SA31B-04

Localized Ionization Patches on the Nightside of Mars and Their Dependence Upon Atmospheric Variations

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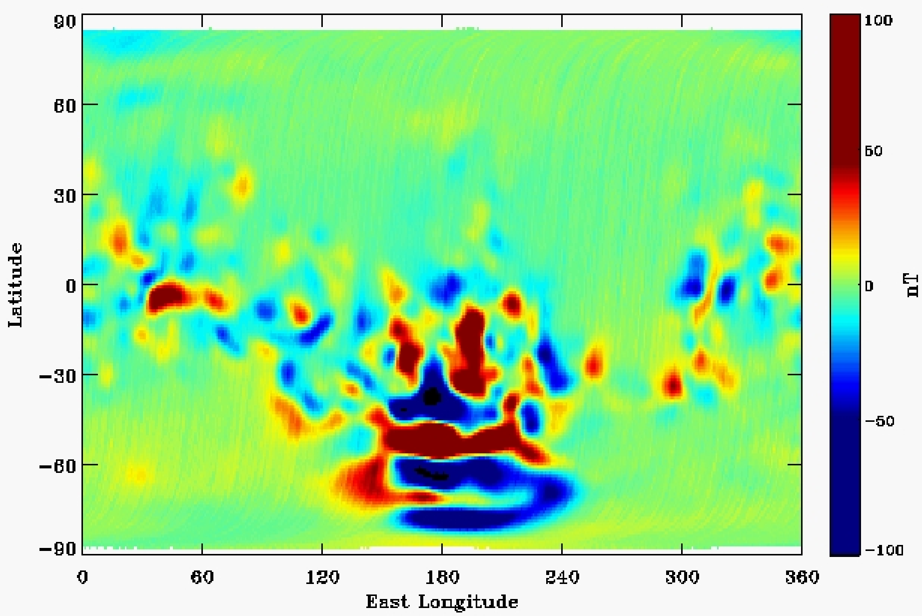
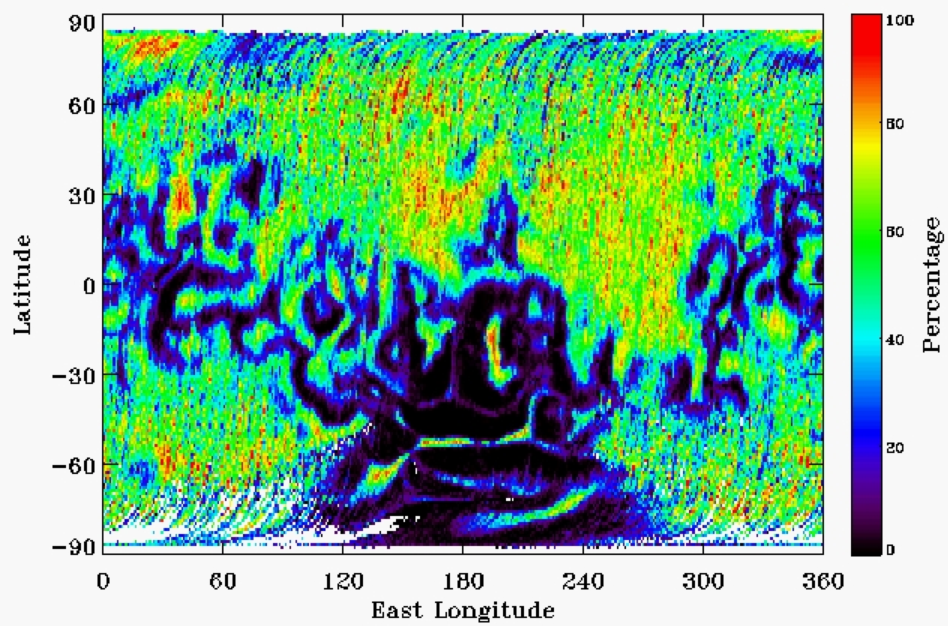
Martian Magnetic Field

- Mars has no global dipole magnetic field
- But it does have strong localized crustal fields
- “Cusps” form in strong field regions where the solar wind has access to the atmosphere (strong B_R + open field = cusps)
- Non-uniform global distribution of cusps (“patchy”)

Map of the magnitude of the radial component of B (B_R)

