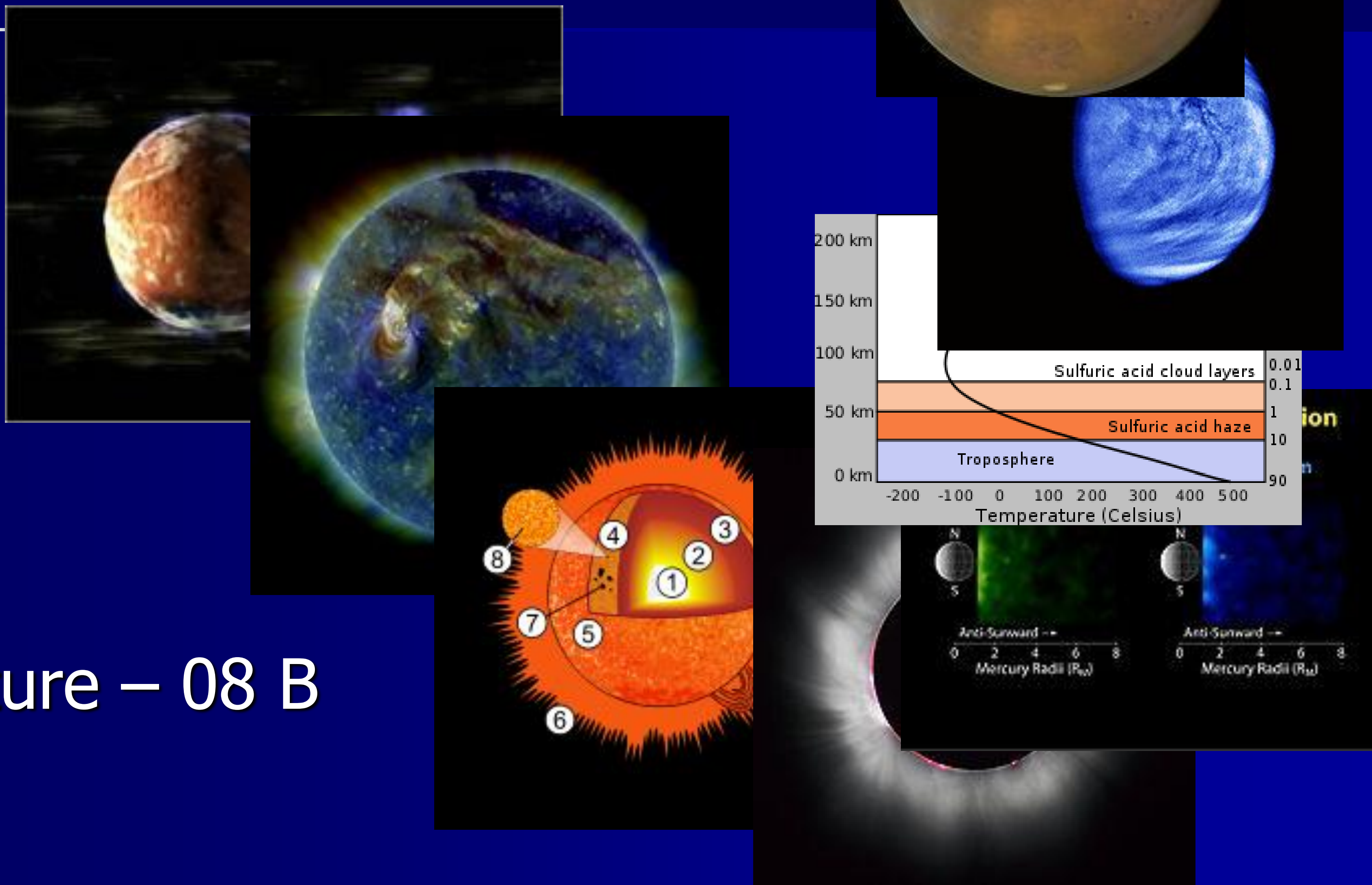
Space Physics

Space & Atmospheric Physics



Lecture – 08 B

The Structure of the Ionosphere and Plasmasphere

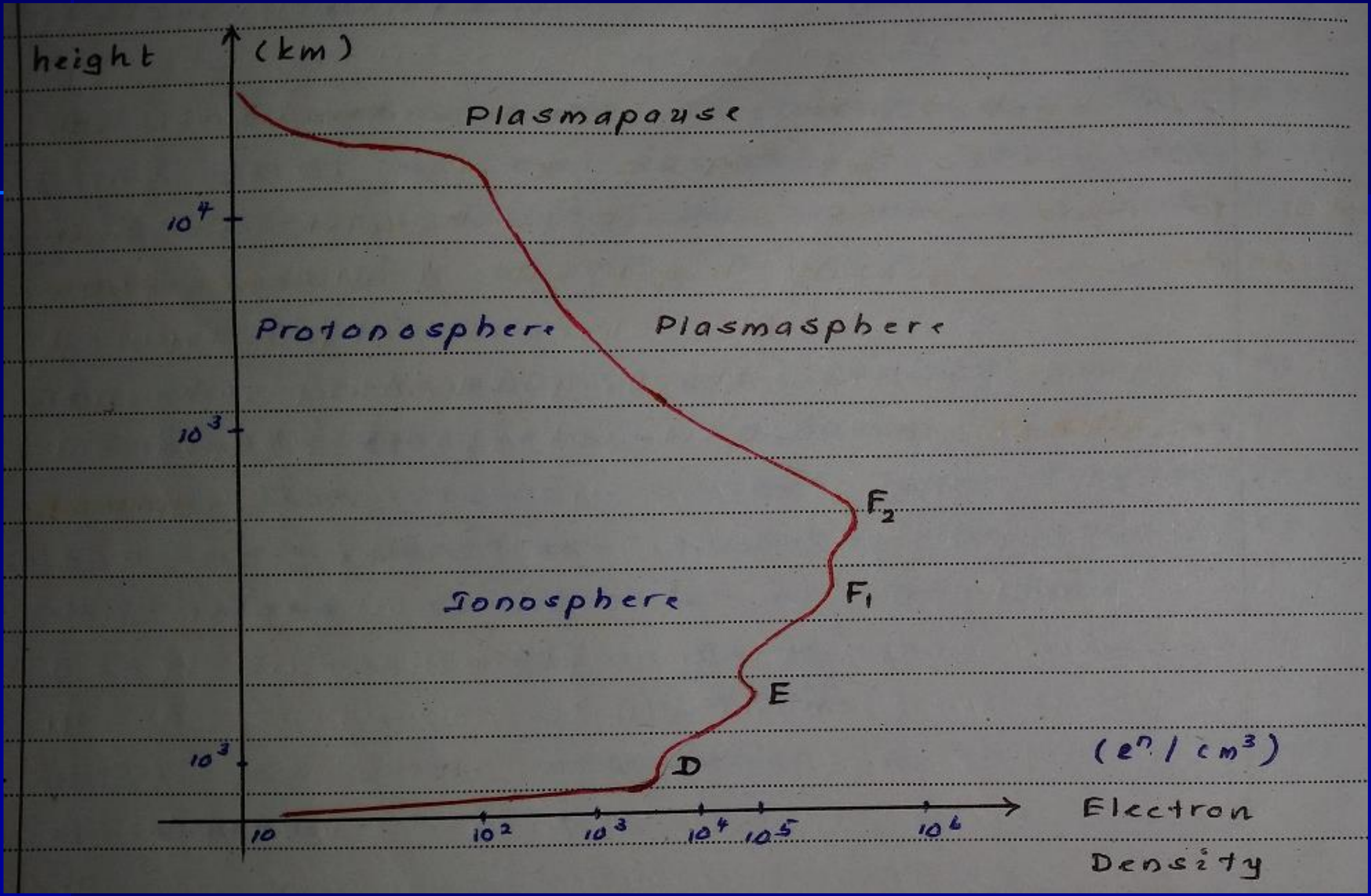
The Structure of the Ionosphere and Plasmasphere

The most obvious difference from the simple **Chapmon Layer Theory** is that the **ionosphere has several peaks of the electron density**. These peaks are called layers and have the names **D-layer**, **E-layer**, **F_1-layer** and **F_2-layer**.

We also have the **plasma pause**, a rather sharp change in electron density, at **a distance of 4 to 5 Earth radii**.

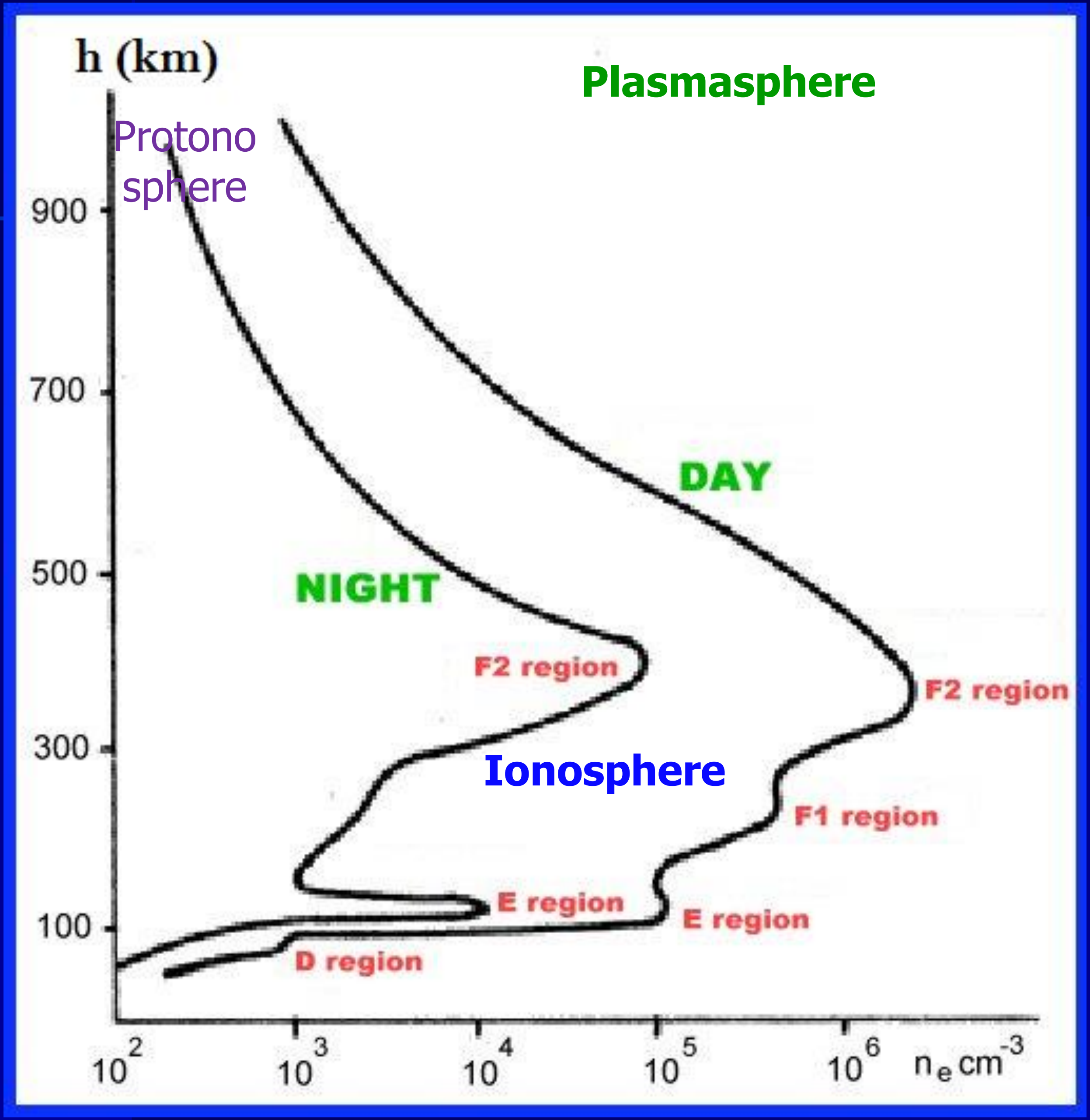
The D, E, F_1 and F_2 layers are formed because the ionizing radiation from the sun is **not monochromatic** and because the atmosphere consists of **several different constituents** which are ionized at different wavelengths of the solar spectrum.

