How does Coronal Magnetic Reconnection Generate Solar Wind Structures and What Will PUNCH See?

(aka PUNCH and ARMS
go hand-in-hand)

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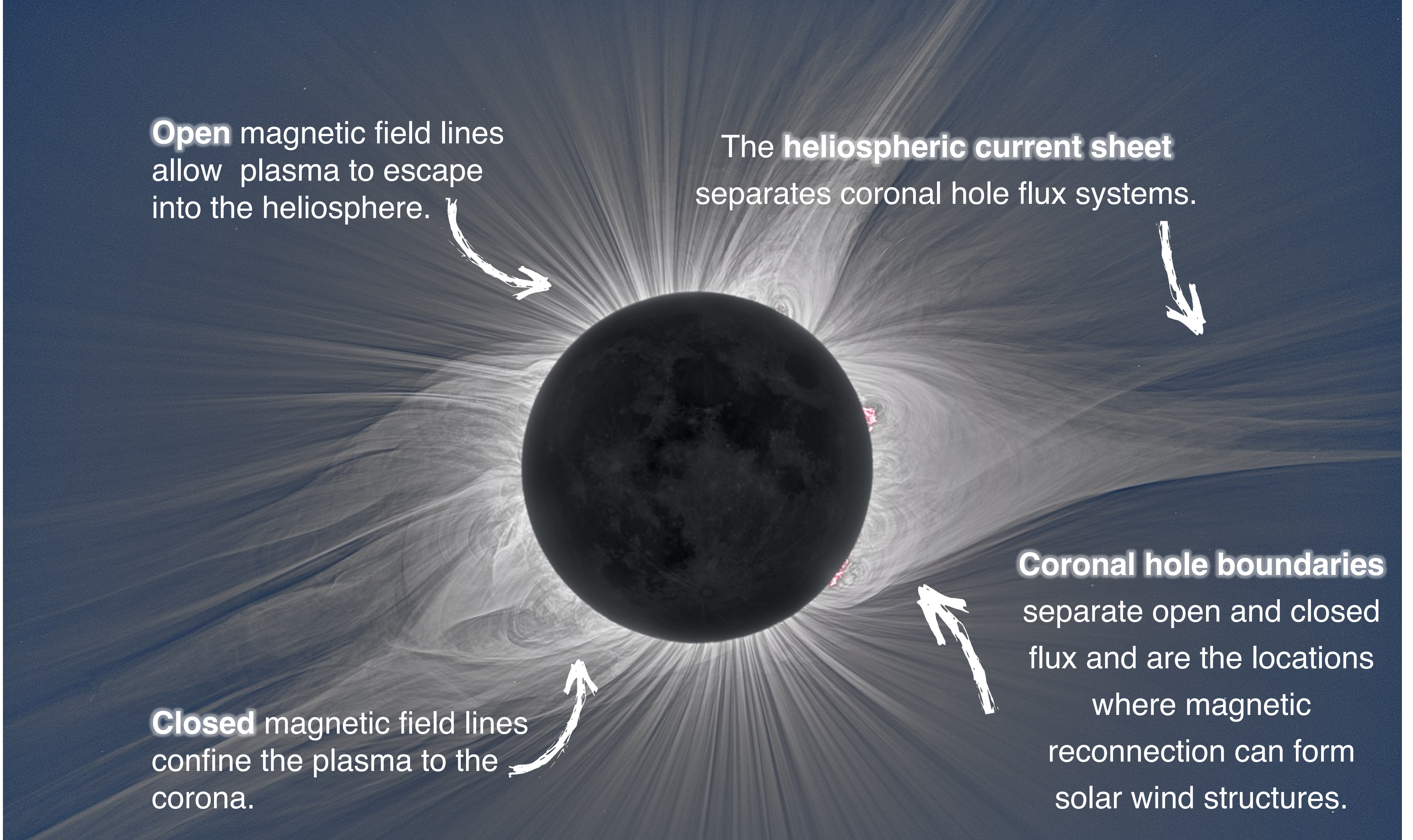
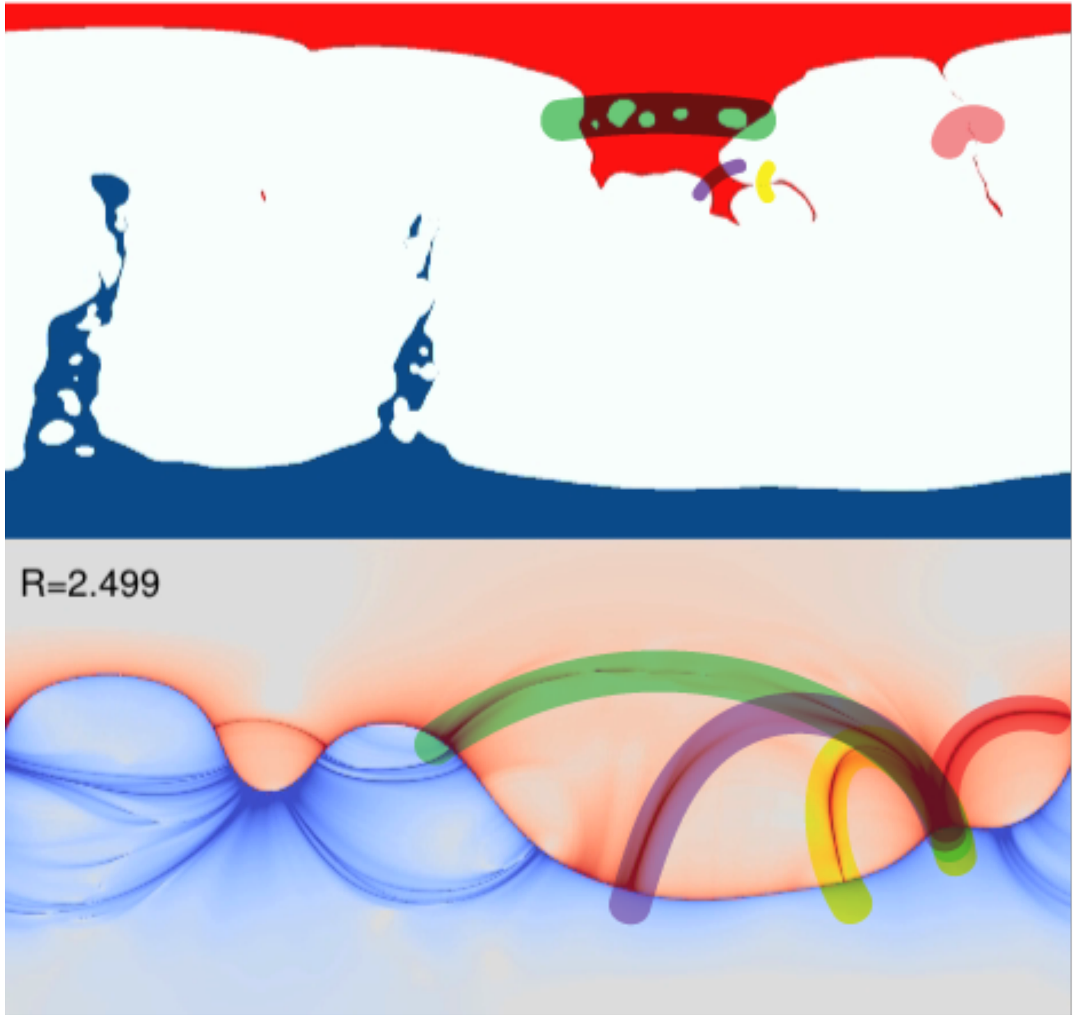

