Forecast-Driven Solar Imaging Requirements

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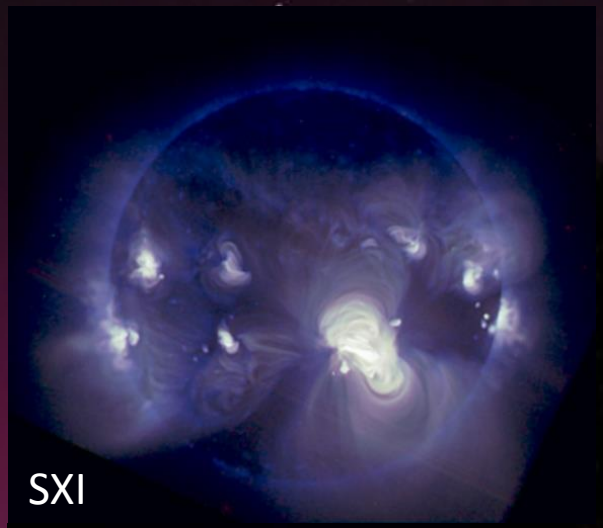
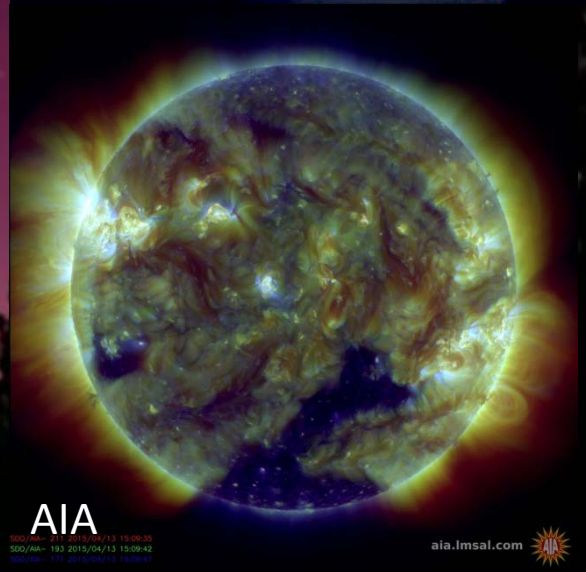
Outline

- Goal of forecast-driven solar imaging
  - Provide as much advance warning of solar wind and radiation conditions at Earth as possible via remote sensing of the sun.
- Space-based observations
  - Inner corona: Flares, CMEs, waves, dimmings, filaments, coronal holes – since the 1970s
  - Outer corona: CME propagation – since the 1980s
  - Surface (and subsurface?): Evolution of active regions and flare probabilities – since the 1990s
- Requirements "Domains"
  - Spatial: Coverage and Resolution
  - Temporal: Cadence and Continuity
  - Spectral: Coverage and Resolution
  - Radiance: Range and resolution

Low Corona Imaging: EUV and SXR

- Objectives
  - Provide advance warning of solar activity
  - Provide warning of recurring geomagnetic storms
  - Provide warning of non-recurring geomagnetic storms
  - Provide warning of solar radiation storms
  - Assess solar flaring probability





Space Weather Scales

- The Radio Blackout and Radiation Storm Space Weather Scales are Derived solely from GOES Observations (XRS, SEISS)
- The Geomagnetic Storm SWx Scale is driven by ground magnetometers
- SXR/EUV images provide broad situational awareness and context across all SWx forecasting

Radio Blackouts			GOES X-ray peak brightness by class and by flux*	Number of events when flux level was met; (number of storm days)
R 5	Extreme	HF Radio: Complete HF (high frequency**) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector. Navigation: Low-frequency navigation signals used by maritime and general aviation systems experience outages on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.	X20 ($2x10^{-3}$)	Fewer than 1 per cycle
R 4	Severe	HF Radio: HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. Navigation: Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days per cycle)
R 3	Strong	HF Radio: Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. Navigation: Low-frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days per cycle)
R 2	Moderate	HF Radio: Limited blackout of HF radio communication on sunlit side of the Earth, loss of radio contact for tens of minutes. Navigation: Degradation of low-frequency navigation signals for tens of minutes.	M5 ($5x10^{-5}$)	350 per cycle (300 days per cycle)
R 1	Minor	HF Radio: Weak or minor degradation of HF radio communication on sunlit side of the Earth, occasional loss of radio contact. Navigation: Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)

Solar Radiation Storms			Flux level of ≥ 10 MeV particles (ions)*	Number of events when flux level was met**
S 5	Extreme	Biological: unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. *** Satellite operations: satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. Other systems: complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle
S 4	Severe	Biological: unavoidable radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: may experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. Other systems: blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.	10^4	3 per cycle
S 3	Strong	Biological: radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. Other systems: degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S 2	Moderate	Biological: passengers and crew in high-flying aircraft at high latitudes may be exposed to elevated radiation risk. *** Satellite operations: infrequent single-event upsets possible. Other systems: effects on HF propagation through the polar regions, and navigation at polar cap locations possibly affected.	10^2	25 per cycle
S1	Minor	Biological: none. Satellite operations: none. Other systems: minor impacts on HF radio in the polar regions.	10	50 per cycle

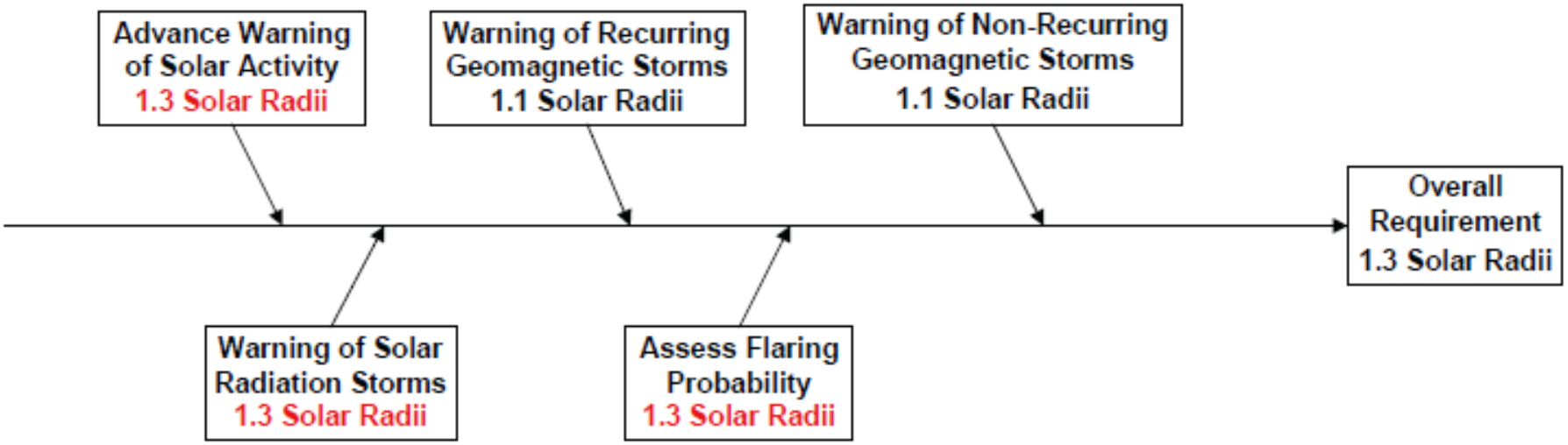
Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days)
G 5	Extreme	Power systems: widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. Spacecraft operations: may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. Other systems: pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.).**	Kp=9	4 per cycle (4 days per cycle)
G 4	Severe	Power systems: possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. Spacecraft operations: may experience surface charging and tracking problems, corrections may be needed for orientation problems. Other systems: induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.).**	Kp=8	100 per cycle (60 days per cycle)
G 3	Strong	Power systems: voltage corrections may be required, false alarms triggered on some protection devices. Spacecraft operations: surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. Other systems: intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.).**	Kp=7	200 per cycle (130 days per cycle)
G 2	Moderate	Power systems: high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. Spacecraft operations: corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. Other systems: HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.).**	Kp=6	600 per cycle (360 days per cycle)
G 1	Minor	Power systems: weak power grid fluctuations can occur. Spacecraft operations: minor impact on satellite operations possible. Other systems: migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine).**	Kp=5	1700 per cycle (900 days per cycle)

