The top of the martian atmosphere

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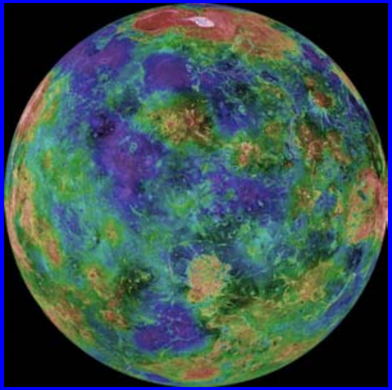
Images

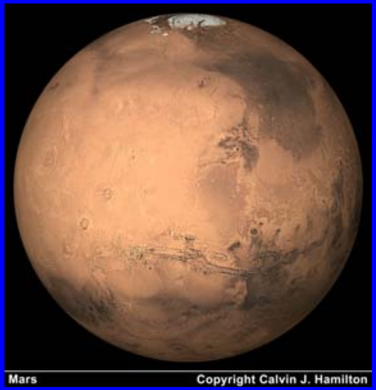
- www.solarviews.com
- The Cosmic Perspective, Bennett et al.

Aim: Describe the current state of the Mars upper atmosphere and its important processes

- Motivation: Atmospheric loss on Venus, Earth, and Mars
- Context: Present-day Venus, Earth, and Mars
- Details: Chemistry, dynamics, energetics, and plasma in the Mars upper atmosphere

Venus, Earth, and Mars – Some Similarities



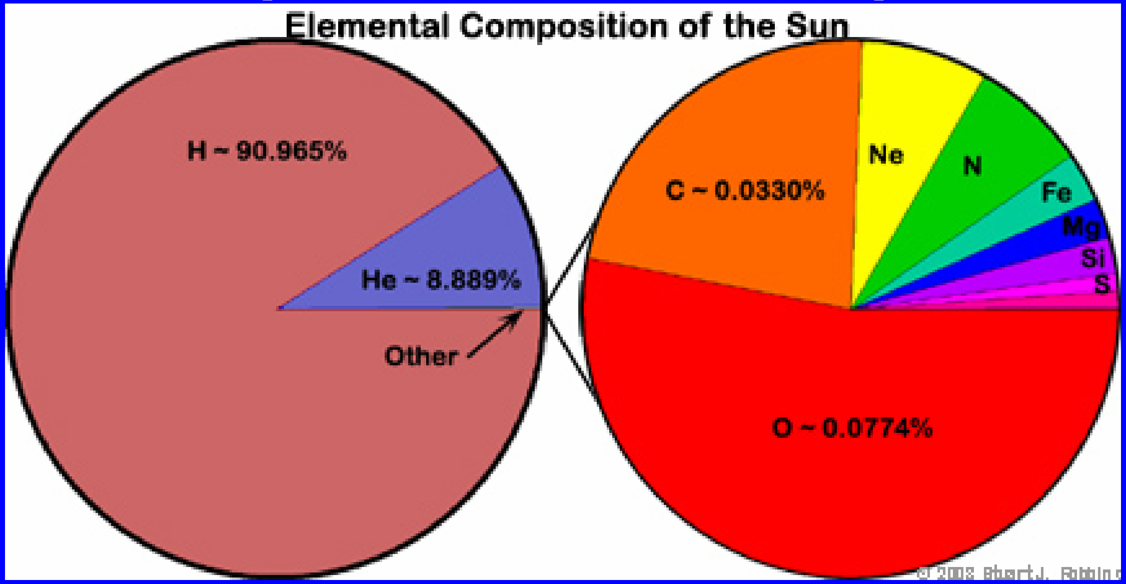


- Rock/metal surfaces and interiors
- Similar bulk compositions, so probably similar primordial atmospheres
- Substantial atmospheres today
- Similar sizes and gravities

Venus, Earth, and Mars – Some Differences

- Distance from Sun: Mars > Earth > Venus, so expect Venus to be hot and Mars cold
- Magnetic field: Earth has strong dipole field, Venus has no field, Mars has regions of strong field and regions of no field
- Size: Mars is smaller than Earth and Venus, so its gravity is weaker

What gases should be common in terrestrial planet atmospheres?



http://filer.case.edu/~sjr16/media/sun_elements.jpg

- H_2O ?
- CO_2 ?
- N_2 ?
- Noble gases ?
- O_2 ?
- Must be abundant in the inner solar system
- Must be volatile enough to be gaseous

Atmospheric Compositions

- Meteorites, Sun, giant planets suggest that H_2O, CO_2, N_2 should be most abundant

- Venus: 100 bar pressure
  - Mostly CO_2, some N_2
- Earth: 1 bar pressure
  - N_2 and O_2 mixture
- Mars: 0.006 bar pressure
  - Mostly CO_2, some N_2

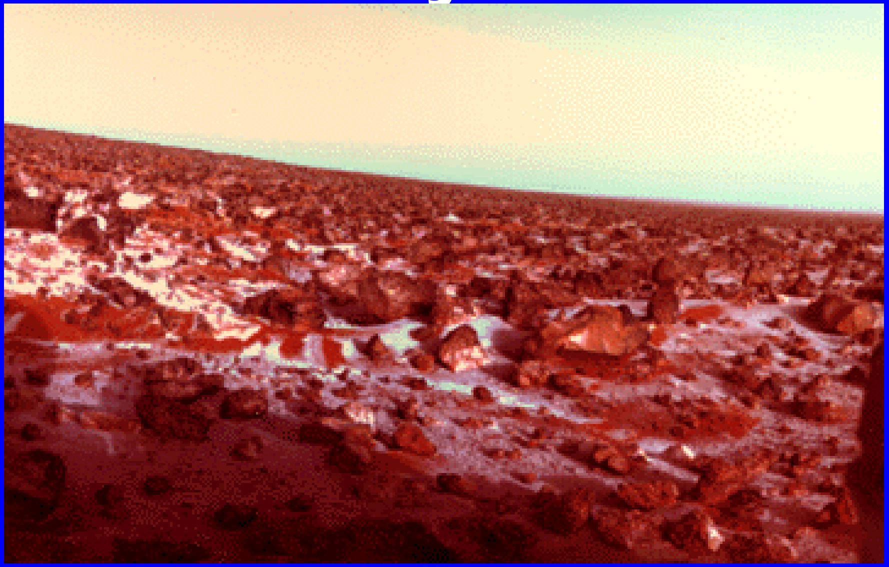
Atmospheric History

http://www.beachyhead.org.uk/_images/_images/_new/7sisters.jpg

http://www.aerofun.ch/image_gallery2/image9.jpg

- Earth: H_2O forms oceans, cannot be dissociated by UV, so no H lost to space. CO_2 dissolves in oceans, forms carbonate rocks. Leaves N_2 dominant gas in atmosphere. Continuous biological activity pumps O_2 into atmosphere and chemical reactions consume O_2

