Tides in the Martian Upper Atmosphere - And Other Topics

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The aim of this talk is to get **YOU** excited about having **ME** as a colleague in CSP

My job - Talk

Your job - Think about how **MY** research interests, past projects, and future plans can relate to **YOURS**

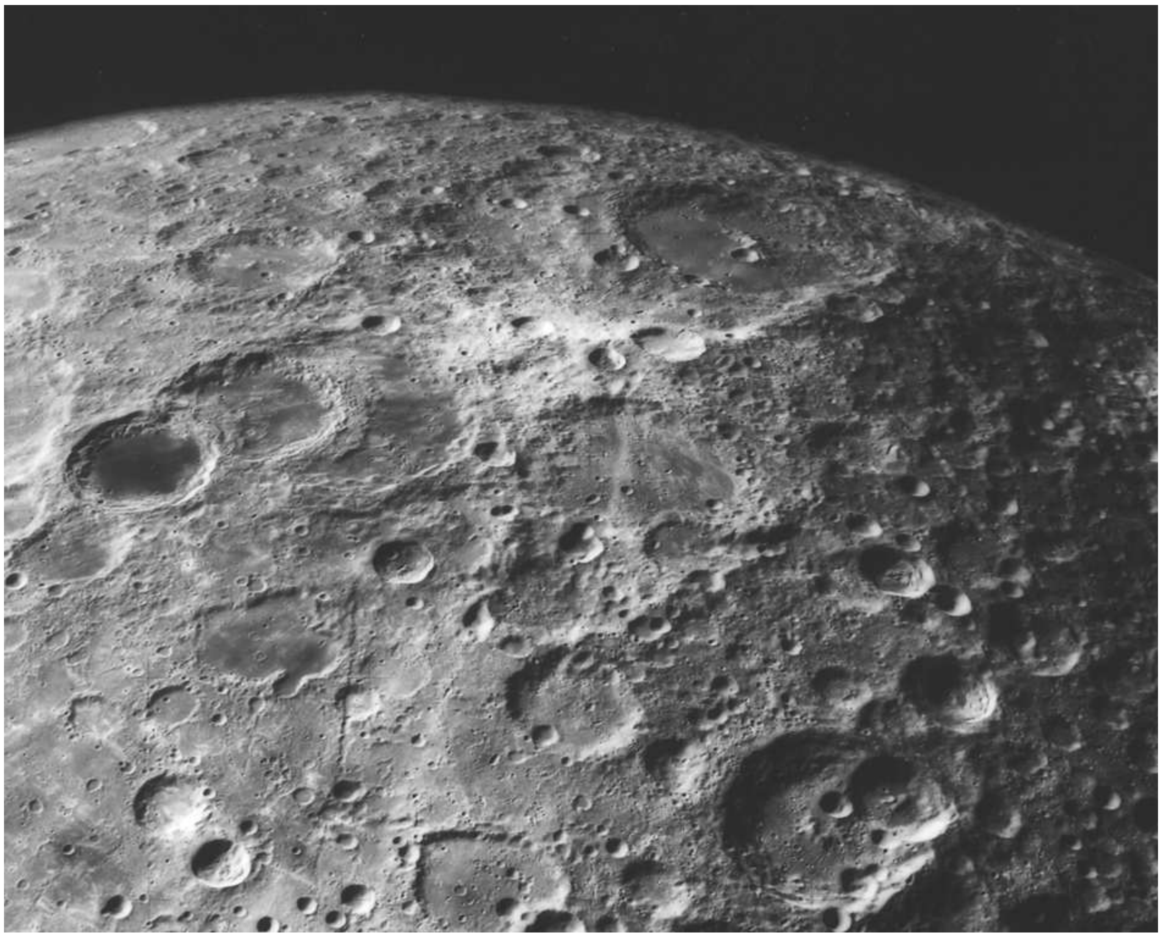
What I'm Going To Talk About

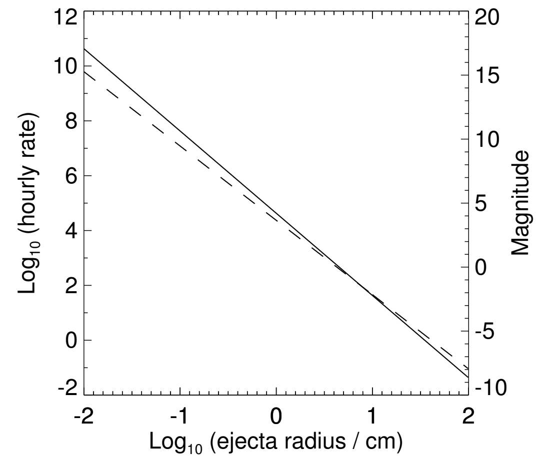
- Overview of my past research projects
- Tides in the martian upper atmosphere analysed using density data from MGS accelerometer - my main PhD topic
- Winds in the martian upper atmosphere - a novel, untested way to measure them
- Ions in the martian upper atmosphere - what I'm working on right now
- Bringing it all together

A Brief History of Me

- Physics bachelors degree, Cambridge, Great Britain
  - lots of theoretical work, not much lab work
- PhD in Planetary Science, University of Arizona, Tucson with advisor Steve Bougher
  - geology, chemistry, atmospheres, meteoritics, etc, still avoiding lab work
- I know that magnetospheres and space plasmas exist, but don't expect me to remember much about them

(1) Age of lunar crater Giordano Bruno

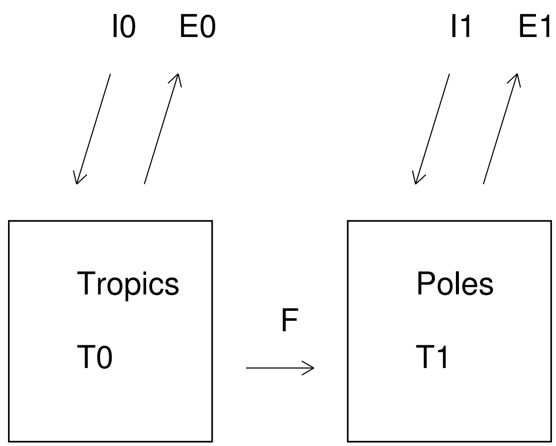




"The moon throbbed like a wounded snake … spewing out … fire, hot coals, and sparks"

