Ten Years of Ionospheric Electrodynamics with Swarm
From Events to Statistics to Models

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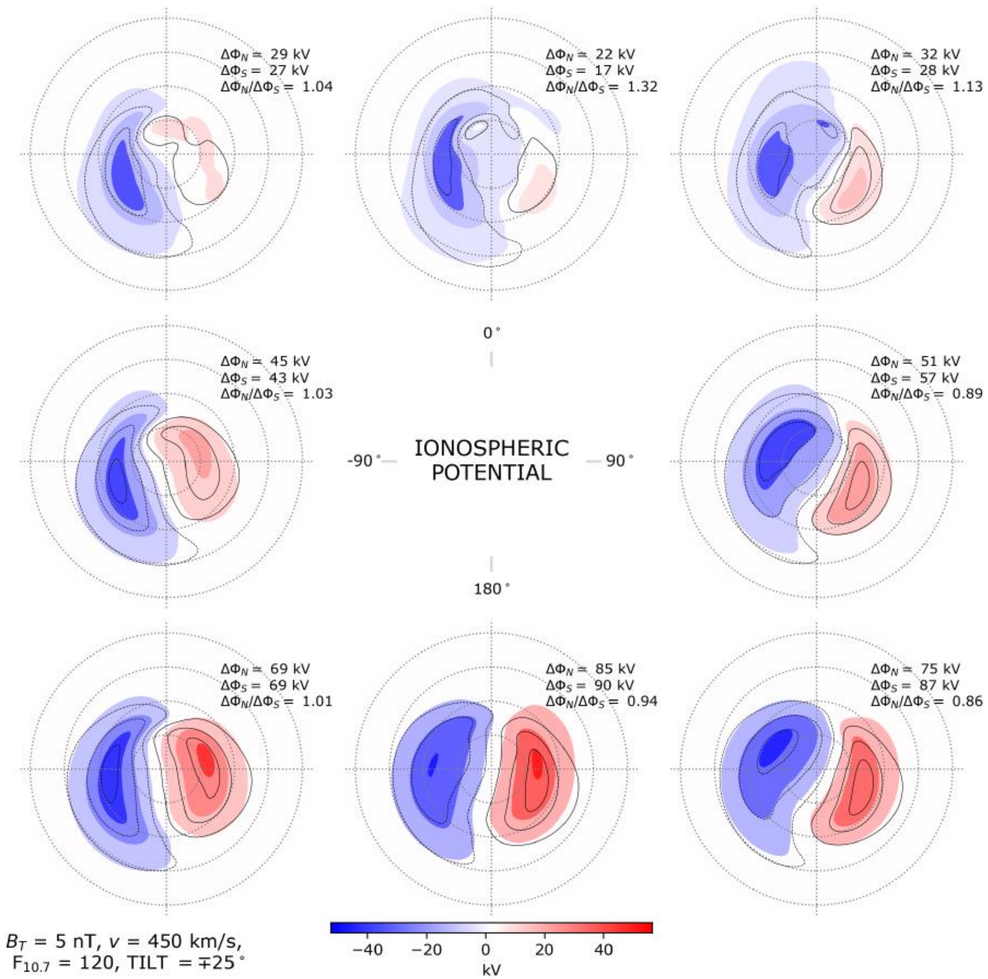
21 February 2024
Edmonton

1.1): Hi-C Model

Swarm High-latitude Convection Model

Electric potential versus IMF clock angle:

Hatch et al., *ANGEO*, in press



- Based on 9 years of Swarm data
- Spherical harmonic fits

- Can be combined with $\delta\mathbf{B}$...

1.1) Hi-C (E - Swarm) + AMPS (δB - CHAMP) = "Swipe"

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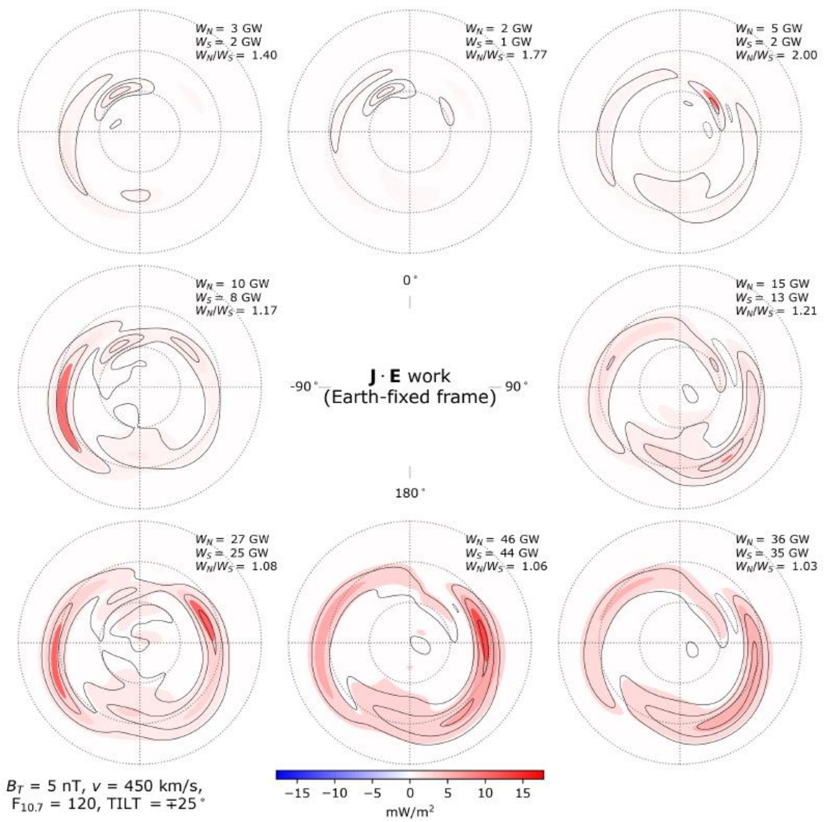
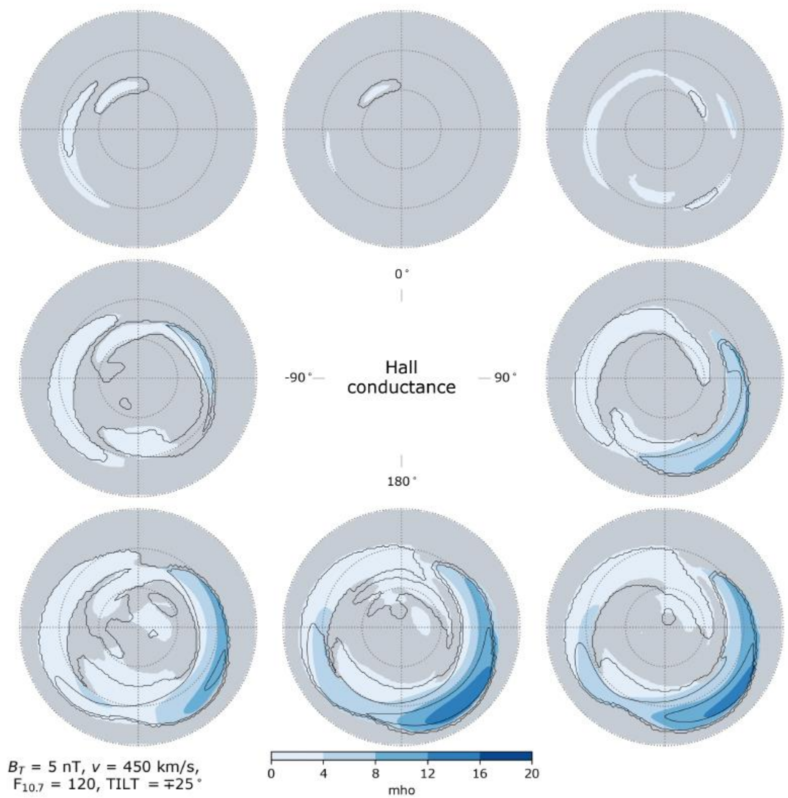
<u>J.E Work:</u>



