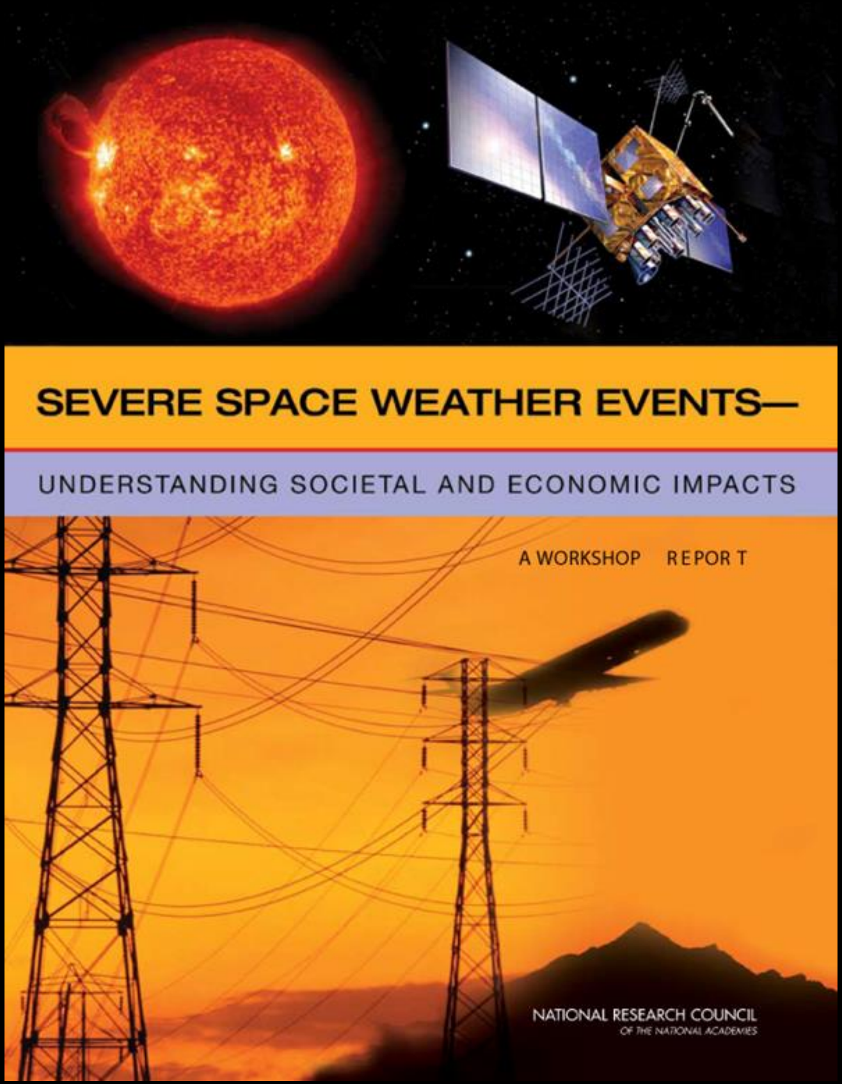

A Major Solar Eruptive Event in July 2012: Defining Extreme Space Weather Scenarios

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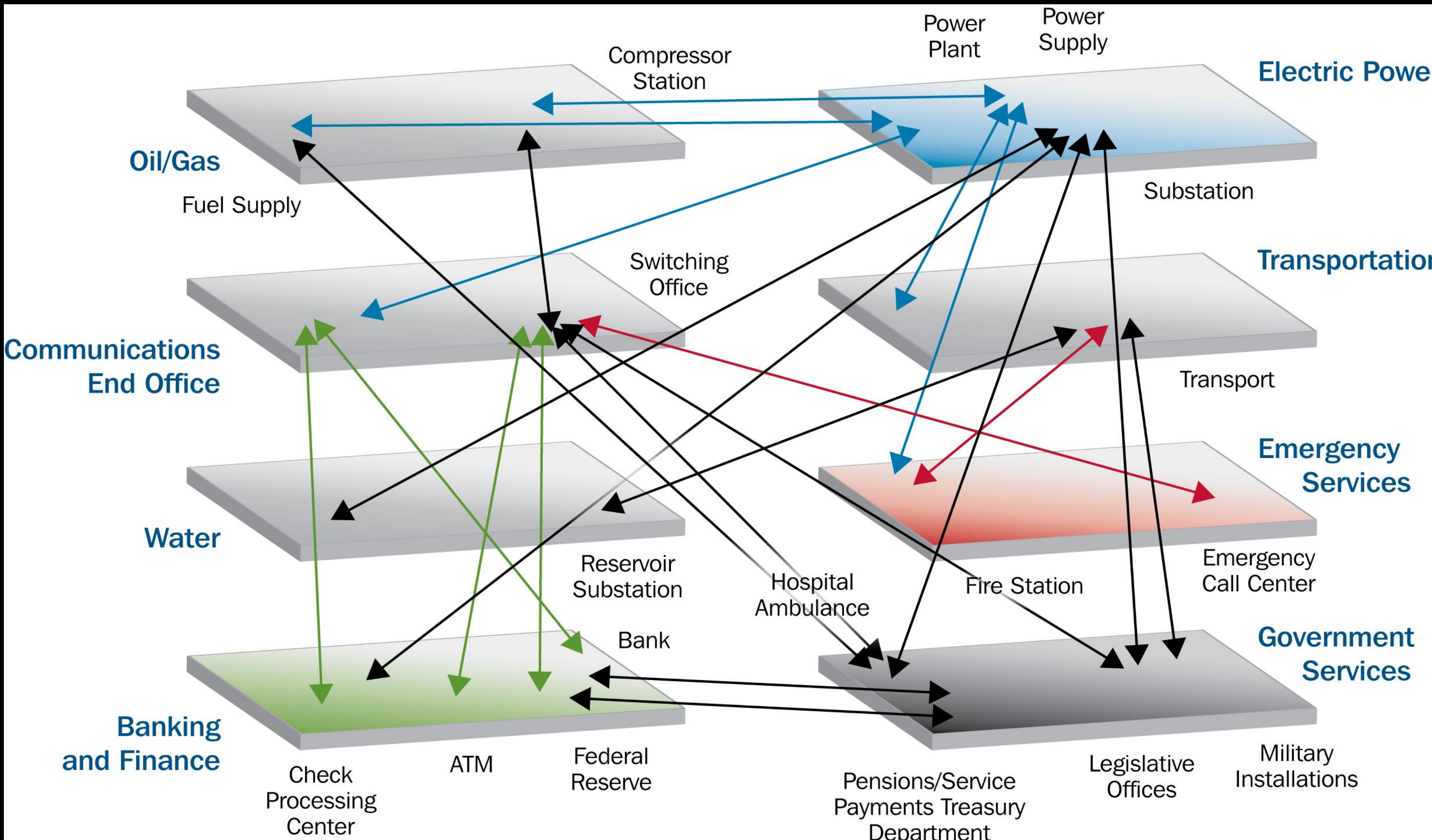
Astrophysical and Planetary Sciences Department

