Tracking CME substructure evolution through the solar wind

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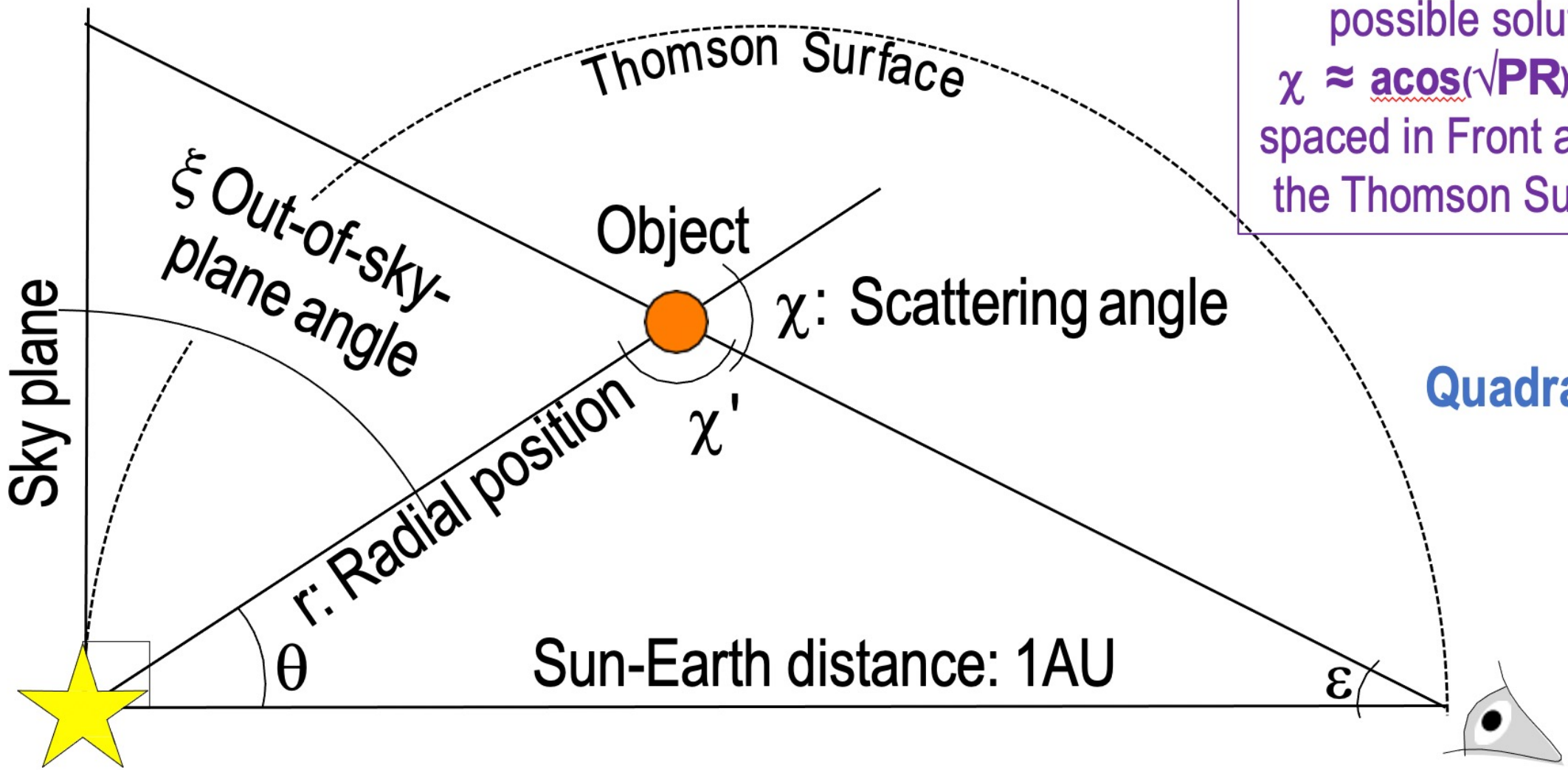
Polarization gives scattering angle χ elongation angle ε is observed.
Out-of-sky angle is then: $\xi = 90° - \theta = -90 + \varepsilon + \chi'$
From Law of Sines radial position of object: $r = (1\ AU)(\sin \varepsilon / \sin \chi')$.

