“Ionospheric Geography”

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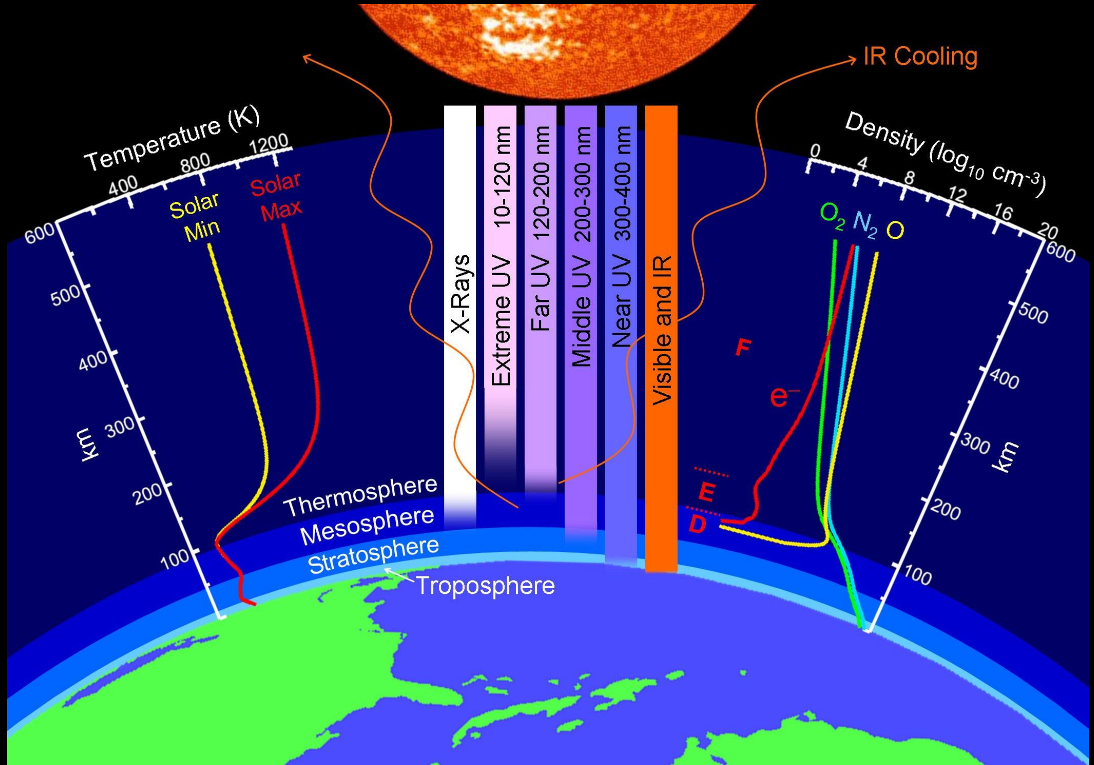
"Ionospheric Geography" Tutorial

By Bea Gallardo-Lacourt

What is the Ionosphere?

- The atmosphere above ~70km that is partially ionized by ultraviolet radiation from the sun
  - This region of partially ionized gas extends upwards to high altitudes where it merges with the magnetosphere
- The ionosphere was discovered in the early 1900s in connection with long distance radio transmissions



- It affects all aspects of radio wave propagation on Earth
- It's an important (and very useful!!) tool in understanding how the sun affects the Earth's environment

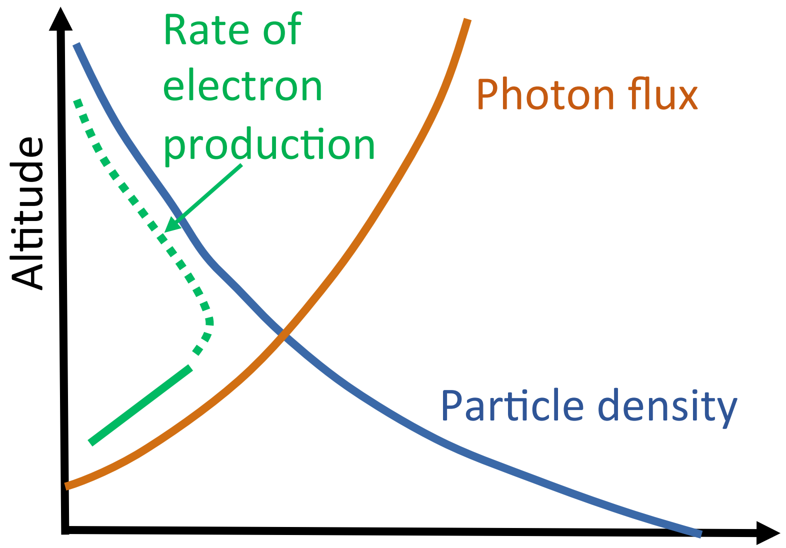
Ionization of the atmosphere

- Formation of layers can be understood by considering ionization of any molecule (or atom) A in the atmosphere

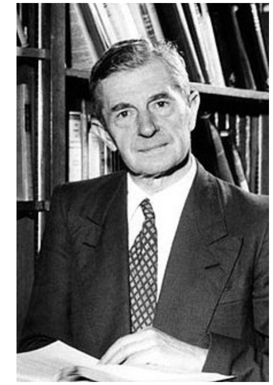
$$A + h\nu \longrightarrow A^{+} + e^{-}$$

Rate of reaction depends on concentration of molecules A and photons *hv*

- At high altitudes there are many photons, but few particles
- At low altitudes there are many particles but few photons of sufficient energy to cause ionization



Chapman Layers

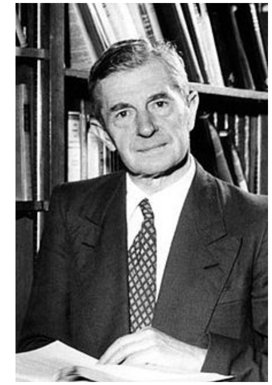


- Sydney Chapman used several assumptions to develop a simplified theoretical model
  - ✓ Atmosphere consists of only one gas
  - ✓ Radiation from the sun is monochromatic
  - ✓ Atmospheric density decreases exponentially with height
  - ✓ Solar radiation is attenuated exponentially
  - ✓ Earth is flat
- Each atmospheric species has its own ionization potential and reaction rate

