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 (Ni 2015, Thorne 1971). 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 energy required for scattering by EMIC waves remains unknown, as the quasi-linear theory traditionally used to analyze wave-particle interactions underestimates scattering of subrelativistic electrons (Cappanolo 2023). This poster aims to move toward an understanding of global EIP fluxes and the energy-domain response of electrons to EMIC waves by using recent data that can resolve the interior of the loss cone at a variety of energies.

Data Source: ELFIN

Electron Fields and Losses Investigation (Angelopoulos 2020)

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

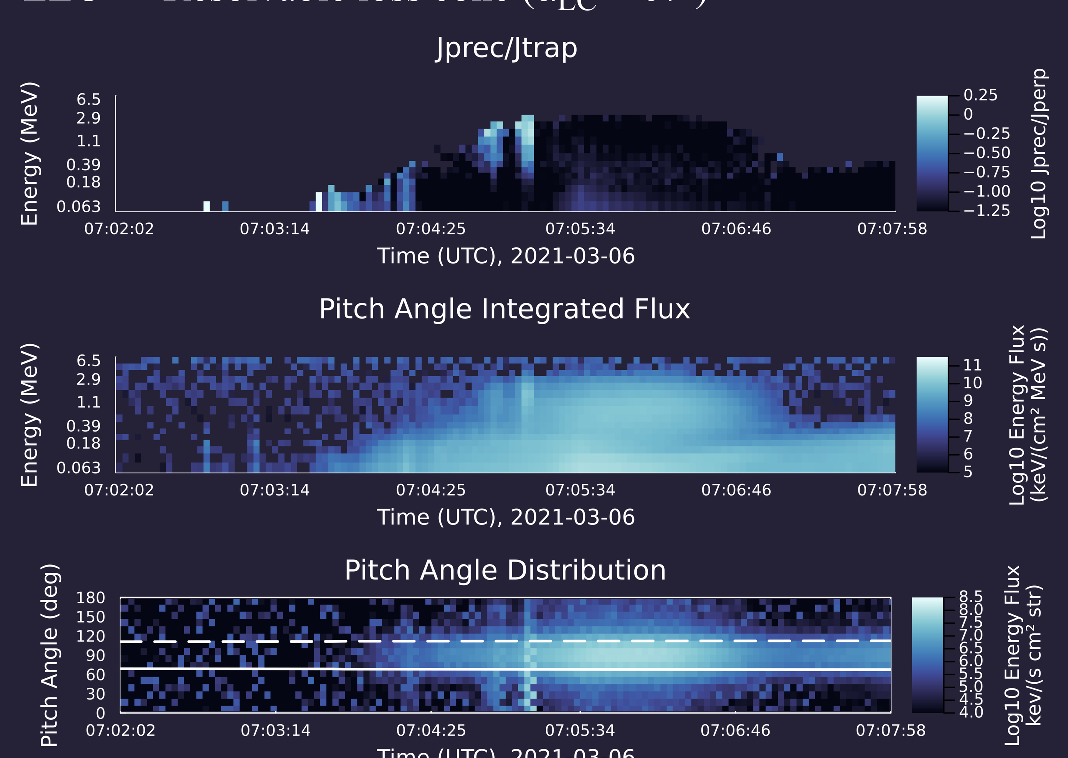

Fig. 1: ELFIN data showing EIP at ~07:05:00 UTC

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.