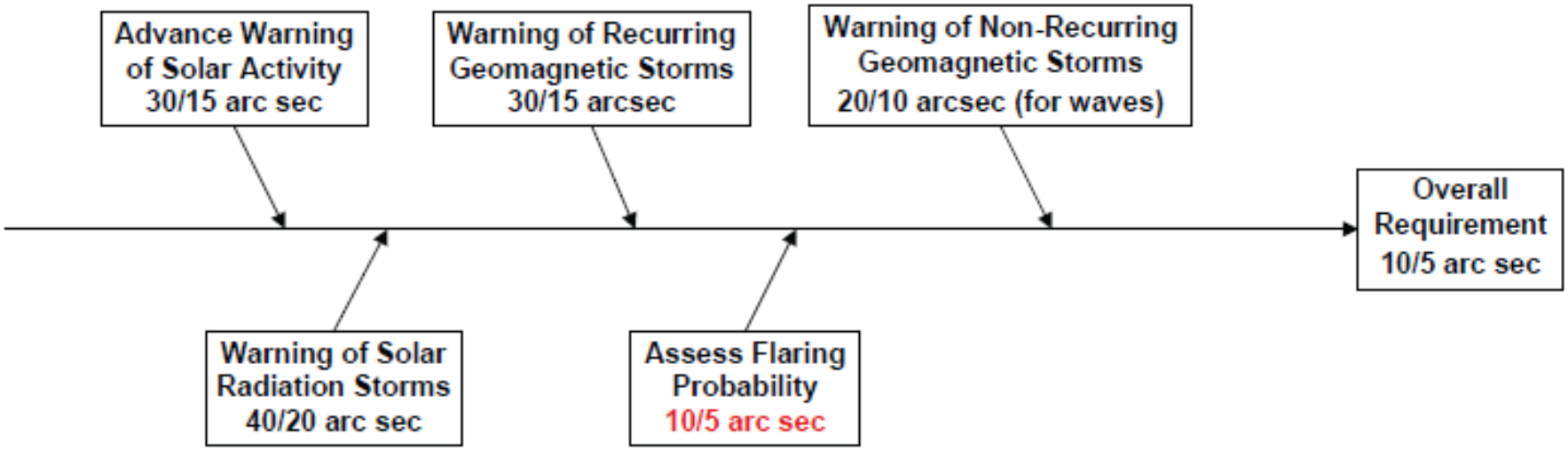
Radiance Range and Resolution

- Range: Dictated by combination of spectral band and phenomena

Wavelength Log (Te)	94Å 6.8	131Å 7.0,7.2	171Å 5.8	195Å 6.1,7.3	284Å 6.3	304Å 4.7
Filaments						
Coronal Holes						
Active Region Complexity						
CMEs (e.g. dimming)						
Flare Location and Morphology						
Quiet Regions						

Spatial Coverage and Resolution



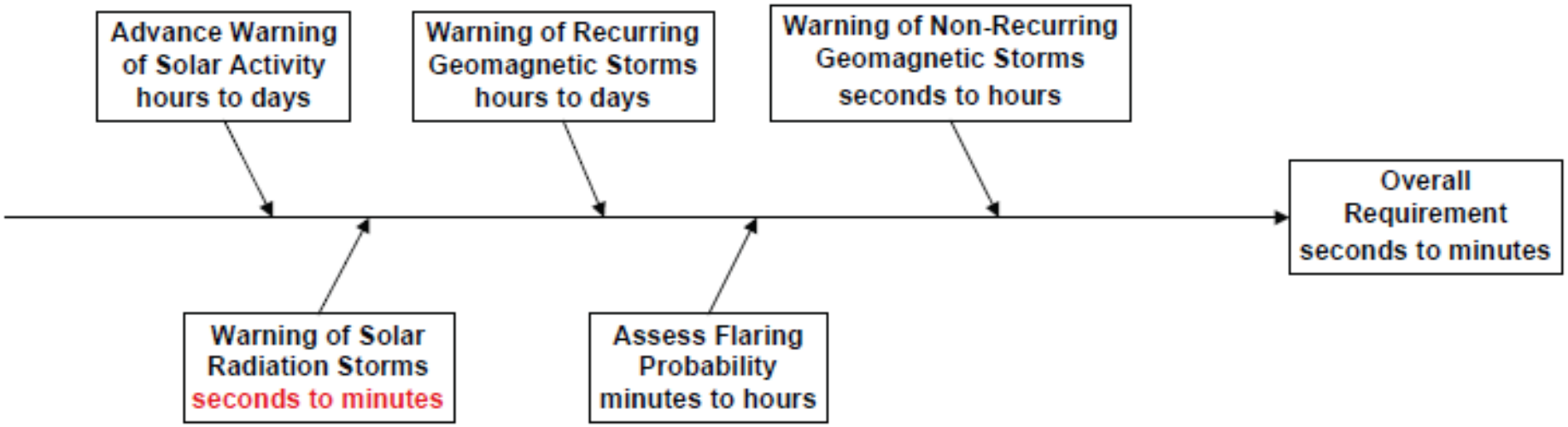


Spectral Coverage and Resolution

- Requirements Drivers:
  - EUV vs. SXR
  - Separation of wavelengths from process/temperature
  - Physical parameter retrieval - DEM
  - Differentiation of phenomena (for humans and automated systems)

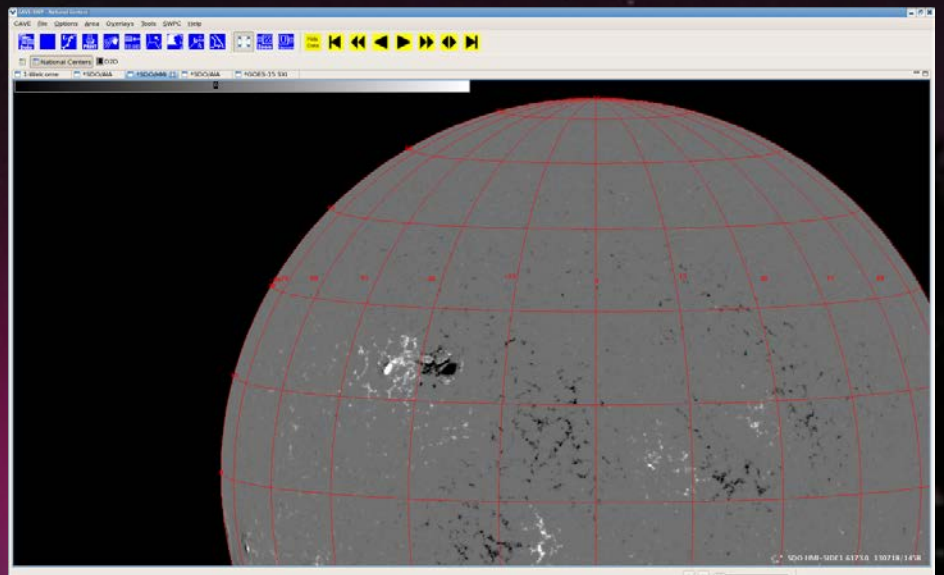
Line	Wavelength	Log T (MK)
Fe XVIII	93.9 Å	6.8
Fe XX	132.8 Å	7.0
Fe IX	171.1 Å	5.8
Fe XII	195.1 Å	6.1
Fe XV	284.3 Å	6.3
He II	303.8 Å	4.7

