Low Energy Electrons in the Mars Plasma Environment

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Abstract

At SwRI, we have developed a new model for the interaction of low energy (0.5 eV – 4 keV) electrons with the upper atmosphere and exosphere of Mars, based on the *Link* [1992] solution of the Boltzmann transport equation. With the new code, we can (simultaneously) model the penetration of shocked solar wind electrons into the atmosphere of Mars, and photoelectron production and escape from within the atmosphere. Unlike previous Mars models, we use a non-isotropic energy-dependent scattering phase function to describe electron pitch angle redistribution in elastic collisions with atmospheric species. In elastic scattering, the primary mechanism for angular redistribution of electrons colliding with heavier particles, the phase function varies from isotropic below 12 eV to strongly forward-peaked by 100 eV.

Abstract (cont'd)

The phase function controls the penetration depth of solar wind electrons into the Mars atmosphere, and the escape flux of photoelectrons out of the atmosphere. Previous models, which either ignore electron transport altogether (the local equilibrium approximation) or use an isotropic phase function, are not realistic in the Mars Express mission scenario. In addition, our model performs a solar emission line-by-line calculation of photoelectron and photoion production, accounting for K-shell photoabsorption and Auger electron ejection, making it the most physically-comprehensive model in the non-relativistic regime.

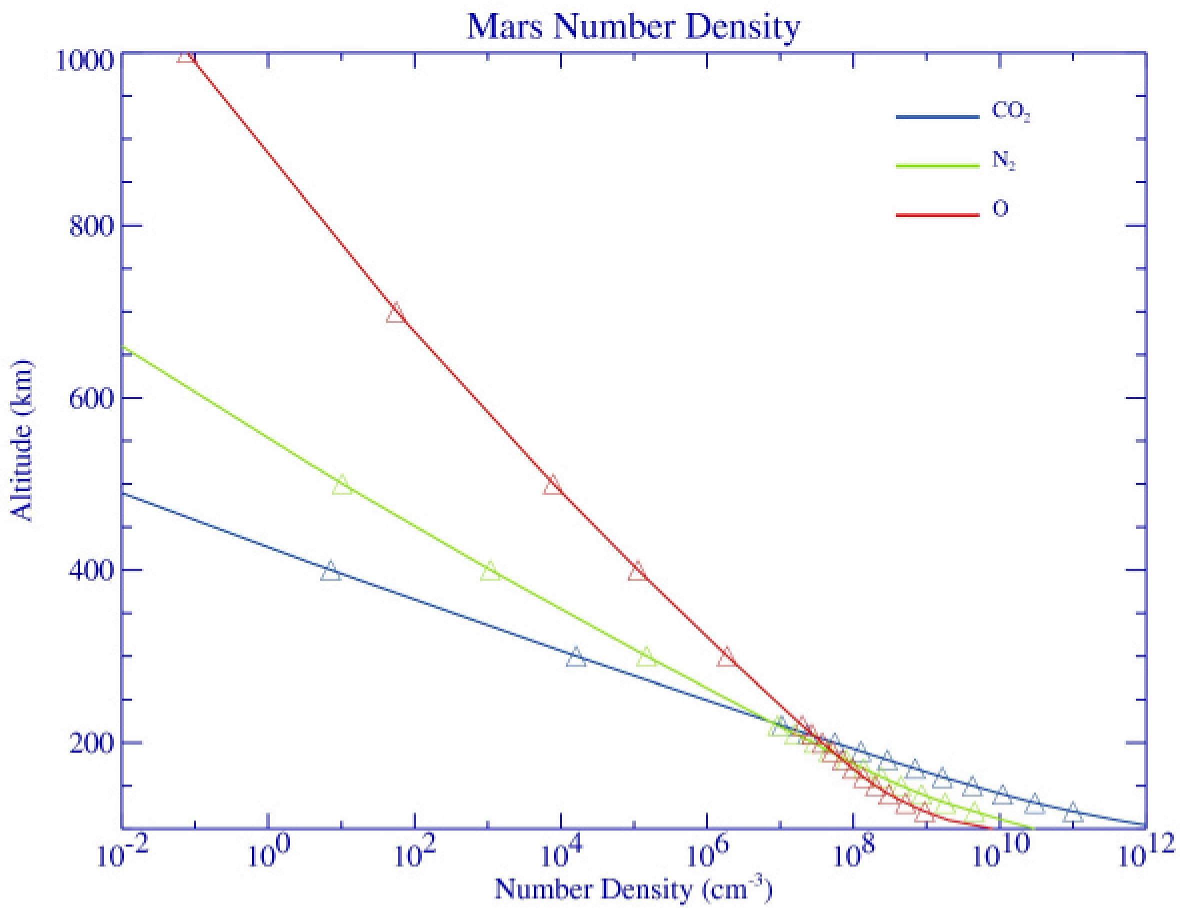
Abstract (cont'd)

