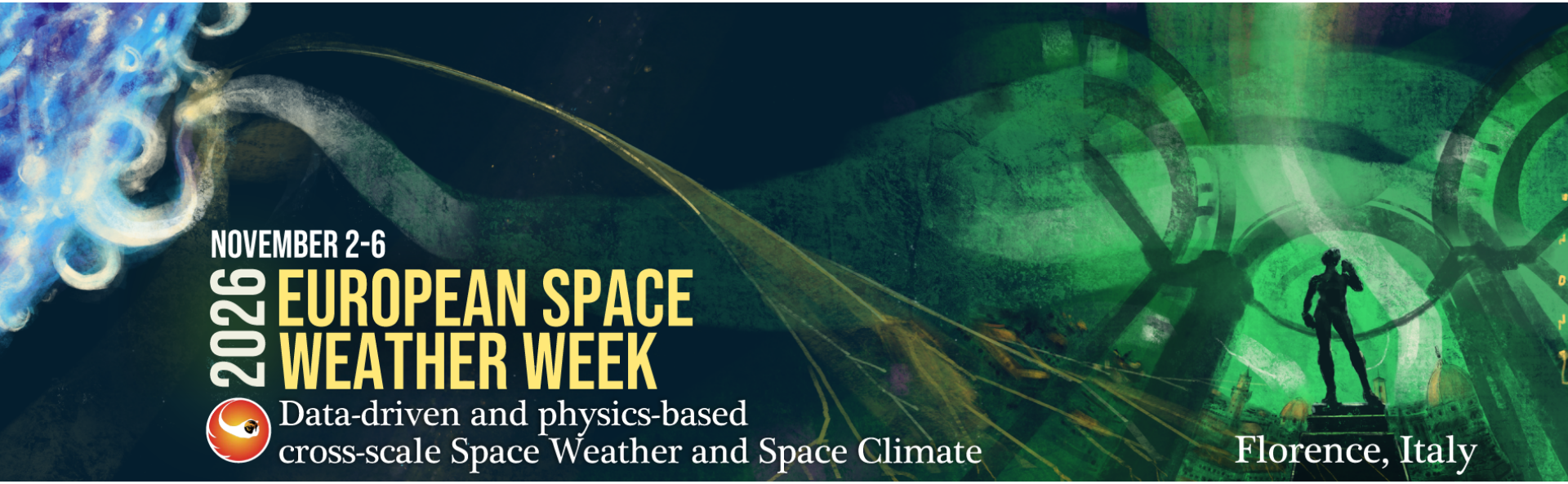
Space Weather Training Course



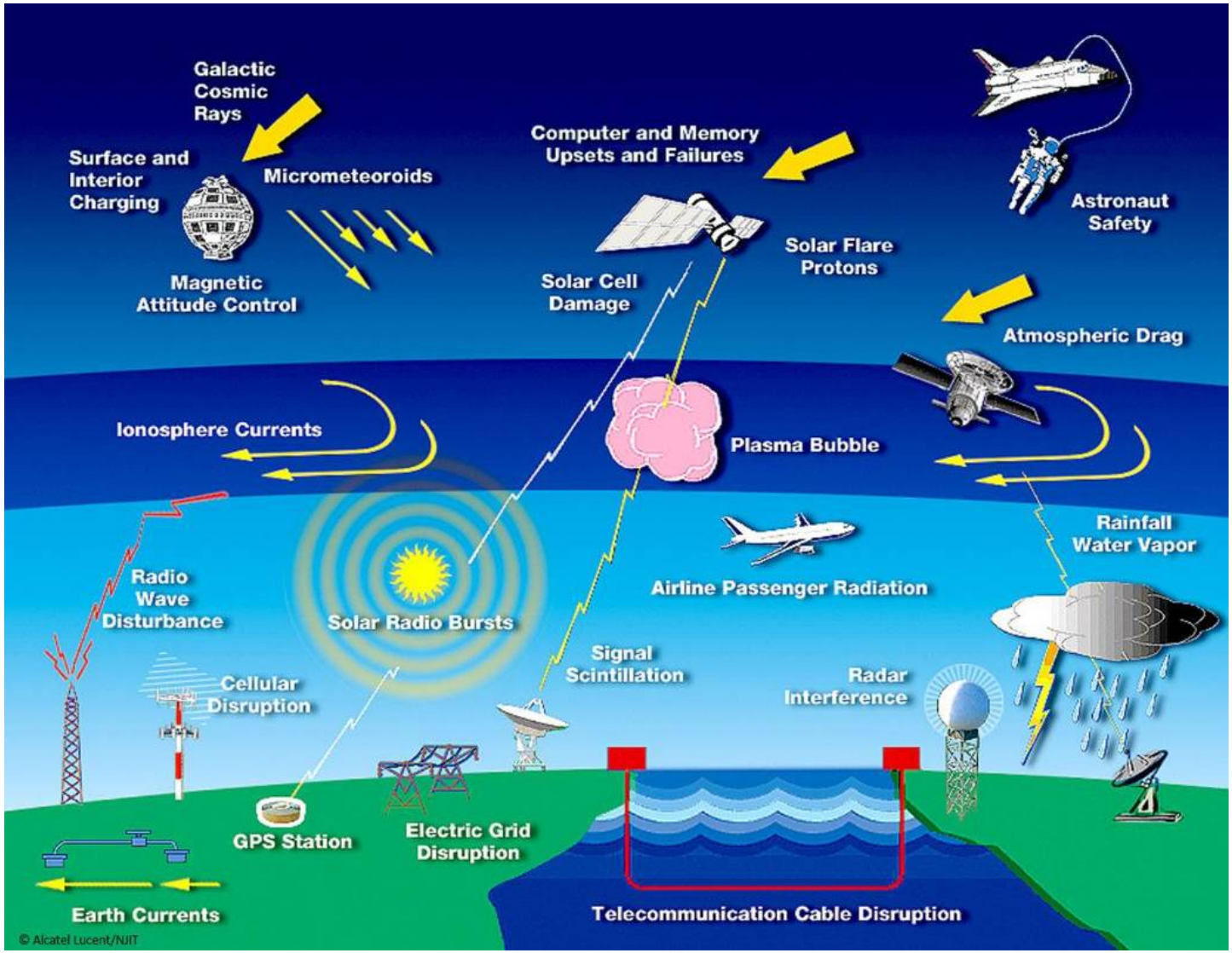
Collaboration of

e-swan

SWEC
Space Weather Education Centre

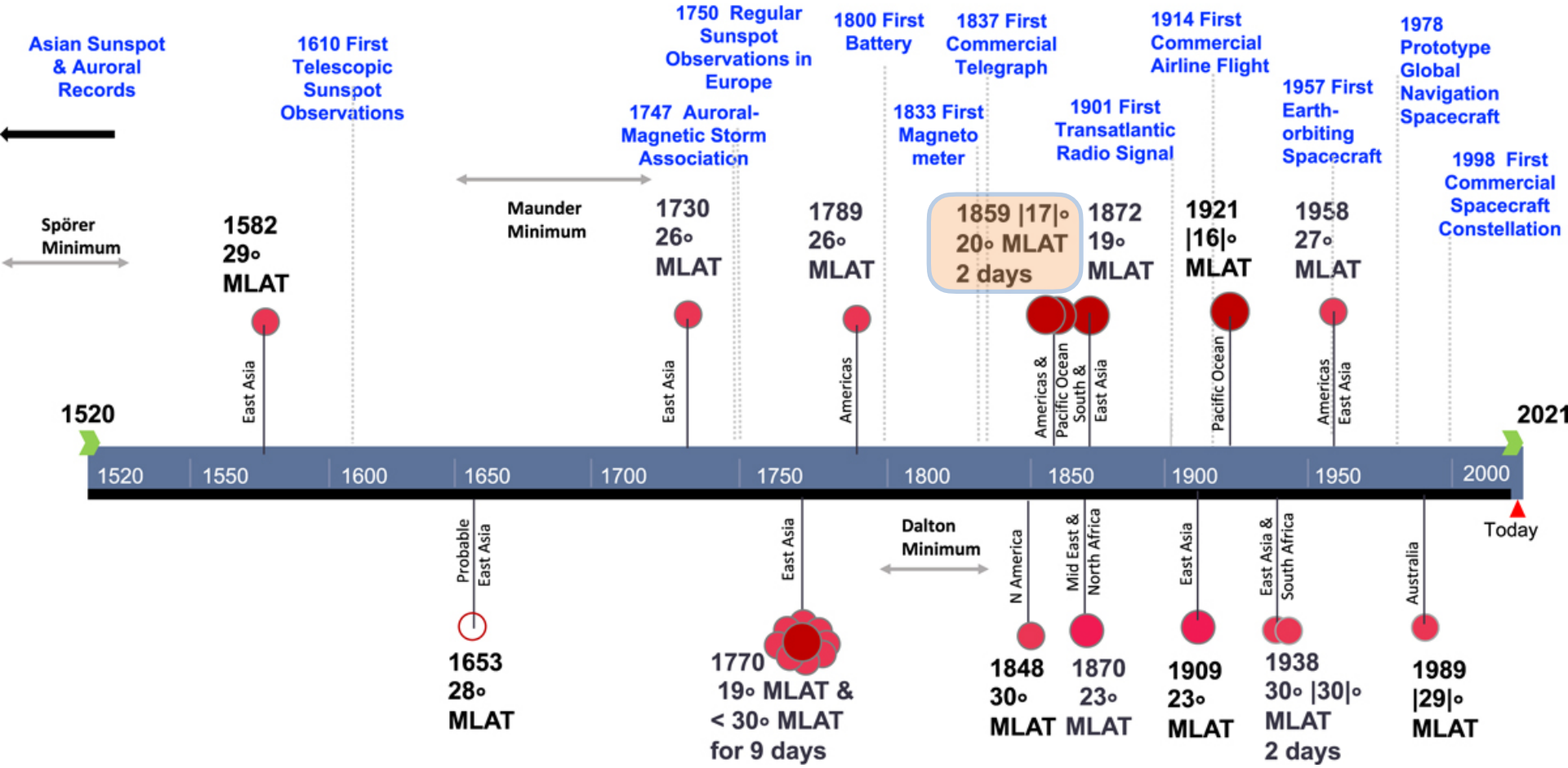
COMMUNITY COORDINATED MODELING CENTER

Space Weather Impacts



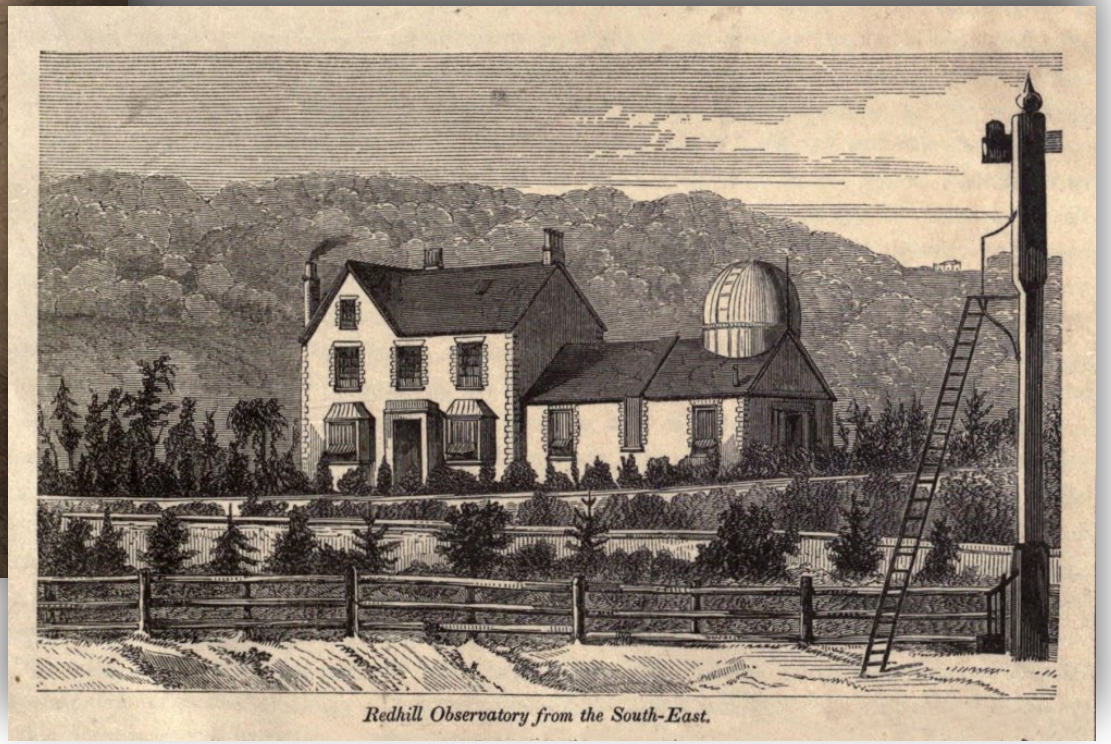
Timeline - 1859

500 Years of Space Weather Storms with Aurora Visible at or Equatorward of 30º Magnetic Latitude



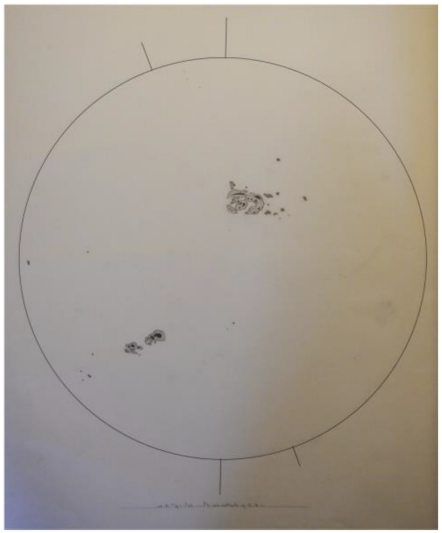
Carrington Event

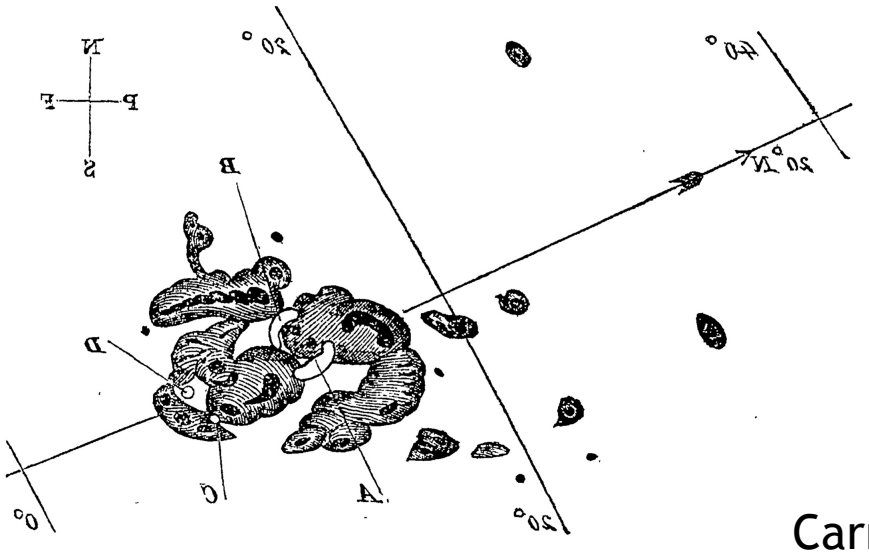




Redhill Observatory from the South-East.

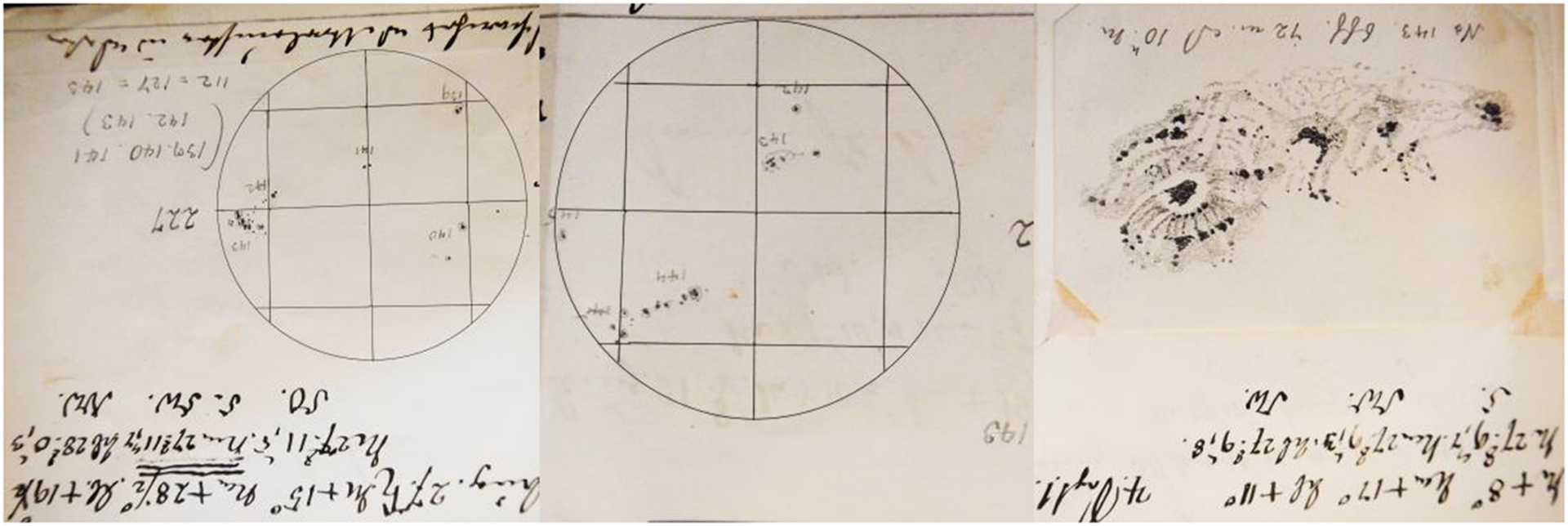
Carrington Event - 1 September 1859



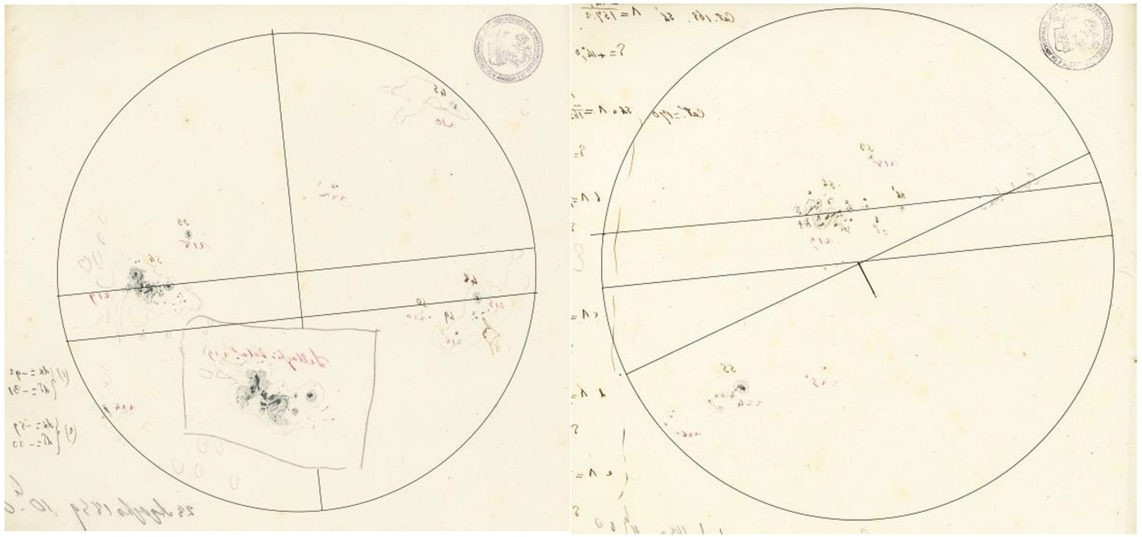


Carrington, 1959

Carrington Event - 1 September 1859

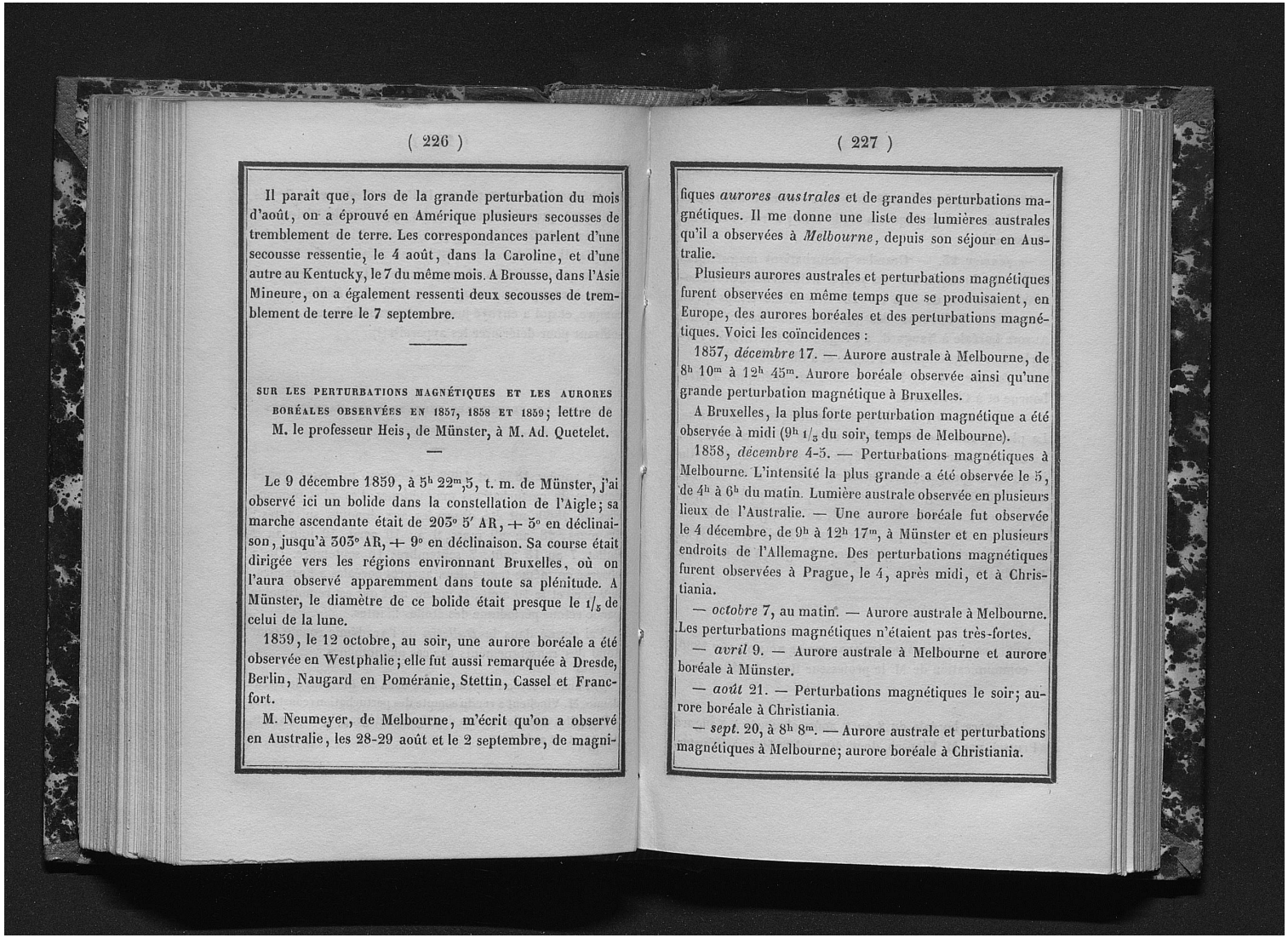


Schwabe, 1959



Secchi, 1959

Carrington Event - 1 September 1859



Il paraît que, lors de la grande perturbation du mois d'août, on a éprouvé en Amérique plusieurs secousses de tremblement de terre. Les correspondances parlent d'une secousse ressentie, le 4 août, dans la Caroline, et d'une autre au Kentucky, le 7 du même mois. A Brousse, dans l'Asie Mineure, on a également ressenti deux secousses de tremblement de terre le 7 septembre.

SUR LES PERTURBATIONS MAGNÉTIQUES ET LES AURORES BORÉALES OBSERVÉES EN 1857, 1858 ET 1859; lettre de M. le professeur Heis, de Münster, à M. Ad. Quetelet.

