

Eastward deflection of a fast coronal mass ejection in interplanetary space

Yuming Wang¹

Collaborators: Quanhao Zhang¹, Jiajia Liu¹, Chenglong Shen¹, Fang Shen², Zicai Yang²,

T. Žic³, B. Vršnak³, D. F. Webb⁴

¹ University of Science and Technology of China, Hefei 230026, China

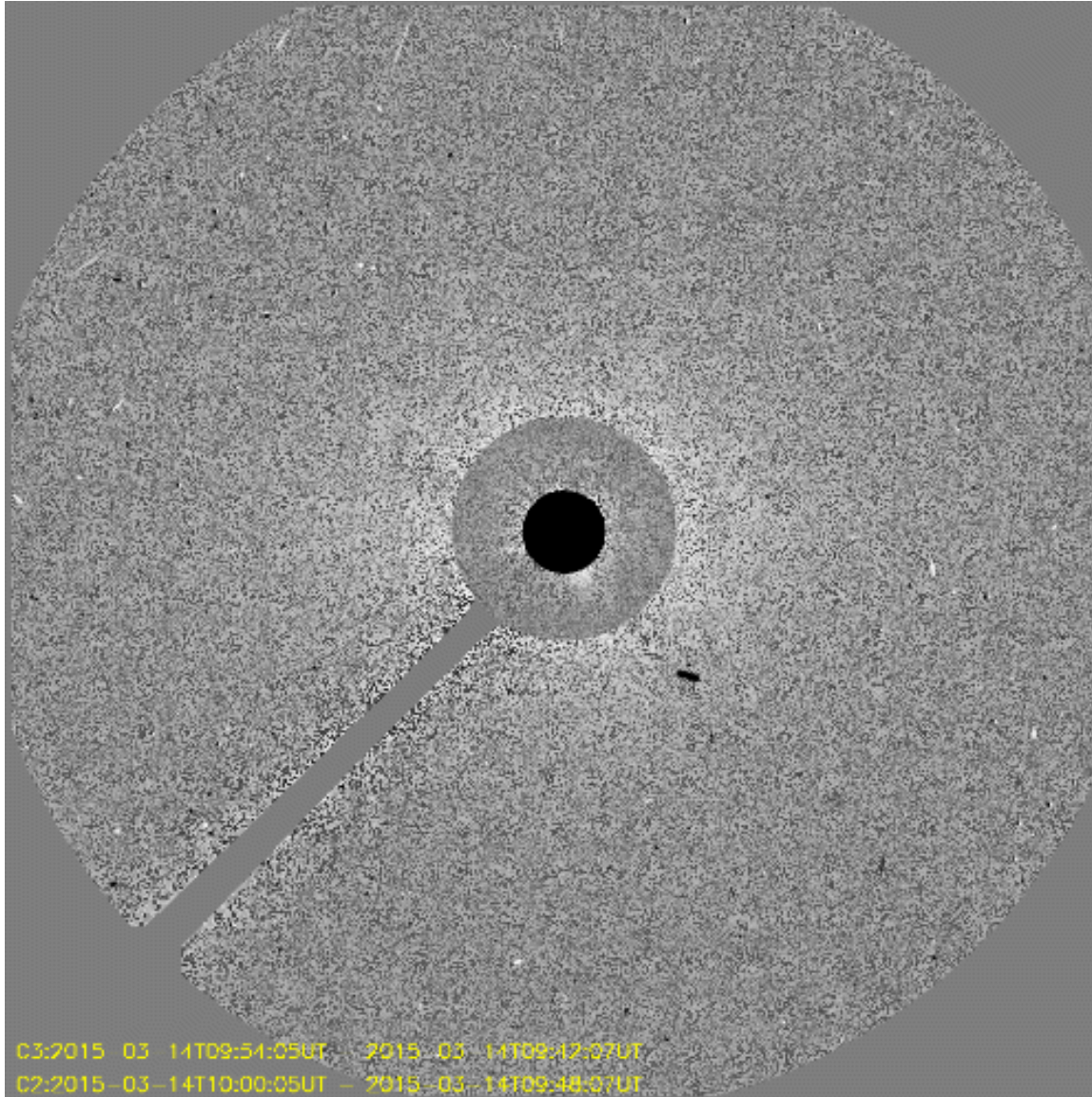
² Center for Space Science and Applied Research, CAS, Beijing 100190, China

³ Hvar Observatory, Croatia

⁴ Boston College, Chestnut Hill, MA, USA

ISEST Workshop, Mexico, 2015-10-28

Two CMEs launched during March 14 – 15

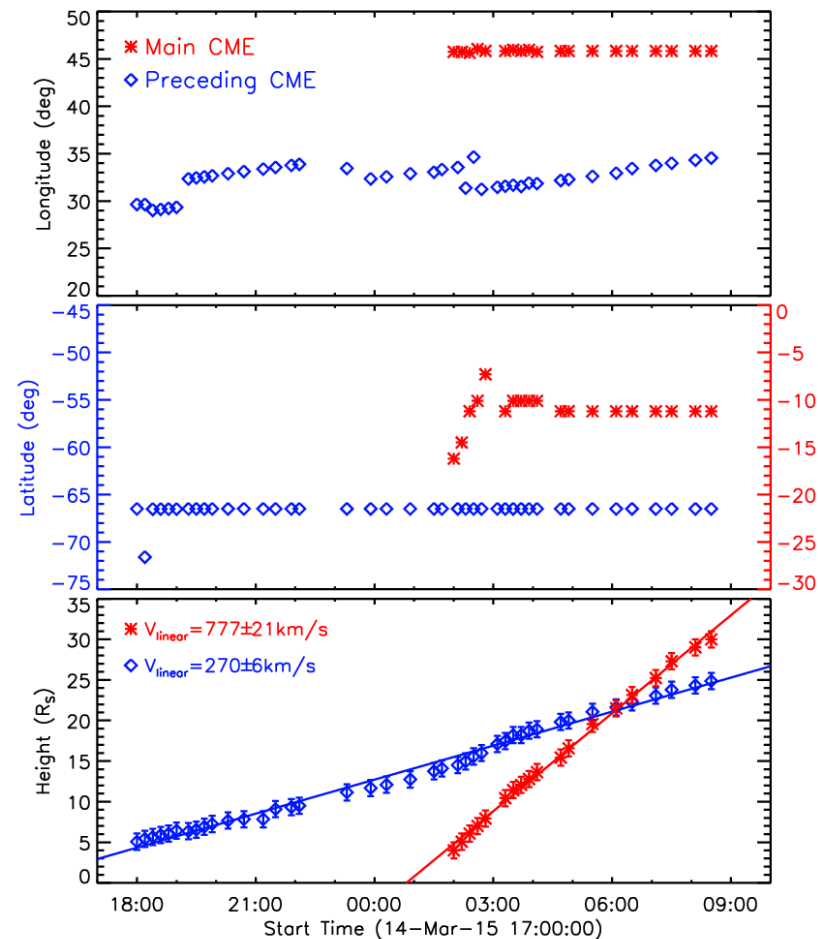
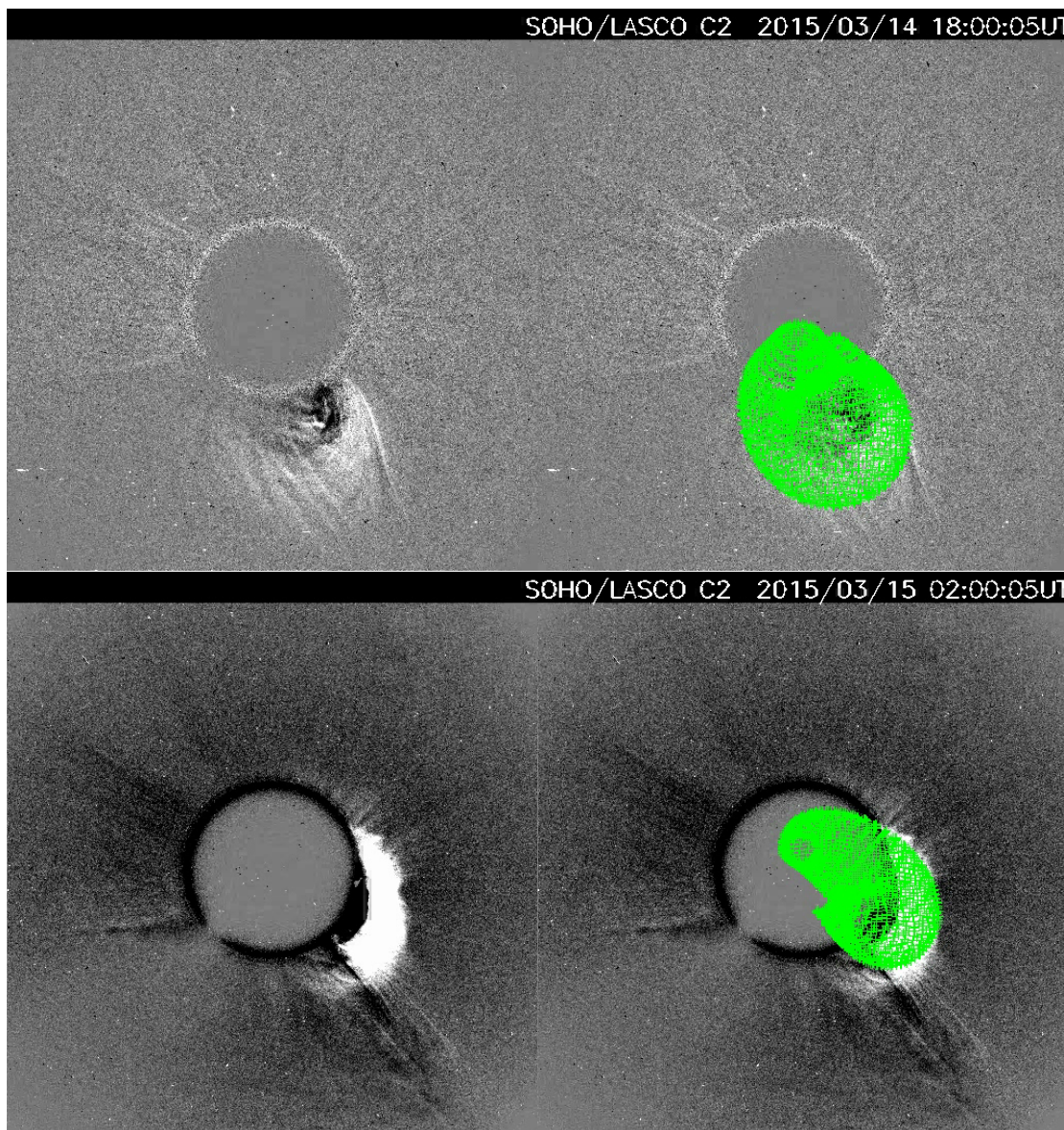


