Heliophysics Big Year
Solar Maximum

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Original (upper left): https://eol.jsc.nasa.gov/SearchPhotos/photo.pl?mission=ISS070&roll=E&frame=20456

HBY is not just citizen science nor eclipses – solar max has opportunities for innovation!

Seeking scientific collaborators, data, and people wranglers

NASA

International Geophysical Year IGY 1957-58

- Radiation Belts
- Sputnik, Explorer I
- Plate Tectonics
- Established NASA
- Nations working together

ANNÉE GÉOPHYSIQUE INTERNATIONALE 1957 1958 INTERNATIONAL GEOPHYSICAL YEAR

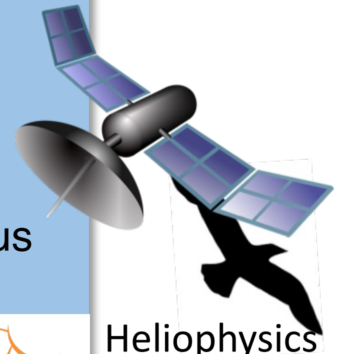
International Heliophysics Year IHY 2007-8

- 50-year Anniversary IGY
- Space Weather
- Scientific Cooperation
- Scientific Capacity Building

INTERNATIONAL HELIOPHYSICAL YEAR IGY 1957 IHY 2007

Heliophysics Big Year HBY 2023-24

- Citizen Science
- Solar Eclipses
- Sun-Geospace System Focus
- Approach to Solar Max
- Solar Superstorm Dynamics



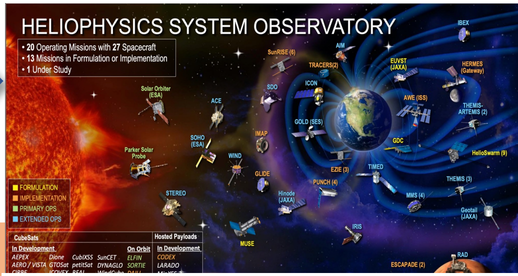
HELIOPHYSICS BIG YEAR

Heliophysics “Birds”, take over for Solar Max

1957-58 → 2007-8 → 2023-24

- International Solar Terrestrial Physics Program,
- Heliophysics System Observatory Created

- Parker Solar Probe: Touch the Sun
- Solar Dynamics Observatory: Big Data
- HSO expanded to 20 operating missions, 2 missions in development, 10 in formulation
- Citizen Science invaluable contributor to science discovery



Citizen Science in the Big Year

Implementation: Heliophysics Big Year, Solar Maximum

As was done in IGY and IHY, the goal is to come together and look for synergistic opportunities that present pathways to scientific advancement with immense potential.

HBY enables us to address ambitious research questions using complementary skills and resources, join efforts through open science across programs, science communities, individual researchers, and citizen scientists, each enriching the others, while actively focusing on inclusion, diversity, equity, & accessibility in ways that:

- Generate excitement
- Enable new discoveries
- Give us quick wins on the time scale of the HBY
- Create legacy associations that will live on after HBY
- Enable innovative, comprehensive analysis of dangerous solar storms

1. Recruit internal NASA and external working groups to:

Develop overall strategy and plans for the first workshop in early 2024 and future interactions

2. Launch "HBY Solar Max" workshop with 3 elements

- Pilot studies of two major storms that occurred in March and April of 2023 (and possibly another in November 2023) associated with red aurora at low latitudes, and other unusual phenomena, with great potential for giving insights into superstorm dynamics.
- Joint session with citizen scientists to integrate their data & inputs of science questions
- Brain-storming sessions to collect input on needed infrastructure based on the pilot studies

3. Seek out mutually beneficial synergies between programs, including:

Year of Open Science	ISWAT	AWS	ISTPNext
SMD Citizen Science	HSO missions	Google	More!
IDEA group	DRIVE Science Centers	CCMC/GSFC	

4. Prioritize IDEA (inclusion, diversity, equity, accessibility) & public outreach

- Ensure that the external advisory group members span diversity elements to guide campaigns and develop plans for infrastructure. Accessibility will be a key consideration.
- Participate in interactions with the public that increase their level of engagement and enhance understanding of space weather, space climate, and societal impacts

5. Optimize existing tools & develop others (when possible)

- Internal and external communications,
- System-level data products for HSO
- Algorithms to stitch together auroral images
- More!

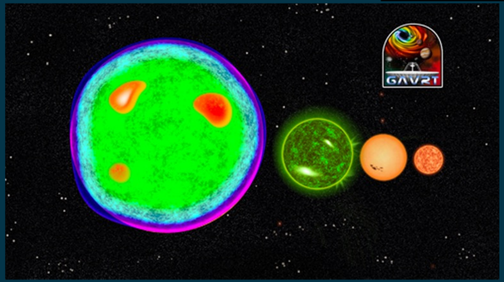
The Helio Big Year is here

Planet Hunters TESS

HELIOPHYSICS BIG YEAR

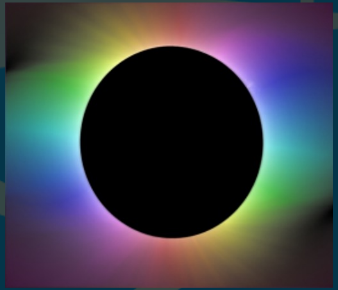
EXOPLANET WATCH

Solar Patrol (GAVRT)



Citizen Science Project ECLIPSE SOUNDSCAPES

Citizen CATE



Dynamic Eclipse Broadcast Initiative

Eclipse Efforts

ECLIPSE MEGAMOVIE

SunSketcher™

+ more by Semeter, Young

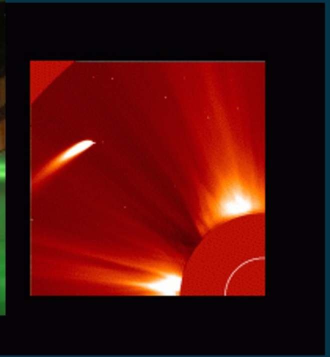
Eclipse projects

For more info, check out overview posts on citizen science from @NASASun and the Aurorasaurus blog.

GLOBE

Aurorasaurus

Sungrazers



December’s Helio Big Year theme is citizen science!

ROSES Opportunities

- H-CSI (3 year) Citizen Science Investigations
  - Step 1 Nov 15 2023
  - Step 2 Jan 26 2024
- Seed funding CSSFP (1 year)
  - NOI (optional!) Nov 21 2023
  - Proposals due Jan 24 2024

Points of contact: Ha-Hoa Hamano, Liz MacDonald
hq-heliobigyear@mail.nasa.gov

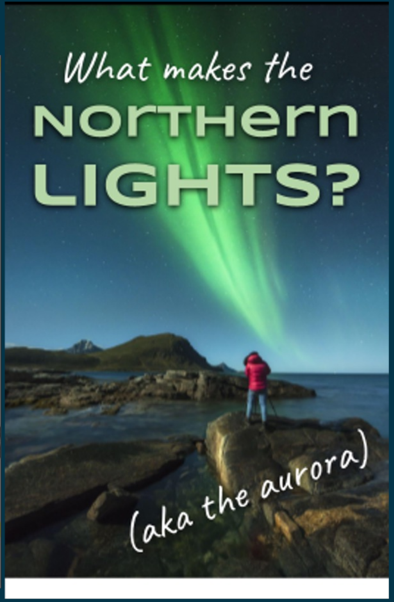
Stay updated with everything HBY. Subscribe to our new community mailing list.

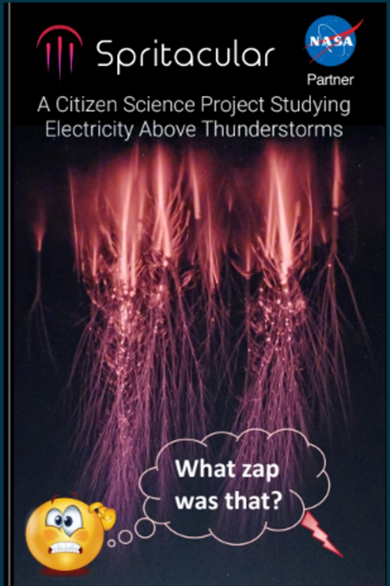
Join in on the fun and create a zine or spotting guide with this template.

New Helio Big Year poster connecting readers to projects and resources

HELIOPHYSICS
BIG YEAR

Preview our participatory HBY Zine activity guide. Look out for a zine digital library debut / use cases.

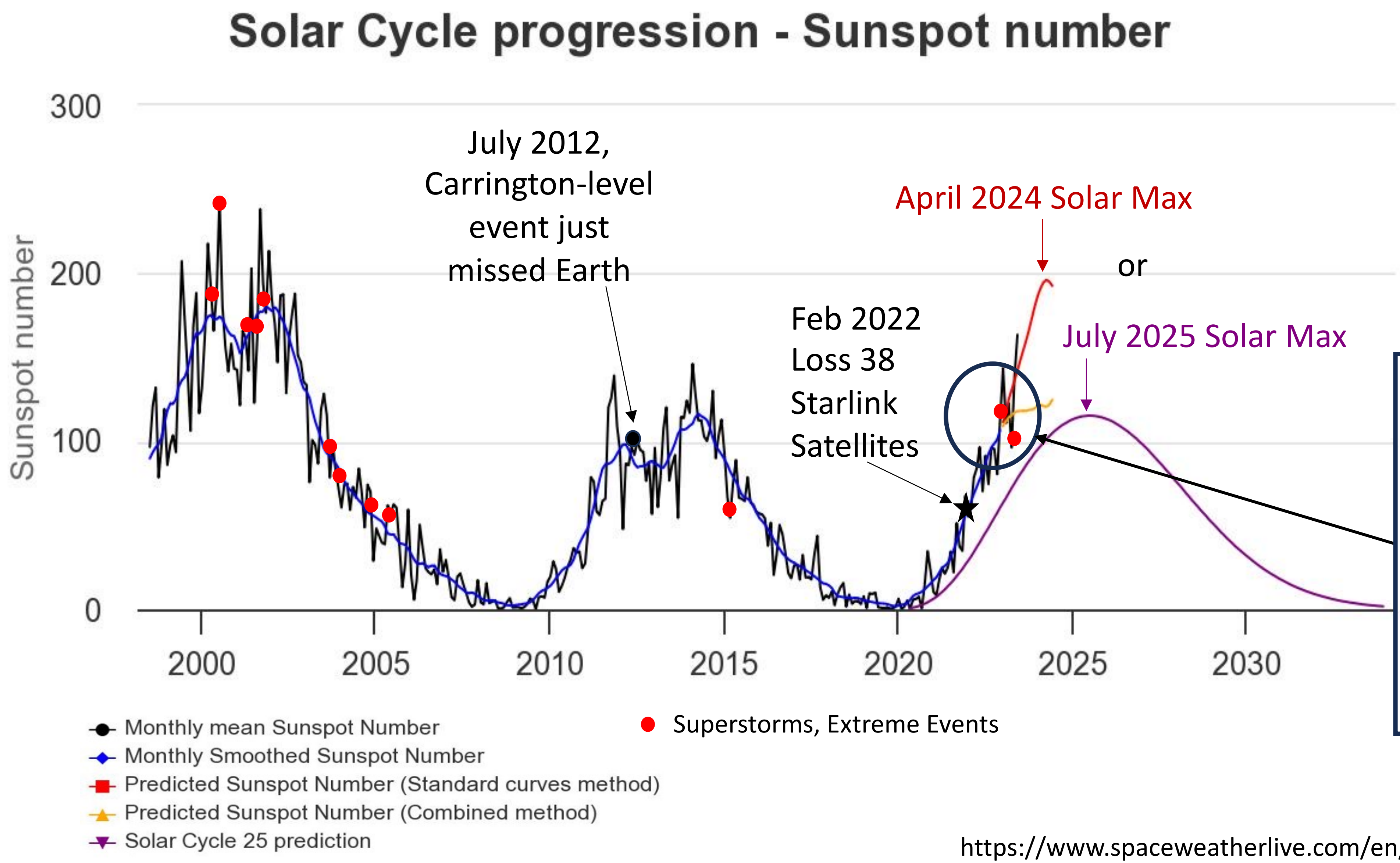




THEMES: Solar Cycle 25

Approach to Solar Maximum 25

Will solar cycle maximum be more intense than predicted? Arrive sooner?



<u>2 Superstorms</u>

- 23-24 March 2023 (-170 nT)
- 23-24 April 2023 (-178, -233)

Both: Erupting filaments

https://www.spaceweatherlive.com/en/solar-activity/solar-cycle.html

Event Studies of Dangerous Superstorms

Interesting & Unusual Storm Features

Compelling Issues for HBY Solar Max Storms

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23-25 March 2023 Solar Storm	23-25 April 2023 Solar Storm
G4 Storm. Predicted to be G1-G2. Min SYM-H = -170 nT Does not cross SYM-H threshold for superstorm.	G4 Storm. Predicted to be G1-G2 Min SYM-H = -178 nT and -233 nT. Does not cross SYM-H threshold for superstorm.
Filament eruption (large uncertainty) – stealth CME	Filament eruption
Vicinity of a recurrent coronal hole	Vicinity of the same recurrent coronal hole next CR
ICME & storm profile remarkably similar to Apr 2023	ICME & storm profile remarkably similar to Mar 2023, 31 days apart
BSN (bow shock normal in Omnidata) reached 12-16 RE in the recovery phase of the storm	BSN (bow shock normal in Omnidata) expanded to >30 RE (?) in the recovery phase of the storm
Red aurora observed in California, New Mexico, North Carolina, Florida (Characteristic of superstorms)	Red aurora observed in California, New Mexico, North Carolina, Florida (Characteristic of superstorms), UK
Visible SAR Arc, STEVE	*Visible* SAR Arc, STEVE, proton auroral spots
Exceeded 1 TW in the upper atmosphere - the 7th strongest storm observed by SABER over past 21.5 yrs	Exceeded 1 TW in the upper atmosphere - the 8th strongest storm observed by SABER over past 21.5 yrs
	Plasma bubbles and EIA crests at unusually high latitudes (~36^o N). Strong PPEF observed. Superfountain?
	Activity in auroral oval abruptly disappears in the storm recovery phase

Odd Similarities (?) What does it imply?

