

First detection of small-scale helical flows in the void of a Coronal Mass Ejection with high-cadence coronagraphic images acquired by the Metis coronagraph on-board Solar Orbiter

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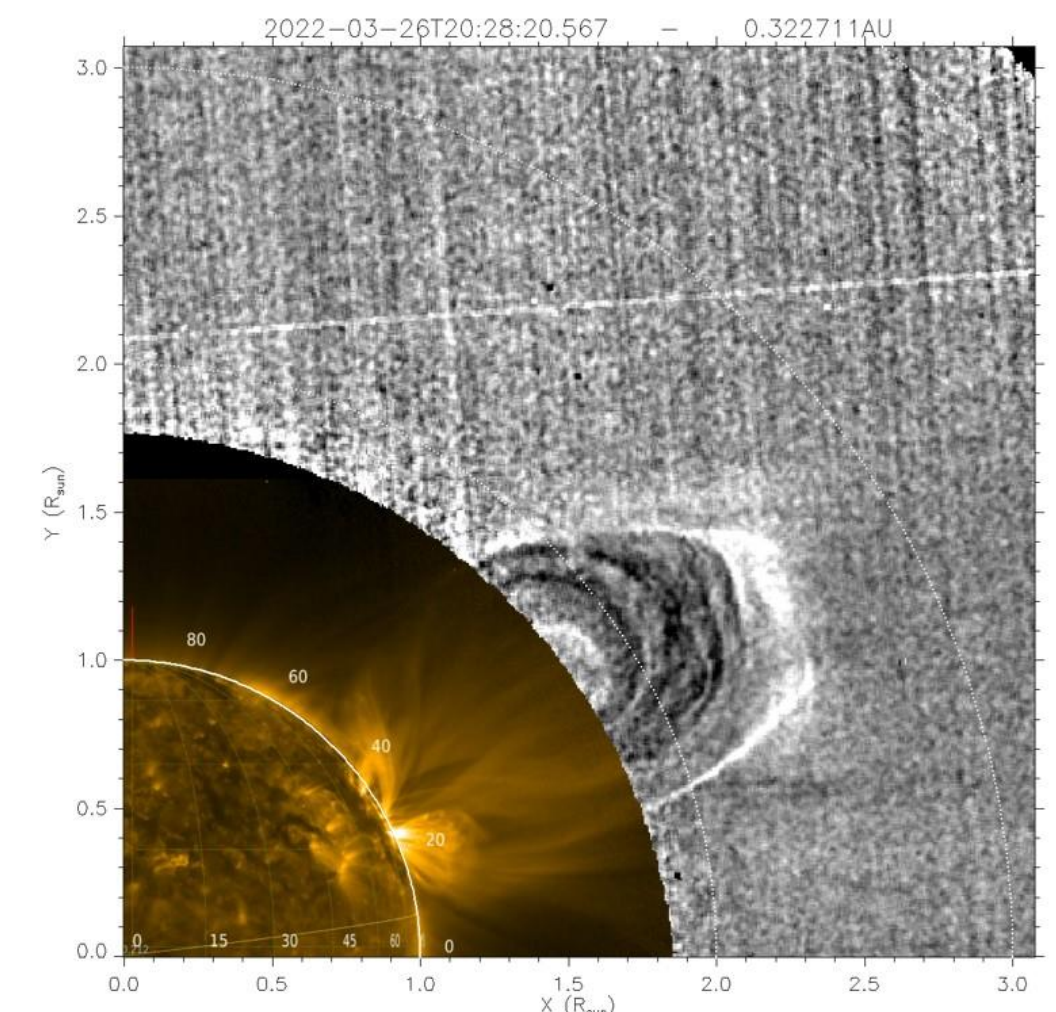
ABSTRACT

