EZIE First Results

Electrojet Zeeman Imaging Explorer

ezie.jhuapl.edu

NASA

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BLUE CANYON TECHNOLOGIES

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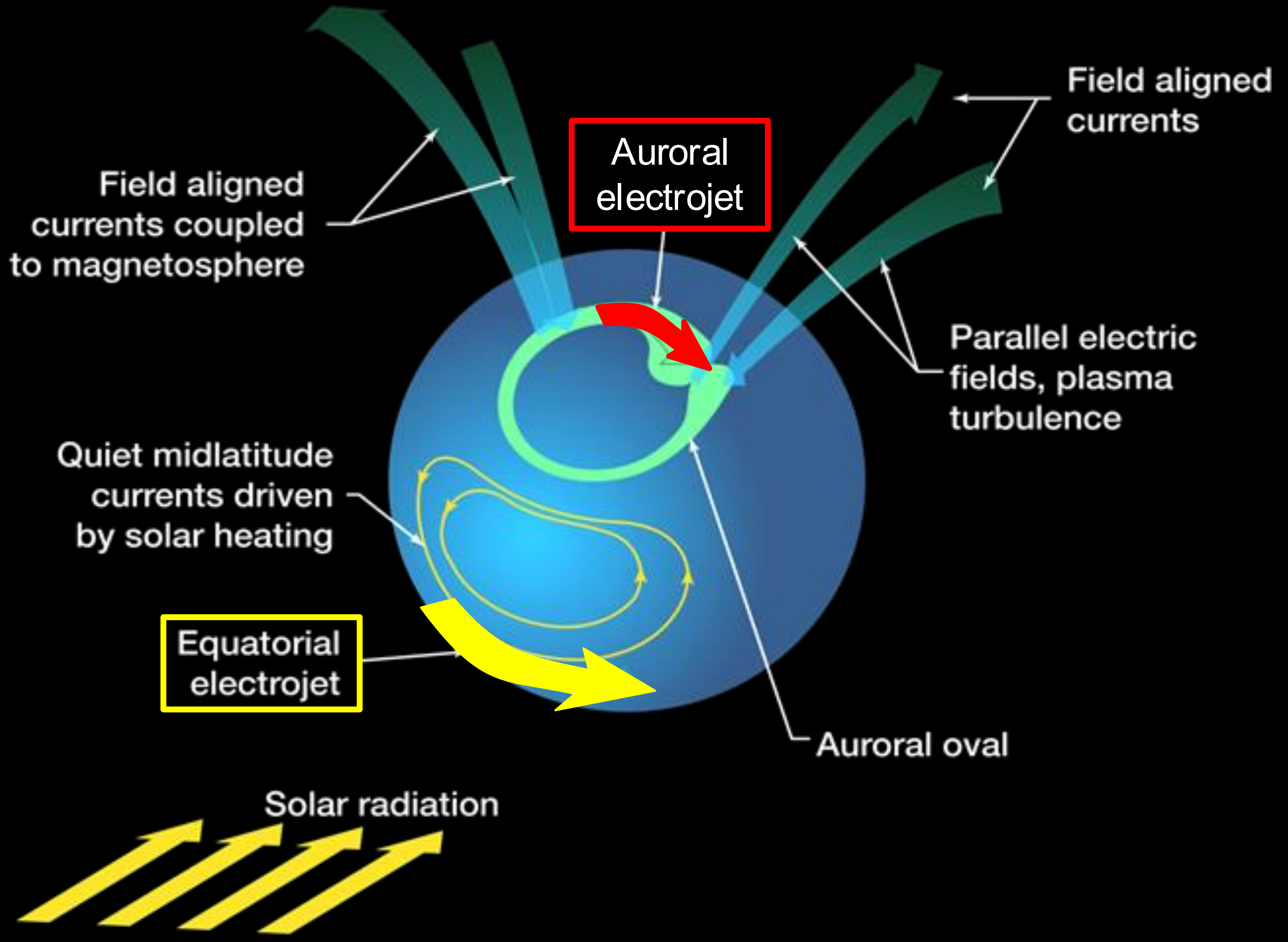
Launch: 3/15/25
Start of nominal science: 5/15/25

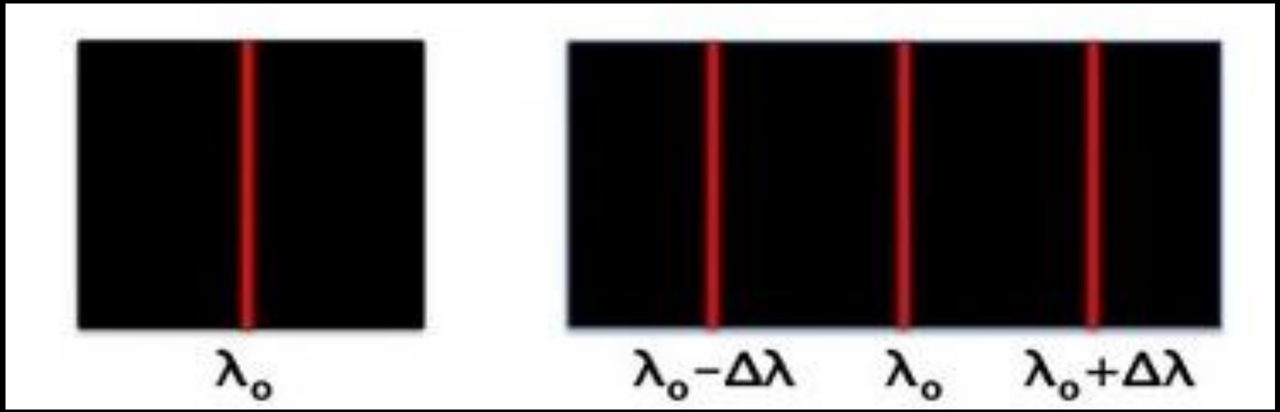
CEDAR/GEM 2025 • Des Moines • June 24, 2025

EZIE measures electrojet currents in the ionosphere

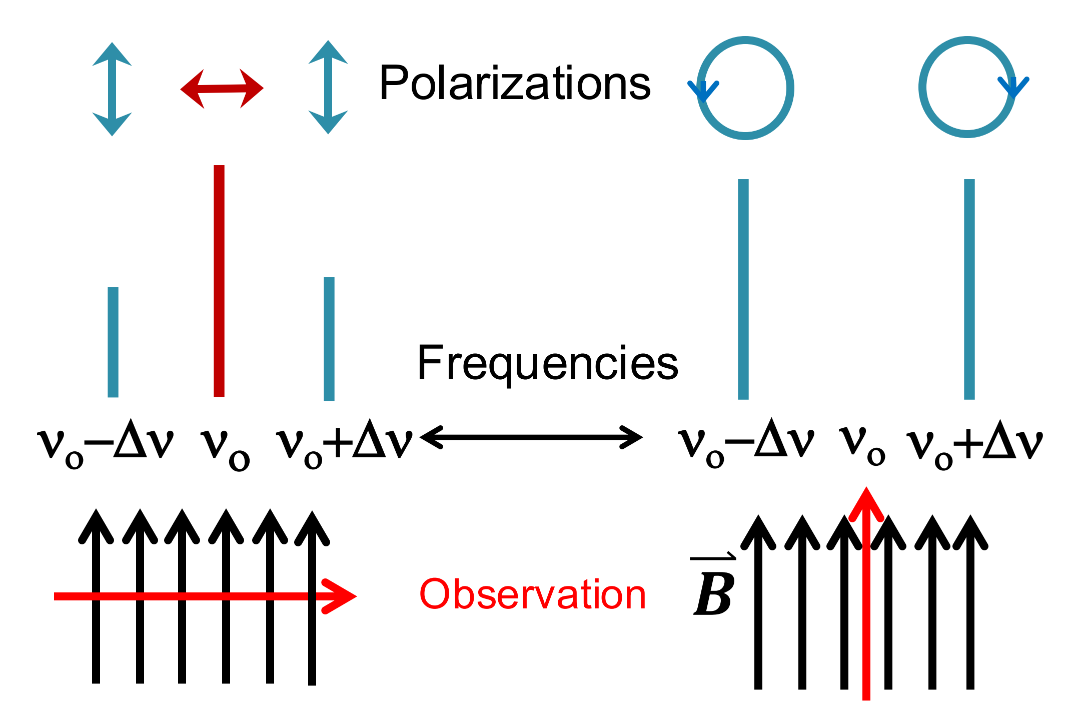


Zeeman effect provides information about vector magnetic field

$\Delta\lambda \approx |B|$



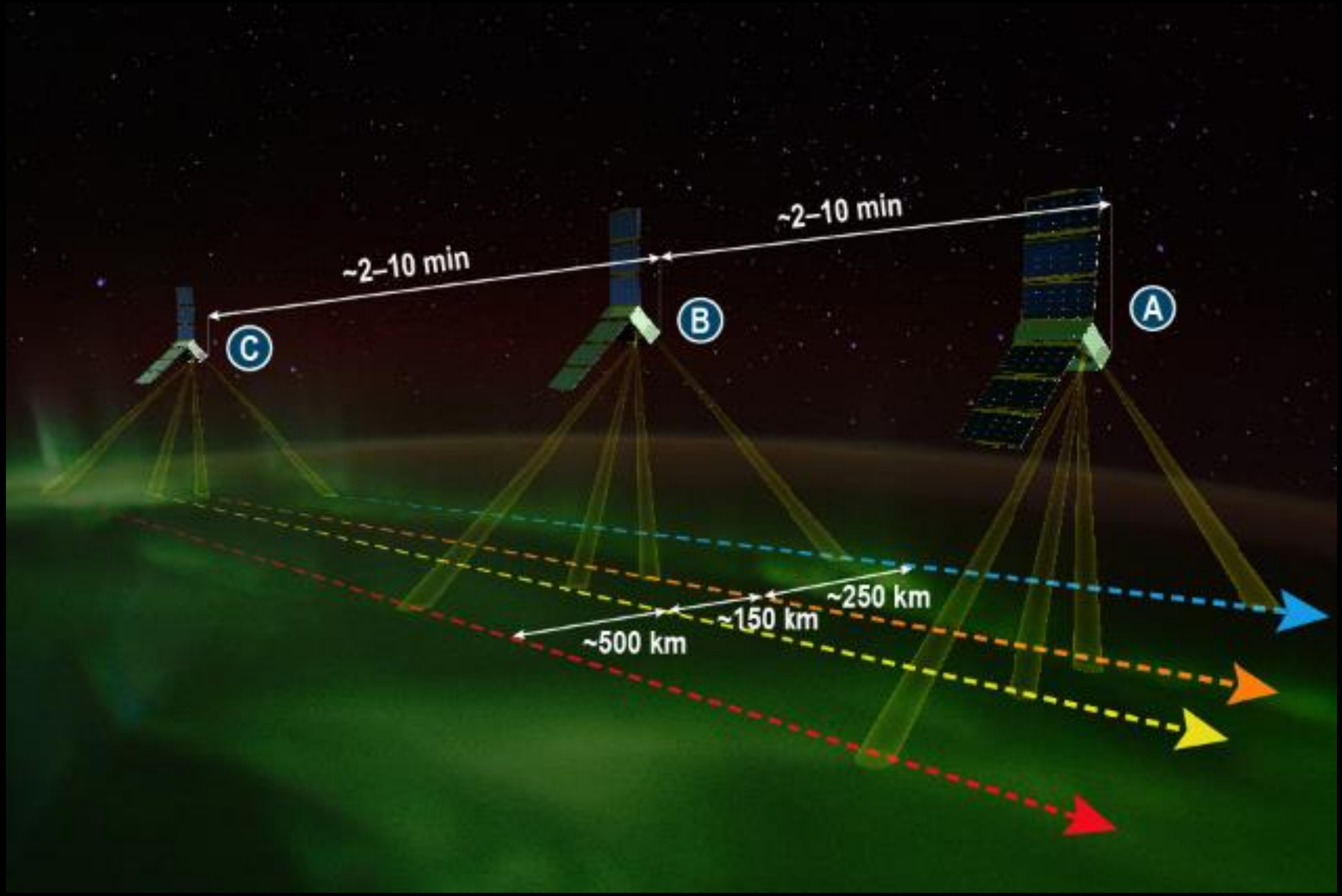
Absence of $\vec{B}$ Presence of $\vec{B}$



