ISEST 2017 Workshop, 18-22 September 2017

What we can learn from the ISEST WG4 Campaign Study of Sun-Earth events?

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Introduction

WG 4 (Campaign Events)

Objectives:

- ♦ To understand cause-effect chain of Sun-Earth activity
- ♦ To develop space weather prediction capability

Task: To study selected events (T, U, P categories)

Present report

- ♦ Analysis of possible flux rope structure in the 11 events
- ♦ Consideration on key factors in the cause-effect chain (CME initiation, ICME propagation, geoeffectiveness, etc.)
- ♦ Report for 4 (5) selected events (Marubashi et al., 2017)

Final comments

- ♦ Difficulties in REAL predictions (cf. retrospective study)

ISEST/MiniMax WG4 Event List

ID	Dates	Solar Events	Solar Wind	Dst	Type
1	2012 July 12-14	X1 flare, CME	Shock, MC	-127	T
2	2012 Oct. 4-8	CME (stealth?)	Shock, MC	-105	P/U (solar source?)
3	2013 Mar. 15-17	M1 flare, CME	Shock, MC?	-132	T
4	2013 June 1	CME?	Shock, CIR?	-119	P (strong storm?)
5	2015 Mar. 15-17	C9 flare, CME	Shock, MC	-223	P/U (super storm?)
6	2015 June 21-24	2 M fls, CMEs	Shock, MC	-204	T?
7	2012 Mar. 7-9	X5 flare, CME	Shock, MC	-131	T
8	2012 July 23-24	2 fls, EPs	STEREO-A (Carrington-type) , T?		
9	2012 Jan. 6	CME, West-Limb	No storm, GLE at Earth P/U		
10	2014 Jan. 7-9	X1 flare, CME	Shock, No MC	-----	P/U (MC deflection)
11	2014 Sep. 10-13	X2 flare, CME	Shock, MC	-75	P/U

Type: T = Textbook, P = Problem, U = Understood

Only yellow-highlighted events are reported

Event No. 5: March 15-17 storm (The largest in Cycle 24)

Question: What caused such an intense storm?

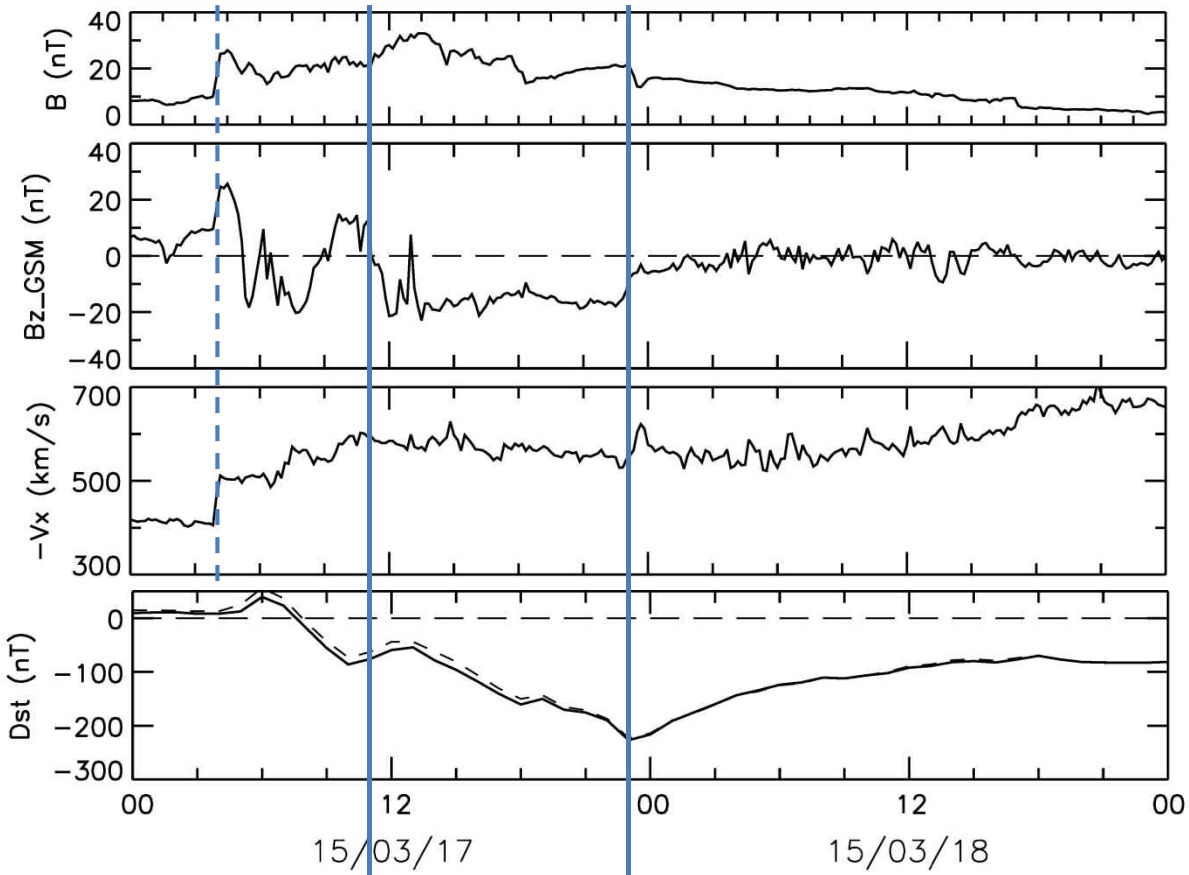
Previous studies

Kamide & Kusano (2015), SpW: Superposition of two storms
Kataoka *et al*. (2015), GRL: Intensification due to pileup effect
Liu et al. (2015), ApJL: GS reconstruction of two MCs
Gopalswamy *et al*. (2015) IE Symp: Comparison with statistics
Wang *et al*. (2016), JGR: Fitted to cylindrical flux rope
Cho et al. (2017), JKAS: Fitted to toroidal flux rope
Marubashi *et al*. (2016), EPS: Toroidal flux rope, Dst development

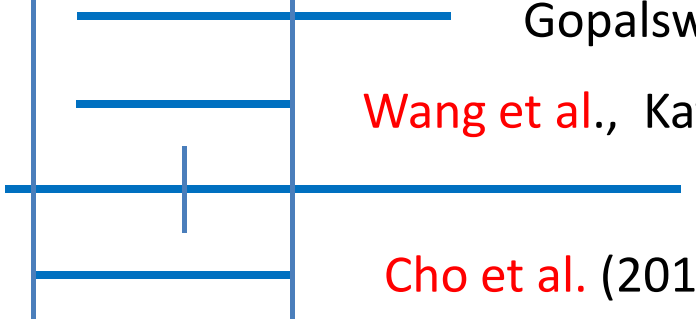
In this talk

Cylinder vs torus: Torus model provides better interpretation.
Dst analysis: The prolonged southward IMF caused the strong storm.

Solar wind features and corresponding Dst variation, March 17-18



Different MC intervals were suggested by previous studies.



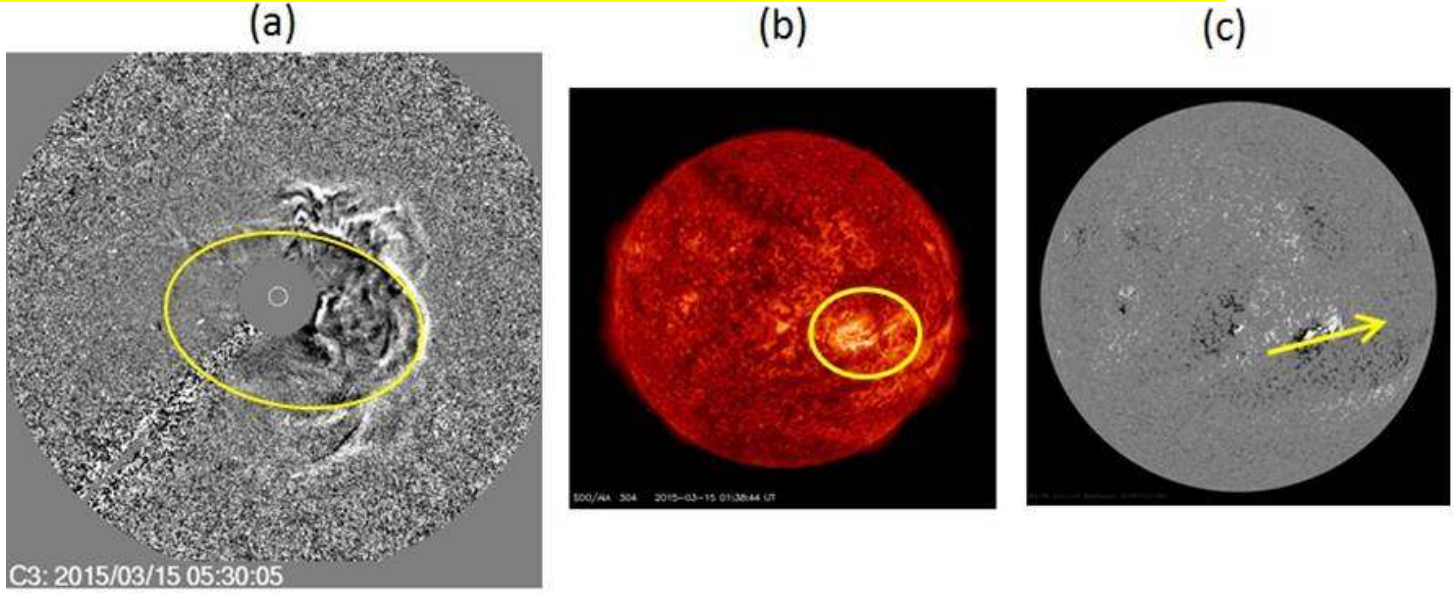
Gopalswamy et al.

Wang et al., Kataoka et al.

Liu et al. (2 MCs)

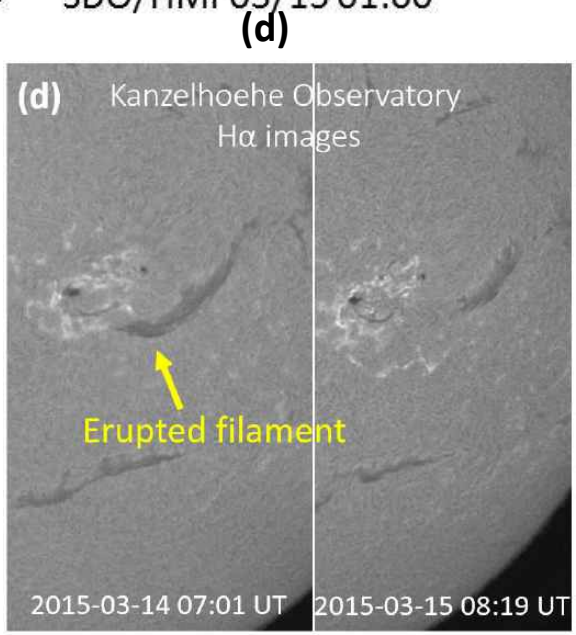
Cho et al. (2017)

Causative solar eruption (commonly accepted)

