Autonomous Detection of Coronal Mass Ejections (CMEs) Using Heliospheric Imager(HI) Data

Samantha Ballard

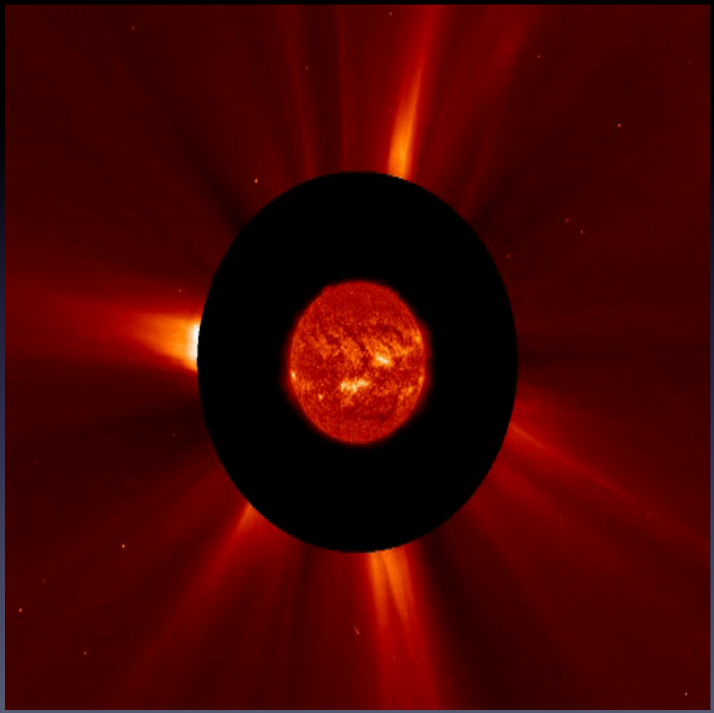
Southwest Research Institute

Advisor: Dr. Tim Howard

Pennsylvania State University

What is a CME?

- An eruption of plasma and magnetic field from the sun
- Typical speed: 400-1000 km/s
- Mass: $10^{11} – 10^{12}$ kg



Why Are They Important?

- CMEs cause Geomagnetic Storms

 - Radiation exposure

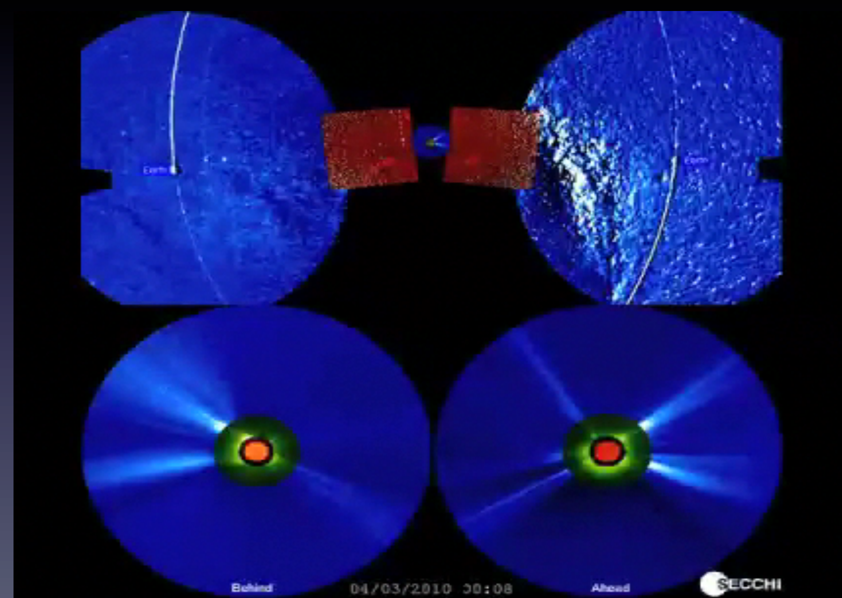
 - Power grid damage

 - Telecommunication disruption

- Space Weather Prediction

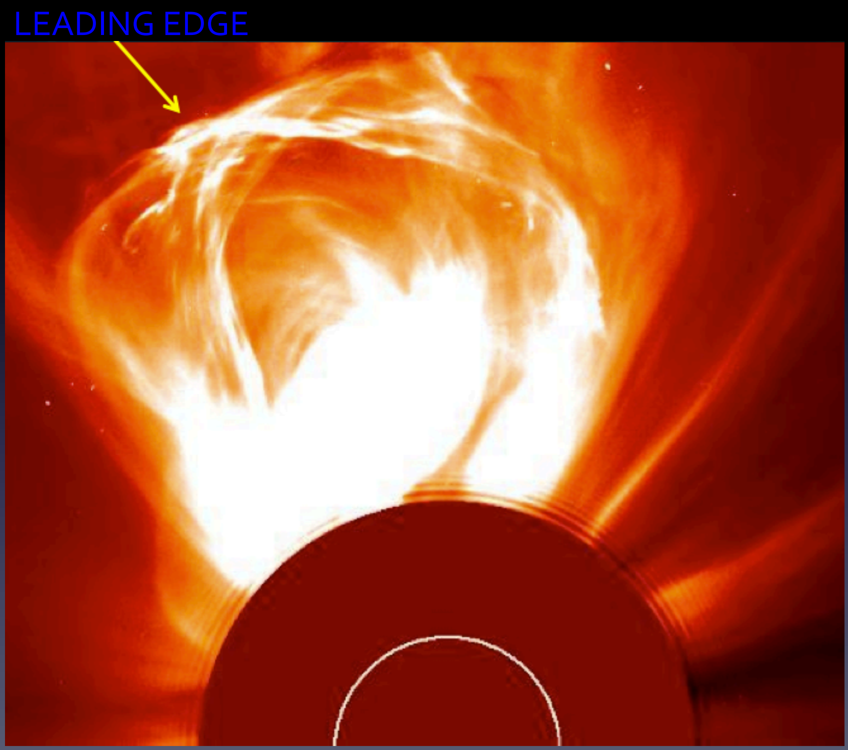
Coronagraph Detection

- Detecting CME has been done with coronagraphs
- We are using Heliospheric Imagers (HI)
- Similar to coronagraphs but have a much wider angle/field of view



What Are We Doing?

