The solar flares' activity of AR3664 during May 2024 and the probability for a new G5 geomagnetic storm

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Abstract The giant sunspot's group AR 3664 has been, to date, the largest of the solar cycle XXV. In the week 7-14 May 2024, it passed from the center to the Eastern limb of the Sun, releasing five major flares of X-class. This complex active region produced on Earth a G5 geomagnetic storm on 10-11 May, the stronger since November 2003, with aurorae observed down to magnetic latitudes of 26°. The probability of having another similar event is discussed by analyzing the activity of the AR 3664 in the far side of the Sun, between 14 and 26 May, through the Coronal Mass Ejections observed by SOHO. The naked eye aspect of the Aurora is also depticted.

Sommario La regione attiva AR3664 è la più grande fin'ora apparsa nel ciclo XXV, ed ha prodotto nella settimana 7-14 maggio già 5 brillamenti di classe X, fino alla sua sparizione dietro il lembo Est. La sua attività nel periodo 14-26 maggio è stata seguita tramite i due coronografi di SOHO, contando le eruzioni di massa coronale (CME) avvenute nel frattempo. Il ciclo di attività della macchia in questione è quindi stimabile dal numero delle CME e dalla classe dei flares emessi, quando erano visibili da Terra.

Dall'andamento delle CME espulse in direzione opposta alla Terra, nel periodo che questa regione attiva è –per noi- dietro il Sole viene valutata quantitativamente la possibilità che sulla Terra si sperimenti una nuova tempesta solare di classe G5, tra fine Maggio e inizio Giugno 2024, con aurore boreali visibili fin dal Mediterraneo ad occhio nudo.

Keywords: Solar activity, Solar flares, Coronal Mass Ejections, Geomagnetic storm, Aurorae.

Introduction: the active region AR 3664 has been the largest of the present cycle XXV up to now. It released five major X-rays flares of class X (units of 10^{-4} W/m^2) between 7 and 14 may.

Since an active region has a life cycle during which the emission of flares rises in number and in energy and afterwards decreases, the aim of this paper is to estimate the activity phase of that region, and the probability to have again strong flares when the spot will be again visible (from 28 may on), with central position in the solar disk around 4 June, near the new Moon, very much favourable condition to observe aurorae worldwide. For such puropose I have examinated the

CME recorded by SOHO from 1 to 25 may 2024.

The case of October-November 2003: AR486 and AR484

The Sun was very active and from 10 October to 11 November 2003 about 38 CME were released by the Sun into space, with a peak from 19 Oct to 7 Nov 2003. Three of them reached the Earth with a resulting aurora display at all latitudes. The coronographs C2 and C3 of SOHO, located at the L1 Lagrangian point of the Earth's orbit, were invested by the CME of 28 Oct 12 UT from 14 UT for 24 hours as it was also for the one of the 29th Oct at 21 UT of 2 Nov at 18 UT.

The flare of 28 oct 2003 was classified[1] as X 17.3, while the one of Nov 04 2003, which did not hit the Earth, was > X 28.

The famous Hallowe'en Geomagnetic Storm of 2003 was the consequence of the X 17.3 flare aiming toward the Earth. The statistics of S4 radio blackouts and G5 severe geomagnetic storms is 4 days per solar cycle, as well as a single X20 solar flare per cycle.[2] For airline passengers an S4 storm corresponds to 10 chest X-rays, while S5 (one per solar cycle) corresponds to about hundred. The sunspot responsible for the strongest flares was AR486, and on the Sun was active also the AR 484.

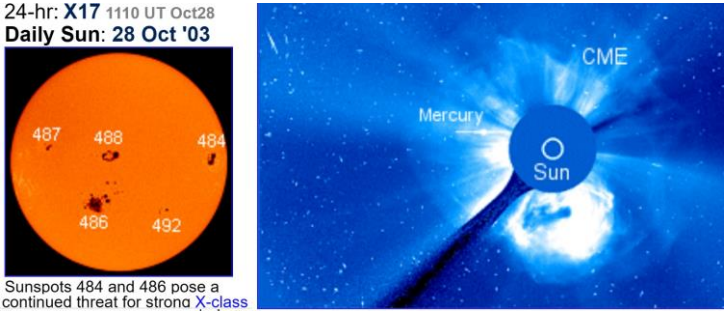


Fig. 1 The Sun with SOHO MDI at 0 UT and with the coronograph C3 at 1218 UT after the CME released toward us.

