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

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WG 4 Participants & History

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

WG4 Participants:

- **A. Asai, D. Biesecker, P. Gallagher, N. Gopalswamy, P. Hess, B. Jackson, E. Kilpua, N. Lugaz, K. Marubashi, L. Mays, C. Moestl, T. Mulligan, T. Nieves-Chinchila, D. Odstrcil, 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 a member or want to be added.

WG 4 History:

- **Focus on 1 Textbook (12-14 July 2012) & 1 Problem (4-8 Oct. 2012) events**
  - **ISEST #1; June 2013; Hvar, CR → N. Nitta & L. Rodriguez**
  - **CAWSES-II Sym.; Nov. 2013; Nagoya, JP → D. Webb & Nitta talks**

- **List expanded to included recent events with interesting challenges**
  - **STP13 + ISEST #2; Oct. 2014; Beijing, CH → D. Webb talk**
  - **SHINE; July 2015; Stowe, VT, USA → D. Webb poster**
  - **ISEST #3; this meeting → WG4 session**

Introduction

- ISEST ("International Study of Earth-affecting Solar Transients") is the VarSITI project whose goal is to understand the origin, evolution and propagation of solar transients (CMEs, flares, CIRs) through the space between the Sun and Earth, and improve the prediction capability for space weather.

- This is a progress report highlighting some work by members of WG 4. The task of WG 4 is to integrate theory, simulations and observations to better understand the chain of cause-effect activities from the Sun to Earth for a small number of carefully selected events.
  - Textbook cases provided to the community; WG 4 also examines less well understood events, such as stealth & problem CMEs.
  - WG 4 wiki: *http://solar.gmu.edu/heliophysics/index.php/Working_Group_4*

- Here we highlight 5 case studies of recent Sun-Earth events. These were chosen to illustrate one "textbook" case and four others for which there were different problems in understanding the chain from cause to geo-effect. Next we present a table showing our list of 11 study events with sources and geo-effects.

ISEST / MiniMax WG 4 Event List

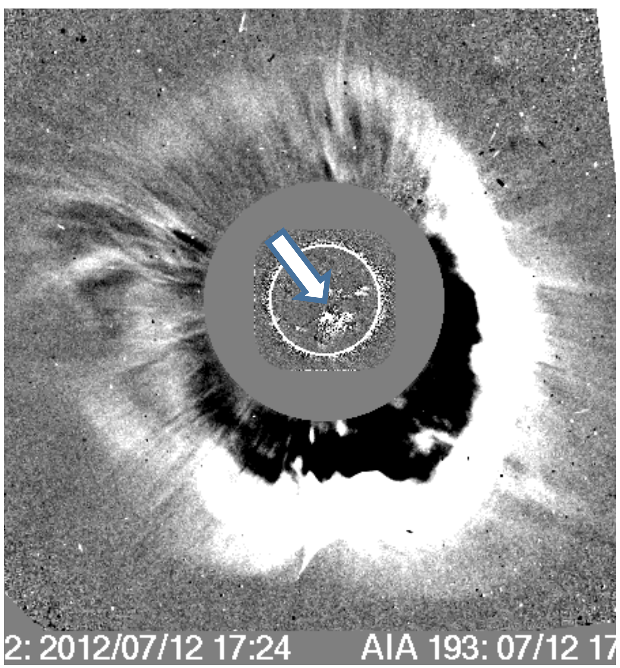
Dates	Source	Geo-response*	Dst	Type
VarSITI-wide Campaign Study Events				
1) 2012 July 12-14	X1 flare, fast CME	Shock, MC, Strong storm	-127	TB
2) 2012 Oct. 4-8	Strong CME, but multiple weak surface signatures, slow propagation to Earth	Medium storm	-105	P
3) 2013 March 15-17	M1 fl, EP, IV, fast halo	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, "Super" storm	-204	
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. 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

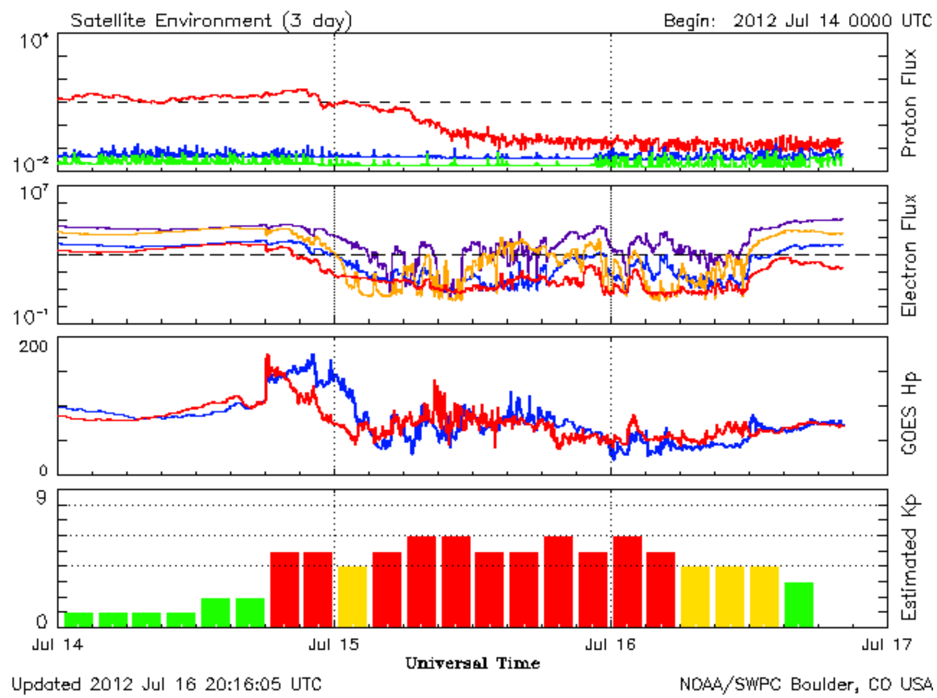
Type: TB = Textbook; U = Understand chain; P = Problem

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 at ~S17°W08° in NOAA AR 11520 (arrow). LASCO full halo CME with initial speed ~1300 km/s.
- On 14 July ICME arrived at L1/Earth with a 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?

8 months ago we had the first "superstorm" of this cycle, on 17-18 March 2015, the St. Patrick's Day storm → -223 nT. It has generated much interest; e.g., it is a special Joint GEM-CEDAR campaign event. 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 LDE flare erupted from the same active region (12297 - S22°W29°).**

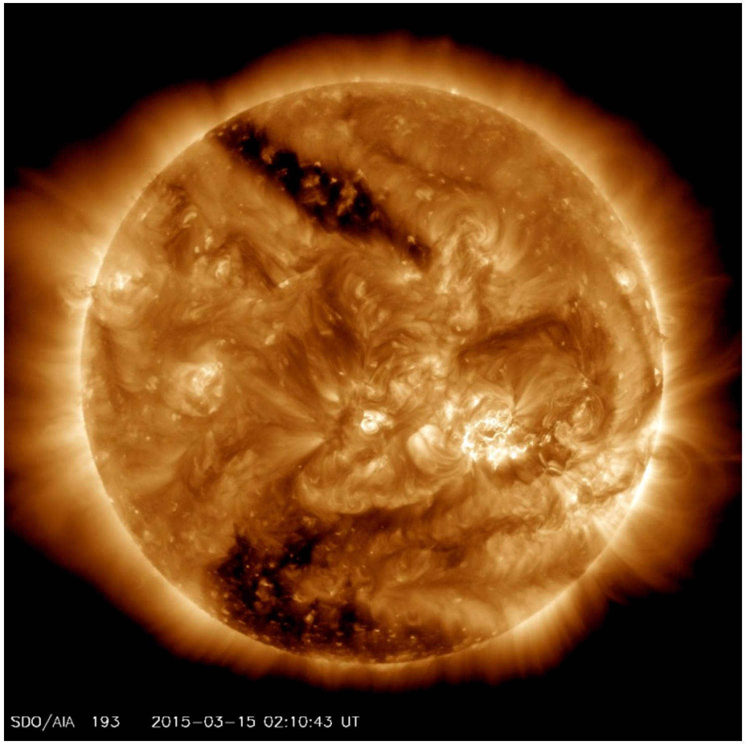
- **3-Day Forecast Issued by NOAA SWPC at 2015 Mar 15, 1230 UTC:**

"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."

