SWARM 10 YEAR ANNIVERSARY SCIENCE CONFERENCE

Canada's Role in Swarm and the Thermal Ion Imagers

David Knudsen and Johnathan Burchill
University of Calgary

Swarm 10 Year Anniversary & Science Conference 2024

Why E?

$$\Sigma_P = \delta B_\perp / (\mu_0 E_\perp)$$

$$\vec{S} = \vec{E} \times \delta\vec{H}$$

$$\emptyset = \int \vec{E} \cdot d\vec{l}$$

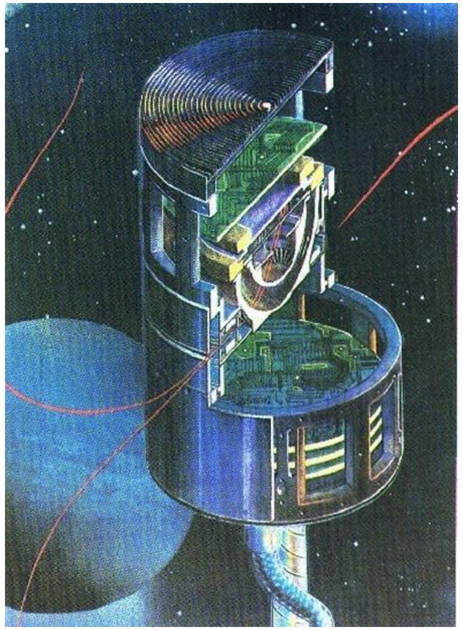
Why ions & TII ?

- $\vec{E} = -\vec{v}_i \times \vec{B}$
- Plasma dynamics

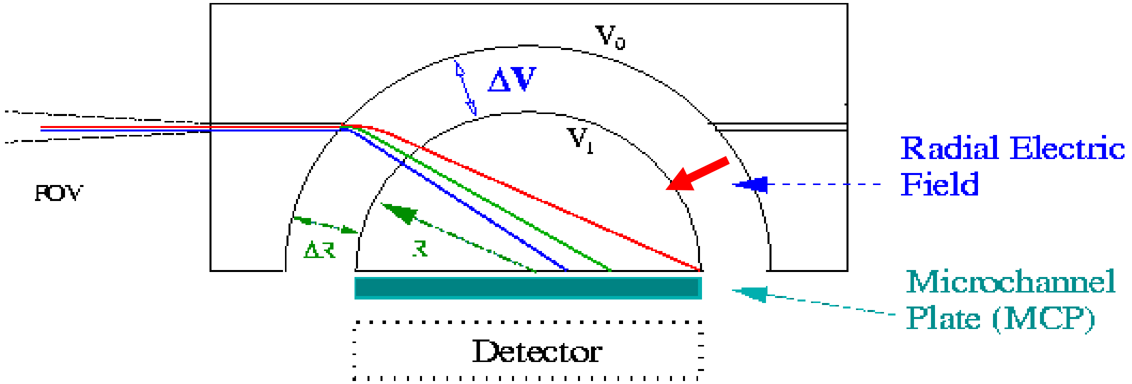
Why Canada?

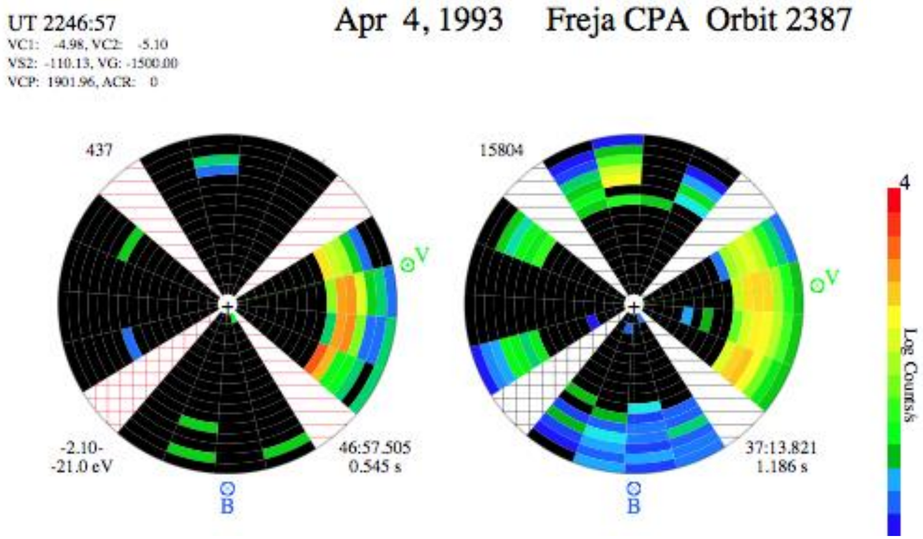
- Canada is an ESA "Cooperating State"
- Heritage w/ low energy ion measurements

Ion Distribution Imaging



Whalen et al. (1994)

