Swarm Absolute Scalar Magnetometer Burst Mode: Observed ELF Signals and their Origins

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Swarm ASM burst-mode data

The absolute scalar magnetometers on-board each Swarm satellite nominally supply a 1Hz data product, down sampled from 50Hz. An experimental 'burst-mode' is also periodically switched on, operating at 250Hz, and thus allowing the bandwidth 0-125Hz to be investigated. Using version 0302 of this dataset, which includes the periods 2014 and 2018-2023 (Fig. 1), we investigate ionospheric signals using frequency-time domain analysis through spectrograms.

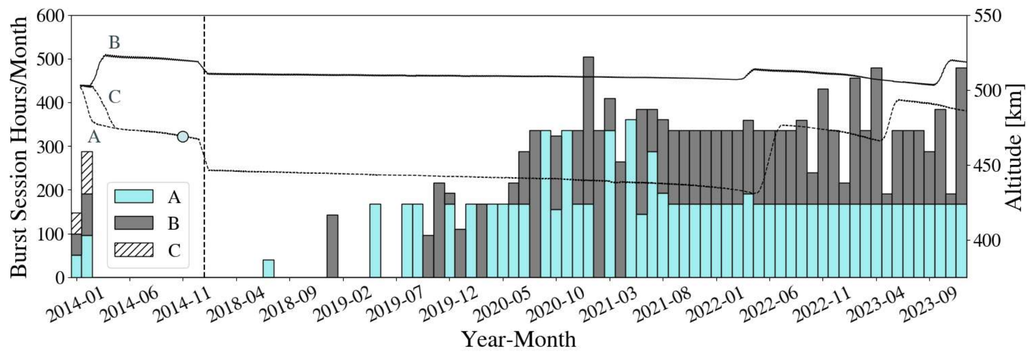

Figure 1: *Number of burst-mode hours per month for all sessions for each satellite. The open white circle indicates where both ASMs on Charlie failed in 2014 and the altitude of each craft is also plotted. The vertical dashed line indicates a break in the data.*

Minimal processing of the data product is performed: we calculate the field residual using CHAOS and remove/replace outliers with a long wavelength fit to the residual, and thus spectral contamination of the frequencies of interest is prevented. We plot the band 15-125Hz, where we find a plethora of manmade, geophysical and instrumental signatures. Novel signals of unknown origin are found, of which we present two thought to be geophysical.

We give an overview of the signals found and describe their origins.

PLHR and ELF Communications

Powerline harmonic radiation (PLHR) leaks into the ionosphere and is detected by Swarm as 50/60Hz lines in spectrograms during nightside orbits, while wave attenuation is lesser due to reduced plasma density. ELF communications, such as the Russian ZEVS transmitter, are also seen strongly up to 1000+ km from the source.

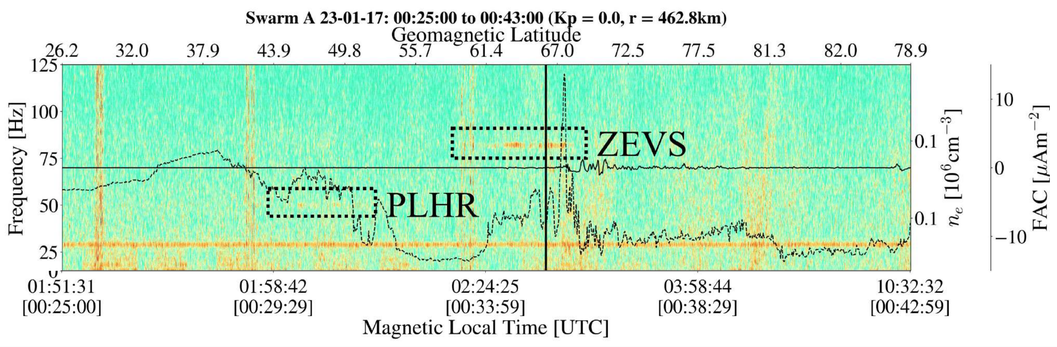

Figure 2: *Burst mode spectrogram during 17th-Jan-2023 showing 50Hz powerline harmonic radiation (PLHR) over Europe and the Russian ZEVS ELF transmitter at 82Hz. PLHR is only seen during nightside orbits. Plasma density (n_e) and field aligned currents (FACs) are plotted as dashed and solid lines, respectively. The solid vertical line is the Swarm estimated auroral oval boundary.*

