



# Radio communications & Ionosphere

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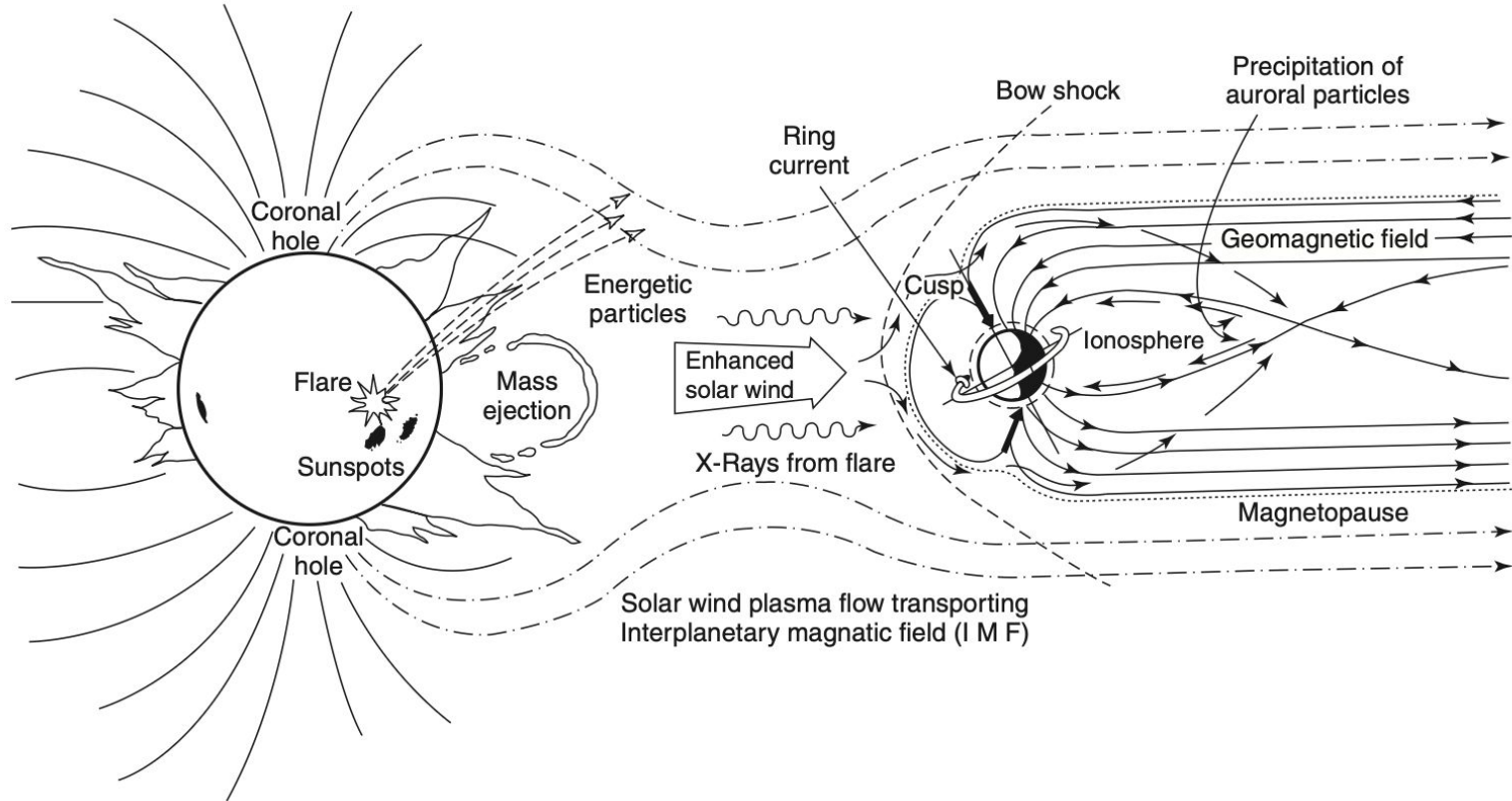


# Agenda

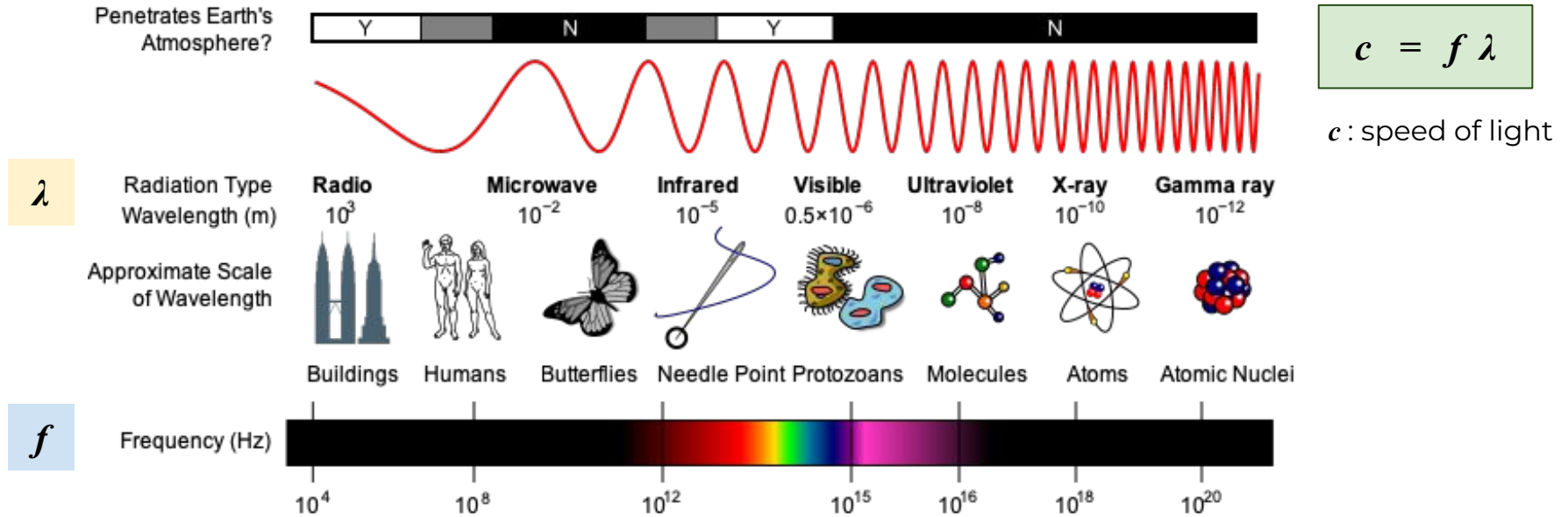
- The issue with radio and the solar-terrestrial environment
- Fundamentals of Electromagnetic Waves
- Propagation Modes for VHF+
- Space Weather Impact on VHF+ radio communications