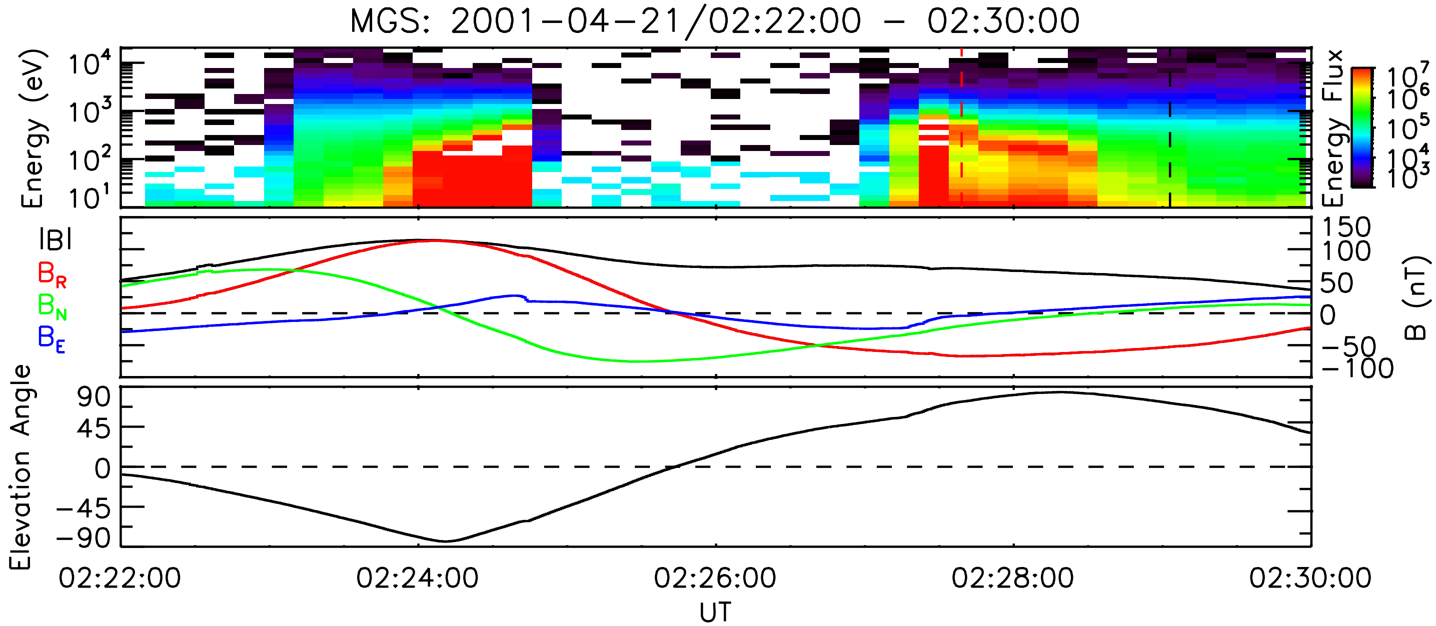


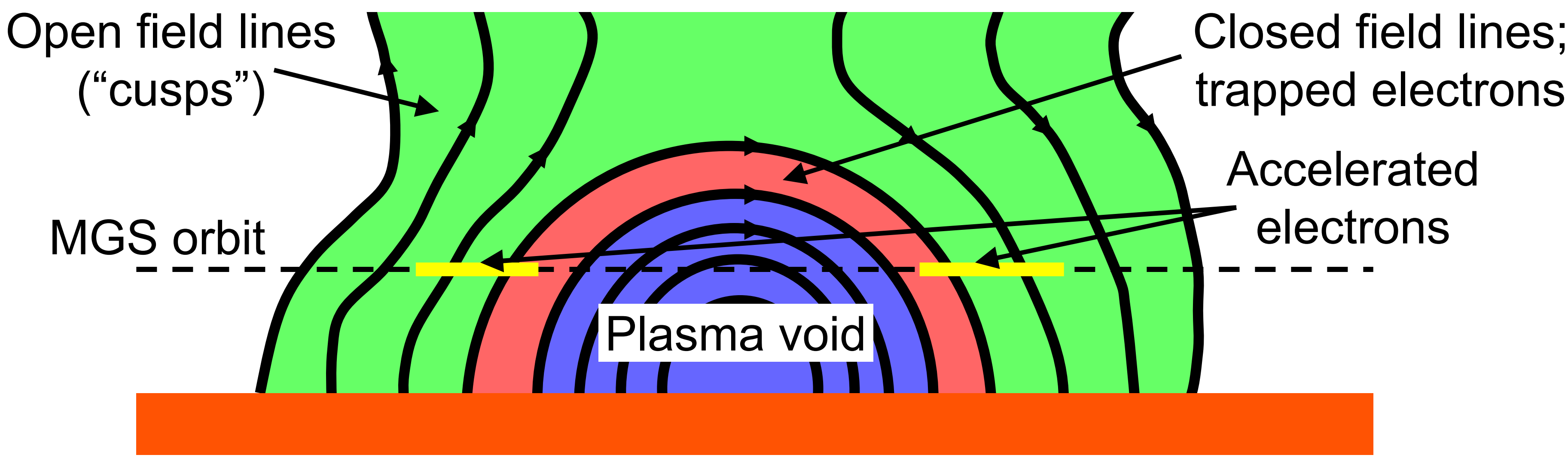
Map of the probability of observing upward loss cones (“open” field lines) on the nightside



