Advancements in Modeling the Global Inner Heliosphere and Interplanetary CMEs in Preparation for PUNCH mission

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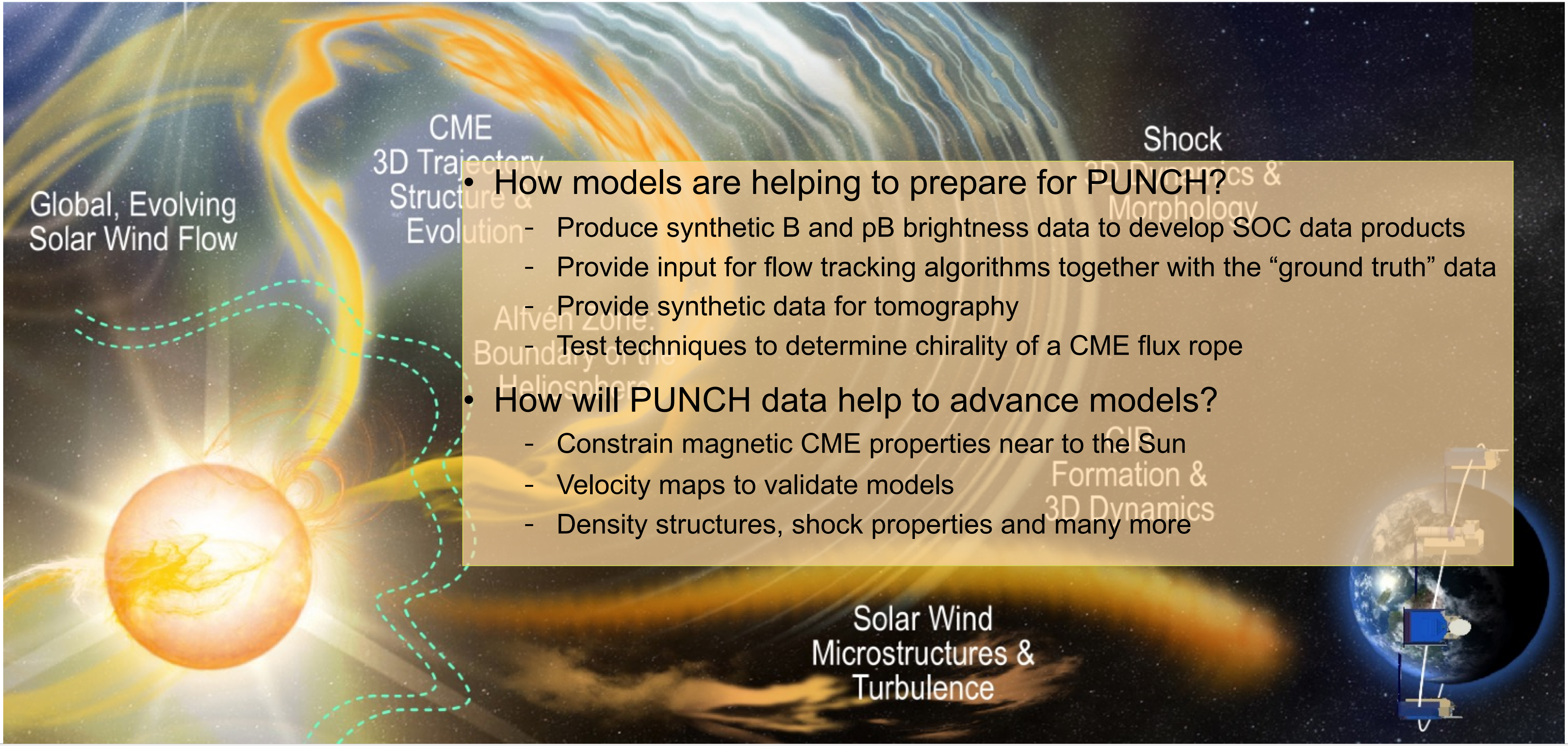
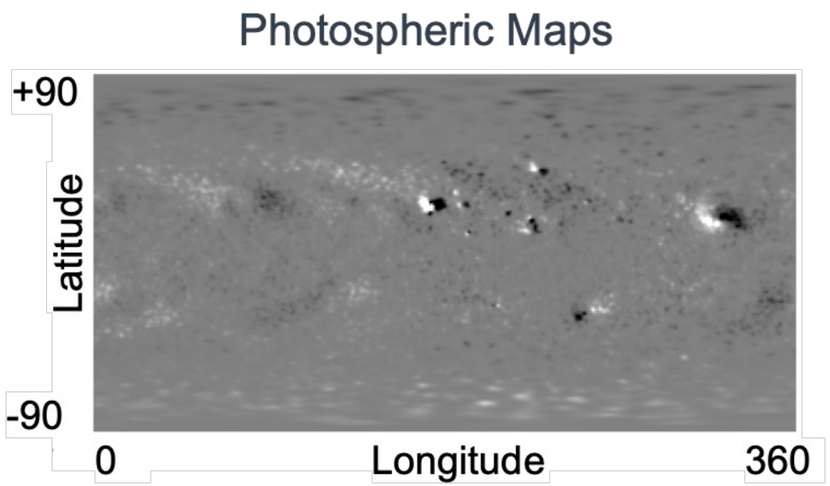
PUNCH and global MHD models

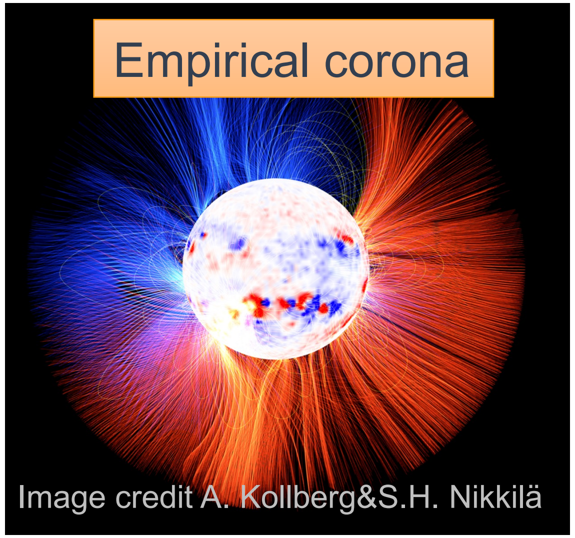


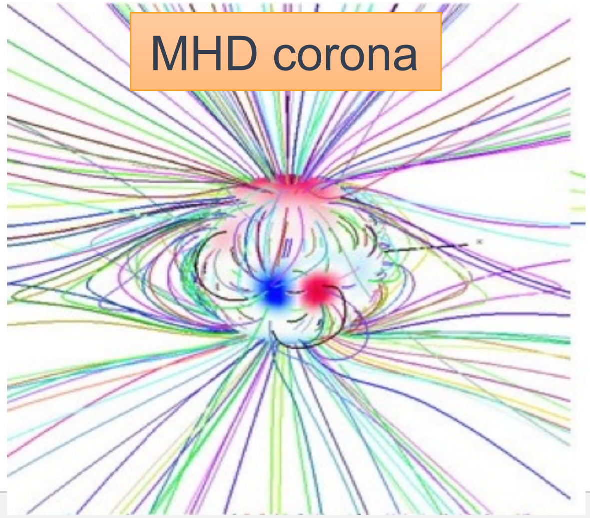
- How models are helping to prepare for PUNCH?
  - Produce synthetic B and pB brightness data to develop SOC data products
  - Provide input for flow tracking algorithms together with the “ground truth” data
  - Provide synthetic data for tomography
  - Test techniques to determine chirality of a CME flux rope
- How will PUNCH data help to advance models?
  - Constrain magnetic CME properties near to the Sun
  - Velocity maps to validate models
  - Density structures, shock properties and many more