In this talk, we present an update of the model results and validation efforts, and discuss future improvements. The latter primarily involves a more comprehensive assessment of the model input data (photoabsorption and electron collision cross sections) and inclusion of magnetic gradients in the Boltzmann equation to account for the crustal magnetization recently discovered by the Mars Global Surveyor (MGS) mission. The electron transport model is now being used to analyze the first direct measurements of photoelectrons and Auger electrons in the Mars environment by the MGS Magnetometer/Electron-Reflectometer experiment.

Figure 1 Comments

- Composition of the upper atmosphere of Mars, showing the dominant gases CO_2, N_2, and O [*Krasnapolsky and Gladstone*, 1996]
- The number densities are about equal at 200 km, where photoelectron transport becomes important
- Below 200 km, CO_2 is the dominant gas
- Above 200 km, O dominates

Figure 1



Mars Number Density
1000
800
600
400
200
Altitude (km)
10^{-2}
10^{0}
10^{2}
10^{4}
10^{6}
10^{8}
10^{10}
10^{12}
Number Density (cm^{-3})
CO_2
N_2
O

Figure 2 Comments

- **Photoelectron fluxes at 309 km, 152 km (peak), and 110 km**
- **Fluxes are integrated over 0 - 180º pitch angle**
- **Peaks in the spectra are due to photoionization into discrete ion states by discrete solar emission lines, *e.g.*,**
  - **the C, N, O Auger peaks**
  - **the He^+ 304 Åphotoionization peaks at 20 - 30 eV**
- **Valleys are due to discrete energy loss by electrons undergoing inelastic collisions with the atmospheric gases**
- **At higher energies (above 60 eV) and altitudes (above 150 km), the atmosphere is optically thin to energetic photons**