The Structure of the Ionosphere and Plasmasphere



A typical daytime profile of the ionosphere and the plasma sphere.

The Structure of the Ionosphere and Plasmasphere



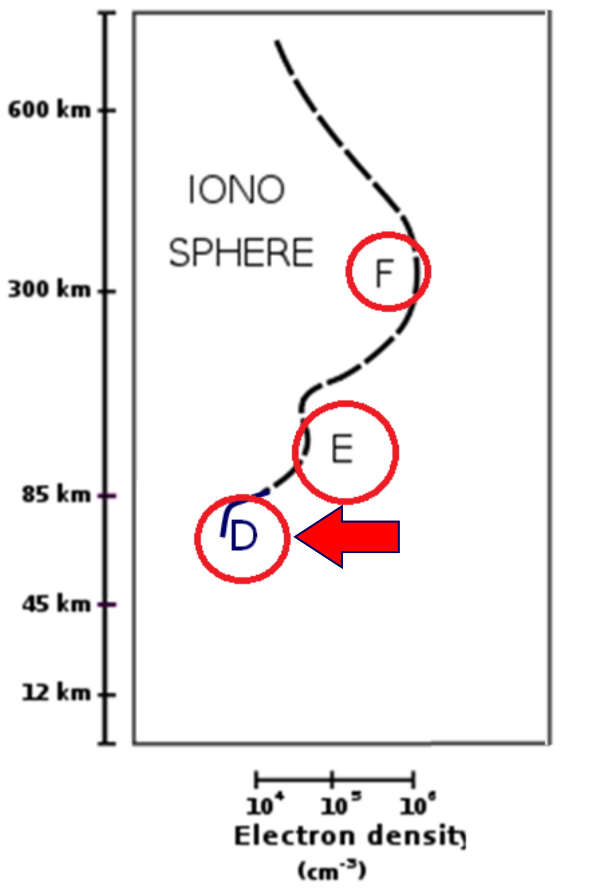
Each one of these ionizing processes reaches its peak at a different attitude which becomes an individual peak of the ionospheric electron density profile. The height dependence of the different loss-mechanisms is also a factor in the formation of the ionosphere layers.

A typical daytime and nighttime profiles of the ionosphere and the plasma sphere.

The Structure of the Ionosphere and Plasmasphere

The D – region

It is present only during the day and covers the range between **60 and 85 km**. Quite often the valley between the D-layer and the E-layer is not very obvious, and as a result the D-layer is not always well defined.

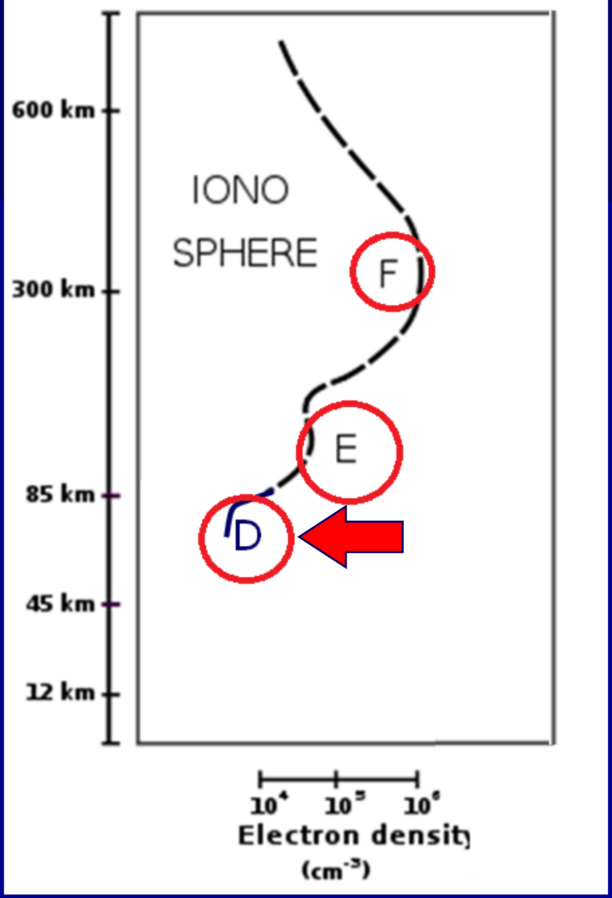


In the **70 to 85 km** range electrons are produced mainly from the ionization of the traces of NO that exit in the upper atmosphere by the Lyman - Alpha radiation (1216 Å) of the Sun. The peak electron density of the D-layer occurs near 80 km and is of the order of $3x10^3$ e^n/cm^3.

The Structure of the Ionosphere and Plasmasphere

The D – region

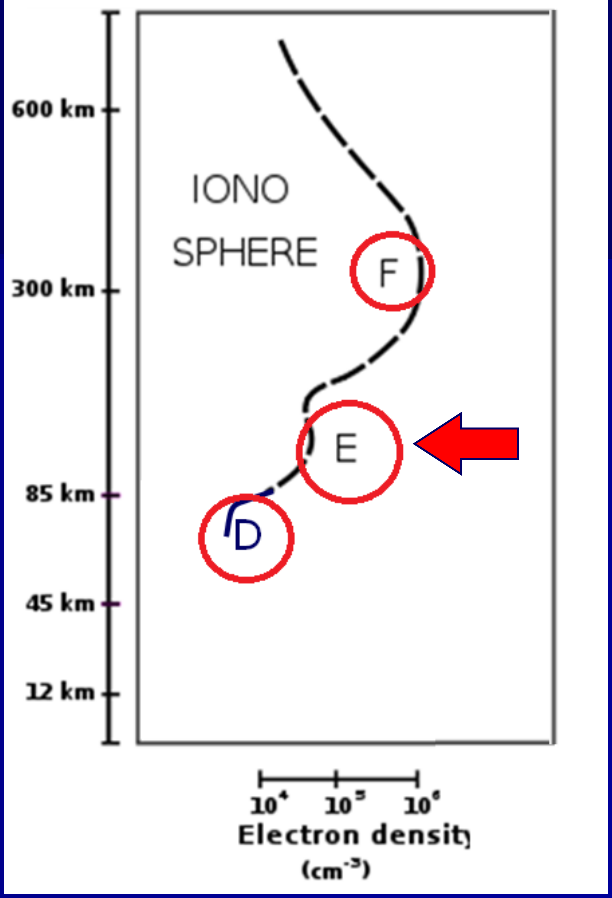
Solar X - rays acting on molecular oxygen and molecular nitrogen contribute also to the ionization of the D -layer. This becomes especially apparent during periods of intense solar activity (solar flares,… etc.) when the electron content of the D- region can increase by more than an order of magnitude.



The Structure of the Ionosphere and Plasmasphere

The E – region

It extends from 85 km to about 150 km and has a daytime maximum of ~$3x10^5$ e^n/cm^3 around 115 km. During the night the electron density decreases by at least two orders of magnitude and the E-layer disappears.



The lower part of the E-region (85-100 km) is ionized mainly by solar x-rays in the 30-100 Å range. Above 100km the ionization is produced mainly by soft x-rays and by UV radiation in the range between 800 Å and the Lymon-β at 1026 Å.

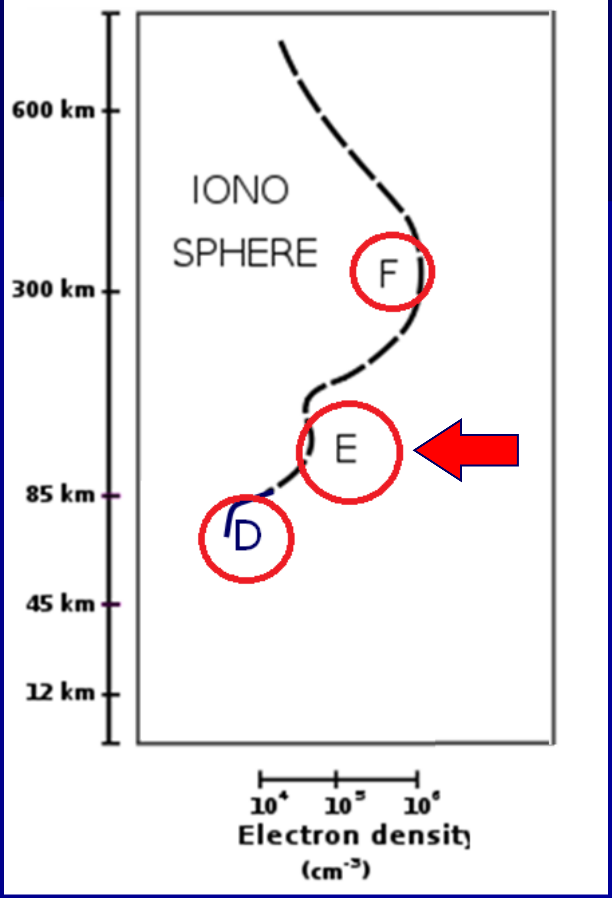
The main ions in the E-region are NO+ and O2+. Though N2+ is produced in large numbers it is virtually absent in the ionosphere because of its extremely high recombination rate. The recombination coefficient of E-layer is, $\alpha \approx 2x10^{-8}$ cm^3/s and the relaxation time is of the order of ~10 min, which explains the rapid disappearance of the E-layer after Sunset.

