Kinematics and consequences of interacting CMEs observed by STEREO/HI

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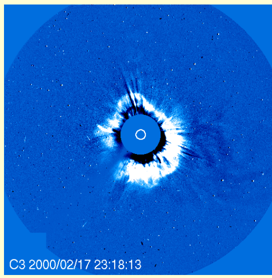
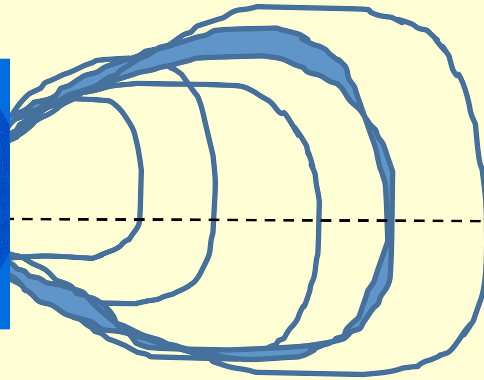
Coronal Mass Ejections (CMEs) are huge expulsion of mass from the Sun and also known to be drivers of many space weather events.

SOHO/LASCO observations

In situ data: single point, 1D

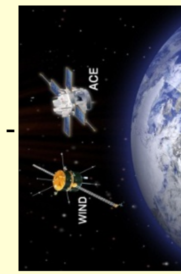
Projected morphology & kinematics





Use of models to fill the gap

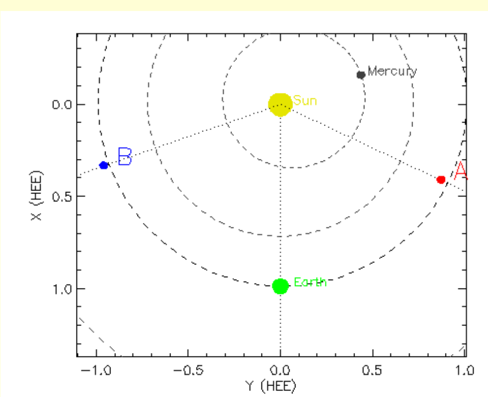
e.g. Drag Based Model, MHD

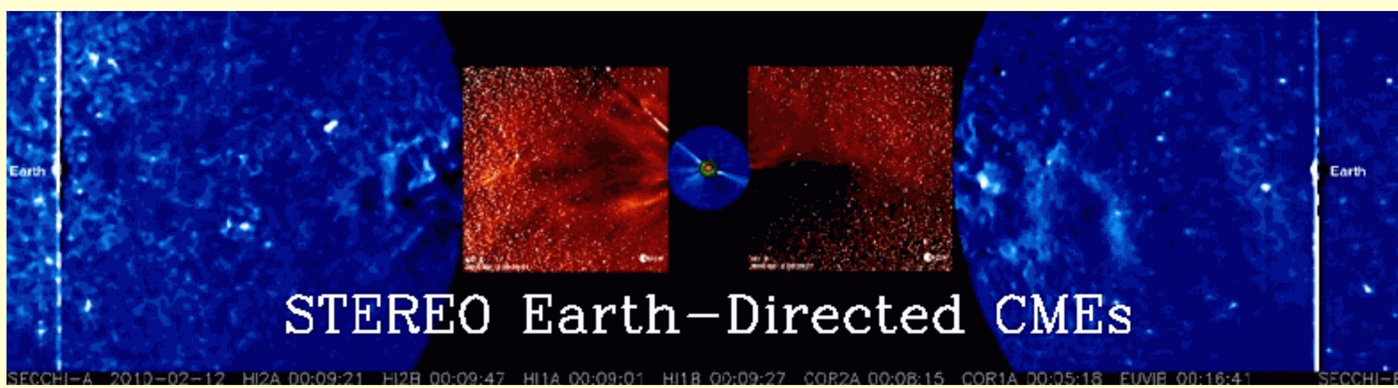


30 Rs

~ 215 Rs

STEREO (A & B) Observations



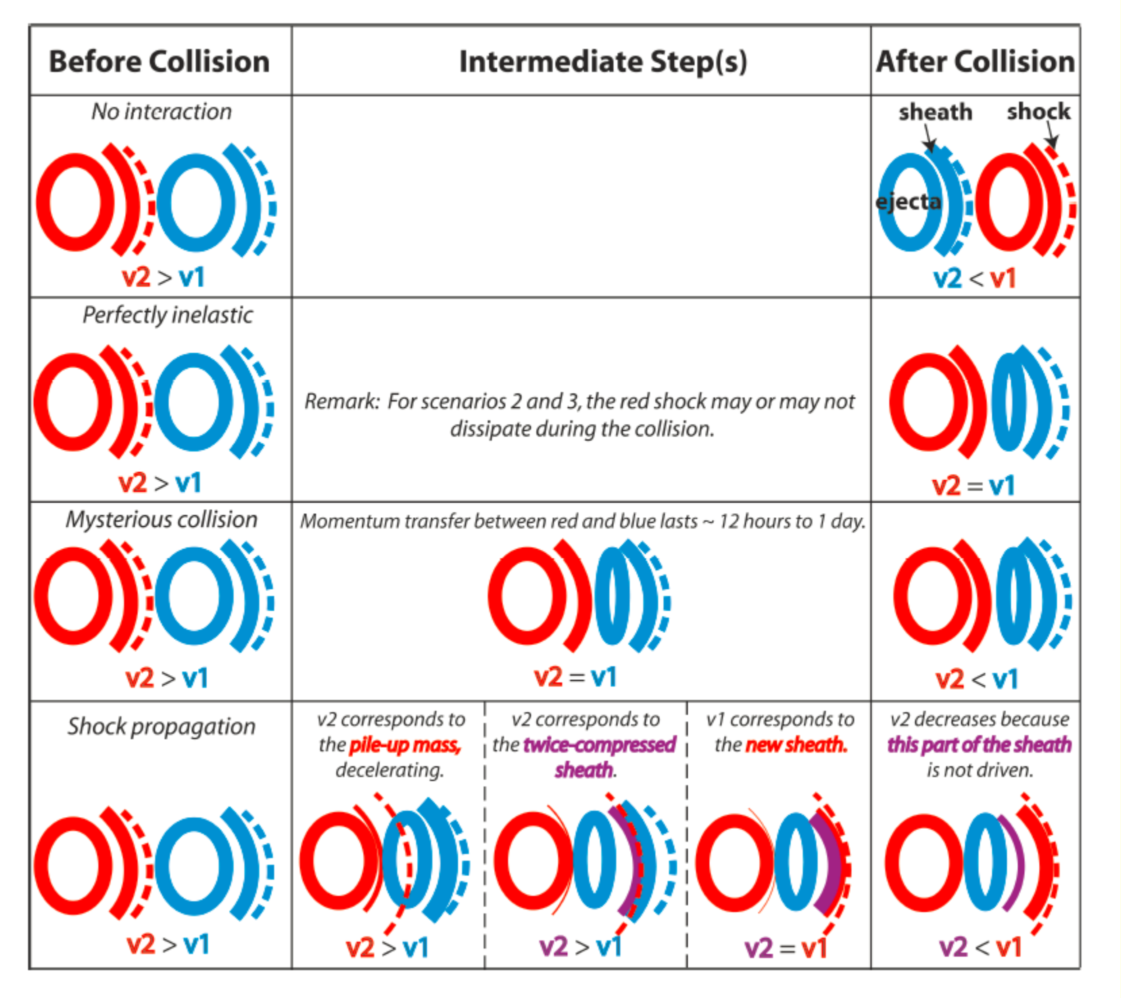


Questions to be addressed

- How does the dynamics of CMEs change after interaction?
- What is the regime/nature of CME-CME collision ?
- What are the consequences of the interaction of CME-shock structure? How does the overtaking shock change the plasma and the magnetic field properties into the preceding magnetic cloud?
- Do interacting CMEs produce different geomagnetic consequences than individual CMEs, on their arrival to magnetosphere?
- What are the favourable conditions for CME merging and the role of magnetic reconnection in it?

Nature of Collision?
Plasma balls with magnetic fields

- Super-elastic (Shen et al. 2012) (e>1)
- Elastic e=1
- Inelastic e<1



Lugaz (2009)

Analysis Approach

- We have selected few cases of interacting CMEs that are earth-directed

- The kinematics of these CMEs have been estimated using