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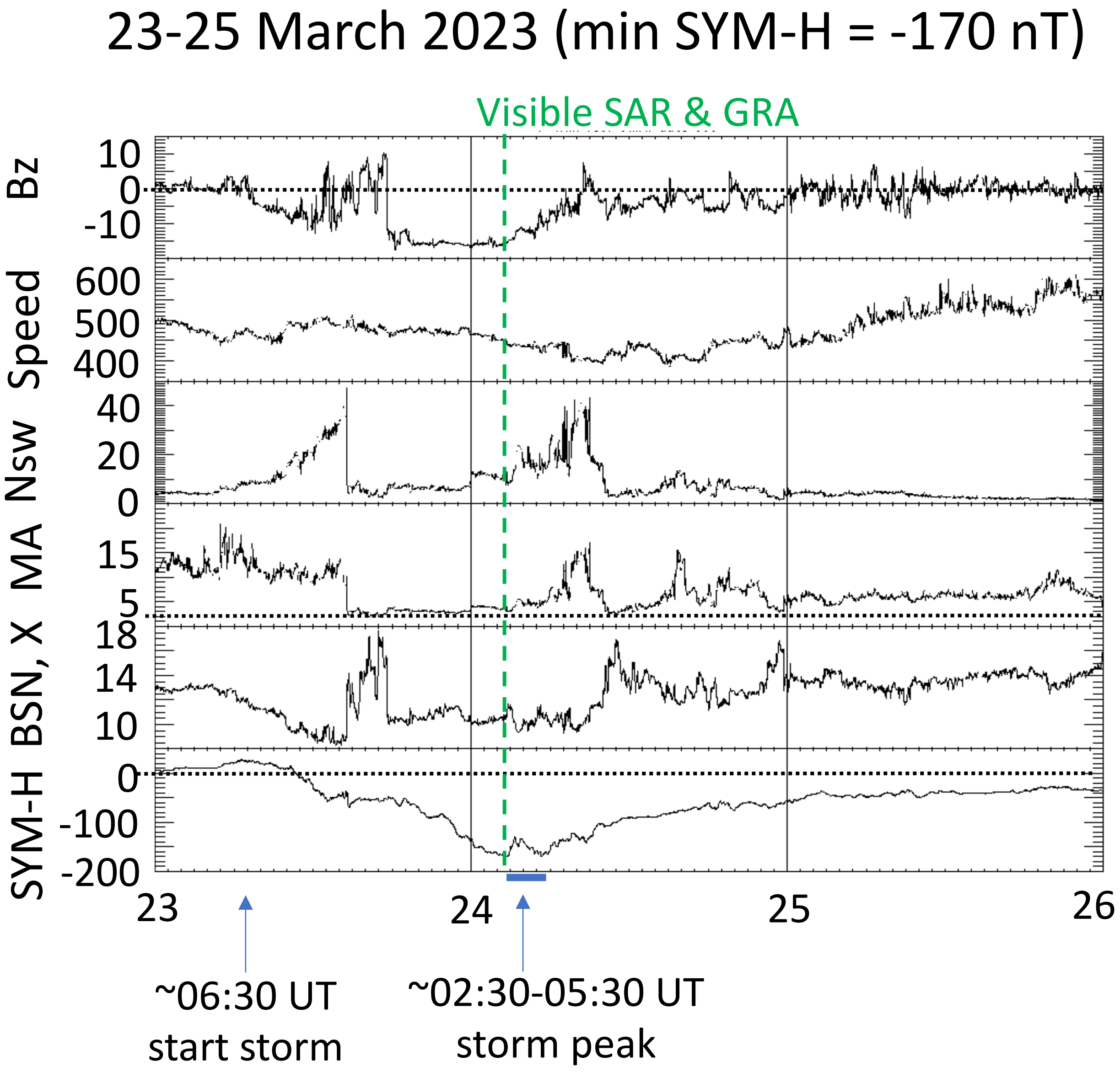
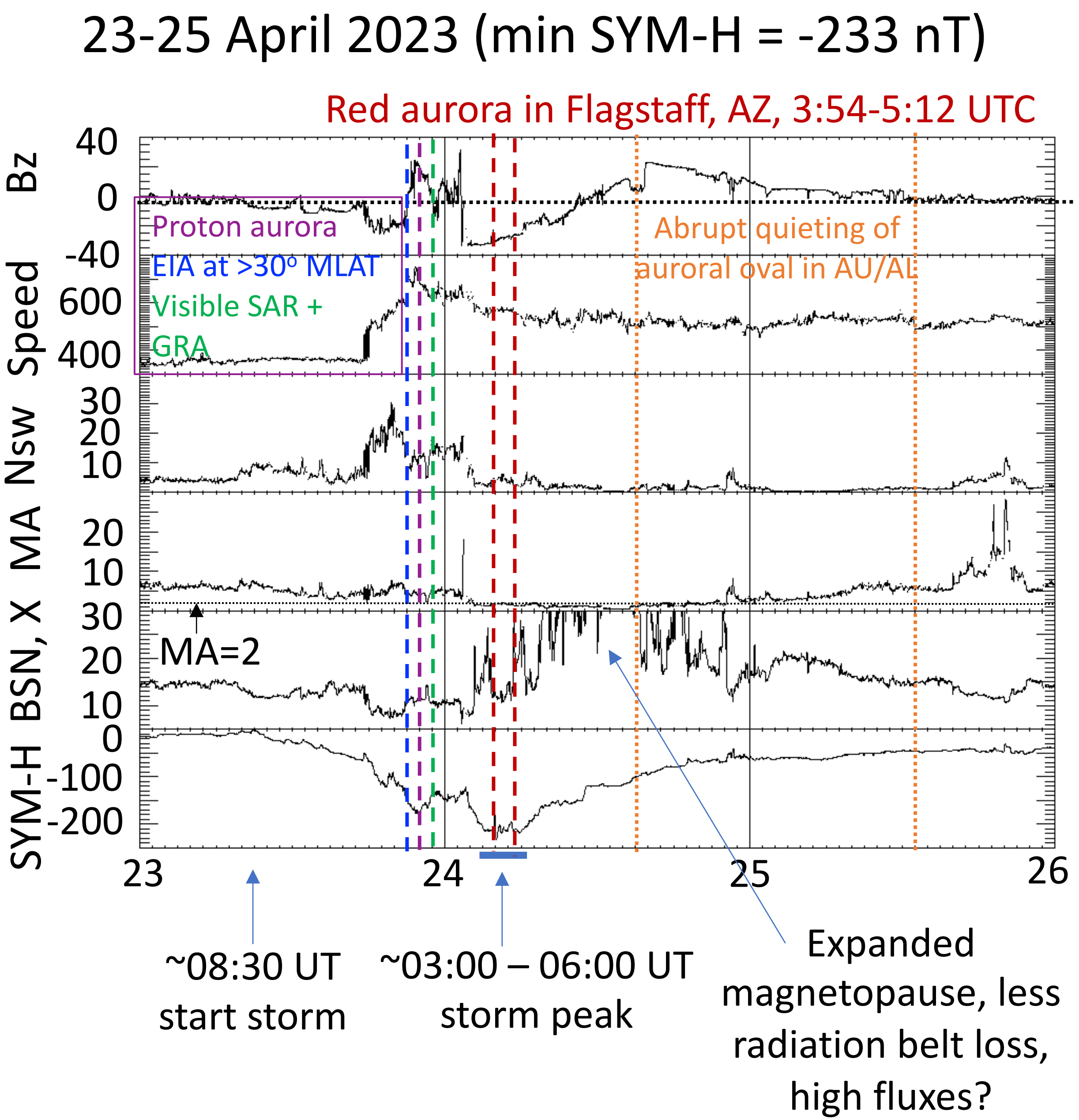
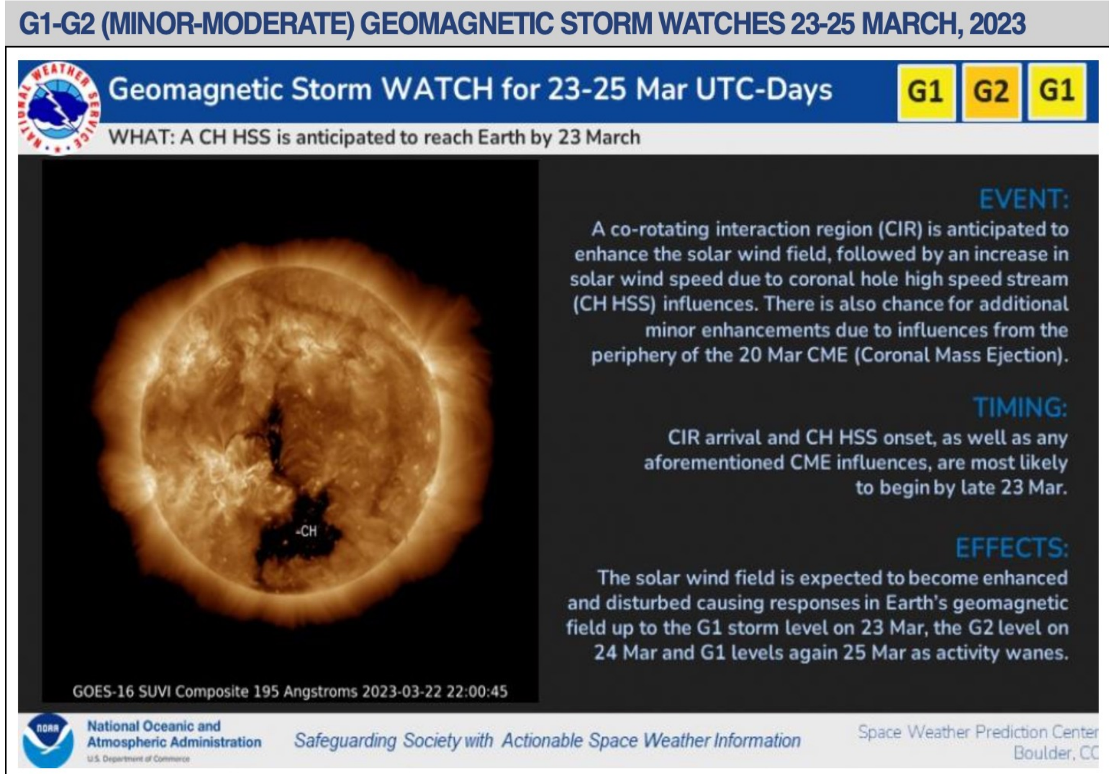




Observations of 23-24 Mar and 23-24 Apr 2023 Storms

Suspected Erupting filament on 20 Mar 2023


G1-G2 (MINOR-MODERATE) GEOMAGNETIC STORM WATCHES 23-25 MARCH, 2023

Geomagnetic Storm WATCH for 23-25 Mar UTC-Days G1 G2 G1

WHAT: A CH HSS is anticipated to reach Earth by 23 March

EVENT:

A co-rotating interaction region (CIR) is anticipated to enhance the solar wind field, followed by an increase in solar wind speed due to coronal hole high speed stream (CH HSS) influences. There is also chance for additional minor enhancements due to influences from the periphery of the 20 Mar CME (Coronal Mass Ejection).

TIMING:

CIR arrival and CH HSS onset, as well as any aforementioned CME influences, are most likely to begin by late 23 Mar.

EFFECTS:

The solar wind field is expected to become enhanced and disturbed causing responses in Earth's geomagnetic field up to the G1 storm level on 23 Mar, the G2 level on 24 Mar and G1 levels again 25 Mar as activity wanes.

GOES-16 SUVI Composite 195 Angstroms 2023-03-22 22:00:45

National Oceanic and Atmospheric Administration

Safeguarding Society with Actionable Space Weather Information

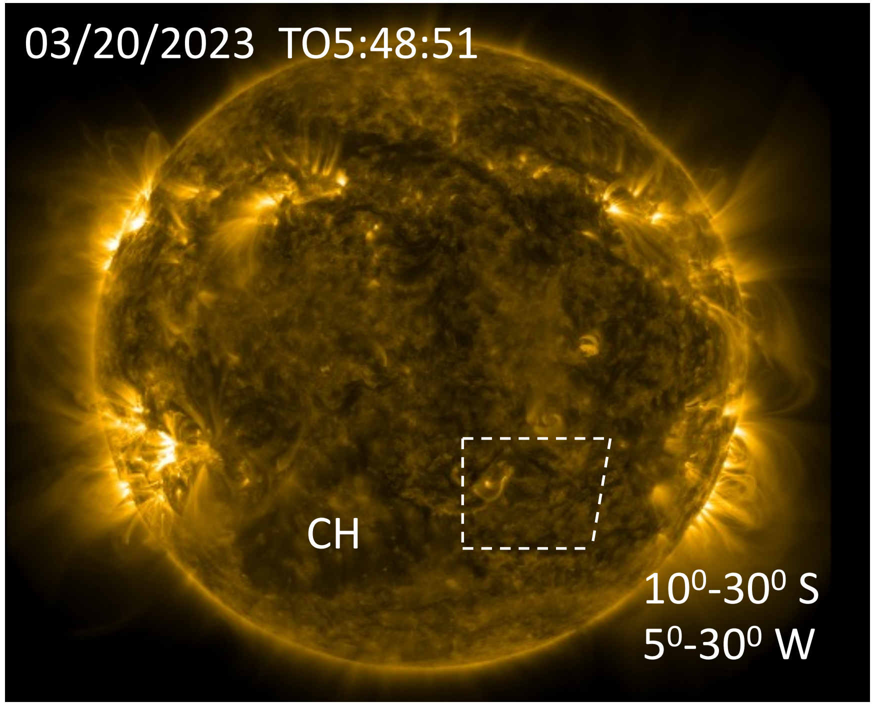
Space Weather Prediction Center Boulder, CO

G1-G2 (MINOR-MODERATE) GEOMAGNETIC STORM WATCHES 23-25 MARCH, 2023

Courtesy CCMC DONKI: A faint, wide CME seen to the southwest in SOHO LASCO C2 imagery during a STEREO A data gap and occurring during a subsequent campaign with limited imagery. Associated with a broad area of coronal restructuring, coronal dimming, destabilization, and filament eruptions seen in SDO 193 and 304 starting around 2023-03-20T01:53Z bounded by an area created by S10 to S30, W05 to W30.

