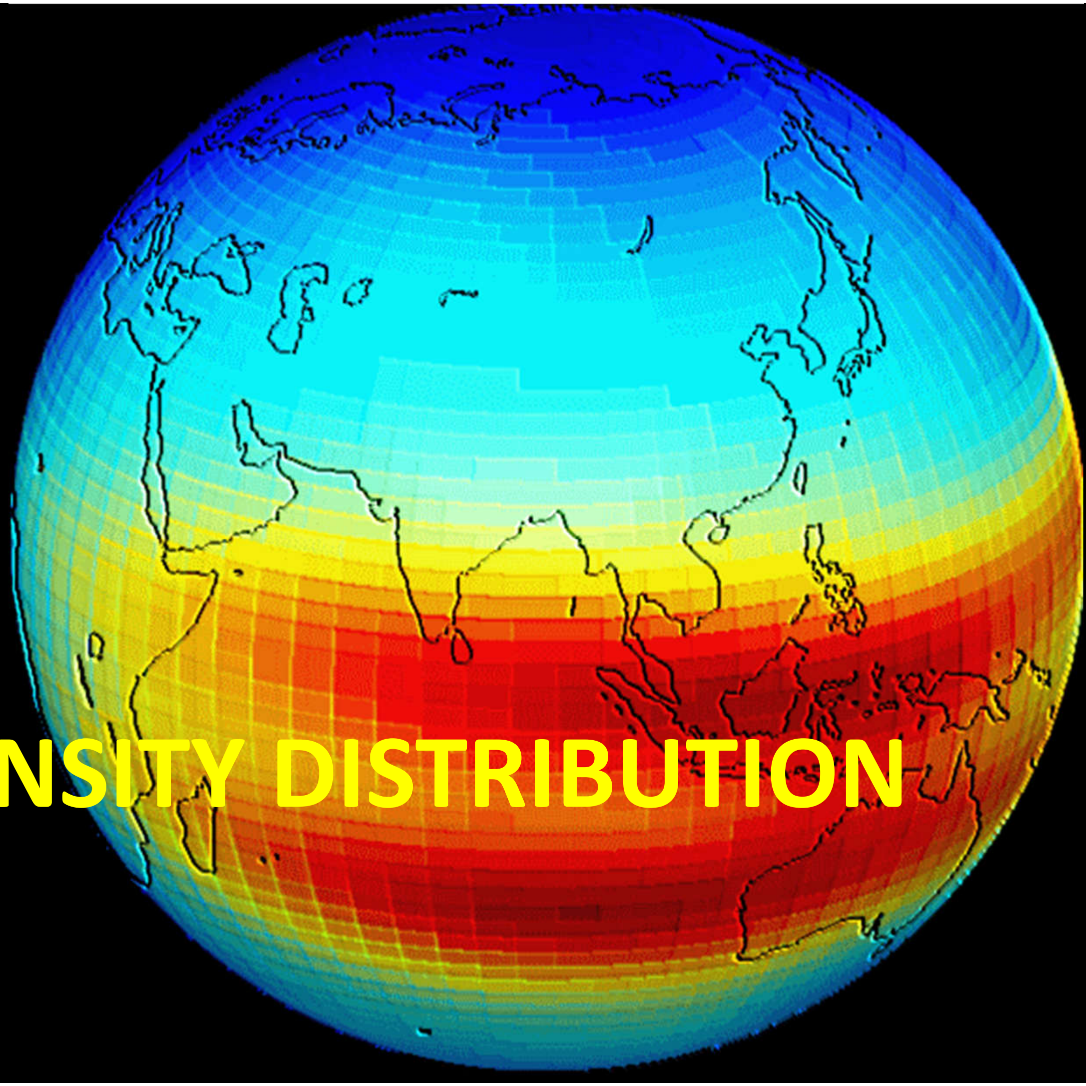
ELECTRON DENSITY DISTRIBUTION



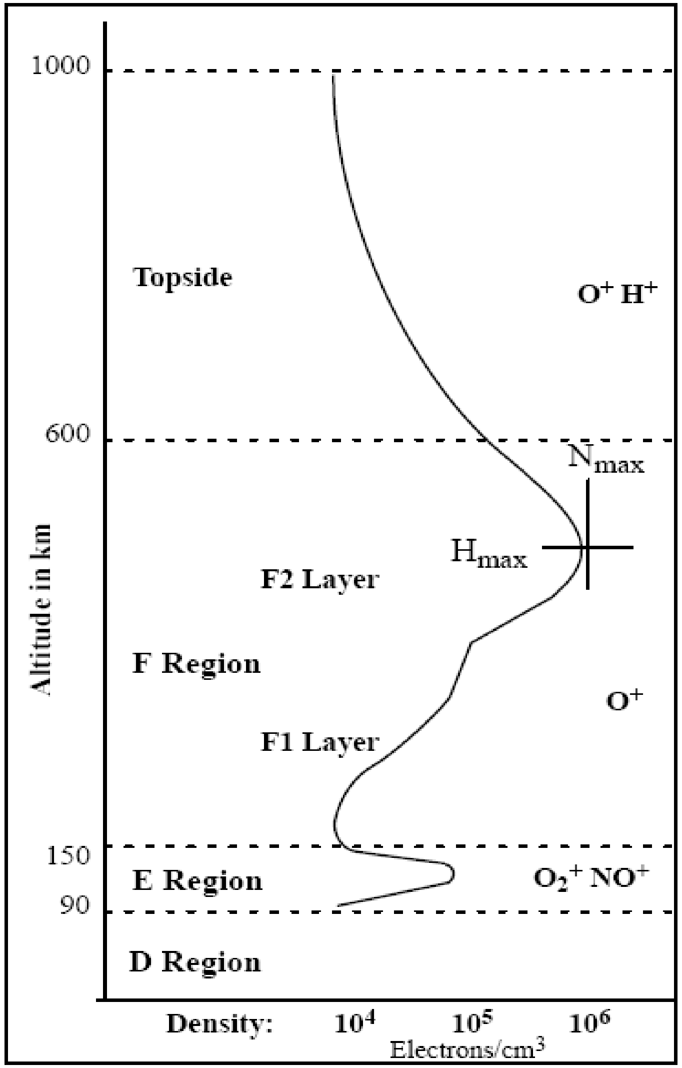
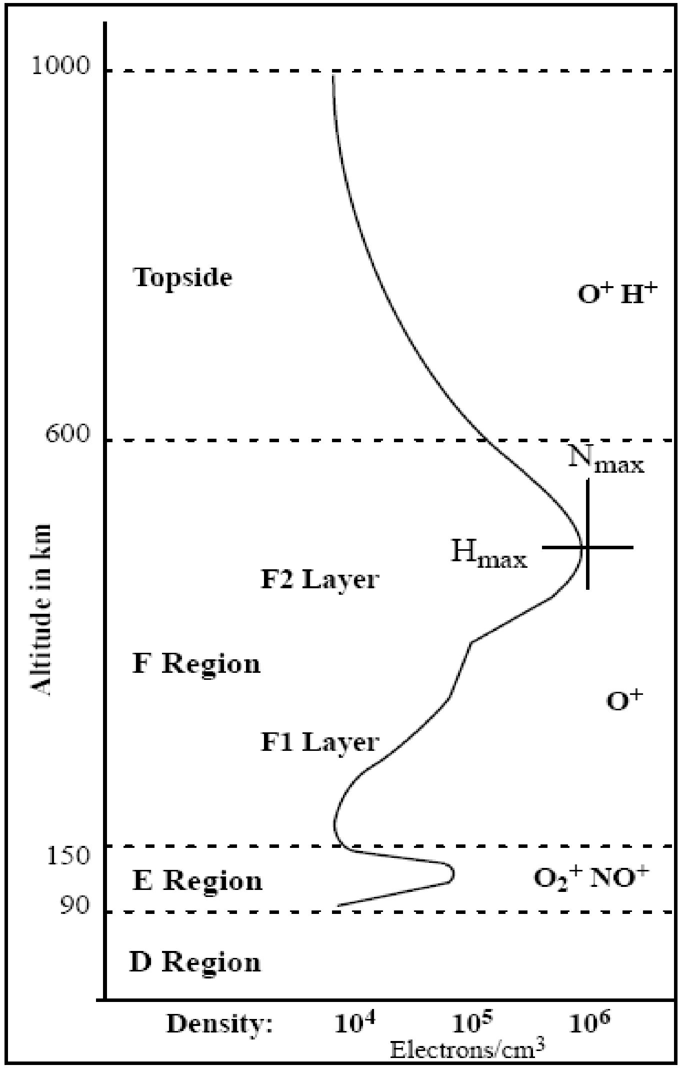