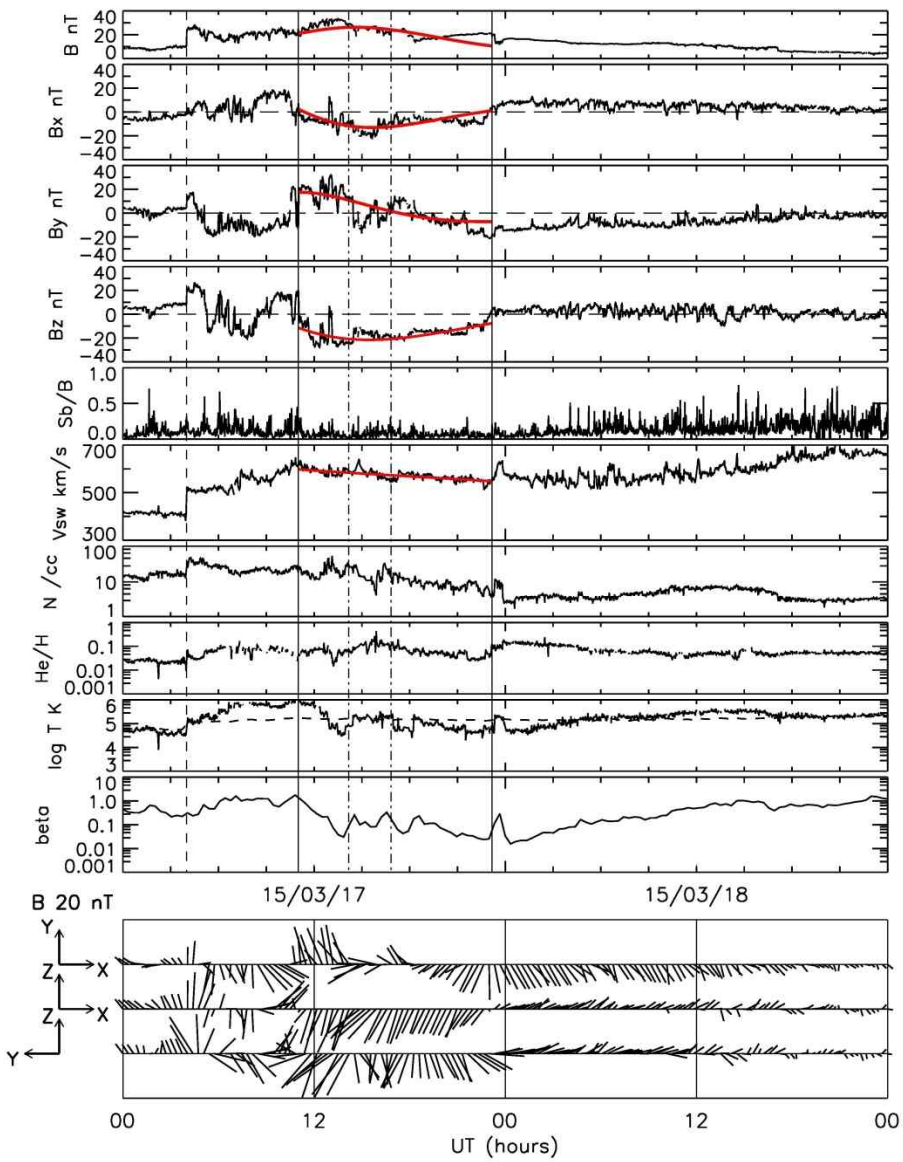


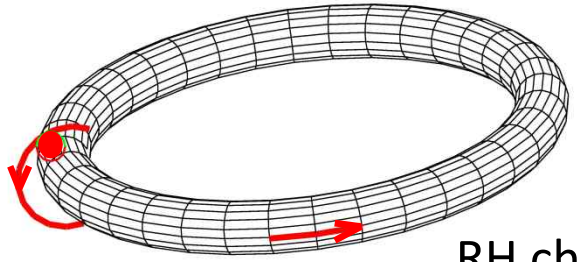
Halo CME: March 15, 01:48 UT (LASCO C2)
C9.1 flare: 01:15 UT, S22W25 (AR 12297)

(a) Full halo CME in LASCO C3 image
(b) Flare ribbons in AIA 304 image
(c) PIL where the main eruption occurred
arrow: orientation of the horizontal field component (for positive helicity)
(d) Filament eruption in H image

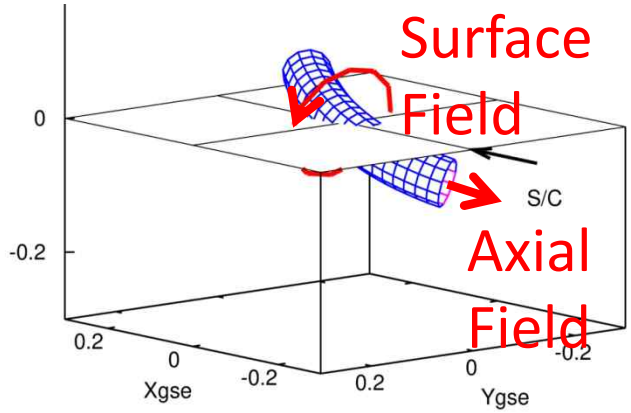


Geometry of interplanetary flux rope (torus-fit)





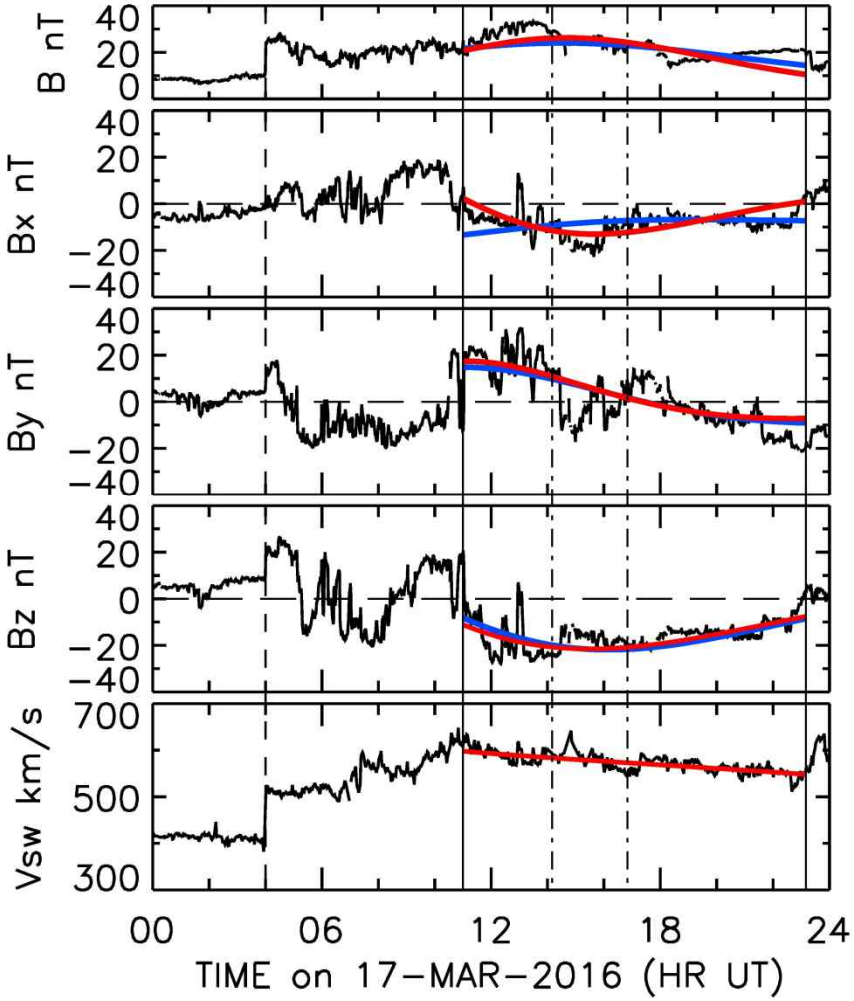
RH chirality



Spacecraft crossed near the eastern flank (consistent with the eruption in the western hemisphere),where the magnetic field is southward throughout passage.

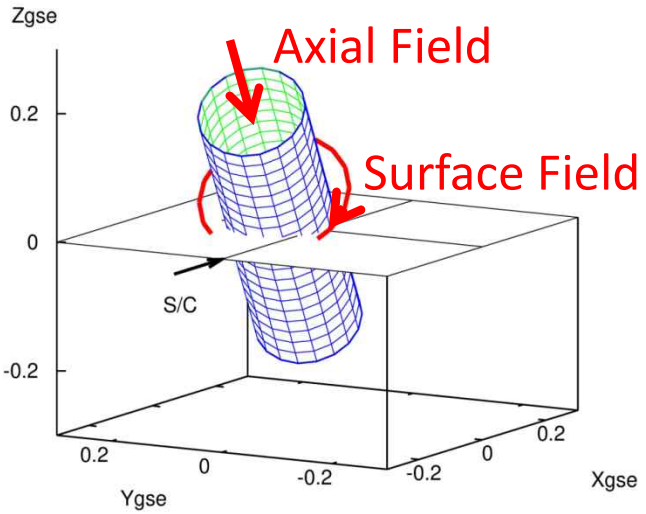
Thus, prolonged southward field attacked the Earth!

Comparison: cylinder vs torus model



red: torus-fit

blue: cylinder-fit



cylinder model

Fit is not so good as torus-fit.

Axis orientation (280) is largely

different from PIL orientation.

Spacecraft passes near the

western edge of flux rope.

Thus, cylinder-fit is unacceptable.

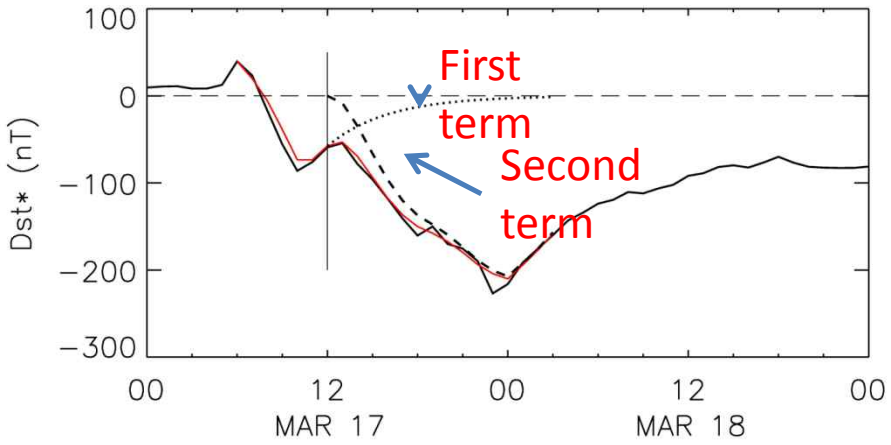
Analysis of Dst Development

According to Burton *et al*. (1975)

$$\frac{dD_{st}^*}{dt} = Q - \frac{D_{st}^*}{\tau}$$ (*Dst**:modified)

Solution is given as:

$$D_{st}^*(t) = e^{-t/\tau} \cdot \left[D_{st}^*(0) + \int_0^t Q_{sw} \cdot e^{t/\tau} dt \right]$$



- Two-step development is NOT the reason for the intense *Dst.*
- Prolonged southward Bz is essential.

Consideration on chain link

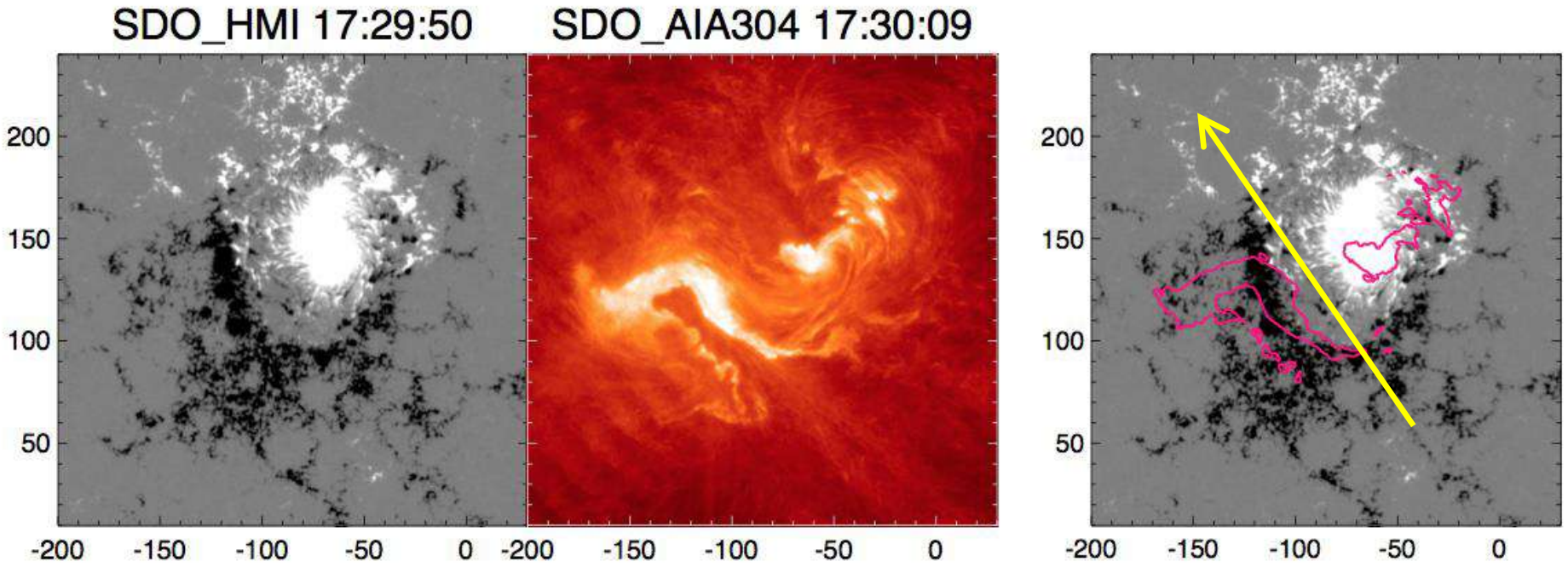
- Flux rope axis: parallel to AR PIL
  - → flux rope formed: parallel to PIL
  - → Rotation effect: insignificant both in corona & in solar wind
- IFR deflection effect:
  - → toward SE plane: required
  - → E-W direction: not clear (because the size is unkown)
  - → If had deflected a bit to WEST, then IFR would not hit Earth.
  - → If had deflected to EAST, then IMF changed S-W-N (shorter duration of Bz < 0.)
- Prediction?