Submitted on 2023-03-20T13:08Z by Chris Stubenrauch

https://kauai.ccmc.gsfc.nasa.gov/DONKI/view/CME/24313/1



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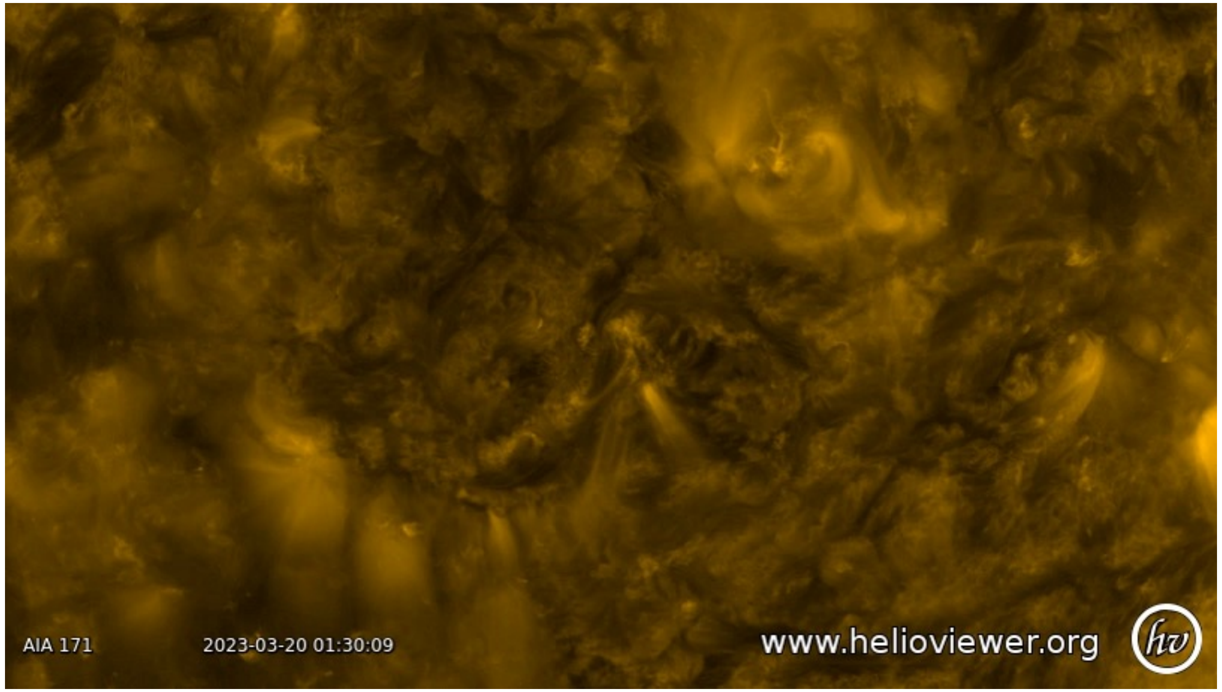
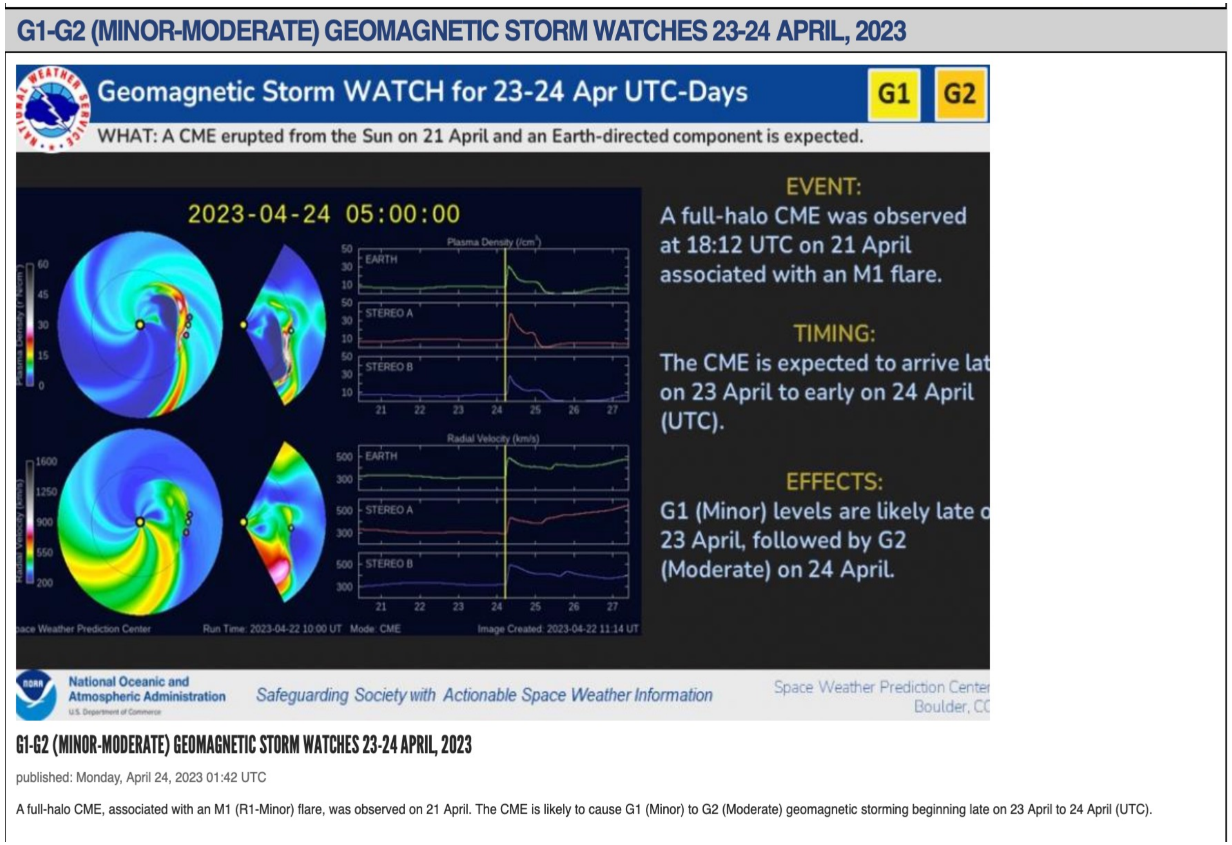


Erupting filament on 21 Apr 2023 associated with M1 Flare



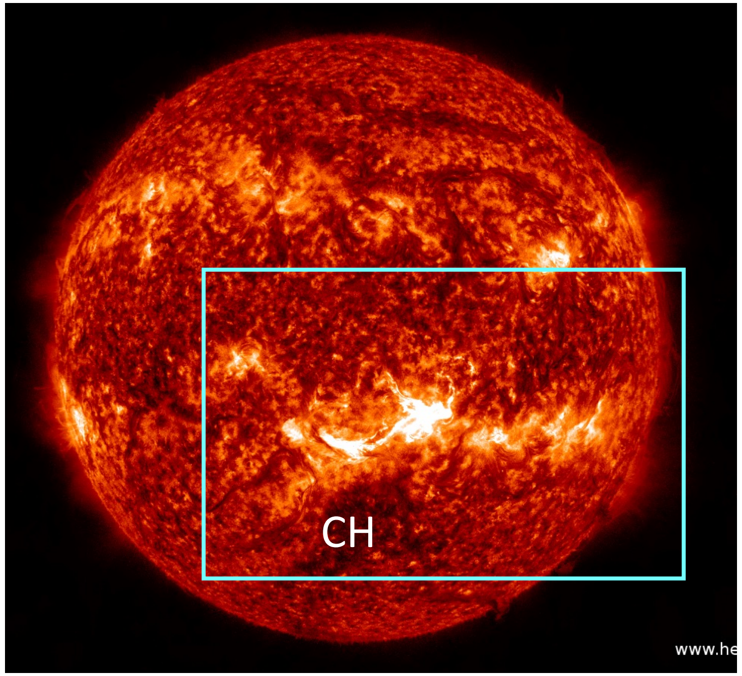
G1-G2 (MINOR-MODERATE) GEOMAGNETIC STORM WATCHES 23-24 APRIL, 2023

G1-G2 (MINOR-MODERATE) GEOMAGNETIC STORM WATCHES 23-24 APRIL, 2023

published: Monday, April 24, 2023 01:42 UTC

A full-halo CME, associated with an M1 (R1-Minor) flare, was observed on 21 April. The CME is likely to cause G1 (Minor) to G2 (Moderate) geomagnetic storming beginning late on 23 April to 24 April (UTC).

2023-04-21 18:09:05 UT



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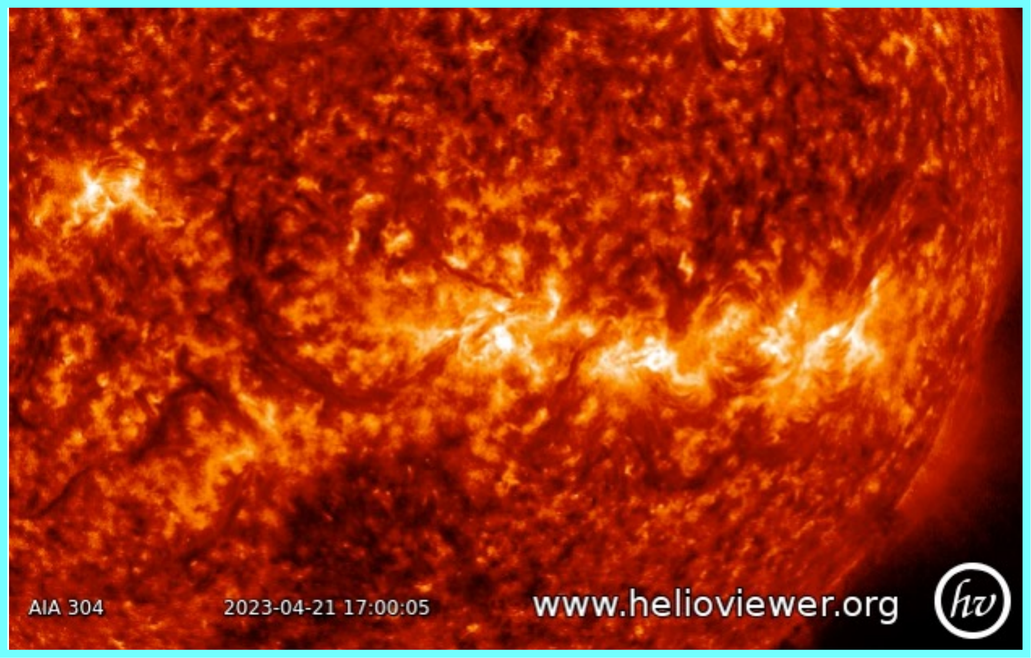

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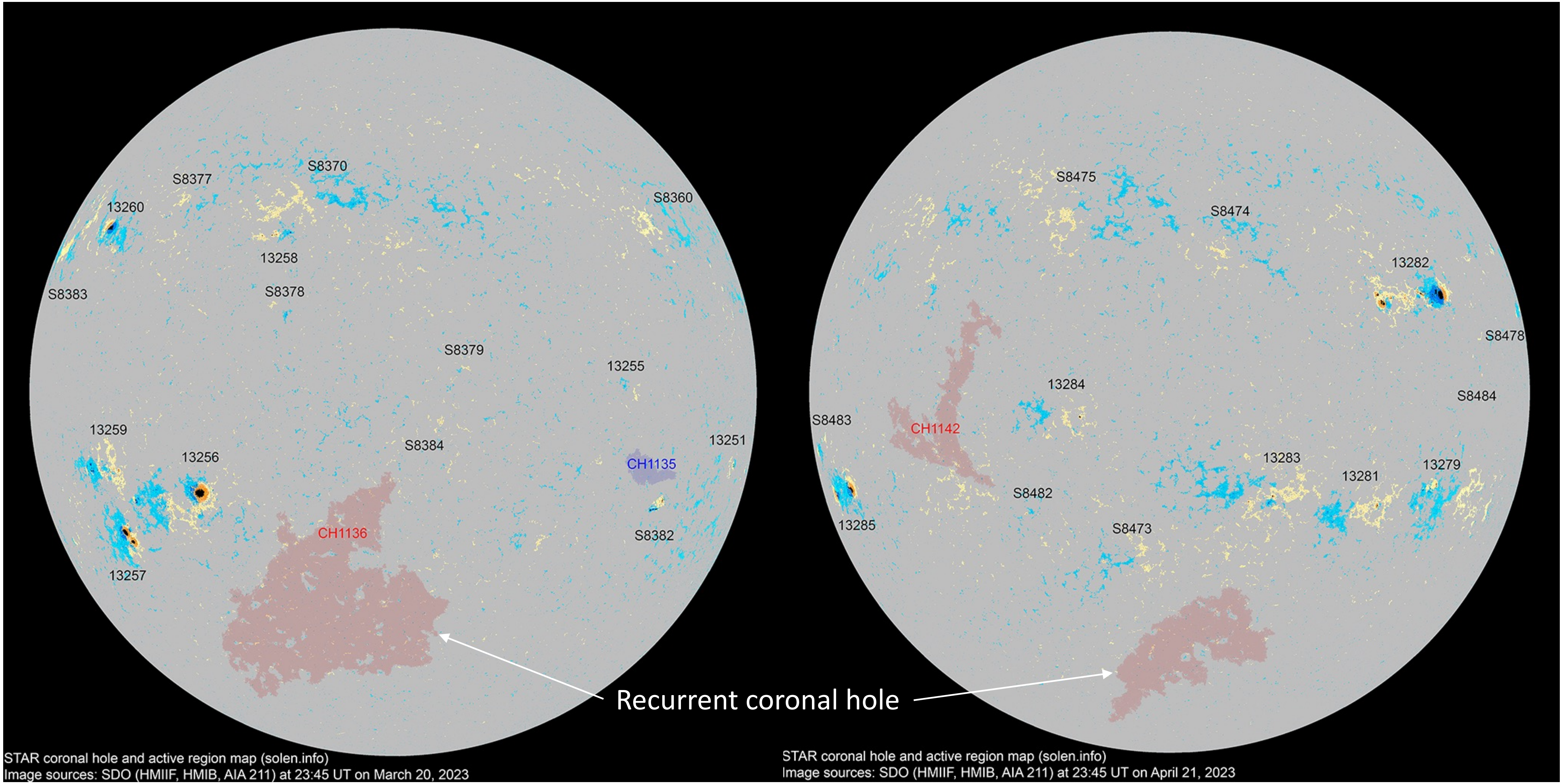

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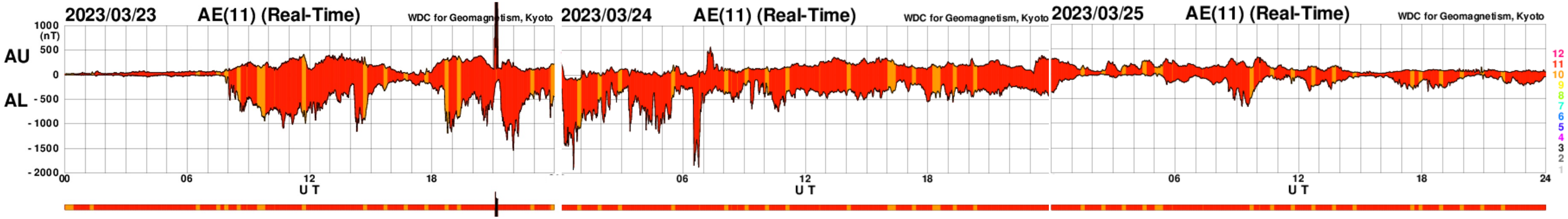
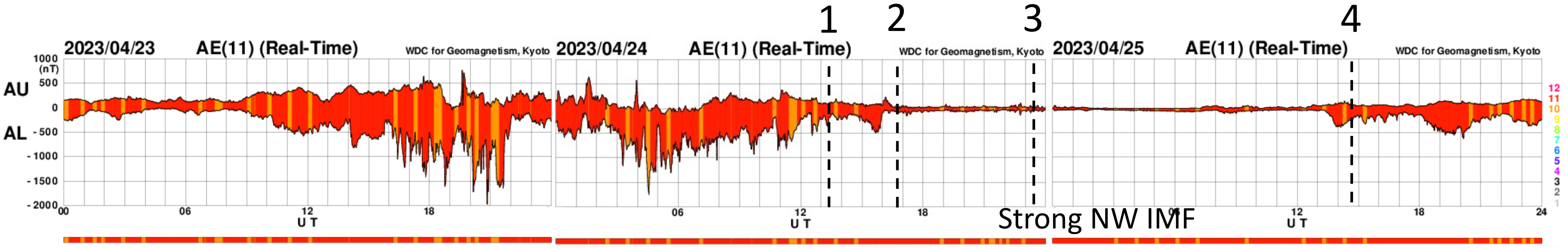
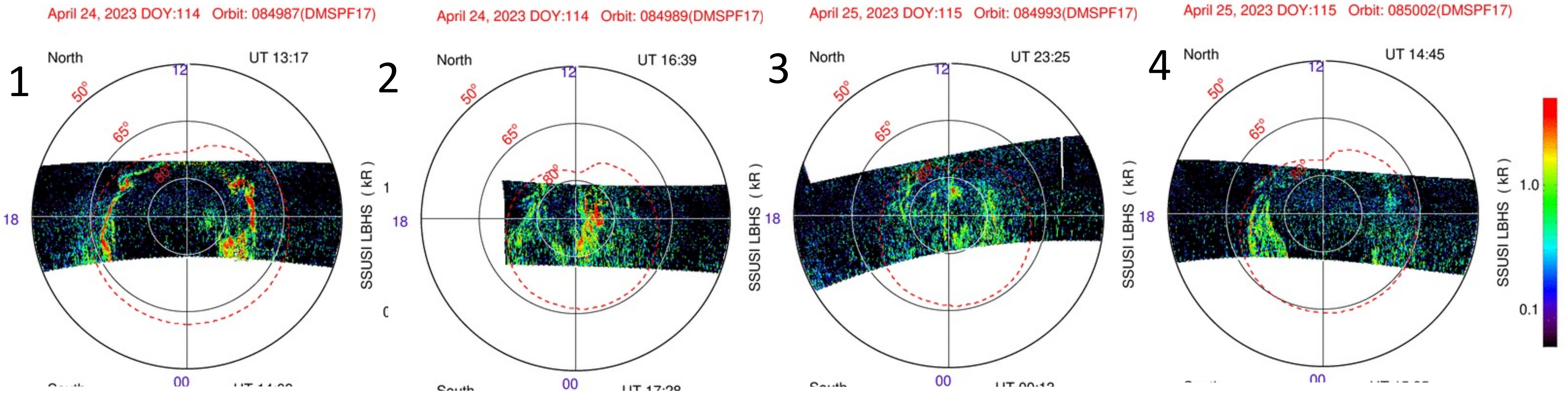