Withers (2001) Meteoritics and Planetary Science, 36, 525-529

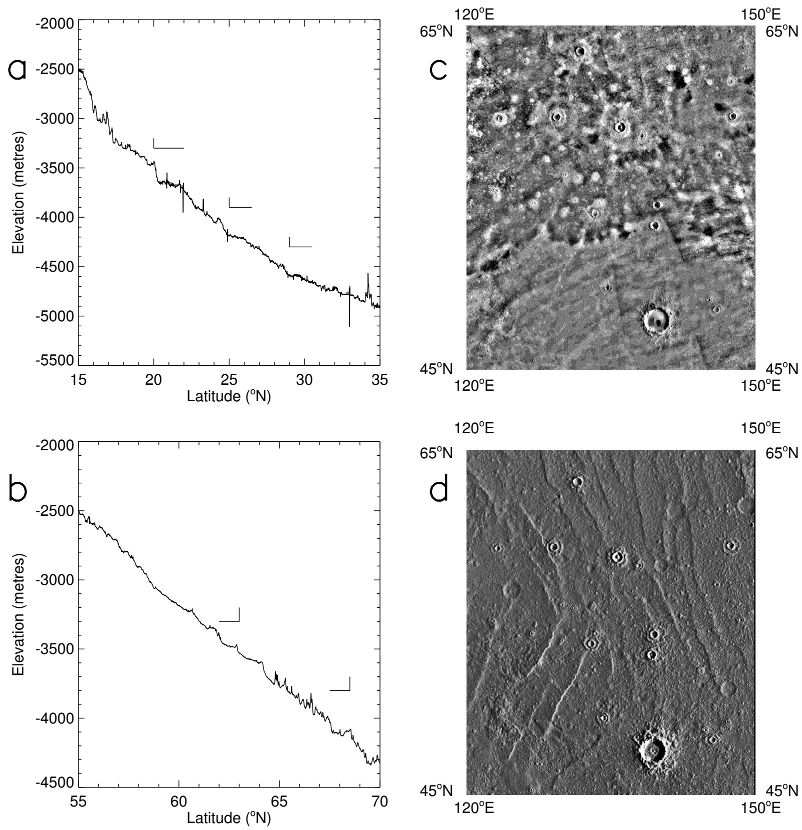
(2) Simple Climate Models



- $I_o - F - E_0 = 0$ (energy balance)
- $I_1 + F - E_1 = 0$
- $E_i = A + BT_i$ (linearize outgoing radiation)
- $F = 2\,D\,(T_0 - T_1)$ (parameterize atmospheric heat transport)
- Extremize entropy production => $4D \sim B$

Lorenz et al (2001) Geophysical Research Letters, 28, 415-418

(3) Enigmatic Northern Plains of Mars



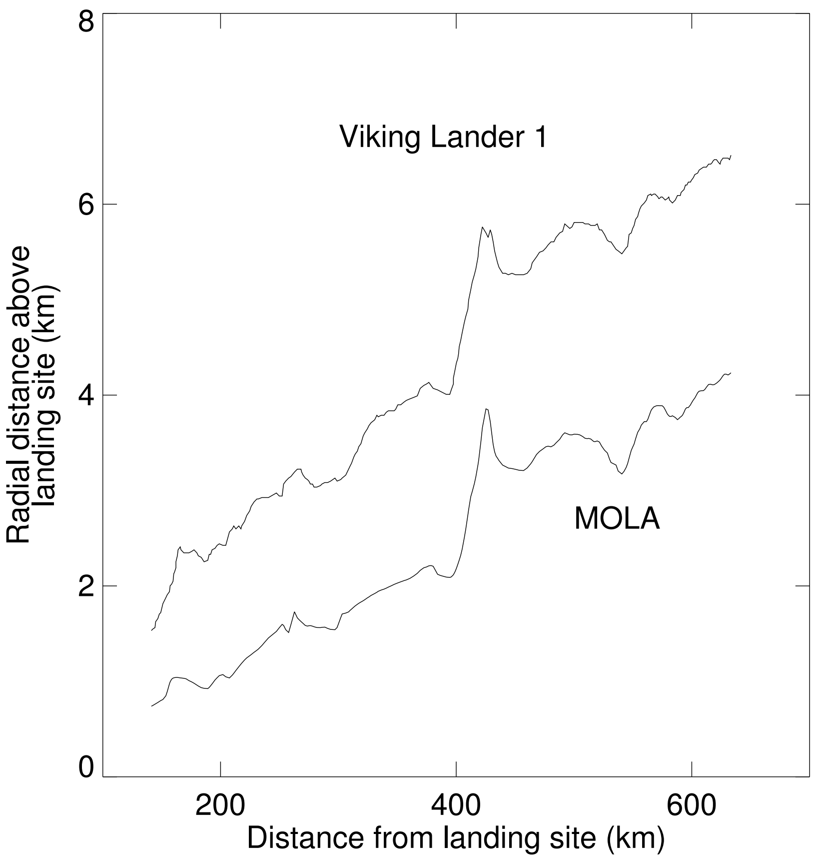
Featureless northern plains are crisscrossed by a network of tectonic ridges.

These ridges are not shorelines; they are related to Tharsis.

By relating these ridges to models, the tectonic evolution of Mars can be better understood.

Withers and Neumann (2001) Nature, 410, 651-651

(4) Comparison of Viking Lander 1 and MOLA Topography



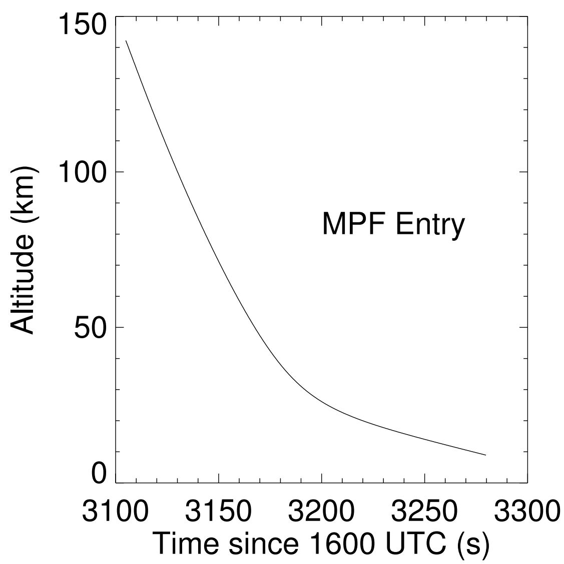
Compare VL1 radar's topographic profile to MOLA topo profile beneath flight path.

