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Model insights into energetic photoelectrons measured by MAVEN

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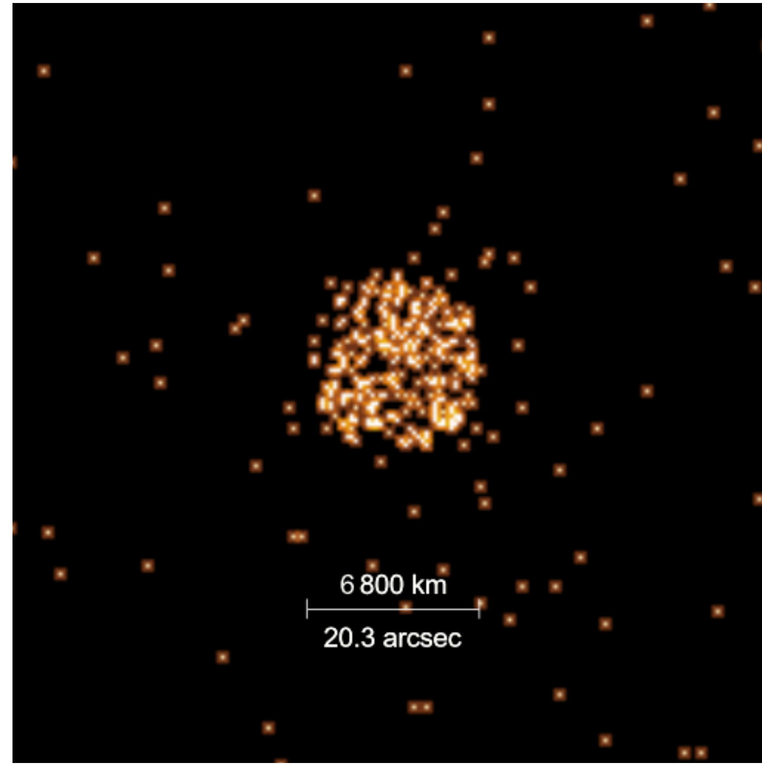
Introduction

- Energy deposition from solar EUV and X-ray in the upper atmosphere
  - Contribution to ionization and heating
- Discovery of X-ray on the disk of Mars in 2001 [*Dennerl*, 2002]
  - Imply existence of energetic (>500 eV) electrons
  - X-ray emitted by ionization from K-shell of C, O and N



Soft X-ray image of Mars made by Chandra [*Dennerl*, 2002]

- Almost all ionization from K-shells produces Auger electrons!!
  - Branching ratio of ~99%

Model description

- Photon energy deposition code (photon code)
  - Generates production rates of suprathermal electrons as a function of altitude and energy.
  - Inputs: Solar irradiances, background neutral densities, cross-sections.

