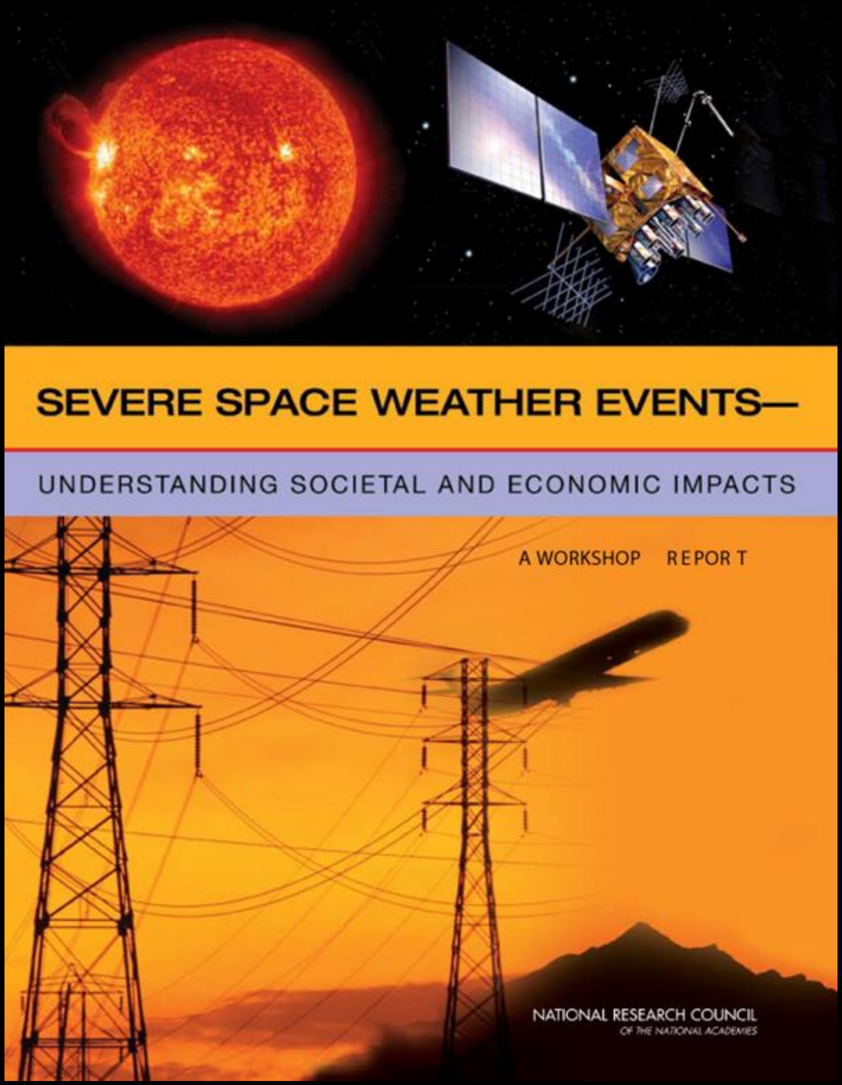
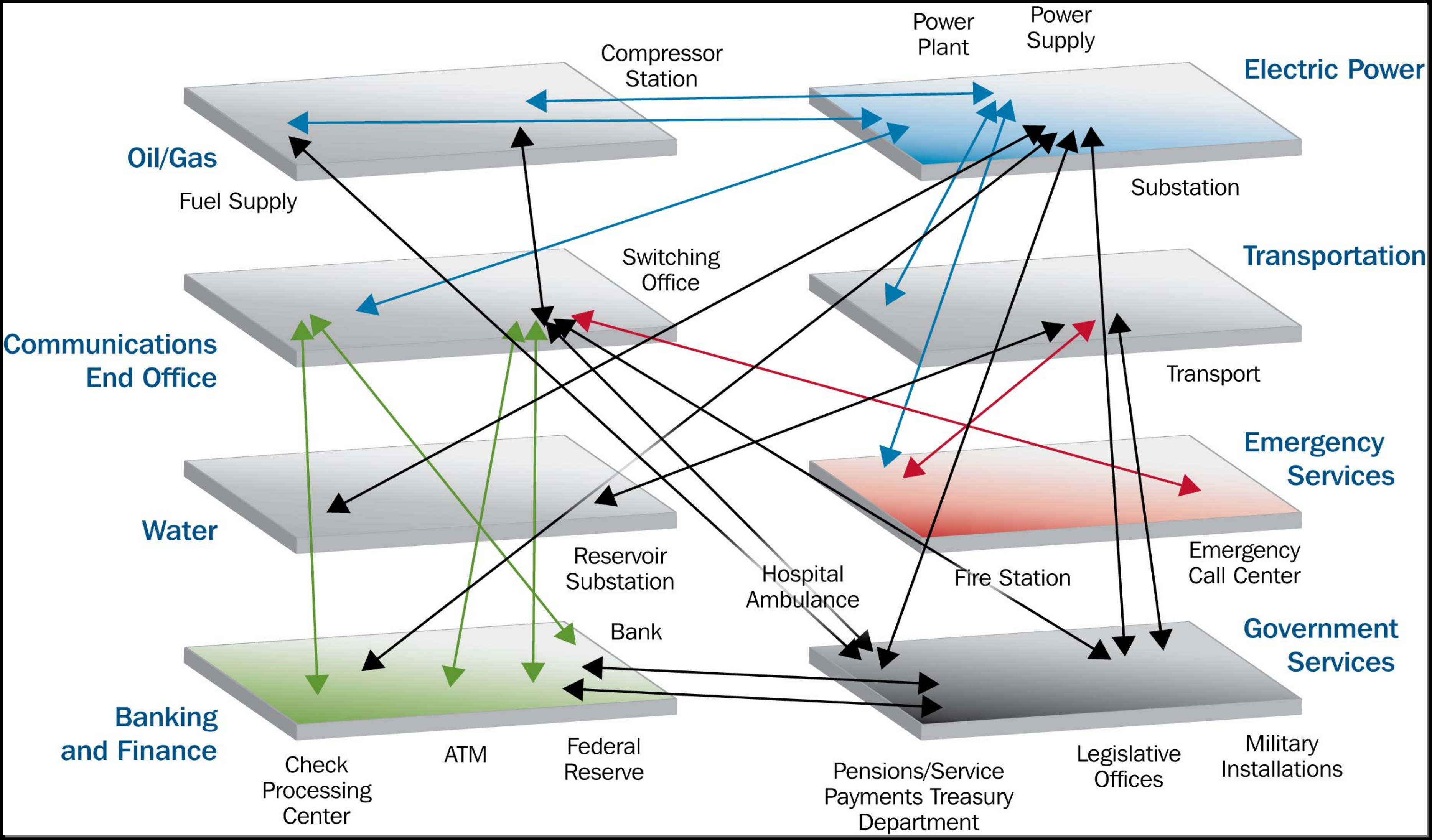


