



EUHFORIA: a solar wind & CME evolution model

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EUHFORIA Rationale

Science:

- 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**

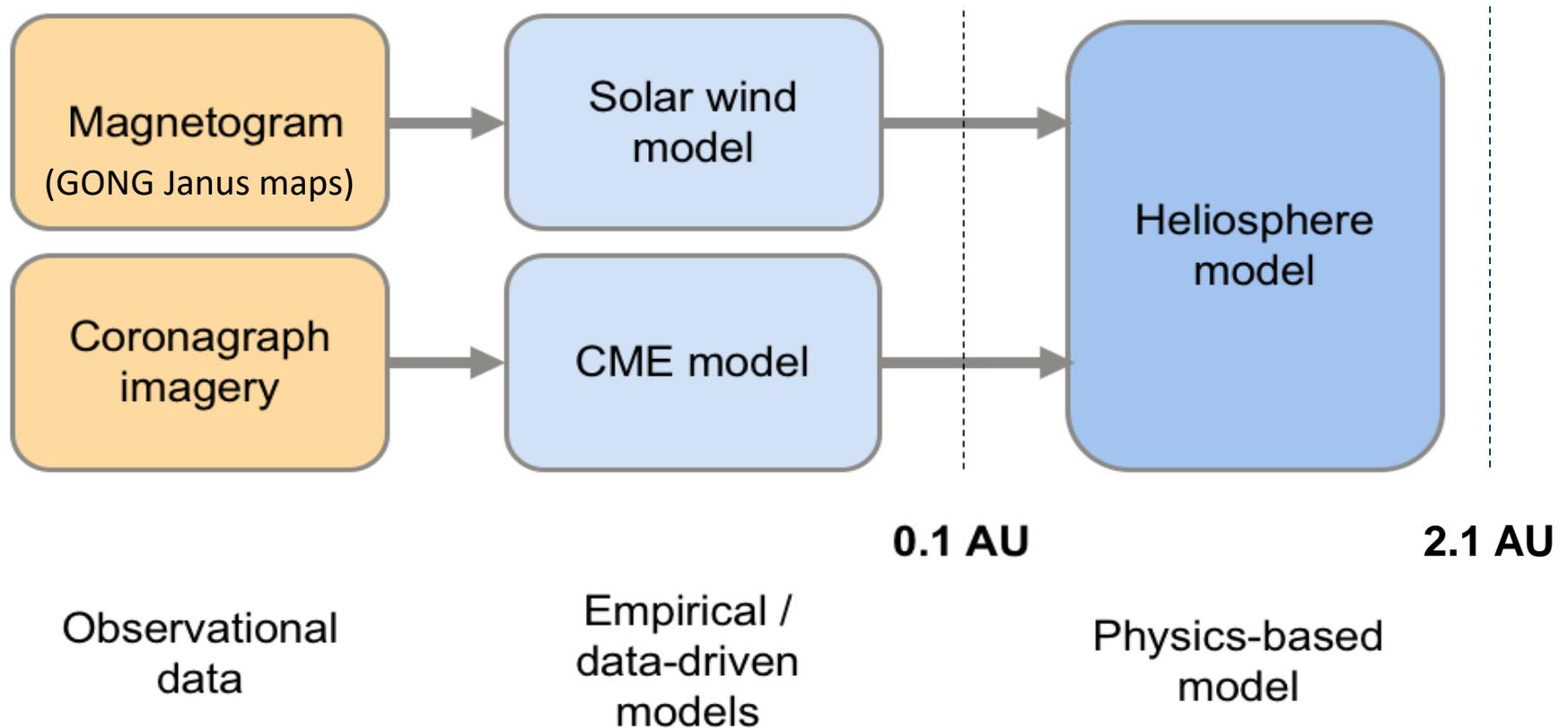
Applications:

- Space weather forecasts (“European ENLIL”)
 - Time of arrival / *Geo-effectiveness*
- Support for space missions (e.g. SolO)

EUHFORIA model is data-driven

EUHFORIA v1.0:

3D heliospheric wind + CME evolution code



EUHFORIA 1.0 validation

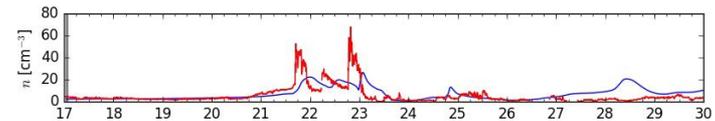
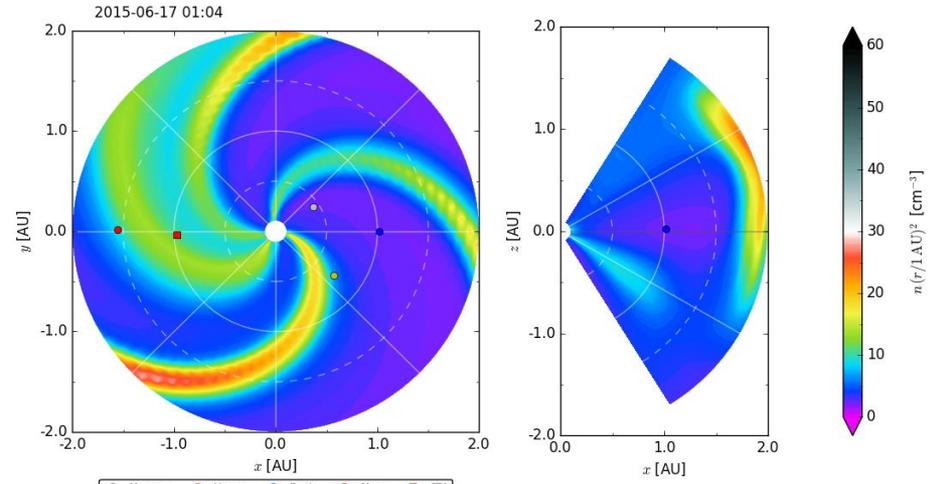
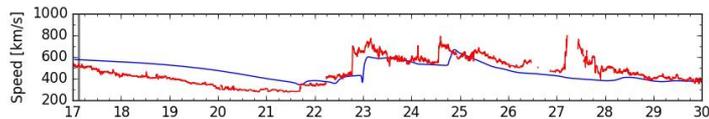
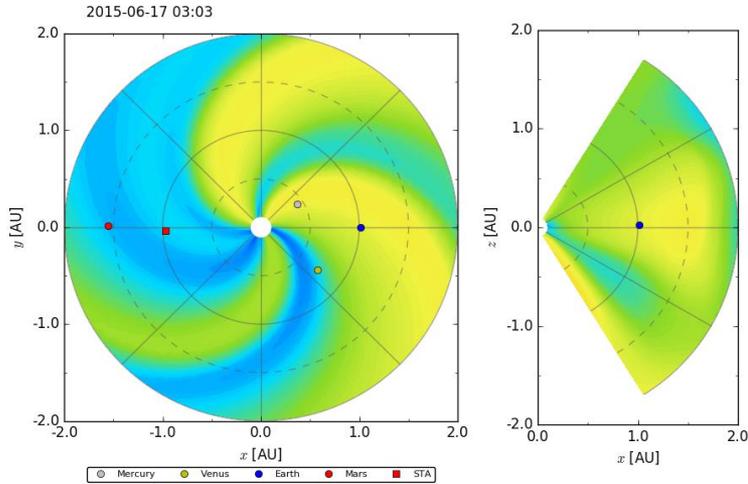
Consider June 18-27, 2015 events

- 17 cone model entries in DONKI, 9 with little or no impact to Earth
- We selected the **5 events most apparently directed to Earth**:

CME Number	Time at 0.1 AU	Lat (deg HEEQ)	Lon (deg HEEQ)	Half-width (deg)	Speed (km/s)
1	2015-06-18T20:00:00	11	-50	45	1000.0
2	2015-06-19T14:59:00	-33	9	54	603.0
3	2015-06-21T05:01:00	7	-8	47	1250.0
4	2015-06-22T21:10:00	14	3	45	1155.0
5	2015-06-25T10:51:00	23	46	41	1450.0

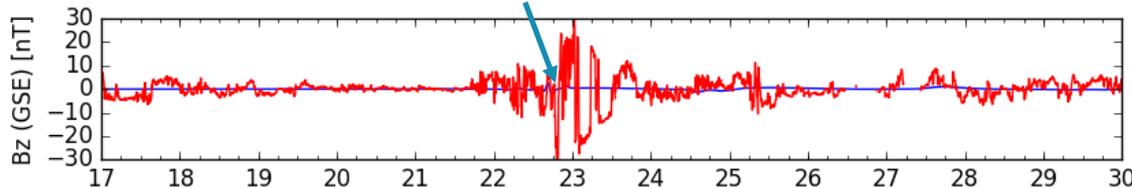
- Events 1, 4 and 5 are related to M-class flares from AR12371
- **No input for density and temperature**, hence assume
 - constant density: $\rho_{\text{CME}} = 10^{-18} \text{ kg m}^{-3}$
 - constant temperature: $T_{\text{CME}} = 0.8 \text{ MK}$

Cone CME model run (June 18-27, 2015 events)