The Structure of the Ionosphere and Plasmasphere

The E – region

The small amount of ionization which persists in the E-region during the night could be due to micrometeorite bombardment.

The relaxation time t_r is the time in which the **electron density would reduce to one half**, if there was no more production of electrons.



.: Diffusion rate,

$$\frac{dN}{dt} \alpha \; -N^2$$

If $t\uparrow$ then, $N\downarrow$

$$-\frac{dN}{N^2} = \alpha \; dt$$

Where alpha is the proportional constant (**Recombination Coefficient**)

$$-\int_{N(0)}^{N(t_r)} N^{-2} dN = \alpha \int_{t=0}^{t_r} dt$$

The Structure of the Ionosphere and Plasmasphere

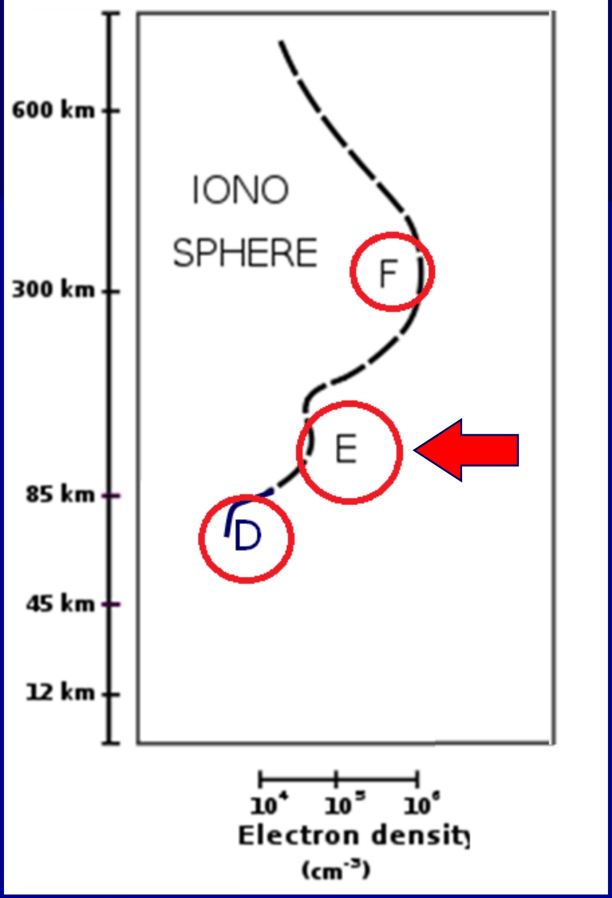
The E – region

.: Diffusion rate,

$$-\left(\frac{1}{N(0)}-\frac{1}{N(t_r)}\right)=\alpha\ t_r$$

We know, $N(t_r)=\dfrac{N(0)}{2}$

$$\therefore\ \ t_r=\frac{1}{\alpha\ N(0)}$$



Studies for the experimental determination of t_r can best be made during Solar Eclipses !

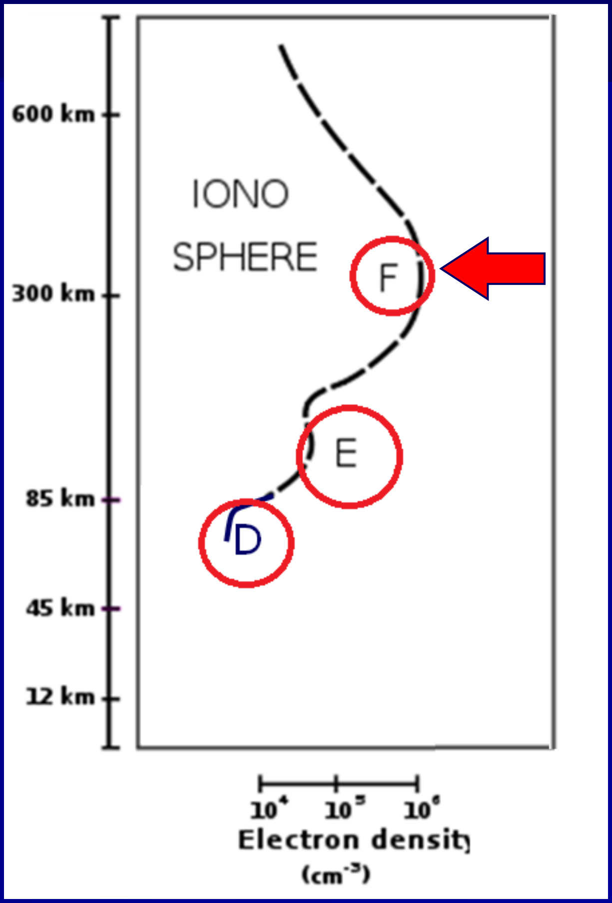
The Structure of the Ionosphere and Plasmasphere

The F1 – region

It is present like the D and E-layers only during the day. It extends from 150 to 200 km with a typical maximum of ~$2x10^5$ e^n/cm^3 around 180 km.

The principle ionizing agent is the Sun's ultra-violet radiation in the 200 Å to 900 Å range. The main atmospheric constituent which is ionized in the F1-region is **atomic oxygen** which diffuses from the lower layers where it is produced from the dissociation of O2.

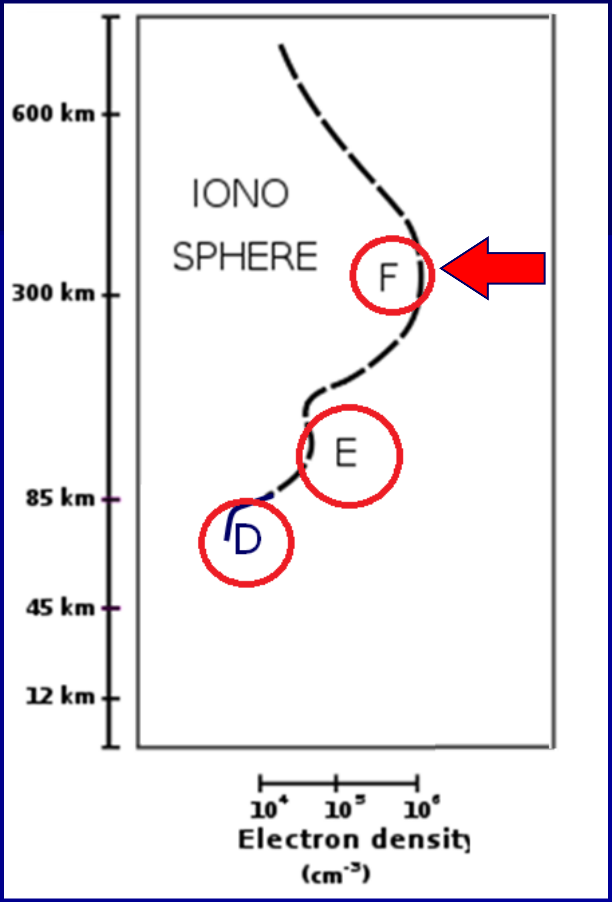
The recombination coefficient of the F1 layer is $\alpha \approx 5x10^{-9}$ cm^3/s and the corresponding relaxation time is similar to the relaxation time of the E-layer.



The Structure of the Ionosphere and Plasmasphere

The F_2 – region

It extends from 200 km to roughly 1000 km and has a **daytime maximum** near 250 km of about ~$5x10^5$ e^n/cm^3. **During the night the D, E and F1 peaks disappear and the ionosphere takes the form of a single layer, called the F-layer, with a maximum of about ~$5x10^5$ e^n/cm^3 around 350 km.**



As we move to higher attitudes the rate at which electrons and irons recombine decreases rapidly with height and the relaxation time at higher attitudes is much longer (~several days)

Electrons can be lost by recombining directly with the positive ions, which are present in approximately equal numbers. It should be mentioned that the neutral atoms are occasionally produced in excited states and they return their ground state they emit **photons** which are responsible for a faint glowing of the sky, a phenomenon which is called **airglow**.

