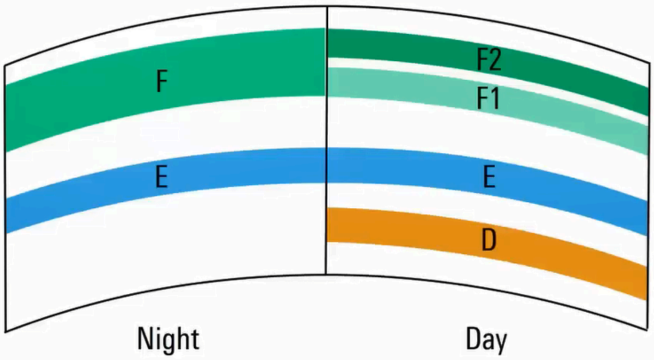
It's all about refraction of HF signals:

About the ionosphere

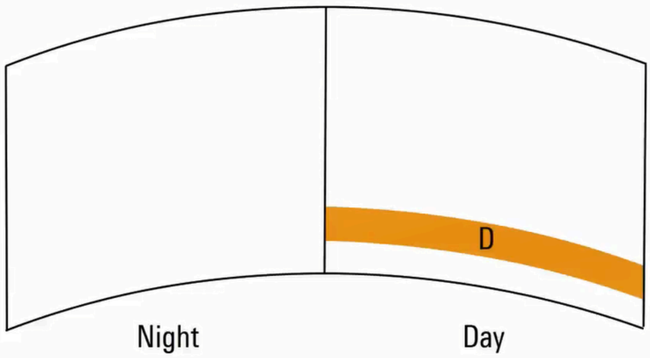
- The ionized region of the Earth's atmosphere is called the **ionosphere**
- Ionization varies by altitude
- Peaks in ionization levels are called layers or regions:
  - The D-layer (60 - 100 km)
  - The E-layer (100 - 125 km)
  - The F-layer (200 - 275 km)
- These differently-ionized layers refract (not reflect) and/or absorb HF signals in different ways



It's all about refraction of HF signals:

D-layer

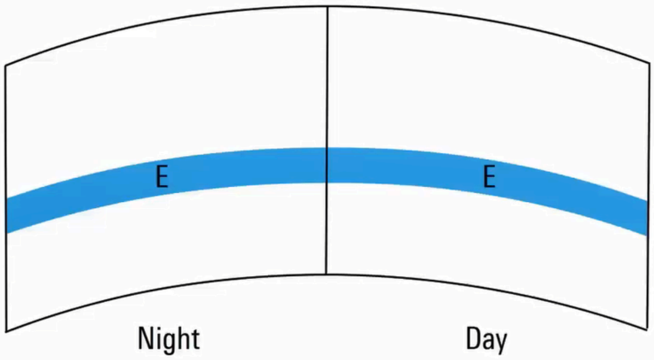
- The D-layer only exists during daytime
  - Disappears at night
- Density of free electrons is too low to refract HF signals
- Primarily **absorbs** HF signals
  - Absorption is higher for lower frequency signals
  - Absorption highest at midday
- D-layer absorption causes higher frequencies to work better in daytime, lower frequencies to work better at night



It's all about refraction of HF signals:

E-layer

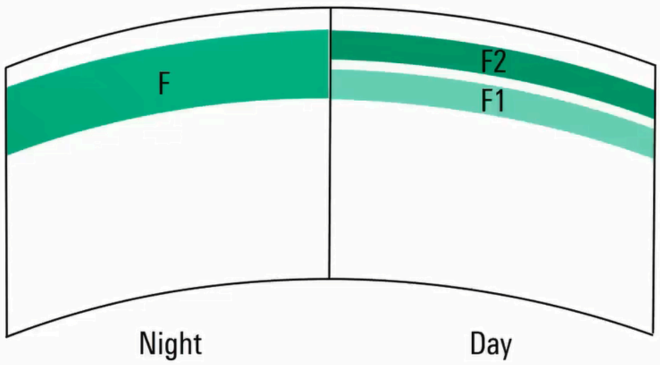
- The E-layer is the first layer that can refract HF signals back towards the Earth
- Relatively thin layer (< 25 km)
- Denser (more highly ionized) during daylight hours, almost disappears at night
- Mostly used for short-range, daytime communication at HF
- The E-layer supports some rather exotic propagation modes (e.g. sporadic-E) that enable long-distance communications at VHF frequencies (up to ~150 MHz)



