- **Announcements**
  - **TA change for HW3 and HW4**
  - **Use Priyanka Sharma**
    - **psharma@lpl.arizona.edu**
    - **Office hours: Tuesday 10.30am-12.30pm**
      Room 316, Kuiper Building
  - **Kevin will return after becoming Dr. Kevin**
  - **HW3 available on the website today**
    - **Due in a week**

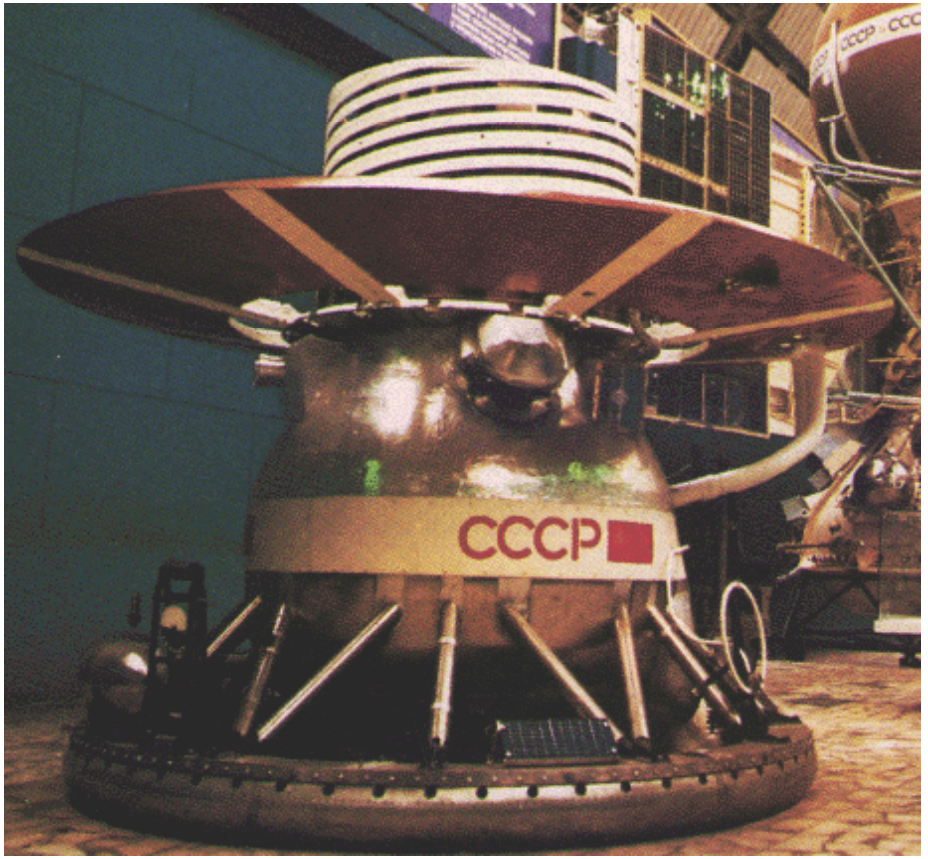
Venus

PTYS/ASTR 206 – The Golden Age of Planetary Exploration

Shane Byrne – shane@lpl.arizona.edu

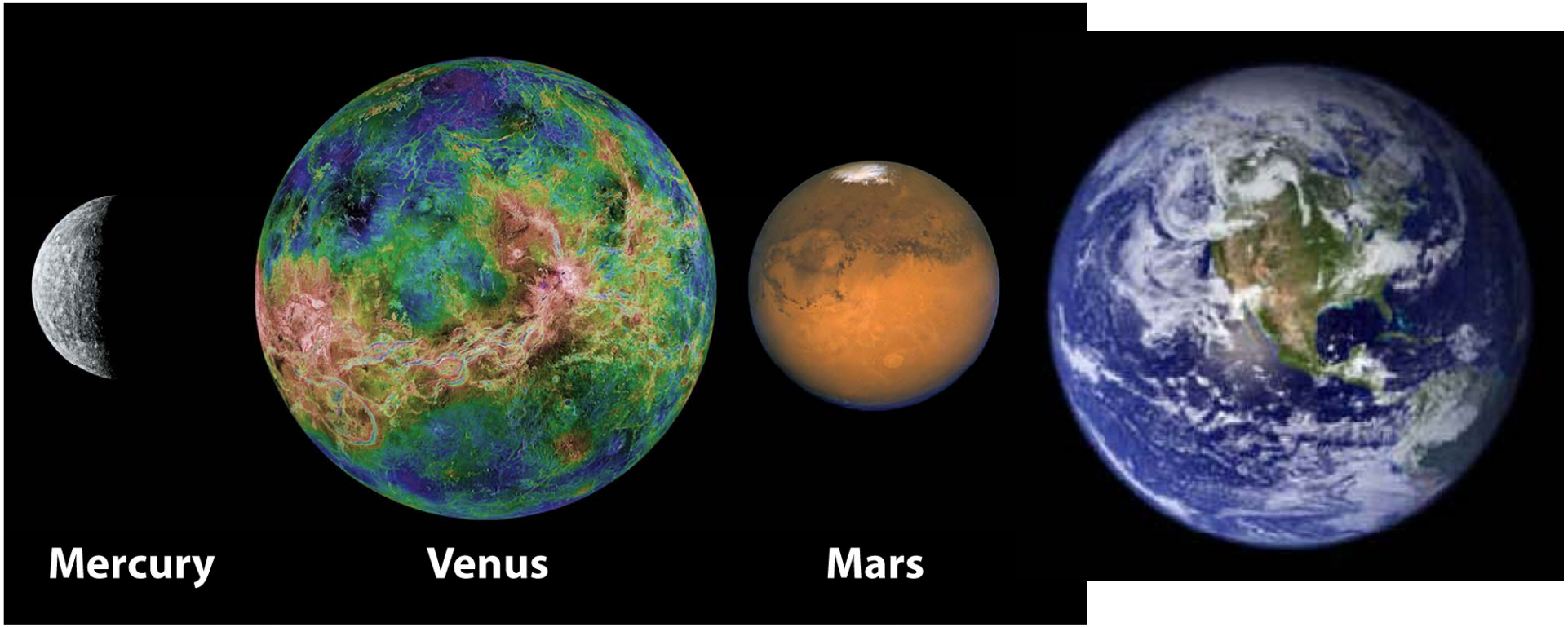
In this lecture…

- Introduction
- Recap on Venus and its atmosphere
  - Super-rotation
  - Tides and retrograde rotation
- Exploring Venus
  - Surface landers
  - Radar instruments
- Surface of Venus
  - Geography and topography
  - Volcanoes everywhere
  - Craters (or the lack of them)
  - Wind action
- Interior of Venus
  - Thin crusts
  - Magnetic fields
- History of Venus – controlled by water
  - A habitable start…
  - Where it all went horribly wrong…
  - Why the Earth escaped the fate of Venus



Introduction

- One of the largest terrestrial planets



Chapter 11 Opener
Universe, Eighth Edition

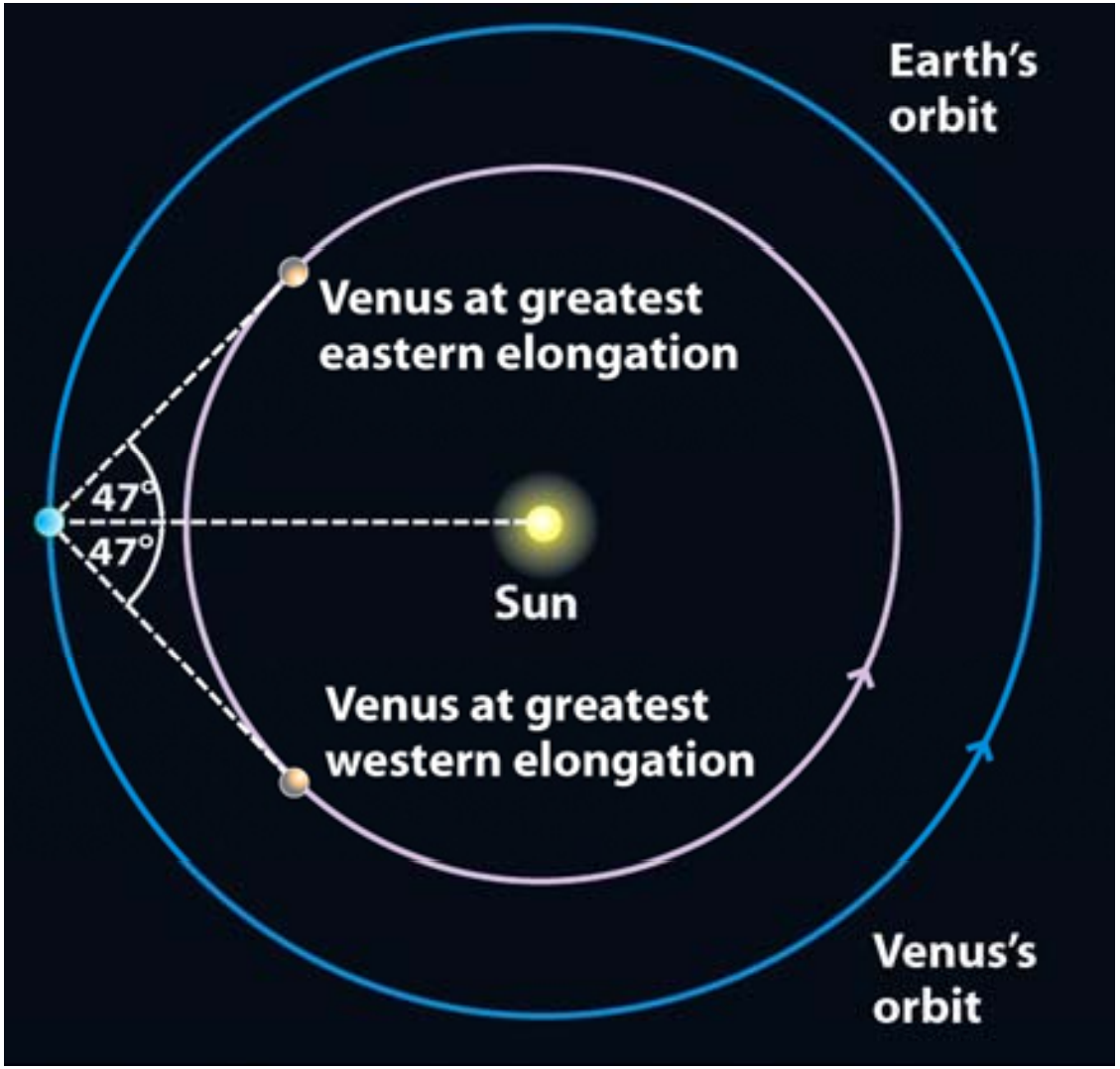
- **Comparison to the Earth**
  - **A sister planet?**

Venus	
Size	95% of the Earth
Mass	82% of the Earth
Density	5243 kg m^{-3} About the same as Earth
Solar Distance	0.72 AU
Year	225 days, 62% of the Earth
Eccentricity	0.007 (almost zero) Circular orbit, like the Earth

Roughly The Same Internal Structure

Roughly The Same Orbit

- **You can see Venus for up to 3 hours after sunset or before sunrise**
- **The brightest planet**
  - **It's covered in very reflective clouds**
  - **It's close to the Sun**
  - **It's close to us**



- **Comparison with the Earth II**
  - **How much solar radiation does Venus receive?**
  - **Remember:** **Solar power = 1367 W m^{-2} / R^2**
  - **Venus is 0.72 AU from the Sun: R=0.72**
  - **So:** **Solar power = 1367 W m^{-2} / 0.72^2**
  - **Solar power at Venus is 2637 W m^{-2} (about twice that of Earth)**

  - **…but Venus reflects 59% of this sunlight – thick cloud cover**
  - **Venus actually absorbs only: 0.41*2637 W m^{-2} = 1082 W m^{-2}**

  - **Not that different than a clear day at Earth's equator!**
  - **People thought that Venus might be some sort of tropical paradise…**
  - **Nobody could see the surface though…**

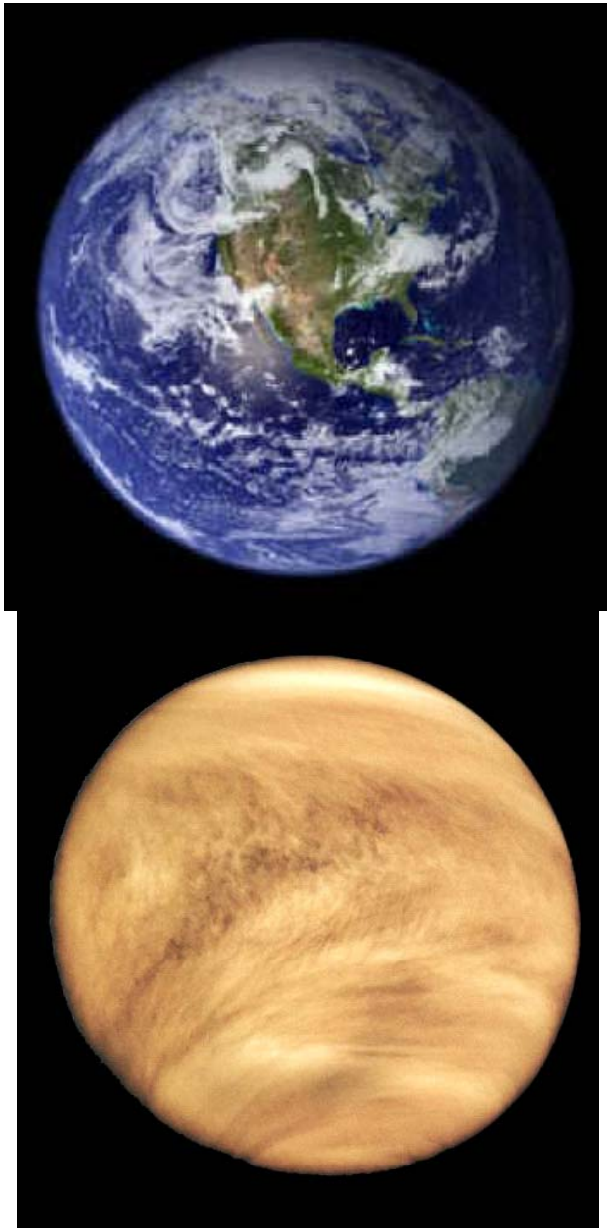
- **Differences from the Earth**
  - **A sister planet? – not really**

Venus	
Atmosphere	Mostly CO_2 (Earth = Mostly nitrogen)
Pressure	90 bars (Earth = 1 bar)
Surface Temp.	750K (Earth = 300 K) (Molten rock ~ 1000 K)
Clouds	Sulfuric acid (Earth = water vapor)
Rotation period	224 Days - retrograde (Earth = 1 day)
Magnetic field	None (Earth has a strong field)
Surface	All volcanic rock (Earth = mix of rock types)