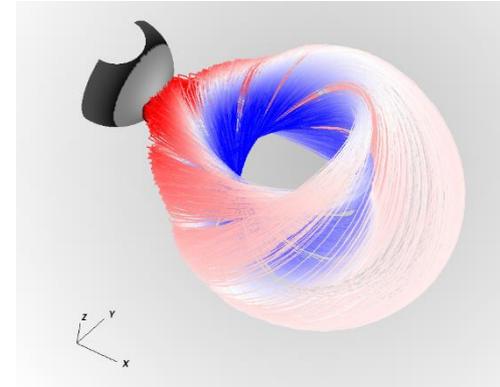
Bad/wrong B_z from Cone CME

Cone model parameters
(speed, direction, timing) from
DONKI database

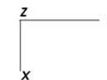
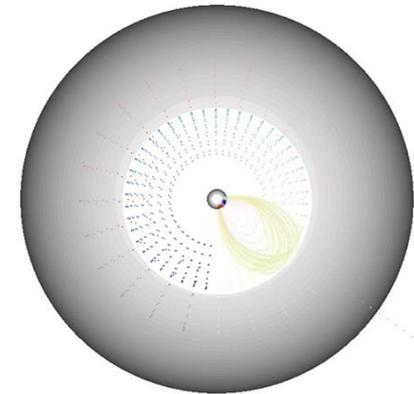


Connecting corona and IP space

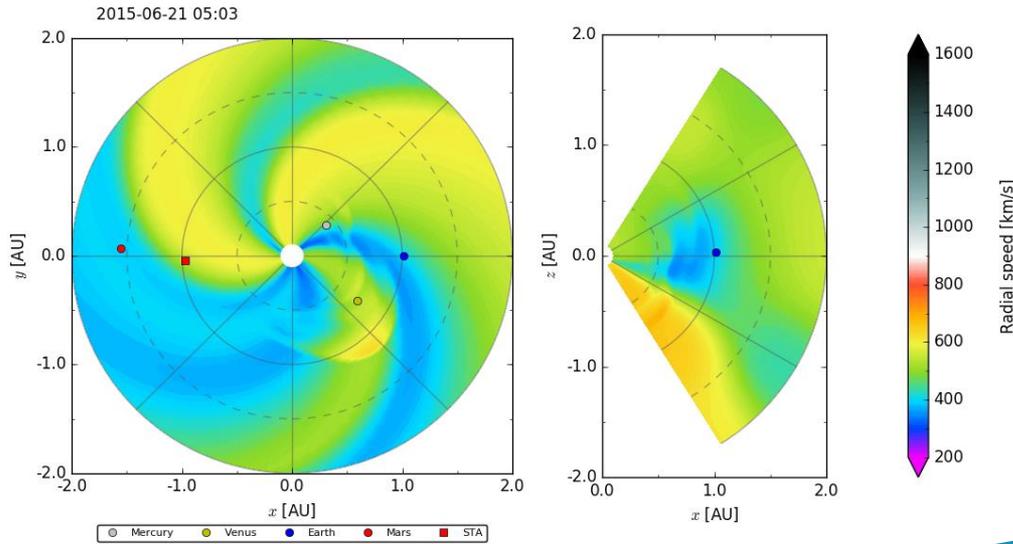
- Employ Gibson & Low 1999 CME model:
 - Analytic solution of the time-dependent 3D MHD equations of a FR **expanding self-similarly**
 - Stretched spheromak-like magnetic field structure
 - *Self-consistently includes low-density cavity, high-density core*
 - Has been used in a number of MHD studies
- Constrain parameters of the model:
 - Fit kinematics to EUV & coronagraph observations or use cone model estimate
 - Use coronal model to estimate magnetic parameters (chirality, flux)