It's all about refraction of HF signals:

F-layer

- Most important layer for skywave
- During the day, the F-layer splits into two layers: F1 and F2
  - Height of these layers varies greatly
- F1-layer
  - supports daytime short- to medium-distance communications
- F2-layer
  - Highest altitude and ionization
  - Responsible for most long-distance HF communications

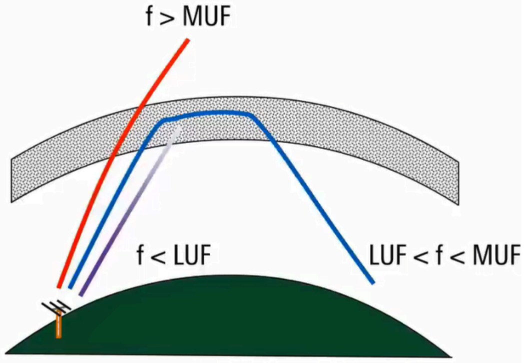


5b.4 • About the ionosphere • 040 • g12348c1

It's all about refraction of HF signals:

MUF and LUF

- Absorption / refraction is a function of signal frequency
- General rule for skywave: use the highest possible frequency for a given destination
  - This is the **maximum usable frequency** (MUF)
  - Signals > MUF are not refracted
  - As ionization increases, MUF usually increases
- Below the **lowest usable frequency** (LUF) communications become difficult or impossible
- LUF is (mostly) a function of noise (poor SNR)
- MUF is a function of the ionosphere
- When LUF > MUF, HF communication is not possible



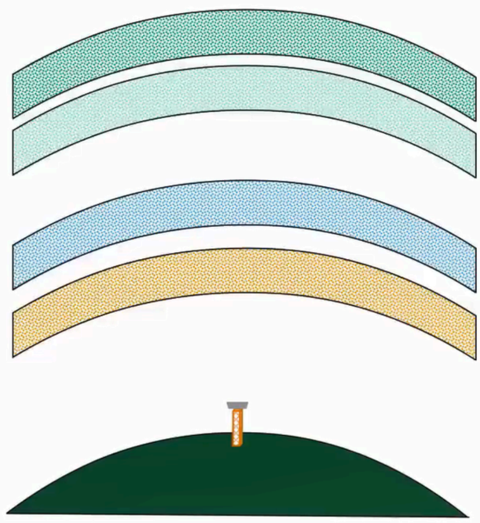
5b.4 • About the ionosphere • 040 • g1g348c1

It's all about refraction of HF signals:

Critical frequency

- The MUF is usually estimated from **critical frequency**
- Measuring critical frequency:
  - Transmit pulses vertically at different frequencies
  - Use return time to estimate layer heights
  - At the critical frequency, the pulse is not returned by the ionosphere (goes into space)
- Critical frequency (f_c) is a function of both the ionization level and the measurement location
- Estimated MUF ≈ 3 to 5 times critical frequency

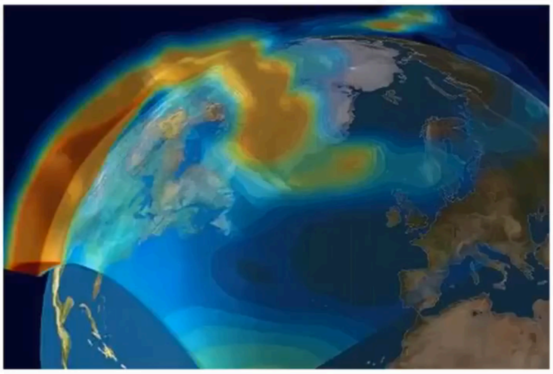
$$MUF = \frac{f_c}{\cos\theta}$$



What factors affect the prediction:

Quantifying the ionosphere

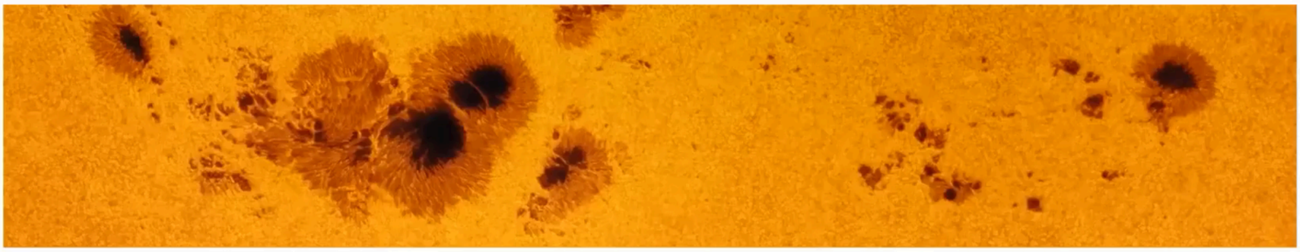
- Critical frequency is an **active** measurement
- Three passive methods for quantifying the state of the ionosphere:
  - Sunspot numbers: **predict** the level of ionization
  - Solar flux index: **measure** the level of ionization
  - Geomagnetic indices: indicate the impact of solar particles on the Earth's magnetic field
- Together these quantities provide a good indication of the current state of the ionosphere and can be used to predict HF propagation.



A higher MUF, too!

Sunspots

- Sunspots are (relatively) cooler surface regions of the Sun (3000 K vs. 6000 K)
  - Last between a few days and a few months
- Associated with powerful magnetic fields
- The number of sunspots correlates with solar activity / radiation
  - More sunspots generally means more atmospheric ionization and better HF propagation



400 years of data!

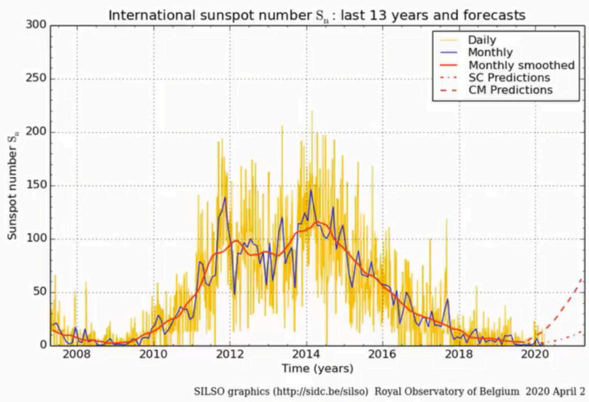
Sunspot number (SSN)

- Daily measurement of sunspots
  - Not a simple count: factors in size and groupings
- Recorded at solar observatories around the world
- Values range from zero to ~250 (max recorded)
- More sunspots → better HF propagation
- Sunspots have been counted and recorded for almost 400 years

Sunspot activity follows a roughly 11 year cycle.

Solar or sunspot cycle

- Sunspot activity follows a roughly 11 year cycle
- At the peak, SSN is ~150 and HF propagation is very good, even at higher frequencies
- At the bottom, SSN is ~0 and HF propagation is poor, especially at higher frequencies
- Sunspot cycle is generally good for long-term predictions of HF propagation
  - However, at several points in history (late 1600s and early 1800s), sunspot numbers stayed very low for several decades



It's a measurement...

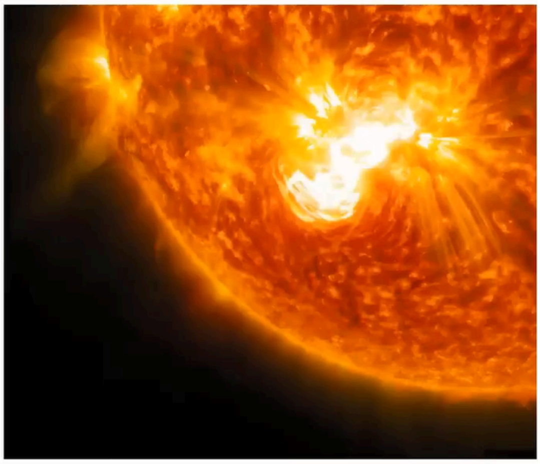
Solar flux index (SFI)

