Can we image reconnection-related flows at the fronts of CMEs?

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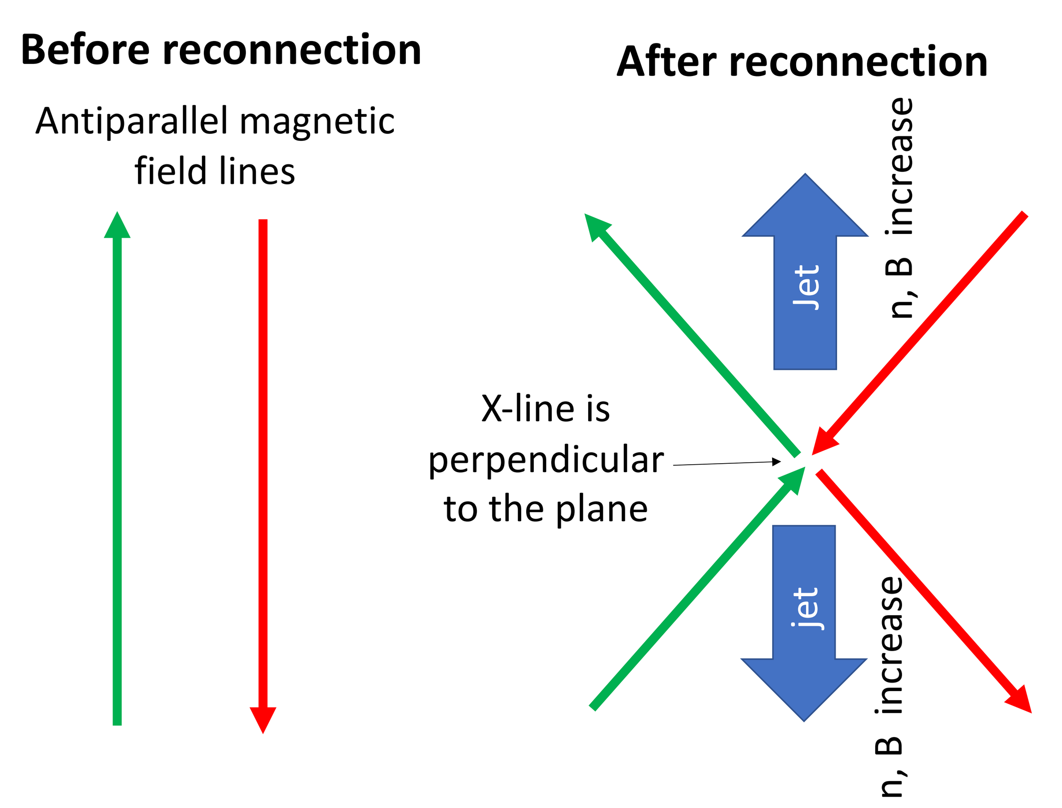
What is reconnection?

- Magnetic reconnection is ubiquitous in space plasmas, and its effects have been observed from the magnetosphere to the solar atmosphere.
- Reconnection changes the magnetic topology, converting magnetic energy into thermal and kinetic.

