Polarimeter to Unify the Corona and Heliosphere

Validation of 3D CME Trajectories through MHD Simulation for the PUNCH Mission

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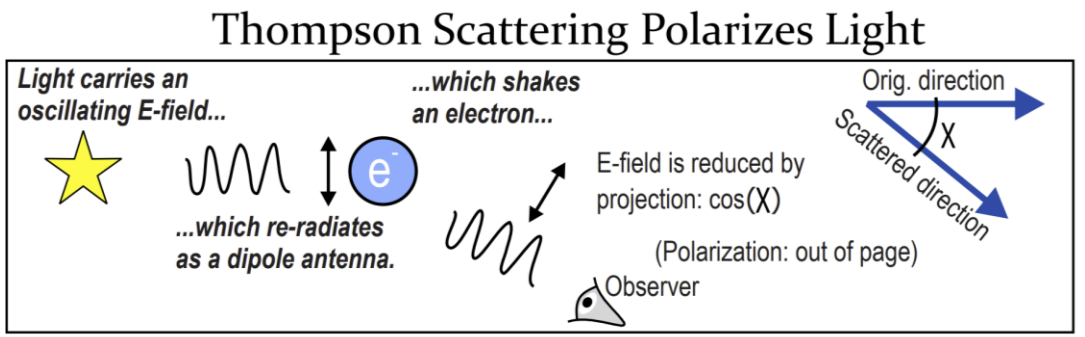
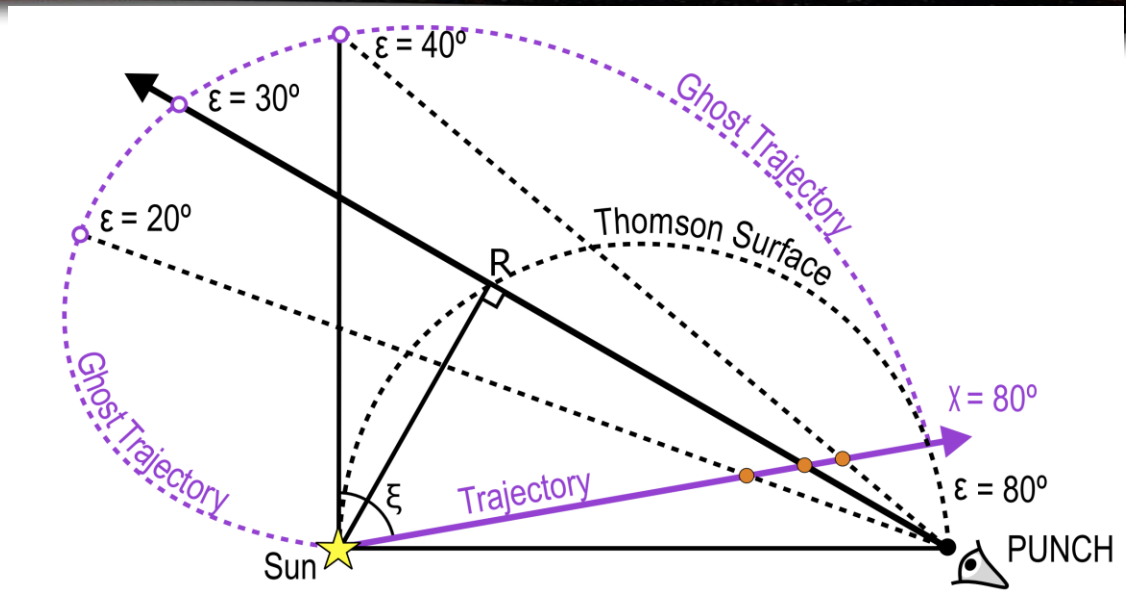
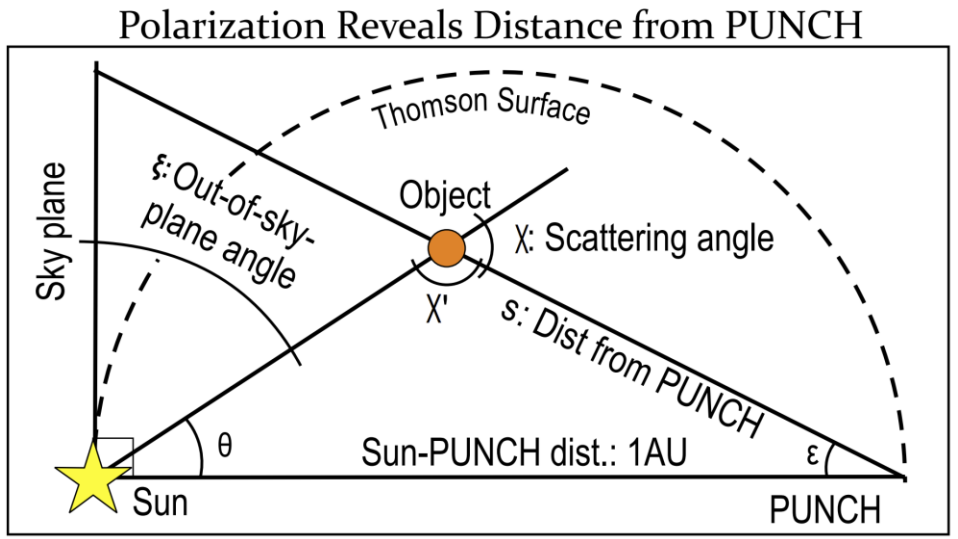
Background