Cadence and Continuity



Importance of Magnetogram Data

- Magnetogram data used directly by forecasters for assessing active region complexity
- Magnetogram data needed to initialize solar wind models
- EUV and magnetogram data are complementary



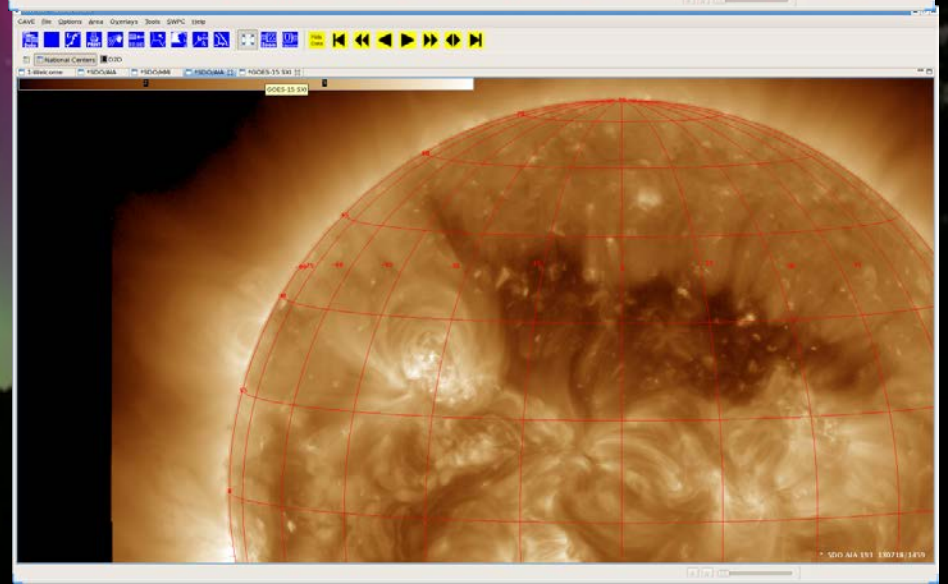
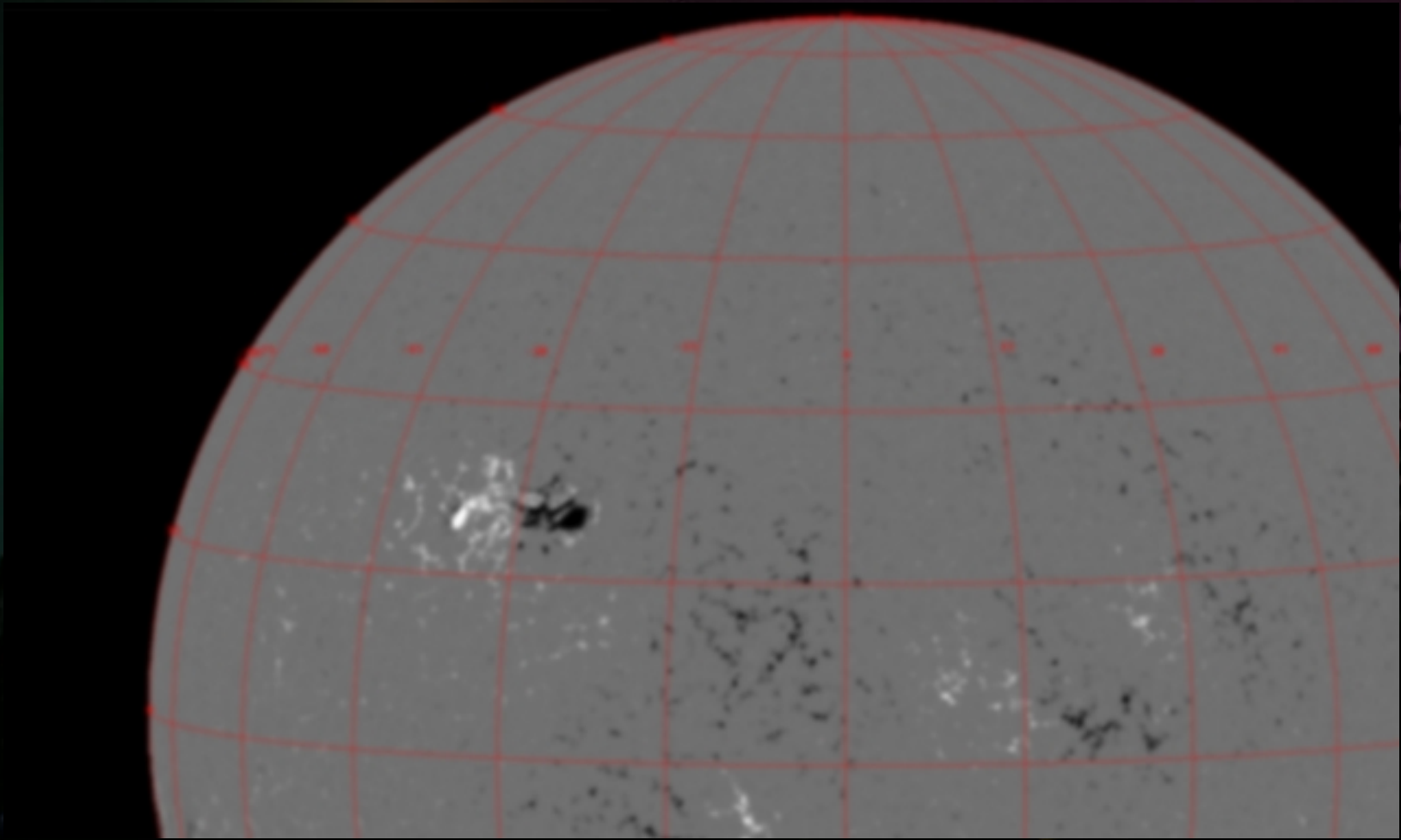


