Evolution and Consequences of Interacting CMEs using STEREO/SECCHI and In Situ Observations

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Outline

- Introduction (Availability of CME Observations in SOHO and STEREO era)
- Interaction of CMEs
- Two Case Studies

(1) Interacting CMEs of 2011 February 13-15

(2) Interacting CMEs of 2012 November 9-10

- Results & Conclusion

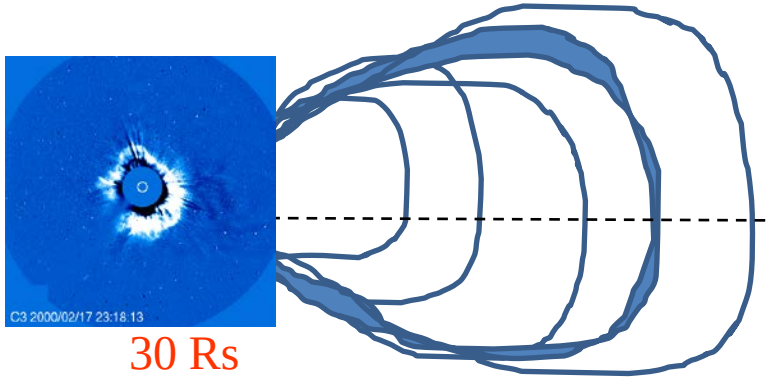
Introduction

- Coronal Mass Ejections (CMEs) are drivers of many space weather events.

Before 2007, SOHO/LASCO at L1

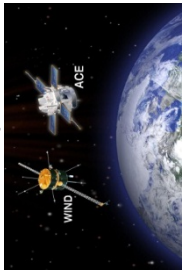
In situ data: single point, 1D

Projected morphology & kinematics



Use of models to fill the gap

e.g. Drag Based Model, MHD

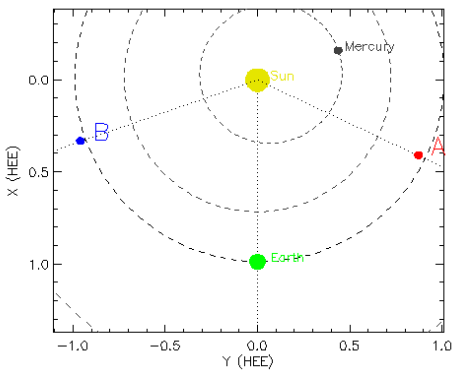


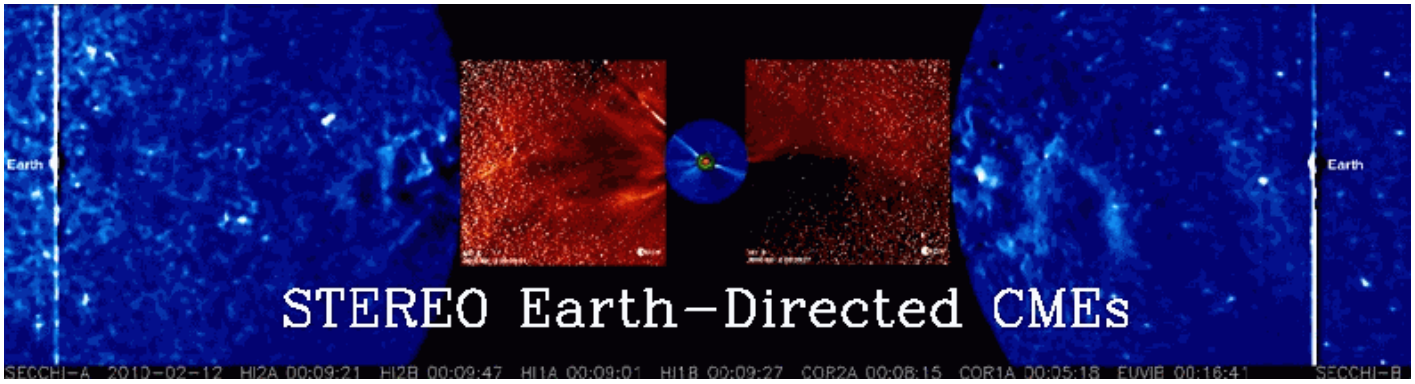
30 Rs

~ 215 Rs

Error in arrival time is because of : (1) Evolution of CMEs is poorly understood.
(2) CME-CME Interaction/collision

Since 2007, Stereoscopic Observations (from STEREO A & B):





CME-CME Interaction

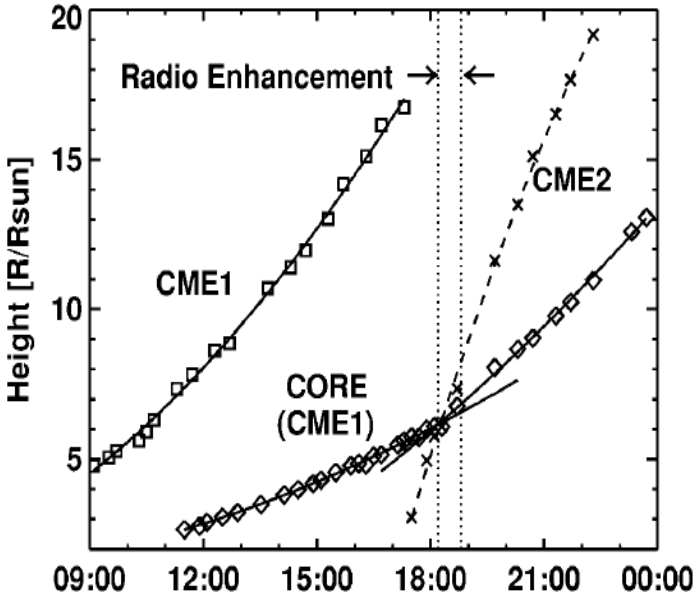
Travel time of CMEs: 1 to 4 days, Launch rate: ~ 4 around solar maximum ➔ Collision or merging (depends on kinematics) & Launch rate: ~ 1 around minimum ➔ Unlikely

Earlier Works Before STEREO

- Intriligator (1976) [Pioneer 9] & Burlaga et al. (1987) [Twin Helios spacecraft] Complex ejecta at by Burlaga et al. (2001)

- Gopalswamy et al. (2001) [SOHO/LASCO and radio data] ➔ Evidence

- Interacted CMEs ➔ Geomagnetic storms (Farrugia et al. 2006; Farrugia & Berdichevsky, 2004) Penetration of shock & its effect on CME parameters.



