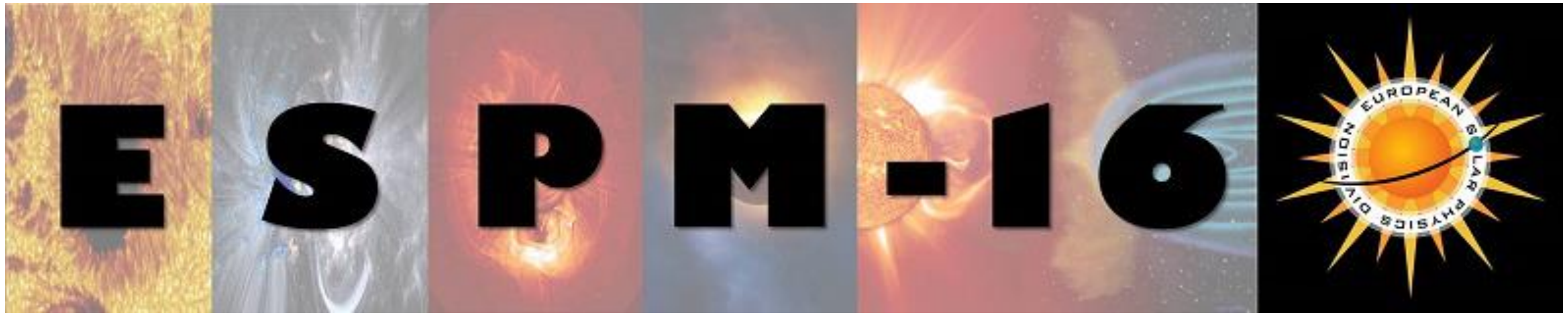
Implementing new techniques to constrain the spheromak model in EUHFORIA and assessing the model results



Ranadeep Sarkar[1]

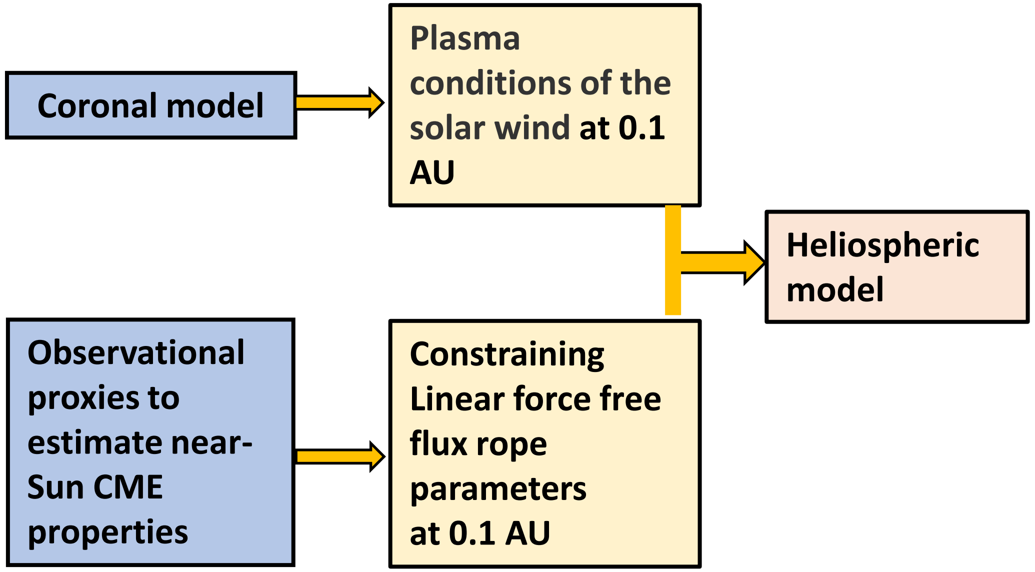
Jens Pomoell, Emilia Kilpua, Eleanna Asvestari, Nicolas Wijsen, Anwesha Maharana, Stefaan Poedts, Luciano Rodriguez and Marilena Mierla