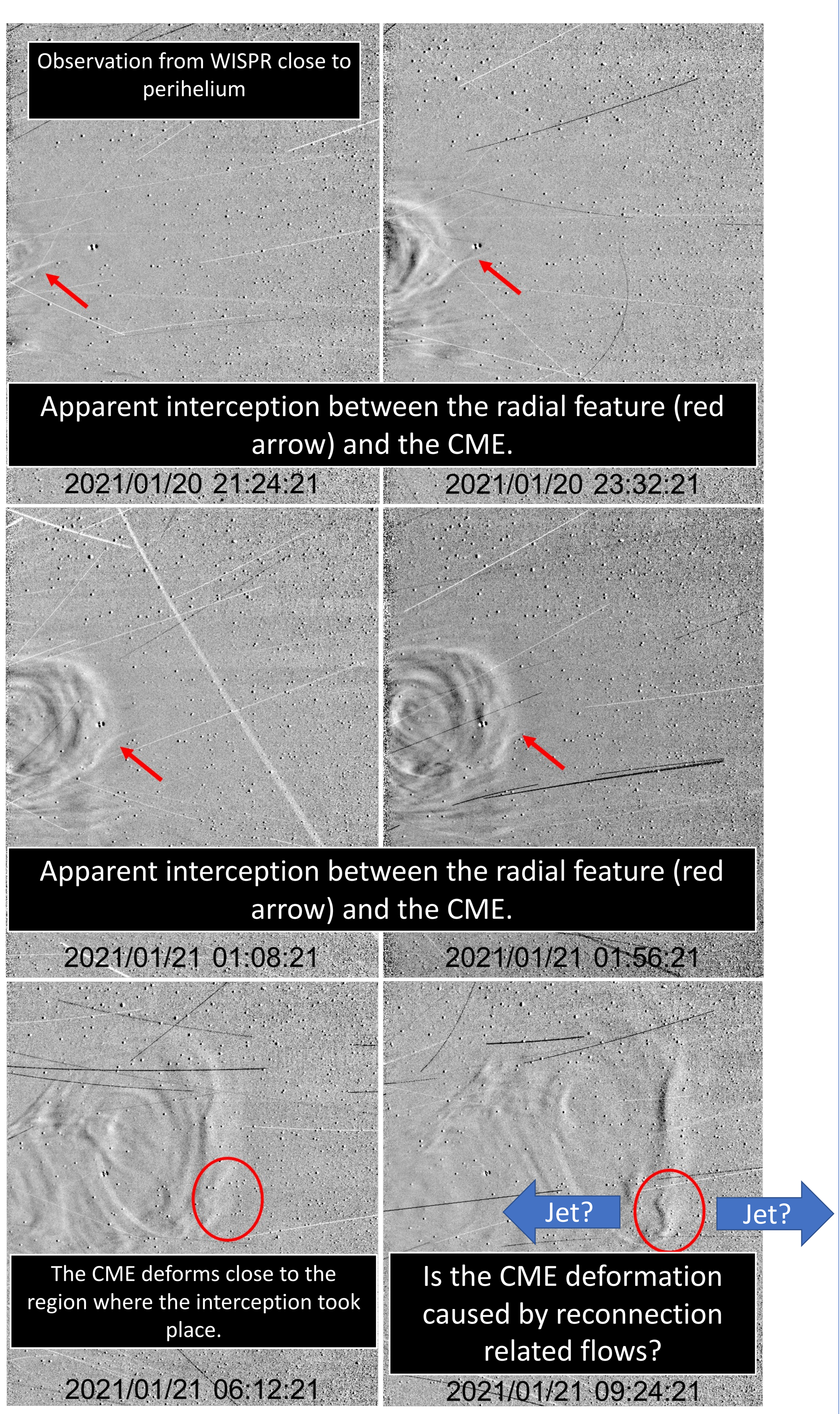


- Reconnection exhausts are common in situ signatures of reconnection. They are pairs of opposing flows along the x-line with increased speed, density, and magnetic field.

Reconnection in the CME leading edge

- Several studies indicate that reconnection may take place at the leading edge of CMEs/ICMEs (Dasso et al, 2006; Schmidt and Cargill, 2003; Manchester, 2014).
- Reconnection rate is the greatest close to the Sun where field and Alfvén speeds are highest (see, e. g., Manchester et al., 2014).
- In situ observations that support reconnection
  - Imbalance of poloidal magnetic field → External CME layers peel off (Ruffenach et al., 2012).
  - Observation of 10+ multiple reconnection exhausts by PSP, some of them are associated with CMEs (Phan et al., 2020).
- Numerical simulations show reconnection in the leading edge of flux rope for fast CMEs. 20% of the CME flux is lost (Manchester et al., 2014).

Is this a reconnection-related flow?