3D position of object: Y, Z from sky-plane projection, X = r cos θ

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



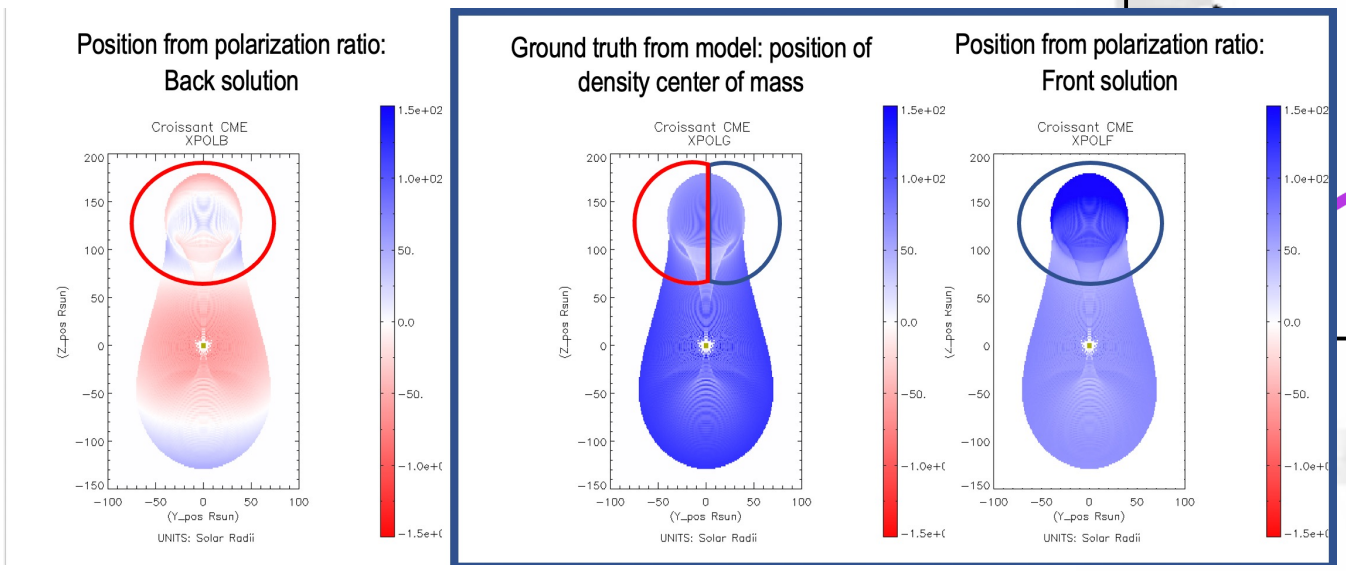
Quadrature view

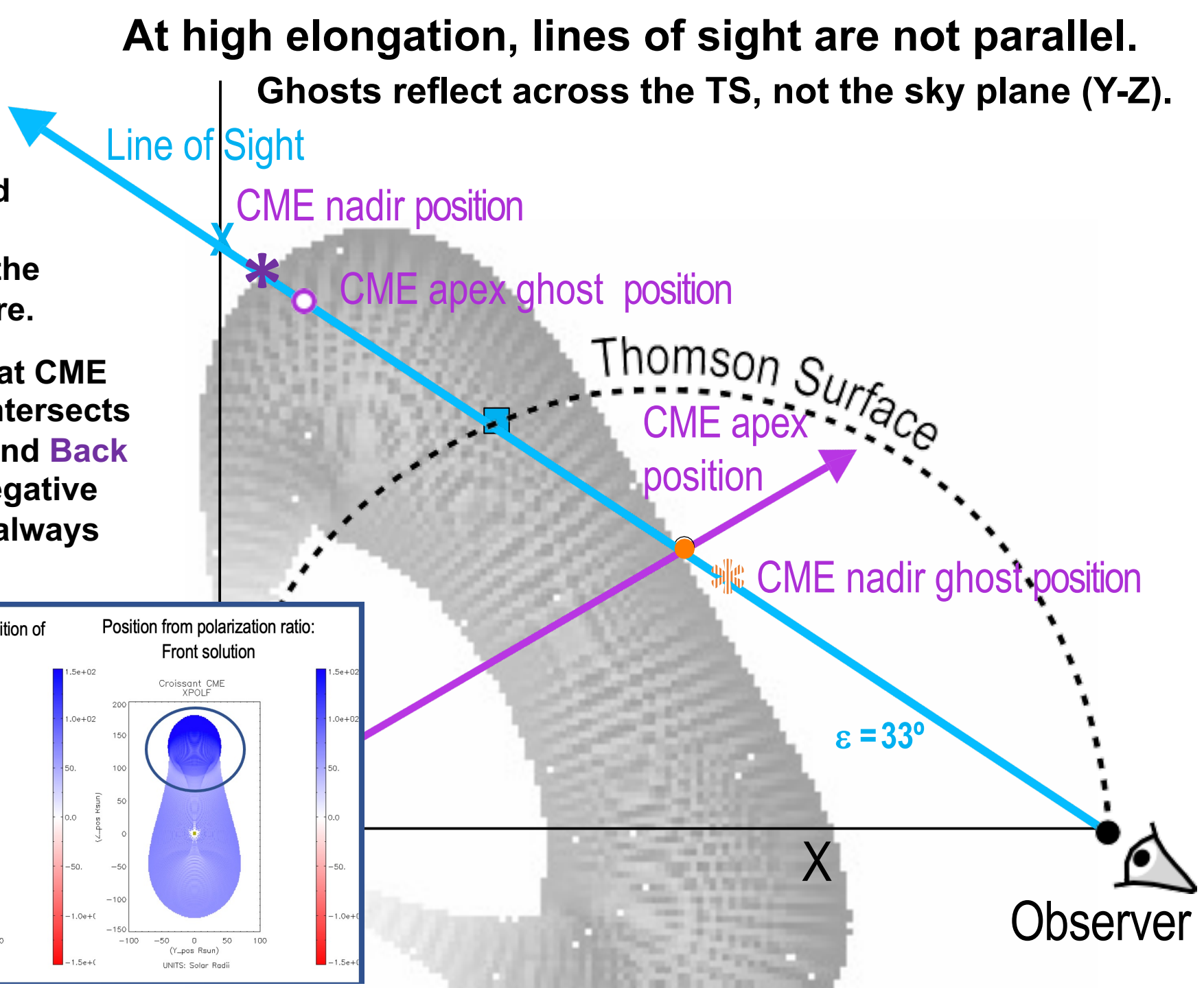
The Front solution is still the real (non-ghost) solution at center and bottom of CME, but the center-of-mass distance (X) from the sky plane is somewhat underestimated because the inner edge of the croissant is closer to the TS than the outer edge and so is weighted more.

