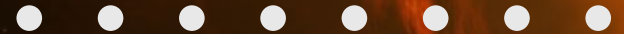


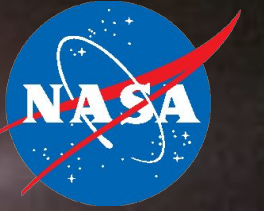
NASA Space Weather Event Response & Vulnerability Space Weather Chain of Events

Presented by Mattie Anastopulos
February 24, 2026



Space Weather Events

- 1 **Solar Flare:** 8 minutes to reach Earth
- 2 **SEP:** Tens of minutes to a few hours
- 3 **CME:** 1 to 4 days (less for very fast events, more for slower events)
- 4 **Coronal Hole High Speed Stream:** Arrive in 2 to 4 days
- 5 **Interplanetary Shock:** Originate from the arrival of a CME or HSS
- 6 **Geomagnetic Storm:** Associated with interplanetary shocks
- 7 **Other Impacts:** Magnetopause Crossing, Radiation Belt Enhancement

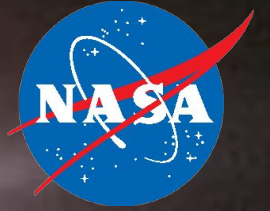


Chains of Events

- 1 Flare/CME
- 2 SEP
- 3 Interplanetary Shock (CME Arrival)
- 4 Geomagnetic Storm
- 5 Magnetopause Crossing
- 6 Radiation Belt Enhancement

- 1 Coronal Hole High Speed Stream
- 2 Geomagnetic Storm
- 3 Radiation Belt Enhancement





Chains of Events

MLK Day Storm

- 1 Flare/CME
- 2 SEP
- 3 Interplanetary Shock (CME Arrival)
- 4 Geomagnetic Storm
- 5 Magnetopause Crossing
- 6 Radiation Belt Enhancement

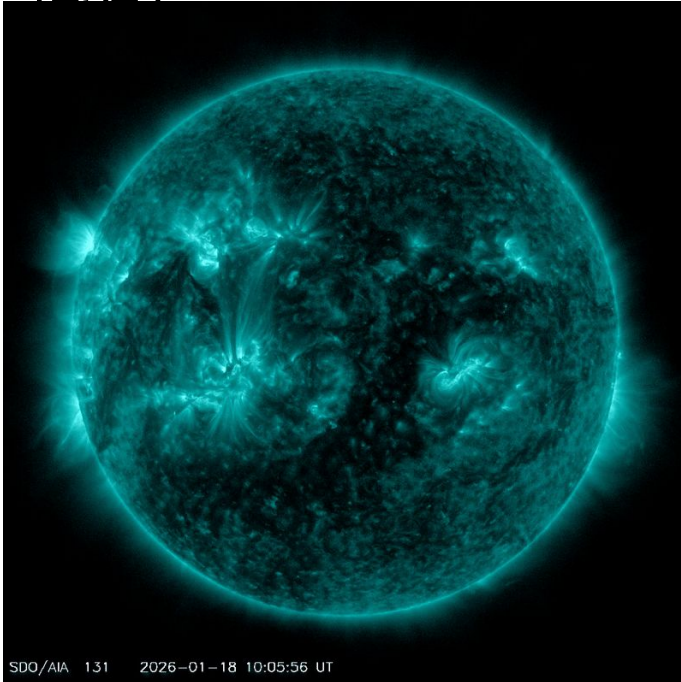
- 1 Coronal Hole High Speed Stream
- 2 Geomagnetic Storm
- 3 Radiation Belt Enhancement



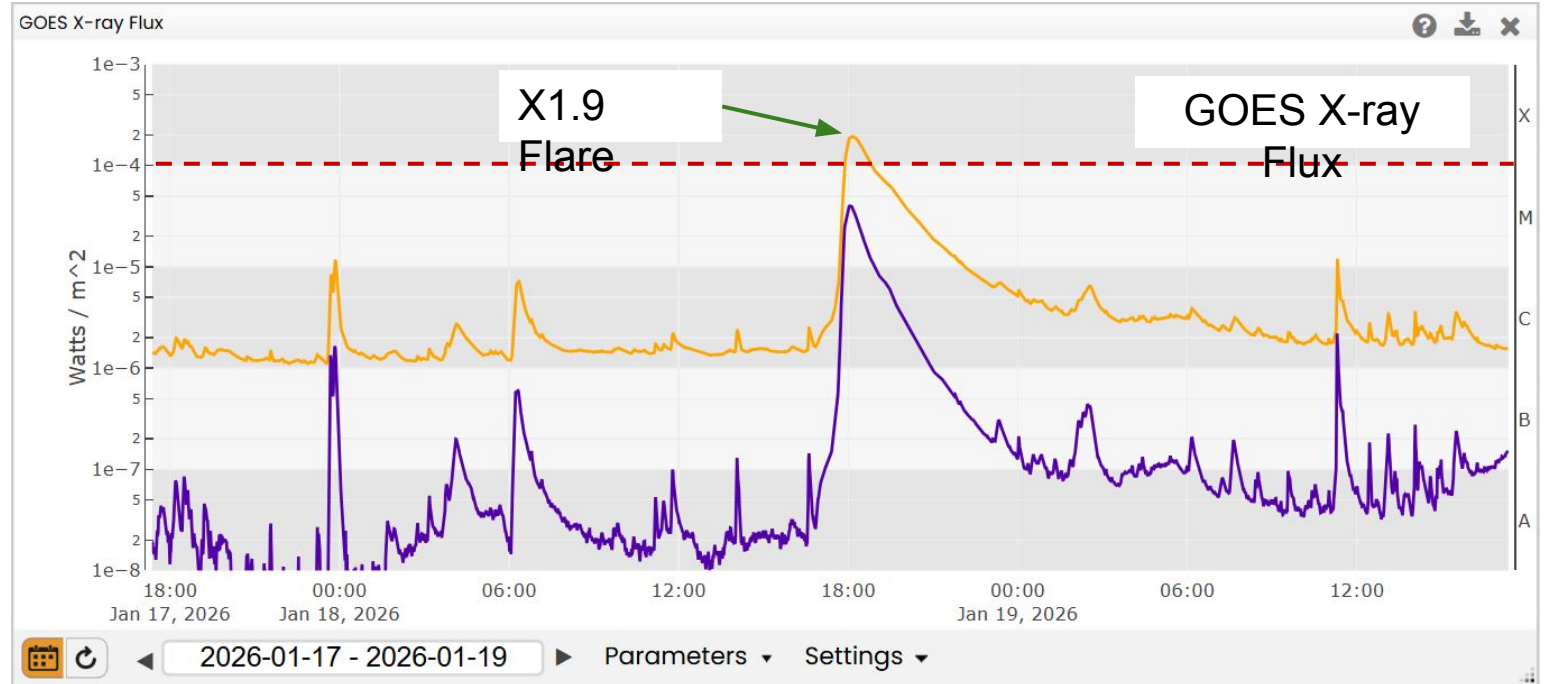
Chain of Events – Solar Flare

2026-01-18T17:27Z - X1.9 Solar Flare from Active Region

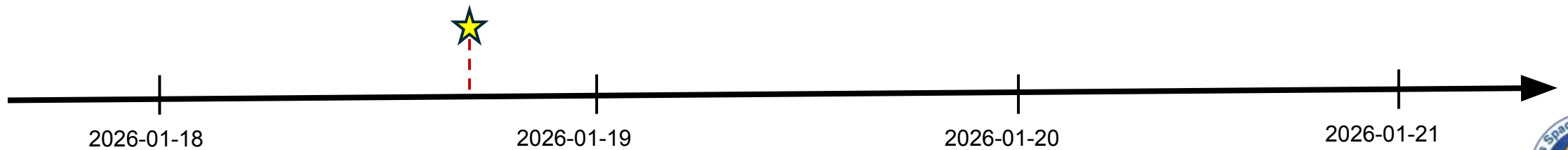
14341



SDO/AIA 131 imagery courtesy of NASA/SDO and the AIA science team



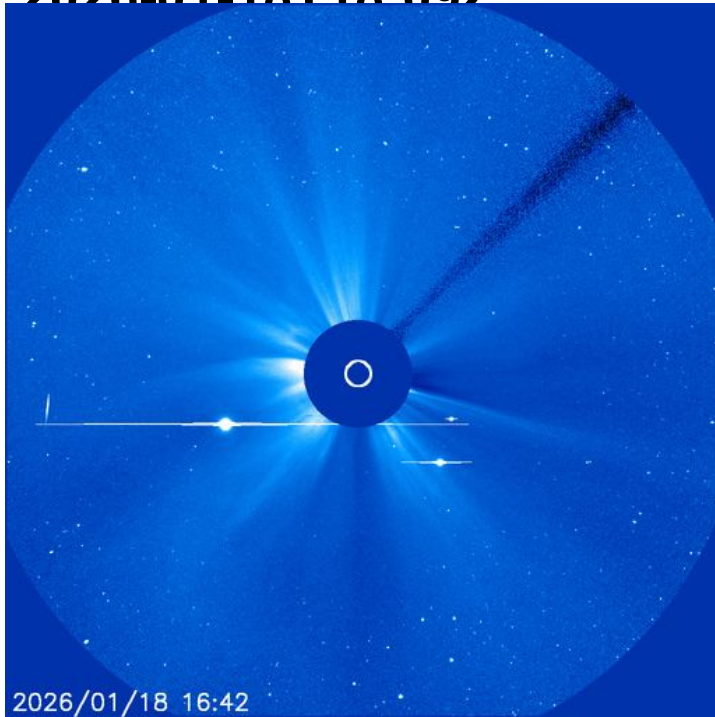
We acknowledge the Community Coordinated Modeling Center (CCMC) for the use of ISWA: <https://ccmc.gsfc.nasa.gov/tools/ISWA/>