Department of Physics

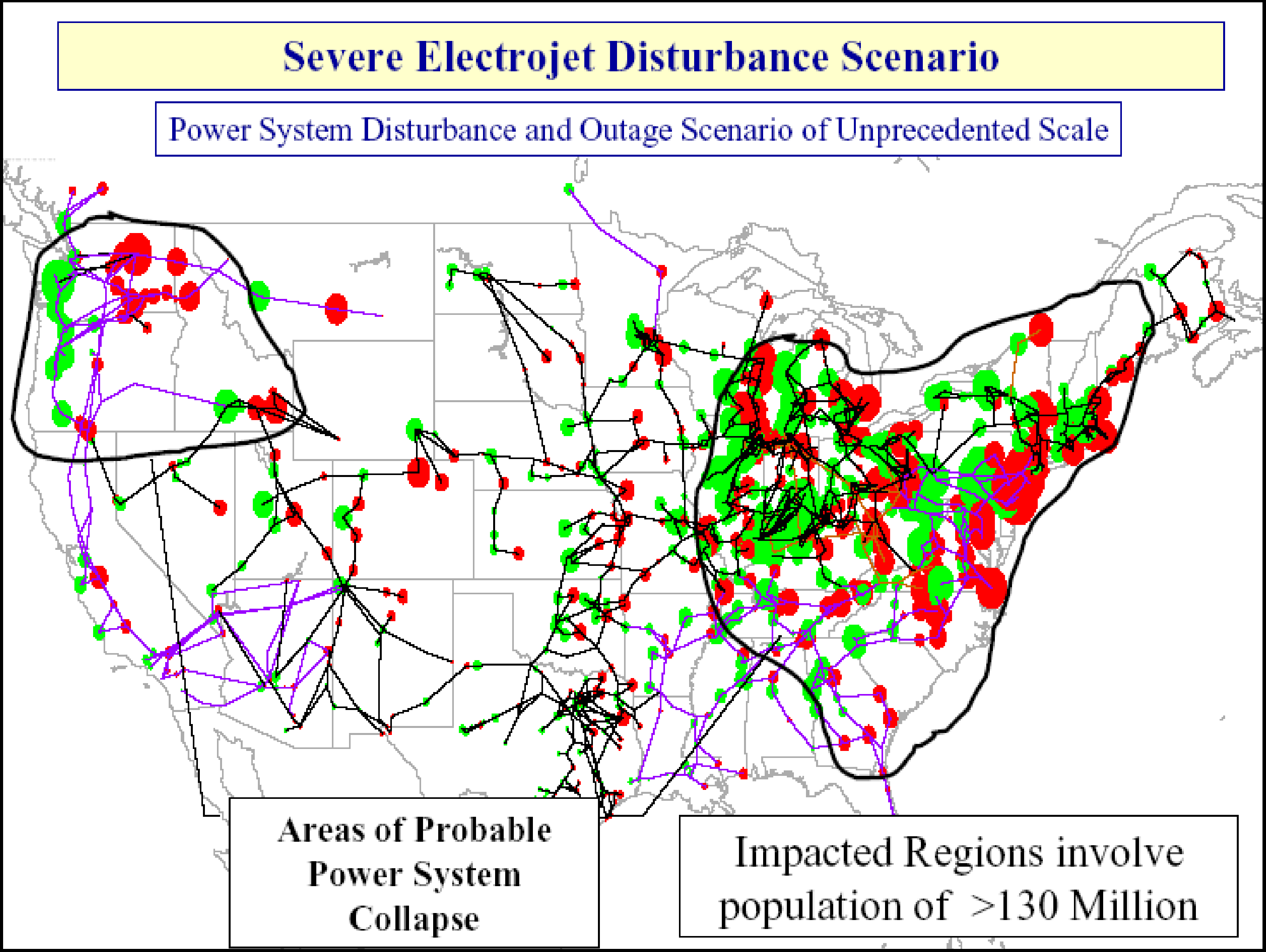
University of Colorado, Boulder

The Interdependencies of Society



[DHS graphic in NRC, 2009]

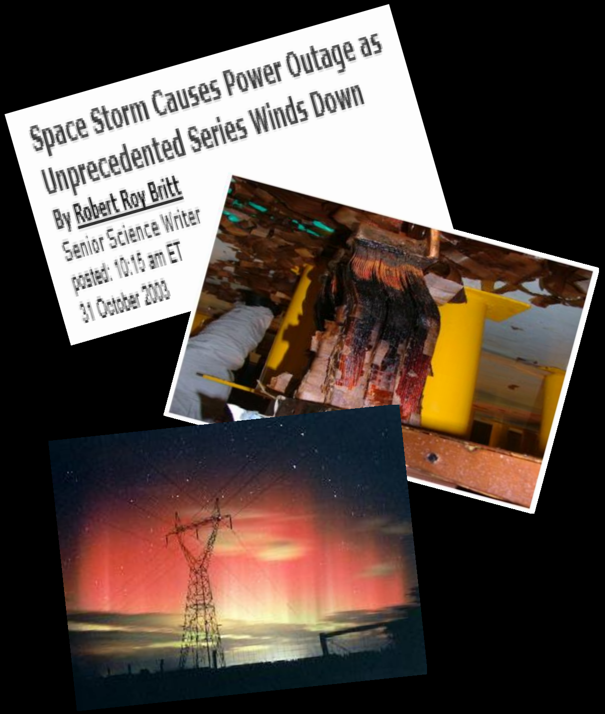
Regional Power Grid Disruptions



Low Frequency/High Consequence:

Increasing Power Grid Vulnerability

"The grid is becoming increasingly vulnerable to space weather events"



Future Directions in Satellite-derived Weather and Climate Information for the Electric Energy Industry – Workshop Report Jun 2004

$1-2 trillion | **Potential loss due to widespread power grid Blackout following severe geomagnetic storm**

4-10 years | **Recovery time from a widespread power grid Blackout following severe geomagnetic storm**

Source: National Academy Workshop on the Societal and Economic Impacts of Severe Space Weather Events held in Washington, D.C., May 2008.

Three recent key papers

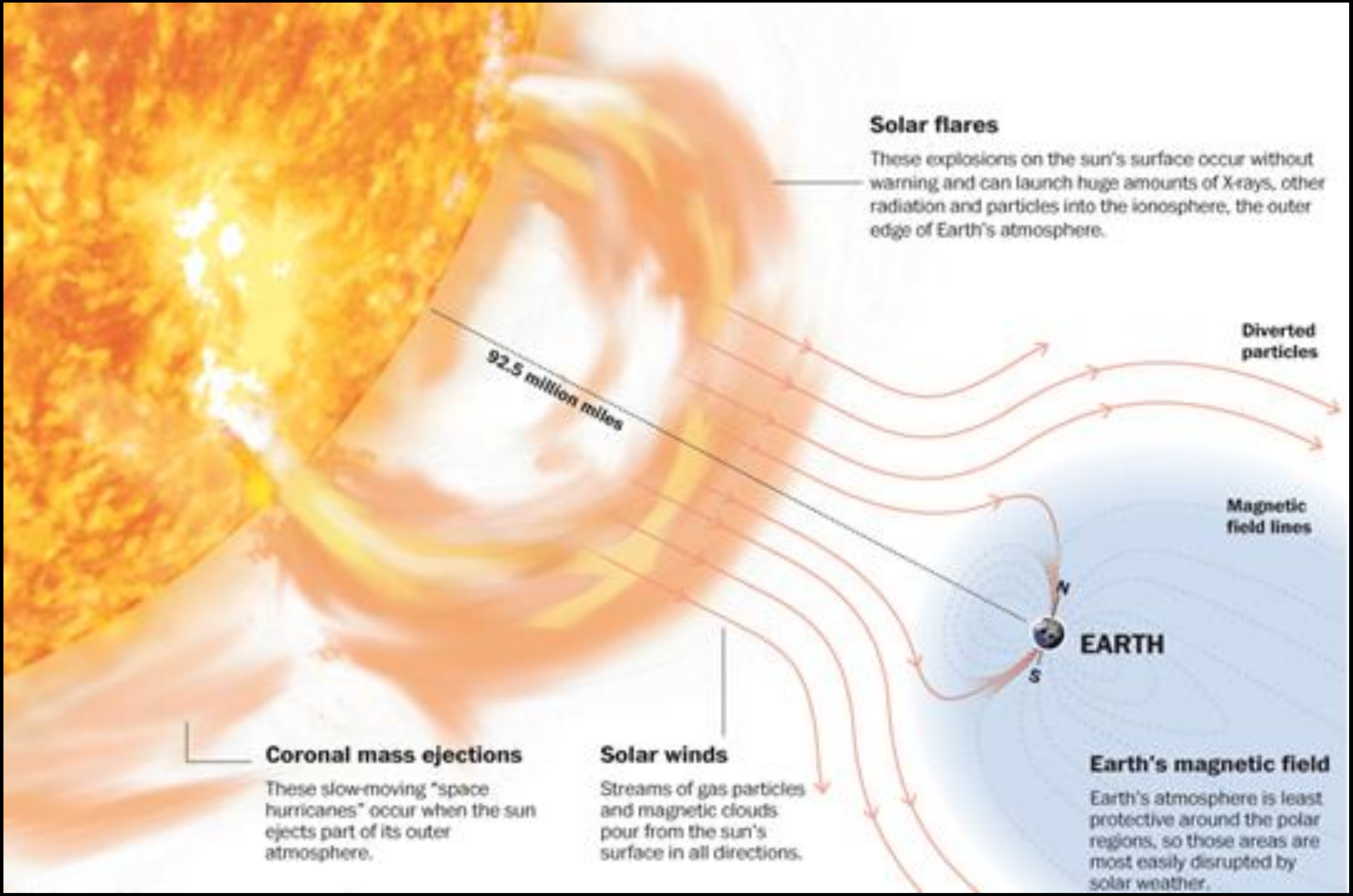
- Citation: Baker, D. N., X. Li, A. Pulkkinen, C. M. Ngwira, M. L. Mays, A. B. Galvin, and K. D. C. Simunac (2013), A major solar eruptive event in July 2012: Defining extreme space weather scenarios, ***Space Weather***, **11**, 585–591, doi:10.1002/swe.20097.