- Automatically detect CME and its leading edge using HI
- Results fed into Tappin-Howard to form 3D reconstruction of CME
- Provides a forecast for CME impact on earth within +/- 5 hours

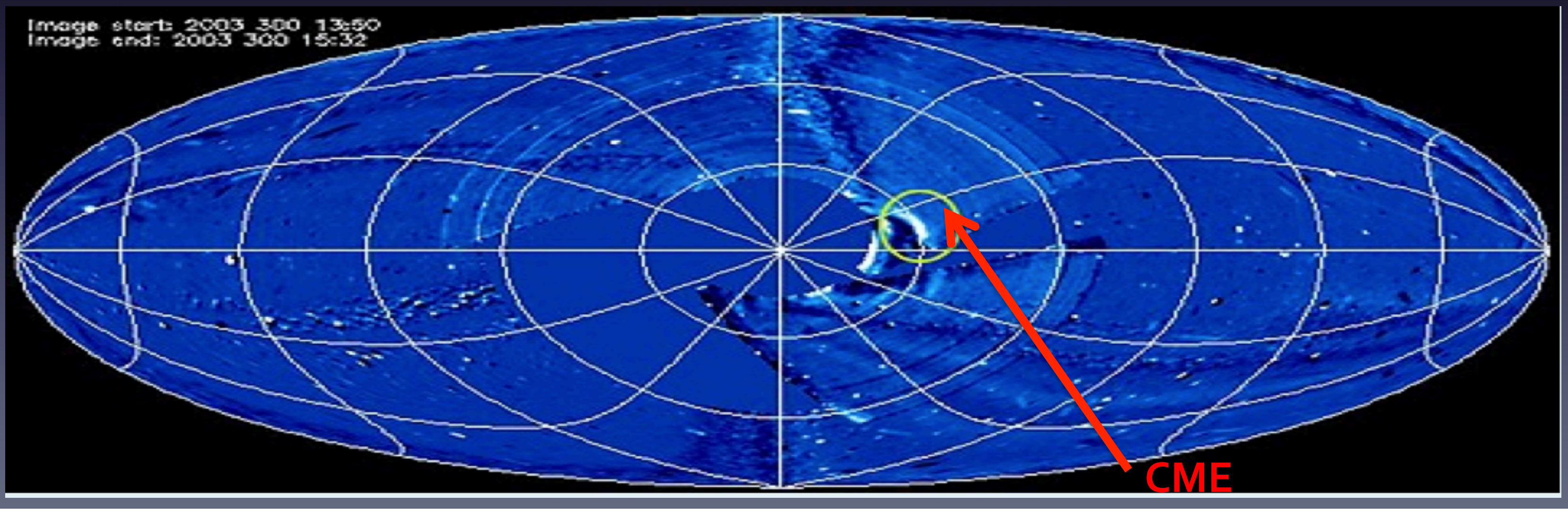


Prior work

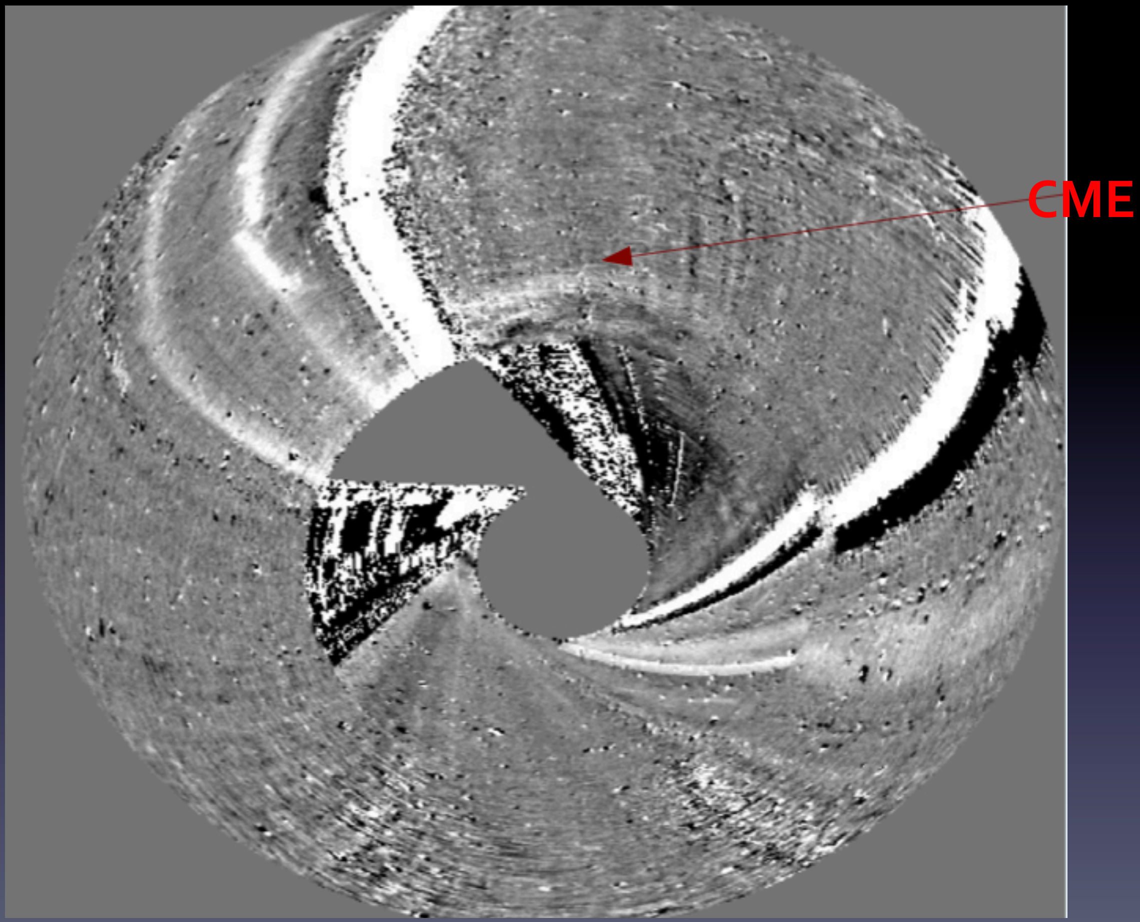
Goals	SMEI	HI
1) Automatically detecting a CME	✓ 2008, 2009: Max Hampson. Devised AICMED	In progress. Started by Christina (2011) and continued by Lauren Biddle (2013)
2) Measuring the leading edge and identify noise in the data	✓ 2010: Robin Thompson (leading edge and noise) 2011: Christina Burns (revised code and completed)	In progress. May not be possible from motion blur
3) 3-D reconstruction (using leading edge) in Tappin-Howard Model	✖ Did not work	Eventual Goal

Solar Mass Ejection Imager (SMEI) Data

- Onboard Coriolis spacecraft
- Now turned off
- Noisy
- Fisheye or Hammer-Aitoff projection, pieced together view of the sky
- Sun in center of field of view