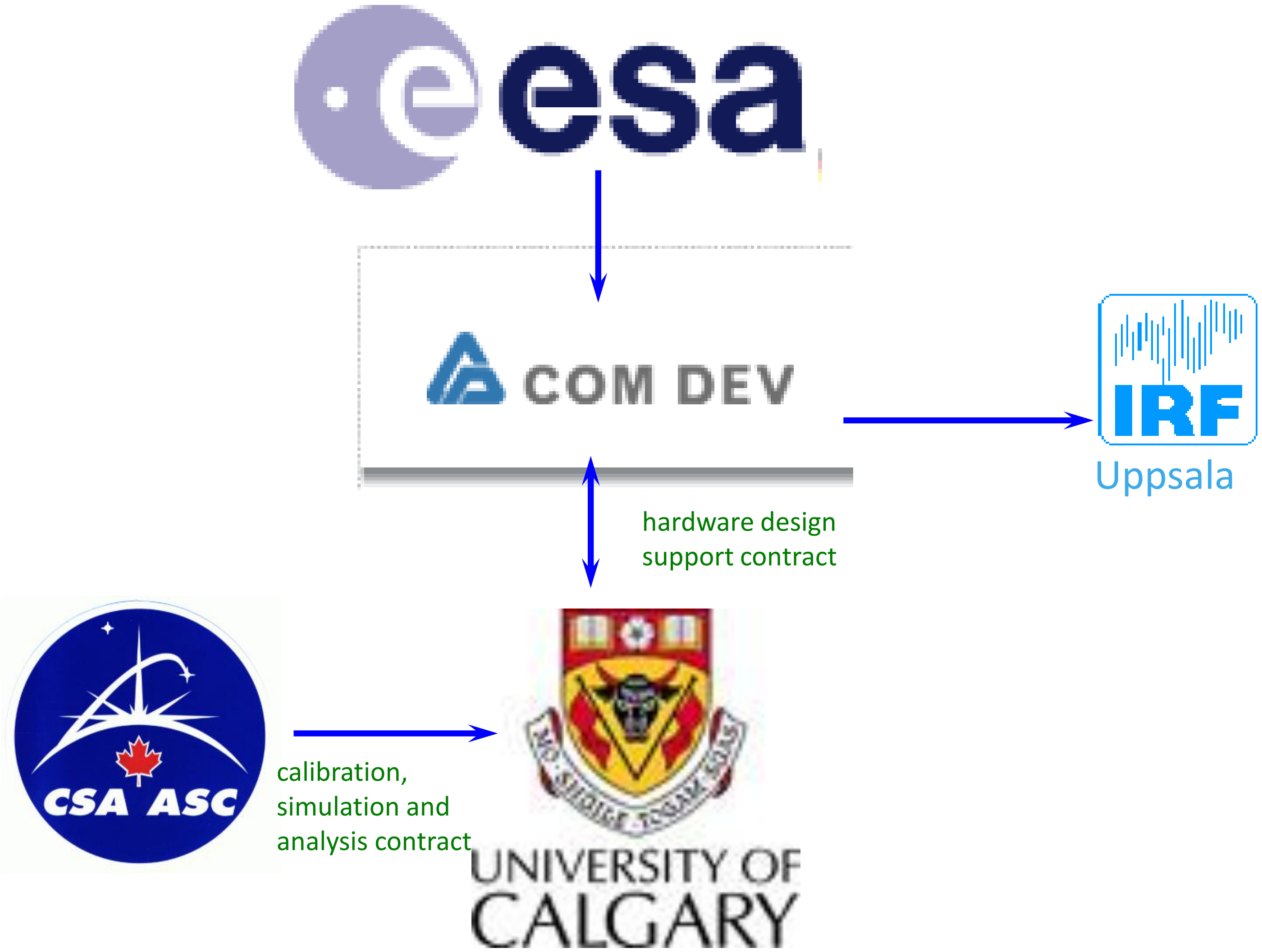




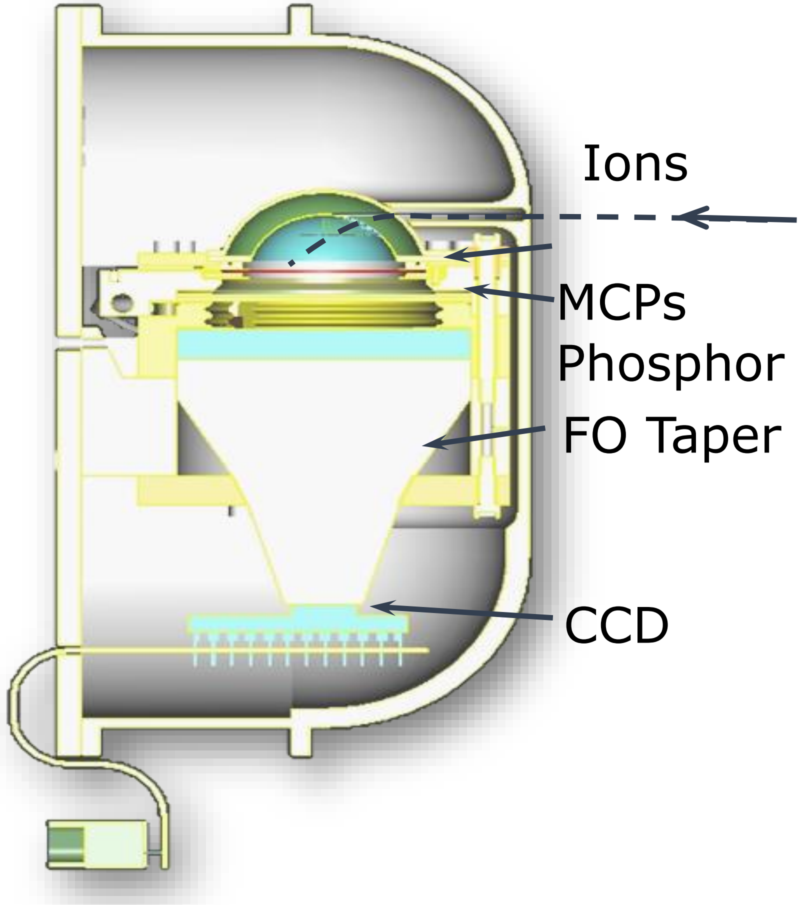
Clear need for improved detector:

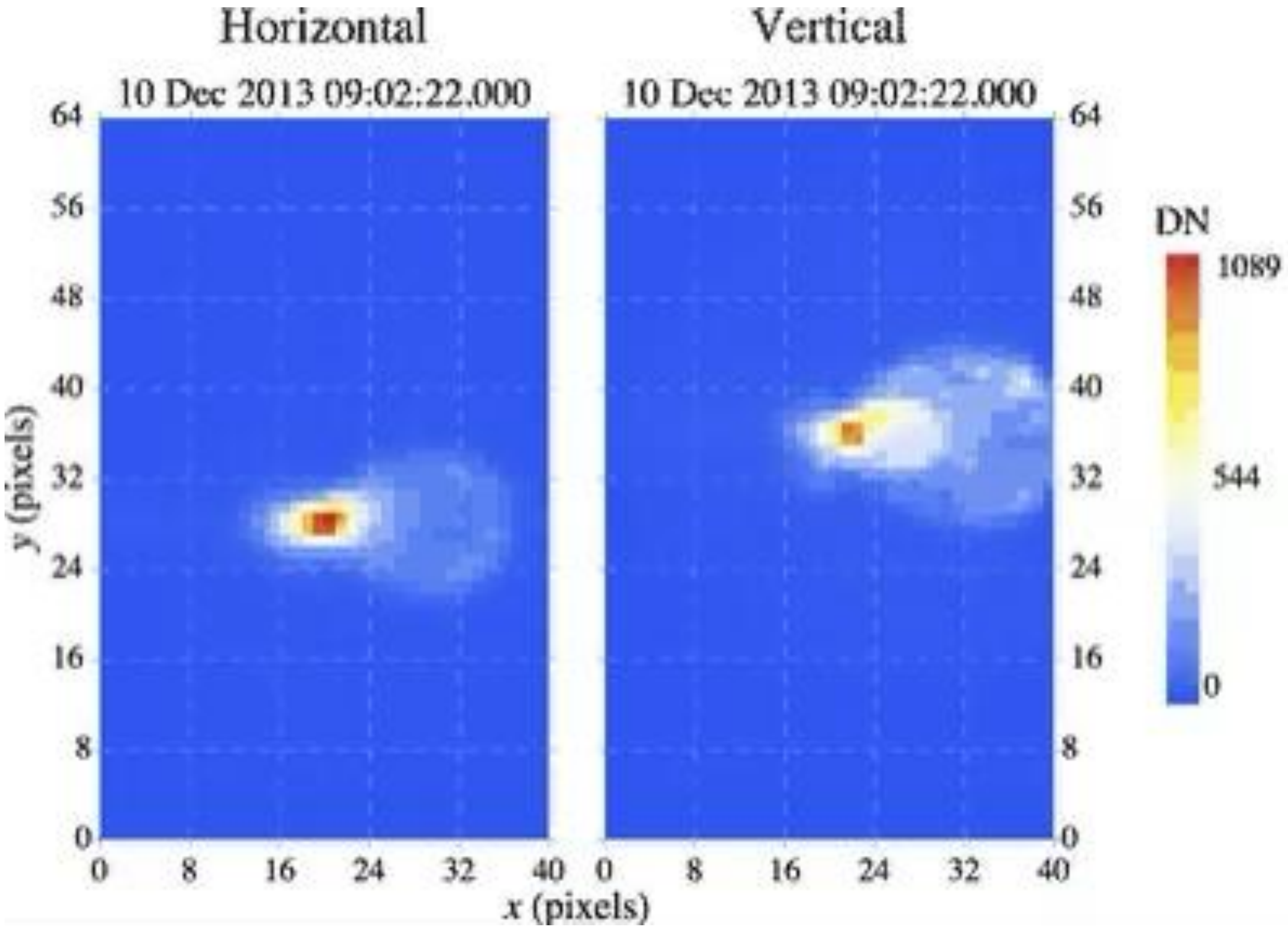
- Sounding rockets (2000-2007)
- ePOP
- Swarm

