EMIC-Induced Precipitation as Measured by ELFIN: Source Regions, Impacts, and Energy Dependence

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Motivation

Electromagnetic Ion-Cyclotron (EMIC) waves are thought to be a primary driver of relativistic electron loss from the outer radiation belt.The atmospheric impact of this high-energy precipitation is poorly-characterized due to a lack of measurements resolving the loss cone. Further, the minimum electron scattering energy for EMIC waves remains unknown, as EMIC waves may violate the assumptions of the quasi-linear theory traditionally used to analyze wave-particle interactions. This poster aims to move toward an understanding of global EIP fluxes and the energy response of electrons to EMIC waves by using recent data that can resolve the interior of the loss cone.

Data Source: ELFIN

- Twin CubeSats in polar LEO
- 3 years of data (2019-2022) over 2 satellites
- 22.5° angular resolution
- LEO ⇒ Resolvable loss cone ($\alpha_{LC} \approx 67°$)

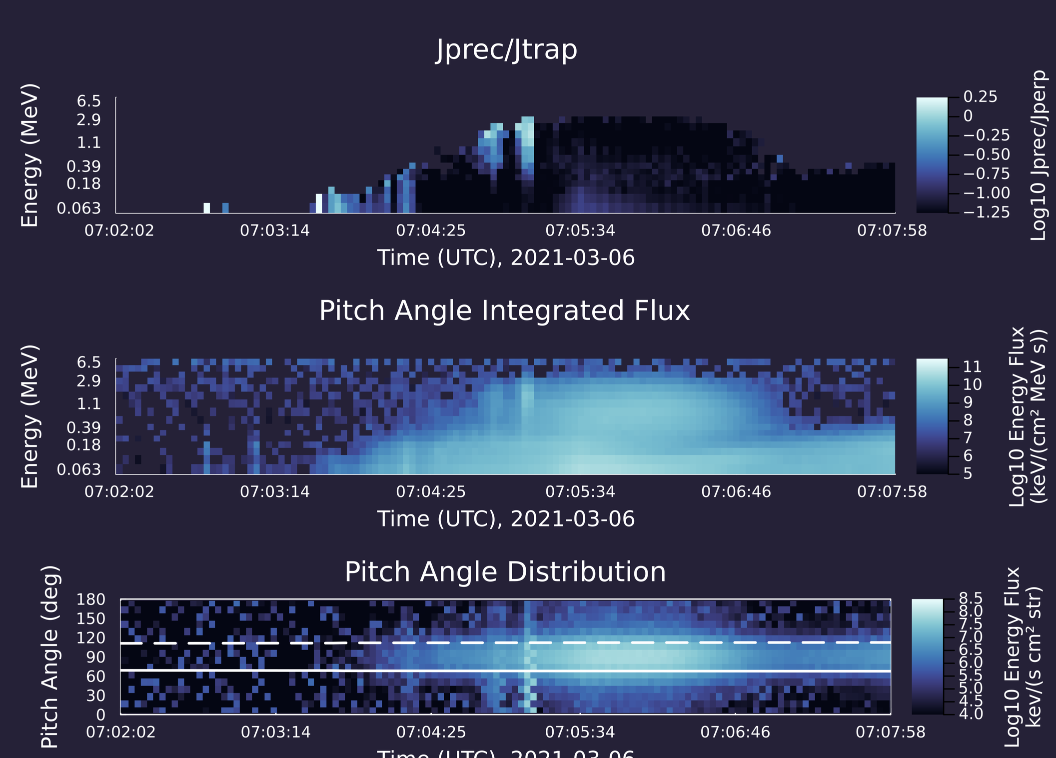


Fig. 1: ELFIN data showing EIP at ~07:05:00

Methods

Candidate EIP events detected using a scoring algorithm. Process: Look at J_{prec}/J_{trap} heatmap (see Fig. 1). For high- (> 500 keV) and low- (<500 keV) energy channels:

1. Remove pixels with low precipitation ($J_{prec}/J_{trap} < 10^{-.75}$)
2. Remove pixels with < 3 nonzero neighbors
3. Vertically sum remaining J_{prec}/J_{trap} values over given energy range

This produces a precipitation score for low and high energy channels. The low energy score is then set to its highest value in the surrounding 4 timesteps on either side to reject detections due to the electron isotropy boundary. A candidate EIP event is returned when:

1. `high-energy score > .75`: Loss cone must be filled at high energies.
2. `high-energy score > low-e score - 1.5`: High energy precipitation must be comparable or larger than low energy precipitation.
3. `low-energy score < 4`: Reject events with very strong low-energy precipitation, e.g. the isotropized plasma sheet.

