Space Weather Mission to L5

Setting the Operational Context

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National Weather Service

What does “Operational” mean?

- National Weather Service standards
  - 24/7/365 staffing of forecasting office.
  - 99+% reliability of observing, processing, and dissemination systems.
  - Redundant power, cooling, and networking at all facilities.
  - Contingency plans for outages of all forecast-critical system elements: e.g. alternate processing sites, backup instruments for observations and backup computers for model runs, etc…

- Space weather forecasting has yet to achieve fully operational status, primarily because of the observing systems.

Characteristics of Operational Weather Satellites

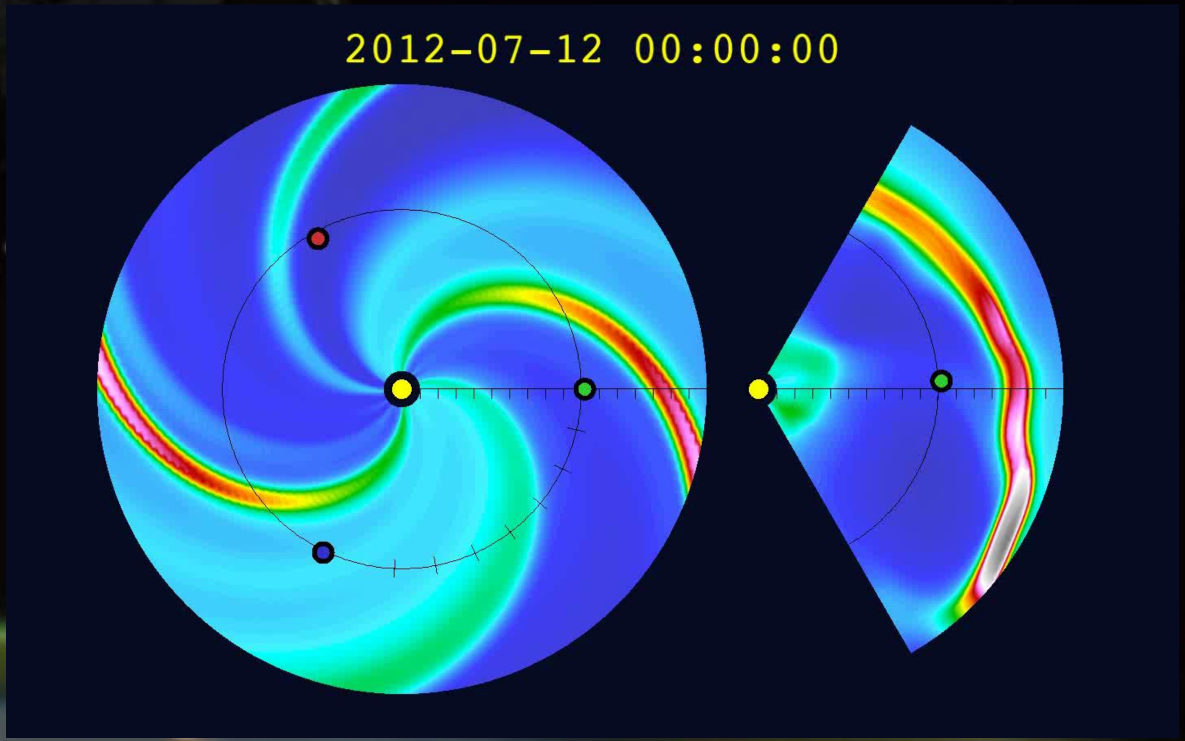
- Systems designed for 10—15 year mission.
- Continuous high cadence data collection and transmission.
- Redundant communication systems.
  - Backup Command/Control and downlink channels.
- Robust and resilient ground-station coverage.
  - Backup stations for C/C and data downlink.
- Data latency to forecast center measured in seconds or minutes.
- Backup satellites in ‘on-orbit’ storage.
- Operational data processing *and dissemination* systems.

Geomagnetic Storm Forecasting

1. Geomagnetic Storm Watch

Issued upon coronagragraph detection of Earth-directed CME and WSA-Enlil model run

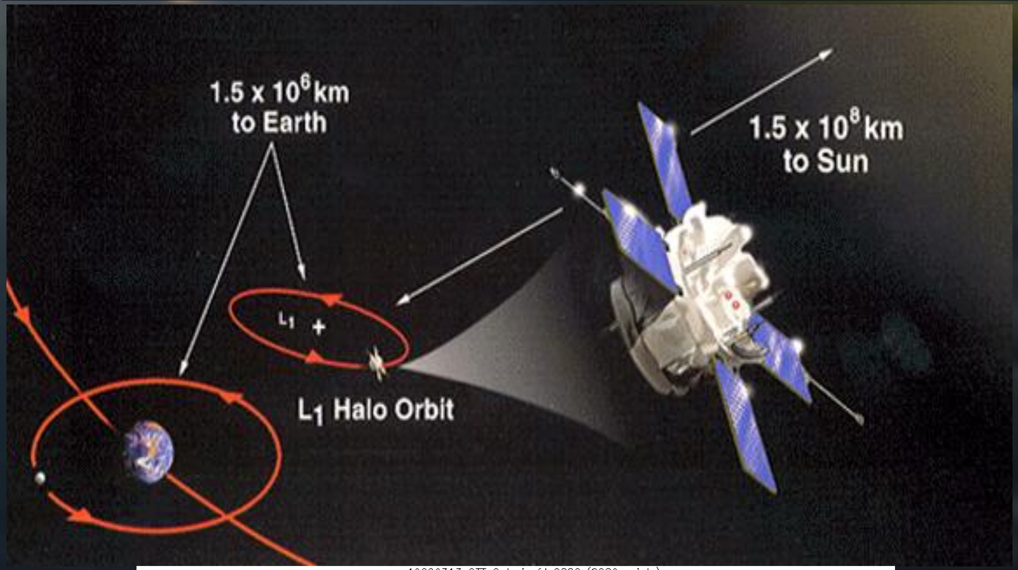
- **15 – 72 hour lead-time**



2. Geomagnetic Storm Warning

Issued upon detection at the ACE (soon DSCOVR) spacecraft at the L1 Lagrange point

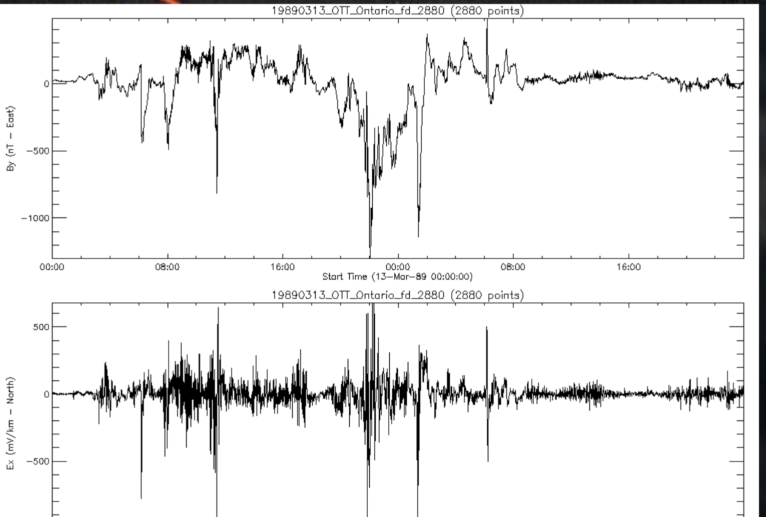
- **15-60 minutes lead-time**
- **First time we get measurement of Bz**



3. Geomagnetic Storm Alert

Issued when geomagnetic storm is detected on USGS magnetometers

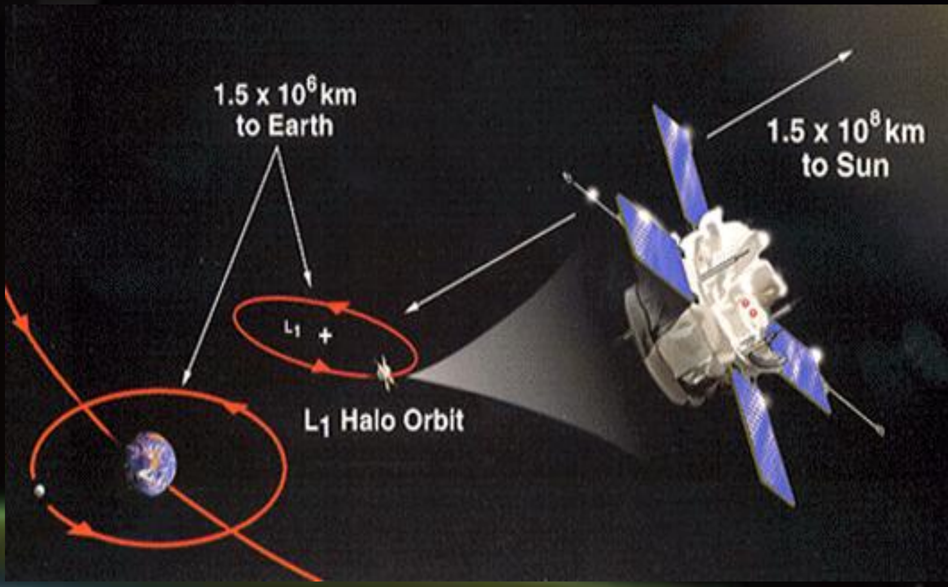
- **Current condition**



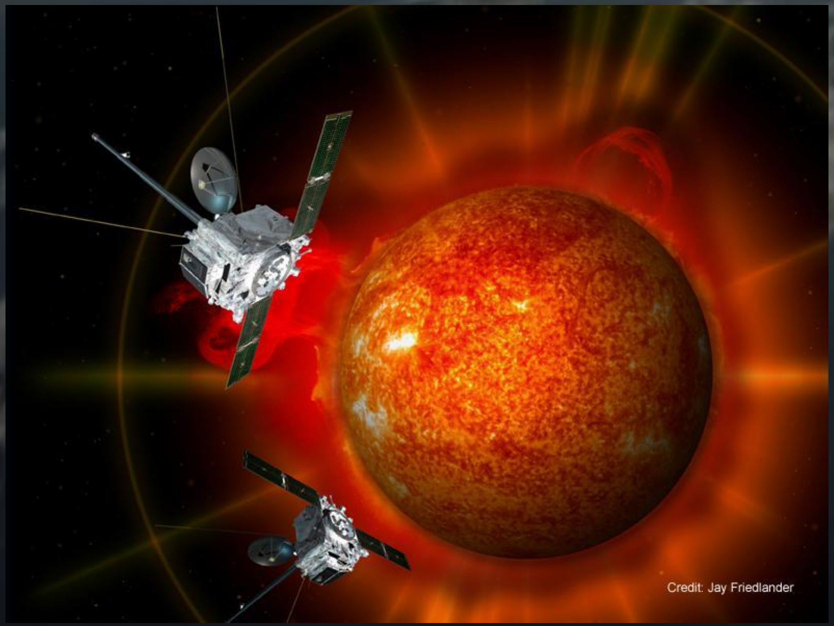
Space-based Data for Space Weather Ops.