Figure 2

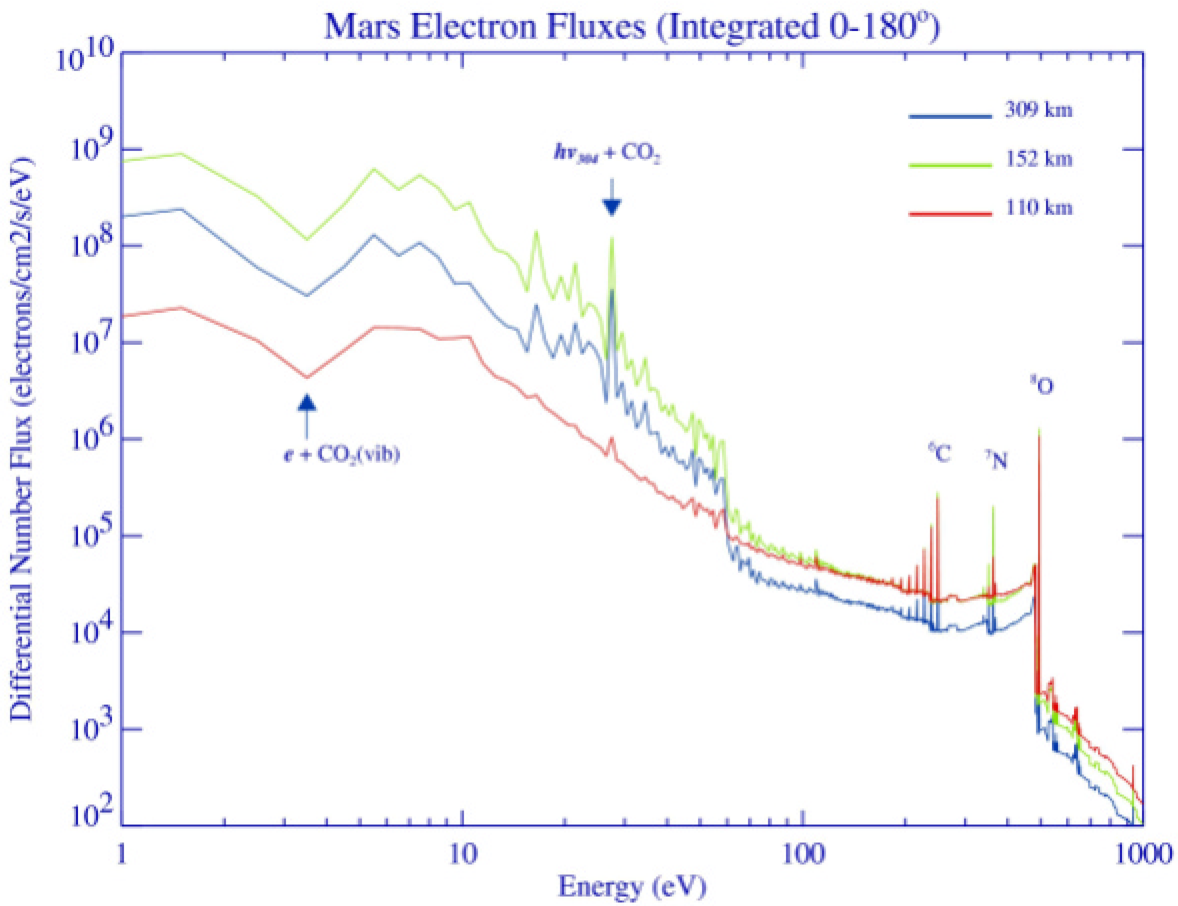
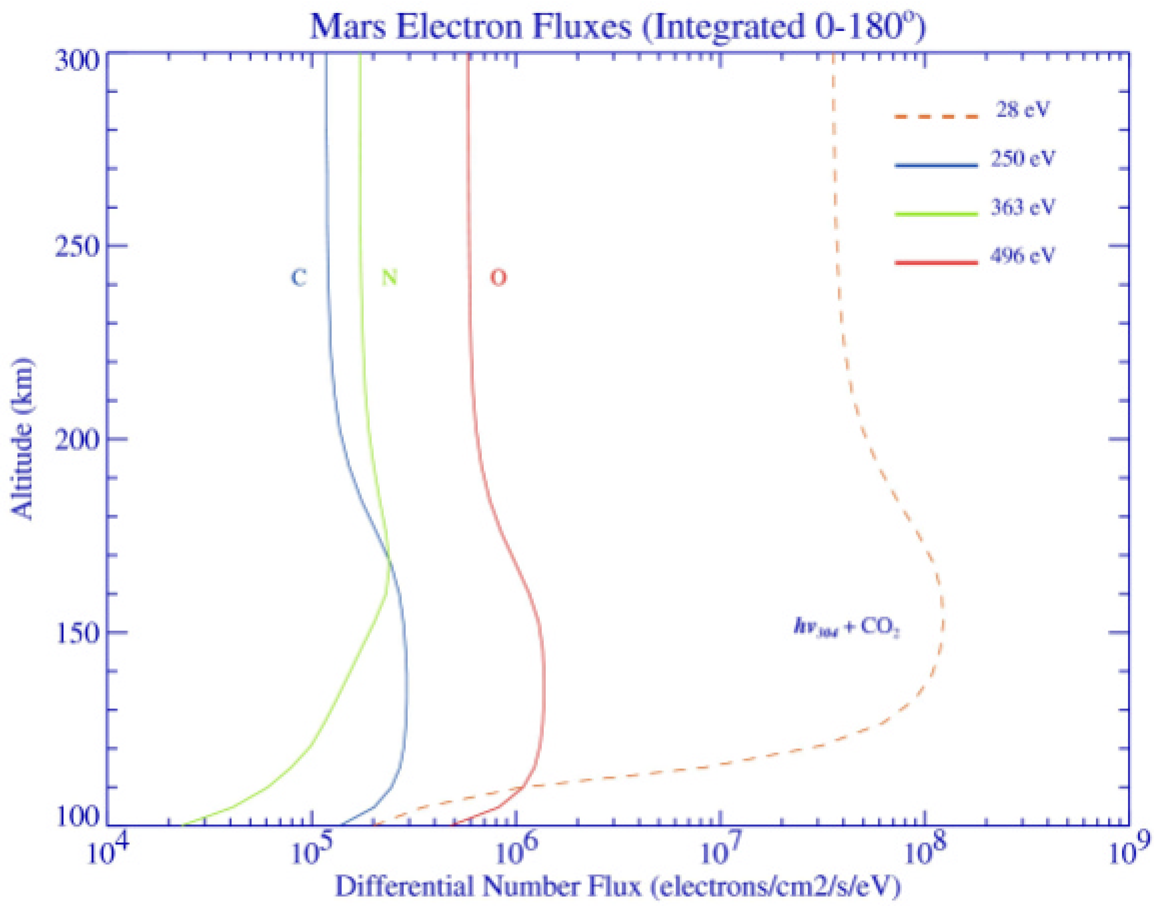

