

# Comparative Aeronomy: Ionospheric Production for Terrestrial Planets

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**Venus** – **Earth** – **Mars**

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# Photo-Production of Ionospheric Layers

Gas	Ionization Potential	Wavelength
O <sub>2</sub>	12.1 eV	≤ 1028 Å Lyman-β included
O	13.6 eV	≤ 910 Å
CO <sub>2</sub>	13.8 eV	≤ 900 Å
N <sub>2</sub>	15.6 eV	≤ 796 Å

# Layer Classification Schemes Possible

- By wavelength (e.g. Bauer, 1973)
  - EUV
  - X-Rays
- By composition (e.g. Prölss, 2004)
  - Atomic Ions
  - Molecular Ions
- By key processes (e.g. Rishbeth and Mendillo, 2004)
  - Photochemistry only
  - Photochemistry and plasma dynamics

- GOAL:  
Conduct a set of simulations of the photo-chemical ionospheric layers of terrestrial planets under identical conditions.
- PARAMETERS:
  - Solar Irradiance for  $F_{10.7}=70$  & 200 at Earth [a]
  - Model Atmospheres for  $F_{10.7}=70$  & 200 at Earth [b]
  - Cross Sections & Reaction Rates [c]
  - Secondary Ionization [d]

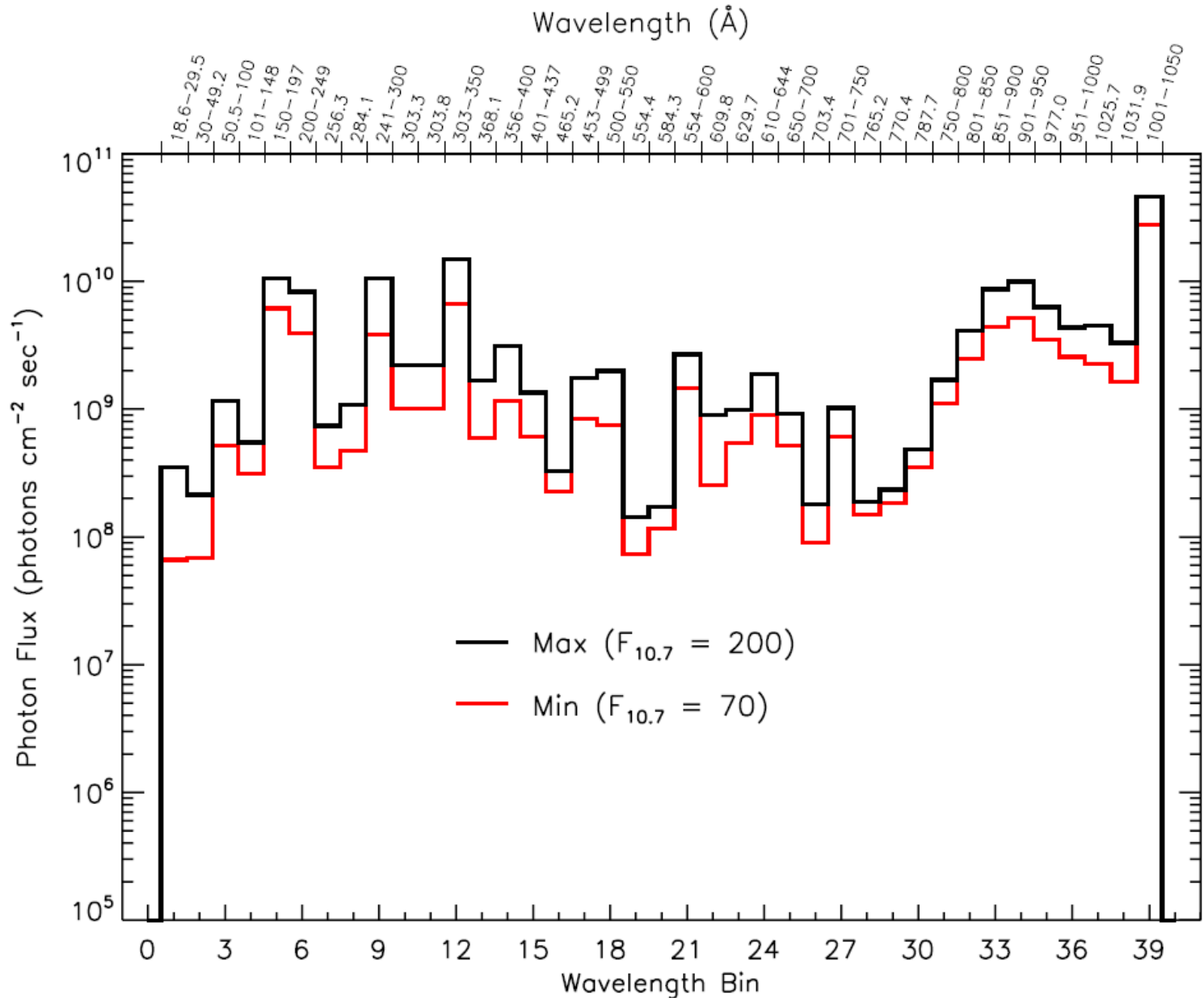
[a] Solar2000 version 2.35 (Tobiska, 2004)

[b] VTGCM & MTGCM (Steve Bougher), MSIS (E-90)

[c] Martinis et al. (2003), Moore et al. (2006)

[d] Fox et al. (1995), Titheridge et al. (1996)

# Solar Irradiance: The SOLAR2000 Model



# Photo-Chemical Equilibrium

## VENUS

## EARTH

## MARS

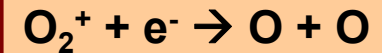
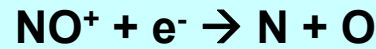
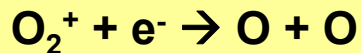
Production ( $P_0$ ):



Transformation:



Loss (L):



For  $P_0 = L$        $P_0 = \alpha N_e^2$

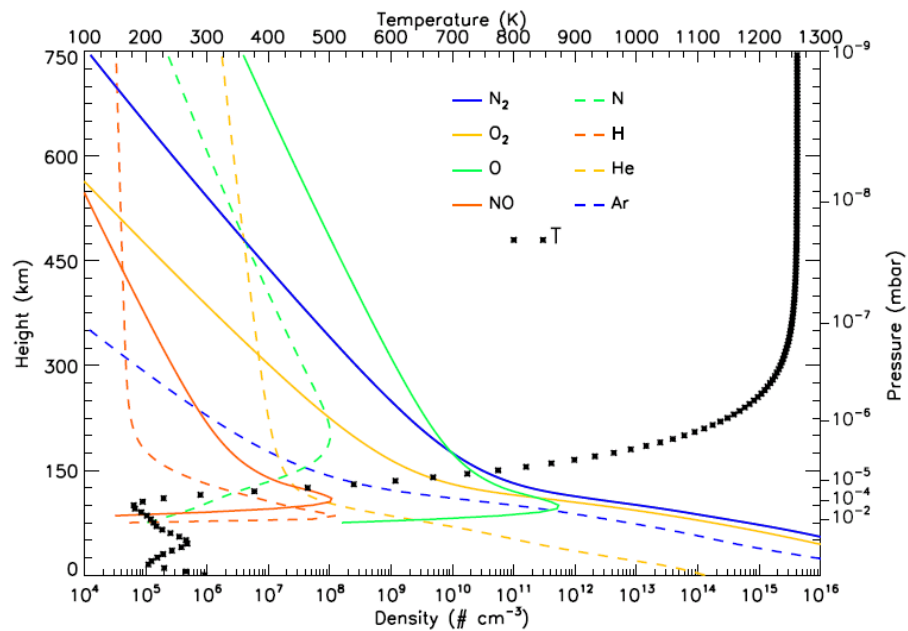
For       $P_0 \propto \Phi_{SUN} \propto \frac{1}{d^2}$

Giving       $N_e(d) \propto \frac{1}{d}$

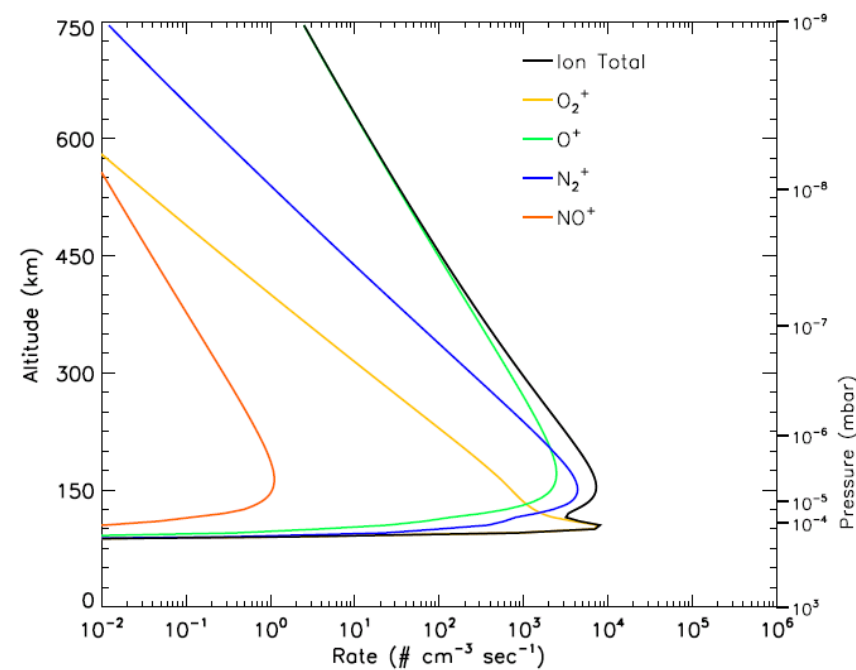
To what extent are results from comprehensive calculations Chapman-esque?

