Characterizing Poynting flux and associated Alfven Waves in multiple discrete auroral arcs

The Static, The Quasi, and the Dynamic

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Background and Event

The Static

The Quasi (static)

The Dynamic

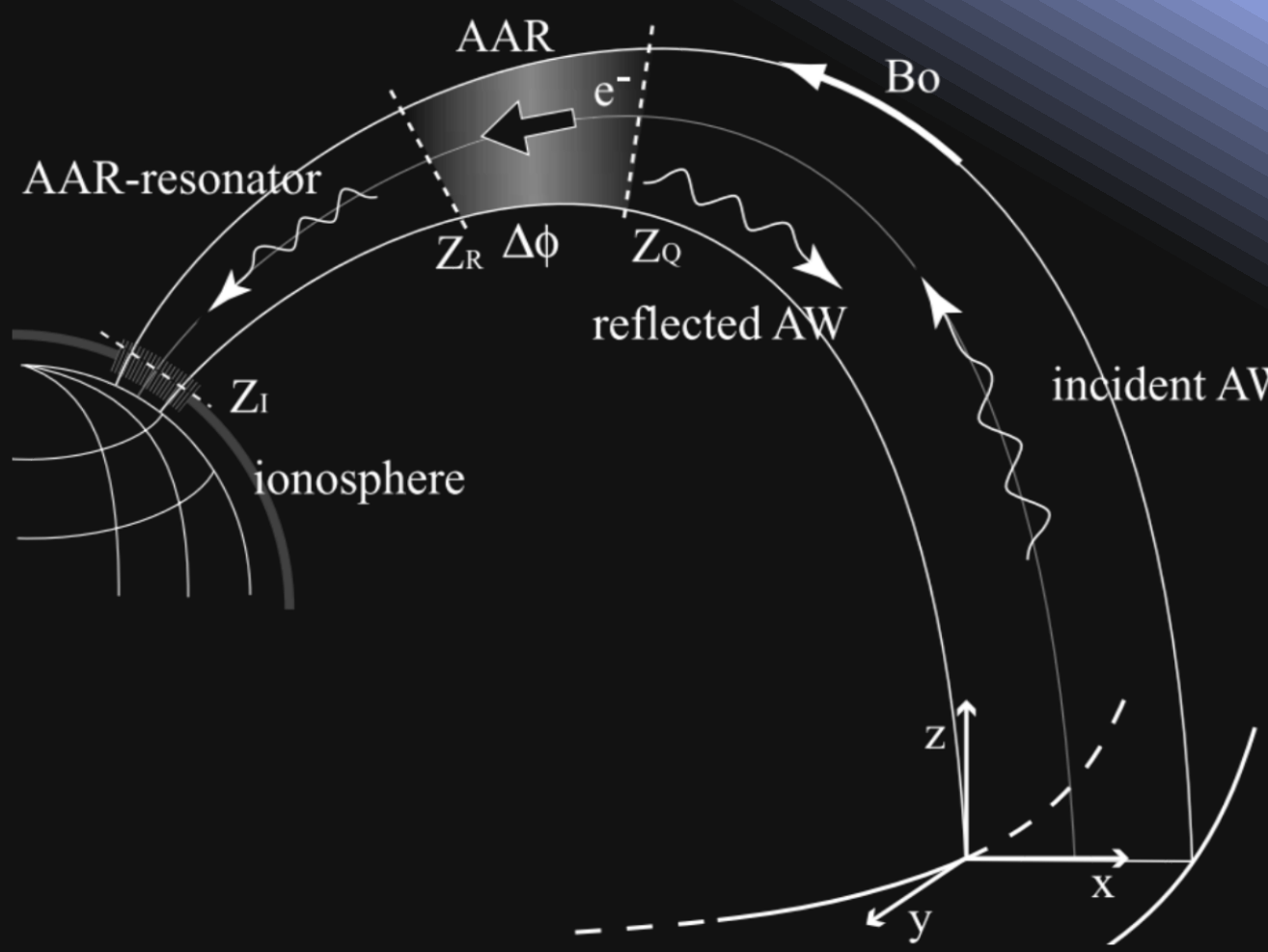
Background

Incident Shear Alfven Waves propagate from the magnetosphere

Travels through an Ionospheric Resonating Cavity which traps, reflects and transmits Alfven waves into the ionosphere.

Shear Alfven waves are known to propagate Poynting flux into the Ionosphere

Alfven waves can be observed and parameterized with the in-situ E/B measurements



Energy budget of Alfven wave interactions with the auroral acceleration region - Scientific Figure on ResearchGate. [accessed 21 Feb, 2024]

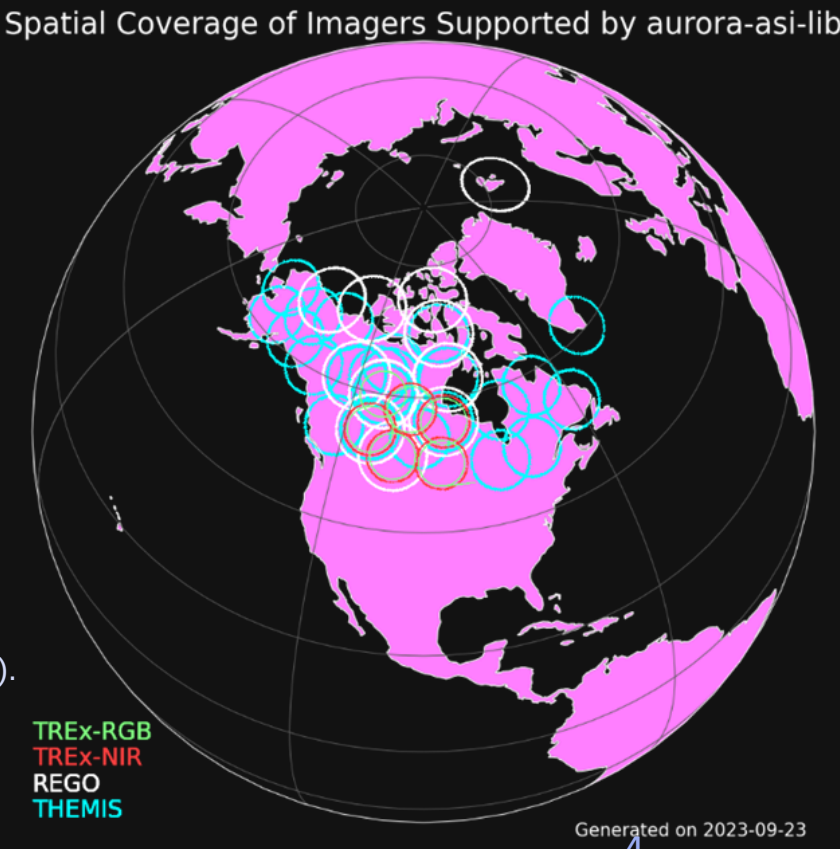
What data products are relevant

Swarm has in-situ vector-wise fields which is necessary for the Alfven and Poynting flux analysis

Various wavelength all sky cameras are provided by the University of Calgary; we can correlate our in-situ field measurements to spectrally-dependent optical emission

Using IRBEM for the magnetic footprint and aurora-asi-lib for plotting.

- Vector Field Magnetometer (VFM)
- Absolute Scalar Magnetometer (ASM)
- Electric Field Instrument (EFI)
- Accelerometer (ACC)



Shumko M, Chaddock D, Gallardo-Lacourt B, Donovan E, Spanswick EL, Halford AJ, Thompson I and Murphy KR (2022). [Aurora-asi-lib and AuroraX) Astron. Space Sci. 9:1009450. doi: 10.3389/fspas.2022.1009450

https://spaceflight101.com/swarm/swarm-spacecraft-overview/ (Swarm Photo)

We acknowledge the use of the IRBEM library v5.0.0, the latest version of which can be found at https://doi.org/10.5281/zenodo.6867552.

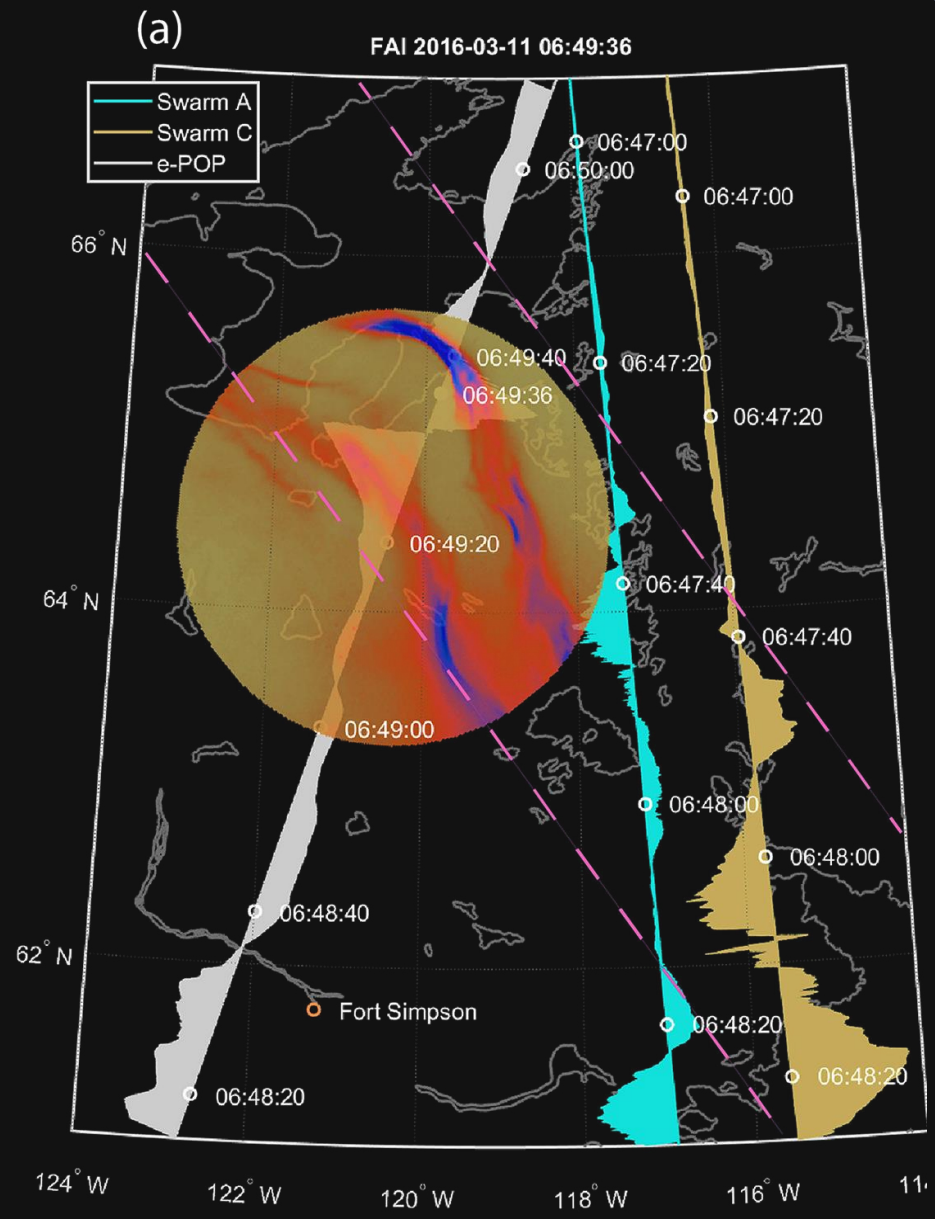
Starting the Search

Miles Et Al. 2018 investigated a conjunction between e-pop and Swarm satellites and examined Alfven waves in discrete auroral arcs

Evidence was found of shear-mode Alfven waves using the cross-component wise E/B ratio

Improvements utilized:

- 7 more years of Swarm spacecraft data
- New All Sky Imagers (TREx ASI)
- Orbital maneuvers conducted in Oct 2019 for 2021 swarm-swarm conjunctions



Miles, D. M., Mann, I. R., Pakhotin, I. P., Burchill, J. K., Howarth, A. D., Knudsen, D. J., … Yau, A. W. (2018). Alfvénic dynamics and fine structuring of discrete auroral arcs: Swarm and e-POP observations. *Geophysical Research Letters*, 45, 545–555.

