An Assessment of Solar Cycle 25 progress through observation of SRBs and associated Geomagnetic Storms

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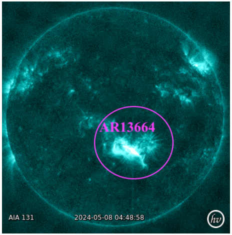
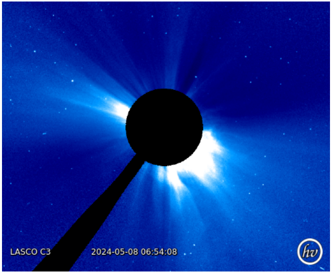
Neustrelitz - Germany, 11 June 2024

Outline

Solar Cycle 25 Maximum in Progress

- Strongest geomagnetic storm (G5) since 2003, 11 May 2024
- It has solar origin: AR13664, Full halo CME, and X-class solar flare (2 days before).
- 

- Solar radio bursts (emission): Type II and type IV.



Interplanetary conditions

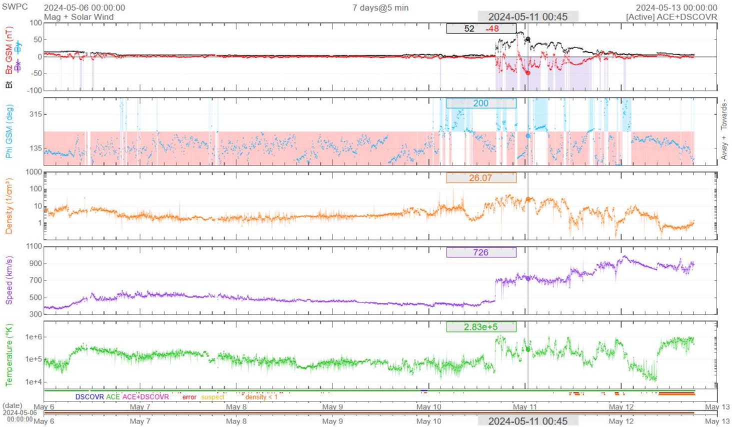


Figure: Disturbances in the Solar Wind parameters, led to geomagnetic storm with Dst = -412 nT.

Solar Energetic Particle Events

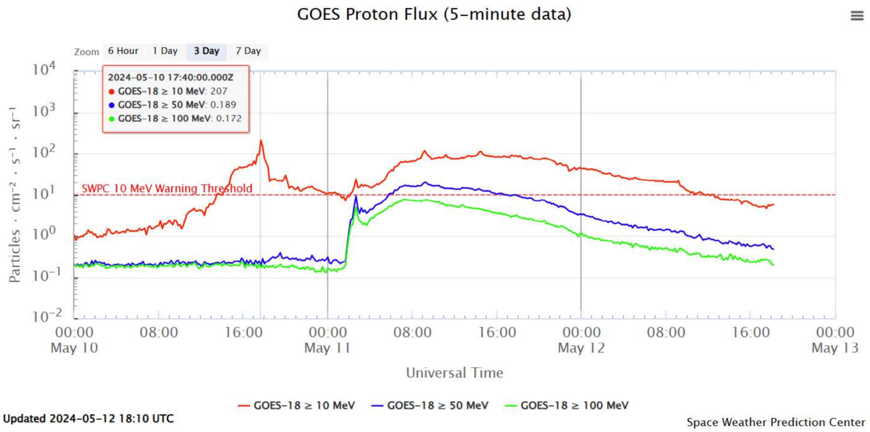


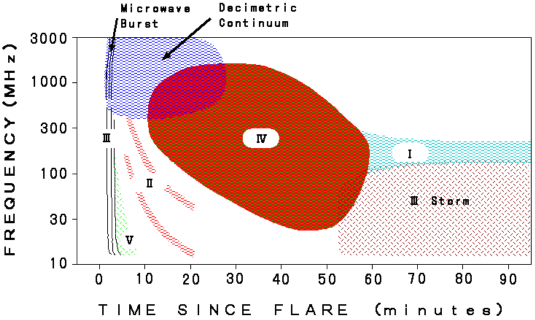
Figure: GOES Proton Flux for particles with energies above 10 MeV exceed the SWPC 10 MeV warning threshold on May 10 at 14:10 UT.