Spectral split → Total magnetic field

Polarization → Vector B-field

EZIE is a 3-CubeSat constellation with 12 instruments

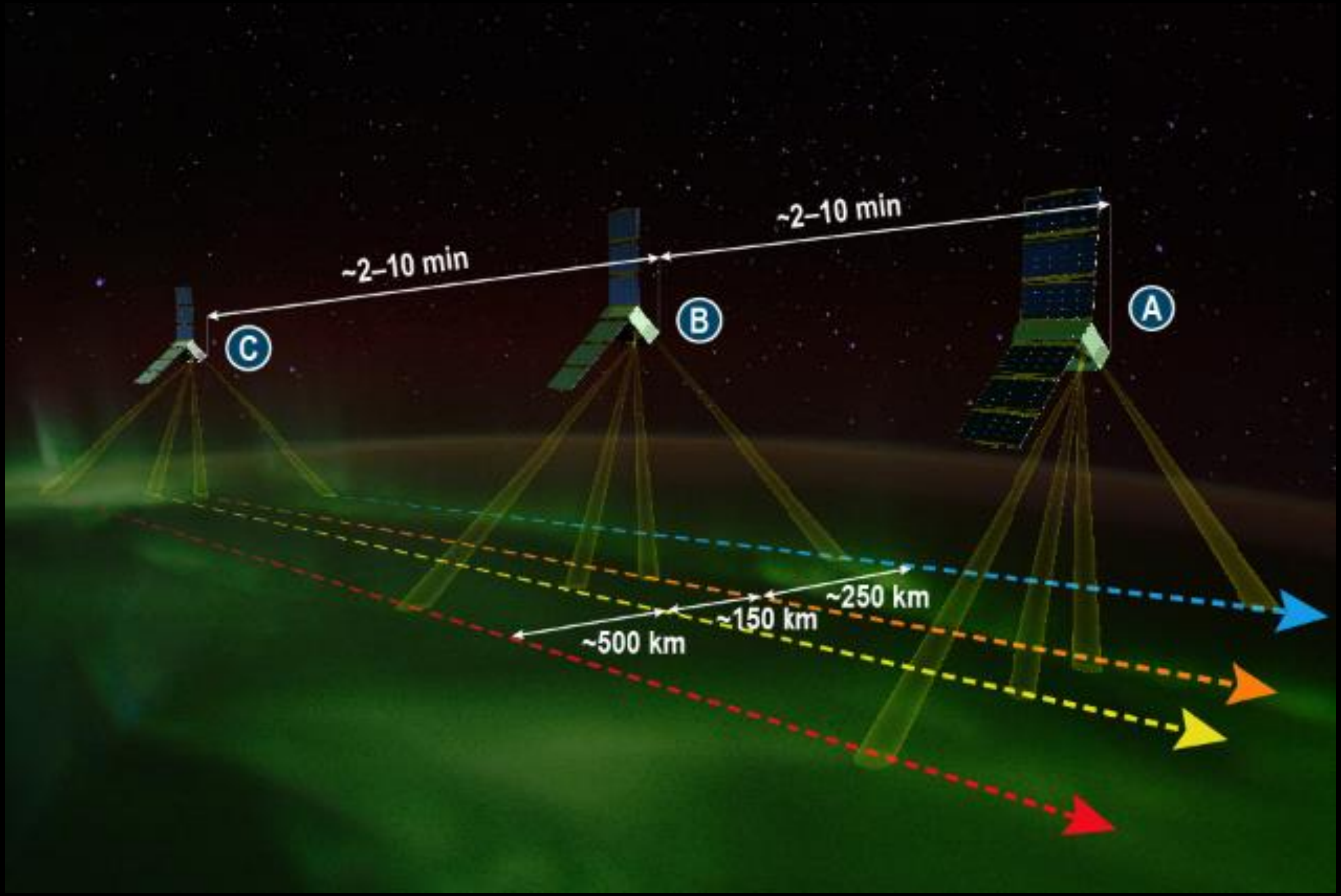


- Electrojet spatial structure
  - Each payload consists of four identical O_2 118-GHz spectro-polarimeters, to remotely measure and image electrojet induced magnetic fields
    => ~150 – 750 km spatial structure

3x Microwave Electrojet Magnetogram (MEM)

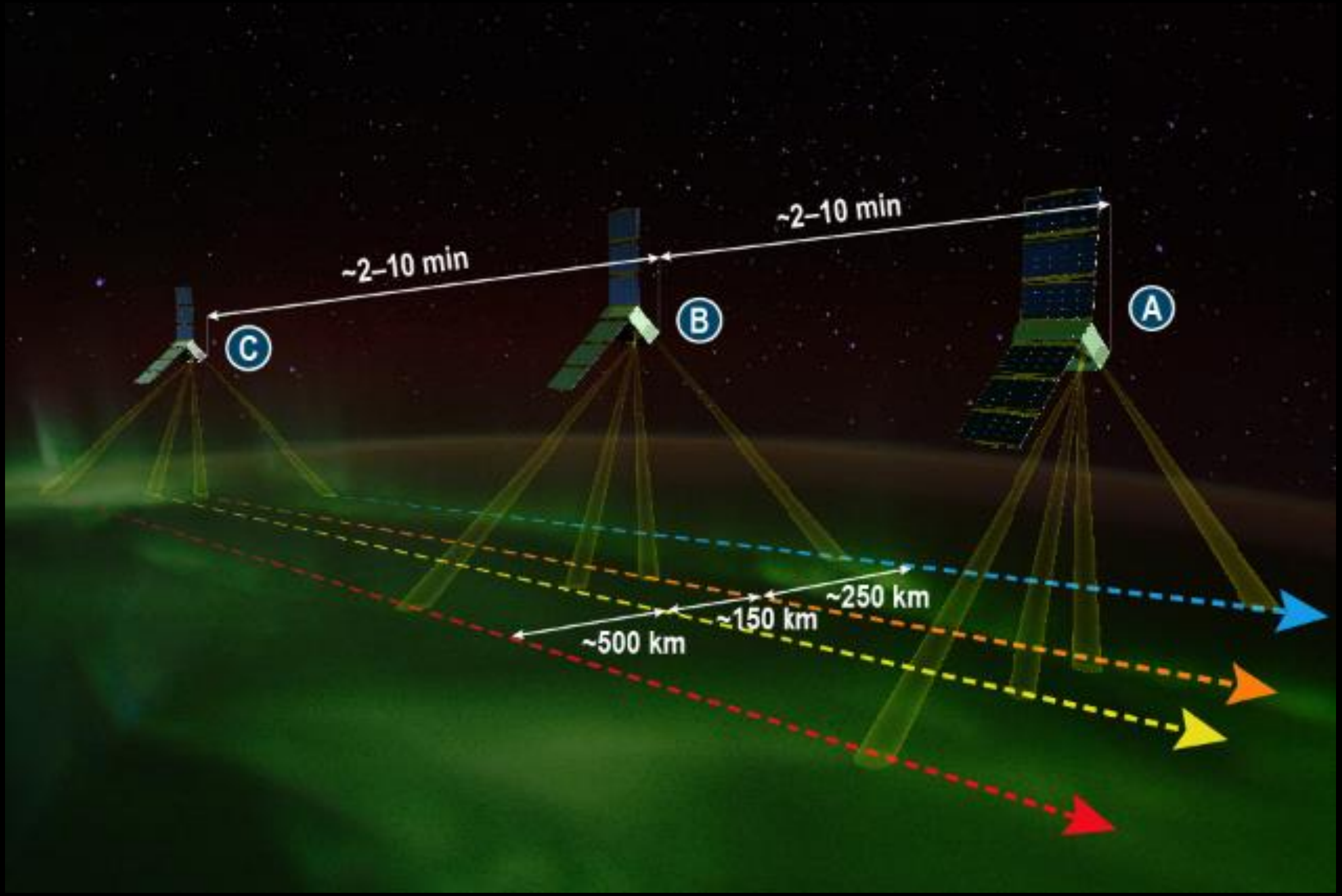
20 cm

EZIE is a 3-CubeSat constellation with 12 instruments

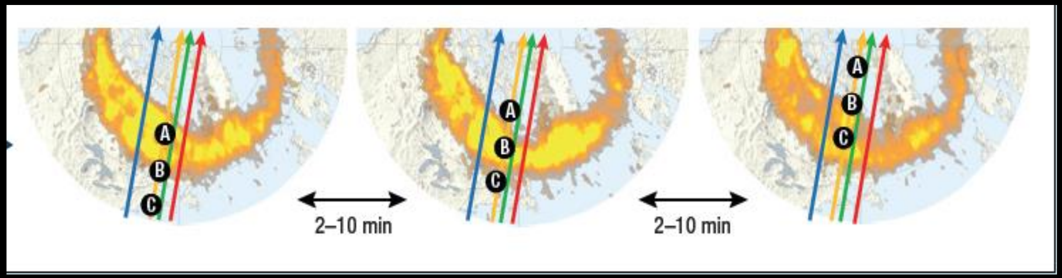


- Electrojet-induced $\vec{B}$ around 80 km, near the electrojet altitudes
  - Derivation of the $\vec{B}$ fields from Zeeman properties of the observed O_2 118-GHz emission
    => 2-D equivalent current map

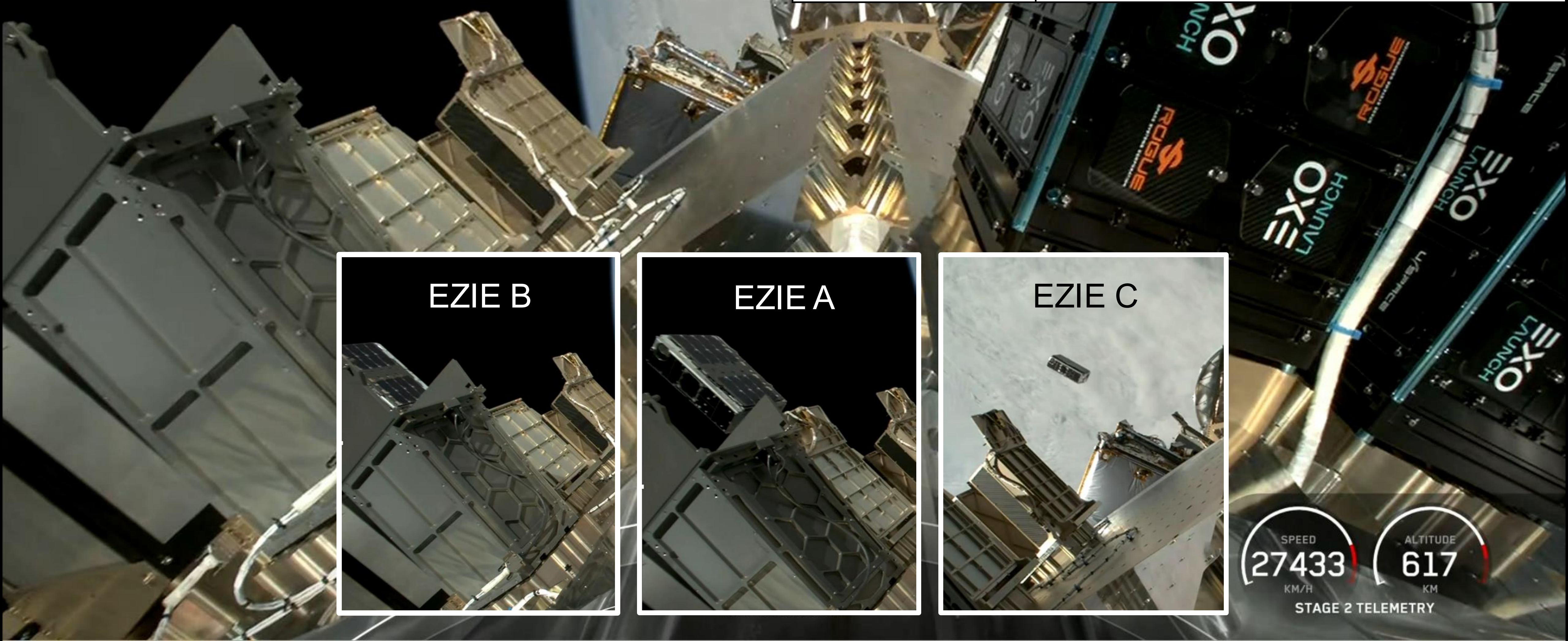
EZIE is a 3-CubeSat constellation with 12 instruments