Swarm EFI (2004+)

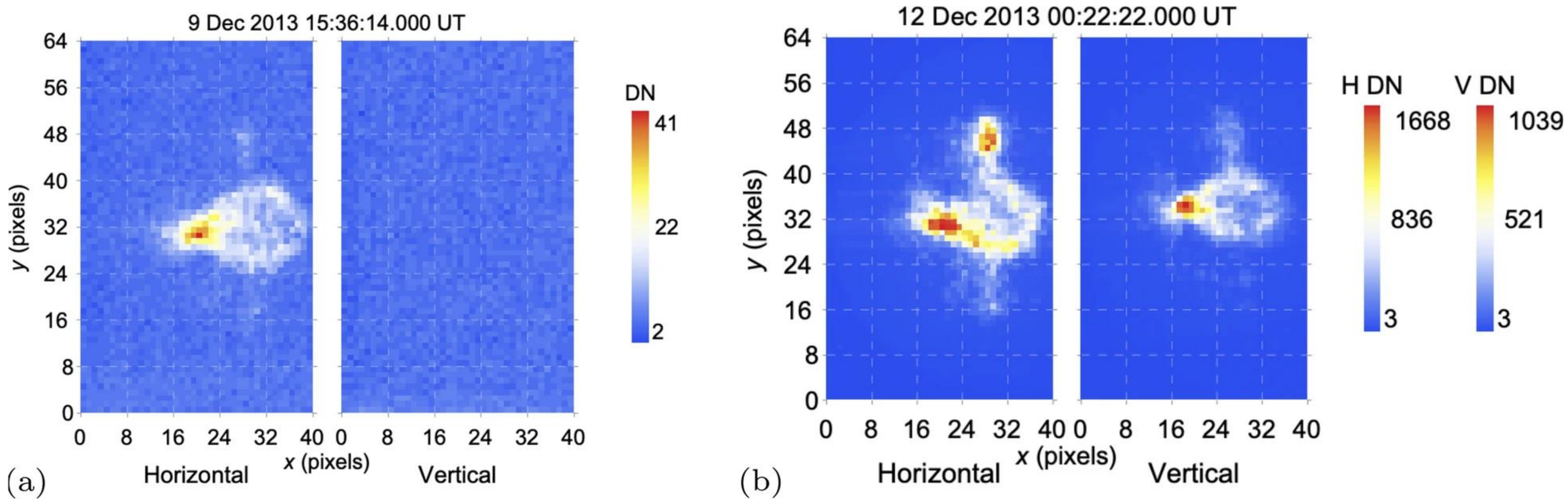


CCD-based imaging



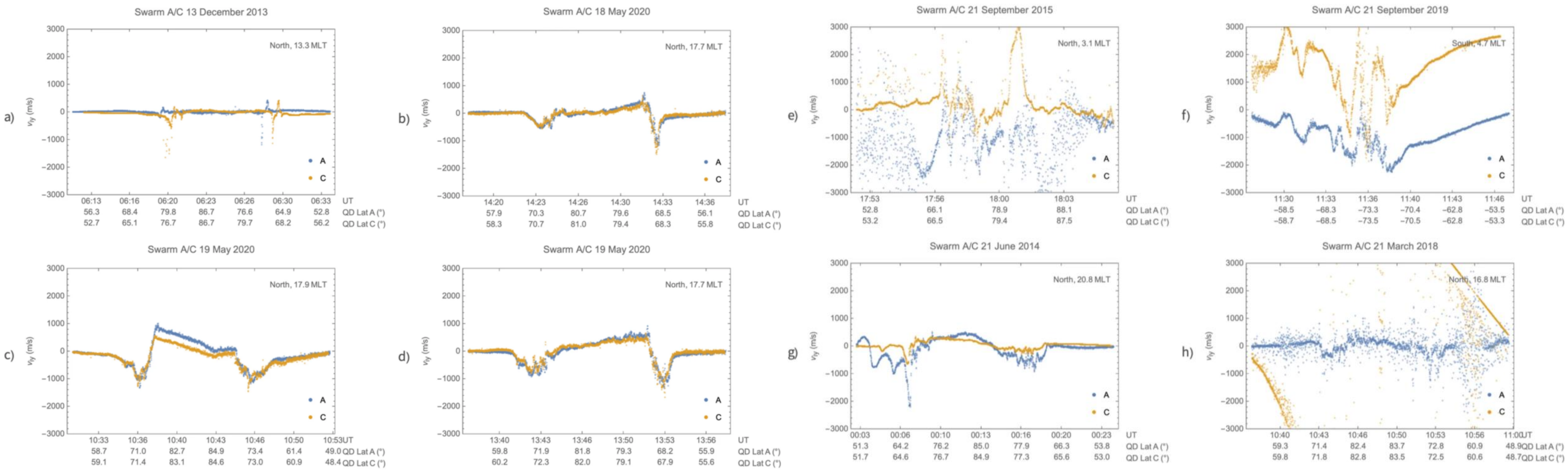


TII Image Anomaly



Burchill and Knudsen (2002)

Swarm A/C v_i comparisons



Burchill and Knudsen (2022)