Mars Electron Fluxes (Integrated 0-180°)
Differential Number Flux (electrons/cm2/s/eV)
Energy (eV)
309 km
152 km
110 km
hv + CO2
e + CO2(vib)
C
N
O
1
10
100
1000

Figure 3 Comments

- **Altitude profiles of electrons at the energy peaks shown in Figure 2**
- **The curves to the left are the Auger peaks of C, N, and O**
- **The C and O profiles are very similar in shape, since both are formed by photoionization of CO_2**
  - **transport of oxygen Auger electrons from CO_2 dominates local production from O at higher altitudes**
- **The model results here explain the absence of a distinct carbon Auger peak by MGS MAG-ER [*Mitchell et al*., 2000]**

Figure 3



Mars Electron Fluxes (Integrated 0-180°)
300
250
200
150
100
Altitude (km)
10^4
10^5
10^6
10^7
10^8
10^9
Differential Number Flux (electrons/cm2/s/eV)
28 eV
250 eV
363 eV
496 eV
C
N
O
$h\nu_{304}$ + CO_2

Figure 4 Comments

- **Photoelectron spectra at 309, 152, and 110 km, computed under different assumptions:**
  - **The green curves show EUV photoionization of L-shell photoelectrons only**
  - **The red curves show L-shell and K-shell *photoelectrons***
  - **The blue curves include ejection of K-shell Auger electrons**
- **Above 150 km, the atmosphere is optically thin to solar EUV, so these photoelectrons dominate below 60 eV**
- **At the lowest altitude, the EUV has been absorbed, and the lack of spectral structure and separation of the curves at low energies is due to energy cascade of degraded primaries**