  (i) Tie-pointing method in COR2 fov
  (ii) Jmaps (time-elongation plots) have been constructed using HI images
  (iii) kinematics of the CMEs are estimated using suitable reconstruction technique, namely stereoscopic or single spacecraft.

- The true masses of the two participating CMEs in interaction have been estimated using the method by Colaninno and Vourlidas (2009).

- Using the estimated kinematics before and after the collision and their true masses, the coefficient of restitution has been calculated for all CMEs, in order to understand the nature of collision.

- In-situ observations obtained from Wind and ACE spacecraft for these interacting CMEs have also been examined, in order to understand the consequences of interaction on the geoeffectiveness of CMEs.

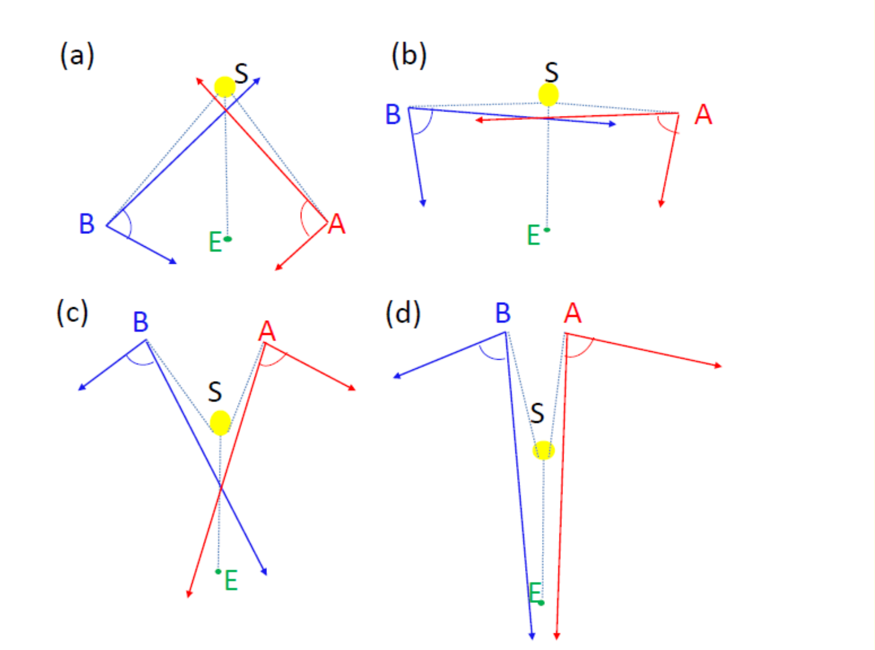
TRACKING CMEs: COR & HI fov

Near the Sun (COR FOV: 1.4-15 Rs)

1. Tie-pointing (Thompson 2009; Mierla et al. 2009)
2. GCS or hollow croissant model (Thernisien et al. 2009)

Far from the Sun (HI FOV: 15-330 Rs)

HI designed to view Sun-Earth Events



Single spacecraft methods:

1. Point P (PP) (Howard et al. 2006)
2. Fixed-Phi (FP) (Kahler and Webb, 2009)
3. Harmonic Mean (Lugaz et al. 2009)
4. Self-Similar Expansion (SSE) (Davies et al. 2012)

Single spacecraft fitting methods:

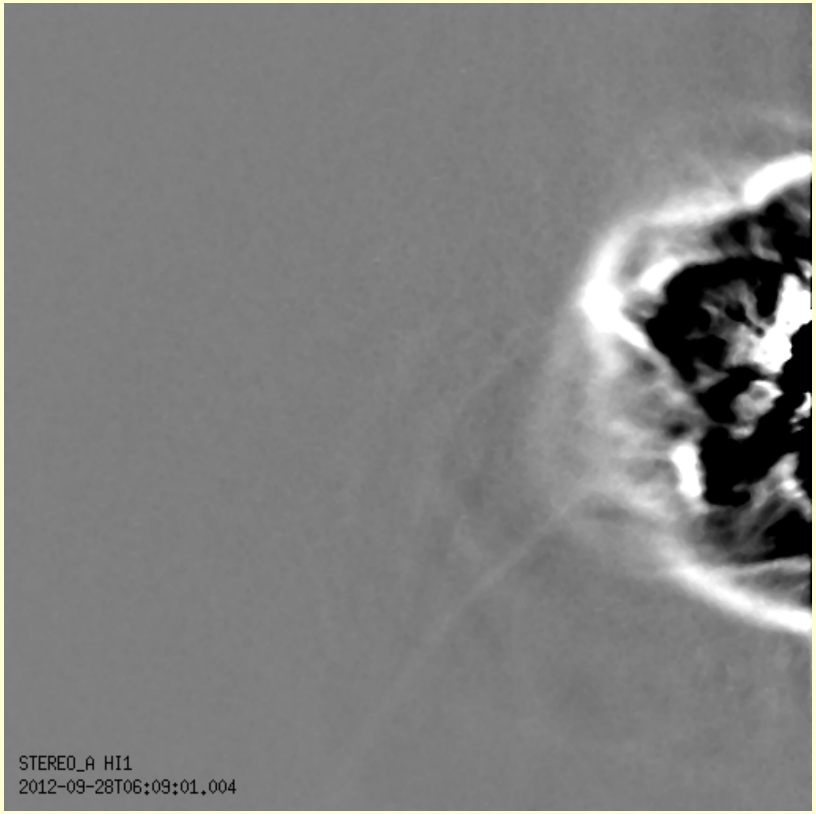
5. Fixed-Phi Fitting (FPF) (Rouillard et al. 2008)
6. Harmonic Mean Fitting (HMF) (Lugaz 2010)
7. Self-Similar Expansion Fitting (SSSEF) (Davies et al. 2012)

