PUNCH Polarization Diagnostics

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PUNCH 4

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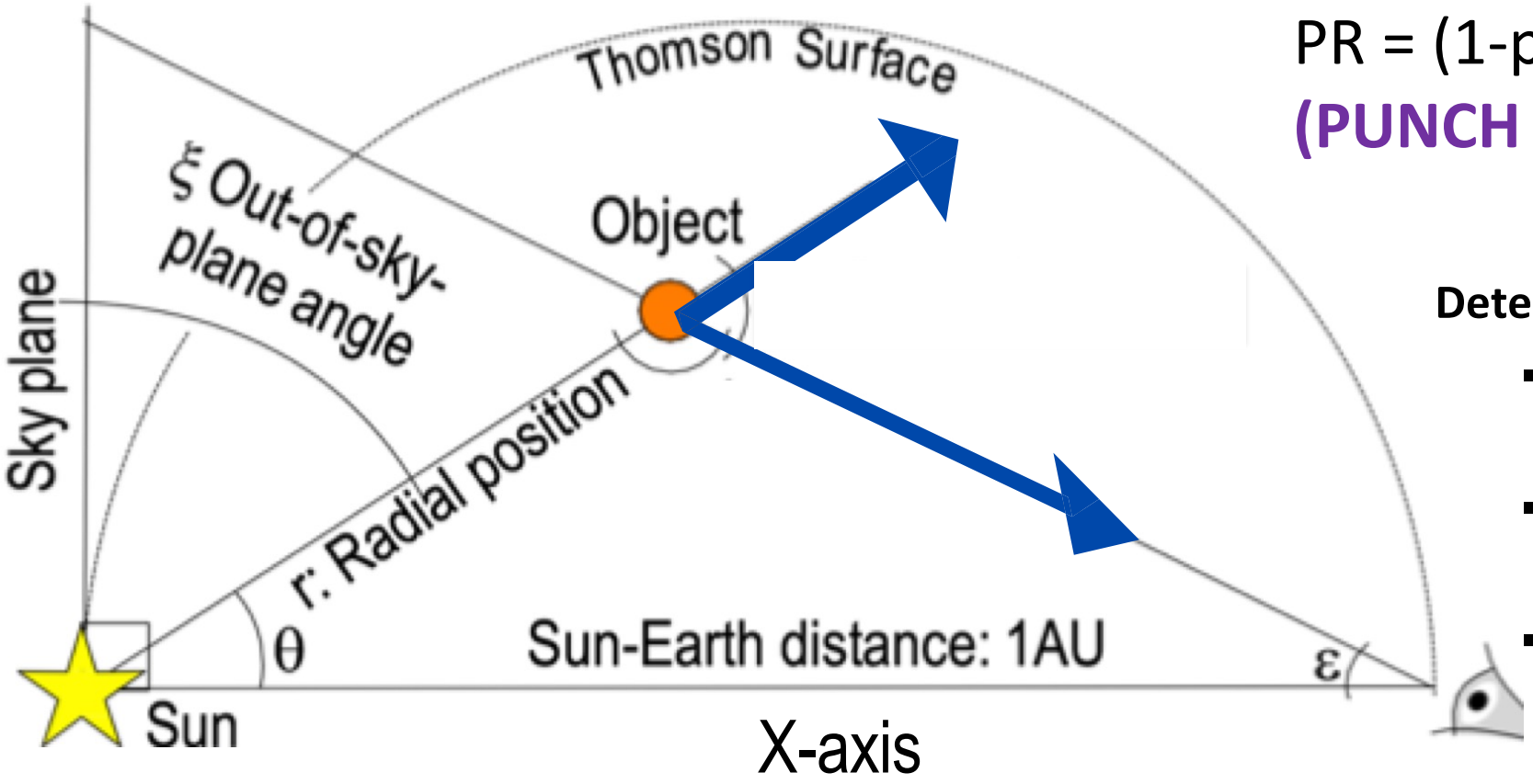
PUNCH polarization → 3D location of scatterer

- Scattering angle χ can be established from ***observed degree of polarization:***

$$PR = 1 - F(r) * \sin^2 \chi .$$



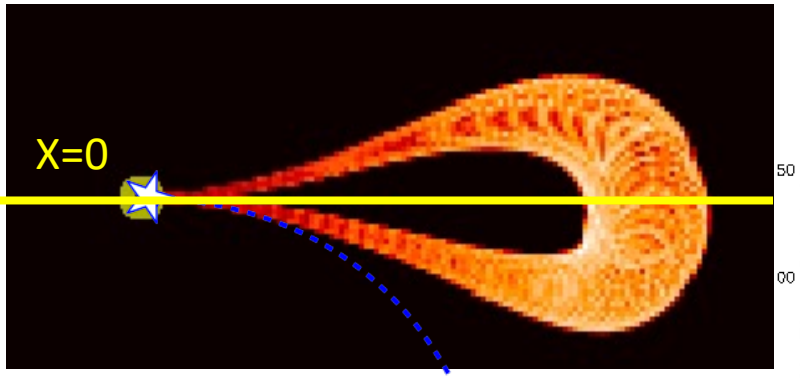
PR = (1-p)/1+p), where **p=pB/B**
(PUNCH observables!)

Determining position in 3D space:

- PR gives scattering angle **χ** for a localized structure like a CME front.
- Can solve for distance from X=0 plane, or distance along LOS from TS
- Position on projected sky plane gives the rest of the 3D position.

Polarization diagnostic of CME location and trajectory

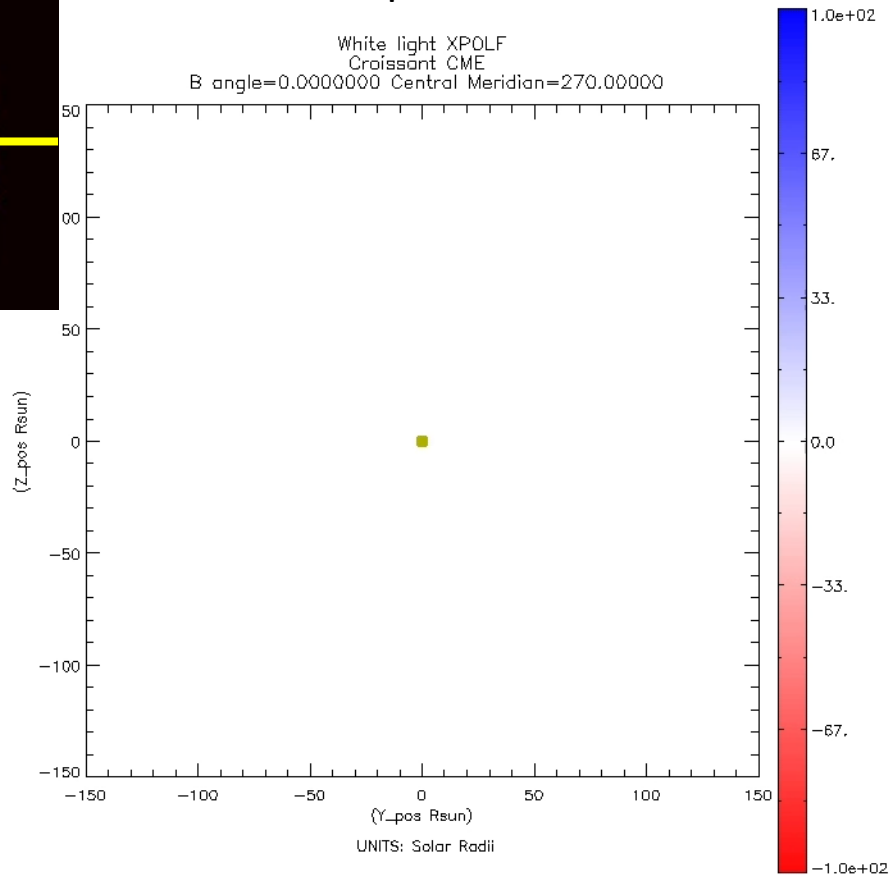
Twisted croissant model: *Thernisien 2011; Hutton & Morgan 2015; 2017* → FORWARD *Gibson et al. 2016*



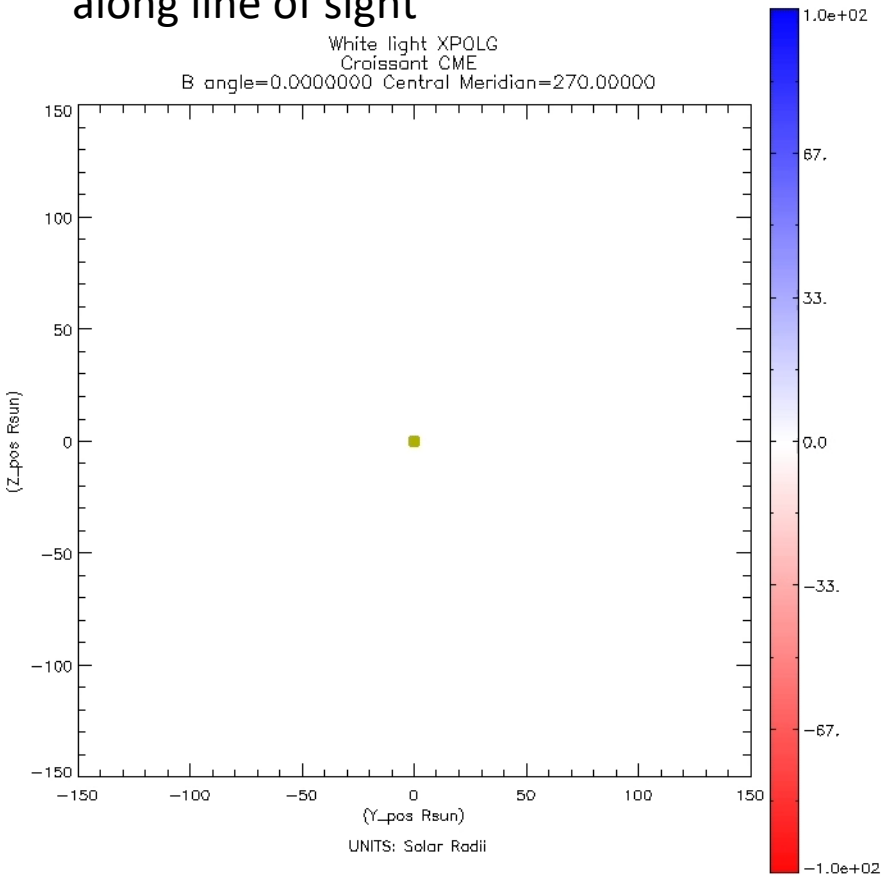
Ghost solution due to two possible solutions to $\chi \approx \arccos(\sqrt{PR})$ — equally spaced in Front and Back of the Thomson Surface (TS)