Image: NOAA

Electron density layers

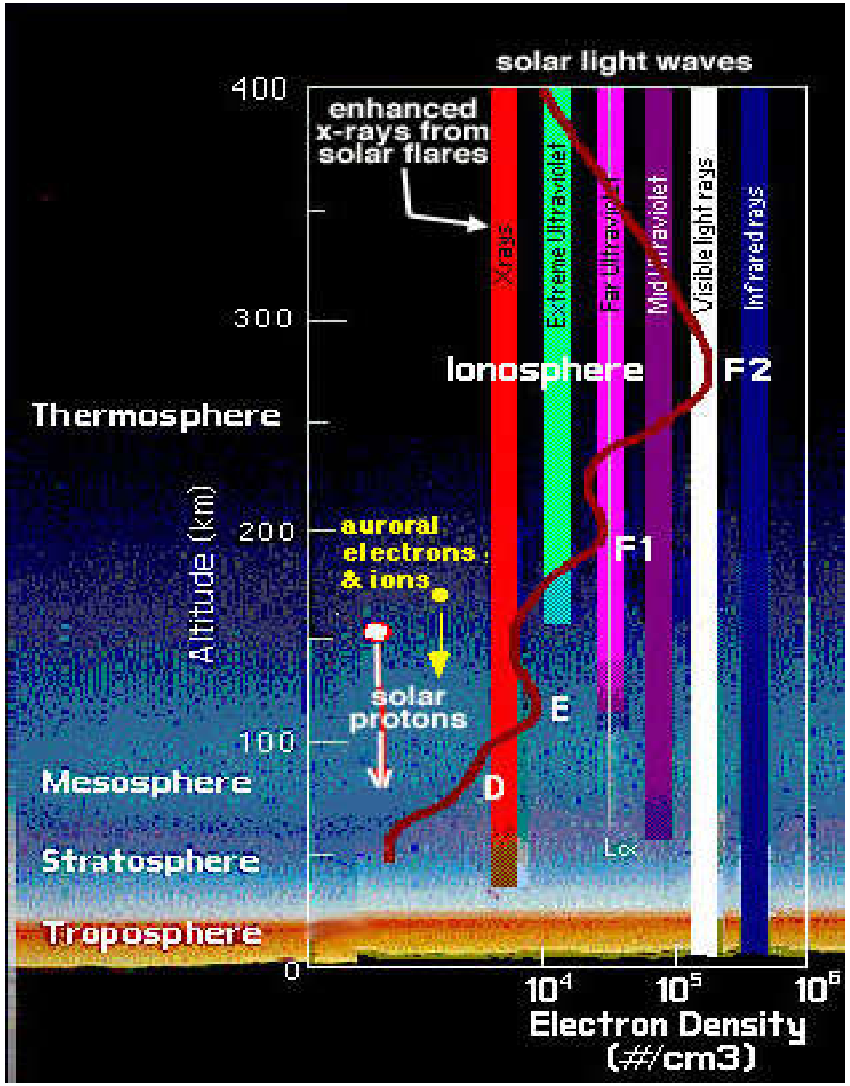
<u>Different Regions of the Ionosphere</u>

- **F** (forms F1 and F2 layers during the day, ionized by EUV 20-80 nm)
- **E** (100 - 120 kms, ionized by EUV 80-103 nm and X-rays 1-20 nm)
- **D** (70 - 90 kms, ionized by X-rays 0.1-1 nm)



1000
600
150
90
Altitude in km
Topside
O+ H+
Nmax
Hmax
F2 Layer
F Region
O+
F1 Layer
E Region
O2+ NO+
D Region
Density:
10^4
10^5
10^6
Electrons/cm3

Image: NOAA



solar light waves
400
300
200
100
0
enhanced x-rays from solar flares
Xrays
Extreme Ultraviolet
Visible light rays
Infrared rays
Ionosphere
F2
Thermosphere
Altitude (km)
auroral electrons & ions
F1
solar protons
E
Mesosphere
D
Stratosphere
Troposphere
10^4
10^5
10^6
Electron Density (#/cm3)

Continuity Equation

Electron density

Continuity equation for ionoized species

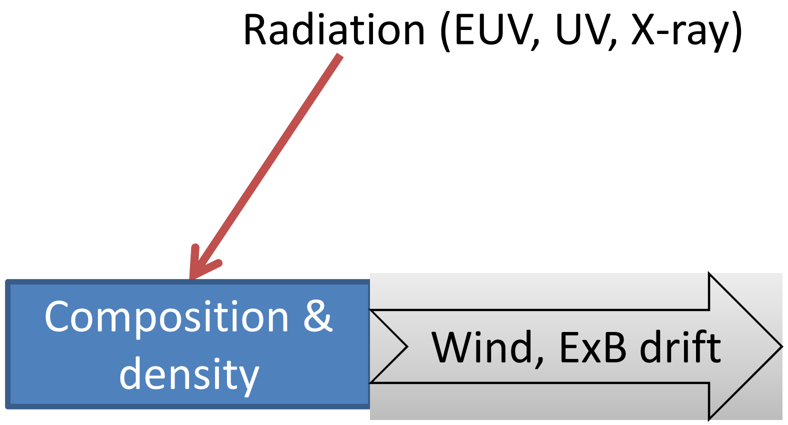
$$\frac{\partial n_j}{\partial t} = (P_j - L_j)M_j - \nabla \cdot (\rho_j V_j)$$

n_j: Density of ionised gas species j

M_j: Mass of j

P_j: Production of j

L_j: Loss von j



Ionisation/ Production

- Primary Photoionisation
- Secondary ionisation
- Particle precipitation

Primary Photoionisation

Simple Photoionisation

$$\mathrm{X} + \mathrm{Photon}(\lambda \lesssim 100\ nm) \rightarrow X^{+} + e$$

$$O + Photon(\lambda \leq 91nm) \rightarrow O^{+} + e$$
$$N_2 + Photon(\lambda \leq 80nm) \rightarrow N_2^{+} + e$$
$$O_2 + Photon(\lambda \leq 103nm) \rightarrow O_2^{+} + e$$