On March 26th, 2022, the ESA Solar Orbiter mission observed the early evolution of a Coronal Mass Ejection (CME). On that day the spacecraft was at a heliocentric distance of 0.32 AU, and a longitude separation from Earth of 74.5 degrees. The CME source region shows no pre-existing filament or flux-rope. The event was first observed in the inner corona by the EUV telescope, showing the initial propagation of the flux-rope in the EUV. Higher up, the event was observed by Metis with the Visible Light channel with an unprecedented time cadence of 20 sec, and a spatial resolution of 20" corresponding to about 4600 km per bin. The sequence of total brightness images shows for the first time small-scale flows going on inside the expanding flux-rope surrounded by multiple nested arch-shaped features. These plasma motions, not observed by EUV, could be connected with the unknown forces accelerating the eruption. Running difference images built with the cadence offered by previous coronagraphs show the well-known three-part structure of this event, but the real identification of these different classical CME parts is less evident in the high-cadence Metis images. Hence, these observations provide new insight into what is normally identified as the global structure of CMEs.

Metis VL running differences (cadence of 20 seconds) → real identification of these different classical CME parts is **less evident** and a **filamentary nested structure** is visible instead.

Combination with **EUV images** from FSI shows **multiple loops** corresponding with **different fronts** in the VL.

These observations provide **new insight** into what is normally identified as the **global CME structure**.



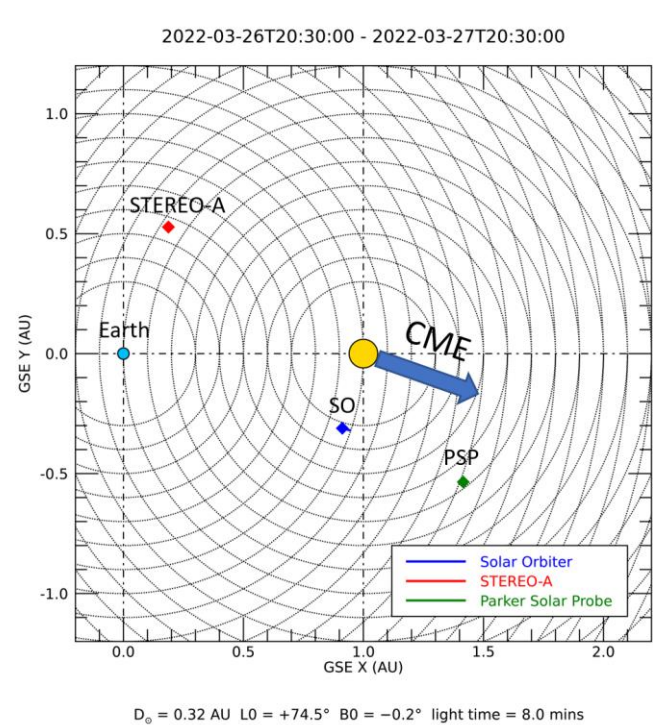
THE MARCH 26TH 2022 EVENT

This CME was observed as:

- **Back-side event** propagating Westward from **SOHO**
- **Back-side event** propagating Eastward from **STEREO-A**
- **Limb event** propagating Westward from **Solar Orbiter**

SOHO LASCO images → faint eruption signature; EUV SWAP images → no clear signature → **back-side event**

STEREO-A images → very weak signature in the COR2 telescope → observation of a **back-side event**