Open magnetic field lines allow plasma to escape into the heliosphere.
The heliospheric current sheet separates coronal hole flux systems.
Coronal hole boundaries separate open and closed flux and are the locations where magnetic reconnection can form solar wind structures.
Closed magnetic field lines confine the plasma to the corona.

Tracing the coronal separatrix-web (S-web) is a way to map the footprint of the OCB in the heliosphere



- Carrington map of coronal holes on the surface of the sun where color indicates polarity and white regions are closed fields.

- The **red** / **blue** boundary shows the top of the helmet streamer.

- Squashing factor *Q* shows the gradients in the mapping of the magnetic field and highlights the S-Web. High *Q* = reconnection is likely. (Titov et al. 2009, Antiochos et al. 2011)

S-Web Movie Courtesy Predictive Science, Inc.

The ARMS MHD Code

The Adaptively Refined MHD Solver (**ARMS**) solves the 3D **ideal MHD** equations in spherical coordinates.

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0$$

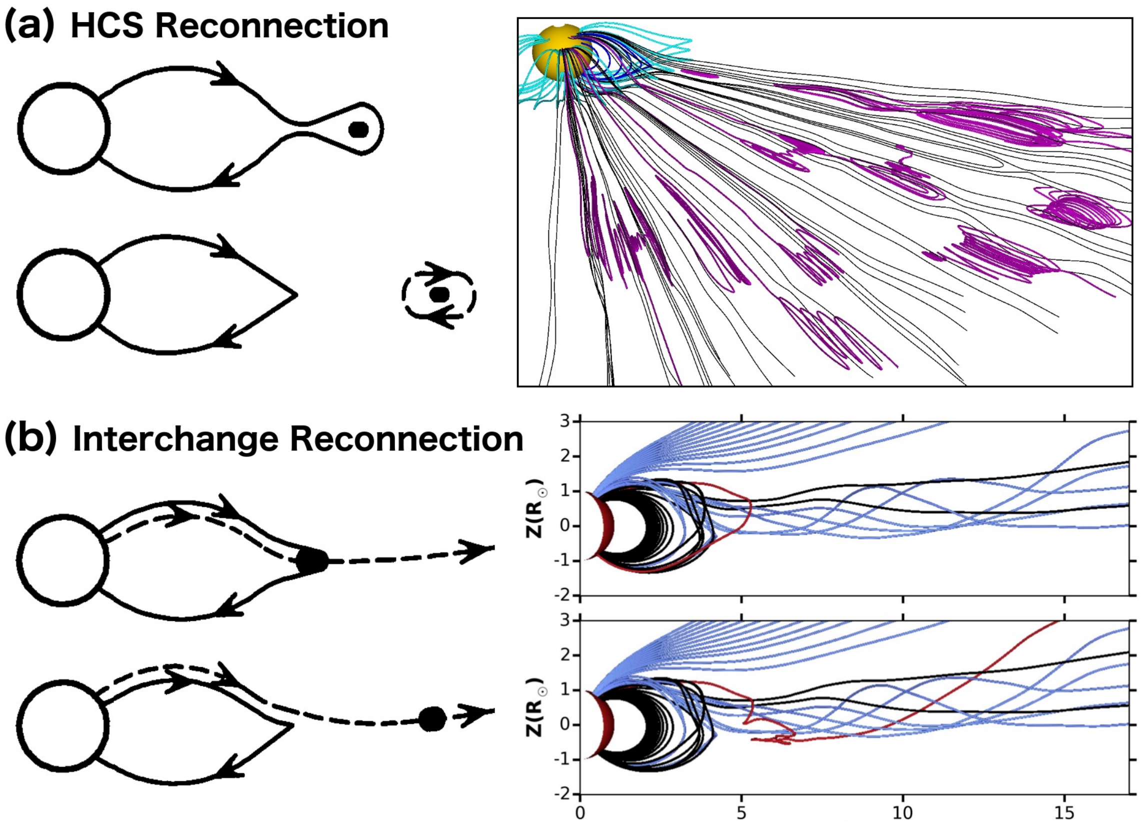
$$\frac{\partial (\rho \vec{v})}{\partial t} + \nabla \cdot (\rho \vec{v}\vec{v}) = \frac{1}{4\pi}(\nabla \times \vec{B}) \times \vec{B} - \rho \vec{g} - \nabla P$$

$$\frac{\partial \vec{B}}{\partial t} = \nabla \times (\vec{v} \times \vec{B})$$

The following simulations:

- **are fully time dynamic**
- **have a self-sustaining isothermal solar wind (**1 MK)
- **utilize adaptive mesh refinement** and **numerical resistivity**.

