Dependence of Interplanetary Coronal Mass Ejection Magnetic Properties on Their Solar Sources

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November 16, 2022

Abstract

Several studies suggest that magnetic reconnection plays an essential role to generate and accelerate most of the erupting coronal magnetic flux ropes such as coronal mass ejections (CMEs). We explore the connection between magnetic properties (magnetic flux and helicity) of interplanetary coronal mass ejection (ICME) flux-ropes (magnetic clouds [MCs]) and those of associated near-sun CME flux-ropes formed in situ by low corona magnetic reconnection. We identify the progenitor CMEs and their solar sources and derive the source region reconnection flux using the post-eruption arcade (PEA) method. Combining the reconnection flux and the geometrical properties of associated CMEs obtained by forward-modeling, we extract the magnetic properties of CME flux ropes at their source. To measure the magnetic properties of 1 AU ICME we use constant-α force-free cylindrical flux rope model fit to in situ observations and directly from the observed magnetic time series rotated to the cloud frame. We investigate whether a significant difference exists in magnetic properties of ICMEs if their solar source is composed of pre-existing flux-ropes (filaments). This study has significant implications in finding the role of reconnection in the formation of twisted flux ropes during a solar eruptive process that transport solar magnetic flux and helicity into interplanetary space.

Dependence of Interplanetary Coronal Mass Ejection Magnetic Properties on Their Solar Sources

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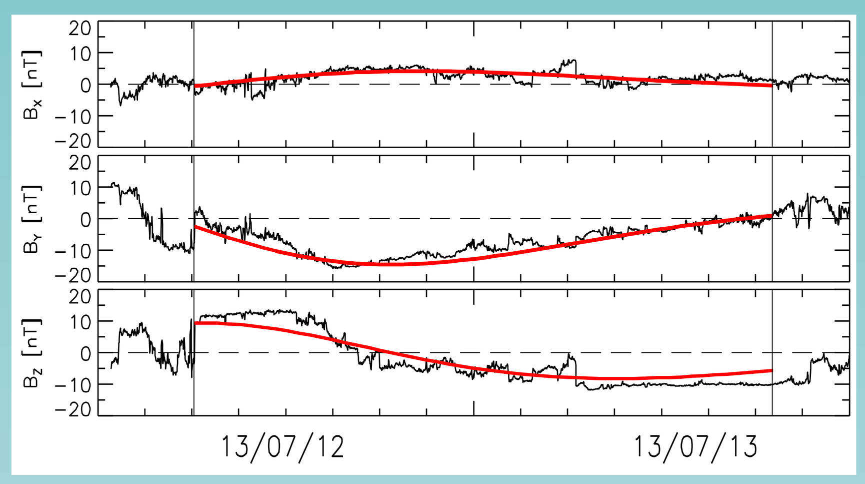
Aim: To explore the connection between magnetic properties (magnetic flux and helicity) of interplanetary coronal mass ejection (ICME) flux-ropes (magnetic clouds [MCs]) and those of associated near-sun coronal mass ejection (CME) flux-ropes formed in situ by low corona magnetic reconnection. To investigate whether a significant difference exists in magnetic properties of ICMEs if their solar source is composed of pre-existing flux-ropes (filaments). This study has significant implications in finding the role of reconnection in formation of twisted flux ropes during a solar eruptive process that transport solar magnetic flux and helicity into interplanetary space.

Background

Magnetic flux and magnetic helicity are conserved during flux rope propagation unless the flux rope significantly reconnects with the surrounding solar-wind magnetic field. The interplanetary magnetic flux budget is closely related to the magnetic reconnection flux (Qiu et al. 2007, Gopalswamy et al. 2017a). The current study presents first quantitative analysis and statistical comparison of magnetic helicity in ICMEs and the helicity invoked in their associated CME flux-ropes during low corona magnetic reconnection.

Measuring magnetic flux and helicity in MC

1. Using constant-alpha cylindrical flux rope fit (Marubashi and Lepping, 2007]):



$\varphi_{MC_{fit}}{}^{AX} = 1.5e21$ Mx

$\varphi_{MC_{fit}}{}^{AZ} = 2.8e21$ Mx

$H_{MC}^{fit} = 5.2e42$ Mx^2

$IF = 0.03$

Fig: Fitting with cylindrical flux rope model to 13 July 2013 MC.

2. Using the Direct method (Dasso et al. 2006):

- Signature of magnetic reconnection at the MC front and rear boundaries:
  - Presence of bifurcated current sheets bounding an exhaust
- Changes in V and B are correlated on one side and anti-correlated on the other side of reconnection exhaust.

