Overview of VarSITI ISEST/MiniMax24 Working Group 4 Studies on Campaign Events

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BOSTON COLLEGE ISR INSTITUTE FOR SCIENTIFIC RESEARCH

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Introduction: ISEST Goals and Approach

ISEST (International Study of Earth-affecting Solar Transients)

- **To improve the scientific understanding of the origin, propagation and evolution of solar transients (CMEs, flares, SIRs) through the space between the Sun and Earth.**

  - Enabled by continuous observations of Sun and heliosphere from an array of spacecraft and ground-based instruments, global numerical simulations of the system, and theoretical analysis.

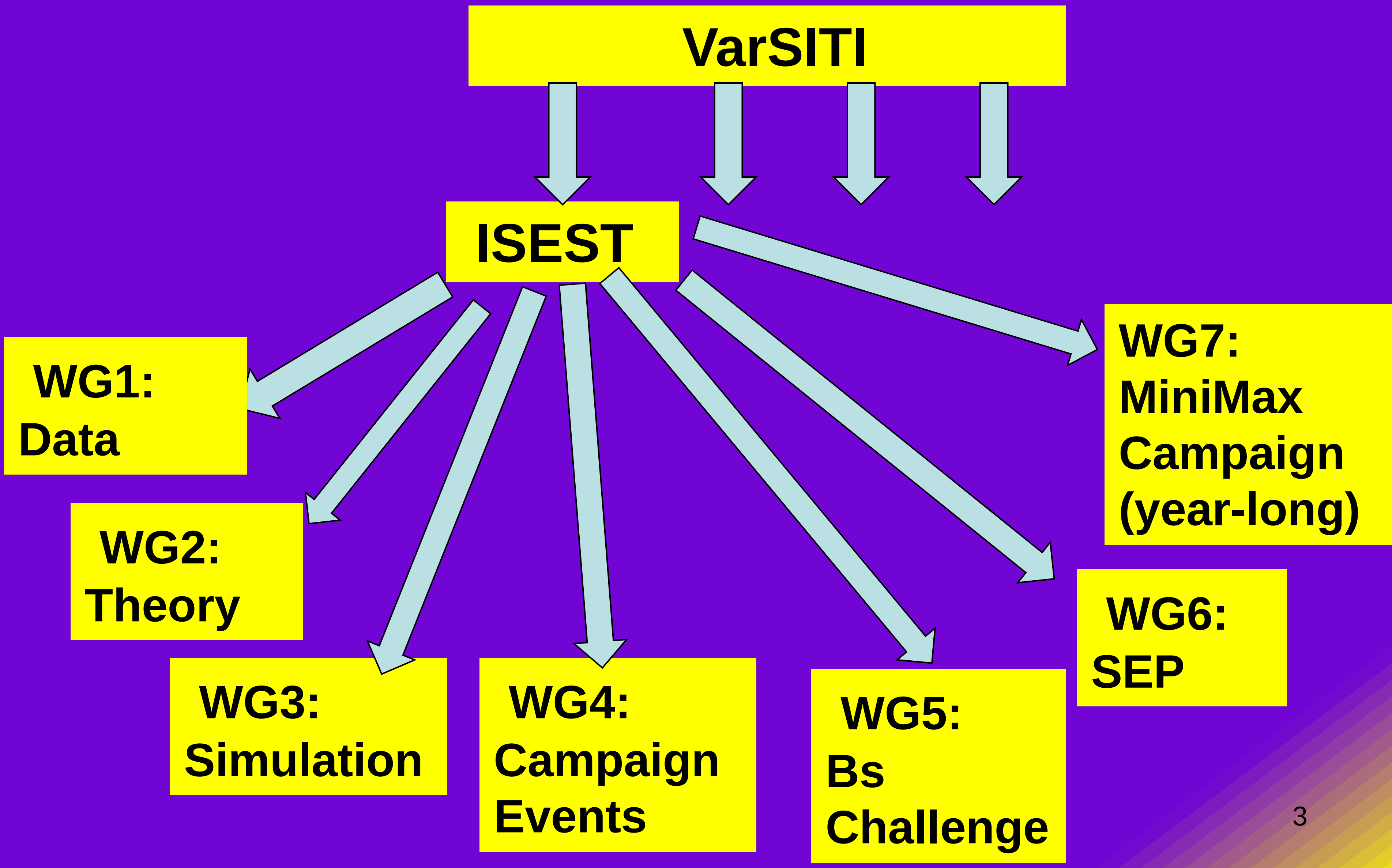
- **To develop/improve the prediction capability for these transients' arrival and potential impacts at Earth.**

  - Issues include the transit times of CMEs and shocks from the Sun to their arrival at Earth and their impacts. Effects of impact → arrival speed, magnetic field orientation (B_z) and its complexity.

- **ISEST Wiki created for data repository, discussion forum & education:**
  http://solar.gmu.edu/heliophysics/index.php/Main_Page

- **To study all the issues and place results in a global picture, ISEST has 7 working groups (WGs) as follows:**

ISEST Working Groups



Introduction: WG4

➢ **Task of WG 4 → integrate theory, simulations and observations to better understand the *chain of cause-effect activity from the Sun to Earth* for a few carefully selected events.**

- **WG 4 examines textbook & less well understood events, eg, stealth & problem CMEs.**
- **Why do forecasts fail and how can we improve them?**
- **Analyze the complications in linking CMEs to ICMEs.**
- **WG 4 wiki: *http://solar.gmu.edu/heliophysics/index.php/Working_Group_4***

➢ **This is a progress report highlighting recent work by members of WG 4.**

➢ **We highlight 5 case studies, incl. 1 "textbook" case and the 2 Sun-Earth events from last year that caused superstorms. These were chosen to illustrate different problems in understanding the chain from cause to geo-effect.**

WG 4 Participants & History

David Webb: WG 4 Leader
Nariaki Nitta: WG 4 Co-Leader

WG4 Participants:

A. Asai, D. Biesecker, V. Bothmer, P. Gallagher, N. Gopalswamy, P. Hess, B. Jackson, E. Kilpua, Y. Liu, N. Lugaz, K. Marubashi, L. Mays, C. Moestl, A. Monga, T. Mulligan, T. Nieves-Chinchila, D. Odstrcil, S. Patsourakos, L. Rodriguez, B. Schmieder, K. Shiokawa, T. Skov, N. Srivastava, M. Temmer, B. Thompson, Y. Wang, C.-C. Wu, J. Zhang

Contact me if you should be want to be added as a member

WG 4 History:

- **Focus on 1 Textbook (12-14 July 2012) & 1 Problem (4-8 Oct. 2012) events**

- ISEST #1	June 2013	Hvar, CR
- CAWSES-II Sym.	Nov. 2013	Nagoya, JP

- **List expanded to included recent events with interesting challenges**

- STP13 + ISEST #2	Oct. 2014	Beijing, CH
- SHINE	July 2015	Stowe, VT, USA
- ISEST #3	Oct. 2015	Mexico City, MX
- VarSITI #1 + ISEST #4	June 2016	Albena, Bulgaria

ISEST / MiniMax WG 4 Event List

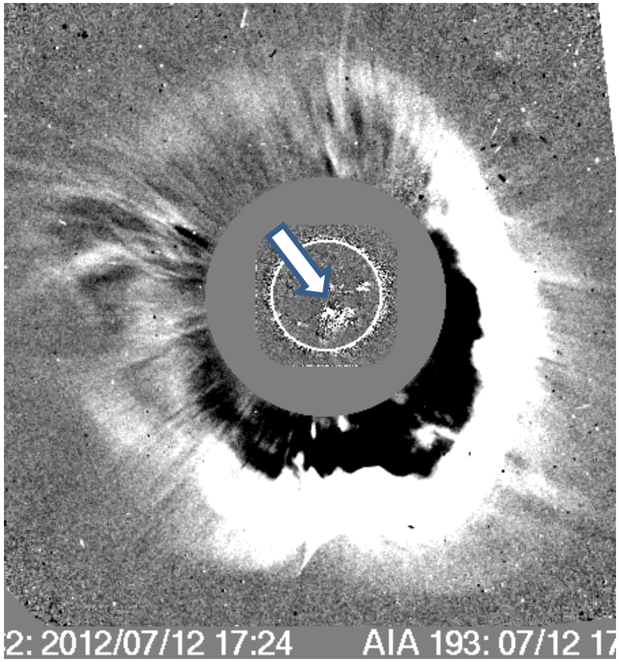
Dates	Source	Geo-response*	Dst	Type
VarSITI-wide Campaign Study Events				
1) 2012 July 12-14	X1 flare, fast CME	Shock, MC, Strong storm	-127	TB
2) 2012 Oct. 4-8	Strong CME, but multiple weak surface signatures, slow propagation to Earth	Medium storm	-105	P
3) 2013 March 15-17	M1 fl, EP, IV, fast halo	Shk, MC?, SEP, Strong stm	-132	TB
4) 2013 June 1	Slow CME on 27 May? CH influence? Cause of Strong stm unclear; CIR?		-119	P
5) 2015 March 15-17	C9;C2 fl, EP, fast CME	Shock, sheath, MC, “Super” storm	-223	P/U?
6) 2015 June 22-24	2 M-fl, fast halo CMEs	Shock, sheath, MC, SEP, “Super” storm	-204	TB?
Other ISEST/MiniMax Study Events				
7) 2012 March 7-9	X5 fl, wave, fast CME	Shock, MC, Strong storm	-131	TB
8) 2012 July 23-24	2 fls, EPs	Extreme ST-A event; “Strong storm“	Carr.-type	TB?
9) 2012 Jan. 6	CME <2000 km/s, over WL.	GLE at Earth	No	P/U
10) 2014 Jan. 7-9	X1 fl, wave, fast asym halo	Shock, SEP. No storm- CH deflection; AR channeling?	No	P/U
11) 2014 Sep. 10-13	X2 fl, wave, sym halo. Evolution of source AR also of interest.	Shock, MC, Mod. storm	-75	P/U

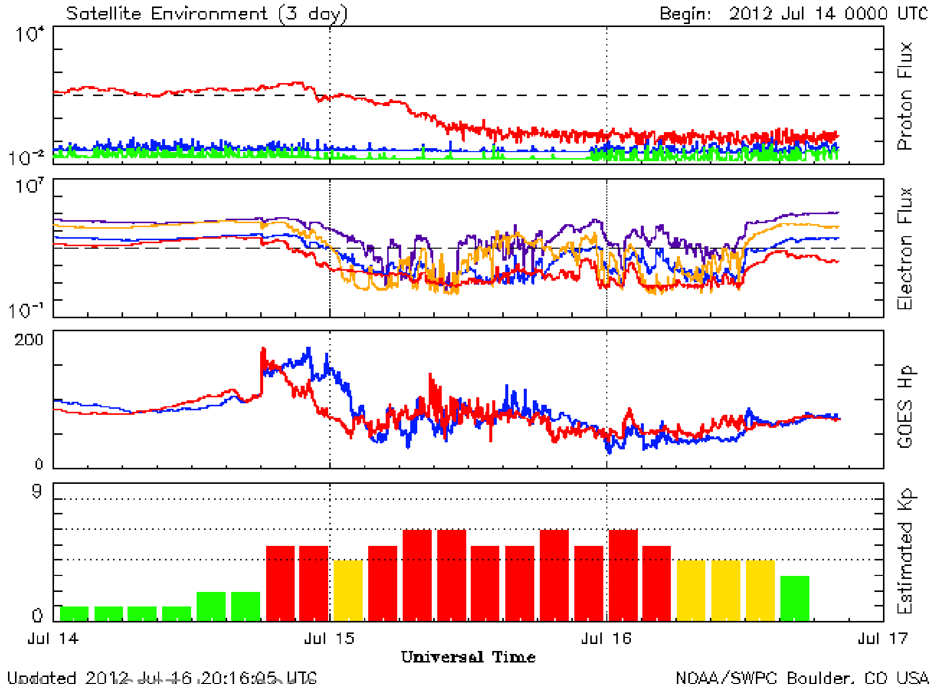
Type: TB = Textbook; U = Understand chain; P = Problem

xx) Events featured in this talk

1) A "Textbook" Event: 12-14 July 2012

- Complete chain of a well-observed Sun-to-Earth event → from solar source, through IP propagation, to its geoeffects. Illustrates the scientific and prediction questions related to space weather.
- On 12 July 2012: X1.4 flare in AR 11520 (arrow). LASCO full halo CME with initial speed ~1300 km/s.
- On 14 July ICME arrived at L1/Earth with shock, sheath, and 2-day long MC. Strong southward IMF in the MC produced a moderate geostorm (peak Dst = -127 nT), *as predicted*, with beautiful aurora over the Earth, extending into the 15th.
- Papers: *Moestl et al. (ApJ, 2014) – Propagation kinematics; Hess & Zhang (ApJ, 2014) – Propagation, drag; Cheng et al. (ApJ, 2014) – FR eruption; Shen et al. (JGR, 2014 – 3D MHD), Dudlik et al. (ApJ, 2014).*





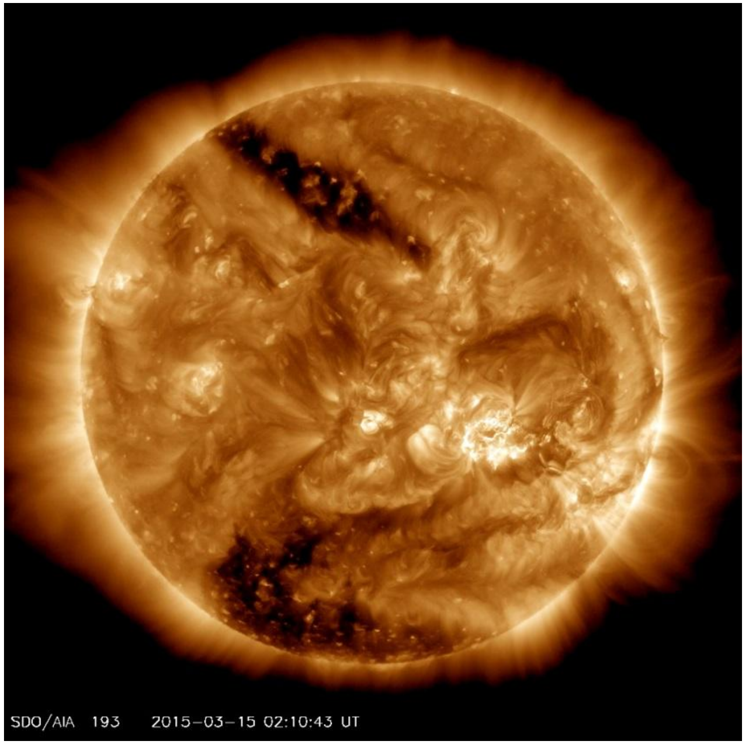
2) Problem Event; Storm Under-Predicted, now Understood?