NOAA GOES

Eumetsat METOP



NASA ACE



NASA STEREO

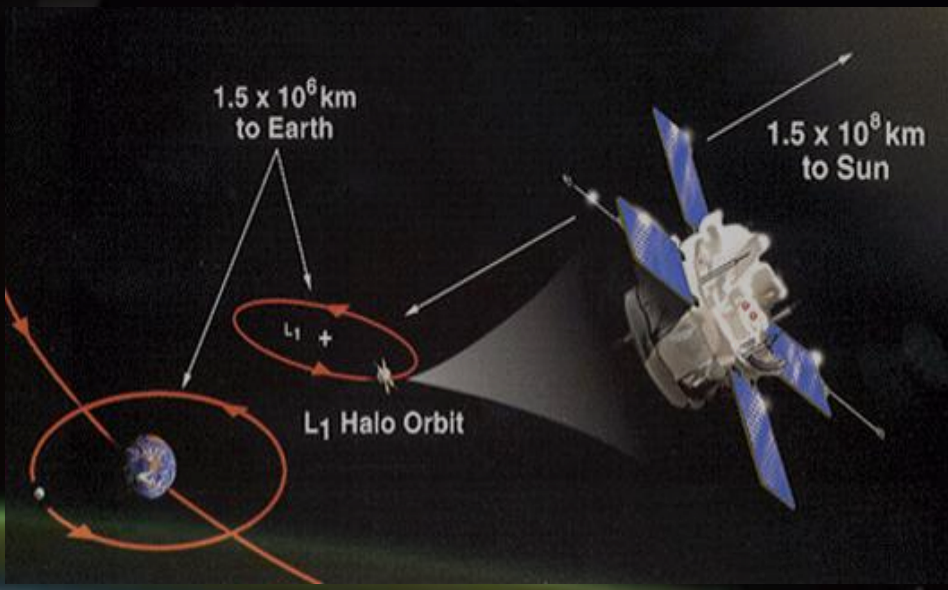
NASA Solar Dynamics Observatory

ESA/NASA SOHO

Space-based Operational Systems…

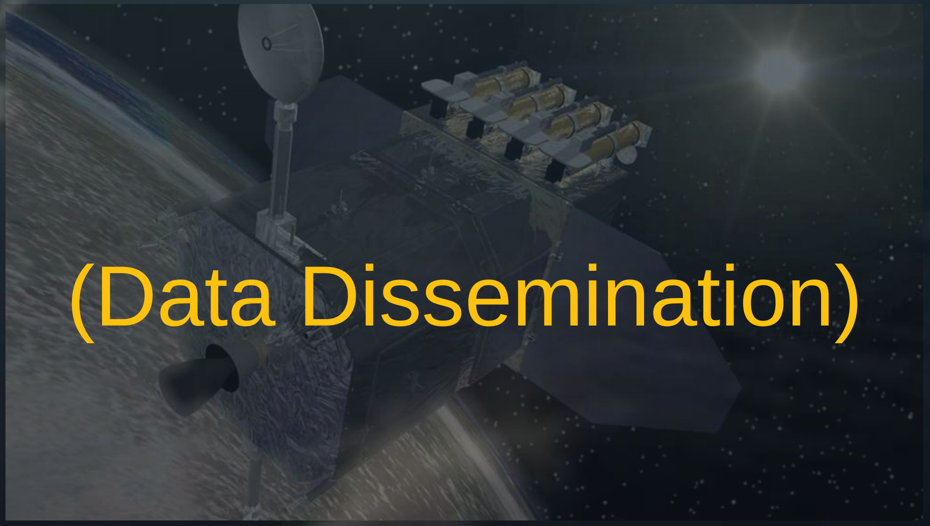
NOAA GOES

Eumetsat METOP

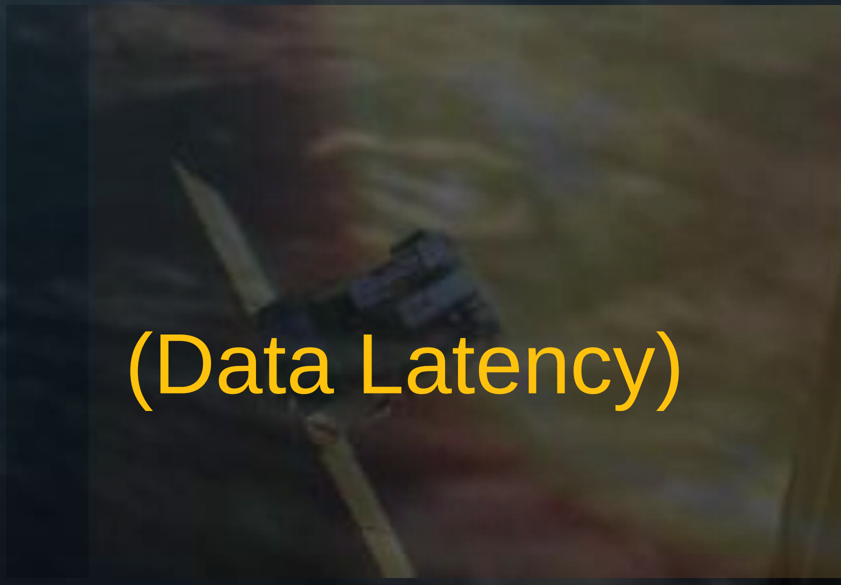


NASA ACE

(Data Availability)

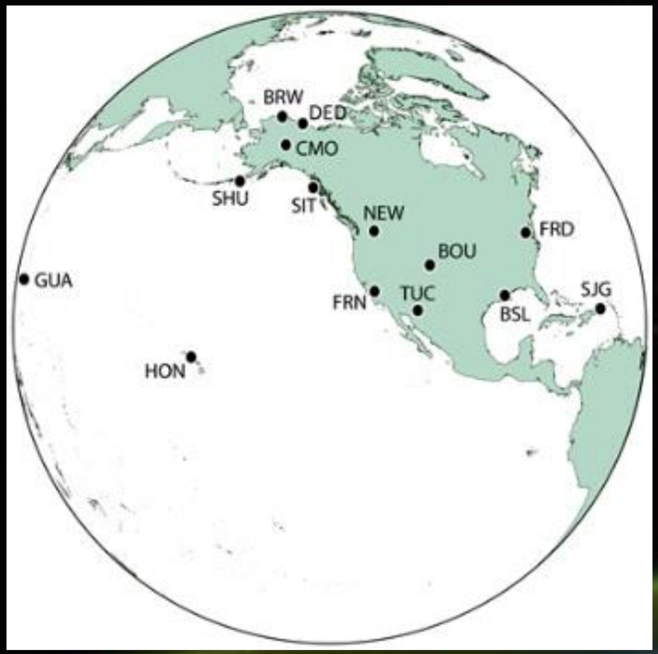


(Data Dissemination)



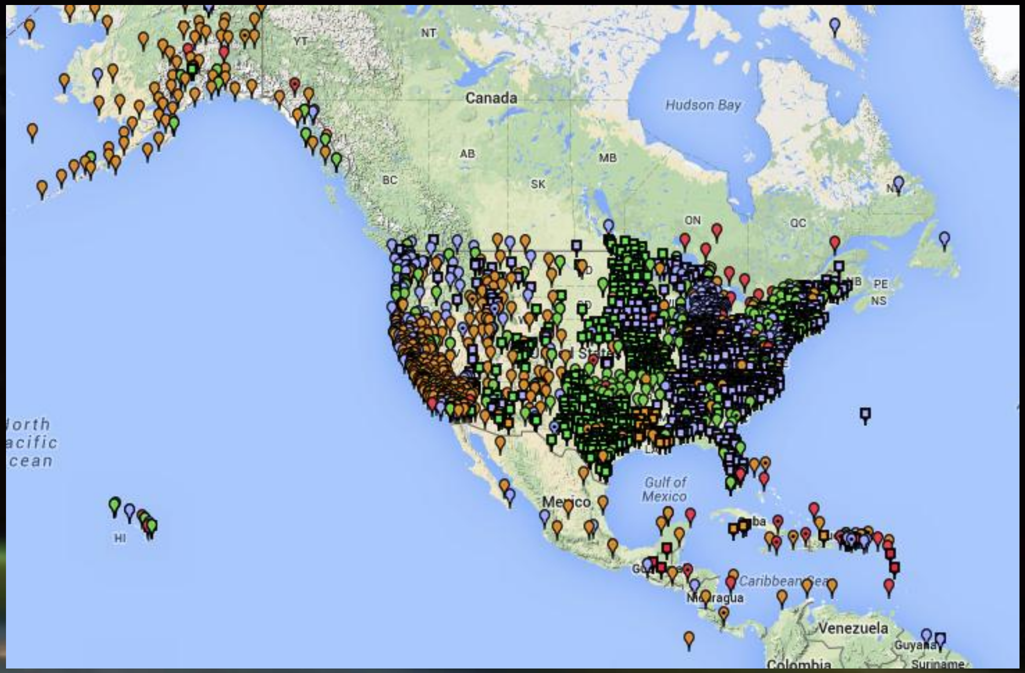
(Data Latency)