  Even if we could predict the shape of the IFR, it is IMPOSSIBLE the encounter geometry!

Event No. 11: 2014 September 12-13 storm

Question: Why the storm was so weak? (originally P)

Causative solar eruption (originally suspected)

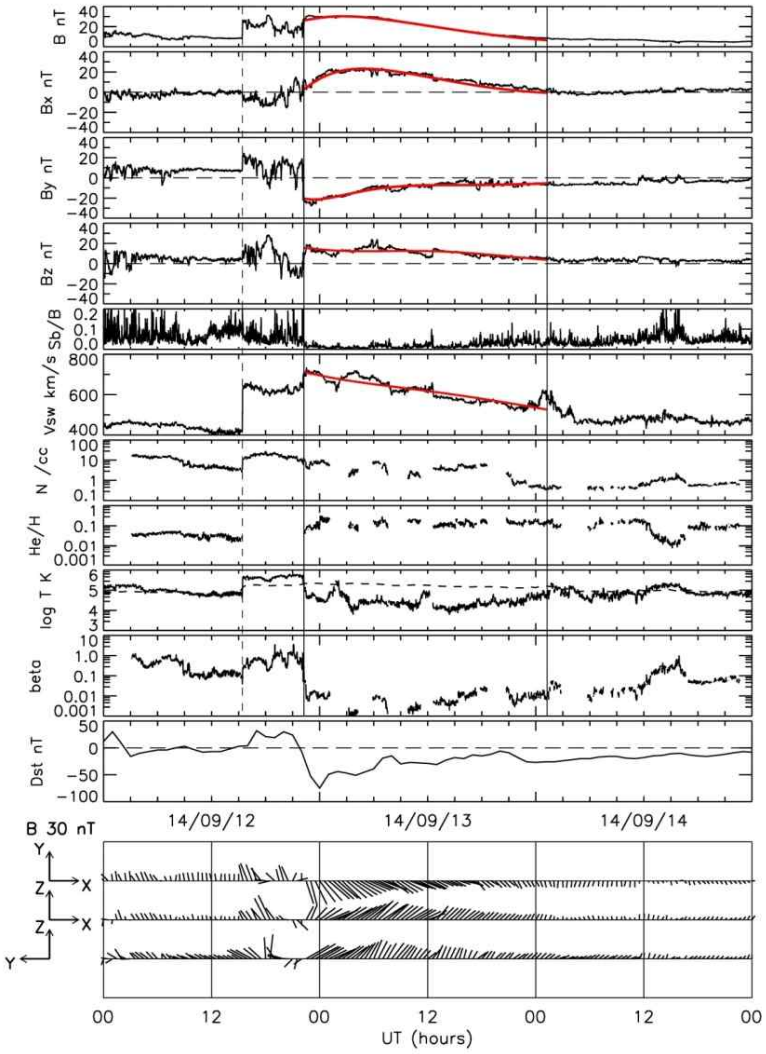


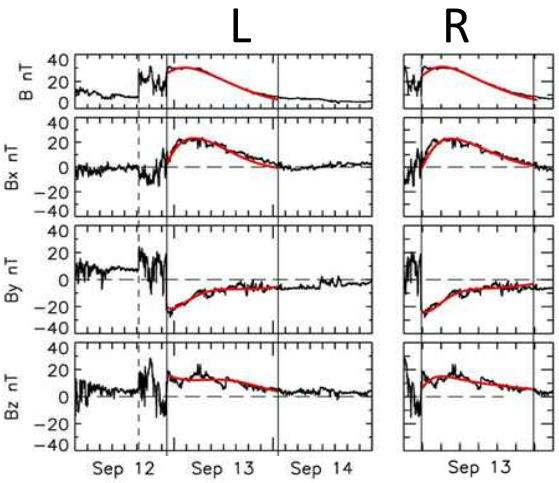
10 September, X1.6 flare, Sep 10/17:21 (start)

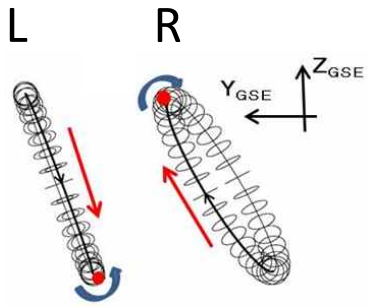
in AR 12158 (N11E05), start: 17:21 UT

A full halo CME : 18:21 UT first appearance in LASCO C2 FOV

Two flux rope geometries: from Torus-fit







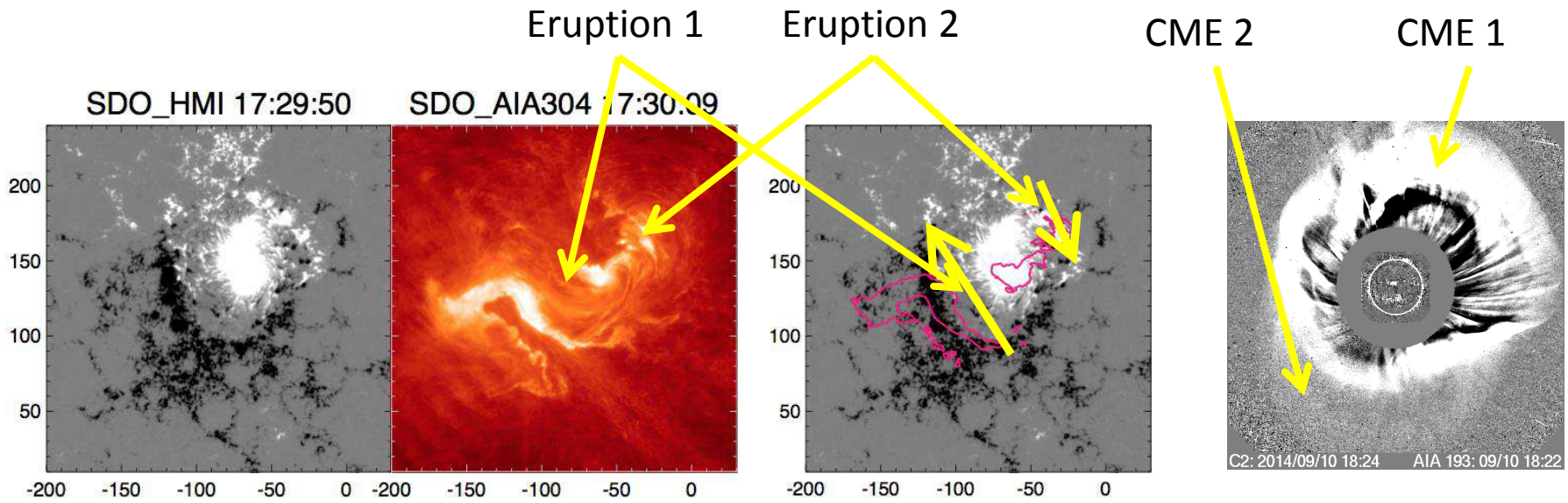
Required polarity change
in the solar source
(if parallelism assumed)

- Both right-handed (R) and left-handed (L) models reproduce the observation.
- Spacecraft passage: southern edge (L)
  northern edge (R)

Bz > 0 throughout the S/C passage

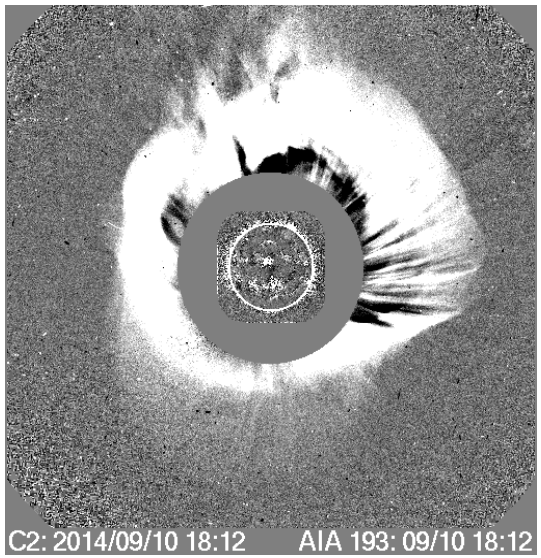
Eruption details (Cho et al., 2017)

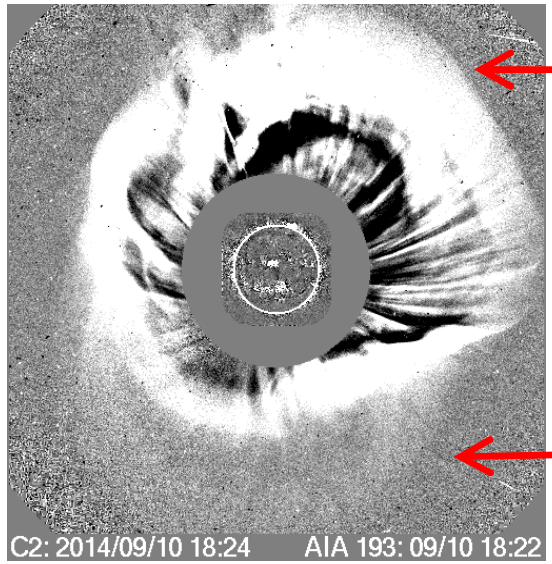
- FACT: a multi-onset event of two separate eruptions:
  - Eruption 1 at N15 E07 , CME 2 (18:00 UT): faint one
  - Eruption 2 at N17 E03 , CME 1 (18:12 UT): prominent one



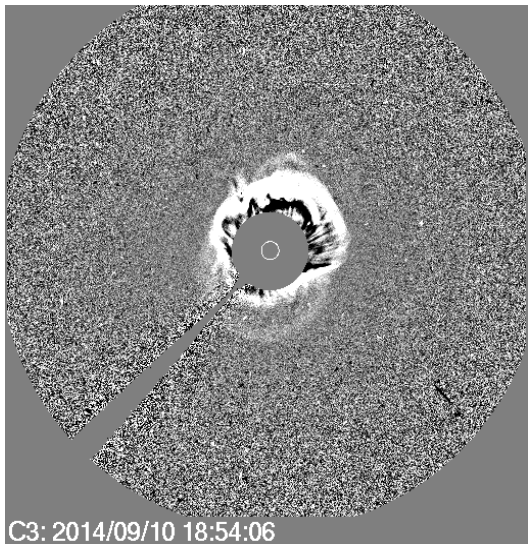
- CME 1 did not hit the Earth.
- CME 2 is the origin of the September 10 flux rope.
  (Required polarity change is satisfied, and axis parallel to PIL.)