Ion composition

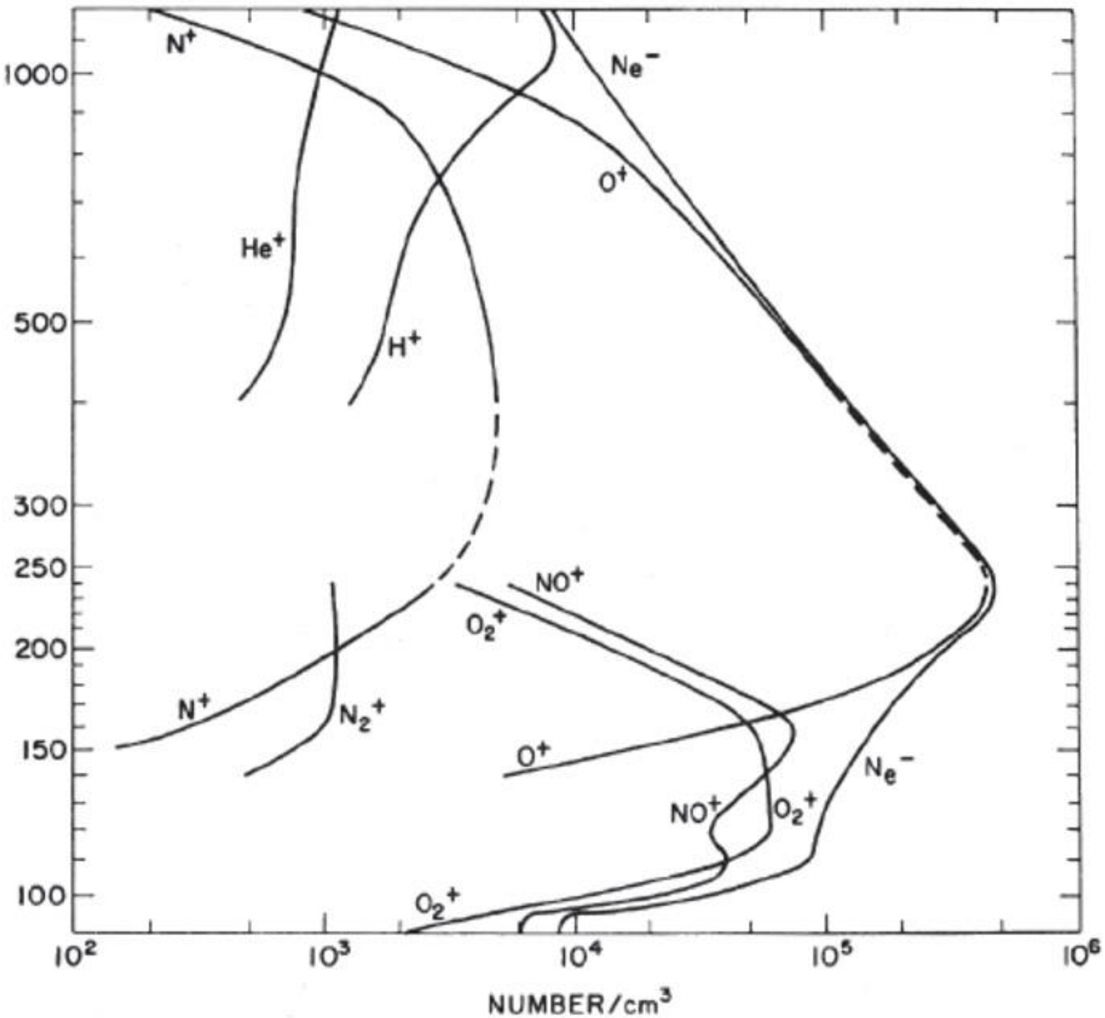
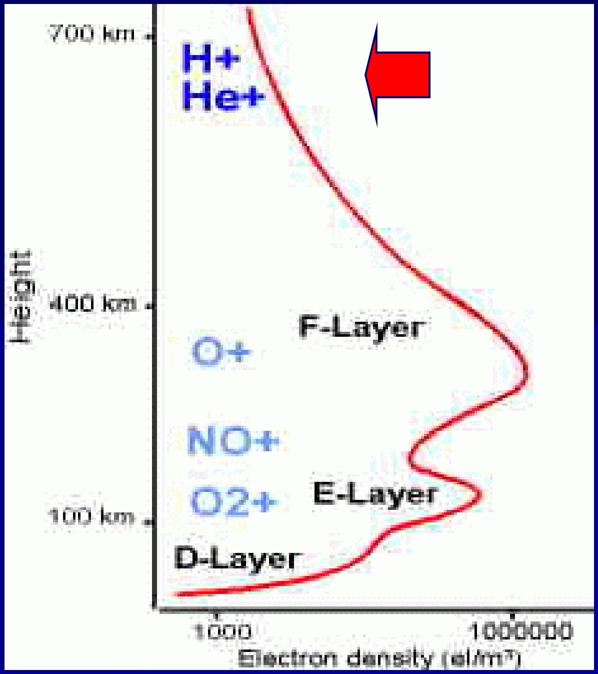


Figure: Daytime solar minimum ion profiles.

- 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 (not shown) contains positive and negative ions (e.g. O_2^-) and ion clusters (e.g. $H^+(H_2O)_n$, $(NO)^+(H_2O)_n$).

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.

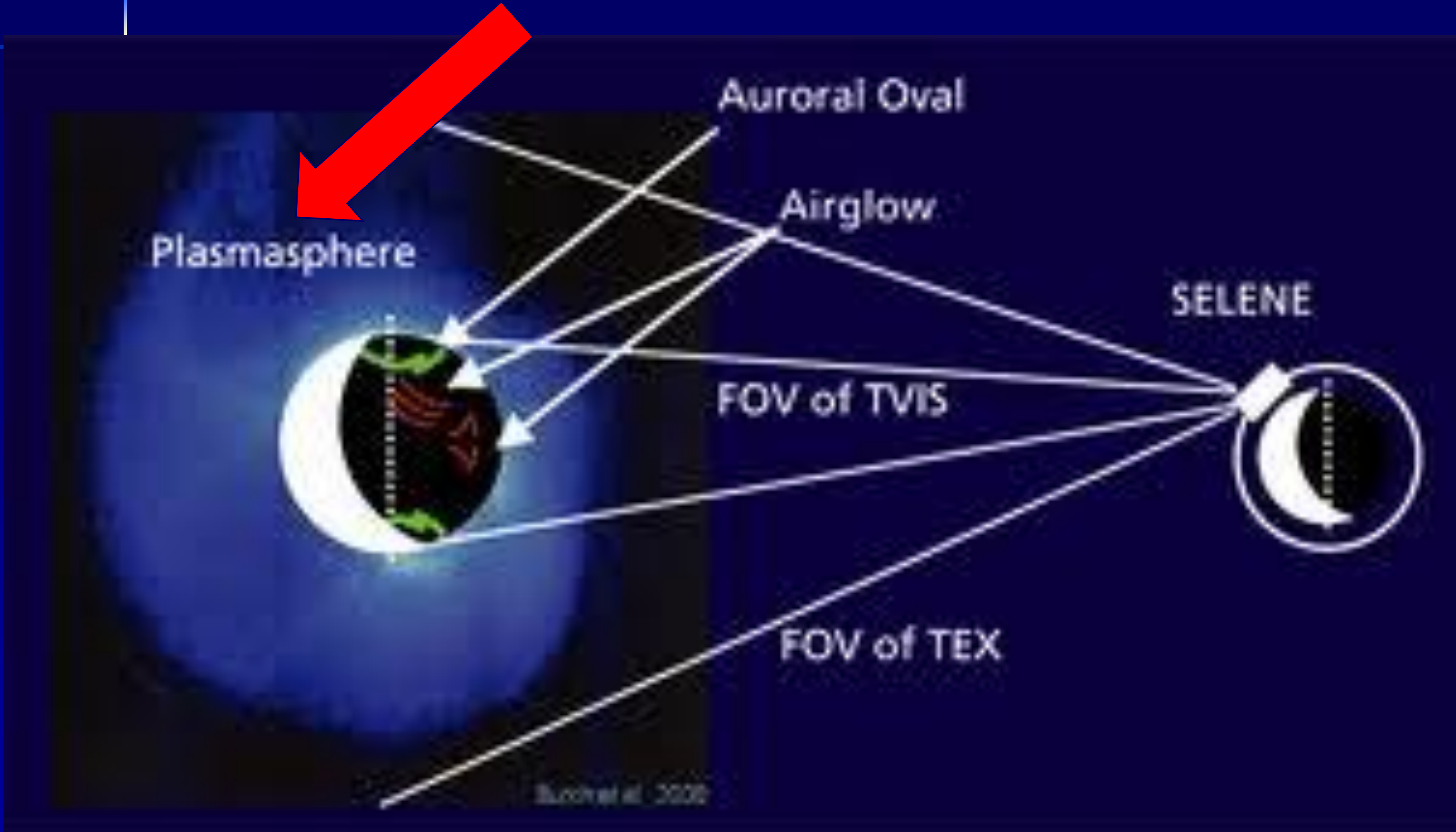


In the presence of the **Earth's Magnetic Field**, which tends to guide the diffusion of the charged particles along the field lines, this becomes a very complicated phenomenon to study.

Contrary to the diffusion of neutral particles, where different species diffuse independently, electrons and ions tend to diffuse as a body because there separation builds up an electric field which brings them back together. This phenomenon is called **ambi-polar diffusion**.

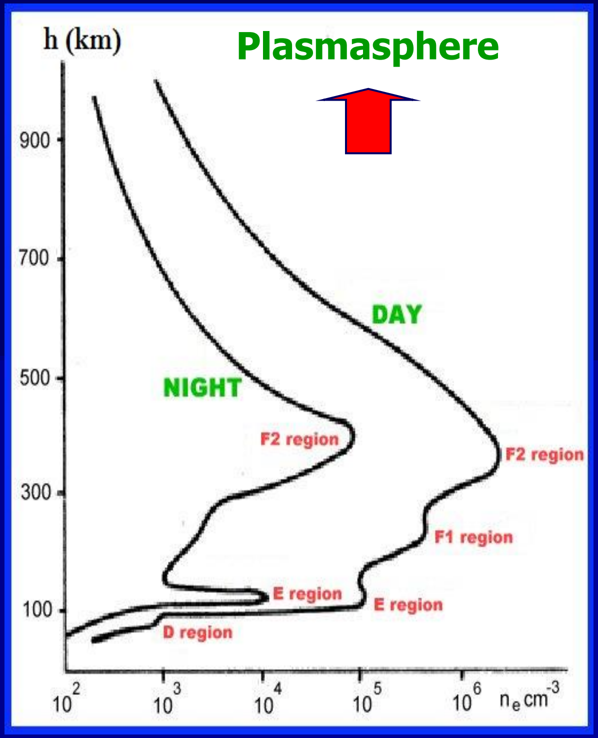
Around 1000 km O+ is replaced by He+ as the predominant ion, and at even higher attitudes (~2500 km) He+ is replaced by H+, i.e.; by free protons. The layer where helium ions dominate is often called **heliosphere** and the region above it is called the **protonosphere**.

