Analysis of Interplanetary Coronal Mass Ejections (ICMEs) Observed by Wind and STEREO

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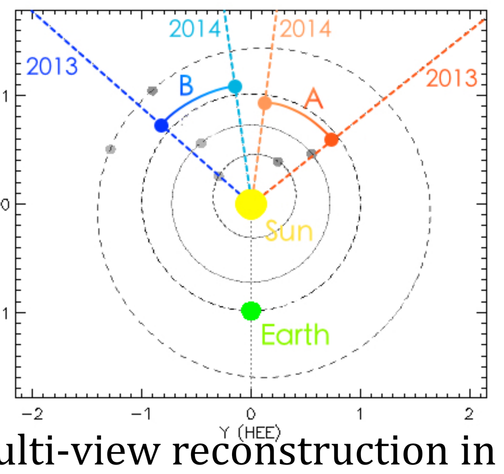
ABSTRACT: Coronal mass ejections (CMEs) expelled from the solar corona are a major space weather driver, both in space and on the ground. The fast-traveling CME plasma, which carries a twisted magnetic field, is a common source of geomagnetic disturbances that can affect a wide range of human technologies. Thus, understanding the magnetic structure and dynamics of CMEs is of critical importance for space weather forecasting. Thanks to the past and current Heliophysics System Observatories (HSOs), we have advanced our understanding by, for instance, connecting the traditional 'magnetic clouds (MC)' with the CMEs. However, our proficiency in unraveling the internal magnetic structure of their counterpart in the interplanetary medium, the ICMEs, is still limited. The goal of this work is to decipher the internal magnetic configuration of ICMEs observed by Wind and STEREO at 1 AU by systematically sorting, studying, and quantifying the internal magnetic structure.

INTRODUCTION

Coronal Mass Ejections (CMEs) are emissions of magnetized plasma from the solar corona into the heliosphere and, as one of the main concerns of Space Weather, unraveling the behavior of their internal magnetic structure is key to develop more accurate forecasting techniques and in-situ analytical models. In this way, multi-spacecraft remote sensing and multipoint in-situ observations have provided important results for the analysis of ICMEs' topology, structure and geometry, yet there is still a long path to go.



In this work, a characterization of the events observed by Wind and STEREO during the time interval of 2013 to 2014 (maximum of solar cycle 24) is made. Also, a small contingent of the CMEs that present the most interesting internal structure based on the in-situ results is selected for multipoint observation analysis and 3D multi-view reconstruction in an attempt to help establish a link between in-situ and remote sensing observations.

TABLE 1

STEREO A		WIND	STEREO B	
2013 171 06/20 11:13	F		2013 170 06/19 15:08	Cx
2013 234 08/22 07:05	**Cx**		**2013 234 08/22 02:10**	**E**
2013 308 11/04 08:56	Cx		2013 309 11/05 02:43	Cx
2014 036 02/05 03:27	Cx	2014 036 02/05 12:50	2014 036 02/05 16:05	Cx
2014 058 02/27 20:46	E		2014 059 02/28 04:23	E
2014 101 04/11 15:24	F-	2014 101 04/11 09:58	2014 102 04/12 02:27	F+
2014 160 06/09 09:30	F-		2014 160 06/09 01:18	F+
2014 223 08/11 09:03	F		2014 223 08/11 06:20	Cx

A special focus on the **Aug 22, 2013** event will be set, in order to show a representative example of the followed working procedure and analysis of the obtained results in this publication.

IN-SITU ANALYSIS AND RESULTS

The results obtained for the multipoint in-situ measurements of both twin STEREO spacecrafts at 1 AU are presented. The displayed graphs correspond to the aforementioned event of study: Aug 22, 2013. The ICME start time is defined by means of the IP shock which is related to a strong discontinuity in the different parameters' values. The magnetic obstacle (MO) [Nieves-Chinchilla, T. *et. al*, 2018] start time is set right after the sheath, where appreciable fluctuations of the magnetic field components are observed.

STEREO A

- Very clear signatures.
- Increase in the module of the magnetic field.
- Rotation of the magnetic field direction.
- Diminution in N_p, V_{th}, β_p.
- Behavioral change around DOY 236.