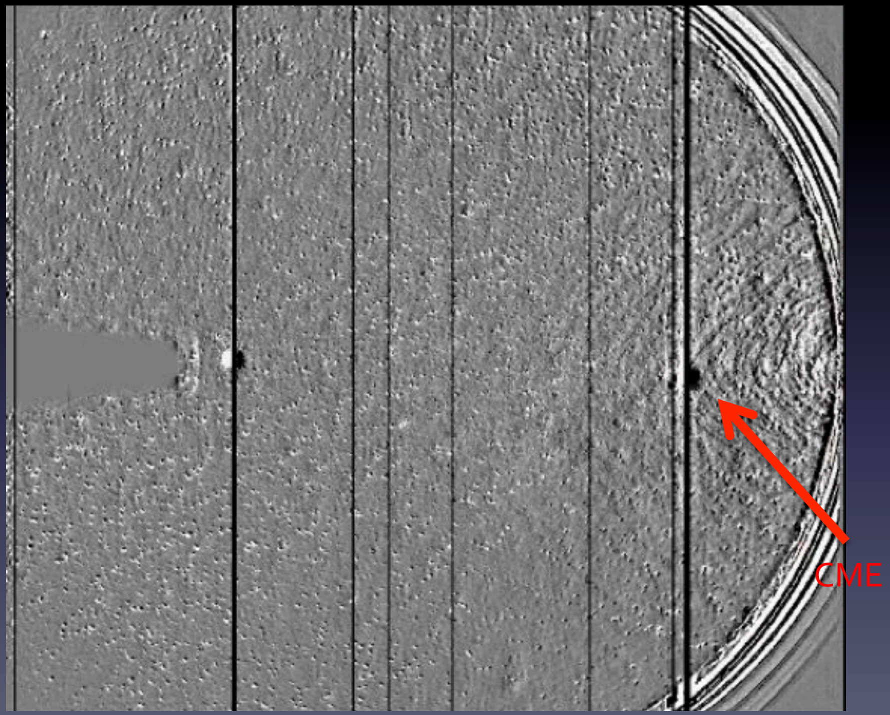
“Raw” SMEI fisheye Image May 2003

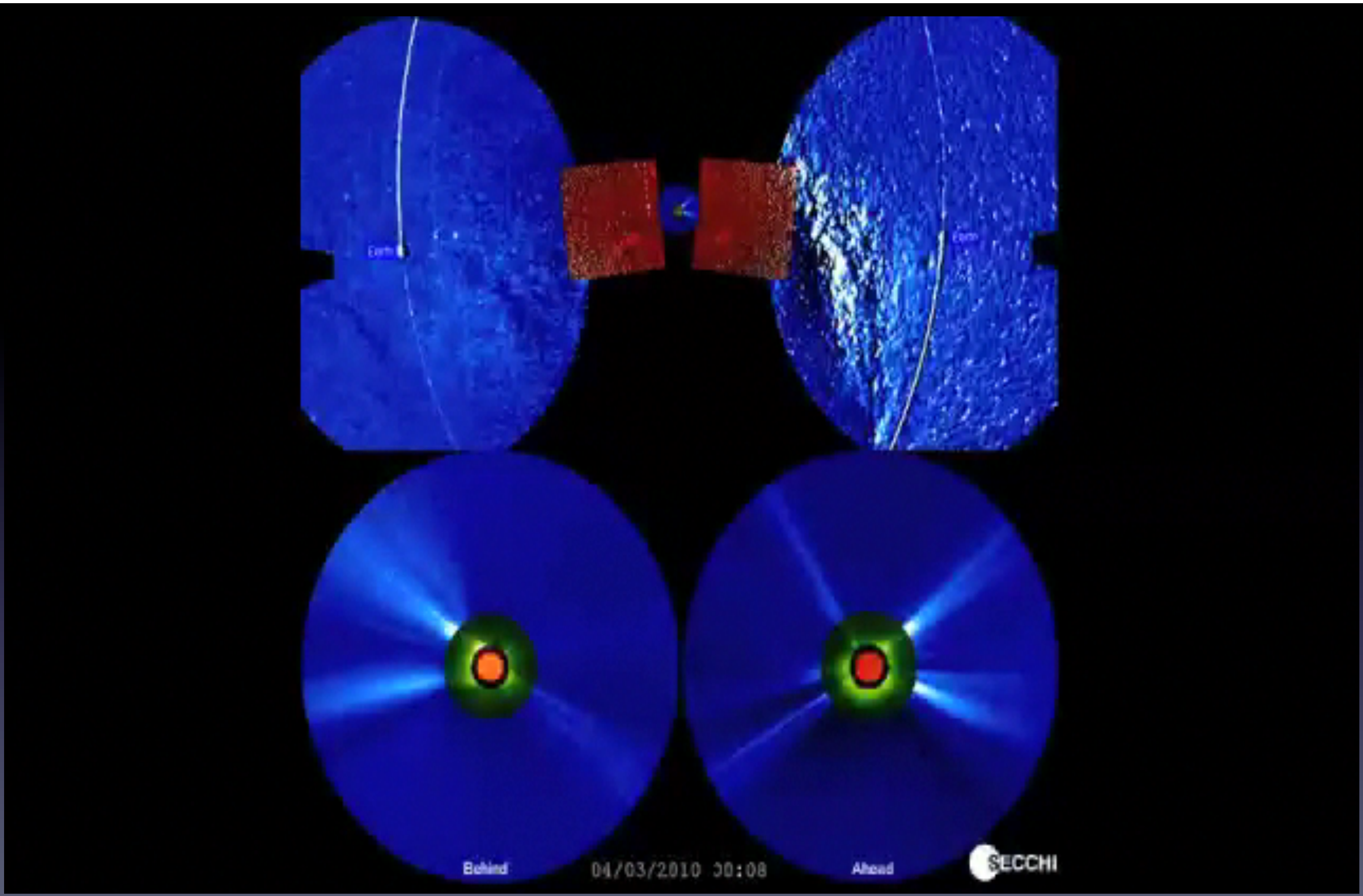


Moving from SMEI to HI

Heliospheric Imager Data (HI-2A)

- onboard NASA's STEREO
- Less noise
- Sun out of field of view
- Can see what CME does in interplantary space
- Problem: possible motion blur




