Space & Atmospheric Physics

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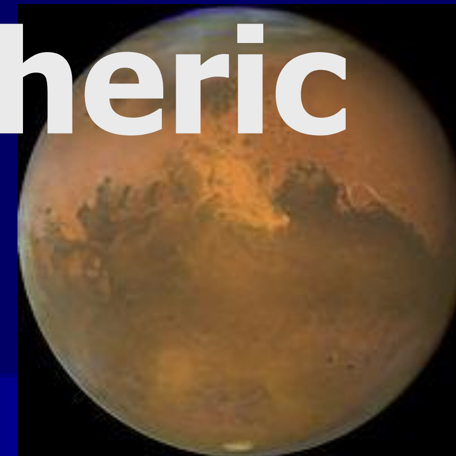
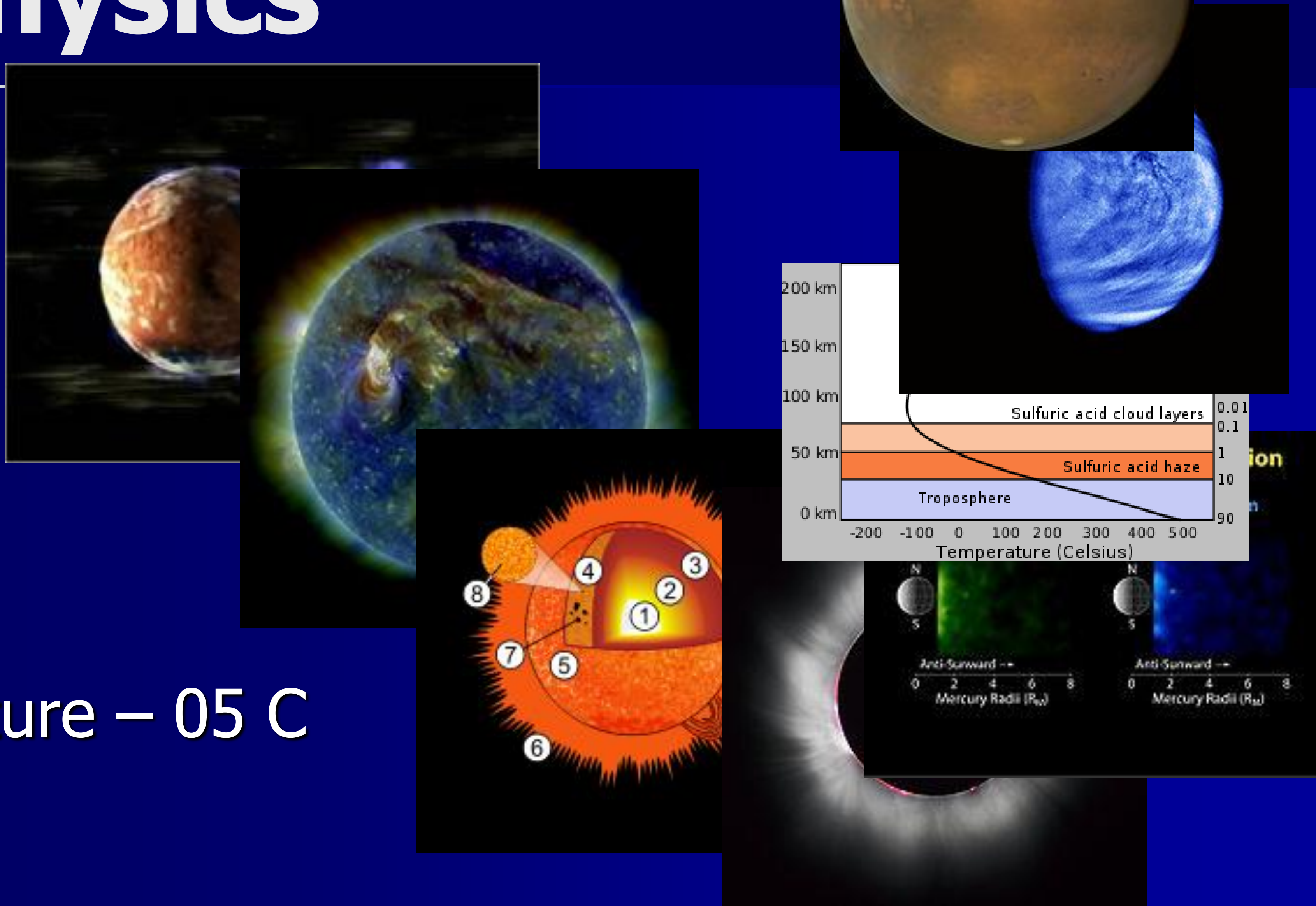