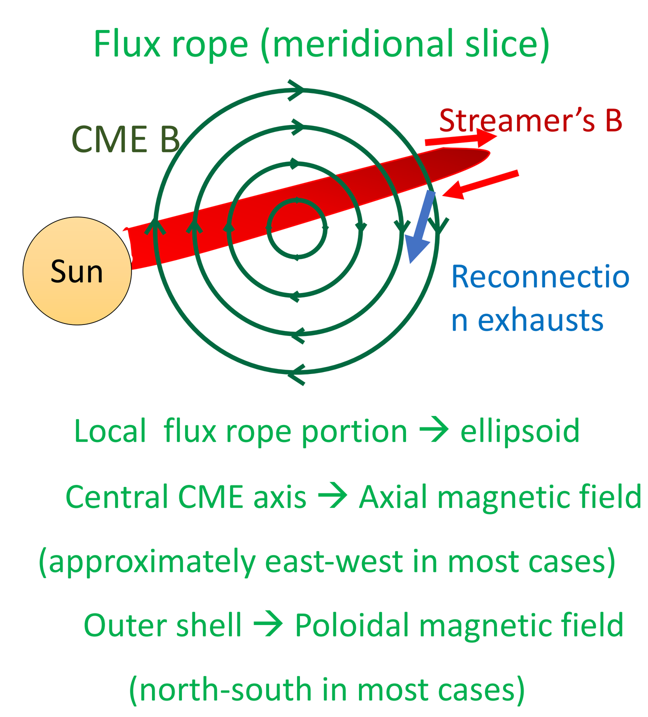


Why reconnection matters?

- Reconnection can change properties of CMEs, impact their propagation, Time-of-arrival at Earth.
- 30% of interplanetary counterparts of CMEs show signs of reconnection (Ruffenach et al., 2015).
- SECCHI and LASCO observe this CME without any deformation (Braga et al., in preparation). Reconnection may trigger CME deformations after the last coronagraph observations.

Is the magnetic field orientation favorable for reconnection?

- We expect that the radial feature has its magnetic field similar to a current sheet.
- This configuration can have at least a component antiparallel to the CME.
- The CME dimple forms in a region close (at least in the same latitude) that the radial feature is located.



Are the changes in density produced by reconnection jets large enough for WISPR to observe it?

- The density in some reconnection related flows doubles when compared to the regular solar wind according to some in situ observations (Phan et al., 2006).
- These flows may be discernable on WISPR images. Creating synthetic images about the deformation can help us determine if this density enhancements are sufficient for WISPR observation.