Each detection was then verified by hand to avoid false positives.

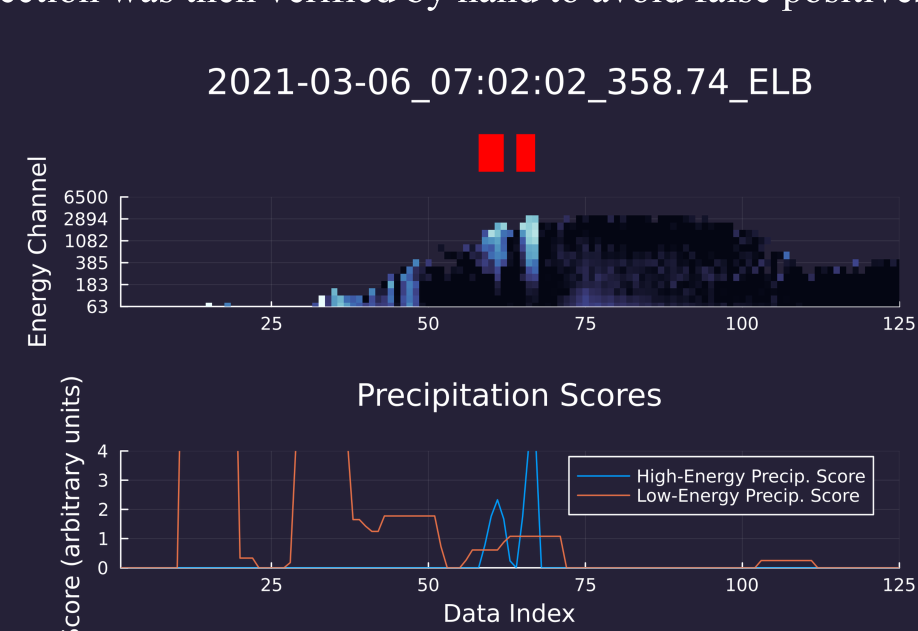
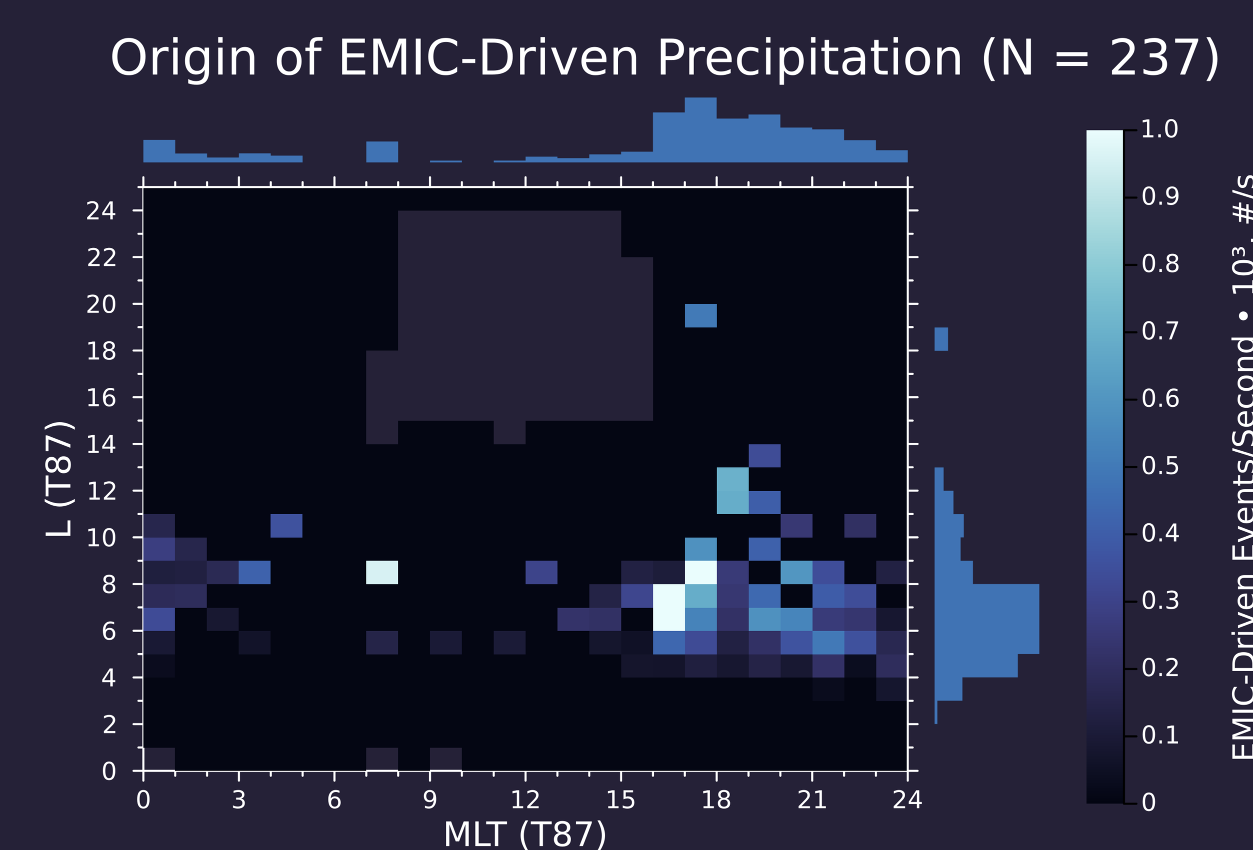


