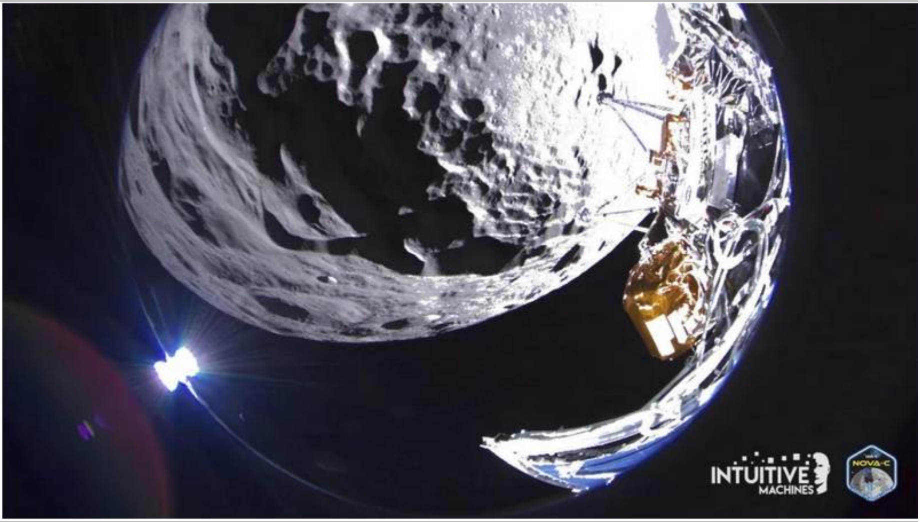
Smart Lander for Investigating the Moon (SLIM)
Jan 2024 (Image: JAXA)

Odysseus Lunar Lander
Feb 2024 (Image: Intuitive Machines)



SCAF 2024: Welcome and NASA Introductory Comments

Joseph I. Minow, PhD
Technical Fellow for Space Environments
NASA Engineering and Safety Center
NASA, Marshall Space Flight Center

Spacecraft Anomalies and Failures 2024
27 March 2024, GSFC, Greenbelt, MD

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Outline

- Introduction and logistics
- Comments on state of Solar Cycle 25 space environment
- Introduction to Day 1 presentations

Introduction

- Welcome to NASA GSFC and SCAF 2024!

- Logistics
  - Fire, weather, restrooms
  - Maps to on-site cafeteria, food options off-ste at check-in desk

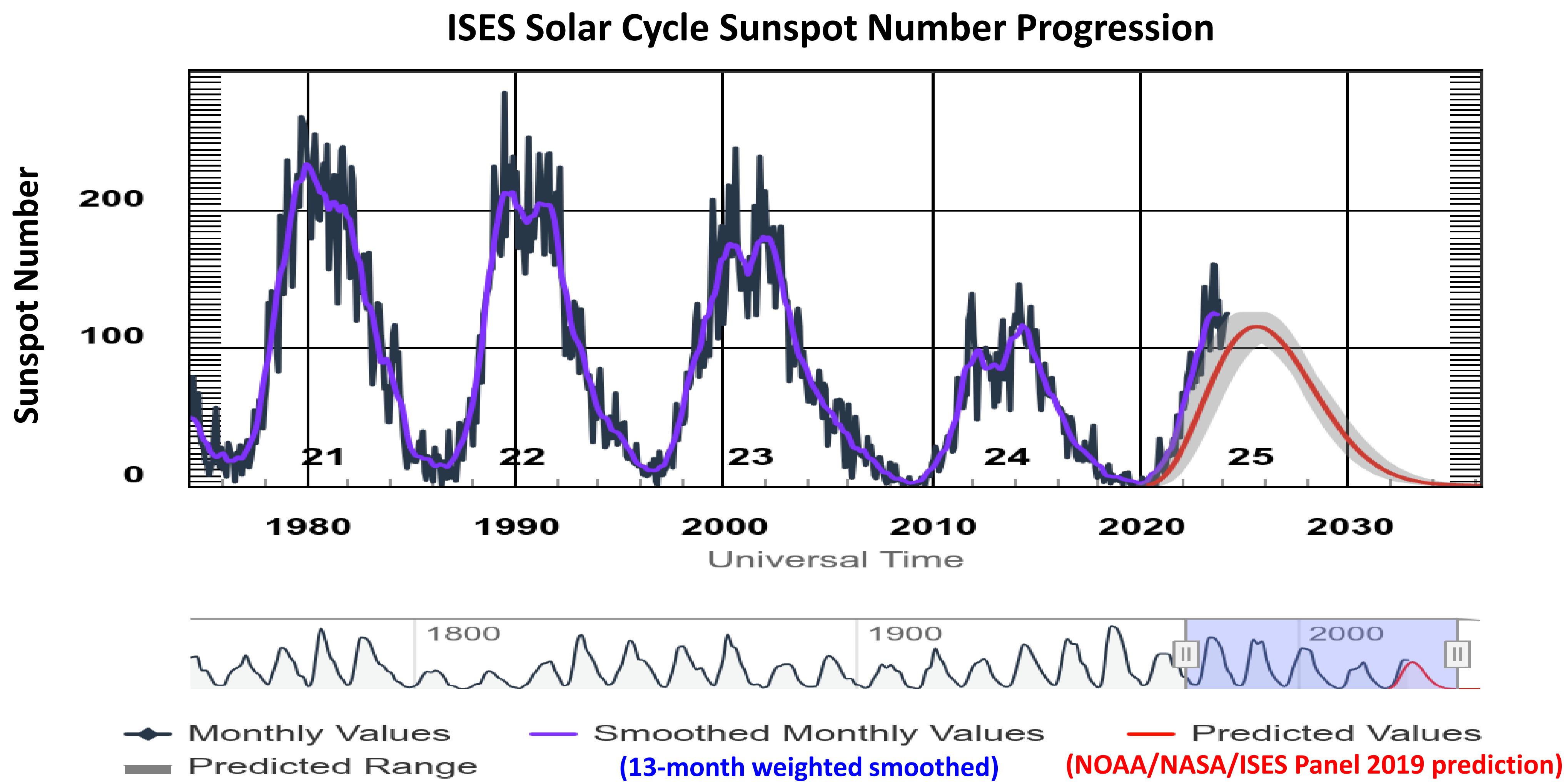
- Wi-fi is available in the auditorium:
  - NASA personnel connect to NASA Device network
  - Non-NASA personnel connect to NASA Guest network

- Session chairs
  - Day 1: Joseph Minow — NASA/MSFC
  - Day 2: Michael Manning — NRO

- Organizing committee
  - Mike Campola — NASA/GSFC
  - Martha Obryan — GSFC/SSAI
  - Linda Parker — MSFC/Space Weather Solutions
  - Mike Squire — NASA/LARC
  - Yihua Zheng — NASA/GSFC

- Let us know if you have questions or need help today!

