# Applications of Computer Vision to Space and Plasma Physics

Erick White [1]

[1]Ann and H.J. Smead Department of Aerospace Engineering Sciences

## Overview

- We have a lot to learn about Earth's magnetic field
- Machine learning is a powerful tool — how can we put it to use in a scientific context?

## Motivation

- The Van Allen Probes mission was launched in 2012 to observe Earth's magnetosphere
  - Recorded data for seven years → intractable to analyze entirely by hand
- Increased prevalence of machine learning
  - Great potential for scientific data analysis
  - "Proof-of-concept" for similar applications to other missions
- Identifying, categorizing, and analyzing EMIC waves
  - EMIC wave distribution (MLT and L-shell)
  - Influencing factors (geomagnetic activity, solar activity, *etc.*)

## Background

- **Magnetosphere:** Region of space surrounding the Earth and dominated by its magnetic field
- **Plasma Wave:** Charged particle event that causes a measurable disturbance in the magnetosphere
  - **EMIC (electromagnetic ion cyclotron) waves** are a type of plasma wave
- **Object Detection:** A branch of machine learning dedicated to identifying certain categories of objects in images
- **YOLO:** You Only Look Once, a near-real-time object detection model used in this project

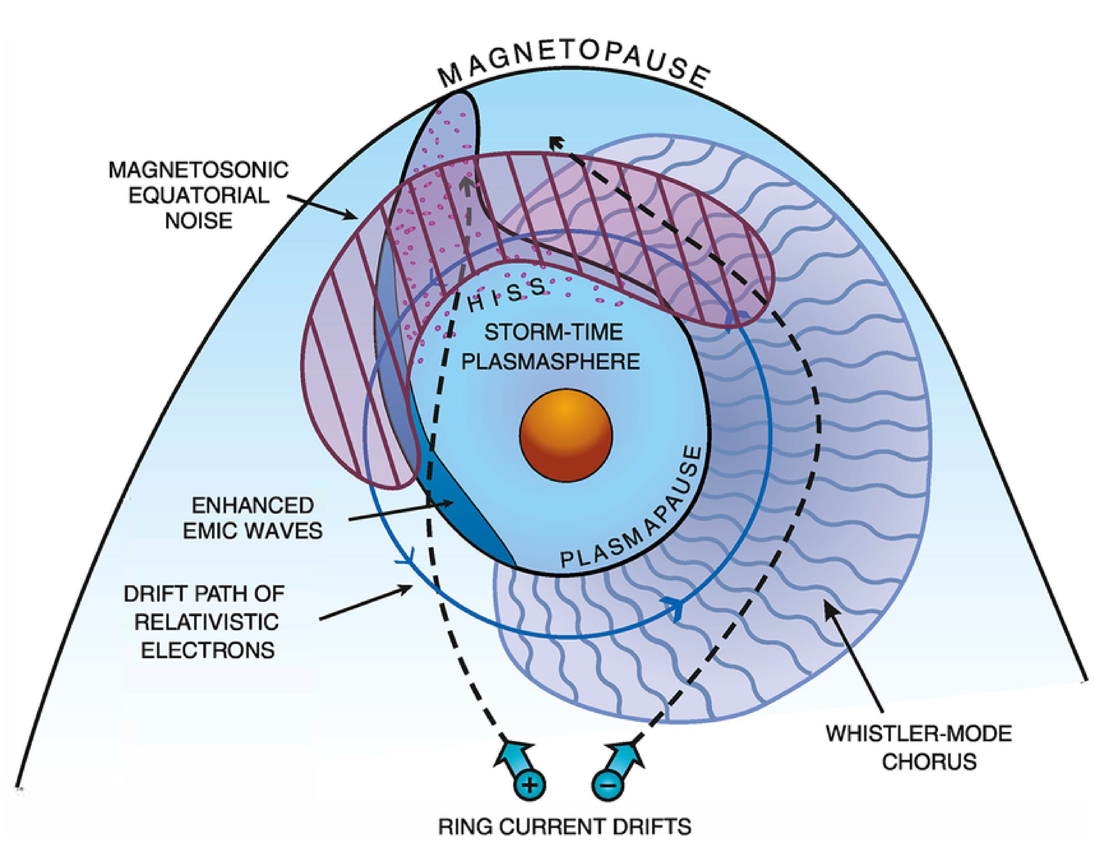


Figure 1. Illustration of magnetosphere and plasma events [1].

