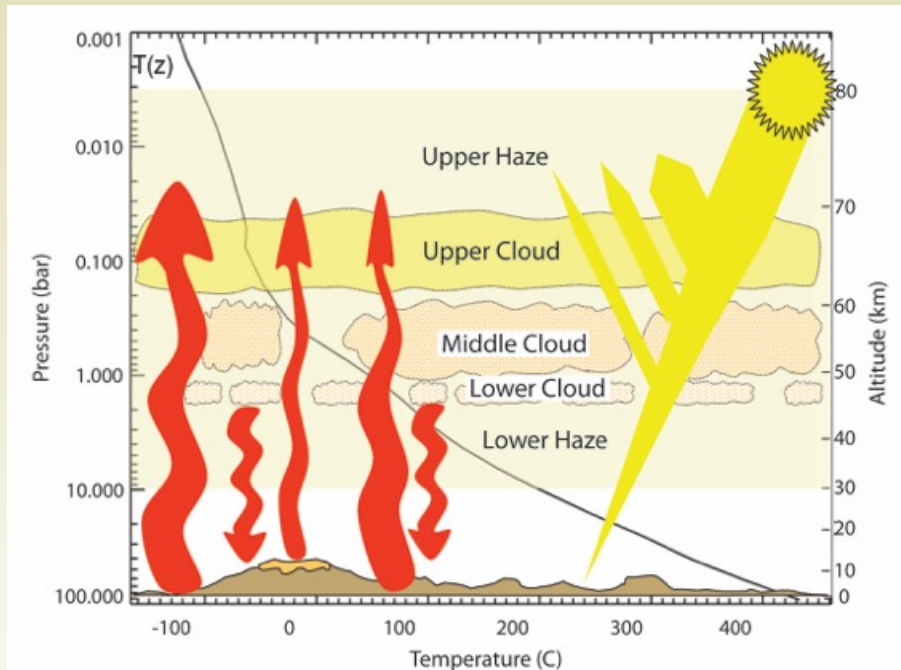


- Venus is almost the same size as Earth (85% Earth's radius; 91% Earth's gravity)
- Venus' "day" is longer than its "year"
 - 1 "year" = 225 Earth days
 - 1 "day" = 243 Earth days
 - Almost perfectly spherical
- Venus rotates backward (retrograde)
- Venus has no seasons
 - Venus' rotation axis is close to vertical (relative to orbital plane)
- Venus has no magnetic field



Venus shrouded in continuous cloud cover

Venus' atmosphere: Earth's evil twin?



Only 10% of incident sunlight reaches the surface.
Surface visibility is like Earth on a very cloudy day.

Very strong greenhouse effect

Atmosphere is 96.5% carbon dioxide

Like a pressure cooker

Surface temperature = 860°F (460°C)
melts lead!

Surface pressure = 92 bar is like being
~ ½ mile deep ocean!

Ferocious winds

Wind speed = >250 mph

60x Venus rotation rate

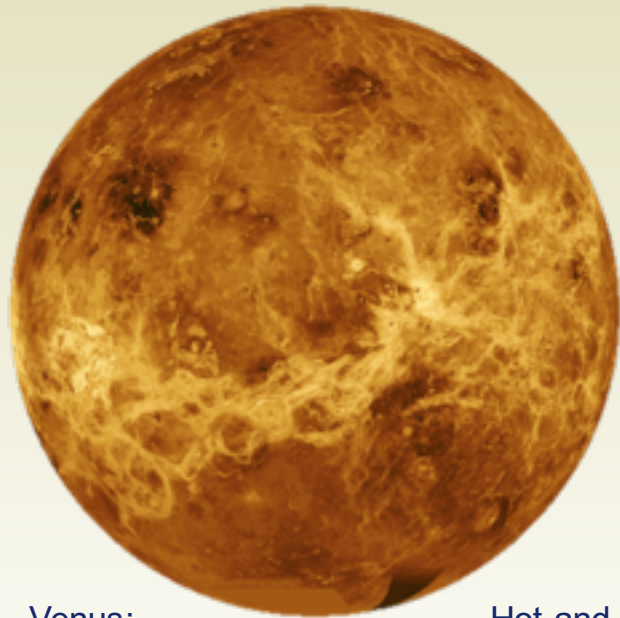
All west, all the time

Only ~2 mi/hour at the surface

Corrosive sulfuric acid clouds

~15 miles thick

Despite similar origins, sizes and masses, Venus and Earth evolved differently:



Venus:

Hot and Dry

When
and
Why?



Earth:

Cool and Wet



> 3,500 Exoplanets have been confirmed
(as of 9/20 [NASA Exoplanet Archive] – growing every day)

Hundreds of these exoplanets are in the Earth-Venus-Mars size range. But, data are lacking to understand where these planets fit along evolutionary pathways.

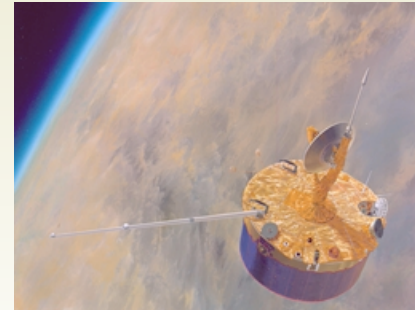
Brief history of Venus exploration

- Venera (USSR; 1961 - 1983)
 - Multiple probes/landers



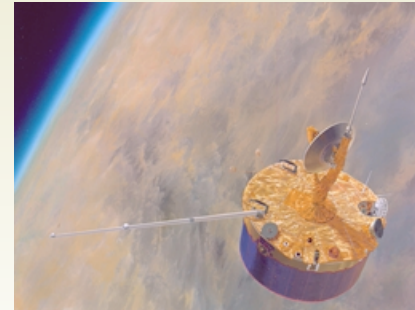
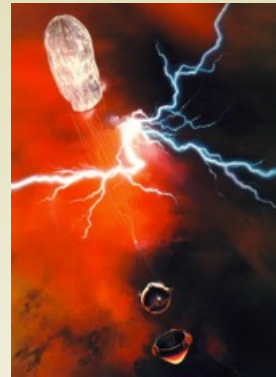
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 - Orbiter