Solar Activity



NOAA Space Weather Prediction Center
https://www.swpc.noaa.gov/products/solar-cycle-progression

New SWPC Solar Cycle Progression Predictions (Experimental)

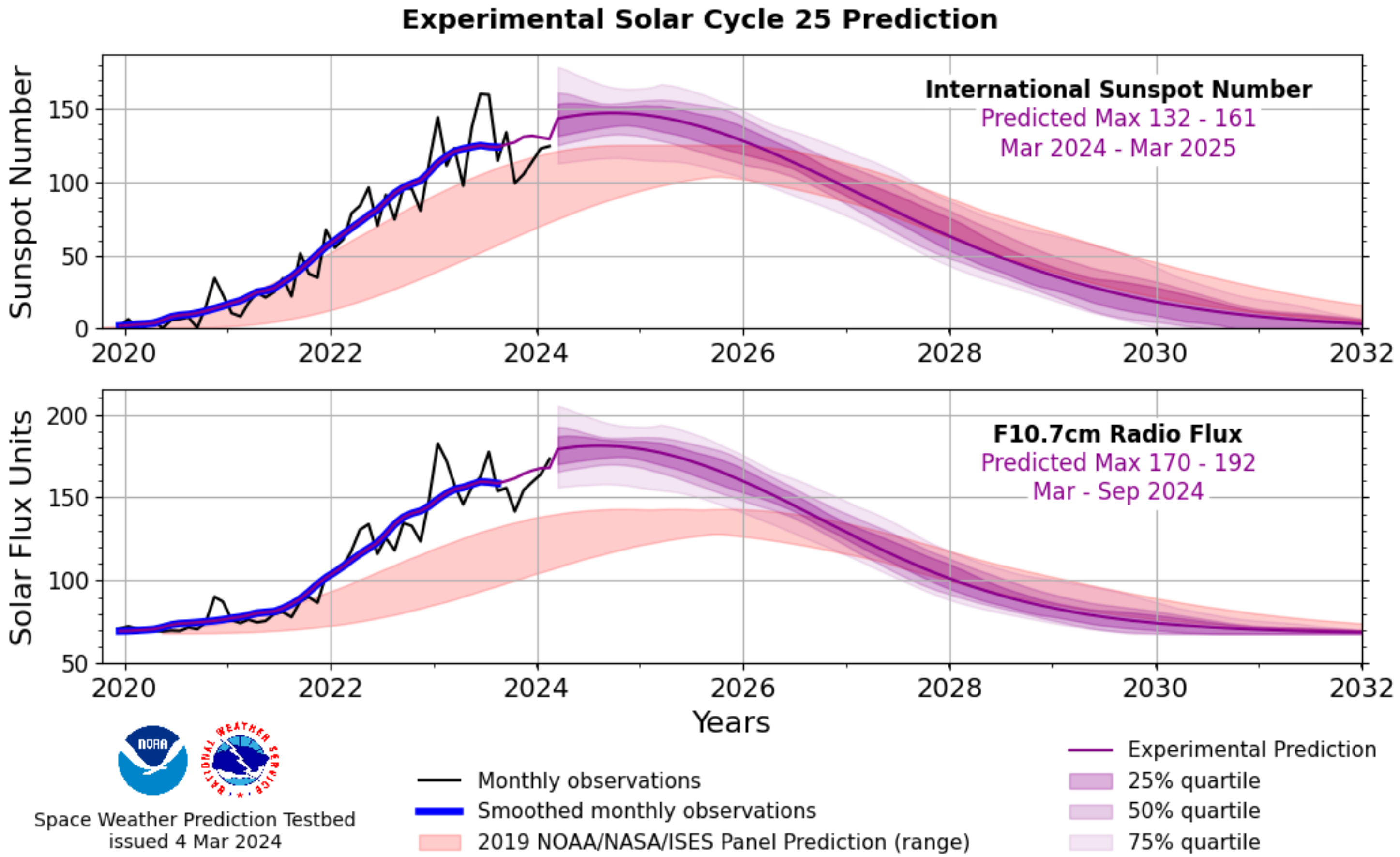
- NOAA's Space Weather Prediction Center released an updated solar cycle progression prediction in December 2023

https://testbed.swpc.noaa.gov/products/solar-cycle-progression-updated-prediction-experimental

- NOAA/NASA/ISES Panel 2019 prediction
    - Cycle 25 peak in July 2025
    - SSN of 115 (range 105 – 125)

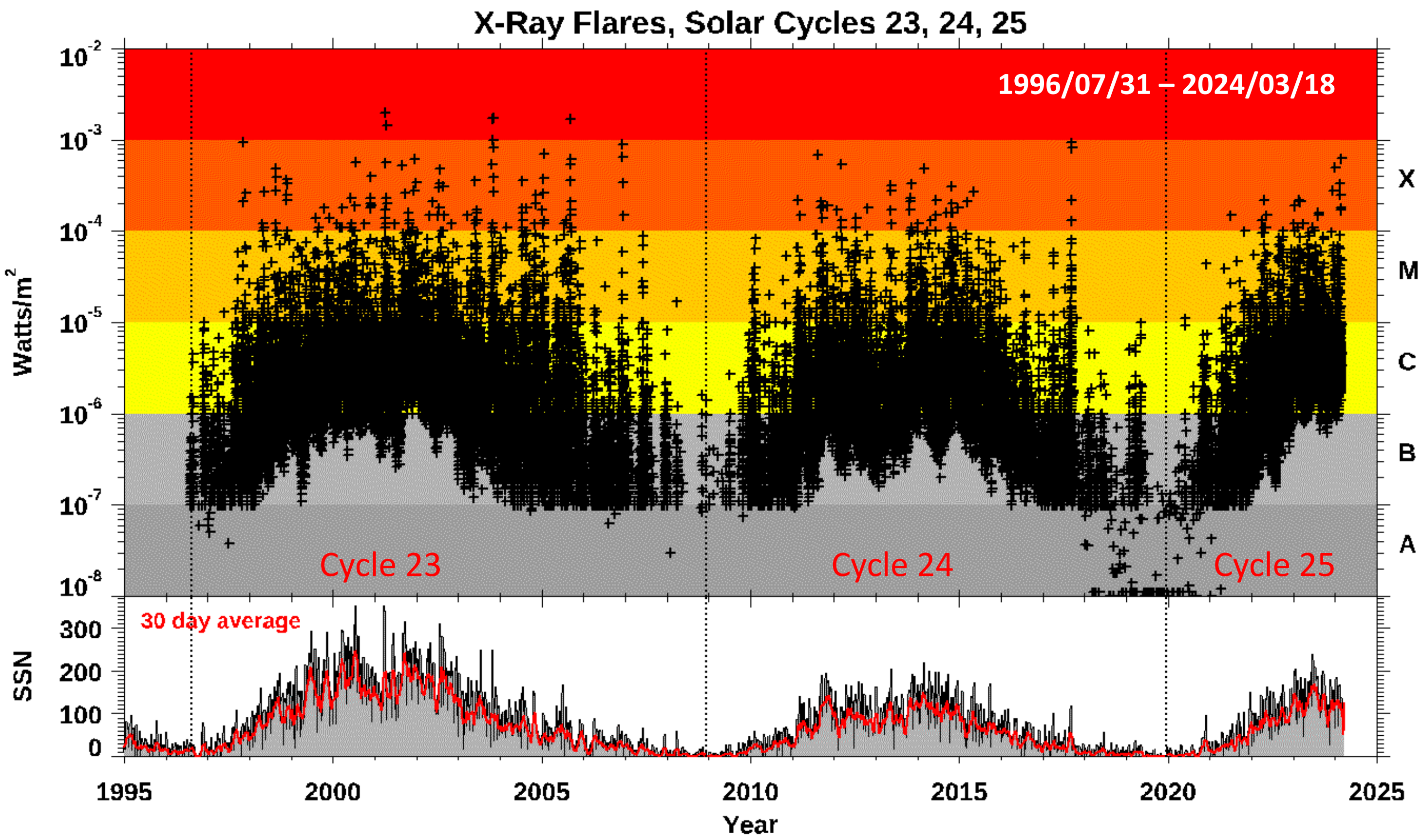
- NOAA SWPC Updated Prediction (experimental)
    - Cycle 25 peak in September 2024
    - SSN of 147 (range 133 – 154)

- Suggests Cycle 25 (current) will ultimately come in between Cycle 23 and Cycle 24 in activity



Solar X-Ray Flares

- Major SWx impact of x-ray flares is increased ionization in the D-region ionosphere which interferes with terrestrial HF radio systems
- Large M and X class flares are correlated with coronal mass ejections and solar particle events (SPE) which can potentially impact satellite operations
- X-ray flares can provide advanced warning for geomagnetic storms, SPEs