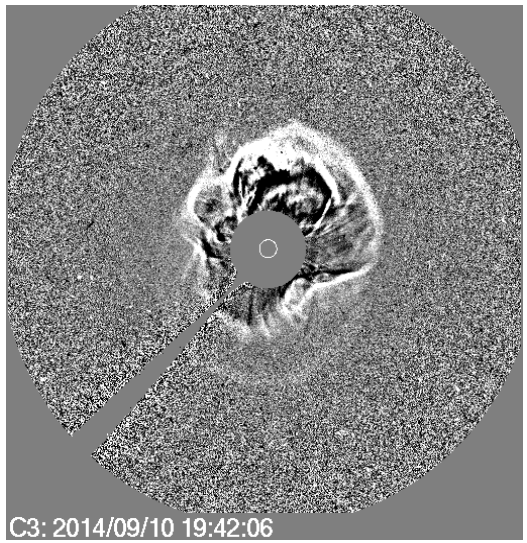
FACT: 2 eruptions and 2 CMEs (one to N, one to S)





CME1: from the western eruption, denser, moved toward the Earth





CME2: from the eastern eruption, lower density, may be a shock,

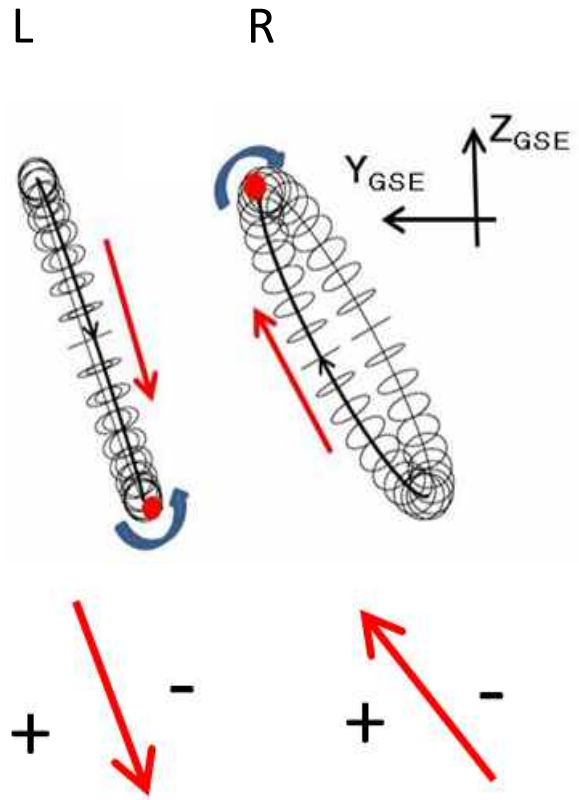
moved to south

Consideration on chain link

♦Flux rope formation, source eruption
→ prominent CME from smaller flare
→ faint CME from larger flare

♦2 CMEs: one hit the Earth, the other not

♦Flux rope (L) axis: parallel to PIL
→ flux rope formed: parallel to PIL
→ Rotation effect: insignificant
both in corona & in solar wind

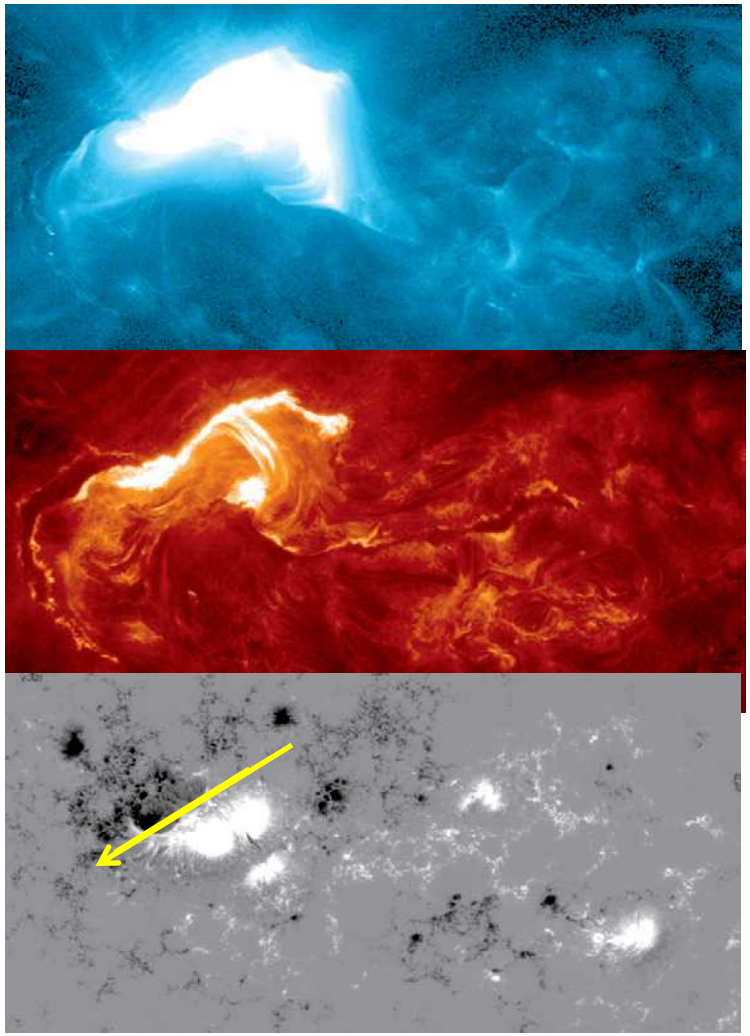


♦IFR deflection
→ very large (CME 2), very small (CME1)
→ If the Earth hit a little East, Bz > 0
→ If CME 1 deflected a little more southward, Bz changed E-S-W

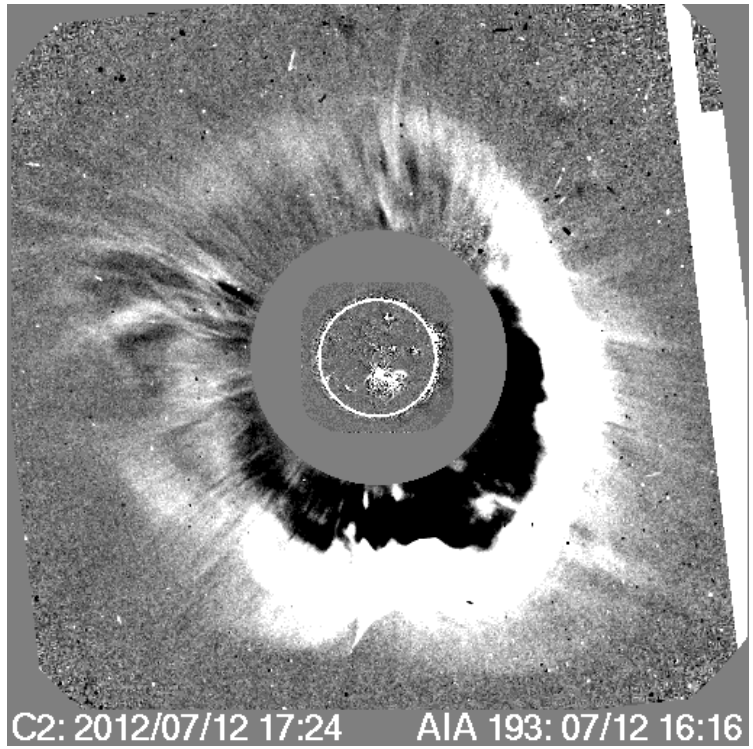
♦Prediction?
Again, IMPOSSIBLE to predict the Earth hitting point?

Event No. 1: 2012 July 12-14 Event (Textbook type)

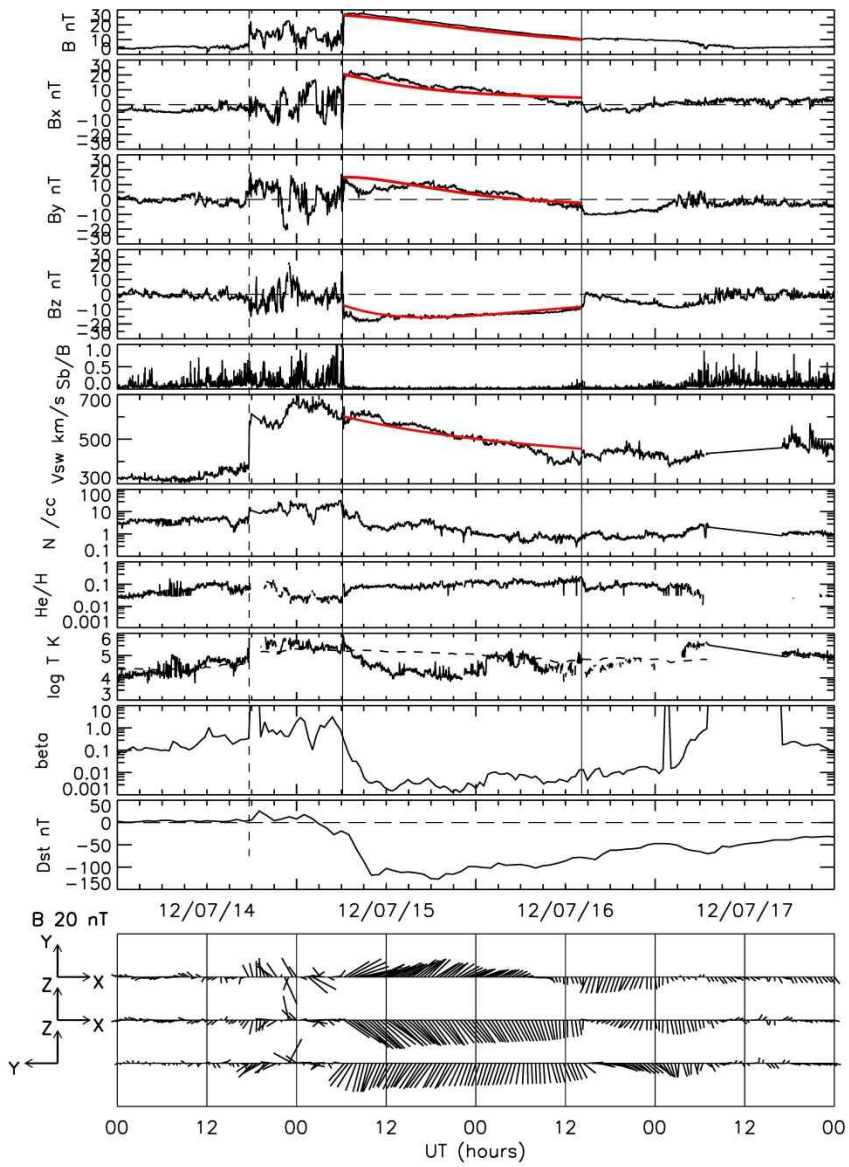
Solar eruption from Dudik et al., 2014

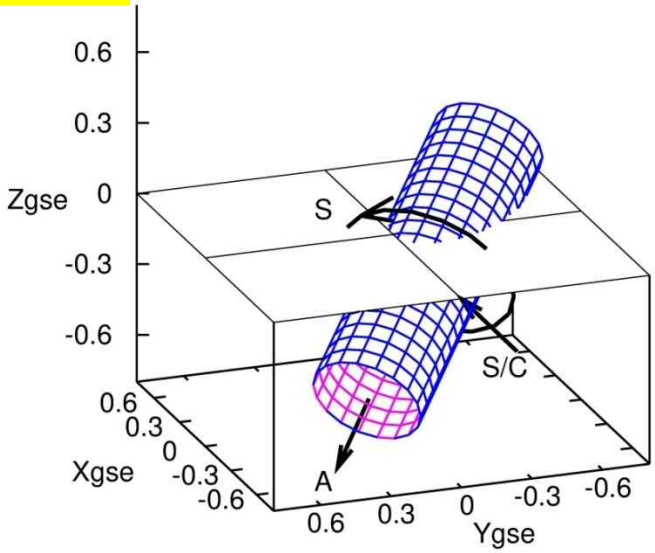


Flare: 2012 July 12, 16:42 (Max)
S14W01 (AR 11520)
2N/X1.4
Full halo CME at 16:48 UT



flux-rope structure from cylinder-fit





Note: Southward field observed throughout the passage, while the PIL at source suggest roughly N-E-S polarity change.

The peculiar encounter explains.

