Probing realistic CME model with the Icarus heliosphere model and PUNCH observations

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The Sun-Earth system

Solar Corona

Inner Heliosphere

Dynamic solar wind interacts with the CMEs

WSA semi-empirical coronal model
(Arge et al 2004)

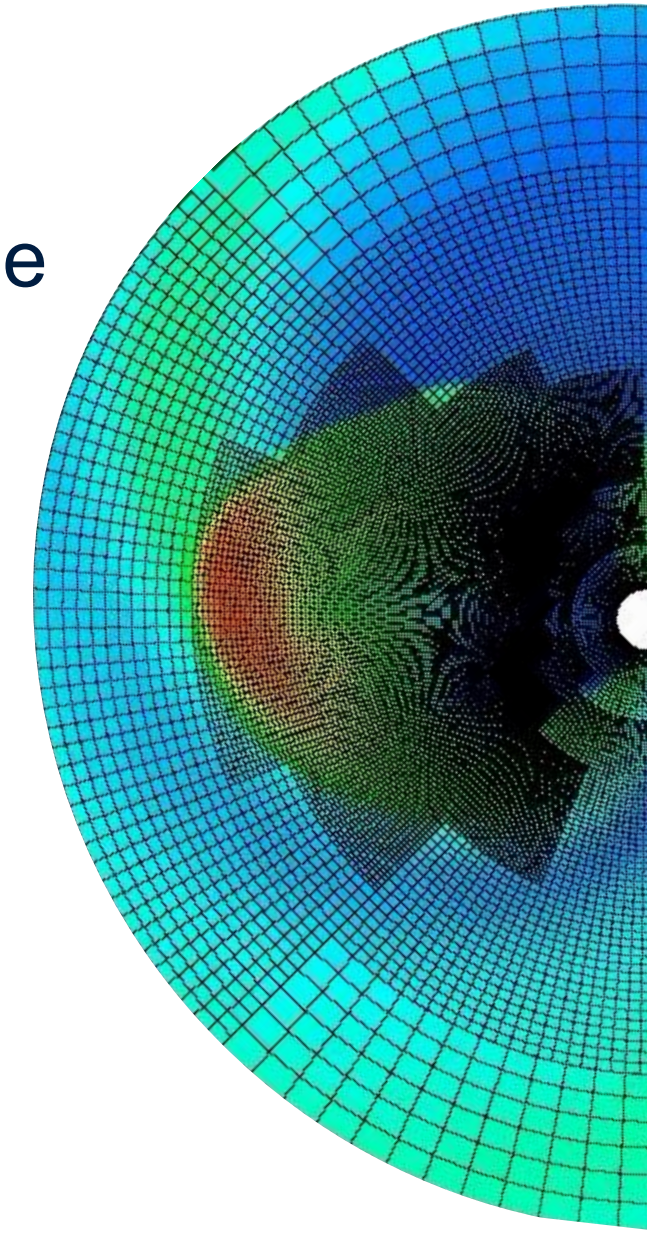
Icarus
(Baratashvili et al. 2025)

0.1 AU

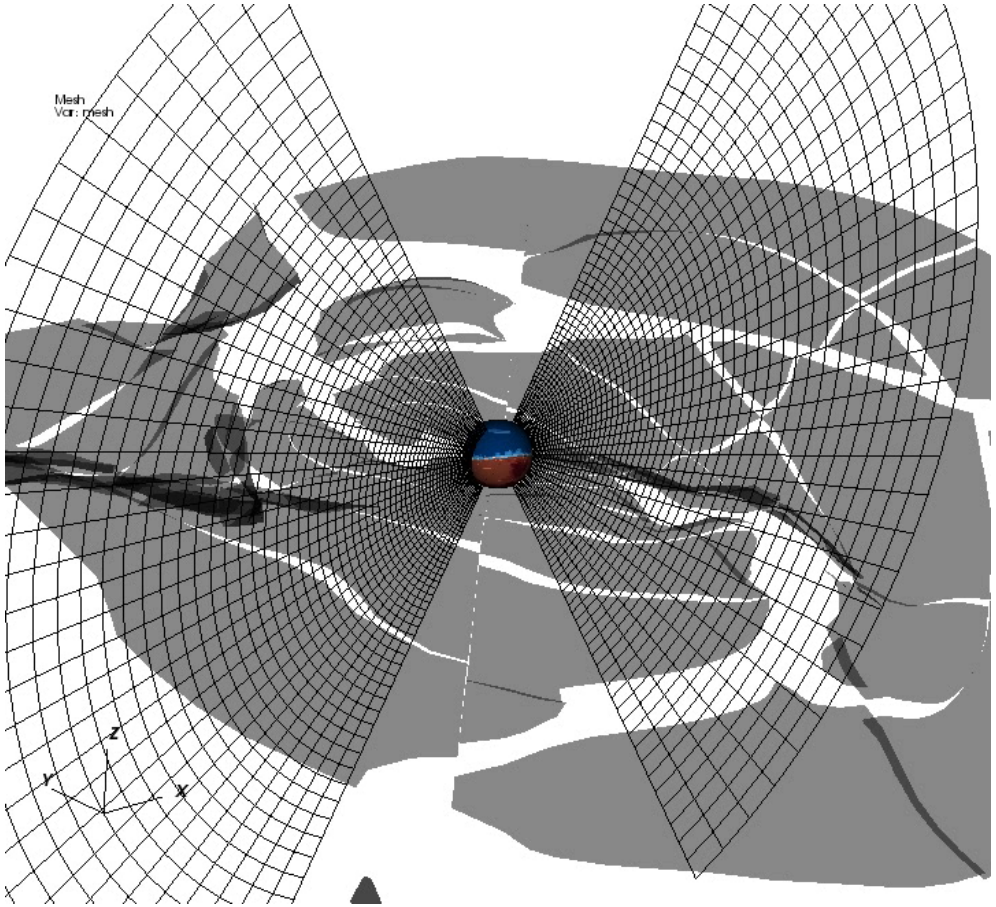
1 AU

Heliospheric modelling with Icarus

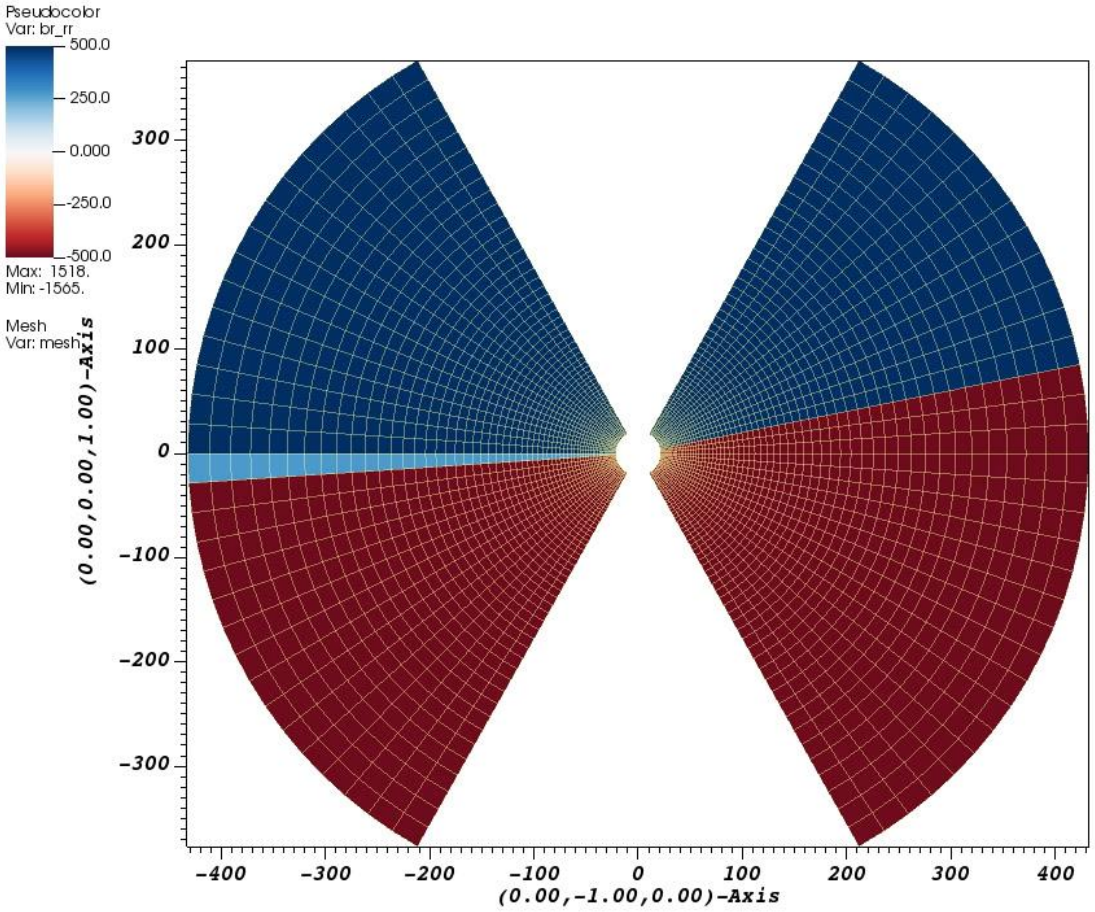
- Icarus (Baratashvili et al. 2025) is implemented within MPI-AMRVAC (Keppens et al.2023) framework with MHD module
- The domain:
  - Radial - (21.5, 432) $R_\odot$
  - Latitudinal - (-60°, 60°) (poles can also be included)
  - Longitudinal - (0°, 360°)
- Co-rotating frame with the Sun
- Optimized numerical methods (Baratashvili et al. 2023)
- Non-magnetized and magnetized CME models
- Time dependent boundary driving
- Supports advanced techniques
  - Radial grid stretching
  - Adaptive mesh refinement (AMR)



