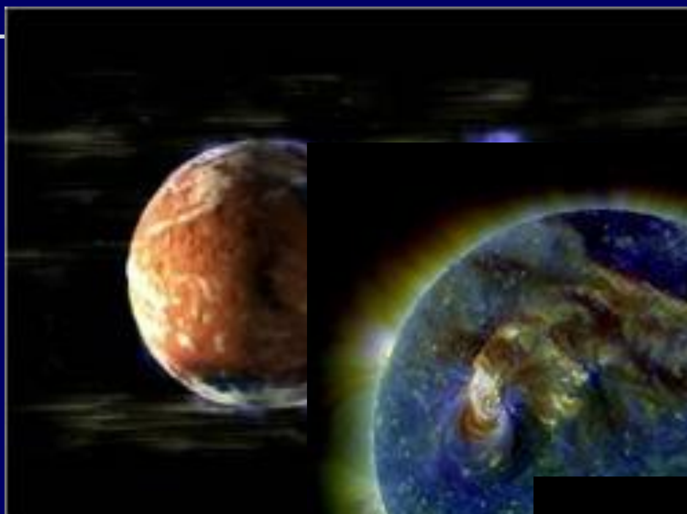
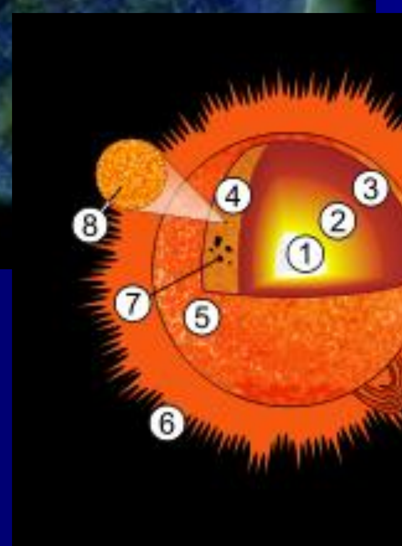
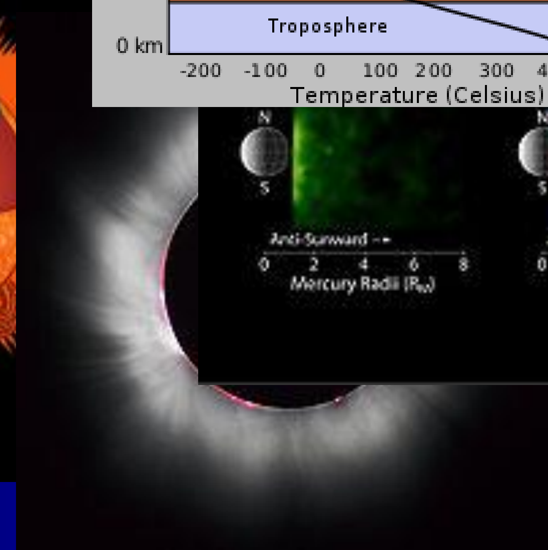
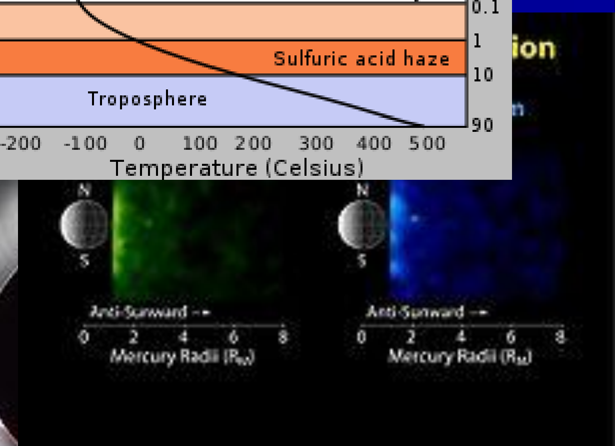
Space Physics

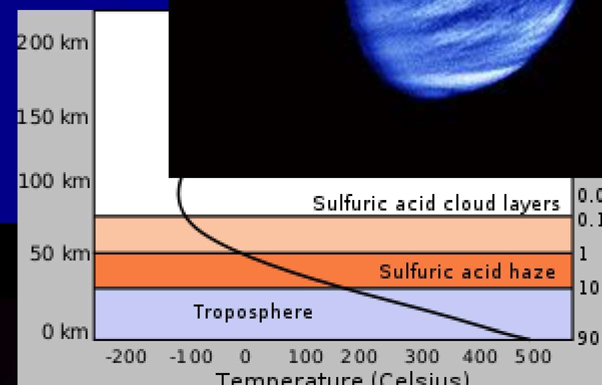
Space Physics

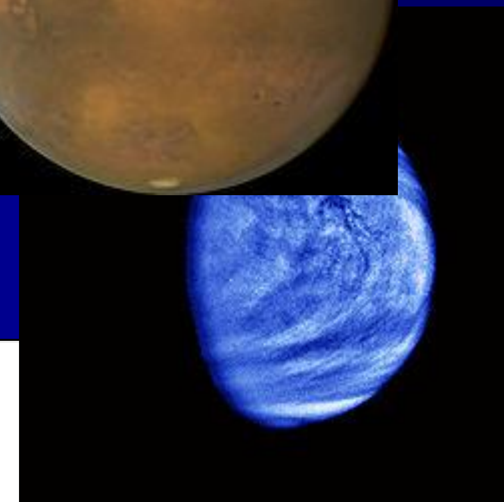


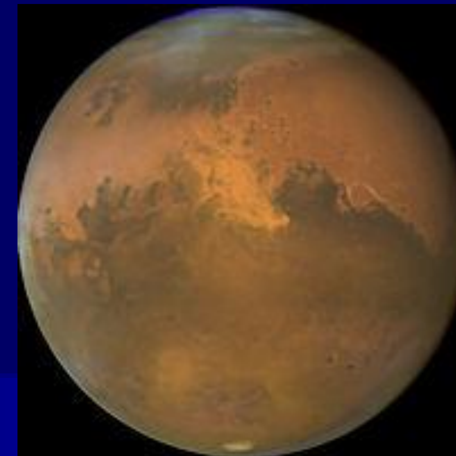












Lecture – 09

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)

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 :

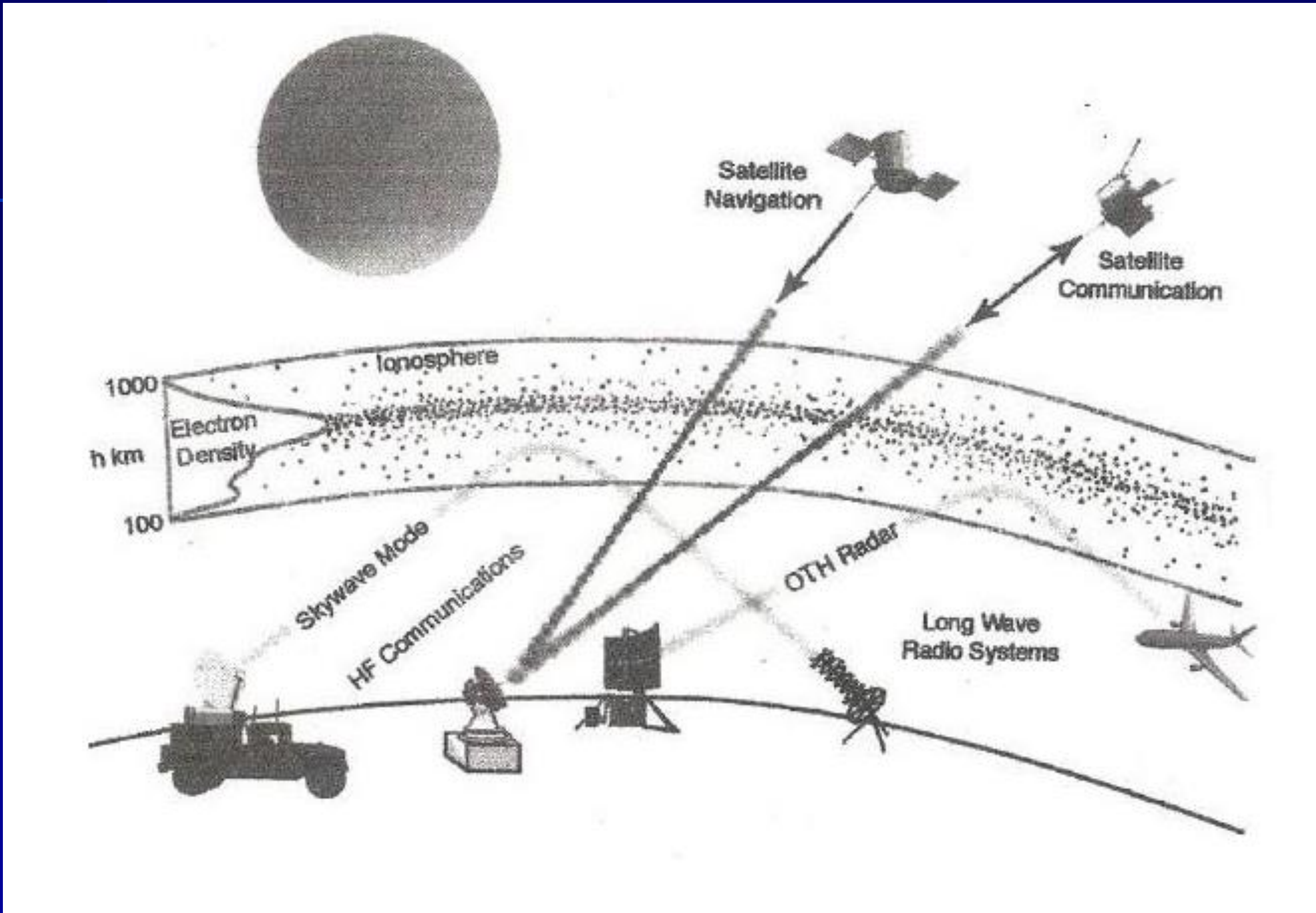
- F region: 150–1000 km, $n_e = 10^{11}$–10^{12} m^{-3} .