Solar radio bursts (SRBs) and CMEs

- CMEs are enormous eruptions of plasma and magnetic fields ejected from the sun into interplanetary space.
- CMEs are typically associated with two types of metric radio bursts: type II bursts and type IV bursts.
- Therefore, type II bursts can serve as a geomagnetic storm precursor.

SRBs

- Type II onset corresponds the height of CME shocks in the solar corona.
- Type IV radio bursts appear continuum in dynamic and signal sources are either stationary or moving.



Motivation and Objective of the study

- Necessity to study SC 25 peak activity maximum and related space weather impacts.
- This study has major objective to monitor the SC 25 activity through analysis of observed SRBs, trends and features during the rising phase of the cycle (2020 – 2023).

Data Observation and methodology

- GMS are disruptions of the Earth's magnetosphere which severily alter the magnetosphere-ionosphere-thermosphere coupling processes.
- Intense GMS ($Dst \leq 100$ nT) are mostly caused by CMEs and CIRs (e.g., Zhang et al., 2007).
- Strong to extreme geomagnetic storms can disrupt power grid systems, space missions, high- frequency communications, and low-frequency navigation, and they usually cause northern and/or southern aurorae.
- The study started by listing all geomagnetic storms between January 2020 and June 2023 based on the disturbed storm time index ($Dst \leq -50$ nT). A total of 35 geomagnetic storms were observed.

Data Observation and methodology

- The radio observations reported here were made with various ground-based radio telescopes that are parts of extended Compound Astronomical Low-frequency Low- cost Instrument for Spectroscopy and Transportable Observatory (e-CALLISTO, https://e-callisto.org/).
- The e-CALLISTO is one of the few radio telescopes currently operational and operates 24 h daily.
- Their space counterparts were checked using the Radio and Plasma Wave Experiment (Bougeret et al., 1995) on Wind spacecraft.

SRBs

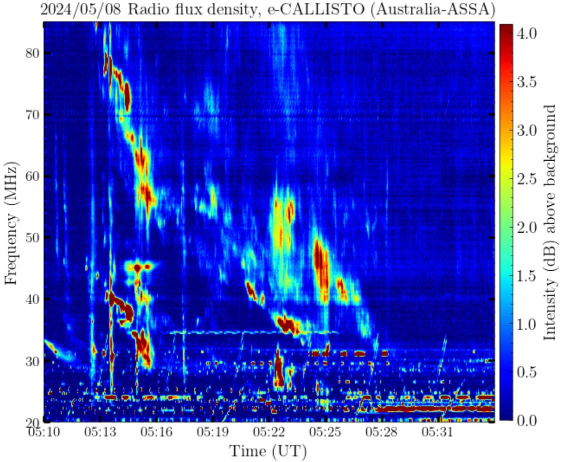


Figure: Type II radio emission followed by Type IV radio emission associated with the CME on 8 May 2024. The geomagnetic storm associated this emission occurred on 11 May 2024 and reached a Dst=-412 nT.

Data Observation and methodology

Fig. 2: CALLISTO core team in the CALLISTO laboratory during tests of the instrument.

Data Observation and methodology

- In a Five days window period, trace back the CME and solar flare sources and associated SRBs.
- CMES: SOHO/LASCO and STEREO.
- Solar flares: solar monitor website (https://solarmonitor.org/)

Summary of Observed data

List of geomagnetic storms and their associated solar radio bursts observations in SC 25 (January 2020 - June 2023), $Dst_{min} < -50nT$.