- Solar activity can also be quantified by measuring the solar noise or flux at 2800 MHz (λ = 10.7 cm)
- Reported as the solar flux index (SFI)
  - Measured in solar flux units (sfu)
  - Measured values in the range 50 - 300
- Solar flux is a measurement, not an observation, so it is more consistent and reliable
  - But doesn't have a 400-year history of values
- Correlates quite well with SSN
  - $SFI \approx 73.4 + 0.62 * SSN$
- Higher SFI → higher MUF → better HF propagation

Short duration events affect the ionosphere:

Solar flares

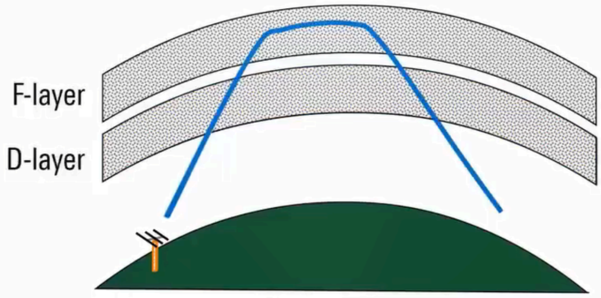
- The ionosphere is also affected by short-duration events occurring on the sun
- Most important of these are solar flares
  - Eruptions causing a rapid rise in radiation and ejection of low- and high-energy particles
- Unpredictable, but more common during peaks in the sunspot cycle
- Solar flares can lead to:
  - Sudden ionospheric disturbances
  - Polar cap absorption
  - Geomagnetic and ionospheric storms



Short duration

Sudden ionospheric disturbance (SID)

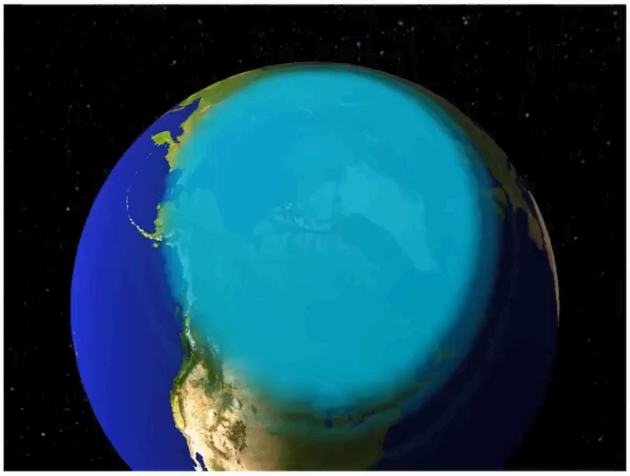
- About 8.5 minutes after a flare, radiation reaches the Earth
  - D layer ionization (and absorption) to increase rapidly, beginning with lower frequencies
  - Only impacts the sunlight hemisphere
  - Usually only lasts about an hour
  - Smaller flares can sometimes even enhance HF at higher frequencies



More short duration effects

Polar cap absorption (PCA)

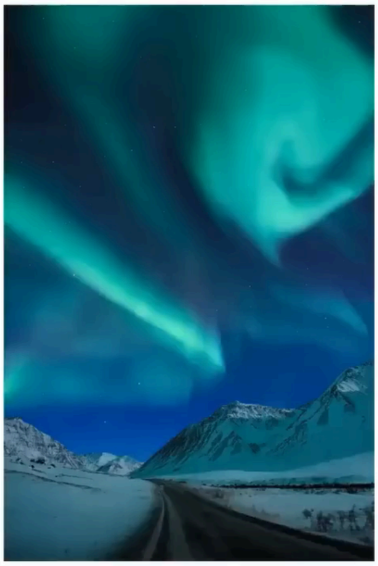
- Several hours after a flare, high energy particles reach the Earth
  - Enter the atmosphere near the poles
  - Increase D-layer absorption in the polar regions
  - Can last for several days
- Blocks HF traveling near the poles
  - Other paths may remain unaffected