Ionosphere can be modeled as superposition of simple Chapman layers

Earth's Atmosphere	Percentage
Nitrogen	78.08%
Oxygen	20.95%
Water	**0 to 4%**
Argon	0.93%
Carbon Dioxide	**0.039%**
Neon	0.0018%
Helium	0.0005%
Methane	**0.00017%**
Hydrogen	0.00005%
Nitrous Oxide	**0.00003%**
Ozone	**0.000004%**

Chapman Layers



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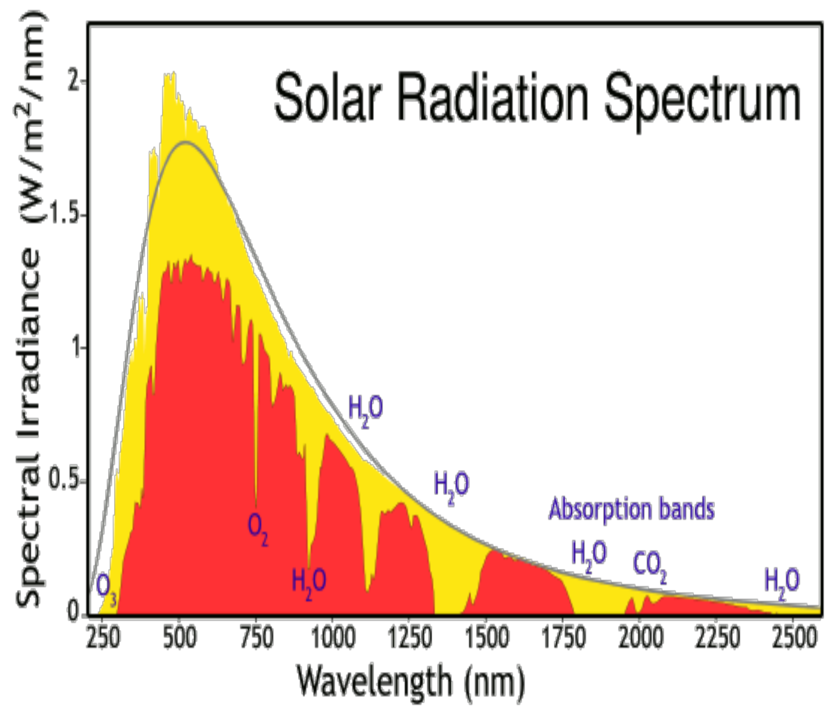

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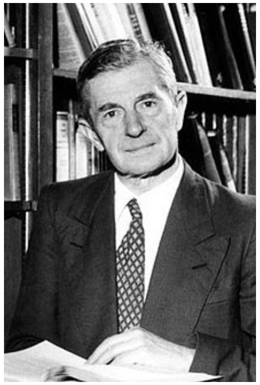
Chapman Layers



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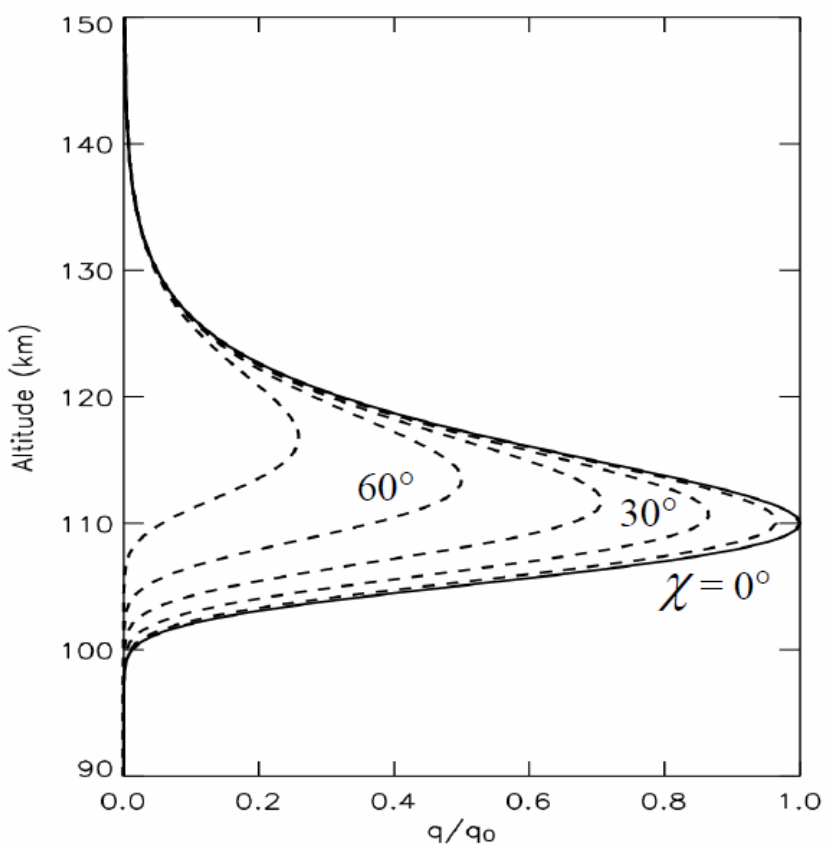
Ionosphere can be modeled as superposition of simple Chapman layers

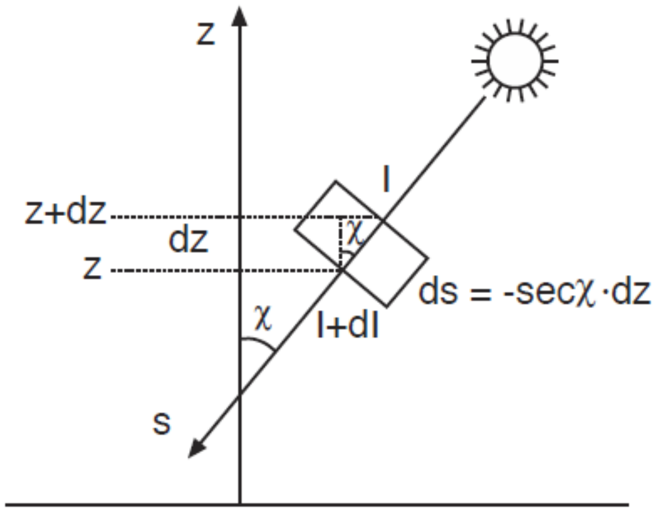
Ionization source: Solar radiation

Chapman production function by using a height variable $h' = h - \ln \sec \chi$:

$$q(\chi, h') = q_{m,0} \cos \chi \cdot \exp \left[1 - h' - e^{-h'} \right] ,$$

where χ is the solar zenith angle and $h = (z - z_{m,0})/H$, where H is the atmospheric scale height.