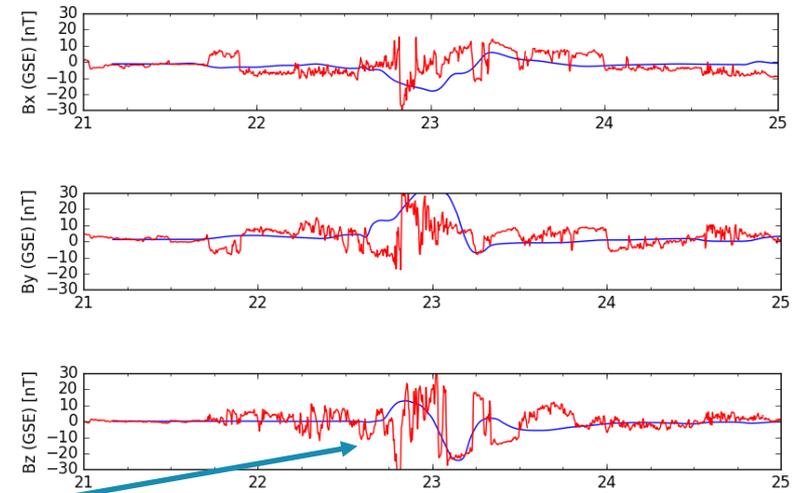
DB: gl_2012-06-18T18-00-00.vtr



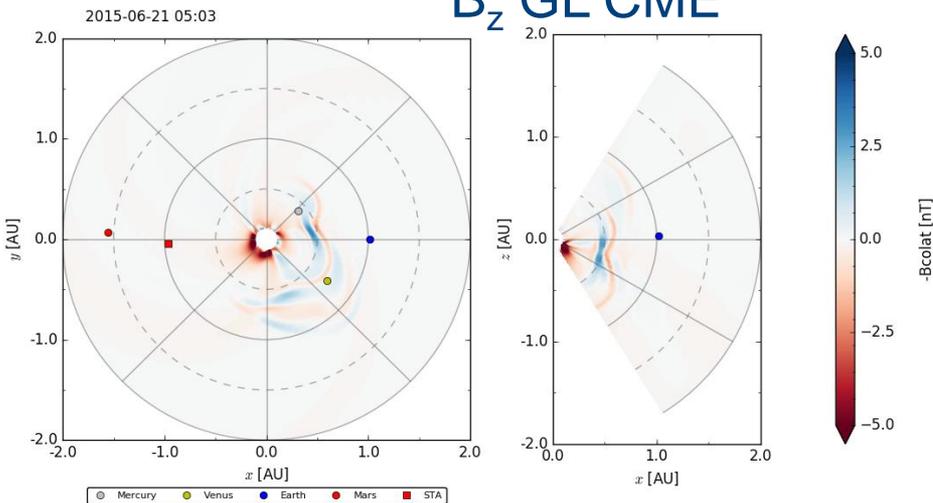
GL flux-rope CME model run



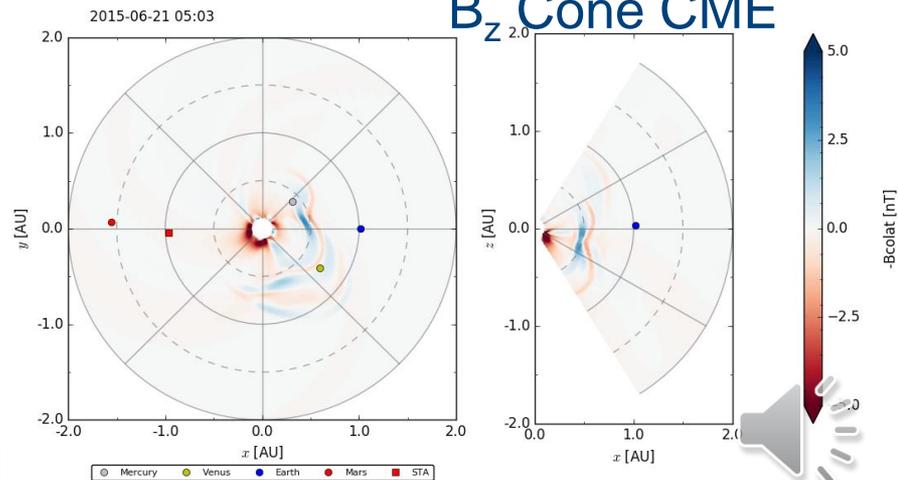
B-comp. fit with GL CME



B_z GL CME

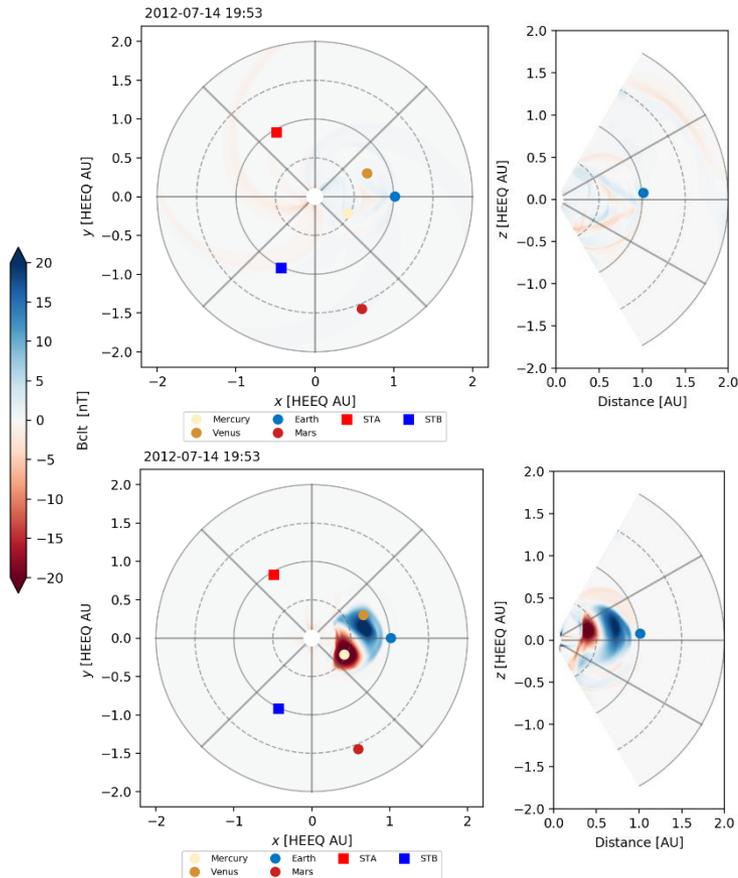


B_z Cone CME



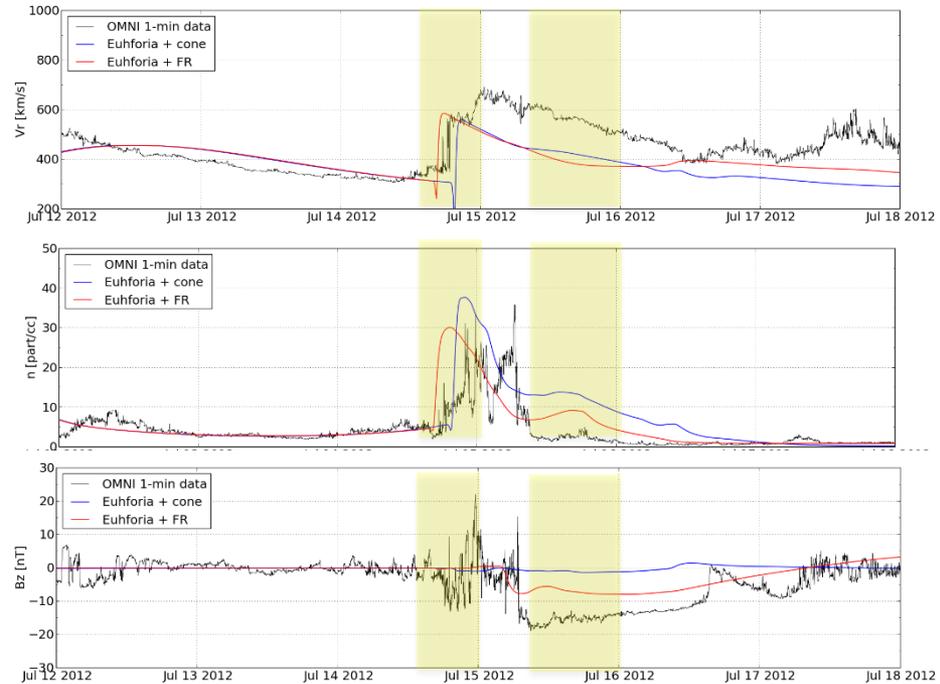
The July 12, 2012 CME: cone vs flux rope EUHFORIA

2D cuts in the solar equatorial plane and meridional plane passing through Earth



EUHFORIA snapshots of the simulated B_{cIt} ($-B_z$) in the solar equatorial plane for the **cone model (top)**, and the **flux rope (bottom)**, on 2012-07-14 at 19:53 UT.

