THEORY GRANT

Simulations of Sun-to-Earth Propagation of Solar Eruptions (SSEPSE)

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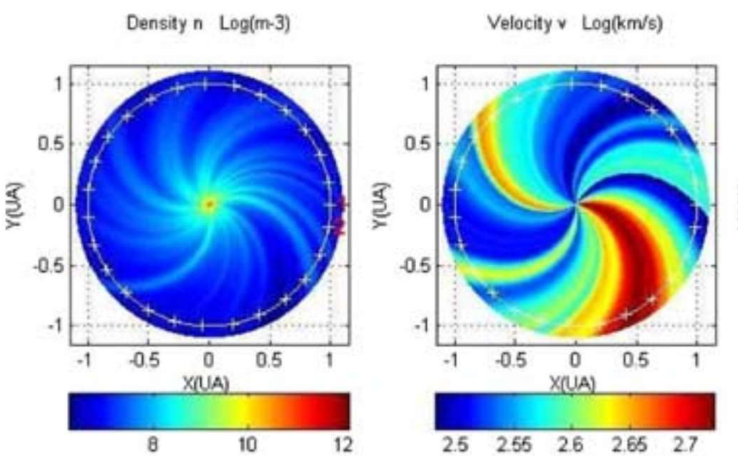
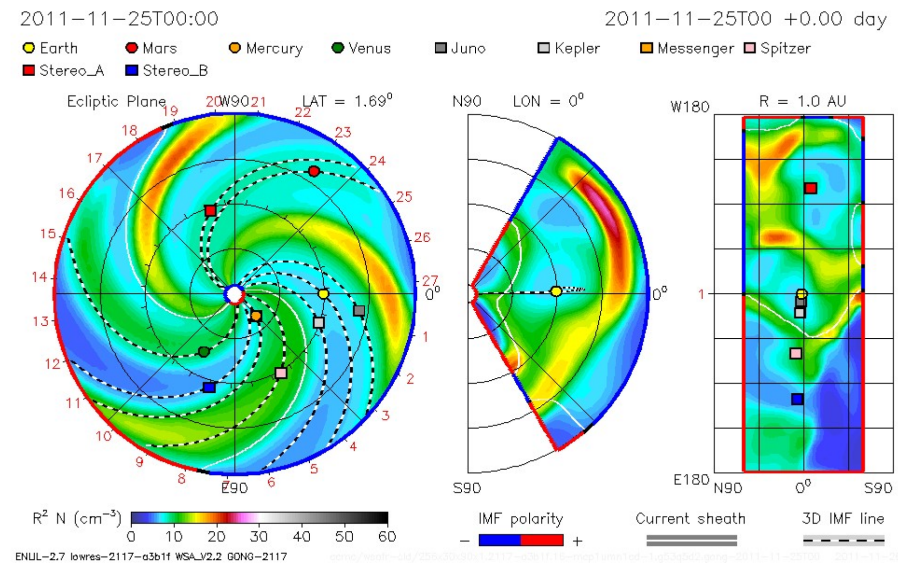
Analytical Models



Florens et al. 2007

Assuming ***stationarity*** in the solar wind conditions it is possible to **track backwards** the plasma trajectories **by following the Parker Spiral** starting from 1 AU in-situ data.

Numerical Models



Starting from 2D **photospheric magnetograms**, different techniques reconstruct the 3D magnetic fields in the inner and intermediate corona, using then numerical and/or empirical methods **to build the i.b.** of a MHD simulation.