$f_p = 2.85\ MHz$ 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** !

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 = $1/\alpha$

Proof : PTO

Penetration Depth

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

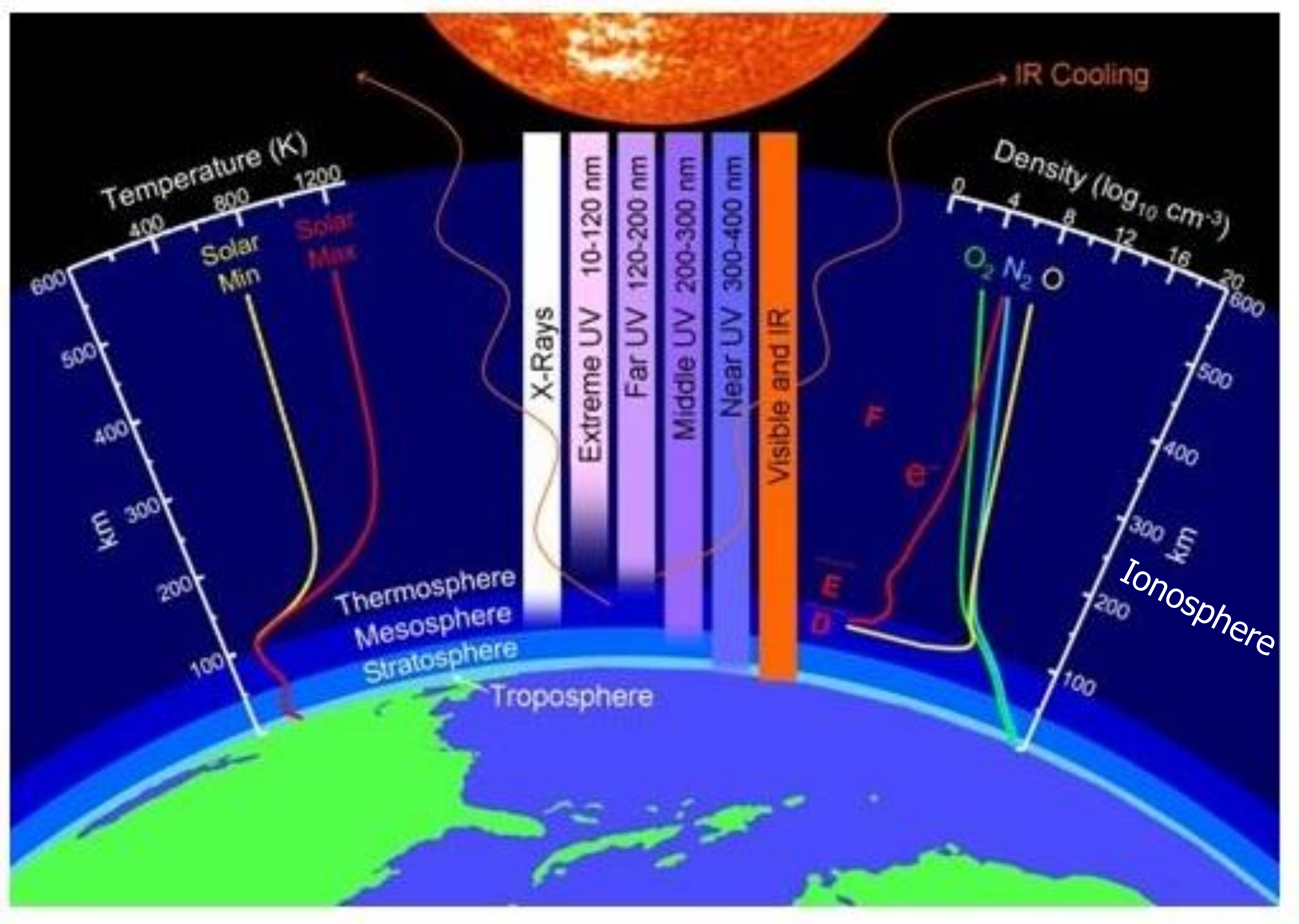
At h = h (Penetration Depth) ➡ $I(h) = I(0)/e$