<u>Conductance</u>:



Hatch et al., *ANGEO*, in press, 2024
Python Package "pyswipe"

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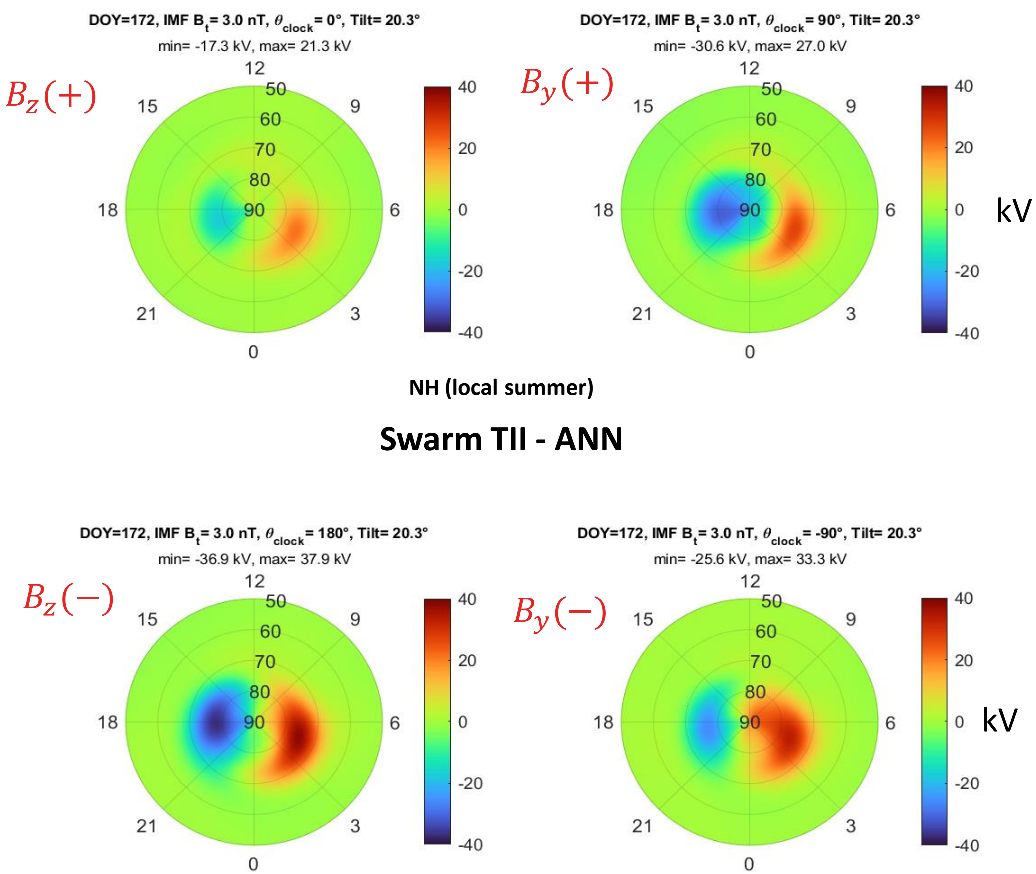
esa

