# Space Physics

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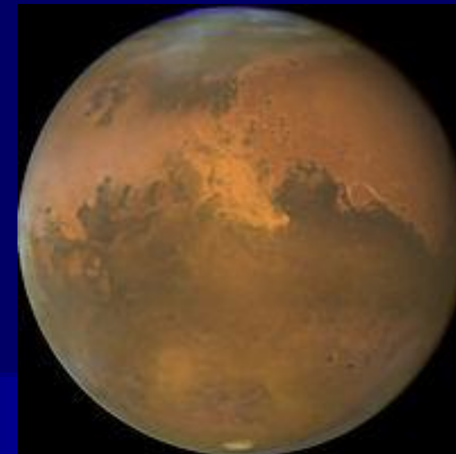
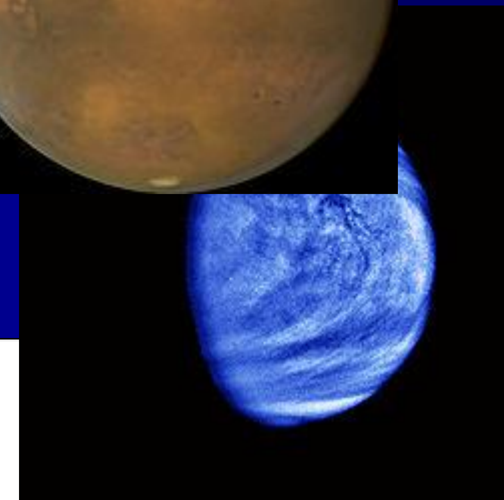
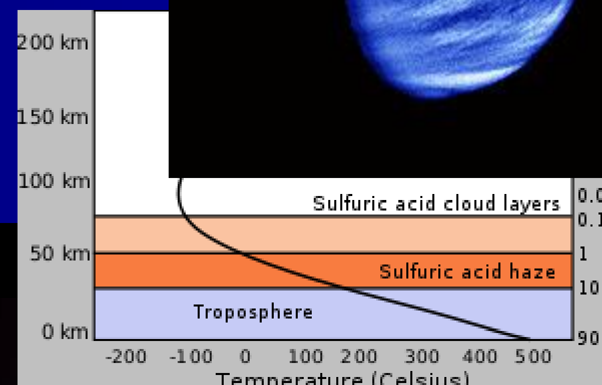
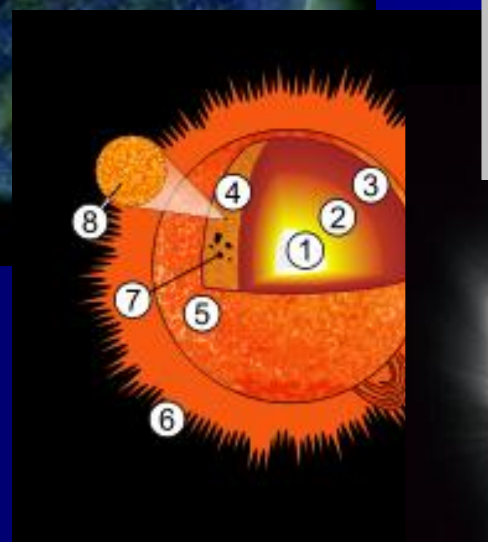
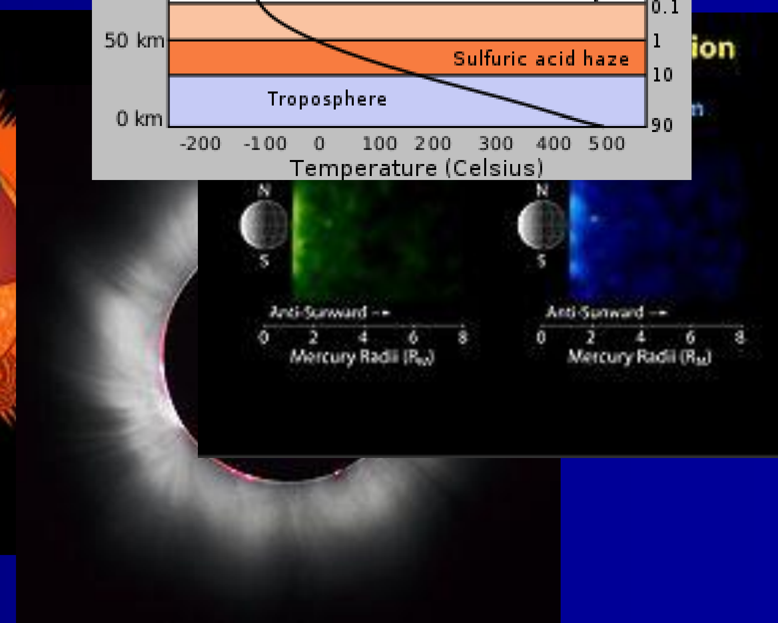







Lecture – 09

# The Ionosphere

Introduction
**The Chapman Layer Theory**
Plasma Frequency
Collision Frequency and Absorption
The Structure of the Ionosphere and the Plasmasphere
Regular and Irregular Variations of the Ionosphere

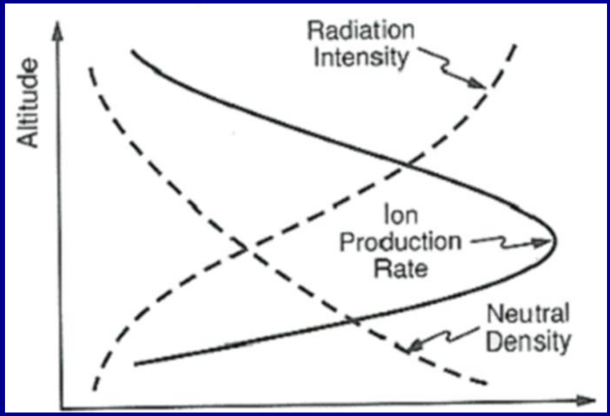
# Chapman layer Theory

## The Ionization of the atmosphere

The ionization of the atmosphere is produced primarily by the Sun's Ultraviolet and X-ray radiation. **The rate *q* at which ion-electron pairs are produced per unit volume is proportional to the intensity of the ionizing radiation *I* and the number density $N_n$ of the neutral atmosphere**, i.e.:

$$q \;\alpha\; I \cdot N_n$$

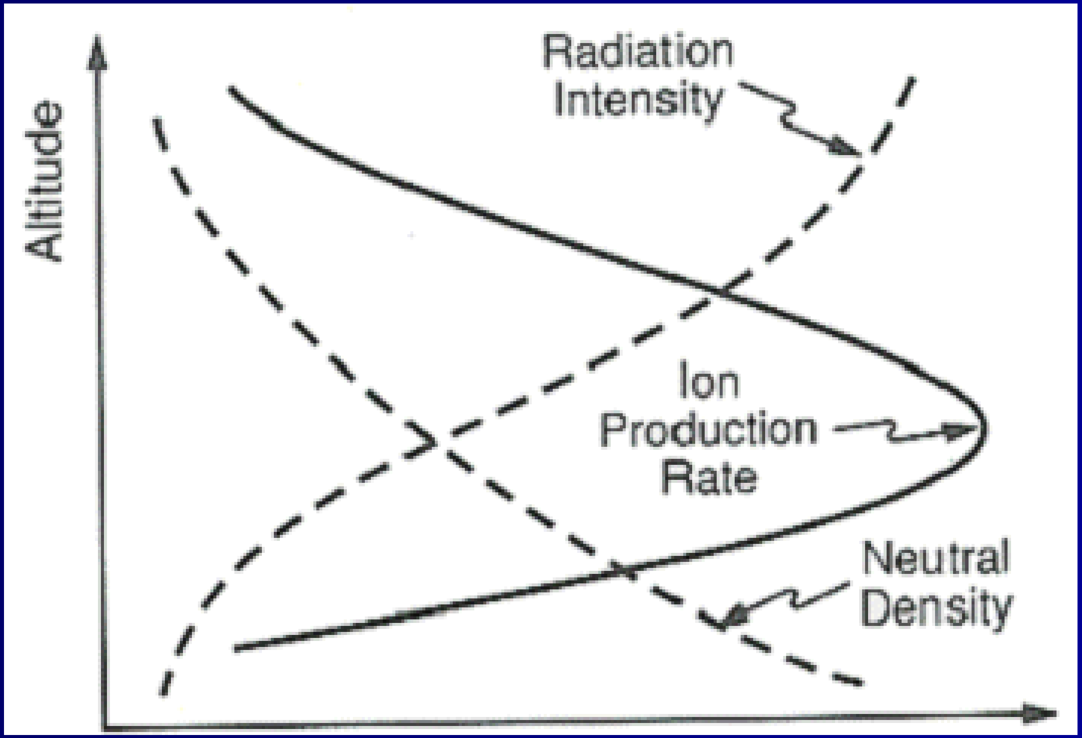
As seen from the following diagram, at high altitudes *q* **is very small because** $N_n$ **is very small.** As the ionizing radiation penetrates deeper into the more dense layers of the atmosphere, *q* reaches a maximum $q_m$ at a height $h_m$ where *I* and $N_n$ reach the best possible combination.



# Chapman layer Theory

## The Ionization of the atmosphere

Below this altitude, the intensity of the ionizing radiation drops rapidly because the energy is spent for the ionization of the atmosphere. As $I$ decreases, $q$ also decreases and finally vanishes near **70 km**.



# Chapman layer Theory

## The Ionization of the atmosphere

Chapman in 1931 produced a very neat theoretical treatment of the problem. In his simplified model, Chapman assumed,

- ◊ an isothermal,
- ◊ horizontally stratified atmosphere,
- ◊ composed of a single gas, which is been ionized by
- ◊ monochromatic radiation from the Sun.

It is obvious that this model is an **over simplification** of the actual conditions.

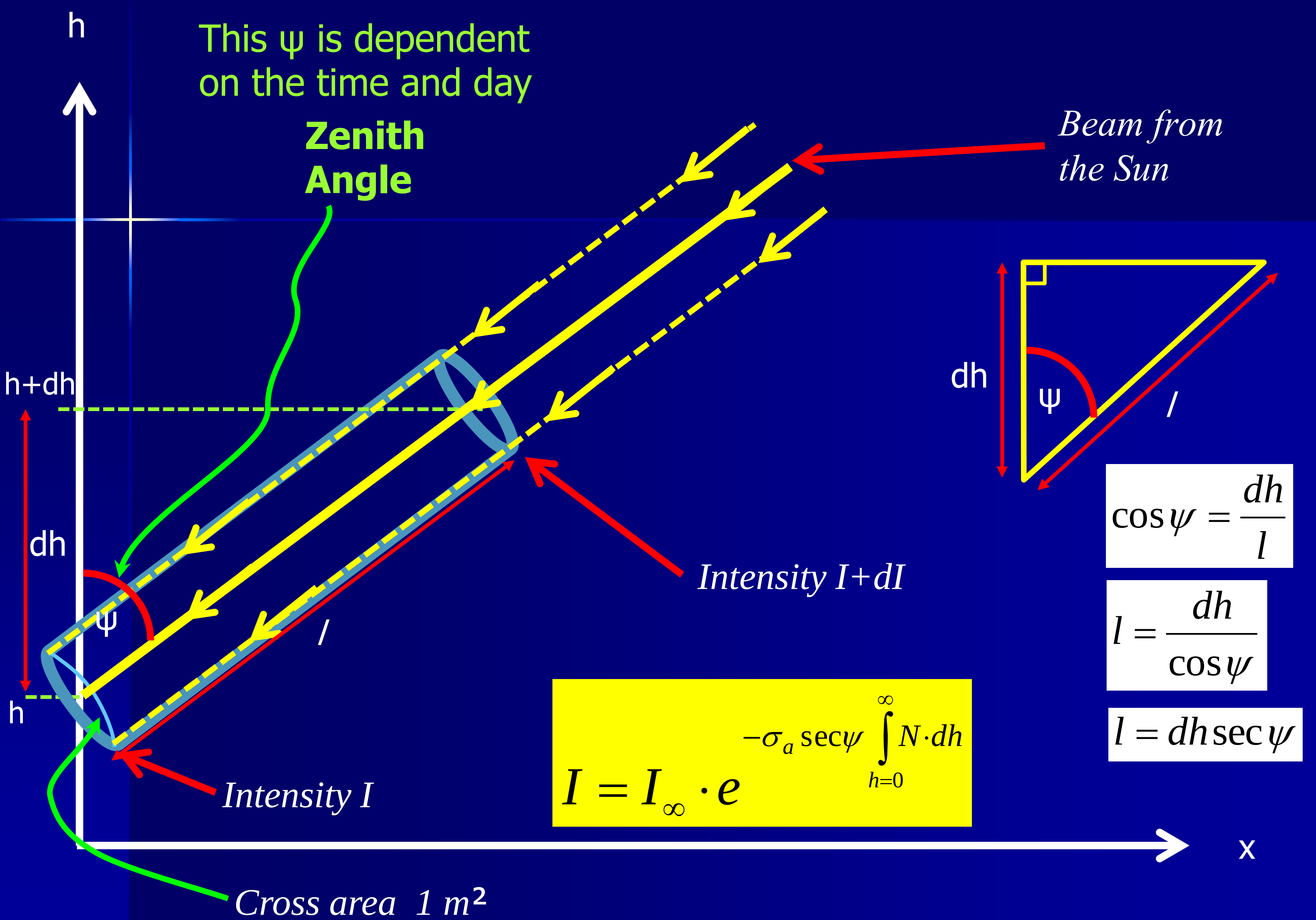
# Chapman layer Theory

The Chapman Layer Theory in 1931 is a very good example of an **ingenious mathematical formulation** of a very complicated physical problem.

## Intensity of Ionizing Radiation :

Let us first compute the absorption sustained by a beam of ionizing radiation at a height *h*. Let the beam have **unit cross-section** and $\psi$ be the angle the beam makes with the vertical (called **Zenith Angle**). The energy of the beam expanded to ionized neutral particles between h and h+dh will be proportional to the intensity of the beam at this height I(h).

P.T.O



h
This ψ is dependent
on the time and day
Zenith
Angle
Beam from
the Sun
h+dh
dh
h
ψ
l
Intensity I+dI
Intensity I
Cross area 1 m²
x
dh
ψ
l
$\cos\psi = \frac{dh}{l}$
$l = \frac{dh}{\cos\psi}$
$l = dh\sec\psi$
$I = I_{\infty} \cdot e^{-\sigma_a \sec\psi \int_{h=0}^{\infty} N \cdot dh}$

# Chapman layer Theory

## Intensity of Ionizing Radiation

*Intensity of Ionizing Radiation at infinity*

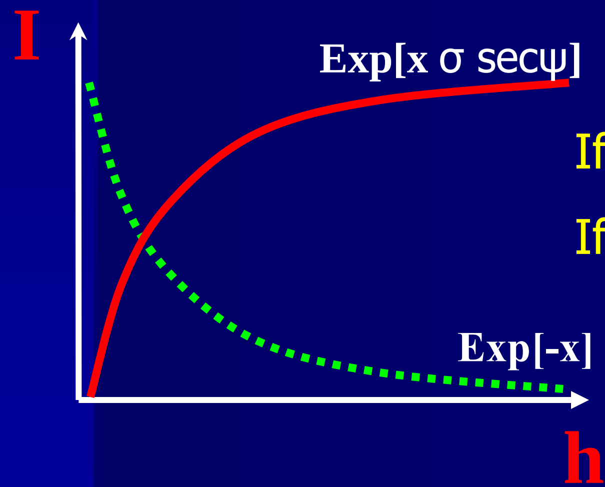
*Absorption Cross-section*

*Zenith Angle*

*Molecular Number Density*

*Intensity of Ionizing Radiation at height h*

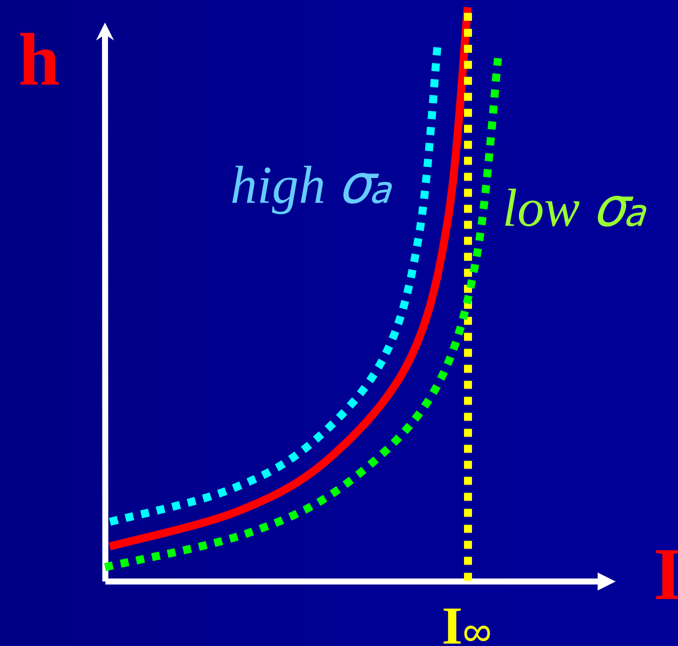
$$I = I_\infty \cdot e^{-\sigma_a \sec\psi \int_{h=0}^{\infty} N \cdot dh}$$




Ionization Radiation (I)

If h ↑ , σ ↓ and

If h ↑ , ψ ↑



# Ionization Wavelength ($\lambda$) :

Ionization of O, $O_2$ , NO and $N_2$ in the Earth atmosphere due to radiation at a particular wavelength from the Sun. This wavelength is called "Ionization Wavelength".

For Ionization

*Given wavelength to ionized*

$$\lambda < \lambda_i$$

*Wave length that is corresponding maximum energy of ionized of a specific material*

| Material | Required wavelength for ionized |
|---|---|
| $N_2$ | 796 Å |
| O | 911 Å |
| $O_2$ | 1118 Å |
| NO | 1340 Å |

$N_2$ *is the more difficult material is to be ionized !*

Ionization Efficiency (η) :

The ratio of the number of ions formed to the number of electrons or protons used in an ionization process OR no of ion-paires per unit absorbed energy.

$$\eta = \frac{No\ of\ ion - pairs\left(e^{n}s\right)}{Absorbed\ energy}$$

If $\lambda > \lambda_i$ ➡ $\eta = 0$ (Because there are no ionized irons)

If $\lambda < \lambda_i$ ➡ $\eta > 0$ (Because there are ionized irons in this case)

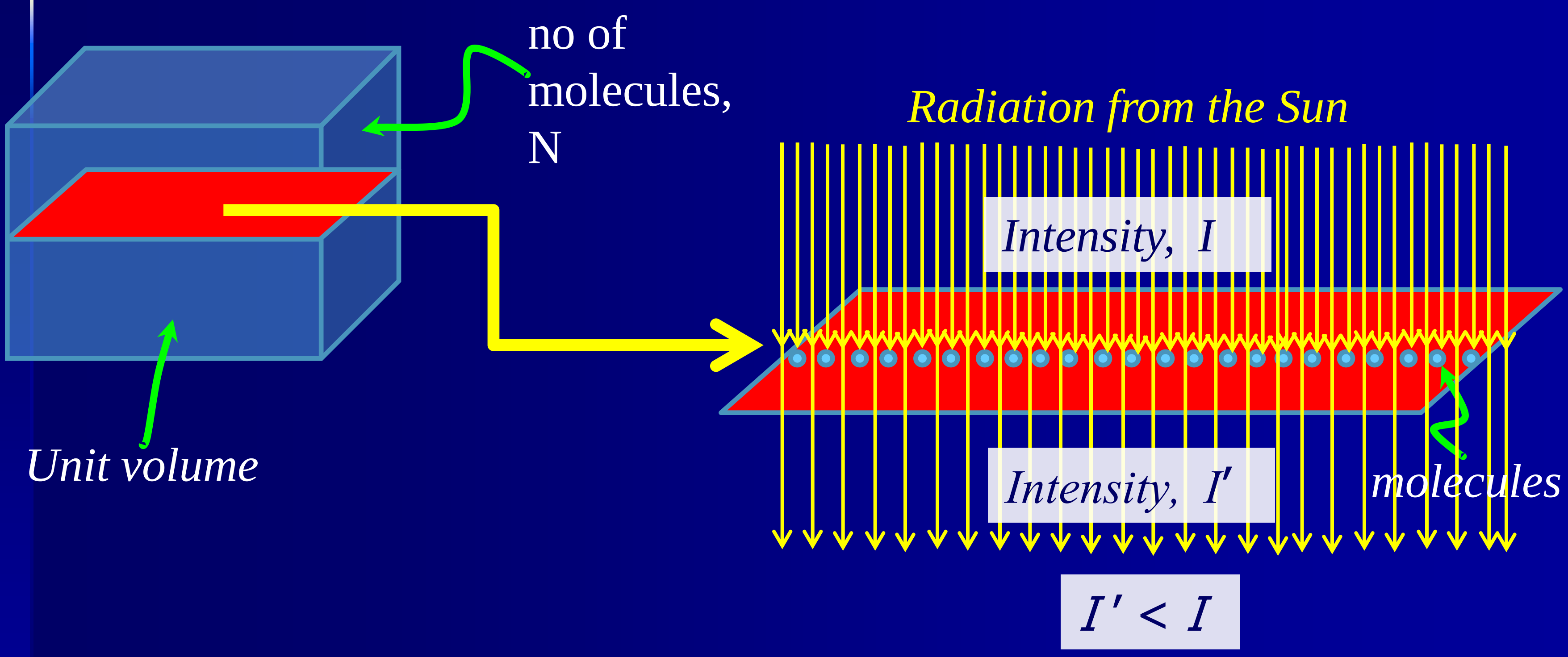
$$\eta = \frac{No\ of\ ion - pairs\left(e^{n}s\right)}{Absorbed\ energy}$$

➡ $No\ of\ ion - pairs\left(e^{n}s\right) \quad \alpha \quad Absorbed\ energy$

# Electron Production Rate (Q)

## Absorbed Intensity ( *dI* )

If we assume there are N no of molecules in an unit volume!