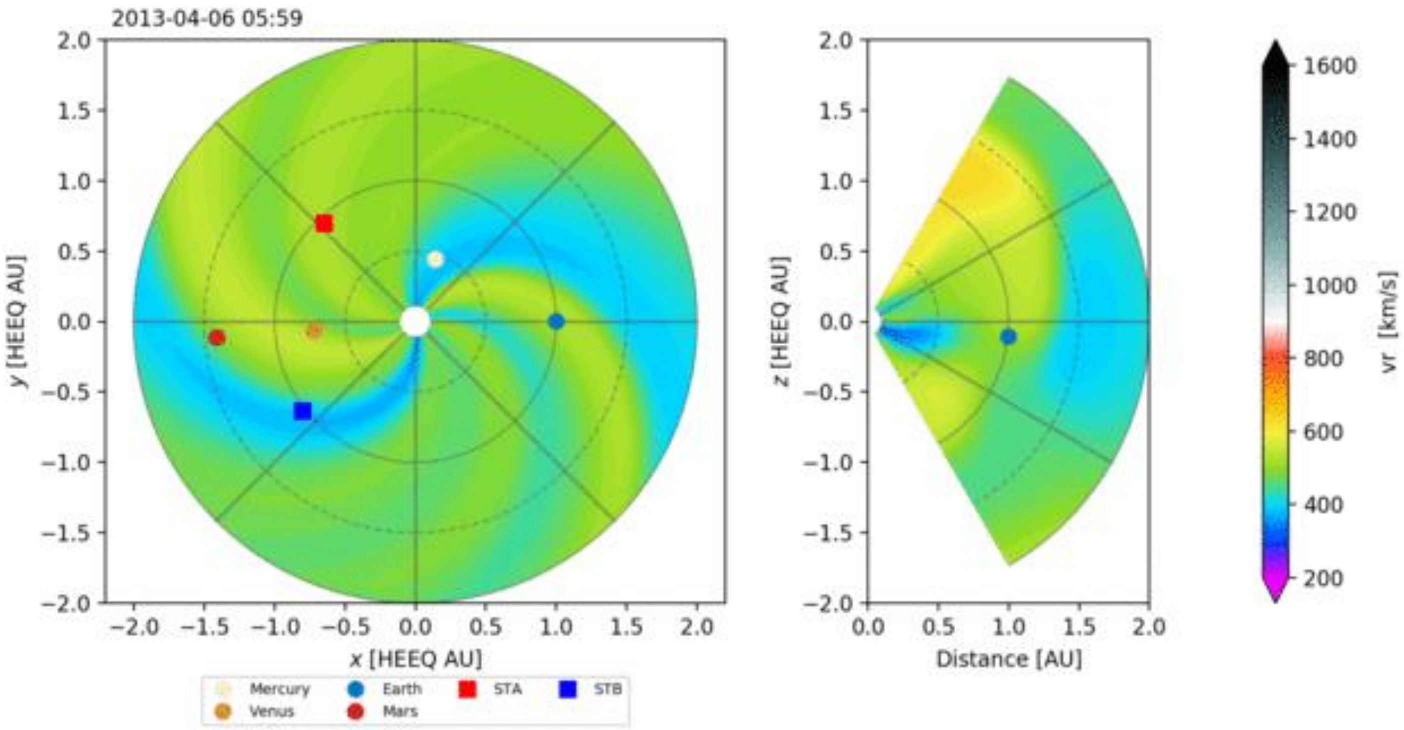
[1]University of Helsinki, Department of Physics, Helsinki, Finland
(ranadeep.sarkar@helsinki.fi)

Introduction

"European heliospheric forecasting information asset" (EUHFORIA) is a physics-based simulation tool designed for space weather forecasting purposes.