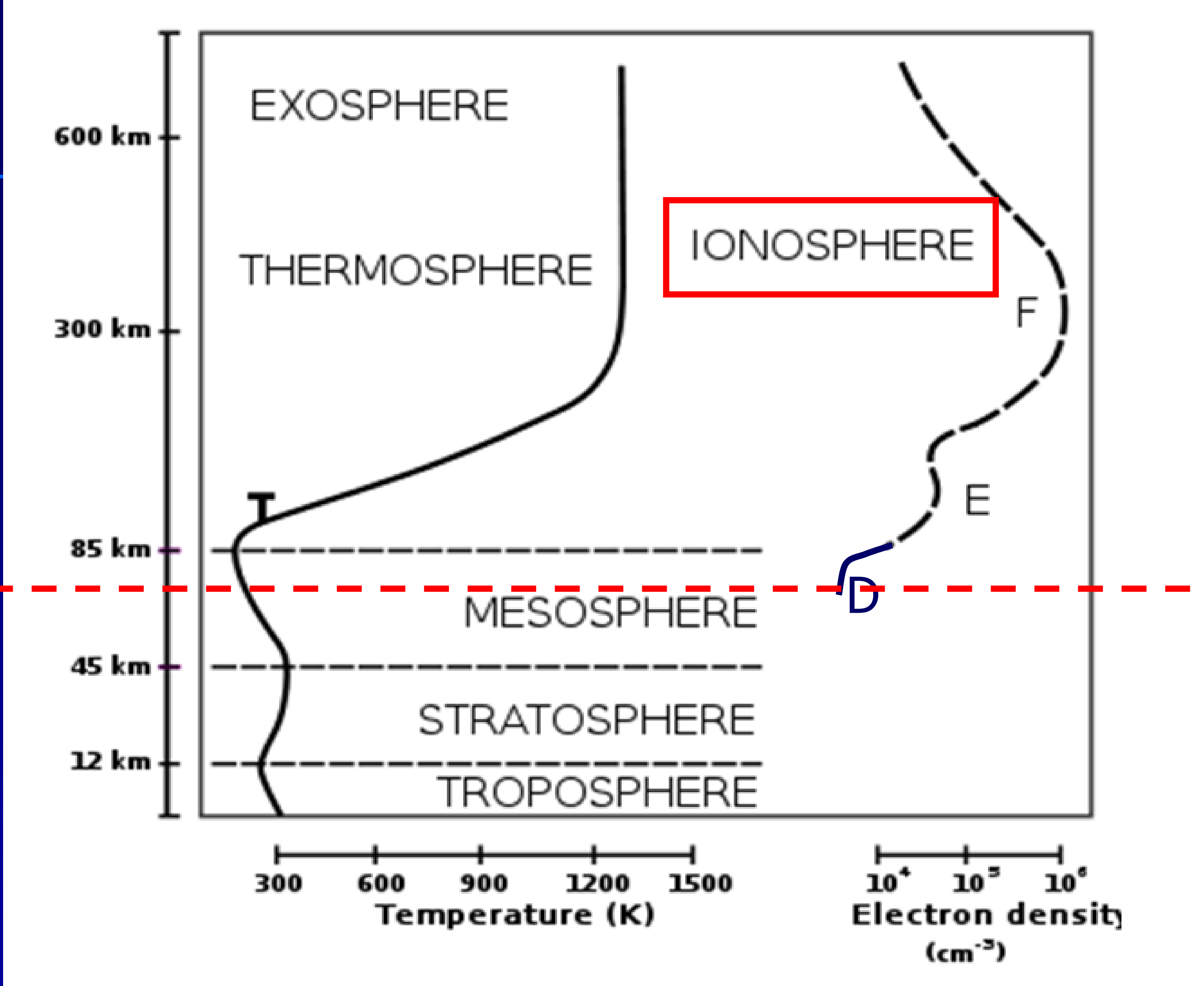


Lecture – 05 C

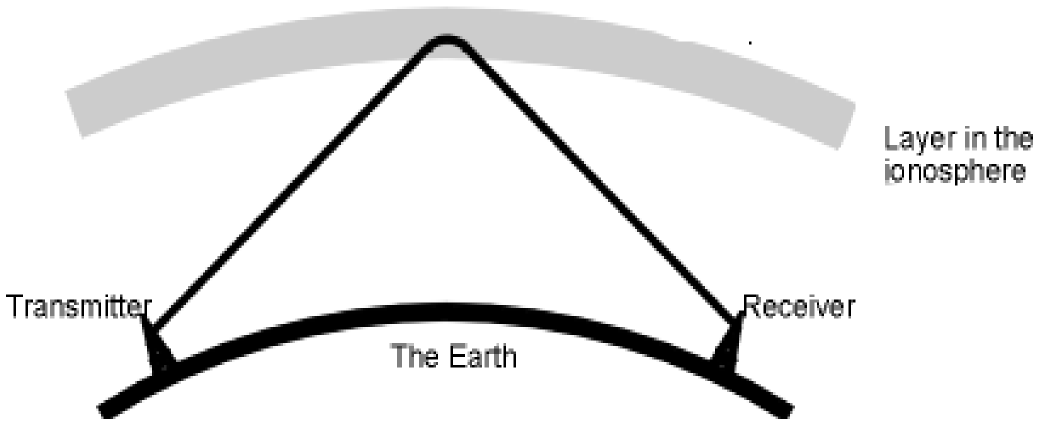
The Ionosphere

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

Relationship of the atmosphere and ionosphere

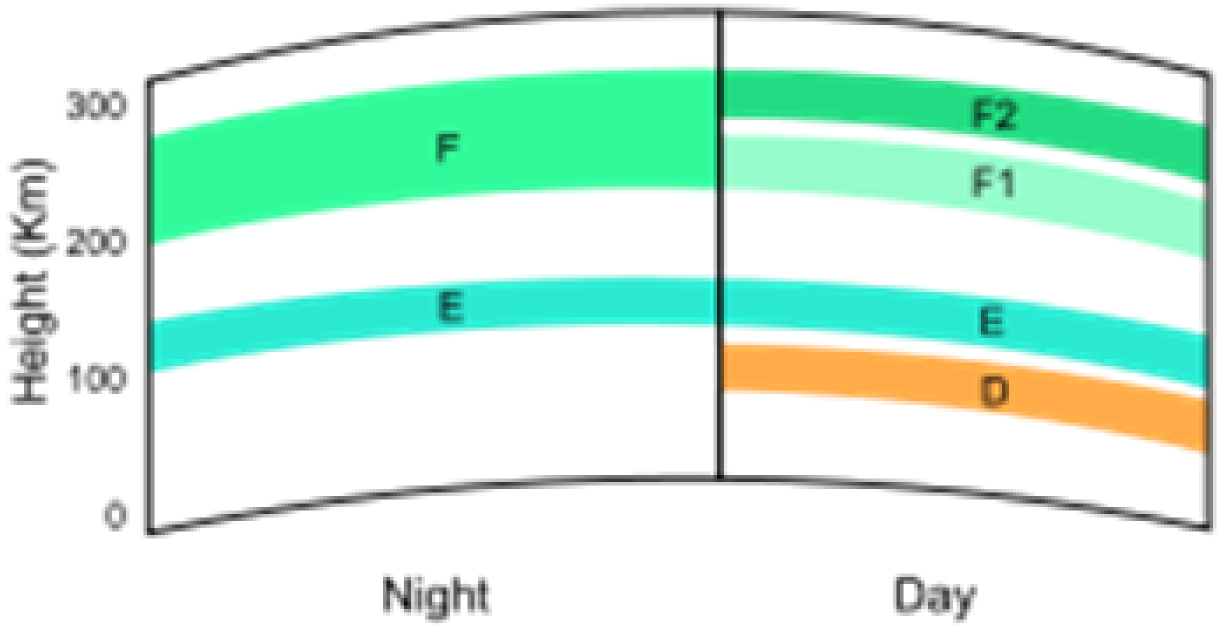


The existence of the ionosphere, as an electrically conducting region of the atmosphere, was first suggested by the Scottish meteorologist Belfour Stwart in 1883. It has practical importance because among other functions, it influences Radio Propagation to distant places on Earth.



Refraction of a radio signal as it enters an ionised region

The ionospheric layers



Ionospheric layers.

The ionospheric layers

D-layer or D-region

The D layer is the innermost layer, 60 km to 90 km above the surface of the Earth. Ionization here is due to **Lyman series-alpha hydrogen radiation** at a **wavelength of 121.5 nm** ionizing **nitric oxide (NO).**

In addition, with high solar activity hard X-rays ($\lambda < 1$ nm) may ionize (N_2, O_2). During the night cosmic rays produce a residual amount of ionization. Recombination is high in the D layer, the net ionization effect is low, but loss of wave energy is great due to frequent collisions of the electrons (about 10 collisions every mili-seconds).