Global MHD modeling of the inner heliosphere: solar wind

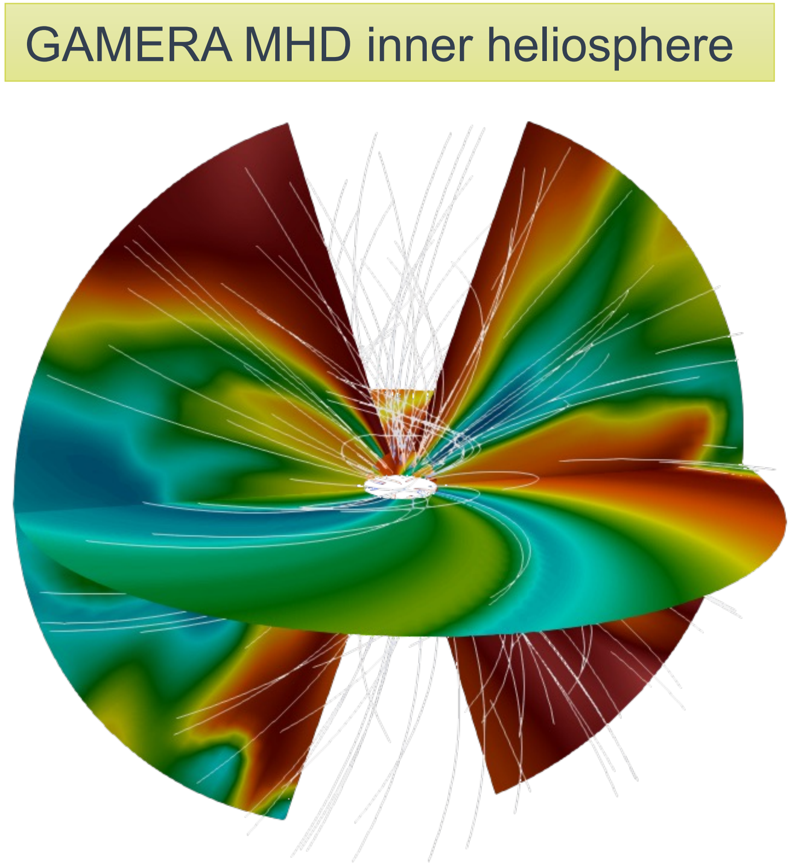
- Inner heliosphere typically refers to a region between 20 R_S and 1-2 AU
- Requires boundary conditions at 20 R_S
  - MHD models of the solar corona
  - Semi-empirical model of the solar corona
- Steady-state or time-dependent







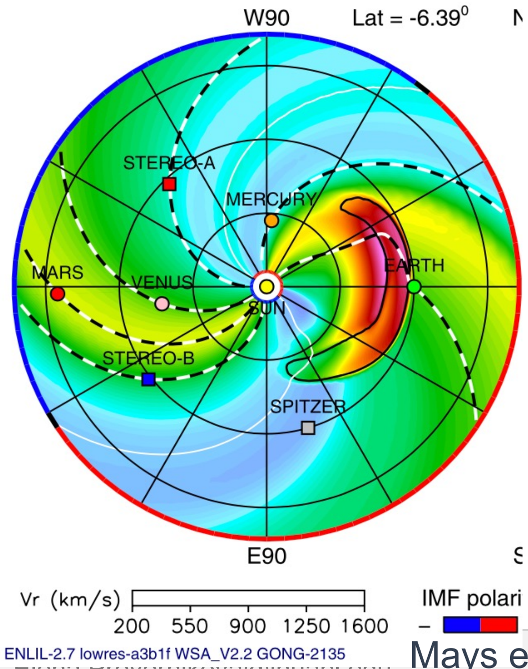
Riley (2006)



Global MHD modeling of the inner heliosphere with a CME

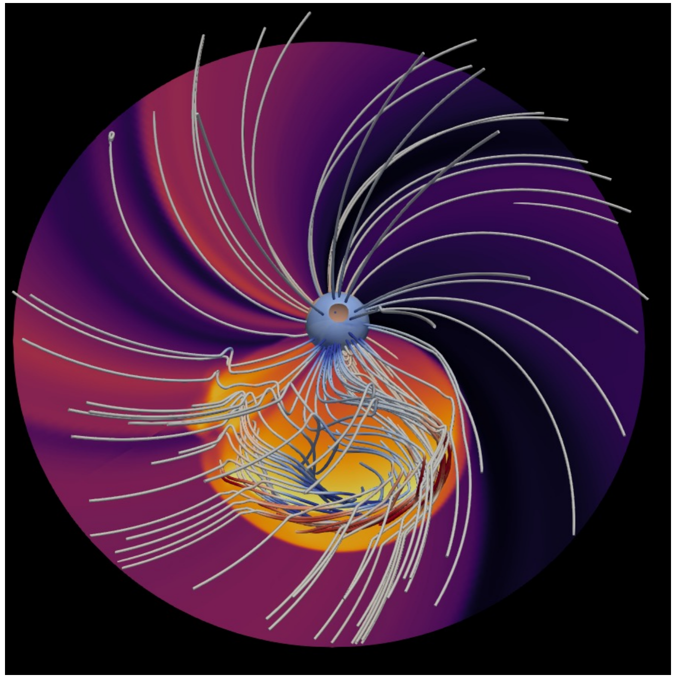
- Global solar wind driven by the output from a semi-empirical coronal model WSA
- CME description
  - Hydrodynamic
  - Including internal magnetic field