Sweeps and Rainbows

Linear and quadratic chirps are found throughout the dataset with varying length, power and shape, sometimes overlapping and in some examples repeating the same pattern orbit-on-orbit. We suspect an instrumental effect however have thus far found no obvious correlation to geophysical parameters and do not find common examples between craft during conjunctions.

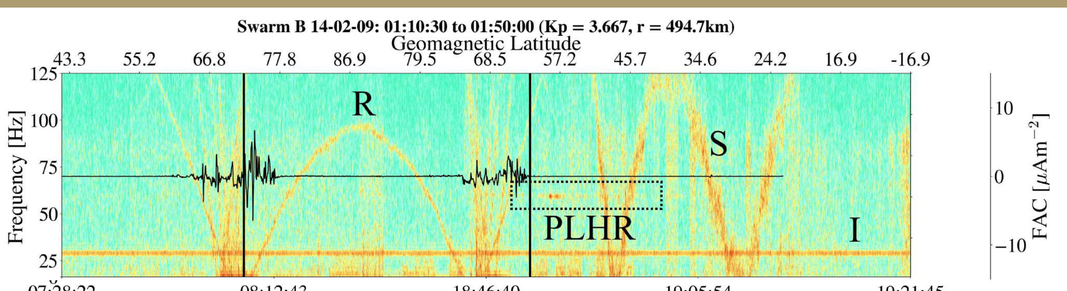

Figure 3: *Burst mode spectrogram during 9th-Feb-2014 showing a 'rainbow' (R), 'sweeps' (S), a known onboard interference (I) and 60Hz powerline harmonic radiation (PLHR) over North America. Vertical black lines mark Swarm-derived auroral boundaries.*

Plasma Bubbles

Equatorial plasma bubbles are a nighttime phenomenon that result in diamagnetic signals in the burst-mode data which are often broadband in nature. They are observed to correlate well to the plasma bubble index product, which relies on the 50Hz data, as shown in Figure 4.

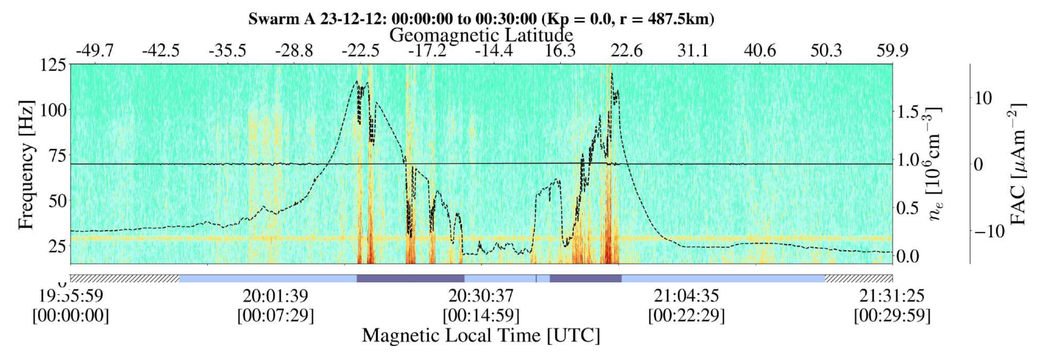

Figure 4: : *Burst mode spectrogram during 12th-Dec-2023 showing a plasma bubble event. Bands of power associated with plasma density depletions align with the derived plasma bubble index (middle panel thin bar), where dark blue indicates the presence of a bubble, light blue is 'quiet', and the hashed regions have no data. Plasma density (n_e) and field aligned currents (FACs) are also plotted as dashed and solid lines, respectively.*

Auroral Hiss

Auroral hiss presents as incoherent structures and is generally banded between 60-100Hz in Swarm data. We find a link to strong field aligned currents but the plasma density also plays an important role. Figure 5 demonstrates how the plasma density can fully attenuate hiss during measurements.