Difference is due to misplaced position of VL1 during entry.

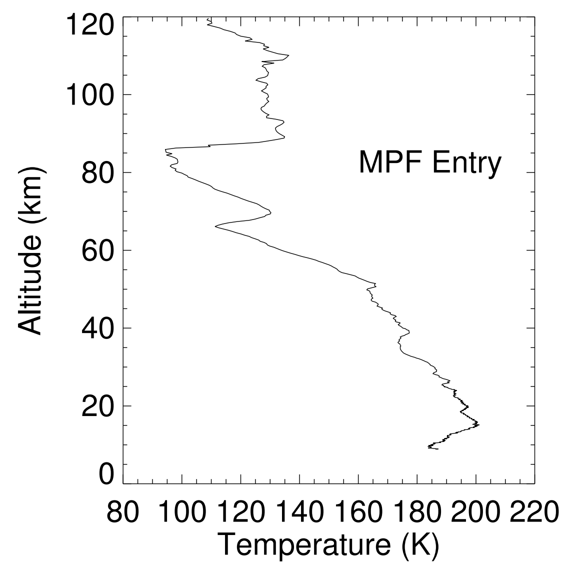
Correct VL1's position, hence correct VL1's vertical profiles of atmospheric structure

Withers et al (2002) Icarus, 159, 259 - 261

(5) Analysis of Entry Accelerometer Data



Preparation for Beagle 2 and MER in December/January

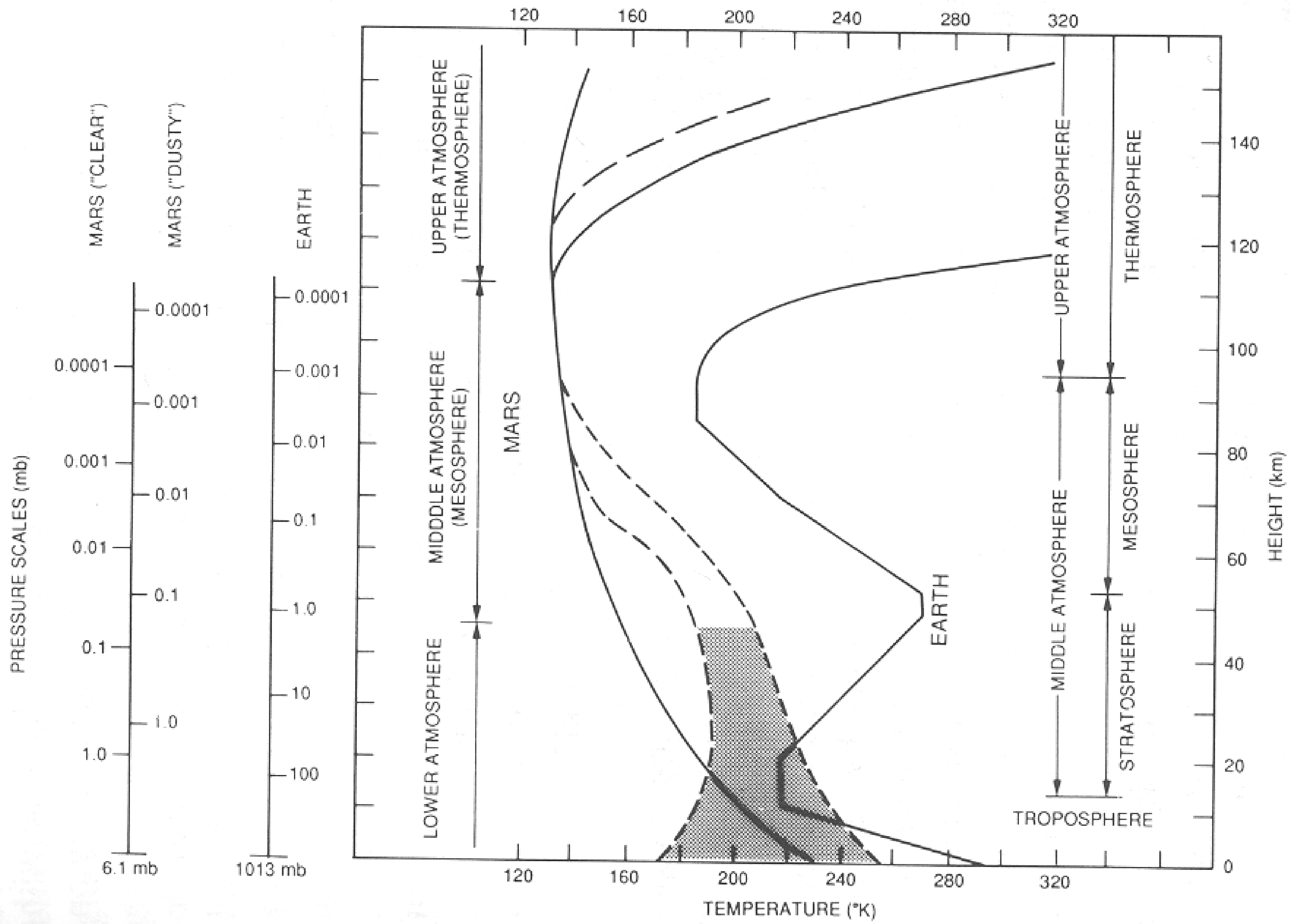


$$a = \frac{C_D A}{2m} \rho V^2$$

Withers et al (2003) Planetary and Space Science, 51, 541-561

The Martian Atmosphere

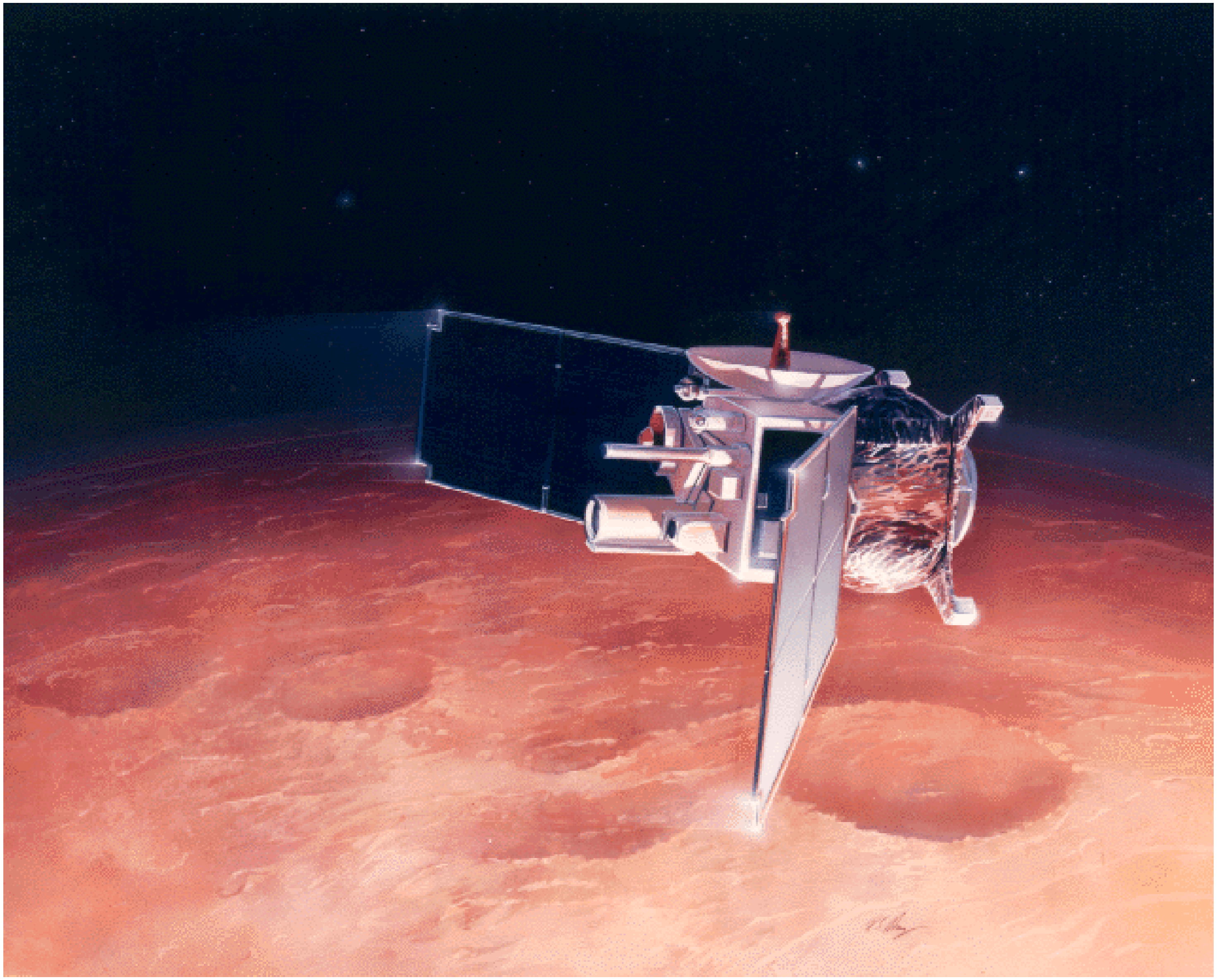
- Weak, bizarre magnetic field causes rich variety of solar wind/magnetosphere phenomena
