Advanced CME flux-rope models in EUHFORIA

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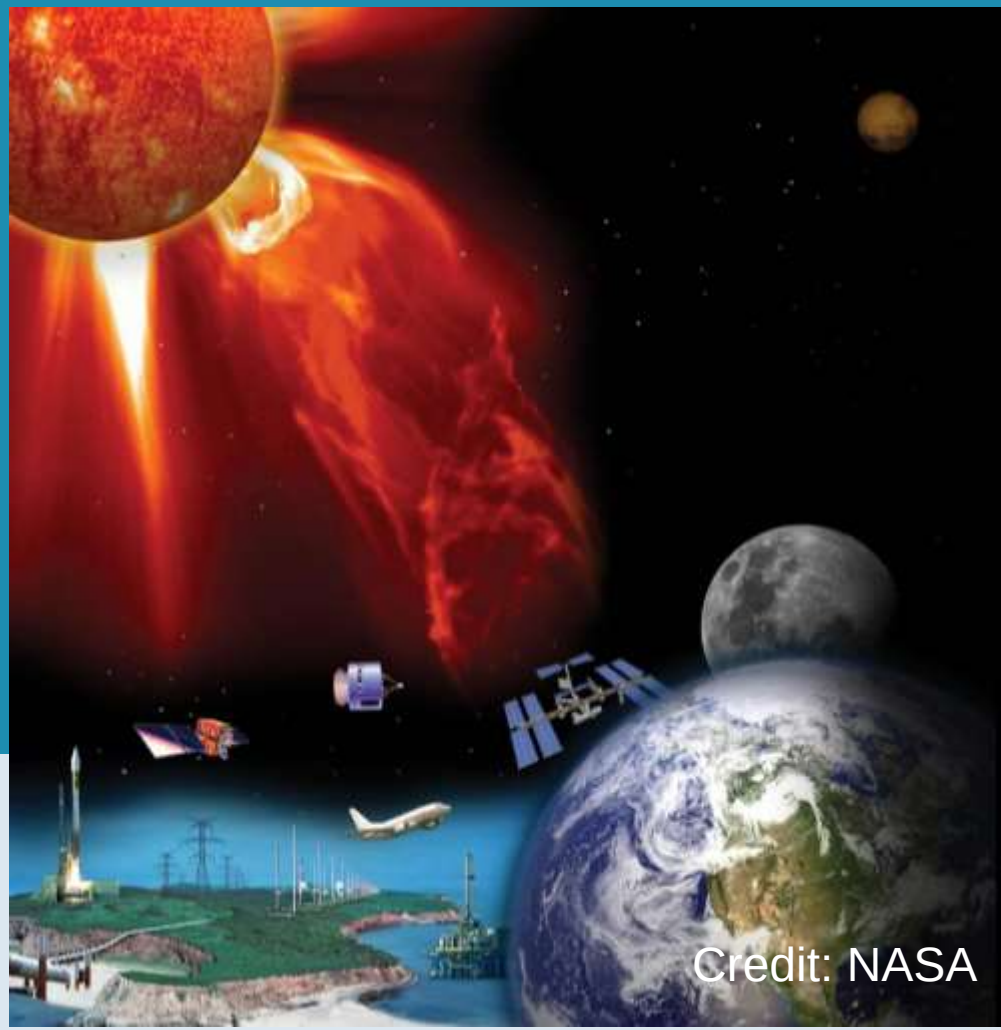


Credit: NASA

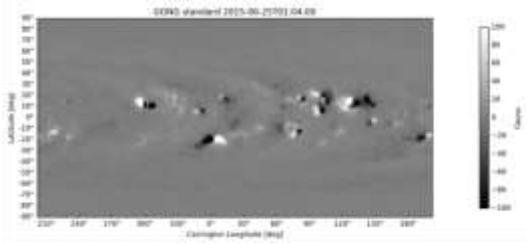
SC8, 21/09/2022

EUHFORIA

‘European heliospheric forecasting information asset’

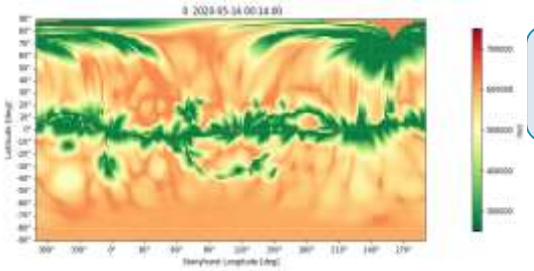
Corona:
Semi-Empirical WSA model

Synoptic Magnetogram (1 R_{sun})



PFSS model
(1 - 2.6 R_{sun})

v_r



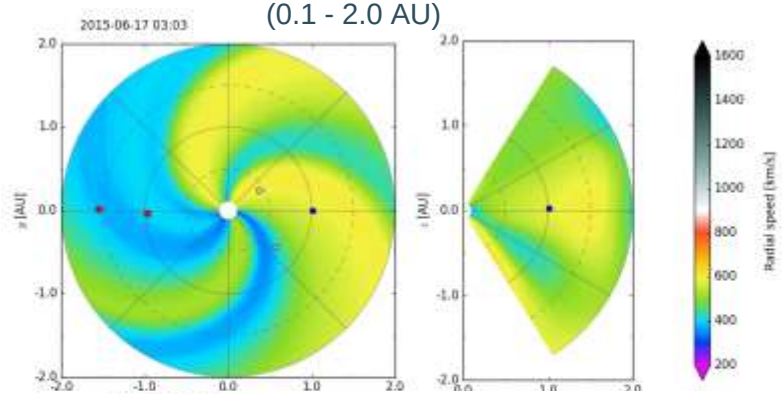
SCS model
(2.3 R_{sun} - 0.1 AU)

MHD parameters (0.1 AU) using empirical relations

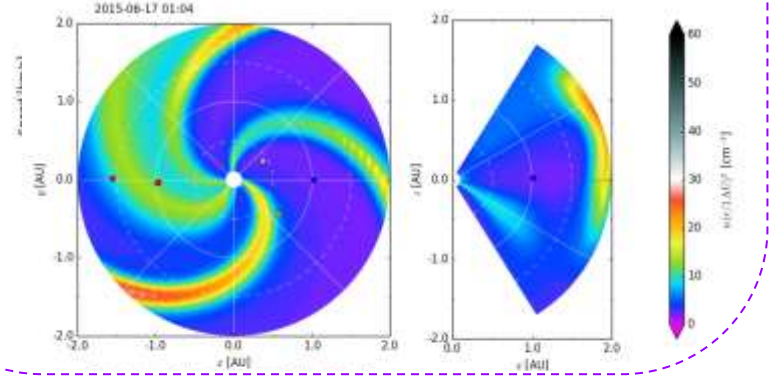
Heliosphere:
3D time dependent ideal MHD model

Evolves MHD parameters ***v***, *n*, ***B***, *T*
(0.1 - 2.0 AU)

v_r



n

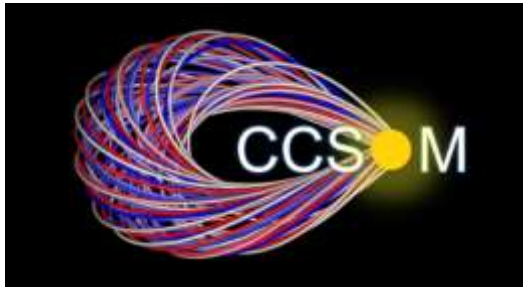


Pomoell & Poedts, 2018

Solar wind relaxation → CME insertion @0.1 AU → Forecasting

Credit: Anwesha Maharana

EUHFORIA Rationale



Science *(CCSOM project)*:

- Quantify the deformation, deflection and erosion of **flux ropes** evolving in the inner heliosphere
- Characterize the magnetosheaths of CMEs
- Clarify the role of CME-CME interactions in enhanced SEP production

Applications:

- Space weather forecasts *("European ENLIL")*
  - Time of arrival / *Geo-effectiveness*
- Support for space missions (e.g. PSP, SolO)
  - Incl. *magnetic connectivity tool*

Credit: Jens Pomoell

CME models in EUHFORIA

Cone-like model (unmagnetised) Pomoell & Poedts, 2018

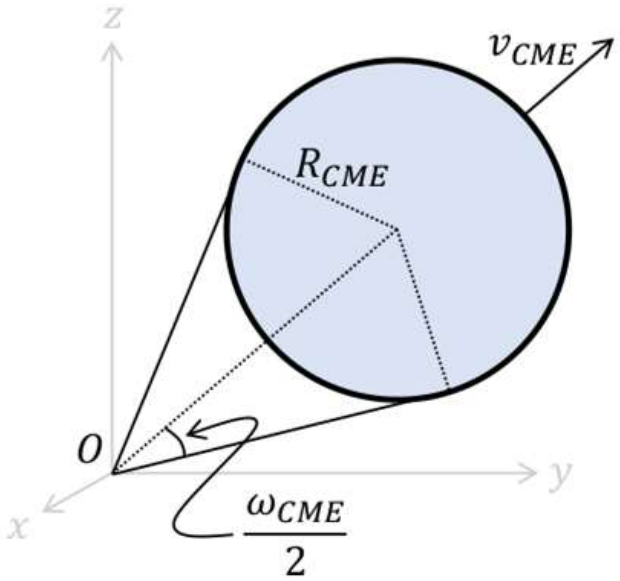


Image courtesy: Camilla Scolini

Spheromak CME (flux rope - spherical geometry) Verbeke et al, 2019

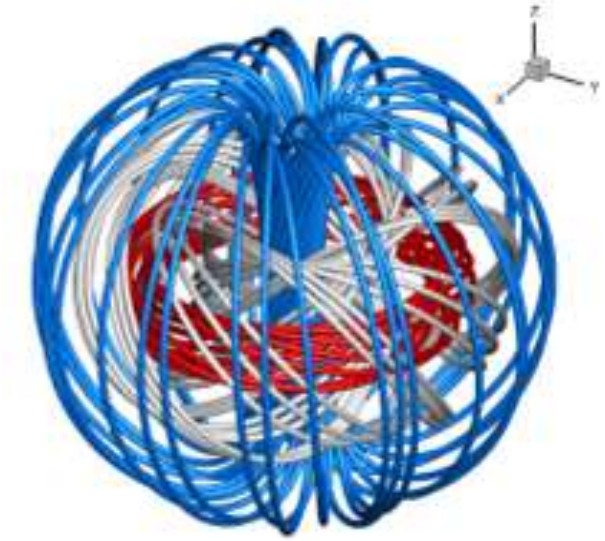
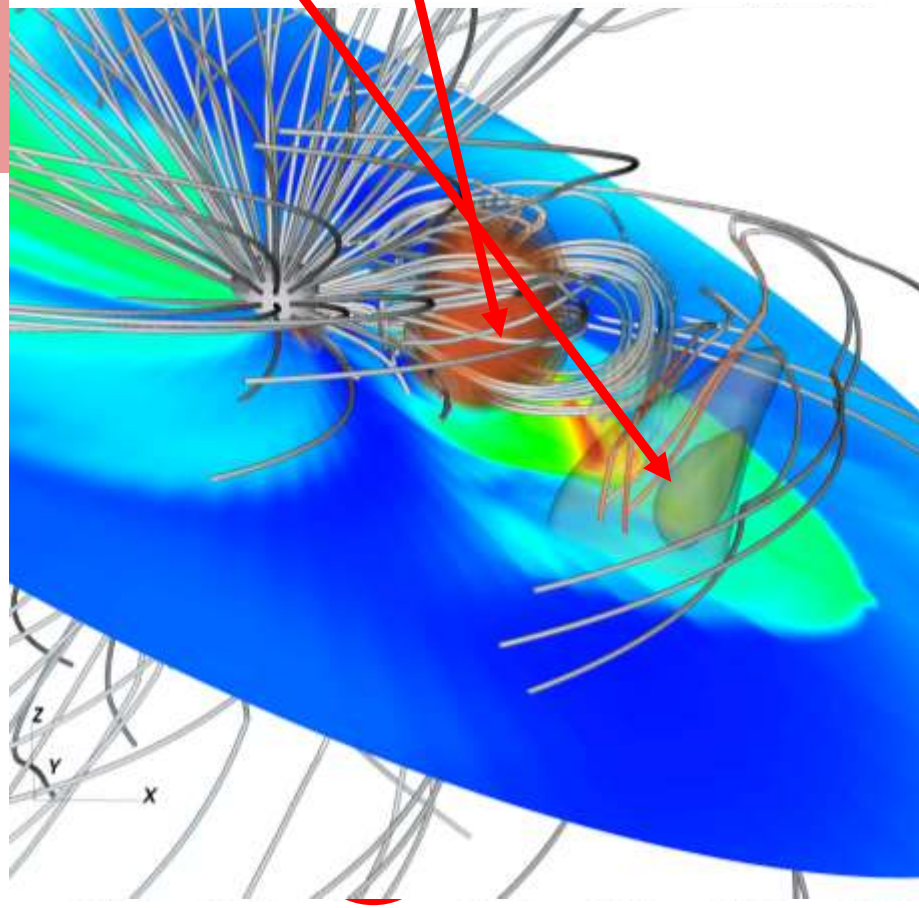


Image courtesy: Camilla Scolini

2 ‘spheromak’ CMEs on Sep 4 & Sep 6, 2017



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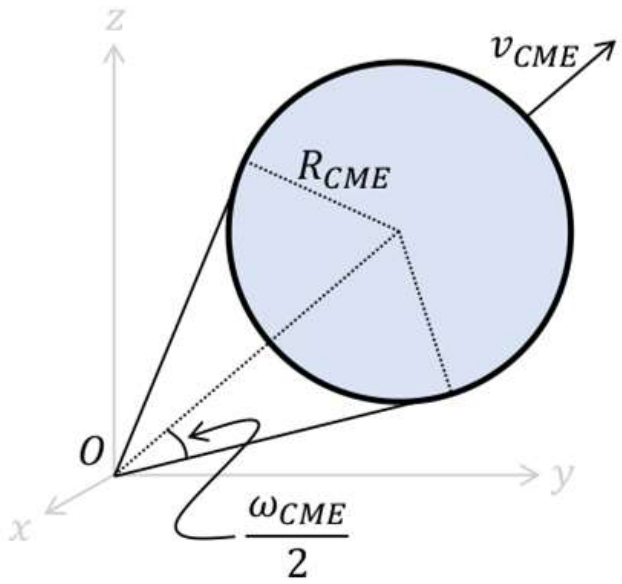

