Morphology of meteoric plasma layers in the ionosphere of Mars as observed by the Mars Global Surveyor Radio Science Experiment

Withers, Mendillo, Hinson and Cahoy
(withers@bu.edu)

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A Typical Mars Ionospheric Profile

Transport important above ~180 km

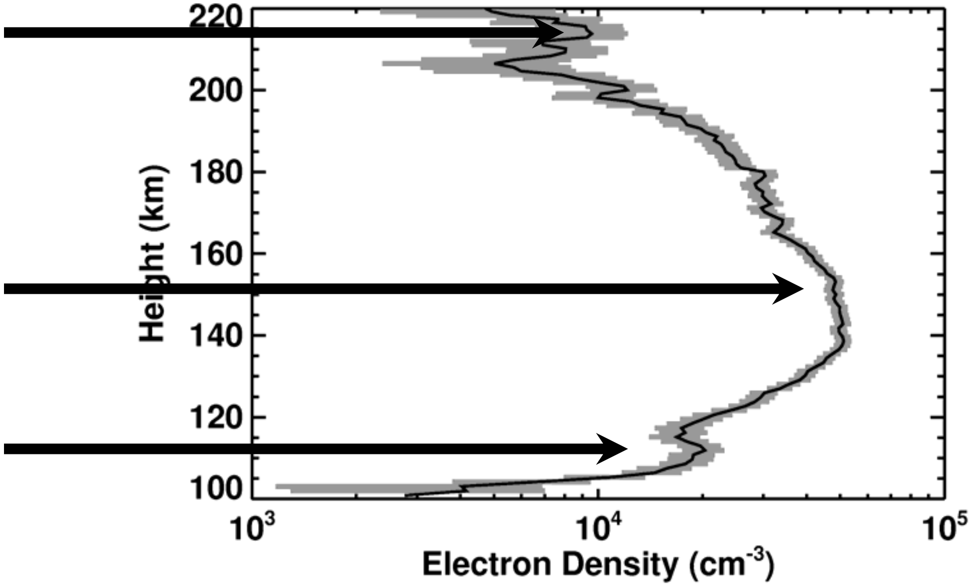
Main peak at 140 km due to EUV photons

Lower peak at 110 km due to X-rays. Each X-ray that is absorbed produces multiple ion-electron pairs

“secondary ionization”

- $CO_2 + h\nu \rightarrow CO_2^+ + e$
  - (production)
- $CO_2^+ + O \rightarrow O_2^+ + CO$
  - (chemistry)
- $O_2^+ + e \rightarrow O + O$
  - (loss)