Fig. 2: Example EIP detections.

Key Points:

- An in-progress EIP detection algorithm is used to create a set of 237 likely EIP events
- These events primarily originate from dusk to midnight at L ≈ 5-10, in line with previous results
- EIP precipitation is strongest at ~MeV energies, extending down to 100s of keV in some cases

EIP Distributions



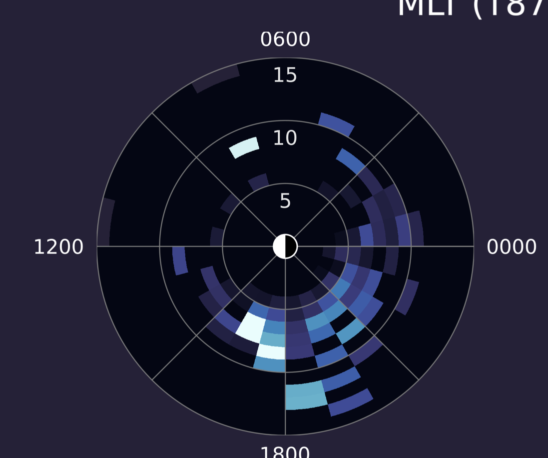


Fig. 3: EIP detection rate shown in MLT/L and a polar projection of same distribution.

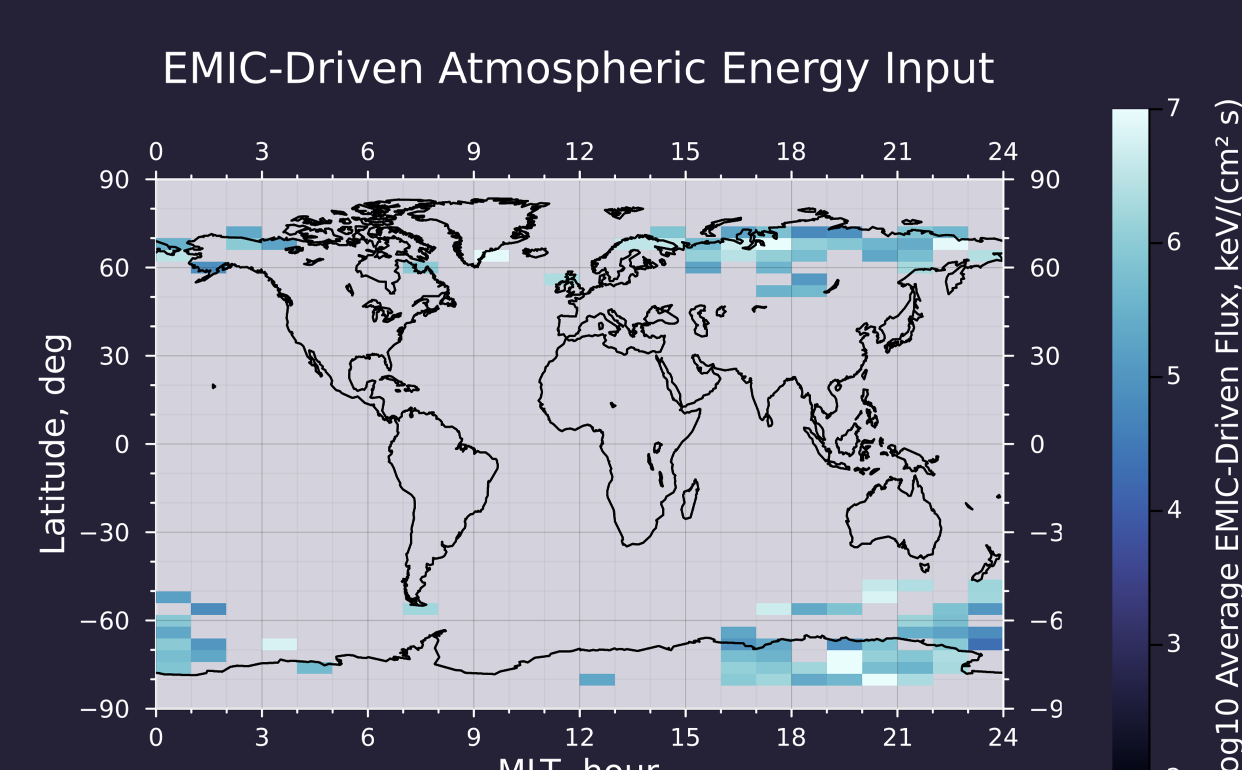


Fig. 4: Global atmospheric energy input due to EIP events analyzed, normalized to the time ELFIN spent in each MLT/latitude bin.

Future Work