Event Found

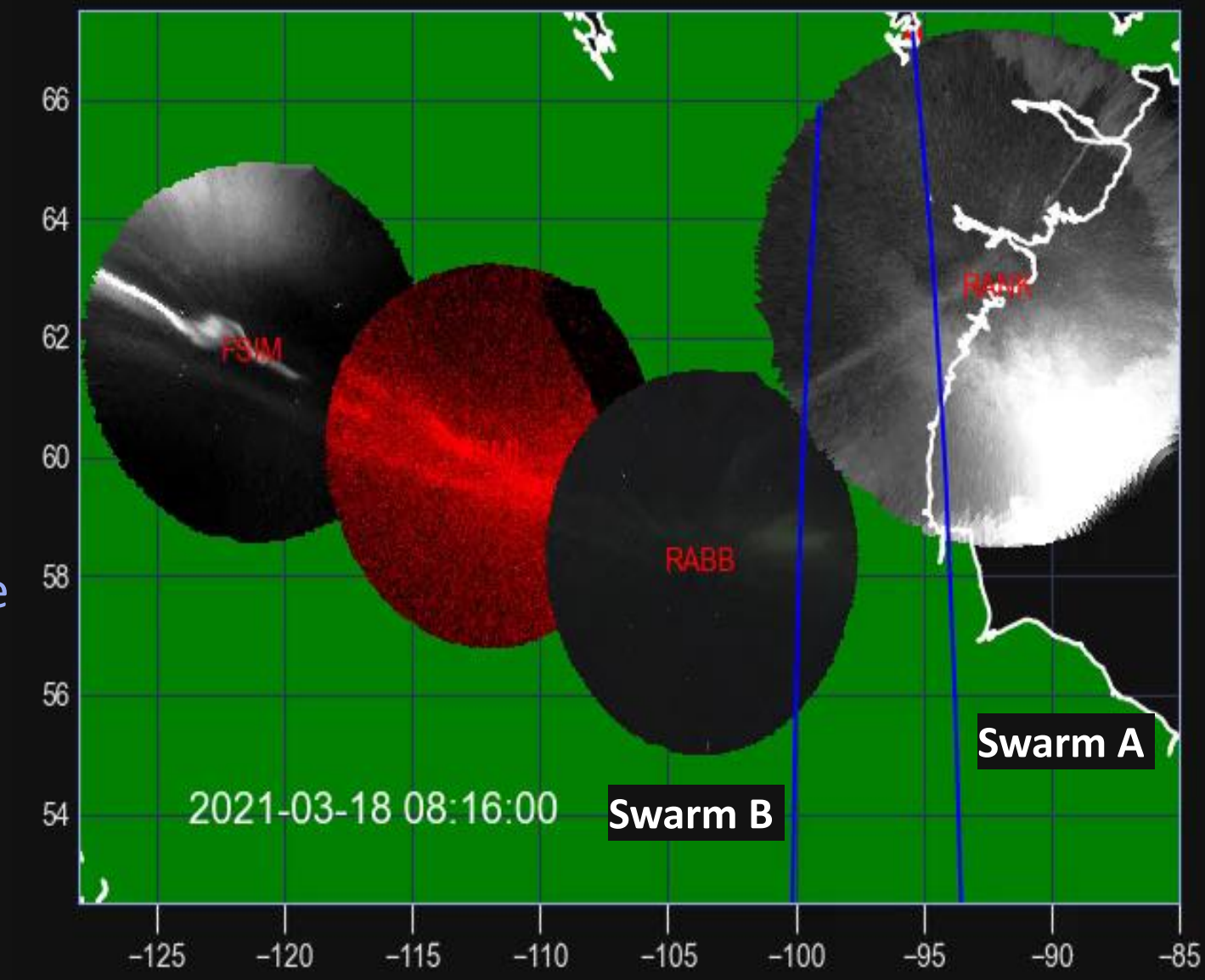
Criteria:

- Multiple ASI fields of view
- Conjunction between Swarm space-craft with high quality in-situ field measurements

Temporal separation of the Swarm space craft is approximately 4 minutes alongside 7° of longitudinal separation

Two discrete (quasi) stable arcs span the high latitude prairies with a streamer over RABB and RANK

Mosiac of All Sky Imagers and Swarm Satellites in Geographic Coordinates



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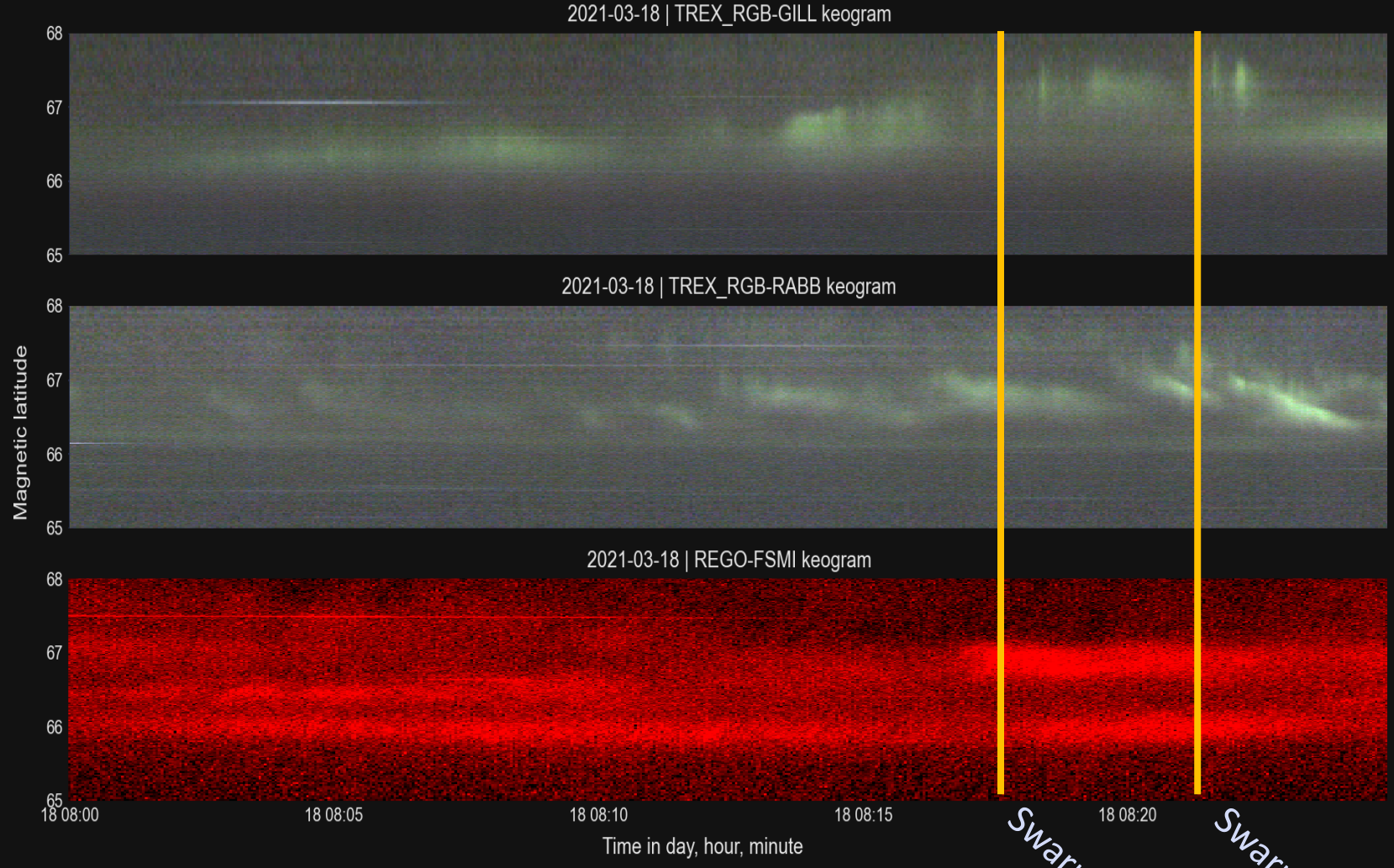
The Stable - ASI

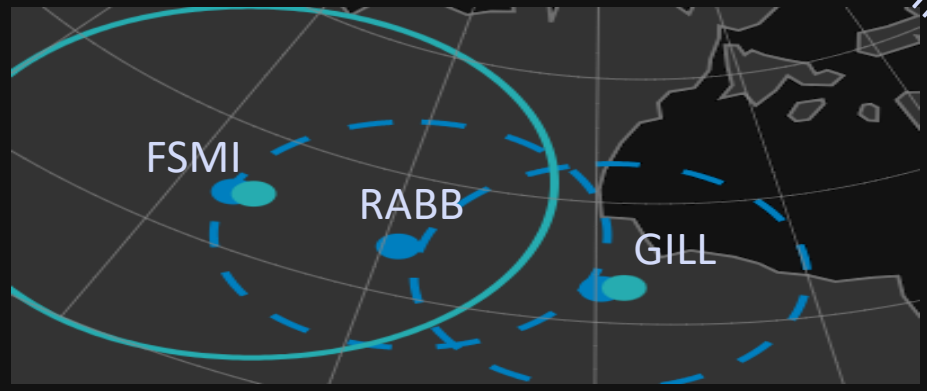
The event is dominated by two conjugate arcs separated by less than a degree in latitude

The poleward arc is stable in red-line and quasi static in the green-line emission.

The equatorial arc is dominant in red-line emissions and faint in green-line emission.

In both RABB and FSMI, the equatorial arc is stable over minute time scales.





