Estimating arrival time of Earth-directed CMEs at *in-situ* spacecraft using COR and HI observations from STEREO

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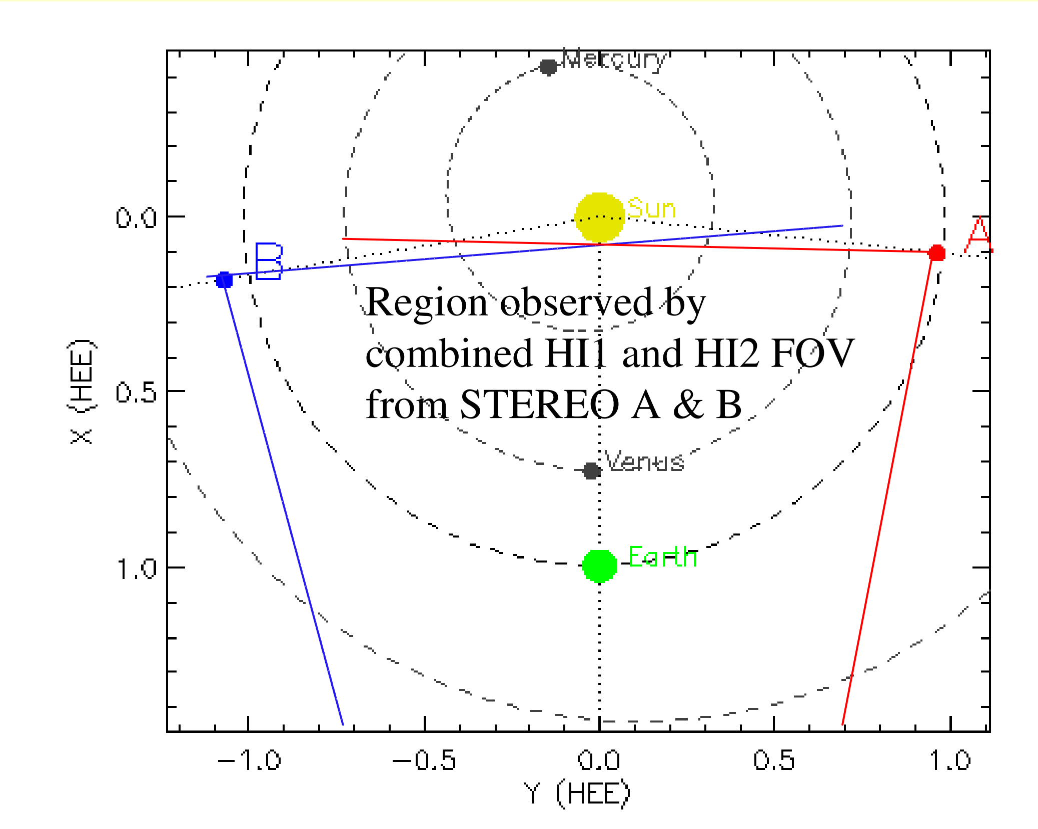
Goals and Steps

- Selected Earth-directed CMEs during 2008-2010
- 3D reconstruction technique on SECCHI/COR observations
- Geometric triangulation on SECCHI/COR and HI observations
- Estimation of arrival time of CMEs near 1 AU using DBM
- Comparison with in-situ observations of CMEs
- Results

Remote Sensing Observations of CMEs

COR1 and COR2 are pointed on the Sun. HI1 (4-24^0) and HI2 (18.7-88.7^0) are off pointed from the sun at solar elongation of 14^0 and 53.7^0 respectively. They have their optical axis aligned in the ecliptic plane.