- Citation: Ngwira, C. M., A. Pulkkinen, M. L. Mays, M. M. Kuznetsova, A. B. Galvin, K. Simunac, D. N. Baker, X. Li, Y. Zheng, and A. Glocer (2013), Simulation of the 23 July 2012 extreme space weather event: What if this extremely rare CME was Earth directed?, ***Space Weather***, **11**, 671–679, doi:10.1002/2013SW000990.

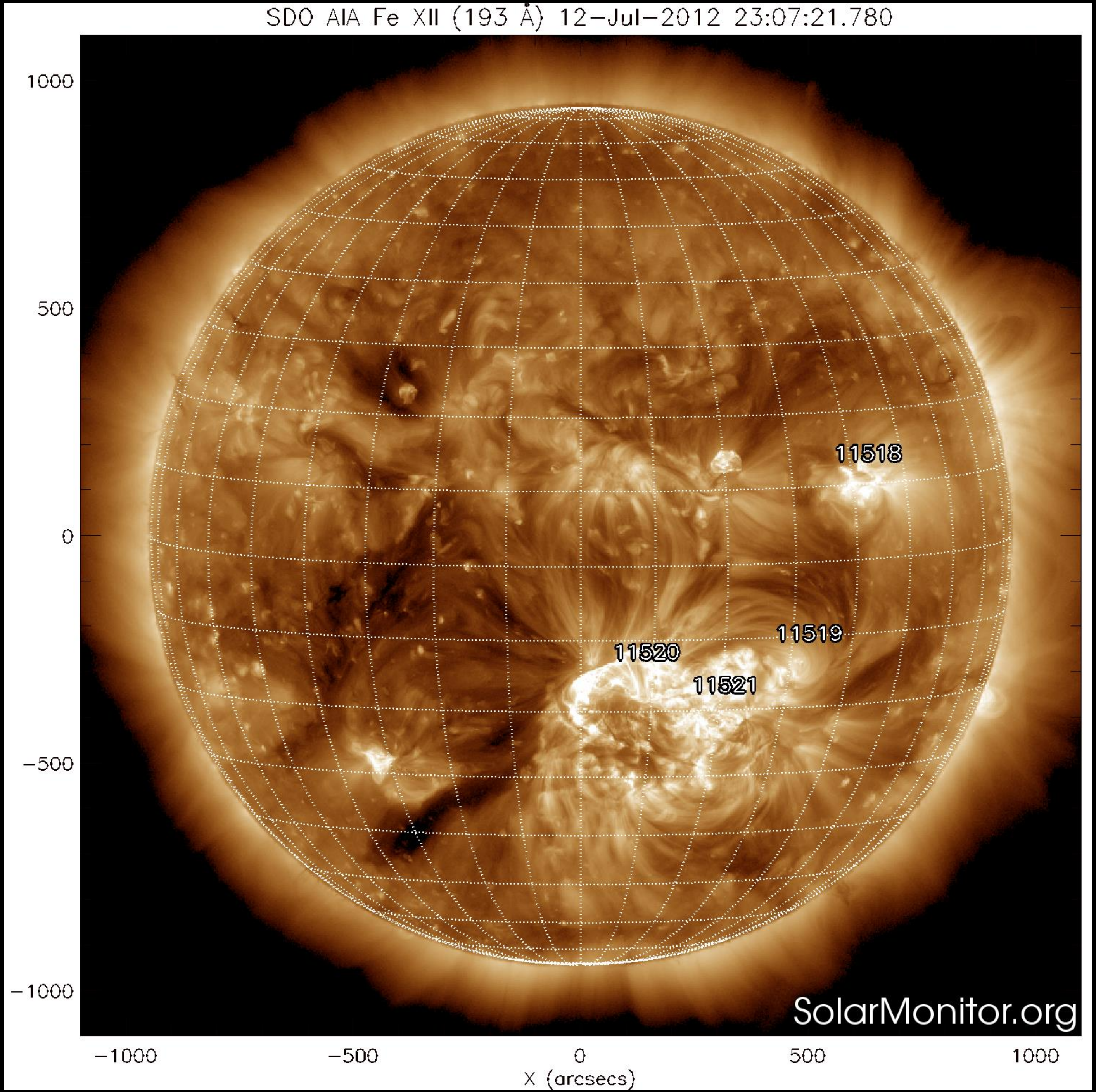
- Citation: Ying D. Liu, J. G. Luhmann, P. Kajdic, E. K.J. Kilpua, N. Lugaz, N. V. Nitta, C. Mostl, B. Lavraud, S. D. Bale, C. J. Farrugia, and A. B. Galvin, Observations of an extreme storm in interplanetary space caused by successive coronal mass ejections, ***Nature Communications***, 18 March 2014, doi: 10.1038/ncomms4481

All of these researchers should be considered coauthors of today's presentation

CME events produce Geomagnetic Disturbances (GMD) which produce Ground Induced Currents (GIC) on Earth