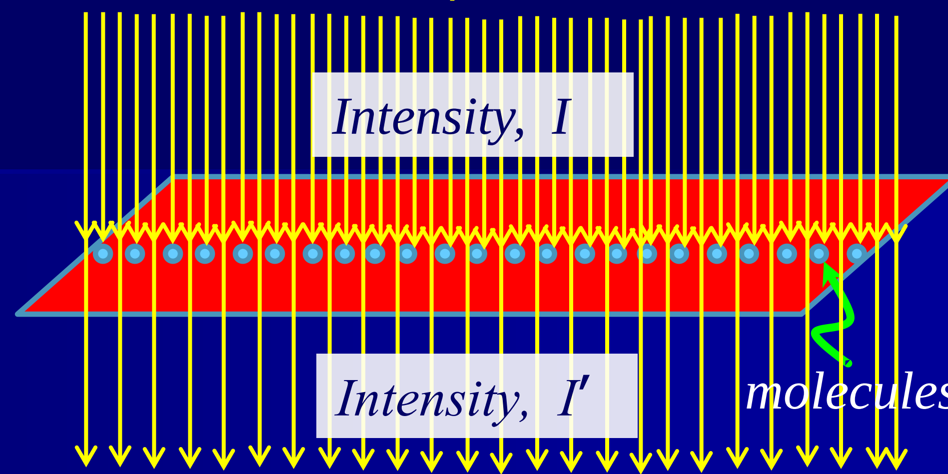

Intensity of the Radiation from the Sun ( $I$ ) comes from the upside to the selected molecules layer. The intensity $I'$ goes through that layer to the downside. $I > I'$ because the amount of $I - I'$ (= $dI$ ) radiation intensity stopped by the molecular layer.

# Electron Production Rate (Q)

## Absorbed Intensity ( *dI* )

*Assume $\sigma_a$ is the Absorption Cross-section area corresponding to the molecules.*

*Radiation from the Sun*




$I' < I$

*Block intensity from the area $N\sigma_a$*

*Cross Area of the molecules in the Unit Area*

$$\frac{dI}{I} = \frac{N\sigma_a}{1}$$

*Intensity from the Sun*

Where, $dI = I - I'$.

*Intensity I comes to the cross area $1m^2$*

*Cross Area of the molecules in the Unit Area*

*Absorbed Intensity*

$$dI = N\sigma_a I$$

*Intensity of the Radiation from the Sun*

# Electron Production Rate (Q)

*Production rate* → $$Q = \eta \times dI = \eta \times N \sigma_a I$$

$$\therefore \quad Q = \frac{\eta e^{-Z}}{eH} I_\infty \cdot e^{1-\sec\psi . e^{-Z}}$$

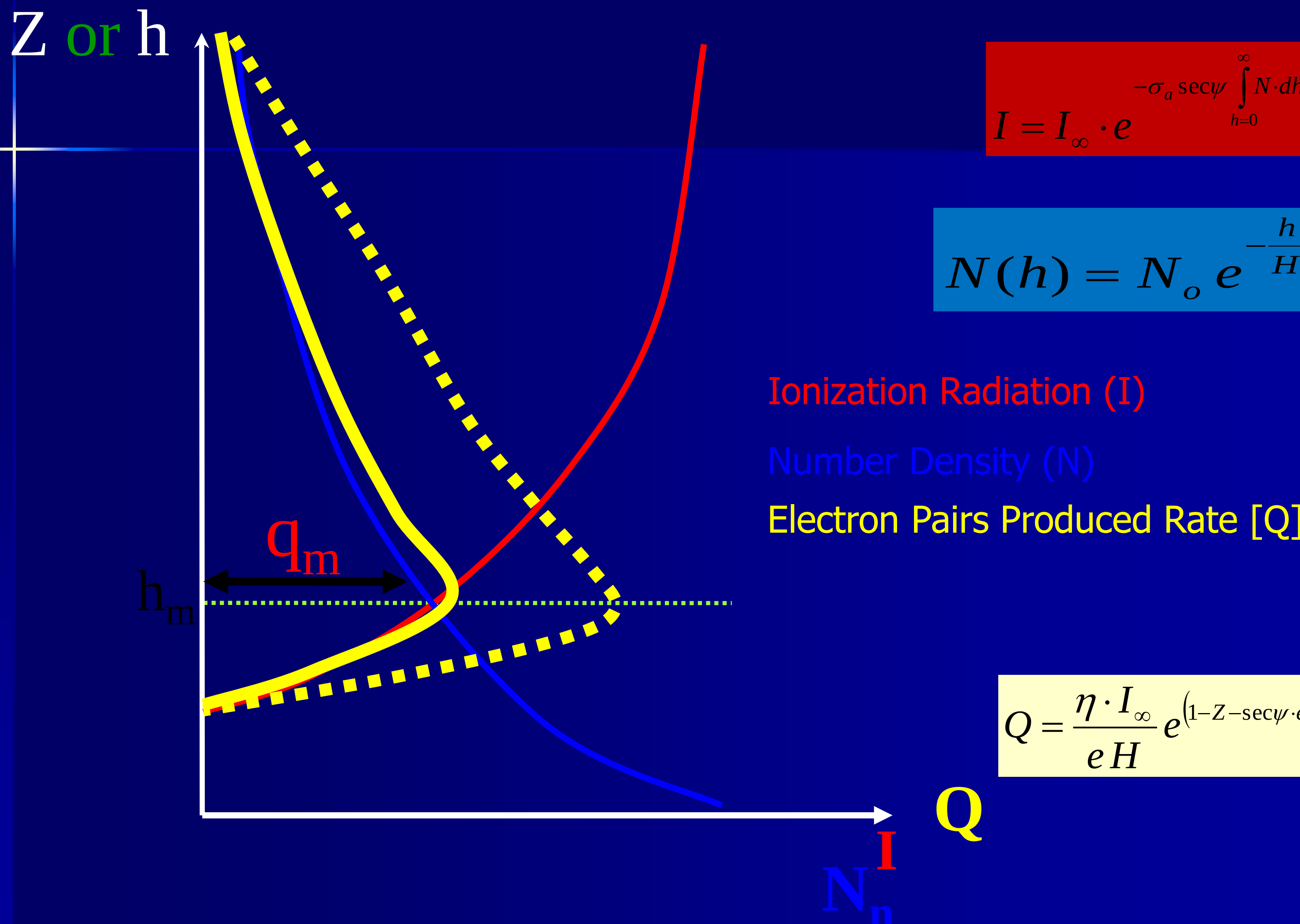
*Where N and Z are dependent variables, because*

$$e^{-Z} = \sigma_a NH$$

***Production rate at any point***

$$Q = \frac{\eta \cdot I_\infty}{eH} e^{\left(1 - Z - \sec\psi \cdot e^{-Z}\right)}$$

# Ionization Radiation (I), Number Density (N) and Electron Pairs Produced Rate [Q]




$$I = I_{\infty} \cdot e^{-\sigma_a \sec\psi \int_{h=0}^{\infty} N \cdot dh}$$

$$N(h) = N_o \, e^{-\frac{h}{H}}$$

$$Q = \frac{\eta \cdot I_{\infty}}{e\,H} e^{\left(1 - Z - \sec\psi \cdot e^{-Z}\right)}$$

# Find the value of $Q_m$

$$Q = \frac{\eta \cdot I_\infty}{eH} e^{\left(1 - Z - \sec\psi \cdot e^{-Z}\right)}$$

$$\ln[Q] = \ln\left[\frac{\eta \cdot I_\infty}{eH} e^{\left(1 - Z - \sec\psi \cdot e^{-Z}\right)}\right]$$

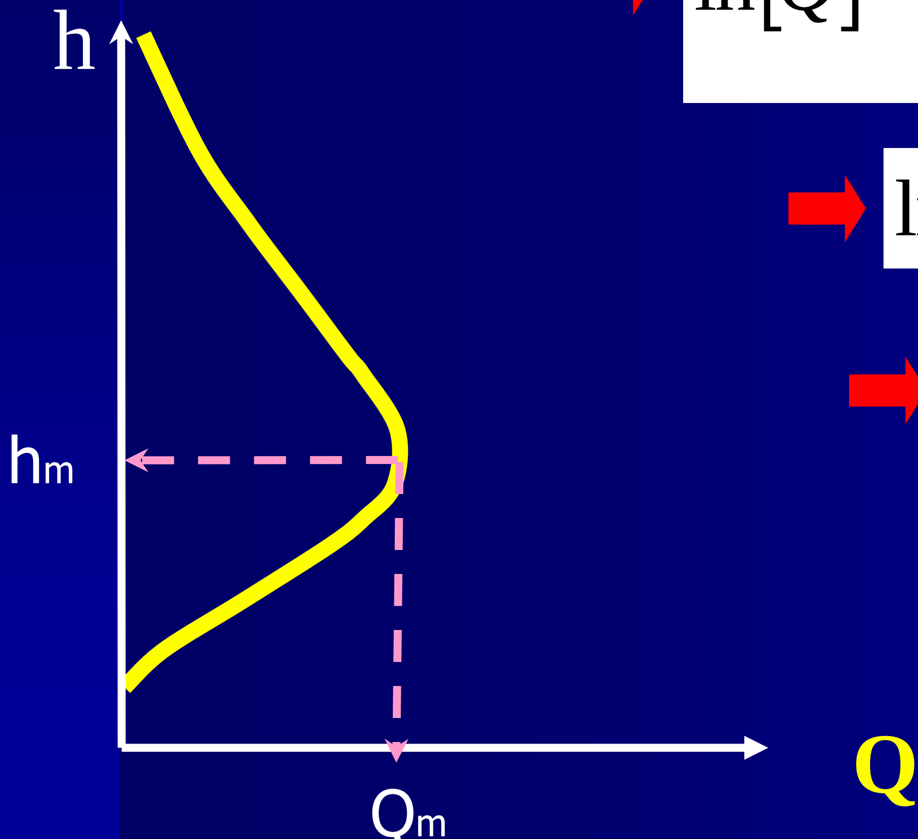
$$\ln[Q] = \ln\left[\frac{\eta \cdot I_\infty}{eH}\right] + \ln\left[e^{\left(1 - Z - \sec\psi \cdot e^{-Z}\right)}\right]$$

constant, c

$$\ln[Q] = c + 1 - Z - \sec\psi \cdot e^{-Z}$$

constant, C

$$\ln[Q] = C - Z - \sec\psi \cdot e^{-Z}$$




*For find the maximum ;*

$$\frac{d(\ln[Q])}{dz} = 0$$

# Find the value of $Q_m$

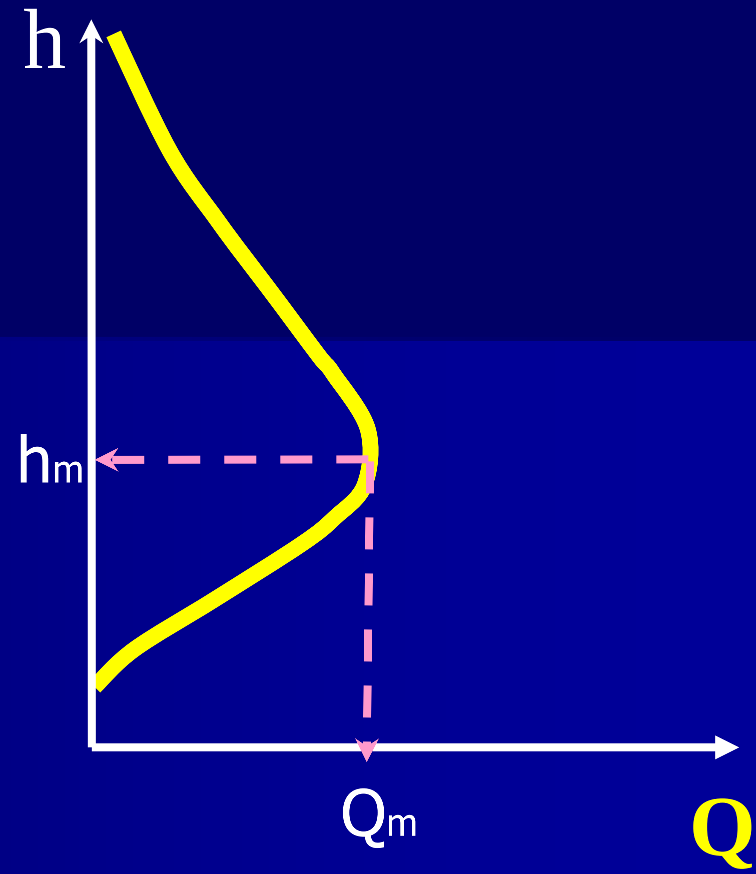
$$\ln[Q] = C - Z - \sec\psi \cdot e^{-Z}$$

$$\frac{d(\ln[Q])}{dz} = \frac{d\left(C - Z - \sec\psi \cdot e^{-Z}\right)}{dz}$$

$$\frac{d(\ln[Q])}{dz} = -1 - \sec\psi \cdot e^{-Z}(-1)$$

*For find the maximum ;*

$$\frac{d(\ln[Q])}{dz} = 0$$




$$\cos\psi = e^{-Z}$$

*We know,*

$$e^{-Z} = \sigma_a N H$$

# Find the value of $Q_m$

$$Q = \frac{\eta \cdot I_\infty}{e H} e^{\left(1 - Z - \sec\psi \cdot e^{-Z}\right)}$$ — 01

*For find the maximum ;*

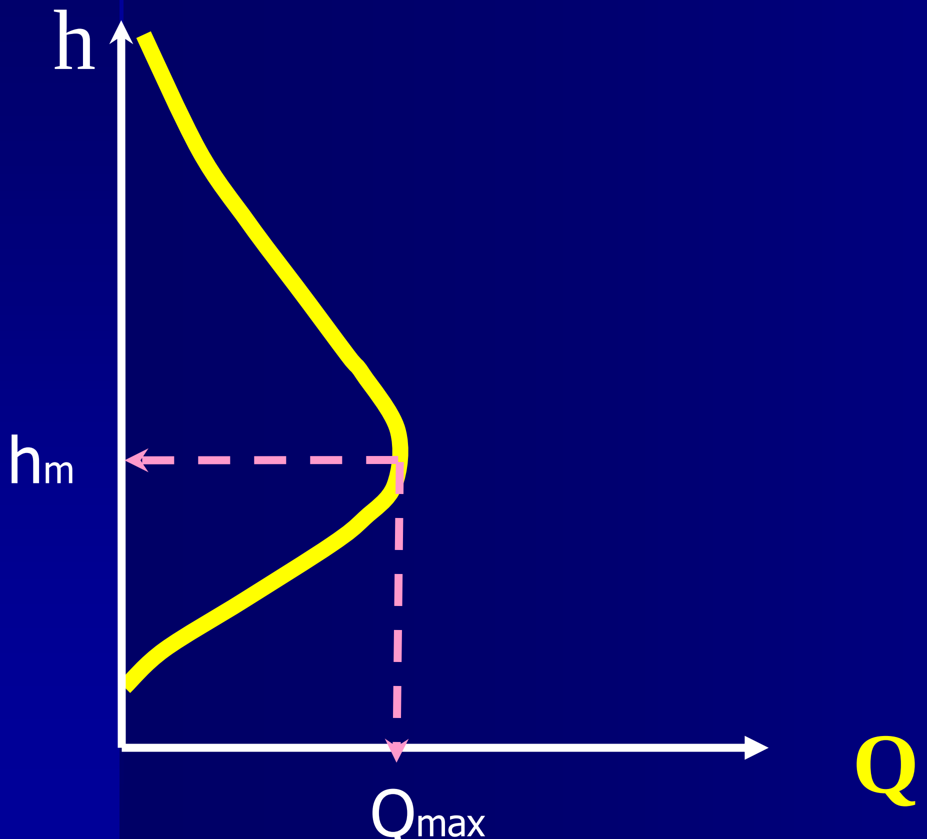
$$\frac{d\left(\ln[Q]\right)}{dz} = 0$$

$$\Rightarrow \cos\psi = e^{-Z}$$

*We know,* $$e^{-Z} = \sigma_a N H$$

*Using equation – 01 :*

$$\Rightarrow Q_{\max} = \frac{\eta \cdot I_\infty}{e H} \cos\psi$$



# Find the value of $Q_m$

$$Q_{max} = \frac{\eta \cdot I_\infty}{e\,H} \cos\psi$$

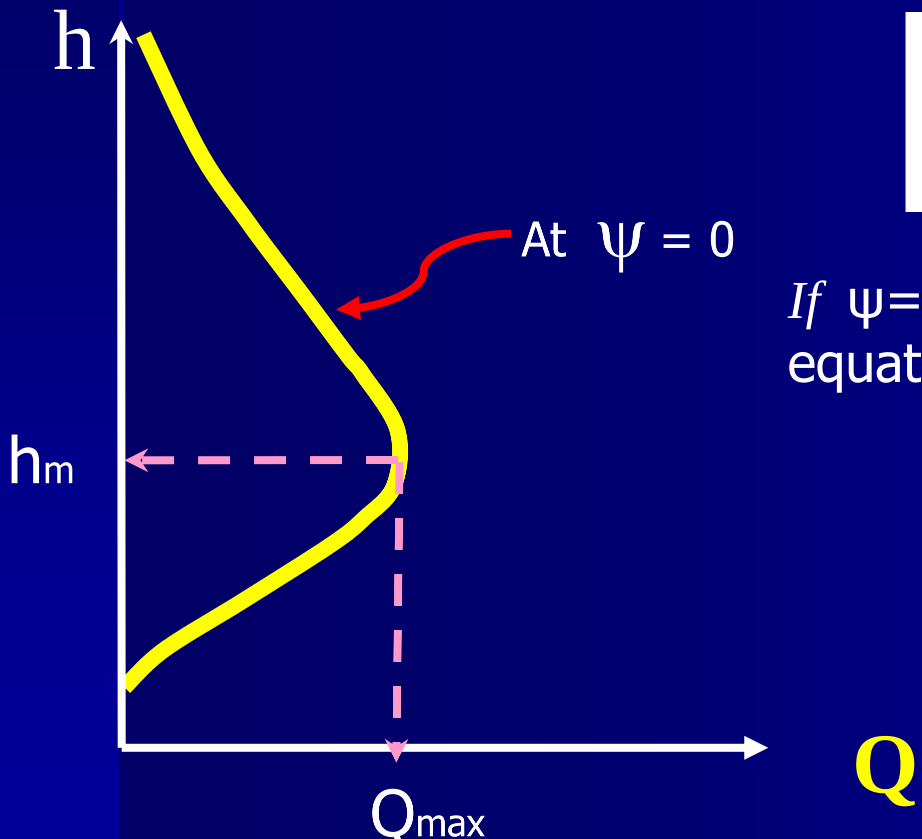
$$\cos\psi = \sigma_a \, N \, H$$

*Production Rate Q :*

$$Q = Q_{max} e^{\left(1 - \sec\psi \cdot e^{-Z}\right)}$$

*If* ψ=0°, Then the Sun is directly up on the equator *:*

$$Q_{max} = \frac{\eta \cdot I_\infty}{e\,H} (1)$$



# Find the value of $Q_m$

$$Q_{max} = \frac{\eta \cdot I_\infty}{e\,H} \cos\psi$$

*If* ψ=30°, Then the Sun is 30° from the equator :

