

# **Classification of High-Energy Particle Precipitation Events Using Computer Vision**

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A dark blue background featuring abstract white and cyan geometric shapes. These include a large rectangle on the right, several horizontal bars of varying lengths, a circle with a cyan outline and a white center, and a cyan circle connected by a line to a cyan rectangle. A cyan triangle is also present on the left side.

## ► INTRODUCTION

# 01

# ► INTRODUCTION



## Radiation Belts

- Donut shaped regions around the Earth
- Protons and electrons trapped in orbit



## Energetic Particle Precipitation (EPP)

- Particles from the radiation belts falling into Earth's atmosphere
- From disruptions such as a coronal mass ejection or other space weather events

## Effects of EPP



- Interrupt telecommunications
- Destroy sensitive electronic components
- Deplete atmospheric ozone



\* EPP plays a significant role in the formation of the Aurora Borealis

# ► MOTIVATION

## Large-Scale Mission

Determine the atmospheric impact of the varying sources of EPP in order to build better predictive models of space weather and climate.

## This Work

Develop tools to automatically create databases of EPP events and their sources from satellite data.

# ► DATA COLLECTION



\* The two ELFIN twins prior to launch! Each one is about the size of a loaf of bread

## ELFIN Cube Satellites



- Electron Losses and Fields Investigation (ELFIN)
- Launched 9/15/18 by UCLA
- Sensors measure energy, incoming angle, and particle flux (rate of particle measurements)
- Direction of an incoming particle determines if it will precipitate into the atmosphere or be trapped in orbit



A dark blue background featuring abstract white line art. The design includes a large, irregular polygonal shape in the upper right, several horizontal bars of varying lengths, and a central dark gray rectangle containing the text '02'. In the lower right, there's a partial view of a circle and a curved line. On the left side, there's a small cyan triangle pointing right.

## ► METHODOLOGY

02

# ► DECIPHERING EPP EVENTS



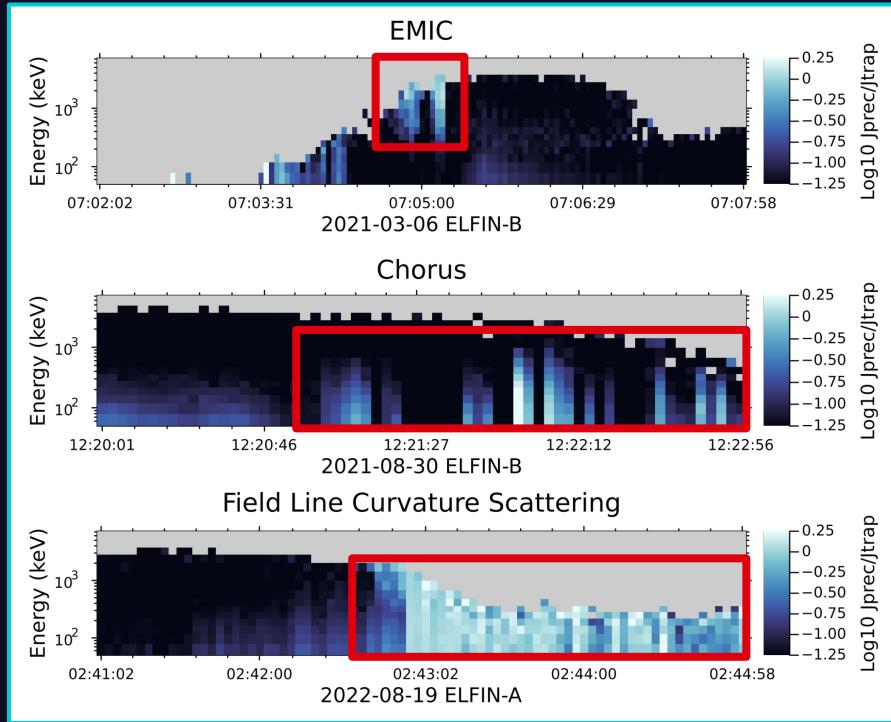
## $J_{\text{Prec}} / J_{\text{Trap}}$ Ratio