As a result high-frequency (HF) radio waves are not reflected by the D layer but suffer loss of energy there in. This is the main reason for absorption of HF radio waves, particularly at 10 MHz and below, with progressively smaller absorption as the frequency gets higher.

The ionospheric layers

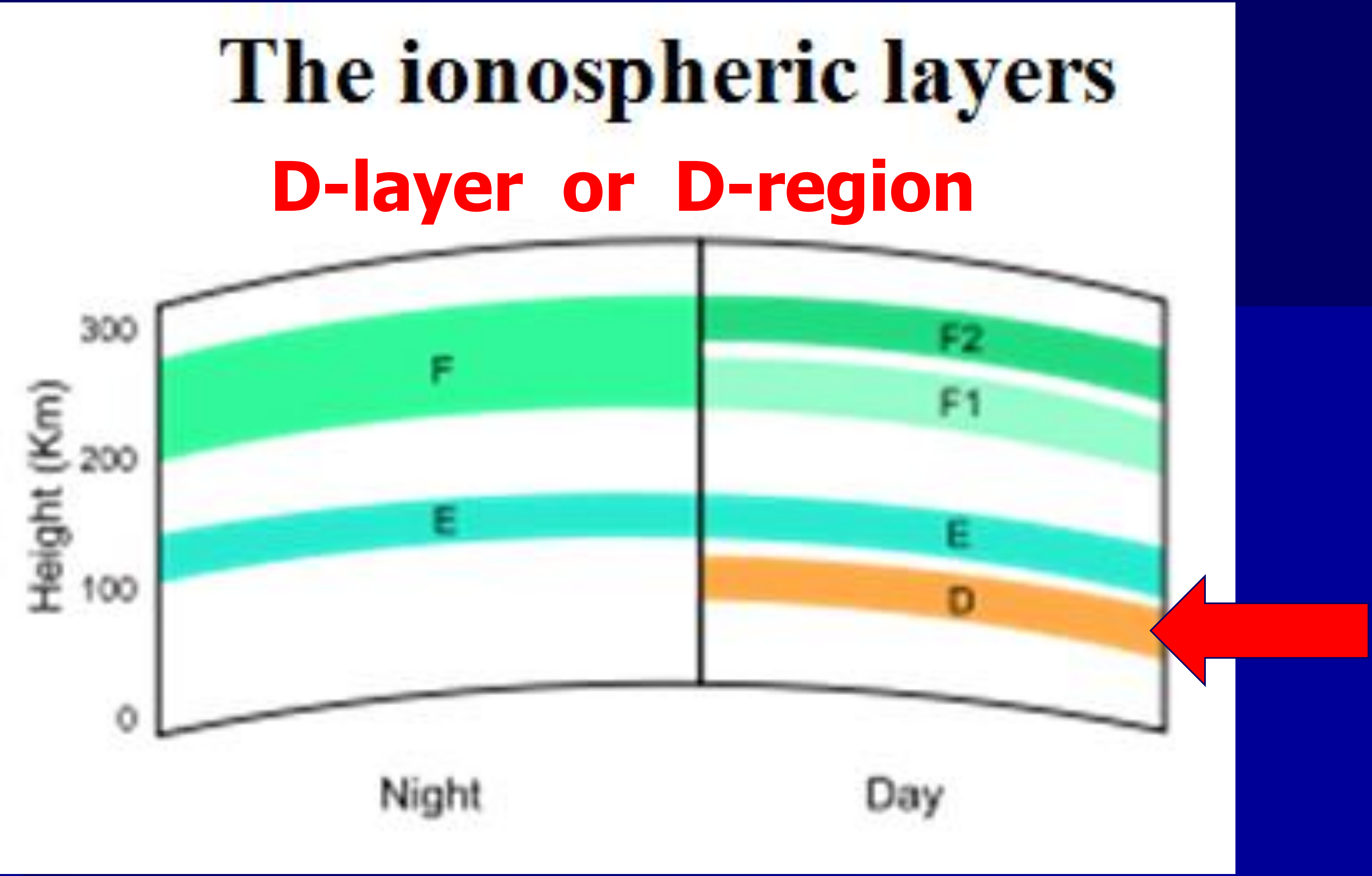
D-layer or D-region

The **absorption is small at night and greatest about mid day**. The layer reduces greatly after Sunset; a small part remains due to galactic cosmic rays. A common example of the D layer in action is the disappearance of distant AM broadcast band stations in the daytime.

During solar proton events, ionization can reach unusually high levels in the D-region over high and polar latitudes. Such very rare events are known as Polar Cap Absorption (or PCA) events, because the increased ionization significantly enhances the absorption of radio signals passing through the region.

In fact, absorption levels can increase by many tens of dB during intense events, which is enough to **absorb most transpolar HF radio signal transmissions**. Such events typically last less than 24 to 48 hours.

Summary : D-layer



Ionization is due to – Lyman series - Alpha

Ionizing of – Nitric Oxide (NO)

Also ionization due to –

Hard X – rays (λ < 1 nm)

Ionizing of – N2, O2

The ionospheric layers

E-layer or E-region

At night the E layer rapidly disappears because the primary source of ionization is no longer present. After sunset an increase in the height of the E layer maximum increases the range to which radio waves can travel by reflection from the layer.

E_s – Sporadic (කඩින් කඩ) E - layer

The E_s layer is **characterized by small, thin clouds of intense ionization, which can support reflection of radio waves**, rarely up to 225 MHz. Sporadic-E events may last **for just a few minutes to several hours**. Sporadic E propagation makes radio amateurs (learner) very excited, as propagation paths that are generally unreachable can open up.

The ionospheric layers

E-layer or E-region

E_s - Sporadic E - layer

There are multiple causes of sporadic-E that are still being pursued by researchers. **This propagation occurs most frequently during the summer months when high signal levels may be reached.**

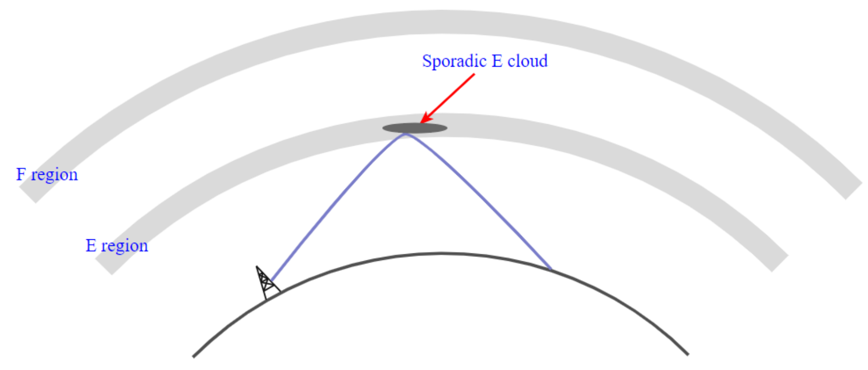
The **skip distances are generally around 1000 km**. VHF TV and FM broadcast also get excited as their signals can be bounced back to Earth by E_s.

