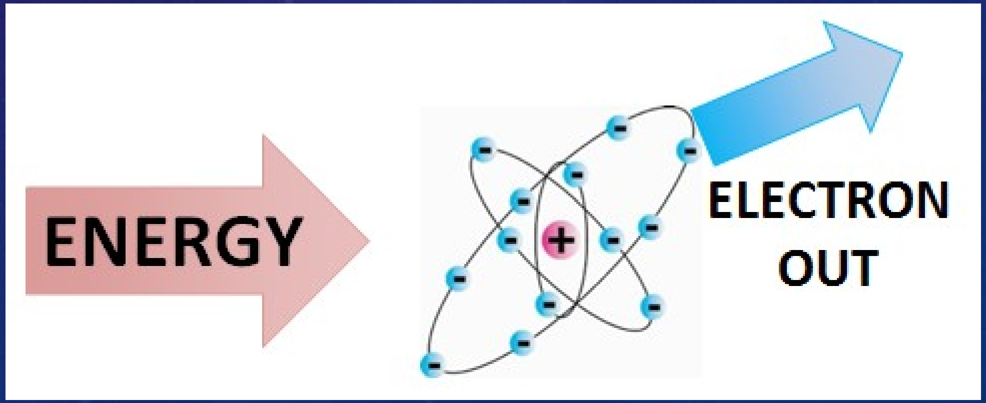
EARTH'S IONOSPHERE: THE SCIENCE

DR. LISA SHIER

JANUARY 29, 2021

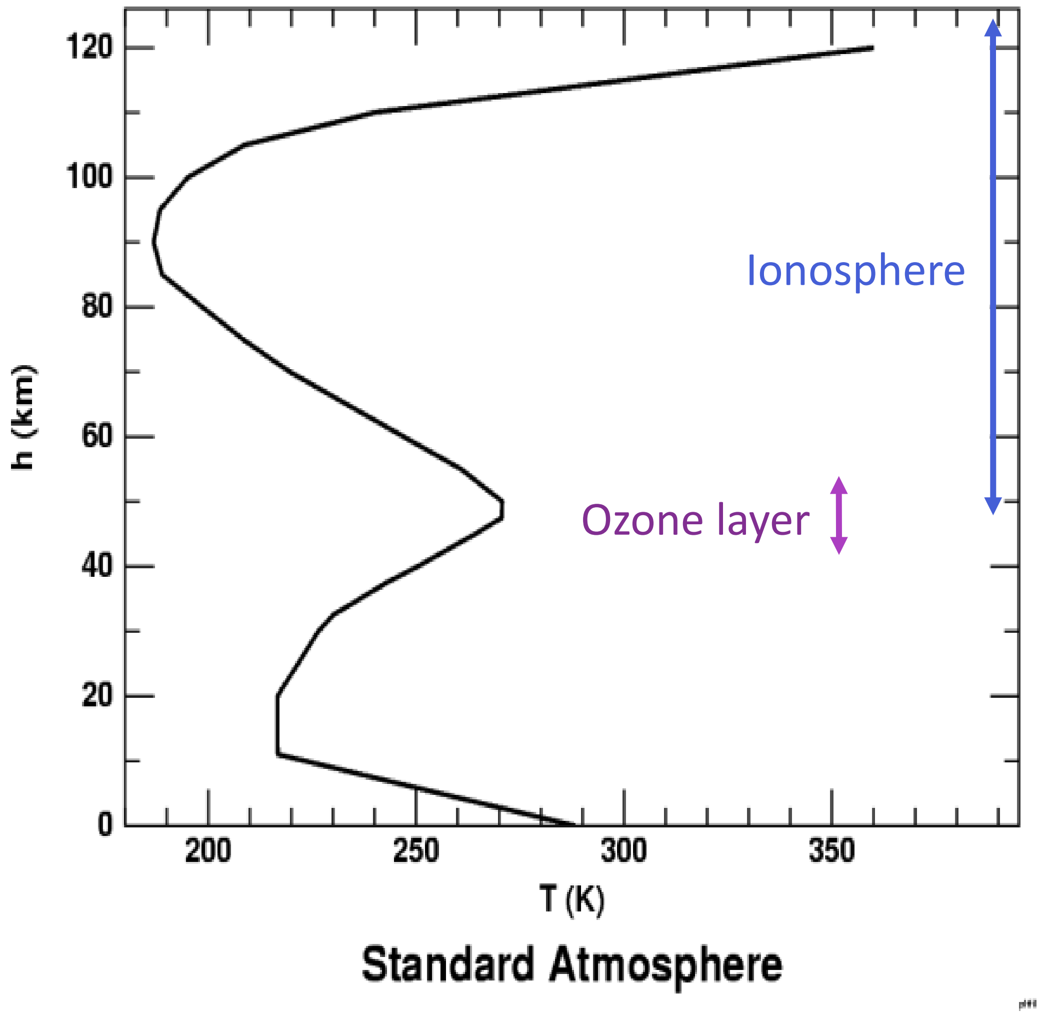
THE BASICS

- Atoms in the Earth’s atmosphere can be stripped of one or more electrons by high energy photons (UV and up) or by collisions with very energetic particles.
- The ionization is temporary – ions and electrons recombine in a short period of time, recreating neutral atoms
- Ionization is confined to the upper layers of the Earth’s atmosphere for two reasons:
  - Recombination time depends on density, so it goes much faster in the lower layers
  - High energy photos and particles tend to hit something before they reach the lowest level of the atmosphere – the troposphere. (Thankfully!   It’s not good for living things.)