- Strength of precipitation relative to non-precipitating population
- Brighter spots indicate more precipitation



## Unique Signature

- Different sources of EPP have unique data signatures
- Used to visually differentiate EPP events



# ► IDENTIFYING EPP EVENTS

## EMIC Waves

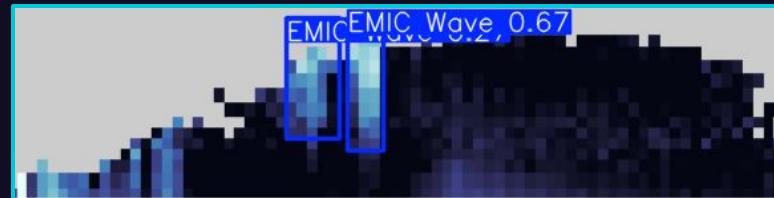


- Electromagnetic Ion Cyclotron Waves (EMIC)
- Elevated precipitation rates at higher energies which tapers off (teardrop shape)
- High community interest due to unique atmospheric impacts (more data!)

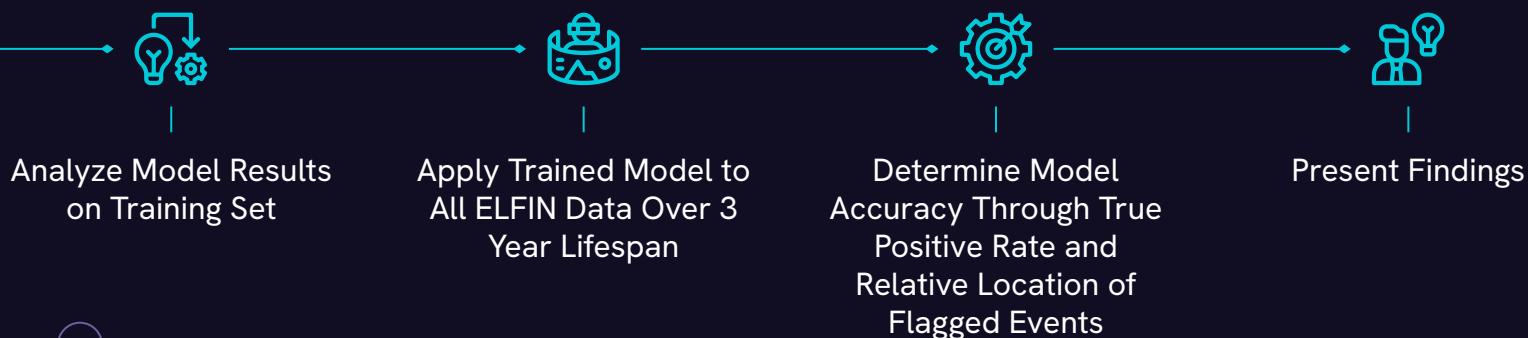
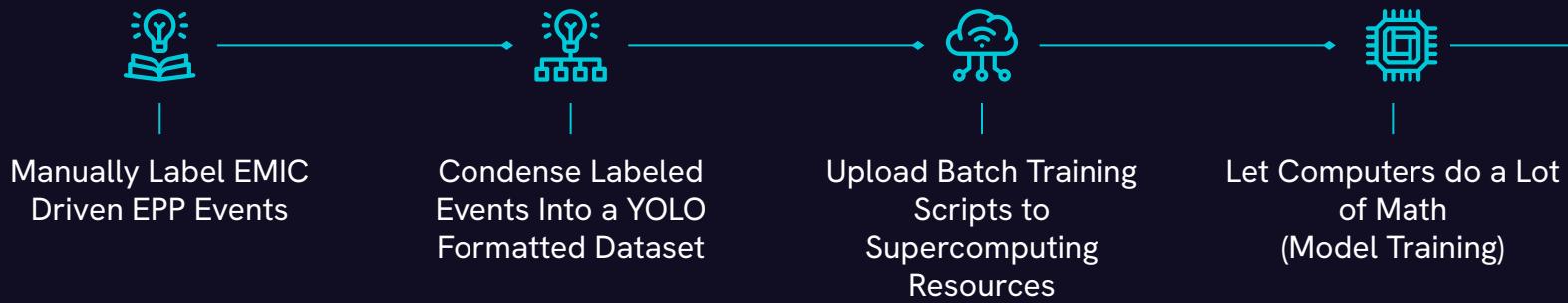