MGS Radio Science data

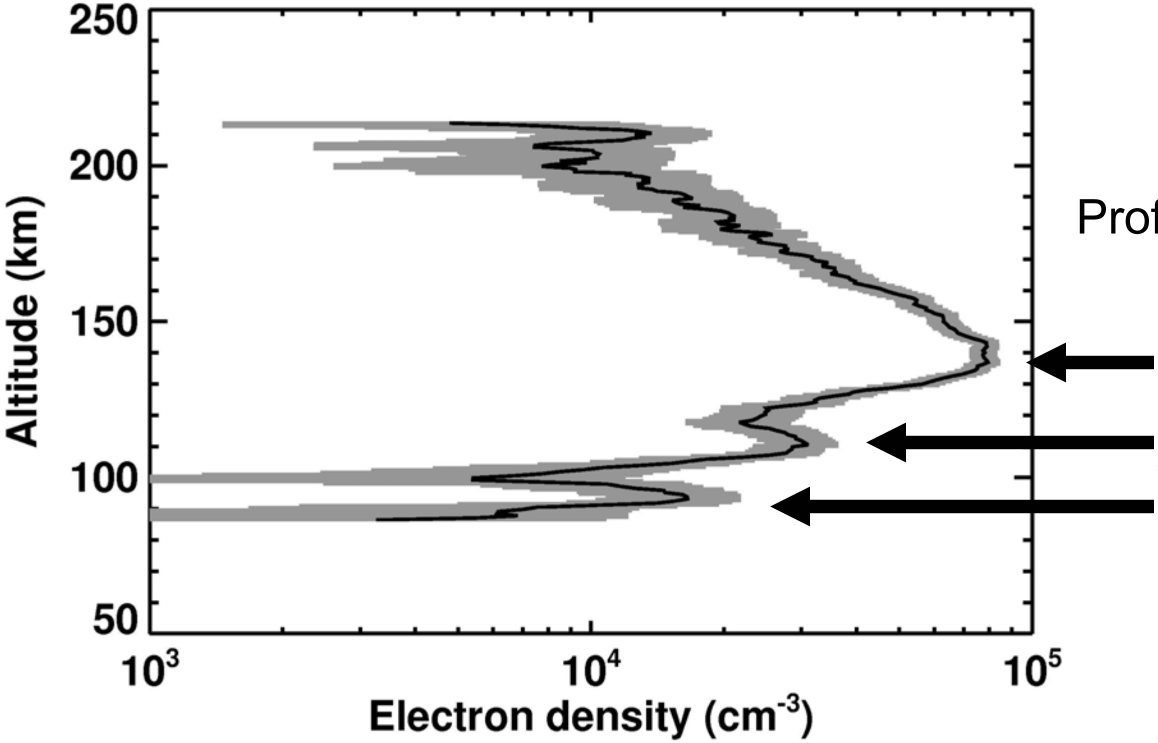


Profile 0337M41A

Main peak is consistent with Chapman theory

Lower layer is hard to model

Meteoric Plasma Layer



Profile 504K56A

EUV layer

X-ray layer

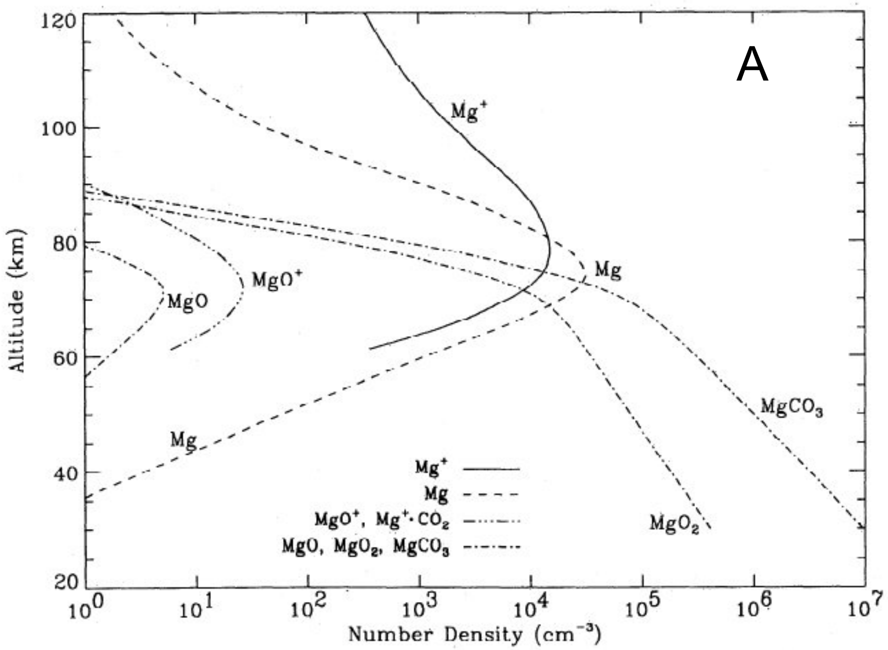
Meteoric layer

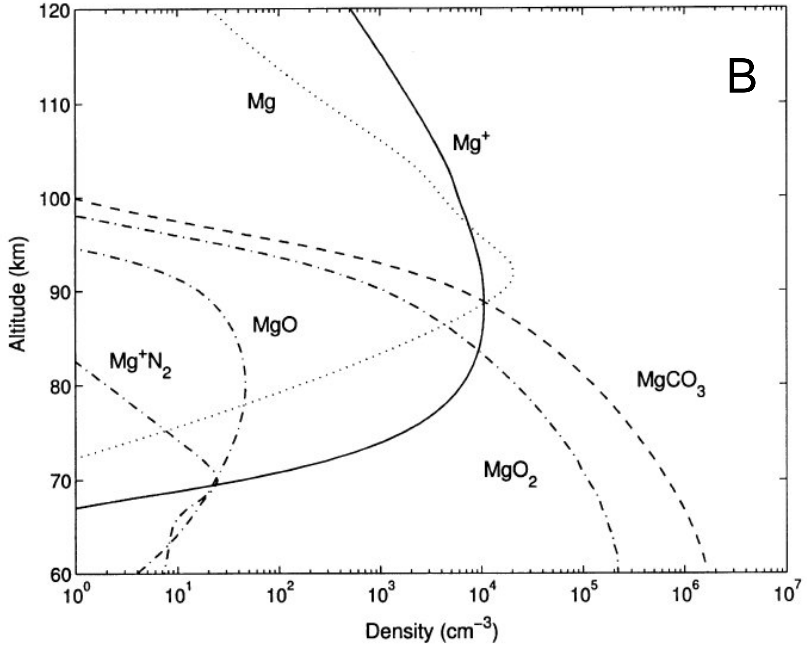
Layer at 90 km is not due to photoionization of CO_2.

Solar spectrum and CO_2 ionization cross-section will not lead to plasma layer.

Particle precipitation could, in theory, produce a layer like this – but no solar activity observed at this time

Theory

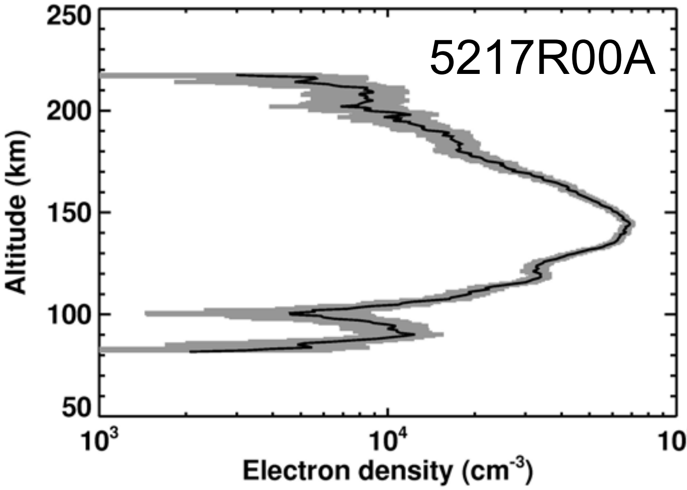


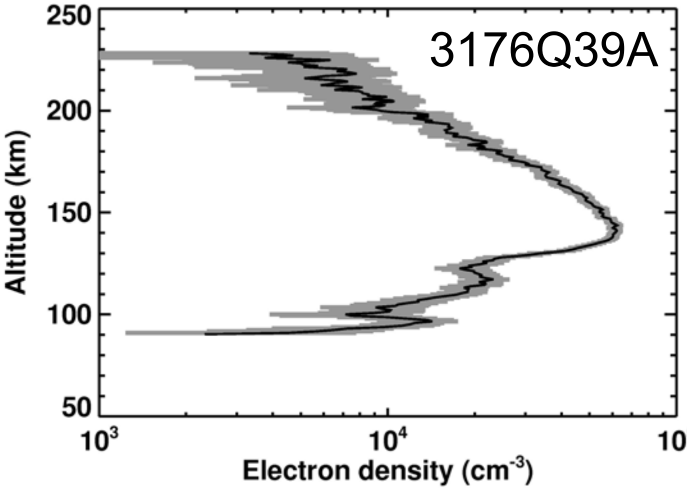


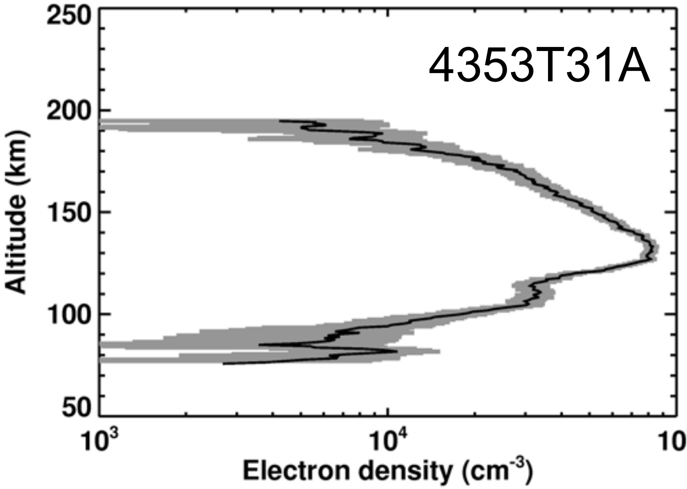
- Models have predicted plasma layers at 90 km due to meteoroid influx.