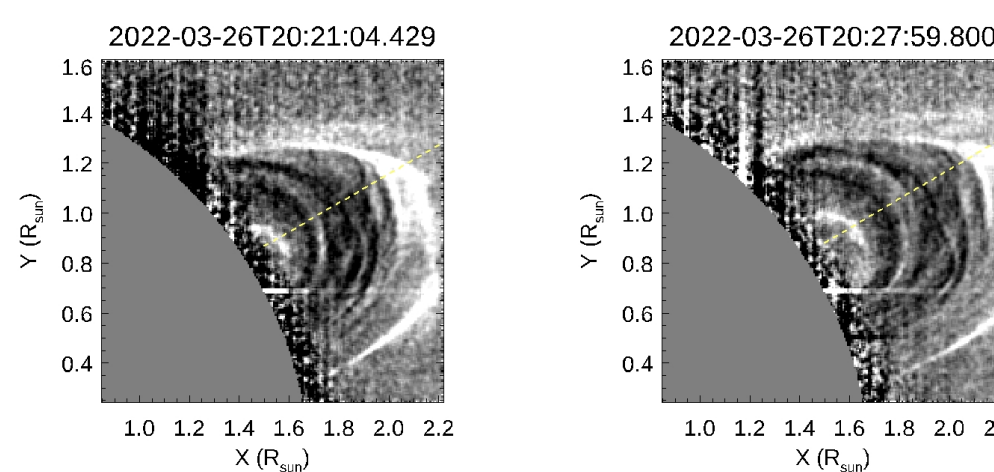


METIS DATA ANALYSIS

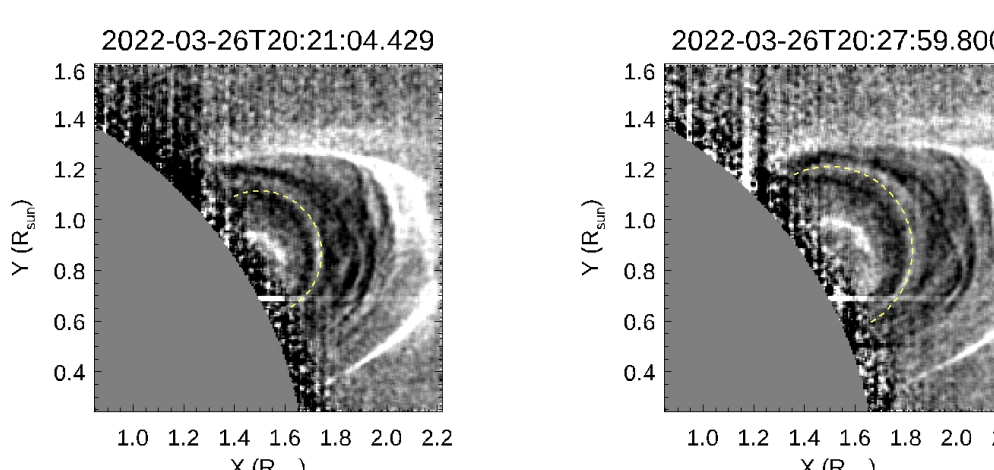
High-cadence (20 sec) Metis tB images show the early evolution of the flux-rope entering in the instrument FOV → normalized running difference images show the presence of a **filamentary nested structure** with very interesting **clock-wise plasma motions** inside the erupting FR (or CME void).

No clear evidence of these motions is observed by EUV 174 and 304 → the moving plasma could be hotter than the typical coronal plasma tracing in the EUV the boundary of the flux-rope, being unobserved by EUV.