# Radio Blackout

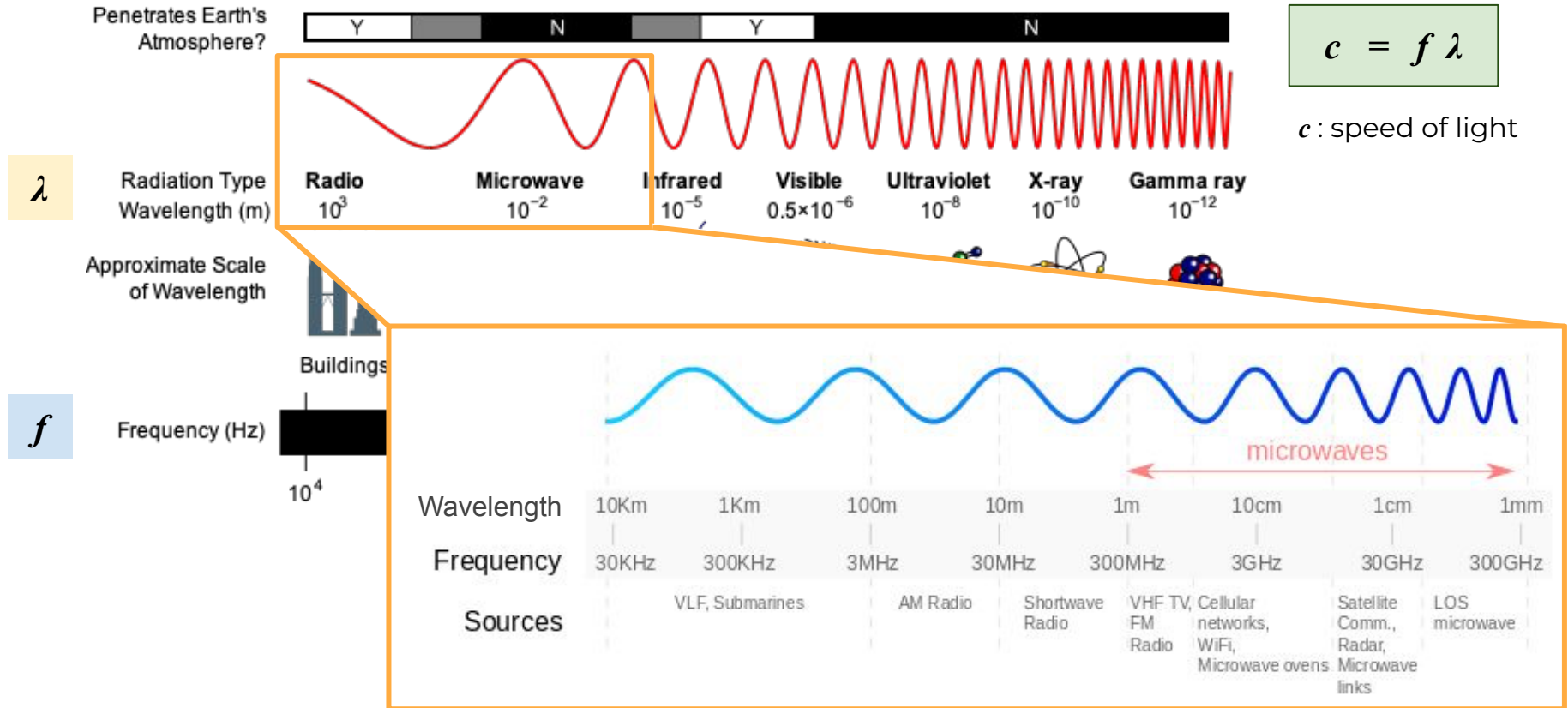
## *Solar-Terrestrial Environment & Radio Communications*