Figure 4

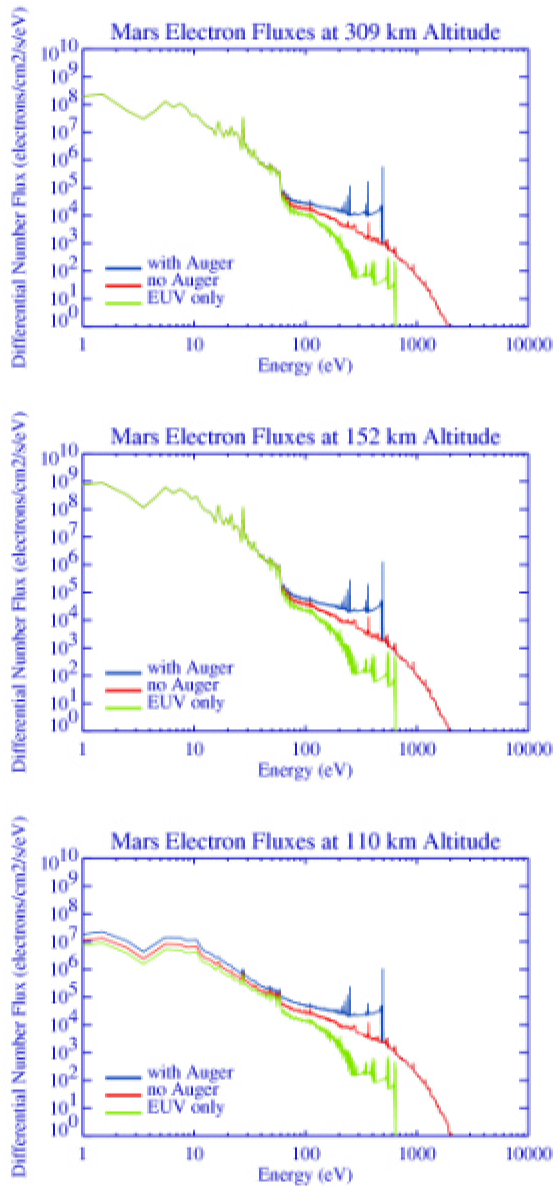
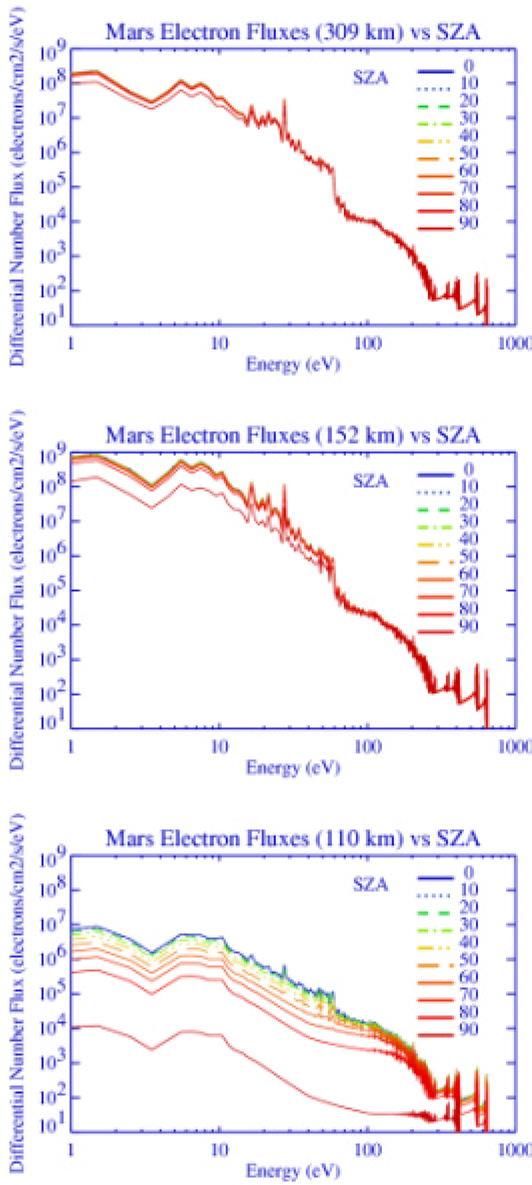

Mars Electron Fluxes at 309 km Altitude
Differential Number Flux (electrons/cm2/s/eV)
Energy (eV)
with Auger
no Auger
EUV only
Mars Electron Fluxes at 152 km Altitude
Differential Number Flux (electrons/cm2/s/eV)
Energy (eV)
with Auger
no Auger
EUV only
Mars Electron Fluxes at 110 km Altitude
Differential Number Flux (electrons/cm2/s/eV)
Energy (eV)
with Auger
no Auger
EUV only

Figure 5 Comments

- Photoelectron spectra at 309, 152, and 110 km, for solar zenith angles 0 - 90º
- At the higher altitudes:
  – the atmosphere is transparent to solar photons except at large zenith angles, where the slant path is longest
- At the lowest altitude:
  – the atmosphere is optically thick to EUV radiation
  – the atmosphere becomes optically thick to solar X-rays at large zenith angles

Figure 5



Mars Electron Fluxes (309 km) vs SZA
Mars Electron Fluxes (152 km) vs SZA
Mars Electron Fluxes (110 km) vs SZA
Differential Number Flux (electrons/cm2/s/eV)
Energy (eV)
SZA
0
10
20
30
40
50
60
70
80
90
1
10
100
1000