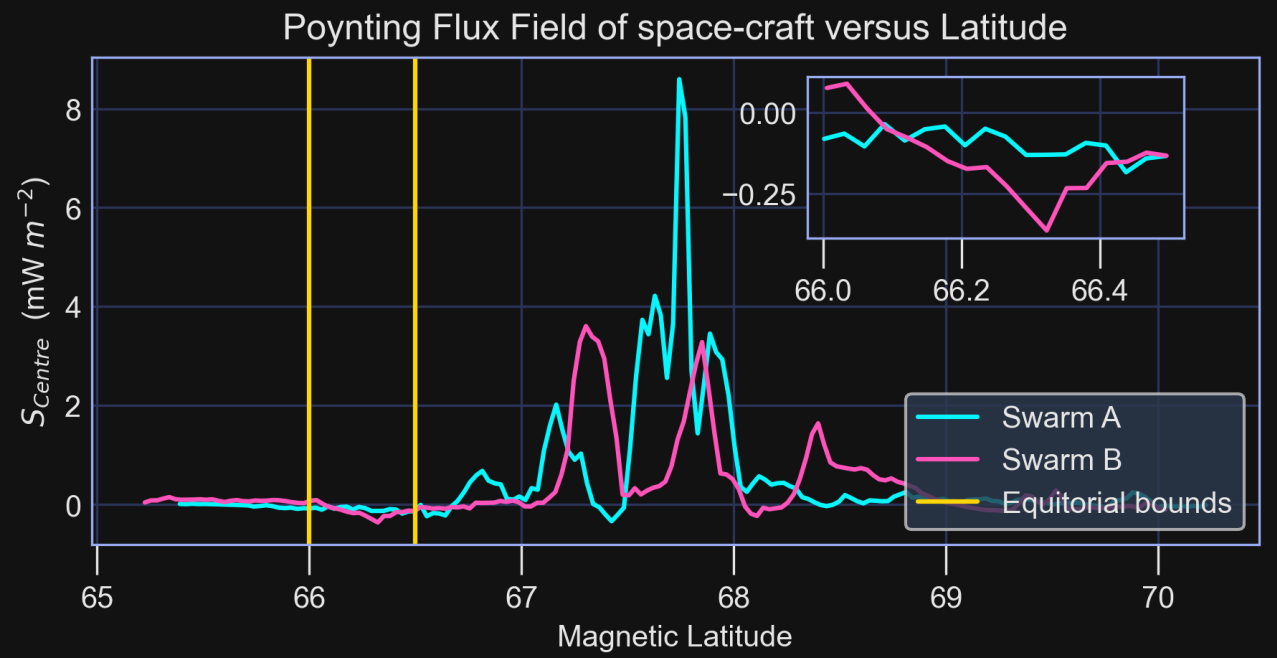
The Stable - Magnetic

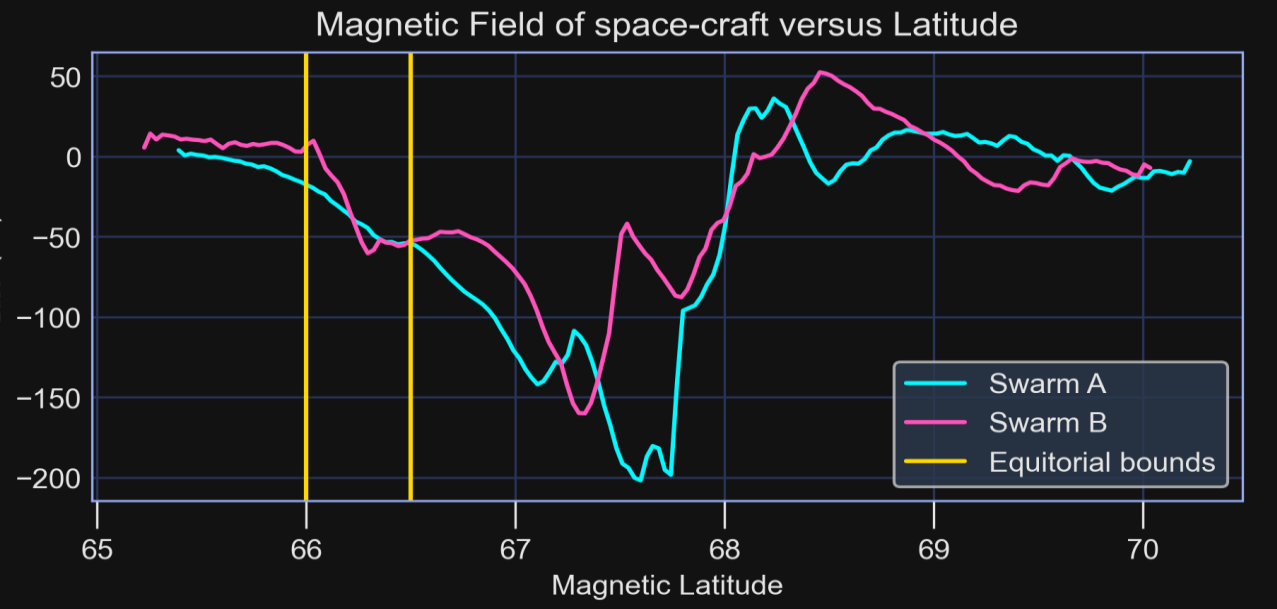
The equatorial arc is approximately along constant magnetic latitude

While close in magnitude, we see a 50 nT drop in Swarm B which is smoothed in Swarm A

Poynting flux is outward. The physical interpretation of negative Poynting flux is flux which is travelling out of the Ionosphere.

While optically consistent, in-situ magnetic data has discrepancies



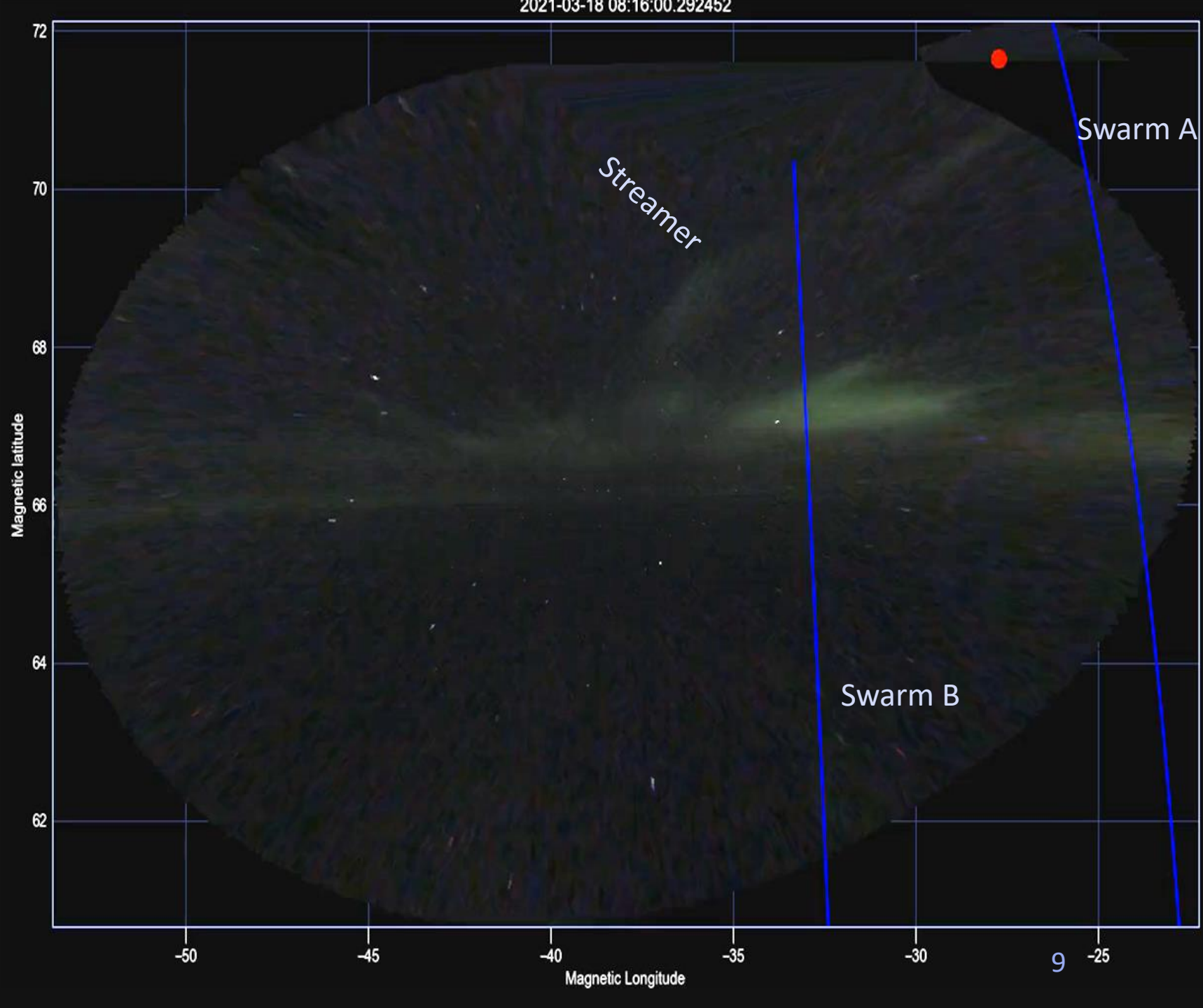


The Quasi - ASI

Can see cycling in the poleward arc originating at the streamer during Swarm B pass (dynamic)

Due to the fisheye effects, the resolution of the aurora near the edges of the map is significantly lower than the near-zenith

The arcs are roughly alongside magnetic latitude but do increase.