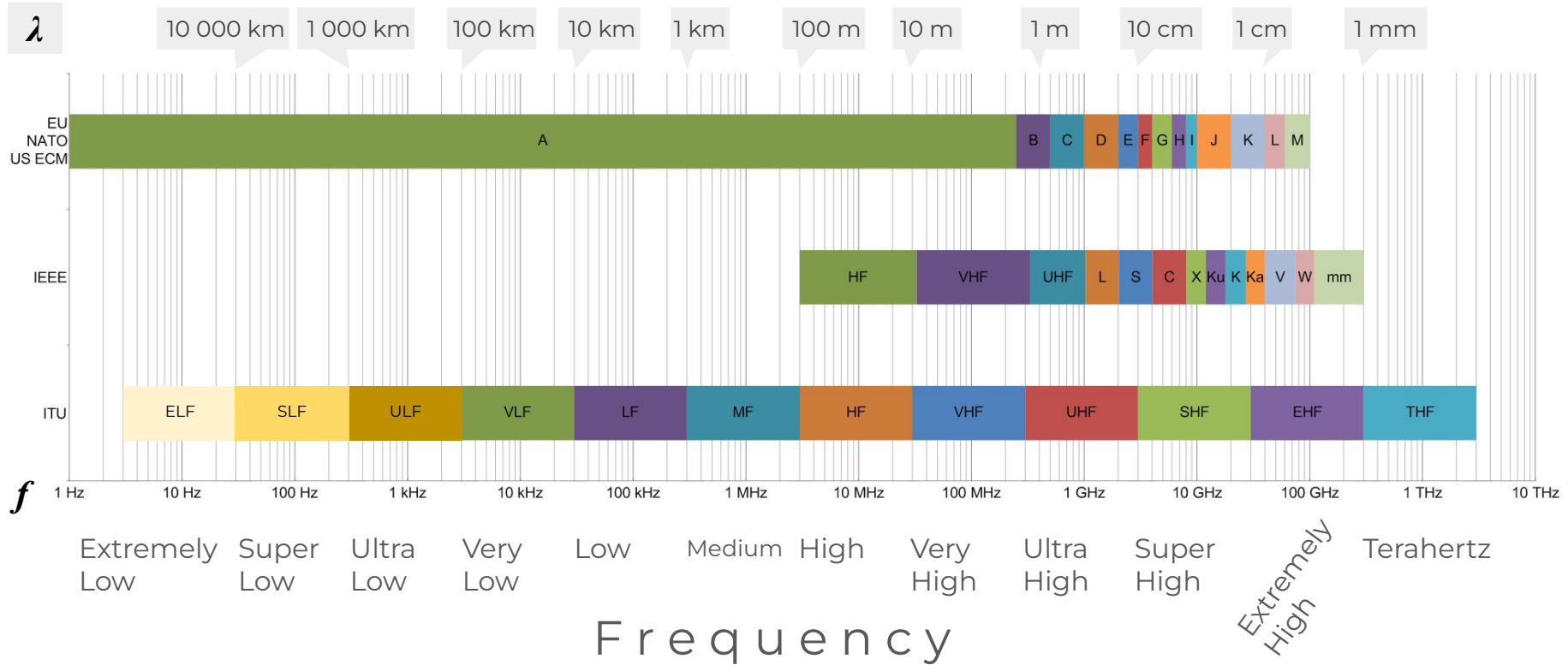
# Electromagnetic spectrum



# Electromagnetic spectrum



# Radio bands

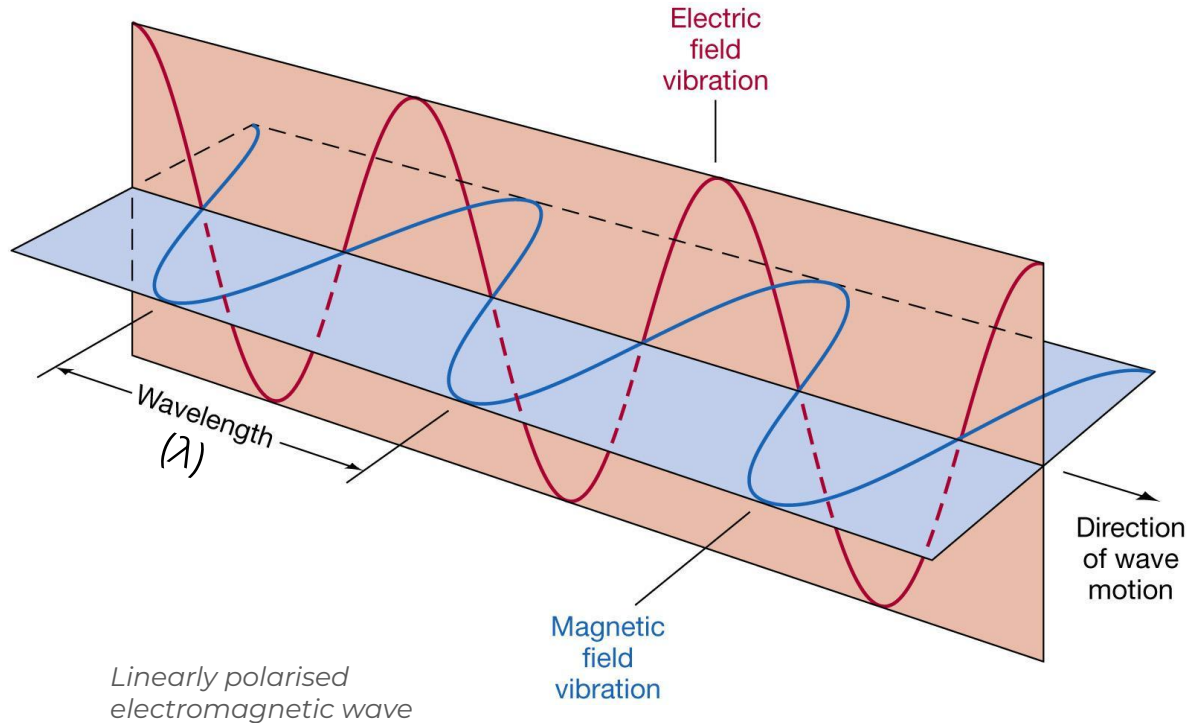


# Primary modes of Propagation

ITU Designation	Frequency Range	Principal Propagation Modes	Principal Uses
Extralow frequency (ELF)	30–300 Hz	Ground wave and Earth–ionosphere waveguide mode	Submarine communication
Very low frequency (VLF)	3–30 kHz	Same as above	Navigation, standard-frequency and -time dissemination
Low frequency (LF)	30–300 kHz	Same as above	Navigation LORAN-C
Medium frequency (MF)	300–3000 kHz	Primarily ground wave, but sky wave at night	AM broadcasting, maritime, aeronautical communication
High frequency (HF)	3–30 MHz	Primarily sky wave, some ground wave	Shortwave broadcasting, amateur, fixed services
Very high frequency (VHF)	30–300 MHz	Primarily LoS, some sky wave at lower VHF	FM broadcasting, television, aeronautical communication
Ultrahigh frequency (UHF)	300–3000 MHz	Primarily LoS, some refraction and scattering by the ionosphere	Television, radar, navigation, aeronautical communication
Superhigh frequency (SHF)	3–30 GHz	Same as above	Radar, space communication