- March 14, ~12:36 UT
 Preceding CME: slow
- March 15, ~01:36 UT
 Main CME: fast

The preceding CME is confirmed to be backside (Gopalswamy and Yashiro, ISEST workshop, 2015)

Kinematic parameters of the CMEs

(GCS forward modeling: Thernisien, ApJS, 194, 33, 2011)



Preceding CME

Main CME

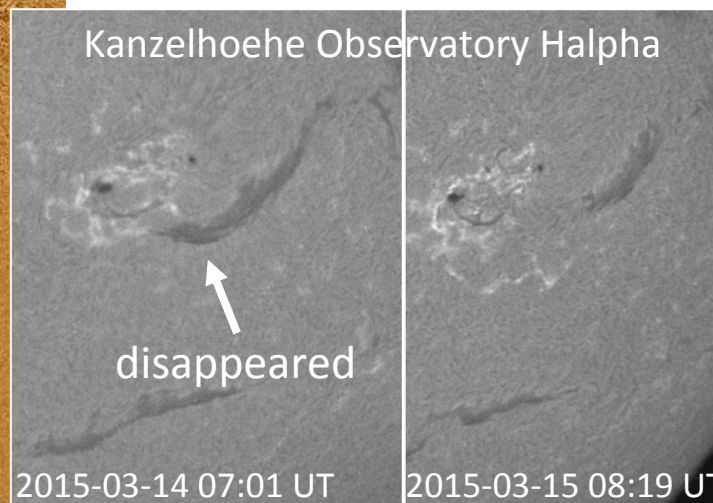
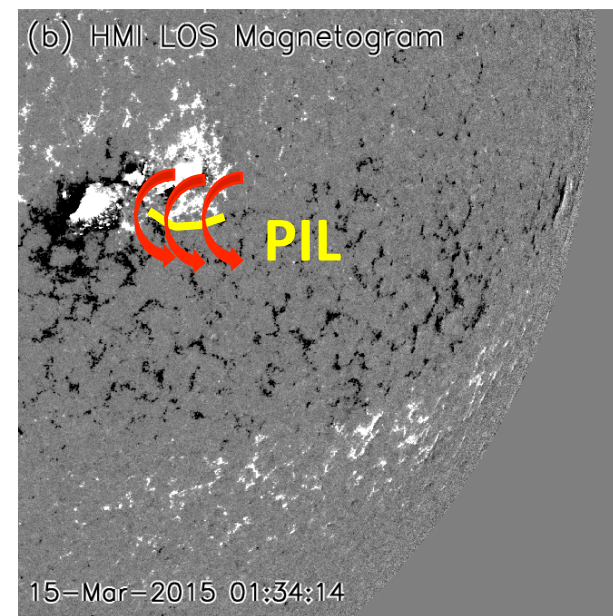
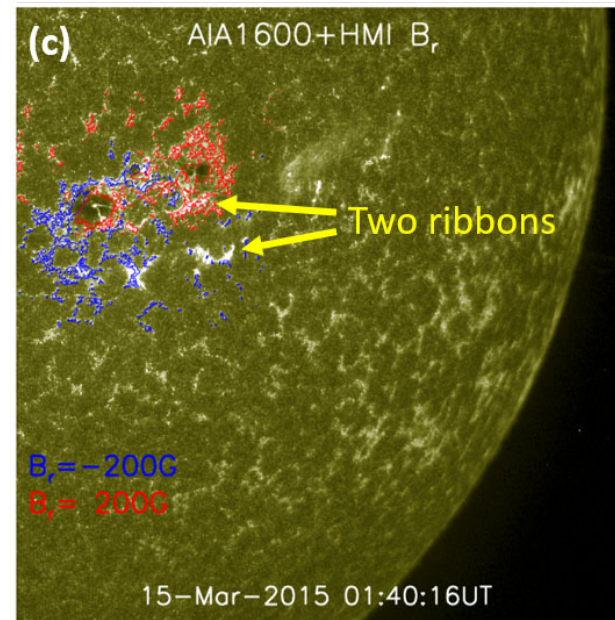
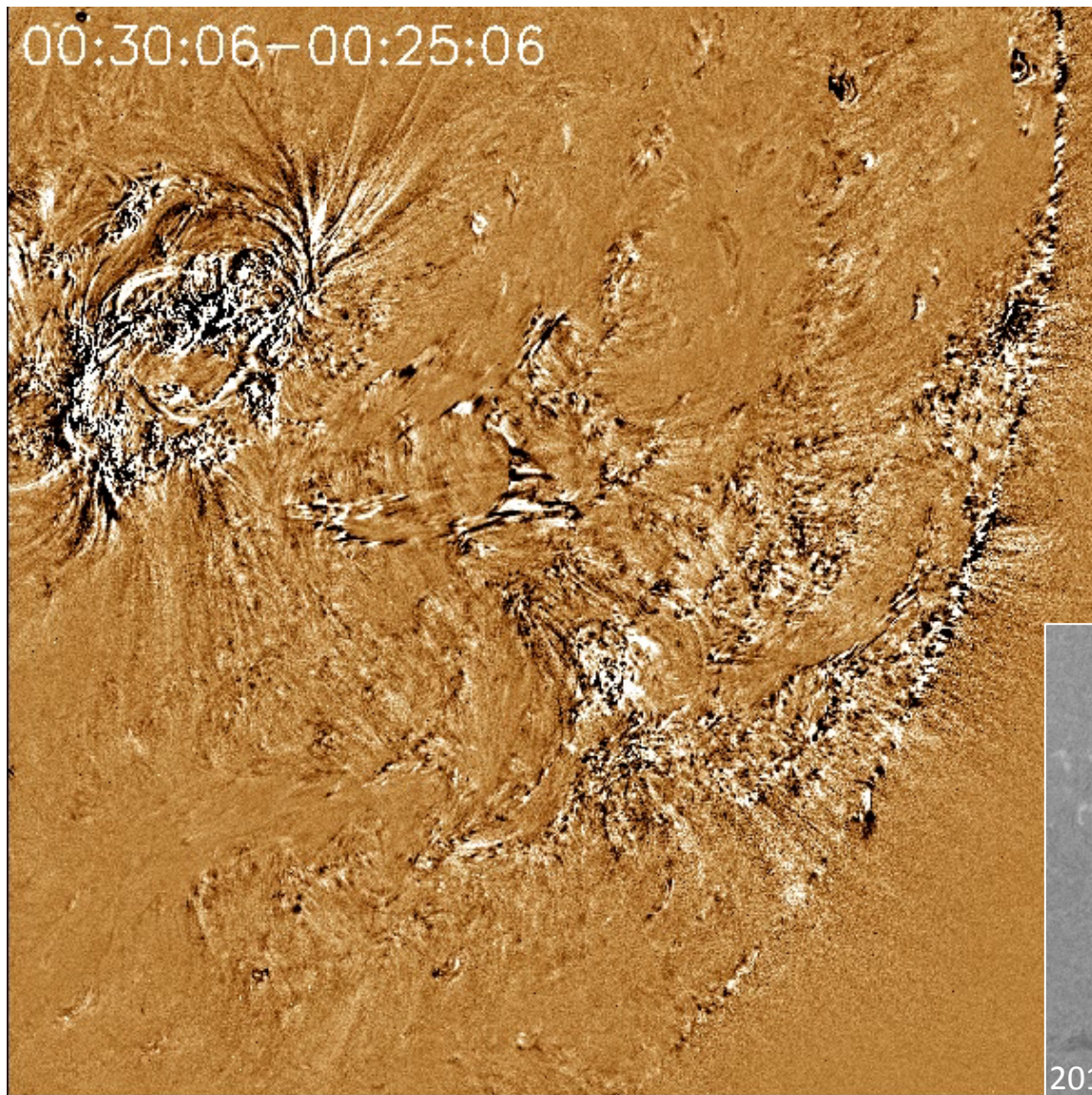
~W35,S66

~W46,S11

Tilt: -20 deg

Tilt: -39 deg

Source region of the main CME



On the solar surface:

~W35,S15

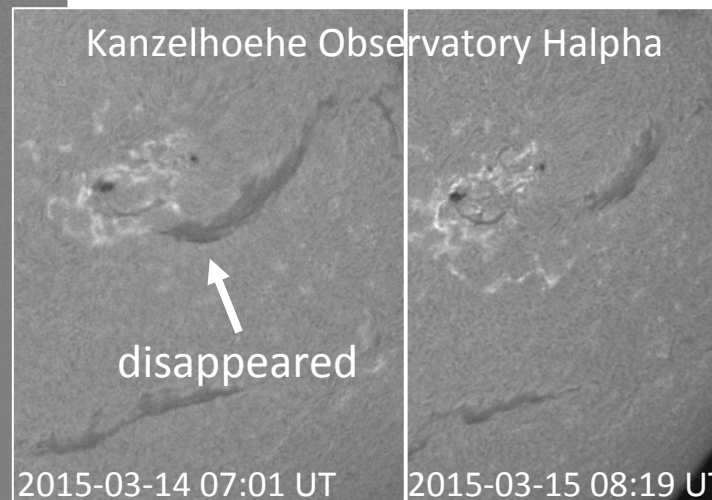
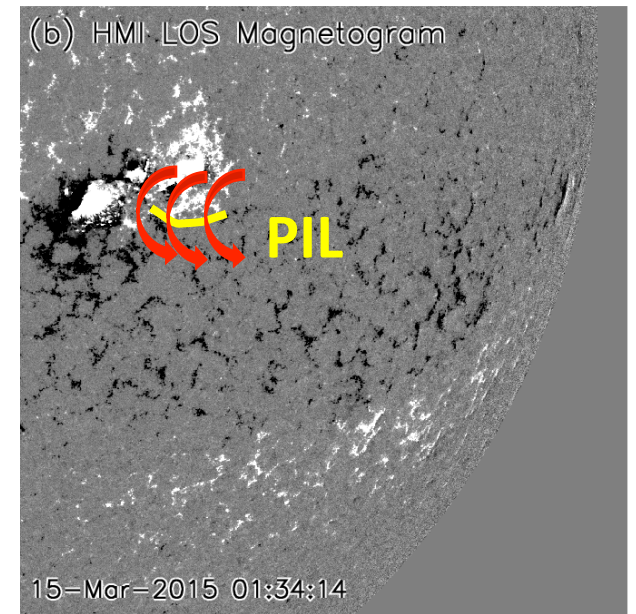
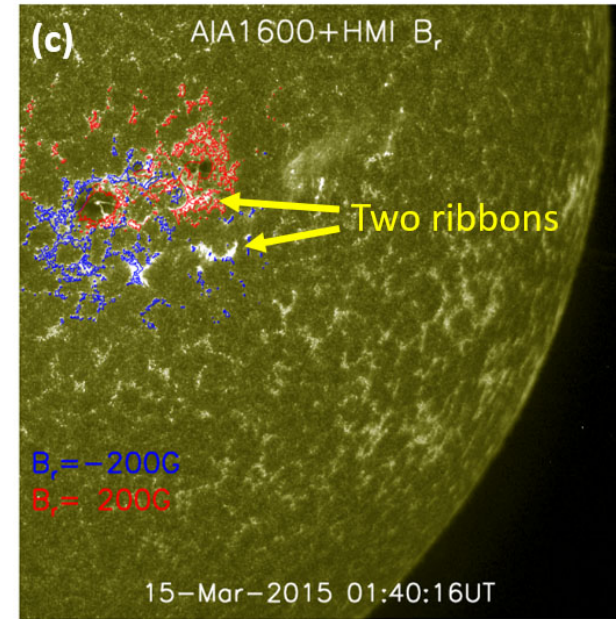
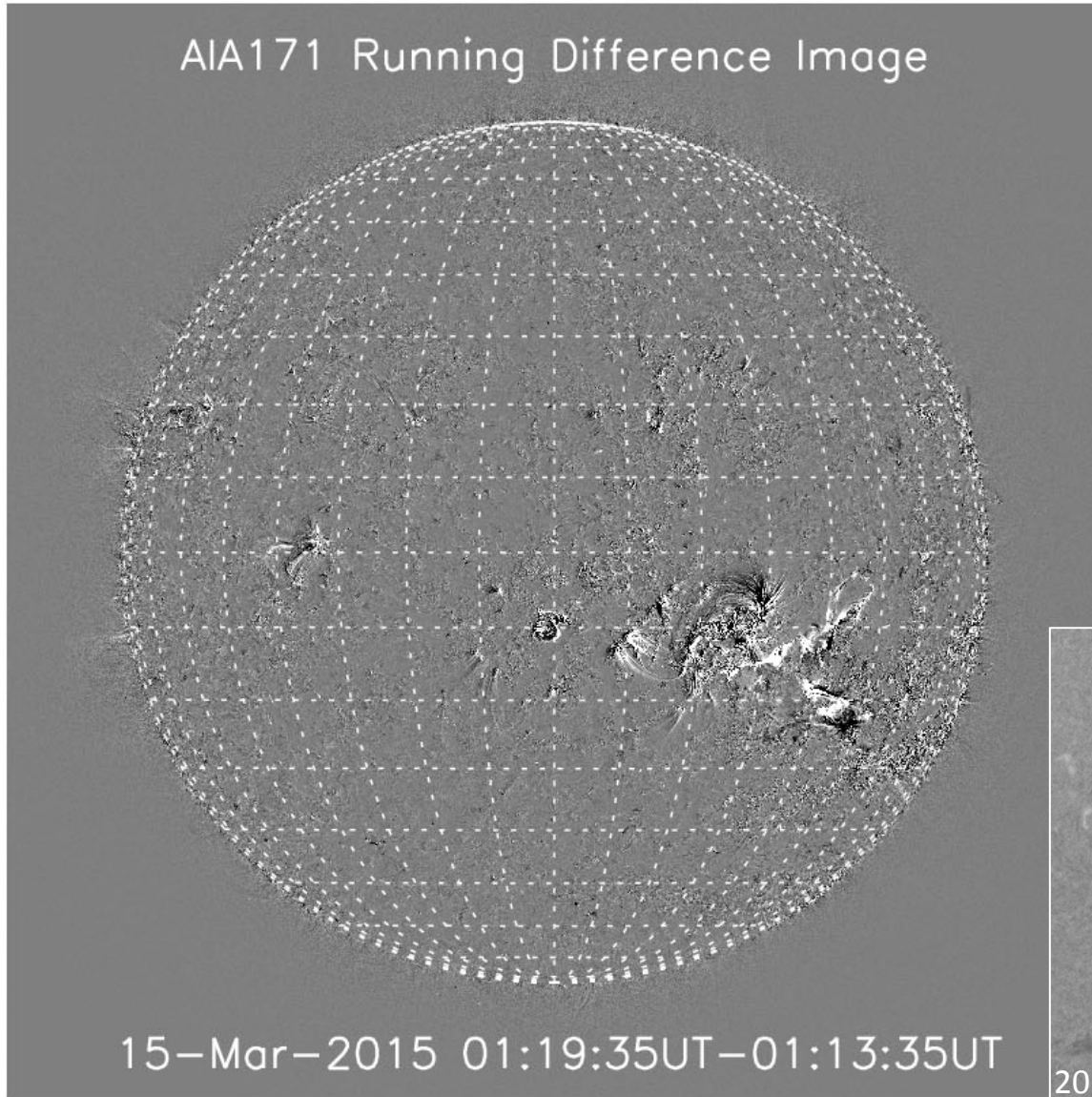
Tilt: -20 ~ 20 deg

Before leaving C3:

~W46,S11,

Tilt: ~-39 deg

Source region of the main CME



On the solar surface:

~W35,S15

Tilt: -20 ~ 20 deg

Before leaving C3:

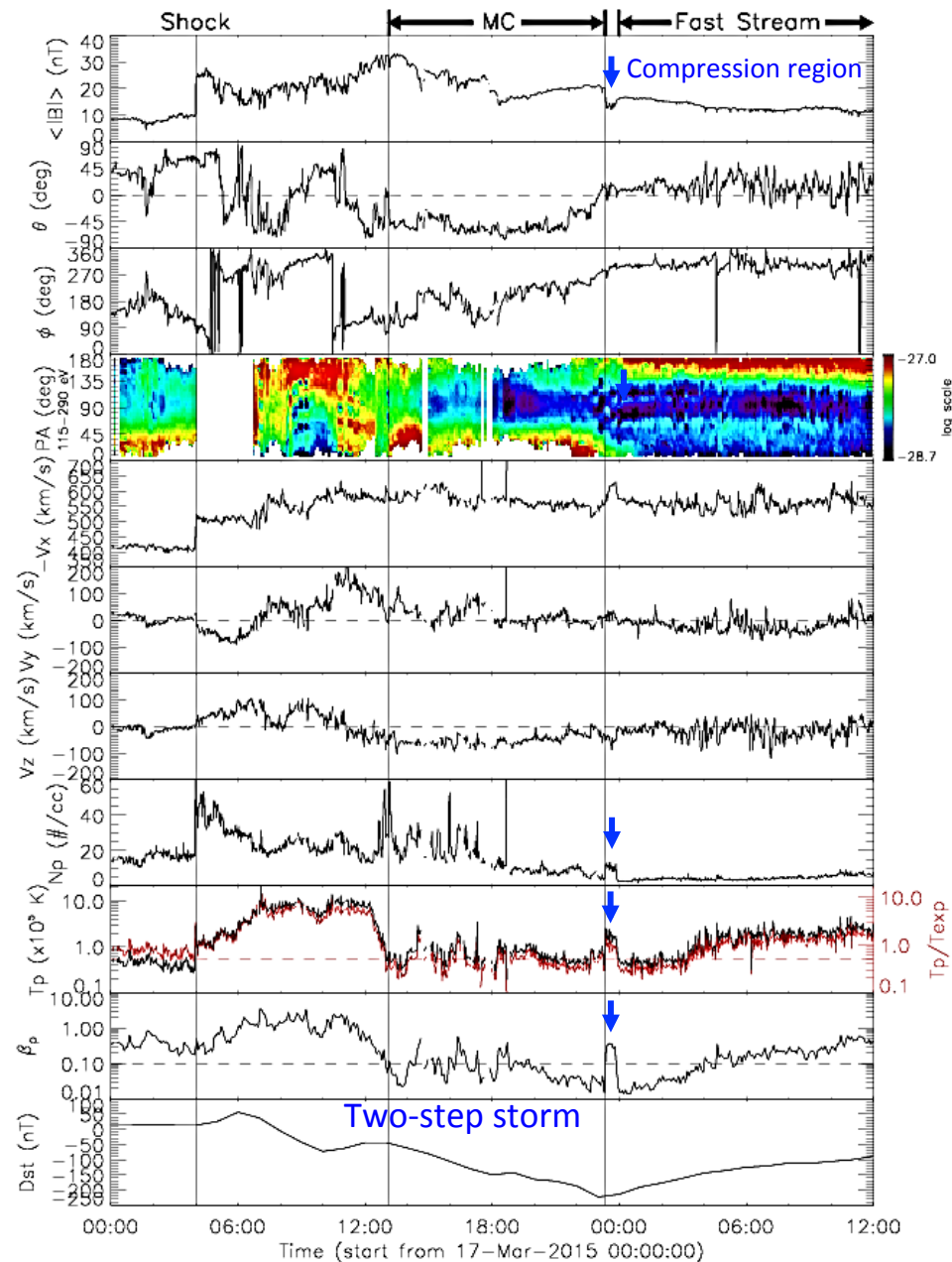
~W46,S11,

Tilt: ~-39 deg

Kinematics of the main CME before leaving the LASCO/C3 FOV

Parameters		Main CME
Propagation direction		W46 S11
Speed of leading edge (km/s)		777
Speed of center (km/s)		563
Aspect ratio		0.38
Tilt angle (deg)		-39
Angular width (deg)	Face-on	169
	Edge-on	42
Comments		With the high inclination of the axis, probably miss the Earth

In situ observations of the main CME at 1 AU



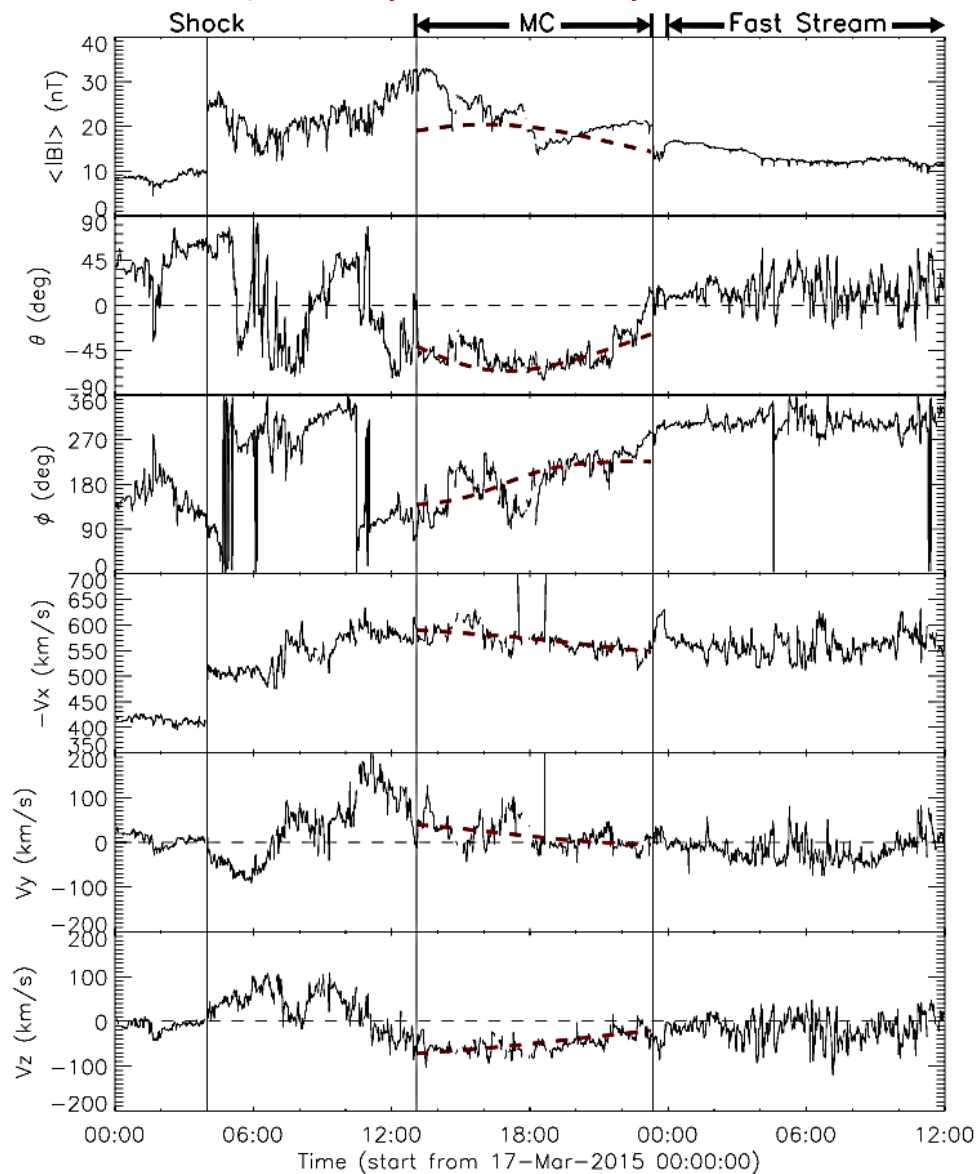
Shock: Mar. 17, 04:00 UT

MC: 13:05 – 23:20 UT

Dst Peak: -223 nT, 23:00 UT

Fitting results of the MC

(velocity-modified cylindrical force-free flux rope model: Y. Wang et al., JGR, 120, 1543, 2015)



$B_0 = 37$ nT (32 nT)
 $R = 0.081$ AU (0.087 AU)

