

Propagation of 50 MHz Radio Waves in the *E*-layer

Mike Hasselbeck WB2FKO

Southeastern VHF Society Conference 2026

Key Concepts

- Refraction vs Reflection
- Modeling the ionosphere with realistic plasma profiles
- Calculating radio wave trajectories
- Effect of Earth magnetic field: Faraday Rotation

F-layer



150 km

E-layer



90 km

D-layer

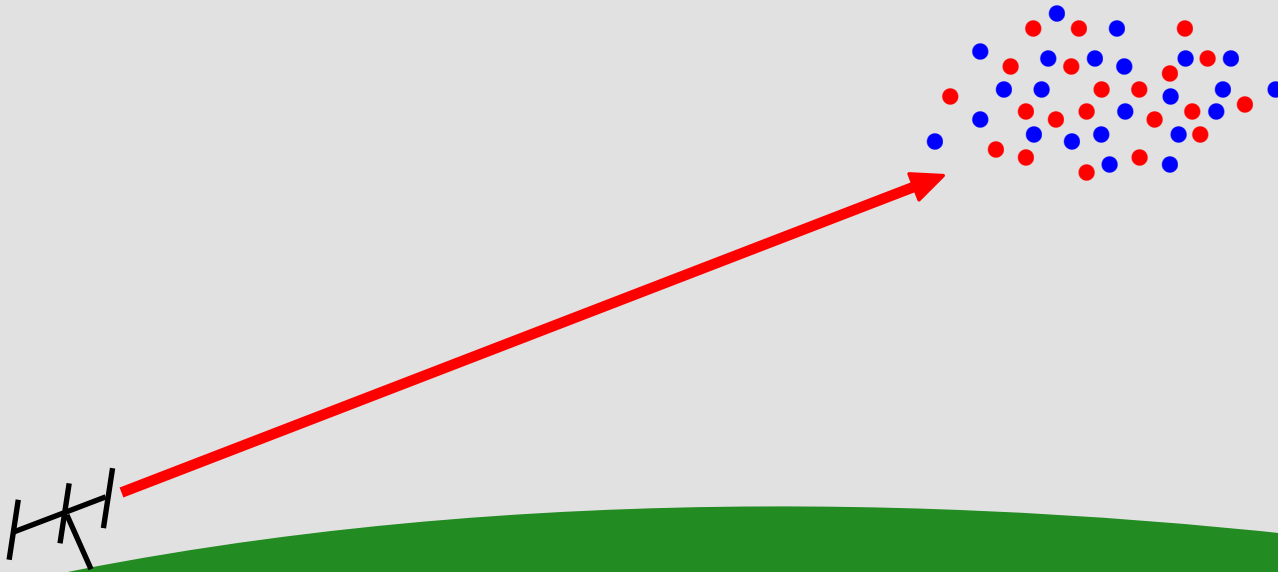


15 km

Troposphere



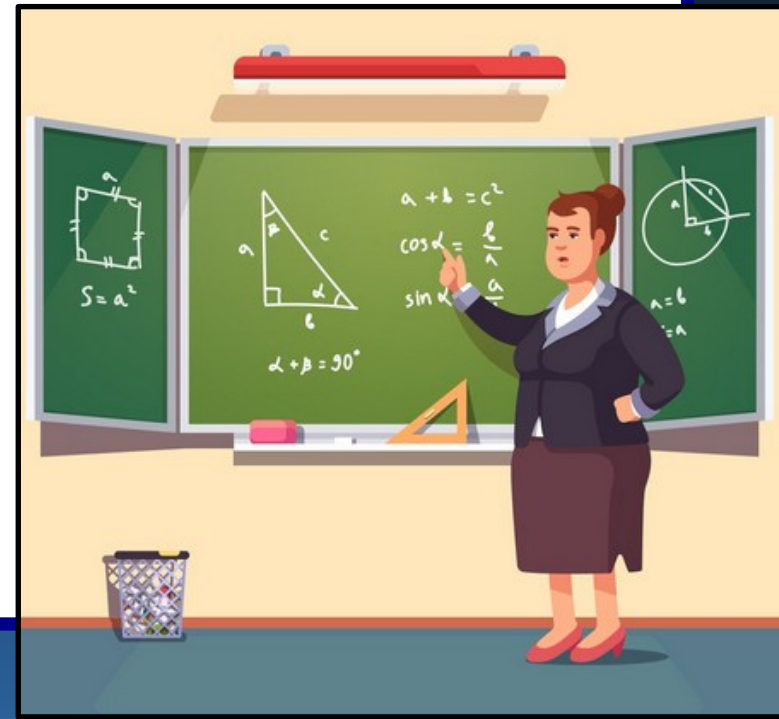
What happens when a radio wave encounters the ionosphere?



Can be understood with high school math

NO CALCULUS!

NO QUANTUM MECHANICS!



REFRACTION: Deflection in the path of an electromagnetic wave as it passes through different media