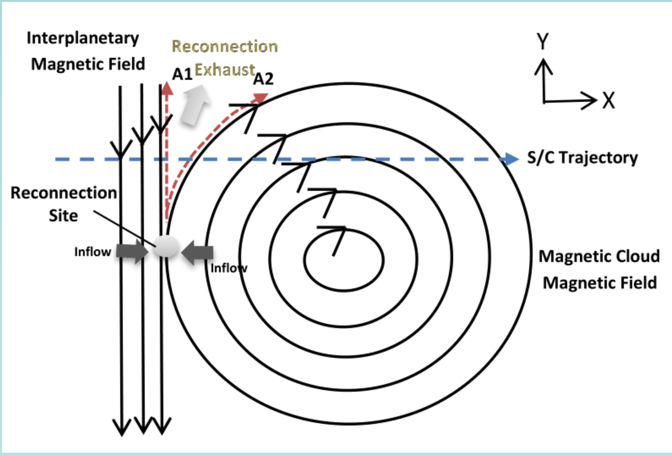


Fig: Schematic of reconnection exhaust at MC front boundary.

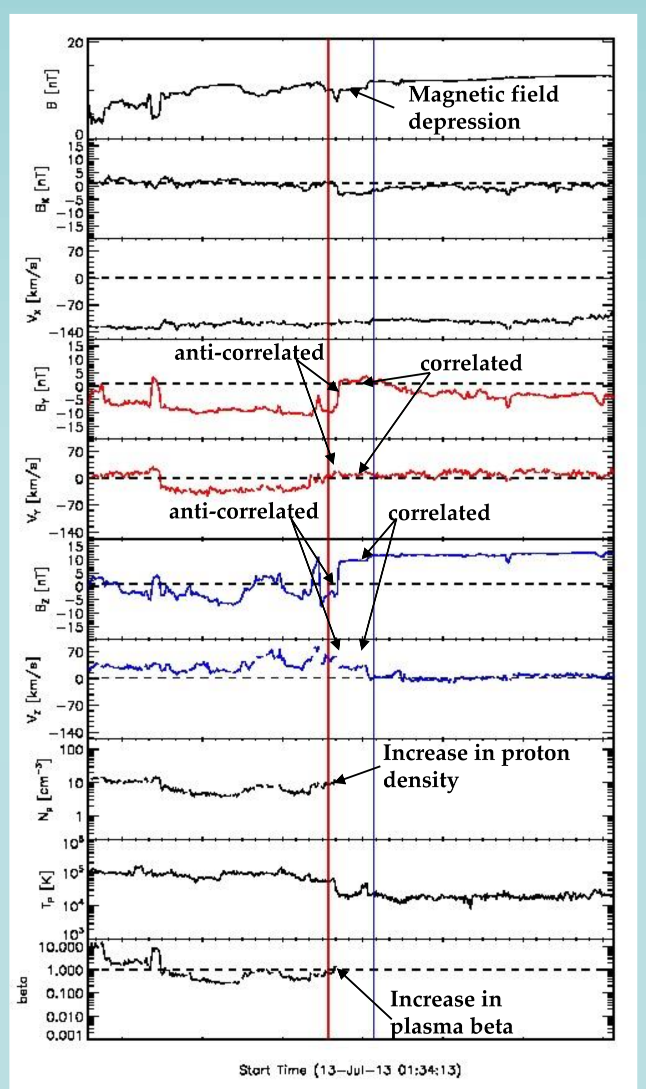


Fig: In-situ signature of magnetic reconnection at the front boundary of 13 July 2013 MC.

Method of event selection

- Clearly observed MCs at 1 au (Richardson and Cane ICME list) with well determined front and rear boundaries.
- MC associated CMEs with identified flux rope structure near the Sun.
- Presence of clear post eruption arcade (PEA) at solar progenitor.