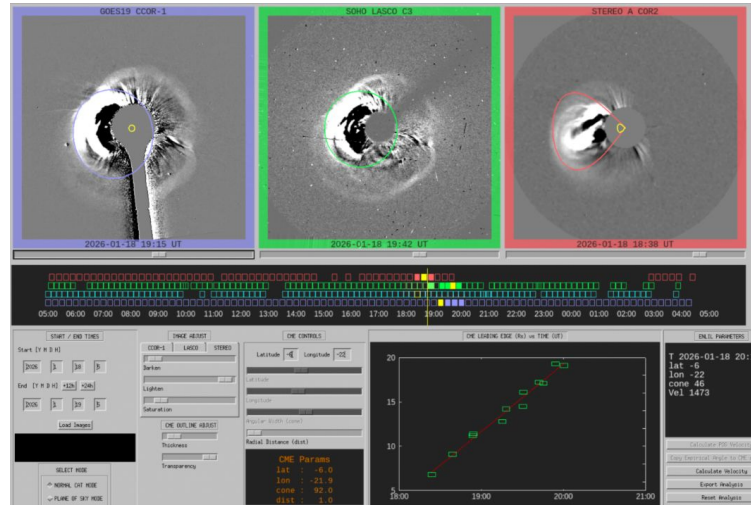
Chain of Events – CME

CME:

2026-01-18T18-09Z

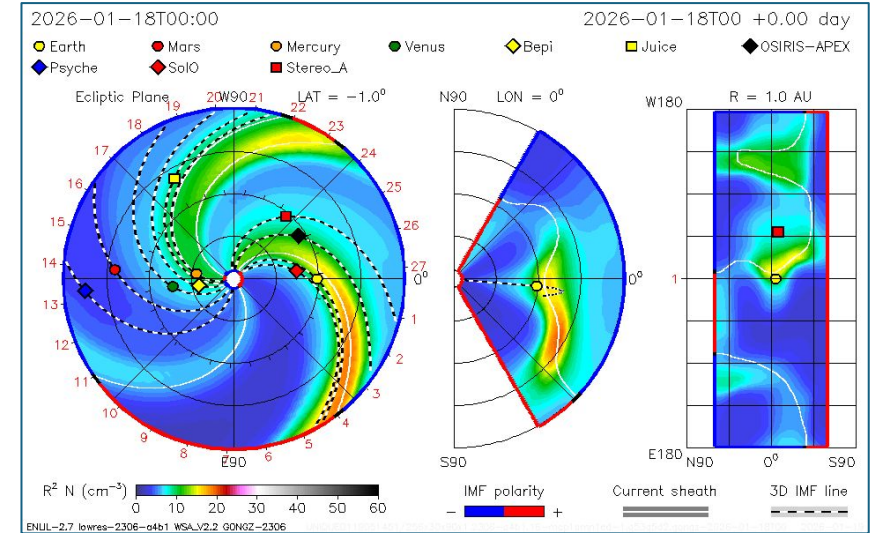


SOHO/LASCO C3 imagery: <https://soho.nascom.nasa.gov/data/Theater/>



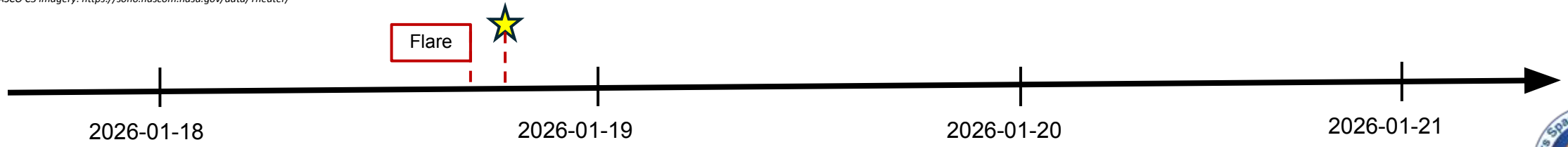
SWPC_CAT tool developed by George Millward and Vic Pizzo at [NOAA SWPC](https://www.noaa.gov/)

Lon/Lat: $-22^\circ / -6^\circ$
 Half-width: 46°
 Velocity: 1473
 km/s



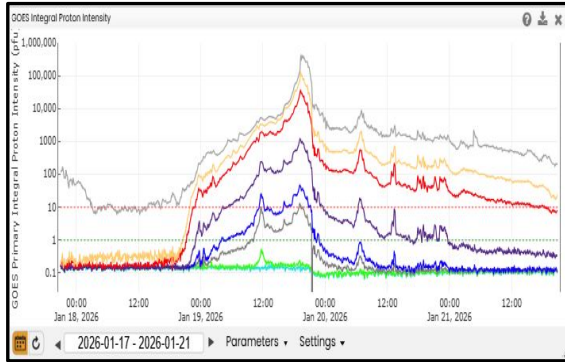
WSA/ENLIL+Cone Model output: https://iswa.gsfc.nasa.gov/downloads/20260118_201700_2_0_anim.tim-den.gif

Predicted Arrival: 2026-01-20T01:22Z
 (+/- 7 hours)

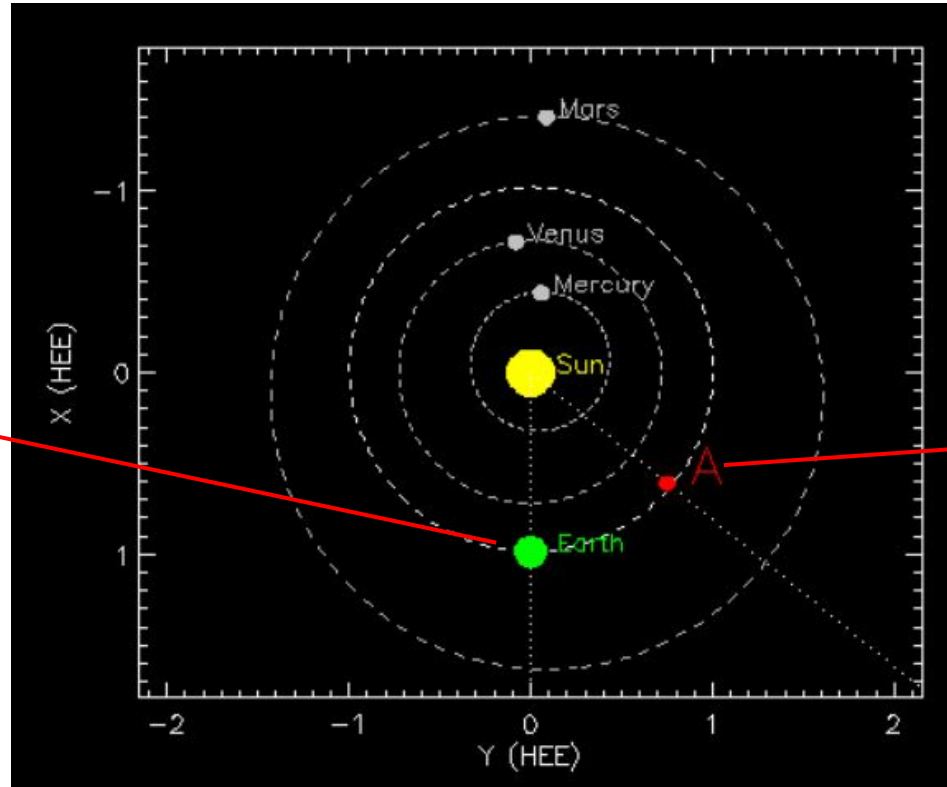
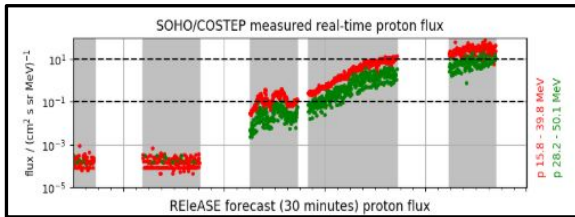


Chain of Events – SEP

GOES



SOHO



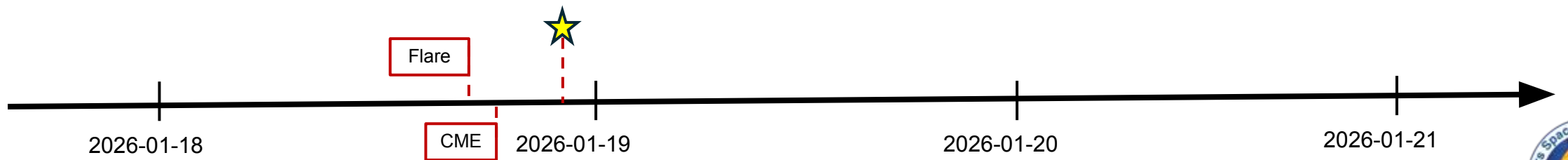
SEP: Tens of minutes to a few hours to reach Earth

STEREO A (51° longitude)



We acknowledge the CCMC for the use of ISWA: <https://ccmc.gsfc.nasa.gov/tools/ISWA/>