- <u>Electrojet temporal evolution near the midnight sector</u>
  - 3 6U CubeSats flying in a pearls-on-a-string formation, with varying separation managed by differential drag
    => ~2–20 min temporal variation



Mission Design Life	18 months (2 months early ops, 16 months science)
Deployment Orbit	600 km altitude, 1030 LTAN, Sun-synchronous
Orbit Configuration	Pearls-on-a-string with 2-10 min separation using differential drag maneuvers (i.e. propulsion not required)
Satellite Mass Limit	16 kg per satellite, 6U Class
Orbit Average Power	38 W, End-Of-Life
Science Data Volume	75 MB / Day / Sat, 361 GB science life 16 months for all satellites at Level 0-3
Launch	SpaceX Falcon 9, Secondary Payload Rideshare, March 15 2025

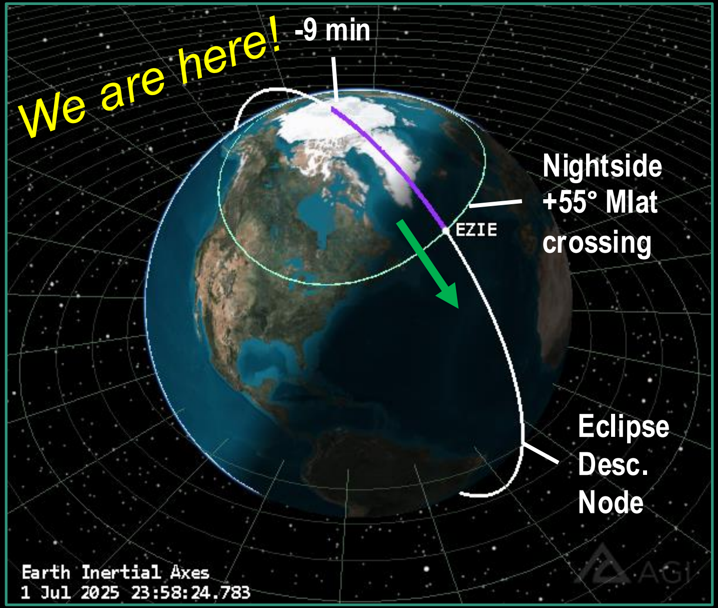


Currently observing northern AEJs every orbit

Northern Summer Solstice Season

Approx. May–Aug

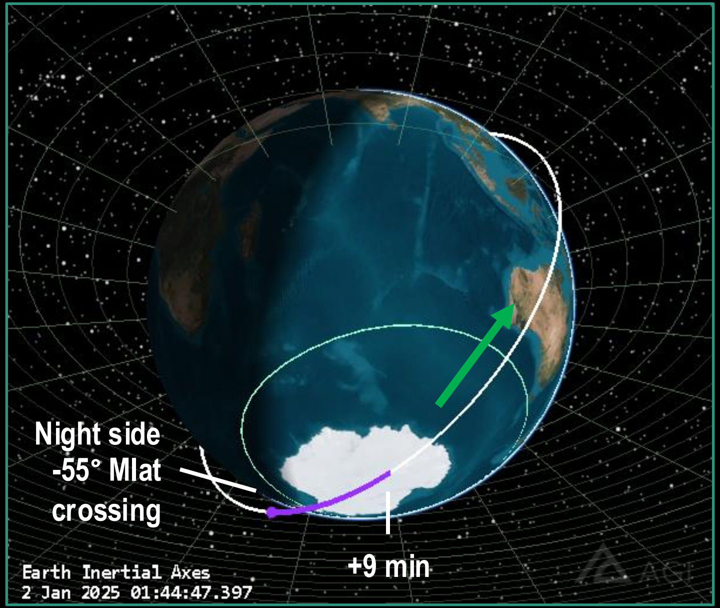
Cadence of Science Collection Periods : Every Orbit



Southern Summer Solstice Season

Approx. Nov–Feb

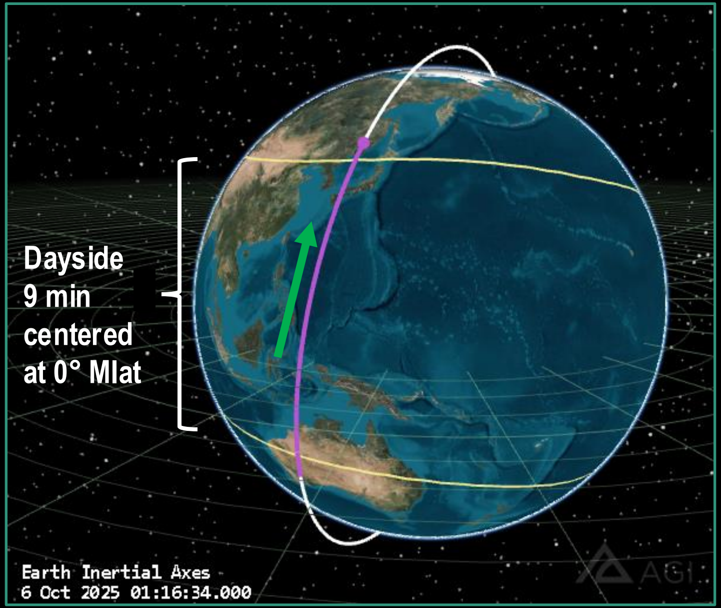
Cadence of Science Collection Periods: Every Orbit



Equinox Season (science augmentation)

Approx. Aug–Nov, Feb–May

Daytime Only, Centered at magnetic equator



Nominal separation:

So, where (and when) are the data?

Data product level	Data product	Reference	Public release date
L1	Geolocated, calibrated brightness temperatures	Misra et al. [in press]	Nov 15, 2025
L2	Vector magnetic fields at ~80 km	Yee et al. [2017, 2021]	Nov 15, 2025
L3	2-D auroral electrojet currents	Laundal et al. [2021]	Nov 15, 2025

https://eziegw.jhuapl.edu

References

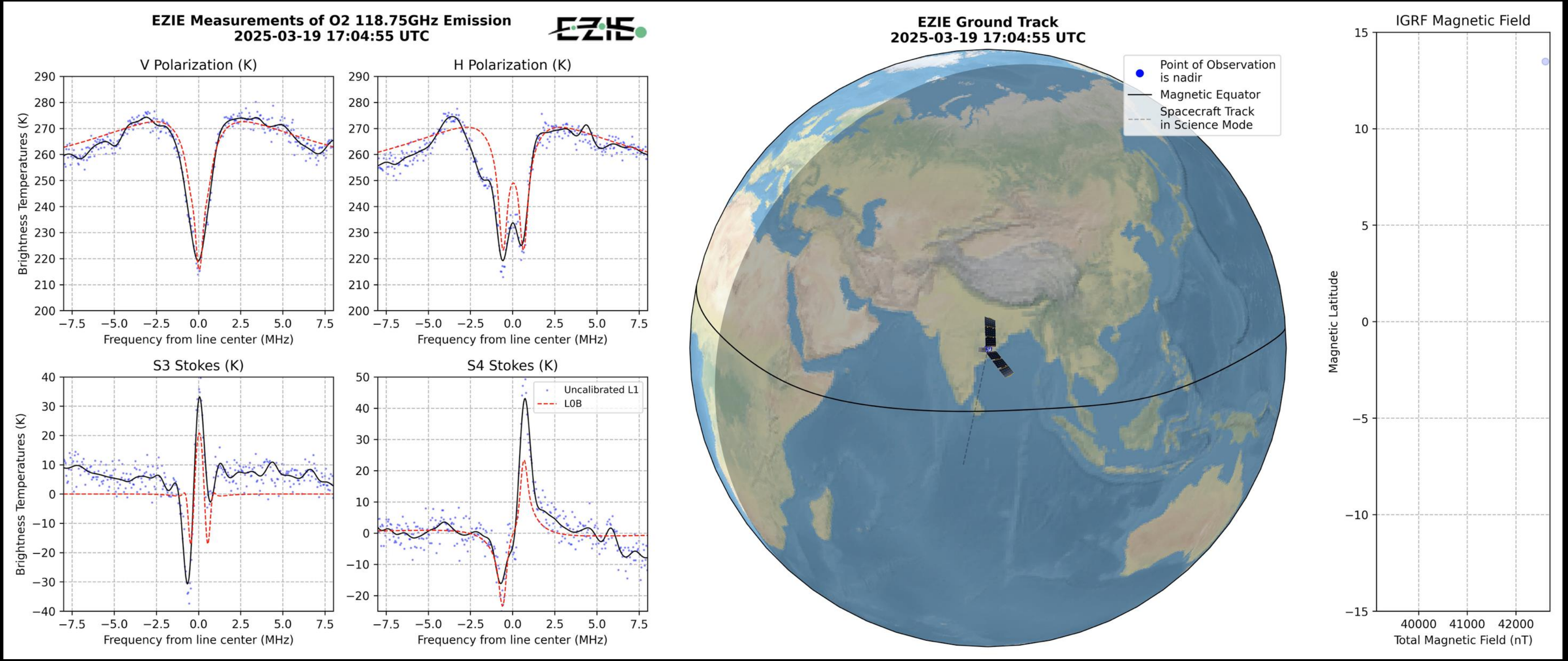
Misra, et al., Spectral Calibration of the Microwave Electrojet Magnetogram Radiometer Instrument on the Electrojet Zeeman Imaging Explorer Mission, *TGRS* [in press]

Yee, et al., First Application of the Zeeman Technique to Remotely Measure Auroral Electrojet Intensity From Space, *GRL* [2017]

Yee, et al., Remote Sensing of Magnetic Fields Induced by Electrojets From Space, pp. 451–468 in *Upper Atmospheric Dynamics and Energetics,* https://doi.org/10.1002/9781119815631.ch21 [2021]

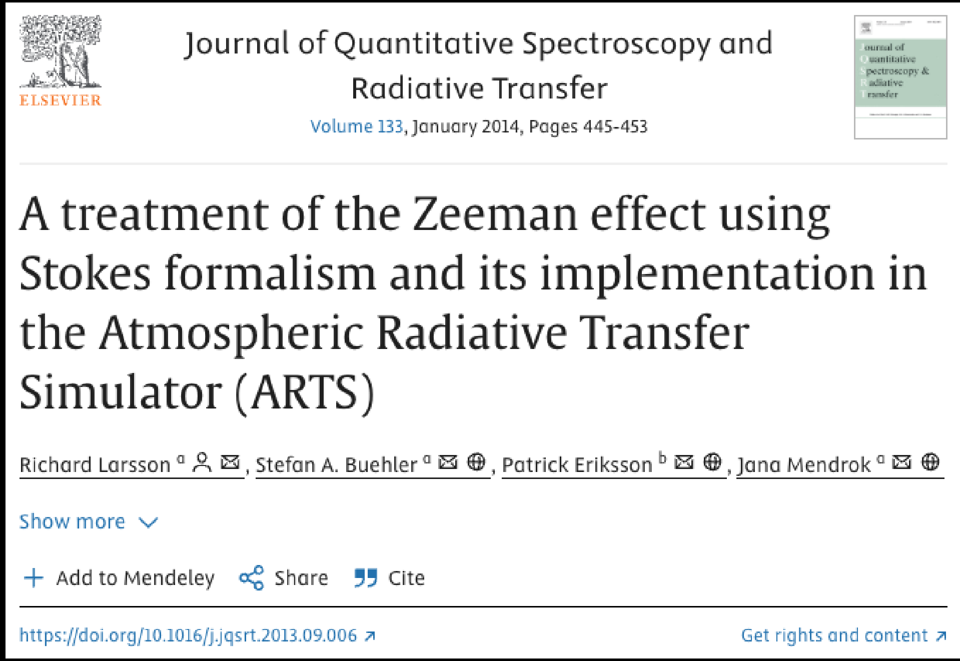
Laundal, et al., Electrojet Estimates From Mesospheric Magnetic Field Measurements, *JGR Space Physics* [2021]