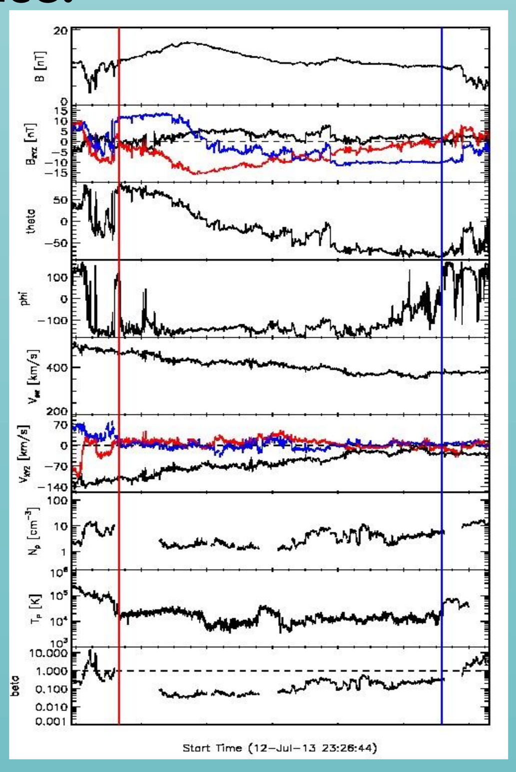


Fig: MC with clearly identified front (red) and rear (blue) boundary

Evaluating solar source of MC:

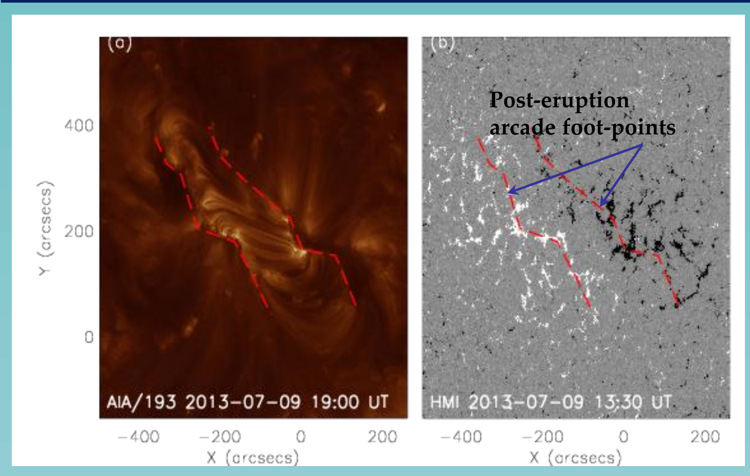


Fig: PEA identified on AIA and HMI on 9 July 2013 [source location: N19E14. φ_{RC}=3.82E+21 Mx.

$\varphi_{RC} = \frac{1}{2}\int_{PEA}|B_{LOS}|dA$ (Gopalswamy et al. 2017a)

CME azimuthal flux ($\varphi^{AZ}{}_{cme}$) =φ_{RC} (Longcope & Beveridge 2007)

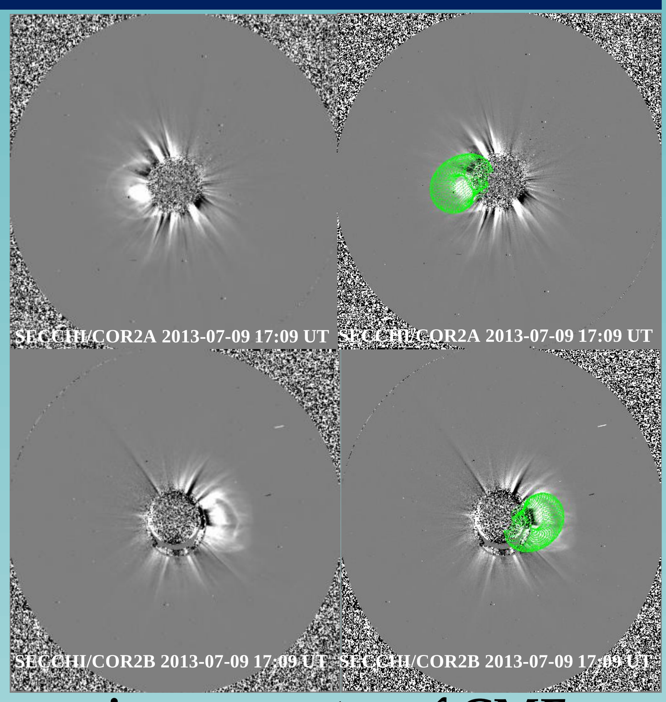
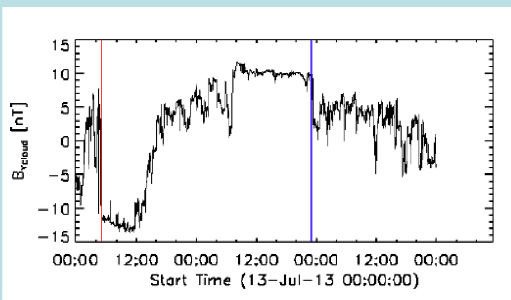


Fig: Measuring geometry of CME. Tilt= -34.7°, Aspect ratio: 0.34, AW= 35°, FR radius= 2.54 Rs.