- With larger zenith angle χ, the peak of ionization rate rises in altitude and decreases by a factor $\cos \chi$.

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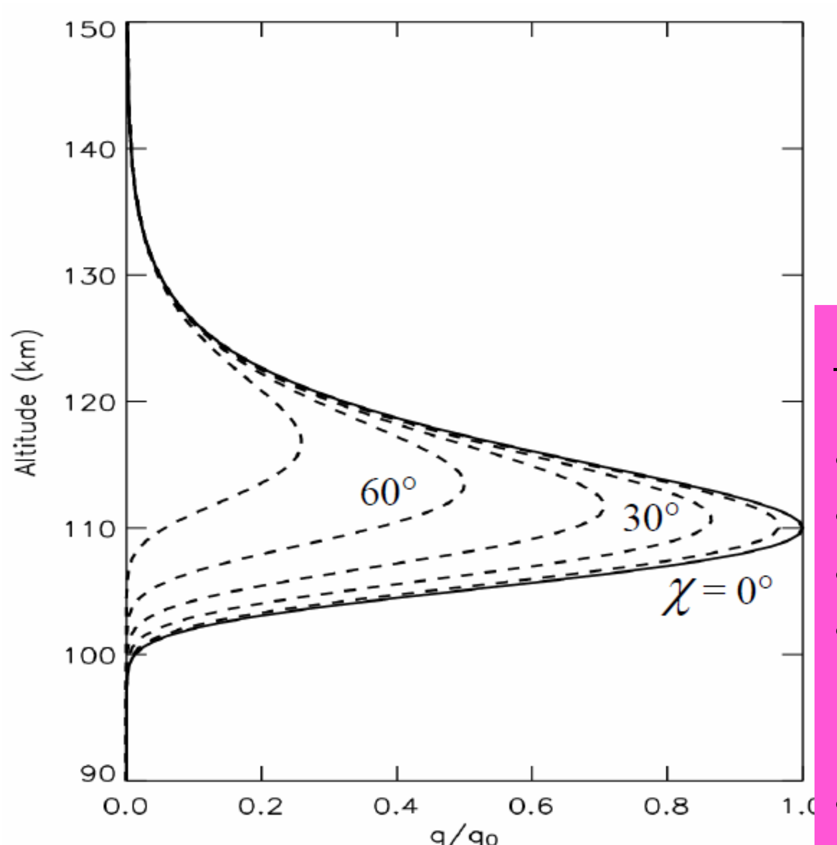
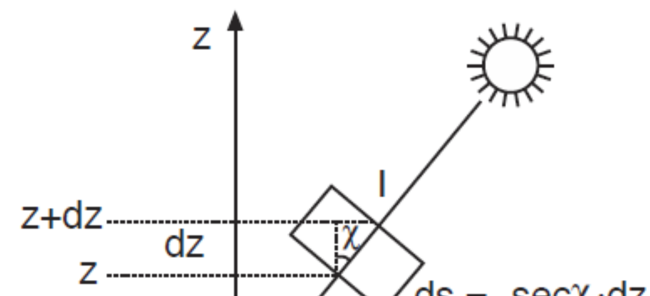


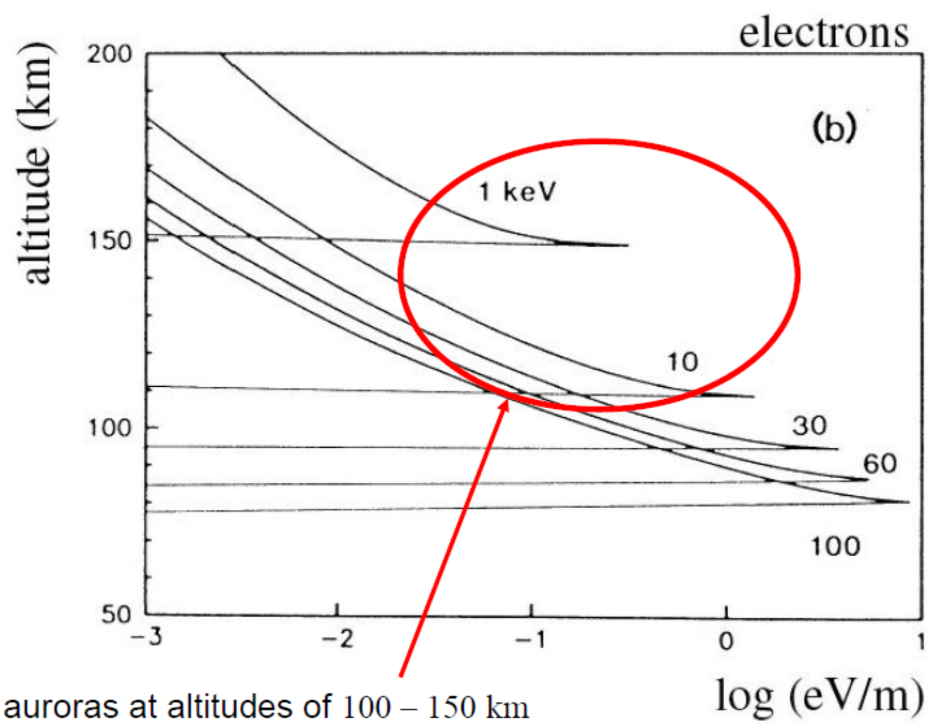


<u>Limitations of Chapman Law</u>

- Effects of magnetic field
- Collisions
- Scale height is not constant
- Assumes steady state
  - No other ionization sources
  - Constant intensity
- Severely underestimate nighttime D-region
- Gives only quantitative description

Ionization source: particle precipitation (electrons)

- In the auroral zone, also precipitating electrons and ions cause ionization
- Much more variable than solar irradiance and thus much more difficult to model
- Maintain ionosphere during the nighttime
  - Before recombination, electrons scatter from the atmosphere and produce bremsstrahlung (x-ray)



Most auroras at altitudes of 100 – 150 km
→ created mainly by 1 – 10-keV electrons