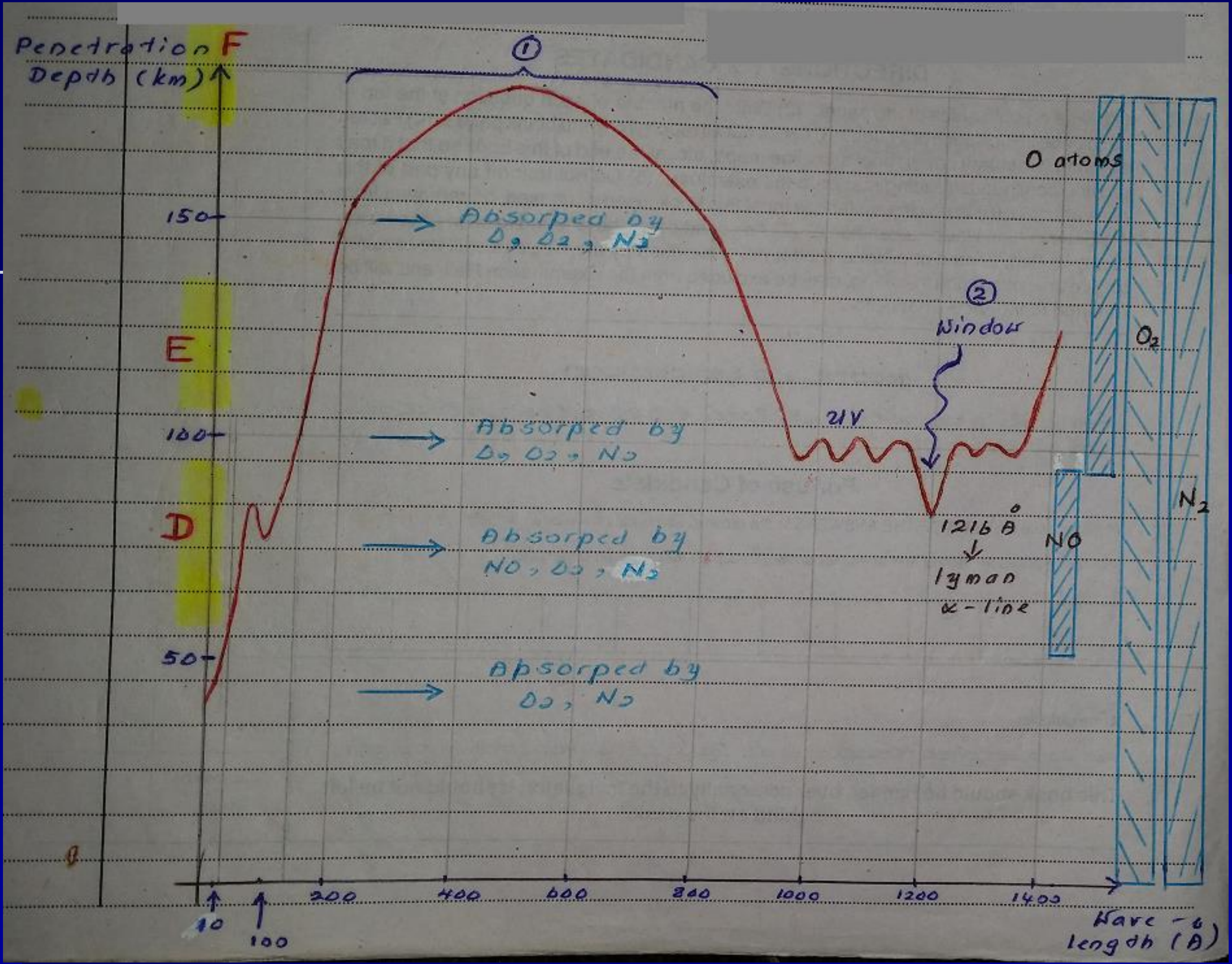
➡ $I(0)/e = I(0)\ e^{-\alpha\ h}$

➡ $e^{-1} = e^{-\alpha\ h}$

➡ $\alpha\ h = 1$

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

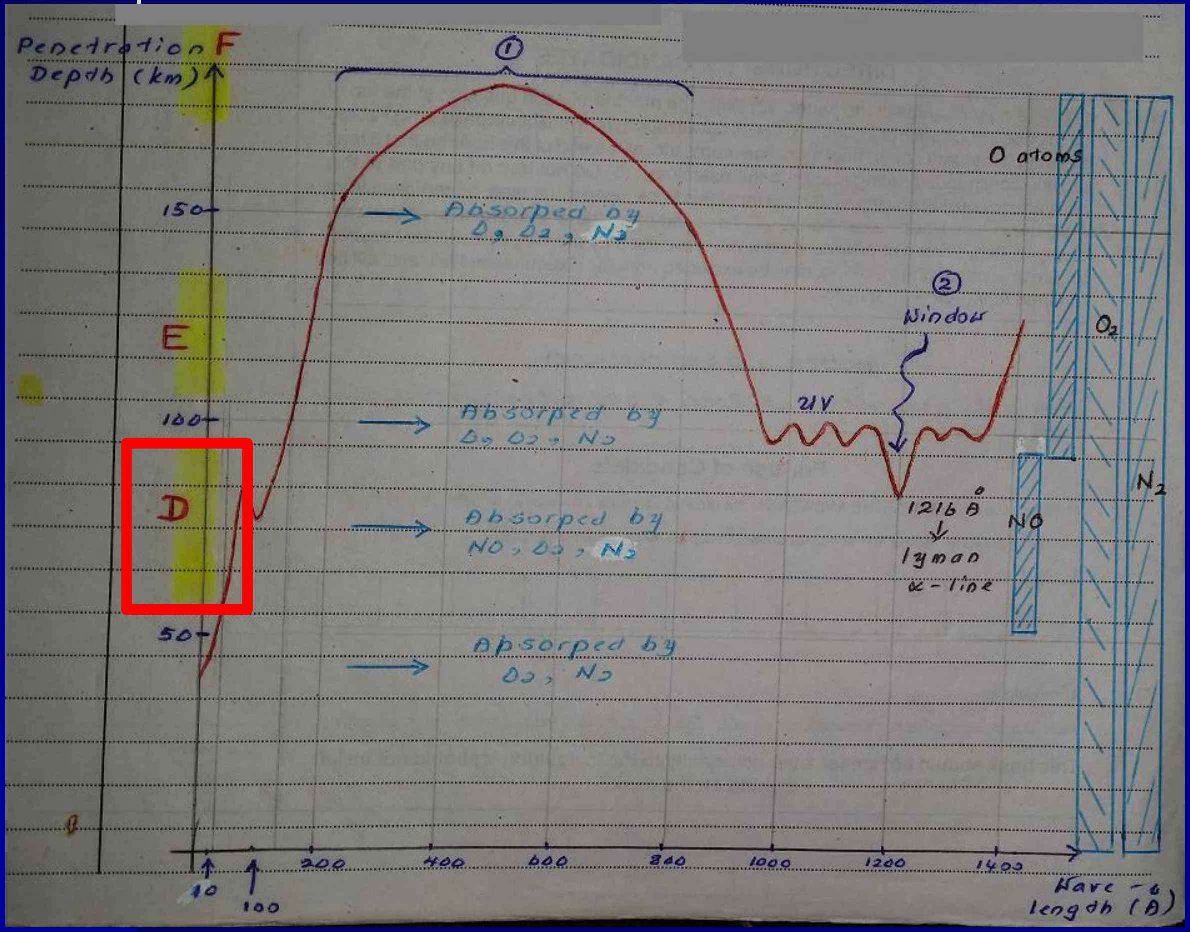

IR Cooling
Temperature (K)
400
800
1200
Solar Min
Solar Max
km
600
500
400
300
200
100
X-Rays
Extreme UV 10-120 nm
Far UV 120-200 nm
Middle UV 200-300 nm
Near UV 300-400 nm
Visible and IR
Thermosphere
Mesosphere
Stratosphere
Troposphere
Density ($\log_{10}$ cm^{-3})
0
4
8
12
16
20
O_2 N_2 O
F
e^-
E
D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



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

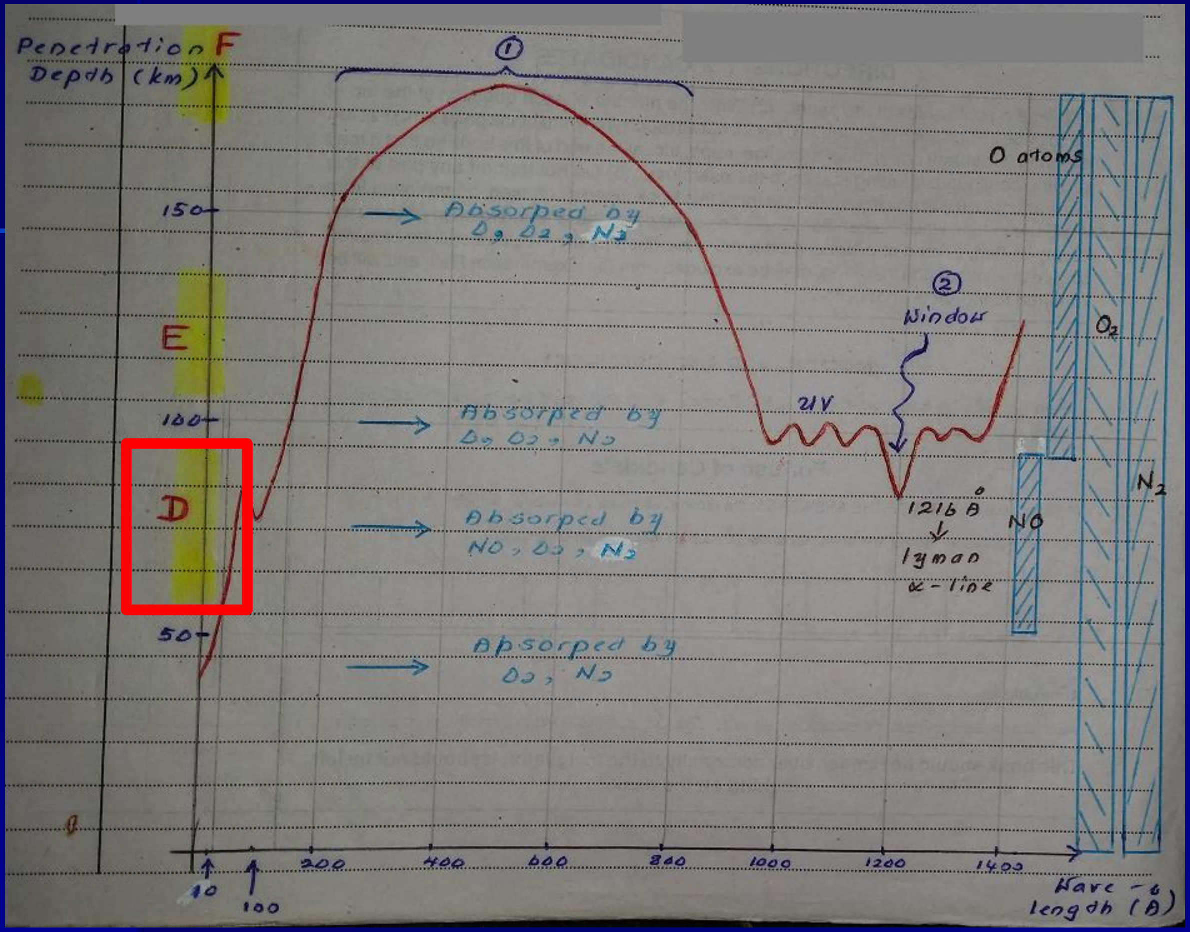
Penetration Depth

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.