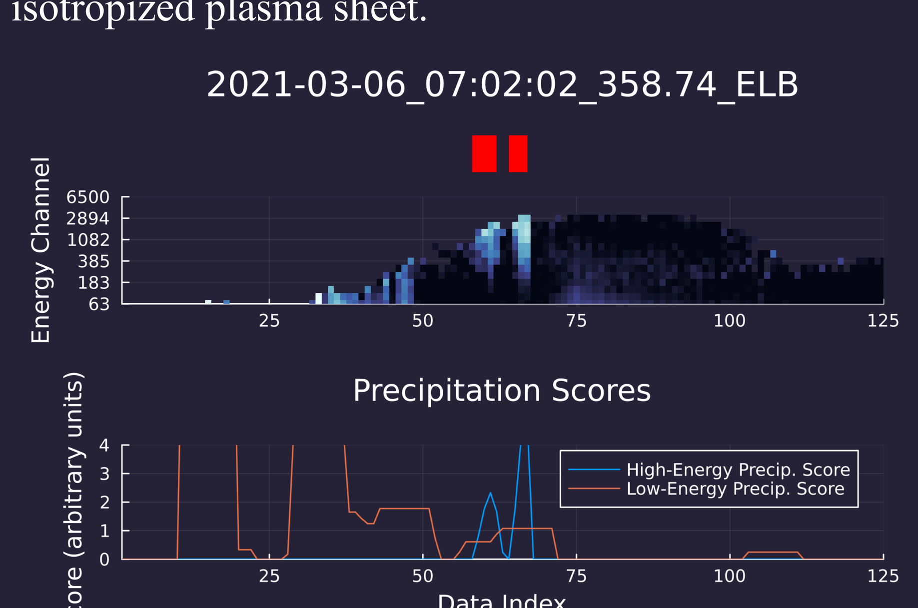

Fig. 2: Example EIP detections.