Atmospheric History

http://www-curator.jsc.nasa.gov/antmet/marsmets/images/viking.gif

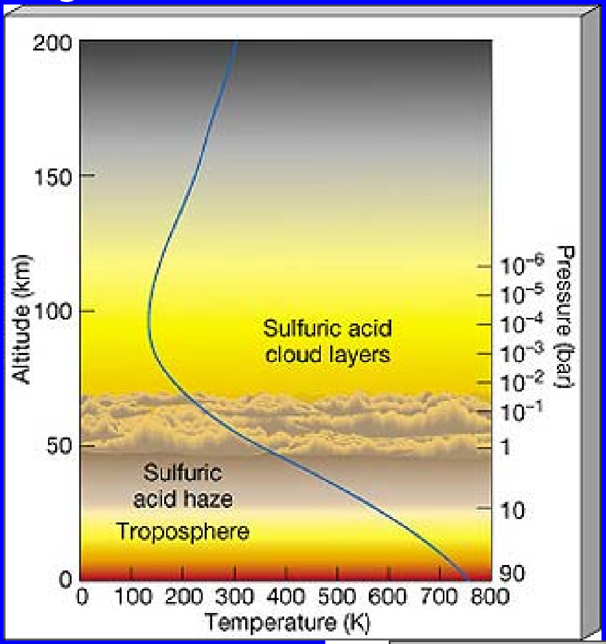
- Venus: Too Hot
  - H_2O in atmosphere photodissociates, H lost to space very rapidly. C, N, O lost more slowly, so CO_2 and N_2 remain in atmosphere
- Mars: Too cold
  - H_2O frozen solid. Low gravity and weak magnetic field mean that CO_2 and N_2 escape rapidly, reducing atmospheric thickness. Some frozen H_2O sublimates into thin atmosphere, is photodissociated and H is lost to space.
- The masses and chemical compositions are explained! But this “story” needs rigorous testing.

Escape Questions

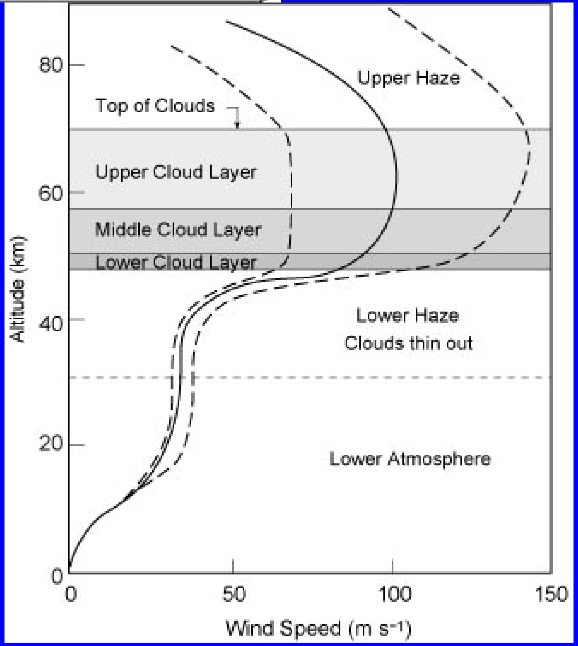
- How did Mars lose 99.9% of primordial atmosphere, yet keep 0.1%?
- What is the history of Mars climate?
- How have magnetic fields affected escape?
- What are dominant escape processes today and how do they operate?
- What is upper atmosphere like today and what processes are important?

Present-Day Venus

- Zero obliquity and eccentricity mean no seasons
- Thick atmosphere, slow rotation mean that weather at surface is same everywhere
- 740 K at surface, slow winds, no storms, no rain
- H_2SO_4 clouds at 50 km, where pressures and temperatures are similar to Earth's surface



http://rst.gsfc.nasa.gov/Sect19/Ven-atmos-profile-CM.jpg



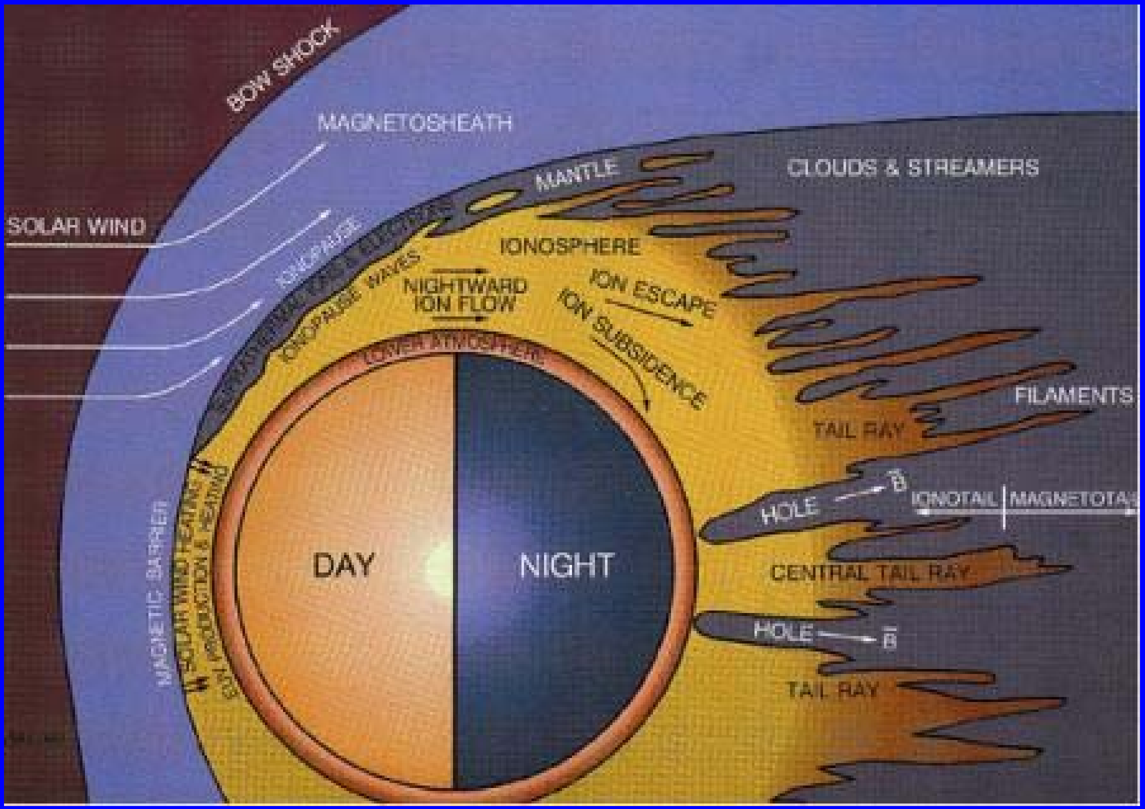
http://ase.tufts.edu/cosmos/pictures/Explore_figs_8/Chapter7/Fig7_3copy.jpg

Venus upper atmosphere

- Reformation of photolysed CO_2 catalysed by Cl, terrestrial implications
- Lots of solar heating, but little day-night transport of energy
- Nightside upper atmosphere is very cold, 100 K, whereas dayside is 300 K
- O / CO_2 ratio plays a major role, more O than CO_2 above 150 km
- Only H is escaping today

