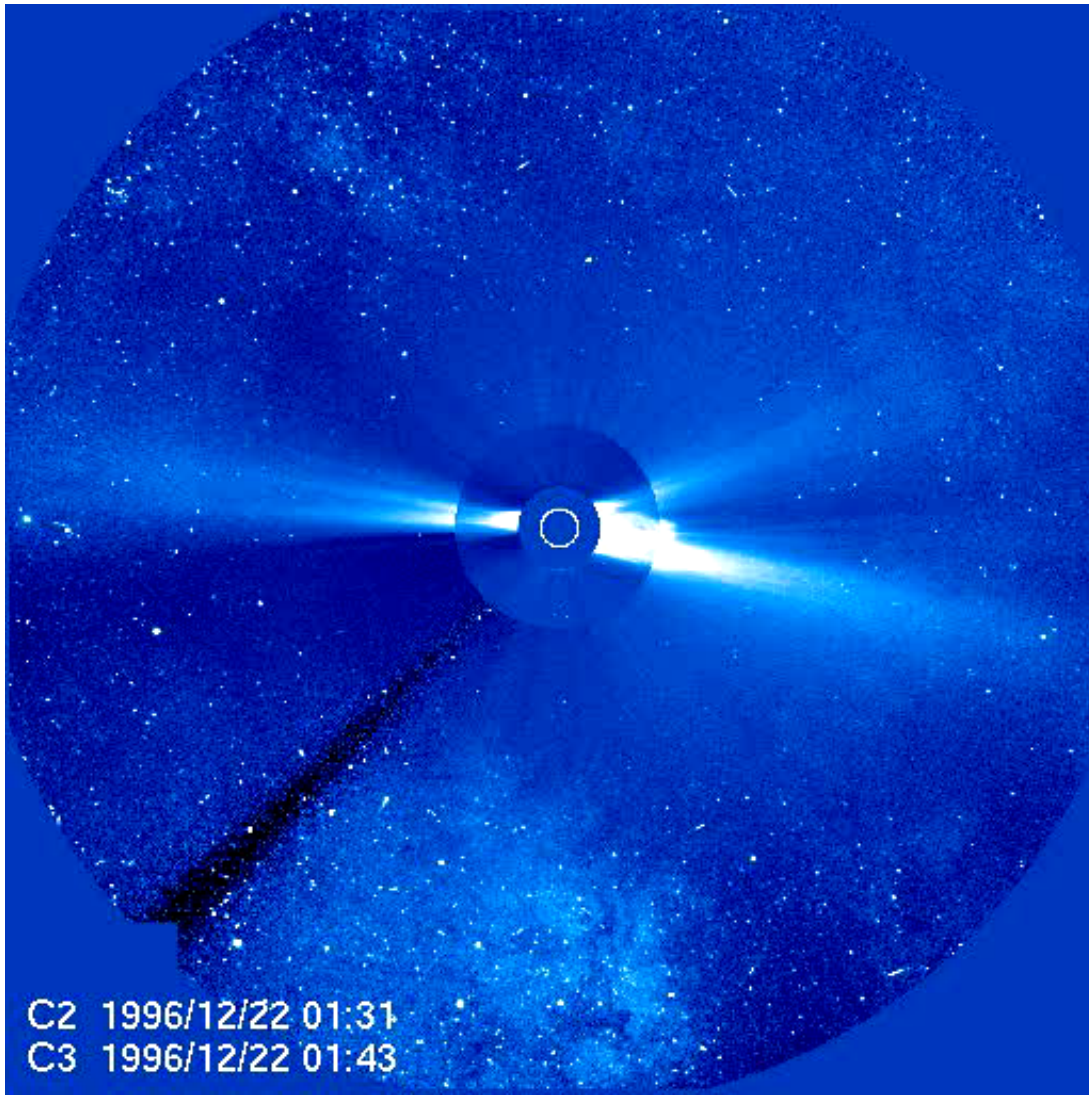
Observing Precursors to the **Important** **Extreme** Storms at the Sun