Distances for one hop propagation can be as close as 900 km or up to 2,500 km. Double-hop reception over 3,500 km is possible too.

The ionospheric layers

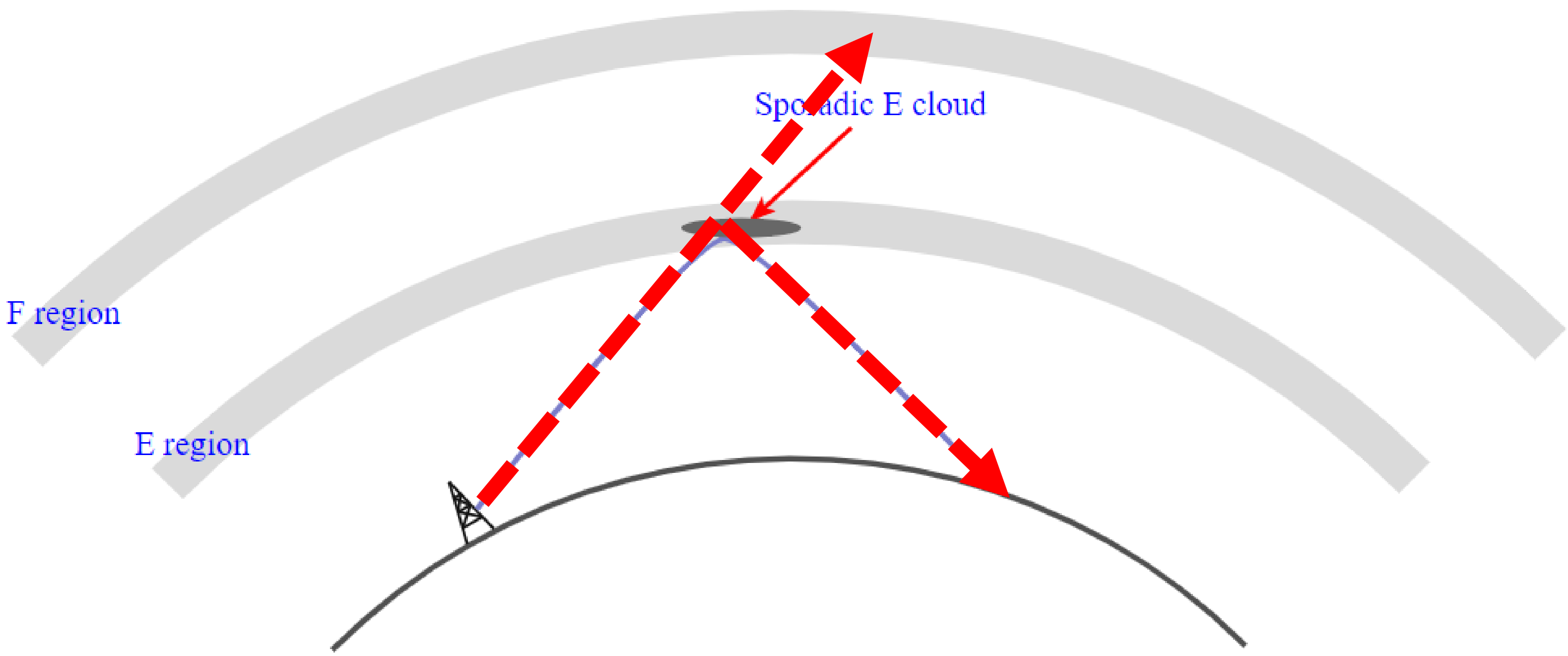
E_s – Sporadic (කඩින් කඩ) layer

E sporadic is a form of **E layer** ionisation that occurs randomly in the ionosphere. It can affect frequencies normally affected by **ionospheric** propagation, but as the levels of ionisation can rise very high, it can affect frequencies much higher than would be expected by normal **E** region ionisation.