Venus ionosphere and plasma

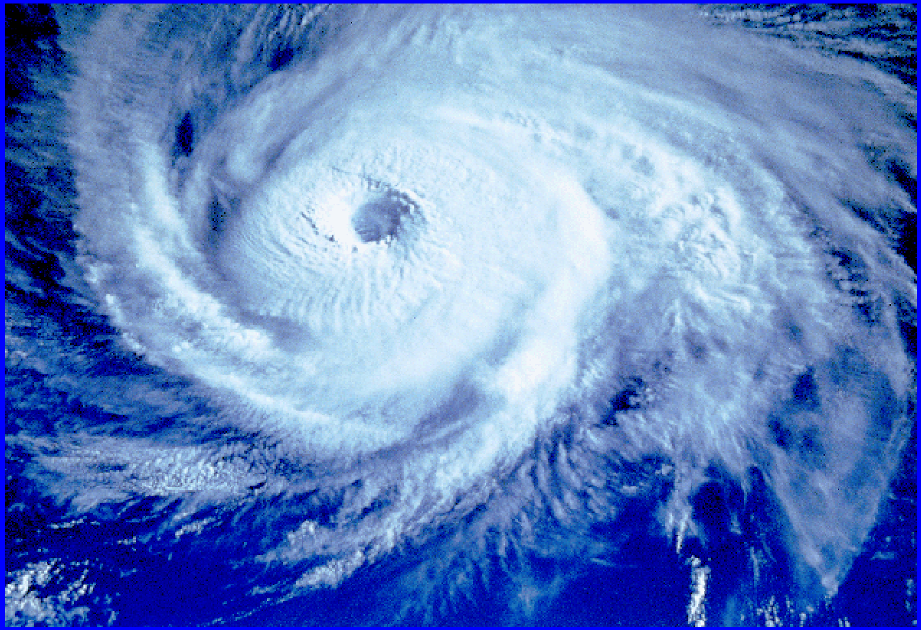
- Ionosphere formed by EUV photoionization of CO_2, but $CO_2^+ + O \rightarrow O_2^+ + CO$
- O_2^+ is dominant at Chapman peak (140 km), O^+ dominant 40 km higher up



http://www3.imperial.ac.uk/spat/research/space_magnetometer_laboratory/spacemissionpages/venusexpresshomepage/science

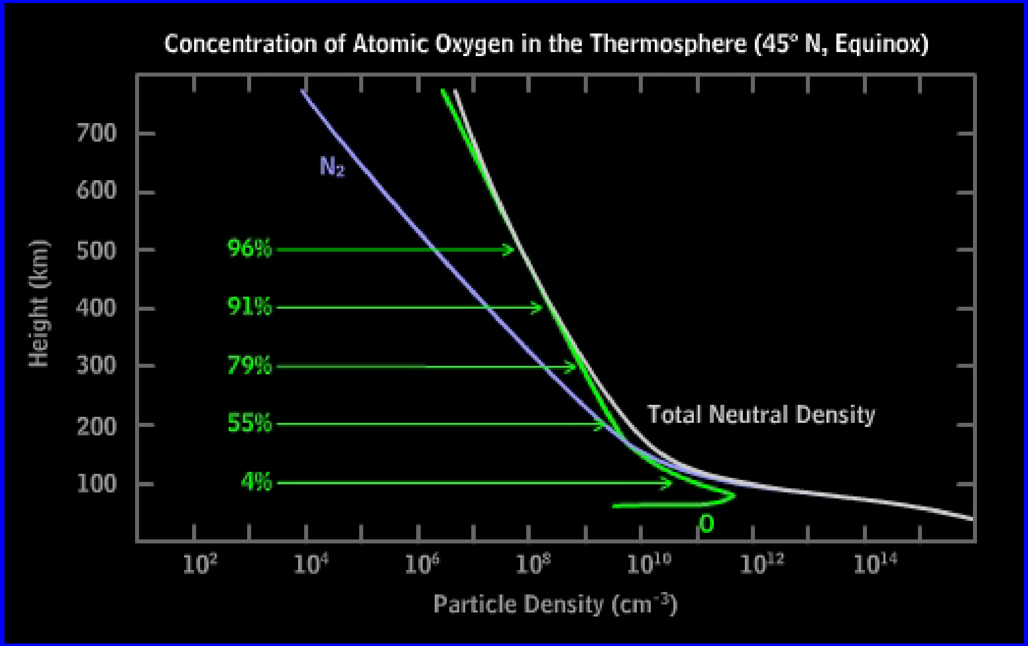
- Transport important near O_2^+/O^+ transition and above
- Magnetic fields due to draping of solar wind around planet
- Nightside ionosphere and magnetic fields are complex and variable, affected by plasma transport across terminator

Present-Day Earth



- Coupled atmosphere and ocean
- Strong seasonal and latitudinal variations, but significant transport of heat from dayside to nightside and equator to poles
- Rapid rotation and ocean/land contrasts drive lots of weather
- Stable global circulation patterns (Hadley cells)