In STEREO era

Interacting CME cases of 2008 November 2 (Shen et al. 2012), and 2010 May 23-24 (Lugaz et al. 2012), 2011 February 13-15 (Maricic et al. 2013, Temmer et al. 2012),

Extensively studied: : 2010 Aug 1 (Harrison et al. 2012, Liu et al. 2012, Mostl et al. 2012, Temmer et al. 2012)

Unanswered Questions/Objectives

- How do the dynamics of CMEs change after interaction? What is the regime of collision ?

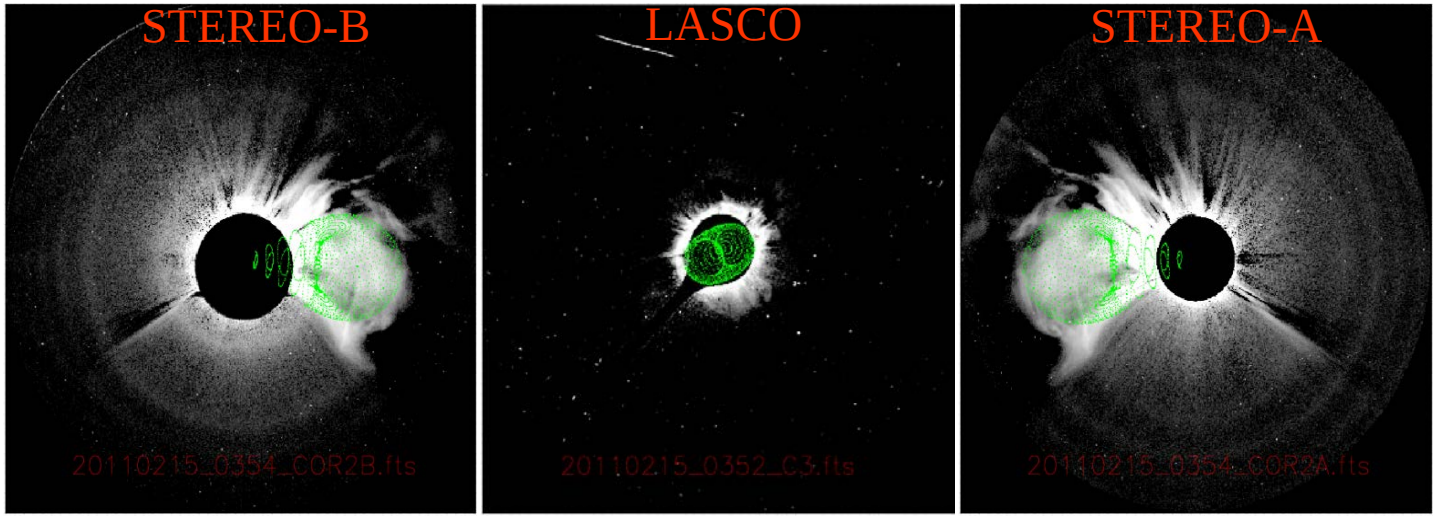
- What are the consequences of the interaction of CME-shock structure? How does the overtaking shock change the plasma and the magnetic field properties into the preceding magnetic cloud?

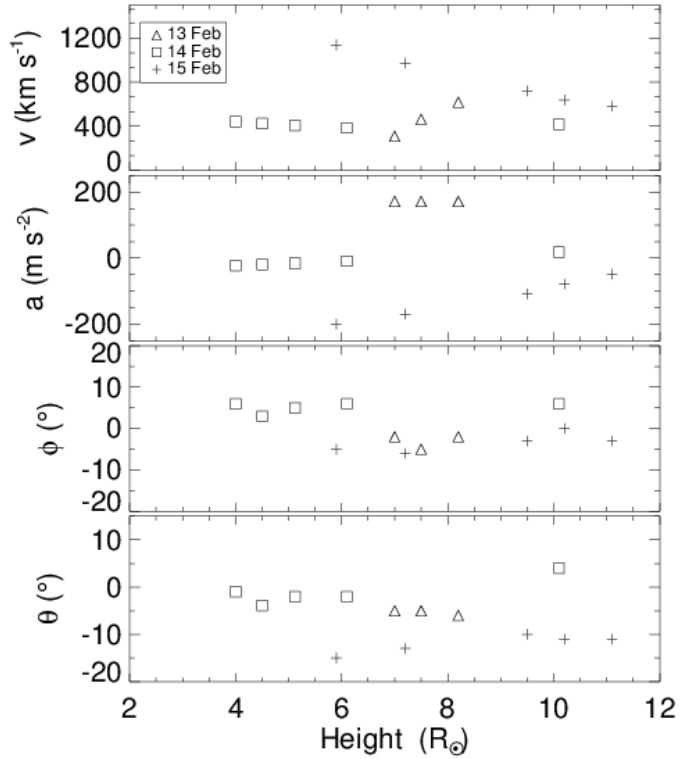
- Do these interacted structures produce different geomagnetic consequences than individual CMEs, on their arrival to magnetosphere?

- What are the favourable conditions for the CME merging and the role of magnetic reconnection in it?