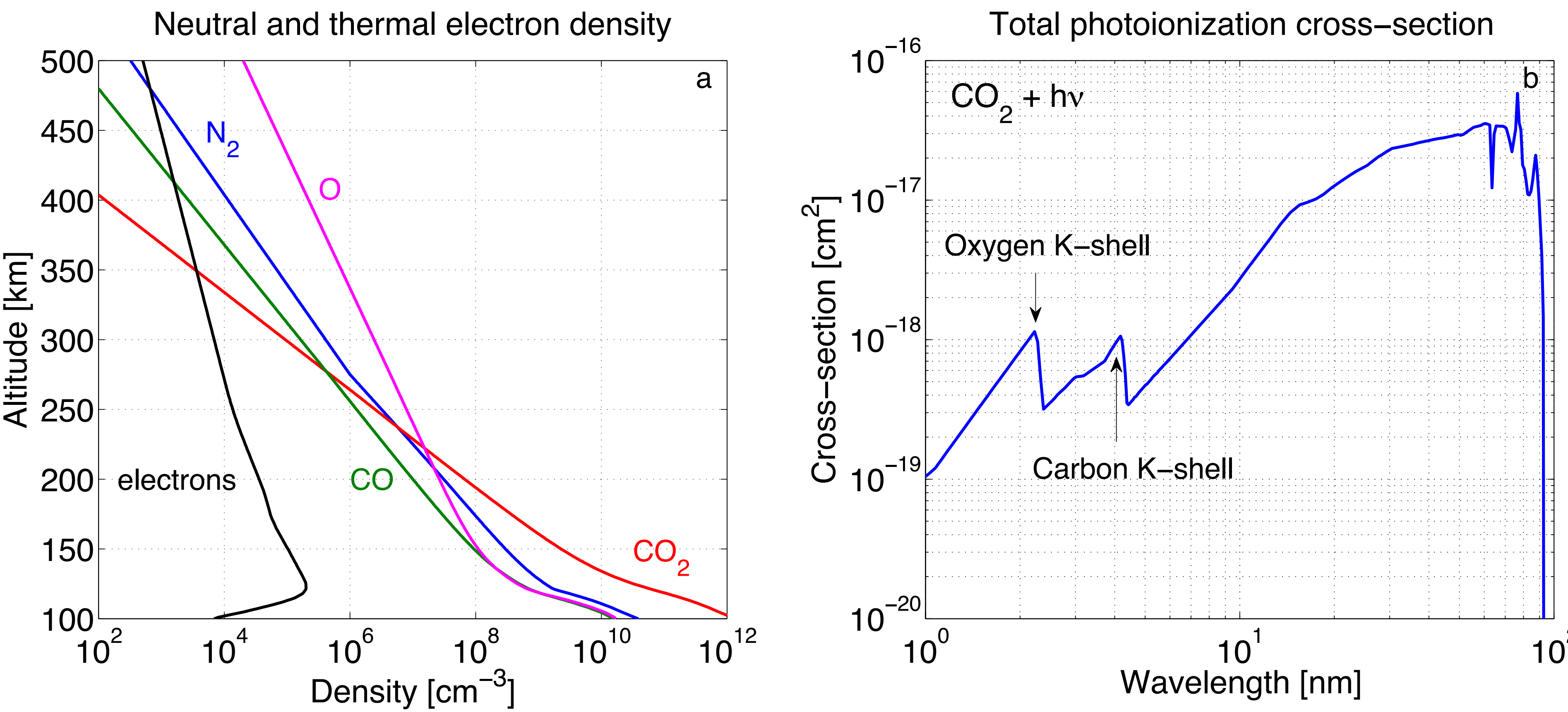
- Two-stream electron transport code (two-stream code)
  - Calculates up and down fluxes of suprathermal electrons.
  - Inputs: Primary production rates, neutral densities and thermal electron densities, electron impact cross-sections, external electron fluxes (boundary condition).

Solar flux model

- Heliospheric Environment Solar Spectrum Radiation (HESSR) model
  - Based on Solar Irradiance Physical Modeling (SRPM) system.
  - e.g., *Fontenla et al.*, [2011]
  - http://www.galactitech.net/hessrdata/Mars/Spectra/

  - Solar irradiances are calculated based on the snapshot daily image.
  - We used wavelength intervals:
    0.05-6.0 nm for $d\lambda = 0.05$ nm
    6.0-160.0 nm for $d\lambda = 1.0$ nm

Background atmosphere



- CO_2, CO, N_2, and O
  - Based on *Bougher* [2012] and *Bougher et al.*, [2009 & 2014]

Background densities & total photoionization cross sections [*Sakai et al.*, 2015]