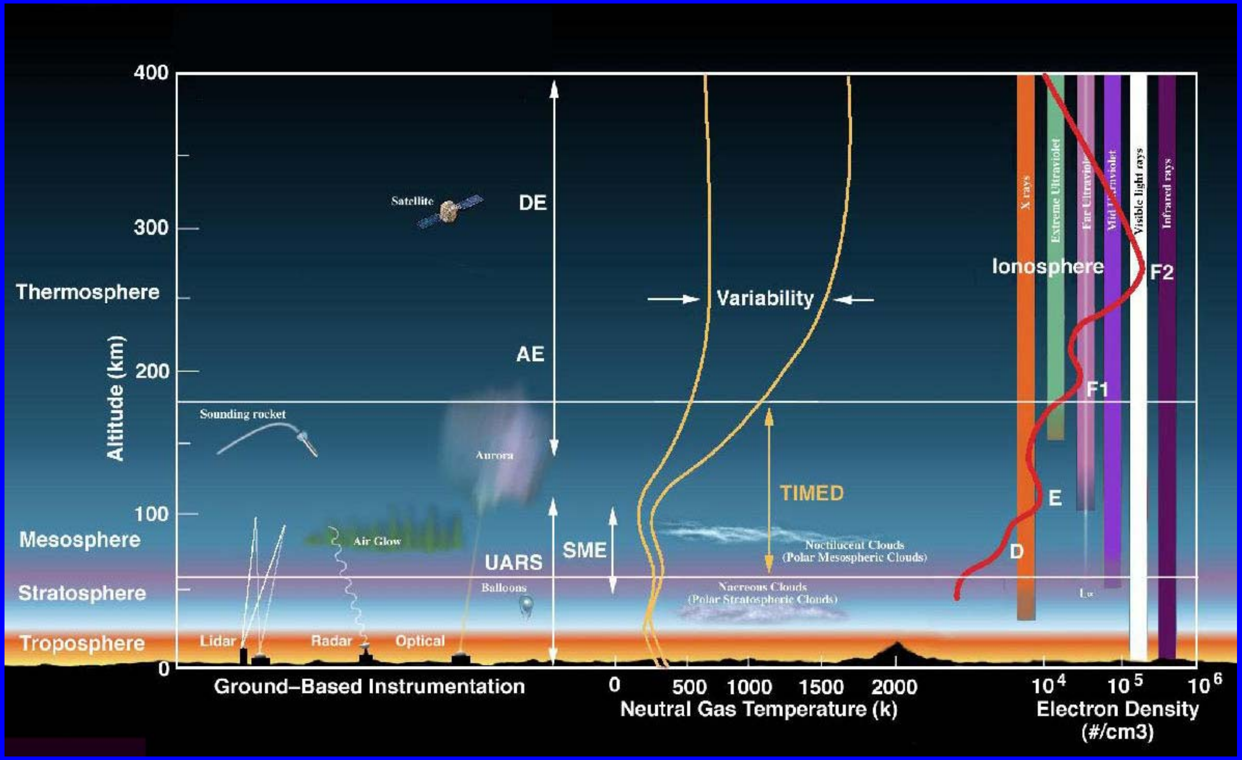
Earth Upper Atmosphere



http://www.meted.ucar.edu/hao/aurora/images/o_concentration.jpg

- O is more abundant than O_2 above 100 km and more abundant than N_2 above 200 km
- T > 800 K above 200 km, much hotter than Venus or Mars. These atmospheres are cooler because CO_2 is very effective at radiating heat, whereas Earth needs higher temperature gradients to conduct heat downwards
- Heating at poles due to magnetic fields guiding solar wind
- Only H is escaping today

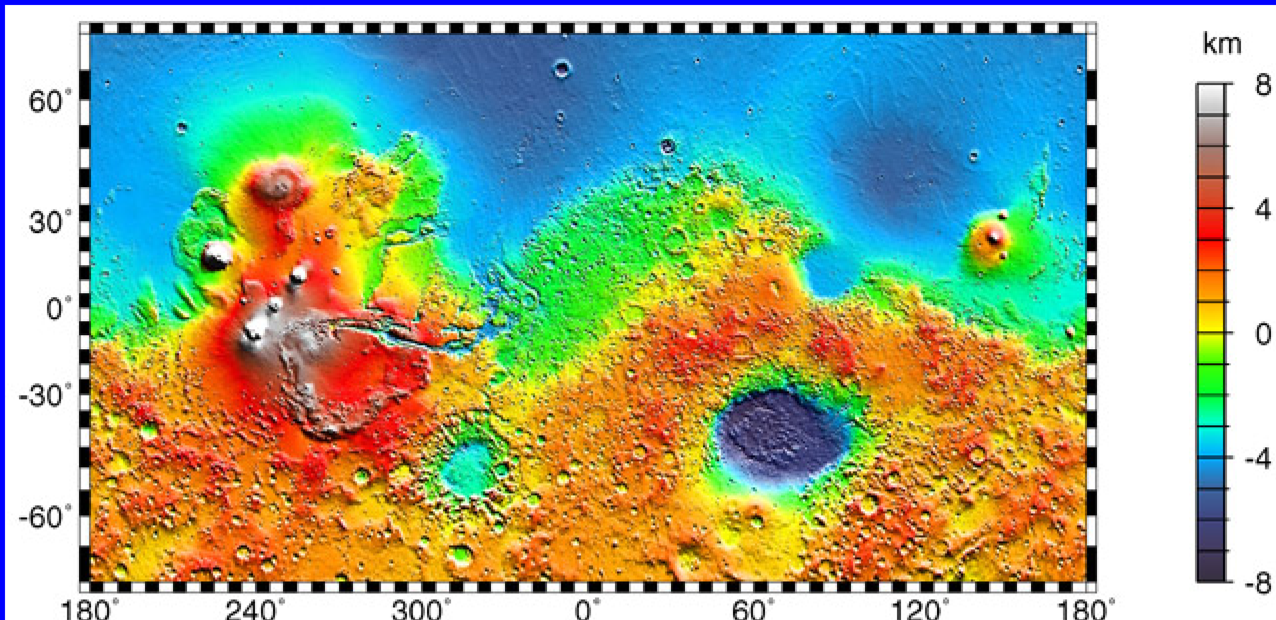
Earth Ionosphere

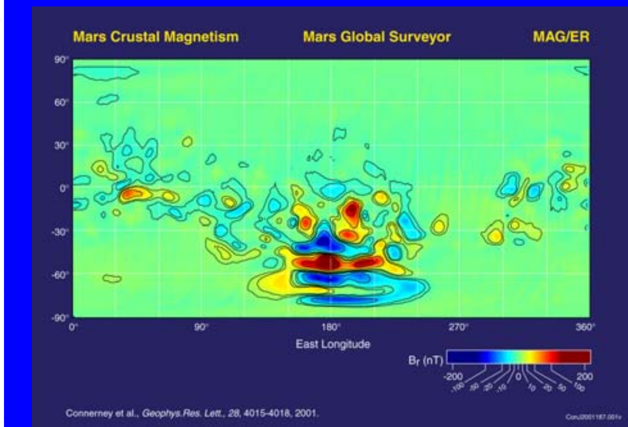


http://www.bu.edu/cism/CISM_Thrusts/ITM.jpg

- O_2^+ and NO^+ dominant at 100 km, where EUV absorption peaks
- O^+ dominant at 300 km (overall peak), where transport plays major role
- Changes from O_2^+/NO^+ to O^+ and from N_2 to O make things complex
- Magnetic fields affect plasma transport, especially at equator and near poles

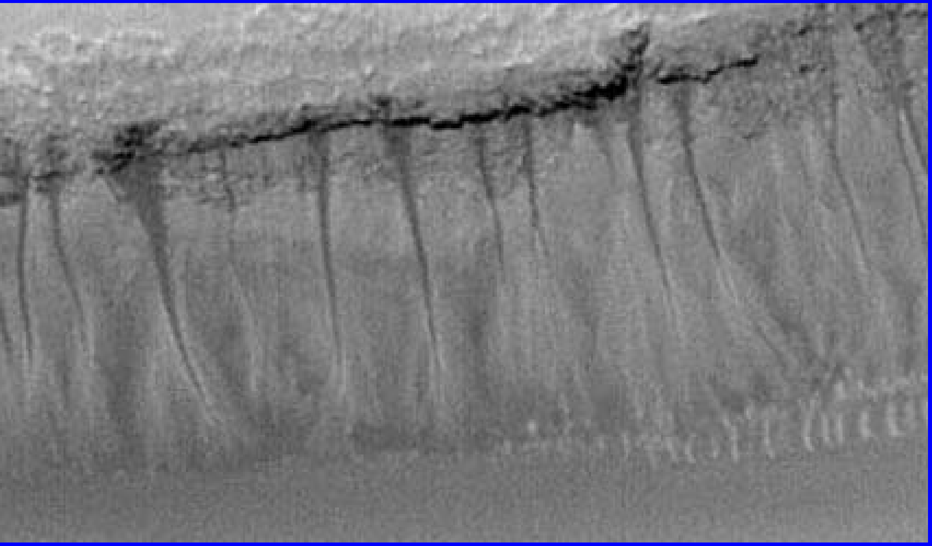
Present-Day Mars





- Minimal wind erosion
- Possible weak ongoing volcanism and tectonism, no evidence for past plate tectonics
- Frozen H_2O at poles and elsewhere
- Frozen CO_2 at poles
- Large canyons, craters, volcanoes