## Computer Vision

- Easy to visually decipher various EPP events by source
- Computer Vision is a subset of artificial intelligence (and not just buzzwords to boost stock price)
- You Only Look Once (YOLO) CV model due to support and documentation



# ► COMPUTER VISION METHODOLOGY

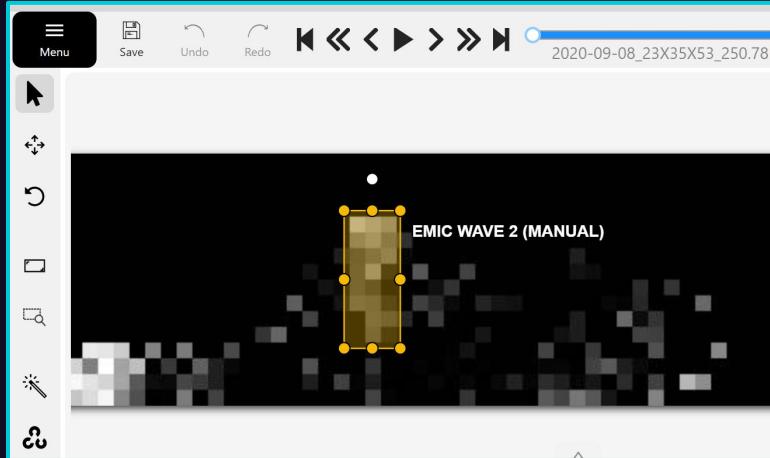


# ► TRAINING SETS

## First Dataset



- 142 Labeled Images
- 1 Type of EPP (EMIC Events Only)
- Higher error surrounding labels (less precise labeling)



\* A screenshot of the image data labeling software we used

## Final Dataset



- 306 Labeled Images
- 4 Types of EPP to Avoid Confounding Events
- Higher label precision



A dark blue background featuring a light blue abstract graphic. The graphic includes a large rectangle with a diagonal line, several horizontal bars of varying lengths, and a central circle connected by lines to other shapes.

## ► RESULTS

03

# ► OUR MODELS

## 1) Initial Model

- Trained overnight on a laptop
- YOLOv8s (2nd smallest YOLO Model)
- Great initial performance

Total Epochs

100

Total # Detections

3837

## 2) Improved Model

- Refined Training Techniques
- Leveraged CU Supercomputer
- YOLOv8x (largest YOLO model)
- Still used our initial training set

100

1310

## 3) Final Model (Best)

- Improved training set
- Trained over days on supercomputer
- YOLOv8x
- Significantly improved performance due to handling of confounding EPP events in training set