Ground-based data for Space Weather Ops

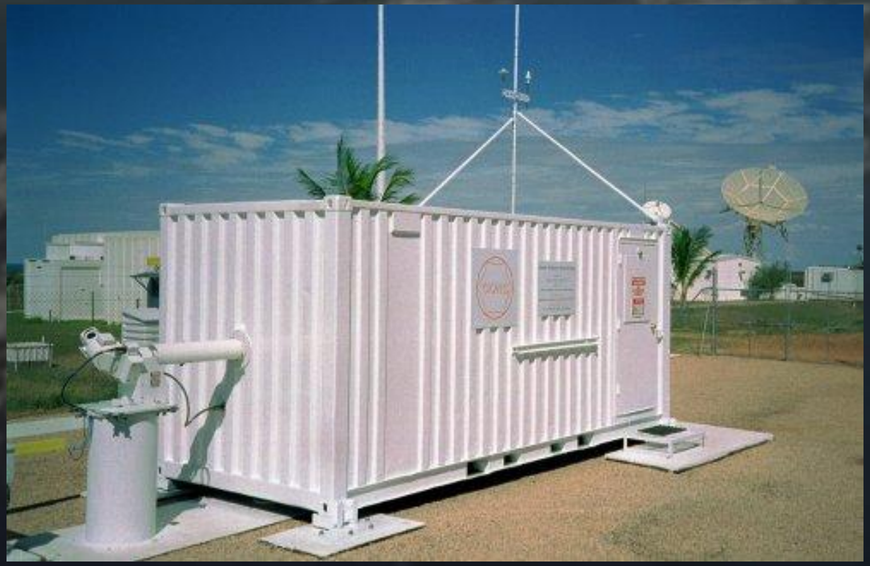


Magnetometer Network

Air Force SEON Network



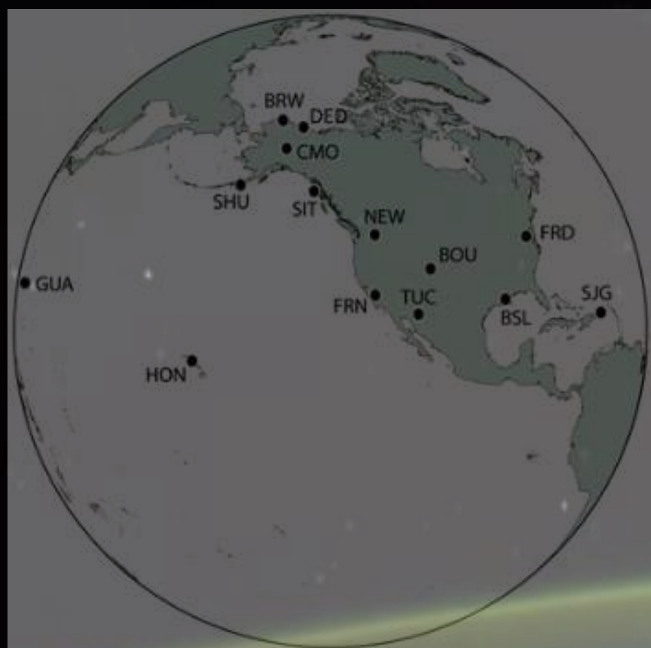
USGS CORS Network



NSF GONG Network

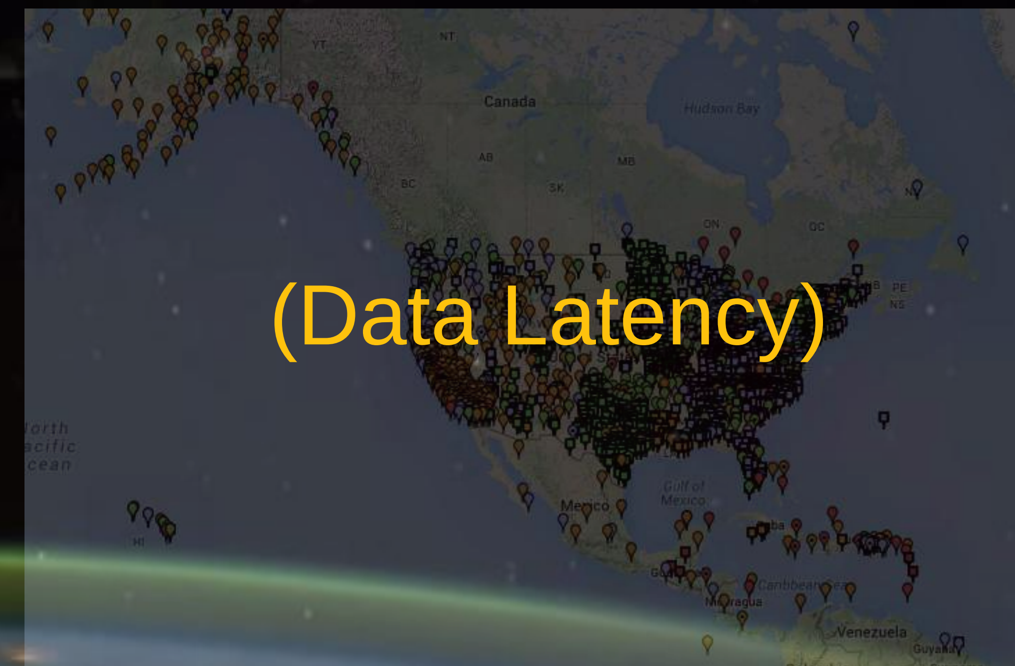
Neutron Monitor Network

Ground-based Operational Systems…



Magnetometer Network

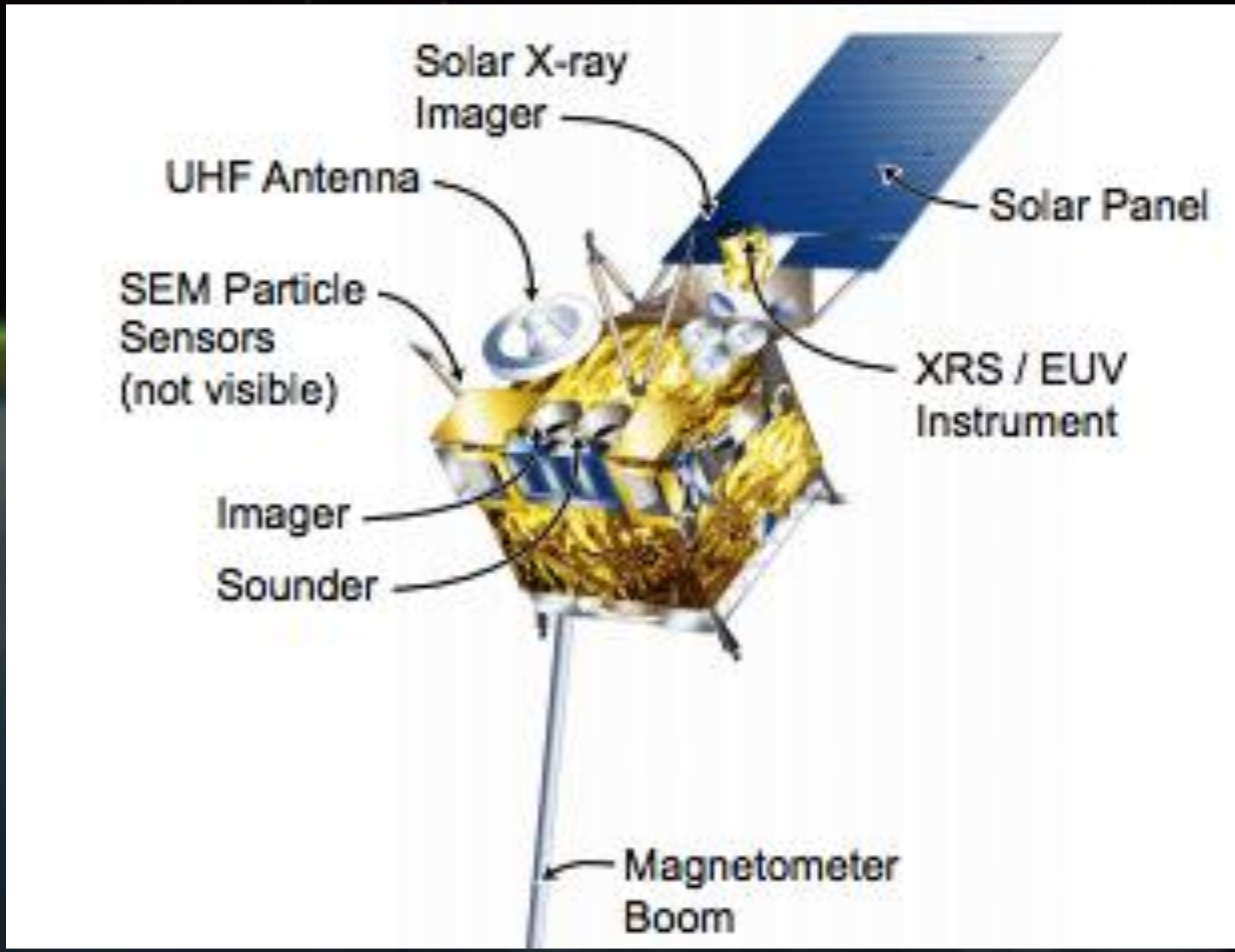
Air Force SEON Network



Current Operational Systems: GOES 13—15

- On-orbit spares.
- Back-up ground stations.
- 7 communications antennas!

  - 2 S-band dipole, 1 UHF, 2 L-band dipole, 1 omni, 1 S-band horn.
- Continuous data transmission.
- XRS data latency to SWPC forecast office 10—12 sec !



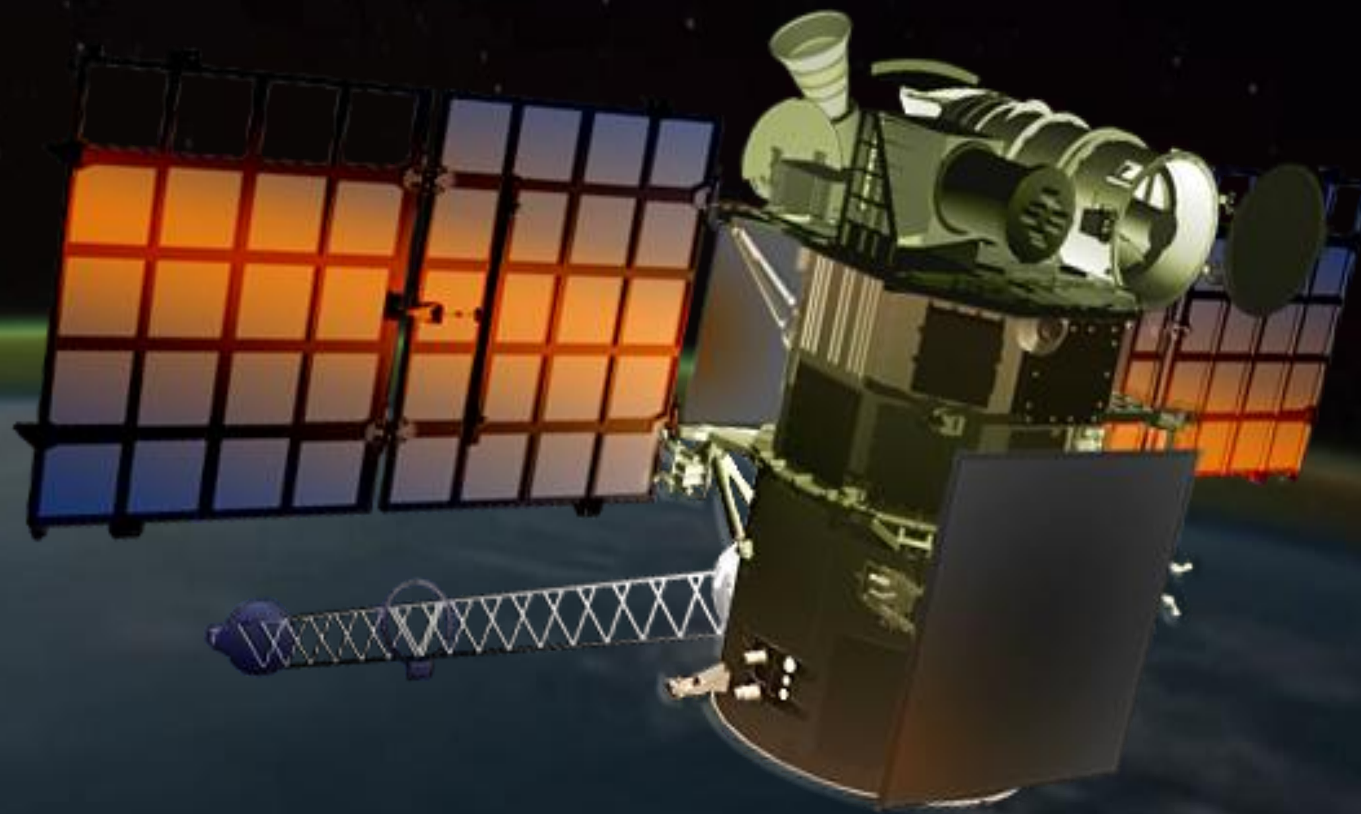
Current Operational Systems: ACE*

- NOAA continuous real-time data beacon.
- RTSW ground-receiving station backed up by AFSCN network.
- Data ingest, processing, and dissemination systems are fully operational at SWPC.
- Data latency to SWPC forecast office ~ 1 min.

- * DSCOVR is replacing ACE for operational forecasting in 2015 (on-orbit spare).

Current Operational Systems: DSCOVR*

- Continuous very high cadence data stream.
- *On-orbit spare (ACE).
- RTSW ground-receving station backed up by AFSCN network.
- Data ingest, processing, and dissemination systems fully operational at SWPC.
- Data latency to SWPC forecast office < 1 min.



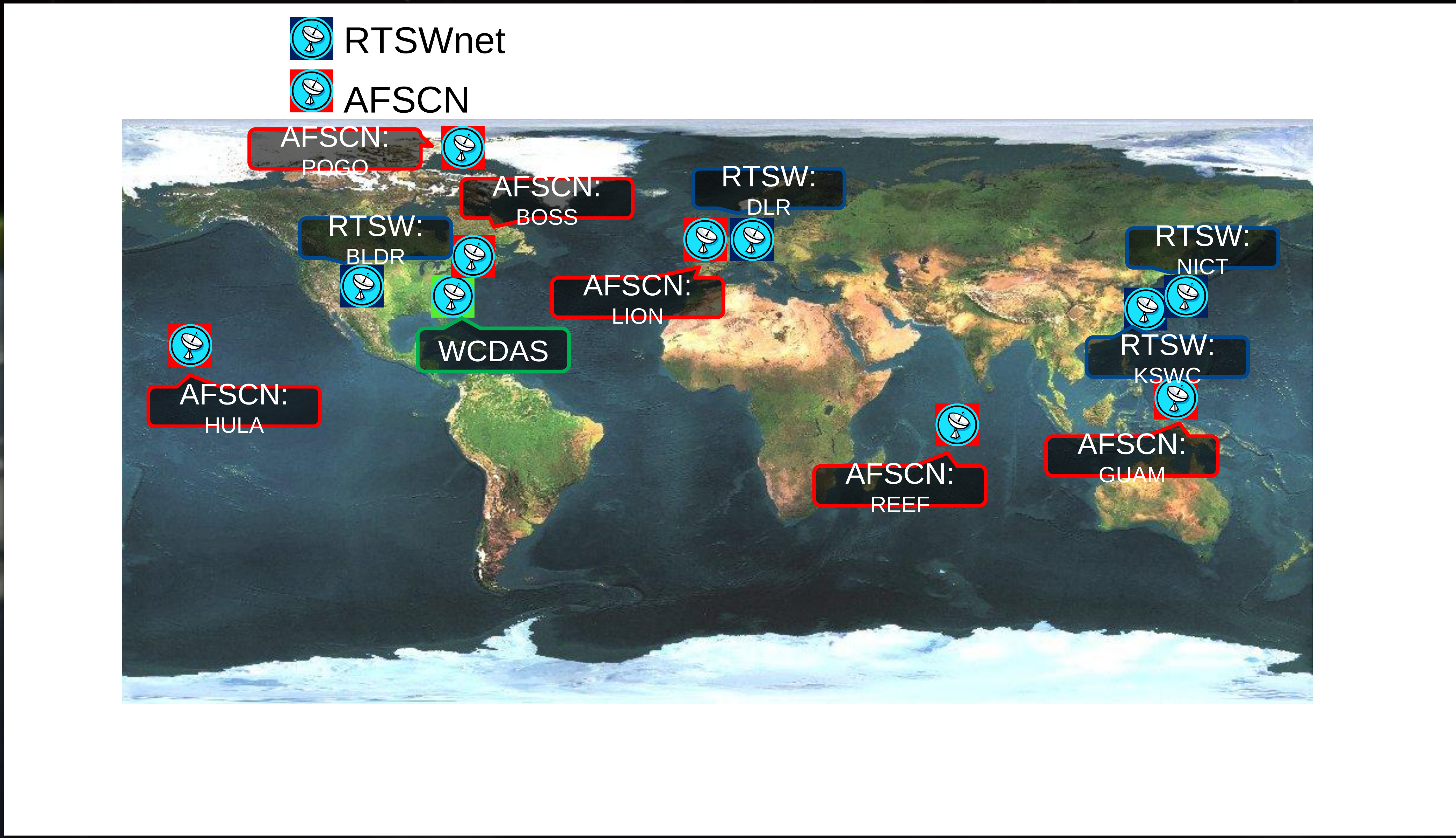
NOAA DSCOVR

Arriving at L1 on June 7—8, 2015!

Real-time Solar Wind Network (RTSW)

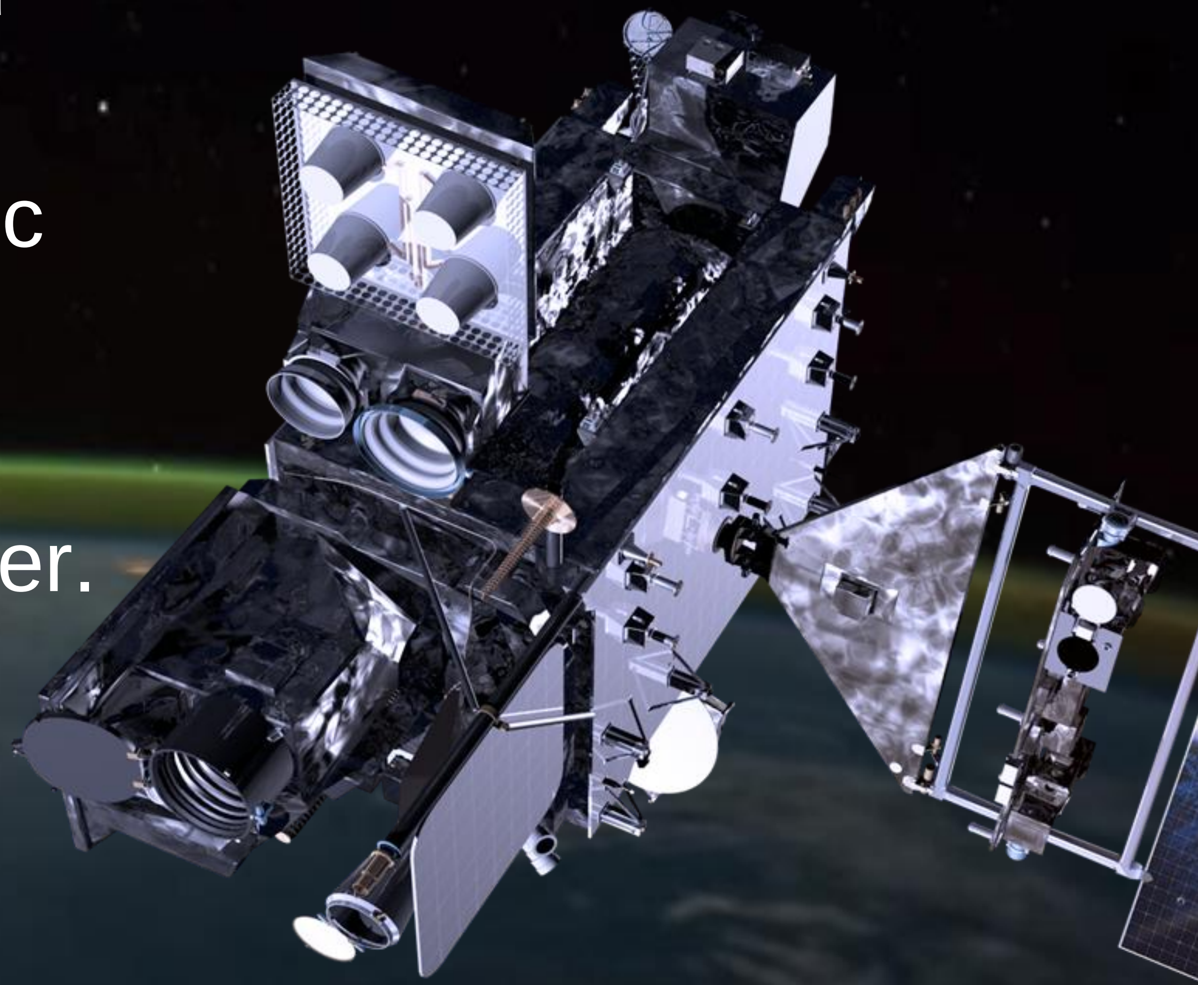
- 24/7 reception from one L1 deep space satellite (ACE → DSCOVR)
- Backup via USAF AFSCN network