Last year we had the first "superstorm" of this cycle, on 15-18 March 2015, the St. Patrick's Day storm. It has generated much interest; e.g., special Joint GEM-CEDAR campaign event; JGR SI. Given the relatively weak preceding solar activity and CMEs offset to the south and west, only a minor storm was forecast.

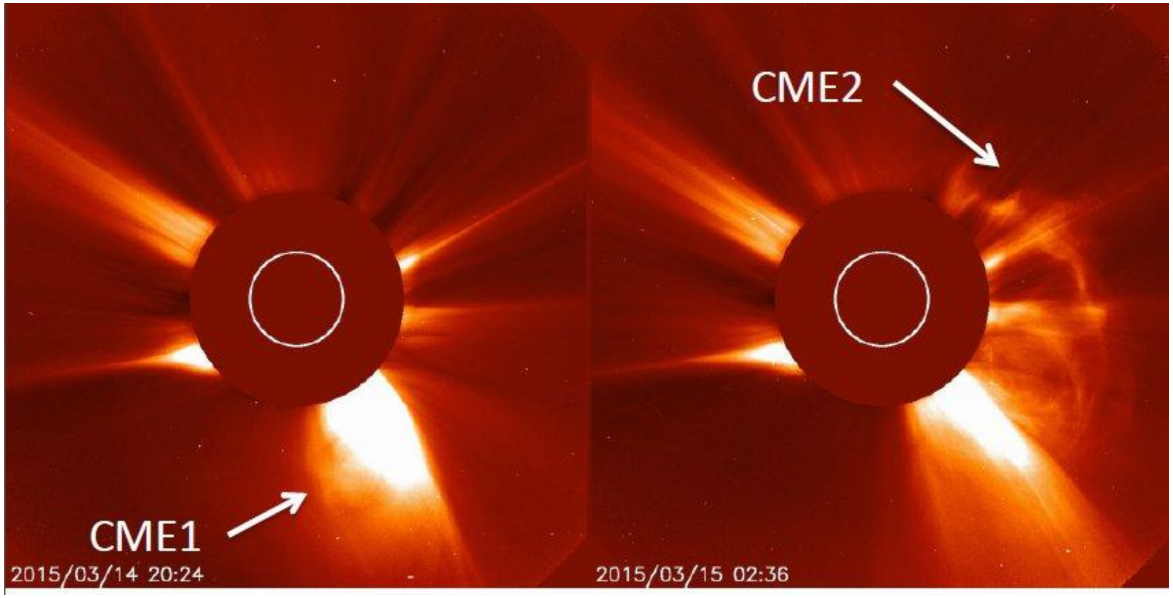
- **A slow CME occurred to the south late on March 14 with a small filament eruption. Then early on March 15 an asymmetric halo CME with a C9.1 flare erupted from the same active region (12297 to SW).**

- **3-Day Forecast Issued by NOAA SWPC on 2015 March 15, 12:30 UT:**
"Initial analysis of coronagraph imagery and subsequent WSA-Enlil model output suggests a glancing blow from the western flank of the CME very late on 17 Mar into 18 Mar… G1 (Minor; Kp=5) geomagnetic storms are likely on day three (18 Mar) due to a combination of CME activity from 15 Mar as well as recurrent coronal hole high speed stream effects."

- ***What happened?***
At the Sun: 2 flares/CMEs occurred.
During transport → Interaction with an SIR & deflection.
At Earth → Major G4 (Kp=8) long-duration storm!



2 Possible Source CMEs Launched on March 14-15



➢ **CME 1 - March 14, ~12:36 UT: slow (350 km/s), toward S**

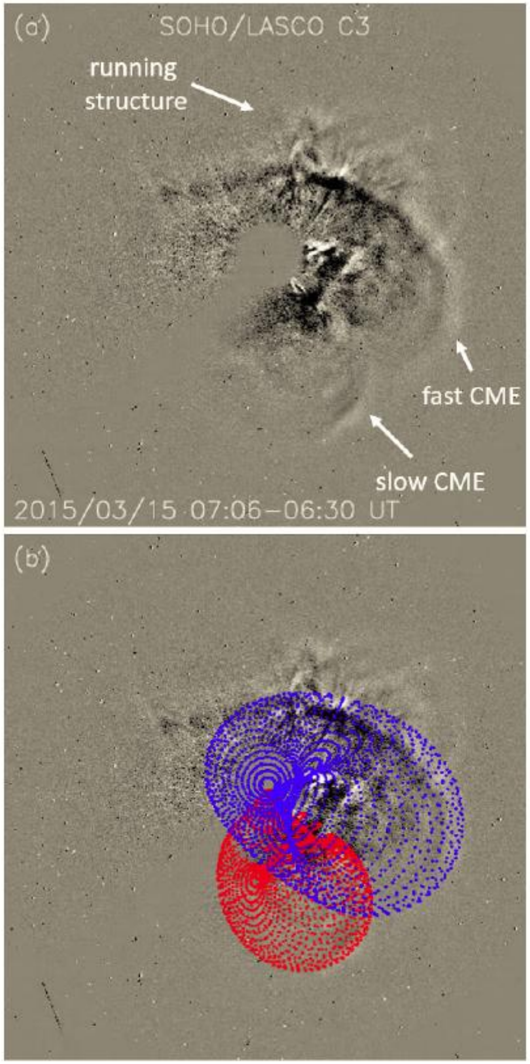
➢ **CME 2 - March 15, ~01:36 UT: fast (1100 km/s), toward W**

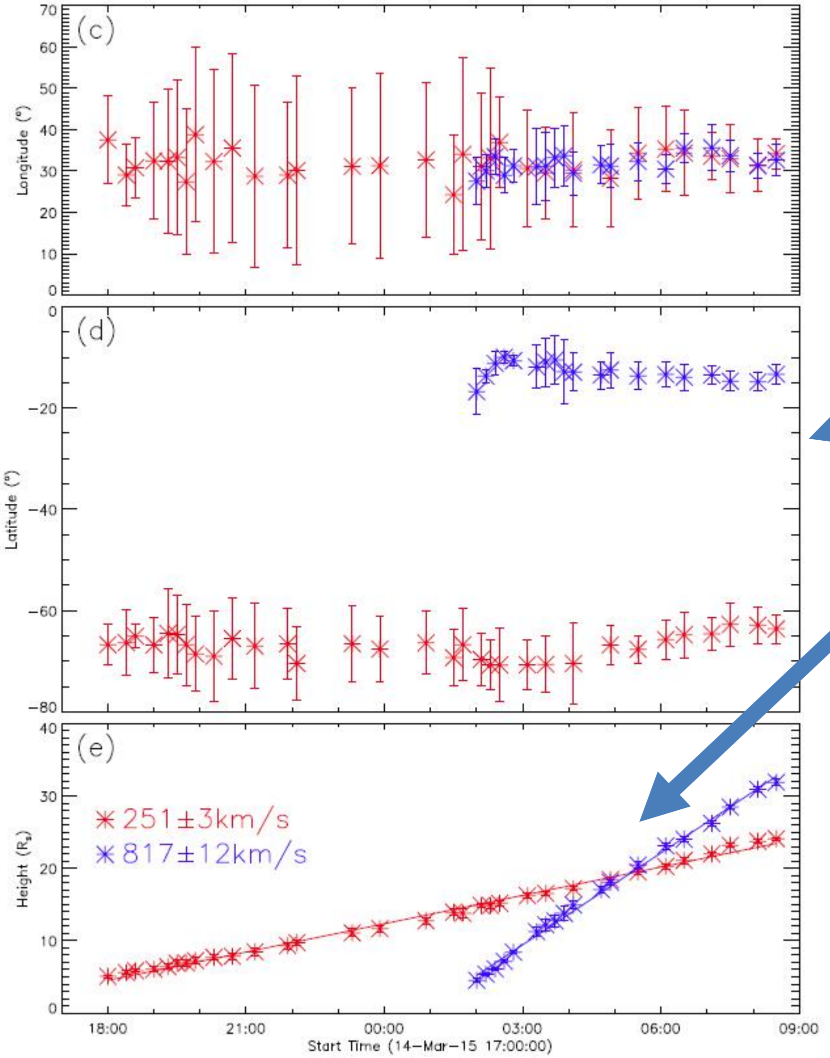
Controversy → Did first CME come from backside or frontside of Sun?

➢ ***Liu et al. (ApJL, 2015)*** **conclude it was frontside, the 2 CMEs interacted and yielded 2 ICMEs at Earth.**

➢ ***Wang et al. (JGR, 2016)*** **conclude from streamer motion and kinematics that is was backside with no interaction. Thus only one CME was geoeff.**

Evidence for No Interaction between CMEs



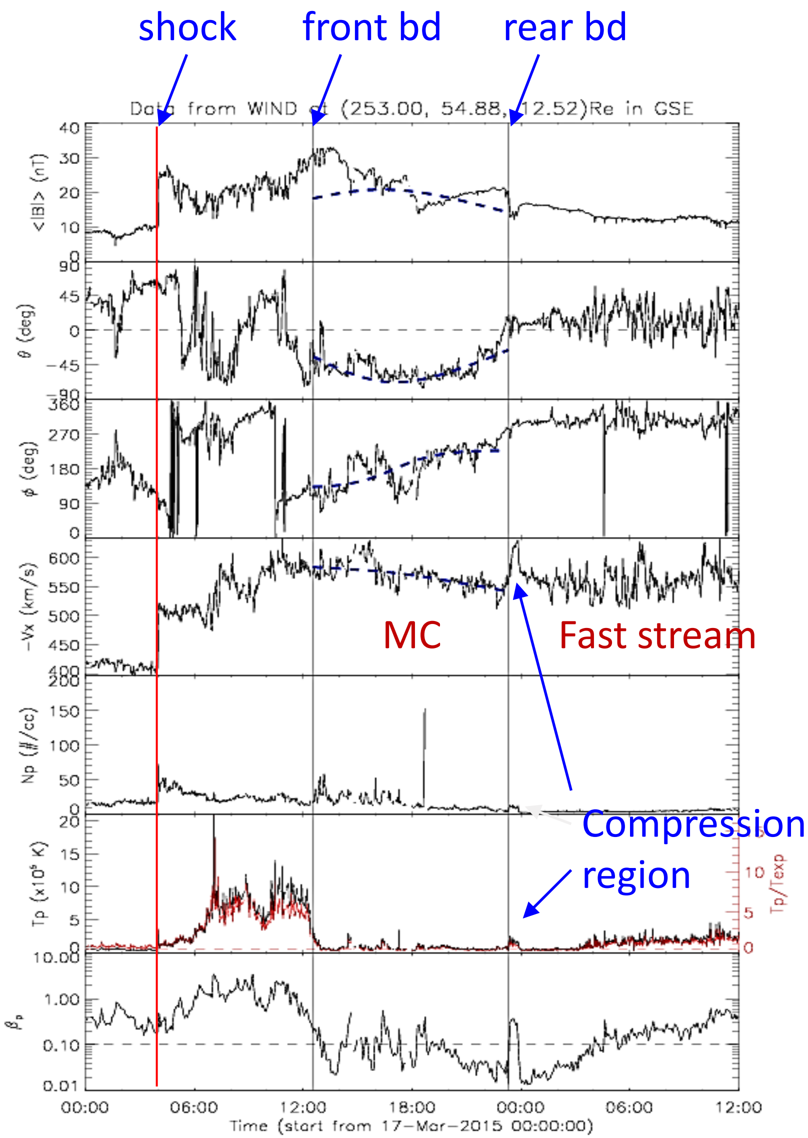


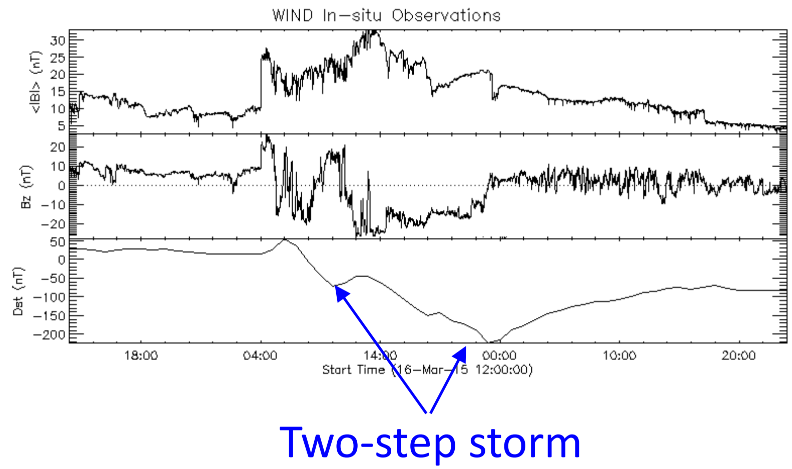
Preceding slow CME unlikely to interact with the fast CME ***(Wang et al., 2016):***

