Eruption and Interplanetary Evolution of a Stealthy Streamer-Blowout CME Observed by PSP at ~ 0.5 AU

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Solar observation of a stealthy Streamer blowout CME

- A class of CMEs emerging from streamers having signatures of flux ropes (FRs) are identified and named as 'streamer-blowout' CMEs (SBO-CME; Sheeley et al., 1982; Vourlidas et al., 2002).
- Prior to SBO-CMEs, overlying streamer gradually swells (evident from STA/COR1 and COR2 observation in our study).
- Afterwards a depletion region is usually detected in the solar corona (evident from STA/COR1 observation in our study).
- CME locations mostly follow the tilt of the heliospheric current sheet (HCS; evident from GCS and ForeCAT coronal modelling (Palmerio et al. 2021)).
- If a CME lacks classic low-coronal signatures it is called Stealth CME (Robbrecht et al., 2009; Howard and Harrison, 2013).
- The studied SBO-CME was a stealth CME (evident from SDO/AIA observation) and appeared as a limb event with classical 3 -part structure (evident from STA/COR2 observation) on June 22, 2020.

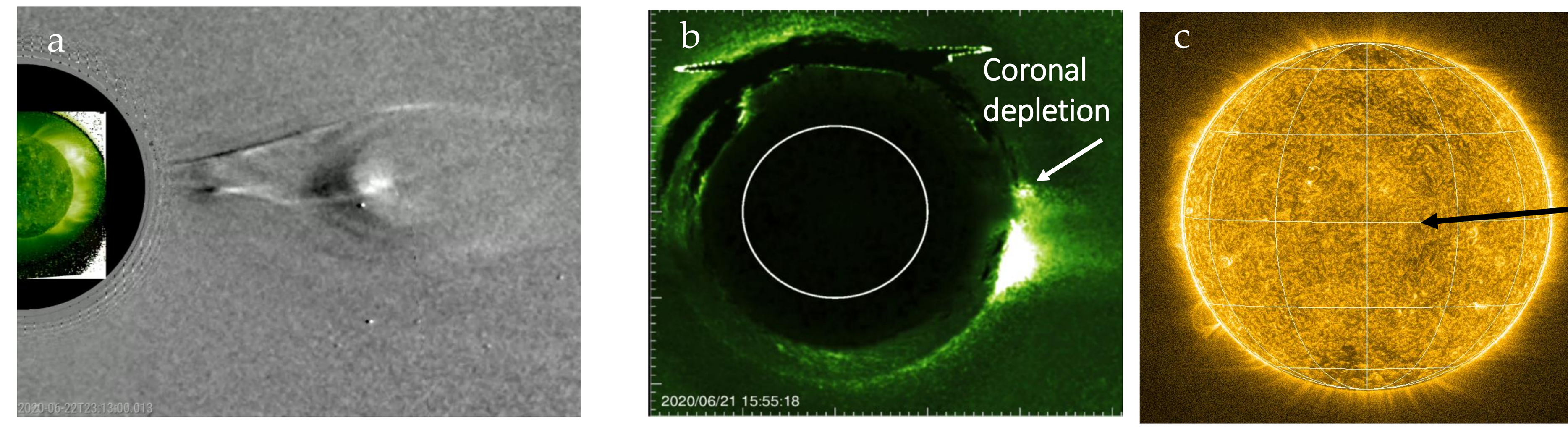


Fig 1: a. Three-part structure CME in STA/COR2, b. Coronal depletion in STA/COR1, c. Solar corona in SDO/AIA 193 A during eruption.

Initiation of the SBO-CME preceded by sequential eruptions

- Off-limb STA/EUVI, COR1, and COR2 imagery and the photospheric magnetic field extrapolation reveal that The SBO-CME (CME #2) was preceded by two sequential eruptions - CME#0 and CME#1.
- Source of CME #0 (pink box in Fig 3b) located outside and to the northwest of the equatorial multipolar flux system (red box in Fig 3b) originating CME #1 and #2.