X-ray flare data source:
https://www.swpc.noaa.gov/products/solar-and-geophysical-event-reports

100 Largest X-Ray Flares in Cycles 23, 24, and 25

Rank	YYYY	DOY	HH:MM	Class	Cycle
1	2001	092	21:51	X20	23
2	2003	308	19:53	X17.4	23
3	2003	301	11:10	X17.2	23
4	2005	250	17:40	X17.0	23
5	2001	105	13:50	X14.4	23
6	2003	302	20:49	X10.0	23
7	1997	310	11:55	X9.4	23
8	2017	249	12:02	X9.3	24
9	2006	339	10:35	X9.0	23
10	2003	306	17:25	X8.3	23
11	2017	253	16:06	X8.2	24
12	2005	020	07:01	X7.1	23
13	2011	221	08:05	X6.9	24
14	2006	340	18:47	X6.5	23
15	2024	053	22:34	X6.3	25
16	2001	347	14:30	X6.2	23
17	2005	252	20:04	X6.2	23
18	2000	196	10:24	X5.7	23
19	2001	096	19:21	X5.6	23
20	2012	067	00:24	X5.4	24
21	2003	296	08:35	X5.4	23
22	2005	251	21:06	X5.4	23
23	2001	237	16:45	X5.3	23
24	2023	365	21:55	X5.0	25
25	2014	056	00:49	X4.9	24
26	1998	230	22:19	X4.9	23
27	2002	204	00:35	X4.8	23
28	2000	331	16:48	X4.0	23
29	2003	307	09:55	X3.9	23
30	1998	231	21:45	X3.9	23
31	2005	017	09:52	X3.8	23
32	1998	326	06:42	X3.7	23
33	2003	148	00:27	X3.6	23
34	2004	198	13:55	X3.6	23
35	2005	252	09:59	X3.6	23
36	2006	347	02:40	X3.4	23
37	2001	362	20:45	X3.4	23
38	2002	201	21:30	X3.3	23
39	2024	040	13:14	X3.3	25
40	2013	309	22:12	X3.3	24
41	1998	332	05:52	X3.3	23
42	2013	134	01:11	X3.2	24
43	2014	297	21:41	X3.1	24
44	2002	236	01:12	X3.1	23
45	2002	196	20:08	X3.0	23
46	2001	345	08:08	X2.8	23
47	1998	230	08:24	X2.8	23
48	2013	133	16:05	X2.8	24
49	2023	348	17:02	X2.8	25
50	2015	125	22:11	X2.7	24
51	1998	126	08:09	X2.7	23
52	2003	307	01:30	X2.7	23
53	2005	015	23:02	X2.6	23
54	2001	267	10:38	X2.6	23
55	1997	331	13:17	X2.6	23
56	2024	047	06:53	X2.5	25
57	2004	315	02:13	X2.5	23
58	1998	326	16:23	X2.5	23
59	2001	100	05:26	X2.3	23
60	2000	329	15:13	X2.3	23
61	2000	158	15:25	X2.3	23
62	2013	302	21:54	X2.3	24
63	2014	161	11:42	X2.2	24
64	1998	327	06:44	X2.2	23
65	2023	048	20:16	X2.2	25
66	2011	046	01:56	X2.2	24
67	2017	249	09:10	X2.2	24
68	2022	110	03:57	X2.2	25
69	2005	253	22:11	X2.1	23
70	2023	062	17:52	X2.1	25
71	2013	298	15:03	X2.1	24
72	2015	070	16:22	X2.1	24
73	1997	308	05:58	X2.1	23
74	2002	140	15:27	X2.1	23
75	2011	249	22:20	X2.1	24
76	2014	300	14:47	X2.0	24
77	2000	329	05:02	X2.0	23
78	2014	299	10:56	X2.0	24
79	2001	102	10:28	X2.0	23
80	2004	312	16:06	X2.0	23
81	2023	009	18:50	X1.9	25
82	2011	267	09:40	X1.9	24
83	2000	194	10:37	X1.9	23
84	2000	330	18:44	X1.9	23
85	2011	307	20:27	X1.9	24
86	2004	197	01:41	X1.8	23
87	2002	199	07:44	X1.8	23
88	2014	354	00:28	X1.8	24
89	2024	052	23:07	X1.8	25
90	2012	297	03:17	X1.8	24
91	2000	084	07:52	X1.8	23
92	2004	231	17:40	X1.8	23
93	1999	287	09:00	X1.8	23
94	2000	329	21:59	X1.8	23
95	2011	250	22:38	X1.8	24
96	2003	160	21:39	X1.7	23
97	2001	088	10:15	X1.7	23
98	2024	053	06:32	X1.7	25
99	2013	298	08:01	X1.7	24
100	2005	256	23:22	X1.7	23

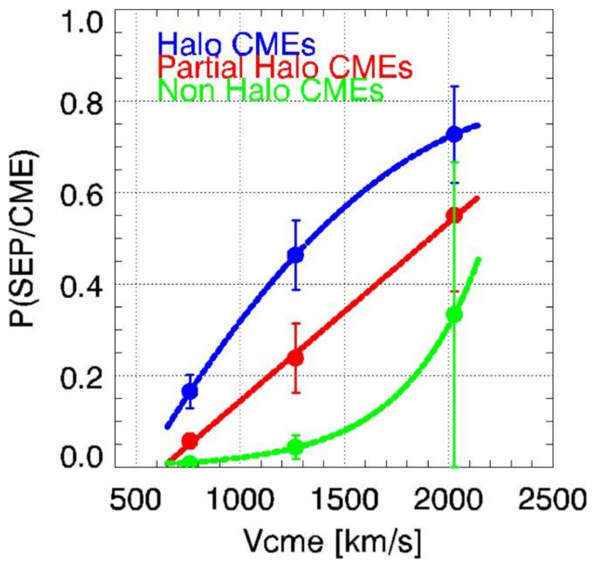
Largest Cycle 25 x-ray flares to date are ≤ X3.3 in intensity with two reaching X5.0 and X6.3