- Thomson Scattering
  - Tracking of CMEs through polarization
- Goal: Determine ξ for time series data, yielding a trajectory
- Distinguish between “ghost” trajectory and “real” trajectory

$$\xi = \varepsilon + \arcsin\left(\pm\sqrt{\frac{1 - pB/B}{1 + pB/B}}\right)$$



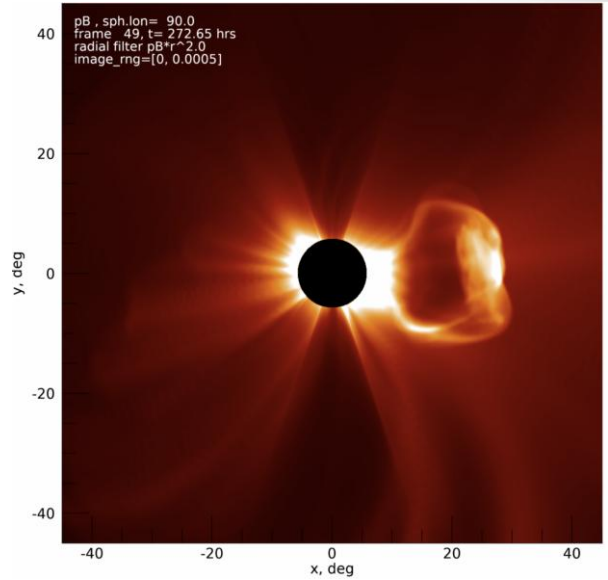




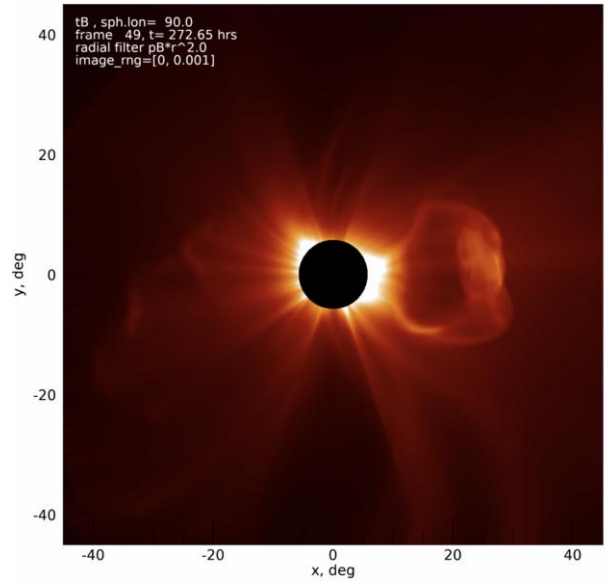
DeForest, Howard, and Tappin (2013)

Introduction

- Hare and Hounds Exercise
  - Simulated CMEs Generated by collaborator Malanushenko, advertised as the “PUNCH CME Challenge”
    - Consist of total brightness (B) and polarized brightness (pB) images.
  - Disseminated to the public for single-blind analysis.
  - Co-authors analyzed these data to generate predictions for time-series trajectory.
- Methodology
  - Manually select point on edge of CME front
  - Analytic inversion
    - pB/B ratio → out of plane exit angle
  - Background subtraction
  - Perspective correction



Polarized Brightness (pB)



Total Brightness(B)

Example simulated pB & B CME Challenge image from “CME 0” dataset

Methodology: Analytic Inversion

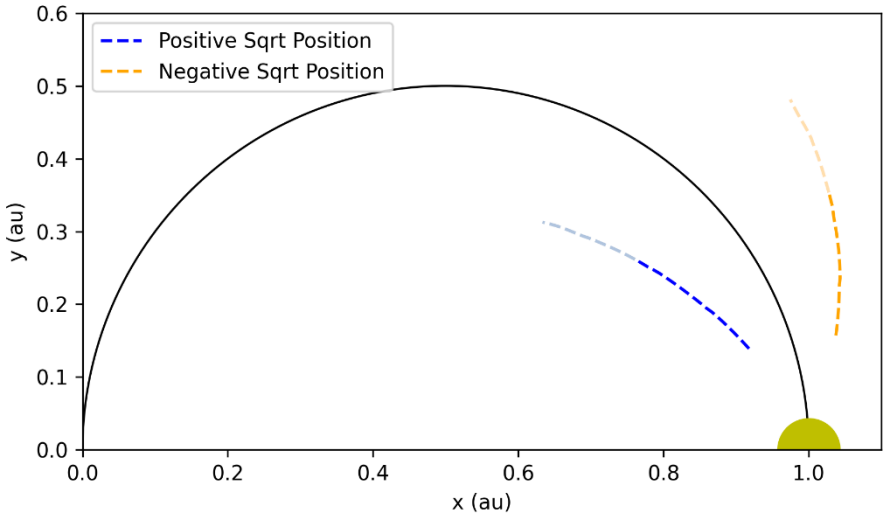
- Initially implemented analytic inversion equation for each pixel without pre-processing.
- Result: Variation in calculated exit angle is explained almost completely by the elongation angle. (Does not model CME trajectory)
  - Cause: The unpolarized F corona polarized K corona distort the pB/B ratio of the CME.