Thomson Surface

Position along line of sight (from X=0) inferred from polarization ratio FRONT



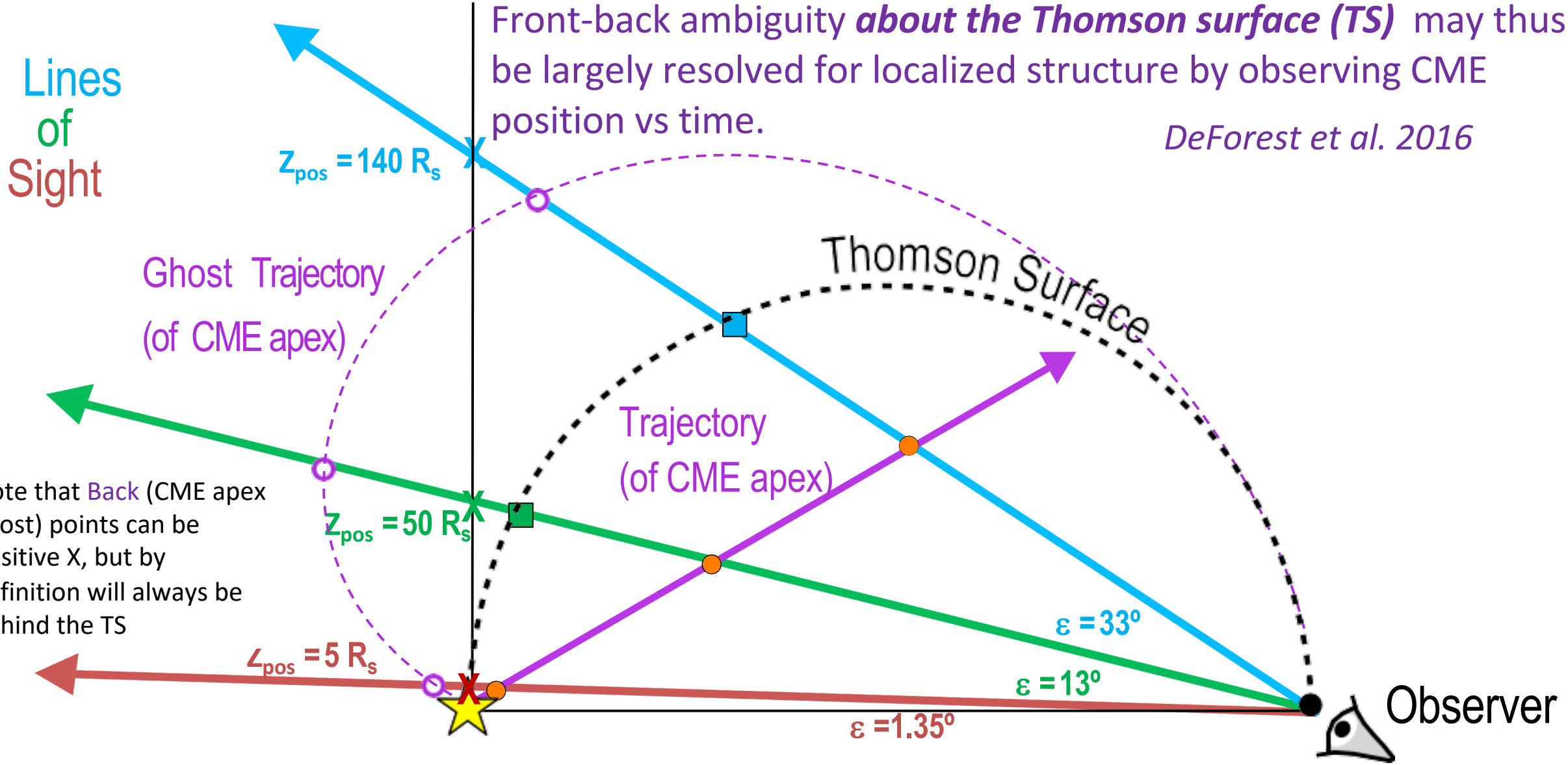
Ground truth position of center of mass along line of sight



Polarization diagnostic of CME location and trajectory

Front-back ambiguity ***about the Thomson surface (TS)*** may thus be largely resolved for localized structure by observing CME position vs time.

DeForest et al. 2016



Note that Back (CME apex ghost) points can be positive X, but by definition will always be behind the TS

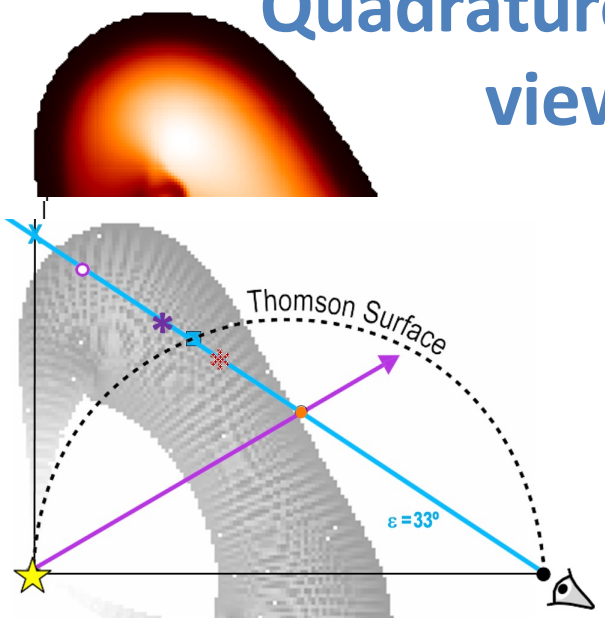
Polarization diagnostic of CME location and trajectory

Case 1: Earth-towards

Clues:

- Front solution stays positive X (blue) and all points get more positive with time. MOSTLY NOT GHOST.
- Back solution starts negative (red) but may become more positive with time, ultimately transitioning to positive X (blue). MOSTLY GHOST.

Quadrature view



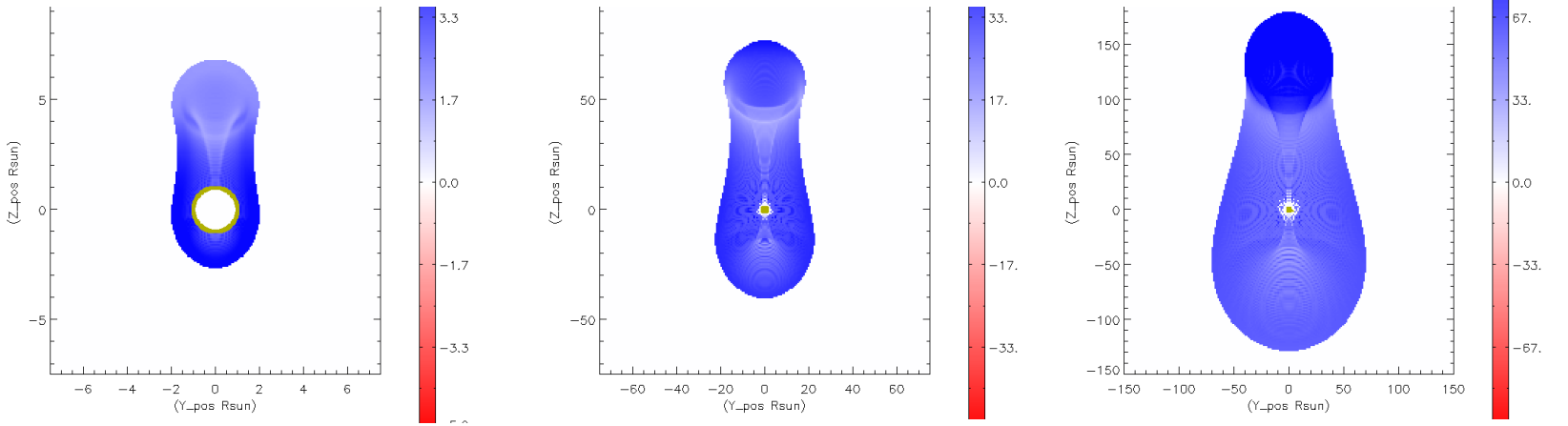
View from Earth

CME apex e =1.35º

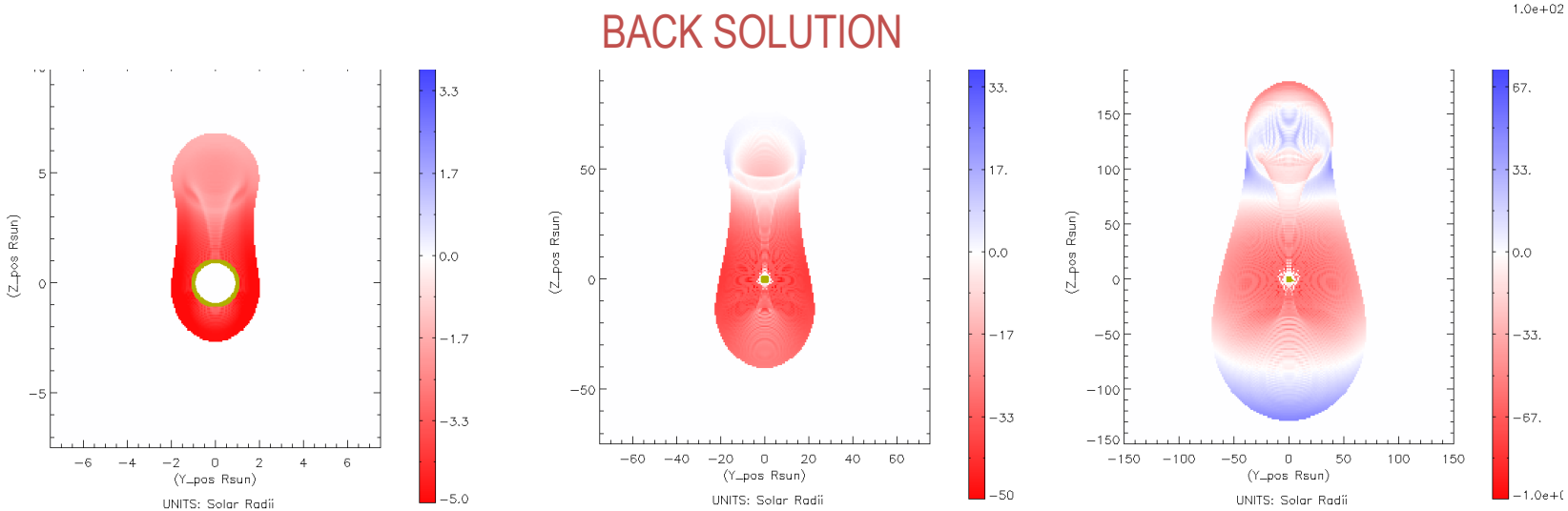
CME apex e =13º

CME apex e =33º

FRONT SOLUTION



BACK SOLUTION



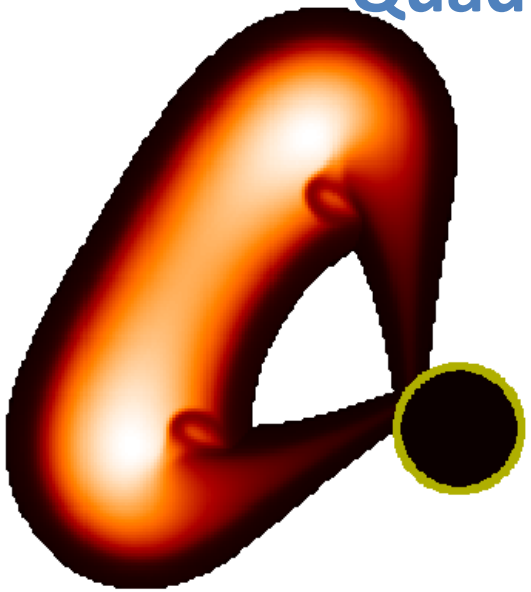
Polarization diagnostic of CME location and trajectory

Case 1: Earth-away

Clues:

- Back solution stays negative (blue) the whole time but all points get more negative with time. NEVER GHOST.
- Front solution stays positive (red) the whole time and all points get more positive with time. ALYWAYS GHOST.

