What's Haunting the FM Band of EDGES?
A Survey of Ionospheric Phenomena

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Introduction to EDGES

The Experiment to Detect the Global Epoch of Reionization Signature

- Table-sized, zenith-pointing ground-based radio spectrometer.
- Designed to measure the sky-averaged 21 cm signal from neutral hydrogen at high redshift.
- Meticulously designed to suppress reflections and reduce chromaticity effects; optimized for high-precision, absolute spectrum measurements.
- Frequency-dependent but direction-independent.

EDGES-3 enjoying the sunset on Adak Island. Figure from the Haystack Observatory EDGES Webpage.

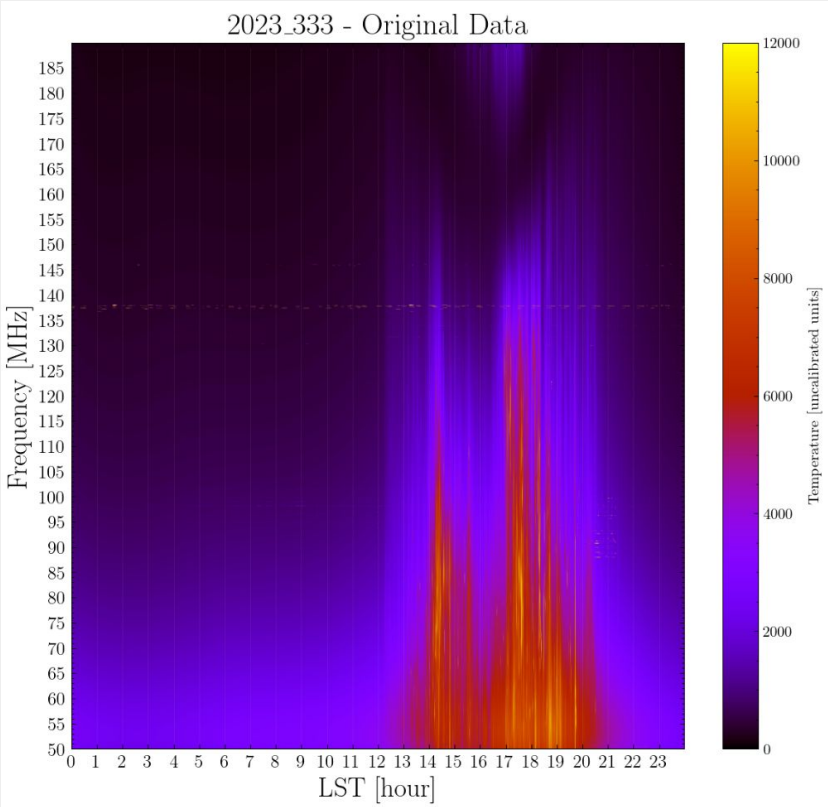
Introduction to EDGES

The Experiment to Detect the Global Epoch of Reionization Signature

- Currently stationed in Inyarrimanha Ilgari Bundara at the CSIRO Murchison Radio-Astronomy Observatory in Western Australia.
- Previous locations include Devon Island (Nunavut, Canada) and Adak Island (Alaska, US) (very cold and far away).
- The 21 cm signal is a tiny perturbation against a sky that is extremely bright at the observing frequencies of interest (so EDGES is very sensitive)!

The EDGES Team on Devon Island. *(Source: The Terror)*

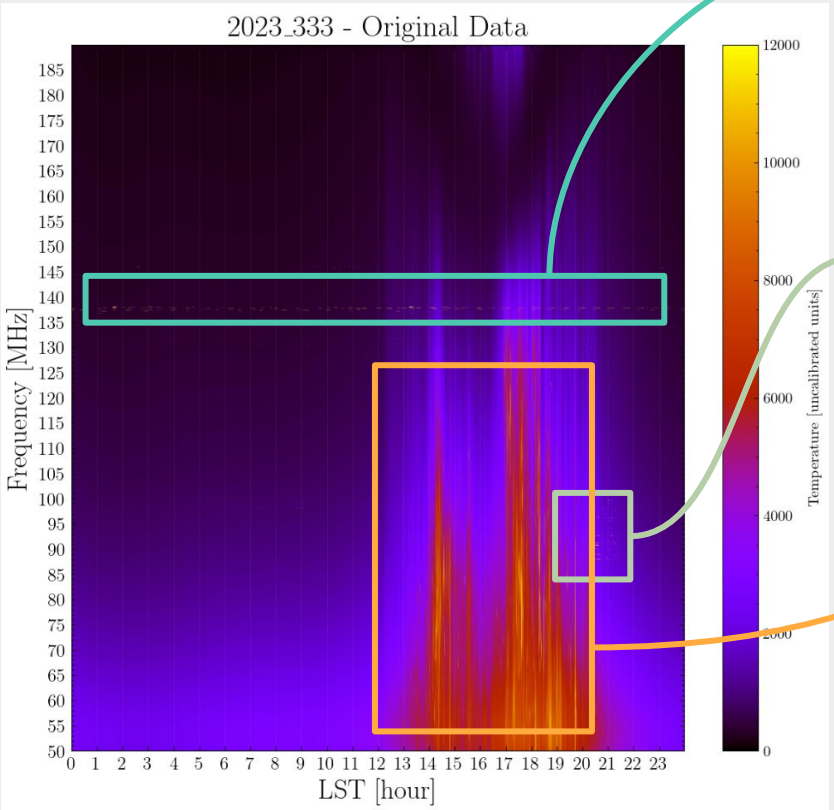
Secondary Science Targets

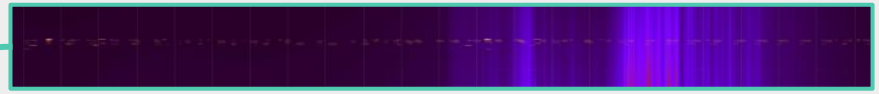


- EDGES data comes in the form of waterfall plots.
    - Frequency on the y-axis.
    - Time on the x-axis.
    - Color as a metric of (uncalibrated) intensity.
- 24 hours of data per day from 2023-2025.
- That's almost 22,000 hours of data!

A waterfall plot of EDGES data from 2023_333. Make note of the huge solar burst around 14:00-21:00 LST!

Secondary Science Targets

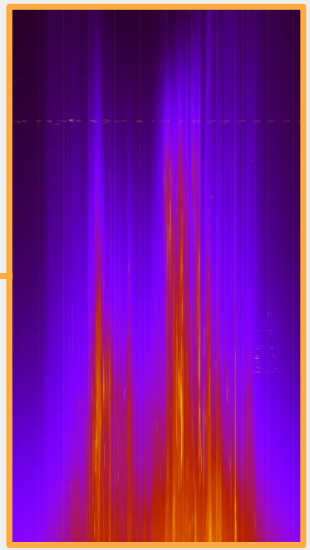




ORBCOMM Satellite Downlink Signal

Activity in the FM Band

Solar Activity

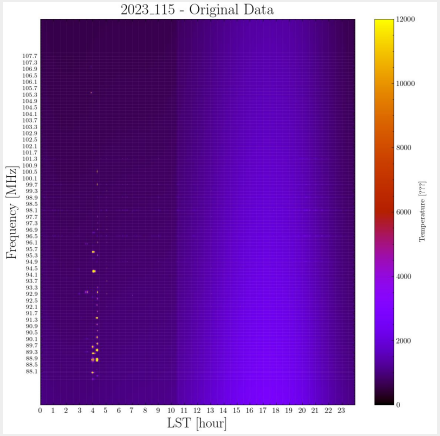


A waterfall plot of EDGES data from 2023_333. Make note of the huge solar burst around 14:00-21:00 LST!

Secondary Science Targets

Cataloging activity:

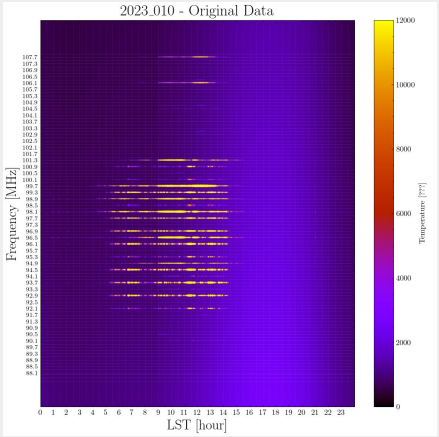
- Narrowed our scope to the FM band (88-108 MHz).
- EDGES data from 2023-2025 featured hundreds of days of observations of reflections from FM transmitters.
- This begs the question: what's producing the FM signals we're seeing in the first place?



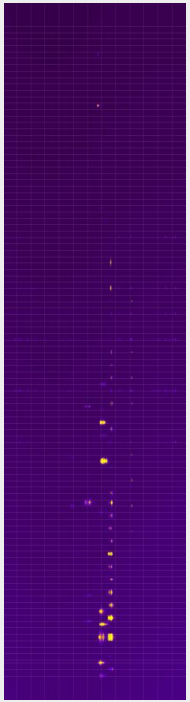
Two waterfall plots from 2023_115 (above) and 2023_010 (below) respectively.

The upper plot displays a brief event from around 4:00 to 4:30 LST, most intense in the lower FM channels but present throughout.

The lower plot displays a much longer series of events from 4:00 to 15:00 LST, with intensity peaks in distinct FM channels.