[1] https://www.spaceweather.com/solarflares/topflares.html

[2] https://www.weather.gov/media/publications/assessments/SWstorms_assessment.pdf Space Weather Storm Assessment; Intense Space Weather Storms October 19 – November 07, 2003 (April, 2004).

Comparison between 2003 Oct-Nov and 2024 May

The aspect of the solar corona appear in May 2024 less bright than in end 2003, and the number and the rate of CME is lower. The condition to have low latitudes aurorae is primarily the precise trajectory of the particles toward the Earth.

The energy of the flare has to be oriented exactly toward the Earth, and the Halloween storm was the result of a major flare exactly on axis. In 2024 a sequence of six flares peaked on May 9th with a X2.2 class flare aimed towar the Earth. [3] The aspect of the CME is more quiet than the 2003 ones. The same sunspot released other X5 and X8.79 flares before going out of our view on May 14 in the far side of the Sun.

The sunspot AR3663 was accompanying the AR3664 in emitting X-class flares, preceding it in the solar rotation, and on 25 may is again visible at the Eastern solar limb.[4]

CME rate for AR 3664 and 3663 vs AR 486 and 484.

The count is done by using SOHO C2 coronograph from May 1 to 25.0 with a 3 days binning and from Oct 16 to Nov 8, 2003.

May '24	1-3	4-6	7-9	10-12	13-15	16-18	19-21	22-24
CME	2	2	4	5	11	7	5	9
Oct '03	16-18	19-21	22-24	25-27	28-30	31-2	3-5	6-8
CME	2	3	5	5	2*	4*	4	2

Table 1. The solar activity in term of CME released.

Assuming for simplicity the same active region responsible of the CME in 2003 and in 2024 cases, the profile of activity in 2003 had a long peak from 19 october to 7 november lasting 19 days, while in 2024 the peak is ongoing, starting from 7 May and lasting 18 days with two local maxima around 14 May and a secondary one on 23 May.

New Moon and Aurorae without the Moon the visibility of an aurora at low latitudes is enhanced. If the big sunspot AR 3664

[3] https://www.spaceweather.com/images2024/10may24/six_CMEs.gif
[4] https://www.spaceweather.com/images2024/25may24/hmi1898.gif

will be able again to continue its activity for a longer time with respect to the 2003 activity of AR484 (50% longer to reach 1 whole month) and if there will be again X-class flares when the spot will be at the solar center, then other aurorae will be at magnetic latitudes as low as 35° (Mediterranean) or even 25°. On 6 June the sunspot AR 3664 will be at the solar center and the Moon is new.

Intrinsically the low probability of a G5 geomagnetic storm, occurred only 22 years ago, is due to the necessary coincidence of geometry Earth-Sun and energy of the flare.

Each of the tens of CME emitted in these periods would have produced a major geo-magnetic storm on Earth if directed correctly. Then the geometrical factor is really important.

Moreover in the sequence of geomagnetic storms of 10-14 May, only the first one produced aurorae visible at naked eye, at Mediterranean sites in the night of 10-11 May.