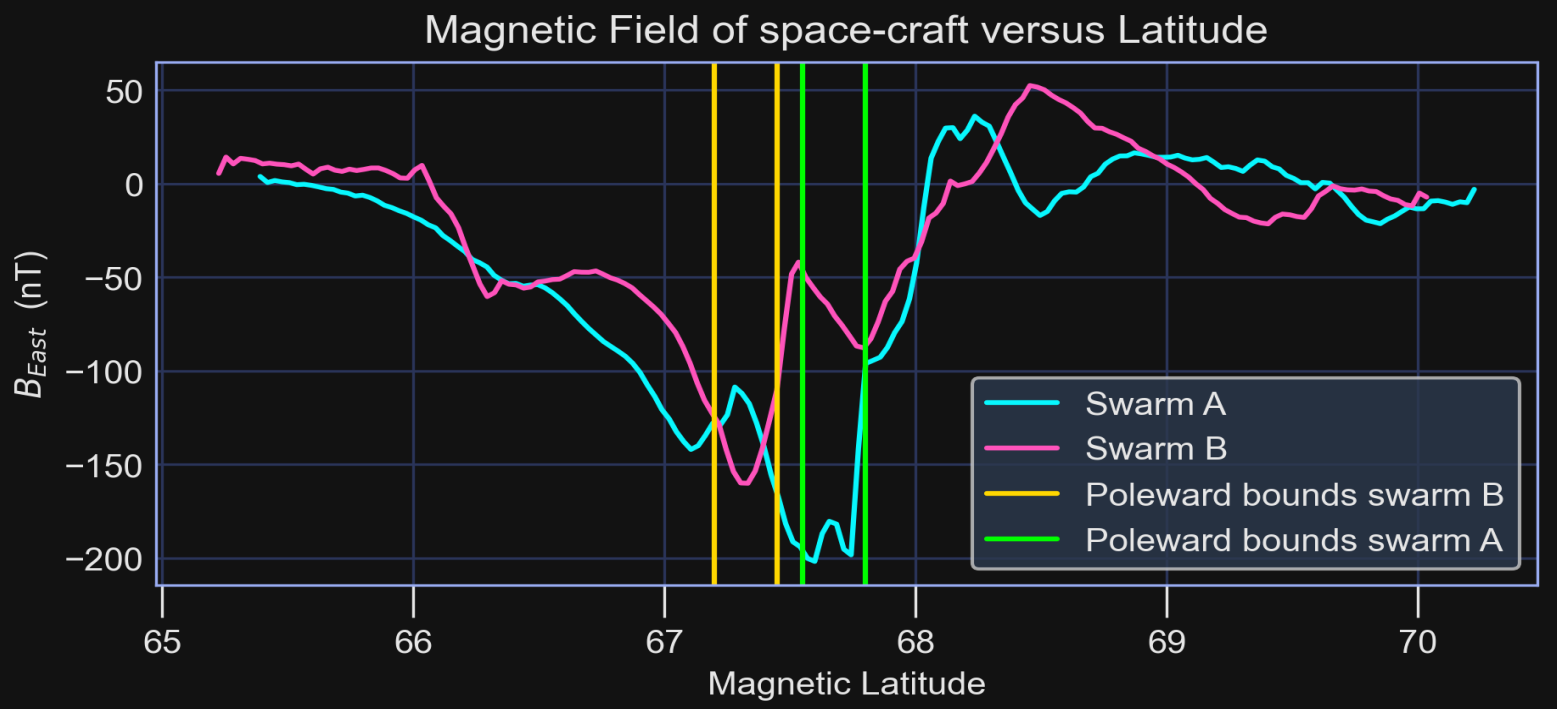
Quasi - Magnetics

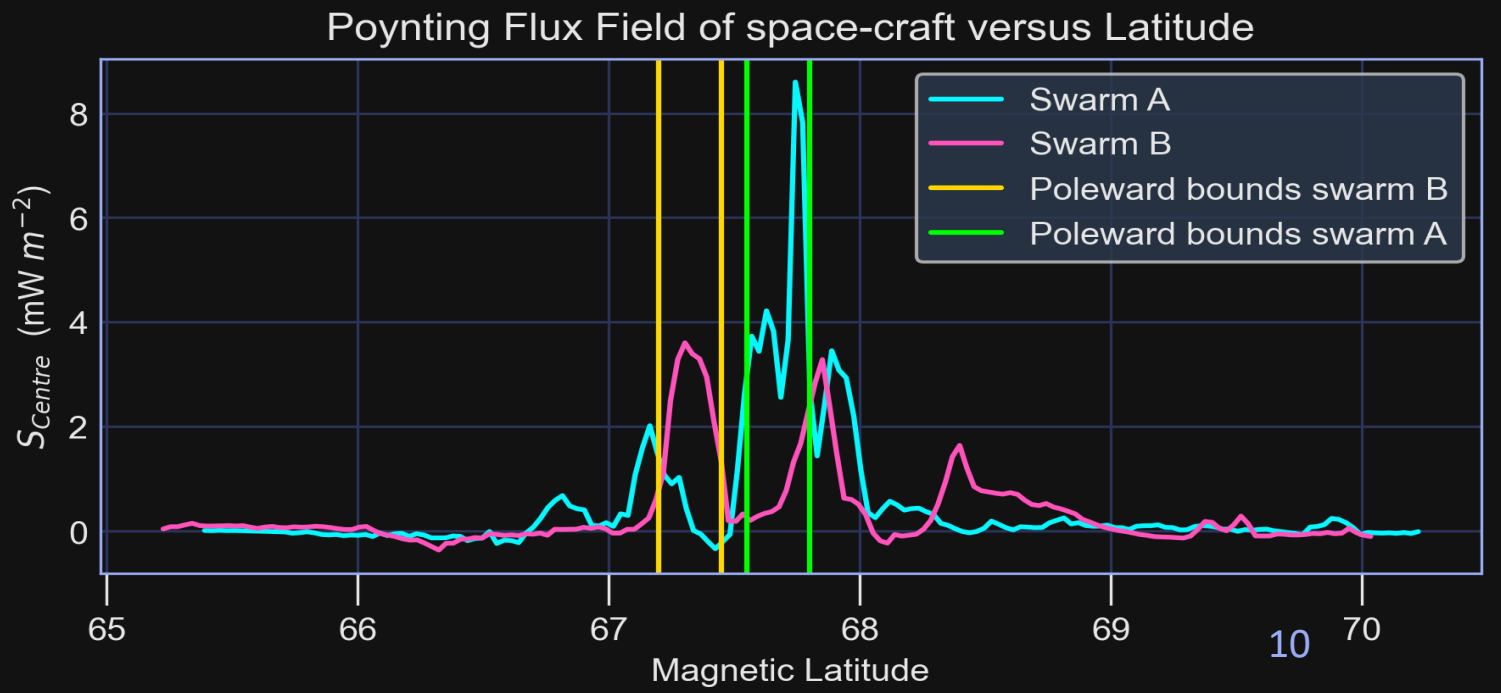
Swarm A has a large spike associated with a field aligned current at the edge of the boundaries which is not present in B

Oscillation in magnetic field at the peak of swarm A which don't exist in swarm A

Difference in magnitude of 50(nT) at the maxima of swarm A and B magnetics!

Working on using sky maps to more accurately find pixel intensity versus Poynting flux (Bounds are Heuristic)



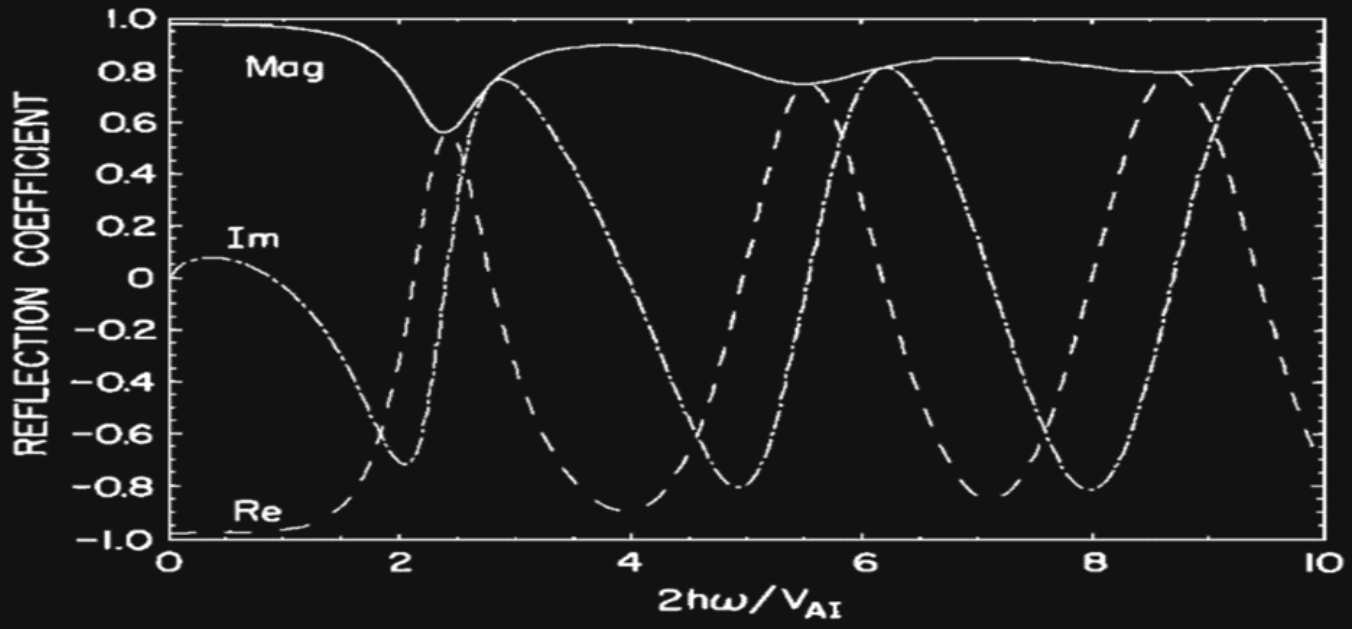


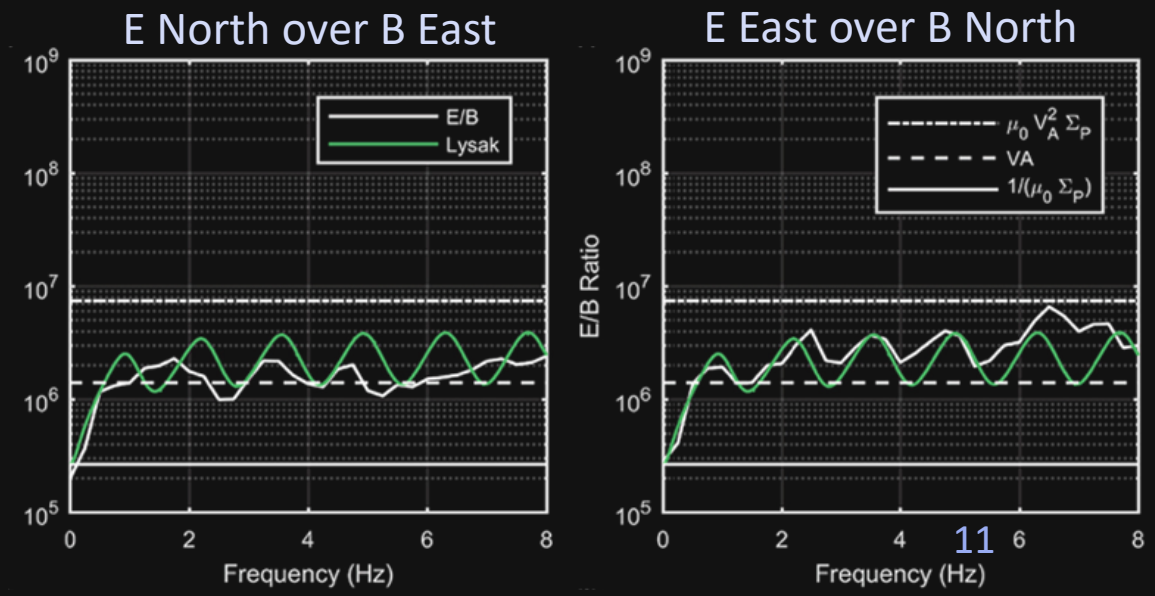
Interlude: Alfven Waves Analysis

Lysak 1991 gives a prescription of Alfven Waves modulated by the Ionospheric Resonating Cavity in the ionosphere with modified Bessel functions

Real component of the ratio used for analysis in our study.

The Ratio of the different polarizations of the wave affects the Poynting flux (x: North, y: East) $S_z = \frac{\delta E_x \, \delta B_y - \delta E_y \, \delta B_x}{\mu_0}$





Lysak, R. L. (1991), Feedback instability of the ionospheric resonant cavity, *J. Geophys. Res.*, 96(A2), 1553–1568

Miles, D. M., Mann, I. R., Pakhotin, I. P., Burchill, J. K., Howarth, A. D., Knudsen, D. J., ... Yau, A. W. (2018). Alfvénic dynamics and fine structuring of discrete auroral arcs: Swarm and e-POP observations. *Geophysical Research Letters*, 45, 545–555.

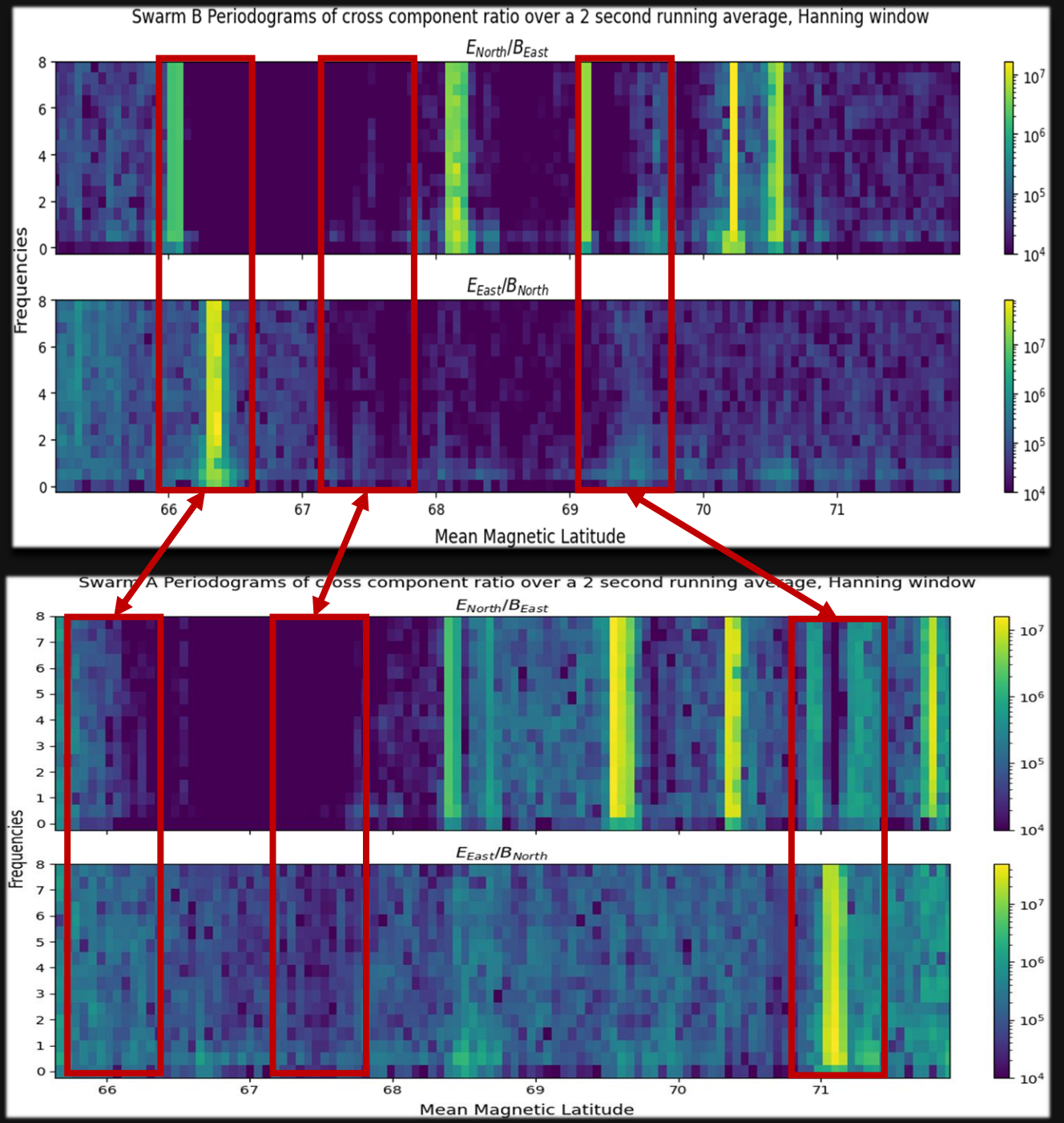
The Dynamic – Magn.