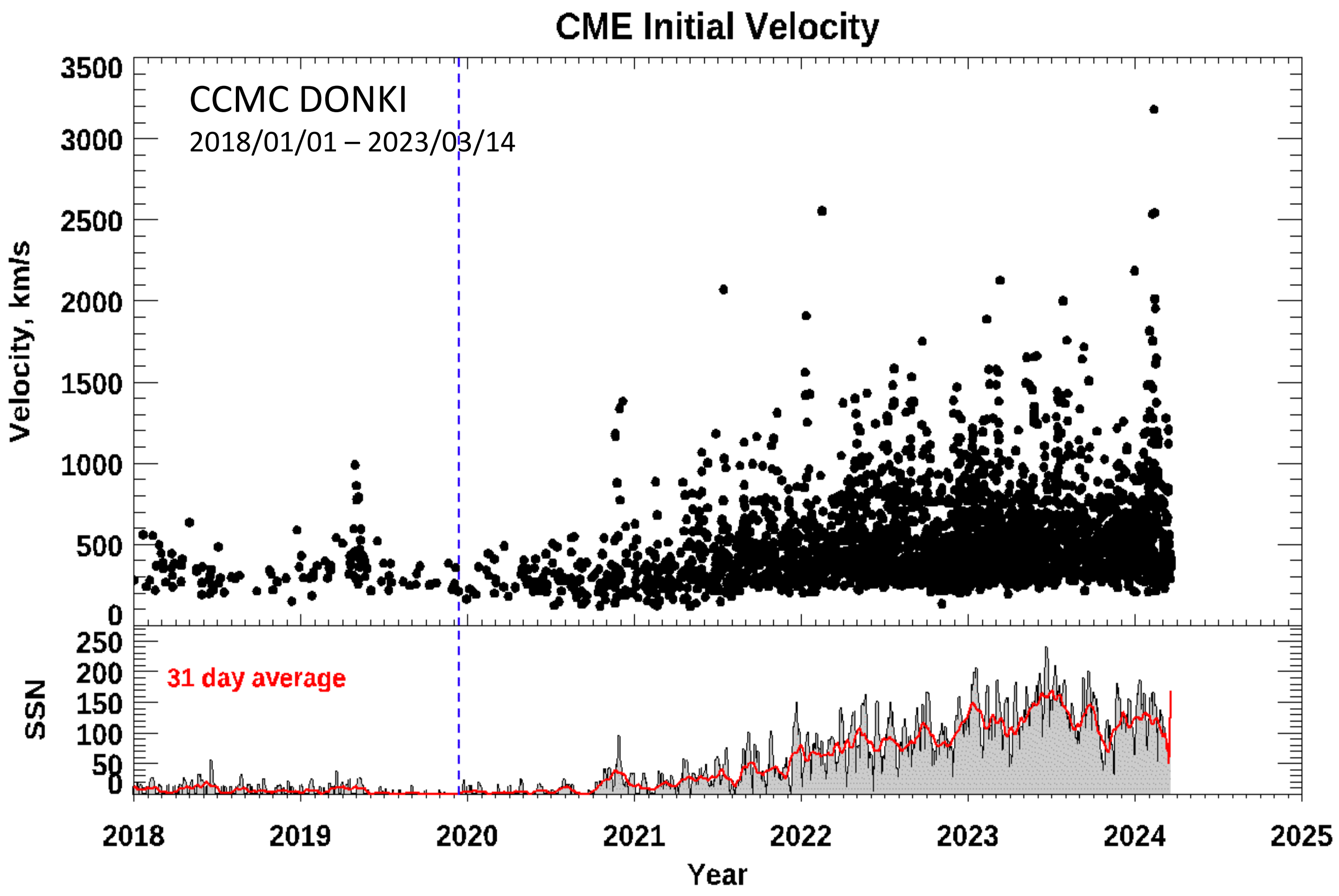
Coronal Mass Ejections (CME)

- CME formation rates and the number of high speed CMEs is correlated with solar activity

- Fast CMEs are particularly geoeffective when headed towards Earth:
  - Relativistic electron enhancements in the outer radiation belt (internal charging)
  - Magnetospheric hot plasma (surface charging)
  - Solar protons and heavy ions (single event effects)
  - Geomagnetically induced currents

Papaioannou et al., 2018

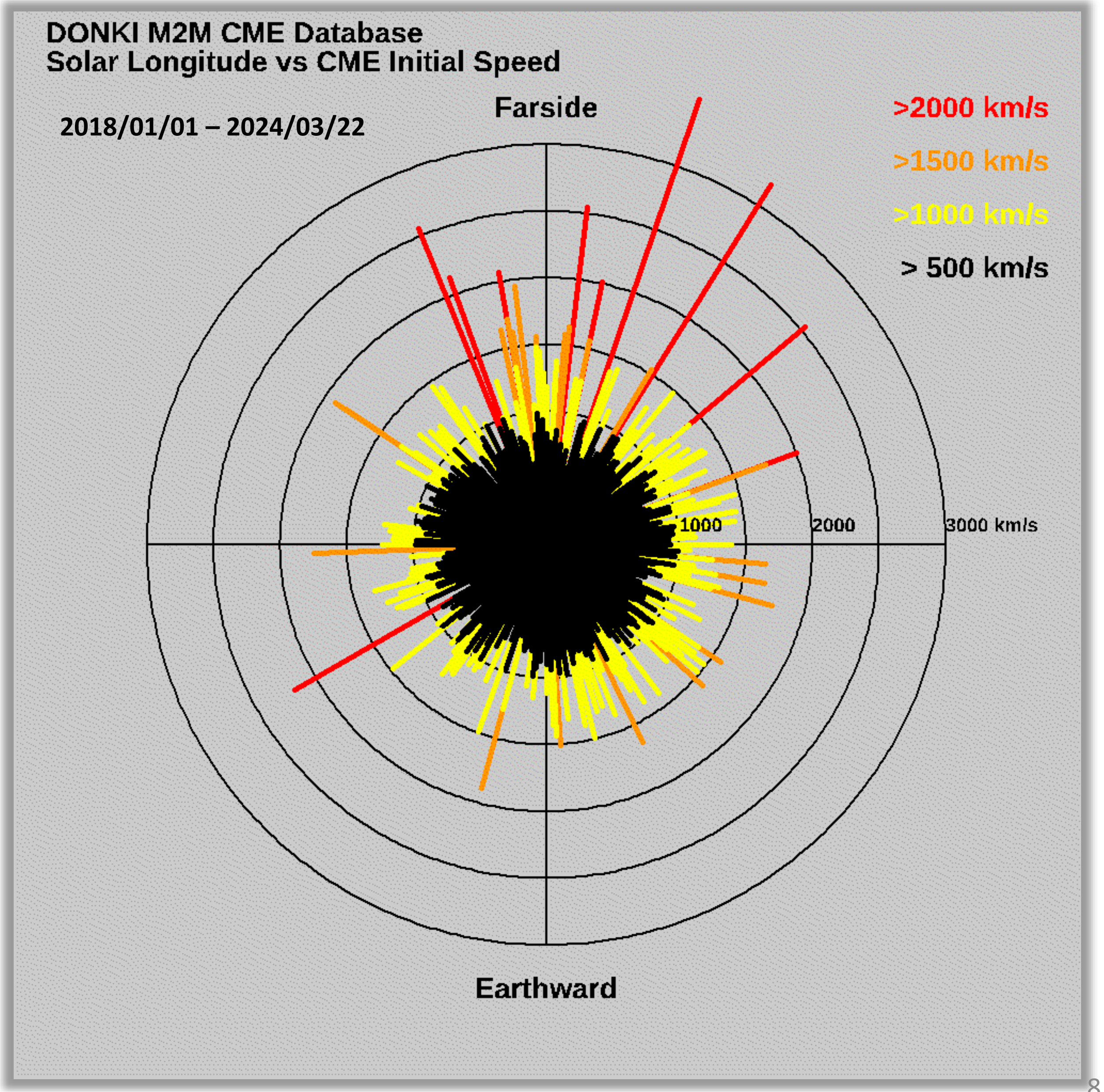




- CME is data from GSFC's Moon to Mars (M2M) Space Weather Office Catalog (most accurate only) available from the GSFC CCMC *Space Weather Database of Notifications, Knowledge, Information* (DONKI) database
- URL: https://ccmc.gsfc.nasa.gov/tools/DONKI/