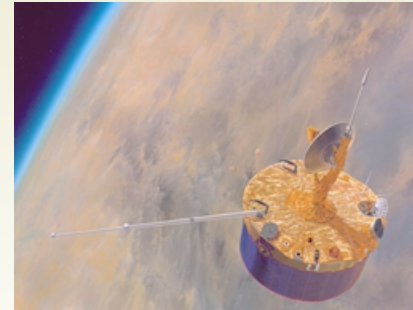
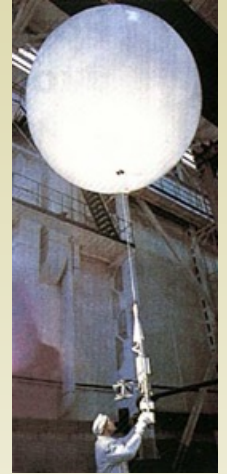
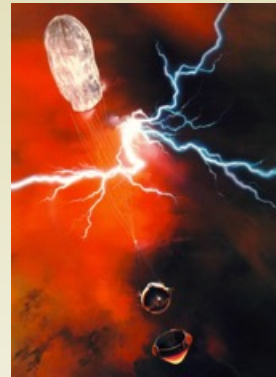
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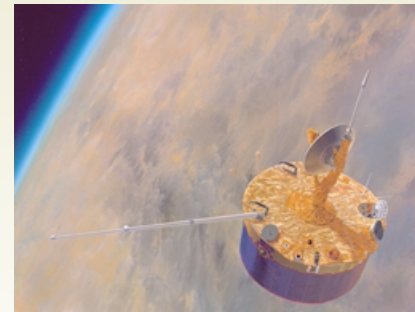
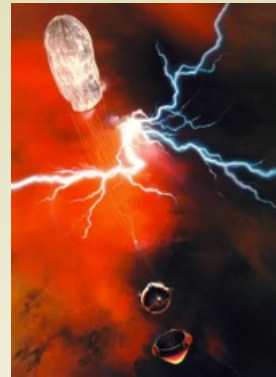
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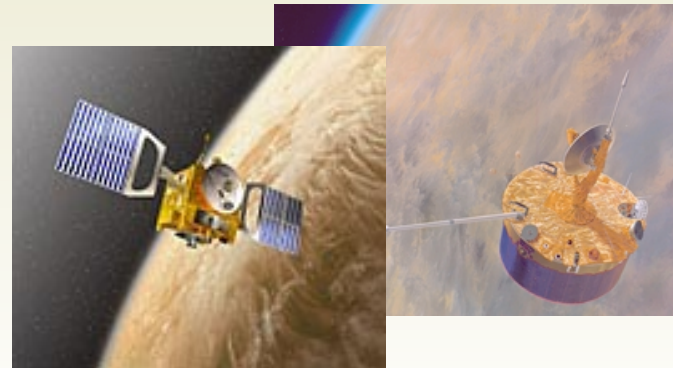
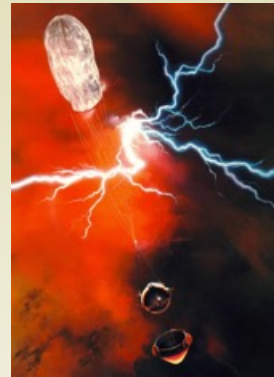
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 - Orbiting radar



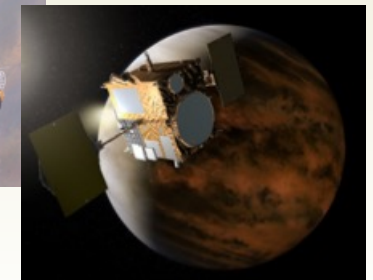
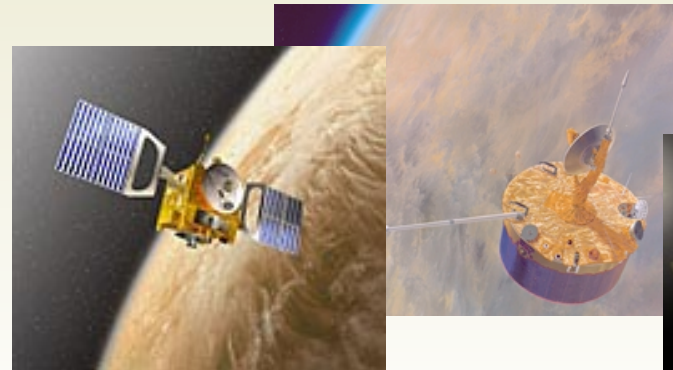
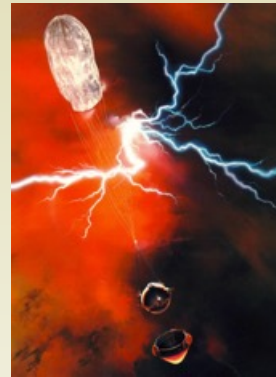
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- Venus Express (ESA; 2006 – 2014)
 - Orbiter, cloud chemistry & dynamics



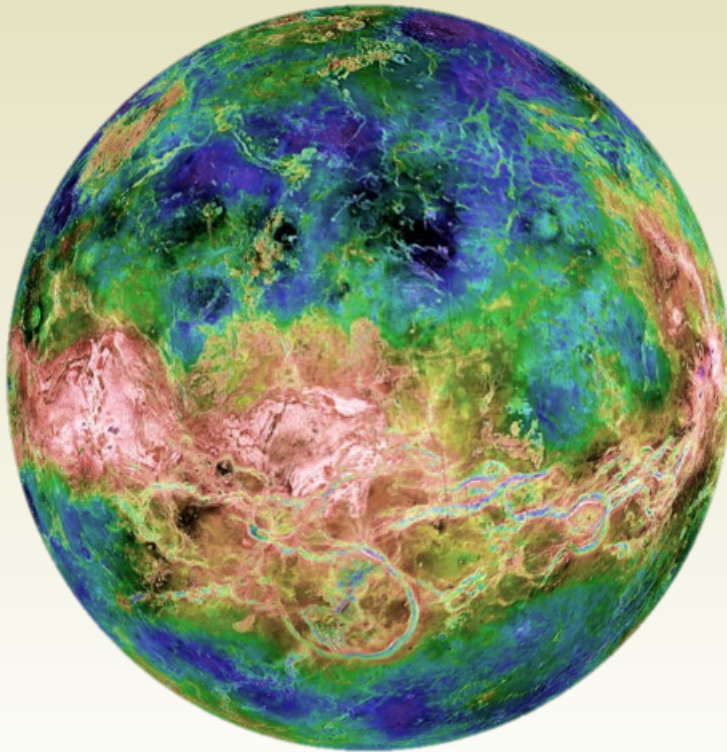
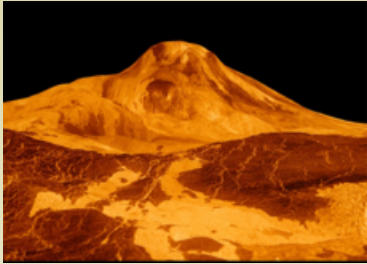
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- Akatsuki (JAXA; 2015 – ?)
 - Orbiter, meteorology & lightning



What we've learned so far...