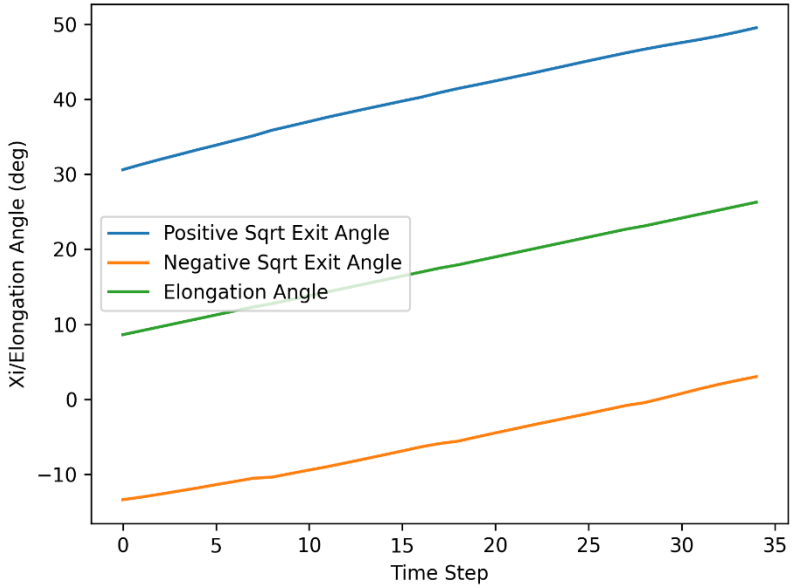
$$\xi = \varepsilon + \arcsin\left(\pm\sqrt{\frac{1 - pB/B}{1 + pB/B}}\right)$$

Out of Plane Exit angle

Elongation angle

Polarization ratio





Methodology: Background Subtraction

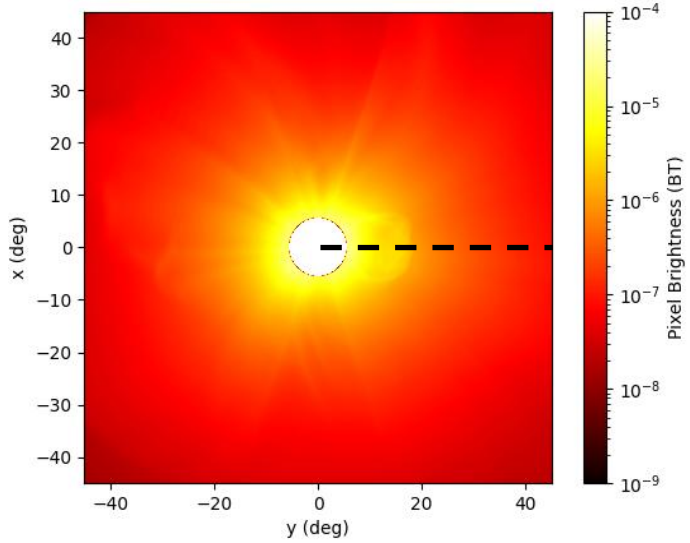
- The time series of the simulated data set is not long enough to establish a reliable long-baseline coronal background image.
- Instead, we subtract out background by modeling brightness as a function of radial distance from the Sun's center.
  - Convert pB and B to radially aligned (B_R) and tangentially aligned (B_T) polarized brightness.

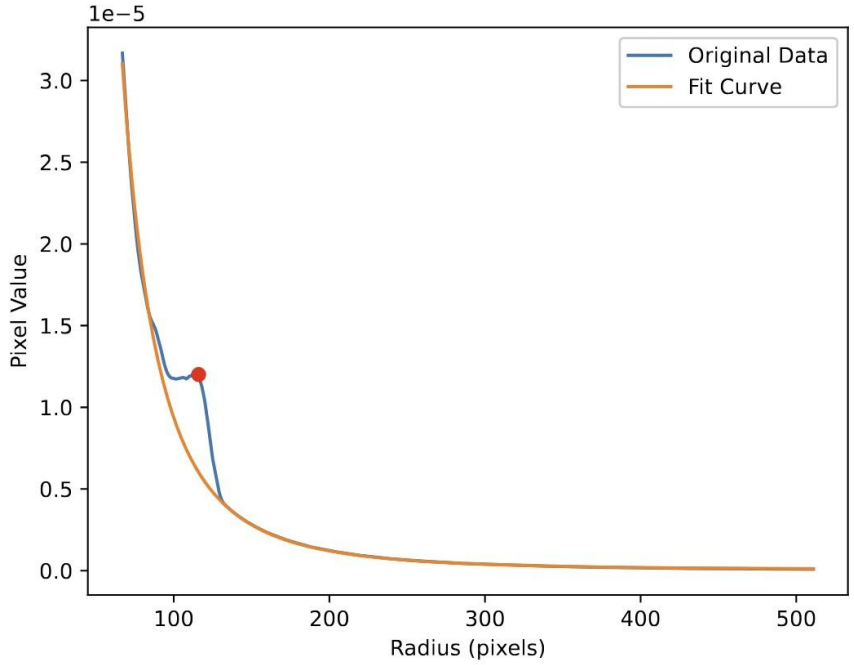
$$B_R = \frac{B - pB}{2} \qquad B_T = \frac{B + pB}{2}$$

  - For each, we generate a fit curve following the functional form below.

$$B(r) = \frac{a}{r^p} + b$$

- Finally, we convert back to pB and B for later analysis.