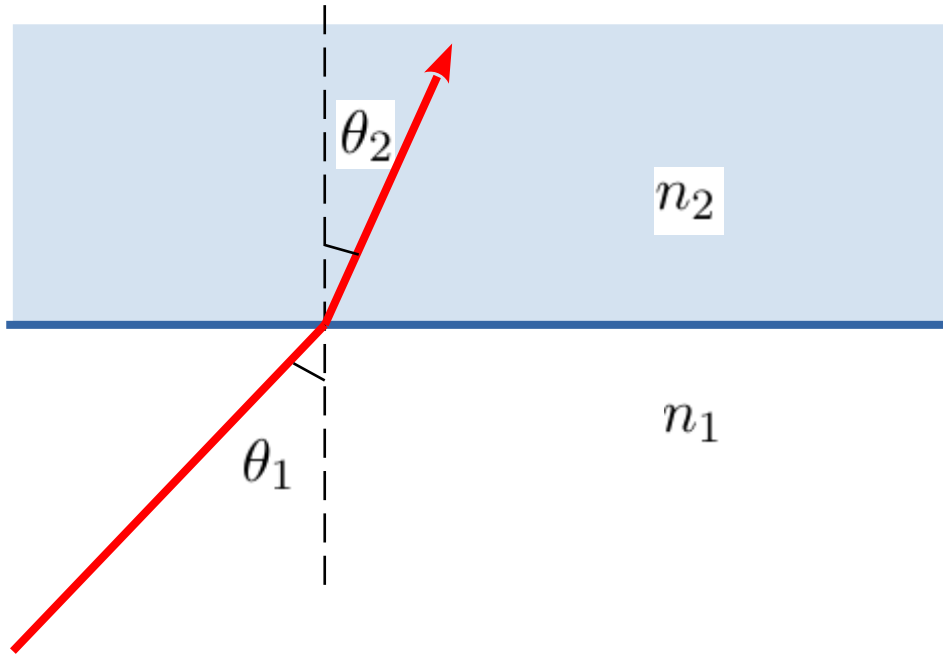


Index of refraction

Air: 1.0

Water: 1.33

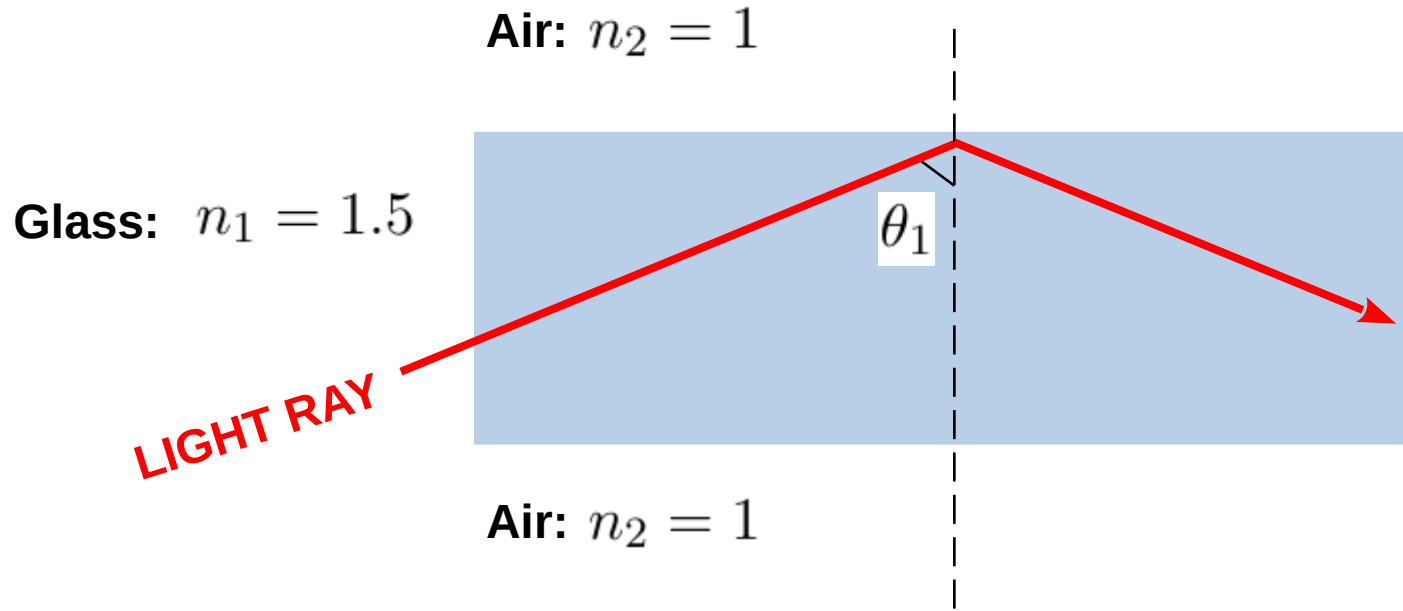
Glass: 1.5



Willebrord Snellius:
1580--1626

Snell's Law of Refraction: $n_1 \sin \theta_1 = n_2 \sin \theta_2$

Total Internal Reflection in Glass Fiber

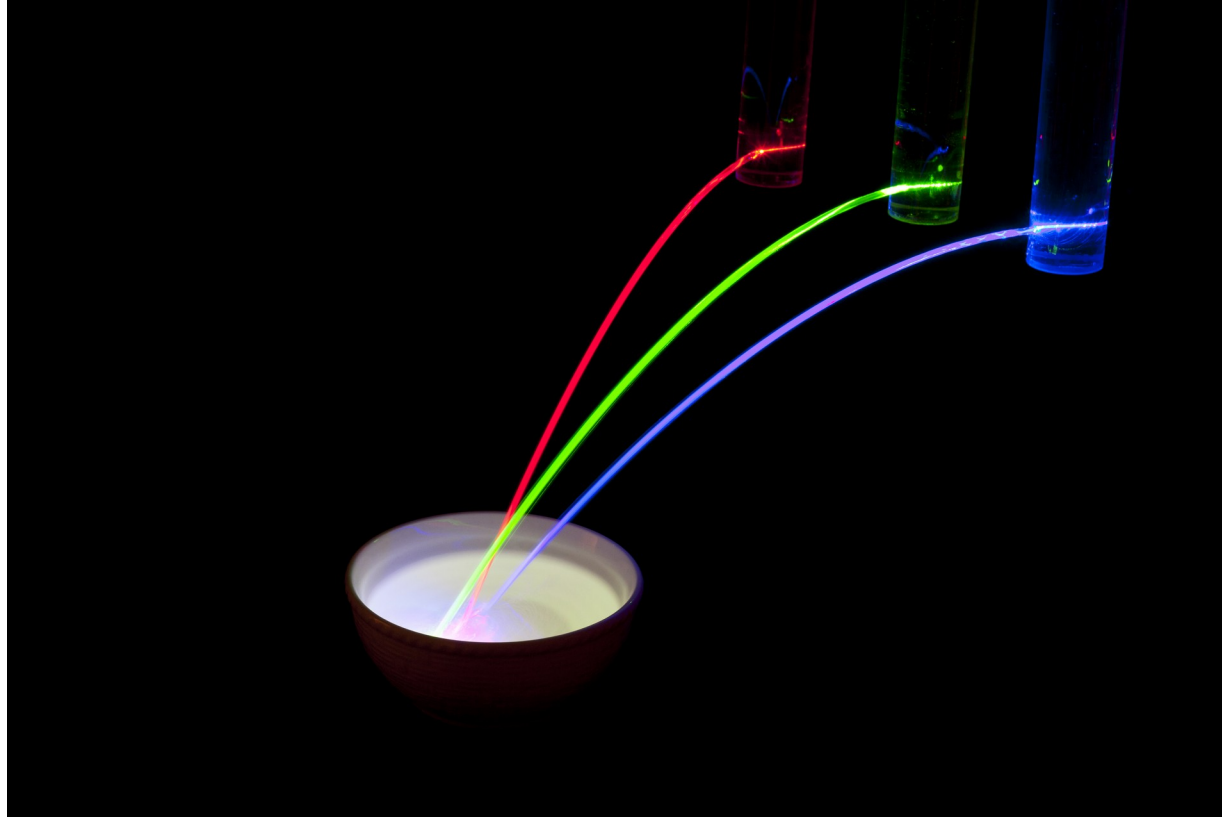


For $\theta_1 > 41^\circ$ Snell's Law has no solution!

These rays are completely reflected – there is no refraction

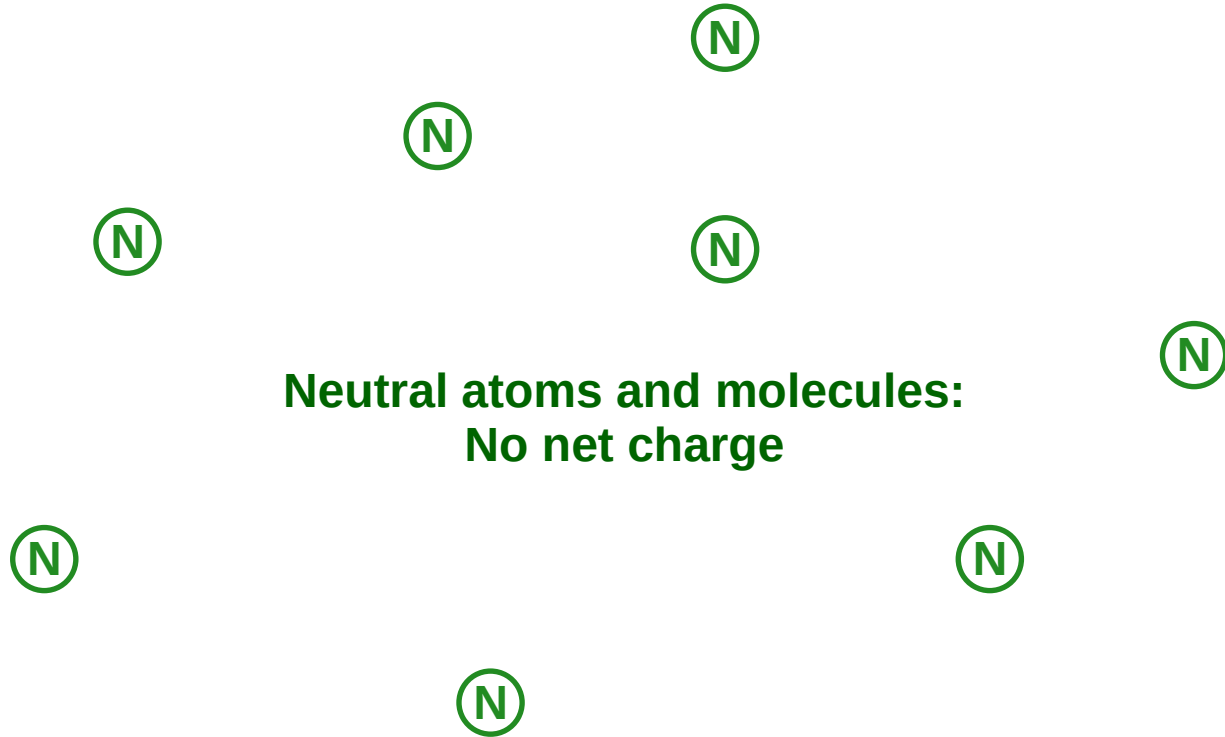
TOTAL INTERNAL REFLECTION:

Laser light launched into liquid Laminar flow streams

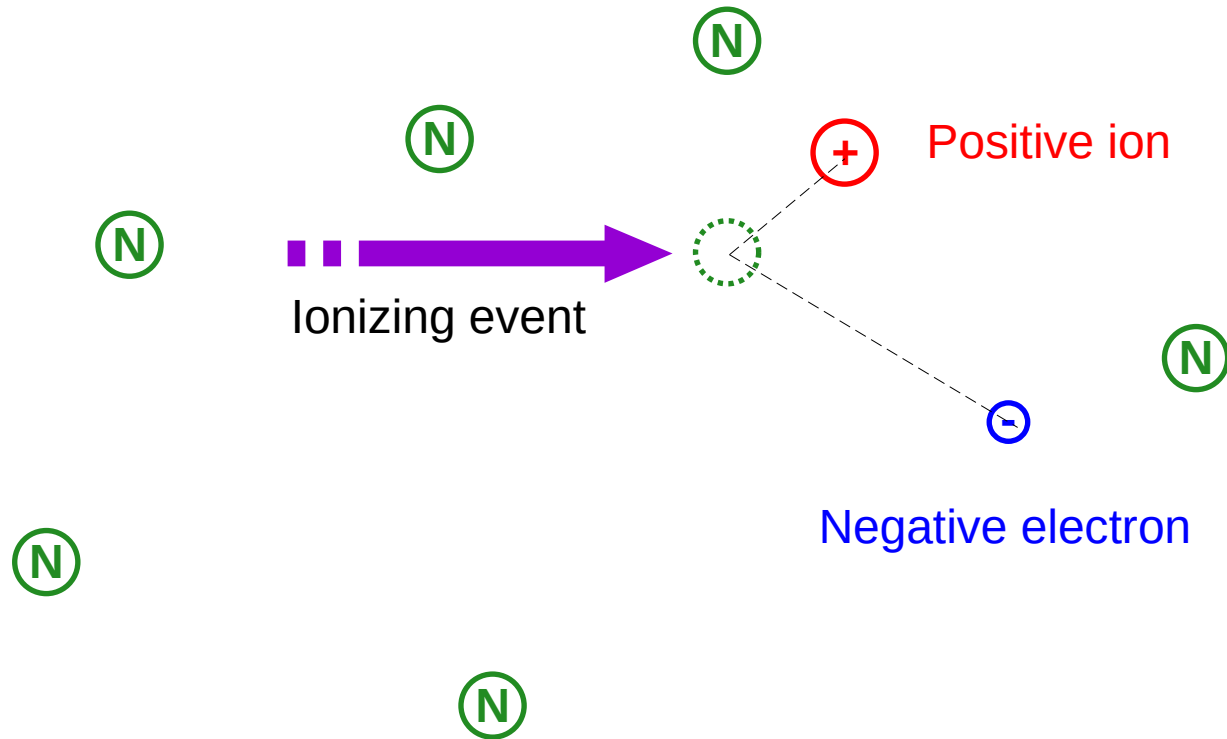


Courtesy of Dr Alexander Albrecht, UNM Physics & Astronomy

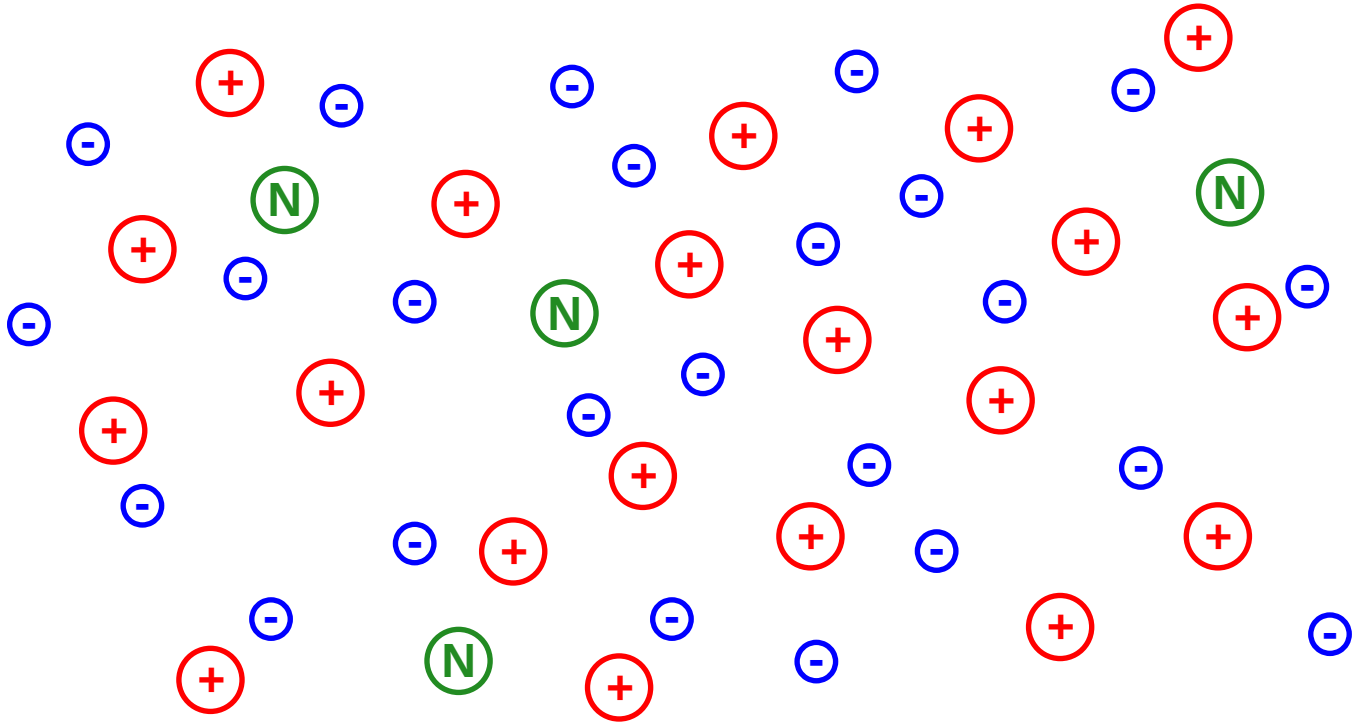
What is the ionosphere?