Time series at Earth

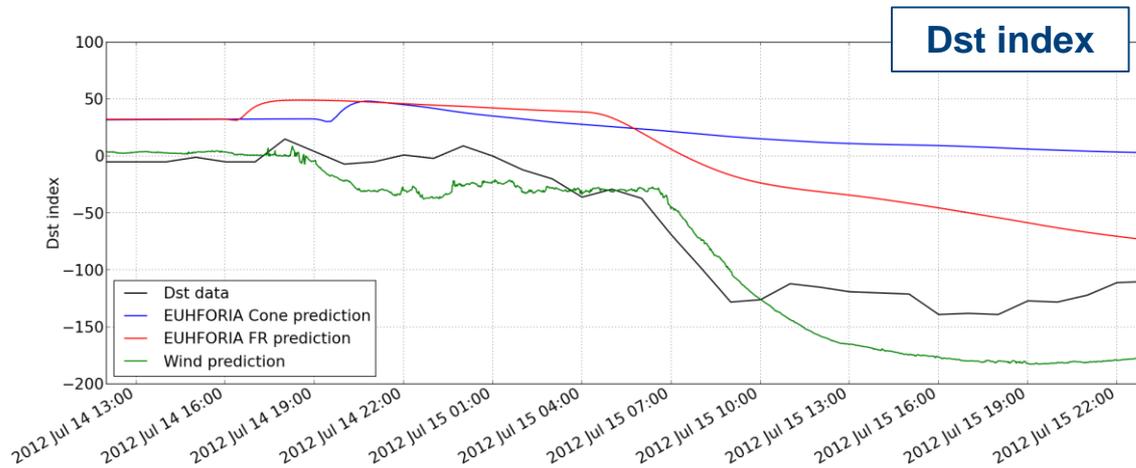
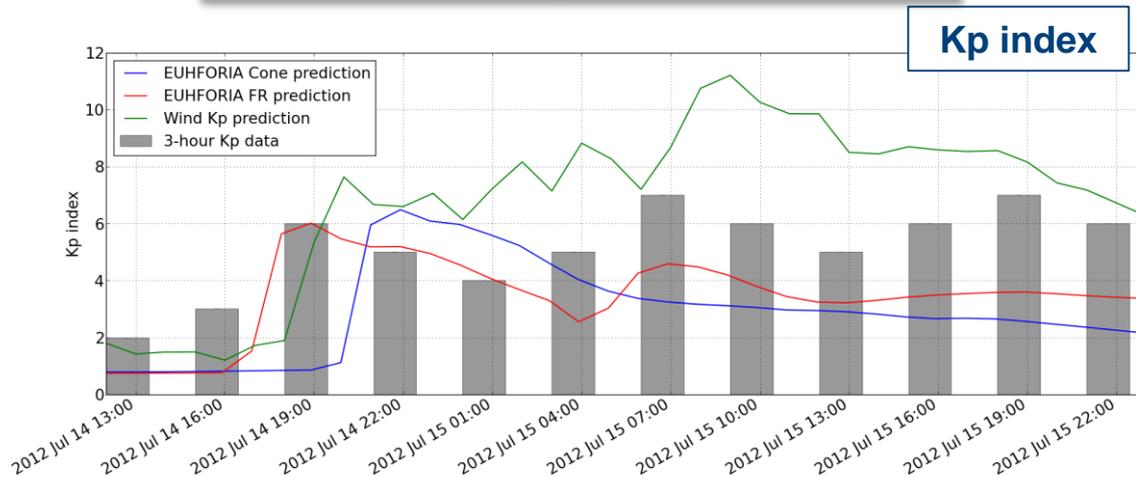


Radial speed, number density, and B_z time series at Earth. Results of EUHFORIA simulation with a 5-min cadence are in blue and red, while OMNI 1-min in-situ data in black. The periods associated with the shock arrival and ICME passage are marked in yellow.

Cf. Scolini et al., Session 4, poster 5

July 12, 2012 CME: EUHFORIA predictive capabilities

Solar wind-geomagnetic activity indices coupling functions



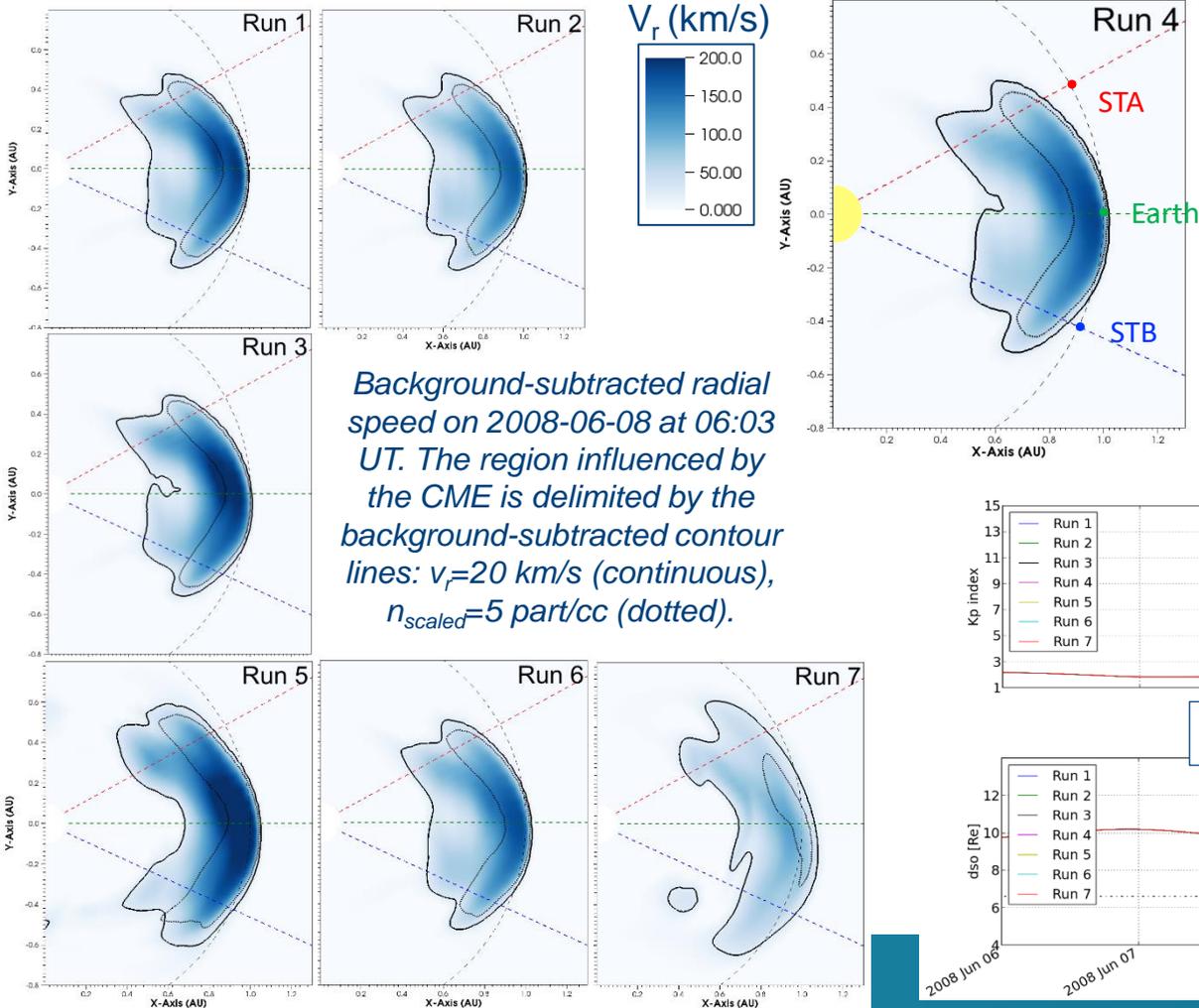
For more information on the July 12, 2012 case study CME studied with EUHFORIA:
Poster #5 in Session #4
by C. Scolini et al.