Present-Day Mars



- 1/3 of atmosphere freezes onto winter polar cap
- Global dust storms
- Large day/night temperature differences
- Surface pressure too low for liquid water to be stable, but ongoing gully formation may require liquid water
- Saturated with H_2O, both H_2O and CO_2 clouds are common

Lower, Middle, Upper

- Lower: 0 – 40 km, exchanges heat with surface and/or suspended dust
- Middle: 40 – 100 km
- Upper: 100 - ?? km, heated by variable solar UV flux, temperature increases with increasing altitude
  - Contains homopause, ionosphere, exobase
- Unlike Earth, regions are not well-defined

The rest of the talk

- Describe upper atmospheric chemistry, dynamics, energetics, and ionosphere
  - Using one illustrative example for each
- Link these examples by how they might affect escape

Chemistry: O and CO_2

- CO_2 is photolysed by UV into CO and O
  - This is a rapid process
- $CO_2 + hv \rightarrow CO + O$ ($\lambda < 1671$ A)
- $O + O + CO_2 \rightarrow O_2 + CO_2$

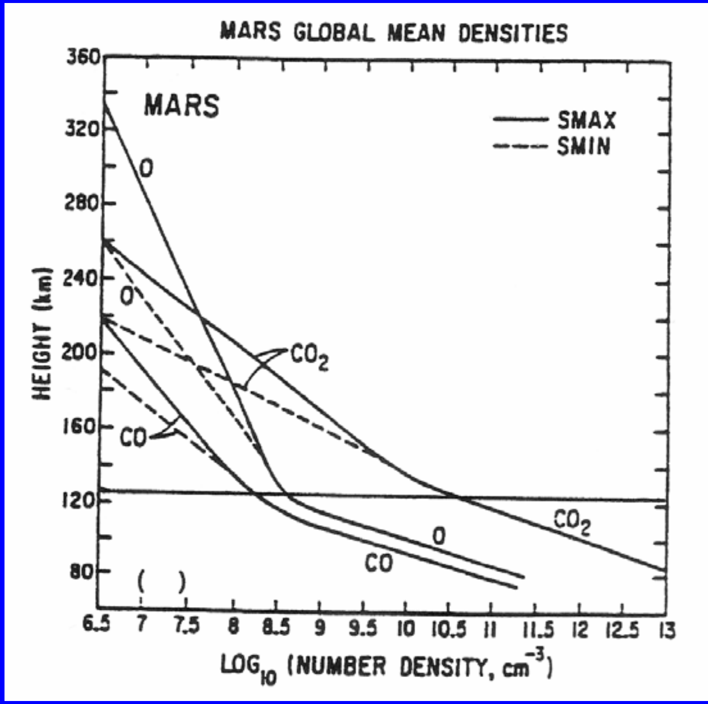
- Why is the atmosphere made of CO_2, not 2 parts CO and 1 part O_2?

Mars surface is very oxidizing

- Species like H, OH, HO_2, and H_2O_2 are relatively abundant and act as catalysts

- CO + OH -> CO_2 + H
- More chemistry oxidizes H back into OH
- Net effect is CO + O -> CO_2
- But not all O is lost…

O in the upper atmosphere

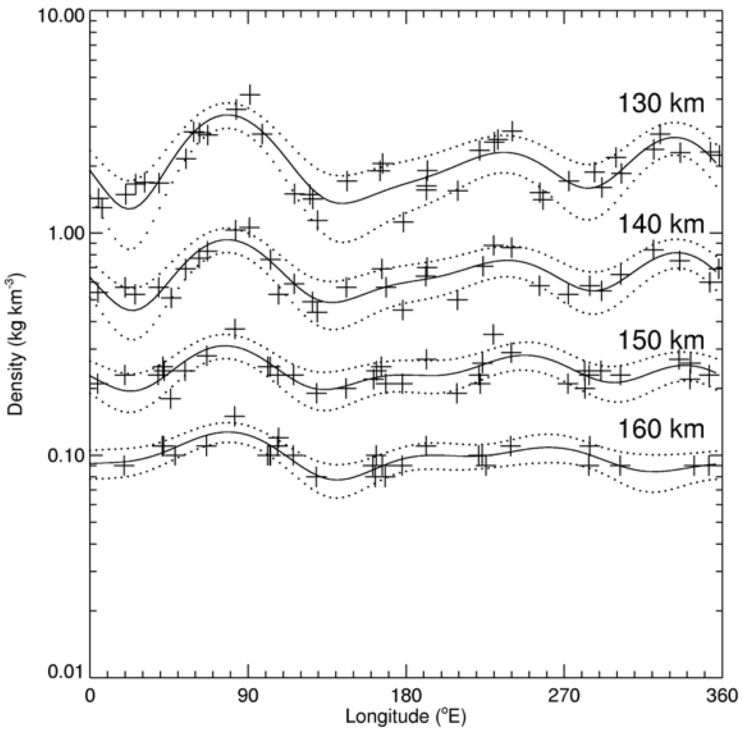


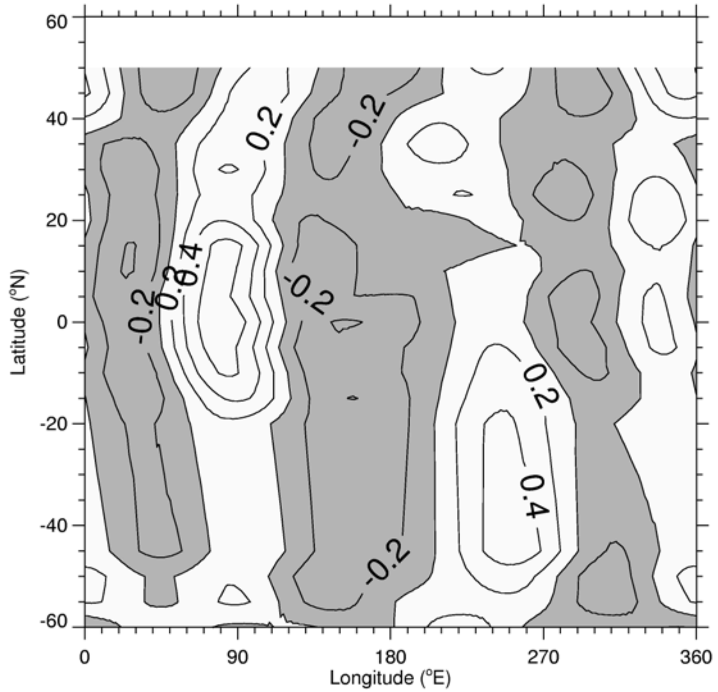
Bougher et al., 2002

- O / CO_2 > 1 above 200 km
- O bumps into CO_2, excites vibrational states (demo)
- CO_2 emits 15 um photon, de-excites
- Important for cooling upper atmosphere