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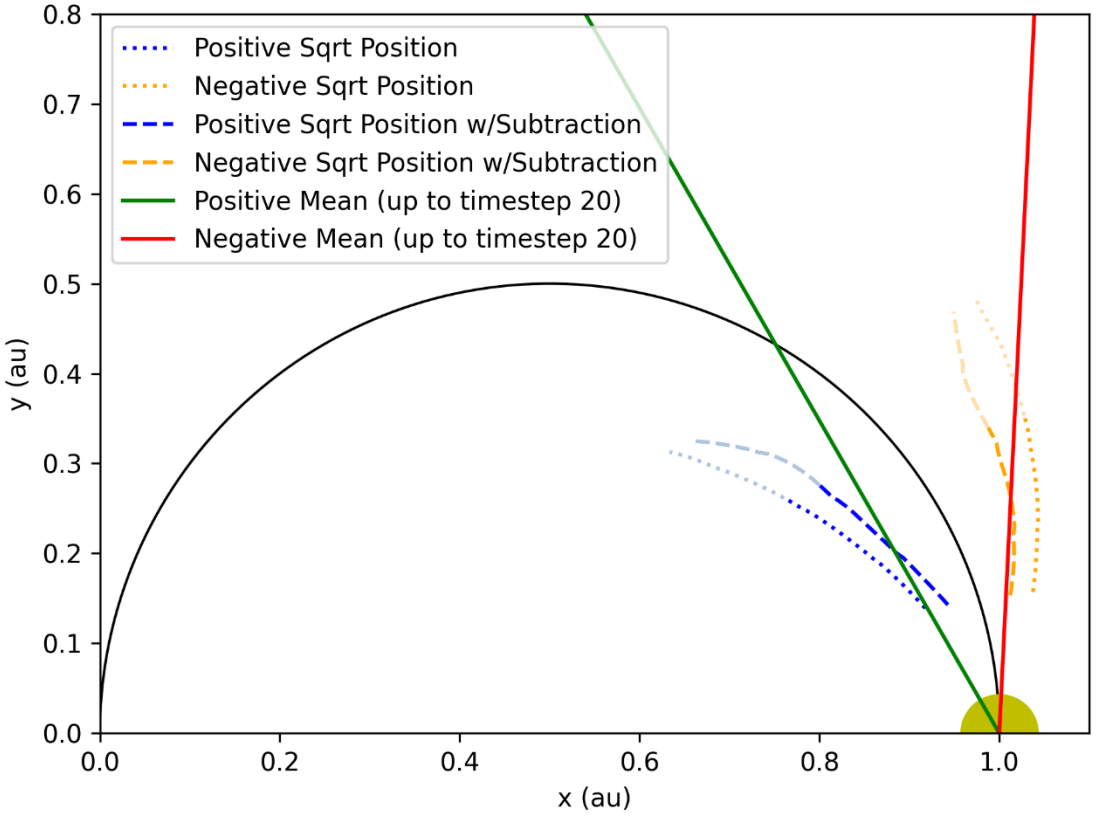
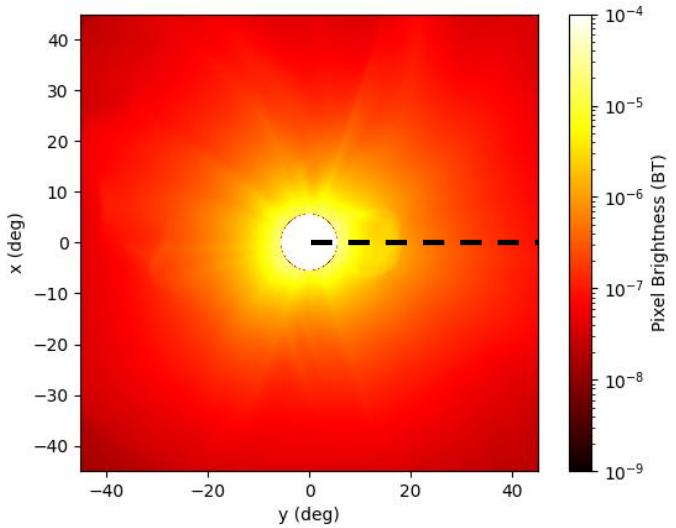
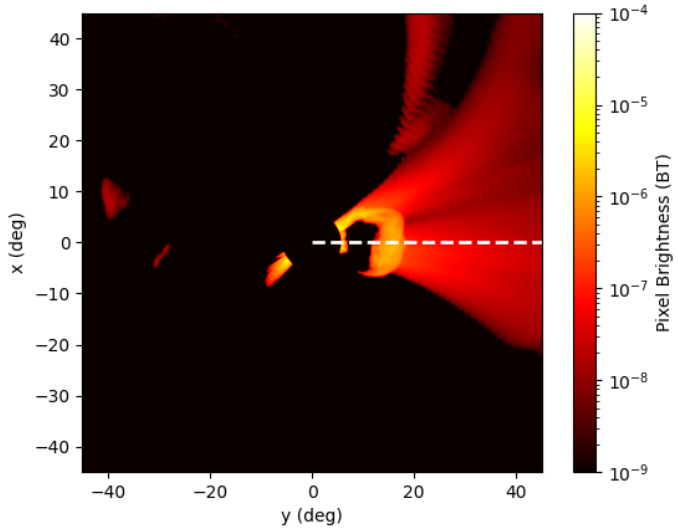