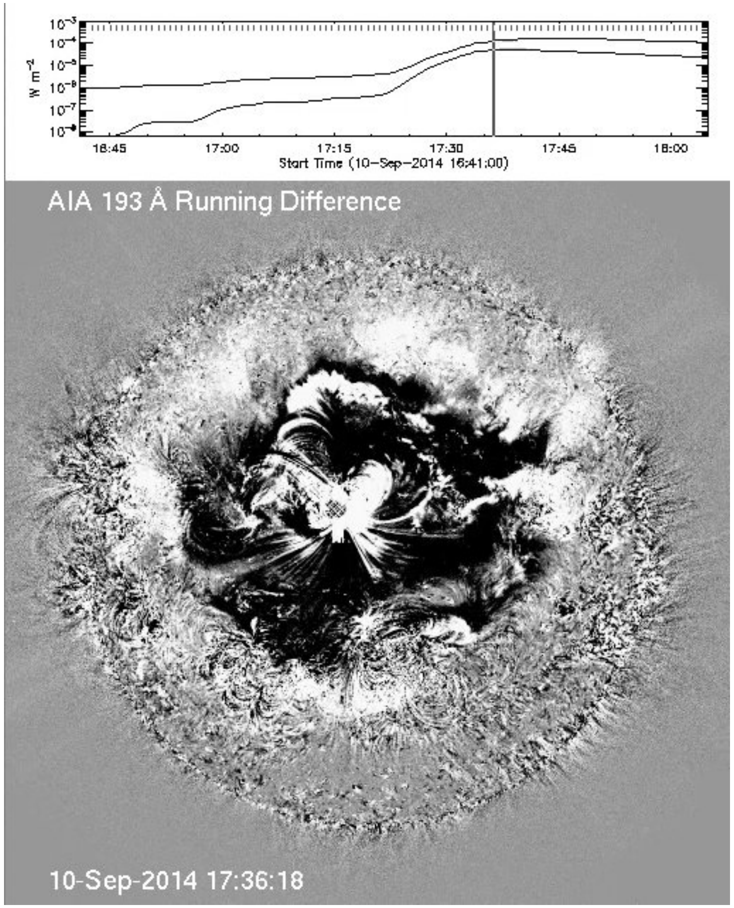
What happened?

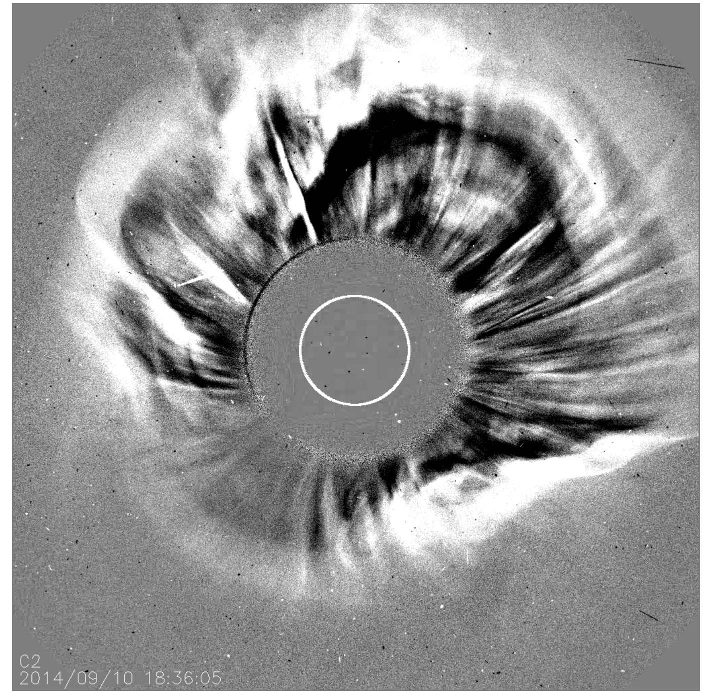
At the Sun: 2 flares/CMEs occurred.
During transport → Interaction with a CIR & deflection.

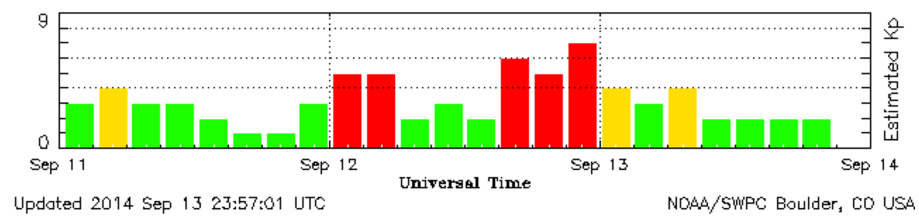
→ Talk by Y. Wang on Wed.



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







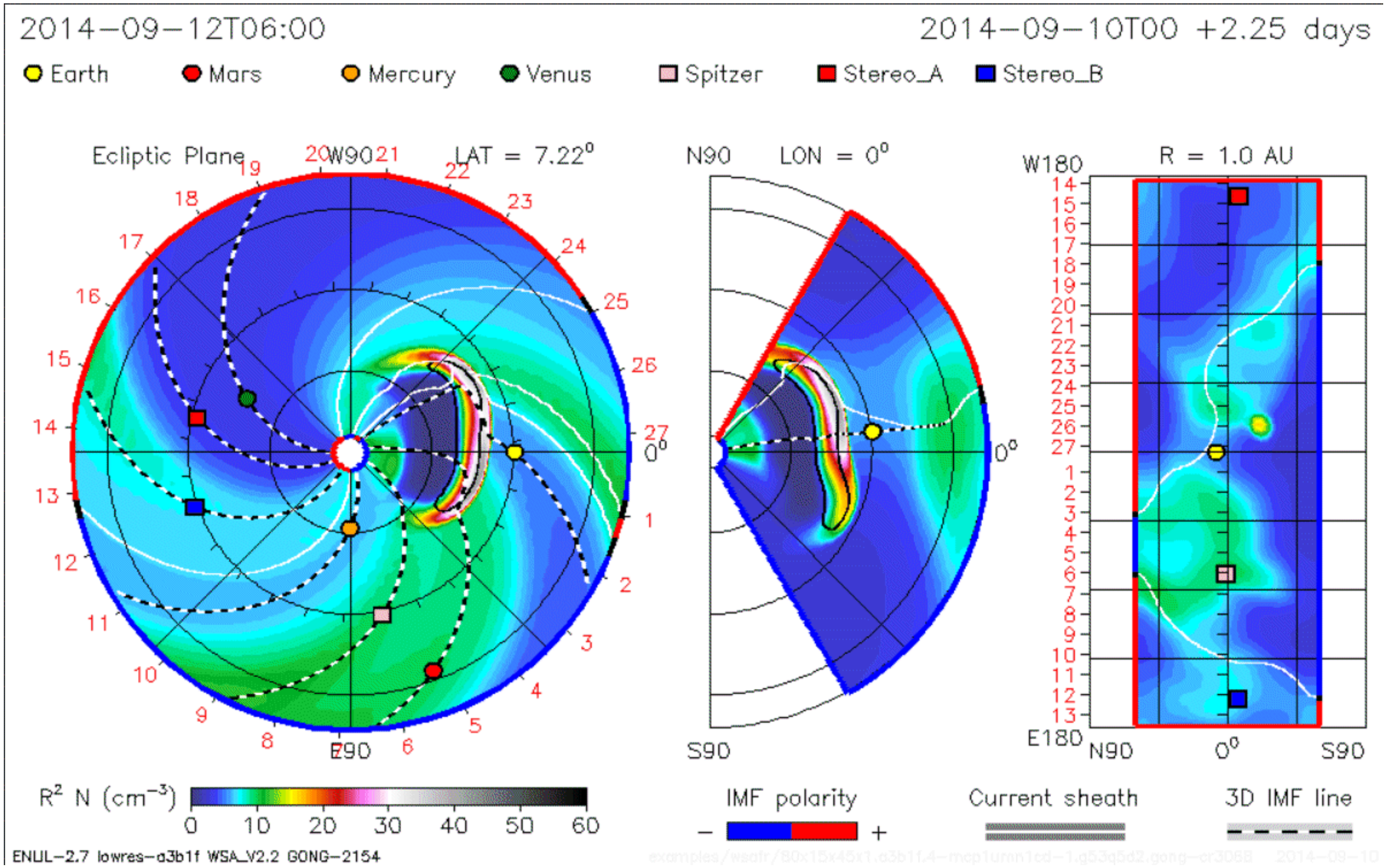
On 10 Sept 2014: X1.6 LDE flare, onset 17:21 UT, at N14°E05° in AR12158. *Left:* 193Å RD showing central dimming and coronal wave.
***Right:* A fast (1400 km/s), symmetric halo CME (LASCO C2).**

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

- 3-Day Forecast Issued by NOAA/SWPC at 11 Sept. 2014, 00:30 UTC.