The Major Solar Eruptive Event in July 2012: Defining Extreme Space Weather Scenarios

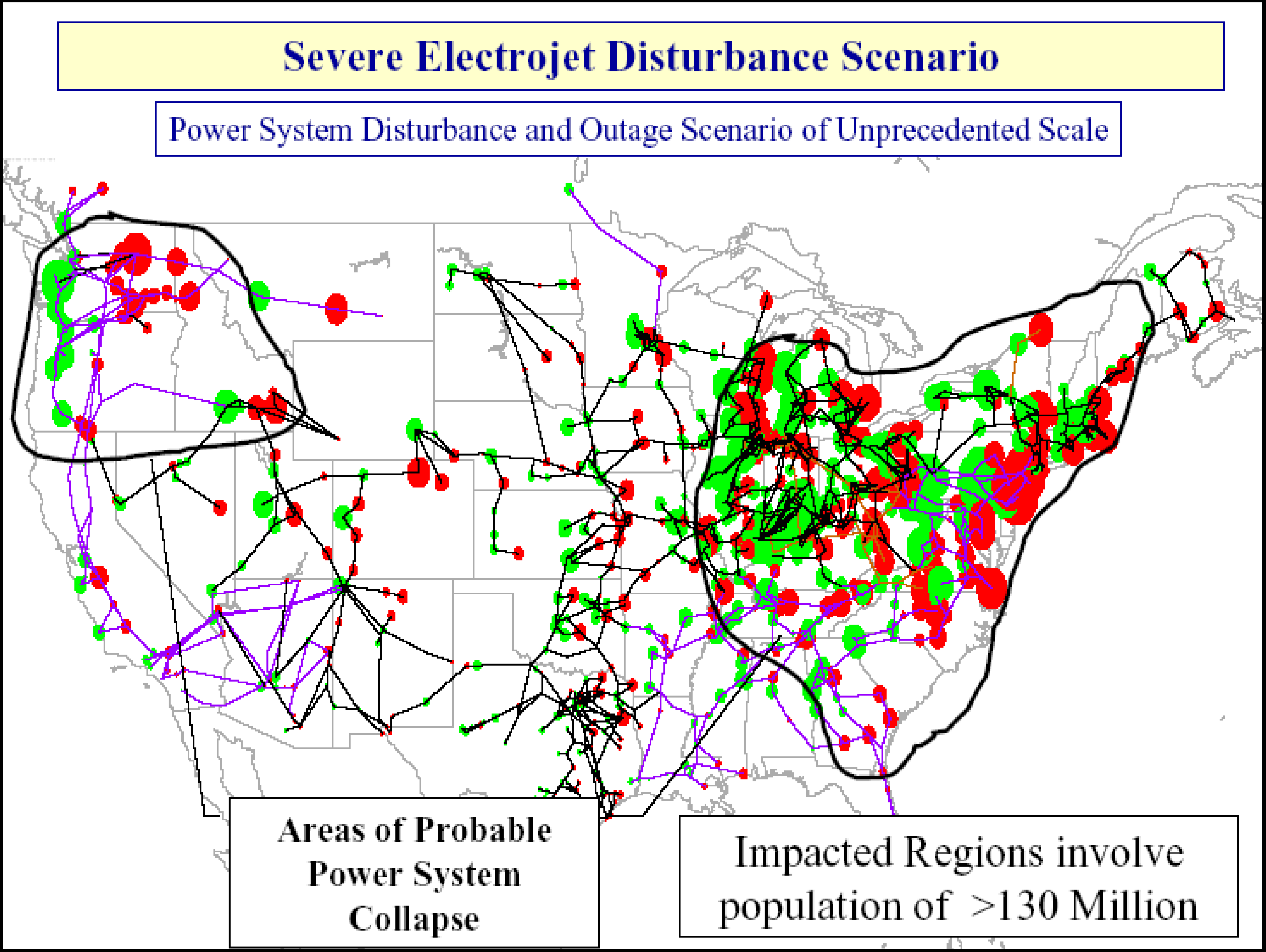
Daniel N. Baker
Laboratory for Atmospheric and Space Physics
Astrophysical and Planetary Sciences Department
Department of Physics
University of Colorado, Boulder