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

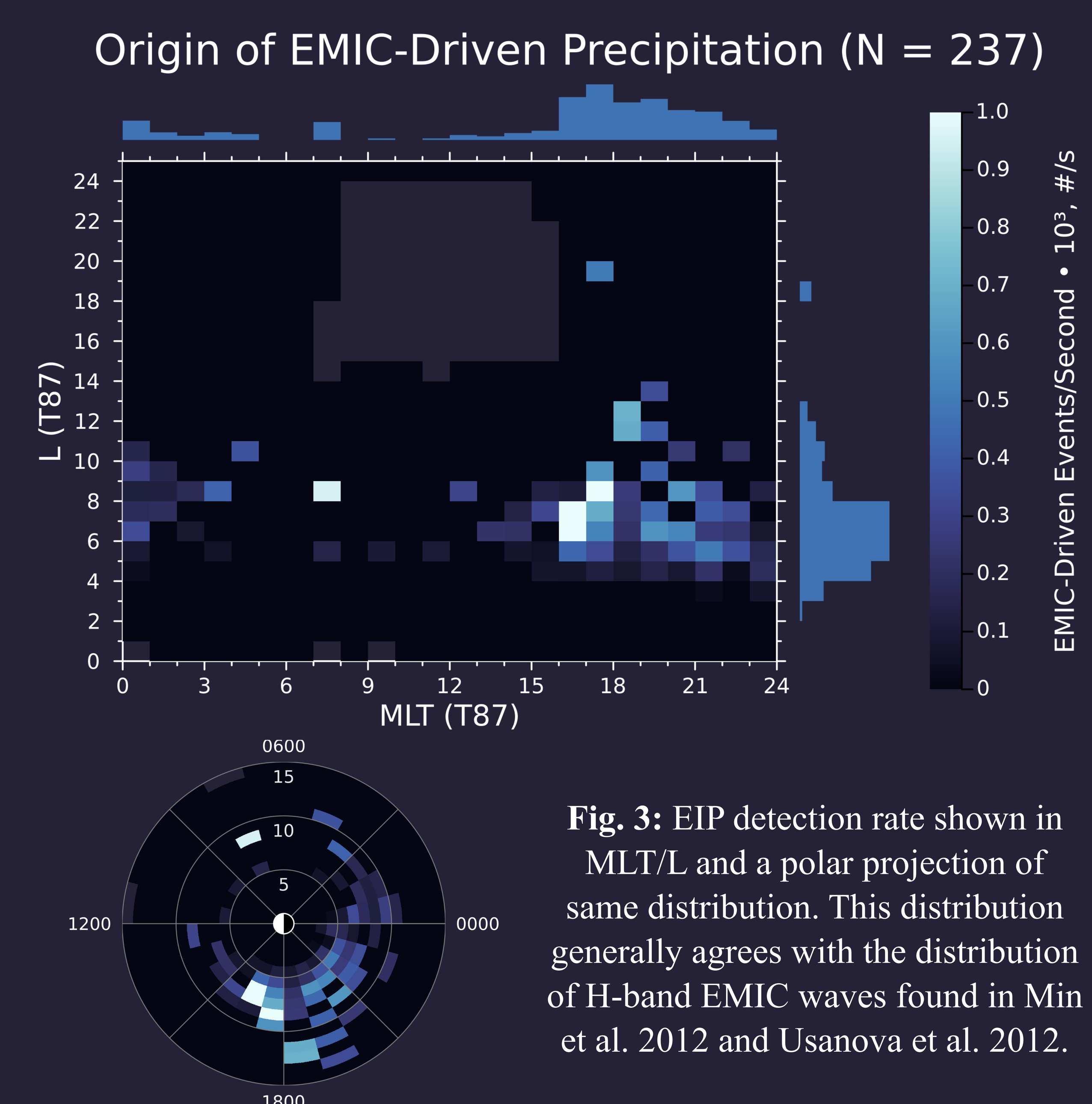

Fig. 3: EIP detection rate shown in MLT/L and a polar projection of same distribution. This distribution generally agrees with the distribution of H-band EMIC waves found in Min et al. 2012 and Usanova et al. 2012.

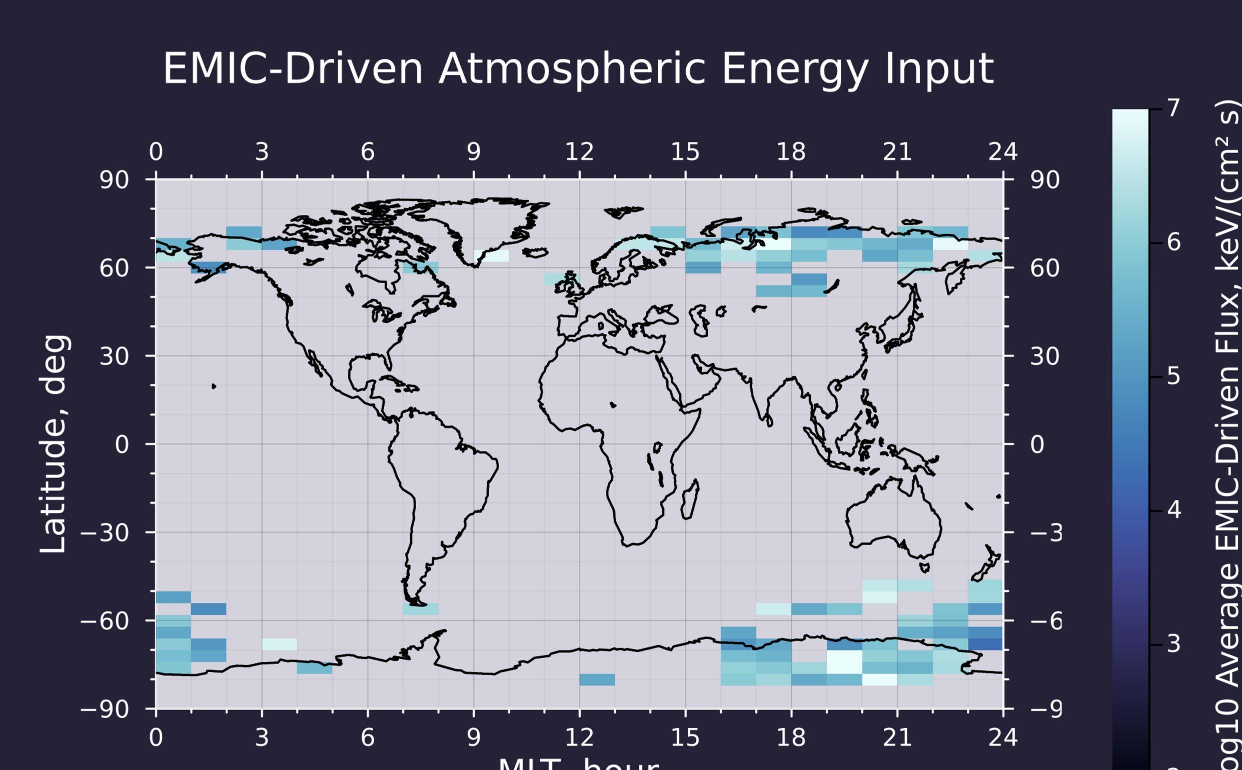

Fig. 4: Global atmospheric energy input due to EIP events analyzed, normalized to the time ELFIN spent in each MLT/latitude bin.