Image Fusion in the Forecast Center



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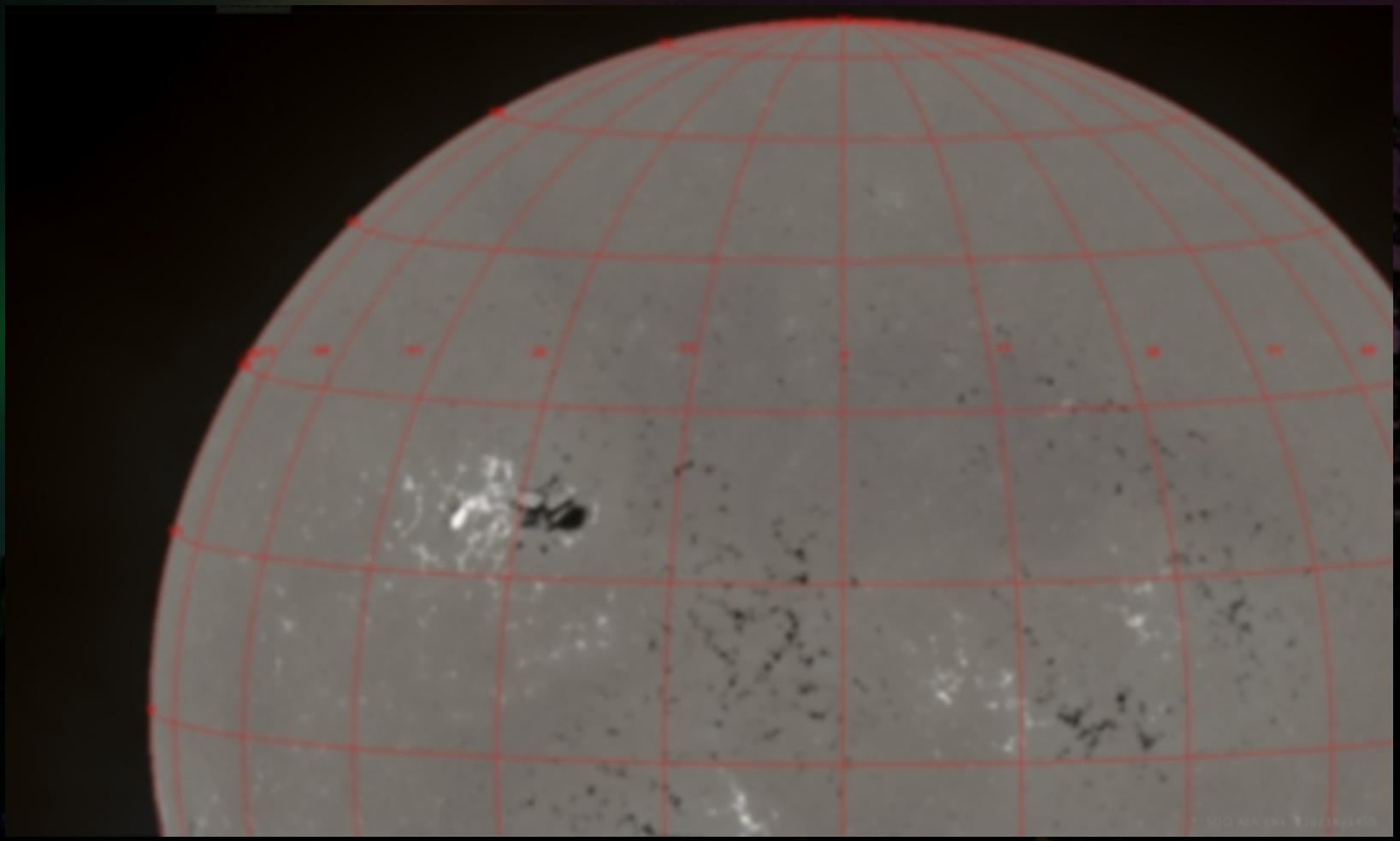

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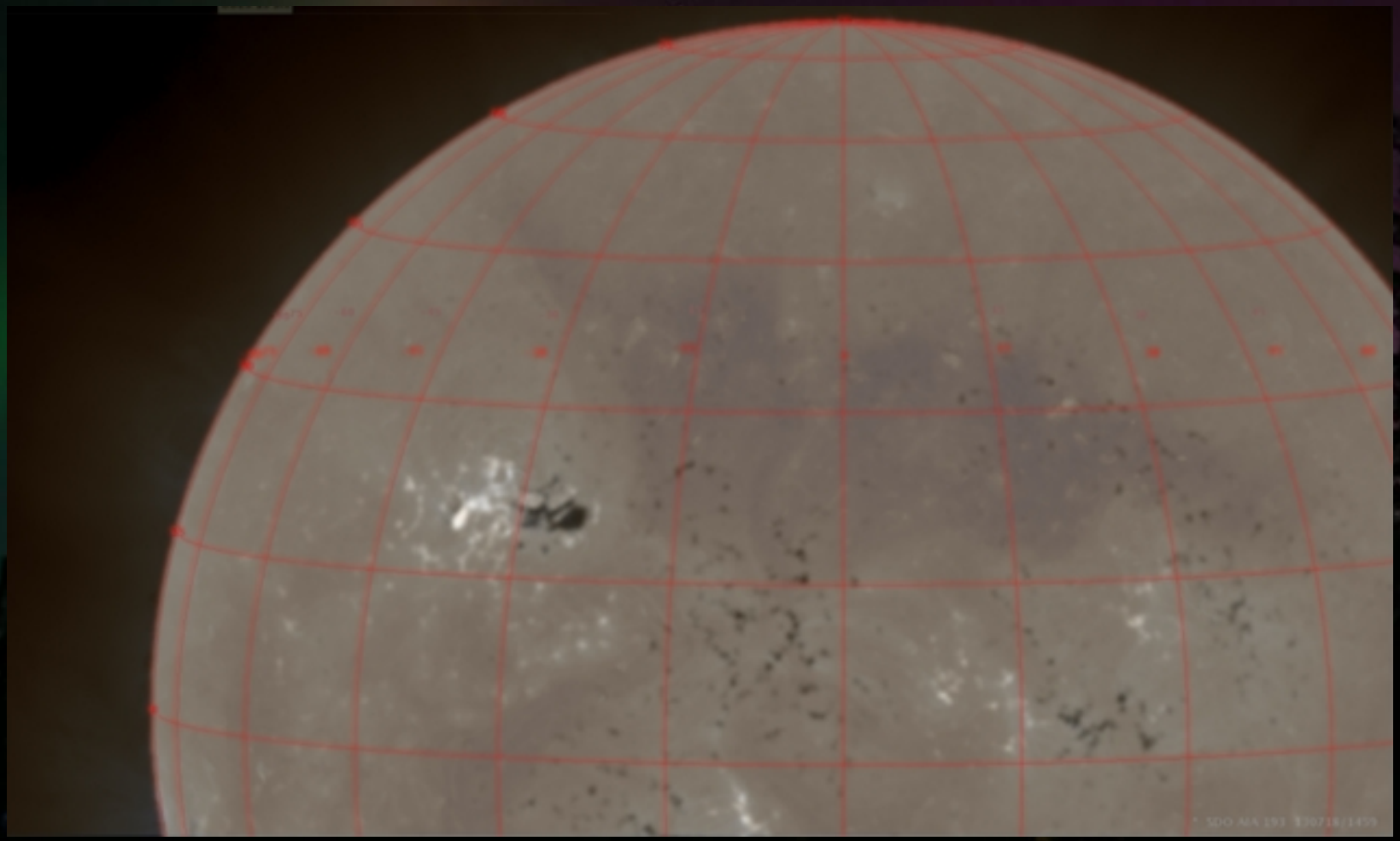