The Interdependencies of Society

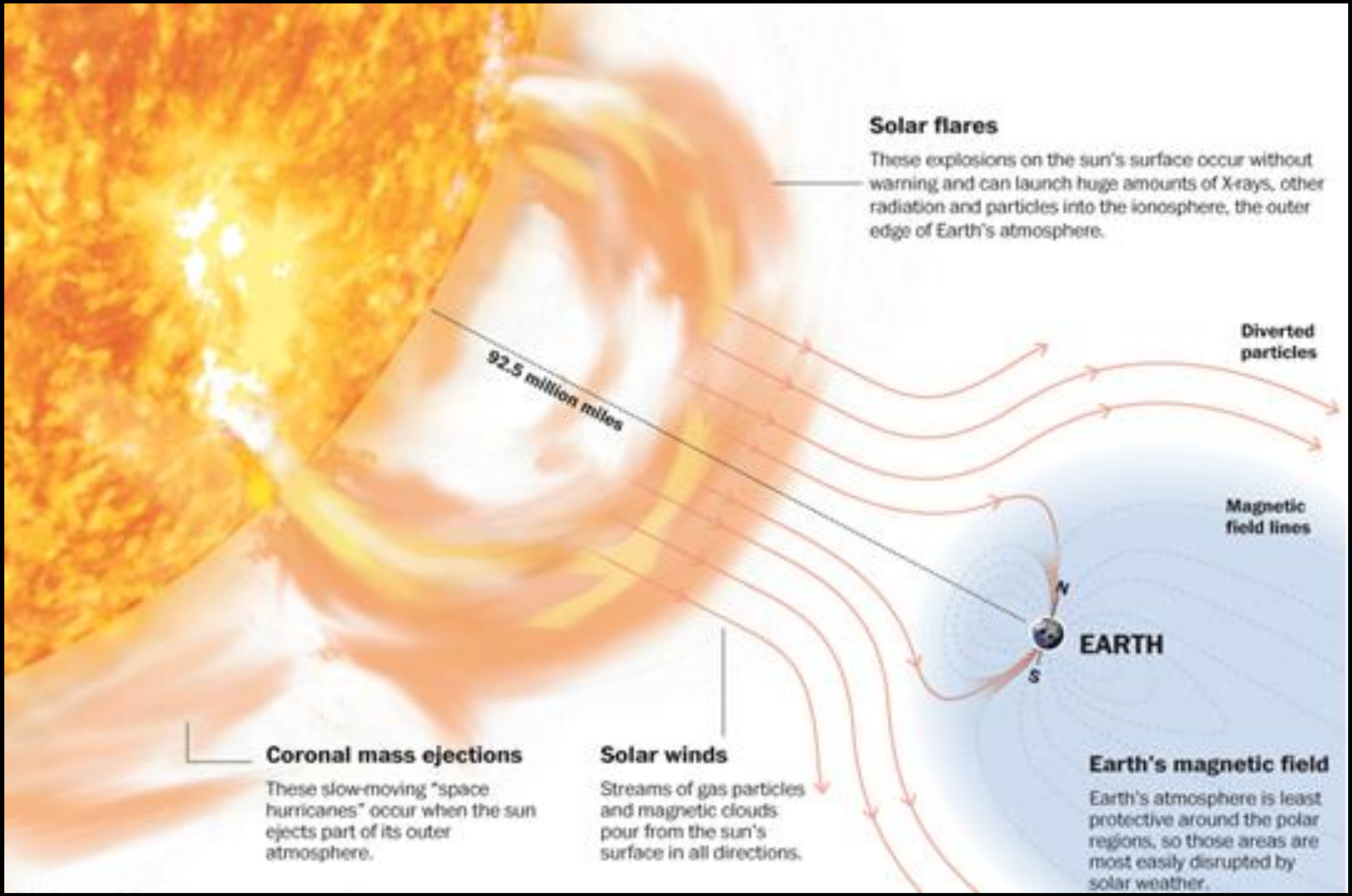


[DHS graphic in NRC, 2009]

Regional Power Grid Disruptions



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



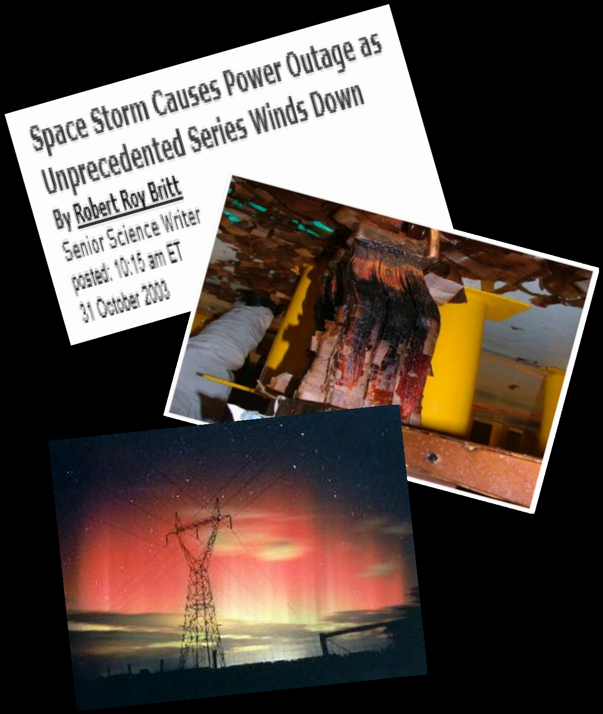
Washington Post Graphic

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.

SWAP: Space Weather Action Plan

- **U. S. National Space Weather Strategy and Action Plan (2015) established Strategic Goals to address gaps in preparedness**
  - *Strategic Goal 1: Establish Benchmarks for Space-Weather Events*
    - **Gap: Understanding the magnitude and frequency of SWx events**
  - *Strategic Goal 2: Enhance Response and Recovery Capabilities*
    - **Gap: Comprehensive guidance for response and recovery**
  - *Strategic Goal 3: Improve Protection and Mitigation Efforts*
    - **Gap: Capability to reduce vulnerability and minimize risk**
  - *Strategic Goal 4: Improve Assessment, Modeling, and Prediction of Impacts on Critical Infrastructure*
    - **Gap: Understanding of actions required during SWx events**
  - *Strategic Goal 5: Improve Space-Weather Services through Advancing Understanding and Forecasting*
    - **Gap: Observation and forecast accuracy, reliability, and timeliness**
  - *Strategic Goal 6: Increase International Cooperation*
    - **Gap: Global engagement and coordination**