- Extreme topography, thin, condensing atmosphere, and ample dust cause unusual atmospheric dynamics
- Climate change
- Atmospheric escape
- Atmosphere-surface interactions
- Water cycle



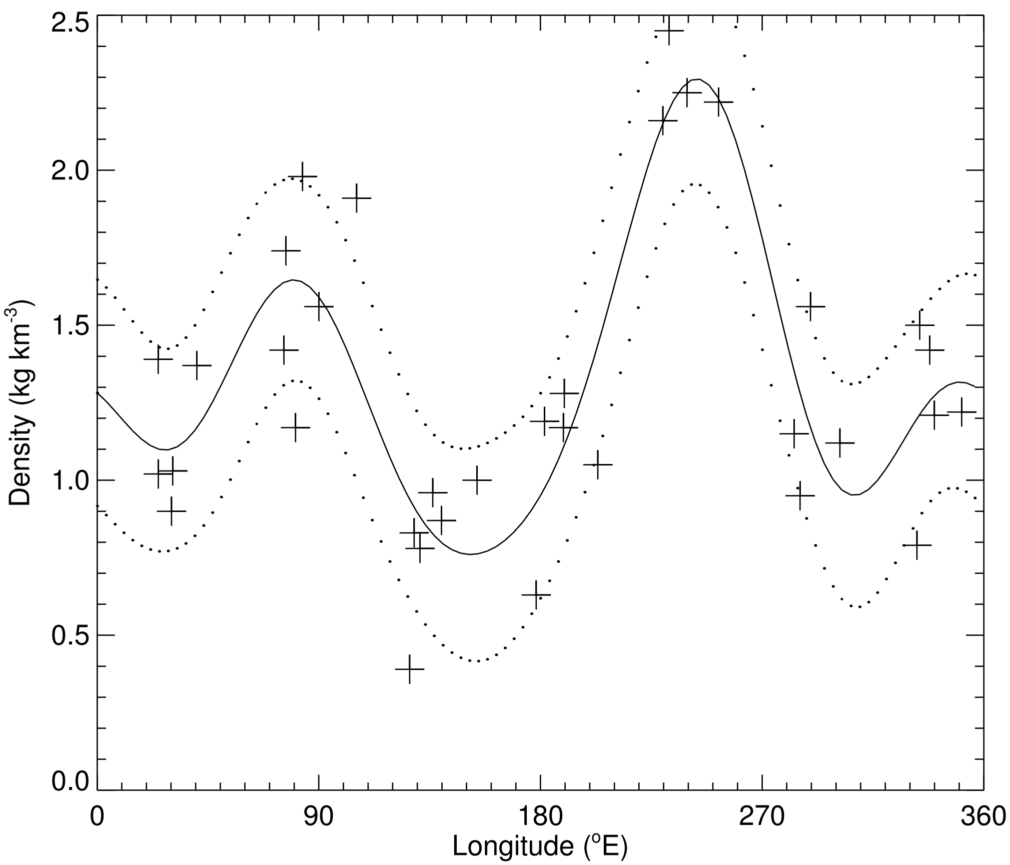
Zurek, Mars Book

The Martian Upper Atmosphere

- 80 - 200 km altitude
- Three temperature profiles, no wind data at all
- Two composition profiles
- Sparse UV airglow observations
- How are compositions, densities, pressures, temperatures, and winds affected by altitude, latitude, season, longitude, time of day, solar cycle? [climate]
- How do they behave on shorter timescales? [weather]