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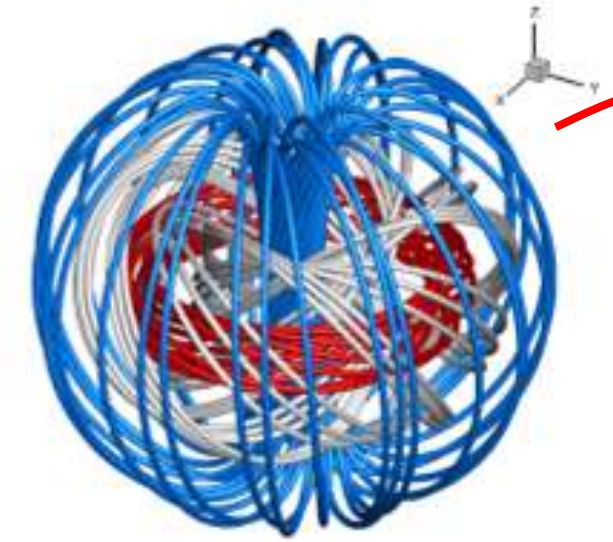
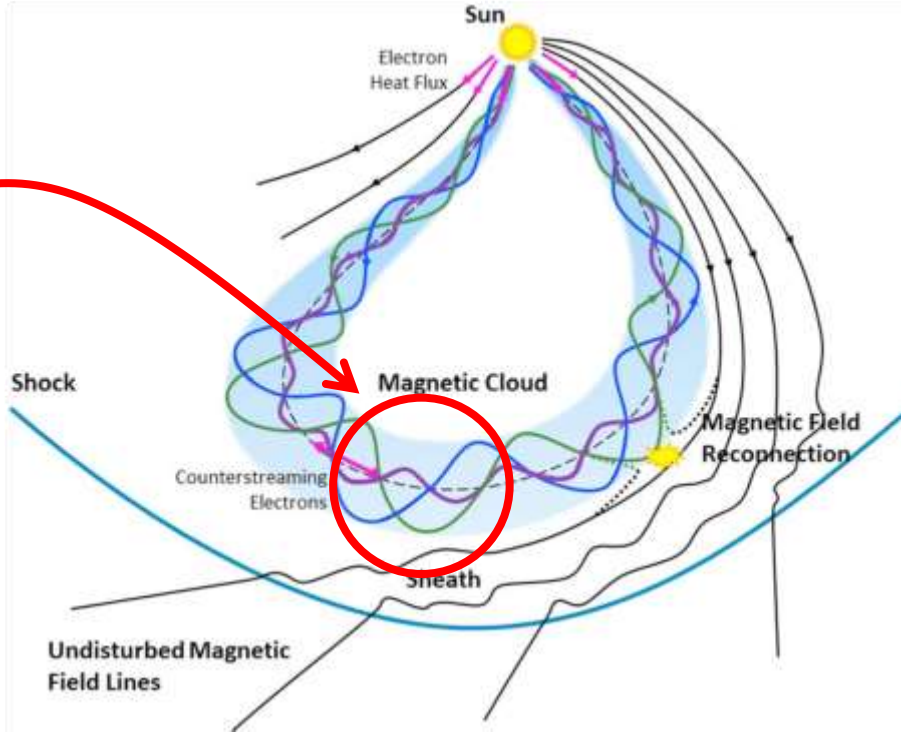


Image courtesy: Camilla Scolini

Cartoon of a magnetic cloud in the heliosphere (Wang+2018c)



CME models in EUHFORIA

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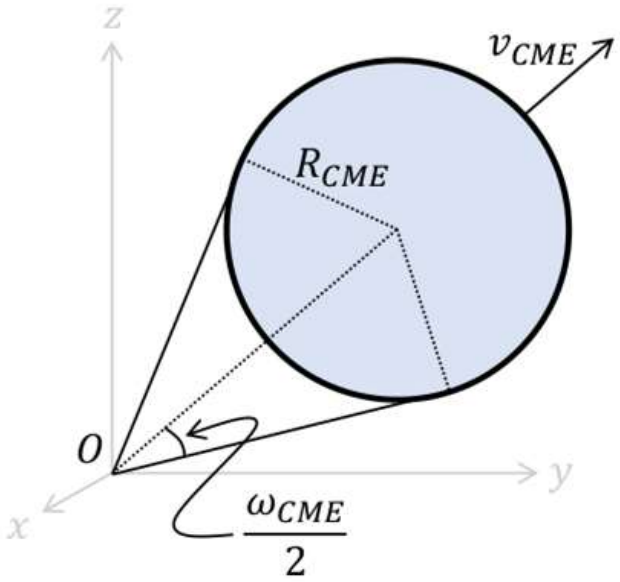

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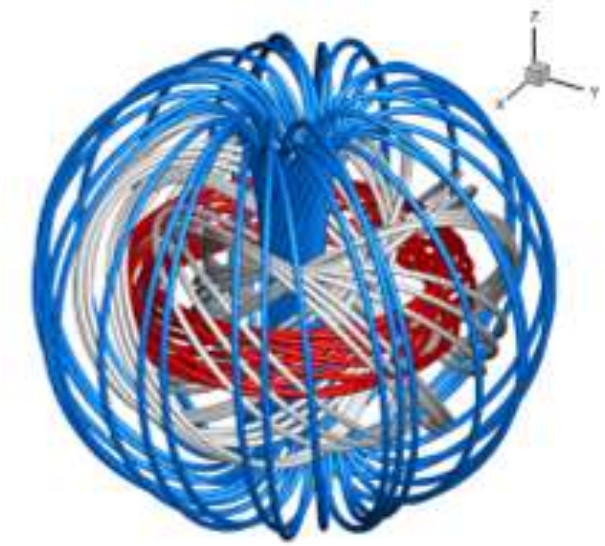
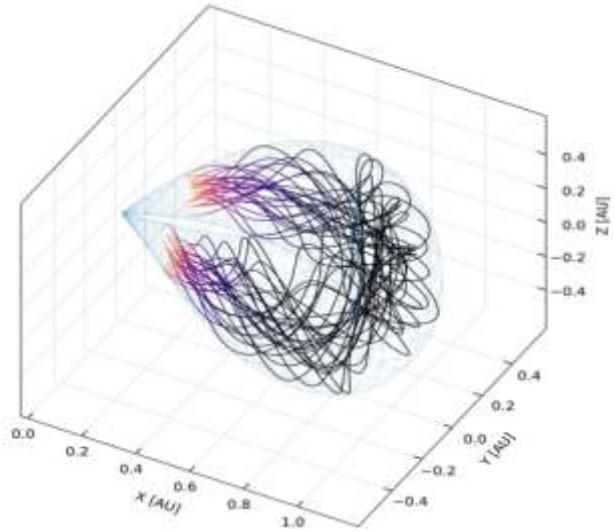