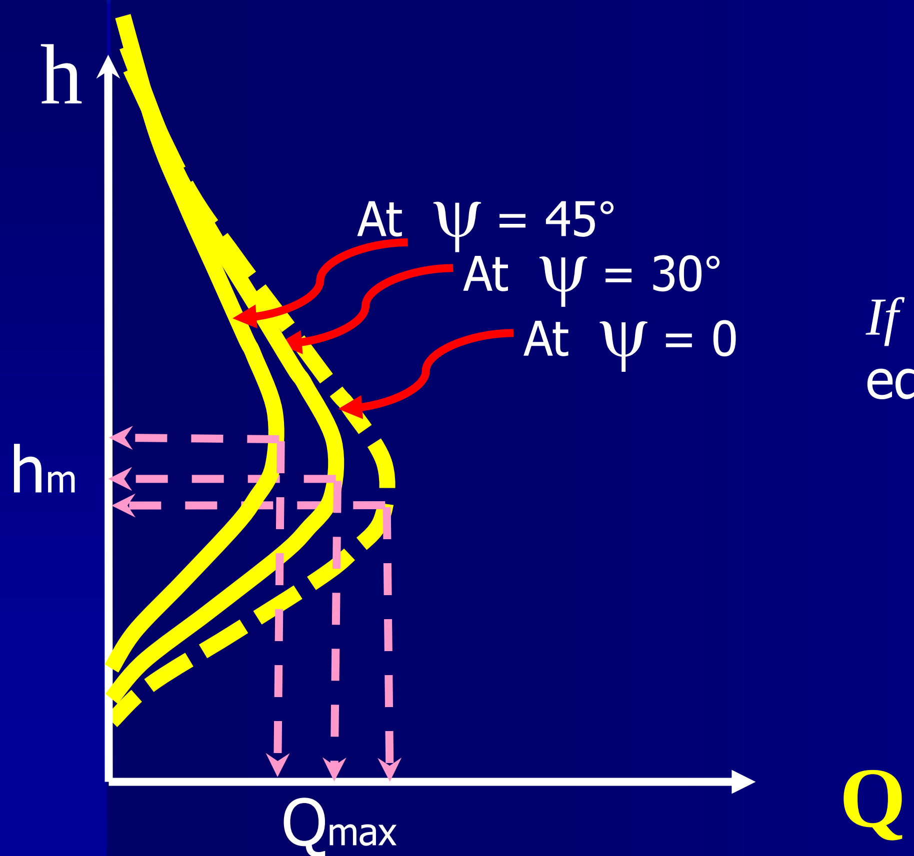
$$Q_{max} = \frac{\eta \cdot I_\infty}{e\,H} (Cos30)$$

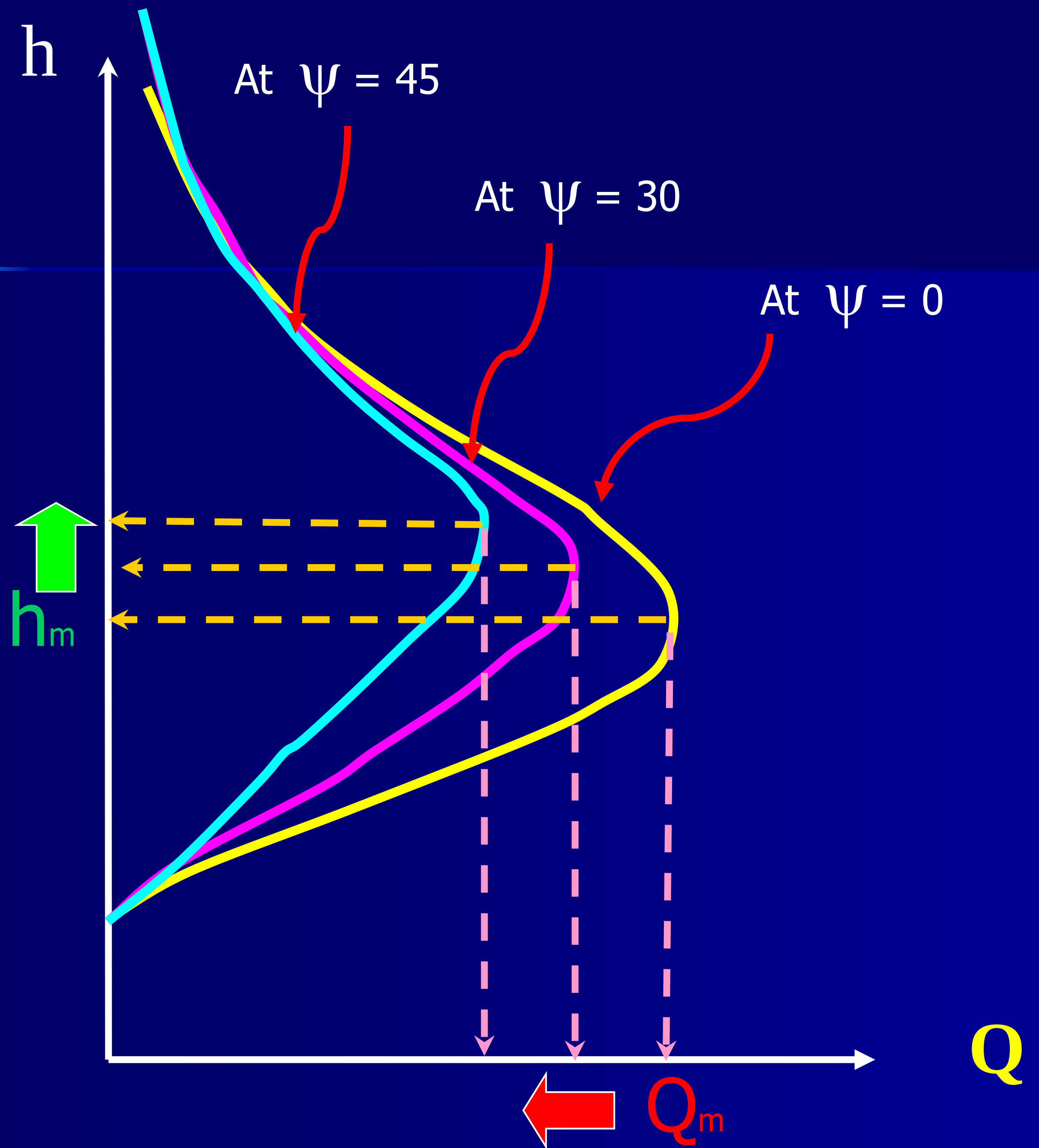
$$Q_{max} = \frac{\eta \cdot I_\infty}{e\,H} (0.8660)$$

*If* ψ=45°, Then the Sun is 45° from the equator :

$$Q_{max} = \frac{\eta \cdot I_\infty}{e\,H} (Cos45)$$

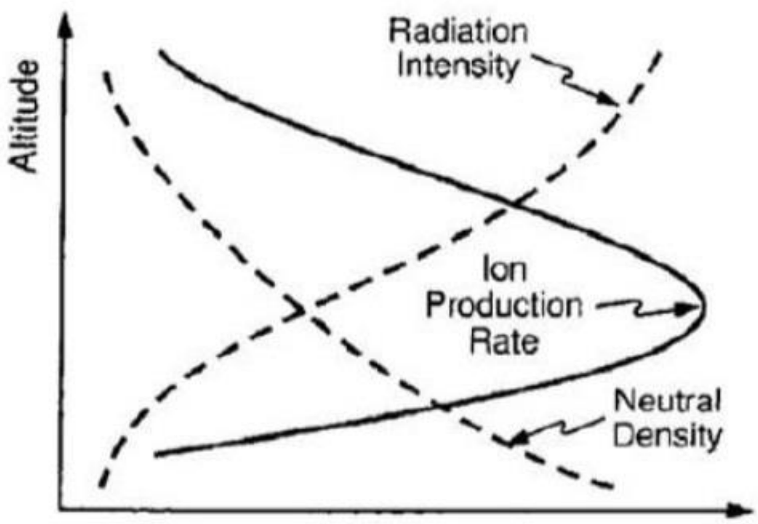
$$Q_{max} = \frac{\eta \cdot I_\infty}{e\,H} (0.7071)$$

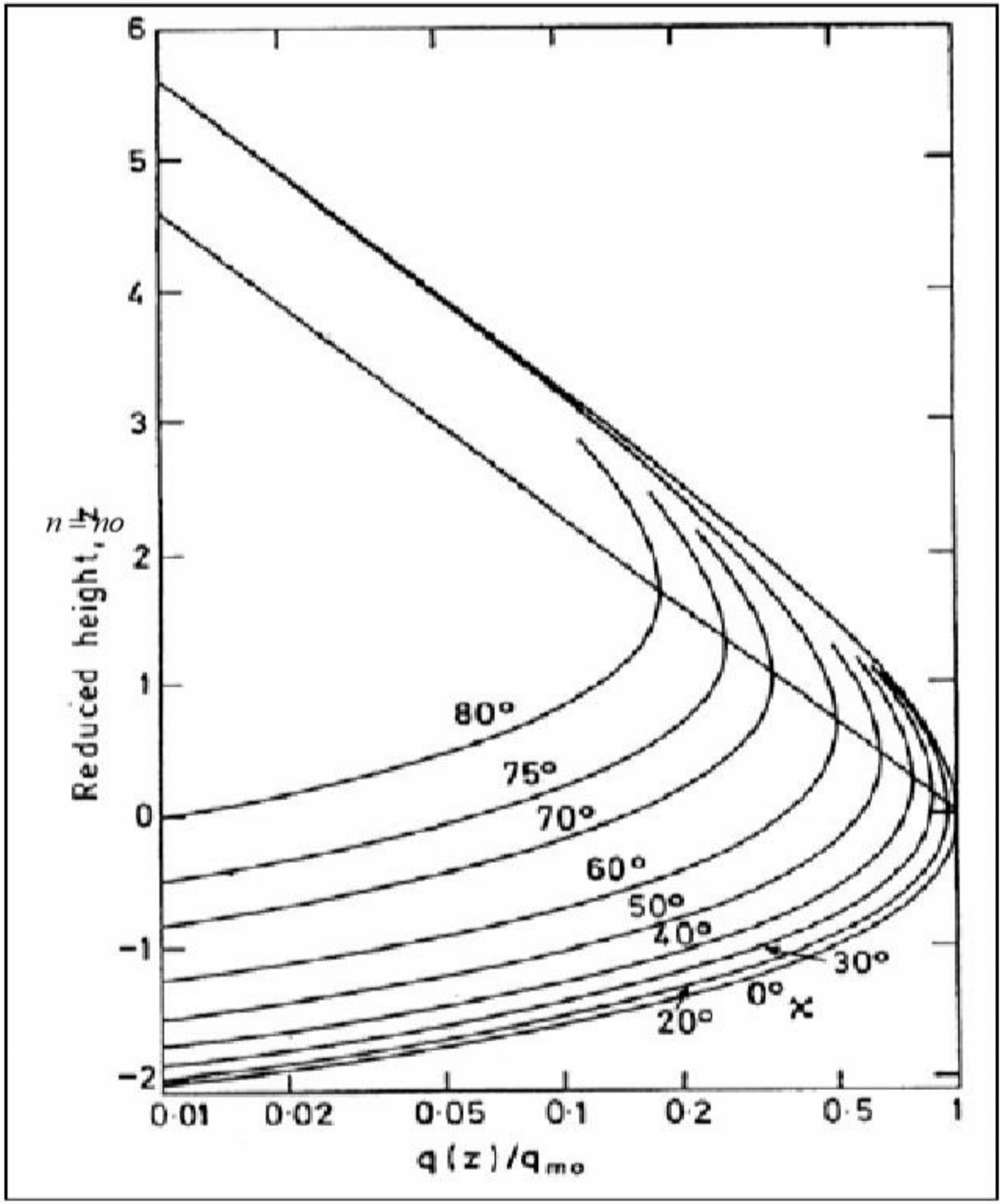




h
At ψ = 45
At ψ = 30
At ψ = 0
hm
Q
Qm

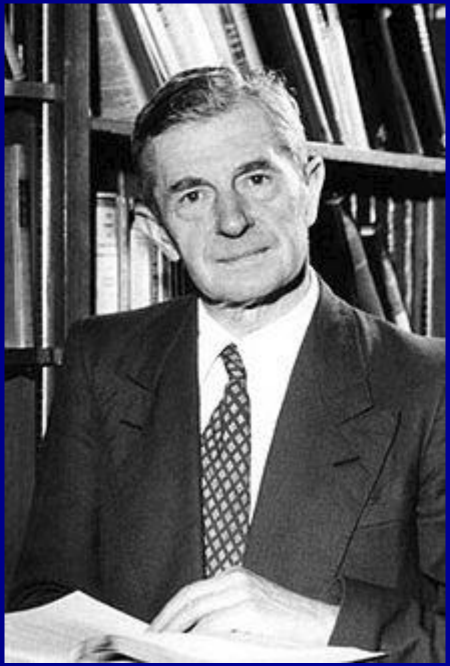
# Chapman's Production Profile



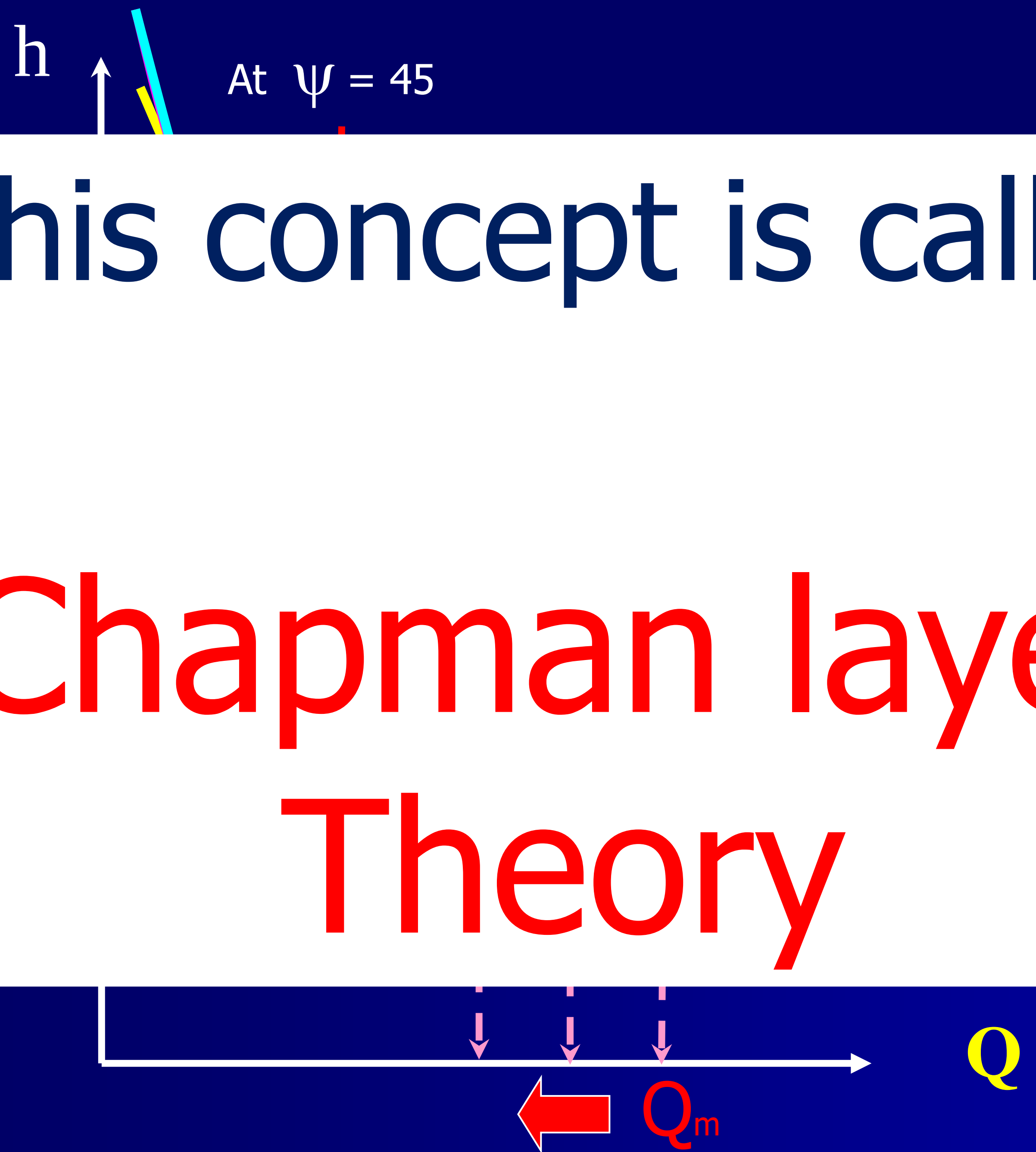



That means ψ is increasing, the maximum value of the Electron Production Rate is decreasing. For that Molecular Number Density of the ionosphere should be decreasing.

.: Region of the $Q_{max}$ is going to far away from the Earth surface. Because N should be decrees. Because h is low, N is high and h is high, N is low.



**Sydney Chapman** FRS (29 January 1888 – 16 June 1970) was a British mathematician and geophysicist. His work on the kinetic theory of gases, solar-terrestrial physics, and the Earth's ozone layer has inspired a broad range of research over many decades. He was Chief Professor of Mathematics at Imperial College London between 1924 and 1946.



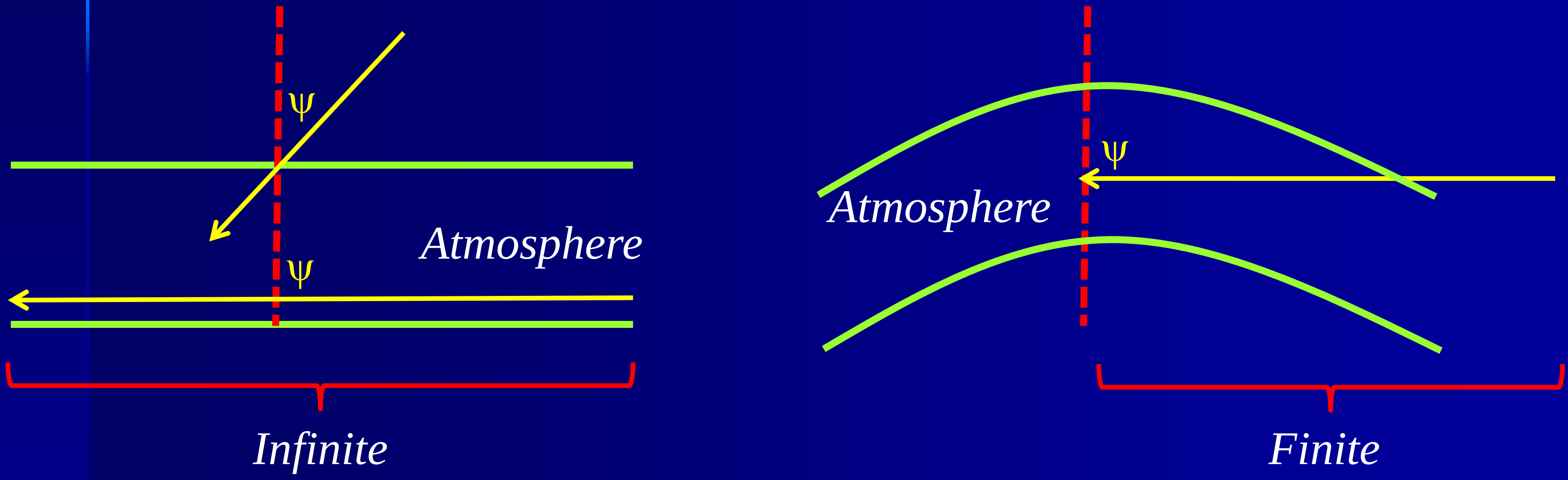

# This concept is called

# Chapman layer Theory

# Chapman layer Theory

## Electron Production Rate (Q)

*If* ψ (**angle of elevation** OR **Zenith Angle**) is high values (~90°), our plate assumption is not corrected.




*If* ψ = 90°, according to our formula and logics, N → 0 !

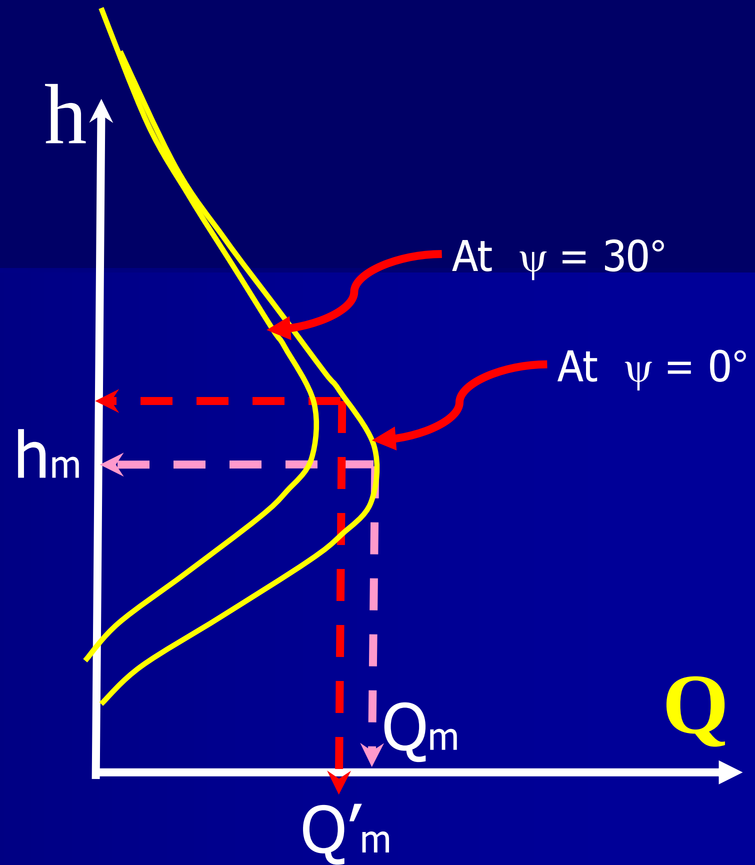
That means $Q_{max}$ is going to infinity. This is theoretical. But practically this should be large value; but not infinity.