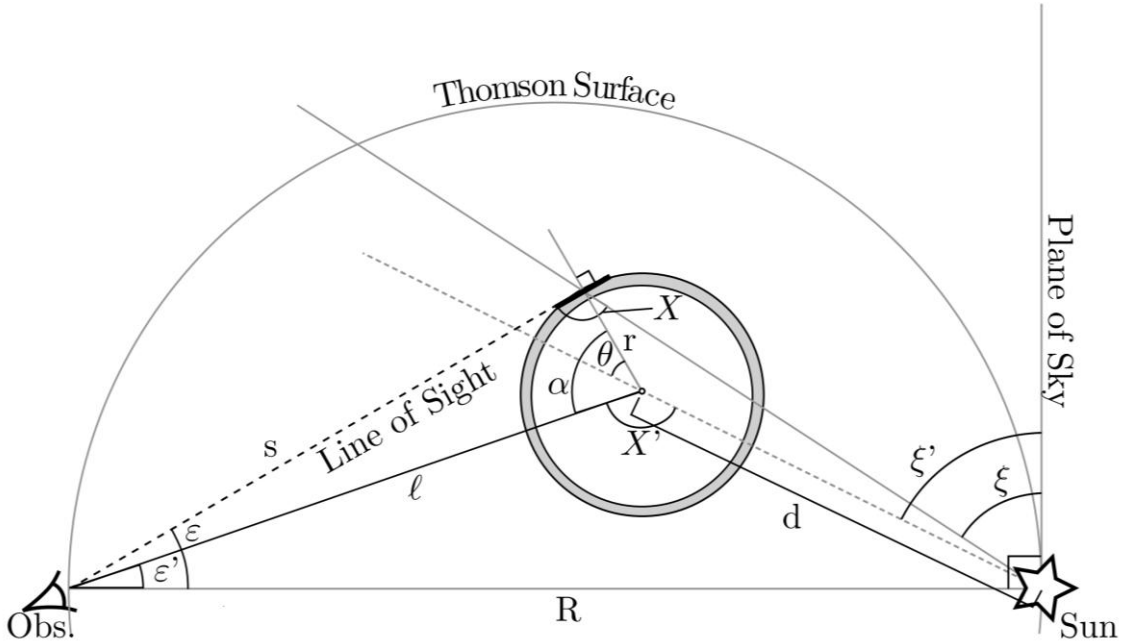
- Background subtraction isolates CME and shifts calculated trajectory towards the Thomson Surface

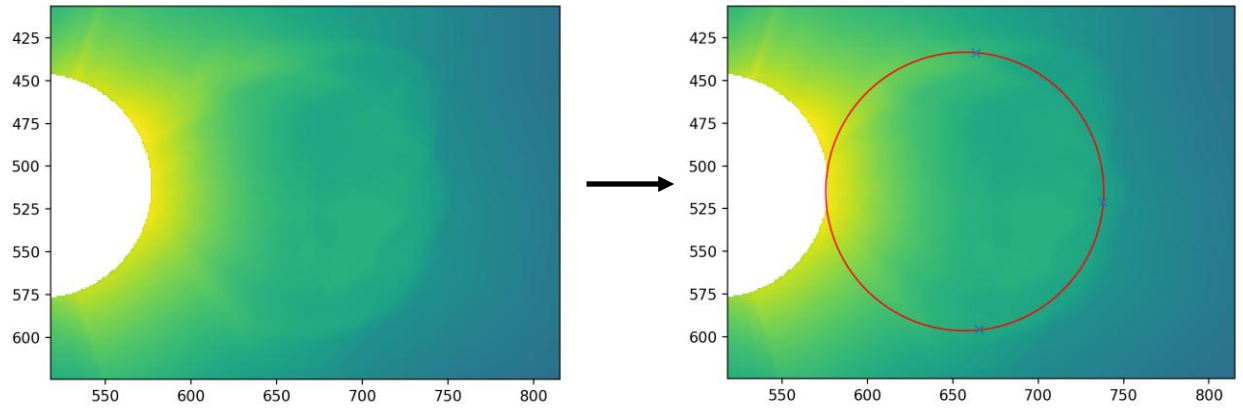
Methodology: Perspective Correction

- The furthest point on the CME from the Sun is not the same as the observed front, where light is compact along the line of sight.
- Solution: we model the CME as a sphere, assuming curvature along scattering plane = curvature along the sky plane.
- Equations below convert between original calculated out-of-plane exit angle, ξ, and corrected exit angle, ξ'.

$$\theta = \arccos\left(\frac{r}{\ell}\right) + \arccos\left(\frac{d^2 + \ell^2 - R^2}{2d\ell}\right) - \pi$$

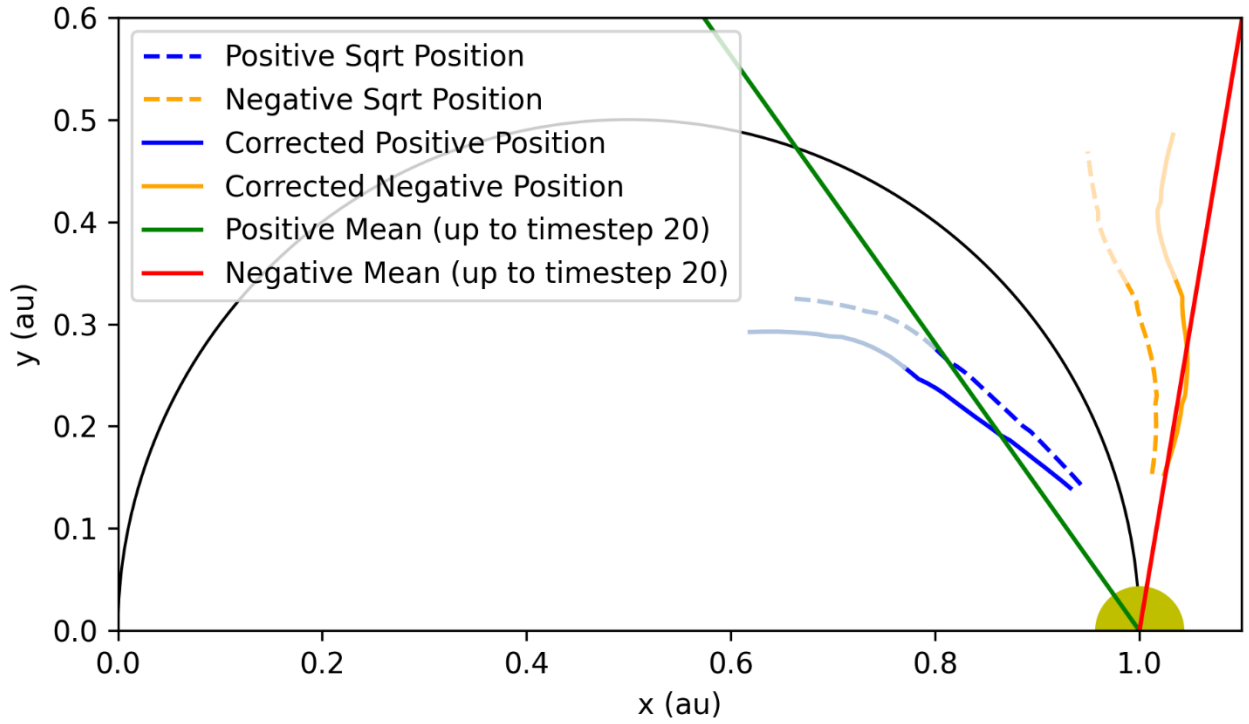
$$\xi' \approx \frac{r\theta}{r+d} + \xi$$