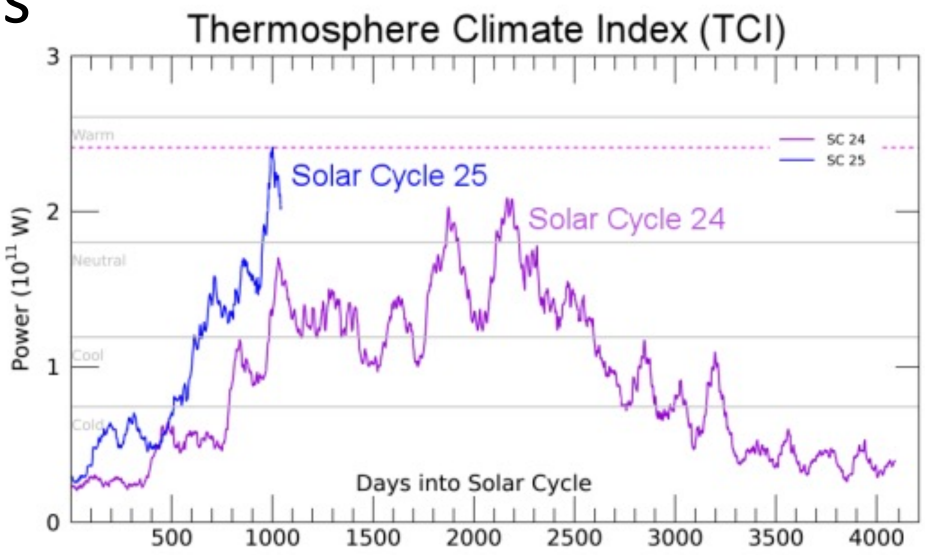


SSUSI, DMSP F17

https://ssusi.jhuapl.edu/gal_AUR



24 March and 24 April 2023 storms: 7th and 8th largest amount of thermal energy in the upper atmosphere in 21.5 years of storms



Above: NASA's daily Thermosphere Climate Index tracks thermal energy in Earth's upper atmosphere. So far, Solar Cycle 25 is far ahead of Solar Cycle 24. Credit: Linda Hunt
https://spaceweather.com/, Jun 2 2023

Thermosphere Climate Index (TCI) tells how much heat (Watts) nitrogen oxide (NO) molecules in the thermosphere are radiating into space absorbed from solar flares and geomagnetic storms. 24 March and 24 April 2023 storms have the 7th and 8th largest TCI numbers observed by TIMED/SABER over the past 21.5 years, at 1.04 TW and 1.02 TW, respectively

23-25 April 2023

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GOLD 135.6 nm image
23 April 2023, 21:10 UT

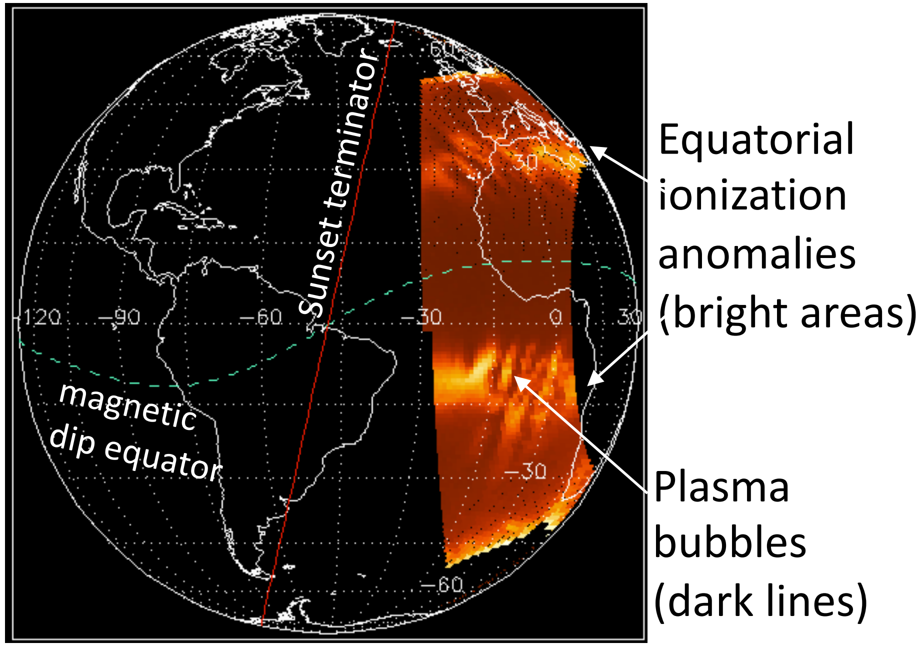


Figure: The bright regions show the equatorial ionization anomalies (EIA) which are far poleward of their normal location, which is ± 15° MLAT. Indicates strong prompt penetration electric fields. The dark lines running through the EIA are low-density plasma bubbles that have been shown to be responsible for communication disruptions at mid-latitudes.
Courtesy: Richard Eastes

Folding in Superstorm Anomaly Detection Results
More details in the"Extra Slides" at the end of the file

How Does Anomaly Detection Fit In?

AWS-NASA engagement = Set of 4 use cases, carried out as part of the HPD participation in the Strategic Data Management Working Group activities…..

Purpose: *"to explore and report on data management options that:*

(1) improve discovery and access for all SMD data,
(2) inform future science data system capabilities needed to enable:
(a) tighter coupling between theory programs and NASA observations as well as
(b) greater scientific discovery by science data users, including those involved in cross-disciplinary/division investigations and citizen scientists."

AWS – NASA Superstorm Use Case

Underlying Principle

Fair to moderate space weather makes up the vast majority of observations and provides a baseline against which to identify superstorms (anomalies)

Physical processes must produce both:

- Typical range of conditions
- Rare extreme events

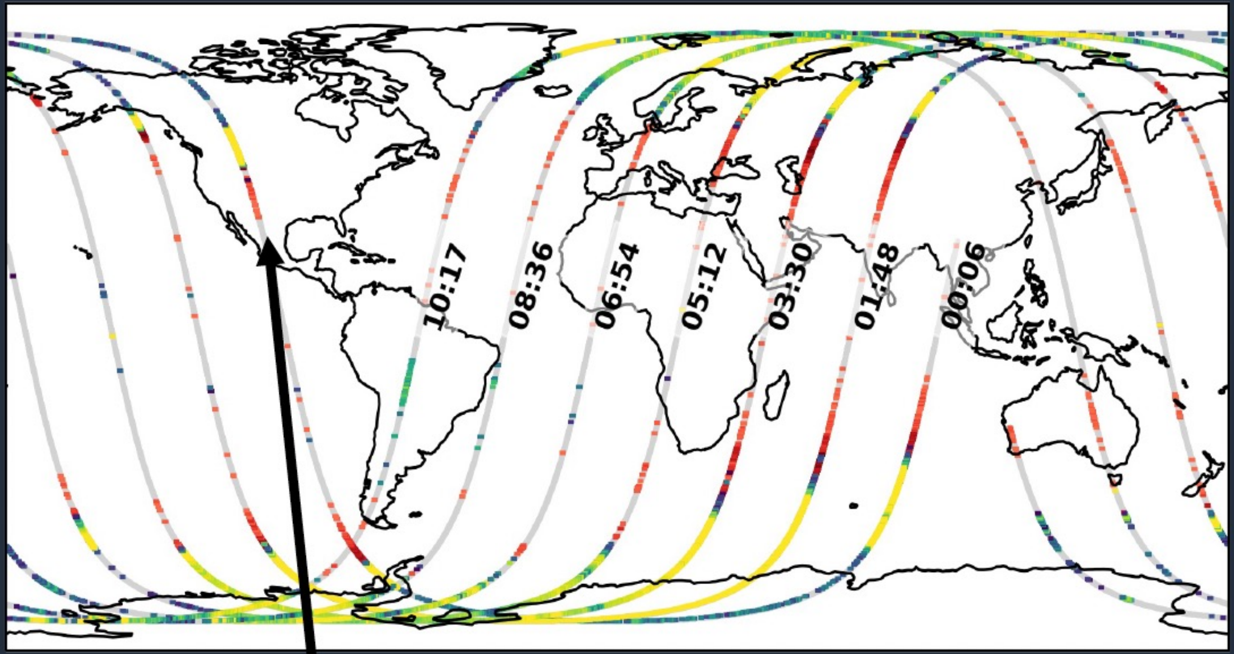
Changes in dynamics are marked by:

- Emergent phenomena
- Significantly modified features

Basis for using anomaly detection:

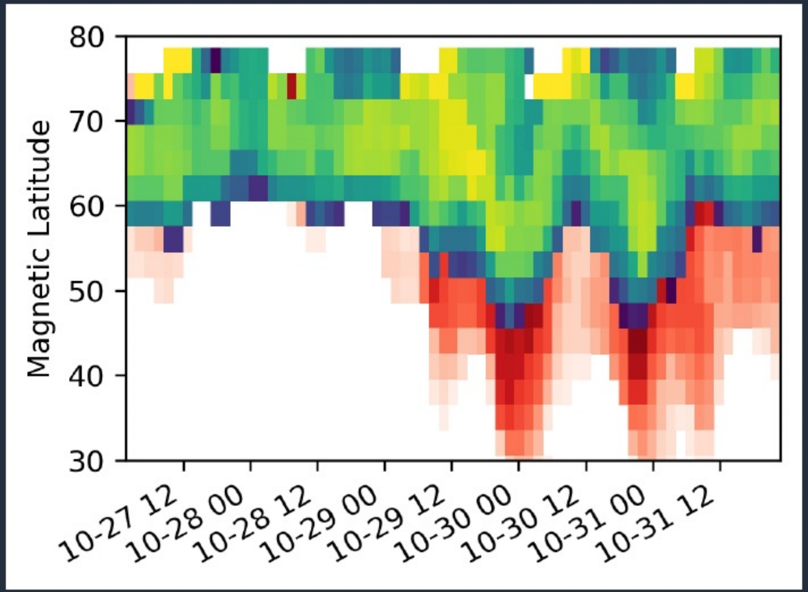
- Identifying changes in dynamics through emergent or anomalous features

Ion precipitation reaches lower latitudes than Electron precipitation during superstorms

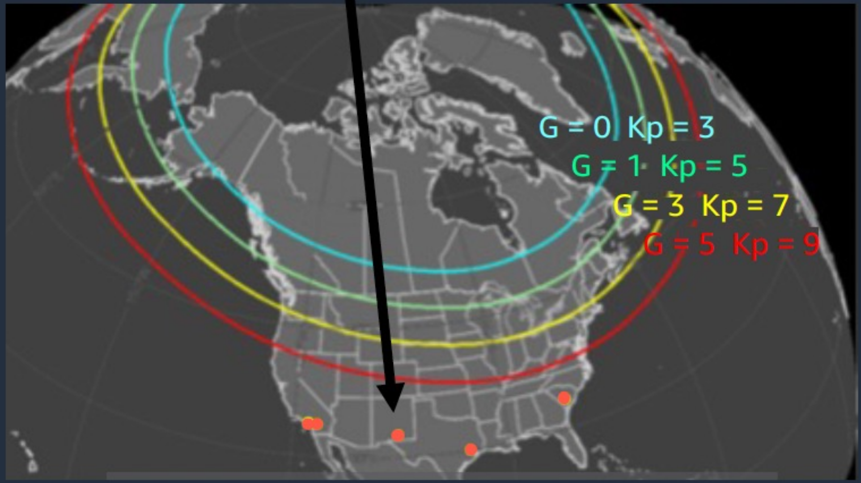


19 channels, of ions and electrons per second (millions / day)