There are 2 types of reconnection that can occur at the open-closed boundary



Sometimes called "pinch-off reconnection"

Higginson et al. (2017a,b)

Wang et al. (2000) summarized processes for slow solar wind streamer blob variability.

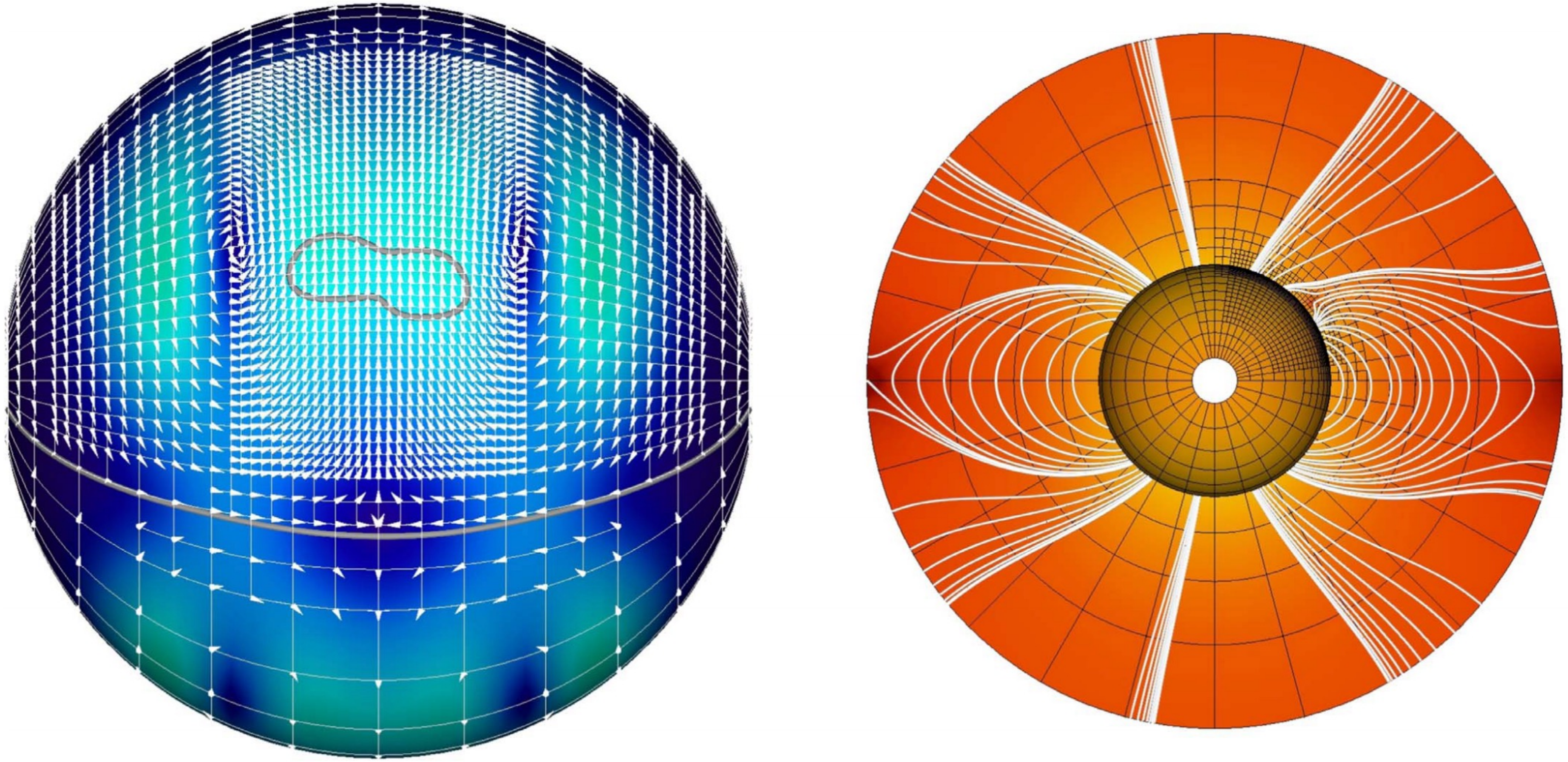
We have 3D ARMS simulations of each process.

At least 3 ways to get these 2 types of dynamics

1. global rearrangement of magnetic flux
2. solar wind interaction with helmet streamer tops
3. photospheric motions

1. Global rearrangement of flux

Scott et al. (2021) used ARMS to move a pseudostreamer structure from the closed to open field, pushing it through the open-closed boundary.