ENLIL+ Cone CME



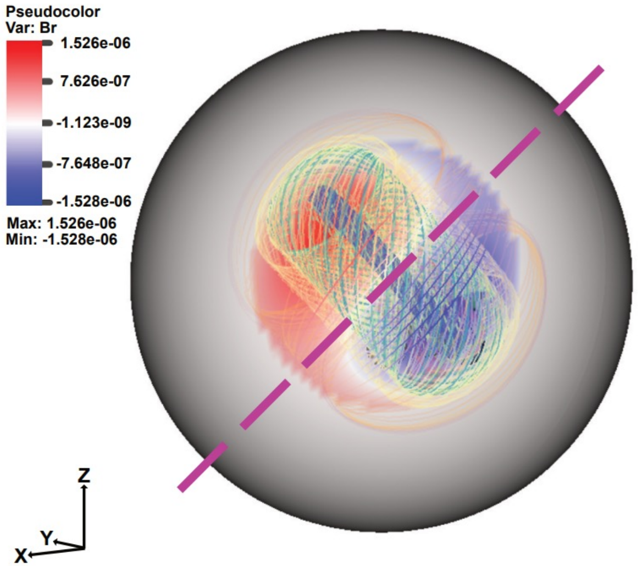
Mays et al 2015

GAMERA+Gibson&Low CME



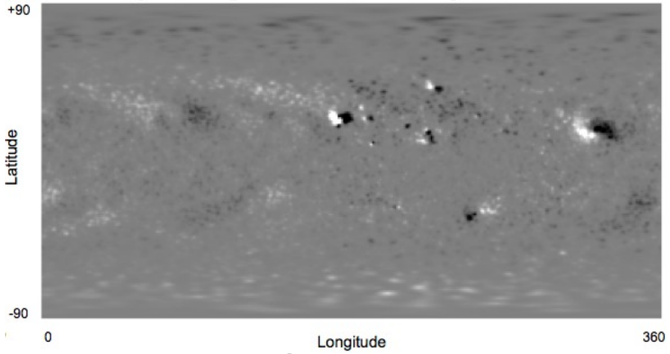
Provornikova et al (in prep)

EUHFORIA+Spheromak CME



Asvestari et al. 2021

Solar Photosphere ADAPT Maps



WSA model

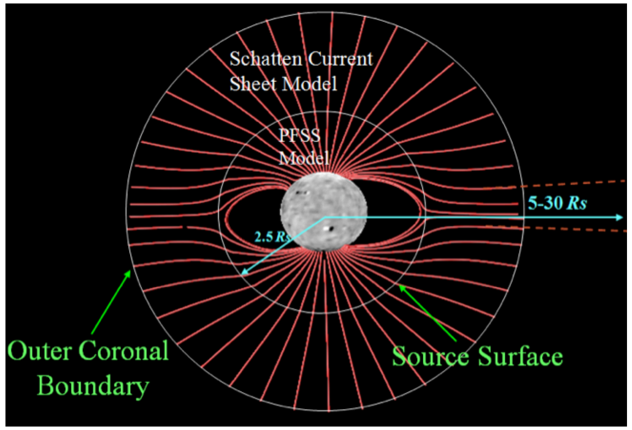
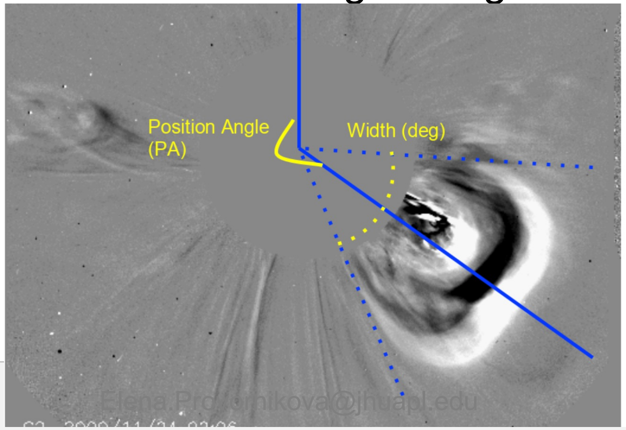


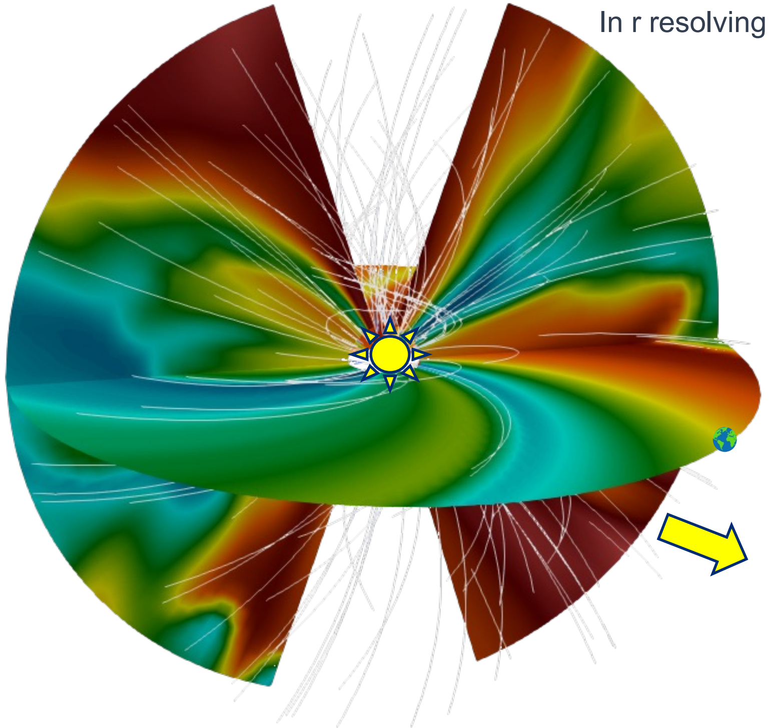
Figure courtesy N. Arge

CME white-light image

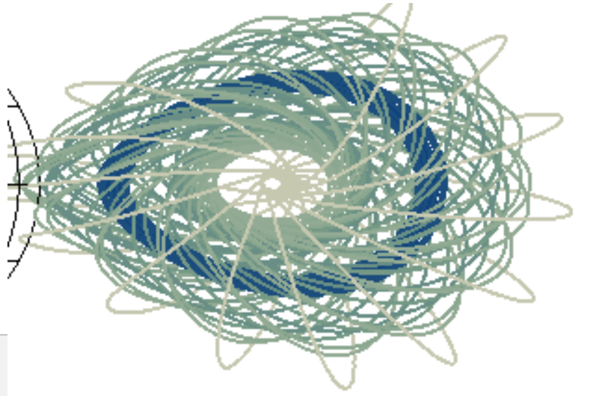


GAMERA Inner Heliosphere model
0.1-1 AU

In r resolving 0.75 R_S

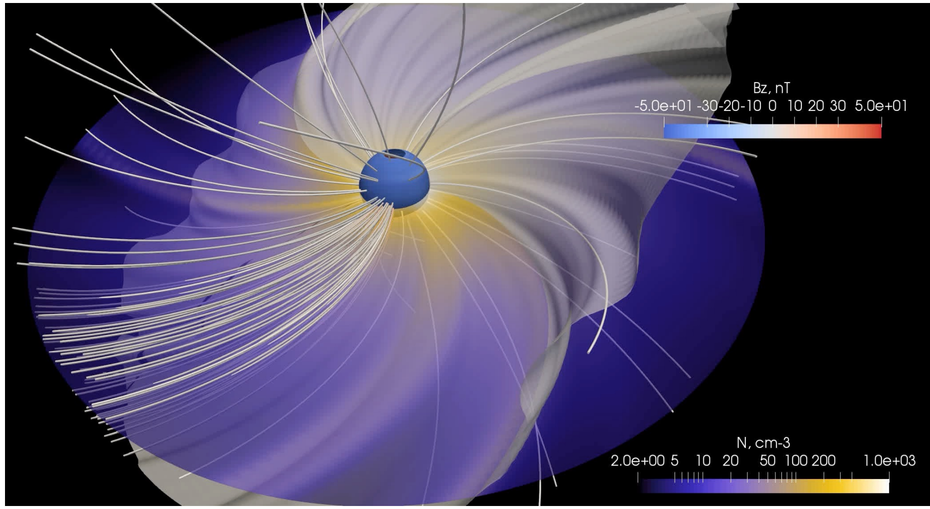


Gibson&Low CME model
(Gibson and Low 1998)