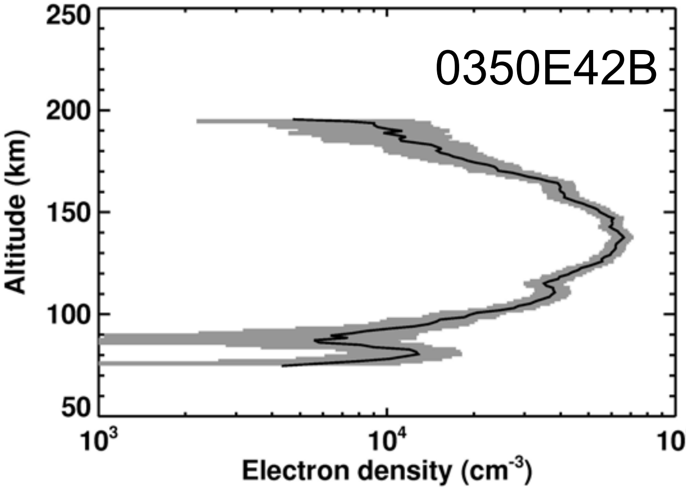
- A – Pesnell and Grebowsky (2000)
- B – Molina-Cuberos et al. (2003)

Additional Observations







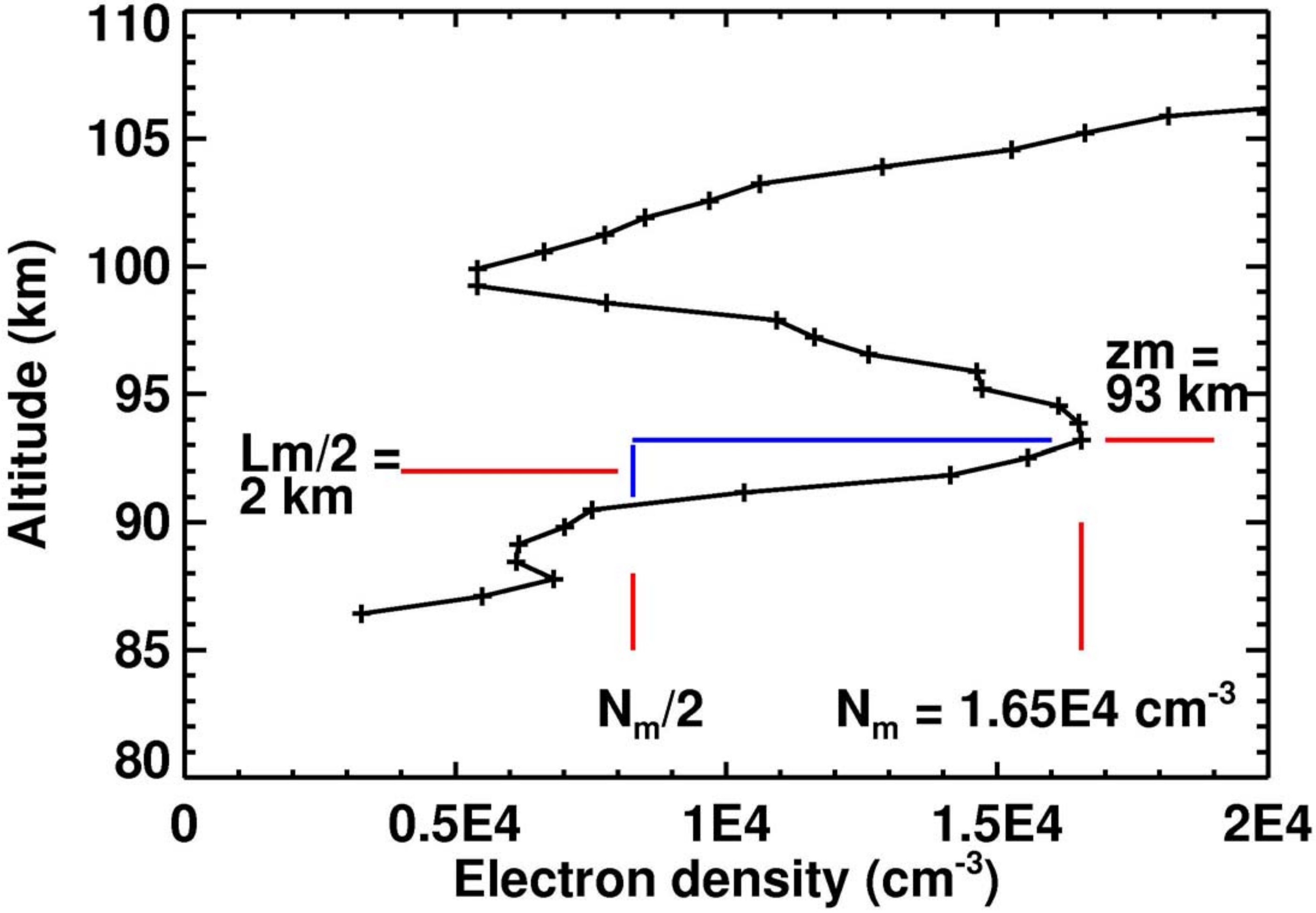


- 71 meteoric plasma layers in 5600 MGS profiles

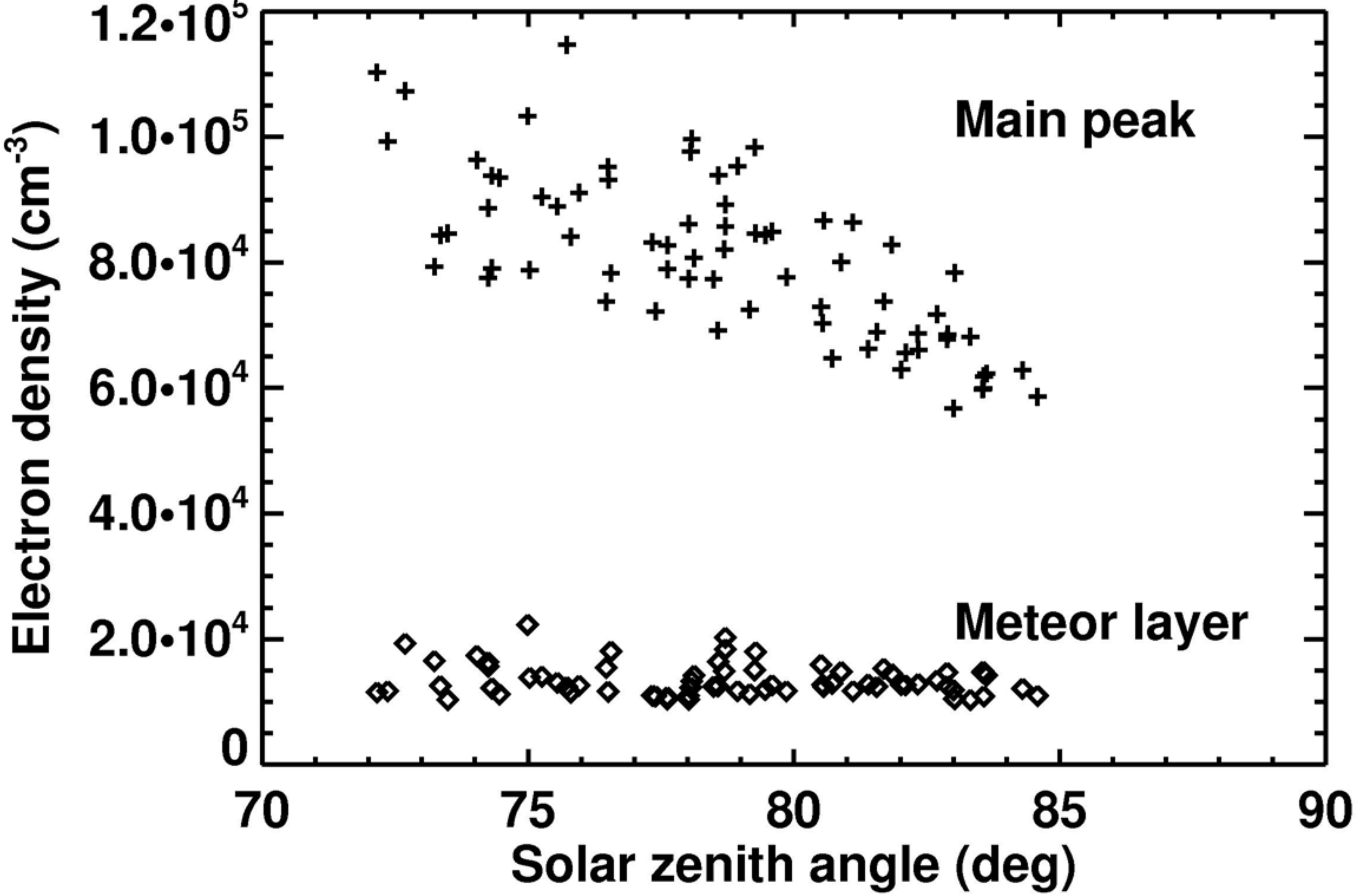