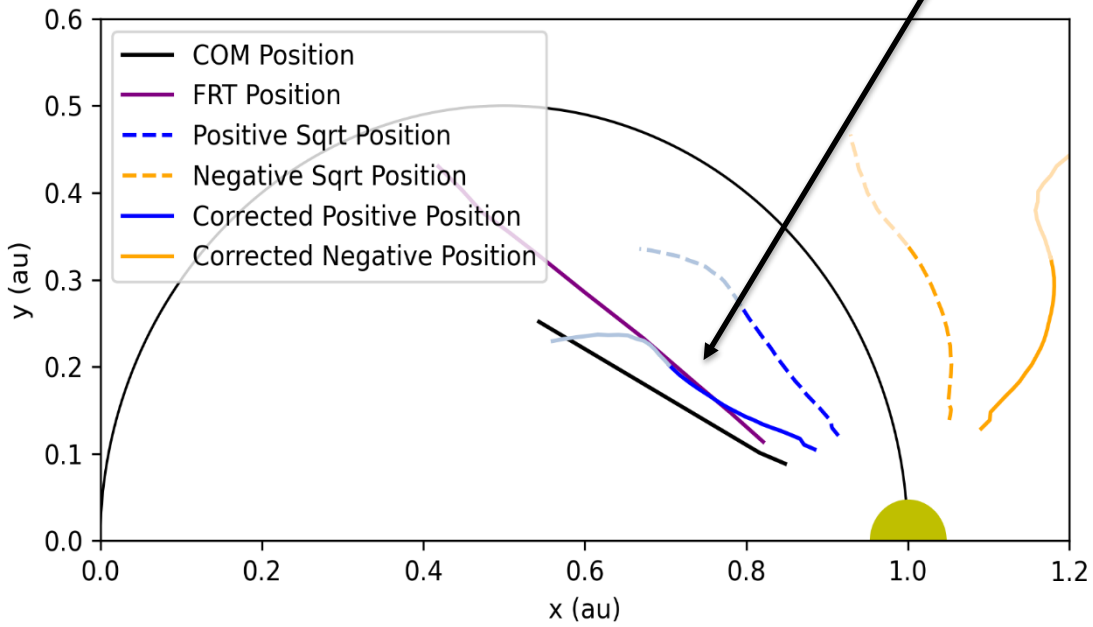
Methodology: Perspective Correction

- Correction shifts estimate CME trajectory away from the Thomson Surface.
- “Ghost” and real trajectory can be distinguished by determining which path is more radial.