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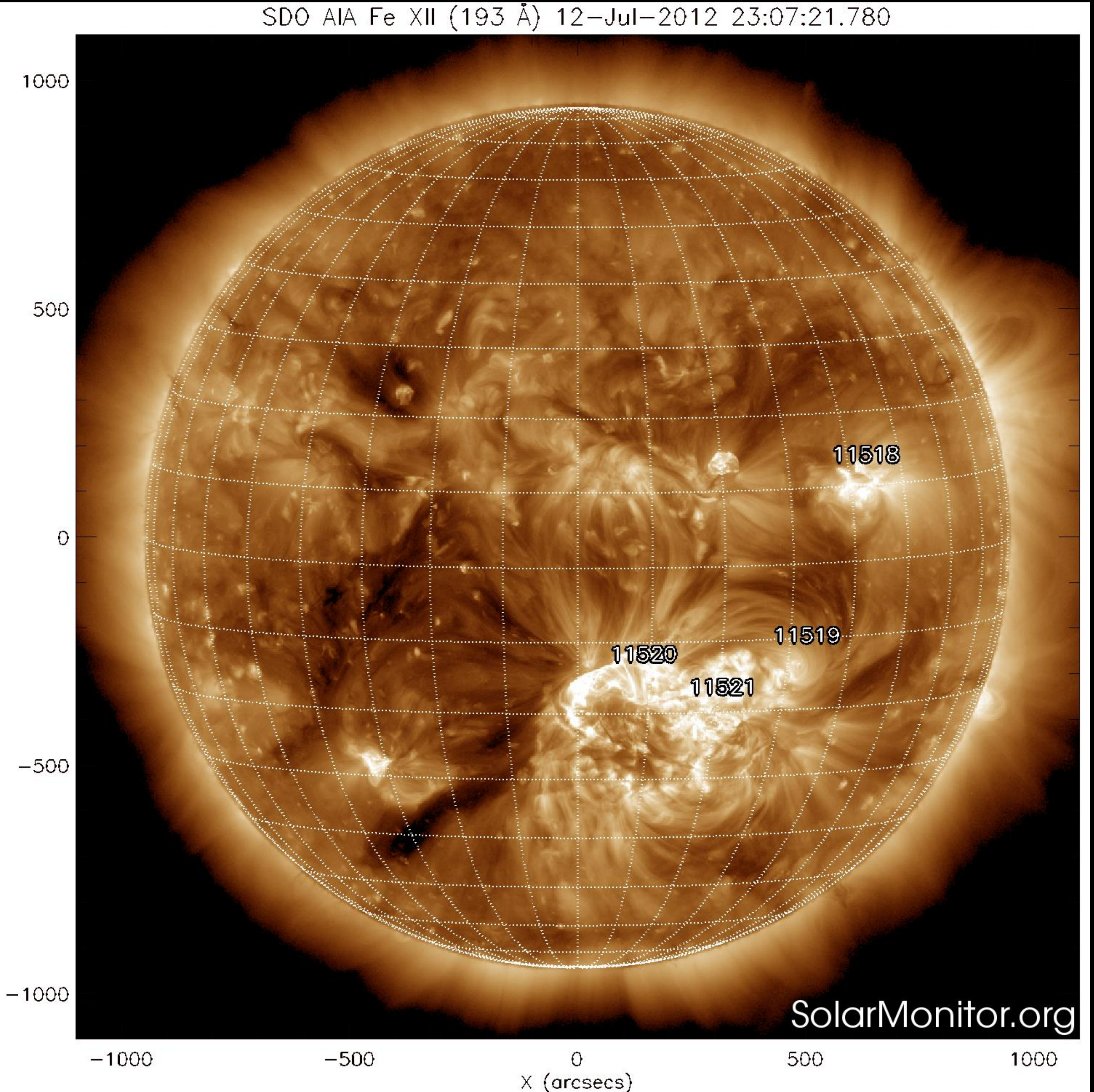