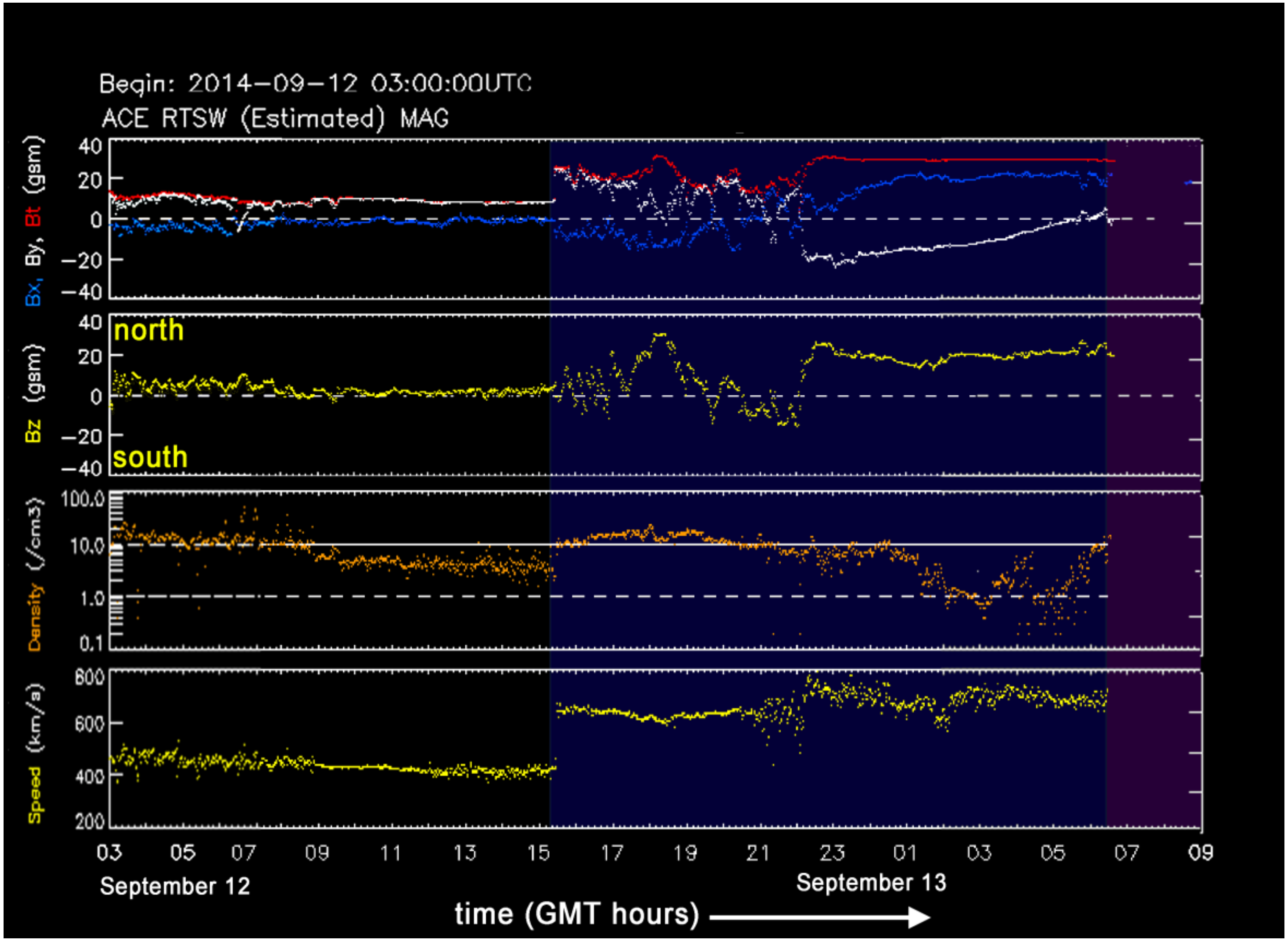
"Later in the day (Sept. 12), the CME from today's X1 flare is expected to arrive, pushing conditions to the severe storm level (G3/Strong) by the beginning of day three (13 Sep)."

- **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.**



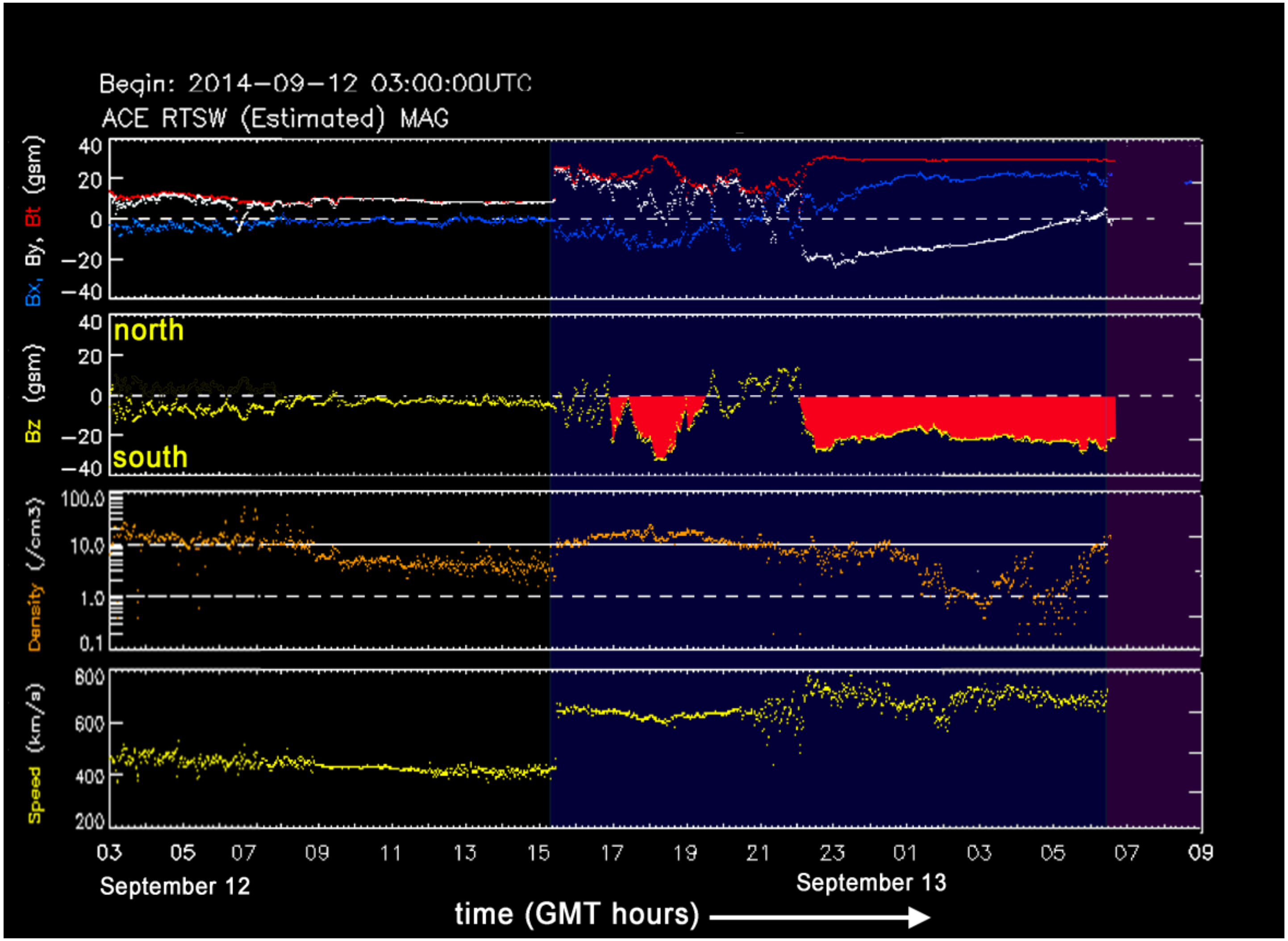
- **A G3 storm = Kp of 7. Indeed Kp reached 7 for one 3-hr interval but the storm was otherwise minor (G1 level).** ***What happened to this strong CME?***

The Answer: B was Strong but Northward!



A strong shock hit followed by a strong, fast ICME with a prolonged sheath region and MC hit L1/Earth late on Sept. 12. But B in the sheath and MC were almost entirely northward. The moderate storm was driven by brief southward B bet. sheath and MC.