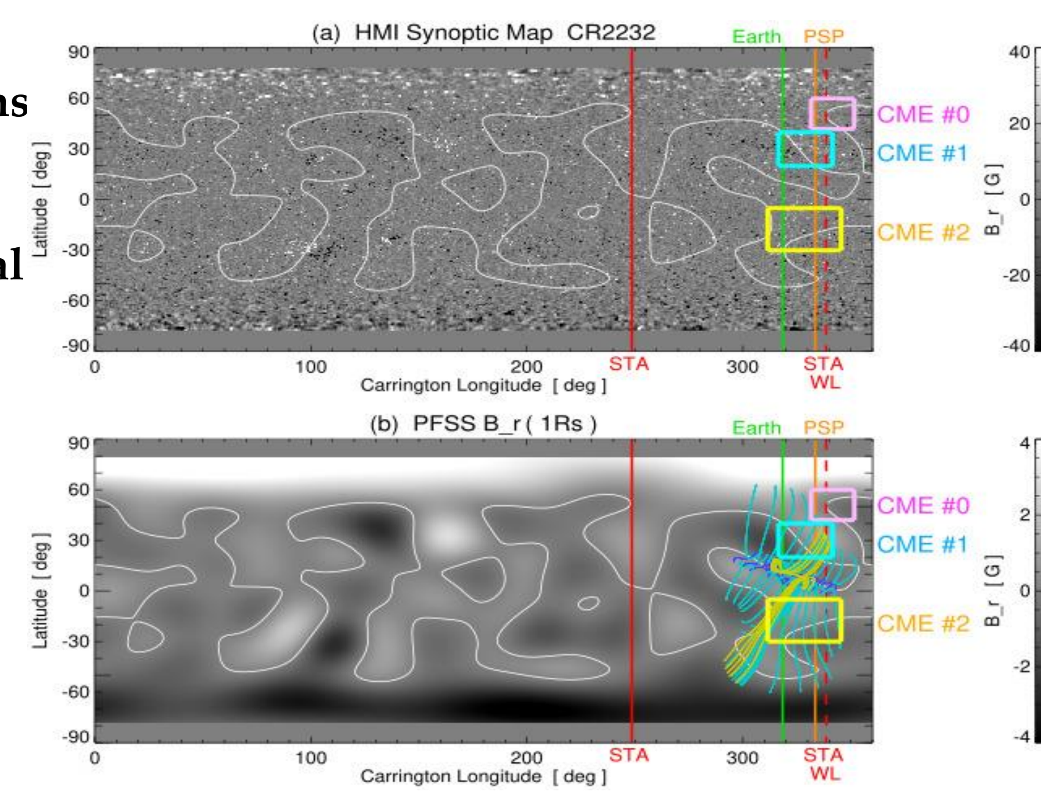


Fig 2: a. Synoptic magnetogram of photospheric Br from SDO/HMI, b. Synoptic magnetogram of the PFSS Br.