Ionization source: particle precipitation (protons)

Proton aurora

- Weak blue emission at 486.1 nm (Hβ) and red emission at 656.3 nm (Hα) as different excitations of neutral hydrogen
- Diffuse glow

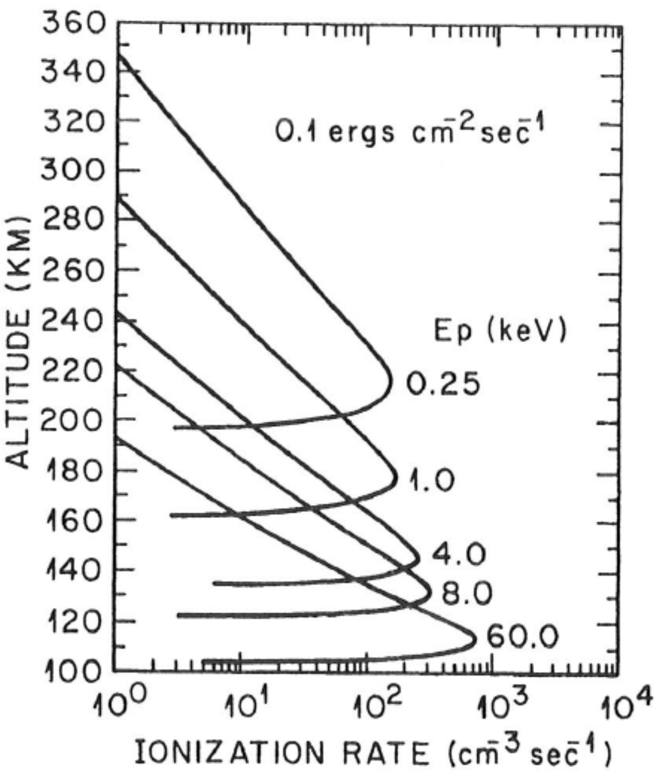
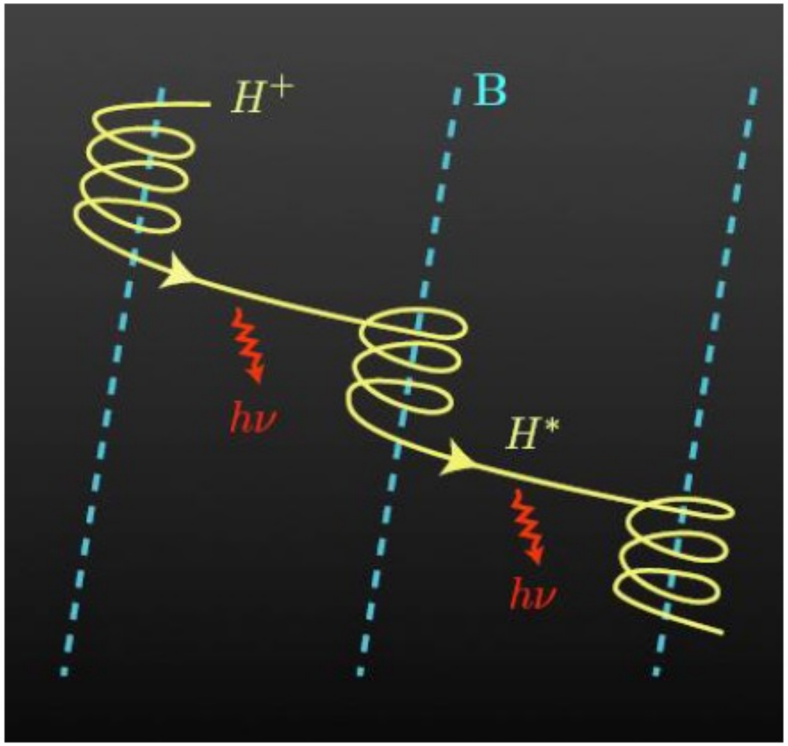
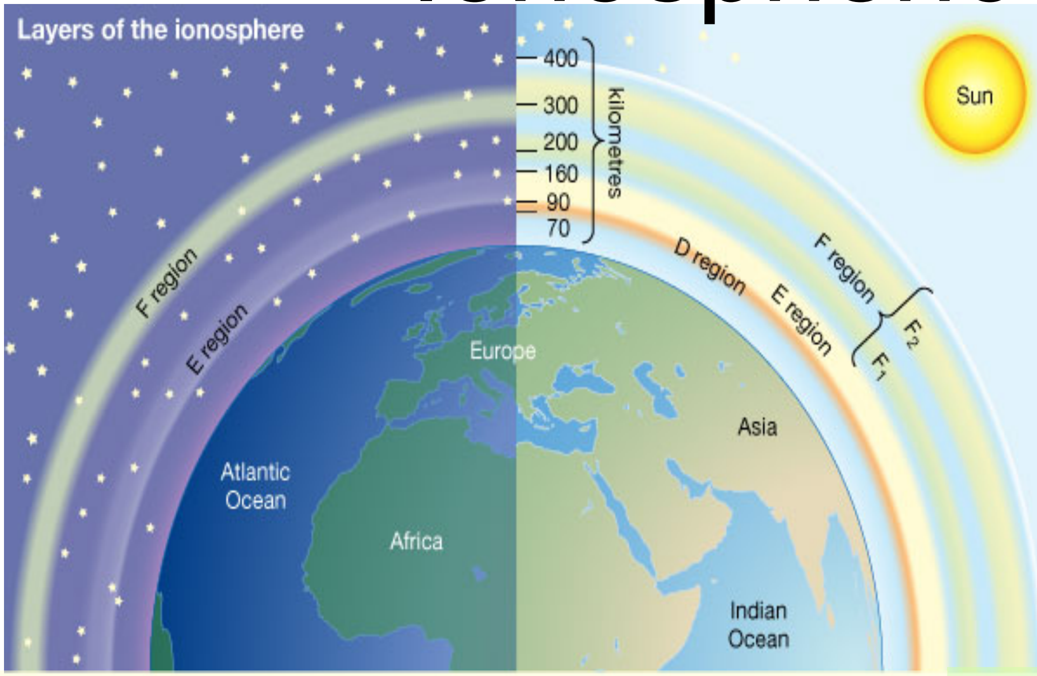


Figure: Ionization rate for monoenergetic protons with energies 0.25–60 keV (Rees, 1982).