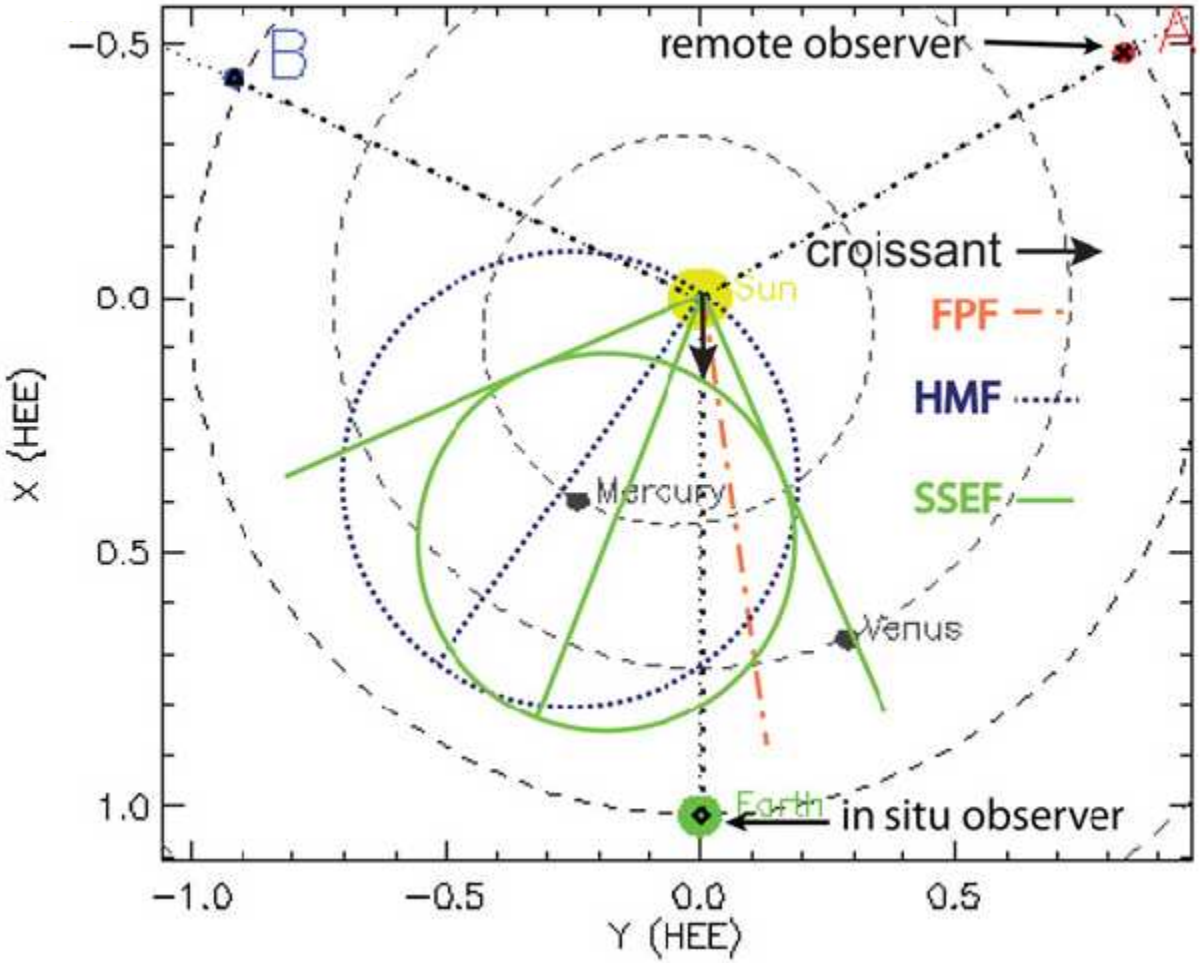
The tilt of cylinder axis: 325

Eastward deflection suggested from the axis tilt.

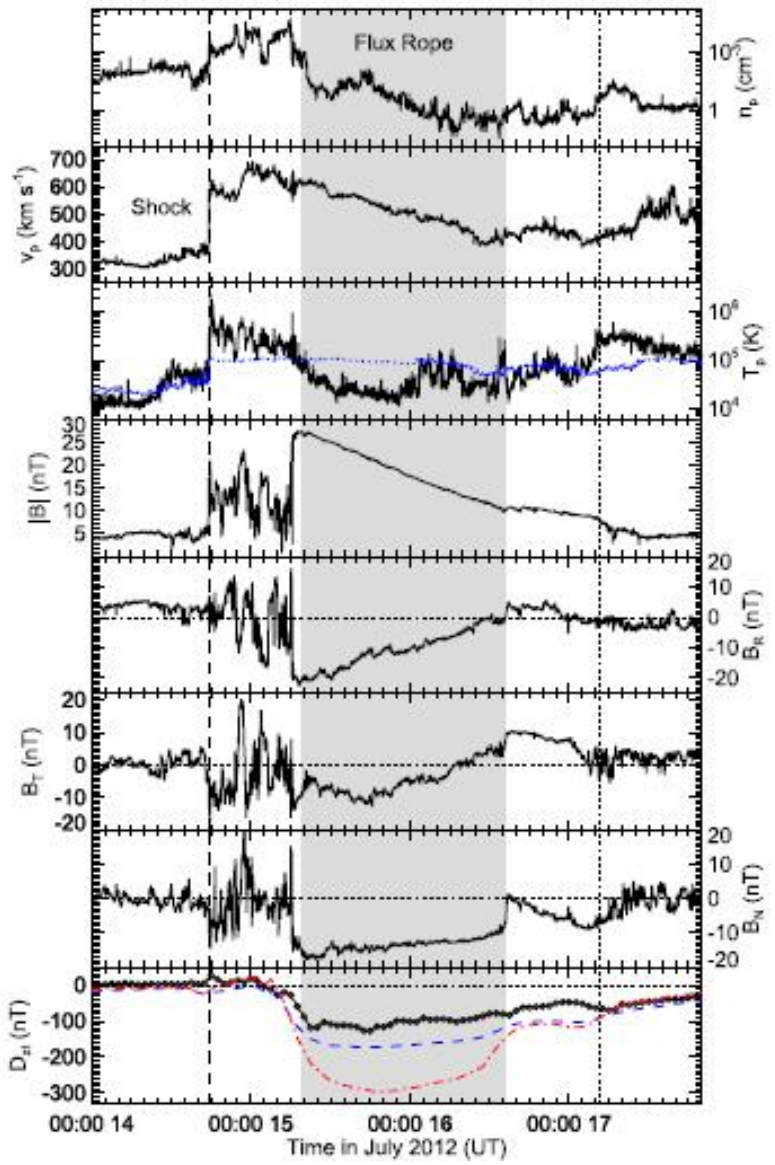
Eastward propagation

Source: S14W01

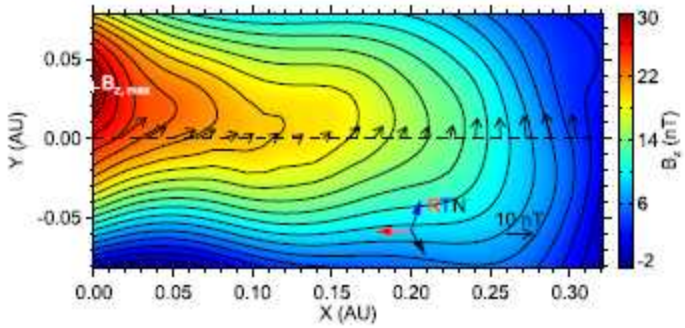
Moestl et al. (2014)
Hu et al. (2016)



Reconstruction by Grad-Shafranov eq.

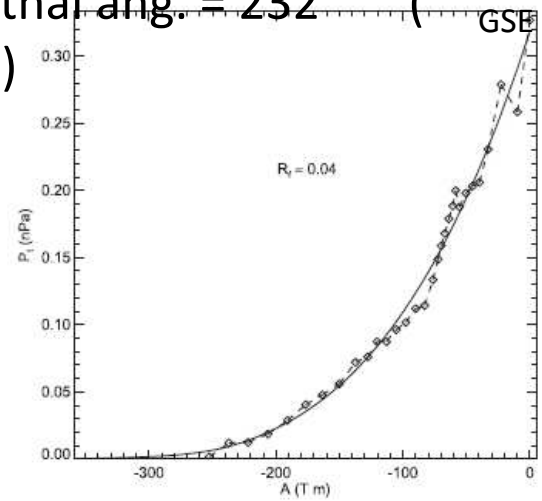


Hu et al., ApJ 829:97, 2016



Elevation = -44 (GSE -44)

Azimthal ang. = 232 (GSE 52)



Perhaps, this is a wrong result caused by relaxing requirement for application of this method.

Consideration on chain link

- Flux rope (L) axis: parallel to PIL
  - → flux rope formed: parallel to PIL
  - → Rotation effect: insignificant
    both in corona & in solar wind

- IFR deflection
  - → Eastward deflection: clear
  - → Northward/Southward deflection: Not clear
    (Size is unknown)

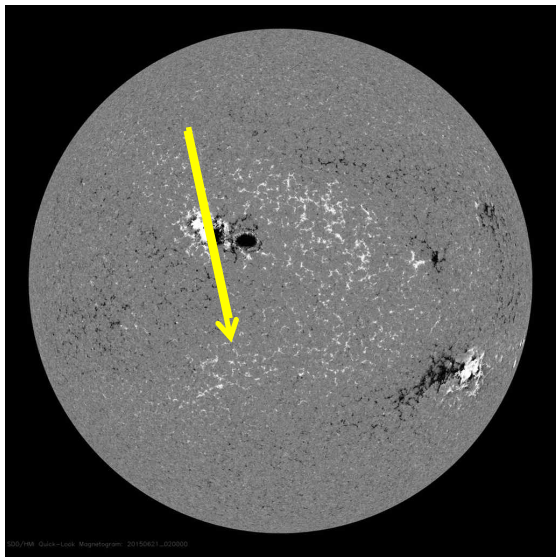
- Southward magnetic field throughout passage:
  Interpreted by the peculiar encounter

- Prediction?
  The peculiar encounter: impossible to predict?

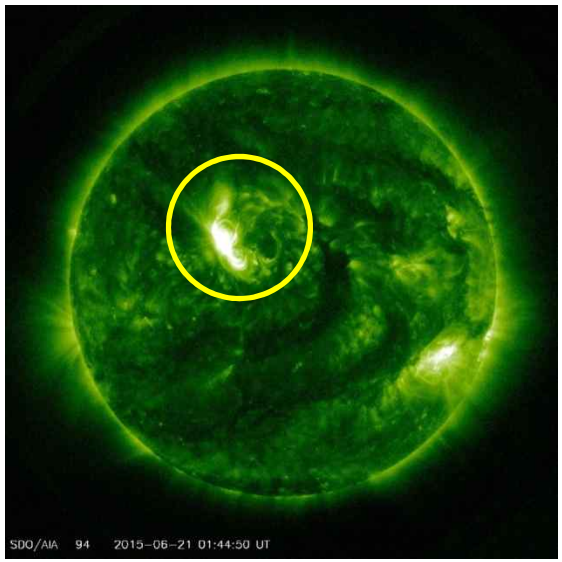
Event No. 6: 2014 Jun 21-24

Minimum Dst = -204 nt (Second biggest storm in Cycle 24)
TB? case with M2.7 flare, halo CME on 21 June, and IFR (MC)