Venus & Earth have been volcanically active,
but the tectonics are very different



Venus: One "Plate"

Venus does not
have plate
tectonics

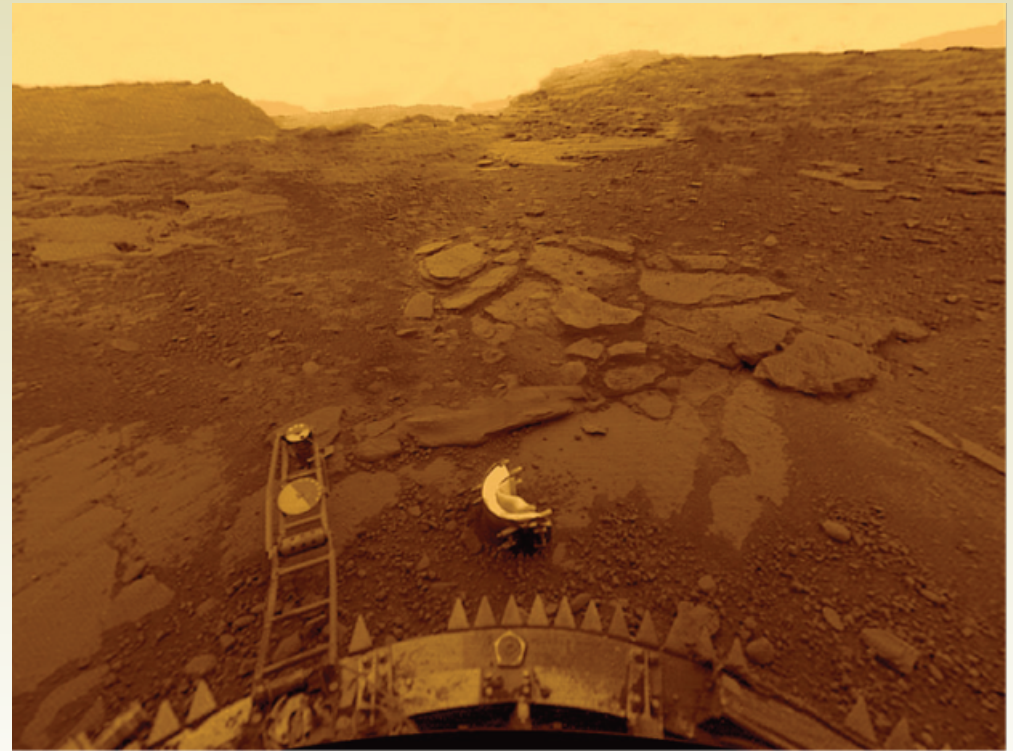


Earth: Plate Tectonics

What does the surface look like?

The only direct views of local-scale geology are from Venera images, acquired >30 years ago for four landing sites in the volcanic plains

Because of the thick cloud cover, the only global images we have of Venus are from radar – difficult to interpret

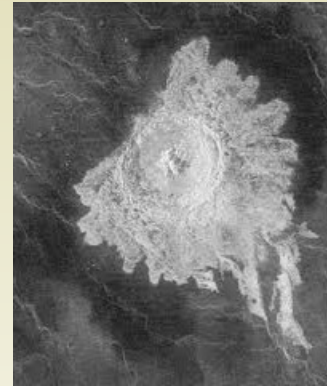


Venera 13 surface image

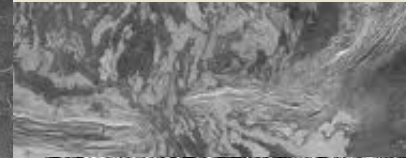
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Venus' surface: Mystery history

- 80% of the surface is volcanic plains (basalt, from Venera)
- Fewer than 1000 impact craters
 - All are fresh & randomly distributed
- Average age of plains is 500 million years old – everywhere
 - Was this a “recent” global resurfacing?
- “Tesserae” are high-elevation, complex ridged terrains
 - No known analog in our solar system.



Revealed by Magellan Radar



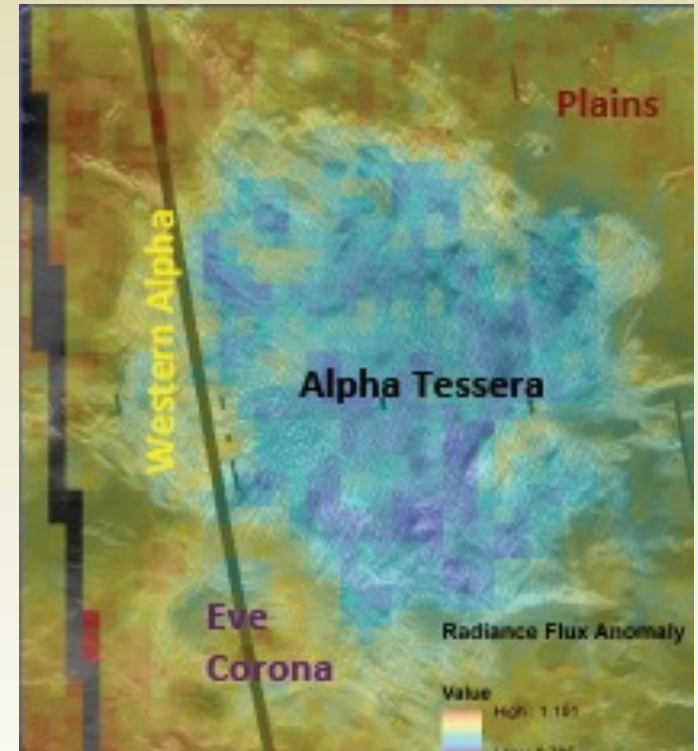
Have the surfaces of Venus and Earth always been so different?

What are tesserae?