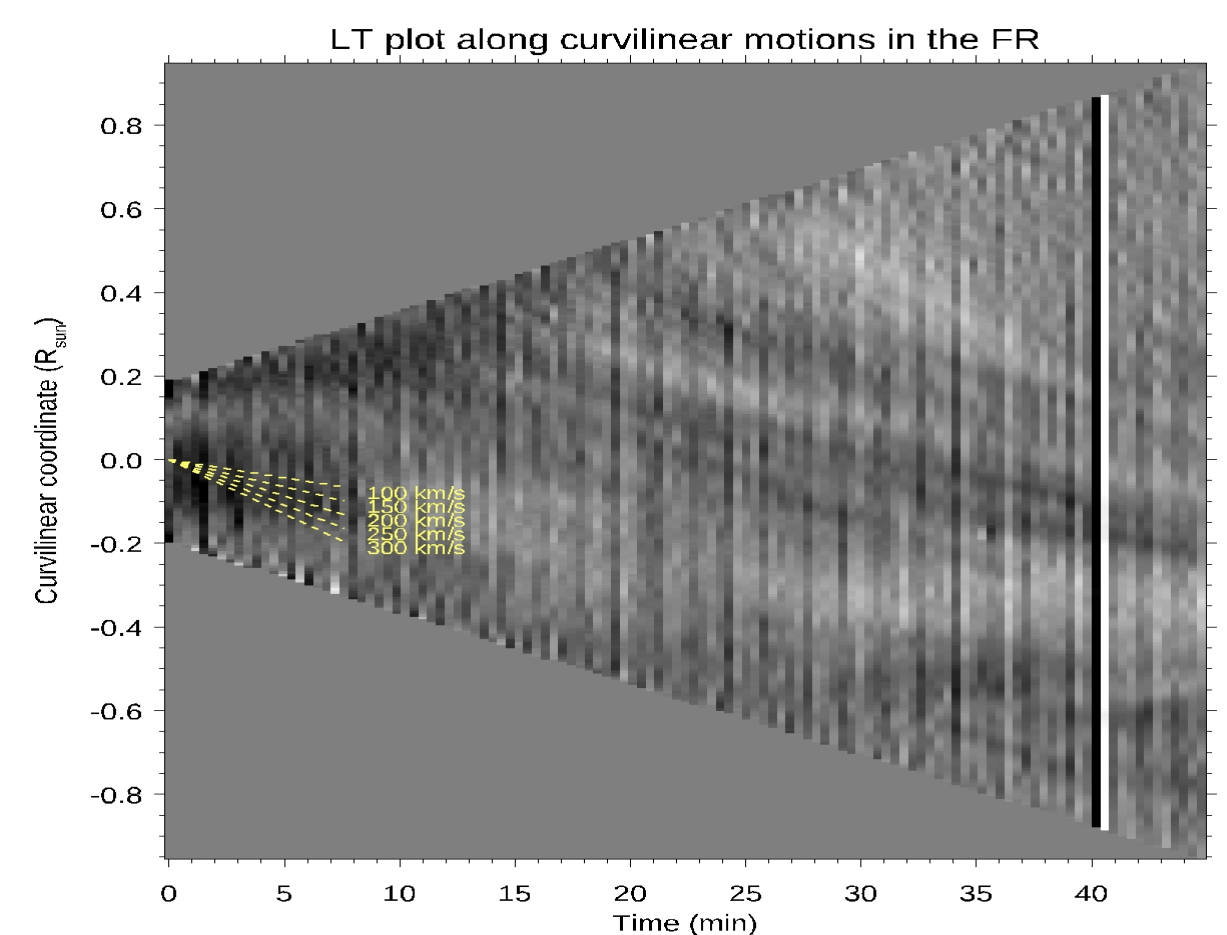
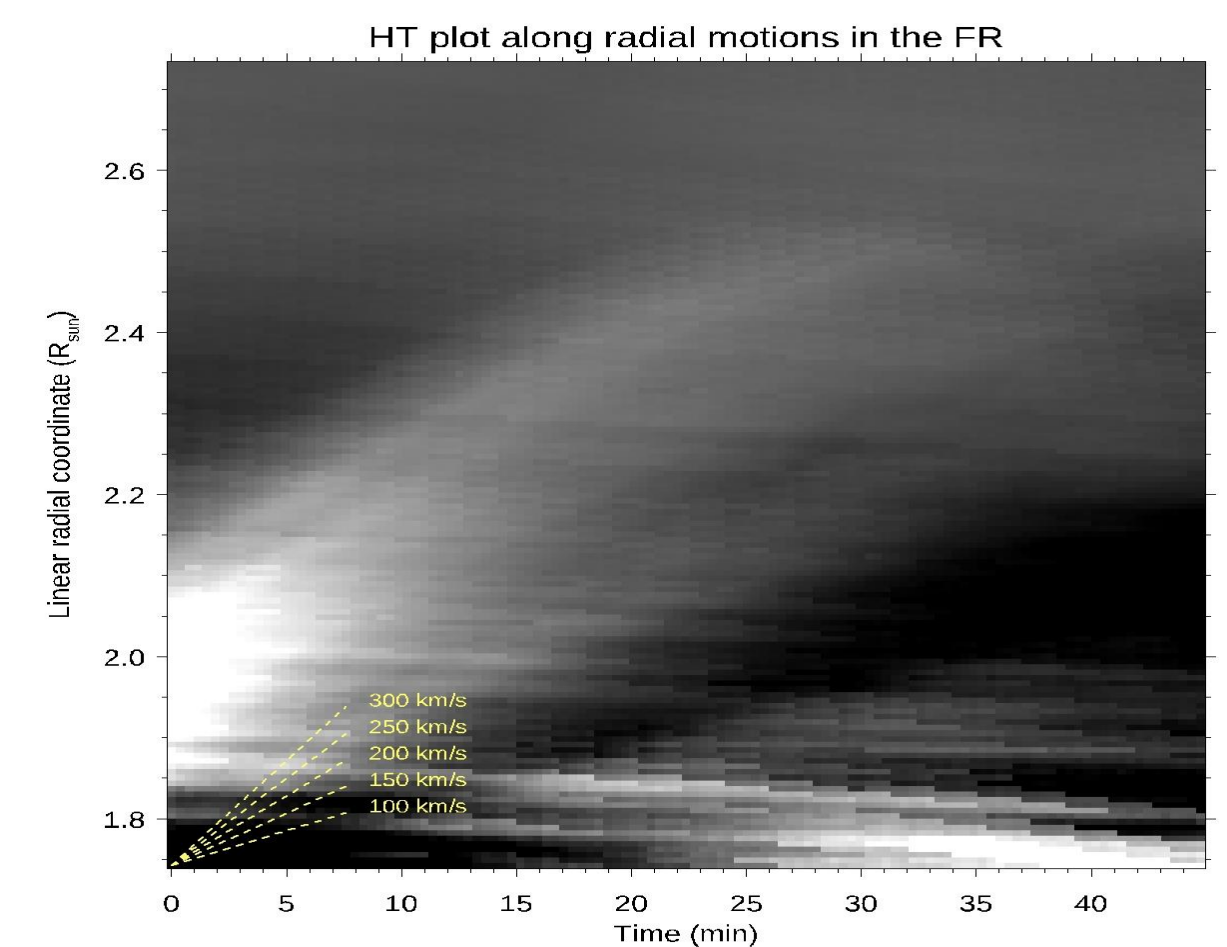
However, at the **lower cadence** offered by the FSI data acquired that day (10 min), the **same flows would have hardly been visible** even in the Metis images.