First light



EZIE Measurements of O2 118.75GHz Emission
2025-03-19 17:04:55 UTC
V Polarization (K)
H Polarization (K)
S3 Stokes (K)
S4 Stokes (K)
Brightness Temperatures (K)
Frequency from line center (MHz)
Uncalibrated L1
L0B
EZIE Ground Track
2025-03-19 17:04:55 UTC
Point of Observation is nadir
Magnetic Equator
Spacecraft Track in Science Mode
IGRF Magnetic Field
Magnetic Latitude
Total Magnetic Field (nT)

EZIE Measurement and Forward Model


Journal of Quantitative Spectroscopy and Radiative Transfer

Volume 133, January 2014, Pages 445-453

A treatment of the Zeeman effect using Stokes formalism and its implementation in the Atmospheric Radiative Transfer Simulator (ARTS)

Richard Larsson [a], Stefan A. Buehler [a], Patrick Eriksson [b], Jana Mendrok [a]

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https://doi.org/10.1016/j.jqsrt.2013.09.006

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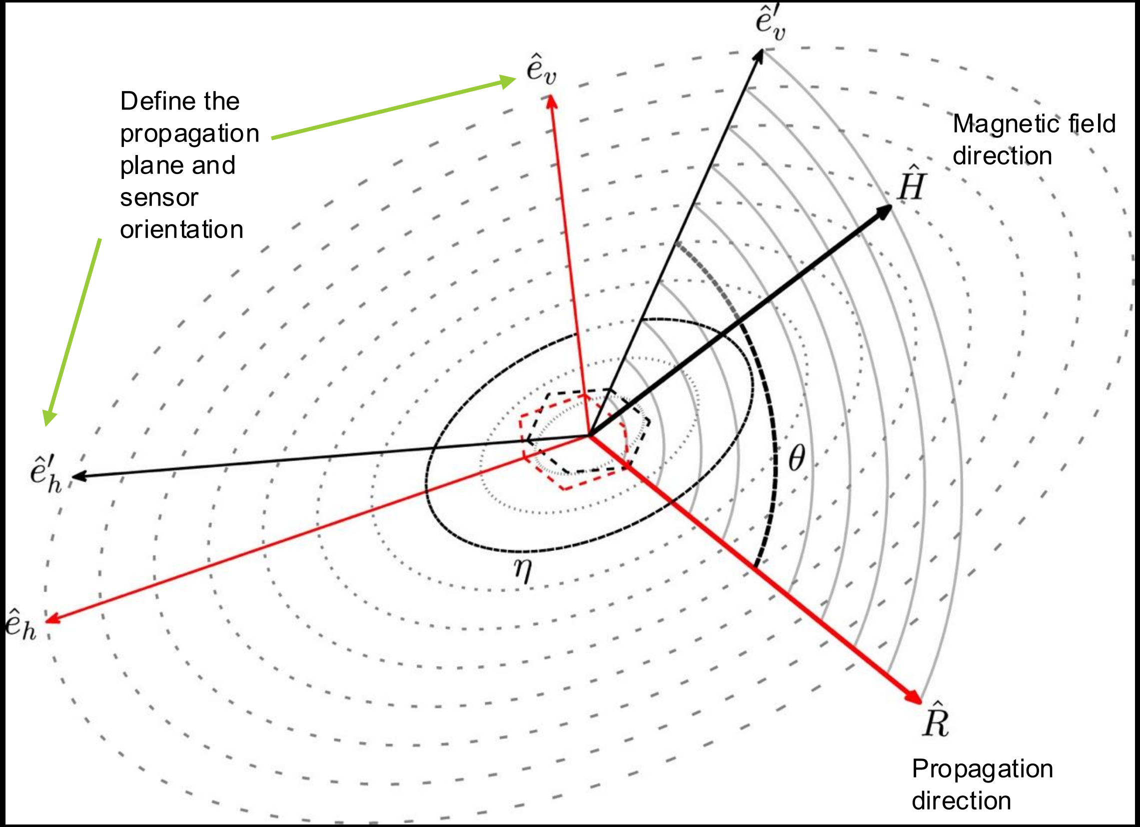
Describes how emissions behave in the presence of a magnetic field **(B)**, molecular rotational transitions split into multiple components:

- **π component** (Δm = 0) – unshifted, linearly polarized
- **σ± components** (Δm = ±1) – shifted, circularly polarized

Results in a **magnetically induced polarization signal** in the emitted radiation.

The amount and type of polarization depend on (among others):

- Magnetic field strength and orientation
- Observation angle
- Frequency offset from line center
- Atmospheric profile



θ = 0° (LOS ∥ B) → only σ^+ and σ^- appear; pure circular polarization (Stokes V)

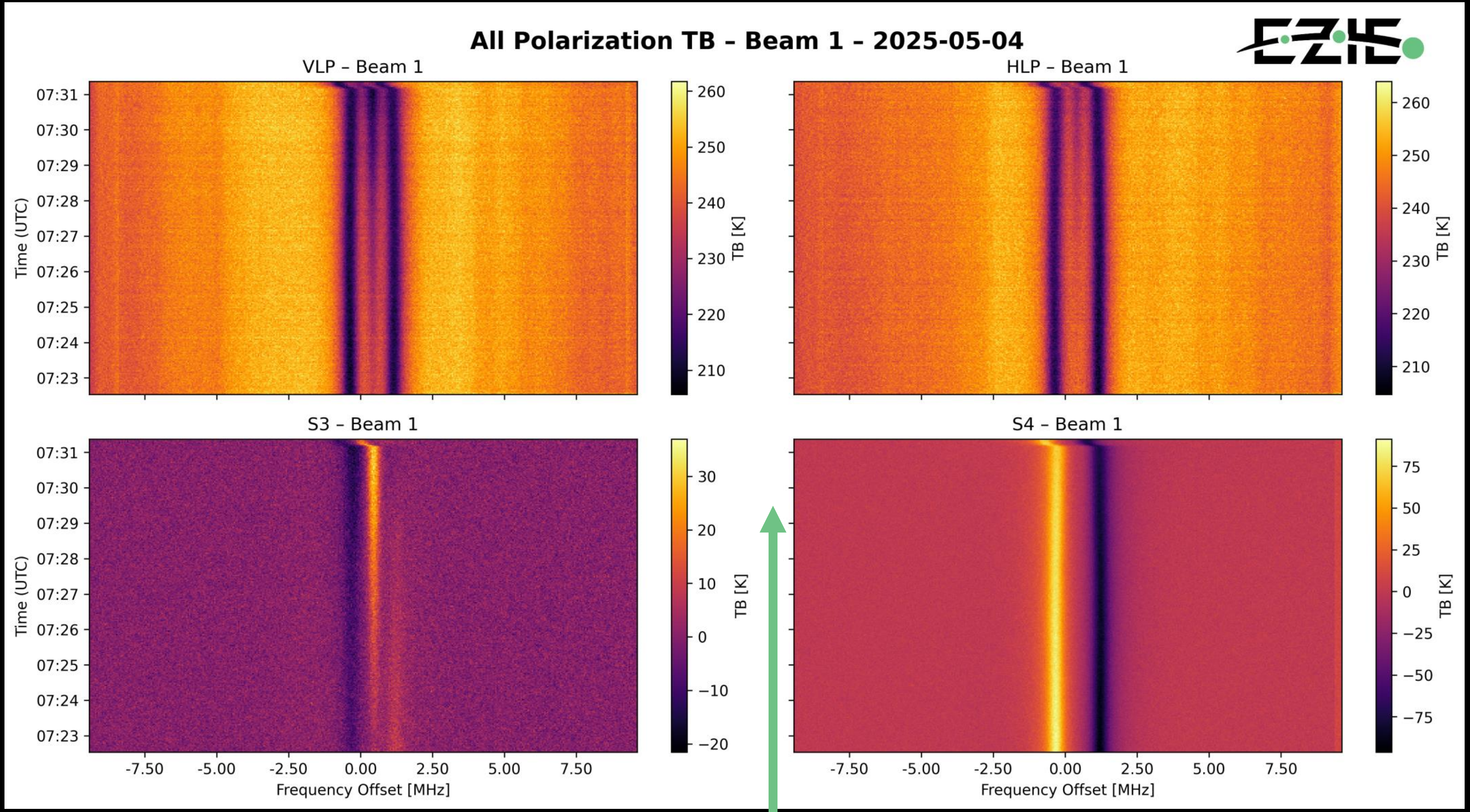
θ = 90° (LOS ⊥ B) → dominant π component (linearly polarized); σ components still present but altered

EZIE L1 Data – Calibrated Radiances

This is a typical EZIE L1 Dataset:

Vertical linear, horizontal linear, S3, and S4 constitute the modified Stokes we measure.

Vertical and horizontal polarizations and S3 are symmetric while S4 is antisymmetric.



Frequency from line center

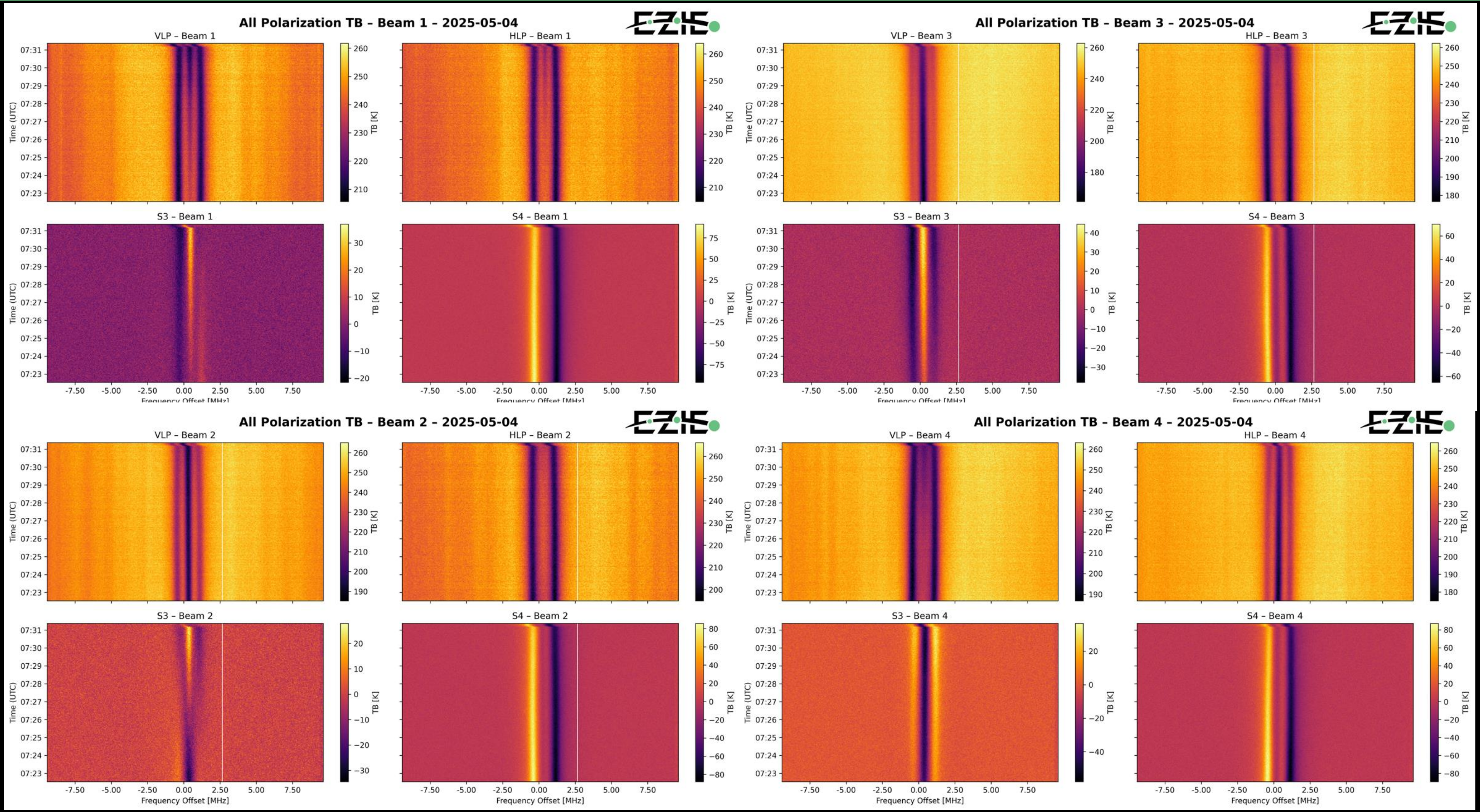
Time (UTC)

Each of the beams produce 9-minute spectra with 1024 spectral channels for each of the 4 look directions and for each of the 3 spacecraft per orbit.