Appear to be “older” than the plains based on stratigraphy

Are they a different kind of rock? Maybe more silica-rich, like Earth’s continents?
Venus Express seems to indicate yes

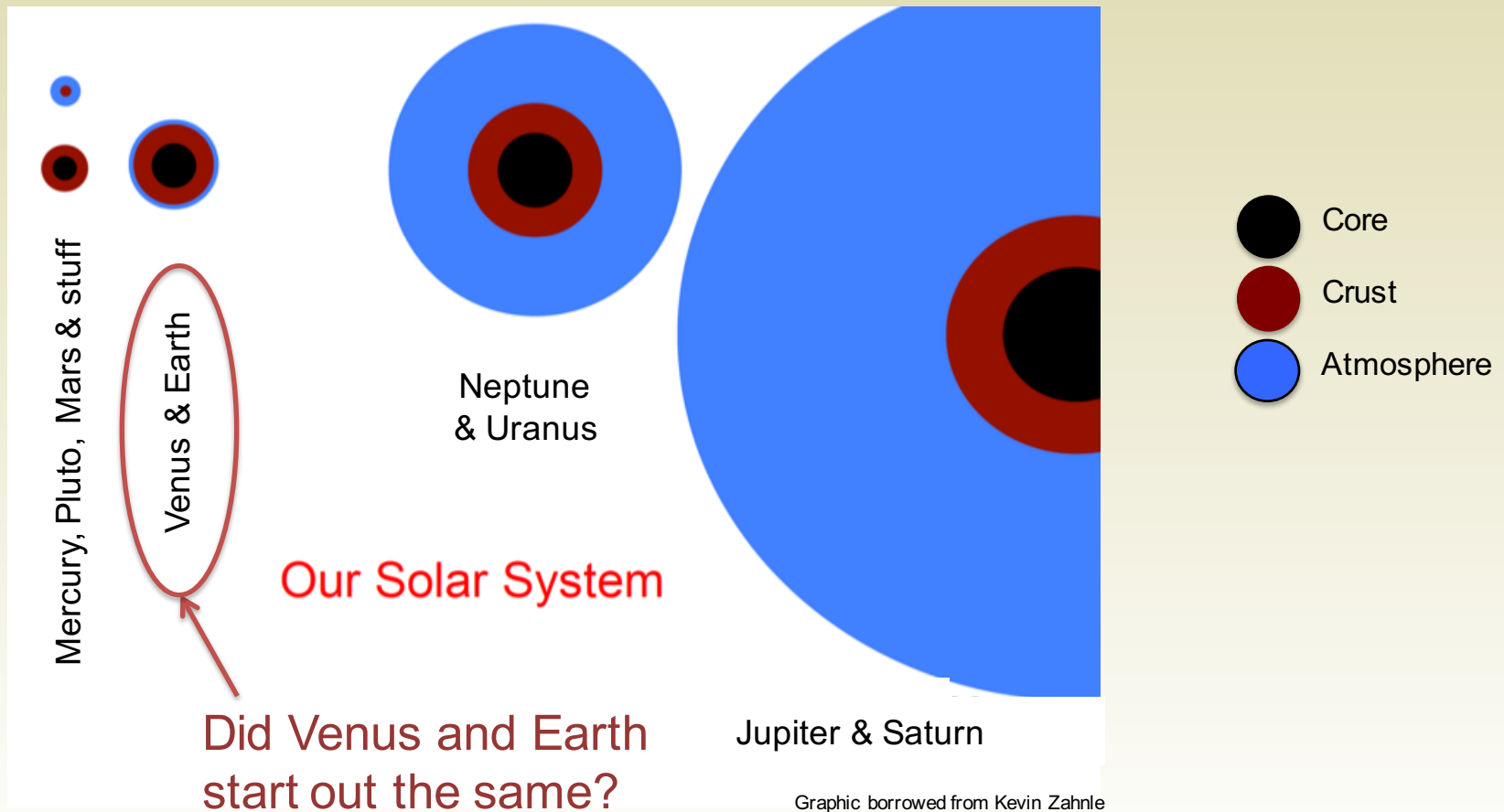
Formation of Earth’s continents required plate tectonics AND oceans. What does this mean for Venus?



Infrared data from Venus Express
[Gilmore et al., 2015]

Elemental chemistry and mineralogy could distinguish mafic versus felsic origin.

Planets in our Solar System



Origin of Venus' atmosphere

- **Neon and argon:** Consistent with Earth and Venus being made from same stuff
- **Krypton:** Story falls apart!
 - Pioneer and Venera discrepant by a factor of 15
- **Xenon:** No measurements of any kind!!
 - Critical to understand if Venus' origin was different from Earth, setting it off on a unique path

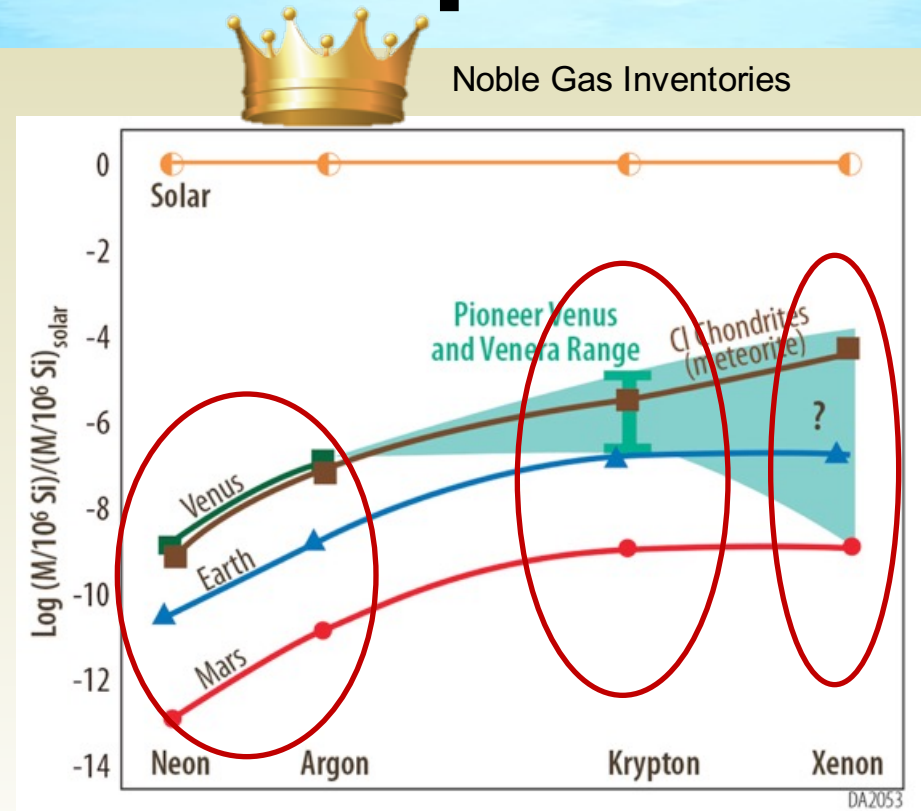
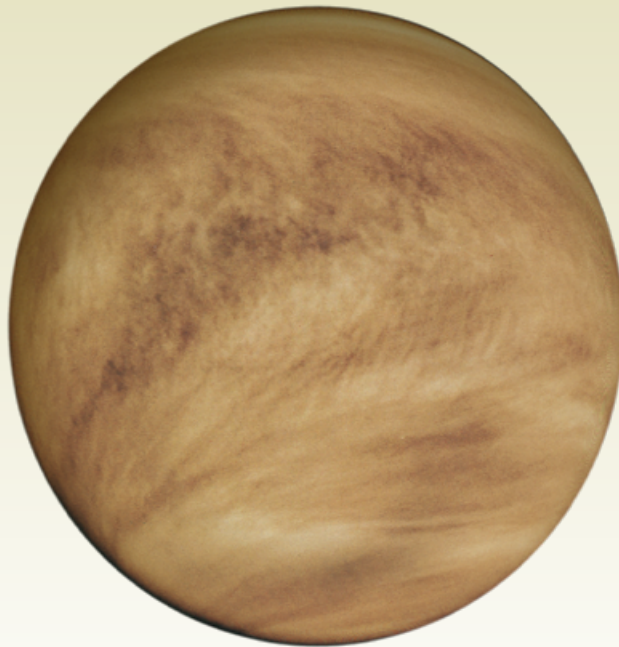