Quadrature view



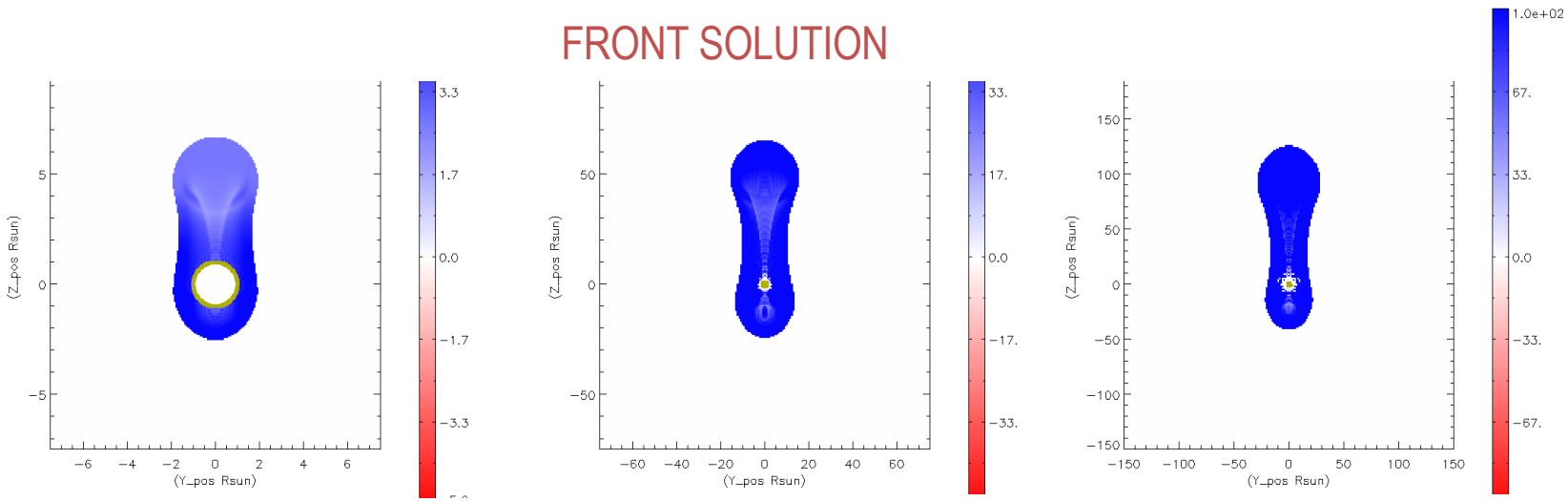
View from Earth

CME apex e =1.35º

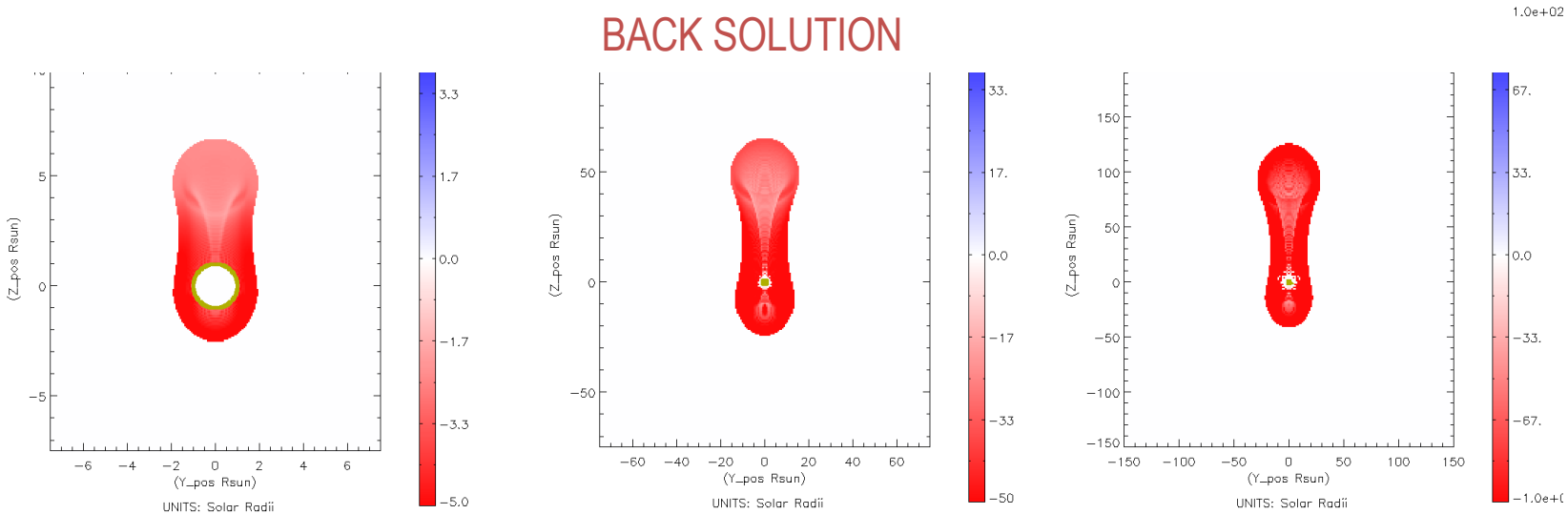
CME apex e =13º

CME apex e =33º

FRONT SOLUTION

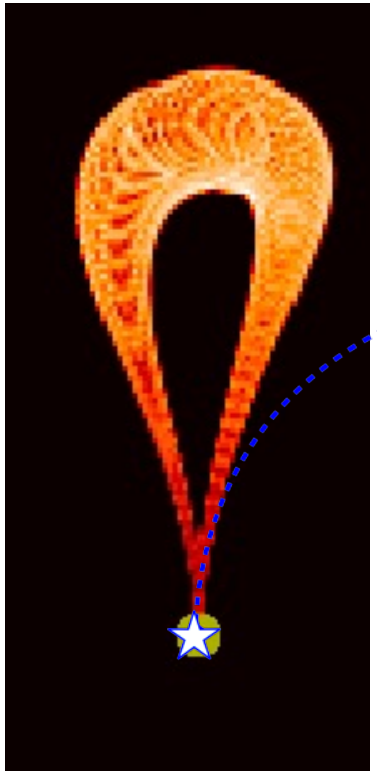


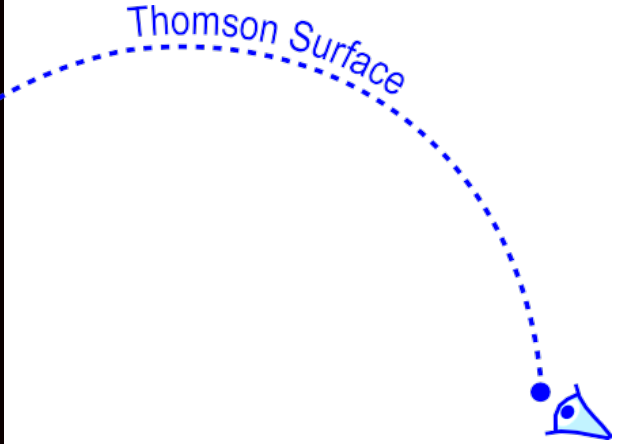
BACK SOLUTION



Polarization diagnostic of background solar wind

Twisted croissant model: *Thernisien 2011; Hutton & Morgan 2015; 2017* **+ density power law background** → FORWARD *Gibson et al. 2016*

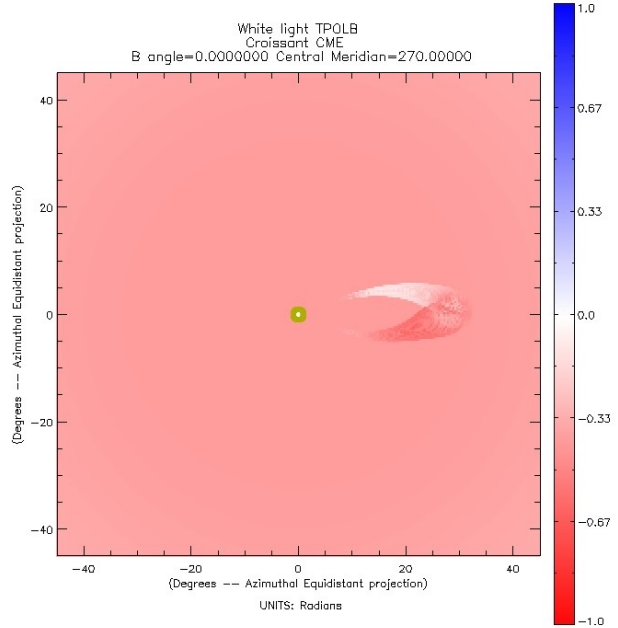




Ground truth position along line of sight (distance from Thomson Sphere)

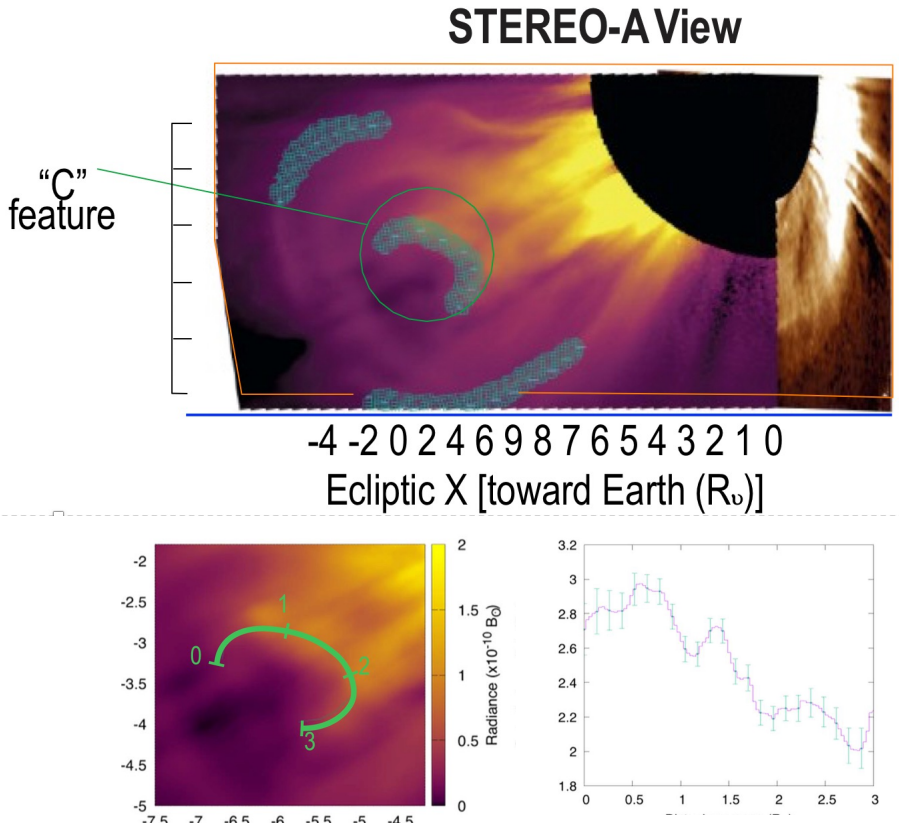
Position along line of sight inferred from polarization ratio