Characteristics of Meteoric Layers

z_m = height of layer (km)
N_m = electron density at z_m
L_m = full width at half maximum of layer

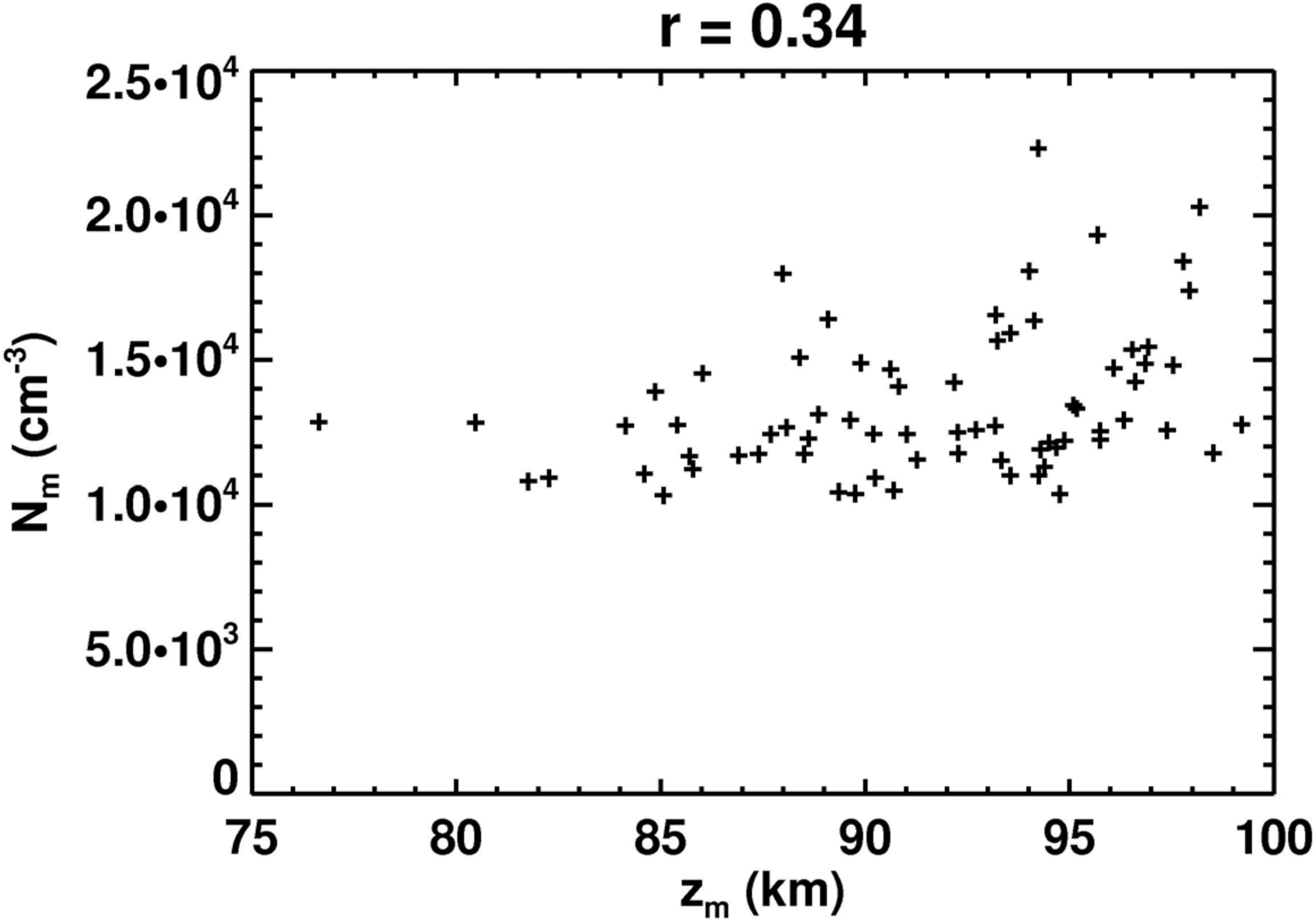
L_m found from $L_m/2$ measured below z_m because equivalent position above z_m is not always well-defined