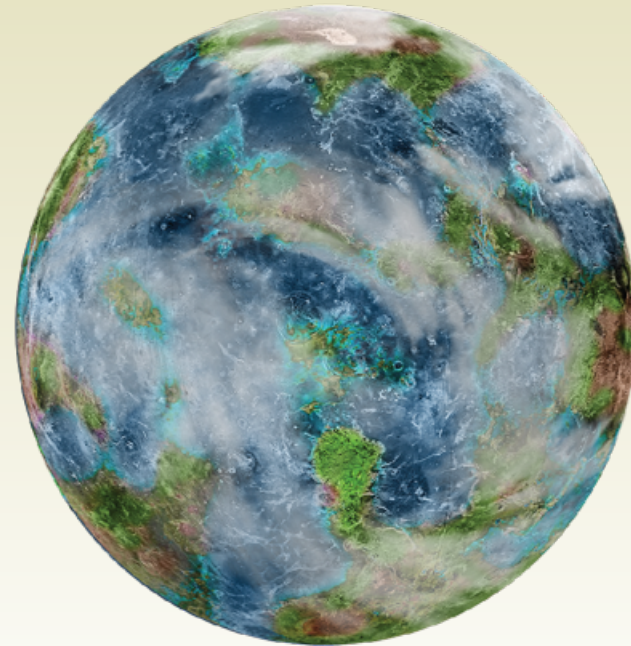
Figure after Baines et al. [2013]

How recently was Venus an ocean world?

Deuterium/Hydrogen enables transformational understanding of oceans on Venus



Venus today



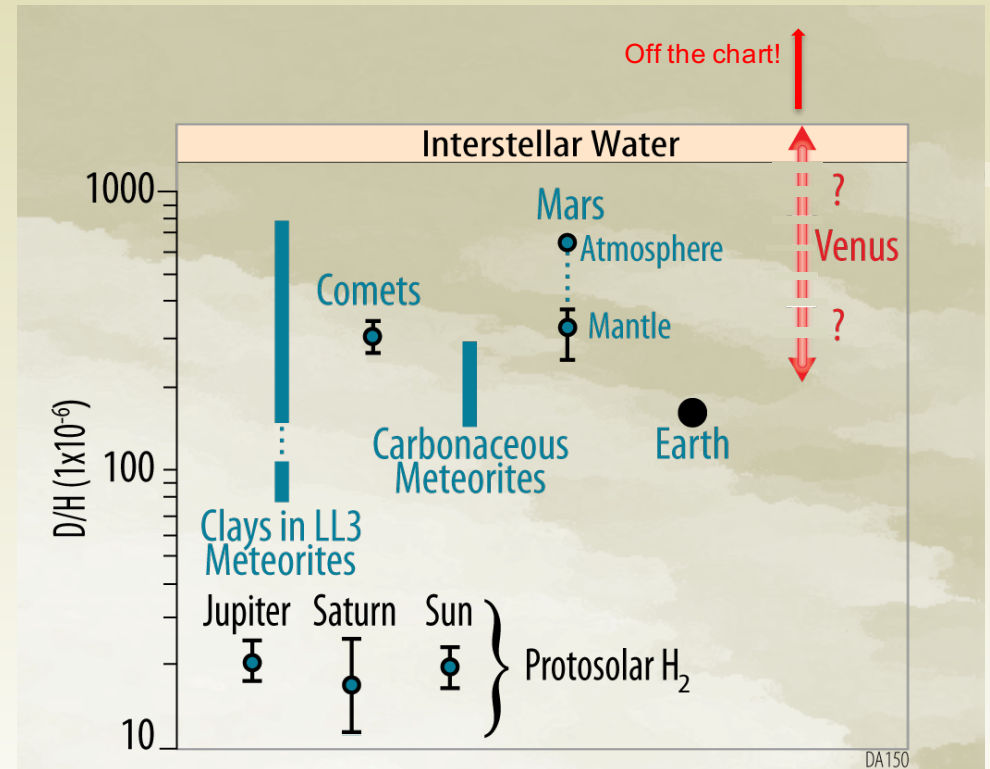
Venus 4Ga? 1Ga?

Need new water measurements!

Amount of water loss in Venus' atmosphere is still controversial

Pioneer measurement was made after inlet was clogged with sulfuric acid droplet (only 1 msmt)

Venus Express measurements above the clouds (~70 km) are as much as 3x greater than those from Pioneer



If we can get a better measurement of the water today, we can use models to determine when Venus lost its water to space.

What 'drives' the Venus atmosphere?