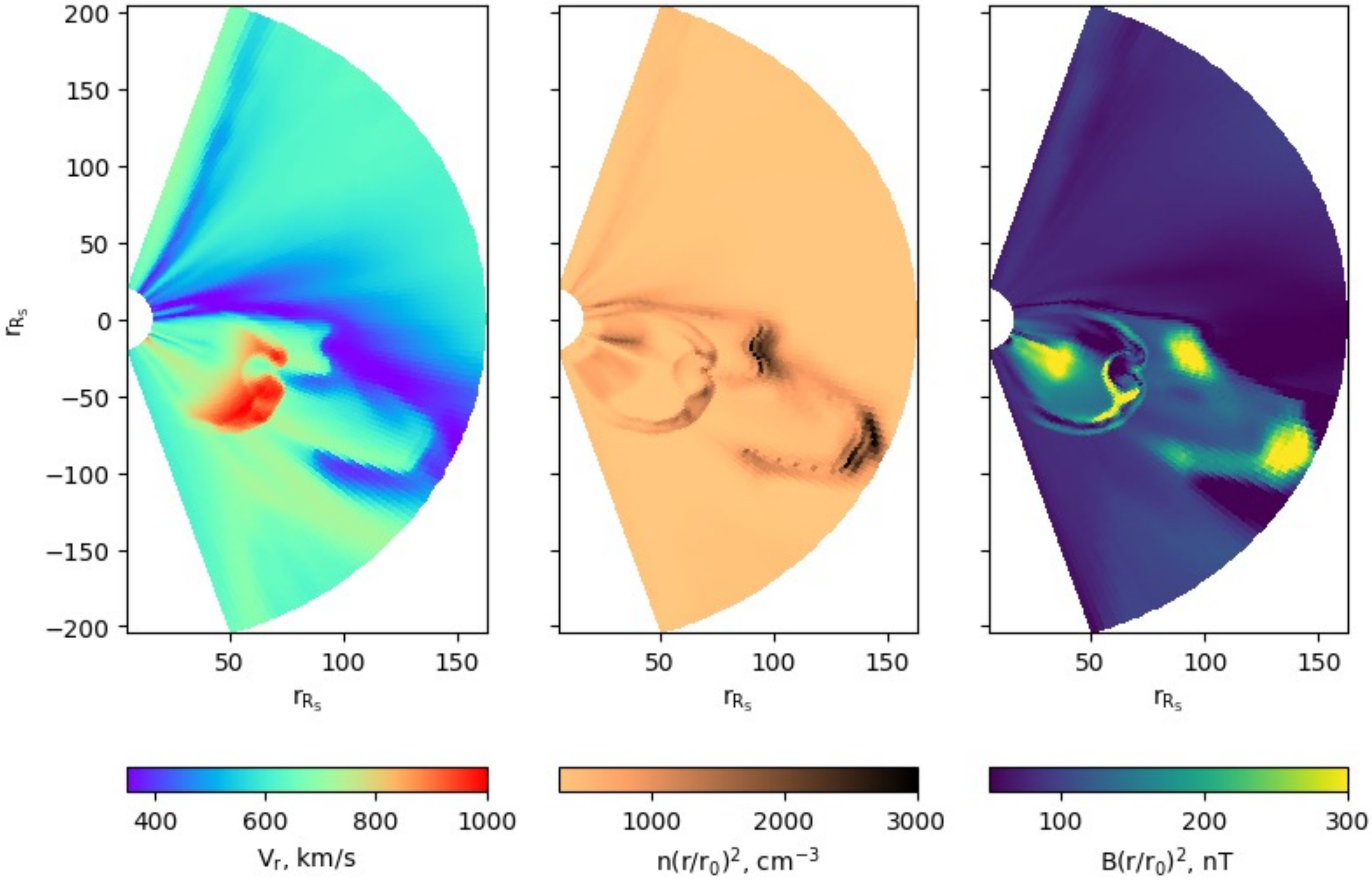


GAMERA
Grid Agnostic MHD for Extended Research Applications

CME in the inner heliosphere



PUNCH CME challenge v2.0

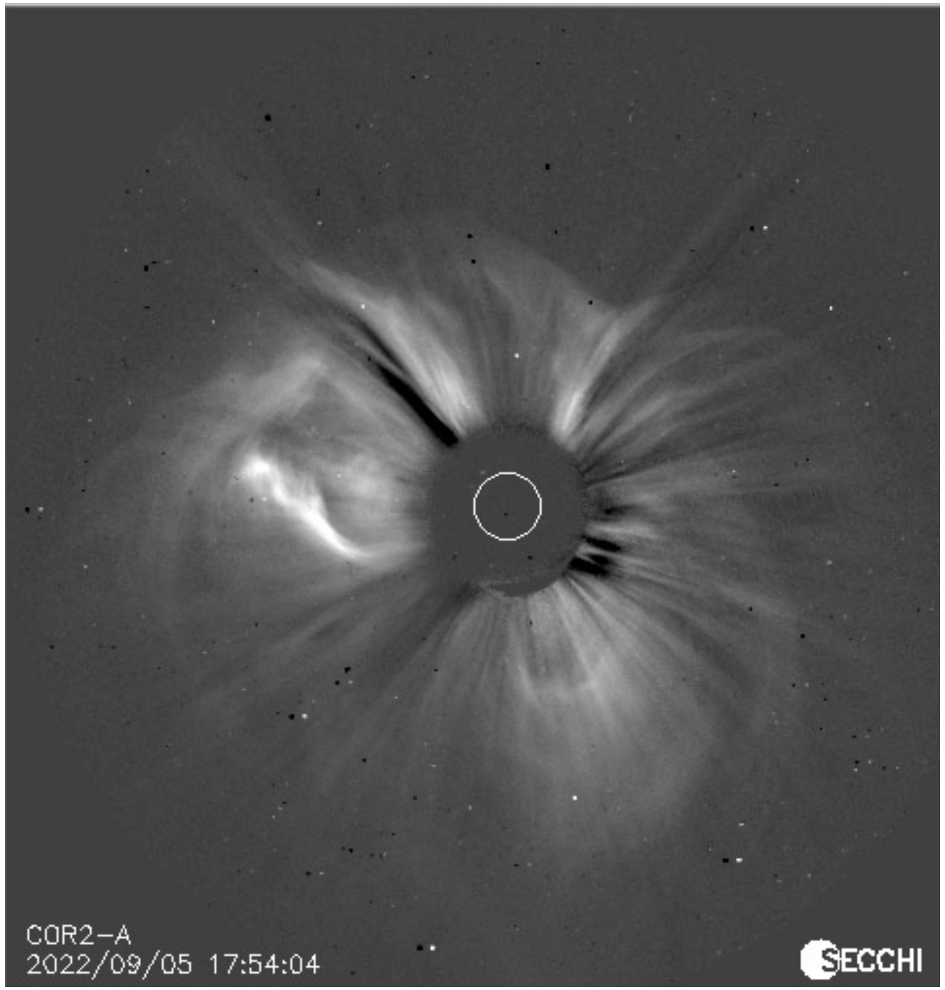


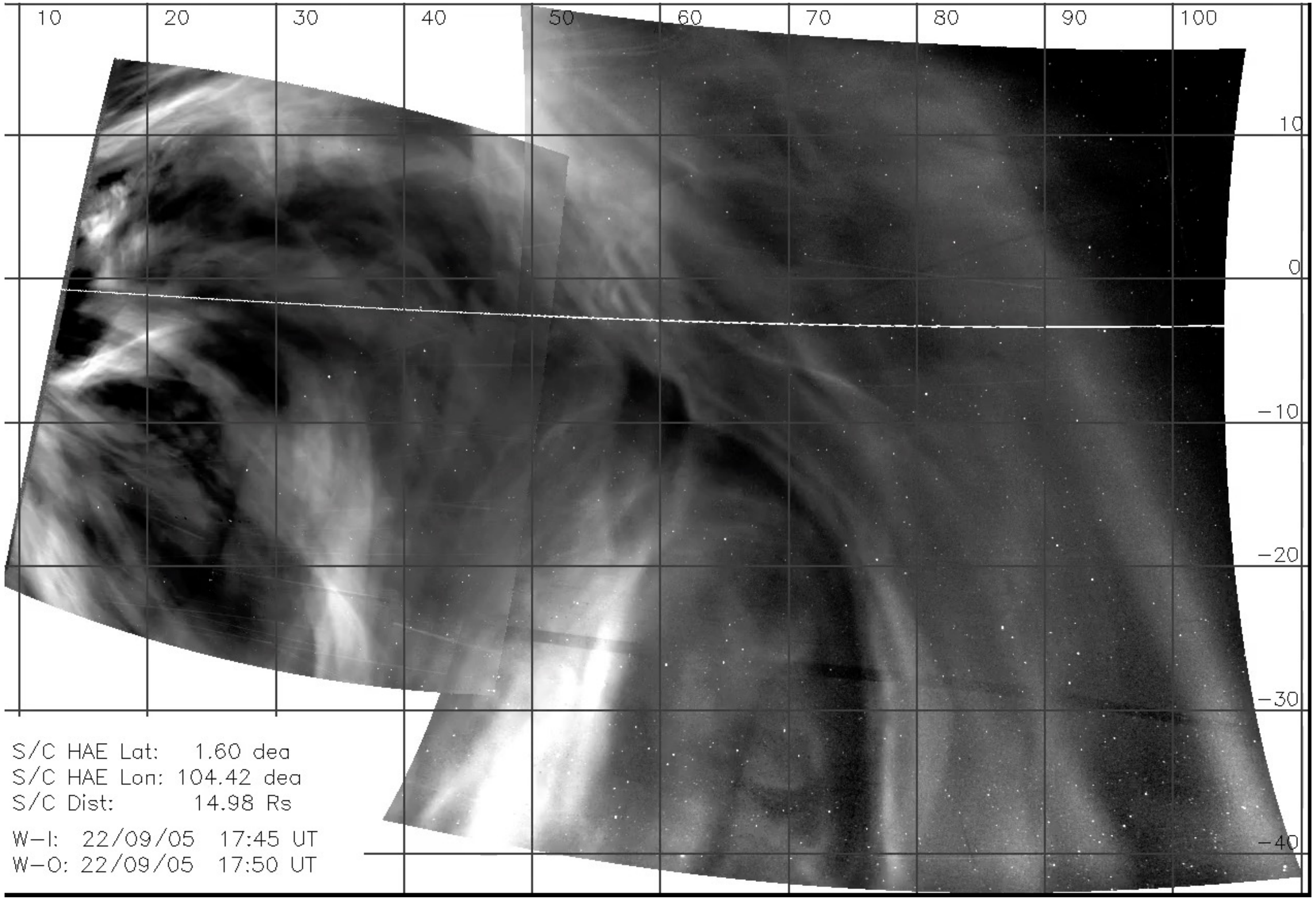
Example simulation