Micrometeorite & Sporadic E Events



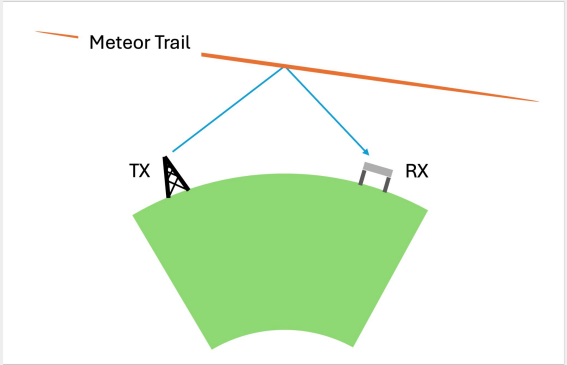
A closer look at the suspected micrometeorite event from 2023_115. Notice how short this event is!

When micrometeorites burn up in the atmosphere, they leave behind a hot trail of ionized plasma.

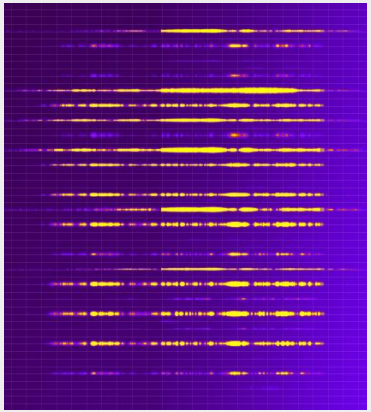
- Transmissions from FM Radio towers can reflect and scatter off of these trails.

I initially suspected that all FM activity were reflections of FM transmissions off of micrometeorite trails.

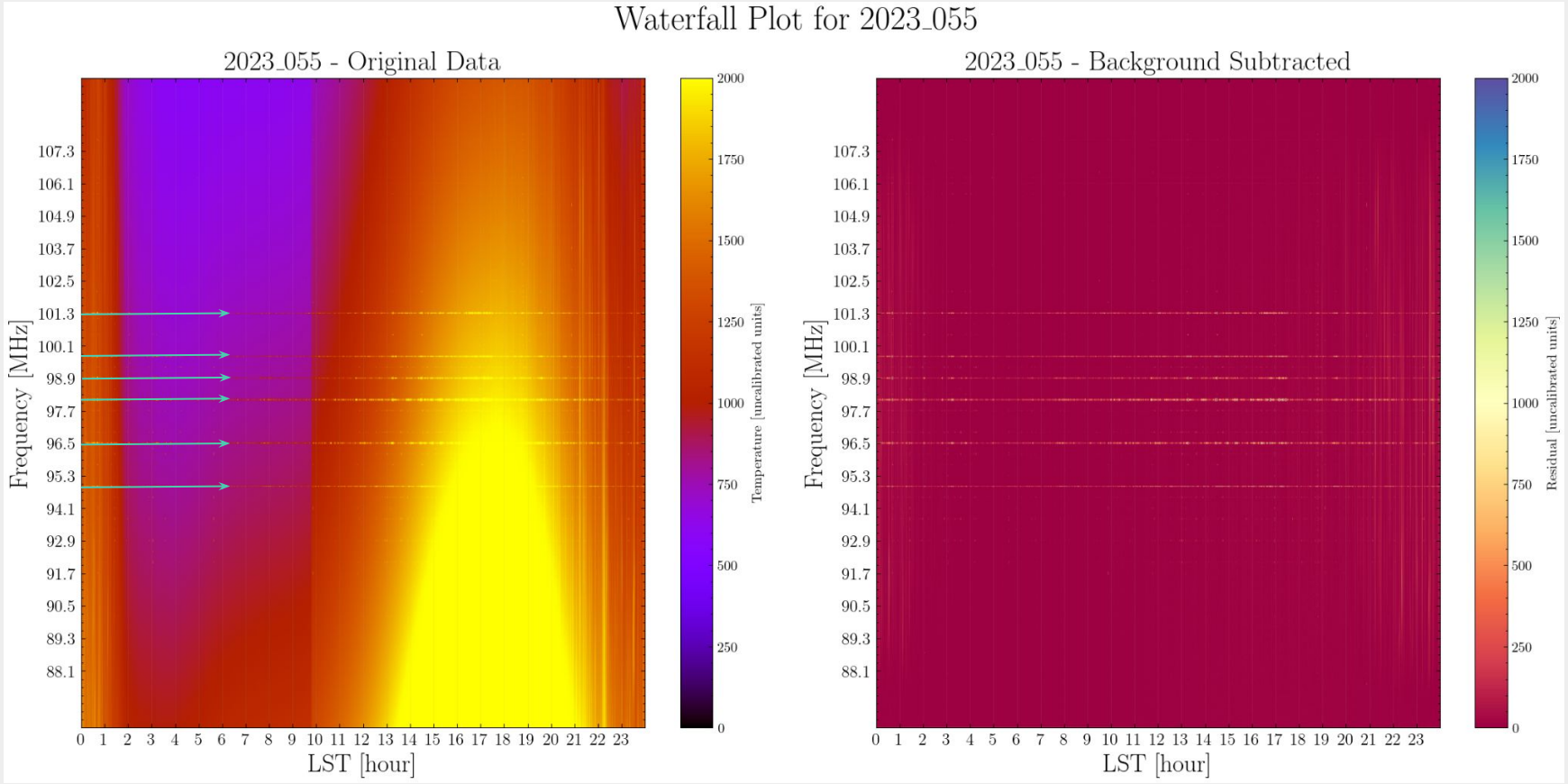
- Micrometeorite events typically last for a few seconds to a few minutes... some of these events were lasting for *hours!*



A graphic demonstrating the forward scattering geometry, showing an FM transmitter, the EDGES receiver, and an ionized meteor trail acting as a specular reflector to couple distant transmissions into the antenna beam.

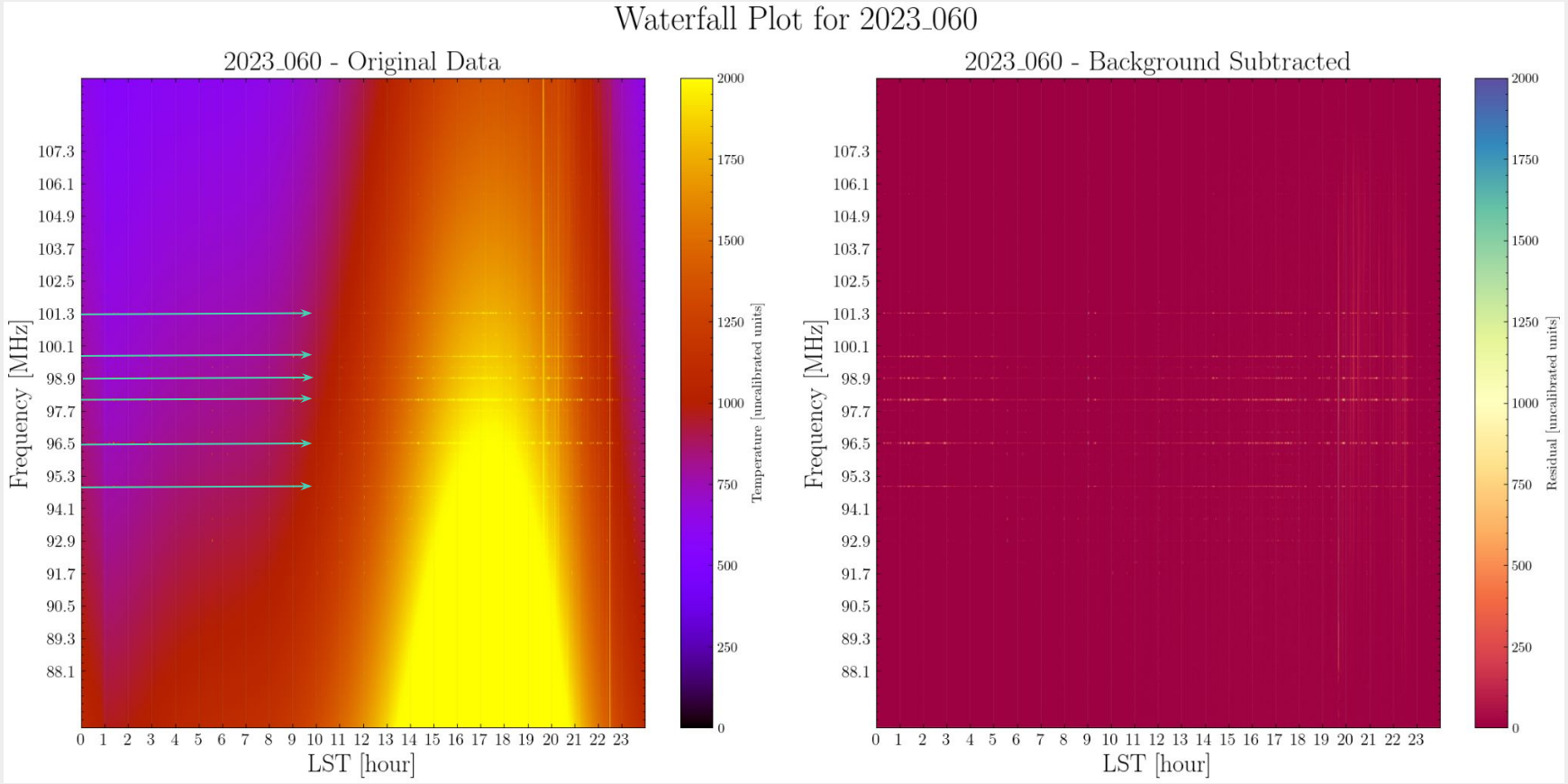


The much longer event from 2023_010. What could it possibly be...?