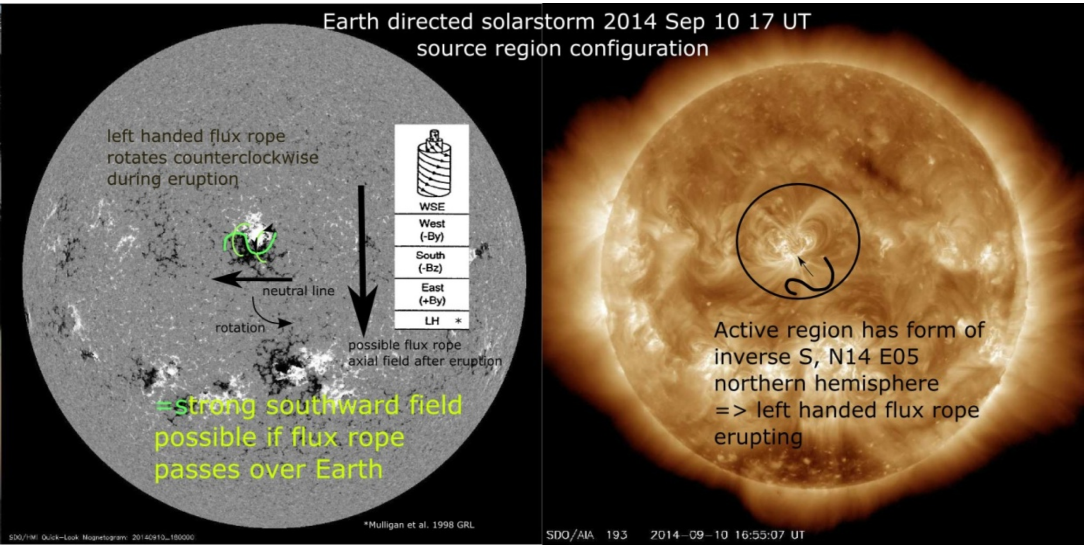
This Could Have Been a Severe Storm!

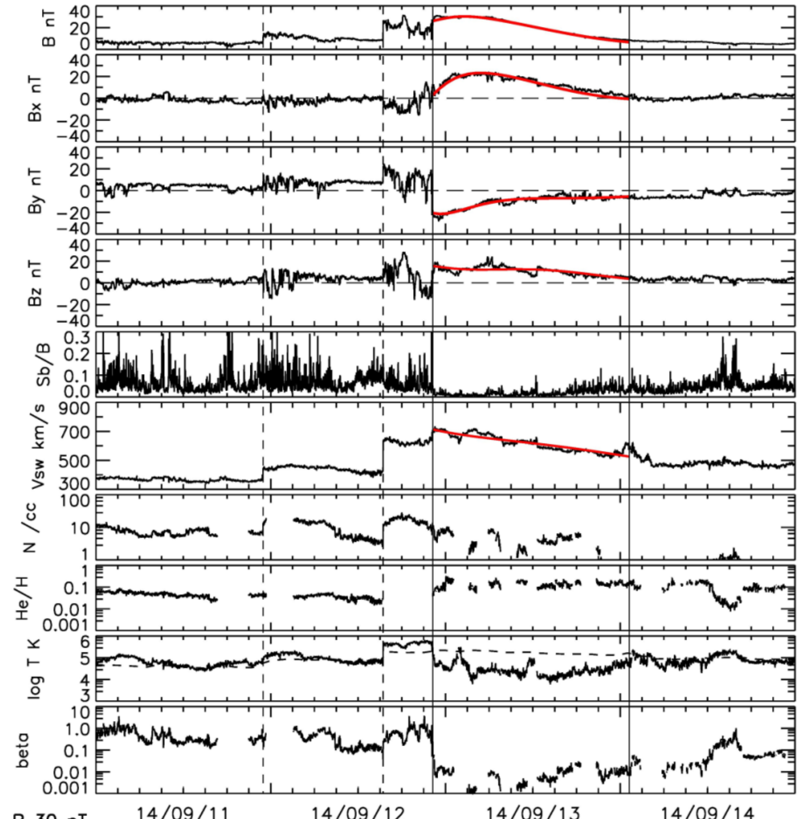


If Bz had been flipped, with a strong southward field, we would have experienced a very large storm, rivaling the October and November 2003 storms.
(From a YouTube video in a SWx forecasting series being produced by Tamitha Skov. See: https://www.youtube.com/user/SpWxfx or http://twitter.com/TamithaSkov)

Flux Rope Fits for 10 September 2014 Event

Predictions of the orientation and geoeffectiveness of the FR varied.

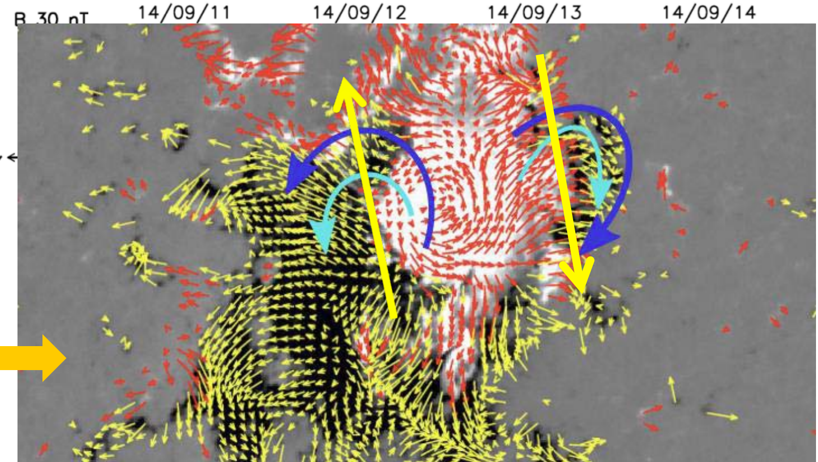




C. Moestl: "the erupting flux rope is Left-Handed and, if it rotated, it should do so anticlockwise on the order of 100° so that the axial field points toward south if the cloud hits Earth."

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).

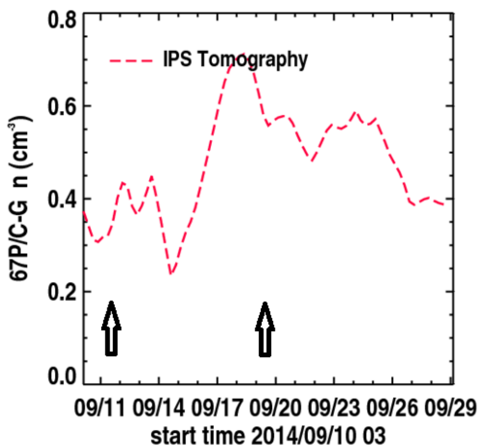
Neither of these predictions were correct! K. Marubashi fit the MC (at ACE) as a LH torus, but had trouble determining the handedness and its orientation was not consistent with source parameters. Later he discovered there were 2 separate eruptions with western one agreeing with FR fit.

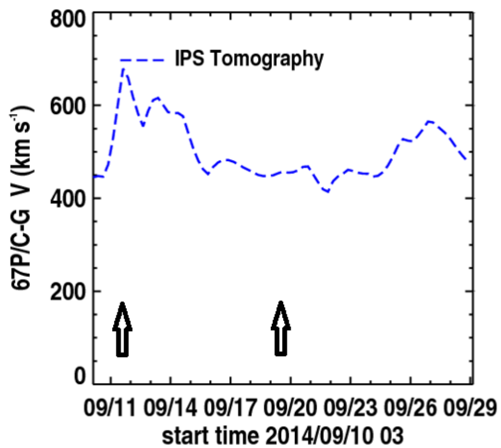


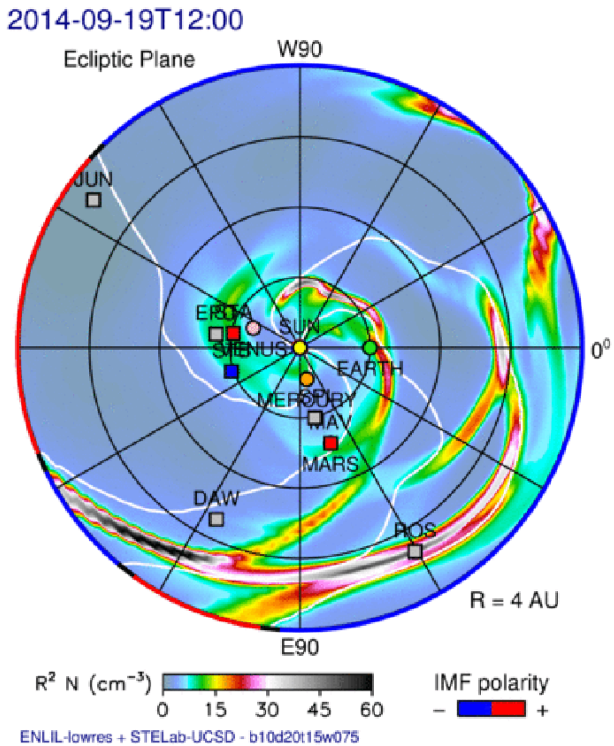
SPACE WEATHER IS GLOBAL!

This and other CMEs on 9-10 Sept. were tracked out to the Rosetta S/C using IPS-driven 3-D tomography and ENLIL modeling → McKenna-Lawlor et al. (EM&P, subm, 2015).