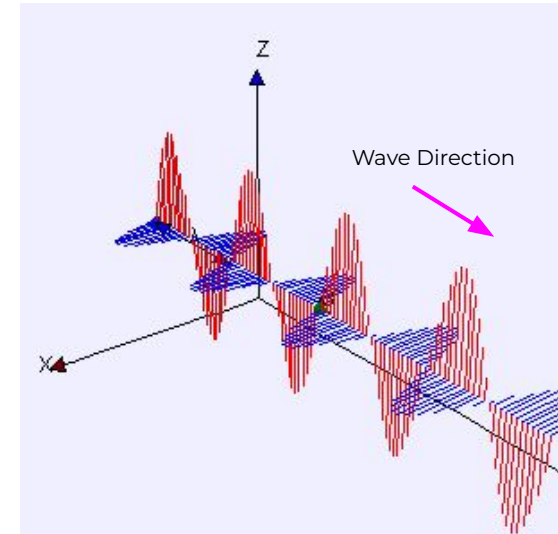
# Electromagnetic wave propagation

*Velocity*



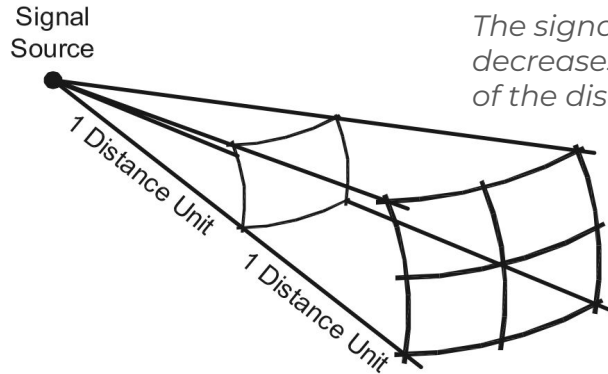
$$c = f \lambda$$

$c \approx 300\,000$  km/s  
**in a vacuum**



# Electromagnetic wave propagation

## Free Space Attenuation & Absorption



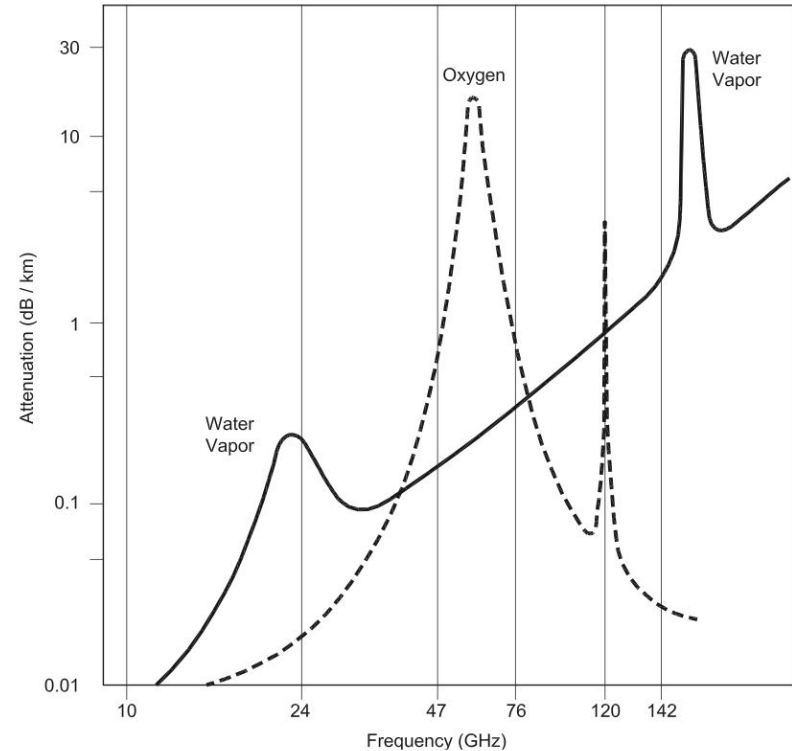
The signal's power density decreases with the square of the distance.

$$L_{fs} = 32.45 + 20 \log d + 20 \log f$$

$L_{fs}$  : Free space path loss [dB]

$d$  : distance [km]

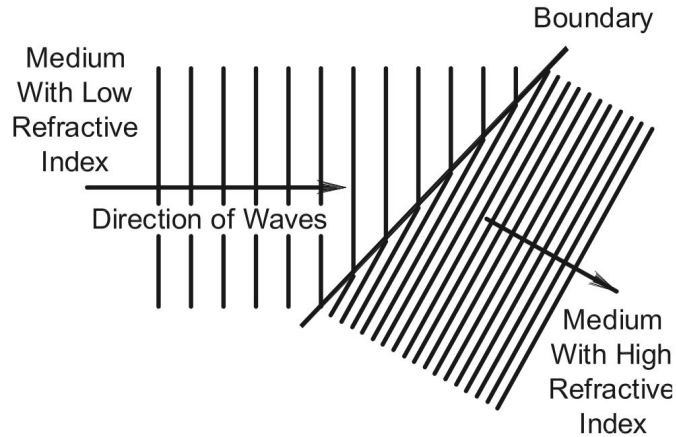
$f$  : frequency [MHz]



Attenuation caused by  $O_2$  and water vapor at  $10 \text{ g/m}^3$  (equivalent to 40% humidity at 25 °C).

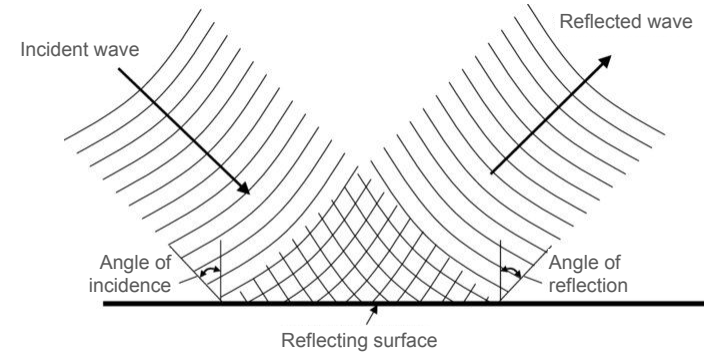
# Electromagnetic wave propagation

## *Refraction, Reflection & (Diffuse) Scattering*



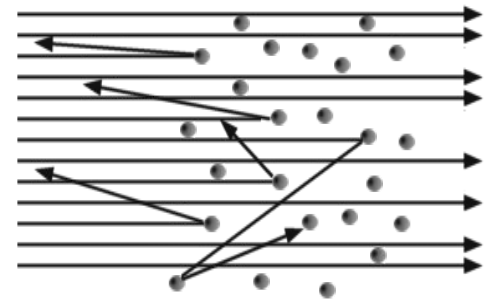
*Radio waves bend at boundaries between media, as one part of the wave slows before the other.*