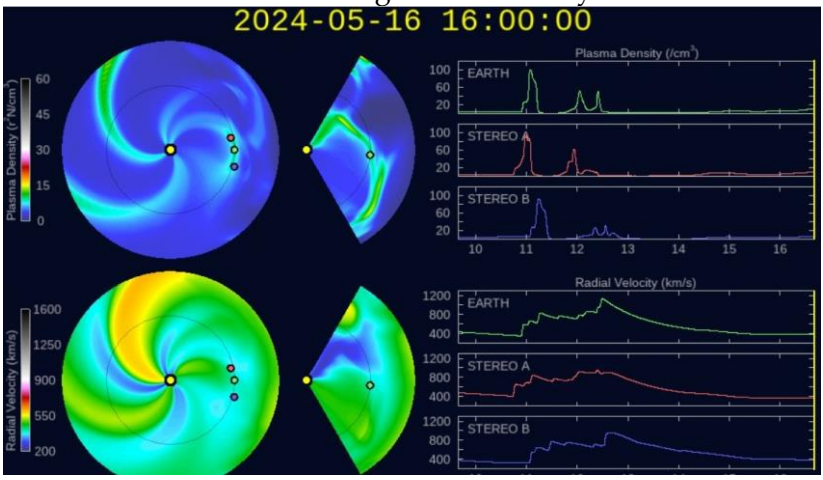


Fig. 2 NOAA service for geomagnetic storms: 100 particles/cm^3 is the plasma density for aurorae displays visible to the naked eye in suburban area at magnetic latitude 35°N, Pescara/IT. Nothing was visible, in the following clear and Moonless nights, at or below 50 particles/cm^3, from Pescara's site.

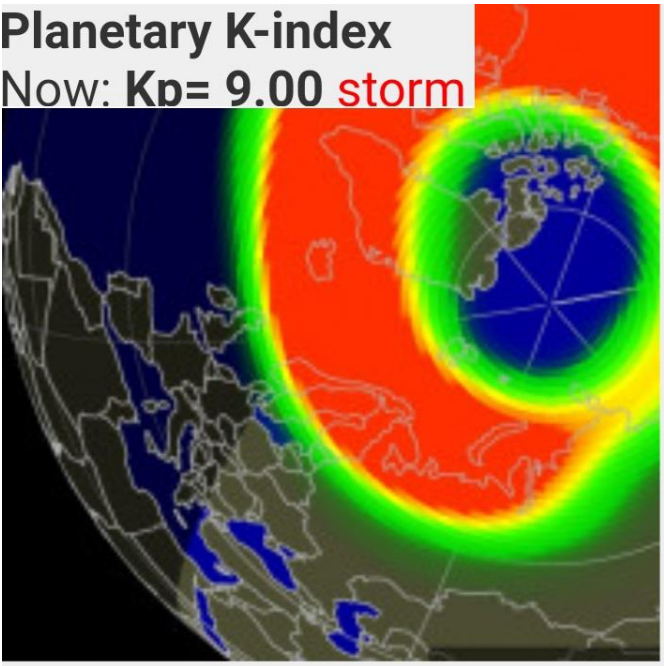


Fig. 3 Aurora oval over Europe at 2 UT of 11 may 2024, during the geomagnetic storm of class G5.

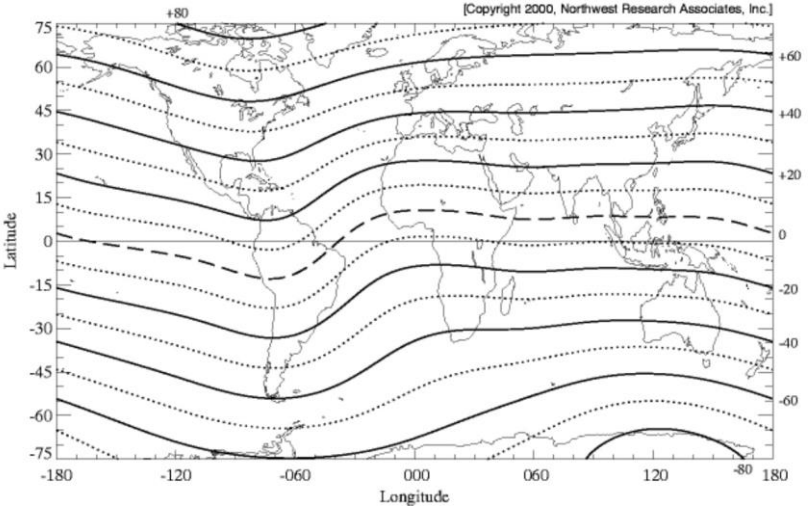


Fig. 4 Geomagnetic latitude (Apex 350 km model, 1990). The central Adriatic sea is at 35° N.