EUHFORIA model framework

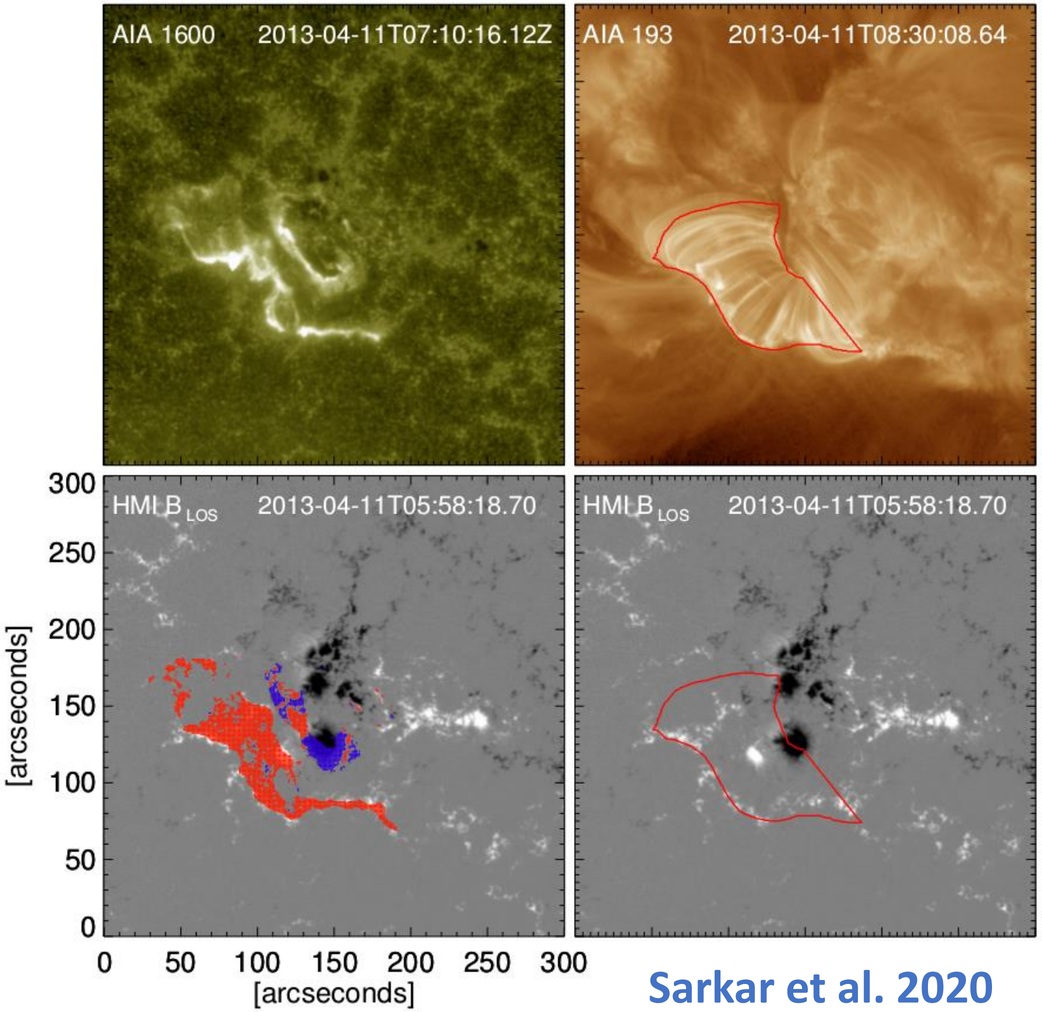




J. Pomoell and S. Poedts, 2018. Scolini et al. 2019

Method to constrain the magnetic flux of a spheromak

The observed reconnection flux can be equated to the poloidal flux of a half/partial torus having arch length constrained from the observations. However, equating the reconnection flux directly to the poloidal flux of a spheromak (embedded with a full torus like structure) may underestimate the desired field-strength of the flux rope.



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Alternate method

Estimating the poloidal flux from the observed reconnection flux as obtained from cumulative flare ribbon area method (Kazachenko et al. 2017) or post-eruption arcade method (Gopalswamy et al. 2018)

↓

Estimating the axial field strength of Lundquist cylindrical flux rope with length equal to the arch length of a CME by equating its poloidal flux to that obtained from observation.

↓

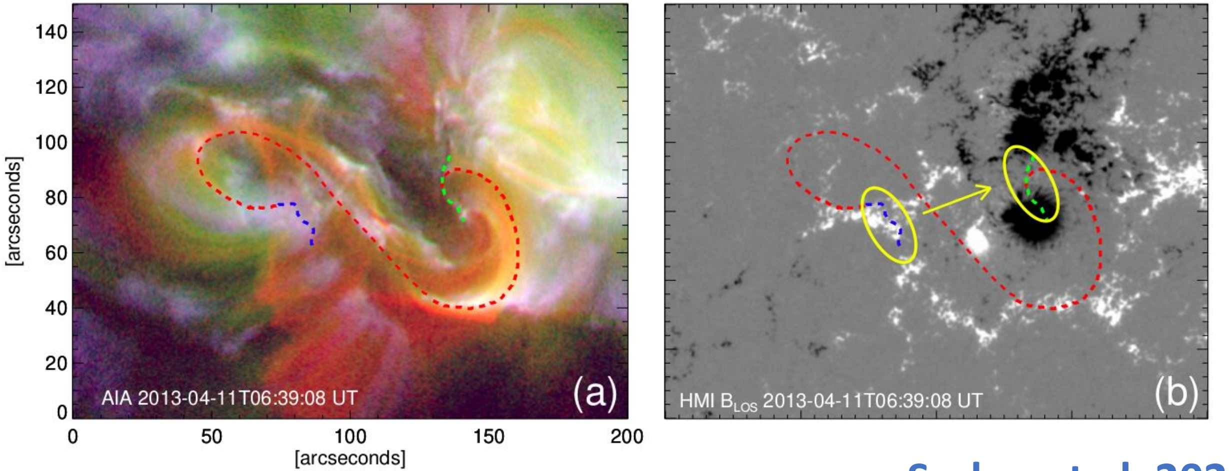
Equating the field strength along the magnetic axis of the Lundquist flux rope to that along the magnetic axis of the spheromak to estimate its toroidal flux

↓

Use the toroidal flux as input for spheromak parameter in Euhforia

EUHFORIA run with observationally constrained parameters for the CME event on 2013 April 11