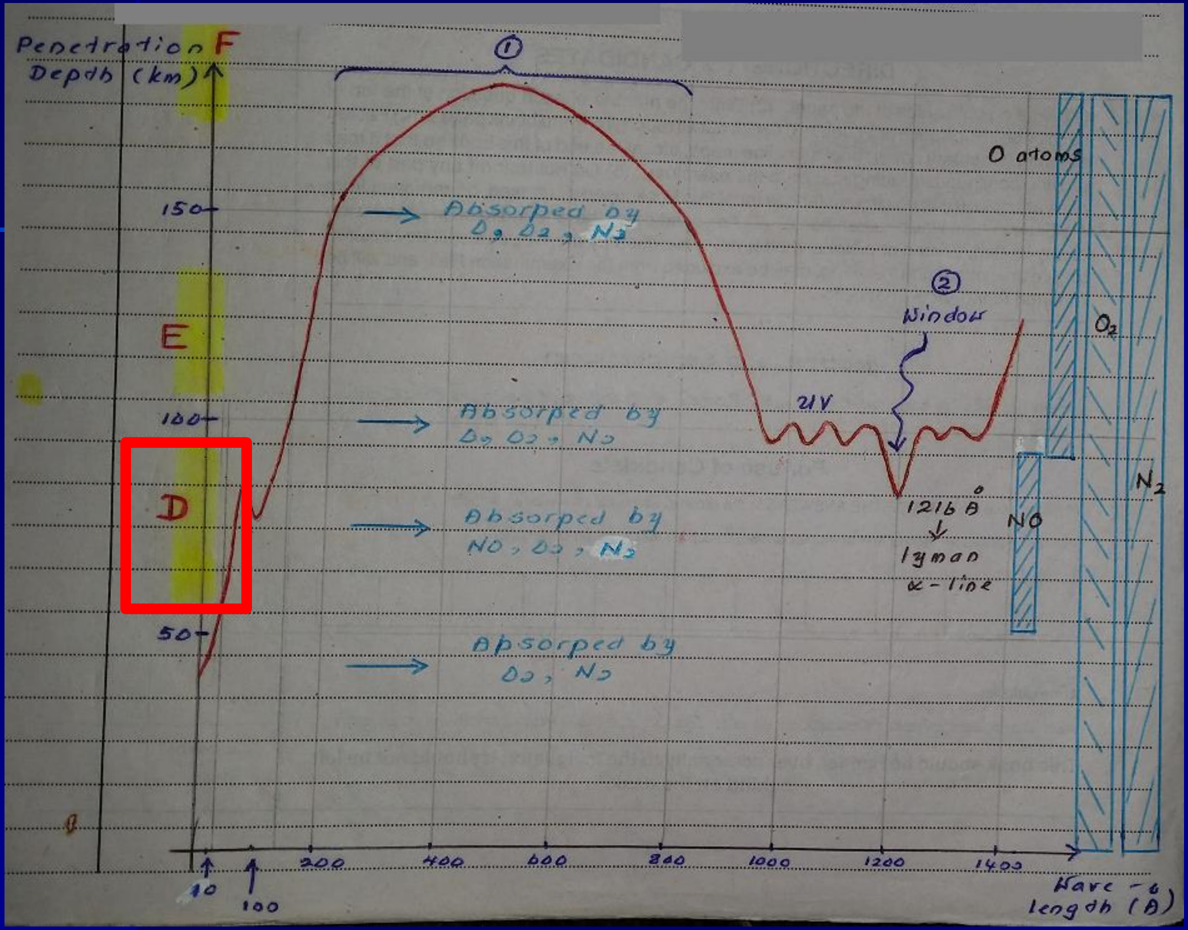
Penetration Depth



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

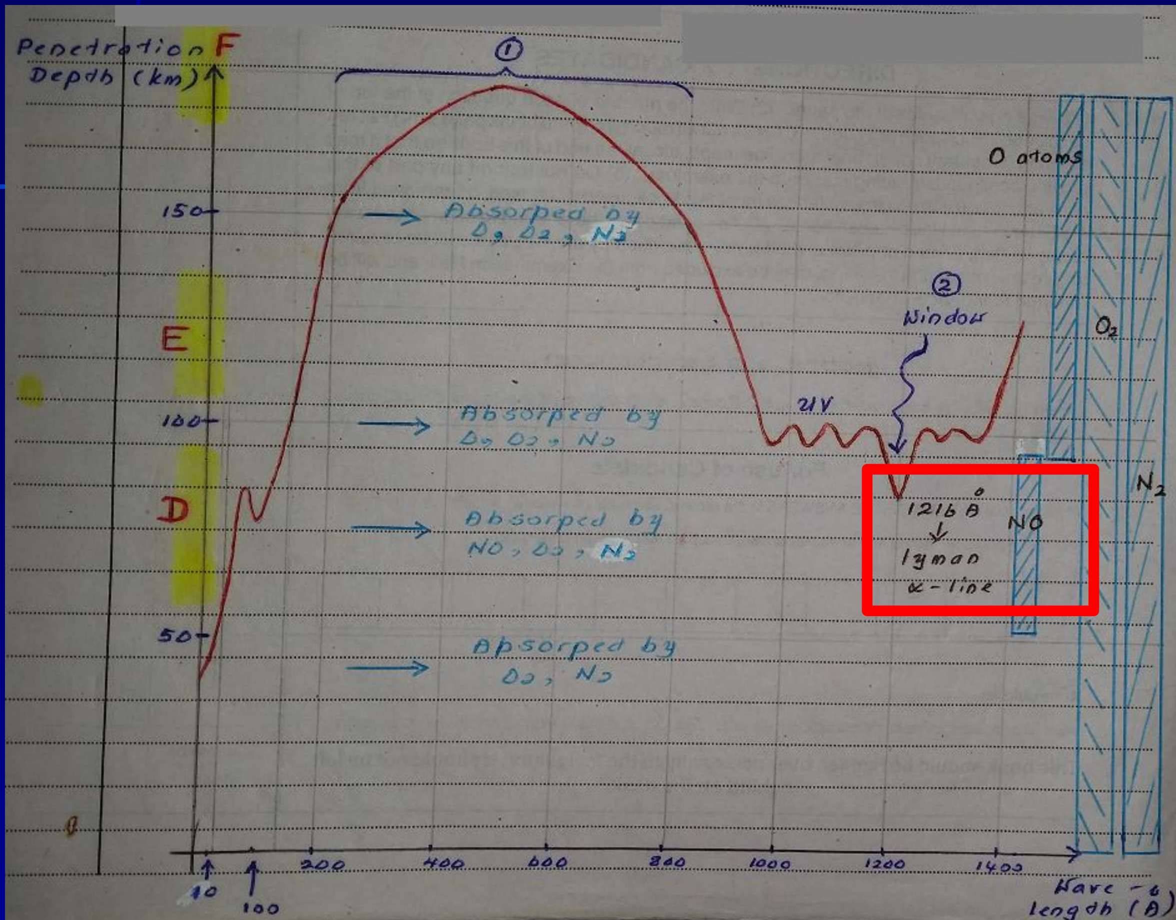
This phenomena has a ~11.2 years cycle !