—

Le 9 décembre 1859, à $5^h\ 22^m,5$, t. m. de Münster, j'ai observé ici un bolide dans la constellation de l'Aigle; sa marche ascendante était de 205° 5′ AR, + 5° en déclinaison, jusqu'à 303° AR, + 9° en déclinaison. Sa course était dirigée vers les régions environnant Bruxelles, où on l'aura observé apparemment dans toute sa plénitude. A Münster, le diamètre de ce bolide était presque le $1/5$ de celui de la lune.

1859, le 12 octobre, au soir, une aurore boréale a été observée en Westphalie; elle fut aussi remarquée à Dresde, Berlin, Naugard en Poméranie, Stettin, Cassel et Francfort.

M. Neumeyer, de Melbourne, m'écrit qu'on a observé en Australie, les 28-29 août et le 2 septembre, de magni-

fiques *aurores australes* et de grandes perturbations magnétiques. Il me donne une liste des lumières australes qu'il a observées à *Melbourne*, depuis son séjour en Australie.

Plusieurs aurores australes et perturbations magnétiques furent observées en même temps que se produisaient, en Europe, des aurores boréales et des perturbations magnétiques. Voici les coïncidences :

1857, *décembre* 17. — Aurore australe à Melbourne, de $8^h\ 10^m$ à $12^h\ 45^m$. Aurore boréale observée ainsi qu'une grande perturbation magnétique à Bruxelles.

A Bruxelles, la plus forte perturbation magnétique a été observée à midi ($9^h\ 1/5$ du soir, temps de Melbourne).