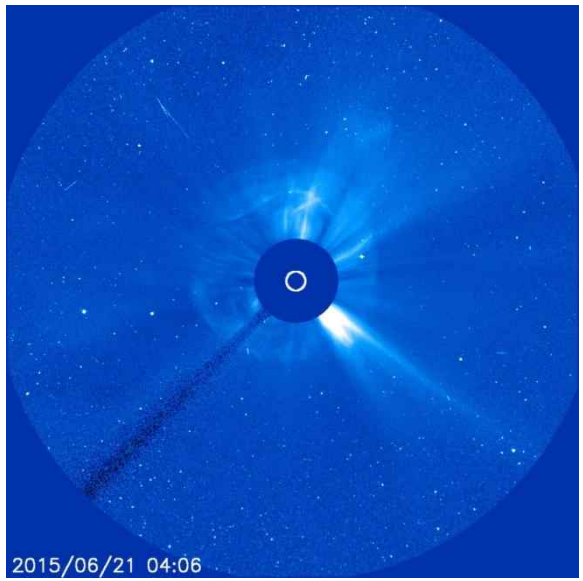
Solar eruption suggested within WG 4



SDO/HMI 2015 June 21 02:00



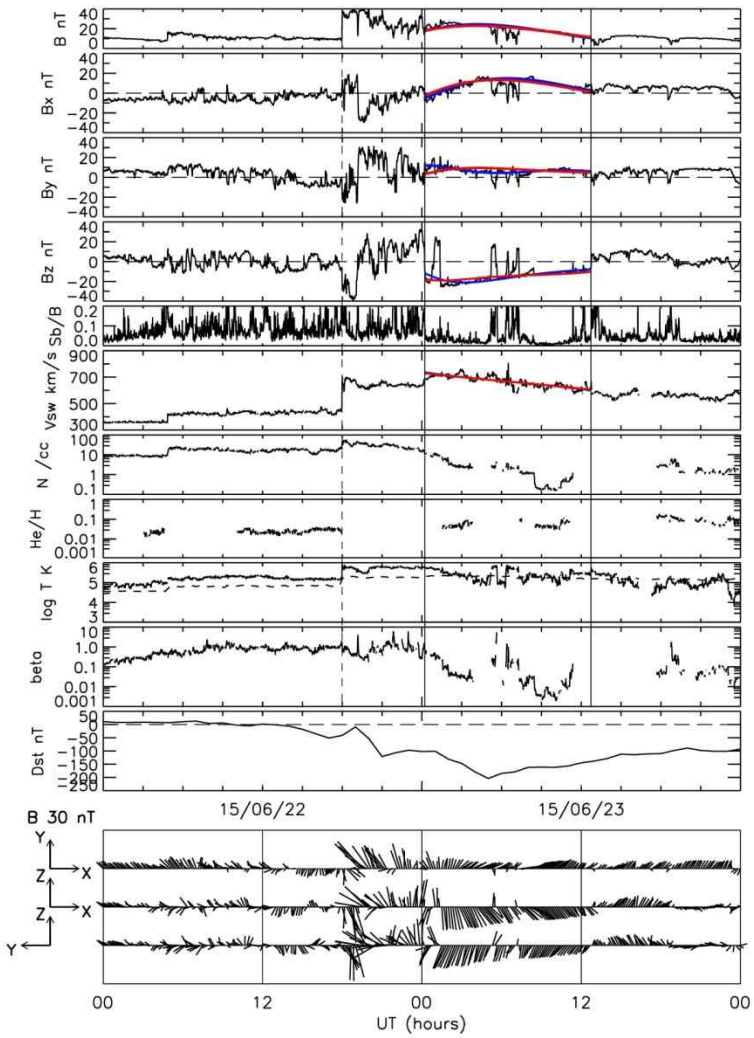
SDO/AIA094 2015 June 21 01:44

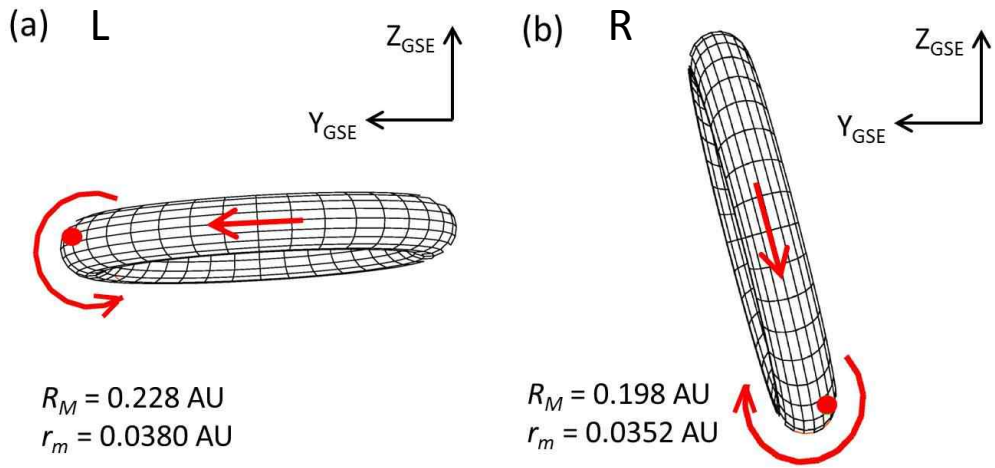


C3: June 21/04:05 UT

This is the only event that deviates from the general feature seen in other vents as described below. <Unsettled>

Two flux rope structures from torus-fit





Required polarity change across PIL
(parallelism assumed between axis and PIL)

Both models reproduce the ACE observations.

IFR Axis orientation:
inconsistent in either of fits.

Blue: Left-handed

Red: Right-handed

Possible approaches toward resolving the problem

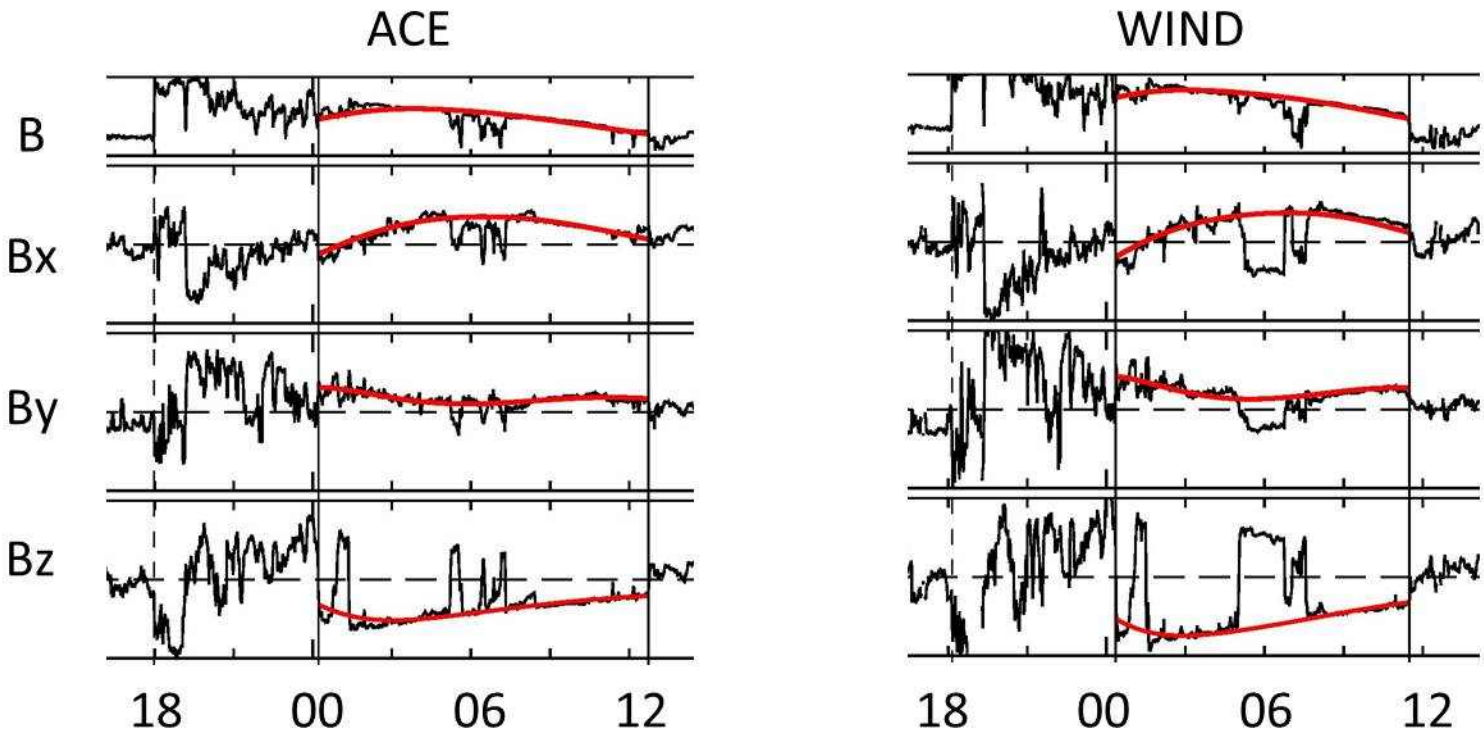
(1) Other possible IFR intervals?
Liu et al. (2016): two separate flux ropes (not shown)

(2) Possibility of other solar source event(s)? This requires:
Careful survey of CMEs
Large deflection of the June 21 CME (avoid Earth hitting)

(3) Attributing to IFR rotation during propagation to Earth
May be needed are:
A different flux rope model (obtained L type: no good)
A different solar source event
Precise interpretation about how it rotated

Possible supporting evidence for approach (2)