# Chapman layer Theory

## Electron Production Rate (Q)

If we want to find the value of $Q'_m$ (using the graph), ψ should be zero. Because ψ>0, there is no point on the graph when $Q=Q'_m$ according to the graph.

That means, if we want to find the value of h corresponding $Q'_m$ :
It is depend on the "Time" of the day,
Eg: at 12:00 pm
at 1:00 pm
at 2:00 pm
. . .

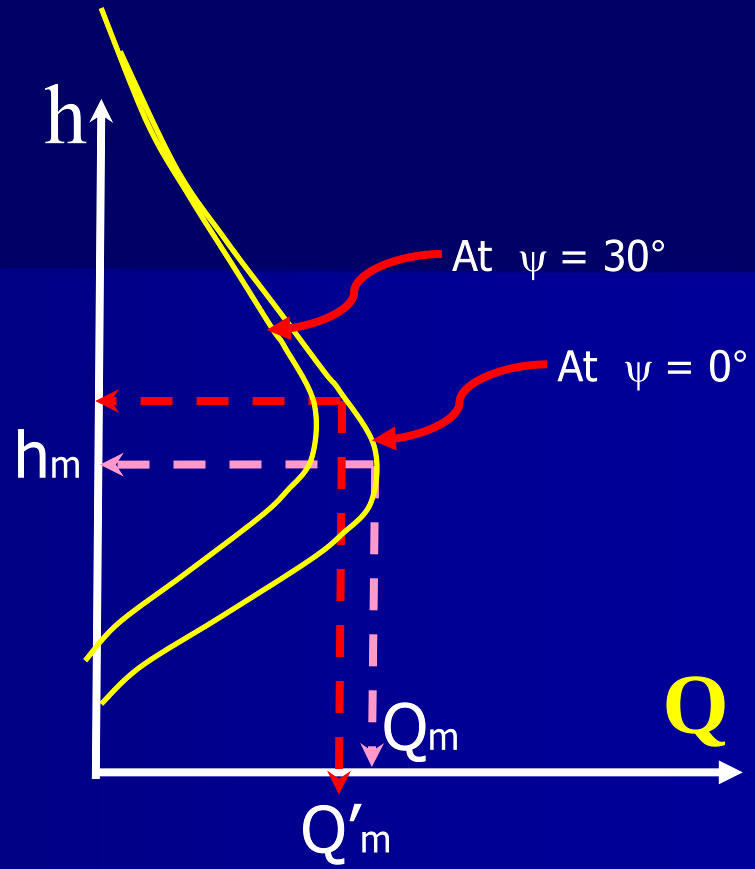



- **At the night** there is **no height to corresponding to our value $Q'_m$** ! Because our graph [according to Chapman Layer Theory] does not exist at night.

# Chapman layer Theory

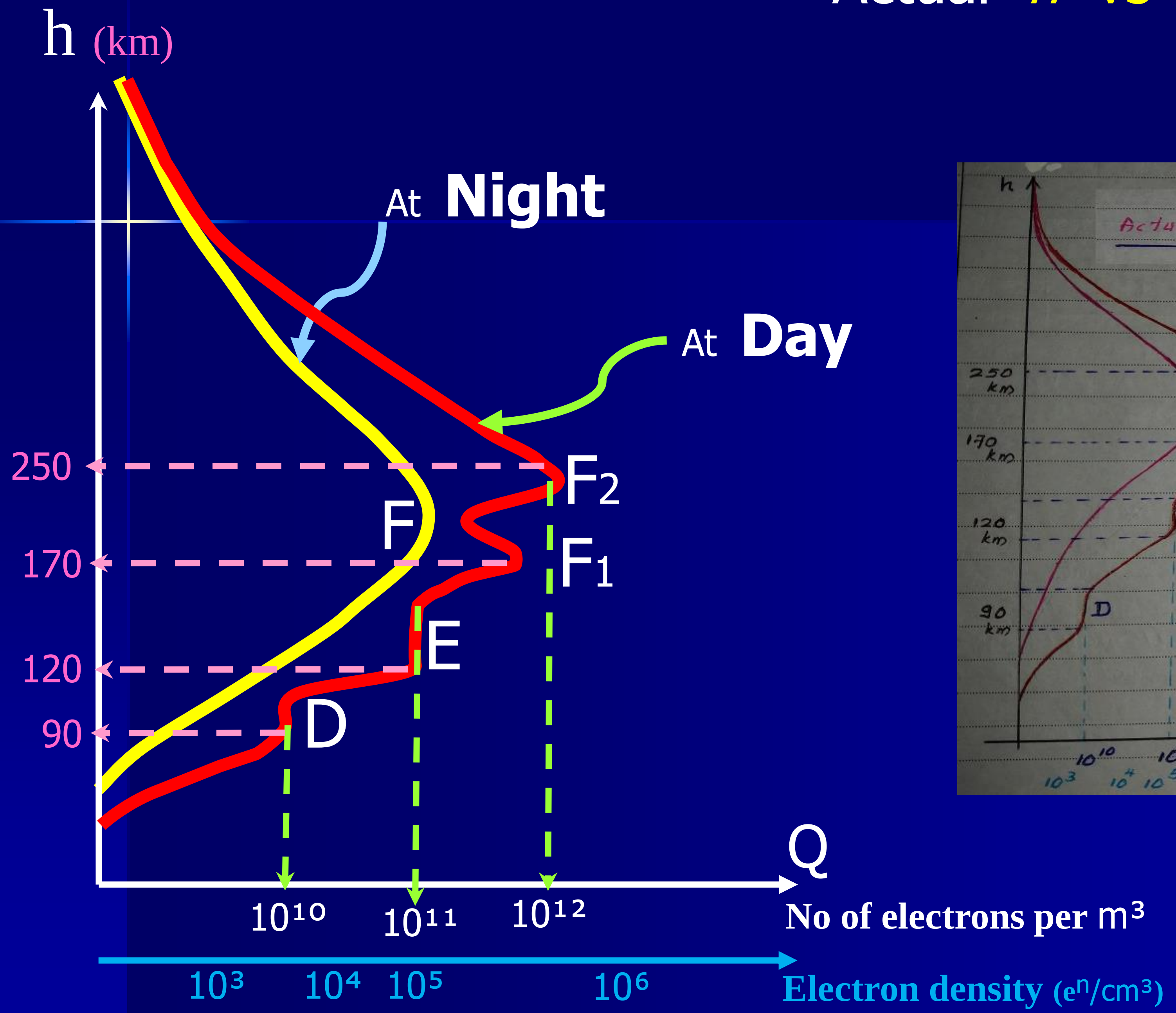
Electron Production Rate (Q)

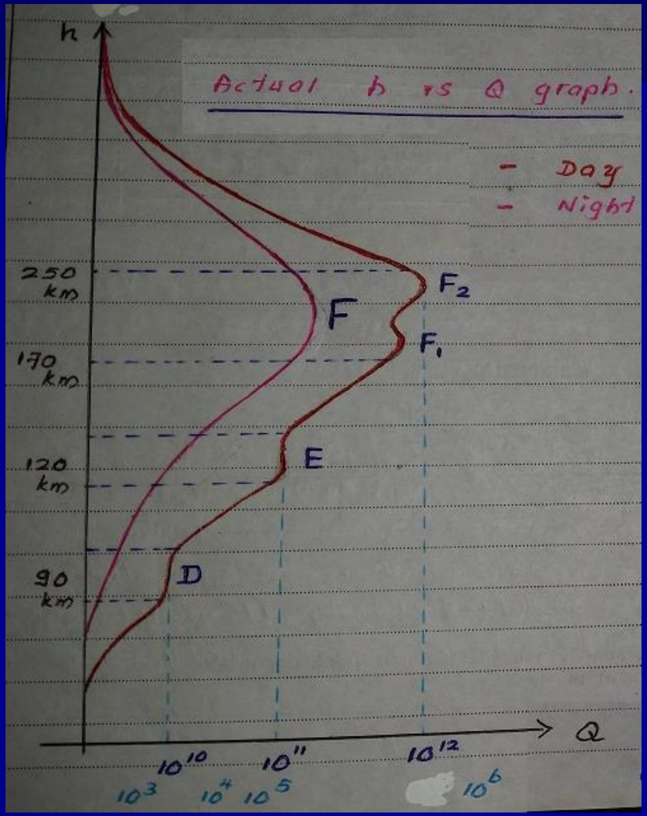
- There are **so many types of gasses in the atmosphere** of the Earth. As a result, the graph of h vs Q **should be contained several peaks**.
- Also if we assume there is a **monochromatic wavelength** comes from the Sun. This is wrong. There should be several peaks of the graph of h vs Q, because of there are **several wavelengths comes from the Sun to ionized the gasses**.




**:. We should consider all the effects that we discussed, before plotting the graph of h vs Q.**

# Actual *h* vs *Q* graph

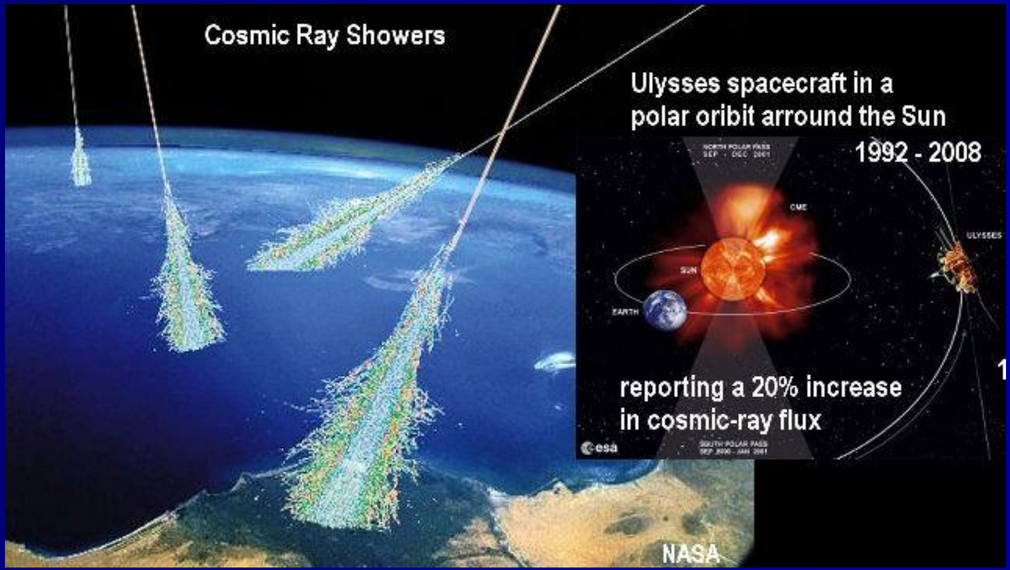


# Chapman layer Theory

- We can not find the value of Q (Electron Production Rate) at night using our derived formula. Because, if ψ > 90° our is formula failed !

$$Q = \frac{\eta \cdot I_\infty}{e H} e^{\left(1 - Z - \sec\psi \cdot e^{-Z}\right)}$$




- Galactic Cosmic Rays :

Galactic Cosmic Rays comes from the Sun and this radiation is spread all over the Universe. As a result this Galactic Cosmic Radiations comes to the Earth. At night there is no rays comes from the Sun, but Galactic Cosmic Radiations comes to the Earth at night. Therefore, there are several number of ionized electrons may exist at the night !

# The Ionosphere

Introduction
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Regular and Irregular Variations of the Ionosphere

# Plasma Frequency

Let us consider an ionized layer with an uniform electron density N and radio waves of frequency f incident normally (at right angles) upon the layer. If the frequency is above a limiting frequency $f_p$ the waves will pass through the layer, whereas if **$f < f_p$** , the waves will be reflected back. This critical frequency is called the **Plasma Frequency, $f_p$** and is proportional to the square root of the **electron density, N** of the Layer

$$f_p \; \alpha \; N^{1/2}$$

# Plasma Frequency

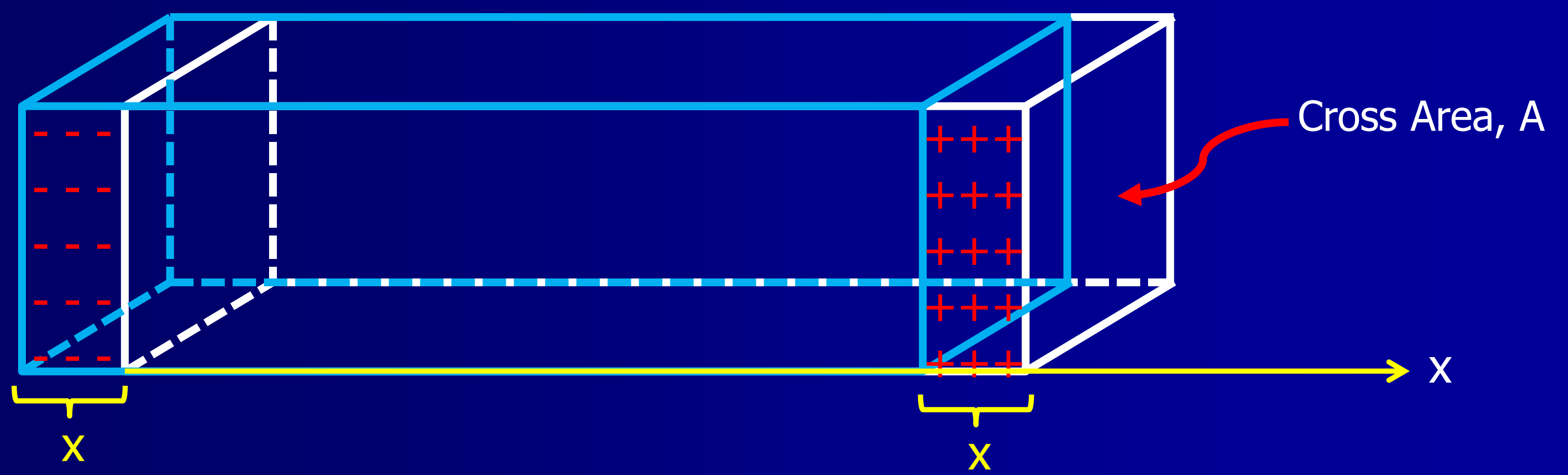
Plasma is the name given to a **mixture of** electrons, ions and neutral particles. When an electromagnetic wave such as the radio wave enters into a plasma, its electric field tends to set the charge particles in motion. The ions, which are about **$10^4$** times heavier than the electrons, respond very little to the weak field of the wave and can be considered as stationary. The light electrons, on the other hand, react readily to the **-eE** force acting on them. (Where -e is the negative charge of an electron )

Let $N_i$ and $N_e$ be the initial number of densities of the ions and electrons. Since the ionosphere is neutral we can set,

$$N_i = N_e = N$$

# Plasma Frequency

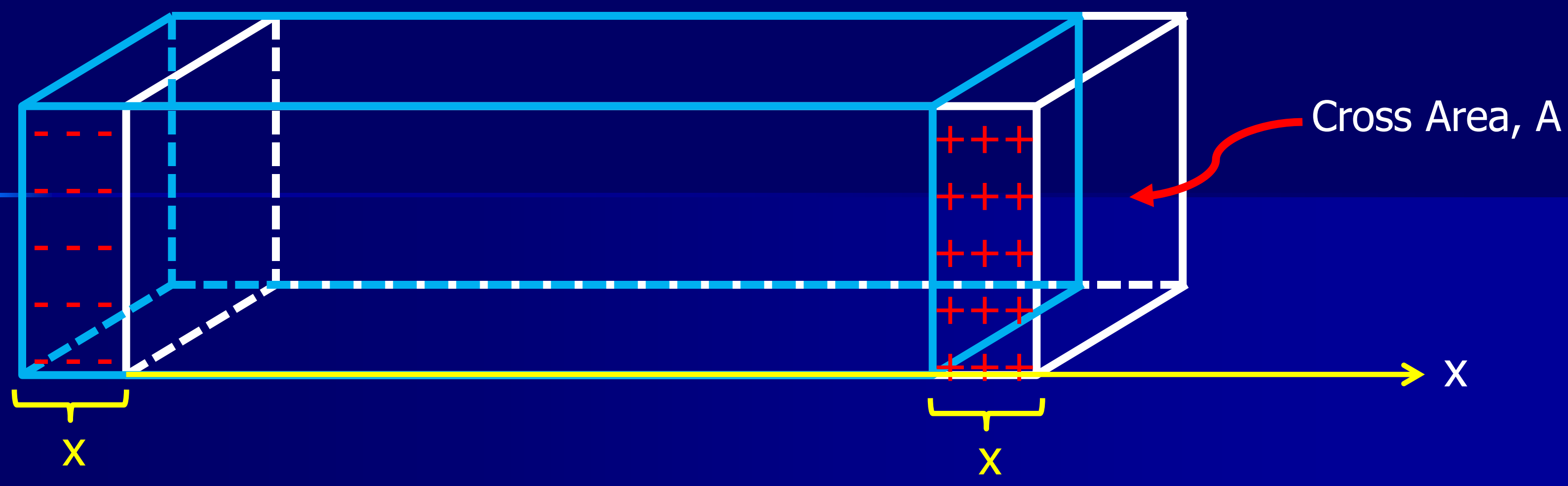
Assuming charge distribution of +ve ions and –ve electrons are separated like the following figure,




For instance, consider a one-dimensional situation in which a slab consisting entirely of one charge species is displaced from its quasi-neutral position by an infinitesimal distance x,

Volume of the charge distribution = $x \times 1\ m^2$

# Plasma Frequency




Number of charges in the Volume = $x \times N$

(Where $N$ is electron (charge) density)

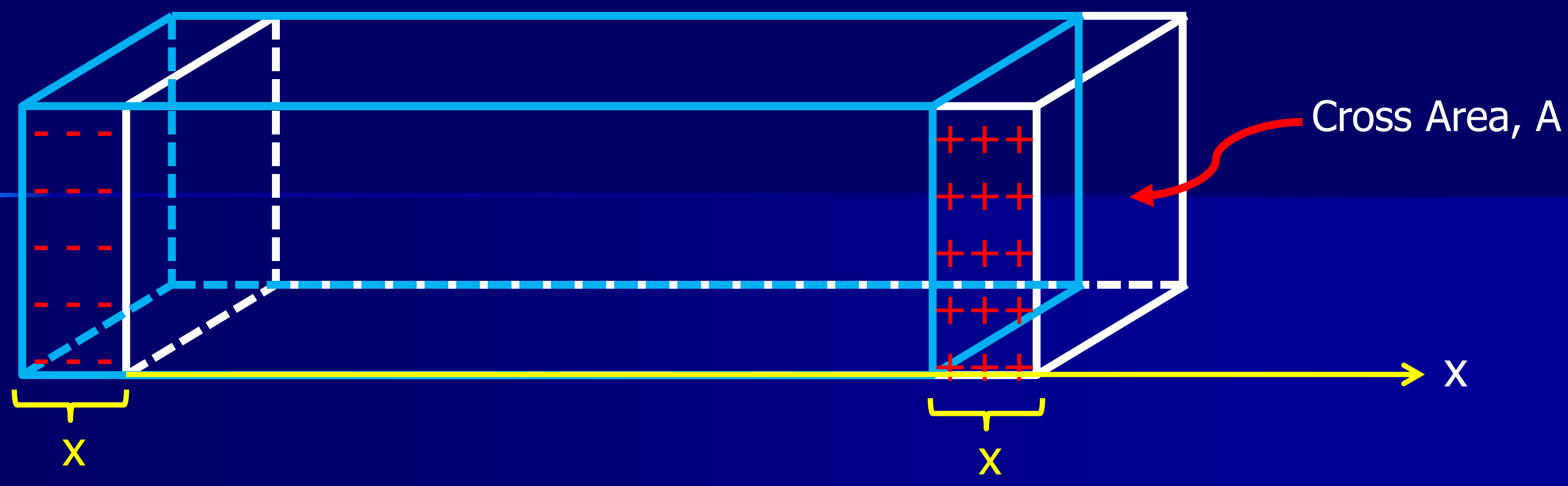
.: Surface charge density = $e \times xN$