Year	Burst date	Burst	Flare			LASCO/STEREO CME		Geomagnetic storm		
		type	Onset	Class	AR	Onset	Speed	CME impact	Dst_{min}	Kp_{max}
	(UT)		(UT)			(UT)	(kms^{-1})	(UT)	(nT)	
2020	Feb 4	....	....	....	....	....	CH	Feb 18 03:30	−52	4-
	April 15	....	....	....	....	04:24	1113	April 20 07:30	-59	5-
	July 19	....	....	....	....	....	CH	July 24 12:30	−52	4-
	Sept 23	....	....	....	....	....	CH	Sep 27 19:30	−57	5+
2021	Feb 25	....	....	....	....	....	Southern Hole	Feb 28 23:30	−58	6-
	April 14	....	....	....	.....	....	Southern Hole	April 17 01:30	−54	5
	April 22 04:38	II & IV	03:54	C3.9	AR12816	05:53	620	April 24 23:13	−53	4+
	May 9 14:32	II	14:19	C2.0	AR12822	15:05	603	May 12 10:30	−61	7
	Aug 23	....	....	....	AR12859	06:48	440	Aug 27 13:00	- 82	5
	Sep 14	....	....	....	AR12868	11:54	819	Sep 17 18:30	−64	5+
	Oct 13 11:51	III	....	....	AR12882	11:00	730	Oct 17 07:26	−55	4
	Nov 1 01:30	II & IV	00:57	M1.5	AR12887	02:00	753	Nov 3 20:25	−105	8
2022	Jan 09 22:52	II	....	....	AR12924	23:12	1283	Jan 14 16:00	−91	6-
	Jan 29 22:55	II &IV	22:45	M1.1	AR12936	23:36	530	Feb 3 00:12	−66	5+
	Jan 30	....	21:33	C1.6	AR12936	21:48	386	Feb 4 12:30	−61	5+
	Feb 6 11:51	III	11:45	C3.1	AR12939	14:00	334	Feb 10 13:53	−60	5
	Mar 10	....	Erupting Filament			18:48	742	March 13 19:30	-85	6+
	April 11 05:11	II & IV	04:59	C1.6	AR12987	05:48	940	April 14 01:17	-81	6
	May 24 22:29	II & III	21:54	C1.8	AR13014	23:12	569	May 27 12:26	-63	5
	July 5 03:59	IV	02:45	C1.8	AR13011	04:36	747	July 7 22:30	-81	5+
	July 15 15:35	IV	15:33	M1.4	AR13055	16:23	557	July 19 03:33	−61	5-
	Aug 5 00:49	III	00:43	C1.1	AR13068	01:53	591	Aug 7 04:50	−59	6-
	Oct 11 08:40	IV	08:36	M3.9	AR13112	08:36	587	Oct 14 03:36	-62	4+
	Nov 3 08:54	III	Gap	Gap	Gap	09:53	453	Nov 7 08:58	−92	5
	Dec 24 03:06	III	02:13	C1.4	AR13174	02:48	984	Dec 26 10:02	-68	4+
2023	22 Dec 30 19:17	II	19:37	M3.7	AR13176	20:24	833	Jan 3 21:50	−61	5-
	Jan 11 08:32	III	08:25	M3.1	AR13186	08:36	1047	Jan 15 07:11	-58	4-
	Feb 11 11:08	IV	10:42	M1.1	AR13220	11:12	1498	Feb 15 04:00	-72	5+
	Feb 11 11:53	III	12:28	M1.5	AR13217	13:53	815	Feb 16 11:49	-53	5
	Feb 24 13:15	III	12:58	C2.9	AR13230	13:26	922	Feb 26 19:27	-138	7-
	Feb 24 20:22	II & IV	20:03	M3.7	AR13229	20:36	1336	Feb 27 04:35		
	Mar 20	....	14:07	C4.4	AR13258	14:00	851	Mar 23 10:21	−163	8
	Apr 21 17:55	II & IV	17:44	M1.7	AR13283	18:36	624	Apr 23 17:39	-212	8
	May 2 05:17	III	04:37	C4.3	AR13288	05:12	802	May 6 01:29	−67	6
	May 16 17:32	II & IV	16:31	M9.6	AR13307	17:24	700	May 19 19:28	−57	6-
	June 13	....	....	....	AR13326	00:23	481	June 16 02:30	-54	6

Results

- The study discovered that three of the four major storms in the current solar cycle ($Dst_{min} < -100\ nT, Kp_{max} \geq 7$) were preceded by solar radio bursts (SRBs).
- The average time between the onset of the solar radio burst and the impact of the CME and/or the HSS on the Earth's magnetosphere for the 23 geomagnetic storms is estimated to be 79 hours, ranging between [48 - 120 h] depending on the dynamics of their sources.
- Four intense geomagnetic storms ($Dst_{min} < -100\ nT$) were used as examples.