Schatten, K. H., N. F. Ness, and J. M. Wilcox (1968) *Influence of a Solar Active Region on the Interplanetary Magnetic Field*, Sol.Phys.,5(2), 240–256

Schatten, K. H. (1971) *Current sheet magnetic model for the solar corona*, Cosmic Electrodynamics,2, 232–245

Florens et al. (2007) *Data-driven solar wind model and prediction of type II bursts*, Geophys. Res. Lett. 34

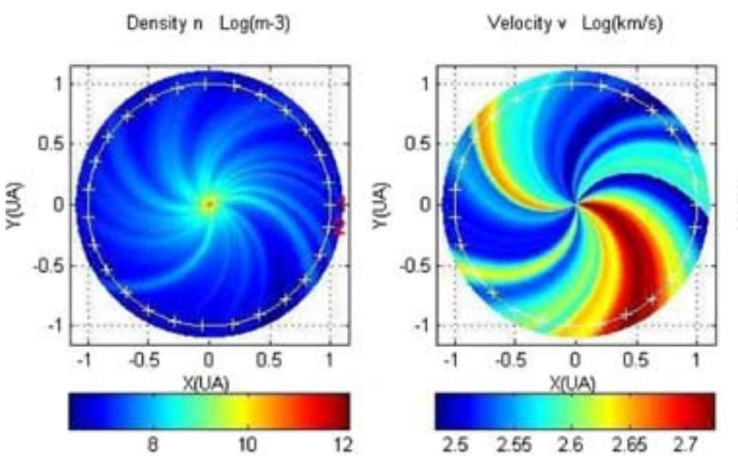
Tasnim et al. (2018) *A generalised equatorial model for the accelerating solar wind*, JGR (SP) 123

Mikić et al. (1999): *Magnetohydrodynamic modeling of the global solar corona*, Phys. Of Plasmas, vol 6, issue 5

Pizzo et al. (2011): ***Wang-Sheeley-Arge-ENLIL*** *Cone Model Transitions to Operations,* Space Weather, Volume 9, S03004

Pomoell & Poedts (2018): ***EUHFORIA****: European heliospheric forecasting information asset*, JSWSC 8, A35

Analytical Models



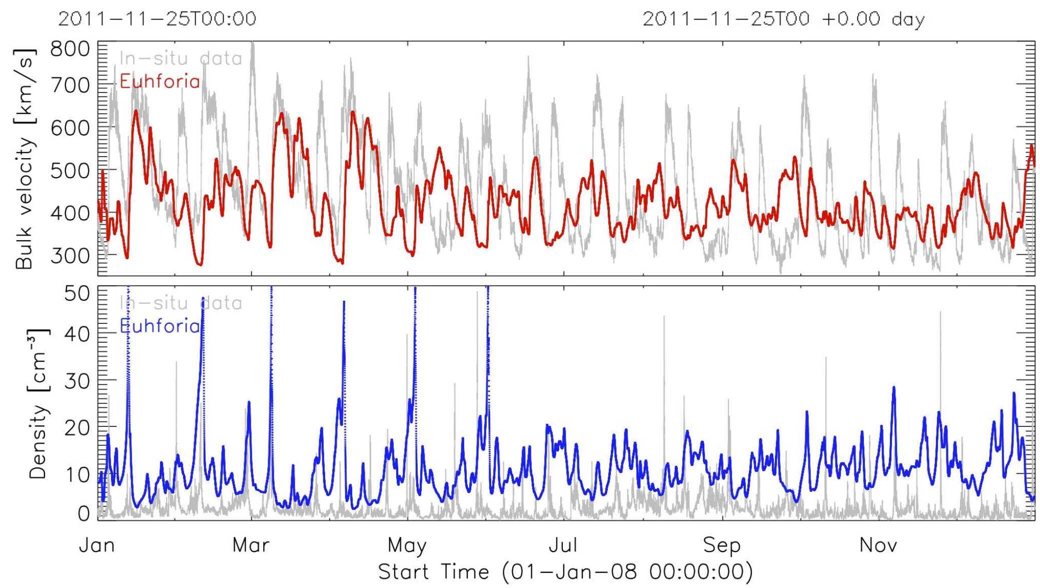
Florens et al. 2007

- Reconstructions **complicated** by stream interaction regions, magnetic clouds, shocks and other **transient phenomena**