Very Different Atmosphere

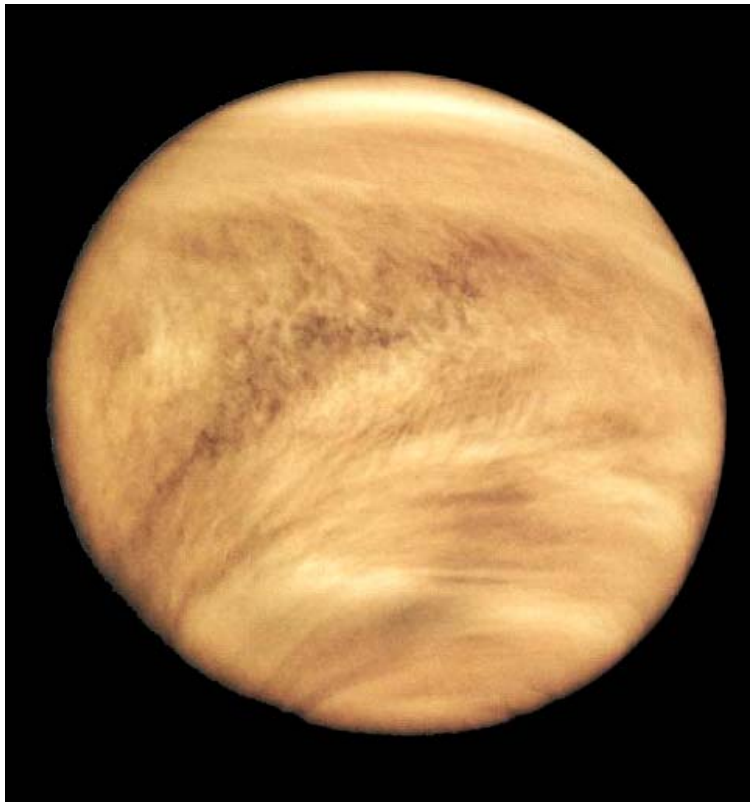
Very Different Spin

Very Different Surface



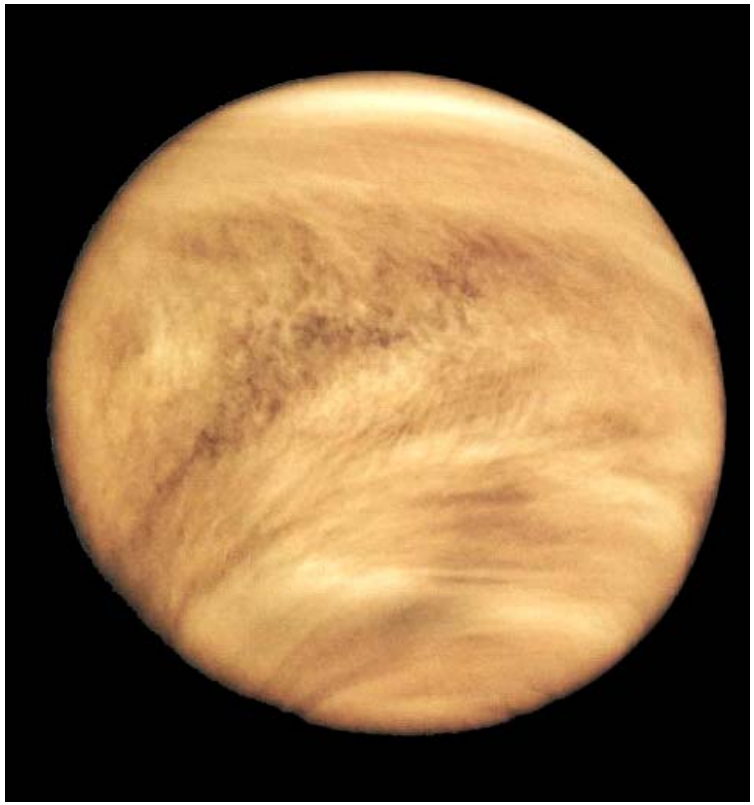
- **So Earth and Venus started off with similar compositions and positions in the solar system**

- **What went wrong for Venus??**
  - **The answer is in front of you…**



- **So Earth and Venus started off with similar compositions and positions in the solar system**

- **What went wrong for Venus??**
  - **The answer is in front of you…**
  - **WATER! – History of Venus depends on the history of its water**



Atmosphere - recap

- **The greenhouse effect**
  - Both Earth and Venus are warmed by the greenhouse effect
  - Greenhouse gases stop thermal radiation escaping to space
  - Earth has ~0.01 bars of CO_2 – Temperature boosted by ~30° C
  - Venus has 86 bars of CO_2 – Temperature boosted by ~400° C

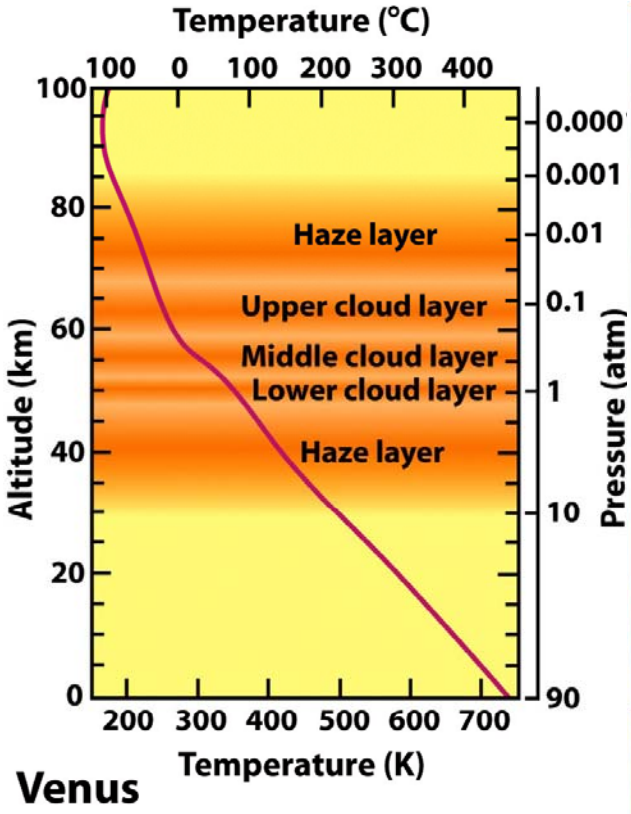
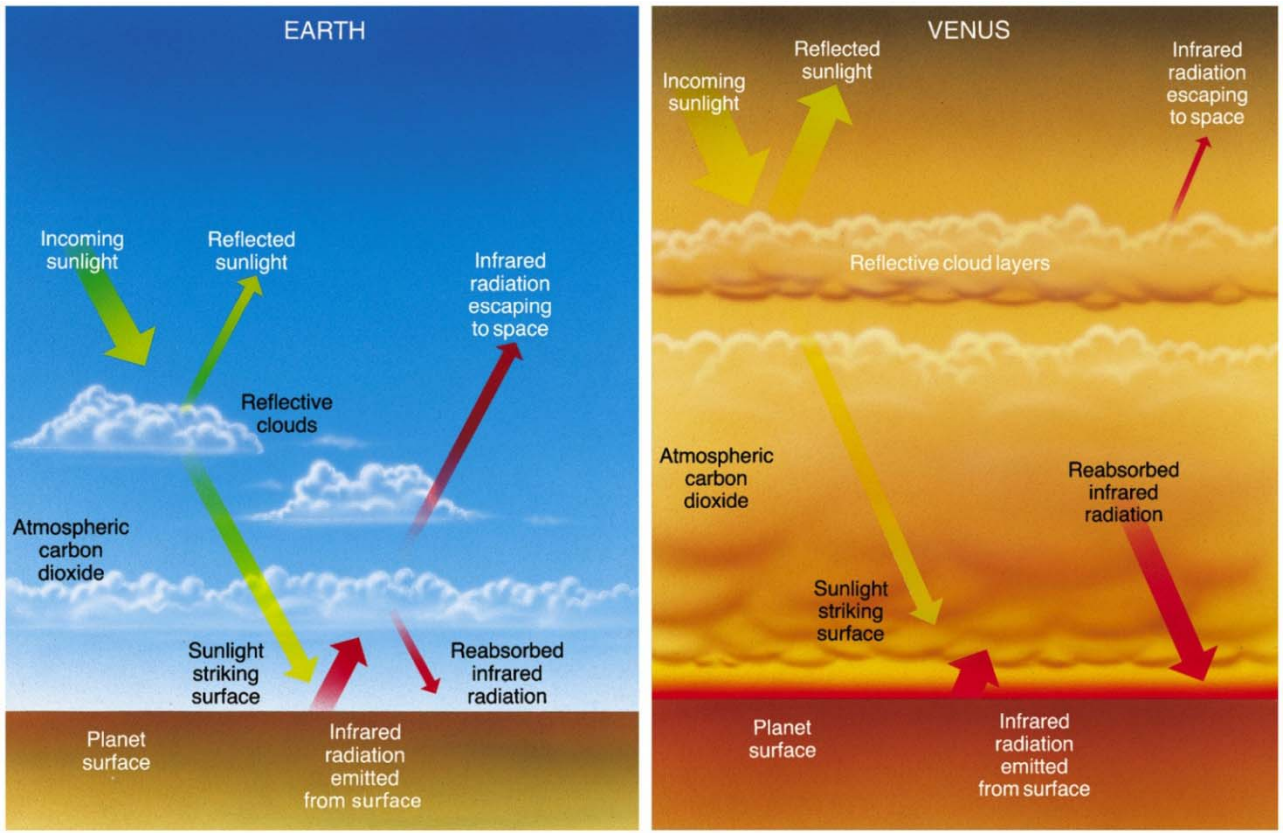


Figure 11-27b
Universe, Eighth Edition



- **Super-rotation**
  - **Clouds on Venus rotate in 4 days!**
  - **People were surprised to learn later that the solid planet rotates only every 224 days**
  - **Atmosphere rotates faster than the planet**

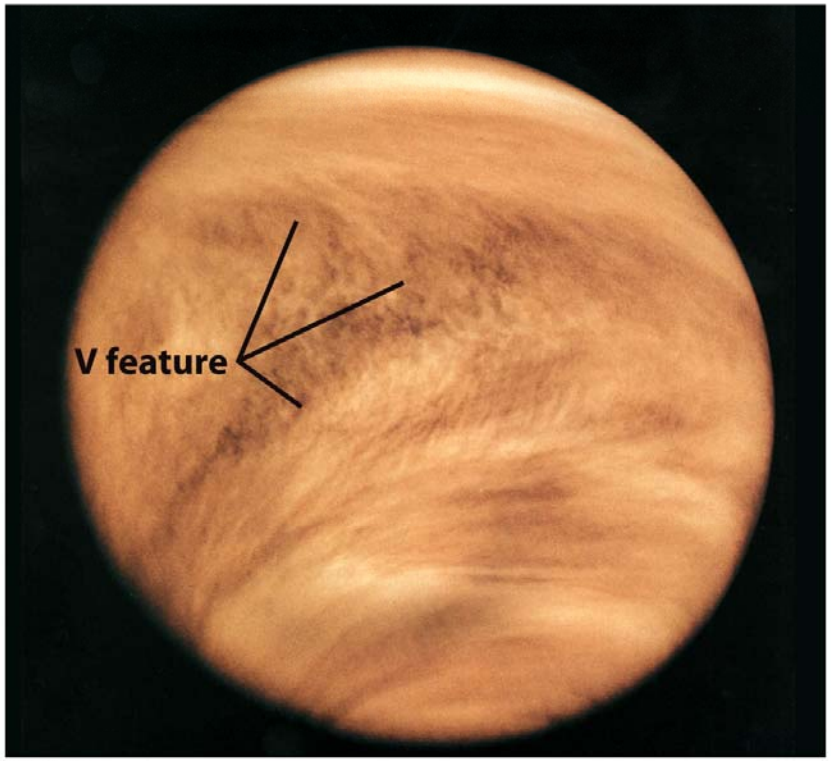
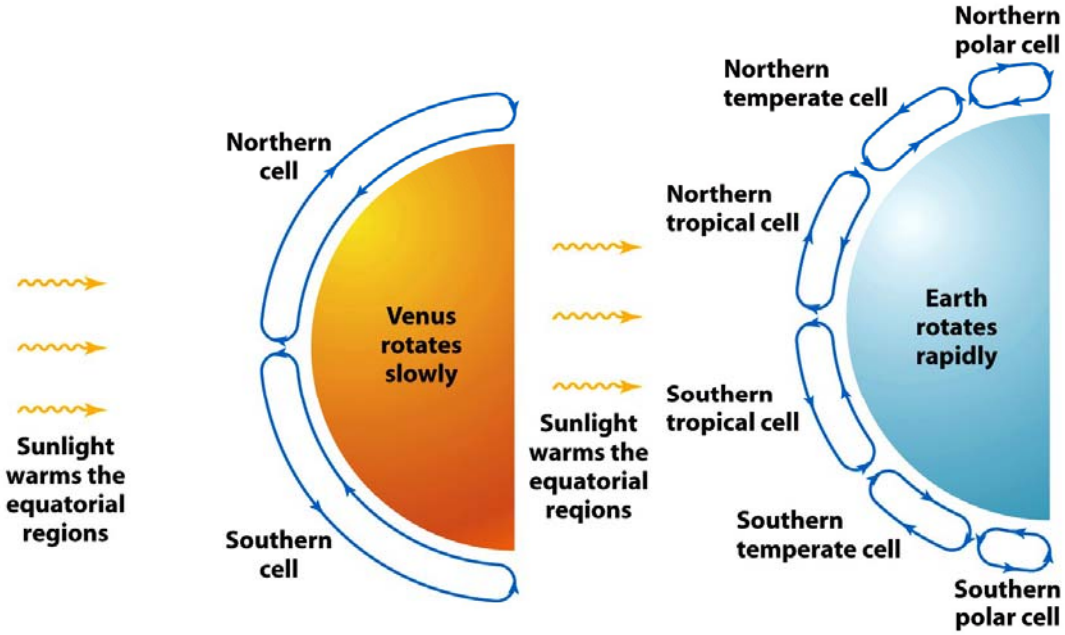


