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Regularly Occurring Scintillation from Field-Aligned Irregularities Observed Using LOFAR

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The LOw Frequency ARray (LOFAR) is a radio telescope covering frequencies of 10-90 MHz and 110-250 MHz. It is centred in the Netherlands, with international stations spread across Europe from Ireland to Latvia. Although its primary purpose is radio astronomy, regular observations of ionospheric scintillation on the bright sources Cygnus A and Cassiopeia A are also made at 25-65 MHz. Within these observations, one regularly occurring phenomenon in observations of Cygnus A is scintillation occurring above some frequency cutoff within the observing band but not below it. This frequency cutoff varies with time, increasing and then decreasing quasi-symmetrically over the course of several hours. This creates a characteristic 'U' shape in the dynamic spectrum (signal intensity as a function of frequency and time, with lower frequencies towards the top of the plot) and so we refer to this phenomenon as 'U-shaped scintillation'.

U-shaped scintillation has been observed exclusively at low elevations ($<\sim 20^\circ$) on quasi-poleward lines of sight, with higher cutoff frequencies corresponding to lower elevations and significant variations between individual events. The occurrence rate of these events is found to be highest in winter / near midnight, although disentangling which of these factors is most important is difficult with the available data. This is because the times at which the observing geometry to Cygnus A is suitable vary with season, meaning there are no chances to observe U-shapes at midnight in summer for example. The occurrence rate also increases with increasing geomagnetic activity, from $\sim$30% at Kp$\leq$ 1 to $\sim$75% at Kp$\geq$ 3 (very few observations are available for Kp>4). Most events are observed by the whole international LOFAR network, indicating that the structures responsible for the scintillation are distributed across a wide range of longitudes ($>\sim 15^\circ$) in addition to being long lived.

Detailed investigation of two U-shaped scintillation events has shown that the structures responsible for the observed scintillation are field-aligned. Alignment with the geomagnetic field is also apparent from the timings of the events, as the midpoint of the observed features (i.e. the point at which the cutoff frequency maximises) is on average slightly offset east of geographic north, matching the local geomagnetic declination. The analysis of individual events also allows possible explanations for the observed frequency cutoff to be tested by comparing predicted variations in cutoff frequency with elevation/time to the observations.