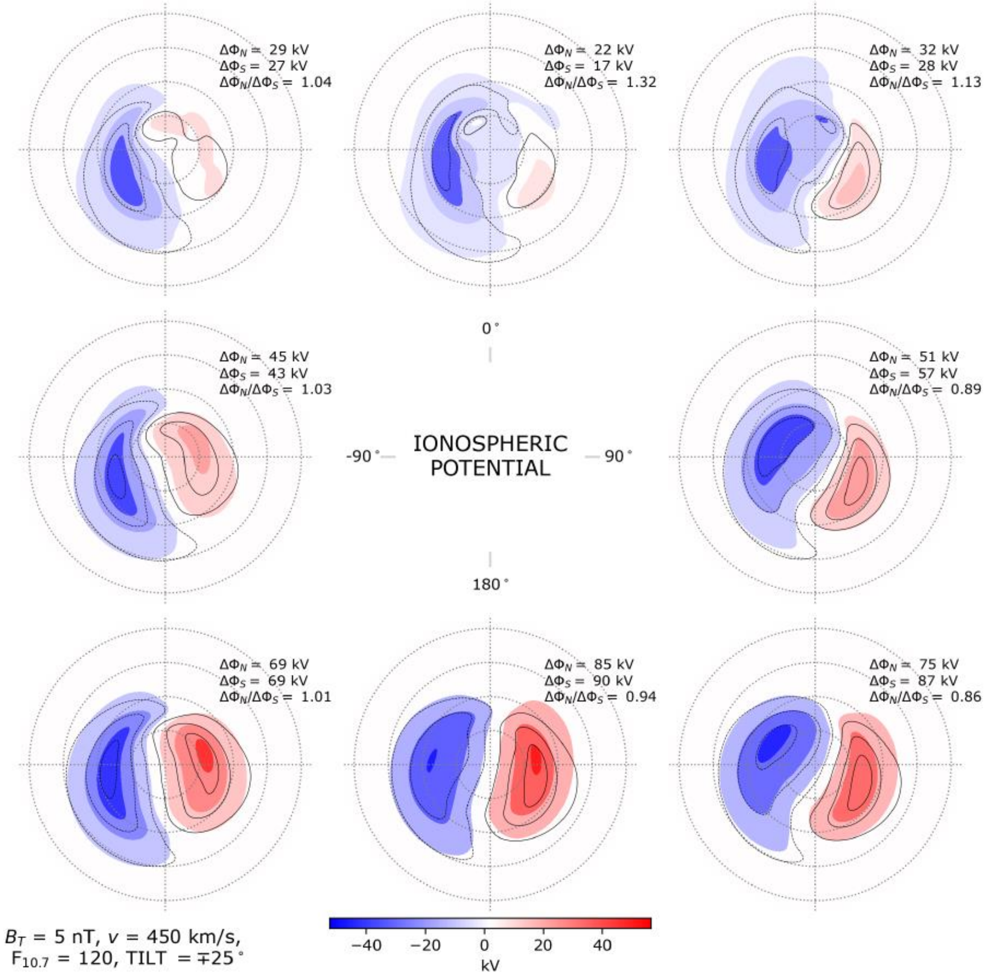
Science evolution

→ **Event studies**

→ **Statistical Studies**

→ **Models (Data & Physics-based)**

Electric potential versus IMF clock angle:



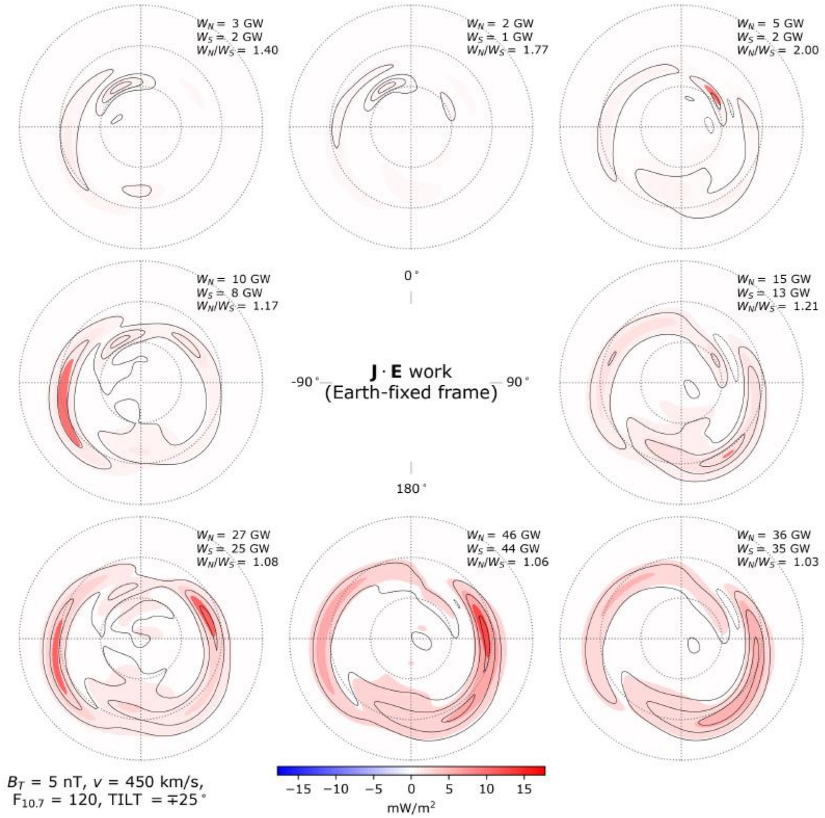
Hi-C Potential Model

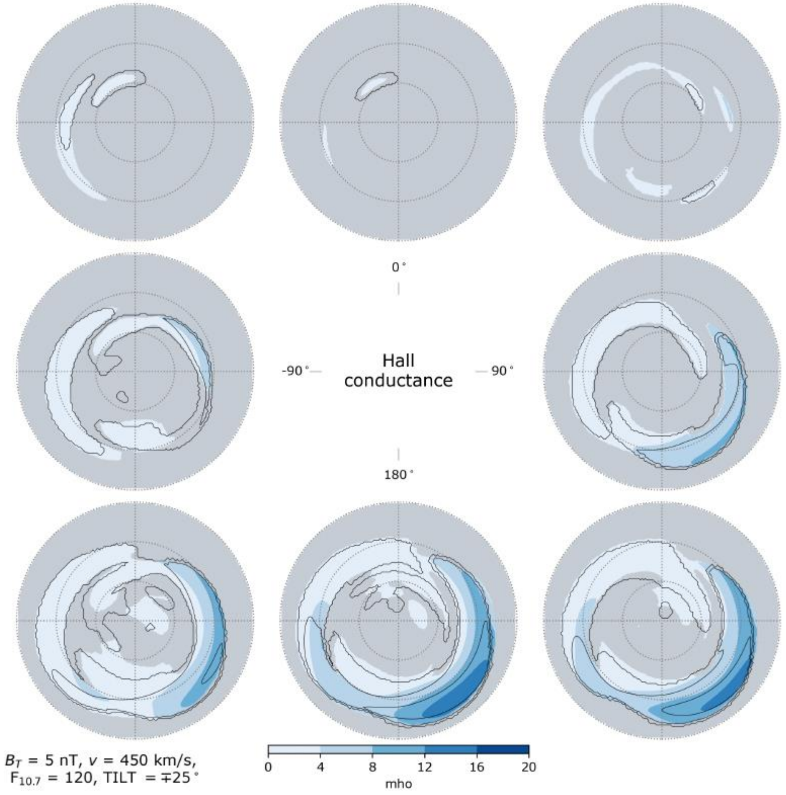
Hatch et al., *ANGEO*, in press

- Based on 9 years of Swarm data
- Spherical harmonic fits
- Can be combined with $\delta\mathbf{B}$...