- Widely separated in latitude → ~ 50°

- No clear acceleration of slow CME or deceleration of fast CME

In-situ observations of the main CME (CME2) at 1 AU





Shock: March 17, 04:00 UT

MC: March 17, 12:30 – 23:20 UT

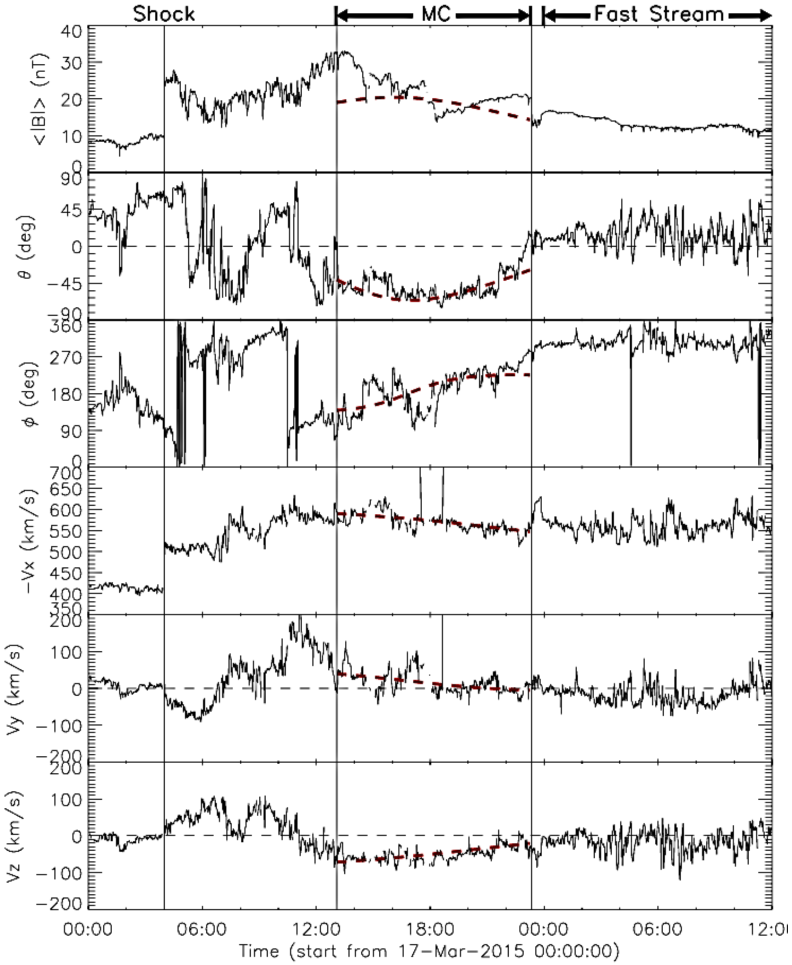
Dst Peak: -223 nT March 17, 23:00 UT

- **WG4 → storm likely enhanced because of interaction of an SIR with one or more CMEs.**
- **Solar wind is enhanced in compression region bet. strong shock and CIR HSS.**
- **Strong B_S in sheath and MC → two-step storm**

(Kamide & Kusano, SWxJ, 2015; Kataoka et al., GRL, 2015).

Y. Wang Fit Results to the MC

(velocity-modified flux rope model: Y. Wang et al., JGR, 2015)



B0 = 32 nT

R = 0.09 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

v_z = -27 km/s

v_exp = 51 km/s

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

Helicity = $(6.0+/-1.3)x10^{42}$ Mx^2

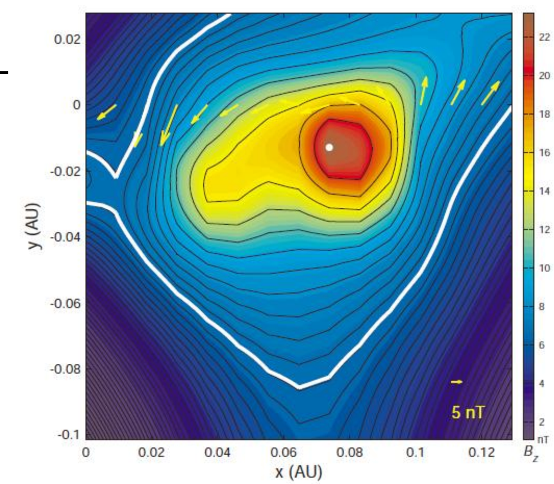
B0 = ~ 23 nT

R = ~0.05 AU

Theta = -47 deg

Phi = 281 deg

H = +1



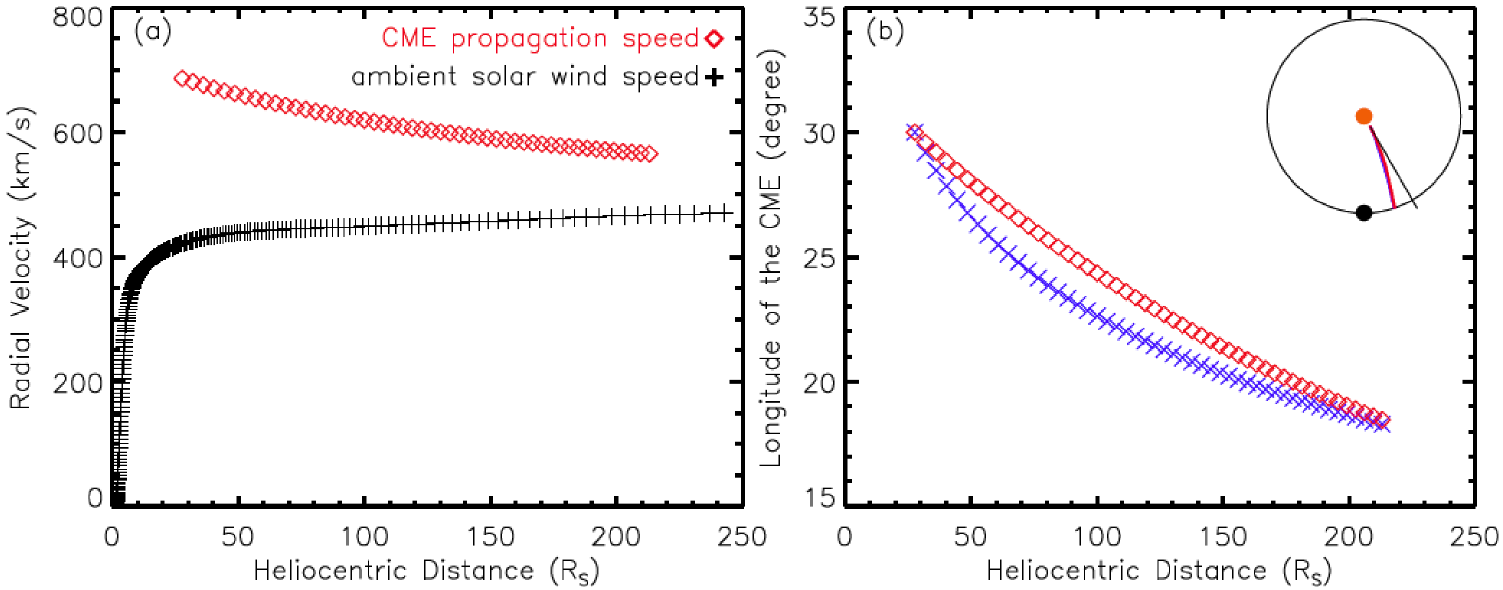
GS reconstruction

Infer the Trajectory of CME in IP Space

Wang et al. (2016)

From 4 different methods:

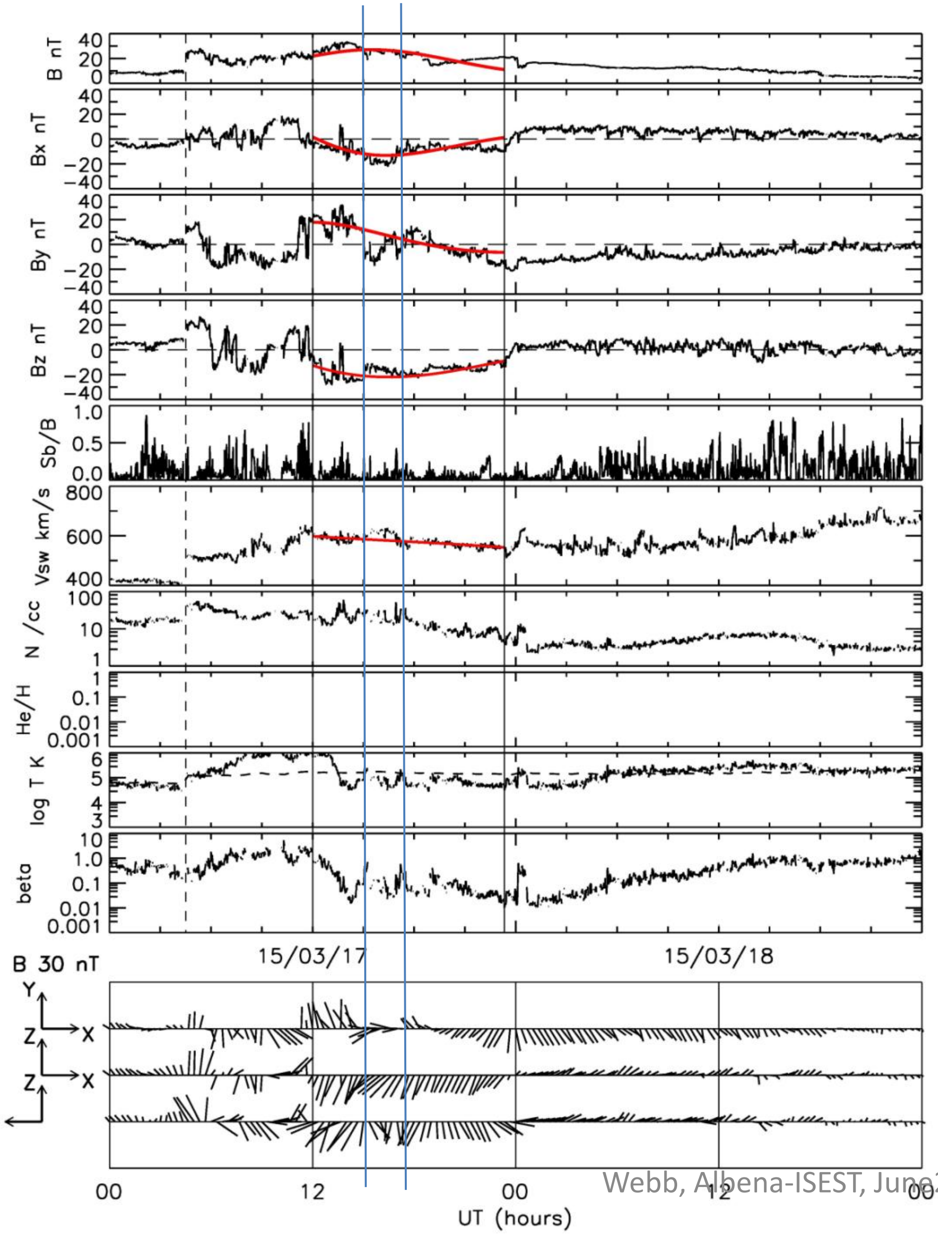
- **MC fitting → V_y ~ 0.1 V_x; Suggests deflection of 12° to the east**
- **Background solar wind → 3-D MHD simulation for CR2161 (*Shen et al., JGR, 2011*)**
- **CME speed --- Drag-based Model (*DBM, Vrsnak, et al., SP, 2013*)**
  DBM results consistent with time of arrival and speed of leading front.
- **CME trajectory --- Model for the CME Deflection in IP Space**
  (*DIPS, Wang et al., SP, 2004; JGR, 2014*)



- **Inferred trajectory bent toward Earth by ~12°, consistent with the MC fitting results.**
- **This deflection likely enhanced the CME's geoeffectiveness.**