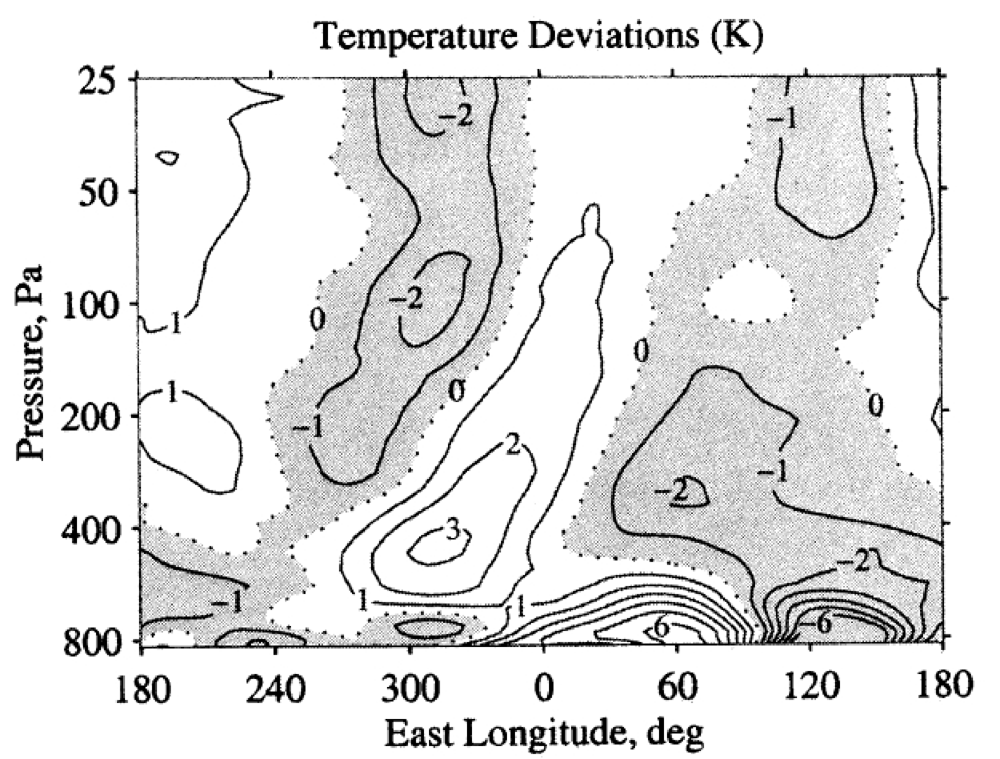
- EUV photons absorbed by CO_2, form CO_2^+ ions
- But $CO_2^+ + O \rightarrow O_2^+ + CO$
- O makes O_2^+ the dominant ion
- Presence of neutral O makes it easy for O to escape, affects temperature of upper atmosphere, and controls composition of the ionosphere

Dynamics - Tides





Source of tides



Hinson et al., 2001

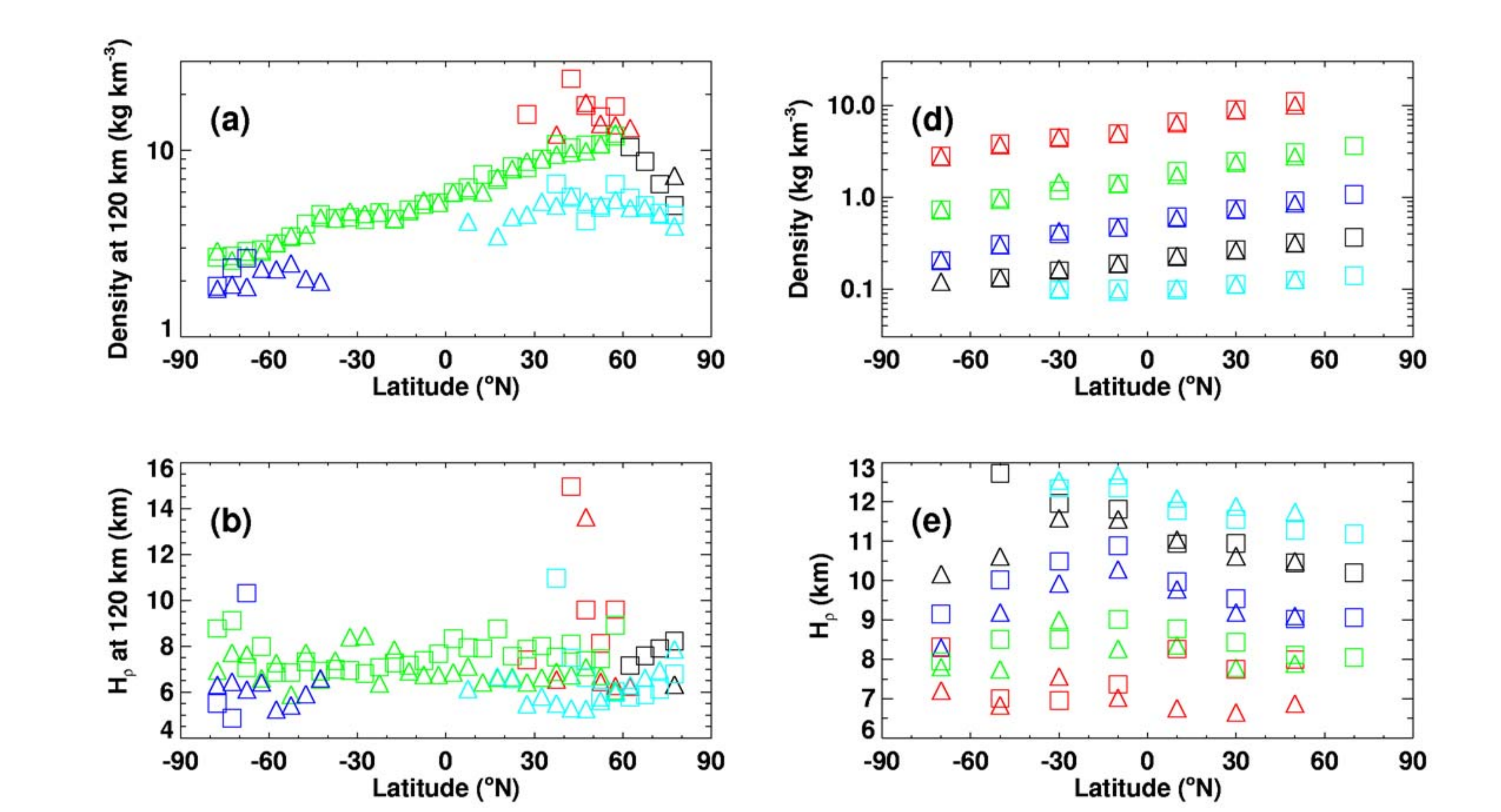
Some modes dissipate as they propagate up
Some modes amplify as they propagate up
Different modes dominant in lower and upper atmosphere

- Must be surface or interior
  - Nothing above surface varies with longitude
- Interaction of migrating tides with topography
- Dynamics of lower and upper atmospheres are linked together

Implications of tides

- Strong dynamics in upper atmosphere
- Circulation patterns will cause heating/cooling
- Breaking of waves and tides deposits energy and momentum into atmosphere
- Winds may transport plasma to regions where escape is easier

Energy – Temperature Variations



Panels a and b: Colours indicate different areobraking seasons/LSTs
NP: Black = dayside, Light Blue = nightside
SP: Green = dayside, Dark Blue = nightside