Default resolution
256x128x256

WISPR observations of September 5, 2022 CME

Close-up WISPR Imaging of the Magnetic Flux Rope

Image/video courtesy
NASA/JHUAPL/NRL
Angelos Vourlidas (JHUAPL)





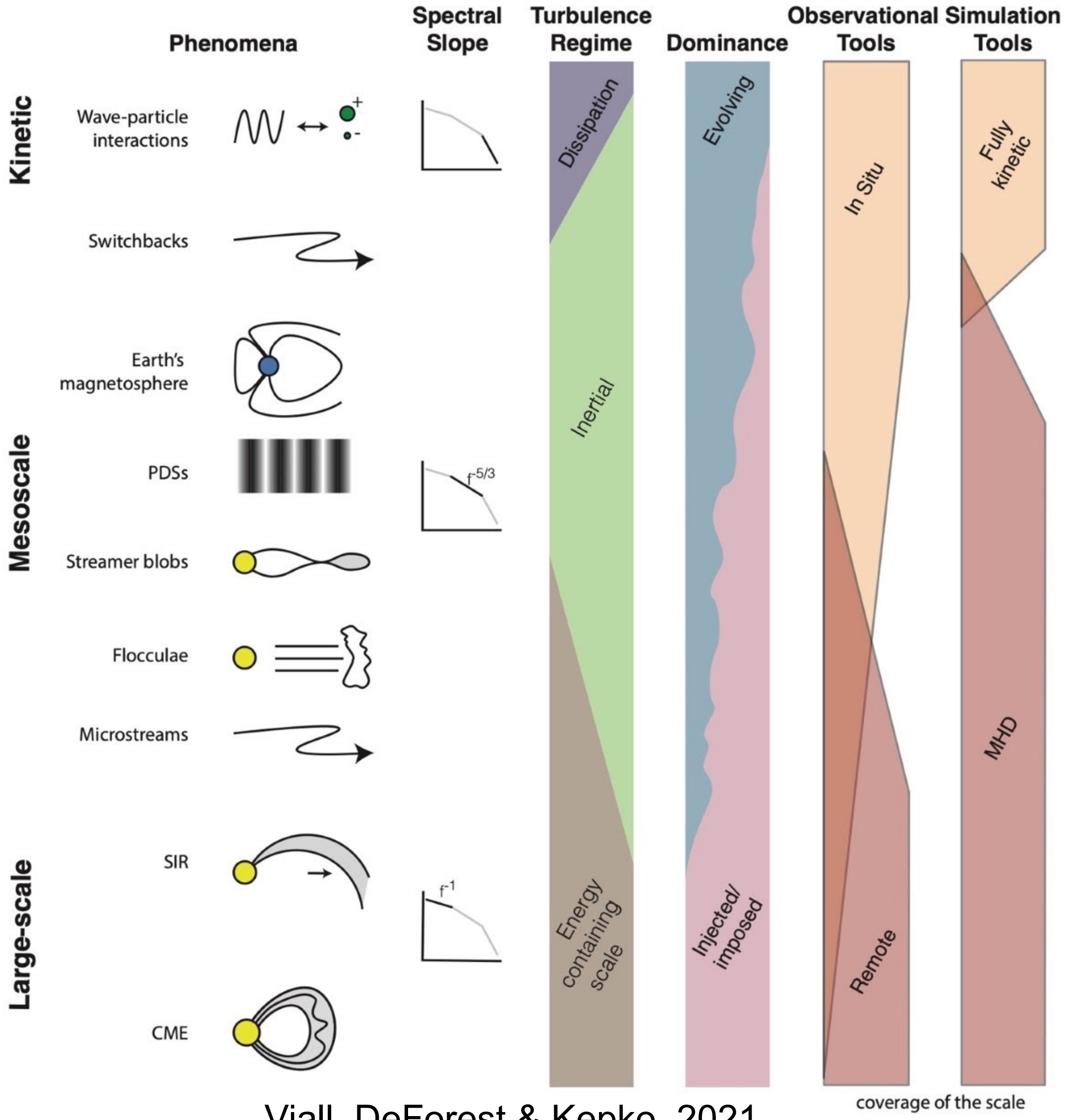
PUNCH will characterize mesoscale structures