Marubashi Independent FR fit to L1/Wind MC data

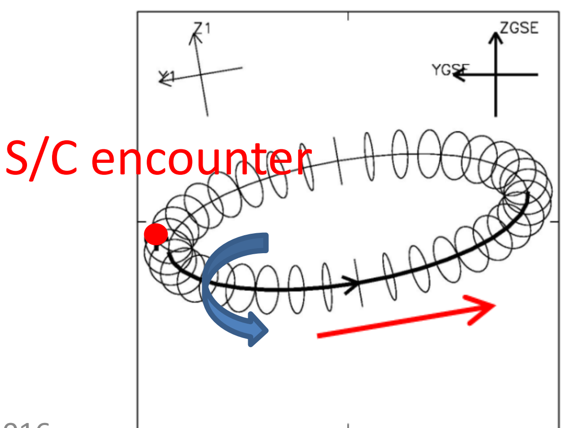
Excluded interval



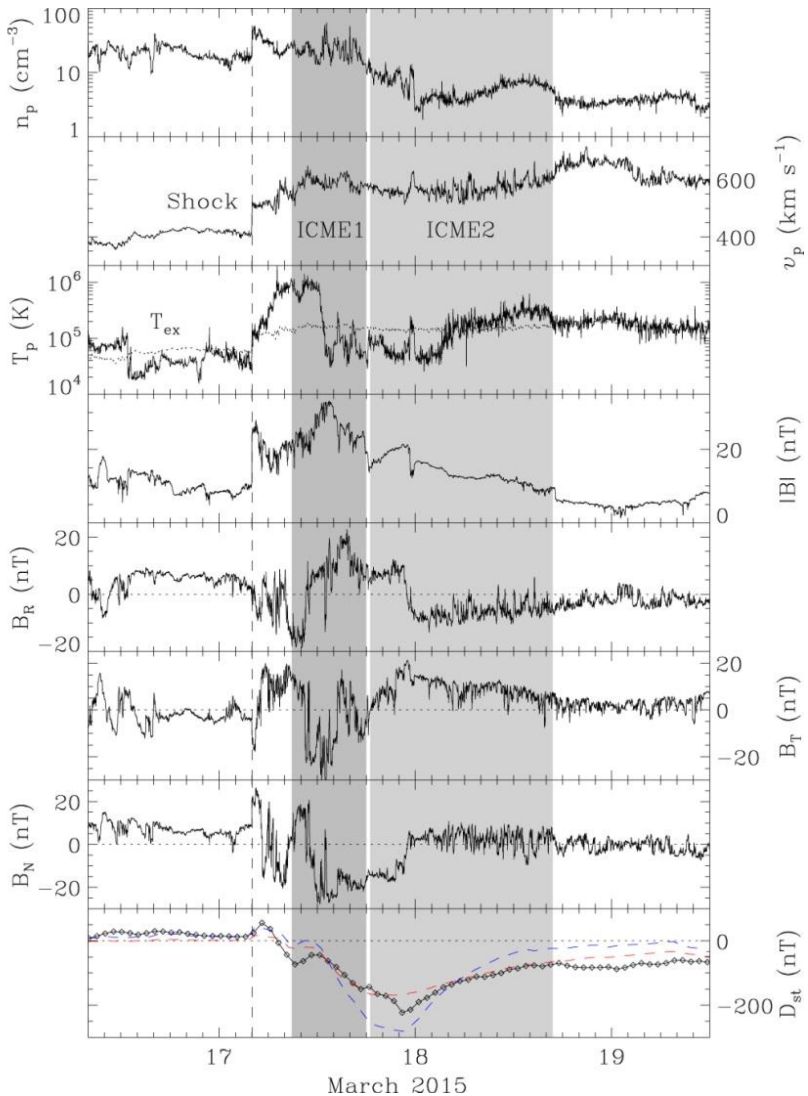
Torus-fit

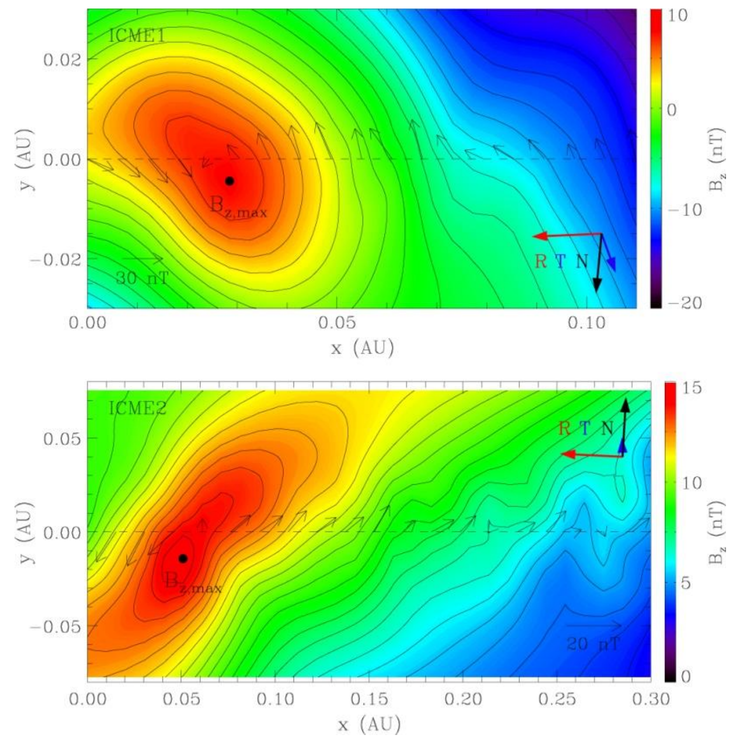
Erms=0.254

U_bulk = 582.2 km/s
decel rate = 0.708 km/s/hour
theta0 = 68.0
phi0 = 155.3
drct = −1
sgn = 1
B_axis = 45.1
R_curv = 0.261 AU
r_cyl = 0.0345 AU
T_xpnd = 33.0 hrs
I.P_z (GSE) = 0.5426
I.P_y (GSE) = 0.4979
I.P_z (rotated) = 0.6178
I.P_y (rotated) = 0.4008
Calculated Traverse Time = 11.3 hrs



G-S Wind Reconstruction of March 2015 FR; 2-step Storm → Sheath-Ejecta-Ejecta *(Liu et al., 2015)*





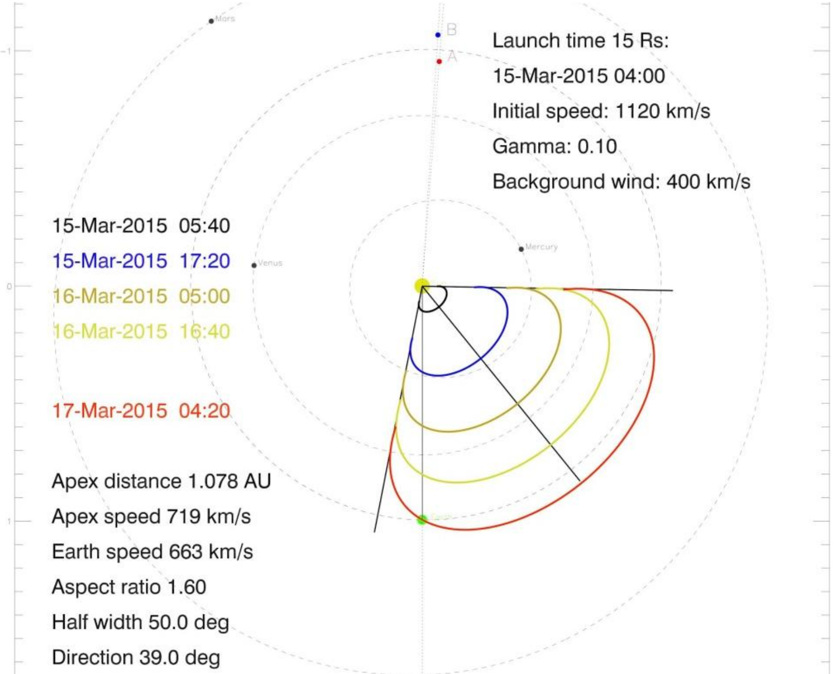
➢ *Liu et al. (2015)* **finds best-fit G-S to *two* FRs, not one. Both FRs are RH w/ opposite orientations. Both have low elevation angles, consistent w/ NL and fil. channel at Sun.**

➢ **Super storm → Southward sheath field + azimuthal MC fields + HSS.**

➢ **The Ellipse evolution (ElEvo) model *(Moestl et al., NC, 2015)* predicts this CME → 40° west of the Sun-Earth line *(right).***

- Since a strong MC hit Earth, there must have been significant deflection of CME towards Earth.

- Agrees with Wang et al. conclusion.



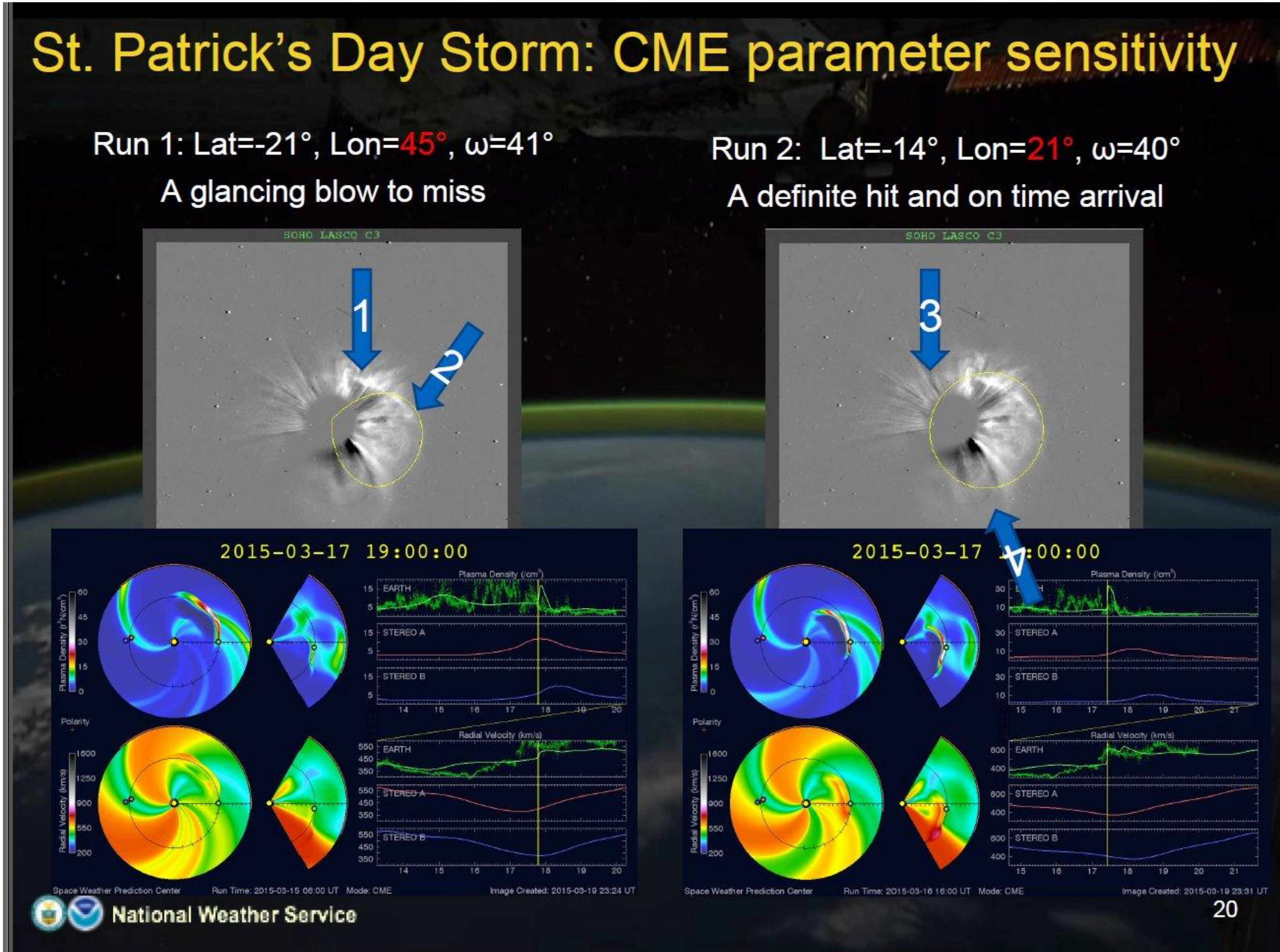
➢ **Marubashi derived two possible FR structures that fit to the obs. IMF variation:**

- A torus fit (shown above), and a cylindrical fit (not shown). His conclusion is that the torus fit (crossing the eastern end of the structure) better matches the observations

➢ ***C-C Wu et al. (2015)* also simulated the event using the global, 3-D time-dependent, MHD model (H3DMHD) to study CME's propagation to Earth.**

- Driven by solar wind data at the inner boundary of the comp. domain; used time-varying, 3-D solar wind V and N reconstructed from IPS data, and magnetic field inner boundary provided by a CSSS closed-loop propagation model *(Jackson et al., ApJL, 2015)*

- This simulation matched well with peak mag. of IP shock and its arrival time at Wind.



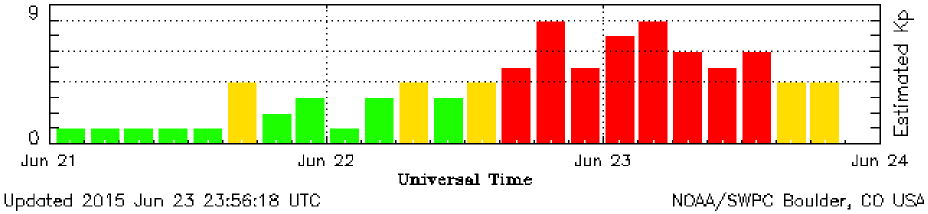
T. Berger, NOAA-SWPC, L5 workshop, 2015

3) Possibly Textbook but a Compound, Interesting Event

- A compound event from a series of 4 shocks arriving over a 3-day span, and one likely ICME on 23-24 June 2015. The 3rd shock and ICME were likely produced by a symmetric halo CME on the 21st. Southward field in multiple shock sheaths and the ICME drove powerful multi-step geo-storm reaching Kp = 9 & Dst = -204 nT.