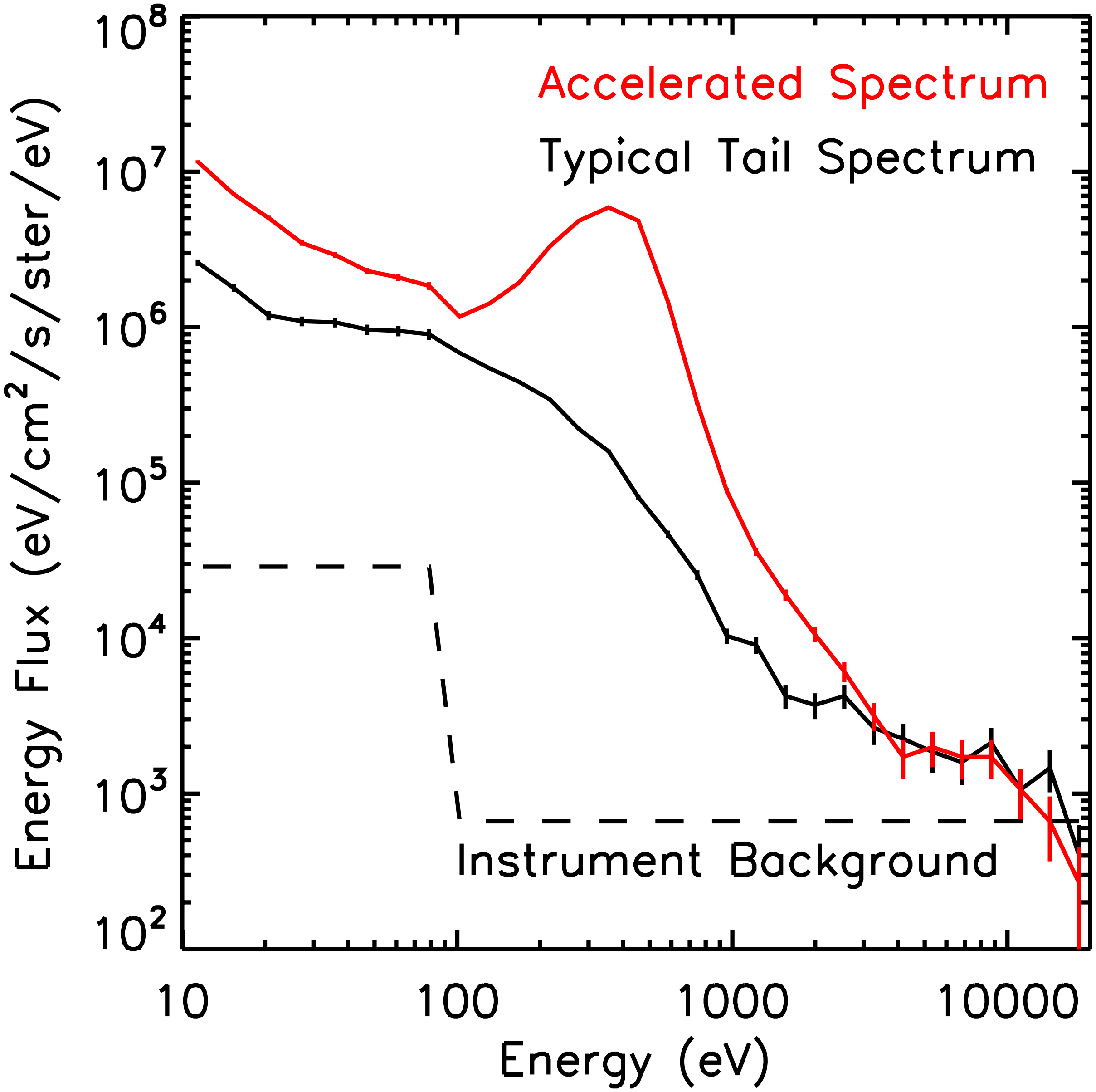
Accelerated Electron Event

(from *Brain et al.* [2006])





Incident Electron Spectra



Two spectra obtained within minutes of each other on 21 April 2001

MGS located near
65° S, 205° E at 400 km
Solar zenith angle ~ 125°

Downward energy flux
for **typical tail spectrum**:
~ 0.6 x 10^{-3} ergs cm^{-2} s^{-1}
for **accelerated spectrum**:
~ 6.0 x 10^{-3} ergs cm^{-2} s^{-1}

Downgoing electrons approximately isotropic from 100 to 1000 eV

Purpose & Methodology

- Model the nightside electron density profile due to electron precipitation using **typical tail** and **accelerated** electron spectra observed by MGS
- The upper atmosphere changes significantly with season and solar cycle
  ➔ *How do these changes affect the precipitation induced ionosphere?*

- Examine four cases:
  - Solar moderate, perihelion, northern winter solstice (L_S = 270°)
  - Solar minimum, perihelion, northern winter solstice (L_S = 270°)
  - Solar moderate, aphelion, northern summer solstice (L_S = 90°)
  - Solar minimum, aphelion, northern summer solstice (L_S = 90°)

- For each case, determine electron density profile, $\mathbf{n_e(z)}$, from

$$\mathbf{n_e(z) = (P(z)/\alpha_{eff}(z))^{1/2}\ cm^{-3}}$$

  where **P(z)** is the total model-calculated ion production rate
  and $\boldsymbol{\alpha_{eff}(z)}$ is the effective recombination rate

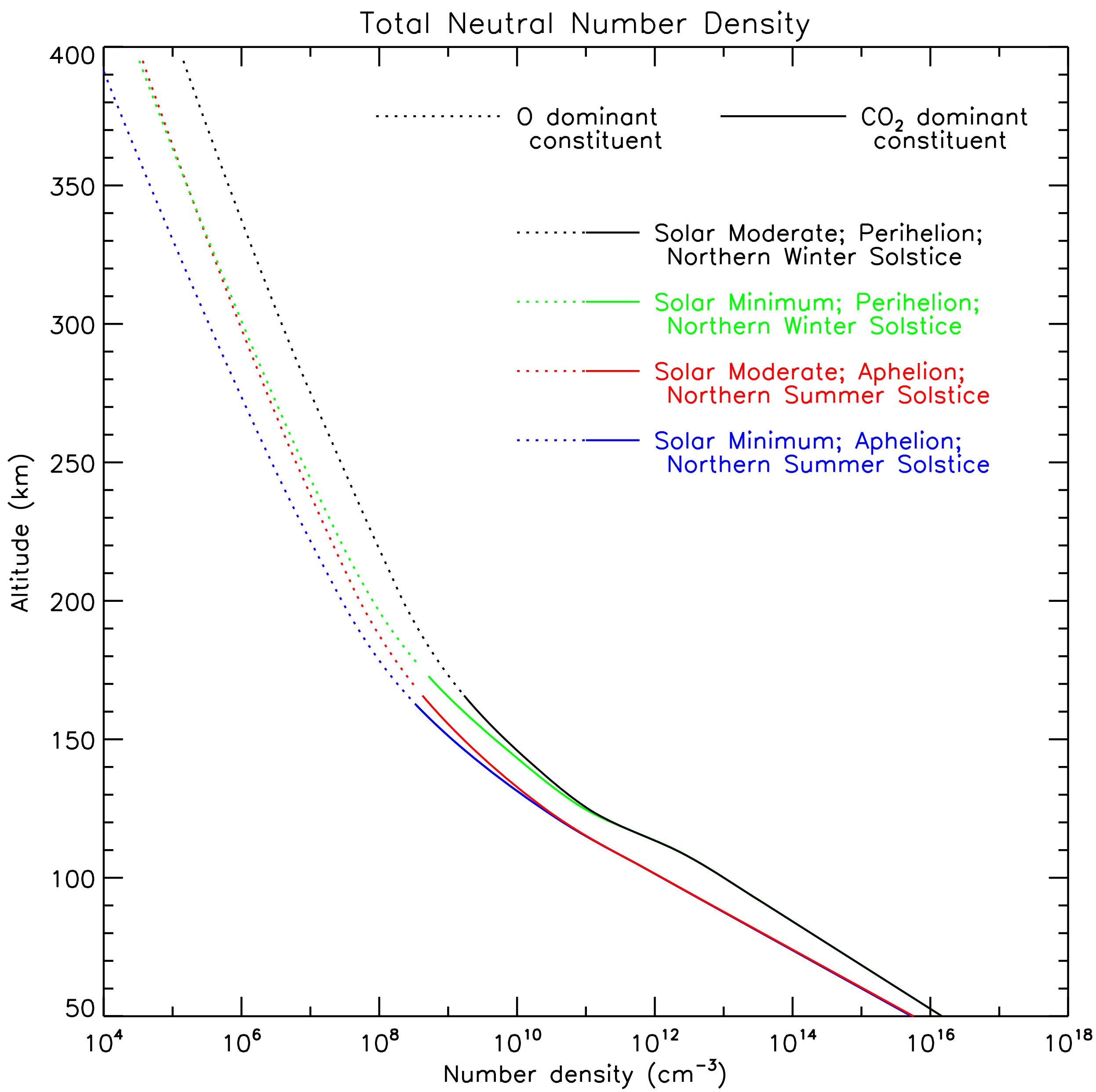
- $\mathbf{O_2^+}$ is the dominant ion in the ionosphere due to rapid chemical reactions; therefore, $\boldsymbol{\alpha_{eff}(z)}$ is equal to the **$\mathbf{O_2^+}$ dissociative recombination rate**