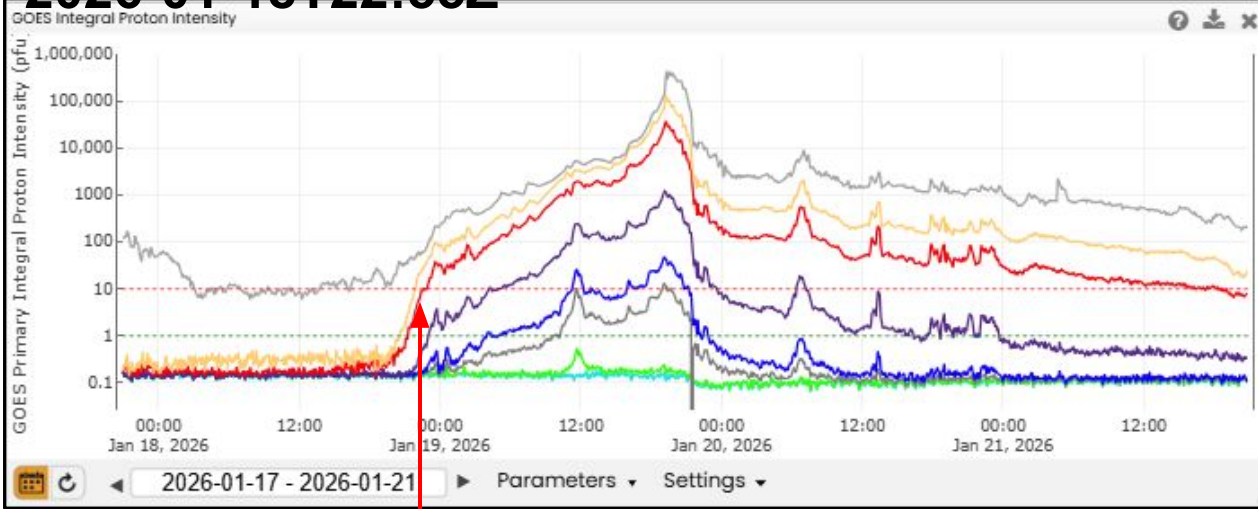
STEREO Science Center: <https://stereo-ssc.nascom.nasa.gov/where.shtml>



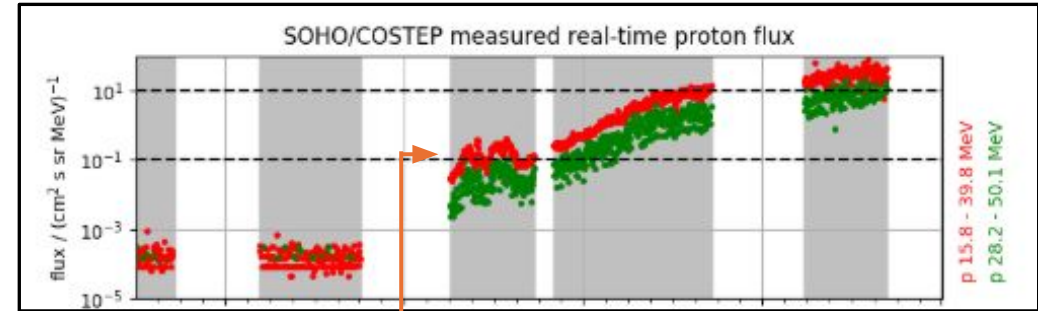
Chain of Events – SEP (continued)

SEP (GOES >10 MeV):

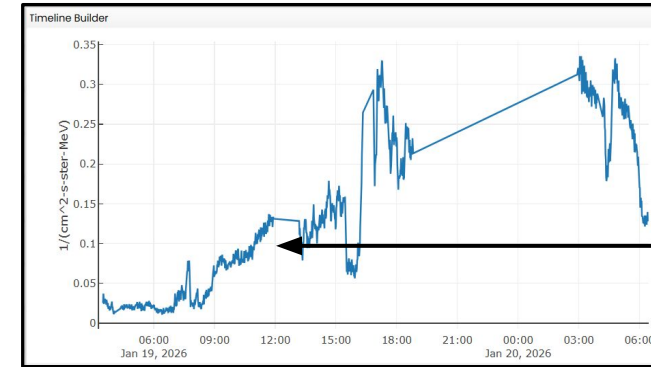
2026-01-18T22:55Z



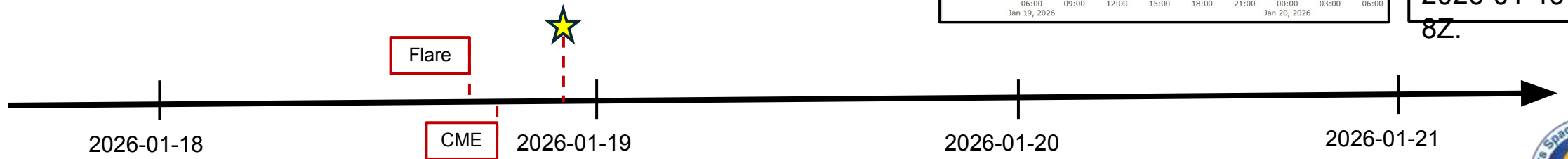
SEP at GOES: The flux of > 10 MeV protons exceeds 10 pfu starting at 2026-01-18T22:55Z.



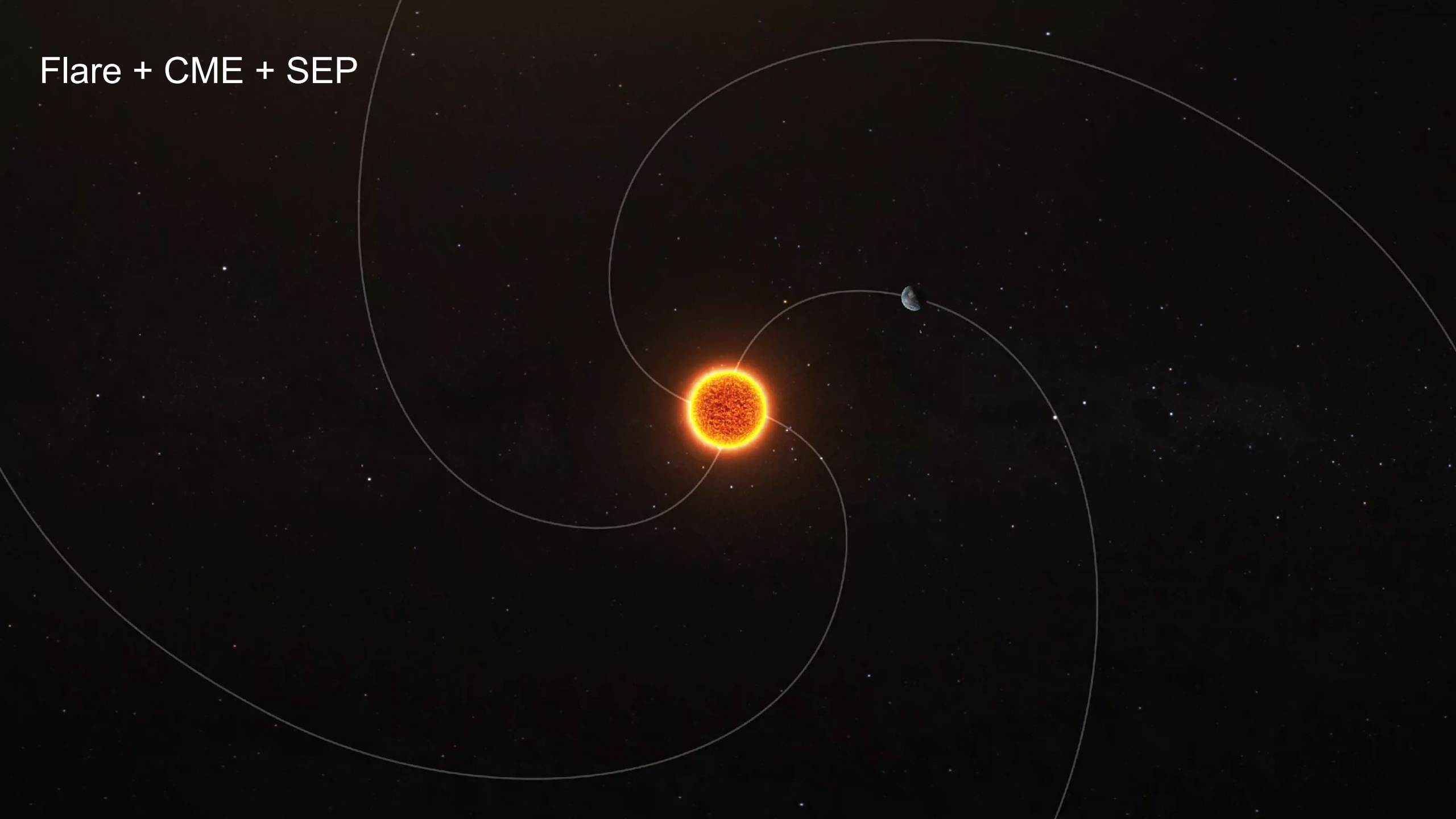
SEP at SOHO COSTEP: The flux of the >15.8 MeV protons channels at SOHO exceeded $10^{(-1)}$ pfu/MeV starting at 2026-01-18T22:33Z.



SEP at STEREO A: The flux of 13-100 MeV protons exceeds $10^{(-1)}$ pfu/MeV starting at 2026-01-19T10:58Z.