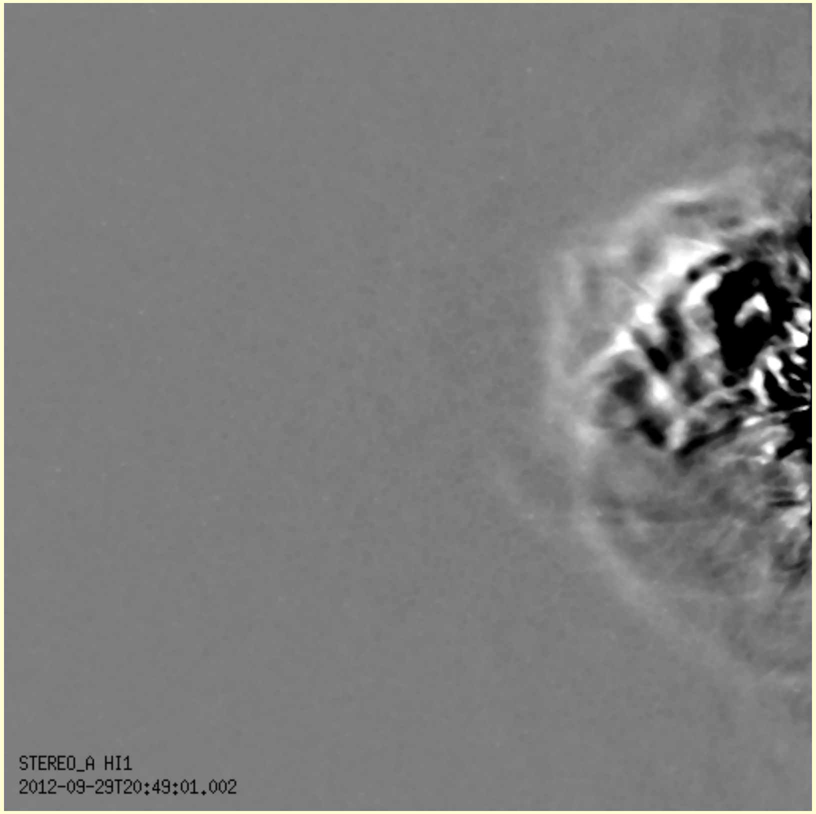
Stereoscopic methods:

8. Geometric Triangulation (GT) (Liu et al. 2010)
9. Tangent to A Sphere (TAS) (Lugaz et al. 2010)
10. Stereoscopic Self-Similar Expansion (SSSE) (Davies et al. 2013)

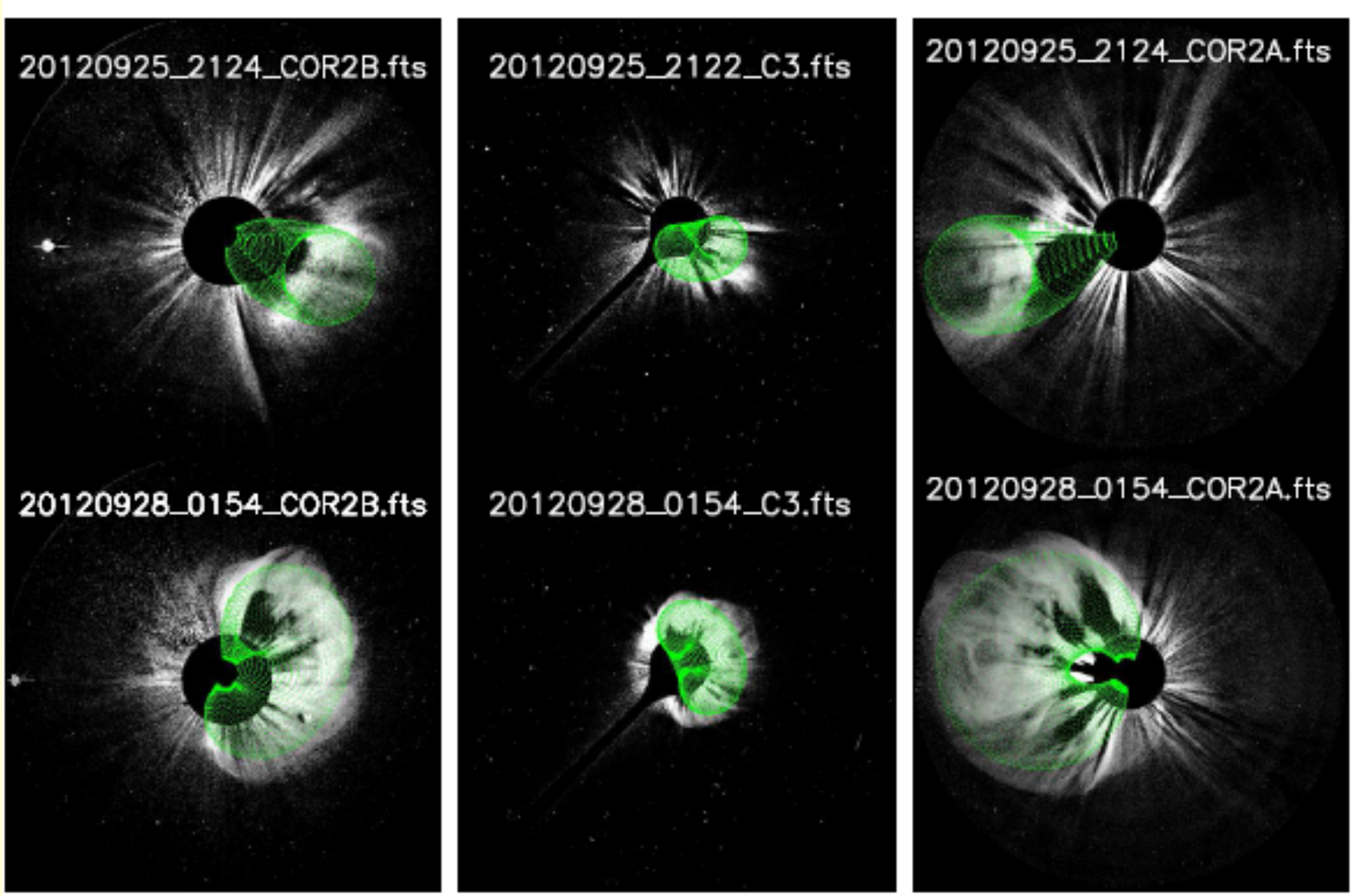
September 25 & 28, 2012 CMEs:

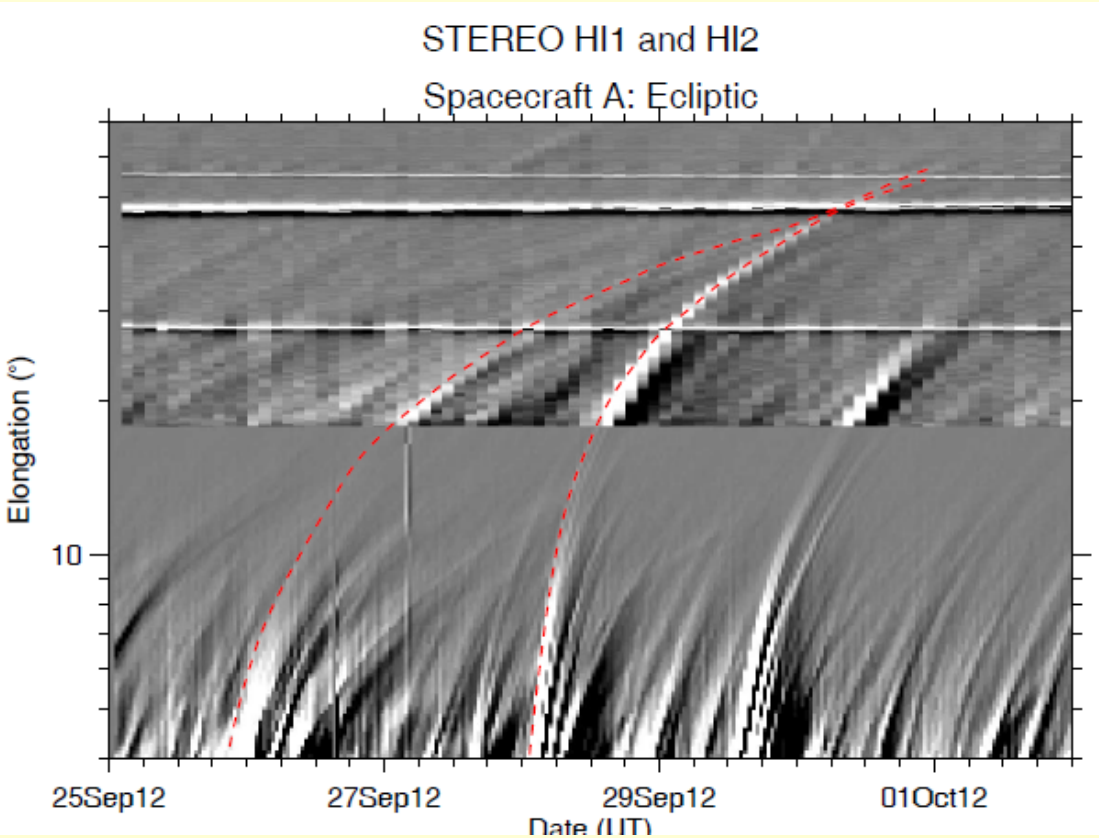
Example of an Elastic Collision

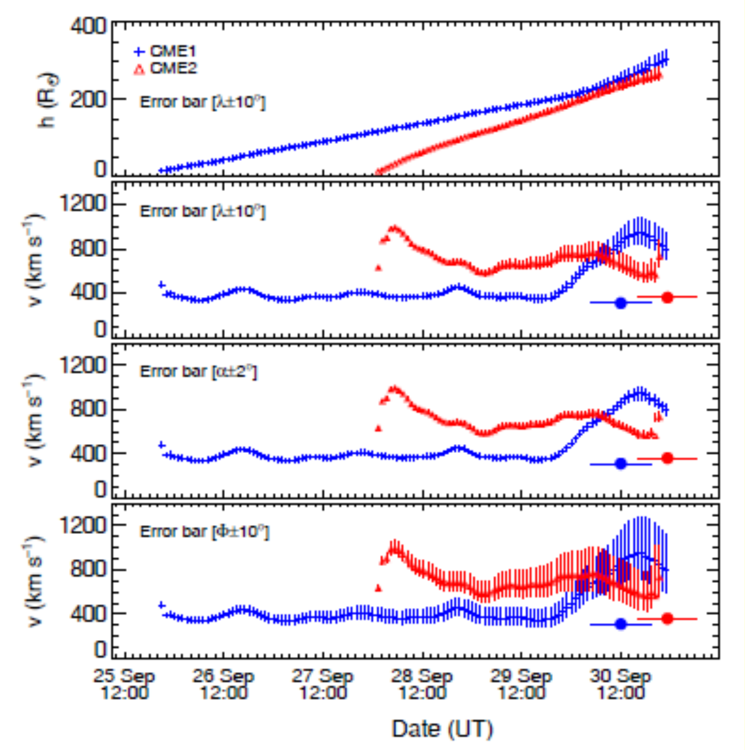




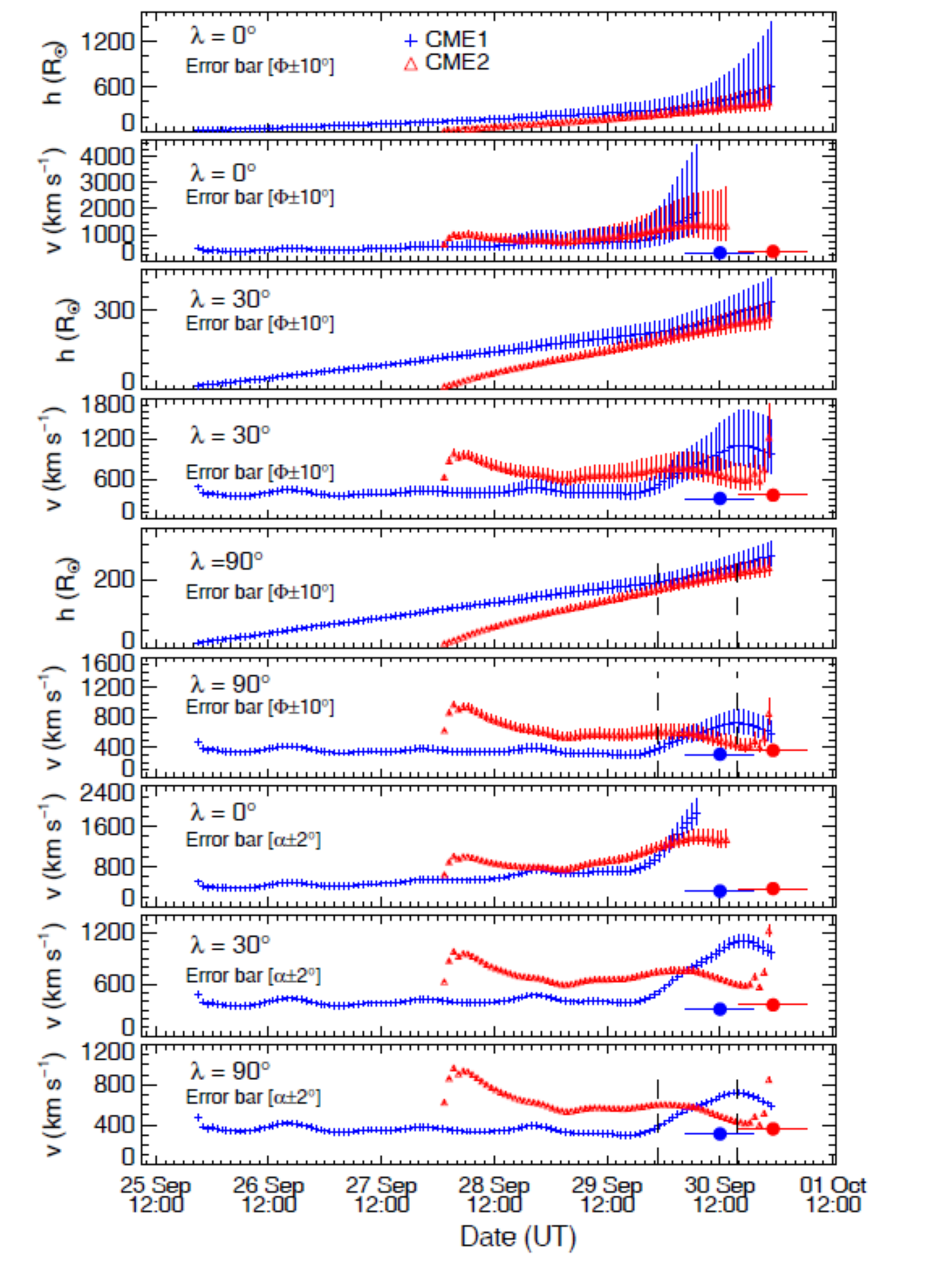
Reconstruction in COR2 fov





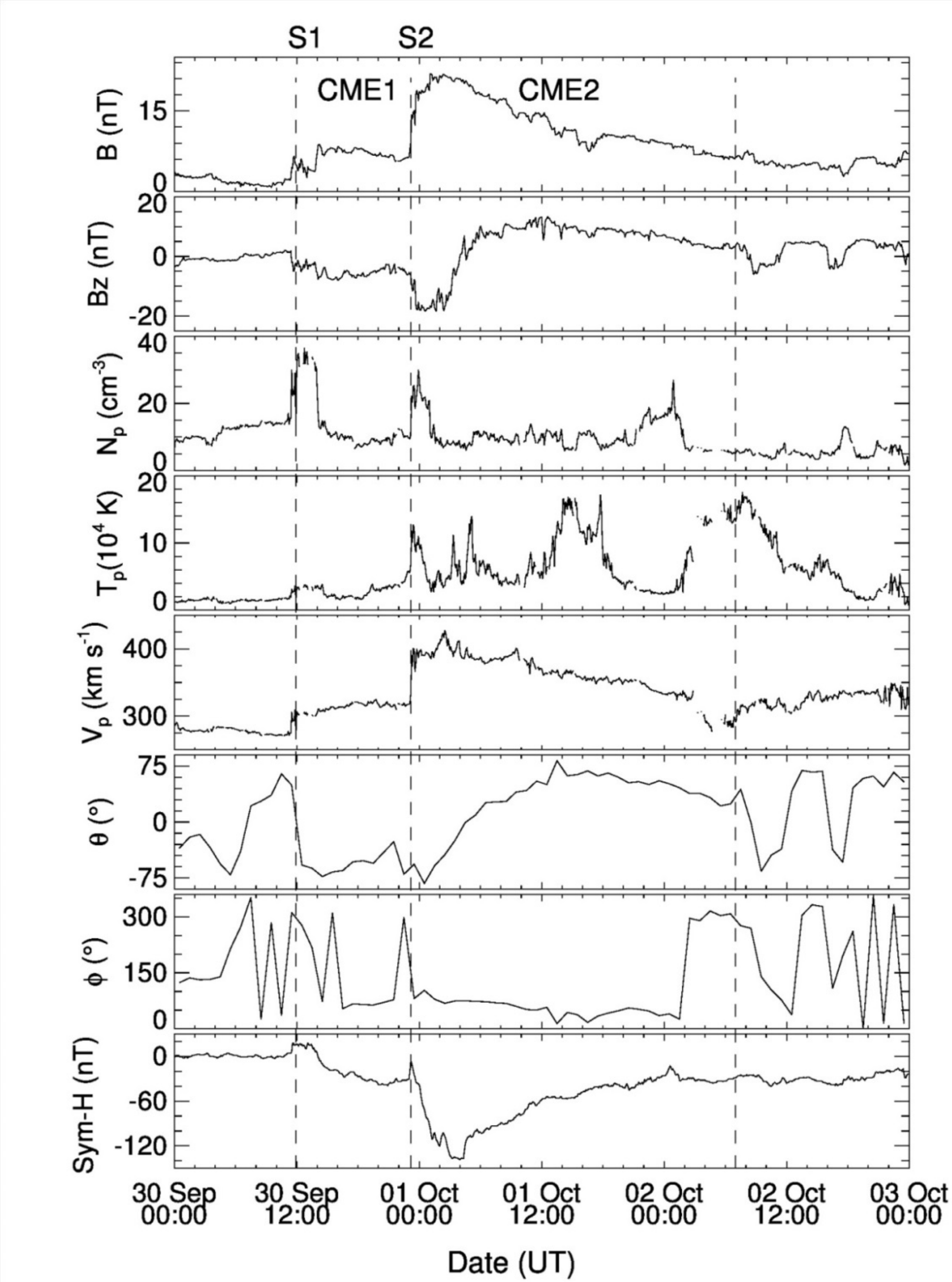


CMEs launched on September 25 (CME1) and 28 (CME2) with 3d speeds approx. 500 and 1200 km/s respectively and directed approx. 19^0 & 25^0 East of the Sun-Earth line, interact close to the Earth on September 30.