Direction of the flux-rope axial field



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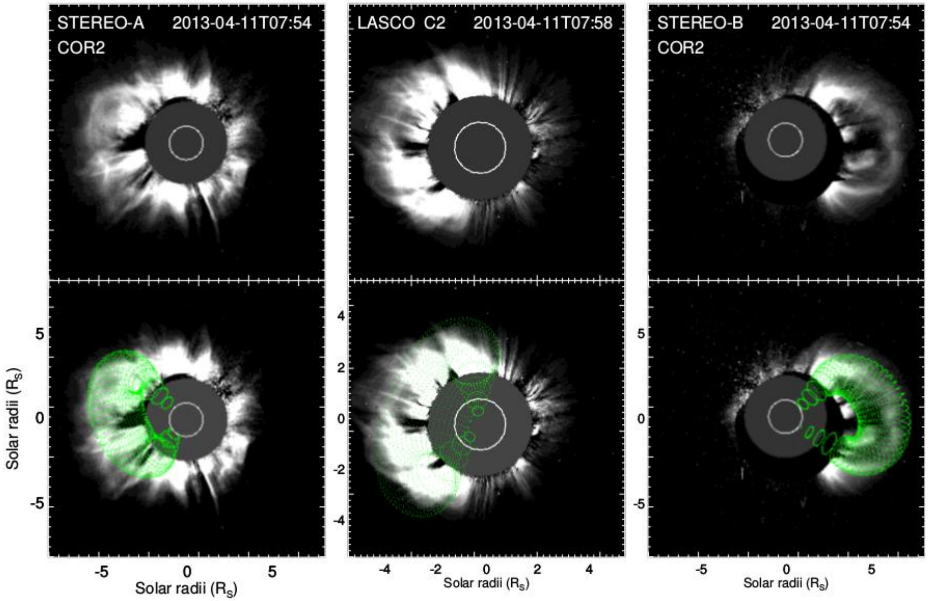
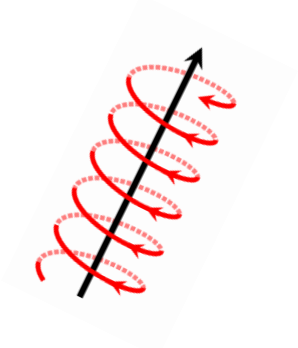
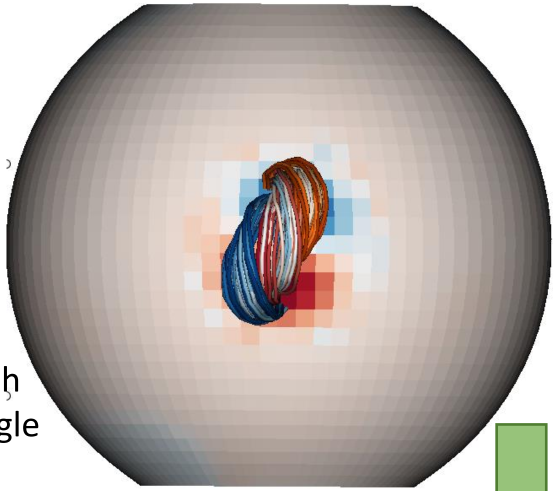
Tilt angle of the flux-rope obtained from GCS Reconstruction



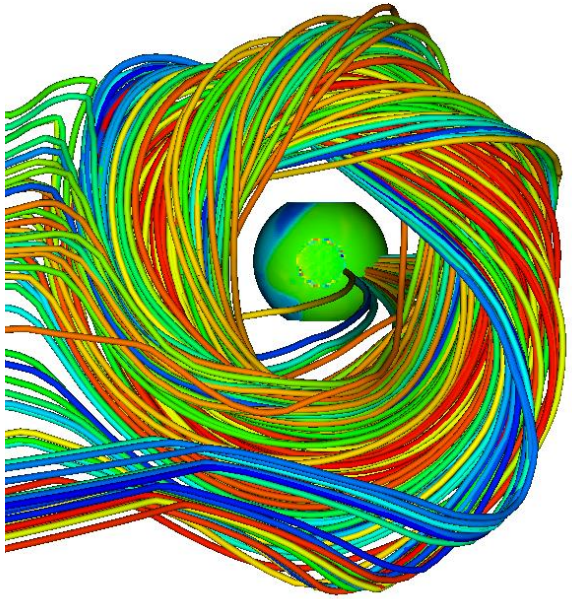
Spheromak tilt during its insertion at 0.1 AU





Northward directed flux-rope with left-handed chirality and a tilt angle of 70^o w.r.t ecliptic plane