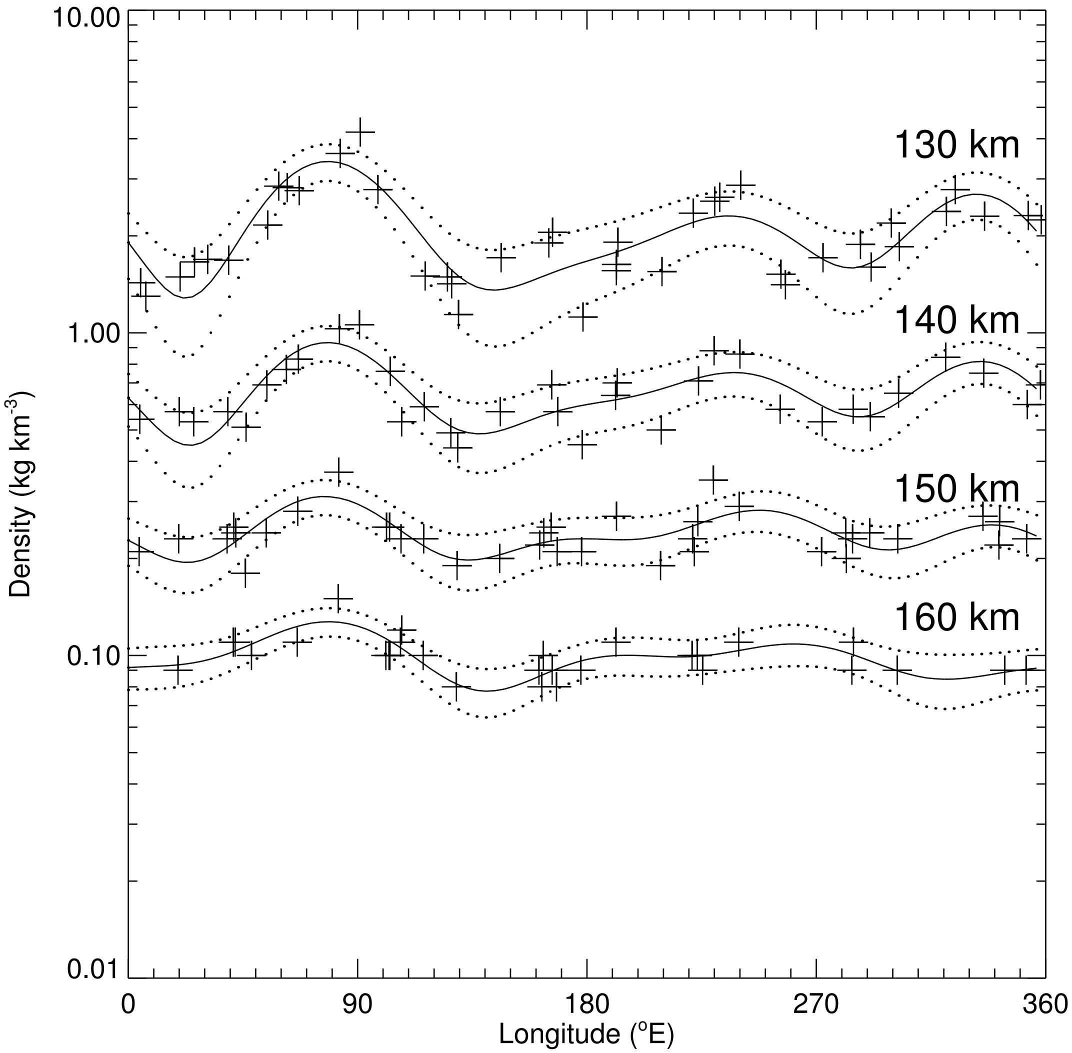
JPL Image



130 km
10°S-20°S
~1 week of data
15hr LST

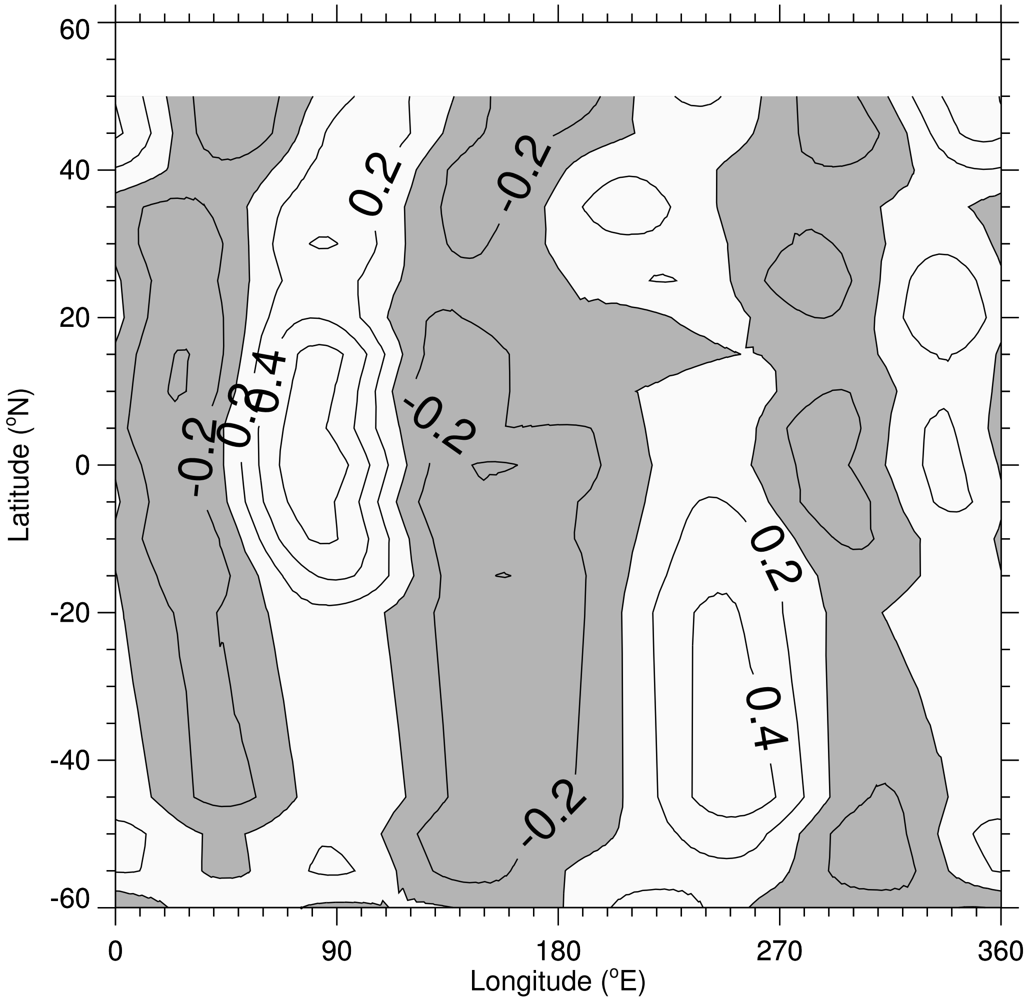
Crosses = data
Solid line = fit
Dotted line =
uncertainty