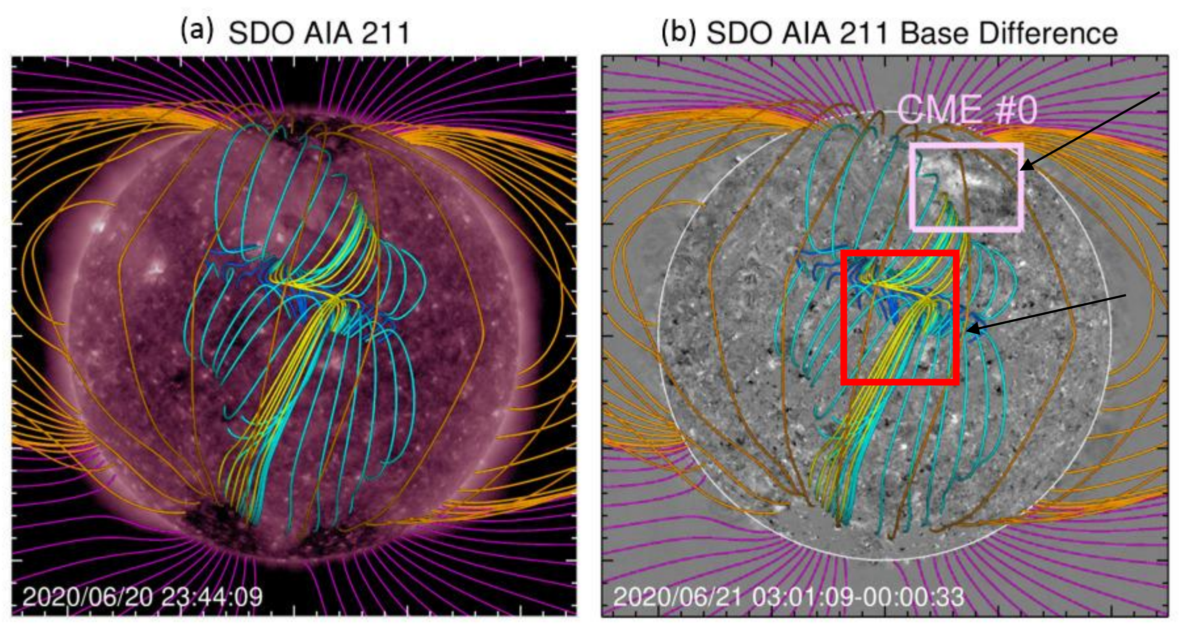


Fig 3: a. SDO/AIA 211 A emission and representative PFSS magnetic field lines. b. PFSS field lines plotted over the base-difference 211 A image.

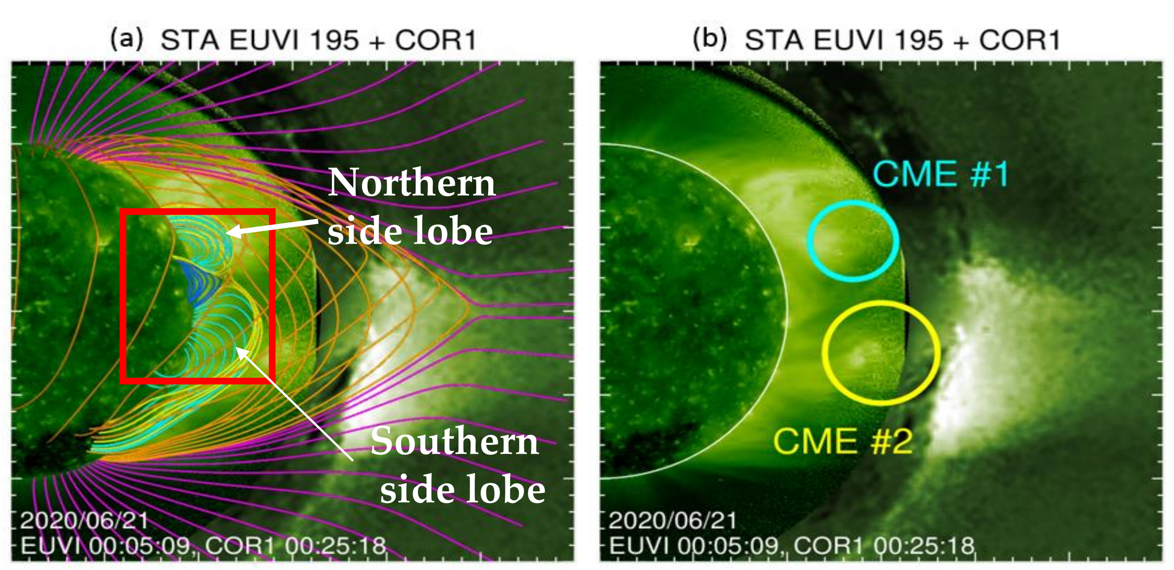


Fig 4: Composite image of the limb-enhanced STA/EUVI 195 A and processed STA/COR1.