J.E Work:

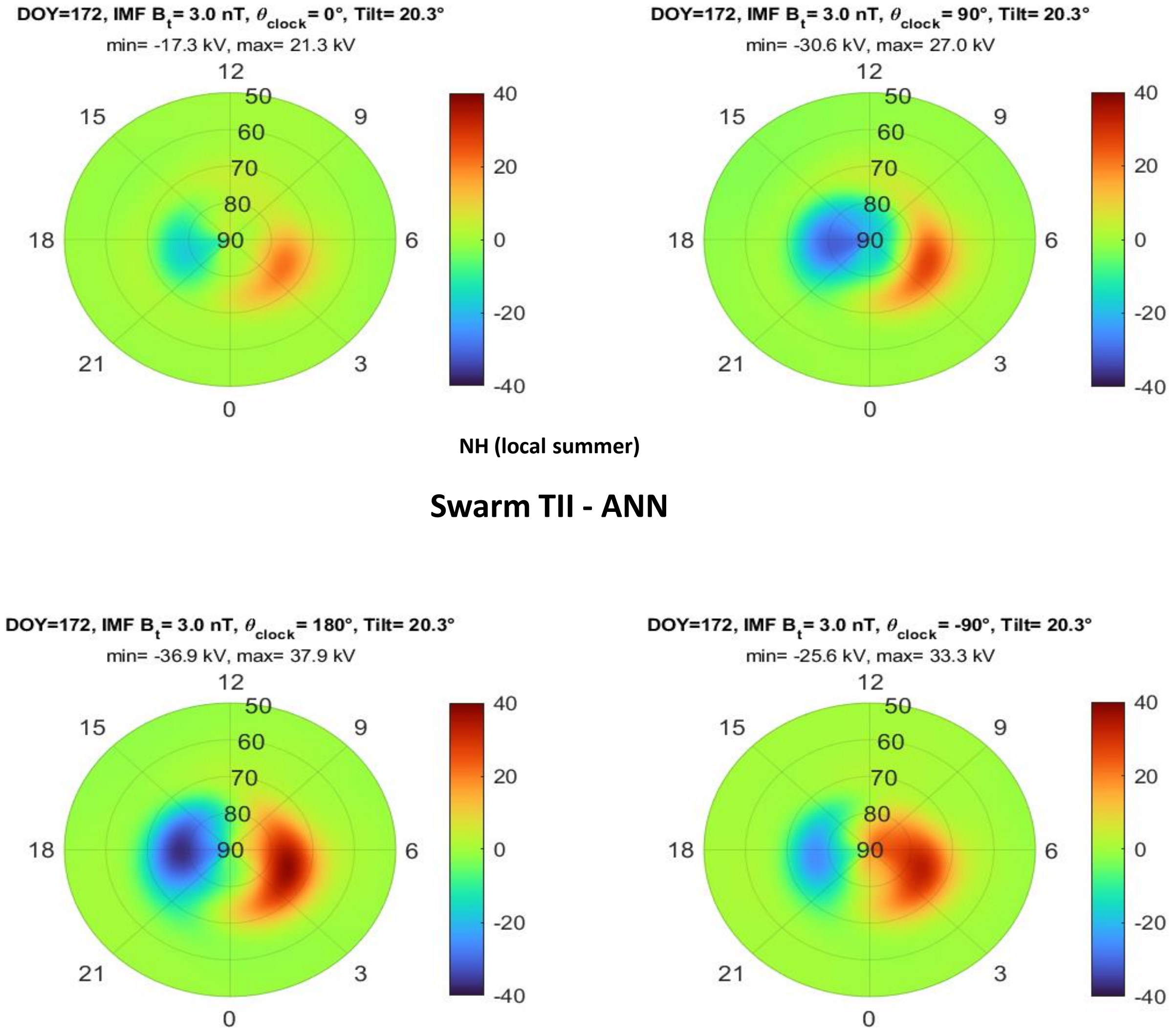
Hi-C (E - Swarm) + AMPS (δB - CHAMP) = “Swipe”





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

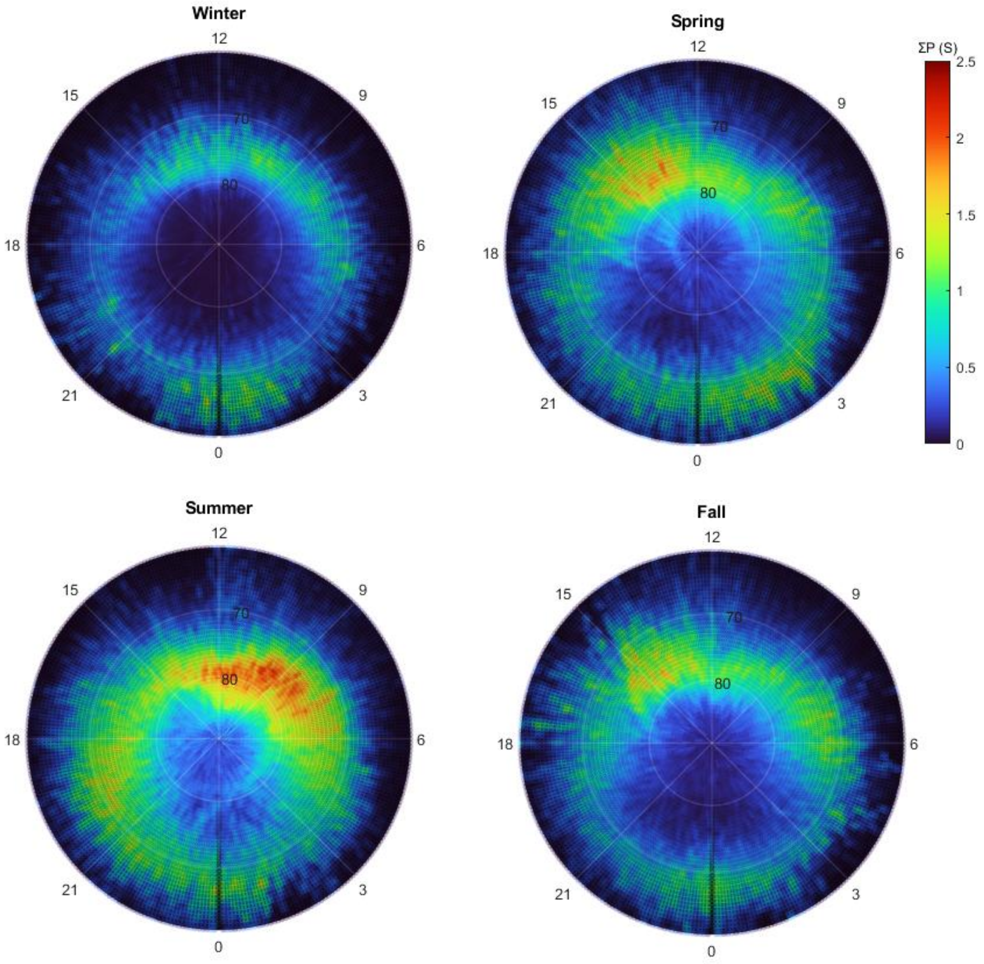
1.2) Swarm TII-ANN Electric Potential Model