- **Not time-dipendent**

Pizzo (1981): *On the application of numerical models to the inverse mapping of solar wind flow structures*, JGR 86(A8)
Jian et al. (2016): *Validation for global solar wind prediction using Ulysses comparison: Multiple coronal and heliospheric models installed at the Community Coordinated Modeling Center*, SW 14, 8
Riley et al. (2018): *Forecasting the Arrival Time of Coronal Mass Ejections: Analysis of the CCMC CME Scoreboard*, SW 16, 9

Numerical Models



- Agreement between the **reconstructed** plasma ***ambient condition*** and the available **in-situ measurements** still **suboptimal**

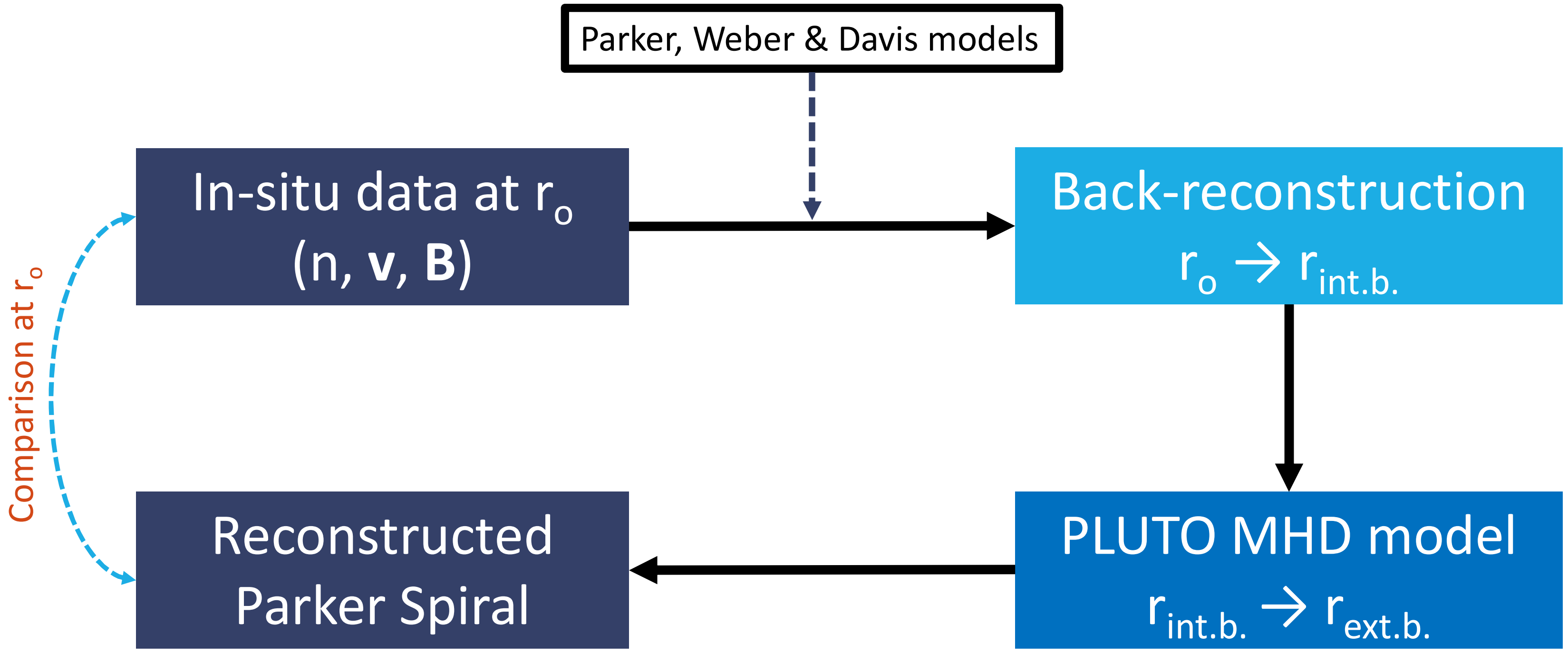
- **Forecasting capability** of solar disturbances still **limited**: standard deviation of predicted CMEs **arrival times** can exceed **20 h**