Comparison of the ACE and Wind observations

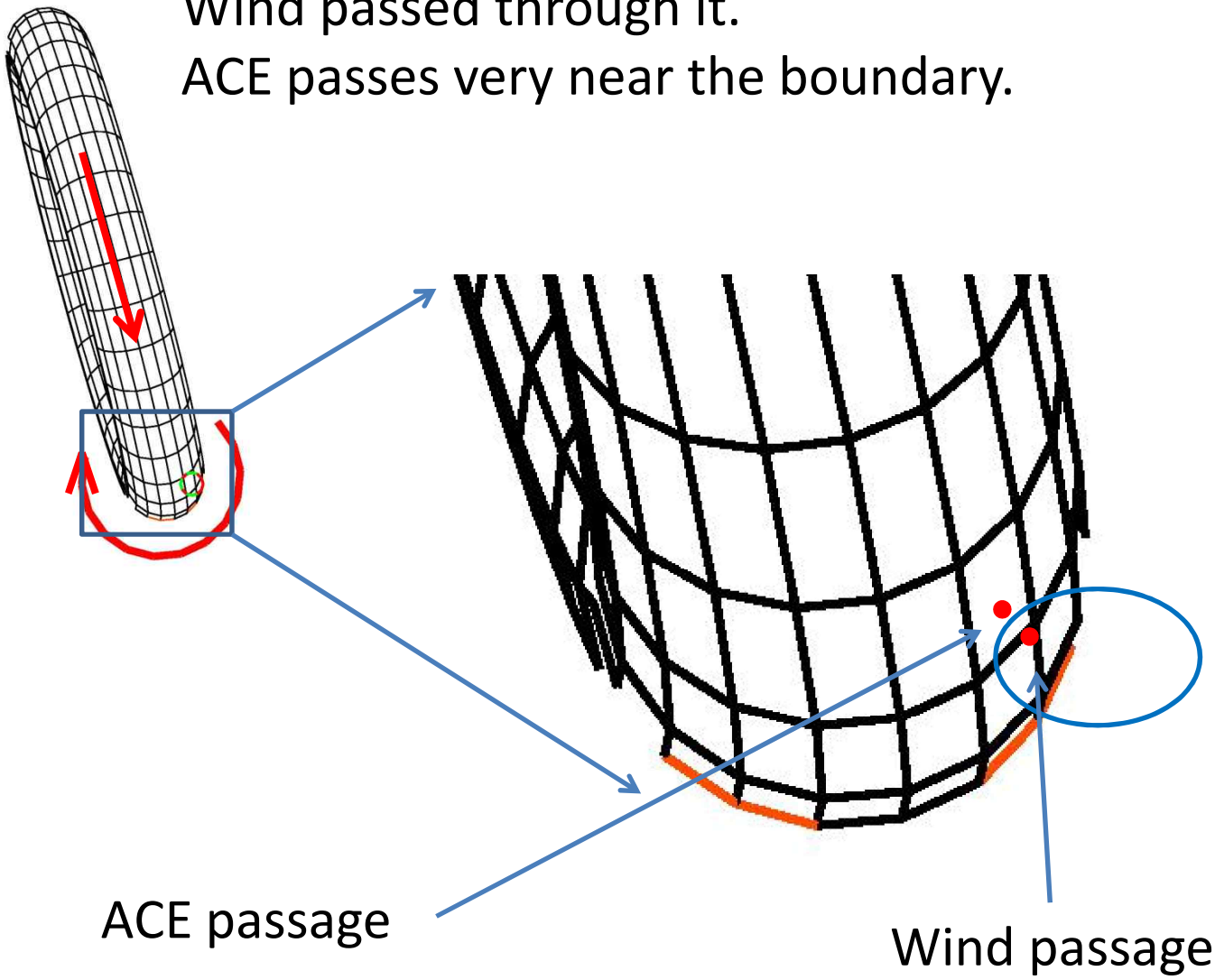


One structure

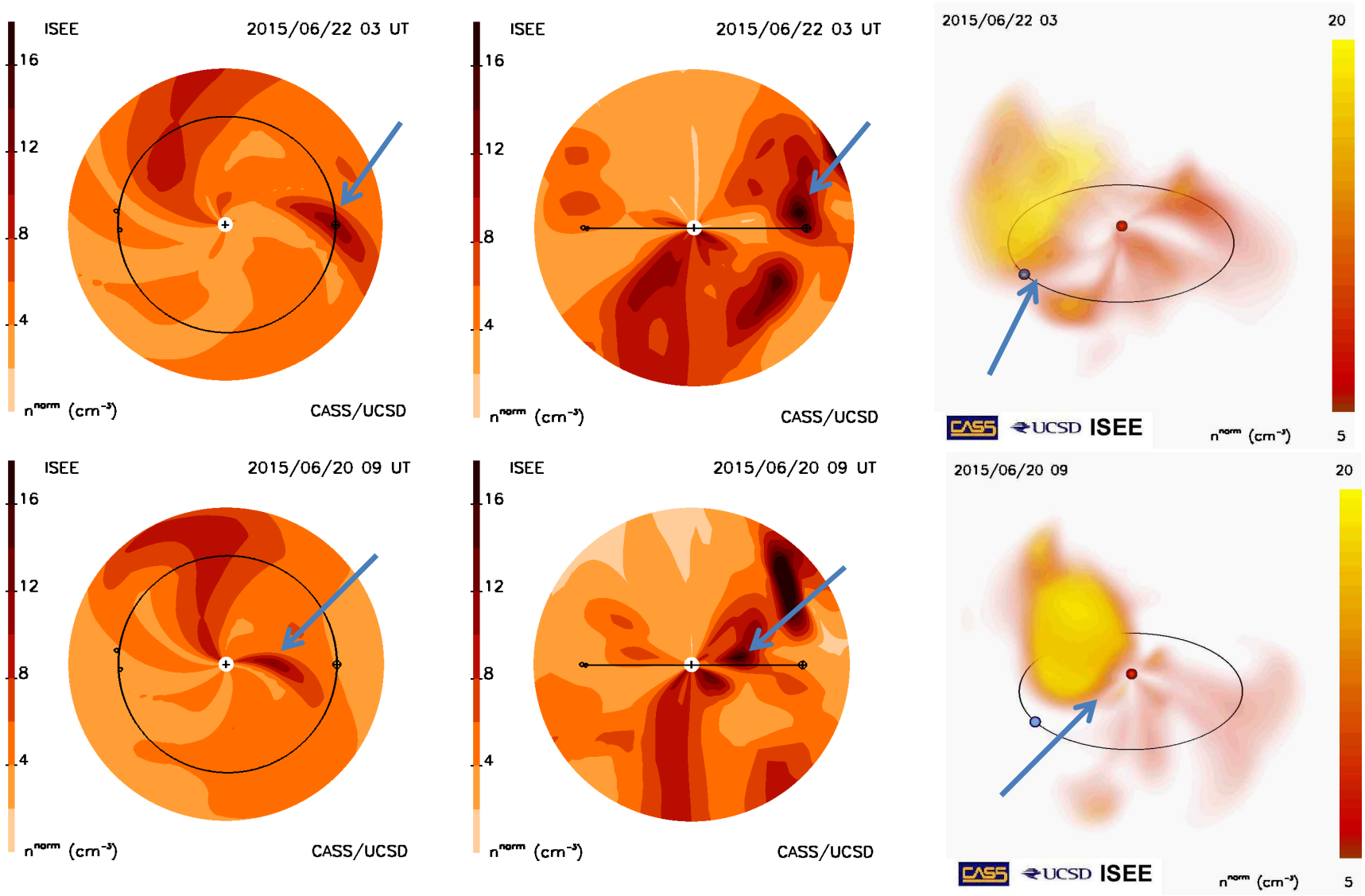
Two structures

Suggested is ….

Some smaller-scale structure penetrates the IFR.
Wind passed through it.
ACE passes very near the boundary.



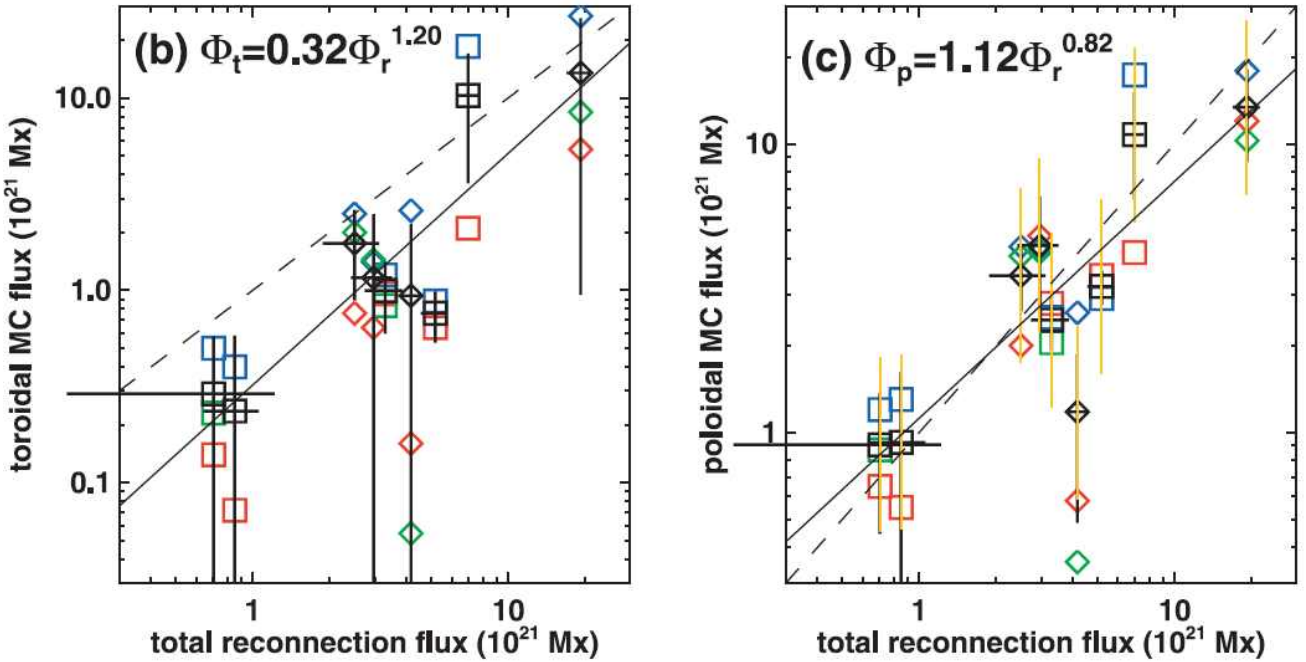
IPS observations shows: the IFR (shock) appears earlier than the flare (June 21/01:42)



What's more about other solar wind quantities needed?

Magnetic field intensity: magnetic flux comparison, Sun and 1 AU

Solar wind velocity: not addressed (relation with IFR is weak)



赤：Qiu et al. (2007)；　青：Leamon et al. (2004)；　緑：Lynch et al. (2005)

From Qiu et al., ApJ (2007)　Other works exist (Hu et al., Gopalswamy et al.)

Global shape of IFR, Distribution of poloidal flux along the axis: necessary but unknown

Summary

We have seen the flux rope structures and their solar origins for the WG 4 campaign events.

It seems possible (at least in principle) to predict magnetic structures of ICMEs from solar observations.

We recognize many problems that need further studies.

- CME-source eruption correspondence: still unclear
- ICME propagation: strongly affects IMF at Earth

We strongly recognize the difficulty of prediction:

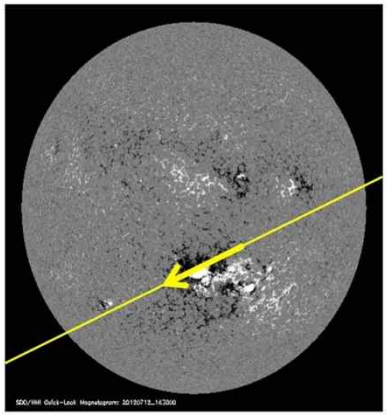
- we may “correctly” predict the shape of ICMEs,
- but what we need is “precise” geometry

Thank you
For
your attention!

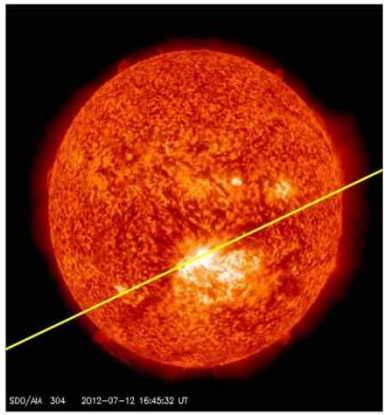
TABLE 2. Analysis Results

ID	Solar Wind (IP Flux Rope)				Solar Source Region		Helicity	tilt
	S/C	Model	R/L	IFR tilt	N/S	PIL tilt	Rule?	agree?
1	WIND	cylinder	R	320	S	325	Yes	Yes
2	WIND	torus	R	323	S	330	Yes	Yes
3	ACE	torus	L	227	N	230	Yes	Yes
4	ACE	torus	L	272	Solar source event is not identified yet			
5	ACE	torus	R	173	S	165	Yes	Yes
6	ACE/WIND	torus	R, L	? ?	Solar source unclear		?	?
7	WIND	torus	L	37	N	42	Yes	Yes
8	SREREO-A	cylinder	R	258	S	(260)	(Yes)	(Yes)
9	ACE/WIND	---	---	---				
10	ACE/WIND	---	---	---				
11	ACE	torus	L	247	N	245	Yes	Yes

Event No.1



SDO/HMI 16:30 12-JUL-2012



AIA 304 16:45 12-JUL-2012

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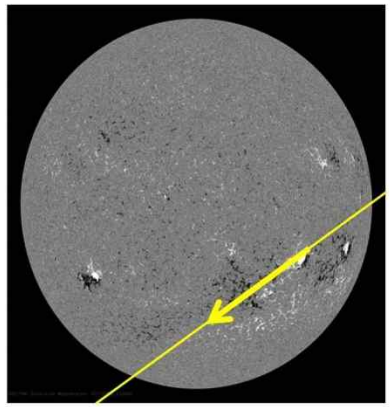
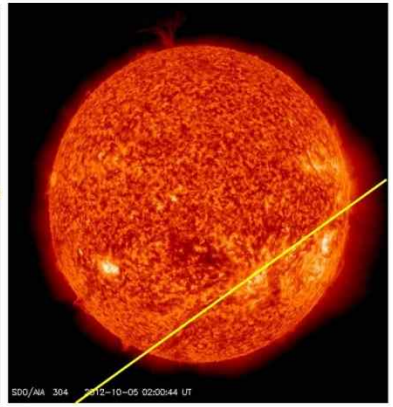
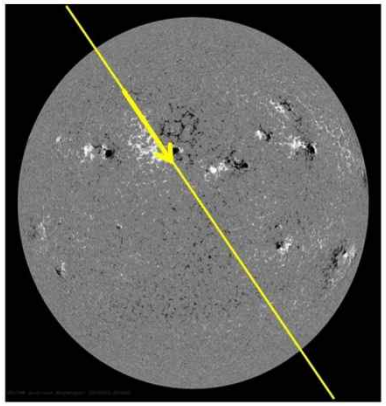