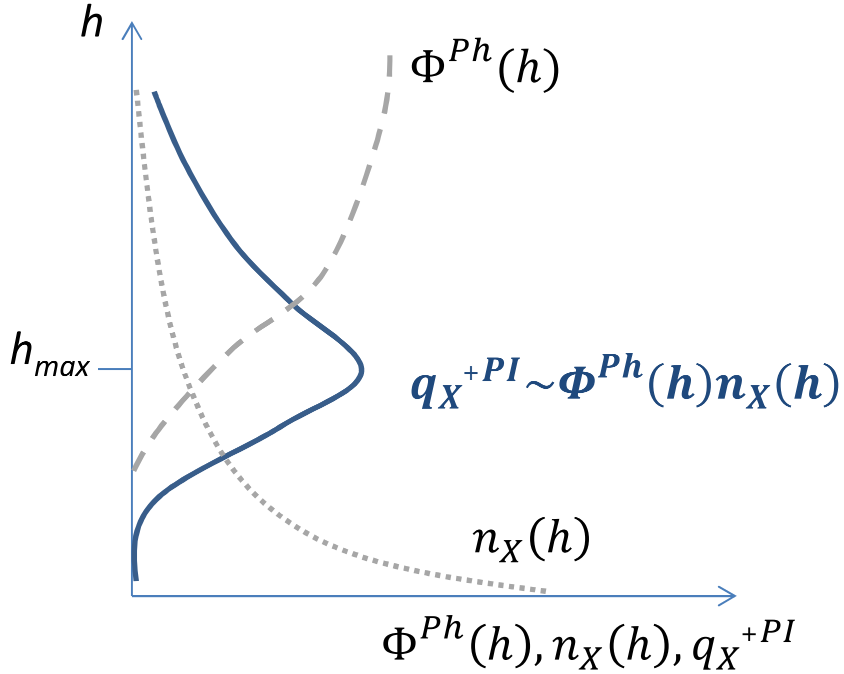
- Primary source of ionisation

Primary Photoionisation

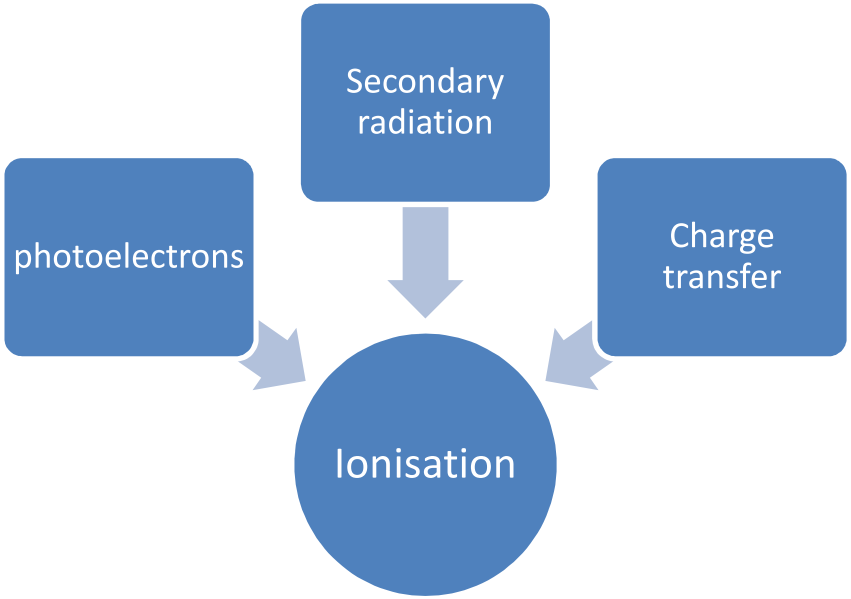
Ionization rate = (radiation intensity)x(ionisation cross section)x(density)

$$q_X{}^{+PI} = \Phi^{Ph} \sigma^I{}_X n_X$$

Development of ionisation production layers



Secondary ionisation



Charge transfer

- $X + Y^{+} \xrightarrow{k_{X,Y^{+}}} X^{+} + Y$
- $k_{X^{+}}$ reaction constant

- Same ion density
- Production of important ions like ${O_2}^{+}$ in the lower ionosphere and H^{+} in the plasmasphere

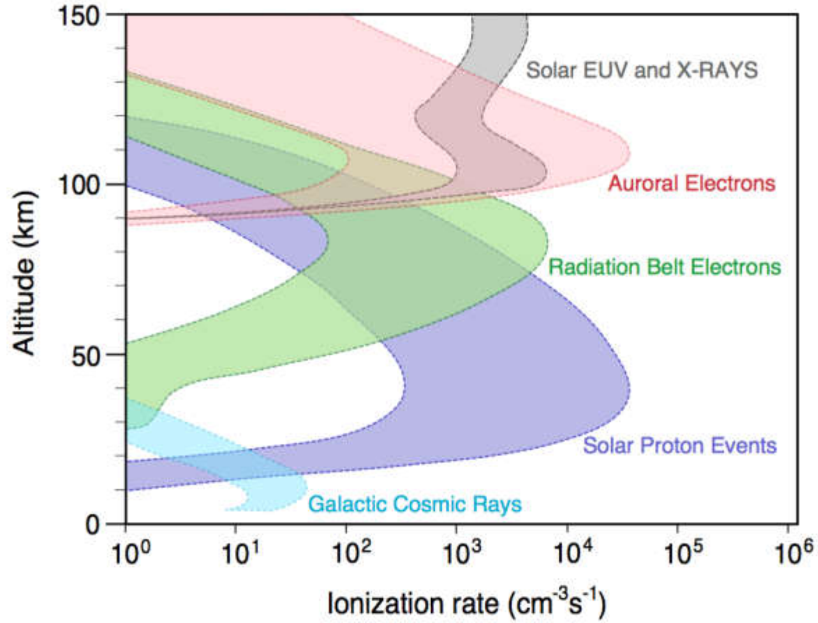
Particle Precipitation

- $X + e_p \rightarrow X^+ + e_p + e_s$
- e_p: primary electron is the precipitating electron
- e_s: secondary electron is the newly produced electron

Important process in high latitudes

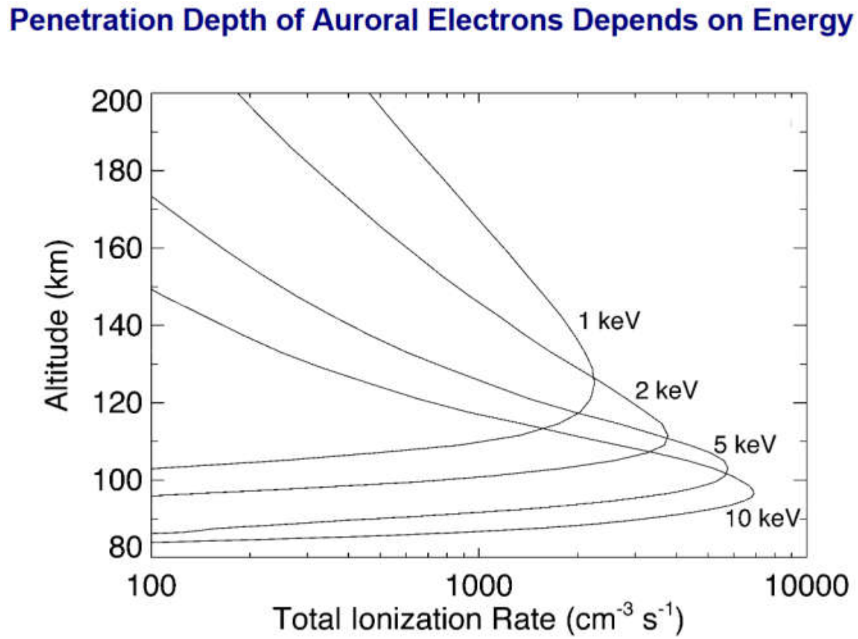
- One precipitating electron has the potential to initiate numerous primary ionisation processes
- Often secondary electrons have enough energy to initiate ionisation
- Higher order electrons (tertiary etc.) also have enough energy for ionisation