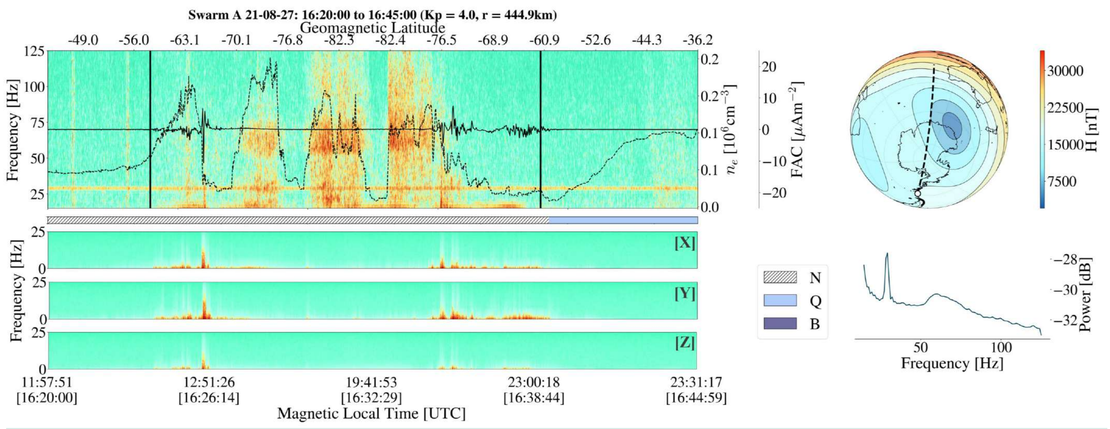

Figure 5: *Burst mode spectrogram during 17th-Aug-2021 showing auroral hiss over the Antarctic. The signal power is modulated by the plasma density (dashed line) and thought to be related to strong field aligned currents (FACs; solid line). Vertical solid lines show the Swarm estimated auoral oval boundaries and the plasma bubble index is also plotted but the index was either quiet (Q) or had no data (N).. The vector 50Hz product spectrograms are also shown, demonstrating coeval lower frequency perturbations.*

Hooks and Antarctic Waves

We find two novel waves we believe to be geophysical in origin in the burst-mode data: 'hooks' (Fig. 6), which are only observed during magnetic local times around 0900 and 1500 and rising tone features (Fig. 7) restricted geographically to the edge of the South Atlantic Anomaly (SAA) region.

Hooks generally last 2-5 minutes but can last up to 20 minutes. In 2023 data, we observe coeval plasma density perturbations and hook modulations (Fig. 6B). 2014 reveals the detection of an event on all three craft simultaneously when in close proximity, supporting a geophysical origin. Hooks are remarkably similar to documented ground observations such as those by Kim et al. (2006, doi:10.1029/2005GL023638) in the Antarctic.

Antarctic rising waves are found only during periods of heightened geomagnetic activity and are restricted to the edge of the SAA region. We hypothesise a solar insolation effect, possibly related to the offset of the south magnetic pole, however further work is required to determine their source-mechanism.