1858, *décembre* 4-5. — Perturbations magnétiques à Melbourne. L'intensité la plus grande a été observée le 5, de 4^h à 6^h du matin. Lumière australe observée en plusieurs lieux de l'Australie. — Une aurore boréale fut observée le 4 décembre, de 9^h à $12^h\ 17^m$, à Münster et en plusieurs endroits de l'Allemagne. Des perturbations magnétiques furent observées à Prague, le 4, après midi, et à Christiania.

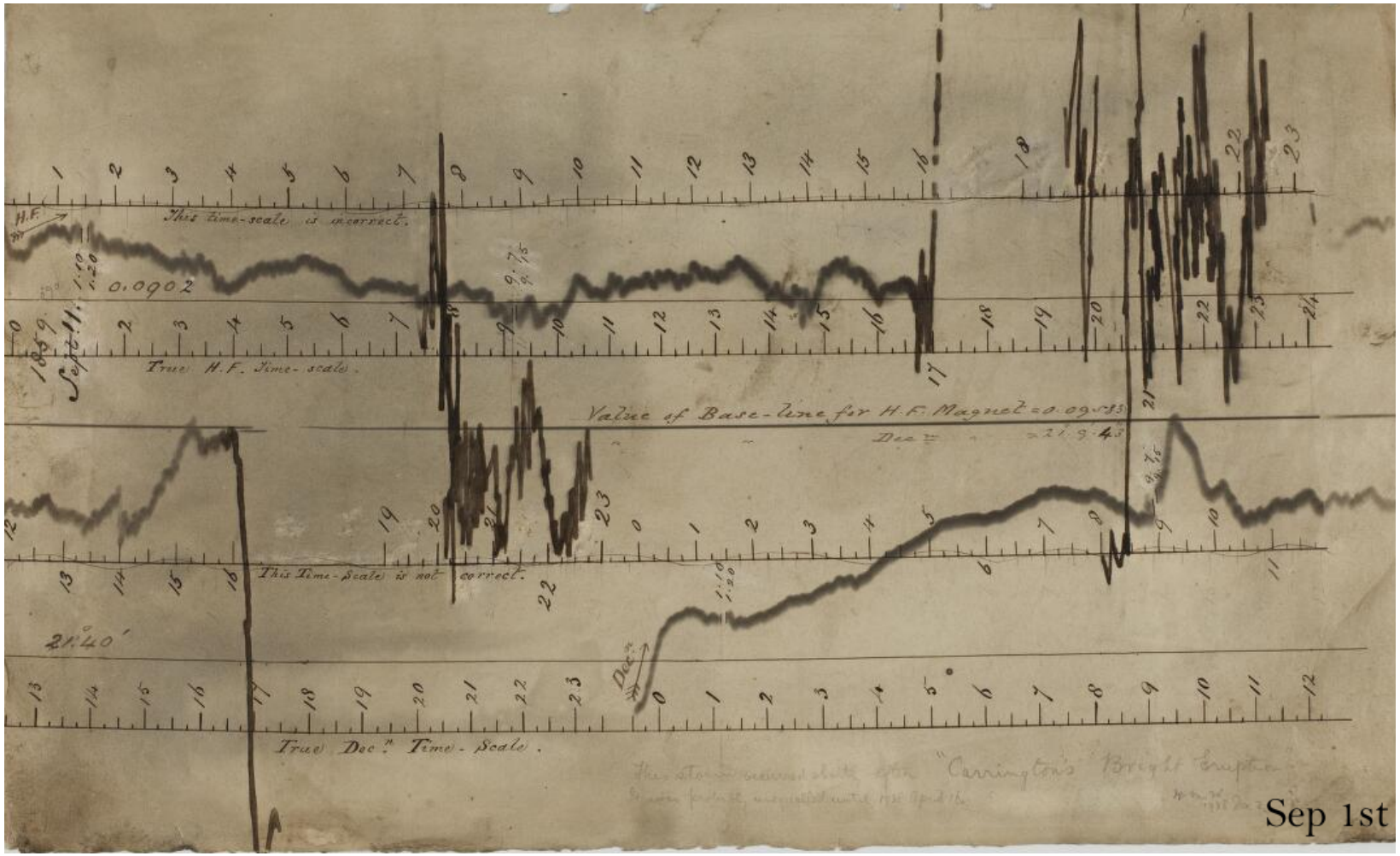
— *octobre* 7, au matin. — Aurore australe à Melbourne. Les perturbations magnétiques n'étaient pas très-fortes.

— *avril* 9. — Aurore australe à Melbourne et aurore boréale à Münster.

— *août* 21. — Perturbations magnétiques le soir; aurore boréale à Christiania.

— *sept.* 20, à $8^h\ 8^m$. — Aurore australe et perturbations magnétiques à Melbourne; aurore boréale à Christiania.

Carrington Event - 1 September 1859



Carrington Event - 1 September 1859

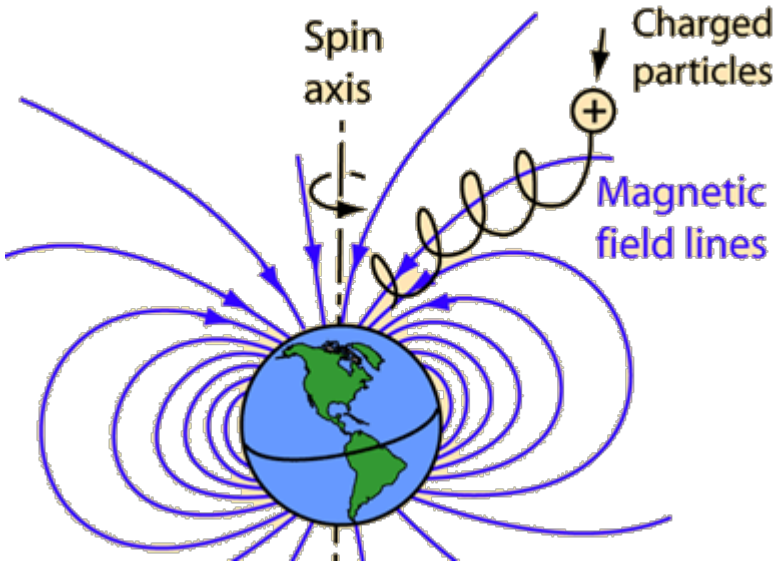


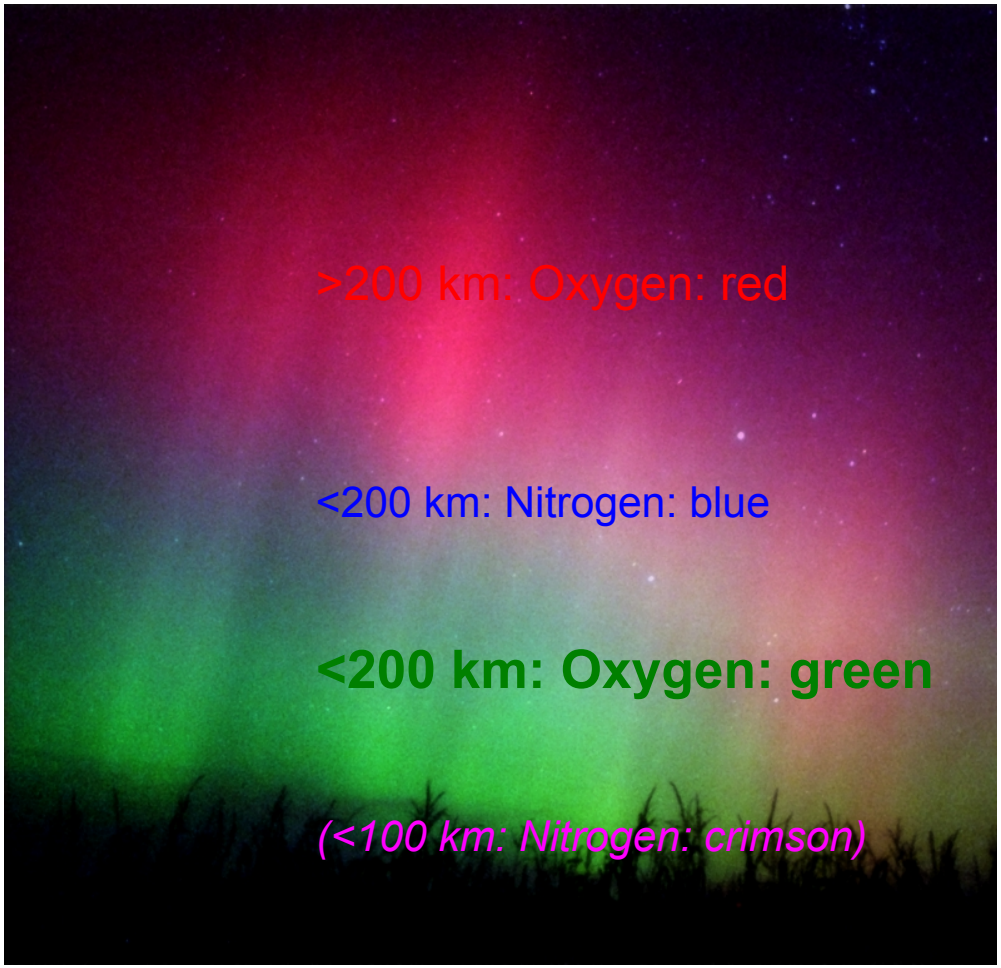
Conversation between two operators of the telegraph line between Boston and Portland on the night of 2 September 1859

Boston operator: *"Please cut off your battery entirely for fifteen minutes."*
Portland operator: *"Will do so. It is now disconnected."*
Boston: *"Mine is disconnected, and we are working with the auroral current. How do you receive my writing?"*
Portland: *"Better than with our batteries on. – Current comes and goes gradually."*
Boston: *"My current is very strong at times, and we can work better without the batteries, as the aurora seems to neutralize and augment our batteries alternately, making current too strong at times for our relay magnets. Suppose we work without batteries while we are affected by this trouble."*
Portland: *"Very well. Shall I go ahead with business?"*
Boston: *"Yes. Go ahead."*

Carrington Event - Effect: Aurora

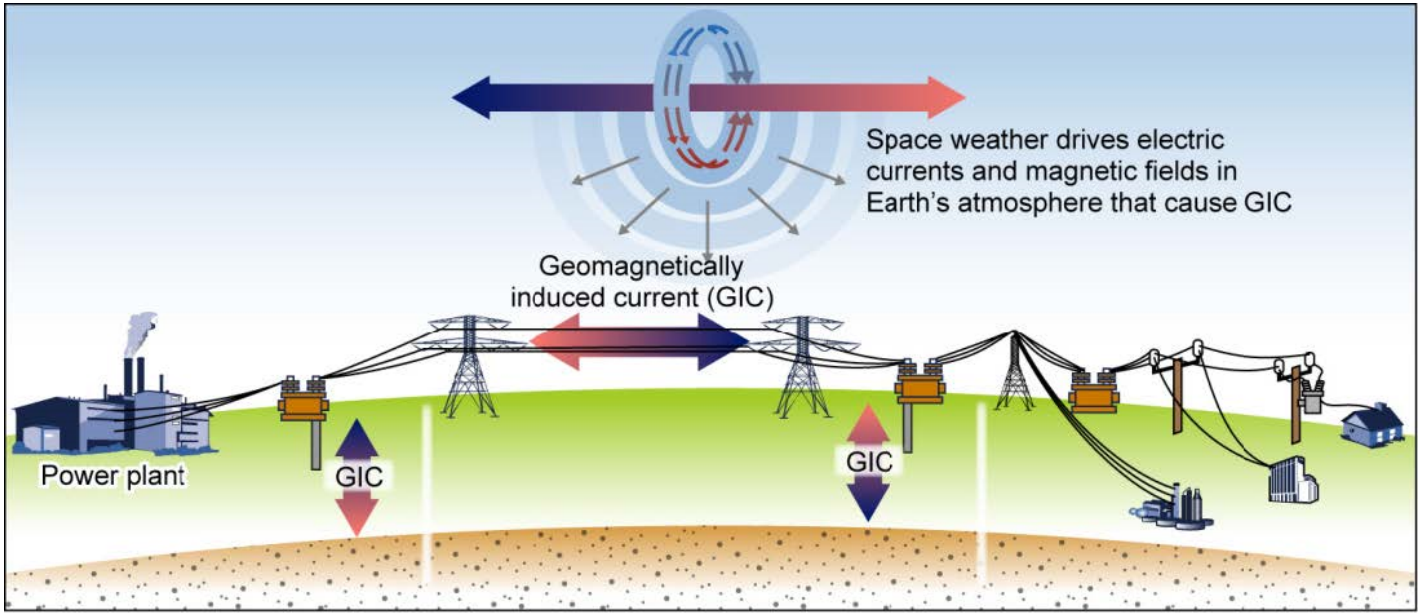
- Aurora as far down as the tropics





Carrington Event - Effect: GIC

- Aurora as far down as the tropics
- Geomagnetically Induced Currents (GICs) in telegraph wires