Image courtesy: Camilla Scolini

FRi3D model (flux rope - extended geometry) Isavnin et al, 2016

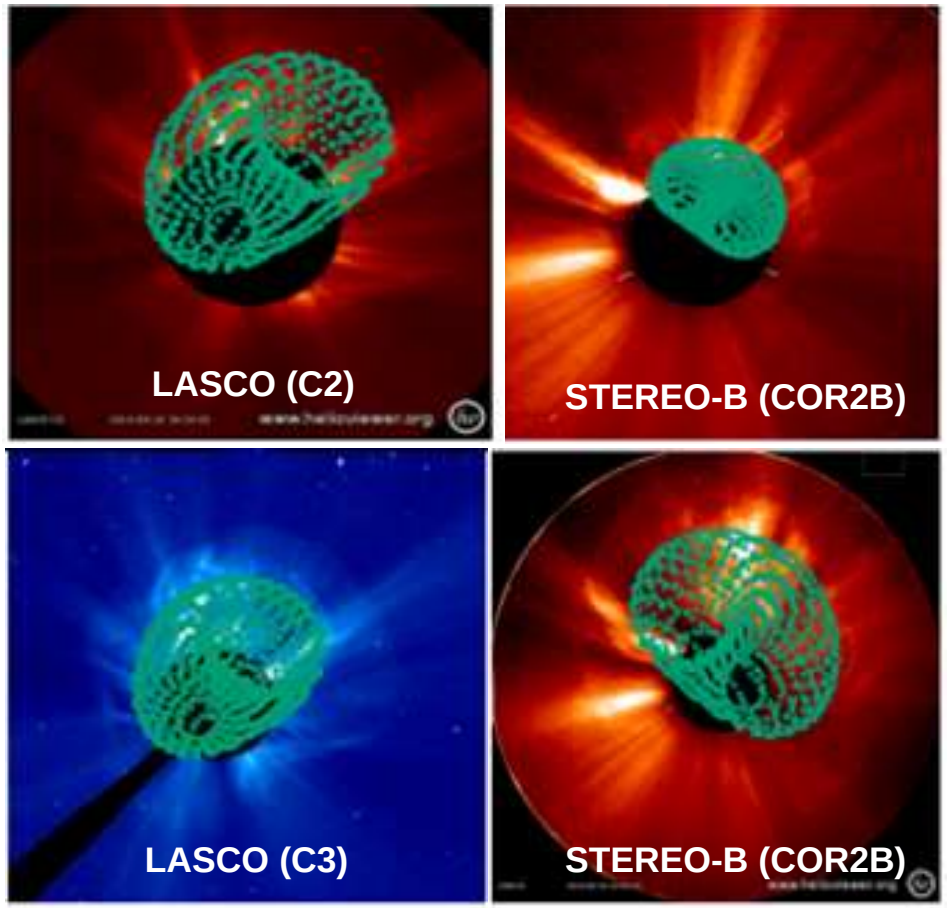


- Stretched flux rope
- Lundquist magnetic field

$$\mathrm{B}_\rho = 0$$
$$\mathrm{B}_\phi = B_0 J_1(\alpha r)$$
$$\mathrm{B}_z = B_0 J_0(\alpha r)$$

