When Does An Ionospheric Layer Start to Ionize?
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That's a simple question with a seemingly simple answer – a layer (more appropriately called a region since the ionization is not a thin shell) starts to ionize when sunlight hits it, right? All one has to do is work through some simple math using the Law of Sines with an Earth-Sun sketch as is Figure 1. Re is the Earth's radius, and h is a height above ground. Alpha, beta, gamma and phi are the depicted angles.

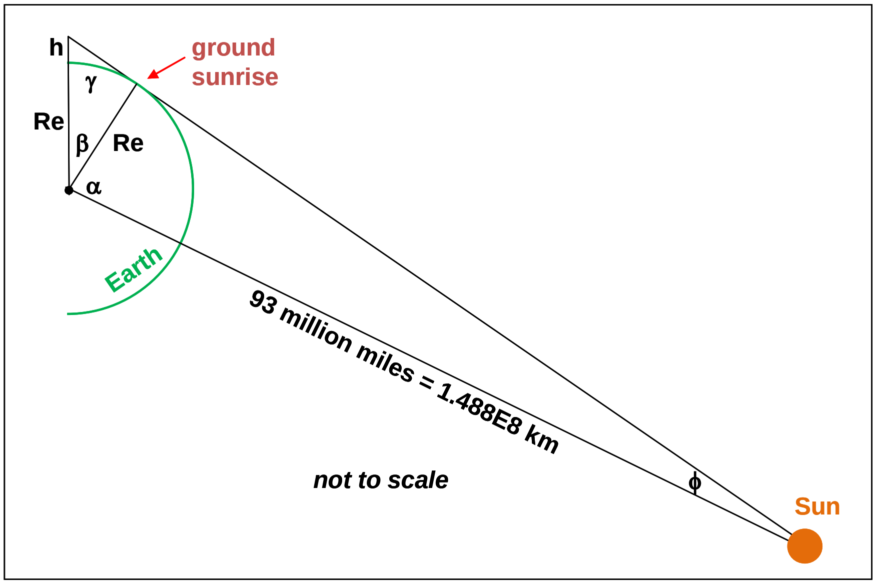

Figure 1 – Earth-Sun geometry

Setting up equations in Excel for the various angles and distances gives us the results of Table 1.

h in km	h is illuminated this many minutes before ground sunrise
0	0
25	20
50	29
75	35
90	38
110	42
200	57
300	69
400	79

Table 1 – Illumination of Height h by Sunlight

For example, if h = 300 km (a typical height for the F_2 region) then sunlight begins illuminating this height about 69 minutes prior to ground sunrise. Similarly, the D region around 90 km begins being illuminated by sunlight about 38 minutes prior to ground sunrise. This then leads us to say that at sunrise the F_2 region is ionized about a half hour before the D region.

Unfortunately there's a fallacy in the above scenario, and it has to do with the word 'sunlight'. Indeed sunlight begins illuminating the various regions prior to ground sunrise per Table 1, but sunlight in this context is visible light. And visible light does not ionize anything. Solar radiation at wavelengths between about 0.1 and 100 nanometers ionize the atmosphere. Visible light is at much longer wavelengths – from 400 to 700 nanometers – and to reiterate, it doesn't ionize anything. Note that solar flux at 10.7 cm is at even longer wavelengths, and it also has nothing to do with ionization – it is simply a proxy for the true ionizing radiation that is at much shorter wavelengths.

When the true ionizing radiation progresses through the atmosphere, it loses energy as it creates free electrons and positive ions. This is why we had to wait for the space age (rockets and satellites) to measure true ionizing radiation – we measure no radiation at these wavelengths at ground level because there's nothing left to measure due to the process of ionization.

Now go back to the Earth-Sun sketch of Figure 1. Note that the ionizing radiation must plow through the atmosphere twice at ground sunrise to reach the height h. If there's nothing left after going through the atmosphere once, then there's certainly nothing left after going through the atmosphere a second time. So visible light may illuminate the height h prior to ground sunrise, but radiation at ionizing wavelengths doesn't do anything at the height h prior to sunrise.

The last half of the last sentence in the preceding paragraph sounds great, but do we have any measured data to back it up? We sure do, and the confirmation of the F2 region comes from ionosonde data. For the F_2 region, Figure 2 is from the Millstone Hill ionosonde on July 15, 2011. The blue data points are foF2 values (F2 region critical frequencies) every 5 minutes.