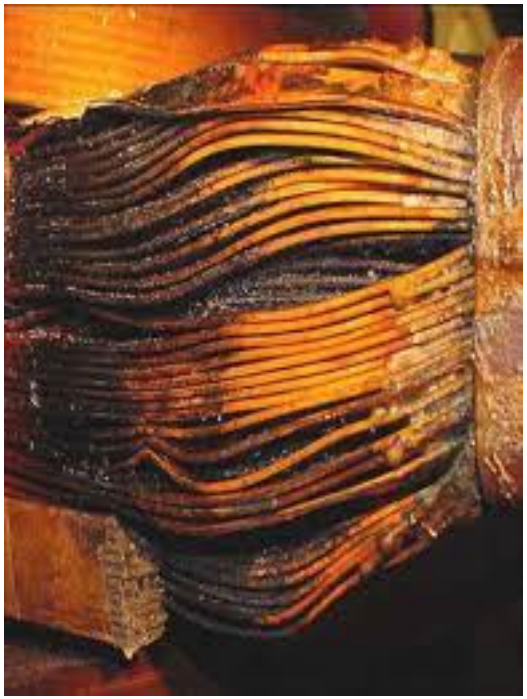
Sources: GAO (presentation); Art Explosion (images). | GAO-19-98

Geomagnetically Induced Currents

- Telegraph
- Affects all long conductors
- Power grid: transformer damage, blackout
- Pipelines: corrosion -> leaks



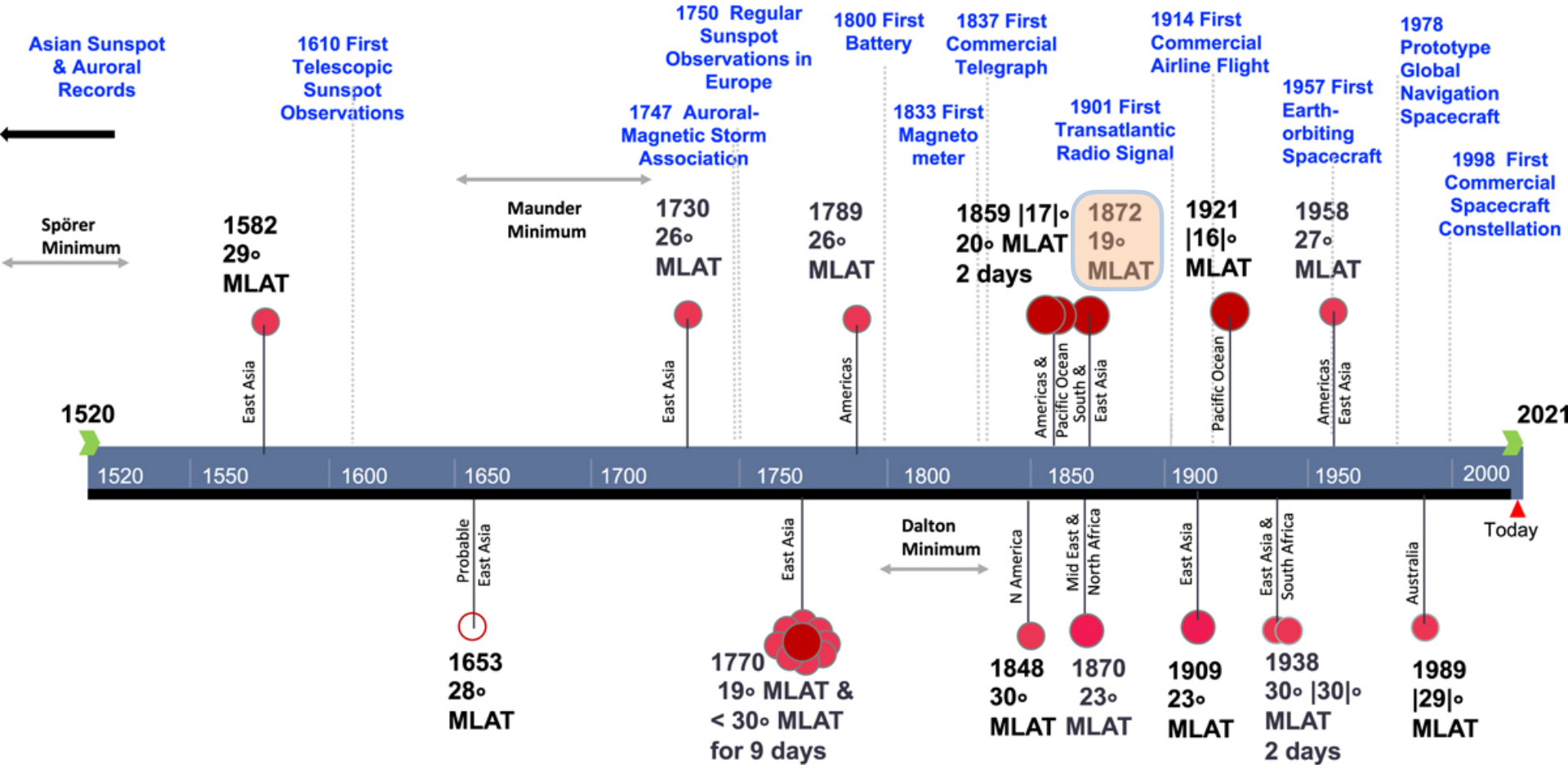
March 1989



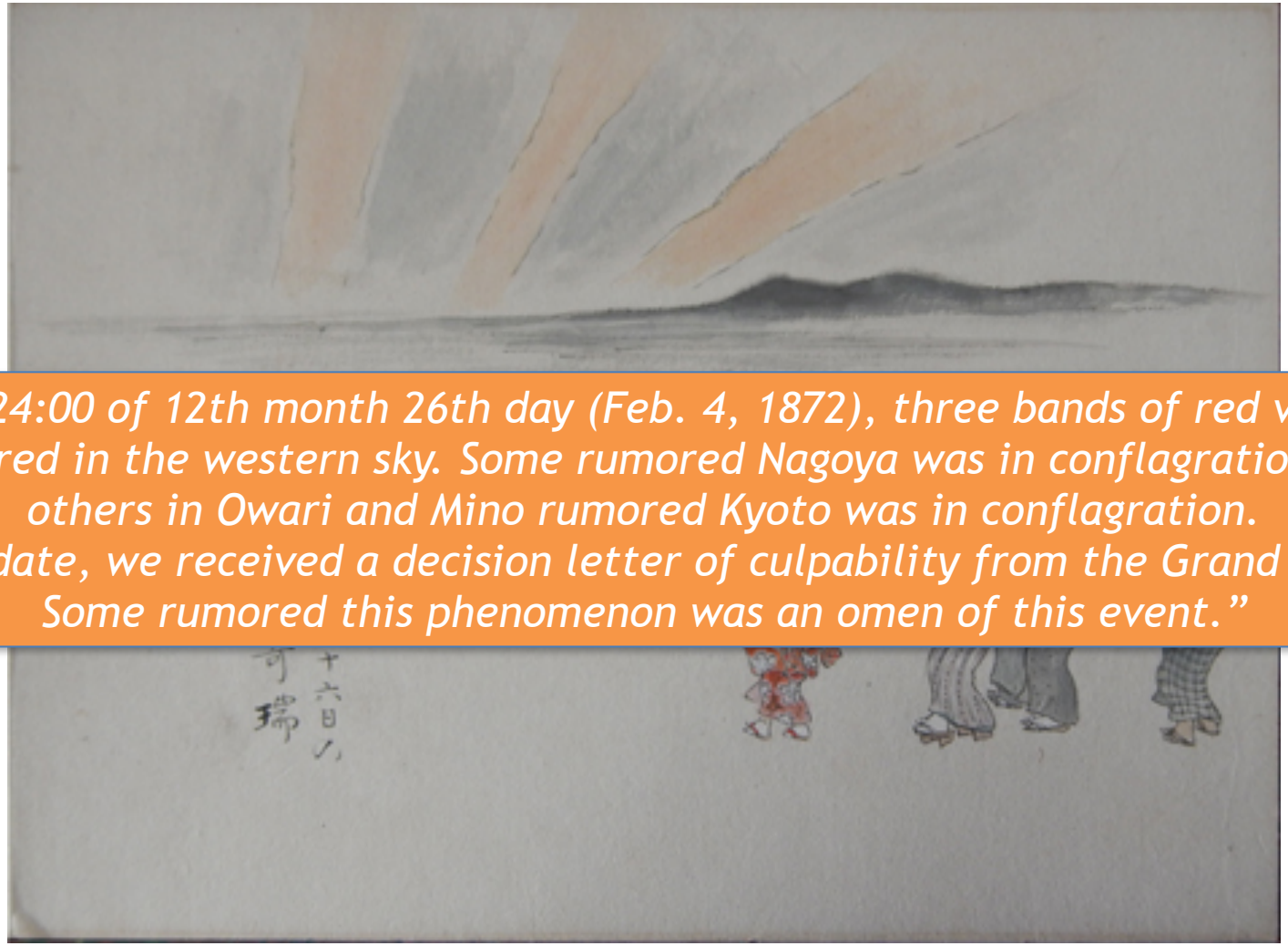


Timeline - 1872

500 Years of Space Weather Storms with Aurora Visible at or Equatorward of 30º Magnetic Latitude



February 1872



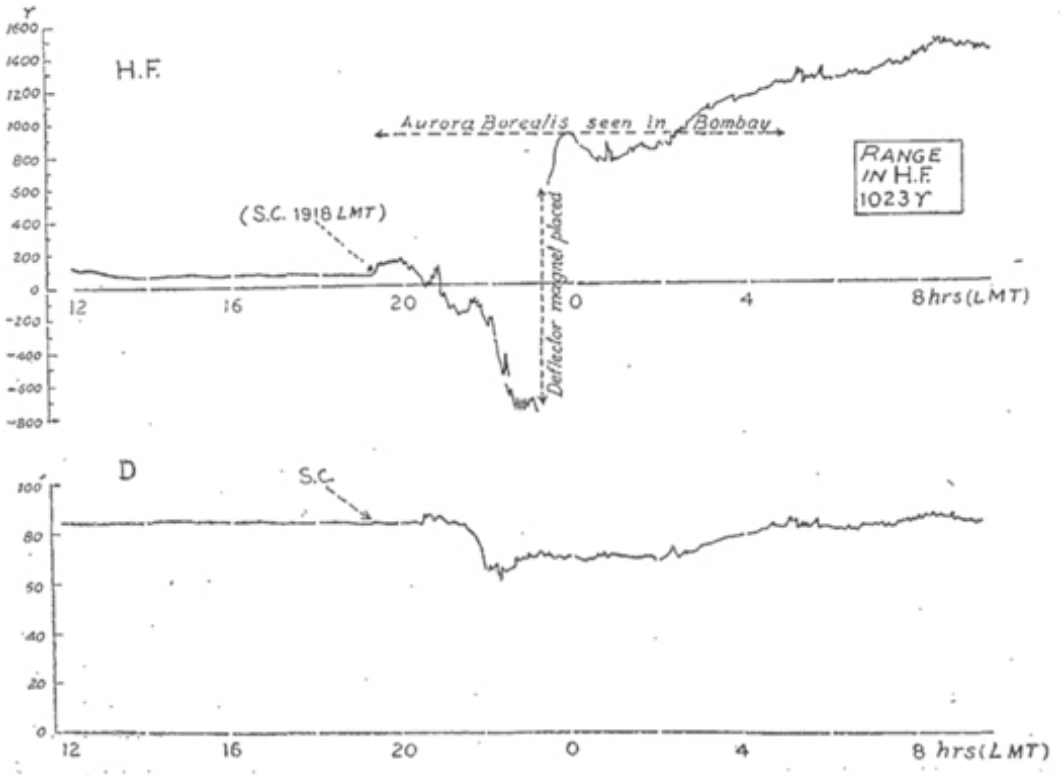
"At 24:00 of 12th month 26th day (Feb. 4, 1872), three bands of red vapor appeared in the western sky. Some rumored Nagoya was in conflagration, and others in Owari and Mino rumored Kyoto was in conflagration.
On this date, we received a decision letter of culpability from the Grand Council.
Some rumored this phenomenon was an omen of this event."