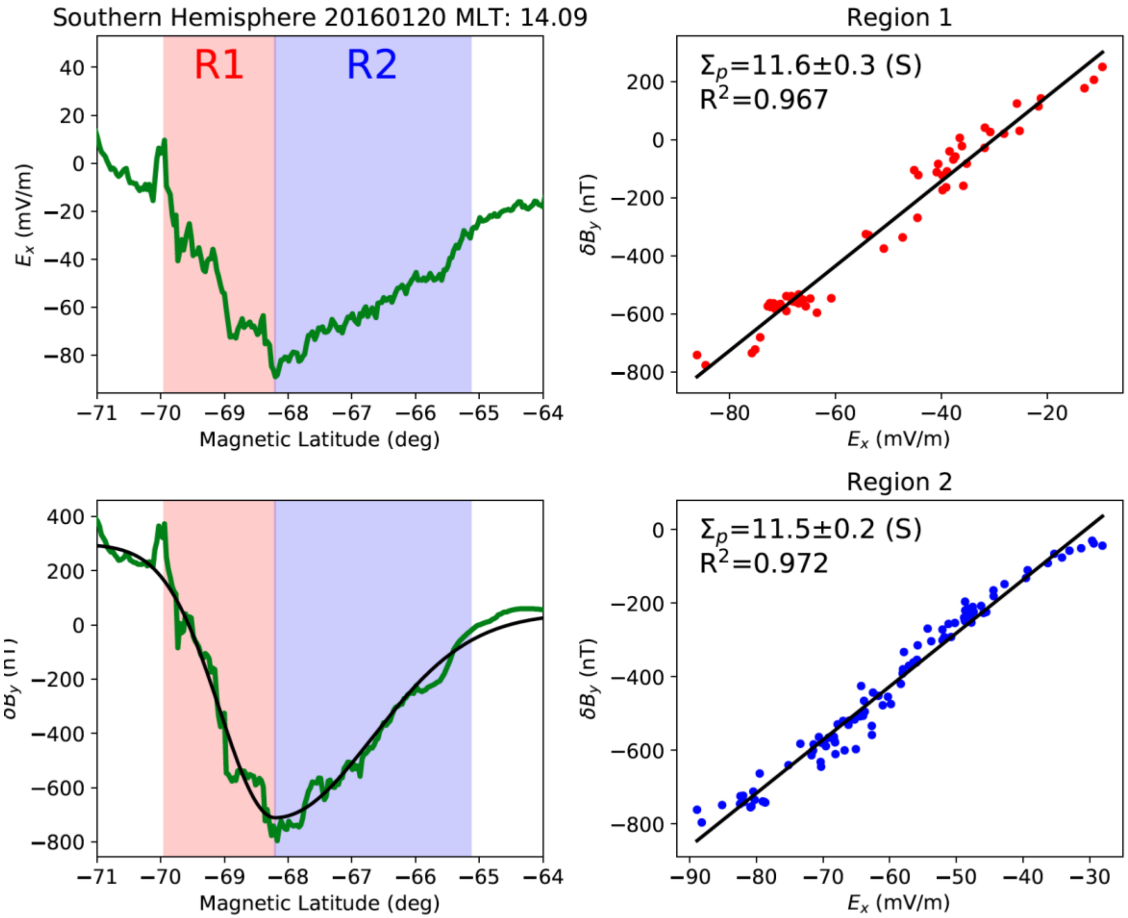
1.2) Swarm TII-ANN Electric Potential Model
Lomidze et al. – talk 16:30 this afternoon



- 9 years of Swarm EFI data (and counting)
- Dependencies on:
  - Season
  - Magnetic Activity
  - Solar Wind
  - Solar Flux (F10.7)
  - Hemisphere

2.1: Ionospheric Conductance

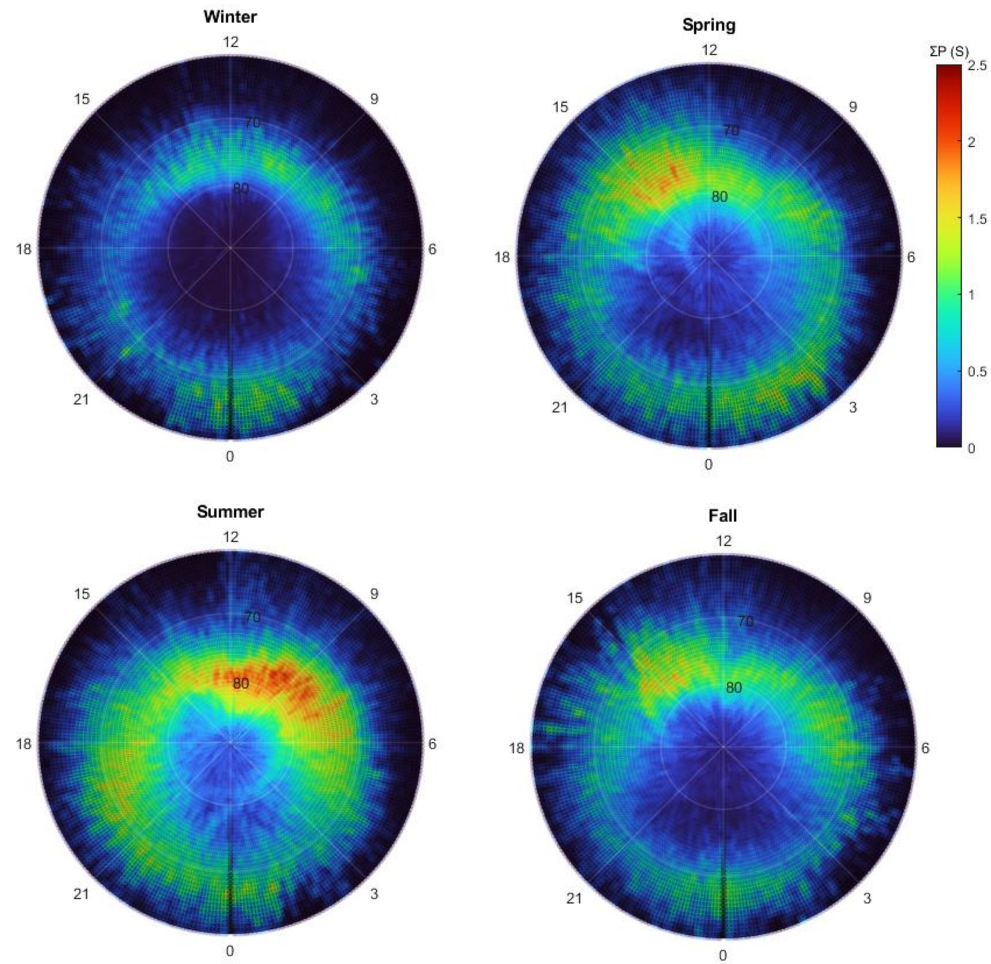
Olifer, L., C. Feltman, R. Ghaffari, S. Henderson, D. Huyghebaert, J. Burchill, A. Jaynes, D. Knudsen, K. McWilliams, J. Moen, A. Spicher, J. Wu , **Swarm Observations of Dawn-Dusk Asymmetries Between Pedersen Conductance in Upward and Downward Field-Aligned Current Regions**, *Earth and Space Science*, 2021



Conclusion:

Dawn-sector $\boldsymbol{\Sigma}_\mathrm{P}$ slightly higher

2.2 – Conductance



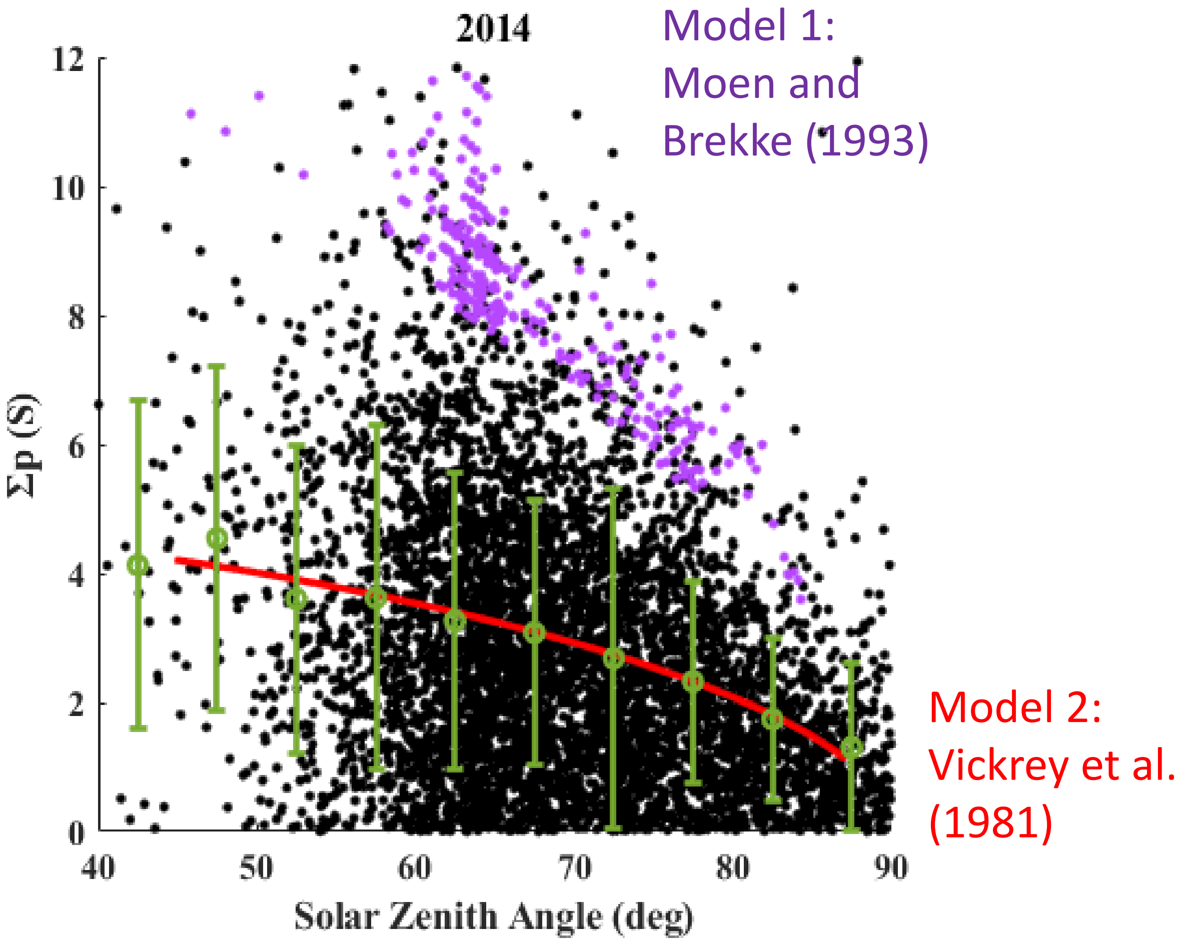
Pourkarim, MSc thesis, 2023 (publication in prep)

- $\sum_P = \delta B_y / \mu_0 E_x$

- ~500 km altitude
- 9 years
- 10-s bins (76 km)

2.2 – Conductance vs SZA

Pourkarim, MSc thesis, 2023 (publication in prep)



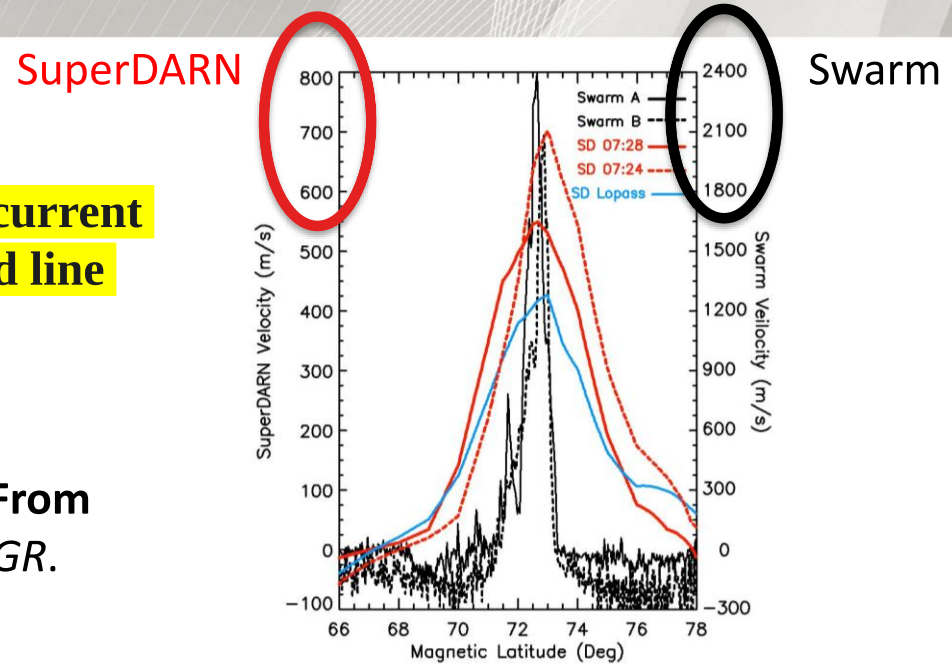
- $\sum_P = \delta B_y / \mu_0 E_x$

- Huge scatter, but
- Reasonable mean

➔ Why?

- Assumes:
  - Static fields
  - Sheet-like
  - No $\mathbf{J}_{Hall}$ contrib

3 - Intense flow channels



3.6) Fenrich, et al., 2021: **Birkeland current boundary flows associated with field line resonances**. *J. Geophys. Res.*, 2021.

3.5) Archer and Knudsen, 2018: **Distinguishing Subauroral Ion Drifts From Birkeland Current Boundary Flows**, *JGR*.