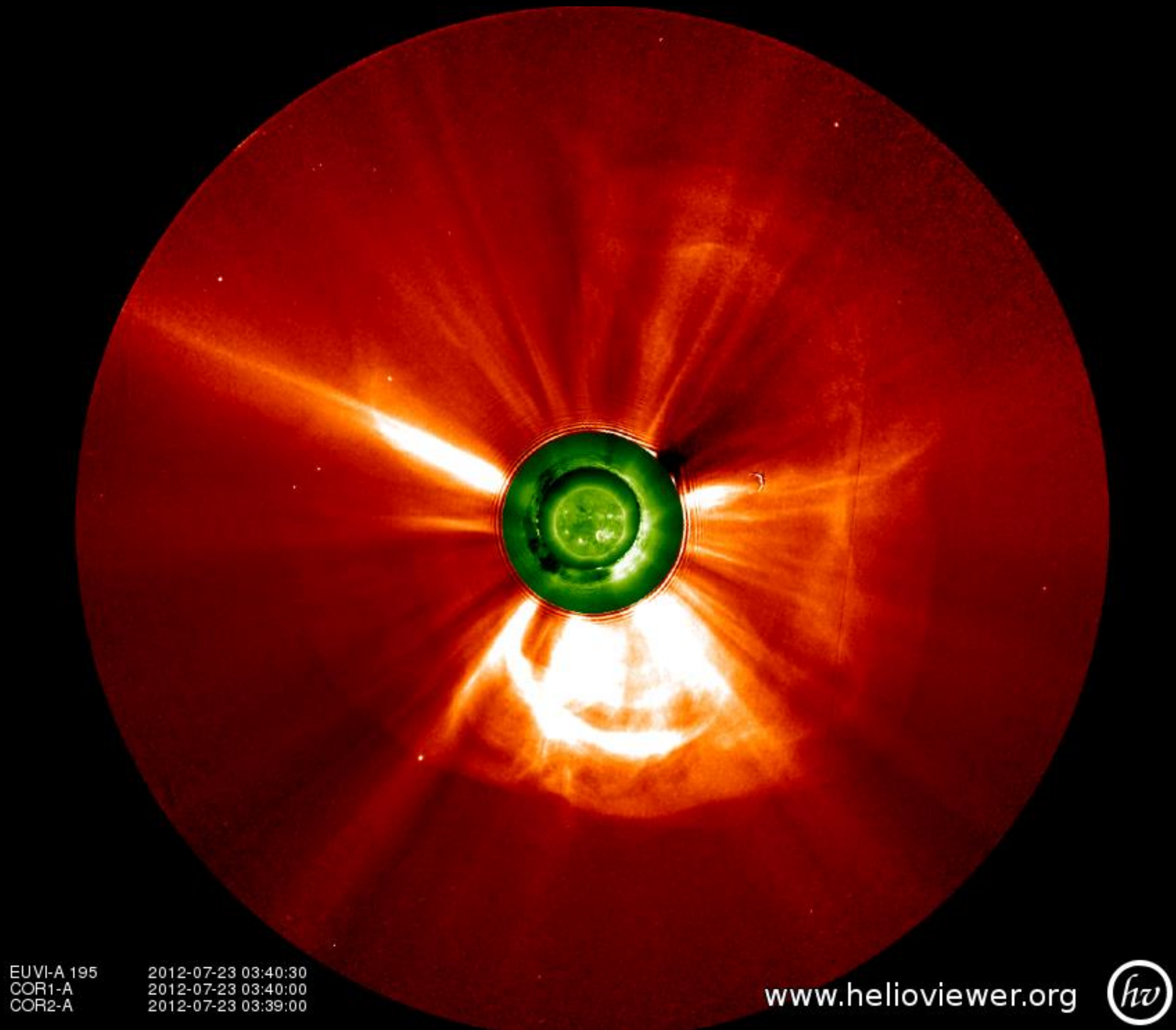
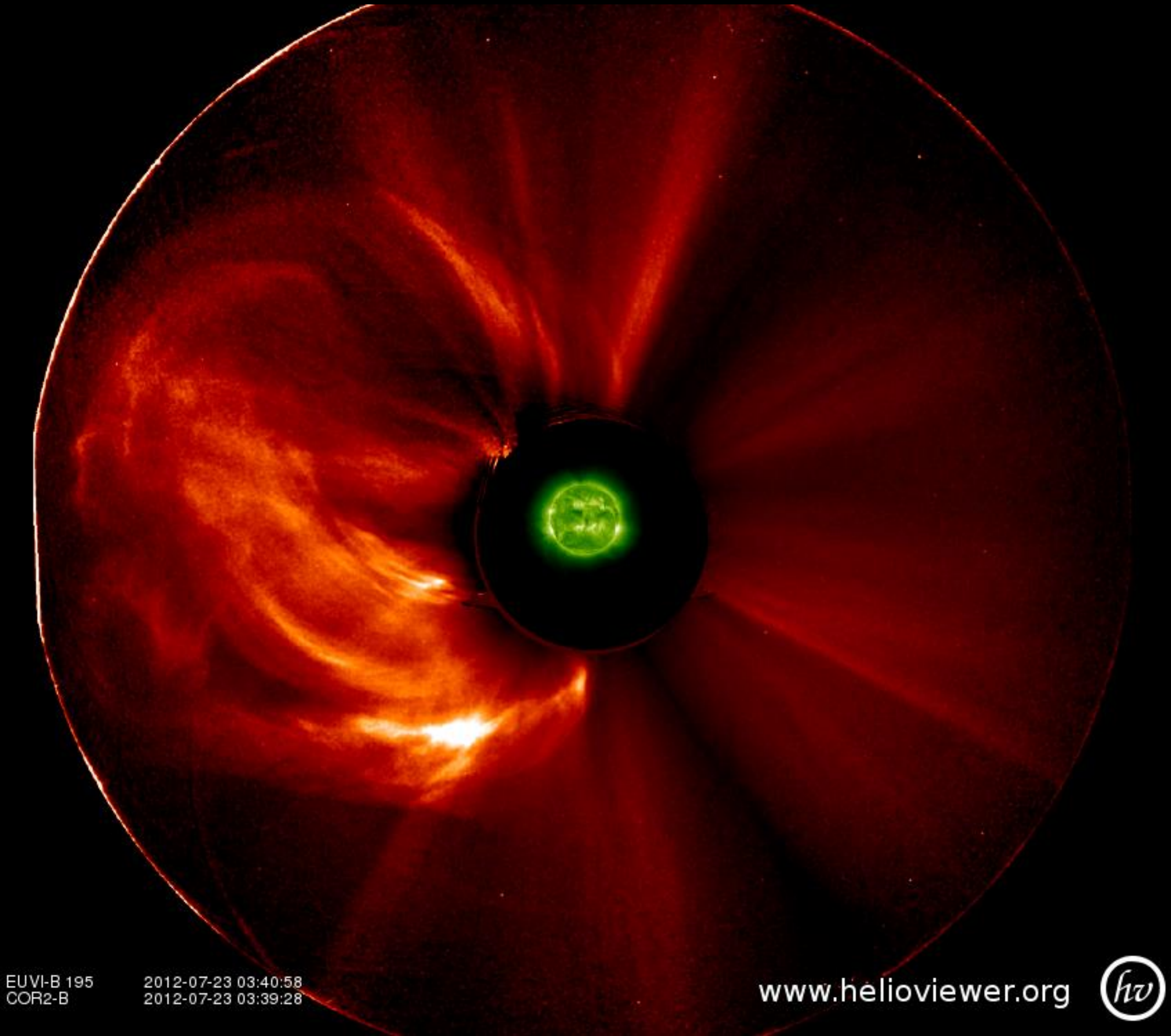