Lomidze et al. (Poster #100)

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

2.1 – Conductance



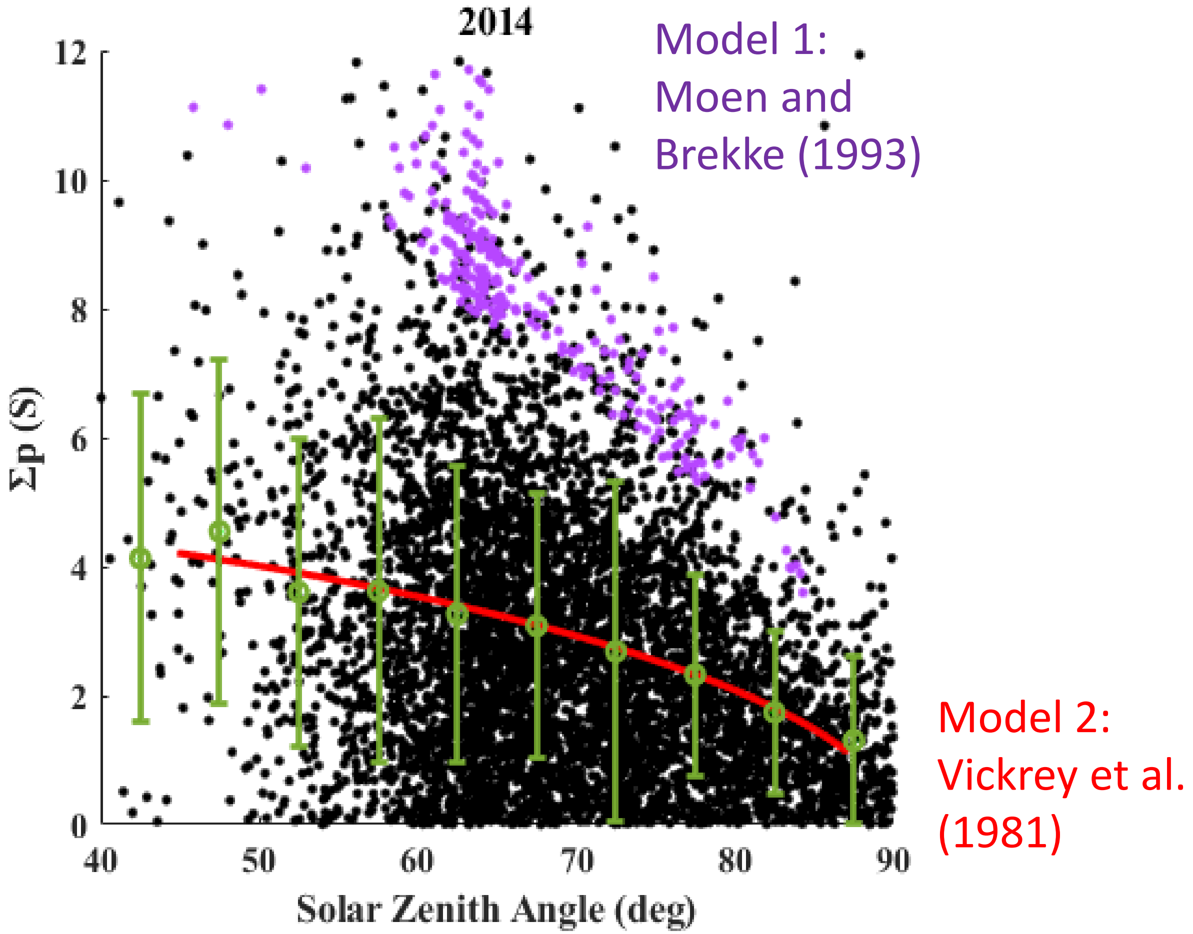
Pourkarim, MSc thesis, 2023 (Poster #63)

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

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

2.1a – Conductance vs SZA

Pourkarim, MSc thesis, 2023 (Poster #63)



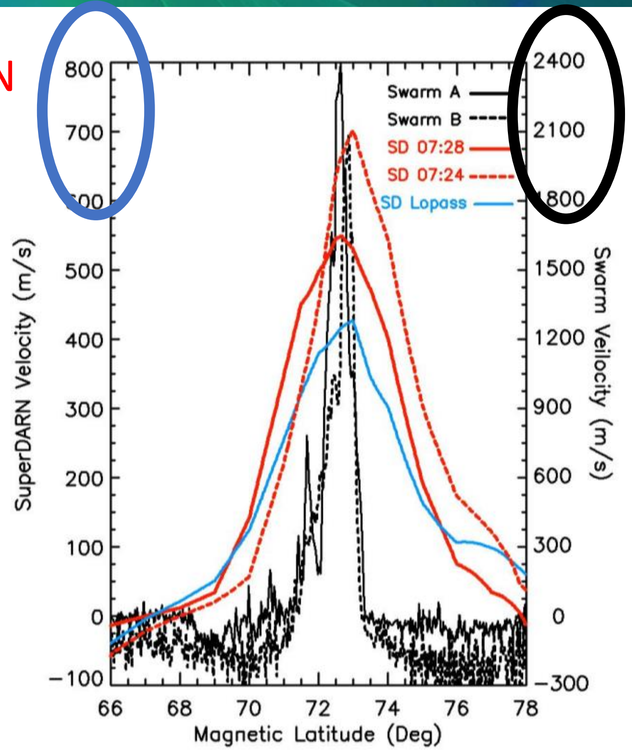
- $\sum_P = \delta B_y / \mu_0 E_x$

- 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.