(a) (b)

Velocity on the surface

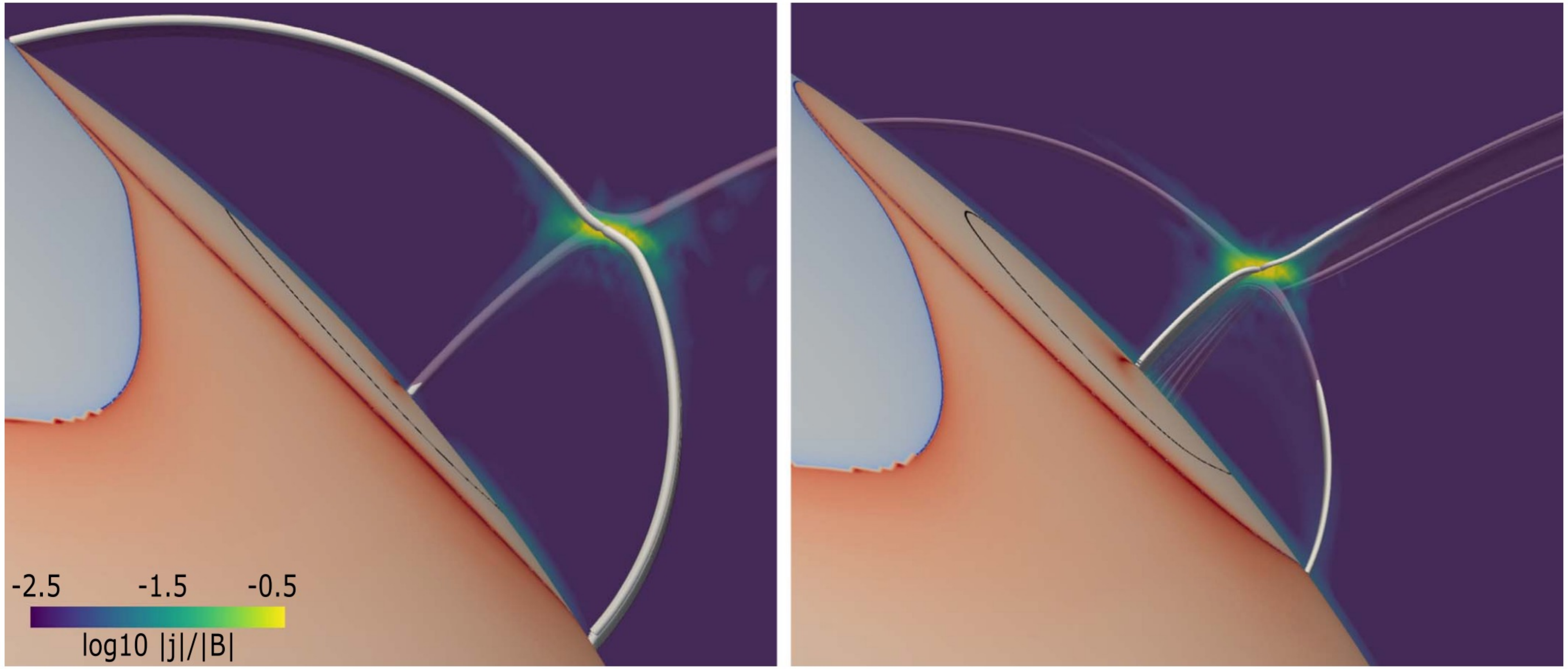
Global topology

Scott et al. (2021)

1. Global rearrangement of flux

This process resulted in copious amounts of interchange reconnection,

which would release plasma from the closed field into the solar wind.