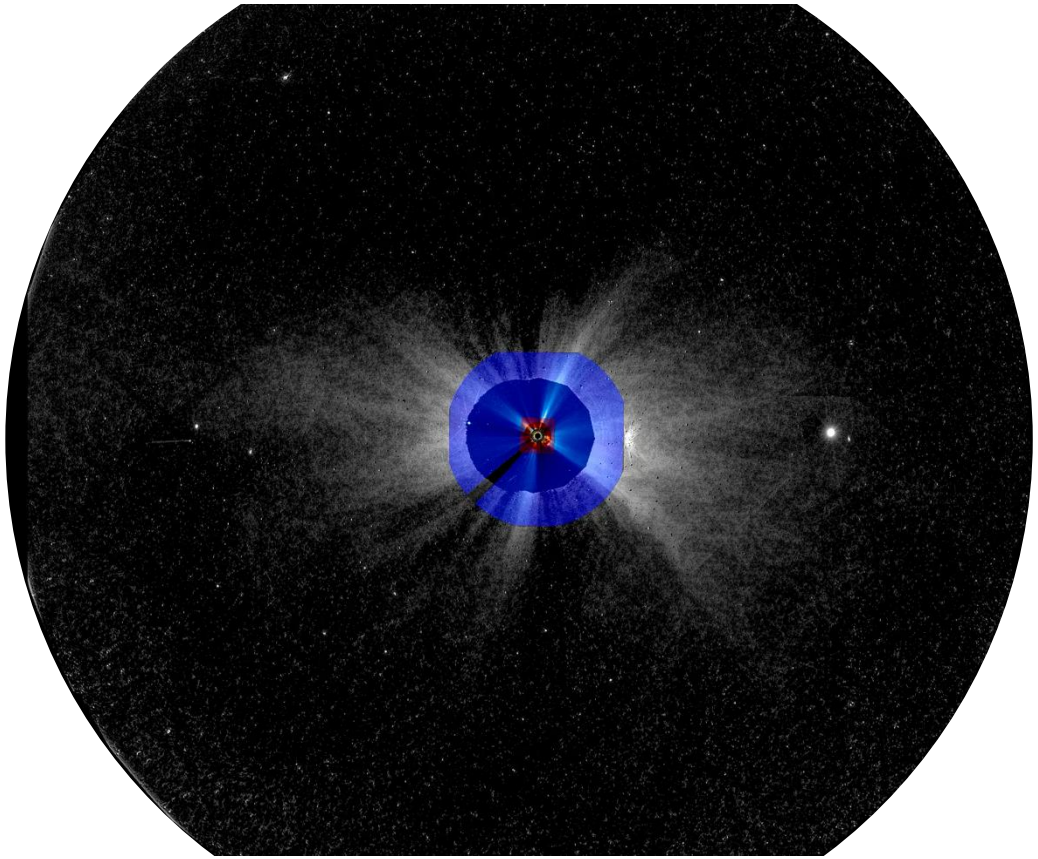
Advanced Techniques: Grid Stretching and Adaptive Mesh Refinement