Particle Precipitation



A. Kero (2020)

Particle precipitation



Source: Solomon

Chemical recombination/ transfer processes

Dissociative recombination of molecular ions	• $XY^+ + e \xrightarrow{k_{XY^+}} X^{(*)} + Y^{(*)}$
Radiative recombination of atomic ions	• $X^+ + e \xrightarrow{k_{X^+}} X^{(*)} + h\nu$
Charge exchange	• $X^+ + Y \xrightarrow{k_{X^+Y}} X^{(*)} + Y^+$
Charge exchange (Ion-atom interaction)	• $X^+ + YZ \xrightarrow{k_{X^+YZ}} XY^+ + Z$

k_{X^+} recombination constant

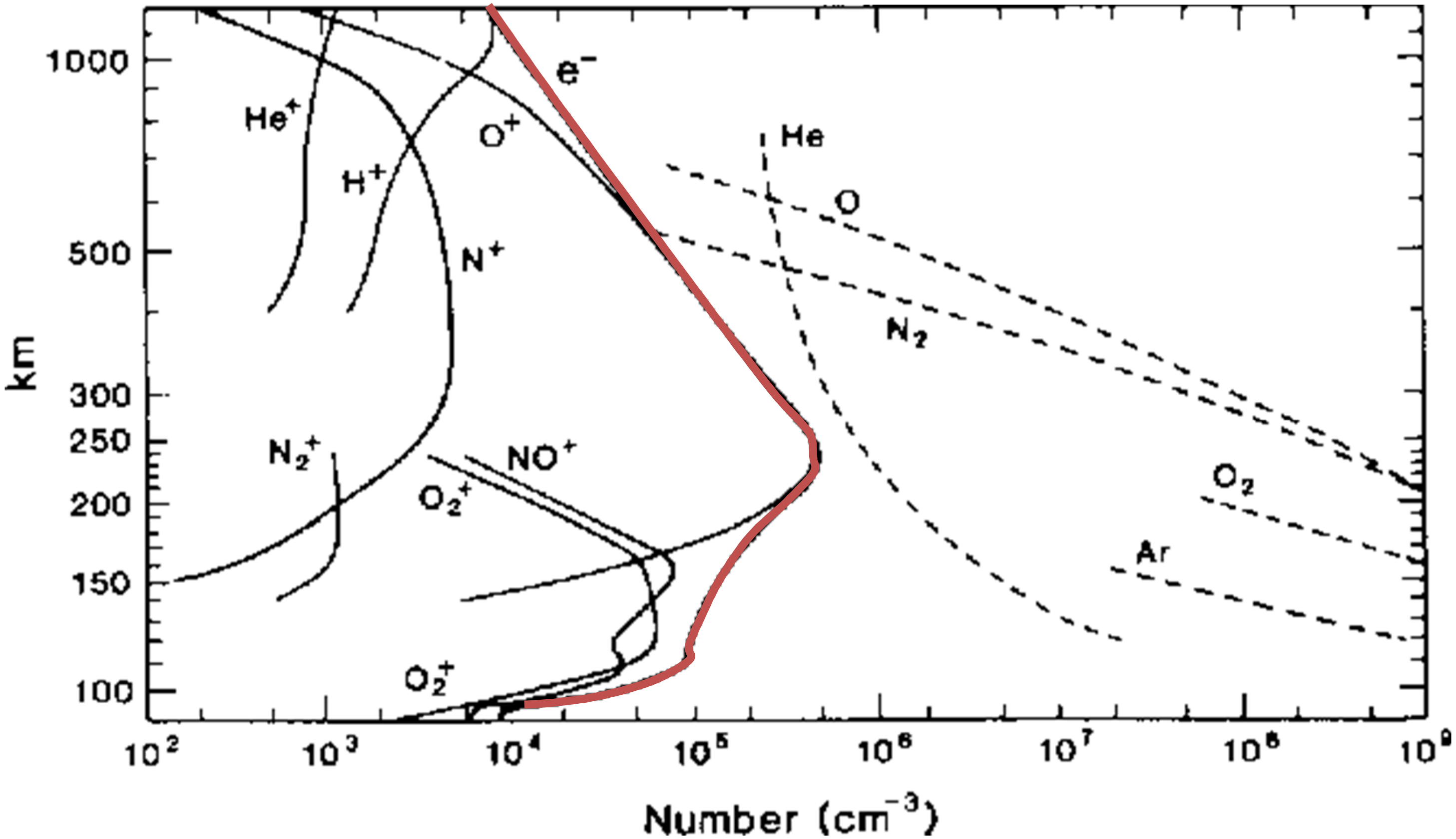
* indicates excited state

(Sheehan & Maurice, 2004, https://doi.org/10.1029/2003JA010132)

Height dependence of loss

E-region	F-region
• $NO^+, O_2{}^+$ are dominating molecular ions • Fastest loss through dissiciative recombination • $L(h) \cong \alpha n^2(h)$ Loss increases like squared increase electron density	• O^+ are dominating molecular ions • Loss mainly trough charge transfer • $L(h) \cong \beta(h)n\,(h)$ Loss coefficient β has most impact on the loss