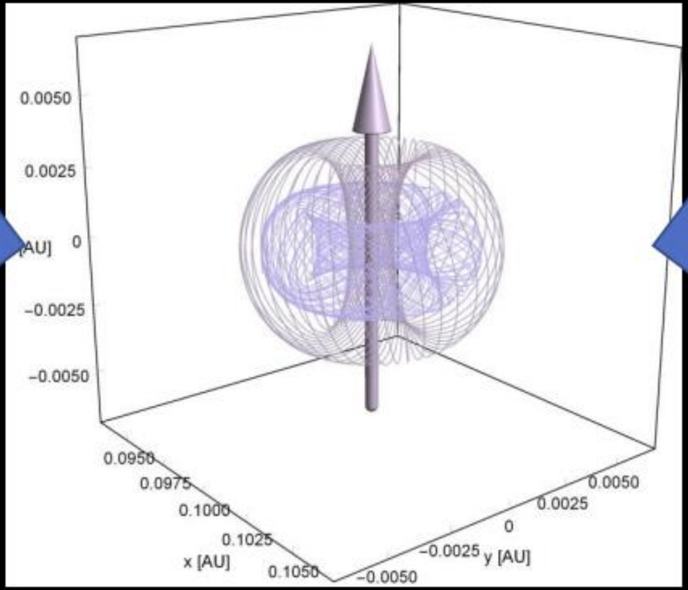
Spheromak tilt at 1 AU



The axis of symmetry of the spheromak undergoes approximately 90^0 of rotation and nearly aligns along the Sun-Earth line

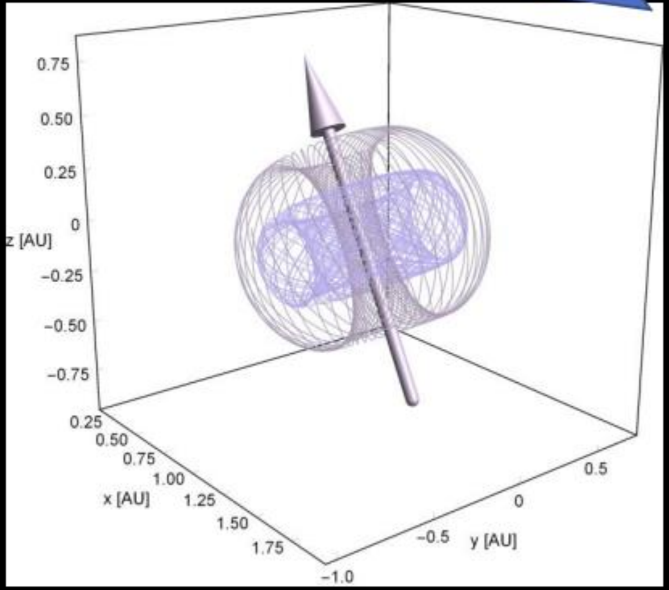
For questions contact eleanna.asvestari@helsinki.fi