Below: Density *(left)* and speed *(right)* at Rosetta derived from UCSD IPS 3-D kinematic tomography. Note large density increase 18-20 Sept. 2014. This increase was from two closely spaced CMEs tracked outward from their onset times on 9 and 10 Sept. The material interacted en route with a CIR.

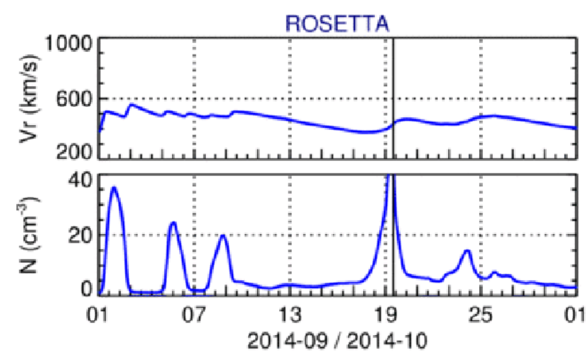




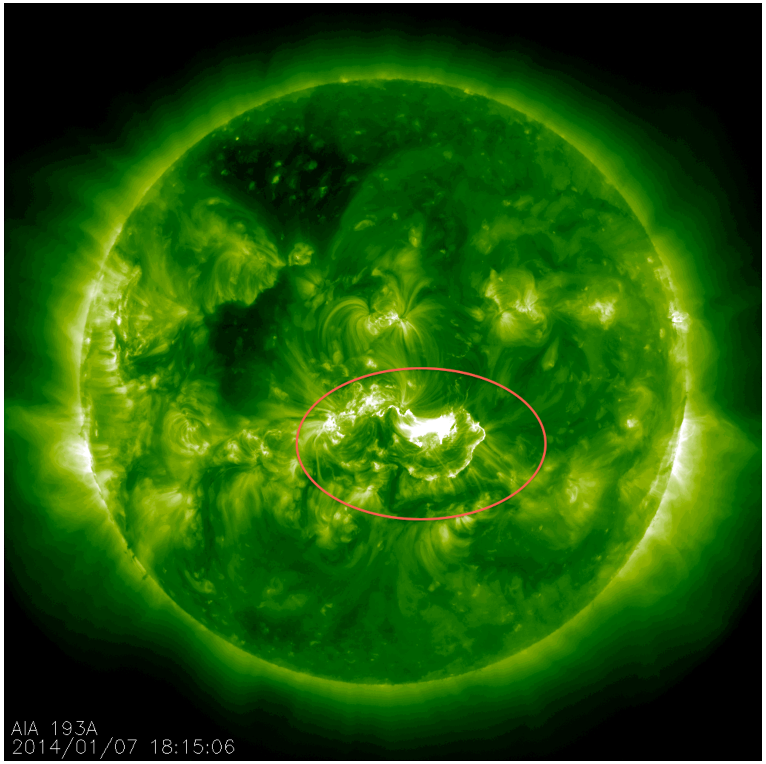


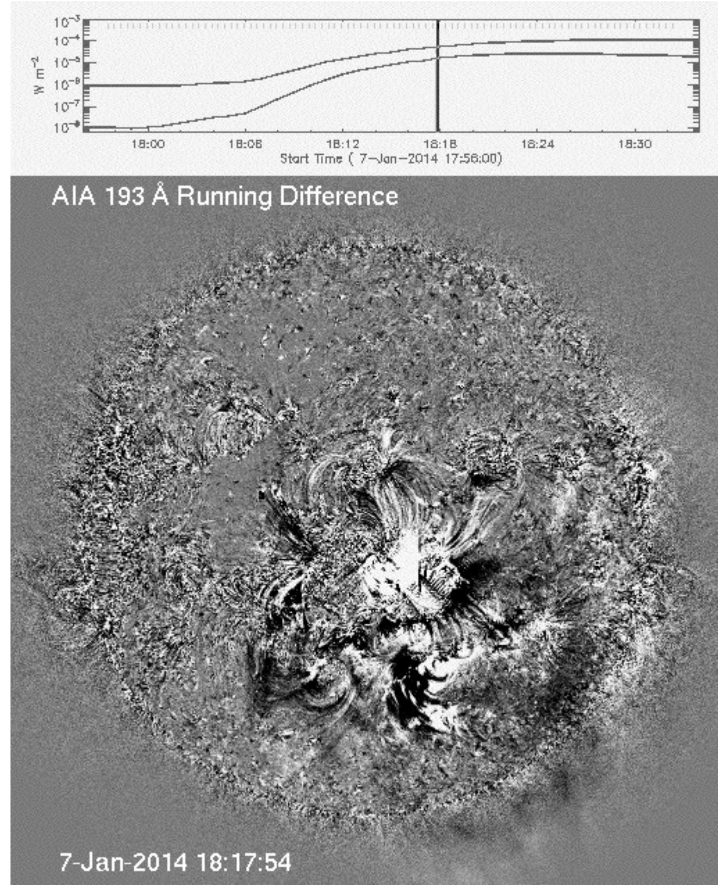
Top Right: IPS-driven ENLIL model ecliptic plot showing density enhancements from shocks and outward flowing CME material at 19 Sept. (12:00UT). The heliospheric current sheet and sector boundaries are also shown.

Bottom: Heliospheric speed and density values at Rosetta derived from IPS-driven ENLIL modeling. The time of the 19 Sept. event observed at Rosetta is shown by the vertical solid line.

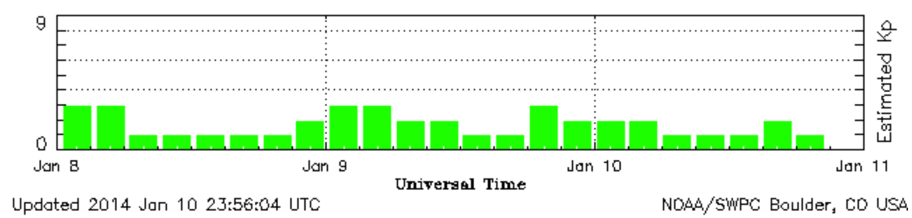


4) Problem Event; A Failed Prediction, now Understood



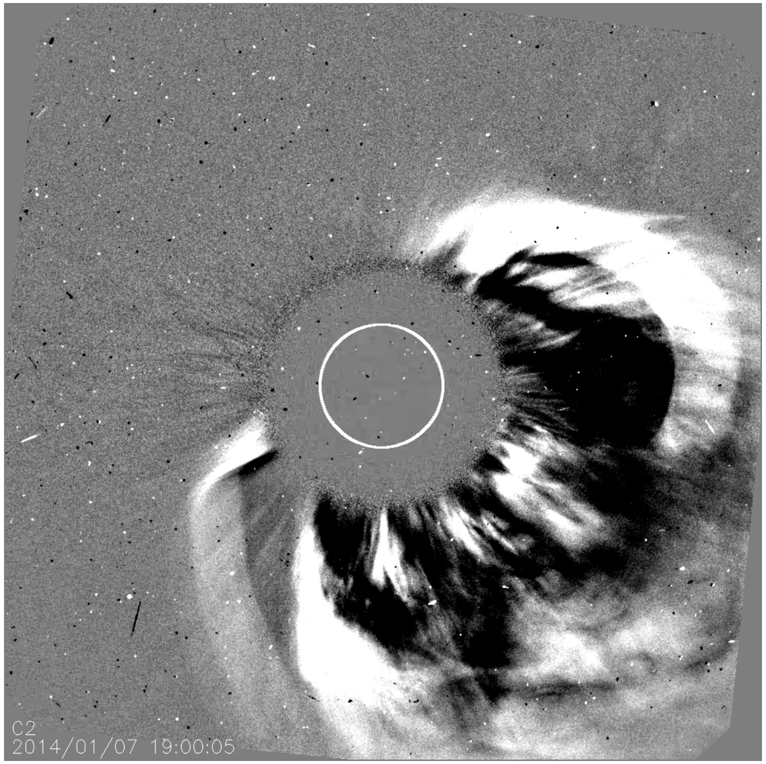


On **7 January 2014****: X1.2 flare, onset 18:04 UT, at S12°W08° in AR11944** ***(above). Right:*** **193Å RD showing dimming and coronal wave. Note wave extends only across the SW third of the disk. Also a very fast, 2100 km/s, halo CME.**



A shock hit Earth on 9 January but there was only a weak ICME and no storm. What happened to the CME? Possible deflection by coronal holes, active region (strong) mag. fields, or propagation effects? Something else?