Junkyo Eshi, 1872

February 1872 - Magnetic Observations

SOME SELECTED MAGNETOGRAMS OF BOMBAY

Date : 4-5 February 1872
Duration of storm : 15 hours
Sudden commencement (H) : 85 γ
Range in H : 1023 γ

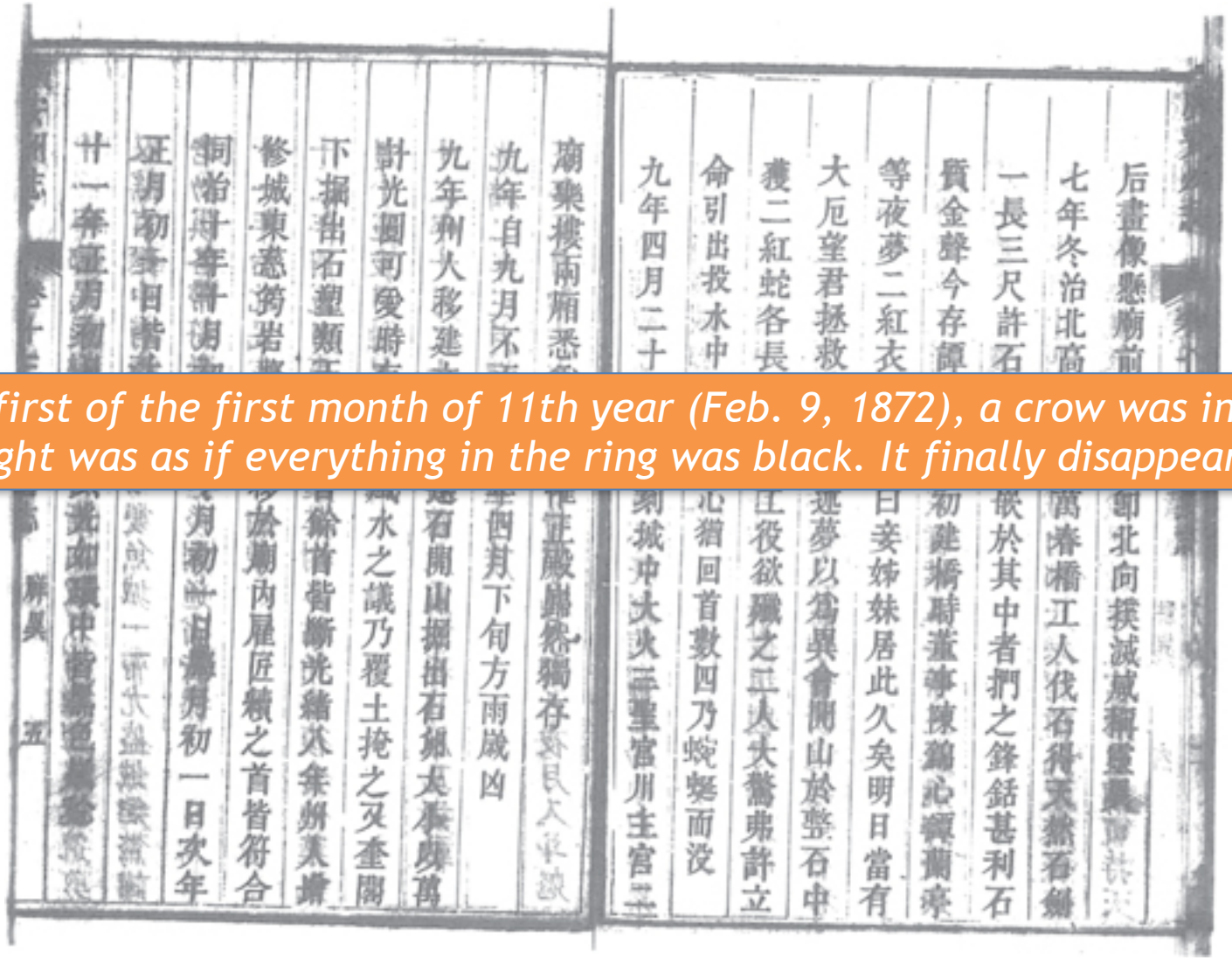


A magnetic storm of great intensity was recorded by Colaba on this day. It was one of the most violent storms since 1857 listed by Chapman and Bartels (*Geomagnetism* Vol. I page 328).

Very intense Aurora Borealis was seen in many places and even in low latitudes like Bombay from the evening of 4th to the morning of 5th. The Aurora Borealis of this date is one of the most brilliant on record. Internal telegraphic Communication and cable communication with England were interrupted for some hours as a result of the storm.

(Bombay LMT is 4 hours 51 minutes ahead of G M T)

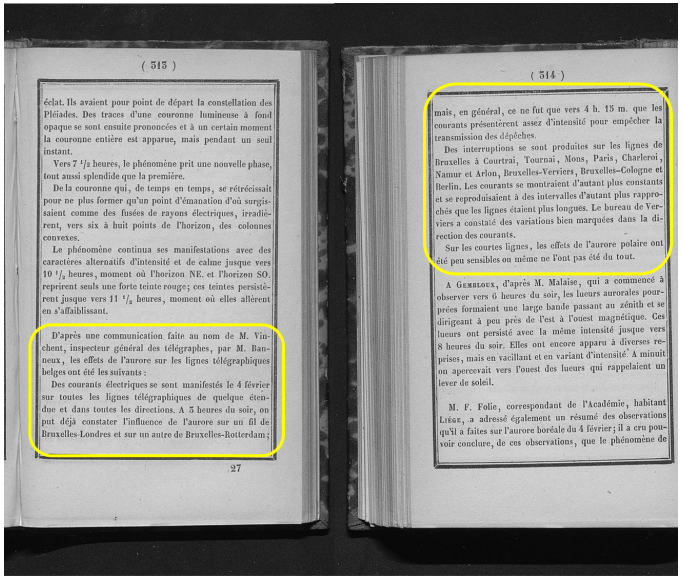
February 1872 - Sunspot Observations



"On the first of the first month of 11th year (Feb. 9, 1872), a crow was in the sun. Its light was as if everything in the ring was black. It finally disappeared."

February 1872 - Reported Impacts

"... electrical currents were present on 4 February on all telegraph lines and in all directions. Affecting already from 3 pm local time the messagery between Brussels and London and between Brussels and Rotterdam, it was not until 4:15 pm that the currents were strong enough as to prohibit the sending of telegraphic messages. Interruptions were observed on all lines, not only in Belgium (e.g. Brussels-Namur, Brussels-Kortrijk), but also on the lines to Paris, Berlin and Cologne. It was noted that the longer the lines, the more constant the currents were and the more they recurred at increasingly shorter intervals."



(513)

éclat. Ils avaient pour point de départ la constellation des Pléiades. Des traces d'une couronne lumineuse à fond opaque se sont ensuite prononcées et à un certain moment la couronne entière est apparue, mais pendant un seul instant.

Vers 7 1/2 heures, le phénomène prit une nouvelle phase, tout aussi splendide que la première.

De la couronne qui, de temps en temps, se rétrécissait pour ne plus former qu'un point d'émanation d'où surgissaient comme des fusées de rayons électriques, irradièrent, vers six à huit points de l'horizon, des colonnes convexes.

Le phénomène continua ses manifestations avec des caractères alternatifs d'intensité et de calme jusque vers 10 1/2 heures, moment où l'horizon NE. et l'horizon SO. reprirent seuls une forte teinte rouge; ces teintes persistèrent jusque vers 11 1/2 heures, moment où elles allèrent en s'affaiblissant.

D'après une communication faite au nom de M. Vinchent, inspecteur général des télégraphes, par M. Banneux, les effets de l'aurore sur les lignes télégraphiques belges ont été les suivants :

Des courants électriques se sont manifestés le 4 février sur toutes les lignes télégraphiques de quelque étendue et dans toutes les directions. A 5 heures du soir, on put déjà constater l'influence de l'aurore sur un fil de Bruxelles-Londres et sur un autre de Bruxelles-Rotterdam;

27

(514)

mais, en général, ce ne fut que vers 4 h. 15 m. que les courants présentèrent assez d'intensité pour empêcher la transmission des dépêches.

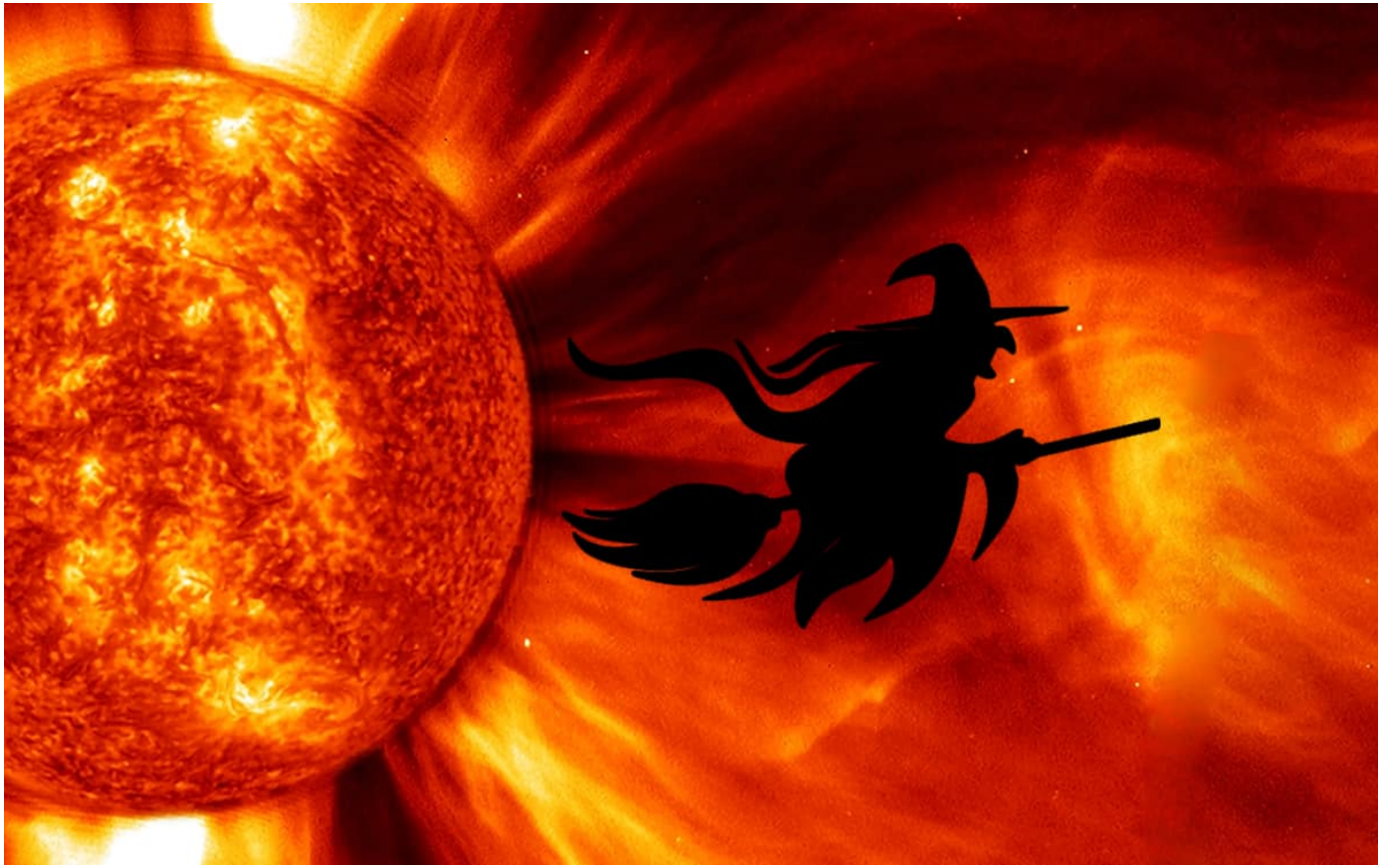
Des interruptions se sont produites sur les lignes de Bruxelles à Courtrai, Tournai, Mons, Paris, Charleroi, Namur et Arlon, Bruxelles-Verviers, Bruxelles-Cologne et Berlin. Les courants se montraient d'autant plus constants et se reproduisaient à des intervalles d'autant plus rapprochés que les lignes étaient plus longues. Le bureau de Verviers a constaté des variations bien marquées dans la direction des courants.

Sur les courtes lignes, les effets de l'aurore polaire ont été peu sensibles ou même ne l'ont pas été du tout.

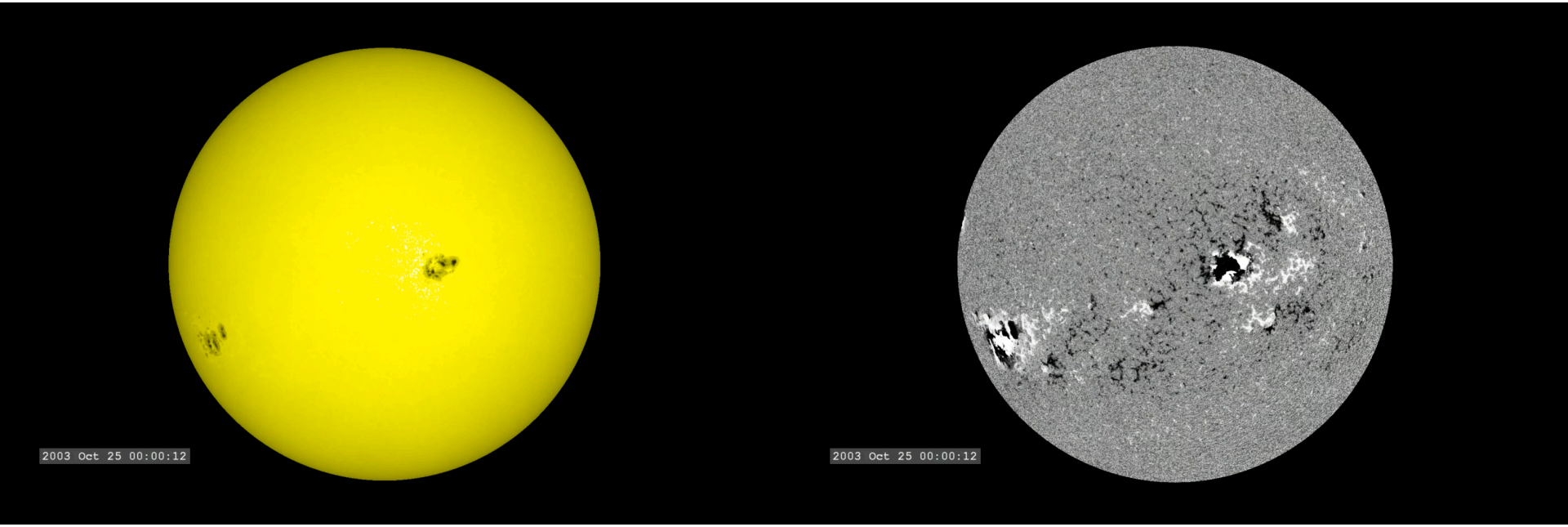
A Gembloux, d'après M. Malaise, qui a commencé à observer vers 6 heures du soir, les lueurs aurorales pourprées formaient une large bande passant au zénith et se dirigeant à peu près de l'est à l'ouest magnétique. Ces lueurs ont persisté avec la même intensité jusque vers 8 heures du soir. Elles ont encore apparu à diverses reprises, mais en vacillant et en variant d'intensité. A minuit on apercevait vers l'ouest des lueurs qui rappelaient un lever de soleil.