- National Institute of Information and Communications Technology **(NICT)** in Tokyo, **Japan**
- Korean Space Weather Center **(KSWC)** in Jeju, **Korea**
- German Aerospace Center **(DLR)** in Neustrelitz, **Germany**
- Wallops Command and Data Acquisition Station **(WCDAS)** in Virginia
- Space Weather Prediction Center **(SWPC)** in Boulder



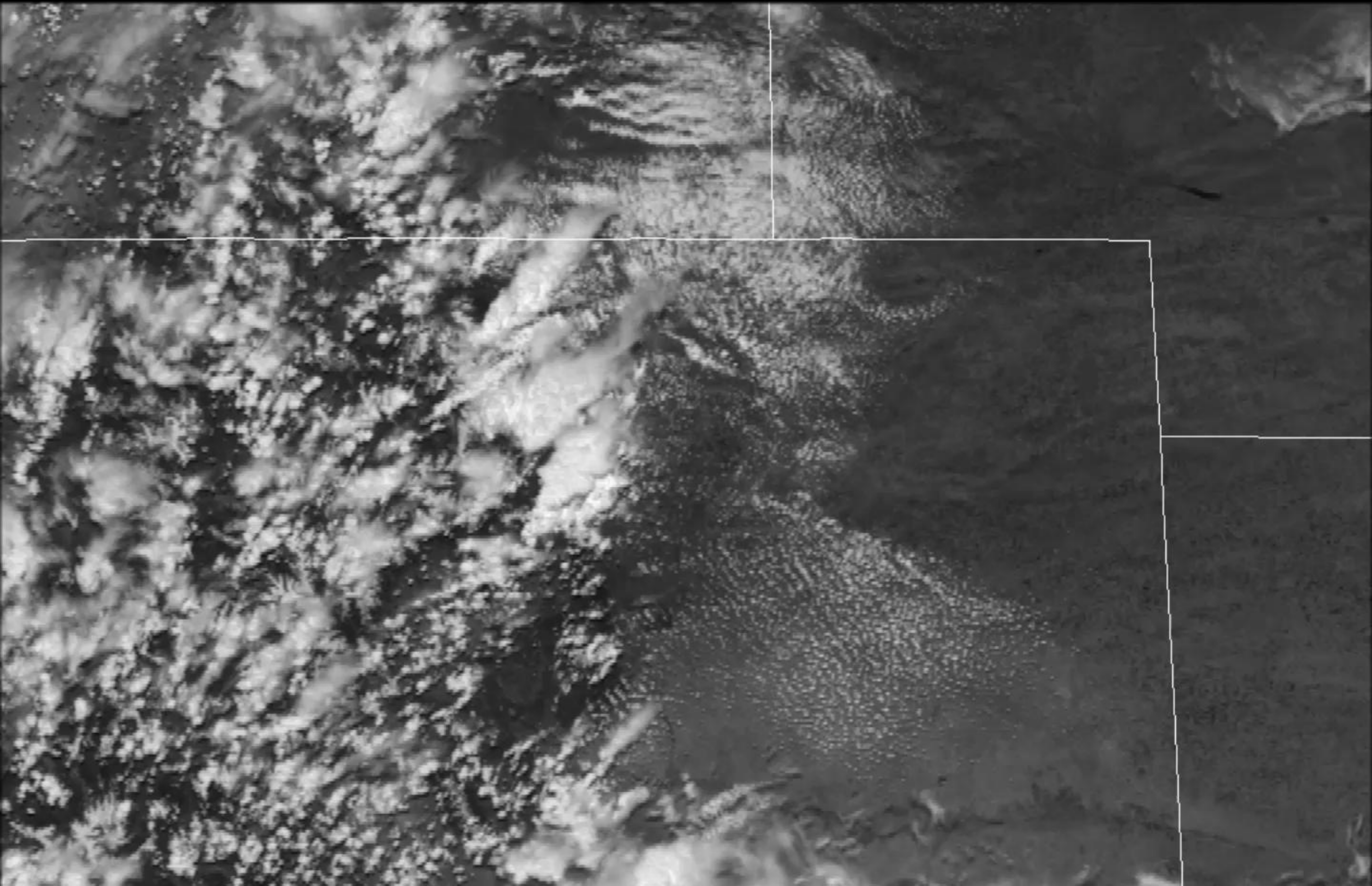
Future Operational Systems: GOES-R

- EXIS – high dynamic range X-ray and EUV photometry.
- SEISS – high dynamic range energetic particle measurements.
- SUVI – new UV solar imager.
- MAG – high sample rate magnetometer.
- Extensive S/C discharge protection.
- Continuous real-time data stream.
- Operational data processing at SWPC with 10—12 sec latency.



NOAA GOES-R
Launching to Geosynch in early 2016

GOES-R will not go into on-orbit storage…



Future Operational Systems: “SWx Follow-On”

- L1 Lissajous orbit.
- Compact Coronagraph (CCOR).
- Solar Wind plasma.
- Solar Wind magnetic field.
- Solar photospheric magnetic field?
- NASA/Earth Science contribution?
- Continuous real-time data stream.

