Space Physics

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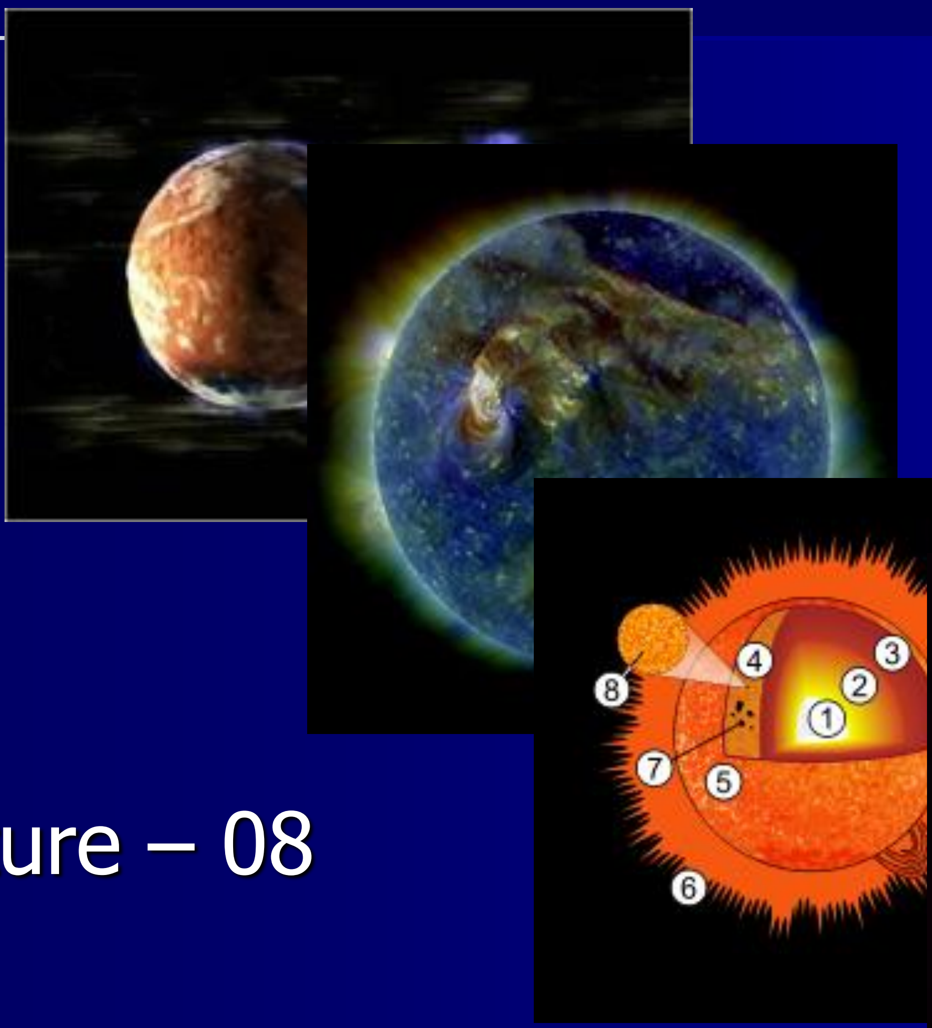
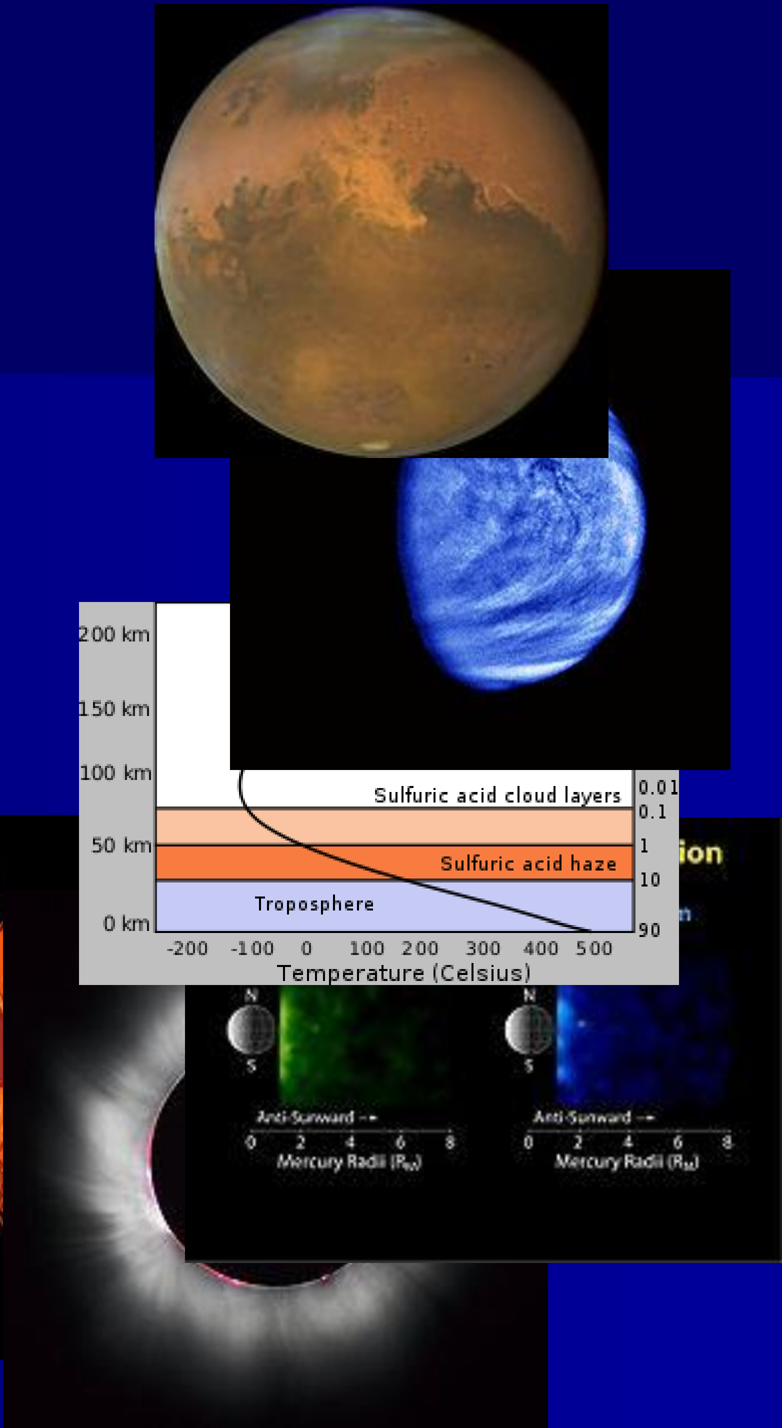