M. F. Folie, correspondant de l'Académie, habitant Liége, a adressé également un résumé des observations qu'il a faites sur l'aurore boréale du 4 février; il a cru pouvoir conclure, de ces observations, que le phénomène de

Halloween Storms

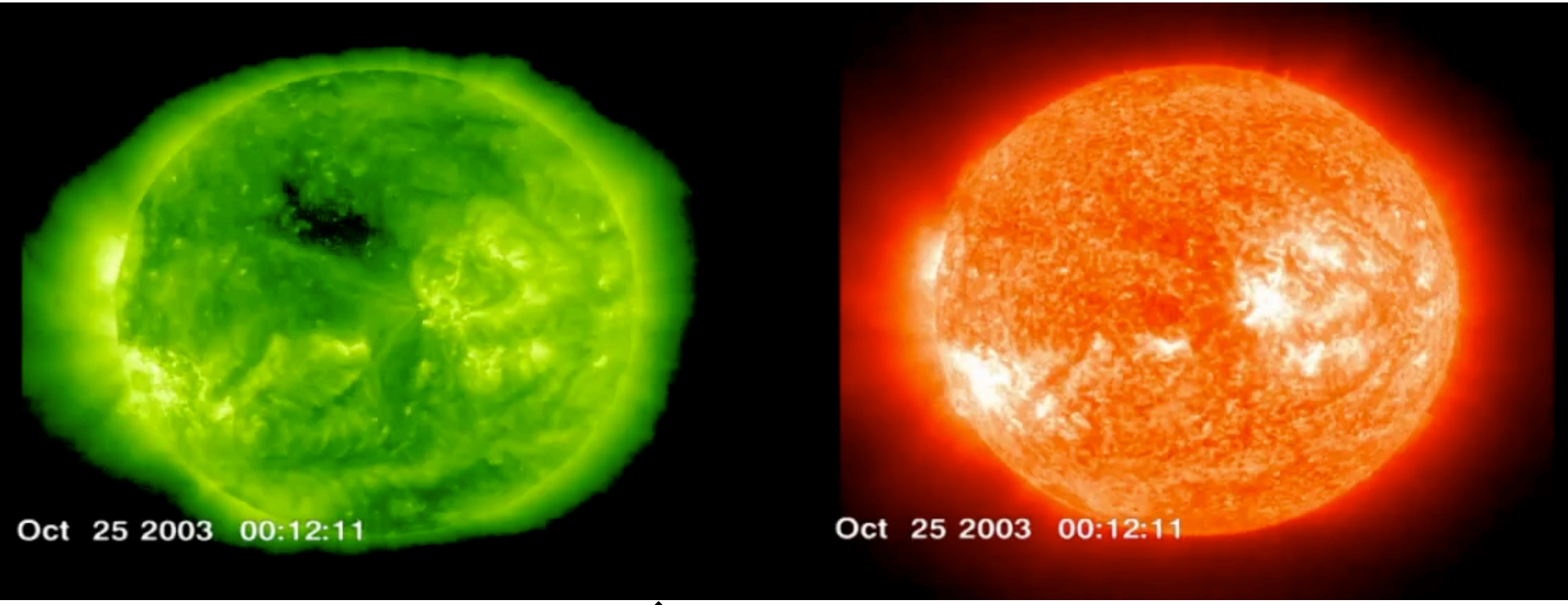


Halloween Storms - Oct/Nov 2003



SOHO/MDI

Halloween Storms - Flares and particles

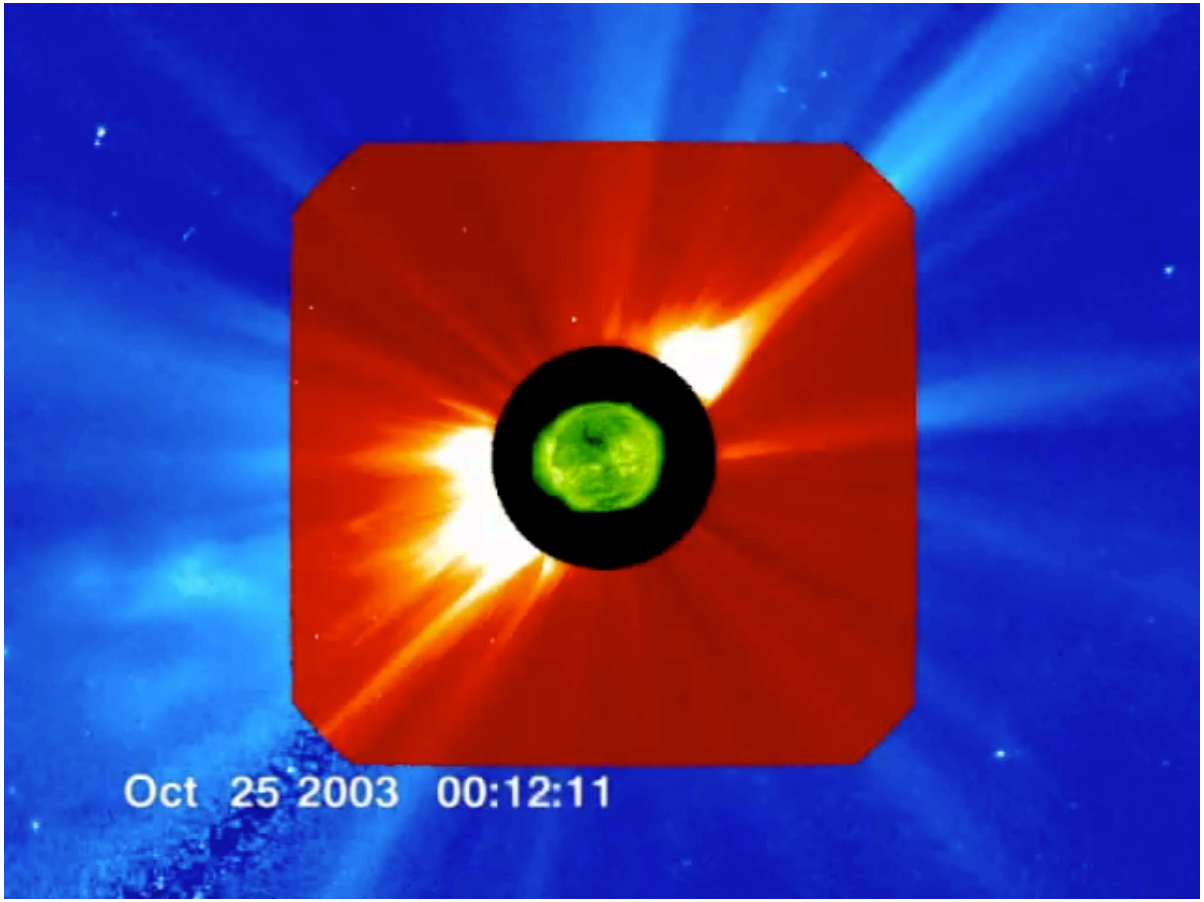


195 A

SOHO/EIT

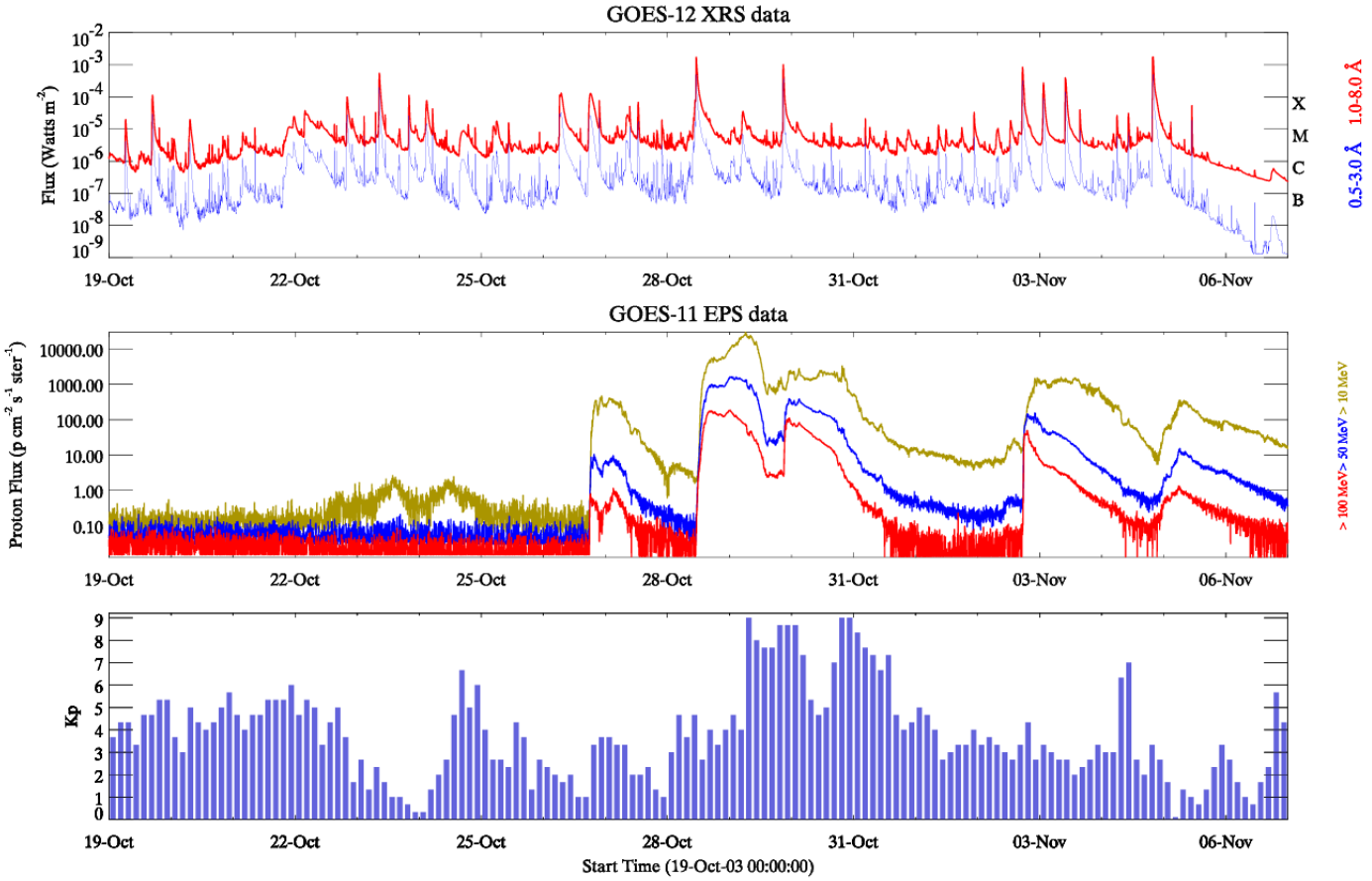
304 A

Halloween Storms - CMEs and particles



SOHO/LASCO

Halloween Storms - Observations



X-ray

Proton Flux

Kp

Figure 1: Summary plot of GOES-12 X-ray flux, GOES-11 proton flux, and Planetary Kp index for 23 October to 7 November 2003.

