

## Ionosphere Properties and Behaviors - Part 12

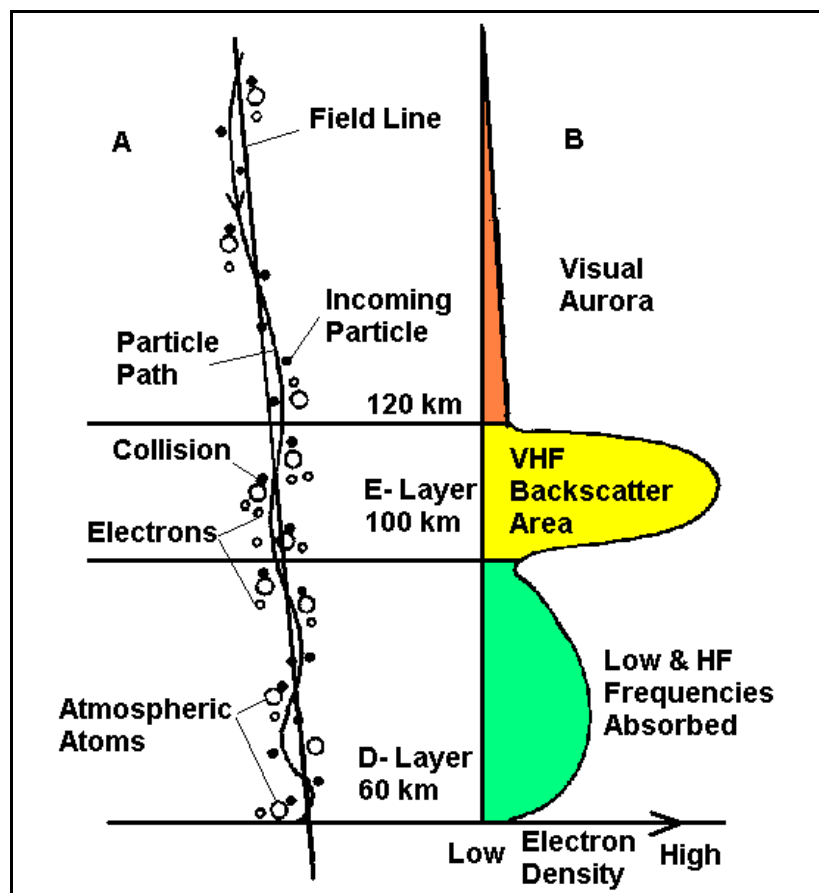
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In the previous issue, I explained how the aurora oval's properties can influence pass-through HF radio signals. Depending on the ionization density and expansion, they might undershoot the oval belts, be highly absorbed or be skewed around. The ovals also more or less screen off HF communications to certain areas on the globe. The lower frequencies bands suffer the most.

I also made a start in explaining the field-aligned properties of the aurora. These properties lead to interesting propagation possibilities for a VHF communication mode, (*aurora backscatter*), which will be part of this issue's subject. Visual aurora and radio aurora are not the same. The visual aurora has nothing to do with radio propagation properties. It is a most beautiful spectacle happening much higher in the ionosphere, but it is a hint that radio aurora can be possible or on their way. The radio aurora influencing our radio communication exists only at the E- and D-regions.

### Visual Auroras Physics

Visual auroras are caused by collisions between the atmospheric particles and the electrons spiraling in from the earth's magnetotail region, **Fig. 62.1**. The depth that any particular electron will penetrate into the ionosphere and atmosphere depends on its energy level. Electrons with an energy level of more than 10keV (kilo electron volts) can reach the E region on the earth's dark side. A wide range of energy levels and the numerous collisions means that interaction takes place over a considerable height range. This is noticed in the visual aurora that can extend from about a height of 1 000 km with energy levels lower than 10 keV and down to the E region. It is obvious that higher energy electrons will penetrate lower and that the chance of collision is more likely due to the increased atmospheric density.



**Fig. 62.1.** Incoming spiraling electrons are entering the ionosphere. The high-energy electrons can enter the E- region to ionize enough at this height to backscatter properties. The highest-energy electrons can penetrate to the D region causing absorptions.