**Flat surface:** reflection angle = incidence angle



**Small particles:**

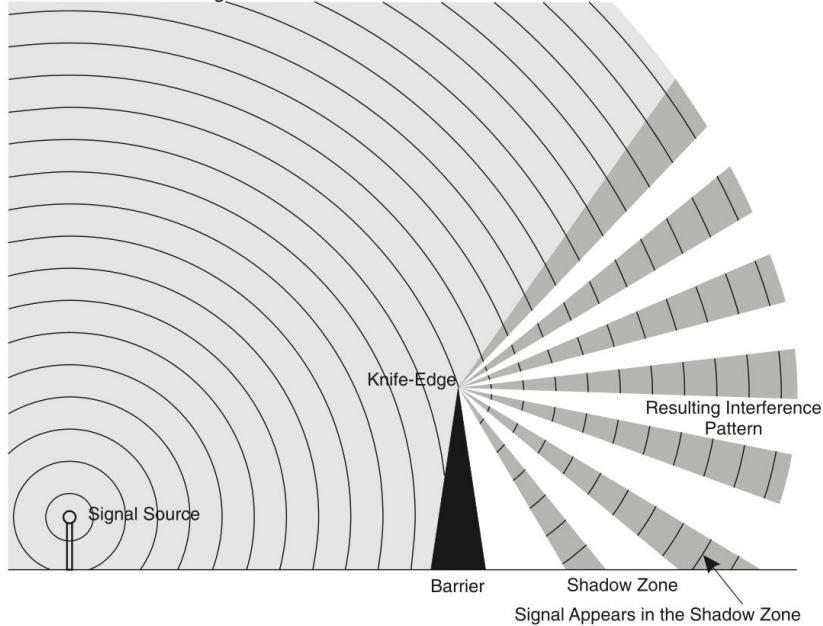
*waves scatter  
in all directions*



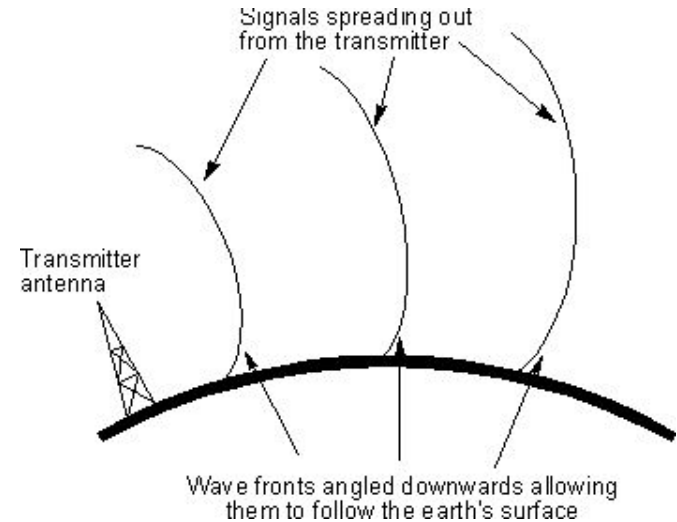
# Electromagnetic wave propagation

## *Knife-edge Diffraction & Ground Wave*

Diffraction at Knife-Edge



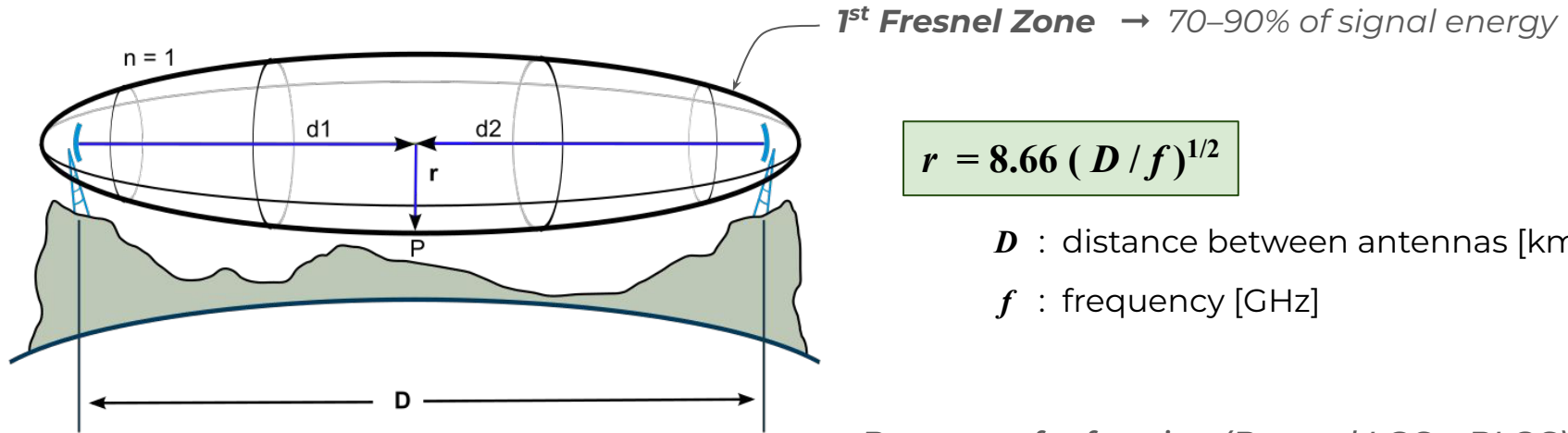
*In free space, signals interfere uniformly, forming an expanding wave. A knife-edge obstacle disrupts this, creating a non-uniform pattern.*



*Radio waves also “bend” over rounded edges. Over Earth’s curved surface, the lower wave front slows, tilting the wave and allowing signals to travel beyond the horizon.*

# Tropospheric propagation

## Line of Sight (LOS)



$$r = 8.66 (D / f)^{1/2}$$

$D$  : distance between antennas [km]

$f$  : frequency [GHz]

### Clearance

Maximum obstruction allowable is 40%

Recommended is 20% or less

Because of refraction (Beyond LOS = BLOS)

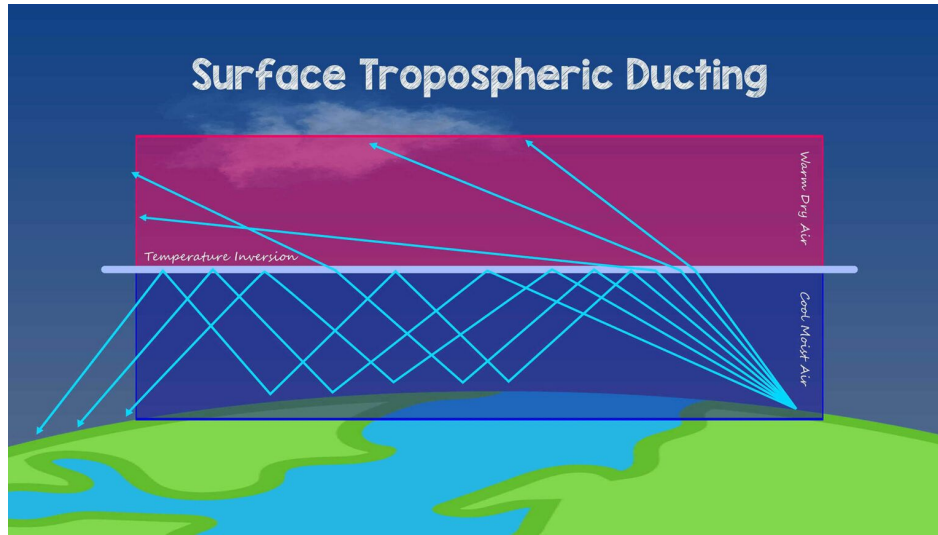
$$D' = (17 h)^{1/2}$$

$D'$  : distance to the radio horizon [km]