[NOAA report]

Halloween Storms - Observations

Table 1a: Solar Activity Summary

X-ray Event and Region					Radio Emissions			Coronal Mass Ejections				NOAA Scales		
Flare Max Date Time	Xray Class	Opt Class	Reg	Location	245 MHz (SFU)	2695 MHz (SFU)	Type II (km/s)	Transit Time (hrs)	Halo Type	Plane of Sky Spd. (km/s)	Shock @ ACE			
19 Oct 1650	X1.1	1n	484	N08E58	650	510	625		P	458		R3		
22 Oct 0351	(Note 1)		484	N07E25		320		59.6	P	651	24/1450	R1		G3
22 Oct 2007	M9.9	Sf	486	S18E78	100	240			P			R2		
23 Oct 0835	X5.4	1b	486	S21E88	10000	1500	967		F	1110		R3		
23 Oct 2004	X1.1	1n	486	S17E84	2500	77						R3		
24 Oct 0254	M7.6	1n	486	S19E72	6800	73						R2		
26 Oct 0654	X1.2	3b	486	S15E44	14000	4000	1302		P	1245		R3		
26 Oct 1819	X1.2	1n	484	N02W38	1100	2000	950	31.8	F	1432	28/0130	R3	S2	G1
26 Oct 2140	M7.6	2n	484	N01W38		57						R2		
27 Oct 0927	M5.0	Sf	486	S16E26		65						R2		
27 Oct 1243	M6.7		486	S17E25	420	59						R2		
28 Oct 1110	X17.2	4b	486	S16E08	490000	13000	1250	19.0	F	2125	29/0559	R4	S4	G5
29 Oct 2049	X10.0	2b	486	S15W02	360000	2500	775	19.0	F	1948	30/1620	R4	S3	G5
02 Nov 1725	X8.3	2b	486	S14W56	24000	7700	1691	37.0	F	1826	04/0600	R3	S3	G3
03 Nov 0130	X2.7	2b	488	N10W83	100	240	1400		P			R3		
03 Nov 0955	X3.9	2f	488	N08W77	3900	4400	869		P			R3		
04 Nov 1950	X28.0	3b	486	S19W83	4800	20000	1268	47.8	F	2381	06/1915	R5	S2	G2
05 Nov 1052	M5.3	Sf	486	S16W90								R2		
Note 2								Note 3, 4			Note 2			

Halloween Storms - Observations

Table 1b: Solar Activity Summary

X-ray Event		Geomagnetic Response				>10 MeV Proton Event				>100 MeV Proton Event			
Flare Max	Xray Class	SI Time	SI Ampl (nT)	Max Kp	Max Ap	Start Time	Peak Flux (PFU)	Peak Time	Dur. (hr)	Start Time	Peak Flux (PFU)	Peak Time	Dur. (hr)
19 Oct 1650	X1.1												
22 Oct 0351	M3.7	24/1529	105	7-	43								
22 Oct 2007	M9.9												
23 Oct 0835	X5.4												
23 Oct 2004	X1.1												
24 Oct 0254	M7.6												
26 Oct 0654	X1.2					26/1825	466	26/2235	24.8				
26 Oct 1819	X1.2	28/0207	10										
26 Oct 2140	M7.6												
27 Oct 0927	M5.0												
27 Oct 1243	M6.7												
28 Oct 1110	X17.5	29/0613	140	9_0	252	28/1215	29525	29/0615	94.7	28/1150	186	29/0015	61.9
29 Oct 2049	X10.0			9_0	221	29/2150	3298	29/1935	61.1	29/2150	110	29/2310	27.9
02 Nov 1725	X8.3	04/0627	72	7_0	39	02/1745	1570	03/1345	51.6	02/1740	49	02/1905	23.7
03 Nov 0130	X2.7												
03 Nov 0955	X3.9												
04 Nov 1950	X28.0	06/1937	31	6-	20	04/2225	353	05/0600	62.1	05/0535	1.3	05/0540	1.5
05 Nov 1052	M5.3												
Note 2		Note 5		Note 2, 6		Note 2, 7		Note 2, 8		Note 2			

Halloween Storms - Impacts on Satellites

- Magnetopause crossings

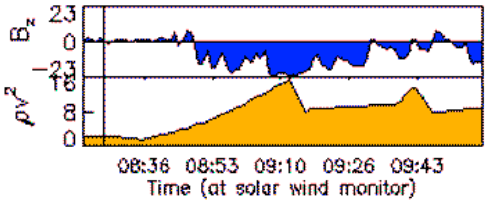
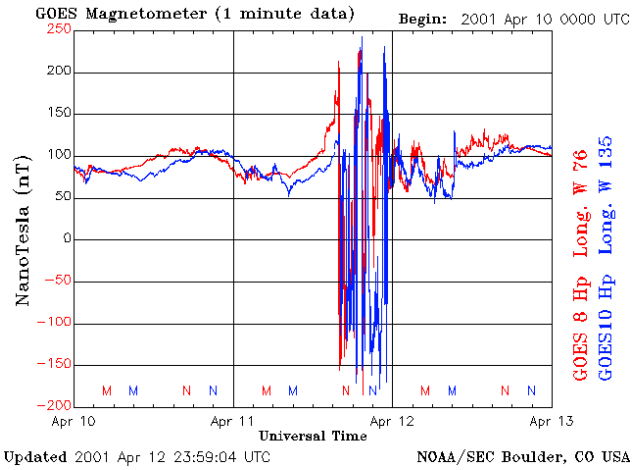
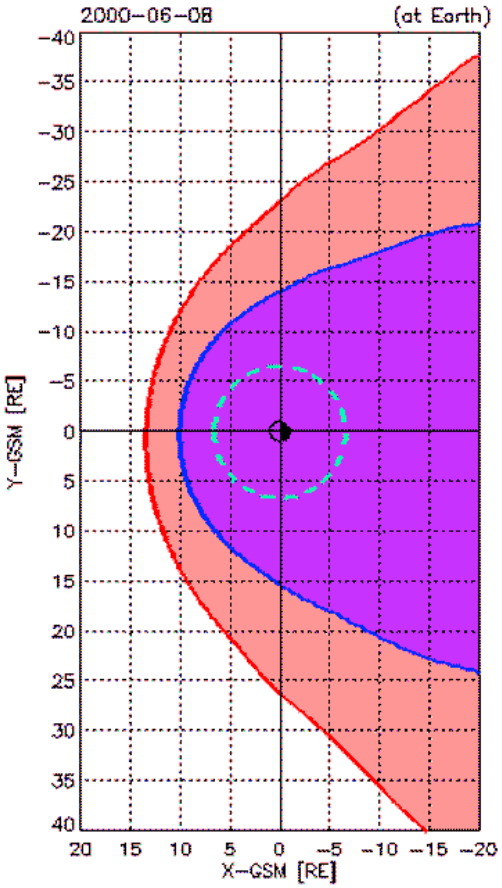


Table 6: Magnetopause Crossing Times

	GOES-8	GOES-9	GOES-10	GOES-12
24 October 2003			1832-1858	1525-1857
29 October 2003	2030-2400	0645-0650 1812-2400	1739-2327	1349-2057
30 October 2003	0000-0112 2006-2320	0000-0130 2035-2320	0004-0005 1736-2239	0033-0034 1737-2353

These estimated times (in UTC) are approximate and based on negative excursions of the Hp magnetic field component in the GOES 0.5 second sampled data. During some of these intervals, the magnetopause moved in an out over GOES many times.





Halloween Storms - Impacts on Satellites

- Magnetopause crossings
- Sensor noise
- Star tracker issues
- Safe mode/shutdown/suspended operations
- Loss of ADEOS-2 (JAXA) after one year in orbit
- Loss of instruments (e.g. Marie on Mars Odyssey)
- …

Halloween Storms - Impacts

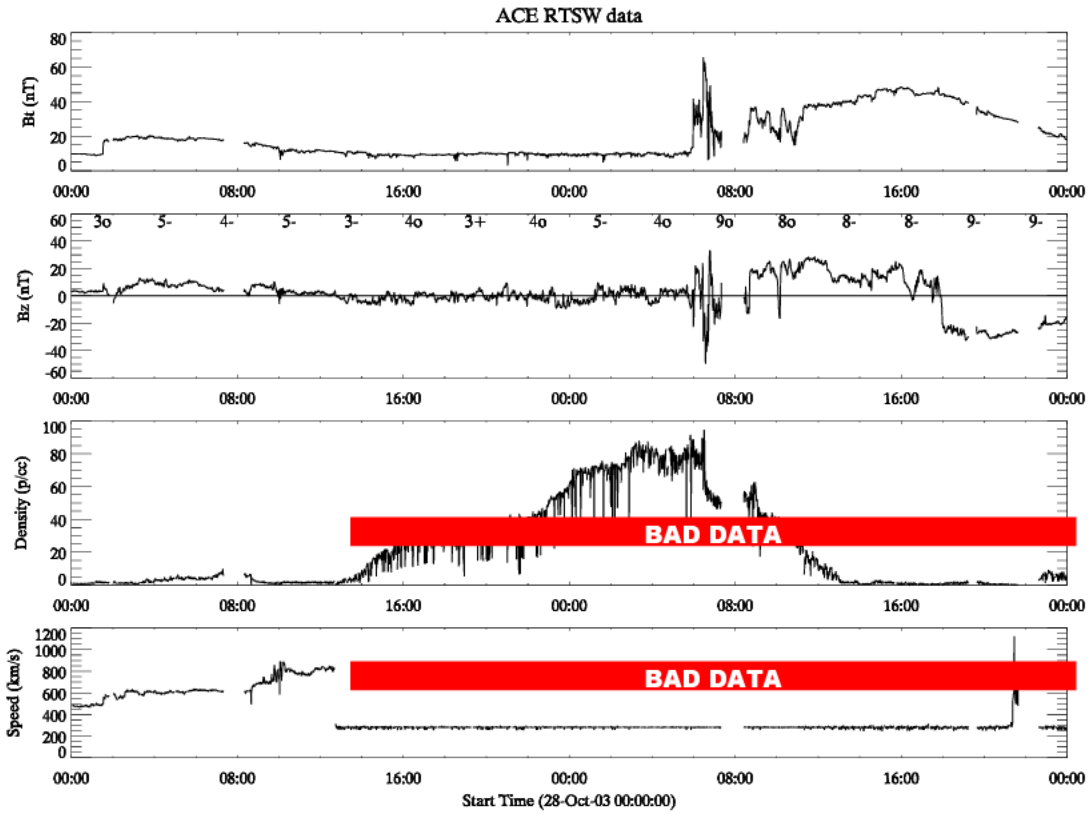


Figure 15: ACE RSTW and Magnetic Field Data for 28-29 October 2003 (speed and density data are invalid after 1200 UTC on 24 October due to contamination from high fluxes of high energy particles)

unavailable from 1220 UTC on 28 October until 0100 UTC on 31 October due to contamination from high fluxes of energetic particles from the proton event

Halloween Storms - Aviation

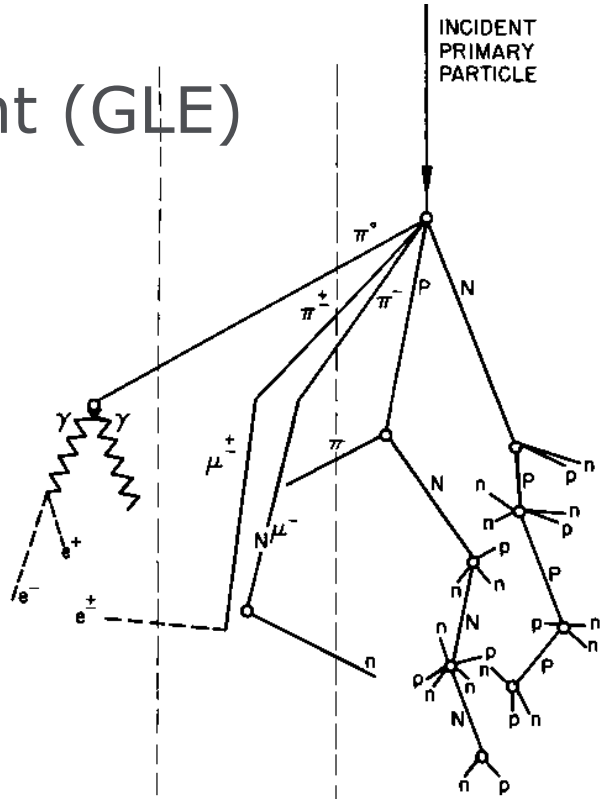
- Communication: degraded HF service (including blackouts) led to rerouting of polar flights
- Navigation: Wide-Area Augmentations System (WAAS) was seriously impacted
- GNSS: companies delayed high resolution land surveying, postponed airborne and marine survey operations, cancelled drilling operations,…



Halloween Storms - Impacts

- Radiation: flights on the U.S. to Europe routes flew at lower altitudes during the severe radiation storm

- Ground Level Enhancement (GLE)



Halloween Storms - Impacts

- GIC: power system failure occurred on 30 October in Malmö, Sweden resulting in blackout conditions for about one hour

- Aurora



Halloween Storms - What would the effects be today?