Interacting CMEs of 2011 February 13-15 (3 CMEs)

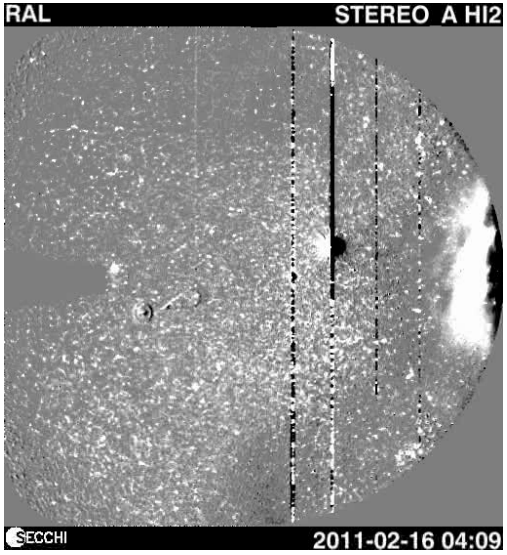
3D reconstruction in COR2 FOV: GCS model (Thernisien et al. 2009)

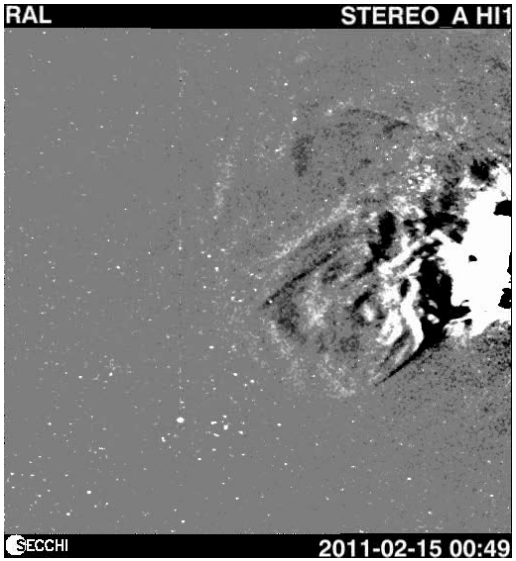




CME1 (Feb13): 618 km/s
CME2 (Feb14): 418 km/s
CME3 (Feb15): 580 km/s

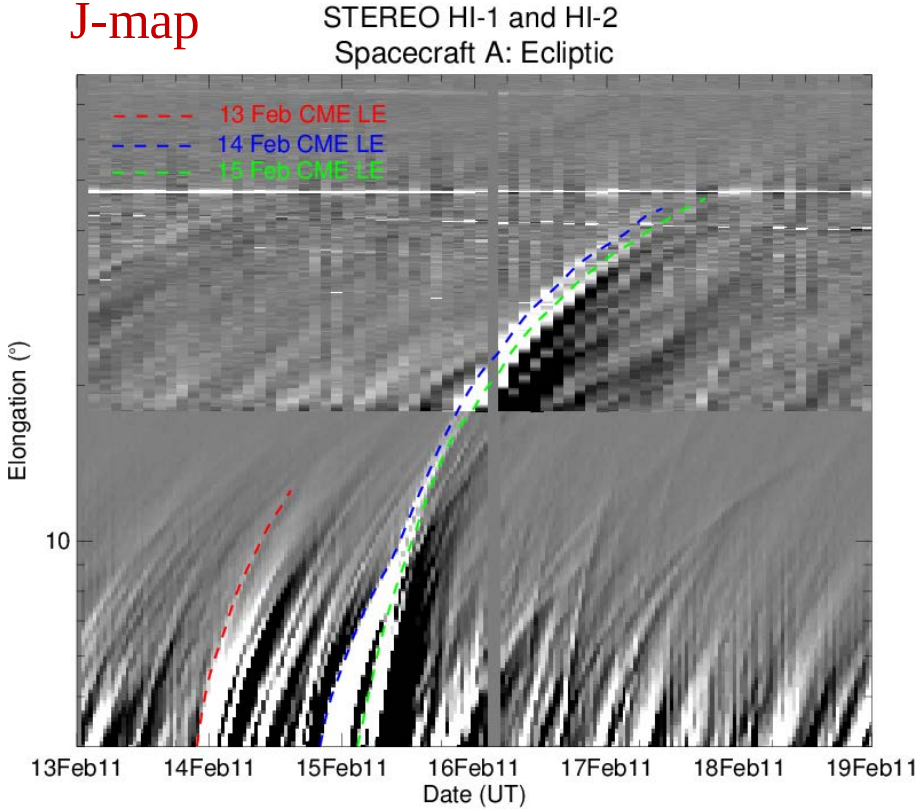
CME2 is launched 9 hr before to CME3.