Penetration Depth



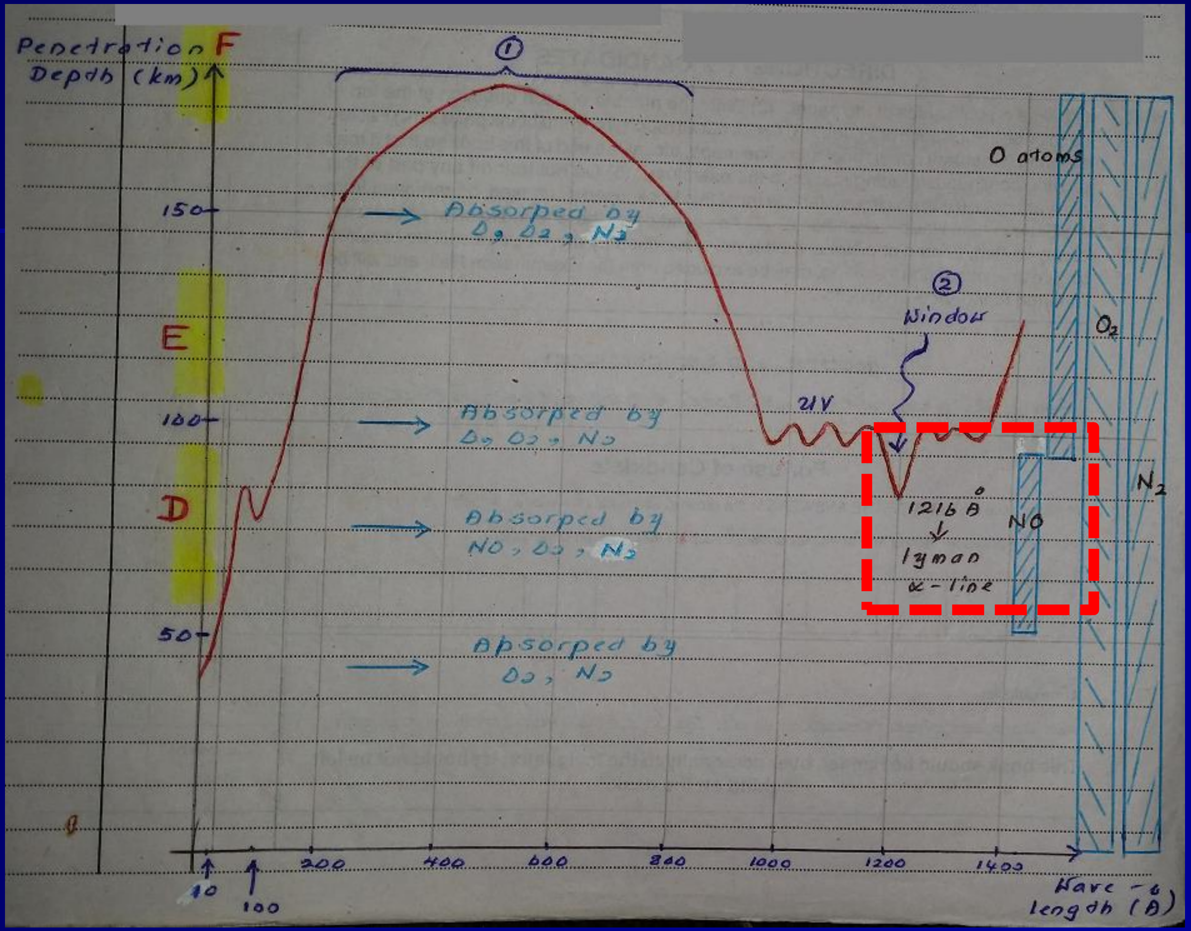
- If a **Solar Flare is created** on the Sun, the **size of the Region-D is increasing** very fast with in several minutes (~8 min & 30 sec)

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**

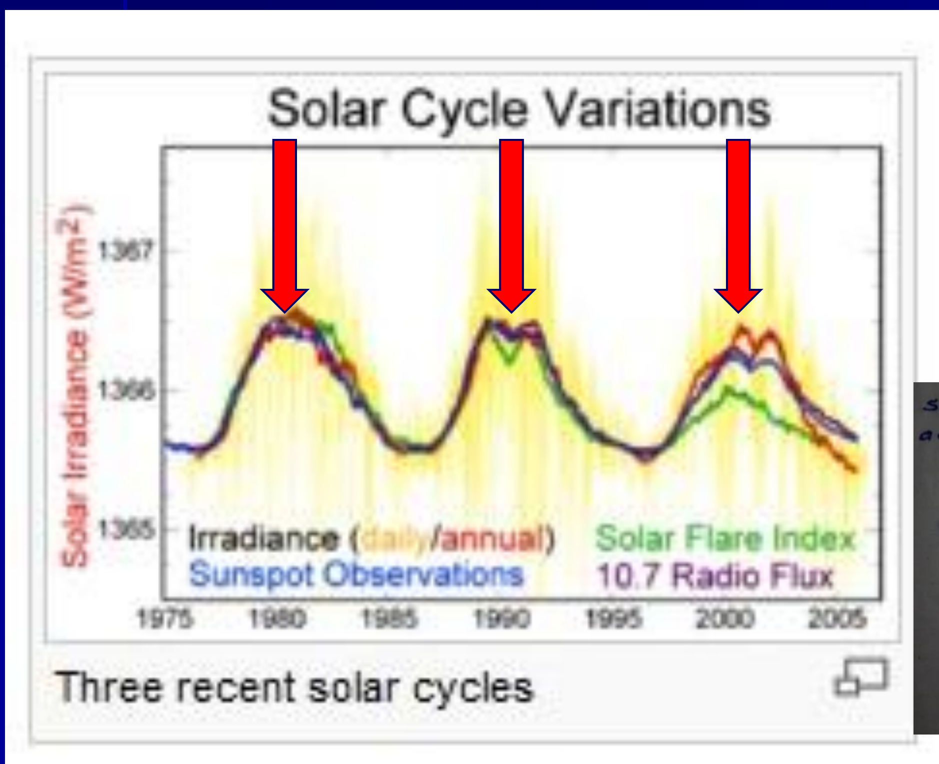
The 27 day cycle due to the intrinsic (true) rotation of the Sun. This cycle is especially noticeable during periods of **high solar activity when a very activity region** might last for more than one rotation of the Sun.

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.

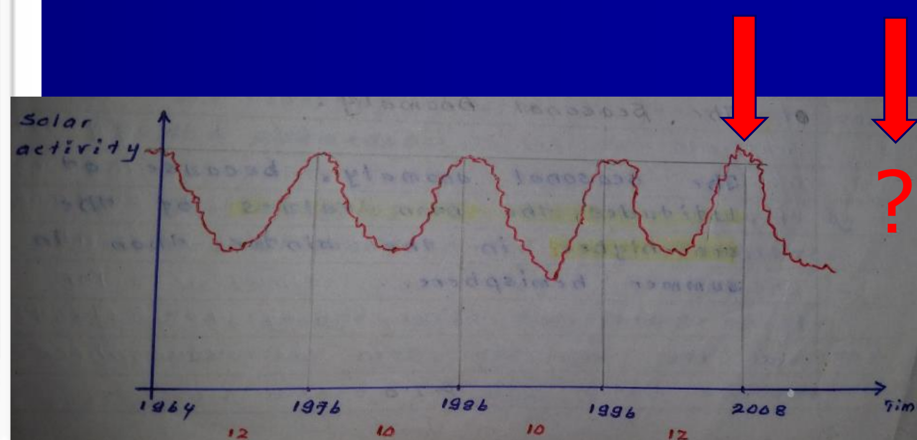
Regular Variations of the Ionosphere

- **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.