$$\boldsymbol{\alpha(z) = 1.95 \times 10^{-7}\ (300/T_e(z))^{0.7}\ cm^3\ s^{-1}}\ \text{for}\ \mathbf{T_e < 1200\ K}$$

  where $\mathbf{T_e}$ is the electron temperature (**assume $\mathbf{T_e}$ = neutral temperature**)

Neutral Atmosphere Profiles (MTGCM)

[*Bougher et al.*, 1999, 2000]



Model contains 5 neutral atmospheric species: CO_2, CO, O_2, O, & N_2 (only total density shown)

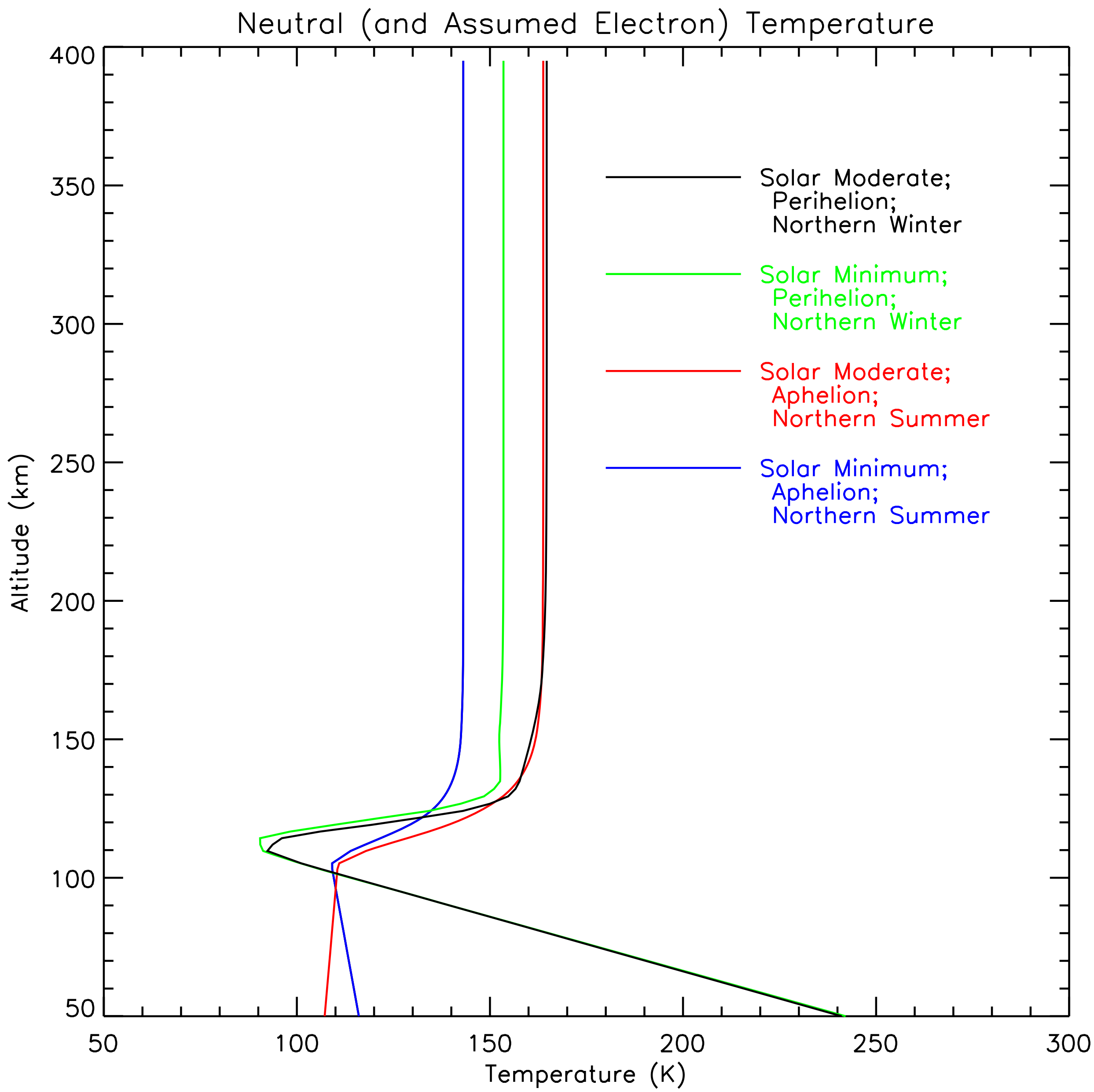
All profiles taken at 2.5° N lat. & 2 AM LT