Two-stream model

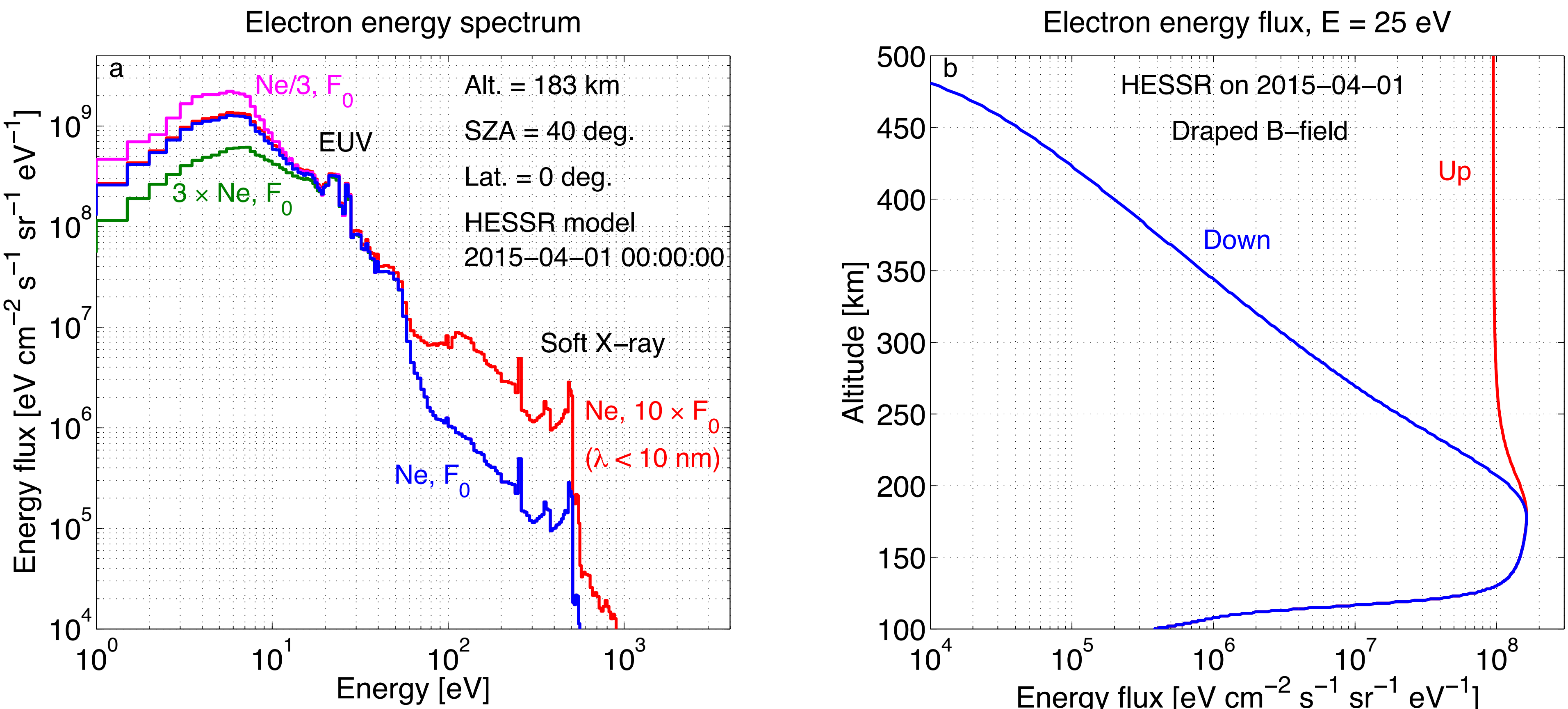
- Suprathermal electron transport model

$$\langle\mu\rangle\frac{d\Phi^{\pm}}{ds}=-\sum_k n_k(s)\left(\sigma_a^k+p_s^k\sigma_s^k\right)\Phi^{\pm}(\varepsilon,s)+\sum_k n_k(s)p_e^k\sigma_e^k\Phi^{\mp}(\varepsilon,s)+\frac{q(\varepsilon,s)}{2}+q^{\pm}(\varepsilon,s)$$

  - Photoionization, electron elastic and inelastic impact cross-sections are taken from *Gan et al.* [1990]
    - CO_2, CO, N_2 and O

cos α: pitch angle, $\sigma_a{}^k$: total inelastic collision cross-section for a neutral species *k*, $p_s{}^k$ and *s*: electron backscatter probability and the cross-section, $p_e{}^k$ and $\sigma_e{}^k$: elastic collision probability and the cross-section, *q*: photoelectron production rate due to direct photoionization, $q^{\pm}$: electron production ratedue to cascading from higher energy by inelastic collisions