Behind
04/03/2010 00:08
Ahead
SECCHI

How it Works

Summary of Code

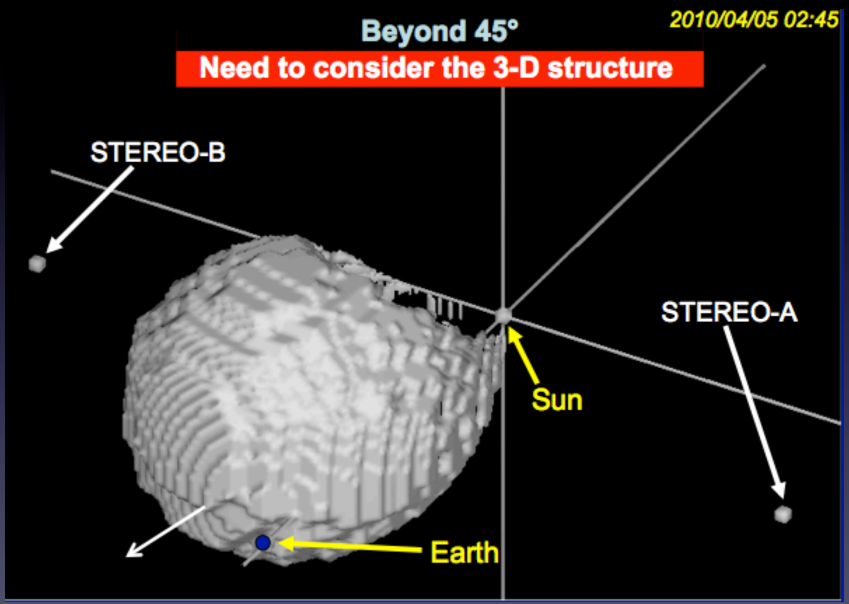
- Read in images
- Form data cube
- Parse and smooth Data
- Use detection tool AiCMED to identify CME events by applying Hough transform
- Detects and records leading edge measurements
- Finds noise
- Splits CMEs
- Convert EA and PA back into pixel coordinates
- Plots CME events with noise and leading edge identified
- Writes leading edge and noise measurements to text files

Output of Leading Edge Measurements

JD	X	Y	Hlon	Hlat	Elong	H-PA	E-PA	Value
2454814.2074769	1005	616	-18.459	8.382	20.213	65.044	69.862	0.0135
2454814.2074769	998	603	-19.004	7.598	20.414	67.725	72.542	0.0234
2454814.2074769	994	589	-19.361	6.720	20.452	70.434	75.252	0.0198
2454814.2074769	996	563	-19.410	5.016	20.024	75.207	80.025	0.0365
2454814.2074769	999	544	-19.340	3.760	19.688	78.776	83.594	0.0348

Tappin Howard Model

- Inputs are CME leading edge measurements and noise gaps
- Compares the measured leading edge data with simulated CMEs
- All done automatically



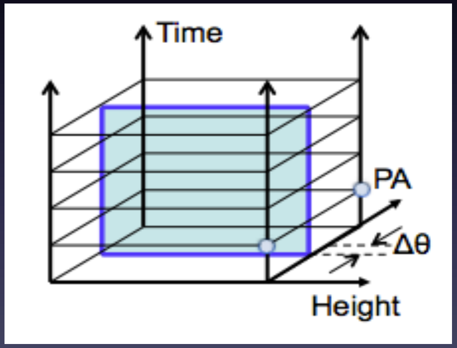
Computer Aided CME Tracking (CACTus) Tool – for Coronagraphs

1. Transform image from Cartesian (x,y) to polar coordinates (r, PA) to map on a new grid

2. Stack collection of images to form a 3D data cube (t, r, PA)

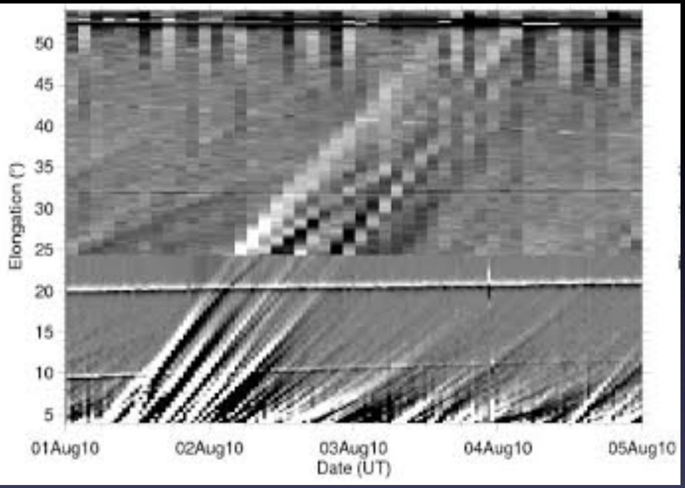
3. Choose a PA through the cube to create a image in (t,r)

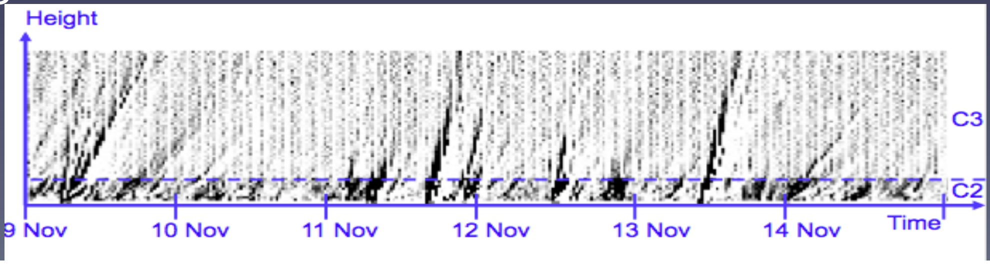
4. Result: distance/time plot for each object that crosses a selected PA



Problem with CACTus

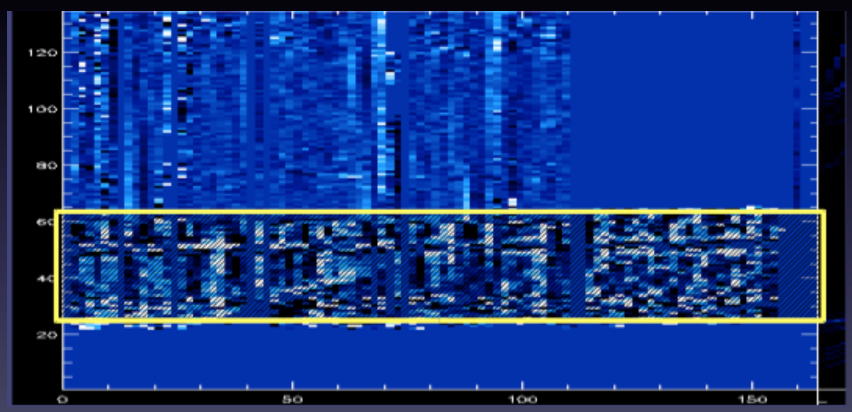
- CACTus can't apply to HI data
- No longer dealing with distance, instead elongation angle
- Much larger range of the sky for HI than coronagraphs
- Lines will be curved instead of straight
- Solution: parsing