Commentary on the naked eye visibility

Galileo used he name "Aurora Borealis" in the Saggiatore,[5] and the testimonies at low magnetic latitudes are extremely rare even under clear and dark skies as in Antiquity.[6]

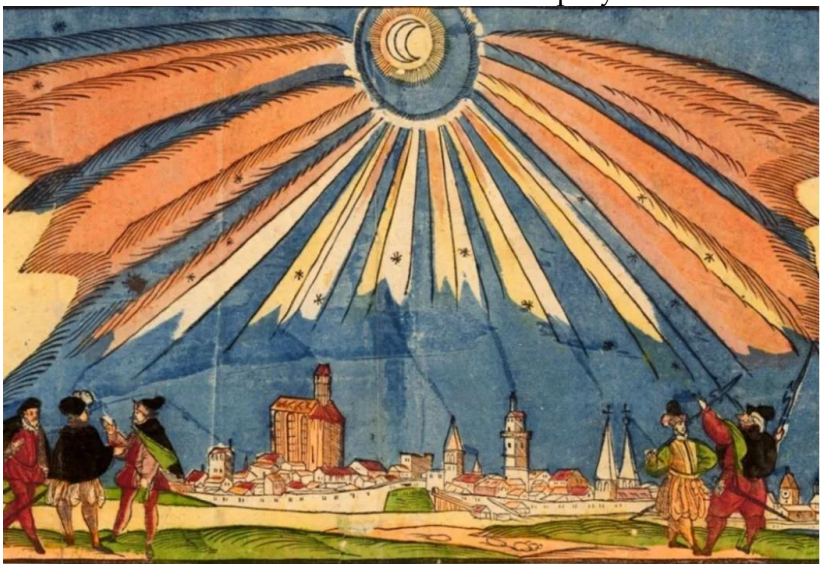


Fig. 5 The Aurora of March 6, 1582 in Augsburg, with nearly full Moon phase.

Mary Mc Intyre[8] said that in the aurora display of 10-11 May 2024 the sky was as bright as with the Full Moon.

This time I could actually [see] some of the colours. The green was a subtle pastel turquoise colour, but the reds and pinks were much more prominent. The purples were extremely vivid on camera, so much so that the only processing I did to my images[7] was to actually reduce the colour saturation, but to my eyes they were a pastel lilac colour. It's definitely the most amount of colour I've ever seen - I could easily see the colours up at the zenith. The red stable aurora

[5] https://ingvambiente.com/2023/03/06/laurora-boreale-del-1582/

[6] Iulius Obsequens, 661 ab Urbe Condita (93 bC) Liber Prodigiorum.

[7] Fellow of the Royal Astronomical Society
https://www.youtube.com/watch?v=ZysKIHp06hk

arcs in the southern sky were quite noticeable red as well but I was struggling to see any movement in them. The aurora was incredibly bright at one point that it was like there was a Full Moon in the sky. It's an experience I never thought I'd have from here and I will certainly never forget it! Oxforshire, May 13, 2024 h 22:59.