$\Theta = -45$ deg

$\Phi = 348$ deg

$H = +1$

$d = -0.82 R$

$t_{\text{cen}} = 17\text{-Mar-2015 } 17:55$ UT

$v_x = -540$ km/s in GSE

$v_y = 59$ km/s

$v_z = -27$ km/s

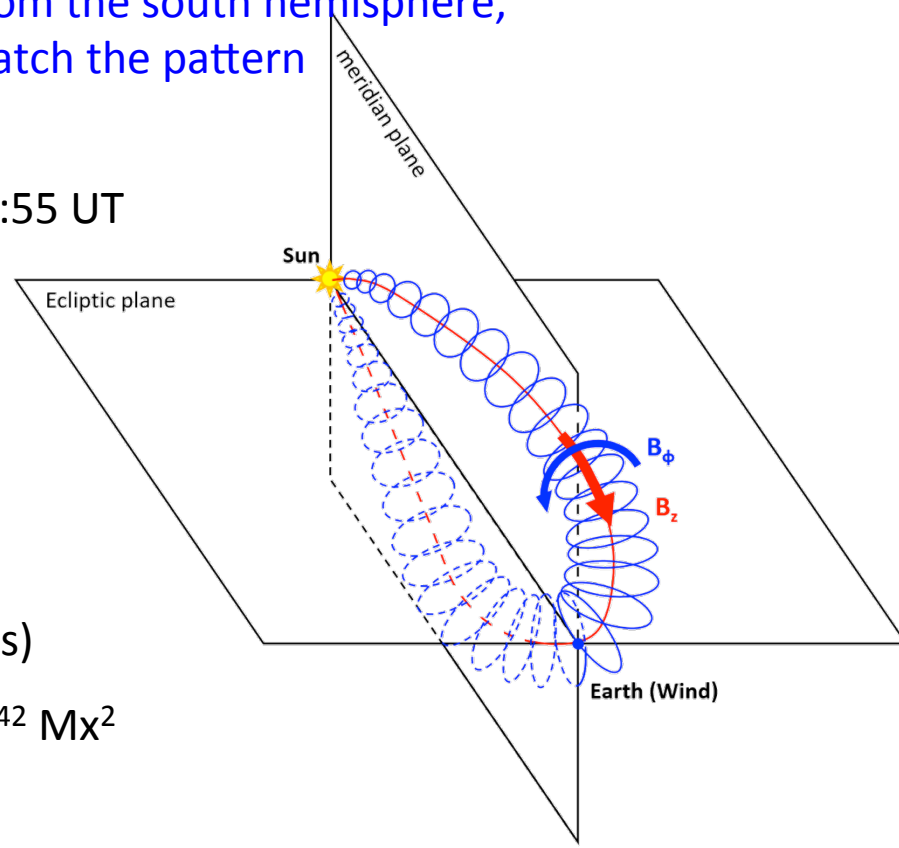
$v_{\text{exp}} = 51$ km/s

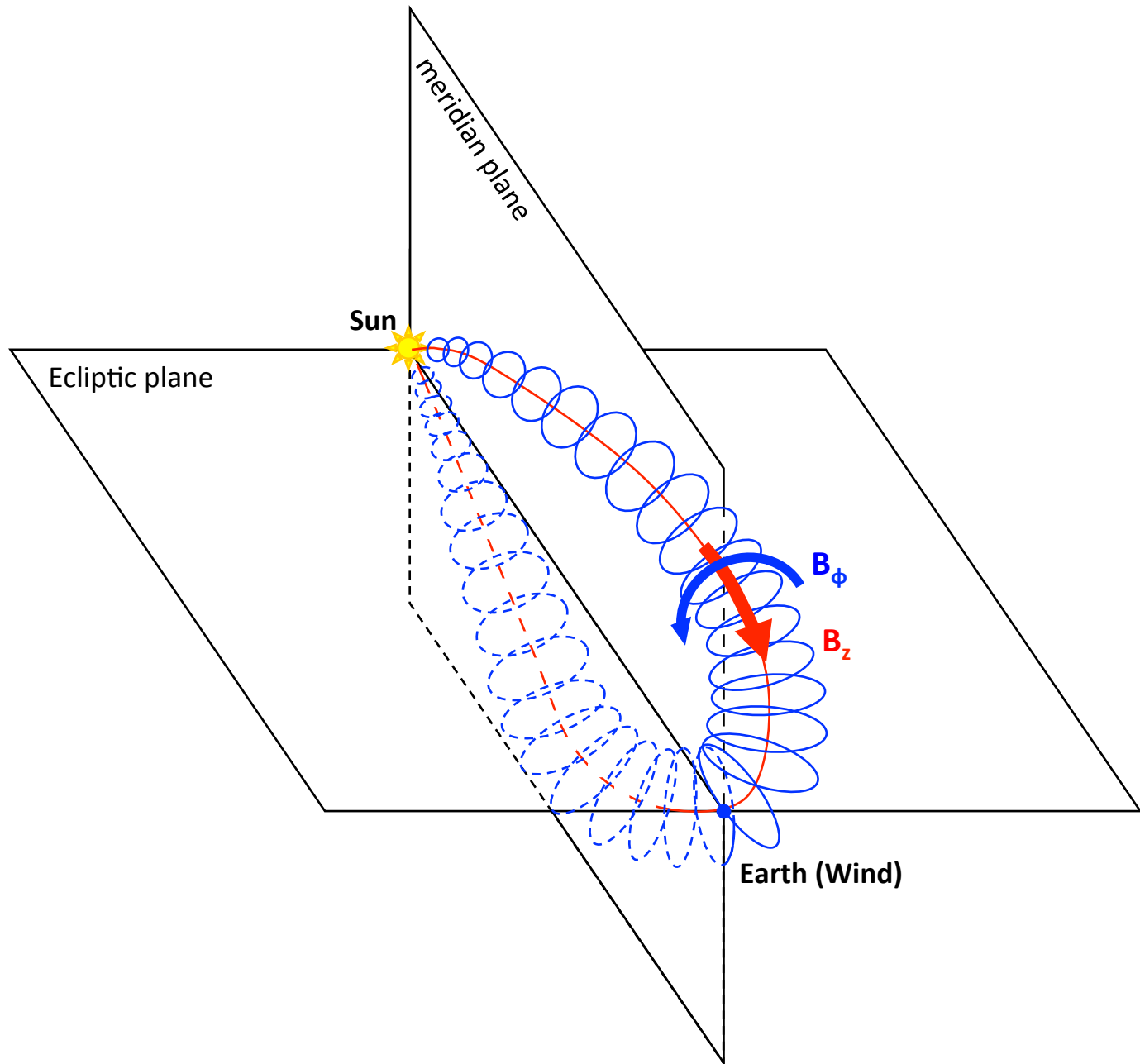
$v_{\text{pol}} = 48$ km/s (45 km/s)

Helicity = $(6.0 \pm 1.3) \times 10^{42} \text{ Mx}^2$

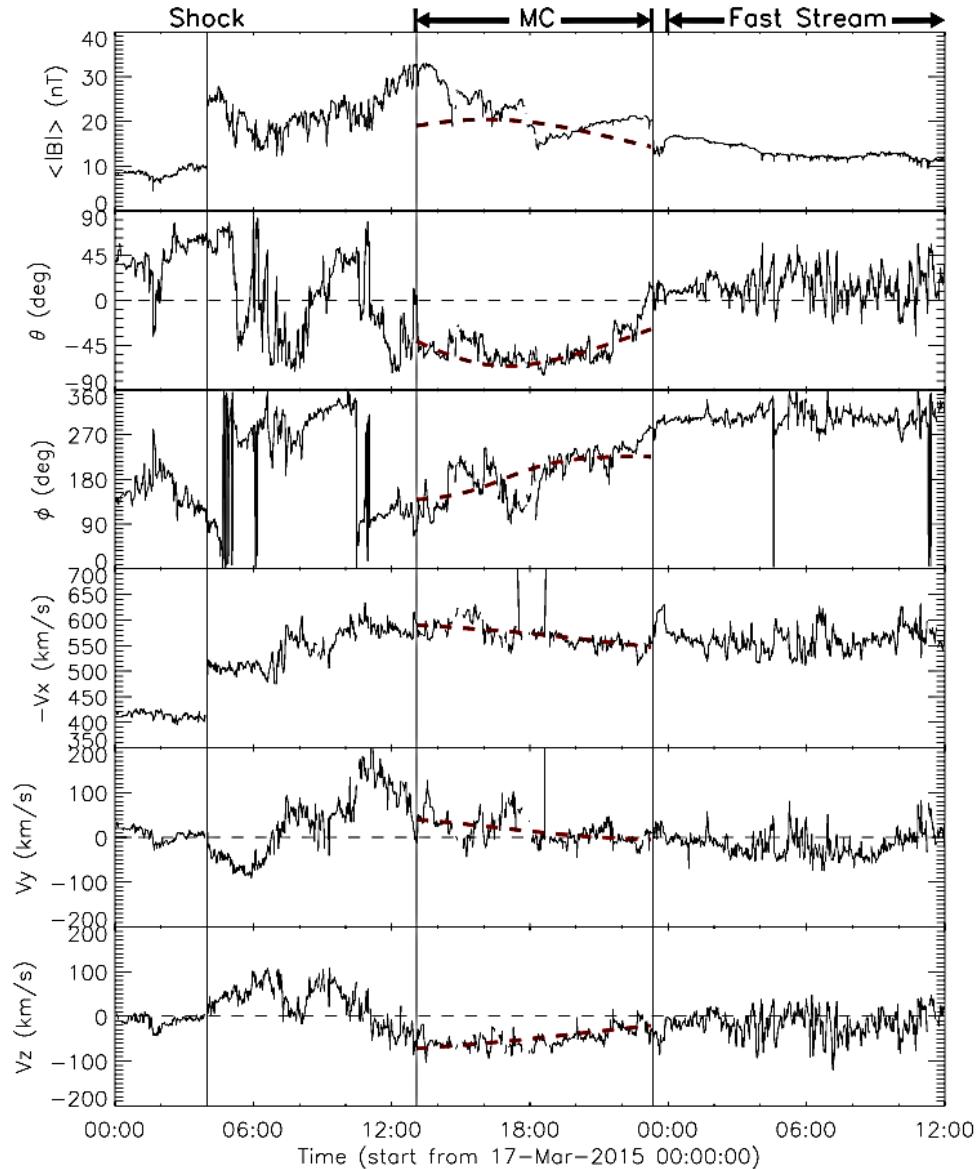
Consistent with the GCS fitting

From the south hemisphere, match the pattern





Hint from the MC fitting results



$B_0 = 37 \text{ nT}$ (32 nT)
 $R = 0.081 \text{ AU}$ (0.087 AU)

Theta = -45 deg

Phi = 348 deg

H = +1

d = -0.82 R

t_cen = 17-Mar-2015 17:55 UT

v_x = -540 km/s in GSE

v_y = 59 km/s --- Deflection? →

v_z = -27 km/s

v_exp = 51 km/s

v_pol = 48 km/s (45 km/s)