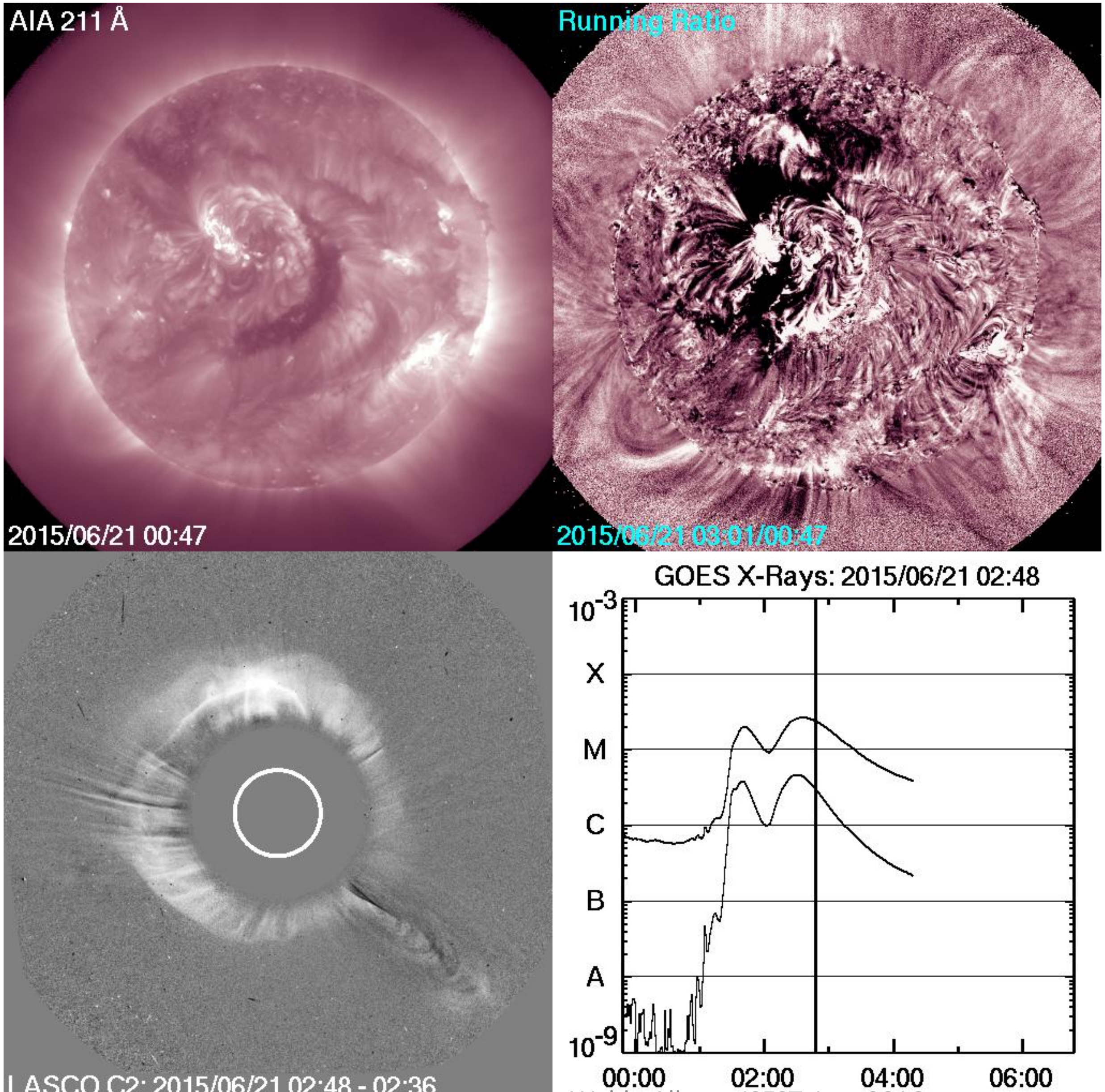
- 3-Day Forecast Issued by NOAA SWPC at 21 June 2015, 2200Z:
"The geomagnetic field is expected to be at unsettled to severe storm levels on day one (22 Jun), unsettled to major storm levels on day two (23 Jun) and quiet to active levels on day three (24 Jun). Protons are expected to cross threshold on day one (22 Jun), are expected to cross threshold on day two (23 Jun) and are likely to cross threshold on day three (24 Jun)."

- So this was a successful forecast in that major to severe storm levels were reached on 22-23 June. The 21 June symmetrical halo CME was the main source (see next). Also the proton flux was enhanced on all 3 days.



- Thus, from the "official" forecast view this was a Textbook event. However, there were 4 flares/filament eruptions and CMEs from AR 12371 on 18-22 June as it rotated toward central meridian that led to the multiple shocks, sheaths and the ICME at L1. These produced a compound event/storm, complicating our understanding of the Sun-Earth chain.

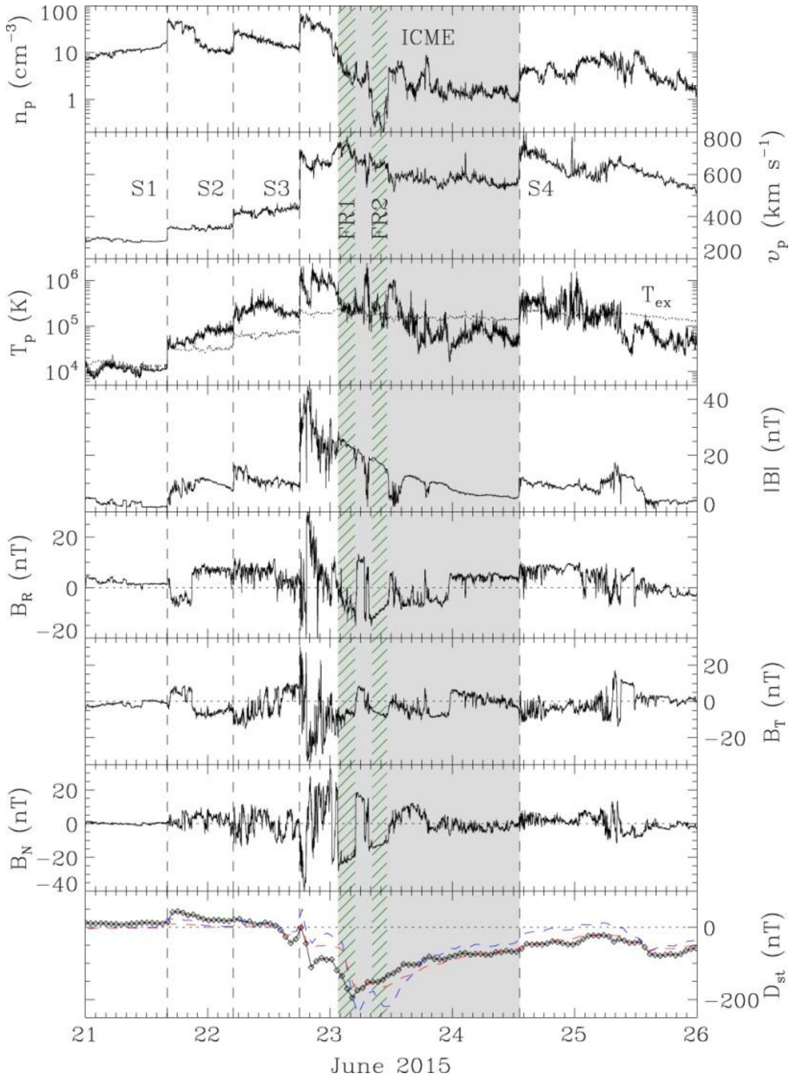
Solar Signatures

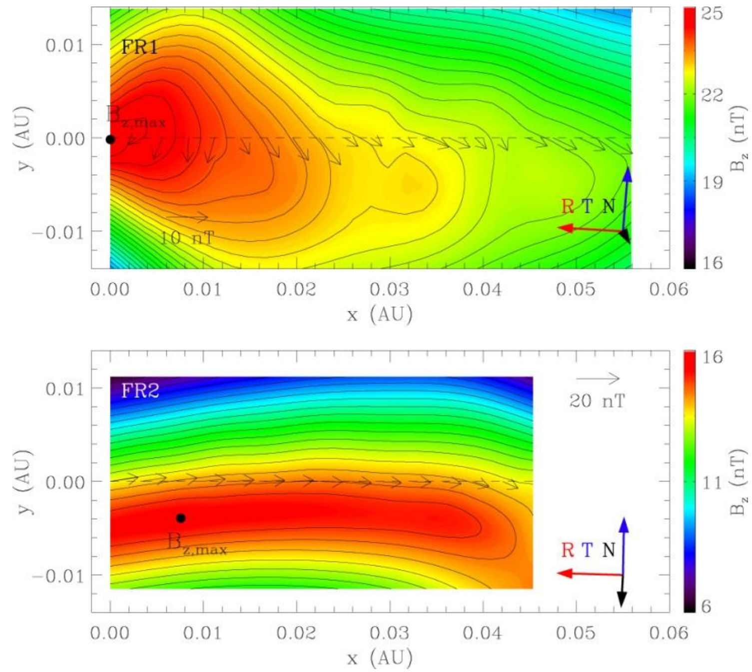


From *N. Nitta* Tweet on June 20:

“Almost circular halo CME (Earth-directed, expected arrival June 23/24)… associated with M flare. Nice dimming.“

G-S Reconstruction of June 2015 FR at Wind; Multi-step Storm → Sheath-Sheath-Ejecta

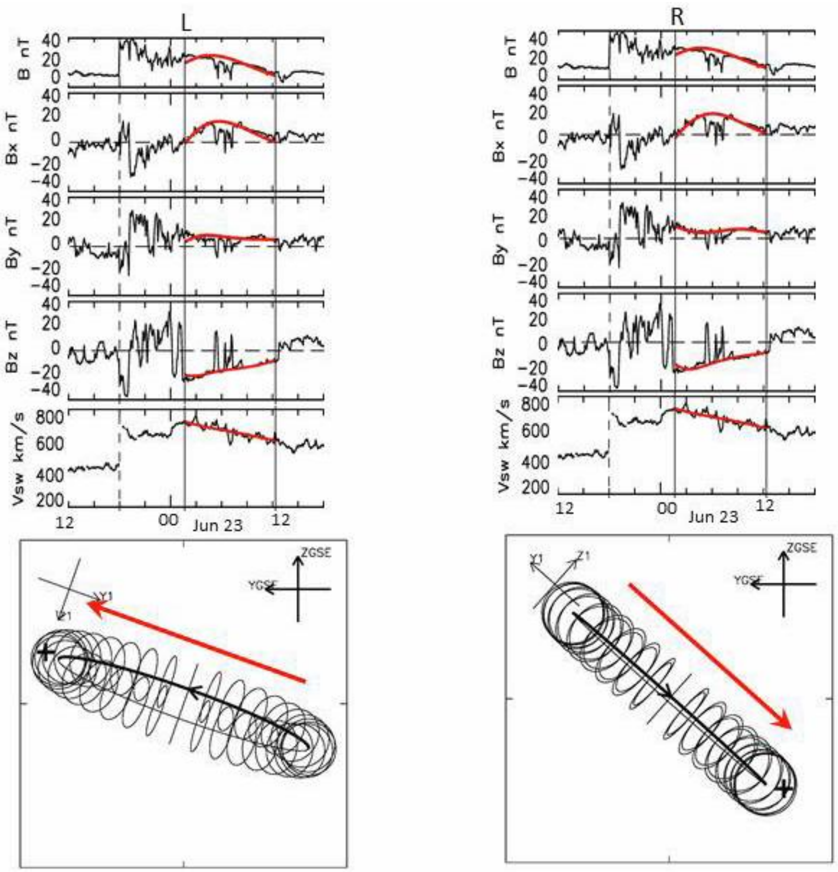




- *Liu et al. (ApJL, 2015)* **finds best-fit G-S reconst. to *two* FRs within *one* ICME. Both FRs were LH, high elevation angles and similar orientations.**

- **Super storm → Multiple shocks + strong axial fields + southward orientations + high SW speed.**

Torus Flux Rope Fits of June 2015 MC



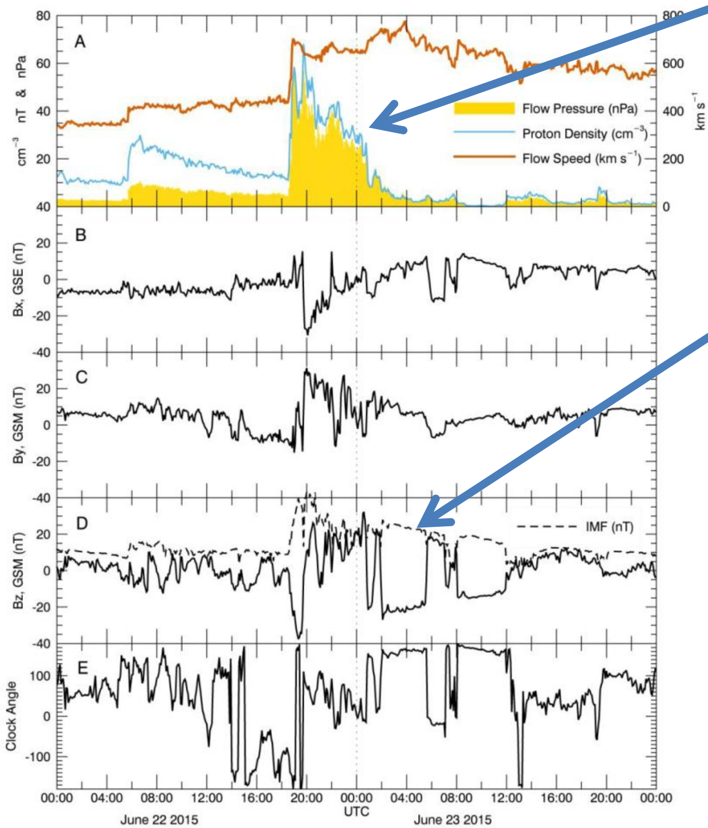
R = 0.157, r = 0.0318
Lat = -69°, Lon = 109°
Erms = 0.161

R = 0.143, r = 0.0340
Lat = 48°, Lon = 272°
Erms = 0.132

Marubashi **assumed a single MC and fit two possible FR torus geometries: RH and LH.**

- **Both yield similar B field variations.**
- **However, if he assumes the 21 June CME is the cause, then its source region has a polarity orientation opposite to that of the FR.**
- **Like the March event, the S/C encounter with the FR yields negative Bz through its passage.**

Magnetosphere and Ionosphere Effects



Reiff et al. (GRL, 2016)

➢ ***E. Kilpua*** **noted possible effect of high plasma density (pressure) on the ring current and, therefore, on Dst.**