NOAA SWx Follow-On
Launching to L1 in 2020—2021

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NRL Compact Coronagraph

- 50% shorter and 30% lighter than STEREO/COR2 heritage
- Replaces SOHO/LASCO

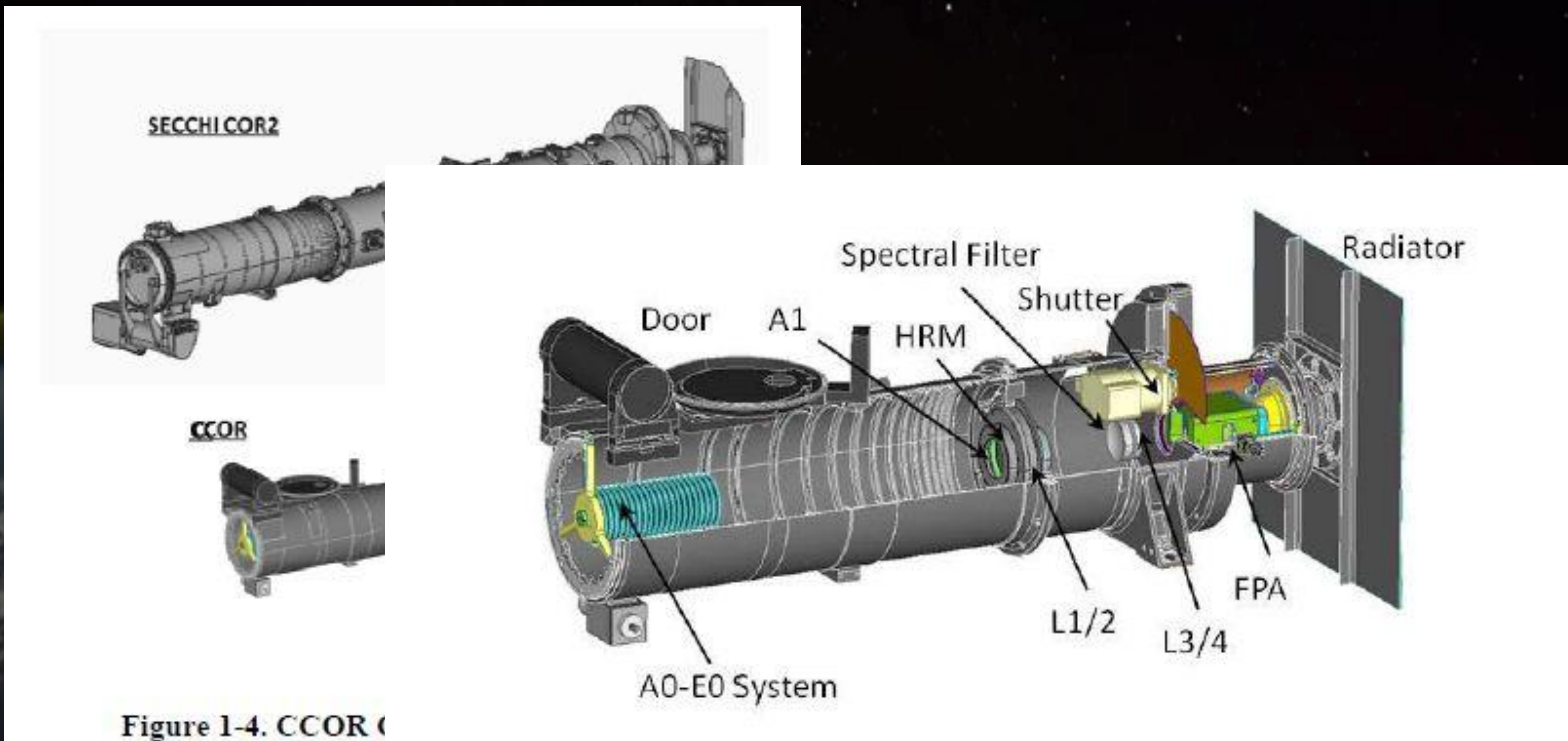


Figure 1-4. CCOR (
SECCHI/

Figure 1-3. CCOR Conceptual Design

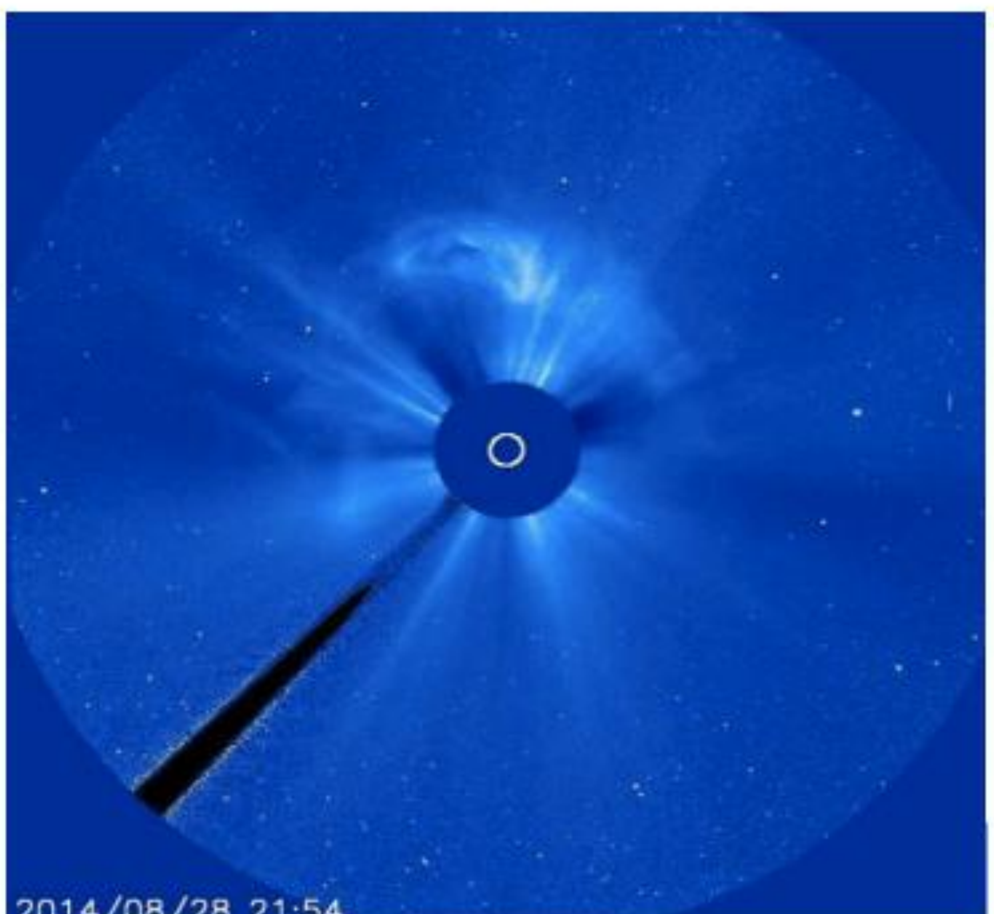
Compact Coronagraph
Courtesy of NRL

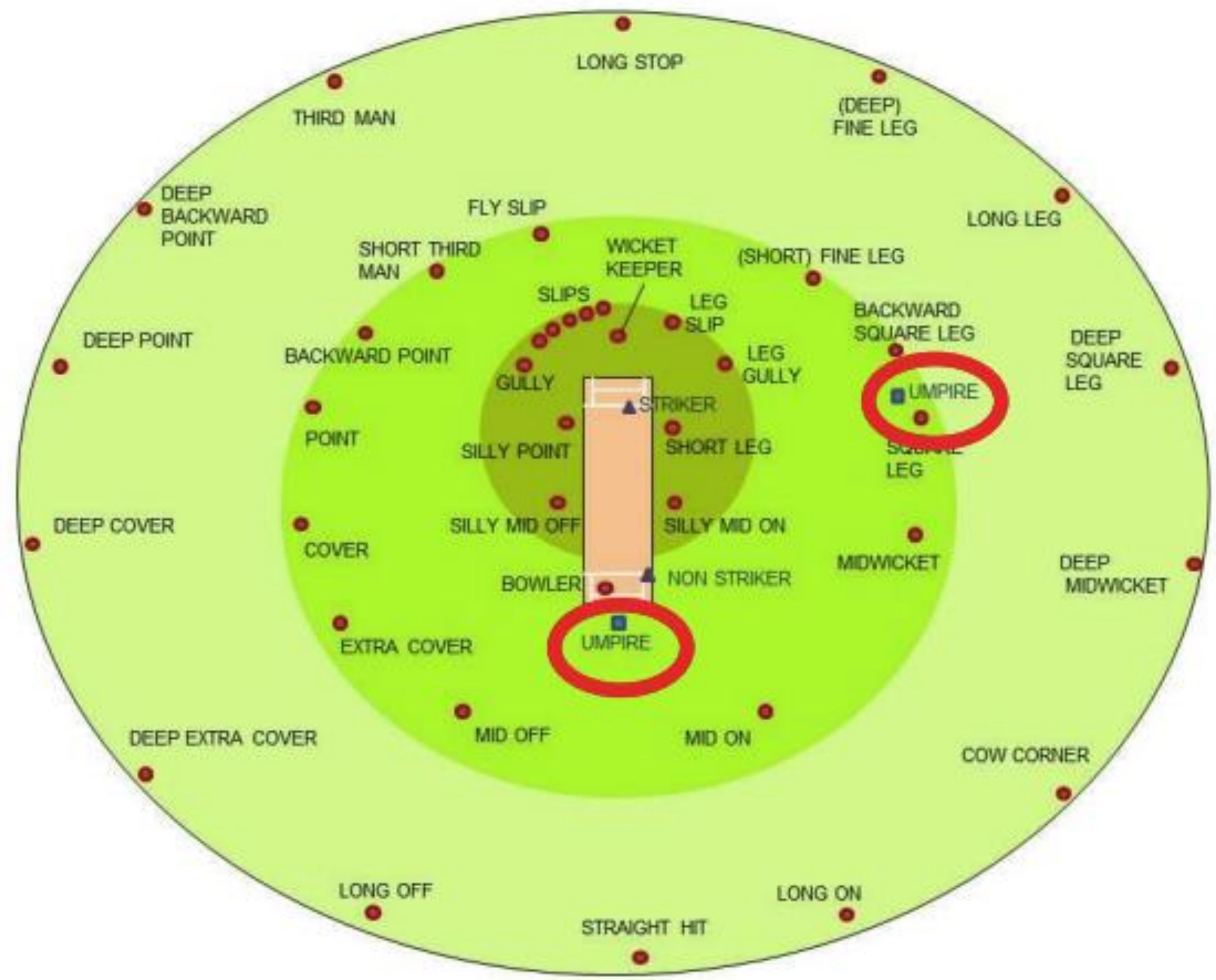
What's Missing?

- "The second umpire".
- Key inputs to the operational WSA/Enlil CME model: location (lat, long), angular width, and radial velocity.

From MOSWOC forecast 29/08/2014:

"SOHO LASCO C3 image showing an almost full halo CME. However it looks highly likely that this is from a back sided filament eruption, and so this CME is headed almost directly away from Earth."



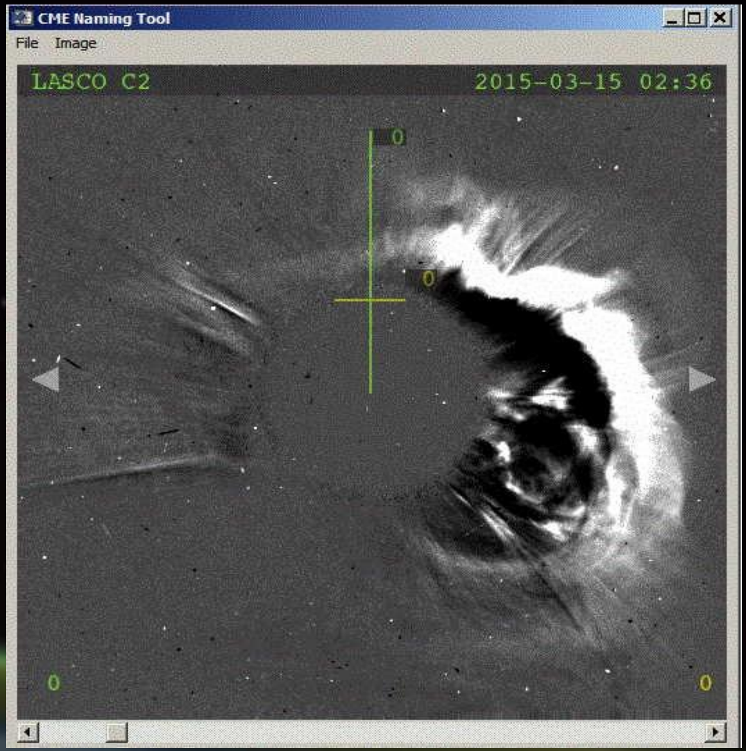


Thanks to Markos Trichas!

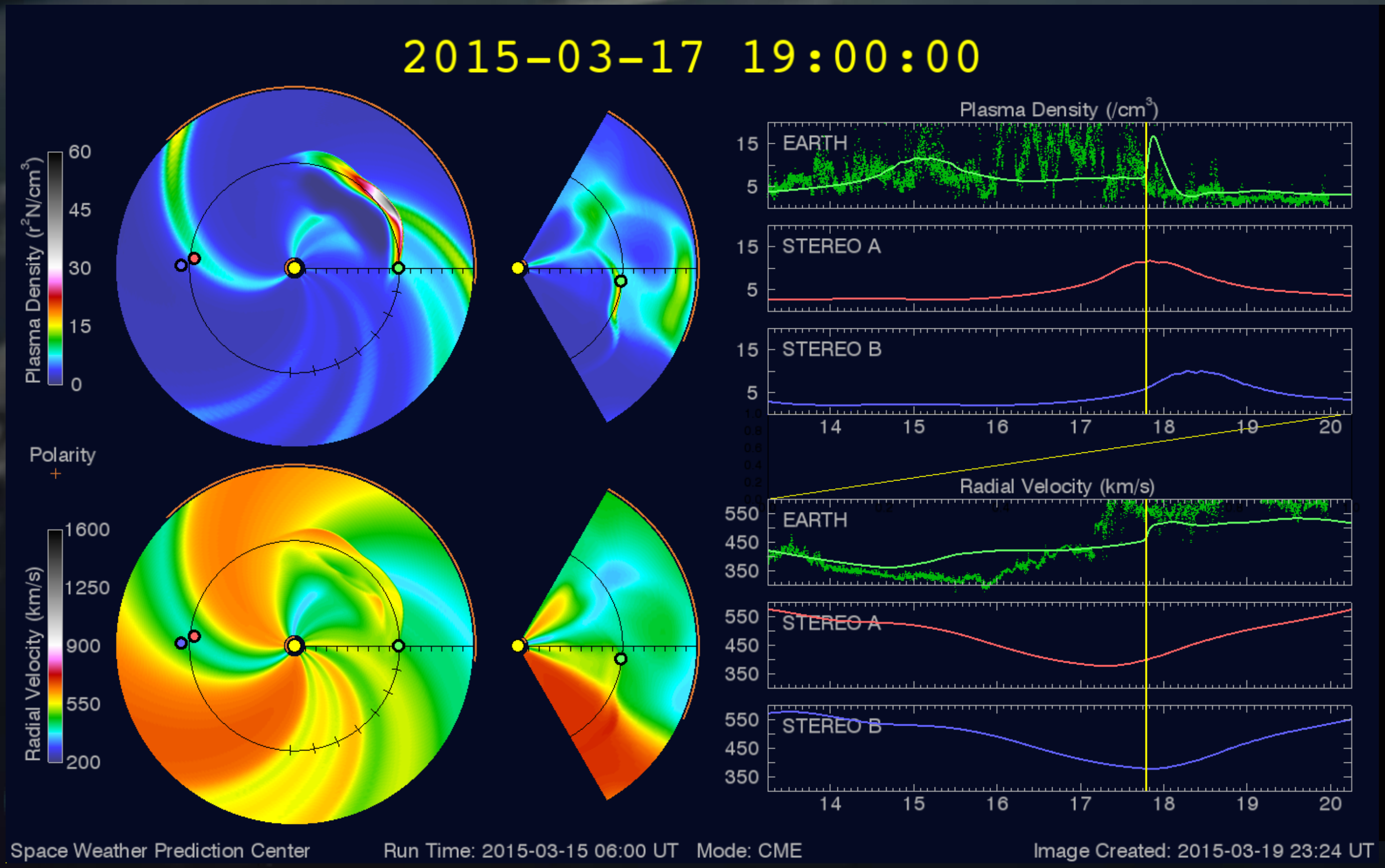
AIRBUS DEFENCE & SPACE

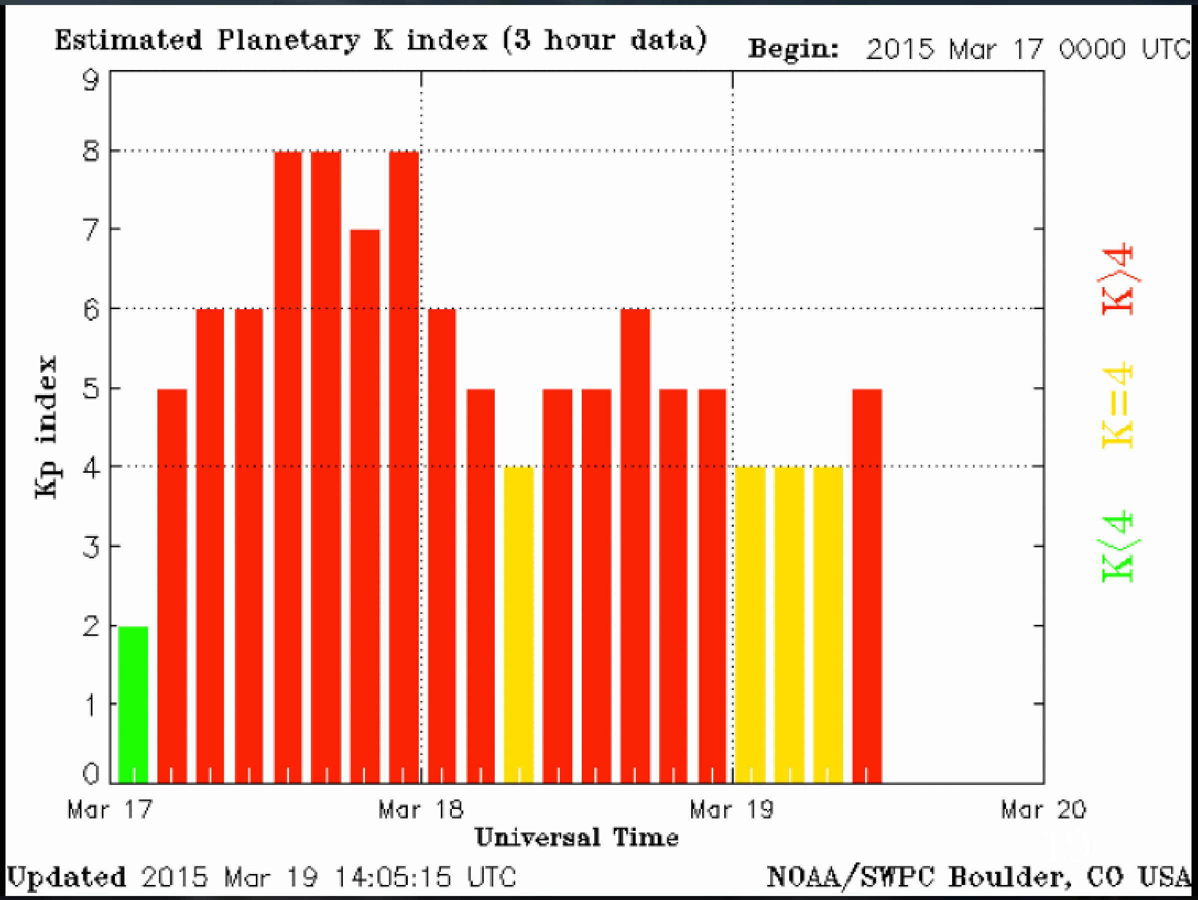
Case Study: St. Patrick's Day Geomag Storm

- West limbward eruption on 15-Mar-2015.
- "Glancing blow" CME predicted with G1 magnitude.
- Actual arrival 15 hours early. Magnitude G4!
- What happened??