344

786

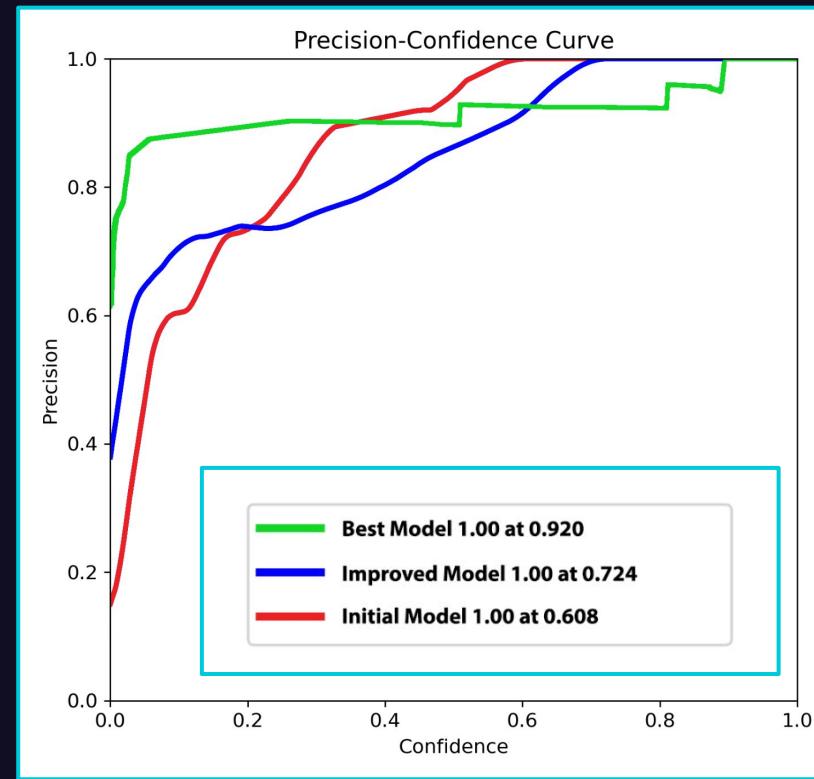
\* Total # Detections found by applying model to lifetime of ELFIN data

# ► MODEL PERFORMANCE

	Training Set Recall	Total # Detections
Best Model	<b>73.6%</b>	<b>786</b>
Improved Model	<b>70.1%</b>	<b>1310</b>
Initial Model	<b>75%</b>	<b>3837</b>

$$\text{Precision} = \frac{\text{Correct Detections}}{\text{Detections}}$$

$$\text{Training Set Recall} = \frac{\text{Correctly Detected Training Events}}{\text{Events in Training Set}}$$



# SUPPORTING ANALYSIS



## L-Shell:

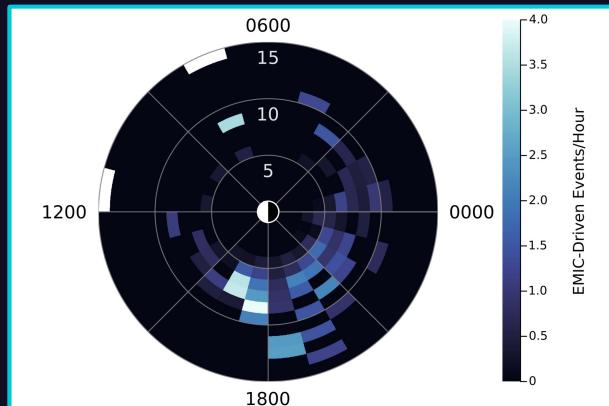
- "# Earth's radius from Earth"
- Indicated by the smaller sub circles inside of the graph

## Magnetic Local Time:

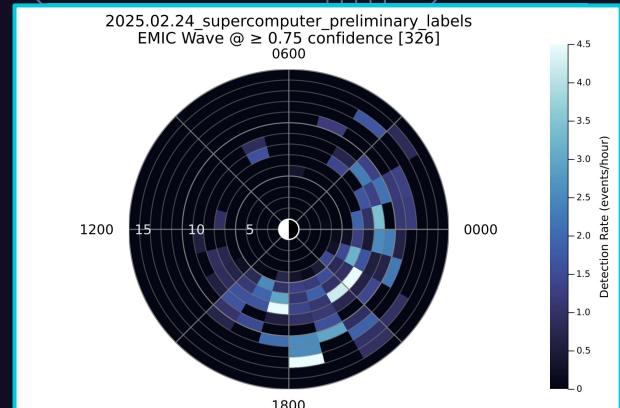
- Satellite's orientation relative to Earth and Sun at recording
- Noon (12:00) always points towards sun (24 hour clock!)