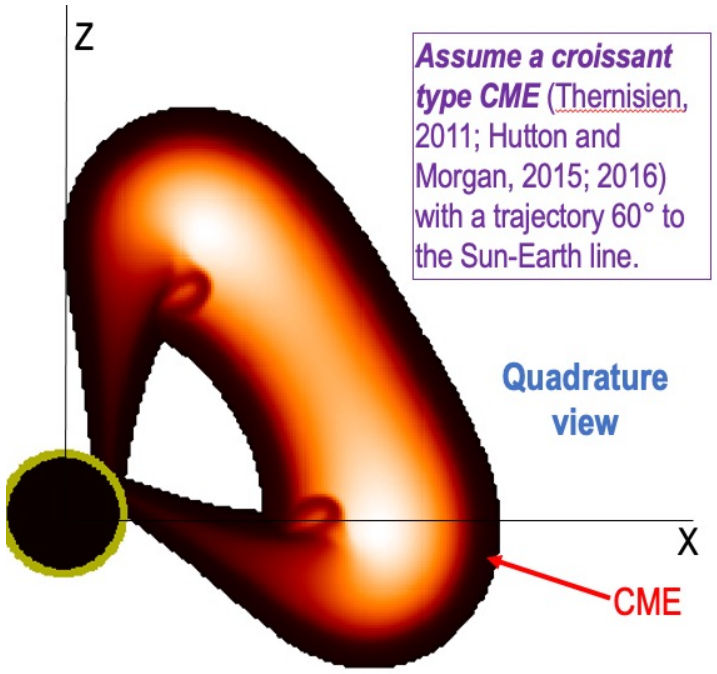
Interpretation of polarization ratio at CME top is complicated because LOS intersects material on both sides of the TS. And Back ghosts can be either positive or negative X, although by definition they will always be outside the TS.

At high elongation, lines of sight are not parallel.

Ghosts reflect across the TS, not the sky plane (Y-Z).







Introduces non-localization in a simple way:

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

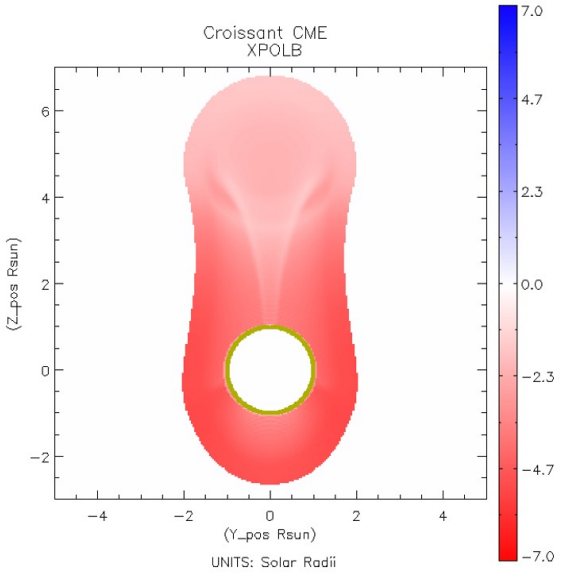
CME apex at low elongation: ε =1.35°

View from Earth

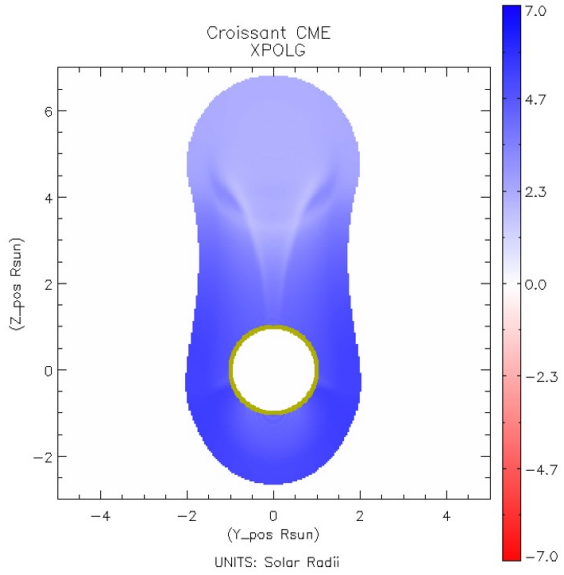
If CME is earth-directed, LOS-integrated polarization ratio from Front solution accurately reproduces ground truth center-of-mass position in 3D ***for low elongations.***

FORWARD-modeled croissant CME (source=0° longitude, 60° colatitude, width=1, angular extent=4; CME axis center = 5 R_{sun})

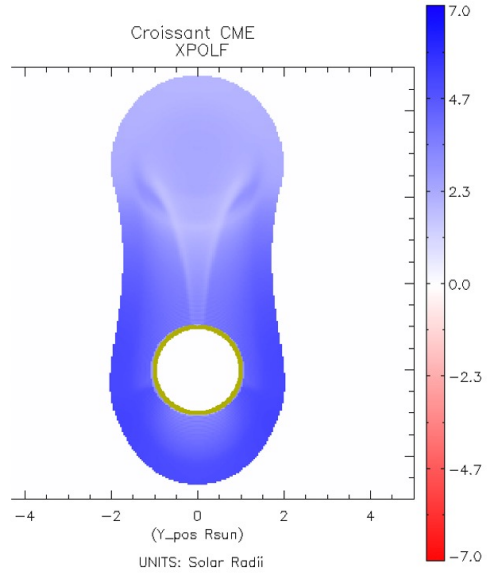
Position from polarization ratio: Back (ghost) solution



Ground truth from model: position of density center of mass



Position from polarization ratio: Front solution



At low elongation, lines of sight are parallel.