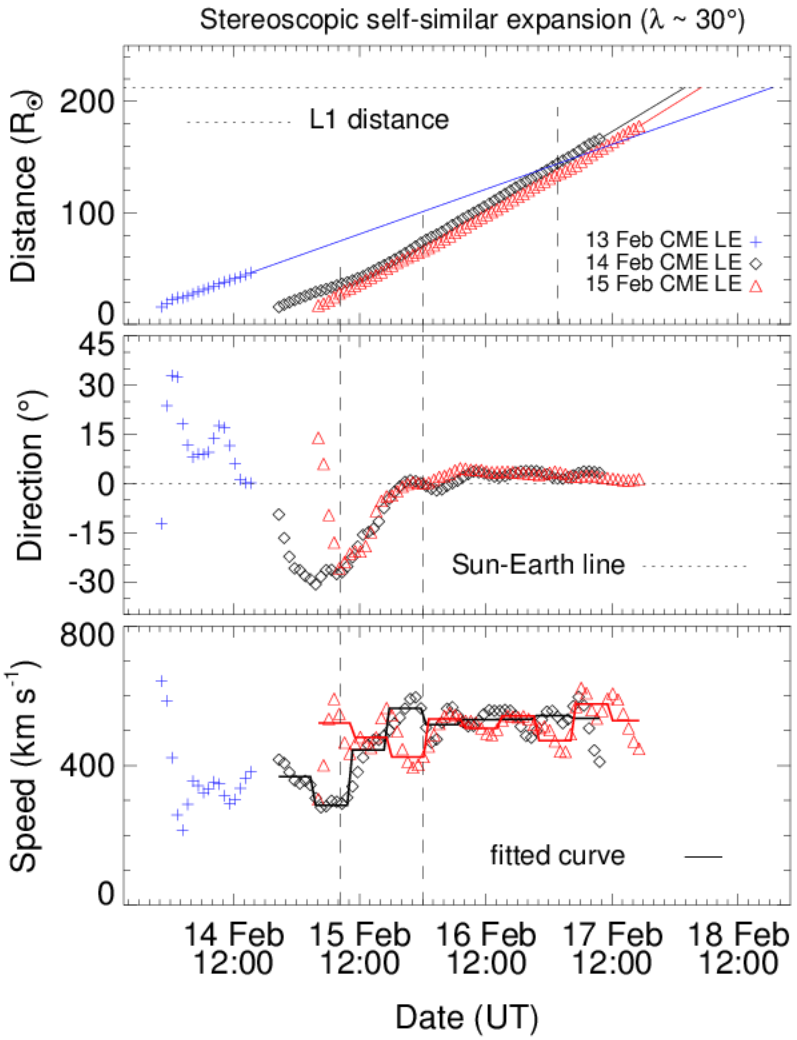




Reconstruction in HI FOV:

J-map





True mass: Colaninno & Vourlidas (2009)

$$M_A / M_B = B_e(\theta_A) / B_e(\theta_A + \Delta)$$

For CME2 at 10 Rs:
True mass M_1 = 5.40 x 10^{12} kg

For CME3 at 12 Rs:
True mass M_2 = 4.78 x 10^{12} kg

Collision phase: 18 hr, speed = 500 km/s
CME2: 300 km/s to 600 km/s.
CME3: 525 km/s to 400 km/s.

Estimation of Coefficient of Restitution (e)

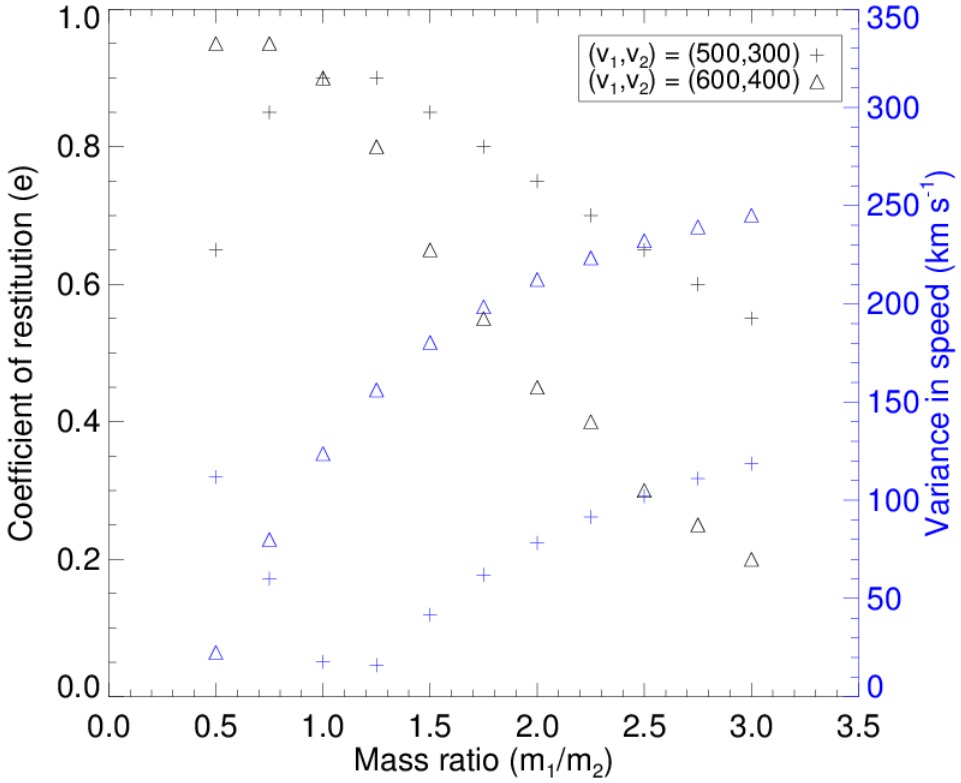
$$e = \frac{v_2 - v_1}{u_1 - u_2}$$

$$v_{1th} = \frac{m_1u_1 + m_2u_2 + m_2e(u_2 - u_1)}{(m_1 + m_2)}$$

$$v_{2th} = \frac{m_1u_1 + m_2u_2 + m_1e(u_1 - u_2)}{(m_1 + m_2)}$$

We define variance

$$\sigma = \sqrt{(v_{1th} - v_1)^2 + (v_{2th} - v_2)^2}$$



For e = 0.90 and variance = 2 km/s when (v_1,v_2) = (500,300) km/s

Total KE decreased by 1.3 %

Momentum of CME2 increased by 68%
Momentum of CME3 decreased by 35%

Uncertainties in mass: Error of 15% considered, then estimated mass ratio (m_1/m_2 = 1.12) can range between 0.97 to 1.28.