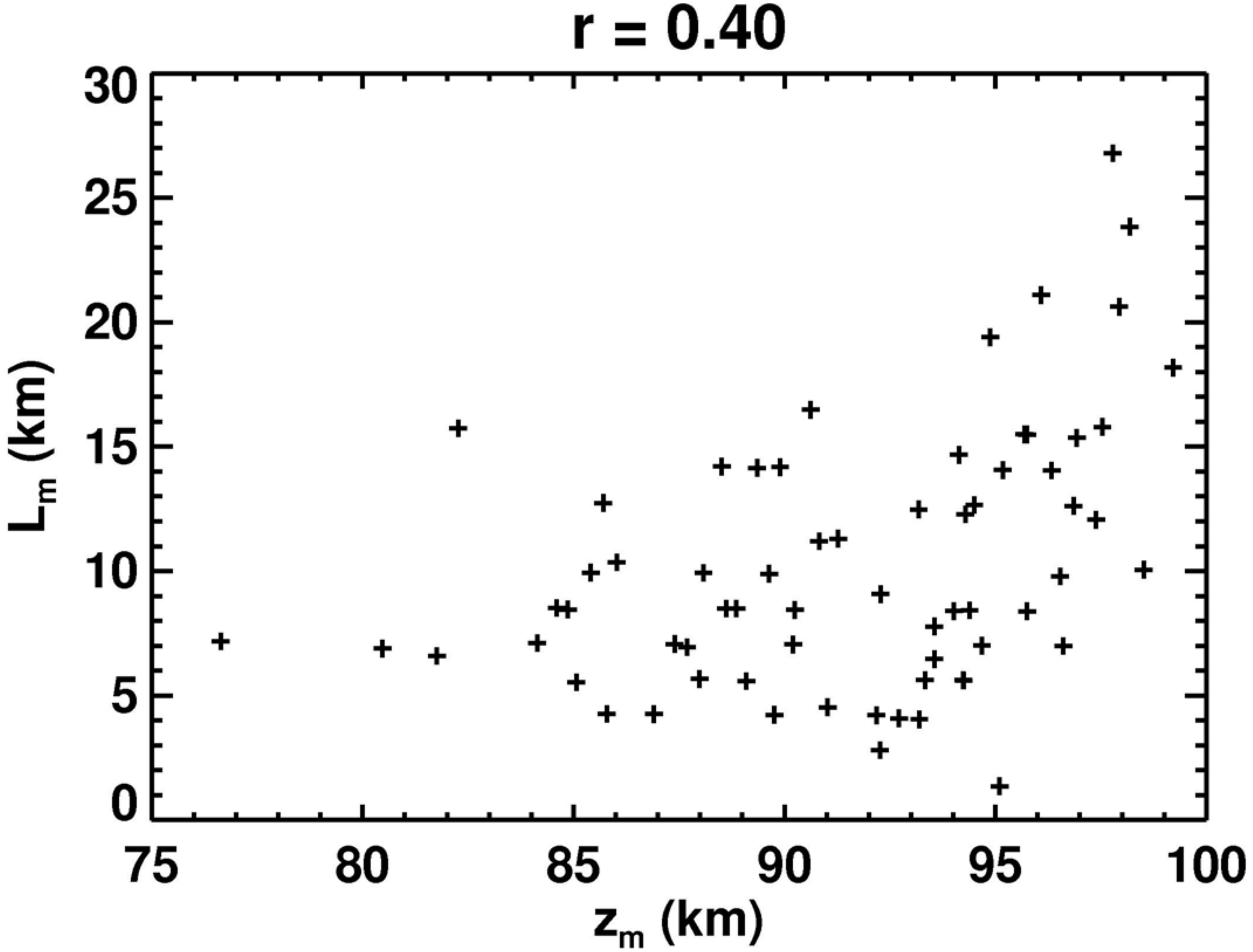
N_m is not controlled by solar zenith angle (SZA)