Figure 11-29
Universe, Eighth Edition

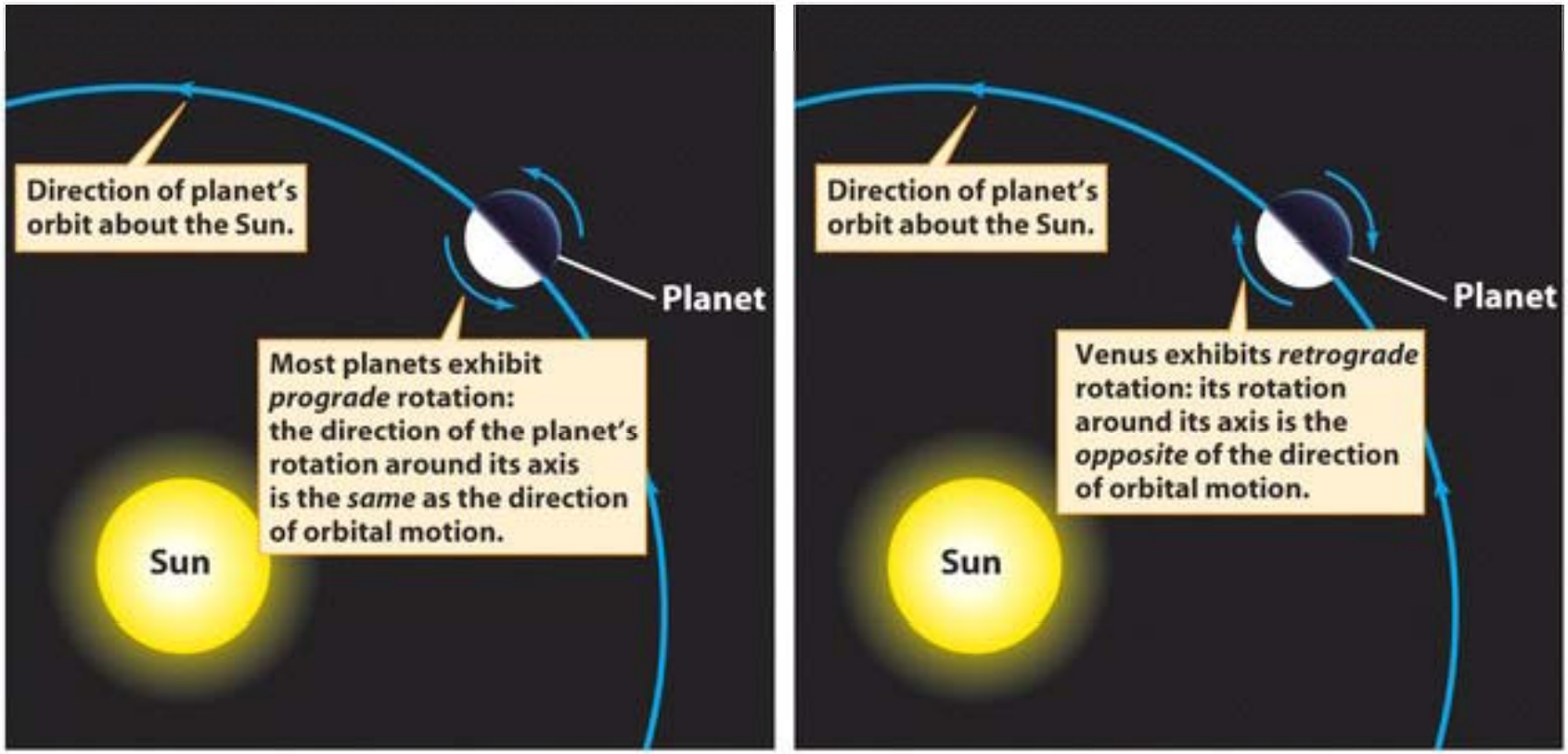


(a) Atmospheric circulation on Venus: two convection cells

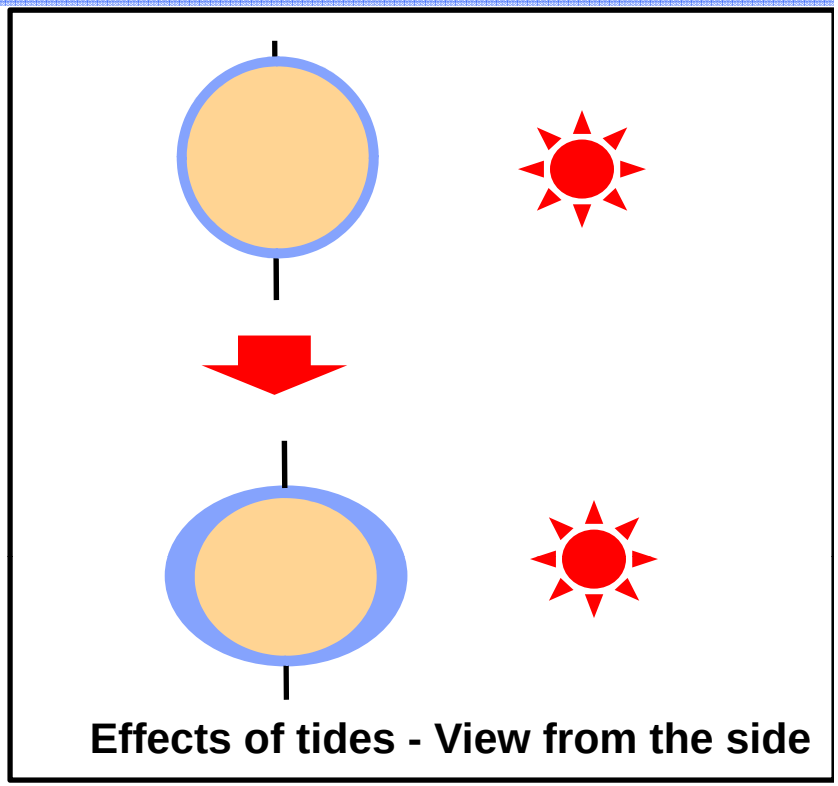
(b) Atmospheric circulation on Earth: six convection cells

Figure 11-28
Universe, Eighth Edition

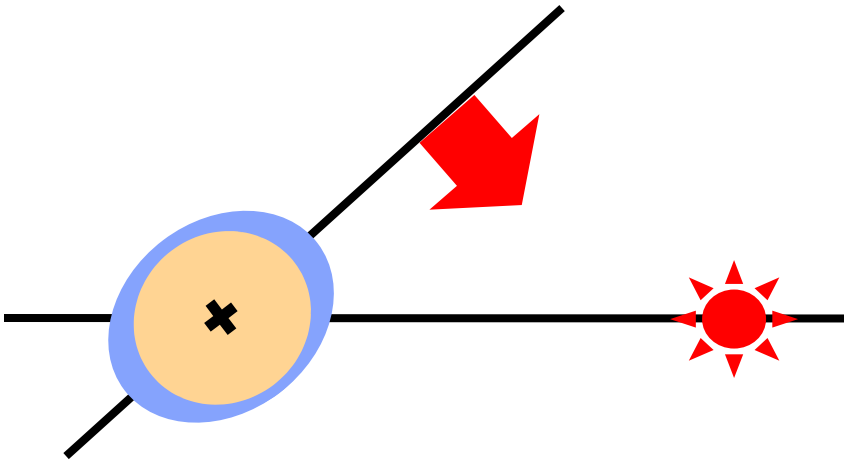
- **Venus's weird rotation….**
  - **Most planets rotate (and orbit) anti-clockwise**
    - **(when viewed from above the North Pole)**
  - **Venus rotates 'backwards'**
  - **Theories?**
    - **Giant impact**
    - **Solar tides**



- **Tidal effects on Spin?**
  - Venus has a huge massive atmosphere…
  - …and is close to the sun
  - Solar tides can slow Venus's rotation
  - Tidal bulge raised by Sun
  - Rotation of Venus carries the bulge around the planet
  - Attraction between the bulge and the Sun slows down Venus's rotation



Effects of tides - View from the side



Solar tides slow down Venus's rotation, but don't explain why it's retrograde

- **Atmosphere is very heavy and rotates very quickly in a retrograde direction**
  - **Drag of atmosphere on the solid planet might have reversed its spin direction**
  - **This only works because….**
    - **The atmosphere is very massive and has lots of momentum…**
    - **Solar tides already did most of the work…**
    - **We have billions of years to get this done…**

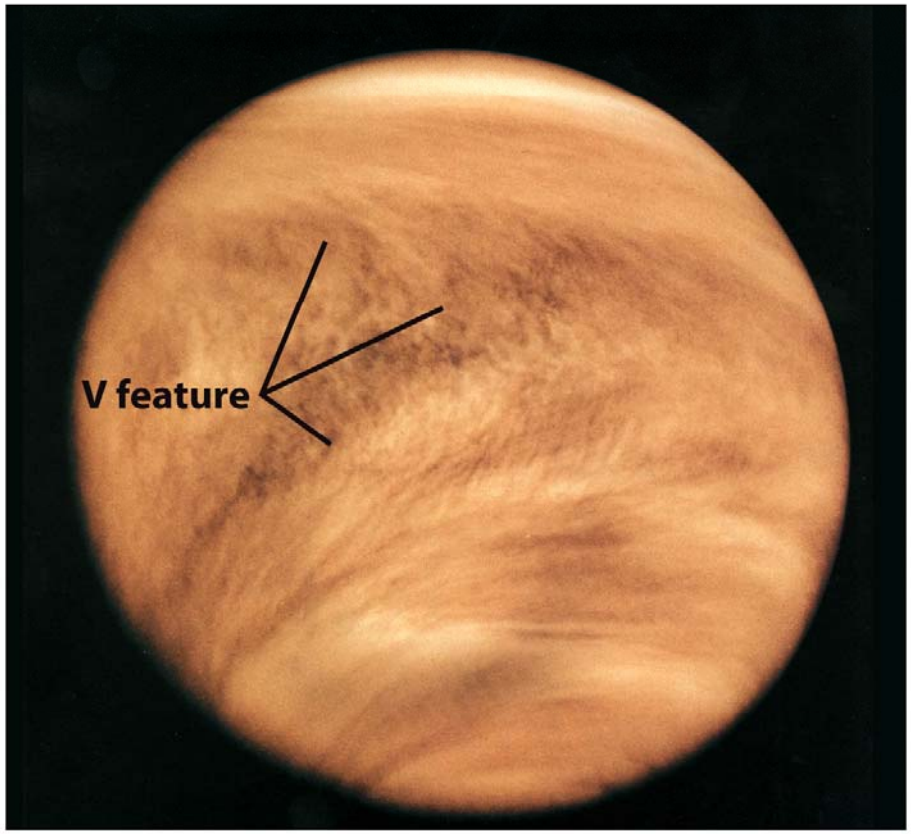
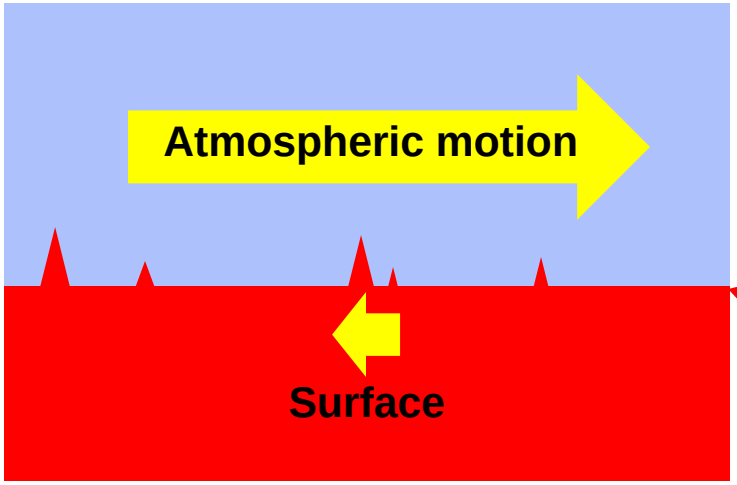


Figure 11-29
Universe, Eighth Edition

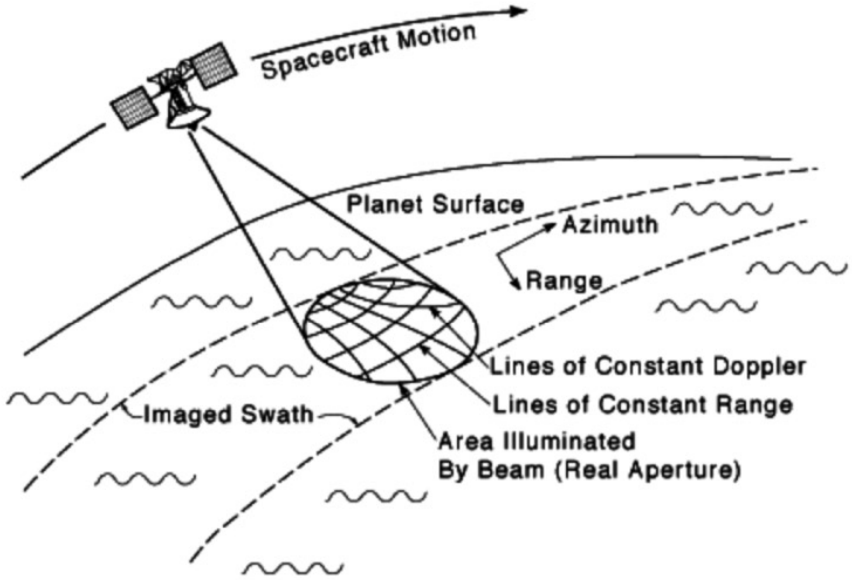


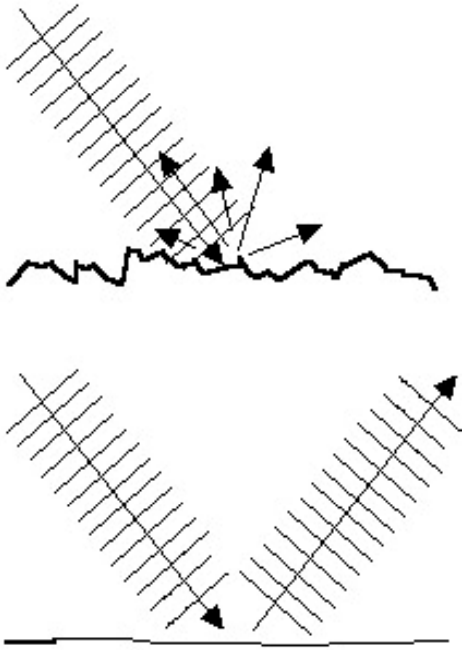
Friction from atmospheric drag on rough surface

- **The other possibility is a giant impact reversed Venus's rotation**

Exploring Venus

- Clouds are very opaque
- Orbiters use radar to see the surface
  - NASA Magellan mission did the most complete mapping (1992-1994)
  - Pioneer Venus (late 1970's)
  - Venera 15 and 16 (1980's)
- Radar looks off to the side
- Light/Dark tones don't correspond to albedo
- Strong radar return from:
  - Terrain that has roughness on the scale of the radar wavelength
  - Large-scale slopes facing the spacecraft





- **Vertical radar system gathers topography**
  - **Send radar pulses to surface – timed echoes**
  - **Converted time delay to distance to figure out where the mountains and valleys are**