PUNCH determines how much and what types of <u>mesoscale structures</u> are solar in origin, and how much and what types develops en route.

Mesoscale structures have scales 10^4-10^6 km (Viall et al. 2021)

To model evolution of mesoscale structures in the solar wind or those associated with CME-solar wind interaction require <u>high-resolution simulations</u>

What types of mesoscale structures develop as a CME propagate in the steady-state solar wind background?

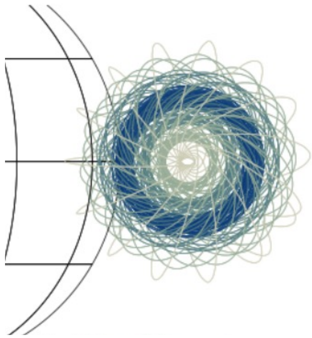


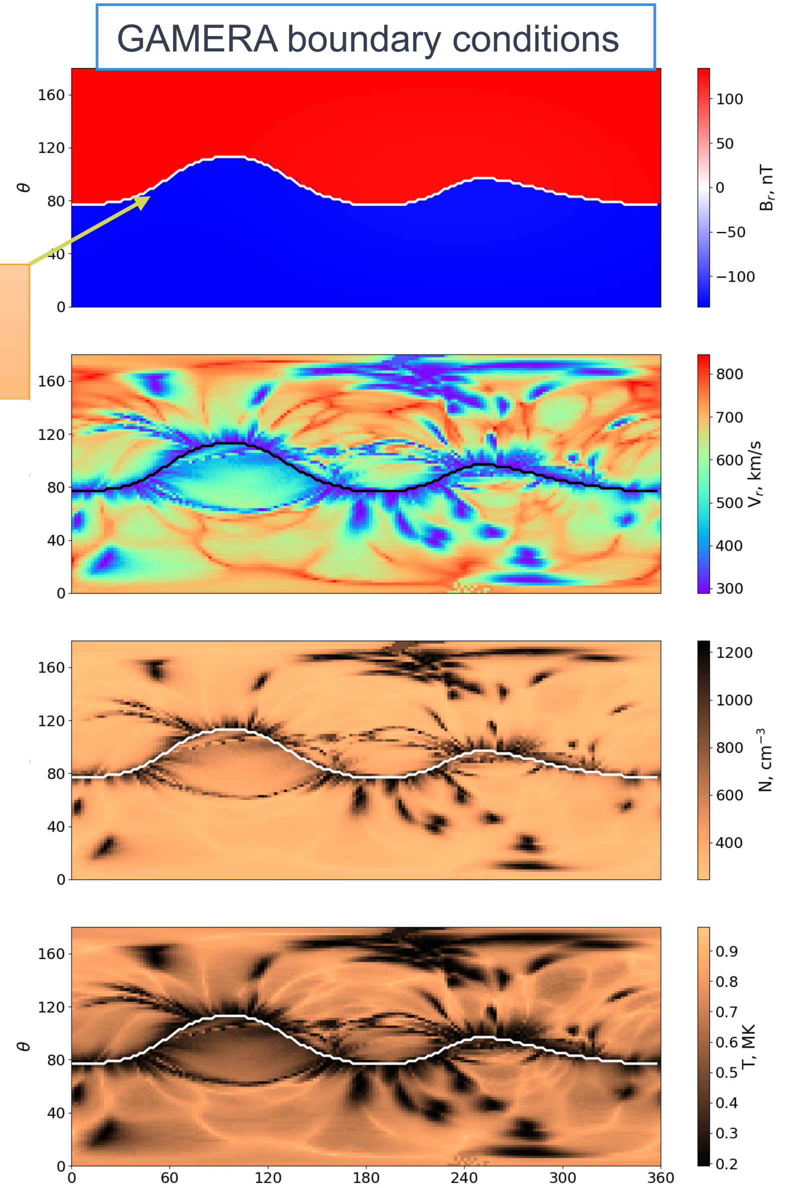
Viall, DeForest & Kepko, 2021

Slide courtesy S. Gibson

Resolving mesoscales with GAMERA: set up for the high-resolution simulation

- Entering inertial range with resolution in the simulation 1024x512x1024
- $\Delta r \times \Delta\theta \times \Delta\varphi = 1.3 \cdot 10^5\ km \times 0.3° \times 0.35°$
- Solar wind background is driven by the WSA map (solar minimum)
- CME is a spheromak provided by the Gibson&Low model
- CME emerges into the solar wind at 21.5 R_S at 900 km/s