The Back solution is just the mirror reflection of the Front.

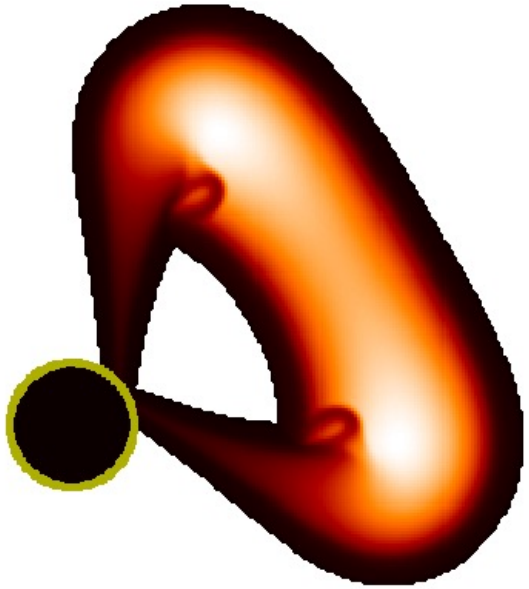
Polarization measurements vs. time can distinguish between Earth-towards and Earth-away

Case 1: Earth-towards

Clues:

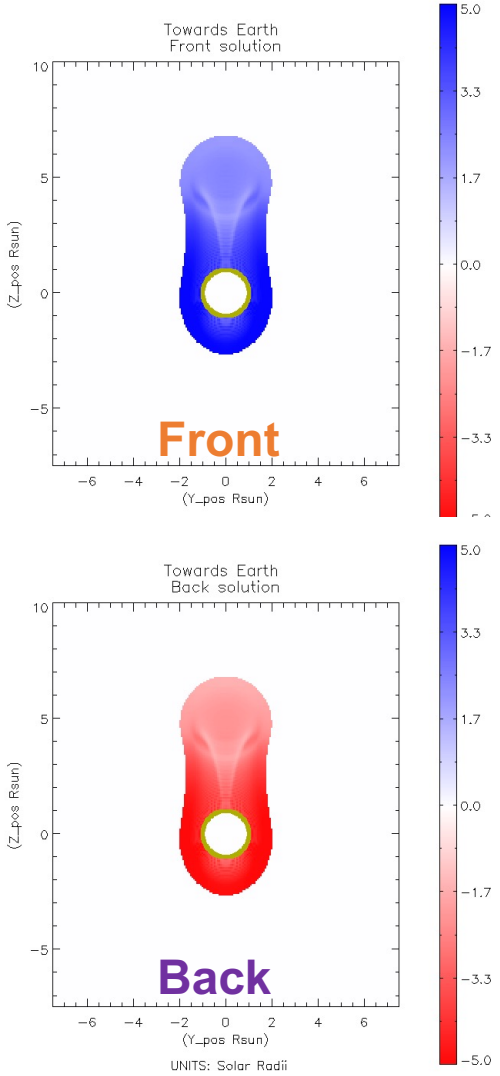
- Front solution LOS position stays positive and all points get more positive with time
- Back solution starts negative but parts get more positive with time, ultimately transitioning to positive X (blue)
- CME generally gets bigger