SDO AIA Fe XII (193 Å) 12-Jul-2012 23:07:21.780
1000
500
0
−500
−1000
11518
11519
11520
11521
SolarMonitor.org
−1000
−500
0
500
1000
X (arcsecs)

STEREO-A NESTED Images

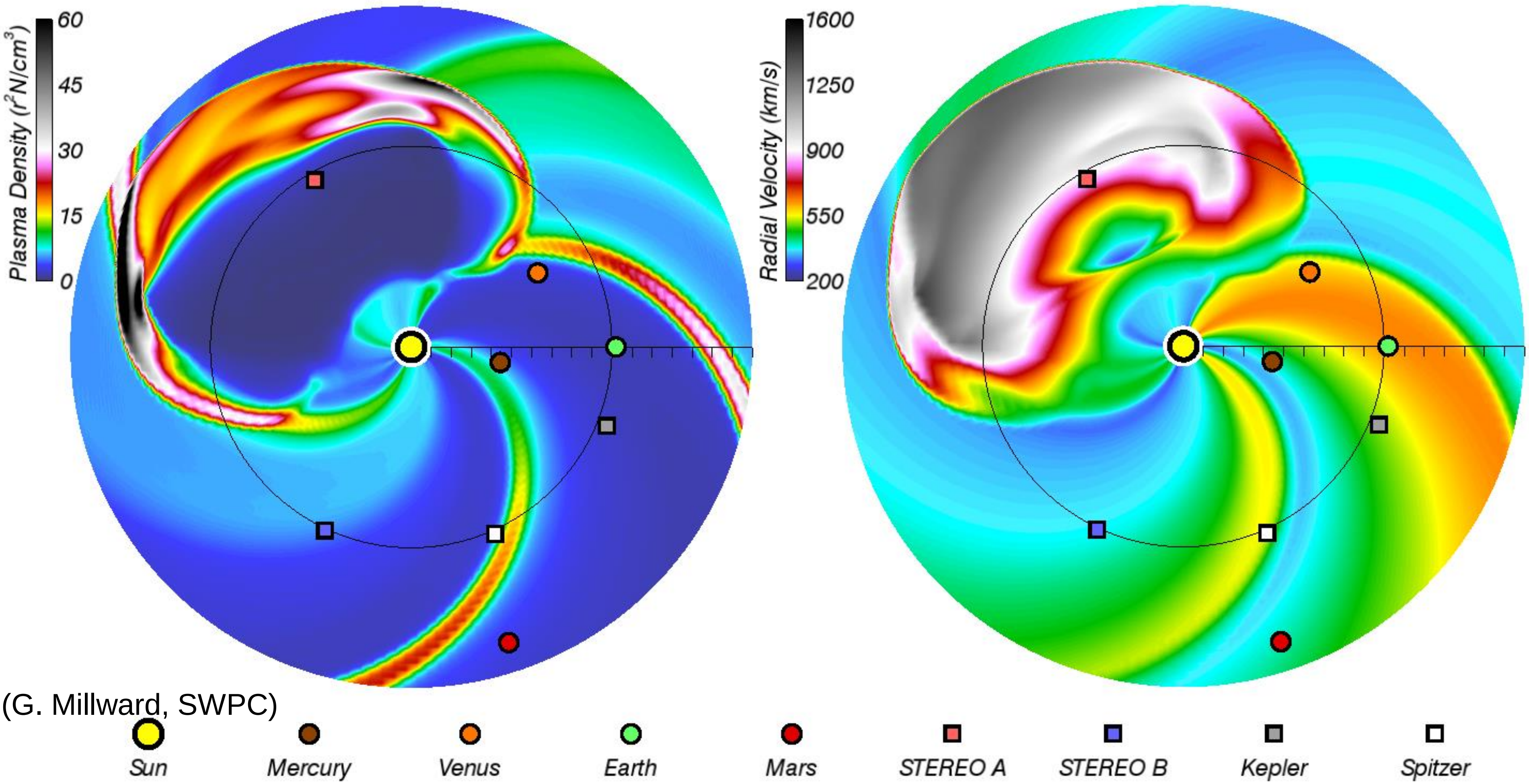


STEREO-B Nested Images



WSA-ENLIL Model: 1200 UT 24 July

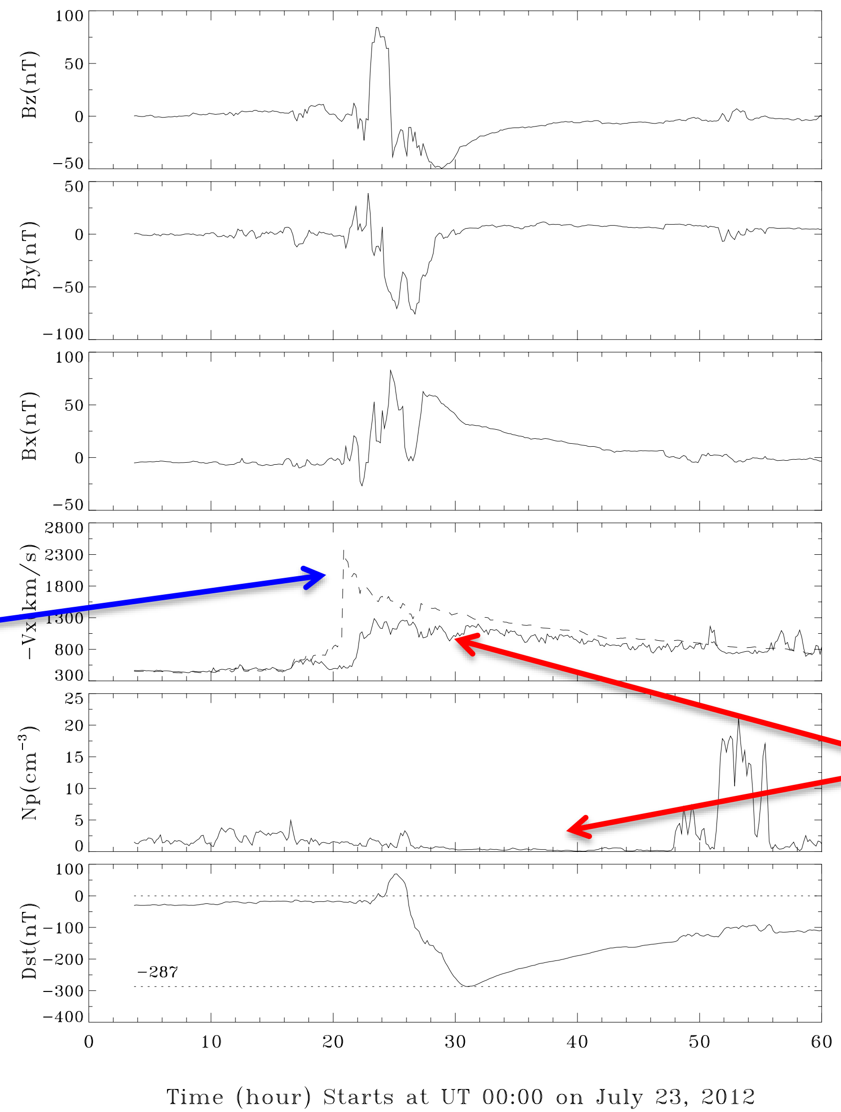
[Baker et al., 2013]



(G. Millward, SWPC)