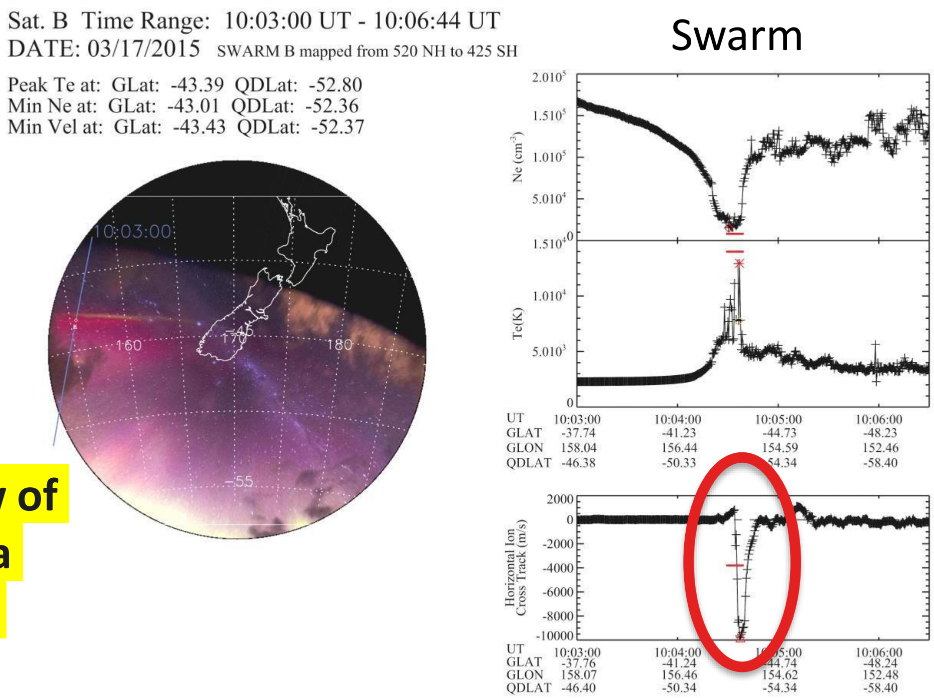
3.4) Aikio et al., 2018: **Swarm satellite and EISCAT radar observations of a plasma flow channel in the auroral oval near magnetic midnight**, *JGR*.

3.3) Archer et al., 2017: **Birkeland current boundary flows**, *JGR*.

3.2) Juusola et al., 2016: **Ionospheric Conductances and Currents of a Morning-Sector Auroral Arc From Swarm-A Electric and Magnetic Field Measurements**, *GRL.*

3.1) Archer et al., **Anisotropic core ion temperatures associated with strong zonal flows and upflows**, GRL, 2015.

4: Intense Flow Channels - STEVE



Swarm

4.3) Martinis, C., et al., 2022: **Rainbow of the Night: First Direct Observation of a SAR arc evolving into STEVE**. *Geophys. Res. Lett.*, 2022.

4.2.) Nishimura, Y. 2019: **Magnetospheric signatures of STEVE: Implications for the magnetospheric energy source and interhemispheric conjugacy**. *Geophys. Res. Lett*, 2019.

10 km/s!

4.1) MacDonald et al., 2018: **New Science in Plain Sight: Citizen Scientists Lead to Discovery of Optical Structure in the Upper Atmosphere**, *Science Advances.*

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5: Auroral Arcs

5.6) Wu et al., 2020: **Swarm survey of Alfvénic fluctuations and their relation to nightside field-aligned current and auroral arc systems**. *JGR*.

5.5) Gillies et al., 2018: **A statistical survey of the 630.0 nm optical signature of periodic auroral arcs resulting from magnetospheric field line resonances**, GRL.

5.4) Wu et al., 2017: **Swarm Observation of Field-Aligned Currents Associated With Multiple Auroral Arc Systems**, *JGR.*

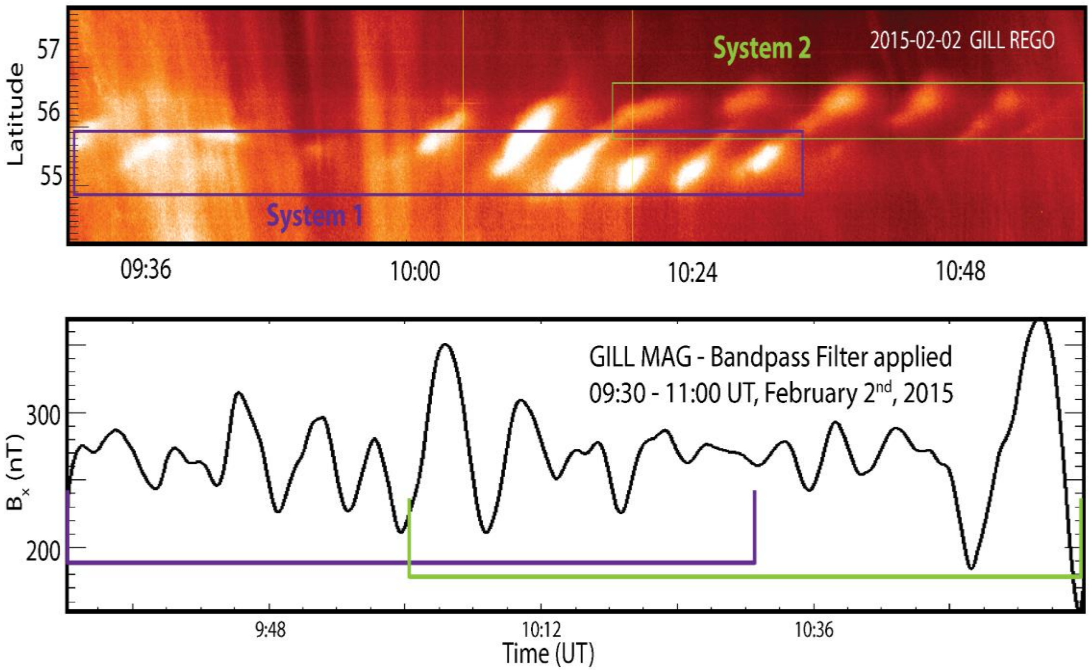
5.3) Gillies et al., 2015: **Swarm observations of field-aligned currents associated with pulsating auroral patches**, *JGR.*