Lecture – 08

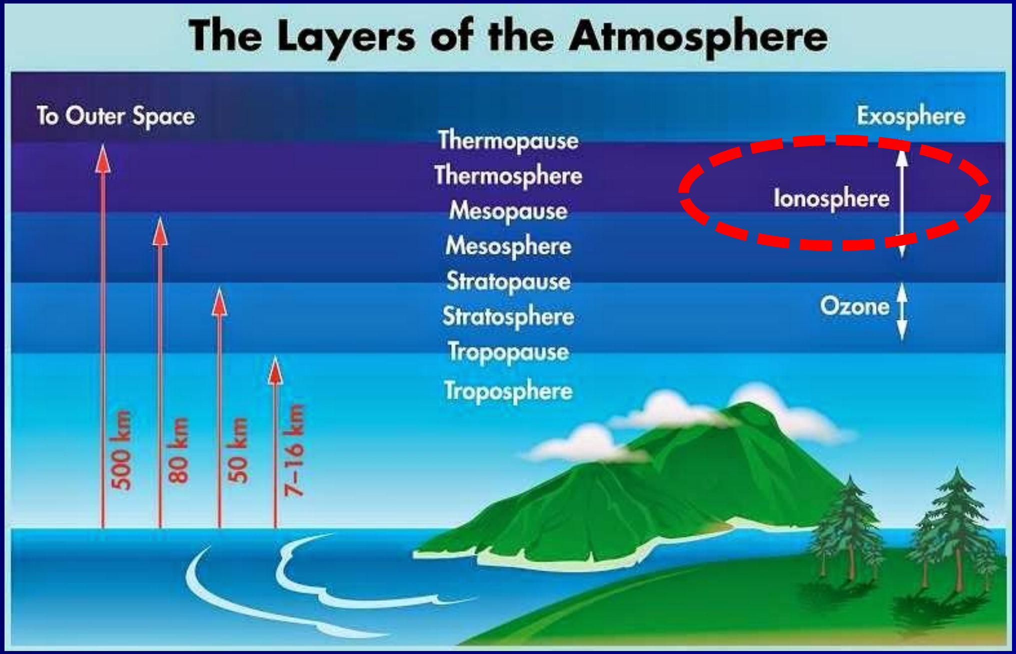
The Ionosphere

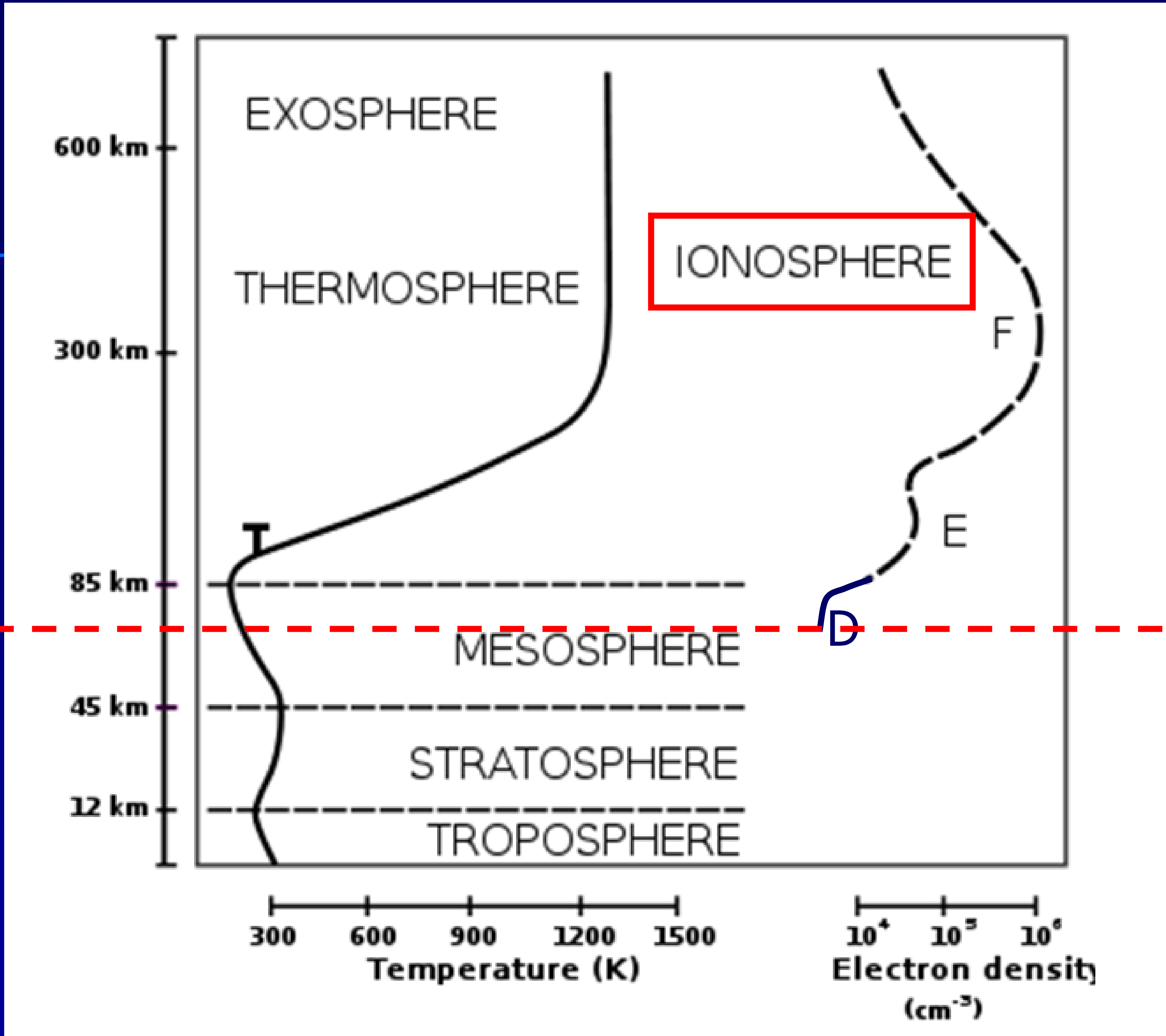
Introduction
The Chapman Layer Theory
Plasma Frequency
Collision Frequency and Absorption
The Structure of the Ionosphere and the Plasmasphere
Regular and Irregular Variations of the Ionosphere

Introduction

The ionosphere is a portion of the upper atmosphere, between the thermosphere and the exosphere, distinguished because it is ionized by solar radiation.

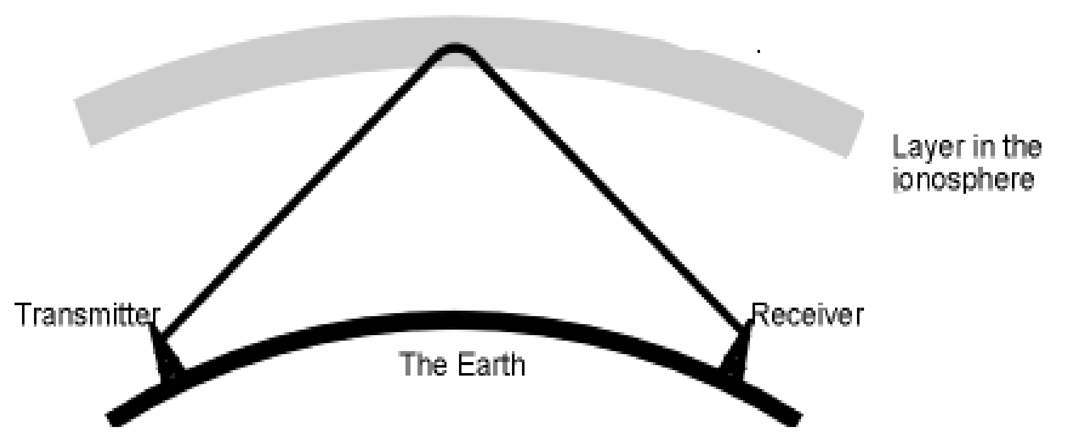
The ionosphere is a shell of **electrons** and **electrically charged atoms** and **molecules** that surrounds the Earth, stretching from a height of about 70 km on up.





EXOSPHERE
THERMOSPHERE
IONOSPHERE
F
E
D
MESOSPHERE
STRATOSPHERE
TROPOSPHERE
600 km
300 km
85 km
45 km
12 km
300
600
900
1200
1500
Temperature (K)
10^4
10^5
10^6
Electron density
(cm^{-3})

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.

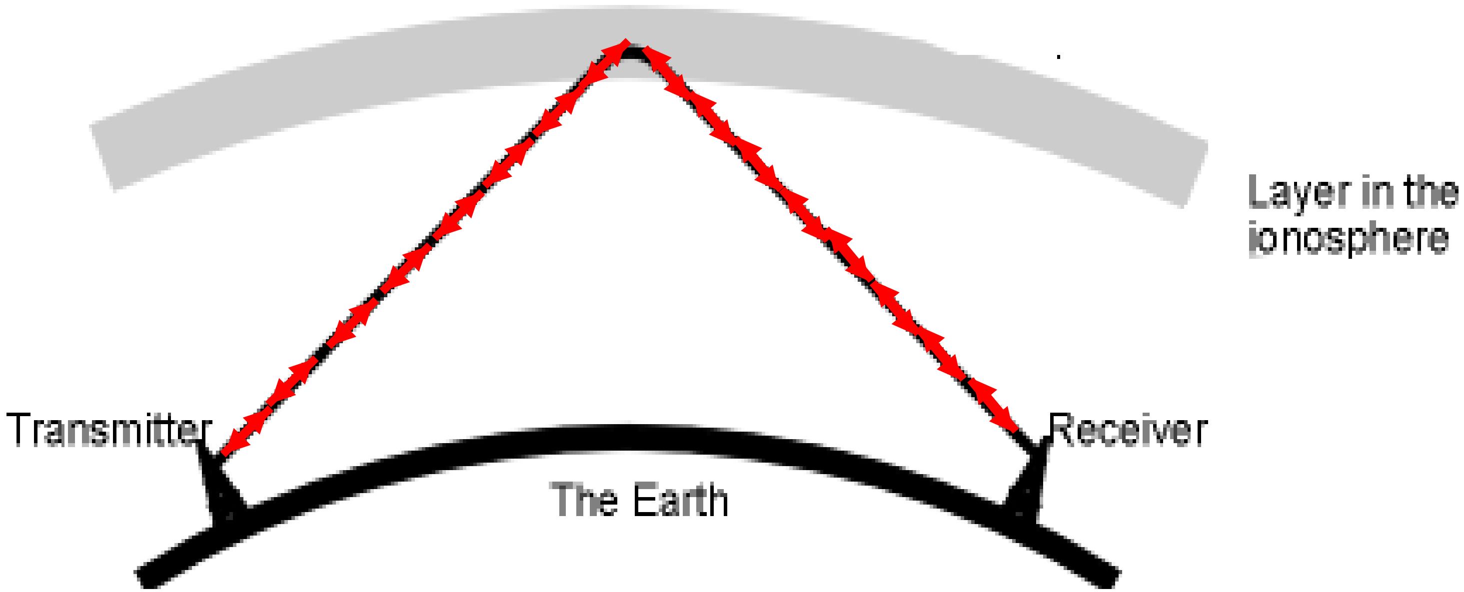


Refraction of a radio signal as it enters an ionised region

Marconi's successful experiments in 1901 of wireless communication across the Atlantic prompted **Heaviside** and **Kennelly** to postulate independently the existence of an ionized layer in the atmosphere. This electrically conducting layer was originally called the **Heaviside** Layer and later the E-Layer because of its many free elections.