Protons may make charge exchange with neutral hydrogen

Ionospheric regions



D region (70-90 km)

- Lowest region, produced by Lyman series alpha radiation (λ= 121.6 nm) ionizing Nitric Oxide (NO)
- Very weakly ionized
- Electron densities of $10^8 - 10^{10}$ e^-/m^3 during the day
- At night, when there is little incident radiation (except for cosmic rays), the D layer mostly disappears except at very high latitudes

E Region (90-140 km)

- Produced by X-ray and far ultraviolet radiation ionizing molecular oxygen (O_2)
- Daylight maximum electron density of about $10^{11} e^-/m^3$
  - Occurs at ~100km
- At night the E layer begins to disappear due to lack of incident radiation
  - This results in the height of maximum density increasing

F1 Layer (140-200km)

- Electron density ~$3\times10^{11} e^-/m^3$
- Caused by ionization of atomic Oxygen (O) by extreme ultraviolet radiation (10-100nm)

F2 Layer (>200km)

- Usually has highest electron density (~$2\times10^{12} e^-/m^3$)
- Consists primarily of ionized atomic Oxygen (O^+) and Nitrogen (N^+)

Ionospheric regions

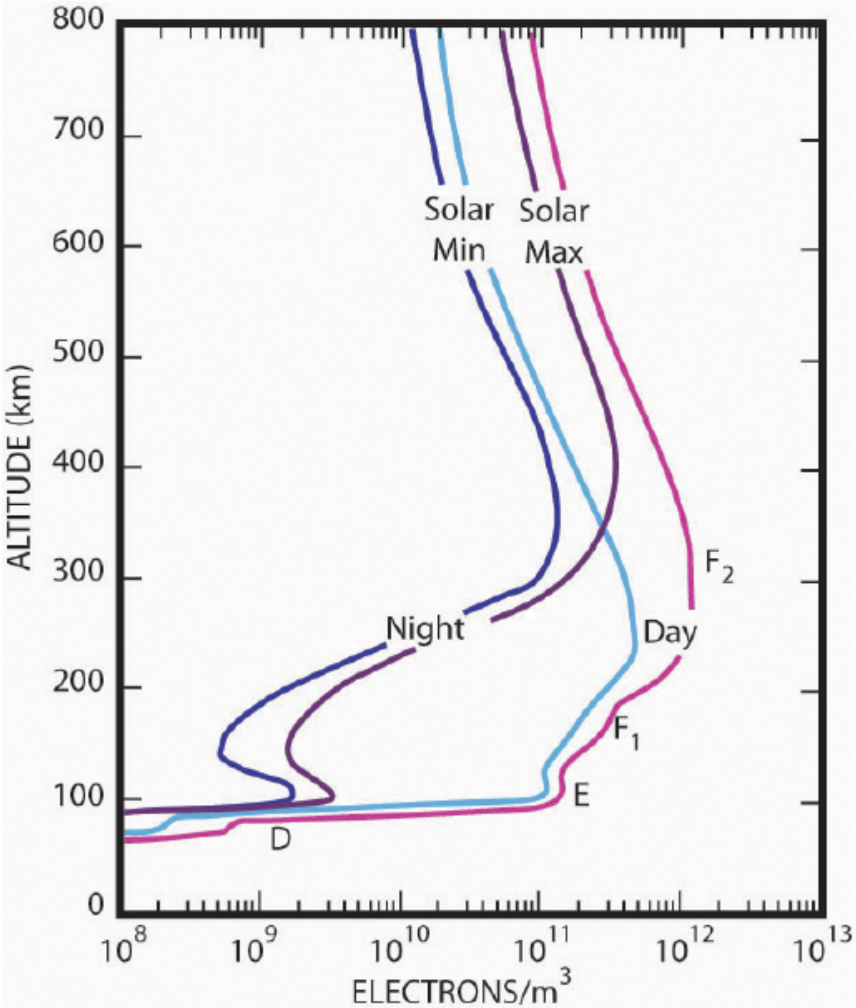


Figure: Typical ionospheric electron density profiles.

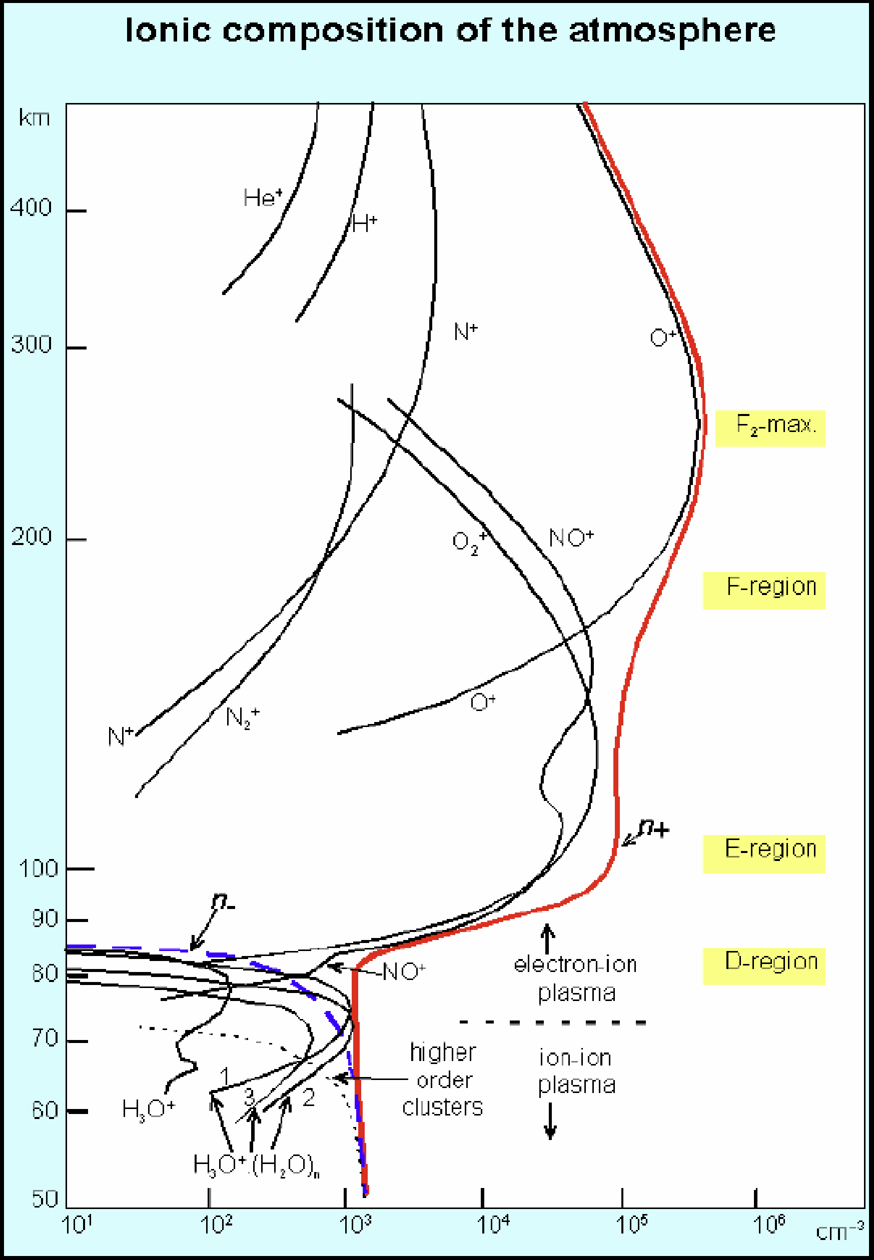
Ionospheric regions and typical daytime electron densities:

- D region: 60–90 km, $n_e = 10^8$–10^{10} m^{-3}
- E region: 90–150 km, $n_e = 10^{10}$–10^{11} m^{-3}
- F region: 150–1000 km, $n_e = 10^{11}$–10^{12} m^{-3} .

Ionosphere has great variability:

- Solar cycle variations (in specific upper F region)
- Day-night variation in lower F, E and D regions
- Space weather effects based on short-term solar variability (lower F, E and D regions)

Ionospheric regions



- O^+ dominates around F region peak and H^+ starts to increase rapidly above 300 km.
- NO^+ and O_2^+ are the dominant ions in E and upper D regions (Ion chemistry: e.g. $N_2^+ + O \longrightarrow NO^+ + N$).
- D-region contains positive and negative ions (e.g. O_2^-) and ion clusters (e.g. $H^+(H_2O)_n$, $(NO)^+(H_2O)_n$).

Latitudinal domains in the ionosphere: The ionosphere at high, middle and low latitudes

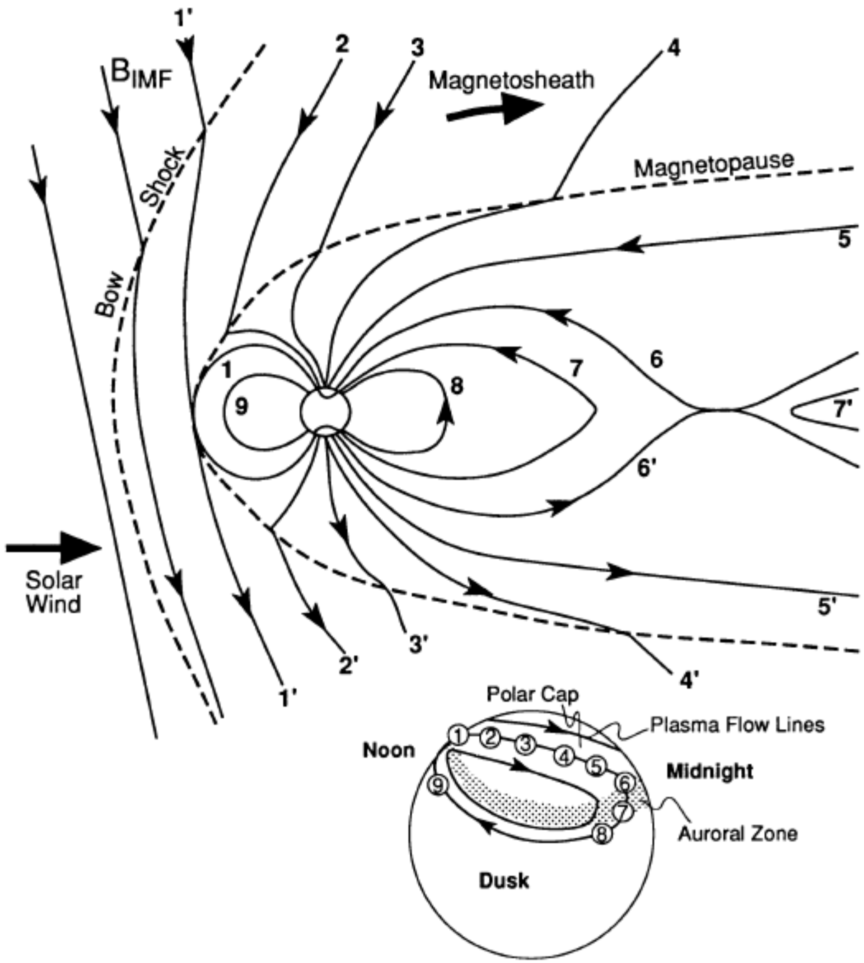
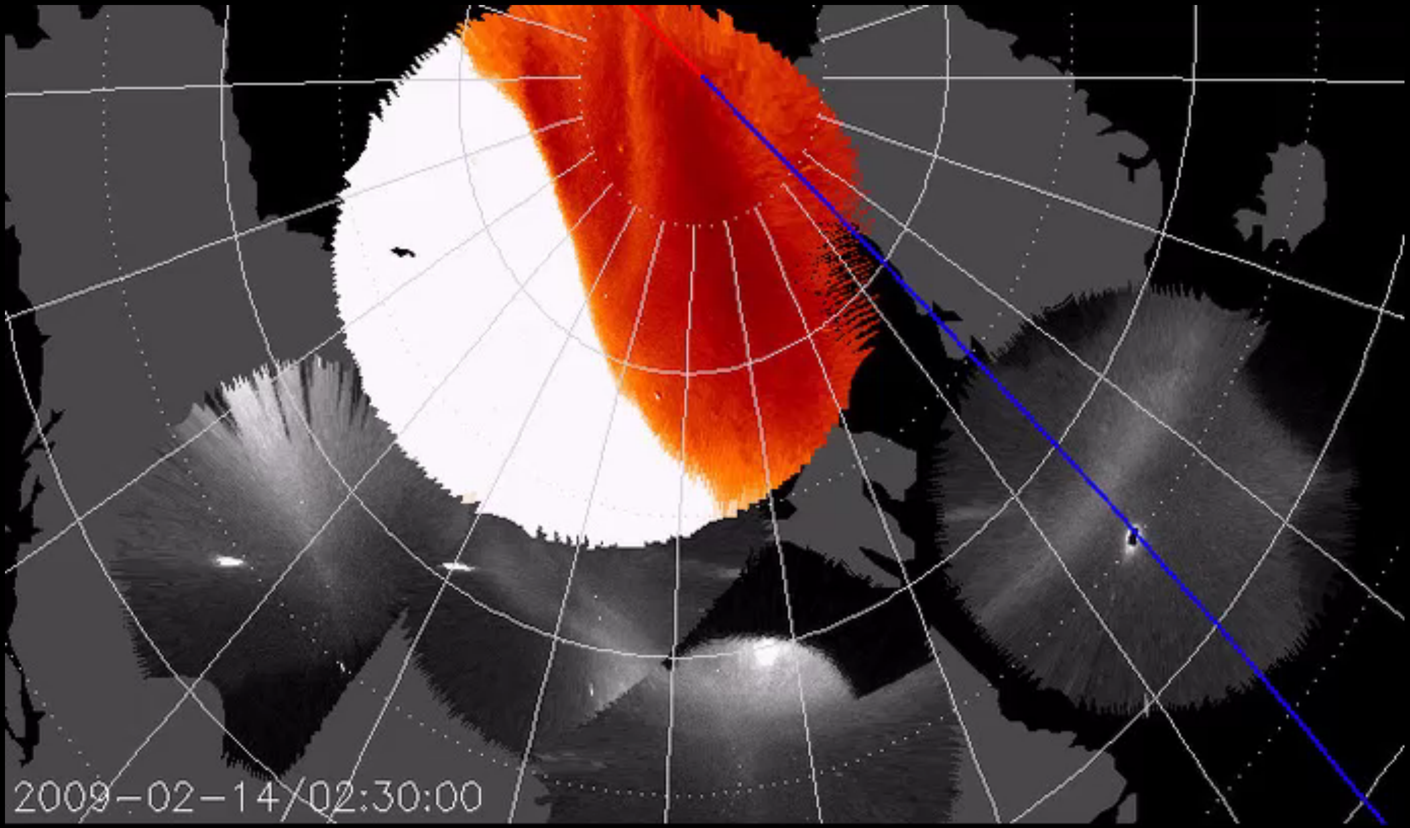