$h$  : height above average terrain [m]

# Tropospheric propagation

## *Surface- and Elevated-Ducting*

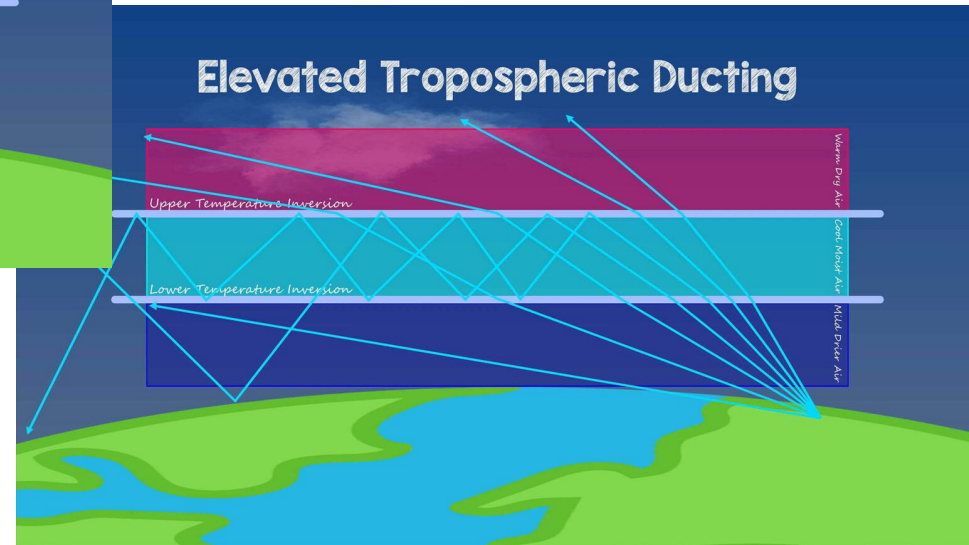


### Tropospheric Ducting

- Refraction bends radio waves back to Earth's surface.
- Enables very strong signals up to 1500 km.
- Caused by temperature inversions (temp.  $\nearrow$  with alt.).
- Enhanced by a drop in humidity  $\rightarrow$  higher refractivity

### Tropospheric Refraction

- Caused by gradients in refractive index (temp., RH, press).
- Extends radio horizon beyond visual line of sight.
- Higher frequencies (microwave bands) show effects first.

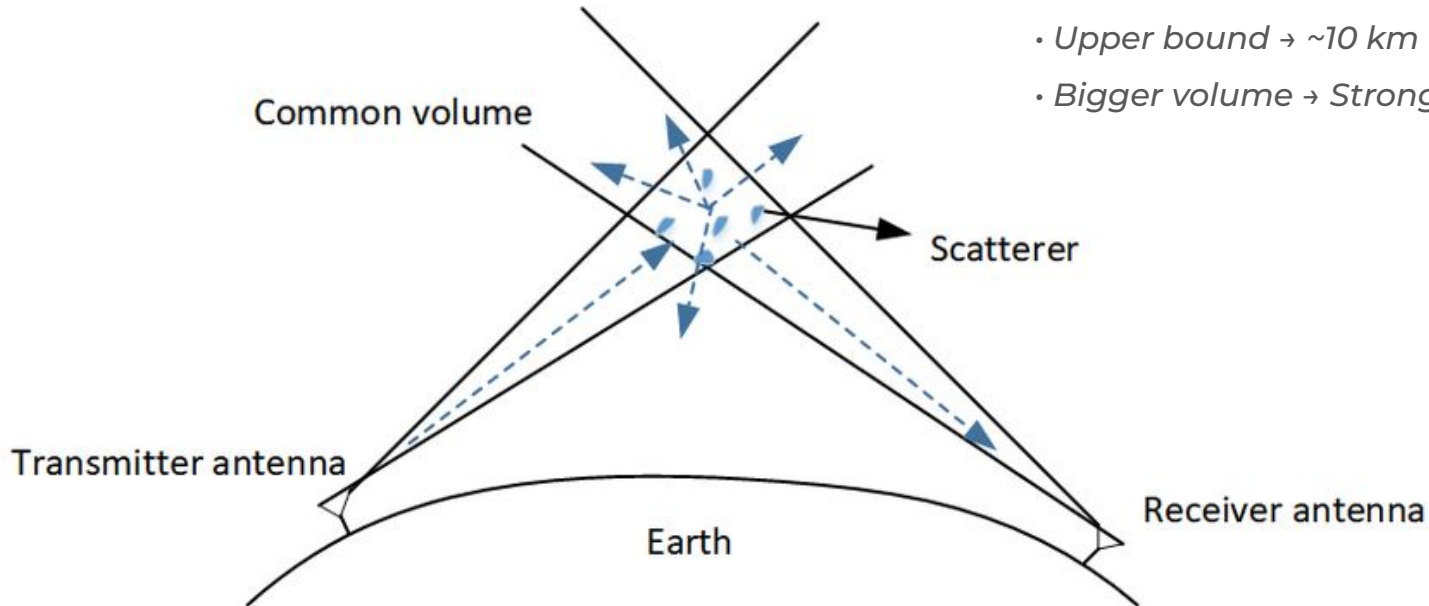


### Elevated Tropospheric Ducting

# Tropospheric propagation

## *Troposcatter*

- Lower bound → Station take-off angle
- Upper bound → ~10 km (troposcatter limit)
- Bigger volume → Stronger signal