- **Our forecasts have been improving, but sometimes fail. The 7 January 2014 X-flare/ CME event arose from NOAA region 11944, which contained a large sunspot group near disk center on this date. 52 flares, incl. 7 M or X class, occurred during its disk passage.**
- **The event was associated with an X1.2 flare, coronal dimming and a wave, strong radio emission and a type II burst, and a strong solar proton event. In LASCO an energetic, fast CME appeared as an asymmetric halo to the SW (below).**
- ***However, despite our expectations and most model predictions, only a weak shock arrived at L1/Earth on 9 January followed by weak ICME signatures with mostly northward field and no significant geomagnetic response.***



- **Joint USAF/NOAA Solar Geophysical Activity Report and Forecast SDF Number 7 Issued at 2200Z on 7 Jan 2014:**

- Geophysical Activity Forecast: The geomagnetic field expected to be at quiet to active levels on 8 Jan, active to major storm levels on 9 Jan, and unsettled to minor storm levels on 10 Jan.

- Protons expected to cross threshold on 8 Jan, 9 Jan, 10 Jan.

Forecast Models Run for Jan. 2014 Event

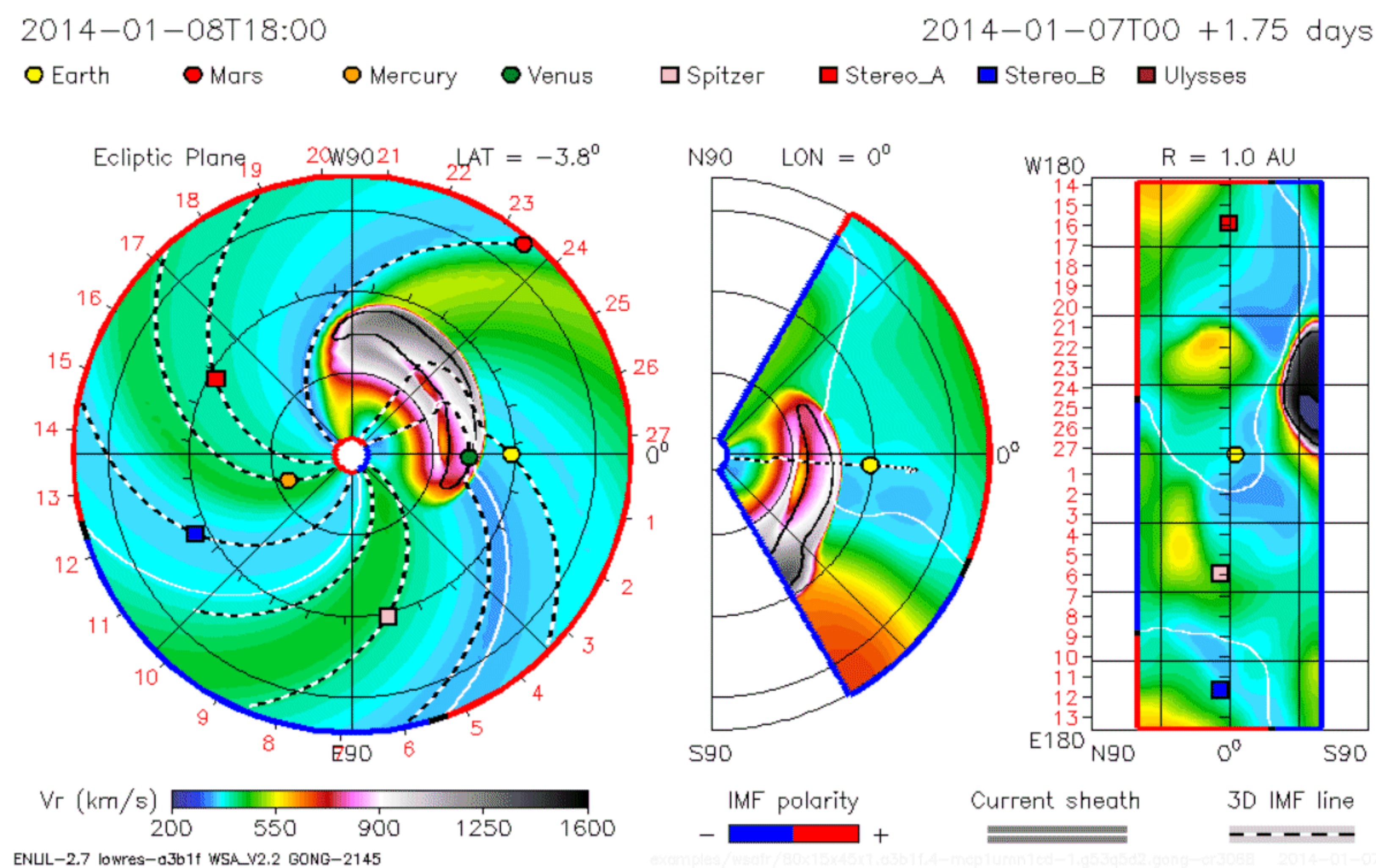
The space weather "Scoreboard" *, developed by the CCMC for the international research community, is a research-based forecasting models validation activity which provides a central location for the community to: 1) submit their forecast in real-time, 2) quickly view all forecasts in real-time and 3) compare forecasting methods when the event has arrived.

Model	Submitter (Developer)	Affiliation
WSA + ENLIL + Cone (separate and ensemble runs)	Mays, duty forecasters (Odstrcil, etc.)	GSFC/SWRC, KSWC, ASFC
STOA (Shock Time of Arrival)	Mays (Dryer)	GSFC/SWRC
Anemomilos	Tobiska	SET SWD
DBM (Drag-Based Model)	Temmer (Vrsnak)	UNIGRAZ
ESA (Empirical Shock Arrival)	Mays (Gopalswamy)	GSFC/SWRC
BHV (Bothmer Heseman Venzmer)	Bothmer	UGOE
COMESEP (COronal Mass Ejections and SEPs)	Devos	SIDC
ESPM (Expansion Speed Prediction Model)	Dal Lago (Schwenn)	INPE

* http://kauai.ccmc.gsfc.nasa.gov/SWScoreBoard/

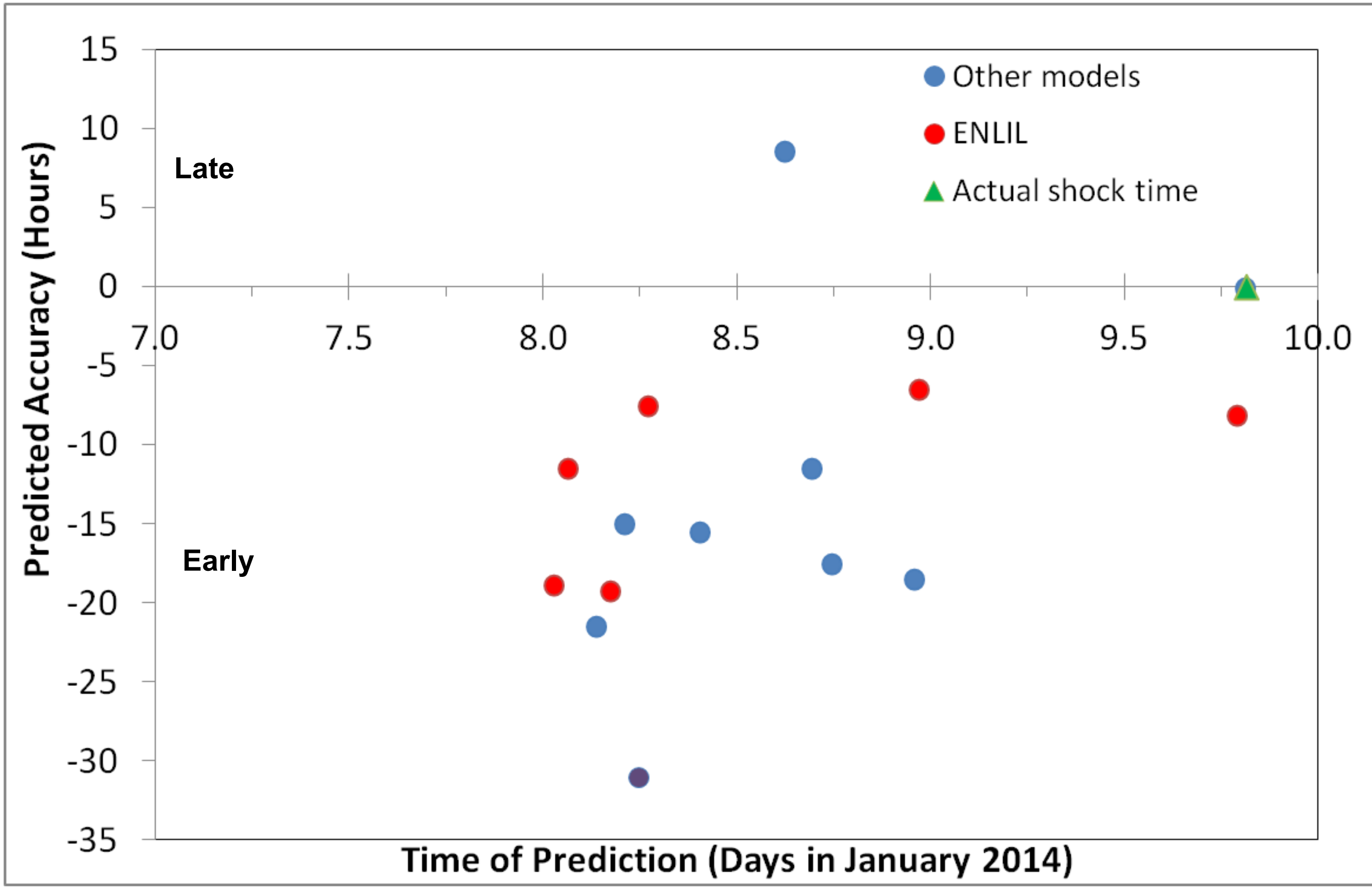
- **CME onset time: 7, 18:24 UT**
- **Actual shock arrival time: 9, 19:32 (ACE - L1)**
- **Sun-1 AU transit time: 2.05 d (49.1 hr.)**