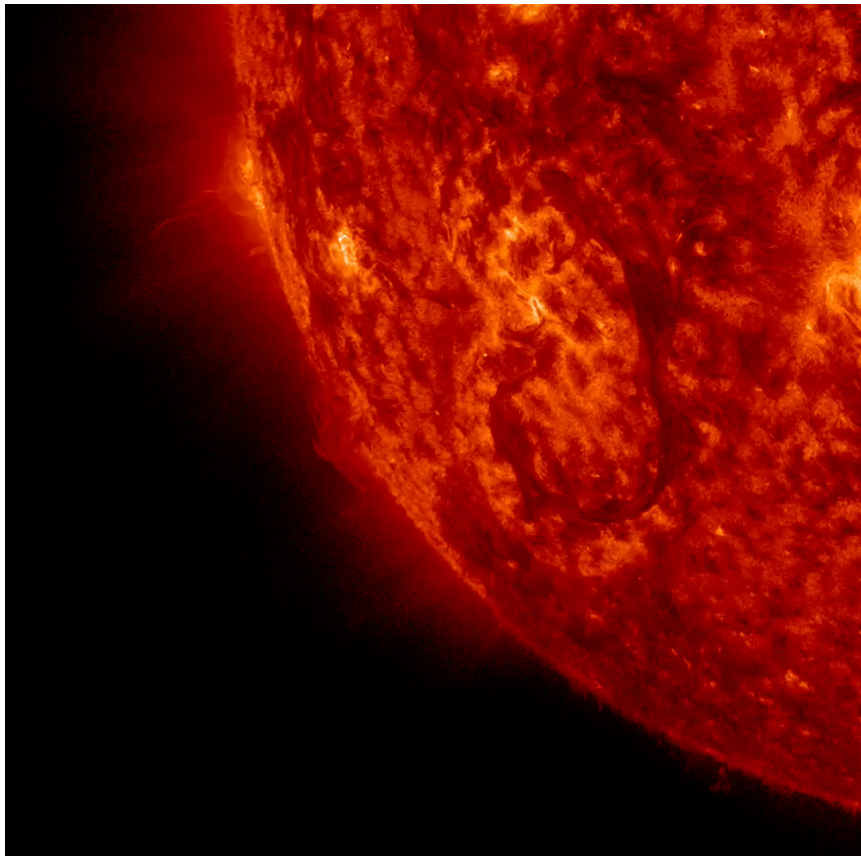
J Todd Hoeksema

Stanford University

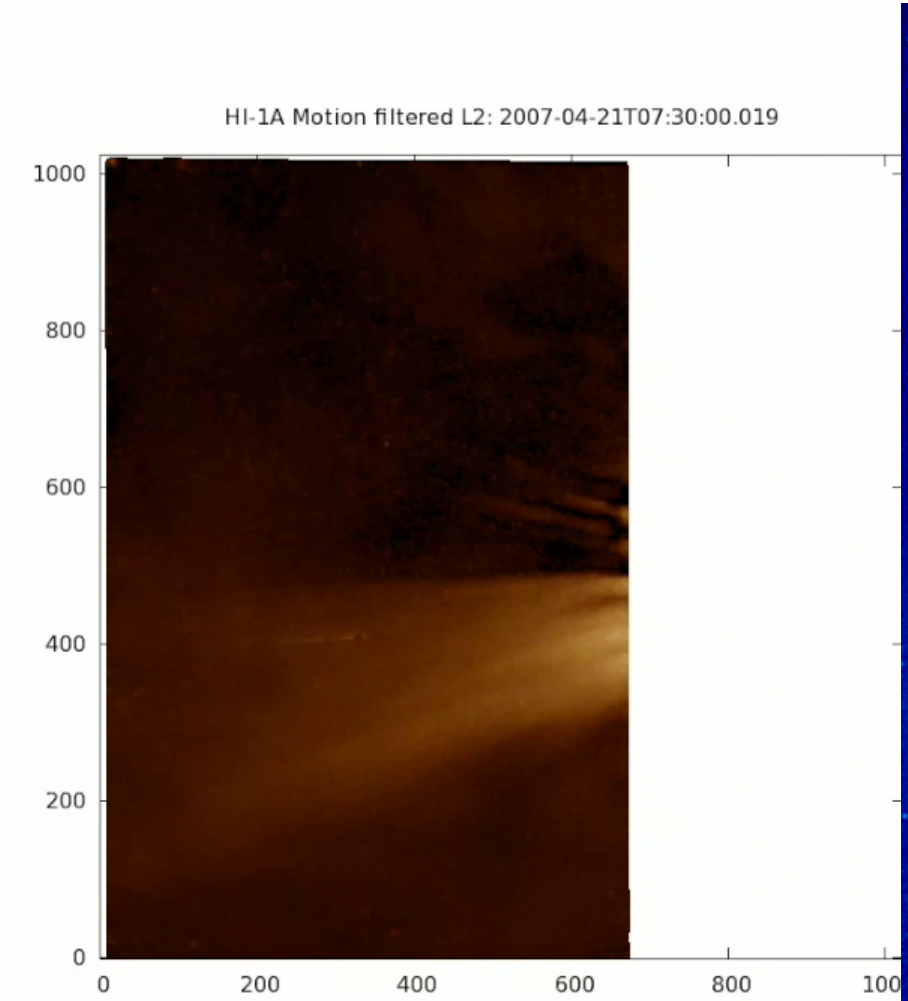


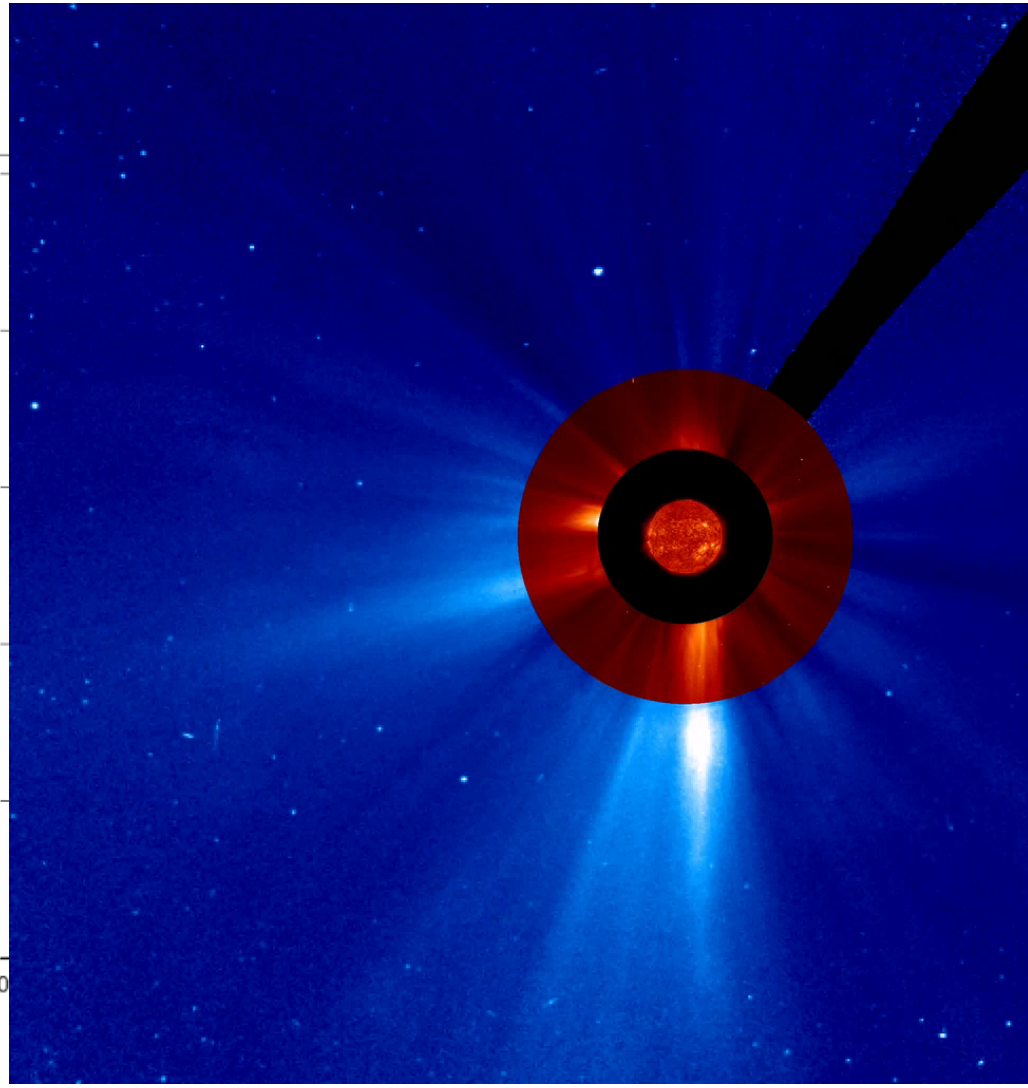
Observing **Important** **Extreme** Storms