Quadrature view

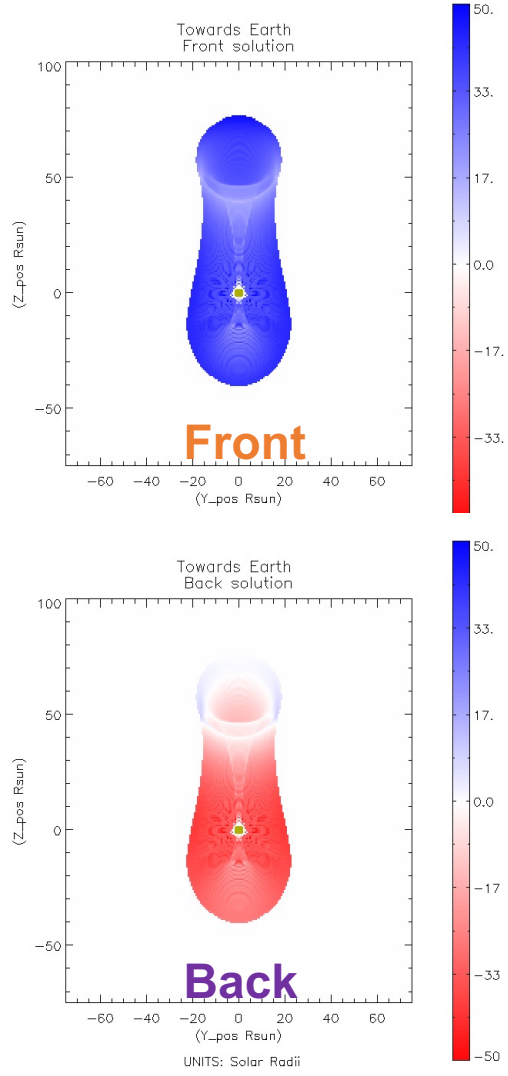


View from Earth

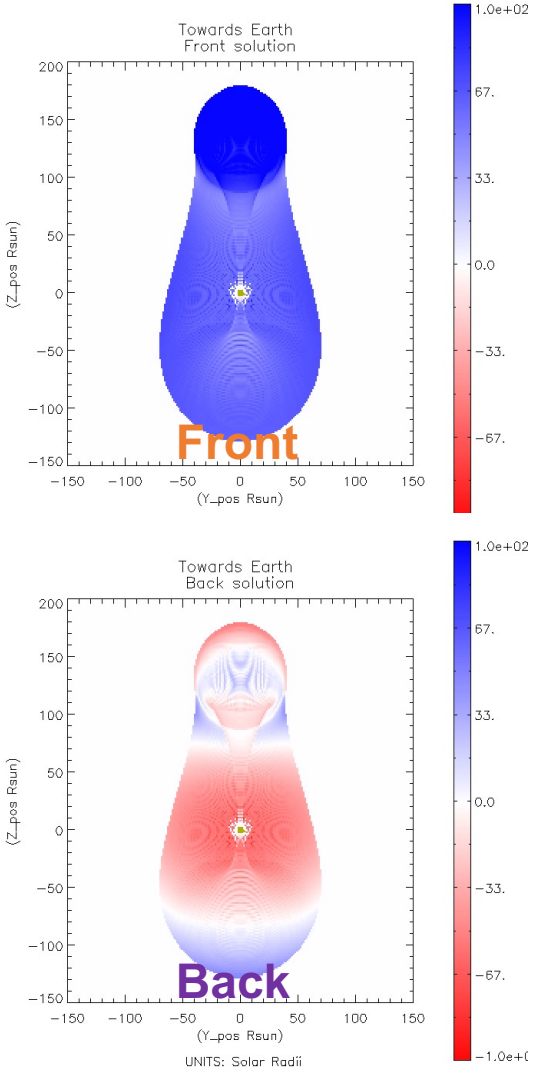
CME apex ε =1.35º



CME apex ε =13º



CME apex ε =33º



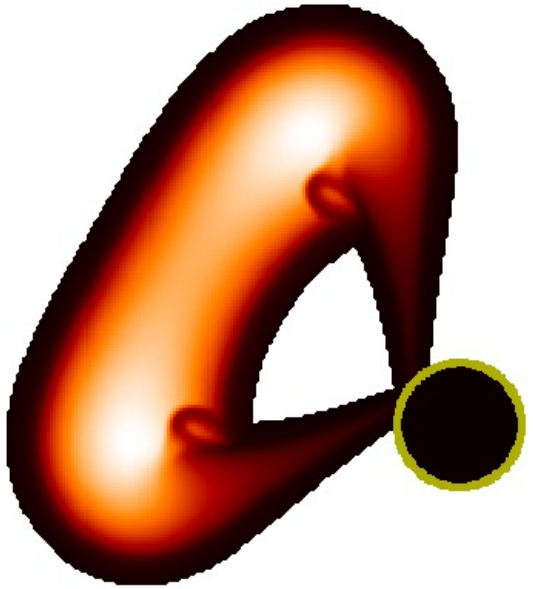
Polarization measurements vs. time can distinguish between Earth-towards and Earth-away

Case 2: Earth-away

Clues:

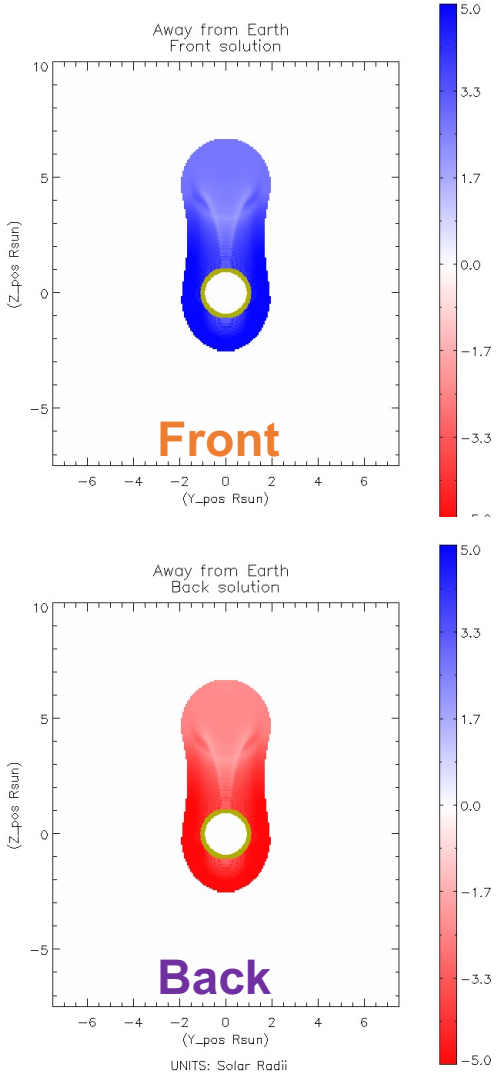
- Back solution LOS position stays negative the whole time and all points get more negative with time
- Front solution LOS position stays positive the whole time and all points get more positive with time
- CME ultimately gets smaller (but asymptotes)