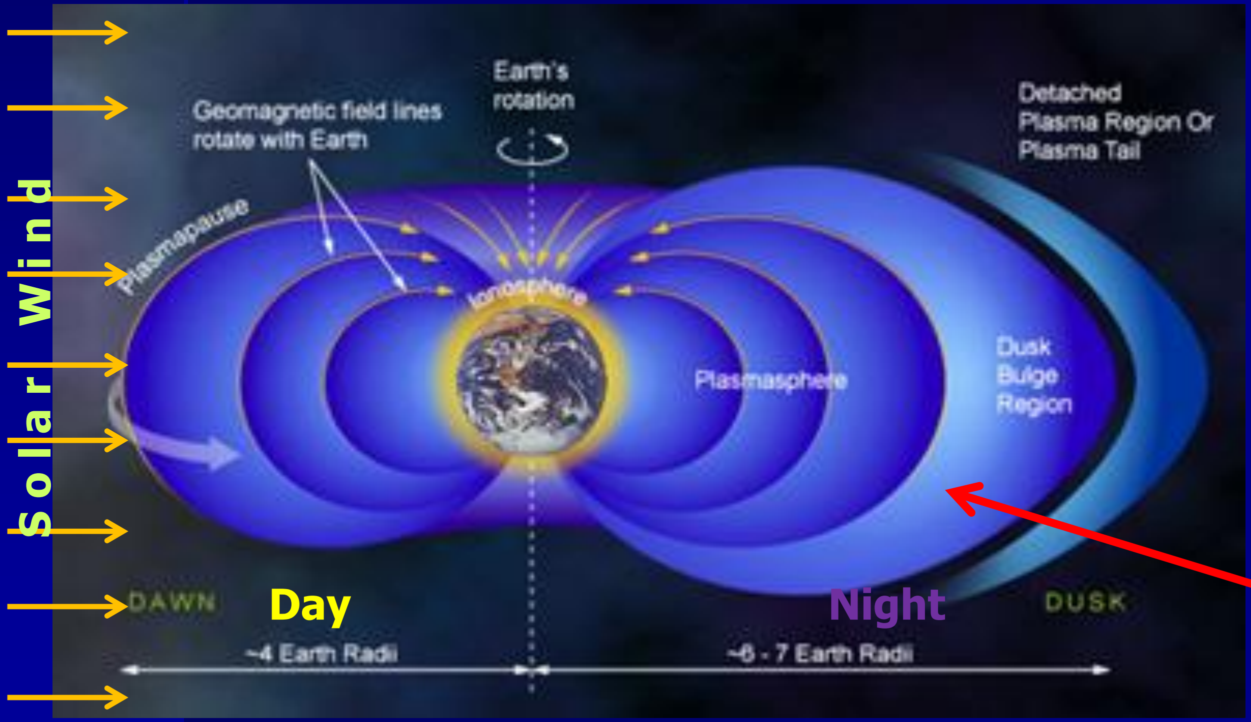
The Plasmasphere



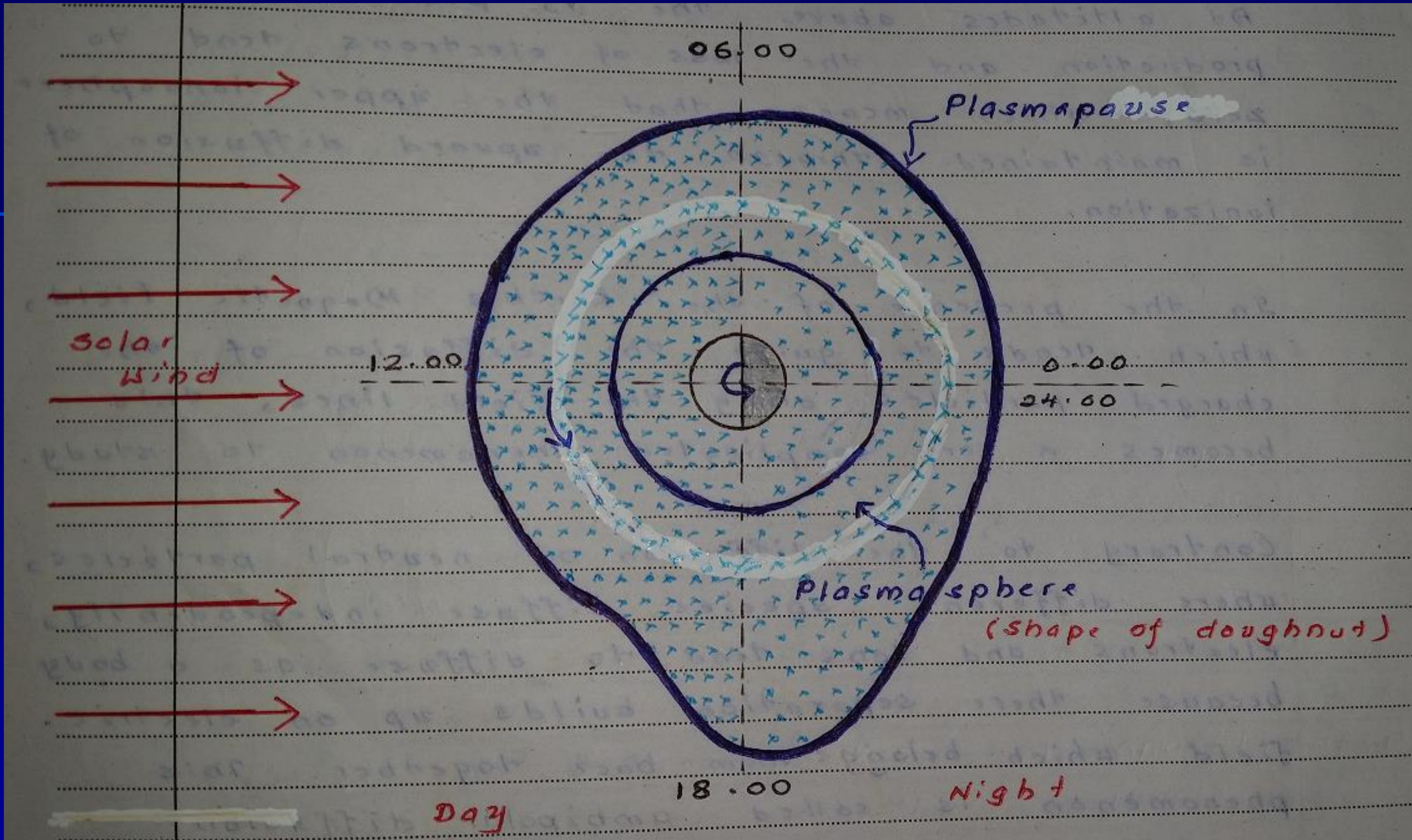
The Plasmasphere

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.

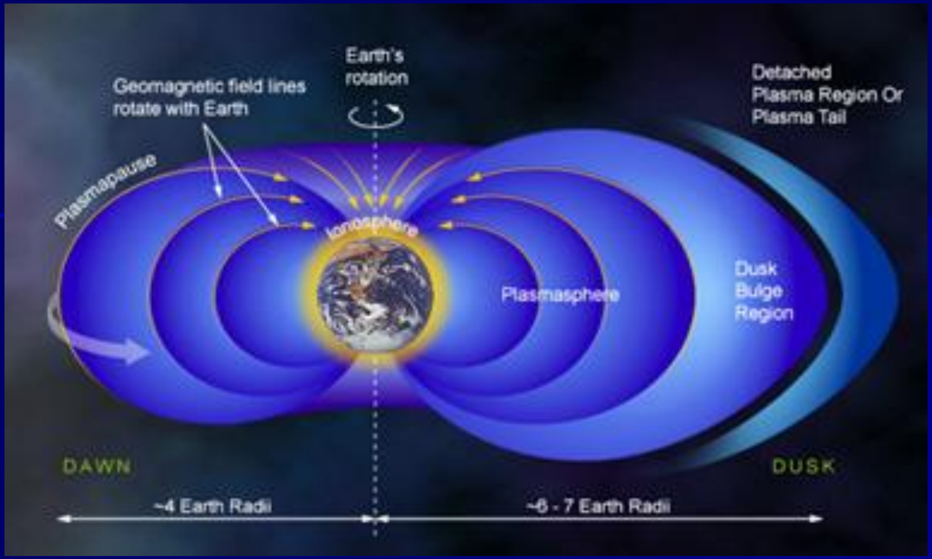




Shape of a doughnut

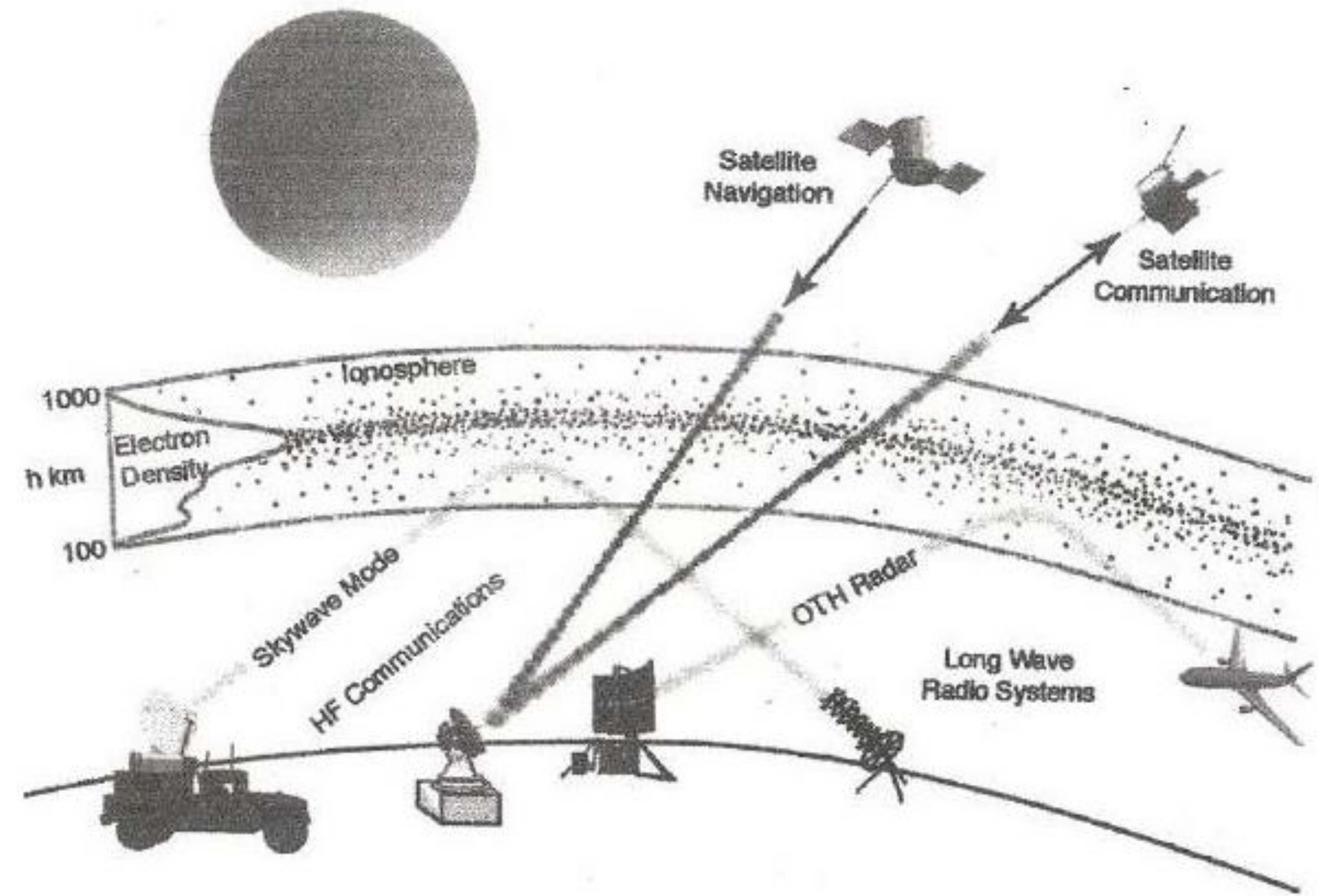

06.00
Plasmapause
Solar wind
12.00
0.00
24.00
Plasmasphere
(shape of doughnut)
18.00
Day
Night

The Plasmasphere & Plasmapause



The boundary of the plasmasphere, which at the equatorial plane occurs at a geocentric distance of 4 or 5 Earth radii, is called the **plasmapouse**. At the plasma pause the **electron density drops** sharply from a few hundred e^n/cm^3 to only a few e^n/cm^3.