Parsing and Smoothing Data

- Parsing: taking subsections of the data in elongation
- Choose a small enough subsection to get a straight line



- Smoothing: 5 Methods
- Best Method: Scaled Median
- Preserves Faint Events

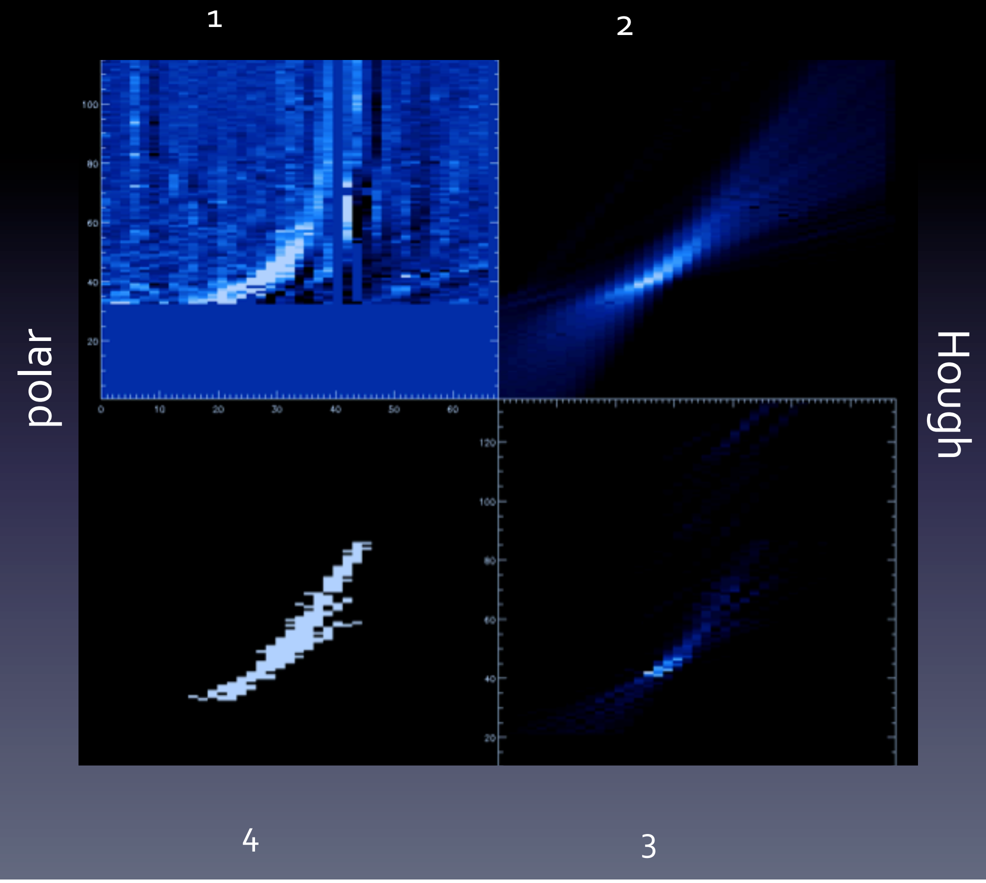
Hough Transform

1) Extracts straight lines from the (t,elongation) image

2) Transforms image to accumulated or Hough space

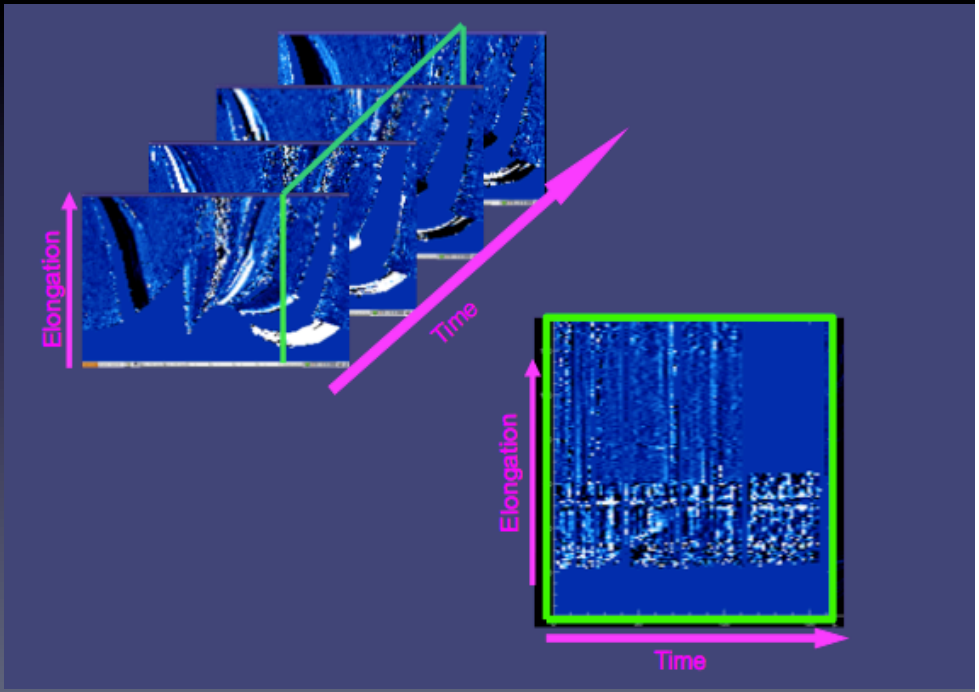
3) Masking and filters applied

4) Transforms back into original coordinates

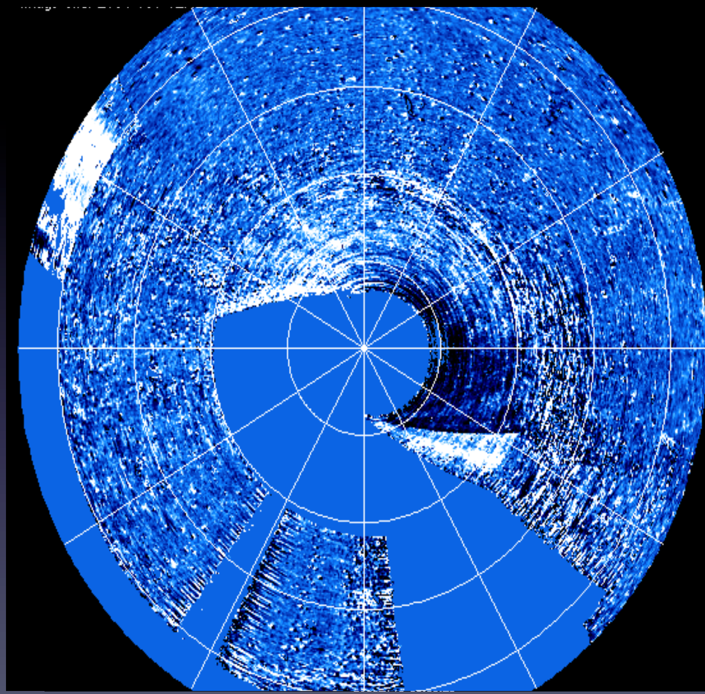


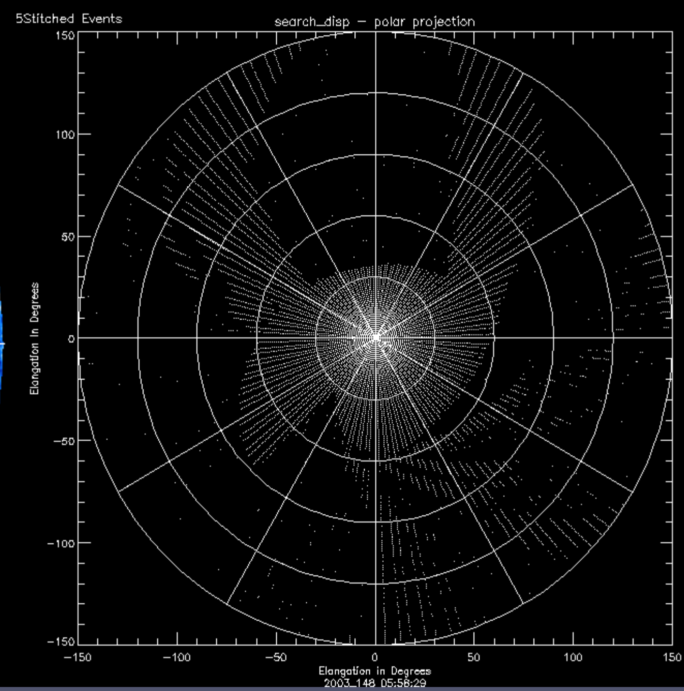
Automatic Interplanetary Coronal Mass Ejection Detection (AICMED) Tool