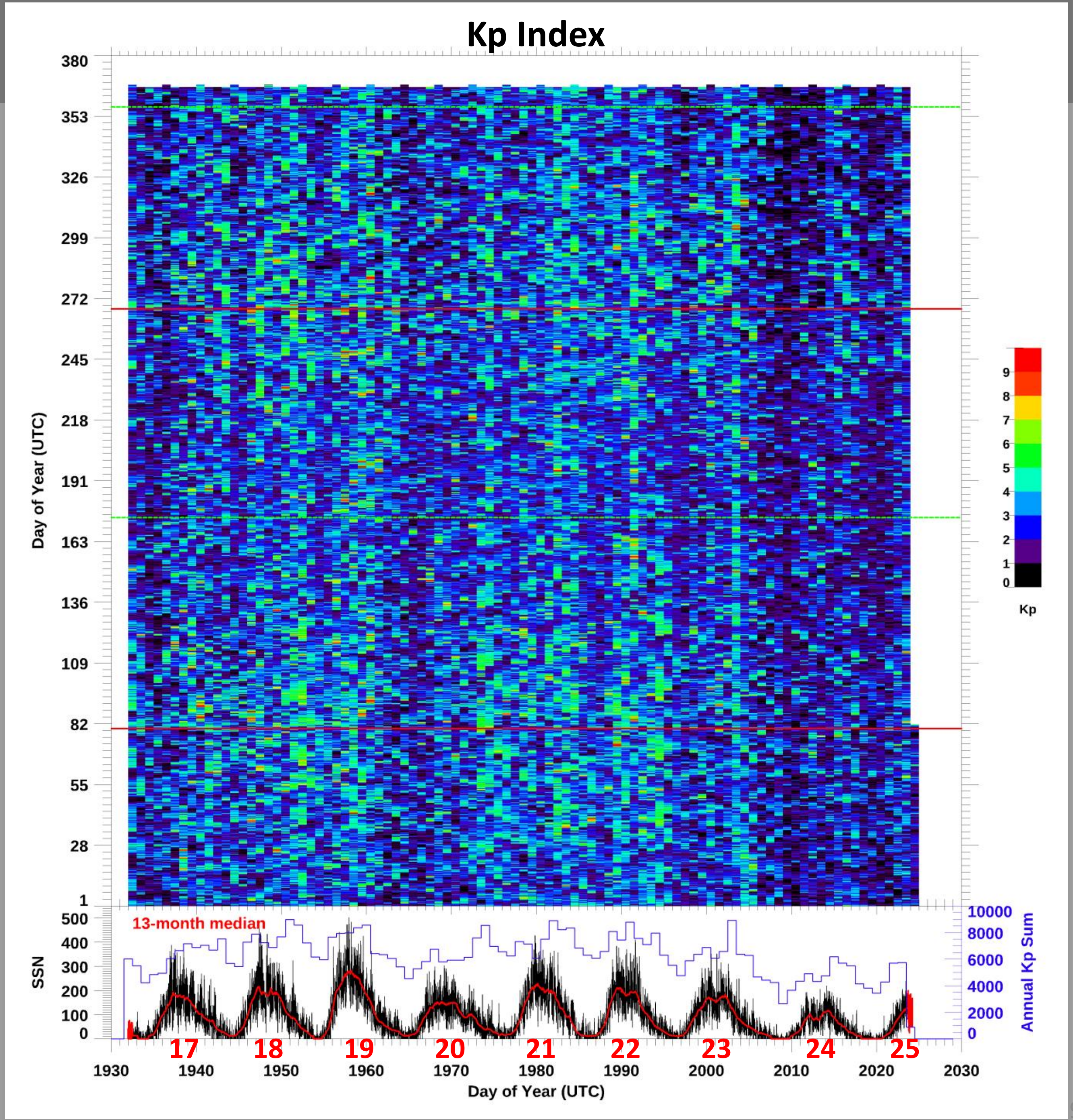
CME Initial Velocity: 2018 to present

- GSFC's Moon to Mars Space Weather Analysis Office estimates the 3-D kinematic properties of CMEs including velocity, half angle, and source location on the Sun using the StereoCaT tool and archives the results on DONKI
- Earth has been relatively lucky so far in Solar Cycle 25 with the fastest CMEs (>2000 km/s) observed to forming primarily on the farside of the Sun with little or no direct impact on near Earth space
- Geomagnetic storm and solar particle event activity has therefore been relatively moderate for the current cycle
- Good for satellite operators!



Geomagnetic Activity

- The geomagnetic Kp index is a convenient proxy used for monitoring geomagnetic storm activity
  - Greatest magnetic disturbance in a chain of midlatitude stations over a 3-hour period
- Geomagnetic storm impacts:
  - Outer belt surface and internal charging
  - LEO satellite drag
  - HF radio propagation interference
  - Radio scintillation
  - Geomagnetic induced currents, power grid fluctuations
- Geomagnetic activity during Solar Cycle 24 and current Cycle 25 have been relatively low compared to geomagnetic storm history from earlier cycles over the past 100 years