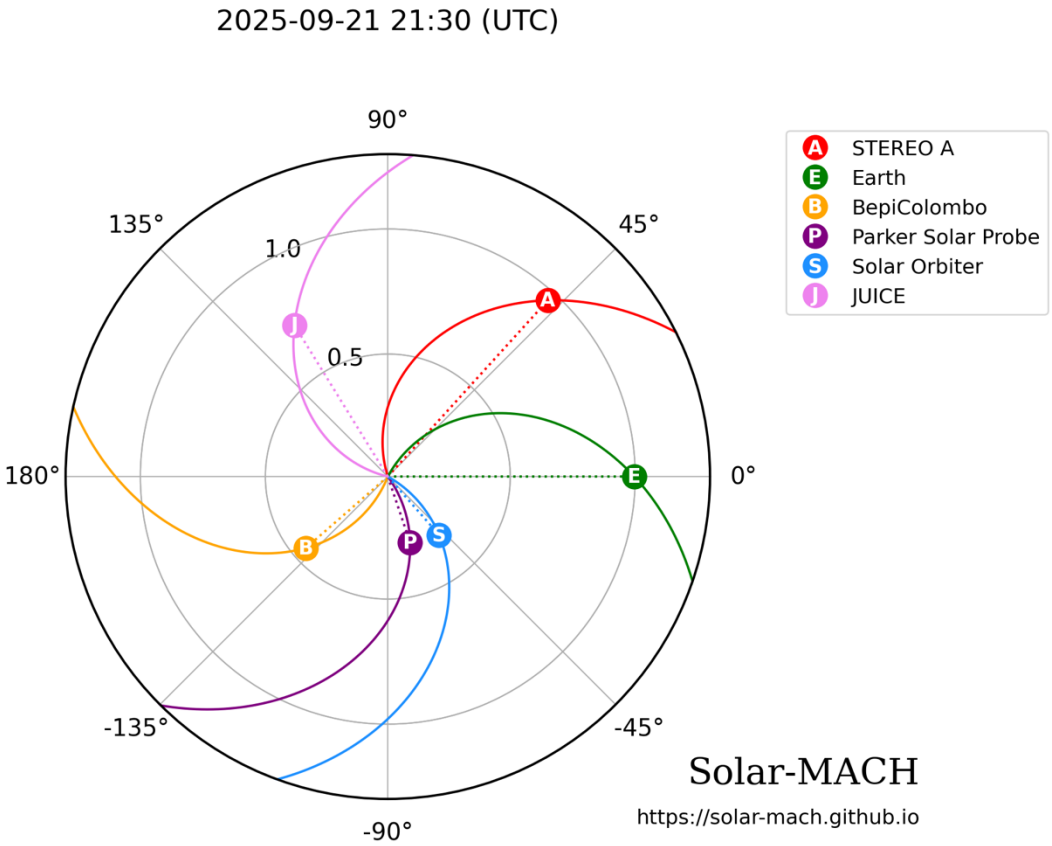
AMR enhanced on the left



September 21, 2025

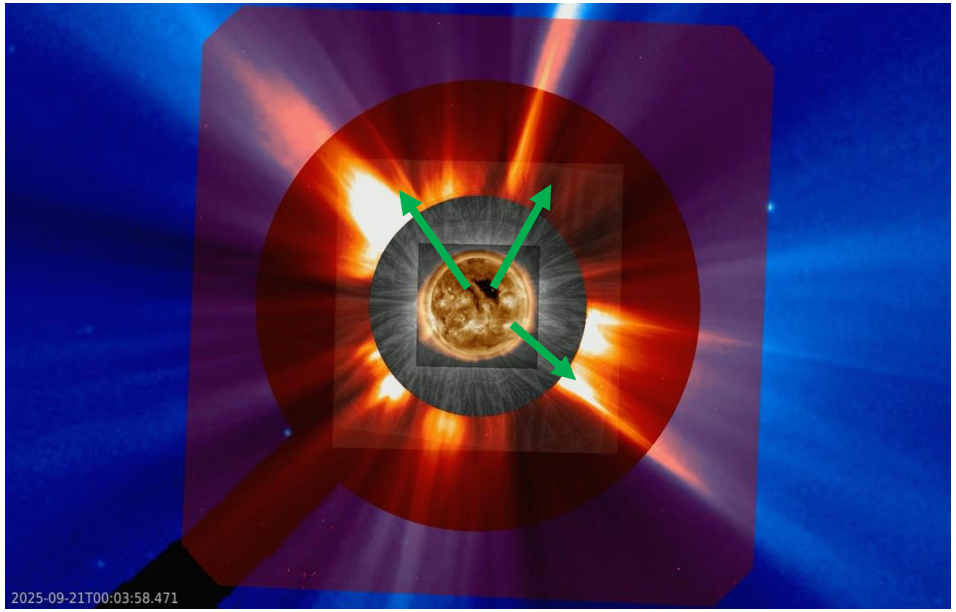


SOHO/LASCO C2+C3 + PUNCH

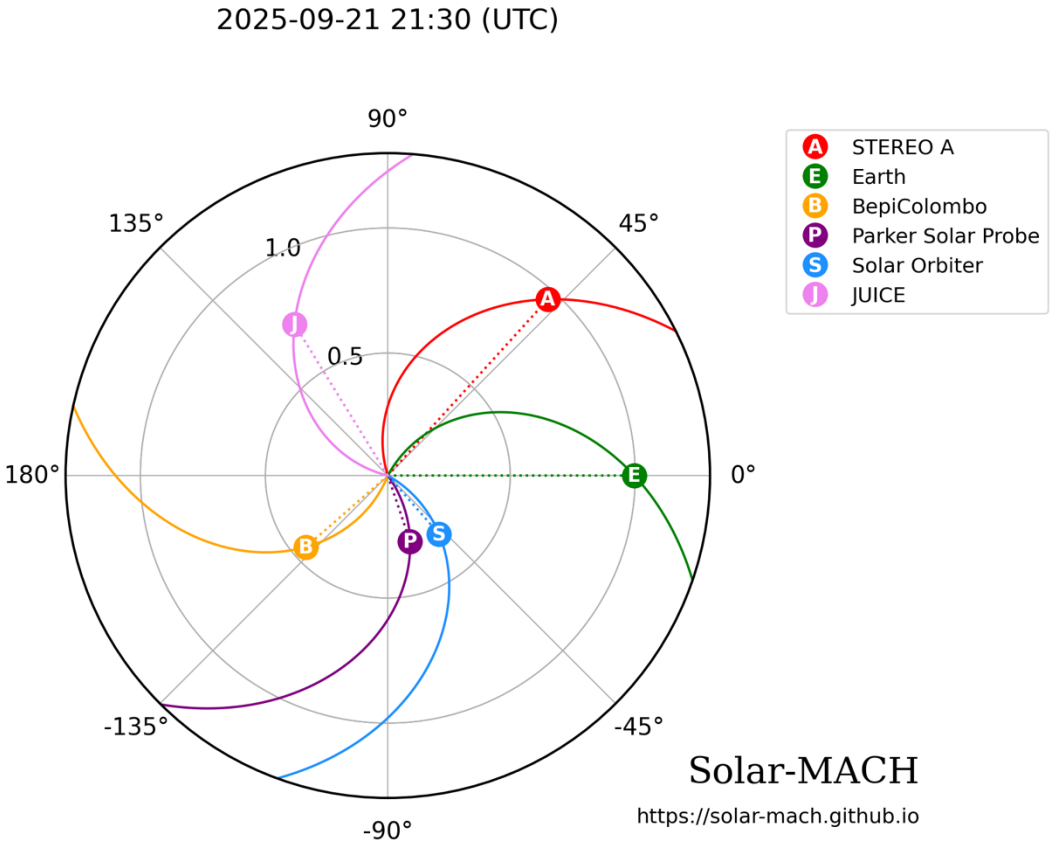


L1 Field of view

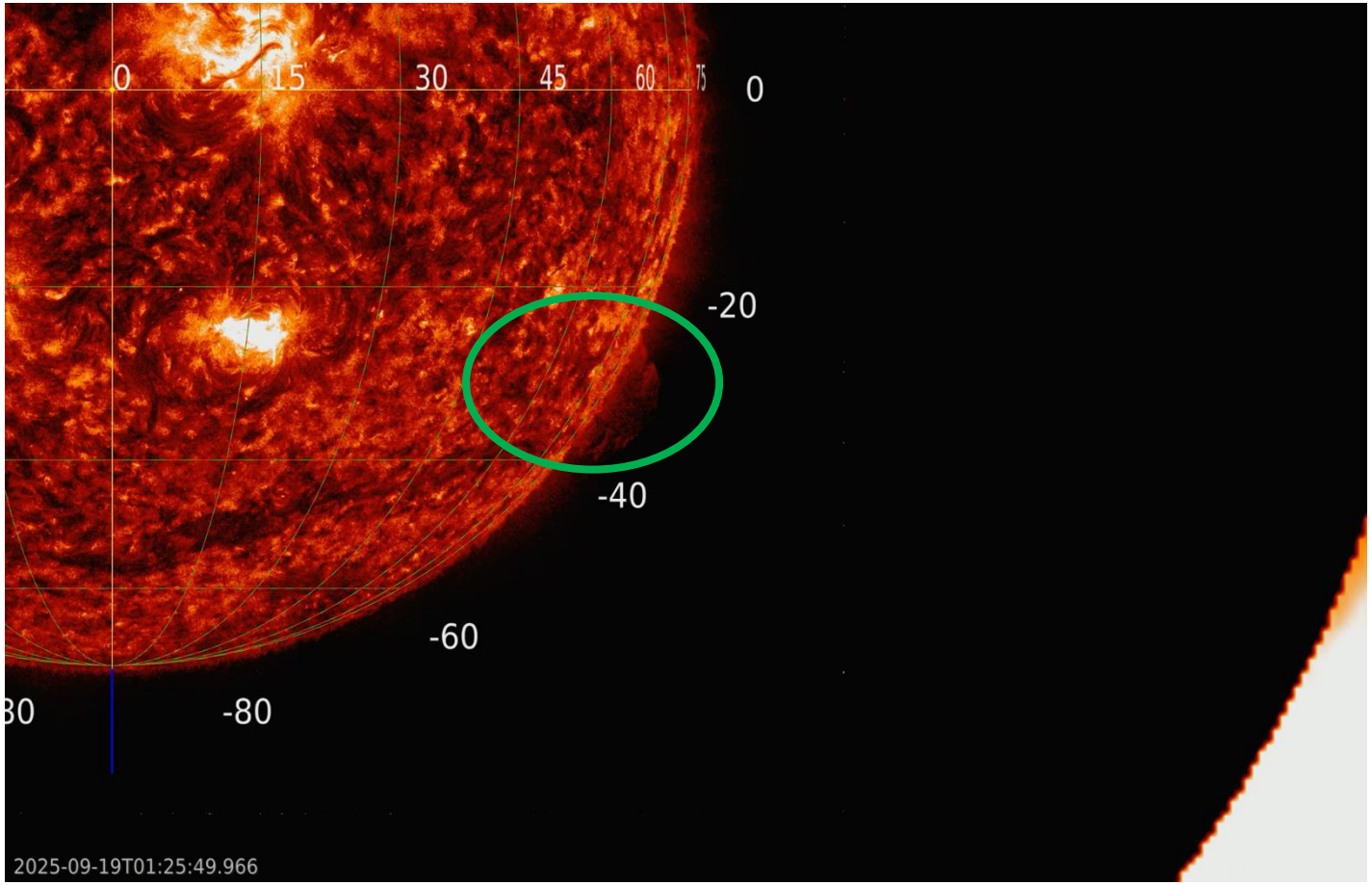
Three CMEs erupted almost simultaneously on September 21, 2025