EZIE L1 Data – Calibrated Radiances

Note the different scales, different offsets from line center, different features,… for each of the different beams.

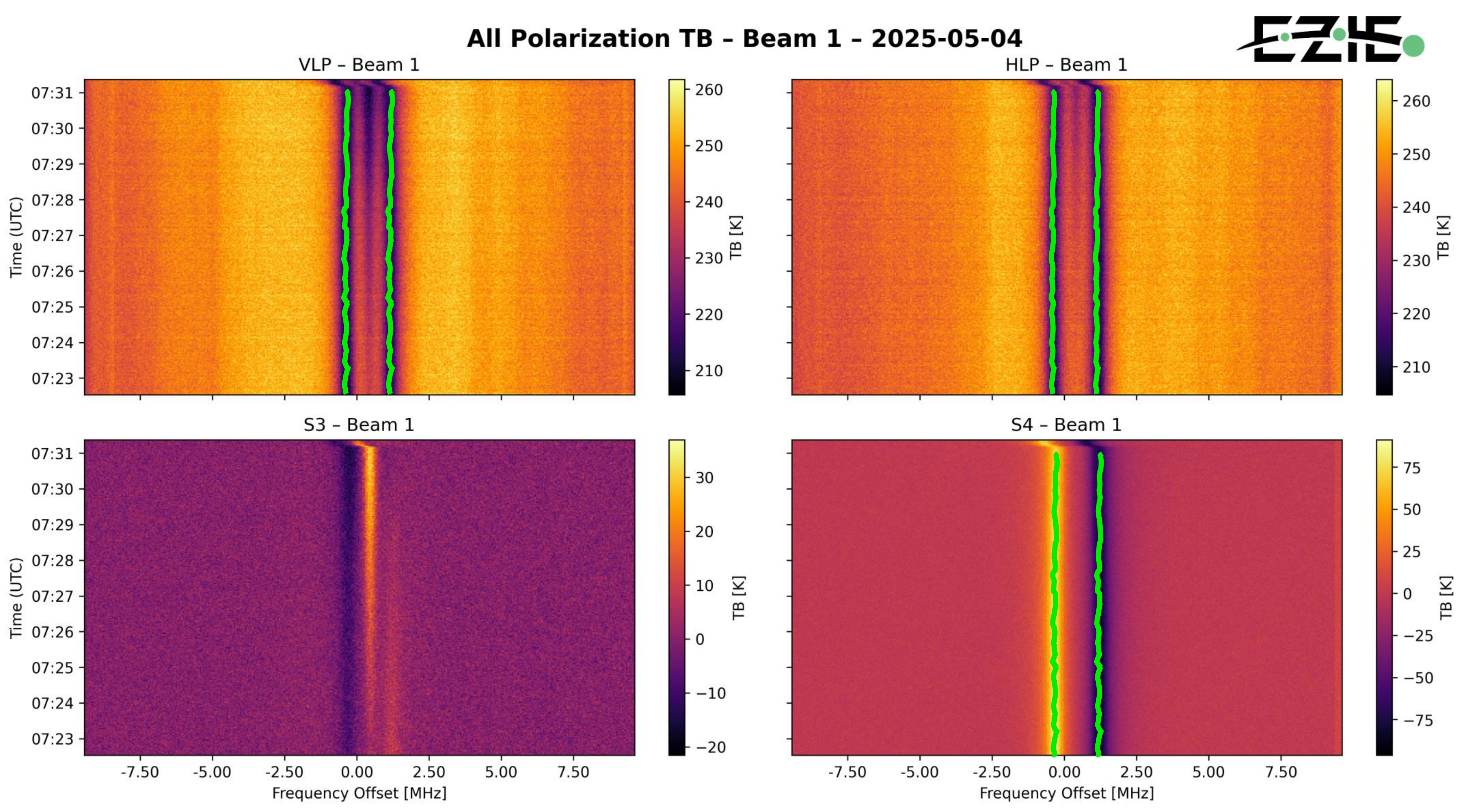
There is a lot of information here!!!



EZIE L2 Data – Total B field

To illustrate the technique, total B was retrieved from the line separation, which is the simplest retrieval possible.

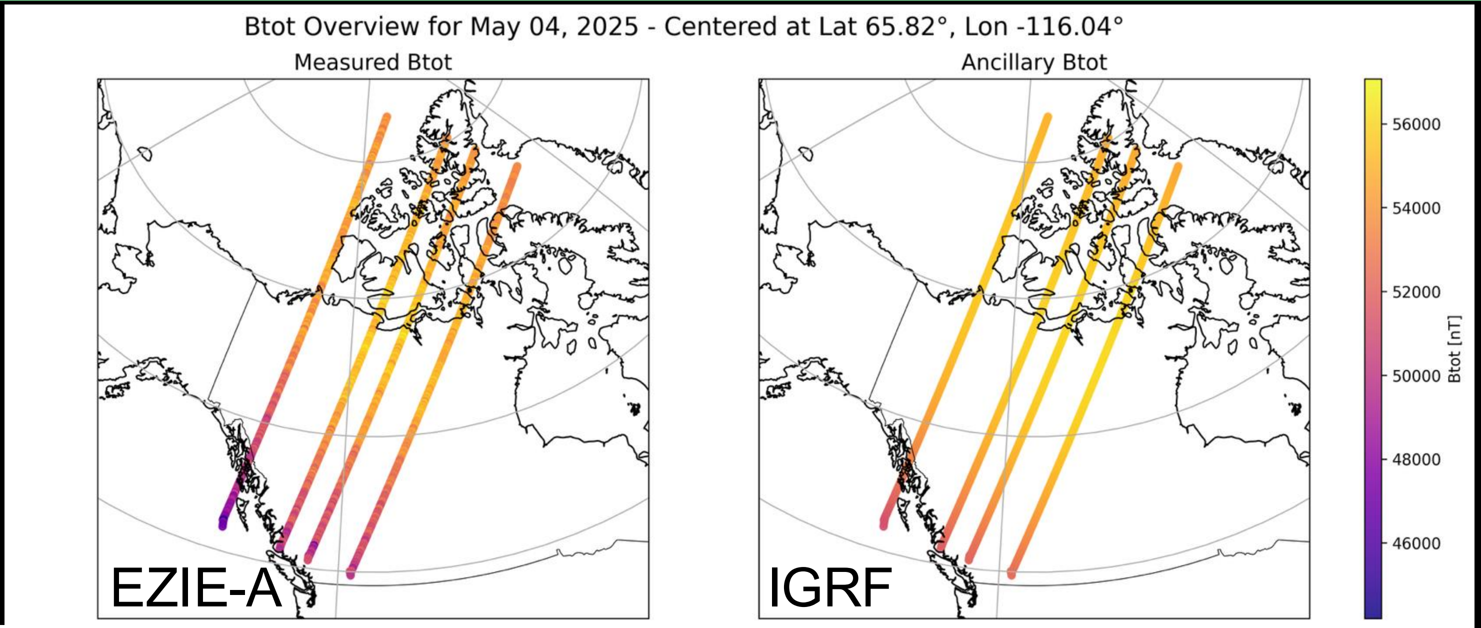
The distance between the vertical lines is proportional to the B field.

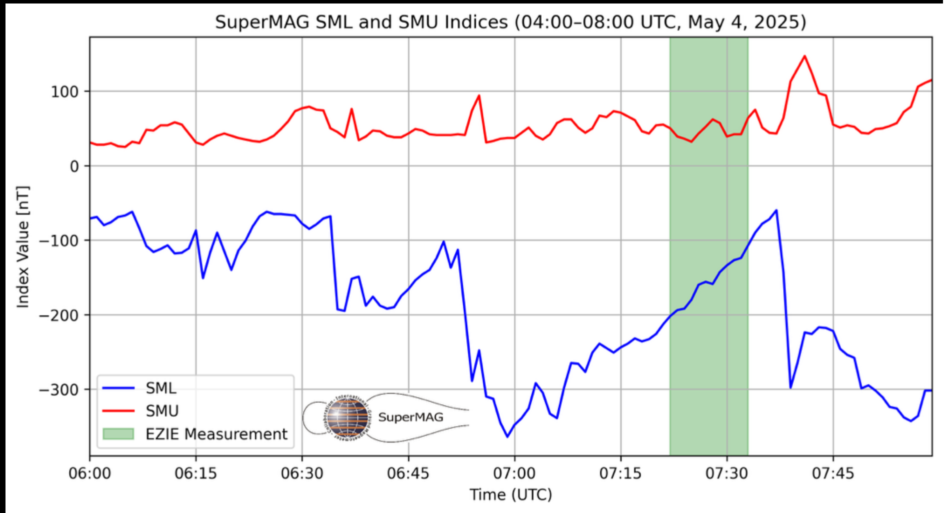


EZIE L2 Data – Total B field

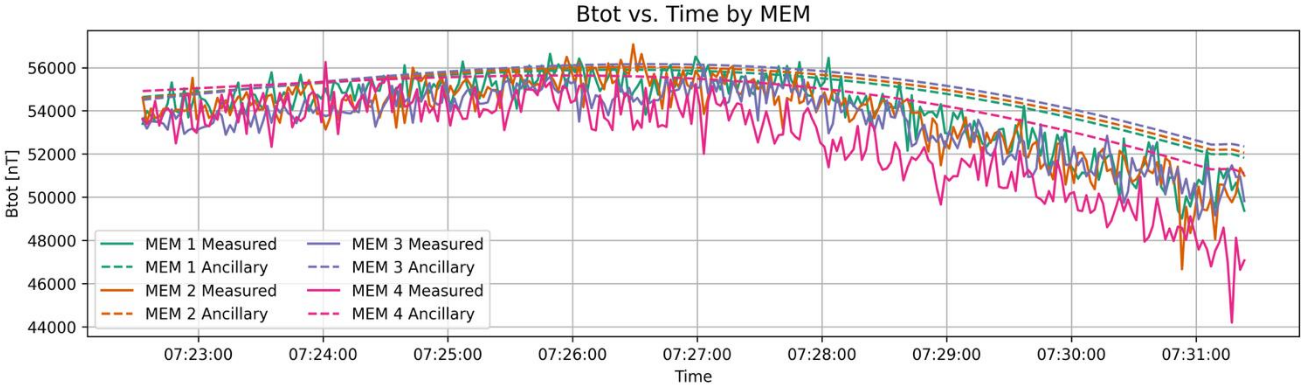
Repeating that for all four beams, along EZIE-A (middle, but representative spacecraft), we get four tracks of magnetic field retrievals.

Here we already notice a deviation from IGRF. Lower plot shows these differences.