(Where $e$ is charge of an electron)

$$\sigma = eNx$$

( The resulting charge density which develops on the leading face of the slab )

# Plasma Frequency



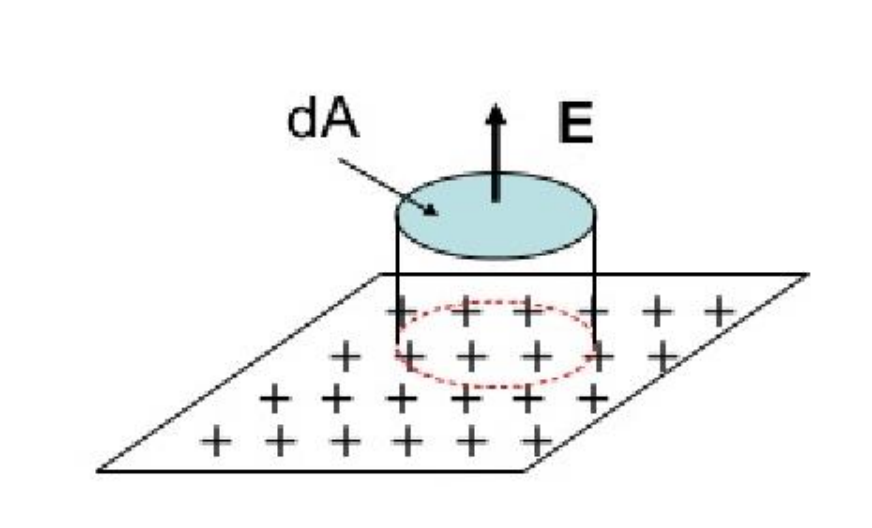

( As equal and opposite charge density develops on the opposite face. The x-direction electric field, generally inside the slab : [Using Gauss law, if we consider this is like a parallel plate situation] )

$$E_x = -\frac{\sigma}{\varepsilon_o}$$

(This negative sign for the direction)

Proof -> P. T. O

# Plasma Frequency




Using Gauss law,

$$\int_S \mathbf{E}.d\mathbf{S} = \frac{Q_{encl}}{\varepsilon_o}$$

We consider this is like a **parallel plate** situation :

$$E \cdot dA = \frac{\sigma.dA}{\varepsilon_o}$$

$$\mathbf{E} = \frac{\sigma}{\varepsilon_o}$$

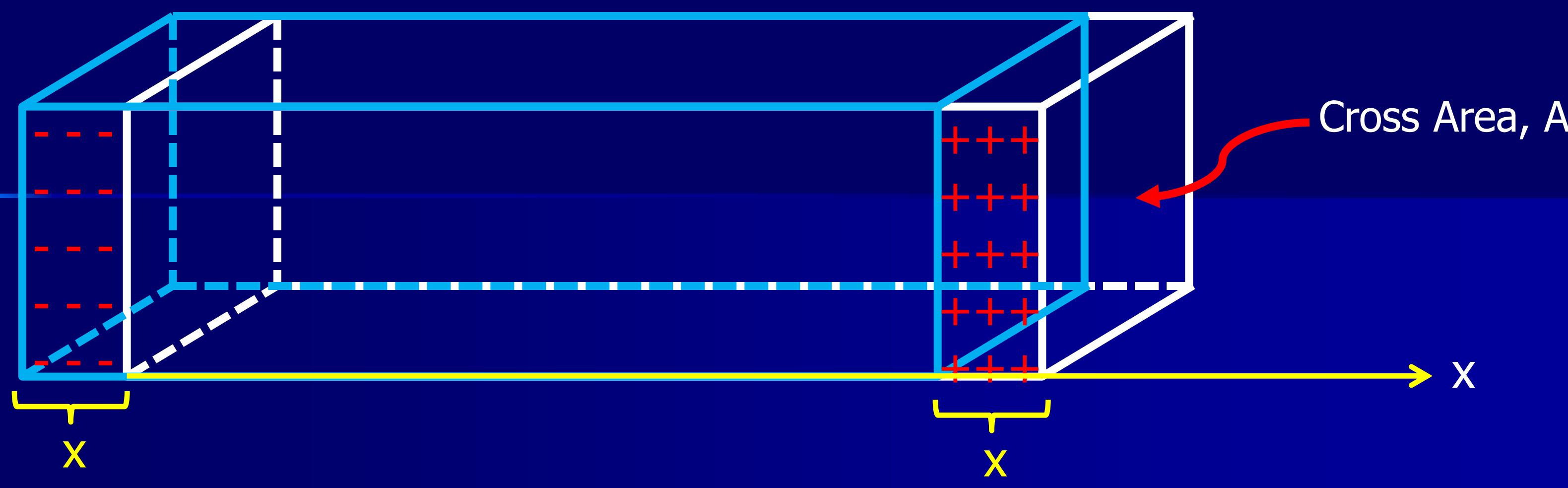
For our case :

$$E_x = -\frac{\sigma}{\varepsilon_o}$$

(This negative sign for the direction)

Force on an electron $F = e \times E$

# Plasma Frequency



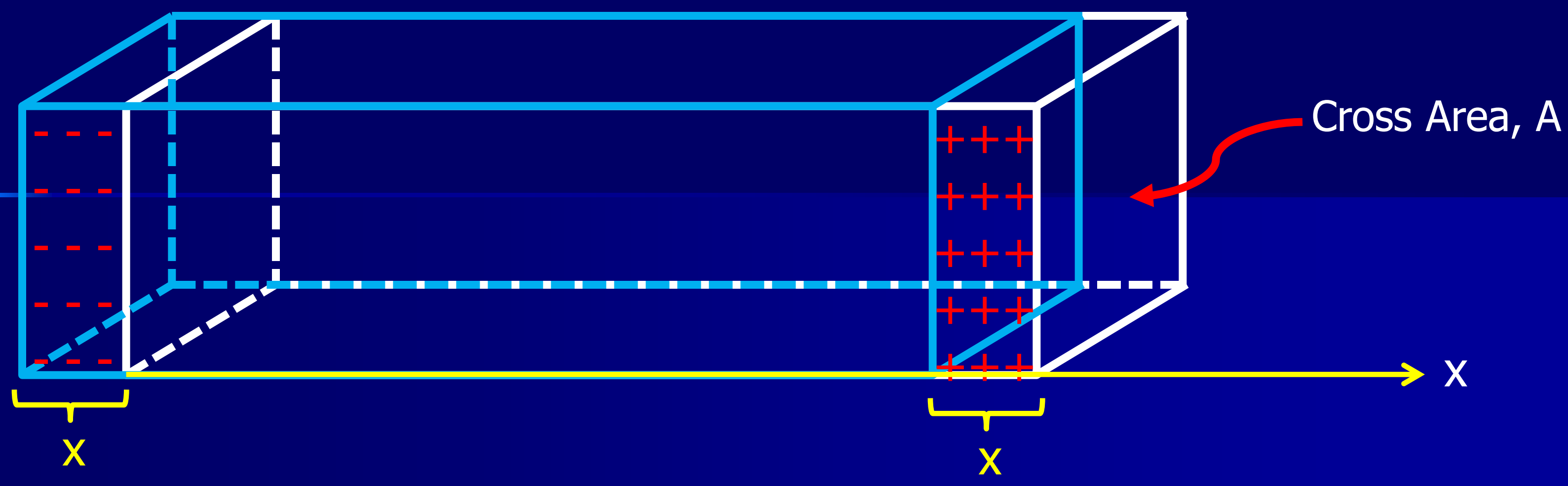

$$F = e \times E$$ ➡ $$F = e \times \left( -\frac{\sigma}{\varepsilon_o} \right)$$ ➡ $$F = e \times \left( -\frac{eNx}{\varepsilon_o} \right)$$

➡ $$F = -\frac{e^2 Nx}{\varepsilon_o}$$

Thus, Newton's 2nd law applied to an individual particle inside the slab yields,

$$\vec{F} = m\vec{a}$$

# Plasma Frequency




$$\vec{F} = m\vec{a}$$

$$\Rightarrow \quad -\frac{e^2 N x}{\varepsilon_o} = m\frac{d^2 x}{dt^2}$$

$$\Rightarrow \quad \ddot{x} = -\frac{e^2 N}{\varepsilon_o m} x$$

This is the equation of the Simple Harmonic Oscillation;

$$\ddot{x} = -\omega^2 x$$

# Plasma Frequency

Then, the Angular Plasma Frequency; $$\omega_p{}^2 = \frac{e^2 N}{\varepsilon_o m}$$ and the Plasma Frequency; $$f_p = \frac{\omega_p}{2\pi}$$

$$\Rightarrow \quad f_p = \frac{e}{2\pi(\varepsilon_o m)^{1/2}} N^{1/2}$$

The *plasma frequency*, is the most fundamental time-scale in plasma physics. Clearly, there is a different plasma frequency for each species. However, the relatively fast electron frequency is, by far, the most important, and references to "the plasma frequency" in text-books invariably mean the *electron* plasma frequency.

# Plasma Frequency

$$f_p = \frac{e}{2\pi(\varepsilon_o m)^{1/2}} N^{1/2}$$

A constant !

Where,

$$e = 1.6 \times 10^{-19} C$$

$$m = 9.1 \times 10^{-31} kg$$

$$\varepsilon_o = 8.85 \times 10^{-12} F\, m^{-1}$$

Then,

$$\frac{e}{2\pi(\varepsilon_o m)^{1/2}} = 8.97 \cong 9$$

$$f_p = 9 N^{1/2}$$

Where, $f_p$ is the Plasma Frequency of the medium ( is measured in Hz )

$N$ is the Molecular Number Density of the medium ( is measured in $e^n / m^3$ )

Eg :

If electron density at some height is $10^{12}$ $e^n/m^3$, Find the plasma frequency of the medium at that height.

$$f_p = 9N^{1/2} \Rightarrow f_p = 9\times\left(10^{12}\right)^{1/2} \Rightarrow f_p = 9\times 10^6$$

$$\Rightarrow f_p = 9\ MHz$$

That means, if we send a Radio Wave of frequency 9 MHz , it is reflected from the region of the atmosphere when the electron density is $10^{12}$ $e^n/m^3$.

That height is situated at **F** region (actually **F2** region)

# Ionospheric regions

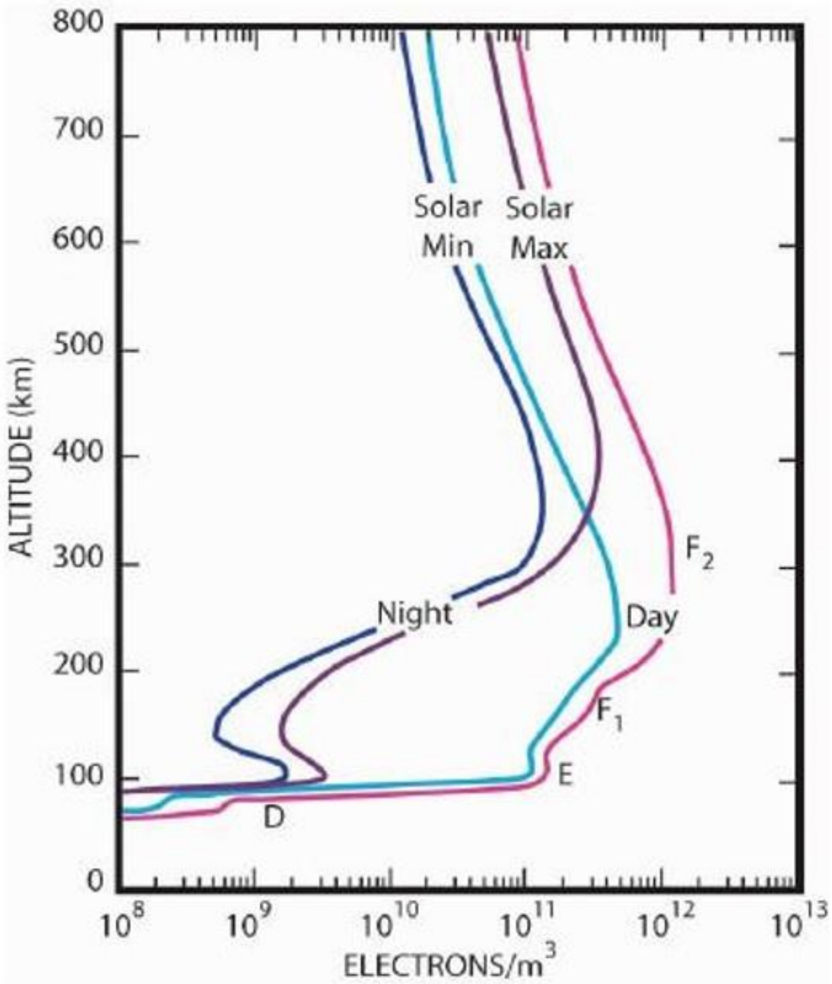



Figure: Typical ionospheric electron density profiles.

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)

## For D region :

- D region: 60–90 km, $n_e = 10^8 – 10^{10}\ m^{-3}$

$f_p = 90\ kHz$ to $f_p = 900\ kHz$

That means, if we send a Radio Wave of frequency 90 kHz to 900 kHz, it is reflected from the **D** region; when the electron density is $10^8$ - $10^{10}$ $e^n/m^3$.

## For E region :

- E region: 90–150 km, $n_e = 10^{10} – 10^{11}\ m^{-3}$

$f_p = 900\ kHz$ to $f_p = 2.85\ MHz$

That means, if we send a Radio Wave of frequency 900 kHz to 2.85 MHz, it is reflected from the **E** region; when the electron density is $10^{10}$ - $10^{11}$ $e^n/m^3$.

## For F region :

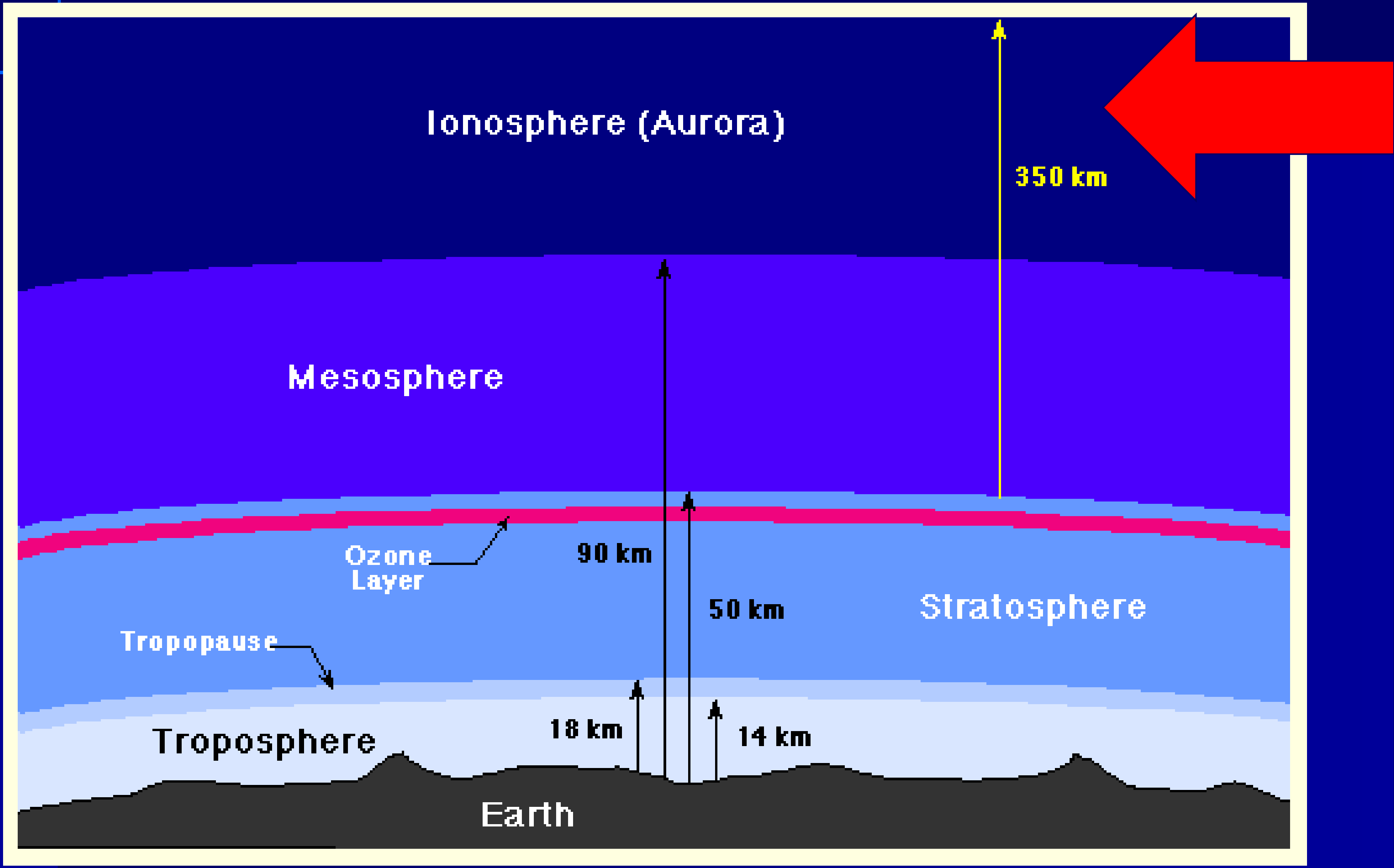
- F region: 150–1000 km, $n_e = 10^{11}$–$10^{12}$ m$^{-3}$ .

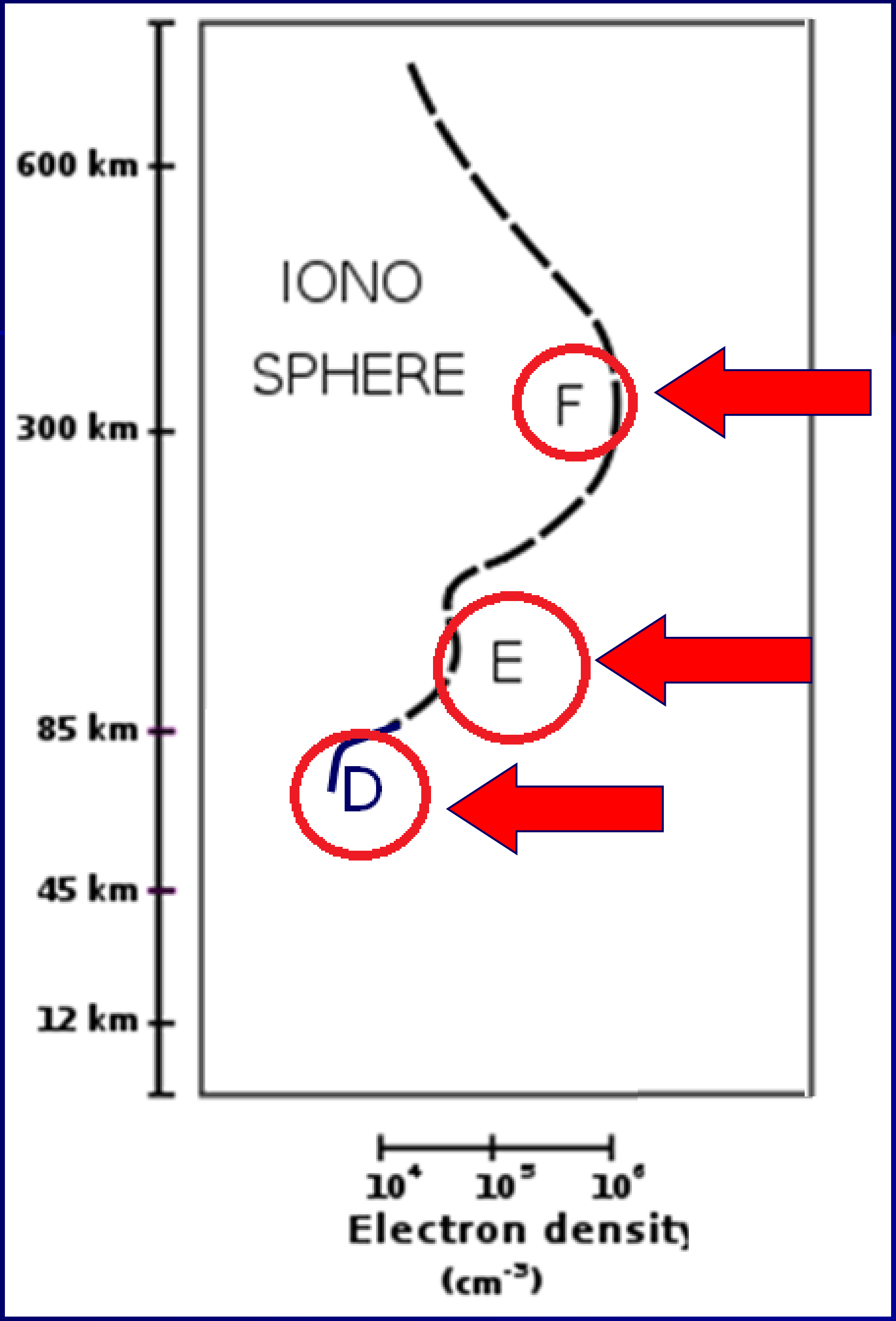
$f_p = 2.85 \ MHz$ to $f_p = 9 \ MHz$

That means, if we send a Radio Wave of frequency 2.85 MHz to 9 MHz, it is reflected from the **F** region; when the electron density is $10^{11}$ - $10^{12}$ $e^n/m^3$.