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
- Quantify atmospheric backscatter of EIP

Open Science

All code used in this analysis is available at `github.com/julia-claxton/2024_GEM_workshop`. ELFIN data are freely available at `data.elfin.ucla.edu`.

EIP Energy Profile

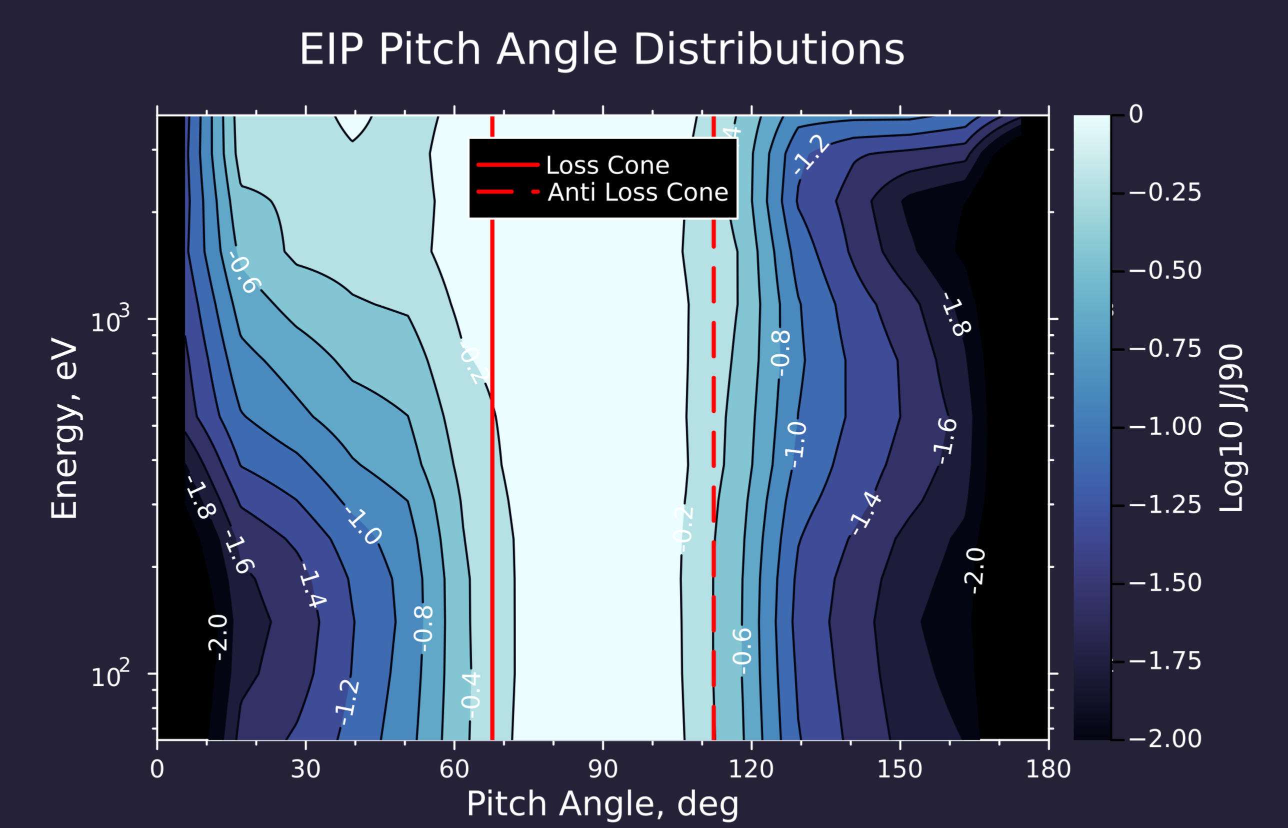

Fig. 4: Average flux of EIP events, normalized to perpendicular flux, in pitch angle-energy space. This demonstrates a filling of the loss cone at high energies, with filling intensity decreasing with energy down to ~200 keV. Atmospheric backscatter can bee seen at ~400 keV in the anti loss cone.