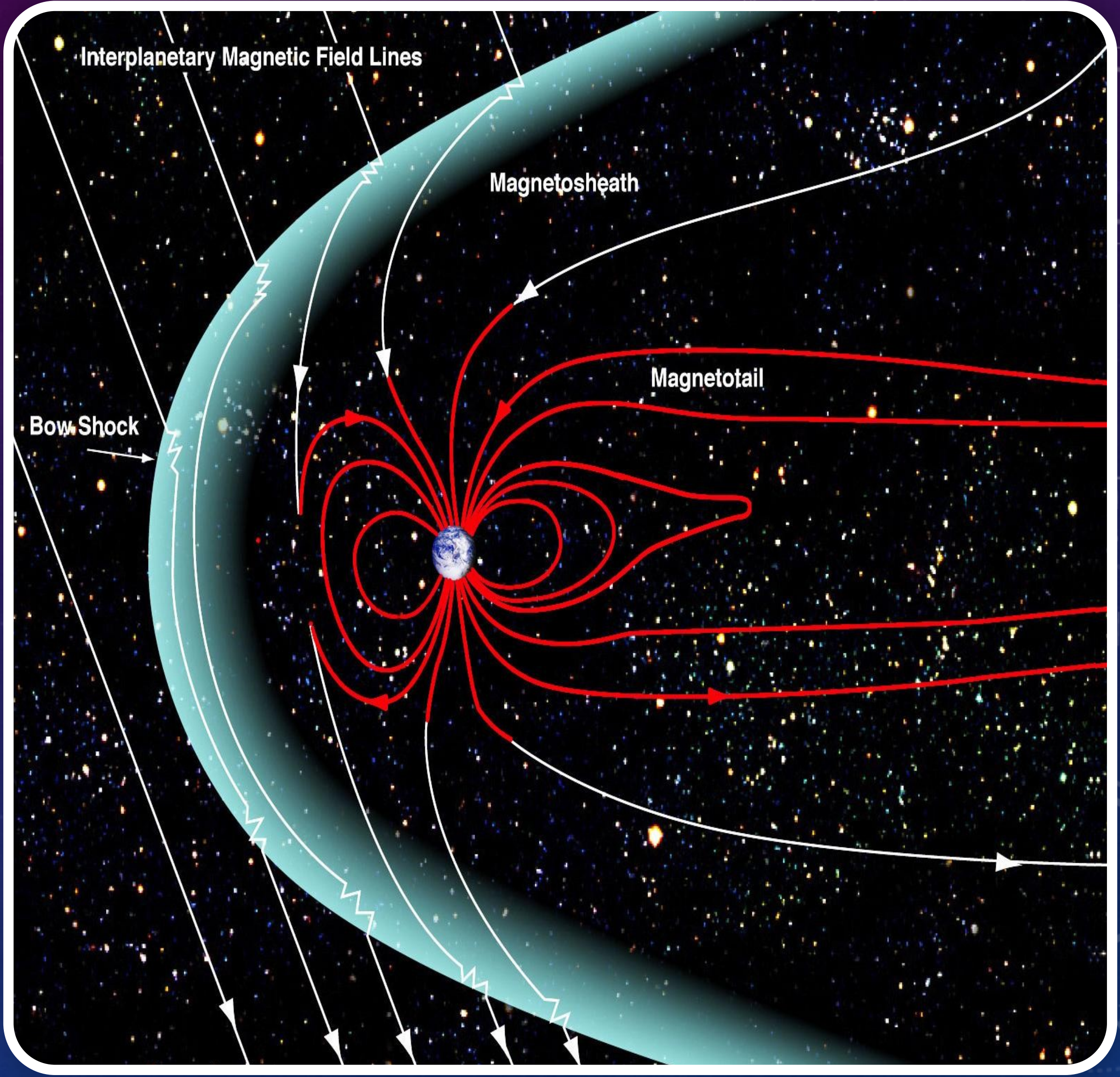
PHYSICAL STATE OF THE UPPER ATMOSPHERE

- Very hot! Ionization dumps a lot of energy into the upper atmosphere. Like the solar corona, it's in a very non thermal equilibrium state.
- The ionosphere occupies the same physical volume as the thermosphere. The difference is that the ionosphere means the charged particles and the thermosphere means the neutral ones.
  - The two interact through collisions



THE MAGNETOSPHERE

- The region of space dominated by the Earth's magnetic field
- Interacts strongly with the ionosphere since it's charged particles in motion
- High energy charged particles of non-terrestrial origin are funneled into the polar regions and mostly excluded from the equatorial and mid-latitude regions.
  - This is the origin of the aurora and why it's confined to high latitude locations