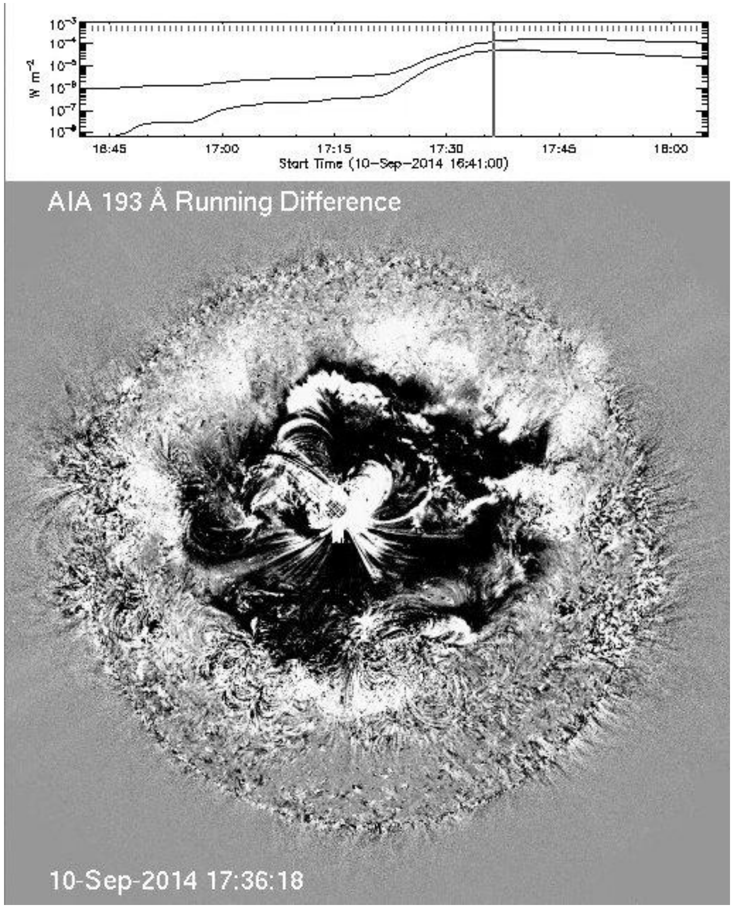
- **"The strongest Bs intervals and the Dst minimum in the … event are indeed preceded by a mainly northward IMF and high density in … sheath.**
- **Such conditions combined may have lead to a particularly dense plasma sheath and enhanced the ring current later when the strong B_S related to (Ying's) FR1 … arrived."**

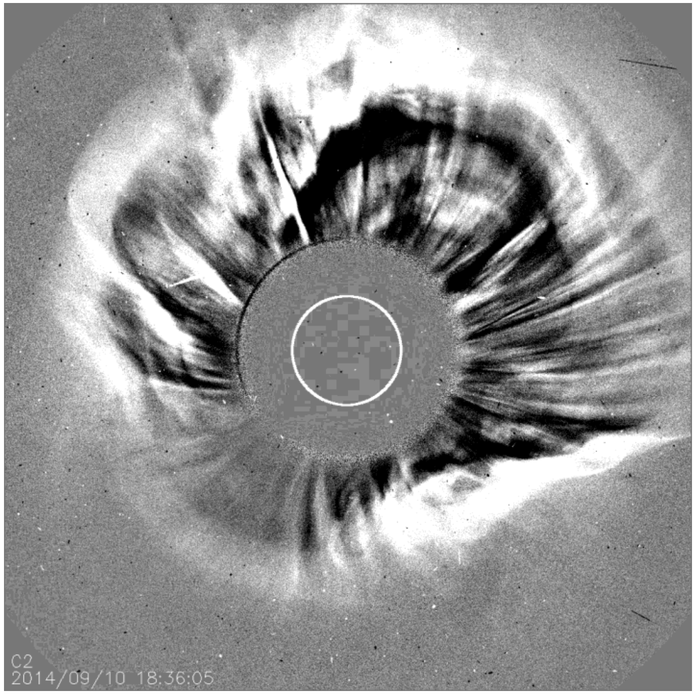
➢ ***N. Lugaz*** **noted that Shock #3 combined with the large dynamic pressure and large duration B_S:**

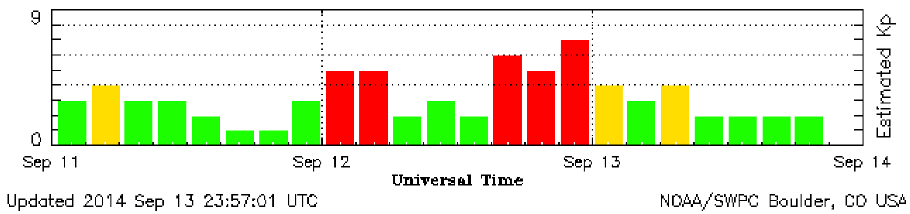
- **Greatly compressed the magnetosphere, e.g.,** ***Le et al. (2016).***
- **The ICME itself had very low density and the solar wind may have had a Mach no. ~1**

➢ **Shock #4 and the CME from 22 June, 18:36 UT arrived with high speed and was probably overtaking the ICME. But not very geoeffective, probably because B was mostly northward.**

4) Problem Event; Storm Over-Predicted, now Understood





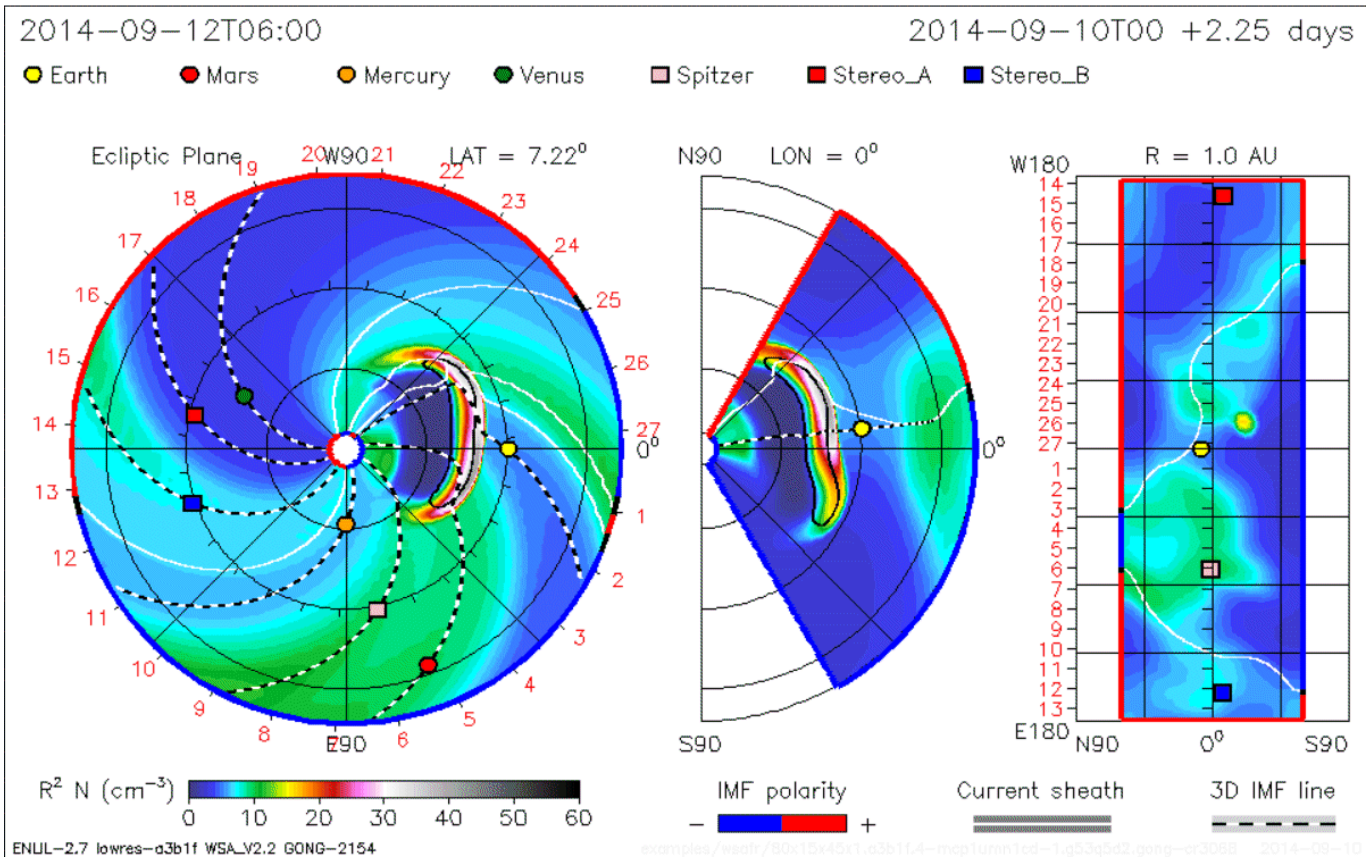


- **On 10 Sept 2014: X1.6 flare in AR12158.**
  - ***Left:* 193Å RD showing central dimming and coronal wave.**
  - ***Right:* A fast (1400 km/s), symmetric halo CME (LASCO C2).**

- ***A major storm was predicted and, indeed, a strong shock hit Earth on Sept. 12 followed by a MC extending into Sept. 13. However storm was small (Dst = -73 nT). Why?***

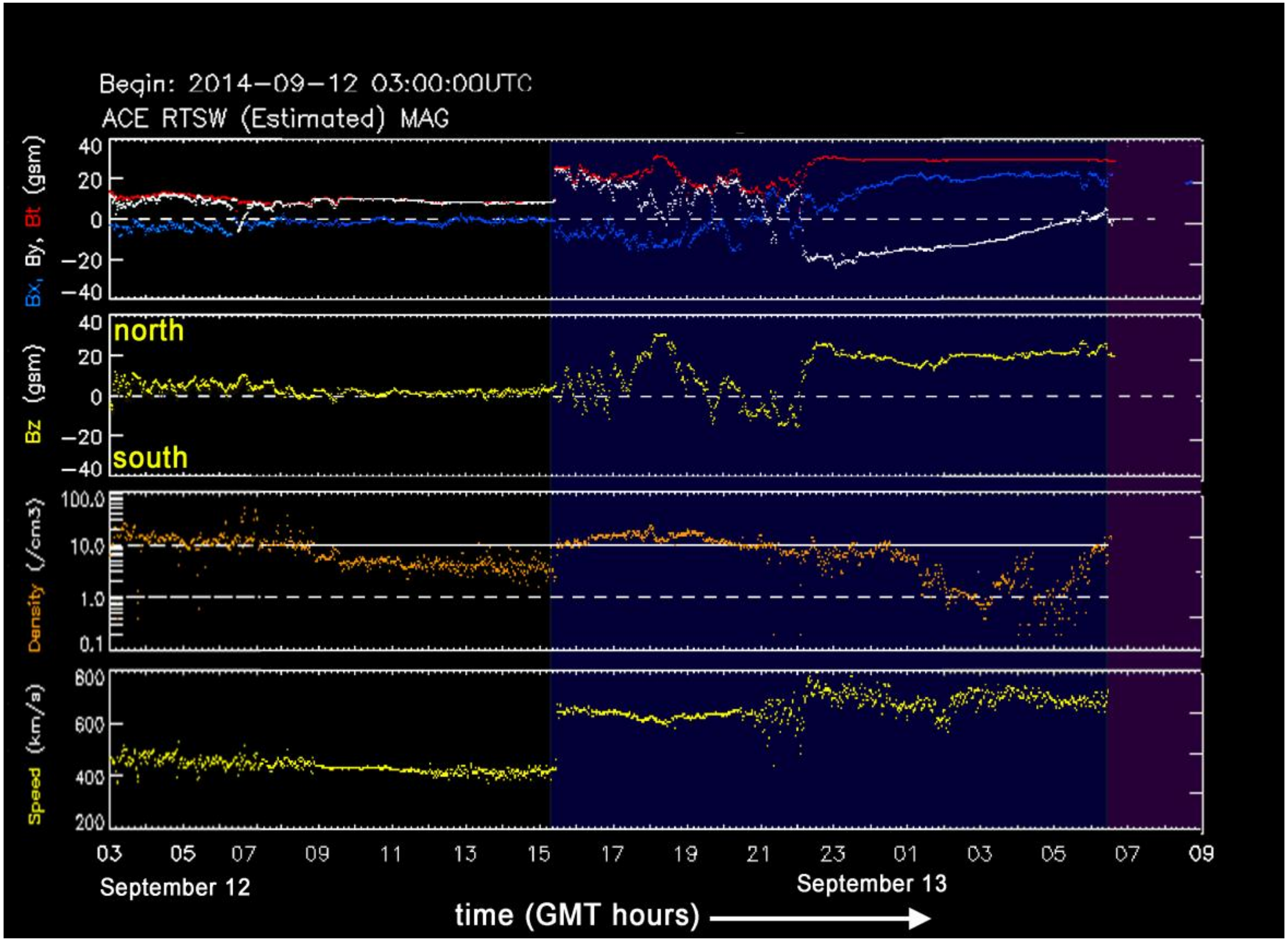
➢ **3-Day Forecast Issued by NOAA/SWPC on 11 Sept. 2014, 00:30 UT:**
“Later in the day (Sept. 12), the CME from today's X1 flare is expected to arrive, pushing conditions to the severe storm level (G3/Strong) by the beginning of day three (13 Sep).”