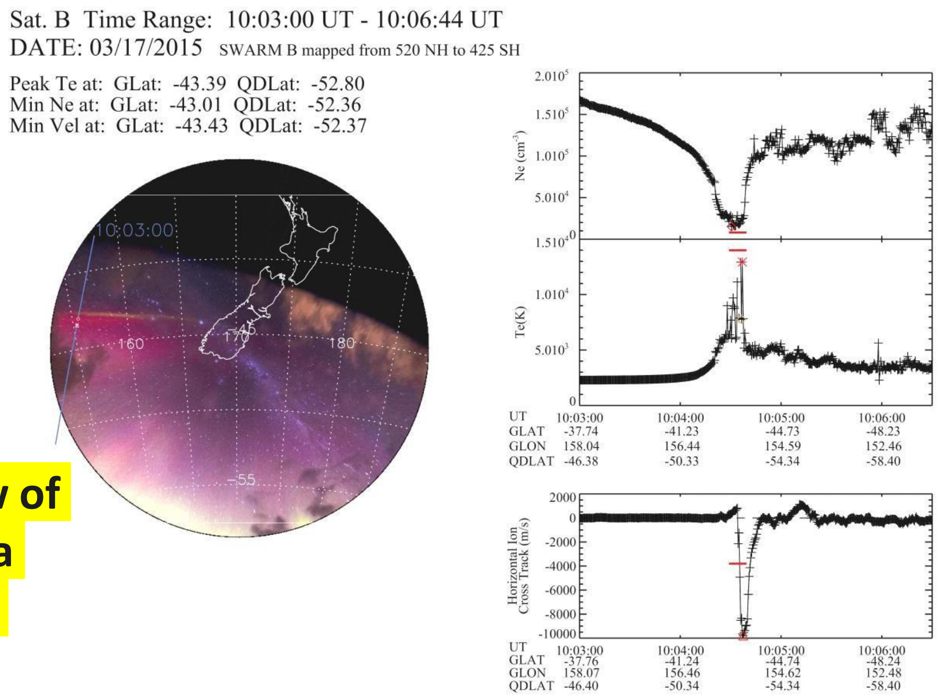
3.5) Archer and Knudsen, 2018: **Distinguishing Subauroral Ion Drifts From Birkeland Current Boundary Flows**, *JGR*.

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.



10 km/s!

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.

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.*

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.

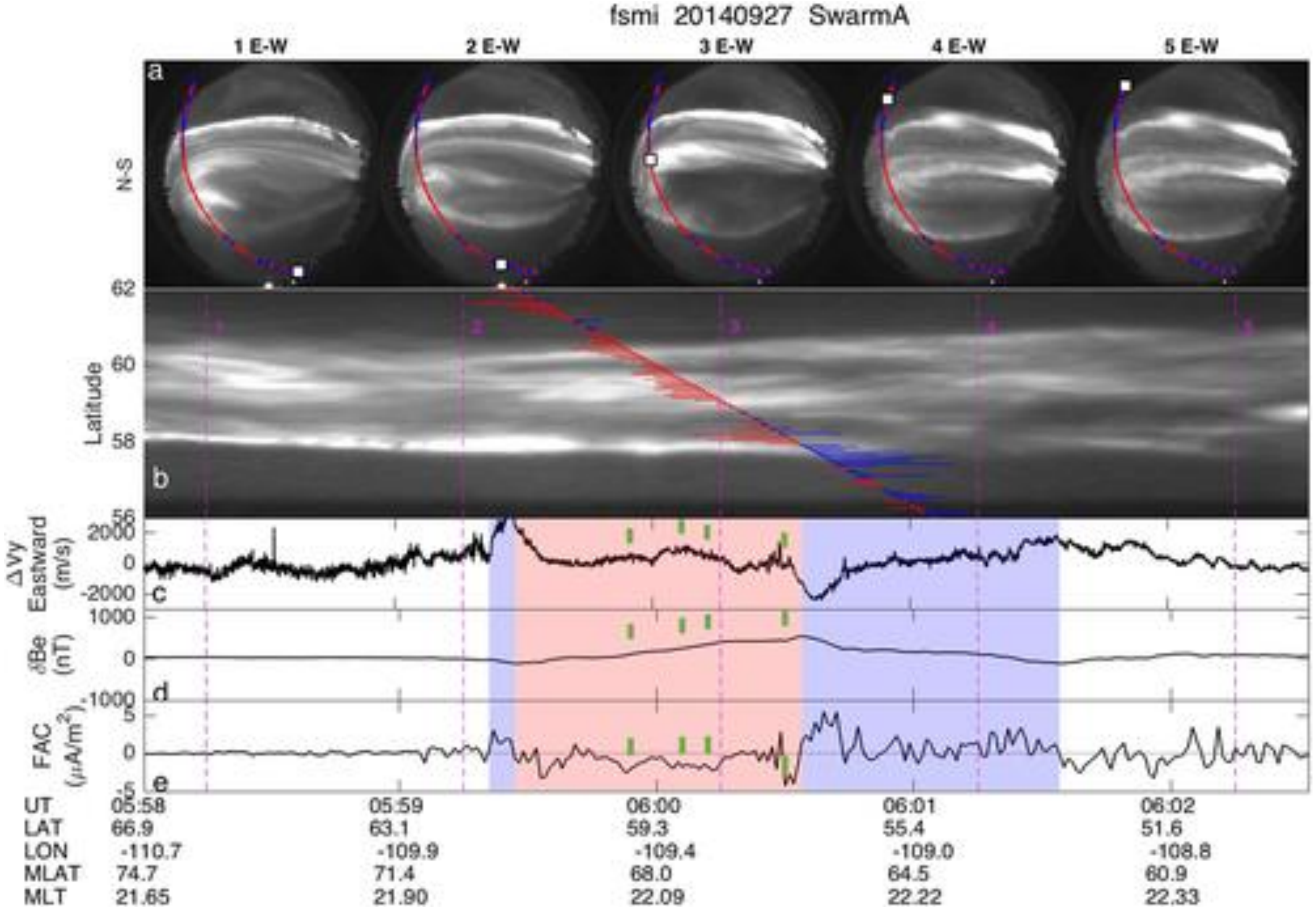
5.4) Wu et al., 2017: **Swarm Observation of Field-Aligned Currents Associated With Multiple Auroral Arc Systems**, *JGR.*

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.*

5.4: Auroral Arcs - Example



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

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*.