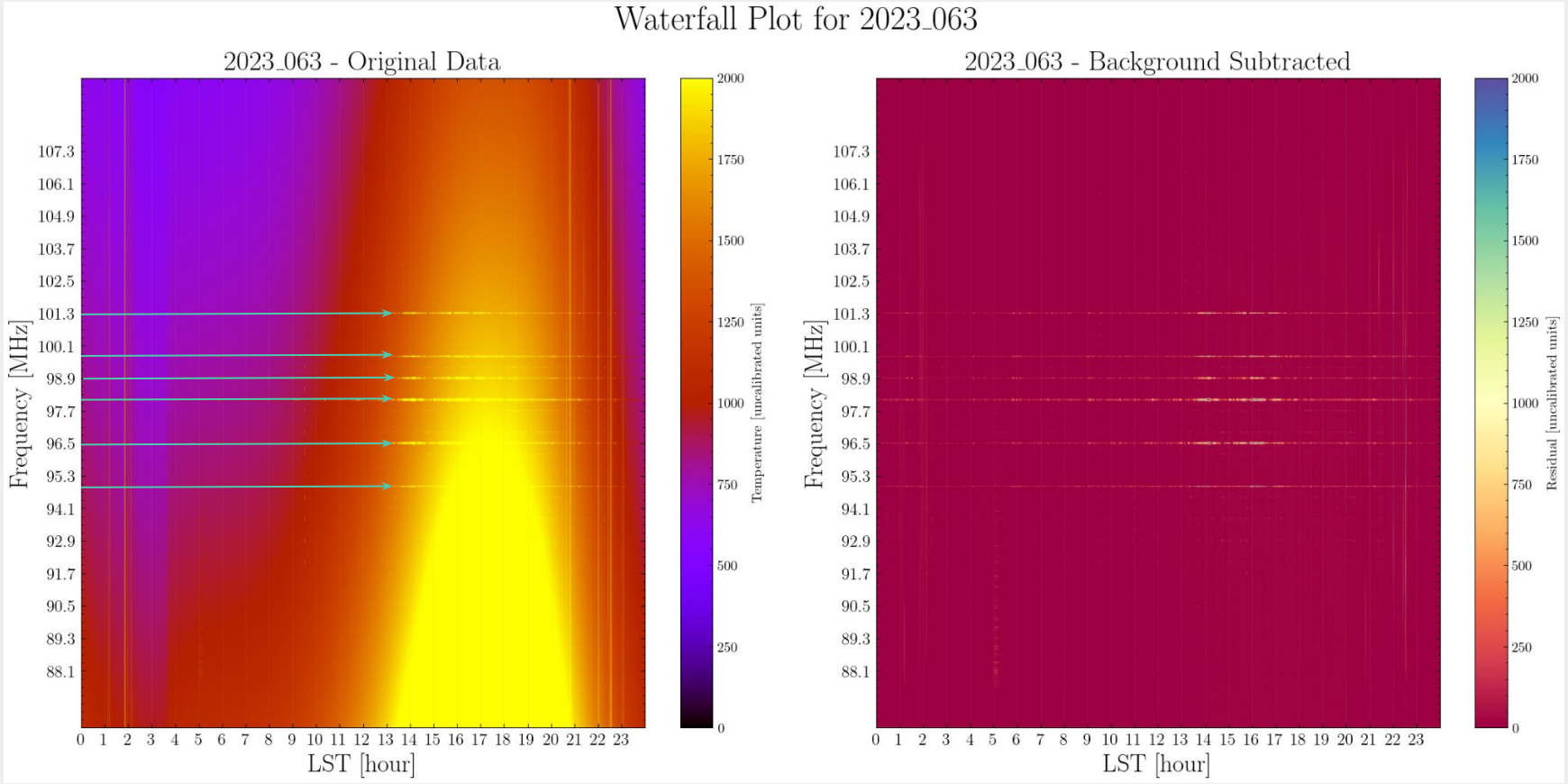
Waterfall plots color-scaled for visibility.

Some channels...



Waterfall plots color-scaled for visibility.

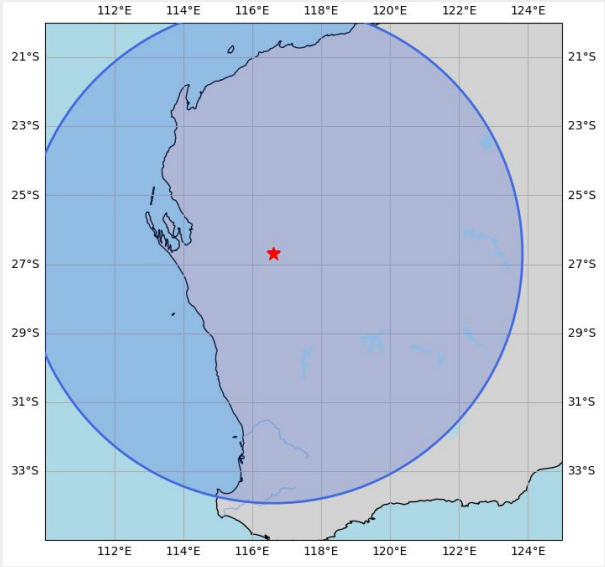
... are always ...



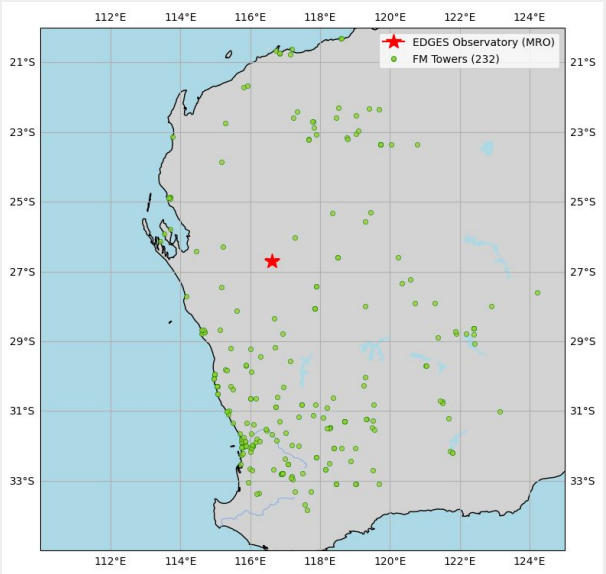
Waterfall plots color-scaled for visibility.

... on!

What specific FM towers' signals are being reflected? Why do their reflections last so long?



A 500 mile radius around the EDGES site.

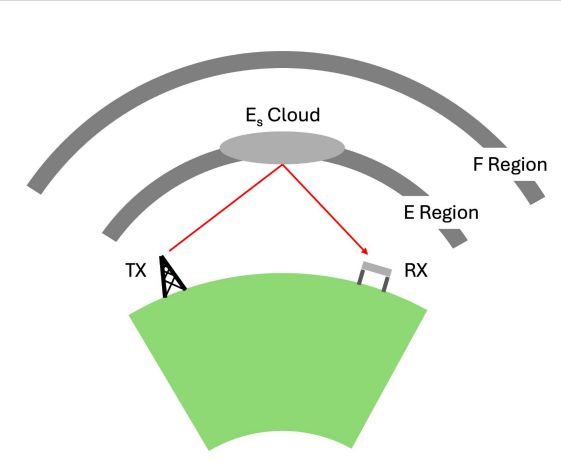


All FM towers within a 500 mile radius of the EDGES site.
Data sourced from *maps.spench.net*.

Could the two event types we're observing be different phenomena?

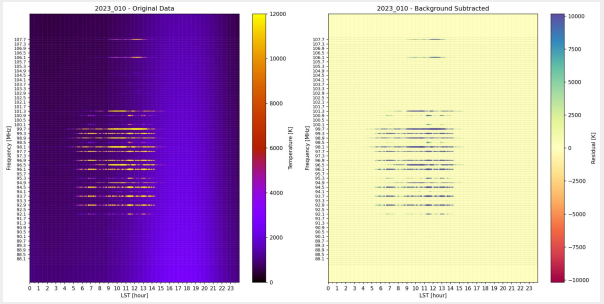
Micrometeorite & Sporadic E Events

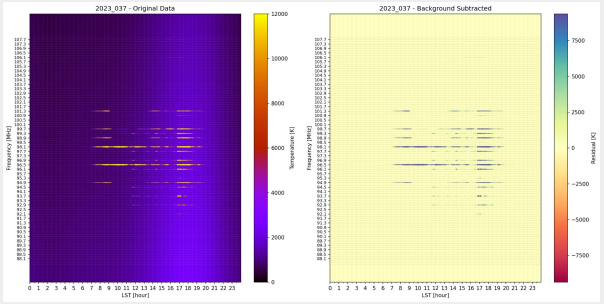
Sporadic E (Es) clouds describe thin, localized patches of enhanced ionization within the Earth's ionosphere.

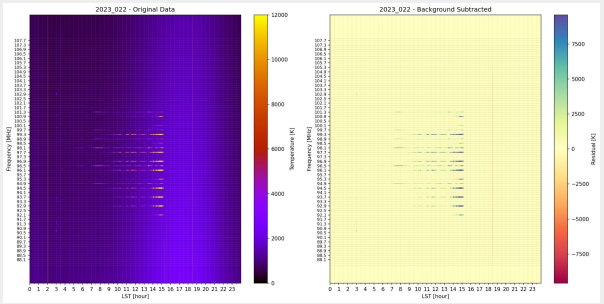


Forward scattering geometry of a Sporadic E event. Note the similarity between this and micrometeorite forward scattering: the difference in event timescales could be explained by the more static nature of the Sporadic E cloud.