→ Cx

STEREO B

- No clear signatures.
- No clear behavioral pattern of the magnetic field rotation.
- Disordered structure.
- Possibly crossing one of the legs.

→ E

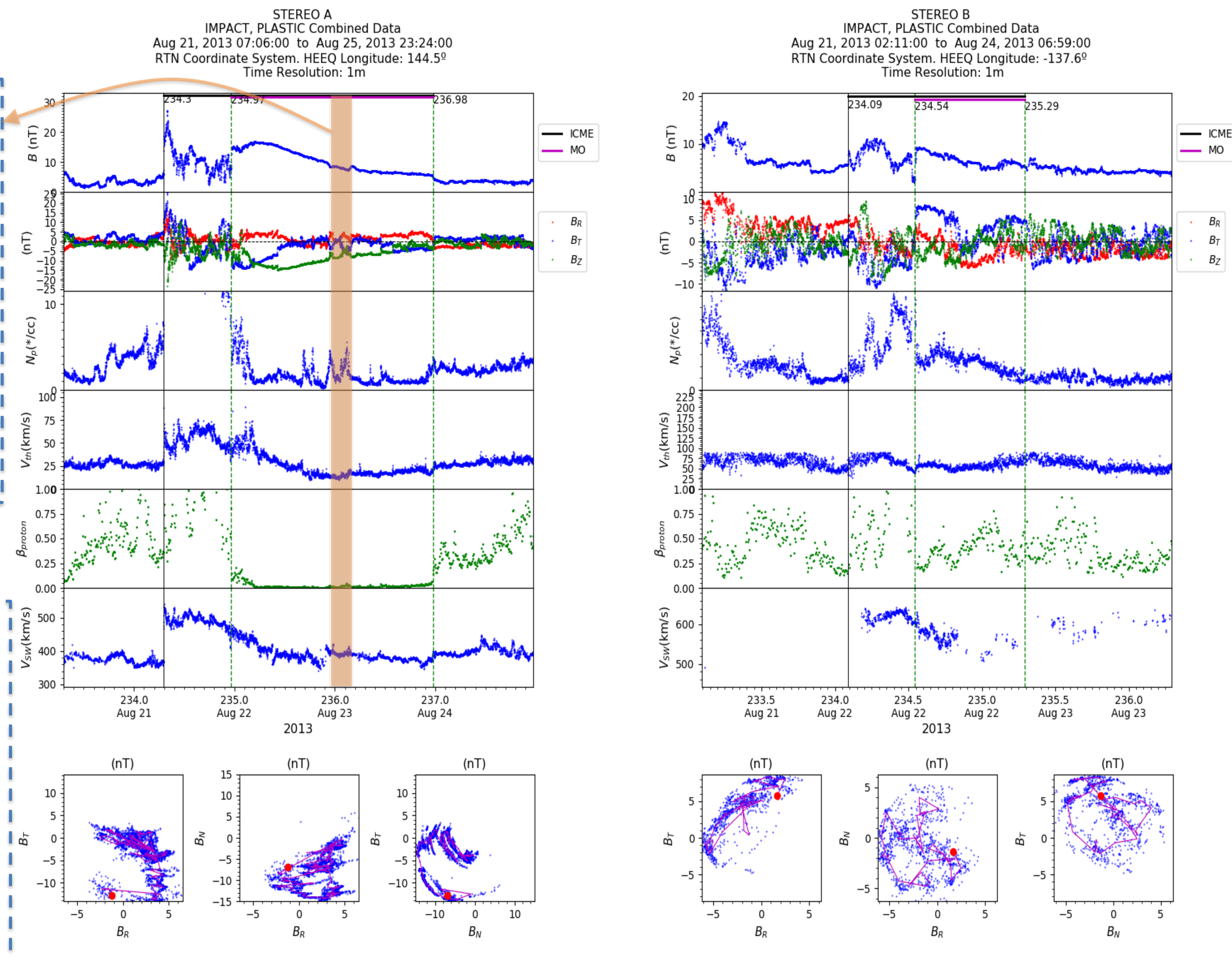


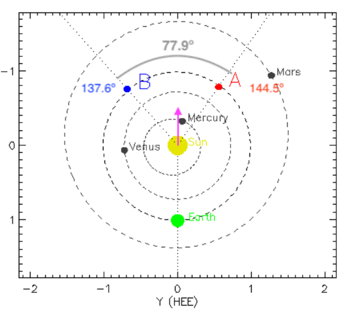
FIG 1 – Multipoint in-situ measurements for both spacecrafts: STEREO A & B.