The E-layer as seen in the following figure, acts as a **reflector** and makes it possible for Radio Signals to bridge large distance over the spherical Earth. The E-layer is an altitude of approximately 110 km.

The Ionosphere acting as a reflector of radio waves making possible radio telecommunication over the horizon.

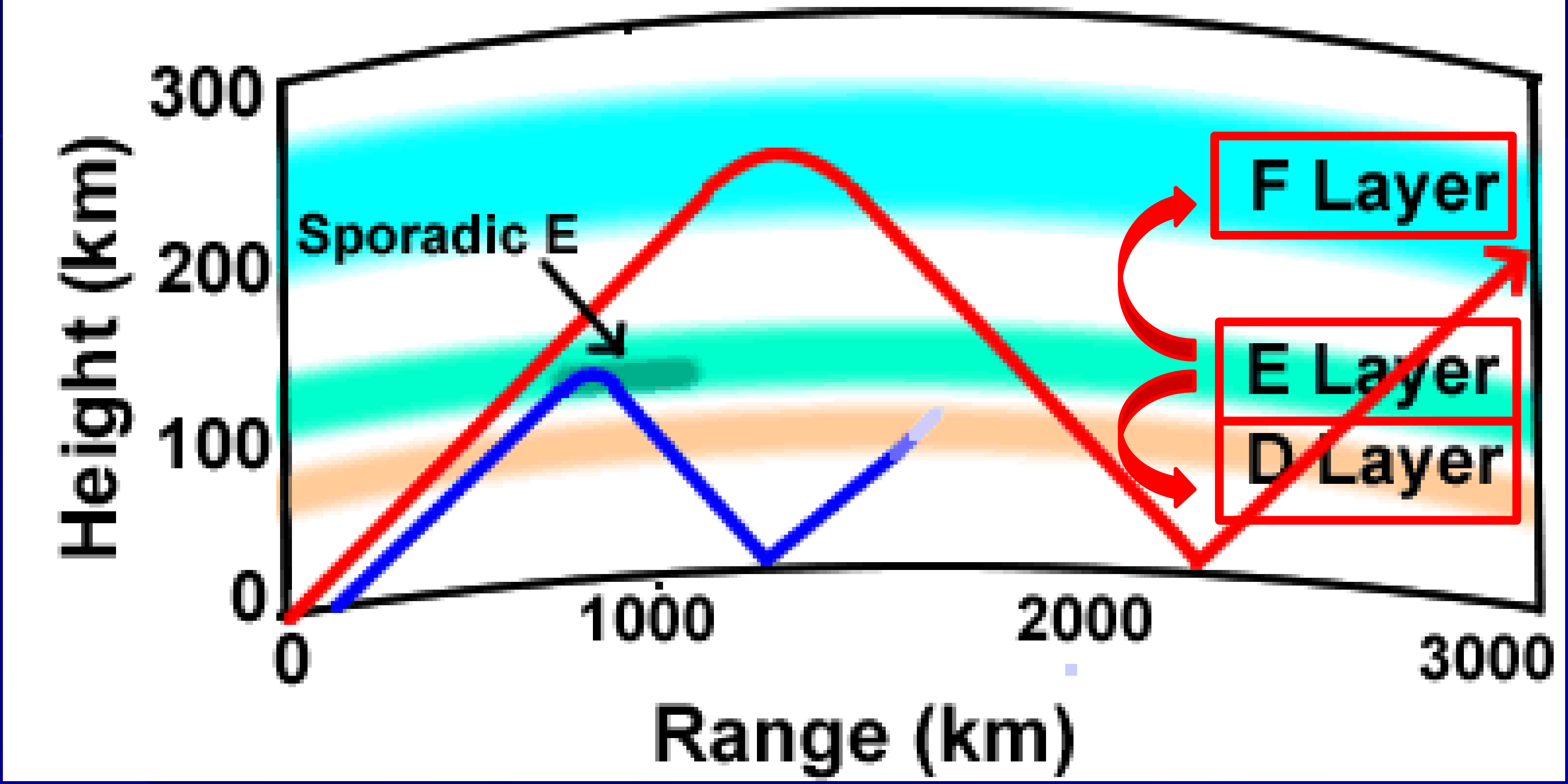


Refraction of a radio signal as it enters an ionised region

The First attempts to **study the structure of the ionosphere with Radio signals bounced back from the ionosphere** were made in **1925** by Appleton and Barnett in England.
Similar ionospheric sounding experiments were performed also in America in **1928** by Brest and Tuve.

An ionospheric sounder consists basically of a **Radio Transmitter** and a **Radio Receiver** connected in a way which allows them to **measure the time interval** between the transmission and the return of the Radio Pulse.

By multiplying one half of this time interval, which is of the order of a millisecond, with the speed of light, we obtain the **heights of the Reflection Layer.**

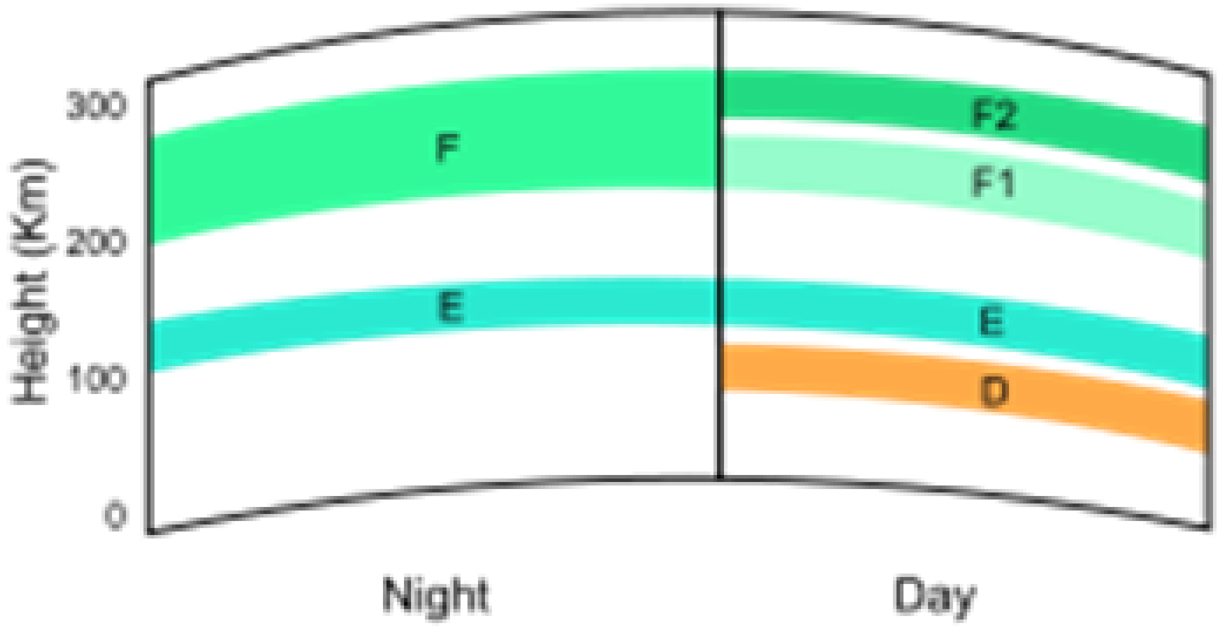

300
200
100
0
Height (km)
Sporadic E
F Layer
E Layer
D Layer
0
1000
2000
3000
Range (km)