Ionizing events create **ELECTRONS** and **IONS**

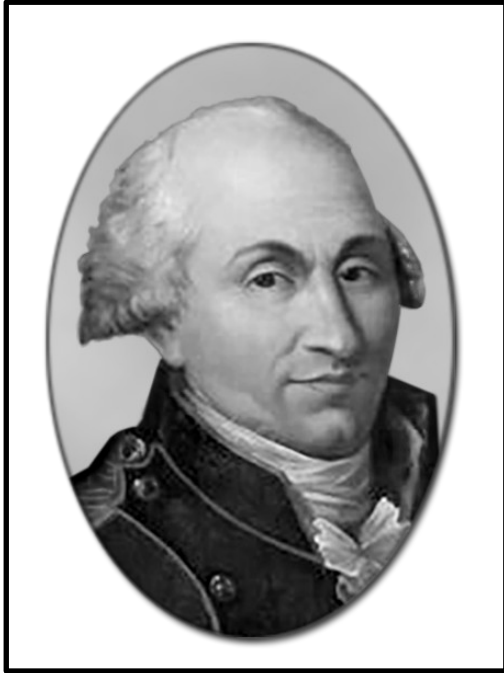


Equal density of **IONS** and **ELECTRONS**

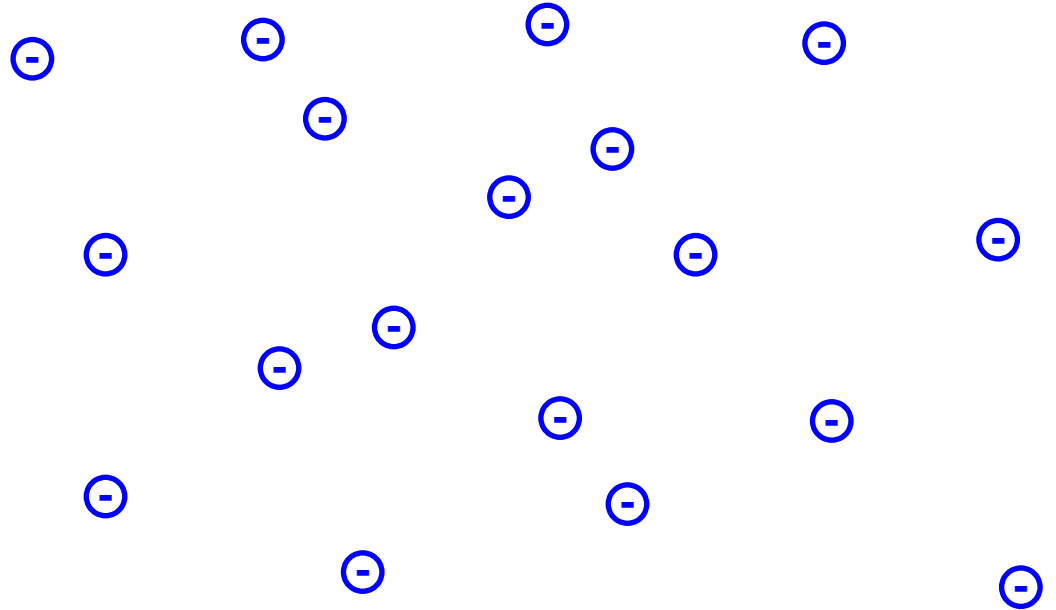


The ensemble is electrostatically neutral: *PLASMA*

It's not just the **Electrons** – The Crucial Role of **Ions**



Charles-Augustin de Coulomb
1736--1806



Coulomb's Law: Like-Charges Repel

In the absence of **positive ions...**

The diagram illustrates the effect of electrostatic repulsion on an electron ensemble. It features 15 blue circles, each containing a minus sign (-), representing electrons. These electrons are arranged in a roughly circular pattern around a central point. Dashed blue lines connect each electron to the center, representing the repulsive forces pushing them away from each other. The text "In the absence of positive ions..." is centered at the top, and "...electrostatic repulsive force blows apart the electron ensemble" is centered at the bottom.

...electrostatic repulsive force
blows apart the electron ensemble



Hendrik Lorentz:
1853--1928

Refractive index of the plasma

$$\sqrt{1 - \kappa \frac{N}{f^2}}$$

N : Density of electrons (or ions)

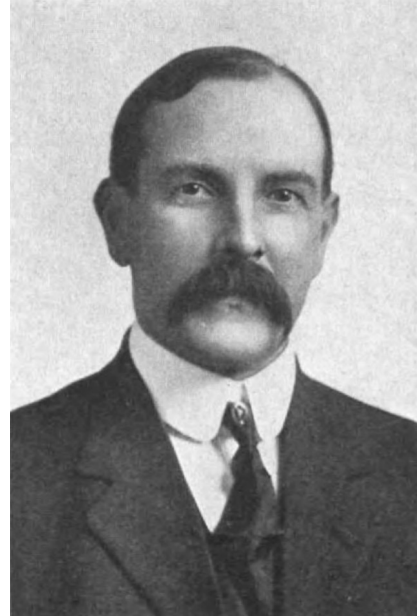
f : Frequency of electromagnetic wave

κ : Constant

**These Englishmen applied the above concepts
to explain radio wave reflection from the ionosphere**



Oliver Heaviside
1850-1925



Arthur Kennelly
1861-1939



Edward Appleton
1892-1965

Snell's Law of Refraction + Lorentz Model:

1) Weak Ionization

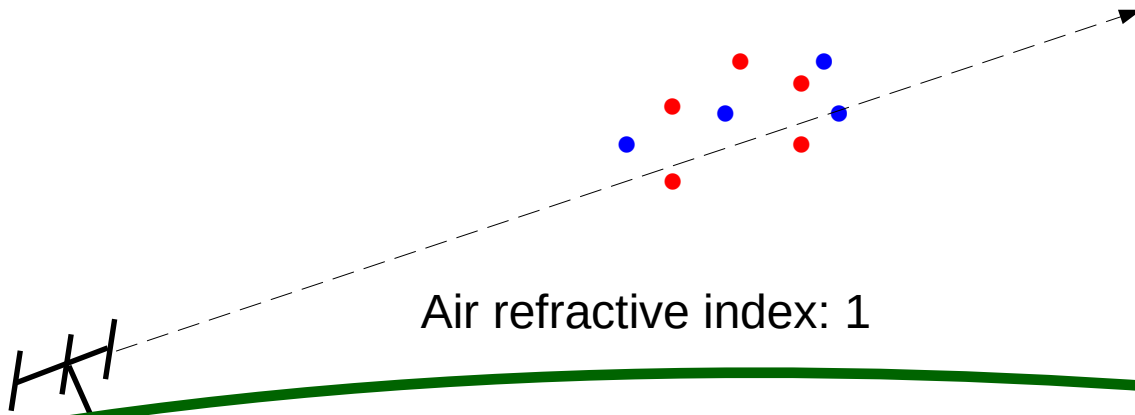
2) Moderate Ionization

3) Strong Ionization

1) Weak Ionization $\Rightarrow N$ is small \Rightarrow Ionosphere Index ≈ 1 \Rightarrow Transparent