Panels d and e: Colours indicate 120 – 160 km in 10 km intervals

Temperature Observations

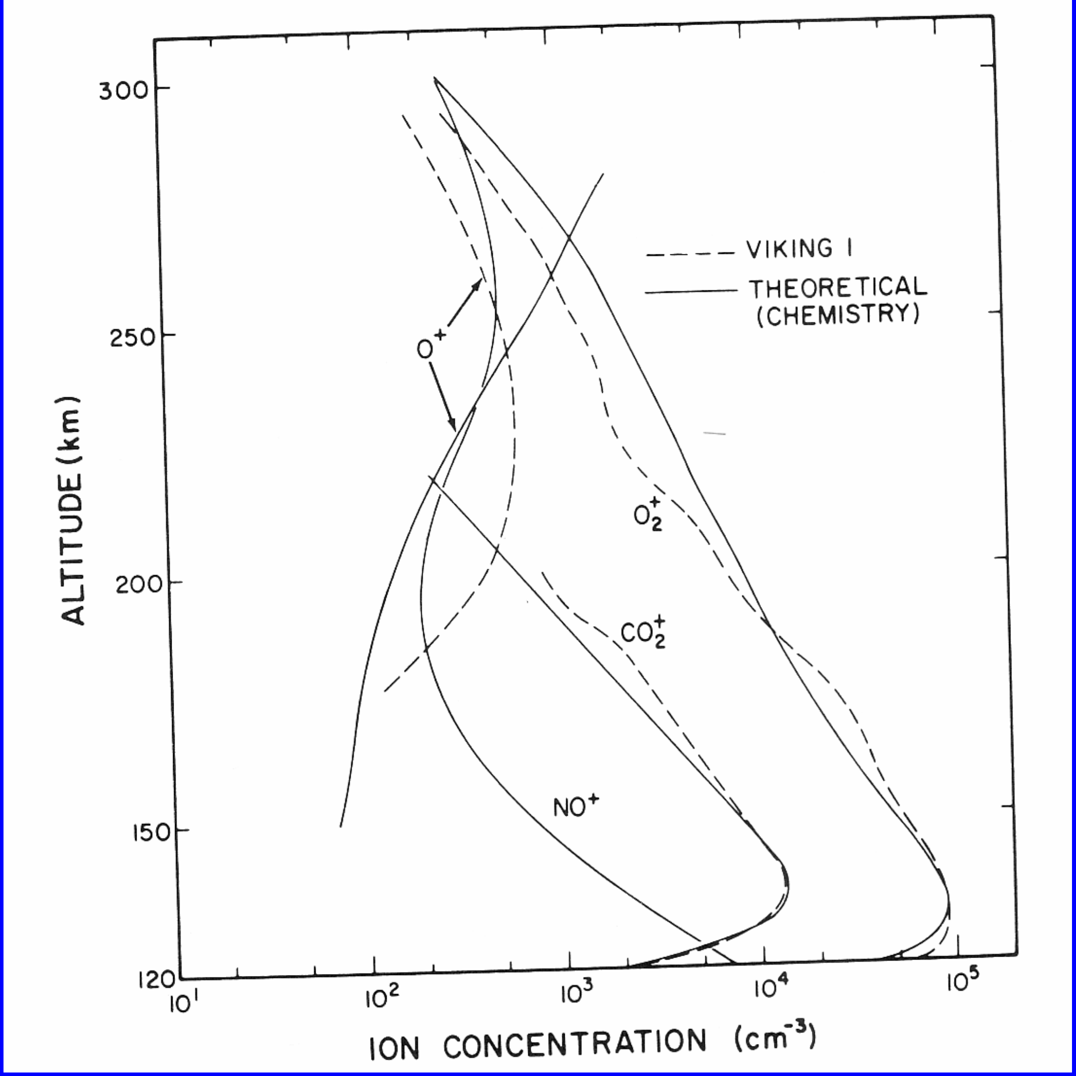
- Vertical temperature gradients much greater than meridional gradients
  - Atmospheric circulation transports heat poleward efficiently
  - Vertical gradients needed to conduct heat downwards into denser atmosphere where CO_2 15 um radiation can radiate heat to space

- Mars: night T = 100K, day T = 150K
- Venus: night T = 100K, day T = 300K
  - Circulation is effective at heating Mars nightside
  - If too cold, nightside would not experience much escape