Helicity = $(6.0 \pm 1.3) \times 10^{42} \text{ Mx}^2$

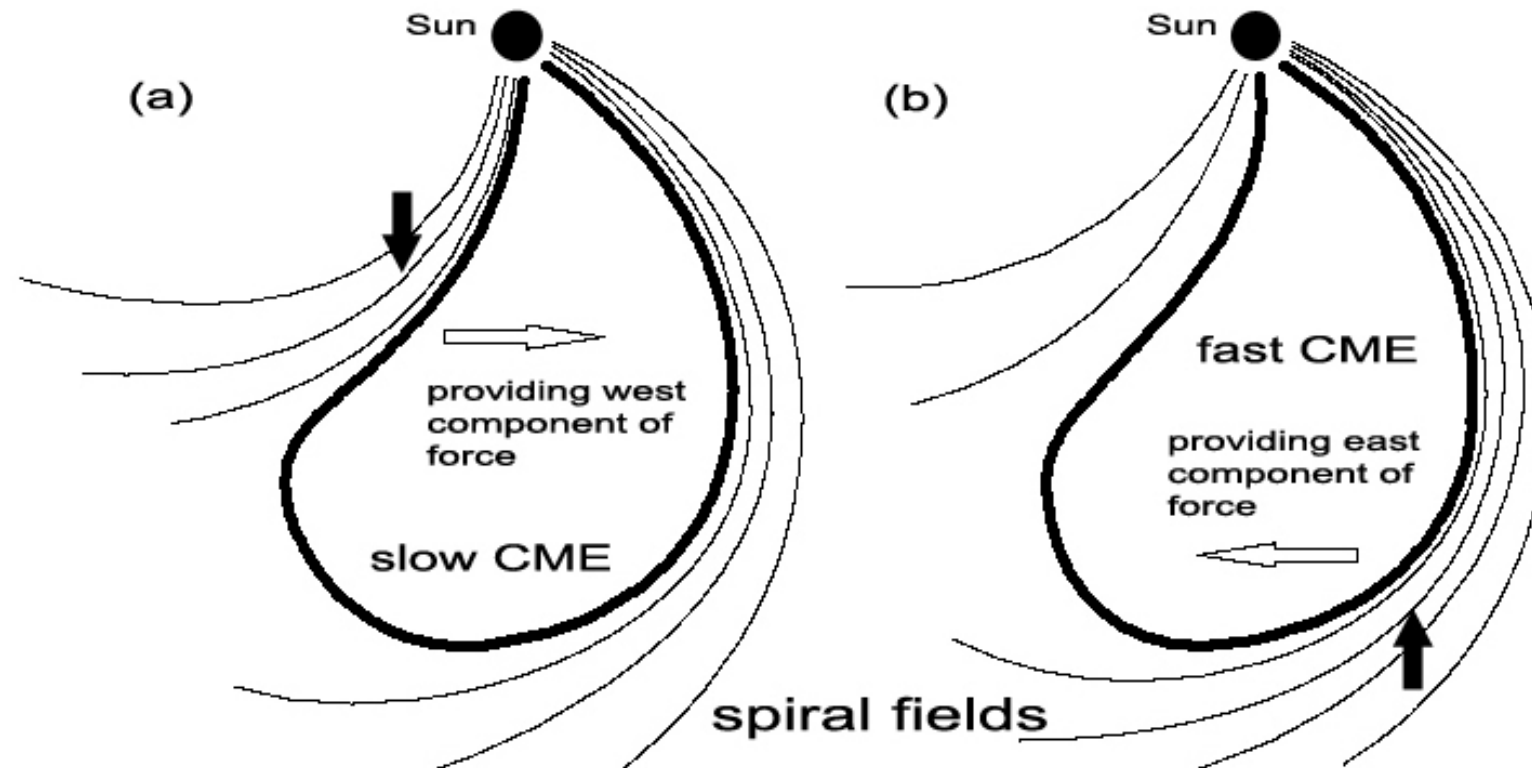
Prediction 1

Assume $v_{\perp y} / v_{\perp x} \approx 0.1$ all the way from 30 Rs to 1 AU, the deflection angle is about 11 deg toward the east.

$$\begin{aligned} d\phi &= -\int_{t_0}^{t_1} \frac{v_{\perp y}}{r} dt \\ \frac{v_{\perp y}}{r} &= -\int_{r_0}^{r_1} \frac{v_{\perp y}}{v_{\perp x}} \frac{dr}{r} \\ \ln \frac{r_1}{r_0} &= \frac{v_{\perp y}}{v_{\perp x}} \ln \frac{r_1}{r_0} \end{aligned} \quad (1)$$

Prediction 2: ICME kinematic deflection model

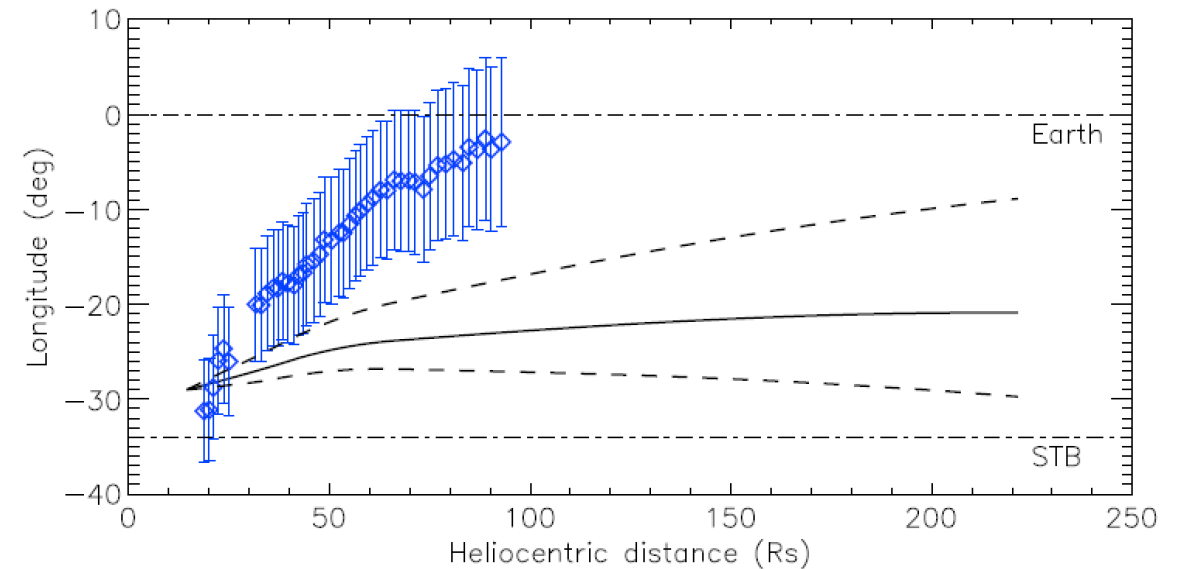
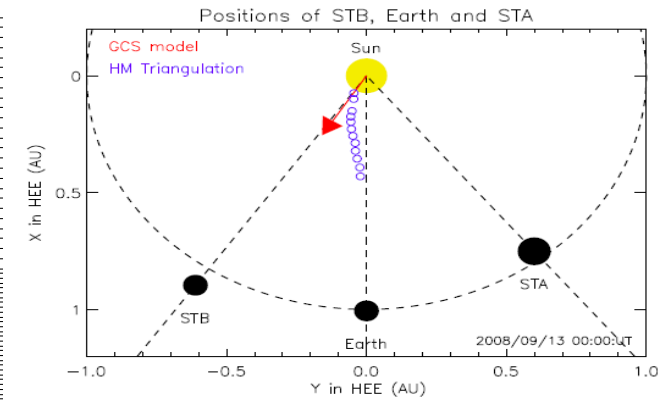
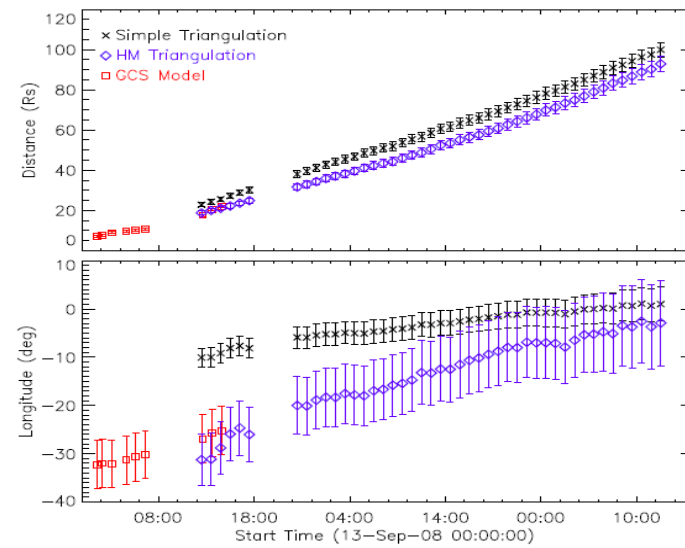
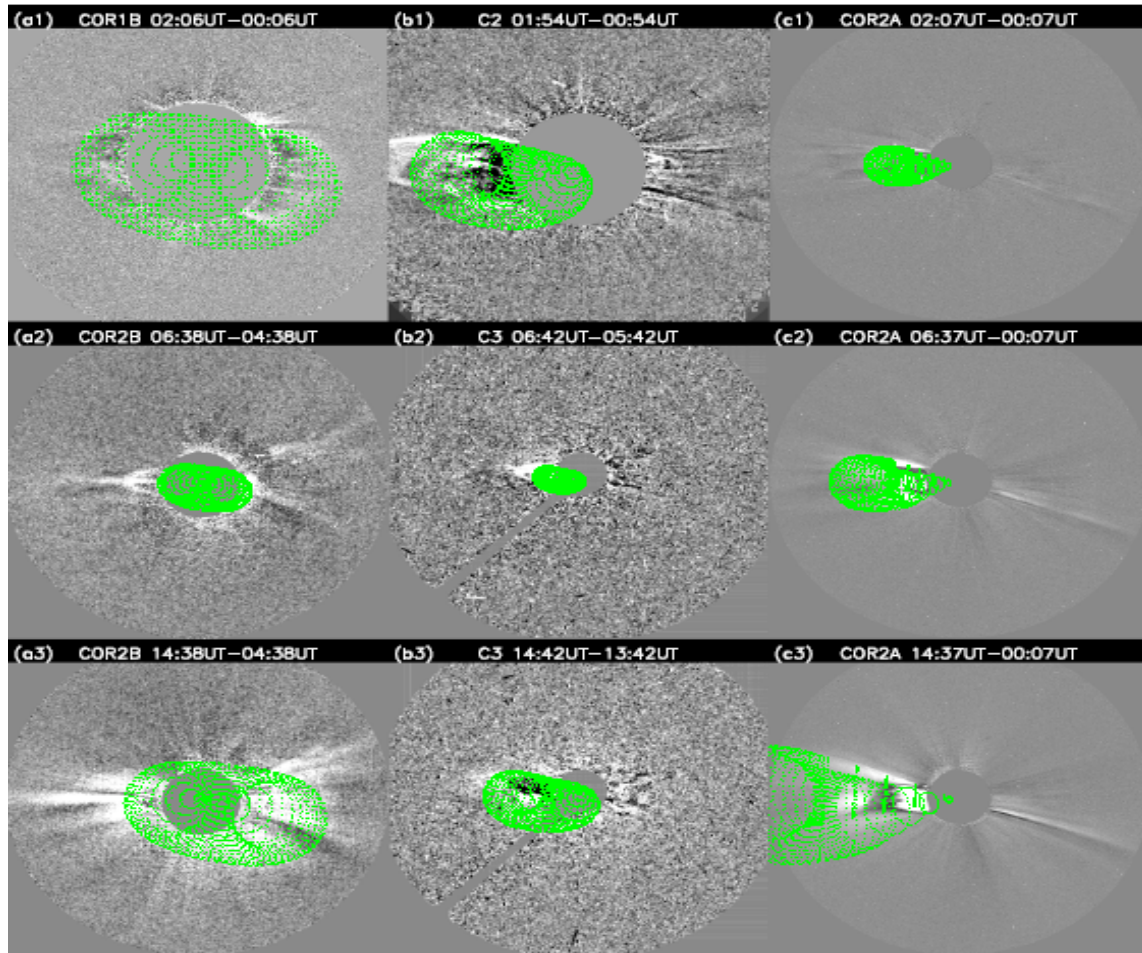
(Y. Wang, et al., SoPh, 222, 329, 2004)