The ionospheric layers

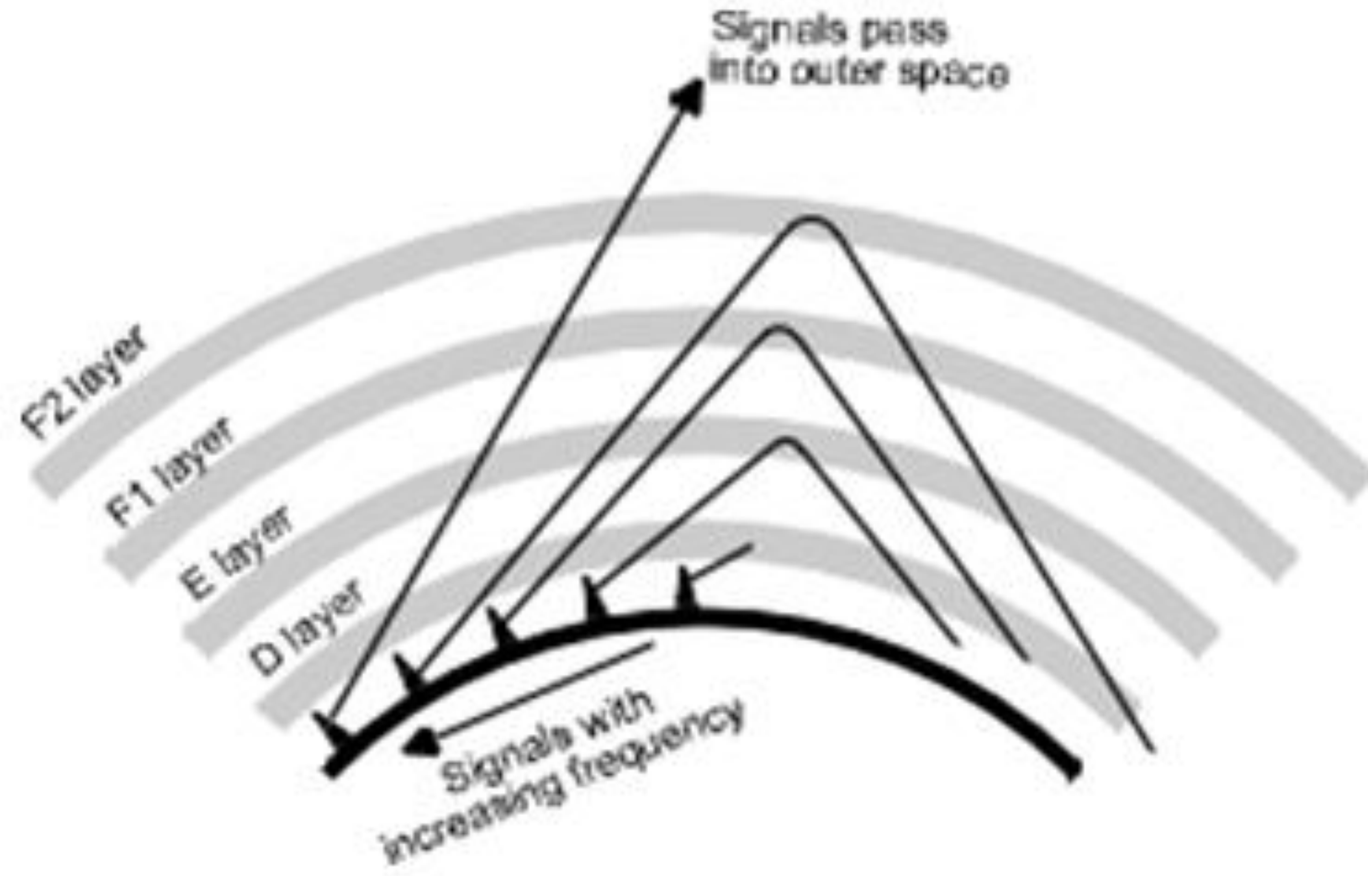
At night the F layer is the only layer of significant ionization present, while the ionization in the E and D layers is extremely low.

During the day, the D and E layers become much more heavily ionized, as does the F layer, which develops an additional, weaker region of ionisation known as the F1 layer. The F2 layer persists by day and night and is the region mainly responsible for the refraction of radio waves.

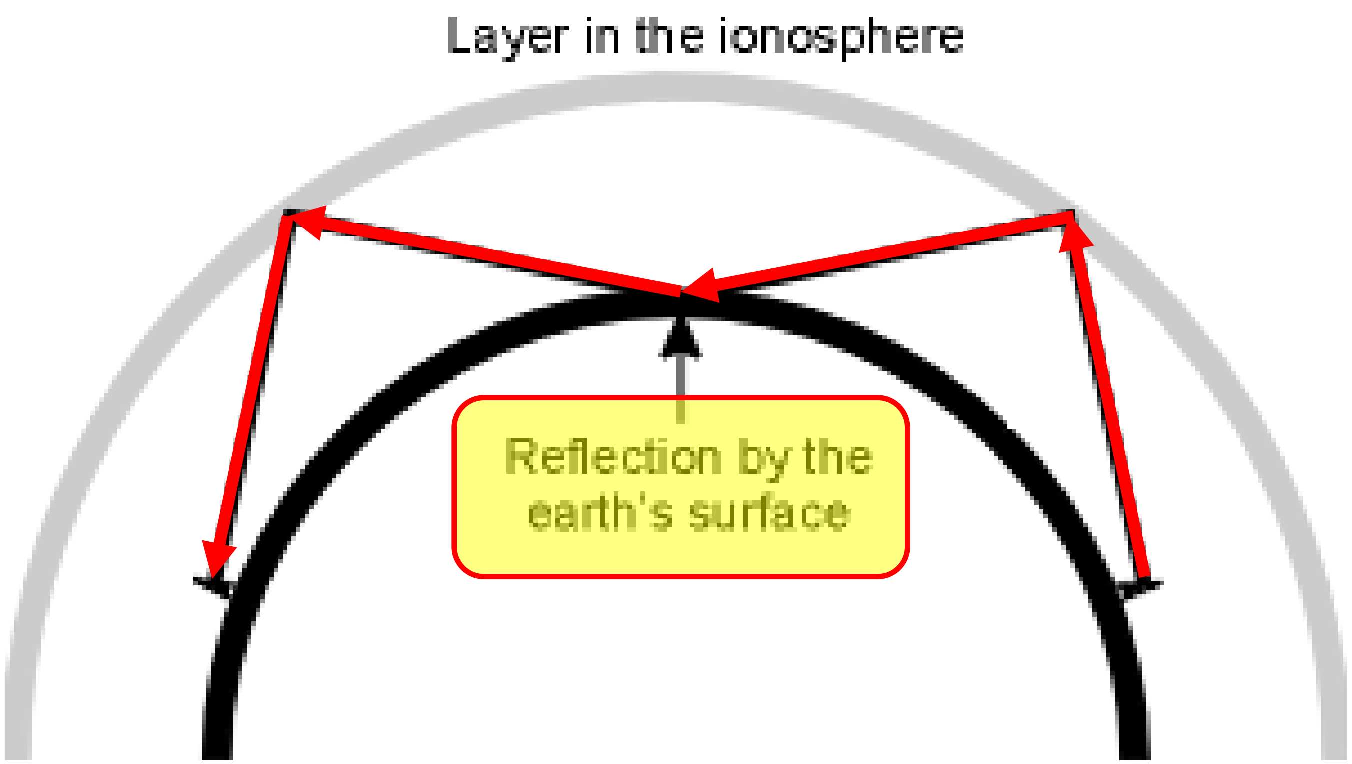
The ionospheric layers



Ionospheric layers.



Signals reflected by the E and F regions



Multiple reflections

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.