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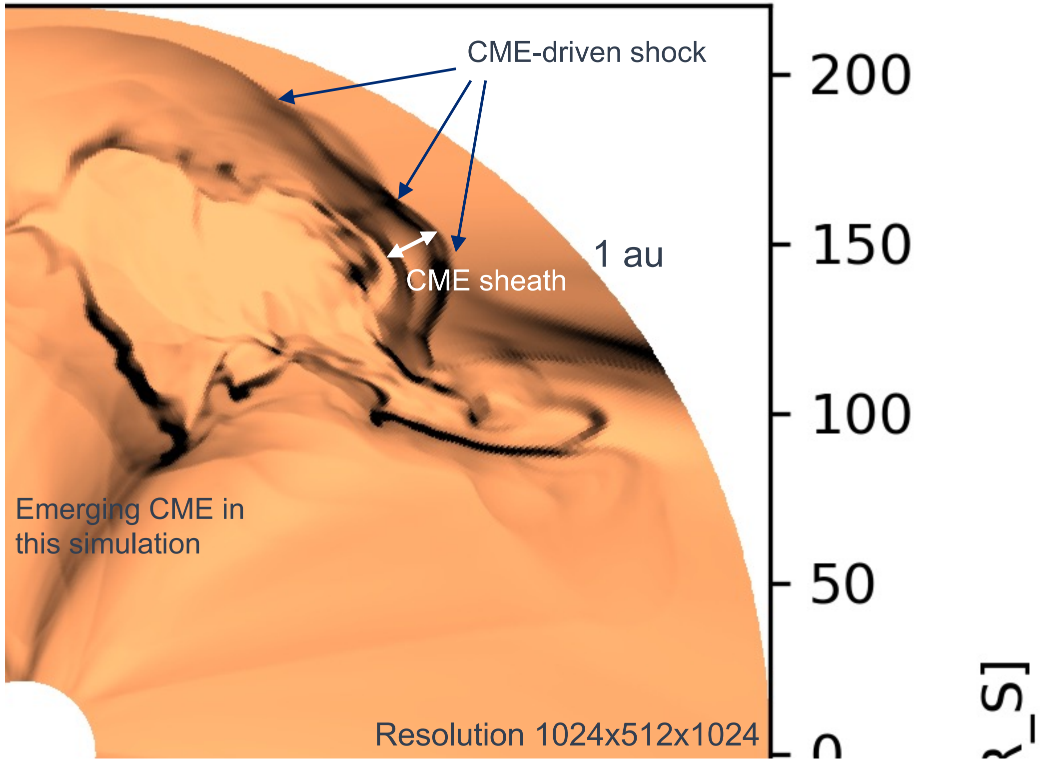
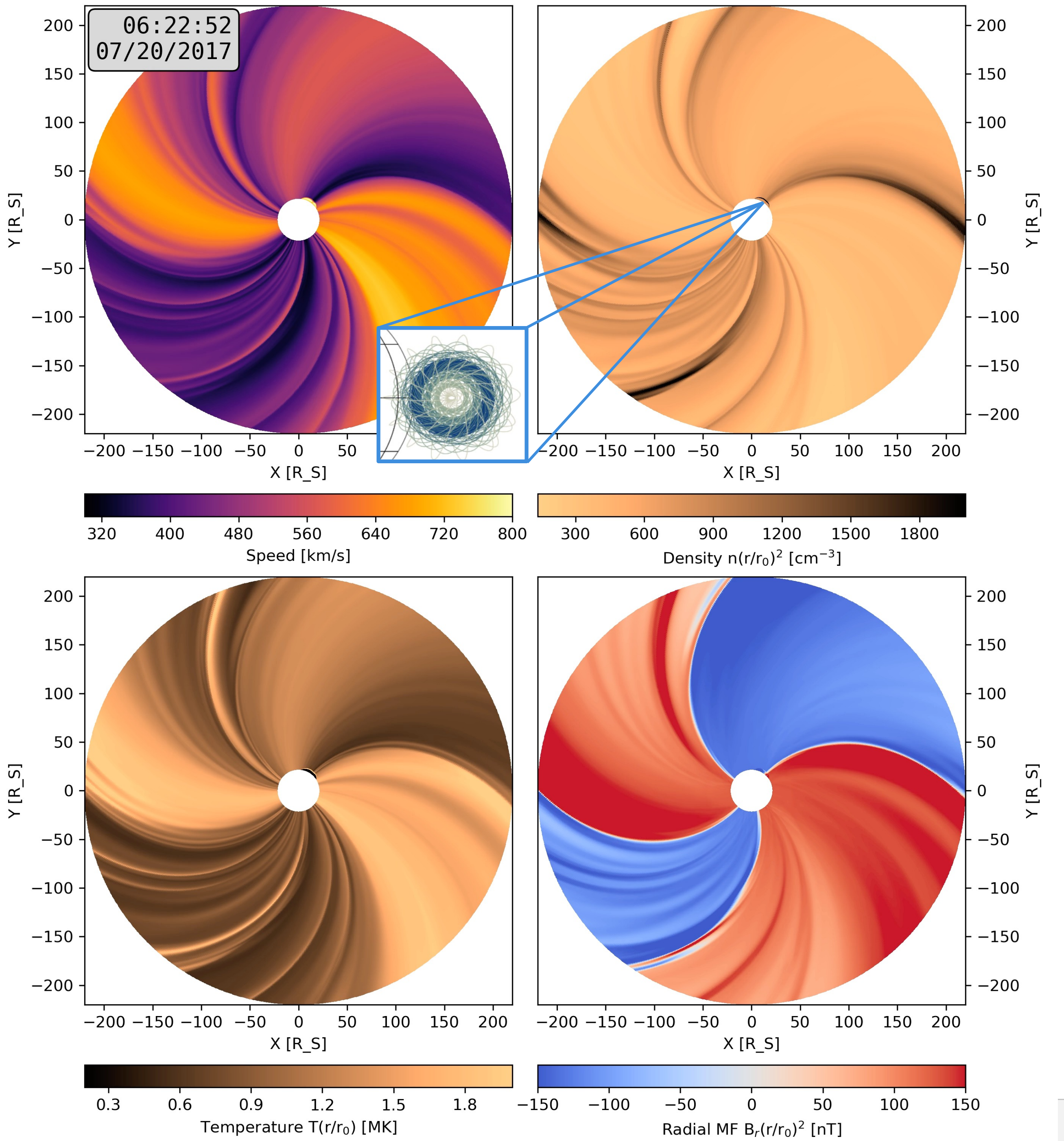
CME propagation in unprecedented high resolution global simulation