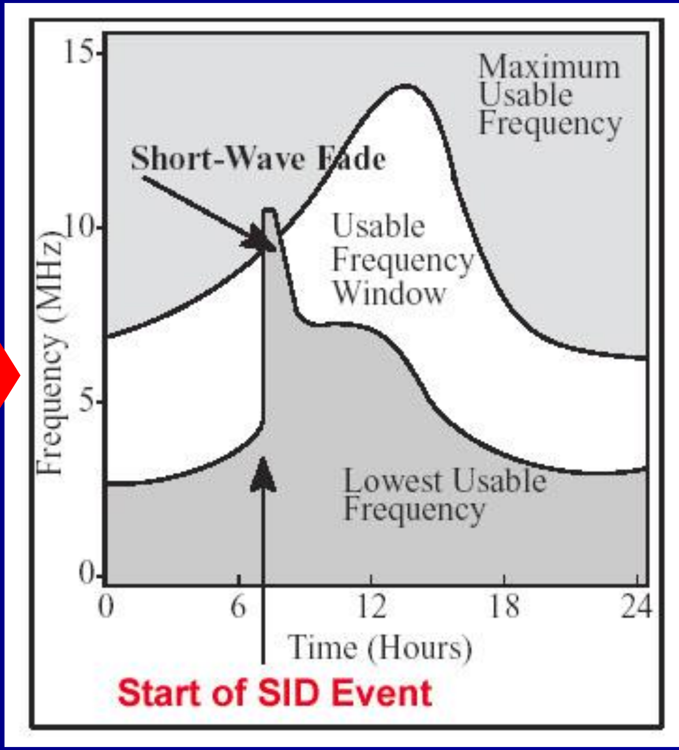
- **The Mid-Latitude Trough**

  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)**

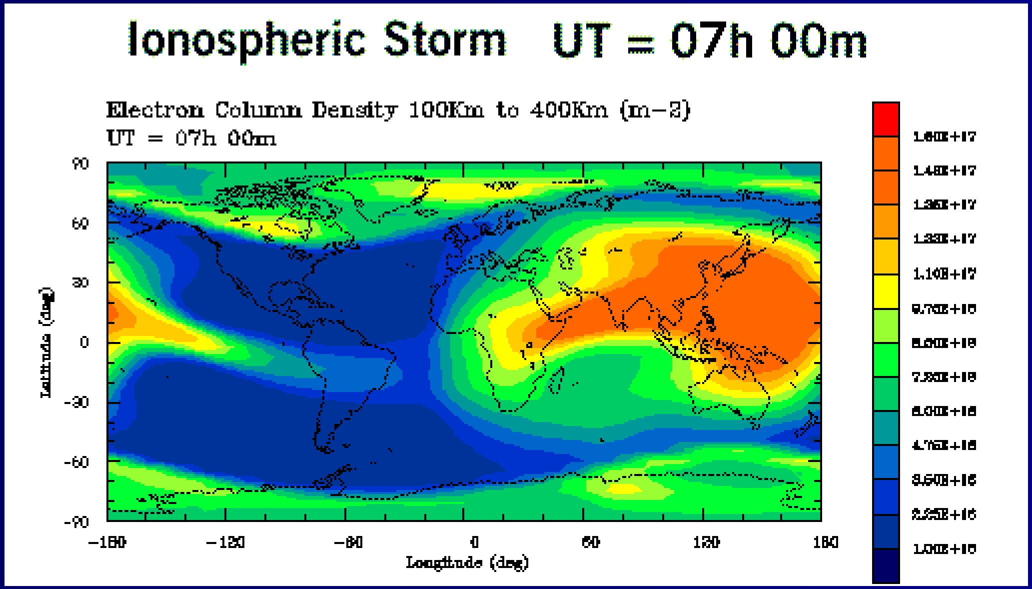
These are caused by the enhanced ultra-violet and X-ray radiation from the Sun during solar flare events. They occur only in the Sun-lit side of the Earth and they last, like the solar flares, from a few minutes to about one hour.



Irregular Variations of the Ionosphere

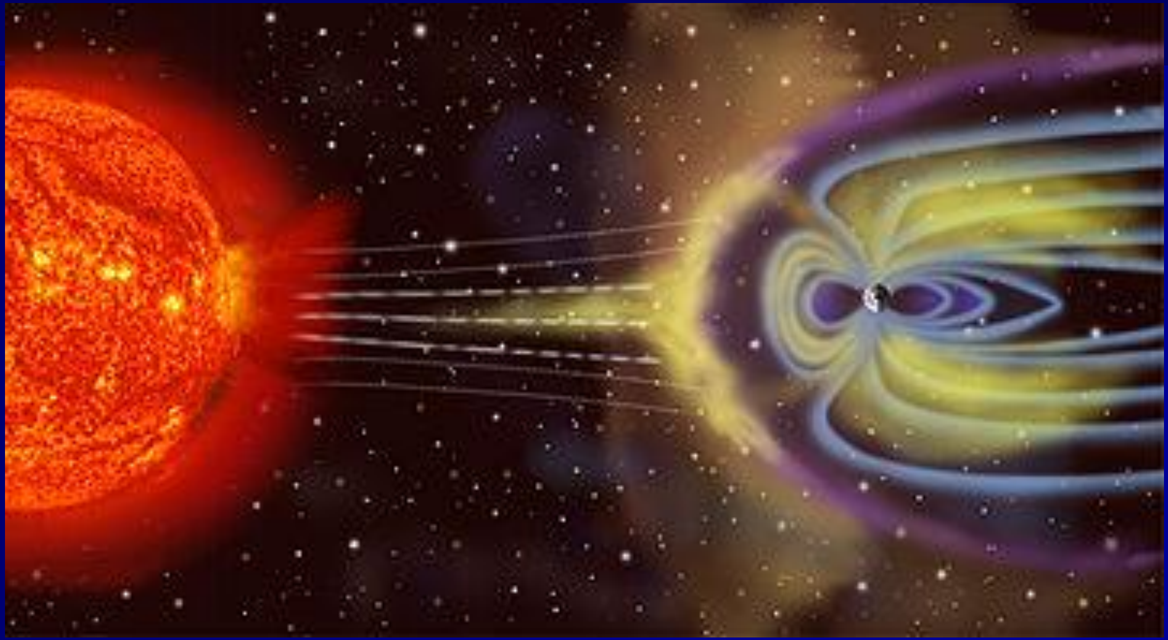
- **Ionospheric Storms**

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.



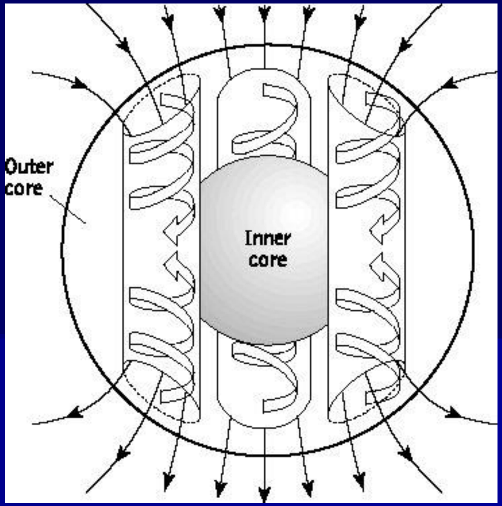
Many diurnal, seasonal and latitudinal storm effects have been discovered and serious efforts have been made for their theoretical interpretation.

The Magnetosphere



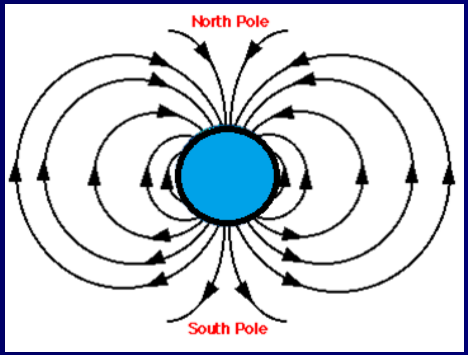
The Earth's Magnetic Fields
The Dipole Magnetic Field
Motion of charged particles in a Dipole Magnetic Field
The Radiation Belts
The boundary and the tail of the Magnetosphere

The Earth's Magnetic Field

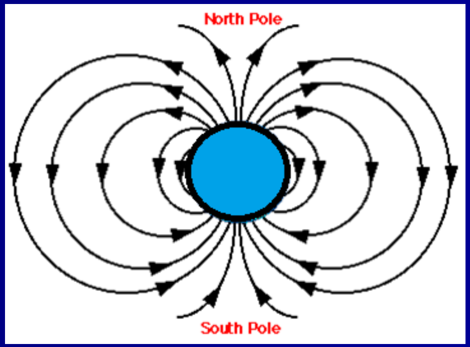


Present theories believe that the Earth's magnetic field arises (appears) from electric currents flowing in the molten metallic core of the planet, which has a radius approximately one-half the radius of the Earth

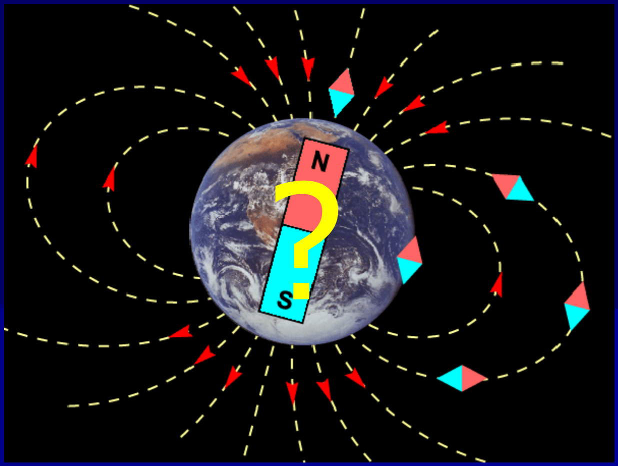
The currents are attributed to a dynamo mechanism operating inside the core. Recent discoveries suggest that the strength and orientation of the terrestrial magnetic field have changed considerably over geological periods. There is also strong evidence that the Earth's magnetic field has reversed its direction several time during the life time of our planet.



Million of years

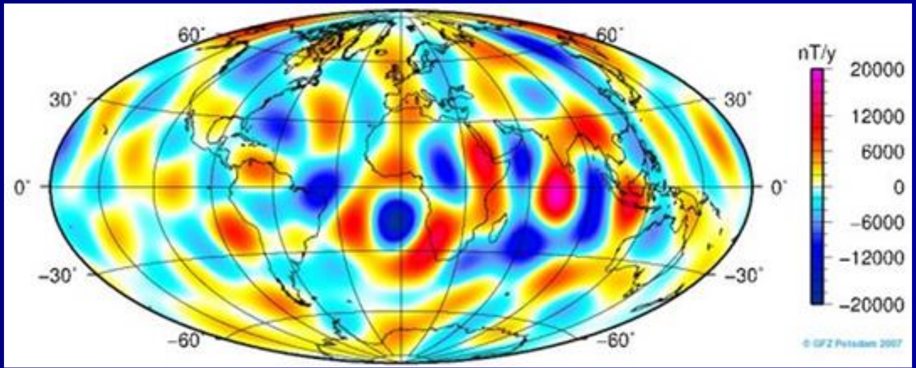


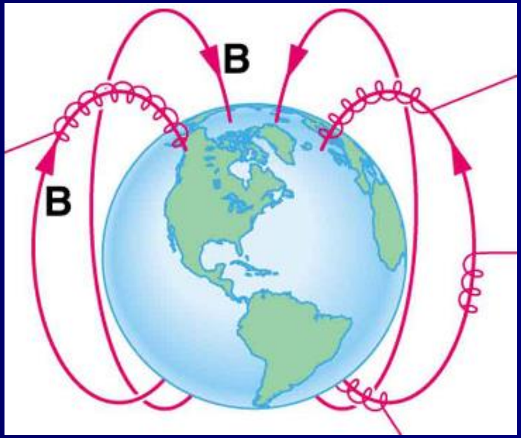
The Earth's Magnetic Field



The Earth's magnetic field resembles a di-pole magnetic field. Large scale regional departures from the dipole field are called geomagnetic anomalies and are attributed to irregular or eddies in the dynamo current system.