At low altitude, seasonal (orbital) effects dominate; density increases by **2.7 x** from aphelion to perihelion

At high altitude, solar cycle effects become important; seasonal change: **4 x**
solar cycle change: **4 x**
➔ **16 x** change in density

Neutral Atmosphere Profiles (MTGCM)

[*Bougher et al.*, 1999, 2000]



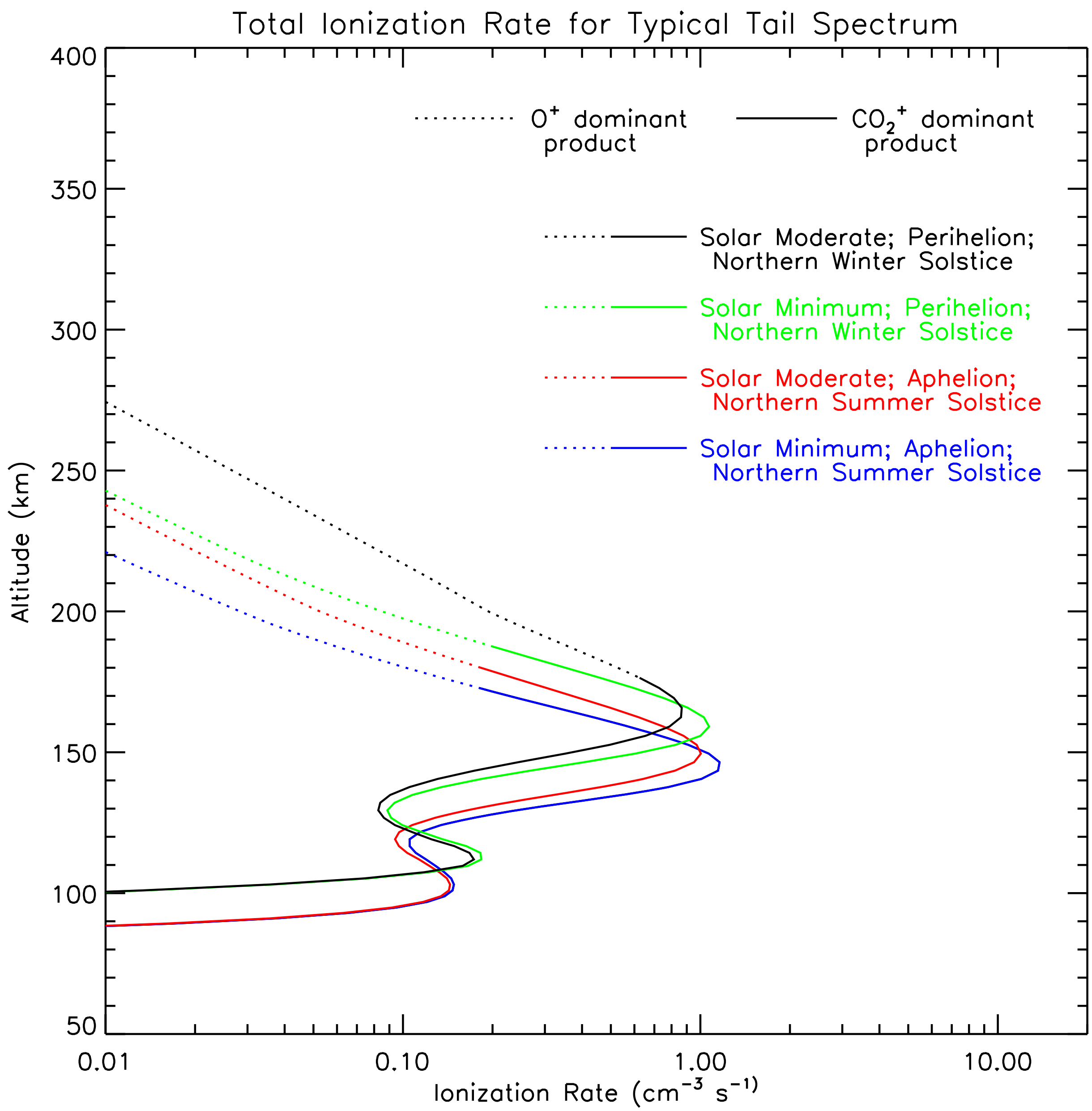
Above ~ 280 km (upper bound of model), assume isothermal atmosphere

At low altitude, season determines temperature

At high altitude, solar cycle effects become important; during solar moderate conditions, no seasonal variation in temperature

In the absence of electron temperature data, **the electron temperature is assumed to be equal to the neutral temperature**

Ionization Rate (Typical Tail Spectrum)