The equatorial arc is in a regime traced by Alfven Waves of opposite Polarization.

No shear Alfven Waves are present in the pole-ward auroral arc.

The streamer arc's region is embedded in Alfvenic activity. At the latitude of the streamer, the arc is bracketed by Alfven waves of North East polarization alongside East North.

There are numerous Alfven waves in Swarm A and B that are not associated with visible optical emissions.

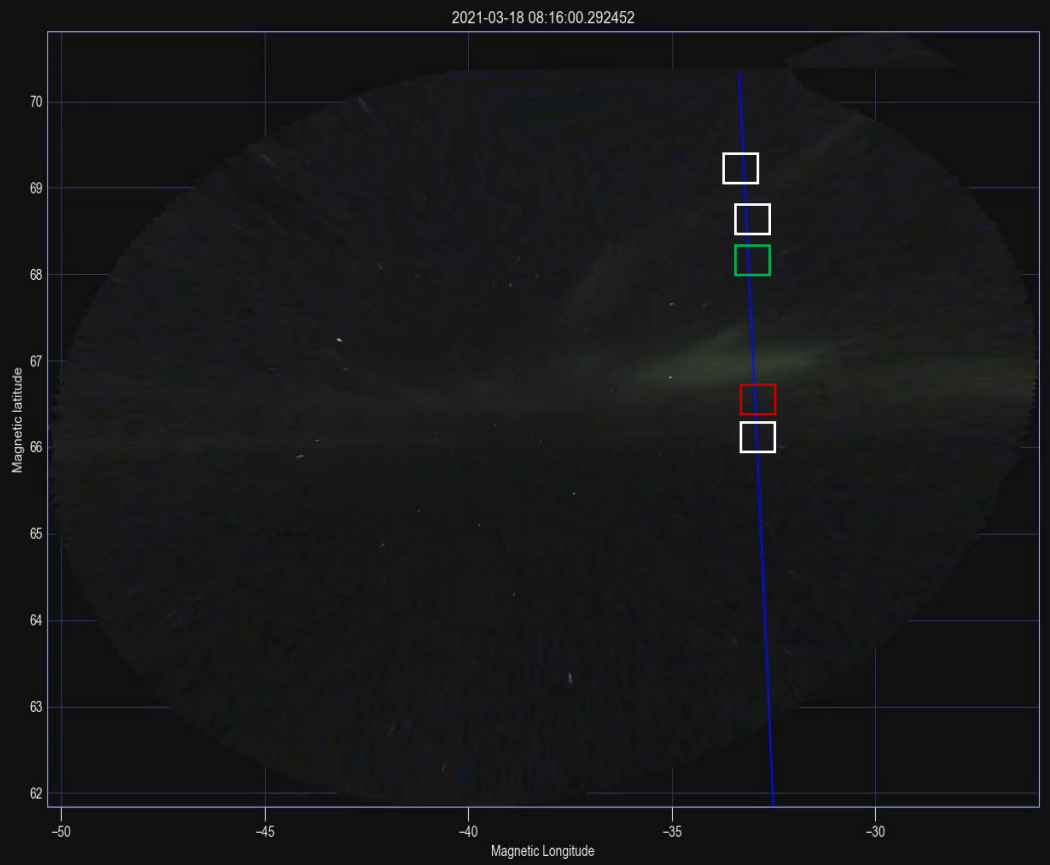


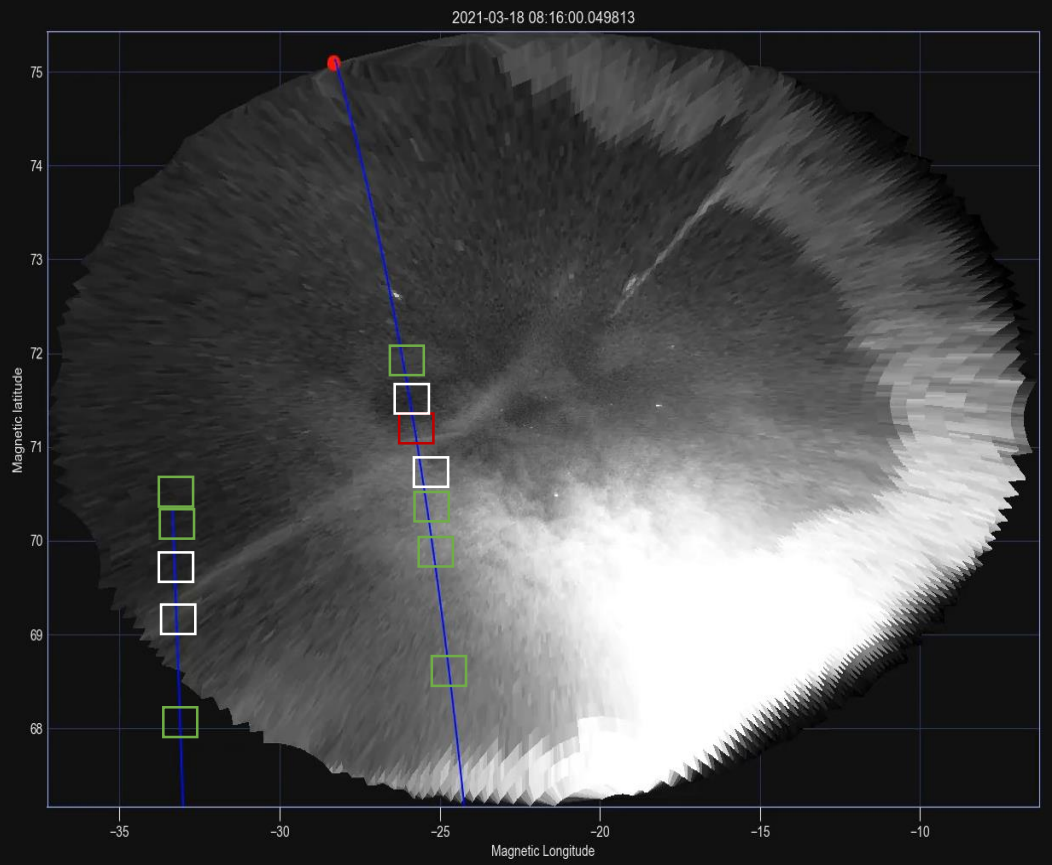
The Dynamic – ASI

East North Polarization

East North Polarization, no arc

North East Polarization



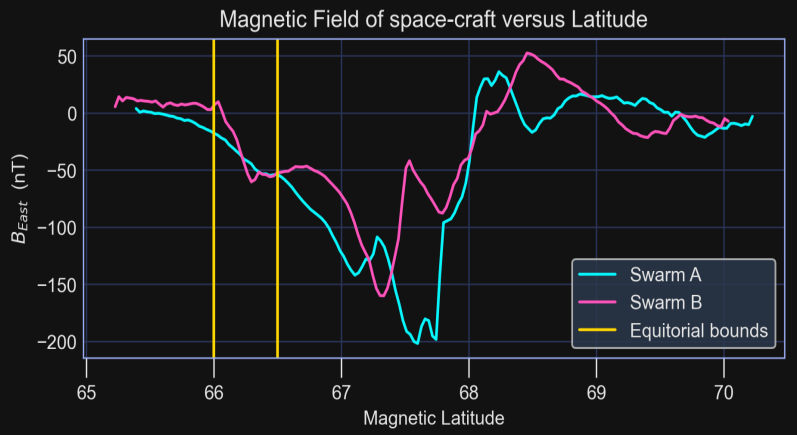


Arcs which are Alfvenic are bracketed by Alfven Waves (streamer and equatorial arc)

Some Arcs don't have visible optical emission. This could be small-scale or at edge of fish-eye capabilities.

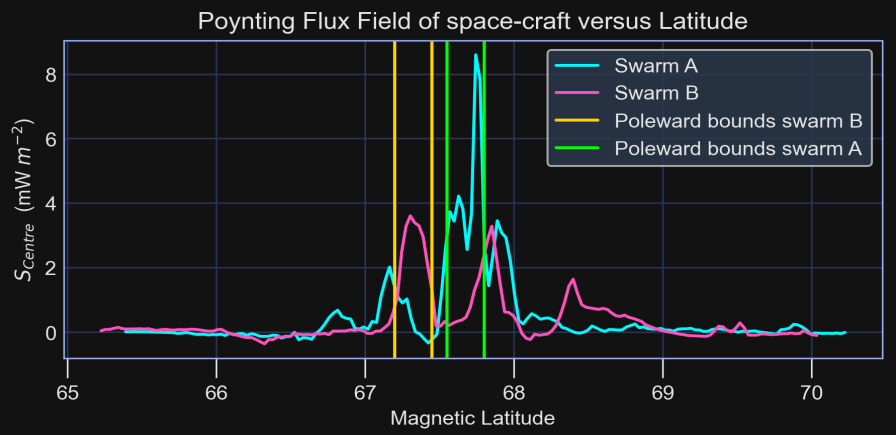
Synthesis and Future Work

The Stable



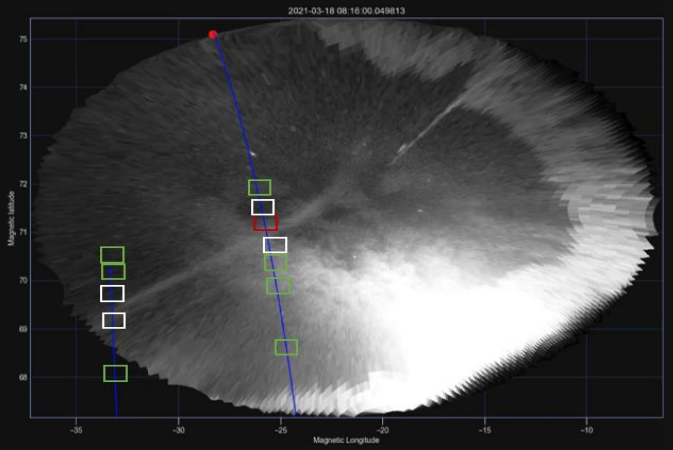
Alfven Waves are modulating aurora here causing change. Alfven waves are not present in swarm A's data so different in-situ data is presented.