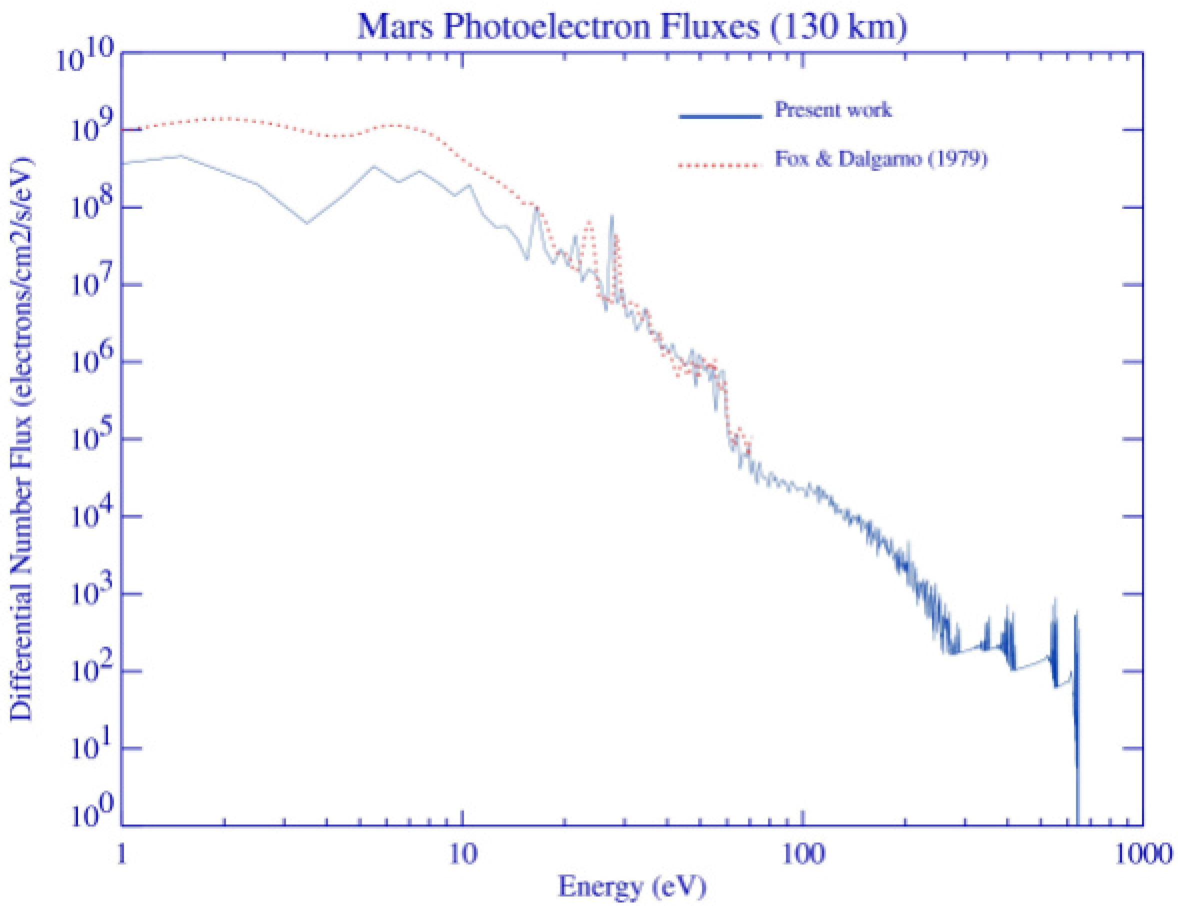
Figures 6 & 7 Comments

- Comparison of the present model results with *Fox and Dalgarno* [1979] and *O. Witasse* (personal communication, 2000)
- The adopted photon and electron cross sections, solar spectra, and model atmospheres differ
- No attempt has been made to normalize the results
- In the 10 - 60 eV region:
  - the results agree very well in magnitude
  - the location of specific peaks and their magnitude show some differences due to assumptions related to final-state ion product distributions

Figures 6 & 7 Comments (more)