Initial spheromak orientation

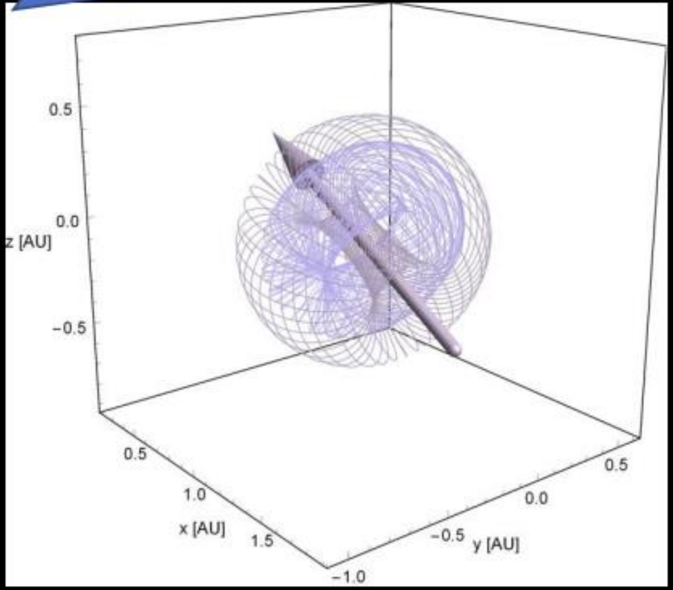


Spheromak inserted in **weak** ambient field

Spheromak inserted in **strong** ambient field



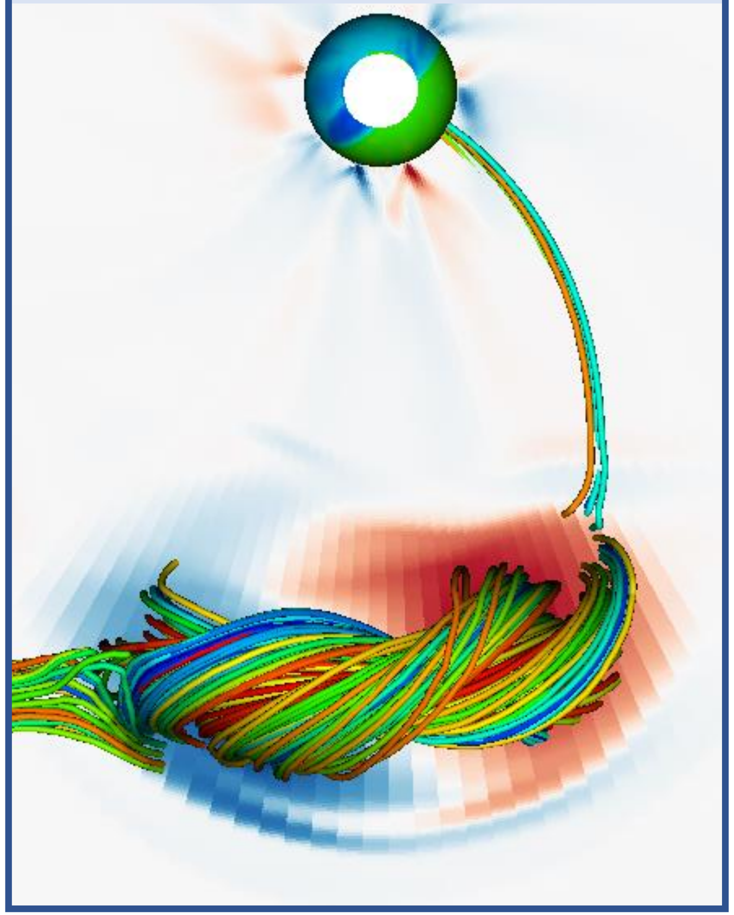
Upon insertion the spheromak starts interacting with the ambient magnetic field and starts rotating (tilting) - its magnetic moment tries to align with the ambient magnetic field in order to lower its magnetic potential energy.



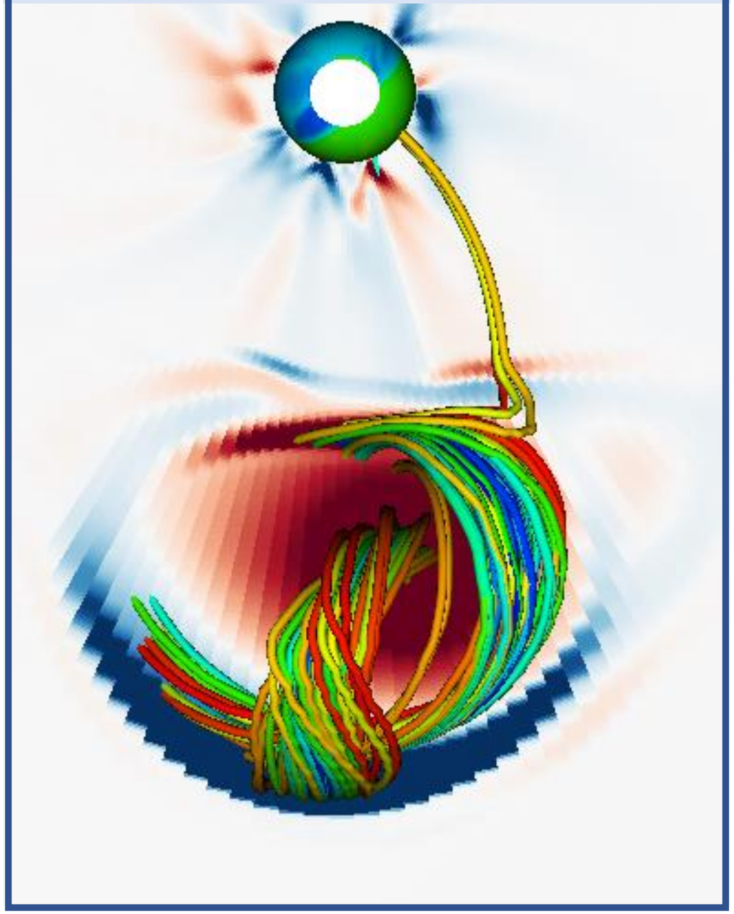
Effect of density on spheromak rotation

Recent observational study show that the average CME density at 20 solar radii ranges between 10^{-18} to 10^{-17} kg/m^3 (Temmer et al. 2021). Therefore, we conduct a set of EUHFORIA simulations by using different density values within the range 10^{-18} to 10^{-17} kg/m^3

Spheromak with nominal density
(5×10^{-18} kg/m^3 **)**



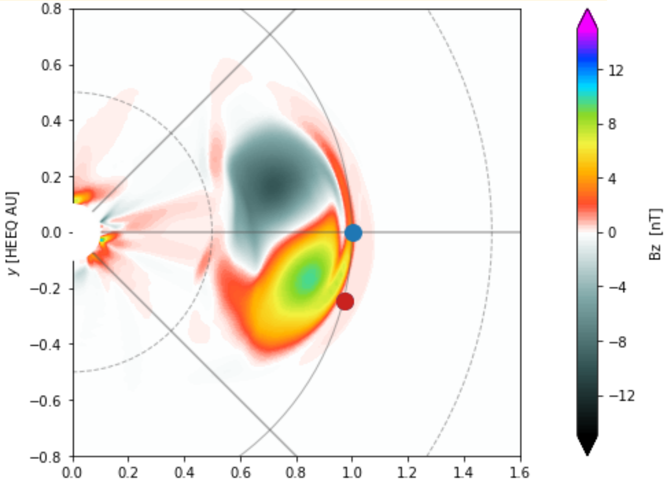
Spheromak with higher density
(5×10^{-17} kg/m^3 **)**