The Quasi

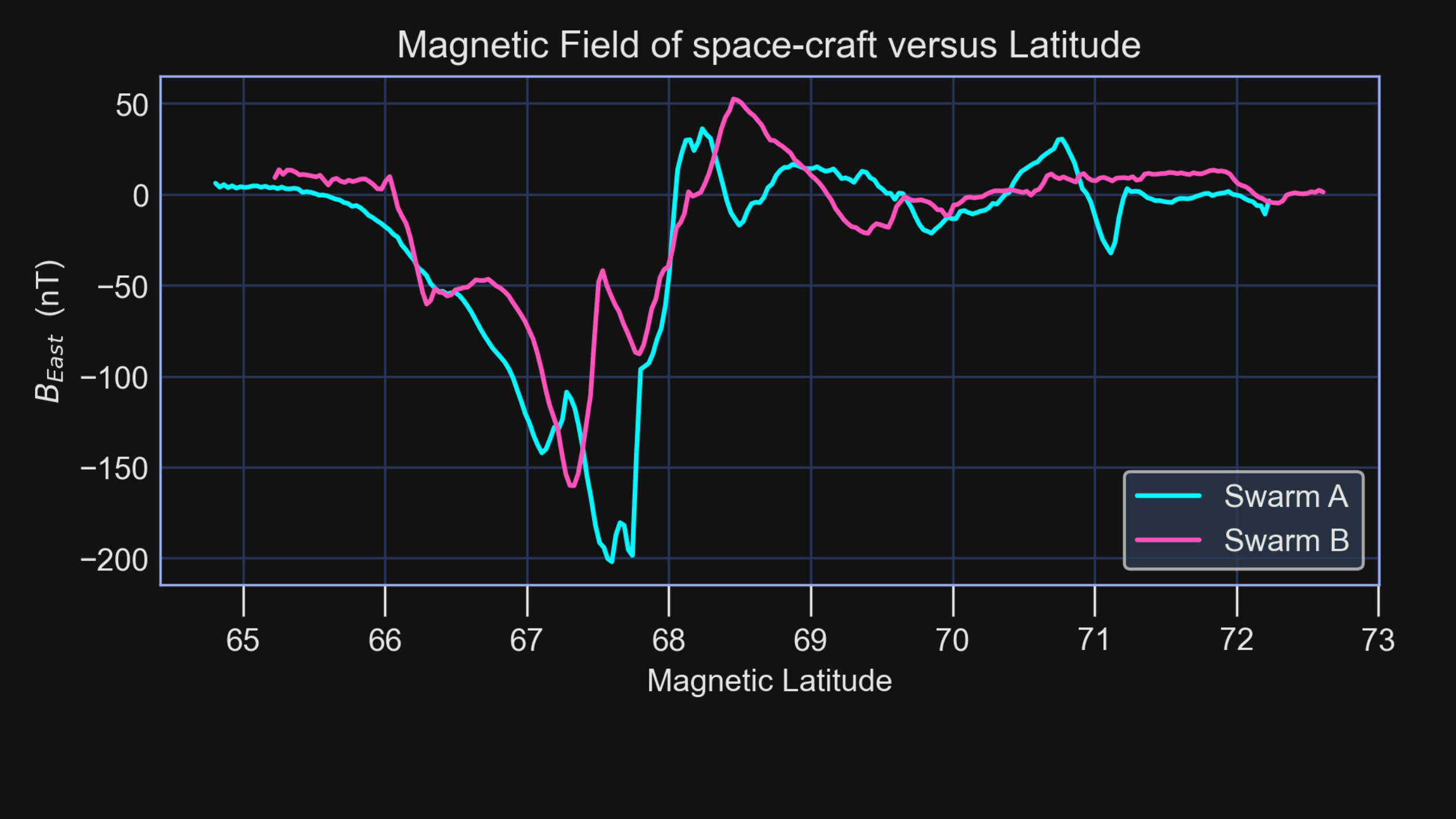


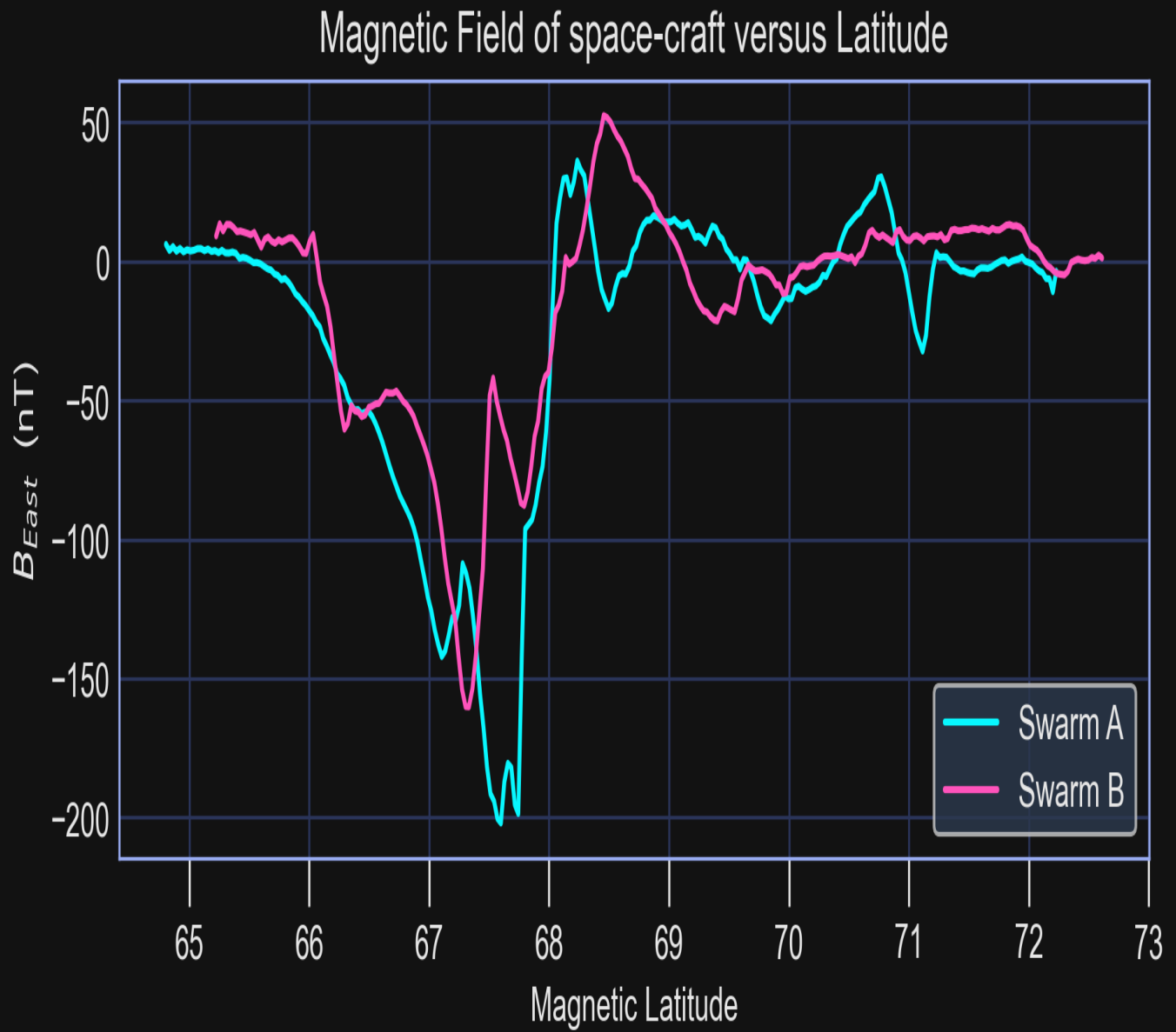
Alfven Waves are NOT modulating aurora here. There must be different effects modulating changes in poynting flux