## Comparing Location:

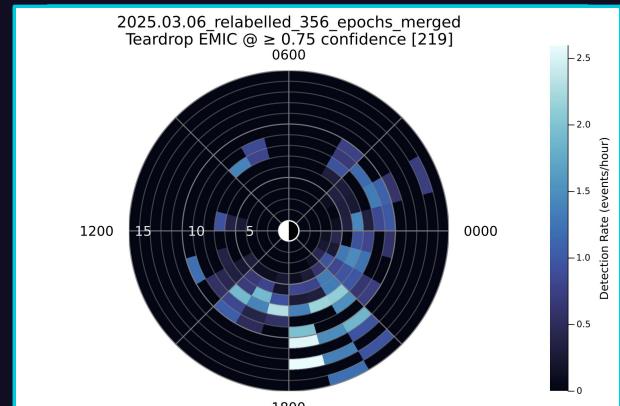
- Events of the same type tend to occur in the same area relative to Earth/Sun



Manual Labels from Previous Work



First Model Detections



Final Model Detections



A dark blue background featuring a light blue rectangular frame. Inside the frame, there are several thin, light blue horizontal and vertical lines forming a grid-like pattern. A small, light blue circle is located near the bottom right corner of the frame. Outside the frame, there are more light blue lines and shapes: a horizontal bar at the top left, a vertical bar at the top center, a horizontal bar at the top right, a horizontal bar with a vertical line inside at the middle right, and a large, semi-transparent light blue circle at the bottom right.

## ► CONCLUSION

# 04

# ► THE FUTURE OF OUR RESEARCH



## Improved Model Performance

- Our biggest limiting factor was training set size
- Larger training sets and experimenting with different algorithms may yield even more accurate models



## Avoid Confounding False Positives

- Our second training set used 4 EPP classes instead of just 1
- We saw a drastic reduction in false positives due to confounding data
- Further dataset improvements may continue this trend



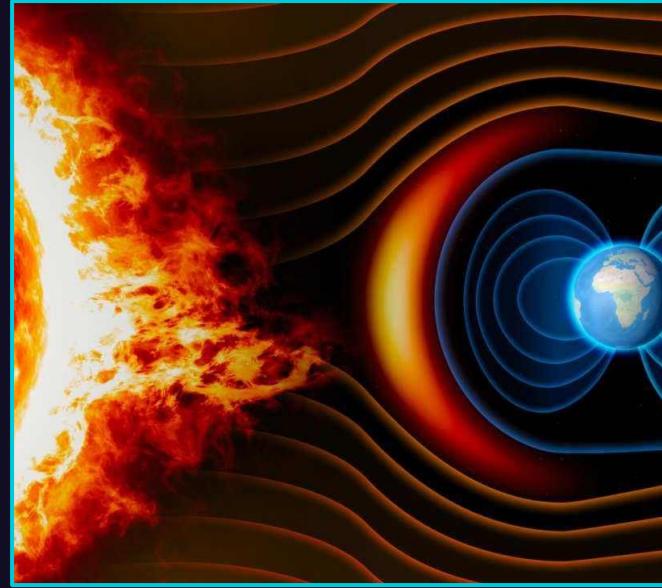
## Impact on the Study of EPP

- Create large dataset to help find patterns in data and improve predictive models
- Save time and resources (to be used elsewhere!)