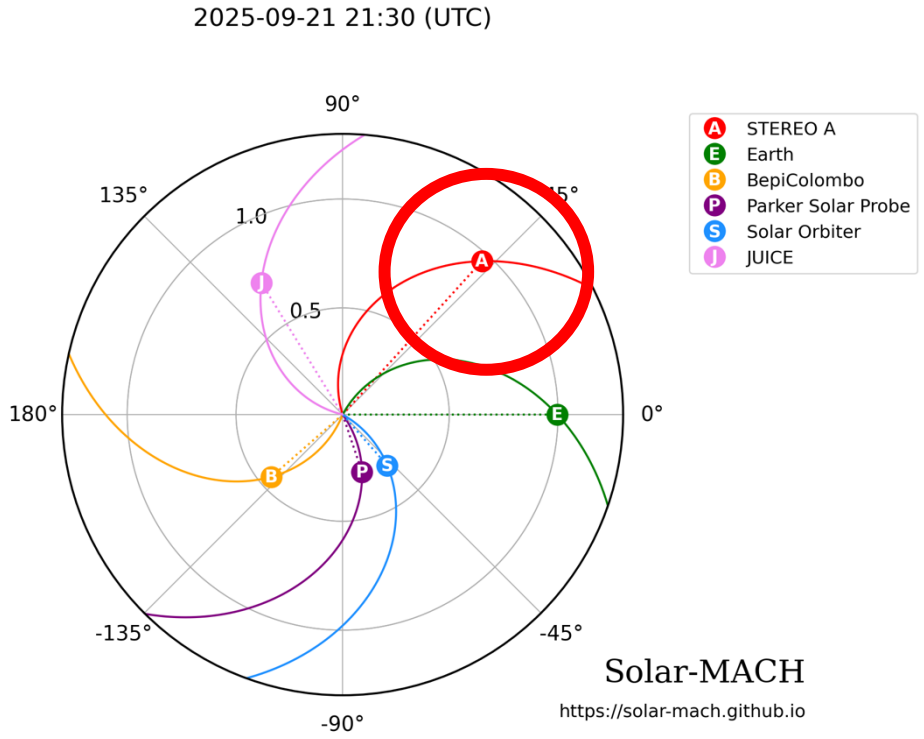


AIA + ASPIICS + SOHO/LASCO C2 + C3



Eruption structure in the south

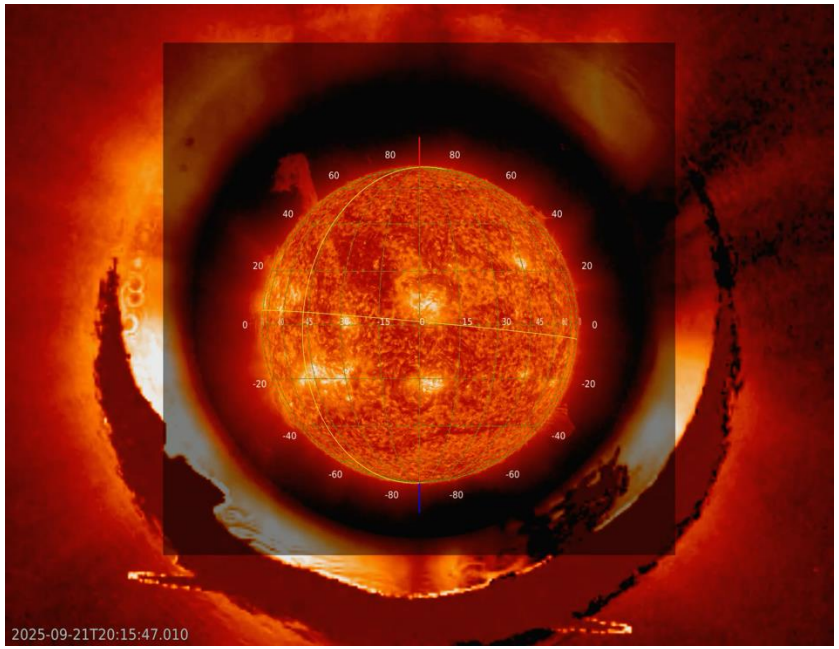


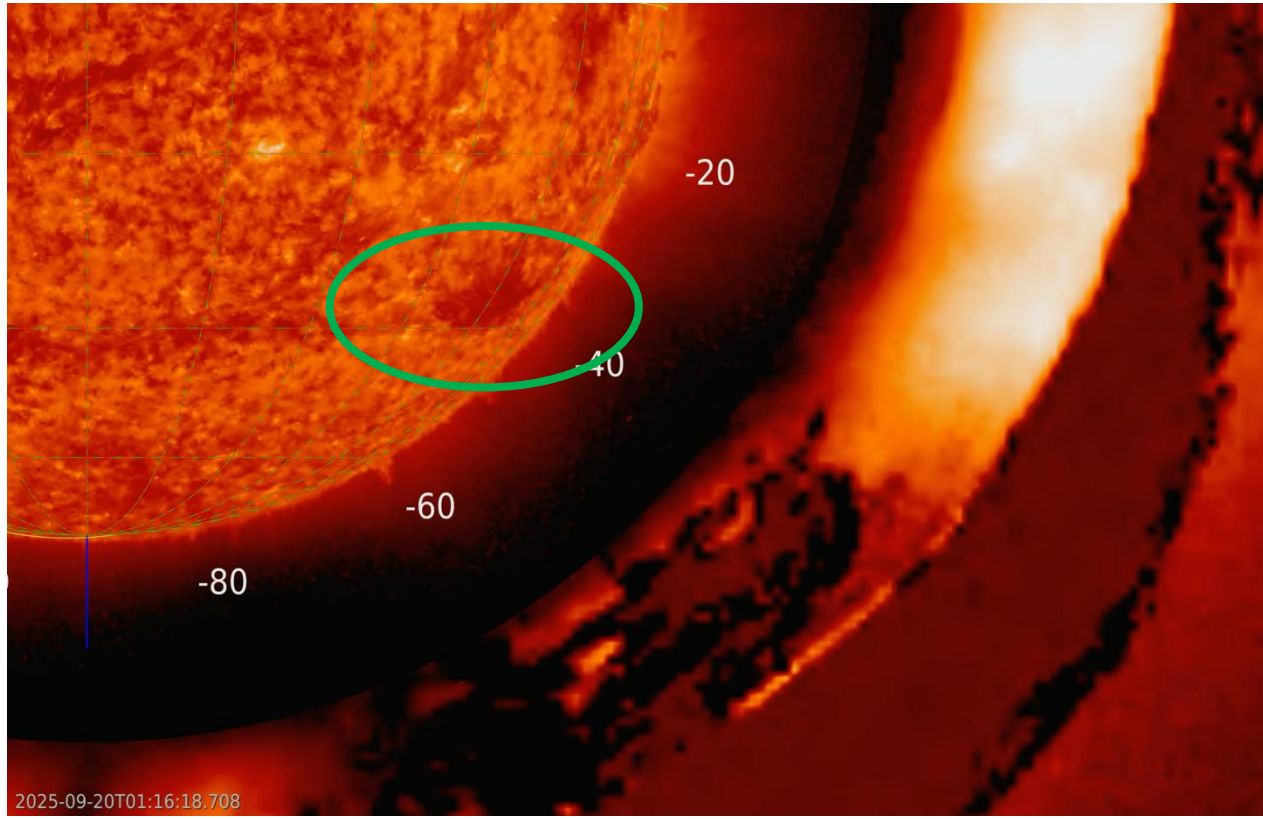


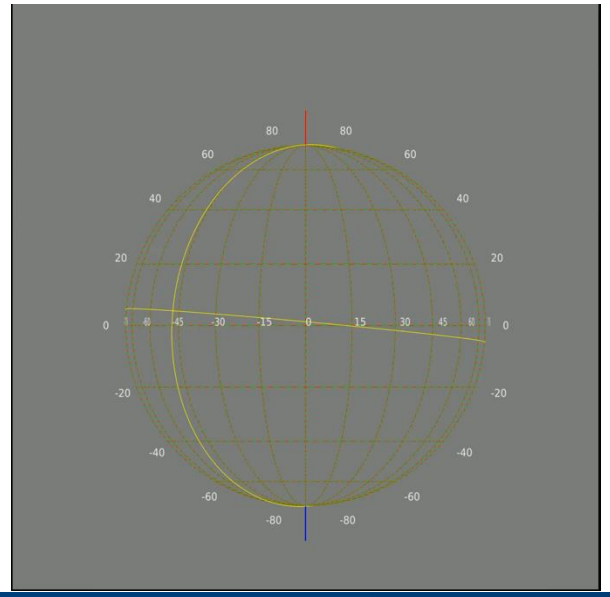
We observe the structure a few days before, also seen in STA

Stereo-A

EUVI 304 + COR1



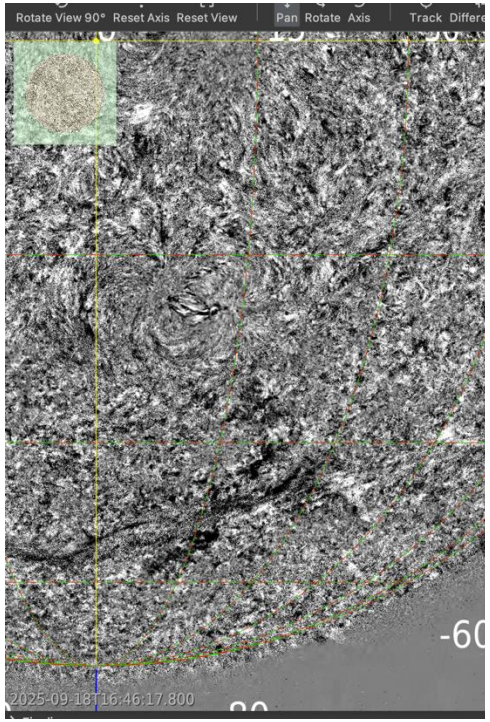




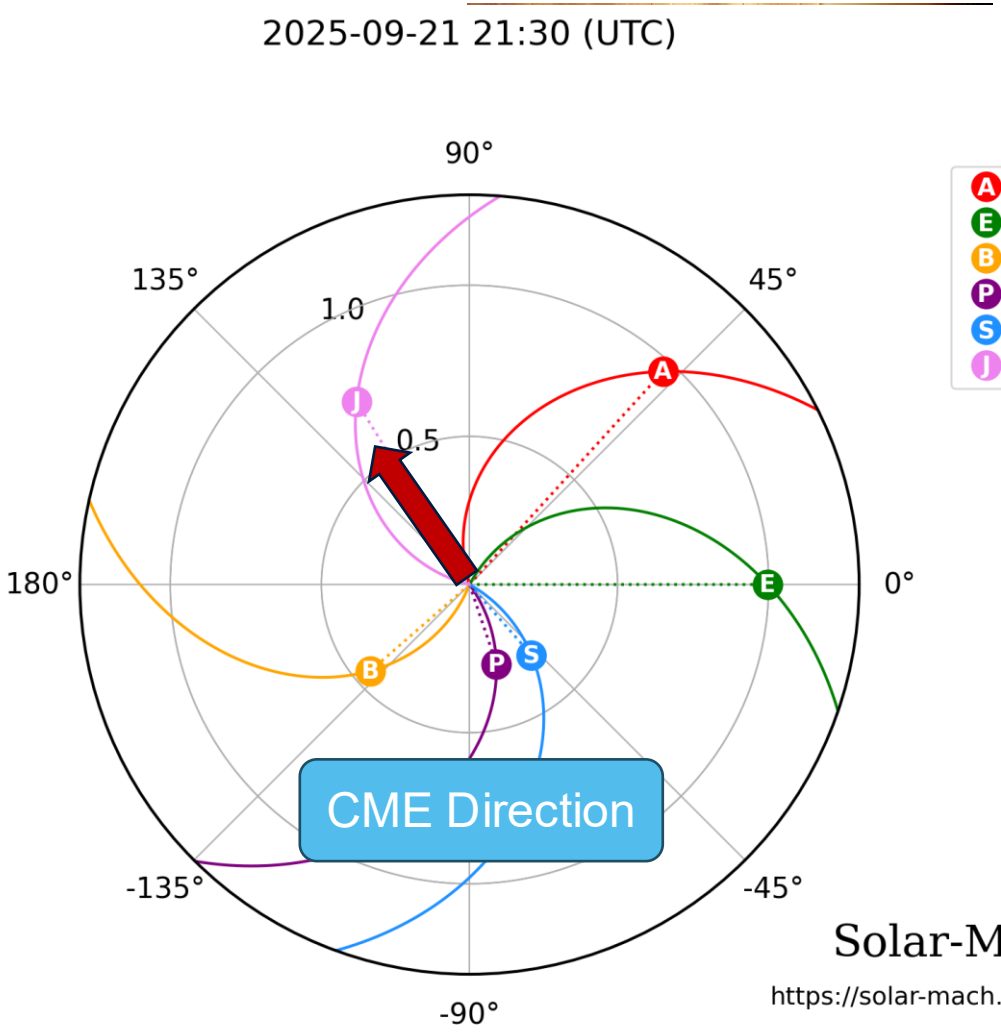
Base difference in EUVI 304

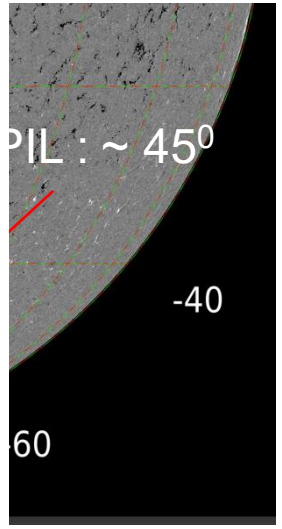
We can look at the magnetic field configuration of the structure a few days before the eruption while we can still see it