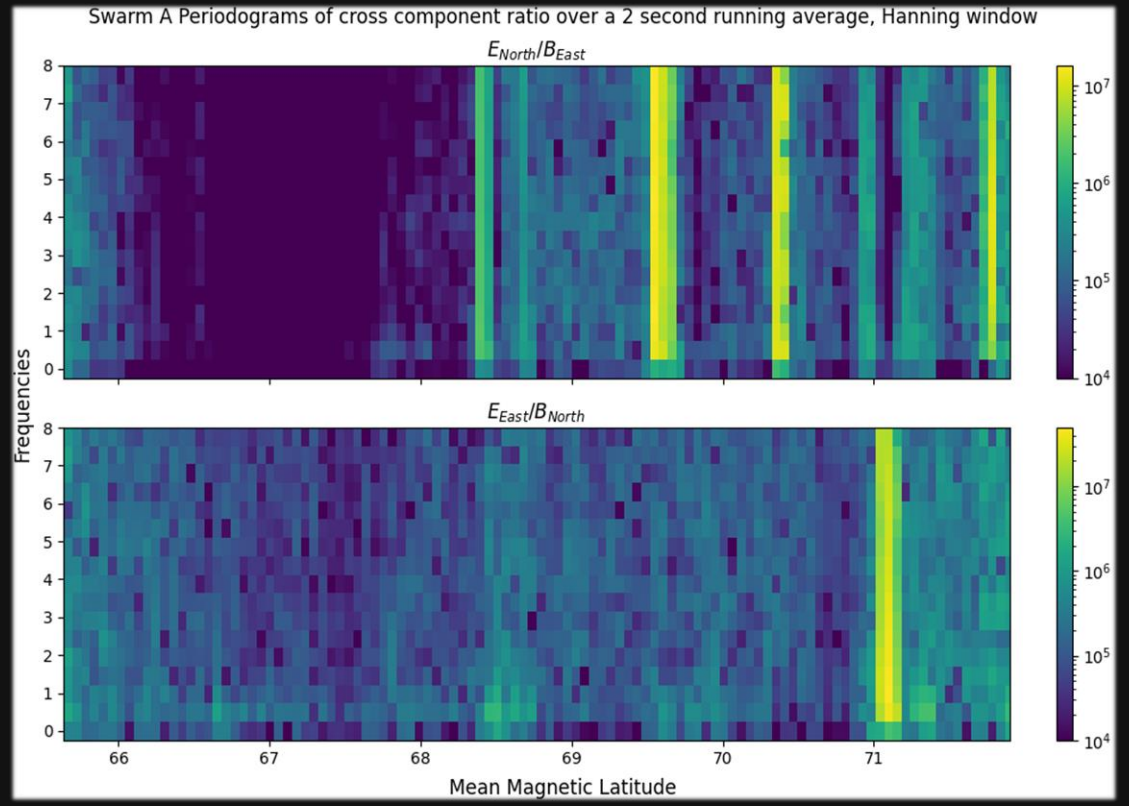
The Dynamic

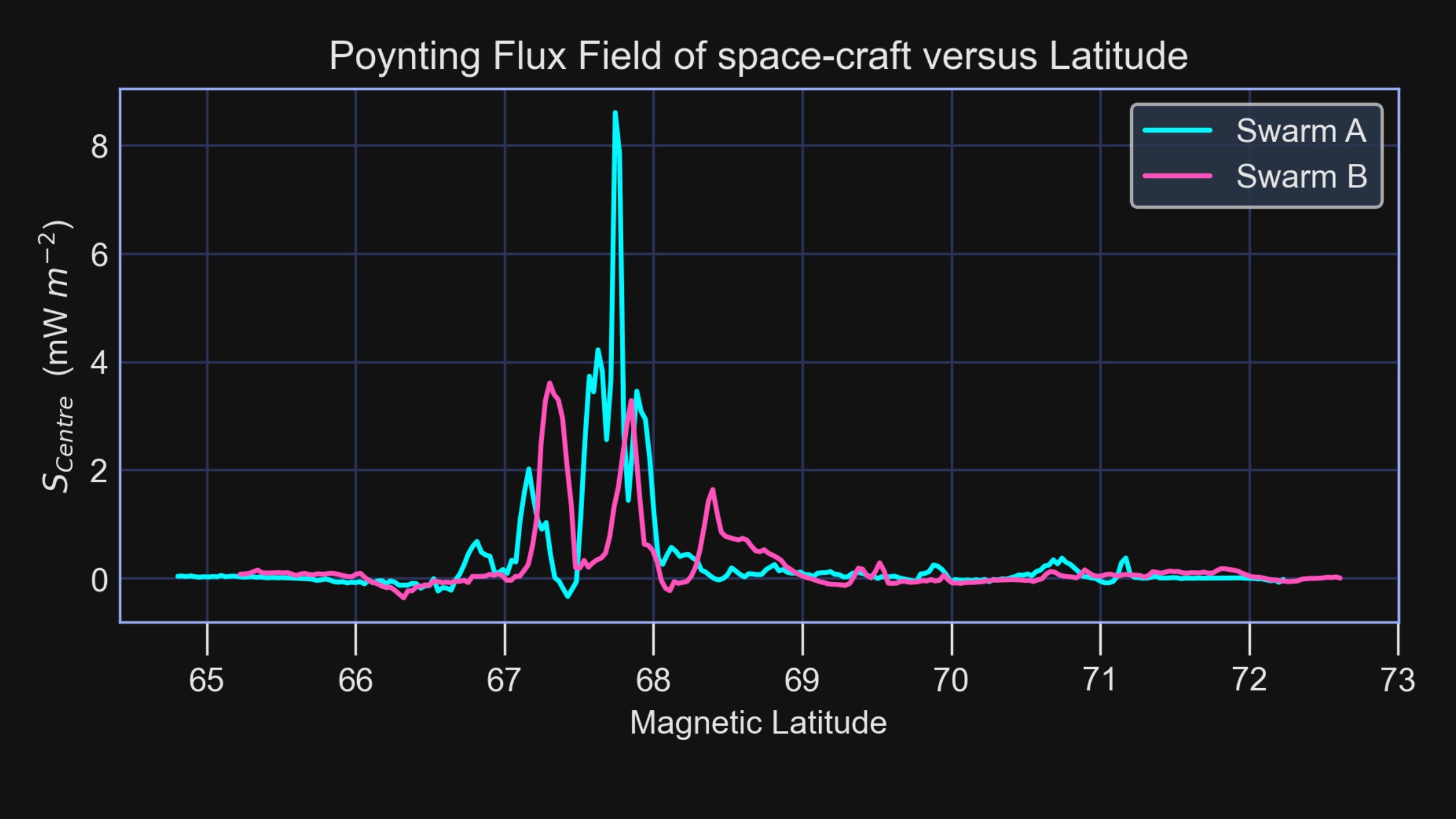


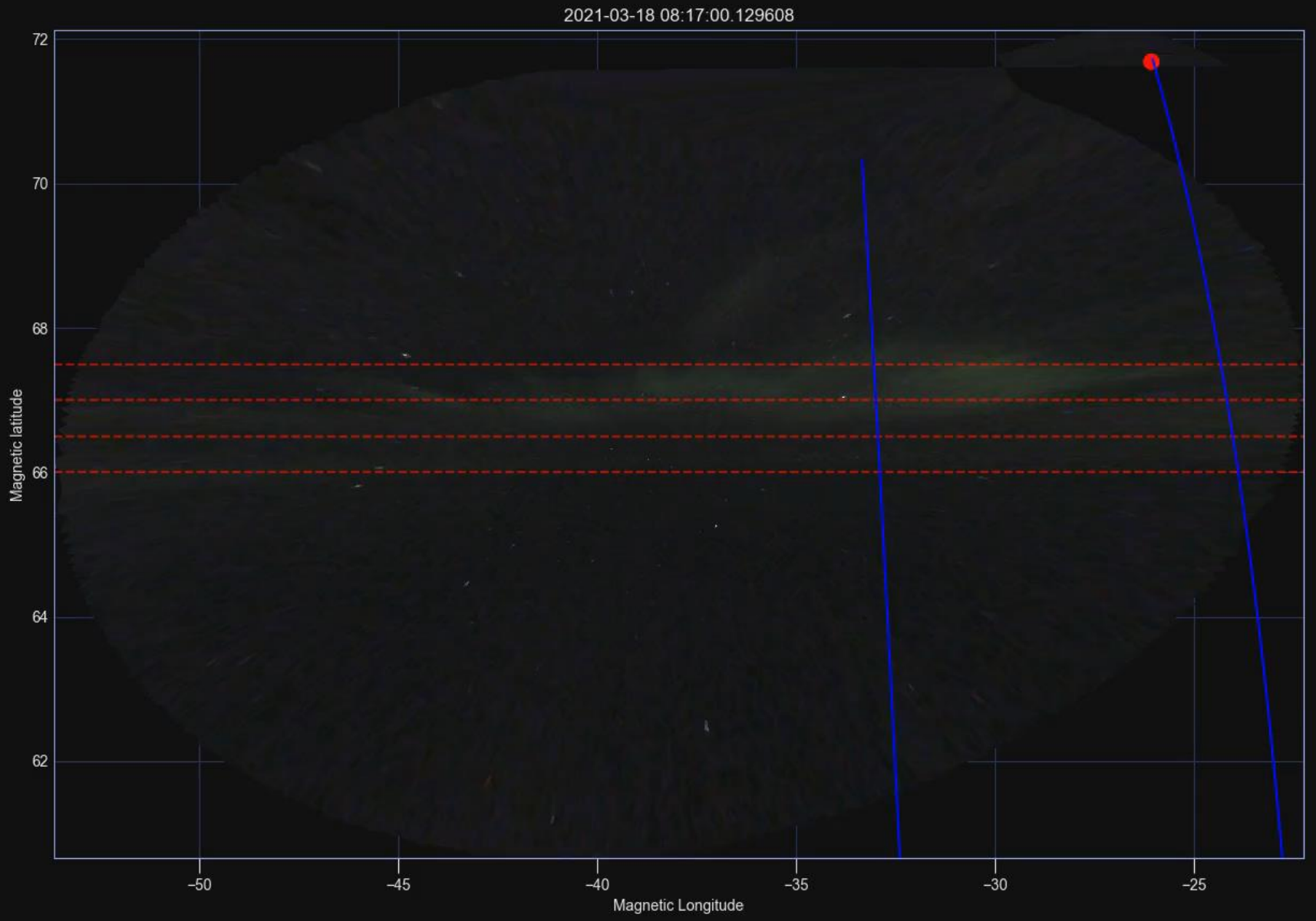
Alfven Waves are quite ubiquitous in our event but how do we quantify the waves themselves?

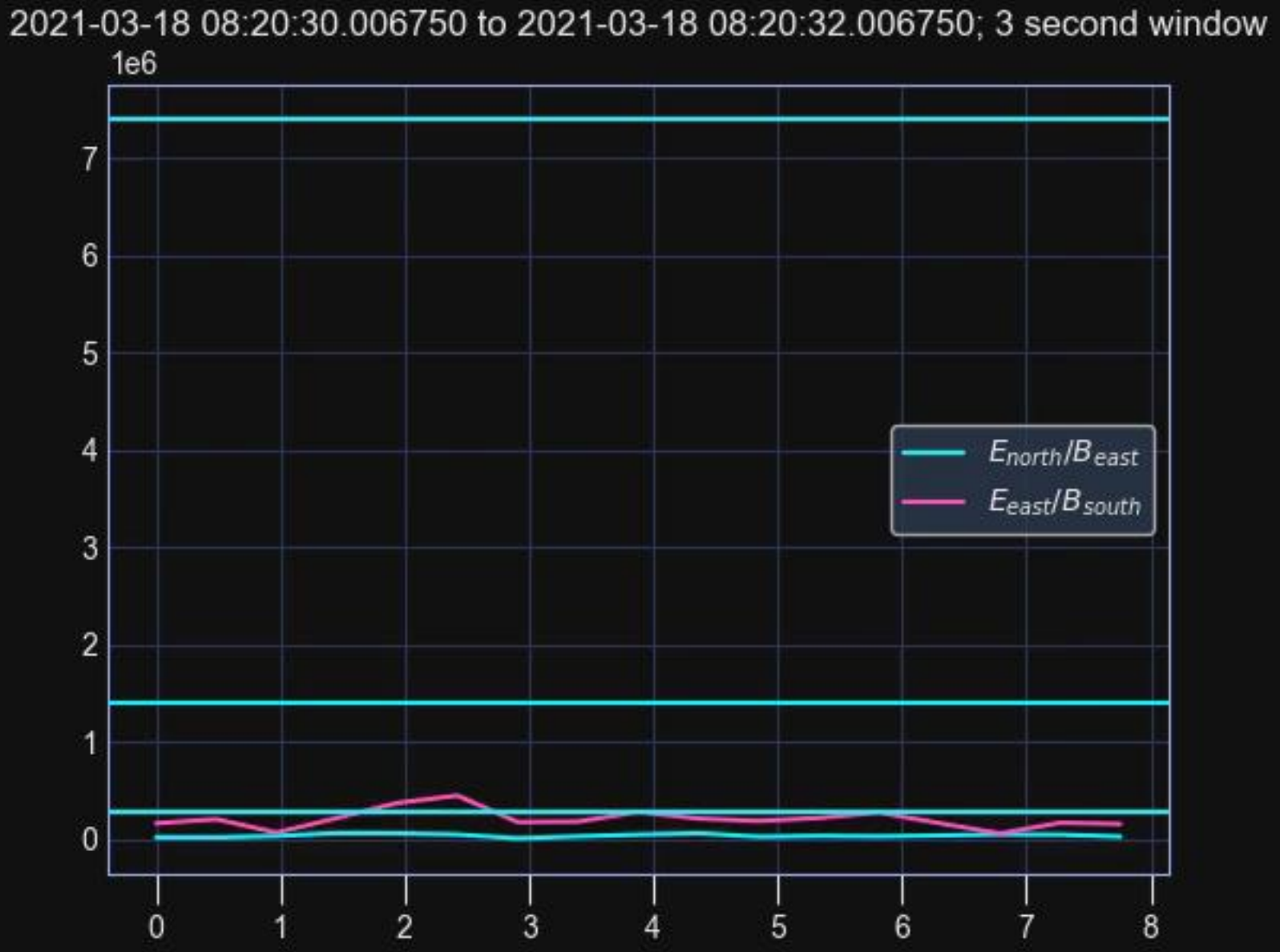

Magnetic Field of space-craft versus Latitude
50
0
−50
−100
−150
−200
B_{East} (nT)
65
66
67
68
69
70
71
72
73
Magnetic Latitude
Swarm A
Swarm B