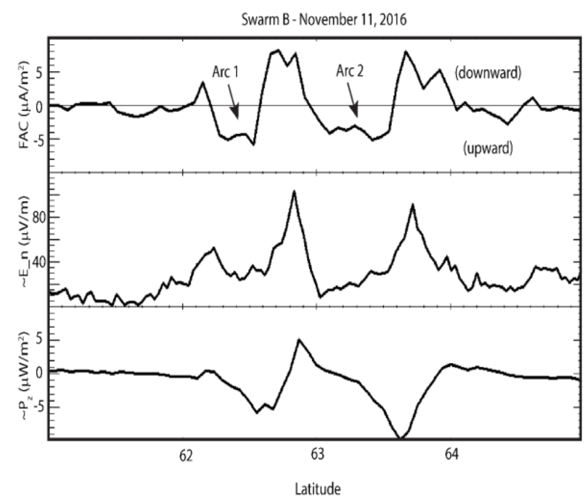
5.2) Juusola et al., 2016: **Ionospheric Conductances and Currents of a Morning-Sector Auroral Arc From Swarm-A Electric and Magnetic Field Measurements**, *GRL.*

5.1) Aikio et al., 2018: **Swarm satellite and EISCAT radar observations of a plasma flow channel in the auroral oval near magnetic midnight**, *JGR.*

5.5: Auroral Arcs - Example

5.5) Gillies et al., 2018: **A statistical survey of the 630.0 nm optical signature of periodic auroral arcs resulting from magnetospheric field line resonances**, GRL.





6: Alfvén waves

6.6) Ghadjari, H. et al., **Post-sunset field-line resonances at equatorial latitudes observed by Swarm**, GRL, 2023.

6.5) Ghadjari, H. et al., 2022: **Standing Alfvén waves within equatorial plasma bubbles**. *Geophys. Res. Lett*.

6.4) Ivarsen et al., 2023: **Observational evidence for the role of Hall conductance in Alfvén wave reflection**, *JGR*.

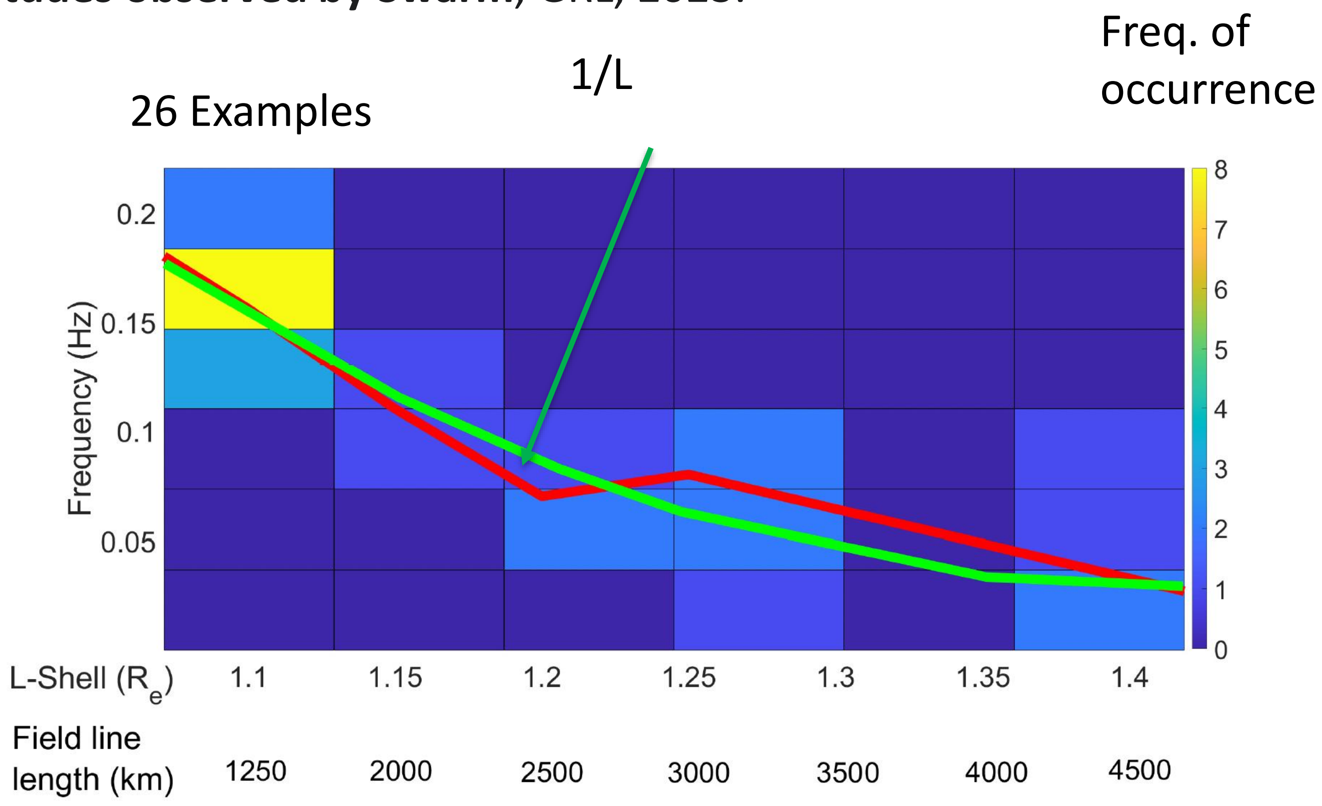
6.3) Wu et al., 2020: **Swarm survey of** Alfvénic **fluctuations and their relation to nightside field-aligned current and auroral arcs systems**, JGR.

6.2) Miles et al., **Alfvénic dynamics and fine structuring of discrete auroral arcs: Swarm and e-POP observations**, *GRL*, 2018.

6.1) Pakhotin et al., **Diagnosing the Role of Alfvén Waves in Magnetosphere-Ionosphere Coupling: Swarm Observations of Large Amplitude Nonstationary Magnetic Perturbations During an Interval of Northward IMF**, *JGR*, 2018.

6: Field-line resonances - example

6.5) Ghadjari, H. et al., **Post-sunset field-line resonances at equatorial latitudes observed by Swarm**, GRL, 2023.



6.7) Naeem et al., **Searching for the auroral signature of Alfvénic turbulence**

DASP presentation Thursday morning, 10:15

7: Poynting Flux

7.6) Billett, D.D., et al. **High-resolution Poynting flux statistics from the Swarm mission: How much is being underestimated at larger scales**? *JGR*, 2022.