Initial Temerin-Li Model Results

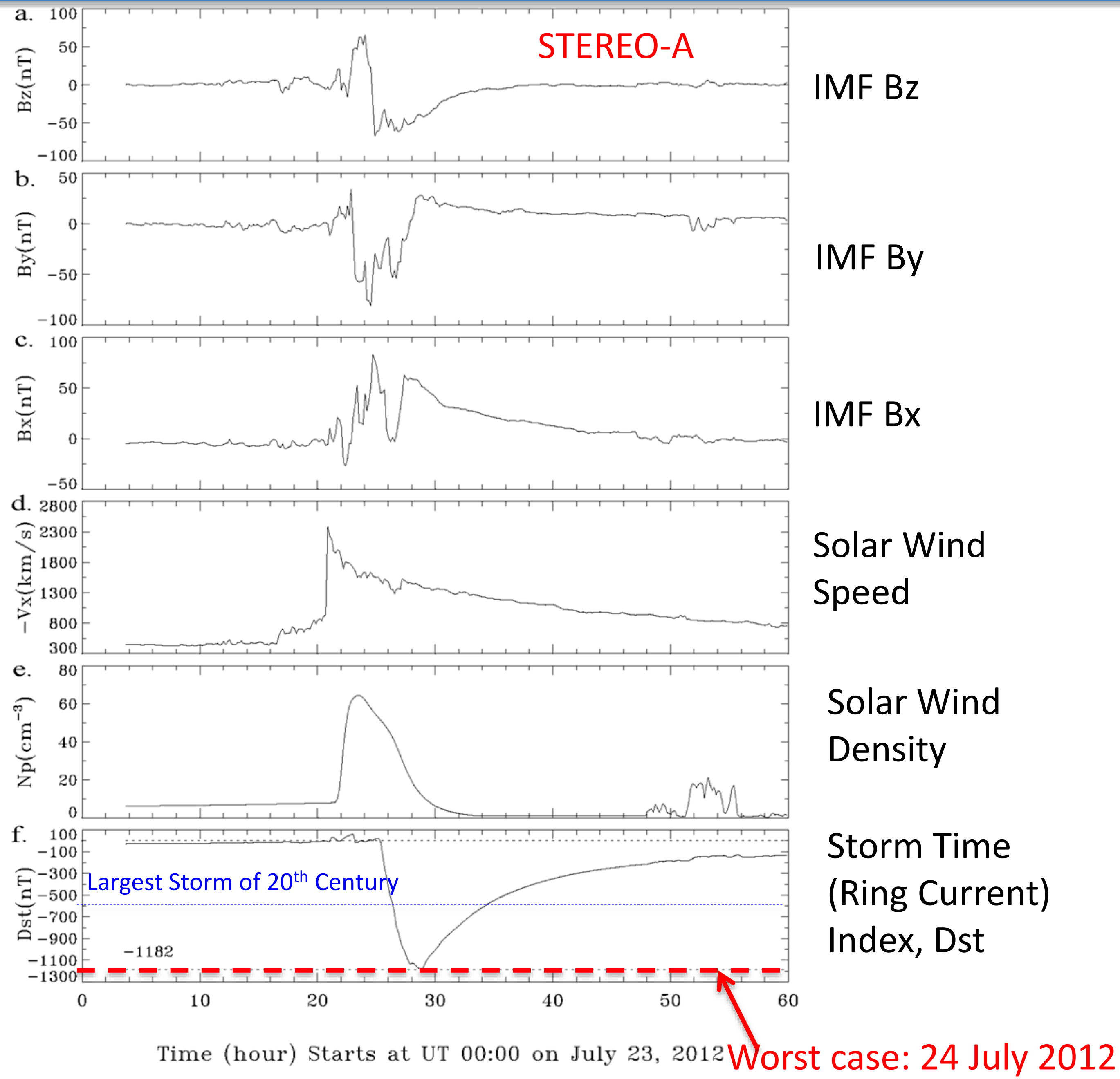
Actual
SW Speed



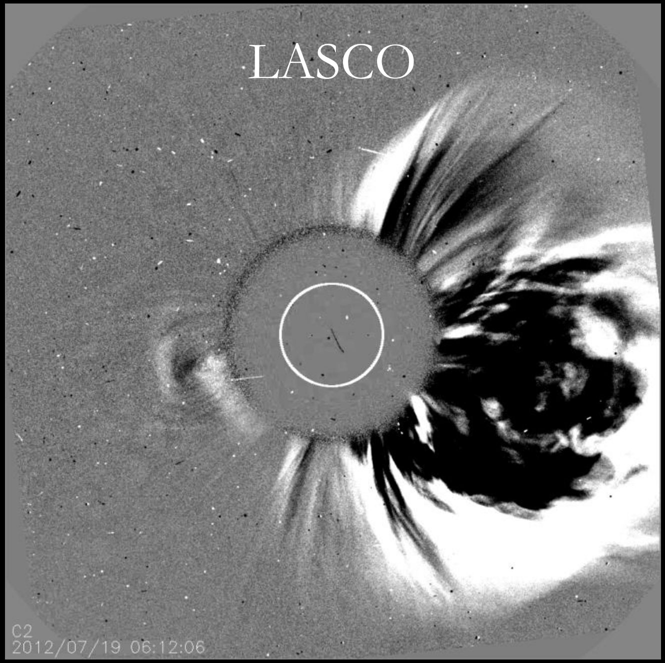
Beacon values

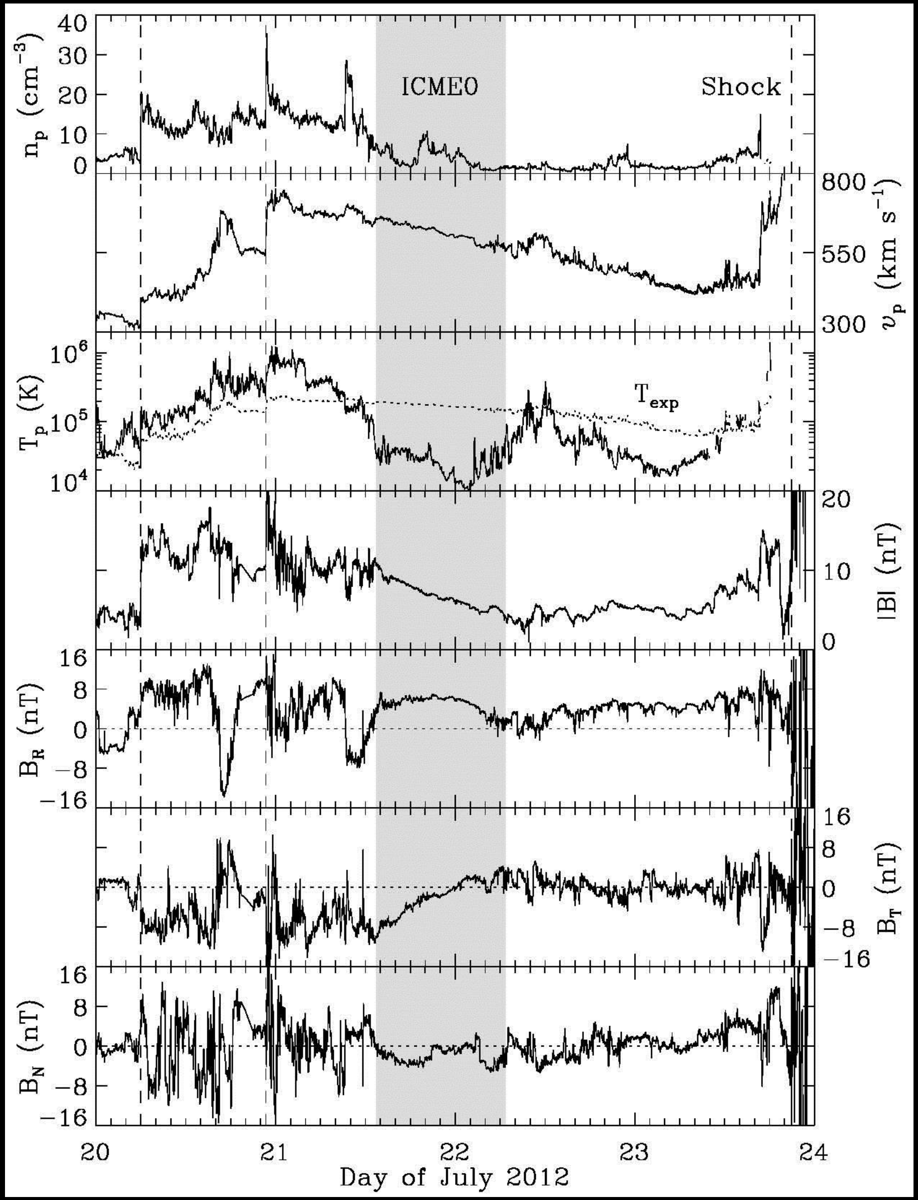
[Baker et al., 2013]