Dynamics of the sequential CMEs using coronagraph (STA/COR2)

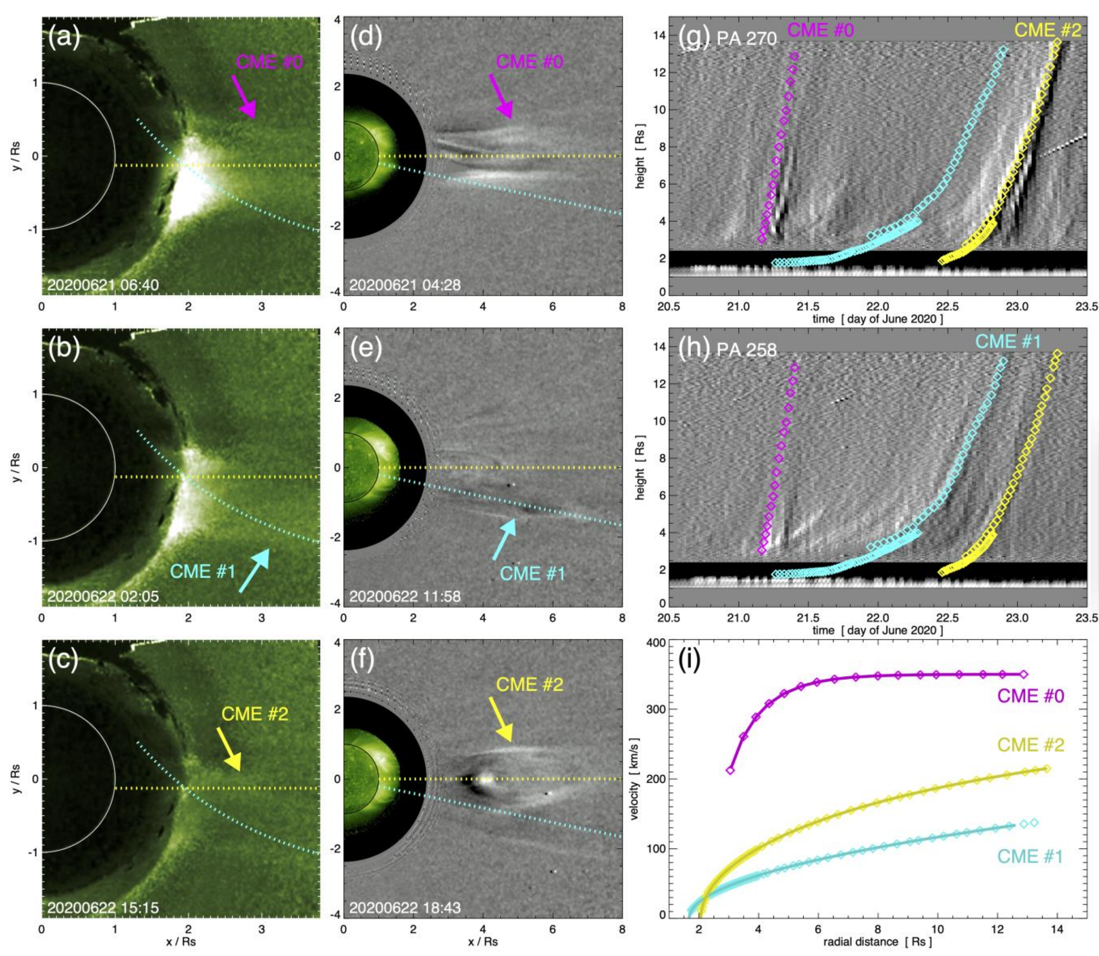


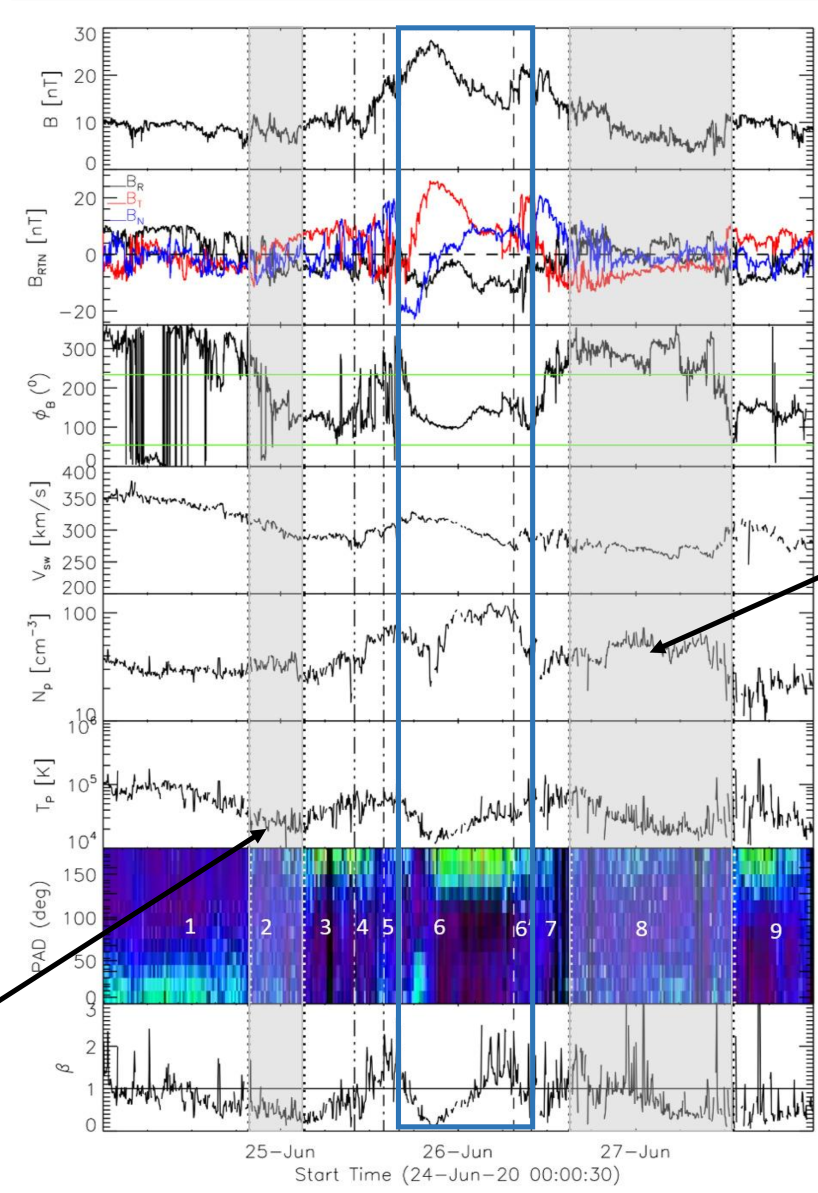
Fig 5: Coronal dynamics for each of the three sequential CMEs over the 2020 Jun 21–22 sequential/sympathetic eruption period.

- STA/HI observation shows CME #0 had the highest speed than CME#1 and #2 at 14 Rs.
- Only the SBO CME was identified with flux rope structure by the Parker Solar Probe at ~0.5 AU

Event	t_0 [day]	r_0 [$R_\odot$]	r_a [$R_\odot$]	v_a [km/s]	$v(r=20R_\odot)$ [km/s]
CME #0	-21.12	2.47	1.26	350.17	350.17
CME #1	-21.58	1.67	1321.0	1472.8	172.90
CME #2	-22.51	2.07	16.54	302.96	246.48

Table 1: Best-fit parameters for the height–time profiles of the three sequential eruptions.