## Spectrogram Generation

- Plasma waves disturb the magnetosphere in a measurable way
- Must optimize spectrograms for EMIC wave detection
  - 0.3125 to 8.28125 Hz range chosen for this project

## Annotation and Model Training

- Problem: How to verify that a signal is an EMIC wave?
  - Lots of unknown signals
  - Not much to verify against
  - Must ensure that model is training on EMIC only
- Solutions:
  - Gyrofrequency annotation: are events where we expect them to be?
  - Visual inspection: Do they *look* right?

Gyrofrequency governing equation: $\omega_c = \dfrac{qB}{m}$

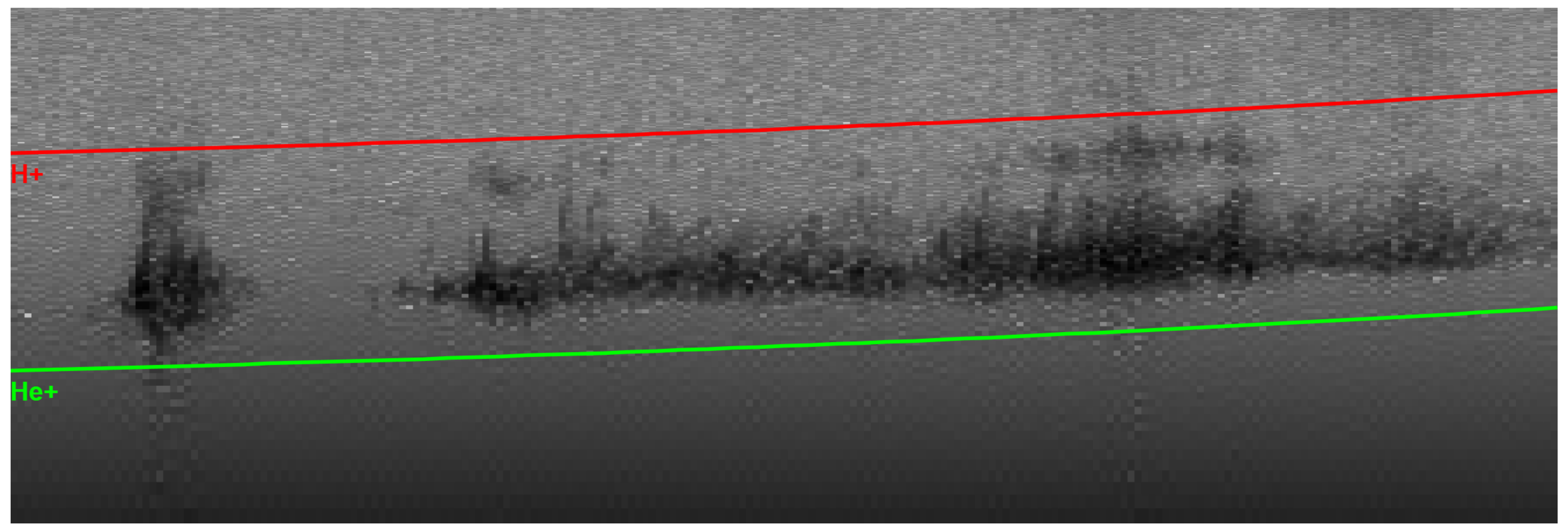


Figure 2. A spectrogram of the magnetosphere with H+ and He+ gyrofrequencies annotated - note how well they line up with the EMIC wave!