➢ **The ENLIL (below) and other model runs at SWPC and GSFC SWRC showed a direct hit at Earth with the average shock time of arrival accurate to within a few hours.**



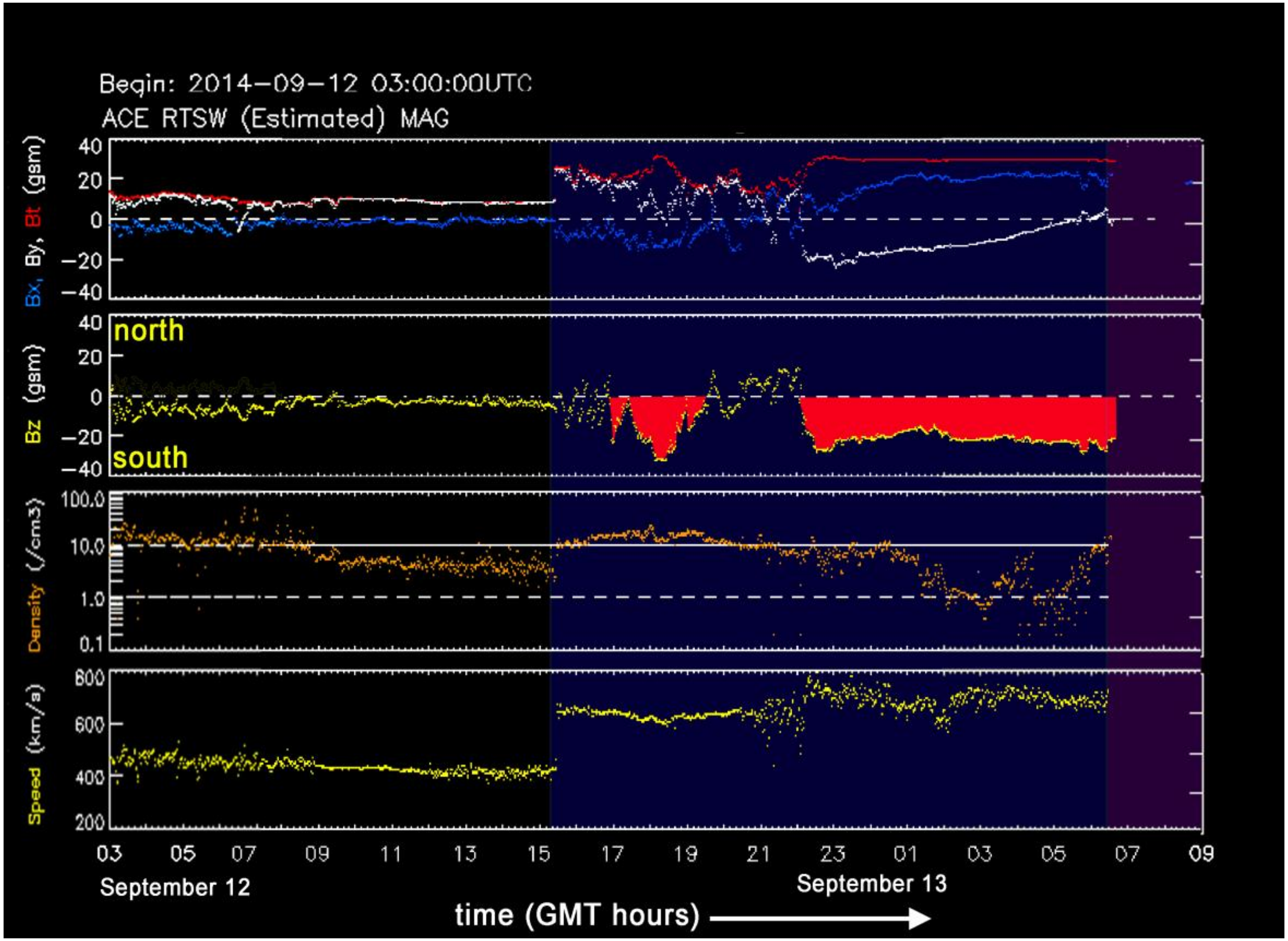
➢ **A G3 storm = Kp of 7. Indeed Kp reached 7 for one 3-hr interval but the storm was otherwise minor (G1 level).** ***What happened to this strong CME?***

The Answer: B was Strong but Northward!



- Strong shock hit followed by strong, fast ICME with prolonged sheath region and MC.
- But B in the sheath and MC almost entirely northward!
- Minor storm driven by brief B_S between sheath and MC.

This Could Have Been a Severe Storm!

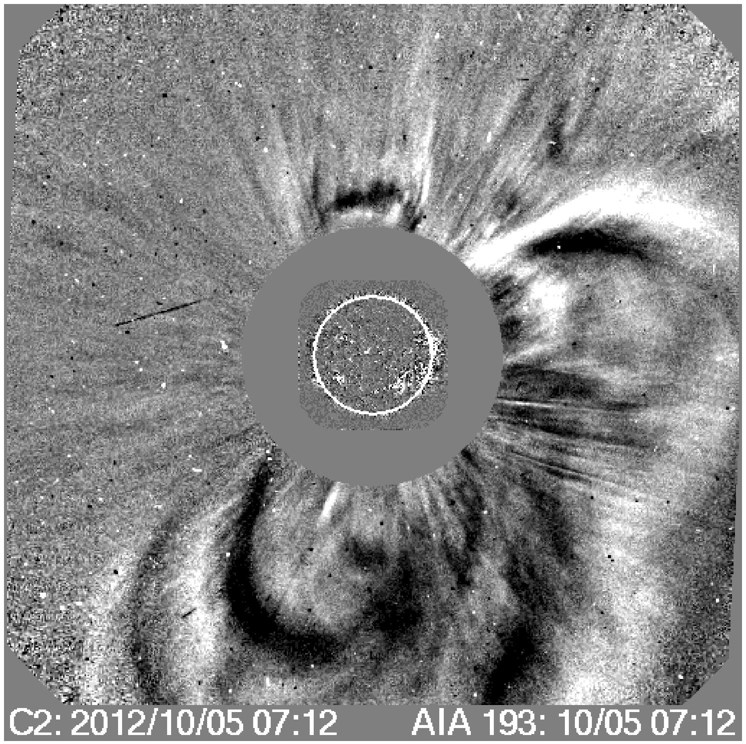


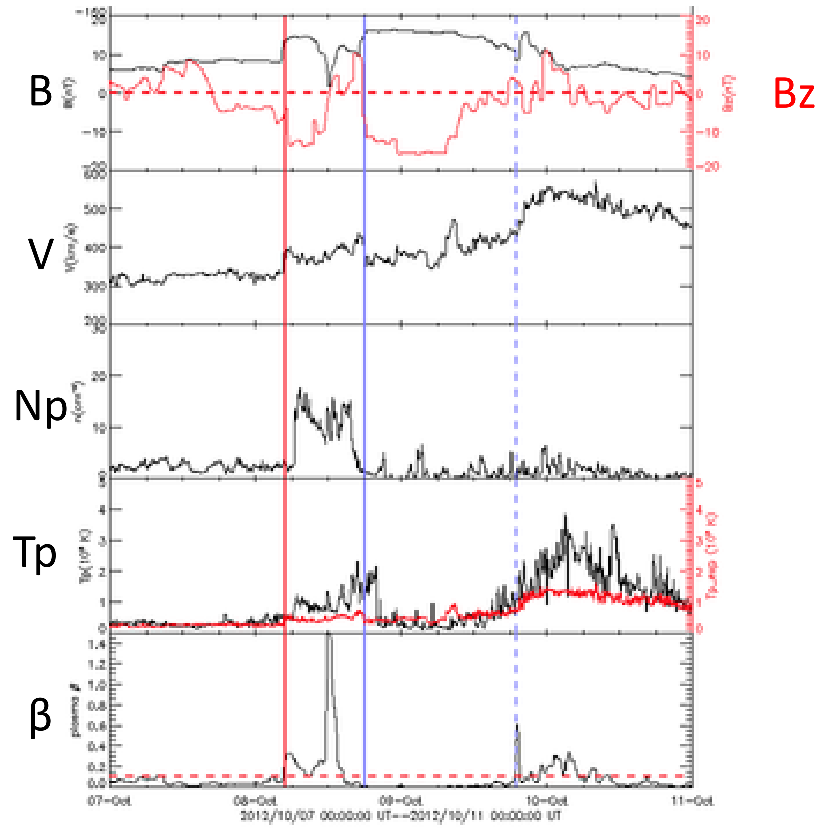
- **If Bz had been flipped, with a strong B_S field, we would have experienced a very large storm, rivaling the October and November 2003 storms.**

(From a YouTube video in a SWx forecasting series being produced by Tamitha Skov. See: https://www.youtube.com/user/SpWxfx or http://twitter.com/TamithaSkov)

5) Problem Event; Still not Understood: 4-9 October 2012

- **Example of problem event (probably not "stealth"):**
  - A clear, bright CME led to an ICME → drove small geostorm
  - But no or very weak surface signatures, there were multiple, weak eruptions, and the favored "source" is to the SW.





- **~20% of important geostorms have CMEs-ICMEs but no compelling signatures in low corona or at Sun's surface.**
- **Finding the sources of slowly evolving CMEs is difficult, even with multiple views.**
- **Challenges for SWx forecasting!**

Summary

- **"Textbook" Event: 12-14 July 2012**
  - **A complete chain of a well-observed Sun-to-Earth event → from solar source, through IP propagation, to its geoeffects.**
- **Problem Event: 17-18 March 2015**
  - **This first "super storm" was under-predicted, but we now understand why.**
  - **Two flares/CMEs occurred at Sun but somewhat offset. The CMEs may have interacted.**
  - **During transport there was interaction with a CIR & deflection toward Earth.**
- **Possibly a textbook event: 21-24 June 2015, but a compound, interesting event.**
  - **Forecast of a severe storm was accurate but probably not to superstorm levels.**
  - **There were multiple shocks and sheaths, strong southward MC axial fields, and high speed solar wind.**
- **Problem Event: 10-12 September 2014**
  - **Storm over-predicted, but we think we now understand why.**
  - **A major storm was predicted → strong long-duration MC shock hit Earth.**
  - **However storm was minor → sheath and MC B field were northward *(source FR orientation hard to predict at Sun).***
- **Problem Event: 4-9 October 2012**
  - **Source apparently a CME and resulting ICME that drove a small geostorm.**
  - **But there were only weak and multiple surface signatures.**

Conclusions

- **Goal of WG4: Integrate observations, theory and simulations to understand the chain of cause-effect dynamics from Sun to Earth/1 AU for carefully selected events.**

- **Develop/improve the prediction capability for these transients' arrival and their potential impacts at Earth.**

- **Textbook cases: Complete chain of a well-observed event from solar source, through IP propagation, to geoeffects.**
- **Not Textbook but Understood cases: Something is missing in the chain of a well-observed event but, *in retrospect,* we understand why. These cases usually involve predictions that failed because they were not geoeffective, or were otherwise not accurate.**
- **Problem cases: The chain is not complete and we do *not* understand why.**

- ICME and storm but source is faint or missing (a "stealth" CME) or multiple sources
OR
- Source is expected to be geoeffective but is not.

- Such events are an important focus of WG4.
- ~20% of important geostorms have CMEs-ICMEs but no compelling solar signatures.
- 10% of storms due to SIR-HSSs. Shock sheath region is also important (but unpredictable)!

Possible Interactions with VarSITI Projects

Event	Storm	ISEST WG2, 3, 5	SPeCIMEN Magntsp	ROSMIC Ionosp	SEE/WG6 Climate	
VarSITI Events						
1) 2012 July12	Strong	X	X			
2) 2012 Oct.4-8	Mod	X	X			
3) 2013 March 15	Strong	X-3	X		SEP	
4) 2013 June1	Strong			X		
5) 2015 March 15	Super	X-3	X	X		2-step, SIR, deflection
6) 2015 June 22	Super	X-3	X	X	SEP	2-step, FD, hi dens.
Other ISEST Events						
7) 2012 March 7	Strong	X	X			
8) 2012 July 23	“Strong“	X	----	----	SEP	
9) 2014 Jan. 6	None	?			GLE	
10) 2014 Jan. 7	None	X			SEP	
11) 2014 Sep. 10	Mod.	X	X			FD

Thank you for your attention!

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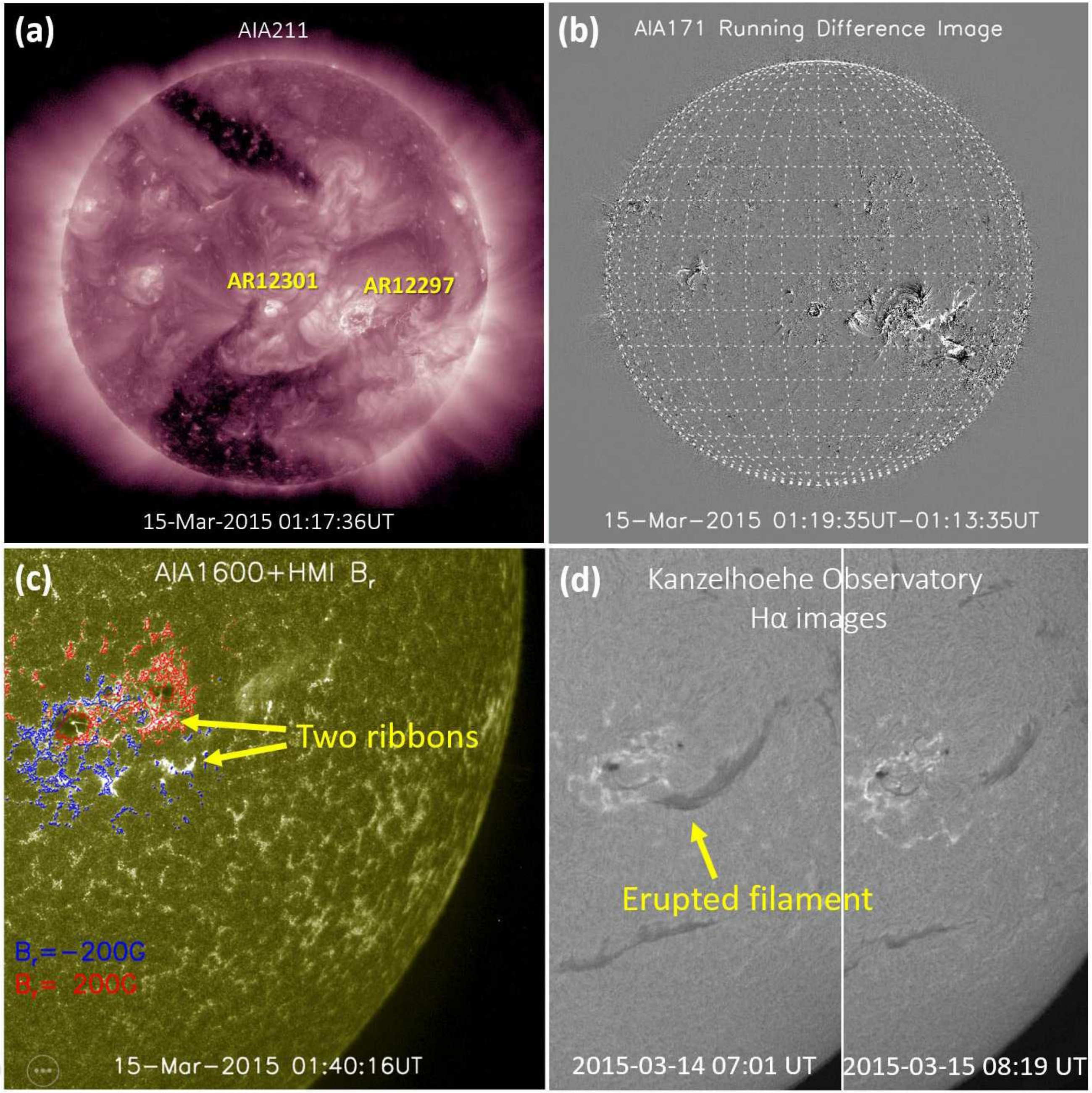
References