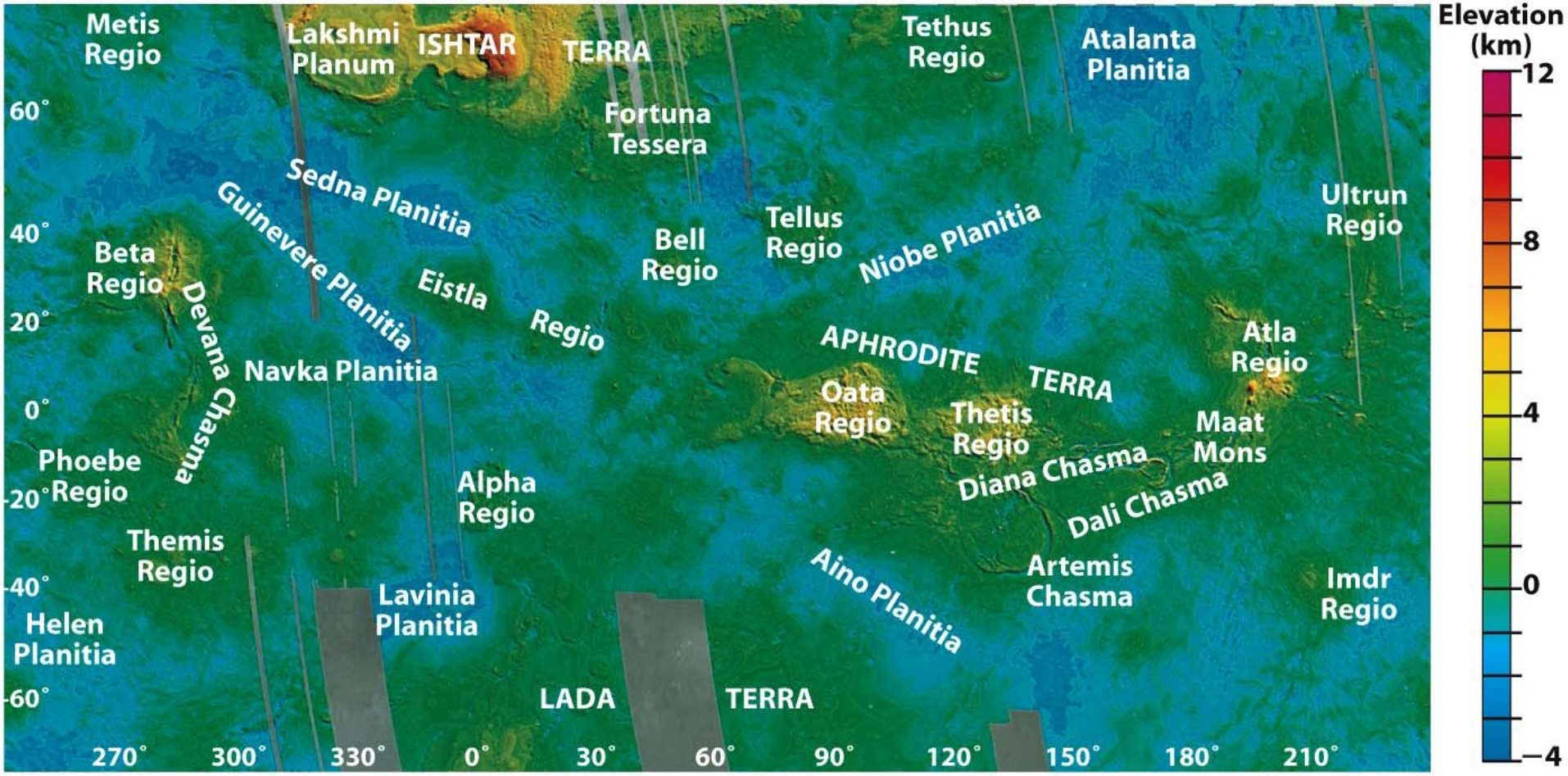
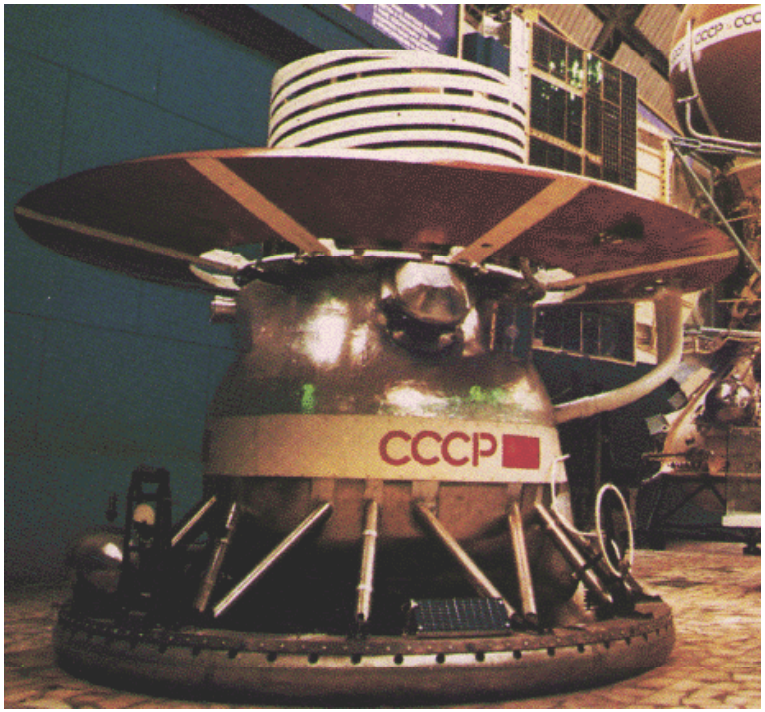
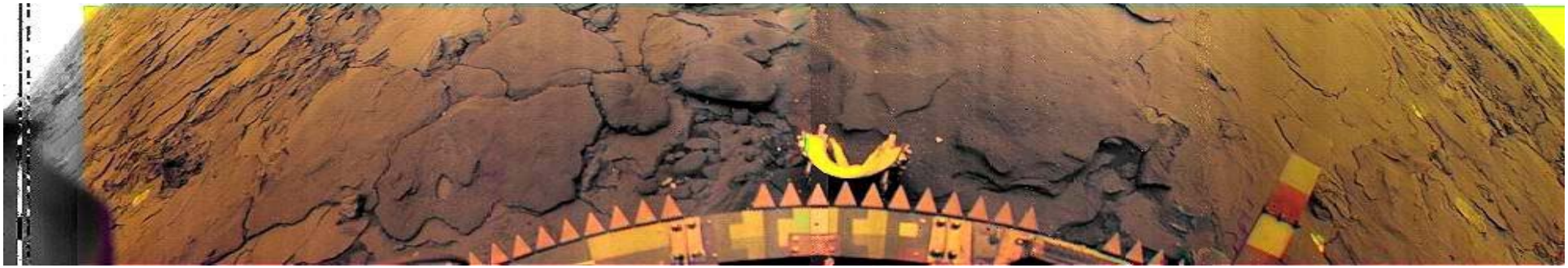


Figure 11-19
Universe, Eighth Edition

- **Landed spacecraft hard to do on Venus**
- **Only glimpse of the surface**
  - **Soviets had 4 successful Venera landings on Venus**
  - **Onboard experiments found basaltic surface**
  - **Dark surface, albedo of 3-10%**
  - **Surface winds of ~ 0.3-1.0 m/s**
  - **Surface temperatures of 740 K**
  - **Landers lasted 45-60 minutes**

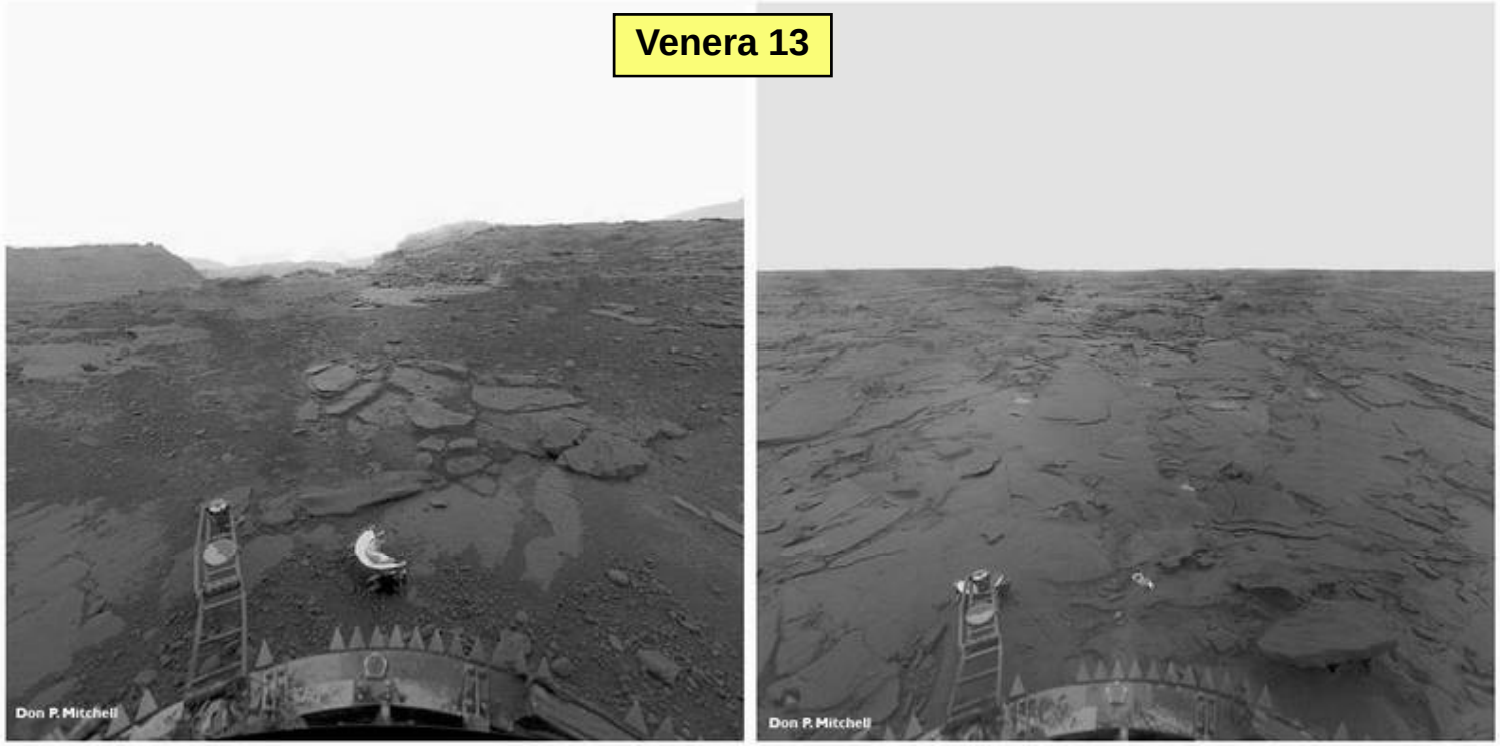


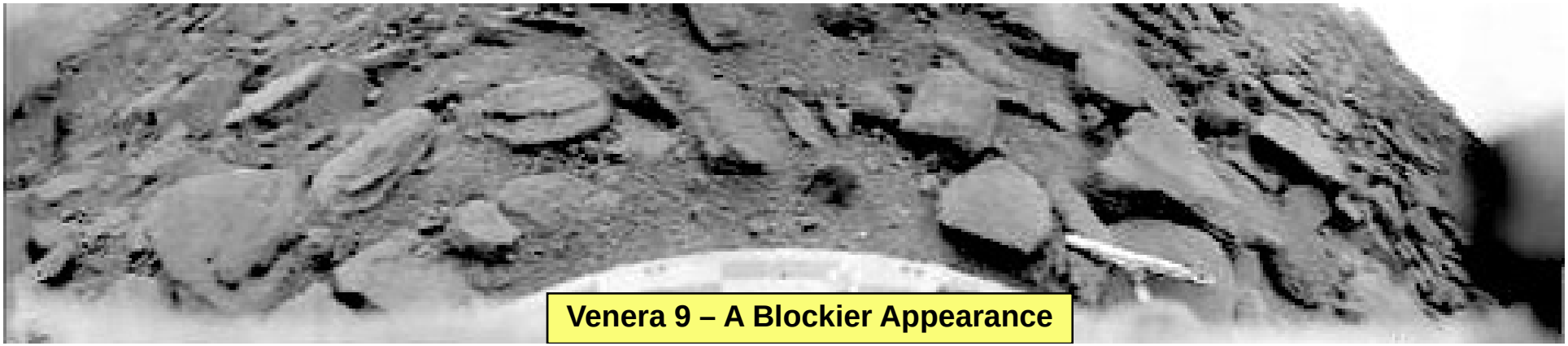


Venera 14 – 13 S, 310 E – March 1982

- **Spherical images can be unwraped into a low-res perspective view**
- **Smooth-ish basaltic rock – low viscosity magmas**