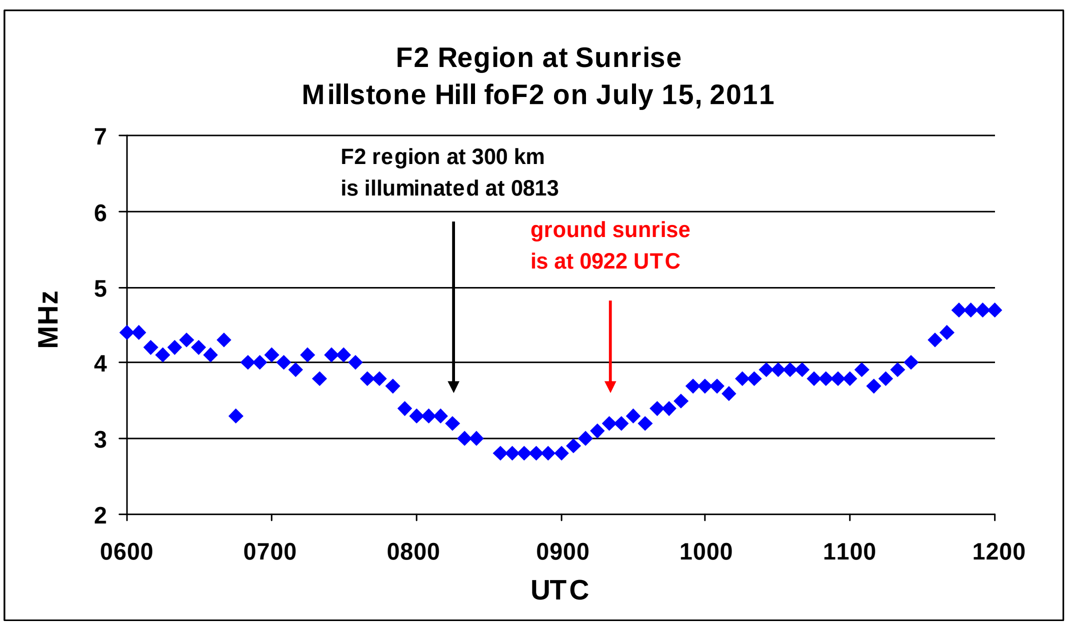

Figure 2 – F2 region at sunrise

Note that when the F2 region at 300 km begins being illuminated by sunlight at 0813 UTC (69 minutes prior to ground sunrise per Table 1), foF2 is still decreasing from being in darkness. The foF2 parameter doesn't start increasing until about 0905 UTC. This is a bit earlier than expected, as ground sunrise at Millstone Hill is 0922 UTC on July 15.

There are two probable causes for this anomaly. First, ionosondes do not have pencil-thin beams. Thus we could be seeing some oblique echoes off of the zenith. Second, some ionizing radiation could be scattered into the dark ionosphere from the daylight side. This could cause early ionization, too. In spite of these anomalies, remember that no ionization was created when the F2 region at 300 km was illuminated by visible light around 0813 UTC.

A similar confirmation can be made for the D region. We'll use data from Thomas F. Trost, *Electron Concentrations in the E and Upper D Region at Arecibo*, **Journal of Geophysical Research**, Vol. 84, No. A6, June 1979. Incoherent scatter radar was used to calculate the electron density. In Figure 3, I plotted the raw data at 90 km from this paper.

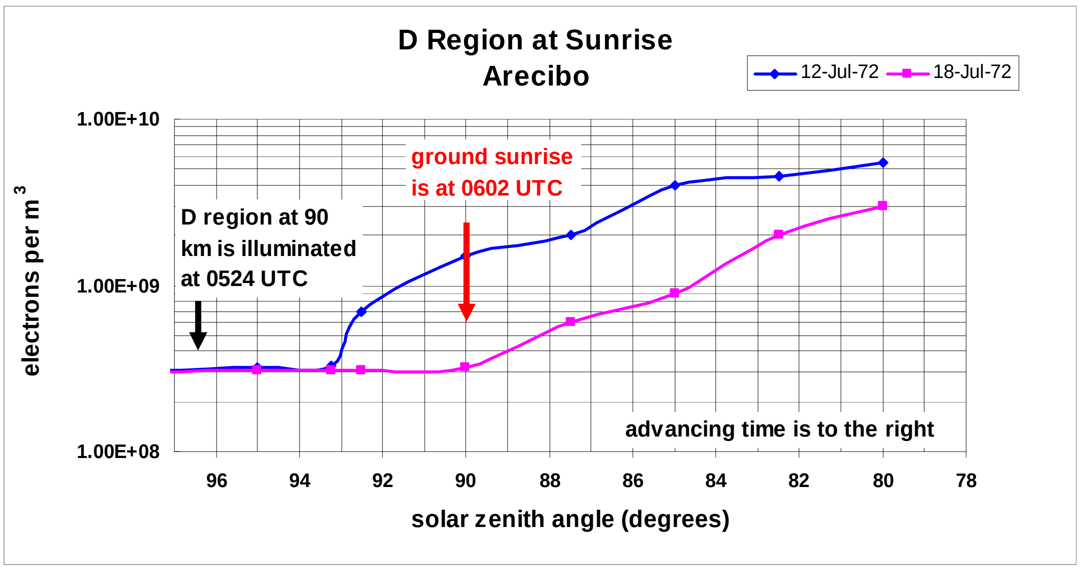

Figure 3 – D region at sunrise

Note that the data is in terms of the solar zenith angle, with ground sunrise at 90^o. Note that on July 18 when the D region begins being illuminated by sunlight at a solar zenith angle of around 96.5^o (which is 0524 UTC – 38 minutes before 0602 UTC), the D region is for all intents and purposes still constant. On July 12, D region ionization at 90 km does start before ground sunrise. This is a good example of the variability of the D region, as topband operators should be quite aware.

As for the D region ionization beginning before ground sunrise, some ionizing radiation from the daylight ionosphere could scatter into the dark ionosphere to produce this ionization before ground sunrise (just like with the F2 region). Additionally, negative ions form in the dark ionosphere when electrons attach to neutral atmospheric constituents. Some of these heavy negative ions have a low enough electron affinity (specifically O_2- and CO_3-) to allow visible light to detach the electron with the result that there are more electrons in the dark ionosphere (which also increases absorption before ground sunrise since absorption is proportional to the number of electrons times the electron-neutral collision frequency). Thus the D region could start ionizing before the F2 region – how's that for a turnaround!

In summary, the various regions may be illuminated by the Sun well before sunrise, but there is theory and evidence that the major ionization isn't taking place yet since it isn't ionizing radiation that gets to the height h in the dark ionosphere. This appears to shoot a big hole in the favored explanation of gray line propagation on the low bands – that there's a magical zone along the terminator. We'll address this issue in the next monthly feature.