ESTIMATION OF THE TWIST IN THE SOLAR MAGNETIC FLUX ROPE USING EUV DATA

Royal Observatory of Belgium

KU LEUVEN

Brenda Daniela Dorsch [1,2], Luciano Rodriguez [1], Jasmina Magdalenić [1,2].

brenda.dorsch@observatory.be

[1] Solar–Terrestrial Centre of Excellence – SIDC, Royal Observatory of Belgium, Brussels, Belgium;
[2] KU Leuven, Leuven, Belgium.

1. STUDY MOTIVATION

FRi3D is a novel flux-rope CME model characterized by a realistic description of CME topology (Fig. 1). It can be inserted in the space weather forecasting tool EUHFORIA. Plasma, geometrical & magentic CME parameters are used for modelling.

The magnetic parameter twist (τ) describes the number of turns in the magnetic field from one foot point to the other.

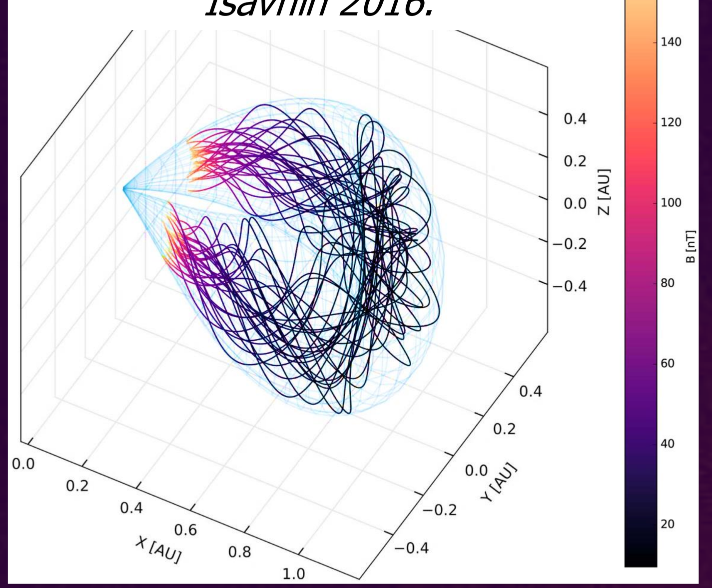

***Fig. 1**: FRi3D model of a CME. Isavnin 2016.*

To date, a fixed value of τ is used for modelling.

Fig. 2 shows EUHFORIA simulation results of a CME event when sistematicaly varying τ.

Results show the impact of τ when modelling CMEs, not only in the CME arrival time but also in the strenght of the magnetic field.

This result was the driver for the statistical study of the MFR twist and development of the method for twist estimation.