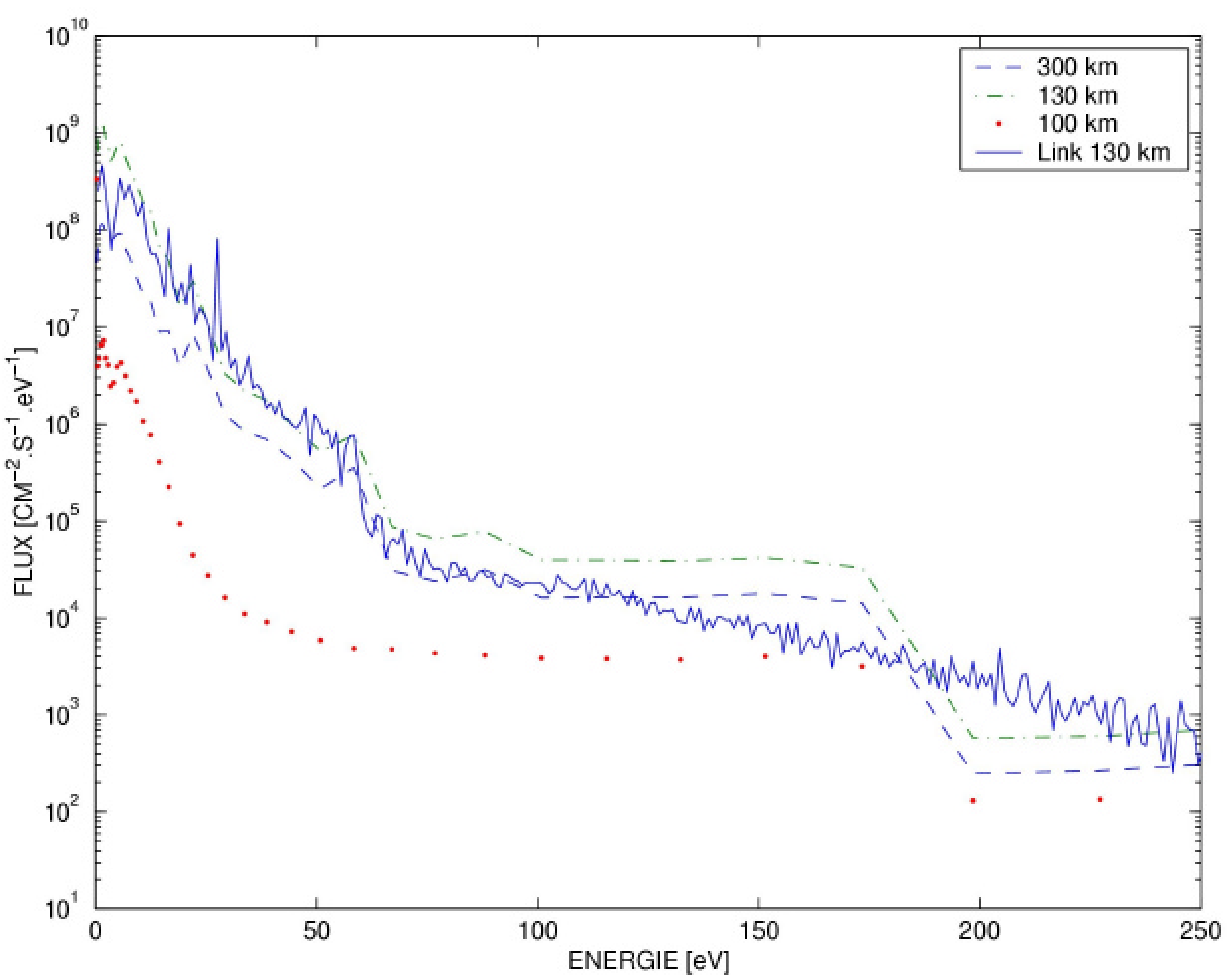
- Below 10 eV, differences are due to the adopted laboratory measurements of the CO_2 vibrational excitation cross sections
- The Fox model extends to only 70 eV, and has no transport
- The Witasse model uses a coarse solar wavelength grid, resulting in a lack of structure above 60 eV