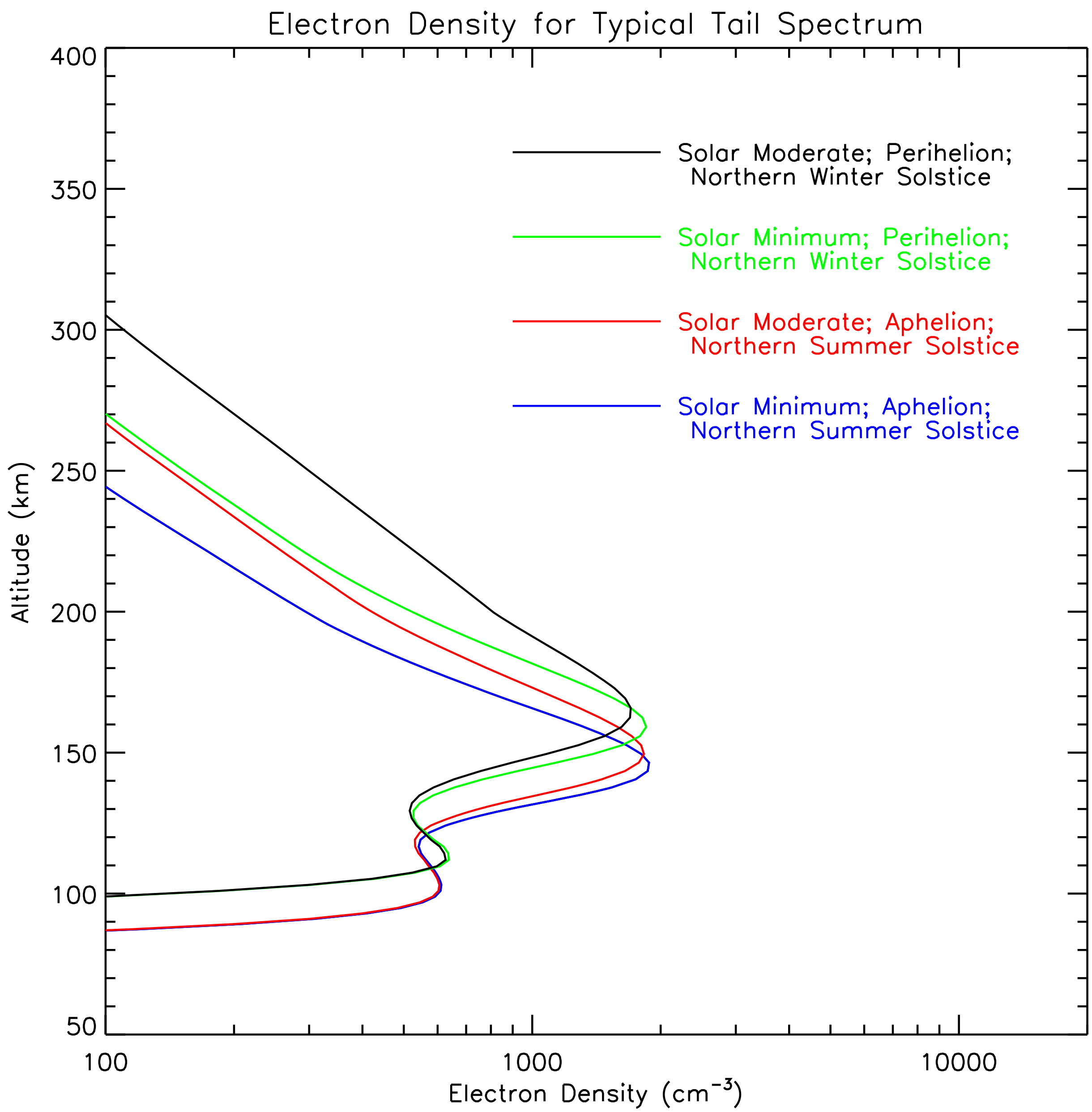


Peak ionization rate at **higher altitude** during **perihelion**
➔ **season** controls **altitude** of peak

Peak ionization rate has **larger magnitude** during **solar minimum**
➔ **solar cycle** controls **magnitude** of peak

Region of ionization **thicker** during **solar moderate** conditions
➔ **solar cycle** controls **thickness** of layer

Electron Density (Typical Tail Spectrum)



Maximum electron density at **higher altitude** during **perihelion**
➔ **season** controls **altitude** of peak

Maximum electron density (slightly) **larger** during **solar minimum**
➔ **solar cycle** controls **magnitude** of peak