Quadrature view

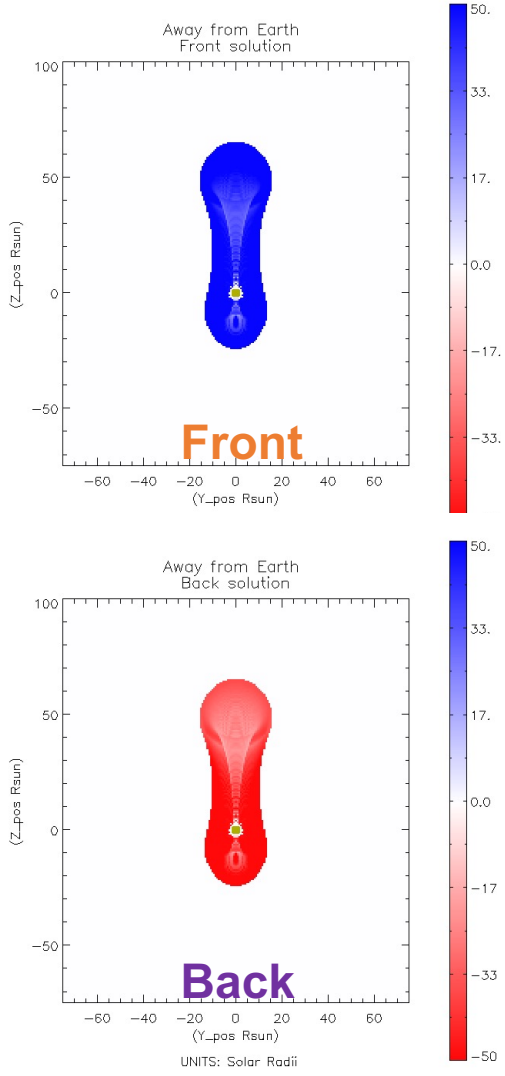


View from Earth

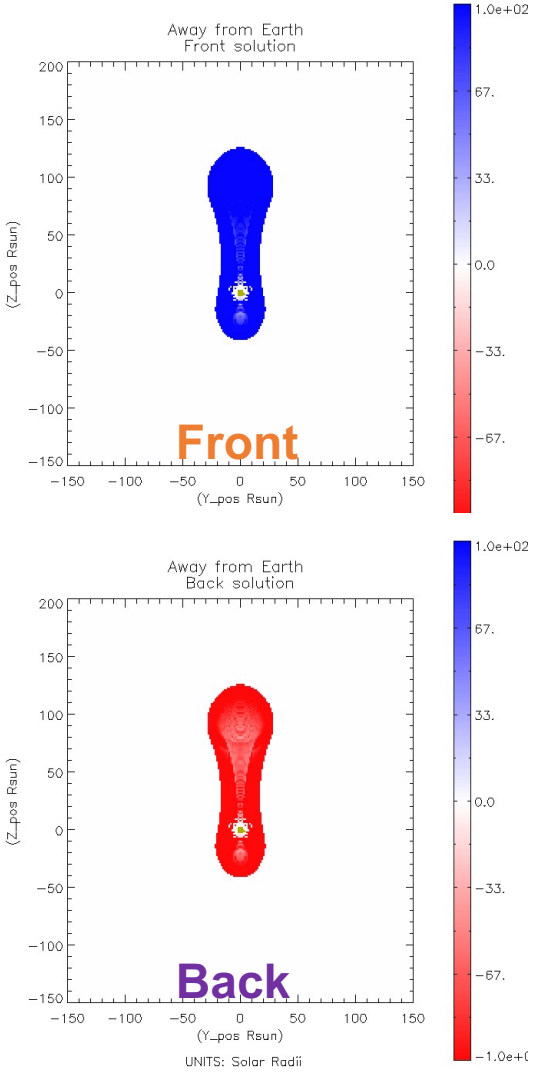
CME apex ε =1.35°



CME apex ε =13°



CME apex ε =33°

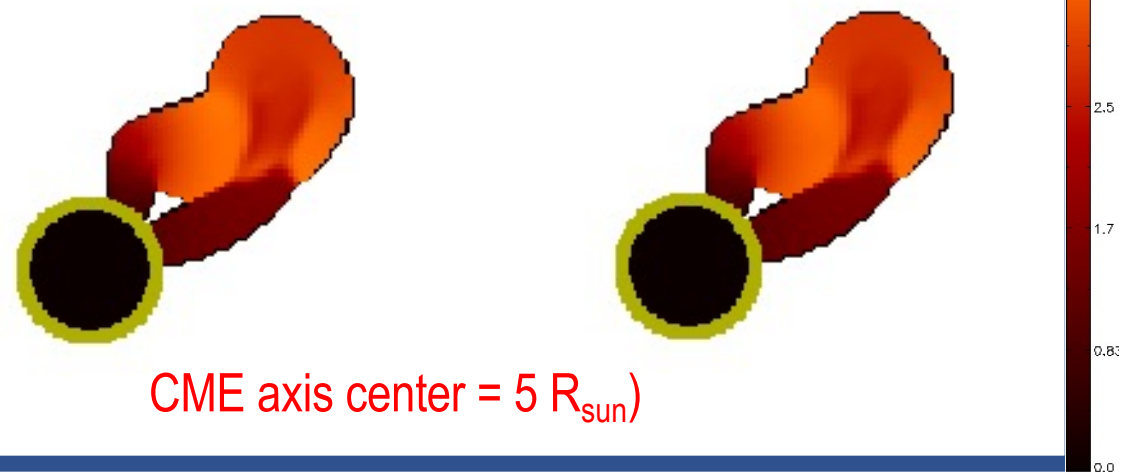


Polarization can be used as a diagnostic of chirality

FORWARD-modeled croissant CME (source=40° longitude, 60° colatitude, width=.4, angular_extent=1, **twist = -0.4**)

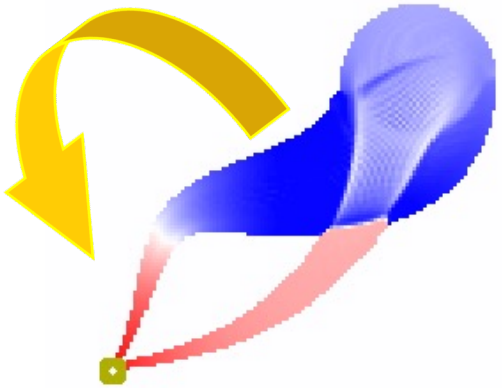
Ground truth position