- What makes a storm at the Sun **extreme**?
- What makes a storm important?
- Examples of Space Weather
- A Failed Prediction
- Recommendations:
  - Decadal Survey
  - COSPAR SWX Roadmap
  - SWORM



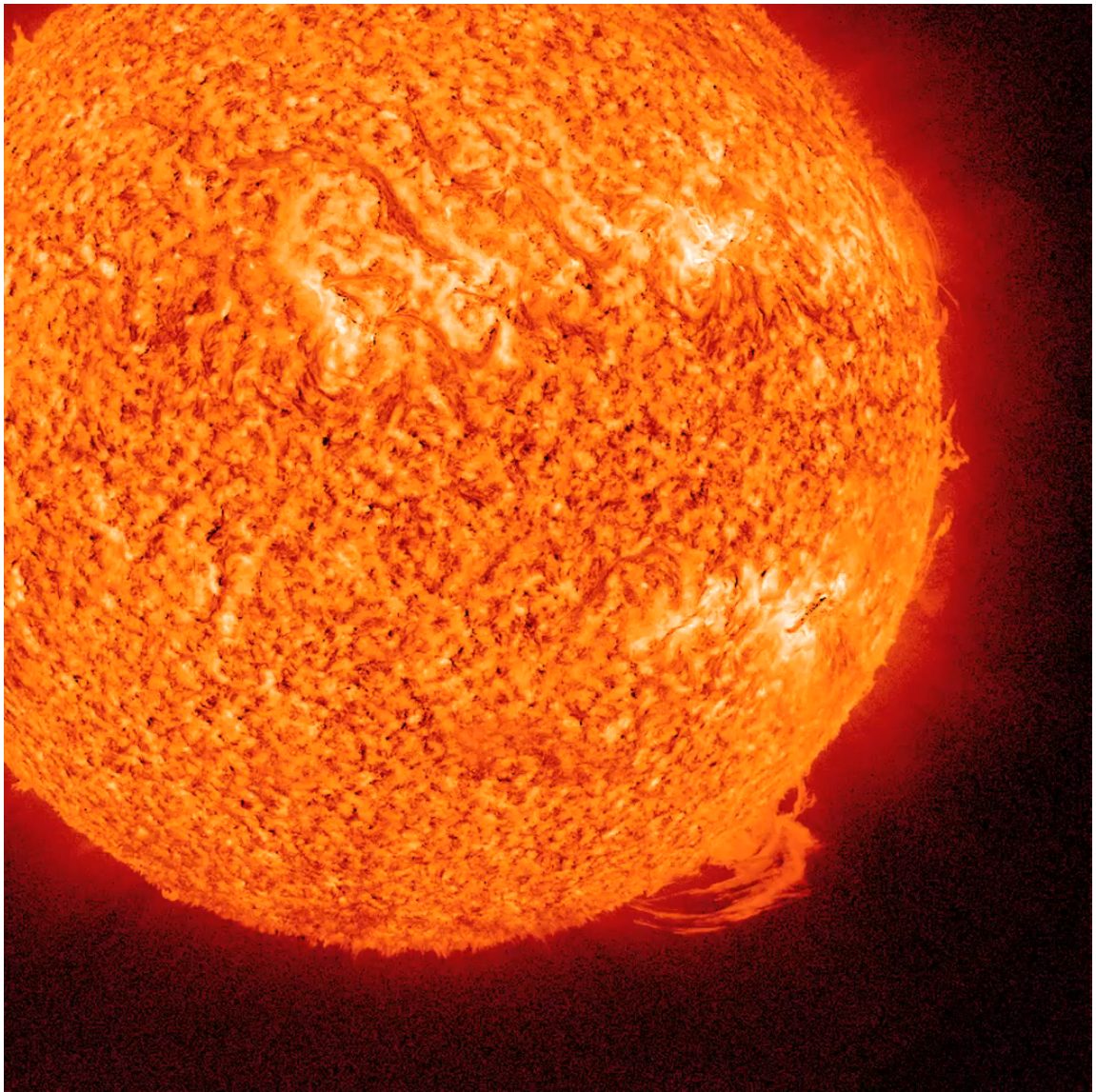
The Corona and Wind Are Always Active



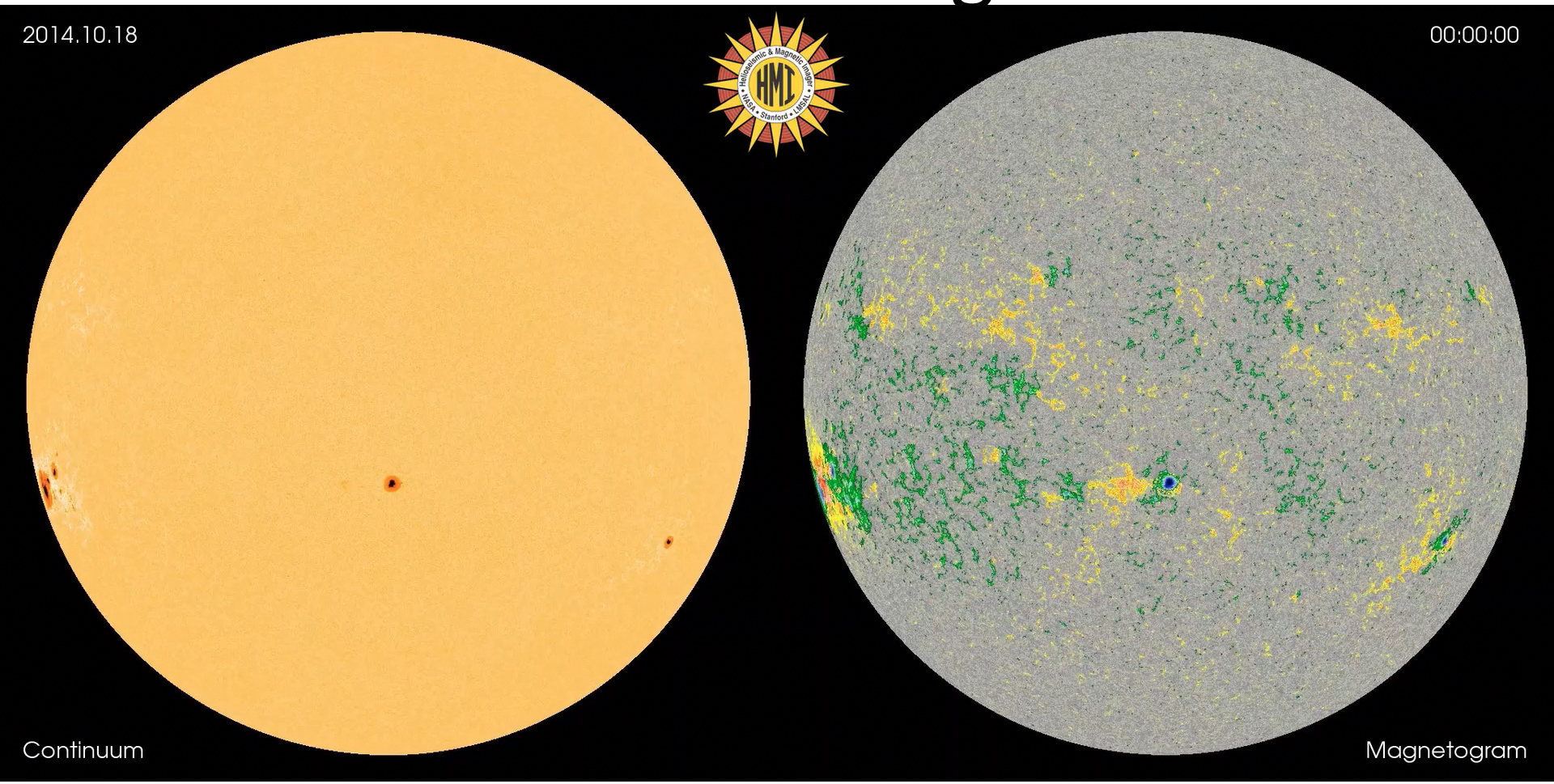


Composite – H1 not to scale x 4