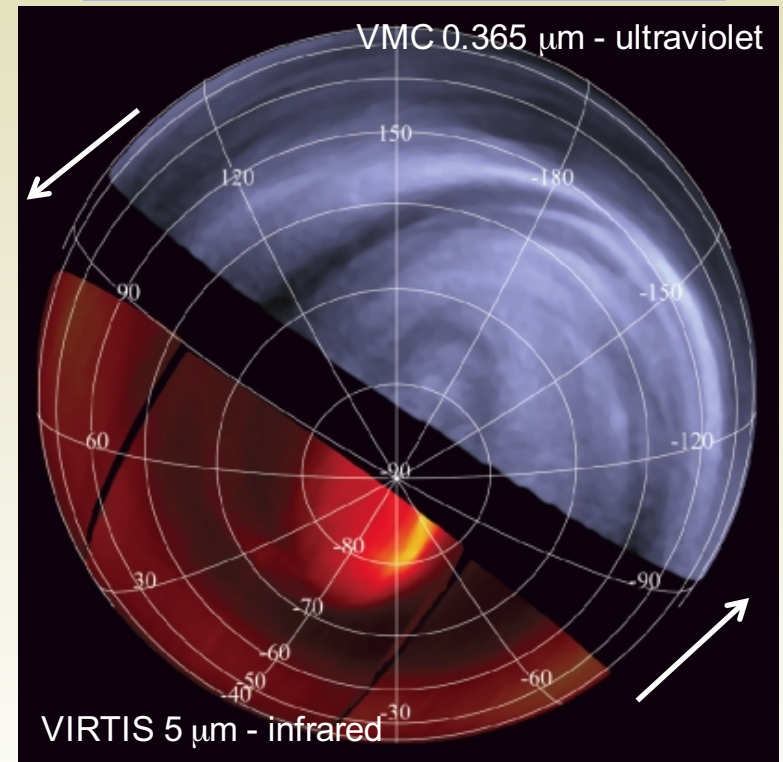
Venus Express observed cloud dynamics

Models cannot explain why clouds move so fast

We don't understand how the sun's interaction with cloud particles (aerosols) affects the chemistry and dynamics of the atmosphere

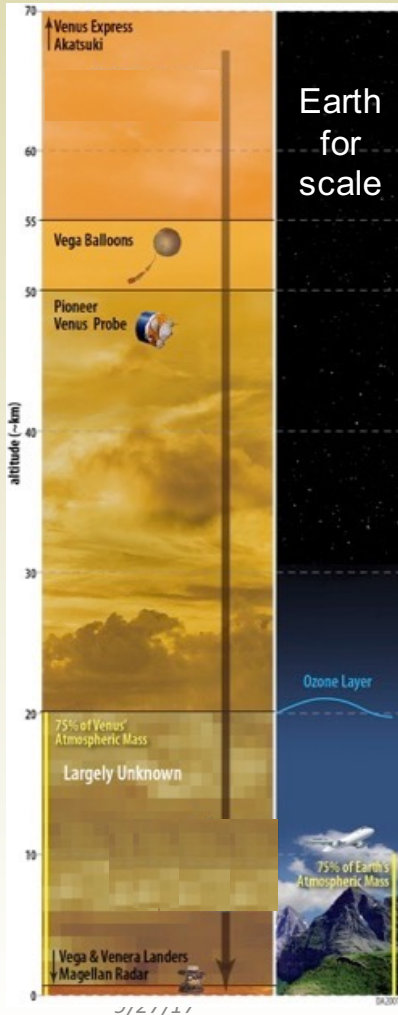
50% of incident UV light is absorbed – by what??

Venus' south polar vortex, as viewed by two instruments on Venus Express

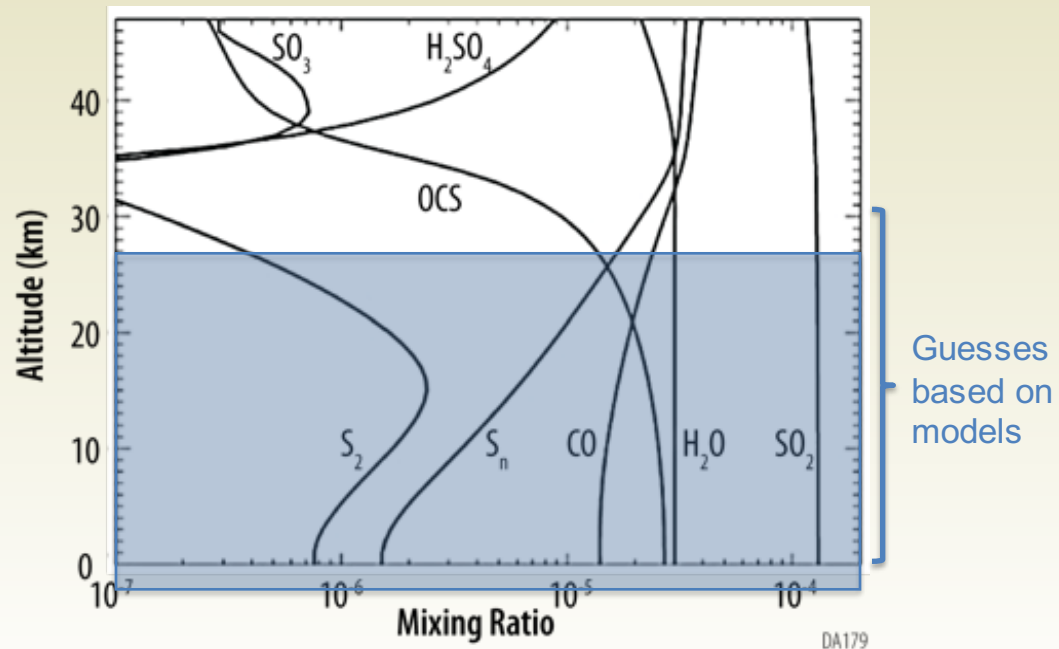


If we can learn how to model Venus' atmosphere, we can better predict Earth's future.

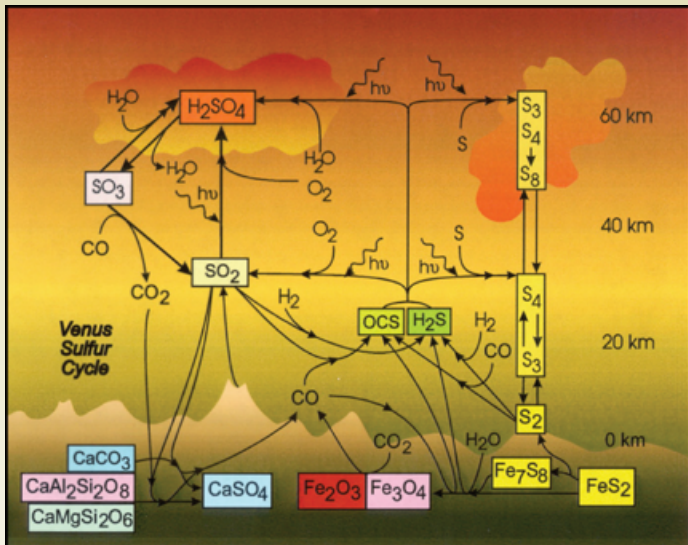
75% of the atmosphere is unexplored!



