Tearing instability and plasmoid formation in pseudo-streamer current sheets from 3D MHD simulations

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Context

The solar wind is a turbulent, magnetized outflow permeated by fluctuations across a wide range of scales, continuously shaped by **solar eruptions**. These eruptions are thought to be triggered by fast **magnetic reconnection** in the corona, where thin **current sheets** naturally form. Such sheets can become unstable to the **tearing instability**, fragmenting into plasmoids that enable rapid energy release.

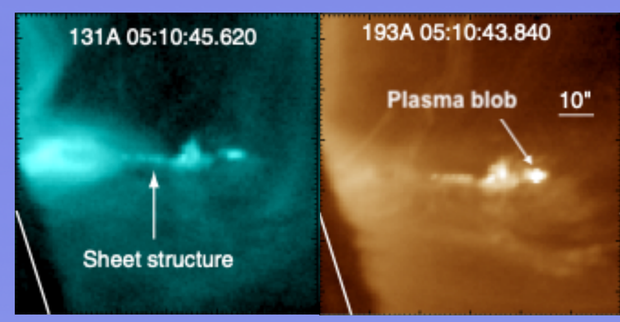
While well understood in local simulations, capturing this process in self-consistent **global coronal models** remains challenging due to scale separation and 3D effects. We investigate the development of tearing instability and plasmoid formation in **pseudo-streamer** configurations using 3D global MHD simulations with the ARMS code. By leveraging **adaptive mesh refinement**, we resolve current sheets and study how their properties and resolution affect instability onset and evolution. While plasmoid do form and evolve non-linearly in our fully 3D global coronal model, the pseudo-streamer geometry appears to limit their formation and reduces their detectability in coronal imaging observations.

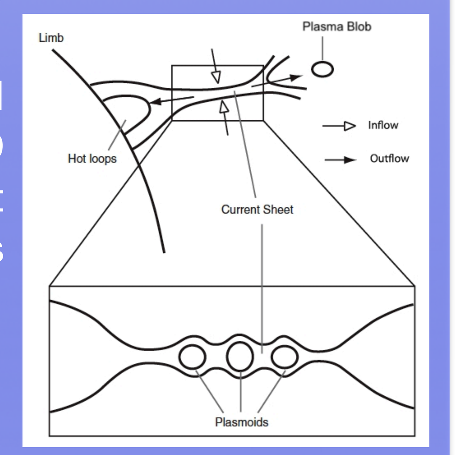
Lundquist Number of the CS — Guide Field Strength — CS Aspect Ratio

$$S \simeq 4\sqrt{1+\zeta^2}\,\frac{RA}{M_{A,in}}$$

Alfvén Number of the Reconnection Inflow

The Lundquist number quantifies the stability of a current sheet. For 2.5D (uniform guide field), the instability criterion is given as $S \geq 10^4$