Results

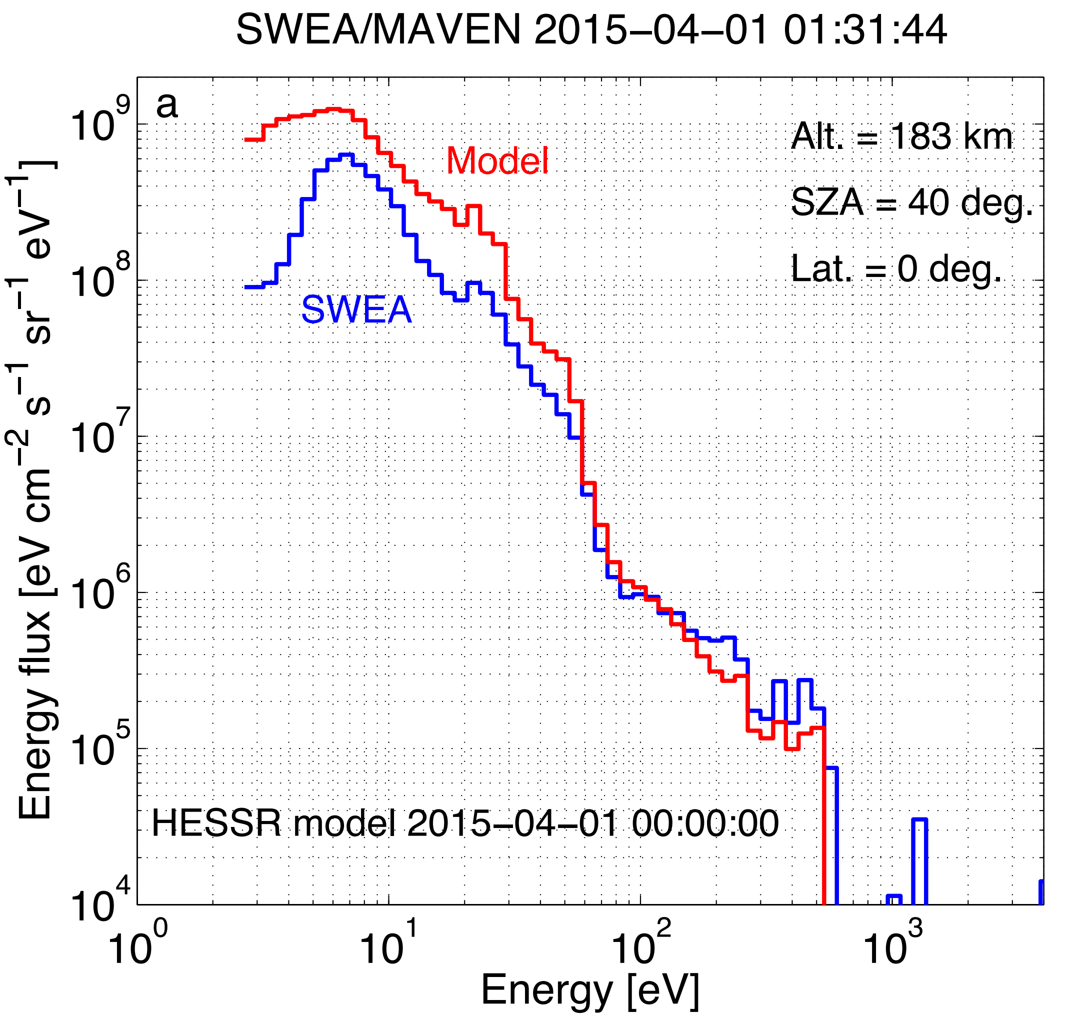


- The thermal electron density affects the electron fluxes at low energies.
- Soft solar X-rays affect the high energy electron flux.
- Transport affects electron fluxes above 200 km.