SBO-CME adjacent interplanetary structures at ~0.5 AU



Isotropic PAD + peak in beta + φ_B hovering between inward-outwrd sector boundary --> HCS/HPS encounter

True sector boundary + isotropic PAD + elevated beta with duration of mins --> HCS/HPS crossing

Fig 6: PSP's in situ observation of the SBO-CME at ~0.5 AU

$$\frac{\phi^{p}_{\mathrm{dir,out}}}{L_{\mathrm{mc}}} = \int_{t_c}^{t_{\mathrm{out}}} B_{y,\mathrm{cloud}}(t)\,\frac{L'_{\mathrm{mc}}(t)}{L_{\mathrm{mc}}}\,v_{x,\mathrm{cloud}}(t)\,dt \quad (1)$$

$$\frac{L'_{\mathrm{mc}}(t)}{L_{\mathrm{mc}}} \approx 1 + \frac{(t - t_{\mathrm{in}})V_{\mathrm{mc}}}{r_{\mathrm{psp}}} \quad (2)$$

(Dasso et al. 2006,2007)

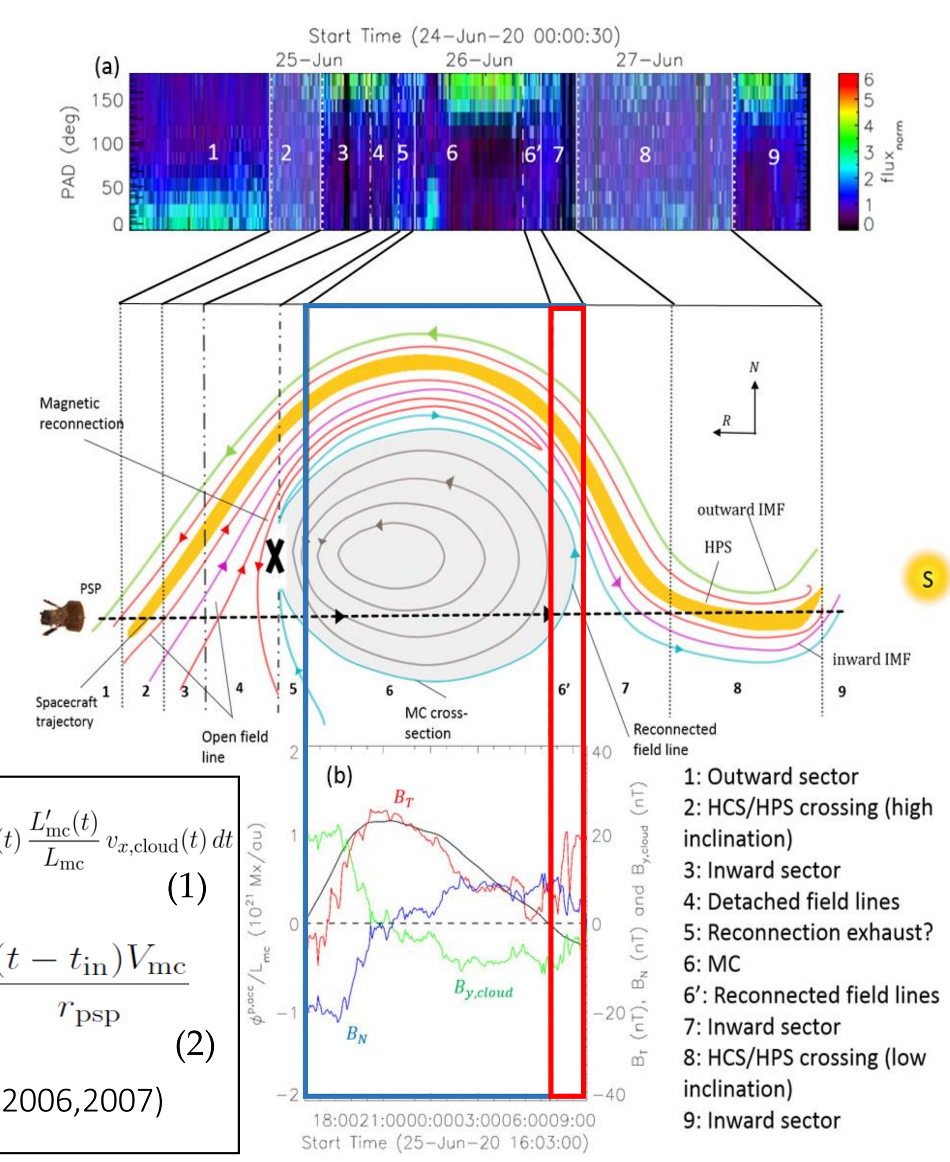


Fig 7: Schematic of IMF draping and flux asymmetry analysis at ~0.5 AU

Quantity	In-situ Reconstruction Method		
	LFF	MVA [a]	mean(LFF, MVA)
Time interval of MC	16:00 UT 25 June – 09:54 UT 26 June		
MC axis orientation (θ_{ax}, ψ_{ax})	(2°, 83°)	(5 ± 6°, 64 ± 2°)	(4°, 74°)
Impact parameter (p_0) [b]	−0.45	−0.65	−0.50
Eigenvalue ratio (λ_2/λ_3) [c]	—	2.3 ± 0.2	—
Root-mean-square error (E_{rms}) [d]	0.32	—	—
Azimuthal flux ($\phi^{p}_{\mathrm{dir,out}}/L_{\mathrm{mc}}$)	1.35×10^{21} Mx/au	$1.5 \pm 0.2 \times 10^{21}$ Mx/au	1.4×10^{21} Mx/au
Percentage of flux erosion (ϕ_{er})	8 %	29 ± 13 %	18 ± 11 %
Time of accumulated azimuthal flux imbalance [e]	t^*_{out} = 07:30 UT 26 June		
Estimated *start time* of the flux erosion [e]	t_{rec} ∼17:00 UT 24 June		
Estimated *start distance* of the flux erosion [e]	r_{rec} ∼0.35 au		

[a] Nested-bootstrap MVA (see Ruffenach et al., 2015).