The estimated true masses of these CMEs are 1.75×10^{15} gm and 9.67×10^{15} gm, indicating that the following CME is approx 5.5 times more massive than the preceding one.

The coeffiicient of restitution e is estimated as 0.86



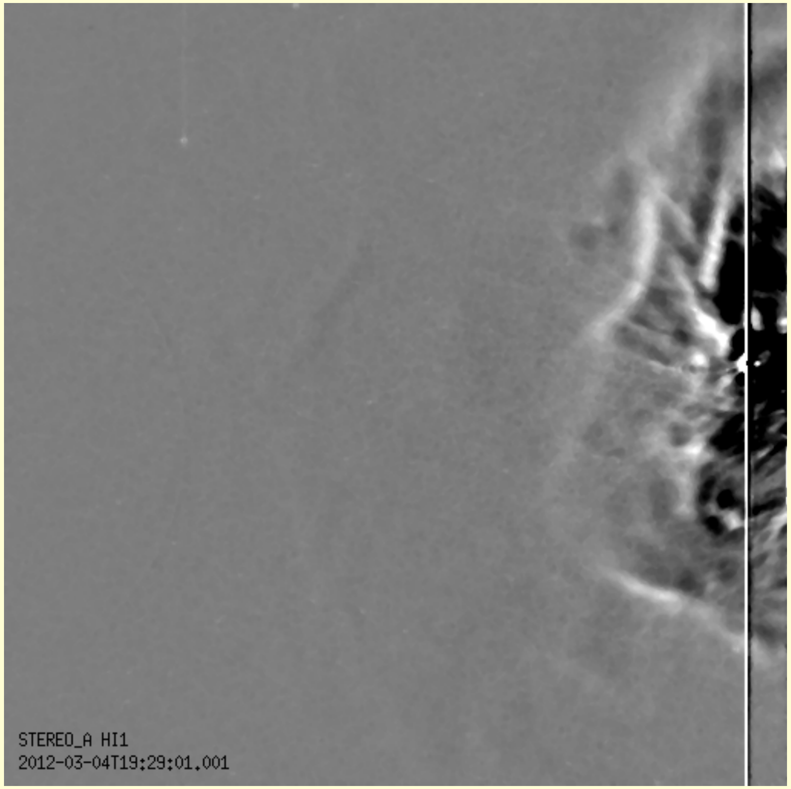
The arrival of the CMEs is marked by two shocks S1& S2.

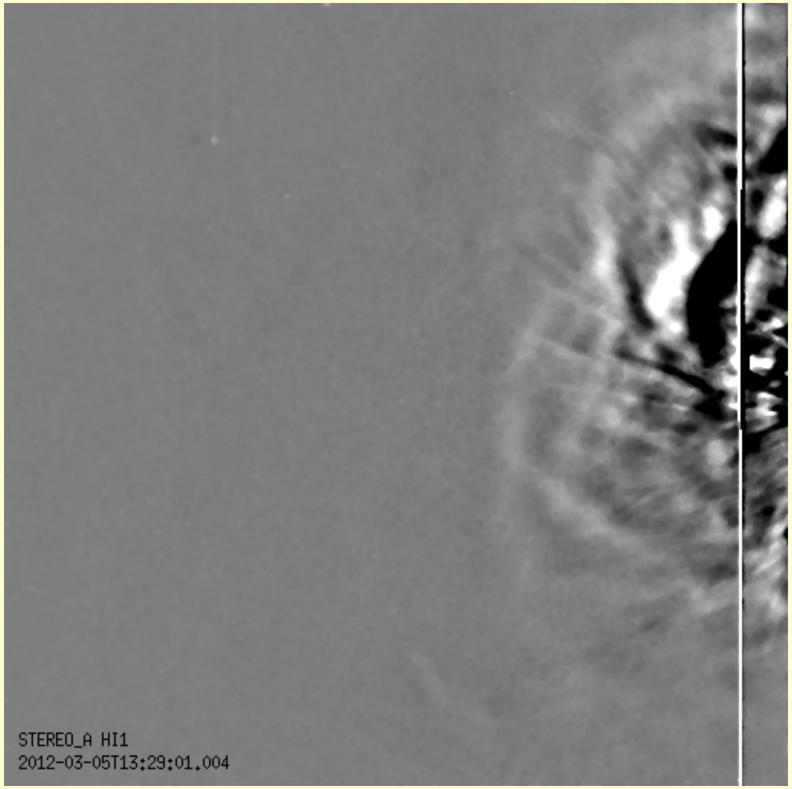
The trailing part of CME1 merges with the leading part of CME2, with a rise in temperature.

Merging of the two CMEs continues beyond the Earth resulting in a two step geomagnetic storm with Dst ~ -119 nT.

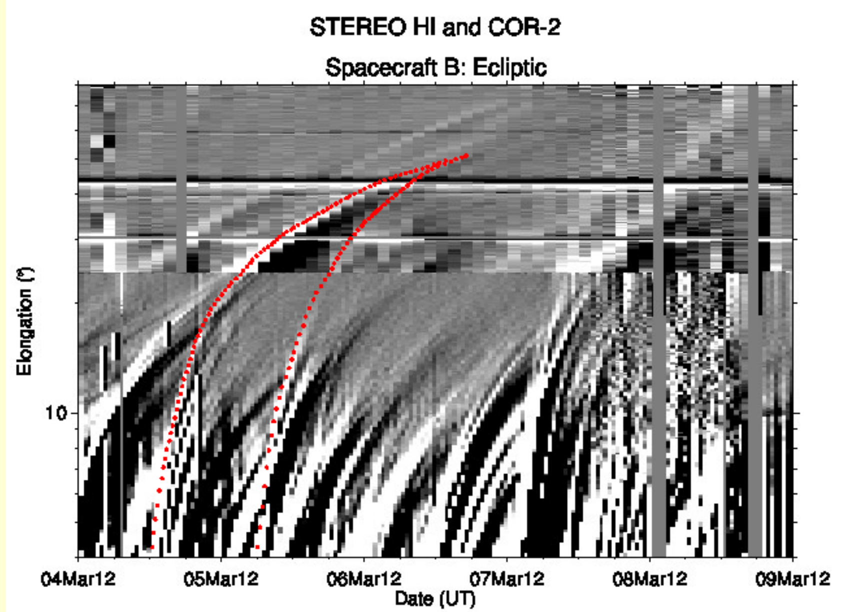
March 4 & 5, 2012 CMEs:

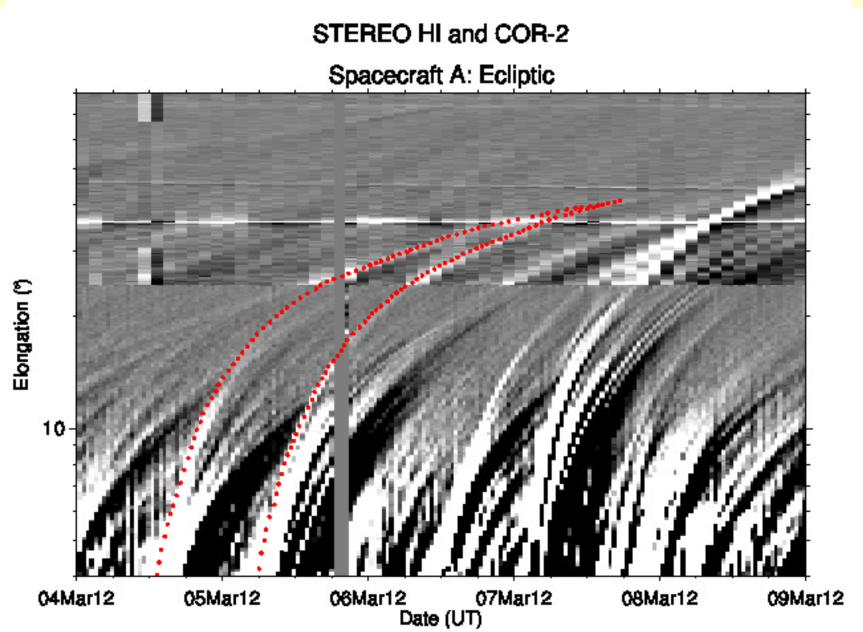
Example of an Inelastic Collision

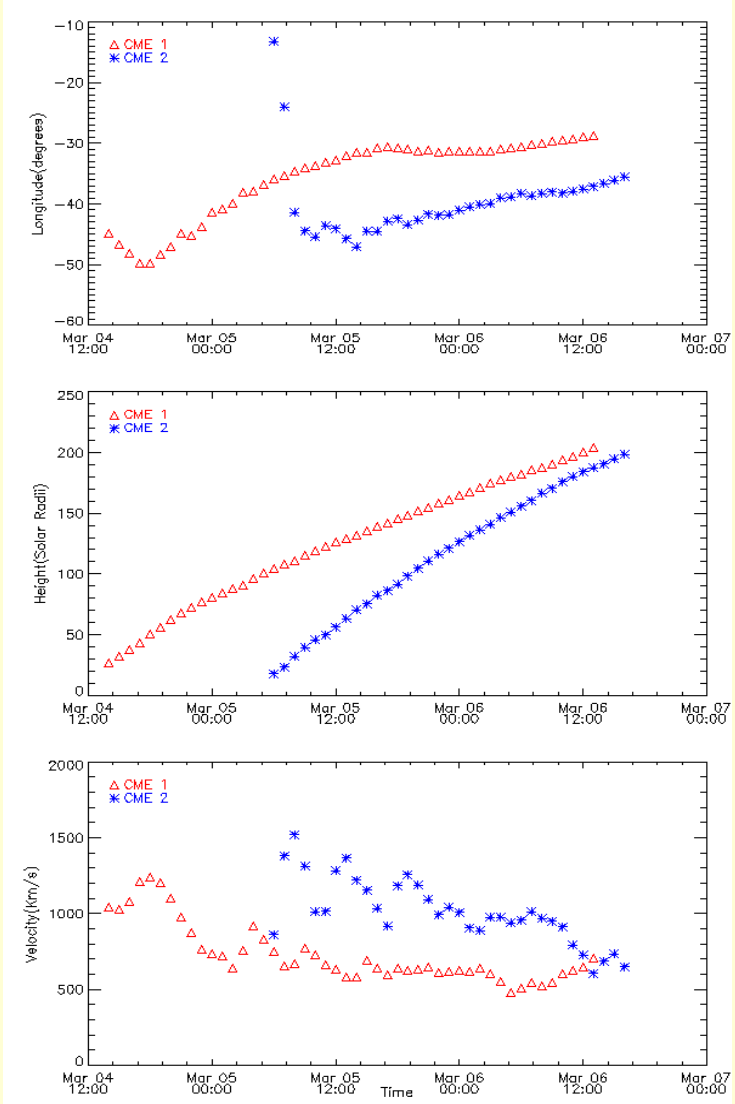




CMEs launched on March 4 (CME1) and 5 (CME2), 2012 with 3d speeds 1500 and 1615 km/s, directed approximately 28^0 & 32^0 east of the Sun-Earth line, interact at approx. 185 solar radii on March 6.