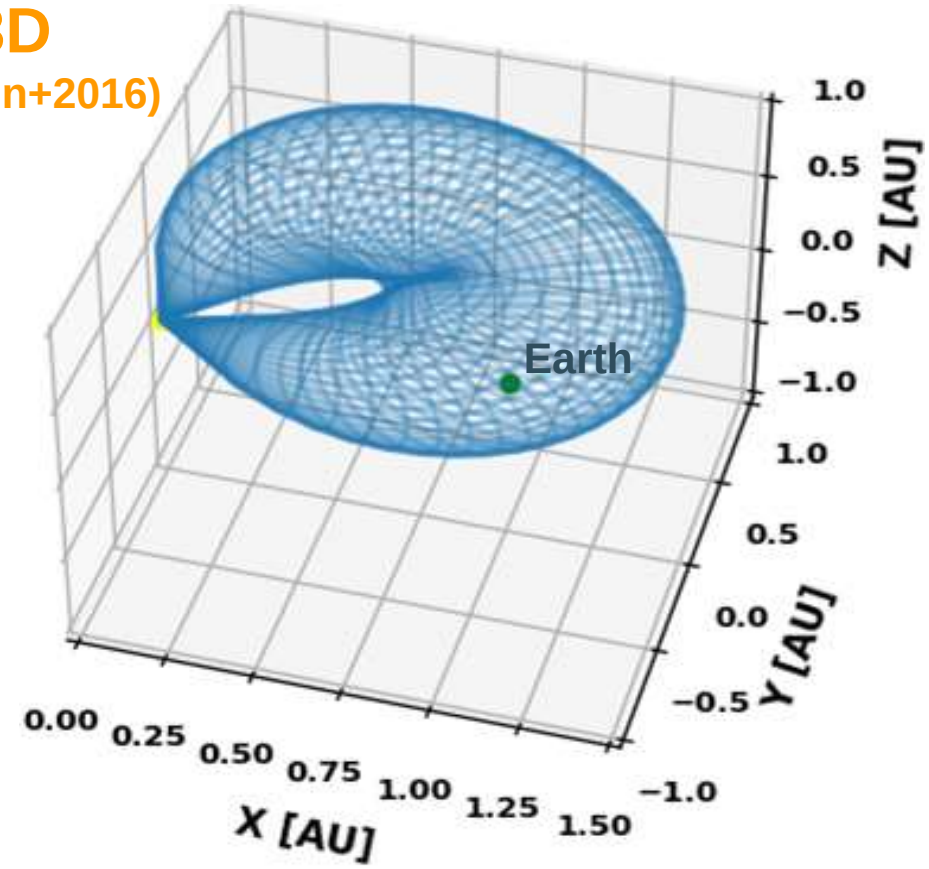
Credit: Anwesha Maharana

FRi3D: advanced flux-rope CME model



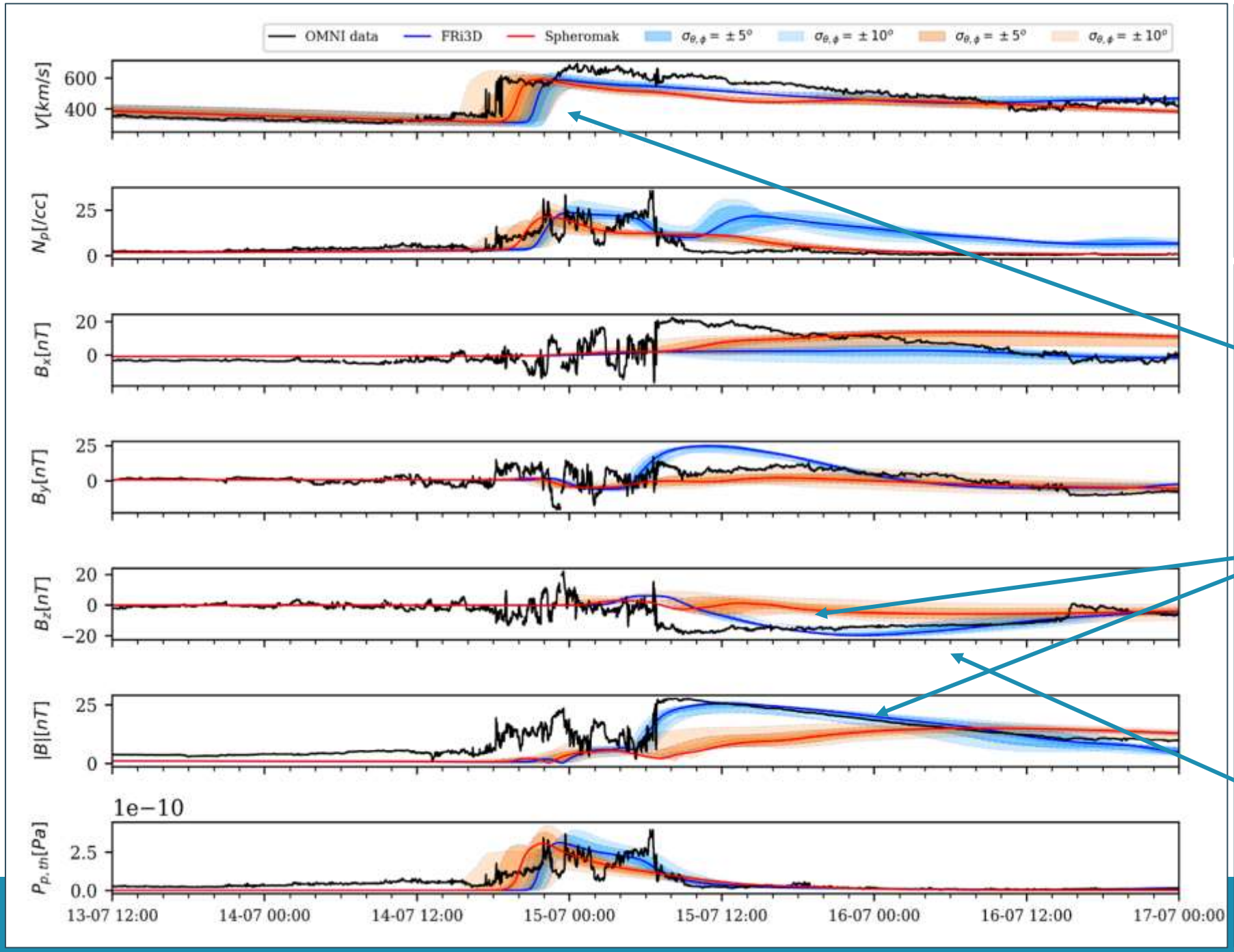
Orientation from 3D reconstruction in sync with the northwest-ward eruption

FRi3D
(Isavnin+2016)



FRi3D flux rope when self-similarly expanded till Earth, suggest **flank encounter.**

credit: Anwesha Maharana



ICME predictions at Earth

- FRi3D arrival time is similar to Spheromak: ~3h delay than observed arrival
- FRi3D enhances the predictions of **B** and **B_z** by around 37% and 76% as compared to spheromak.
- Prolonged magnetic field enhancement reproduced by FRi3D

Maharana et al, 2022

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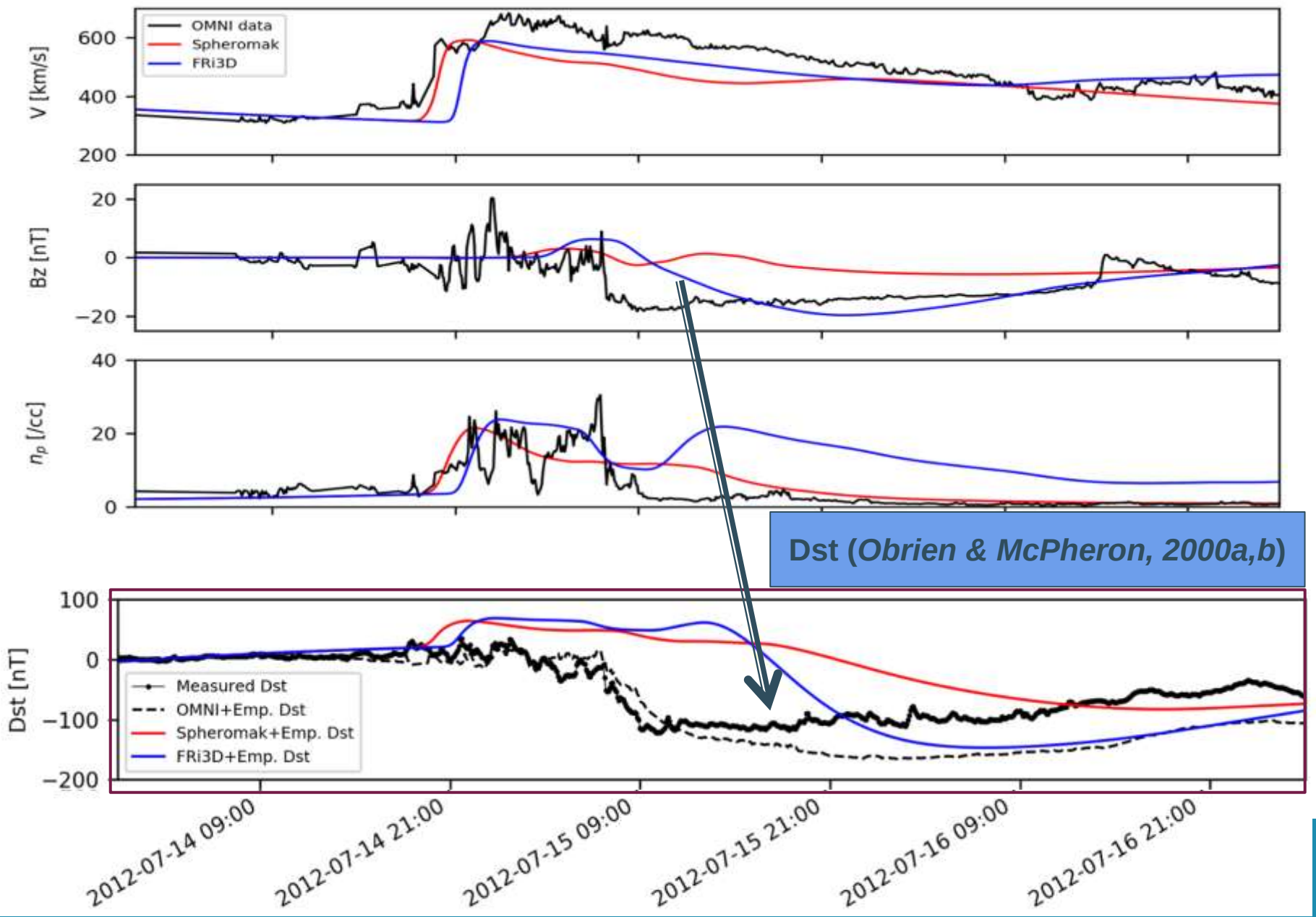
Geo-effectiveness predictions by CME models in EUHFORIA



Dst (*Obrien & McPheron, 2000a,b*)

- Using modelled solar wind plasma properties at Earth, empirical geomagnetic indices are computed.
- Solar wind - Dst coupling formula (***Obrien & McPheron, 2000a,b***)

$$\frac{d}{dt}Dst^* = Q(t) - \frac{Dst^*}{\tau}$$

$$Dst = Dst^* + a\sqrt{P_{dyn}} - b$$

Quiet condition:

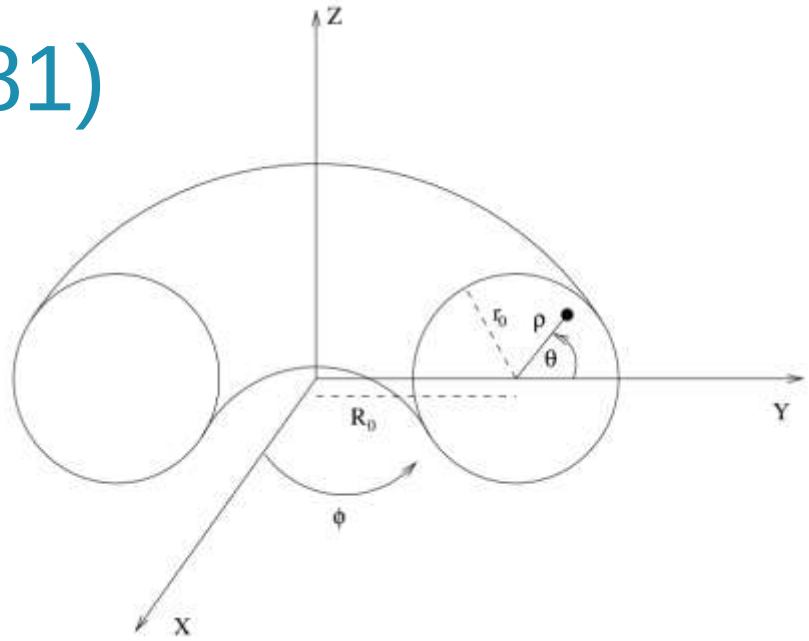
$$Dst(t = 0) = 0.0$$

- Improved minimum Bz modelled by FRi3D predicts the minimum Dst

Maharana et al, 2022

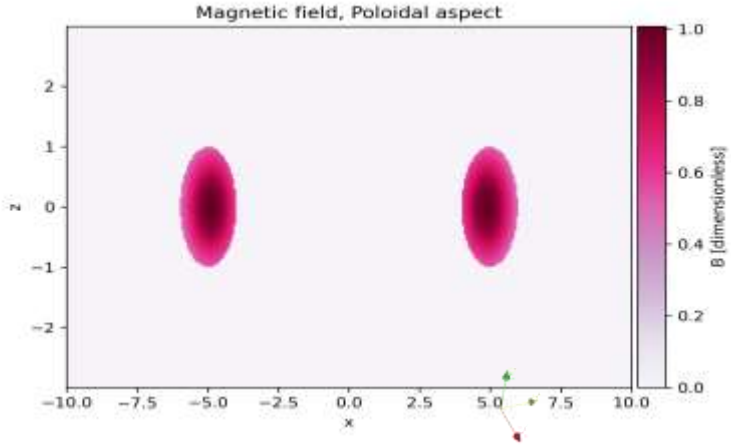
Miller & Turner CME model (1981)

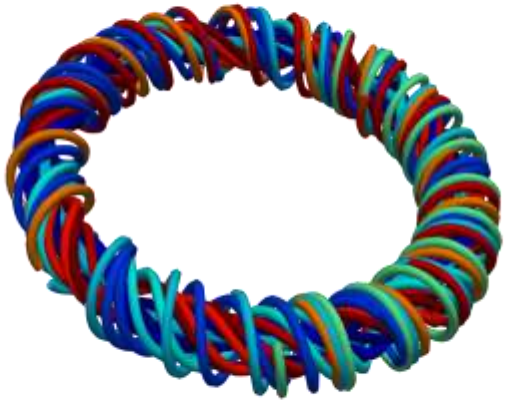
$$
\begin{aligned}
B_\rho &= B_0 \frac{R_0 - 2\rho\cos\theta}{2\alpha R_0(R_0 + \rho\cos\theta)} J_0(\alpha\rho)\sin\theta, \\
B_\varphi &= B_0 \left(1 - \frac{\rho}{2R_0}\cos\theta\right) J_0(\alpha\rho), \\
B_\theta &= B_0 \frac{R_0 - 2\rho\cos\theta}{2\alpha R_0(R_0 + \rho\cos\theta)} J_0(\alpha\rho)\cos\theta \\
&\quad - B_0 \left(1 - \frac{\rho}{2R_0}\cos\theta\right) J_1(\alpha\rho).
\end{aligned}
$$



- Maximum magnetic field strength is close to the axis and reduces outward

- This magnetic field is *by definition divergence-free* and *approximates the force-free condition for large aspect ratios*