Each orbit becomes one time step

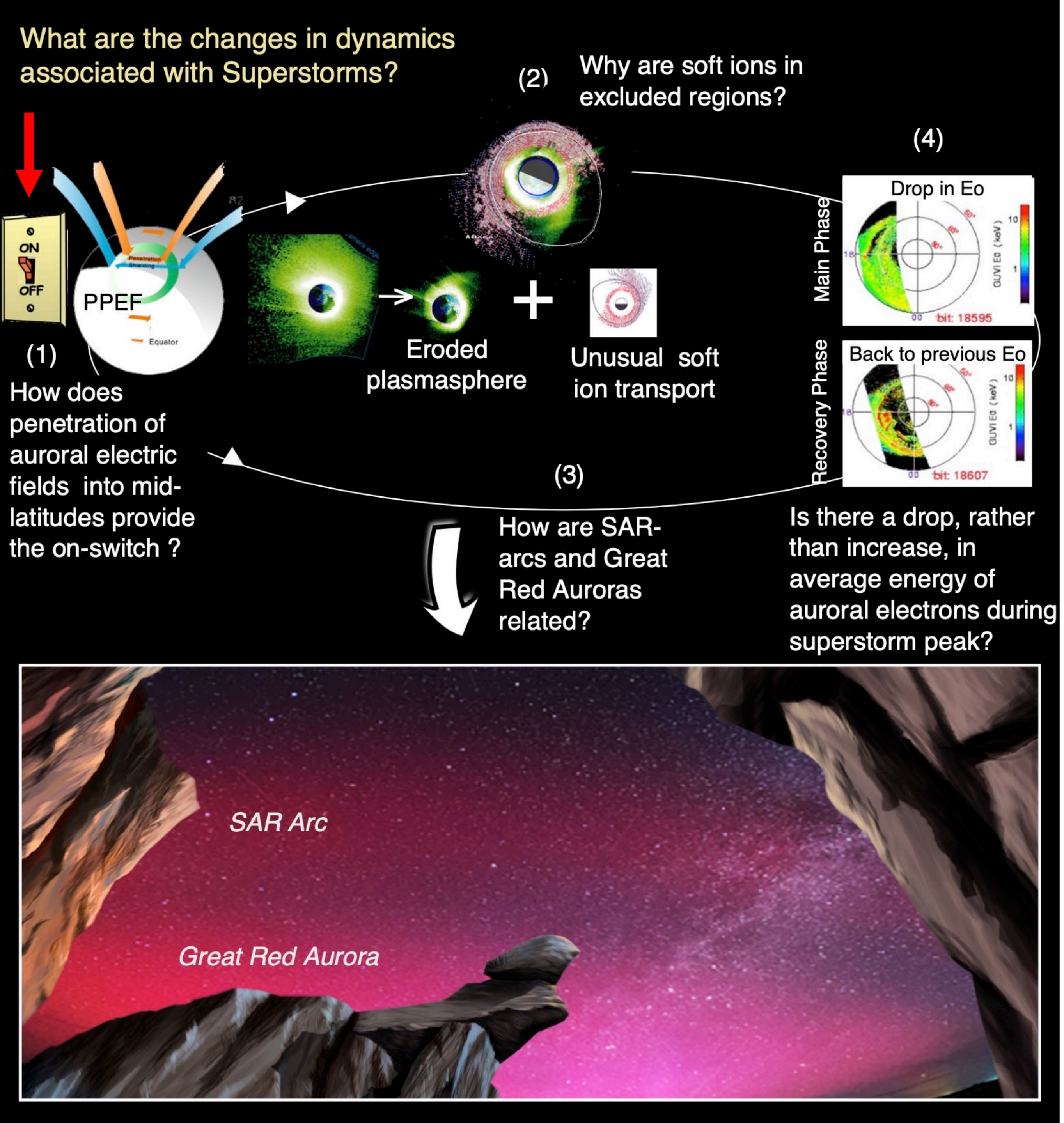


- **Need ML-ready data**
  - Impractical to use full data stream
  - Remove detector anomalies and nuisance signals—median filtering
  - Careful data reduction (averaging/filtering) to preserve signals of interest



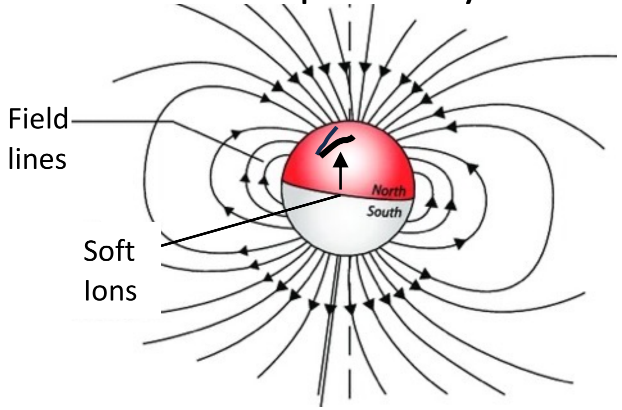
Ion precipitation reaches as far south as red aurora observations (red dots)

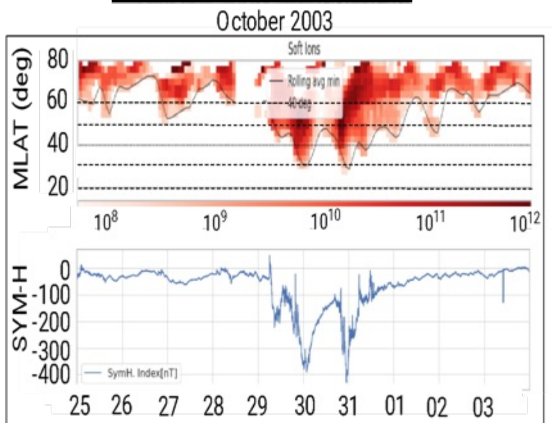
aws

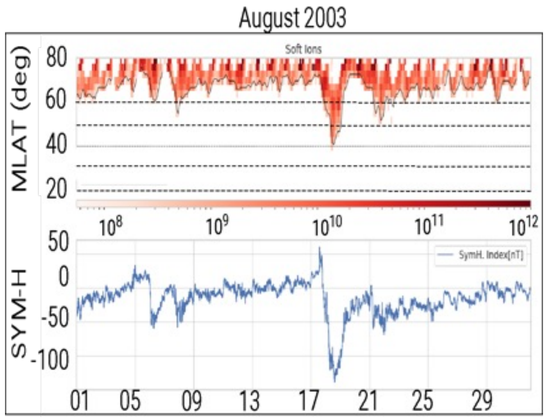


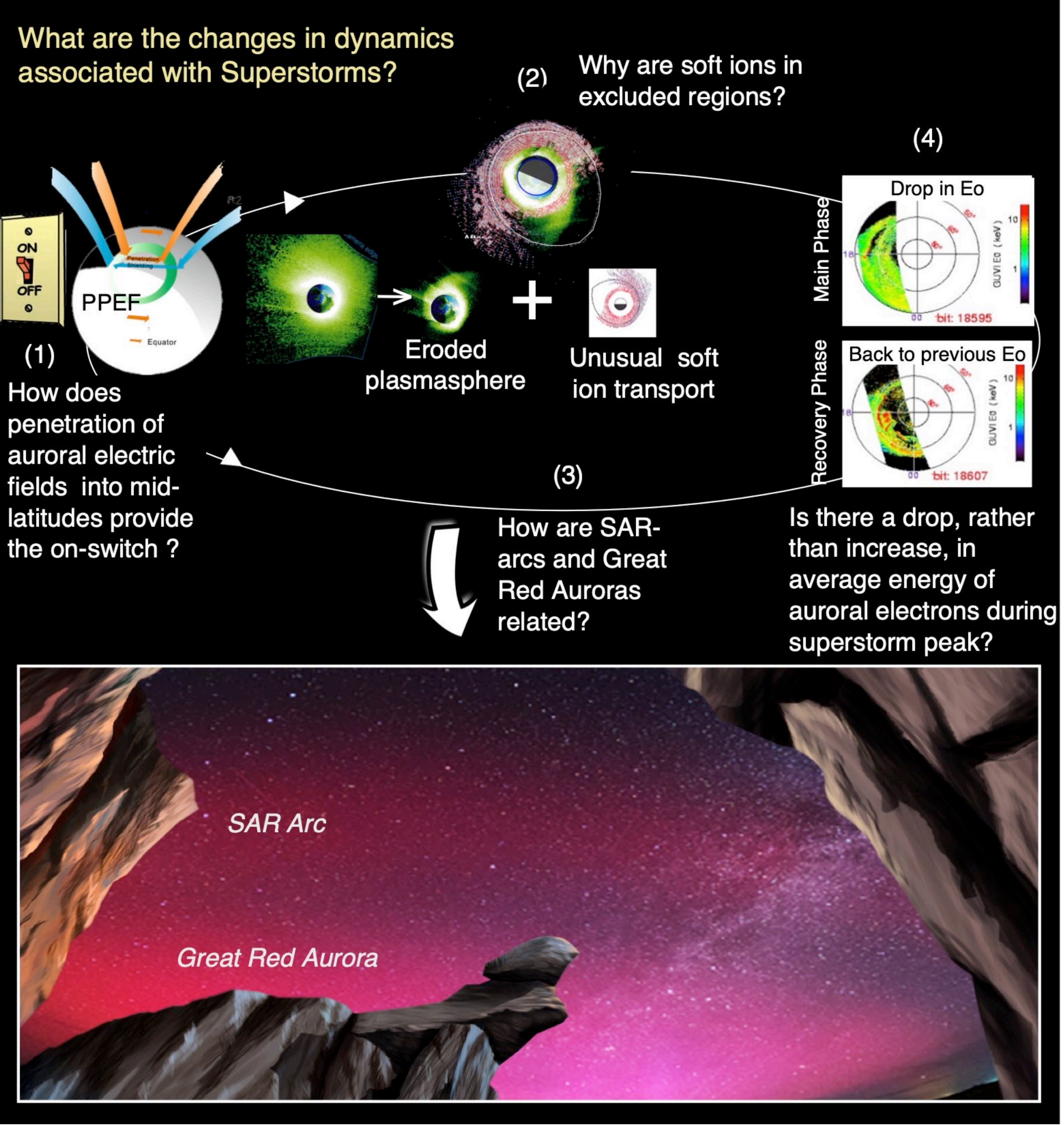
Bottom Line: Why are soft ions in excluded regions? What determines deepest MLAT?

- PPEF is responsible for not only bringing the ions into midlatitudes but for stripping away the outer plasmasphere.
- Soft ions are able to penetrate to unusually low-latitudes.
- The equatorward transport is halted as these ions enter the plasmasphere and are depleted by Coulomb collisions.







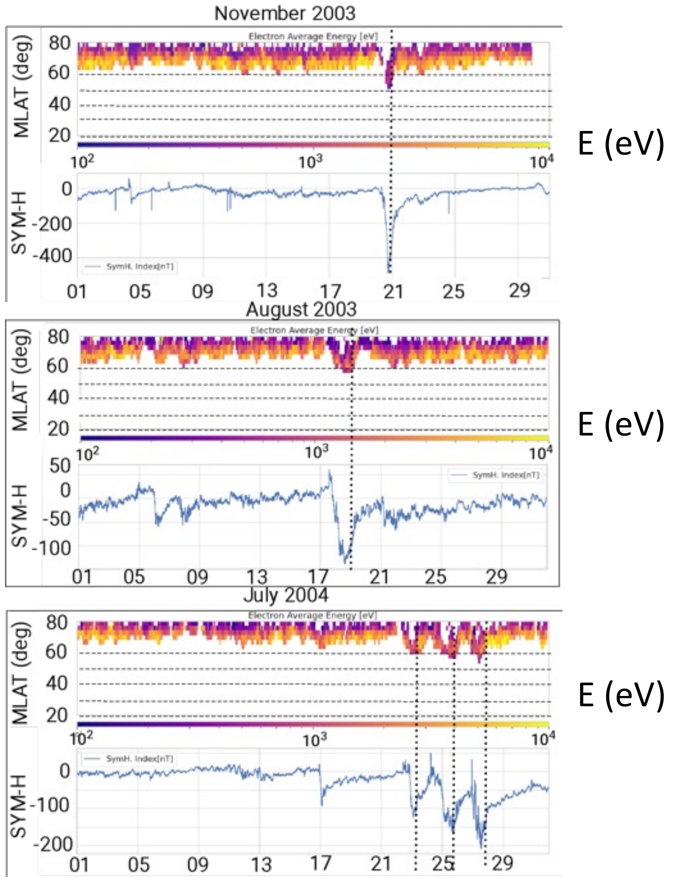


Bottom Line: Average energy of auroral electrons drops during superstorms?

- The Geospace AD algorithm identifies (to our knowledge for the first time) a drop in the average energy of auroral electrons during the main phase as a *characteristic* feature of superstorms. Studies carried out for only a few cases [*Sivjee and Shen*, 1997; *Steele et al.*, 1998; *Hecht et al.*, 2008]
- How the decrease in average energy is related to storm severity and other storm processes requires further study.

.

This drop in energy had consequences for storm dynamics because lower energy than normal field-aligned current carriers resulted in closure currents at higher altitudes, and unusual conductance profiles. Changes coupling [c.f., *Huang and Burke*, 2004]



Drawing in Researchers & Citizen Scientists to Explore Sun-Geospace with Compelling Questions & Innovative Approaches

Compelling questions can be designed to engage all Helio discipline areas & Citizen Scientists

Discipline	Potential Compelling Campaign Focus Areas
System	Are these superstorms? Is a superstorm just a larger version of a storm or have dynamics changed? Are these 2 storm events superstorms? Proto-superstorms?
Solar	What is source of the stealth CME driving the 23 Mar 2023 storm?
Helio	Is it significant that (1) the filaments erupted 31 days apart, (2) near the same recurrent coronal hole, (3) the storms started within hours UT of each other upon arrival at Earth and peaked in the same 3-6 UT interval on the 2nd day.
Helio	What links the coronal hole and filament eruption? Does the process persist and recur during the next CR? If so can this increase the predictability of superstorms?
Helio/Mag	Are planar magnetic structures (PMS) a factor in the enhanced geoeffectiveness of the ICME during 23-24 April 2023 storm [Ghag, et al., 2023]
Mag	In these events, what disrupts ring current shielding of mid/low-latitude regions? How do resulting long-duration PPEFs create superstorm-like dynamics?
ITM/MAG	Are the Equatorial Anomalies and bubbles interacting with the plasmasphere? With storm enhanced densities?
ITM	What is pumping large amounts of heat into the upper atmosphere?
Citizen Science	When & where do unusual auroral forms appear? How is that related to size and phase of the storm?

Extra slides

Strategy: Heliophysics Big Year, Solar Maximum

Vision

- Leverage the HBY to develop a lasting structure that supports worldwide collaboration in the analysis of dangerous solar storms

Mission

- Carry out pilots that explore what is needed to support: (1) seamless use of the HSO as a system-level observatory, (2) collaborative workspaces for open science, (3) data commons areas that are easily accessible for researchers, citizen scientists, and the public

1. Seek New Understanding of Dangerous Solar Storms

Use event campaigns as a powerful tool to focus multidisciplinary researchers on questions of mutual interest in how dangerous magnetic storms develop from sun to geospace & their consequences

2. Integrate Citizen Science as a Critical Element

Incorporate Citizen Science for key information on storms not attainable in other ways

3. Adopt Principles of Open Science

Build on examples of worldwide collaboration during IGY1957-58 and IHY 2007-8 to create an open science environment that spurs innovation and new insights