The **plasmasphere** is filled with thermal plasma [a plasma with a Maxwellian Distribution of velocities and a temperature of a few thousand degrees kelvin] with diffuses upwards from the upper ionosphere.



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

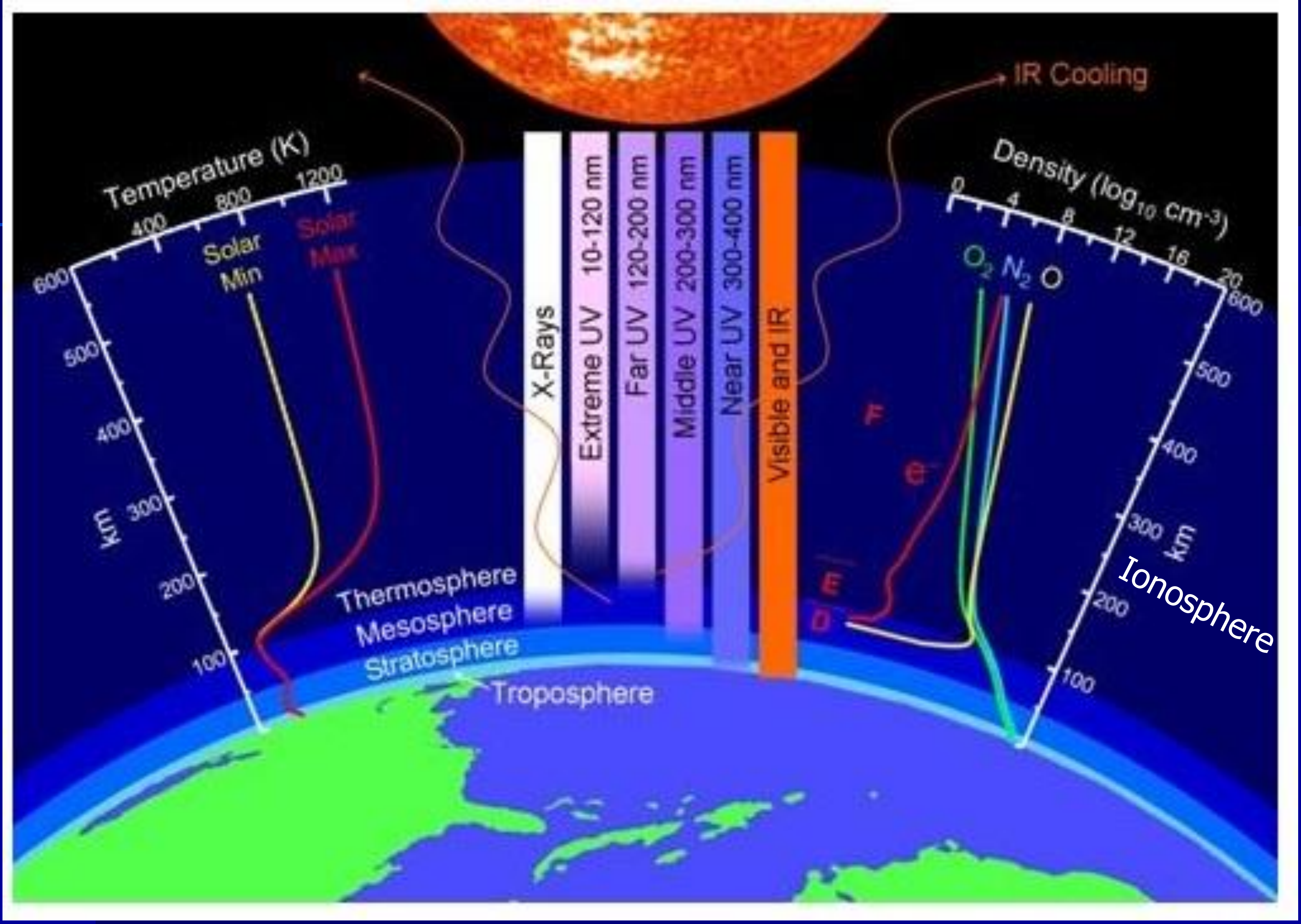
Penetration Depth

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

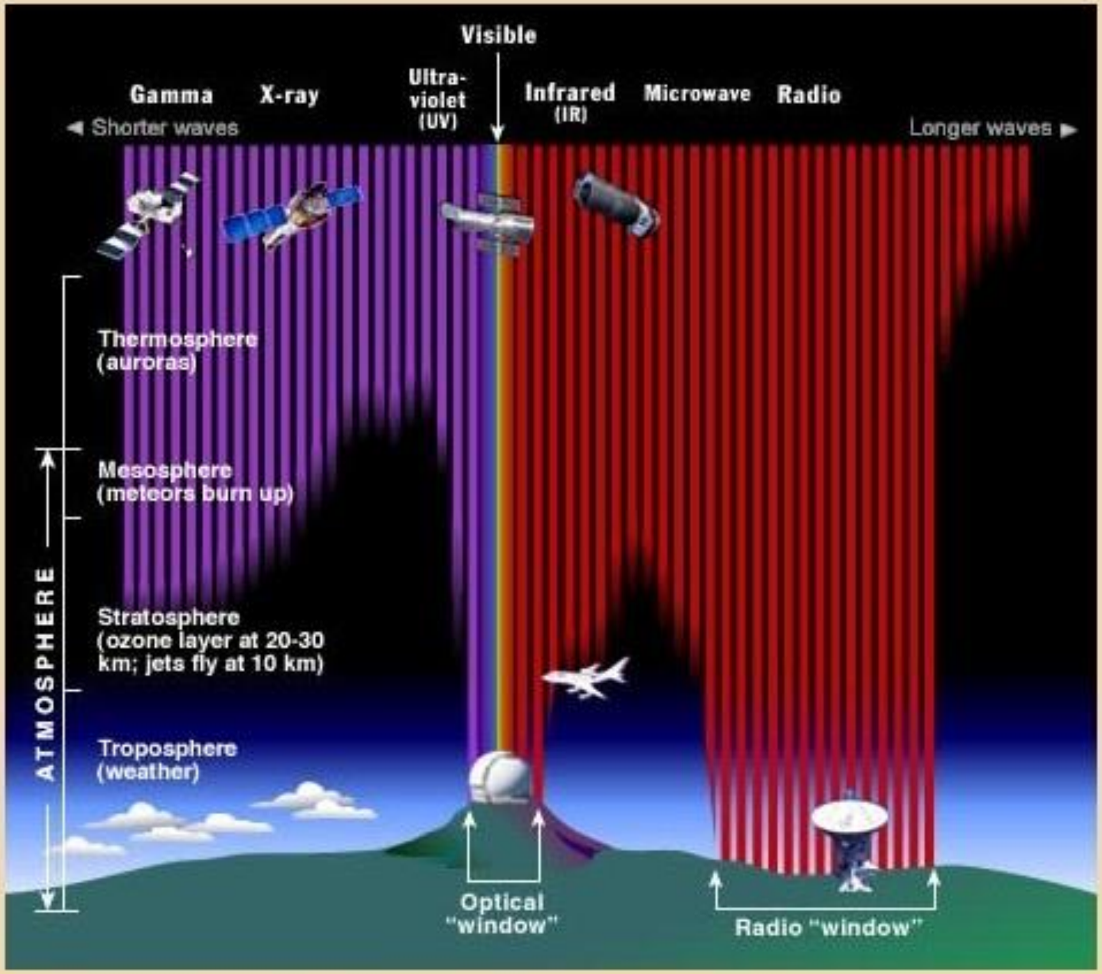
Where ***alpha*** is some constant.