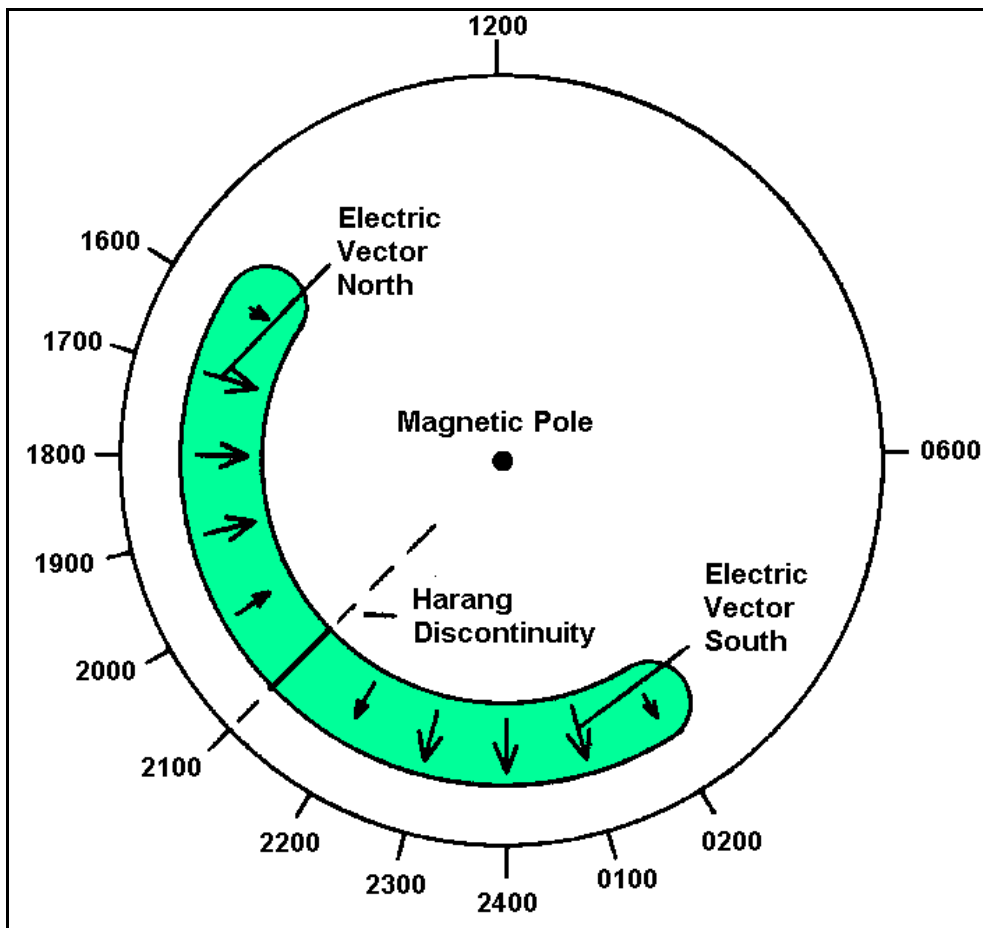
When reaching the very high density of the separated oxygen and nitrogen gases in the E region, where atmospheric atoms are plentiful, massive interaction takes place. Collisions of the spiraling particles with atmospheric atoms can excite them to ionization, and collisions with molecules can excite and break them into atoms. When, as they must, atoms or molecules return to their normal state again by capturing an electron or by correcting their electron orbits, a photon of light is produced. The spectral color line of the light indicates which atom it is and which orbital changes are taking place. The main colors are white, red and green due to the spectral lines of atomic oxygen and nitrogen, which are plentiful at ionospheric heights. Although the electrons are aligned to the magnetic lines, the light given off by the visual aurora can be seen from any angle. Sometimes visual aurora can occur in small isolated patches; at other times it can be an event covering thousands of kilometers or miles across. These visual forms extend from quiet arcs or rays to rapidly moving curtains and pulsating forms of changing color and intensity. Witnessing a good visual aurora formation is a most beautiful and never-to-be-forgotten experience.