4. Prioritize IDEA (inclusion, diversity, equity, accessibility)

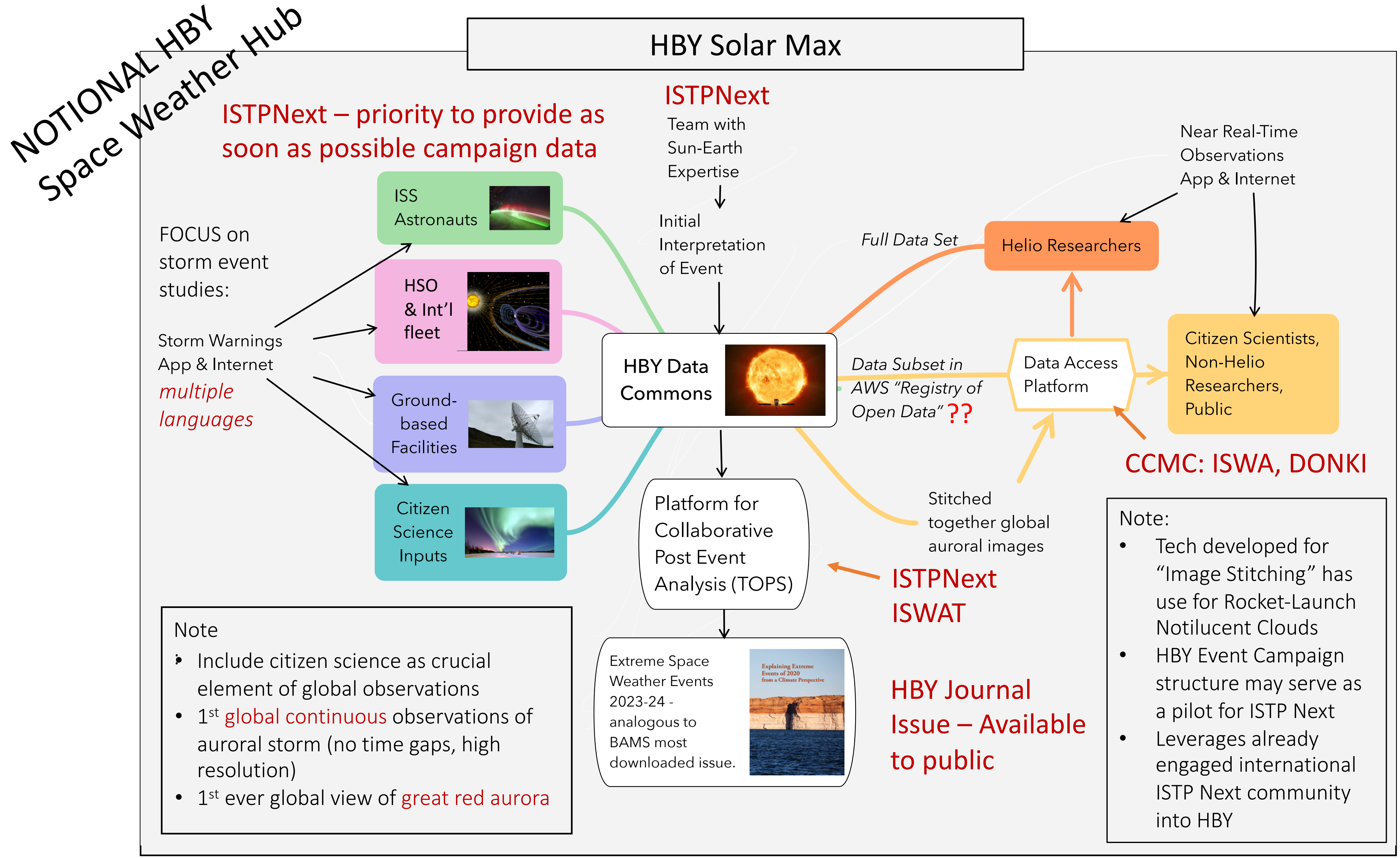
Identify synergies and areas for cross-collaboration, strengthen and forge relationships with underrepresented communities, innovate outreach activities with IDEA as a major focus.

5. Optimize Existing Tools & Develop Others

Including internal and external communications, HSO as a system observatory, public engagement, campaign structure with an accessible data commons for observations & models, open spaces for collaborative analysis, synergies between space-based & ground-based observations, etc.

6. Recruit Partners

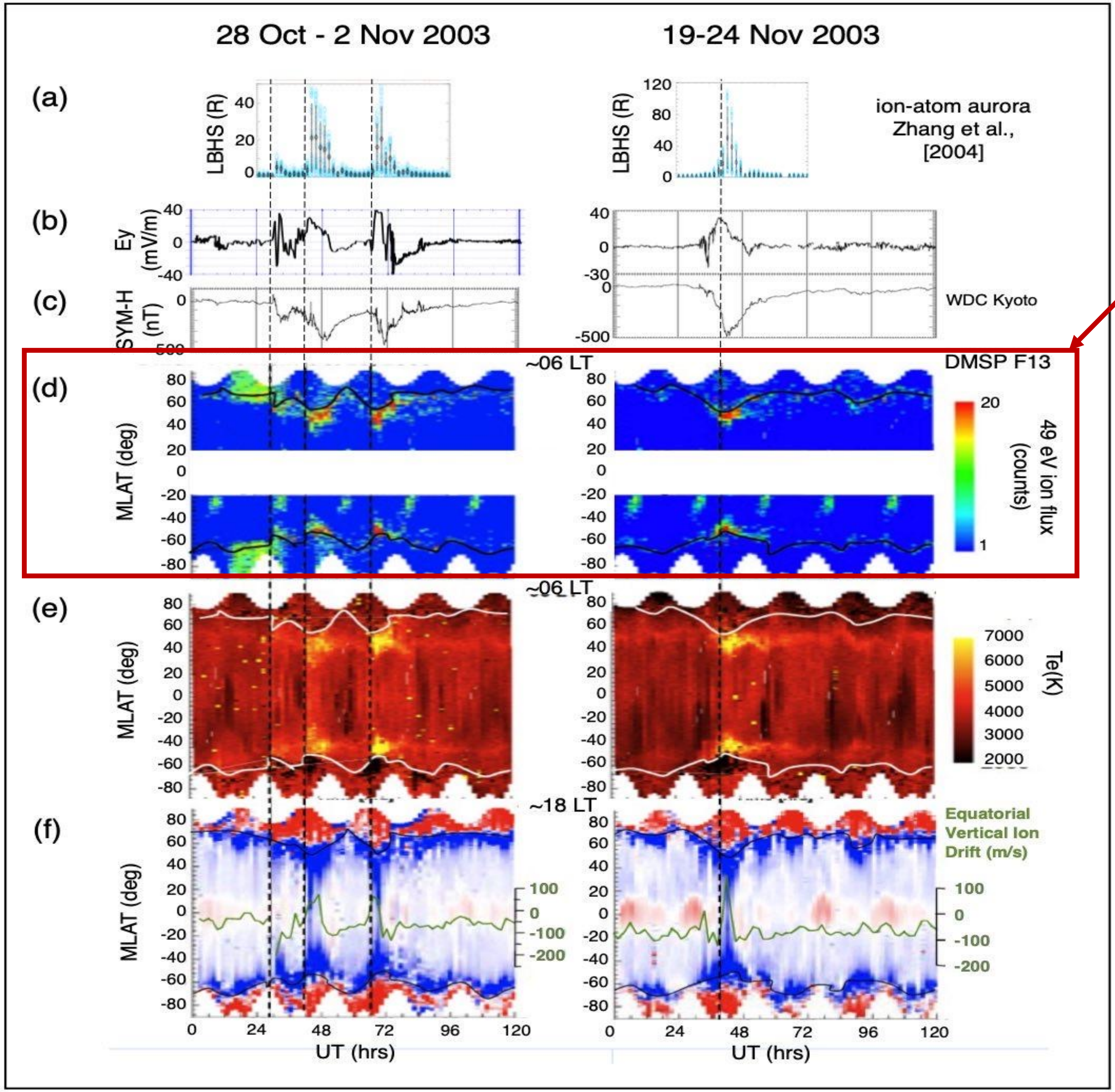
Foster mutually beneficial engagement with partners & stakeholders including agency (i.e., GSFC, Langley), interagency (NSF, NOAA, DoD, etc.), international (i.e., ESA, ISTPNext, ISWAT), commercial (i.e. cloud providers), educational (i.e., science centers, universities) partners, & the public


NOTIONAL HBY
Space Weather Hub
HBY Solar Max
ISTPNext – priority to provide as soon as possible campaign data
ISTPNext
Team with Sun-Earth Expertise
Initial Interpretation of Event
FOCUS on storm event studies:
Storm Warnings App & Internet
multiple languages
ISS Astronauts
HSO & Int'l fleet
Ground-based Facilities
Citizen Science Inputs
HBY Data Commons
Full Data Set
Helio Researchers
Near Real-Time Observations App & Internet
Data Subset in AWS "Registry of Open Data" ??
Data Access Platform
Citizen Scientists, Non-Helio Researchers, Public
CCMC: ISWA, DONKI
Stitched together global auroral images
Platform for Collaborative Post Event Analysis (TOPS)
ISTPNext
ISWAT
Extreme Space Weather Events 2023-24 - analogous to BAMS most downloaded issue.
Explaining Extreme Events of 2020 from a Climate Perspective
HBY Journal Issue – Available to public
Note
• Include citizen science as crucial element of global observations
• 1st global continuous observations of auroral storm (no time gaps, high resolution)
• 1st ever global view of great red aurora
Note:
• Tech developed for "Image Stitching" has use for Rocket-Launch Notilucent Clouds
• HBY Event Campaign structure may serve as a pilot for ISTP Next
• Leverages already engaged international ISTP Next community into HBY

Putting into context with recent research findings

1) Long-duration prompt penetration electric fields [*Maruyama et al.*, 2007] result from:
   - Extreme magnetotail stretching due to rapid and continuous reconnection
   - Creates induction electric fields
   - Prevent the ring current from drifting inward to fully shield the convection E field
2) When the shielding breaks down the dynamics of the storm changes
3) Strong PPEFs can drive extreme erosion of the plasmasphere [*Obana et al.*, 2019].
   - For example, plasmapause at 35^0 ILAT or L~1.5 in some longitudes during 29-31 Oct 2003 superstorm [*Baker et al.,* 2004]
4) Particle tracing indicates that strong variable PPEFs are able to bring soft (< 1 keV) ions dawnward and to unusually low latitudes (at times <33^o IL) during superstorms [*Huang et al.*, 2006]
5) These ions are an additional energy source for SAR-arcs, pushing them into visible range

Use Anomaly Detection to determine which storms have low-latitude soft ions and what determines how far they penetrate.



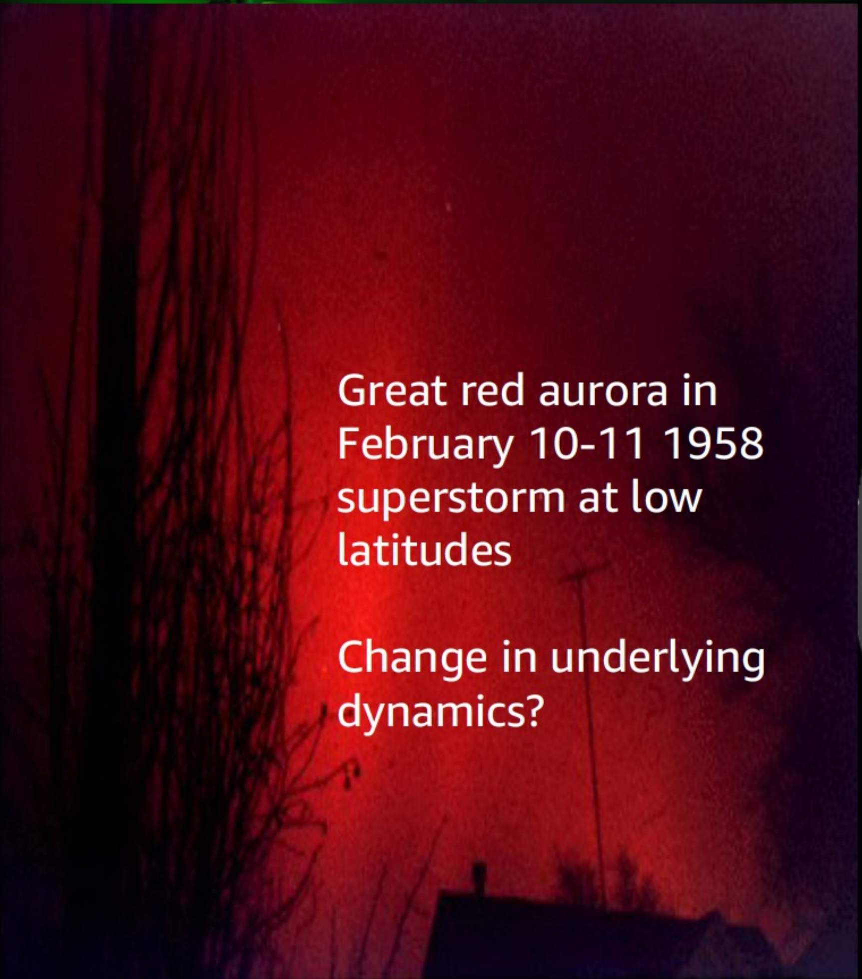
Emergent features in superstorms

- DMSP F13 particle precipitation data
  - Bring to science-quality
  - Make ML-ready
- Feature Engineering
  - <1 keV ions
  - >1 keV auroral electrons
  - Average energy of auroral electrons
- Unsupervised Learning because of rarity of superstorms, not enough training data

The DMSP particle data accepted into the AWS registry of open data (at https://registry.opendata.aws/dmspssj/)