$$d\phi = \Omega \left(\frac{1}{V_r} - \frac{1}{V_{sw}} \right) dr \quad (2)$$

Example: A slow CME deflected westward in interplanetary space

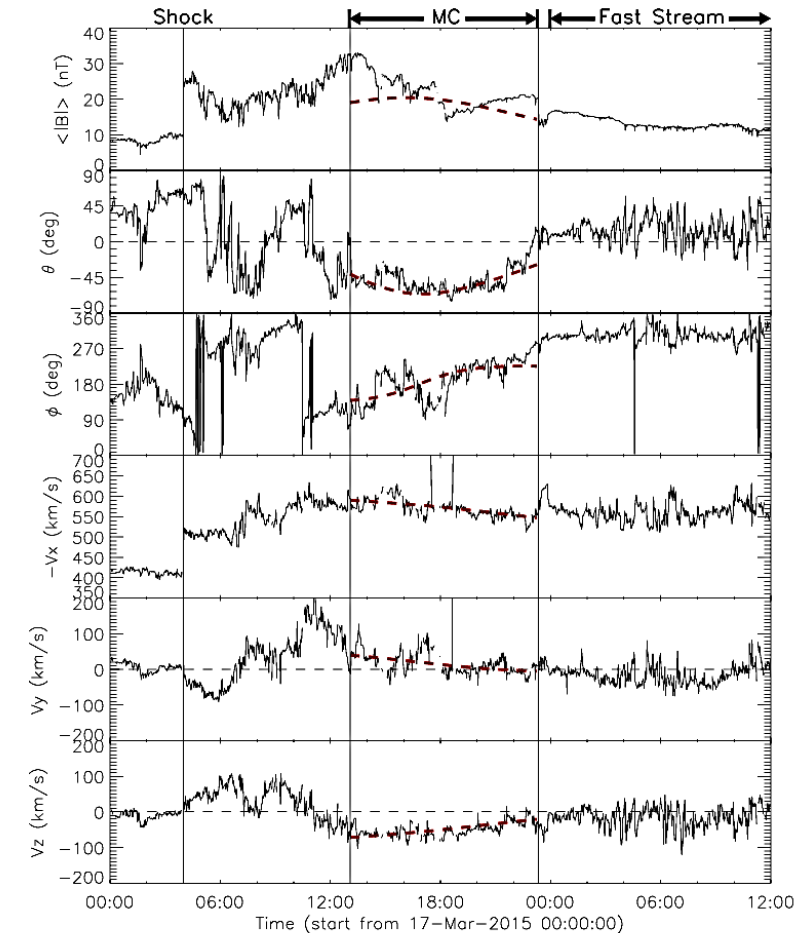
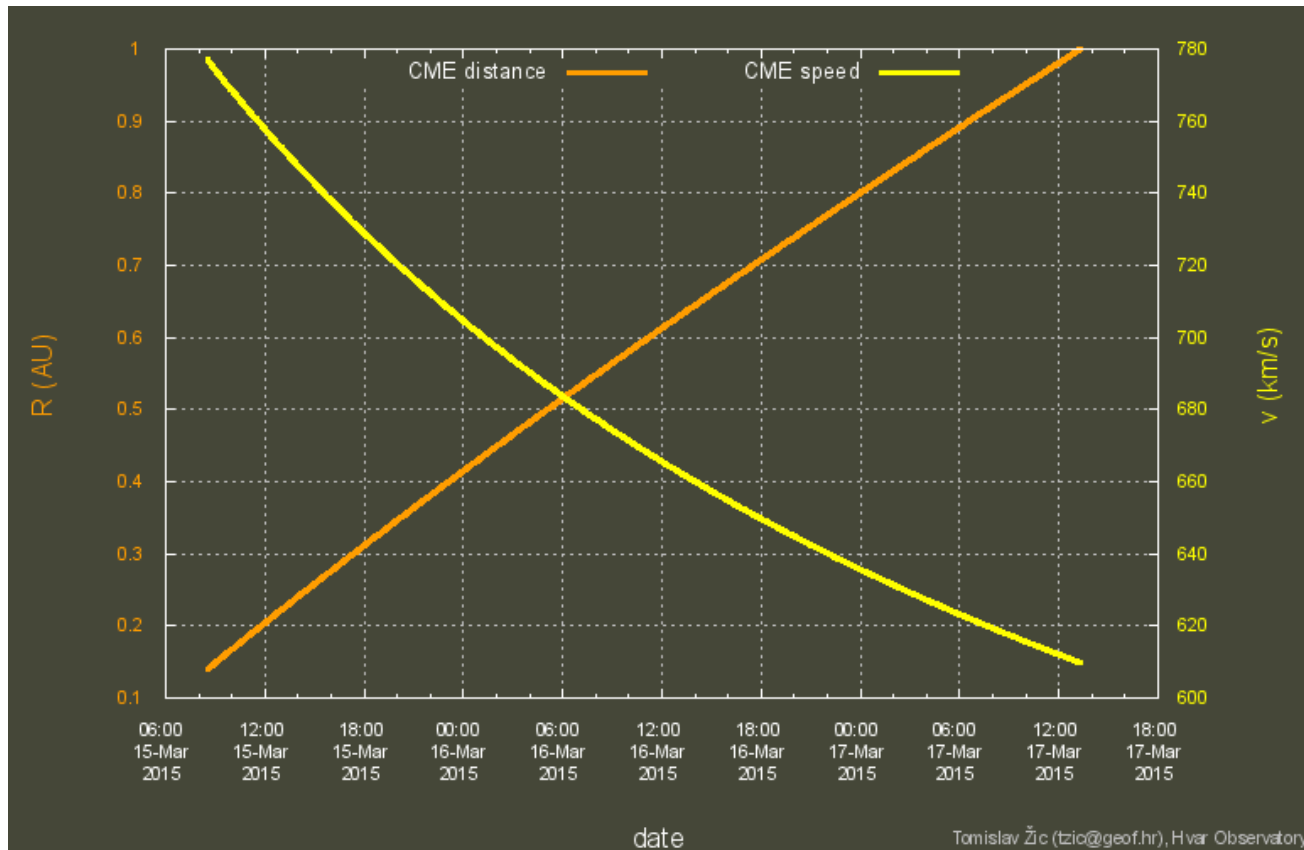
(Y. Wang et al., JGR, 119, 5117, 2014)



Slow CME initiated on 2008 September 12

Speed of the CME leading edge derived from the drag-based model

(Vrsnak, et al., SoPh, 285, 295, 2013)



- Input parameters:

$$r_0 = 30 R_S, V_{cme0} = 777 \text{ km/s}, V_{sw} = 410 \text{ km/s}, \Gamma = 0.12 \times 10^{-7} \text{ km}^{-1}$$