Polarization ratio for croissant + background

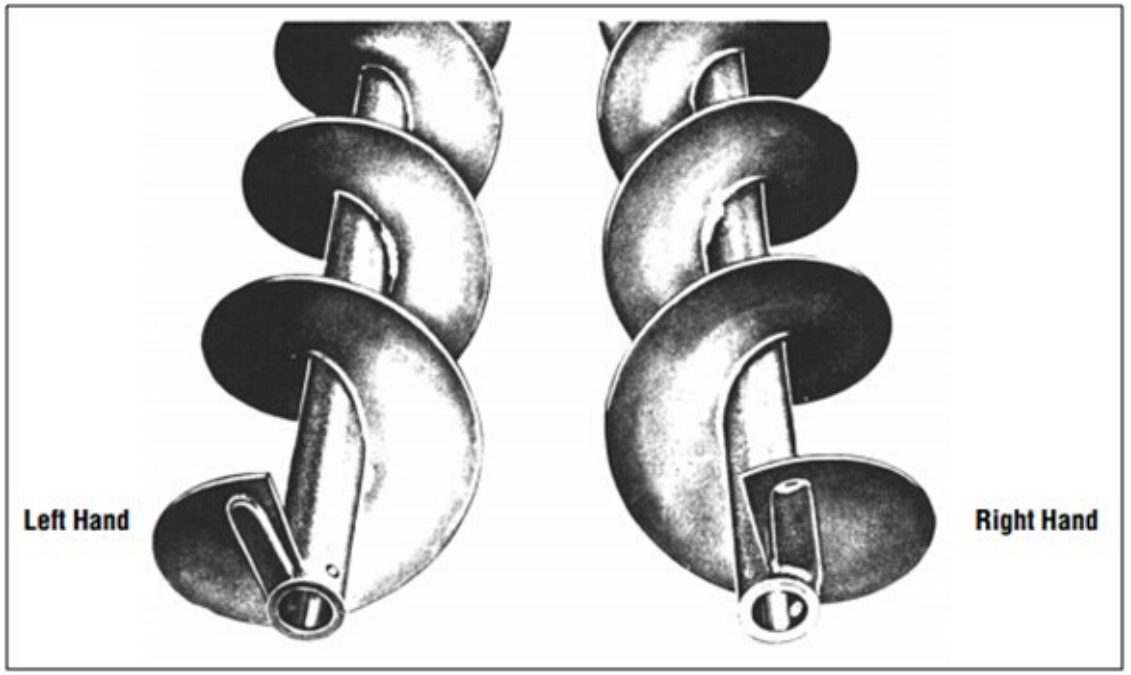


Measuring chiral structure and predicting Bz

Flux rope chirality: Polarization provides 3D position of features; Direction of rotation back to front yields chirality. *Deforest et al. 2017*



Counterclockwise back to front: right-hand twist.



Left-hand chirality: clockwise back to front

Right-hand chirality: counterclockwise back to front

Measuring chiral structure and predicting Bz

Twisted croissant CME model *(Morgan, 2015; 2016)*.

Ground truth position

Polarization sol'n

CME axis center = 5 R_{sun})

Twisted croissant
Earth-toward (oblique)
View from Earth

Clockwise rotation back to front: ***left-handed flux rope.***

Ground truth position

Polarization sol'n

CME axis center = 50 R_{sun})

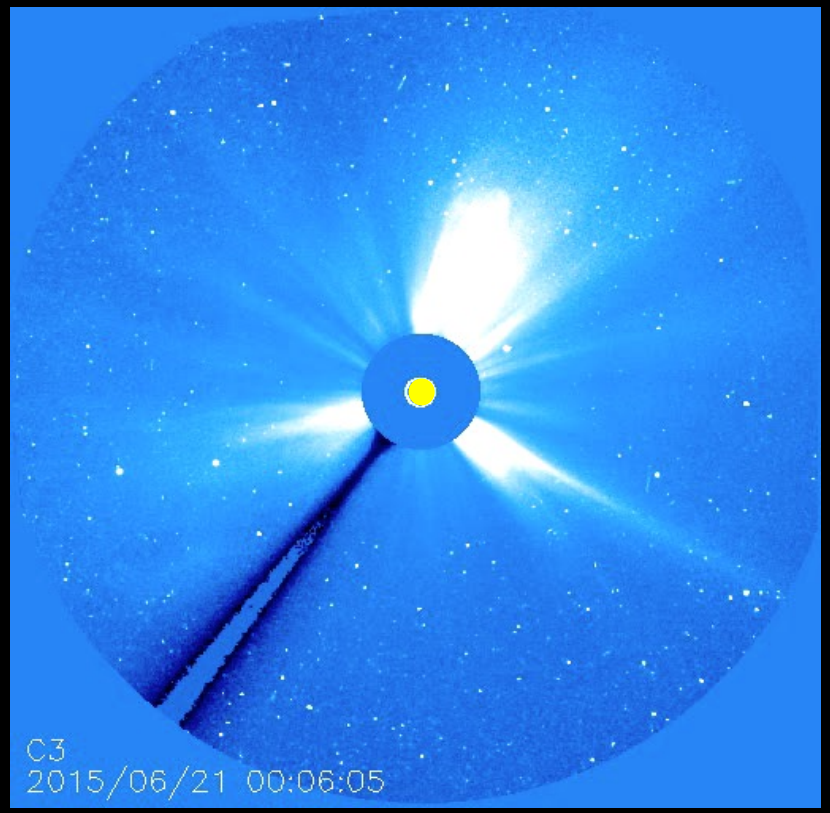
Conclusions

- The 3D position center-of-mass position of the CME is well captured using polarization analysis.
- Ambiguity of whether Front vs Back solutions apply can be dealt with by observing time series, obtaining a localized trajectory for localized sources.
- PUNCH polarization presents a tool for distinguishing between left-handed and right-handed CME flux ropes, which when coupled with magnetic polarity information of the CME source predicts Bz.
- PUNCH polarization can diagnose the power-law fall-off of the background solar wind!

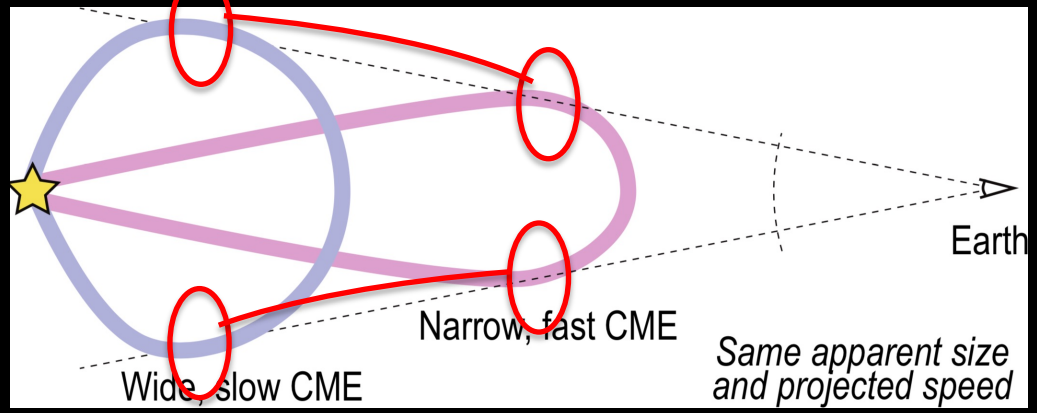
EXTRA SLIDES

PUNCH tracks space weather events in 3D

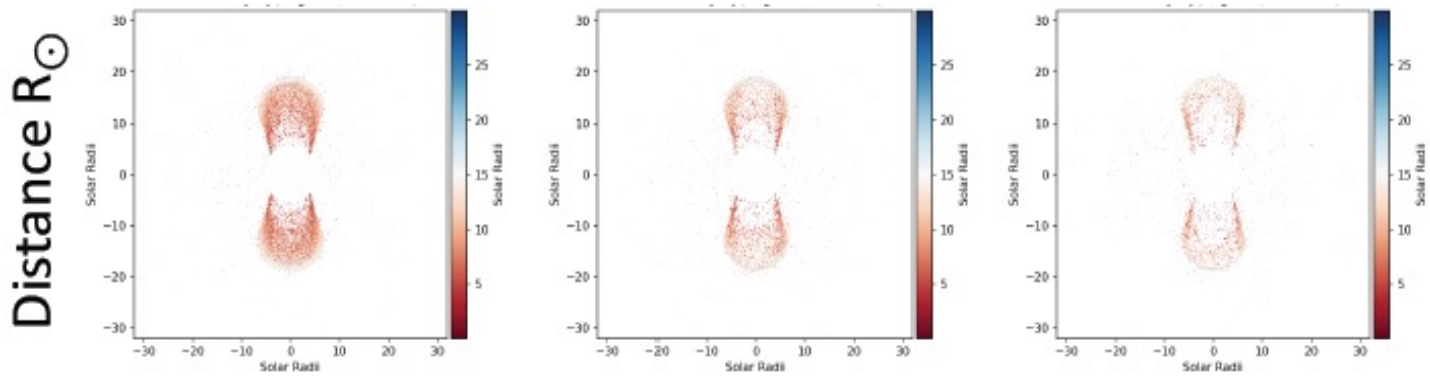
SOHO/LASCO C3 coronagraph (matches inner PUNCH FOV)



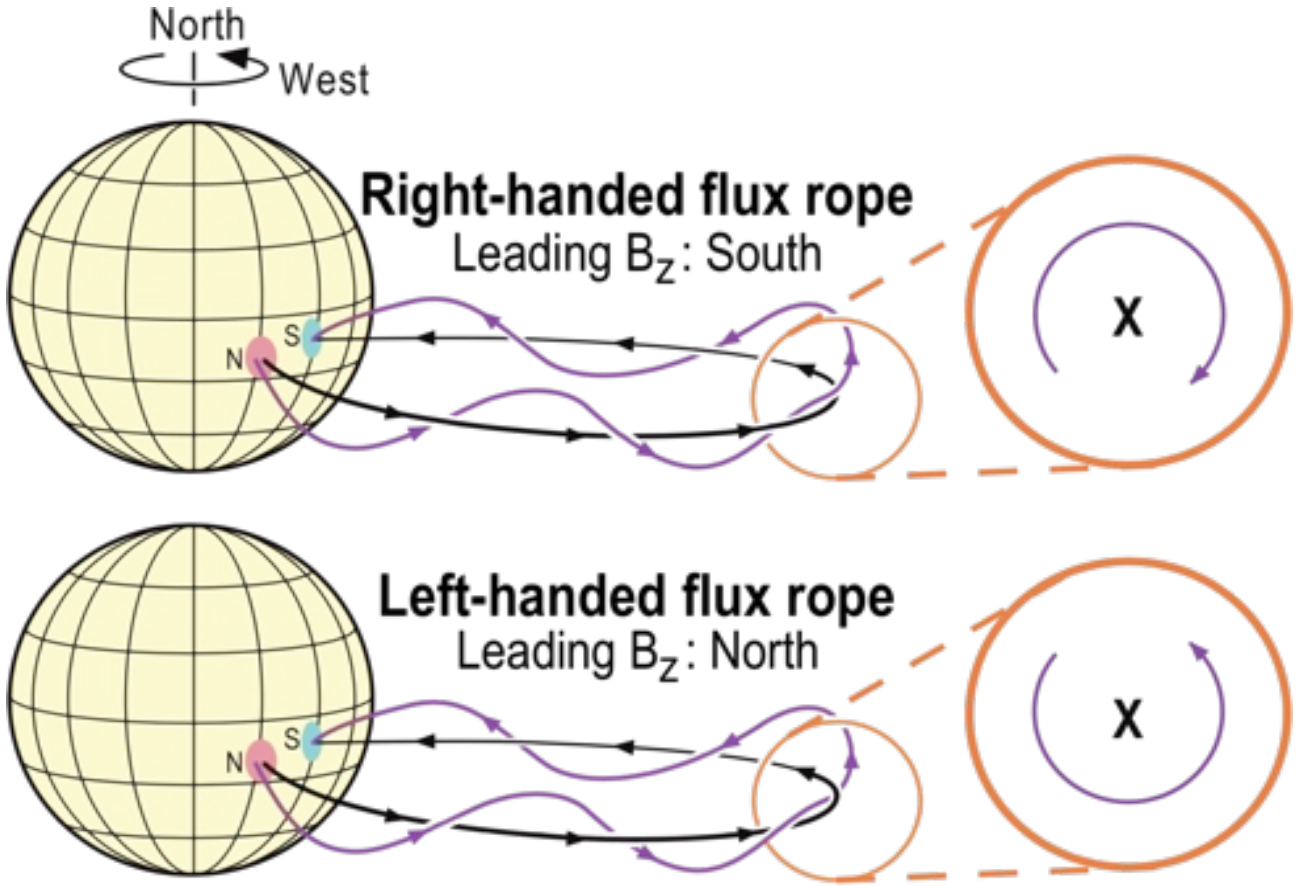
Coronal mass ejection 3D trajectory tracking improves understanding of space weather.