Washington Post Graphic



SDO AIA Fe XII (193 Å) 12-Jul-2012 23:07:21.780
1000
500
0
−500
−1000
−1000
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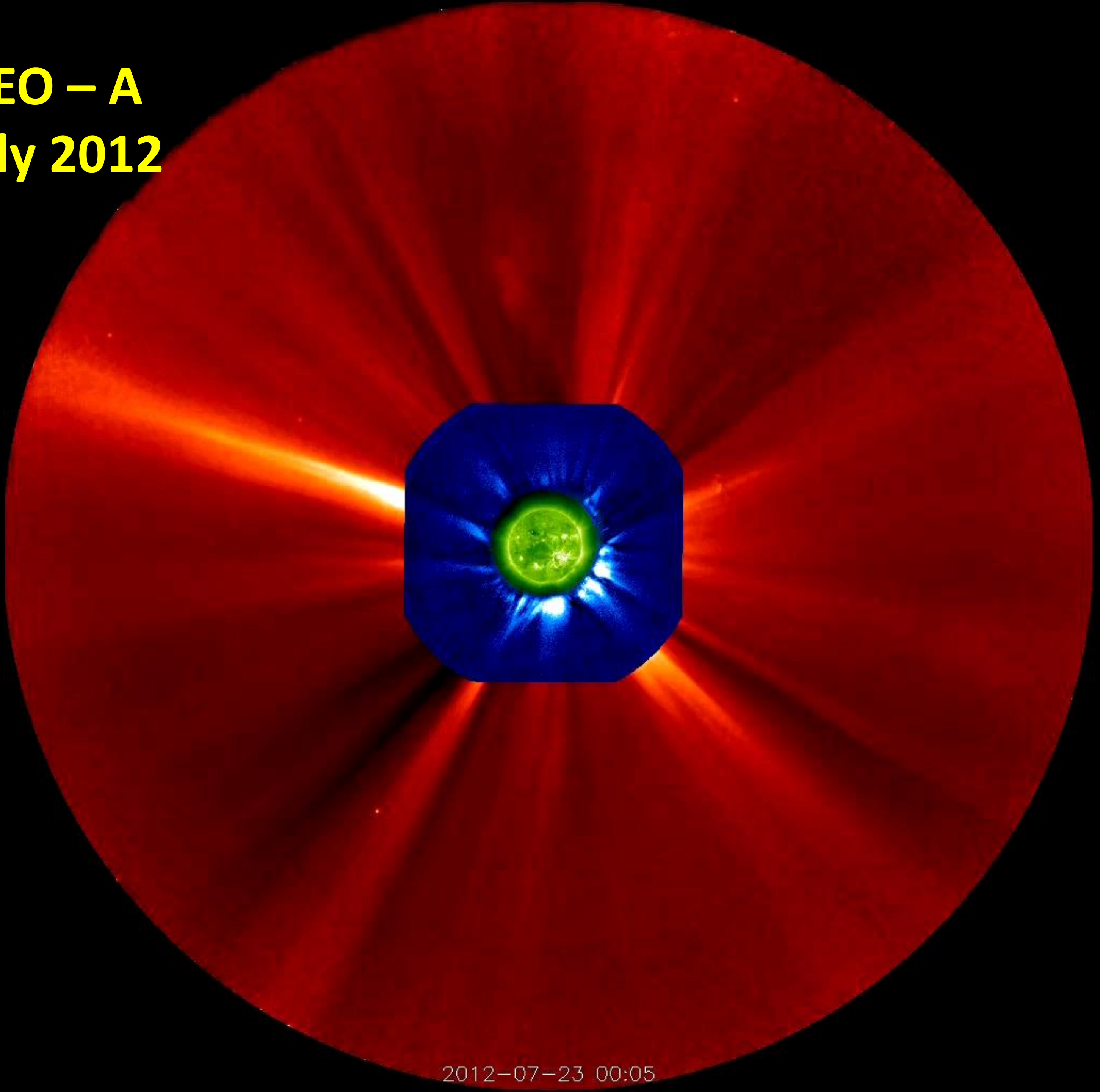
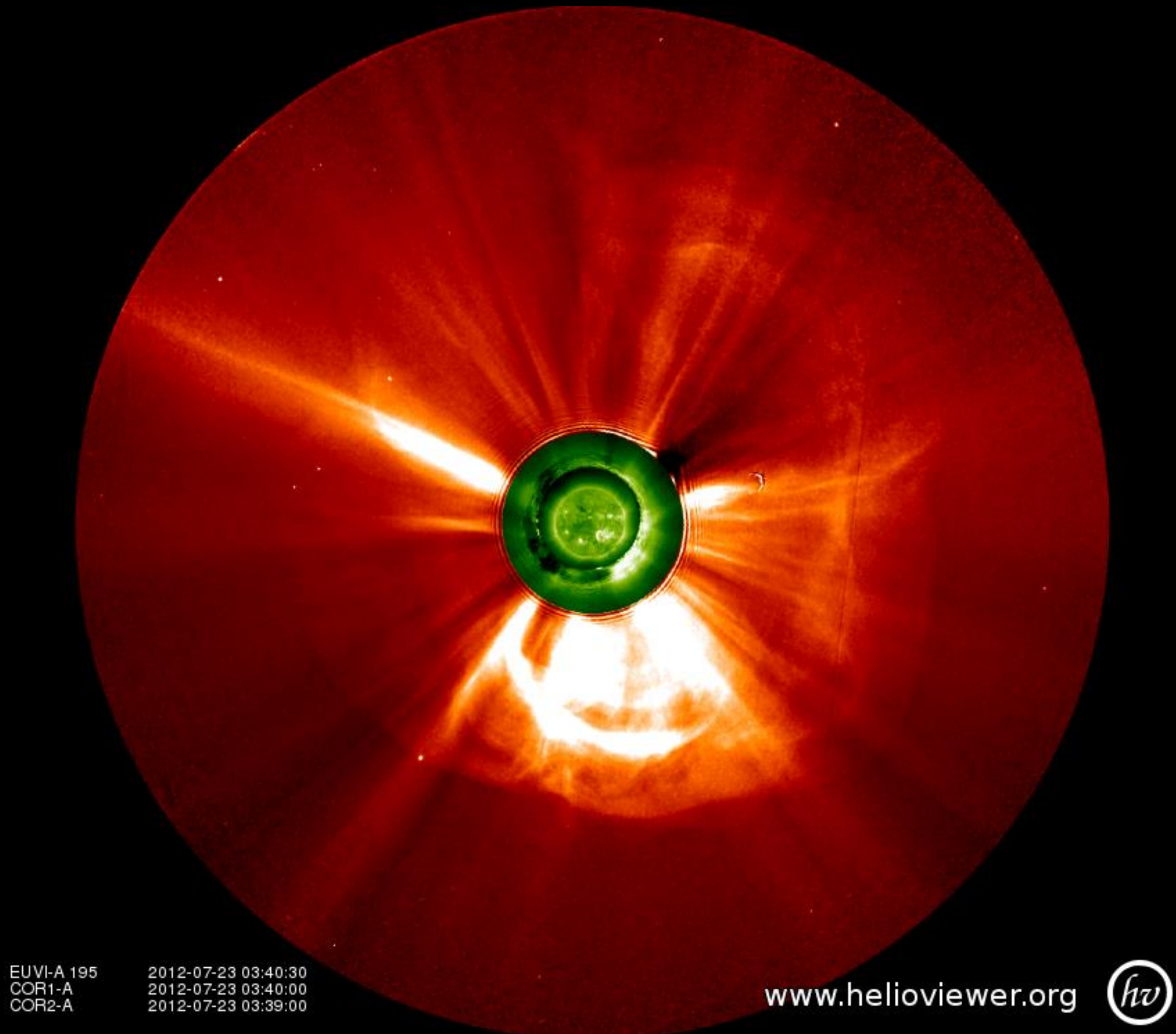
0
500
1000
X (arcsecs)
11518
11519
11520
11521
SolarMonitor.org