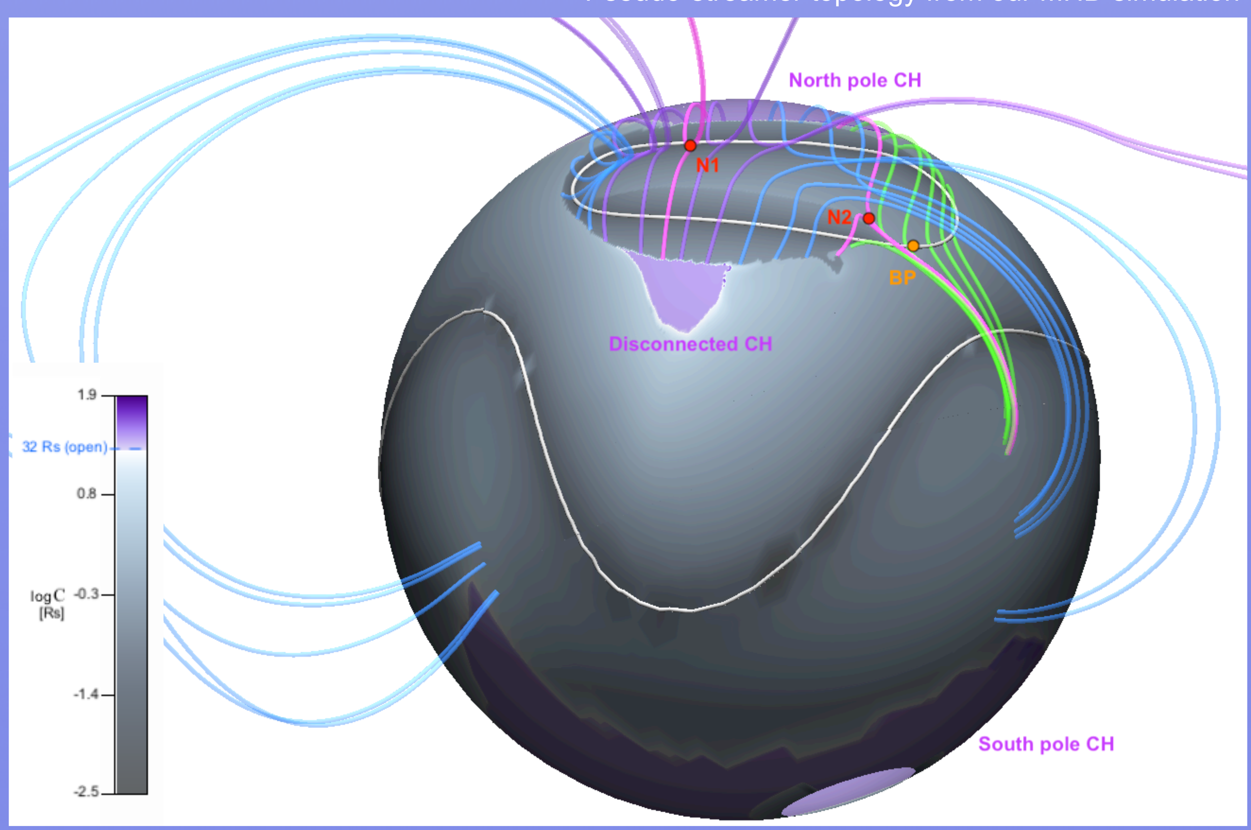




Takasao et al, 2012

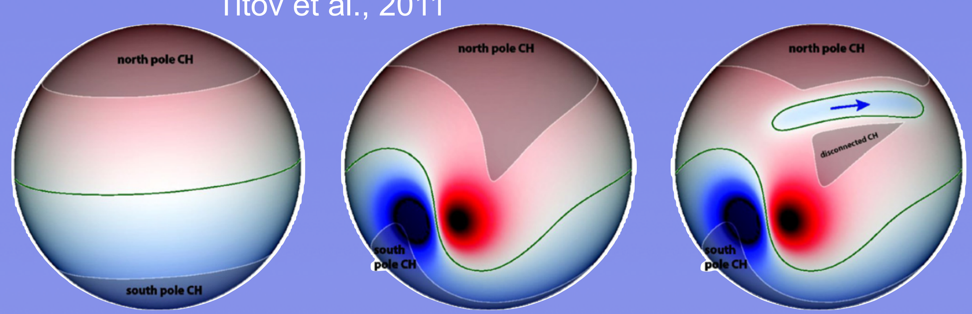
Simulation Setup

Pseudo-streamer topology from our MHD simulation



Sub-photospheric dipoles create the appropriate topology. A magnetically closed dome separating 2 coronal holes: a **pseudo-streamer**

Titov et al., 2011



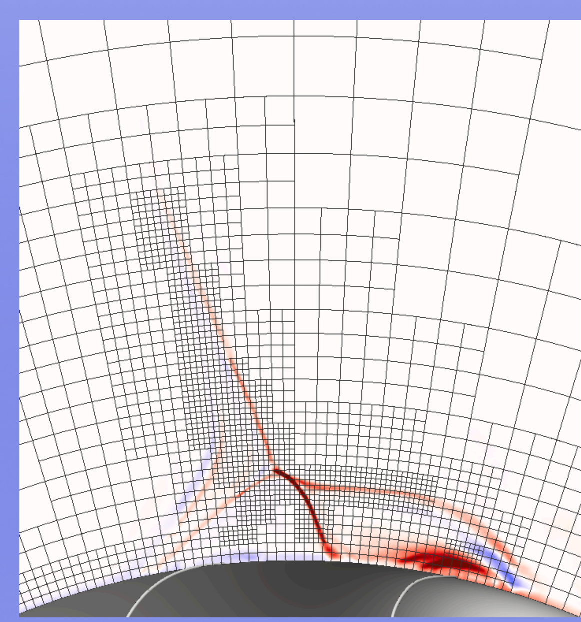
Whiskey, 2017

Methods

ARMS code (DeVore & Antiochos 2008)
-> solves ideal MHD in spherical 3D with AMR

$$\partial_t\rho + \nabla\cdot(\rho u) = 0$$
$$\partial_t(\rho u) + \nabla\cdot(\rho u\otimes u) = -\nabla p + \rho g - \frac{1}{\mu_0}(\nabla\times B)\times B$$
$$\partial_t B = \nabla\times(u\times B)$$