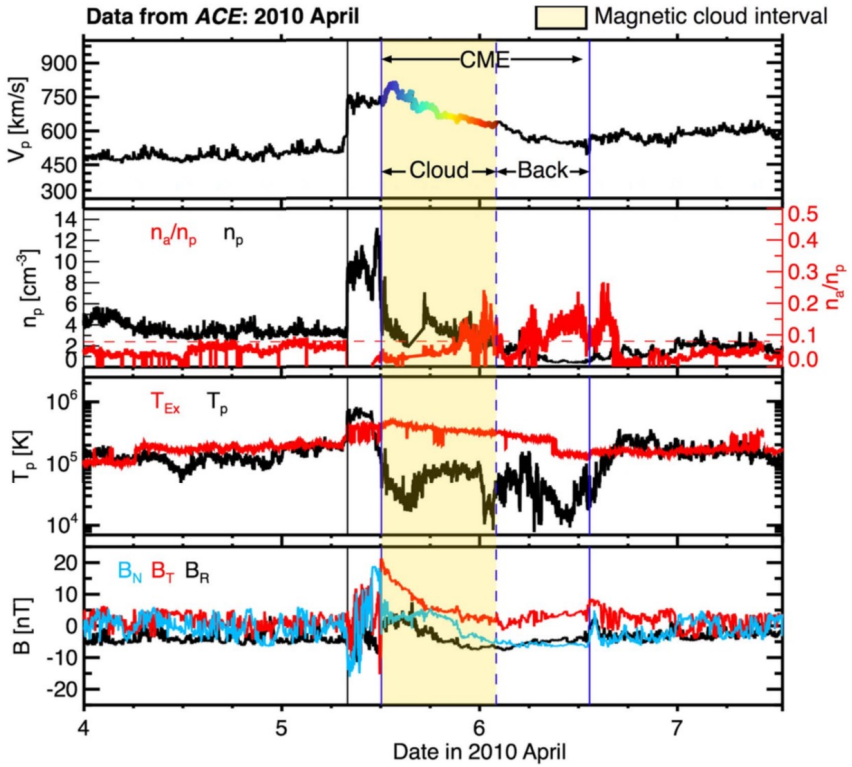


Noised distance from PUNCH polarization ratio



Measuring chiral structure and predicting Bz



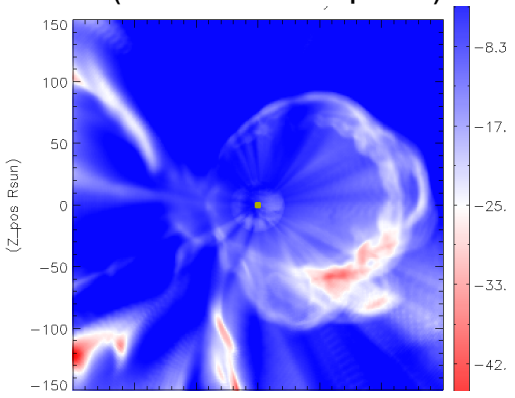


PUNCH 3D measurements of CME core chirality are the “missing link” between photospheric magnetograms and forecasts of leading-edge B_z (which indicates geoeffectiveness).

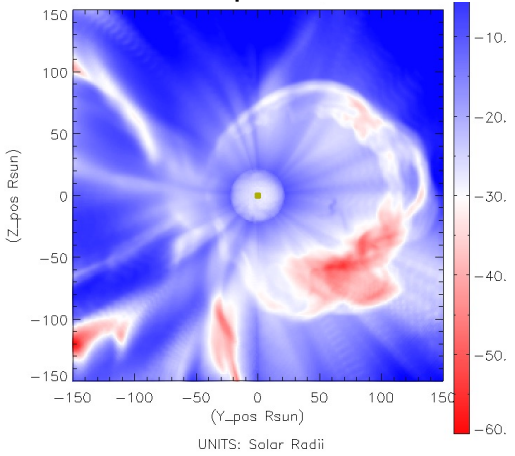
Polarization diagnostic of CMEs in the solar wind

Gamera MHD solar wind (driven by WSA-Gibson&Low solar inputs) → FORWARD

Ground truth from model:
position of density center of mass
(relative to X=0 plane)

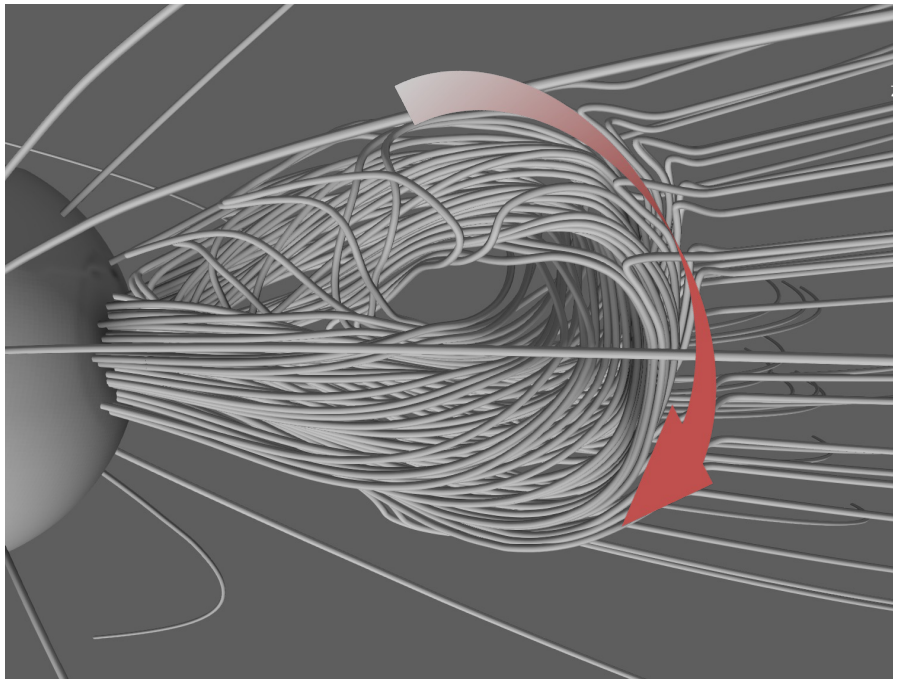


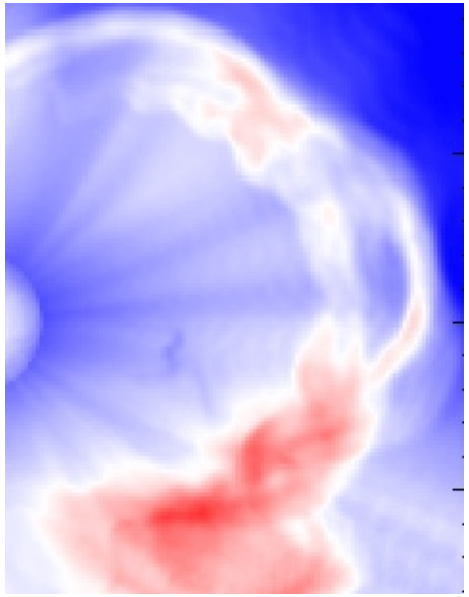
Position from polarization ratio



Even without subtracting off the background, polarization ratio captures the 3D position of the CME substructure well

Interpreting chirality will require 3D analysis

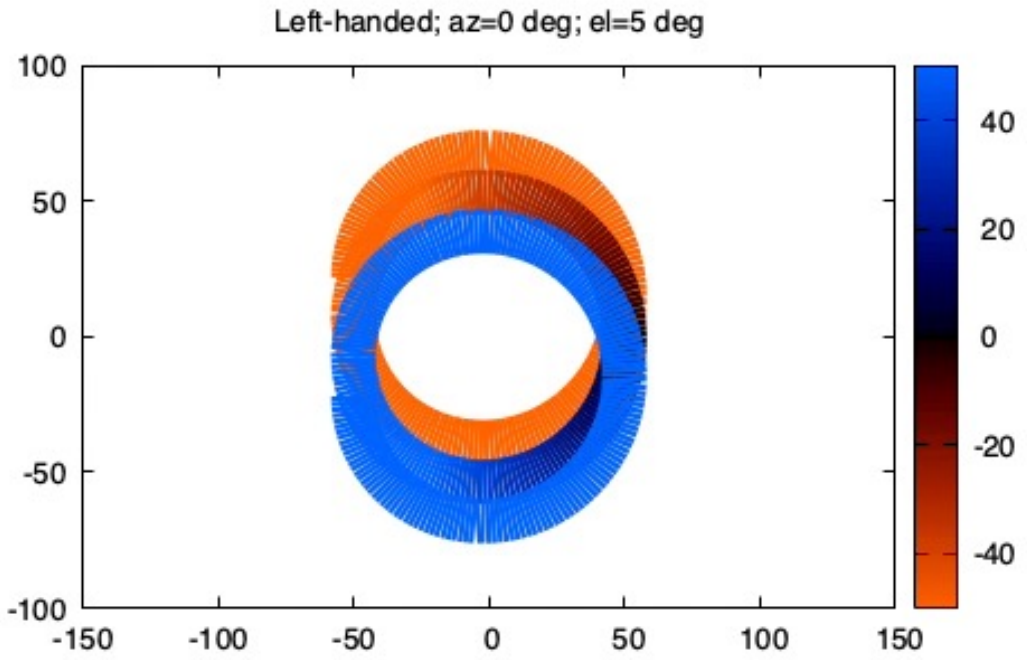


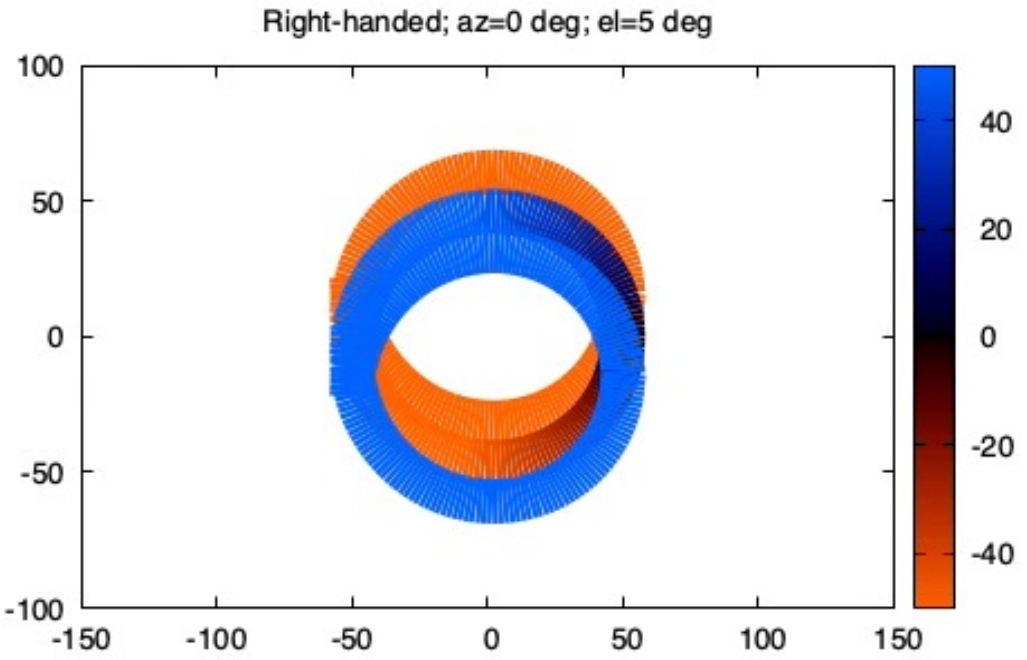


Using polarization data to diagnose chirality

Left-hand chirality: clockwise back to front (red to blue)