Examples of photoelectron energy fluxes [*Sakai et al.*, 2015]

Comparison with SWEA

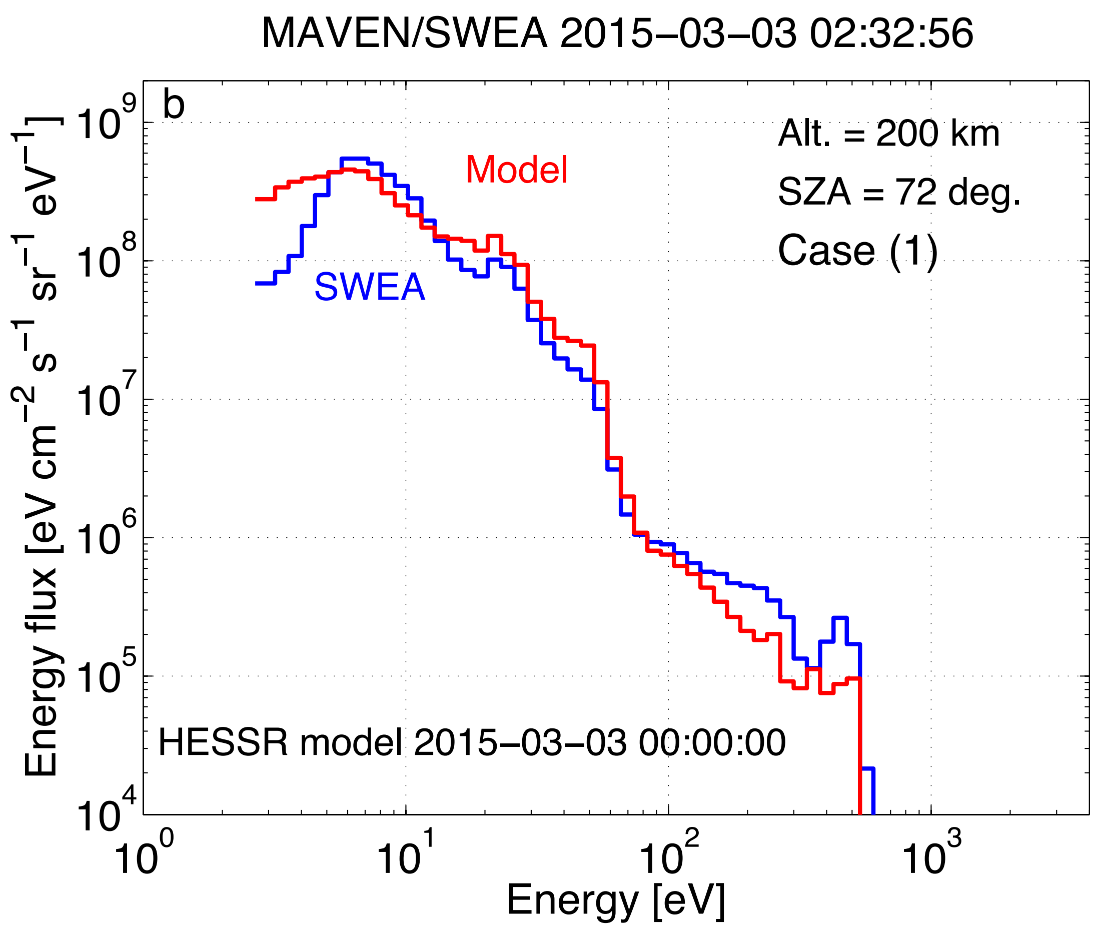
- Quiet solar condition (no flare)
    - Agrees with SWEA observations at high energies.
    - Does not agree with SWEA data at low energies on 1 April.
        - Note: Electron and neutral densities for SZA of 60˚ not 40˚.
        - Note: FISM fluxes are lower than the HESSR solar flux.