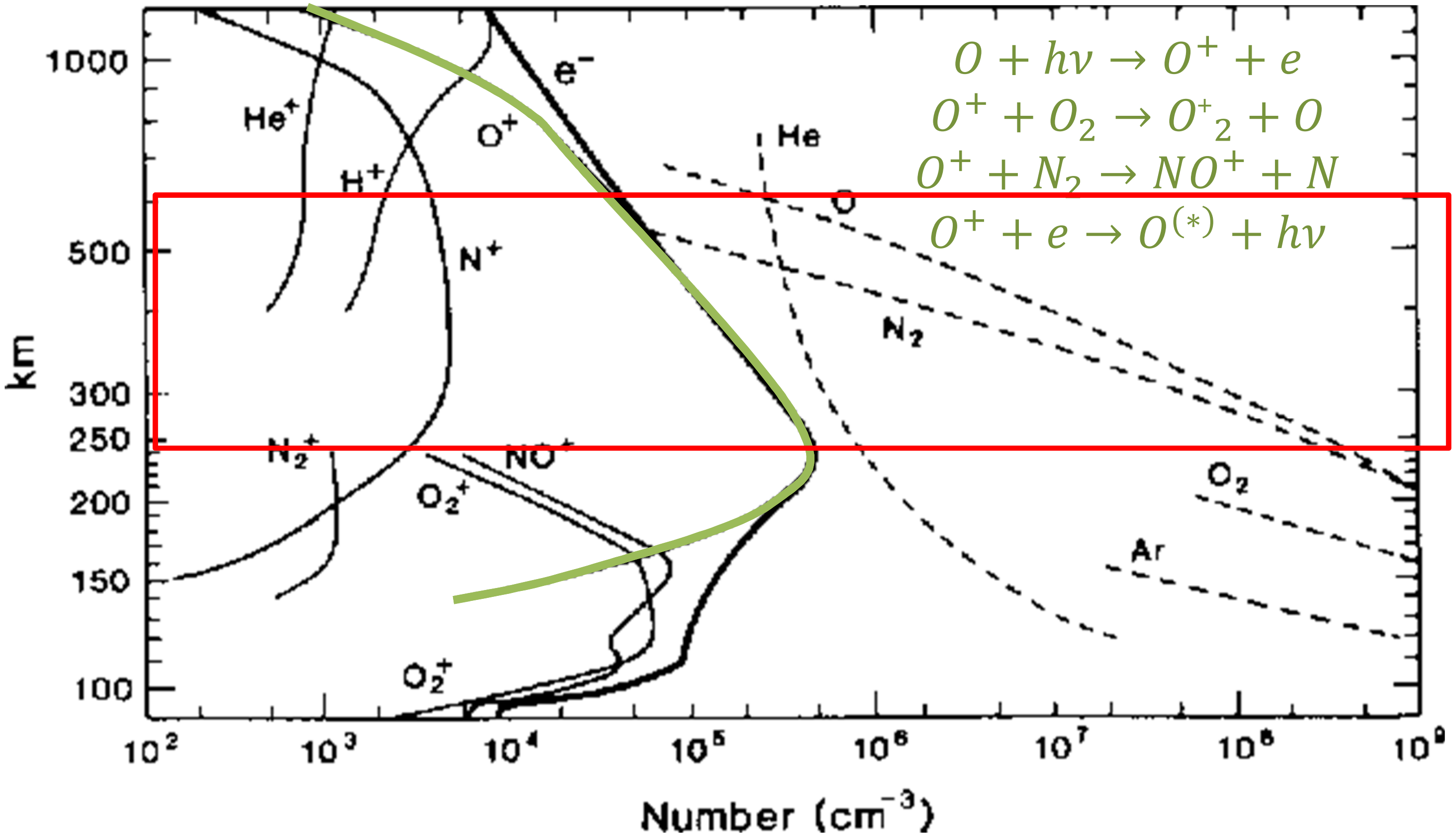
Consideration for composition



International quiet solar year daytime ionospheric and atmospheric composition based on mass spectrometer measurements.

Johnson (1969), Luhmann(1995)

Consideration for composition

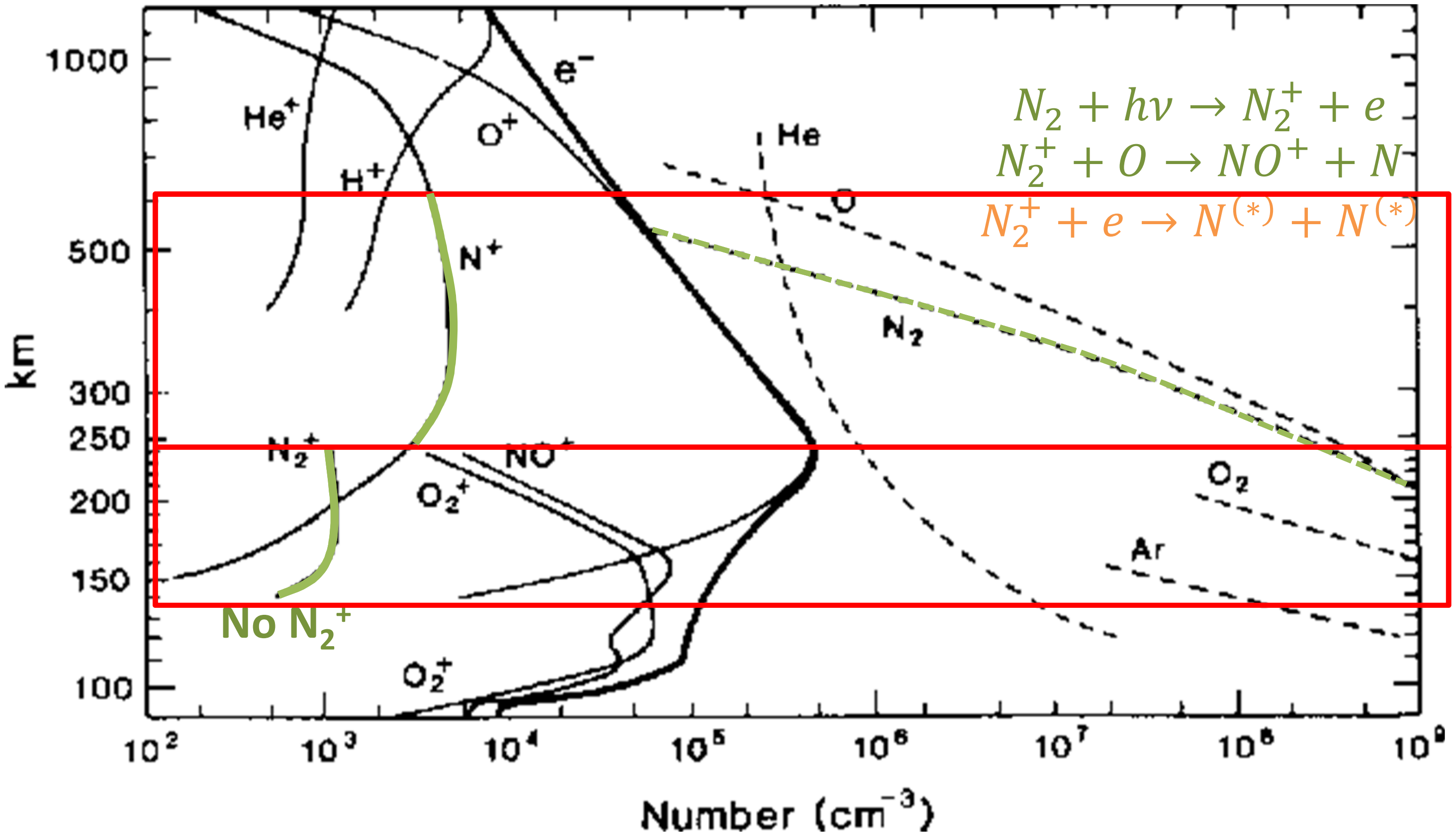


Dominance of O+ in the F-region

- Source is photoionisation
- Main loss through charge transfer with N_2 or O_2
- Loss through radiative recombination is low