$A_0 + A_1\cos\lambda + B_1\sin\lambda + A_2\cos2\lambda + B_2\sin2\lambda + \ldots$



130 km
10^{o}N – 20^{o}N
~1-2 weeks data
15hr LST

Peaks, troughs are fixed in longitude



130 km
17 - 15hr LST
>few weeks data
$L_S = 30^o - 80^o$

(Fit-Zonal Mean) /
(Zonal Mean)

Phases near constant with lat, but amplitudes change with lat

Modelling of the zonal structure (1)

- Solar heating comprises diurnal and semidiurnal components
- Creates **migrating** disturbances which track Sun across sky with form ~ $\cos[\sigma\Omega t_{UT}+\sigma\lambda - \phi]$ and σ=1 or 2 (dimensionless)
- Ω=rotational freq, t_{UT} = Universal time, λ=longitude, ϕ=phase

- Interacts with and is modulated by some zonal asymmetry (such as topography) with true zonal wavenumber *m*.
- Resulting **non-migrating** disturbance ~ $\cos[\sigma\Omega t_{UT}+s\lambda - \phi]$ where $s = (\sigma +/- m)$
- Zonal wavenumber changes, frequency does not
- Change from t_{UT} to t_{LST}: $\cos[\sigma\Omega t_{LST} +/- m\lambda - \phi]$
- This is seen by MGS ACC as wave *m* zonal structure

Modelling of the zonal structure (2)

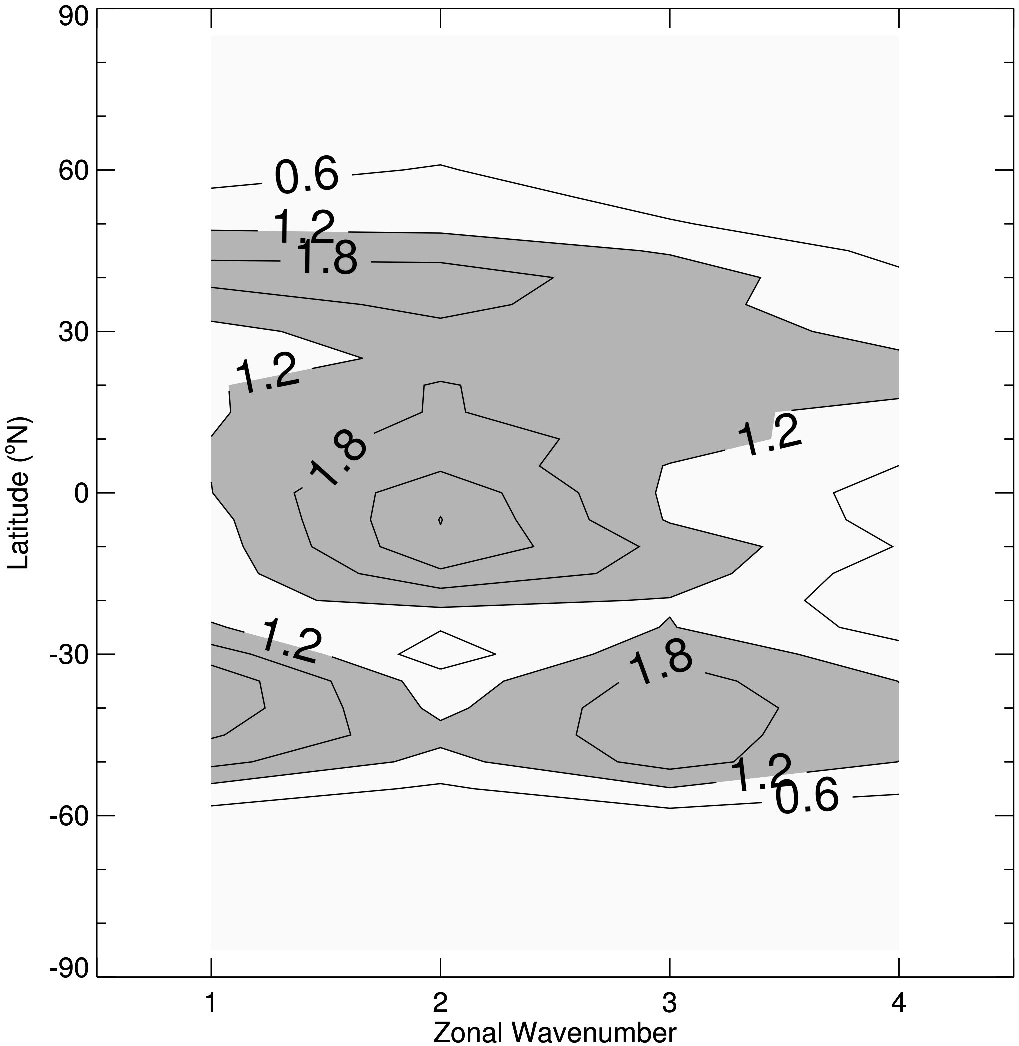
- Given $\cos[m\lambda - \phi]$ in MGS ACC data, what are σ and s of disturbance and what is the cause of m?
- Wave-1 zonal structure could be from **non-migrating** disturbances where $(\sigma,s) = (1,0), (1,2), (2,1)$ or $(2,3)$
- Global-scale disturbances with harmonic relationship to a forcing like solar heating are **tides**, can be studied with Laplace's classical tidal theory

- Arbitrary disturbance with a given (σ,s) can be represented as infinite sum of basis functions labelled with (σ,s,n), use Hough functions instead of Fourier series
- Does latitudinal structure overlap well with solar heating?
- Does vertical structure permit upward propagation?