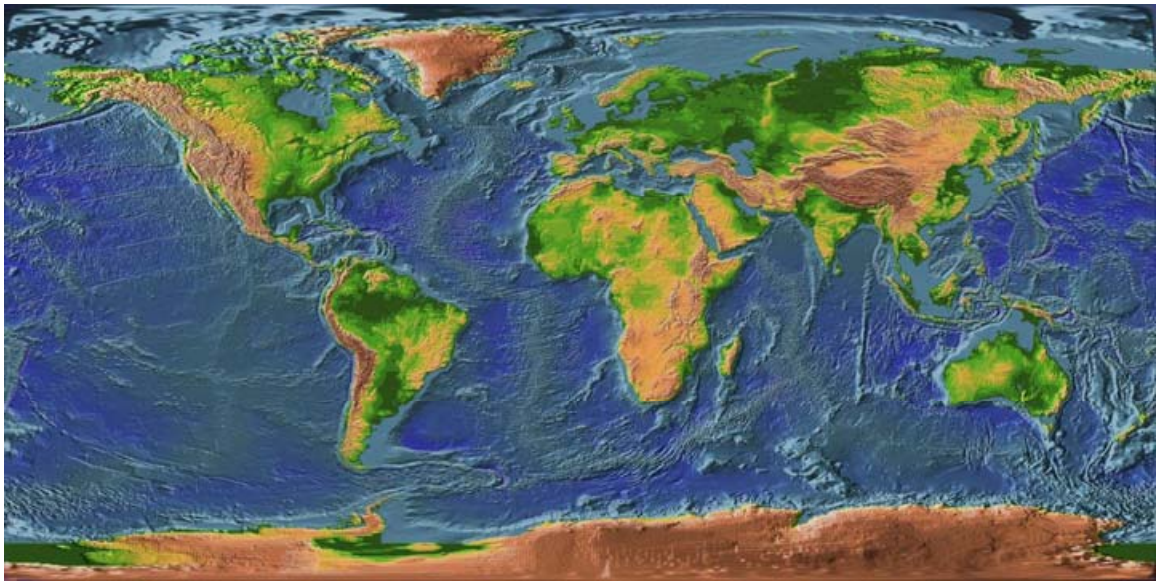
Venera 13

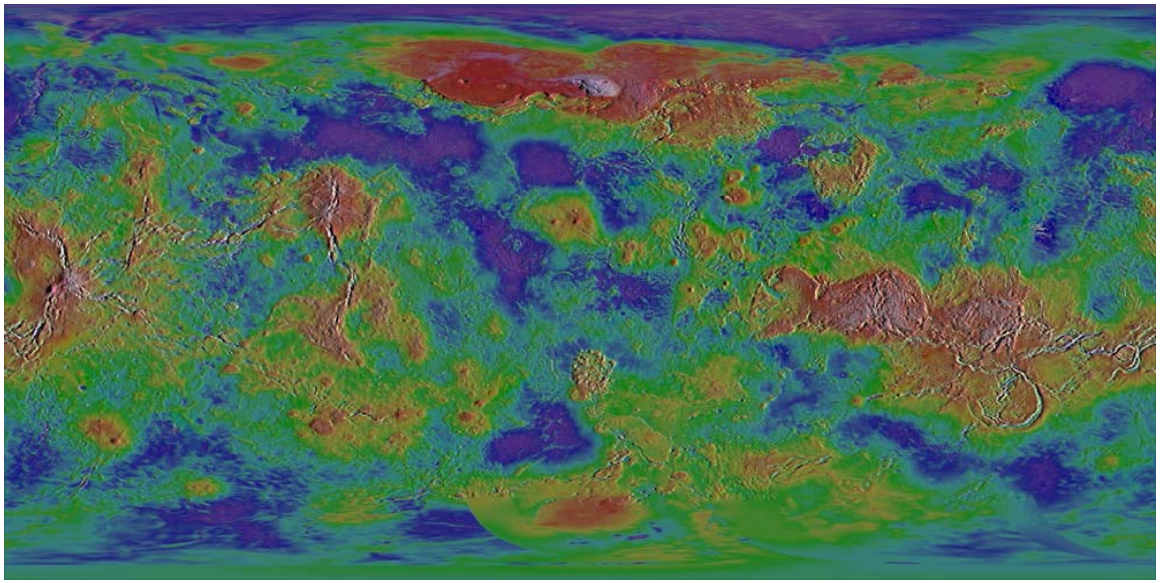


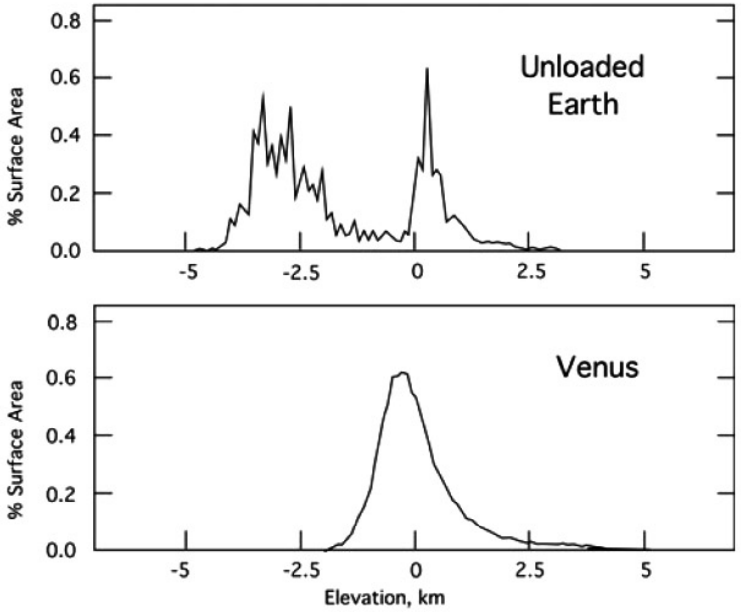


Venera 9 – A Blockier Appearance

Surface of Venus

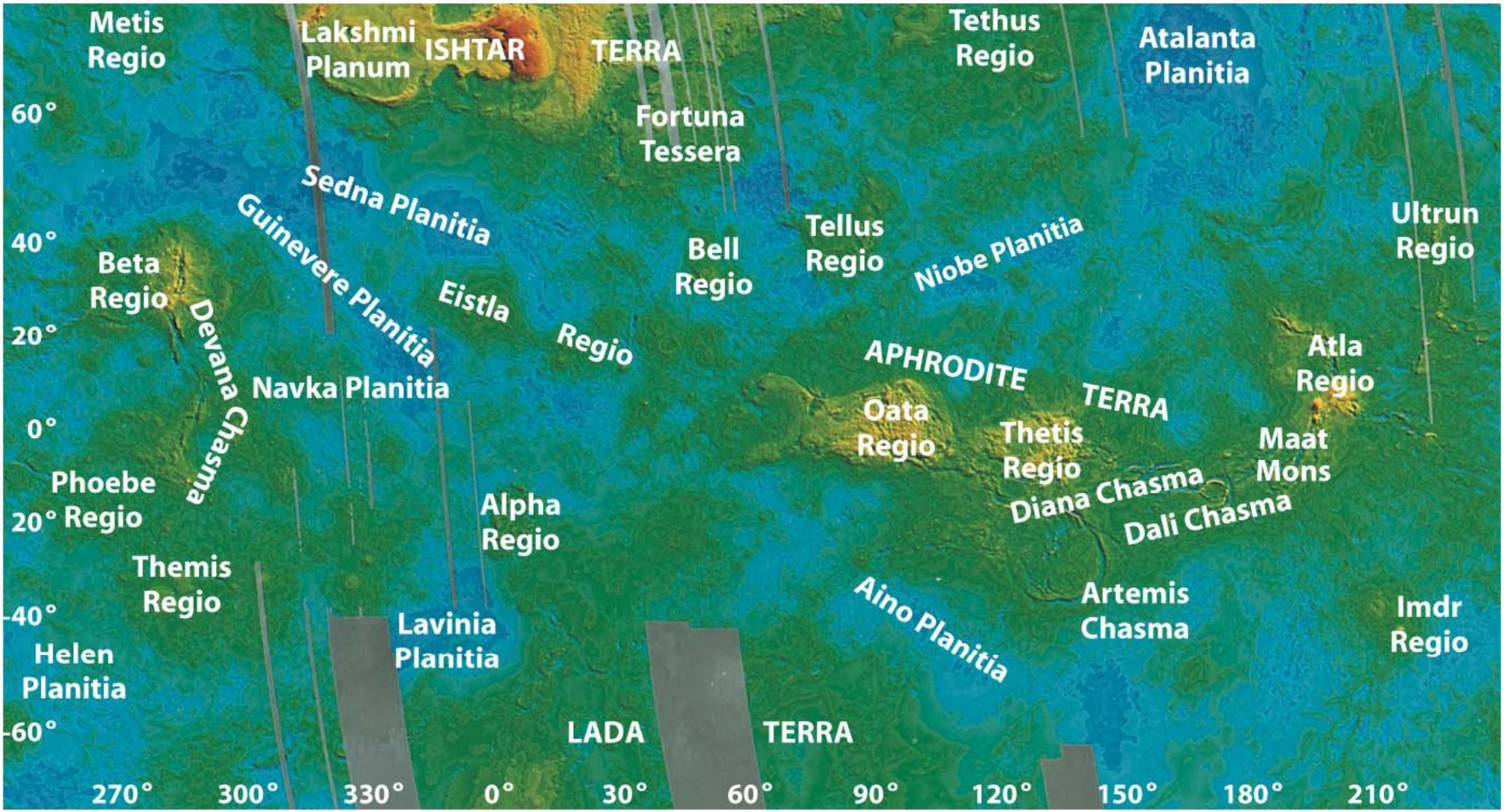




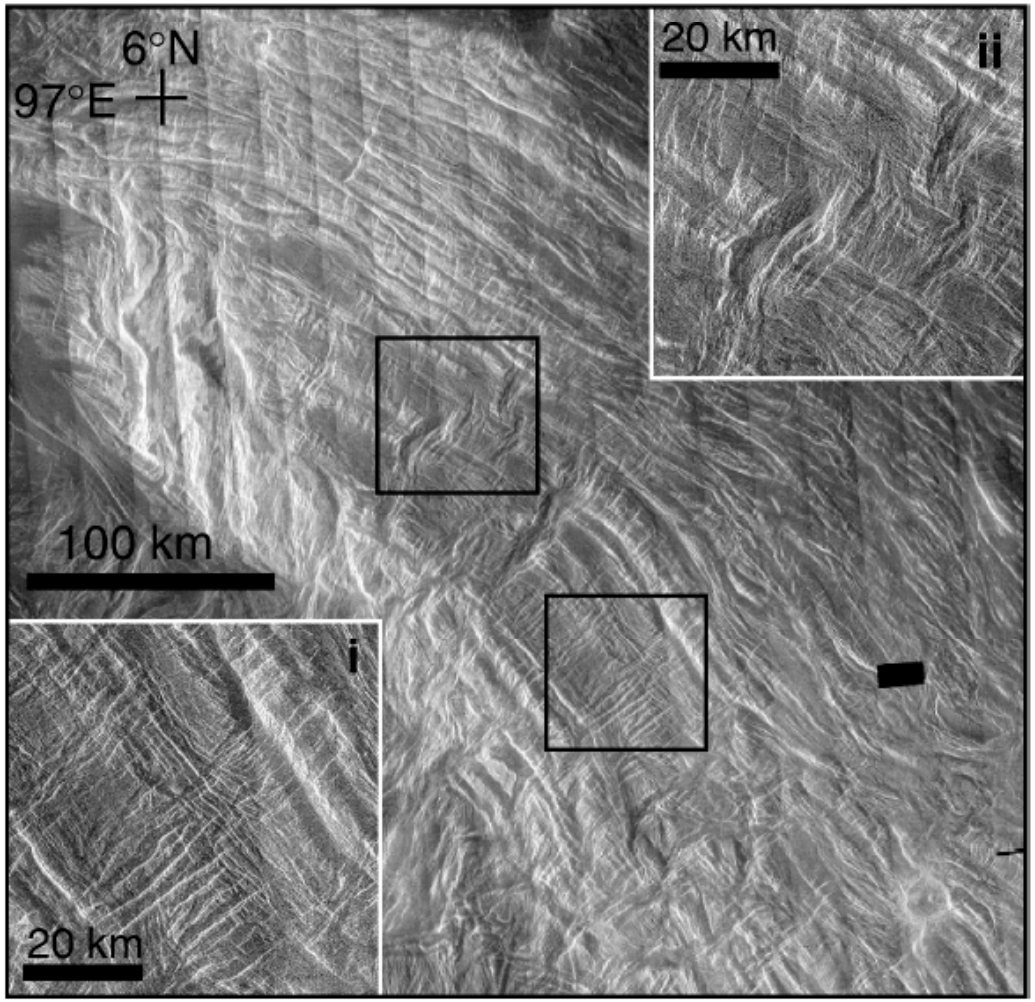


- **Earth has obvious topography dichotomy**
  - **High continents**
  - **Low ocean floors**
- **Venus has a unimodal hypsogram**
  - **No plate tectonics**
  - **Several volcanic plains**
  - **Several crustal plateaus**

- **98% coverage from Magellan**
  - **High-standing crustal plateaus**
  - **Low-lying volcanic plains**



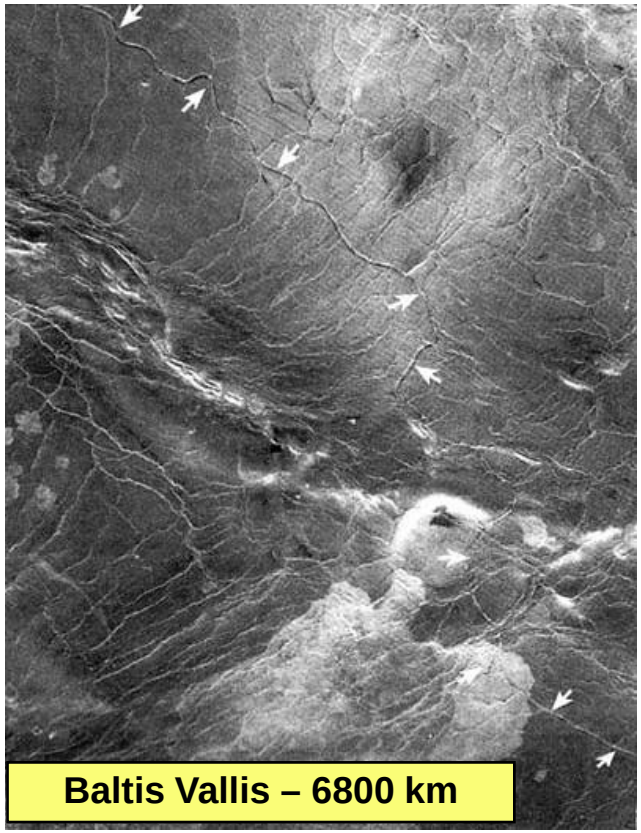
- **Crustal Plateaus**
  - **Steep-sided, flat-topped, quasi-circular**
  - **1000-3000km across, raised by 0.5-4km**
- **Dominated by Tesserae**
  - **Regions of complexly deformed material**
  - **Contain several episodes of both extension and compression.**
  - **Extremely rough (bright) at radar wavelength**
- **Controlled by Mantle convection**

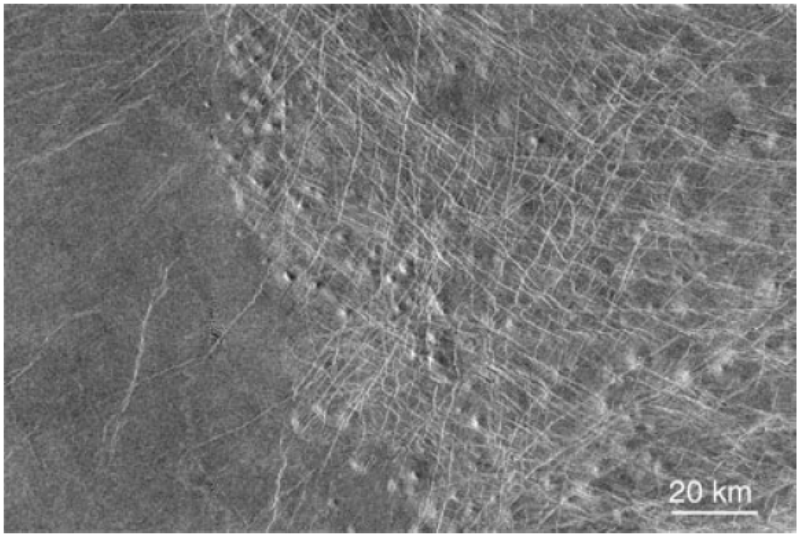


- **Volcanic plains**
  - Surface dominated by volcanic material
  - Come in two types
  - Low relief – gently rolling terrain

- **Ridged plains – 70 % Venusian surface**
  - High-yield, non-viscous eruptions of basalt
    - Gentle slopes and smooth surfaces
    - Long run-out flows 100-200 km
    - Chemical analysis – Venera 9, 10, 13 & Vega 1, 2
  - Contain sinuous channels
    - 2-5 km wide, 100's km long
    - Baltis Vallis is 6800 km long, longest channel in the solar system

- **Shield plains**
  - Much less common, usually a few 100 km across
  - Fields of gentle sloping volcanic shields