Penetration Depth = $1/\alpha$

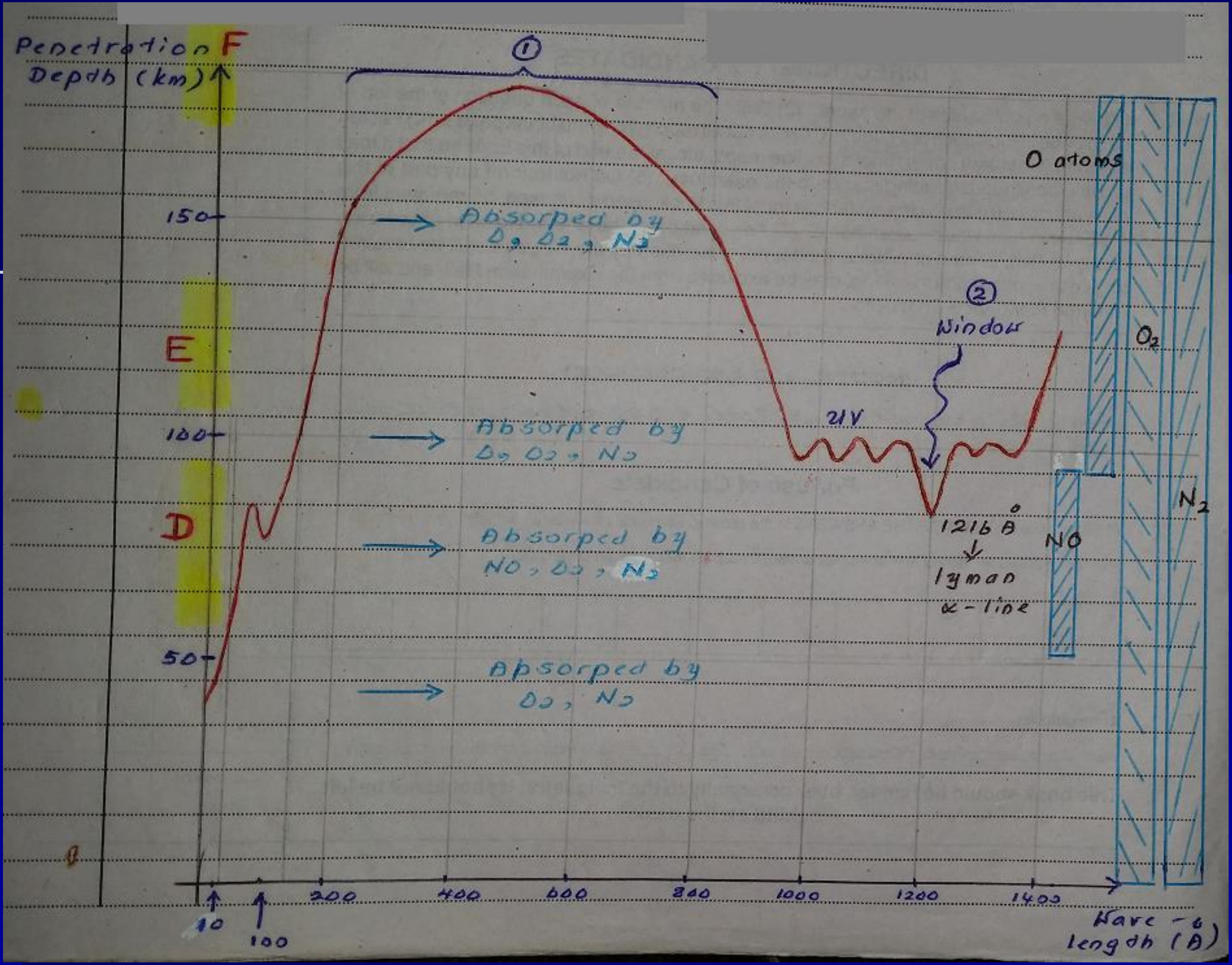


IR Cooling
Temperature (K)
400
800
1200
600
500
400
300
200
100
km
Solar Min
Solar Max
X-Rays
Extreme UV 10-120 nm
Far UV 120-200 nm
Middle UV 200-300 nm
Near UV 300-400 nm
Visible and IR
Density (log_{10} cm^{-3})
0
4
8
12
16
20
O_2 N_2 O
F
e^-
E
D
Thermosphere
Mesosphere
Stratosphere
Troposphere
Ionosphere

Solar EM Radiation Penetration into Earth's Atmosphere



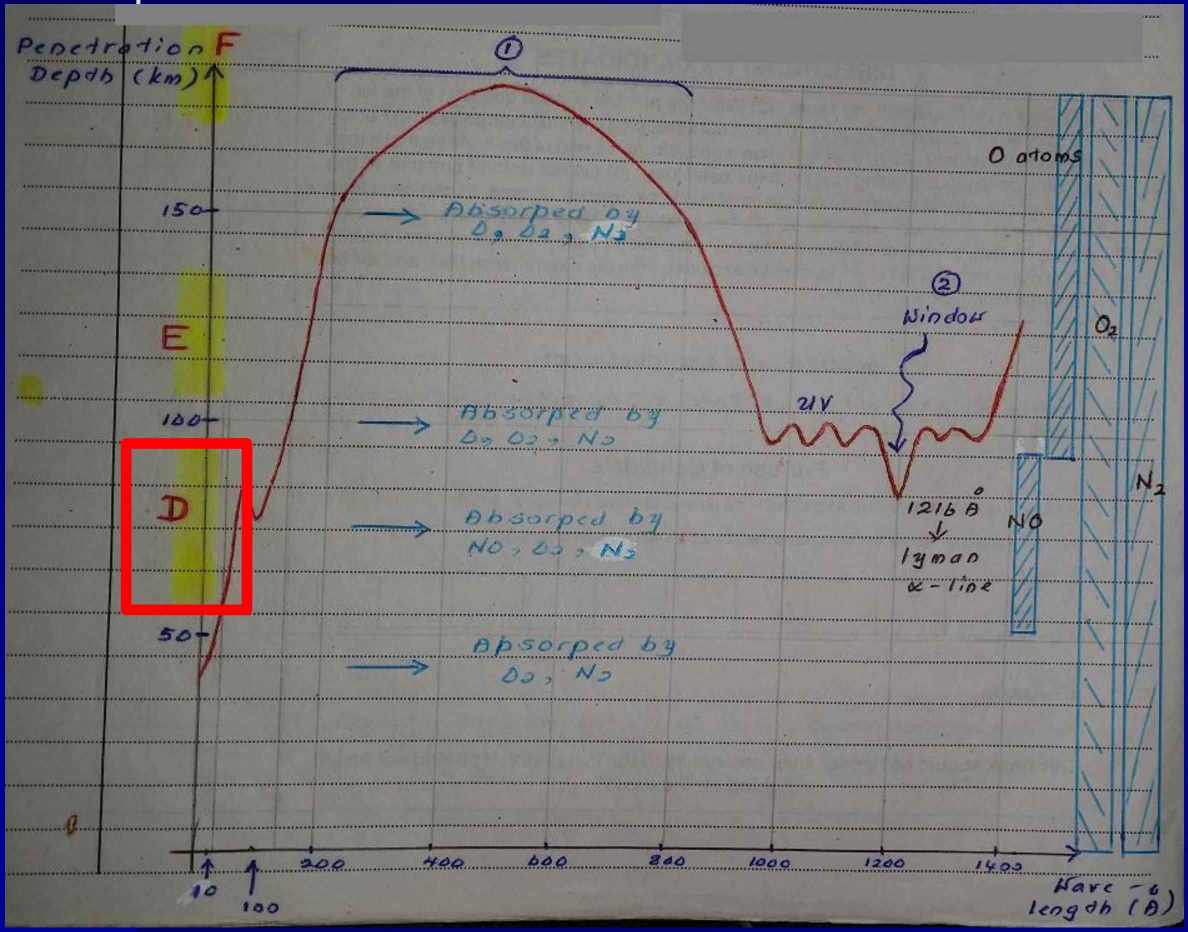
Various wavelengths of solar EM radiation penetrate Earth's atmosphere to various depths. Fortunately for us, all of the high energy X-rays and most UV is filtered out long before it reaches the ground. Much of the infrared radiation is also absorbed by our atmosphere far above our heads. Most radio waves do make it to the ground, along with a narrow "window" of IR, UV, and visible light frequencies. **Credit:** Image courtesy STCI/JHU/NASA.



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

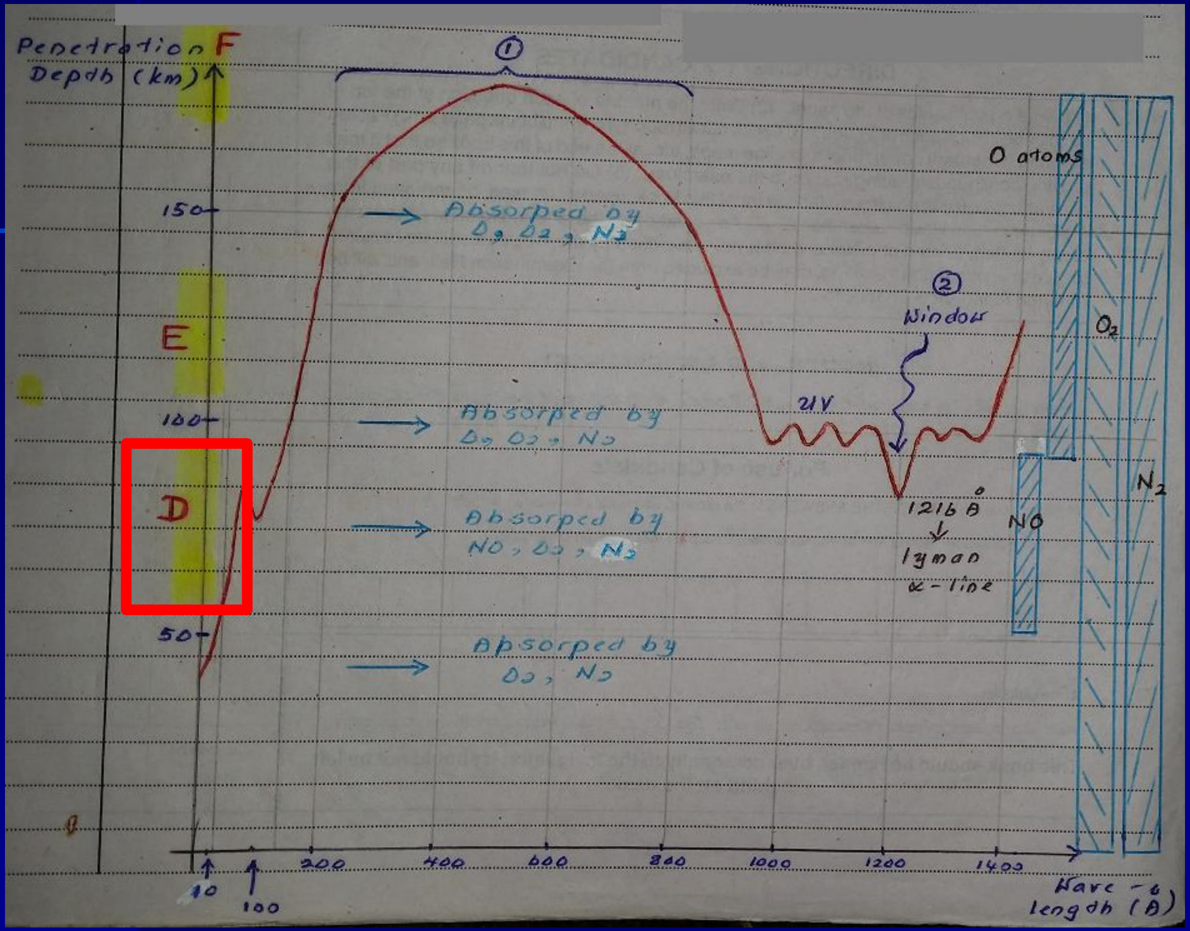
Penetration Depth

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.