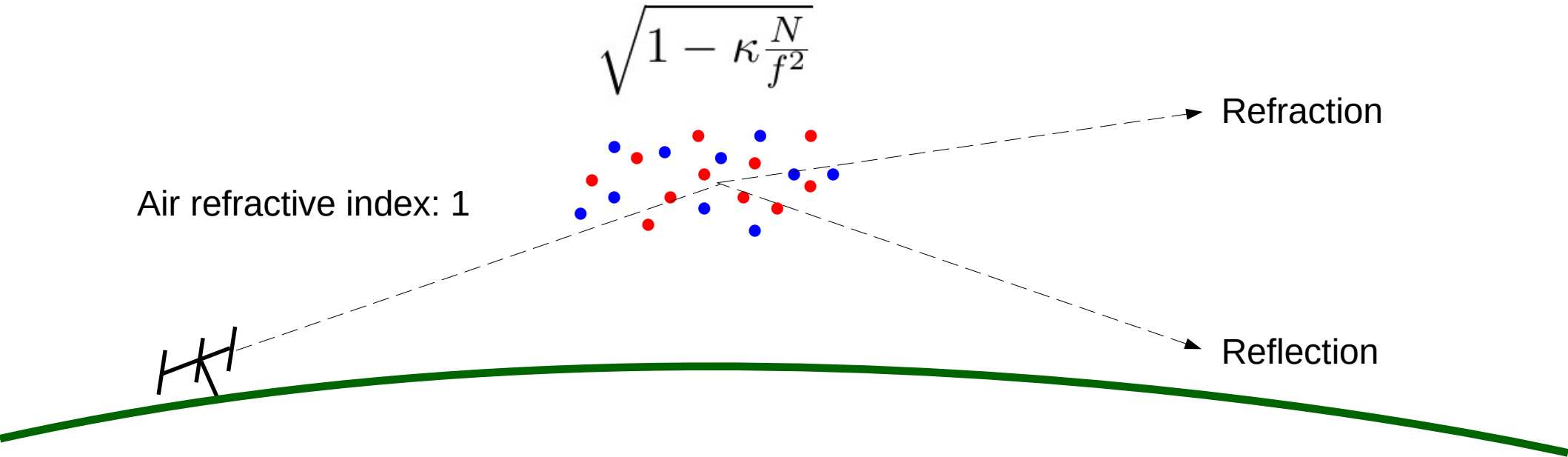
$$\sqrt{1 - \kappa \frac{N}{f^2}}$$

Ionosphere refractive index: 1



Air refractive index: 1

2) Moderate Ionization: Ionosphere refractive index < 1



Depends on plasma density, radio frequency, incidence angle, polarization

$$\sqrt{1 - \kappa \frac{N}{f^2}}$$

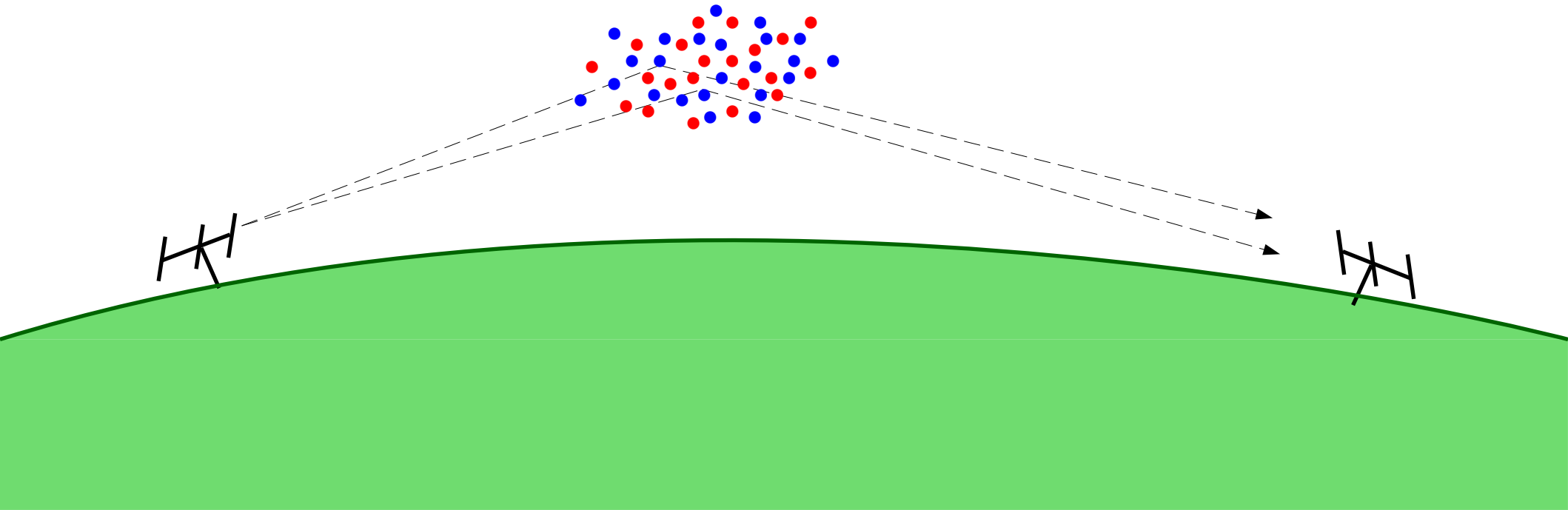
What happens when: $\kappa \frac{N}{f^2} > 1$???

Refractive index of ionosphere becomes imaginary

Ionosphere appears *metallic* to the electromagnetic wave

3) Strong Ionization. Metallic cloud is opaque

Electromagnetic wave is completely **REFLECTED**



Contemporary amateur radio literature INCORRECTLY states that **REFRACTION** by the ionosphere returns signals to the earth



Simple physics shows it's actually **REFLECTION**

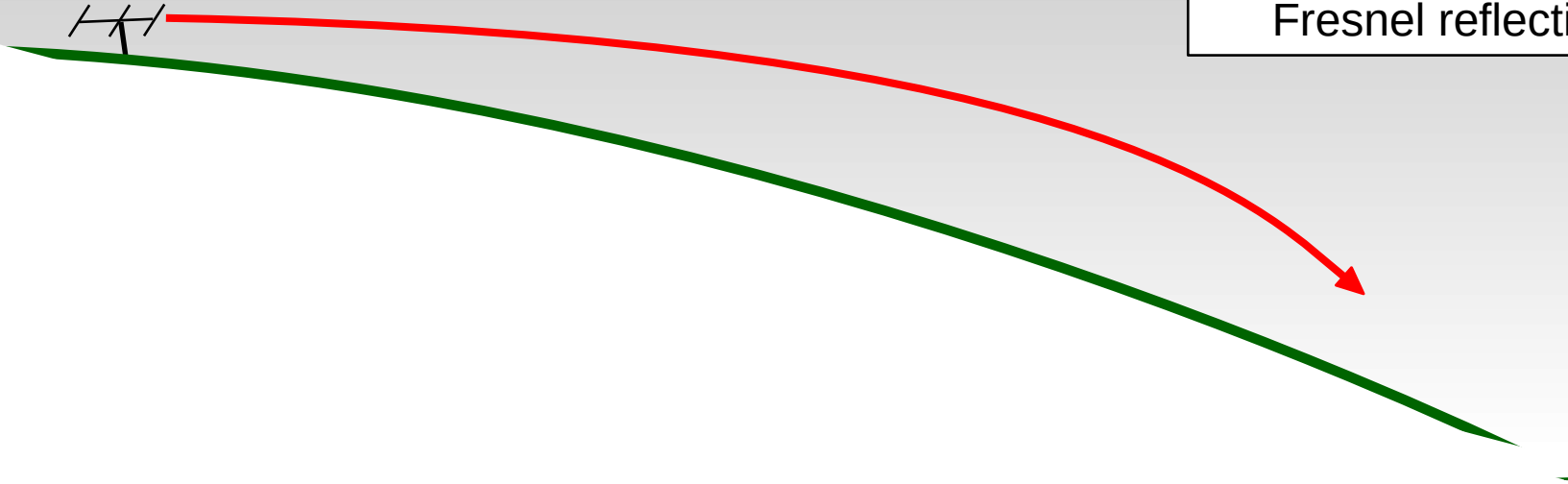
MORE ACCURATE MODEL

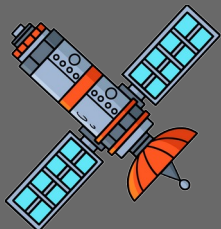
Ray tracing

Plasma gradients in *E*-layer

Earth curvature

Fresnel reflection





Too low for satellites...

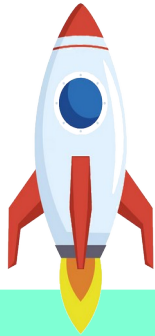

↑
E-layer 90–150 km

Measuring ionization here is difficult!

...and too high for weather balloons



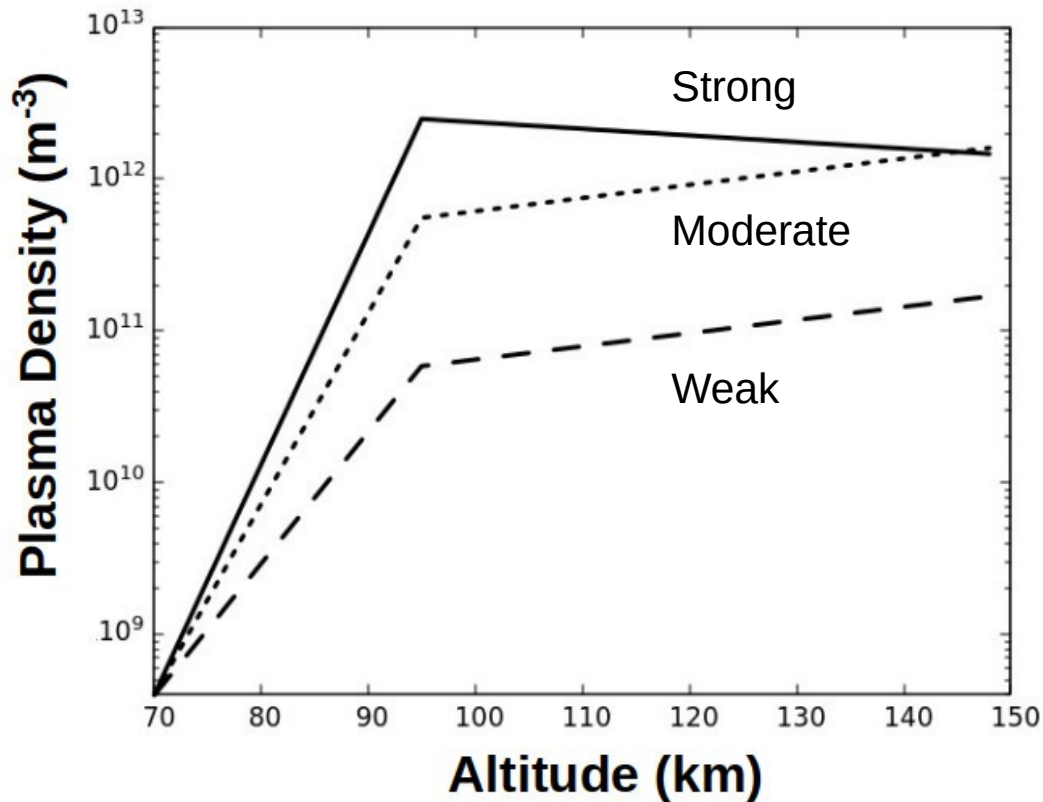
E-layer 90–150 km



***Sounding rockets have provided
the most reliable data***

Database: Faraday International Reference Ionosphere

Model: Double-Exponential (J. Geophysical Research: Space Physics, 2021)