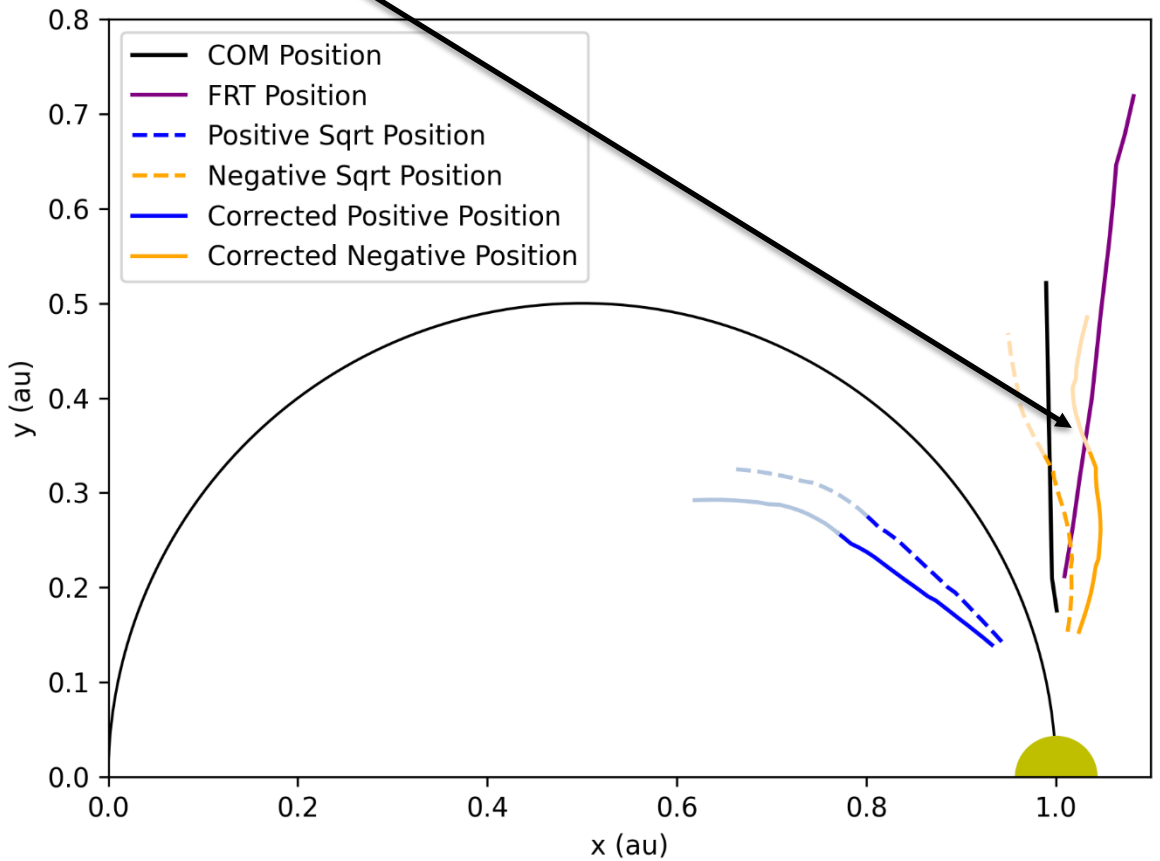
Results

- Comparison with ground truth
  - Demonstrated 3D tracking of a realistic CME event using the polarization signal from a simulated PUNCH instrument.
  - Applied to multiple CMEs and perspectives



30° E Observer Perspective

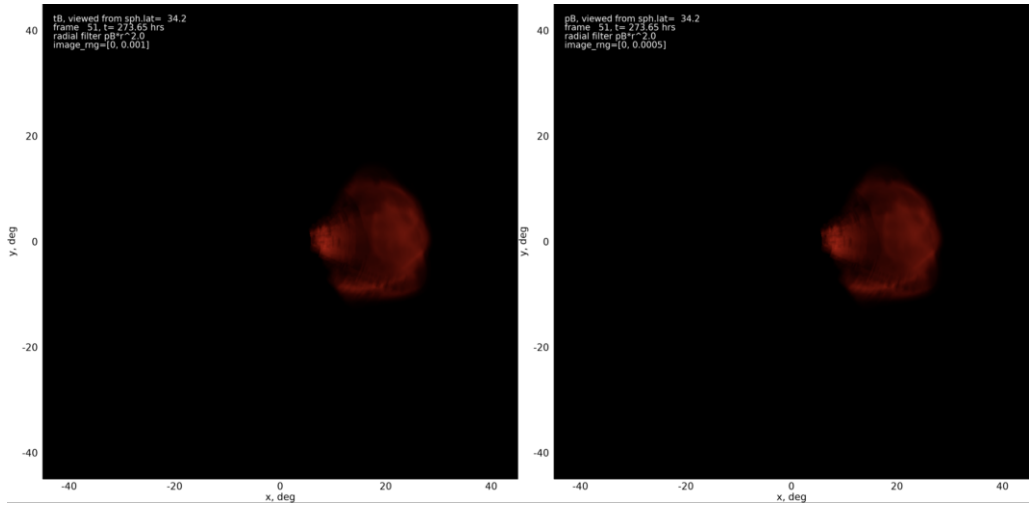
Calculated Trajectory
Consistent with Ground Truth