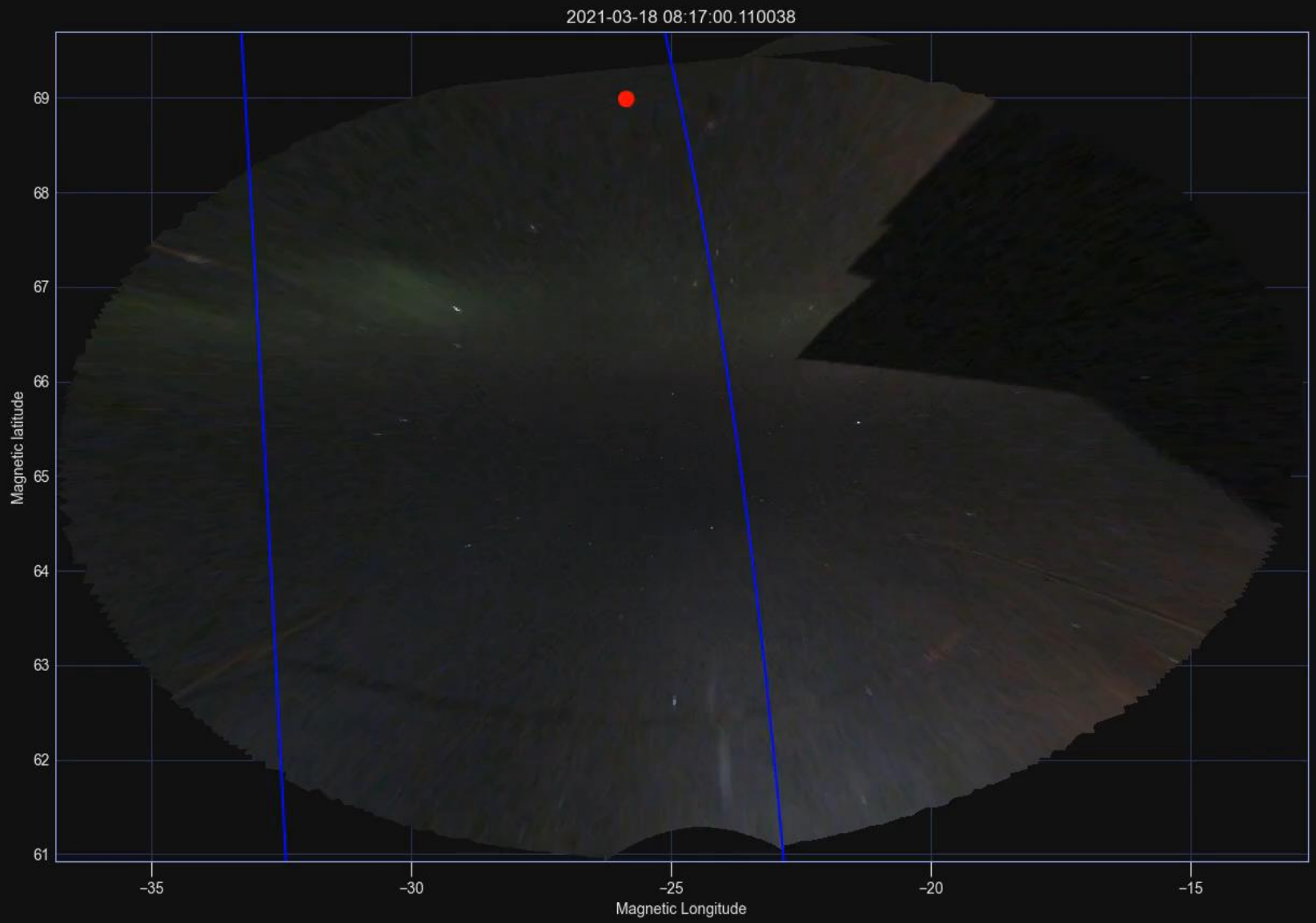

Magnetic Field of space-craft versus Latitude
50
0
-50
-100
-150
-200
B_{East} (nT)
65
66
67
68
69
70
71
72
73
Magnetic Latitude
Swarm A
Swarm B

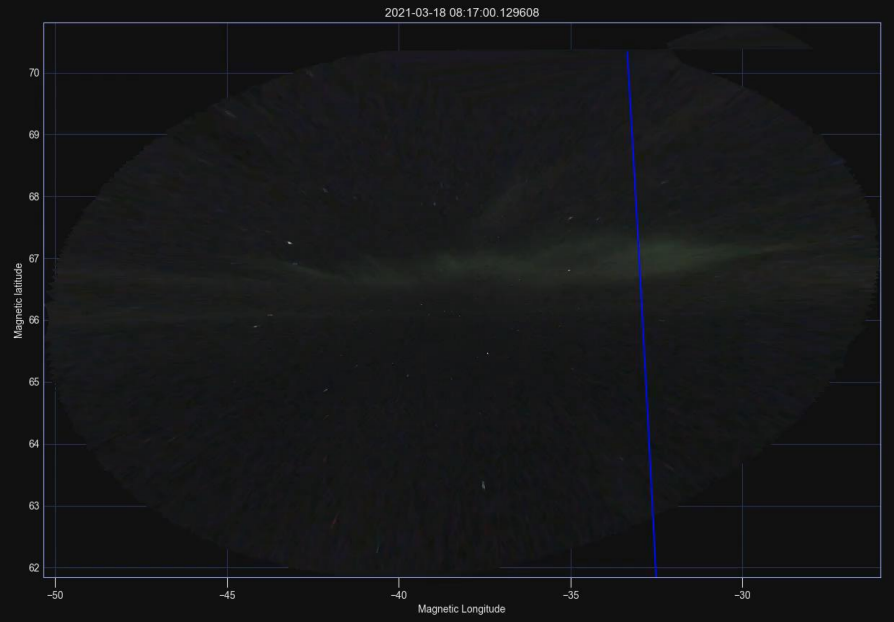

Swarm A Periodograms of cross component ratio over a 2 second running average, Hanning window
E_{North}/B_{East}
E_{East}/B_{North}
Frequencies
0
1
2
3
4
5
6
7
8
10^4
10^5
10^6
10^7
66
67
68
69
70
71
Mean Magnetic Latitude


Poynting Flux Field of space-craft versus Latitude
Swarm A
Swarm B
S_{Centre} (mW m^{-2})
0
2
4
6
8
65
66
67
68
69
70
71
72
73
Magnetic Latitude


2021-03-18 08:17:00.129608
72
70
68
66
64
62
Magnetic latitude
−50
−45
−40
−35
−30
−25
Magnetic Longitude


2021-03-18 08:20:30.006750 to 2021-03-18 08:20:32.006750; 3 second window
1e6
7
6
5
4
3
2
1
0
0
1
2
3
4
5
6
7
8
E_{north}/B_{east}
E_{east}/B_{south}


2021-03-18 08:17:00.110038
69
68
67
66
65
64
63
62
61
Magnetic latitude
−35
−30
−25
−20
−15
Magnetic Longitude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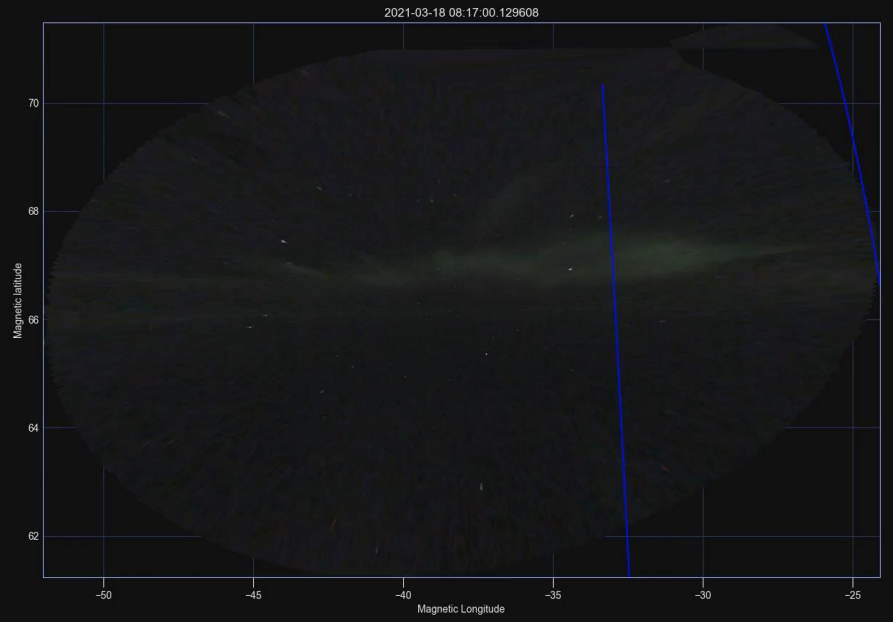
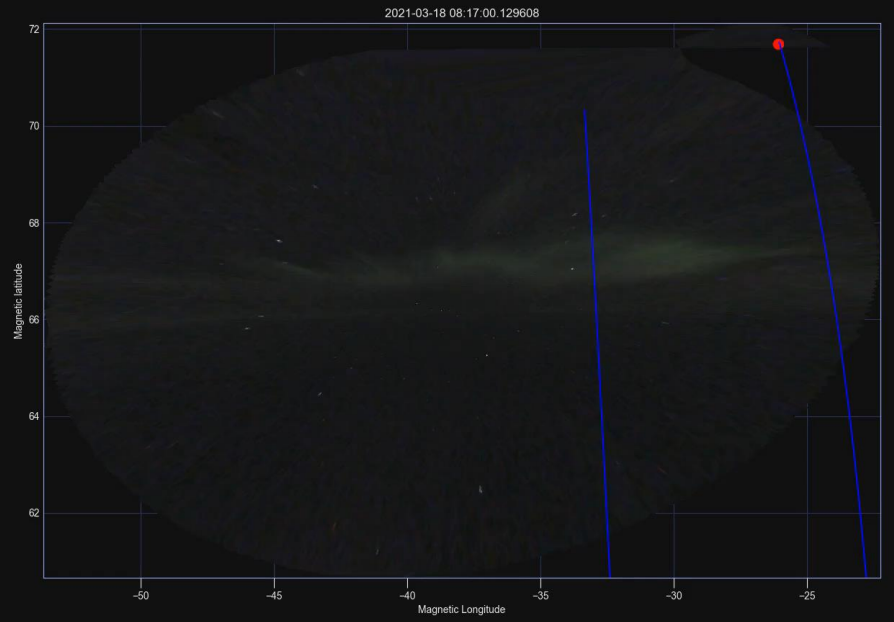
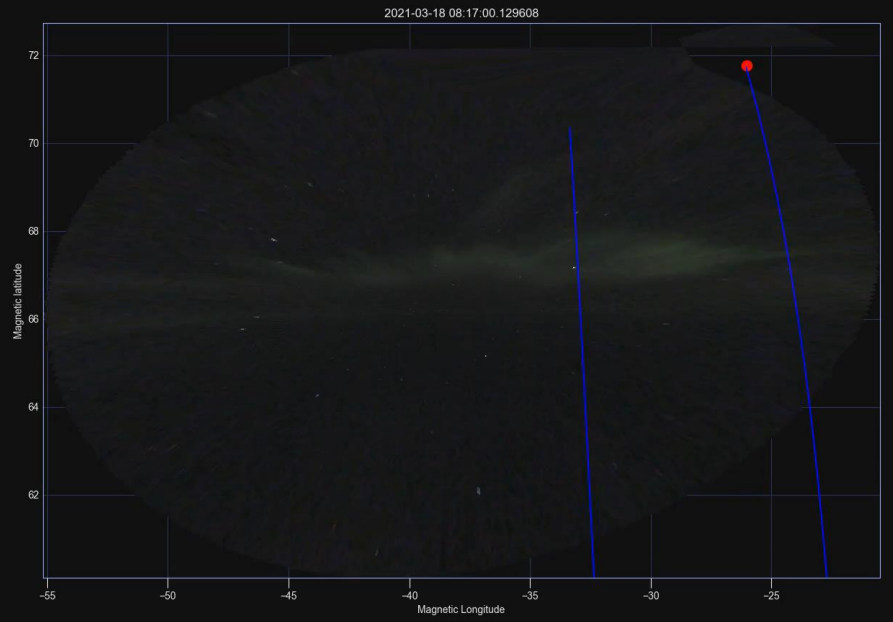
Magnetic latitude
Magnetic Longitude


2021-03-18 08:17:00.129608
Magnetic latitude
Magnetic Longitude


2021-03-18 08:17:00.129608
Magnetic latitude
Magnetic Longitude


2021-03-18 08:17:00.129608
Magnetic latitude
Magnetic Longitude