Figure 6



Mars Photoelectron Fluxes (130 km)
Present work
Fox & Dalgarno (1979)
Differential Number Flux (electrons/cm2/s/eV)
Energy (eV)

Figure 7

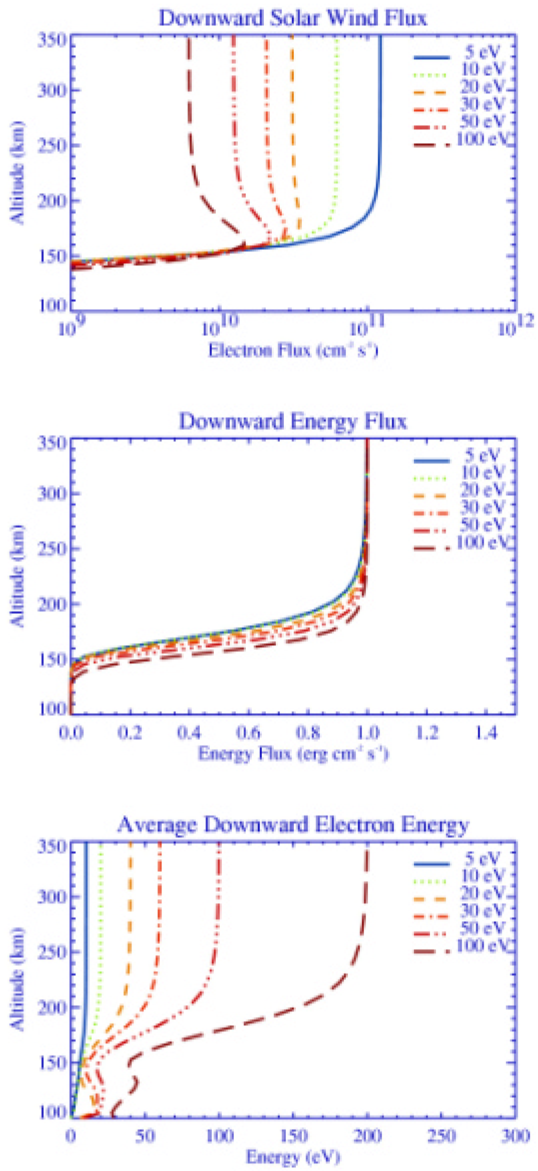


300 km
130 km
100 km
Link 130 km
FLUX [CM^{-2}.S^{-1}.eV^{-1}]
ENERGIE [eV]
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
0
50
100
150
200
250

Figure 8 Comments

- A ‘solar wind’ calculation:
- 1 erg cm^{-2} s^{-1} Maxwellian electrons with characteristic energies E_o = 5 - 100 eV are incident upon the atmosphere
- Upper panel:
  - the number flux at the top reflects the chosen normalization
- Middle panel:
  - penetration depth of electrons with different E_o
- Lower panel:
  - average energy of the downward electrons, equal to 2 E_o at the top of the atmosphere

Figure 8


Downward Solar Wind Flux
Altitude (km)
Electron Flux (cm⁻² s⁻¹)
5 eV
10 eV
20 eV
30 eV
50 eV
100 eV
Downward Energy Flux
Altitude (km)
Energy Flux (erg cm⁻² s⁻¹)
Average Downward Electron Energy
Altitude (km)
Energy (eV)

Summary

- On Mars, most (95%) photoelectrons are produced below 200 km by solar EUV photoionization of CO_2
  - CO_2 is the major gas below 200 km
  - the photoelectron flux peaks near 150 km
- Above 200 km, transport from below dominates local production from N_2 and O (low gas densities)
  - local (no transport) models are not valid above 200 km
- Altitude profiles of C and O Auger electrons are congruent
  - both are produced by photodissociative ionization of CO_2
  - the model explains the absence of a detectable carbon peak in the MGS MAG-ER measurements [*Mitchell et al*., 2000]

Future Plans

- Update the photoionization branching ratios for CO_2^+, CO^+, O^+, and C^+ channels
- update the electronic and vibrational energy loss cross sections for CO_2
- incorporate magnetic gradients into the Boltzmann transport model
- perform analysis of MGS MAG-ER photoelectron and solar wind data (underway)