Hinterreiter et al. (2019): *Assessing the Performance of EUHFORIA Modeling the Background Solar Wind*, Sol. Phys. 294:170
Riley et al. (2018): *Forecasting the Arrival Time of Coronal Mass Ejections: Analysis of the CCMC CME Scoreboard*, SW 16, 9

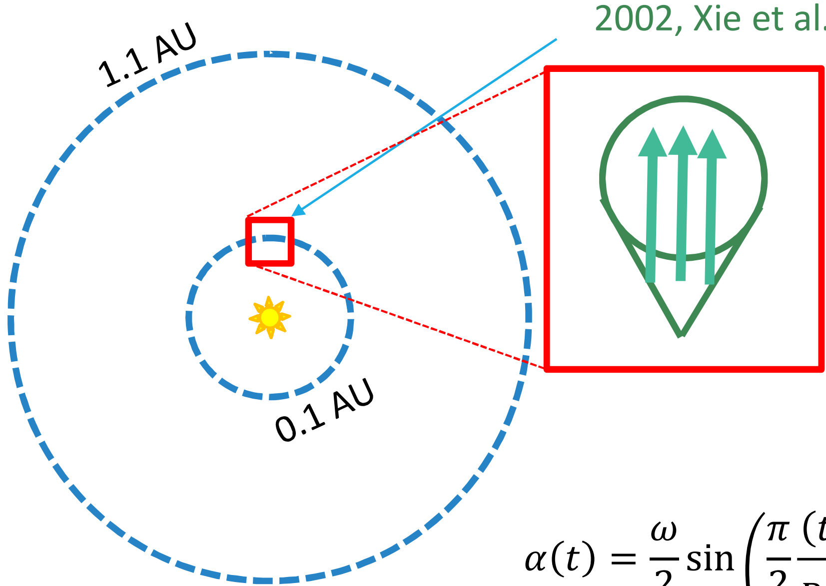
RIMAP

Reverse In-situ and MHD Approach

Combining the best of both approaches to offer **an alternative method** to the reconstruction of the Parker Spiral



Modeling of ICMEs in RIMAP: cone model



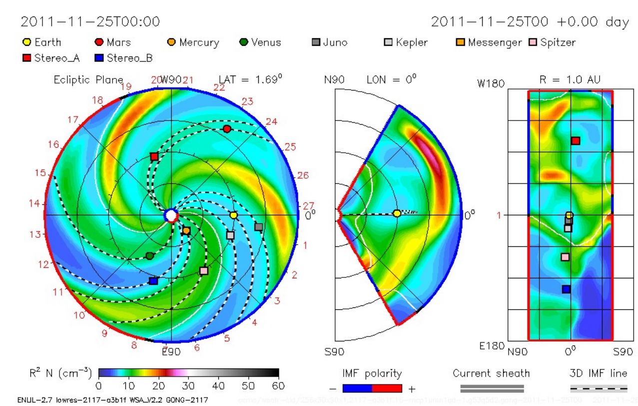
We insert in the inner radial boundary of RIMAP an **ice-cream cone model** (Zhao et al. 2002, Xie et al. 2004, Gopalswamy et al. 2009).

Cone models assume that close to the Sun, **in the early phases* of the ICME propagation, its angular width and velocity remain constant**. Thus the perturbation can be described as a homogeneous plasma cloud, isotropic in expansion and with entirely radial bulk velocity.