The CME radial propagation speed has been measured by defining a radial coordinate and building the classical HT-map → front (void) speed on the order of 170-200 km/s (100-150 km/s), with **no clear signature for acceleration**.



Smaller-scale plasma motions inside the CME void have been tracked by defining a curvilinear coordinate moving together with the flux-rope at 125 km/s and extracting the LT-map → initial speed of **≈ 200 km/s larger than the void propagation speed**, possible negative acceleration leading to a **final speed closer to the void propagation speed**. Other tracks show constant speed **≈ 200 km/s**.

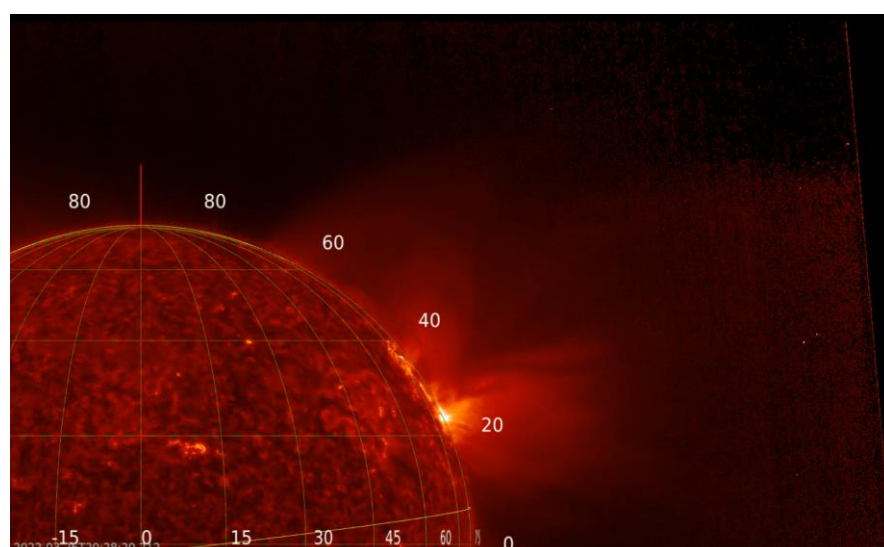
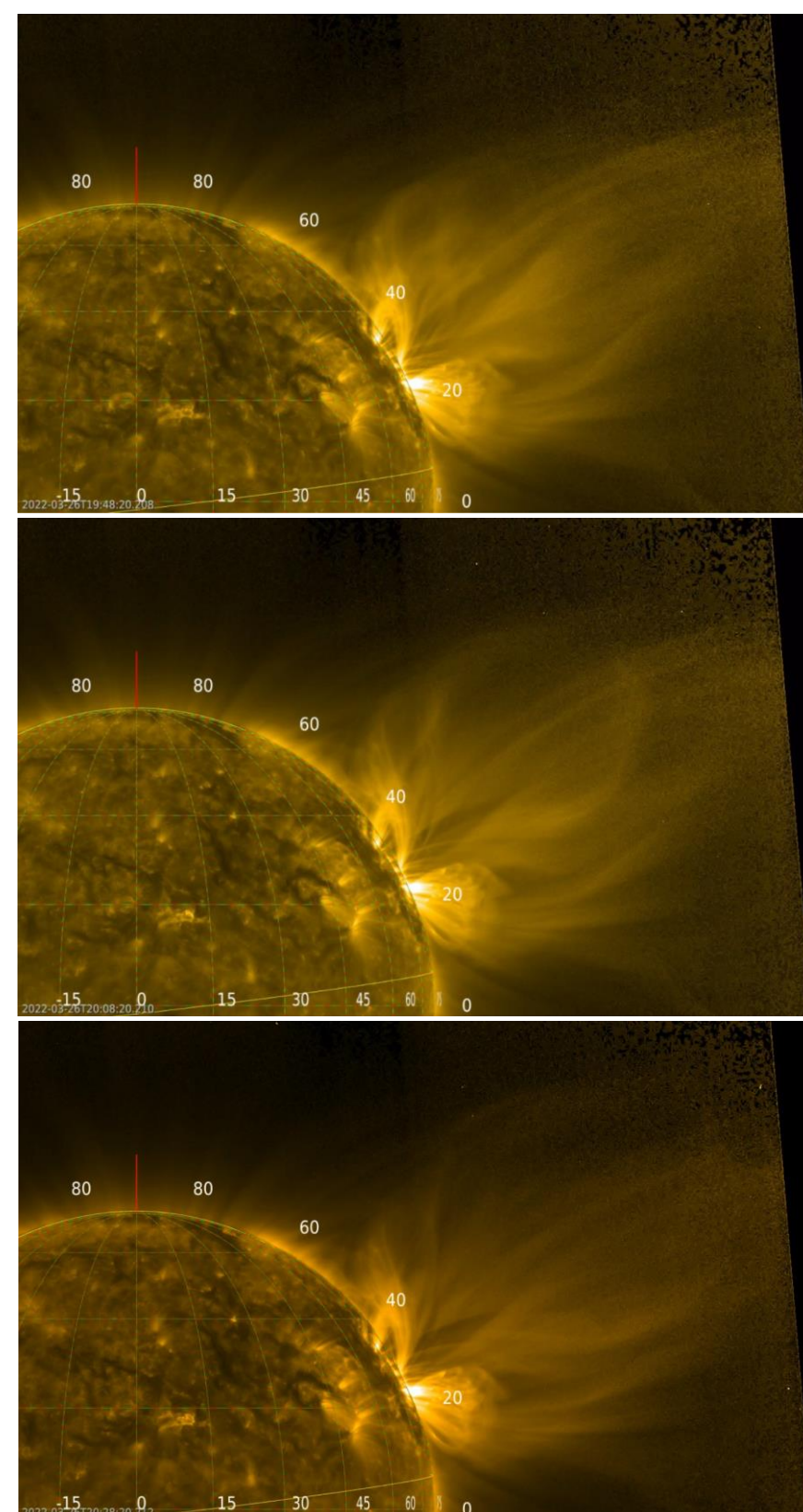