AR 12297 CME 15-Mar-2015





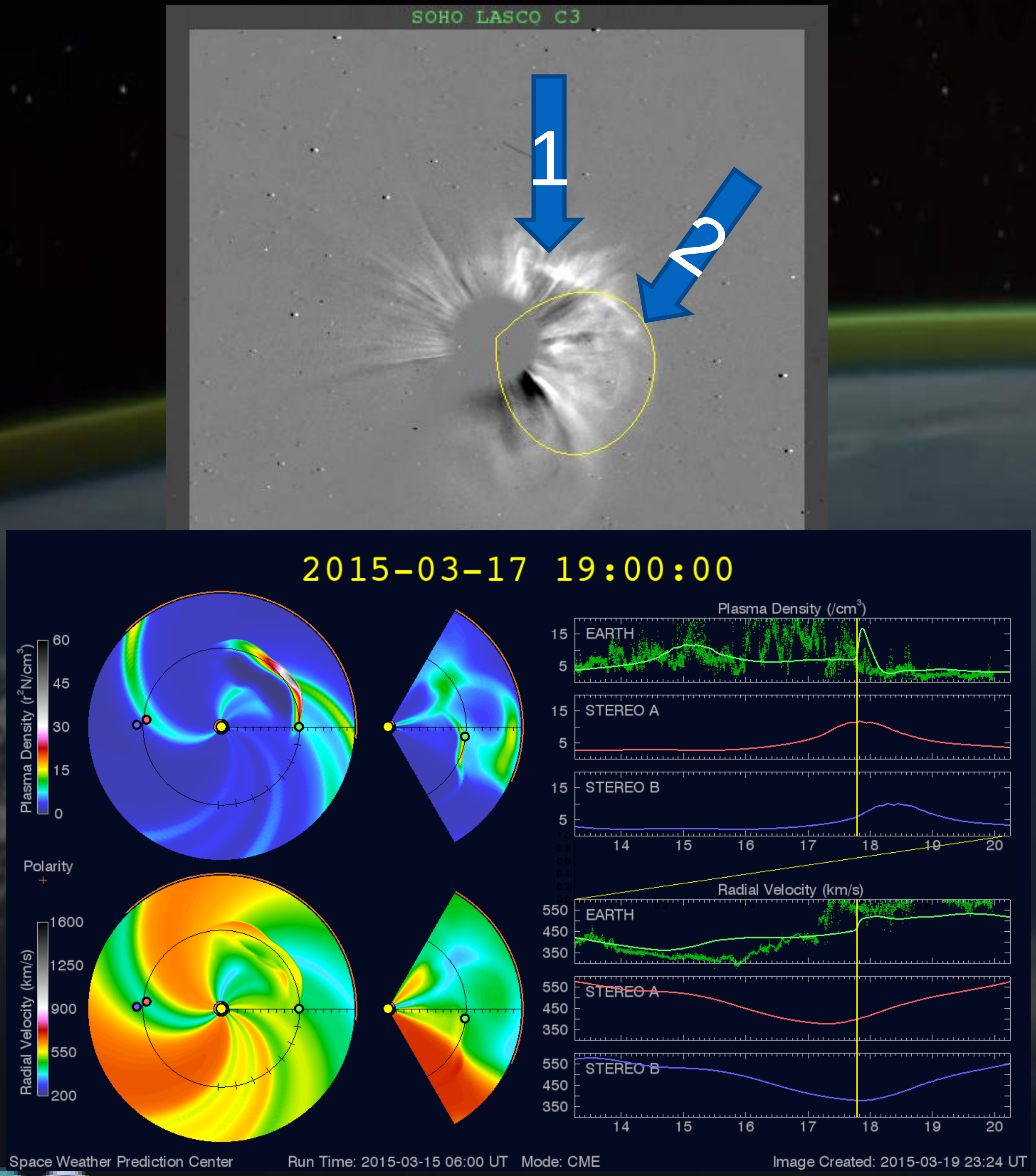
St. Patrick's Day Storm: CME parameter sensitivity

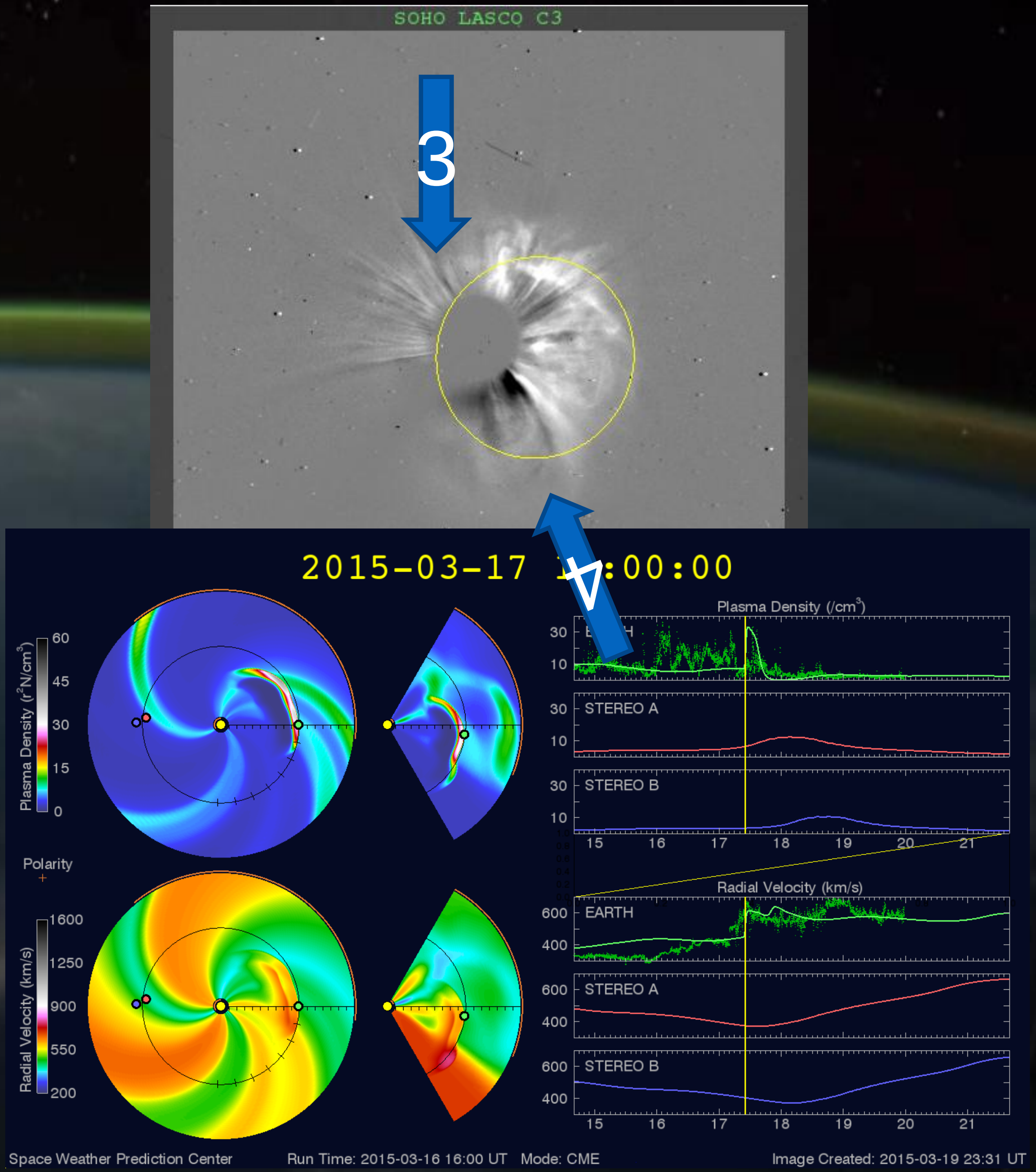
Run 1: Lat=-21°, Lon=45°, ω=41°

A glancing blow to miss

Run 2: Lat=-14°, Lon=21°, ω=40°

A definite hit and on time arrival





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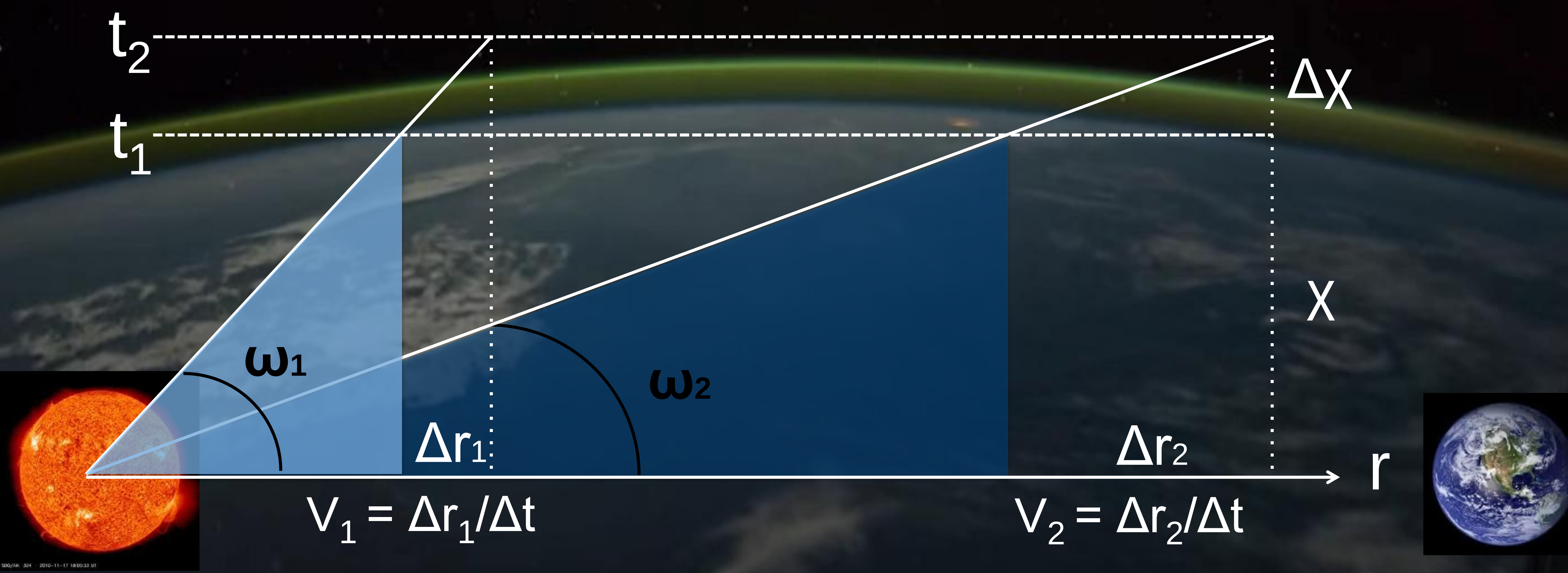
The More Subtle Problem

- For same plane of sky (POS) projection, slower and wider CME has same signature as faster and narrower CME.
- Most challenging parameter fit from “L1 only” observations is accurate CME angular width.

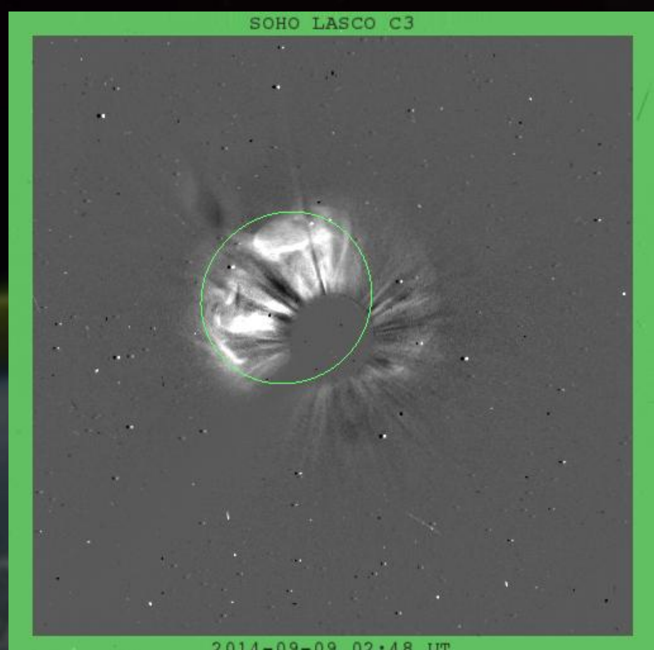


$$V_2/V_1 = \tan(w_2)/\tan(w_1)$$

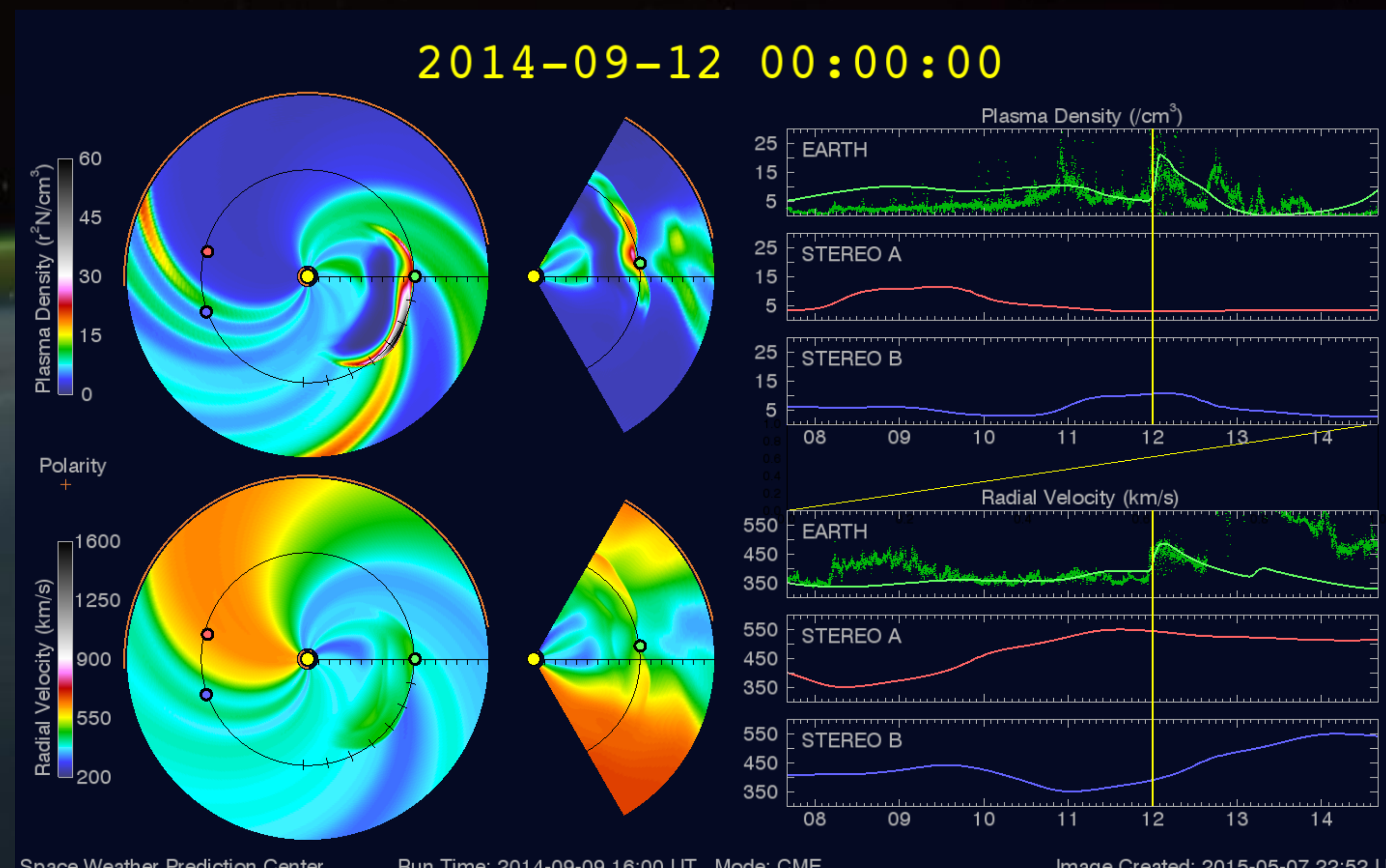
Millward et al., SWx Journal, vol. 11, 57, 2013.