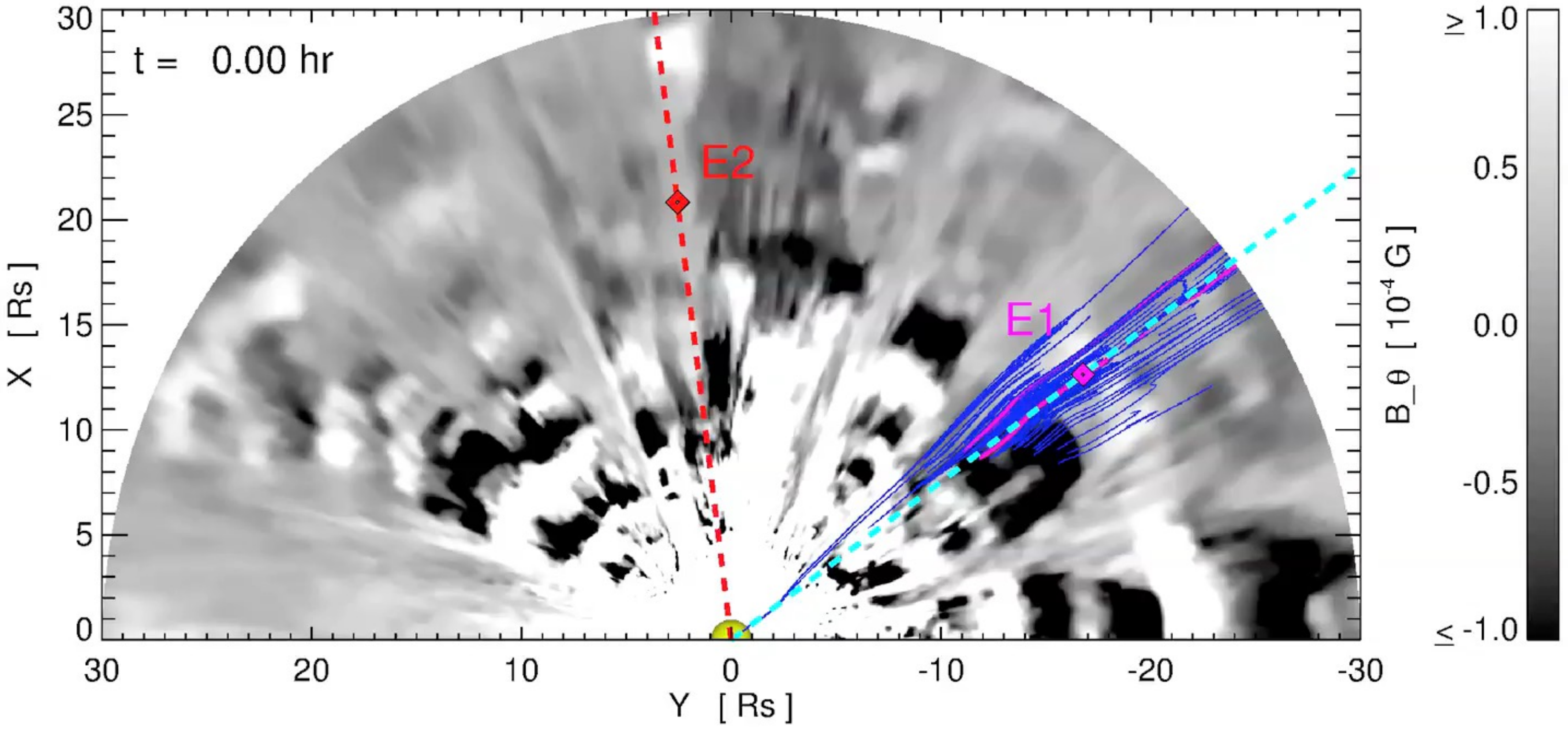
(a) SN_2: Current Density

(b) TN_3: Current Density

Scott et al. (2021)

2. Interaction of OCB with the solar wind

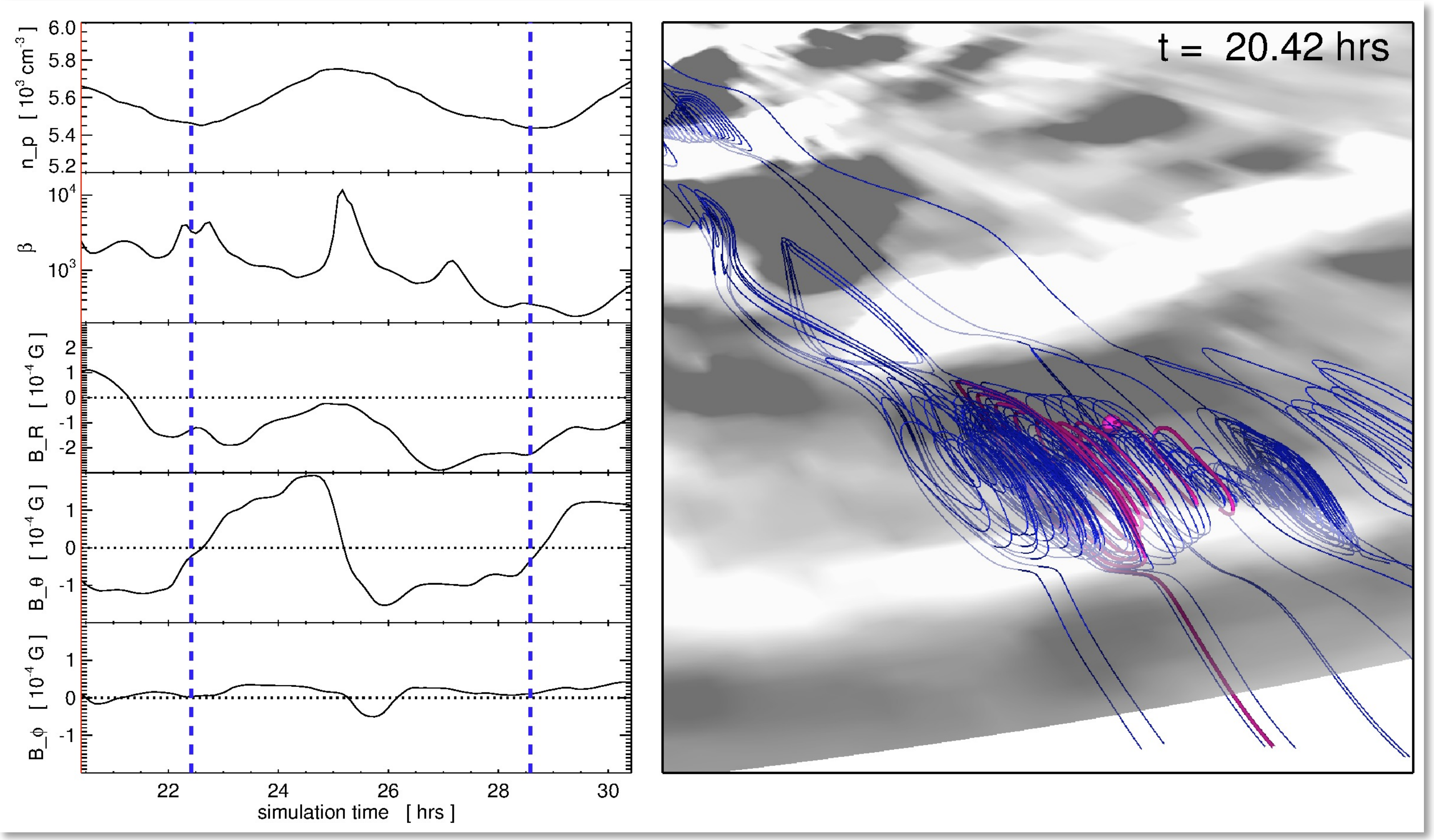
Higginson & Lynch (2018) identified the release of magnetic flux ropes resulting from pinch-off reconnection at the top of the helmet streamer.



Higginson & Lynch (2018)

2. Interaction of OCB with the solar wind

These “blobs” were interconnected and filled the heliospheric current sheet.



Higginson & Lynch (2018)

2. Interaction of OCB with the solar wind

Recently, Lynch 2020 demonstrated that these “pinch-offs” would result in coronal inflows (in/out pairs).