(Howard et al., 2008)



In the plane of sky relative to viewing location:

COR1: 1.5-4.0 R_s

COR2 : 2.5-15 R_s

HI1: 15-90 R_s

HI2: 70-330 R_s

26 October 2010

- Selected events:

1. 12 December 2008 CME
2. 07 February 2010 CME
3. 12 February 2010 CME
4. 14 March 2010 CME
5. 03 April 2010 CME
6. 08 April 2010 CME
7. 10 October 2010 CME
8. 26 October 2010 CME

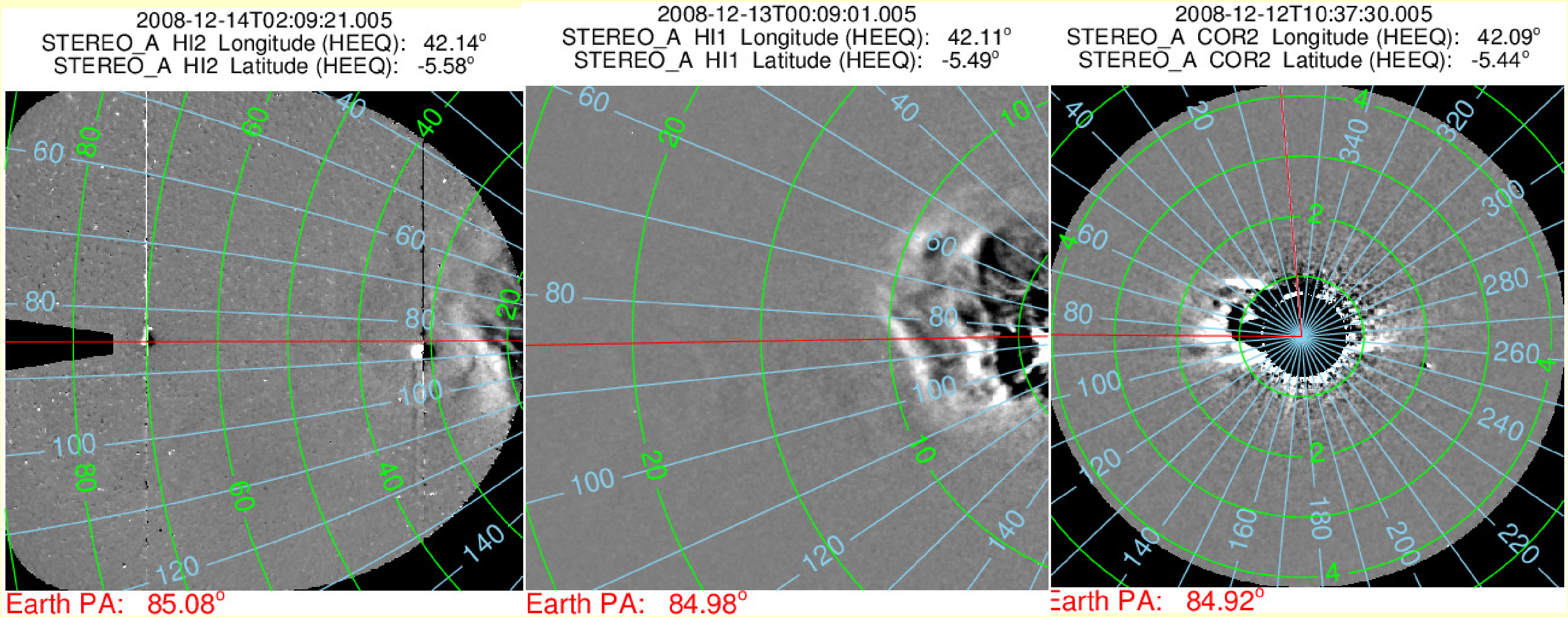
Selected events cover a range of speed and different separation angle between twin STEREO spacecraft during 2008 – 2010.

These Earth-directed CMEs could be observed in remote sensing (SECCHI) as well as in-situ (ACE/WIND).

Provide an opportunity to compare our predicted arrival time with the actual.

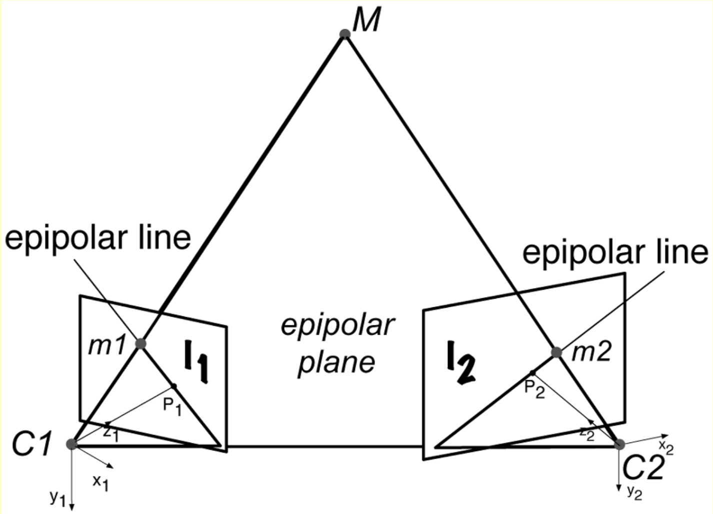
•Need to convert the CME elongation angle (sun-observer-moving feature angle) to true distance from the Sun.