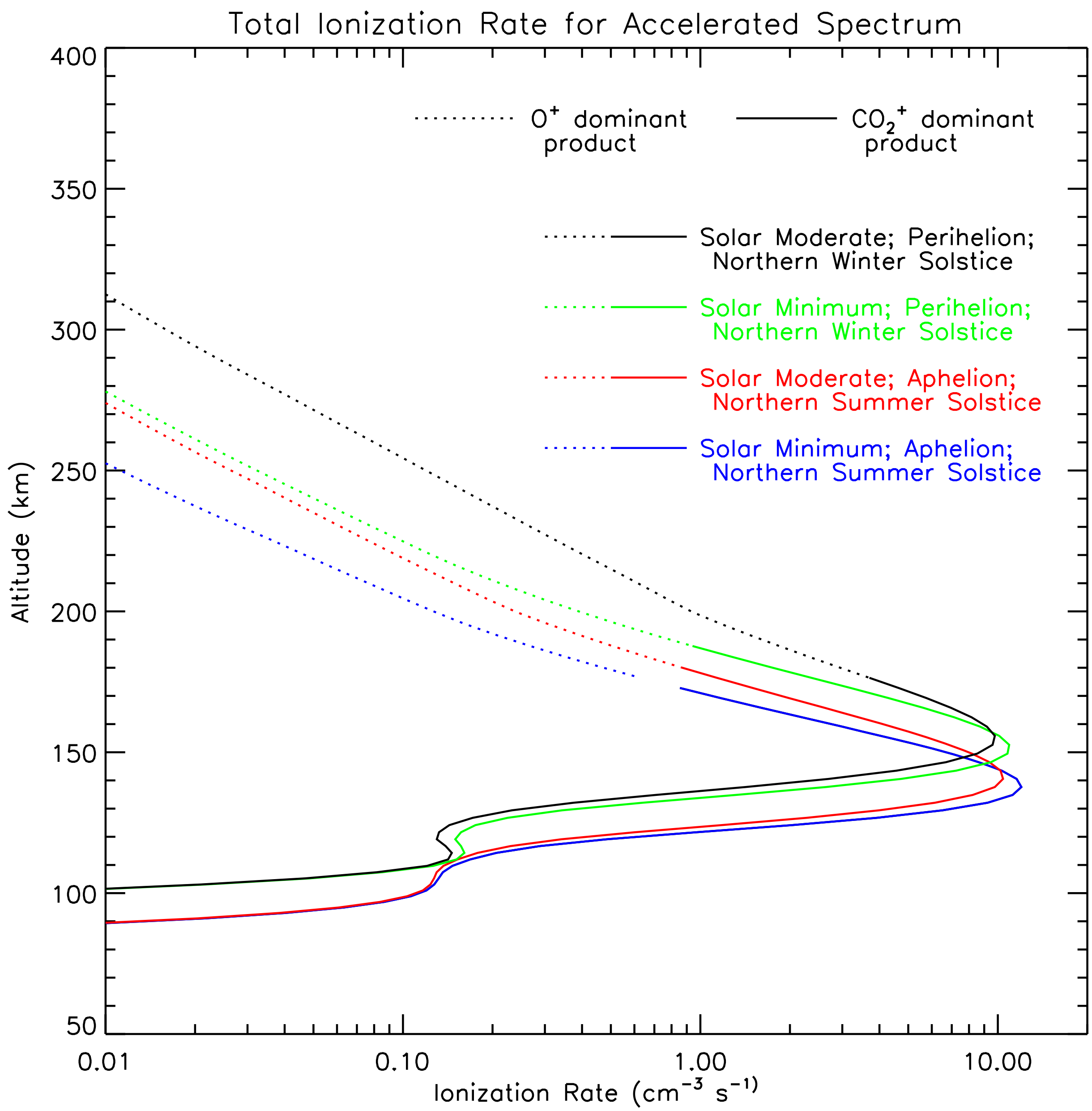
Ionosphere **thicker** during **solar moderate** conditions
➔ **solar cycle** controls **thickness** of layer

Thicker layer = **larger TEC**

Comparison of Atmospheric Models (Typical Tail Spectrum)

Atmospheric model	Maximum ionization rate (P^{max}) [cm^{-3} s^{-1}]	Maximum electron density (n_e^{max}) [cm^{-3}]	Altitude of n_e^{max} [km]	Total Electron Content (TEC) [10^{14} m^{-2}]
Solar moderate; perihelion; northern winter	0.87	1700	166	1.35
Solar minimum; perihelion; northern winter	1.07	1850	159	1.15
Solar moderate; aphelion; northern summer	1.00	1830	149	1.20
Solar minimum; aphelion; northern summer	1.16	1880	146	1.07

Ionization Rate (Accelerated Spectrum)



Peak ionization rate at **higher altitude** during **perihelion**
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Peak ionization rate has **larger magnitude** during **solar minimum**
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Region of ionization **thicker** during **solar moderate** conditions
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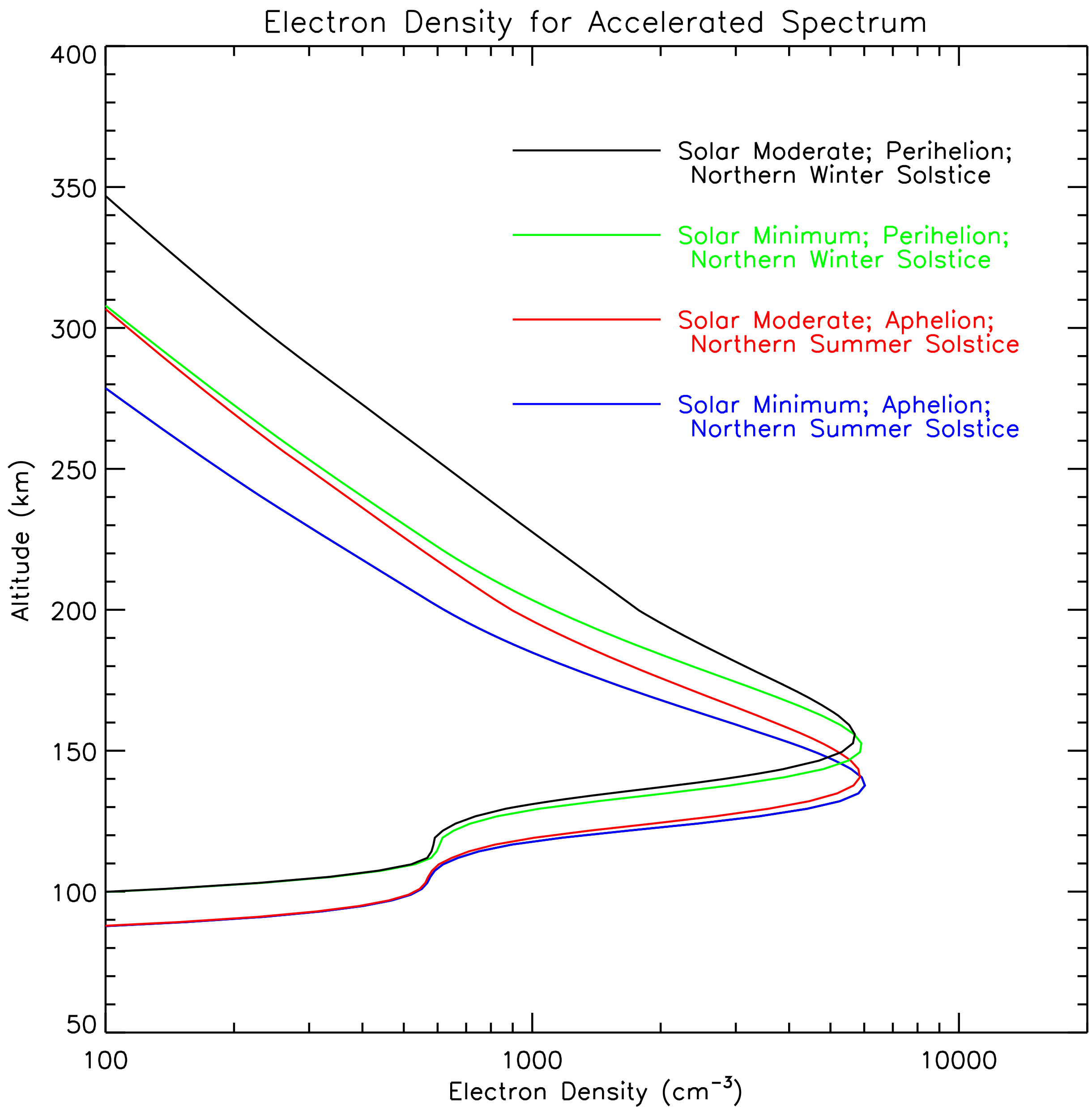
Electron Density (Accelerated Spectrum)