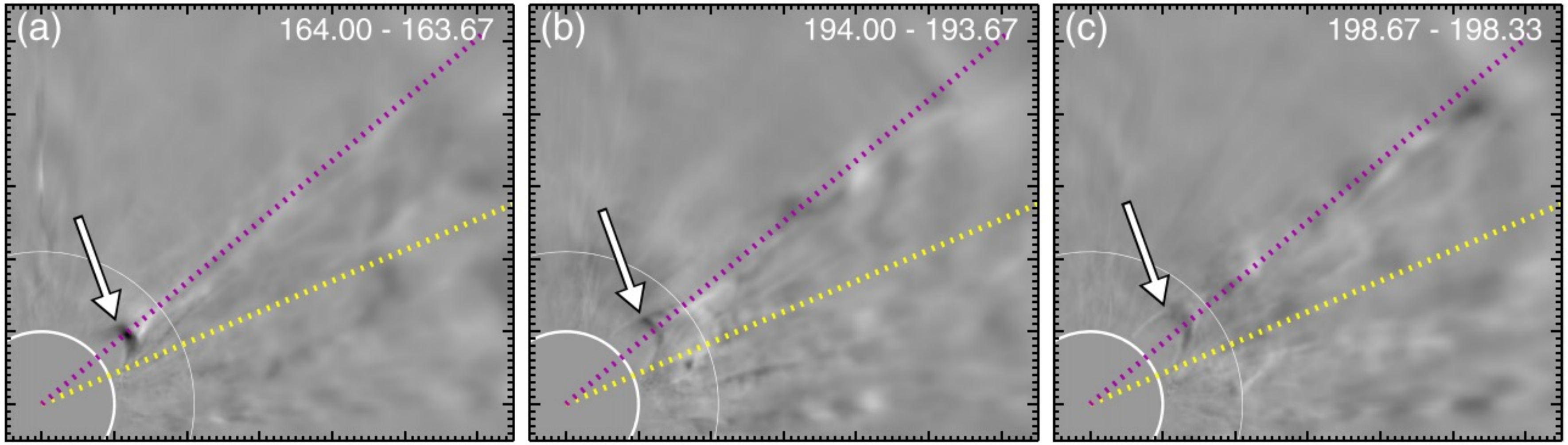


Figure 3. Representative examples of “shrinking-loop” inflows along the PA 310° radial cut (dotted purple line) in the same format as Figures 2(d)–(f). Arrows indicate the darker leading loop and brighter training cusp.

Lynch (2020)

2. Interaction of OCB with the solar wind

Lynch 2020 tracked "in and out" pairs from helmet streamer pinch-off reconnection.

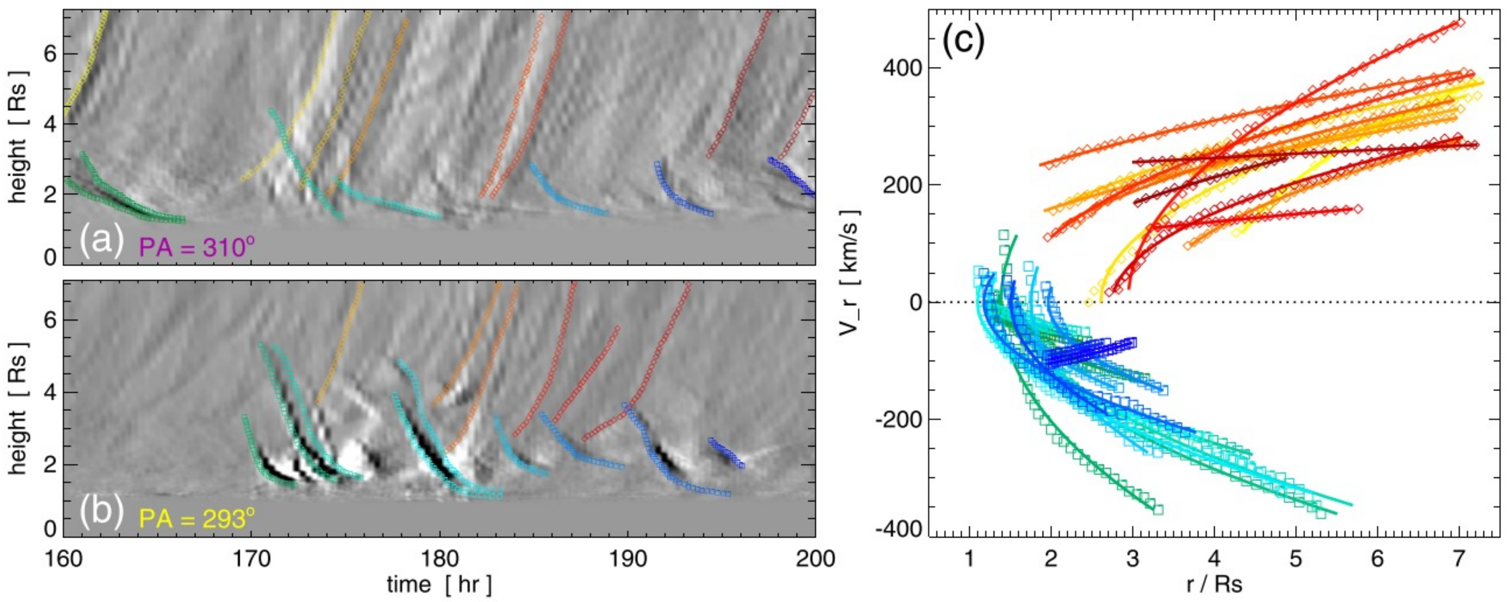
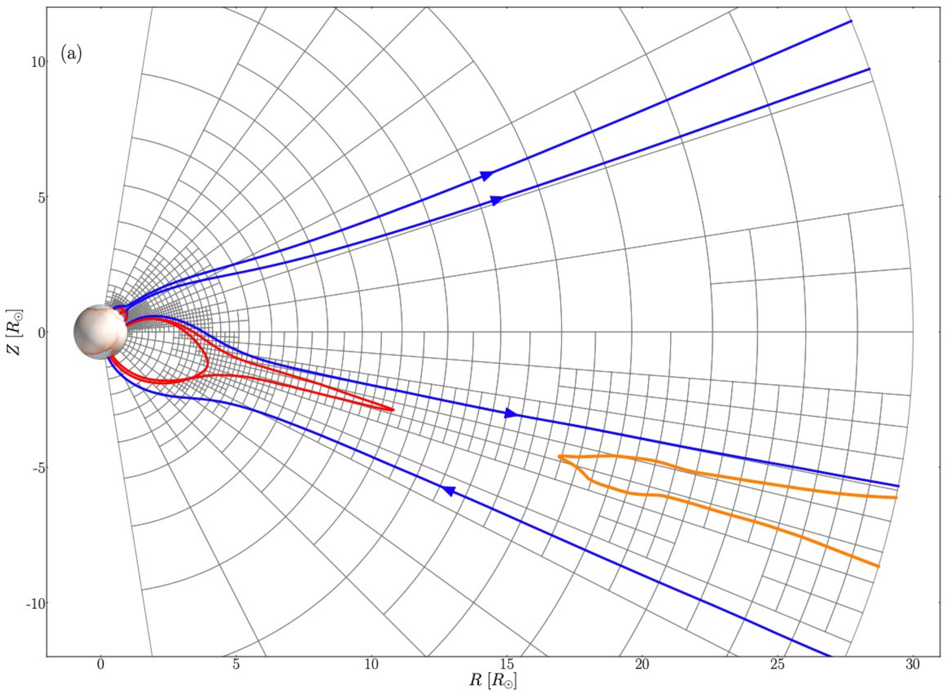