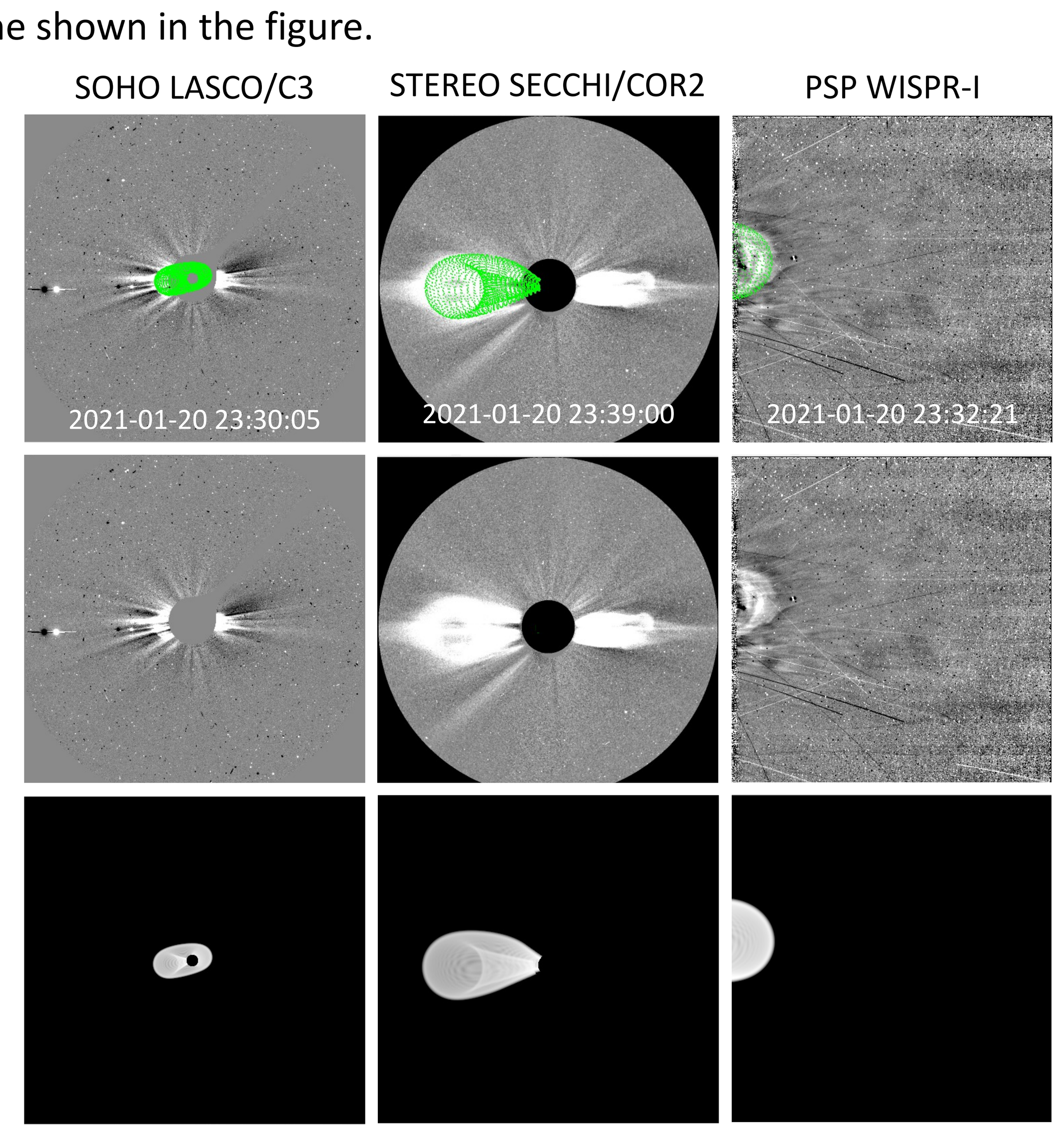
Are reconnection jets large enough for imaging observations?

Recent in situ observations from PSP suggest the following for reconnection jet's size:

- lengths can exceed 3 solar radii (Phan et al, 2020).
- widths can be ~0.5 solar radii (Phan et al, 2020).

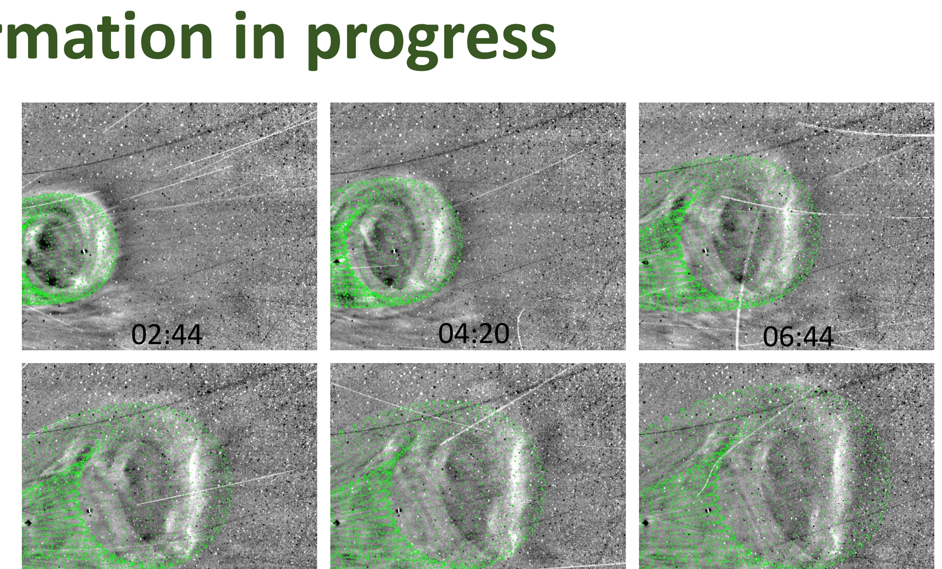
Before the CME deformation

- We can model the CME as a flux rope using the GCS (from Thernisien et al., 2011) model up to ~0.1 au. Thus, the CME is no deformation until the time shown in the figure.