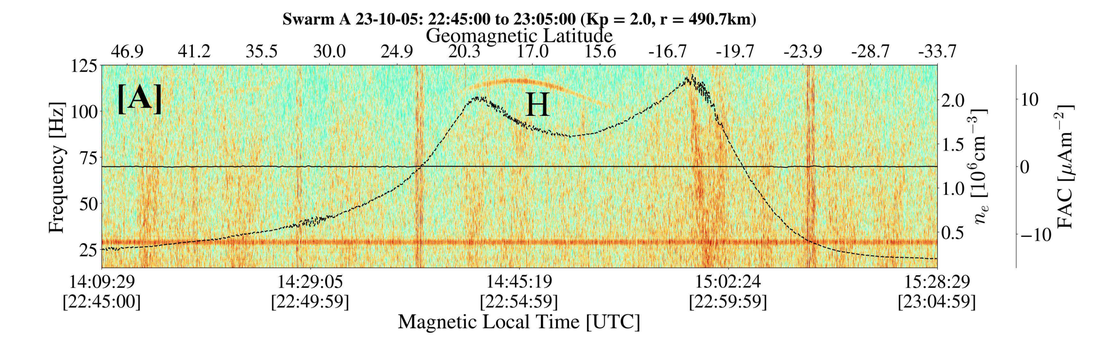

Figure 6: : *Burst mode spectrogram during 5th-Oct-2023 showing [A] a typical hook like-structure (H), and [B] an example of a hook modulating while coeval plasma density perturbations are measured. . Plasma density (n_e) and field aligned currents (FACs) are plotted as dashed and solid lines, respectively.*

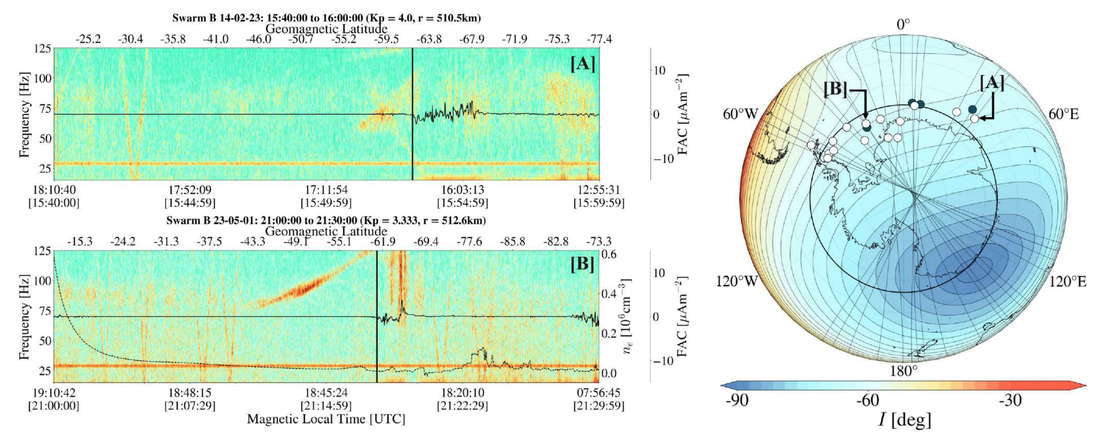

Figure 7: : *Burst mode spectrograms during 23rd-Feb-2014 [A] and 1st-May-2023 [B] showing rising tone signals found over the Antarctic during heightened geomagnetic activity. Plasma density (n_e) and field aligned currents (FACs) are also plotted as dashed and solid lines, respectively and vertical black lines mark Swarm-derived auroral boundaries. All examples found thus far are plotted geographically to the right of the spectrograms, with light and dark open circles indicating Swarm Bravo and Alpha events respectively. The inclination contours are plotted for 2022 using CHAOS. The solid black circle marks -66.5° geographic latitude. .*

Summary

- The ASM burst-mode data can detect ionospheric signals, both of manmade (e.g. powerline harmonic radiation) and geophysical (e.g. plasma bubbles) origin.
- Hooks are confined to magnetic local times 0900/1500, but no mechanism can be confidently speculated.
- Antarctic waves are confined to the South Atlantic Anomaly region and are possibly related to a solar insolation effect coupled with high geomagnetic activity.

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