The ionospheric layers

D-layer or D-region

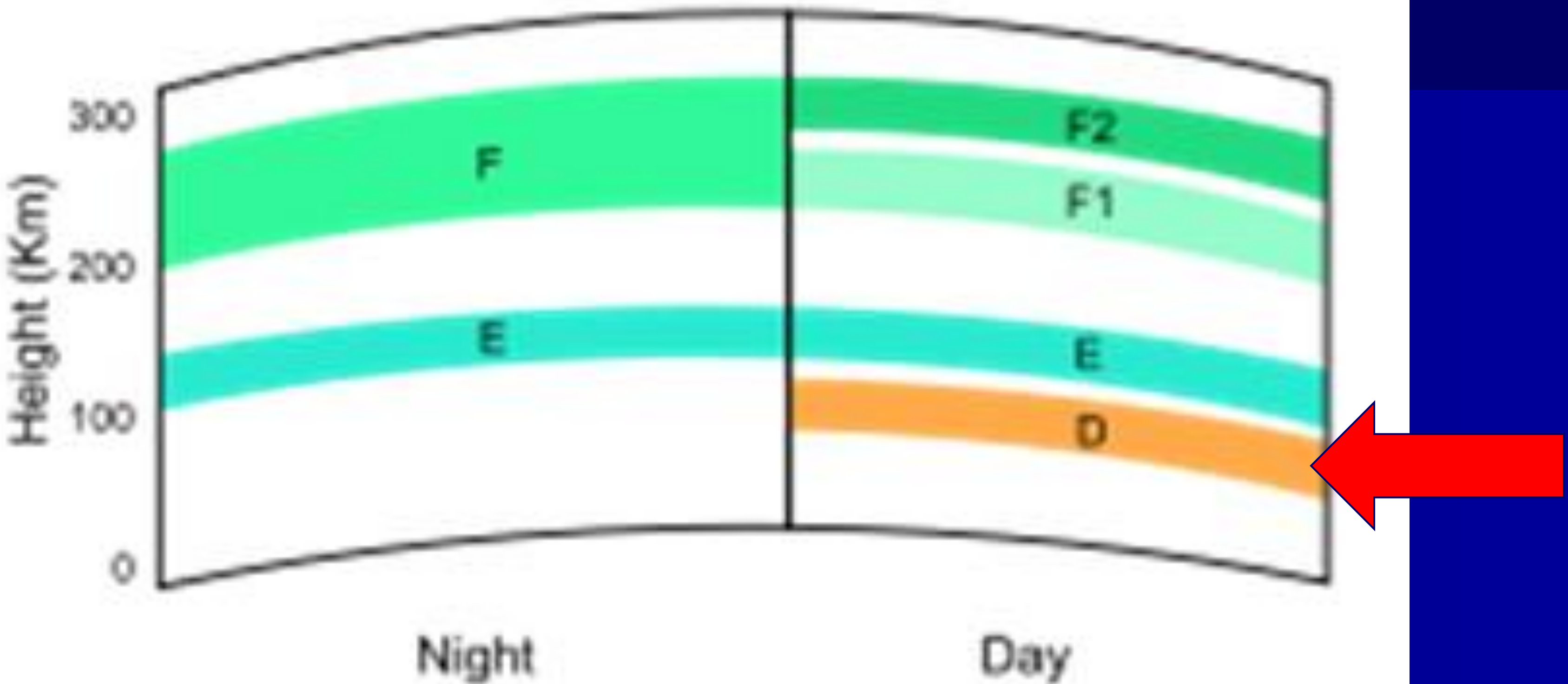
Recombination is high in the D layer, the net ionization effect is low, but loss of wave energy is great due to frequent collisions of the electrons (about 10 collisions every mili-seconds).

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



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

The E - layer is the middle layer, 90 km to 120 km above the surface of the Earth.

Ionization is due to **soft X-ray (1–10 nm)** and **far ultraviolet (UV)** solar radiation ionization of molecular oxygen (O_2).

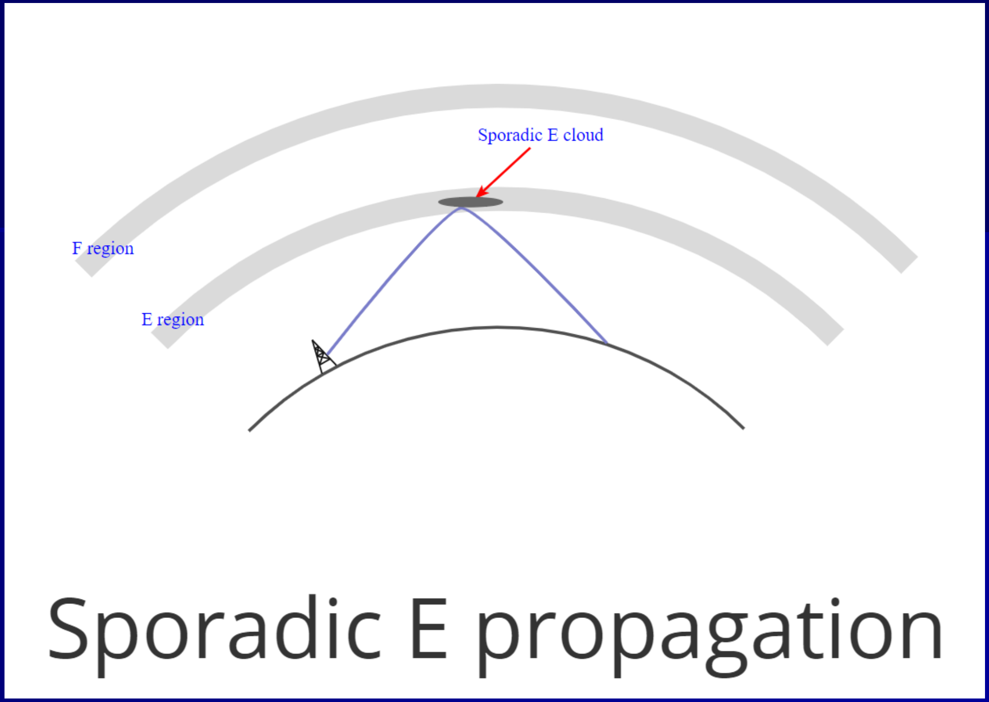
Normally this layer can only reflect radio waves having frequencies **lower than about 10 MHz** and may contribute a bit to absorption on frequencies above.

However, **during intense** (quick) **Sporadic E events, the E_s layer (Sporadic E layer) can reflect frequencies up to 50 MHz and higher.**

The ionospheric layers

E$_s$ – Sporadic (කඩින් කඩ) layer

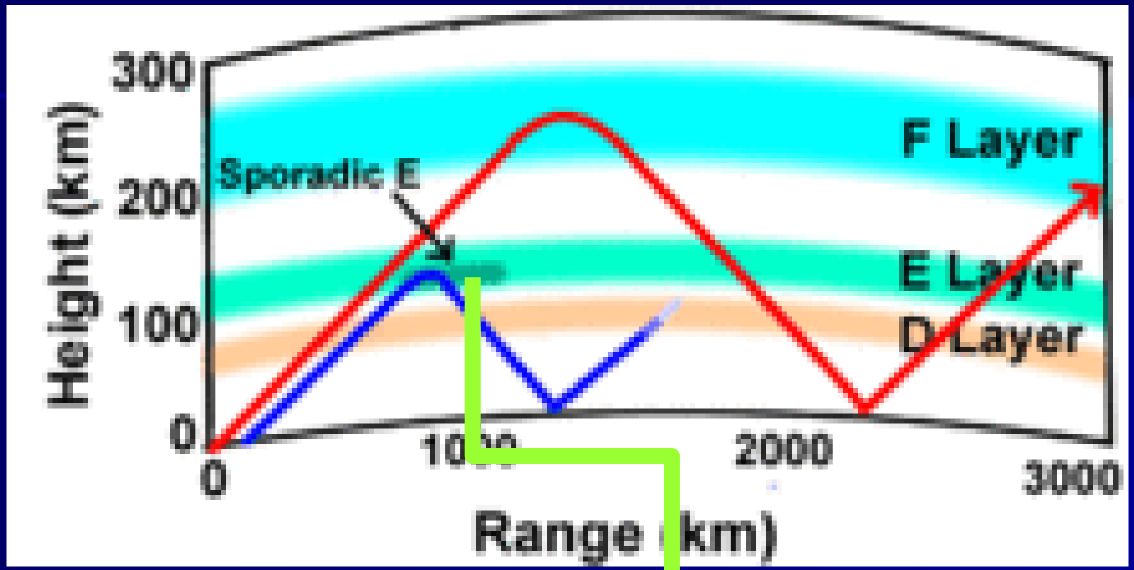
E sporadic is a form of **E layer** ionisation that occurs randomly in the ionosphere. It can affect frequencies normally affected by **ionospheric** propagation, but as the levels of ionisation can rise very high, it can affect frequencies much higher than would be expected by normal **E** region ionisation.