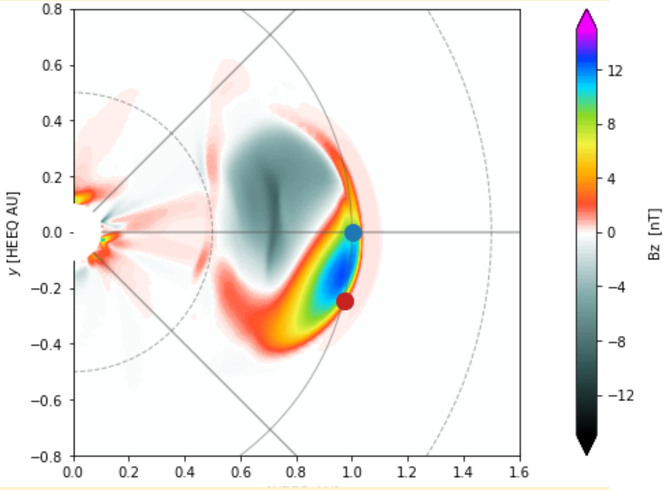
Spheromak rotation is lesser in case of higher densities.

Evolution of spheromak with different density values

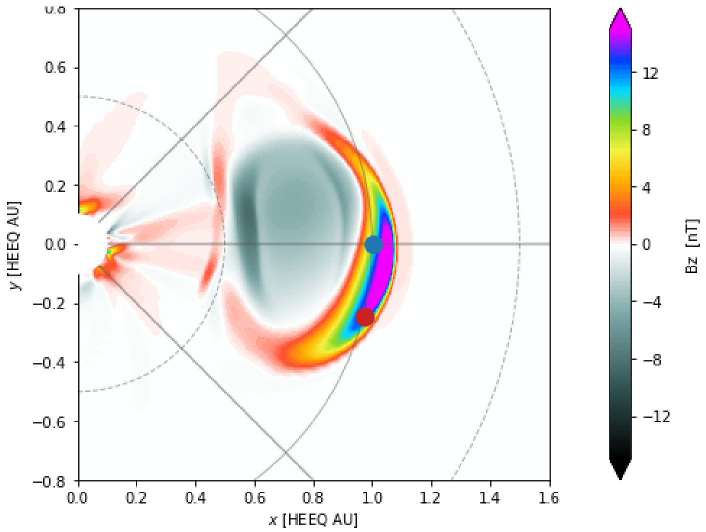
Density 0.5×10^{-17} kg/m^3



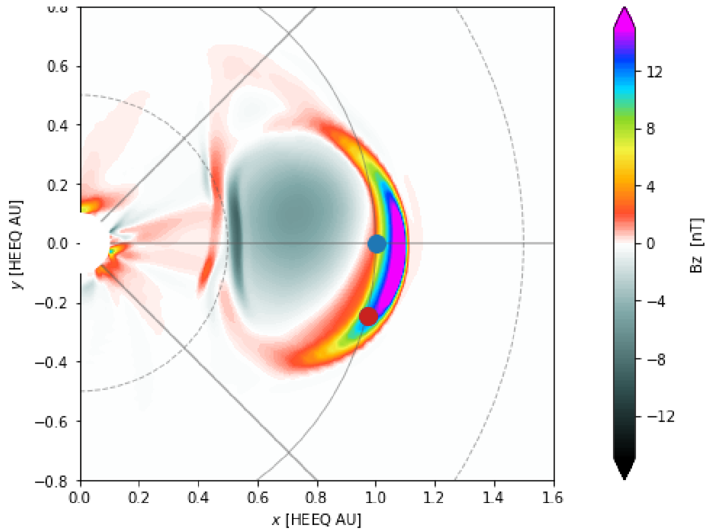
Density 1×10^{-17} kg/m^3



Density 2.5×10^{-17} kg/m^3



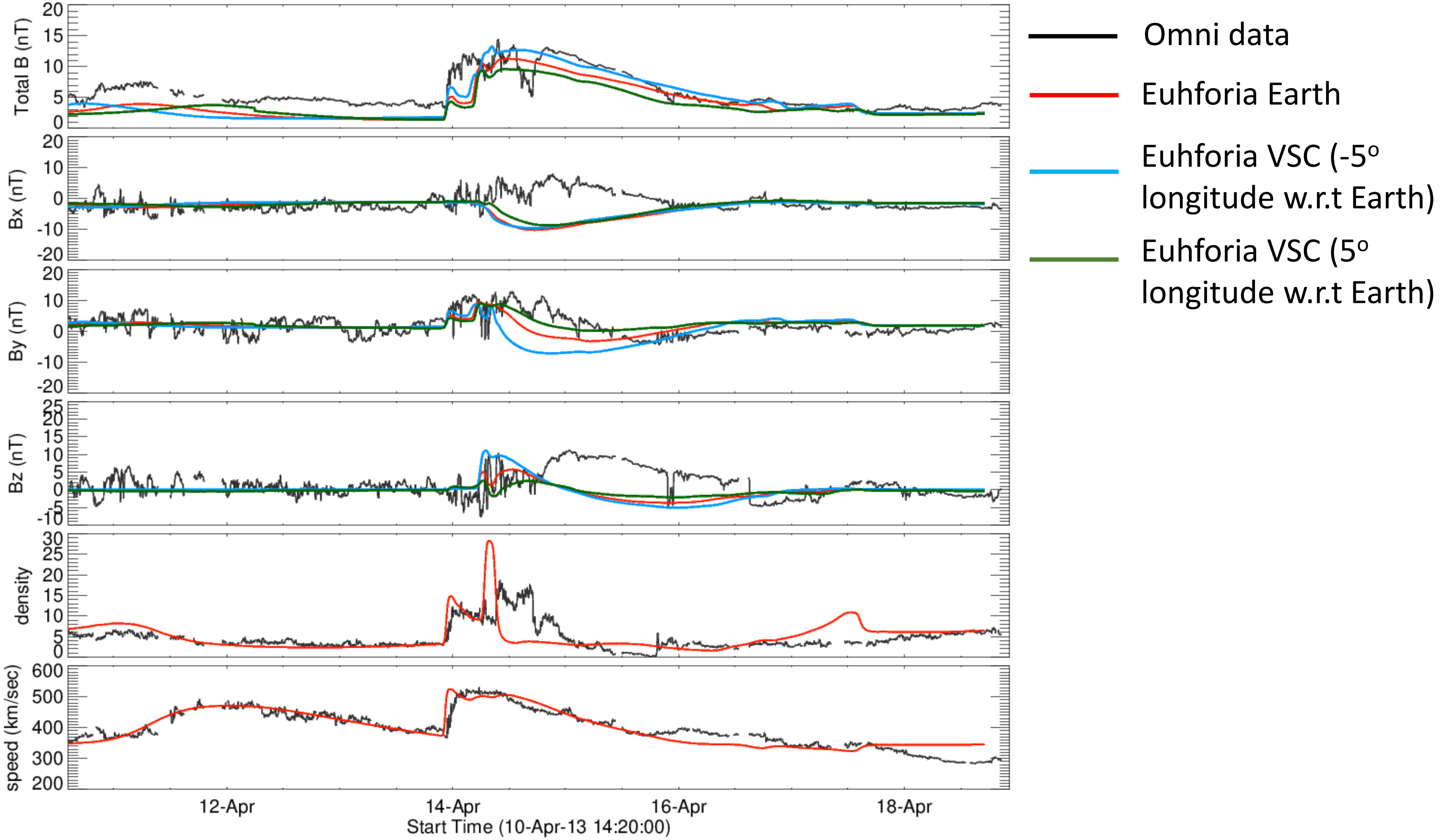
Density 5×10^{-17} kg/m^3



The nature of expansion is no more self-similar for high density cases*. Simulation run with higher velocity and nominal density of the spheromak shows similar results as the nominal velocity and high density runs*

Comparison of model results with in-situ observations

Spheromak input parameters	
Radius	7.2 Rs
Density	1×10^{-17} kg/m^3
Temp	0.8×10^6 K
Helicity	-1
Tilt	-70°
Flux	2.4×10^{13} wb



In this run, 1×10^{-17} kg/m^3 has been used as input density which is obtained from observation

Summary

- We have proposed a new method to constrain the magnetic flux of a spheromak. In stead of equating the reconnection flux to the poloidal flux of a spheromak, we propose to estimate the field strength along the magnetic axis of the spheromak by using the Lundquist flux rope model and the observed value of reconnection flux.

- We validate the tool for an Earth impacting CME event on 2013 April 11. The simulation results show that for a nominal density value of the spheromak, its axis of symmetry undergoes approximately 90^0 of rotation and nearly aligns along the Sun-Earth line. This is in line with the finding of 'Spheromak-tilting-instability' as reported in Asvestari et al. 2021 (submitted).

- Running a set of simulations by using different density values within the observed range, we find that Spheromak rotation is lesser in case of higher densities. However, the nature of expansion of the spheromak is no more self-similar for high density cases.

- Simulation run with higher velocity and nominal density of the spheromak shows similar results as the nominal velocity and high density runs. This indicates that the overall momentum of a spheromak plays a decisive role to seize the rotation caused by the 'Spheromak-tilting-instability'.

- Future work will focus on quantifying the spheromak rotation in different background heliospheric conditions and finding more practical solution to tackle the spheromak rotation problem.

Sarkar et al. 2021 (In preparation)