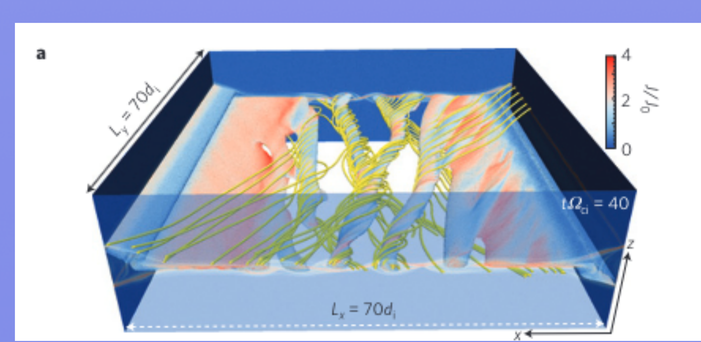
-> Whole-Sun from the corona to the solar wind from r=1 Rs to 33 Rs
-> Isothermal Parker solar wind
-> 2 runs with different level of refinement



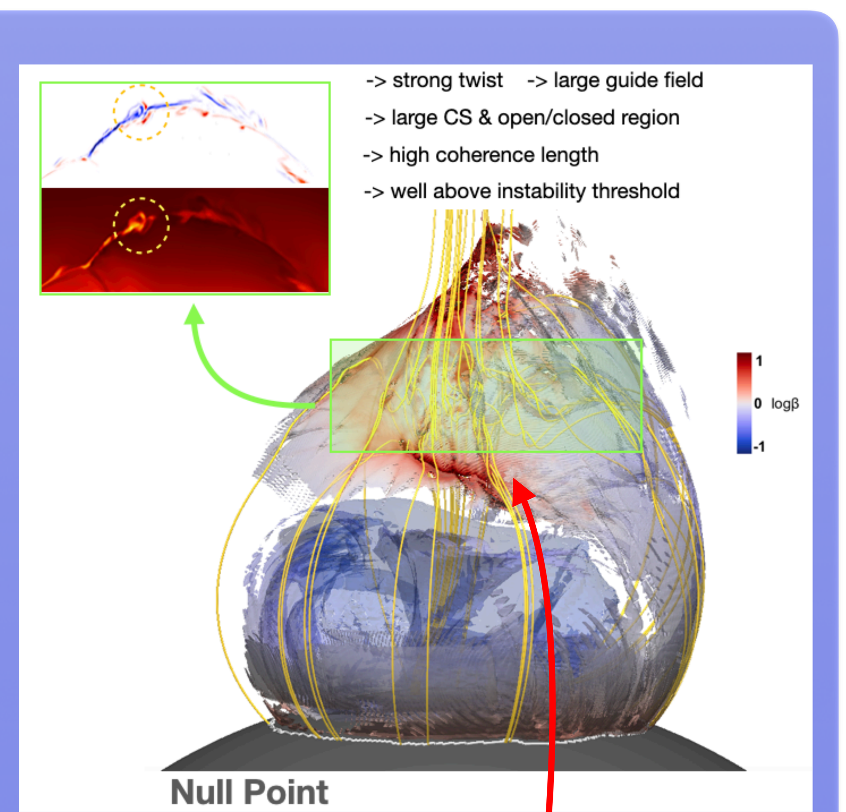
Adaptive Mesh Refinement

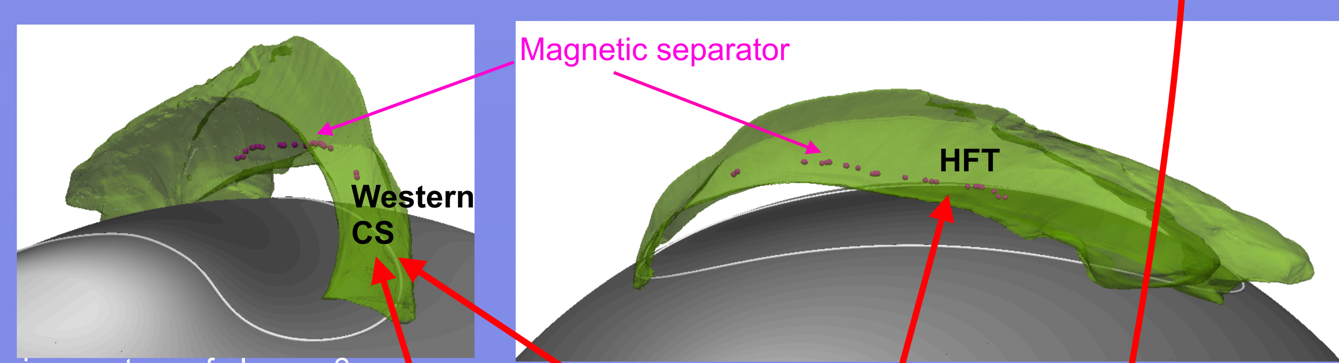
Regime Comparison

- PIC // Fluid MHD
- Preconditioned // Self-consistent