- Believed to form through mechanisms such as wind-shear convergence of long-lived metal ions, modulated by geomagnetic and tidal forcing.
- No conclusive theory has yet been formulated as to the origin or behavior of sporadic E.



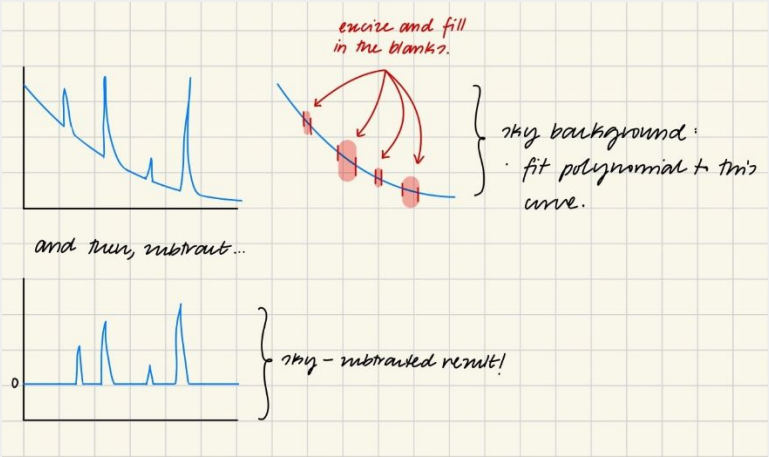


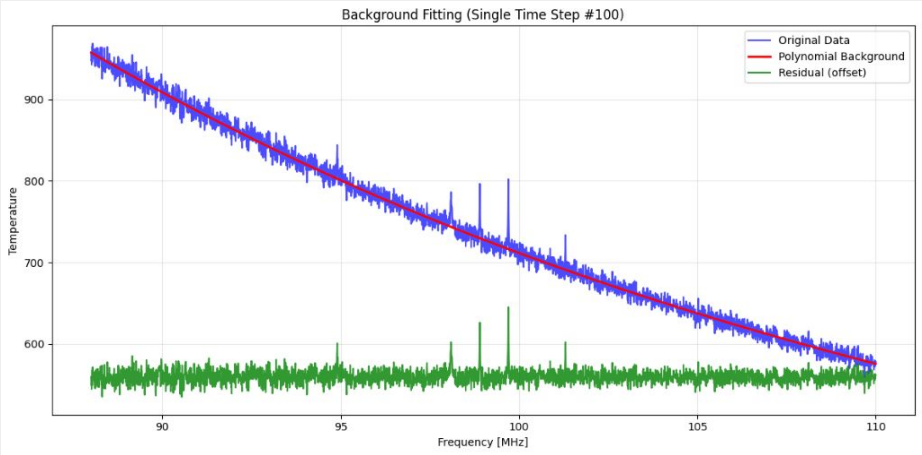


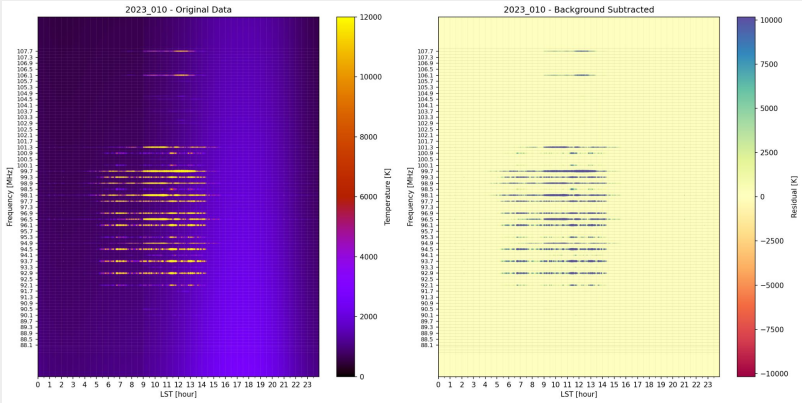
Event Analysis

Data Processing:

- Sky background subtraction by fitting third-order polynomial to spectrum of each timestep across frequency access, excluding frequency channels corresponding to known FM station carriers with a ± 0.15 MHz buffer.

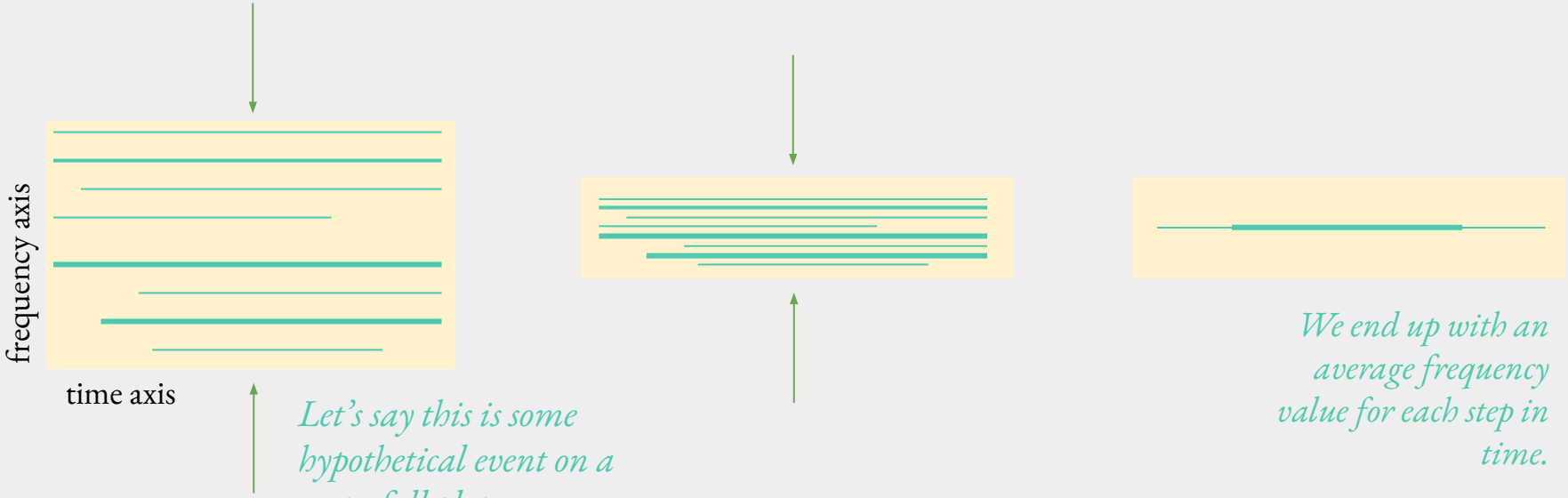






Event Analysis

Squashing along the frequency axis:

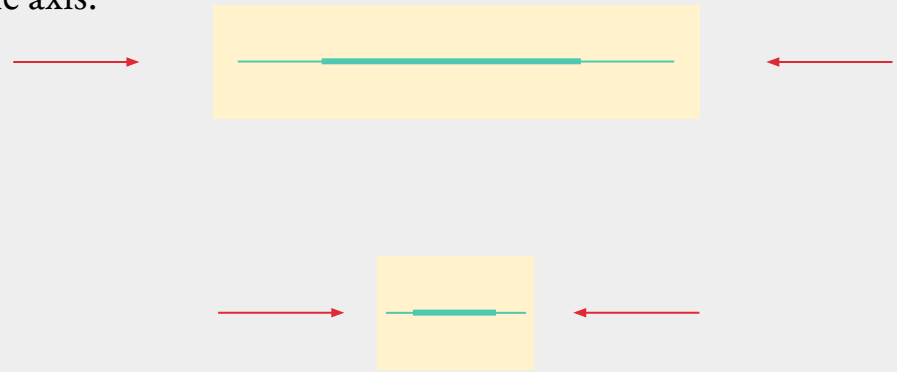


Let's say this is some hypothetical event on a waterfall plot.

We end up with an average frequency value for each step in time.

Event Analysis

Squashing along the time axis:



average
intensity value!

Event Analysis

Devising a metric for Sporadic E Activity:

- Days with Sporadic E activity show periods of heightened activity within the FM channels:

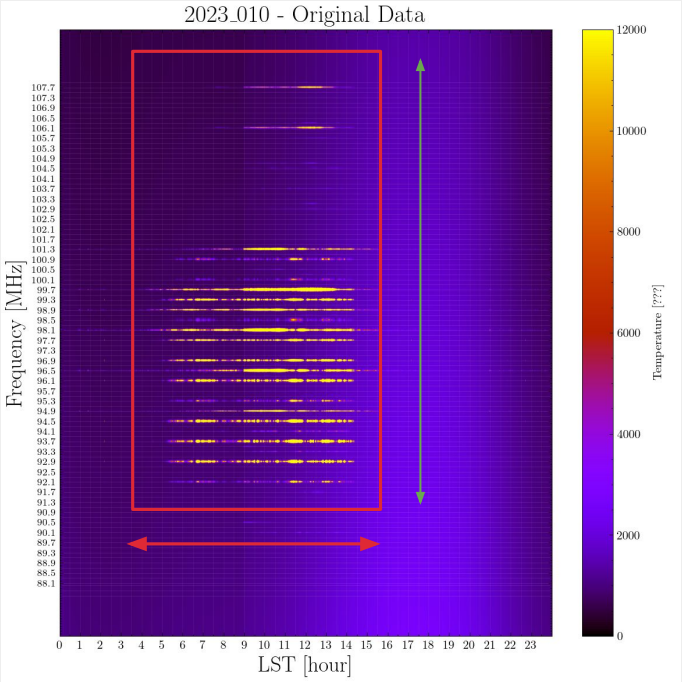
  88.1, 88.3, 88.5, 88.7, 88.9, ..., 107.7, 107.9 MHz

- For event days, compute average intensity value of active FM channels over event time period.