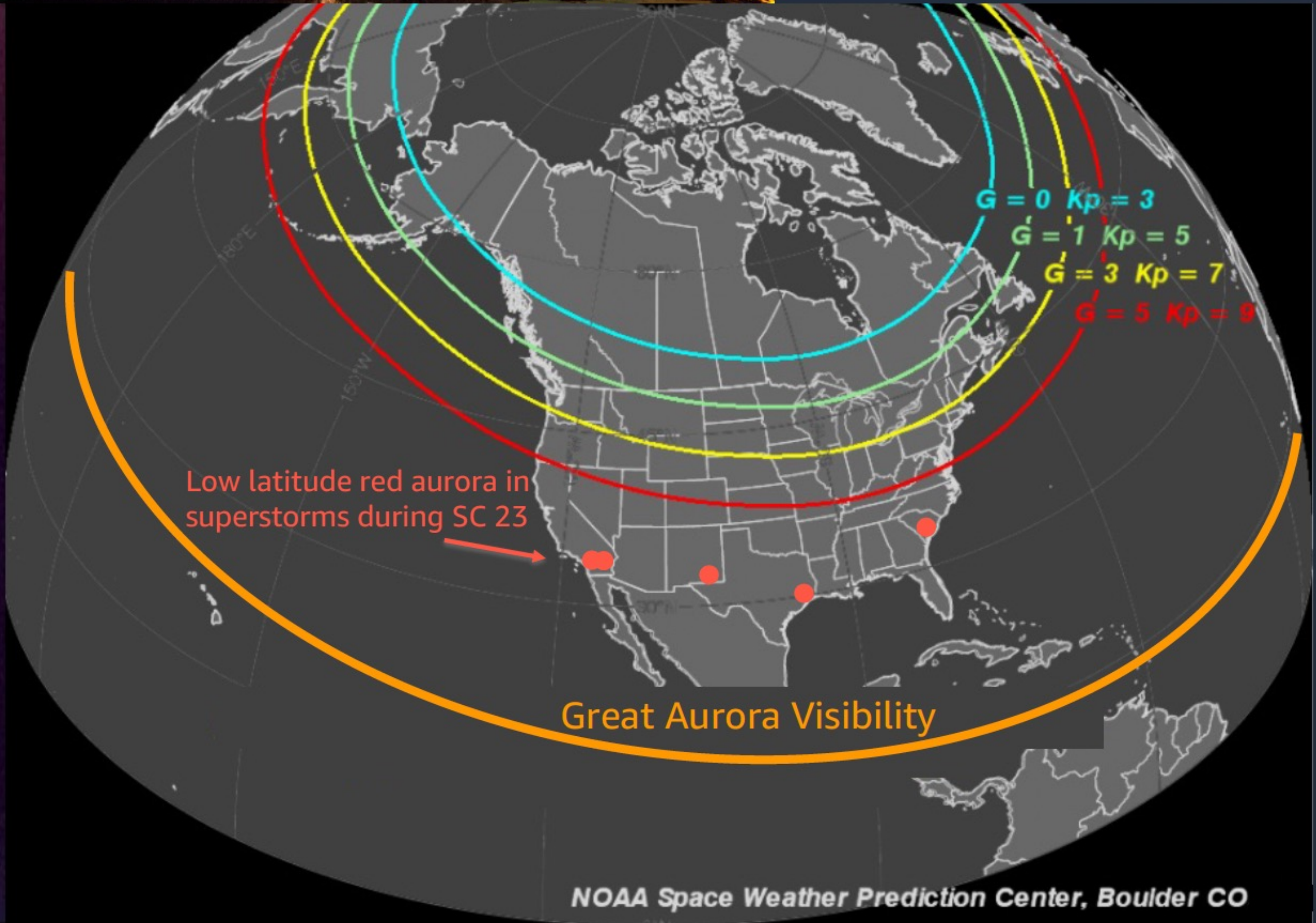
Anomalous features of storms

Most common auroral emission is green & at high latitudes



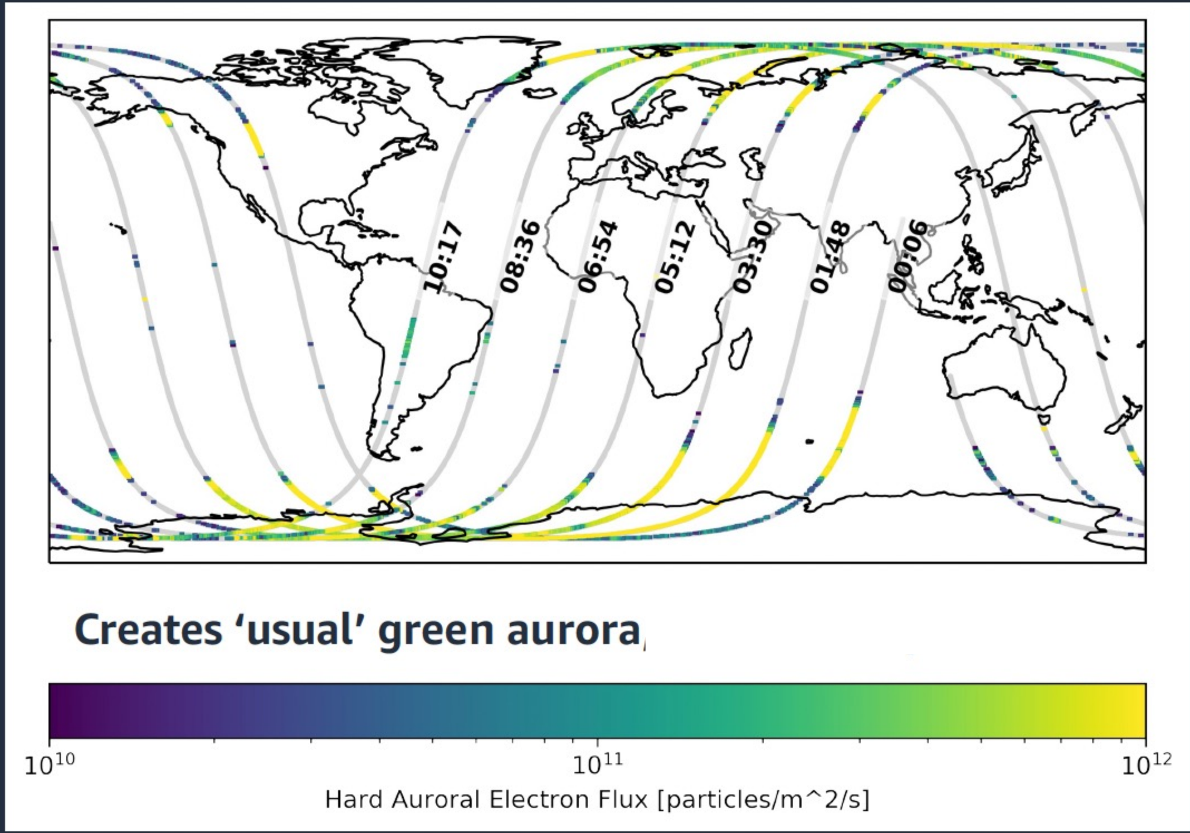
Great red aurora in February 10-11 1958 superstorm at low latitudes

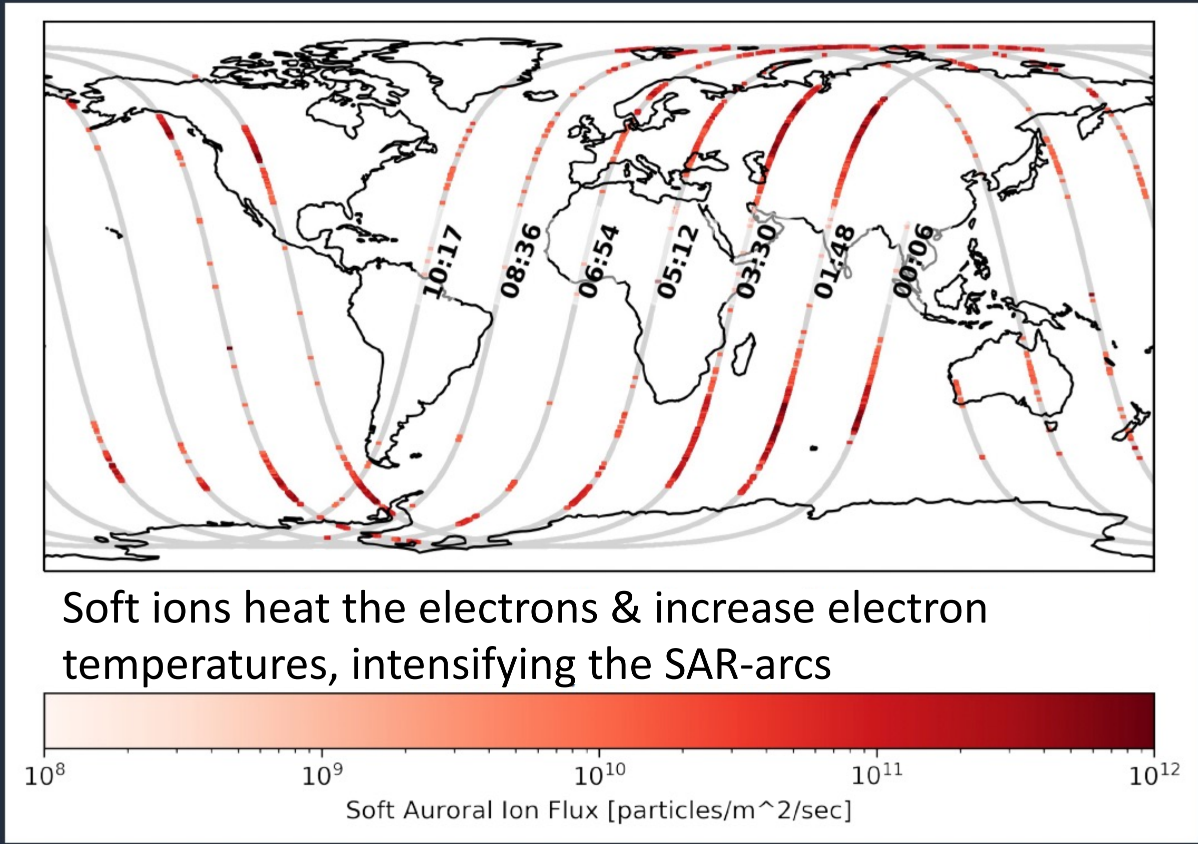
Change in underlying dynamics?



Particle Precipitation During a Superstorm:

Electron precipitation at higher latitudes than Ion precipitation





DMSP F13 2003-10-30

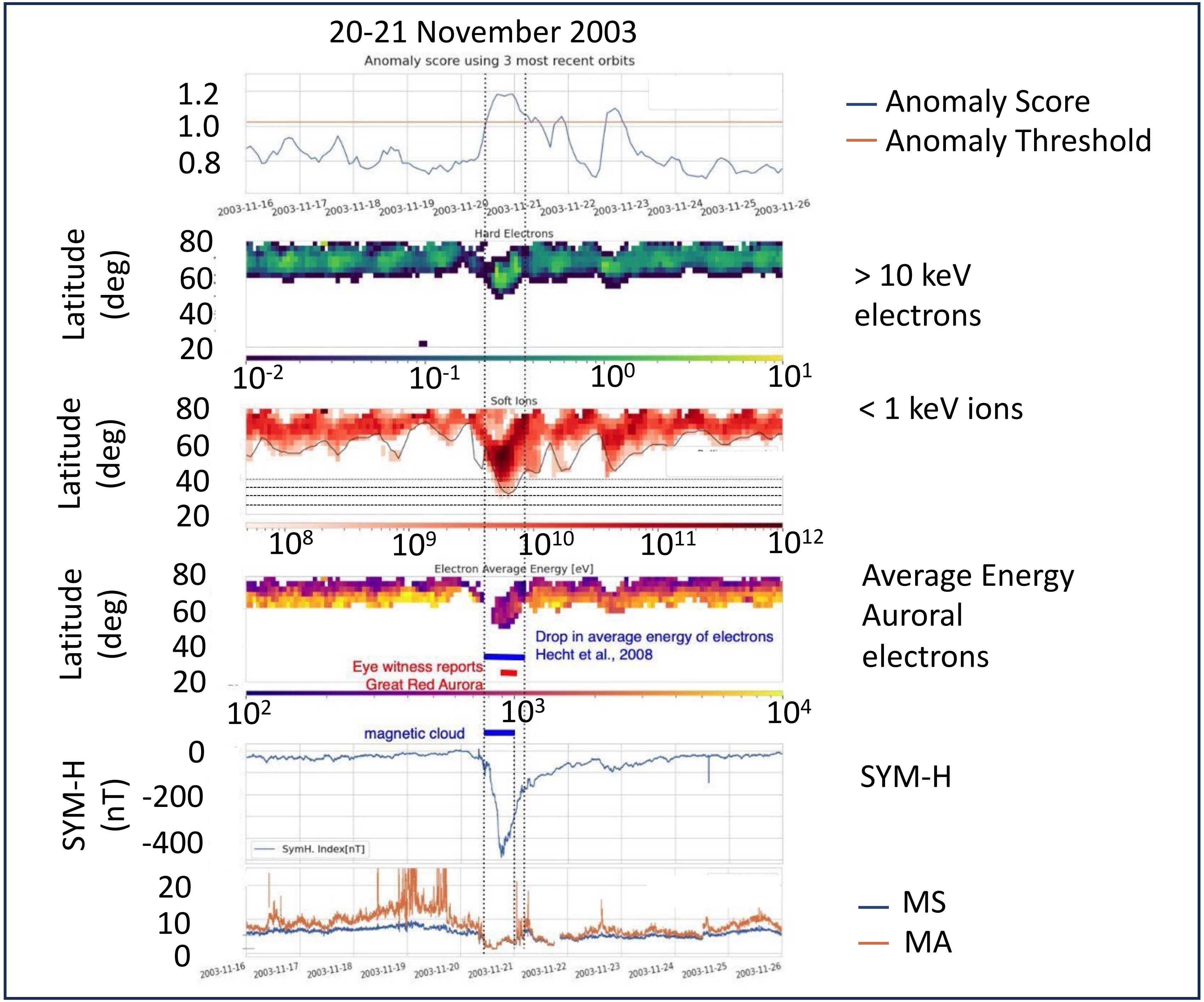
- Specifically look at hard electrons and soft ions

Example of Anomaly Detection Results

- Trained RCF model using 2000-2002 DMSP data
  - Input includes soft ion flux (red), hard electron flux (green/blue) and average electron energy (bottom plot)
  - Included time-lags (past 3 orbits)
- Model outputs continuous anomaly score value for every data point
  - Set threshold of 3std above mean as “anomaly”

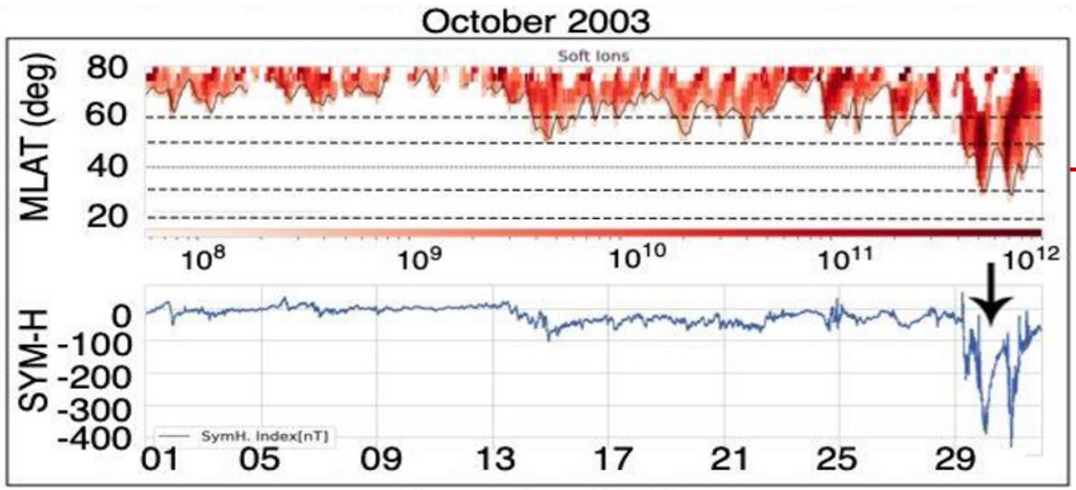
SYM-H & MA/MS was not used in the anomaly detection

SYM-H only plotted with results for a comparison to the previous standard for superstorms



What determines how far equatorward soft ions penetrate? Soft ions during most superstorms penetrate as deeply equatorward as 25° - 35°).