But if we send **UHF (300 MHz)** or **VHF (30 MHz)** signal (Radio Wave); the wave **goes through the ionosphere without any reflection** !

# The Structure of the Ionosphere



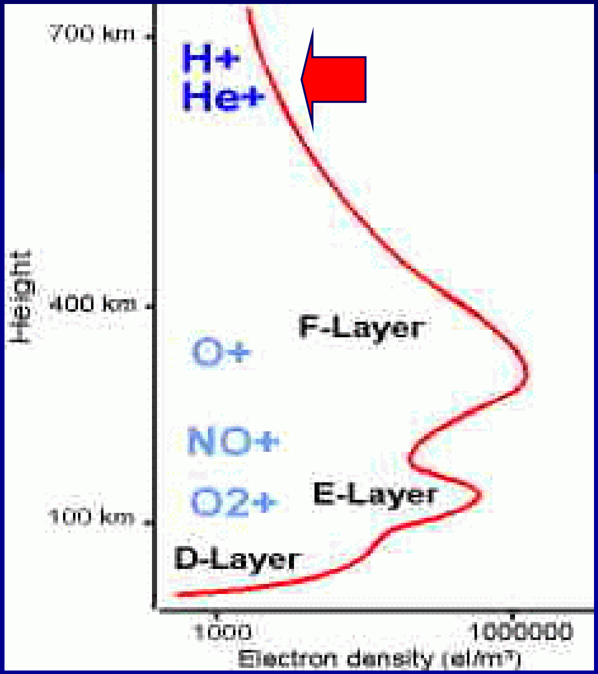


600 km
300 km
85 km
45 km
12 km
IONO
SPHERE
F
E
D
10⁴ 10⁵ 10⁶
Electron density
(cm⁻³)

# The Upper Ionosphere

**At attitudes above the $F_2$ peak both the production and the loss of electrons tend to Zero, which means that the upper ionosphere is maintained through the upward diffusion of ionization.**

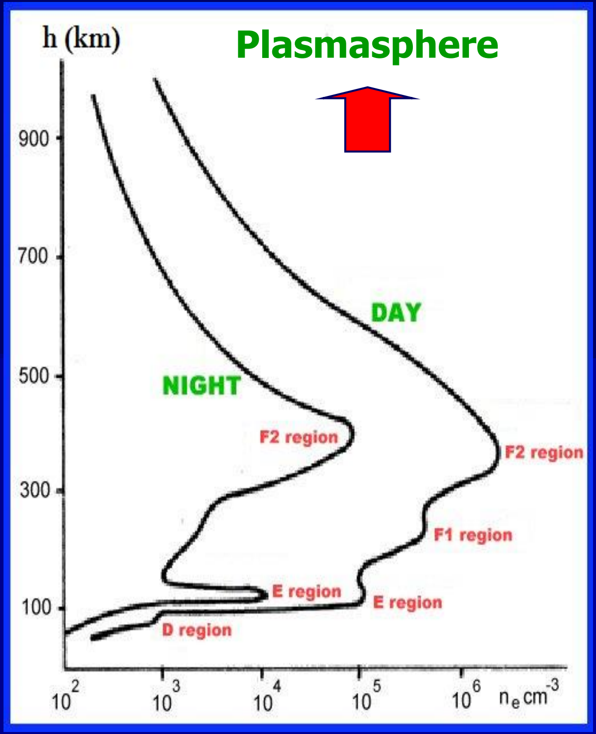
In the presence of the **Earth's Magnetic Field**, which tends to guide the diffusion of the charged particles along the field lines, this becomes a very complicated phenomenon to study.

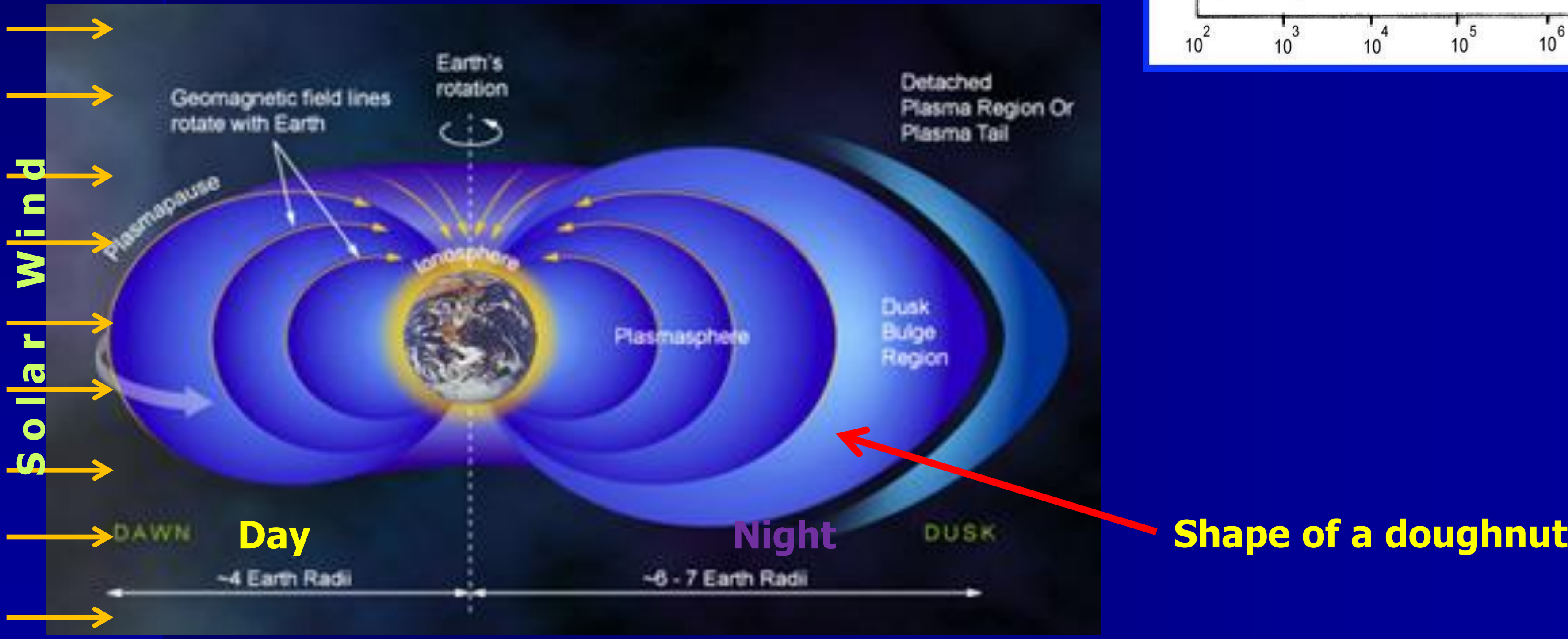



Around 1000 km O+ is replaced by He+ as the predominant ion, and at even higher attitudes (~2500 km) He+ is replaced by H+, i.e.; by free protons. The layer where helium ions dominate is often called **heliosphere** and the region above it is called the **protonosphere**.

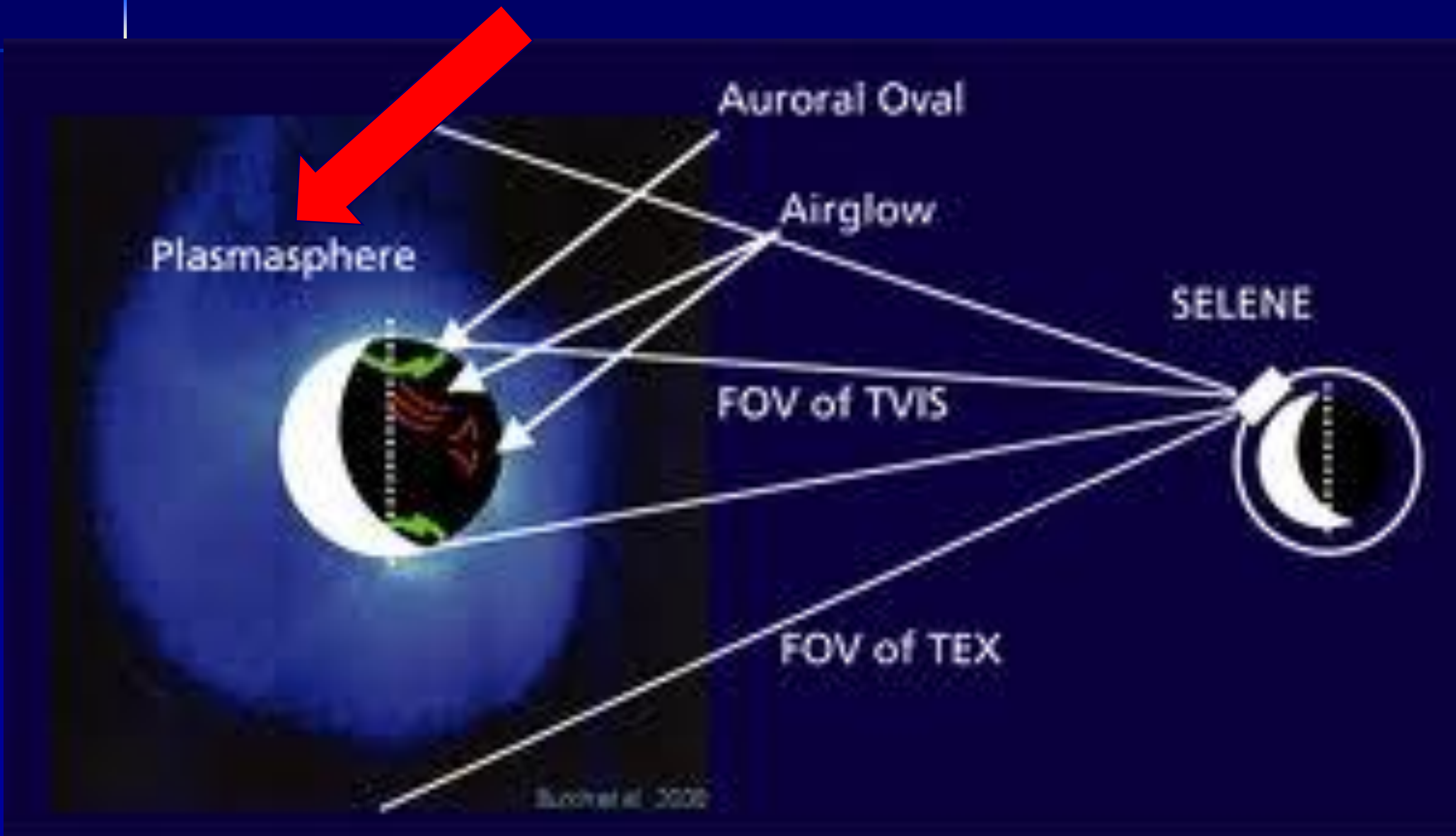
# The Plasmasphere

This is the region of the Earth's ionized atmosphere which basically follows the rotation of the Earth. The plasmasphere has the shape of a doughut, very much like the volume formed by the lines of the Earths dipole magnetic field which provides the link that keeps the plasmasphere rotating with Earth.

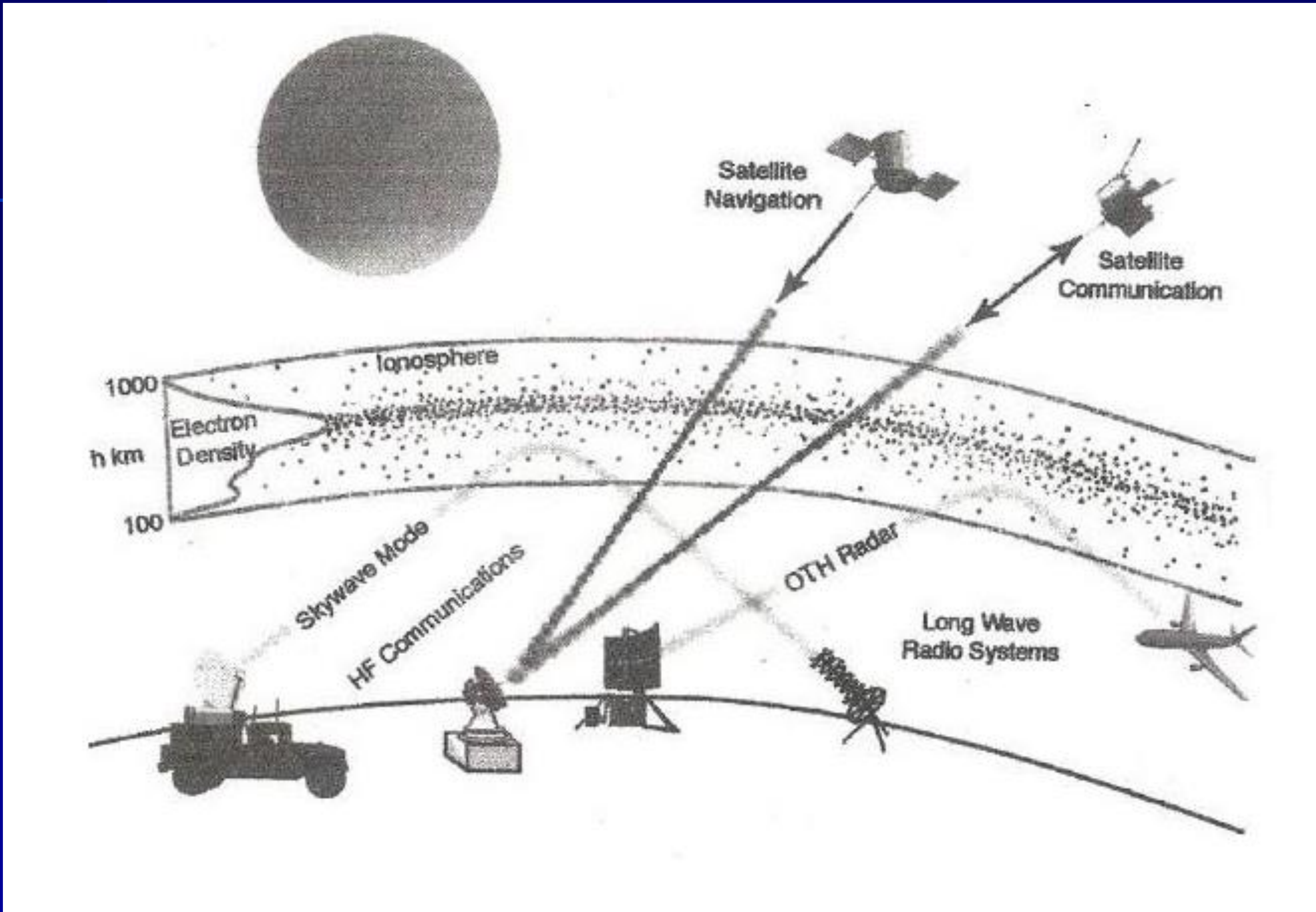


# The Plasmasphere



# Penetration Depth



Satellite
Navigation
Satellite
Communication
Ionosphere
1000
Electron
Density
h km
100
Skywave Mode
HF Communications
OTH Radar
Long Wave
Radio Systems

# Penetration Depth

Penetration Depth is defined as the depth at which the intensity of the radiation in the atmosphere falls to 1/e (~37%) of its original value of the surface.

The equation of the intensity;

$$I(h) = I(0)\ e^{-\alpha\ h}$$

Where ***alpha*** is some constant.

Penetration Depth = $\frac{1}{\alpha}$

Proof : PTO

# Penetration Depth

$$I(h) = I(0)\, e^{-\alpha h}$$

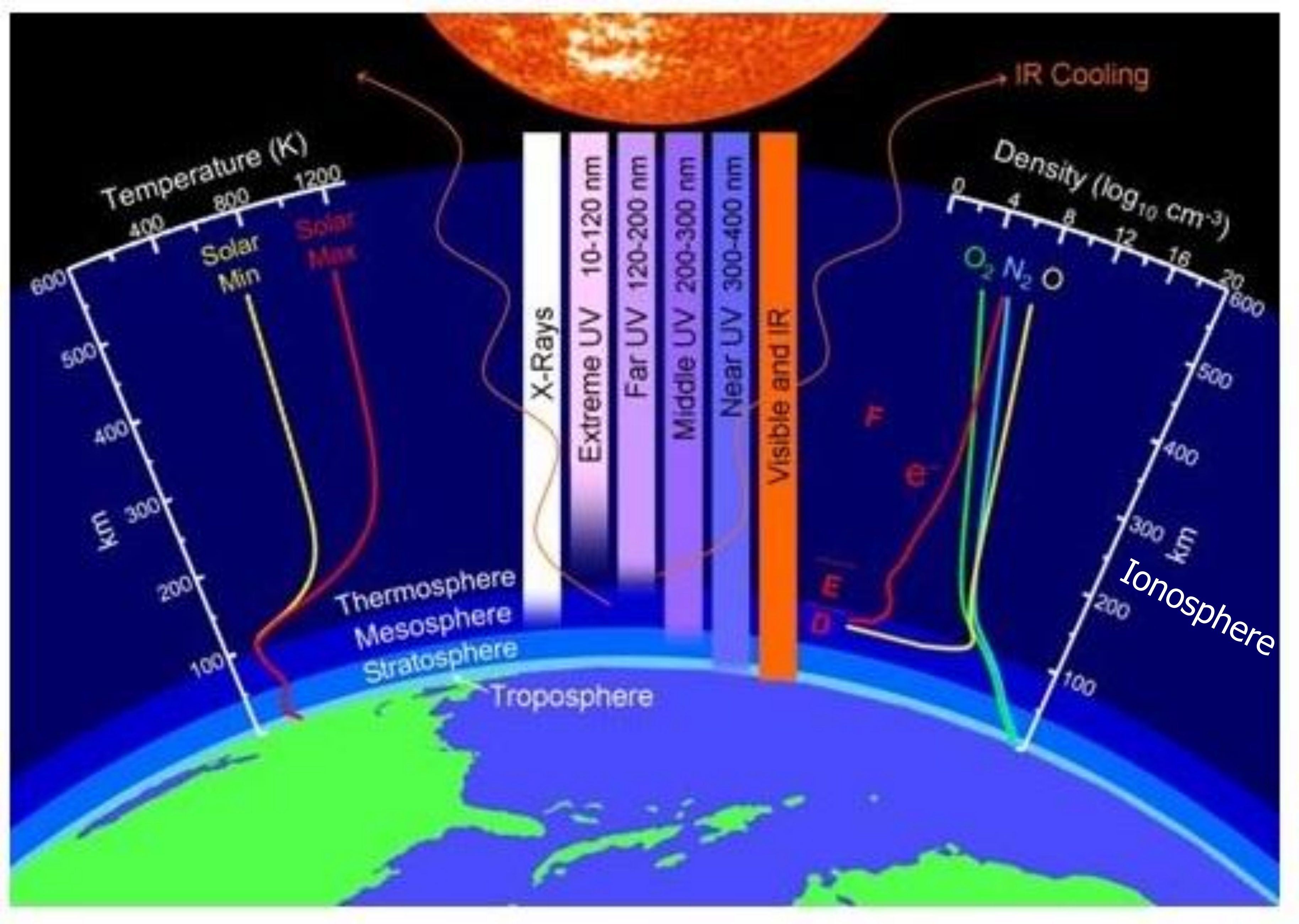
At h = h (Penetration Depth) ➡ $I(h) = I(0)/e$