# Earth Neutral Atmosphere – Solar Max

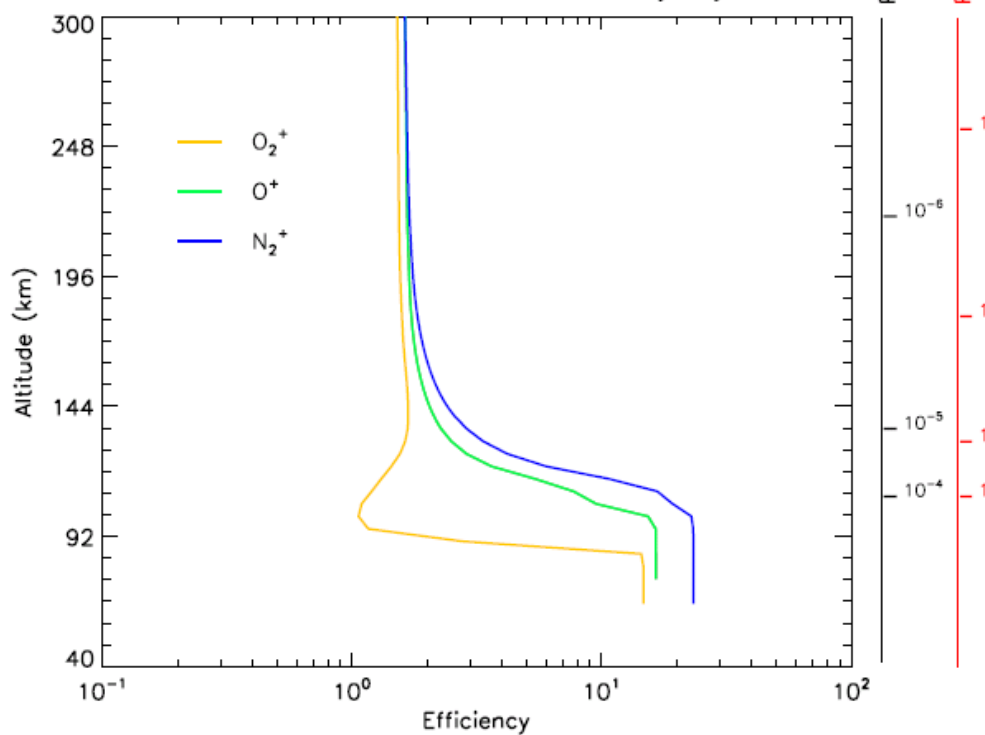
# EARTH



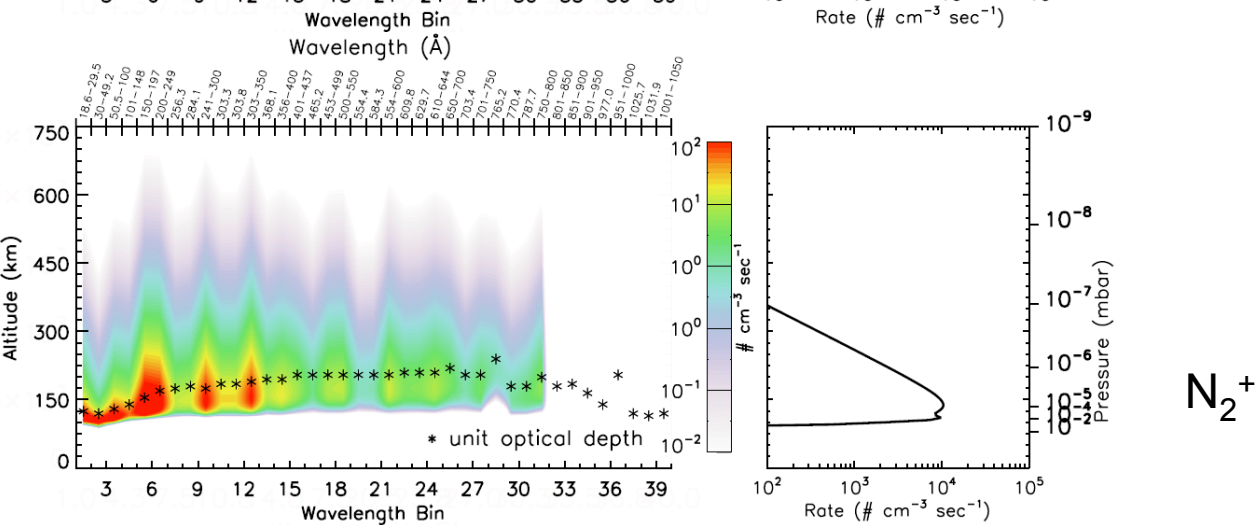
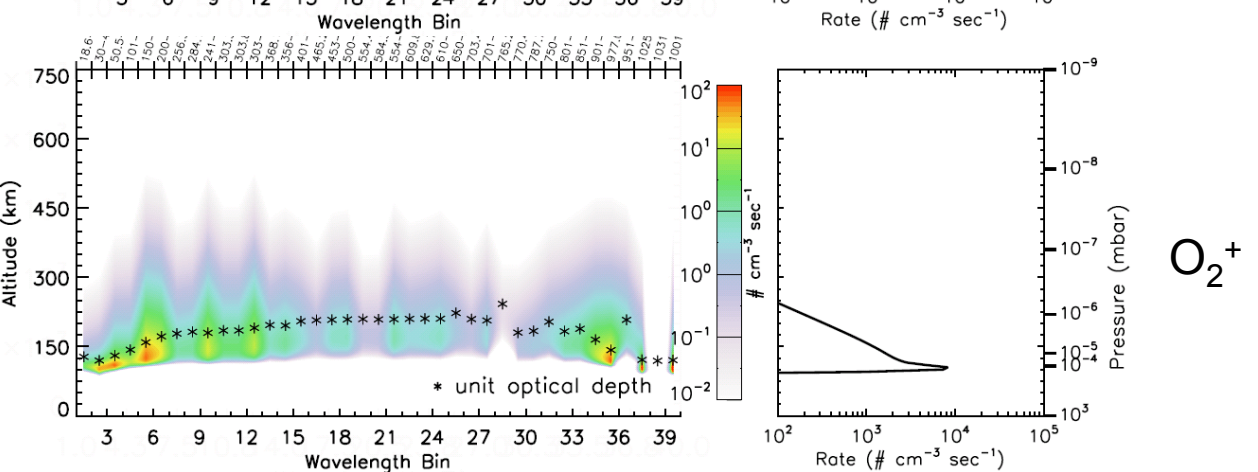
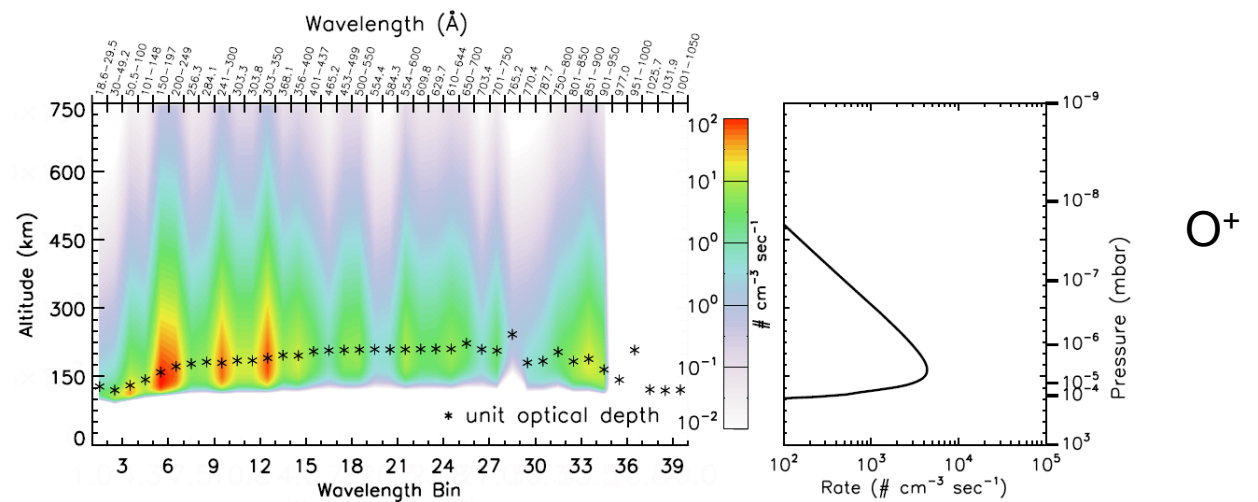
# Earth: Primary Production Rates, Solar Max