- Annotations tell the model where EMIC waves are to train on
- Lots of judgement calls
  - What is/isn't an EMIC wave?
  - Need experienced space scientist to help differentiate
- YOLO can directly process annotated images
- A couple of big pitfalls
  - Incorrect annotations can lead to bad predictions!
  - Finding enough events can be a challenge

## Results

- Results seem promising!
  - The latest version of the model has a mean average precision (mAP50) of 0.738
    - Have only annotated around two and a half years so far out of seven, so can expect many more events to train on
- Model can automatically quantify confidence of detections

## Model Performance

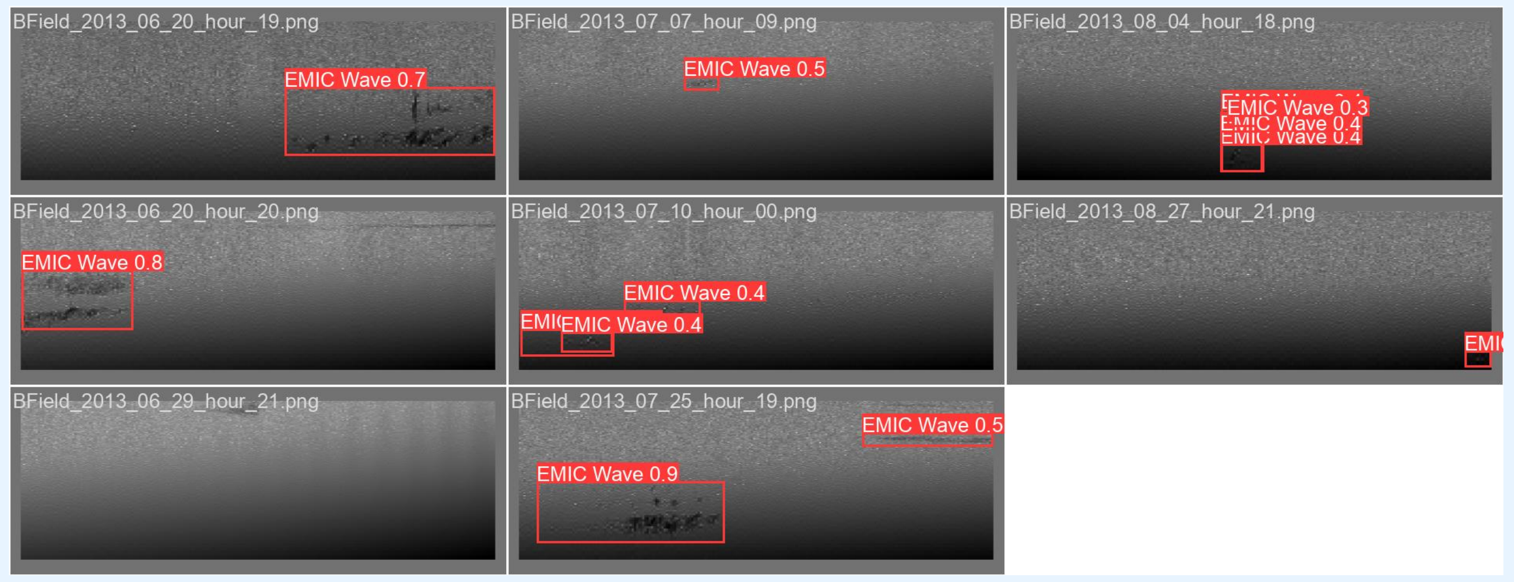


Figure 3. Model predictions for several spectrograms with likely EMIC wave events.

## Conclusions

- Potentially more versatile than current methods employed
- Machine learning can be integrated efficiently into a scientific workflow
- Events have been found with longer durations than previously expected
- EMIC waves lack the distinct shape some plasma waves have

## Future Work

- Quantifying where these waves occur
  - Polar plots
  - Do they happen where we think they do?
  - How do they compare to other plasma waves?
- Expanding to other missions
  - Main issue: consistent spectrograms
  - Image size affects model results
  - Feasibility of a standardized spectrogram generation method

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[1] Richard Mansergh Thorne. "Radiation belt dynamics: The importance of wave-particle interactions". In: *Geophysical Research Letters* (2010).