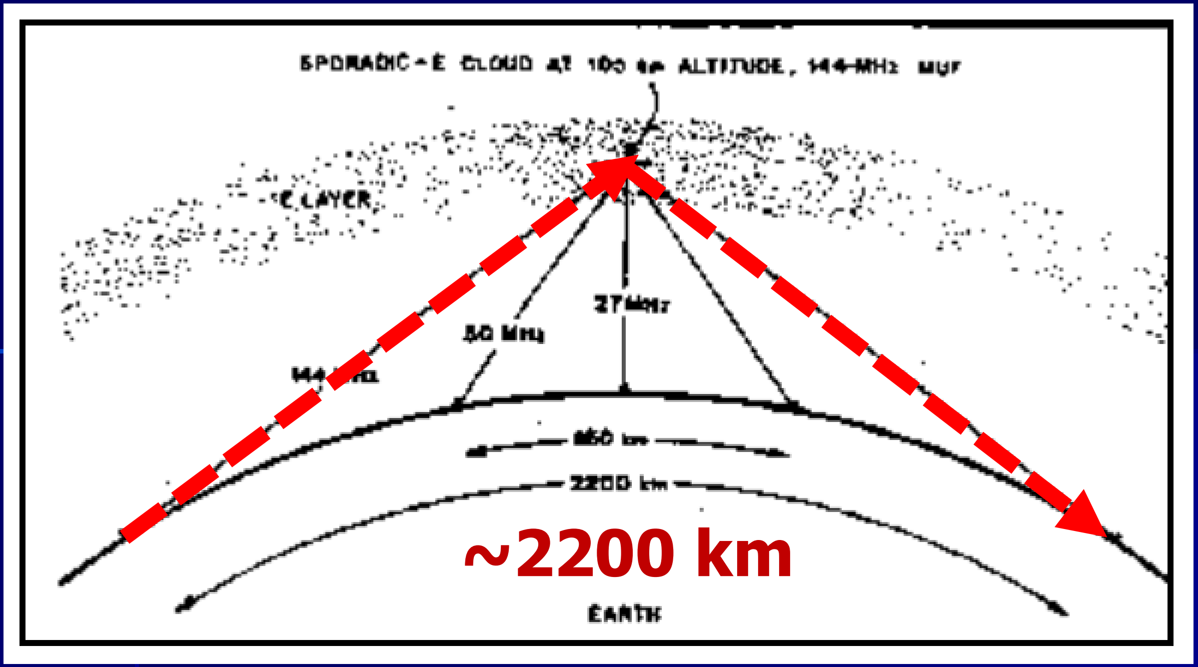


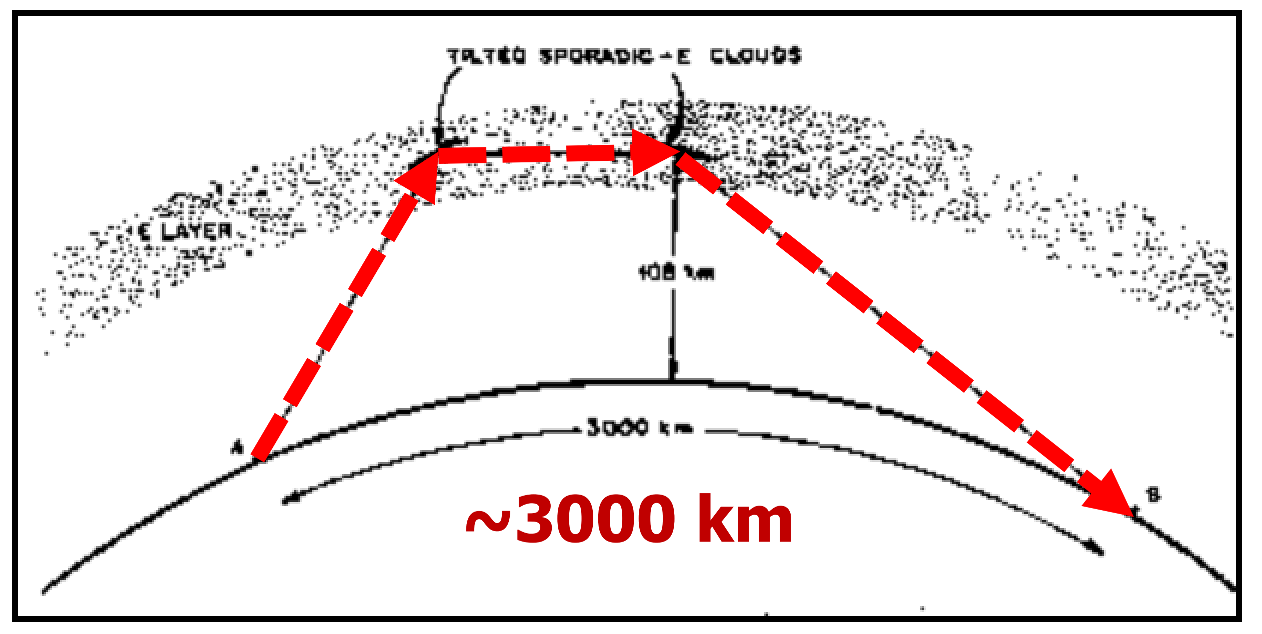
Sporadic E propagation

Sporadic E propagation bounces signals off smaller "clouds" of unusually ionized atmospheric gas in the lower E-region (located at altitudes of approx. 90 to 160 km).



Sporadic E propagation

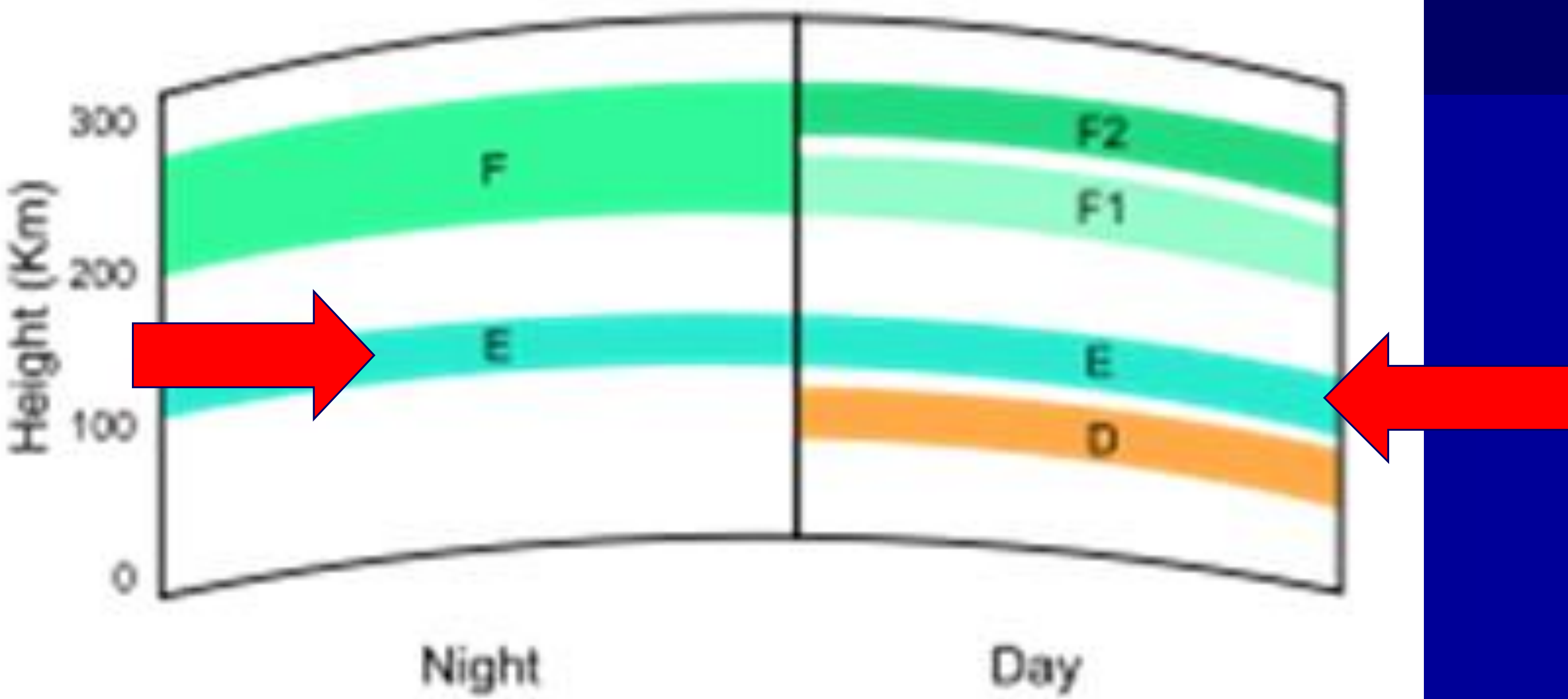

SPORADIC-E CLOUD AT 100 km ALTITUDE, 144-MHz MUF
E LAYER
27 MHz
50 MHz
144 MHz
2200 km
EARTH
~2200 km


TILTED SPORADIC-E CLOUDS
E LAYER
100 km
3000 km
A
B
~3000 km

Summary : E-layer

The ionospheric layers

E-layer or E-region



Ionization is due to –

Soft X – rays (λ, 1-10 nm) &

Far Ultra Violet

Ionizing of – Molecular Oxygen (O)