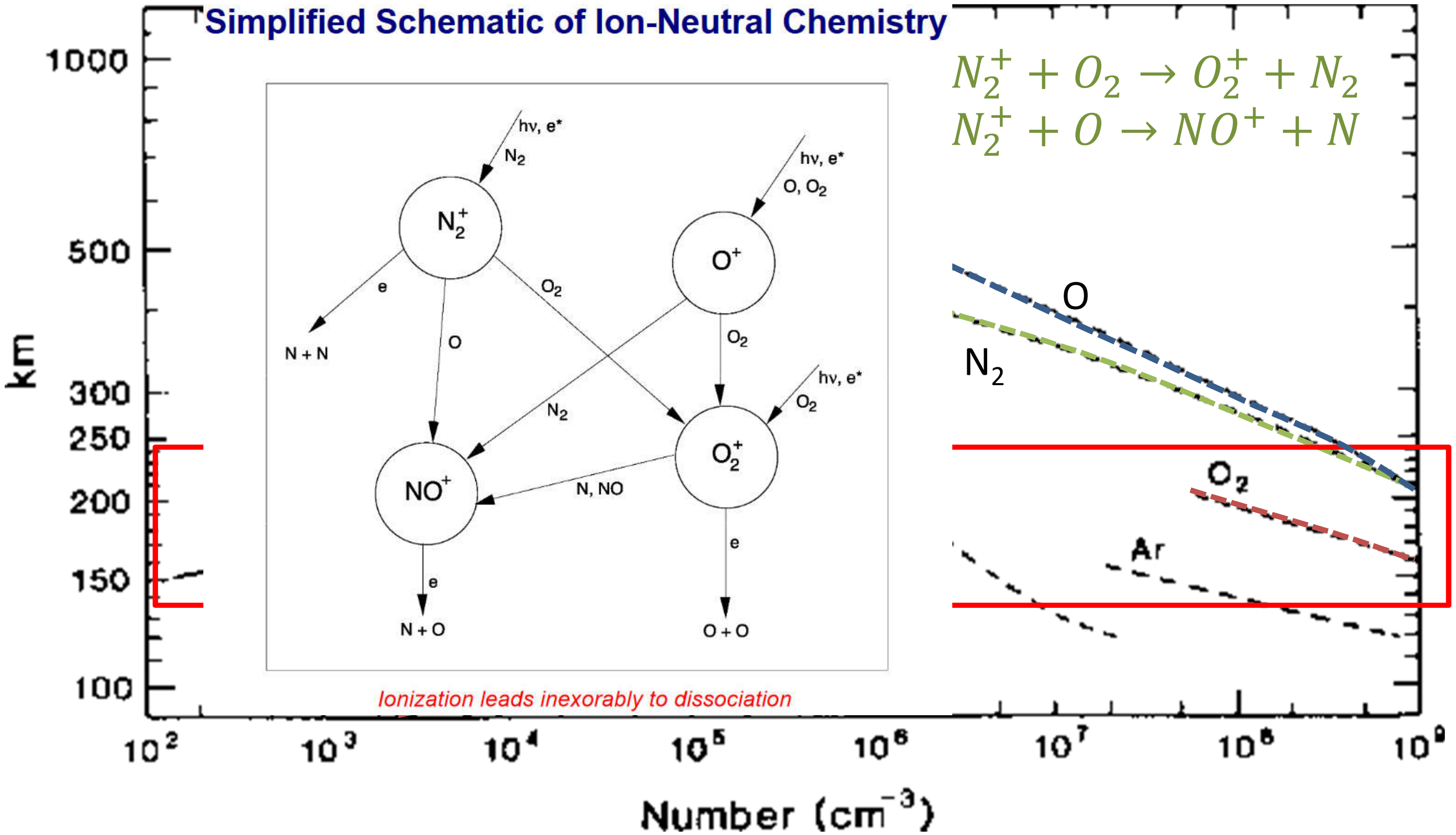
→ Importance of [O/N2] ratio

Consideration for composition



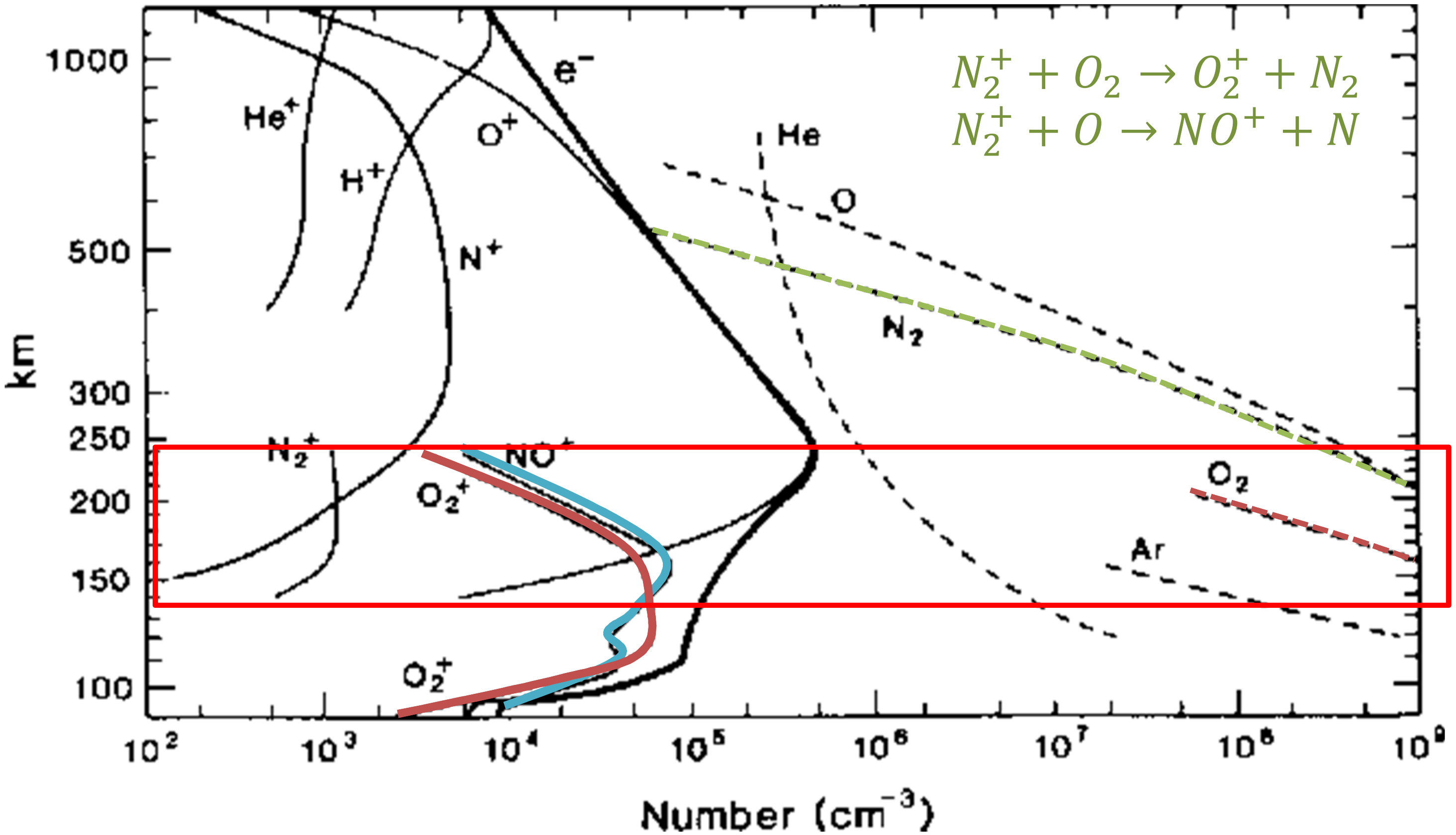
- Dissociative recobination is so fast in the topside ionosphere, that the **N_2^+ basically not exists**
- In the bottom side F-region, speed of dissociative recombination decreases

Consideration for composition



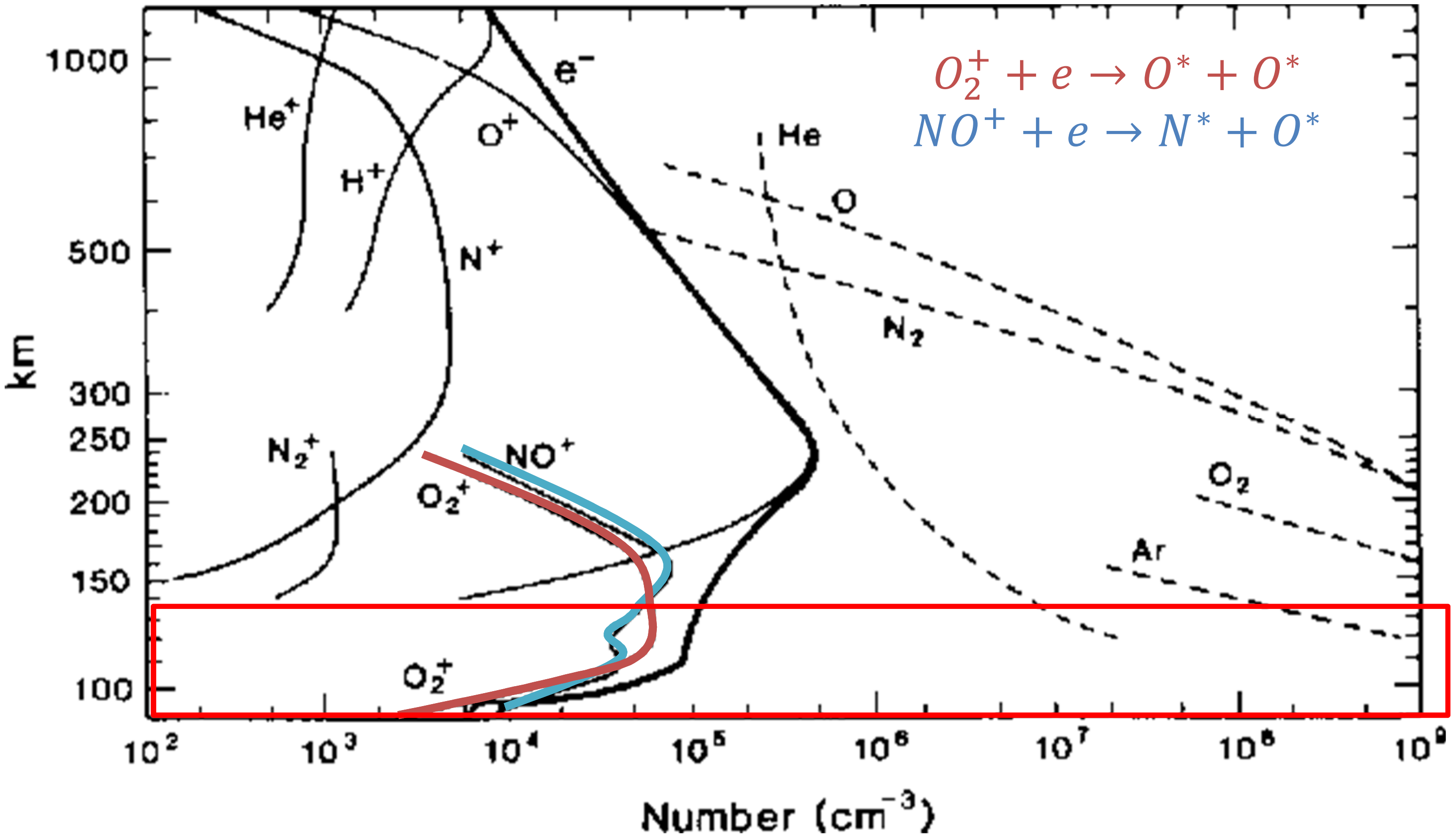
- O+ dominance decreases with decreasing altitude
- Dissociative recombination is slower
- Loss of N_2^+ becomes dominated by charge transfer