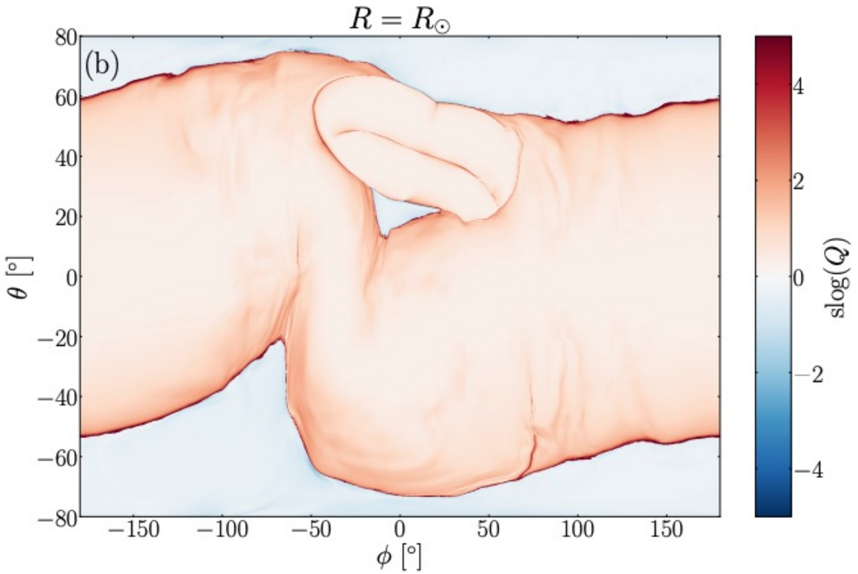
Figure 4. Height–time plots for the two radial cuts in Figures 2 and 3 and their resulting velocity profiles. Panel (a): PA 310° samples an edge-on portion of the helmet streamer belt. Panel (b): PA 293° samples a face-on portion of the helmet streamer belt. Panel (c): each of the $v_r(r)$ profiles derived from the quadratic fits to the height–time data in (a) and (b). The inflow (outflow) tracks are shown in the green–cyan–blue (yellow–orange–red) color gradient.

These pairs are viewed most easily when the HCS is highly tilted with respect to the viewer.

Lynch (2020)

3. Photospheric motions drive the OCB





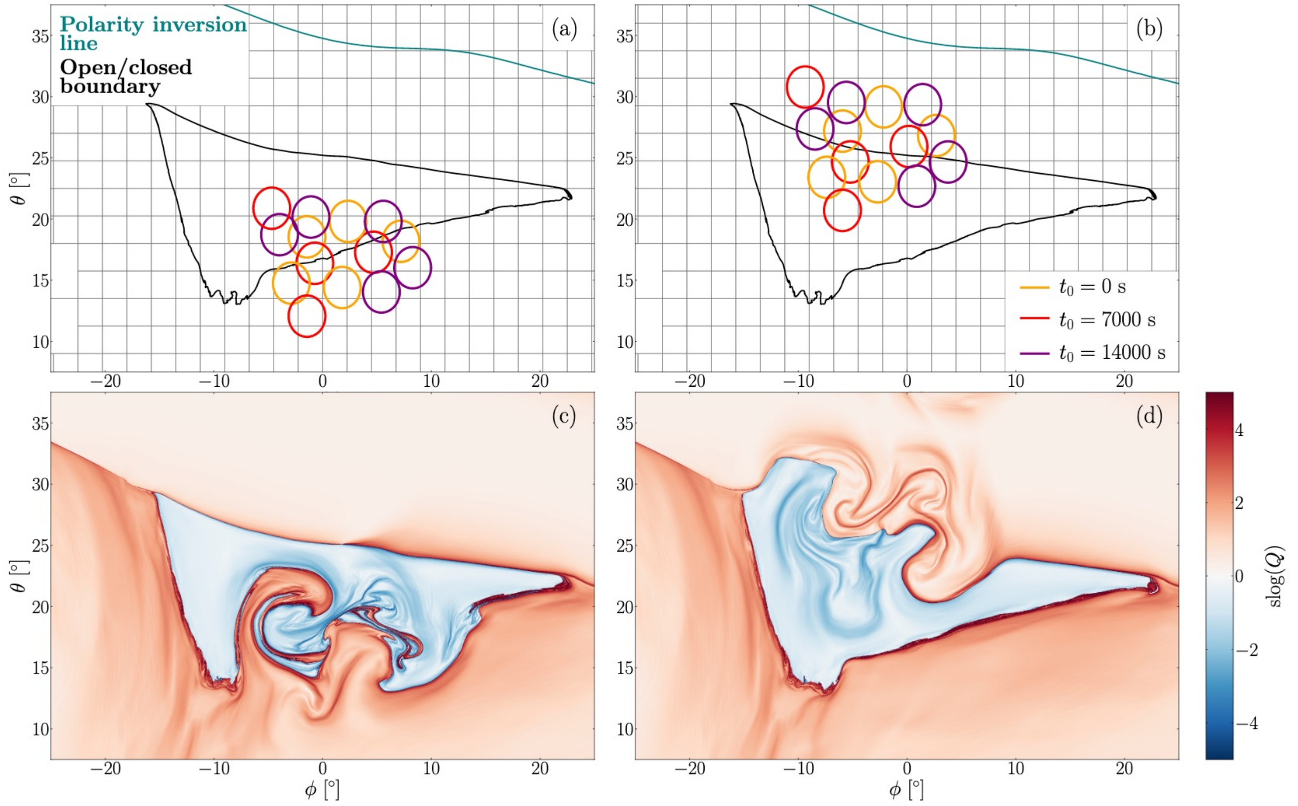
Squashing factor on the surface of the domain outlines the coronal hole boundaries.