*Some superstorms shaded blue remained ≥ 45°



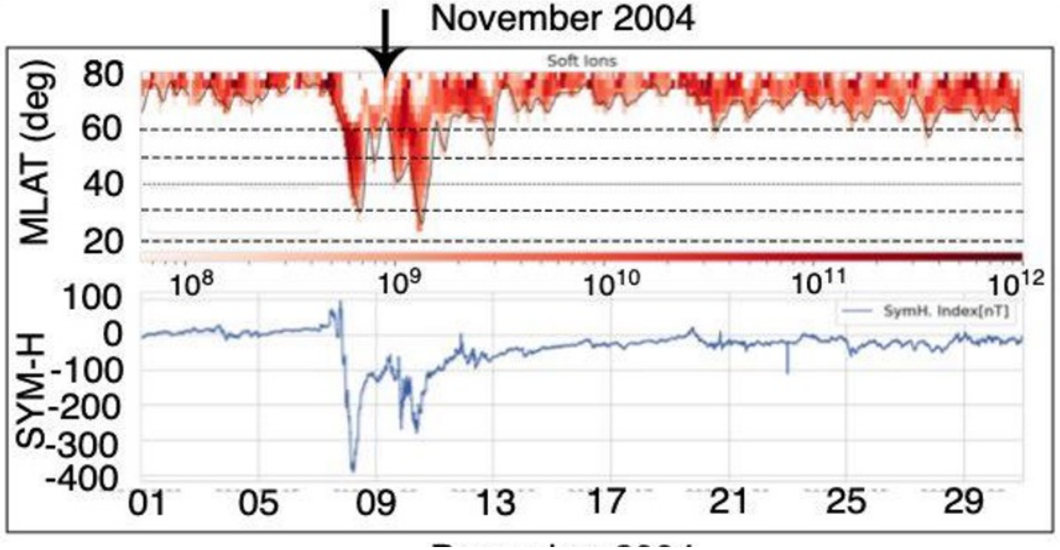
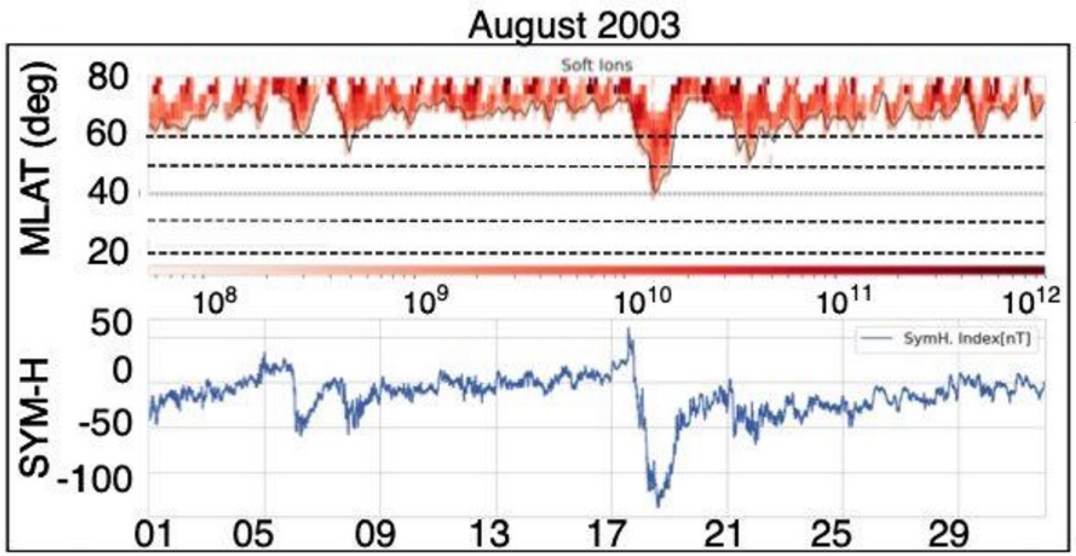


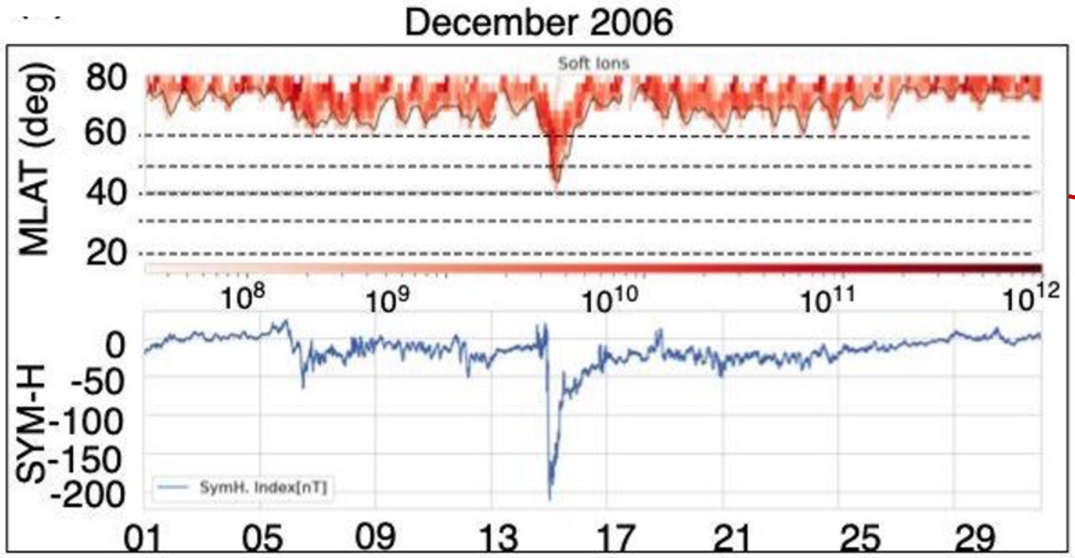
Table 2. Geomagnetic Storms in Which Warm Ions Reached the Lowest MLATs

Date	Minimum SYM-H (nT)	MLAT=ILAT (°) at Earth's surface	Date	Minimum SYM-H (nT)	MLAT=ILAT (°) at Earth's surface
5/04/98 *	-272	45	11/24/01	-230	40
8/27/98 *	-170	40	10/01/02	-150	45
9/25/98 *	-215	40	10/04/02	-125	45
11/08/98	-180	45	8/18/03	-135	40
11/09/98	-130	40	10/30/03 *	-391	30
10/22/99 *	-225	40	10/30/03 *	-432	30
4/07/00 *	-310	35	11/20/03 *	-490	30
7/16/00 *	-340	35	7/25/04	-175	35
8/12/00 *	-235	40	7/27/04 *	-210	30
9/18/00 *	-200	40	11/08/04 *	-400	30
10/05/00 *	-185	45	11/09/04 *	-270	40
3/20/01	-165	45	11/10/04 *	-280	25
3/31/01 *	-430	35	5/15/05 *	-300	50
4/11/01 *	-280	45	9/11/05 *	-135	40
10/21/01 *	-220	45	12/15/06 *	-210	45
11/06/01 *	-320	35			

MLAT/ILAT	L	MLAT/ILAT	L	MLAT/ILAT	L	MLAT/ILAT	L
25°	1.22	30°	1.33	35°	1.5	40°	1.7
45°	2.0	50°	2.4	55°	3.0	60°	4.0

What determines how far equatorward soft ions penetrate? Not only a function of storm size





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MLAT/ILAT	L	MLAT/ILAT	L	MLAT/ILAT	L	MLAT/ILAT	L
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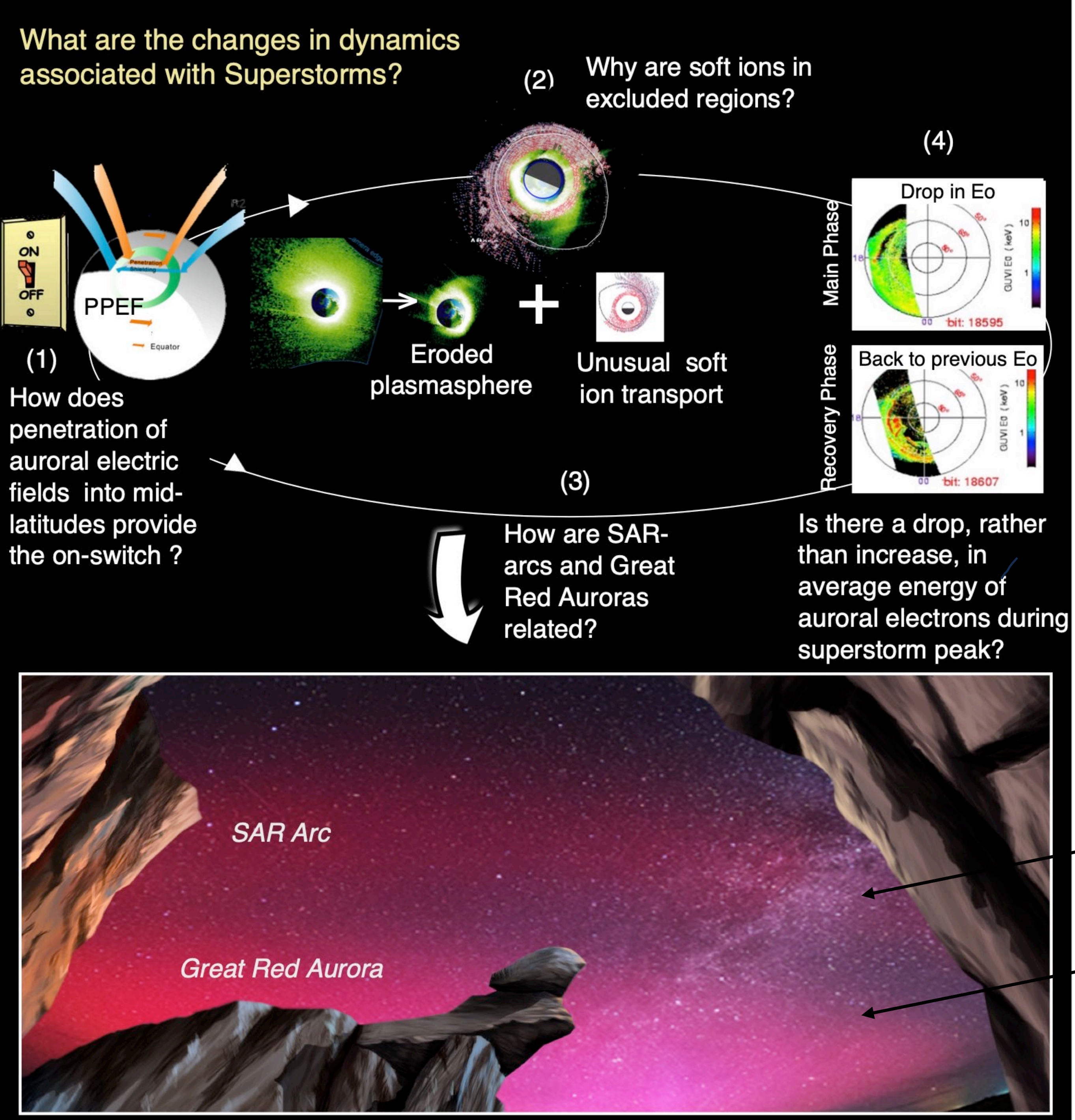

Bottom Line: How are SAR-arcs & Great Red Auroras related?

- SAR-arcs reach high intensities in association with the peak region of soft ions (red)
- Separated from the equatorward edge of the auroral oval (green) by as much as 20° ILAT.
- The Great Red Aurora is associated with the equatorward edge of the auroral oval.
- This raises the possibility that SAR-arcs formed the low-latitude boundary of great red auroras extending them into view of the lowest latitude observers in the historical records.

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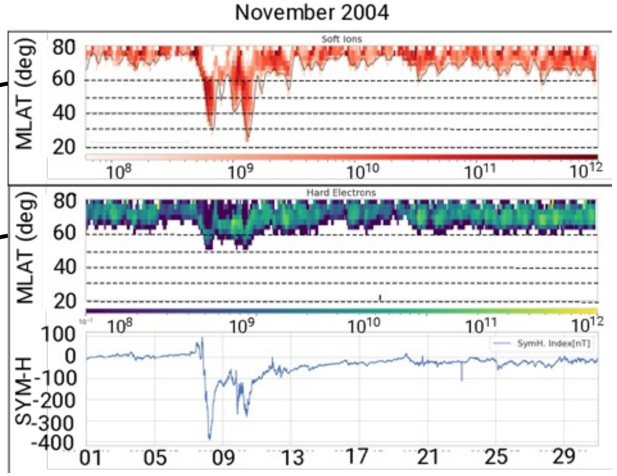

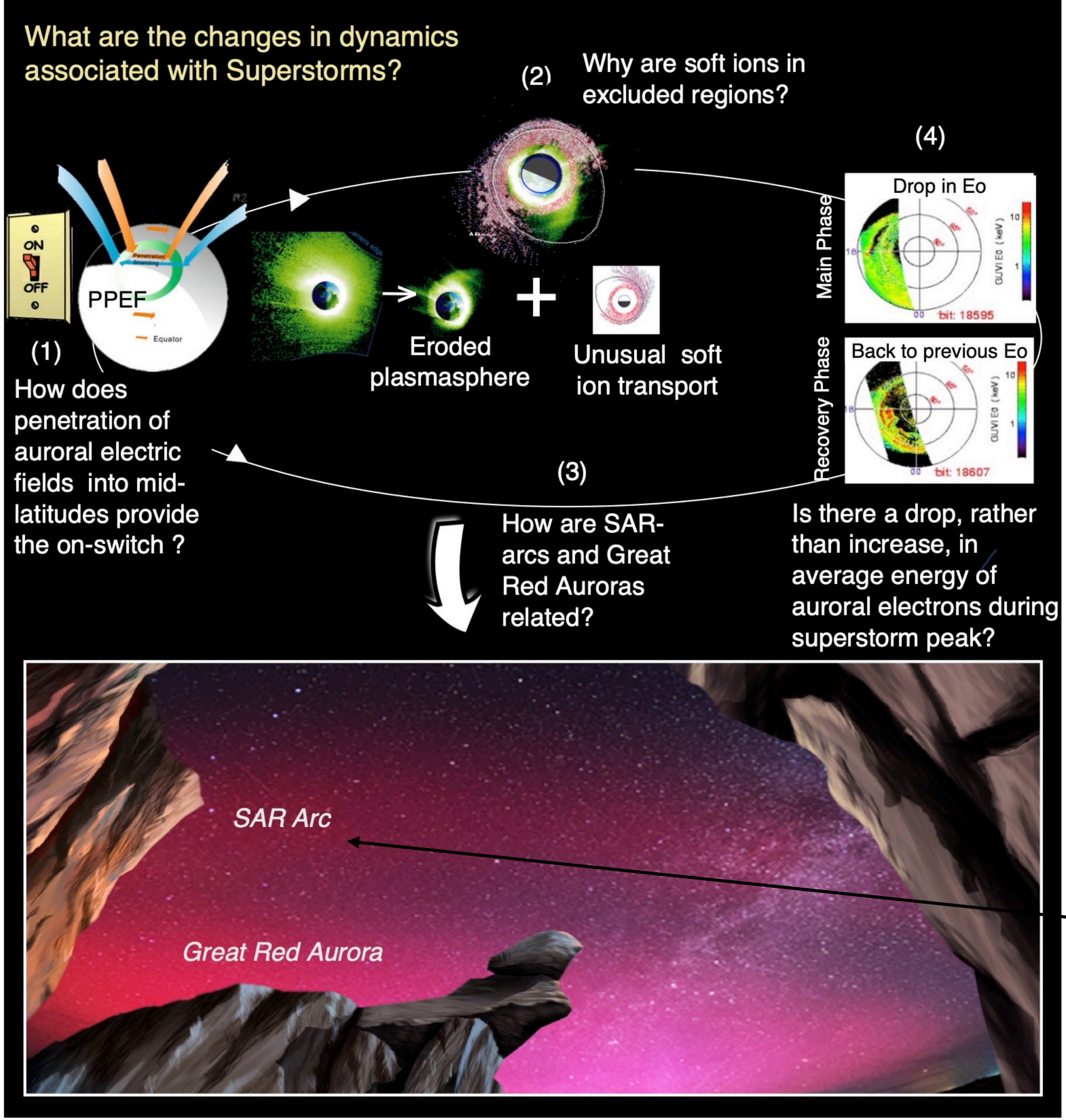

How are SAR-arcs & Great Red Auroras (GRAs) related?

The location at which the soft ions terminate their equatorward motion is the location of maximum heating of the thermal electrons by the soft ions due to Coulomb collisions

It is where the additional enhancement in the electron temperature occurs.

If large enough, this additional temperature increase pushes the SAR-arcs into the visible range.