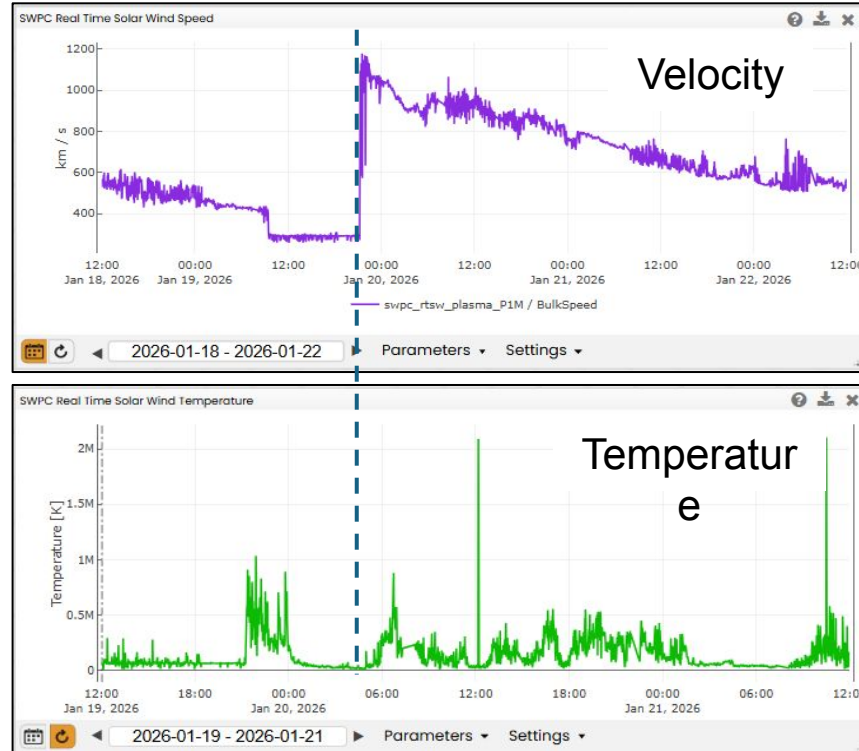
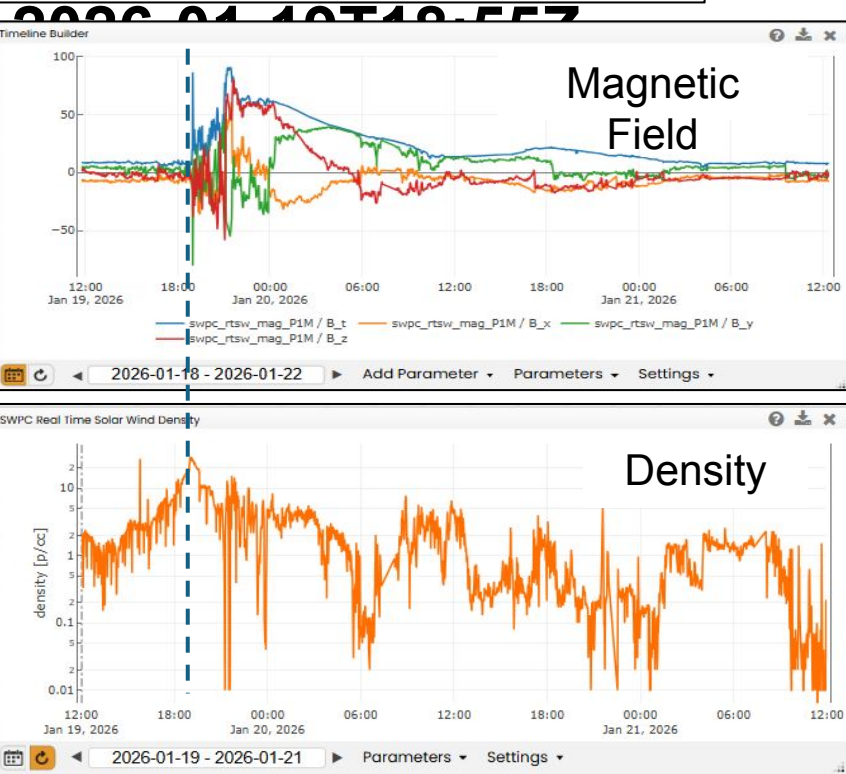


Flare + CME + SEP



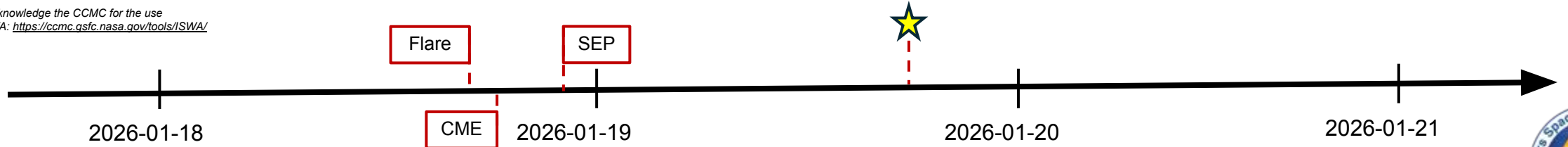
Chain of Events – CME Arrival

IPS:



Predicted Arrival:
2026-01-20T01:22
Z (+/- 7 hours)
Actual Arrival:
2026-01-19T18:55
Z (6.5 hours early)

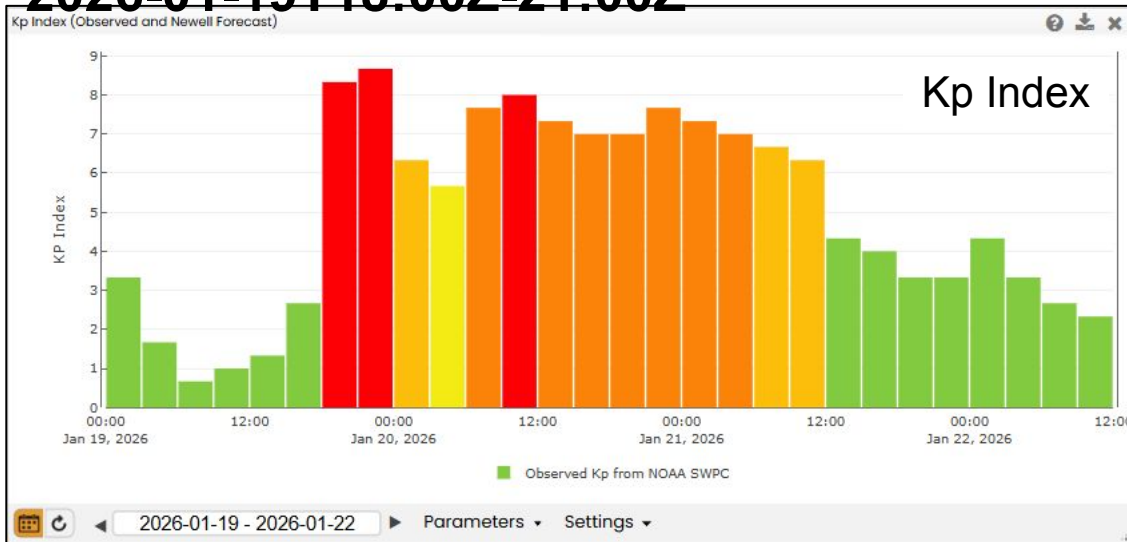
We acknowledge the CCMC for the use of ISWA: <https://ccmc.asfc.nasa.gov/tools/ISWA/>



Chain of Events – Geomagnetic Storm

GST:

2026-01-19T18:00Z-21:00Z



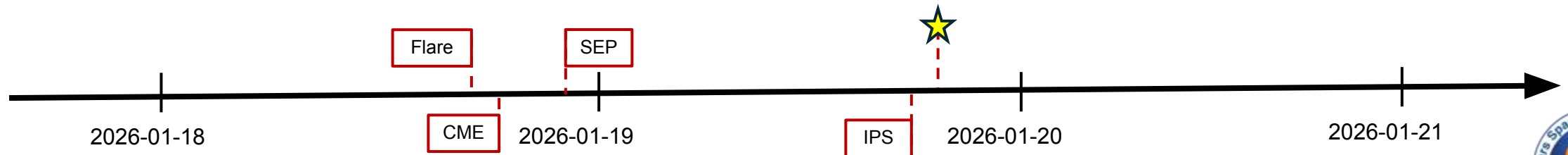
We acknowledge the CCMC for the use of ISWA: <https://ccmc.gsfc.nasa.gov/tools/ISWA/>

Scale	Description	Physical measure
G 5	Extreme	Kp = 9
G 4	Severe	Kp = 8, including a 9-
G 3	Strong	Kp = 7
G 2	Moderate	Kp = 6
G 1	Minor	Kp = 5

NOAA: <https://www.swpc.noaa.gov/noaa-scales-explanation>

Severe geomagnetic storm observed with 14 total synoptic periods of geomagnetic storming.

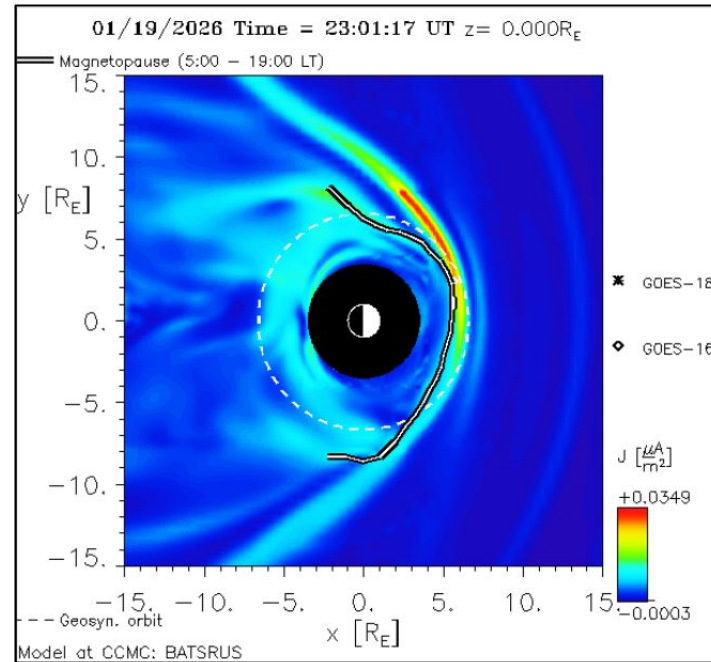
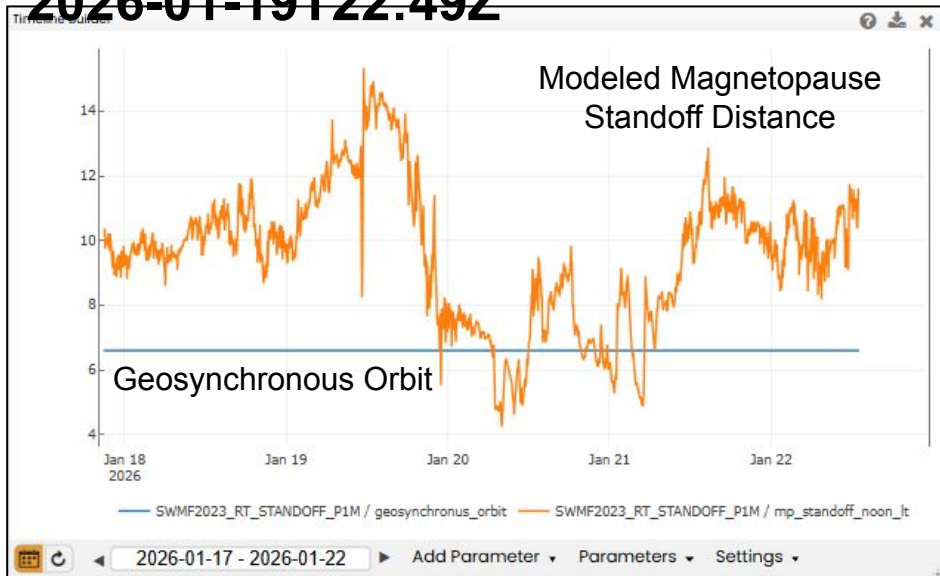
The Kp index (“planetarische Kennziffer”) quantifies disturbances in the horizontal component of Earth’s magnetic field with values ranging from 0-9.