- Applies CACTus, parsing and Hough transform processes to SMEI data
- Rebins data into PA and EA
- Images are stacked into a data cube (t, elongation, position angle)
- For each PA slice, the Hough space filtering and masking process
- Across a range of subsections of elongations (parsing)
- Returns data to Cartesian space (x,y)



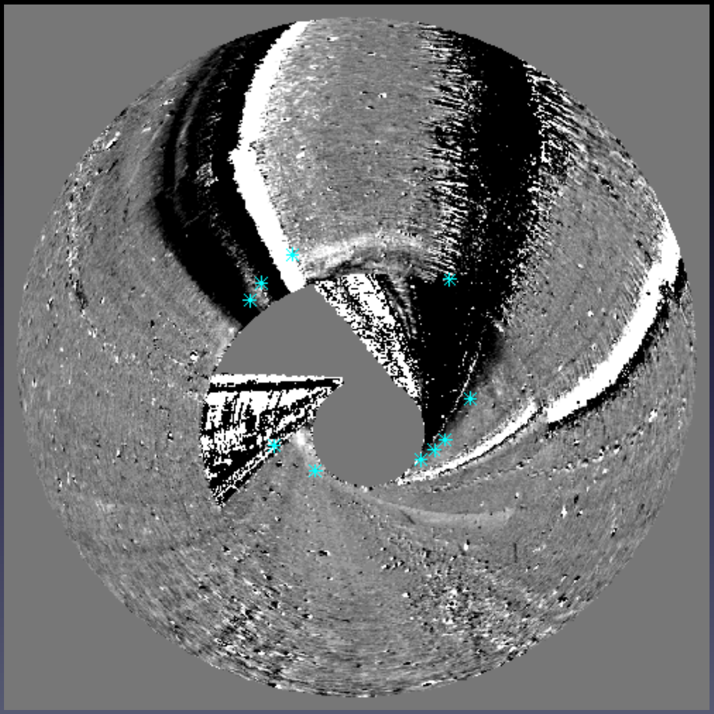
Success With SMEI





Limitations of SMEI

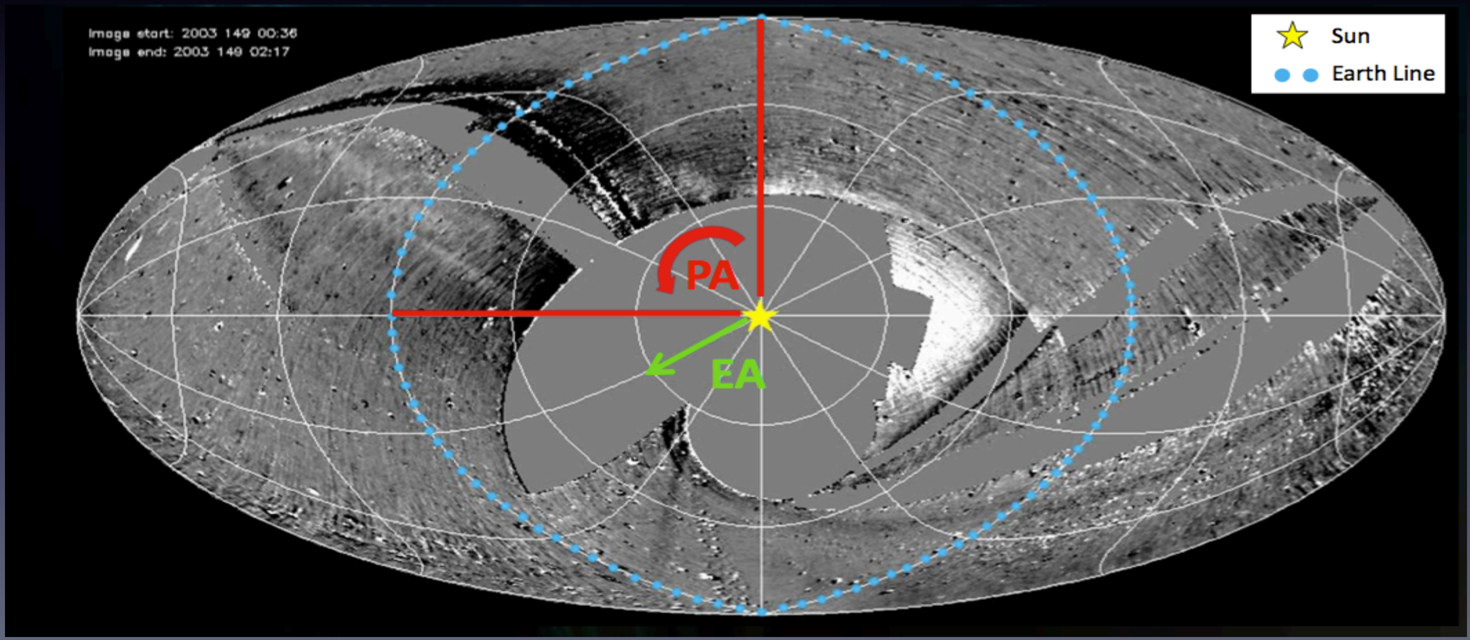
- SMEI images are VERY noisy
- Noise gaps are crucial for correct detection of CMEs
- Some CMEs could be hidden behind the noise
- Did not work for TH