More short duration:

Geomagnetic and ionospheric storms

- Lower energy particles arrive at 20-40 hours after a flare
- Low energy particles are also generated by a coronal mass ejection (CME)
- These particles can cause a **geomagnetic storm**
  - Create visible aurora
  - Can interfere with GPS, satellites, power-distribution, etc.
  - Can lead to an **ionospheric storm**
    - lowers the MUF and degrades HF propagation
    - If MUF becomes ≤ LUF, a complete skywave blackout occurs



Magnetic fluctuations caused by ionosphereic disturbances

A and K indices

- A and K values measure **magnetic** fluctuations caused by ionospheric disturbances such as solar flares
  - Lower values → more stable ionosphere
- Measured at observatories around the planet
  - Local values of A and K can be averaged to product planetary values (Ap and Kp)
- A calculated daily, K measured every 3 hours
  - K indicates a current disturbance
  - A indicates how long the disturbance has been occurring

A	K	Conditions
0	0	Quiet
2-3	1	Quiet
4	1	Quiet / unsettled
7	2	Unsettled
15-27	3-4	Active
48	5	Minor storm
60	6	Major storm
132	7	Severe storm
208+	8+	Very severe storm

5b.4 • About the ionosphere • 140 • e65dfad7

Summary

Summary

- Skywave is the mode used for global HF communications
- Signals are refracted / absorbed by the ionosphere
  - Function of signal frequency, incident angle, and ionization
- Ionization increases
  - During daylight hours
  - As sunspots increase
- Solar events can unexpectedly disrupt the ionosphere
  - Solar flares
  - Coronal mass ejections
- SSN, SFI, and A/K indices are used to quantify the ionosphere

5c.3 • Earth-Moon-Earth • 000 • aa08fd05

Not straightforward. Watch out for Galactic noise.

Propagation: Modes of Propagation

EME = Earth-Moon-Earth

Bouncing signals off the moon (aka Moonbounce)

Usually VHF , UHF or SHF

Usually high power and high gain antennas

Low noise receiver helps

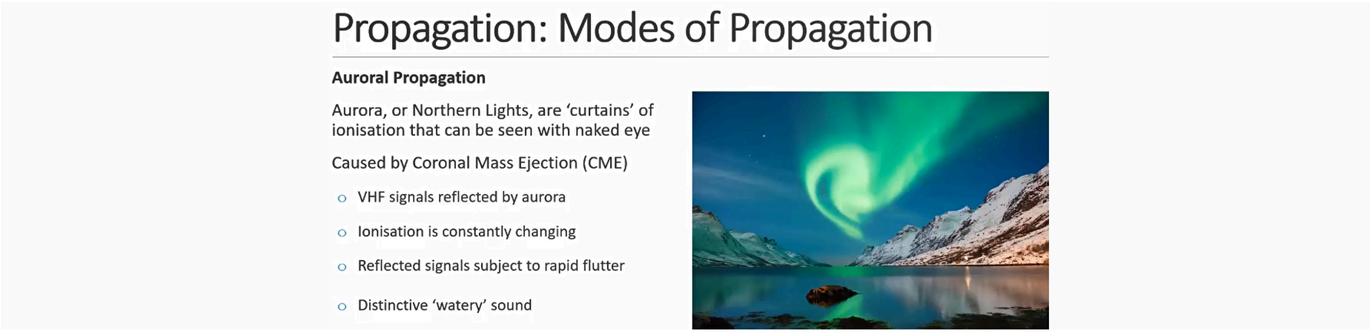
Weak Signal data modes making it easier

Not straightforward:
- Distance involved: around 400,000km x 2
- Moon is a poor reflector of RF
- Moon is not stationary, so tracking is required
- 2.5 second delay

Very good outline on RSGB website:
- rsgb.org/main/technical/space-satellites/moonbounce/