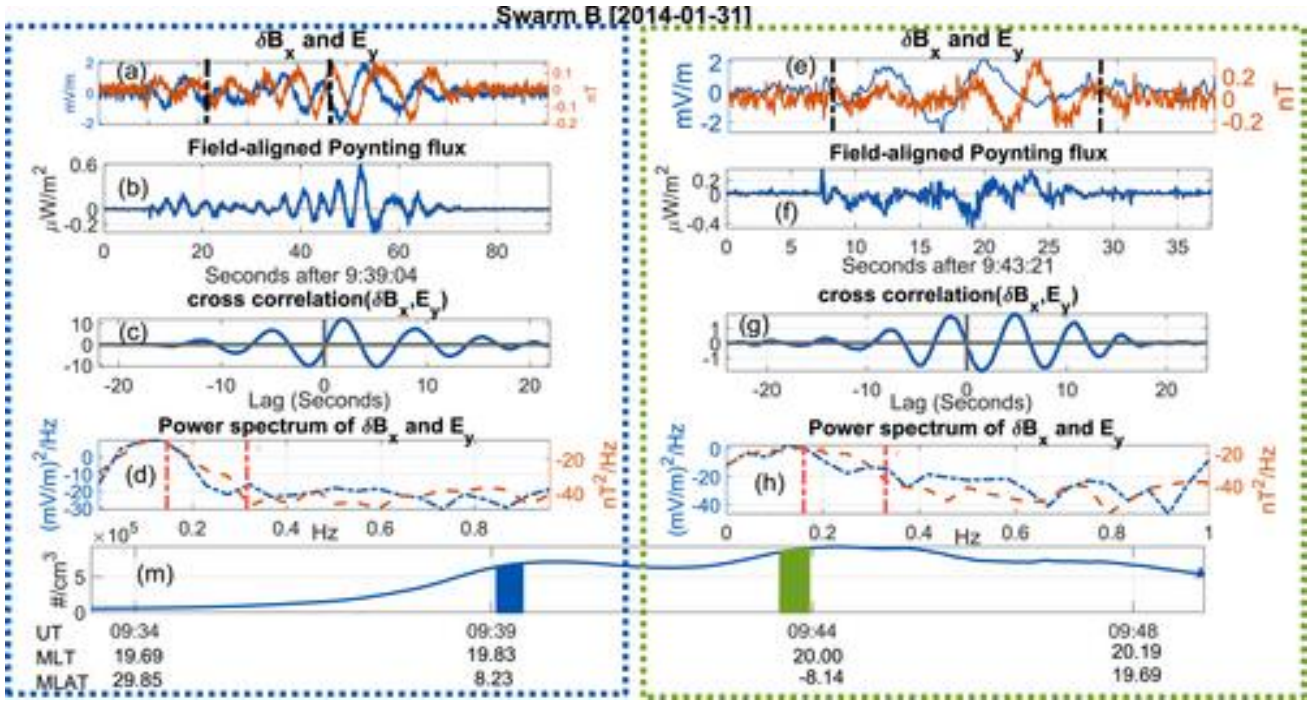
6.3) Wu et al., 2020: **Swarm survey of Alfvénic fluctuations and their relation to nightside field-aligned current and auroral arcs systems**, JGR.

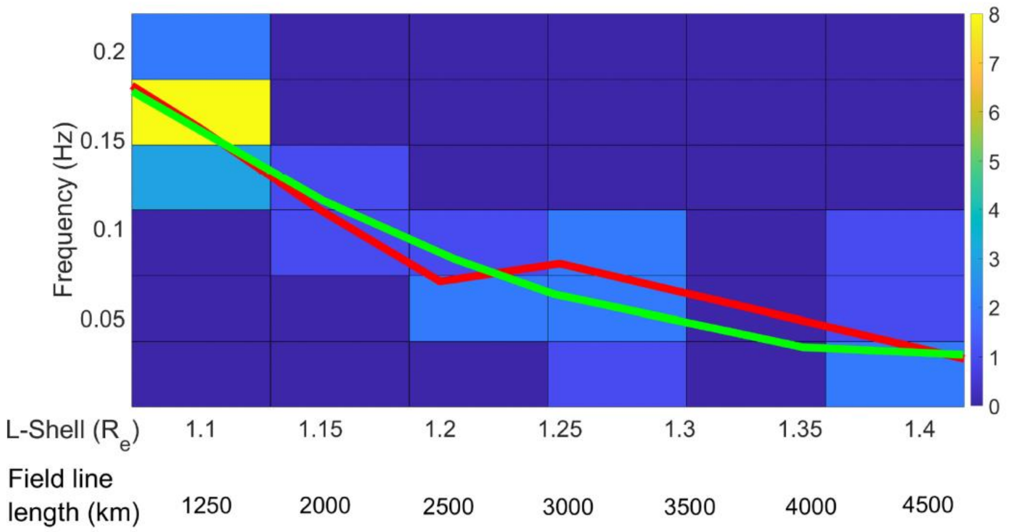
6.2) Miles et al., **Alfvénic dynamics and fine structuring of discrete auroral arcs: Swarm and e-POP observations**, *GRL*, 2018.

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: Alfvénic field-line resonance - example

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





7: Poynting Flux

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

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.

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)

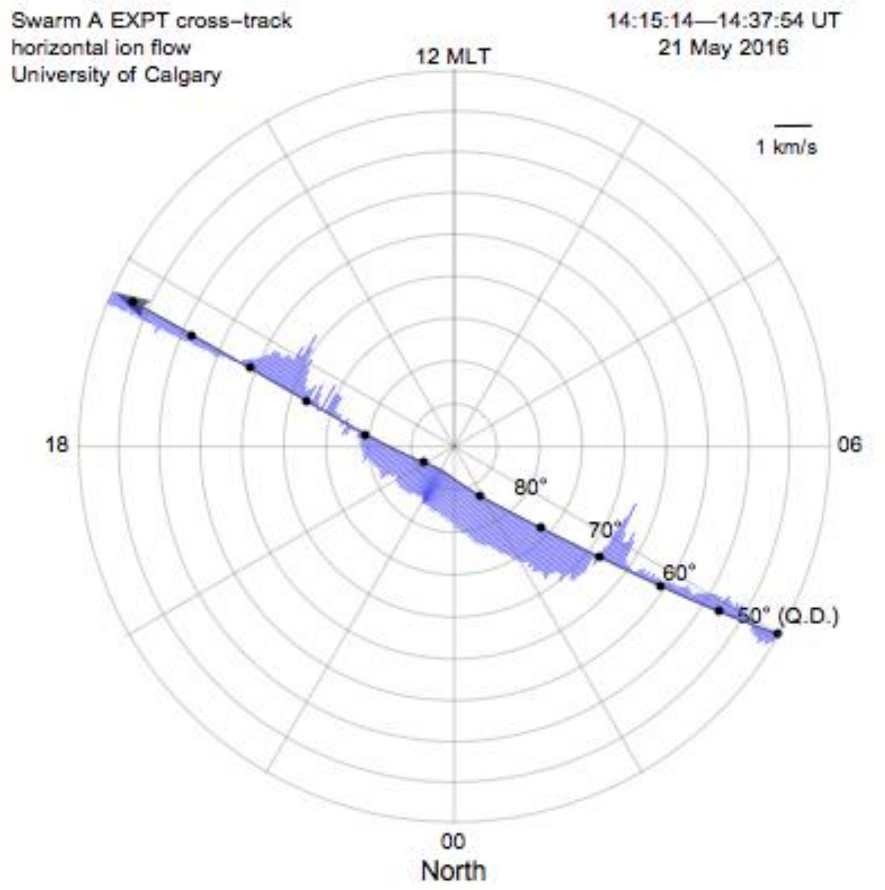
9.3) Koustov et al., 2018: **A comparison of cross-track ion drift measured by the Swarm satellites and plasma convection velocity measured by SuperDARN**. *JGR.*

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 January 2024. See esa.int/Swarm



Sincere thank you to:

- Roger, Rune, Anja, MAG
- ESA Project Team, FOS, PLSO, ARB board
- Swarm DISC & EFI Science Discussion Group
- Airbus, COM DEV/Honeywell
- Canadian Space Agency
- Alexei Kouznetsov, Levan Lomidze