EUI DATA

EUI 174 images from Solar Orbiter (10 min cadence) show a limb eruption of a **twisted flux-rope**, propagating North-West, followed by the formation of rising **post-eruption loops**, clear signature of post-eruption magnetic reconnection.

EUI 304 images from Solar Orbiter show no evidence of **any prominence eruption**, in agreement with the lack of filament observations days before in H-alpha.

Both EUI channels show **no evidence of flows** propagating inside the expanding fluxrope (but **low cadence 10 min**).



METIS DATA

Time	Obs.	Binning	Cadence
00:00 - 19:40 UT	pB	1x1	20 min.
19:40 - 20:10 UT	Fixed pol. (120 img)	2x2	1 sec.
20:10 - 20:50 UT	tB (120 img)	2x2	20 sec.
20:50 - 23:20 UT	pB	2x2	30 min.
23:30 - 23:59 UT	pB (1 sequence)	4x4	Low-latency

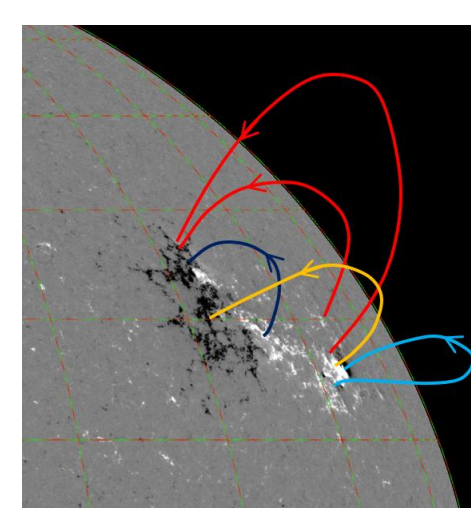
"LASCO-like" VL running differences (cadence of 20 minutes) show the classical **"3-part structure"** (bright front, dark cavity, bright core).

DISCUSSION

Candidate source region 12965 **mostly bipolar**, dominated by toroidal field, showing in EUV and SXR almost potential AR loop system, with a **smaller scale negative polarity** embedded in a **larger scale positive polarity** region. When the AR crosses the limb, **no clear evidence of a pre-existing flux-rope 6 days before the eruption**; H-alpha images show no filaments in this AR → **No pre-existing FR**, eruption possibly related to **rising arcades forming the FR during the eruption**.

PROPOSED INTERPRETATION

One week before the eruption the AIA images show a **large-scale loop system** connecting the two main polarities of the AR (**red**), and other smaller-scale loop systems connecting other polarities (**orange, blue, and light blue**).



Representation of main loop systems with orientations given by photospheric polarities.
HMI at 2022/03/18, 19:35:43

The clock-wise plasma motions observed by Metis in the CME-void and unobserved by EUV (174 and 304) could be related to **magnetic reconnections** occurring at the base of the rising inner arcade in the **northward footpoint** → **plasma propagating clockwise in the fluxrope with temperatures higher than $\approx 10^{6.3}$ K ≈ 2 MK** thus unobserved by EUV 304.