# Earth: Production Rate Efficiency by Altitude

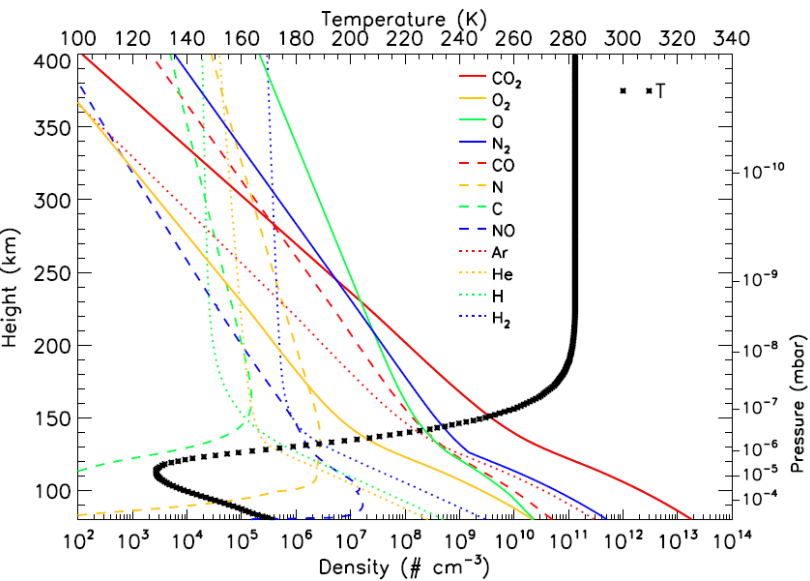


# EARTH

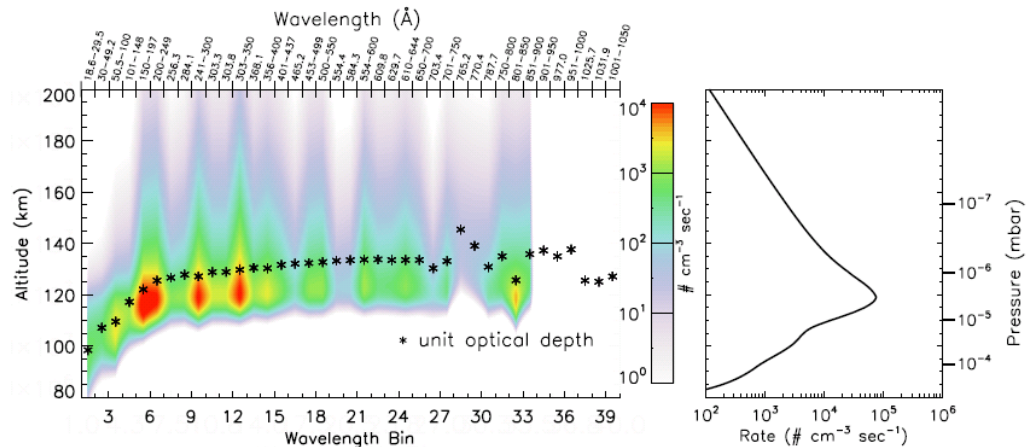


Total  
Production  
Rates  
for  
Solar  
Max

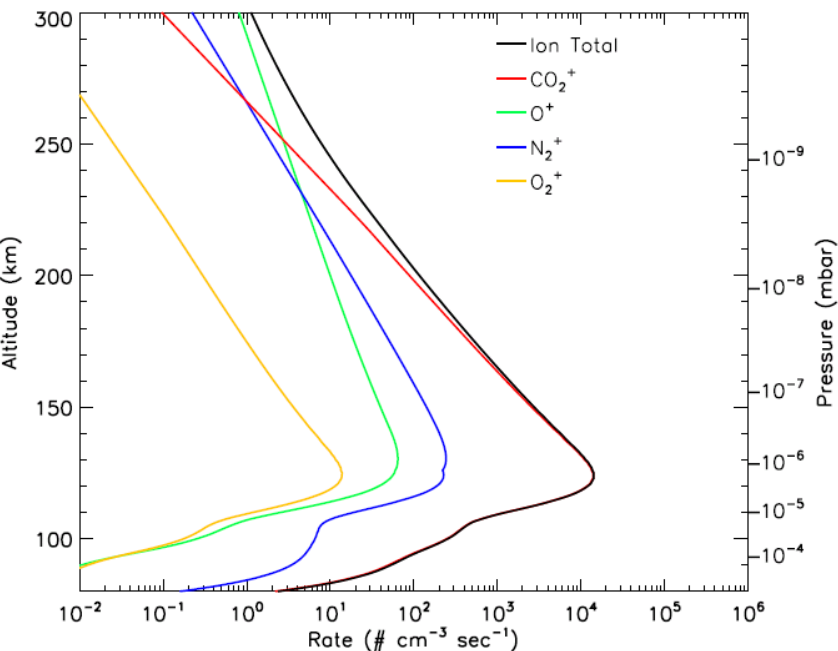
## Mars Neutral Atmosphere – Solar Max



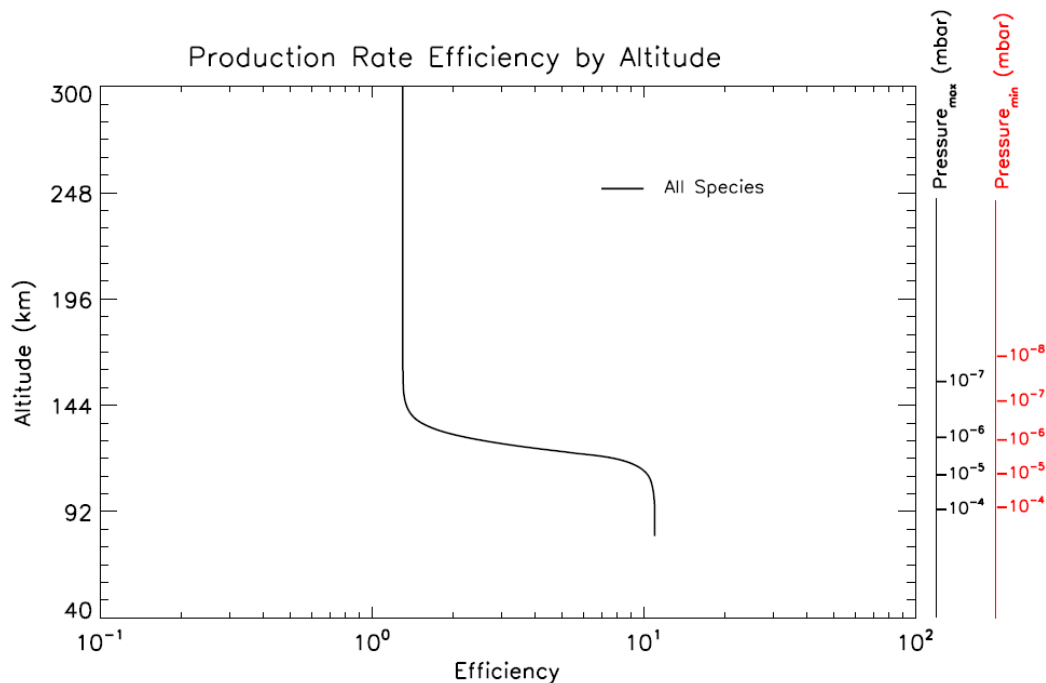
## Mars: $\text{CO}_2^+$ Total Production Rates, Solar Max