- $\varphi_{MC_{DM}}{}^{AZ} = 2\pi L\int_{t_{in}}^{t_{out}} B_{y,cloud}(t')V_{x,cloud}dt' = 2\pi L\int_0^R B_{y,cloud}(r')dr'$
- $\varphi_{MC_{DM}}{}^{AX} = 2\pi\int_0^R B_{Z,cloud}(r')dr'$
- $H^{DM}{}_{MC} = 2\int_0^R B_{y,cloud}(r')\varphi_{MC_{DM}}{}^{AX}(r')dr'$



$R^{DM}{}_{MC}$ (au)	$\varphi_{MC_{DM}}{}^{AX}$ ($10^{21}Mx$)	$\varphi_{MC_{DM}}{}^{AZ}$ ($10^{21}Mx$)	H_{MC}^{DM} ($10^{42}Mx^2$)
0.2	2.0	2.9	7.54

Table: Magnetic properties of MC using Direct method

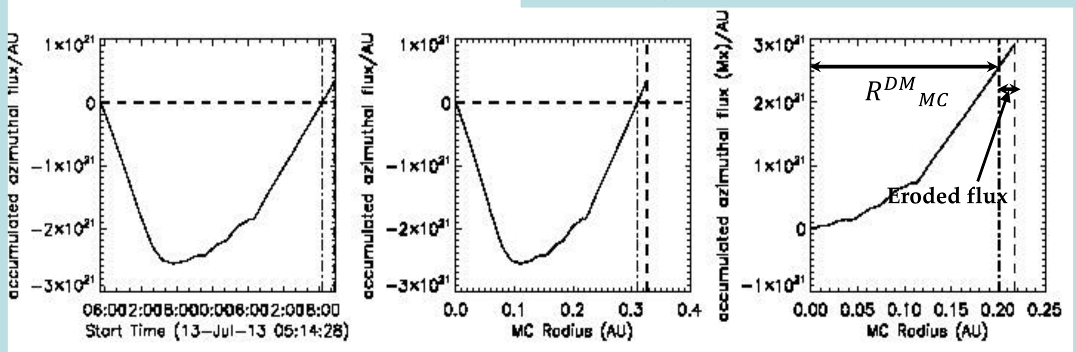


Fig: Measurement of MC azimuthal magnetic flux using direct method

Comparison between magnetic flux and helicity of MC and their progenitorial flux-ropes:

- MC toroidal flux is a small fraction of azimuthal flux and φ_{RC}. It implies ICME FRs are highly twisted.
- Strong correlations and linear relationships exist between MC azimuthal and reconnection flux, and MC and CME helicity.