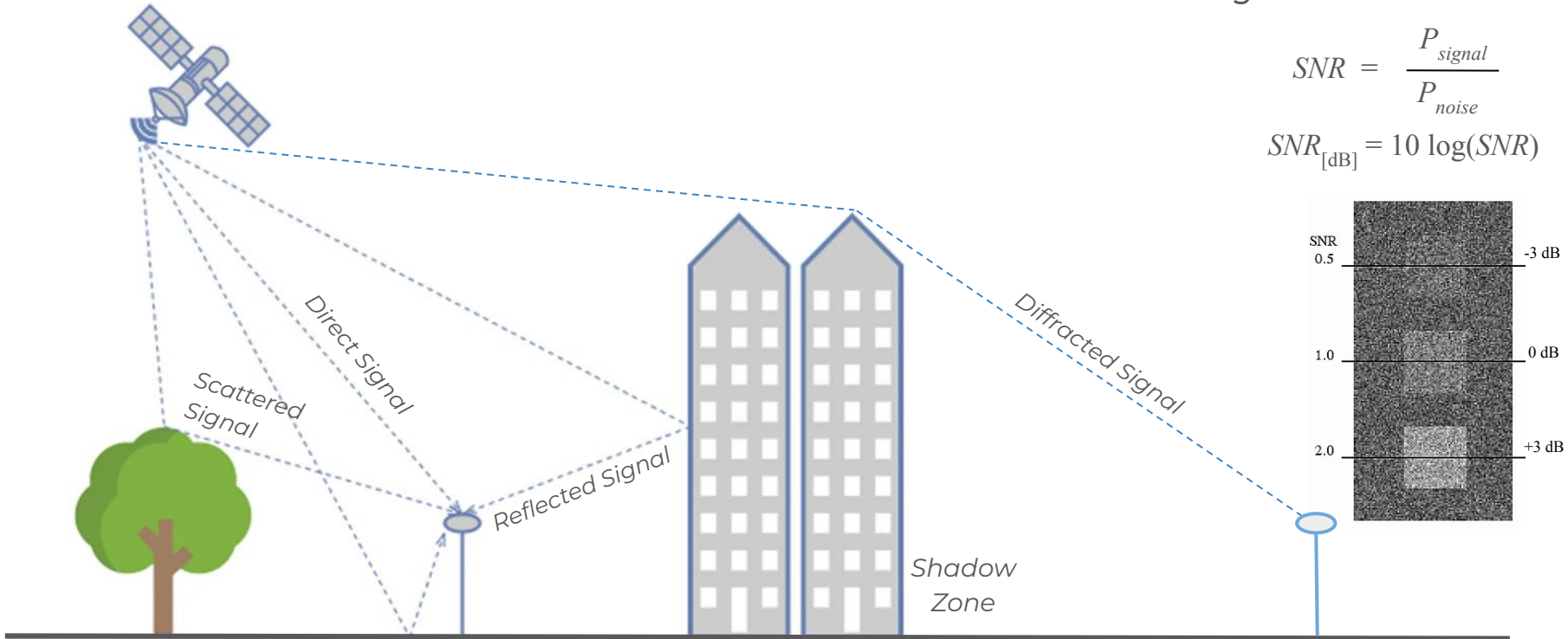
# Tropospheric propagation

## *Tropospheric fading*

- Atmospheric varies (density & humidity) → Signal refraction
- Multiple paths → Addition or cancellation
- Wind → Changing paths → Scintillation fading
- Stars twinkle = same process
- Effect increases with frequency & distance
- Minor for VHF/UHF, major for microwave links