Plausible Worst-Case Scenario



Cause of minimal slowdown



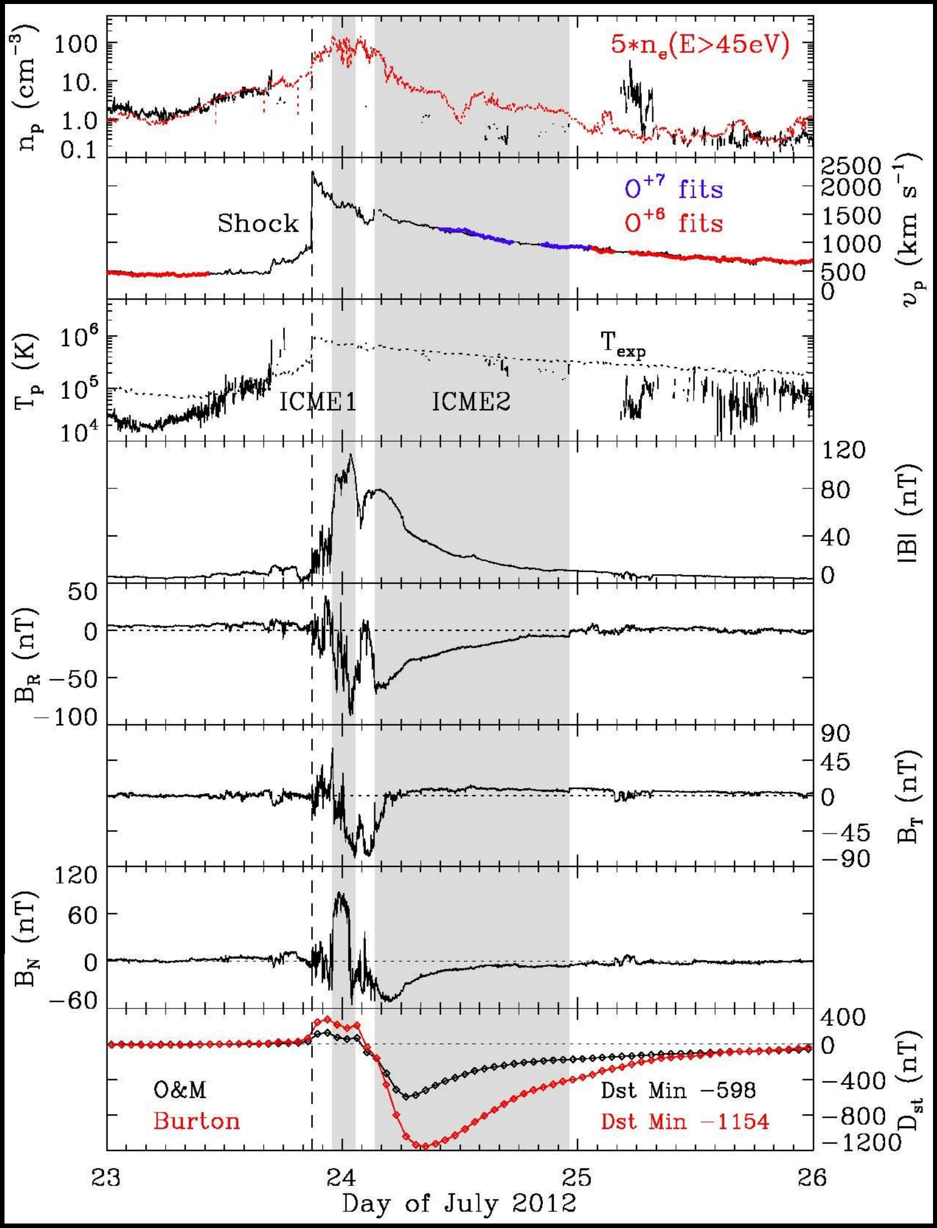


- A series of preceding eruptions occurred on the Sun including the July 19 CME (from the same active region);
- The July 23 event was moving through a density depletion region (as low as 1 cm^{-3}) with radial magnetic fields.

Y. Liu et al., 2014

Detailed 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 (~2300 km/s) and the peak magnetic field strength (109 nT) were among the largest on record as measured near 1 AU;
- The event was not slowed down very much by the ambient medium;
- The estimated minimum Dst was ~-1150 nT, which was 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.



Y. Liu et al. [2014]

Summary

- The operational space weather community has long sought a defensible, plausible “worst case” space weather scenario (better documented 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
- 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 plasma 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.**

Several relevant 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 (2014), Observations of an extreme storm in interplanetary space caused by successive coronal mass ejections, ***Nature Communications***, doi: 10.1038/ncomms4481

Thanks to all these colleagues.

Thank you—Questions?