Spectacular Events Sometimes Don’t Completely Erupt



We Observe The Magnetic Field



A Curious Event in January 2014

Huge Solar Flare Delays Private Rocket Launch to Space Station until Thursday

by Tariq Malik, Managing Editor | January 08, 2014 08:10am ET

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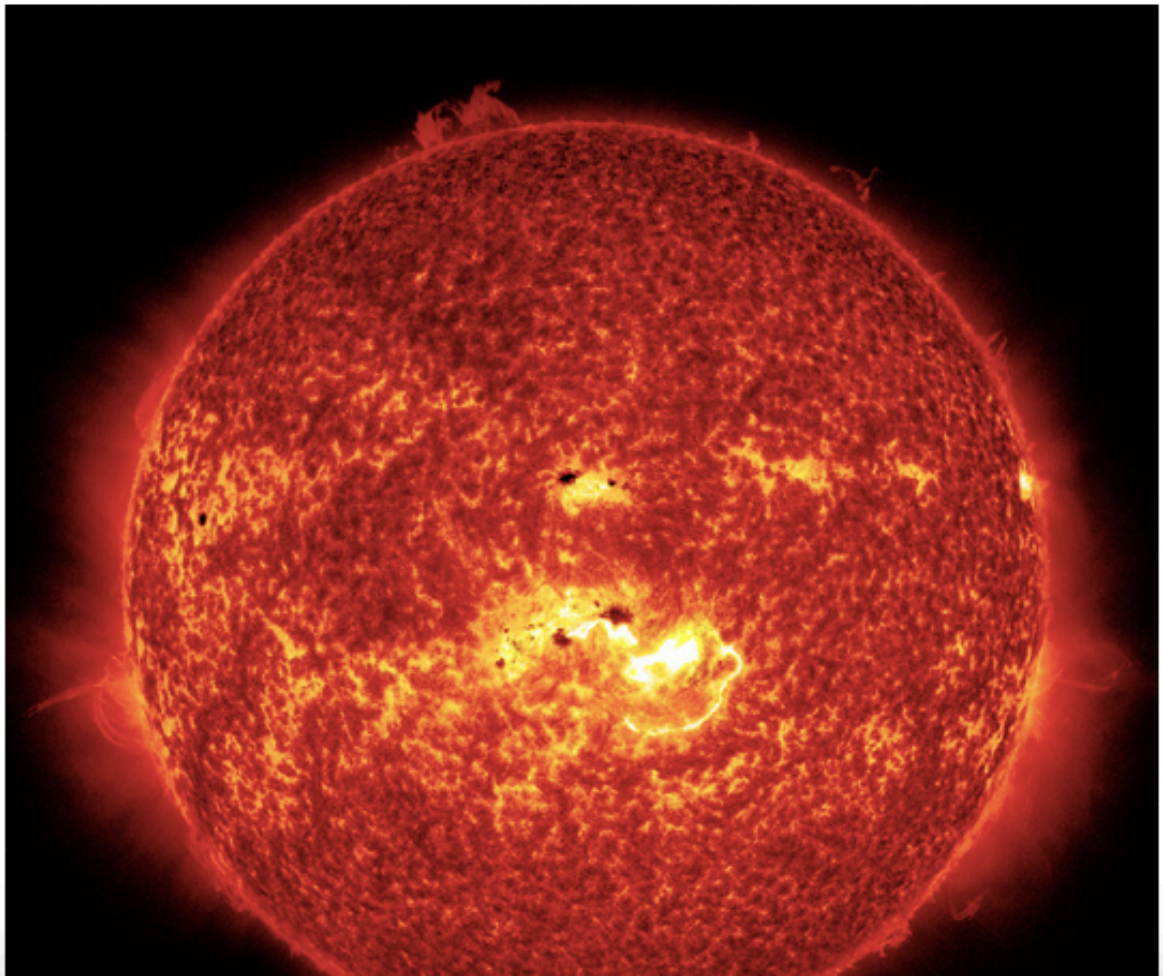