### **Radio Auroras Physics**

Radio auroras require very much higher electron levels than those needed for visual ones. They also only occur in the E-layer region where there is sufficient density of atoms to enable enough ionization by collisions. The precipitating solar particle rain on electrons down from above is a nearly vertical motion by spiraling around the magnetic field lines. I explained previously that there are massive electrojet currents flowing round the auroral oval, an eastward pointing one in the afternoon-evening sector and a westward one in the midnight-morning sector. The electrons and ions are therefore affected by a horizontal electric field perpendicular to the near vertical magnetic field lines. The afternoon electric field is generally much stronger than the midnight one. The reason for this is because the primary electron input from the magnetotail region comes in on the dusk side and goes out on the dawn side. Therefore, it is only the secondary much weaker currents that produce the aurora there and tells us why the afternoon radio auroras are generally much larger and stronger than the midnight ones. The further away from the magnetic pole or the nearer to the equator we are, the weaker the horizontal electric field and intensity of the auroras, **Fig. 62.3**.

The positive ions and the negative electrons start to move in different directions by the combined effect of the magnetic and electric forces. The electrons are moving by gyrating away from the magnetic midnight toward the daylight side, either to the east or the west (the Harang discontinuity). The positive ions tend to cross the width of the auroral oval, either northerly in the eastward electrojet or southerly in the westward electrojet, creating an electric field vector that changes at the Harang discontinuity. **Fig. 62.2**.

The combined effect of fast moving gyrating electrons traveling one way and the slow traveling positive ions crossing their path another way, in conjunction with the magnetic and electric forces, creates a two-stream instability. The result of this instability is that dense electron nonhomogeneous field aligned columns form. The movement of the columns is about the speed of sound and mainly in easterly or westerly direction with a southerly drift (assuming the North Pole aurora). As the columns move away from the source of the collision ionization and electric drive forces, they get weaker in the more equatorial ionosphere and dissipate their energy and die out.