Chain of Events – Magnetopause Crossing

MPC:

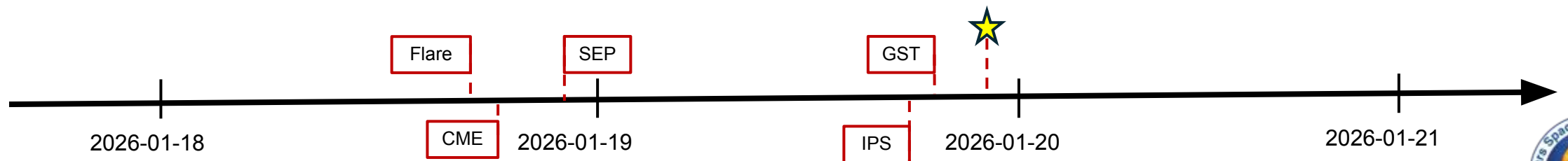
2026-01-19T22:49Z



Modeled Magnetopause Crossing:
 “Strong compression of the magnetosphere detected. Simulations carried out at the NASA Community Coordinated Modeling Center indicate that the magnetopause separating magnetospheric and solar wind plasma is close to the geosynchronous orbit starting at 2026-01-19T22:49Z... NASA spacecraft at geosynchronous orbits may be exposed to solar wind plasma and magnetic field conditions.”

We acknowledge the CCMC for the use of ISWA: <https://ccmc.gsfc.nasa.gov/tools/ISWA/>

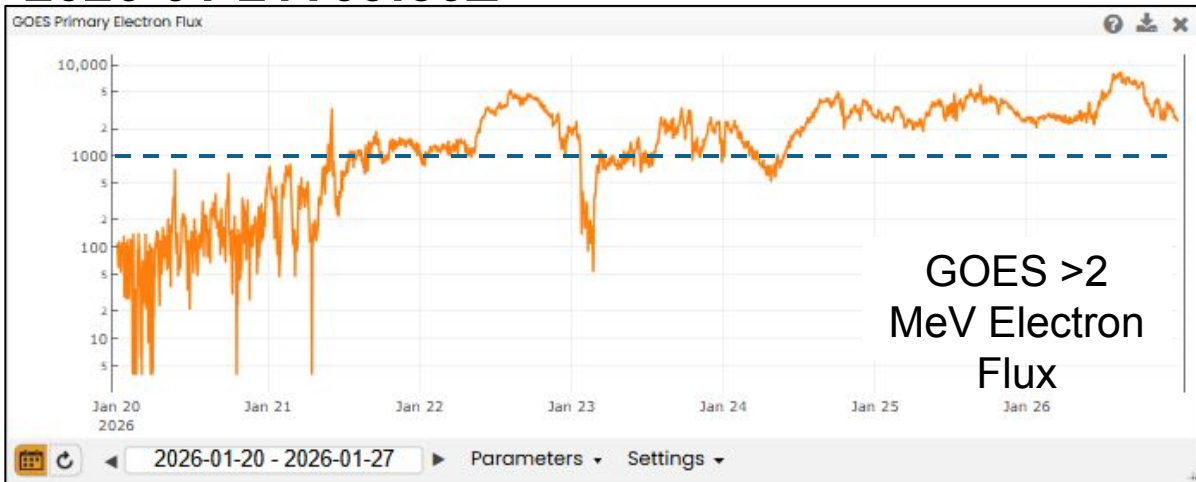
SWMF Model: <https://ccmc.gsfc.nasa.gov/models/SWMF-2023/>



Chain of Events – Radiation Belt Enhancement

RBE:

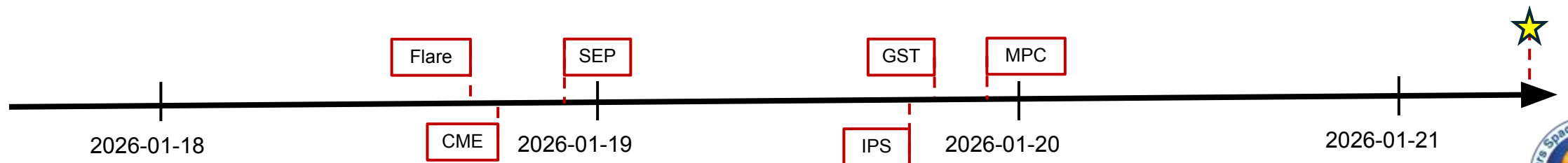
2026-01-21T09:30Z



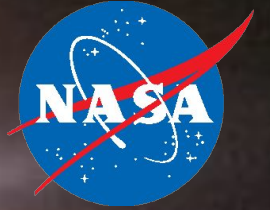
We acknowledge the CCMC for the use of ISWA: <https://ccmc.gsfc.nasa.gov/tools/ISWA/>

Radiation Belt Enhancement:

“Significantly elevated energetic electron fluxes in the Earth's outer radiation belt. **GOES "greater than 2.0 MeV" integral electron flux is above 1000 pfu starting at 2026-01-21T09:30Z...** NASA spacecraft at GEO, MEO and other orbits passing through or in the vicinity of the Earth's outer radiation belt can be impacted.”



Chains of Events



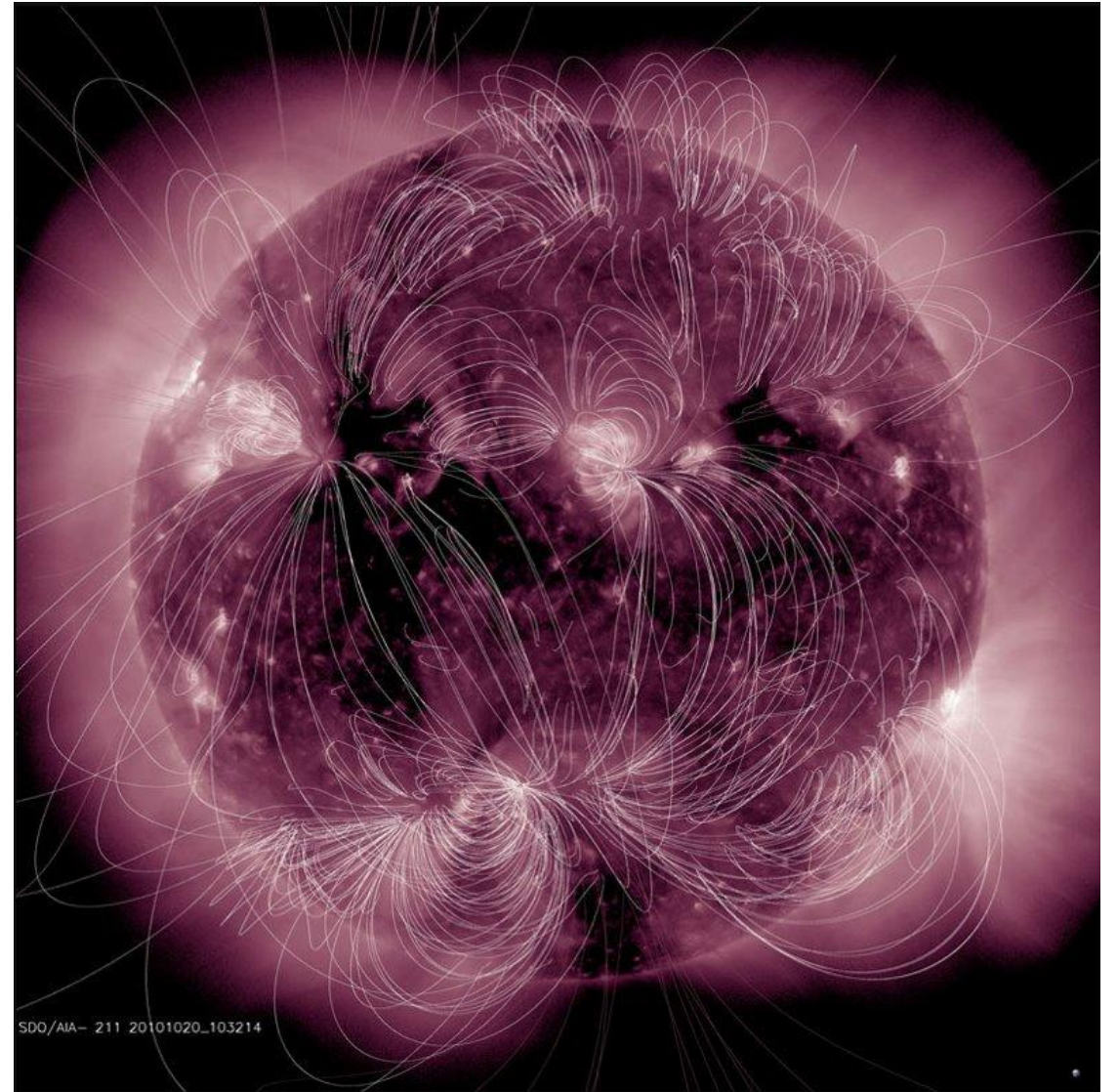
- 1 Flare/CME
- 2 SEP
- 3 Interplanetary Shock (CME/HSS Arrival)
- 4 Geomagnetic Storm
- 5 Magnetopause Crossing
- 6 Radiation Belt Enhancement

- 1 Coronal Hole High Speed Stream
- 2 Geomagnetic Storm
- 3 Radiation Belt Enhancement



Coronal Hole High Speed Streams

- Correspond to regions of “open” magnetic fields – the field lines extend into interplanetary space instead of connecting back to the Sun
- This results in areas that are cooler and less dense, creating the appearance of a “hole” in the Sun



NASA/SDO AIA + PFSS (potential field source surface model): <https://sdo.gsfc.nasa.gov/gallery/main/item/37>

Stream Interaction Regions (SIRs) and CIRs

- Since high speed streams are less tightly wound on the Parker spiral compared to slower ambient solar wind, the faster solar wind overtakes the slower wind ahead of it and creates a compression region called a “stream interaction region” or SIR
- High speed streams from persistent coronal holes over multiple solar rotations are called corotating interaction regions (CIRs).