  - For non-event days, compute average intensity value of active FM channels over full 24 hours.

What can we do with this data?

compute average intensity of active channels across frequency axis...



... and average this intensity value over time.

Simple, but it works!

Event Analysis

small-scale trends → *large-scale trends*

Individual Event Analysis

Full Width at Half Maximum plots of active channels during events

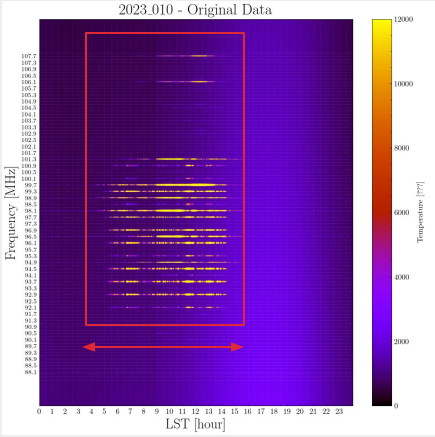
Diurnal Patterns in Event Occurrence

Catalog of daily event start times

Multi-Year Trends in Activity

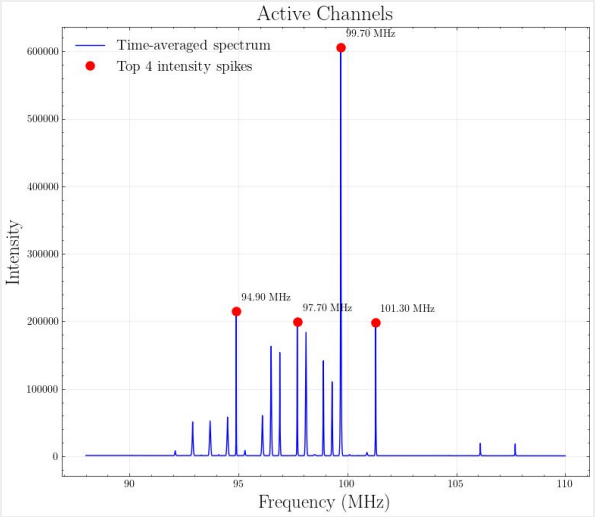
Seasonal trends in FM intensity as a metric of event intensity and occurrence rates

Correlation with solar parameters from OMNI dataset to evaluate concurrence with changes in geomagnetic activity

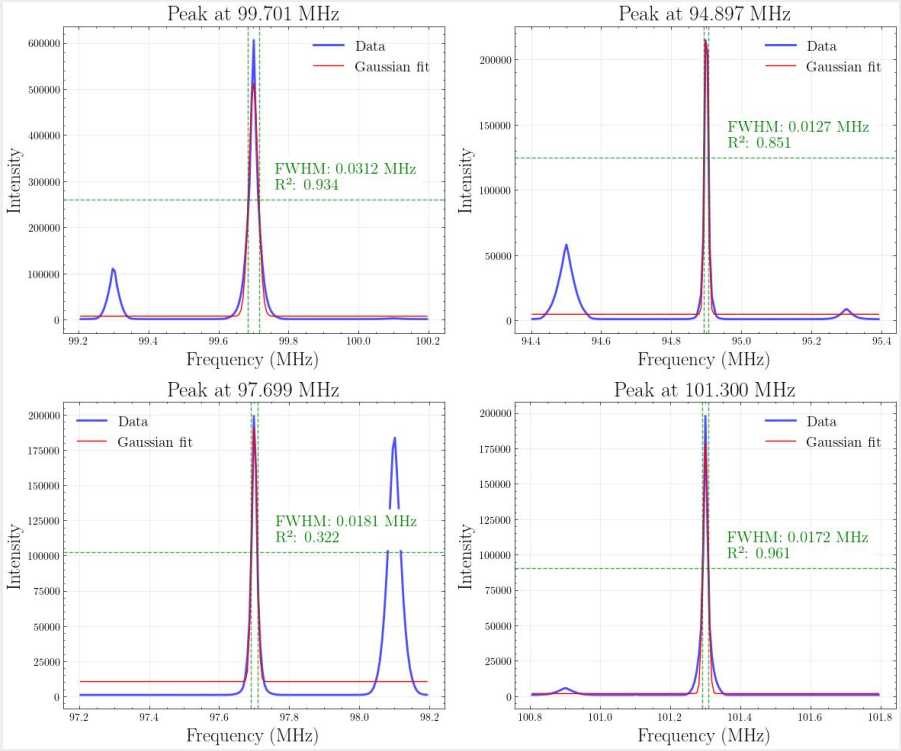


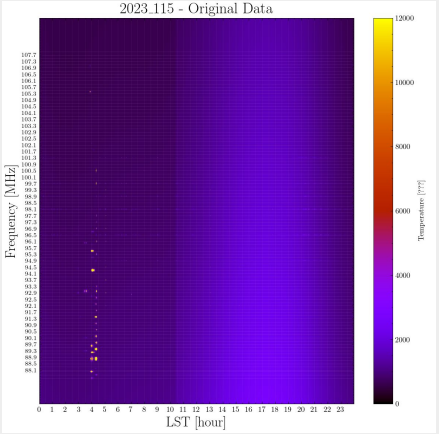
For a suspected Sporadic E event day:

I averaged the intensity over this time window and identified the peaks...



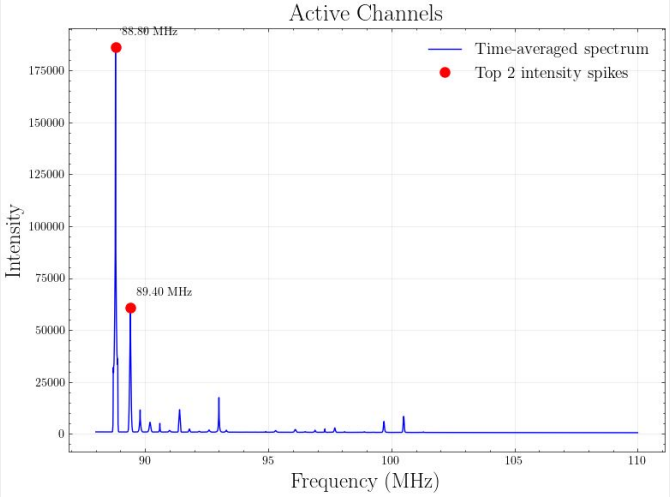
Plotting the FWHM of each of these channels...



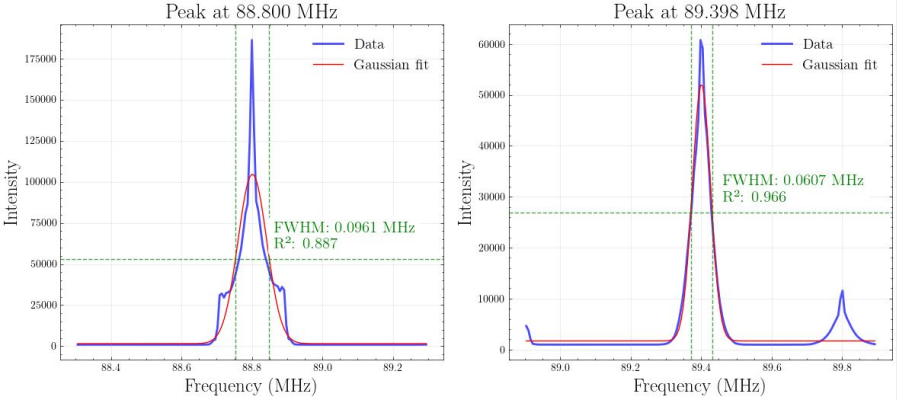


For a suspected micrometeorite event day:

I averaged the intensity over this time window and identified the peaks...