The evolution of 12 December 2010 CME as observed by SECCHI A COR2, HI1 and HI2 is shown below.

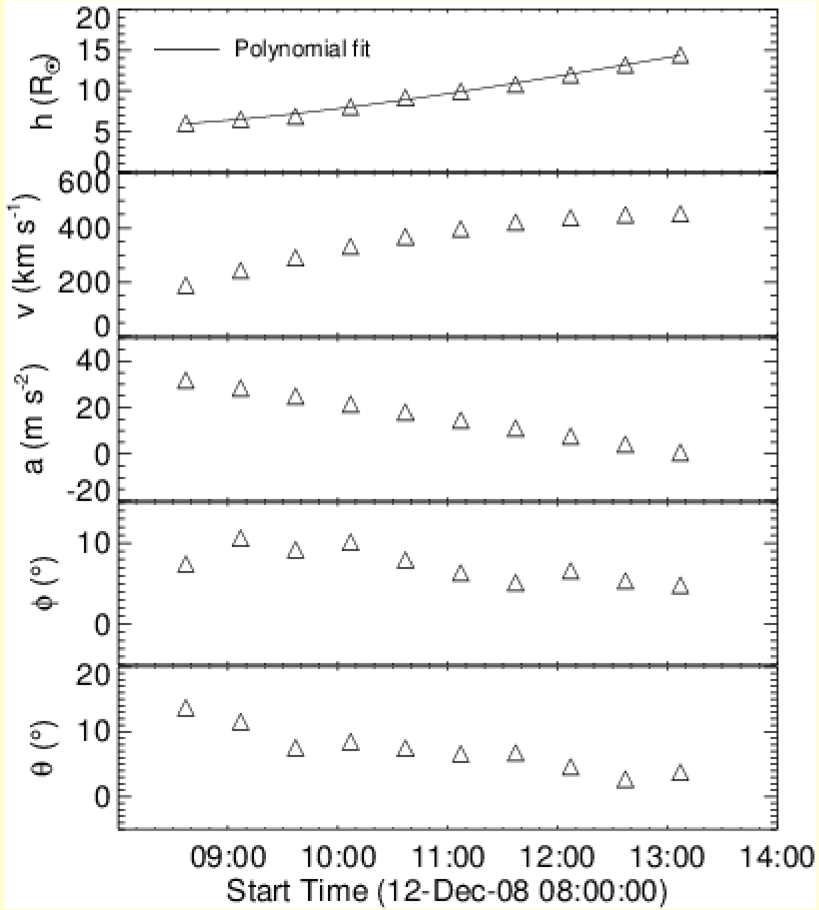


The horizontal red line marks the position angle of Earth. Contour of elongation angle (green) and position angle (blue) are overdrawn on images. Vertical line in COR2 image marks the zero degree position angle.

- Implementing tie-pointing technique on 12 December 2008 CME:

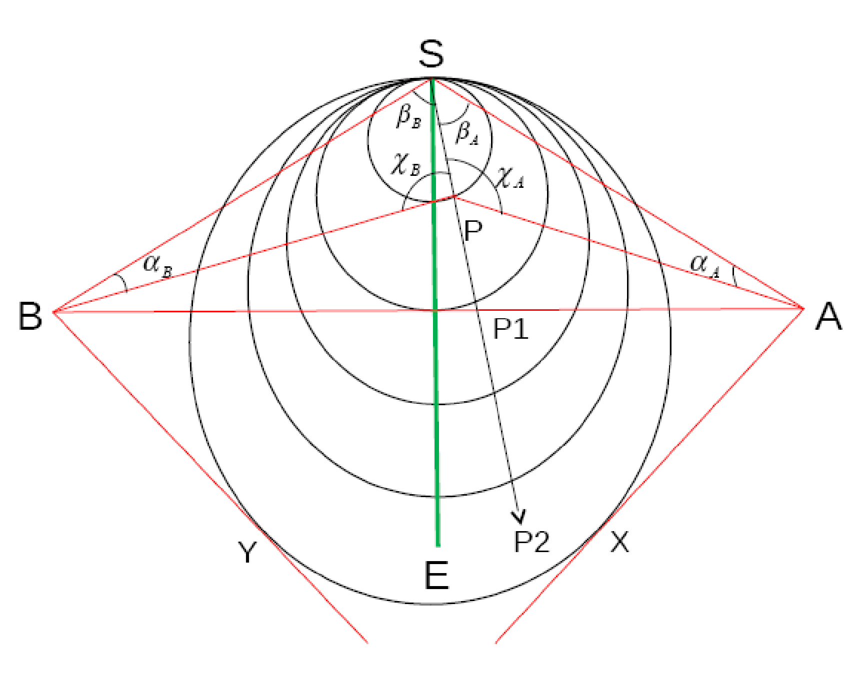


If we assume that the estimated true speed (453 km s^{-1} at 14 R_s) of CME is constant beyond COR2 FOV, then the estimated arrival time of CME at 1 AU (L1) is at 01:45 on 16 December 2008.



From top to bottom, the panels show the true height, radial velocity, acceleration, longitude and latitude of CME leading edge and time on X-axis. Stonyhurst latitude and longitude show that CME is Earth-directed.

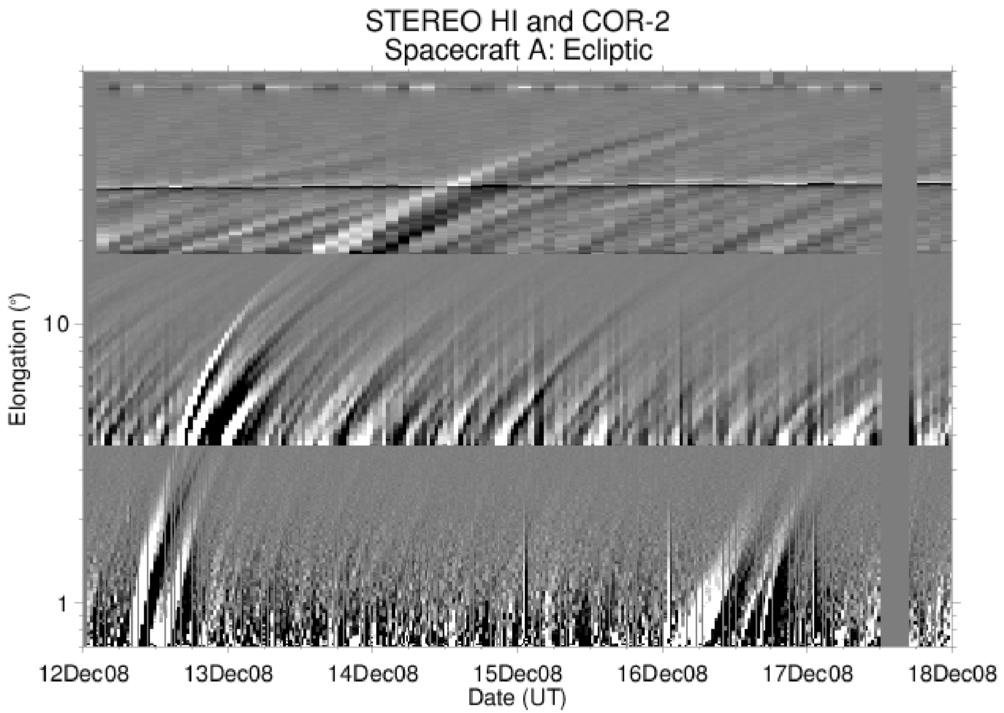
Geometric Triangulation on SECCHI/HI observations