Comparison of models with SWEA [*Sakai et al.*, 2015]

Comparison with SWEA

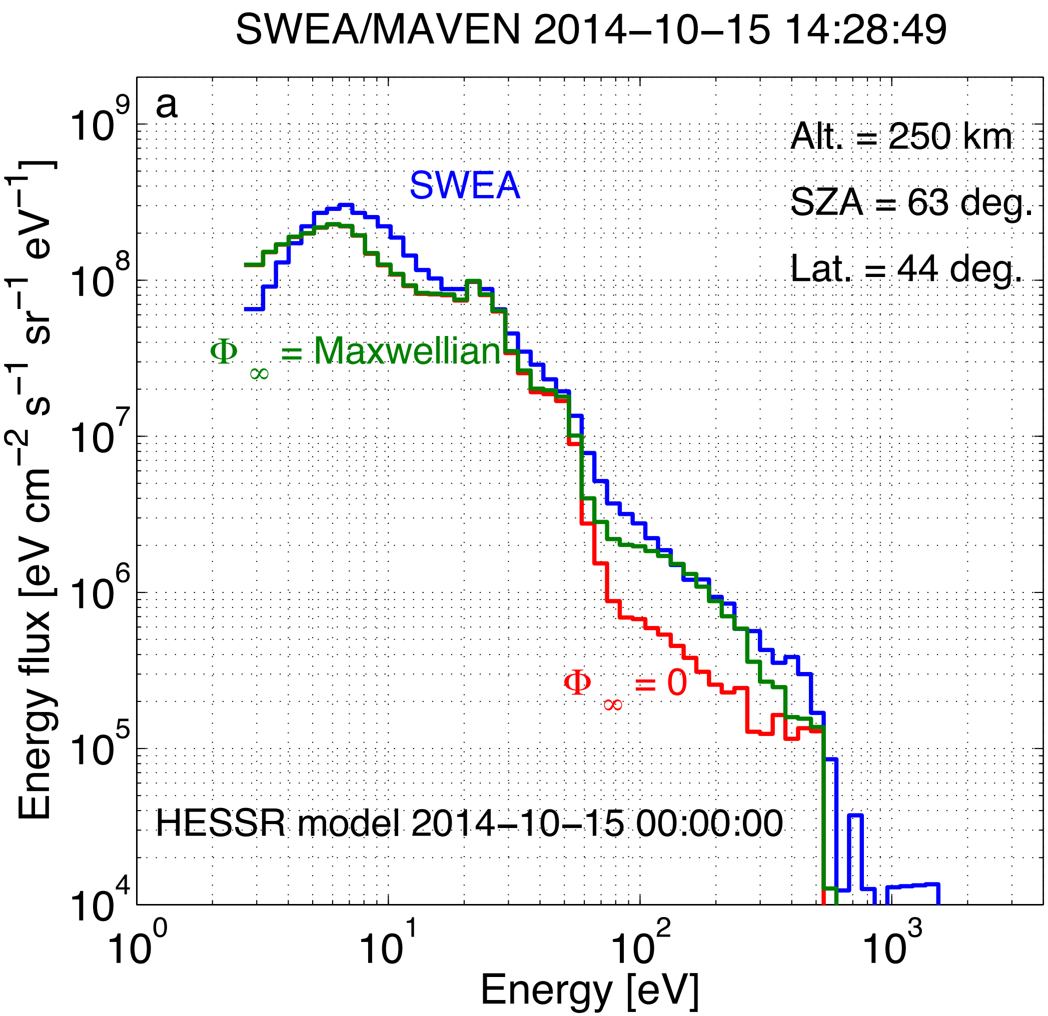
- Quiet solar condition (no flare)
  - Model agrees with SWEA observations at all energies.



Comparison of models with SWEA [*Sakai et al.*, 2015]

Comparison with SWEA

- Enhanced magnetosheath (tail) electrons are included in our model (0.5 cm^{-3} & 50 eV).
  - Agrees with SWEA observations at low energies.
  - Agrees with SWEA at high energies if tail electron is included.