The 24 April 2023 GMS event

- On 21 April 2023, the CALLISTO station at Arecibo Observatory (Puerto Rico, USA, 18.22°N, 66.59°S) observed a type II radio burst from 17:55 UT to 18:11 UT which was overlapped by a type IV burst from 17:59 UT to 18:14 UT, followed by another type II burst from 18:15 UT to 18:18 UT, as shown in Figure below and no space counterpart associated with it that could be observed.
- These bursts are associated with a GOES soft X-ray flare of class M1.7 detected at 17:44 UT, originating in the AR13283 active region.
- A CME appeared in the LASCO field of view (FOV) coronagraph at 18:36 UT and in STEREO-A/COR1 at 18:23 UT, near the end of the flare.
- The CME impacted the Earth's magnetosphere on 23 April 2023 at 17:39 UT (commencement of the storm), after 47hours 44 minutes from the registration of associated type II burst.
- Intense storm occurred on 24 April 2023 with Dst=-212 nT at 05:30 UT.

The 21 April 2023 radio emissions

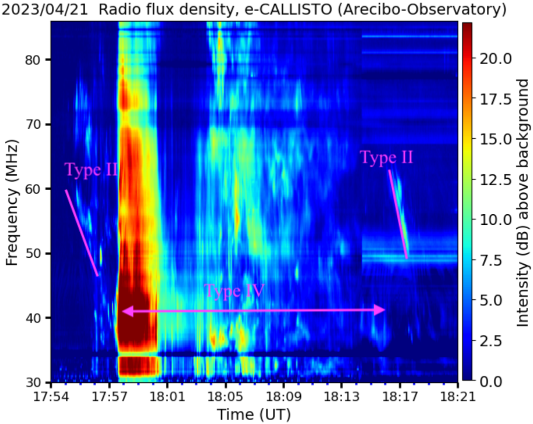


Figure: Type II bursts between 17:55 UT and 18:11 UT overlapped by type IV burst between 17:59 UT and 18:14 UT followed by another type II burst from 18:15 UT to 18:18 UT on 21 April 2023. SRBs were associated with a strong storm on 23rd April, with Dst peak minimu: Dst = -212nT.

Solar origin of the 24 April 2023 GMS event

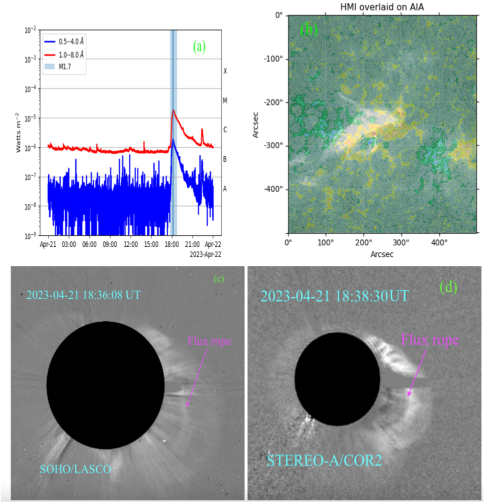


Fig. 2. (a) Epoch of GOES X-ray flares on 21 April 2023 (b) location of associated active region AR12887 on the solar disc overlapped by the HMI. (c) SOHO/LASCO-C2 coronagraph 15 min difference image of the CME obtained on 21 April 2023 at 18:36 UT. (d) STEREO-A/COR1 at 18:23 UT, a 15-minute difference image of the same CME. The black circles represent the coronagraphs' occulting discs. The CME observed by SOHO/LASCO-C2 is fainter than that observed by STEREO-A/COR2 because the central position angle of the CME with respect to the plane of sky is greater for SOHO/ LASCO. In all cases, the magenta arrows indicate the flux ropes that are radially expanding.

Conclusion

- We present the preliminary results of solar radio observations and associated geomagnetic activity for SC 25 from January 2020 to June 2023.
- The study finds that 23 solar radio bursts of type II, III, and IV bursts diagnose the geomagnetic storms with $Dst \leq -50\ nt$ among 35 storms reported of SC 25.
- The time delay between the registration of solar radio bursts and the arrival of CMEs and/or HSS near the Earth's magneto-sphere was estimated to be [48 – 120 h], with an average of 79 h for 23 geomagnetic storms associated with solar radio bursts.
- SRBs can effectively be used as proxies for GMS occurrences.
- Important study for space weather modeling and prediction as the cycle 25 enters its maximum activity.

More details in

- T. Ndacyayisenga, Jean Uwamahoro et al. (2024). An Assessment of Solar Cycle 25 progress through observation of SRBs and associated Geomagnetic Storms. **Advances in Space**, vol. 73, Pages 6274 – 6287.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