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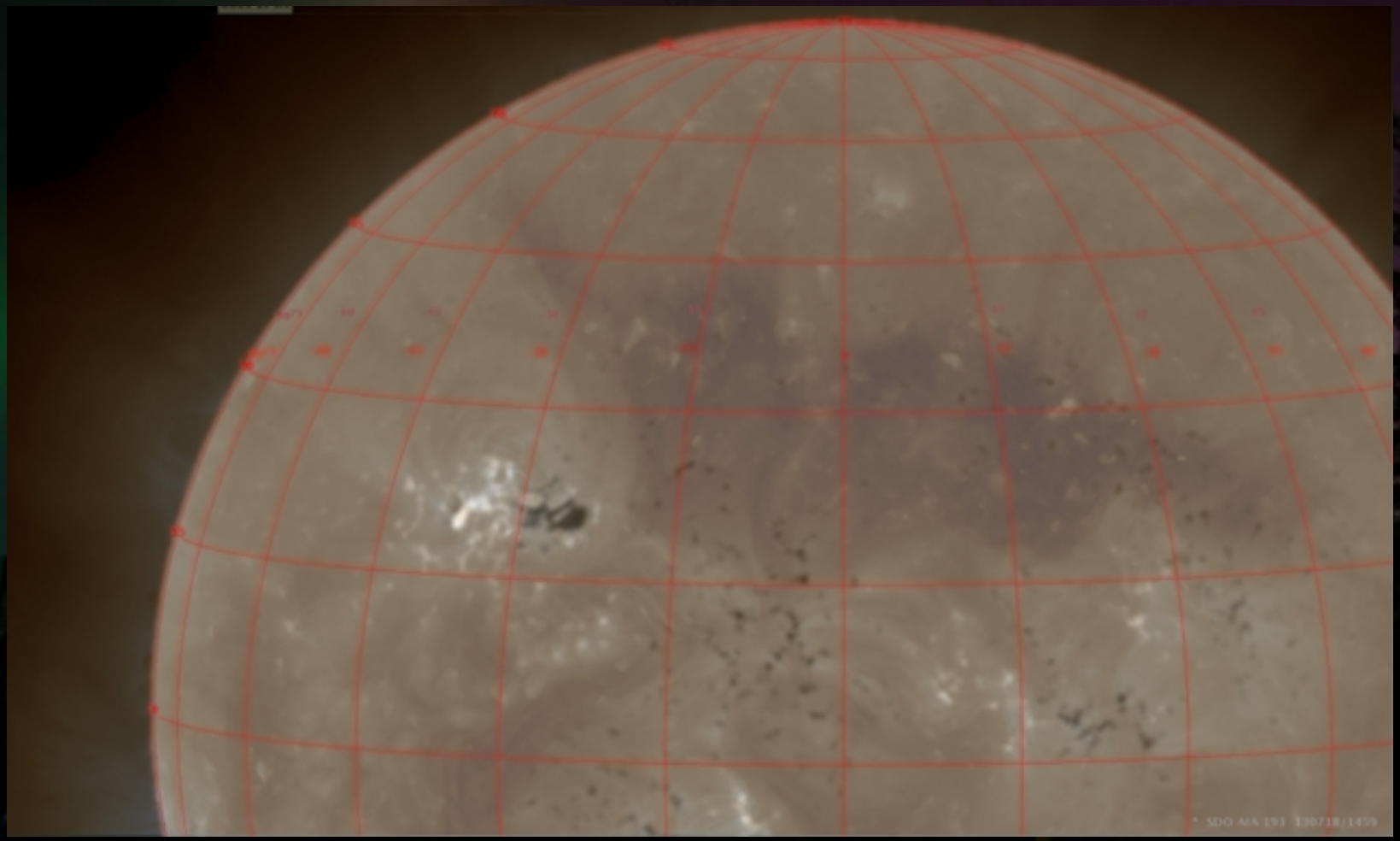

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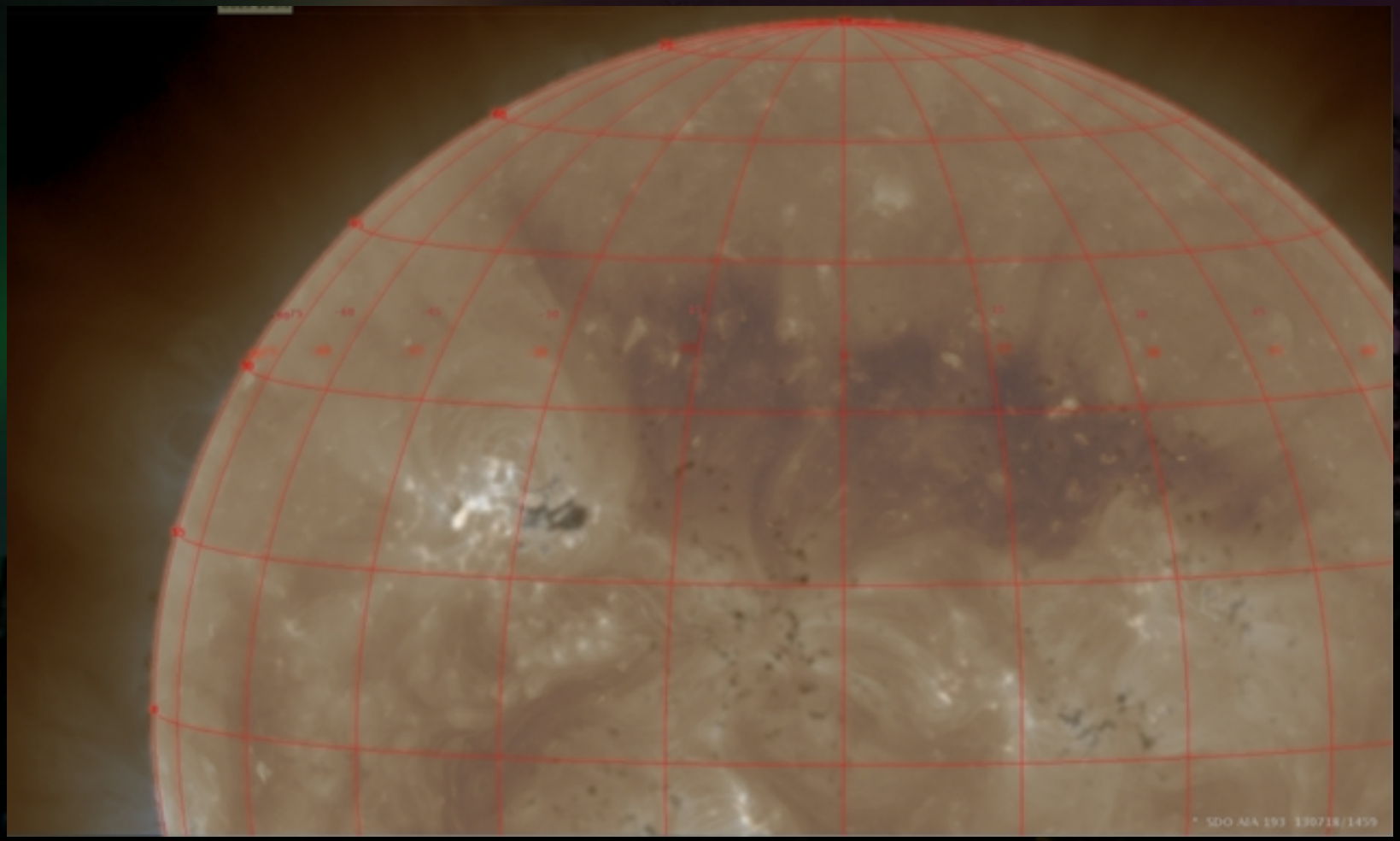