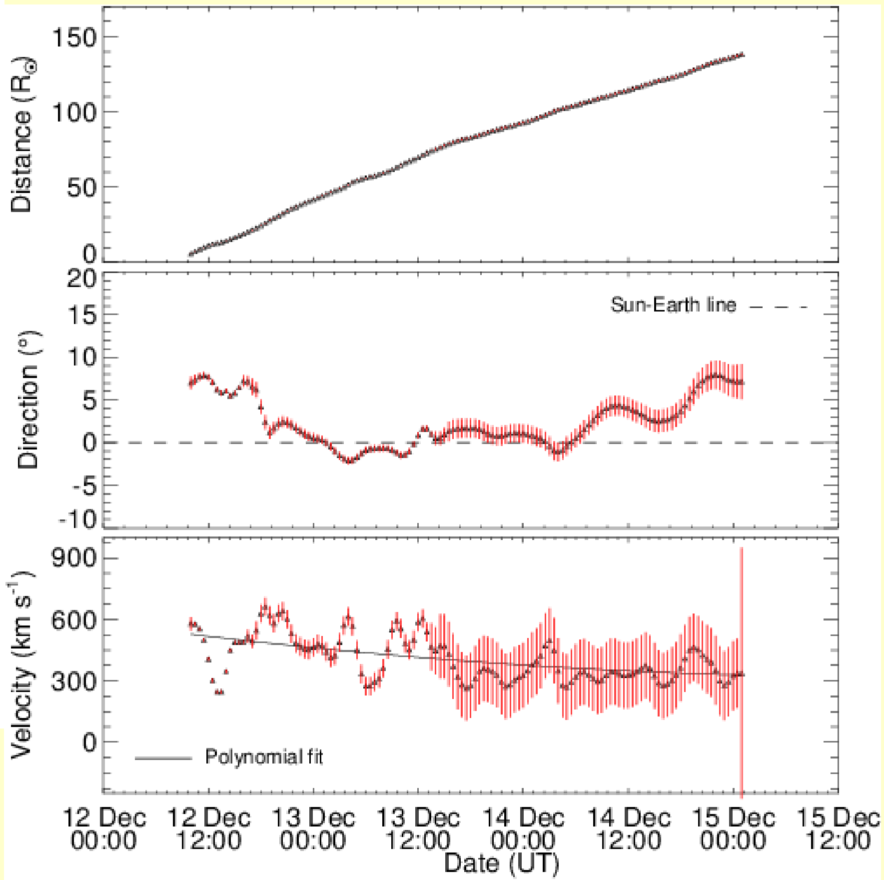


Use of J-map with geometric triangulation technique allows us to get the true velocity and propagation direction of CMEs in the heliosphere.

In this implemented geometric triangulation technique developed by Liu et al. (2010), the effect of Thomson scattering is not taken in to account. However, for the Earth-directed events this effect will be minimized due to nearly equal Thomson scattering angle (χ_A & χB) for both STEREO locations.

J-maps for tracking the feature in the heliosphere





J-map is constructed along the ecliptic using running difference images of the COR2, HI1 and HI2 for the STEREO A spacecraft.

CME is moving in the E direction from the Sun-Earth line.

Decelerating trend of CME.

Plot of the derived distance, propagation direction and velocity of tracked CME.

Velocity is calculated from the adjacent distance points using 3- point Lagrange interpolation

Estimating arrival time of CMEs using Drag based model

- The key role of solar wind in the propagation of CMEs beyond the 20 R_s is well established.

(Vrsnak et al., 2010, 2012)

$$a_d = -\gamma(v-w)\,|\,v-w\,|$$

Drag acceleration

γ lies in the average range of $0.2 \times 10^{-7} - 2.0 \times 10^{-7}$ km^{-1}.

where

$$\gamma = \frac{c_d A \rho_w}{m}$$

$$A = \prod\left(\frac{\phi}{2} r\right)^2$$

$$n_w(R) = \frac{8.0\times10^7}{R^6} + \frac{4.1\times10^6}{R^4} + \frac{3.3\times10^5}{R^2}$$

$$w(R) = w_1 \frac{n_1 R_1^{\;2}}{n(R)R^2}$$

v ~ CME speed
w ~ ambient SW speed
c_d ~ dimensional drag coefficient
A ~ cross sectional area of CME
ϕ ~ CME cone angular width
ρ_w ~ ambient solar wind density
m ~ CME mass

Subscript "1" represents the value at 1 AU.