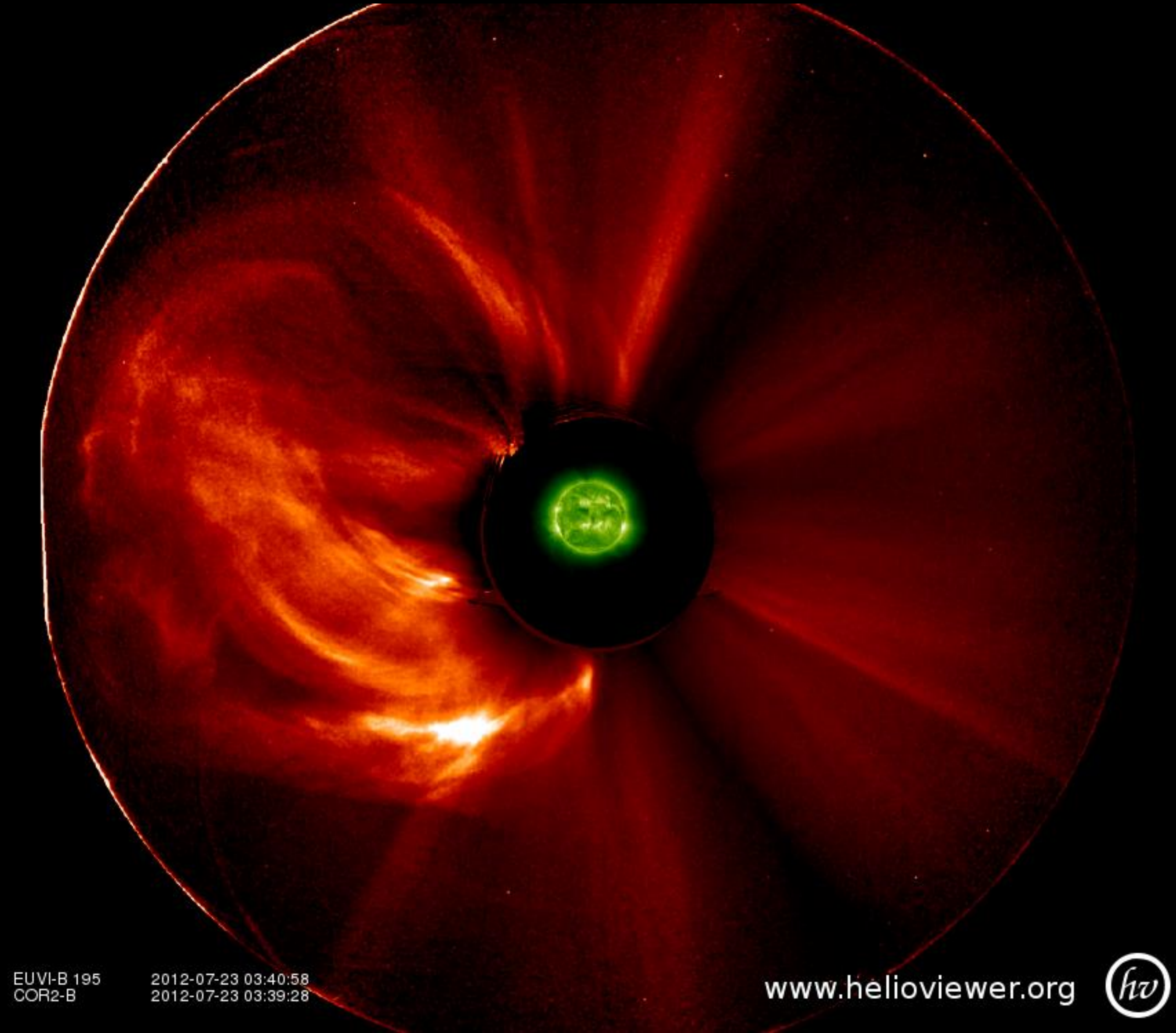
STEREO – A
23 July 2012



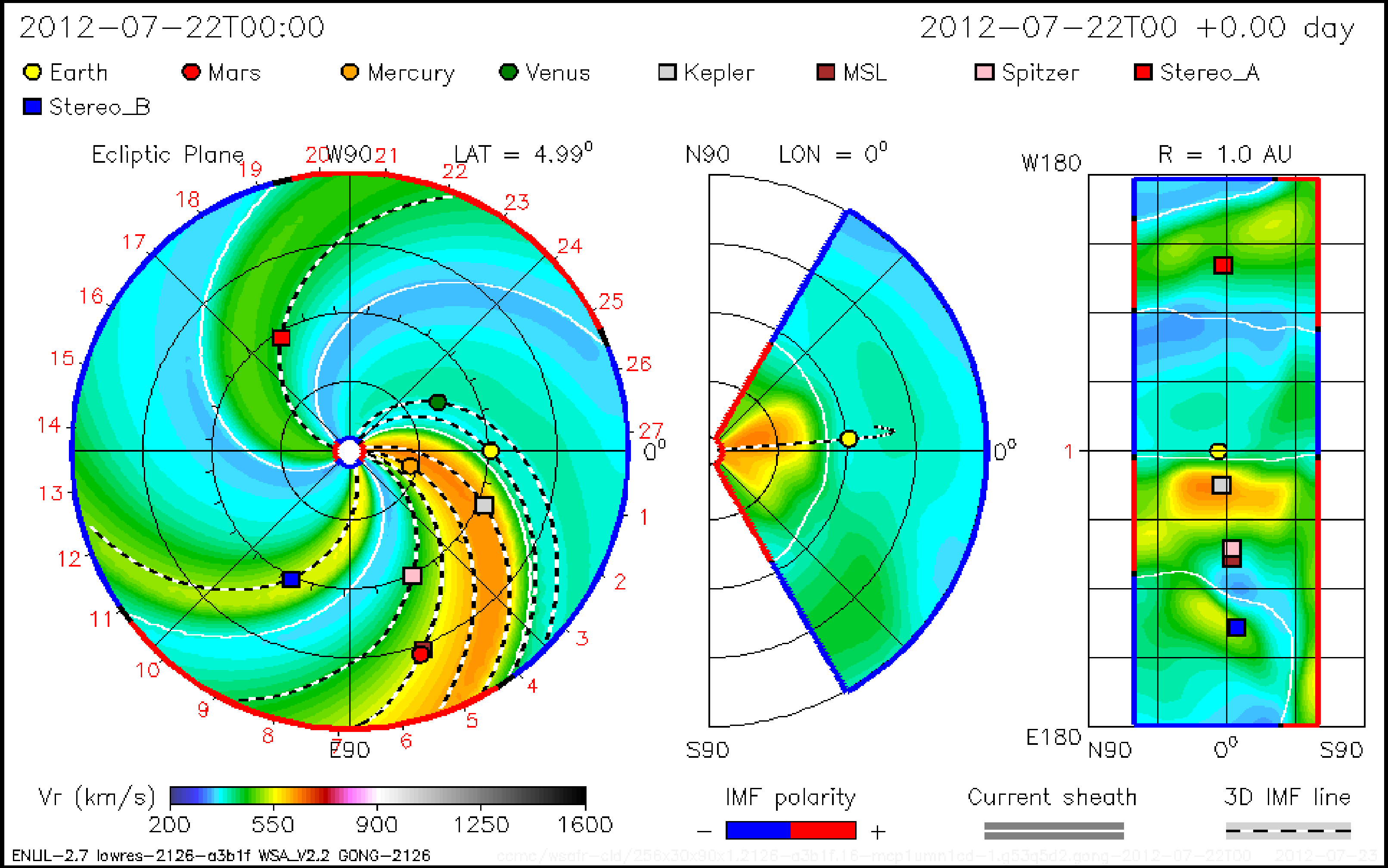
STEREO-A NESTED Images



STEREO-B Nested Images

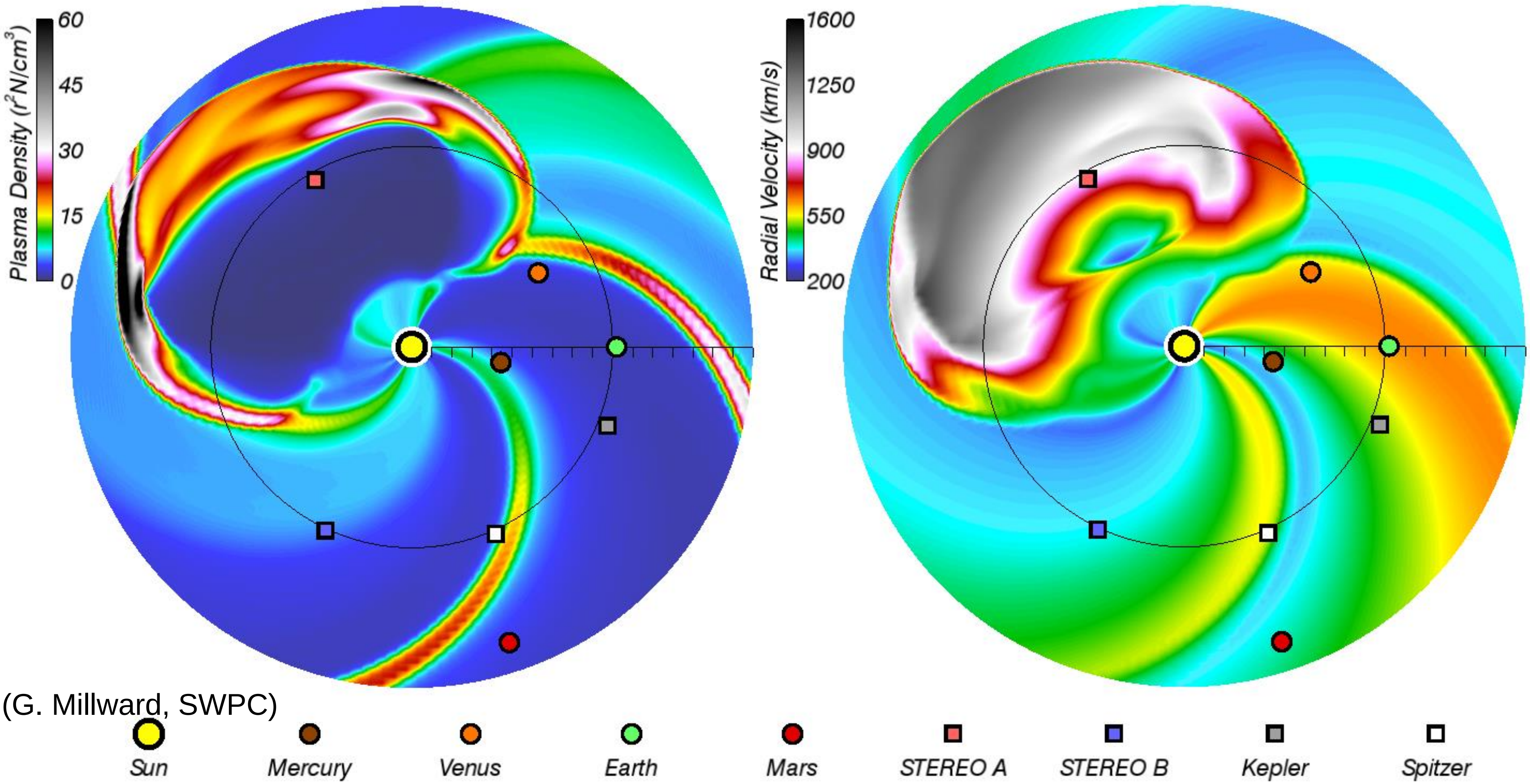


WSA-ENLIL Model: Solar Wind Speed