- Fast // Slow driving
- Explosive // Effusive topology
- Large // Small geometry



Daughton et al, 2012



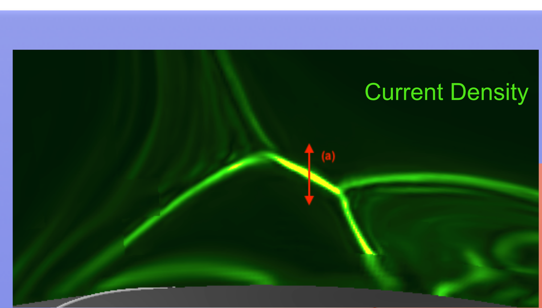


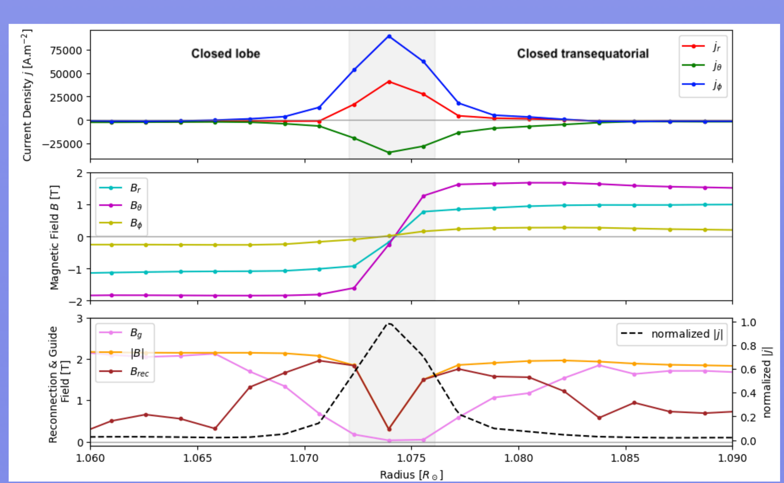
iso-contour of plasma β

	WEST (ref=6)	WEST (ref=5)	HFT (ref=6)	NP (ref=6)
S	10^4	5×10^3	10^2	7×10^4
RA	50	25	6	330
ζ	10 %	10 %	30 %	50 %
$M_{A,in}$	5 %	5 %	25 %	2 %