[b] A negative value means the spacecraft crosses south of the MC axis.
[c] The intermediate (λ_2) to minimum (λ_3) eignenvalue ratio determined from MVA.
[d] Defined as $E_{\mathrm{rms}} = \left(\sum_{i=1}^{N}\left[\mathbf{B}^{\mathrm{obs}}(t_i) - \mathbf{B}^{\mathrm{LFF}}(t_i)\right]^2\right)^{1/2}/(N \max|\mathbf{B}^{\mathrm{obs}}|)$ in Marubashi and Lepping (2007).
[e] Calculated using the mean(LFF, nested-bootstrap MVA) values.

$$t_{rec} = t_{in} - \delta t \quad (3)$$

$$\delta t = \frac{(t_{\mathrm{out}} - t^*_{\mathrm{out}})\,V_{\mathrm{sw}}(t_{\mathrm{out}})}{V_{\mathrm{mc}} - V_{\mathrm{sw}}(t_{\mathrm{out}})}$$

$$r_{\mathrm{rec}} = V_{tr}\left(t_{rec} - t_{\mathrm{start}}\right) \quad (4)$$

Table 2: Summary of results obtained from the ICME in-situ flux analysis at PSP.

Summary and Conclusion

- The SBO CME eruption was part of a multi-stage, sequential (and most likely sympathetic) eruption scenario (Lynch and Edmondson 2013).
- PSP witnessed the draping of heliospheric large-scale structures (magnetic field lines and HCS/HPS) about the SBO-CME flux rope at 0.5 AU.
- Inclination (~29°) of HCS behind the CME was smaller than the inclination(~41°) of plasma sheet in front of the CME – the CME had an asymmetric, expanding, and non-circular FR structure.
- Draped heiospheric field lines had magnetic reconnection with the CME flux rope resulted in erosion of ~18% of the CME's azimuthal flux.
- Analyzing the MC's back region populated with reconnected field lines, we estimated that the reconnection initiated after a heliocentric distance of ~0.35 AU.

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