Mishra, W., and Srivastava, N., ApJ, 2014, 794, 64

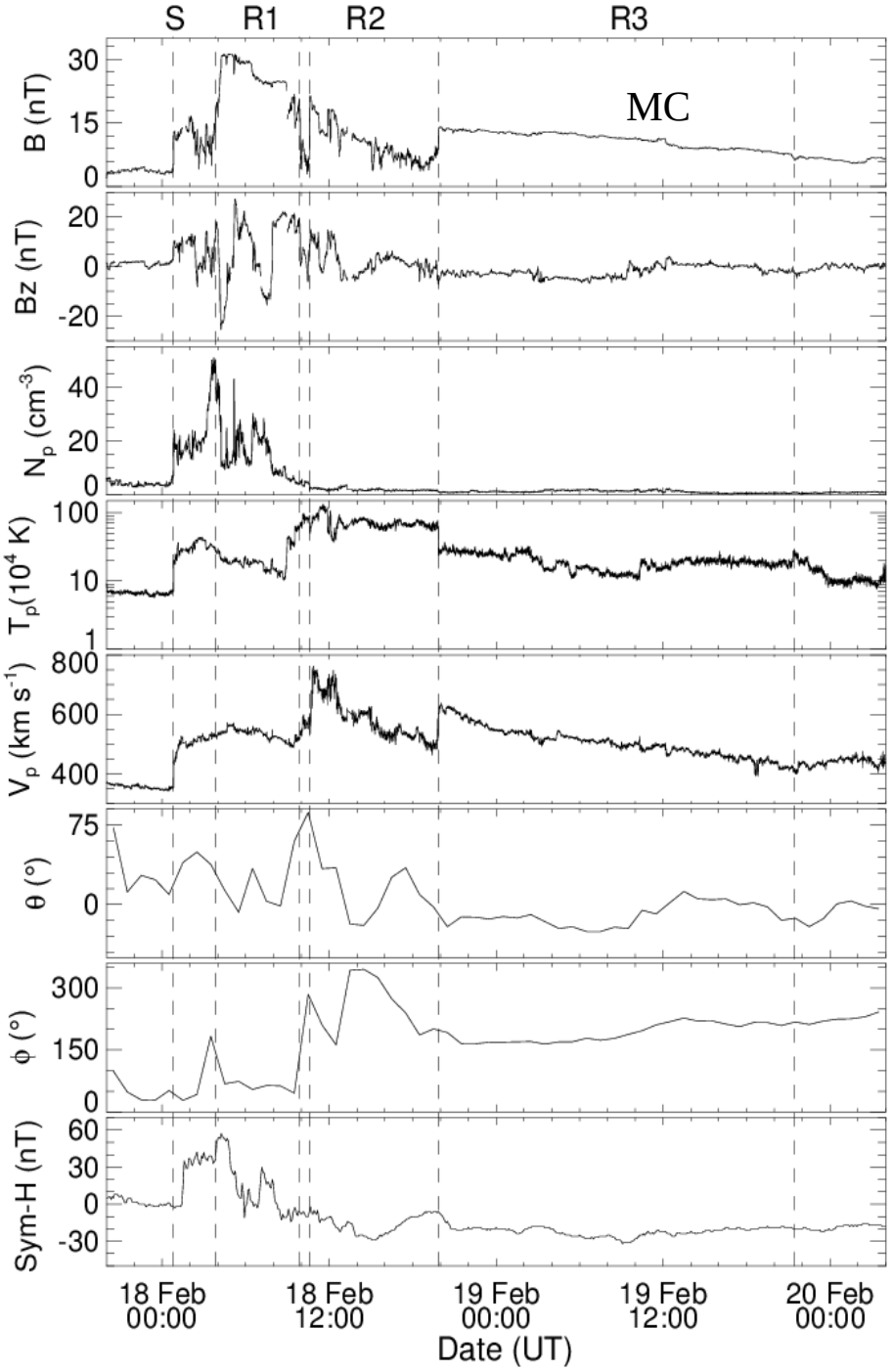
In situ Observations and arrival time of Interacting CMEs of February 13-15

Predicted arrival times improved using speeds obtained in HI (especially, post-collision speed).

MH = 09:52 – 10:37 UT, R2 is overheated. Fast expansion of R2 (reconnection at its front possibly).

SSC =57 nT but only minor geomagnetic storm (Dst~ -30nT) .

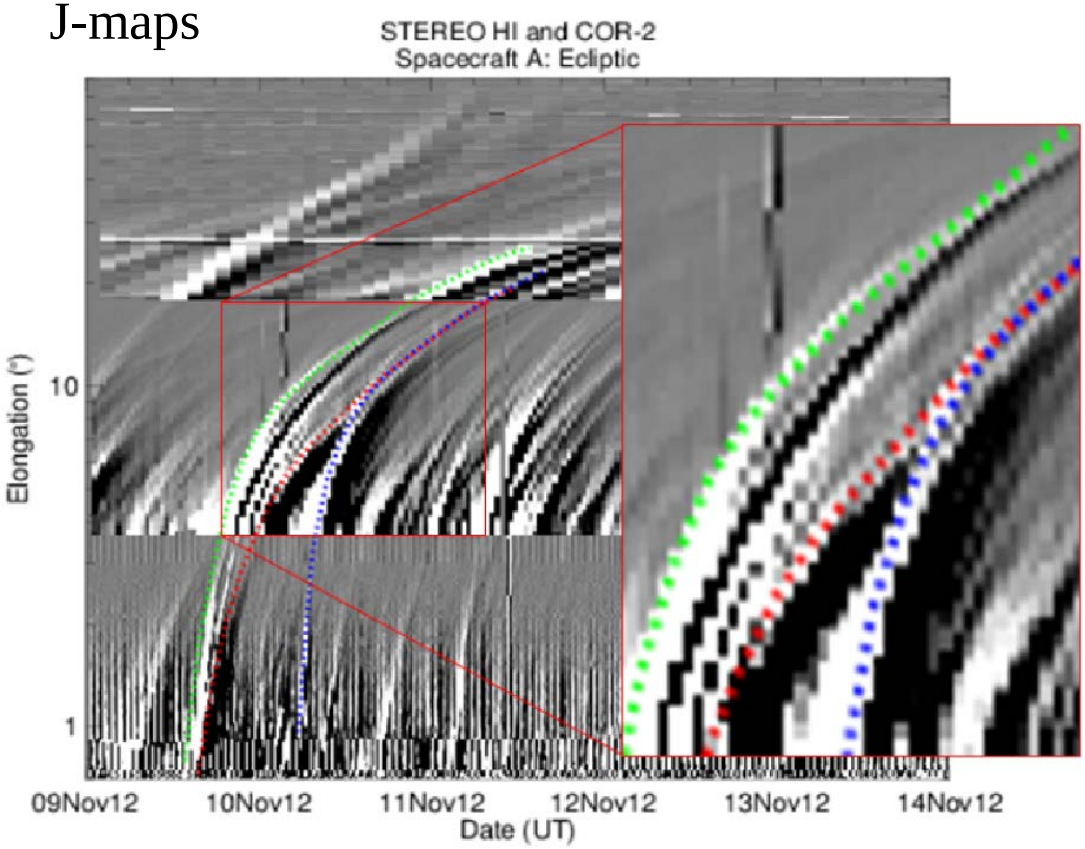
Possibility of flank encounter or incorrect association cannot be ignored.