MY CONTRIBUTIONS

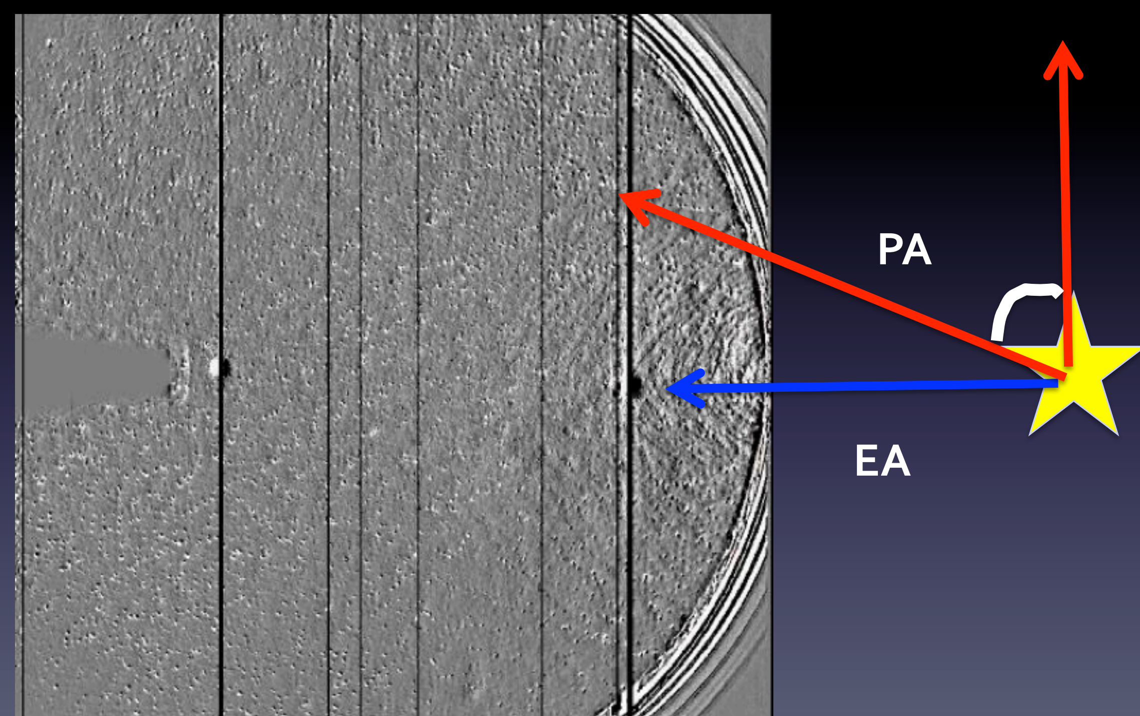
SMEI Coordinate System

- Whole sky projection with Sun at center
- Position Angle (PA) ranges 0 to 360 degrees
- Elongation (EA) starts at 0 degrees



HI-2A Coordinate System

- PA range from 30 to 150 degrees
- EA starts around 20 degrees
- The sun is not in the center of the image



Transforming to Pixel Coordinates (SMEI)

- 4 quadrants

x = c cos(A)

y = c sin(A)

- 1 degree EA = 2 pixels,

  c = 2 x EA

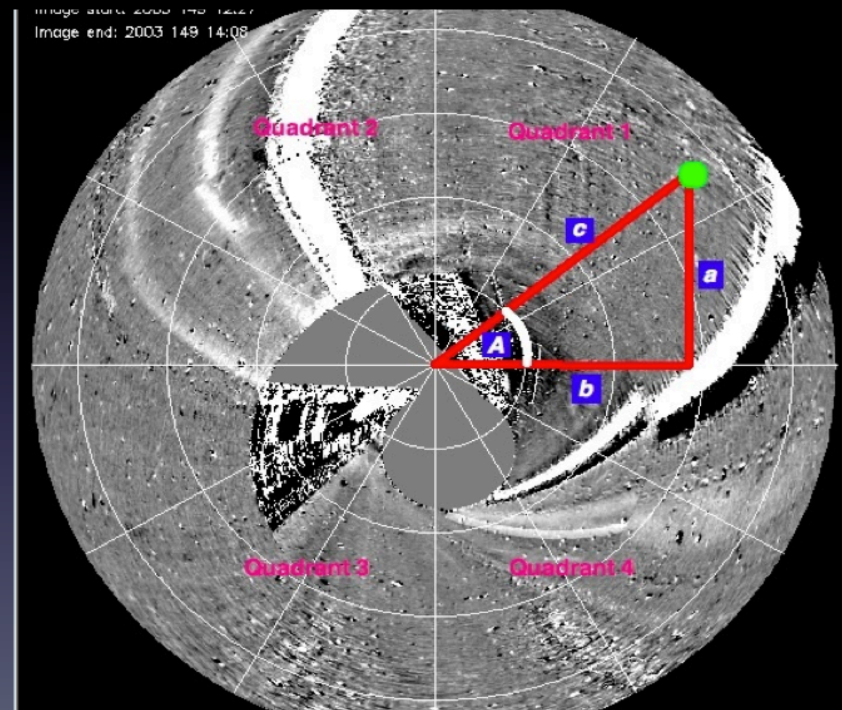
- Dimensions: 560 x 560

Use trigonometry

A = P.A. - 3*Pi/2

x= 280 + c*cos(A)

y= 280 + c*sin(A)