- Not a fixed magnetic field.   Can be significantly distorted by charged particles
  - Like from a coronal mass ejection



VARIABILITY IN THE IONOSPHERE

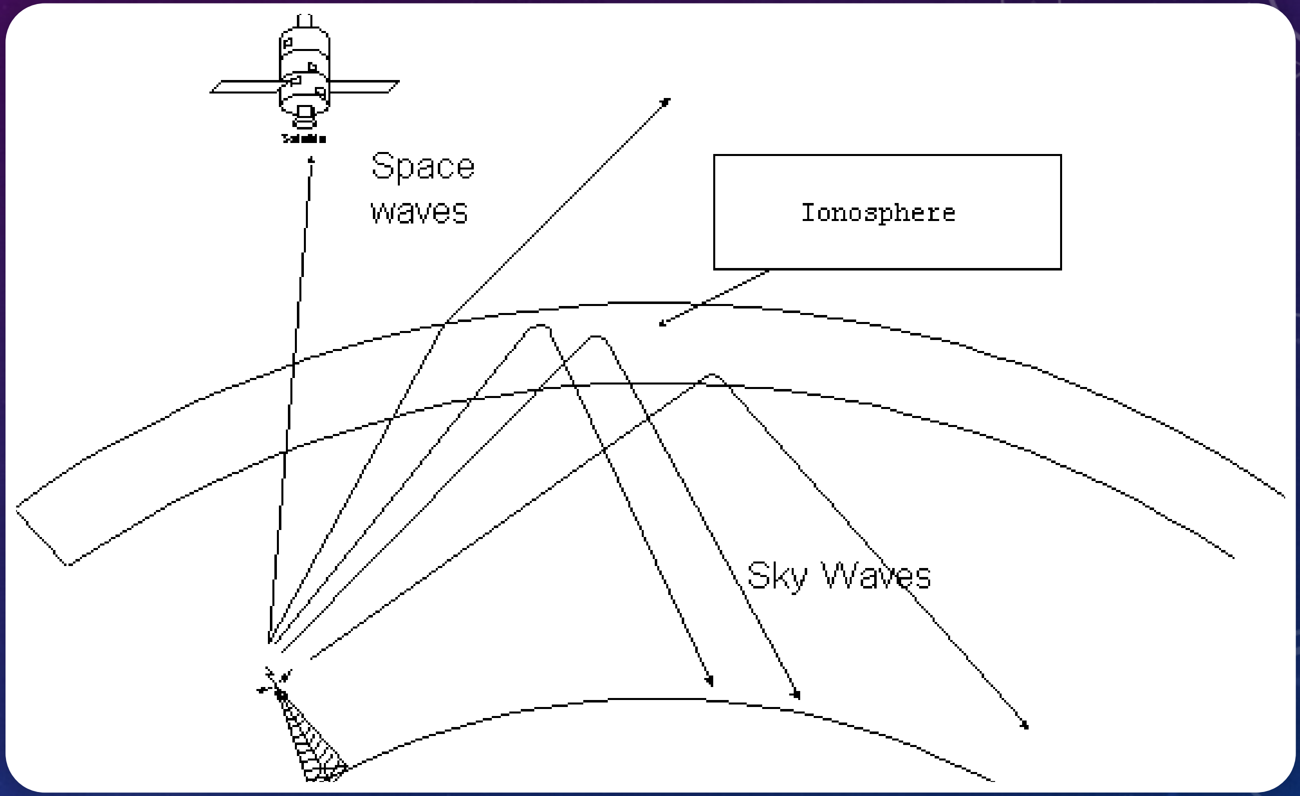
- If you thought weather on the ground is variable and unpredictable, you haven't seen anything yet!
- Variations in temperature, ionization, and density can be a couple orders of magnitude
- Why?
  - What happens on the ground is mostly determined by optical and infrared flux of the sun. The solar luminosity is very constant, so we just have to deal with the consequences of uneven heating due to clouds, seasons, etc.
  - The ionosphere mostly responds to the UV and X-ray flux of the sun which is quite variable.
  - Occasional bombardment of the magnetosphere and atmosphere by energetic charged particles can cause massive changes – a geomagnetic storm.