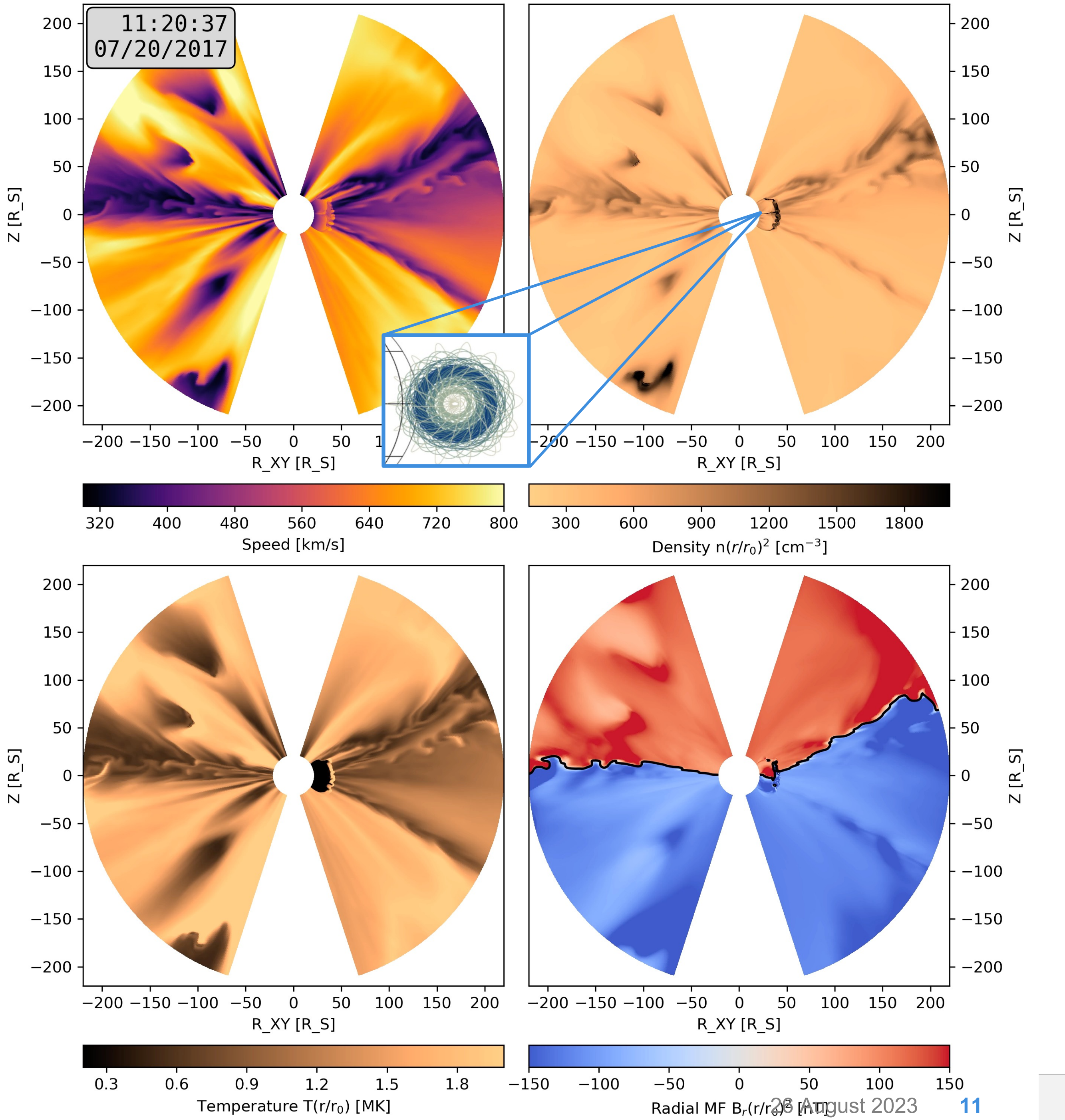
- Highly distorted CME with irregular shock and sheath evolving from emerging a spheromak CME
- Resolving scales ~10^5 km





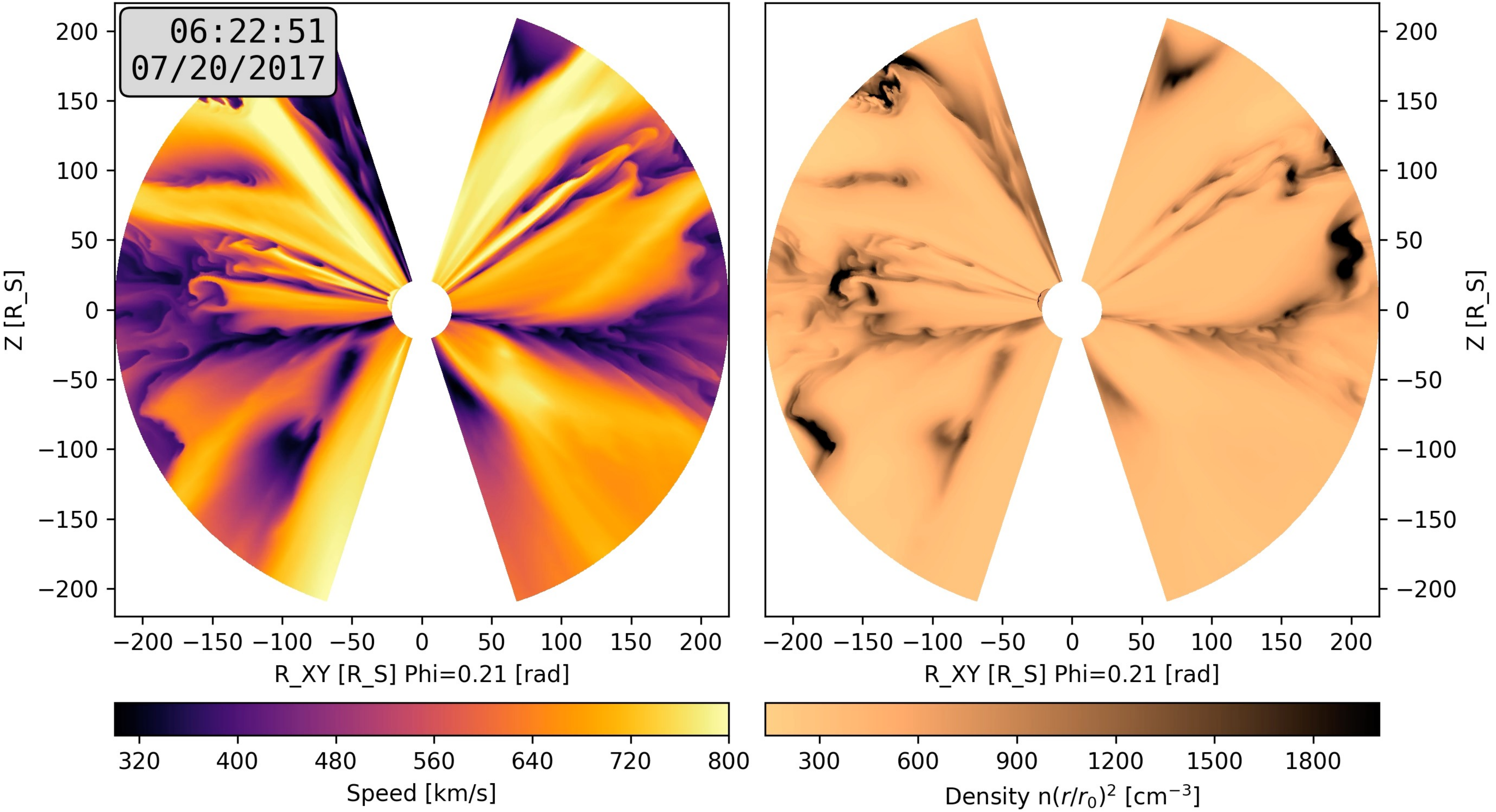
CME propagation in unprecedented high resolution global simulation

- The emerged spheromak structure is "destroyed"
- Irregular CME front traces interactions with the fast and slow solar wind streams
- Compression in the sheath varies along the CME surface
- *How does such a distorted CME looks in polarized brightness images?*



Pushing the envelope

2048x1024x2048 simulation
Resolving spatial scales $7*10^4$ km



Summary and Next Steps

- GAMERA+Gibson&Low model integration provides physics-based simulations of ICMEs for PUNCH tomography analysis and SOC data products
- Newly developed integration of models is efficiently parallelized and scalable which enables the highest resolution ever achieved in global simulations of this type (resolving $7*10^4$ km)
- Plenty of mesoscale structures develop in interaction of a CME and background solar wind structure: corrugated CME shock, structured sheath and highly distorted shape of a CME

Future plans:

- Tracking flows in solar with with an ICME
- Mesoscale structures as seen in tB and pB