SDO/HMI 02:00 05-OCT-2012

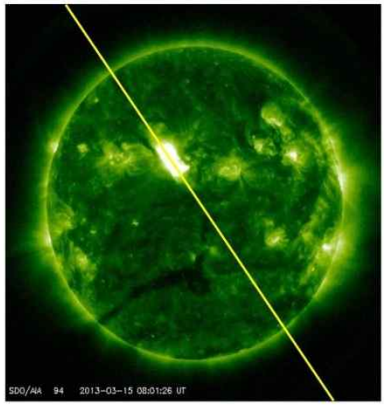


AIA 304 02:00 05-OCT-2012

Event No. 3

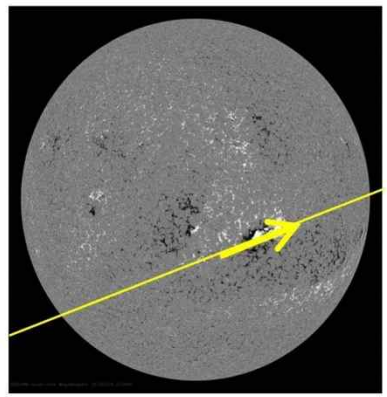


SDO/HMI 05:30 15-MAR-2013

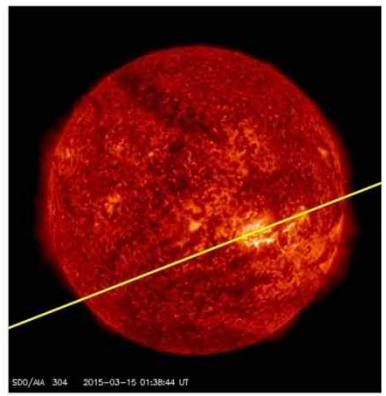


AIA 094 08:01 15-MAR-2013

Event No. 5

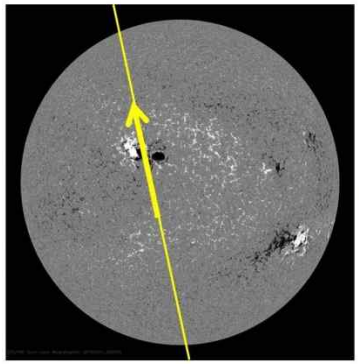


SDO/HMI 01:00 15-MAR-2015

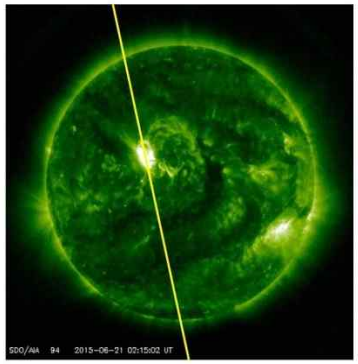


AIA 304 01:38 15-MAR-2015

Event No. 6

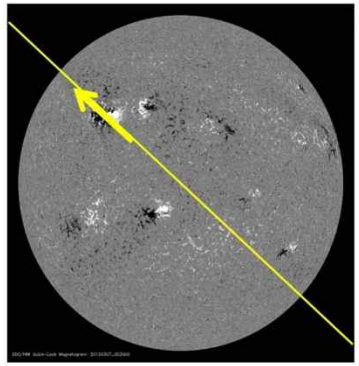


SDO/HMI 02:00 21-JUN-2015

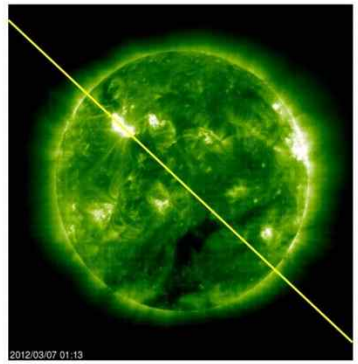


AIA 094 02:15 15-JUN-2015

Event No. 7



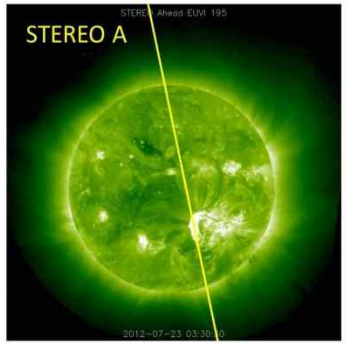
SDO/HMI 00:30 07-MAR-2012



AIA 094 01:13 07-MAR-2012

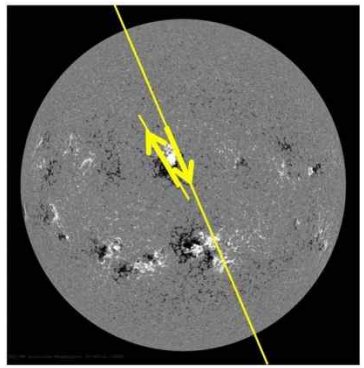
Event No. 8

No Magnetic Field Data (STEREO)

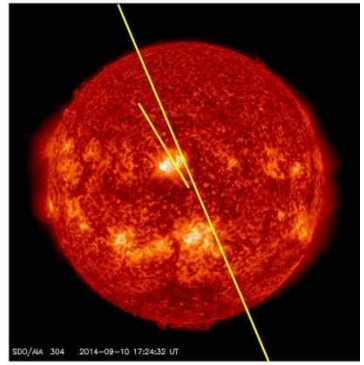


EUVI 03:35 23-JUL-2012

Event No. 11

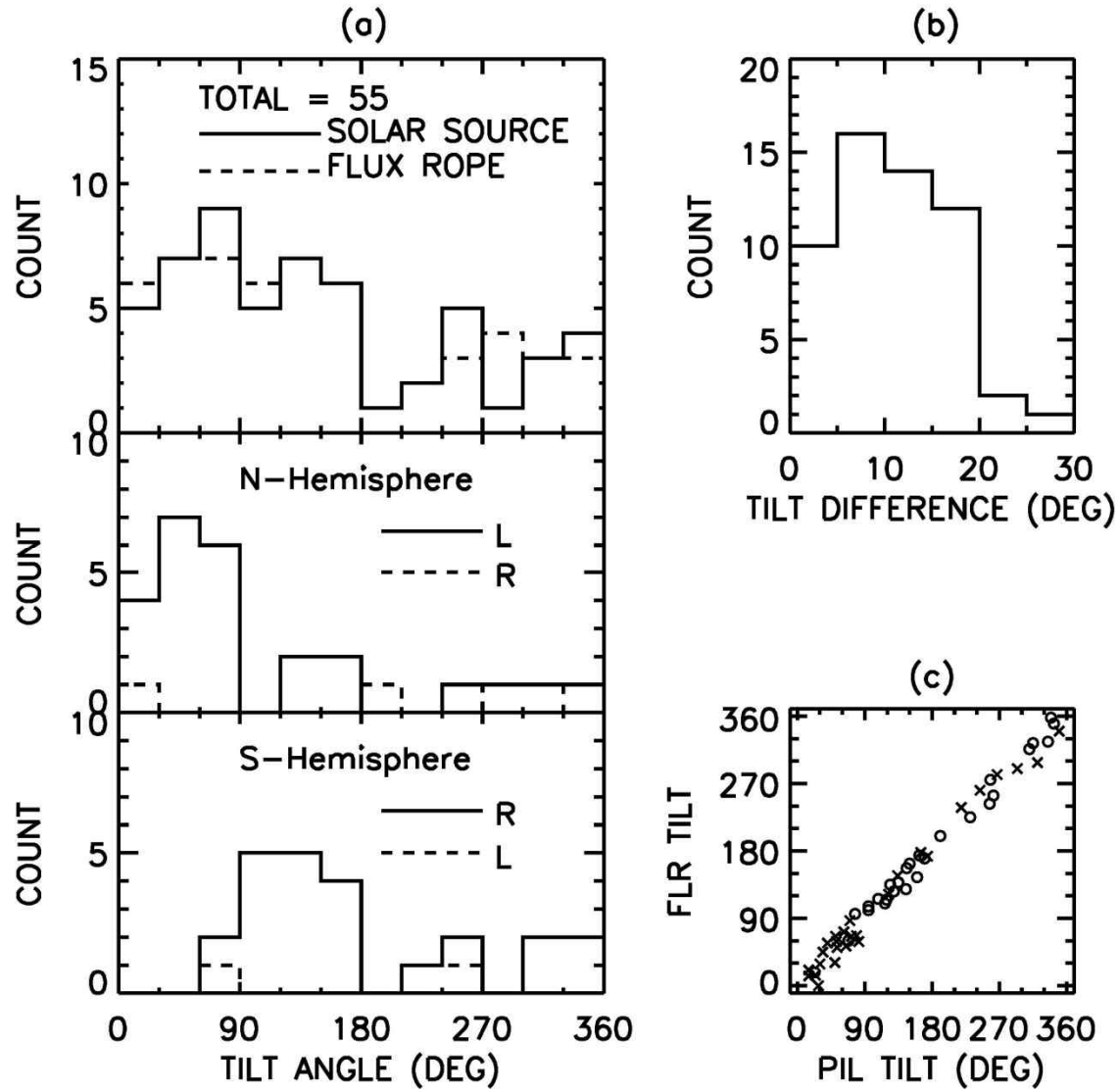


SDO/HMI 17:30 10-SEP-2014

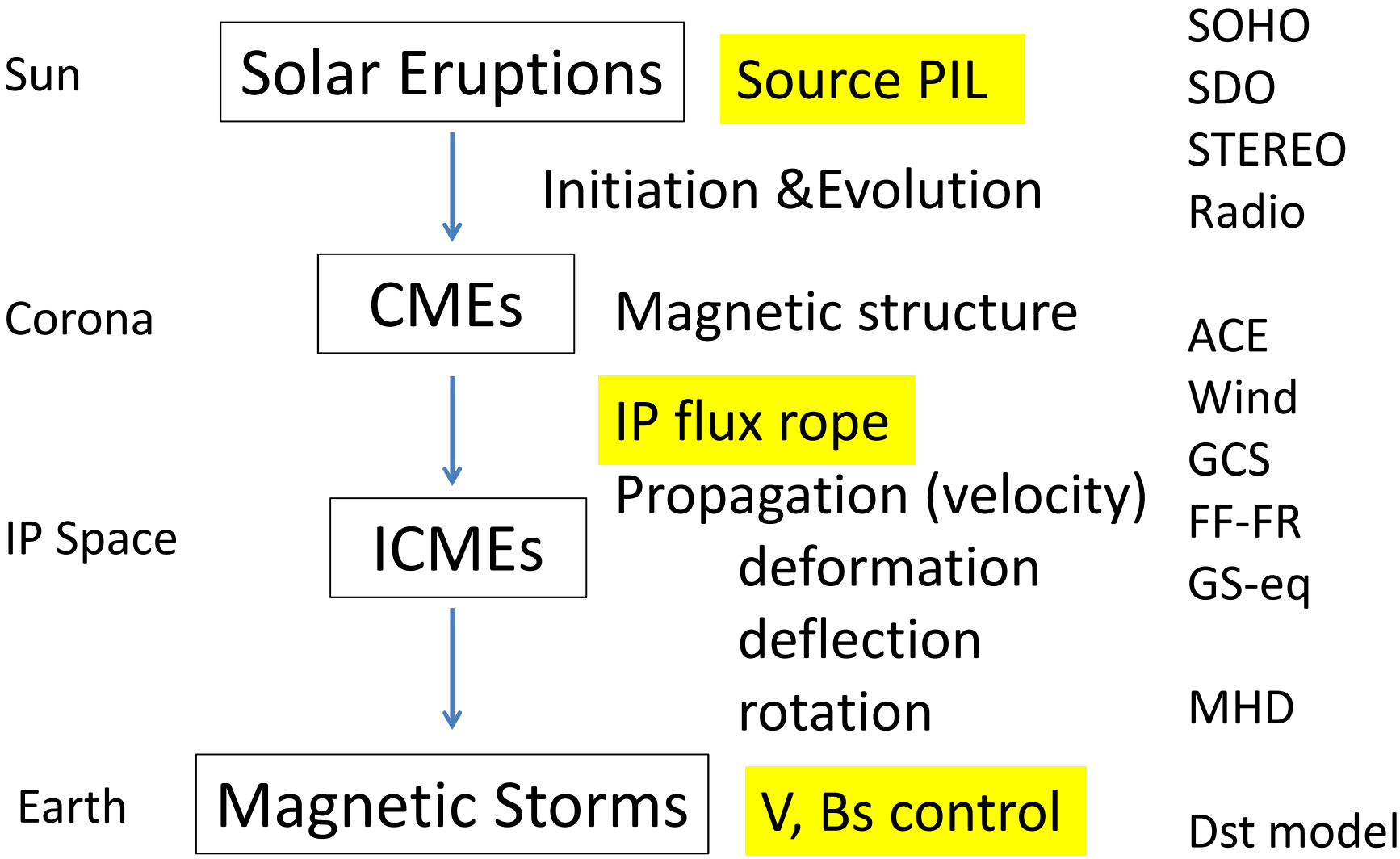


AIA 304 17:24 10-SEP-2014

統計結果：（1）磁気ロープ軸が発生域のPILに平行、（2）helicity rule



Marubashi et al., Solar Phys (2015) 290: 1371-1397. DOI 10.1007/s11207-015-0681-4


Sun
Solar Eruptions
Source PIL
SOHO
SDO
STEREO
Radio
Initiation &Evolution
Corona
CMEs
Magnetic structure
ACE
Wind
GCS
FF-FR
GS-eq
IP flux rope
Propagation (velocity)
deformation
deflection
rotation
IP Space
ICMEs
MHD
Earth
Magnetic Storms
V, Bs control
Dst model