N_m and z_m are correlated

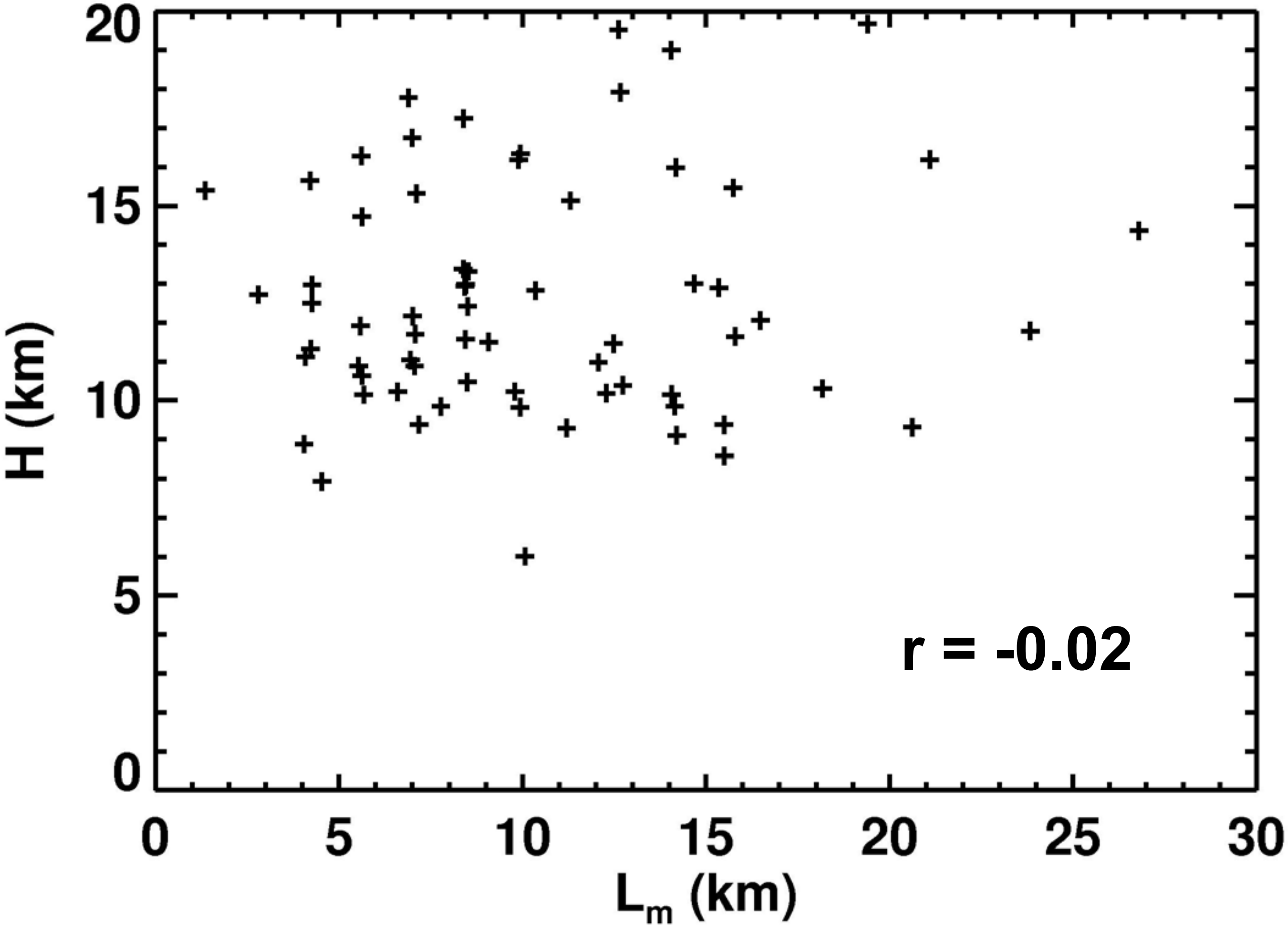


L_m and z_m are correlated



L_m is not controlled by H

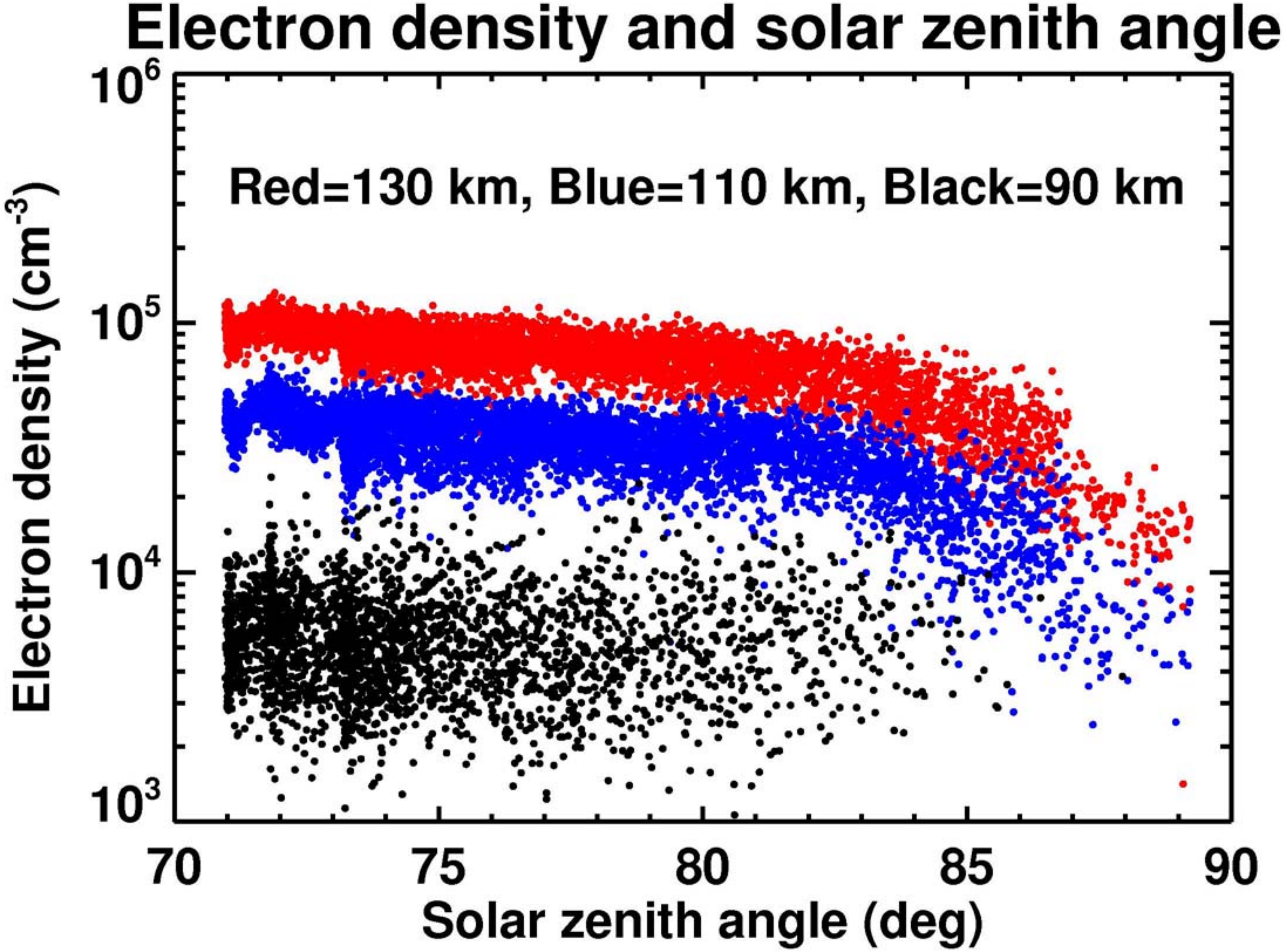
(neutral scale height H found by fitting shape of main peak)



Summary of analysis

- N_m does not show any dependence on solar zenith angle
- z_m and N_m are positively correlated
- z_m and L_m are positively correlated
- L_m does not behave as anticipated
  - L_m is not correlated with H
  - Values of L_m range from <2 km to >20 km
  - Almost 30% of values of L_m are more than 1σ away from the mean; only 10% of values of H are more than 1σ away from the mean

Electron density depends on solar zenith angle at 130 km and 110 km, but not at 90 km



Why no SZA control at 90 km?