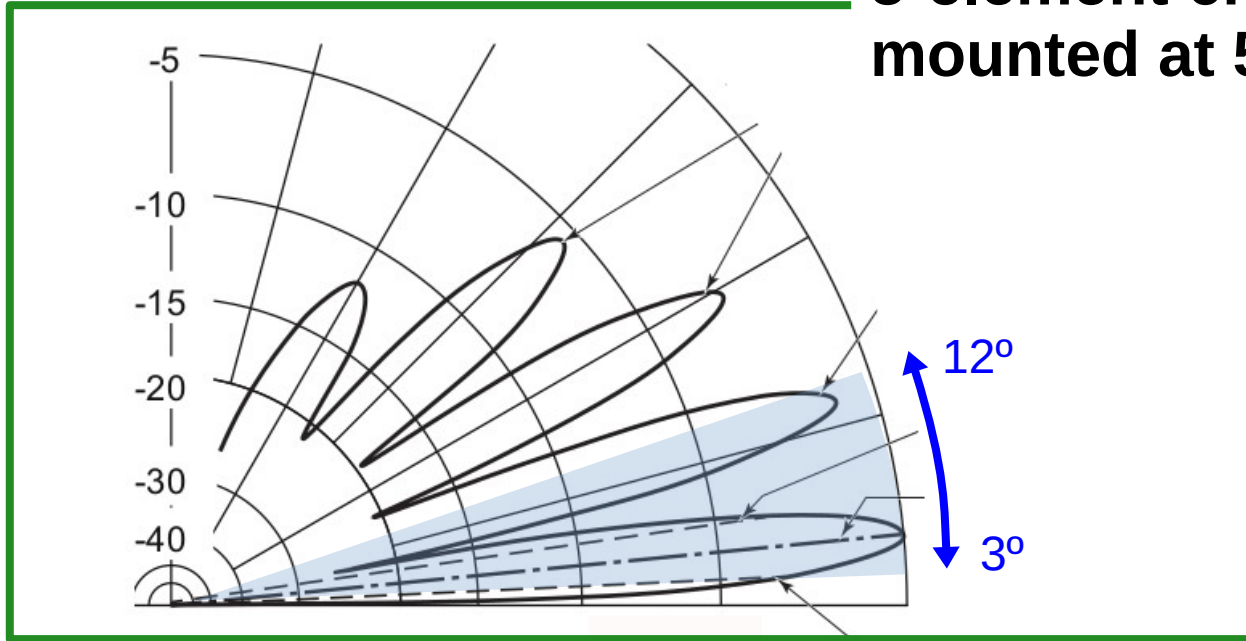


Use 3 different ionization profiles to analyze sporadic-E propagation:

- Weak
- Moderate
- Strong

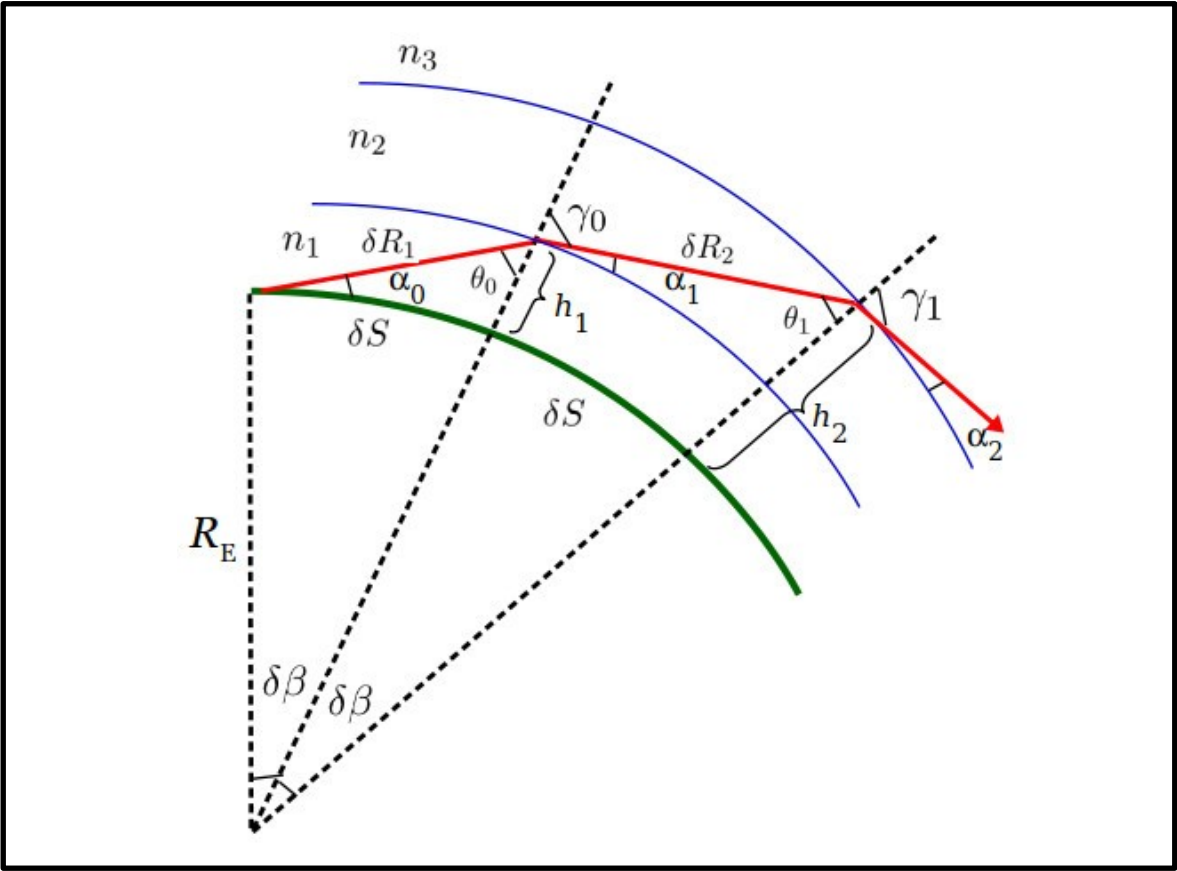
Antenna Takeoff Angle Range: 3–12 degrees

5-element 6m yagi
mounted at 50 ft

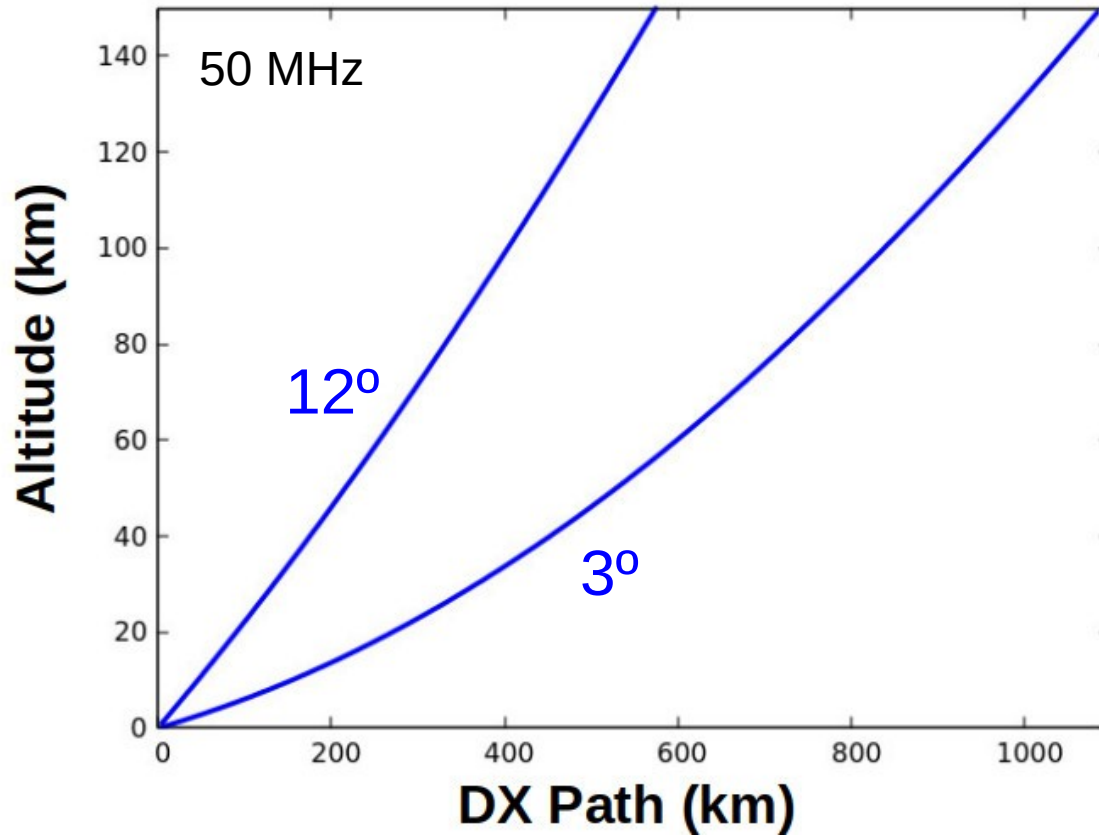


Ref: The ARRL Antenna Book

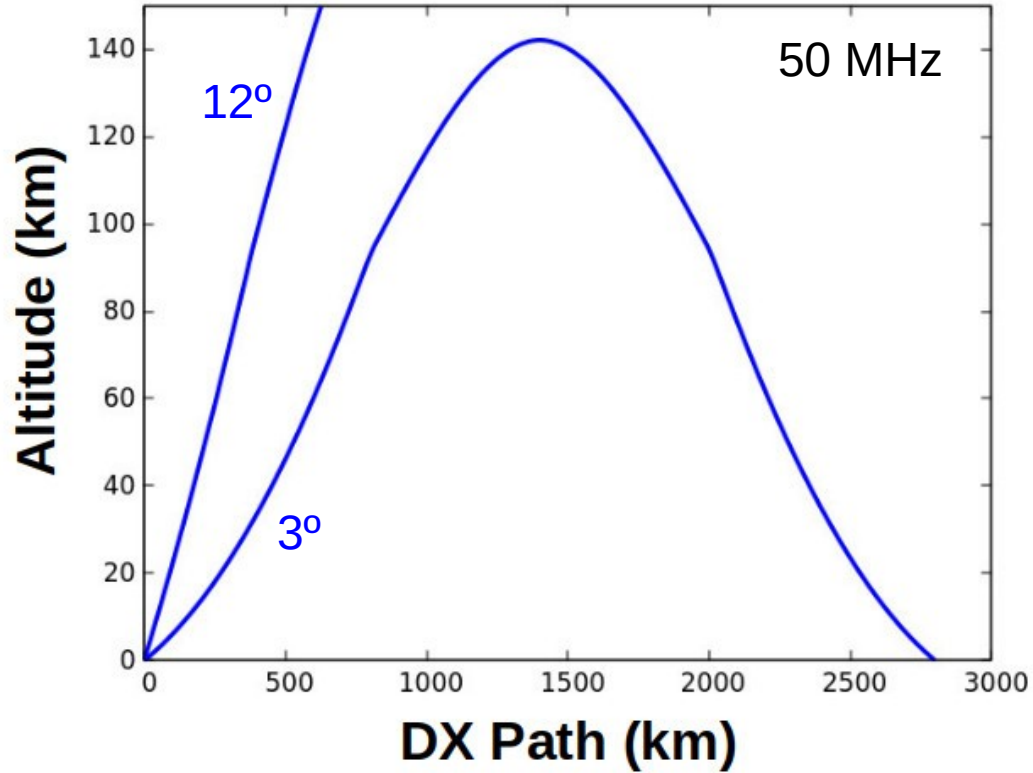
Numerical Analysis: Ray tracing through concentric plasma shells