- Very few measurements below 30 km
- Chemical processes completely unconstrained in the lowest 15 km of the Venus atmosphere



How do the surface and atmosphere interact?



Proposed by Bruce Fegley

What role do trace gases play?
 – SO_2 , H_2O , OCS , H_2S

How are the sulfuric acid clouds maintained?

Can chemical weathering of the surface provide the sulfur?

Is an active volcanic source required to supply sulfur?

Understanding the role of trace gases on Venus helps put limits on natural climate drivers.

Is Venus still volcanically active?

If so, could we tell?



Artist's rendition of active volcanoes on Venus

Venus' interior should still be hot (like Earth)

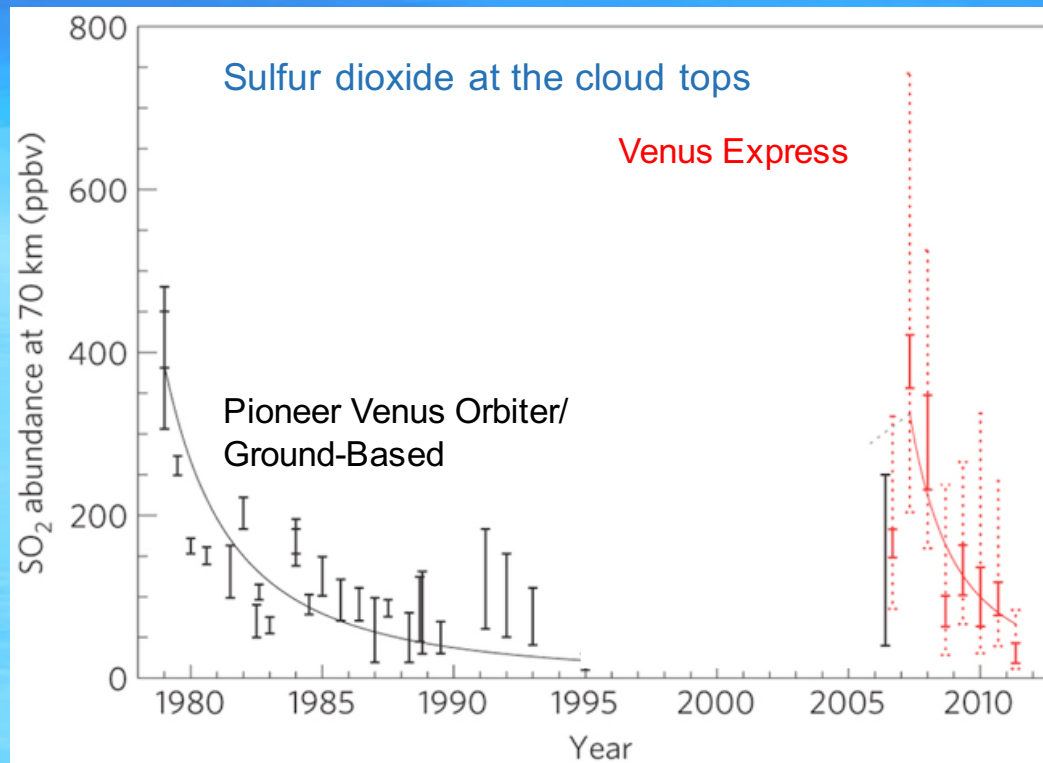
- Because Venus and Earth are about the same size

Earth loses most of its heat at plate boundaries

How does Venus lose heat?

- “Heat pipe” volcanoes?
- Periodic “overtun” events?
- Can these types of events be the source of sulfur?

Evidence for “current” volcanism?



What caused “spikes” in sulfur dioxide?

- Pioneer Venus (1978) and Venus Express (2007) both saw spikes
- Seen at the cloud tops - 43 miles high (70 km)

Models can predict how much water and sulfur we should be looking for and where.

What can provide “pulse” of SO₂?

Large explosive volcanic eruption?

On Earth, the largest plumes rise to 20-25 miles altitude (35-40 km - 4x higher than commercial aircraft fly)

On Venus, very difficult to drive a plume to cloud top altitudes because the lowest atmosphere is so hot and dense

Other hypotheses:

- Periodic overturn event in the clouds?
- Meteorite disturbance?

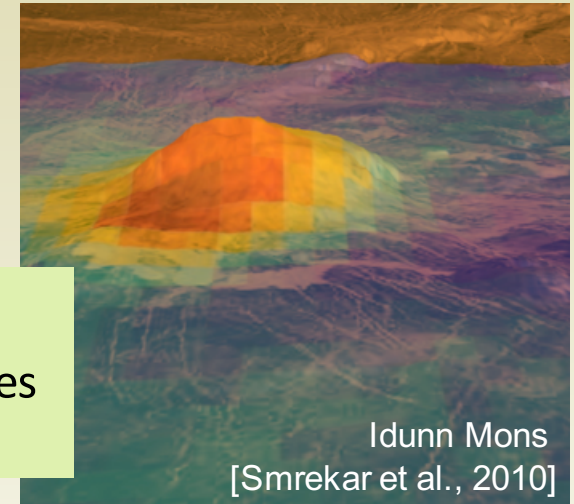


Pinatubo, 1991

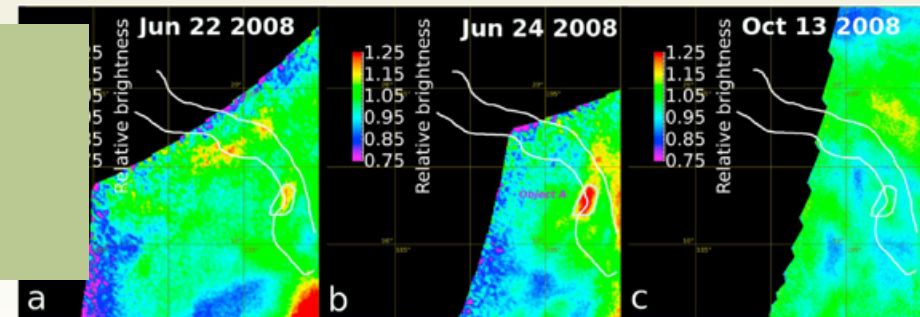
Other possible evidence?