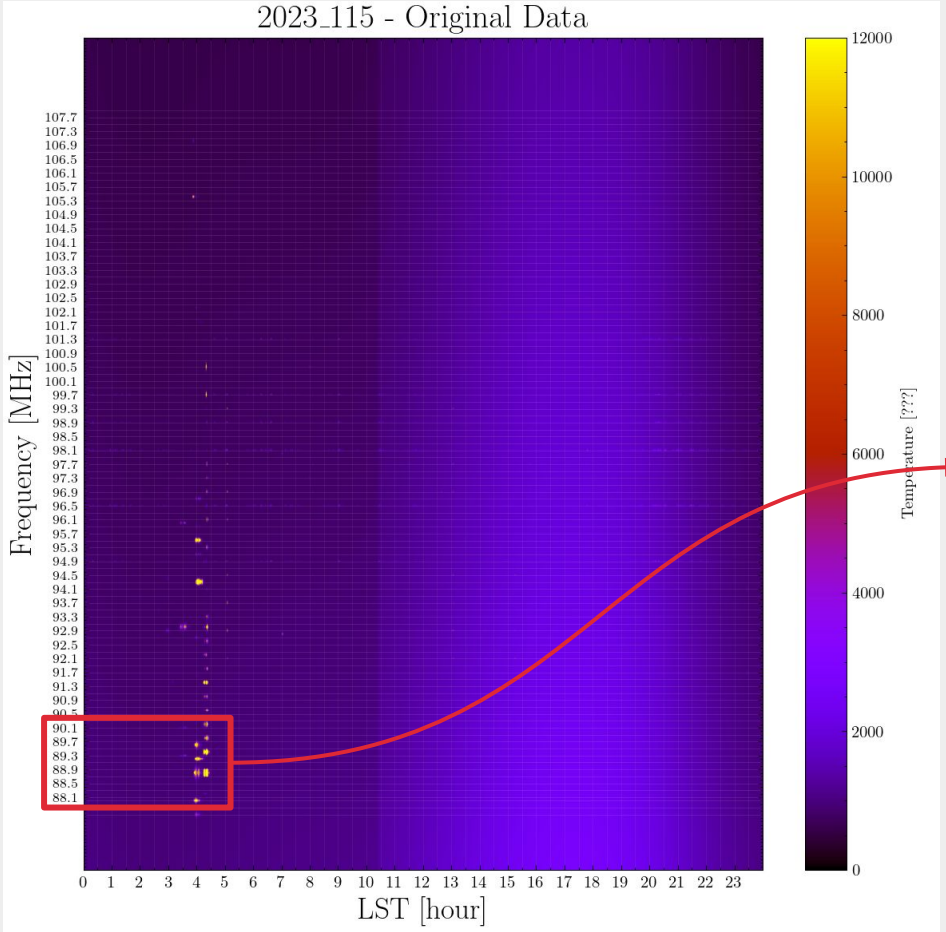


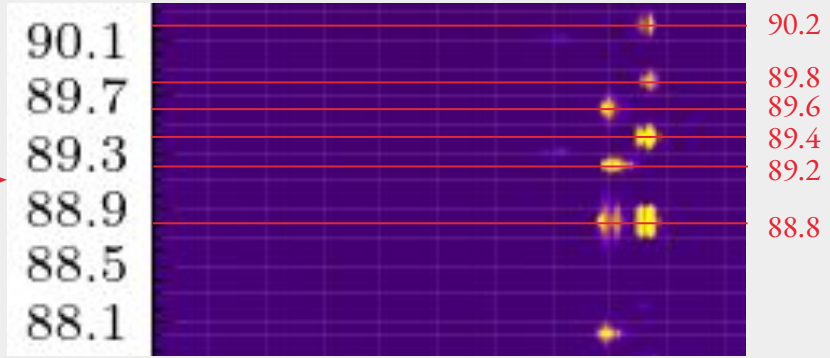
These appear much wider, with FHWMs of 0.0961 MHz and 0.0607 MHz, respectively.



Plotting the FWHM of each of these channels...

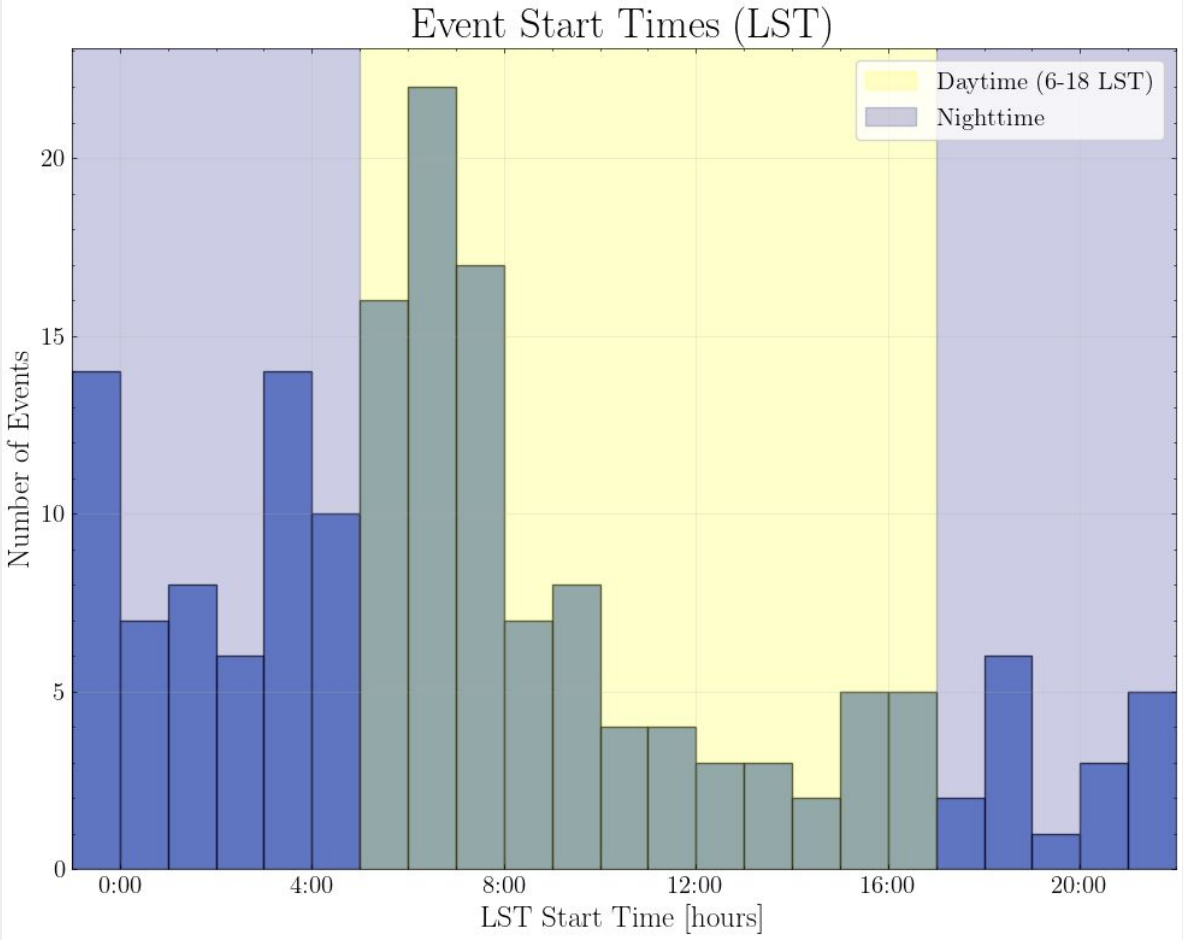
What's more...



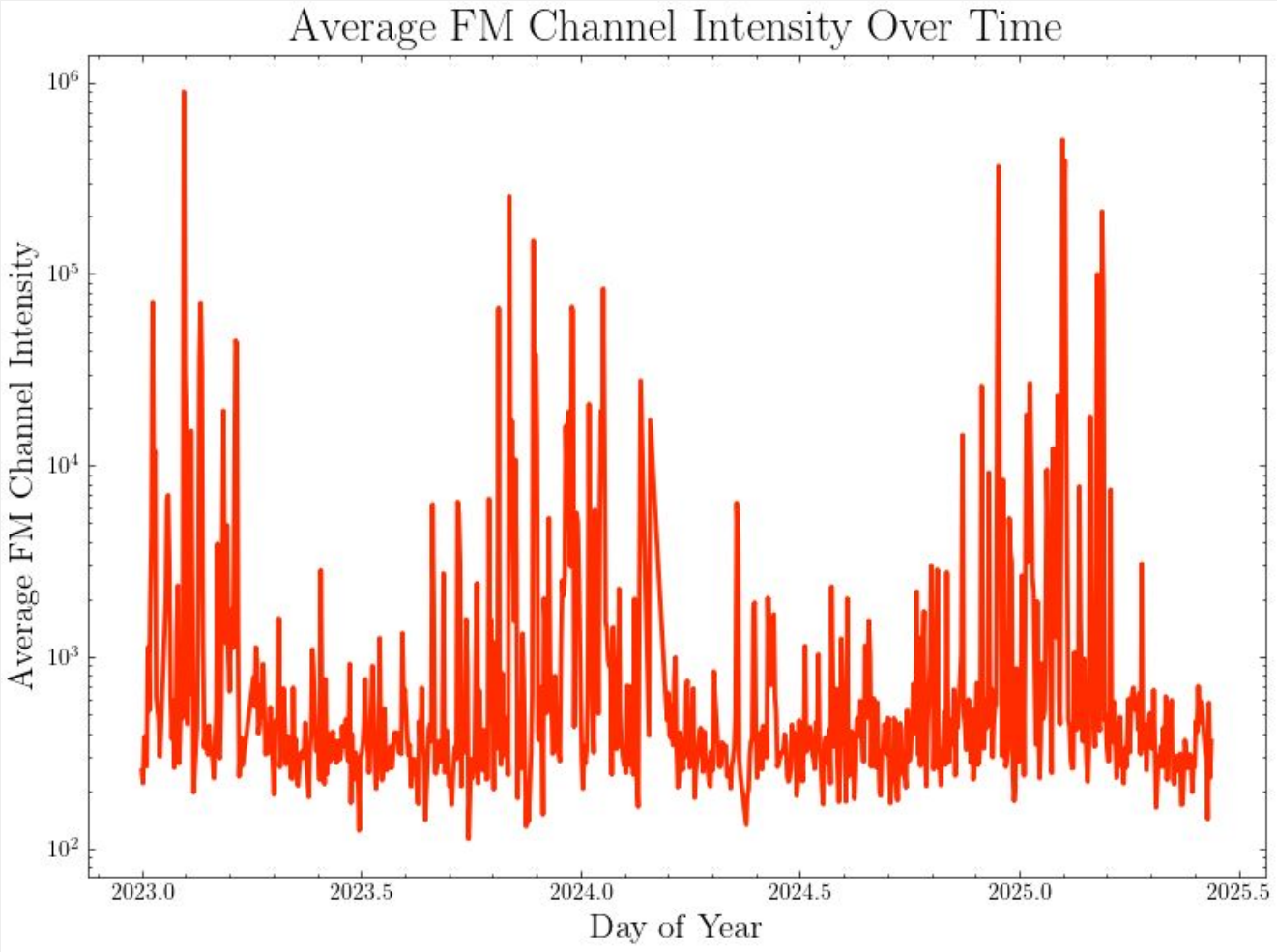


None of these are FM channels (or rather, all of them are FM channels offset by ± 0.1 MHz...)