E_s – Sporadic E-layer

The ionospheric layers

F-layer or F-region

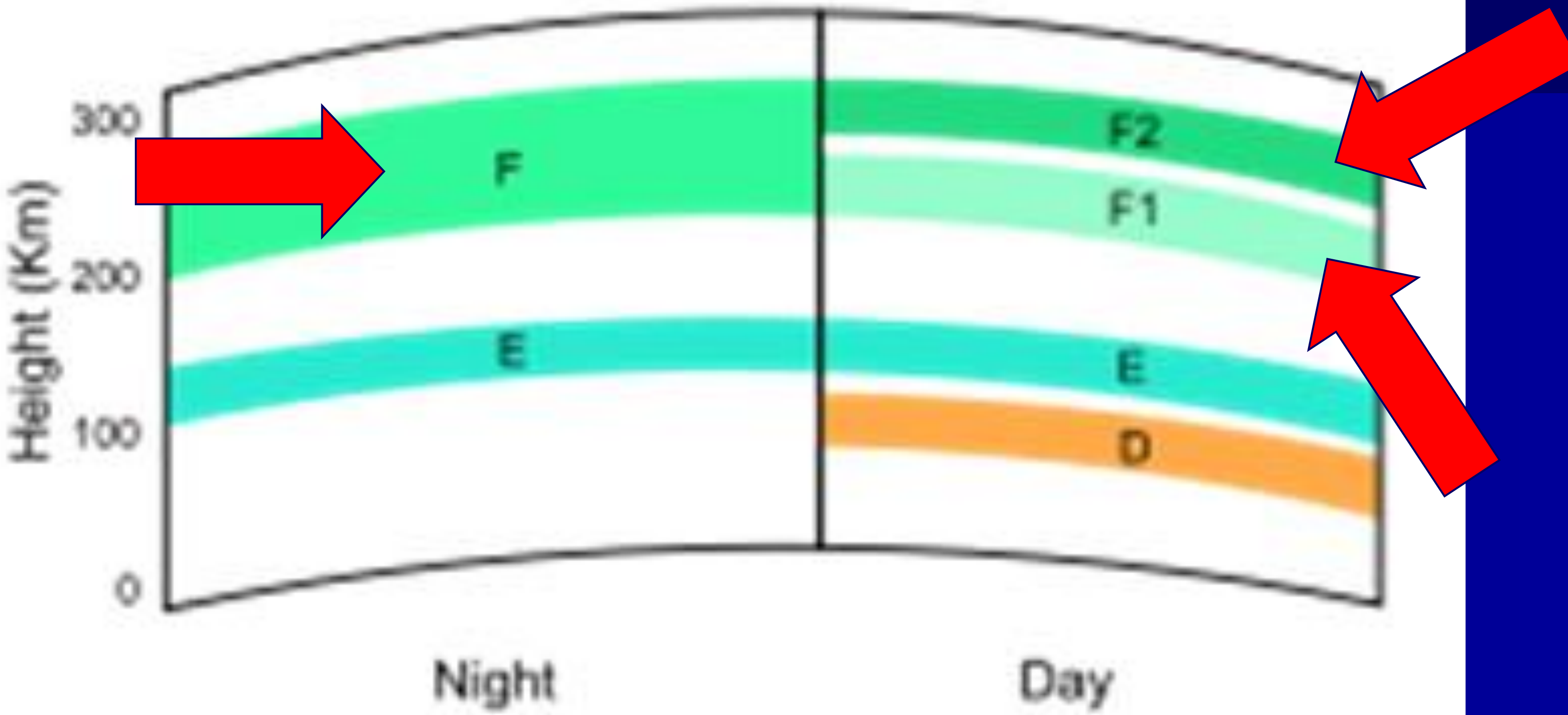
The F layer or F region, also known as the **Appleton layer**, extends from about 200 km to more than 500 km above the surface of Earth. It is the **densest point of the ionosphere, which implies signals penetrating this layer will escape into space**. Beyond this layer is the topside ionosphere. **Here extreme ultraviolet (UV, 10–100 nm)** solar radiation **ionizes atomic oxygen**.

The F layer consists of one layer at night, but during the day, a deformation often forms in the profile that is labeled F_1. The F_2 layer remains by day and night responsible for most sky wave propagation of radio waves, facilitating high frequency (HF or shortwave, SW) radio communications over long distances.

Summary : F-layer

The ionospheric layers

F-layer or F-region



Ionization is due to –

Extreme Ultra Violet

(λ, 10-100 nm)

Ionizing of – Atomic Oxygen

F_1 and F_2 - layer

The Ionosphere

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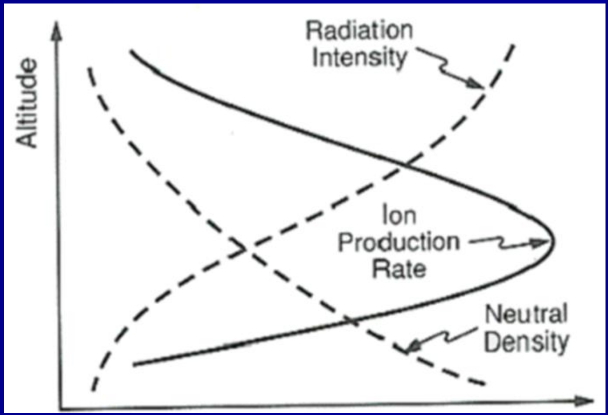
Chapman layer Theory

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.:

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

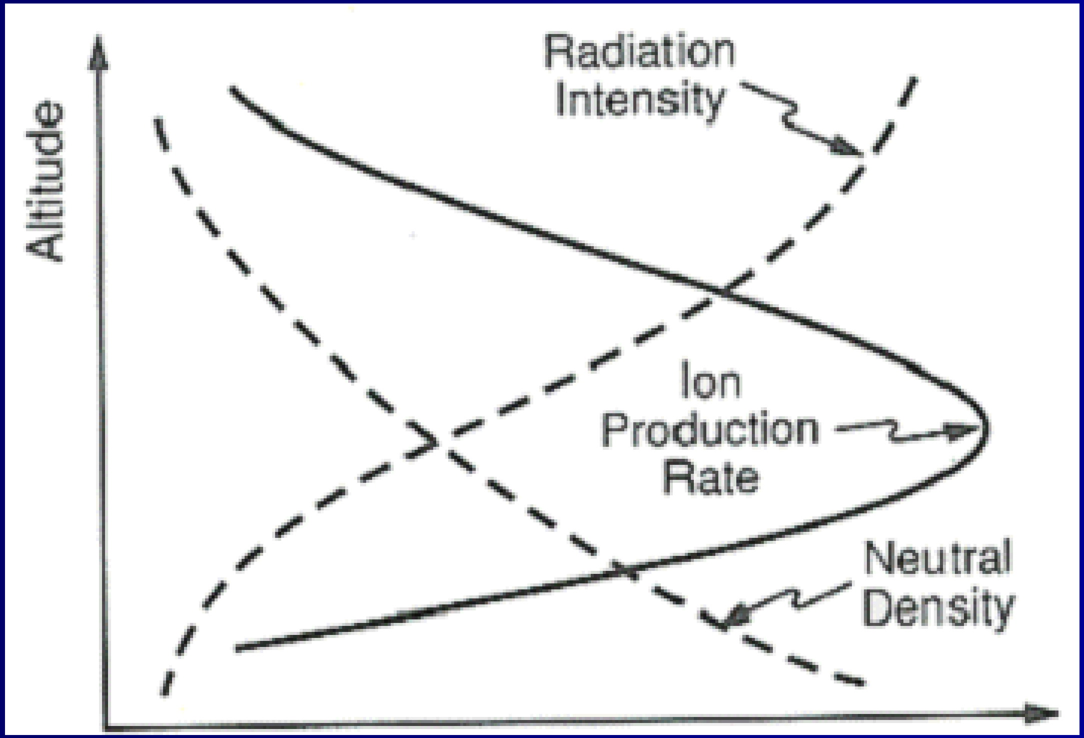
As seen from the following diagram, at high altitudes q **is very small because** N_n **is very small.** As the ionizing radiation penetrates deeper into the more dense layers of the atmosphere, q reaches a maximum q_m at a height h_m where I and N_n reach the best possible combination.