Disk-Center X Flare of January 2014

AIA
1600

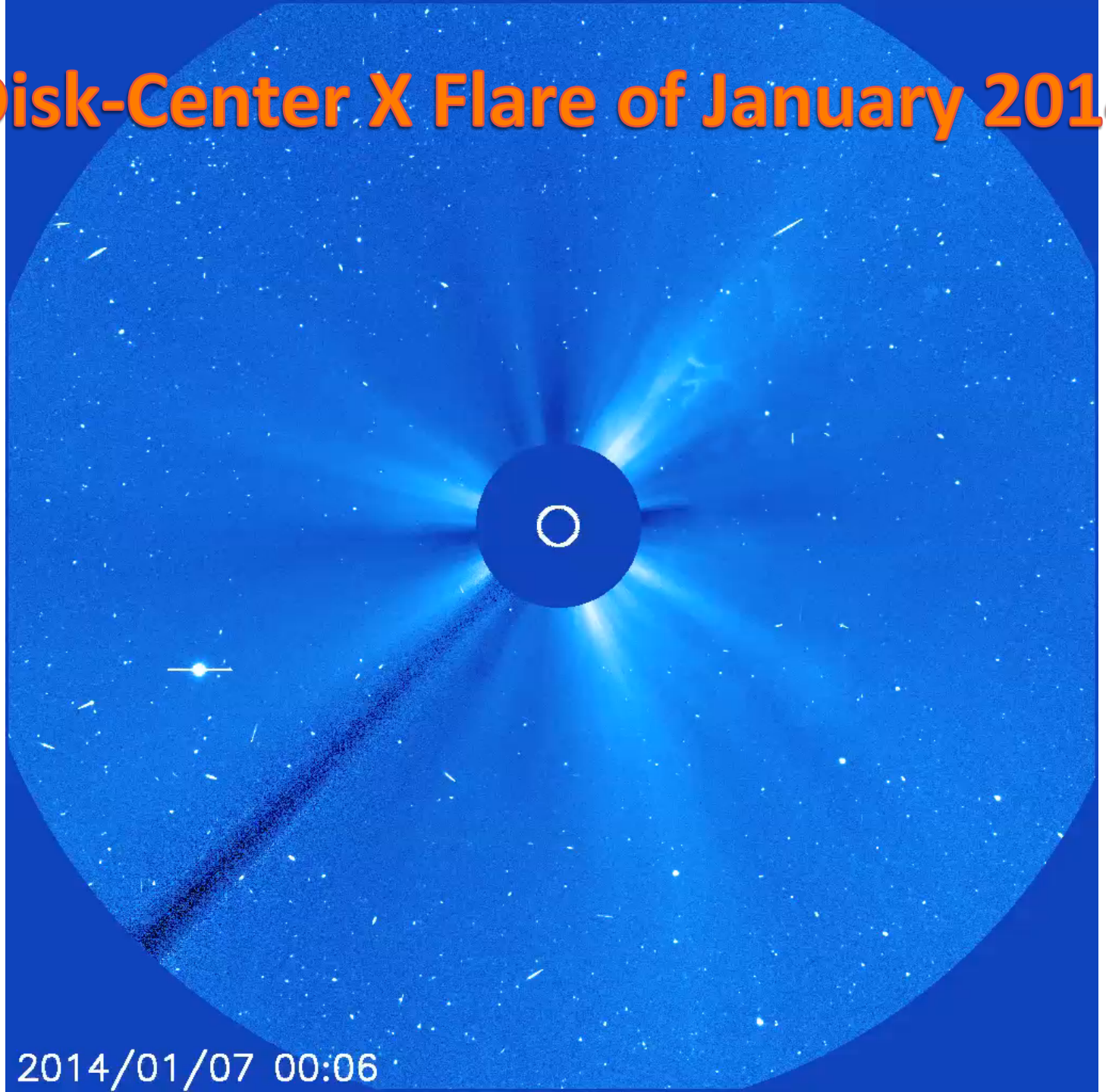
Disk-Center X Flare of January 2014

HMI
MAG

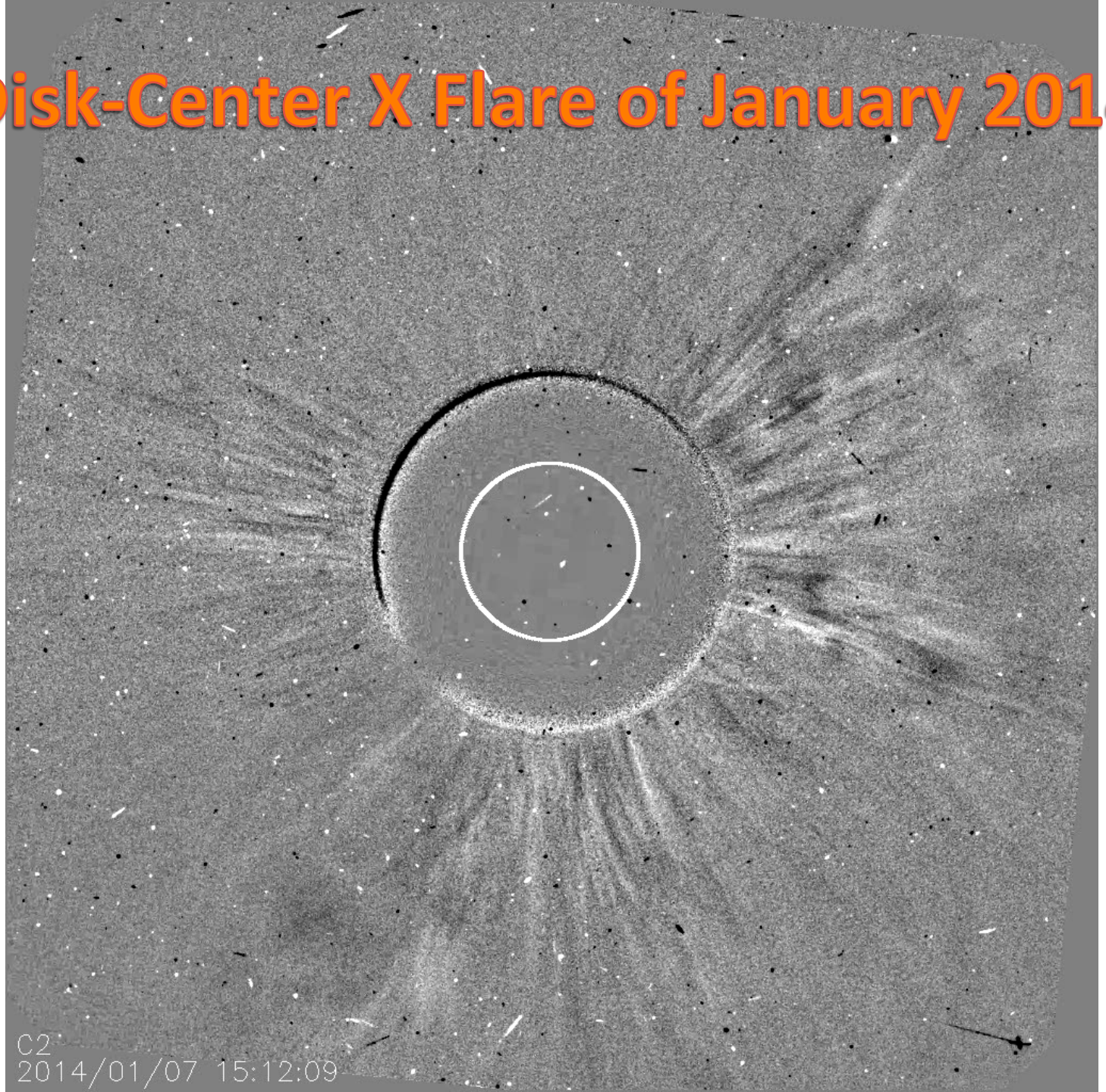
Disk-Center X Flare of January 2014

AIA
193

Disk-Center X Flare of January 2014



Disk-Center X Flare of January 2014

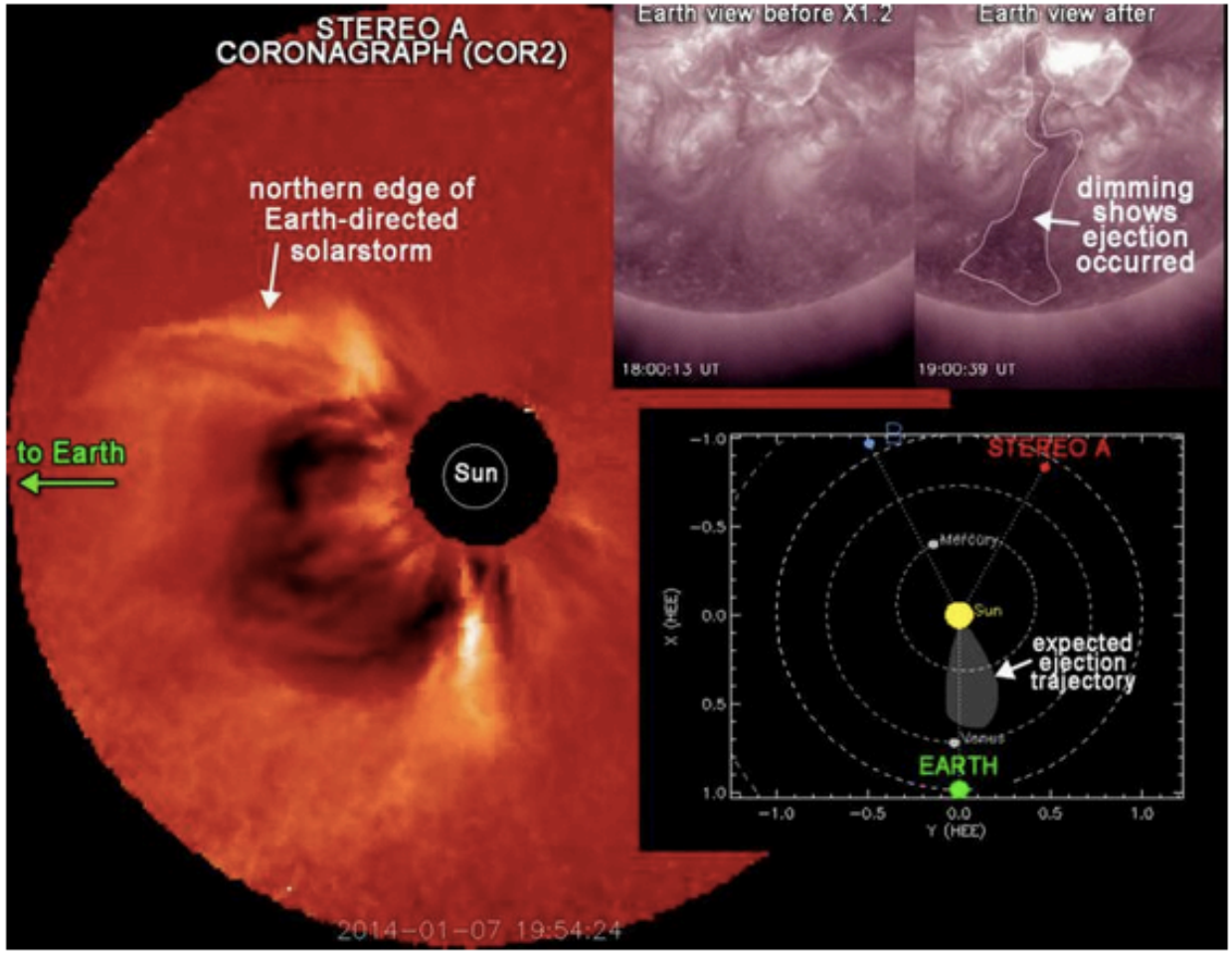


From NASA Spaceweather:

Get Ready…

> *Giant sunspot AR1944 erupted on Jan 7th at approximately 1832 UT, producing a powerful X1-class solar flare. First-look coronagraph images from the STEREO-Ahead spacecraft appear to show a coro*
> *site. **If so, the***
> *tuned for updat*
> *Heliophysics F*
>
> *One of the bigg*
> *solar disk, putti*
> *Raybell photog*
> *yesterday from*

This graphic from **Tamitha Skov**



Predictions – FAIL!!!