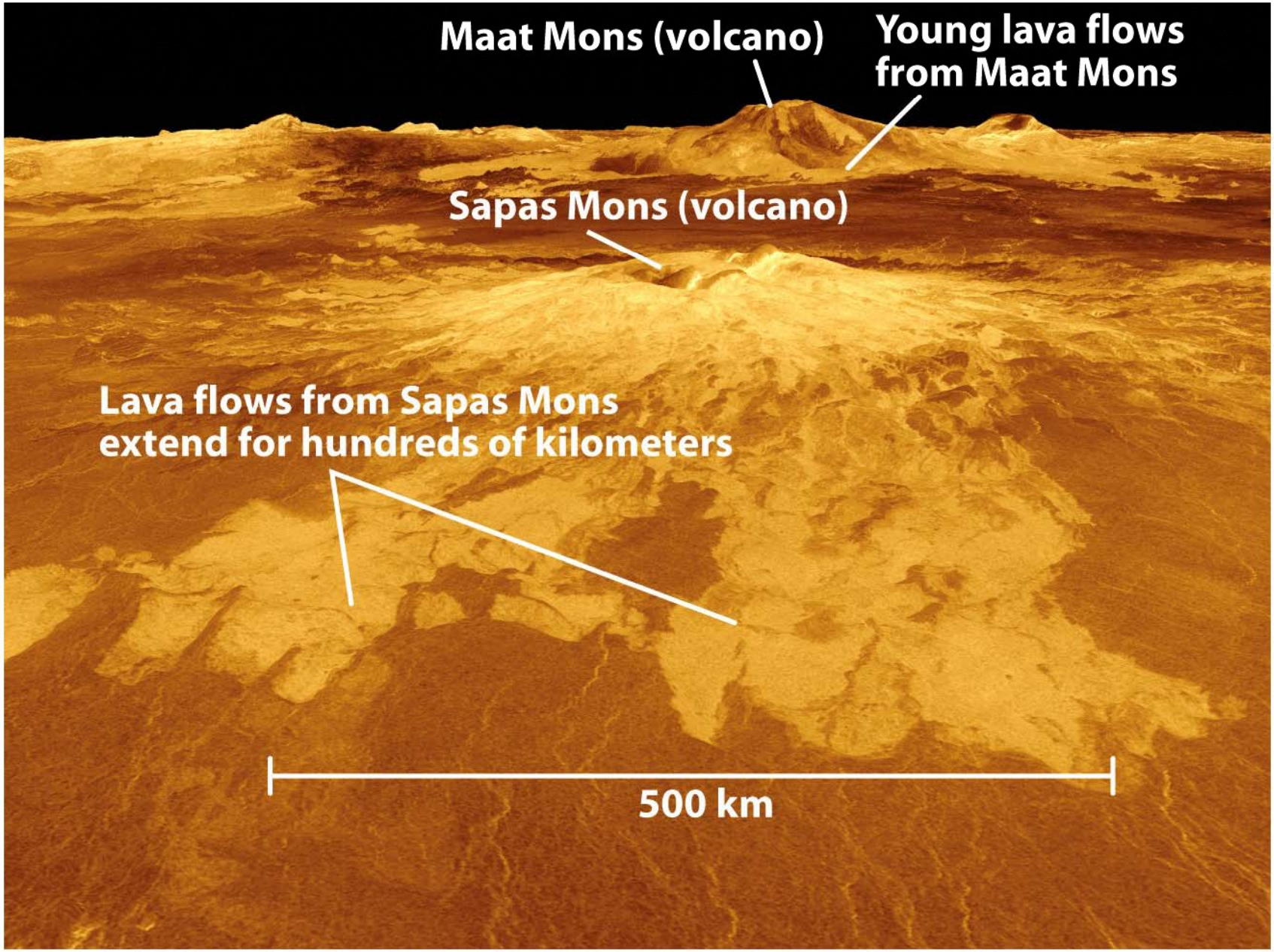
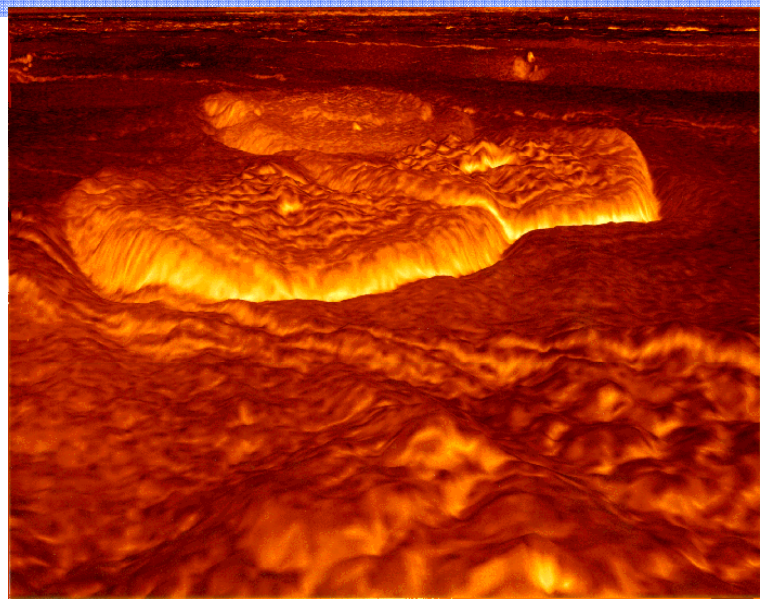
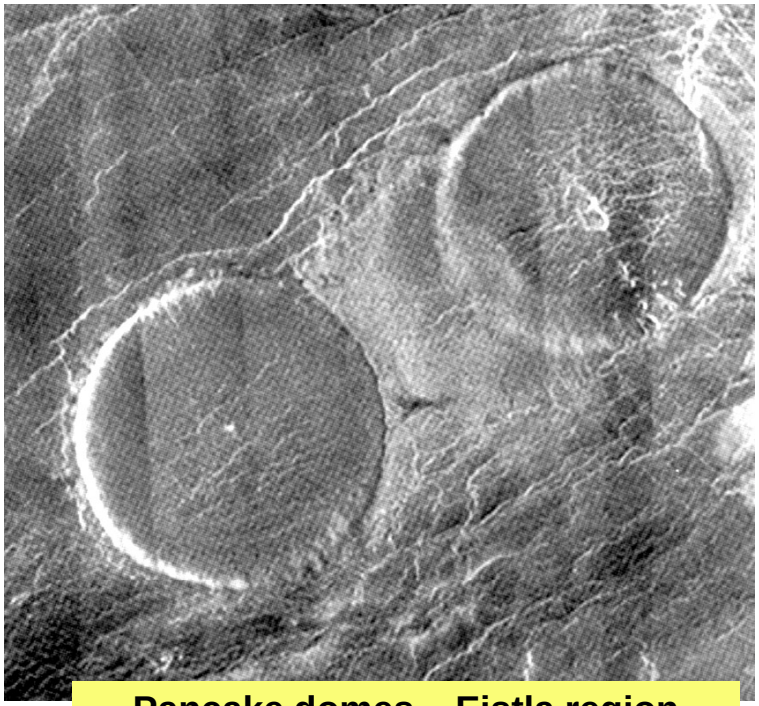


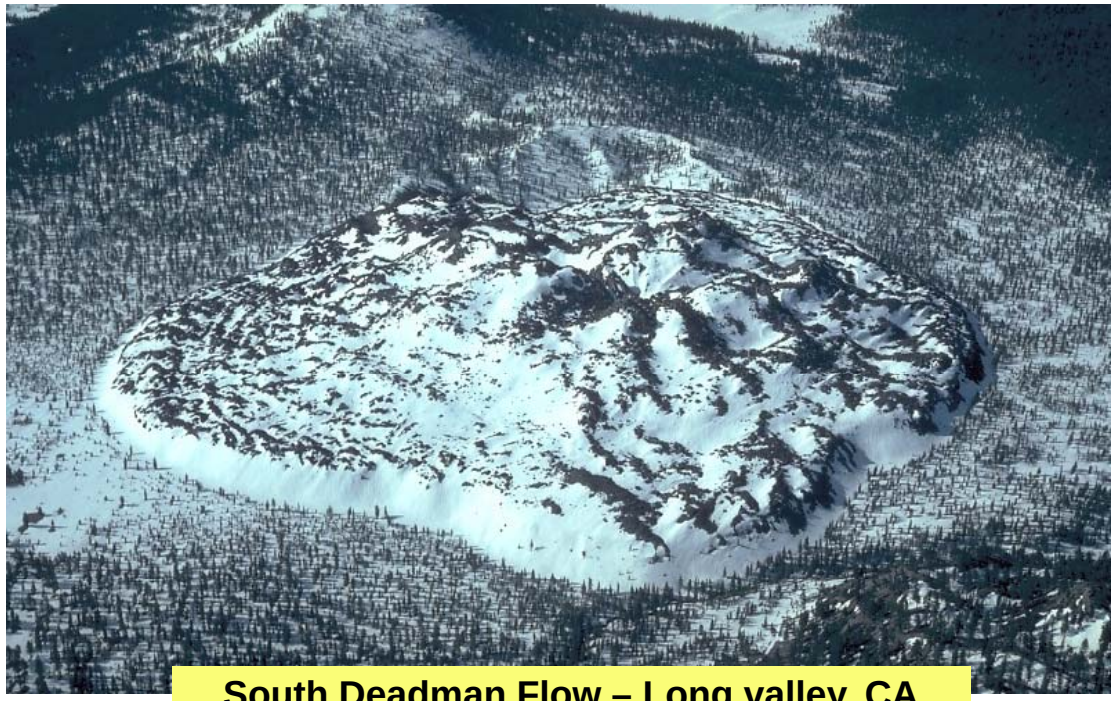
Figure 11-24a
Universe, Eighth Edition

- **Some volcanoes on Venus do have viscous lava**
  - **On Earth these would be explosive stratovolcanoes**
  - **On Venus the high pressures keep the gases in the magma dissolved**
    - **No explosions**
    - **Pancake domes**



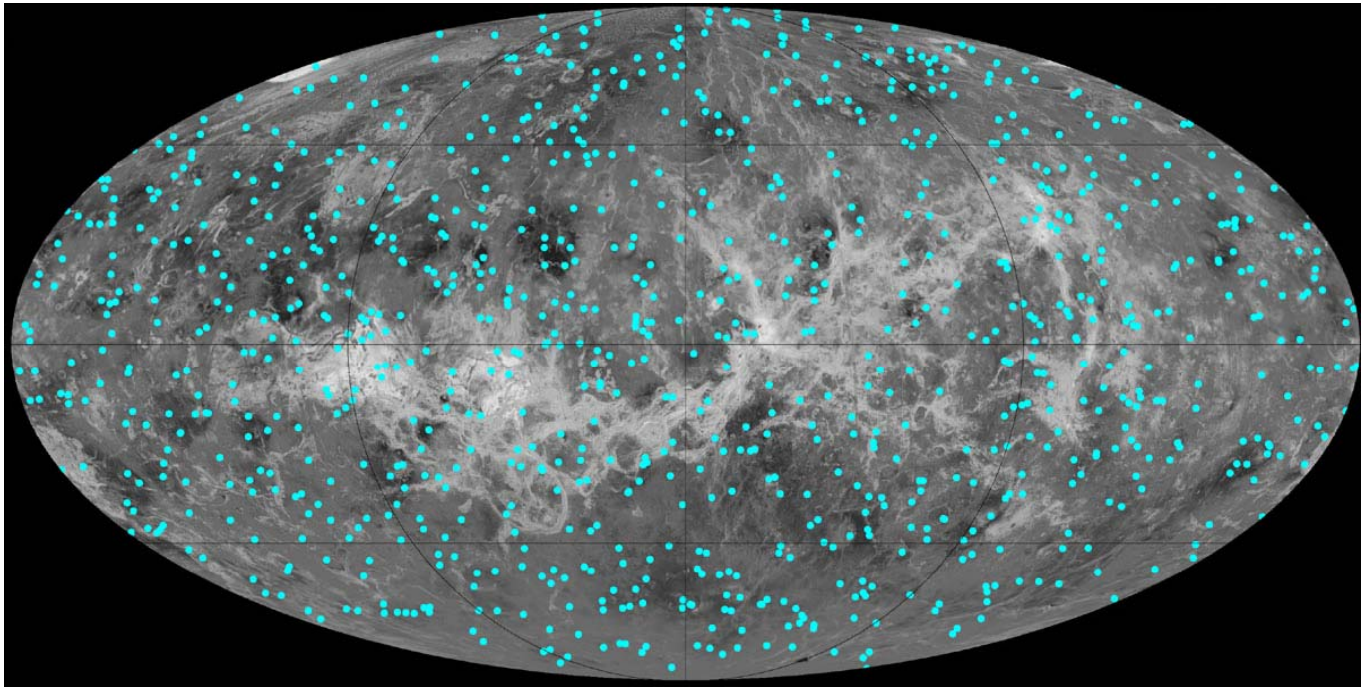


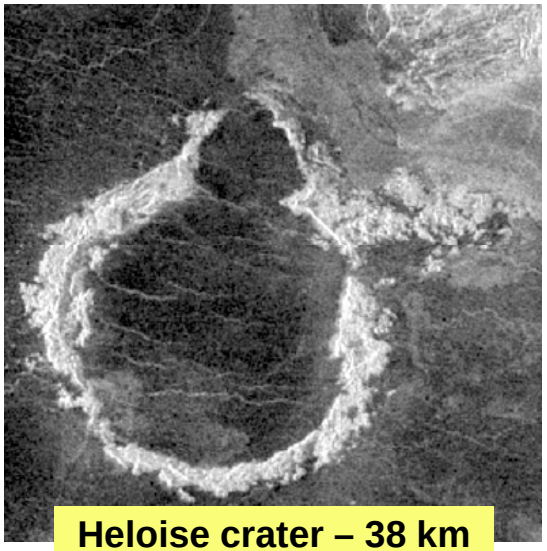
Pancake domes – Eistla region



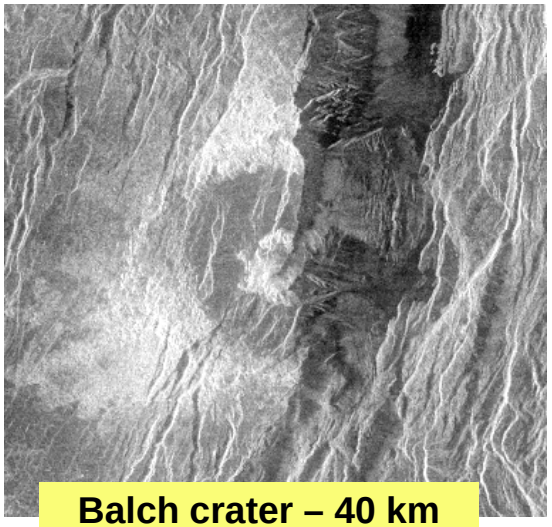
South Deadman Flow – Long valley, CA

- **Craters on Venus tell a strange story**
  - **Only ~1000 craters - Randomly distributed**
  - **Imply that the surface is only 700-800 Myr old**
    - **Catastrophic resurfacing**
    - **Continual removal**
    - **Occurred over the entire planet**
  - **What happened for the first 3.8 billion years on Venus?**