Parameter estimation



On 16.09 14:31 it is at
On 21.09 21:31 it mus

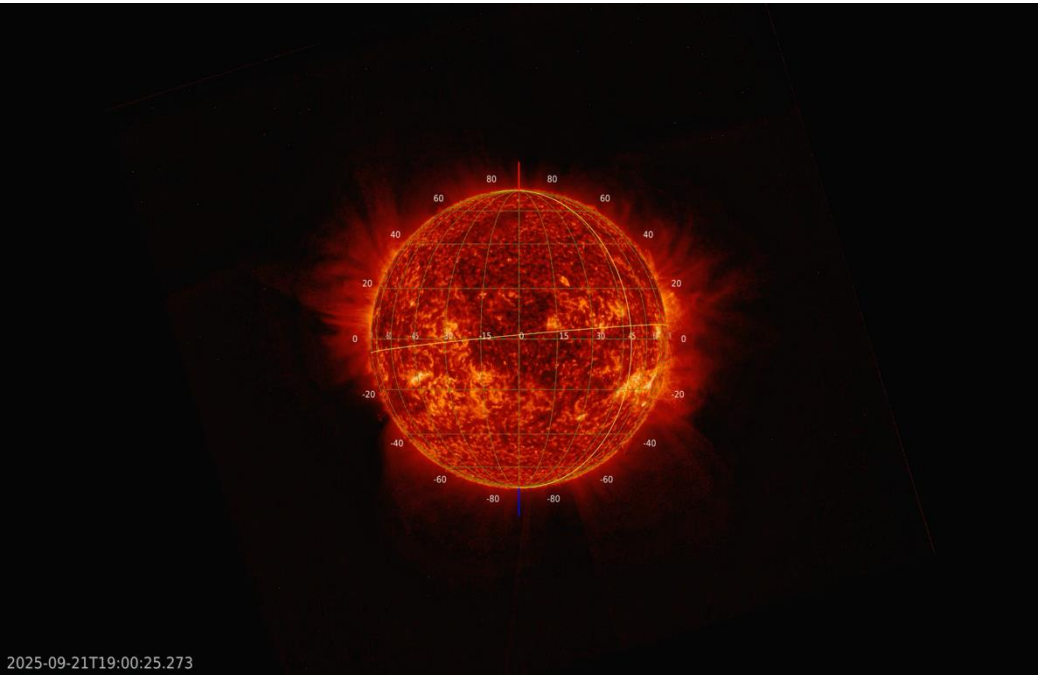




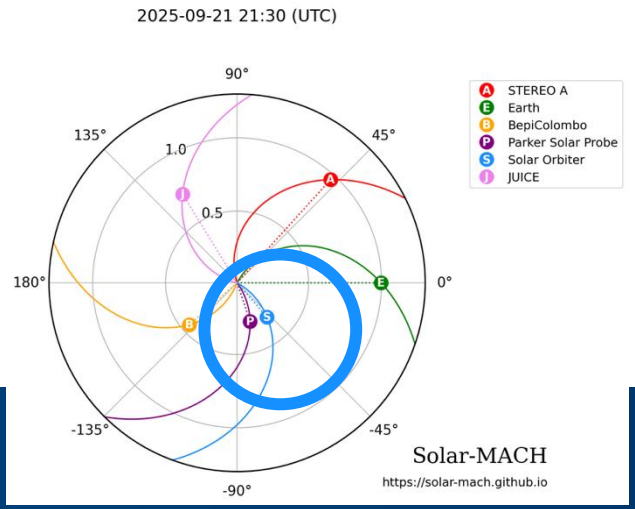
We can assume positive helicity since it is in the south

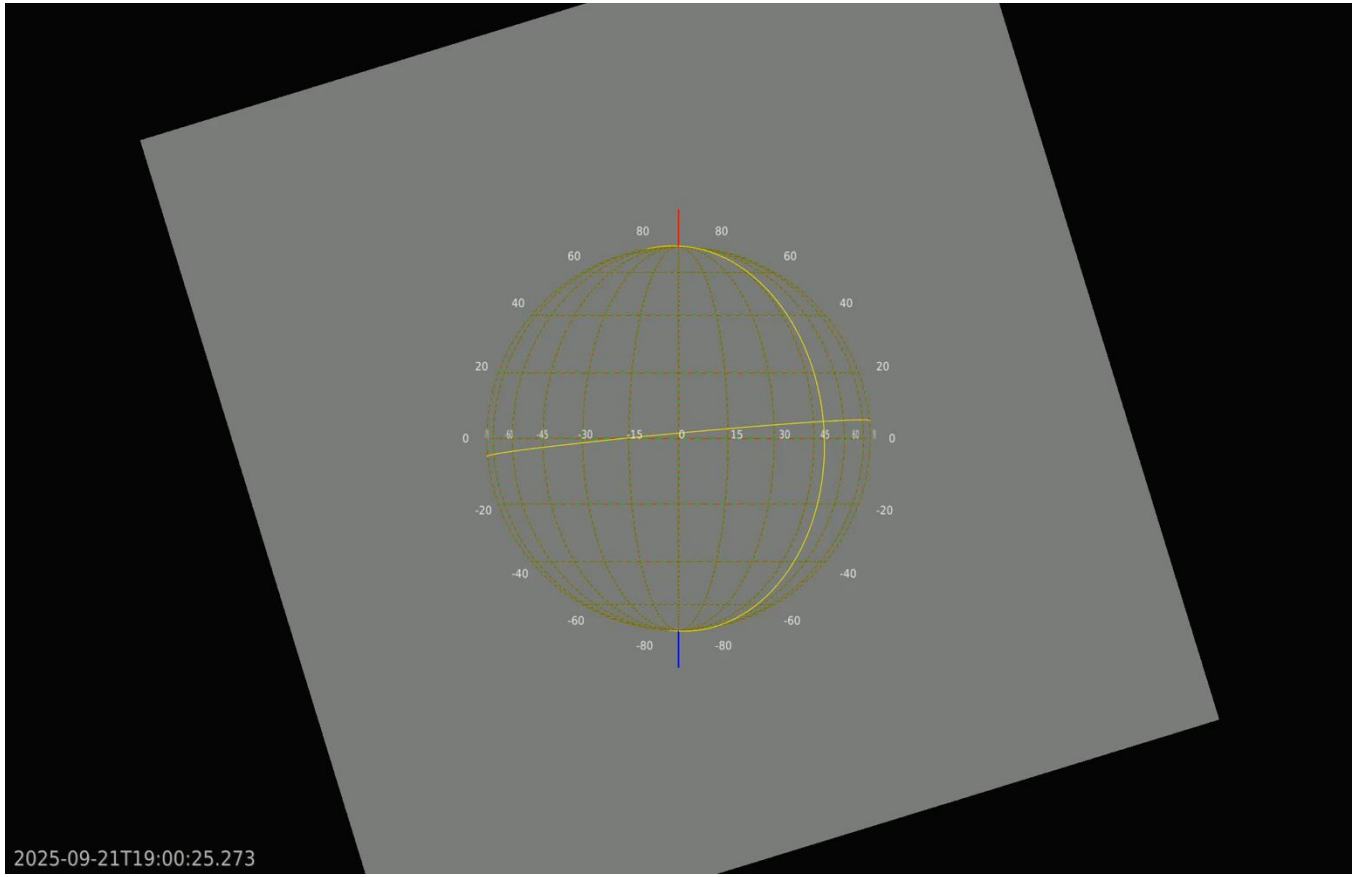
	September 21
hi, theta)	(130, -32)
	NA
	ESW/NES
	45 (-135 spheromak)
	600 km/s
At 21.5	22.09.2025 05:19

Solar Orbiter



EUI 304



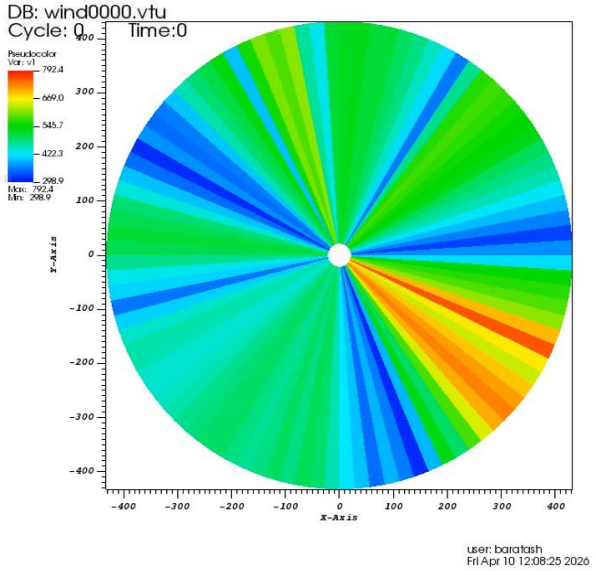


Difference in EUI 304

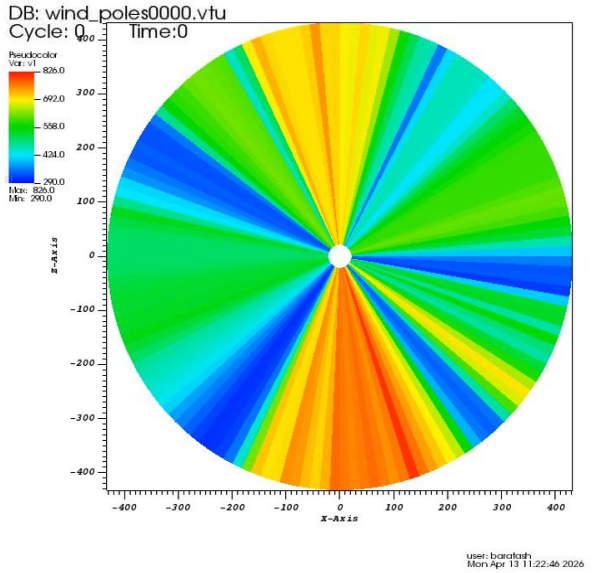
Icarus simulations

- First, time-dependent background solar wind modelled
  - From 10.09.2025 – 30.10.2025 – 1h cadence
- We included the poles since the CMEs have high altitudes