Right-hand chirality: counterclockwise back to front (red to blue)



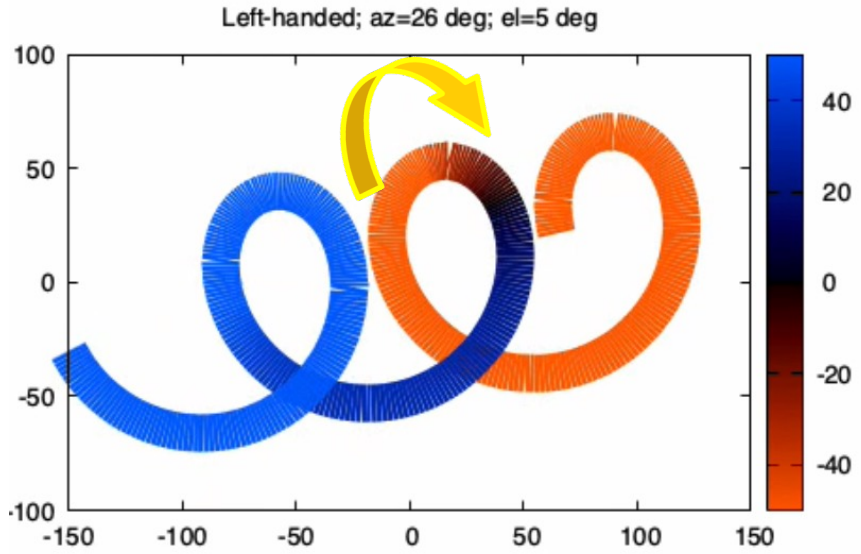


Using polarization data to diagnose chirality

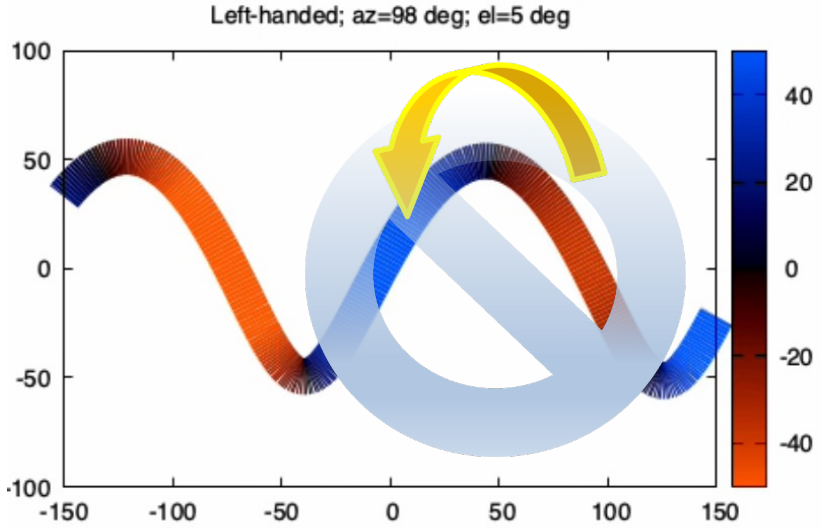
Left-hand chirality: clockwise back to front (red to blue)

3D structure can be rotated, resolving ambiguity.

Oblique view: circulation clear



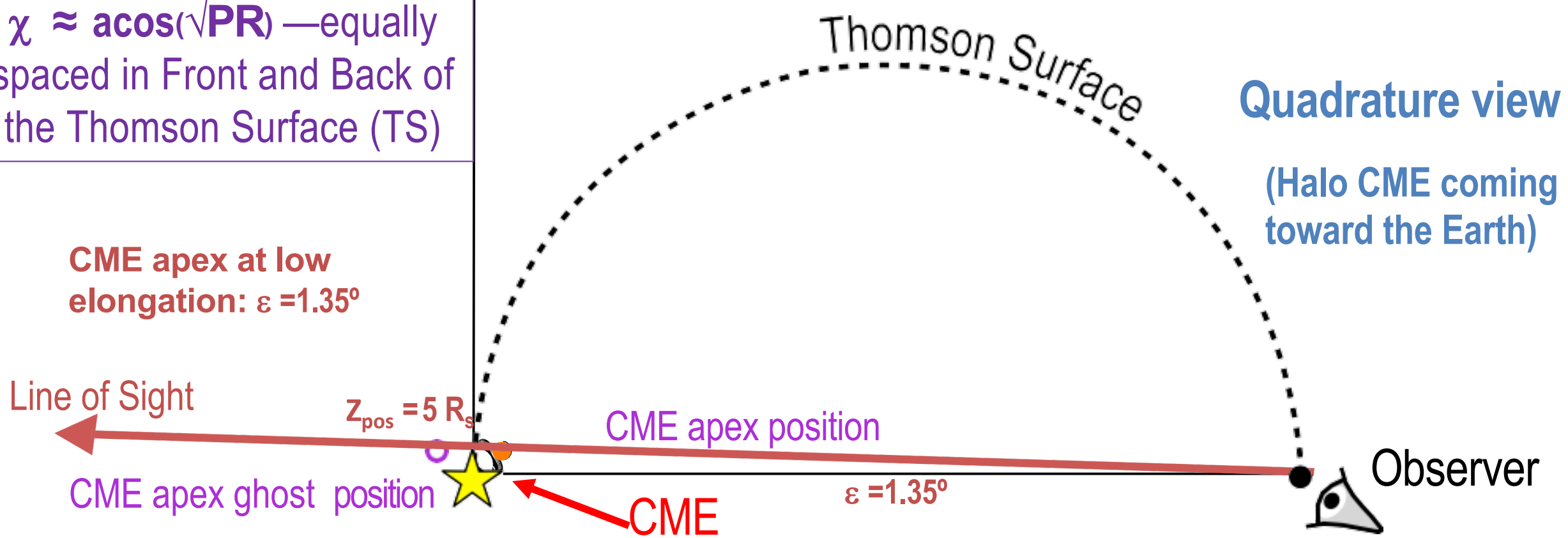
Perpendicular to axis: Misleading!!!!



Polarization diagnostic of CME trajectory

Lines of sight pass through the near and far sides of the shell of the croissant. The polarization ratio can diagnose the position of the center of mass between these localized structures (DeForest et al., 2017)

Ghost solution due to two possible solutions to $\chi \approx \mathbf{acos}(\sqrt{\mathbf{PR}})$ —equally spaced in Front and Back of the Thomson Surface (TS)

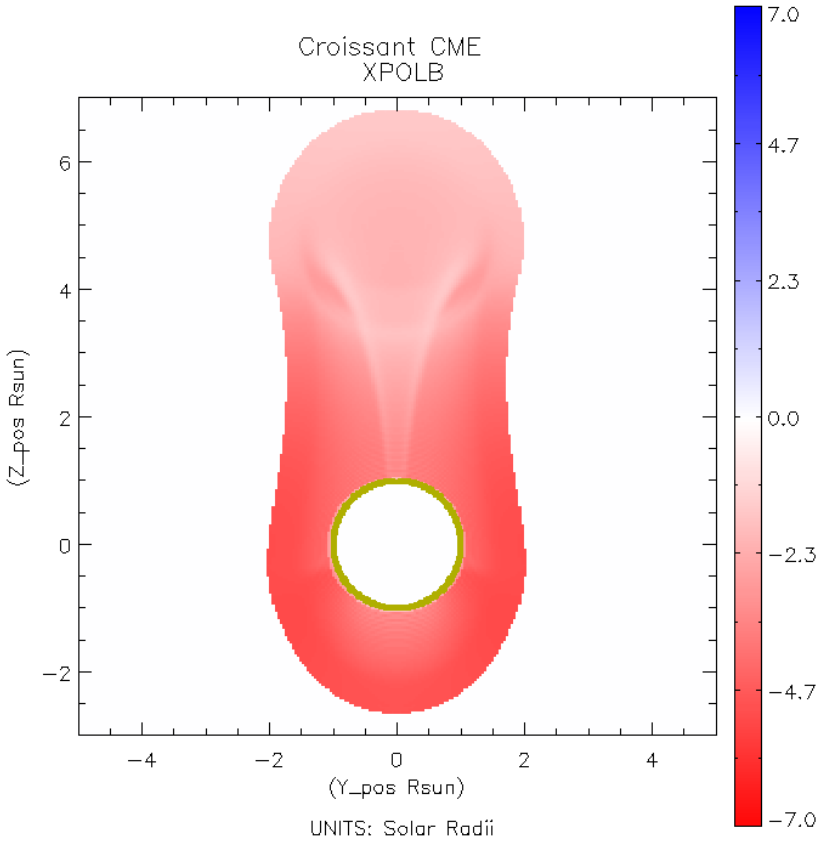


Polarization diagnostic of CME trajectory

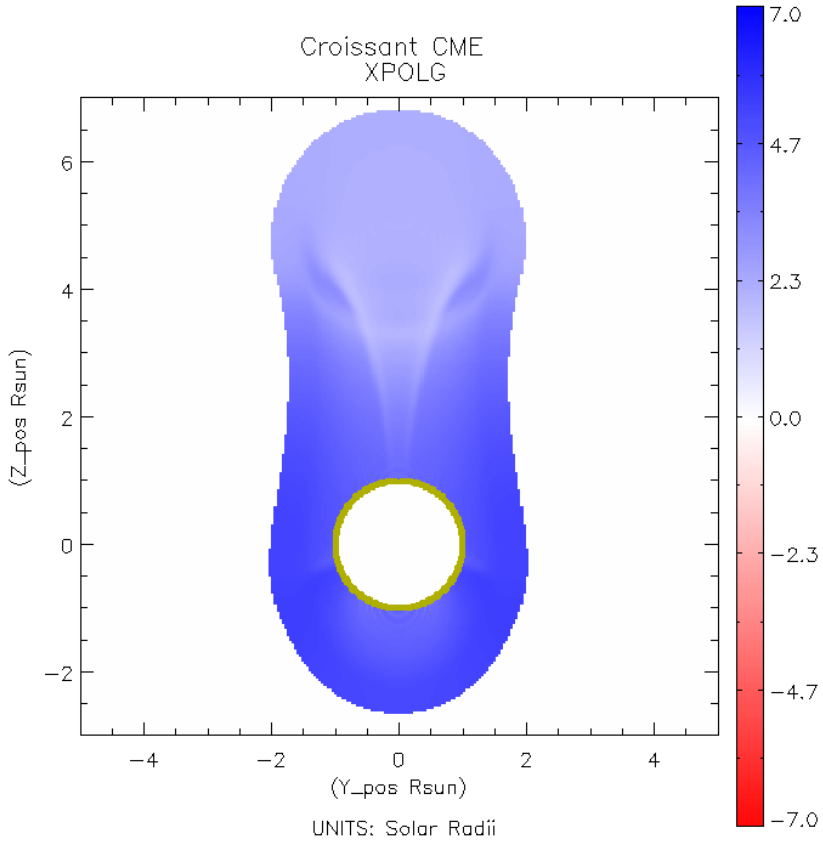
If CME is earth-directed, LOS-integrated polarization ratio from Front solution accurately reproduces ground truth center-of-mass position in 3D ***for low elongations.***