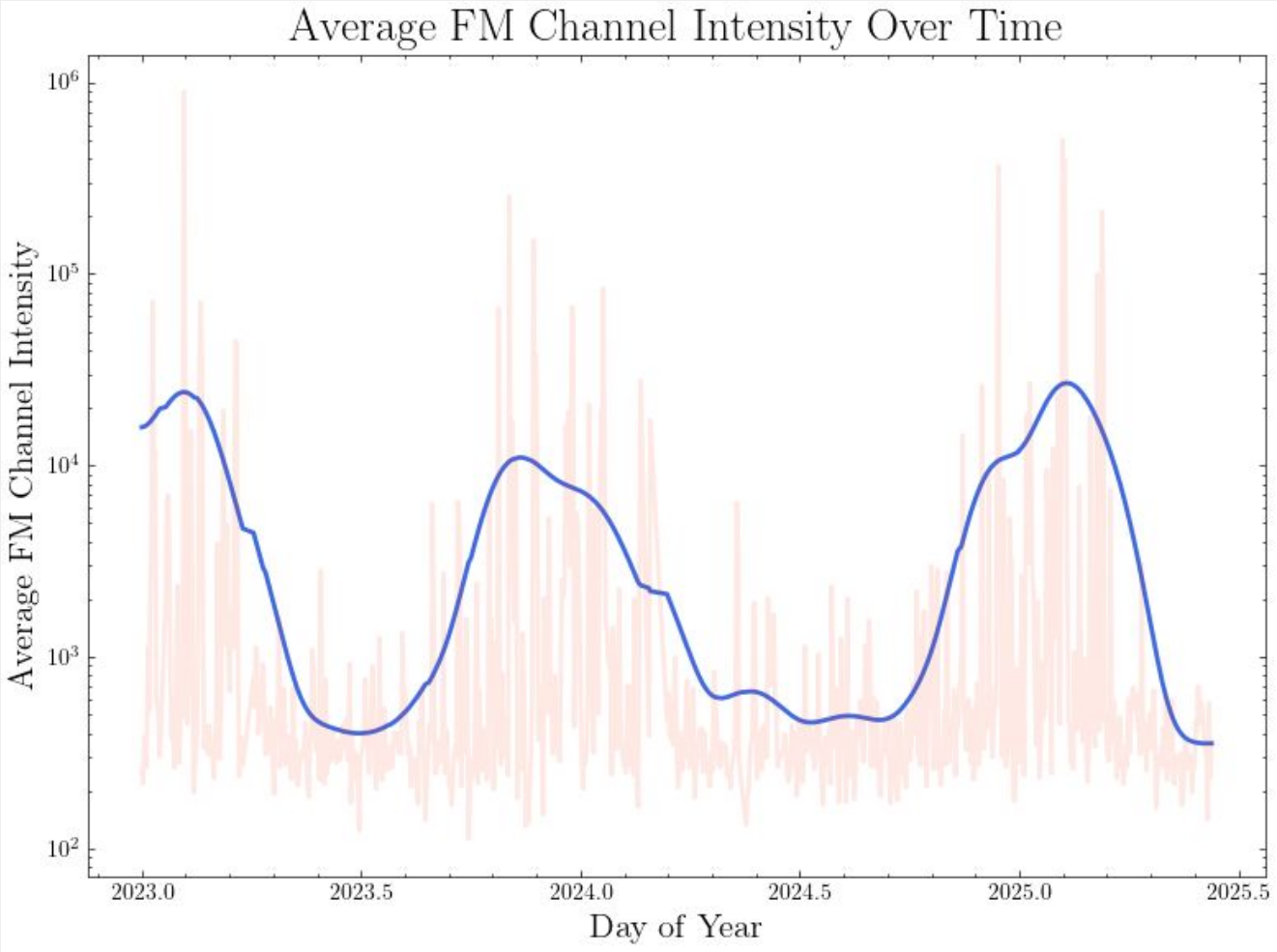
A histogram of the start times in Local Sidereal Time (LST) of each detected event.



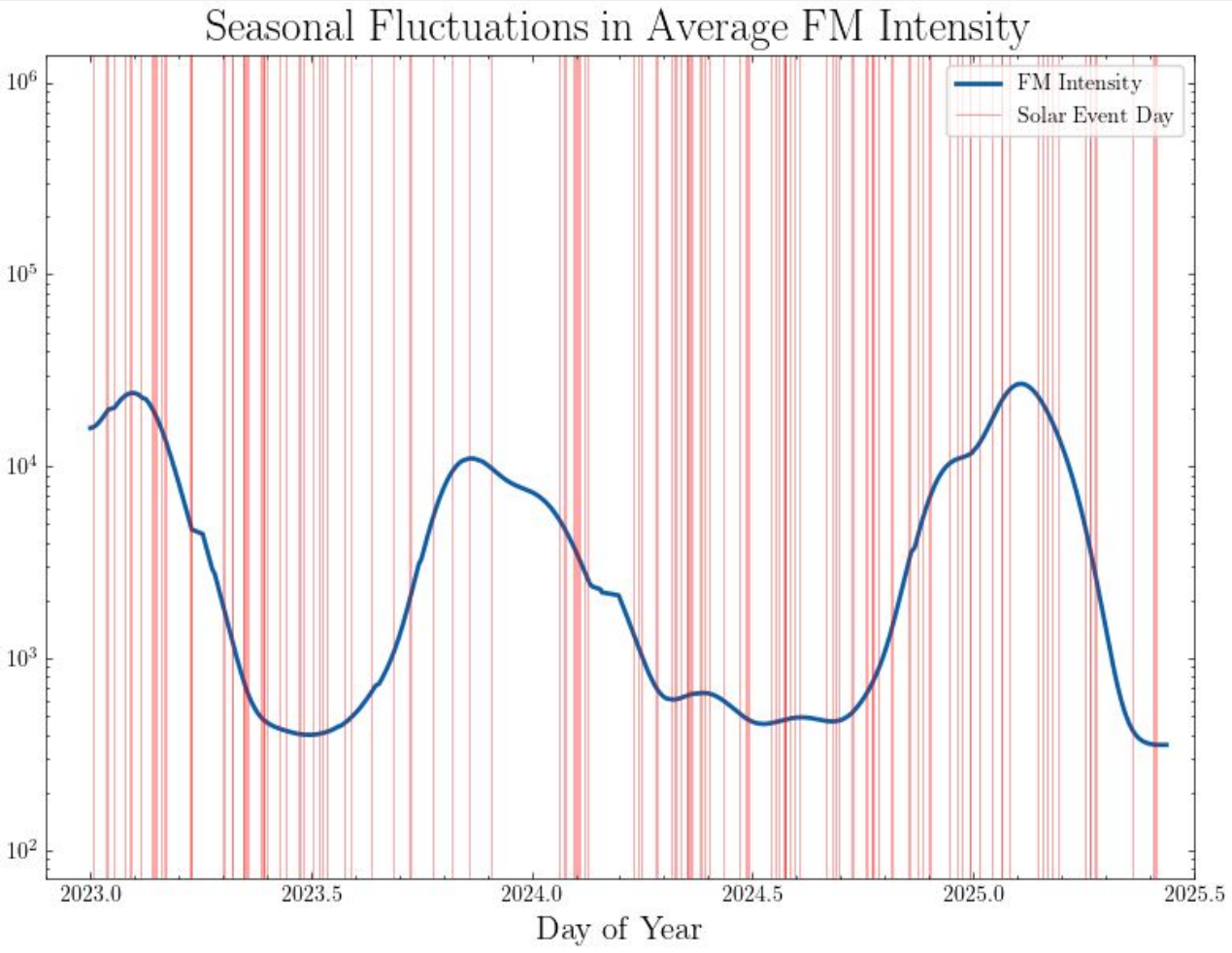
A line plot of the average FM channel intensity for a given day from 2023-2025.