Equatorial plane



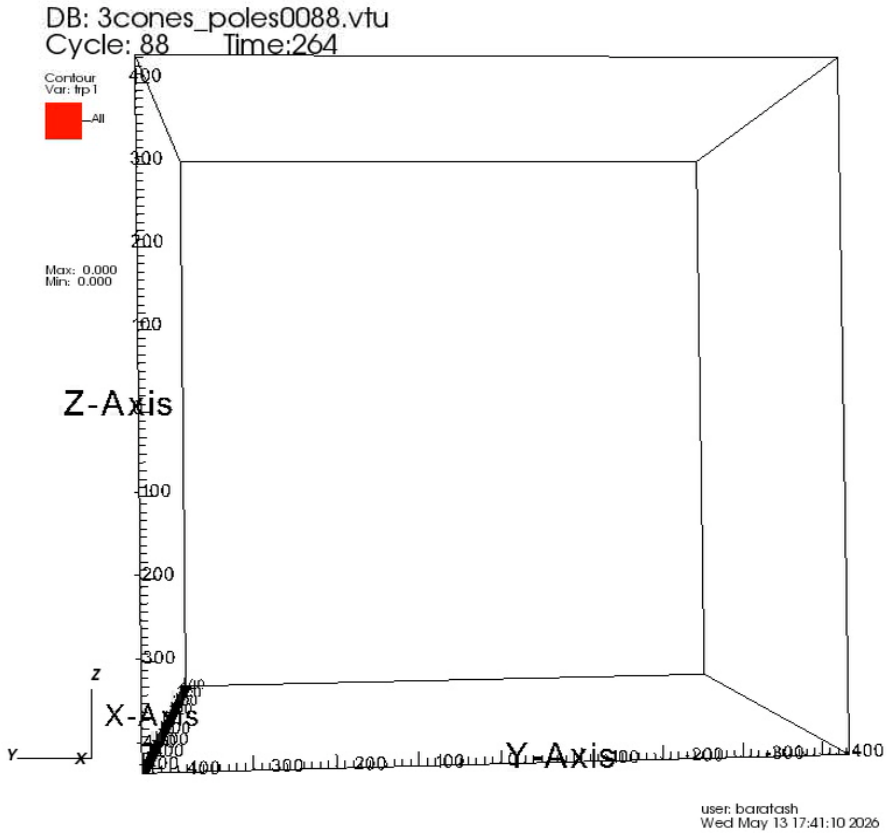
Meridional plane



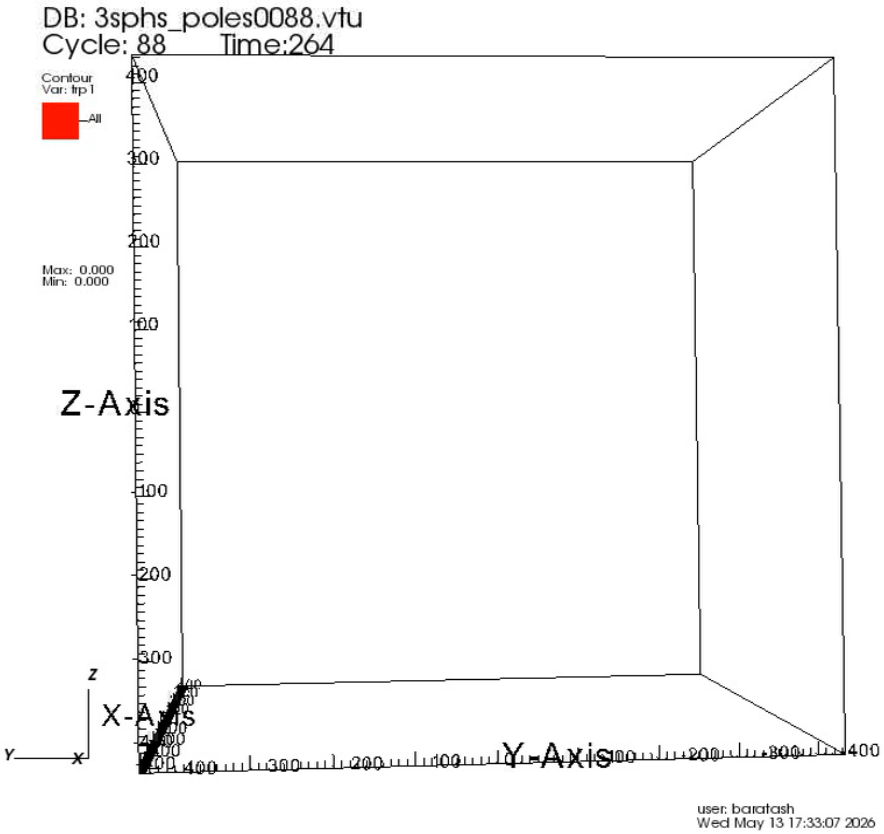
Spheromak in Icarus – Baratashvili et al., 2024a
Cone model – Scollini et al. 2018

Cone and Spheromak CMEs injected

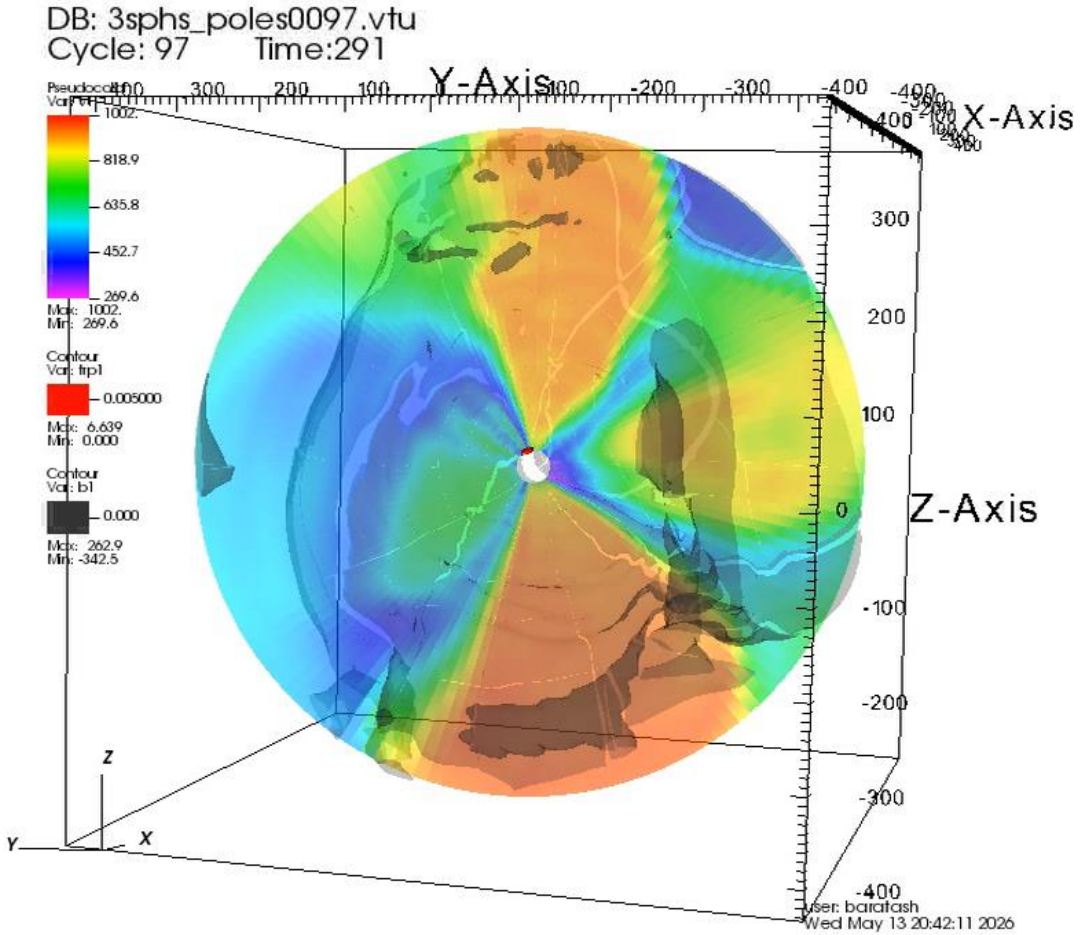
Cone: CME density



Spheromak: CME density



Spheromak CME in the meridional plane



- Background – radial velocity
- Heliospheric current sheet – shaded grey
- Contours of the CME density - red