HOW RF INTERACTS WITH CHARGED PARTICLES

- Depends strongly on frequency
  - The lower the frequency, the strong the effect.
- Depends on Total Electron Content, the total number of electrons encountered by RF as it passes through the ionosphere.
- RF traveling through a charged medium will be bent or refracted.
- RF will share some of its energy with nearly free electrons.
  - As long as the electrons stay free, the RF signal will continue to propagate
- If the free electrons sharing RF energy recombine, the energy will be lost to the RF signal
  - Effective absorption of RF

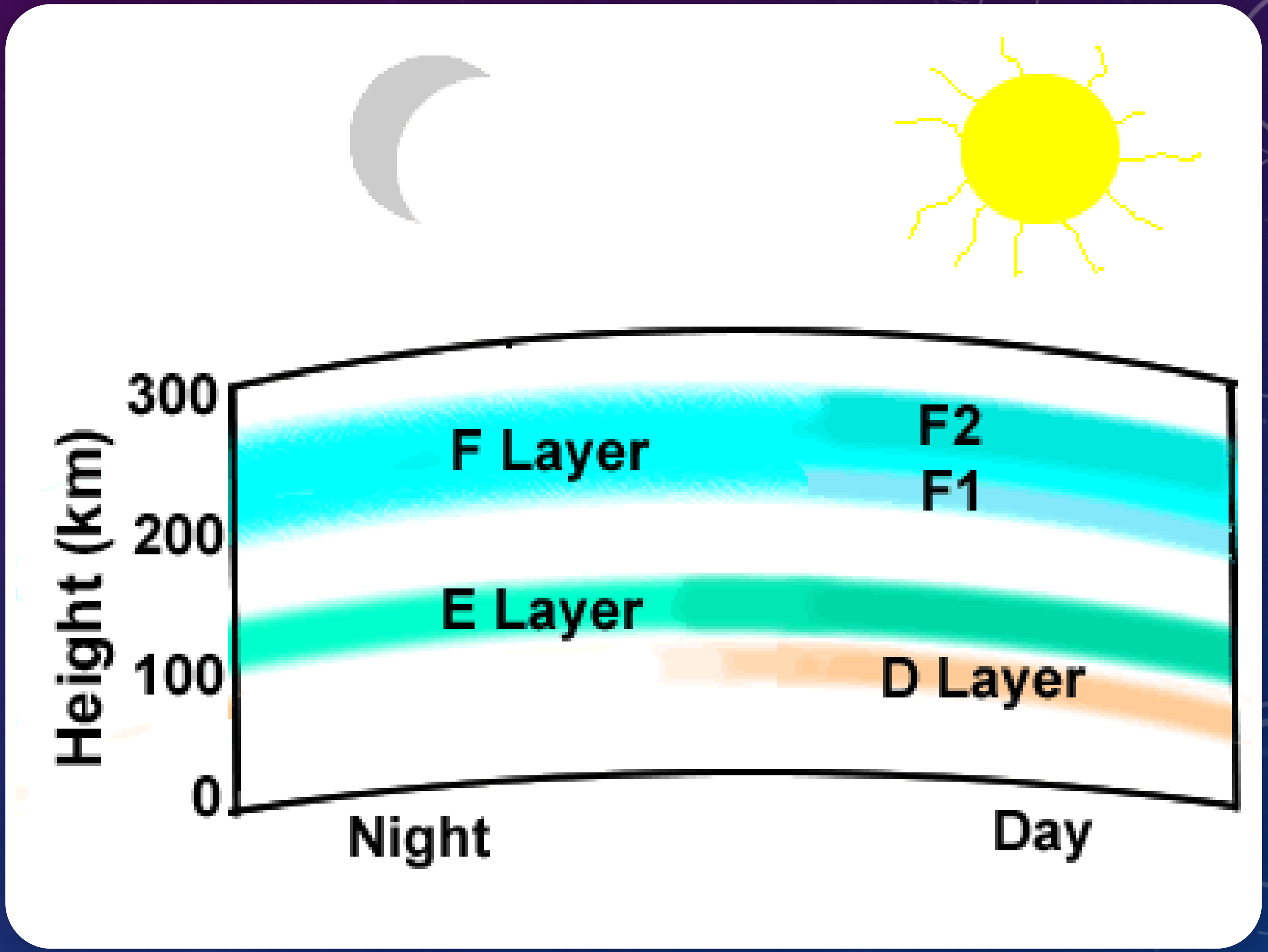
WHY TAKE-OFF ANGLE IS IMPORTANT

- The total number of electrons encountered gets larger as the take-off angle decreases.
- Affects everything
  - Whether the signal is absorbed or not
  - Whether is signal is bounced at all or lost to space
  - How far the signal goes in one bounce



LAYERS OF THE IONOSPHERE

- We generally talk about the D, E, and F layer.
- The number of charged particles in each layer depends on the balance between ionization by high energy solar photons and recombination.
    - Dependences with time, time of day, latitude, season, solar flux, just to name a few significant factors



THE D LAYER

- The lowest and densest part of the ionosphere, defined to be below 100 km.
- High particle density means that free ions and electrons have a good chance of interacting and recombining.
  - D layer tends to disappear quickly after dark, as ions recombine and no new ones are created
  - Tends to absorb the lower frequency RF, below about 20m.

THE E LAYER

- The part from 100-150 km altitude
- This is the part that produces the aurora
- Thins during the night, as recombination happens slowly
- Source of sporadic E skip, from extra dense clumps of ions.
  - Exactly what causes this is still unknown