Figure: IMF coupling to the magnetosphere.

- High-latitude ionosphere (polar cap, cusp, auroral oval): intense electric fields mapping from the magnetosphere, particle precipitation, effects of magnetospheric substorms.
- Mid-latitude ionosphere: occasionaly high-latitude electric fields may penetrate to mid-latitudes, effects of magnetic storms.
- Low-latitude ionosphere: small electric fields, high day-time conductivities due to solar radiation (equatorial electrojet).

High-Latitude Ionosphere

Flow channel from the polar cap as a precursor of substorm onset



[Nishimura et al., 2013]

- Polar cap patches are localized enhancements in ionospheric density.
- Polar cap arcs are arcs propagating in the polar cap during periods of northward IMF
- Poleward boundary intensifications (PBI) are intensifications along the poleward boundary of the auroral oval
- Auroral stremers are roughly north-south aligned arcs that travels within the auroral oval

High-Latitude Ionosphere

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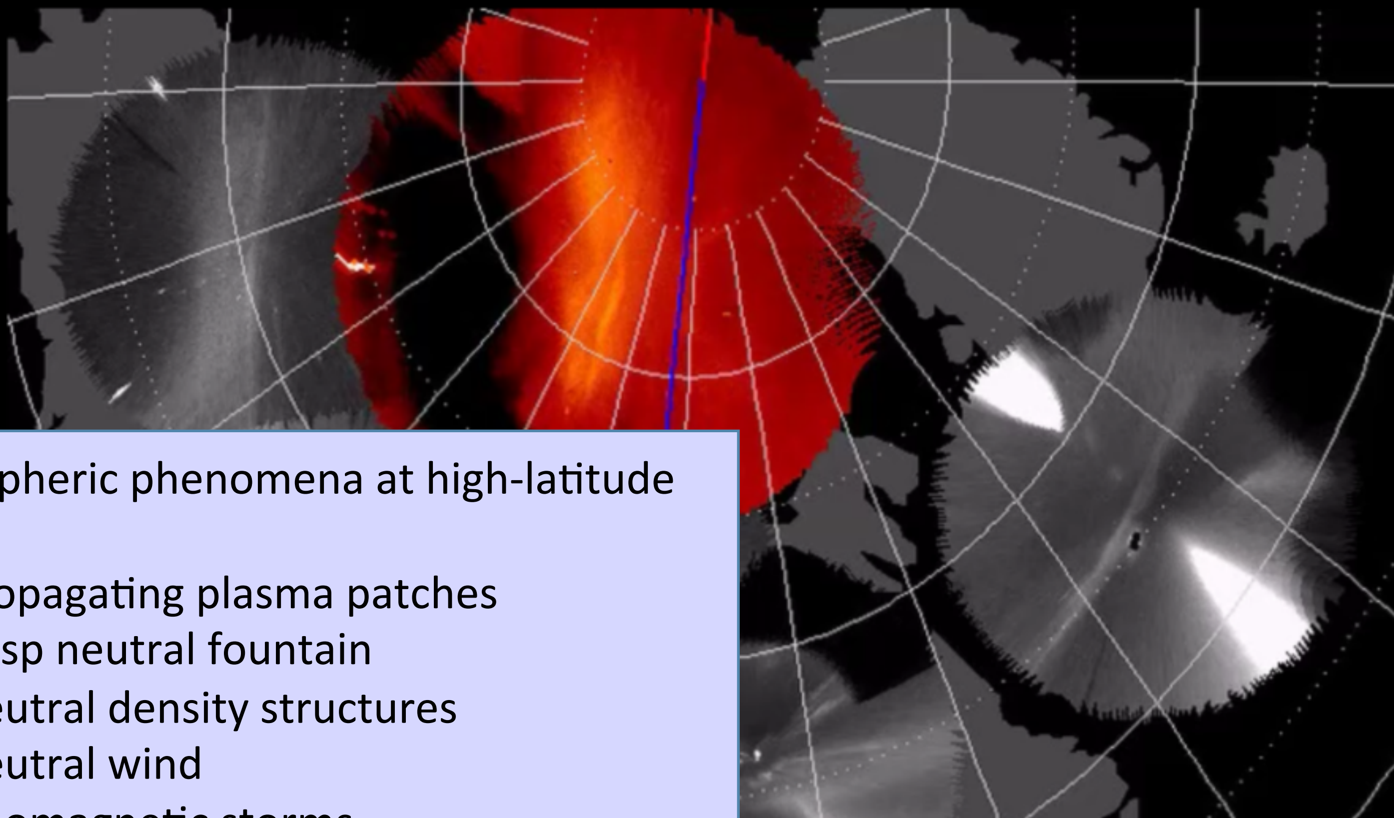
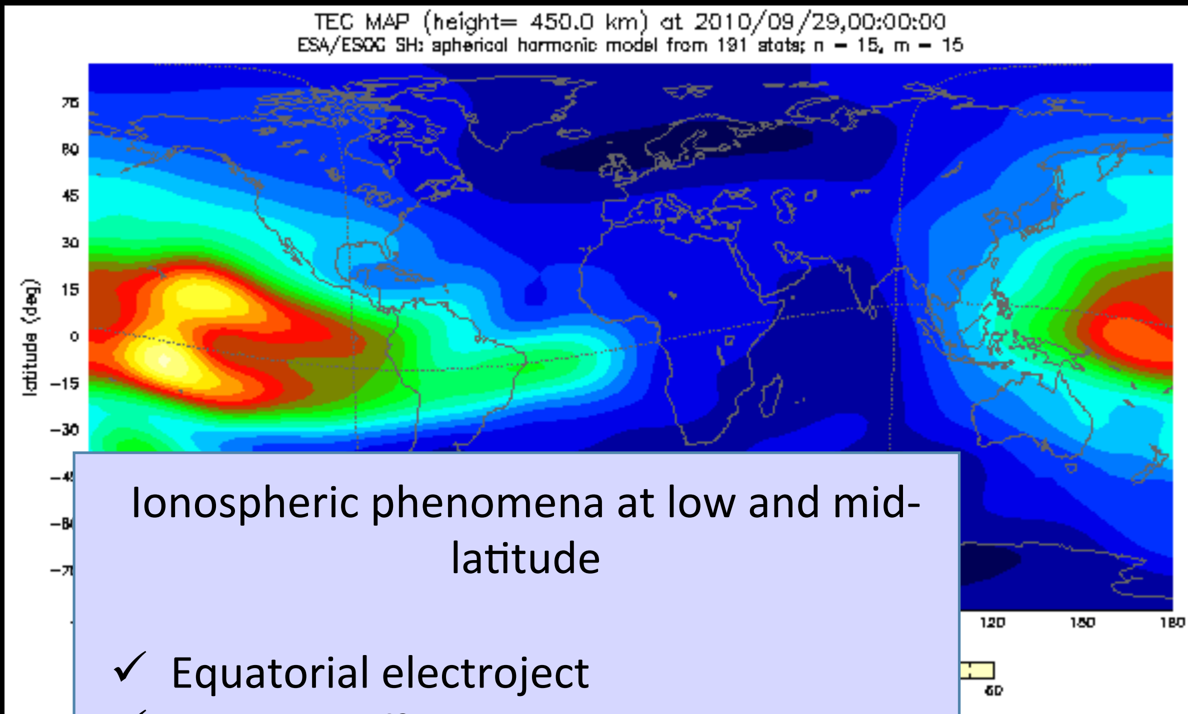


[Nishimura et al., 2013]

Ionospheric phenomena at high-latitude