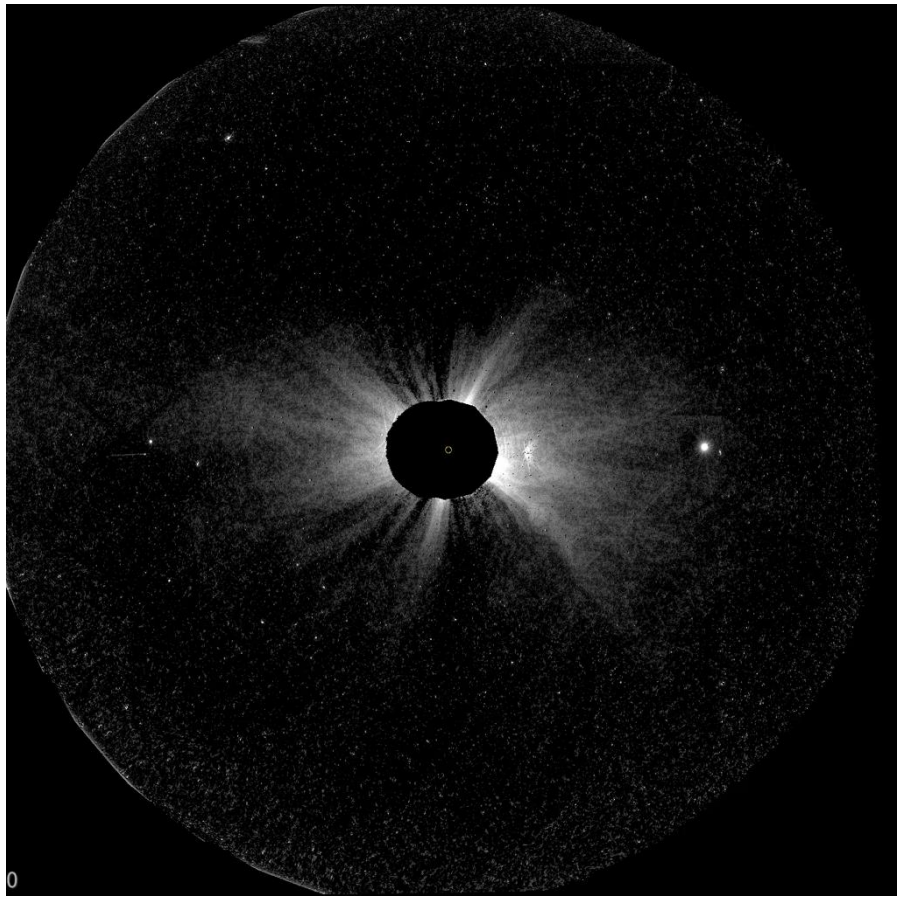
Note* the movie is in the co-rotating frame fixed to earth location when CMEs erupt

Synthetic white-light image – cone CME

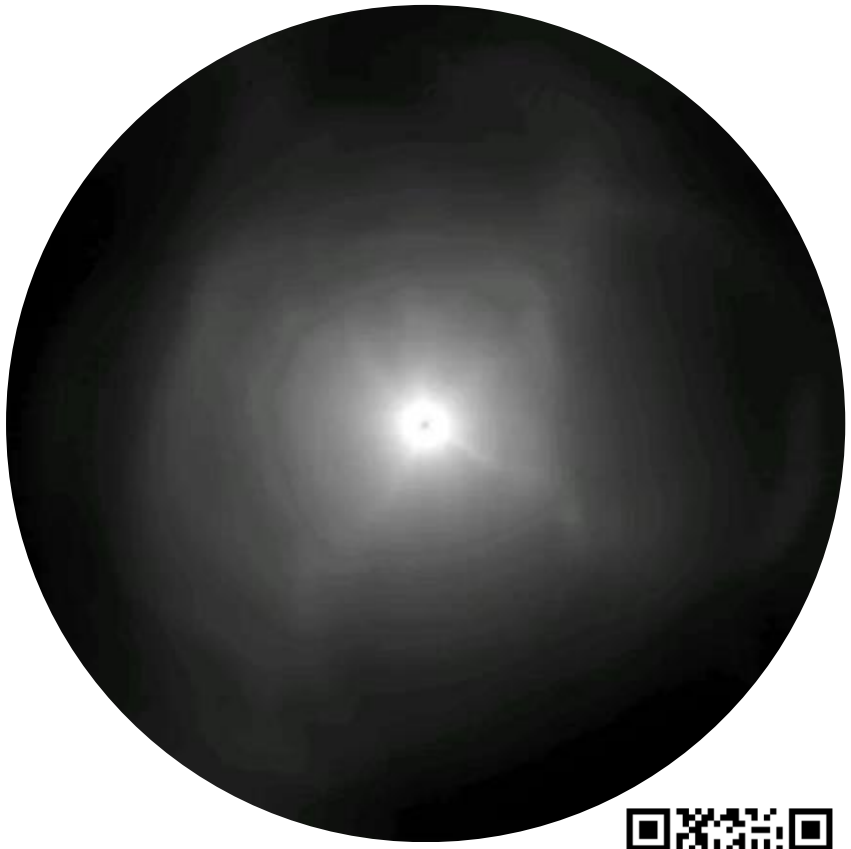
FoMo model

Van Doorsselaere et al. 2016

PUNCH – PAM – V0K



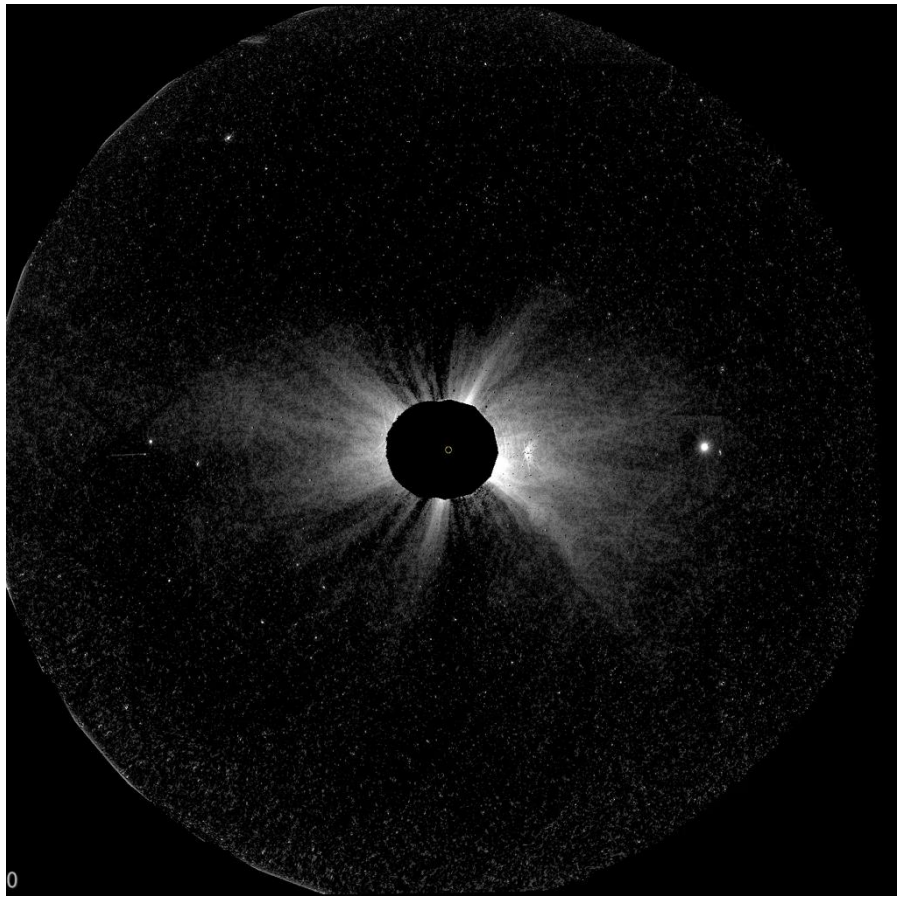
Synthetic white-light image – spheromak CME