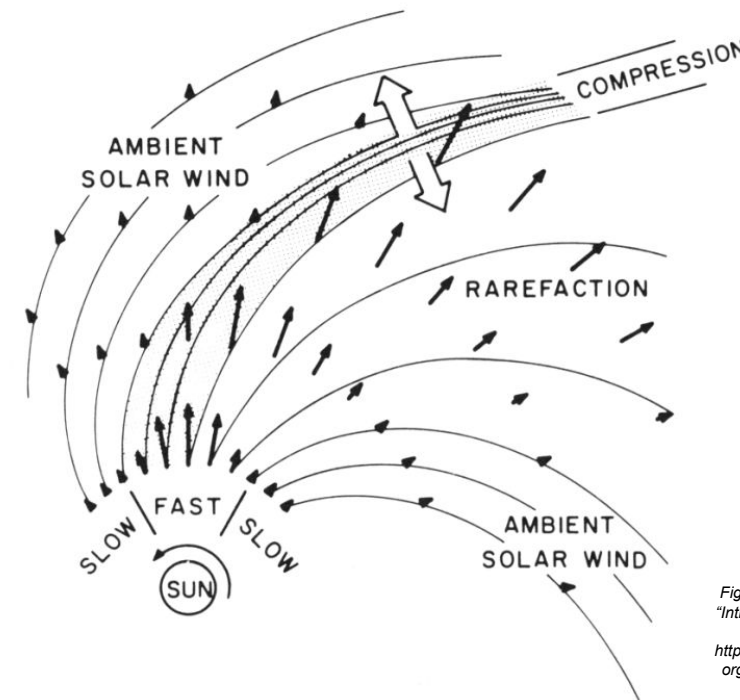
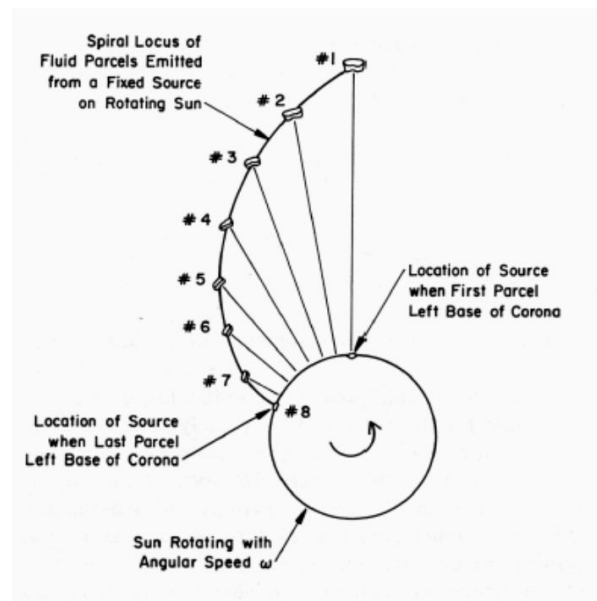
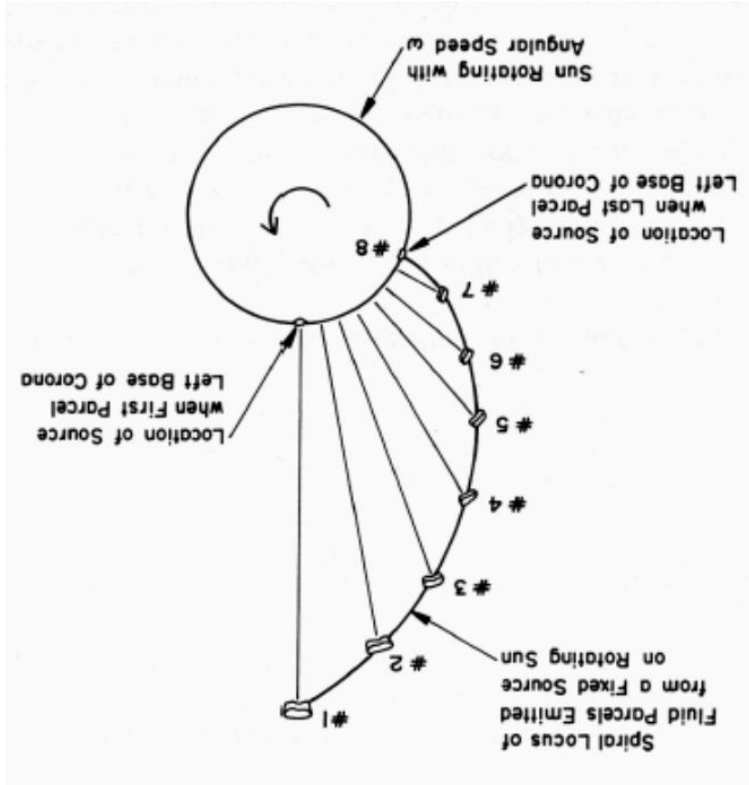
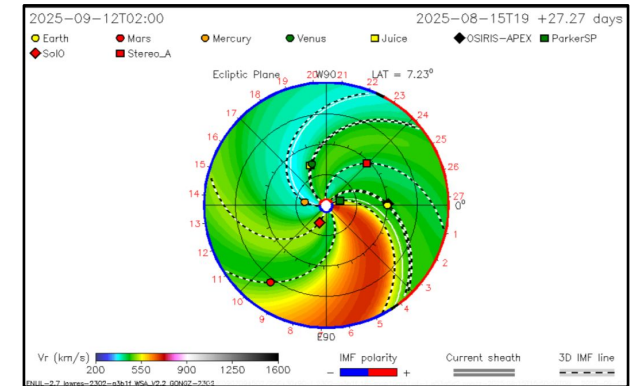
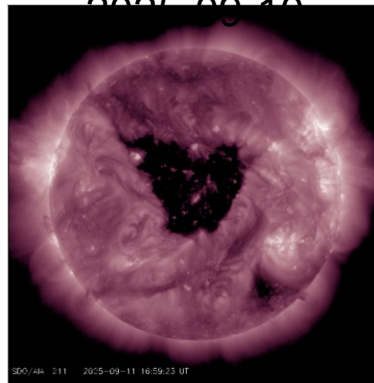


Fig 4.5 and 4.13 from "Introduction to Space Physics" textbook <http://www.cambridge.org/us/knowledge/isbn/item1145043>

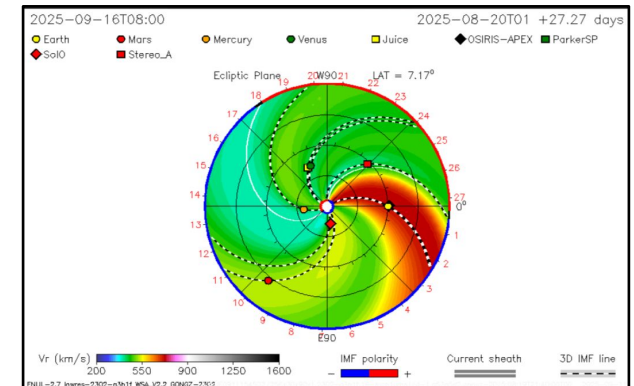
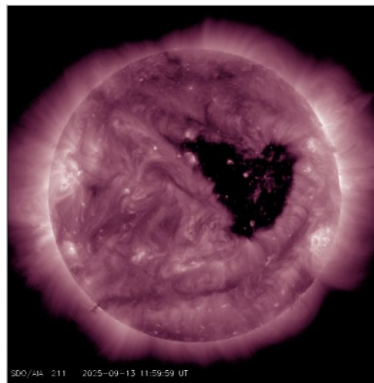
Chain of Events – Coronal Hole