Predicted arrival time using kinematics +DBM

- Using true velocity of 12 December 2008 CME at 138 R_s in the ecliptic plane as an input in the drag based model, with drag parameter value of 0.2 x 10^{-7} and w = 350, estimated arrival time of CME at 1 AU is 16 December 2008 at 20:25 UT.
- With drag parameter of 2.0 x 10^{-7} , arrival time of CME is 16 December at 19:55 UT.
- Transit velocity at L1 is ~ 338 km s^{-1} .
- Actual arrival time is at 16 December 23:50 UT.

Results

The kinematics of 8 CMEs is studied using GT technique.
The arrival time of bright feature is expected to match with the arrival of enhanced density feature in *in-situ* observations.

CME dates	Actual T_{arr} (Peak density time)	Error in predicted T_{arr} at L1 (hr)		Actual v1 at L1 (km s^{-1})	Error in predicted v1 at L1 (kms^{-1}) [γ = 0.2 – 2.0 (10^{-7} km^{-1})]
		Kinematics + Drag Based Model [γ = 0.2 – 2.0 (10^{-7} km $^{-1}$)]	Distance + Polynomial fit		
12 Dec.2008	16 Dec. 23:50	-3.4 to -3.9	+6.5	356	-25 to -18
07 Feb. 2010	11 Feb. 02:05	-4.3 to -3.2	-1.2	370	+72 to +23
12 Feb. 2010	15 Feb. 23:15	-8.7 to -7.9	-7.1	320	+122 to +81
14 Mar.2010	17 Mar. 21:45	-0.6 to +3.2	-5.4	453	-16 to -75
03 Apr. 2010	05 Apr 12:00	+5.5	-3.0	720	-96

CME dates	Actual T_{arr} (Peak density time)	Error in predicted T_{arr} at L1 (hr)		Actual v1 at L1 (km s^{-1})	Error in predicted v1 at L1 (kms^{-1}) [$\gamma = 0.2 – 2.0$ (10^{-7} km^{-1})]
		Kinematics + Drag Based Model [$\gamma = 0.2 – 2.0$ (10^{-7} km^{-1})]	Distance + Polynomial fit		
08 Apr. 2010	11 Apr. 14:10	-4.4 to -1.2	-7.6	426	+85 to -24
10 Oct. 2010	15 Oct. 06:05	+5.5 to +5.6	-7.2	300	+54 to +53
26 Oct. 2010	31 Oct. 03:30	-3.7 to -4.0	-18.9	365	-24 to -22

Using COR2 observations alone:

CME dates	Actual arrival time (UT) of CME leading edge at L1	Error in predicted arrival time	Measured velocity of CME leading edge at L1	Velocity (Km s^{-1}) in COR2 FOV
12 Dec. 2008	17 Dec. 04:39	-26.9	365	453
07 Feb. 2010	11Feb. 12:47	-21.8	360	480
12 Feb. 2010	16 Feb. 04:32	-41.5	310	867
14 Mar. 2010	17 Mar. 21:19	+27	450	335
03 April 2010	05 Apr. 13:43	-2.3	800	816
08 April 2010	12 Apr. 02:10	-9.5	410	478
26 Oct. 2010	31 Oct. 06:30	-46.7	365	600

Discussion and Summary

- It is clear that better prediction of CME arrival time at 1 AU is possible using GT technique combined with DBM than using only COR2 observations.
- Analysis carried out for 03 April and 08 April 2010 CME show that speed of these CMEs did not change much during their propagation from COR2 to L1.
- Extrapolating the fitted second order polynomial for estimated distance in HI FOV can give better accuracy in arrival time prediction if the CME is tracked up to large elongation, as for 07 February 2010 CME.

Our study shows that using GT technique on HIs observations combined with DBM improve the prediction of arrival time (with in 3 to 9 hrs.) of CME at 1 AU.

Transit speed of tracked feature at 1 AU can be well predicted using GT technique combined with DBM.

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Thank you !