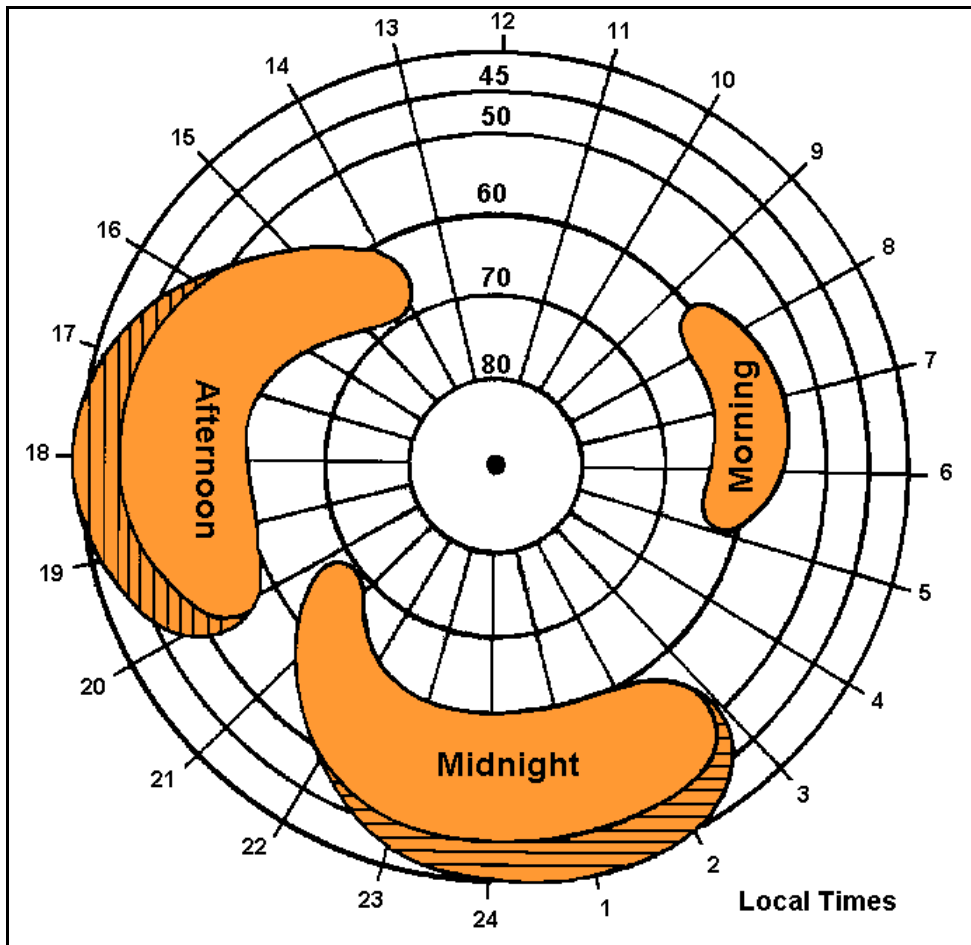


**Fig. 62.2.** The Harang discontinuity is centered on the magnetic midnight. Note the electric vector change.

#### Field aligned ionization at E region heights

Radio auroras can start and stop rather quickly and abruptly. The question is why? The earth is rotating at the aurora latitudes with a surface speed of 1125 km/hour (700 miles/hour). Therefore, we run very rapidly out of or into view of the ends of the electrojet current area where the dense ionized columns are formed and also where the Harang discontinuity occurs, and the reversing electric field cannot support the column structure.

There are definite time zones in which radio auroras will most likely occur. Not every event conforms rigidly to an exact daily pattern. Long-term studies showed that over a reasonable time scale of a few years, the daily pattern is very variable. Also the more intense the aurora, the more it extends towards the equatorial direction. There are two main time zones from about 15:00 to 19:00 hours, the afternoon phase, and 22:00 to 03:00 hours, the Midnight phase. Occasionally auroras might appear at other times, such as in the early mornings, 05:00 to 08:30 hours, although this is rare, **Fig.62.3**. Note that times are local and not UTC.



**Fig. 62.3.** Electron dense columns form mostly in the afternoon and midnight, occasionally in the morning. Note the times are local not UTC.

The electron dense columns are as explained aligned to the earth's magnetic field dip angle. This means that any transmitted or received wave sees them at a definite angle. With high auroral ionization, VHF radio waves can be backscattered and even the highest frequencies of the HF bands as well. This might happen along the same path if the wave reaches the zone with a suitable angle (the radar requirement). But in all other cases the signal will be scattered and sent somewhere else. This can be to a location in front or behind of your location and not necessary in line with the auroral curtain and your QTH. It might also be side-backscattered.

#### Summing up the requirements for radio auroras

- Increased solar wind speed and magnetic forces by solar disturbances, that compress the earth's field on the sun-facing side giving rise to triggers reverberating throughout the field
- A coupling between the interplanetary and the earth's magnetic field that results in transferring solar wind plasma into the magnetotail region and field aligned currents that move some of this plasma into the lower ionosphere.
- Reconnections of the magnetotail field lines can force also the plasma back towards the earth's ionosphere.
- Generation of massive field-aligned electric currents in the magnetotail and the lower ionosphere.
- The main radio auroras take place where the eastward or westward electrojet electric currents are flowing and generating dense electron magnetically field-aligned columns.

- At the Harang discontinuity where the horizontal electric field reversal occurs there is practically no radio aurora found in spite of the fact that this discontinuity does not affect so much the visual auroras.
- Doppler shift is always occurring, which makes radio auroral radio signals sound so distinctive. This is caused by the gyrating electrons and the wave-like motions of the dense electron columns.