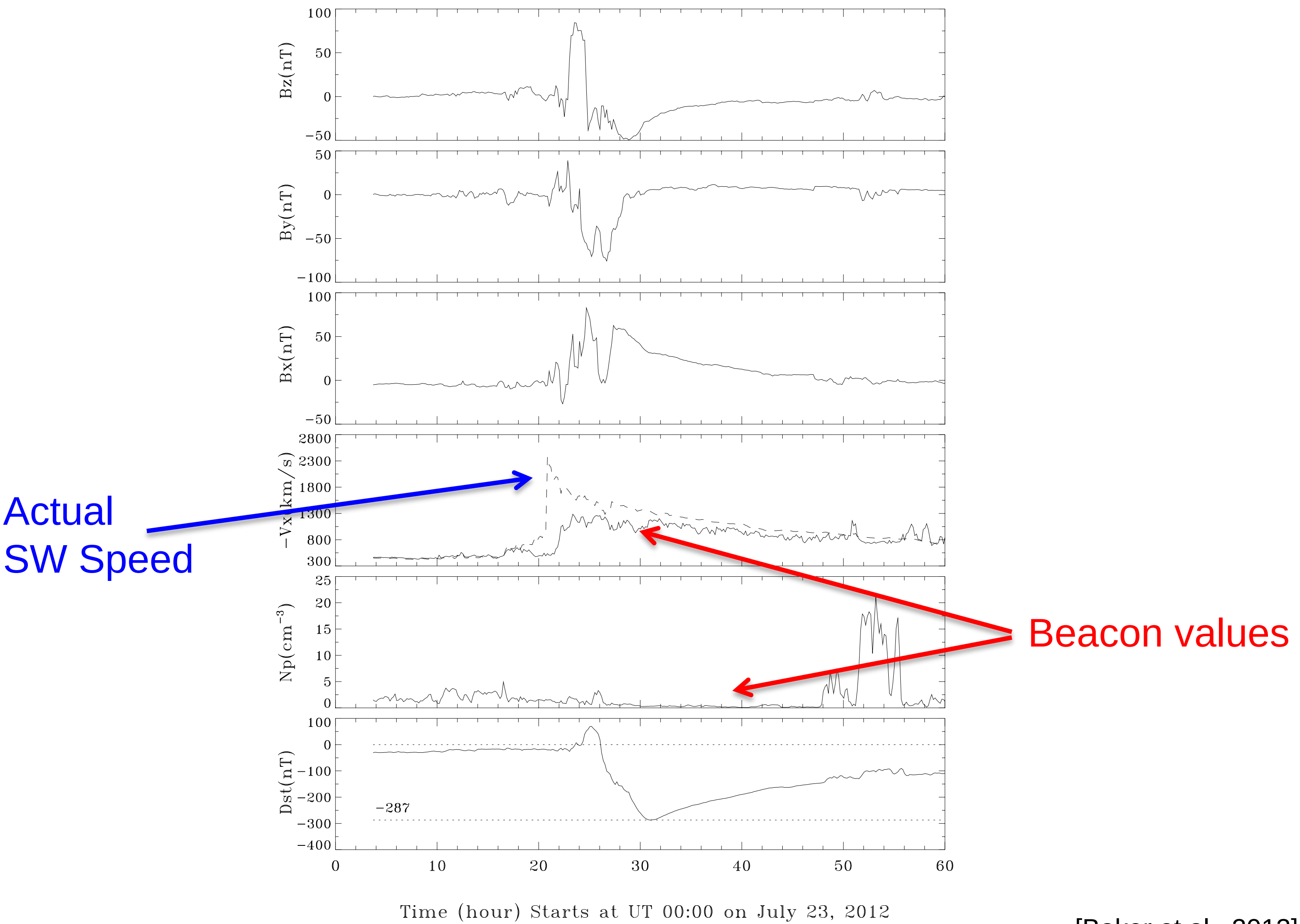
WSA-ENLIL Model: 1200 UT 24 July

[Baker et al., 2013]



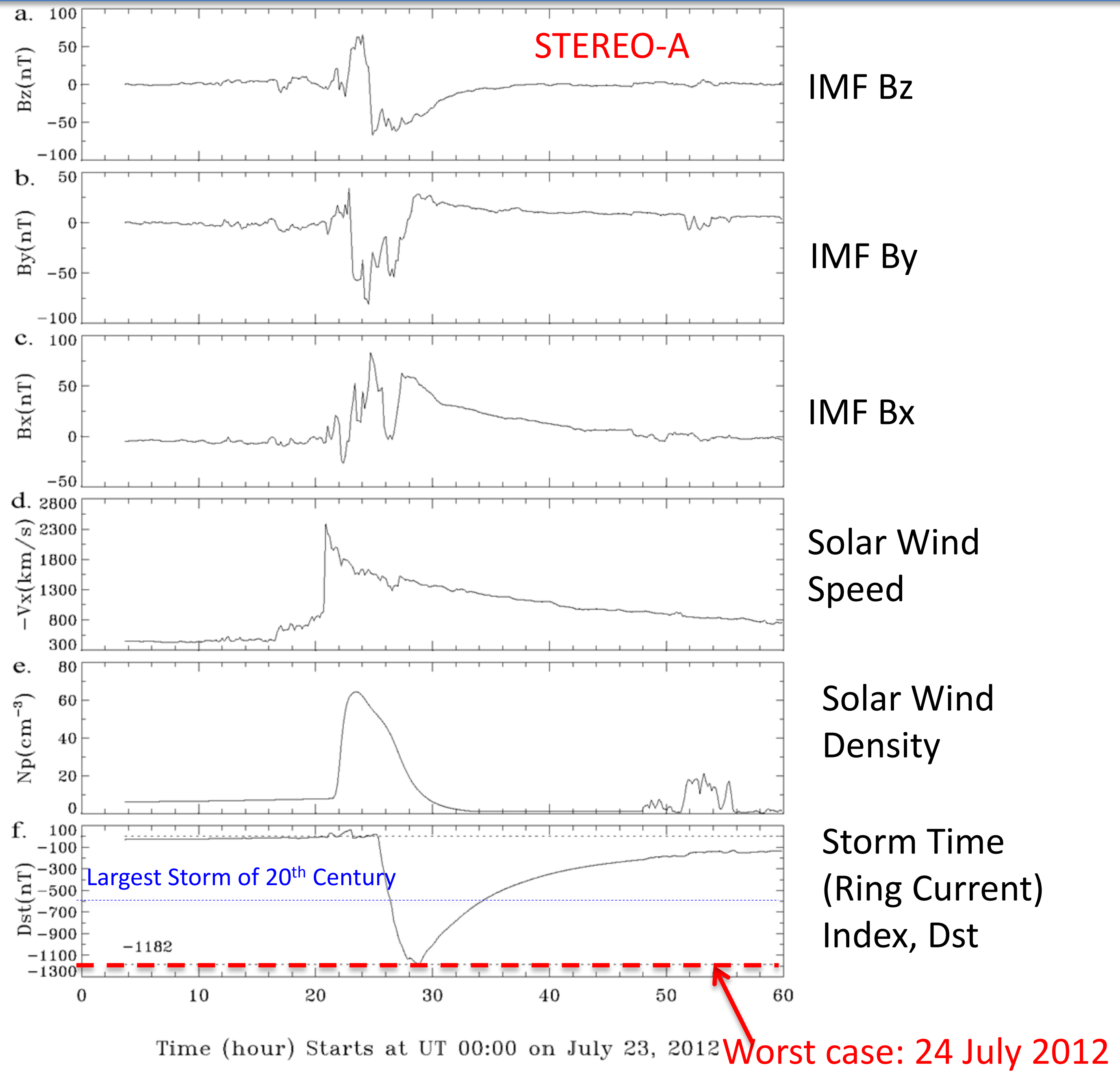
(G. Millward, SWPC)

Initial Temerin-Li Model Results



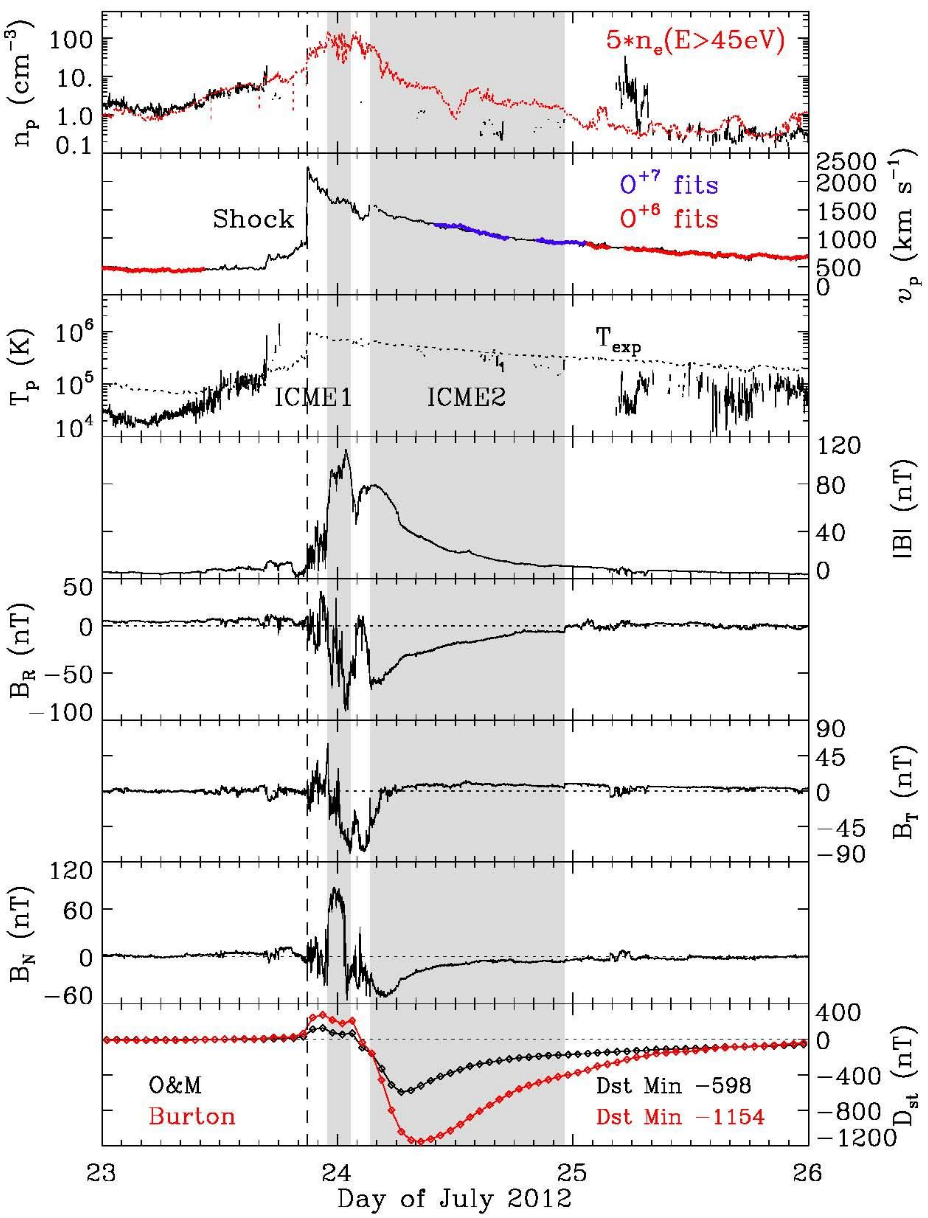
[Baker et al., 2013]