Maximum electron density at **higher altitude** during **perihelion**
➔ **season** controls **altitude** of peak

Maximum electron density (slightly) **larger** during **solar minimum**
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Ionosphere **thicker** during **solar moderate** conditions
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Thicker layer = **larger TEC**

Comparison of Atmospheric Models (Accelerated Spectrum)

Atmospheric model	Maximum ionization rate (P^{max}) [cm^{-3} s^{-1}]	Maximum electron density (n_e^{max}) [cm^{-3}]	Altitude of n_e^{max} [km]	Total Electron Content (TEC) [10^{14} m^{-2}]
Solar moderate; perihelion; northern winter	9.77	5700	156	3.47
Solar minimum; perihelion; northern winter	10.92	5900	153	2.95
Solar moderate; aphelion; northern summer	10.41	5860	140	3.06
Solar minimum; aphelion; northern summer	12.00	6020	138	2.72

Comparison of Atmospheric Models (Accelerated vs. Typical Tail Spectrum)

Atmospheric model	$\frac{n_e^{max} \text{ accelerated}}{n_e^{max} \text{ typical}}$	$\frac{\text{TEC accelerated}}{\text{TEC typical}}$	Δh n_e^{max} [km] typical – accelerated
Solar moderate; perihelion; northern winter	3.35	2.57	10
Solar minimum; perihelion; northern winter	3.19	2.55	6
Solar moderate; aphelion; northern summer	3.20	2.56	9
Solar minimum; aphelion; northern summer	3.20	2.54	8

Summary & Implications

- In all 4 cases, the accelerated spectrum increased $\mathbf{n_e^{max}}$ by a factor of ~ **3** and **TEC** by ~ **2.5** over that produced by the typical tail spectrum
- Since **cusps** are **localized** and have a **patchy** global distribution, regions of **enhanced** $\mathbf{n_e}$ and **TEC** will be **localized** and **patchy**
- **Largest** $\mathbf{P^{max}}$ and $\mathbf{n_e^{max}}$ occur during **solar minimum** at **aphelion**
  ➔ atmosphere most rarefied and **coolest** (smallest scale height)
  thinnest ionospheric layer and **smallest TEC**
- **Smallest** $\mathbf{P^{max}}$ and $\mathbf{n_e^{max}}$ occur during **solar moderate** at **perihelion**
  ➔ atmosphere densest and **warmest** (largest scale height)
  thickest ionospheric layer and **largest TEC**
- Between these **two extremes**, $\mathbf{P^{max}}$ changes by ~ **30%**
  $\mathbf{n_e^{max}}$ changes by ~ **10%**
  TEC changes by ~ **25%**

➔ **Variations in the upper atmospheric scale height (i.e., temperature) over different seasonal and solar cycle conditions play a prominent role in determining variations in the ionospheric profiles**

Summary & Implications (continued)

- **Seasonal** (orbital) variations control the **altitude** of P^{max} and n_e^{max}
  Altitude of P^{max} and n_e^{max} **increases** by **10%** from **aphelion** to **perihelion**
  (No signficant difference between solar minimum and solar moderate)
- **Solar cycle** variations control the **magnitude** of P^{max} and n_e^{max}
  P^{max} increases by **17%** from **solar moderate** to **solar minimum**
  (P^{max} increases by **10%** from perihelion to aphelion)
  n_e^{max} increases by **4.4%** from **solar moderate** to **solar minimum**
  (n_e^{max} increases by **3.5%** from perihelion to aphelion)
- **Solar cycle** variations control the **thickness** of the ionosphere and **TEC**
  TEC increases by **15%** from **solar minimum** to **solar moderate**
  (TEC increases by **10%** from aphelion to perihelion)
- Only consider solar minimum vs. solar moderate conditions here;
  solar cycle effects should be **more dramatic** during **solar maximum**
- At high altitude, **T_e** is probably **greater than** the **neutral temperature**;
  as **T_e** increases → **α_{eff}** decreases → **n_e** increases ($n_e \sim T_e^{0.35}$)
  ➔ we are probably **underestimating** n_e