Weak Ionization: Rays escape *E*-layer at 150 km altitude



Moderate Ionization



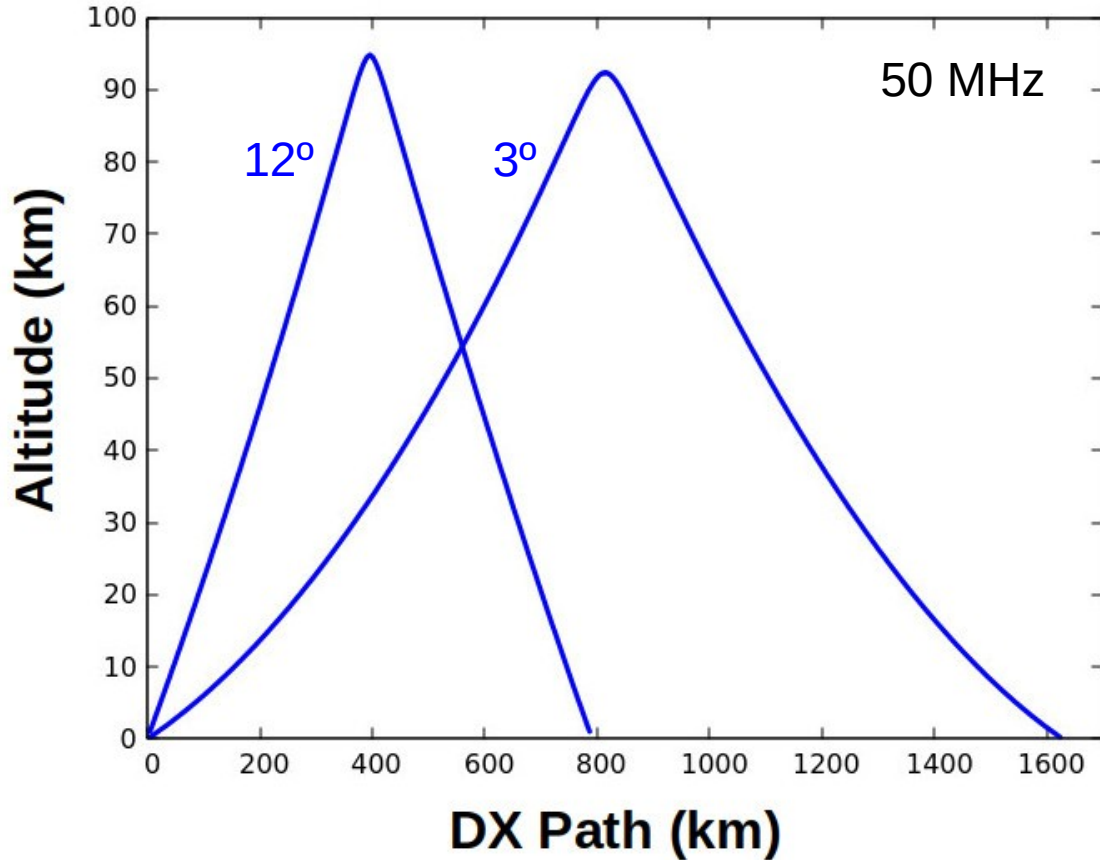
Only low takeoff angles reflected

Reflection at altitude 142 km

DX path 2800 km

Refraction bends ray just below apogee

Strong Ionization

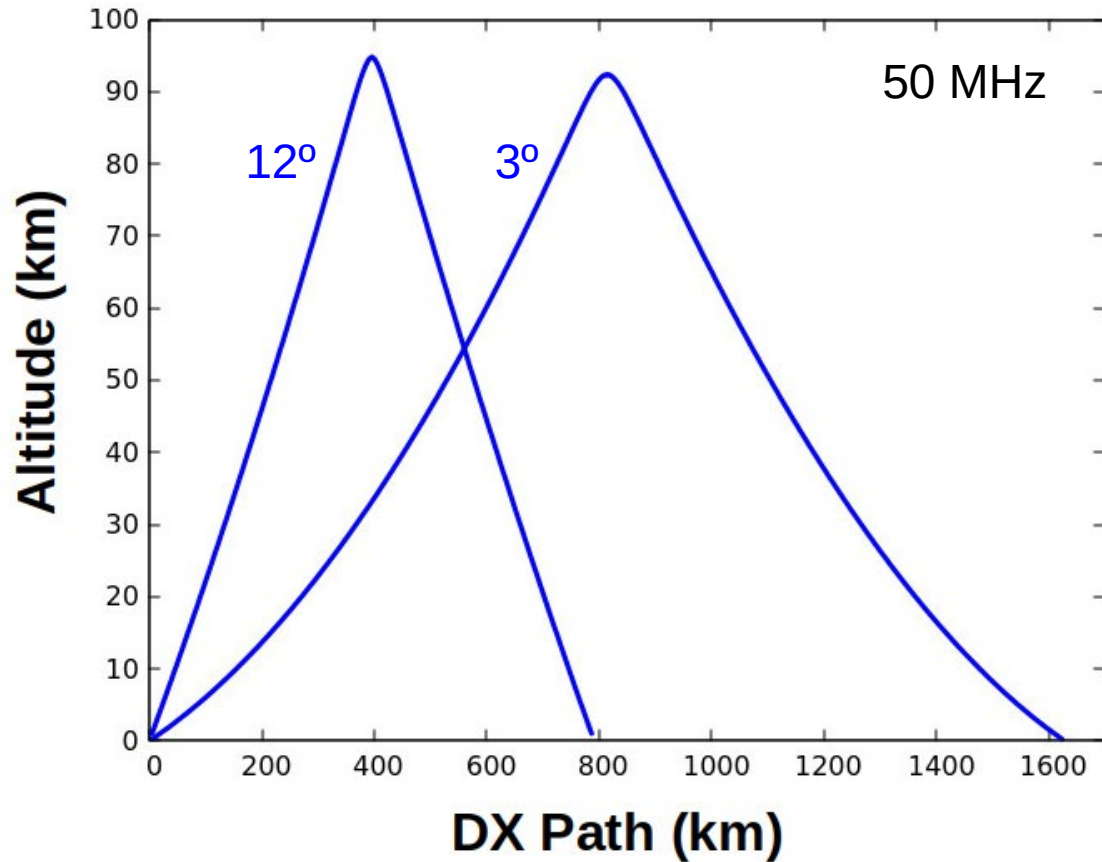


All rays 3–12° reflected

Reflection altitude drops to 92 km

DX path decreases to 1623 km
for 3° antenna takeoff angle

Strong Ionization



Rays reflected at lower altitude

DX path reduced

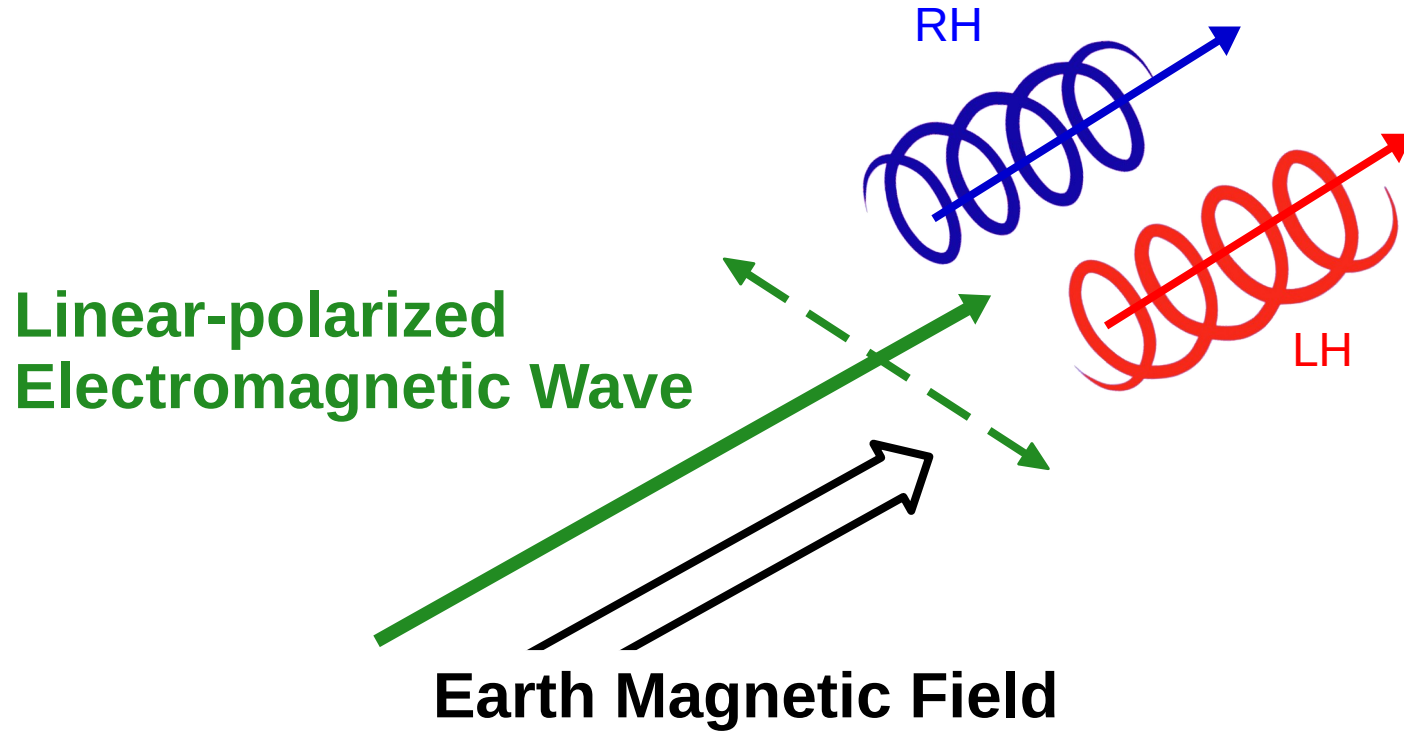
Alert to potential opening at 144 MHz

What about the Earth magnetic field?