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

The ionospheric layers

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

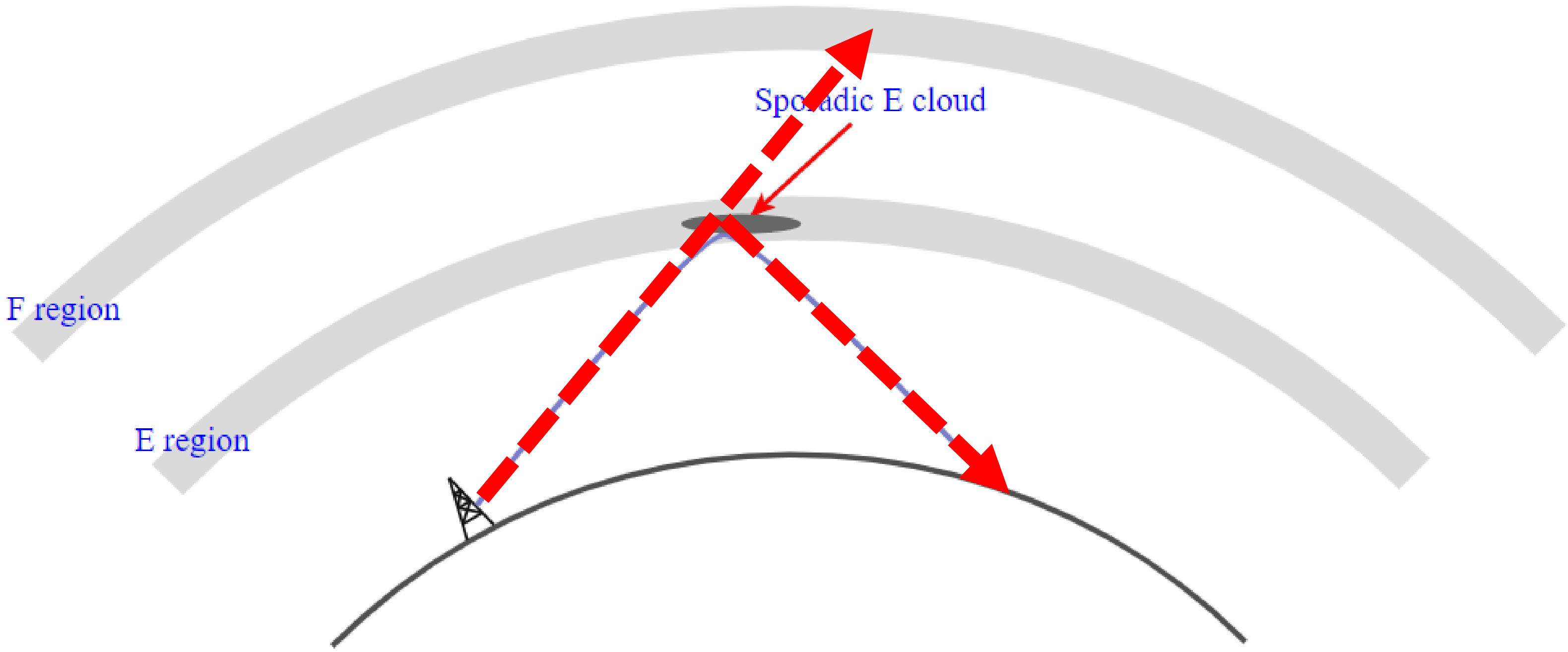
E-layer or E-region

E_s - Sporadic E - layer

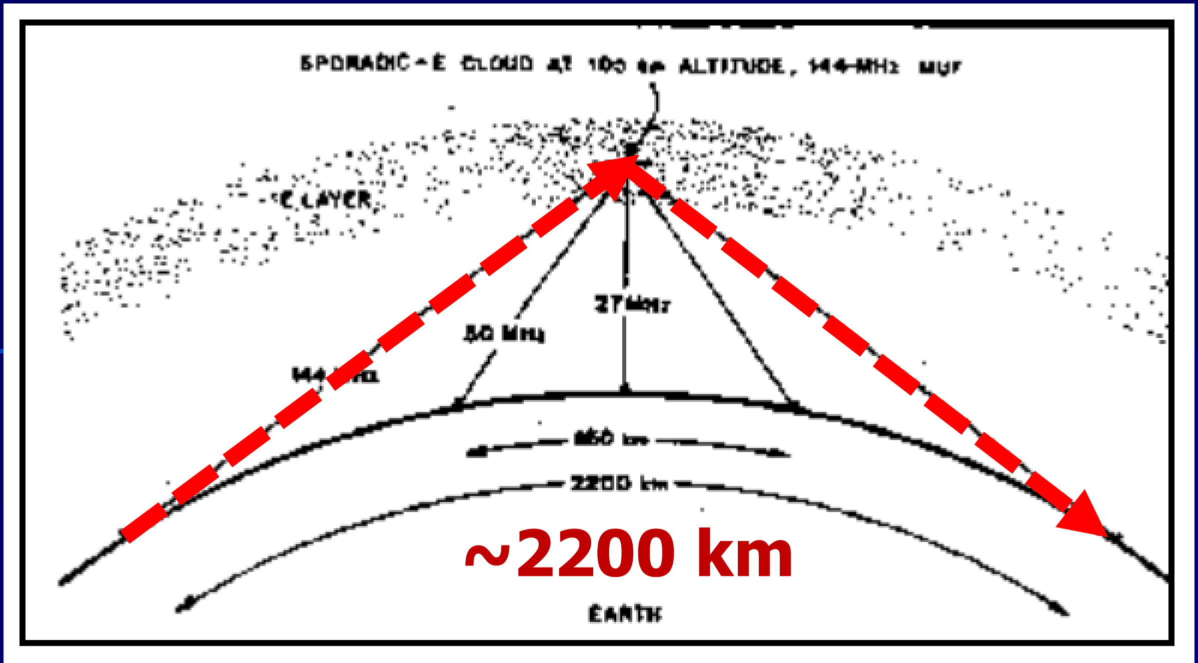
There are multiple causes of sporadic-E that are still being pursued by researchers. This propagation occurs most frequently during the summer months when high signal levels may be reached.

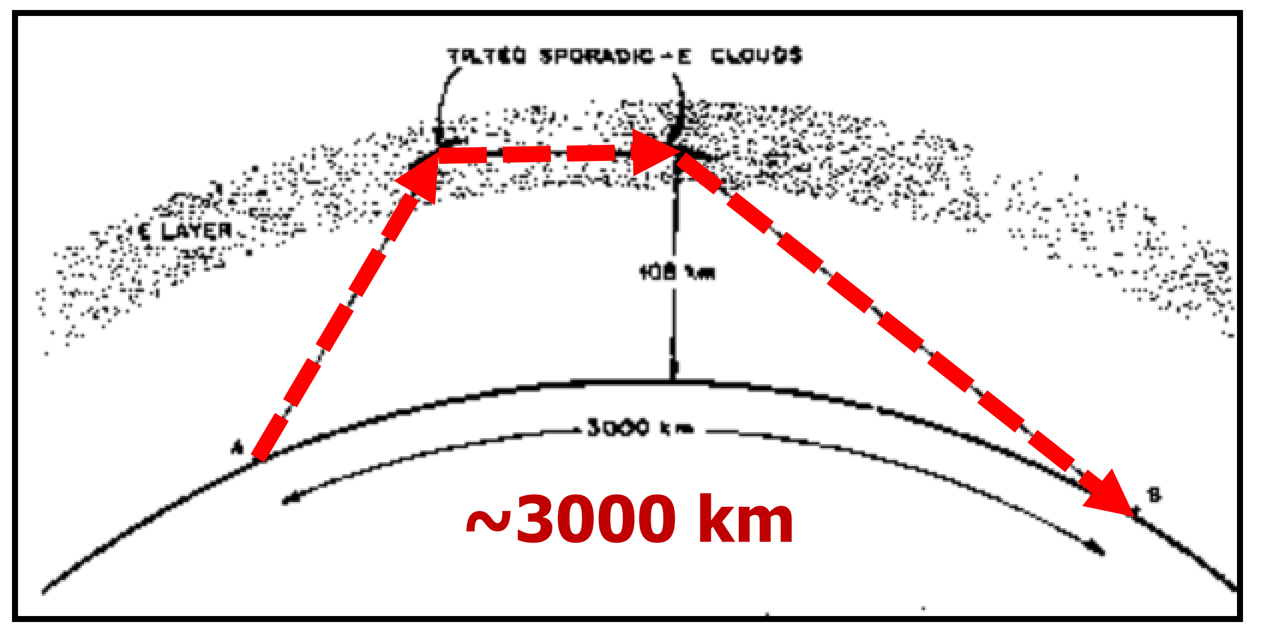
The **skip distances are generally around 1000 km**. VHF TV and FM broadcast also get excited as their signals can be bounced back to Earth by E_s.

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.