## Mars: Primary Production Rates, Solar Max

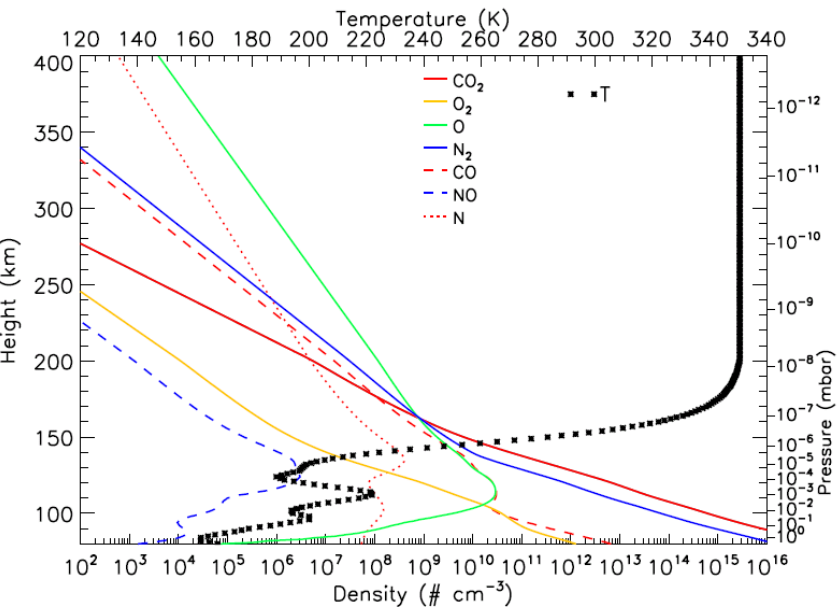


## Production Rate Efficiency by Altitude

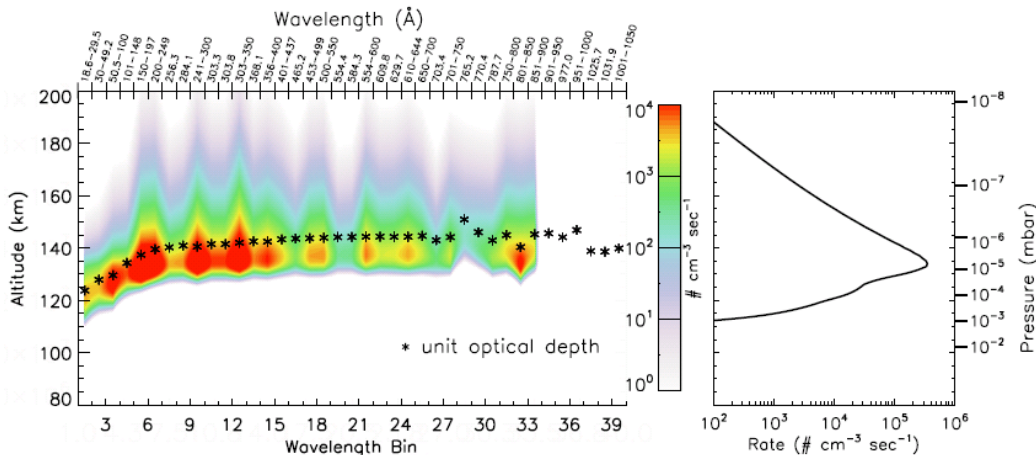


# Venus Neutral Atmosphere – Solar Max

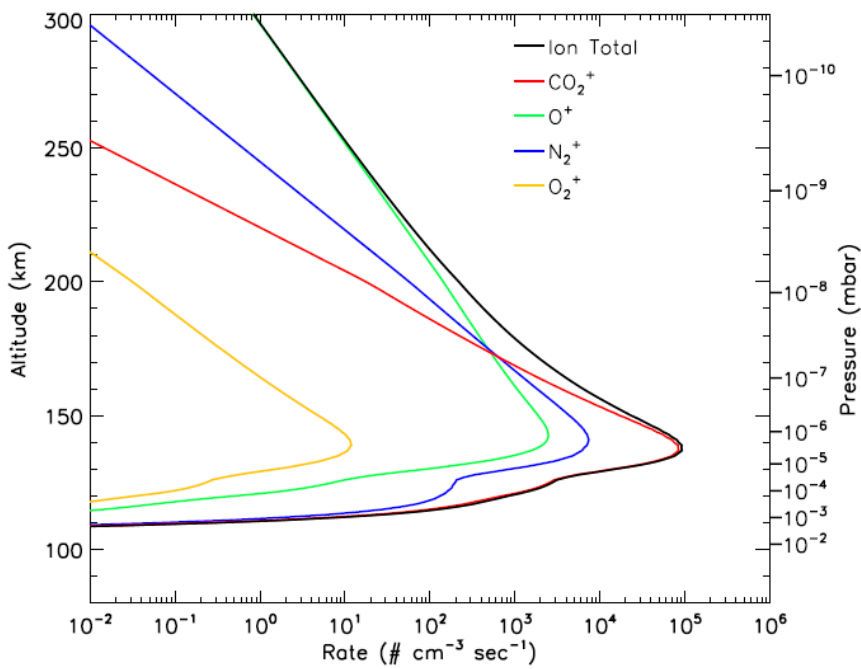
# VENUS



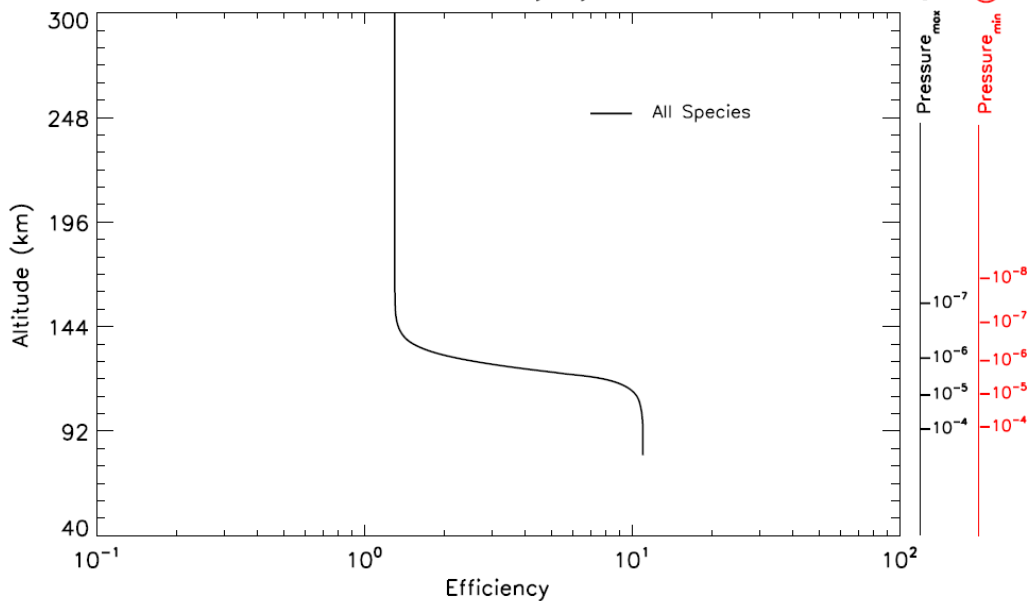
## Venus: CO<sub>2</sub><sup>+</sup> Total Production Rates, Solar Max