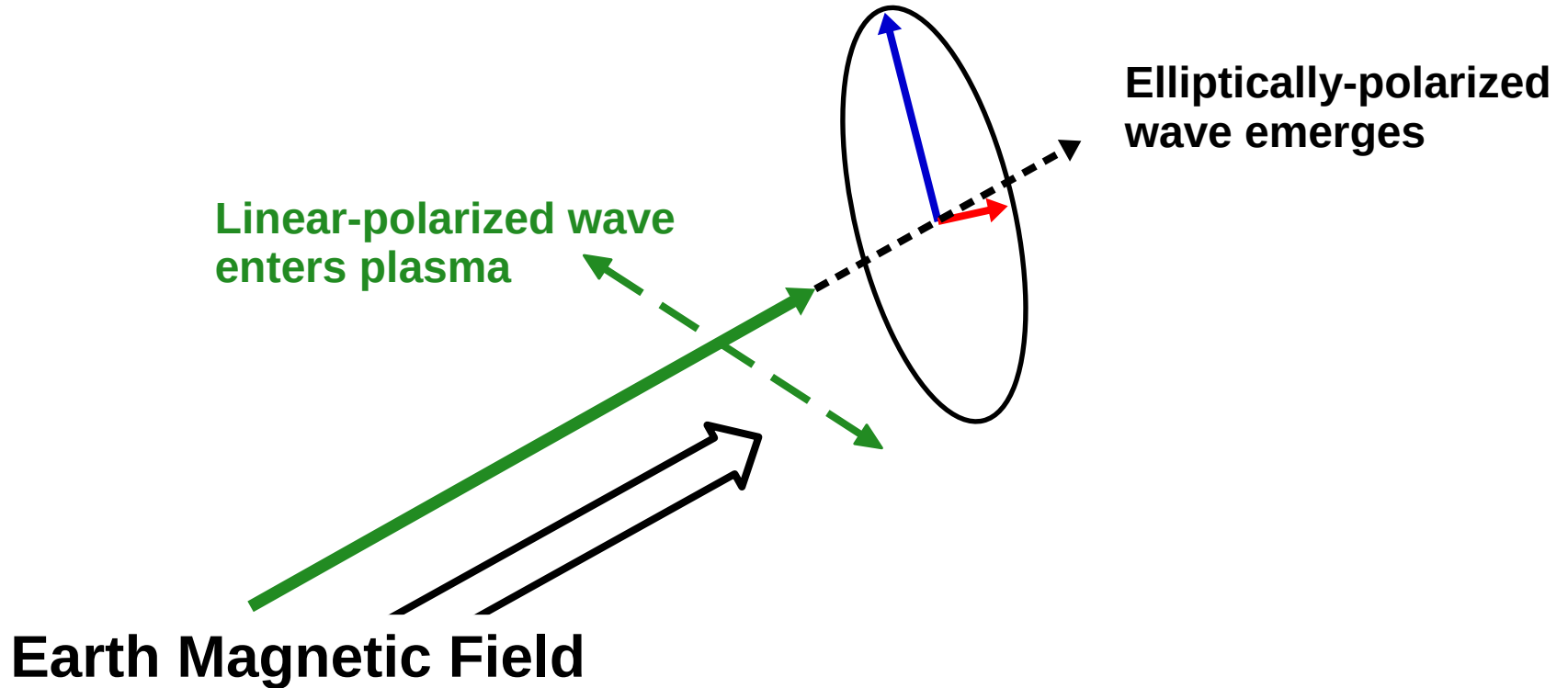
Magneto-Ionic Effects: Faraday Rotation

Left- and right-hand circular polarized waves created in the plasma



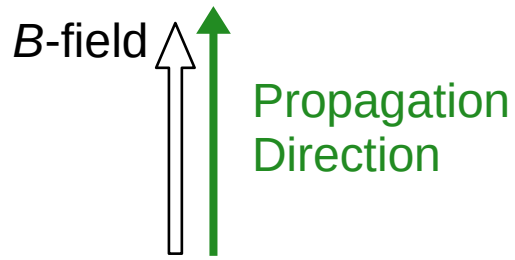
Vector sum of LH and RH Circular is *Elliptical*

Ellipticity/tilt depends on amplitude & phase of **LH** relative to **RH** wave

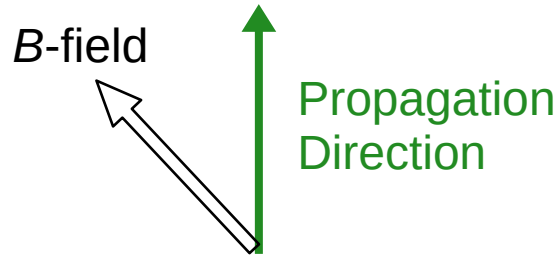


Faraday Rotation:

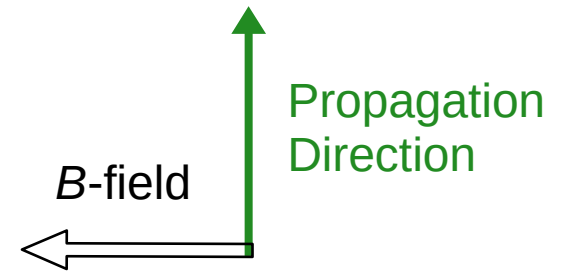
Depends on angle between **RF path** and Earth **B-field**



**Maximum
Rotation**



**Moderate
Rotation**



**Minimal
Rotation**

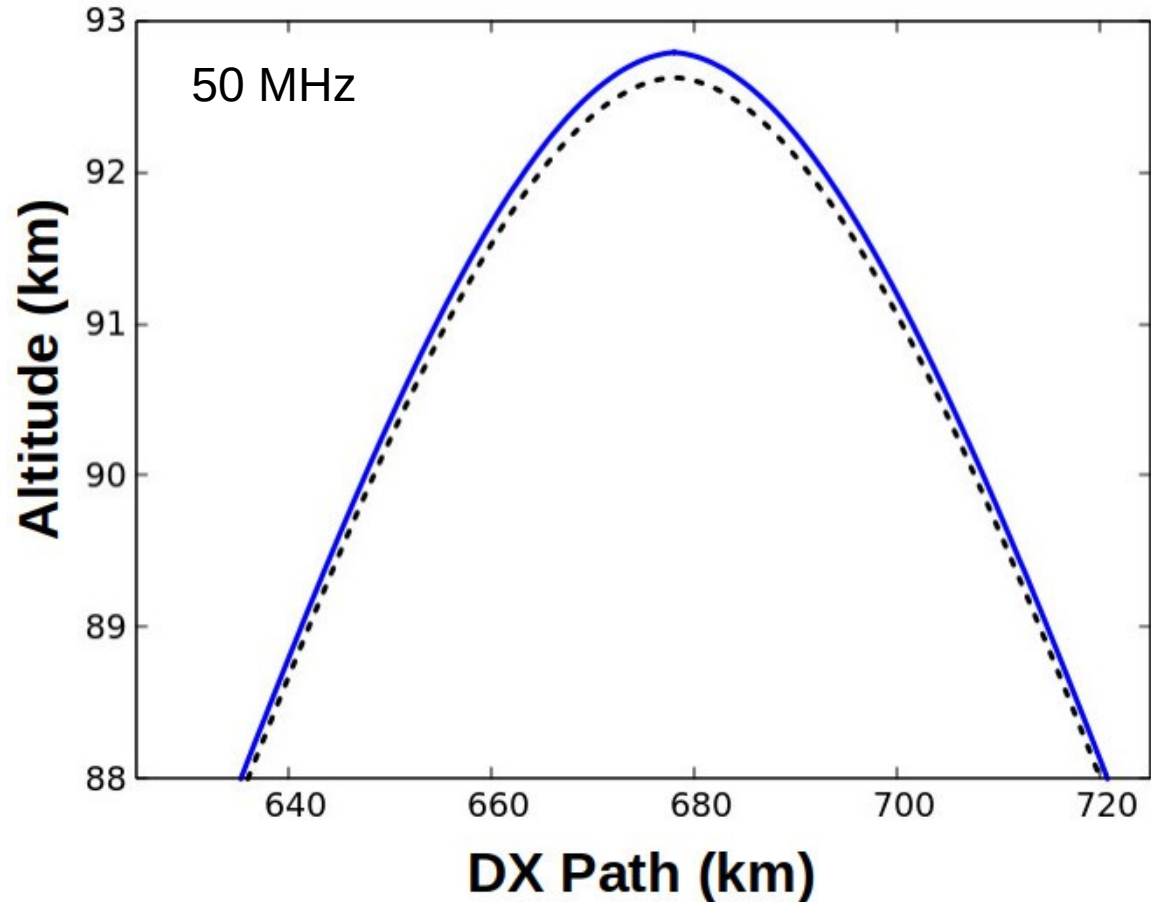
Faraday Rotation depends on propagation length in plasma



Increases with plasma density...