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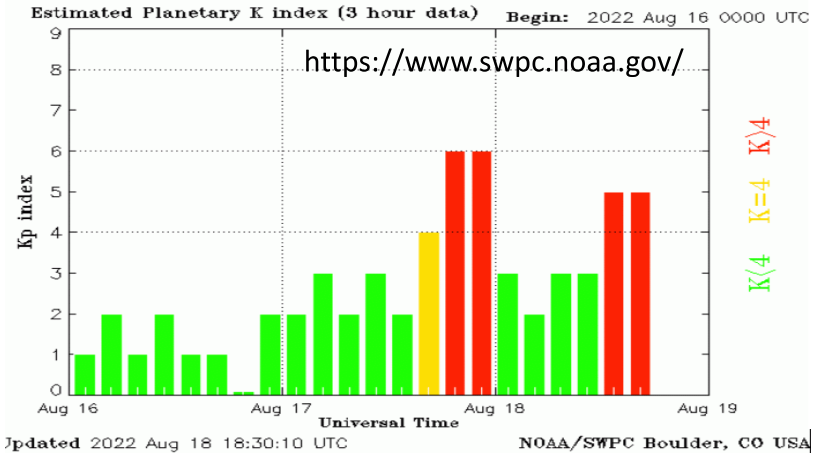
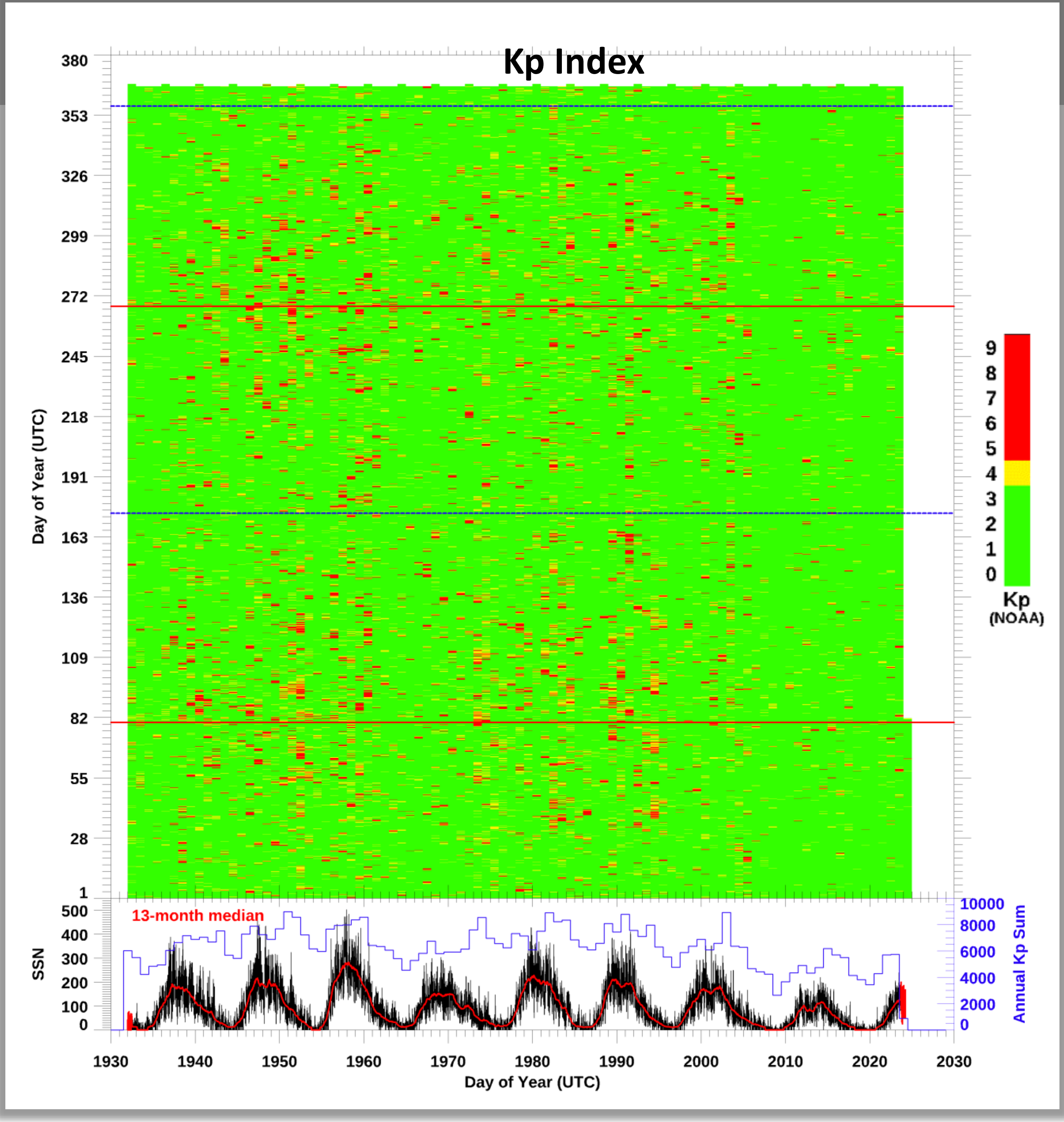
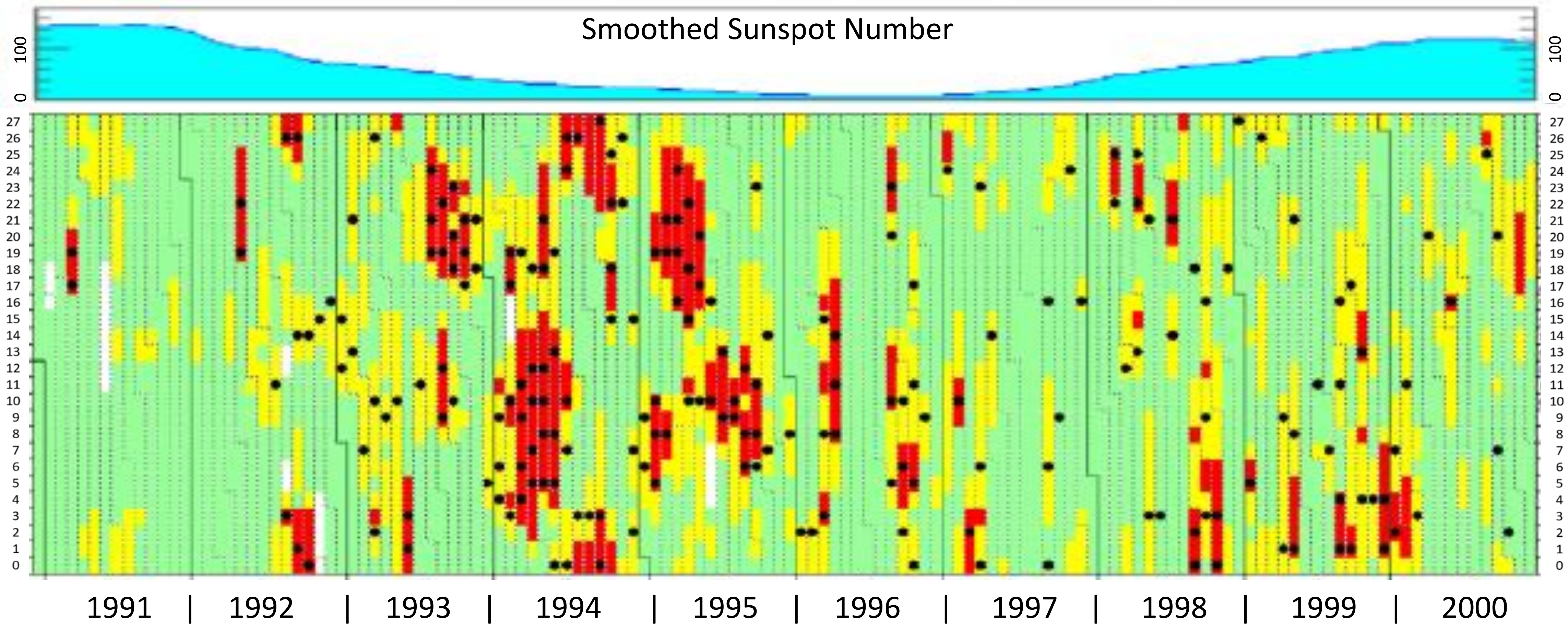




GOES Internal Charging Anomalies (Phantom Commands) in GEO



< 10^8 1/cm^2-sr ≤   < 10^9 1/cm^2-sr ≤

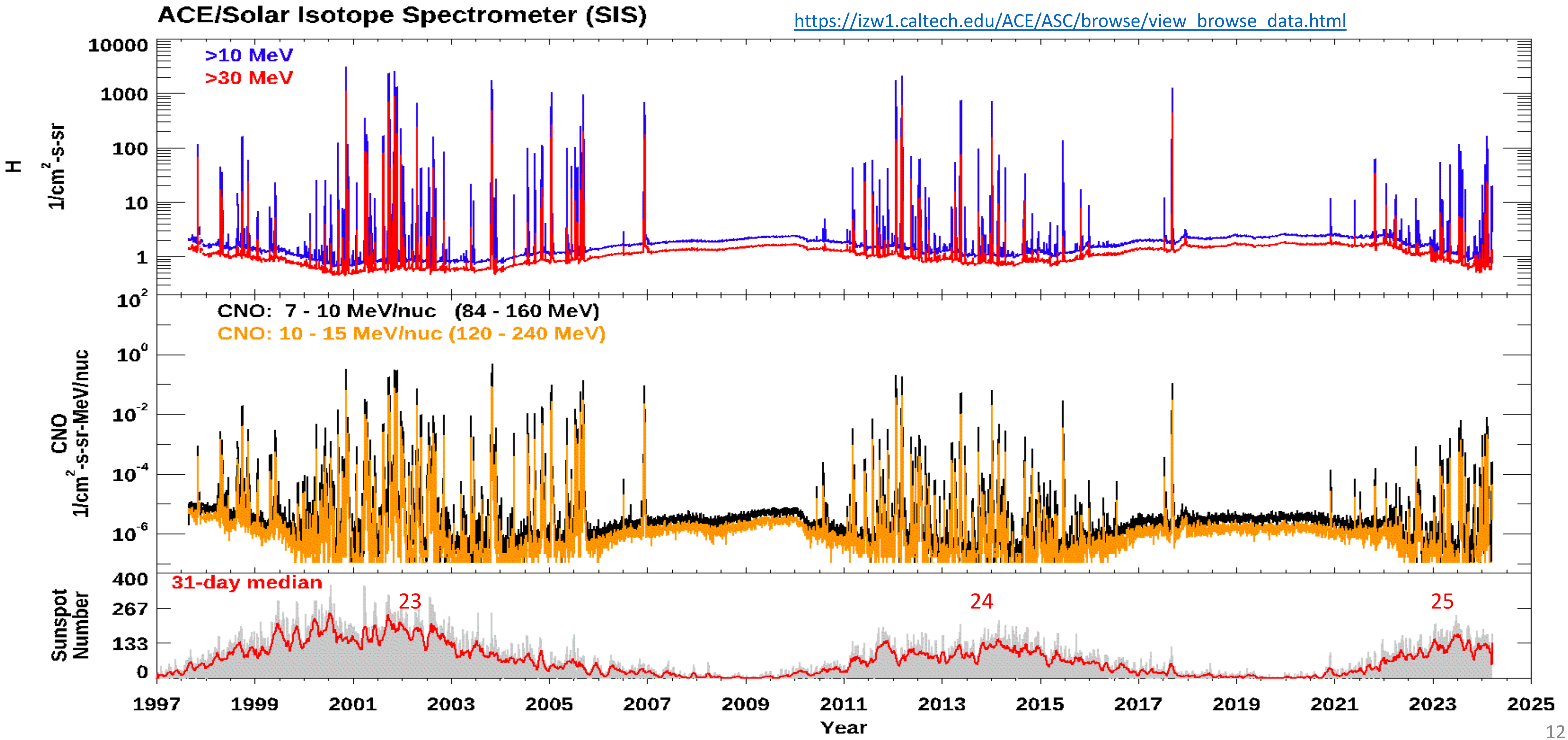
(adapted from Wrenn et al., 2002)

Fig. 1. (a) 2-day fluence of >2 MeV electrons at GEO showing 214 correlated phantom commands. (b) smoothed sunspot number from January 1991 to December 2000.