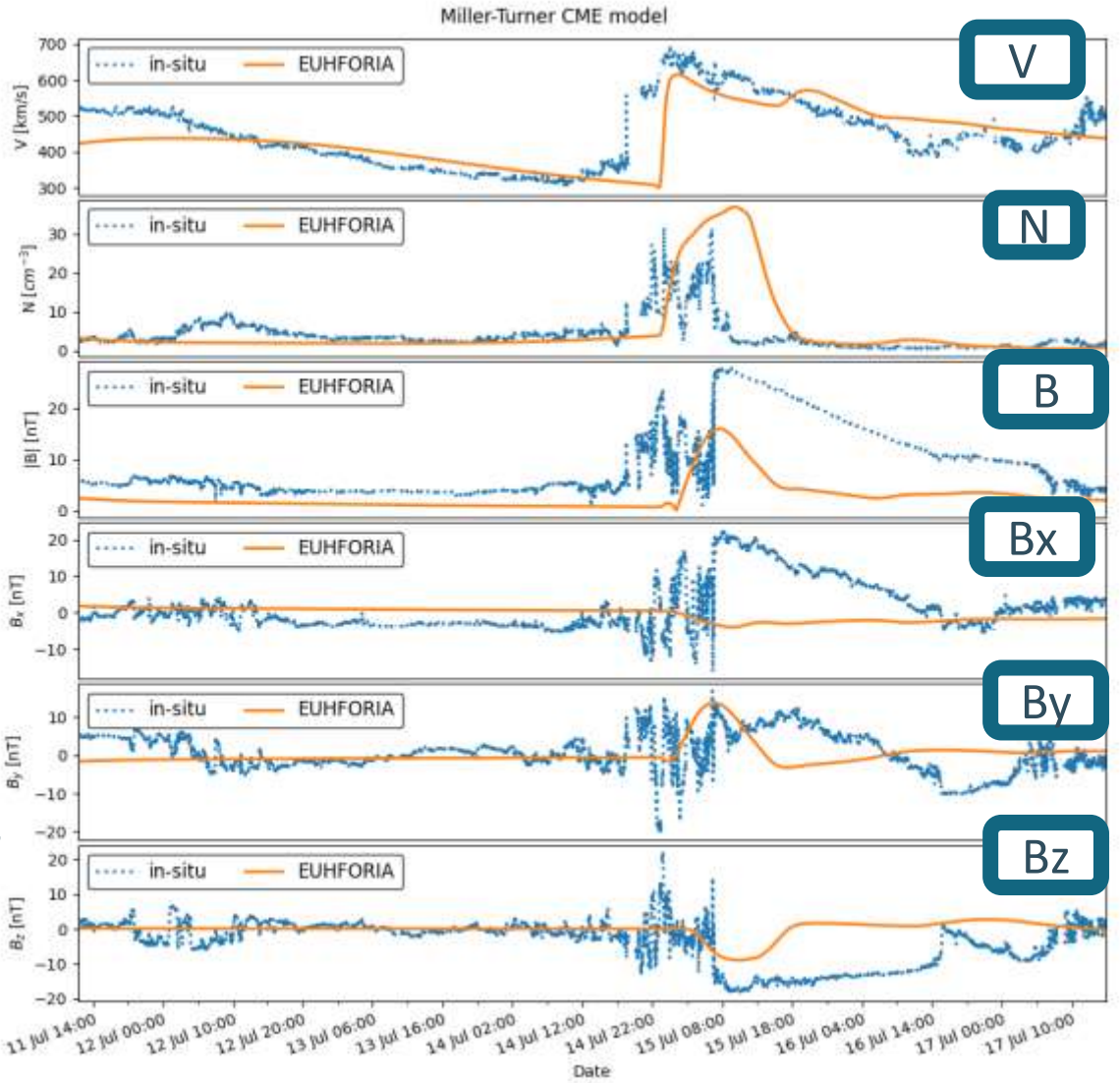
credit: Anwesha Maharana & Luis Linan

Validation of Miller & Turner CME model in EUHFORIA

Halo CME event on 12 July 2012

- Vr = 763 km/s
- T = 0.8 MK
- Tilt = 0°
- R = 10 , a = 5
- B0 = 1. 10^{-6} T
- n = 10^{-17} kg m^{-3}

- **More stable and realistic** (for CME) than the Soloviev model
- Offers *less free parameters than Soloviev torus* (no influence on the magnetic field distribution, nor the poloidal shape…)
- Optimisation of implementation required to model the magnetic cloud better



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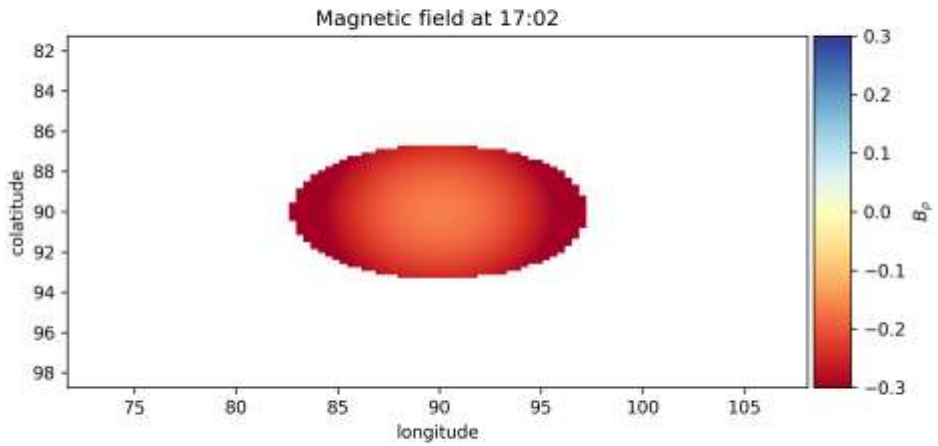
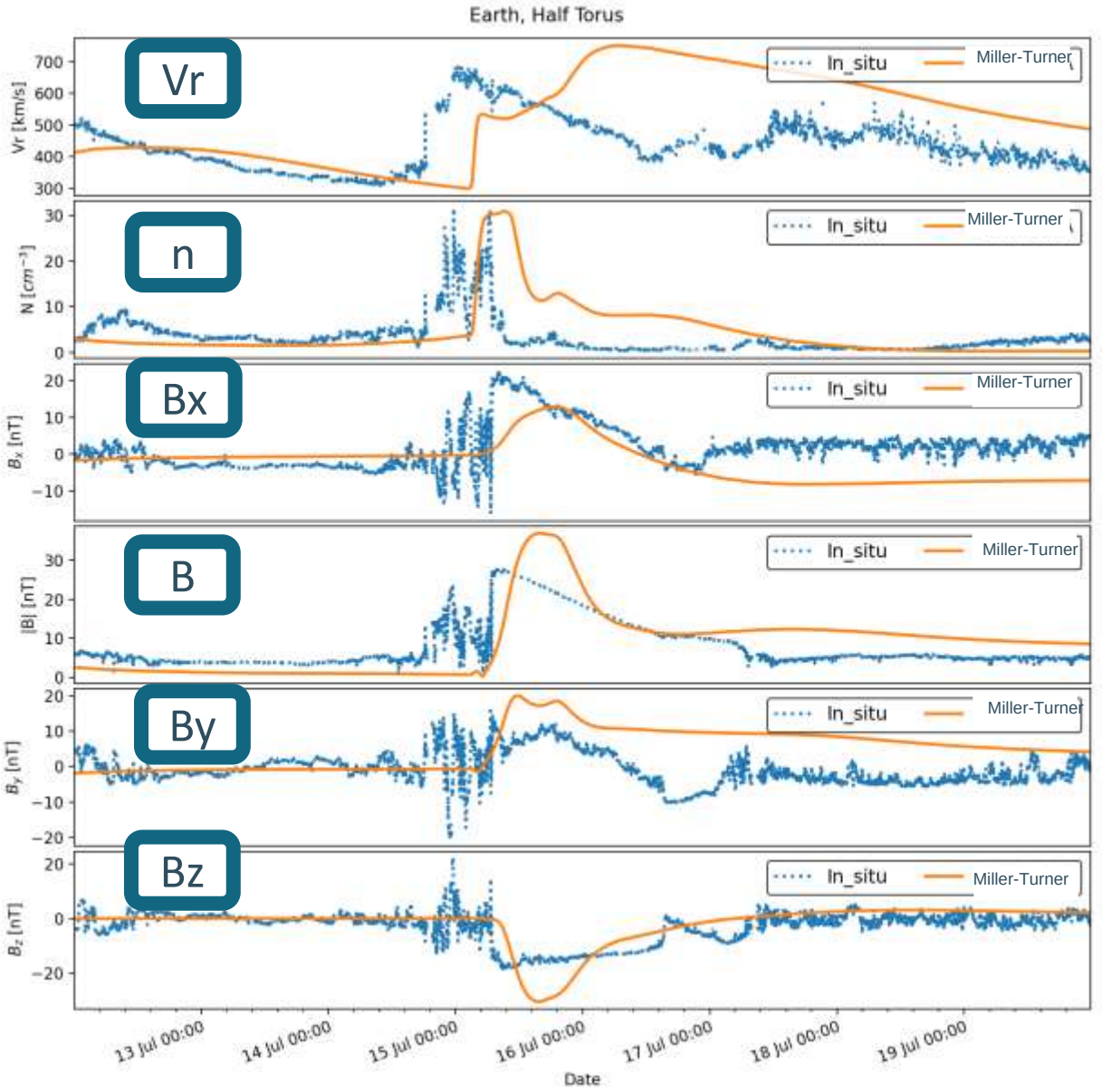
Half torus in ICARUS