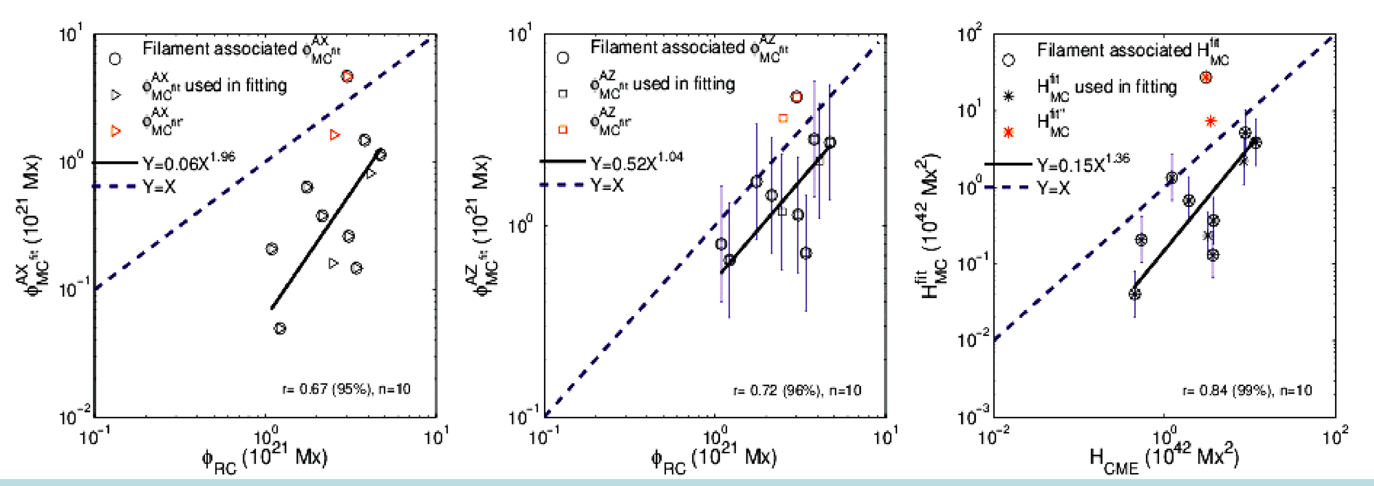


Fig: Comparison of magnetic flux and helicity of MCs and associated CME flux-ropes . MC magnetic properties are measured using flux-rope fitting method. Error bars include the MC length uncertainties.

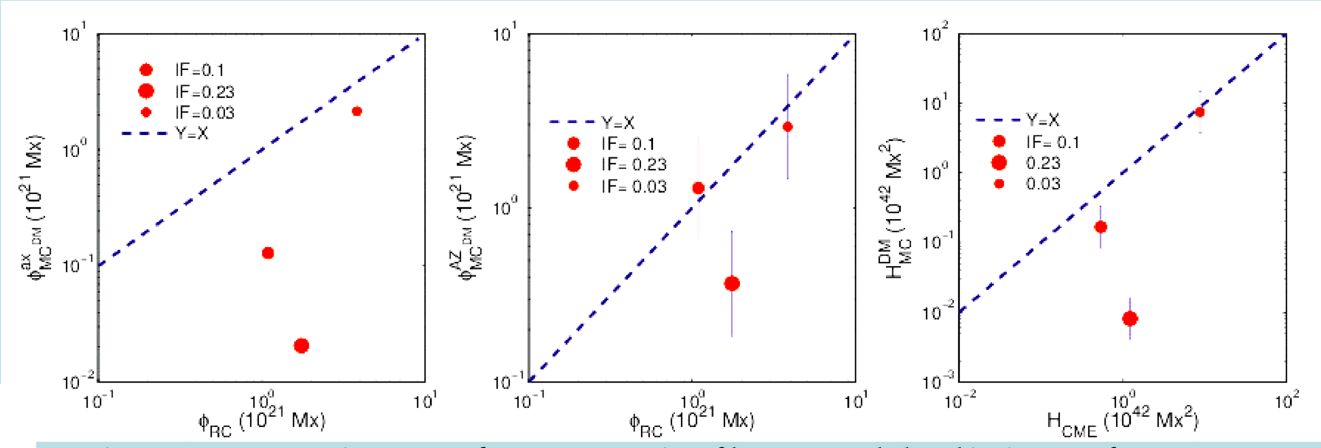


Fig: Comparison of magnetic flux and helicity of MCs and associated CME flux-ropes . MC magnetic properties are measured using the direct method. Error bars include the MC length uncertainties.

- MC azimuthal flux and φ_{RC}, MC and CME helicities are very close to the $X = Y$ line (for (L=2 au) when the direct method is applied to measure ICME magnetic properties.
- No significant difference is found in the flux and helicity relationships when ICMEs are associated with pre-existing flux-ropes at their solar sources.

Conclusion

- The results of this study show that magnetic properties in MCs are highly relevant to those of associated CME flux-ropes that are formed due to low-corona reconnection.
- Erupting filaments do not seem to carry significant pre-existing flux and helicity.
- Our results support the scenario of eruptive magnetic flux ropes formed in situ by magnetic reconnection during the eruption.

References

- Dasso, S., C. H. Mandrini, P. Démoulin, and M. L. Luoni 2006,A&A, 455, 349.
- Longcope, D. W., & Beveridge, C. 2007, ApJ, 669, 621.
- Qiu, J., Hu, Q., Howard, T. A., & urchyshyn, V. B. 2007, ApJ, 659, 758.
- Gopalswamy, N., Yashiro, S., Akiyama, S., & Xie, H. 2017a, SoPh, 292, 65.
- Marubashi, K., & Lepping, R. P. 2007, Annales Geophysicae, 25, 2453

Acknowledgement

We acknowledge the use of data from SDO, STEREO, SOHO, and ACE. We acknowledge the support from the Ministry of Human Resource Development through CESSI for our research. We thank Dr. Benoit Lavraud for his valuable suggestions.

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