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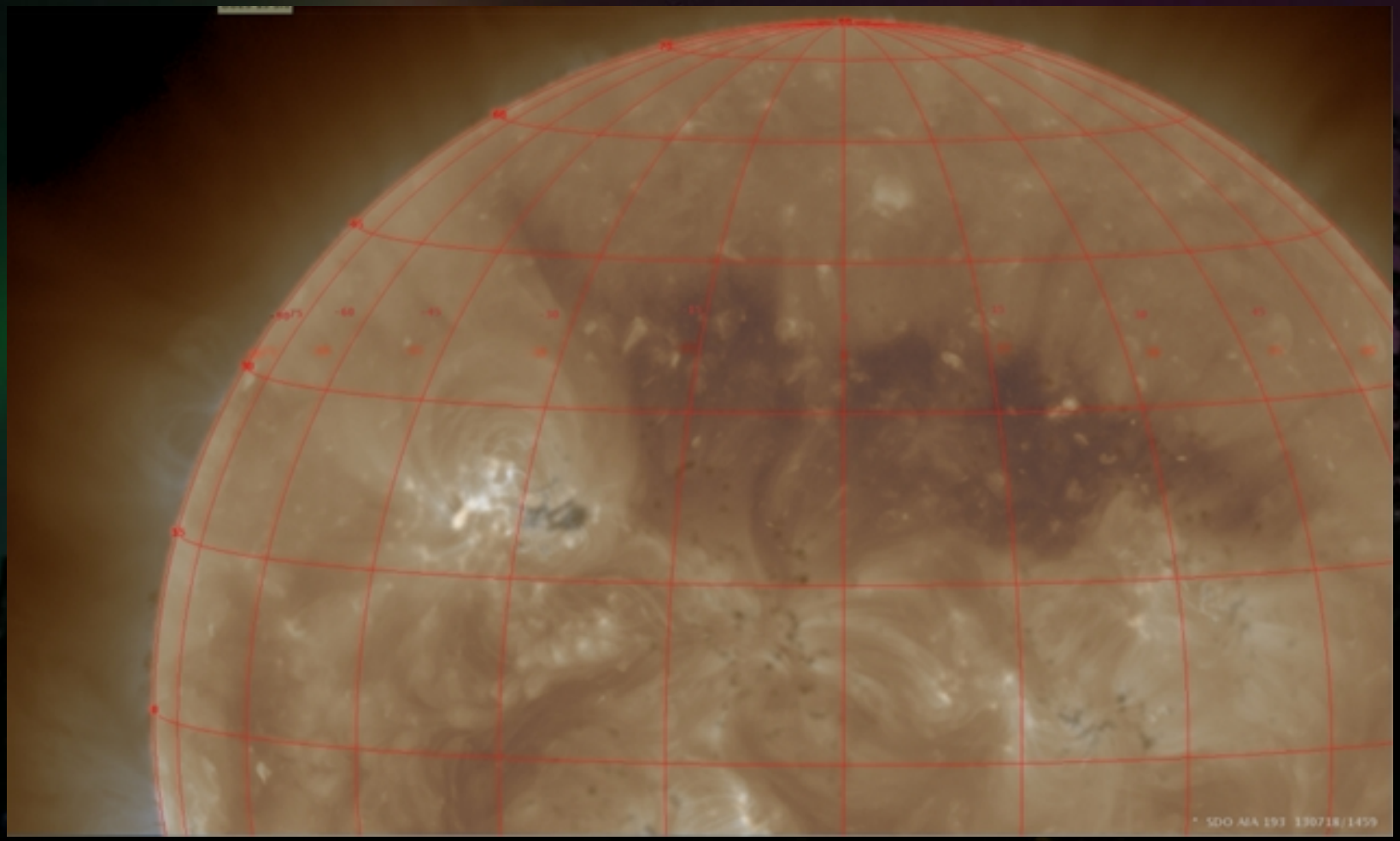

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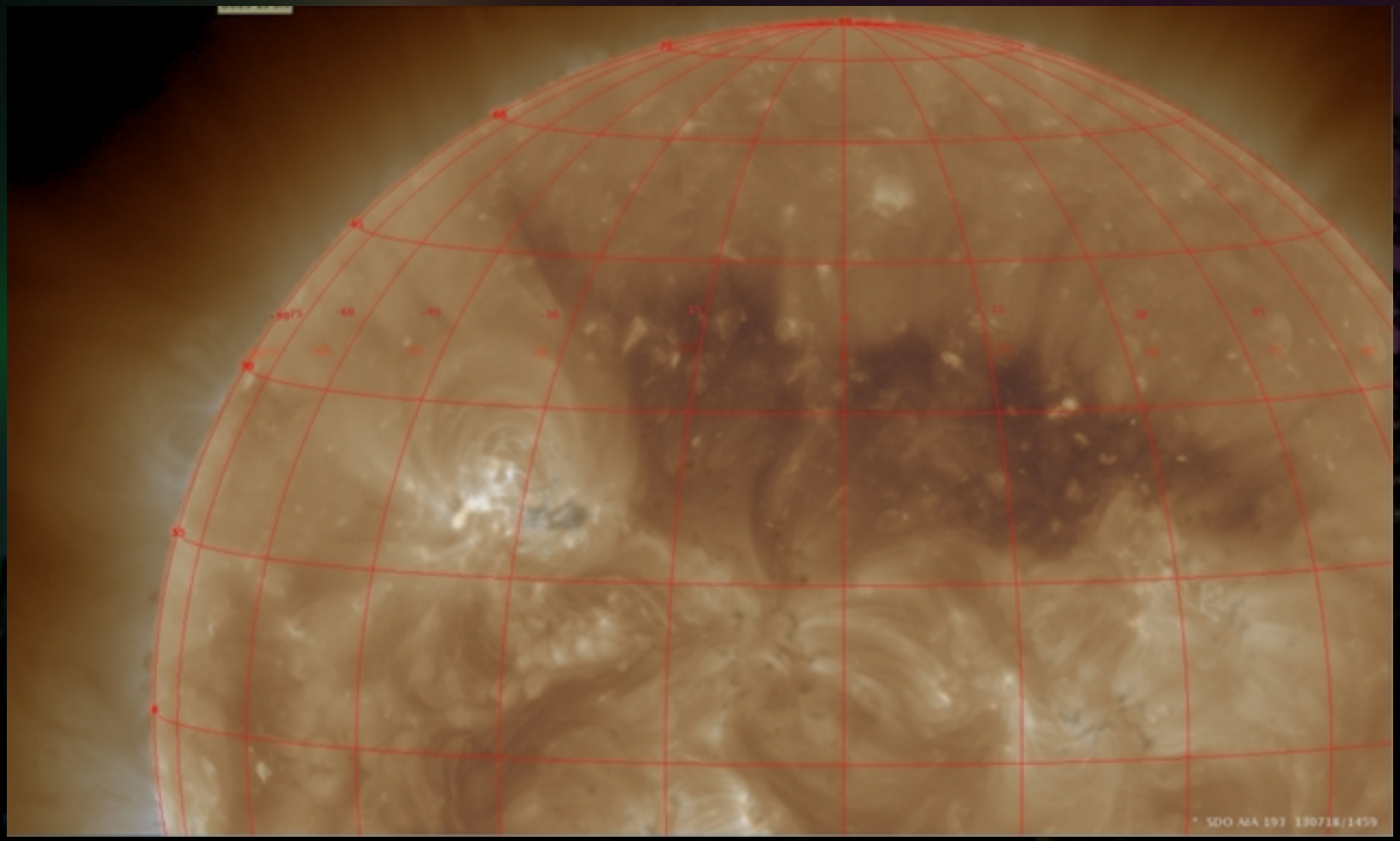