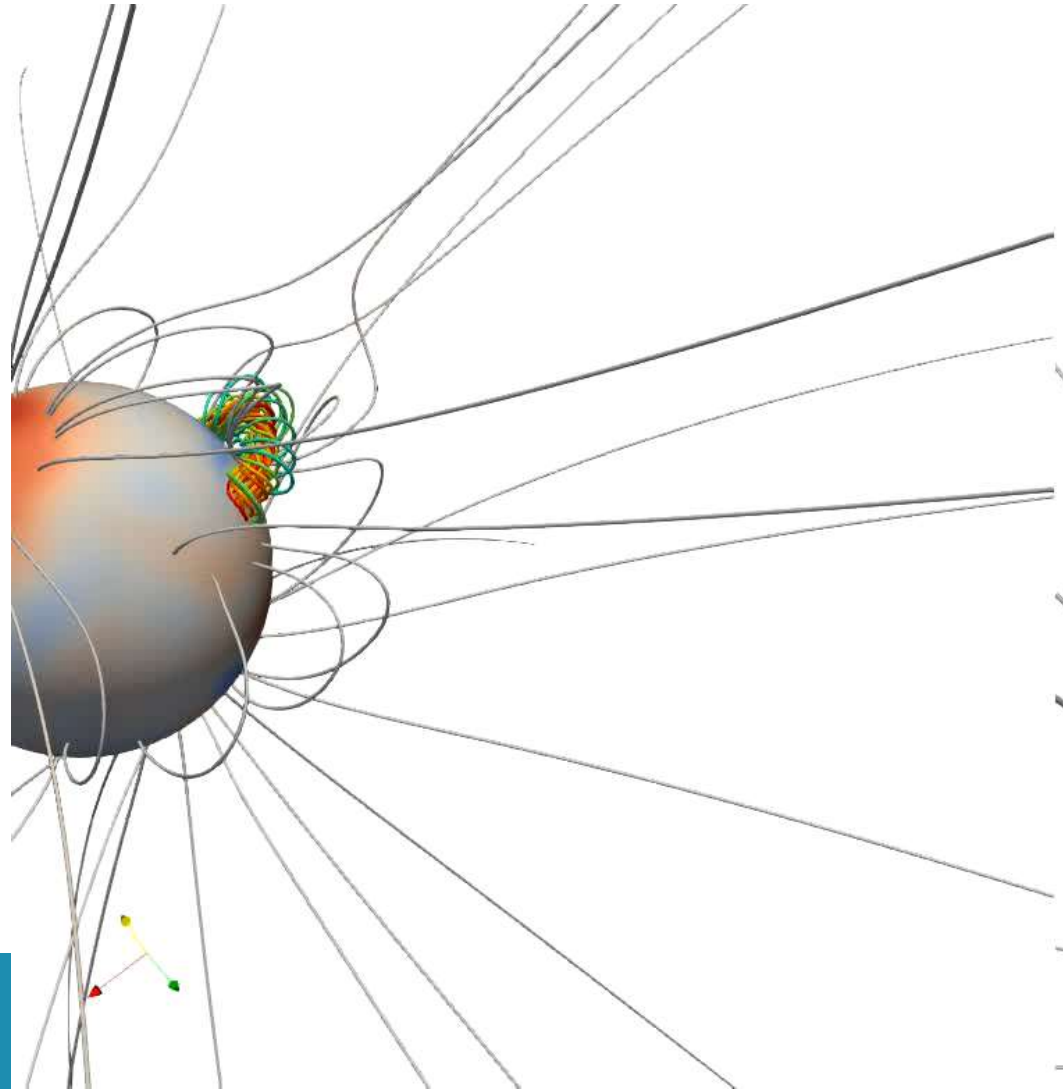


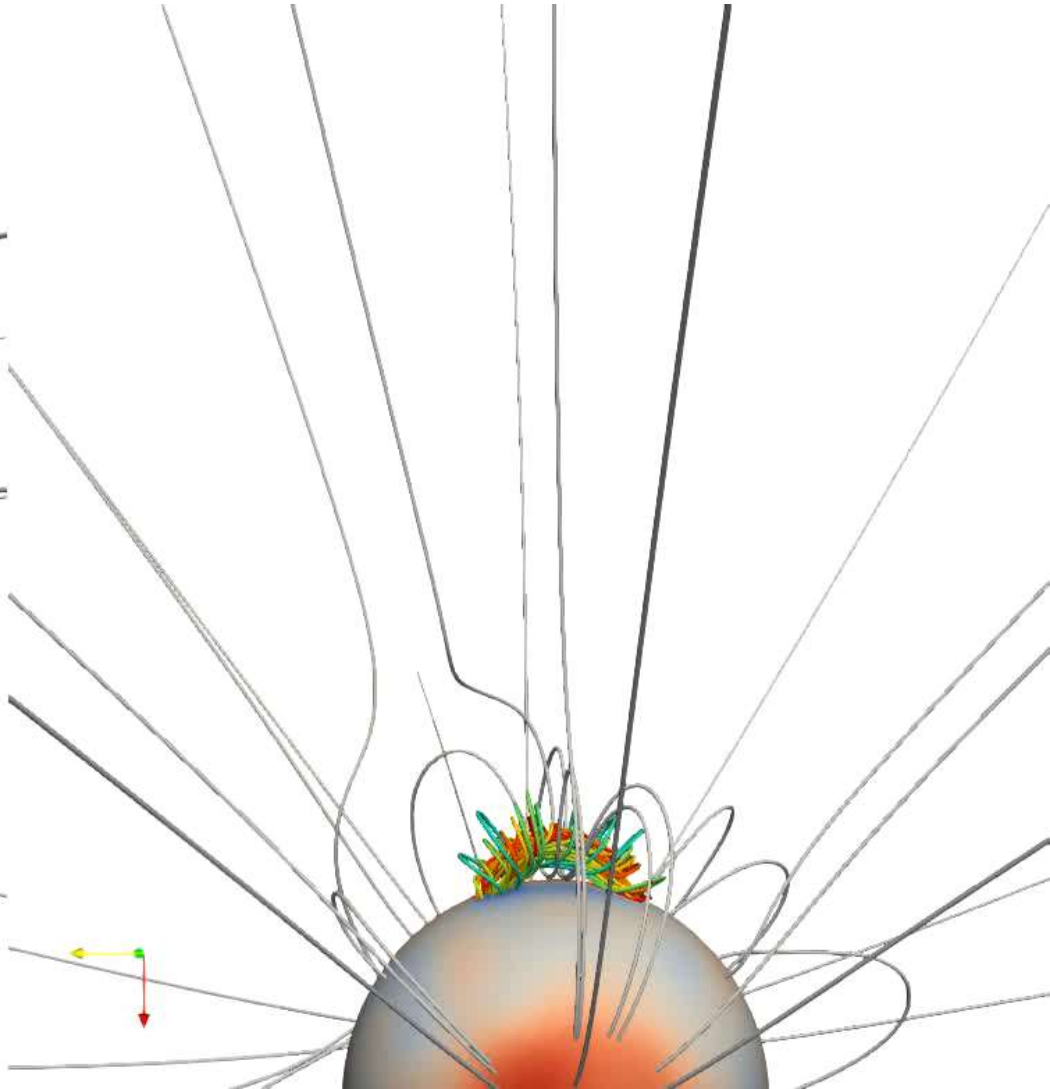
- We maintain the torus at the half of its crossing and we keep a constant injection
- Allows stabilization of the model and much more « *realistic* » prediction
- But: problematic in the case of successive CMEs
- The free parameters are also harder to choose (e.g`. the injection time…)

credit: Anwesha Maharana & Luis Linan

TDm flux-rope CME model in COCONUT

Credit: Luis Linan & Florian Régnault





Modified Titov-Démoulin CME superposed on a magnetogram-based COCONUT corona

THANK YOU! EUHFORIA is also available in euhforiaonline.com

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Some references:

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Other references: **EUHFORIA web page**: euhforia.com/