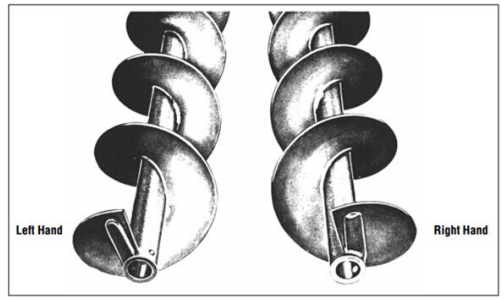
Front polarization sol'n



CME axis center = 5 R_{sun})

Counterclockwise rotation front to back (blue to red): ***left-handed flux rope.***





Twisted croissant

Earth-toward (oblique)

View from Earth

Ground truth position

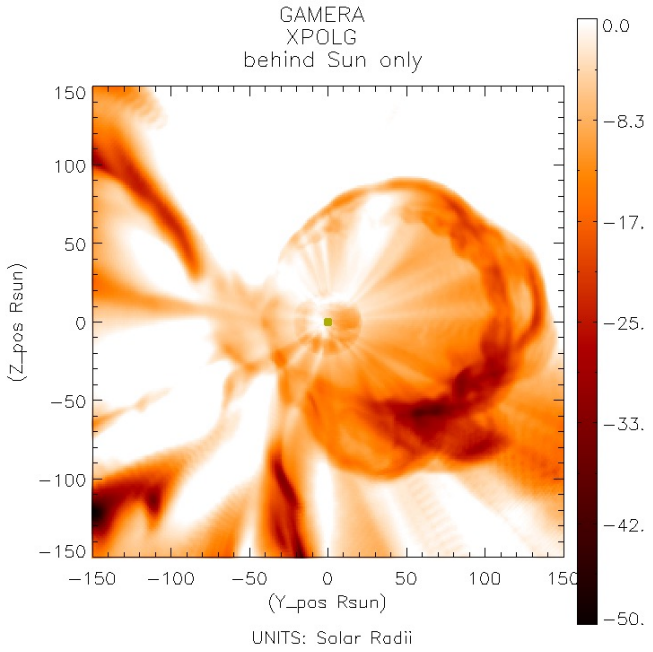
Front polarization sol'n

CME axis center = 50 R_{sun})

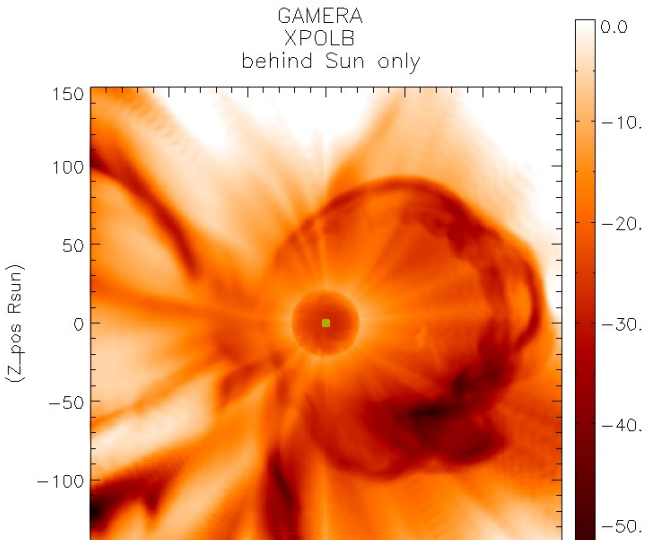
Polarization diagnostics on MHD model with background solar wind: GAMERA