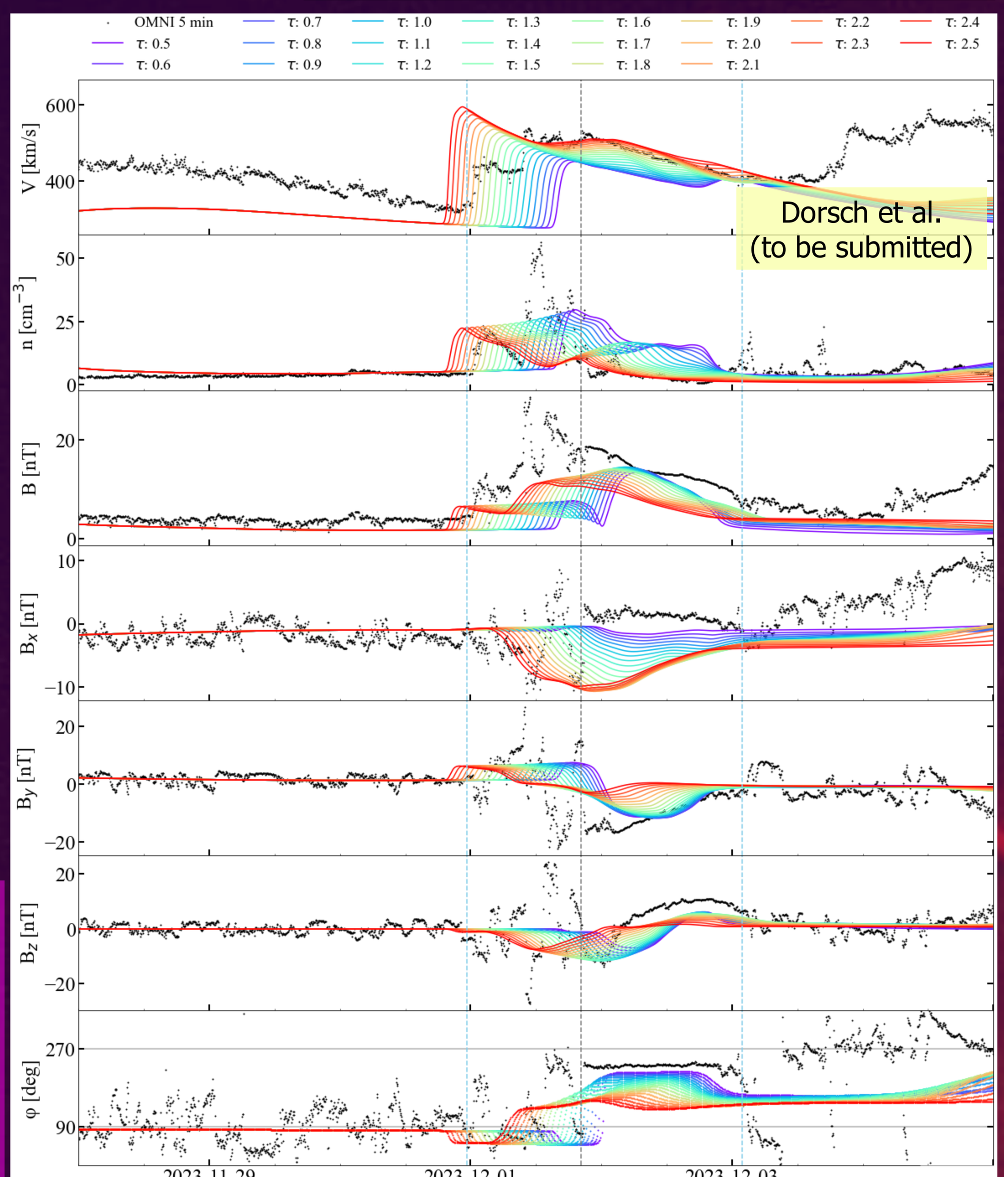

***Fig. 2**: EUHFORIA+FRi3D simulations. Different lines resulted from changing τ from 0.5 to 2.5 (steps of 0.1).*

2. TWIST CALCULATION

Magnetic twist can be estimated using different methods, but most are not easily integrated into time-sensitive SW forecasting workflow, since they require time-consuming analysis and/or high-quality magnetic data (e.g., Titov & Démoulin 1999, Wiegelmann 2004, etc.).

Here we provide the method for estimation of τ that is easily applicable in the SW framework.

The methodology is based on Guo et al. (2021) work, where τ is derived from the axial length to minor ratio **L/a** of the associated magnetic flux rope (MFR) in 3D: $|\tau| = 0.26(L/a) - 0.15$ (Eq.1).