11-Sep-2014 "Double CME" Example

- Fit to the 1st CME (M5 flare on 10-Sep-2014).
- Width decrease → faster → earlier arrival time



CAT derived parameters
Lat = 24°
Lon = -23°
Width = 43°
Speed = 767 km/s



Model run predicted arrival: 2014-09-12 00:00
Actual shock at ACE arrival: 2014-09-11 22:58

Error: 1:02 (very good)

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11-Sep-2014 "Double CME" Example

- Fit to the 1st CME (M5 flare on 10-Sep-2014).
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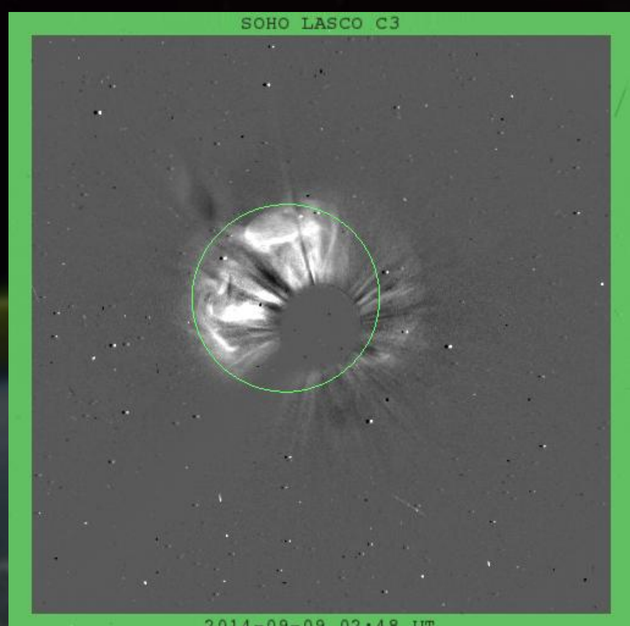
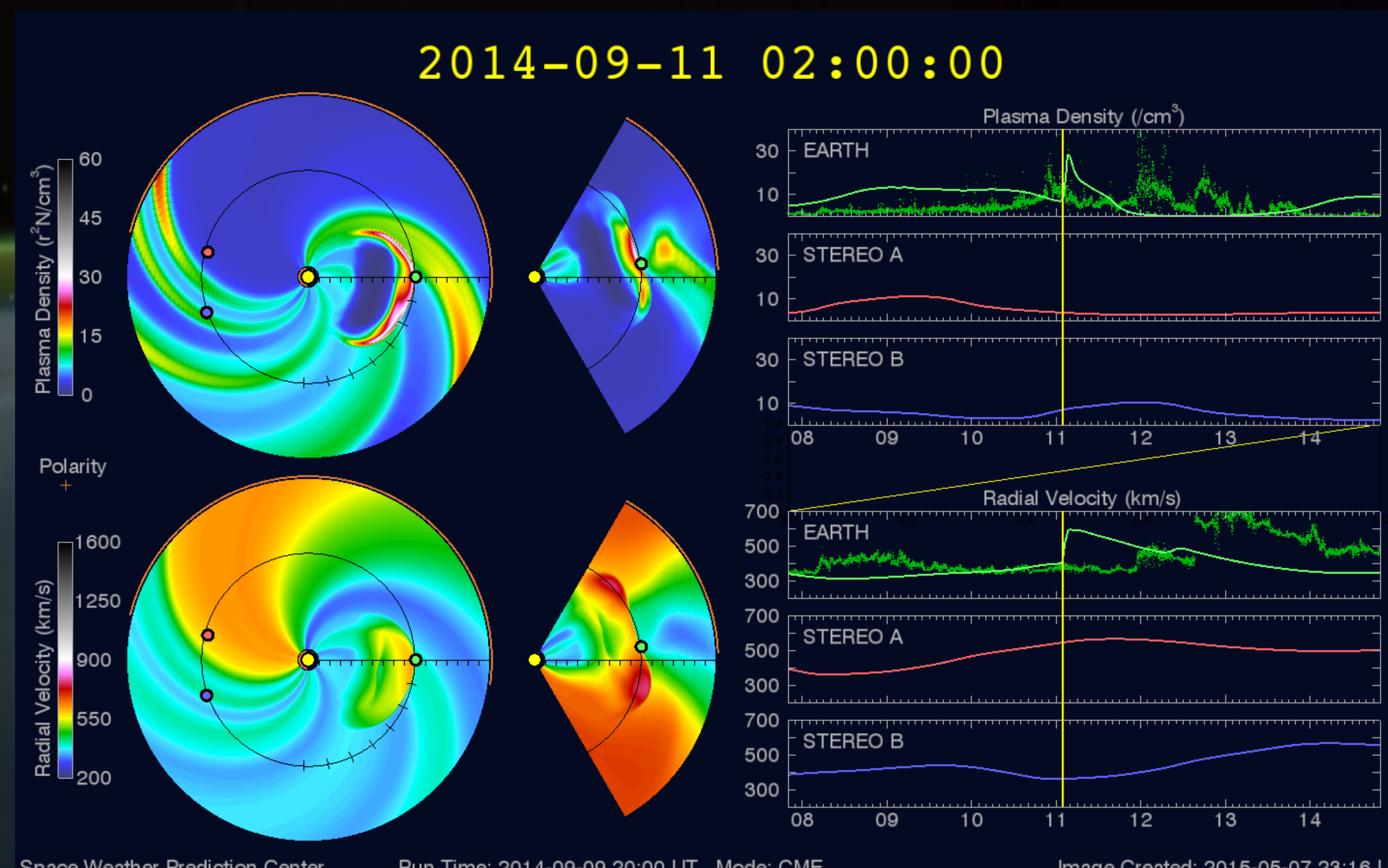


CAT derived parameters
Lat = 16°
Lon = -12°
Width = 36° (-6.5)
Speed = 1271 km/s



Model run predicted arrival: 2014-09-11 02:00
Actual shock arrival time: 2014-09-11 22:58

Error: -20:58 (horrible)

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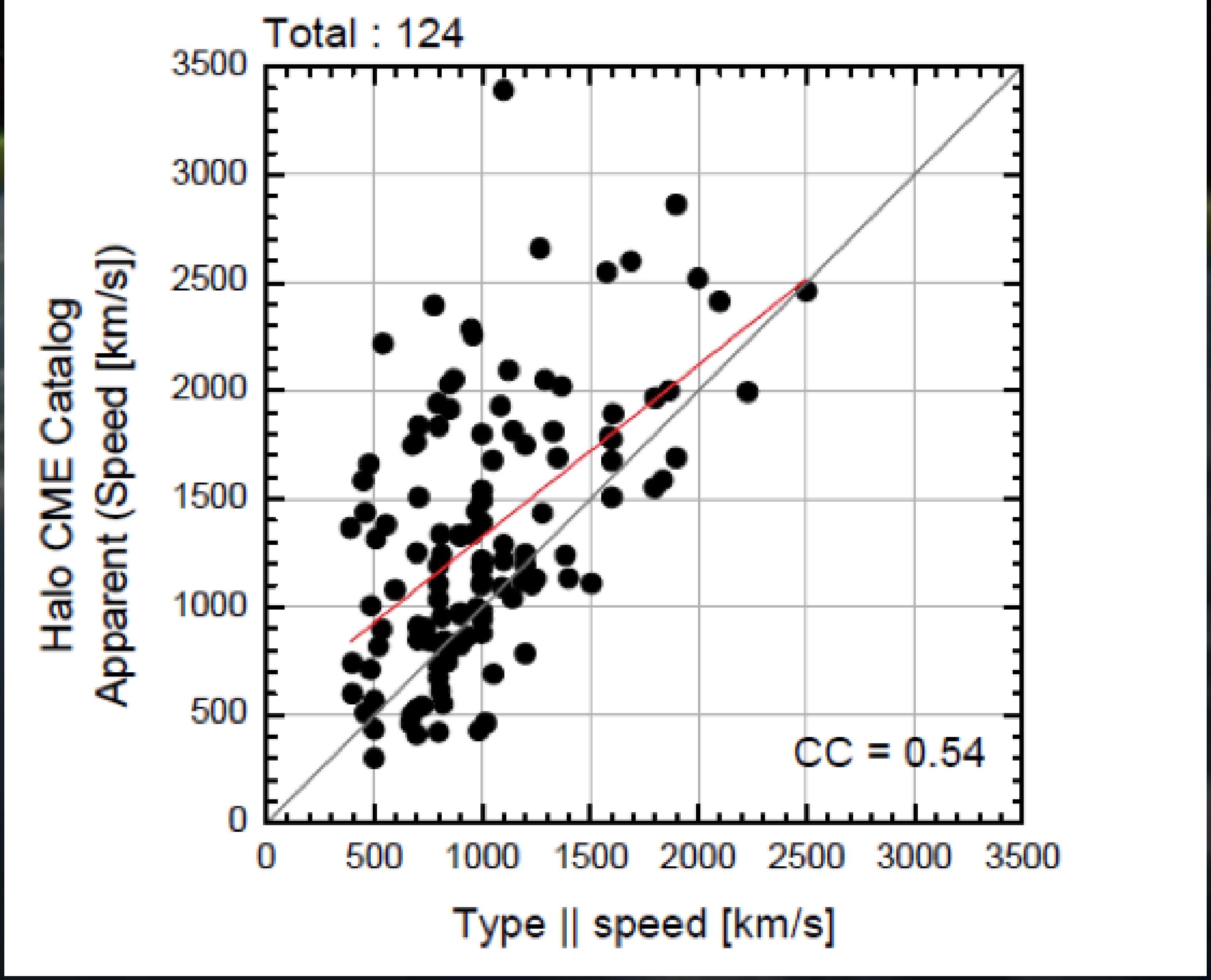
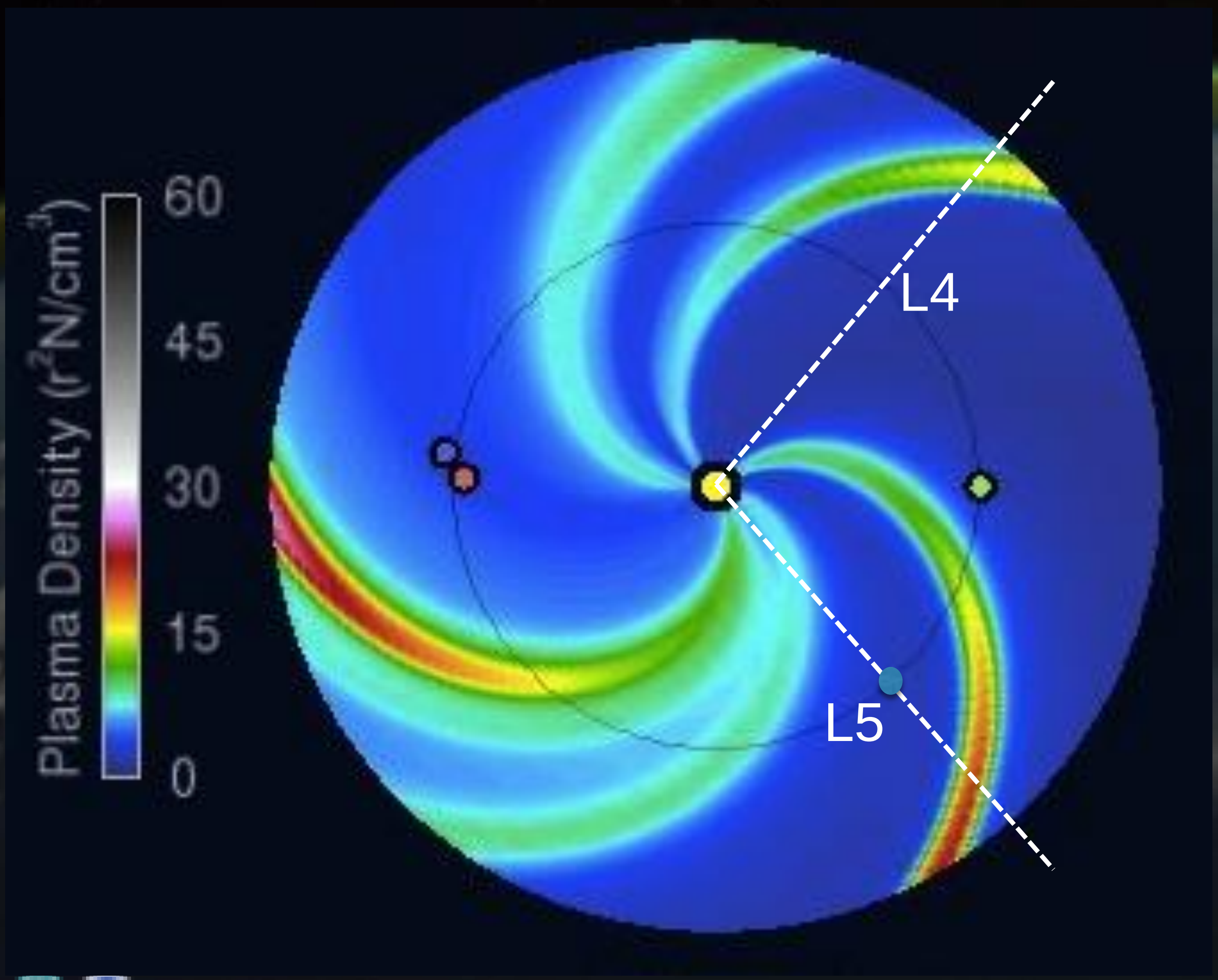
Can we use radio bursts to constrain CME speed?