View from Earth: ε =1.35°

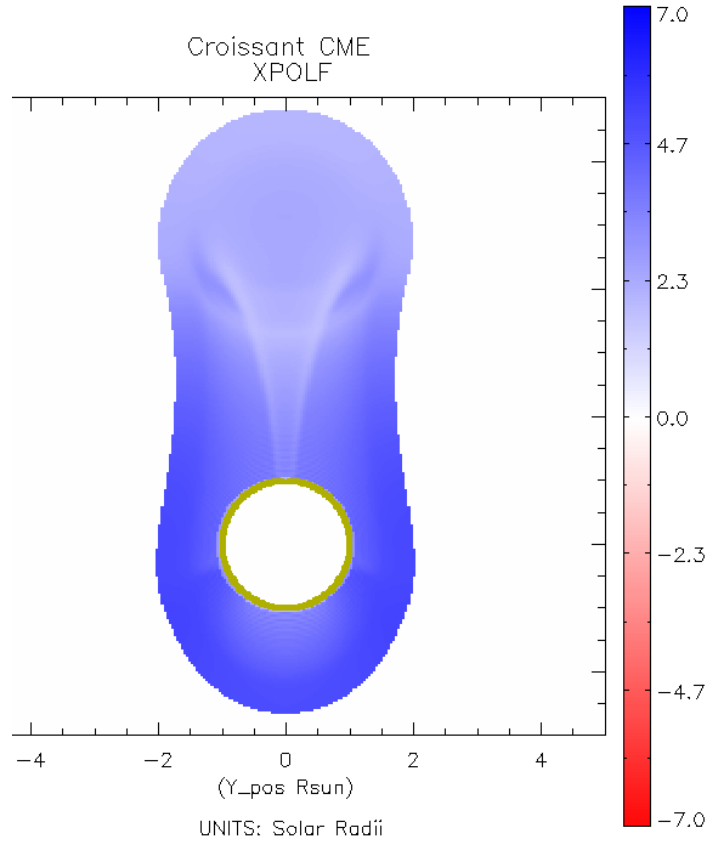
Position from polarization ratio: Back (ghost) solution



Ground truth from model: position of density center of mass

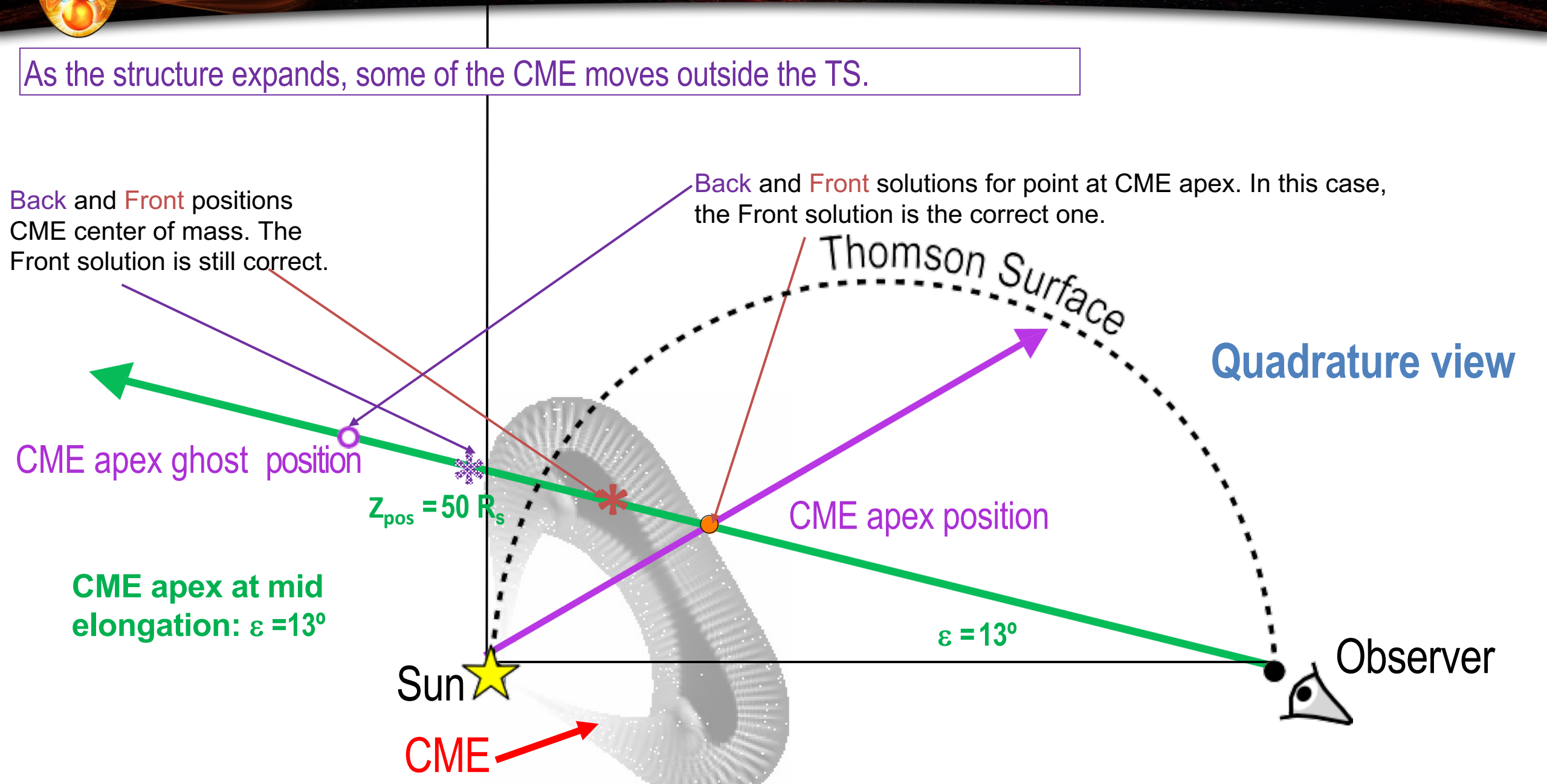


Position from polarization ratio: Front solution



Polarization diagnostic of CME trajectory

As the structure expands, some of the CME moves outside the TS.

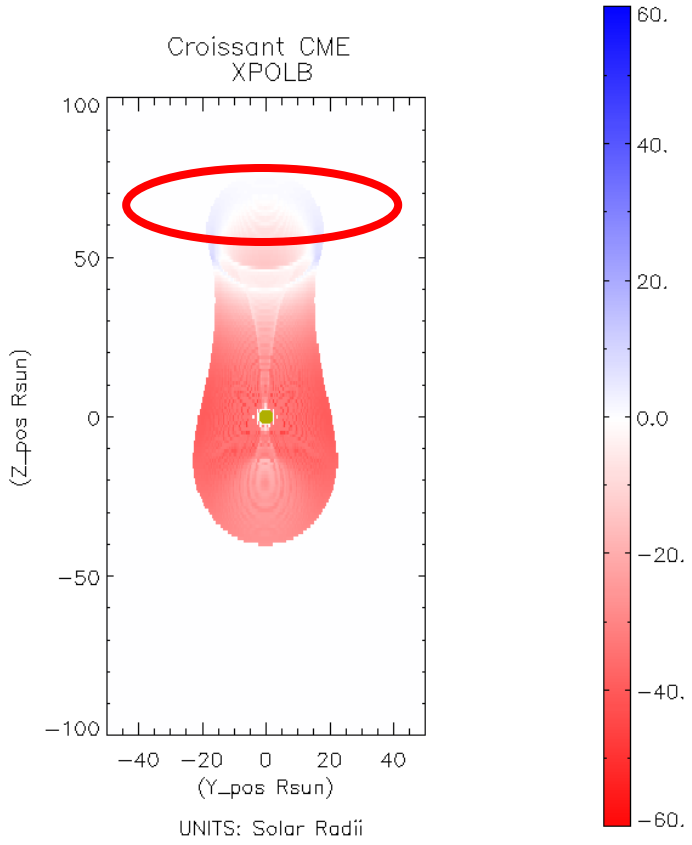


Polarization diagnostic of CME trajectory

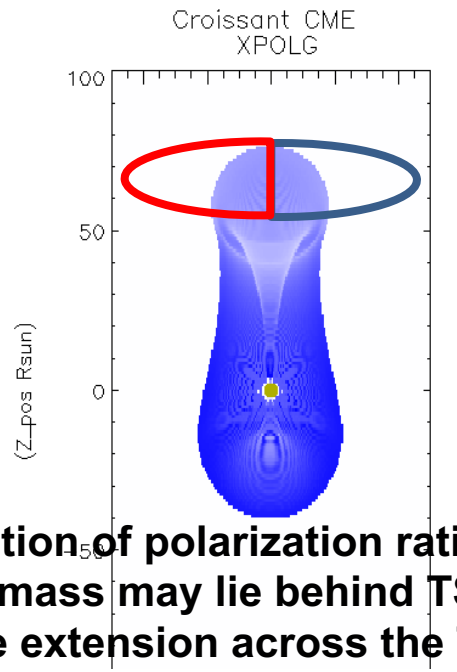
As the structure expands, some of the CME moves outside the TS. For such points, the Back solution shifts to positive X (blue).