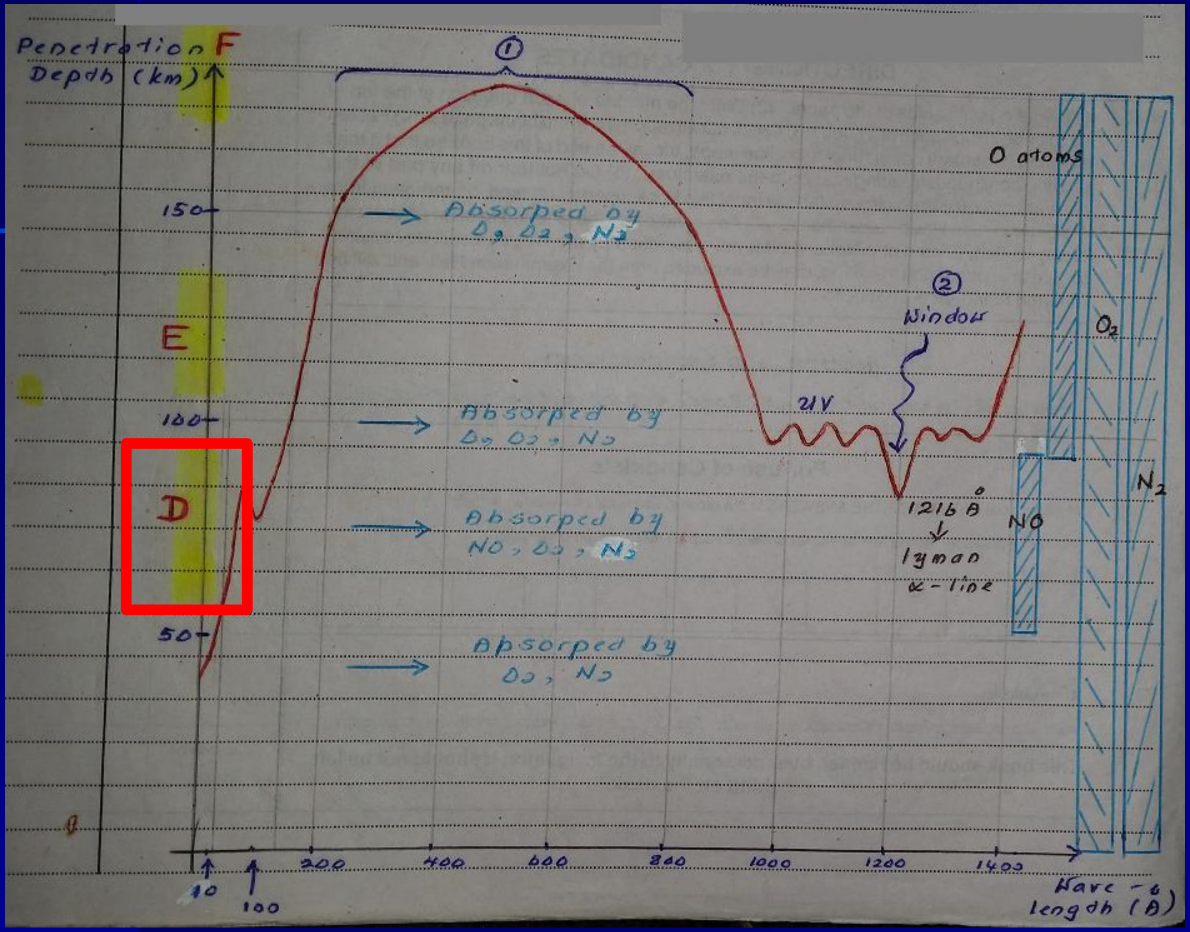
Penetration Depth



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

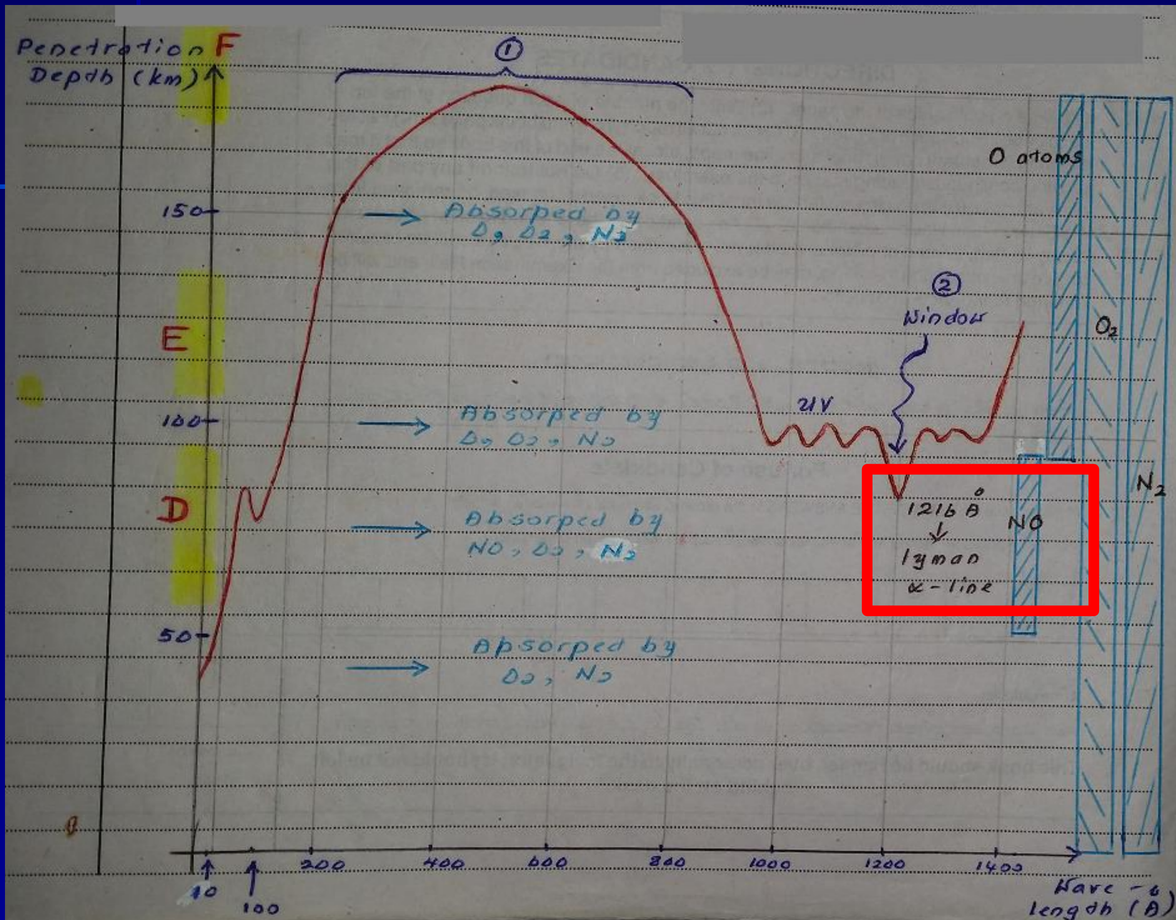
This phenomena has a ~11.2 years cycle !

Penetration Depth



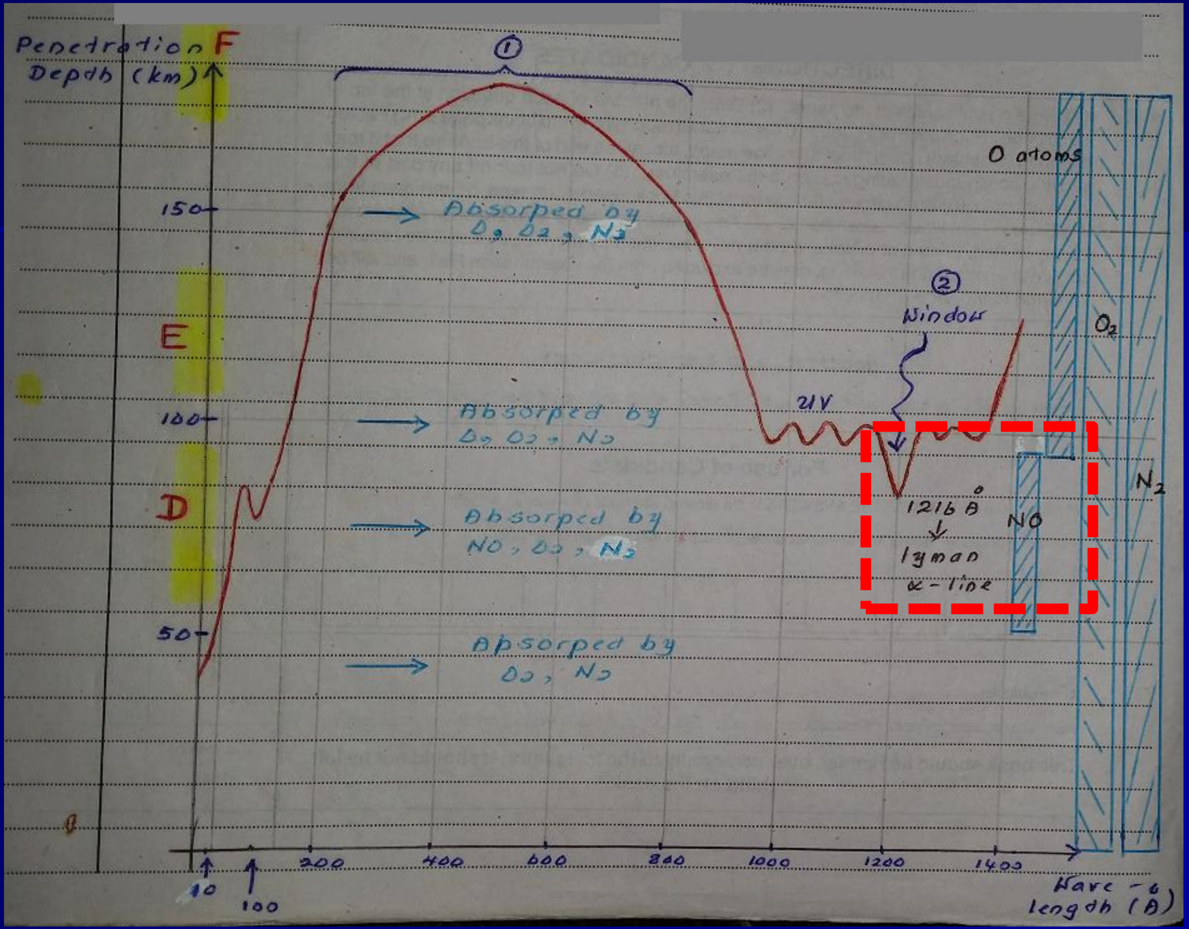
- If a **Solar Flare is created** on the Sun, the **size of the Region-D is increasing** very fast with in several minutes (~8 min & 30 sec)

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.!

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.


Thank You !
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