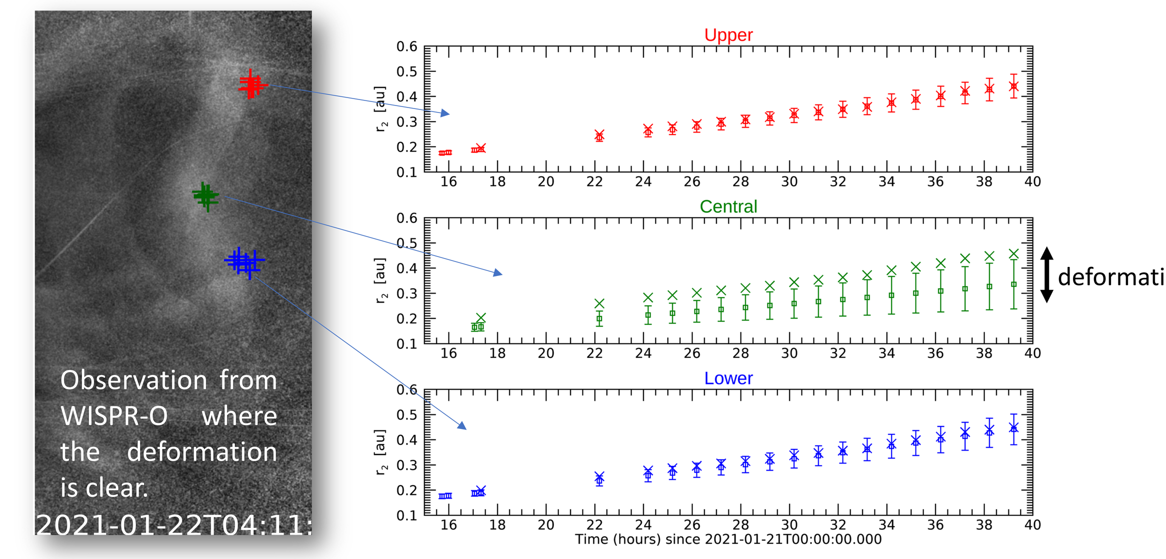
- The radial feature intercepts the CME front right after 0.1 au.

Deformation in progress



WISPR inner camera observes the deformation taking place. All images here are from 2021-01-21.

After the CME deformation



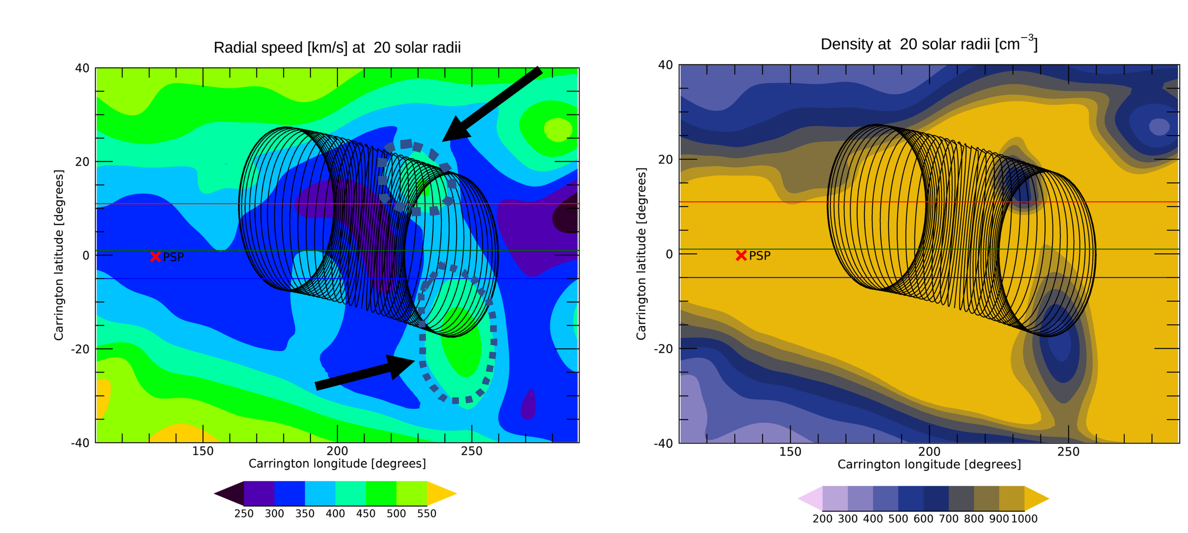
Crosses: CME "croissant" model leading edge position, which does not have any deformation, and considers a self-similar propagation since 0.1 au.