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.

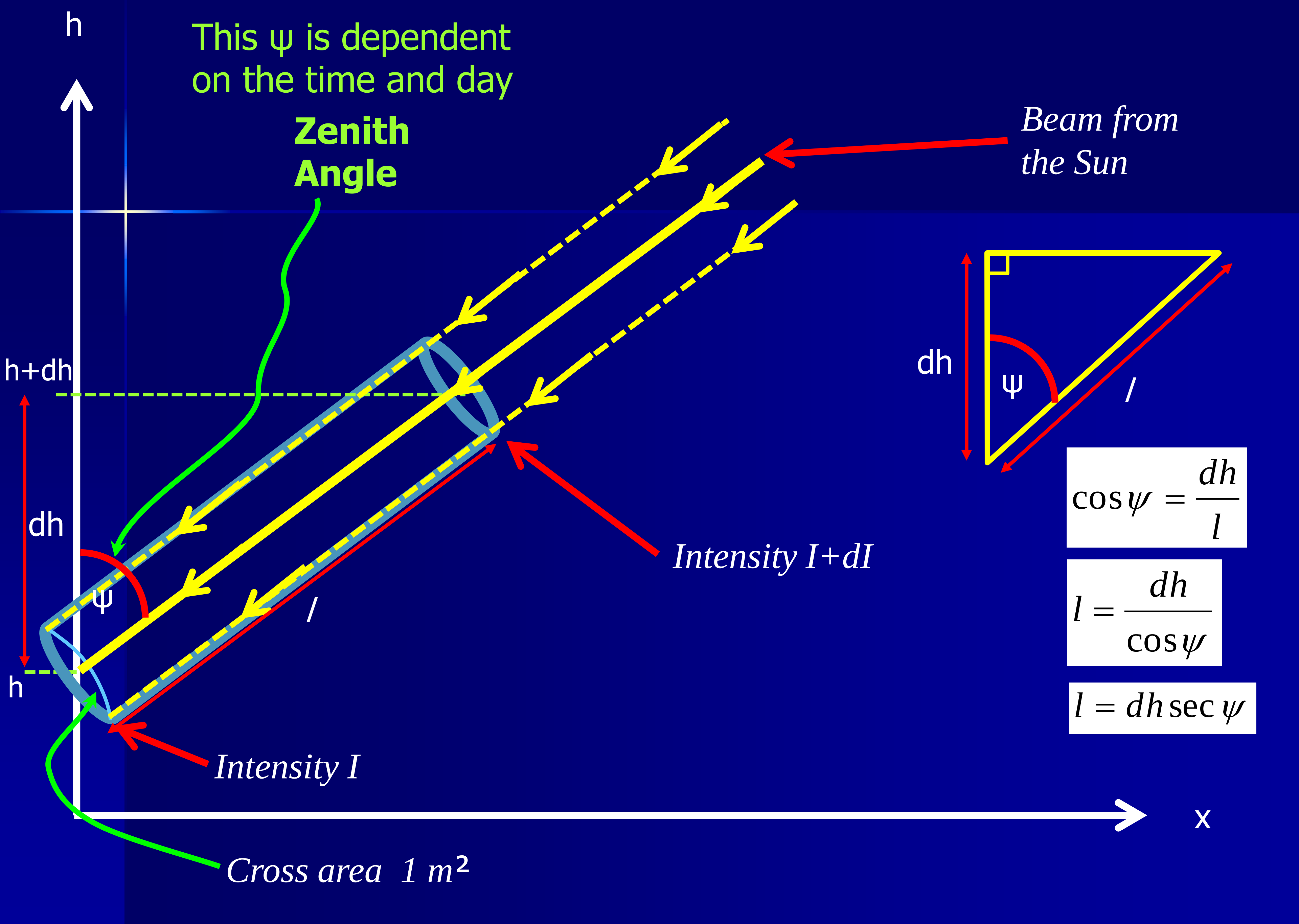
Chapman layer Theory

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 ψ 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).

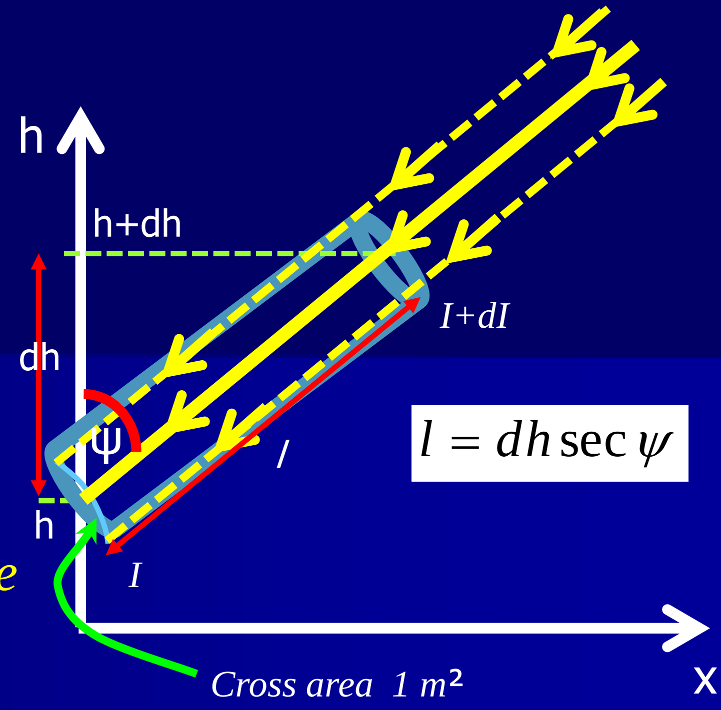
P.T.O



h
This ψ is dependent on the time and day
Zenith Angle
Beam from the Sun
h+dh
dh
ψ
l
Intensity I+dI
h
Intensity I
x
Cross area 1 m²
dh
ψ
l
$\cos\psi = \frac{dh}{l}$
$l = \frac{dh}{\cos\psi}$
$l = dh\sec\psi$