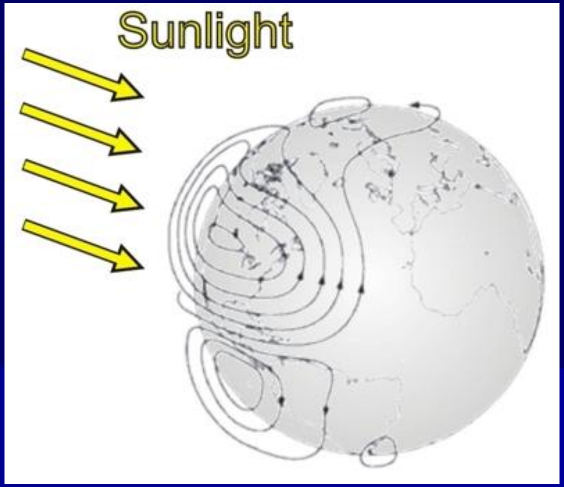
There are also smaller size anomalies due to local mineral deposits which are called surface magnetic anomalies and are helpful in locating these deposits of ferromagnetic materials.



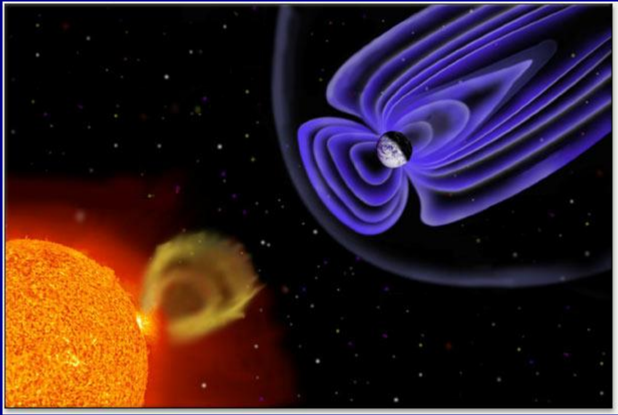


A very small components (less than 0.1%) of the terrestrial magnetic field is due to currents of charge particles in the outer atmosphere of the Earth.

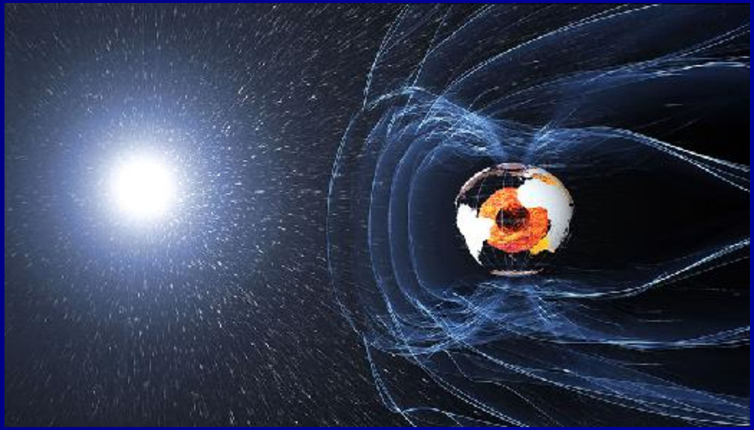
The Earth's Magnetic Field



The sq-currents, eg: which circulates between the Sunlit and the dark hemisphere, is responsible for the small, regular diurnal (daytime) variations of the magnetic field observed on the ground.



After a large solar flare, the enhanced flux of energetic particles from the Sun can produce strong ring currents of the charged particles around the Earth that can produce large fluctuations (occasionally as high as 3%) of the terrestrial magnetic field. These magnetic disturbances, which might last for several days, are described by the different indices of geomagnetic activity.

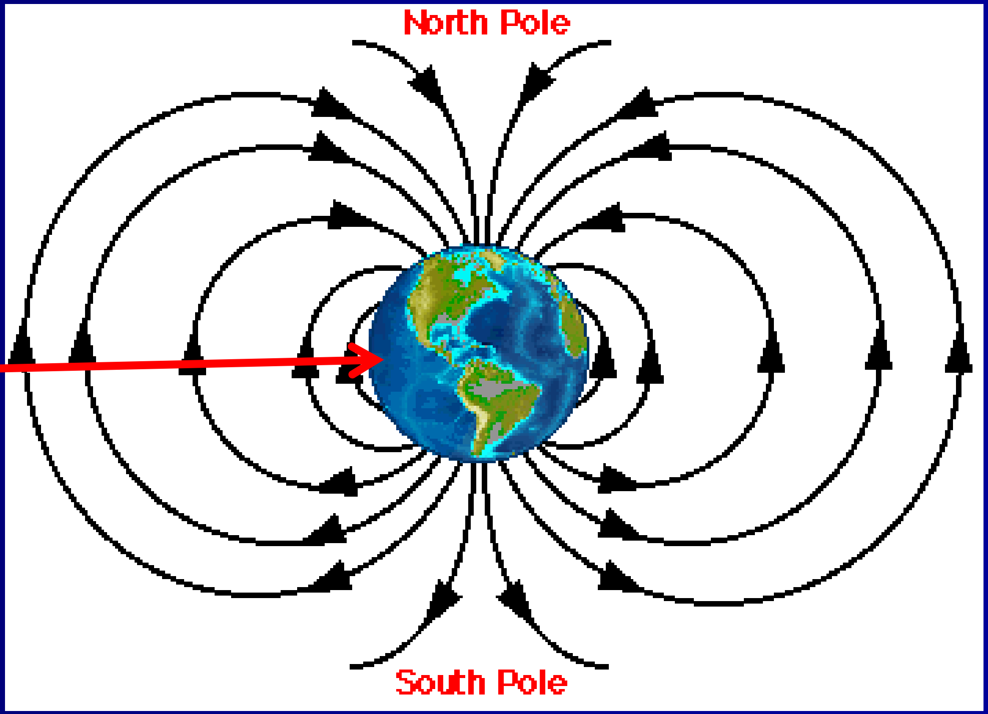


The Earth's Magnetic Field

The magnetic field of the Earth can be represented to a good approximation, by a **dipole-field** with a magnetic moment $M = 8.05 \pm 0.02 \times 10^{25}$ Gauss cm^3. The intensity of the field at the equator is ~0.3 Gauss and at poles ~0.6 Gauss.

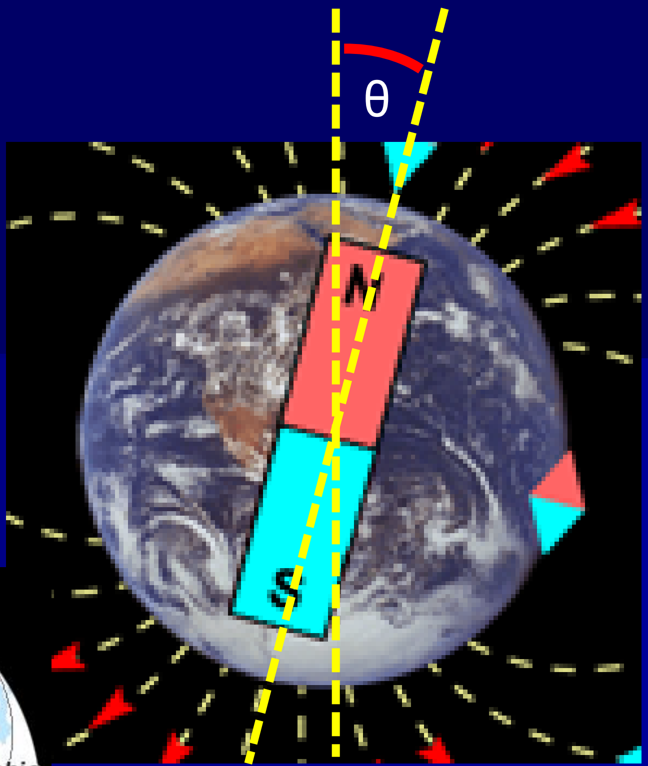
$$1 \text{ Gauss (G)} = \sim 1 \times 10^{-4} \text{ Tesla (T)}$$

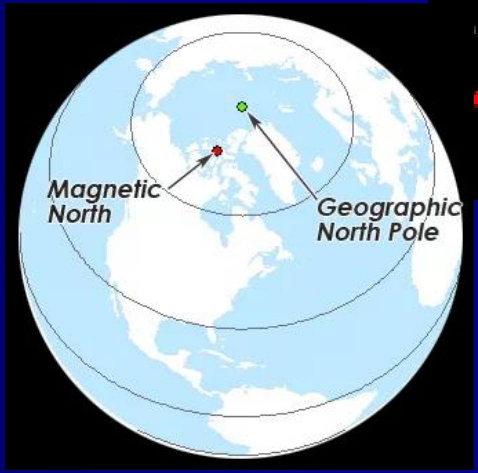
The Earth magnetic field intensity at the equator ~40,000 nT.