Plausible Worst-Case Scenario



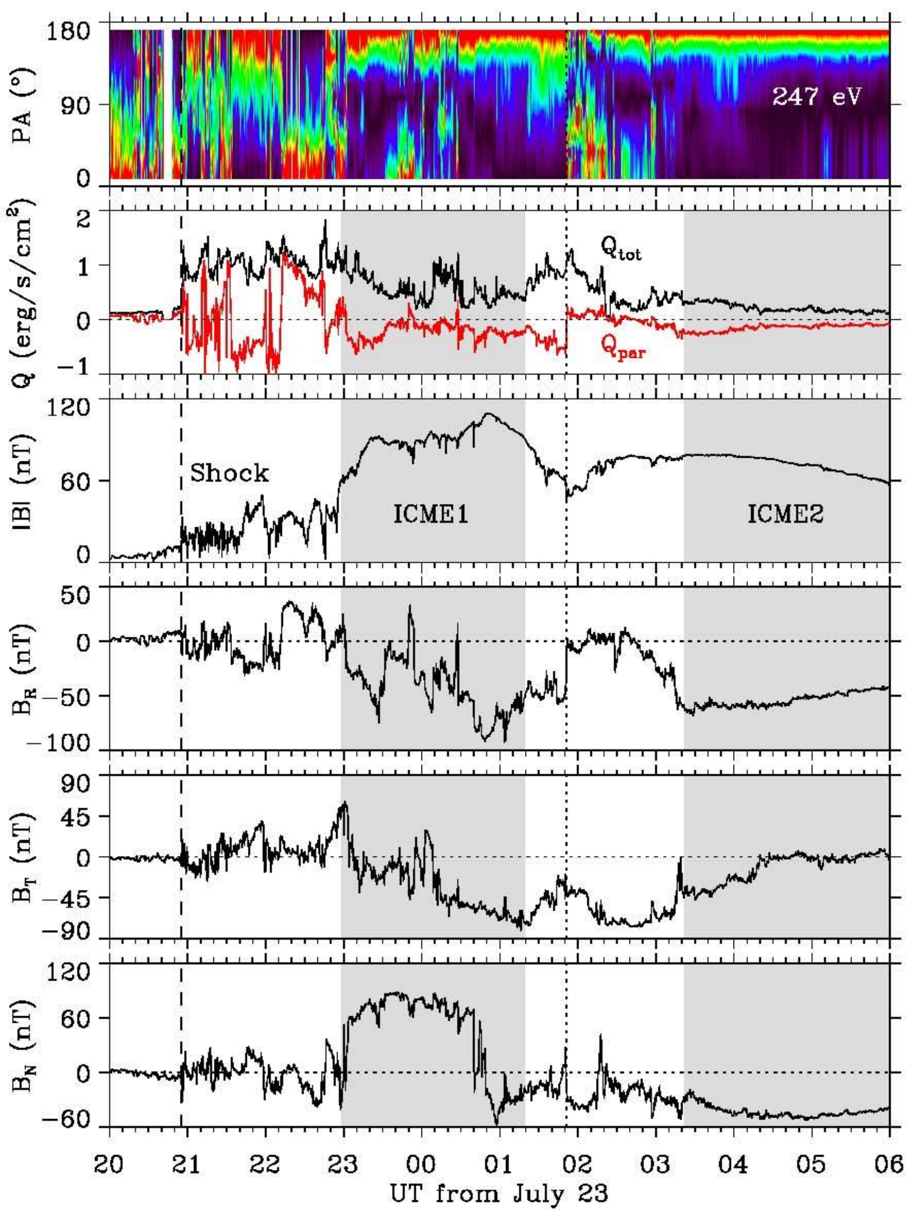
In situ signatures at STEREO A

- A forward shock passed STEREO A at 20:55 UT on July 23, with a transit time of only 18.6 hours;
- Two ICMEs can be identified behind the shock;
- Both the peak speed (2246 km/s) and the peak magnetic field strength (109 nT) are among the few largest on record ever measured near 1 AU;
- The event was not slowed down much by the ambient medium;
- The estimated minimum Dst is -1150 — -600 nT, which seems more intense than the most severe geomagnetic storm of the space age! Consistent with Russell et al. 2013, Baker et al. 2013, and Ngwira et al. 2013.



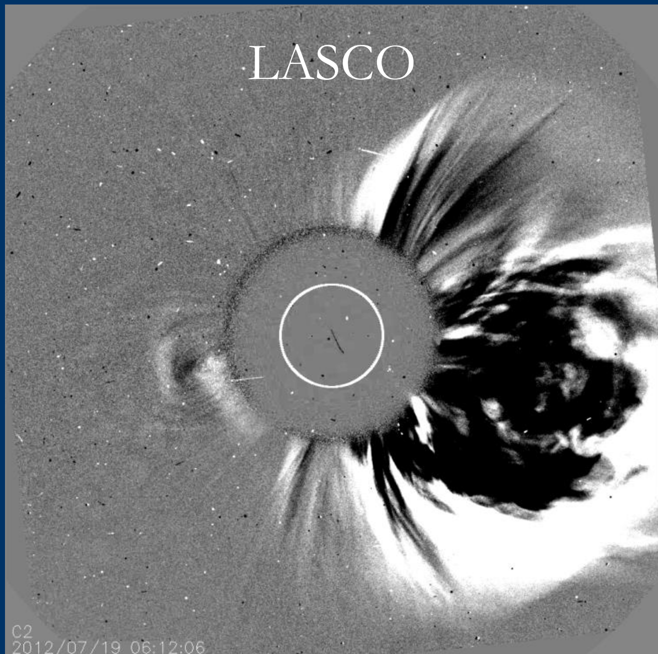
[Ying Liu et al.]