Classification Criteria

Three types of configurations are distinguished depending on the parameters' behavior within the MO interval:

- **Flux rope**: organized magnetic topology. When there is clear in-situ signatures smooth and large magnetic field rotations are often observed.
  - F: ~180º B rotation.
  - F+: >180º B rotation.
  - F-: < 180º B rotation.
- **Ejecta (E)**: no ordered topology or monotonic change in the magnetic field.
- **Complex (Cx)**: when there is a change in the natural comportment of the parameters, leading to two or more linked configurations.

REMOTE SENSING AND 3D MULTIVIEW RECONSTRUCTION



From the ICME IP shock time detection at each spacecraft (*Table 1*) and the in-situ measurements (*Figure 1*), the CME remote sensing identification was performed. The STEREO/SECCHI EUVI 195, COR1 and COR2 images were used to track the time evolution of the CME for the later 3D reconstruction (*Figure 4*). In this way, the CME is first observed with COR1 at 2013-08-19T22:35:29 and with COR2 at 2013-08-19T23:09:15. The separation of the spacecrafts at the time of detection is 77.9º, being STEREO A and B located at a longitude of 144º and B 137.6º, respectively, and the CME ejected at ~170º.

Self-similar expansion:

In this case, the self-similar expansion approximation can be assumed both from the in-situ and remote sensing results: 1) Appreciably higher speeds in the MO front than in the back are observed and 2) The CME does not significantly change its appearance as it expands away from the Sun.

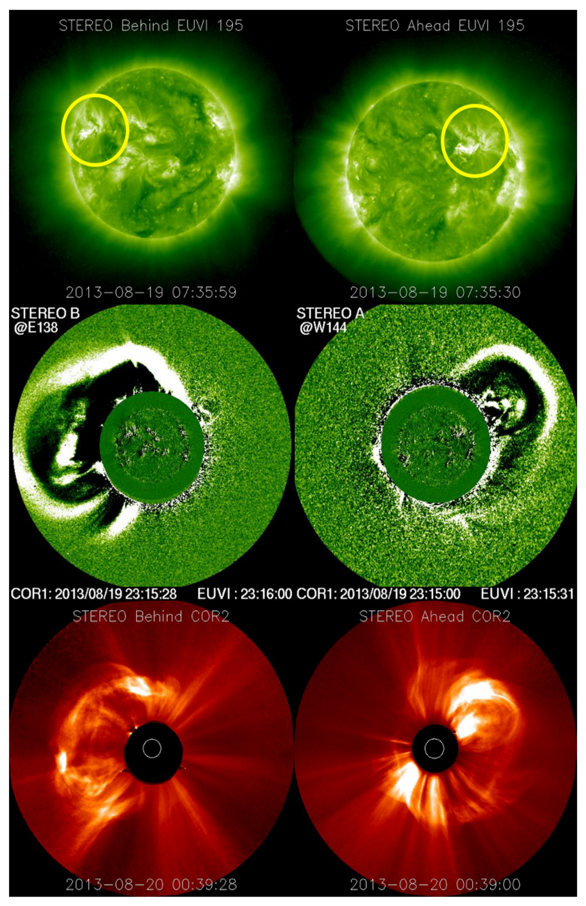


FIG 4 – EUVI 195, COR1RD and COR2 images.

3D Reconstruction

In order to study the three-dimensional morphology, position and kinematics of the CME observed by the coronagraphs, the Graduated Cylindrical Shell (GCS) model [Thernisien *et al.*, 2011] has been used.