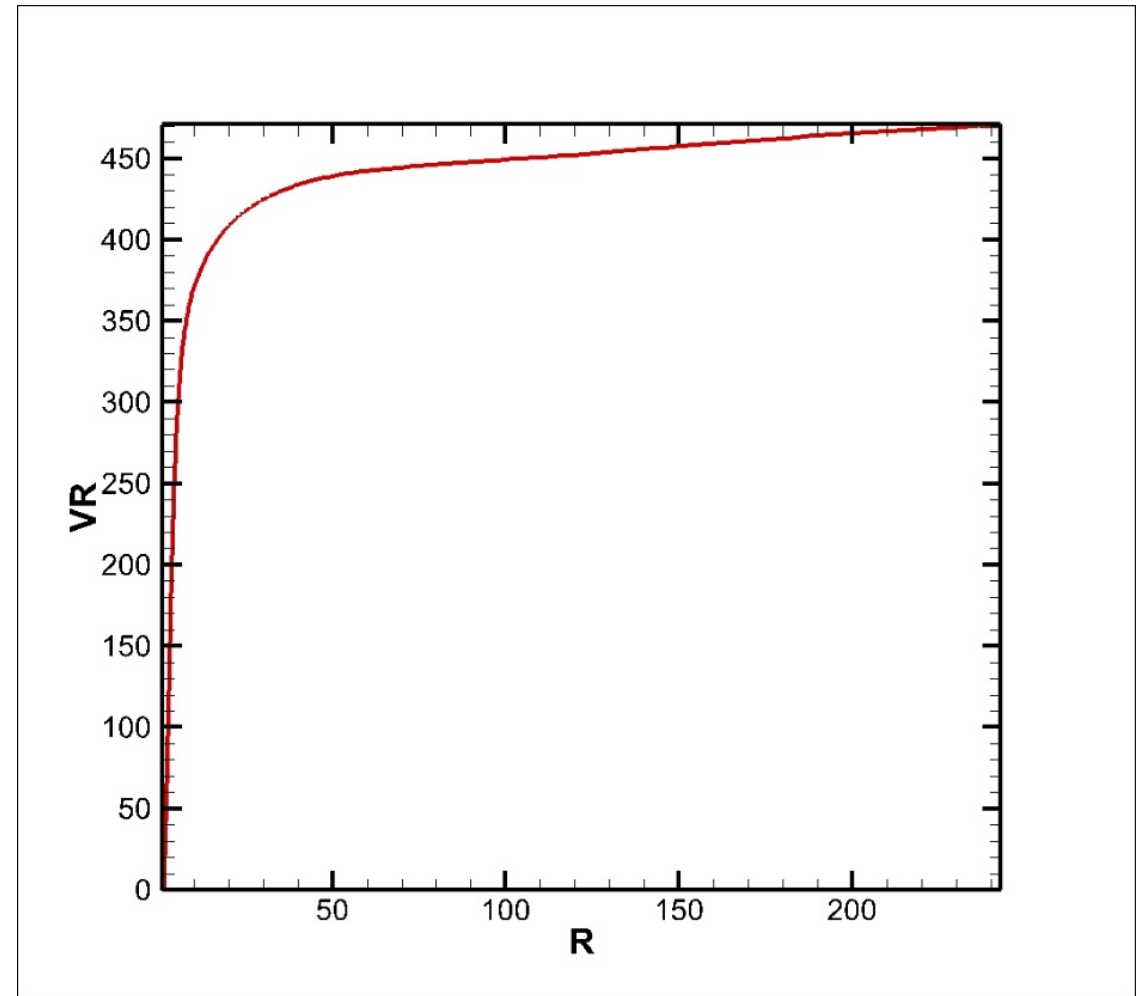
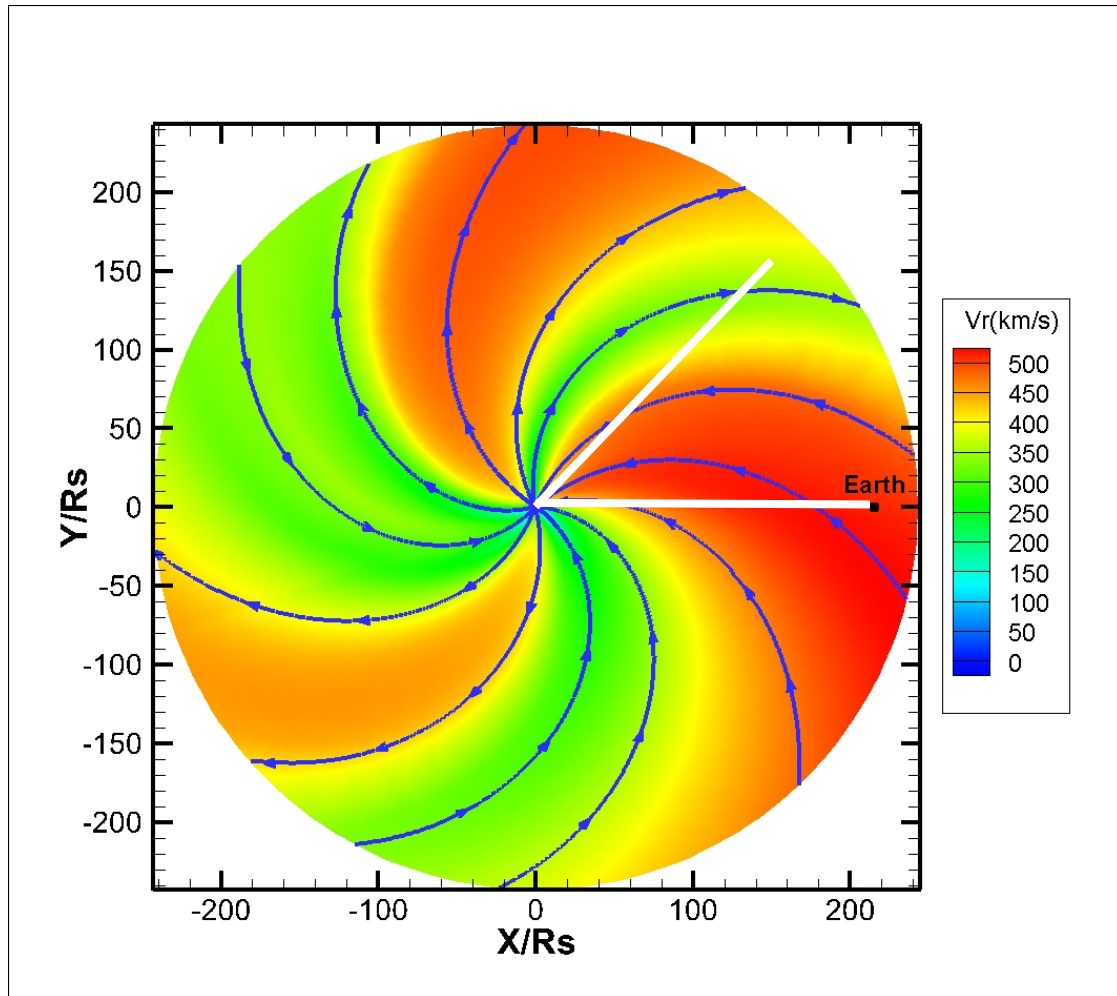
- Output:

$$\text{Arrival at March 17, 13:18 UT, } V_{cme} = 610 \text{ km/s, } t = 52.8 \text{ hr}$$

- Consistent with in-situ obs: arrival at 13:05 UT, and speed of about 600 km/s at the leading front.

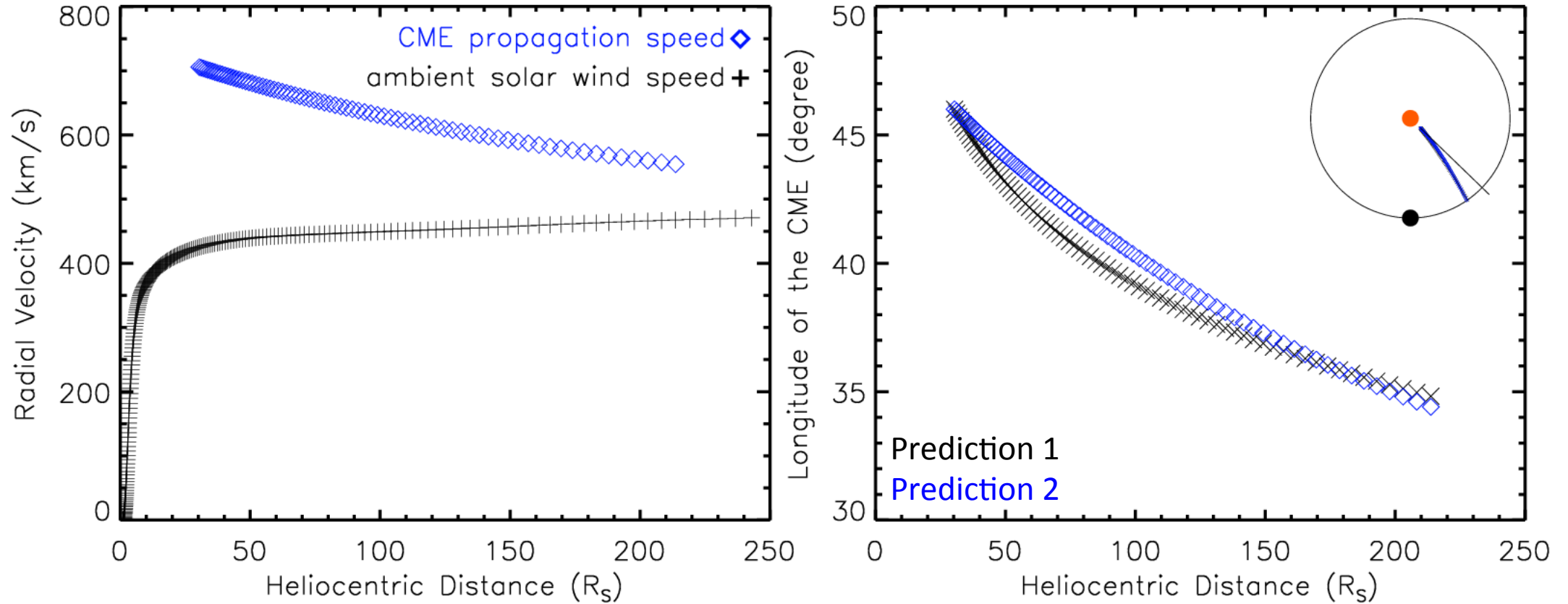
Background solar wind

(F. Shen, et al., JGR, 2007; JGR, 2011)



2015-03-16 00 UT

Deflection of the CME predicted by the model



Deflected toward the east by about 12 degrees, in agreement with prediction 1

Summary

- The 2015 March 15 CME originally directed toward the west of the Earth by about 46 degrees.
- It is not expected to be detected at the Earth due to its highly inclined flux rope axis.
- A corresponding MC was indeed observed at the Earth.
- Deflected propagation in interplanetary space is a promising explanation:
 - MC fitting to the in-situ data
 - CME kinematic deflection model } Deflection angle ~ 12 degrees
- The case studies of this **fast** CME and the **slow** CME on 2008 September 12 complete the picture of the CME deflection in interplanetary space.

Thanks for your attention!