Central Meridian –



Geoeffective – 2025-09-14



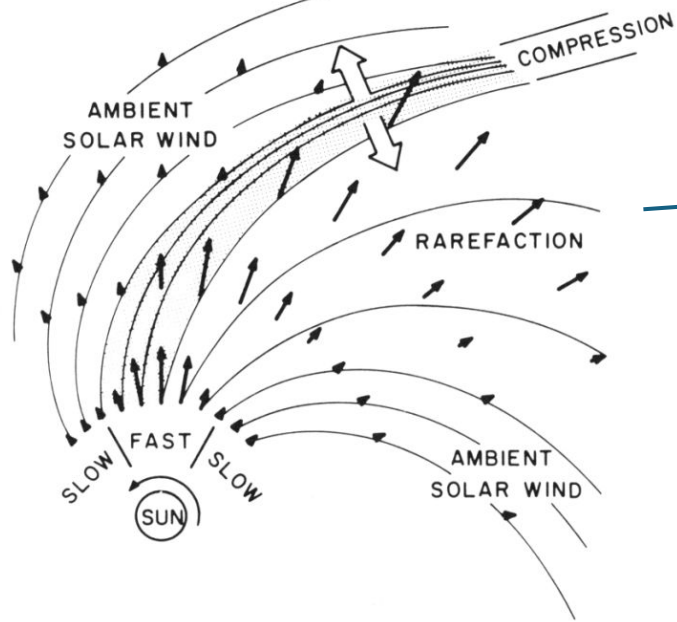
NASA/SDO AIA 211

ENLIL Model: <https://ccmc.gsfc.nasa.gov/models/ENLIL~2.9e>

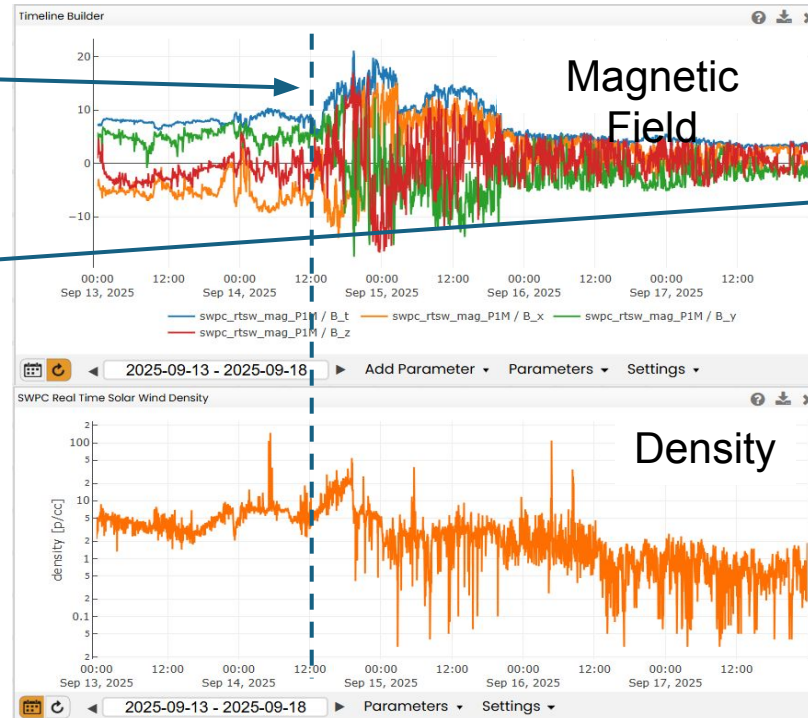


Chain of Events – Coronal Hole High Speed Stream

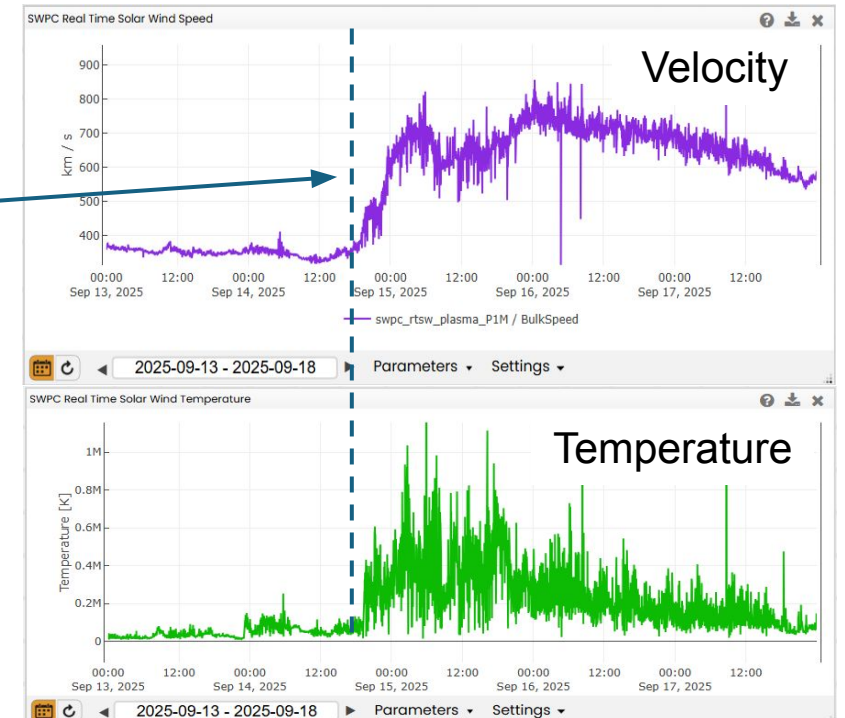
HSS:
2025-09-14T19:10Z



CIR: 2025-09-14T12:00Z



HSS: 2025-09-14T19:10Z



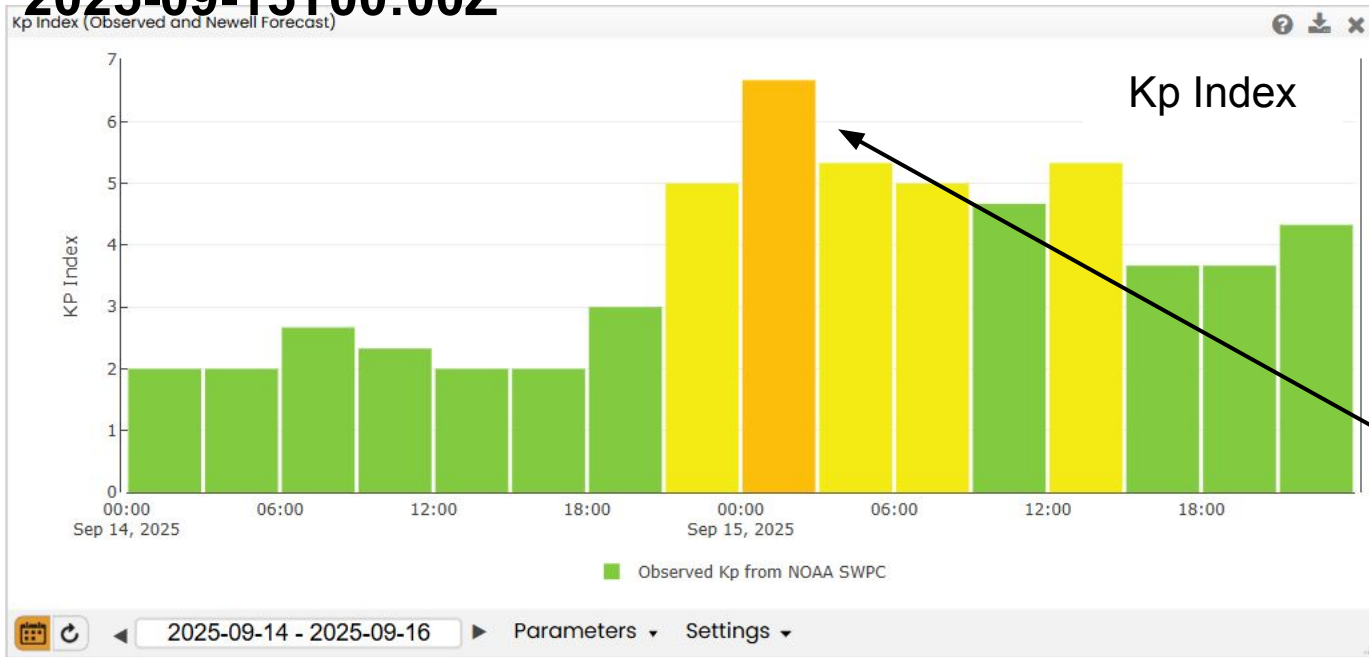
We acknowledge the CCMC for the use of ISWA: <https://ccmc.gsfc.nasa.gov/tools/ISWA/>



Chain of Events – Geomagnetic Storm

GST:

2025-09-15T00:00Z

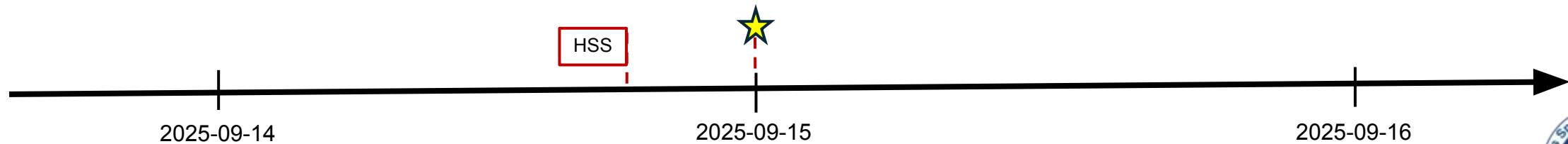


Scale	Description	Physical measure
G 5	Extreme	Kp = 9
G 4	Severe	Kp = 8, including a 9-
G 3	Strong	Kp = 7
G 2	Moderate	Kp = 6
G 1	Minor	Kp = 5

Geomagnetic storms related to high speed streams are typically longer in duration but weaker overall

NOAA: <https://www.swpc.noaa.gov/noaa-scales-explanation>

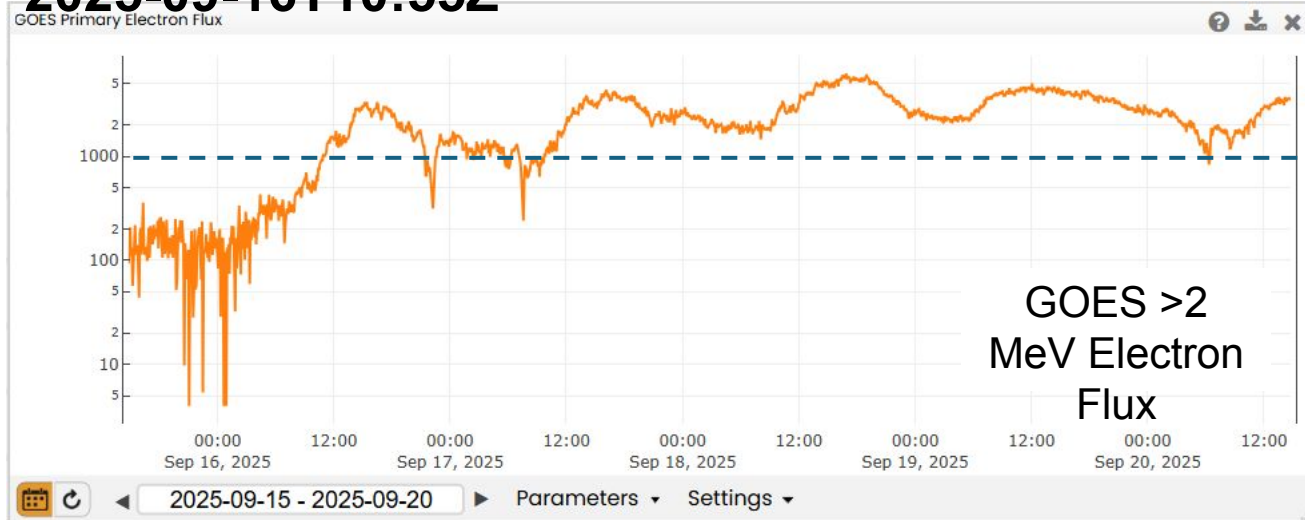
We acknowledge the CCMC for the use of ISWA: <https://ccmc.gsfc.nasa.gov/tools/ISWA/>