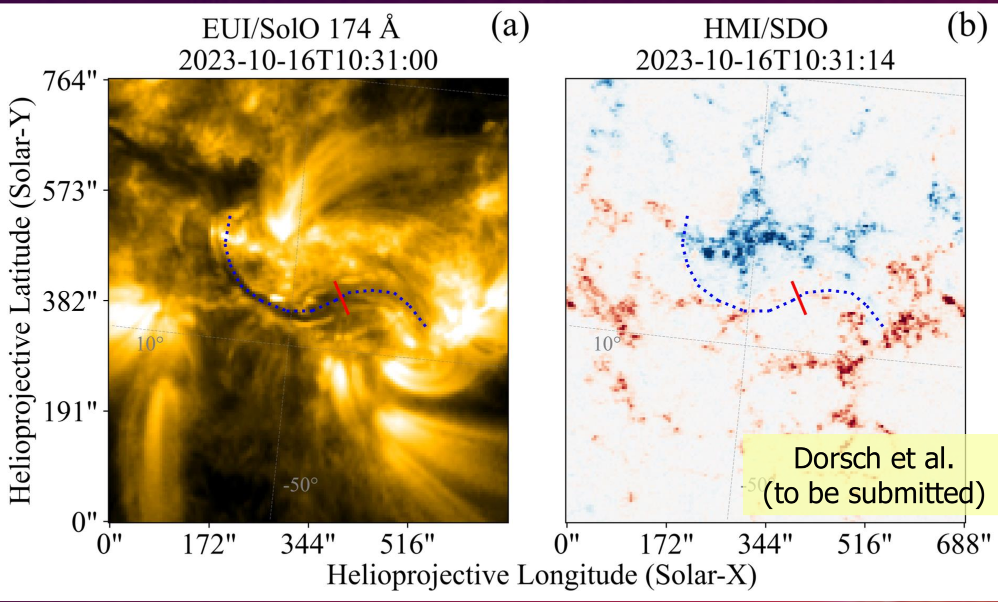

***Fig. 3**: Example of L/a measurement with developed tool. Blue (red) dotted line represents length (width) of the MFR. (a) EUI/FSI174 image . (b) HMI magnetogram.*

We use EUV data to estimate the 2D projection of **L/a** and calculate τ from Eq. 1.
It is important to take into account *projection effects* & *magnetic field complexity*.

We developed an interactive tool to easily estimate τ from a selected EUV & magentogram data (Fig. 3).

3. DATA & METHOD

- 43 MFR events with associated CME and in most cases flare activity.
- EUV data (171 Å wavelength or close to) from AIA/SDO, EUVI/STEREO & EUI/SolO, when available. 23 events were observed by the 3 missions, 17 by SDO & STEREO; and 3 only by SDO.
- Measurement of τ for each event & instrument is performed 5 times, using the developed tool. Averaged τ is taken for each event/spacecraft.
- Coronagraph images were used to estimate CME speed from 3D reconstruction.
- Flare energy size data from GOES/SXI data.

4. RESULTS

Assessing the projection effect

Fig.4 shows the τ vs. the position of the spacecraft as a relative absolute longitude. We used events observed simultaneously by EUI, AIA & EUVI, i.e. a subset of 23 out of 43. Results indicate a clear and consistent dependence of the estimated τ on the vantage point of the observer, suggesting a strong influence of projection.

$$\tau_f = \tau_i - 0.15\left(\frac{Lon_f - Lon_i}{10^\circ}\right) \quad \text{Eq. 2}$$

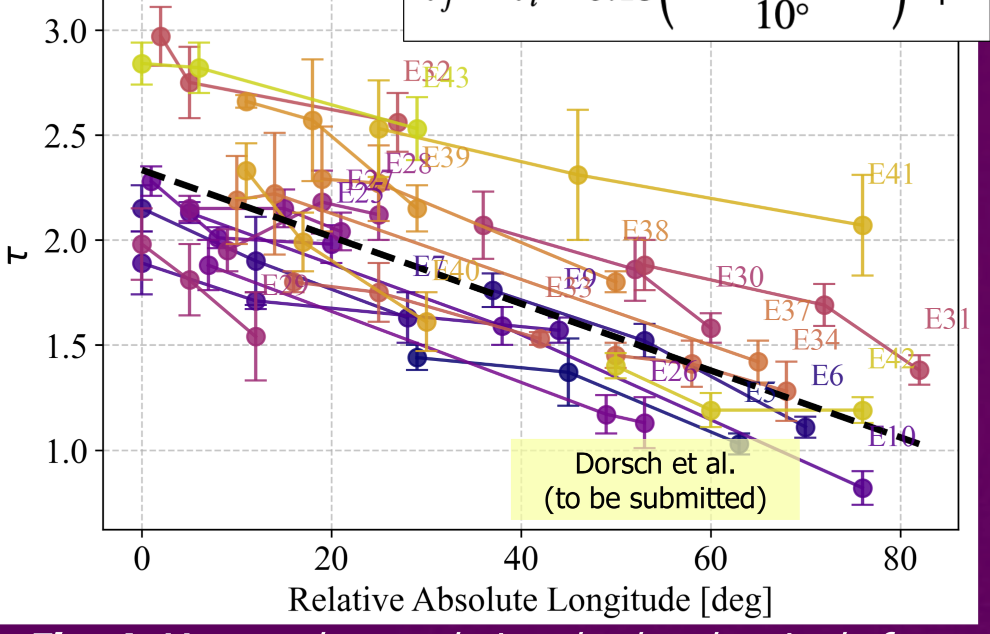

***Fig. 4**: Measured τ vs relative absolute longitude for a subset of 23 events. All events, colour-coded, were observed from 3 vantage points.*

We describe the trend with a linear fit (black dashed line), with the general form defined by Eq.2. We applied Eq.2 to deproject τ to central meridian and averaged to one single value per event, τ_d, used in further statistical analysis.