Due to this simple geometry, cone models are particularly **convenient for routine applications** in space-weather forecasting (es. Scolini et al. 2018).

$$\alpha(t) = \frac{\omega}{2}\sin\left(\frac{\pi}{2}\frac{(t-t_0)v_0}{R_b \sin\left(\frac{\omega}{2}\right)}\right)$$

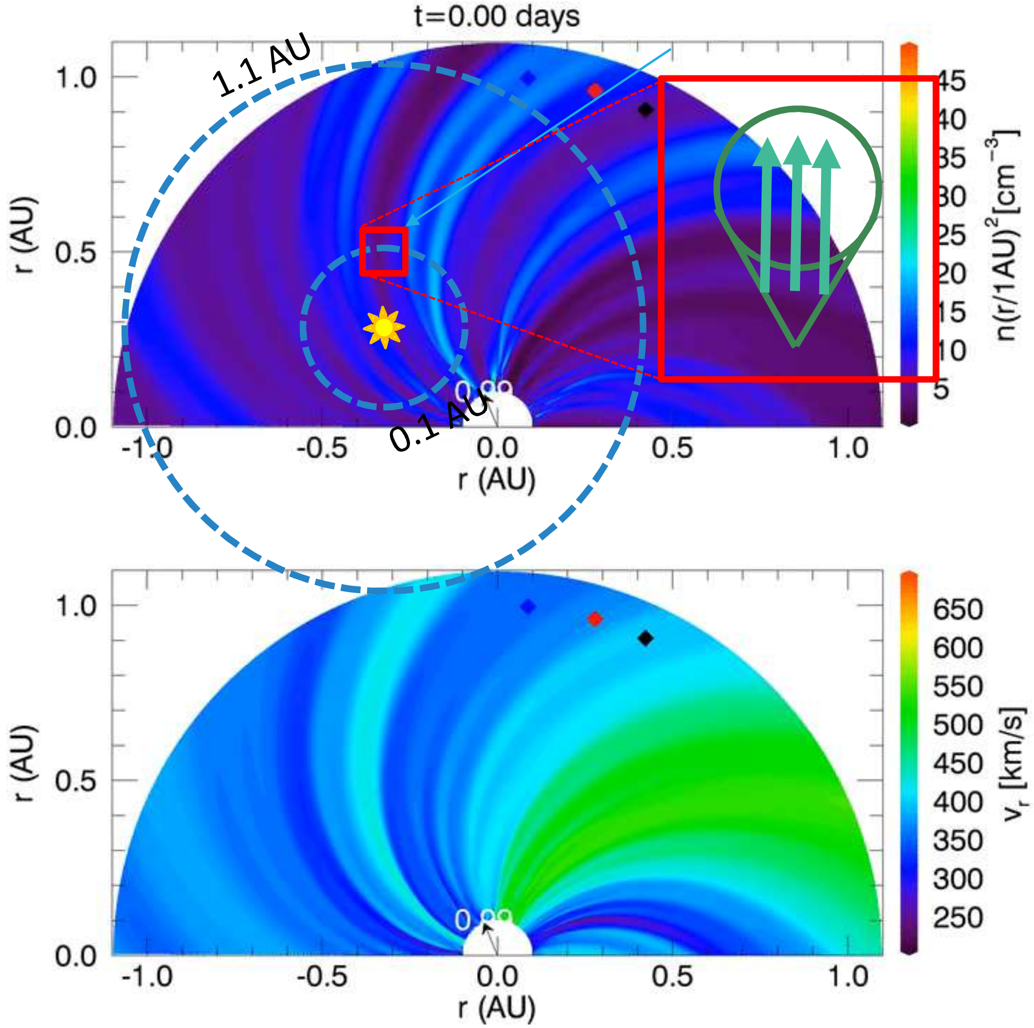
if $(\varphi - \varphi_0)^2 \leq \alpha^2(t)$, the background **solar wind parameters are replaced with the perturbation ones**.