7.5) Rodríguez-Zuluaga, et al. 2022. **Topside equatorial spread F-related field-aligned Poynting flux: observations and simulations**. *Earth, Planets and Space*, *74*(1), 2022.

7.4) Pakhotin, I.P., Mann, I.R., Xie, K. *et al.* **Northern preference for terrestrial electromagnetic energy input from space weather**. *Nat Commun.*, (2021).

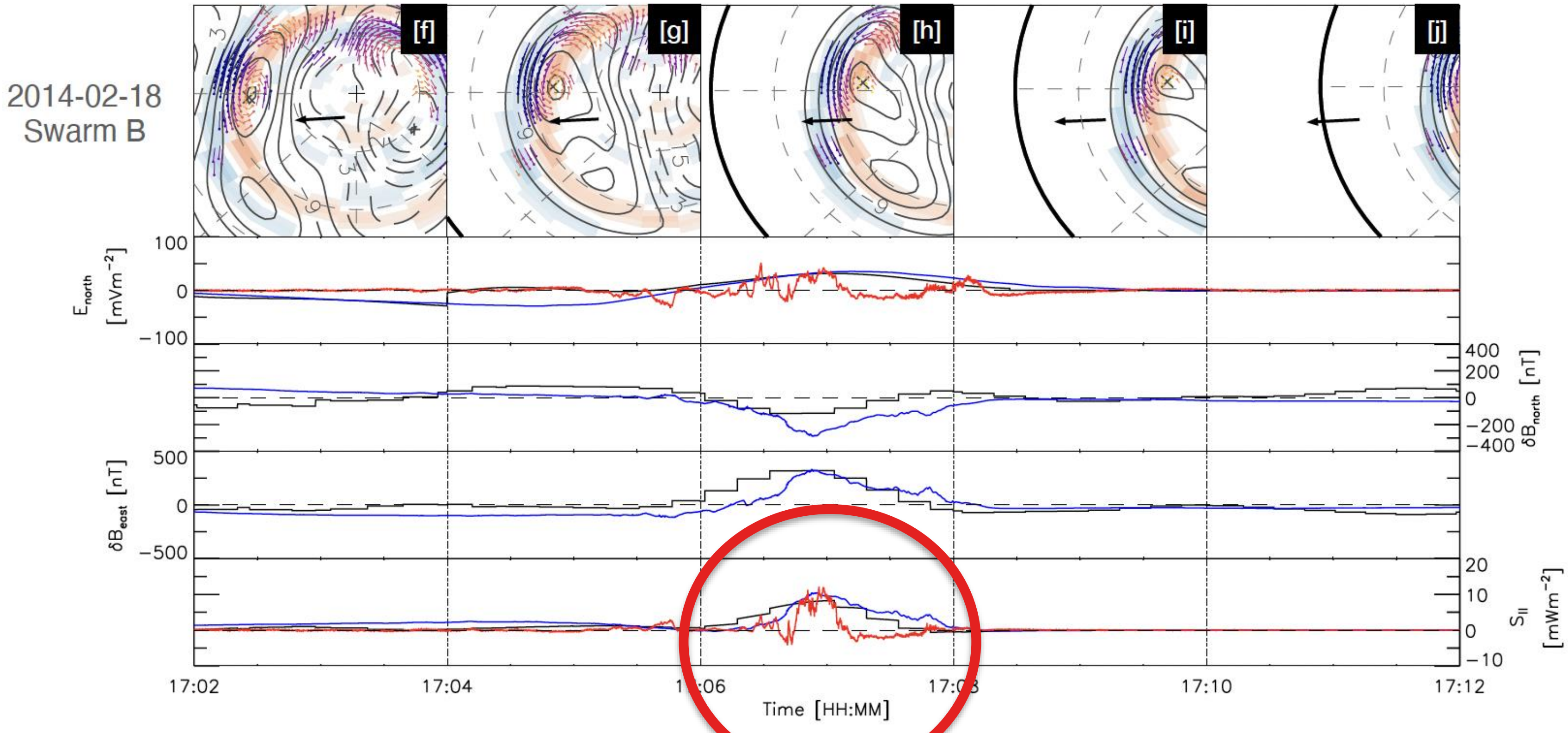
7.3) Rodríguez-Zuluaga et al, **On the direction of the Poynting flux associated with equatorial plasma depletions as derived from Swarm**, *GRL*, 2017.

7.2) Park et al., **Alfvén waves in the auroral region, their Poynting flux, and reflection coefficient as estimated from Swarm observations**, *JGR*, 2017
Swarm, *GRL*, 2017.

7.1) Park et al., **Statistical survey of nighttime midlatitude magnetic fluctuations: Their source location and Poynting flux as derived from the Swarm constellation**, *JGR*, 2016.

7: Poynting Flux - example

7.7) Billett et al., 2023: **Multi-scale Ionospheric Poynting Fluxes Using Ground and Space-Based Observations,** *JGR*.