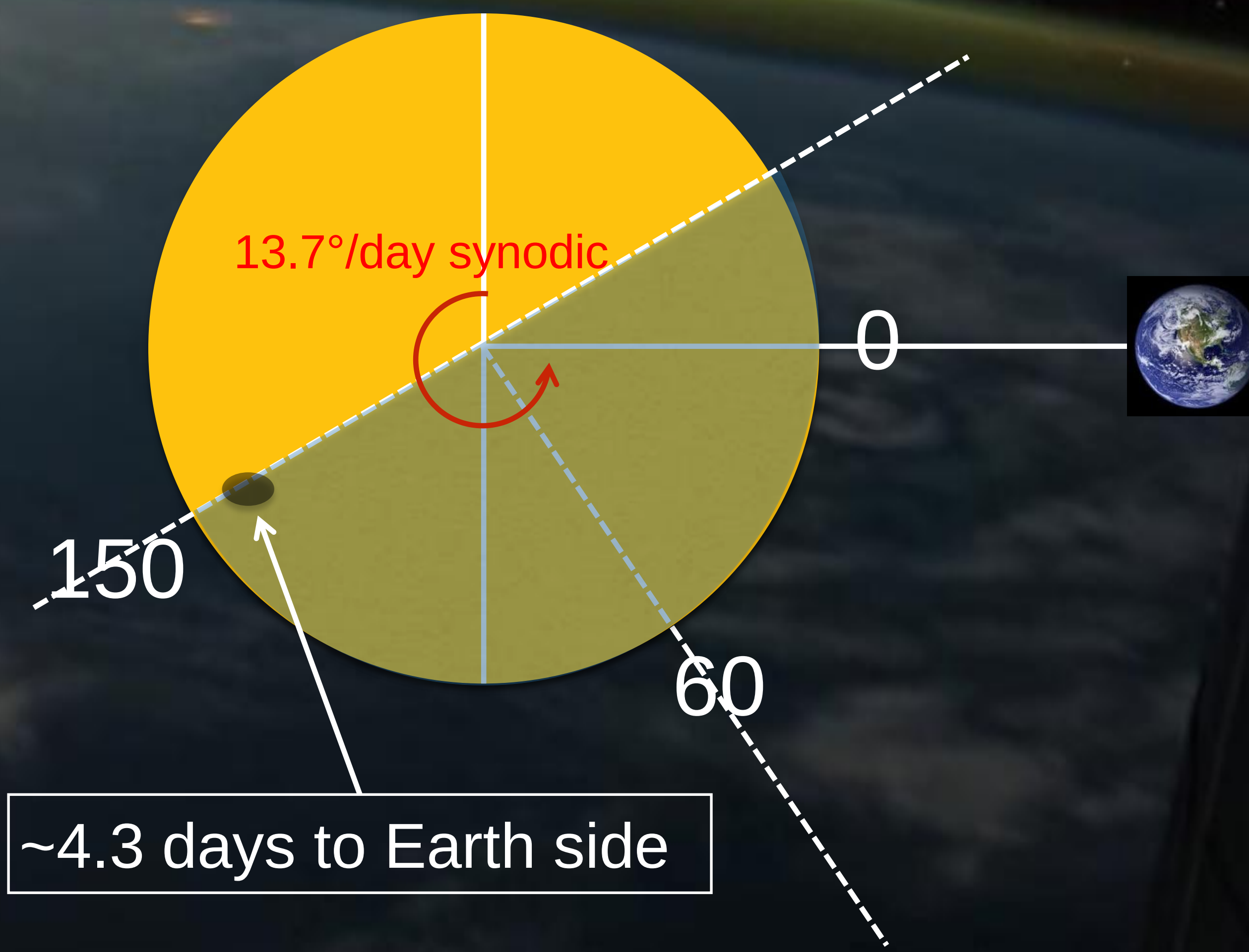
- Study of Type II radio bursts by S. Park, Korea RRA, 2015.
- 124 CMEs between 1997 and 2006.
- LASCO vs. Type II CME speed correlation coefficient = 0.54.
- Short answer: No.



Additional operational considerations for L5

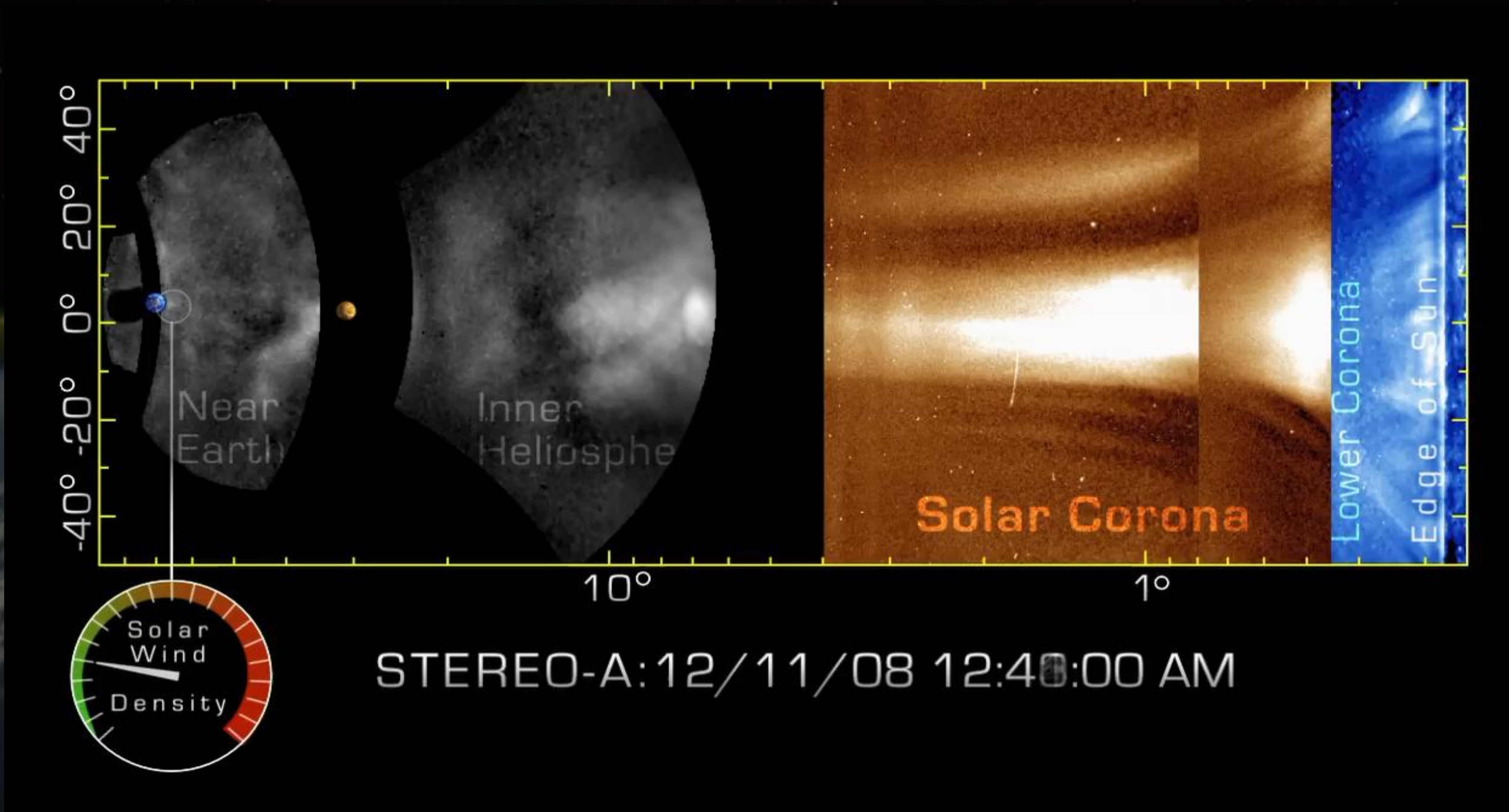
- Gives ~3 days forecast of Parker spiral solar wind conditions that will effect Earth.
- Can give several days to one week forecast of active regions rotating onto Earth-facing disk.





Additional operational considerations for L5

- Integration of Heliospheric Imaging (HI) could give "data assimilative" corrections to CME propagation models.



Courtesy Craig DeForest

National Space Weather Strategy

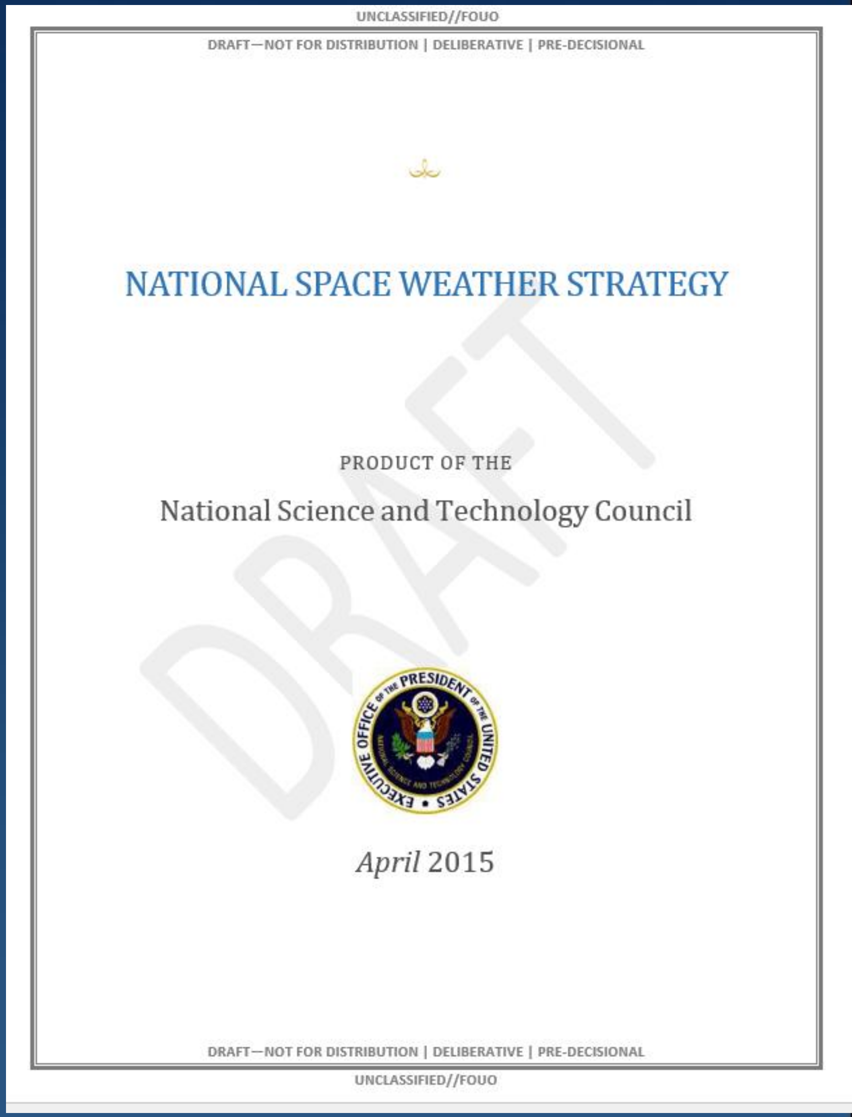
Nov 2014 – Space Weather Operations, Research, and Mitigation (SWORM) Task Force is established

Tasked to develop:

- National Space Weather Strategy
- Space Weather Action Plan

Open for public comment on the federal register:

www.dhs.gov/national-space-weather-strategy



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NATIONAL SPACE WEATHER STRATEGY

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National Science and Technology Council

April 2015

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Conclusions

- Operational space weather missions have distinct requirements
  - Continuous high cadence data collection rate.
  - Robust and resilient S/C and instrument design.
  - Continuous data downlink and transmission to forecast center.
  - Data latency to forecast center measured in seconds or minutes.
  - Operational data processing, associated models, and input tools.
  - Back-up instrument, data collection, *and processing/dissemination* systems.
- Operational space weather mission to L5
  - Makes the most sense in the context of an operational mission to L1 with similar (or ideally identical) instrumentation and capabilities.
  - Need “two umpires”!
  - Added advantage: with two coronagraphs on deep-space operational satellites, the coronagraph capability gains “on-orbit” spare status.