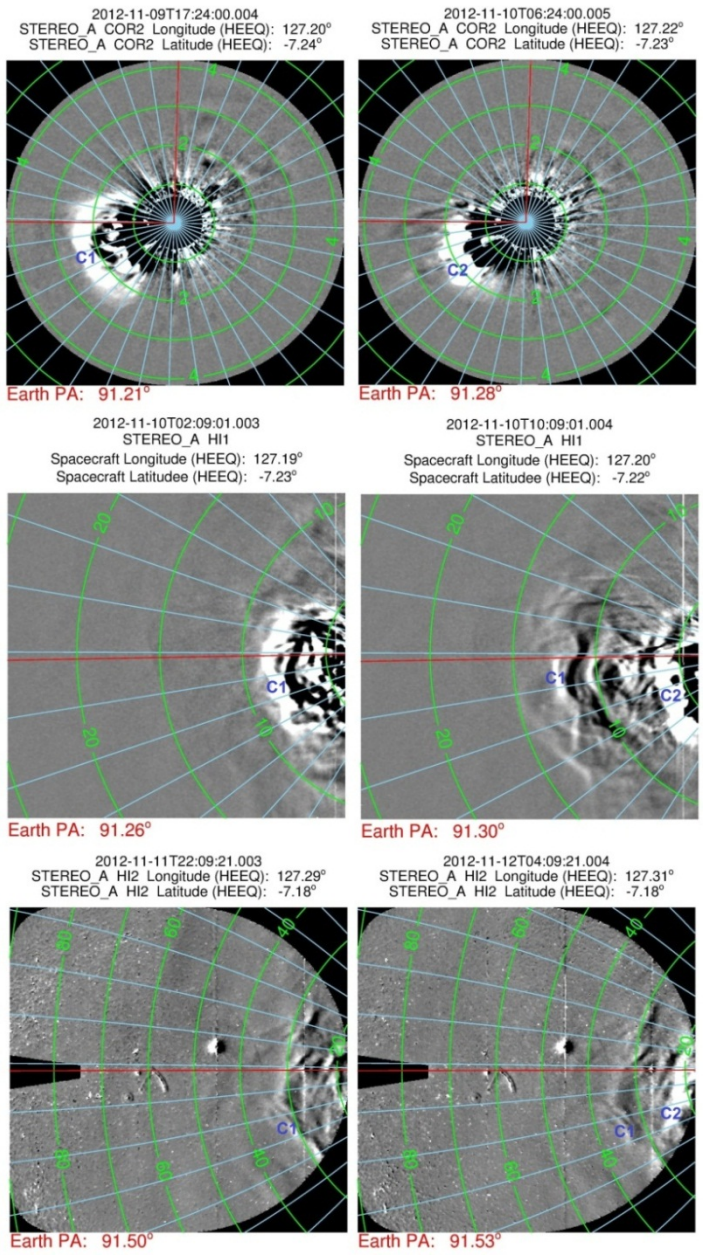


Interacting CMEs of 2012 November 9-10

3D speed: CME1 (Nov9): 620 km/s,
CME2 (Nov10): 910 km/s at approx. 15 Rs.
Both are Earth-directed.