Aslanyan et al. (2021, in prep) simulated the boundaries of a helmet streamer and pseudostreamer.

Aslanyan et al. (2021, in prep)

3. Photospheric motions drive the OCB

They used circular rotations on the surface to approximate supergranular driving on each type of boundary.



Helmet streamer

Pseudostreamer

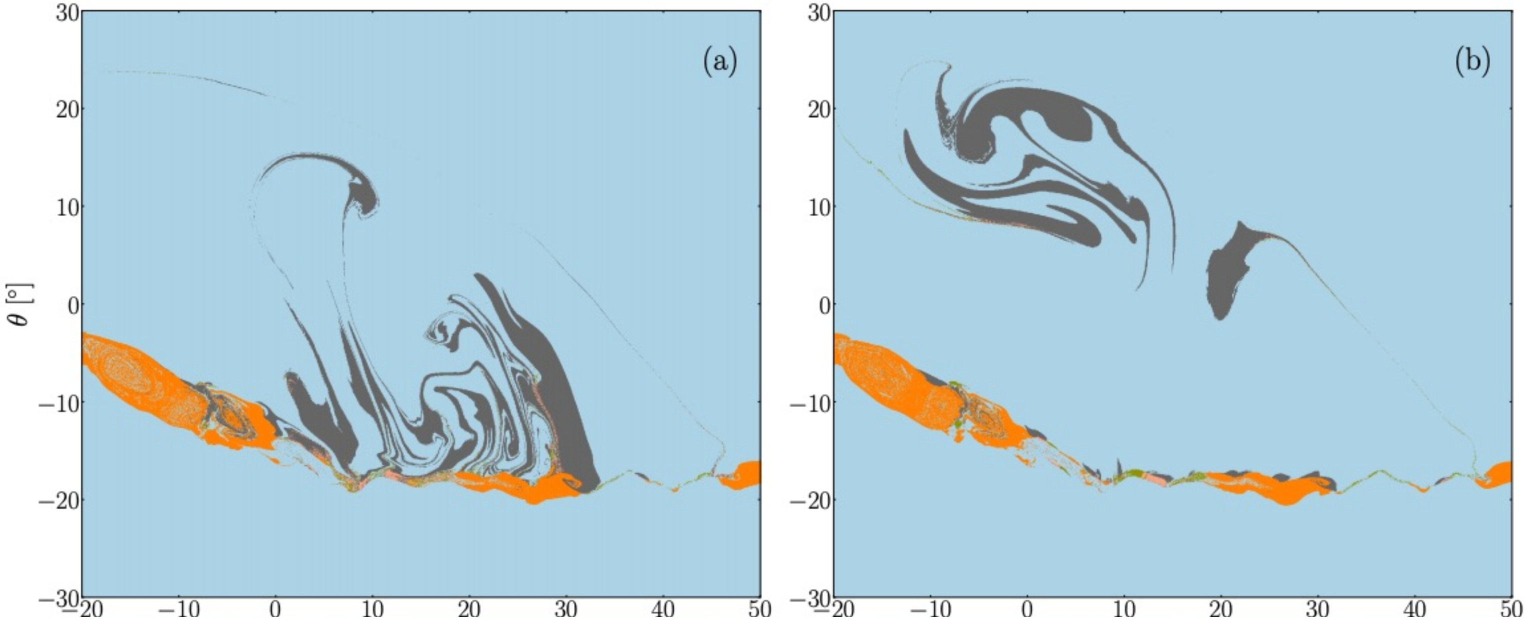
Aslanyan et al. (2021, in prep)

3. Photospheric motions drive the OCB

Grey regions show locations where magnetic field lines have experienced interchange reconnection and are now open in the heliosphere.

Orange field lines are disconnected from the photosphere.

At 20 R-Sun



Helmet streamer

Pseudostreamer

Aslanyan et al. (2021, in prep)

At least 3 ways to get 2 types of dynamics of reconnection dynamics

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What will be the signatures in the solar wind?

1. Density enhancements – *re: Lynch 2020 and others – could depend strongly on viewing angle!*
2. Magnetic structure – *flux ropes at the HCS, alfven waves from PS???*
3. Signatures associated with originally closed field plasma *("slow" wind)*