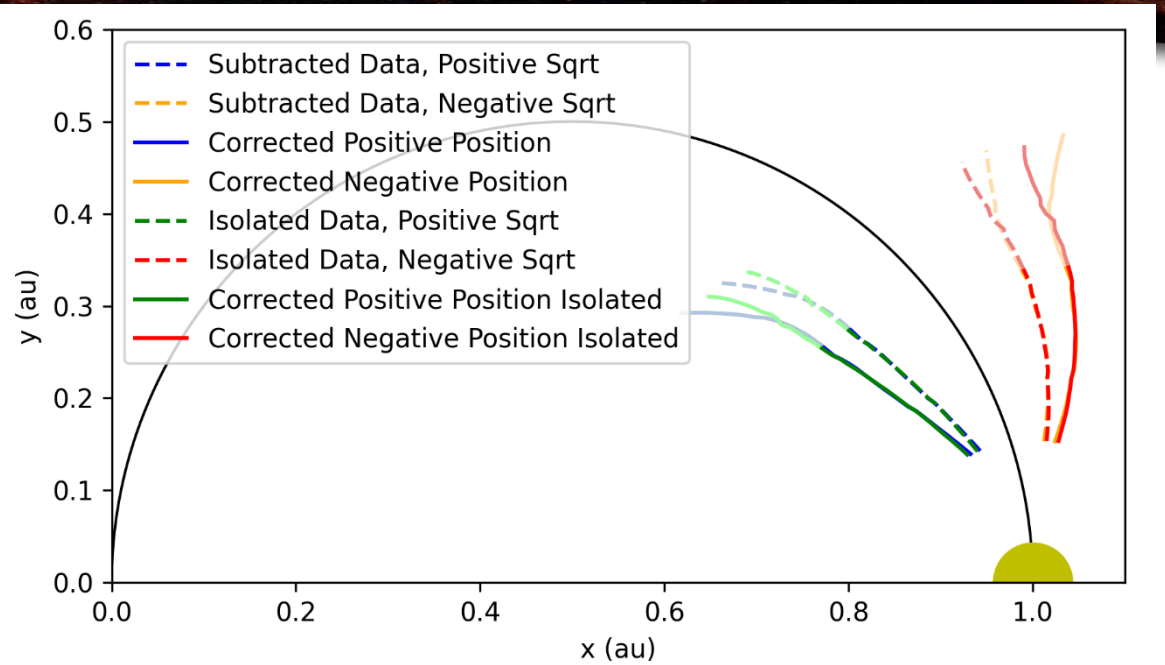


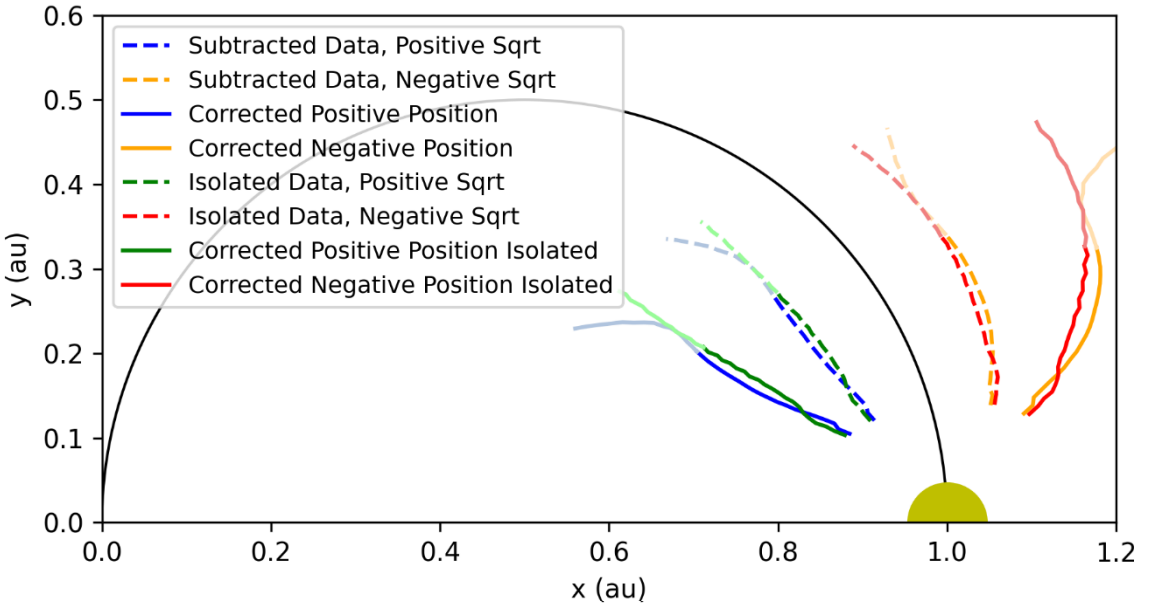
90° E Observer Perspective

Results

- Isolated data
  - Background is removed in the simulation (equivalent to “perfect” background subtraction)
  - Used as a baseline to determine effectiveness of background subtraction model



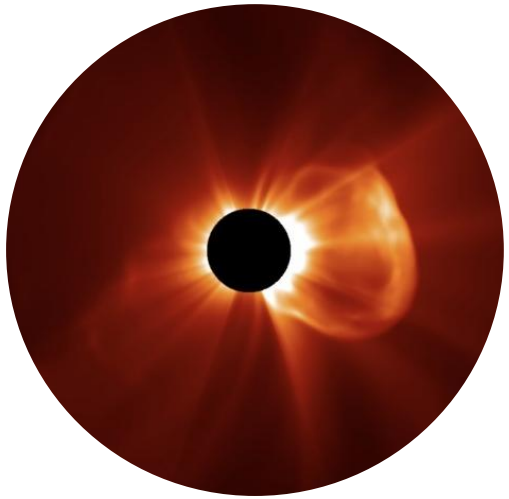




Conclusion, Limitations, & Next Steps

Summary:

- With time-series observations of the polarization ratio on the CME front, we distinguish between “ghost” and “real” CME trajectories
- Fitting an analytic function to the background of a CME image allows us to effectively isolate the CME
- By modeling the surface of a CME as a sphere, we analytically correct for perspective effects



Limitations:

- Methodology tested on few CMEs
- Performed on simulated data
- Hand-selected CME front and boundary

Next Steps:

- ➢ Implement on PUNCH flight data
- ➢ Create a baseline with a larger dataset of simulated CMEs
- ➢ Implement automated front and curvature detection

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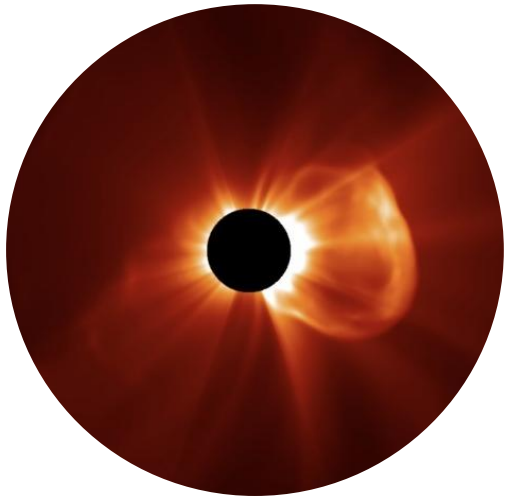
GO PUNCH!



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