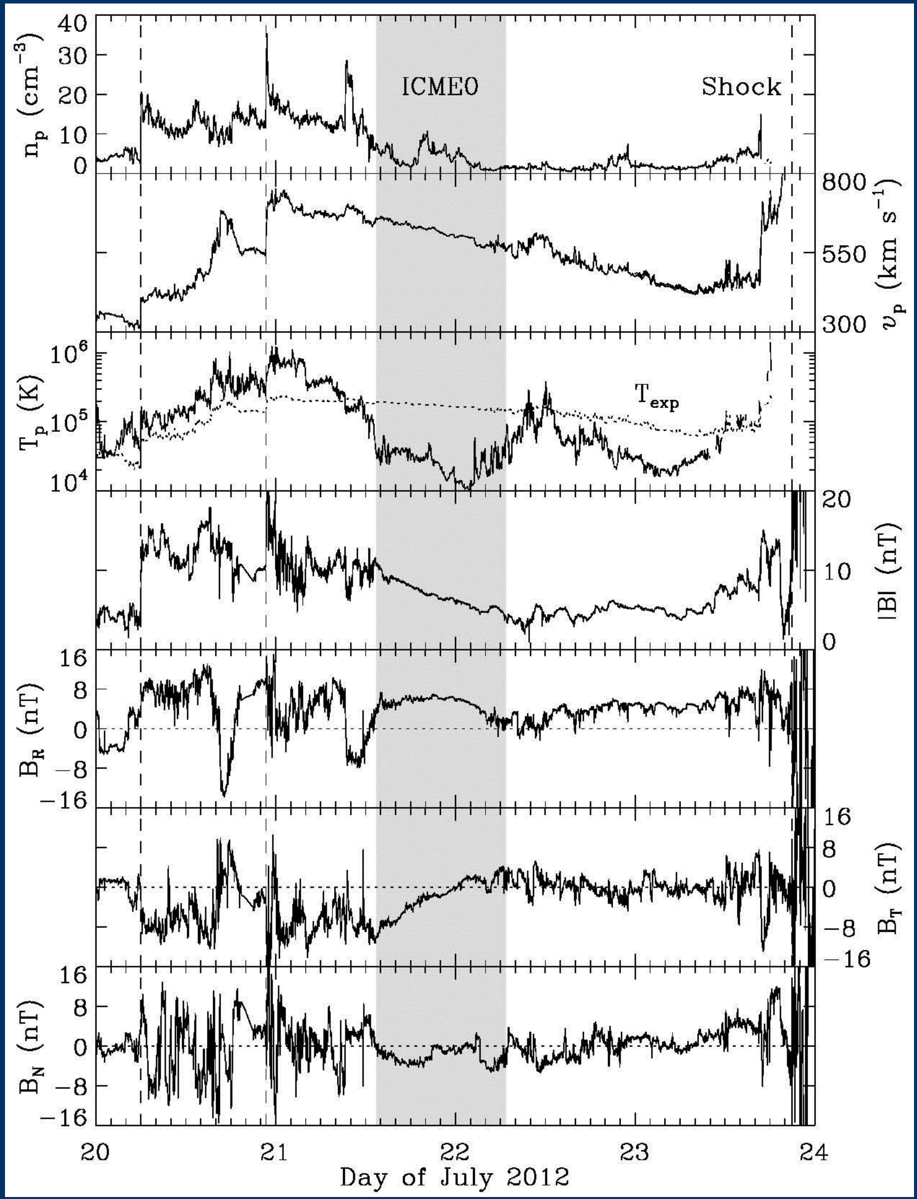
Cause of strong magnetic field



- Combination of imaging with in situ indicates that the mechanism of creating the extremely strong magnetic field is CME-CME interaction;
- The interval of ICME1 is very short, probably owing to compression by ICME2 from behind;
- Electron pitch angle distribution becomes irregular in the region between the two ICMEs;
- The heliospheric current sheet was entrained in the CME-CME interaction region (01:51 UT);
- Electron heat flux is enhanced in ICME1 and the interaction interface but decreases into ICME2.

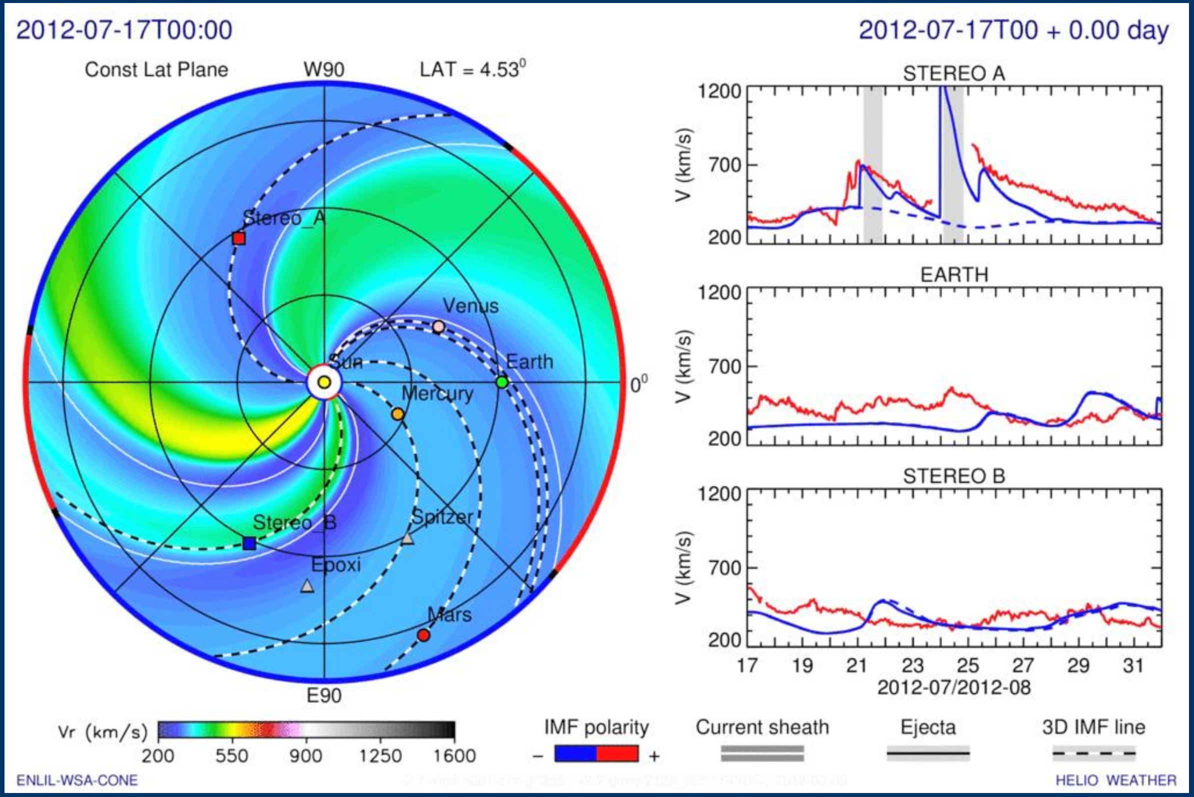
Cause of minimal slowdown





- A series of preceding eruptions occurred on the Sun including the July 19 CME (from the same active region);
- The July 23 event was moving through a density depletion region (as low as 1 cm^{-3}) with radial magnetic fields.

ENLIL MHD simulations (D. Odstrcil)



- Preliminary modeling captures some of the features (i.e., rarefaction and field line stretching by preceding eruptions), but the solar wind speed and magnetic field near 1 AU are significantly underestimated;
- To reproduce the key space weather elements the physical processes associated with the CME-CME interaction have to be properly treated.

Summary

- The operational space weather community has long sought a defensible, plausible "worst case" space weather scenario (better than Carrington event)
- Nature performed an almost ideal active experiment on 23-24 July 2012: Powerful solar storm but directed away from Earth and key technical assets
- Recent research results shown here demonstrate how interactions between consecutive CMEs (Liu et al.) resulted in a "perfect storm" near 1 AU, i.e., nonlinear amplification of the events into an extreme one.
- This view of the generation of extreme space weather, especially how a magnetic field larger than 100 nT was produced inside an ICME near 1 AU and preconditioning of the heliosphere for minimal CME deceleration, emphasizes the crucial importance of CME-CME interactions in space weather research and forecasting.
- July 2012 storm should be adopted by policy makers and space weather professionals to "war game" emergency preparedness planning for extreme Space Weather events.

Thank you—Questions?

Key Steps From 2012 EIS Summit

- **Establish severe space weather working group** to identify and define the most reasonable extreme space weather event(s) that might be the basis for operators of the bulk power grid and for system engineers to base threat analysis upon;
- **Identification of the critical infrastructures and facilities** that MUST continue to have power across the nation during extreme space weather events or during EMP attack scenarios (spearheaded by FERC);
- **Detailed modeling of the effects and interconnections of the national power grid** under the influence of severe space weather (Point 1. above) or other threat such as EMP attack (undertaken by companies, system engineers, and operators with the protection of key assets in Point 2. above);
- **Specific and detailed work to identify techniques and engineering solutions that would keep GIC (or EMP) isolated** from key infrastructure (blocking solutions). This would require work by power engineers and transformer experts.

D. N. Baker, Space Weather Journal, July 2012)

NERC GMD Task Force

- Coordinated action between utilities, government agencies, and research organizations in U.S. and Canada
  - Implementing recommendations from 2012 Interim Report on GMD
  - Developing tools to assess and mitigate risk
- Research effort is producing extreme event models
  - Extended regional statistics for 1-in-100 year storm
  - Theoretical maximum field for various geomagnetic latitudes
- Developing open-source tools for planners to calculate GIC and perform system analysis
  - Guide for calculating GIC in the power system
  - Equipment models and guidelines for system analysis
  - Guide for evaluating GIC mitigation measures

[Courtesy Mark Olson, NERC]