EDGES Memo 428: Ionospheric Scintillation

J. Vierinen and A. E. E. Rogers

September 2023

1 Introduction

The EDGES observations at Devon Island are affected by power fluctuations that occur on a time-scale of the 15-second three position switch cycle. An example of these power fluctuations is shown in Figure 1. This memo explores ionospheric scintillation Cassiopeia A and Cygnus A as an explanation for these power fluctuations, which is a plausible cause.

The ionosphere tends to have more irregularities at high latitudes as compared with mid latitudes. These irregularities are partly created due to interplanetary electric fields carried by the solar wind causing plasma to convect and to structure into turbulent eddies of plasma density fluctuations across a wide range of spatial scales from meters to hundreds of kilometers. Magnetospheric currents also tend to close in the high latitude ionosphere. These currents are associated with acceleration of charge particles to ionizing energies, which can create a plasma density structure that is highly variable in space and time.

The main F-region ionospheric instability is thought to be the gradient drift instability (e.g., [5], [2]). The Farley-Buneman instability [4] on the other hand can be found in the E-region (90-120 km) where ion-neutral collision-rates are are sufficiently high, but electron-ion collisions are not too high.

It is probable that the F-region ionospheric irregularities are the primary mechanism for causing scintillation of strong and compact radio sources such as Cassiopeia-A or Cygnus-A [3]. These sources are strong and compact enough to scintillate in the presence of irregularities within the ionosphere [3]. Because these source are strong and always above the horizon during the EDGES recording, it is plausible that their scintillation can still be seen in the observations.

2 Normalized power fluctuations

In order to visualize the power fluctuations in the data, we can plot the normalized fluctuations in power $T_1(f,t) = T(f,t)/\overline{T(f)}$ where $\overline{T(f)} = \langle T(f,t)\rangle_t$ is the mean antenna temperature for a given frequency f over the observation interval.

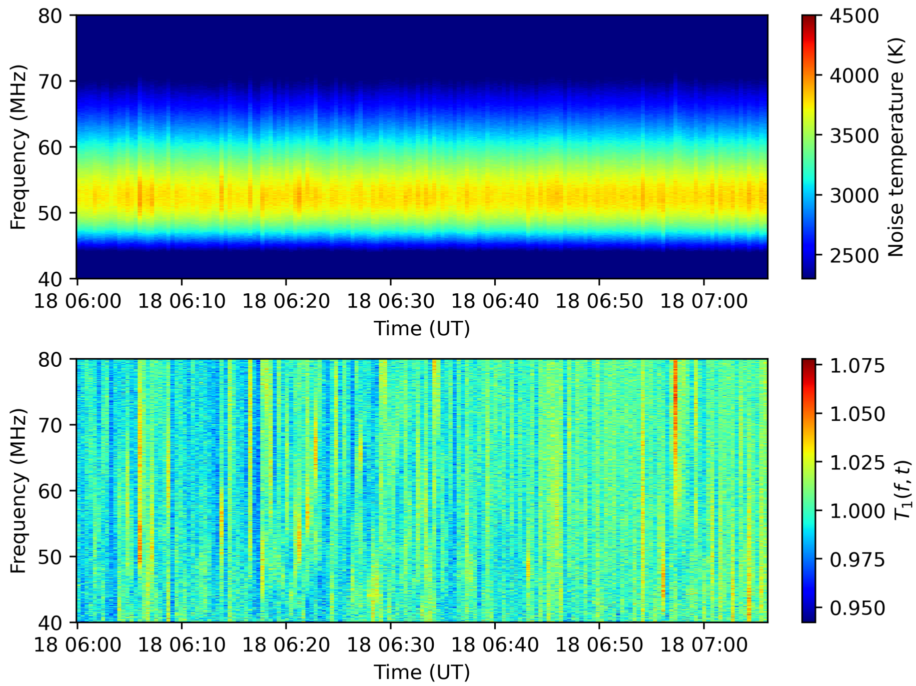

Figure 1: Power fluctuations observed with the EDGES Devon Island on August 18th 2022 between 6:00 and 7:00 (UTC). Top: uncalibrated antenna temperature. Bottom: Normalized power fluctuations $T_1(f, t)$

3 Ionospheric scintillations observed with a directive antenna

Figure 2 depicts power fluctuations of Cygnus-A due to ionospheric turbulence, measured using the northernmost LOFAR system, which is deployed in Kilpisjärvi in Northern Finland. The fluctuations are somewhat similar to the ones observed in the EDGES measurement on Devon Island.

With a high gain antenna, the fluctuations in power are up to 30%, but with the EDGES antenna only up to 7.5%. Both Cassiopeia A and and Cygnus A are strong radio sources, and it is possible that their contribution even in a wide beam would be sufficiently high for the ionospheric scintillation to account the observed power fluctuations in the EDGES antenna.