The reconstruction of seven images has been made, from 2013-08-19T23:54:00 (h = 8.79 R/Rs) to 2013-08-19T02:24:00 (h = 22.07 R/Rs). An example of the different model parameters' values is provided in *Table 2* at 01:54.

The COR2 images are displayed in a base-difference format, with an image from before the CME subtracted from each CME image. The EUVI images shown correspond to 21:54 h.

ENLIL model results

Using as inputs the GCS parameters when the CME has already reached a h = 21.5 R/Rs, the simulation displayed in *Figure 3* shows how the CME crosses STEREO A and B once it approaches the spacecrafts.

FIG 2 – 3D Remote reconstruction by means of the GCS model.

Date	Time	Long [º]	Lat [º]	Tilt [º]
08/20/13	1:54:00	326,459	-5,5908	59,814

H [R/Rs]	Ratio	Half Ang [º]	V [km/s]
20,4286	0,406604	37,4535	1066

TABLE 2 – Reconstruction parameters at 1:54 am.

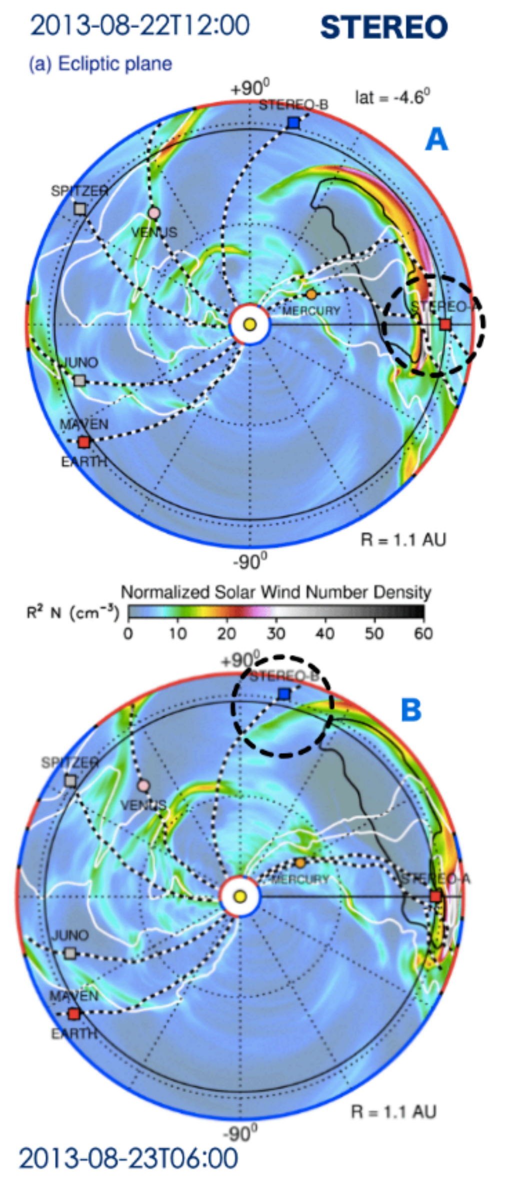


FIG 3 – STA and B encounter with the CME simulation.

CONCLUSIONS

- The in-situ characterization within the time range 2013– 2014 (maximum SC 24) for the STEREO events has been conducted by differentiating between F, Cx and E for each case.
- The Aug 22, 2013 event has been further studied due to its multipoint observation and multi-view remote sensing possibilities. Thus, it is concluded that the structure identified by STA corresponds to a Cx and in the case of STB to an E.
- The aforementioned CME has been reconstructed by using de GCS model to analyze its three dimensional configuration.
- The ENLIL model provides one more prove of its multipoint + multiview possibilities and an explanation for the STB in-situ measurements: they probably correspond to one of the legs of the CME.

FUTURE WORK

- As Messenger is located within the trajectory of the CME, it will be interesting to analyze its in-situ measurements data and compare it with the results obtained by STA.
- Use the Circular Cylindrical Analytical Flux Rope Model for MC [Nieves-Chinchilla, T.] to study the similarities between the remote sensing and in-situ products.

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