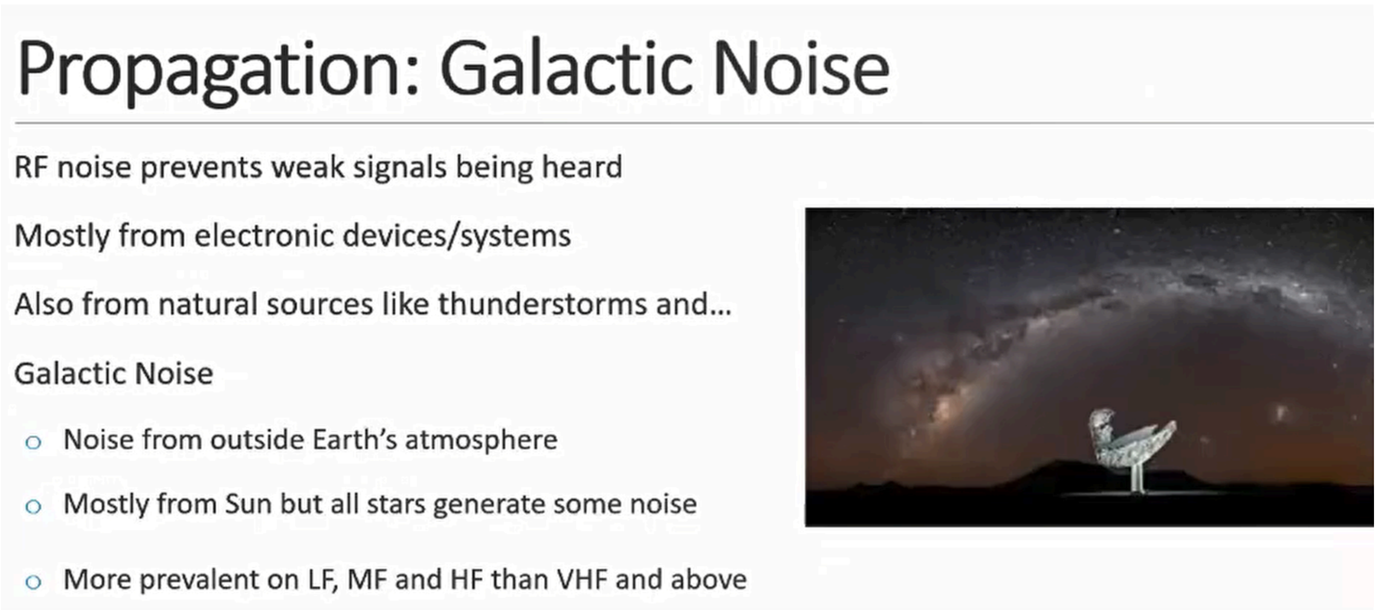
5c.3 • Auroral Propagation • 000 • 20d2184a

The Aurora is primarily caused by charged solar particles being swept towards the poles by the earth's magnetic field. The resulting ionisation can be quite intense, and reflect radio waves. Recall that AURORAL IONISED CURTAINS form vertically in the ionosphere, and that movement of these curtains cause rapid flutter on the signals. The rapid fluttering typical of VHF auroral contacts is caused by the random movements of the auroral curtains, which can reflect VHF radio waves.



5d.1 • Galactic Noise • 000 • 033cacd4

Random noise originating outside the earth's atmosphere. When operating EME (Earth-Moon-Earth) doing 'moon bounce' it can raise the noise floor.



5d.2 • Link Budget • 000 • 038c10e1

Here is an example:

Propagation: Link Budget

Example :

Transmitter power 400W = 26dBW

Transmitter feeder loss -6dB

Transmit antenna gain +10dB

Path loss -106dB

Receive antenna gain +8dB

Receive feeder loss -2dB

Add and subtract all dB to give received power

= 26 – 6 + 10 – 106 + 8 – 2 = -70dBW

-70dBW means 1W divided by 10, 7 times

= 100nW = 2.3mV into 50Ω

Calculation: $P = V^2 \div R$, so $V^2 = P \times R$

If $V^2 = 100 \times 10^{-9} \times 50 = 5 \times 10^{-6}$

Then $V = \sqrt{5 \times 10^{-6}} = 2.236 \times 10^{-3} = 2.3$mV

5d.2 • Link Budget • 010 • 71f41ec8