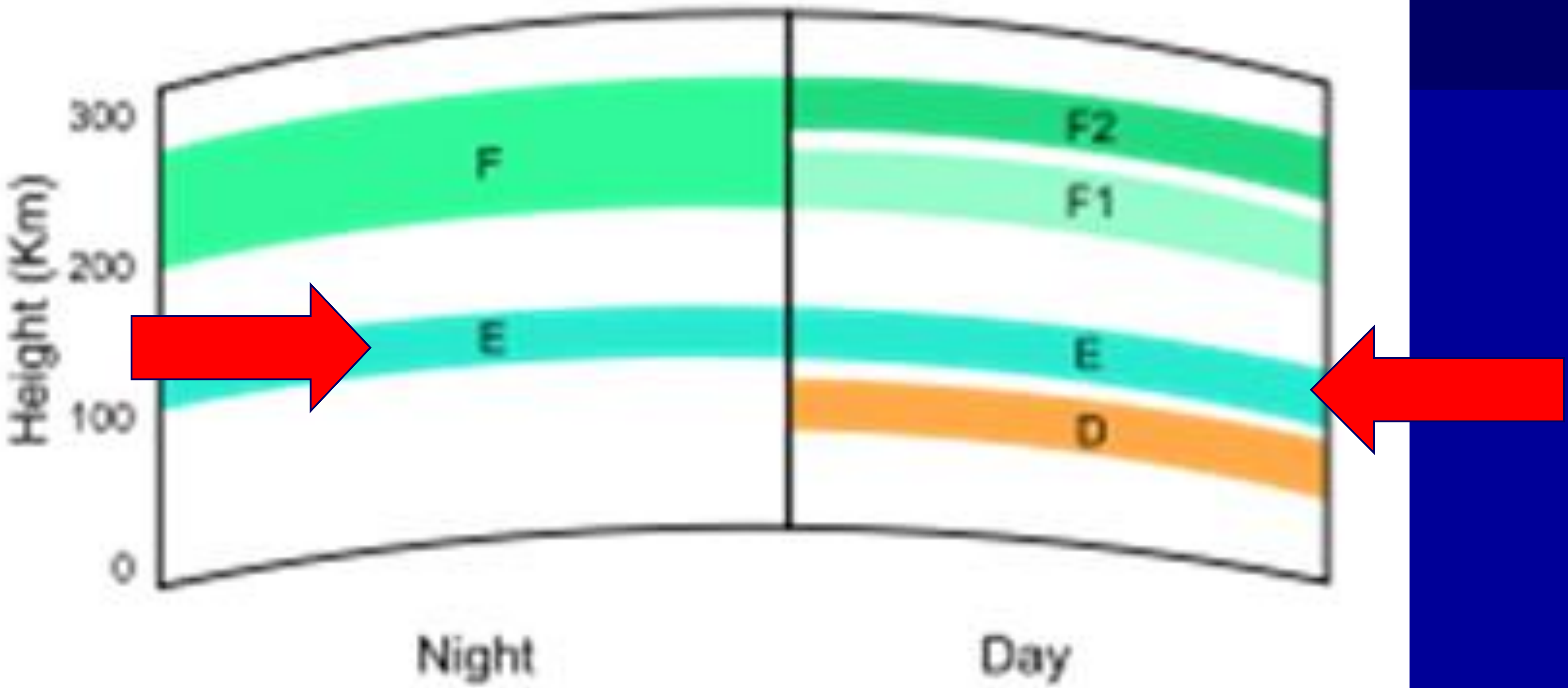
Sporadic E propagation


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


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

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 ionospheric layers

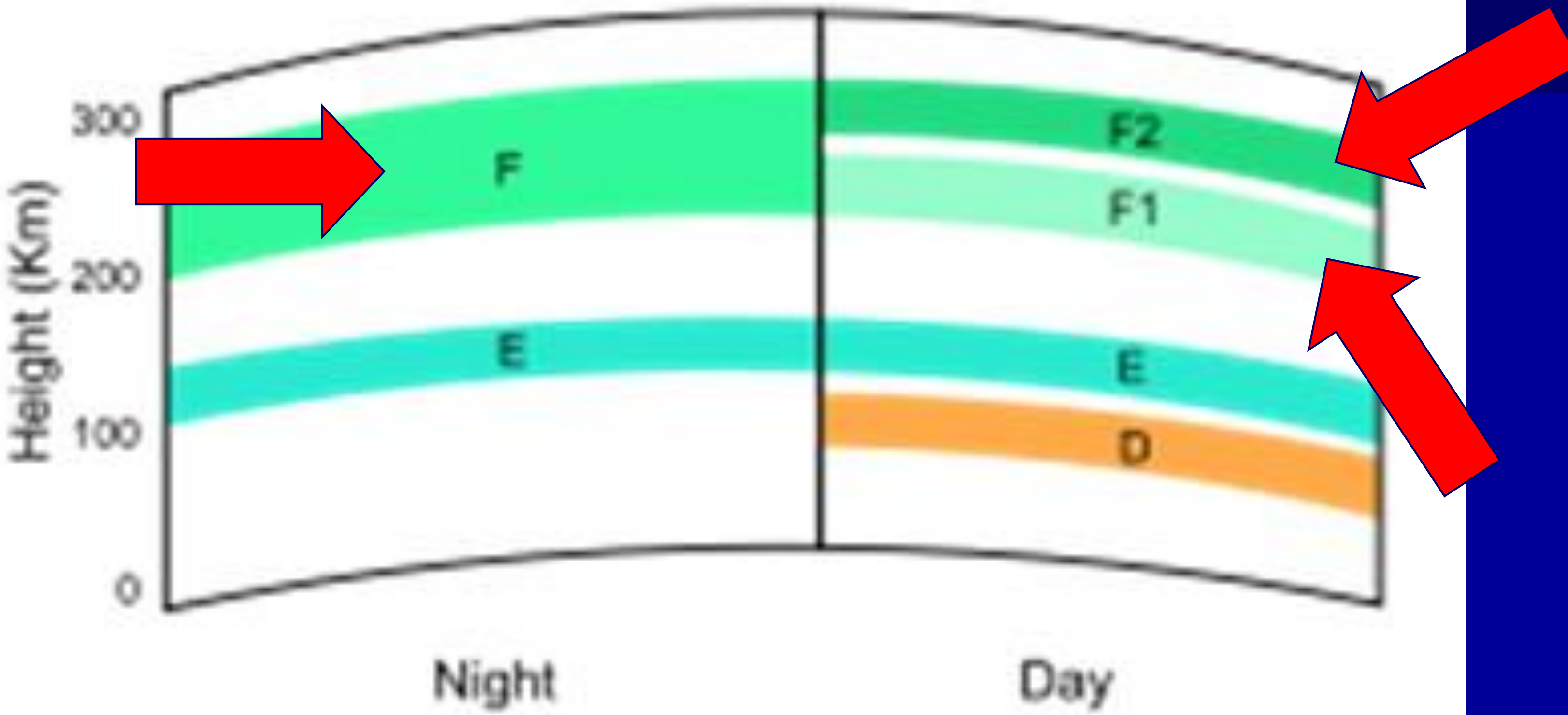
F-layer or F-region

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.

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

Ionospheric regions

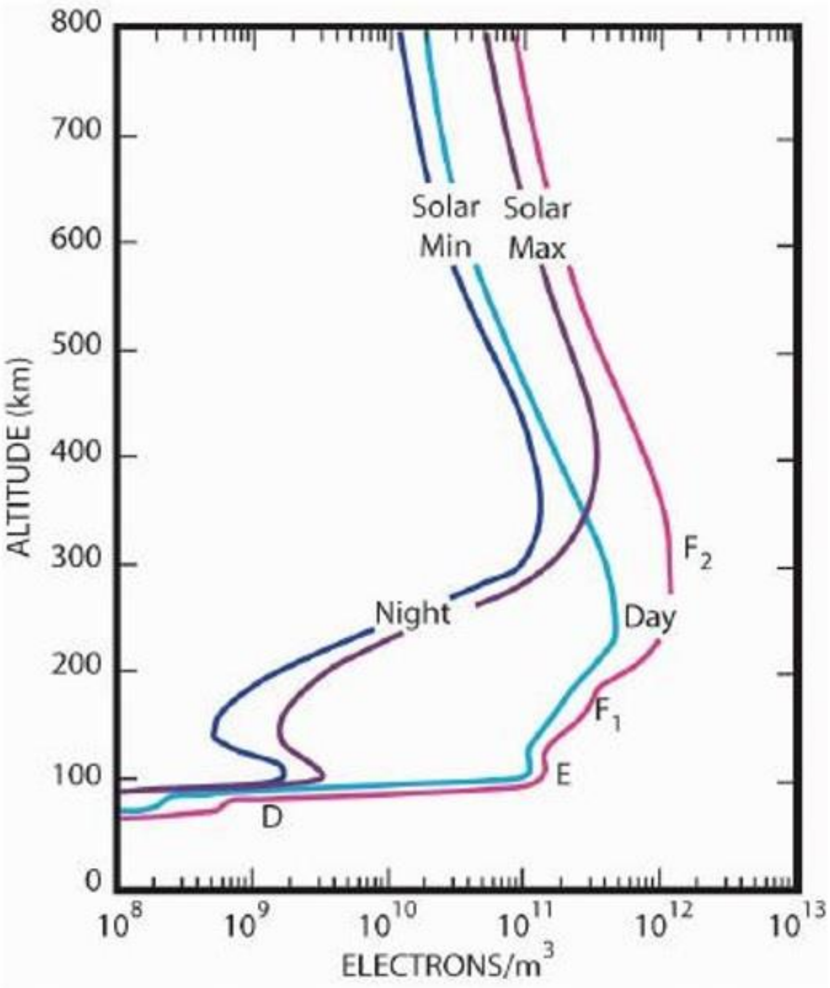


Figure: Typical ionospheric electron density profiles.