A crude estimate for a plausible value of $T_1(f,t)$ for the EDGES antenna can be obtained as follows. The effective area of the KAIRA station is 500 m^2. For a bright source with 20 kJy brightness, this would yield an antenna noise temperature of $T_{src} = 3600$ K. Based on Figure 2, the relative source temperature can fluctuate up to 30%, meaning that the noise temperature can go up to 4700 K due to ionospheric scintillation. The KAIRA system has 48 antennas. If we make an assumption that the directivity of the EDGES system is 1/48 of KAIRA, and that the background sky noise temperature is $T_{sky} = 500$ K, we obtain 4% power fluctuations when a 20 kJy source in the beam is increased in power by 30%:

$$T_1 = \frac{T_{sky}\frac{47}{48} + 1.3T_{src}\frac{1}{48}}{T_{sky}\frac{47}{48} + T_{src}\frac{1}{48}} \approx 1.04 \tag{1}$$

This is of comparable magnitude as the normalized power fluctuations shown in Figure 1. The above estimate probably underestimates the expected ionospheric scintillation power fluctuations on the EDGES system, which is likely to have a lower system noise temperature than the LOFAR system and a slightly larger antenna gain than used in our estimate.

4 Chromatic effects

Cassiopeia A and Cygnus A both have a spectral index that deviates significantly from the galactic synchrotron emission (-0.77 for Cas-A) [1], and it is probable that this would need to be taken into account in the background subtraction process.

Figure 2 shows that the scintillation can cause frequency structuring that is localized in time. It would require some additional modeling to determine what chromatic effects are caused by ionospheric scintillation of strong compact radio sources for long term averages of measured sky noise power.

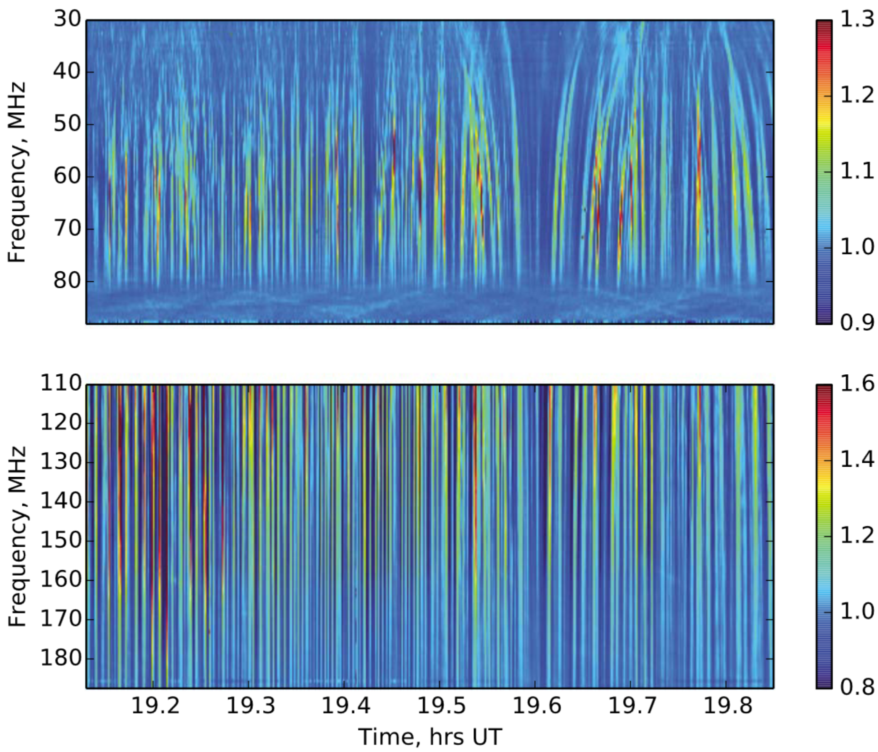

Figure 2: Normalized power fluctuations $T_1(f, t)$ due to ionospheric scintillation observed a a high latitude LOFAR station (KAIRA). Figure from [3].

References

[1] JWM Baars, R Genzel, IIK Pauliny-Toth, and A Witzel. The absolute spectrum of cas a-an accurate flux density scale and a set of secondary calibrators. *Astronomy and Astrophysics, vol. 61, no. 1, Oct. 1977, p. 99-106.*, 61:99–106, 1977.

[2] Sunanda Basu, Sa Basu, E MacKenzie, WR Coley, JR Sharber, and WR Hoegy. Plasma structuring by the gradient drift instability at high latitudes and comparison with velocity shear driven processes. *Journal of Geophysical Research: Space Physics*, 95(A6):7799–7818, 1990.

[3] RA Fallows, WA Coles, D McKay-Bukowski, J Vierinen, II Virtanen, M Postila, Th Ulich, C-F Enell, A Kero, T Iinatti, et al. Broadband meter-wavelength observations of ionospheric scintillation. *Journal of Geophysical Research: Space Physics*, 119(12):10–544, 2014.

[4] MM Oppenheim and Ya S Dimant. Kinetic simulations of 3-d farley-buneman turbulence and anomalous electron heating. *Journal of Geophysical Research: Space Physics*, 118(3):1306–1318, 2013.

[5] Andres Spicher, T Cameron, EM Grono, KN Yakymenko, Stephan C Buchert, Lasse Boy Novock Clausen, David J Knudsen, Kathryn A McWilliams, and Joran Idar Moen. Observation of polar cap patches and calculation of gradient drift instability growth times: A swarm case study. *Geophysical Research Letters*, 42(2):201–206, 2015.