# ► CONCLUSION



Our results indicates a promising future for the use of computer vision (and Artificial Intelligence) to identify EPP events in large datasets



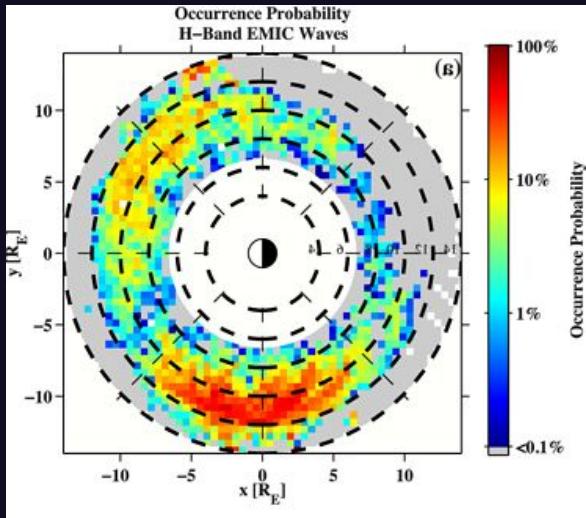
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u

Special thank you to Julia Claxton for her guidance, teachings, and **patience!**

(emphasis on patience)

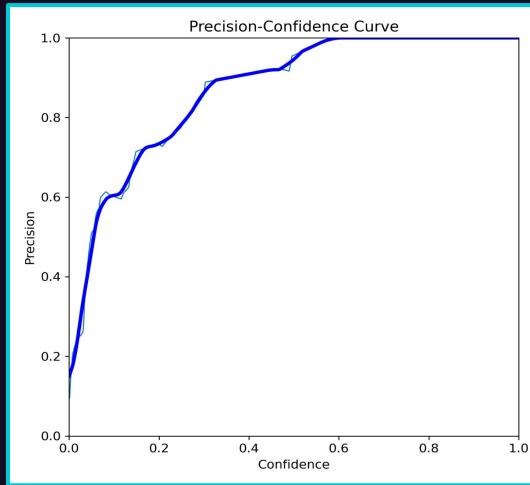


*Min+ 2012*

## Original Model Performance Slides

# ► MODEL PERFORMANCE

— EMIC Wave  
— all classes 1.00 at 0.608



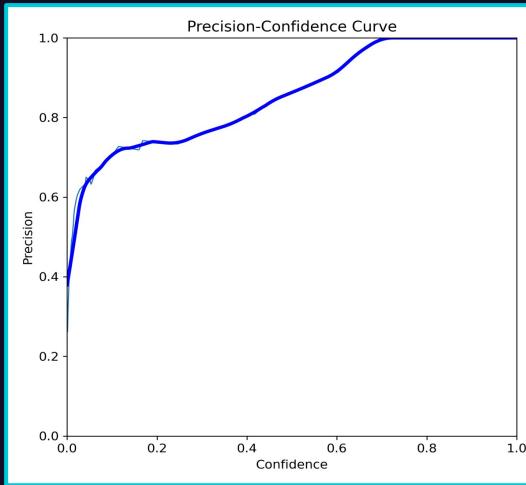
Initial Model

**75%**

Training Set Recall

**3837**

Total # Detections



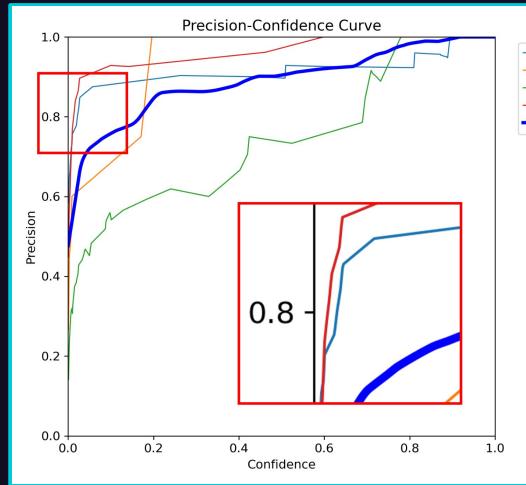
Refined Training Techniques

**70.1%**

Training Set Recall

**1310**

Total # Detections



Updated Training Set

**73.6%**

Training Set Recall

**786**

Total # Detections

**Training Set Recall:**  
 $\frac{\# \text{ Correctly Detected Training Events}}{\# \text{ Events in Training Set}}$

**Precision:**  
 $\frac{\# \text{ Correct Detections}}{\# \text{ Detections}}$