  - Can cause ionospheric skip at frequencies as high as VHF
  - Most common in June, but happens with some frequency all summer

THE F LAYER

- Very high altitudes, generally 200 km and up. Particle density is quite low, so recombination times are quite long.
  - The F-layer sticks around all night
  - Unlike the D-Layer, far more likely to refract RF than to absorb it
- This is what allows for long-range skip.
- Mostly useful at night, when the D-layer is gone and the E-layer is weak.

SOME NUMBERS WE USE TO EVALUATE THE IONOSPHERE

- Critical Frequency
  - Given an incidence angle of 0 (straight up), RF higher than this frequency will go through the ionosphere. RF lower than this frequency will be reflected.
  - Exact value varies, but is larger in the daytime.
- Maximum Usable Frequency
  - The maximum usable frequency for a particular communications path using ionospheric skip. For low angles of incidence, it is often 3-5 times the critical frequency. Mostly related to ion density in the E and F layers.
- Lowest Usable Frequency
  - The lowest frequency that will provide satisfactory communications between two stations. Depends some on antenna gain and transmit power. Highest during the day and during solar maximum. Mostly related to ion density in the D Layer.

HOW DOES SOLAR ACTIVITY AFFECT THE IONOSPHERE AND RF PROPAGATION?

- Very active sun – lots of UV, occasional coronal mass ejection (CME)
  - Lots of ionization at all levels of the ionosphere
  - Not a great time for 80m and especially 160 m.
  - Higher frequencies bounce really well, but variability means you may have to try a few things before finding what works that day and hour.
- Boring sun
  - Relatively low levels of ionization, F layer weak
  - Possible and necessary to use lower frequencies than for the active sun case
  - May be hard to get higher frequencies to bounce well, unless you find sporadic E.