J-maps



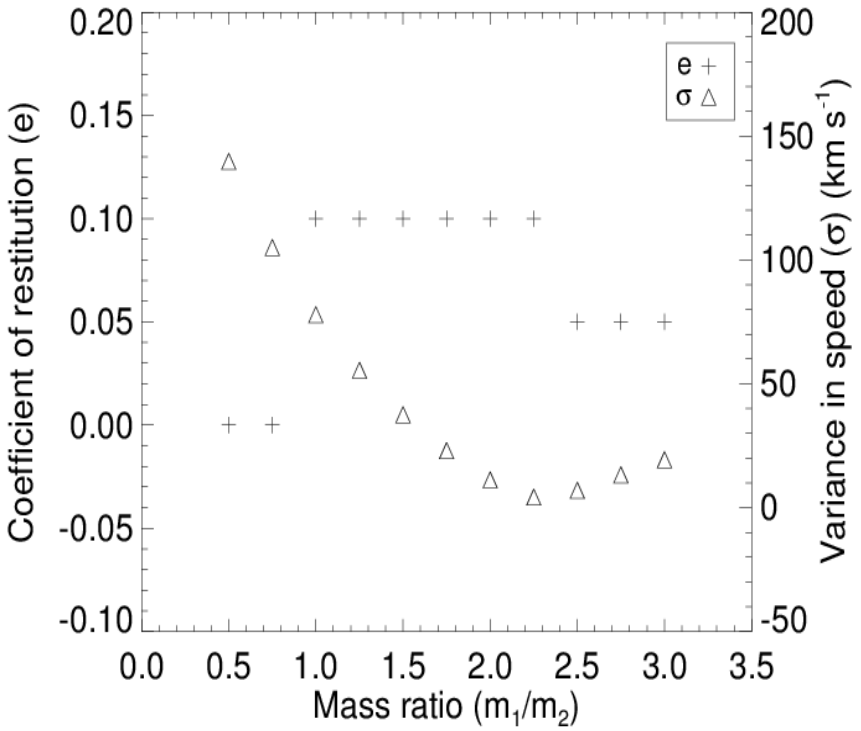


Green: CME1 Leading edge (LE),
Red: CME1 Trailing edge (TE), Blue: CME2 LE

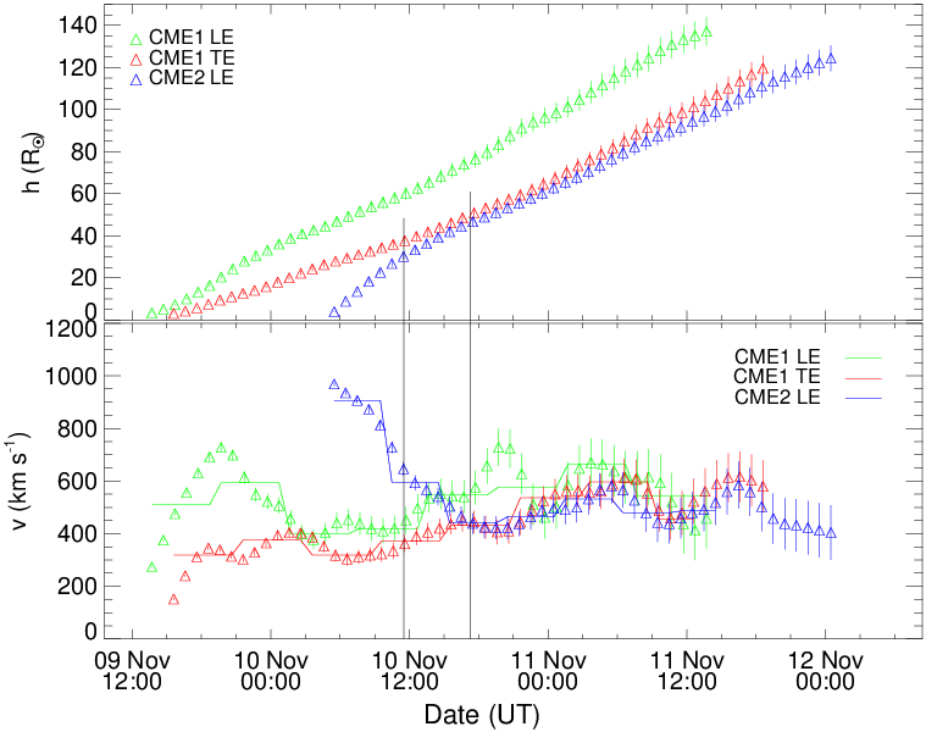
Nature of Collision of Interacting CMEs

Collision close to perfectly inelastic (e ~ 0.1).

Nov 10 at 11:30 UT (37-30 Rs) –
Nov 10 at 17:15 UT (50-46 Rs)