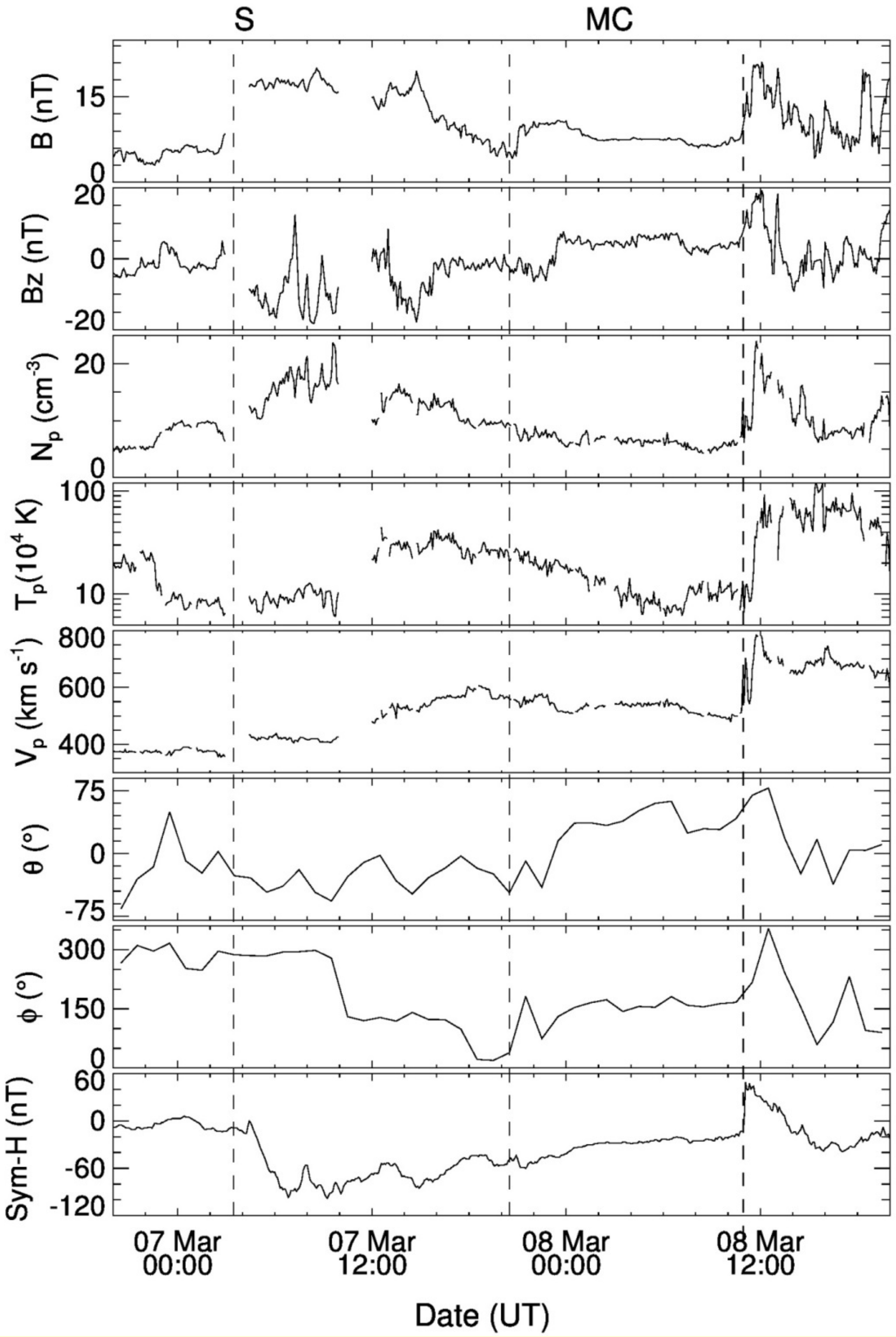






The time-elongation plots (J-maps) show that the two CMEs start to interact in the HI2 fov at a distance of approx. 185 solar radii on March 6.

The true masses of these CMEs have been estimated & are 4.5×10^{15} gm and 13.4×10^{15} gm, respectively. e is estimated to be 0.2, i.e. the collision lies in inelastic regime.



In-situ Data

The two CMEs merge after interaction and arrive at the Earth with a single shock and extended sheath region with increased temperature.

This is followed by the passage of a magnetic cloud

The merged structure (sheath region) leads to a geomagnetic storm with Dst ~ -95 nT.

Observed cases of Interacting CMEs (STEREO/SECCHI observations)

Interacting CMEs	CME1 Source Location, NOAA No.	CME2, Source Location, NOAA No.	propagation direction of CME1 &2 (longitude)	Interaction location (Rsun)	Collision Type	Mass ratio (M2/M1)	Momentum exchange	Dst (nT)
August 3 &4, 2011	11261, N16W30	11261, N19W36	14.8^0, 19.2^0	157	perfectly inelastic	1.38		-113
January 18 & 19, 2012	11401 N19E38	11402, N32E22	-2^0,-77^0	85	perfectly inelastic	3.2	74%, -11%	-69
March 4 &5, 2012	11429, N19E61	11429,N17E52	-28^0, -32^0	~185	inelastic (0.2)	3.2	36%, -40%	-95
September 25 &28, 2012	11575, N08W04	11575, N09W30	-19.5^0, -6^0	Merging at the Earth (215 & beyond)	elastic (0.86)	5.54	195%, -38%	-119
February 14 &15, 2011	11158,S20W04	11158,S20W10	6^0,-3^0	25	elastic (0.89)	1.08	68%, -35%	-30
November 9 &10, 2012	Near 11608, S20E09	11608,S21W04	-10^0, -2^0	35	perfectly inelastic	0.48	23%, -31%	-108
May 23 & 24, 2010	N19W12	N18W26	11^0, 28^0	45	Inelastic (0.2)	0.5	27%, -35%	-85
June 13 & 14, 2012	11504, S16E18	11504, S17E06	-7^0, -3^0	90	perfectly inelastic	1.1	57%, -24%	-71
October 25, 2013	11882, S08E73	11882, S06E69	-77^0, -71^0	40	perfectly inelastic	1.23	42%, -19%	-55

Summary

- Interaction of CMEs observed close to the sun as well as near the Earth. The closest distance is 25 solar radii (one event). Rest occur at a distance beyond 35 solar radii. (outside the field-of-view of LASCO-C3). Therefore, only few interactions have been reported in SOHO era.

- Our study shows, that interaction is more probable when the CMEs are launched from the same source region, in the same direction within a few hours (less than a day). Since the re- build-up and release of energy takes a finite time, it is more likely that in general, CMEs will interact in the heliosphere in the HI field of view at a distance close to the Earth.

- Nature of collision of interacting CMEs reported here, is mostly inelastic; sometimes also found to be elastic.

- Mass ratio of the participating CMEs varies from 0.5-5.5 Significant momentum exchange takes place during interaction, with increase in the preceding and decrease in the following CME.

Summary

- Merging of CMEs probable when CME-CME interaction occurs closer to the Sun than the earth. This is possible when the events are fast and/or occur close in time. The merged structure generally leads to a single step storm, sheath region responsible for the intensification of the storm.

- Two step storm signatures observed when the interaction occurs close to the Earth or events occur far in time and/or are slower in speed.

- Heating of plasma (upto $10^5\ {}^0K$) is a probable indicator of interaction.

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- Using the post-interaction speeds of CMEs participating in interaction, it is found that the arrival time estimates are improved.

Questions need to be addressed

- How much change is expected if a 2D or 3D picture of collision considered instead of 1D, with a possible change in propagation direction of centroid of the interacting CMEs?
- What is the effect of including CME expansion speed in our calculation?
- Are there other observational signatures available for precisely marking the start and end of the collision phase?
- How important is the role of orientation of CME flux ropes in deciding the nature of collision? What is the relative role of orientation of flux ropes, mass and speed of interacting CMEs in deciding their merging or preserving their distinctness.
- Does the participation of total mass of a CME in collision sound well?
- What is the role of characteristic of CMEs, their location and the duration of collision phase in deciding the nature of collision