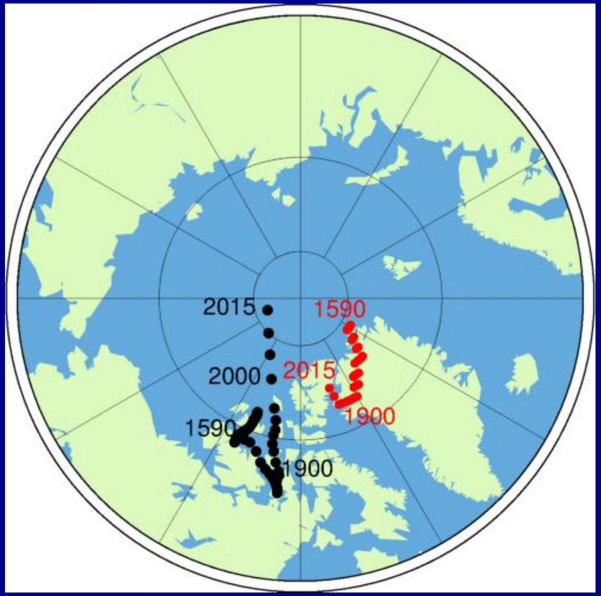
The Earth's Magnetic Field

The centered dipole (its axis passes through the center of the Earth) which fits best the Earth's magnetic field has its axis directed along the line (79°N, 290°E) to (79°S, 110°E). These are referred to respectively as the **north geomagnetic pole** and the **south geomagnetic pole**.



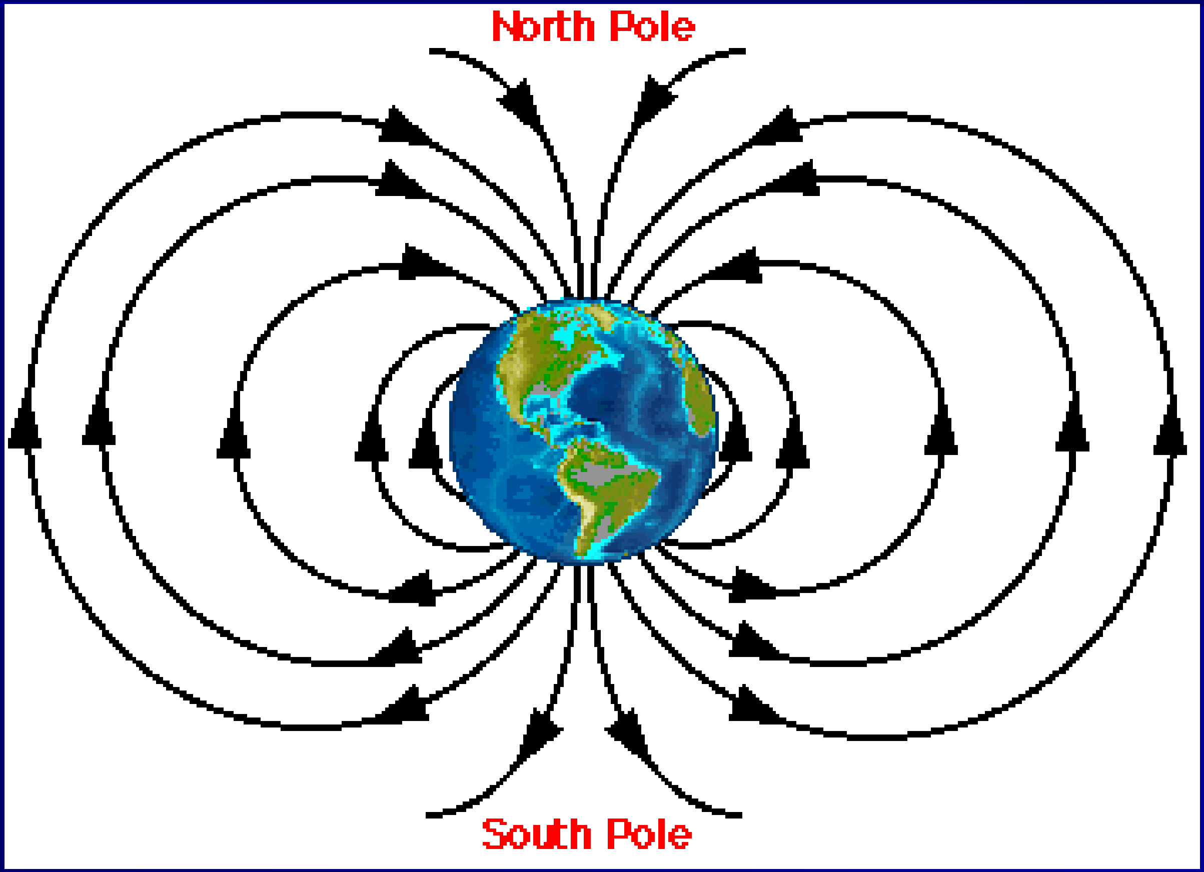


The **actual magnetic poles** are asymmetrically (unsymmetrically) located at (73°N, 262°E) to (68°S, 145°E).

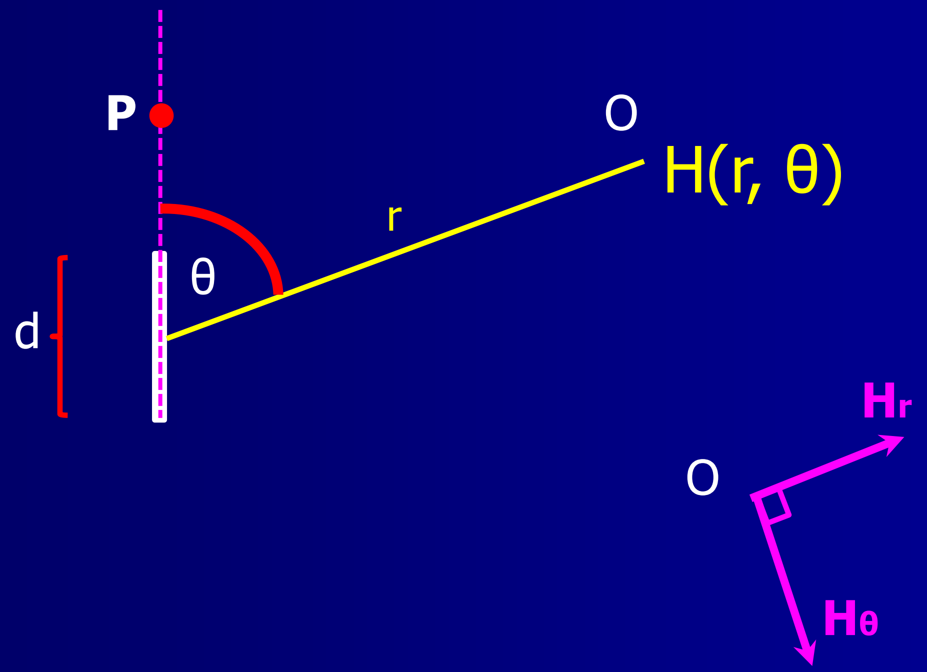


The **Earth magnetic poles** are changing with time !

The Earth’s Magnetic Field



The Dipole Magnetic Field



$$H_r = \frac{\mu_o}{4\pi} \cdot \frac{2M}{r^3} \cos\theta$$

$$H_\theta = \frac{\mu_o}{4\pi} \cdot \frac{M}{r^3} \sin\theta$$