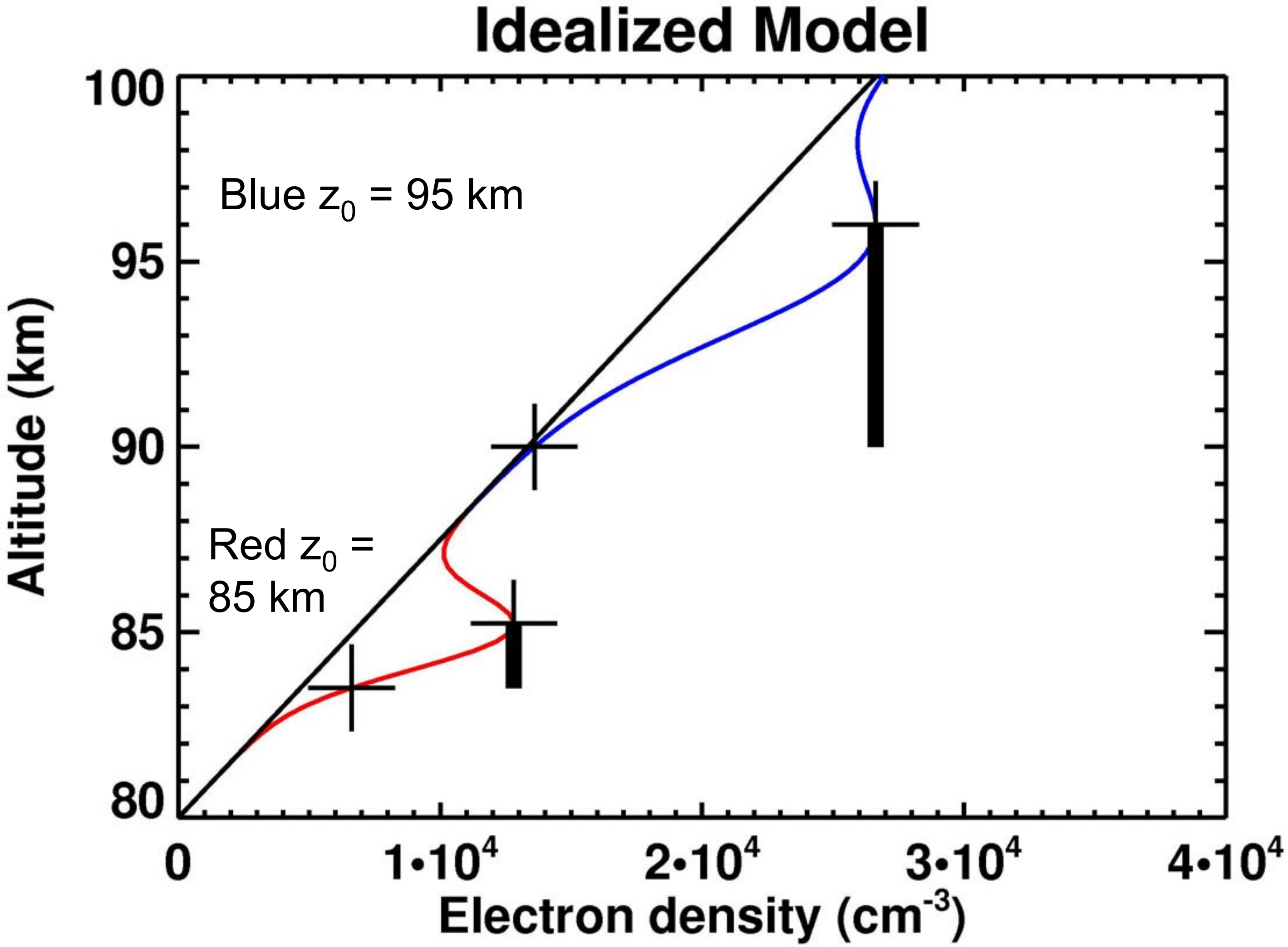
- Expect Chapman-like SZA dependence if solar irradiance is constant because ionosphere controlled by photochemical processes (not transport) at 90 km
- Ions produced by photoionization from photons with $\lambda < 5$ nm – soft X-rays
- Solar irradiance is so variable at these wavelengths that variability in irradiance overwhelms trends with SZA

Idealized Model

- Two components
  - Background ionosphere in absence of meteors, N decreases as altitude decreases
  - Meteoric effects, contributes a narrow layer of excess plasma whose altitude varies due to changes in meteoroid speed and neutral density levels
- Determine relationships between z_m, N_m, L_m and H for fixed N_{bgd} and variable altitude of meteoric layer
- Solar variability causes slope and magnitude of N_{bgd} to vary, which puts a lot of scatter in real data but does not destroy underlying trends
- Assume that changes in N_{bgd} due to SZA changes are overwhelmed by effects of solar variability

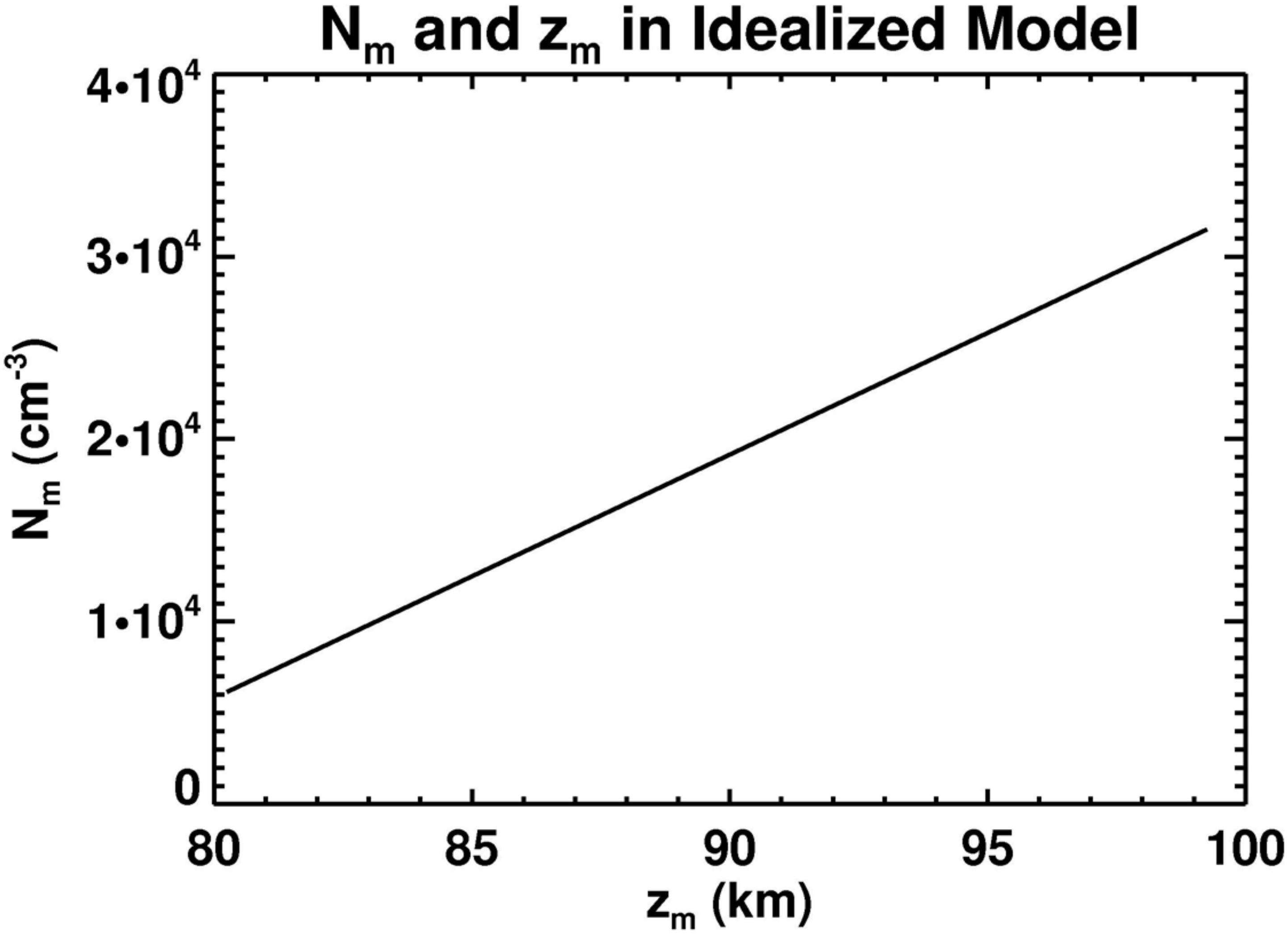
Idealized Model

- Background ionosphere $N_{bgd}(z)$ given by:
  - N_{bgd} varies linearly with z
  - $N_{bgd} = 0$ at $z=80$ km, $N_{bgd} = 4E4$ at 110 km
- Meteoric contribution $N_{met}(z)$ given by:
  - $N_{met}(z) = N_0 \exp(-x^2/2s^2)$
  - $x = z - z_0$, $s = 2$ km, z_0 varies
- Total electron density $N = N_{bgd} + N_{met}$