WSA-ENLIL-Cone Run (Velocity) for 7-14 Jan. 2014

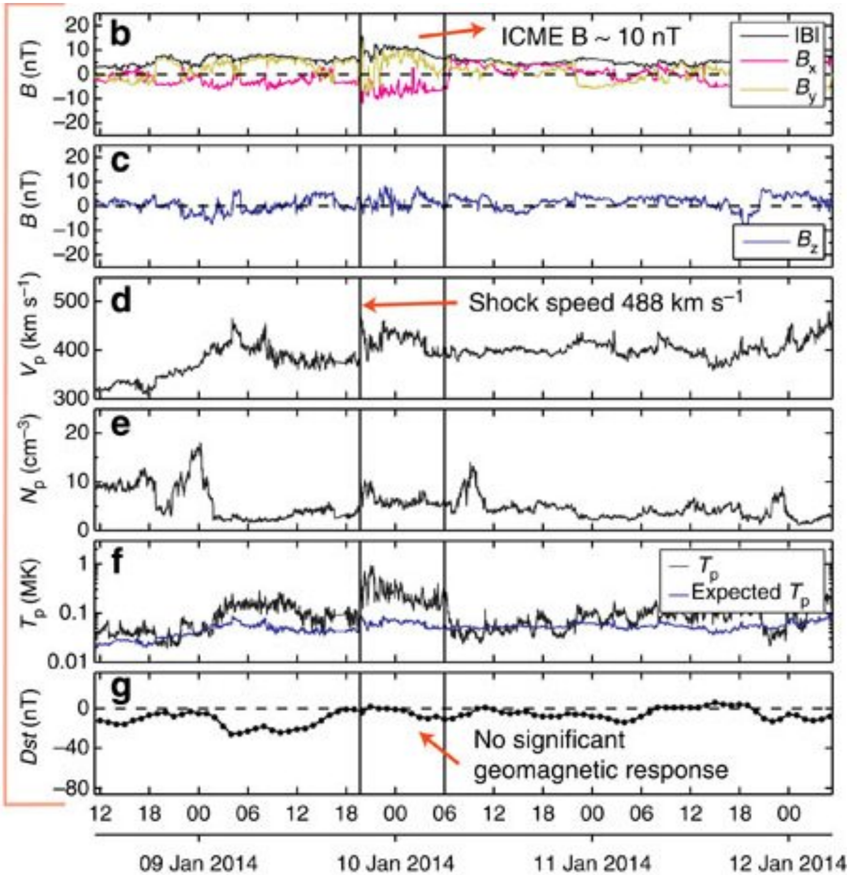


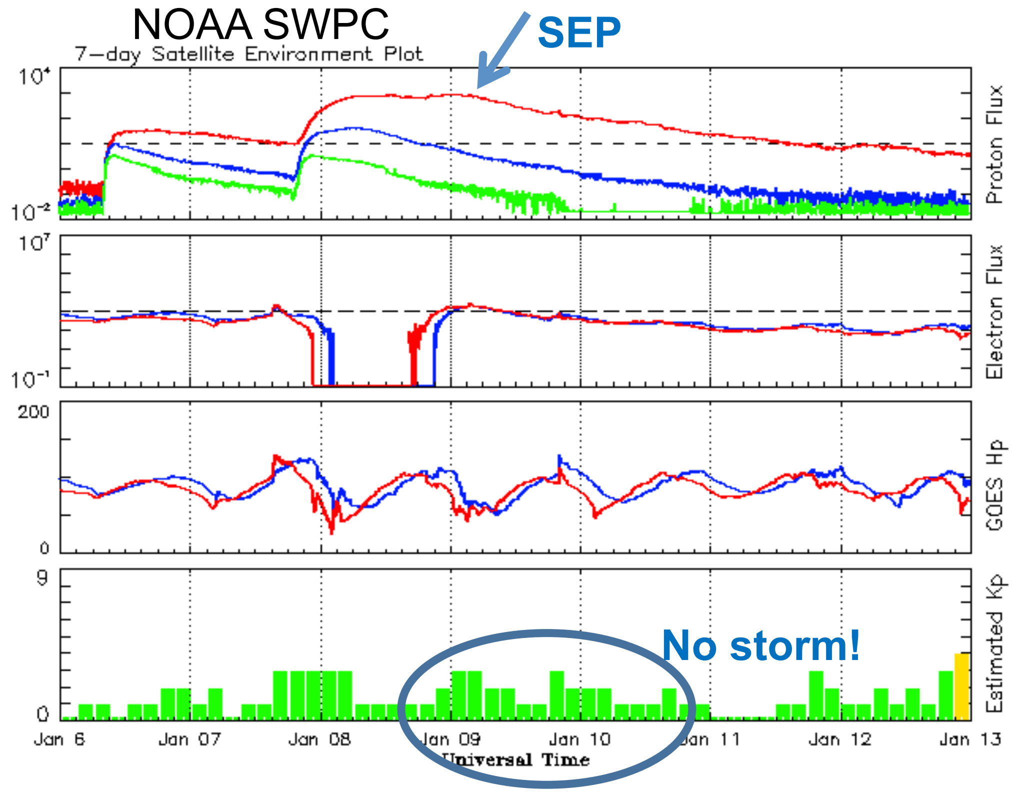
Already this suggests that most of the CME passed to west and south of Earth.

Plot of NRT CCMC Scoreboard Forecasts for January 2014 Event



- Averages for all models: Accuracy = -12.95 hr.; Lead time = 34.3 hr.
- Most models have arrival too early