Consideration for composition



- O+ dominance decreases with decreasing altitude
- Dissociative recombination is slower
- Loss of N_2^+ becomes dominated by charge transfer
- **O_2^+ and NO^+ dominating ions in lower altitudes**

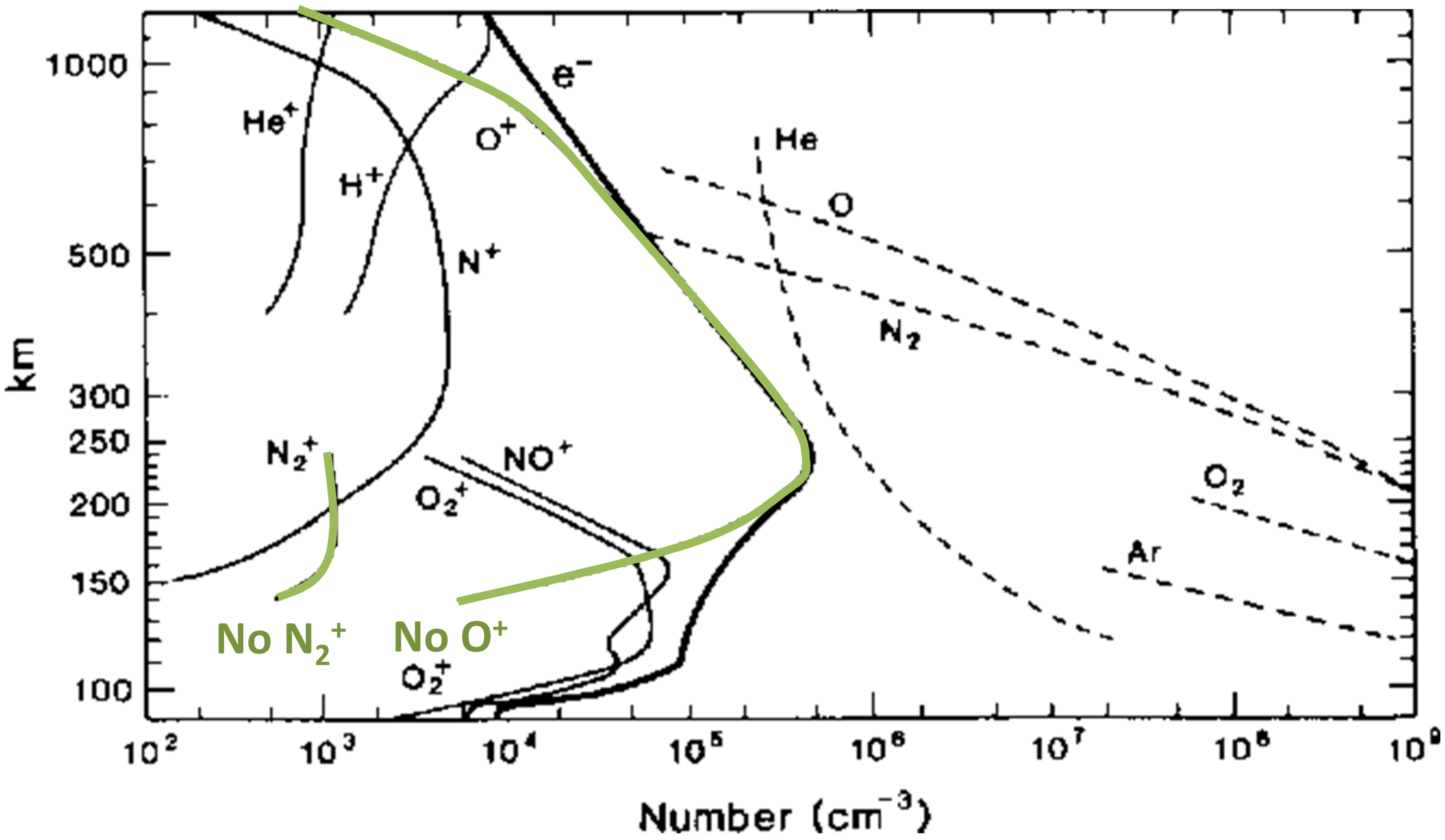
Consideration for composition



O_2 and N_2 are dominating molecules in E-region

- Very effective production of NO+ in the E-region through charge transfer
- Photoionisation is minor, because of low density of NO
- Loss of NO+ through dissociative recombination is slower