Transforming to Pixel Coordinates (HI)

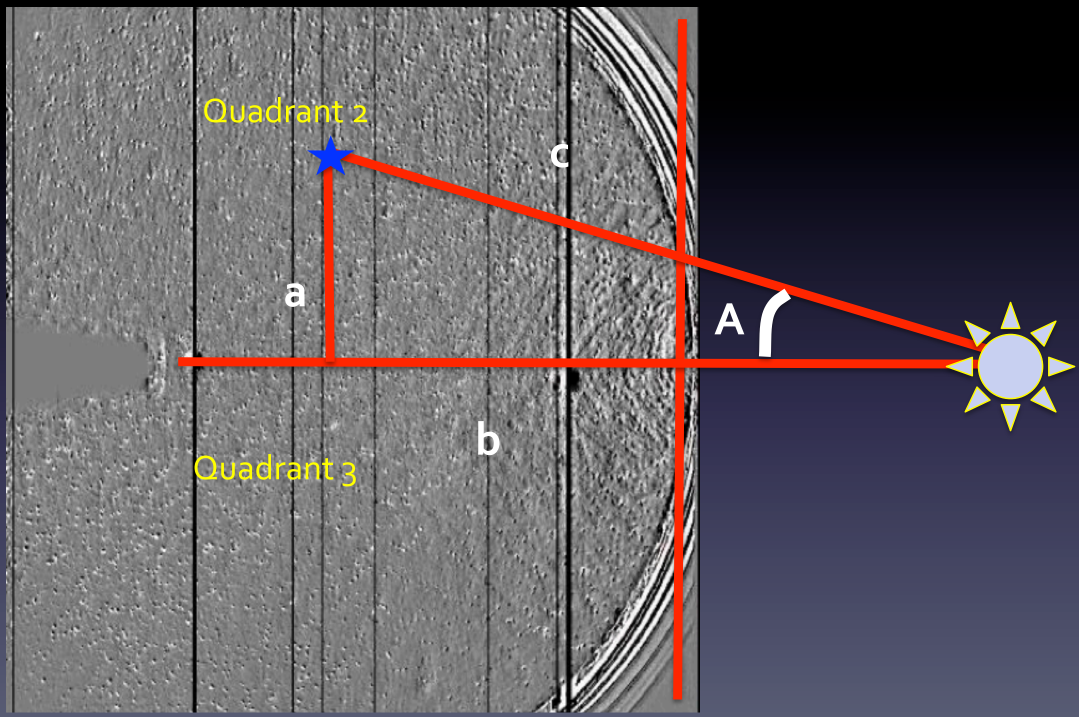
- 2 quadrants
- 1 degree elongation = 30 pixels, c = 30 x EA
- Dimensions: 1024 x 1024

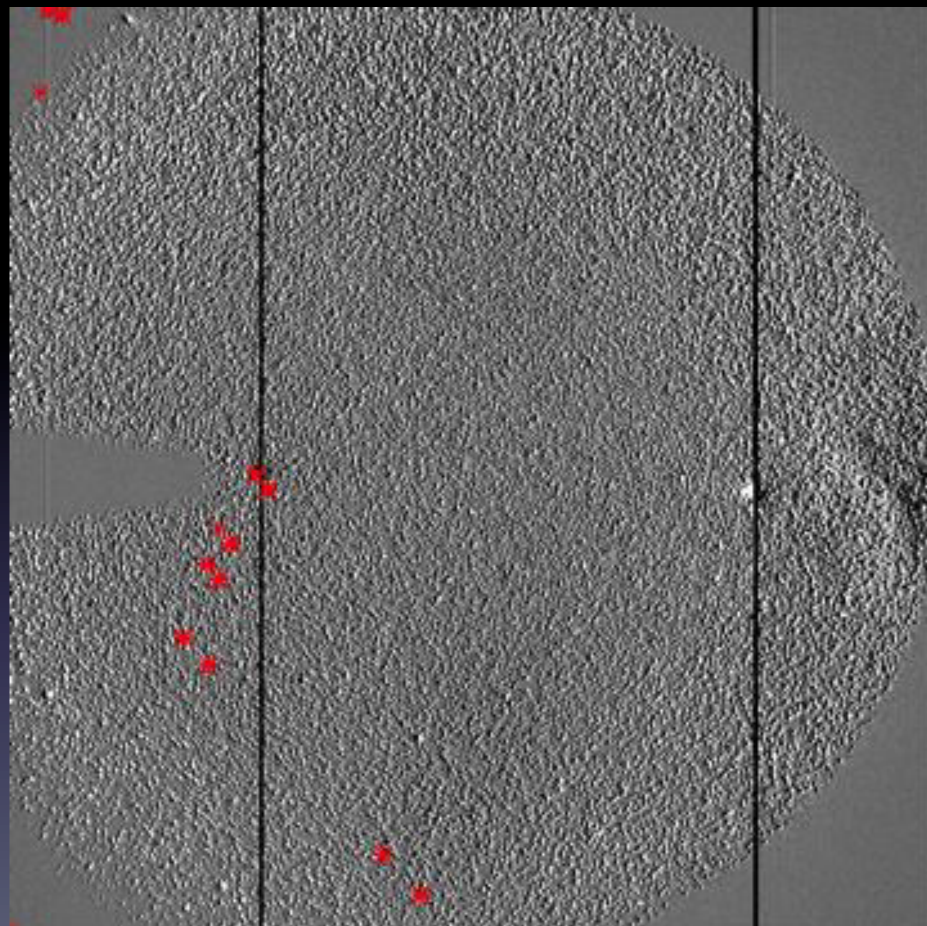
Trignometry:

A = 90 – PA

X = 2700 – c sinA

Y = 512 + c cosA





1) Read in images	☑
2) Form data cube (number of images, EA, PA)	☑
3) Parse and smooth data	☑
4) Use detection tool AiCMED to identify CME events by applying Hough transform	?
5) Detect and record leading edge measurements	☒
6) Find noise	☒
7) Convert EA and PA back into pixel coordinates	☑
8) Plot CME events with indentified noise and leading edge	☒
9) Write measurements to text files	☑

Next Steps

- Analyze parsing and Hough transform part of the code
- Tweak detection parameters/thresholds if necessary
- Figure out why the code isn't picking out the correct EA and PA for the CME
- Identify the noise
- Detecting the leading edge SHOULD come easily
- Feed into TH model to get 3D reconstruction of CME

Acknowledgments

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