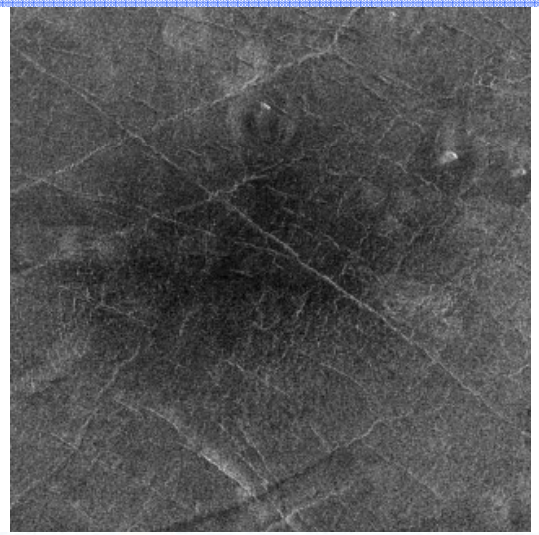


Heloise crater – 38 km

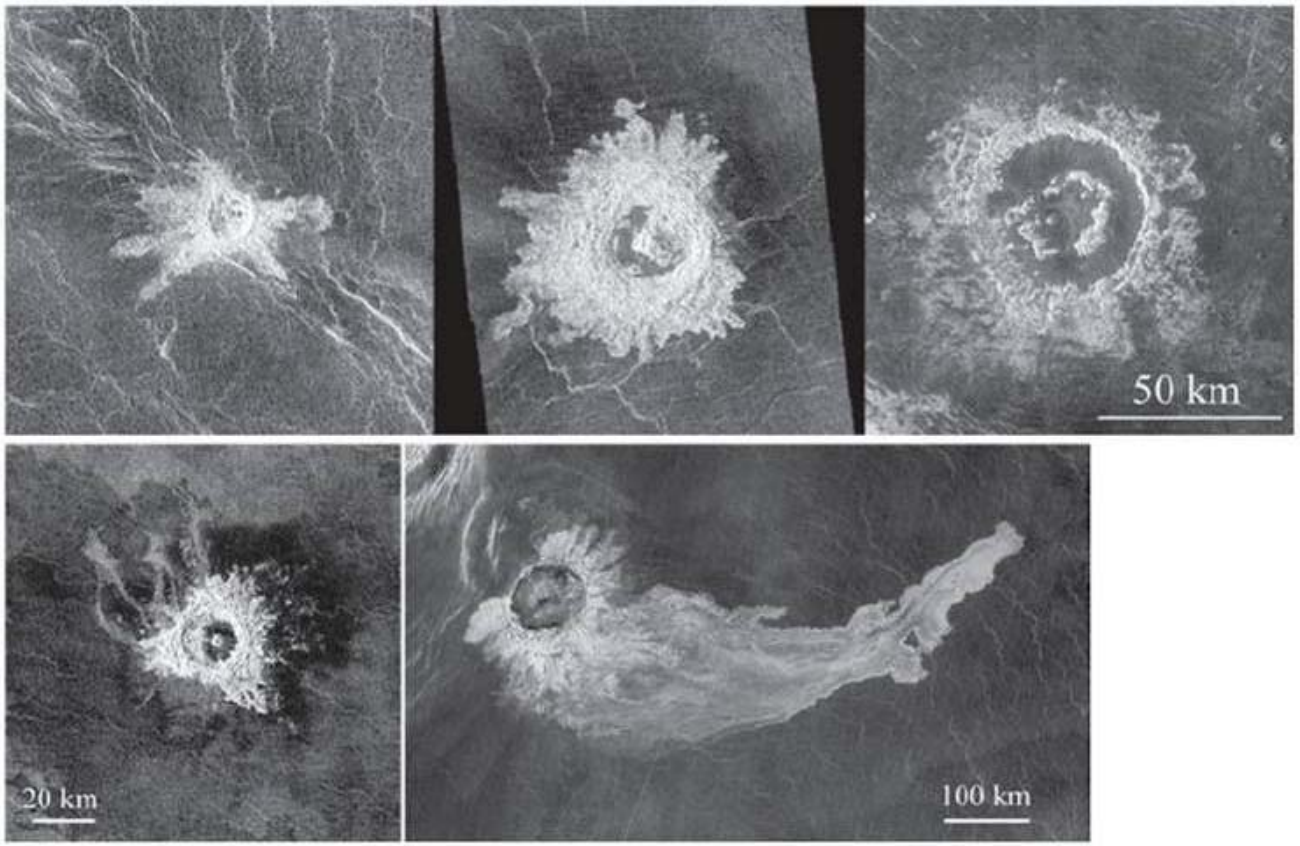


Balch crater – 40 km

- **All craters > 3km in size**
  - **Atmosphere stops any smaller impacts from reaching the surface**
  - **'Burn' marks on the surface (smooth areas) maybe the result of impactors exploding in the atmosphere**

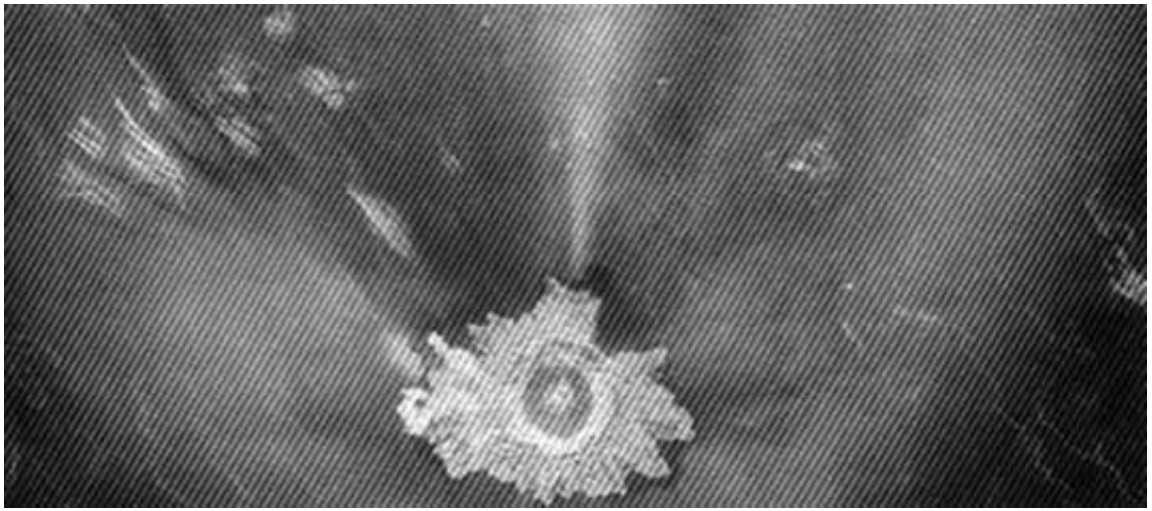


- **Impacts can trigger volcanic activity**



Wind on Venus?

- Surface winds speeds are very low
  - 0.3-1.0 m/s
- However the atmosphere is very dense
  - Some near-surface material can be moved
  - Volcanic material can be carried by the wind
  - Volcanic cones can create wind shadows



- Craters can throw debris higher in the atmosphere where the winds are stronger

Interior of Venus

- **The lithosphere of Venus behaves very differently than that of the Earth**
  - **Earth has large plates that collide and can slide underneath earth other**
    - **Pushes up mountains**
  - **Venus has many small patches of crust that get pushed up and pulled down from below**

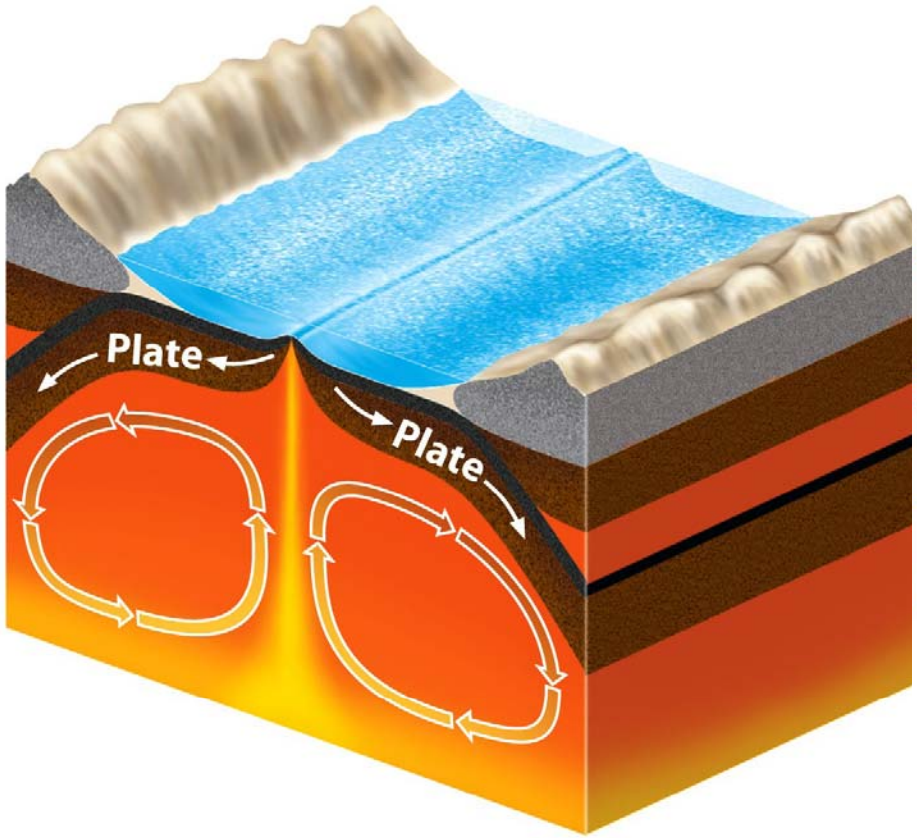


Figure 11-22 part 1
Universe, Eighth Edition

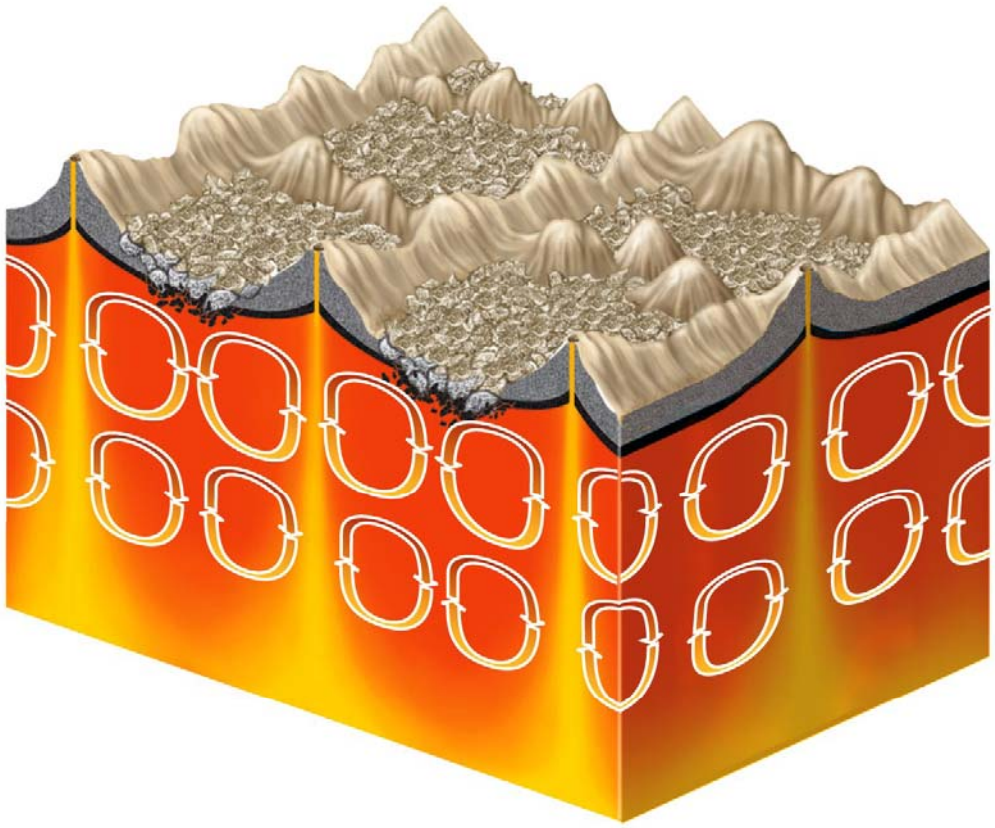
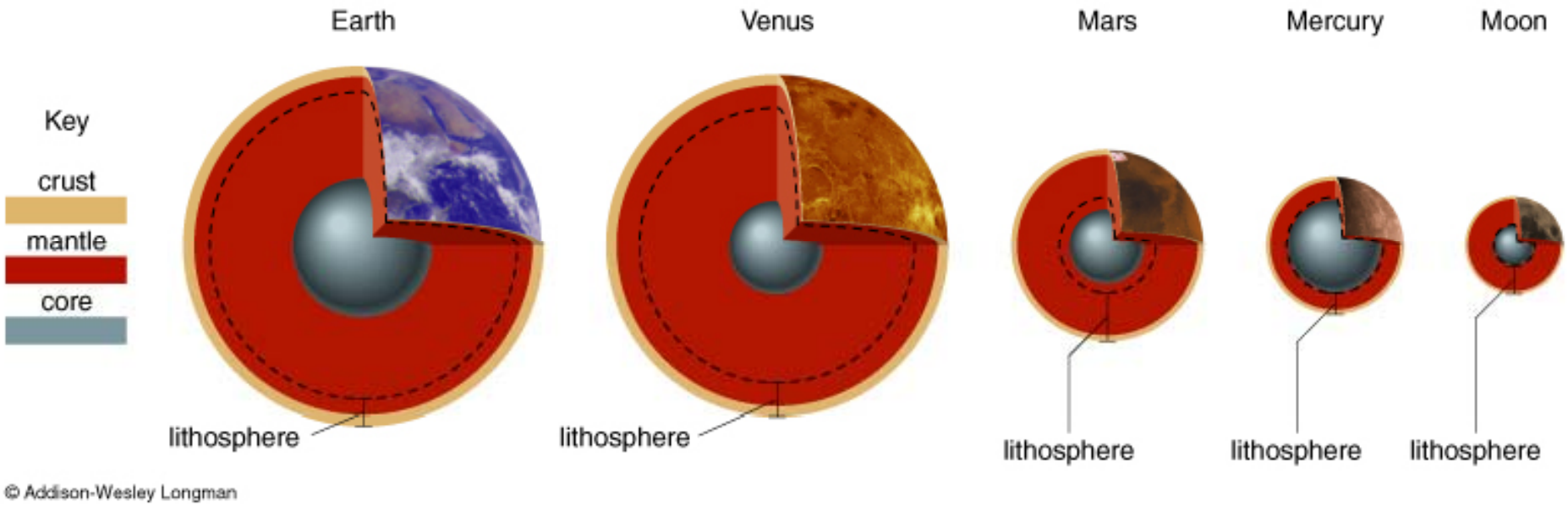