Comparison between the observed and predicted Kp and Dst indices. Predictions are obtained using empirical relations from [Newell et al., 2008] and [O'Brien and McPherron, 2000], taking as input time series from Wind, EUHFORIA Cone and EUHFORIA FR at Earth.

Parameter study: cone CME shapes in EUHFORIA

We have tested the effect of different spherical CME shapes in EUHFORIA comparing the results at different spacecraft locations at 1 AU and the impact on geo-effectiveness

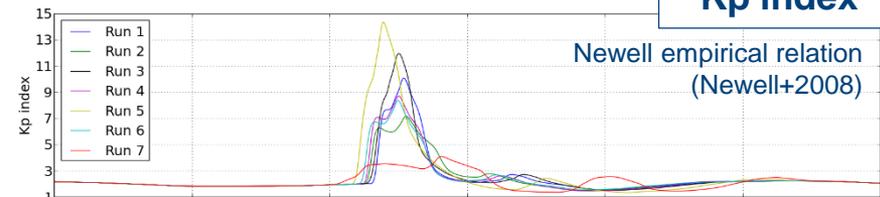
CME shape in the solar equatorial plane



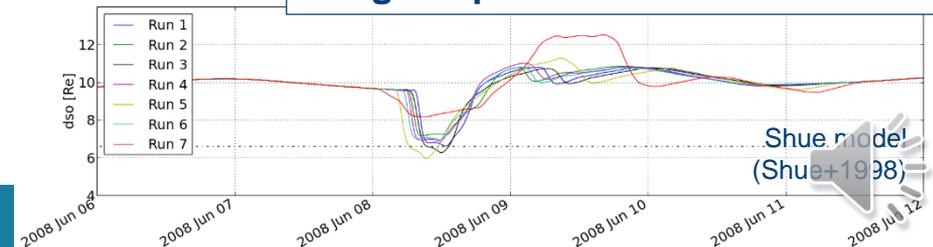
For more information about the effect of different CME shapes in EUHFORIA:
Poster #6 in Session #4
 by C. Scolini et al.