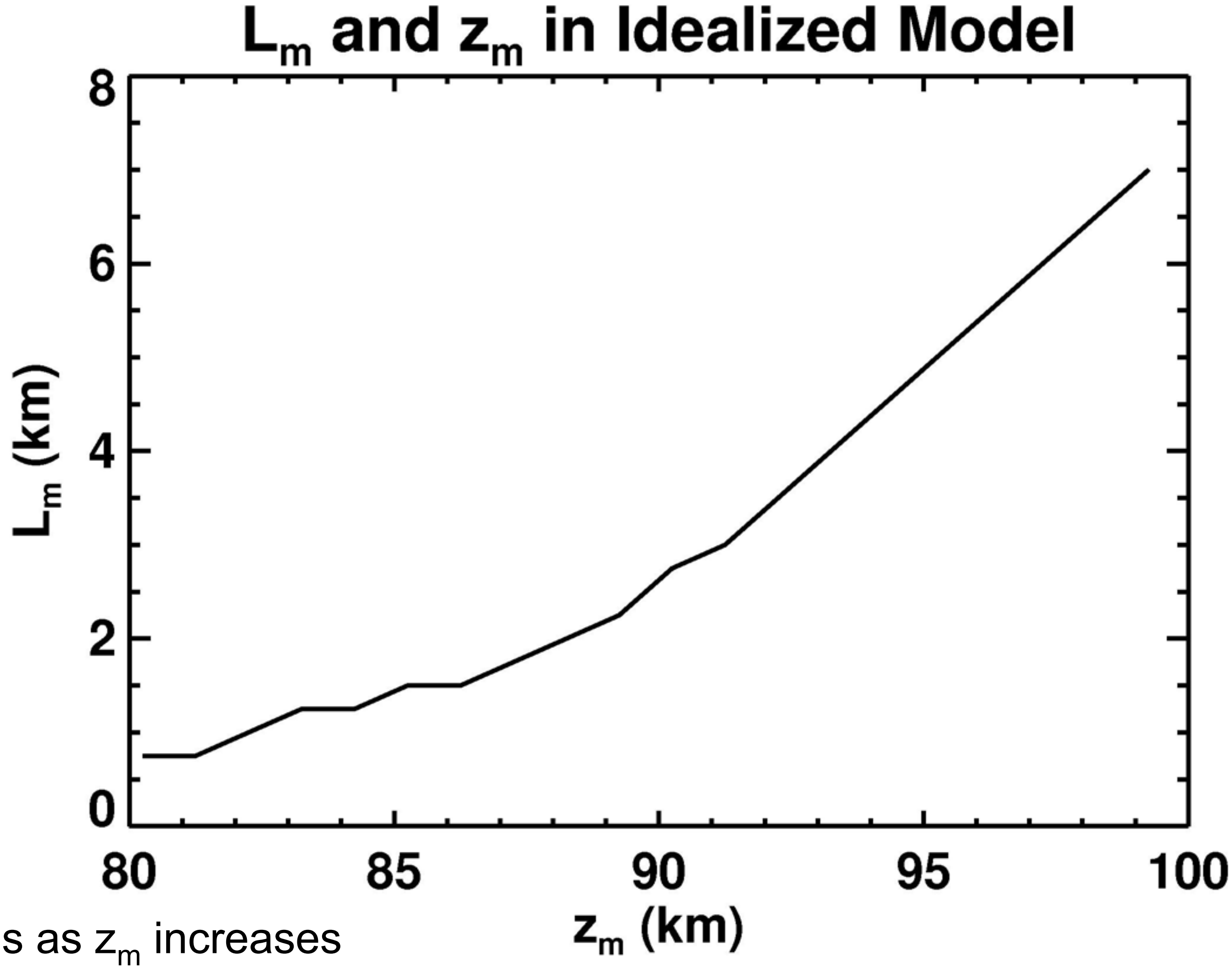


Crosses mark z_m and N_m for each meteoric layer <u>and</u> location where $N=N_m/2$
Thick vertical lines have length of $L_m/2$

Vary z_0 only, observe that N_m increases and L_m increases as z_m increases



L_m increases as z_m increases, as observed



L_m and z_m in Idealized Model

L_m increases as z_m increases

L_m has large range from 1 km to 7 km

L_m varies even though dNbgd/dz and width s of N_{met} are fixed, which explains why L_m does not appear to depend on H. Both dNbgd/dz and s may vary with H

Challenges for Theorists

- What typical values of z_m, N_m and L_m are predicted?
- What processes control z_m, N_m and L_m?
- Can sophisticated models of the ionospheric effects of meteoroids explain these observations?
- What are the main production and loss processes for meteoric ions?
- What is the lifetime of a meteoric ion?
- Do transport processes affect meteoric ion densities?

Conclusions from Observations

- Many meteoric layers are observed in MGS ionospheric profiles
  - z_m = 91 km (5 km std. dev.)
  - $N_{m,}$= 1.3E4 cm^{-3} (0.3E4 cm^{-3} std. dev.)
  - L_m = 10 km (5 km std. dev.)
- L_m and N_m increase as z_m increases
- None of z_m, N_m and L_m depend on SZA, which is consistent with high solar variability at the relevant wavelengths

Conclusions from Model

- Observations are qualitatively consistent with a very simple model
- Model requires SZA effects to be overwhelmed by solar variability
- Meteoric layer characteristics in model vary due only to altitude of meteor ablation varying
  - Speed of incident meteors vary
  - Altitude of critical pressure level varies
- Model inputs could be refined and tuned to quantitatively reproduce observations

Predictions

- z_m will vary with season and latitude due to dependence of meteoric layer on altitude of ablation
- L_m will depend very little on H
- Consideration of solar variability will be essential for interpreting observations and for comparing observations to model
- Development of models that can reproduce the typical observations <u>and</u> variability will be challenging