Berger, T., presentation at the L5 workshop, London, May 2015
Bothmer, V. & R. Schwenn, Ann. Geophys., 16, 1, 1998
Cheng, X. et al., ApJ, 789, 93, 2014
D'Huys, E., D. Seaton, S. Poedts, & D. Berghmans, ApJ, 795, 49, 2014
Dudlik et al., ApJ, 2014
Gopalswamy, N., H. Xie, S. Akiyama, P. Makela, S. Yashiro, E, P & S, 66, 104, 2014.
Gopalswamy, N. et al., 14th Intl. IES, Alexandria, VA, May 2015
Hess, P. & J. Zhang, ApJ, 792, 49, 2014
Jackson, B. et al., ApJL, 803, L1, 2015
Kamide, Y & K. Kusano, Space Weather, 13, 2015
Kataoka, R., D. Shiota, E. Kilpua & K. Keika, GRL, 42, 5155, 2015
Liou, K. et al., JASTP, 121, 32, 2014
Liu, Y. et al., ApJL, 809, L34, 2015
McKenna-Lawlor et al. EM&P, subm, 2015
Moestl, C. et al., ApJ, 787, 119, 2014
Moestl, C. et al., Nature Comm., 6, 7135, 2015
Nitta, N., SCOSTEP 13th Quadrennial STP Symp. (STP13), Oct. 2014, Xi'An, China
Rieff, P. et al., JGR, in press, 2016
Shen, F. et al., JGR, 116, A09,103, 2011
Shen, F. et al., JGR, 119, 7128, 2014
Vrsnak, B. et al., SP, 285, 295, 2013
Wang, R. et al., ApJ, in press, 2015
Wang, Y. et al., SP, 222, 329, 2004
Wang, Y. et al., JGR, 119, 5117, 2014
Wang, Y. et al., JGR, 120, 1543, 2015
Wang, y. et al., JGR, subm. 2016
Wu, C-C et al., SCOSTEP-WDS Workshop at NICT, Japan, Sept. 2015

Source Region of Fast CME

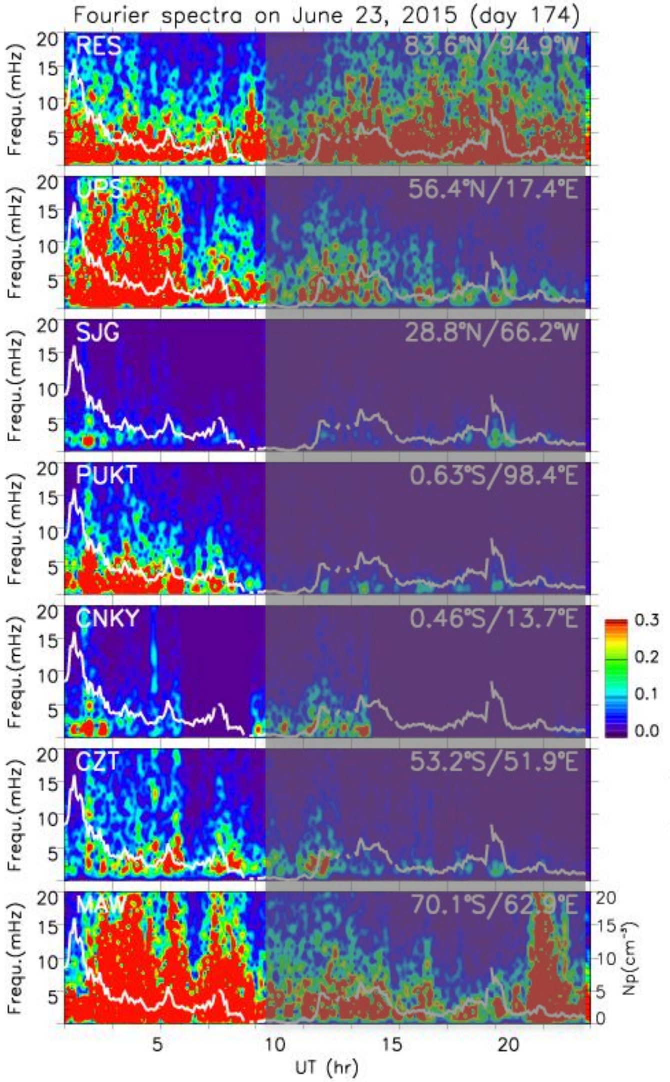
(Wang et al. , 2016)

However, there was activity in the same region (AR12297) on March 14 and the filament could have erupted anytime bet. the daily Hα images shown.



Solar wind-magnetosphere-ionosphere coupling impact on equatorial ionosphere

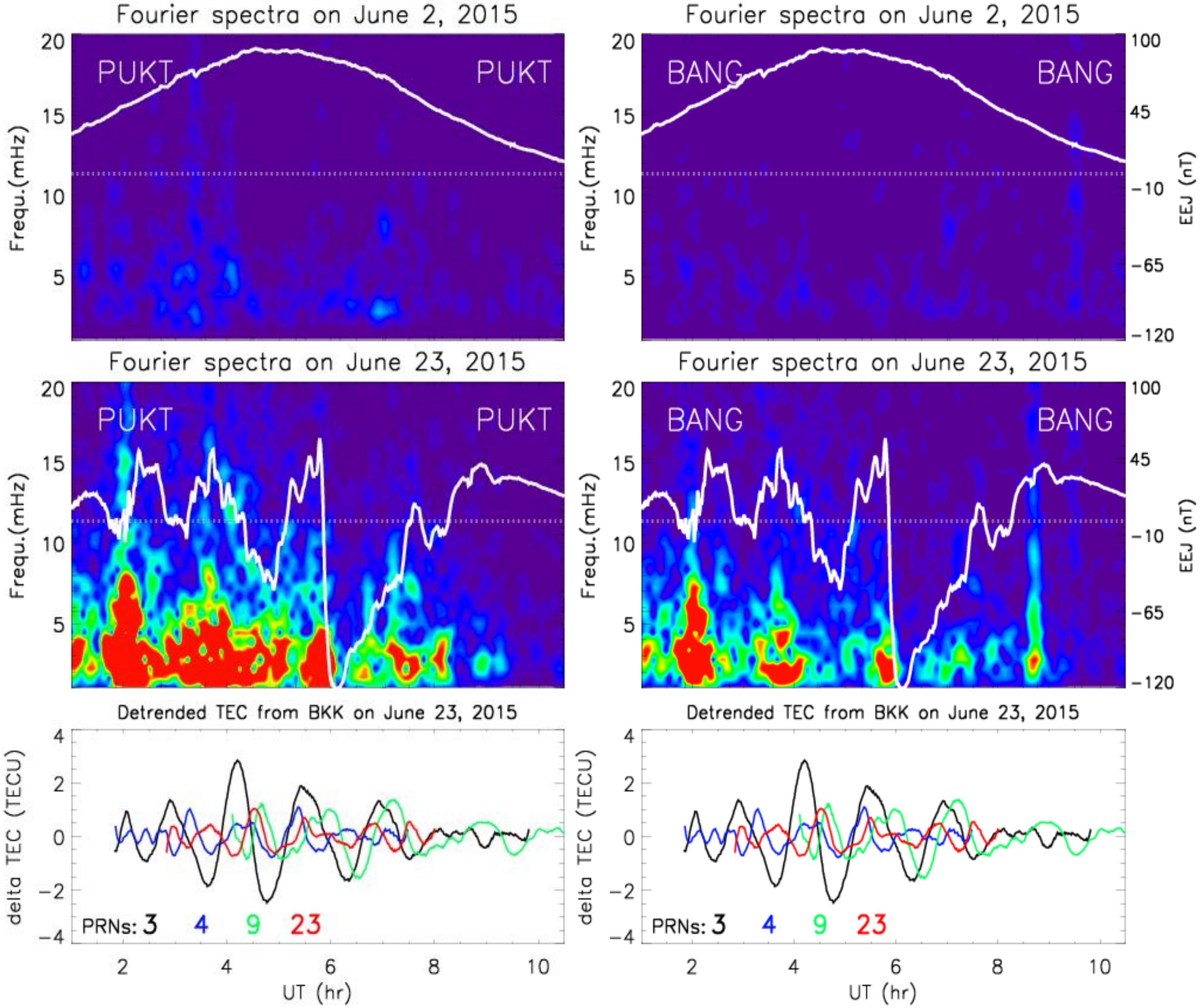
ULF wave penetration on 23 June 2015



Ionosphere response to ULF wave

On 23 June at Phuket

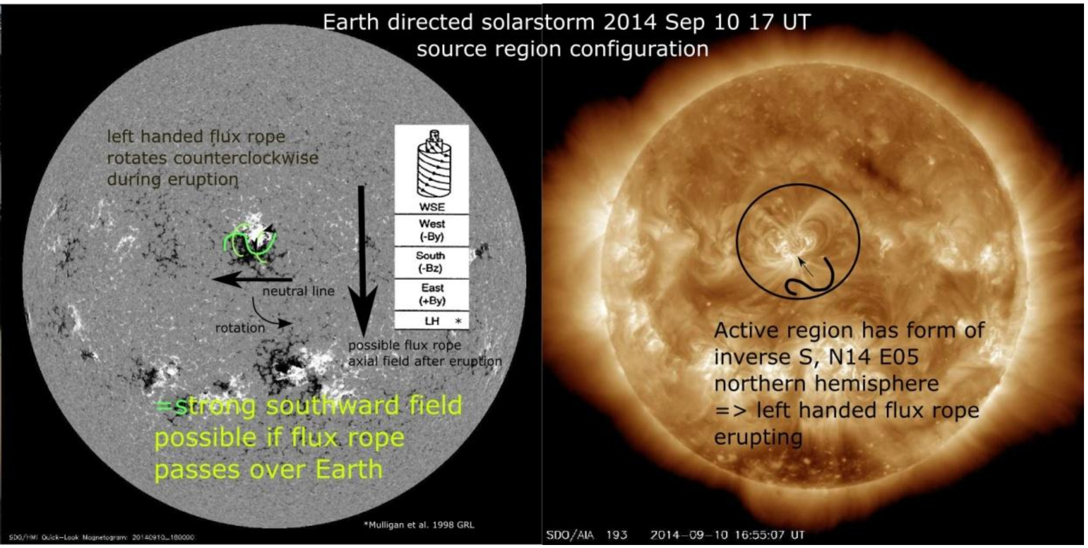
On 23 June at Bangkok

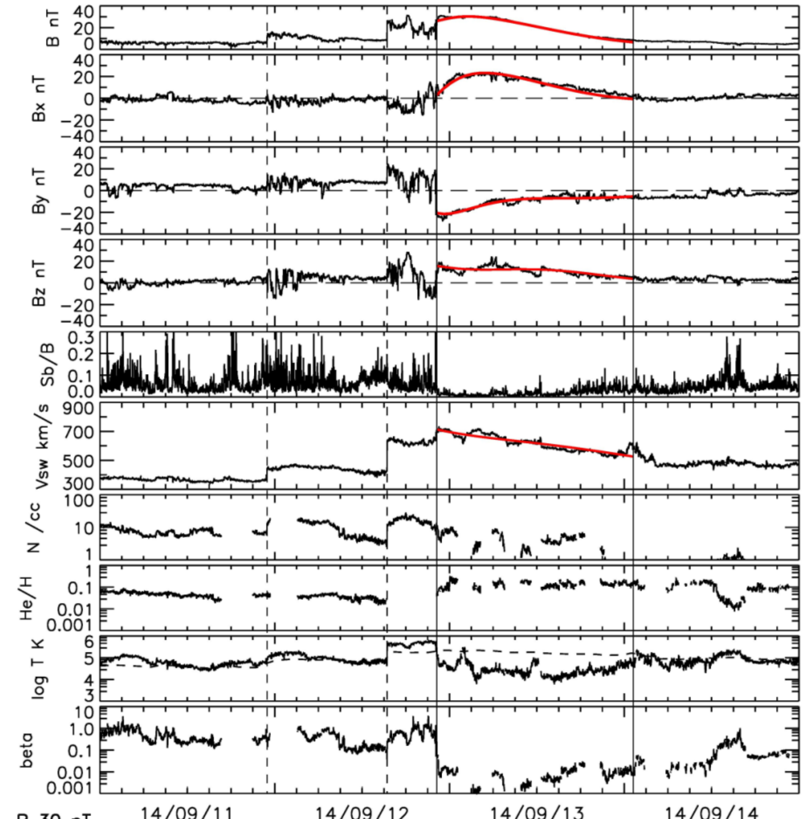


LT = UT +7

Flux Rope Fits for 10 September 2014 Event

Predictions of the orientation and geoeffectiveness of the FR varied.





- C. Moestl: "the erupting flux rope is Left-Handed and, if it rotated, it should do so anticlockwise on the order of 100° so that the axial field points toward south if the cloud hits Earth."
- V. Bothmer: the expected rope should be horizontal, not vertical, with possible kinks. There is no flux rope rotation, resulting in a LH, SEN FR according to Bothmer & Schwenn (1998).
- Neither of these predictions were correct! K. Marubashi fit the MC (at ACE) as a LH torus, but had trouble determining the handedness and its orientation was not consistent with source parameters. Later he discovered there were 2 separate eruptions with western one agreeing with FR fit.