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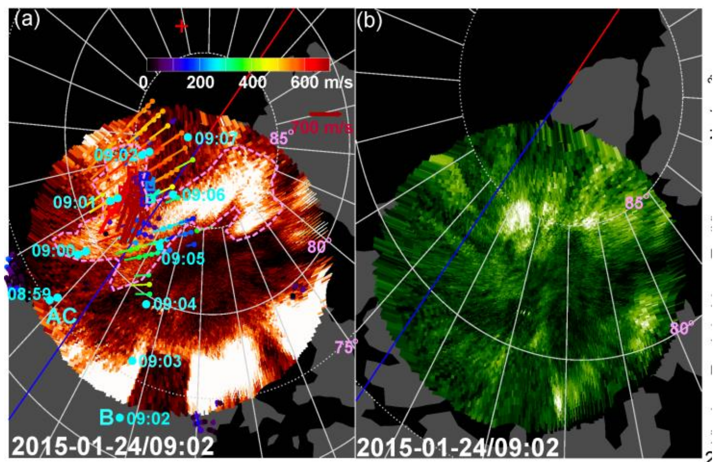
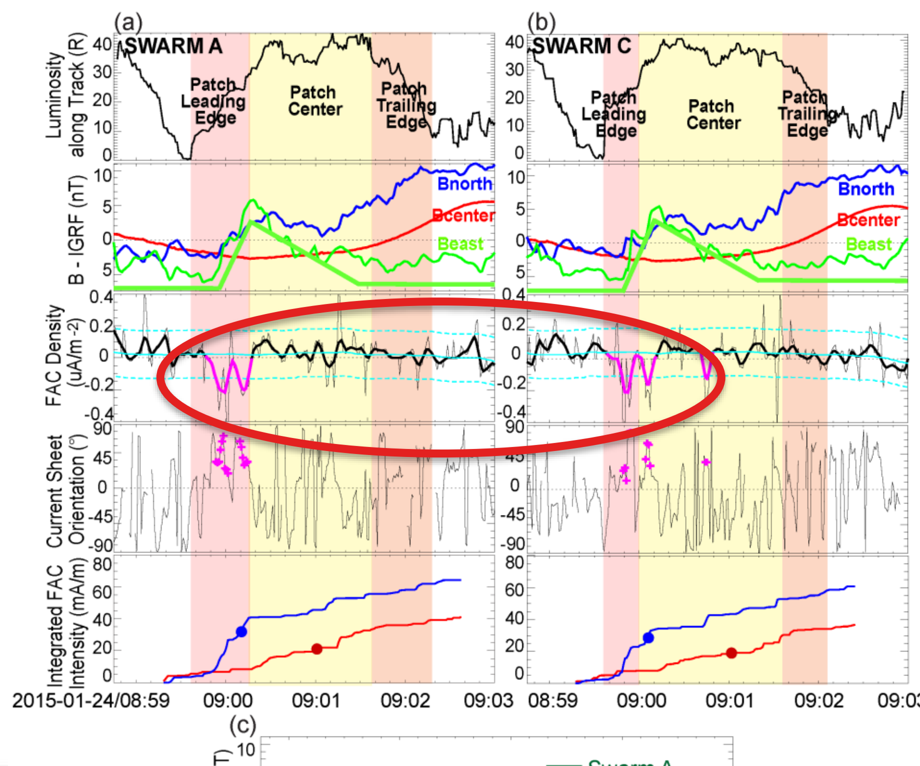
8: Polar Cap Patches

8.1) Spicher et al., **Observation of polar cap patches and calculation of gradient drift instability growth times: A Swarm case study**, *GRL*, 2015.

8.2) Goodwin et al., **Swarm in situ observations of F-region polar cap patches created by cusp precipitation**, *GRL*, 2015.

8.3) Zou et al., **Localized field-aligned currents in the polar cap associated with airglow patches**, *JGR*, 2016.





9: Instrument, Calibration, & Validation

9.5) Burchill and Knudsen (2022): **Swarm Thermal Ion Imager measurement performance.** *Earth, Planets and Space.*

9.4) Lomidze et al., 2019: **Validity study of the Swarm horizontal cross-track ion drift velocities in the high-latitude ionosphere**, *Earth and Space Science.* Ion drifts consistent with Weimer (2005)

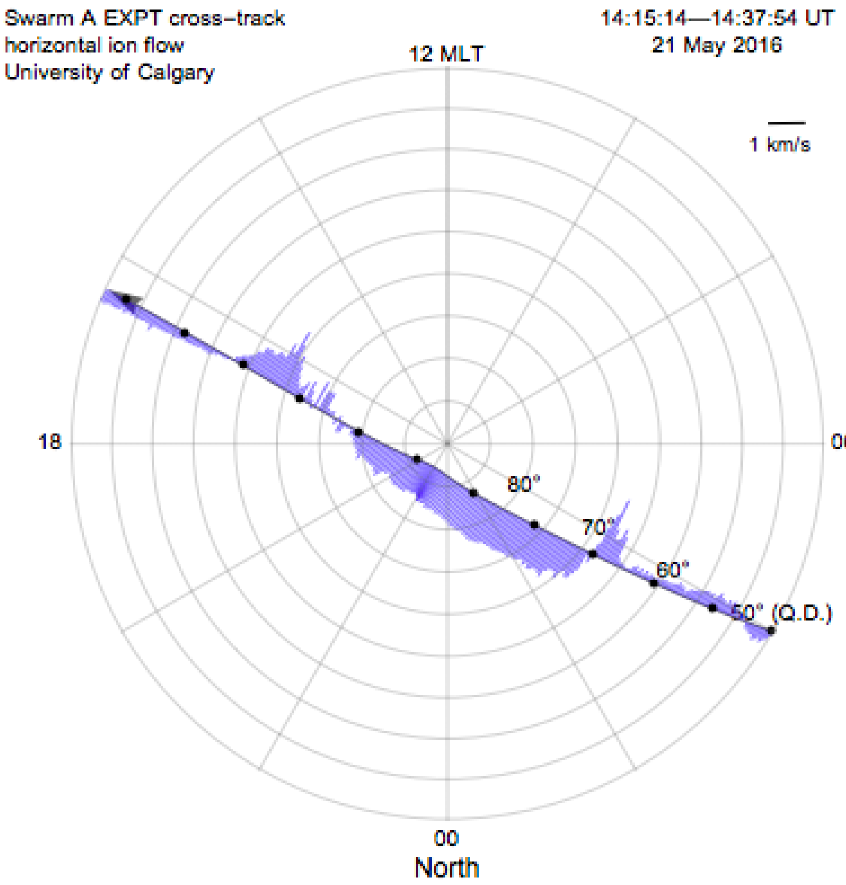
9.3) Koustov et al., 2018: **A comparison of cross-track ion drift measured by the Swarm satellites and plasma convection velocity measured by SuperDARN**. *JGR.*

9.2) DJ Knudsen, JK Burchill, SC Buchert, AI Eriksson, Reine Gill, J-E Wahlund, Lennart Åhlén, M Smith, B Moffat., **Thermal ion imagers and Langmuir probes in the Swarm electric field instruments**, *JGR*, 2017.

9.1) Fiori et al., 2016: **Calibration and assessment of Swarm ion drift measurements using a comparison with a statistical convection model**, *Earth, Planets and Space.*

TII Data availability and acknowledgements

- Cross-track velocity available through Sept 2023. See esa.int/Swarm
- ESA Swarm operations funded through Dec 2025
- Extension to 2030+ is possible



Thanks to:
ESA, DISC, PLSO and ARB board
Swarm EFI Science Discussion Group
Canadian Space Agency