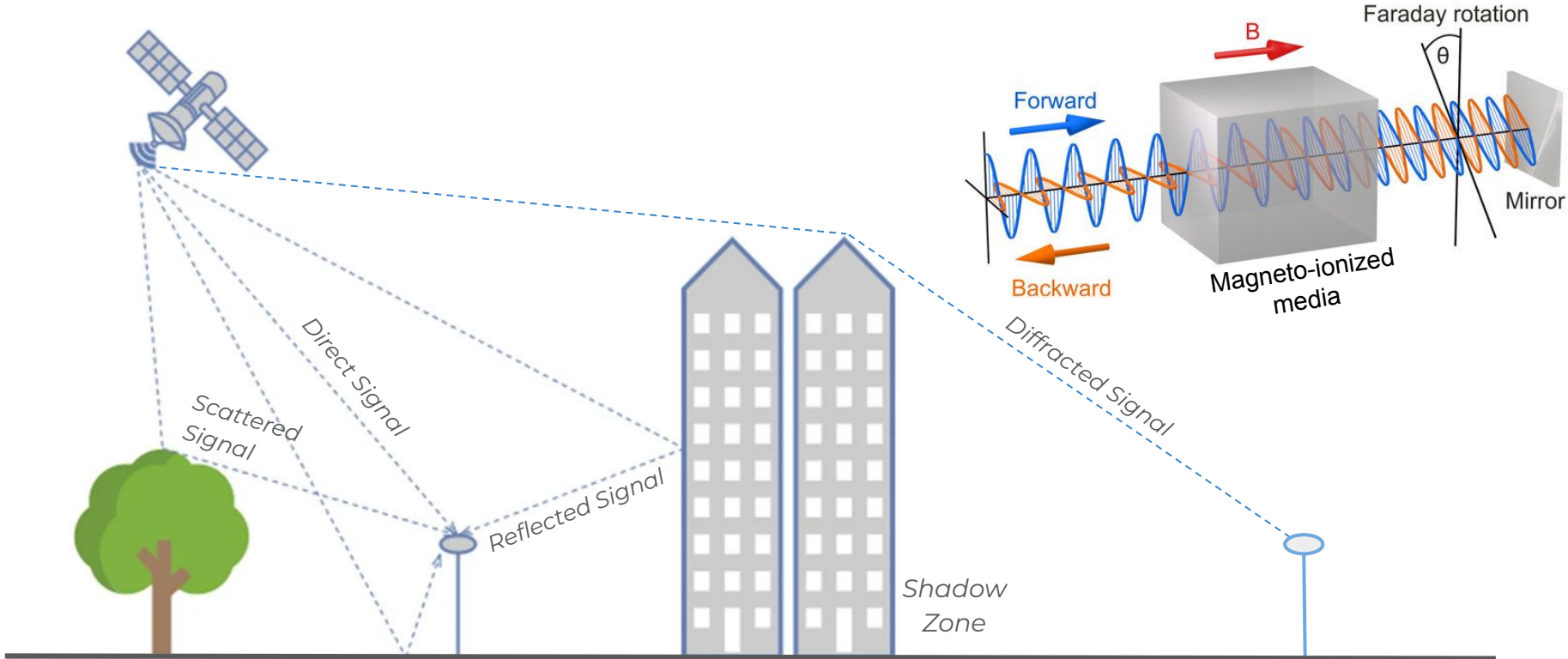
# Earth-Space Propagation

*Satellite LOS, Non-LOS, Multi-Path environment*



# Earth-Space Propagation

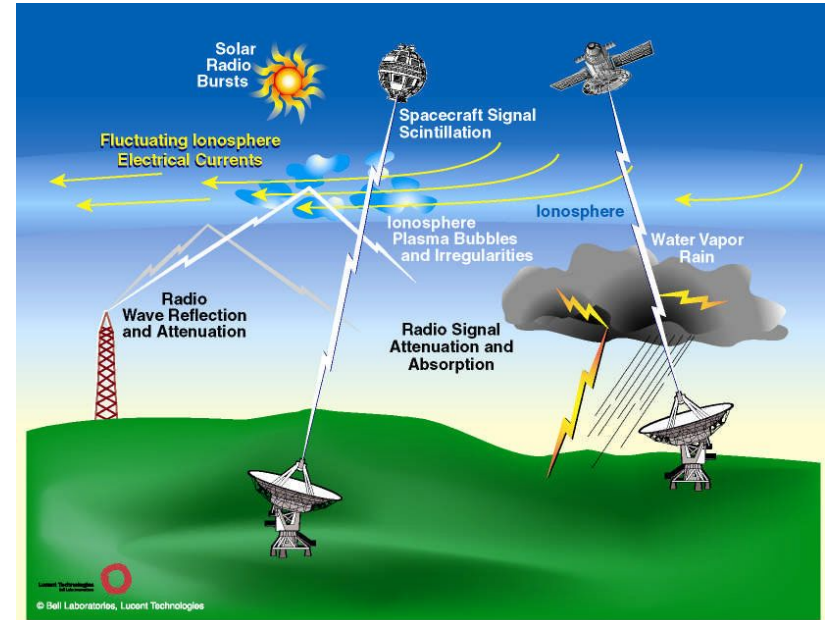
*Satellite LOS, Non-LOS, Multi-Path environment*



# Space Weather Impacts on VHF<sup>+</sup>

## *Ionospheric Scintillation*

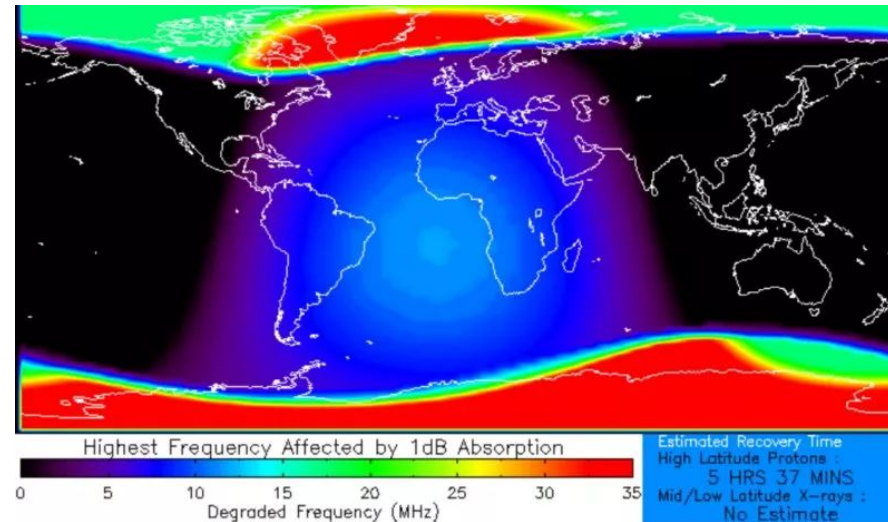
- Flares & CMEs → Energy + particles
- Ionosphere → Turbulent density patches (“bubbles”)
- Impact:
  - Rapid fading
  - Phase changes
- Affected Services:
  - Satellite phone networks
  - Satellite Internet
  - GPS/GNSS Navigation
  - Military satellite links



# Space Weather Impacts on VHF<sup>+</sup>

## *Polar Cap Absorption (PCA)*

- Solar Flare → Energetic protons guided to poles by Earth's magnetic field
- Penetrate D-layer (60–90 km) → Strong ionization
- It can last for days
- Impact:
  - Polar Communication Blackout
  - Phase changes
- Affected Services:
  - Aviation/Shipping routes over the poles
  - Comms with satellites in polar orbits
  - Scientific ops in Artic/Antartic



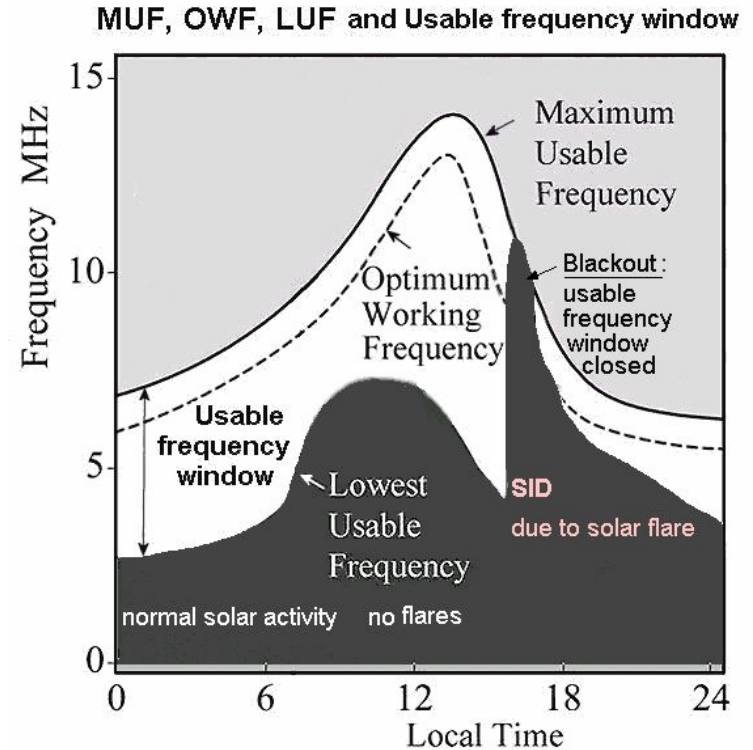
Normal X-ray Background  
Product Valid At : 2024-02-14 12:40 UTC

Minor Proton Flux  
NOAA/SWPC Boulder, CO USA

# Space Weather Impacts on VHF<sup>+</sup>

## *Sudden Ionospheric Disturbances (SIDs)*

- Solar flare X-rays/EUV reach Earth in 8 min → sudden D-layer ionization (sunlit side).
- Impact:
  - Absorption → HF/VHF blackout (sunlit side)
  - Duration: Minutes to ~1 h (flare strength dependant)



# Questions?



*Panorama of the Humain Radio-Astronomy Station*



<https://sidc.be/humain/home>

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