Gamera CME simulation: Away from Earth

Ground truth from model:
position of density center of mass

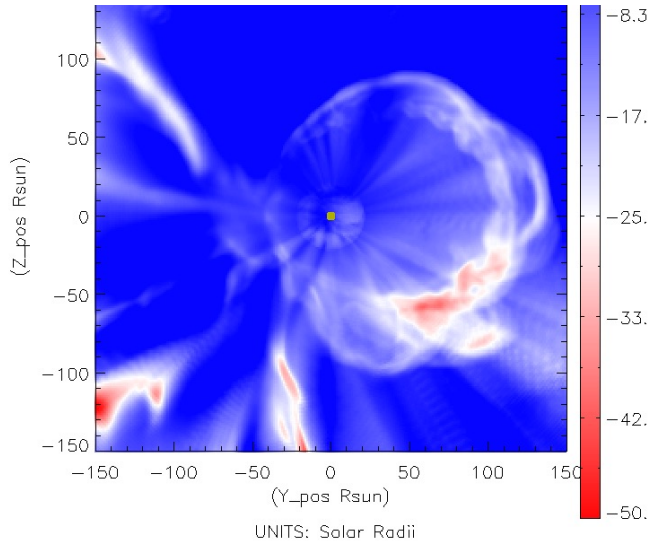


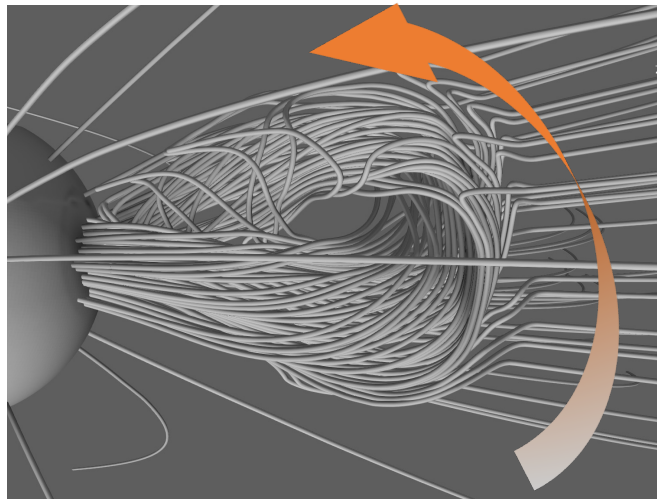
Position from polarization ratio:
Back solution

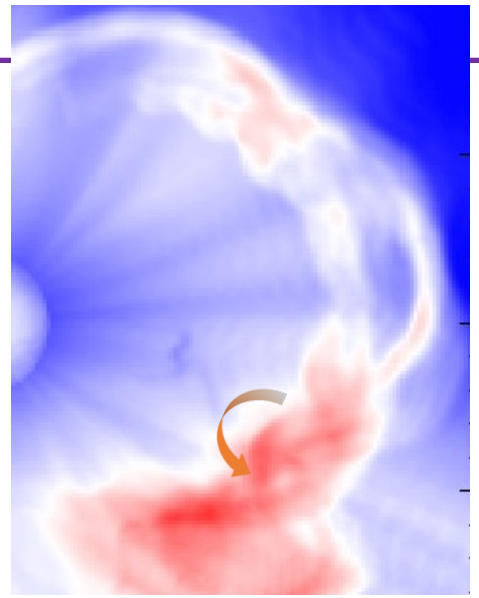


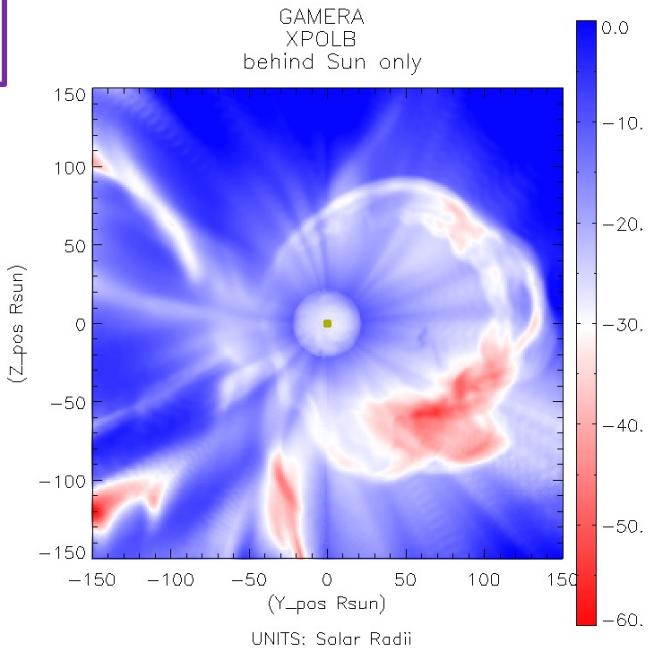
Even without subtracting off the background, the Back solution captures the 3D position of the CME substructure well

Simulation is counterclockwise rotation front to back (blue to red): left-handed flux rope. Although it is possible to see features consistent with this in the polarization analysis, ambiguities remain.









Conclusions

- The 3D position of the CME front is well captured using polarization analysis for small elongations
- Analysis gets more complex for higher elongations especially if there are multiple localized structures along the line of sight with differing proximities to the Thomson Surface.
- Ambiguity of whether Front vs Back solutions apply can be dealt with by observing time series.
- Polarization presents a tool for distinguishing between left-handed and right-handed CME flux ropes. However, the oblique view (perpendicular to the axis) can be ambiguous. 3D realization of the feature allows rotation to a viewing angle along the axis, ultimately required for establishing chirality.