- Improve algorithm to accept EIP with low-energy precipitation
- Reduce need for human verification of EIP detection
- Expand dataset to capture majority of EIP measured by ELFIN

Open Science:

All code used in this analysis is available at `github.com/julia-claxton/`. ELFIN data are freely available at `data.elfin.ucla.edu`.

EIP Energy Profile

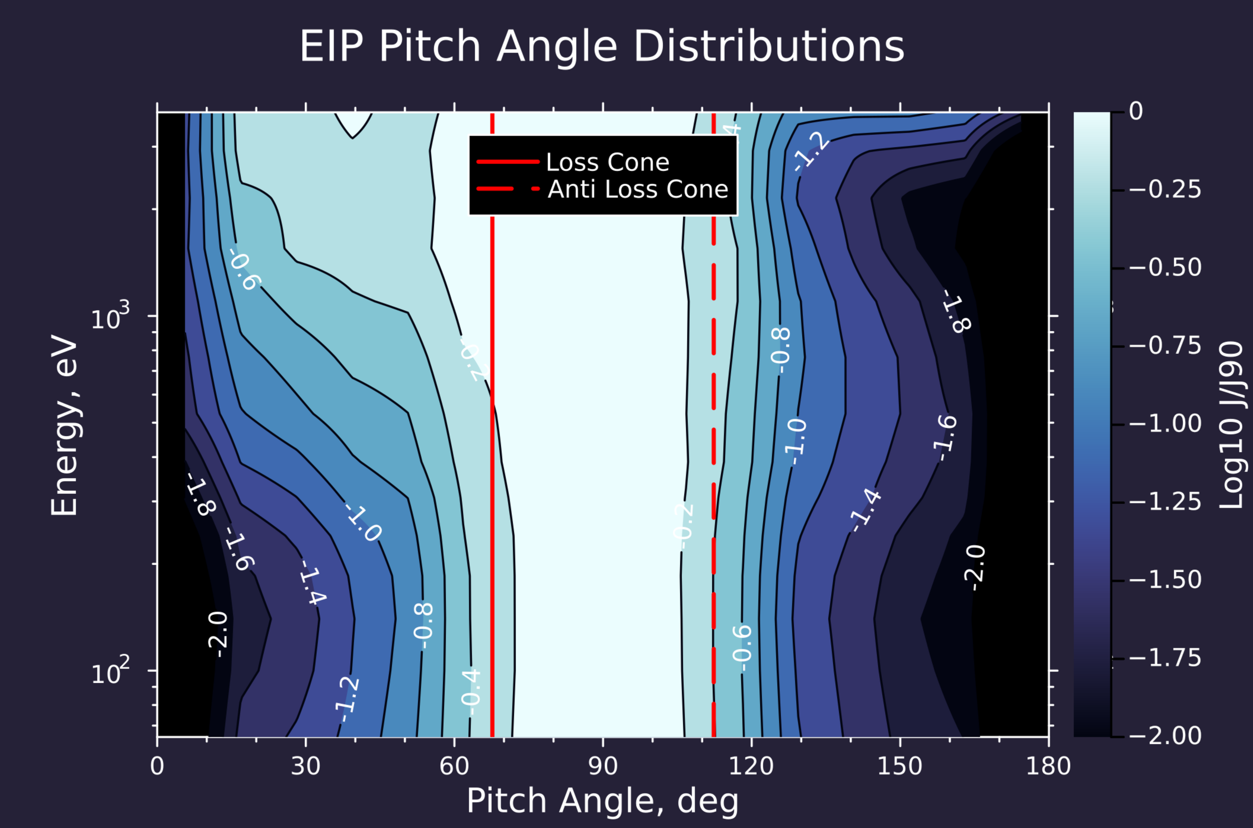


Fig. 4: Average flux of EIP events, normalized to perpendicular flux, in pitch angle-energy space. This demonstrates a filling of the loss cone at high energies, with filling intensity decreasing with energy down to ~200 keV. Atmospheric backscatter can bee seen at ~400 keV in the anti loss cone.