MFR twist association with CME speed (V_{CME}) and flare energy– A novel study

We studied the dependence of τ_d on the variation of V_{CME} and included the flare size information (Fig.5 left panel). We obtained a polynomial relation & assessed its robustness with bootstrap resampling to the correlation C (Fig.5 right panel).

Full dataset (Fig.5a) shows correlation with moderate but coherent spread, indicating association between τ_d & V_{CME}. The τ_d decreases with V_{CME} increase up to ~900 km/s and then increases for the faster CMEs. However, events associated with X-class flares seem to be scattered from the fit.

We repeated the analysis excluding X-class assoc. events (Fig.5b). The subset of 33 events (associated to C-,M-class flares) imrpoved both C and 95% CI.

From Fig.6 we observed the X-class assoc. events exhibits a noticeably different behaviour. Nevertheless, the overall relation is mainly shaped by events assoc. with lower energy flares (C- & M-class).

We conclude the obtained relationship can be employed as observational-based proxy for estimation of MFR twist (Eq.3).

$$\tau_d(V_{norm}) = 0.16\,V_{norm}^2 - 0.2\,V_{norm} + 2.2$$
$$V_{norm} = \left(\frac{V_{CME} - 776\ km\ s^{-1}}{243\ km\ s^{-1}}\right) \quad \text{Eq. 3}$$