Geoeffectiveness predictions

Kp index

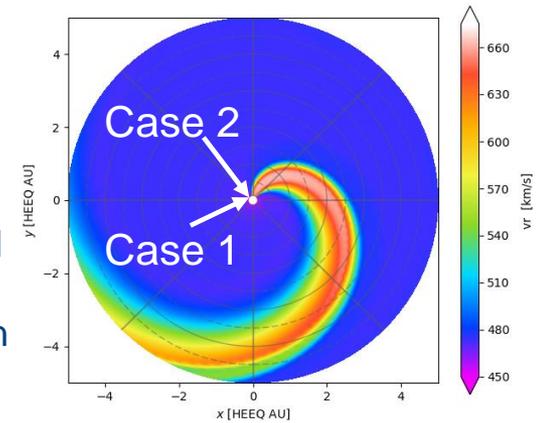


Magnetopause stand-off distance

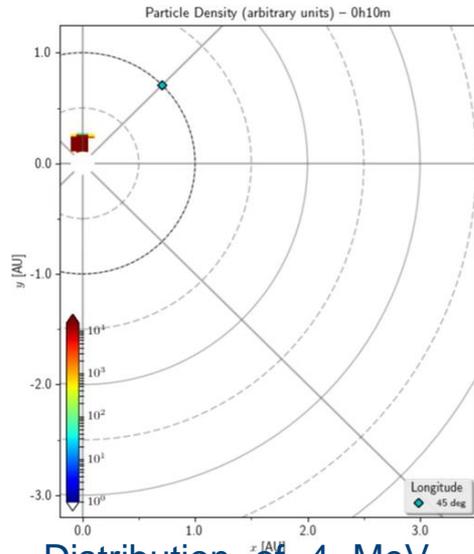


Combining EUHFORIA with a Monte Carlo SEP transport model

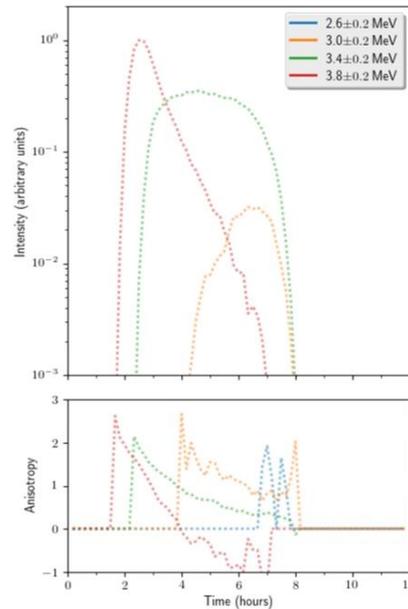
SW V_r and locations of injection zones



SEPs injected in the **slow** solar wind

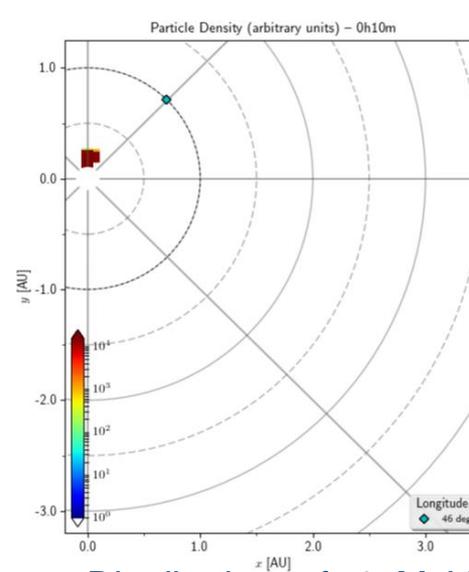


Distribution of 4 MeV protons after the impulsive injection in the **slow SW** at 0.1 AU.

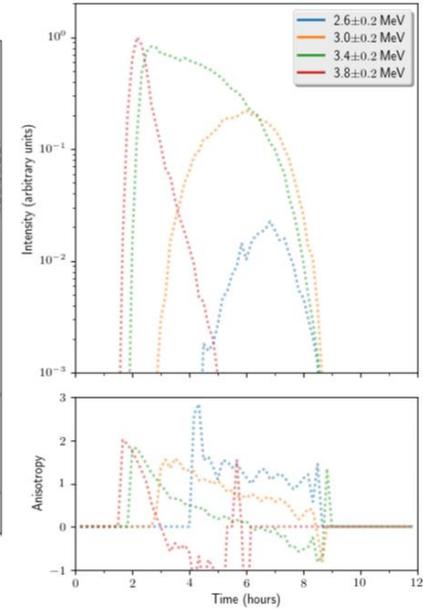


Observer near inner boundary injection zone.

SEPs Injected in the **Fast** solar wind Stream



Distribution of 4 MeV protons after injection in the **CIR** at 0.1 AU.



Summary and outlook

- ***EUHFORIA v. 1.0*** ready
 - ✓ Spheromak and GL flux rope incorporated
 - ✓ Ensemble modeling supported
 - ✓ Forecasting operations at SIDC/ROB being tested
 - ✓ Parameter studies for validation, accuracy tests ongoing
- **Data-driven corona & FR model proceeding:**
 - ✓ Data-driven MFM simulations currently running
 - ✓ NLFFF - MFM comparison underway
 - ✓ Other FR CMEs being tested: TD, FRI3D,...
 - ✓ Coupling NLFFF and magnetized CMEs, testing the estimation of magnetic parameters
- **Towards integrated SEP event modeling:**
 - ✓ EUHFORIA combined with a Monte Carlo SEP transport model
 - ✓ Plans to include Coronal Shock Acceleration (CSA) simulation model and SOLar Particle Acceleration in Coronal Shocks (SOLPACS) of Vainio, Afanasiev, et al.