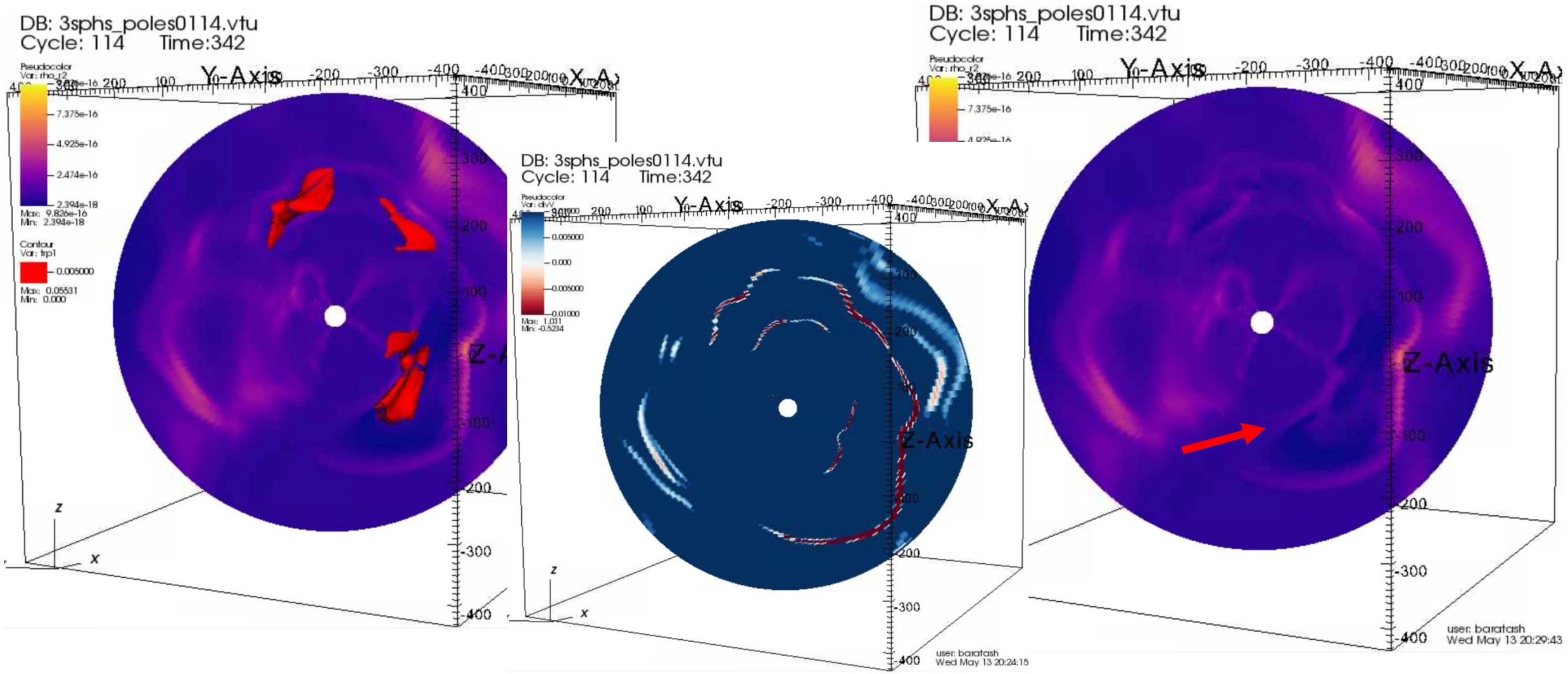
FoMo model

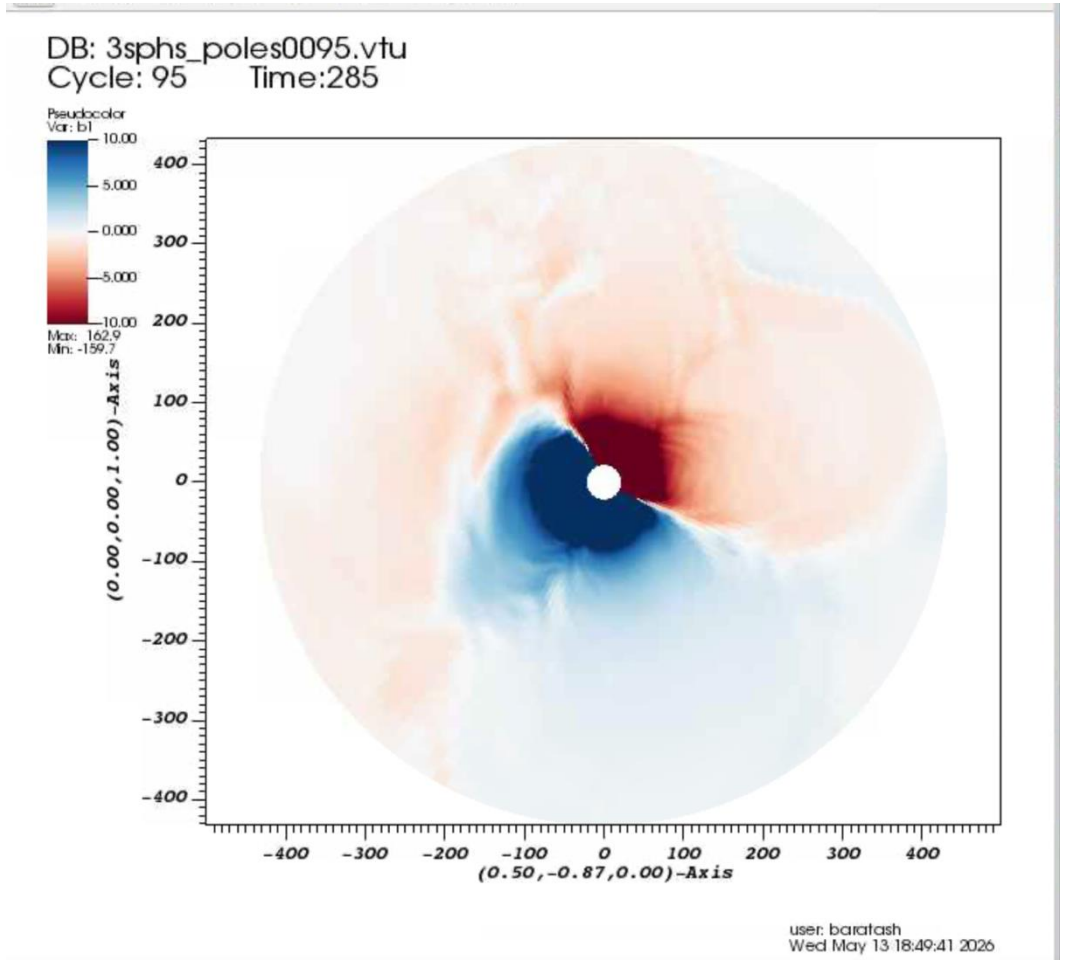
Van Doorsselaere et al. 2016

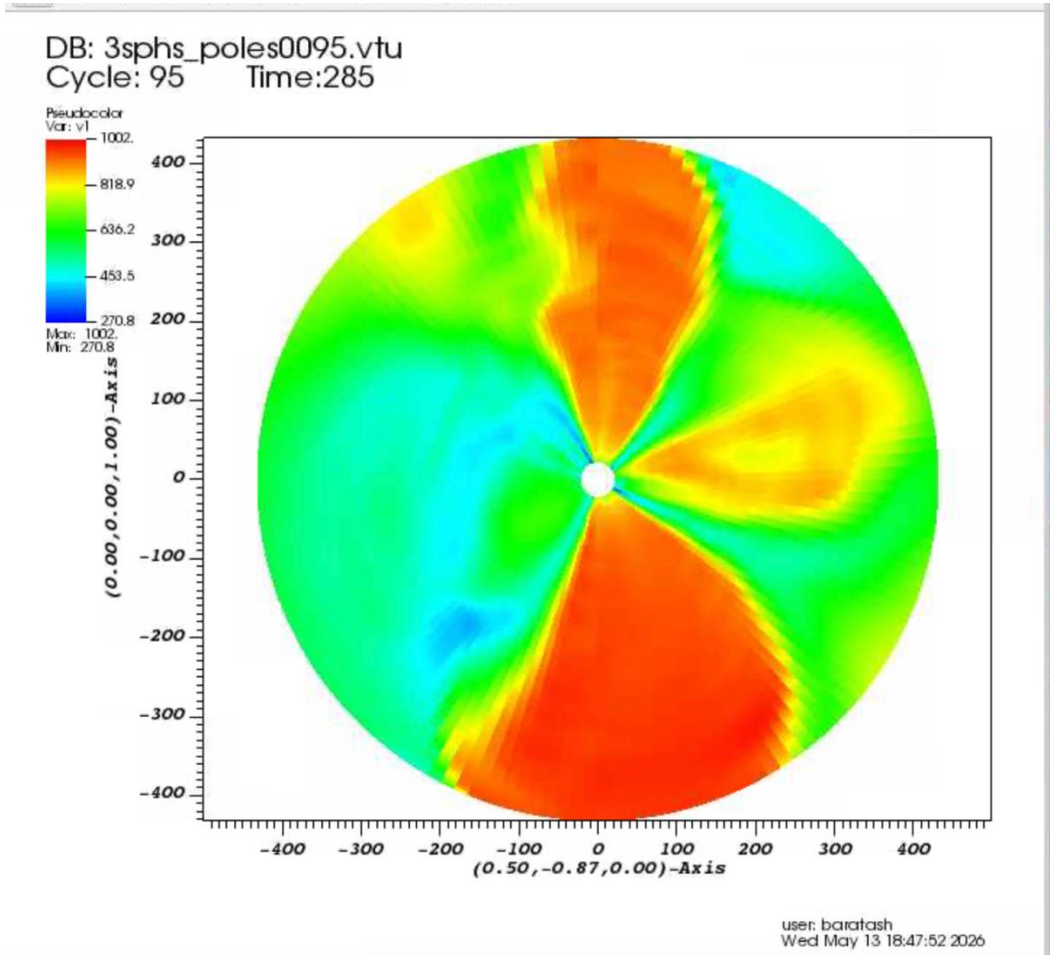
PUNCH – PAM – V0K



Enhanced density behind the CME




DB: 3sphs_poles0095.vtu
Cycle: 95 Time:285
Pseudocolor
Var: b1
10.00
5.000
0.000
-5.000
-10.00
Max: 162.9
Min: -159.7
(0.00,0.00,1.00)-Axis
(0.50,-0.87,0.00)-Axis
user: baratash
Wed May 13 18:49:41 2026


DB: 3sphs_poles0095.vtu
Cycle: 95 Time:285
Pseudocolor
Var: v1
1002.
818.9
636.2
453.5
270.8
Max: 1002.
Min: 270.8
(0.00,0.00,1.00)-Axis
(0.50,-0.87,0.00)-Axis
user: baratash
Wed May 13 18:47:52 2026

Summary and future prospects

Thank you!

- We are injecting FRI3D CME model which has a more complex and realistic structure
- We are connecting Icarus to FORWARD WL tool
- We are generating movies in inertial frame to compare with PUNCH
- Gradually add CMEs in September – October 2025

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