Squares: the kinematics of each points in independent from the remaining (Braga & Vourlidas, 2021 A&A).

Alternative explanations for CME deformation

1) structured solar wind

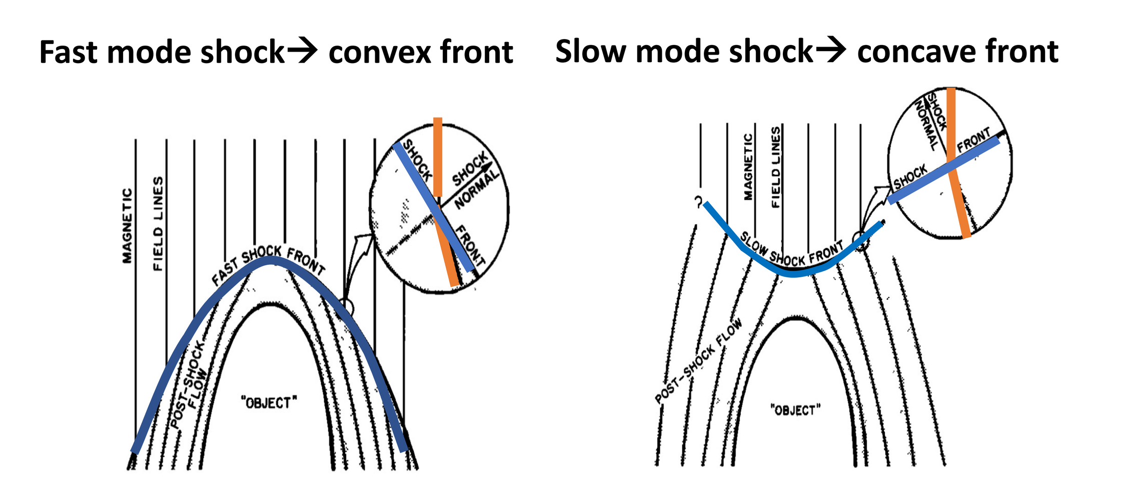
The CME dimple is located close to the solar equator, where the solar wind speed is lower. MHD solar coronal models support this argument.



The CME projected over the background solar wind model speed (left) and density (right) at 20 solar radii. We are using a MHD background solar wind model from Predictive Science Inc.'s CORona-HELiosphere (CORHEL) framework here.

2) slow mode shock

We can have a slow-mode shock if the velocity in the shock frame of reference and normal to its front does not exceed the Alfvén speed both ahead and behind the shock, but exceeds the upstream sound speed.



Hundhausen et al. (1987)

Hundhausen et al. (1987) suggests that for the concave shock front is related to the angle between the shock normal and the magnetic field. This angle decreases (increases) for slow (fast) mode shocks in the post-shock region.

Final remarks

We have some conditions that favor reconnection in the CME's leading edge:

- Approximately antiparallel magnetic fields pushed closer.
- Proximity to the Sun --> higher Alfvén speed, higher reconnection rate.

We also have conditions that support the imaging of reconnection-related flows by WISPR:

- They were observed in situ by PSP in the solar distances that the WISPR field of view covers.
- They are large enough (up to 3 solar radii in length, 0.5 solar radii of width).
- Their density and speed can be 2x times than the regular solar wind.

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CORHEL model output is available from the Predictive Science Inc. website: https://www.predsci.com/hmi/data_access.php