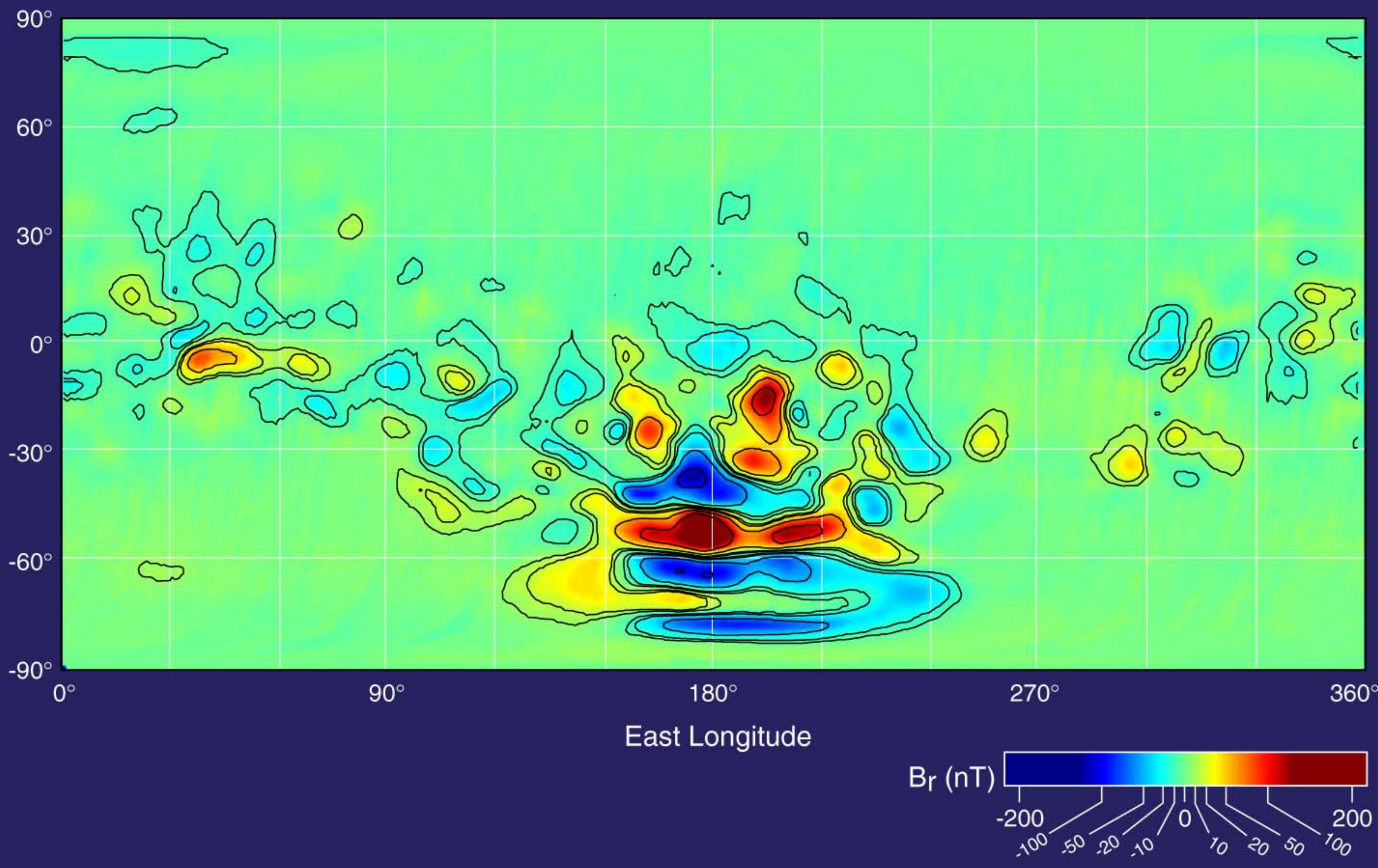
Ionosphere – Magnetic Fields

- $CO_2 + hv \rightarrow CO_2^+ + e$
- $CO_2^+ + O \rightarrow O_2^+ + CO$
- $O_2^+ + e \rightarrow O + O$

- Photochemical Chapman layer below ~180 km
- Transport important above there
- X-rays form second, lower peak that's hard to model
- Not enough ion or neutral composition data



Mars Crustal Magnetism **Mars Global Surveyor** **MAG/ER**



Connerney et al., *Geophys.Res. Lett.*, *28,* 4015-4018, 2001.

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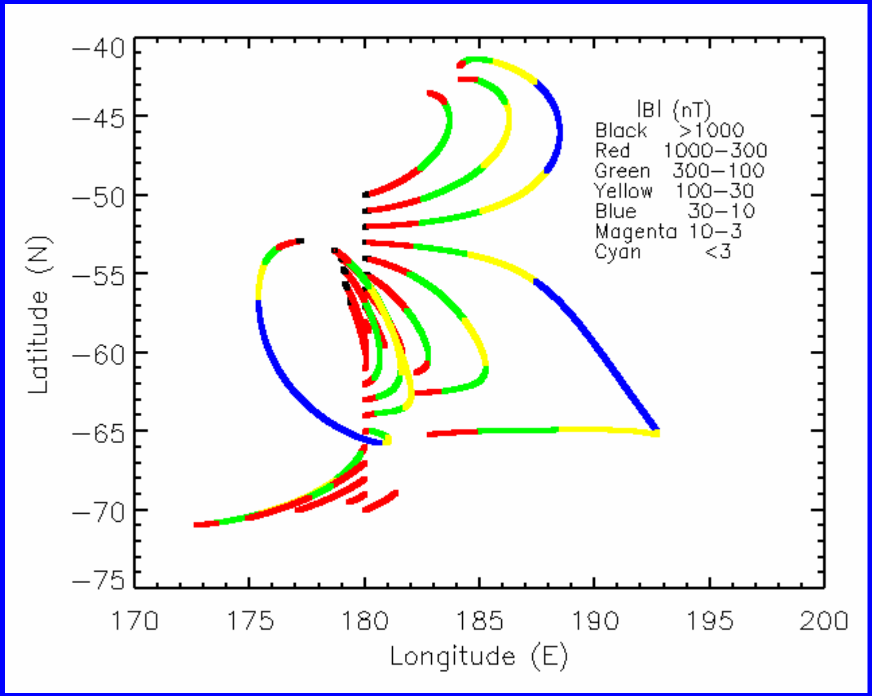

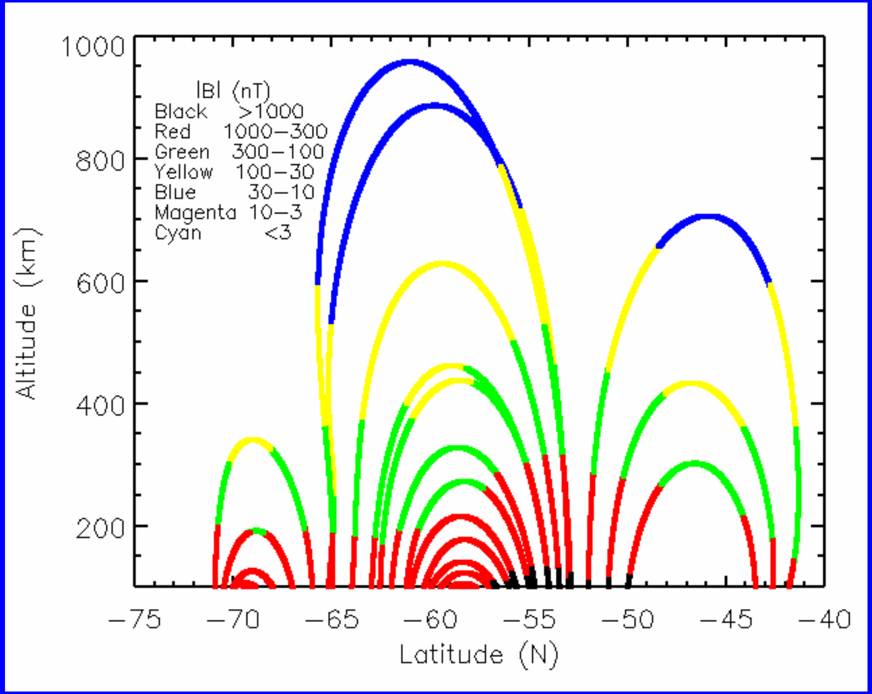

- This is not like Earth
- Field is not dipolar
- Field is not always strong
- Field geometry gives me a headache

- Plasma transport in Mars ionosphere is hard to model without magnetic fields
- How do magnetic fields affect transport?

- Next: I want to convince you that a problem exists. I do not offer a solution to the problem in this talk. Speculation.

Earth

- Below 100 km, ions and electrons collide with neutrals, not frozen to fieldlines
- Between 100 km and 160 km, electrons, but not ions, are frozen to fieldlines
  - Dynamo region, horizontal currents flow, but transport of plasma has no effect on electron densities
- Above 160 km, ions and electrons are frozen to fieldlines
  - When transport dominates photochemistry (>200 km?), ions and electrons move together along fieldlines
  - Ambipolar diffusion, no currents

Earth

- Two different theories for charged particle motion
  - Currents allowed, but gravity and pressure gradients neglected. Plasma transport does not change electron densities. Dynamo theory, sometimes with empirical electric field model
  - No currents allowed, plasma transport does affect electron densities. Ambipolar diffusion along fieldlines
- Works due to separation of regions
- Will fail on Mars

Conclusions

- Mars atmosphere is an integrated system. Lower and upper regions are not isolated.
- Chemistry (O / CO_2) affects energetics (CO_2 cooling), dynamics (winds) affect ionosphere (ion-drag), etc.
- Comparisons to Venus and Earth are helpful, but not always right.
- Effects of magnetic fields on ion/electron motion are an interesting problem.