Chain of Events – Radiation Belt Enhancement

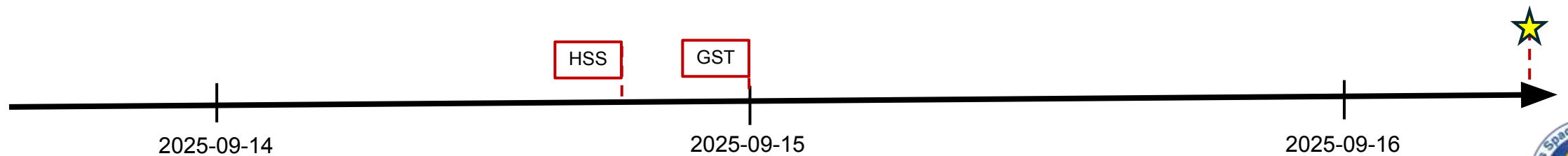
RBE:

2025-09-16T10:55Z



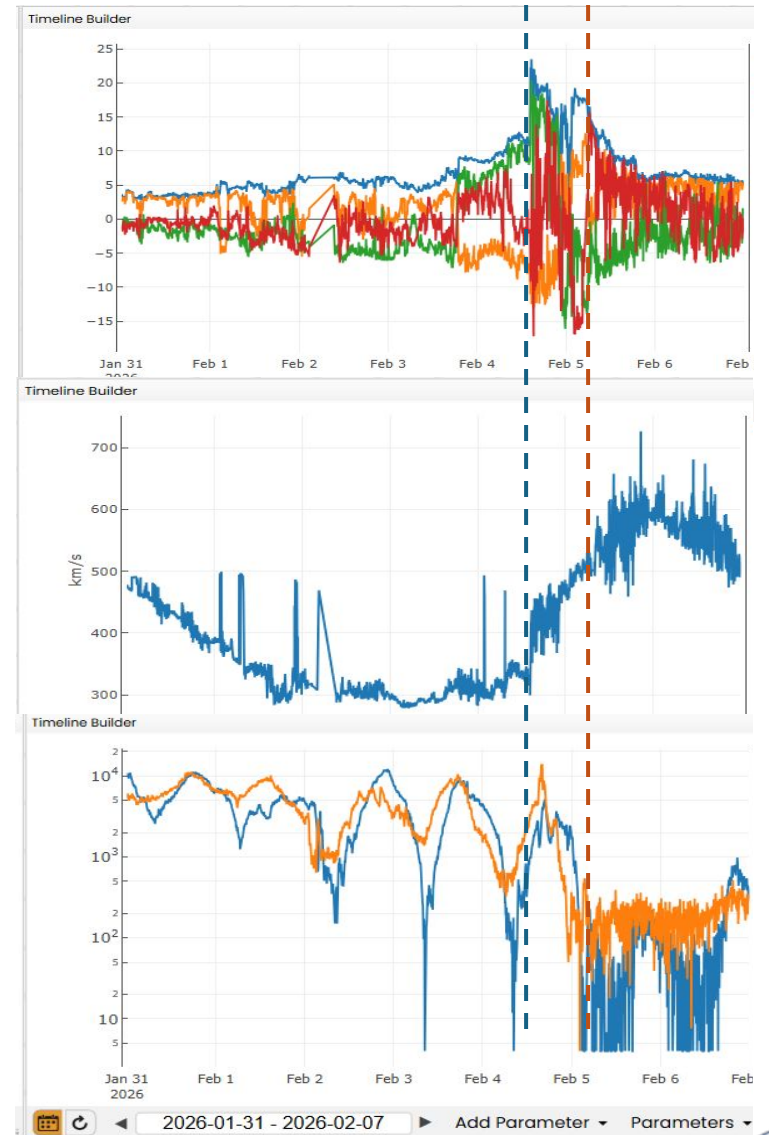
We acknowledge the CCMC for the use of ISWA: <https://ccmc.asfc.nasa.gov/tools/ISWA/>

Radiation Belt Enhancement:
“Significantly elevated energetic electron fluxes in the Earth's outer radiation belt. GOES "greater than 2.0 MeV" integral electron flux is above 1000 pfu starting at 2025-09-16T10:55Z... NASA spacecraft at GEO, MEO and other orbits passing through or in the vicinity of the Earth's outer radiation belt can be impacted.”



In Real Time...

- Events develop in “real time” requiring you to make an assessment based only on the available data, not what you expect may happen.
- Multiple chain of events can occur at the same time.
- Mystery/surprise signatures may arise from lack of available data.



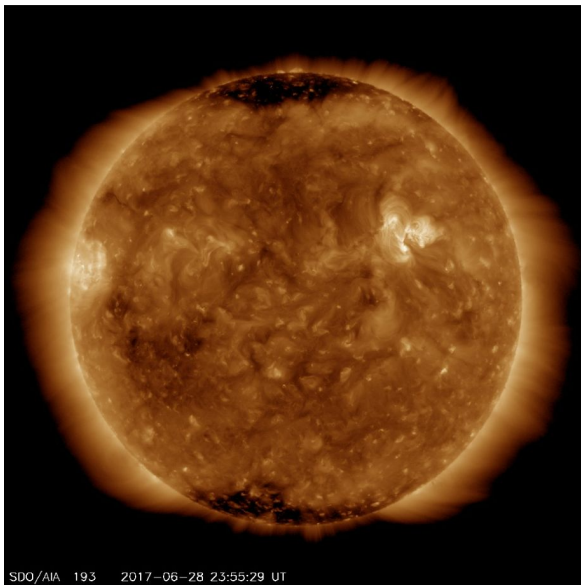
We acknowledge the CCMC for the use of ISWA: <https://ccmc.gsfc.nasa.gov/tools/ISWA/>



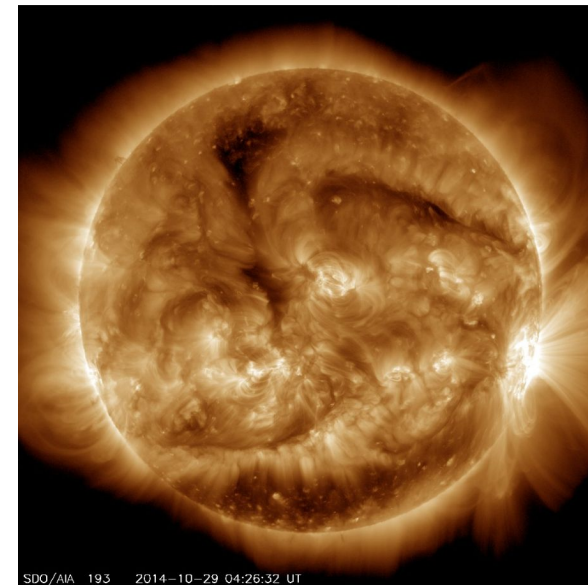
Solar Minimum vs Solar Maximum

- Coronal holes can form at any time during the solar cycle.
- During solar minimum large coronal holes tend to be prominent near the poles and can be present for up to ~7 years.
- During solar maximum coronal holes exist at all latitudes but are less persistent.

Solar Minimum: 2017



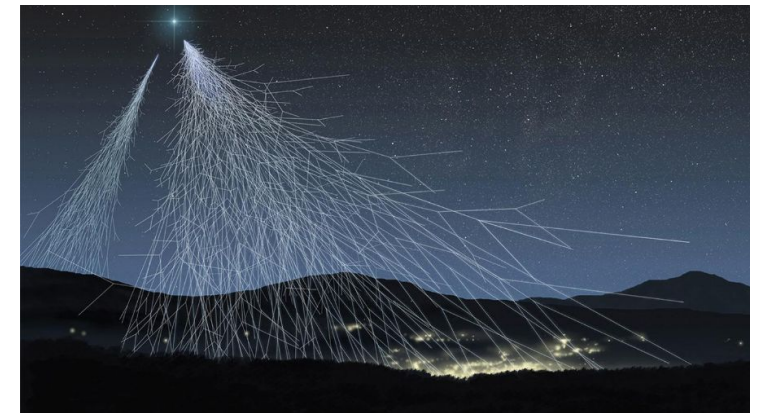
Solar Maximum: 2014



NASA/SDO AIA 193

Other Phenomena - Galactic Cosmic Rays

- High energy particles originating outside of the solar system (i.e. from supernova).
- Anticorrelated with solar activity: more intense during solar minimum. During solar maximum, the expanded heliosphere acts as a shield from less energetic GCRs.
- GCRs can damage hardware on spacecraft and pose a radiation hazard to astronauts on crewed missions.




<https://news.uchicago.edu/explainer/what-are-cosmic-rays>

Chain of Events Summary

1 Flare/CME 

2 SEP 

3 Interplanetary Shock (CME Arrival) 

4 Geomagnetic Storm 

5 Magnetopause Crossing 

6 Radiation Belt Enhancement 

1 High Speed Stream 

2 Geomagnetic Storm 

3 Radiation Belt Enhancement 