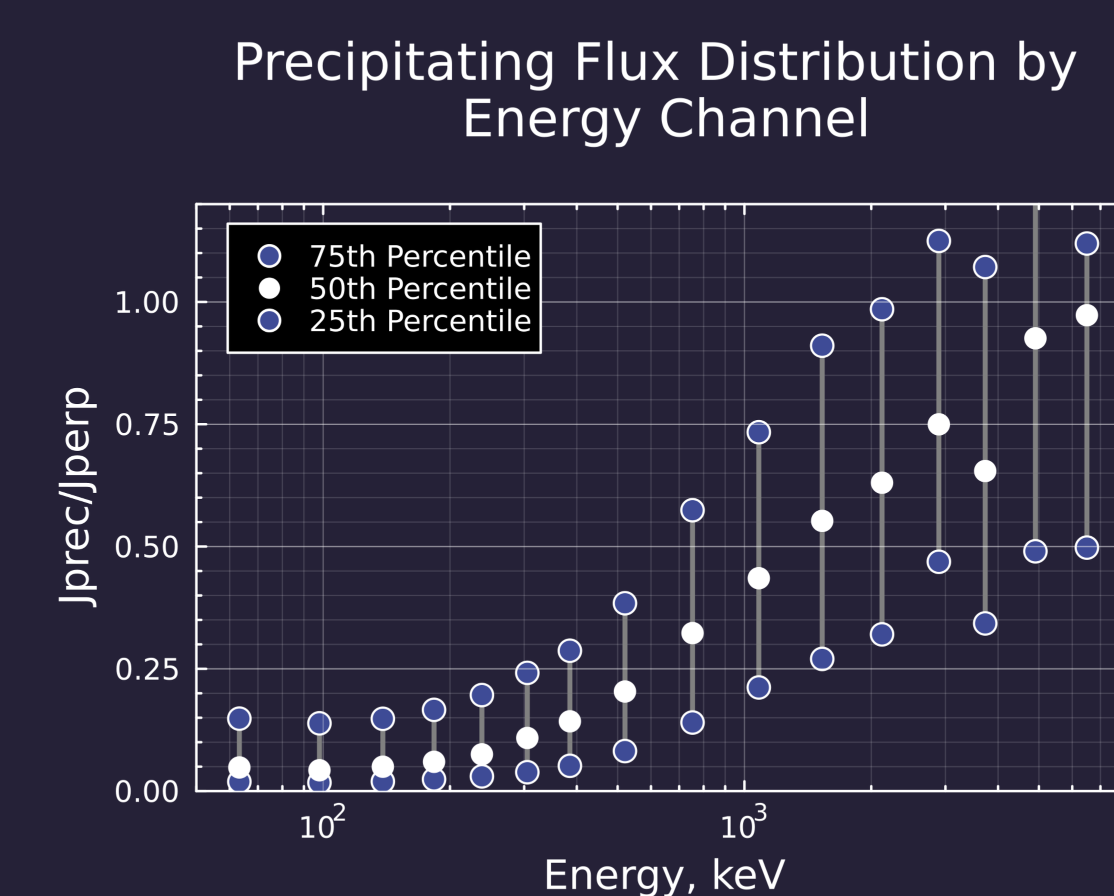


Fig. 6: Quantiles of J_{prec}/J_{trap} distribution for each of ELFIN's energy channels. Precipitating flux increases with increasing energy, beginning in the 100s of keV range.

Findings

- EIP events can be detected in particle data by looking for patterns of increasing J_{prec}/J_{perp} with increasing energy
- EIP identification does not require conjunctions with other instruments
- EMIC-induced precipitation originates from dusk to nightside at L ≈ 5-10
- In this set of events, EMIC scattering begins at ~400 keV

Limitations

- EIP selection punishes low-energy precipitation, potentially excluding EIP events with sub-MeV effects
- Varying loss cone coverage requires extrapolation, leading to some inaccuracy in precipitating flux estimates

References

Literature:
Capannolo+ 2024, `https://doi.org/10.1029/2023GL103519.`

Angelopoulos+ 2020, `https://doi.org/10.1007/s11214-020-00721-7`

Software:
G. Van Rossum+ 1995, Python reference manual.

Bezanson+ 2017, `https://doi.org/10.1137/141000671`

Morley+, `https://doi.org/10.5281/zenodo.3252523`