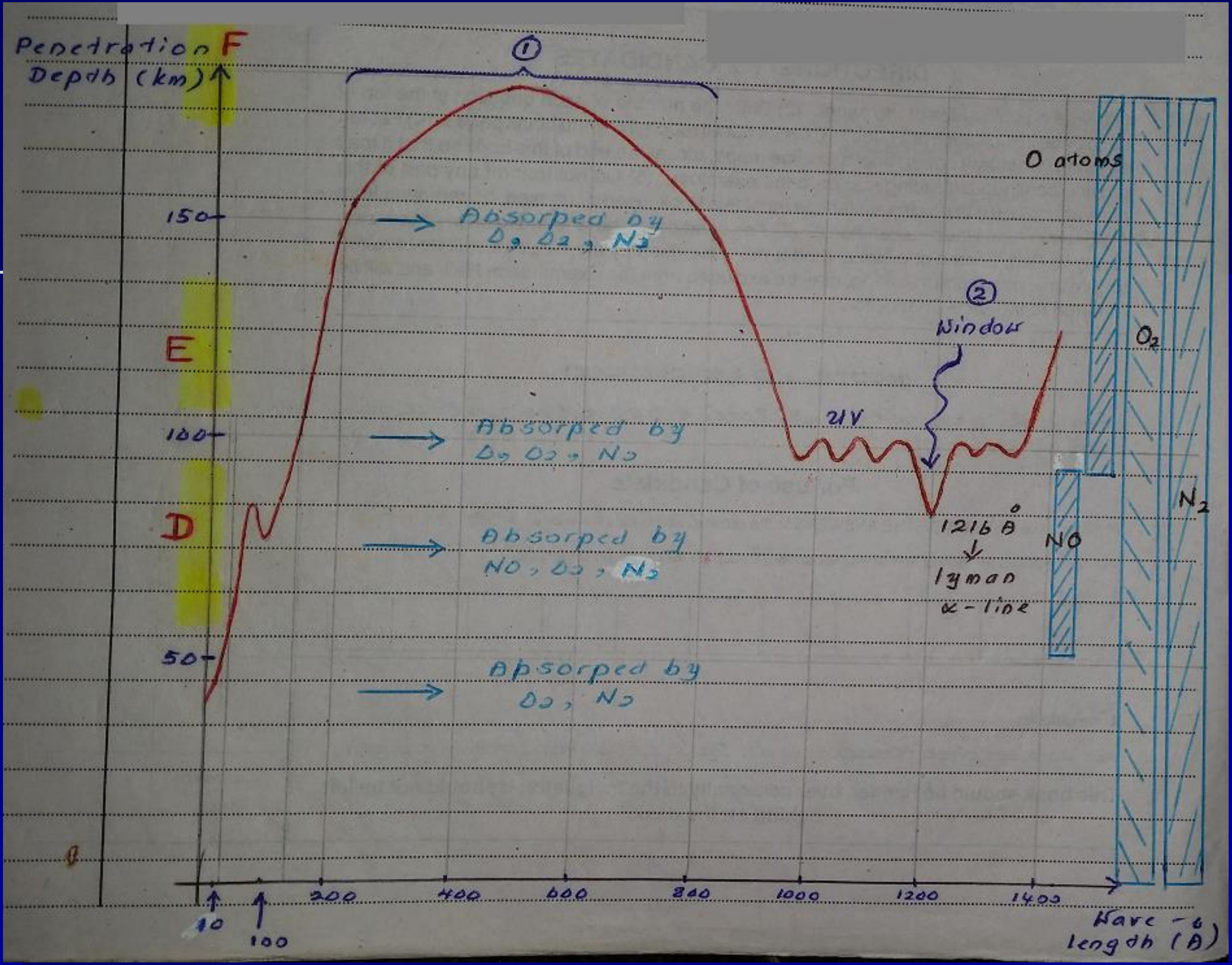
➡ $$I(0)/e = I(0)\, e^{-\alpha h}$$

➡ $$e^{-1} = e^{-\alpha h}$$

➡ $$\alpha h = 1$$

➡ $$h = 1/\alpha$$ ; Where h is Penetration Depth

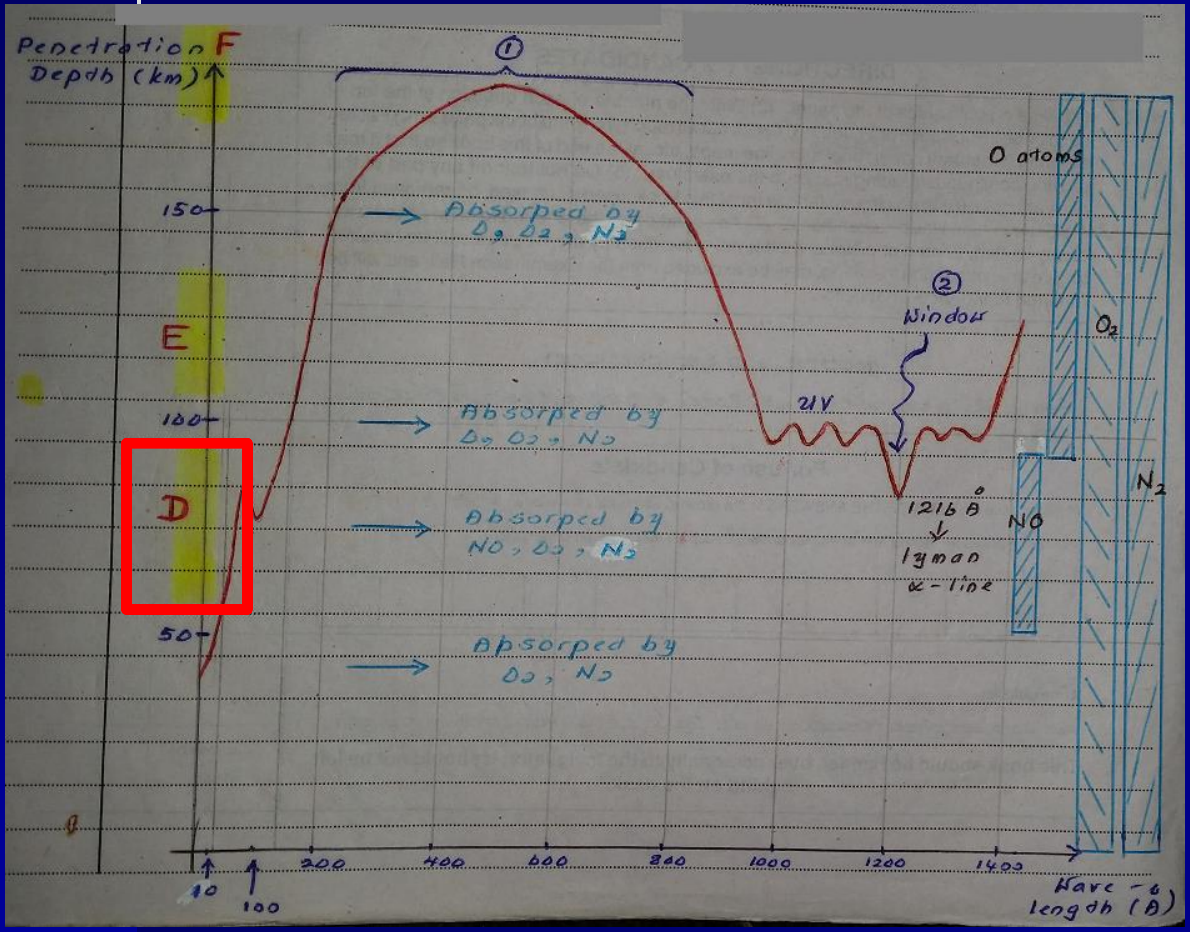

IR Cooling
Temperature (K)
400
800
1200
600
500
400
300
200
100
km
Solar Min
Solar Max
X-Rays
Extreme UV 10-120 nm
Far UV 120-200 nm
Middle UV 200-300 nm
Near UV 300-400 nm
Visible and IR
Density ($log_{10}$ $cm^{-3}$)
0
4
8
12
16
20
$O_2$ $N_2$ O
F
$e^-$
E
D
Thermosphere
Mesosphere
Stratosphere
Troposphere
Ionosphere




**The graph of Penetration Depth vs wave-length of the Radiation comes from the Sun**

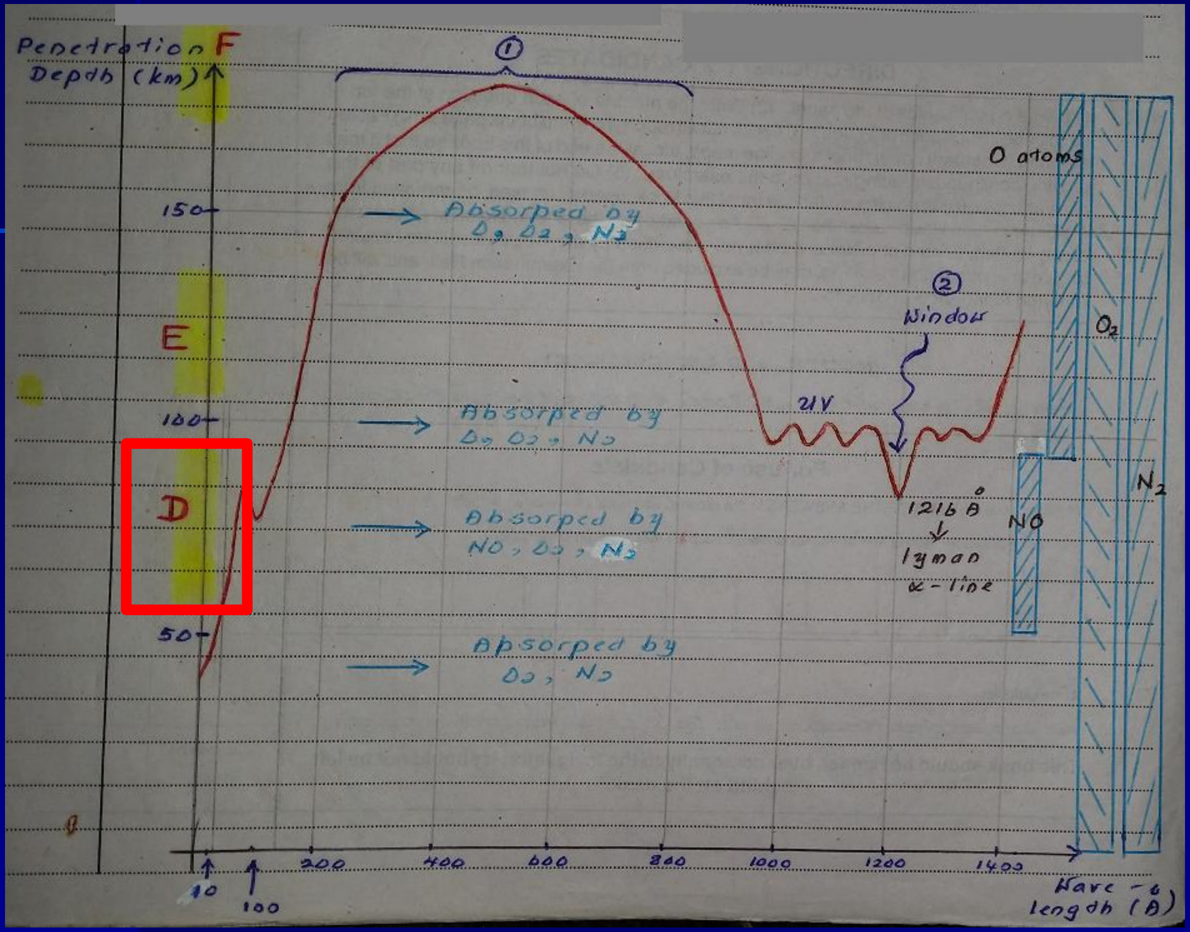
# Penetration Depth

This diagram indicates penetration depth of the radiation comes from the Sun. Also that radiation comes from the upper side of the atmosphere to the surface of the Earth.




- Cause of the D-Region of the ionosphere, wavelength of the radiation 10 Å comes from the Sun.

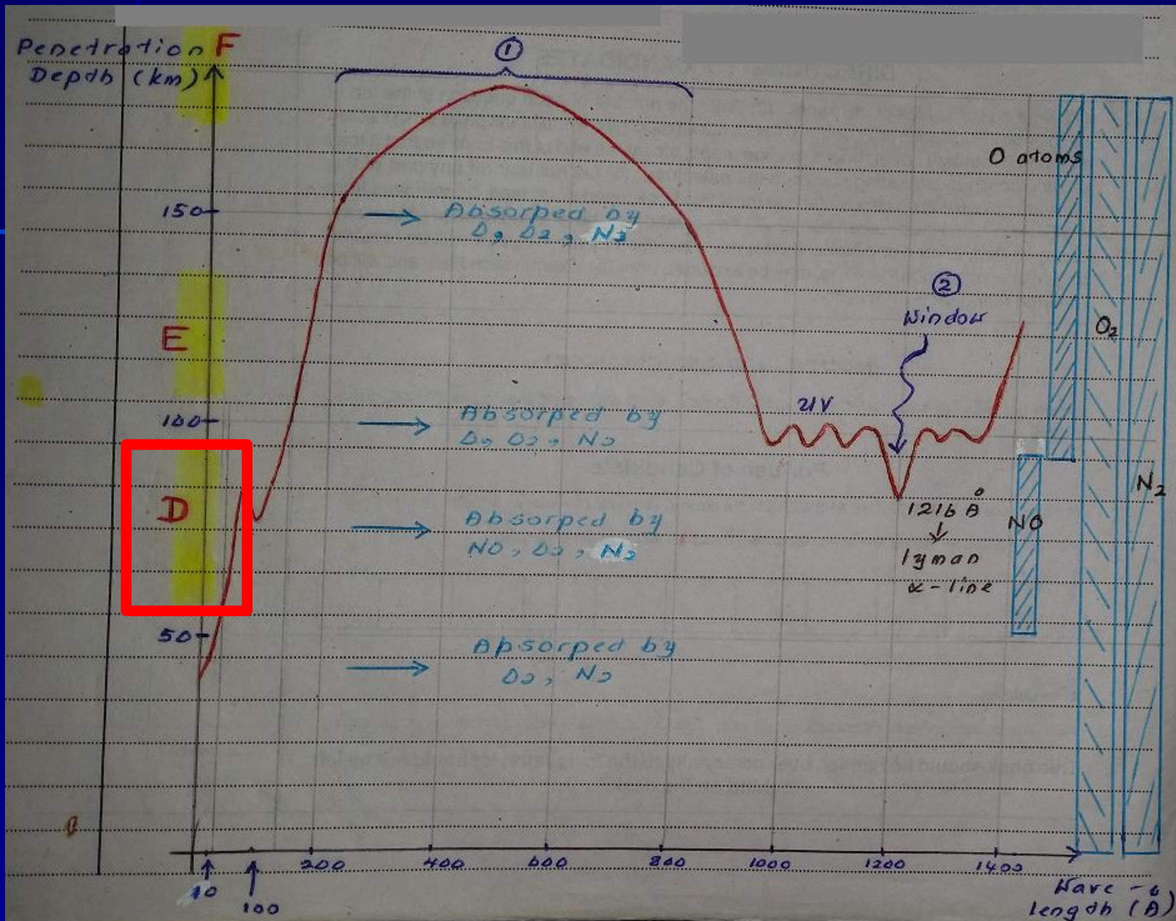
# Penetration Depth




- The size of the D-Region is **increasing** when the season of the **increase of the Solar Activity**.

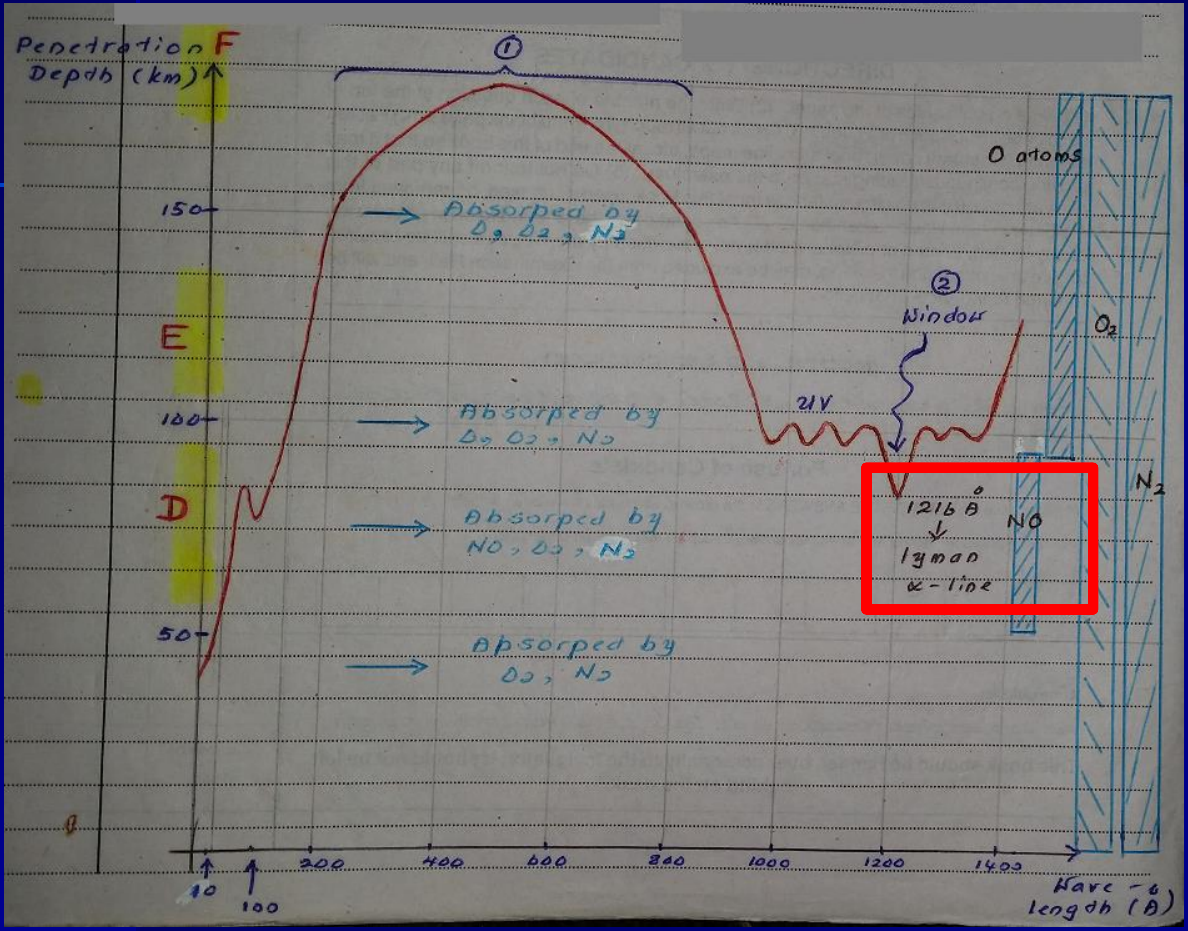
**This phenomena has a ~11.2 years cycle !**

# Penetration Depth



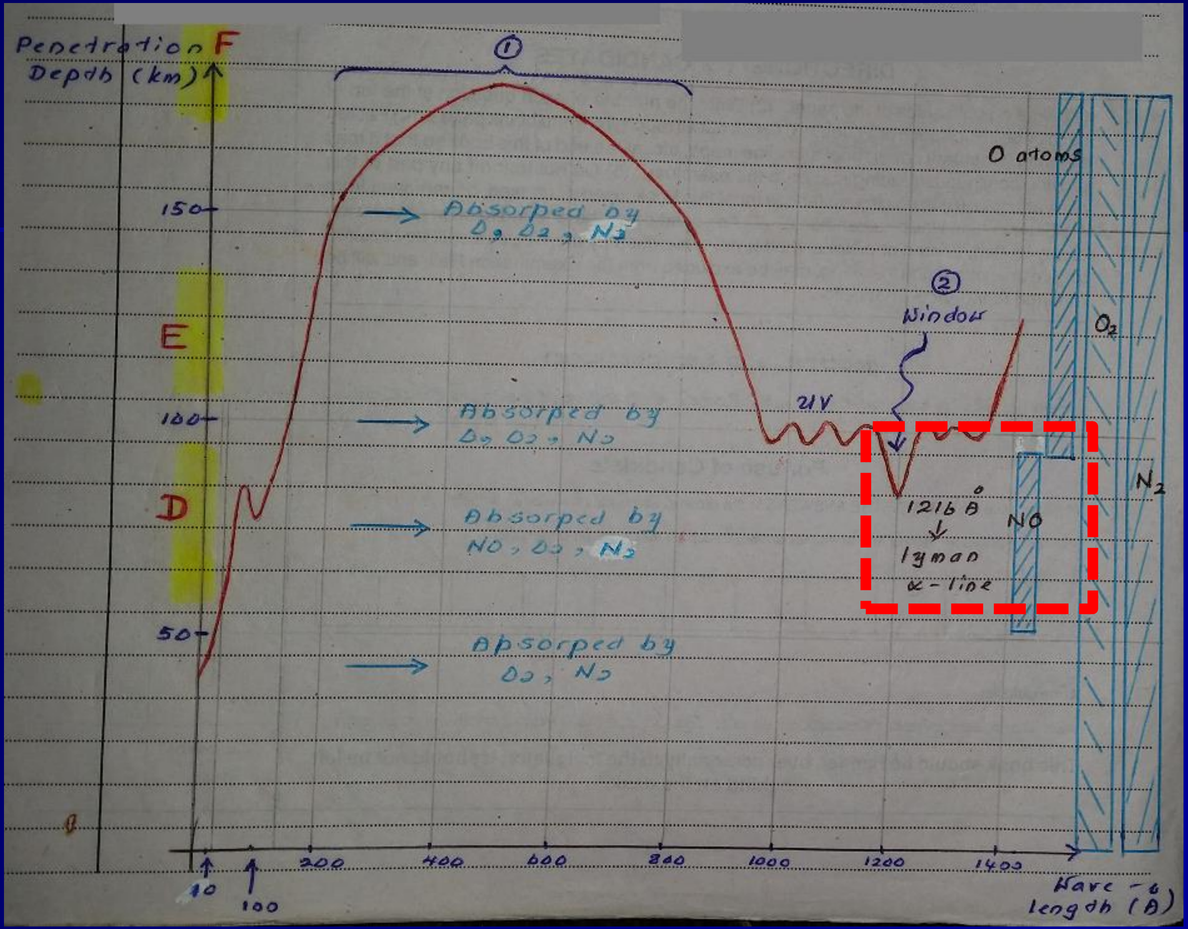

- If a **Solar Flare is created** on the Sun, the **size of the Region-D is increasing** very fast with in several minutes (~8 min & 30 sec)

# Penetration Depth




- Lyman alpha-radiation (1216 Å) absorbed by **NO** in the atmosphere.