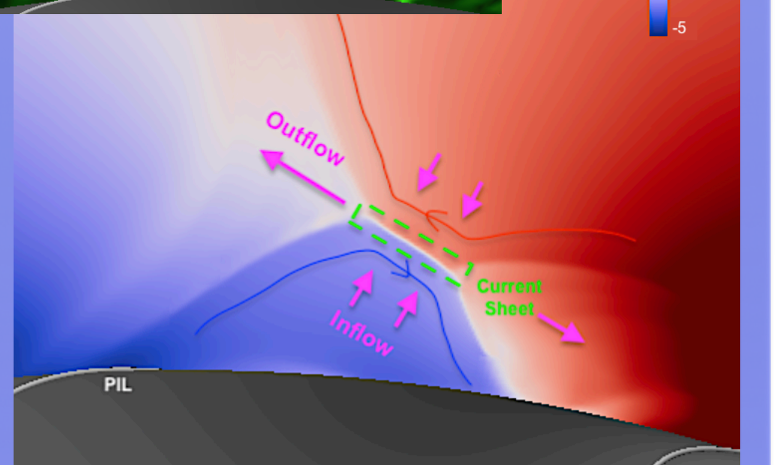
With coarser refinement (ref=5 or 6), we fall below instability threshold of 10^4. The Hyperbolic Flux Tube which has naturally formed around the extended separator of the PS seems to restrict the squashing of the CS, almost by a factor 10. This effect that arises only by considering a genuine 3D model needs to be investigated further

Current Sheet Specs





Radial cut (a) through the western (ref=6) CS



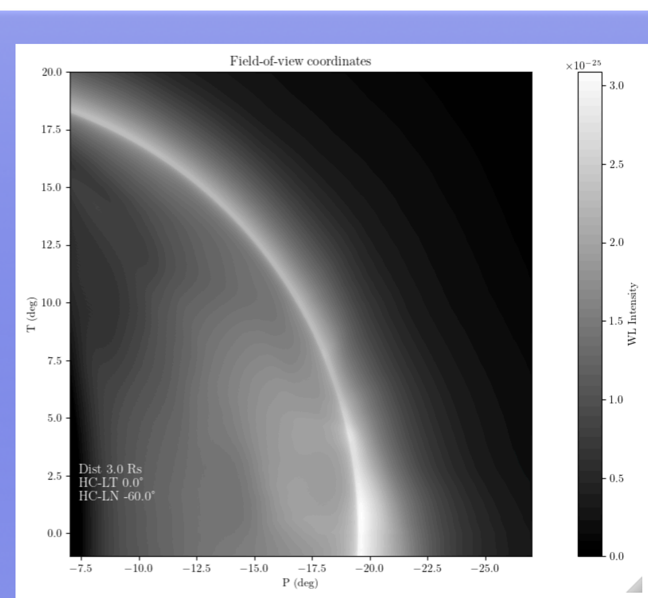
Transverse B field

After the system is initialised and relaxed, we apply a photospheric forcing to shear the separator of the PS in order to self-consistently create a current sheet. In the western part of the PS, we indeed form a Harris sheet that has been extended enough to be subject to tearing.

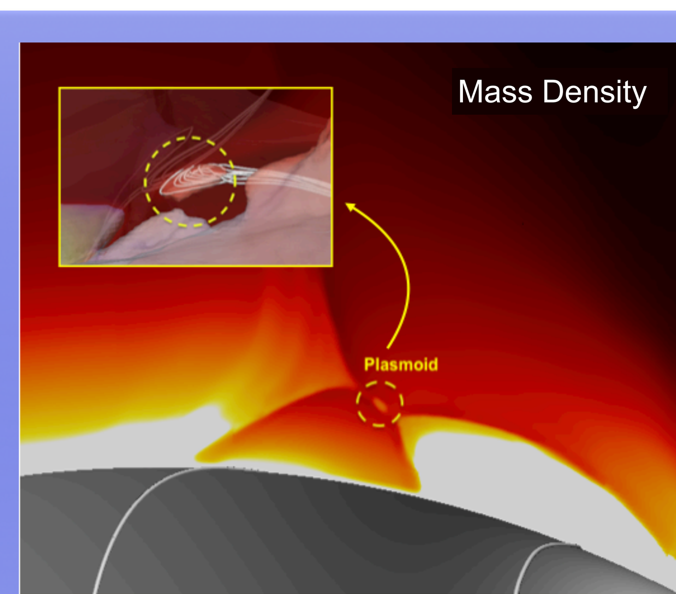
Conclusions

1. **Three-dimensional tearing** is still largely misunderstood
2. The HFT structure constrains the growth of **unstable current sheets**
3. Pseudo-streamers are not likely to produce and eject stable **plasma blobs**
4. These plasma blobs are not easily detectable with **white-light imaging**

Geometry and **topology** affect the onset and evolution of tearing instability in coronal configurations



Synthetic White-Light Image



Density 2D slice + isocontour (subpanel)