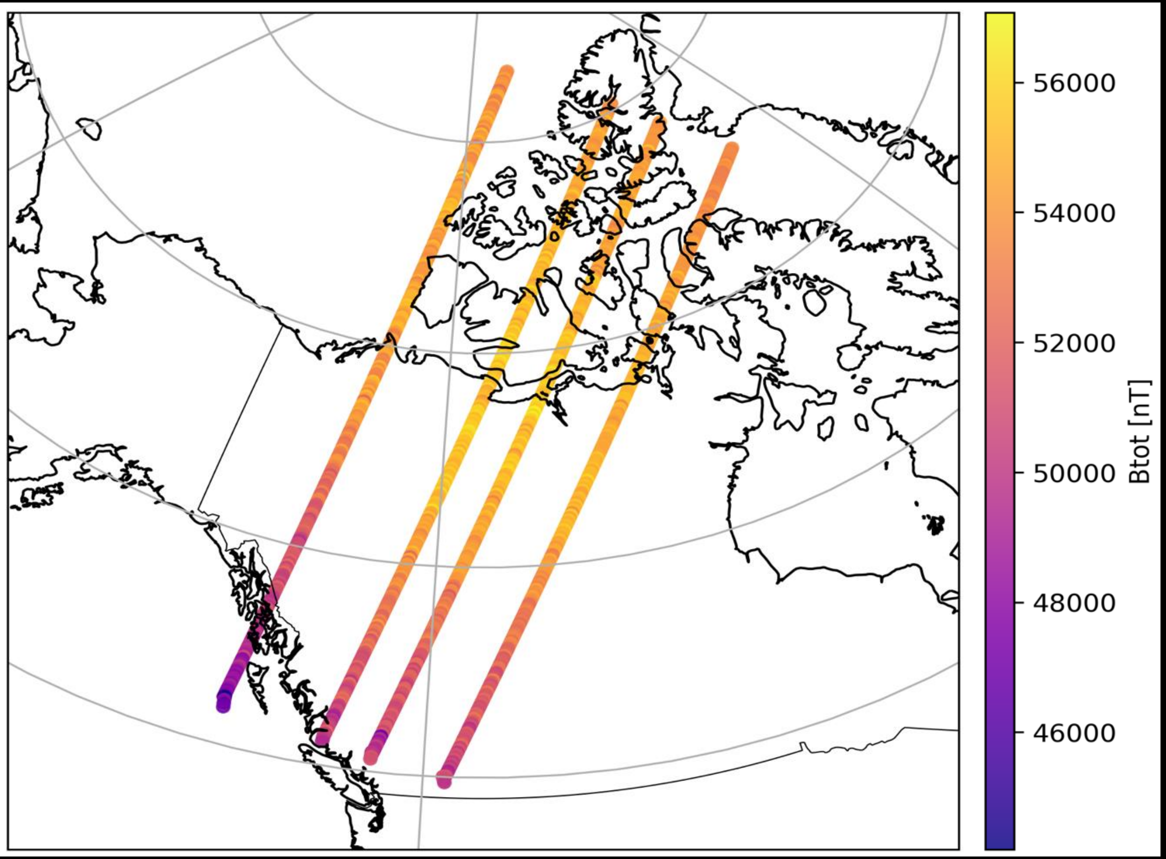
← SuperMAG SML indicates the presence of a substorm during this pass

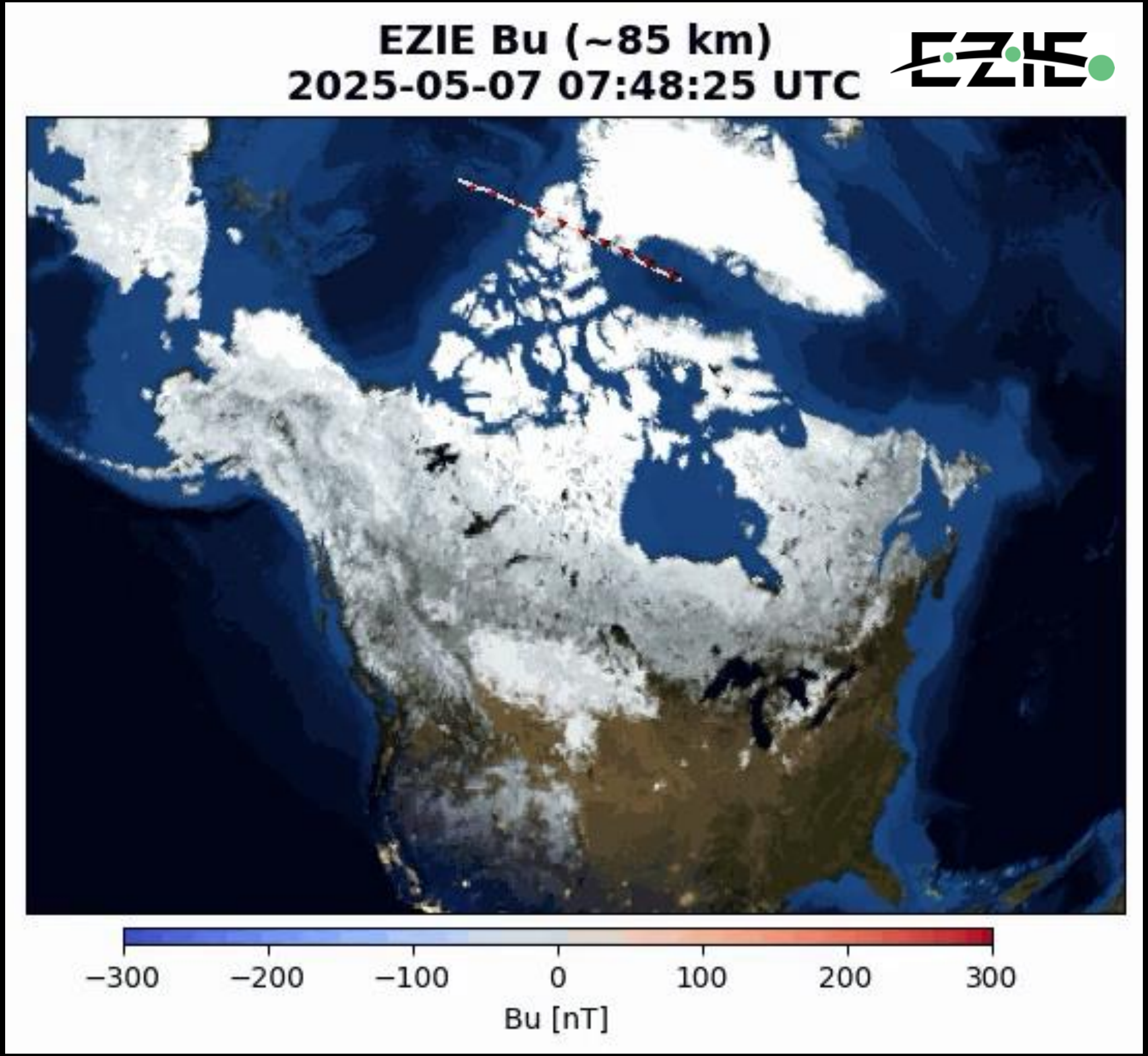


EZIE L3 Data – AEJ Equivalent Currents

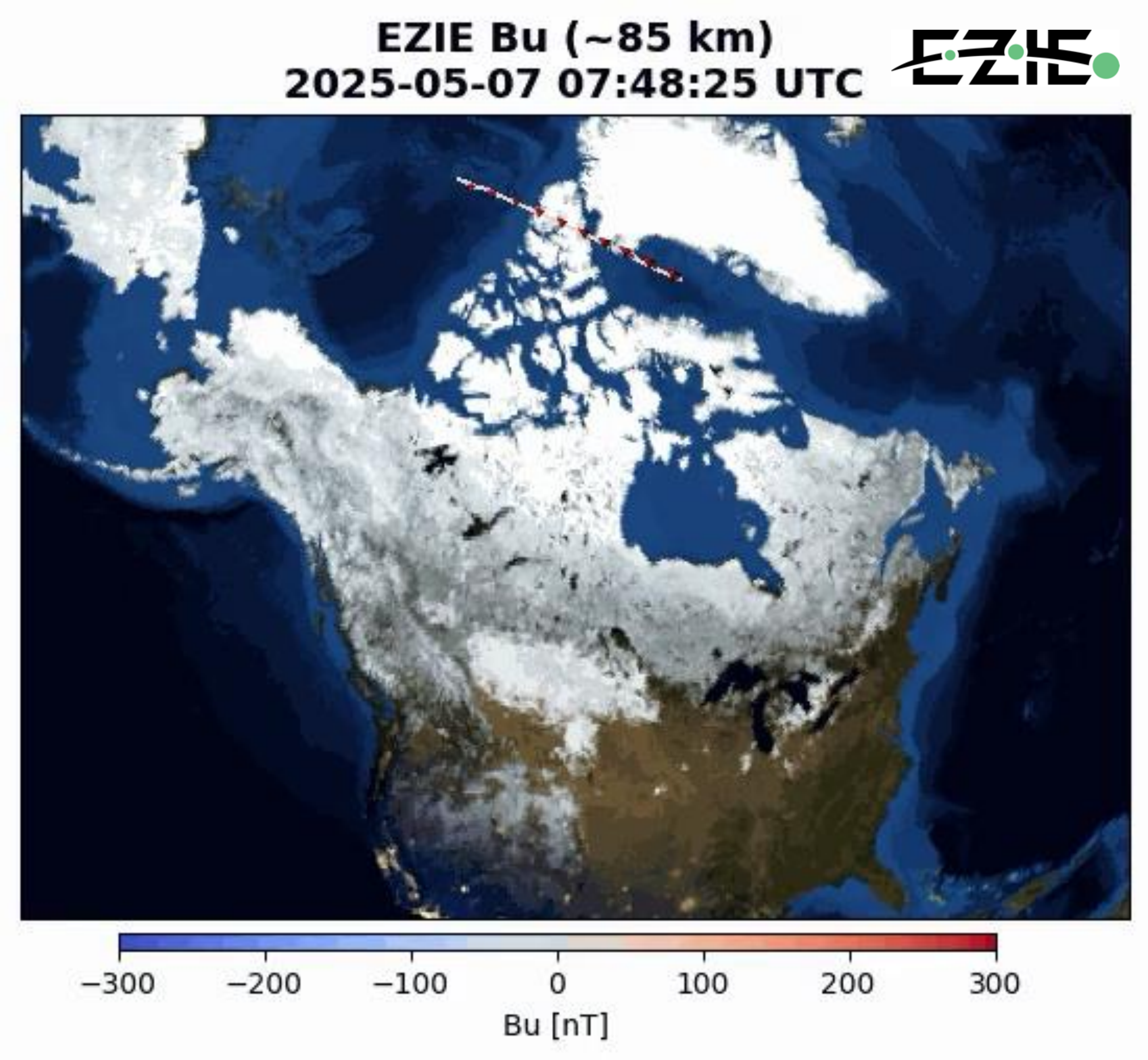
The EZIE L3 data retrieval works with both the total B field or the individual components.