Modelling of the zonal structure (3)

- Reject the (σ,*s*,*n*) Hough functions which cannot affect upper atmosphere, if all (σ,*s*,*n*) for a given (σ,*s*) are rejected then that (σ,*s*) tidal mode is not present in upper atmosphere
- I conclude that (σ,*s*) = (1,-1); (σ,*s*) = (2,-1); (σ,*s*) = (1,-2) dominate – consistent with Wilson's GCM predictions

- What is the cause of *m*?
- For a wave *m* zonal asymmetry such as topography to interact with migrating disturbances, its latitudinal profile must, like solar heating, be peaked in equatorial regions and decrease monotonically towards the poles
- Examine topography, thermal inertia, and albedo…



Zonal harmonics
Of topography

Waves 1 and 4 are poor overlaps with solar heating, but waves 2 and 3 are good overlaps

All components of thermal inertia and albedo are poor

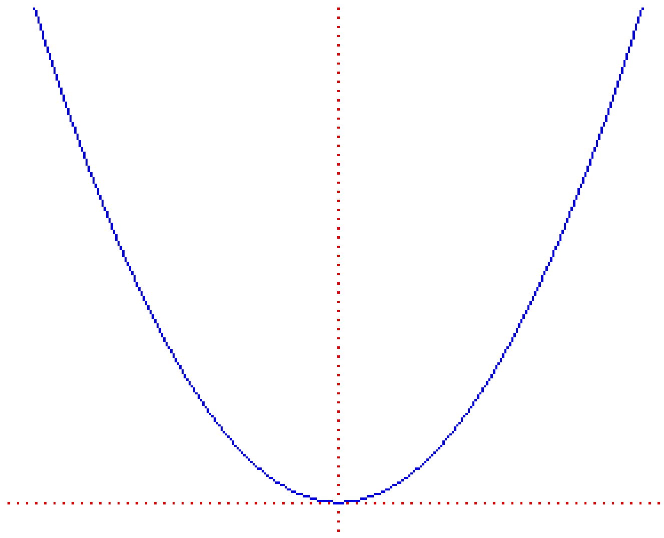
Consistent with strong waves 2 and 3 in data

Conclusions on this topic

- I have characterized zonal structure in the martian upper atmosphere as a function of altitude, latitude, and LST.
- Its week-to-week stability and broad latitudinal range require a planetary-scale cause – thermal tides.
- Comparison of observations and simple theory has led to the identification of several dominant tidal modes.
- Topography generates these tides.
- Tides have long been known to play a major role in the lower atmosphere of Mars. This work is the first detailed study of their importance in the upper atmosphere.

Withers et al. (2003) Icarus, 164, 14-32

Development of a novel "Balanced Arch" technique for measuring winds



$$\frac{1}{\rho}\frac{\partial p}{\partial r} = \frac{-GM}{r^2} = g_{eff,r}$$

$$\frac{1}{\rho r}\frac{\partial p}{\partial \theta} = 2\,\Omega\, v_\phi \cos\theta + g_{eff,\theta}$$

$$-v_\phi = \frac{\left(\int_{entry}^{peri} \rho\, g_{eff,r}\, dr + \int_{entry}^{peri} \rho\, r\, g_{eff,\theta}\, d\theta\right) - (\textit{same but exit})}{\left(\int_{entry}^{peri} 2\,\Omega\,\rho\, r \cos\theta\right) - (\textit{same but exit})}$$

$$\frac{2\,(p_i - p_o)}{p_i + p_o} = \sqrt{2\pi R/H}\,\frac{2\,\Omega\, v_\phi \cos\theta}{g}$$

Test on terrestrial wind/density data?

Other Possible Projects with MGS and ODY ACC data

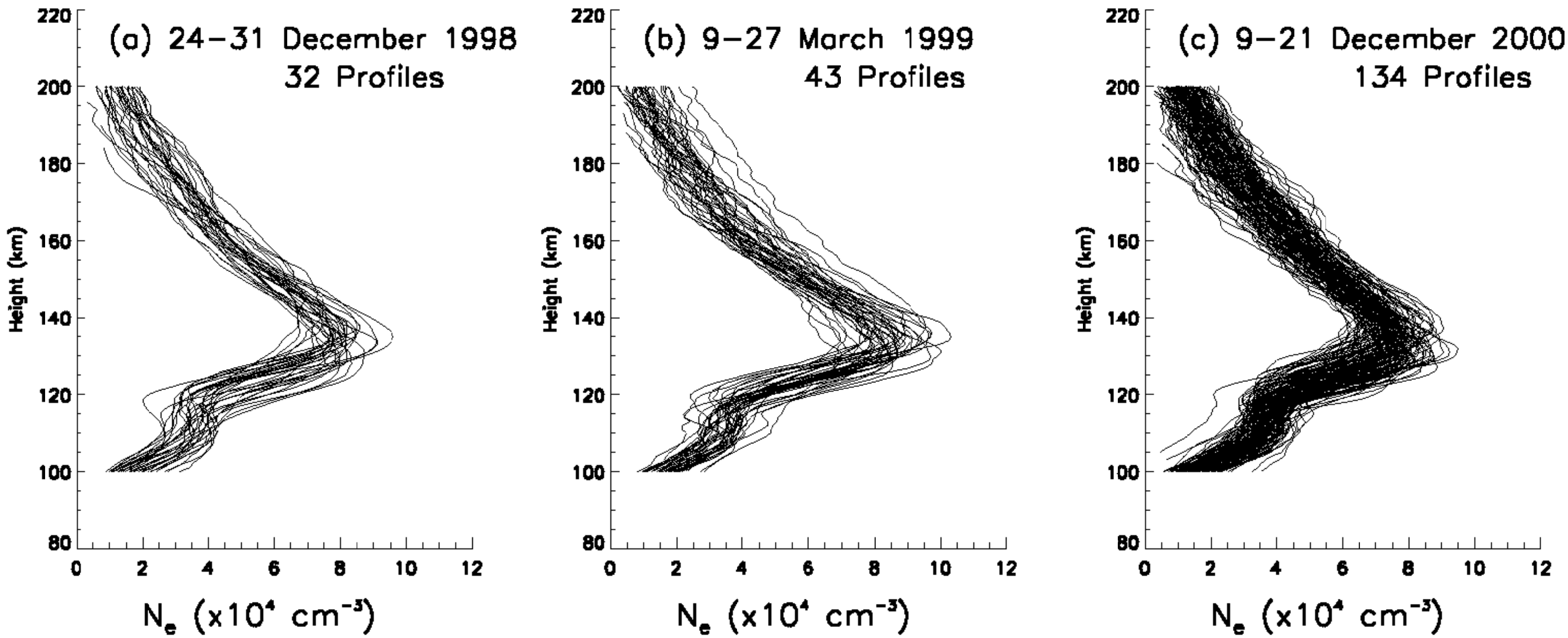
- Temperatures
- Small-scale density oscillations
- Compare zonal-mean densities and tides to model
- Density response to flares, CMEs
- Still in “discovery mode” with these datasets, there are lots of easy, worthwhile tasks to do