Solar Particle Events (SPE) and Galactic Cosmic Rays (GCR)

ACE Browse Data (Daily Averages) from 1997/08/25 to 2023/03/18

https://izw1.caltech.edu/ACE/ASC/browse/view_browse_data.html



6 -12 Feb 2024
Series of X-ray Flares and SPEs

- **X-ray flares associated with SPEs***

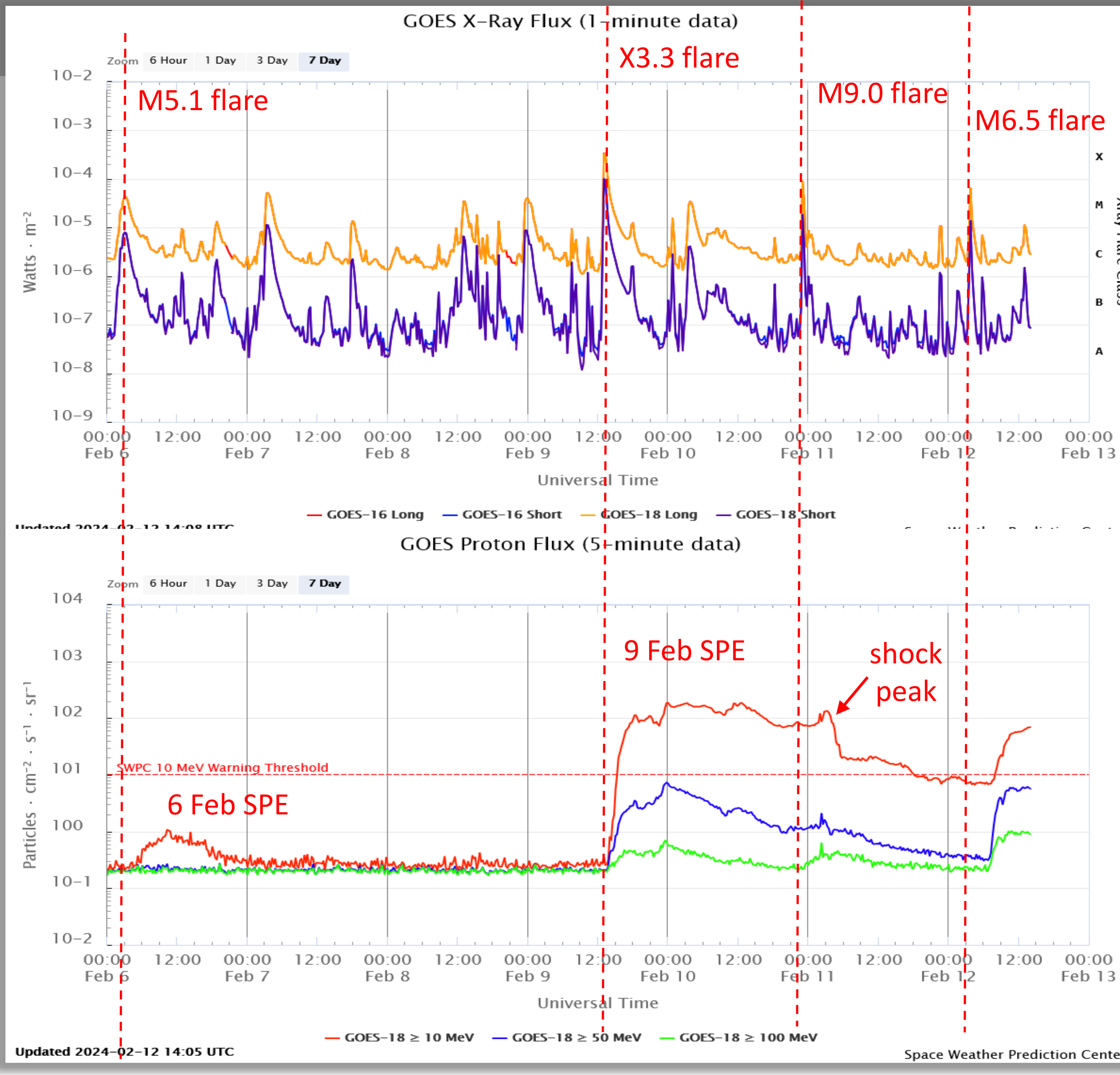
X-ray Flare (W/m²)	Peak Flux (UTC)	Source Region	Solar Location (deg)	CME Speed (km/s)	Direction (deg)
M5.1	2024-02-06 03:31	13575	S36 W80		
X3.3	2024-02-09 13:14	13575	S37 W100	2226	110/-33
M9.0	2024-02-10 23:07	13576	S12 W13	912	13/16
M6.5	2024-02-12 03:48	13576	S16 W25		

- **Solar Particle Events (SPE)****

X-ray Flare (W/m²)	Peak Proton Flux (pfu)			
	≥10 MeV	≥50 MeV	≥60 MeV	≥100 MeV
M5.1	1.076	0.272	0.269	0.266
X3.3	187.1	7.344	4.094	0.698
shock peak	134.5	2.076	1.476	0.625
M6.5	69.5^	6.168^	3.955^	1.019^

^Flux still increasing, values are the most recent but peak flux could be higher

Sources:
*GSFC Moon to Mars Space Weather Analysis Office
**NOAA Space Weather Prediction Center



