

EGU25-4831, updated on 18 Apr 2026

<https://doi.org/10.5194/egusphere-egu25-4831>

EGU General Assembly 2025

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Spacecraft observations of VLF transmitter signals and their propagation

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Military very low frequency (VLF) transmitters represent a significant anthropogenic source of electromagnetic waves. Their signals can travel considerable distances within the Earth-ionosphere waveguide, but they also penetrate the ionosphere and propagate through the inner magnetosphere. There, they can be readily observed by spacecraft instruments with sufficient frequency resolution and range, and they can precipitate energetic electrons trapped in the Van Allen radiation belts.

We use 23 years of measurements from the WHISPER instruments on board the four Cluster spacecraft, operating at frequencies up to 80 kHz, to investigate the observed intensities of VLF transmitter signals. The signals are about an order of magnitude more intense at night than during the day, and they appear to be confined within the plasmasphere. The unique latitudinal coverage of the Cluster spacecraft measurements allows us to investigate frequency cut-offs in the transmitter spectra. These cut-offs are mostly consistent with nonducted propagation, though occasional partial ducting seems necessary to explain signals spanning otherwise inaccessible regions. The observed intensity patterns are compared with the calculations of Starks et al. (2020), demonstrating an overall agreement in the pattern, but with the observed wave intensities by a factor of about 2-3 lower than predicted.