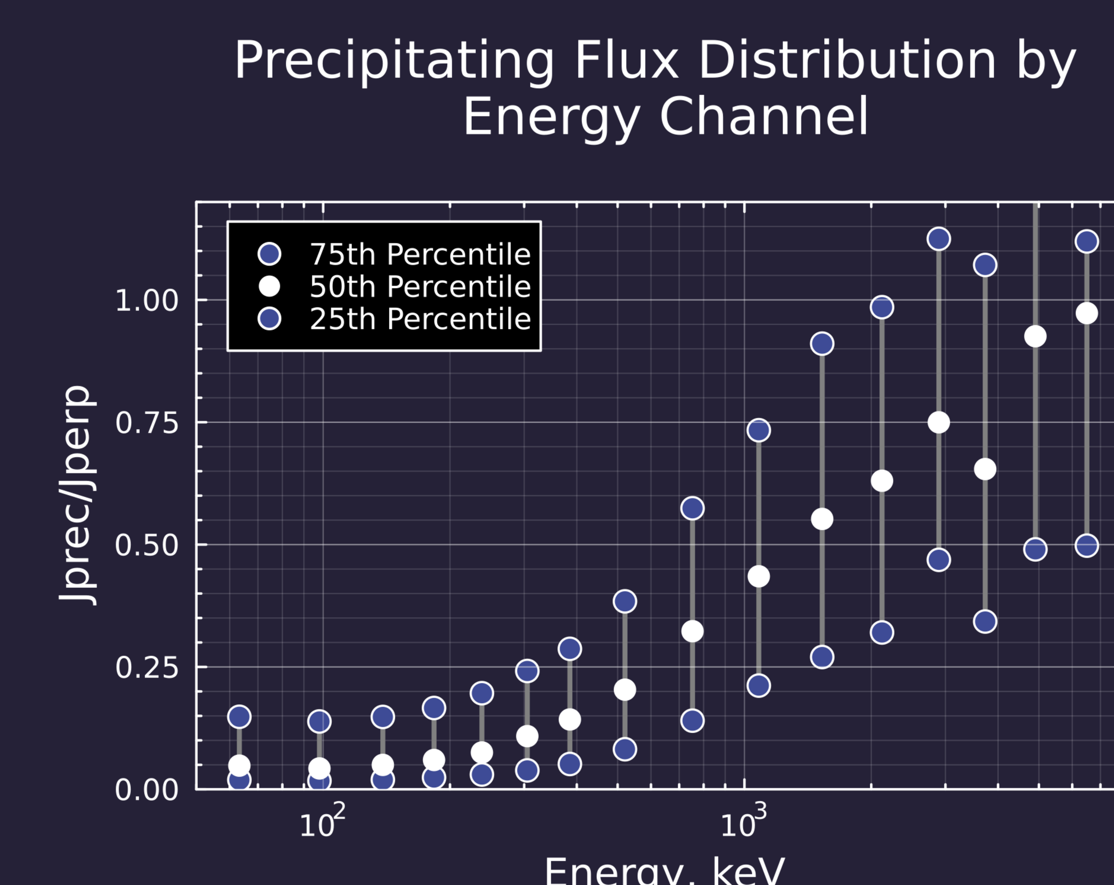

Fig. 6: Quantiles of J_{prec}/J_{trap} distribution for each of ELFIN's energy channels. Precipitating flux increases with increasing energy, beginning in the 100s of keV range.

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

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Thorne+ 1971, `https://doi.org/10.1029/JA076i019p04446`
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Software:
G. Van Rossum+ 1995, Python reference manual.
Bezanson+ 2017, `https://doi.org/10.1137/141000671`
Morley+, `https://doi.org/10.5281/zenodo.3252523`