## Venus: Primary Production Rates, Solar Max

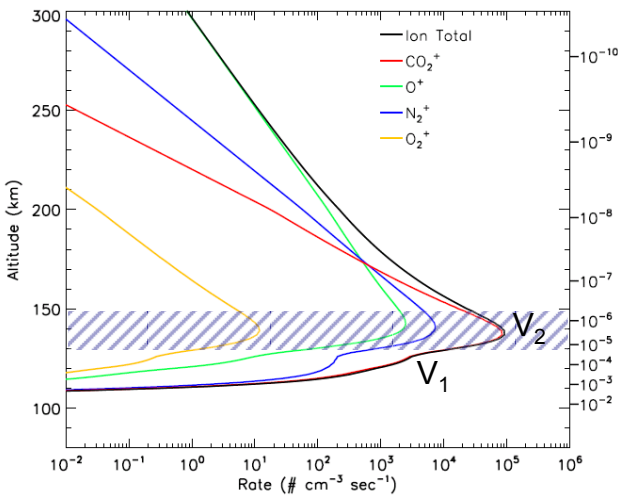


## Production Rate Efficiency by Altitude

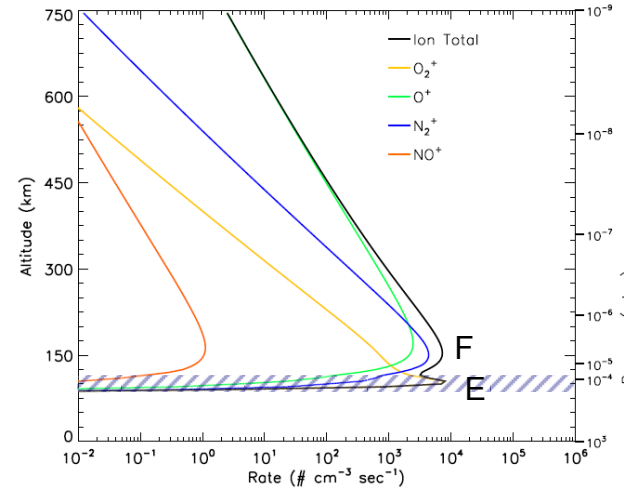


# Comparative Molecular Ion Photochemical Layers

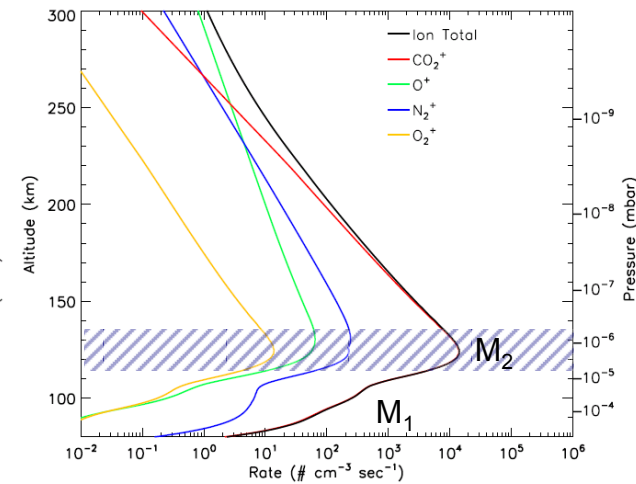
Venus: Primary Production Rates, Solar Max



Earth: Primary Production Rates, Solar Max



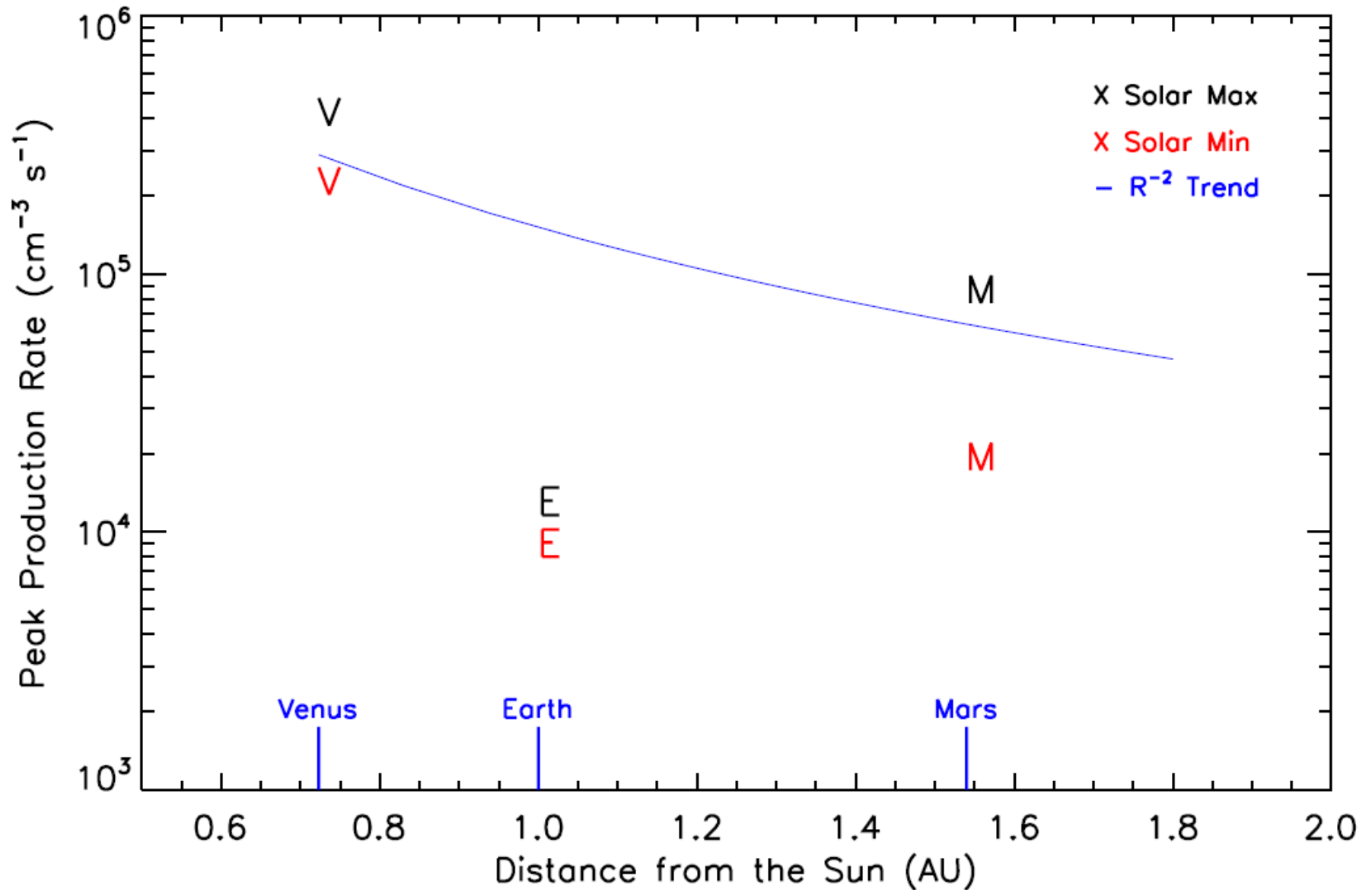
Mars: Primary Production Rates, Solar Max



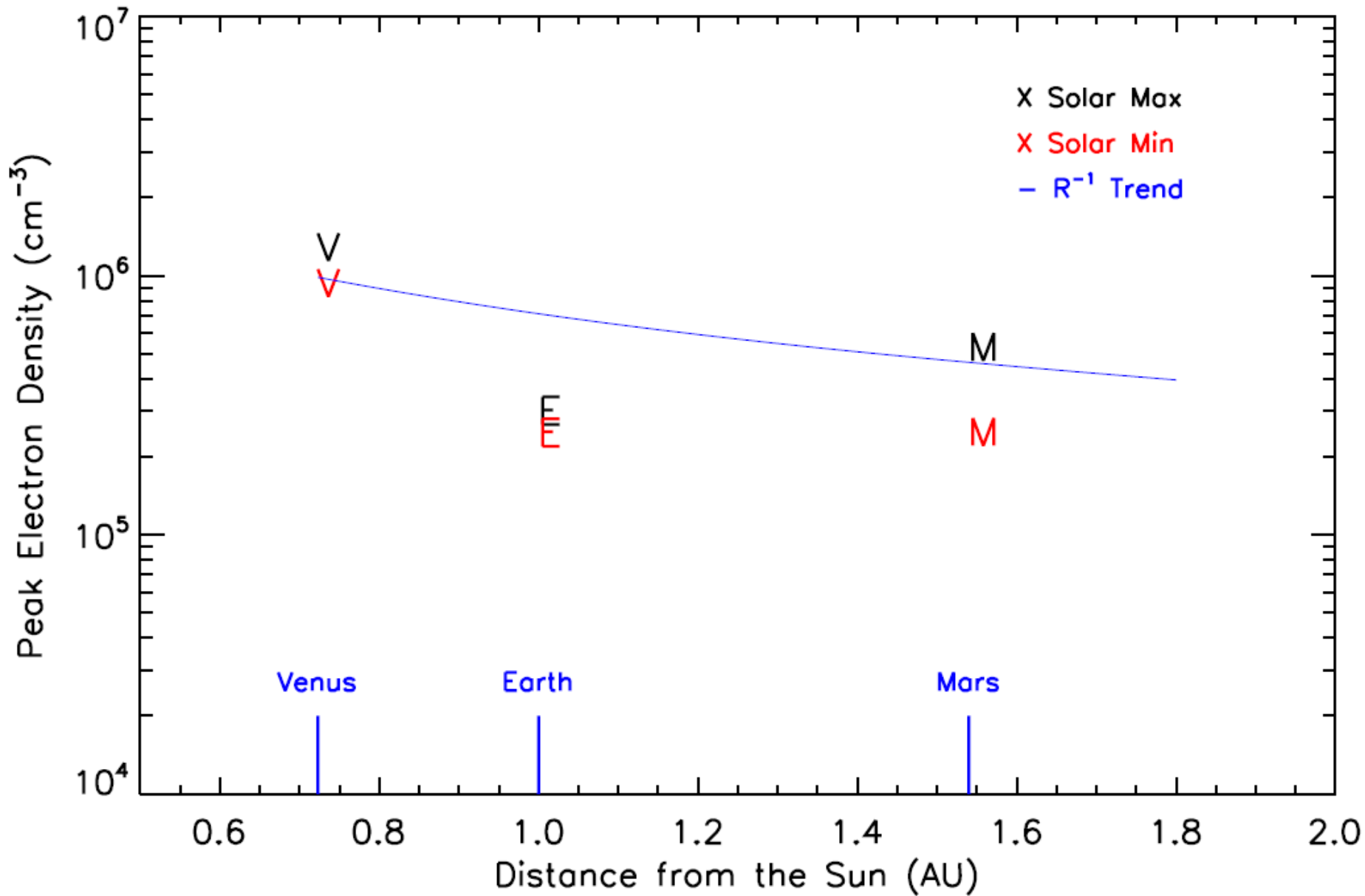
## Neutral Atmosphere Properties at Main Photochemical Layers