# Penetration Depth




- The Lyman alpha-ray (1216 Å) **going through the 100 km region** to lower region ( < 100 km)

**This phenomena is called "Window"** of the **100 km region from the surface** of the Earth.!

# Penetration Depth (Summary)

This diagram indicates penetration depth of the radiation comes from the Sun. Also that radiation comes from the upper side of the atmosphere to the surface of the Earth.

- Cause of the D-Region of the ionosphere, wavelength of the radiation 10 Å comes from the Sun.

- Lyman alpha-radiation (1216 Å) absorbed by **NO** in the atmosphere.

- The size of the D-Region is **increasing** when the season of the **increase of the Solar Activity**.

  **This phenomena has a ~11.2 years cycle !**

- If a **Solar Flare is created** on the Sun, the **size of the Region-D is increasing** very fast with in several minutes (~8 min & 30 sec)

- The Lyman alpha-ray (1216 Å) **going through the 100 km region** to lower region ( < 100 km)

  **This phenomena is called "Window"** of the **100 km region from the surface** of the Earth.!

# Regular and Irregular Variations of the Ionosphere

Reference!

# Regular and Irregular Variations of the Ionosphere

The ionosphere we have described up to now and the numerical values we have given refer to an average, or typical as some people prefer to call it, **ionosphere**.
In practice these values vary by more than an order of magnitude with **time** and **location**.
some of these changes follow a known pattern, whereas others come and go on an irregular basis.

# Regular Variations of the Ionosphere

- **The Latitudinal Dependence**

The latitudinal dependence of the ionospheric parameters, **mainly due to the change of the solar zenith angle with latitude**, but also **due to the change in the dip angle of the Earth's magnetic field**. There is also a **small longitudinal variation** because the **Earth's Magnetic Field various with longitude** along any given geographic latitude. The $N_m$ (Maximum Molecular Number Density - electrons) can easily **vary by an order of magnitude from the polar to the equatorial regions**.

- **The Diurnal Variation**

The diurnal variation of the ionosphere which includes the peaking of the electron density usually in the early afternoon, the **sharp changes near sunrise and unset,** and the **disappearance of the lower layers during the night**. The $N_m$ can again vary by an order of magnitude between night and day.

# Regular Variations of the Ionosphere

- **The Seasonal Variation**

The seasonal variation, which is also due to the change in the average zenith angle of the Sun as we move **between the summer and winter solstices** (සූර්ය නිවෘත්තිය).

- **The 27 Day Cycle**

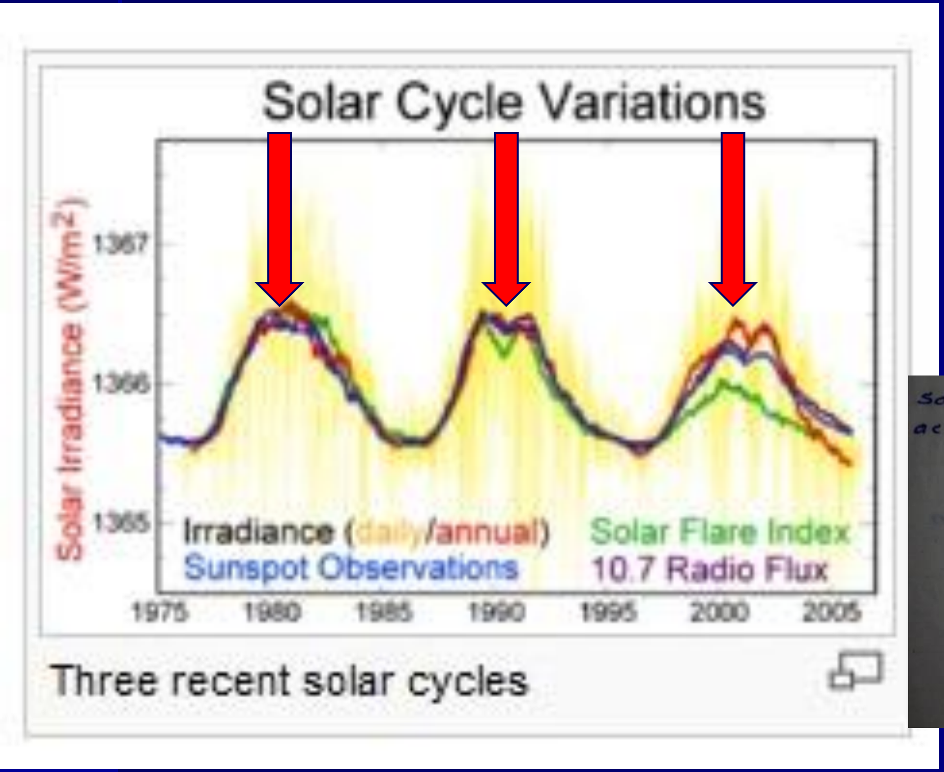
The 27 day cycle due to the intrinsic (true) rotation of the Sun. This cycle is especially noticeable during periods of **high solar activity when a very activity region** might last for more than one rotation of the Sun.

Active regions also have a tendency (willingness) to form in the same general area of other past active regions so that there is often a long lasting longitudinal asymmetry of activity on the Sun.

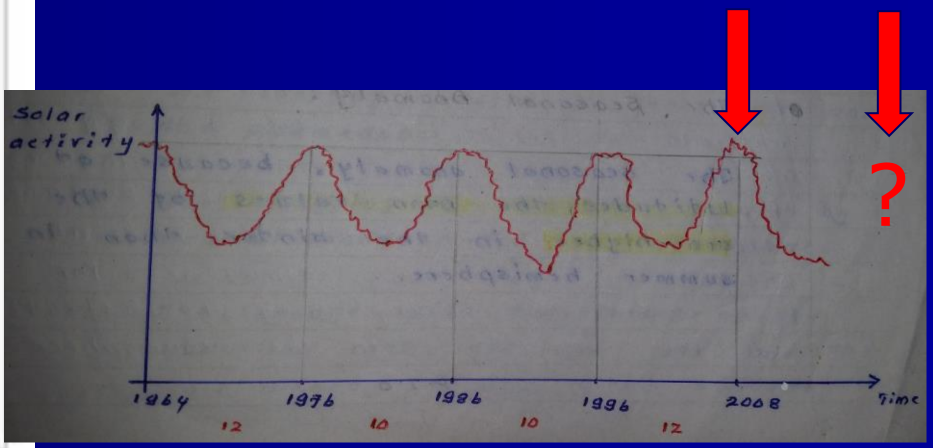
# Regular Variations of the Ionosphere

- **The 11 year Solar Cycle**

The 11 year solar cycle, which represents the fairly regular increase and decrease of the solar activity and therefore of the ionizing radiation from the Sun with a period of approximately **11.1 years** (may be 11.2 years). The last solar maximum occurred in 2008 !



Three recent solar cycles



| Solar Cycles | | | | | | |
|---|---|---|---|---|---|---|
| Cycle | Started | Finished | Duration (years) | Maximum (monthly SSN (Smoothed Sunspot Number))[4] | Minimum (monthly SSN; end of cycle)[5][6] | Spotless Days (end of cycle)[7][8][9] |
| Solar cycle 1 | March 1755 | June 1766 | 11.3 | 86.5 | 11.2 | |
| Solar cycle 2 | June 1766 | June 1775 | 9.0 | 115.8 | 7.2 | |
| Solar cycle 3 | June 1775 | September 1784 | 9.3 | 158.5 | 9.5 | |
| Solar cycle 4 | September 1784 | May 1798 | 13.7 | 141.1 | 3.2 | |
| Solar cycle 5 | May 1798 | December 1810 | 12.6 | 49.2 | 0.0 | |
| Solar cycle 6 | December 1810 | May 1823 | 12.4 | 48.7 | 0.1 | |
| Solar cycle 7 | May 1823 | November 1833 | 10.5 | 71.5 | 7.3 | |
| Solar cycle 8 | November 1833 | July 1843 | 9.8 | 146.9 | 10.6 | |
| Solar cycle 9 | July 1843 | December 1855 | 12.4 | 131.9 | 3.2 | ~654 |
| Solar cycle 10 | December 1855 | March 1867 | 11.3 | 97.3 | 5.2 | ~406 |
| Solar cycle 11 | March 1867 | December 1878 | 11.8 | 140.3 | 2.2 | ~1028 |
| Solar cycle 12 | December 1878 | March 1890 | 11.3 | 74.6 | 5.0 | ~736 |
| Solar cycle 13 | March 1890 | February 1902 | 11.9 | 87.9 (Jan 1894) | 2.7 | ~938 |
| Solar cycle 14 | February 1902 | August 1913 | 11.5 | 64.2 (Feb 1906) | 1.5 | ~1019 |
| Solar cycle 15 | August 1913 | August 1923 | 10.0 | 105.4 (Aug 1917) | 5.6 | 534 |
| Solar cycle 16 | August 1923 | September 1933 | 10.1 | 78.1 (Apr 1928) | 3.5 | 568 |
| Solar cycle 17 | September 1933 | February 1944 | 10.4 | 119.2 (Apr 1937) | 7.7 | 269 |
| Solar cycle 18 | February 1944 | April 1954 | 10.2 | 151.8 (May 1947) | 3.4 | 446 |
| Solar cycle 19 | April 1954 | October 1964 | 10.5 | 201.3 (Mar 1958) | 9.6 | 227 |
| Solar cycle 20 | October 1964 | June 1976 | 11.7 | 110.6 (Nov 1968) | 12.2 | 272 |
| Solar cycle 21 | June 1976 | September 1986 | 10.3 | 164.5 (Dec 1979) | 12.3 | 273 |
| Solar cycle 22 | September 1986 | May 1996 | 9.7 | 158.5 (Jul 1989) | 8.0 | 309 |
| Solar cycle 23 | May 1996 | December 2008 [10] | 12.6 | 120.8 (Mar 2000) | 1.7 | 820 (through Jan 15, 2011) [11] |
| Solar cycle 24 | December 2008 [10] | | | | | |
| Mean | | | 11.1 | 114.1 | 5.8 | |

# Regular Variations of the Ionosphere

- **The 11 year Solar Cycle**

The fact that all these variations follow a rather well-prescribed pattern does not necessarily mean that these patterns follow the predictions of the simple Chapman layer theory. According to the Chapman theory, for example, the highest $F_0$, $F_2$ and the lowest $h_m$ must occur when the Sun reaches the smallest zenith angle, which naturally occurs at noon. The Chapman theory also predicts lower critical frequencies at higher latitudes and for the same latitude lower critical frequencies in the winder hemisphere.

All the variations of the ionosphere that do not follow the predictions of the Chapman Theory came to be known as **anomalies** and over the years many anomalies of this kind have been reported and diseased in the literature.

**Thus we have:**

- **The Equatorial or Geomagnetic Anomaly**
- **The Seasonal Anomaly**
- **The December Anomaly**
- **The Diurnal Anomaly**

# Irregular Variations of the Ionosphere

Besides the different anomalies which we have discussed above, the ionosphere shows also the following **structural irregularities**.

- **The Sporadic - E**

  **The sporadic-E, which is the frequent formation of a thin layer (1-5 km) of excess ionization at an attitude of about 110 km.** The electron density of this layer can exceed by more than a factor of two the ambient electron density of the E-region.

  **The sporadic-E has been studied extensively both from the theoretical and the experimental point of view, but still there is no general agreement on the cause of this phenomenon**. According to one of the more widely discussed theories, the appearance of the sporadic-E is due to strong shear winds which often develop near the maximum of the E-layer.

# **Irregular Variations** of the Ionosphere

- **The Spread F**

**Ionograms occasionally show a large spread in the equivalent height from which the F-region echoes are returned.** This time spread, which is much broader than the time width of the transmitted radio pulses, is produced either by a blobby structure of the F-region which causes in depth multiple scattering, or by a wavy structure of the F-region which permits the reflection of the radio waves by curved surface at different distance from the vertical. This phenomenon might last sometimes for several hours and is usually a good indication of disturbed conditions in the ionosphere.

- **The Ionospheric Irregularities**

**The ionospheric irregularities, which represent local perturbations (කැළඹීම) by a few percent in the electron density of the ionosphere.** These irregularities are often elongated (long) along the lines of the Earth's Magnetic Field and their dimensions are of the order of 1 to 10 km.

# Irregular Variations of the Ionosphere

- **Travelling Ionospheric Disturbances**

  **These are large size perturbations of the electron density extending sometimes over 1000 km.** They have been observed to travel with speeds of the order of 300 $ms^{-1}$ over large distances and occasionally to make a full circle around the globe. The mechanism causing these large scale disturbances is not well understood. One possible suggestion is that they are produced by the sudden precipitation (running down) of a large number of energetic particles either in the polar regions or in the vicinity of a magnetic anomaly.

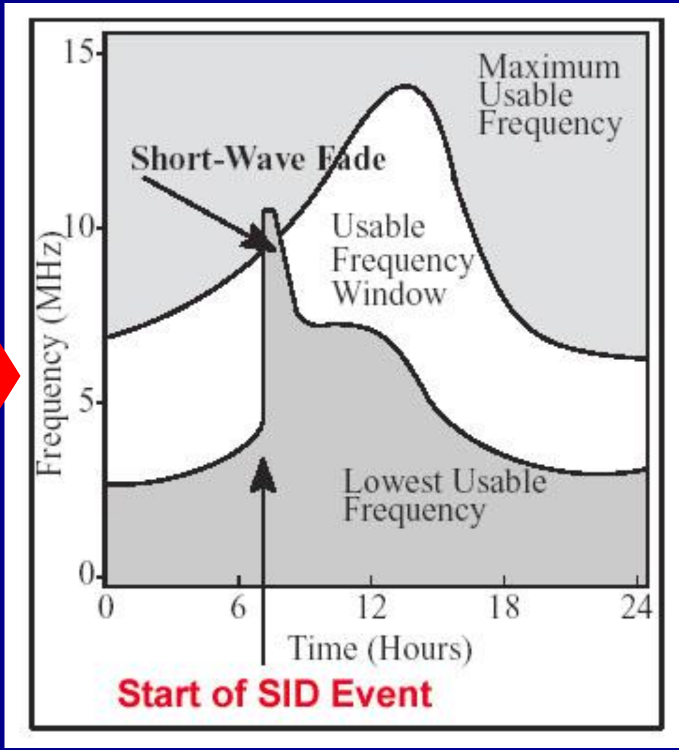
- **The Mid-Latitude Trough**

  This is a minimum in the electron densities of the ionosphere which develops primarily during the night time at a geomagnetic latitude (dip latitude) of approximately 60 degrees.

# Irregular Variations of the Ionosphere

- **Sudden Ionospheric Disturbances ( S I D )**

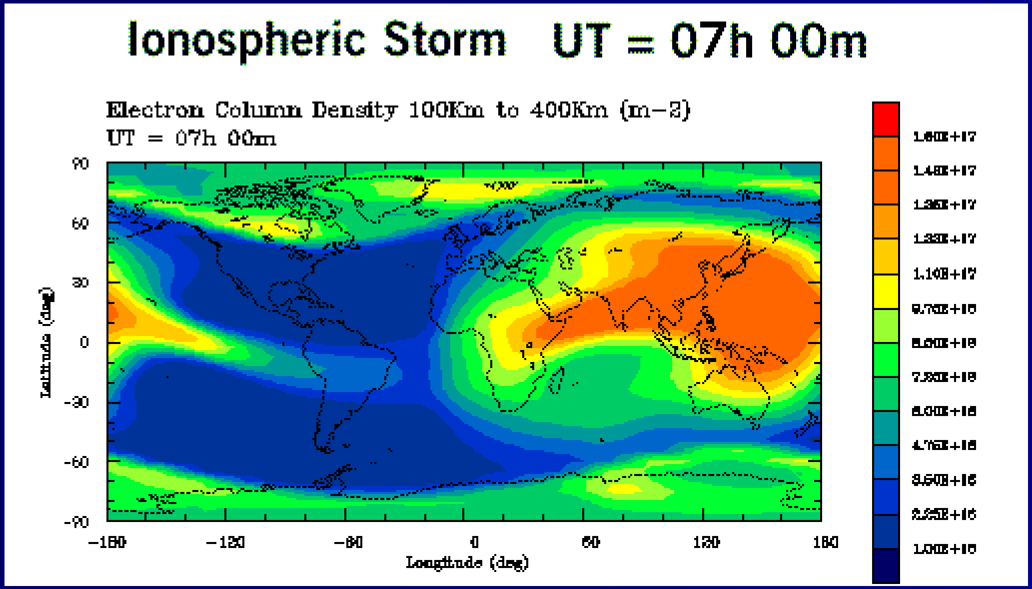
**These are caused by the enhanced ultra-violet and X-ray radiation from the Sun during solar flare events. They occur only in the Sun-lit side of the Earth and they last, like the solar flares, from a few minutes to about one hour.**



# Irregular Variations of the Ionosphere

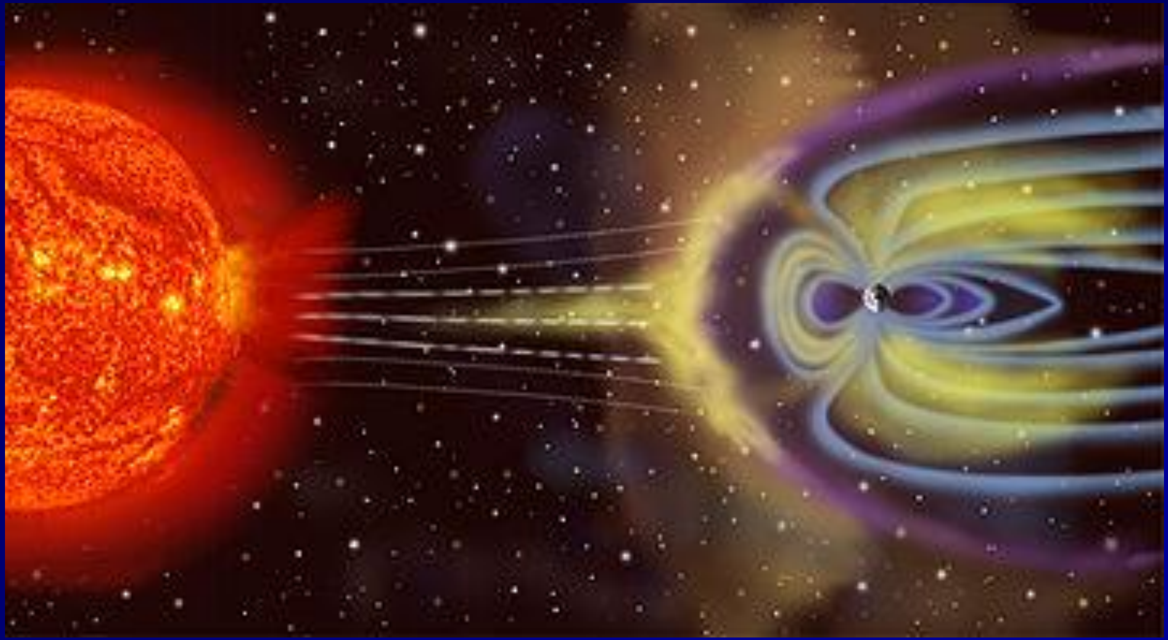
- **Ionospheric Storms**

  **These are closely associated with geomagnetic storms and can last from one to four days affecting the ionosphere over the entire globe.** Observations of the unusual behavior of the ionosphere during these storms have been made and continue to be made by many groups around the world.




Many diurnal, seasonal and latitudinal storm effects have been discovered and serious efforts have been made for their theoretical interpretation.

# The Magnetosphere



The Earth's Magnetic Fields
The Dipole Magnetic Field
Motion of charged particles in a Dipole Magnetic Field
The Radiation Belts
The boundary and the tail of the Magnetosphere