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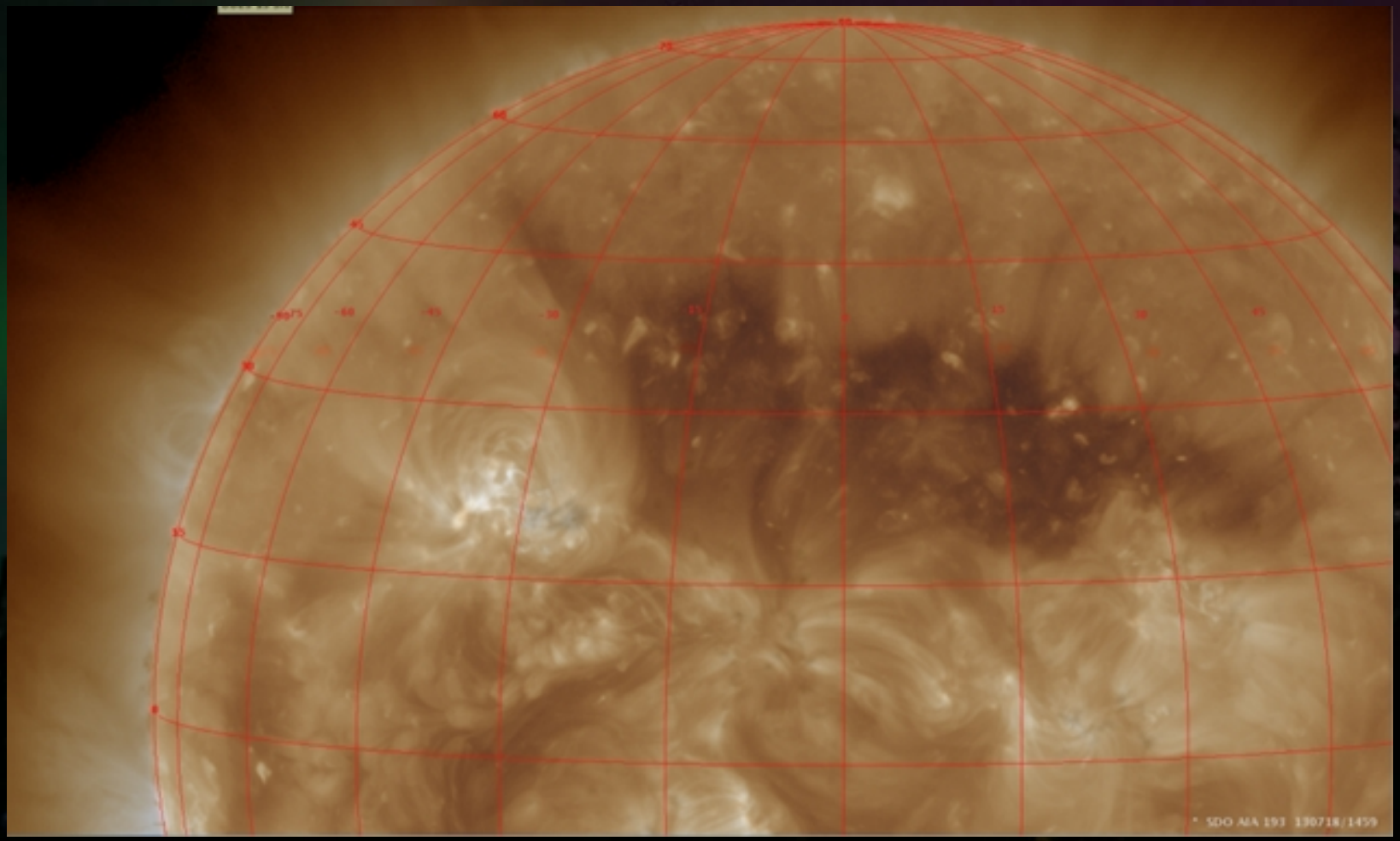

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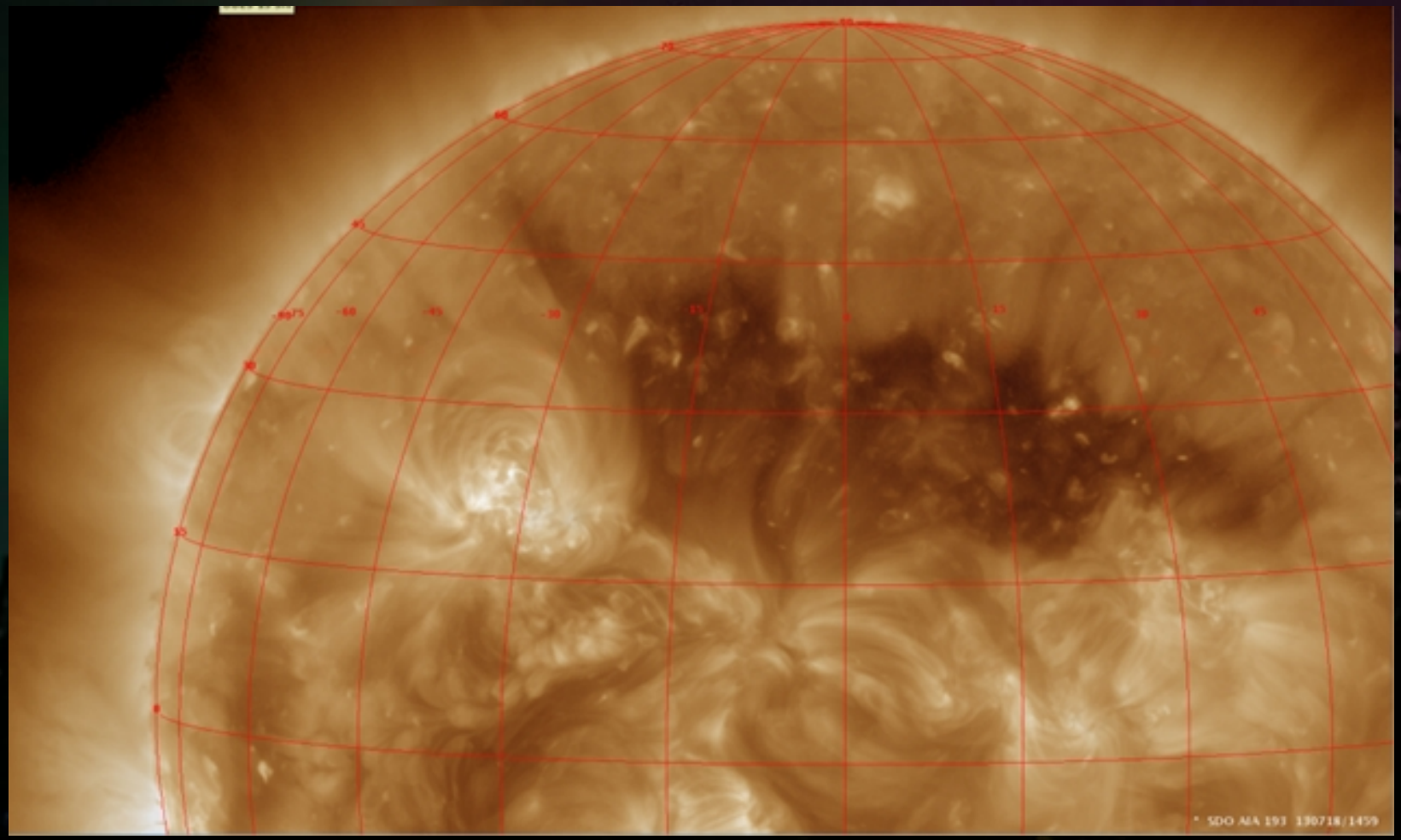