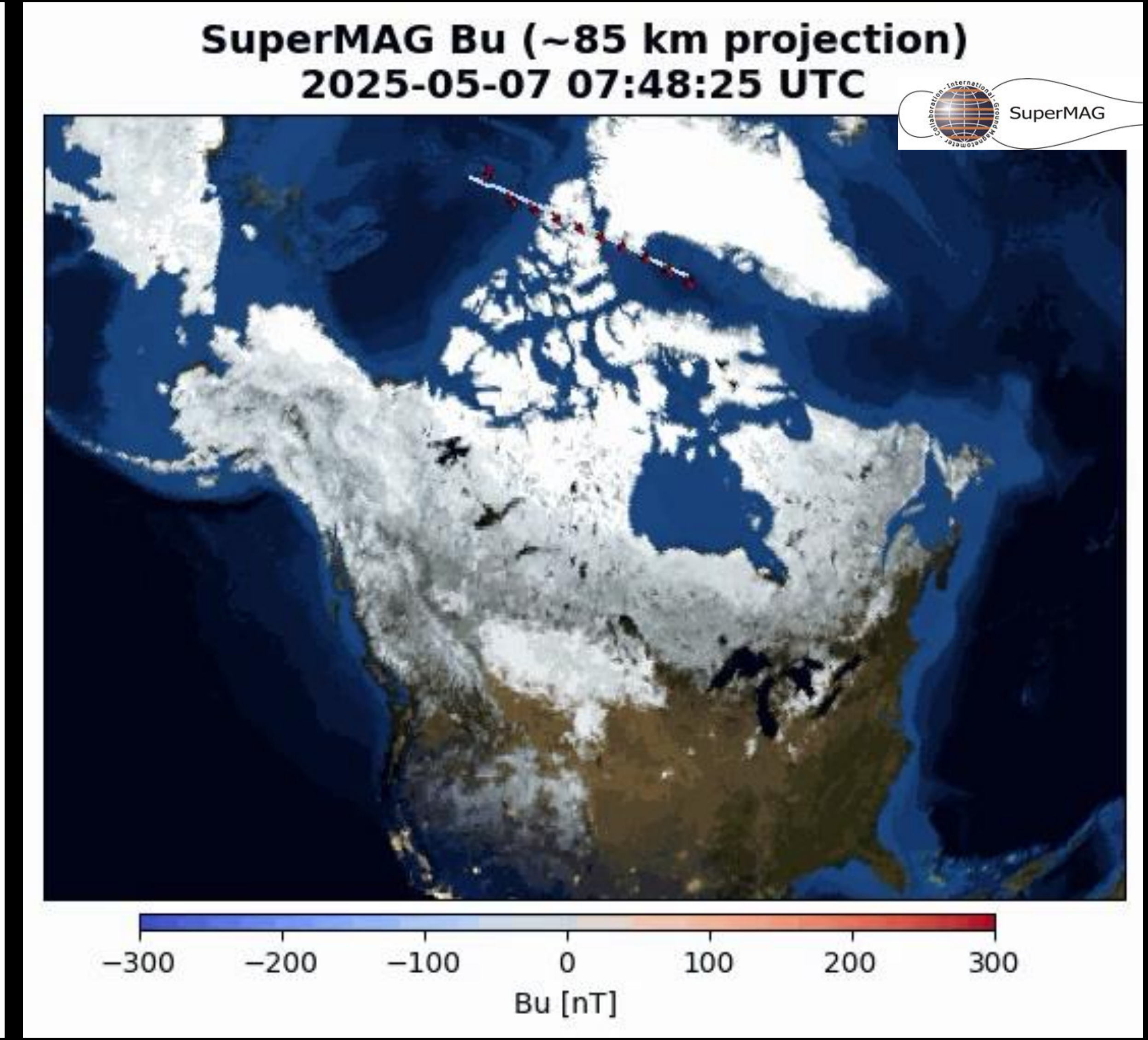
Using the preliminary Total B below we get this →