...but weakens with frequency

LH and RH ray paths near apogee in strong ionization profile



TX: Horizontal polarization

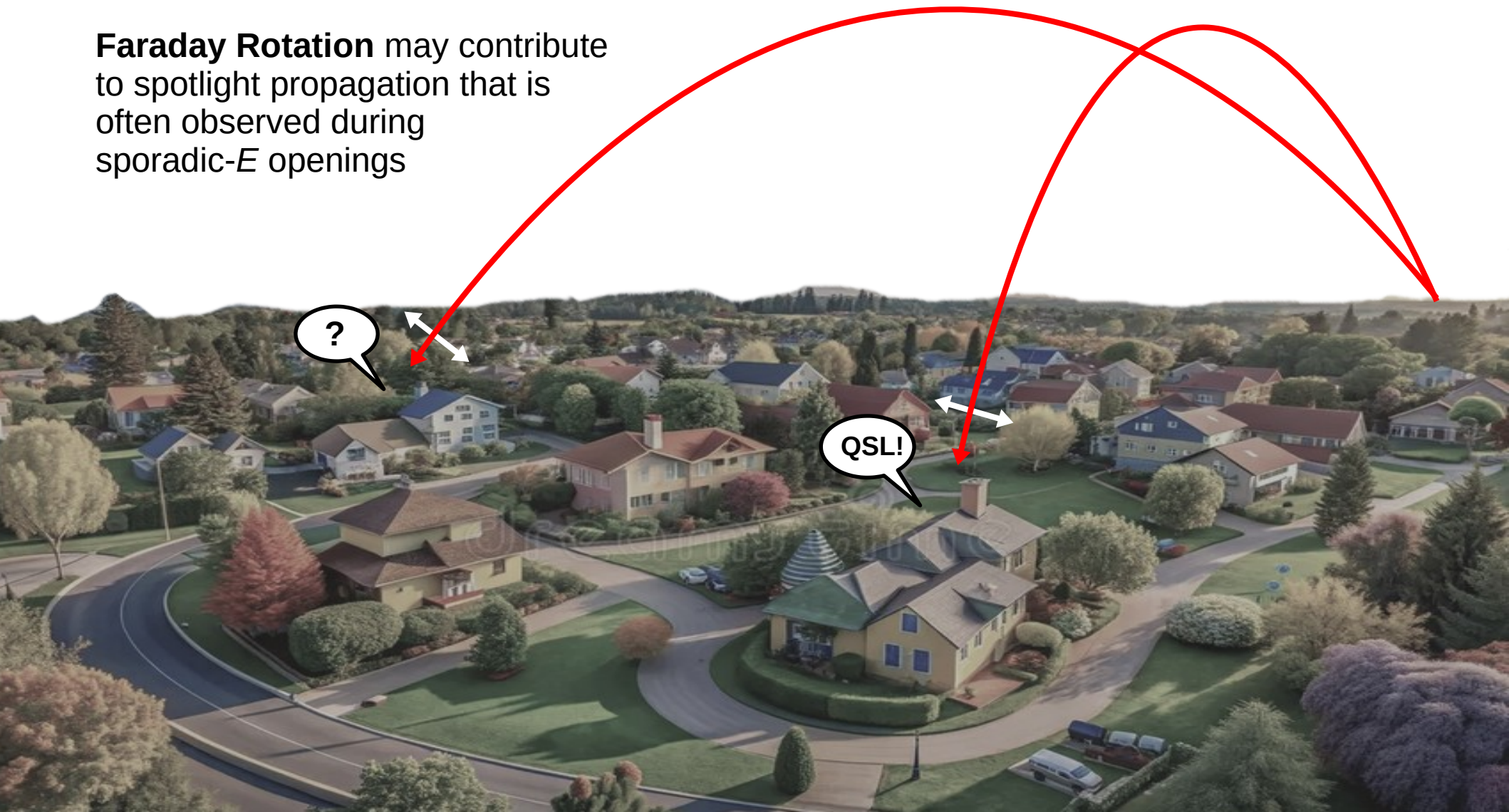
LH-RH path length difference
between TX and RX: 60m

60m \approx 10 wavelengths

Phase difference: $0-2\pi$

**Elliptical polarization of
any orientation can be
expected at receiver**

Faraday Rotation may contribute to spotlight propagation that is often observed during sporadic-E openings



Polarization rotation of OY6BEC/B measured near London



1270 km path

Horizontally polarized TX

Cross-polarized dual RX

50.402 MHz

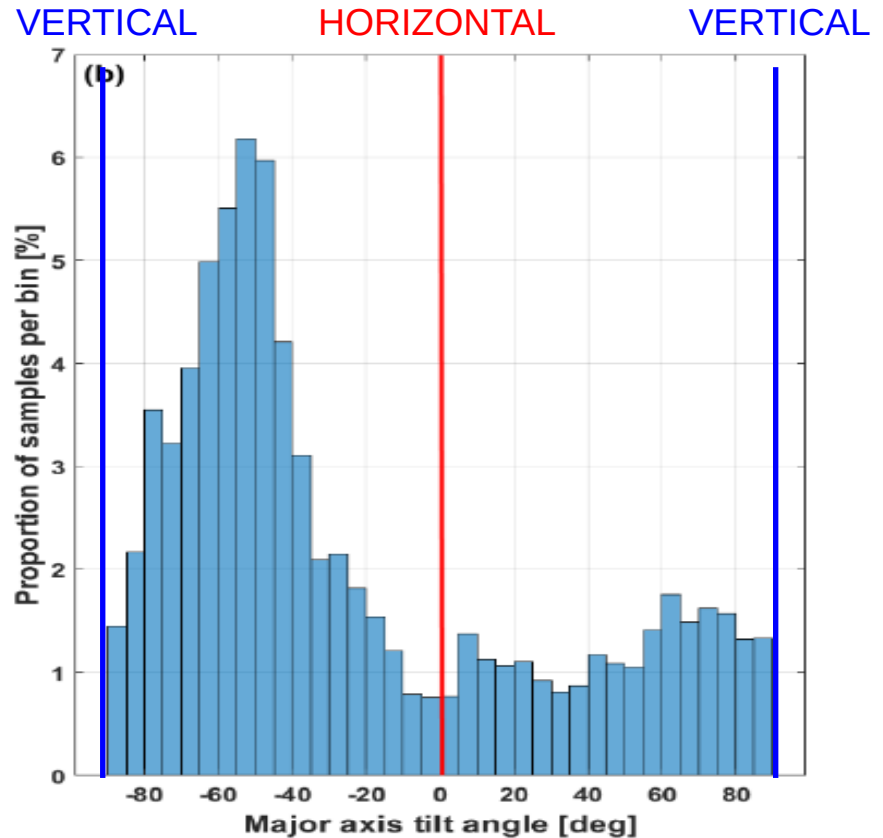
Ellipticity measurements of 50 MHz beacons in EU

40 min measurement time

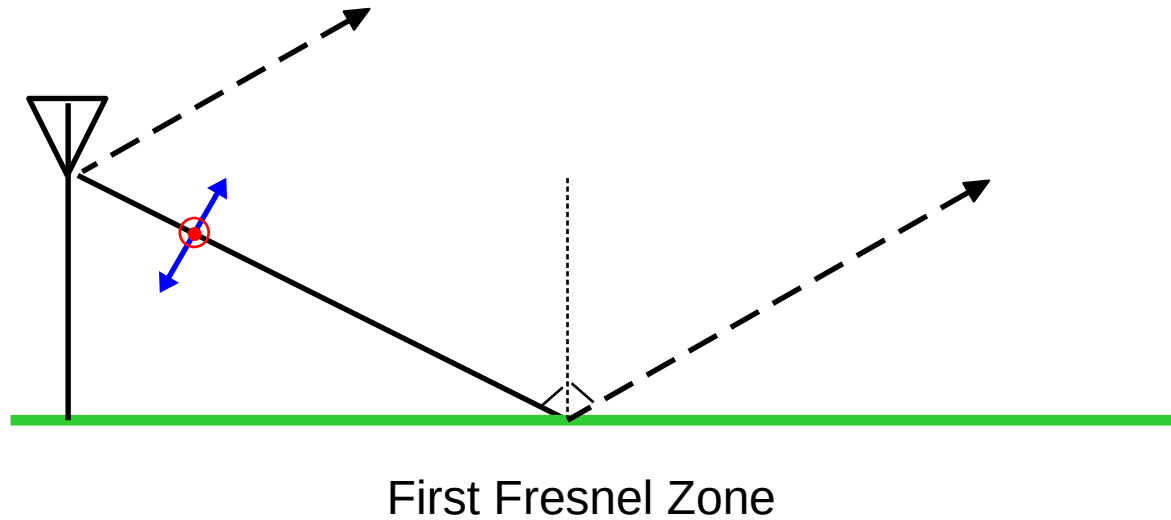
Data taken August 2018

Rapid polarization rotation

Ref: Deacon et al, Atmosphere (2022)
University of Bath, UK

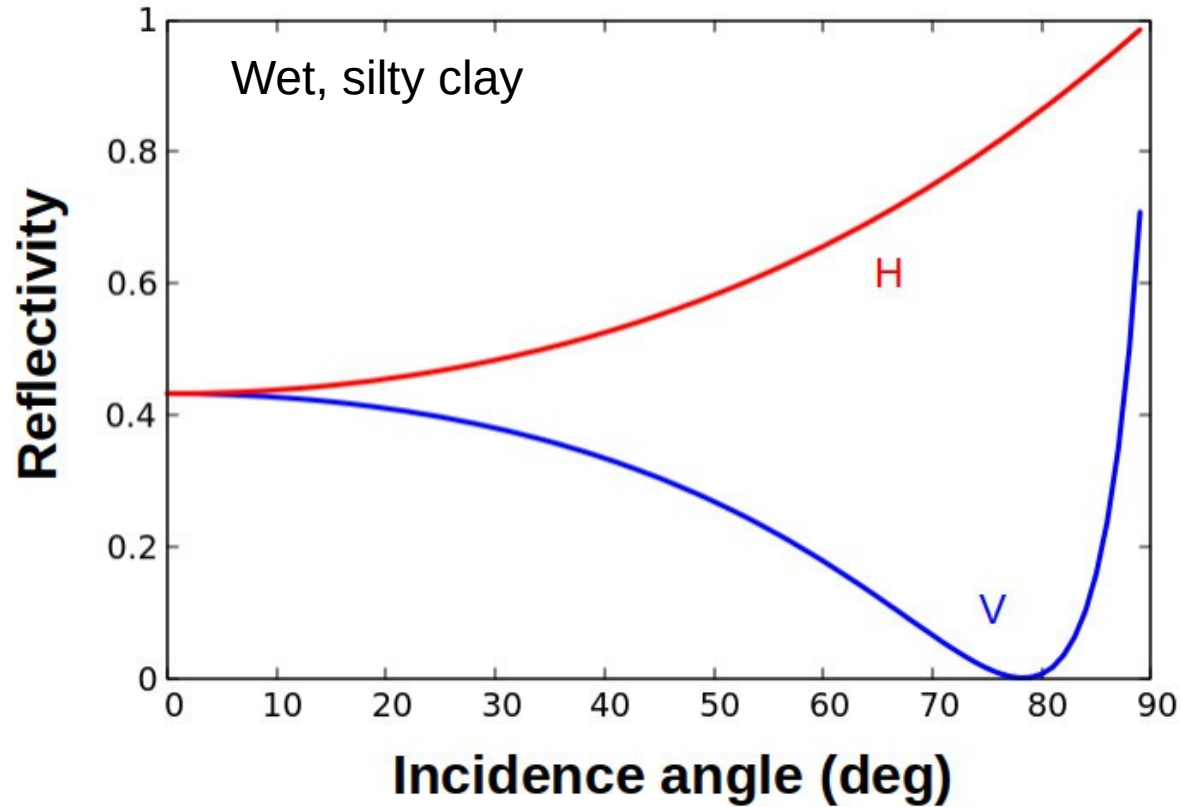


Which polarization is better for working DX? **Horizontal** or **Vertical**?



Pseudo-Brewster Angle:

Vertical polarization strongly absorbed by the soil





SUMMARY: KEY POINTS

- Refraction and reflection work in tandem to enable sporadic-*E* propagation
- Increasing *E*-layer ionization can dramatically reduce the DX distance
- Faraday Rotation is generally present on both terrestrial and EME paths

ACKNOWLEDGEMENT: J Duffey KK6MC