View from Earth: ε =13°

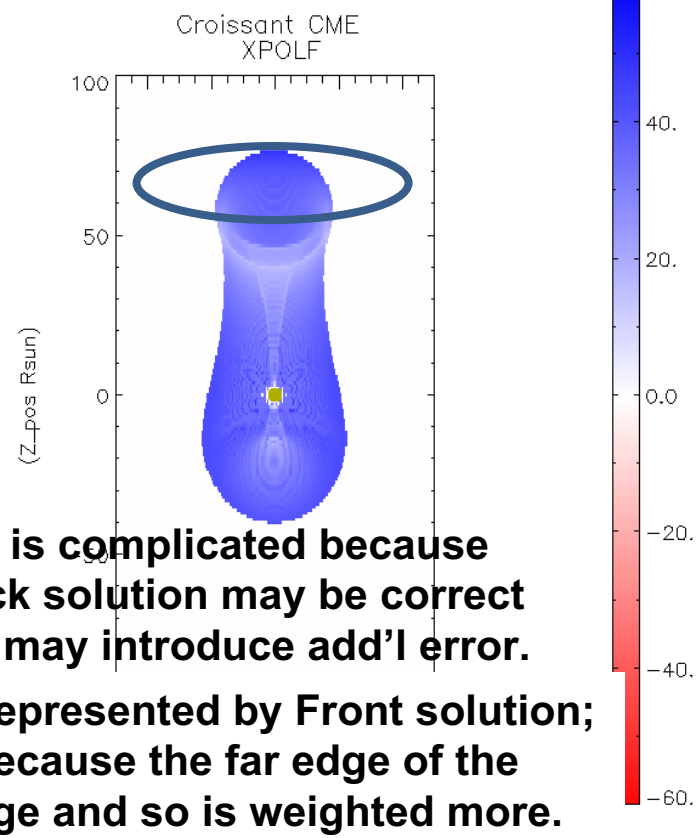
Position from polarization ratio: Back (mostly ghost) solution



Ground truth from model: position of density center of mass



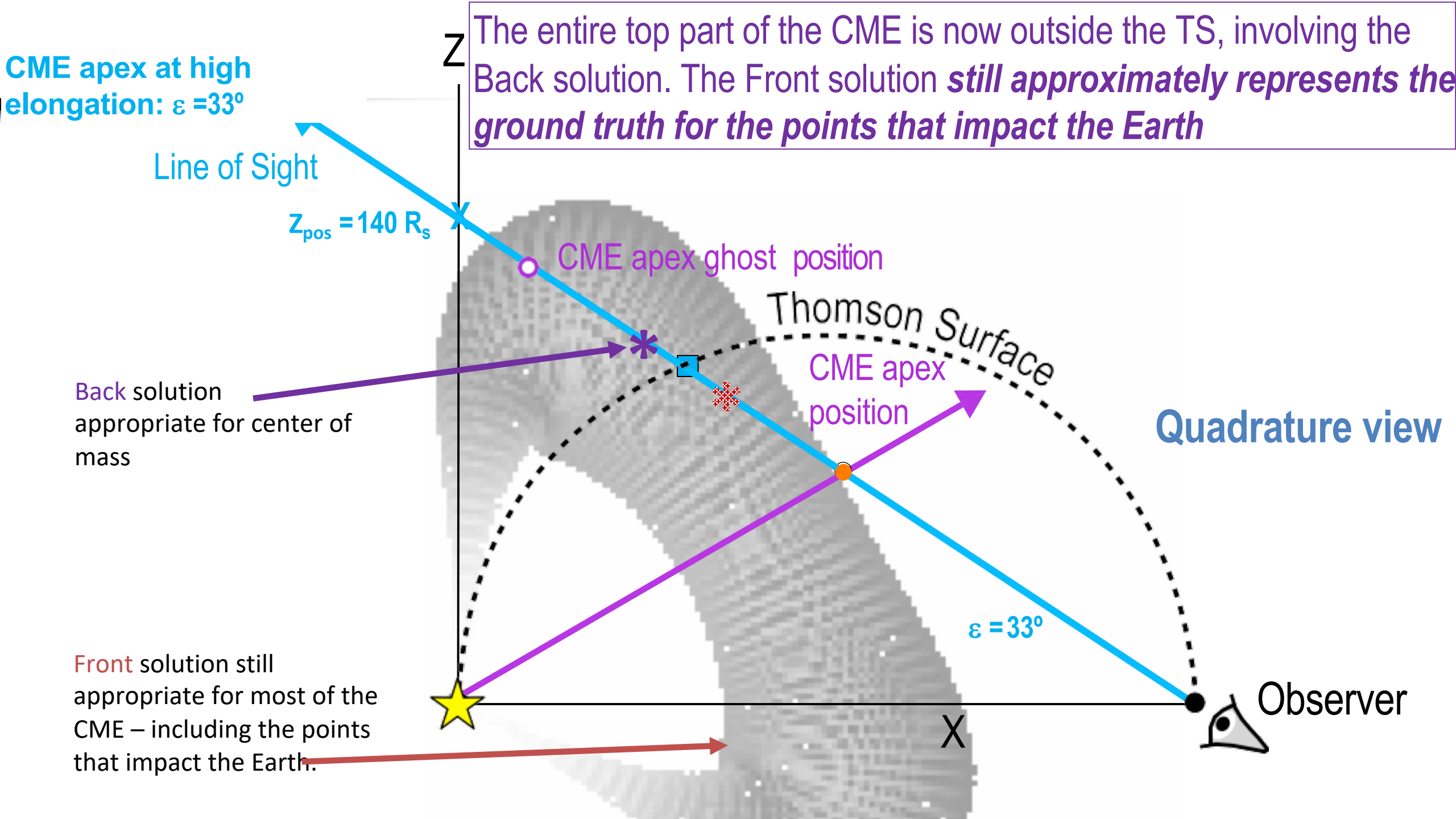
Position from polarization ratio: Front solution



Interpretation of polarization ratio at CME top is complicated because center of mass may lie behind TS, and so Back solution may be correct there. The extension across the TS boundary may introduce add'l error.

Points at center and bottom of CME are still represented by Front solution; their distance is somewhat underestimated because the far edge of the croissant is closer to the TS than the near edge and so is weighted more.

The entire top part of the CME is now outside the TS, involving the Back solution. The Front solution ***still approximately represents the ground truth for the points that impact the Earth***



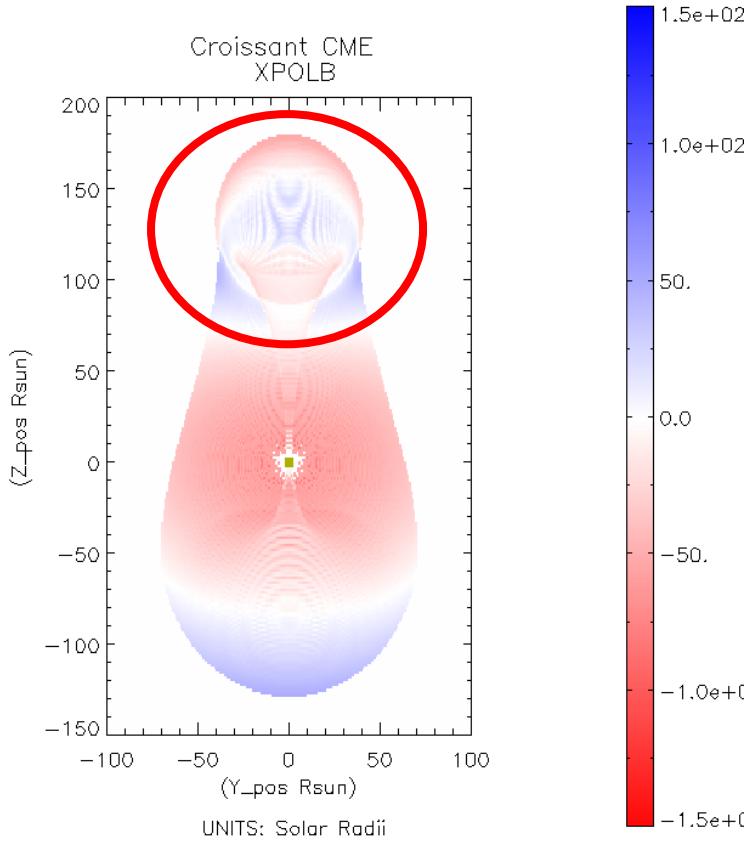
CME apex at mid elongation: ε =33°

View from Earth

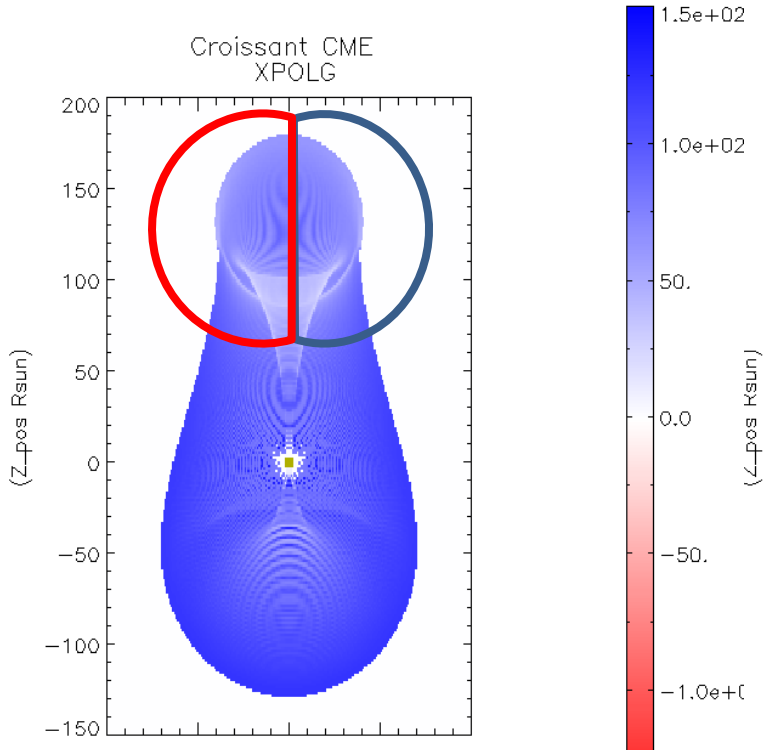
The entire top part of the CME is now outside the TS, involving the Back solution. The Front solution ***still approximately represents the ground truth for the points that impact the Earth***

FORWARD-modeled croissant CME (source=0° longitude, 60° colatitude, width=1, angular_extent=4; CME axis center = 100 R_{sun})

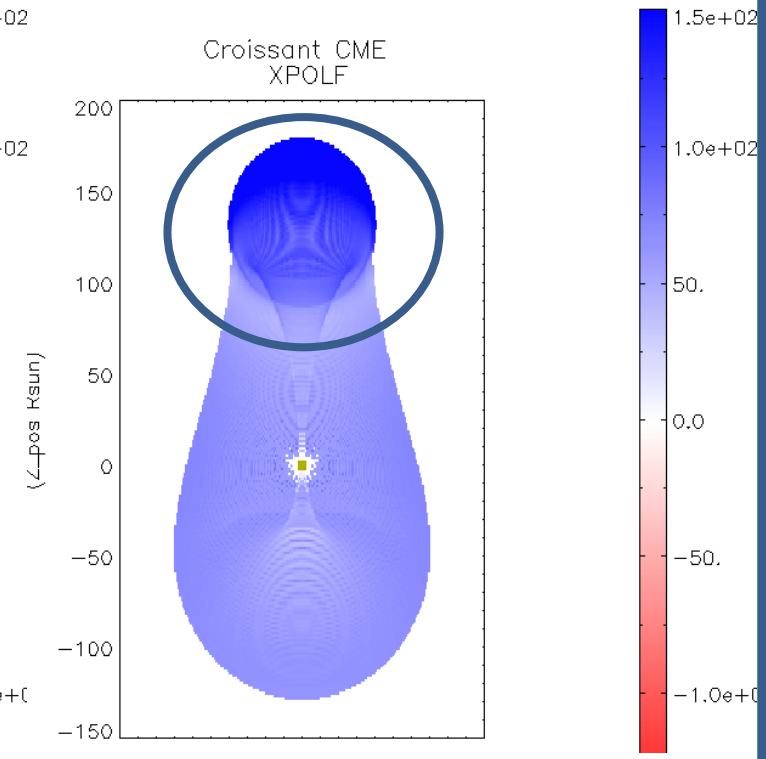
Position from polarization ratio: Back solution



Ground truth from model: position of density center of mass



Position from polarization ratio: Front solution



Top region LOS intersect both Back and Front solutions. Points at center & bottom still represented by Front but biased by far edge proximity to TS.