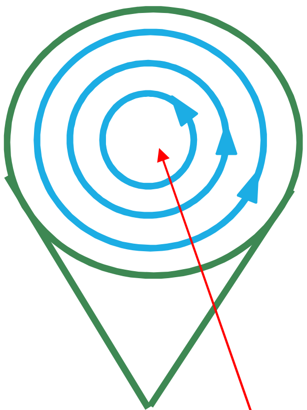
Unmagnetized ICME propagation with ENLIL

Modeling of ICMEs in RIMAP

- **Cone model** (*e.g.* Zhao et al. 2002, Gopalswamy et al. 2009) in the RIMAP inner radial boundary;
- Density and plasma temperature inside the ICME **homogeneous** (n_0 = 600 cm^{-3} and T_0 = 5 10^5 K);
- An artificial, passive scalar is added to the ICME model → **flow tracer T_r** obeys a simple advection equation and does not interact with the physical quantities of the model;
- ICME initial velocity **v_0=800 km/s**;
  Parker spiral recostructed by RIMAP using WIND data of March 2009;
  Super-imposed, in white, the iso-lines of T_{rg};
- The **ICME remain compact**, even in the absence of internal flux-rope, traveling across the highly structured configuration.



Modeling of ICMEs in RIMAP: work in progress

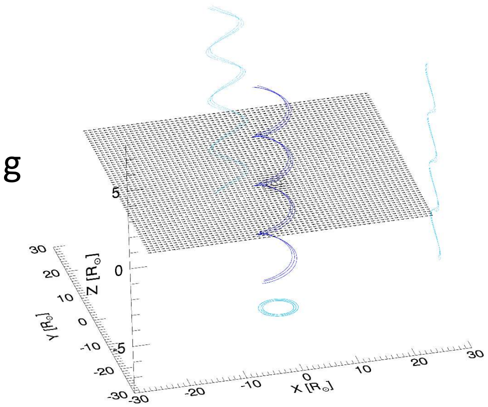


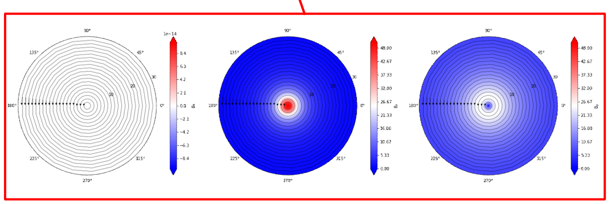
- **1/3** of ICMEs at 1AU shows clear **magnetic cloud** signatures (e.g. Cane and Richardson 2003), but this fraction is probably larger (e.g. Jian et al. 2006, Kilpua et al. 2011);

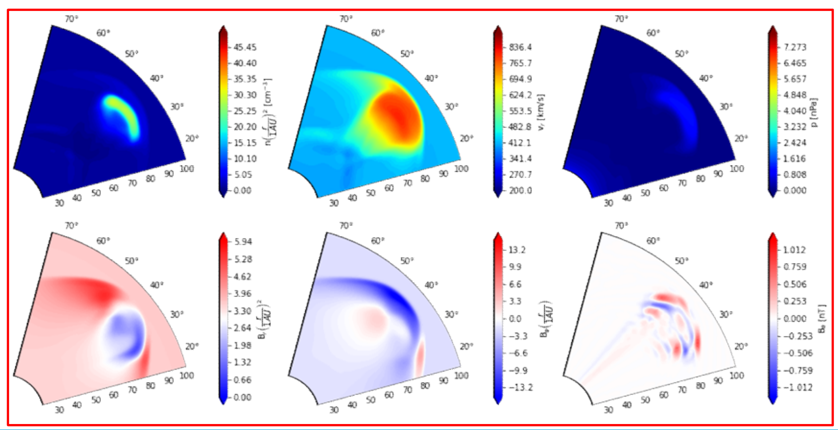
- Magnetic clouds can be described by cylindrical symmetric flux ropes with **force-free B**. One of the simplest solution is the Gold & Hoyle 1960 one, generalized by Low & Berger 2003:

$$B_R = 0,\ B_z = \frac{B_0}{1 + k^2R^2},\ B_\varphi = kRB_z$$

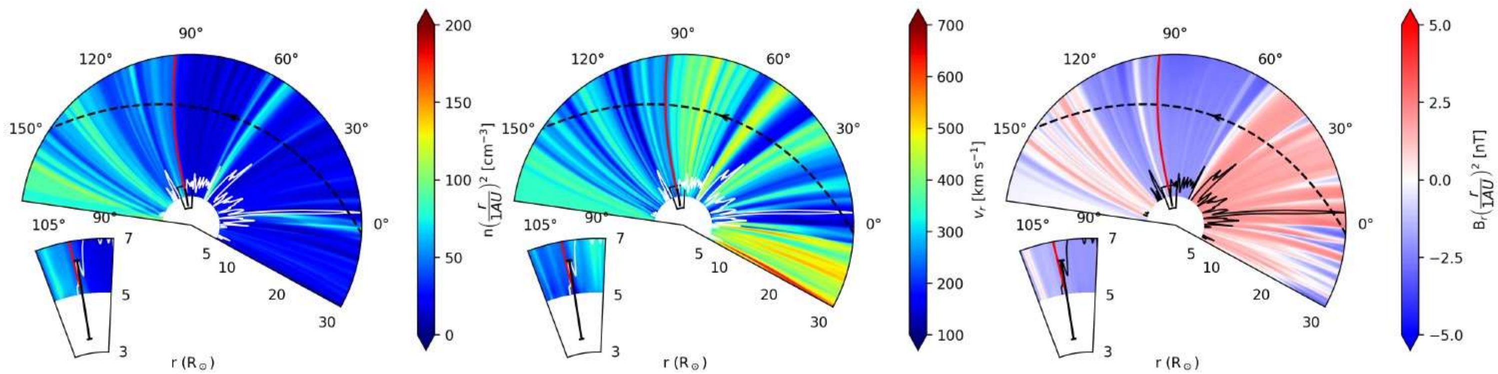
- We are inscribing diffent flux-ropes into the cone-modelled ICME, studying its propagation across the RIMAP-reconstructed Parker spiral.





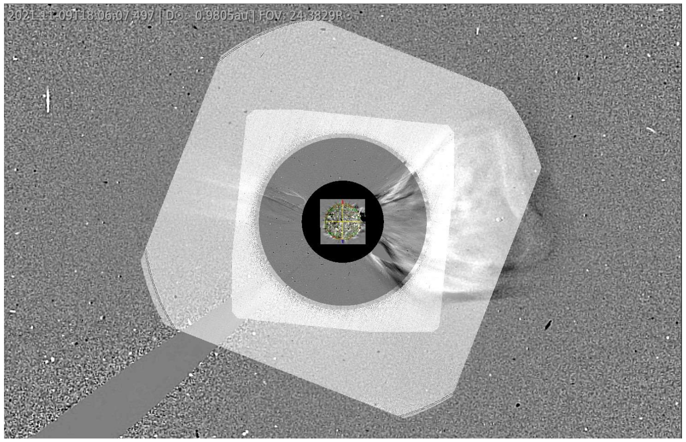


Boundary conditions from observations



- **Pre-CME background plasma conditions** will be reconstructed with RIMAP combining Solar Orbiter/ Metis observations and/or Parker Solar Probe data (e.g. Biondo et al. 2022);

- **CME kinematic and thermodynamic conditions** will be reconstructed combining Solar Orbiter/ Metis observations and SOHO/ LASCO-C2 & C3 observations; in particular, the plasma thermodynamic conditions inside the CME will be derived combining VL and UV (H I Lyman-α) images acquired by Metis (e.g. Bemporad 2022), as well as the **plasma conditions across the shock front**.



Biondo R. Bemporad A. Pagano P. et al. (2022): *Connecting Solar Orbiter remote-sensing observations and Parker Solar Probe in-situ measurements with a numerical MHD reconstruction of the Parker spiral*, A&A, in press
Bemporad A. (2022): *Temperature and Thermal Energy of a Coronal Mass Ejection*, Symmetry, vol. 14, issue 3, p. 468