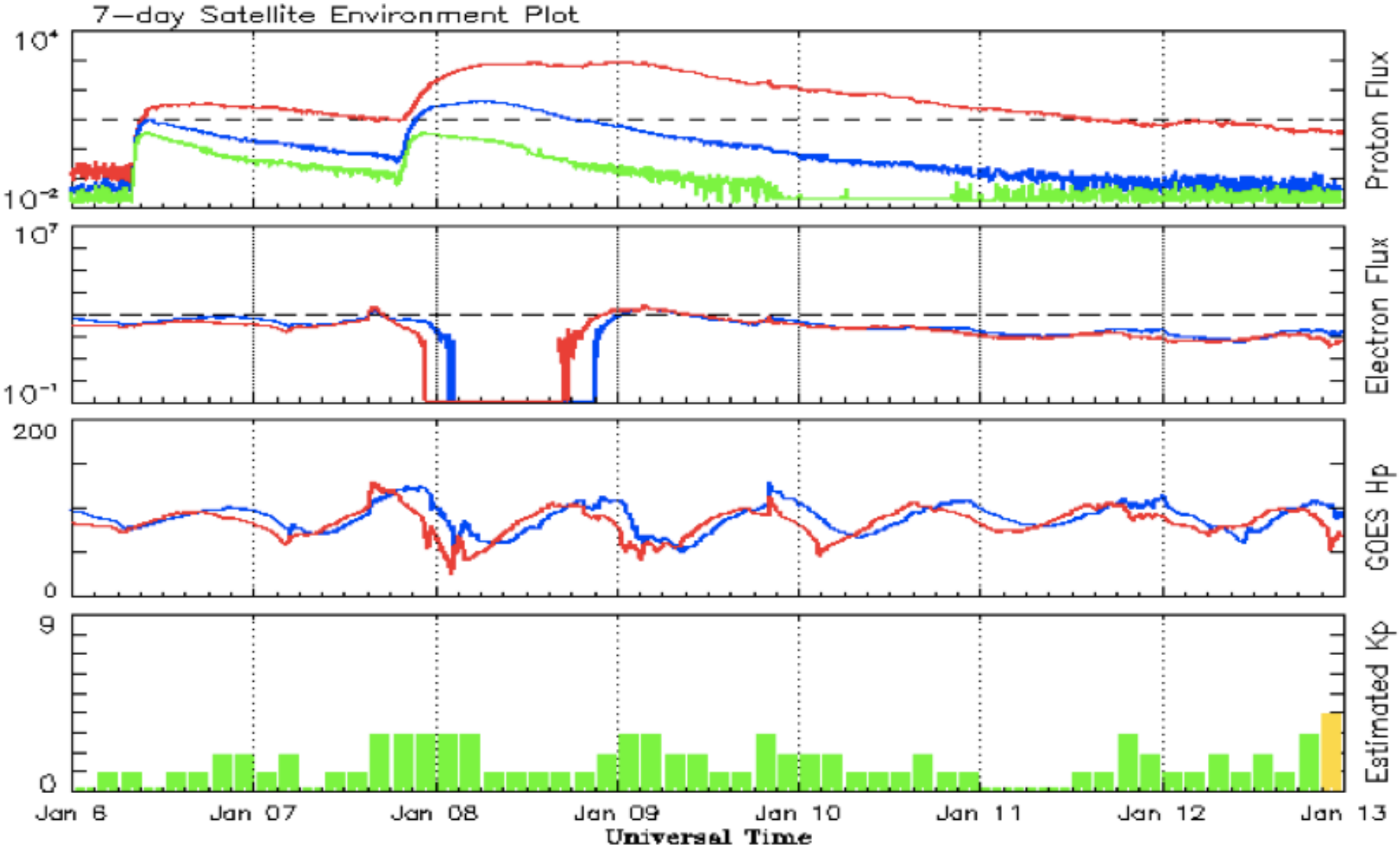
CME: 2014-01-07T18:24:00-CME-001

Actual Shock Arrival Time: 2014-01-09T19:32Z

Observed Geomagnetic Storm Params: Max Kp: 3.0

Predicted Shock Arrival Time	Difference (hrs)	Lead Time (hrs)	Predicted Geomagnetic Storm Parameter(s)	Method
2014-01-09T06:35Z	**-12.95**	**---**	**Max Kp Range: 6.0 - 7.625**	**Average of all Methods**
2014-01-09T19:26Z (-10.0h, +10.0h)	-0.10	46.53	----	STOA
2014-01-09T00:38Z (-7.0h, +7.0h)	-18.90	42.85	Max Kp Range: 6.0 - 8.0	WSA-ENLIL + Cone (GSFC SWRC)
2014-01-09T08:00Z	-11.53	42.02	Max Kp Range: 6.0 - 7.0	WSA-ENLIL + Cone (NOAA/SWPC)
2014-01-08T22:00Z	-21.53	40.25	Dst min. in nT: -146 Dst min. time: 2014-01-09T11:00Z	Anemomilos
2014-01-09T00:17Z (-6.9h, +9.2h)	-19.25	39.35	Max Kp Range: 6.0 - 8.0	Ensemble WSA-ENLIL + Cone (GSFC SWRC)
2014-01-09T04:30Z (-2.5h, +2.5h)	-15.03	38.50	Max Kp Range: 5.0 - 8.0	Other (SIDC)
2014-01-08T12:30Z	-31.03	37.57	----	ESA
2014-01-09T12:00Z (-7.0h, +7.0h)	-7.53	37.00	----	WSA-ENLIL + Cone
2014-01-09T04:00Z (-6.0h, +6.0h)	-15.53	33.83	----	DBM
2014-01-10T04:04Z (-16.0h, +36.0h)	8.53	28.60	Max Kp Range: 8.0 - 8.0 Dst min. in nT: -300	COMESEP
2014-01-09T08:02Z	-11.50	26.92	----	Expansion Speed Prediction Model
2014-01-09T02:00Z	-17.53	25.65	Max Kp Range: 8.0 - 9.0	BHV
2014-01-09T01:00Z	-18.53	20.53	Dst min. in nT: -142 Dst min. time: 2014-01-09T12:00Z	Anemomilos
2014-01-09T13:00Z (-7.0h, +7.0h)	-6.53	20.25	Max Kp Range: 6.0 - 8.0	WSA-ENLIL + Cone
2014-01-09T11:22Z (-11.7h, +9.1h)	-8.17	0.58	Max Kp Range: 3.0 - 5.0	Ensemble WSA-ENLIL + Cone (GSFC SWRC)

Predictions – FAIL!!!



Weekly Geosynchronous Satellite Environment Summary
Week Beginning 06 January 2014

We know a lot!

- Photospheric magnetic field on the Earth side
- Bright loops on the limb & visible disk
- Occurrence of flares and coronal dimming
- Coronal dynamics around the limb
- Some about modeling ARs, the corona & SW
- Helioseismology of the far side from Earth
- Some radio knowledge of corona and SW
- In situ measurements at various spacecraft

We know a Lot! What is Missing?