3D Reconstruction in HI FOV

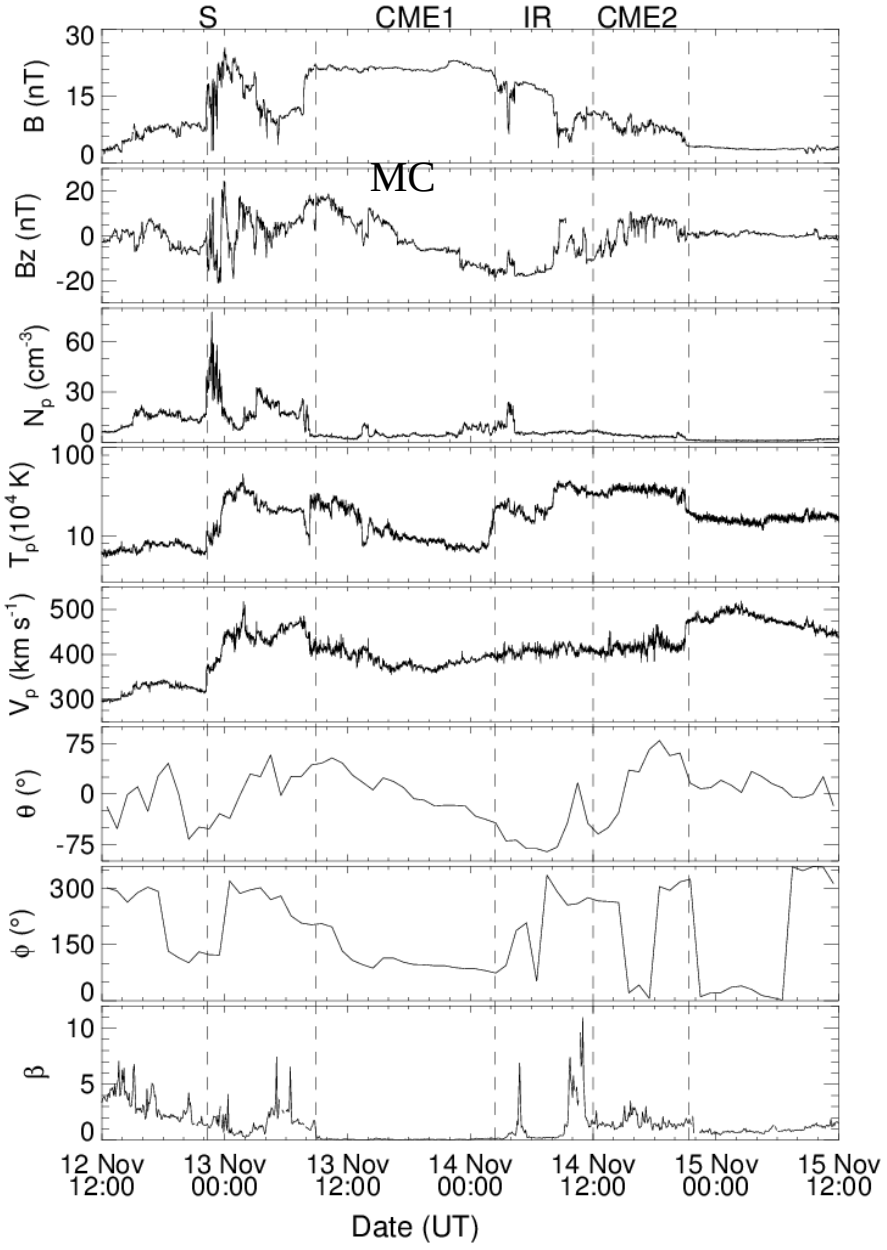


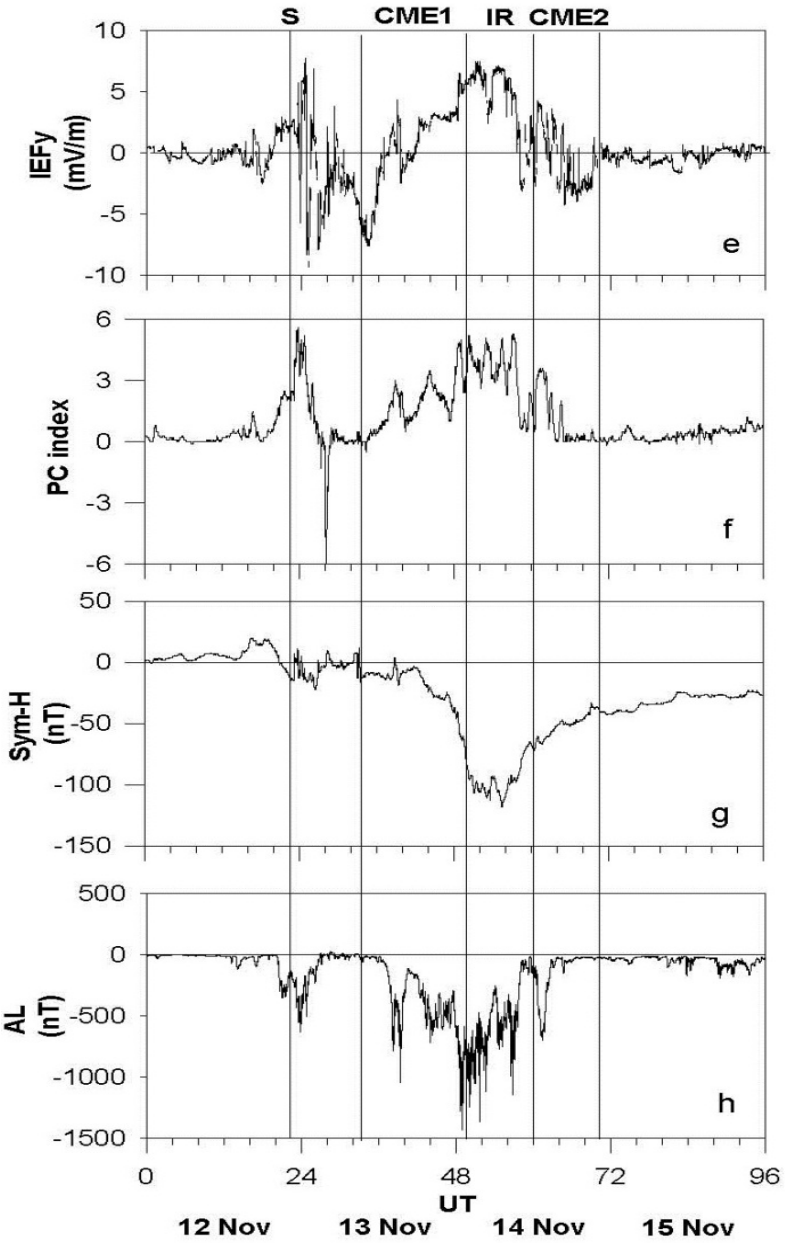
Observed (u_1, u_2) = (365,625) km/s
& (v_1,v_2) = (450,430) km/s

True Mass Calculation:

$M_1 = 4.66 \times 10^{12}$ kg
$M_2 = 2.27 \times 10^{12}$ kg

In Situ Observations and Arrival Time of Interacting CMEs of November 9-10





Mishra, W., Srivastava, N., and Chakrabarty, D., 2014, Solar Physics, (in press)

Results

Characteristics	2011 February 13-15 CMEs	2012 November 9-10 CMEs
Interaction distance	CME2-CME3 at 25 Rs (expected at 37 Rs from speeds in COR2).	CME1-CME2 at 35 Rs (expected at 130 Rs from speeds in COR2).
Momentum exchange	35% to 68%	23% to 30%
Total kinetic energy	Reduced by 1.3%	Reduced by 6.7%
Nature of collision	Close to elastic	Close to perfectly inelastic
Geomagnetic	Minor storm (Dst=-30nT), Strong SSC	Major Storm (Dst=-108nT)

Conclusions

- CMEs (launched in quick succession) cannot be treated as completely isolated magnetized plasma blobs, for understanding their evolution & propagation in the heliosphere.
- Evidence of CME-CME collision is revealed. In situ observations also provide evidence of collision in the formation of magnetic holes and the heating and compression of CMEs.
- Nature of CME interaction may be elastic/inelastic.
- Use of 3D speed in COR2 FOV is not sufficient for arrival time estimation, at least for fast, decelerating, and interacting CMEs. Improved prediction of arrival time of CMEs using their post-collision kinematics.
- Collision occurs much closer to the Sun than expected based on COR2 observations. Tracking of different features of CMEs in HI FOV (longer elongation) and their association with in situ observations is necessary for understanding their evolution in the heliosphere.
- Heliospheric and geomagnetic consequences of colliding/interacting CMEs are significant and depend on the interaction region (IR).

Thank you