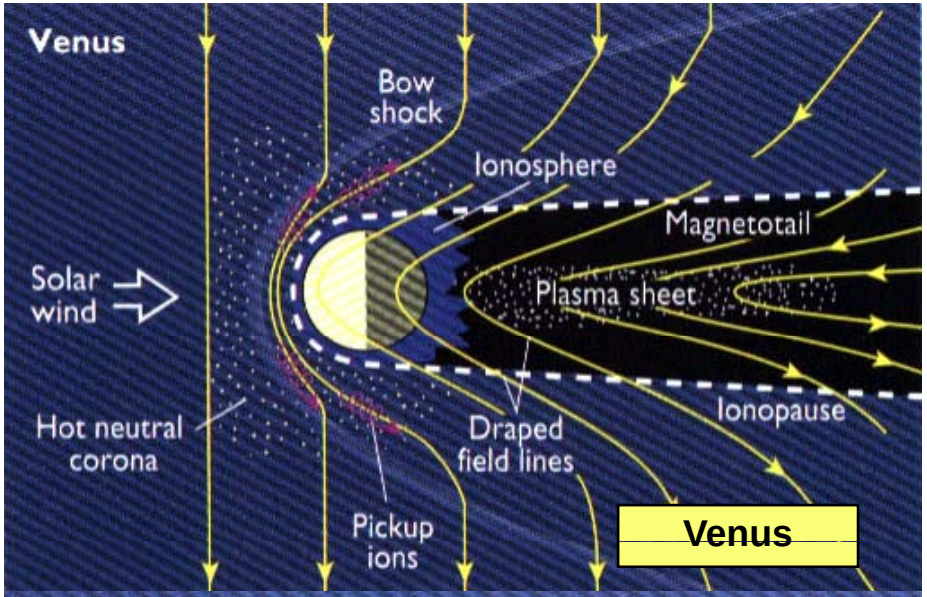
Figure 11-22 part 2
Universe, Eighth Edition

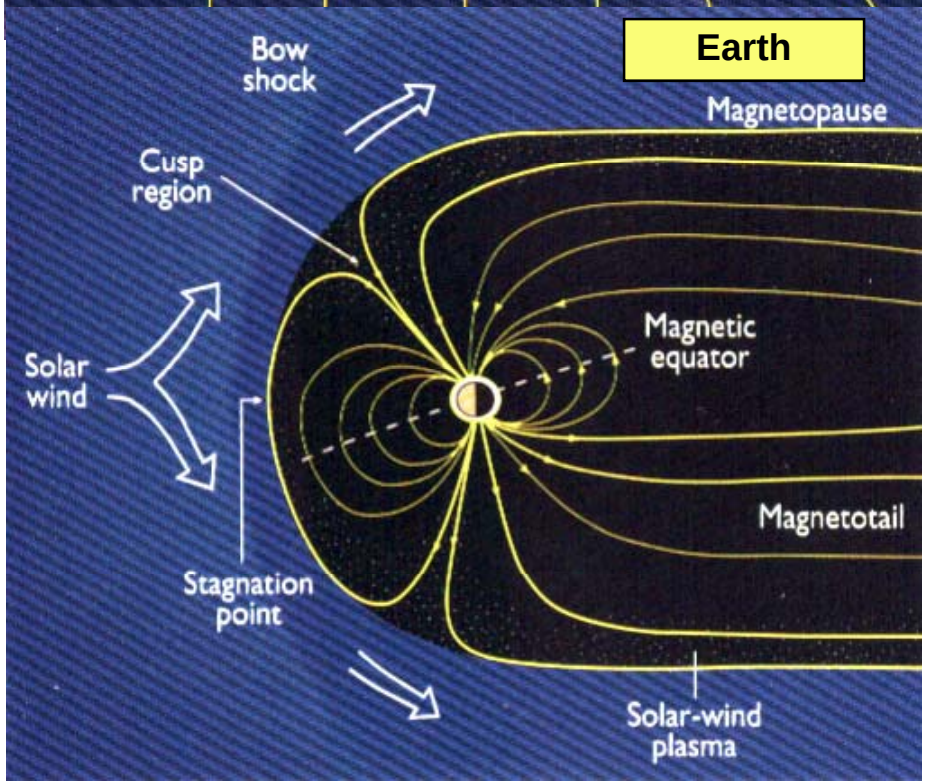
- **Venus almost certainly has a liquid iron core**
  - **Similar composition to the Earth**
  - **High surface temperatures means Venus's interior cools more slowly**
  - **Slow rotation means it cannot produce a magnetic field**



Magnetic field?				
Earth Yes	Venus No	Mars Remnant	Mercury Yes	Moon No

- **Consequences of no magnetic field**
  - **Solar wind is a stream of particles coming from the Sun**
  - **Solar wind directly hits the atmosphere and strips away material**
  - **Venus can lose water this way**





History of Venus

- Starting conditions much the same as the Earth
- CO_2 and water injected into atmosphere from volcanoes (or delivered by comets)
- Venus pressure and temperature increases
- Water can stay liquid for a while due to high pressures
- Eventually all the water evaporates
  - Increases the greenhouse effect even more
- High temperatures bake CO_2 out of existing rocks
  - Increases the greenhouse effect even more
- The sun also gets warmer with time

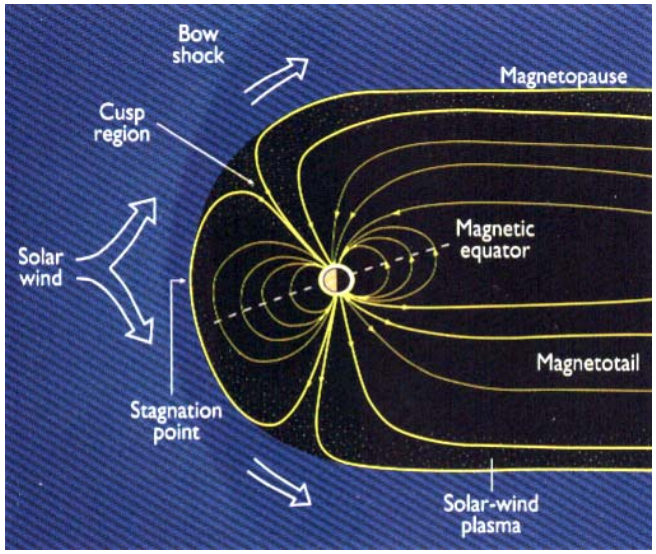
Figure 11-33
Universe, Eighth Edition

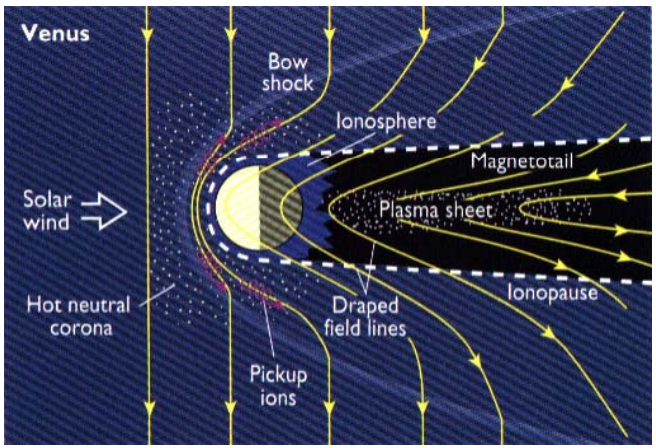
- **We call this the runaway greenhouse effect**

- **Another possible consequence**
  - **Venus now has a very massive atmosphere**
  - **Solar tides can slow the planet's spin rate**
  - **Causes planet's magnetic field to shut down**

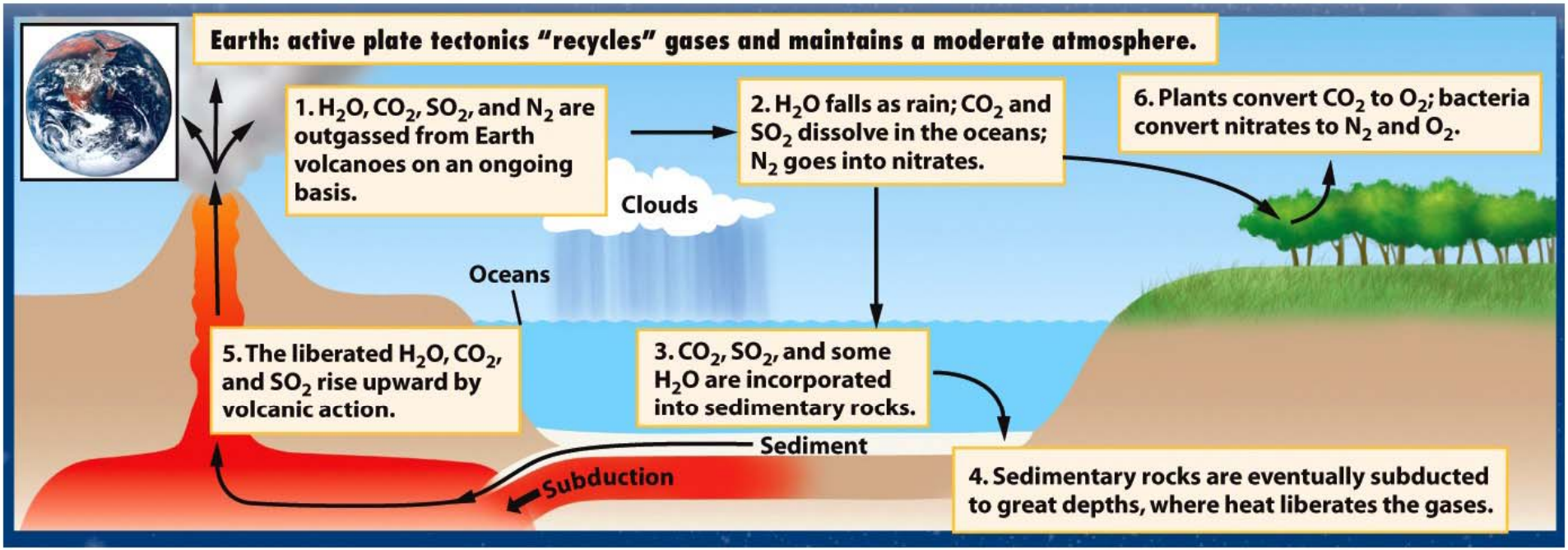
- **Water vapor breaks up via UV radiation**
  - **Break-up H_2O into 2 x H^+ and an O^{2-} ions**
  - **No magnetic field means H^+ ions stripped away**
  - **Water is lost permanently**

- **Venus can never get back out of its current state**

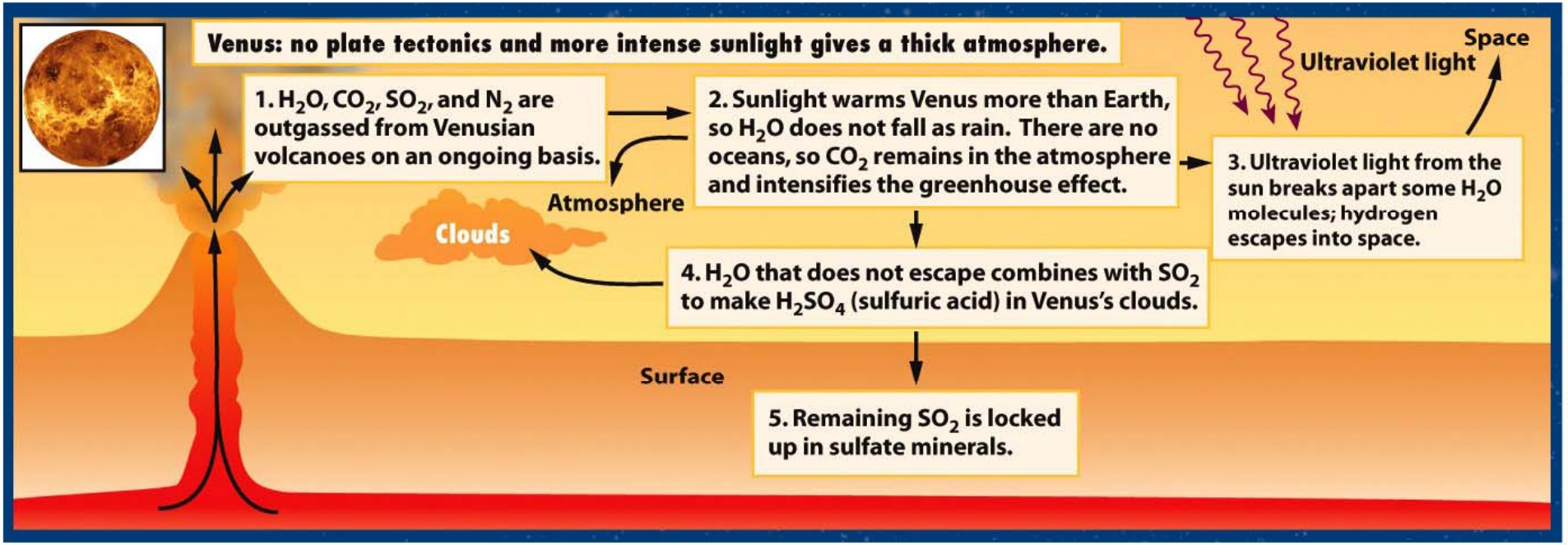




- **Why didn't this happen on the Earth ?**
  - **Earth has water that rains**
  - **Rain dissolves CO_2 from the atmosphere**
    - **Forms carbonic acid**
  - **This acidified rainwater weathers away rocks**
  - **Washes into the ocean and forms carbonate rocks**
  - **Carbonate rocks eventually recycled by plate tectonics**
- **The rock-cycle keeps all this in balance**
  - **Sometimes this gets out of sync e.g. snowball Earth – stops weathering**



- **Venus started with plenty of water**
  - **Temperatures were just a little too high to allow rainfall**
  - **Atmospheric CO_2 didn't dissolve and form carbonate rocks**
- **Venus and Earth have the same amount of CO_2**
  - **Earth's CO_2 is locked up in carbonate rocks**
  - **Venus's CO_2 is still all in the atmosphere**
- **Same for sulfur compounds produced by volcanoes**
  - **SO_2 (sulfur dioxide) on Earth dissolves in the oceans**
  - **SO_2 on Venus stays in the atmosphere and forms clouds of sulfuric acid**



In this lecture…

- Recap on Venus and its atmosphere
  - Thick enough to have changed the planet's rotation?
- Exploring Venus
  - Landers and radar
- Surface of Venus
  - Volcanoes & lack of craters
- Interior of Venus
  - No plate tectonics
- History of Venus – controlled by water
  - Escape of water seals the fate of Venus

Next: Mars - Early History

- Reading
  - Chapter 11-Venus sections to revise this lecture
  - Chapter 11-Mars sections for next two lectures