	@ $V_2$	@ E	@ $M_2$
Altitude (km)	137	105	123
Density ( $\text{cm}^{-3}$ )	$1.51 \times 10^{11}$	$5.42 \times 10^{12}$	$8.80 \times 10^{10}$
Pressure (mbar)	$3.72 \times 10^{-6}$	$1.46 \times 10^{-4}$	$1.78 \times 10^{-6}$

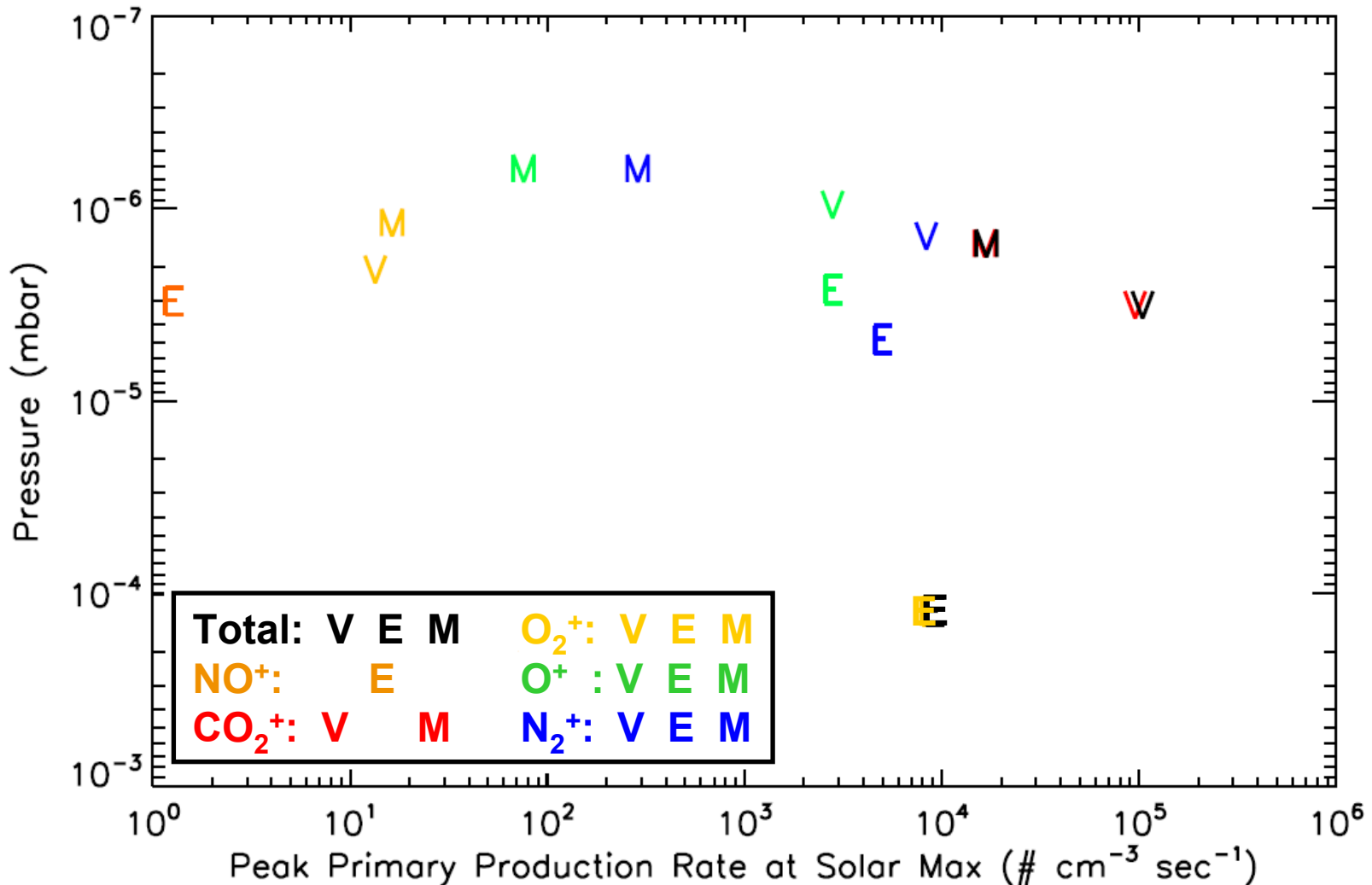
# Peak Total Production Rates



# Peak Electron Densities (PCE)

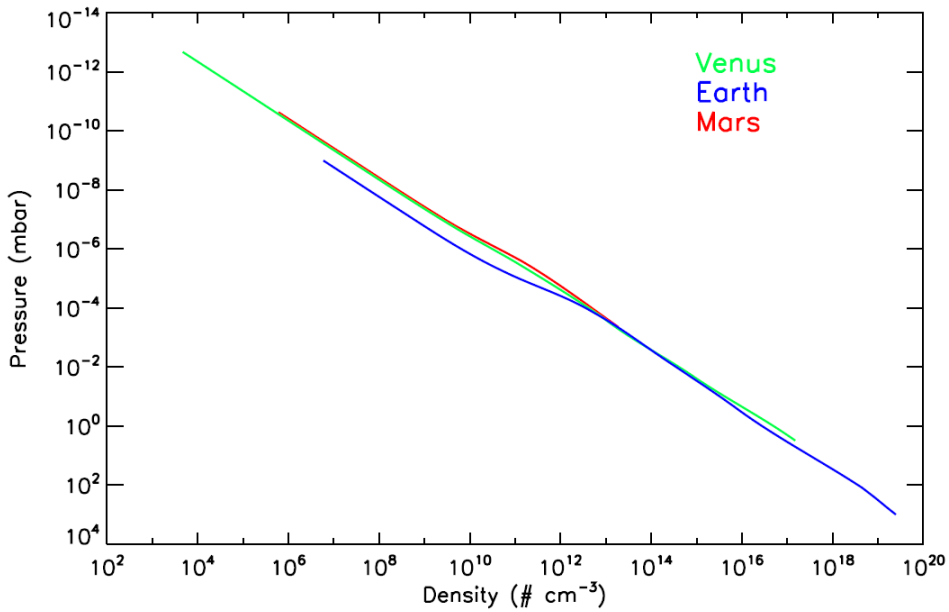


# Comparing Pressure Levels for Different Ions

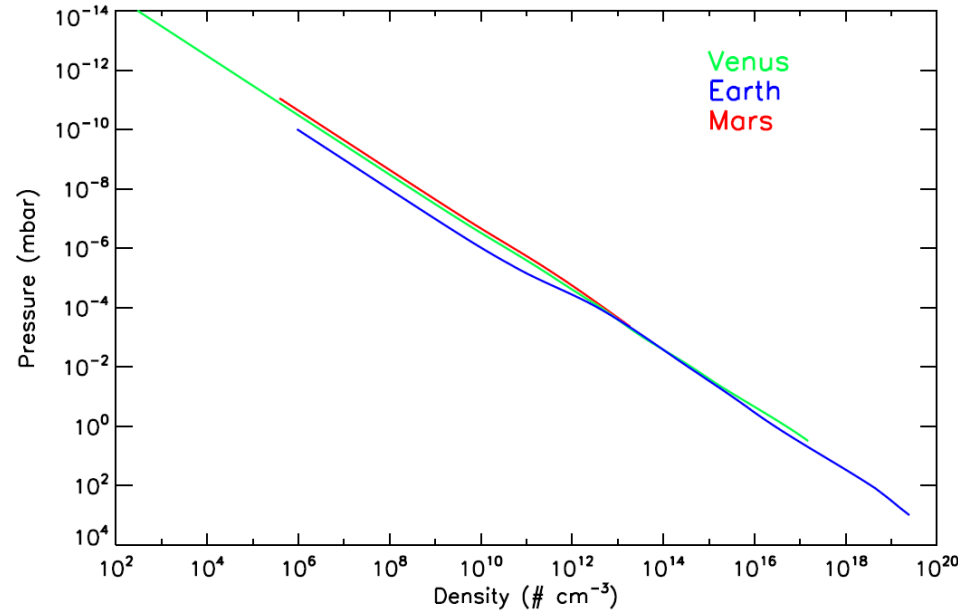


# Pressure vs. Neutral Density

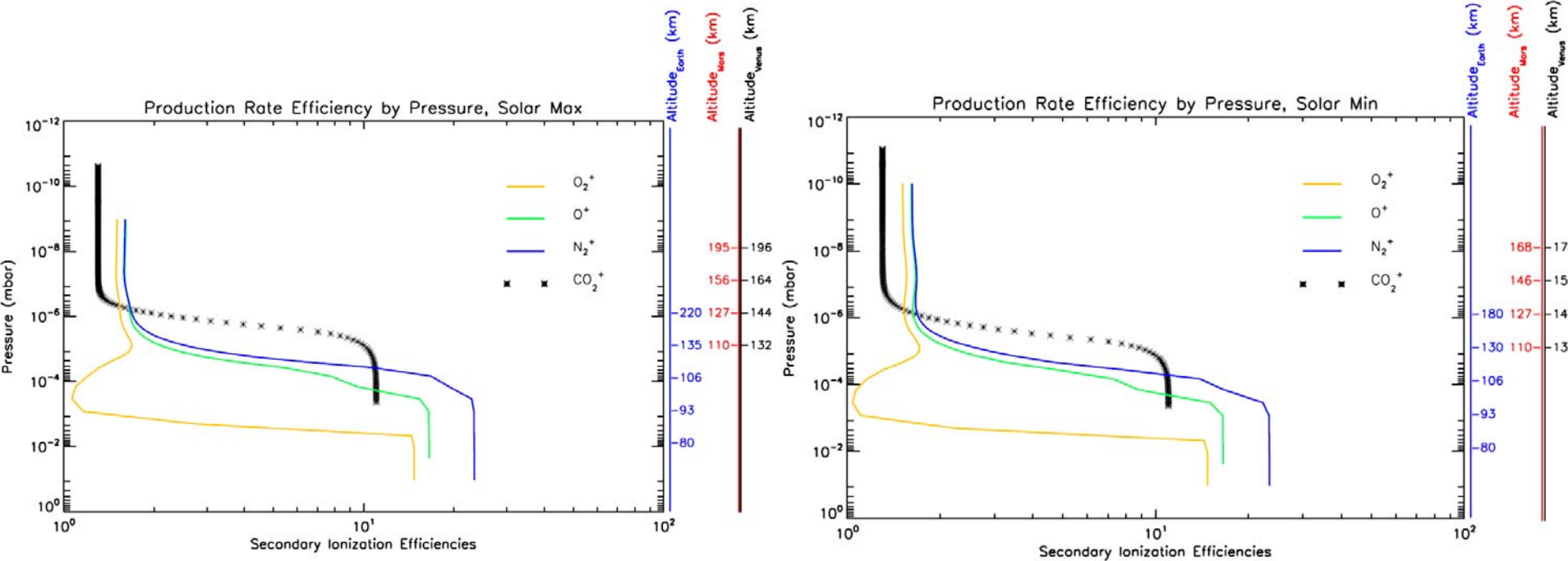
Planet Neutral Density vs. Press., Solar Max



Planet Neutral Density vs. Press., Solar Min



# Secondary Ionization Efficiency



# Conclusions

- Conducted a consistent study of photochemical ionospheric layers for Venus-Earth-Mars.
- Used latest neutral atmospheres, solar irradiance values, and reaction rates.
- Primary photo-ionization well ordered by peak production at constant pressure level.
- Mars and Venus production and resultant electron density scale “appropriately” but not “precisely” as Chapman-esque.
- Only major inconsistency is for  $O_2^+$  at Earth.
- Secondary Ionization by photo-electrons requires additional work.

# Ionization Frequencies: J-Values

Venus (d=0.723 AU;  $\tau = 0$ )

Species	Solar Max (s <sup>-1</sup> )	Solar Min (s <sup>-1</sup> )
O <sup>+</sup>	1.2199489e-006	5.7153666e-007
CO <sub>2</sub> <sup>+</sup>	3.1902971e-006	1.5147798e-006
N <sub>2</sub> <sup>+</sup>	1.8469907e-006	8.5990601e-007
O <sub>2</sub> <sup>+</sup>	2.8654194e-006	1.3775232e-006
CO <sup>+</sup>	2.0285499e-006	9.6946727e-007

Earth (d = 1.00 AU;  $\tau = 0$ )

Species	Solar Max (s <sup>-1</sup> )	Solar Min (s <sup>-1</sup> )
O <sup>+</sup>	6.3770263e-007	2.9875877e-007