The Martian Ionosphere

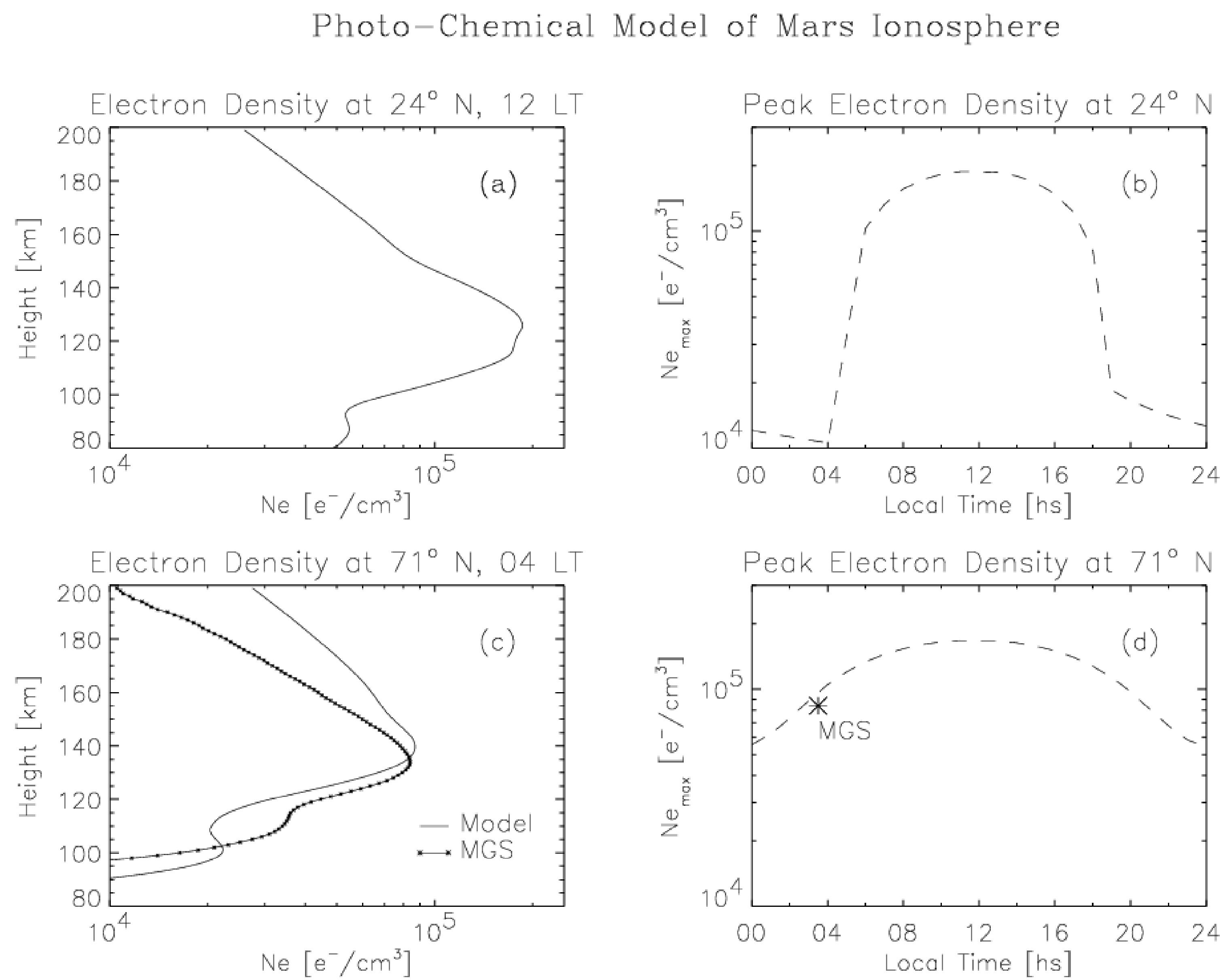
- Site of interactions between solar wind, bizarre magnetosphere, neutral atmosphere, solar UV flux
- Mars is a second laboratory for studying Space Weather, where ideas developed for Earth can be tested
- Important for understanding escape processes
- Want to understand its climate and weather

Ionospheric Data

- MGS radio occultations provide ~1000 profiles of Ne(z), most around 70^{o}N and 80^o solar zenith angle
- CO_2 is the dominant neutral, but O_2^+ is the dominant ion
- Photochemically-controlled, Chapman-like
- I am extending the studies of Mendillo, Martinis, Smith, etc



Mendillo et al.



Martinis et al.

Plans for Ionospheric Work (1)

- Fit Chapman functions to both peaks, study peak heights and magnitudes
- Variations with longitude, neutral atmosphere
- Deduce neutral temperatures
- Total electron content, slab thickness
- Day-to-day variabilities in Ne(z)
- Response to solar variability - flares and CMEs - and simultaneous response on Earth

Plans for Ionospheric Work (2)

- Develop photochemical model of Martinis
- Add plasma diffusion
- Improve background neutral atmosphere
- Understand secondary peak better - what fluxes and atmospheric properties are needed to reproduce its large variability?
- Study changes in ion/neutral composition with altitude

Clarke and Escape

- Another likely project in the future...
- HST and Mars Express
- UV observations of hot, escaping atoms
- Study escape rates and how they vary

Bringing it all together

- Wide range of interests across planetary science
- Apparent Mars bias due to latest data and missions
- Data analysis with simple models
- Not experimental or instrumentation work
- Not development of complex models