- The Sun, heliosphere, and geospace are individually global systems - we only observe parts of them and distant parts matter. (Observations)
- History counts – we need to know the past to understand energy storage, energy release, evolution and propagation, seed particles, etc. (Observation and Modeling)
- Those systems interact in complex ways – Bz and preconditioning. (Modeling and Observations)
- We know very little about the Sun's interior – when will hazardous emergence stop? (Modeling)
- Our knowledge of the corona is limited & sparse (Observations)

What's missing for the **Important Extreme** Events?

- **Predicting eruptions is at best qualitative**
- **Availability of stored energy is uncertain**
- **Initial & evolving direction of CME B is uncertain**
- **Initial & evolving CME direction & speed as well**
- **Prior conditions are only partially known**
- **Flux emergence is a complete mystery**
- **We have very little experience with extreme events – do they behave differently?**

Solar and Space Physics Decadal Survey (2012)

Separate Recommendations for Space Weather and Space Climatology

TABLE S.2 Summary of Top-Level Decadal Survey Applications Recommendations

Priority	Recommendation	NASA	NSF	Other
1.0	Recharter the National Space Weather Program	X	X	X
2.0	Work in a multiagency partnership to achieve continuity of solar and solar wind observations	X	X	X
2.1	Continue solar wind observations from L1 (DSCOVR, IMAP)	X		X
2.2	Continue space-based coronagraph and solar magnetic field measurements	X		X
2.3	Evaluate new observations, platforms, and locations	X	X	X
2.4	Establish a space weather research program at NOAA to effectively transition research to operations			X
2.5	Develop and maintain distinct funding lines for basic space physics research and for space weather specification and forecasting	X	X	X

COSPAR Space Weather Roadmap

Focus is on high-priority challenges in key areas of research

leading to a better understanding of the space environment and

demonstrable improvement in the provision of timely, reliable information

pertinent to effects on civilian space- and ground-based systems,

for all stakeholders around the world.

Most Recent (2015) Comprehensive Strategic Study

cosparhq.cnes.fr/scientific-structure/cospar-scientific-roadmaps

COSPAR Space Weather Roadmap (for solar and heliospheric only)

Maintain key capabilities (ground + space):

- **Solar vector B, EUV/X-ray imaging, GOES flares,**
- **Spectral irradiance, Coronagraph(s!),**
- **Radio observations of inner heliosphere,**
- **"L1" SW plasma, fields & composition, SEP(s!)**

Deploy new/improved instrumentation:

- **Binocular coronagraph, hi-res multi-height B in ARs; B at multiple viewing angles around heliosphere, more SEP locations**

This all critically requires something more…

COSPAR Space Weather Roadmap (for solar and heliospheric only)

Model Capability, Archival Research, Data Infrastructure and Expertise Development

- **NRT AR models to assess destabilization sensitivity**
- **Data-driven models of local and global coronal field – both stable and eruptive – and of the solar wind**
- **Coronal magnetic field measurements and models**
- **Particle acceleration and propagation in heliosphere**
- **Ensemble models of AR to understand energy conversion**

SWORM Task Force in the U.S.

National Science & Technology Council led by OSTP

Will reduce U.S. vulnerability to SWX: Power, Aerospace, PNT

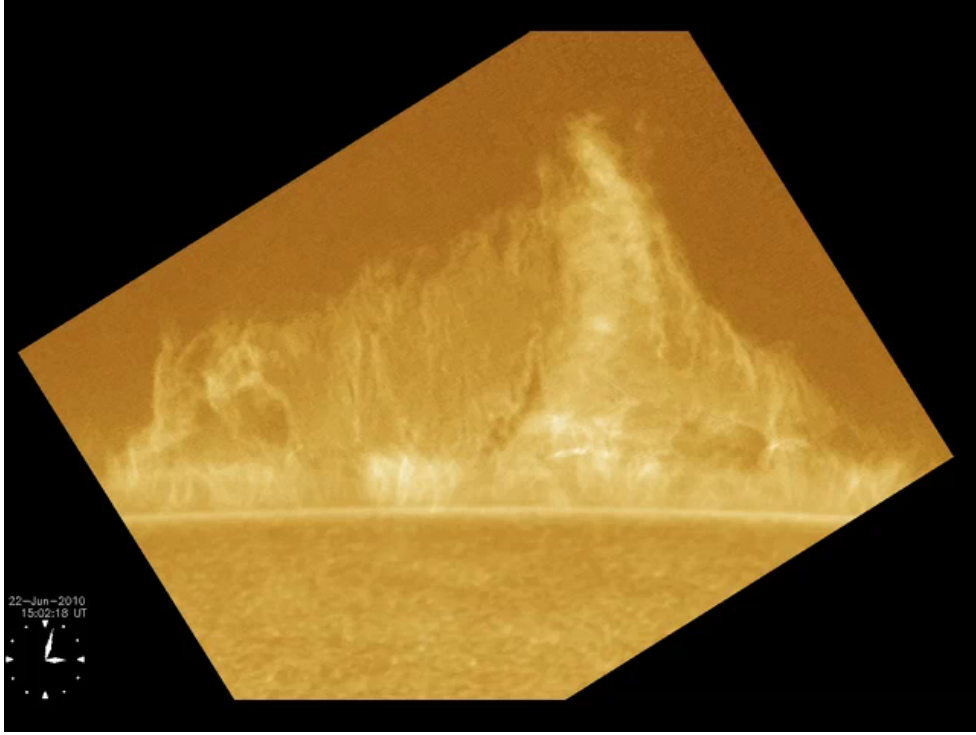
Proposed Goals (May) Leading to Action Plan (Summer)

- Establish Benchmarks for Space Weather Events
- Enhance Response and Recovery Capabilities
- Improve Protection and Mitigation Efforts
- Improve Assessment, Modeling and Prediction of Impacts on Critical Services
- Improve Space Weather Services through Advancing Understanding and Forecasting
- Increase International Cooperation

OSTP, DHS, FEMA, NWS, NOAA, NASA, NSF, DoD, OMB, etc.

Summary

If we are looking, the likely sources of EXTREME events are recognizable once they have emerged through the photosphere, limiting how far in advance forecasts can be made - for now.



A prominence seen over the solar limb by Hinode.

Identifying IMPORTANT events is more problematic because details truly matter. We have some clear ideas about what must be done to improve our capabilities, and at least we can observe them from Earth.