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)

The Ionosphere

Introduction

The Chapman Layer Theory

Plasma Frequency

Collision Frequency and Absorption

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Regular and Irregular Variations of the Ionosphere

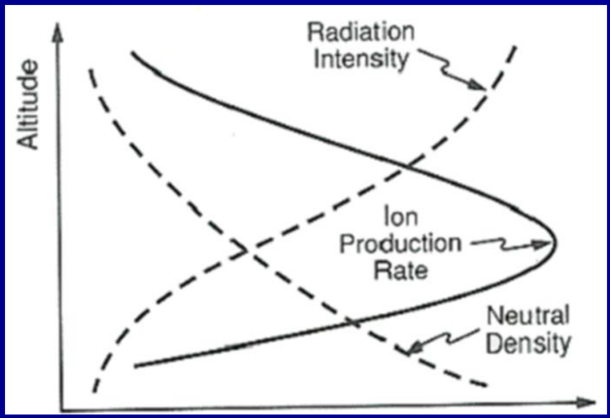
Chapman layer Theory

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.:

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

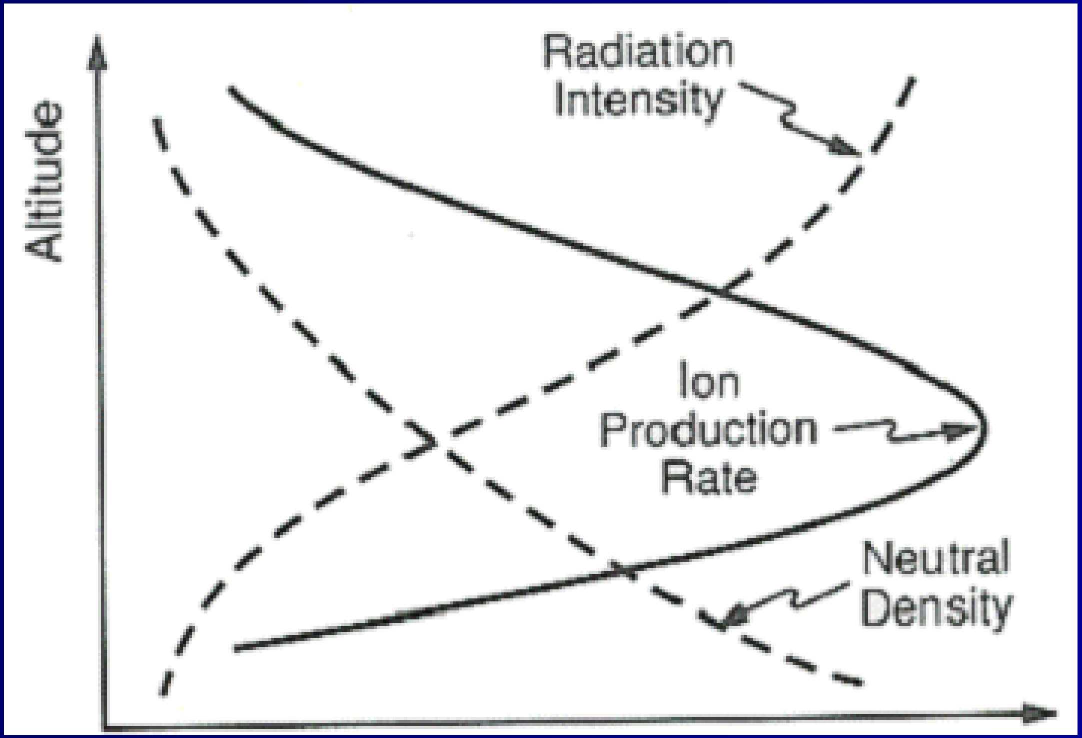
As seen from the following diagram, at high altitudes q **is very small because N_n is very small.** As the ionizing radiation penetrates deeper into the more dense layers of the atmosphere, q reaches a maximum q_m at a height h_m where I and N_n reach the best possible combination.



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.

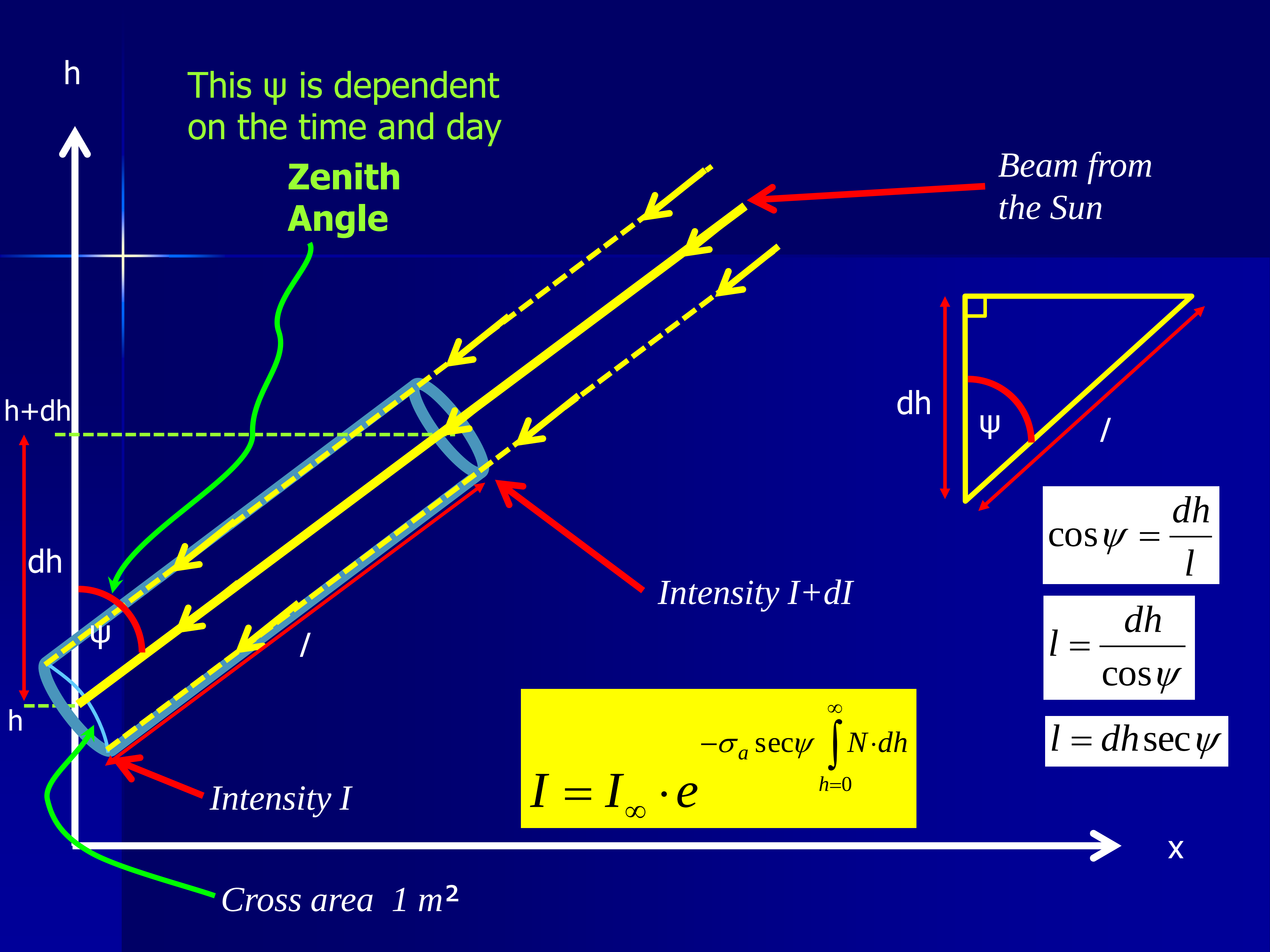
Chapman layer Theory

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 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
h
Intensity I+dI
Intensity I
Cross area 1 m²
x
$\cos\psi = \frac{dh}{l}$
$l = \frac{dh}{\cos\psi}$
$l = dh\sec\psi$
$I = I_\infty \cdot e^{-\sigma_a \sec\psi \int_{h=0}^{\infty} N \cdot dh}$


Thank You !
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