If the molecular number density is N,
Number of molecules in the selected area :

$$= N \times V$$
$$= N \times l \times 1$$
$$= N dh \sec\psi$$



$$l = dh \sec\psi$$

Total cross section : $= \sigma_a \times N dh \sec\psi$

Where σ_a *is Absorption Cross-section*

(Absorption Cross-section is the ability of a molecule to absorb a photon of a particular wavelength and polarization)

The amount of radiation absorbed in this selected layer will be,

$$dI = I \times \sigma_a N dh \sec\psi$$

For the total region : Integrating from the height h to ∞,

$$\int_{I=I}^{I=I_\infty} \frac{dI}{I} = \int_{h=h}^{h=\infty} \sigma_a N \sec\psi \; dh$$

(Assume the intensity of ionizing radiation at infinity is I_∞ *and intensity of ionizing radiation at h is I)*

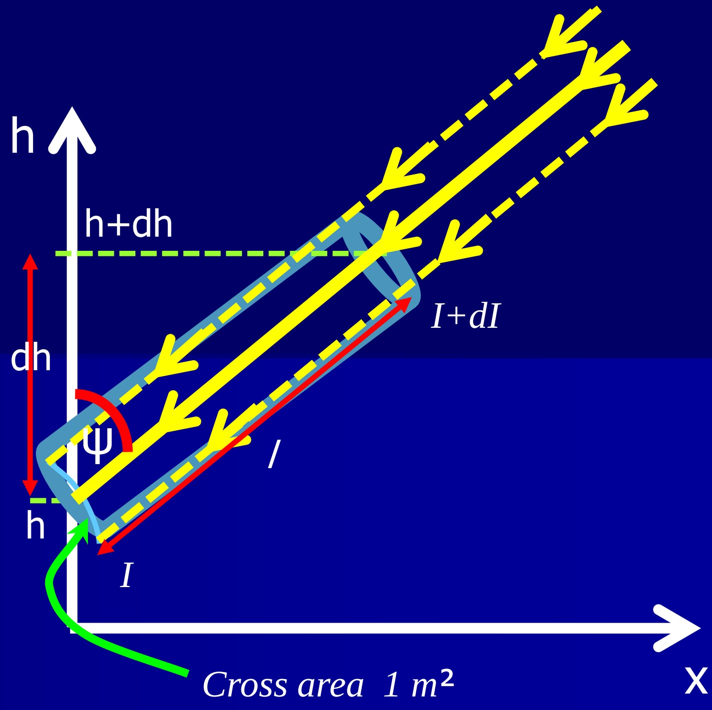
$$\int_{I=I}^{I=I_\infty} \frac{dI}{I} = \int_{h=h}^{h=\infty} \sigma_a N \sec\psi \; dh$$

$$\left[\ln I\right]_{I=I}^{I=I_\infty} = \sigma_a \sec\psi \int_{h=h}^{h=\infty} N dh$$

$$\ln\left(\frac{I_\infty}{I}\right) = \sigma_a \sec\psi \int_{h=h}^{h=\infty} N dh$$

$$\ln\left(\frac{I}{I_\infty}\right) = -\sigma_a \sec\psi \int_{h=h}^{h=\infty} N dh$$

$$I = I_\infty e^{\left(-\sigma_a \sec\psi \int_{h=h}^{h=\infty} N dh\right)}$$



Chapman layer Theory

Intensity of Ionizing Radiation

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

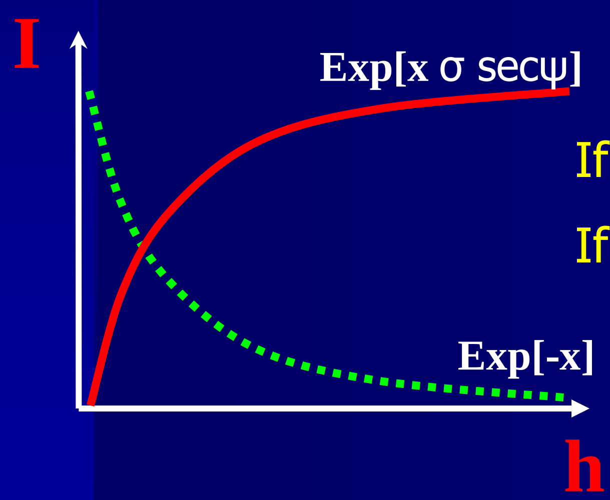
Intensity of Ionizing Radiation at infinity → I_{∞}

Intensity of Ionizing Radiation at height h → I

Absorption Cross-section → σ_a

Zenith Angle → ψ

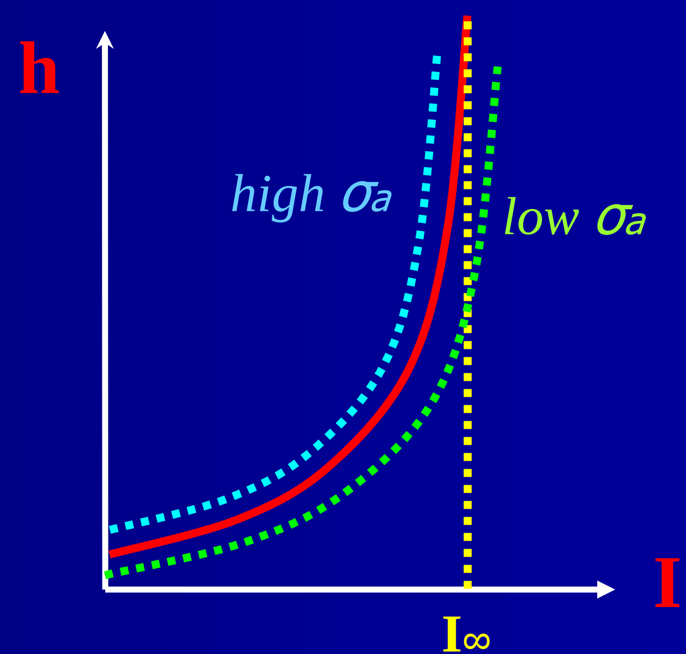
Molecular Number Density → N



If h ↑ , σ ↓ and

If h ↑ , ψ ↑

Ionization Radiation (I)




Thank You !
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