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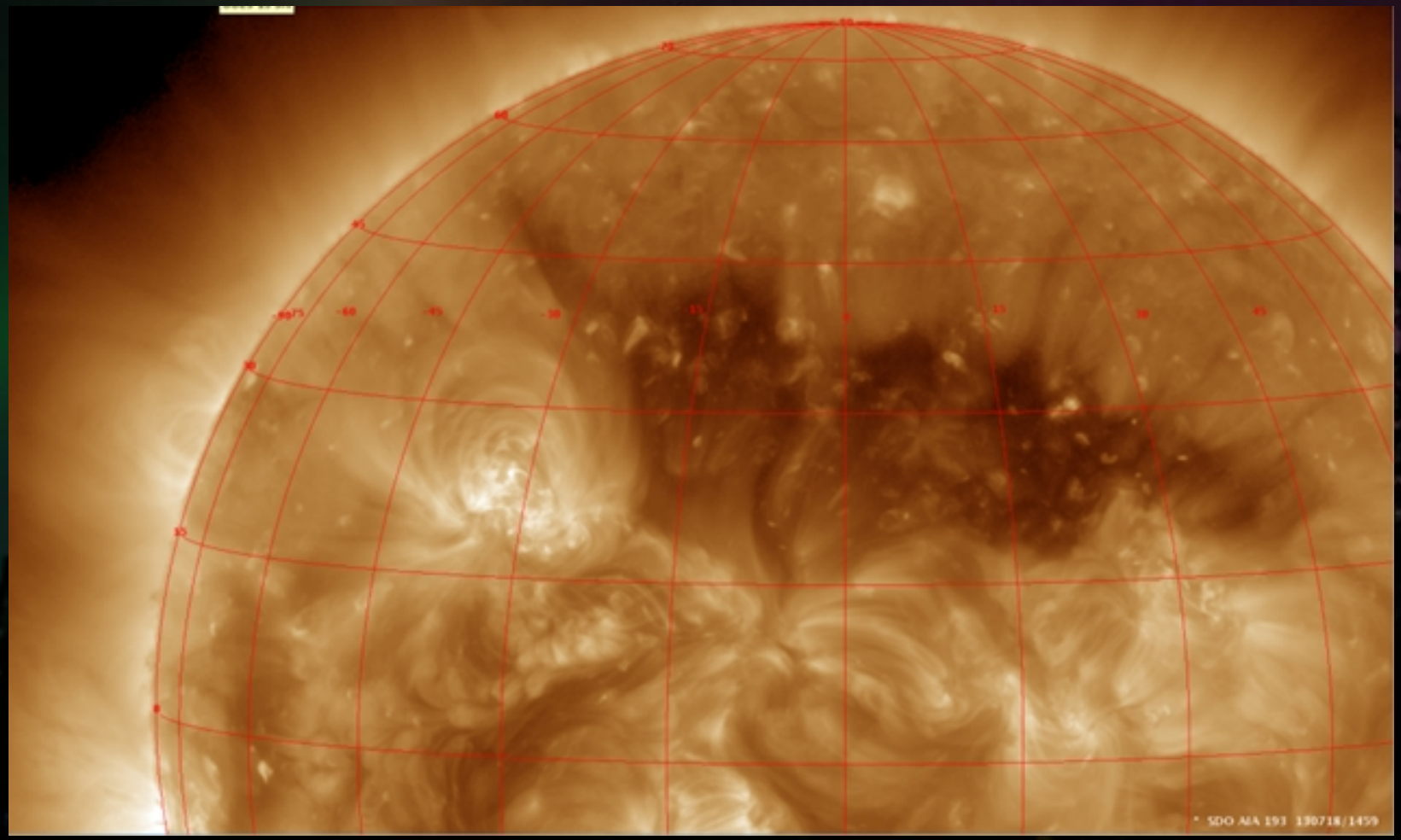
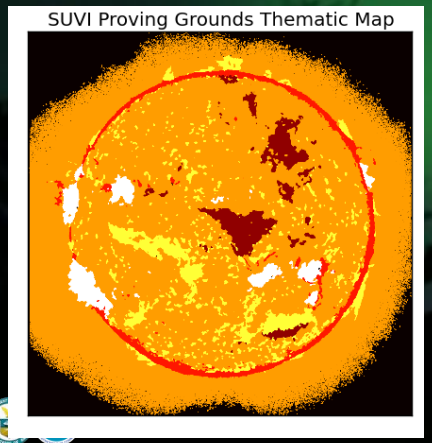
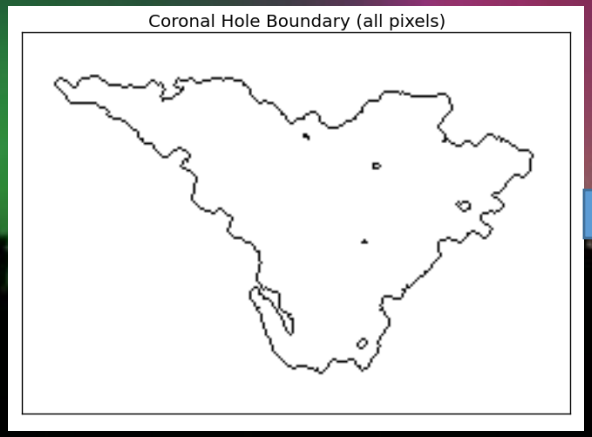
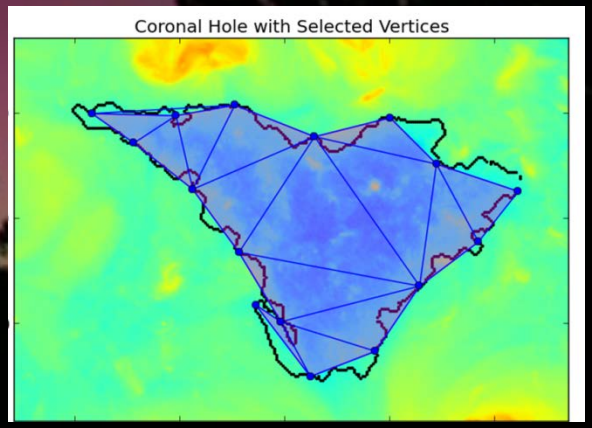


Classification versus Assimilation

- GOES-R
  - Thematic maps (multispectral pixel classifier) improvements
  - Bright regions – associated with solar active regions
  - Flare location – hottest & brightest of bright regions
  - Coronal Hole Boundaries – dark areas of strong, outflowing solar wind
- GOES-VW
  - Retrieval of physical parameters?
  - Model validation / assimilation?







Agenda

- Forecast-Driven Solar Imaging Requirements – Hill
- GOES-R SUVI Capabilities and Products – Darnel
- Flare Location – Jones
- Coronal Holes – Hock
- DEM Retrieval – Plowman
- Magnetograms – Leka
- Coronagraph – Biesecker
- Discussion