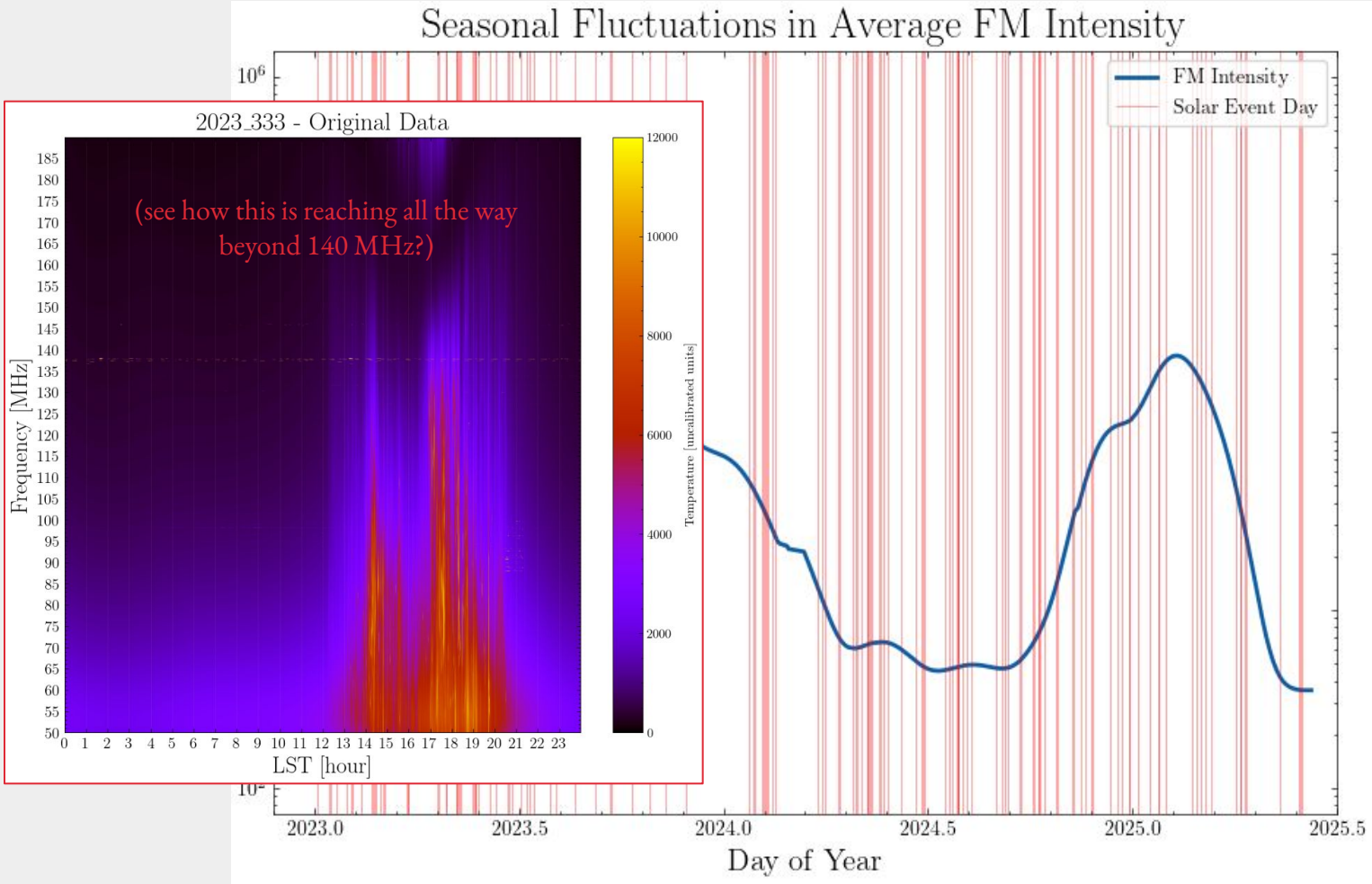


Gaussian smoothed data from the previous line plot.



Gaussian smoothed data from the previous line plot, with days featuring solar bursts flagged in red.




Seasonal Fluctuations in Average FM Intensity
FM Intensity
Solar Event Day
Day of Year
2023.0
2023.5
2024.0
2024.5
2025.0
2025.5
2023_333 - Original Data
(see how this is reaching all the way beyond 140 MHz?)
Frequency [MHz]
LST [hour]
Temperature [uncalibrated units]

Event Analysis

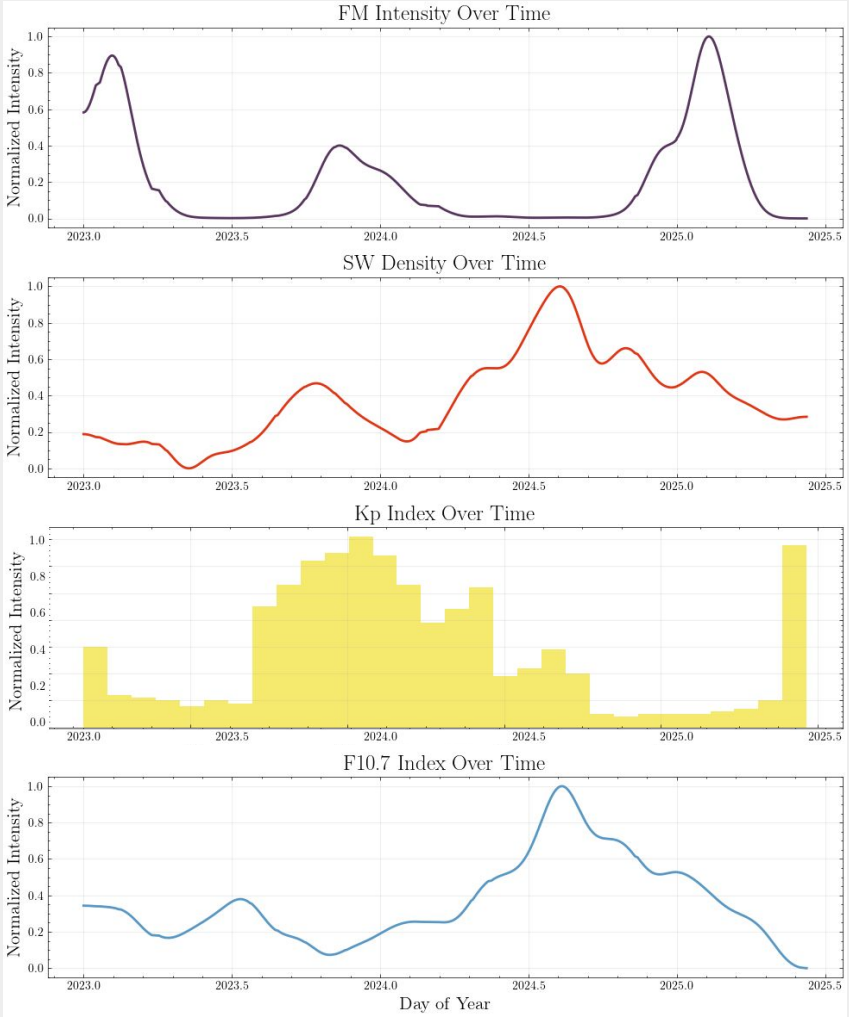
Is there any relationship between Sporadic E occurrence and solar/geomagnetic activity?

"Because of the different results emerging from existing literature, the subject of the influence of solar activity on the Es layer is still not completely resolved and further investigations are needed."

Pietrella et al. (2014)

- Solar Wind Proton Density
- Kp Index
- F10.7 Index

A comparison of the (smoothed) Daily FM Intensity to the OMNIWeb solar parameters: SW Density, Kp Index, and the F10.7 Index.



Results & Future Inquiry

Even under more rigorous scrutiny, the relationship between Sporadic E and solar/geomagnetic activity is not well understood.

Though unable to identify a correlation, w**e did observe a seasonal trend in FM intensity that aligns with what we would expect from mid-latitude Sporadic E** in the Southern Hemisphere.

We also hypothesize that the two different event types observed originate from micrometeorite-induced forward scattering and Sporadic E, respectively.

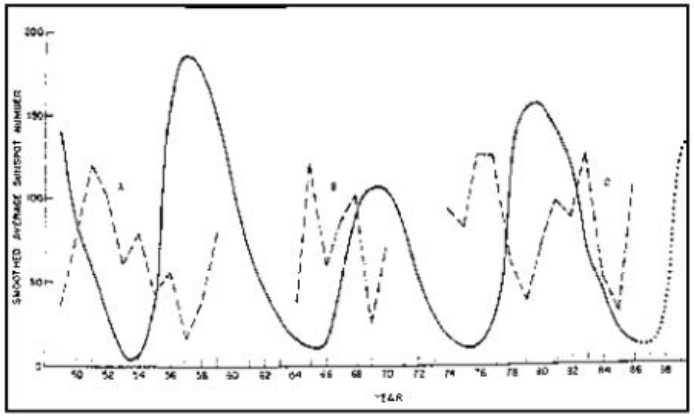


Fig 4: Relationship between the solar cycle (solid curve) and the occurrence of sporadic-E in the northern temperate zone. The three studies of sporadic-E occurrence shown here used different criteria and are not directly comparable.

Sporadic E propagation at VHF. copyright ARRL By Emil Pocock, W3EP. April 1988.

"In the mid-latitudes, the correlation coefficient between the solar activity and the Es intensity is positive and negative during day and night time, respectively... However, there are also several studies suggesting that the solar and geomagnetic activities do not affect the Es occurrence.

Thus, the Es occurrence and its temporal variation are still not understood in detail, and there may be local effects to be identified."

Eunbyeol, J. et al. (2019)

Results & Future Inquiry

What can we do with FM tower location and TX channel data?

Mapping regional variations in Sporadic E activity based on trends in illuminated channels, triangulating locations of MM events via doppler shifting.

How can we further verify the nature of so-called micrometeorite vs. Sporadic E events?

Improving approach to automated data filtering (time windowing, channel selection, distinguishing between multiple overlapping events).

How can we better understand the relationship between solar and geomagnetic activity and Sporadic E?

More refined comparison/correlation to solar parameters, better metric for gauging Sporadic E activity.

Questions?

Acknowledgments

This work was conducted through the MIT Haystack Observatory REU program and could not have been accomplished without the extensive mentorship and guidance of Rigel Cappallo, John Barrett, and Alan Rogers, along with valuable support from the EDGES team at Arizona State University. Financial support was provided by NSF Award 2243909.

Observations were carried out at Inyarrimanha Ilgari Bundara, the CSIRO Murchison Radio-Astronomy Observatory in Western Australia, located on the traditional lands of the Wajarri Yamaji people. We acknowledge the Wajarri Yamaji as the traditional owners of this land, and thank them for their continued support of scientific research conducted at this site.

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