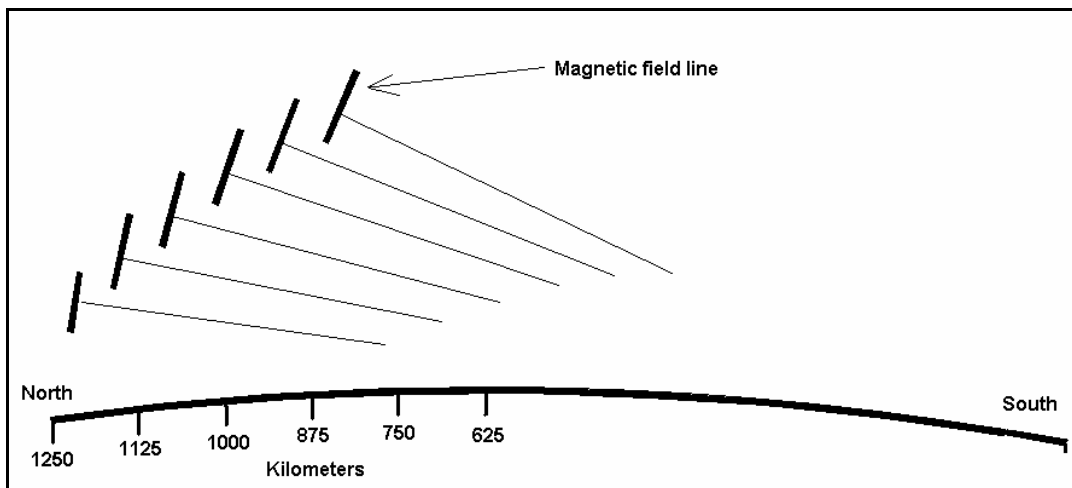
### The technique of VHF backward scattered communication

Communications by radio aurora backscatter is the best known and experienced in the northern half area of the northern hemisphere. The reason for this the region contains the most land area active radio amateurs. Till now I have not found or read any reports or data of radio communications done via the South Pole aurora. Self evidently these communications exist, because the similar auroral processes are happening there and leading to the same properties.

### Backscatter communication

If we look up the magnetic meridian then our signal would see the aurora column structure at the E-layer at different angles. The angle depends on the range from your location to the column structures and the location of the aurora zone itself. The auroral zone location is variable and depends on the geomagnetic and interplanetary activity.

First we interpret the specular 90 degrees angle (radar backscatter). The elevation angle differs depending on the distance between the QTH location and the aurora edge with its aligned columns. The further the aurora edge is from your location the more vertical the inclination of the field aligned columns and the smaller the elevation TOA (Take Off Angle) will be, until we reach the line of sight limit at about 1 250 km, **Fig. 62.4**. The angles our signals would see depend on just where you are and how far the aurora is expanded southward. The specular angle is strongly related to your location latitude, but also slightly to your longitude. It all depends if you are in line or east or west of the magnetic meridian.