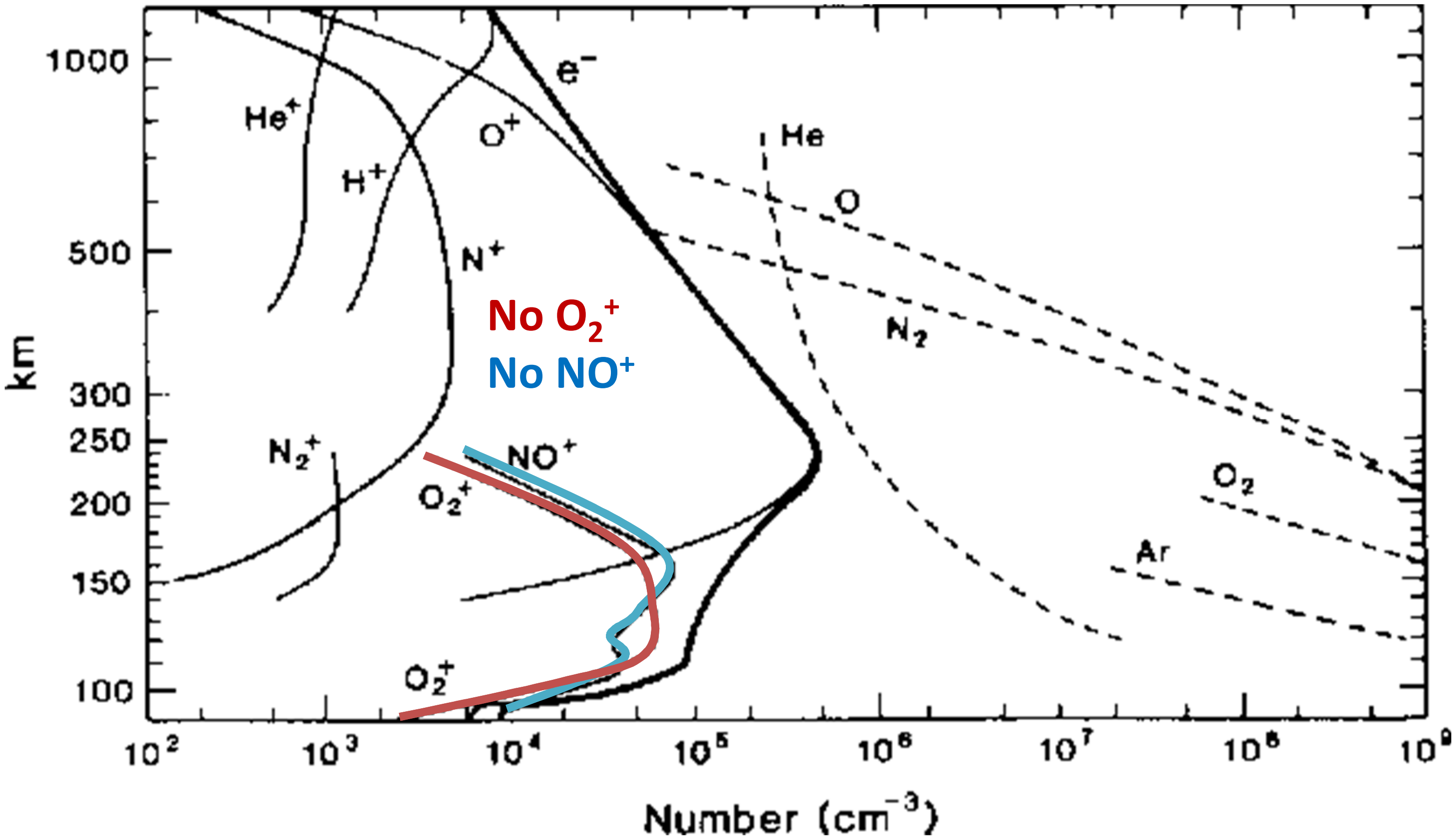
Consideration for composition



No O^+ and N_2^+ in E-region because of

- little production in that region
- Exponential increase of loss coefficient with decreasing height

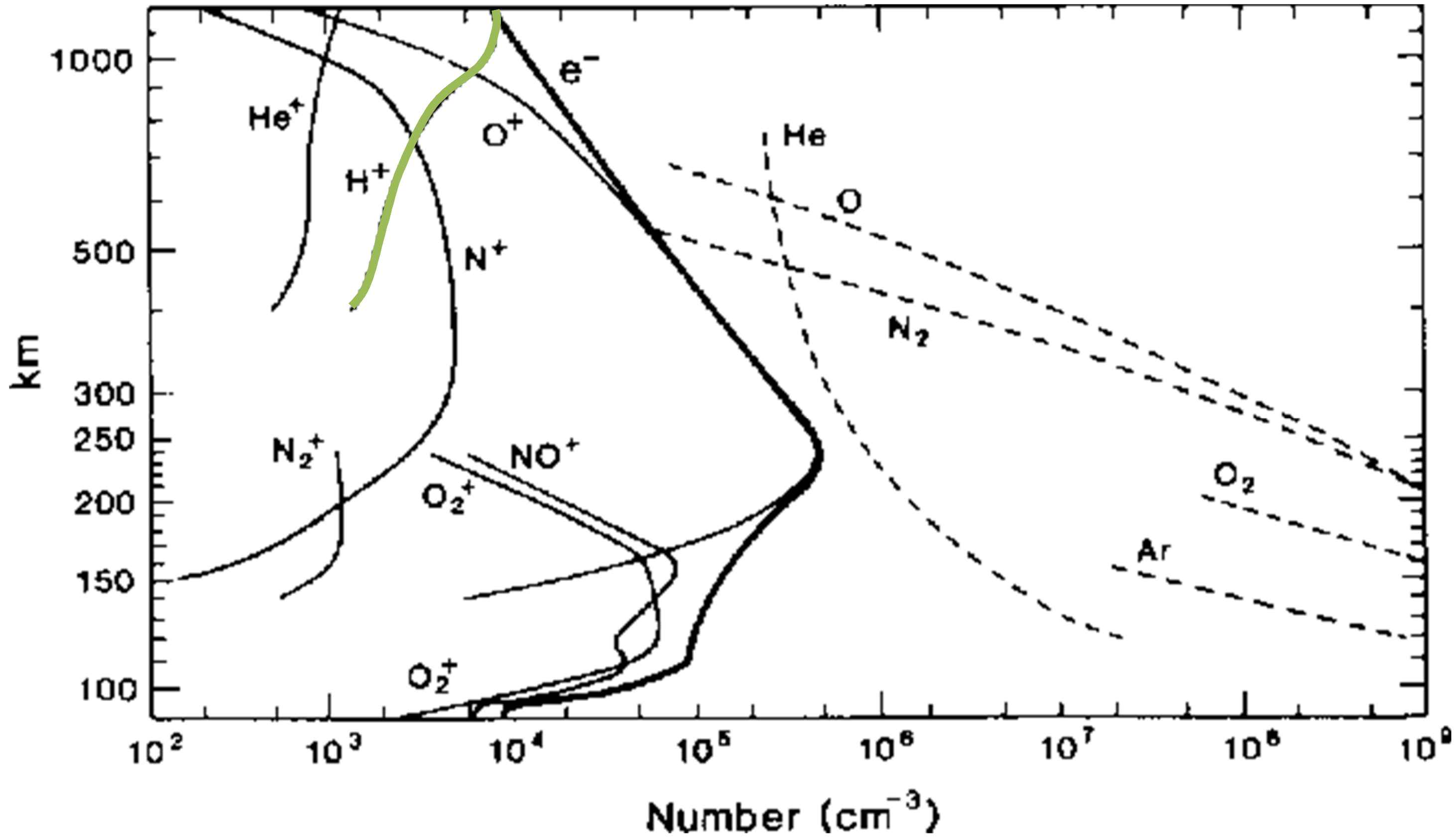
Consideration for composition



No O_2^+ and NO^+ in the F-region because of

- decreasing production with altitude and
- Loss rates increase due to increasing electron density

Consideration for composition



Dominance of H^+ because of

- Effectiv production through charge transfer
- At the same time there is a loss of O^+ through the same reaction

D-Layer

- 50-95 km
- Electron density normally does not have a distinct peak
- H-Lymann alpha radiation (lambda=121.5 nm) penetrates down into the D-layer and has enough energy to ionize NO (which is found in small amounts) → production in 70-95 km
- Below 70 km, ionisation from high energetic cosmic radiation
- Contribution of solar X-rays
- All processes are height- and temperature-dependent

EXERCISES

TEC-F10 correlation

- Task 1
  - Plot F10.7 for the period 1998-2021
  - Plot local TEC (~Neustrelitz) for the same period in a comparable format
- Task 2
  - Plot local TEC for the full year 2008 and compare to F10.7 and kp or ap

Seasonal Anomaly

- Use e.g. IRI and MSIS
  - Plot local (~Neustrelitz) number density of atomic oxygen and molecular nitrogen at ~ 250 km altitude for the full year 2008
  - Plot the ratio [O/N2] for the same location and period
  - Plot TEC for the same location and period