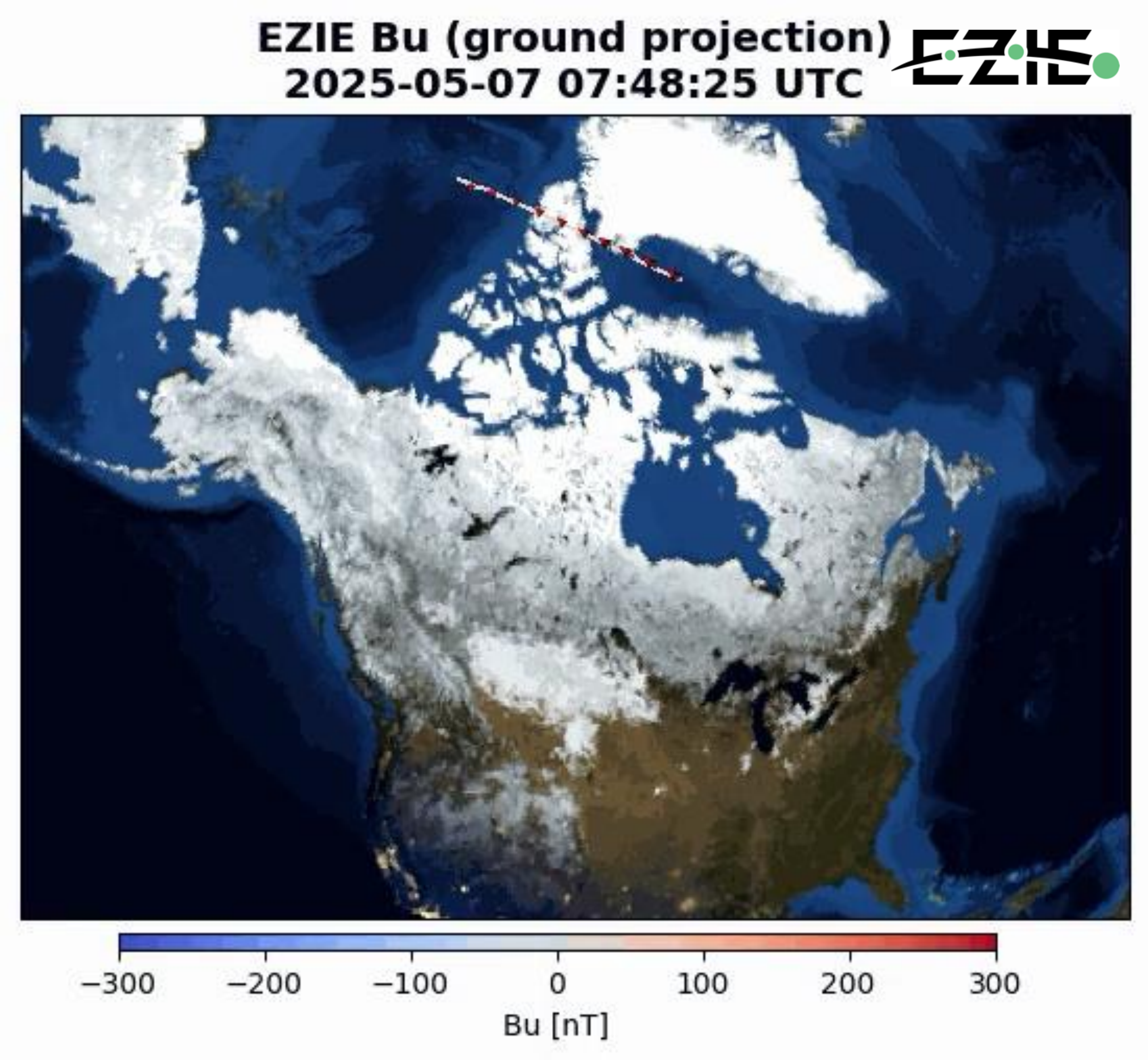


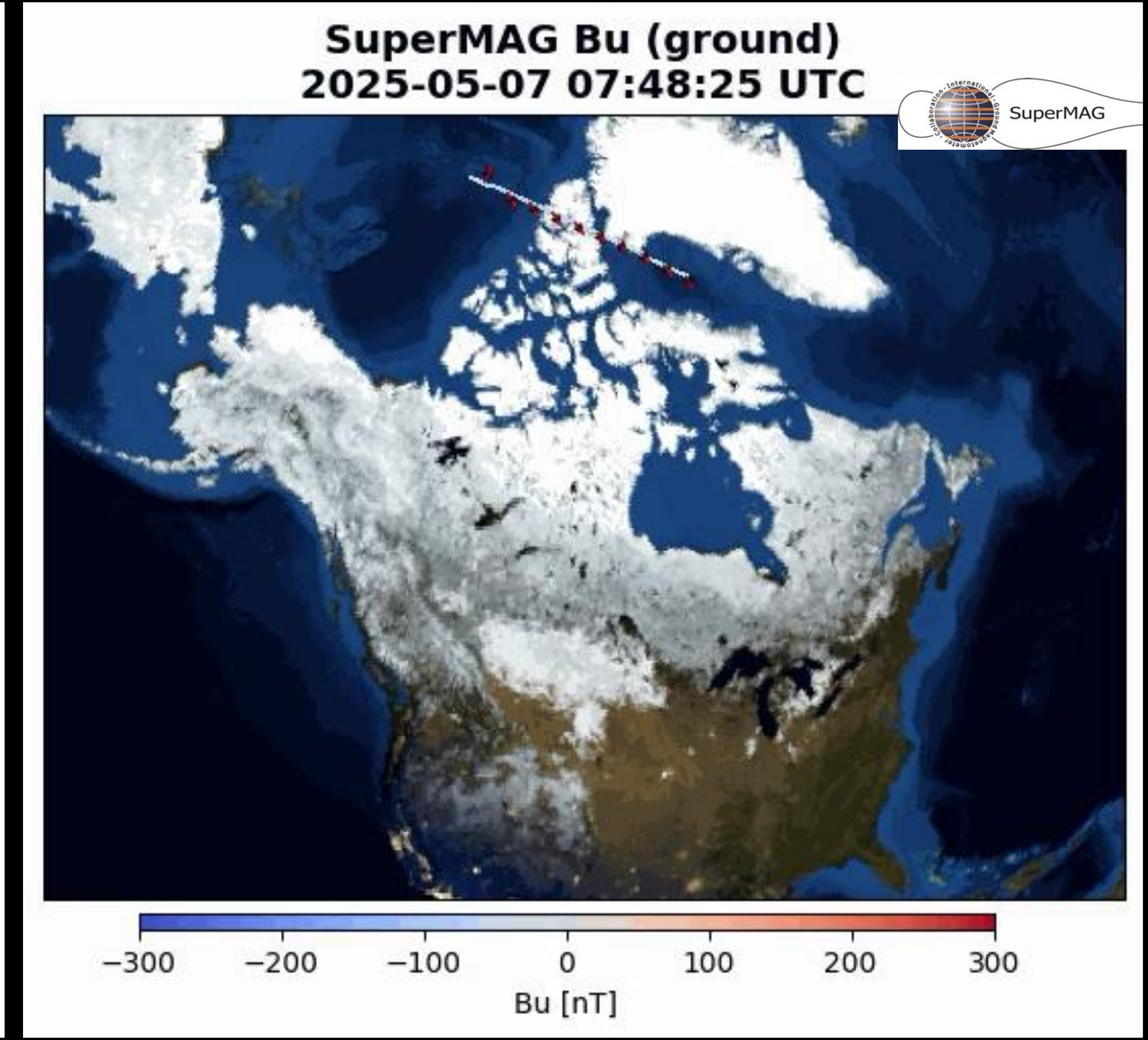
EZIE L3 Data – AEJ Equivalent Currents





EZIE L3 Data – AEJ Equivalent Currents

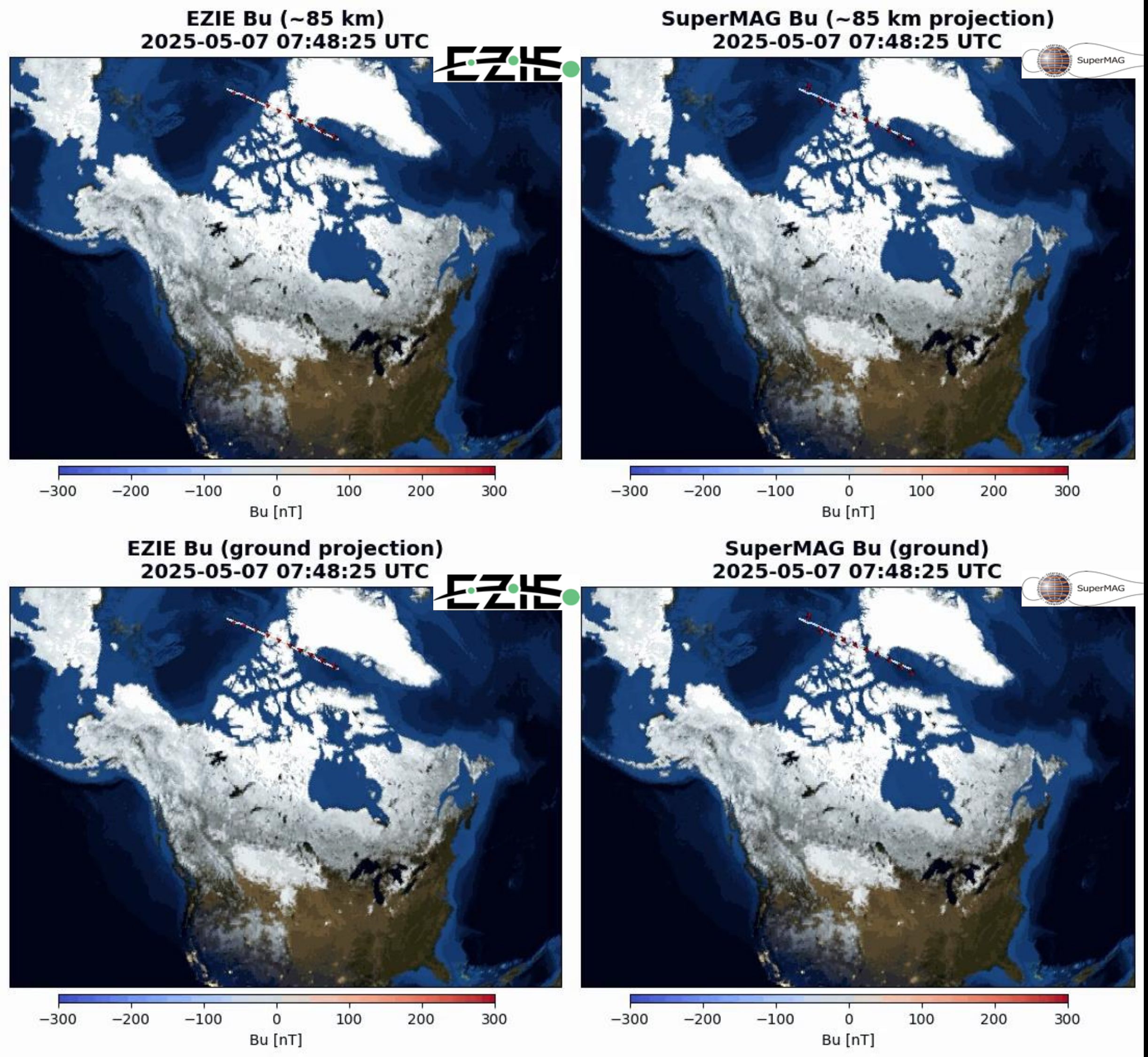




EZIE L3 Data – AEJ Equivalent Currents

Caveats:
- These results are very preliminary and with various caveats related to the calibration of L1 data and the L2 retrieval algorithms.
- There are many identified implementations to the algorithms that will significantly improve these results.

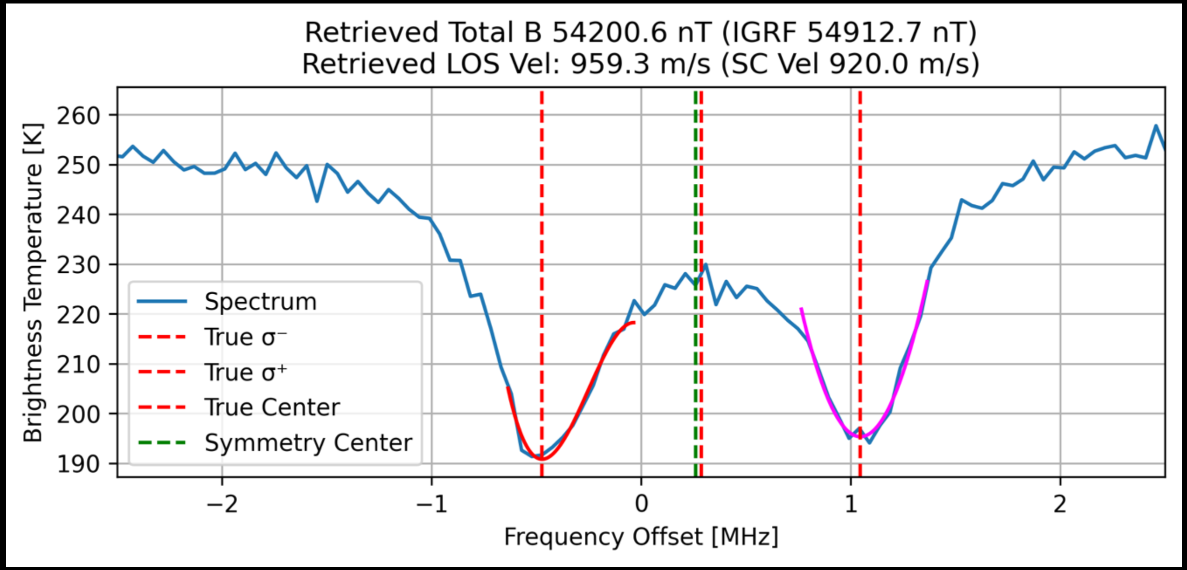
EZIE Side:
- Preliminary EZIE results show good agreement with the large-scale features of SuperMAG (10 magnetometer stations were used to retrieve the currents)
- Full EZIE data release will contain much higher spatial resolution and multi spacecraft.

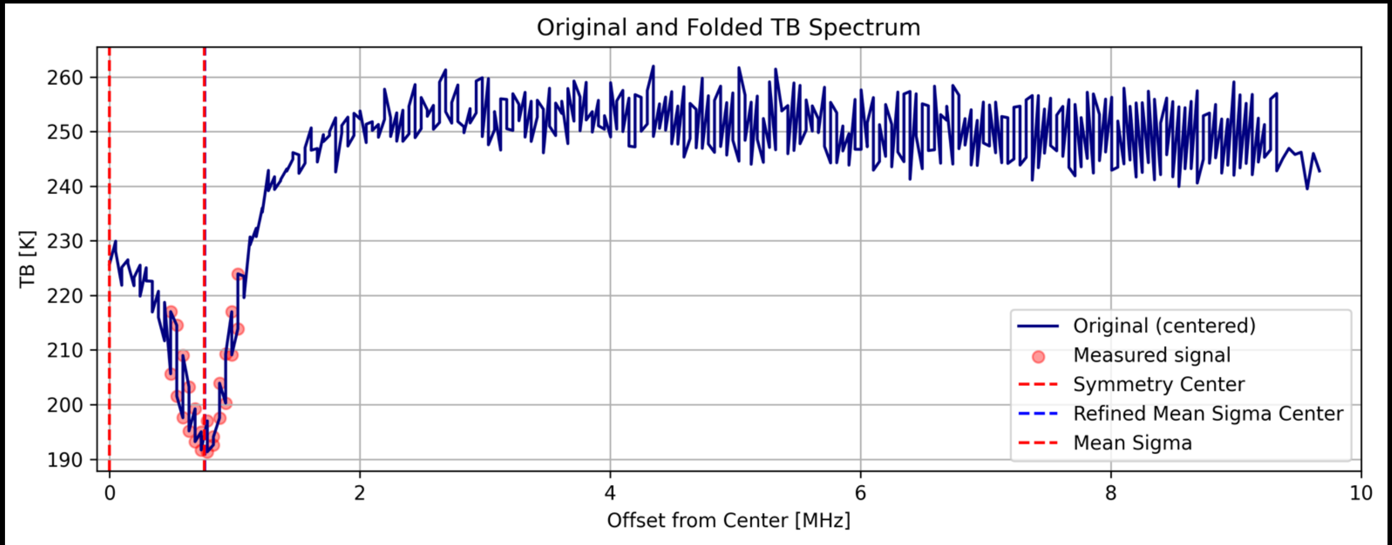


EZIE and the CEDAR Community Interest

Beyond the EZIE magnetic field measurements, the EZIE technique also enables the retrieval of line-of-sight neutral winds and temperature profiles.

- **Neutral winds**
  - Doppler shift from perceived line center (O_2 emission at 118.75 GHz) ~400Hz/(m/s).
  - Instrument alignment needs assessment.
  - After shifting the perceived line center to 0 MHz, it is easy to see the symmetric nature of the Zeeman splitting.



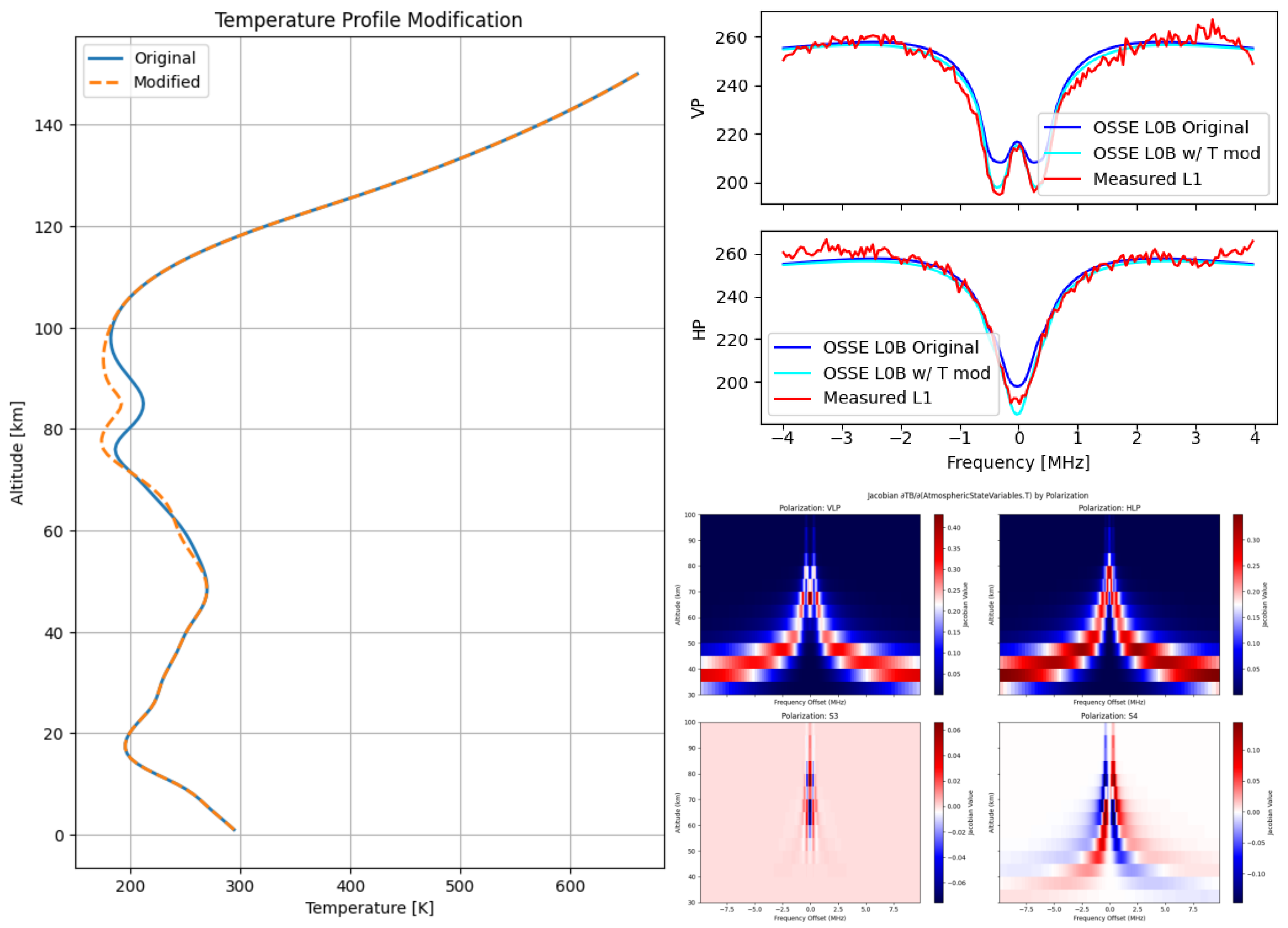


EZIE and the CEDAR Community Interest

Beyond the EZIE magnetic field measurements, the EZIE technique also enables the retrieval of line-of-sight neutral winds and temperature profiles.

- **Temperature profile**
  - The information about the temperature profile is contained in the spectra:
    - Red: Measured radiances
    - Blue: Forward model with MSIS
    - Cyan: Forward model with modified T profile.

Temperature retrieval is computationally intensive but possible (altitude-dependent of numerical Jacobian calculation). Capability is being developed and will be tested for future data release.



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EZIE Reading material:

EZIE Science Gateway:
https://eziegw.jhuapl.edu/

EZIEMag Gateway
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EZIE

Electrojet Zeeman Imaging Explorer

Come talk to us!

Sam Yee

Jesper Gjerloev

William Swartz

Rafael Mesquita

Ask me about EZIE-Mag