O <sub>2</sub> <sup>+</sup>	1.4978378e-006	7.2007129e-007
N <sub>2</sub> <sup>+</sup>	9.6547558e-007	4.4949779e-007
NO <sup>+</sup>	1.1204404e-006	5.2350767e-007
N <sup>+</sup>	5.3933410e-007	2.5892483e-007
Ar <sup>+</sup>	7.5082446e-007	3.6633992e-007
He <sup>+</sup>	1.6725689e-007	7.3432783e-008
H <sup>+</sup>	1.4278622e-007	7.5586167e-008

Mars (d = 1.54 AU;  $\tau = 0$ )

Species	Solar Max (s <sup>-1</sup> )	Solar Min (s <sup>-1</sup> )
O <sub>2</sub> <sup>+</sup>	7.1240791e-007	2.7437560e-007
O <sup>+</sup>	3.0330681e-007	1.1383889e-007
CO <sub>2</sub> <sup>+</sup>	7.9317982e-007	3.0171443e-007
N <sub>2</sub> <sup>+</sup>	4.5920356e-007	1.7127641e-007
CO <sup>+</sup>	5.0434326e-007	1.9309886e-007
Ar <sup>+</sup>	3.5711029e-007	1.3958998e-007
NO <sup>+</sup>	5.3290859e-007	1.9947710e-007
H <sub>2</sub> <sup>+</sup>	6.1225497e-007	2.7599047e-007
H <sup>+</sup>	6.7912585e-008	2.8801315e-008
He <sup>+</sup>	7.9551426e-008	2.7980790e-008

# Ionization Frequencies at 1 AU

<b>Species</b>	<b>Solar Max (s<sup>-1</sup>)</b>	<b>Solar Min (s<sup>-1</sup>)</b>
O <sup>+</sup>	6.3770263e-007	2.9875877e-007
O <sub>2</sub> <sup>+</sup>	1.4978378e-006	7.2007129e-007
N <sub>2</sub> <sup>+</sup>	9.6547558e-007	4.4949779e-007
NO <sup>+</sup>	1.1204404e-006	5.2350767e-007
CO <sub>2</sub> <sup>+</sup>	2.4608405e-006	1.0935337e-006
CO <sup>+</sup>	1.5647251e-006	6.9986750e-007
H <sub>2</sub> <sup>+</sup>	1.8995212e-006	1.0002998e-006
N <sup>+</sup>	5.3933410e-007	2.5892483e-007
Ar <sup>+</sup>	7.5082446e-007	3.6633992e-007
He <sup>+</sup>	1.6725689e-007	7.3432783e-008
H <sup>+</sup>	1.4278622e-007	7.5586167e-008

# Variability of Molecular Ion Ionospheres

Earth's E-layer:  $\sigma_{\text{tot}} \approx \sigma_{\text{photons}}$   
(5-10%)