Venus Express observed unusual anomalies in surface reflectance near volcanoes

“younger” surfaces at potentially active volcanoes



Anomalies that come and go in plausibly volcanically active areas



Ganiki Chasma [Shalygin et al., 2015]



NASA's “Discovery” Program

- The Discovery program supports small (\$500M) missions:
 - DAWN, GRAIL, MESSENGER, Mars Pathfinder, Kepler, InSight....
- NASA holds a competition every few years for planetary mission concepts
 - 28 concepts submitted in 2015 competition
 - Five selected for 9 month study: 2 Venus (including DAVINCI) + 3 asteroid
 - Lucy and Psyche (both asteroid missions) selected to fly



9/27/17

DAVINCI

Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging

Probe mission focused on:

- Noble gases
- Composition of the atmosphere below 12 km where 2/3 of atmospheric mass resides (unexplored)
- Atmosphere interaction with the surface
- Tessera morphology



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New Frontiers Program



NASA supports ~2 medium (\$1B) missions per decade (3 so far):

- ❖ **New Horizons** encountered Pluto in July 2015
- ❖ **Juno** is currently in orbit at Jupiter
- ❖ **OSIRIS-REx** is *en route* to Bennu to collect sample; arrives August 2018

Venus is one of 6 targets allowed in the current competition (28 April 2017)

- ❖ 13 proposals submitted
- ❖ 3 Venus concepts proposed (including VICI)



VICI: Venus In situ Composition Investigations

Lander mission focused on understanding Venus through time by measuring:

- Noble gases
- Atmosphere composition below 12 km where 2/3 of atmospheric mass resides (unexplored)
- Atmosphere interaction with the surface
- Tessera chemistry, mineralogy, & morphology

International Opportunities?

***Other agencies are also thinking about Venus
(but no firms plans)***

EUROPE

Current call for “Medium” class missions is underway

EnVision is a Venus orbiter with radar and infrared spectrometer

If selected, probably wouldn't launch until late 2020s

RUSSIA

Developing a concept called “Venera-D” (long-lived)

NASA is funding US participation in a joint US-Russian Science Definition Team

Mission includes orbiters, aerial platforms, and landers

Earliest launch probably late 2020s or even 2030



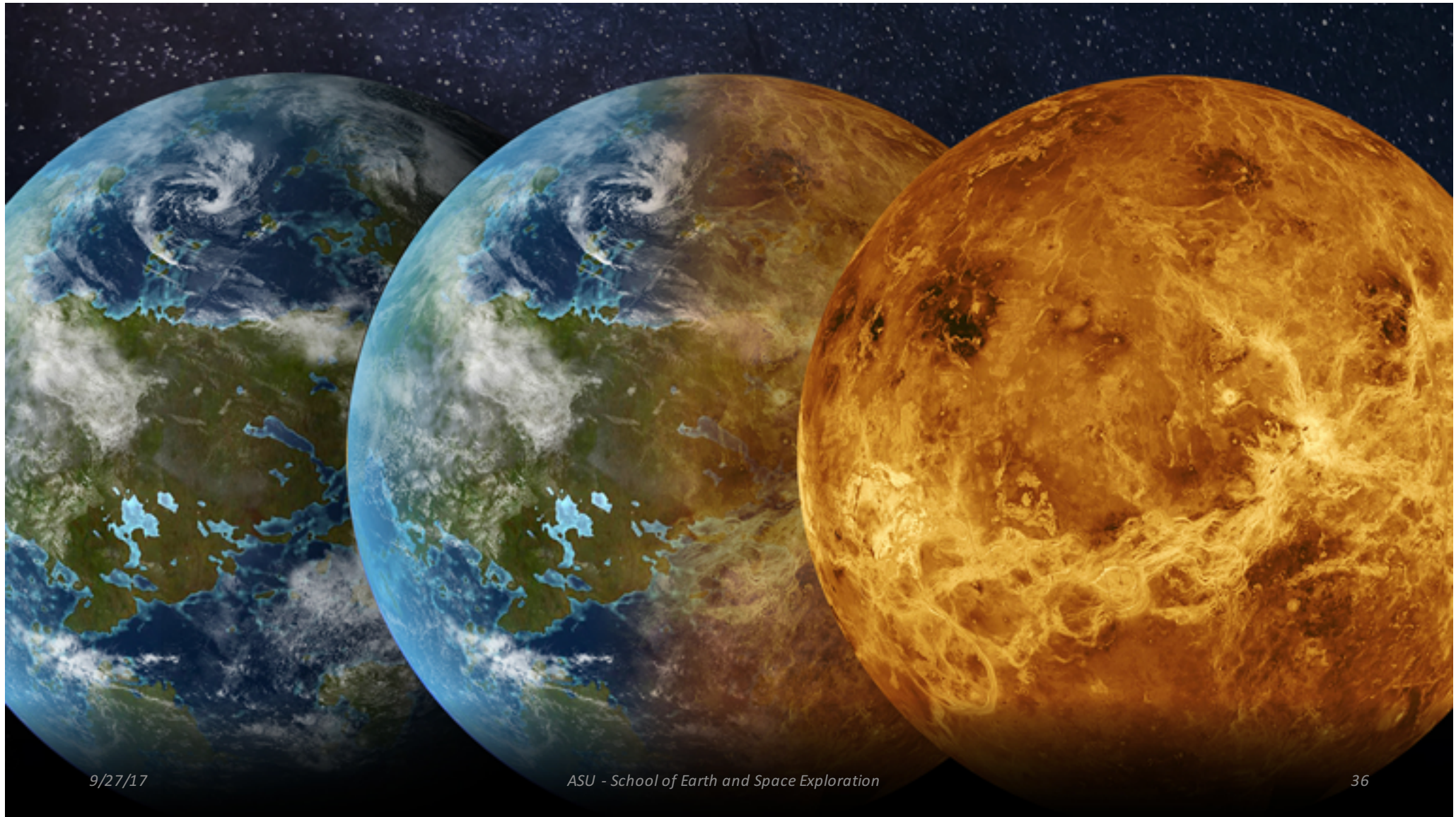
In Summary



- Venus is very similar to Earth in many ways, but...
- Venus evolved very differently
- We don't yet understand when or why Venus evolution diverged from Earth, but we need to
- There are currently NO planned Venus missions by any international space agency

After 6 orbital missions since 1978, an *in situ* mission is needed to provide new observations of Venus:

- to understand the formation and evolution of rocky planets,
- including planets outside our solar system



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