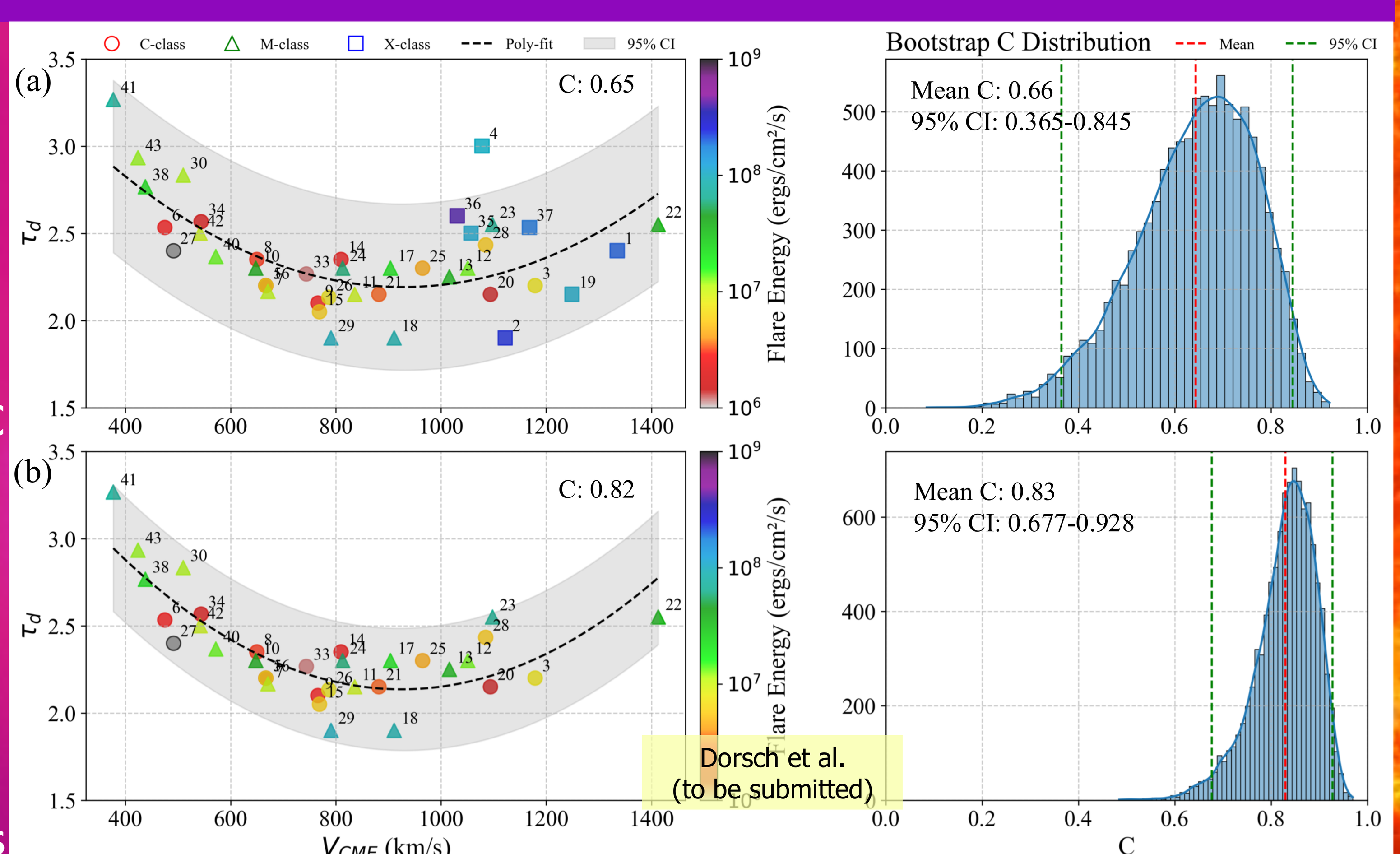

***Fig. 5**: Left panels: dependence of τ_d on the variation of V_{CME}. Black dashed line defines the polynomial fit and the grey area the 95% confidence interval (CI). Flare energy is colour-coded. Right panels: bootstrap distribution of correlation (C) value for 10.000 empirically-based samples; mean C value and the 95% CI of the distribution are defined by red and green vertical dashed lines, respectively. Top to bottom: (a) events with an associated flare (40); (b) subset of events with associated C- and M-class flare (33).*

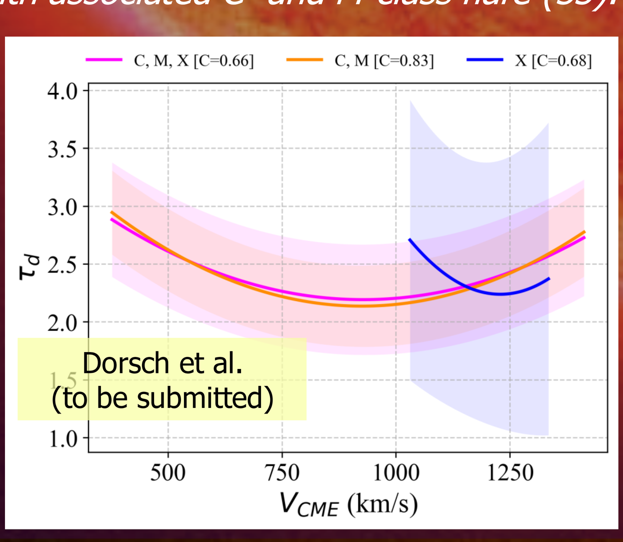

***Fig. 6**: Overlapped 2nd-degree poly-fit of three subsets. Full dataset (magenta), C- & M-class flare assoc. events (orange), and X-class assoc. events (blue). C values are from bootstrap result.*

5. SUMMARY & CONCLUSION

- EUHFORIA simulations with FRi3D model show a clear impact of twist parameter in CME modelling in the arrival time, and in the strenght of the CME magnetic field, which is currently of interest to improve for better CME forcasting.
- We proposed a method, easily integrated into the space weather operational workflow, for the estimation of the MFR τ parameter using EUV data.
- We assessed the projection effect in MFR τ estimation. Measurement of τ from different spacecraft show a clear and consistent dependence on the observer viewing point. Such relation was described by a linear regression, which we used to deproject the τ to the central meridian and got an average value τ_d per event.
- We analyzed the relation between τ_d and V_{CME} in associacion with flare energy size. Statistical results suggest a significant relationship between τ_d and V_{CME} mostly for events associated with lower flare energy (C- & M-class). We propose a observational-based proxy to estimate the solar MFR twist from CME speed, which can be estimated using white light observations.
- The results of this work are of relevance for for better understanting of MFR; but also for real-time space weather forecasting, where time-senstivie desitions are taken and straightforward methods to estimate key CME parameters are necessary.