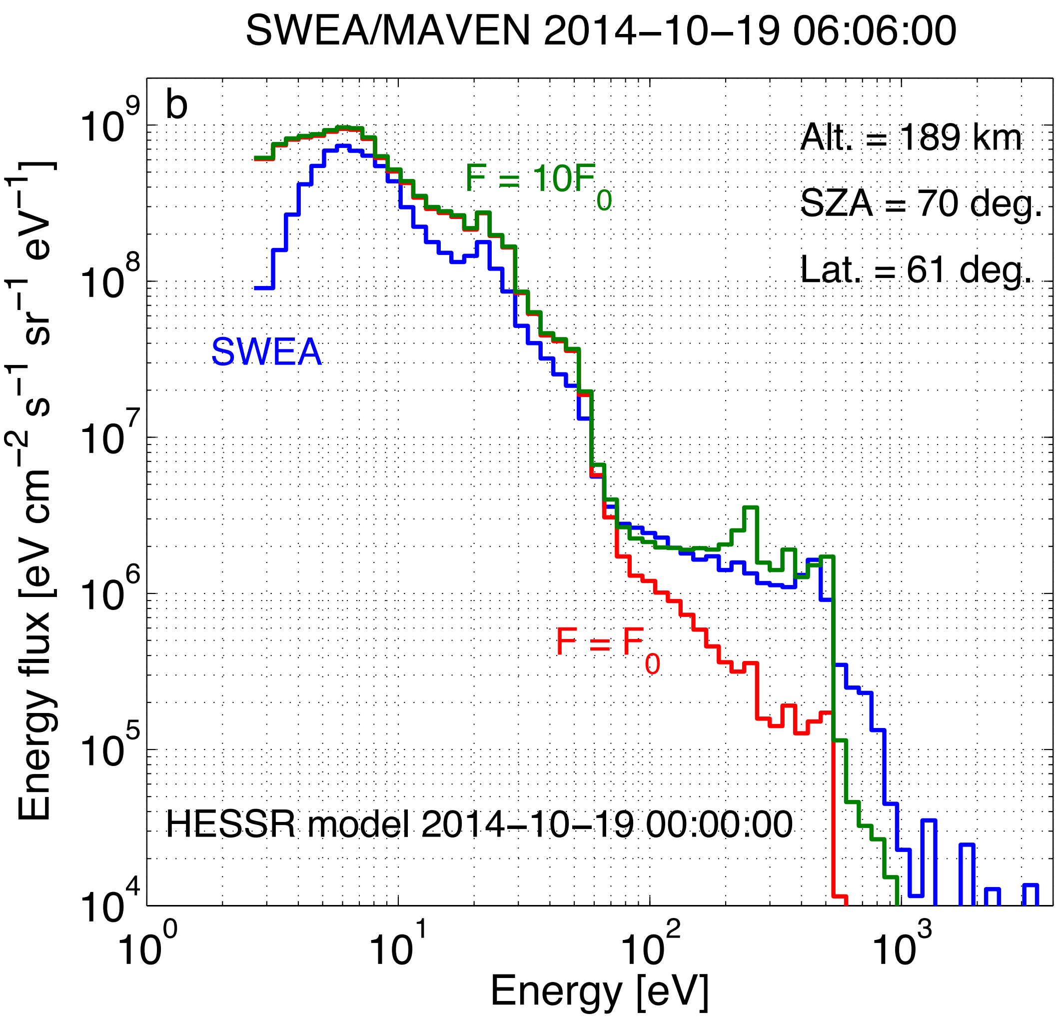


- External electrons affect the ionospheric suprathermal electron distribution!

Comparison of models with SWEA [*Sakai et al.*, 2015]

Comparison with SWEA

- Flare and CME case
  - Model agrees with SWEA observations at low energies.
  - Agrees with SWEA at high (flare) energies with high solar flux (λ < 5.0 nm). EUVM in this case shows high X-ray flux. Not in HESSR.



- Solar activity also affects the ionospheric suprathermal electron in the Martian ionosphere!!

Comparison of models with SWEA [*Sakai et al.*, 2015]

Summary

- We investigated suprathermal electrons in the Martian upper atmosphere.
- Model and SWEA spectra have Auger electrons.
- Suprathermal electron distributions depend on several factors.
  - External electron conditions (e.g., magnetosheath or tail distributions)
  - Solar activity
  - Neutral and electron densities in the atmosphere.

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