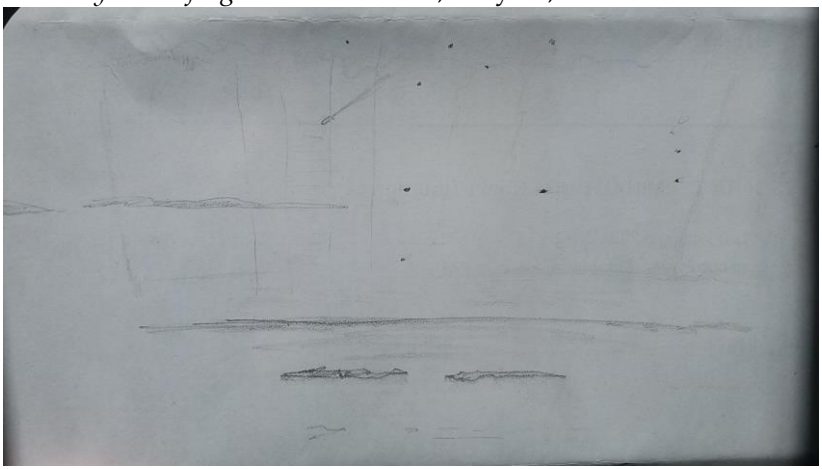


Fig. 6 The sketch of the Aurora between 3 and 4 AM (1 and 2 UT) of May 11 as seen with the naked eye from Pes cara.

The stars of Cassiopeia and Perseus-Andromeda were well visible under the curtains in motion. Three bright pillars were moving all the time in the area of 50° in azimut and 15° in altitude. The colors white for the pillars and greenish – reddish for the curtains were barely visible. The surface brightness of the Aurora was much lower than the yellow lunar halo seen on May 12 at 23:30 PM. The humidity at the seaside made the Aurora not visible near the horizon. The seaside faced North, so no direct lights were affecting my view, but I was able to perceive two breakwater rocks in front of me at 100 m. Two linear clouds were moving South passing over the Aurora. I would not have seen the Aurora if I were not aware of its presence, especially after 2:02 when a local electric alarm played. The limiting magnitude of the stars visible to the naked eye a few degrees near the horizon was 3 (Gamma Persei and Delta Andromedae). The nearby M31 galaxy was visible with a 6x18 monocular + two shooting stars.

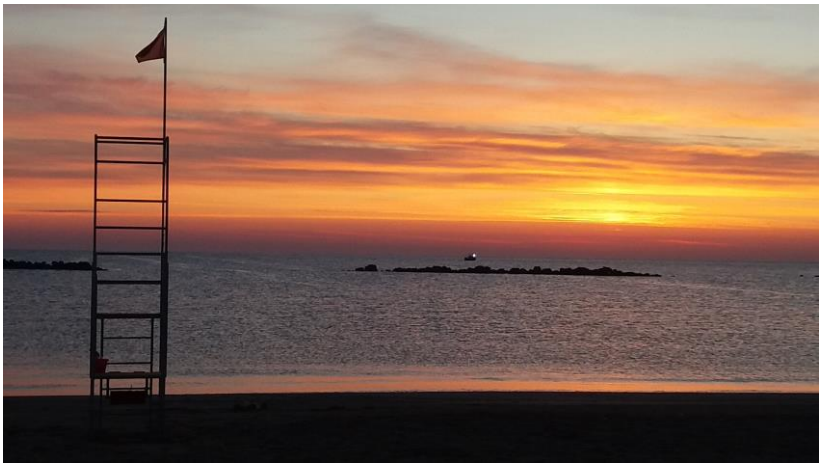


Fig. 7 *Pescara's Aurora point*, were my observations took place, before sunrise on May 13, 2024, on the baywatch place.

The aurora borealis of May 10/11 2024 has been registered by many smartphones and cameras; my naked eye account[8] is in continuity with the medieval and antique accounts: 50°x15° was the area of the Auroral display in azimuth and altitude, with very pale colors green, red and white pillars, at seaside.

Conclusions and perspectives

Predictions on the K_P index are available for a month ahead,[9] but their validity for a strong geomagnetic storm, with effects on the Mediterranean sky, is reliable only within 24 hours. The activity of the Sun in 14-25 May 2024 may be a prelude of other X-ray flares, with CME aiming toward the Earth, restoring the exceptional conditions of 10/11 May, when the hemisphere of the Mediterranean Europe was exposed to the Aurora for all that Moonless night. For Mediterranean observers the Aurora center is within 20° from azimuth North, so it is mandatory to have this horizon clear from lightglows, better from mountains and free from low obstacles.

[8] https://drive.google.com/file/d/1j9knjvncgnJhYVYTf85wEel_lJNA35LW

[9] https://www.spaceweatherlive.com/it/attivita-aurorale/previsione-aurora.html