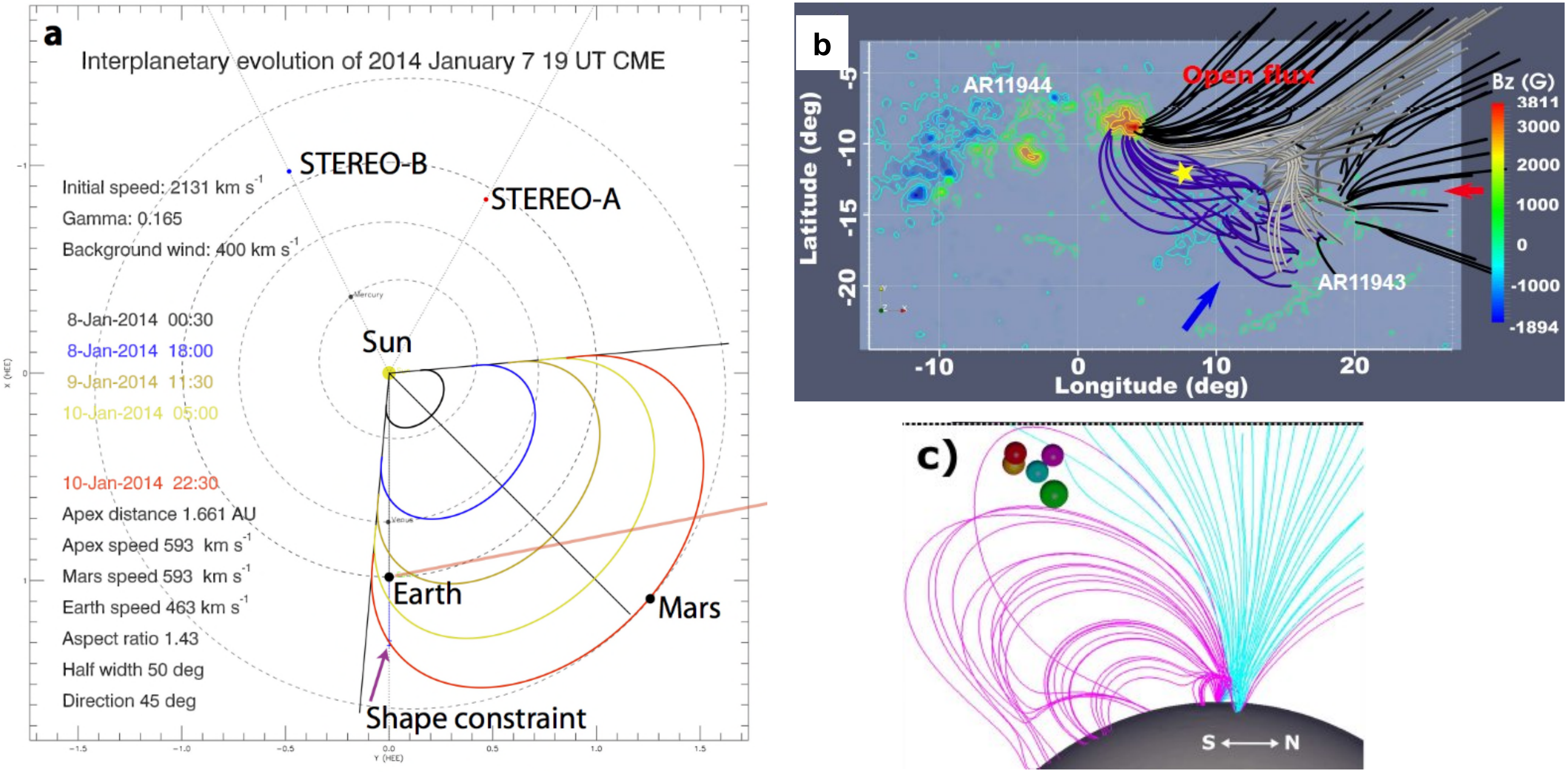




RESULTS AT 1 AU:

- **Moderate shock and sheath in solar wind; maybe weak ICME.**
- **Flare/CME produced a large SEP event agreeing with NOAA forecast but …**
  - There was no geostorm! CCMC Scorecard runs predicted a storm in max Kp range = 5.0 - 9.0 and min Dst range = -142 to -300 nT.
  - The actual max Kp = ~3 and Dst < -14 nT.

Modeling of Shock Propagation & Coronal Magnetic Fields



(a) ElEvo Model; *Moestl et al., NC (2015).* Ecliptic positions of planets and spacecraft on 7 Jan. Shape of CME shock given by Ellipse evolution (ElEvo) model plotted for different timesteps. Model parameters (bottom left) are for last timestep at *tMars*. (b) *R. Wang et al. (2015):* NLFFF model of coronal magnetic fields of source region at 18:00 UT. Different magnetic flux bundles represented by different color field lines. Yellow star marks the location of CME source region. (c) PFSS reconstruction of mag field above source region. Open (cyan) and streamer belt (purple) mag field lines viewed from west. Circles are centers of CME mass from polarimetry at different heights/times.

Conclusions for Event 4

- **CCMC model run results: The predicted CME (shock) arrival times averaged ½ day too early, e.g., the CME was too fast. This suggests that the CME was decelerated during its propagation, or Earth encountered only the flank, or something else (?)**

- **Why was this energetic, near-Sun center event not very geoeffective?**

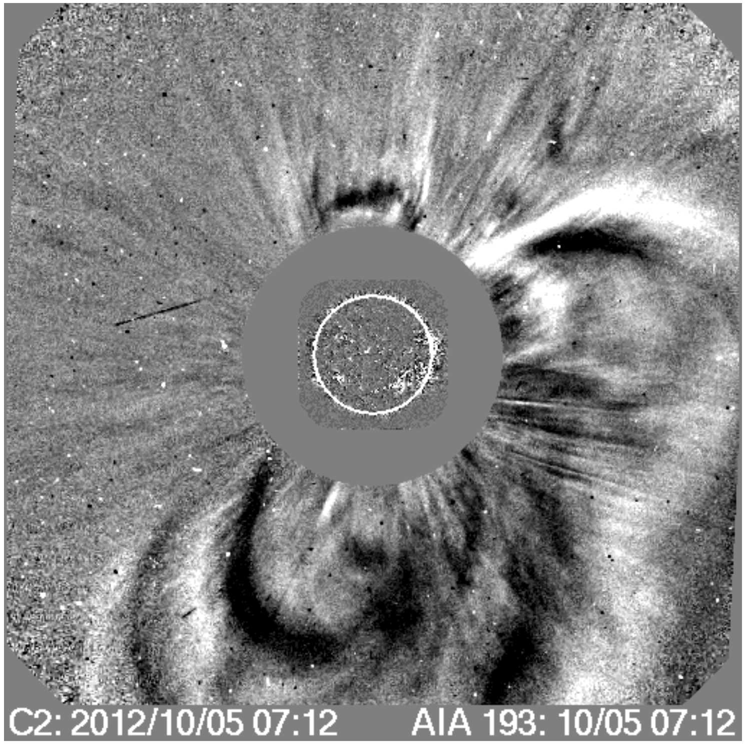
- The CME was offset and propagated to the southwest.

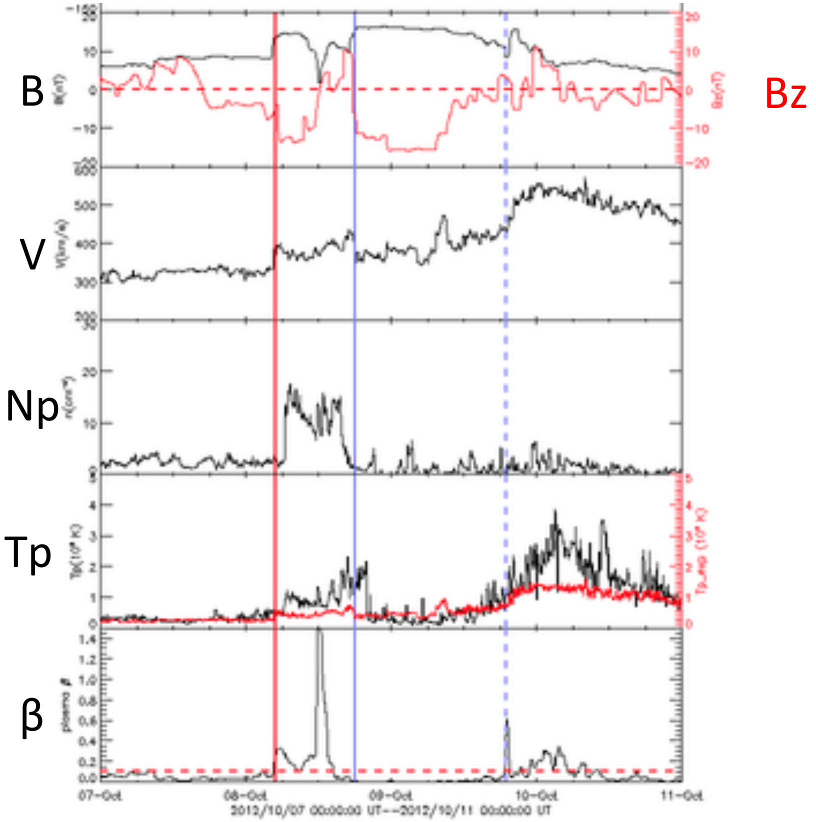
- In the ecliptic plane projection, the CME nose was aimed ~45° to the west of the Sun-Earth line.

- *Moestl et al. (NC, 2015)* and *R. Wang et al. (ApJ, 2015)* argue that the CME was strongly "channeled" away from Sun center by the AR magnetic fields. *Gopalswamy et al. (EPS, 2014)* suggest that the large coronal holes in the NE deflected the CME, at least contributing to its non-radial propagation.

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

- **Example of a problem event:**
  - A clear, bright CME and an ICME; drove small geostorm
  - But no or very weak surface signatures (e.g., flares, dimmings, filament eruptions, etc.). Also, there were multiple, weak eruptions.





- **~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 particularly difficult, even with multiple views.**
- **Challenges for SWx forecasting!**

Conclusions for WG 4

- **Integrate observations, theory and simulations to understand 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 signatures. in low corona or at Sun's surface. We need to solve this!
10% due to CIR-HSSs. The shock sheath region is also important (but unpredictable)!

Themes for WG 4 Session on Wednesday

- **Understanding cause-effect chain from Sun to Earth, with focus on examining these problem or controversial events to better understand how they are produced and propagate.**

  - Why do forecasts fail and how can we improve them?
  - Analyze the complications that arise when linking CMEs to ICMEs.
  - Focus is on controversial geoeffective CME/ICME pairs during the STEREO and SDO eras *(STEREO from 2007; SDO from 2010)*

- ***Talks and Discussion:***

  T. Nieves-Chinchila *(Invited – given by N. Savani)* → Topologies of CME Flux Ropes

  N. Srivastava → COMESEP forecasts
  R. Montes → Ionospheric effects
  Y. Wang → IP deflection of CMEs
  S. Kaushik → Predicting storm dynamics

Extra slides

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