https://www.swpc.noaa.gov/

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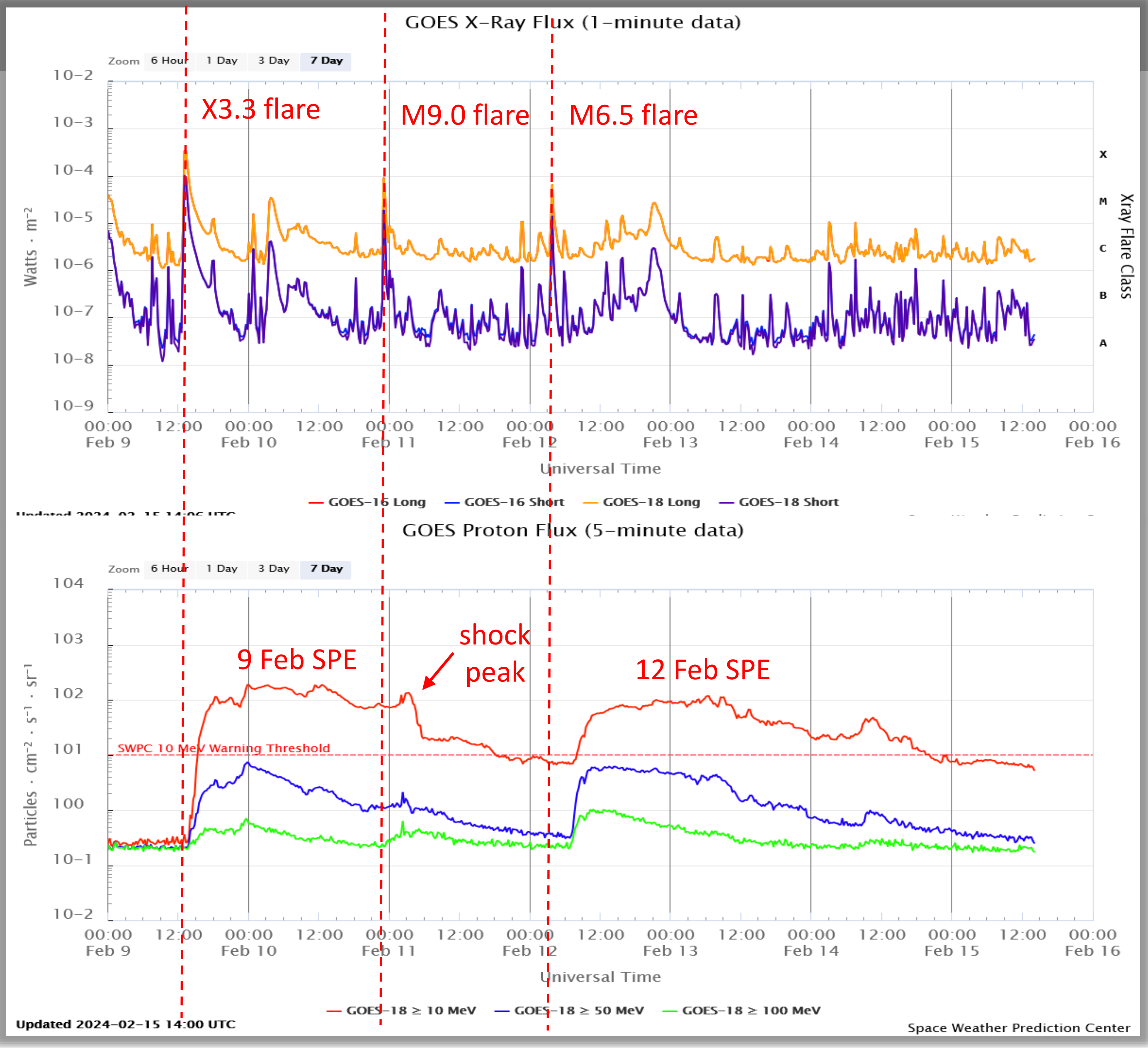
X3.3	187.1	7.344	4.094	0.698
shock peak	134.5	2.076	1.476	0.625
M6.5	117.6^	6.168^	3.955^	1.019^

^Update: peak proton flux for period 12 – 16 Feb

Sources:
*GSFC Moon to Mars Space Weather Analysis Office
**NOAA Space Weather Prediction Center



https://www.swpc.noaa.gov/

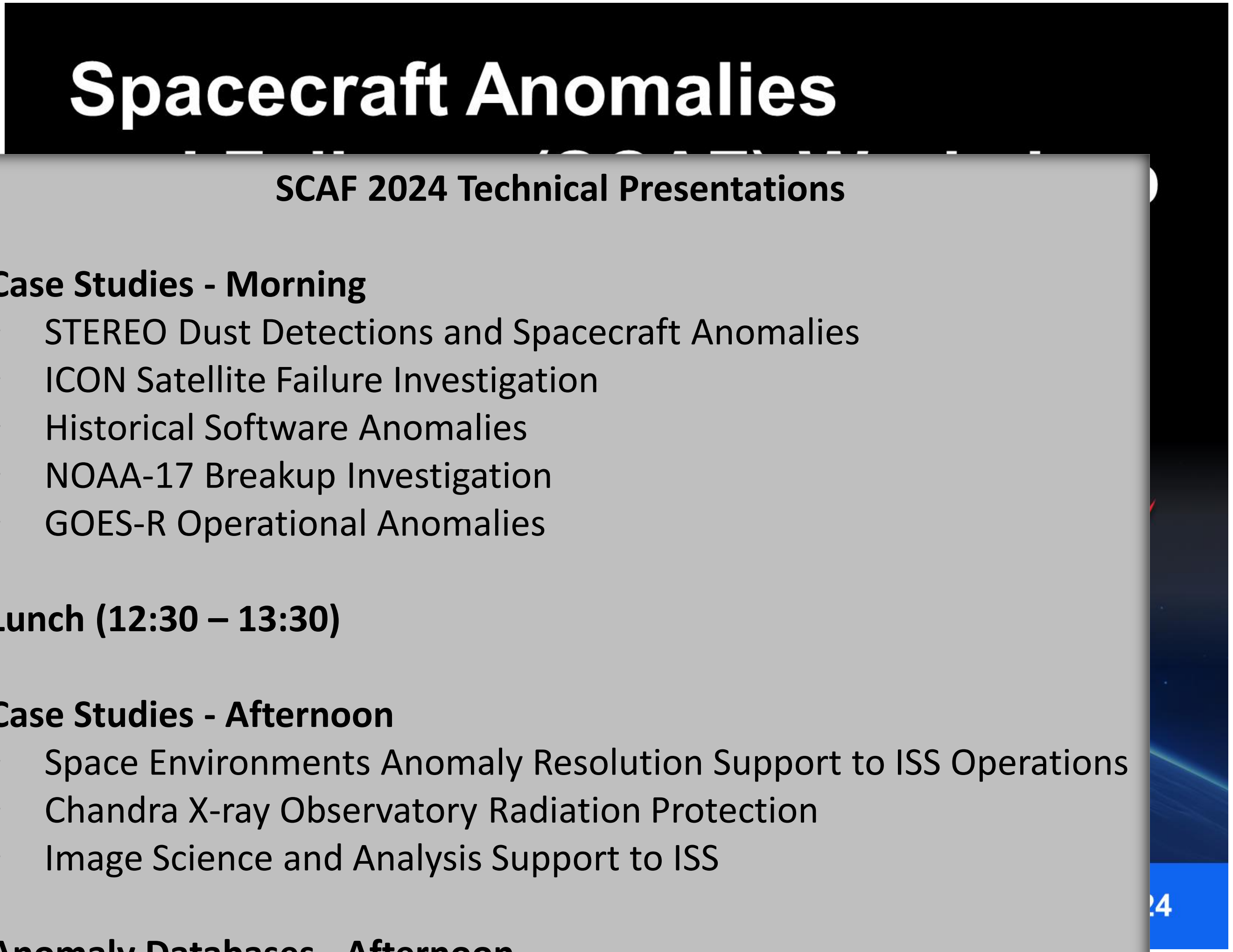
SCAF 2024 Presentations

- The SCAF 2024 organizing committee selected today's Day 1 presentations because they represent a variety of issues encountered on both active and decommissioned satellites that range from anomalies to a mission ending failure

- The morning presentations are case studies of anomalies and failures in NASA and NOAA spacecraft and an investigation into software errors in spacecraft, aircraft, planetary landers, and terrestrial power systems

- The first three presentations following lunch will focus on techniques used by the International Space Station and Chandra X-ray Observatory programs to identify and mitigate on-orbit anomalies

- The final two afternoon presentations discuss the GSFC SOARS anomaly database and tools that are being developed to couple space environments information with anomaly reports contained in the database



SCAF 2024 Technical Presentations

Case Studies - Morning
- STEREO Dust Detections and Spacecraft Anomalies
- ICON Satellite Failure Investigation
- Historical Software Anomalies
- NOAA-17 Breakup Investigation
- GOES-R Operational Anomalies

Lunch (12:30 – 13:30)

Case Studies - Afternoon
- Space Environments Anomaly Resolution Support to ISS Operations
- Chandra X-ray Observatory Radiation Protection
- Image Science and Analysis Support to ISS

Anomaly Databases - Afternoon
- Radiation Events in GSFC SOARS Database
- SPARK Anomaly Tool Applied to SOARS Radiation Anomalies