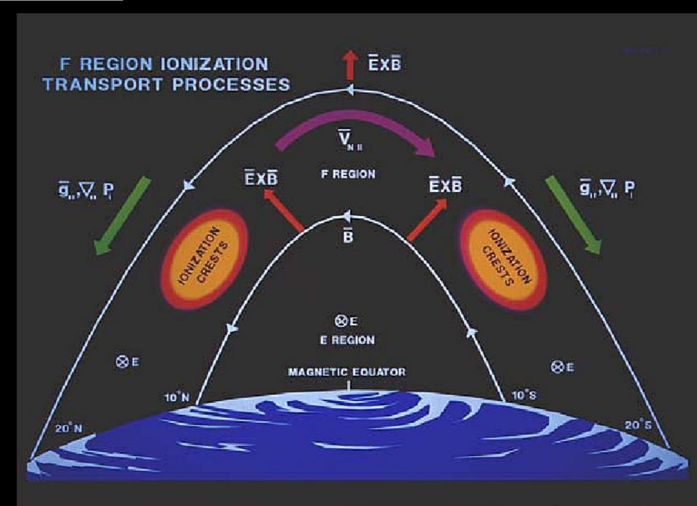
- ✓ Propagating plasma patches
- ✓ Cusp neutral fountain
- ✓ Neutral density structures
- ✓ Neutral wind
- ✓ Geomagnetic storms
- ✓ Substorms
- ✓ Energetic ion outflow

Low and mid-Latitude Ionosphere



Ionospheric phenomena at low and mid-latitude

- ✓ Equatorial electroject
- ✓ Fountain effect
- ✓ Subauroral polarization streams (SAPS)
- ✓ South Atlantic anomalies
- ✓ Equatorial bubbles
- ✓ Tide and gravity waves
- ✓ Ionospheric storms
- ✓ Equatorial plasma instabilities
- ✓ Sporadic E layers
- ✓ Mid-latitude plasma instabilities



Concluding remarks

The Ionosphere is amazingly interesting!!!!!

- The ionosphere is a partially ionized layer above 70km
- Ionosphere shows solar activity dependence
- Ionized by: Solar radiation and particle precipitation
- The ionosphere has layers: D, E and F
- The ionosphere has different latitudinal domains: polar cap, auroral zone, sub-auroral latitudes, mid-latitudes, low latitudes, equatorial zone)

Many thanks to the organizers, specially Victoriya and Lindsay, for giving me the possibility to present this tutorial

And many many thanks to Victor Pinto for helping me in downloading  cool videos for the tutorial