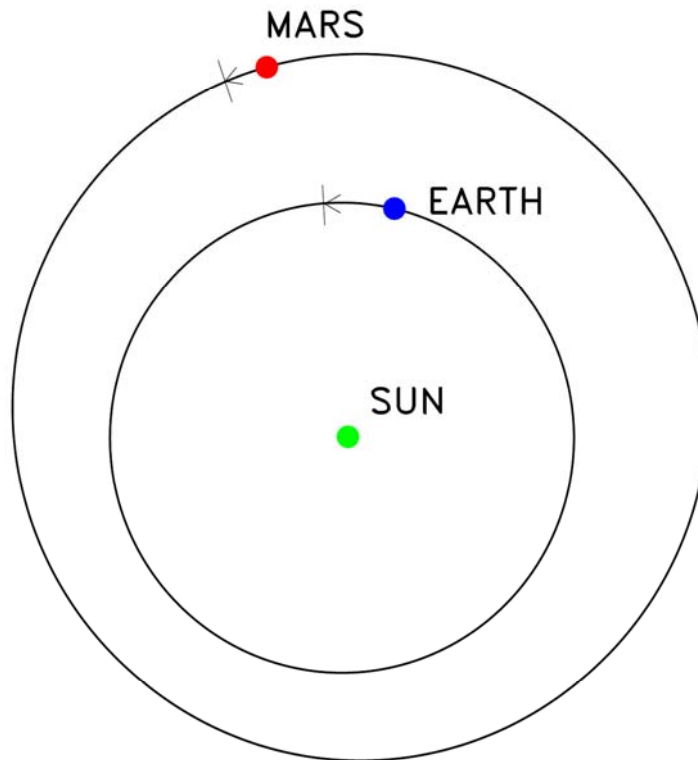
Mars' M1 + M2 layers:  $\sigma_{\text{tot}} \approx \sigma_{\text{photons}}$   
(10%) (5%)

Do models reproduce these?

# Ionospheric Variability at Mars and Earth

## MGS at Mars: Solar System Geometry

9–27 March 1999



Observing Conditions:

Lat. =  $69.7^{\circ}\text{N} - 73.3^{\circ}\text{N}$

Lon. =  $26.5^{\circ} - 273.0^{\circ}\text{N}$

LT = 3.6–4.1 hr

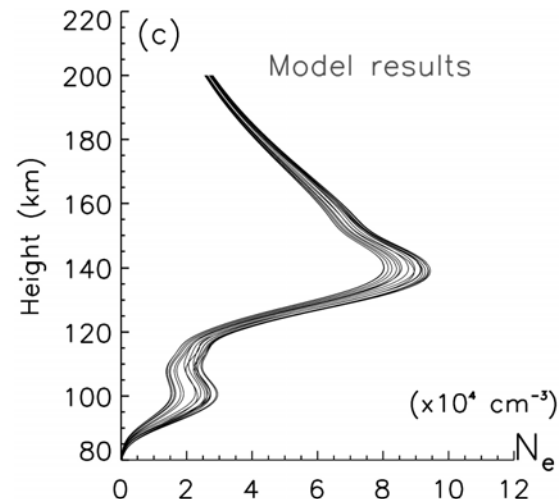
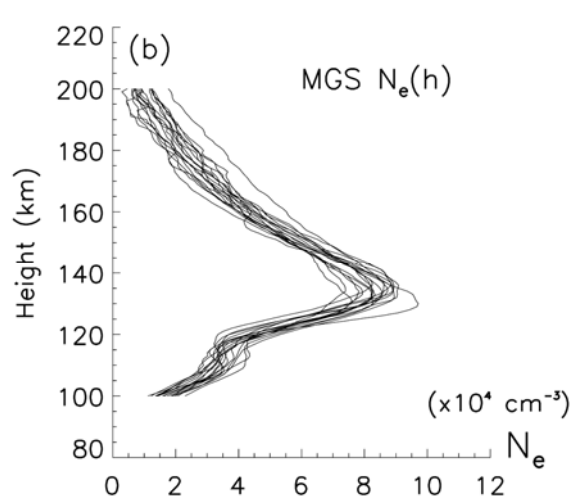
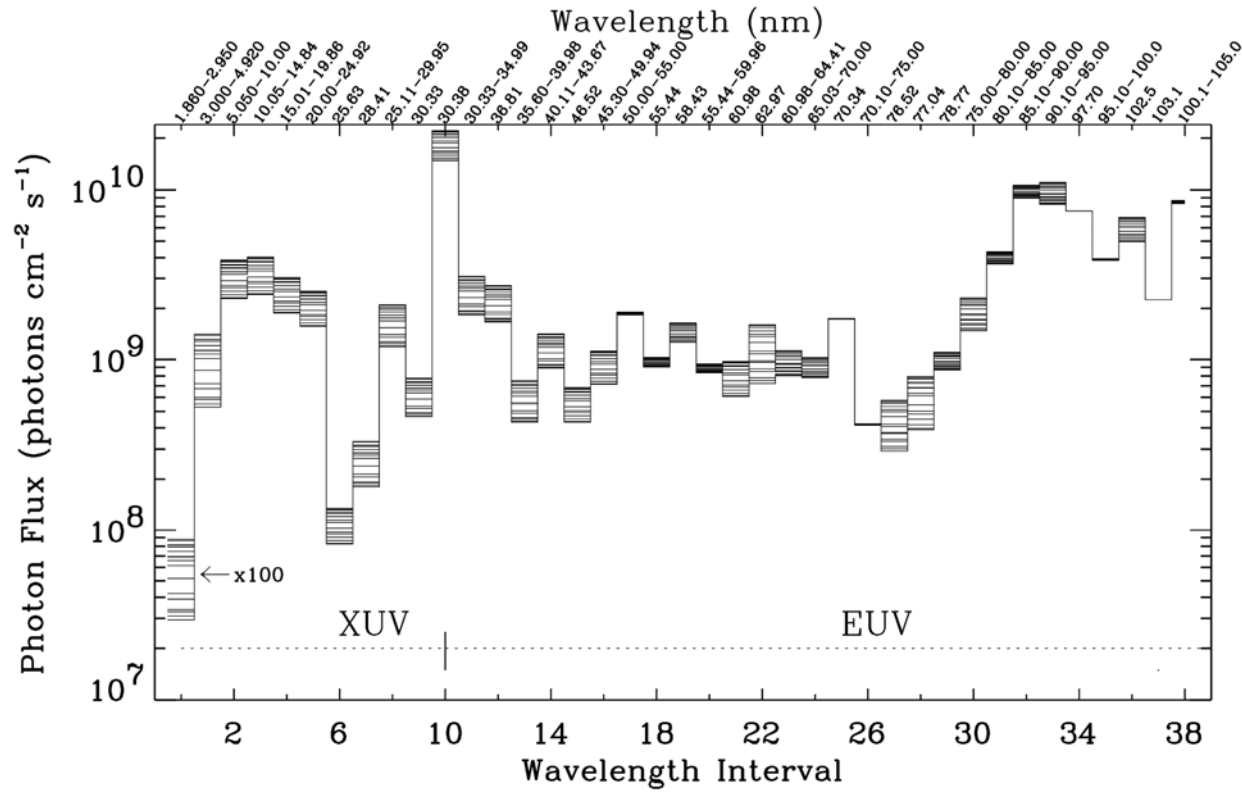
$\chi = 76.5^{\circ} - 77.8^{\circ}$

F10.7 = 103–155

--- Mars-at-oppositions allows Solar variations seen at Earth to be applied to Mars

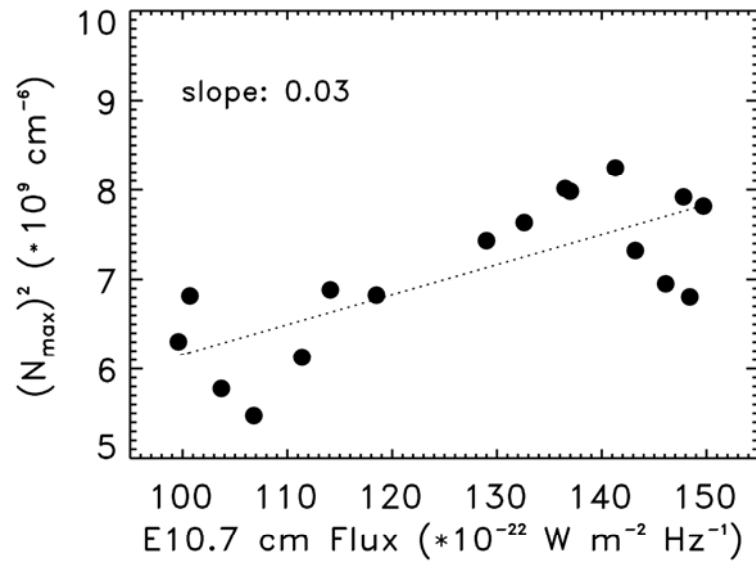
# Solar Variability → Ionospheric Variability

# MARS



COMPARATIVE IONOSPHERES: 9–27 MARCH 1999

Mars



Earth