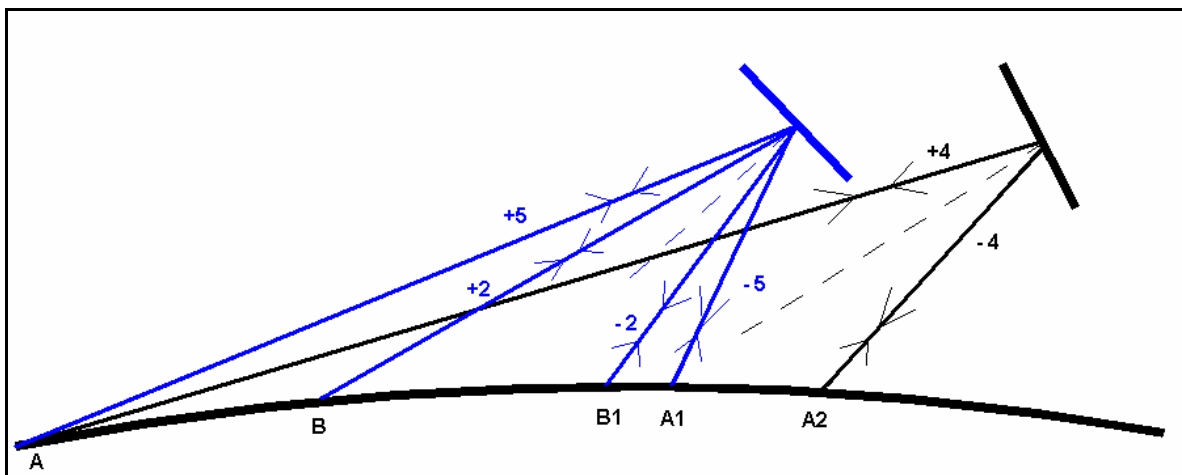


**Fig. 62.4.** The different specular angles of the aligned columns with different distances away from a given location.

So far we looked only to the specular angle backscatter with its radar properties, which is of little use for us to communicate with locations elsewhere than our near neighborhoods. We are dealing with columns of ionization and it should be understood that each one scatters signals over a wider area seen North-South and deviating from it, East or West. A lot of aurora contacts can be made when the signals are backscattered via angles higher or lower than the specular angle. Depending on whether the angle is higher or lower, you can reach areas between your location and the auroral zone or areas further away from the auroral zone than your location is (overshooting). These two reachable areas do not necessary need to be located in line with the aurora backscatter point and your location. Most backscatter deviates from that straight line Westward or Eastward.

In **Fig. 62.5**, you find some examples of two-station aurora backscatter communication possibilities. Any of the stations A, B, A1, A2, or B1 can be TX or RX. Two locations of the auroral highly ionized columns are considered, one closer to the magnetic pole than the other.

- Example with the aurora oval the closest to the magnetic pole, communication circuit between **A** and **A2**. An angle of incidence of **+4** and **-4** degrees is here considered. Seen from location **A** the station reaches a location in front of him looking pole ward; seen from **A2** position is this station communicating with a station behind him. The backscattered radio signals are overshooting his location.
- Example with the aurora oval further away from the magnetic pole, communication circuit between **A** and **A1**. An angle of incidence of **+5** and **-5** degrees is here considered. The same rules of waves path count here for the reciprocal contact, either being TX or RX.
- Example with the aurora oval further away from the magnetic pole, communication circuit between **B** and **B1**. An angle of incidence of **+2** and **-2** degrees is here considered. The smaller the angle differences from the specular angle, the smaller the actual distance between the two station locations.



**Fig. 62.5.** Backscatter with propagating angles differing from the specular angle, see text.

As mentioned above, the closer you are located to the auroral zone, the higher the TOA will have to be. VHF antennas usually have very narrow beamwidths; therefore, giving an upward elevation tilt to your antenna can give easily a signal gain difference of 3 dB. It is not an exception that the VHF DX hunters use an antenna array rotatable in both azimuth and elevation.

Radio aurora backscattered signals have a characteristic hissing-steam or band-saw sounds imparted to CW code signals and make telephony extremely difficult. In spite of these degrading signal sounds, it is a fascinating mode of communication. The Doppler is a complex component and can change throughout an event. Sometimes the spread in frequency dominates; sometime the spread is small but the shift in frequency is predominant. The actual amount of Doppler shift also depends on the operating frequency. At 28 MHz it is very small, less than 100Hz, but at 144 MHz it can be up to 500 Hz.

The aurora is a fascinating and mysterious phenomenon; hopefully the mystery is better understood by now. During my series about radio propagation I often used ionograms to illustrate ionospheric properties. Time has come to study in more depth these ionograms and how they are made and what they can tell us and how to interpret them. In the next issue, I shall start to unveil the ionograms, so stay tuned.

### **Additional notes on the measurements by the POES satellite**

In previous chapter, I did not specify that the on board particle detector measurements are only up to 20KeV and to a height down to 100 km. This is the visual aurora. So, higher energy electrons that get down to the D region are not measured and the available POES maps do not directly tell us anything about absorption or auroral-E intensity. But, these maps give us an up-to-date picture of where the auroral zone and the Harang discontinuity are found. With other words we can determine rather exactly the angle of the highly ionized columns our signals will encounter and the areas that might be available to VHF backscatter communications.

A rule of thumb is also this one: bright discrete auroral forms lead to lots of E region ionization. The auroral zone is not necessarily full of ionization that degrades HF.

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