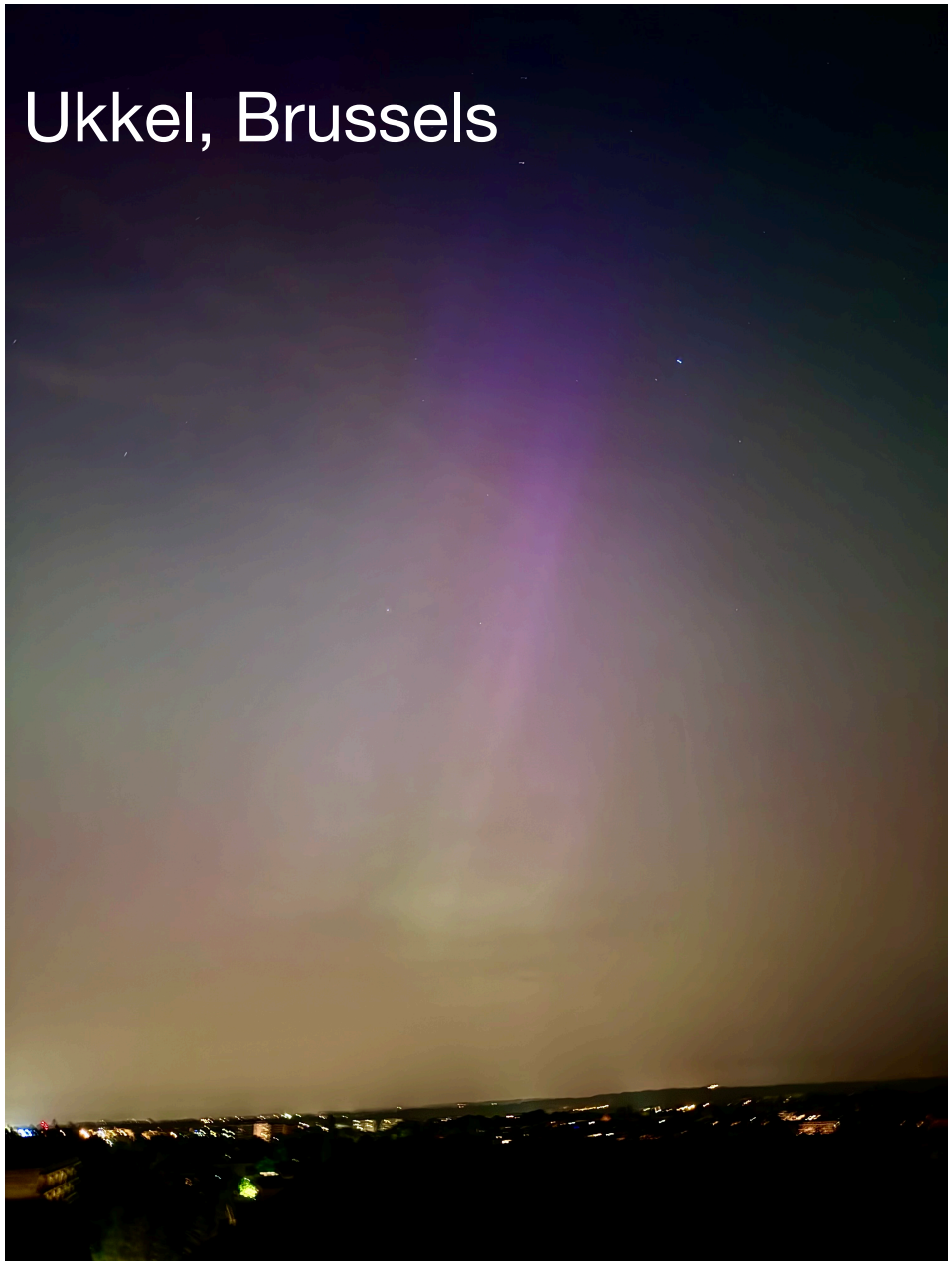


"No story tonight; the wi-fi's out. Good night, sweetie."

May 2024

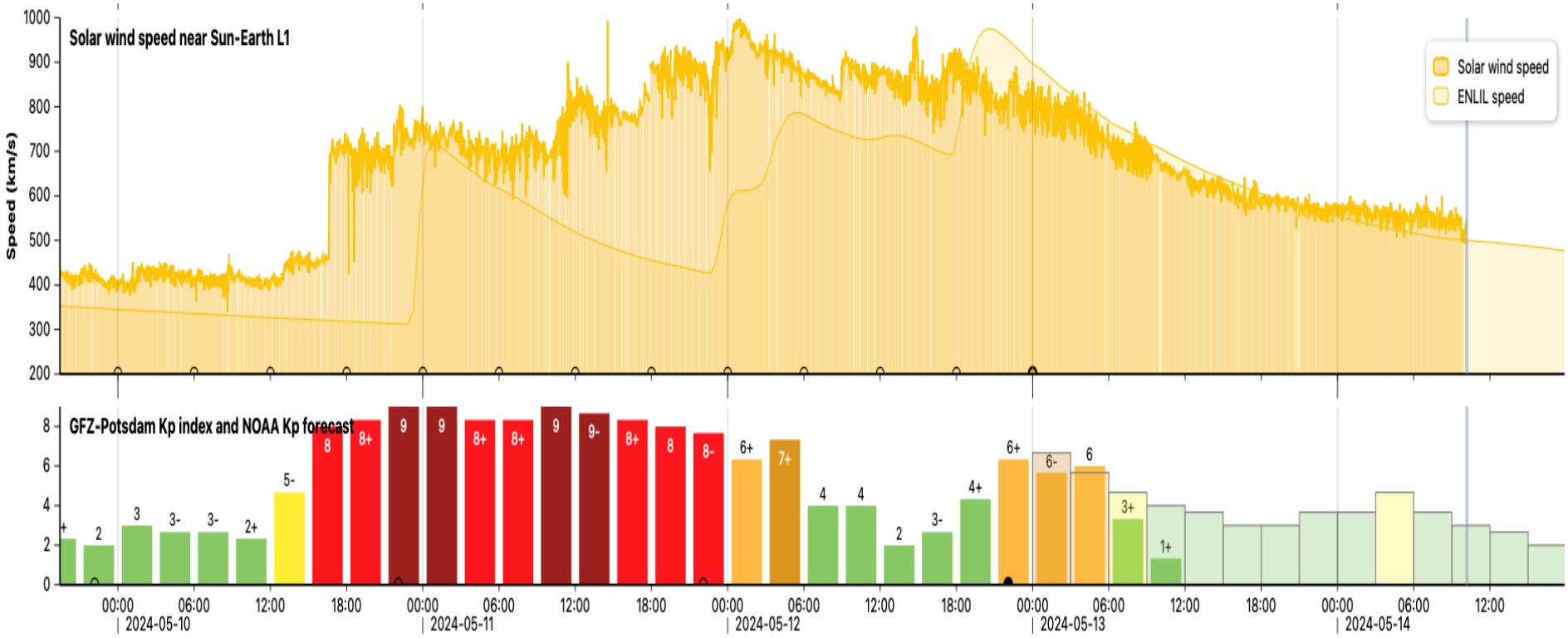


May 2024 - Aurora



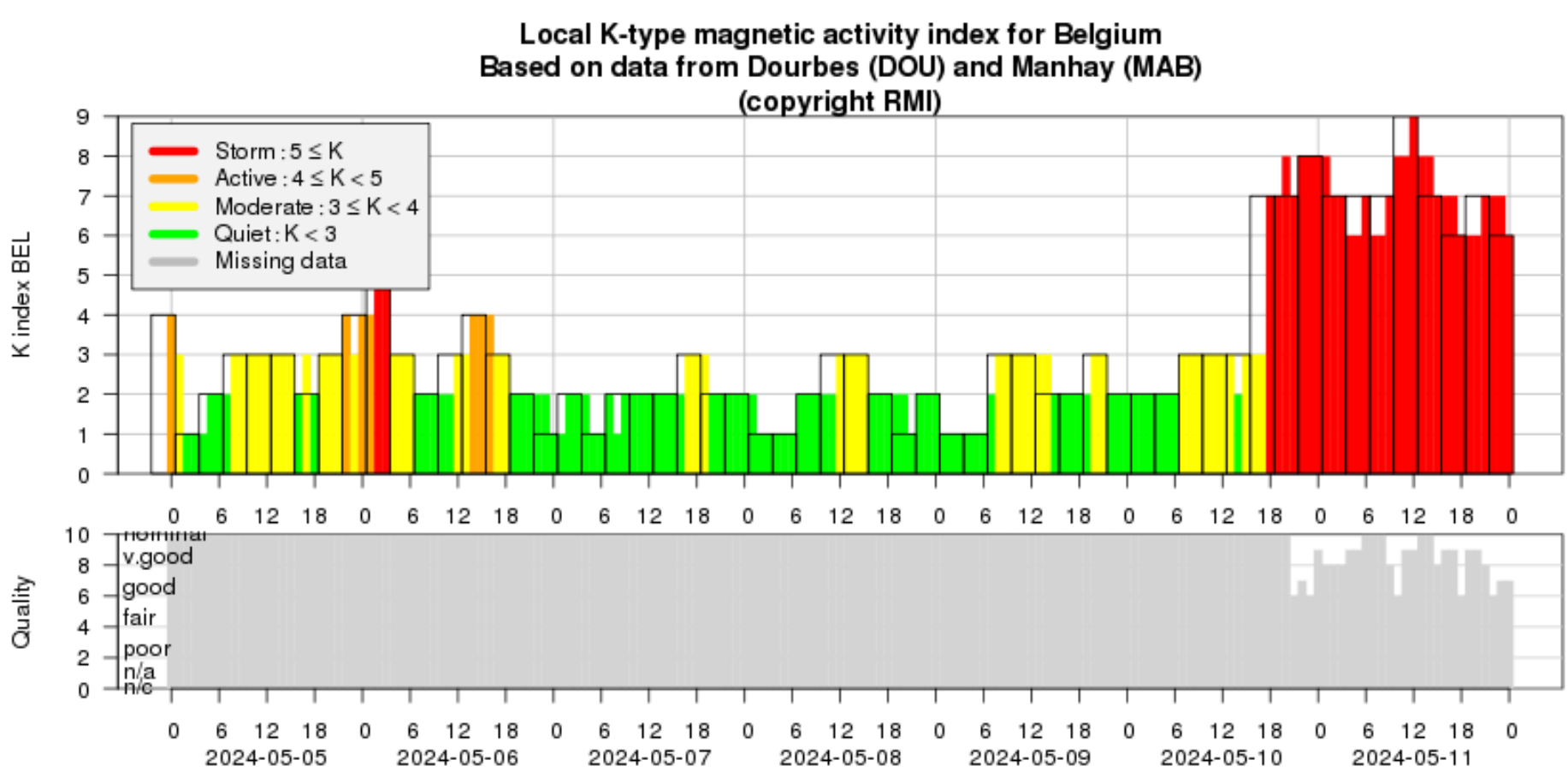


May 2024 - Observations



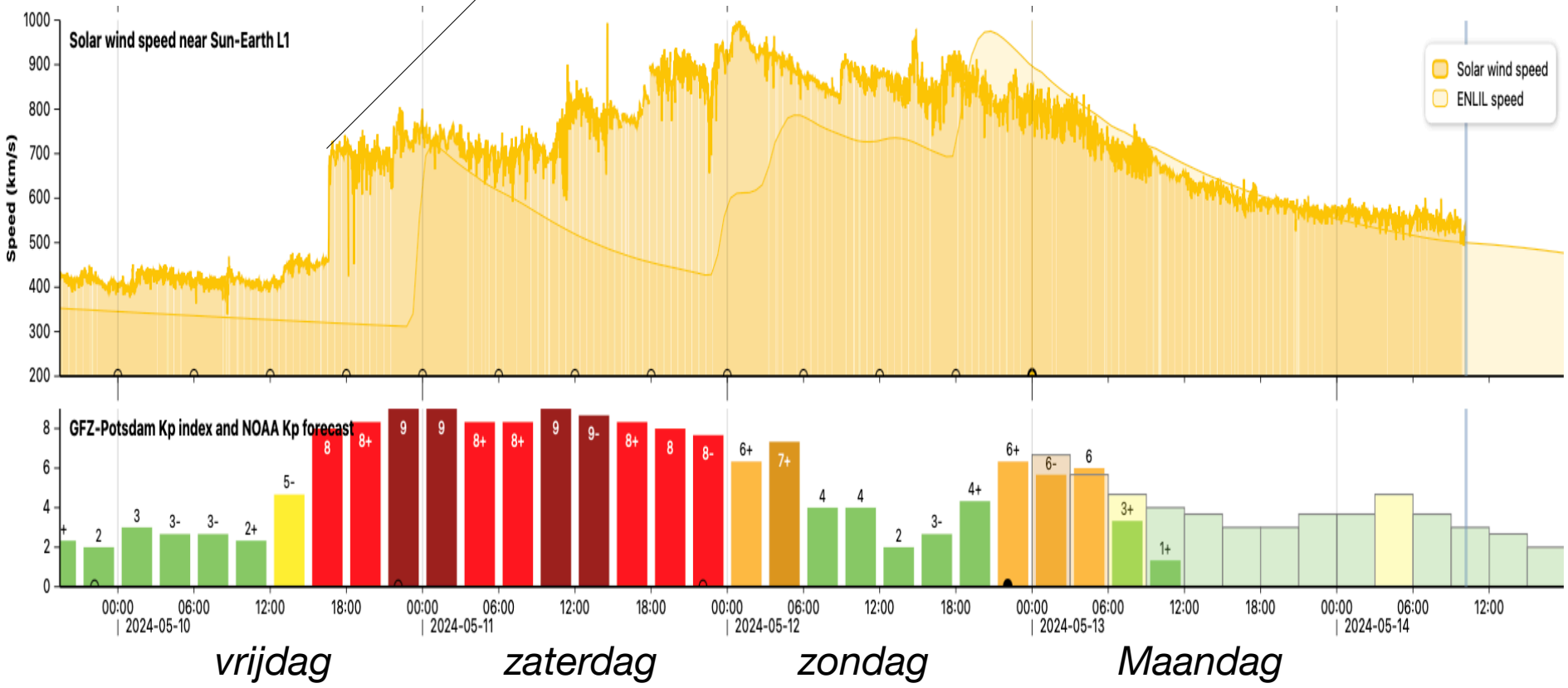
http://spaceweather.knmi.nl/viewer

May 2024 - Observations



May 2024 - Observations

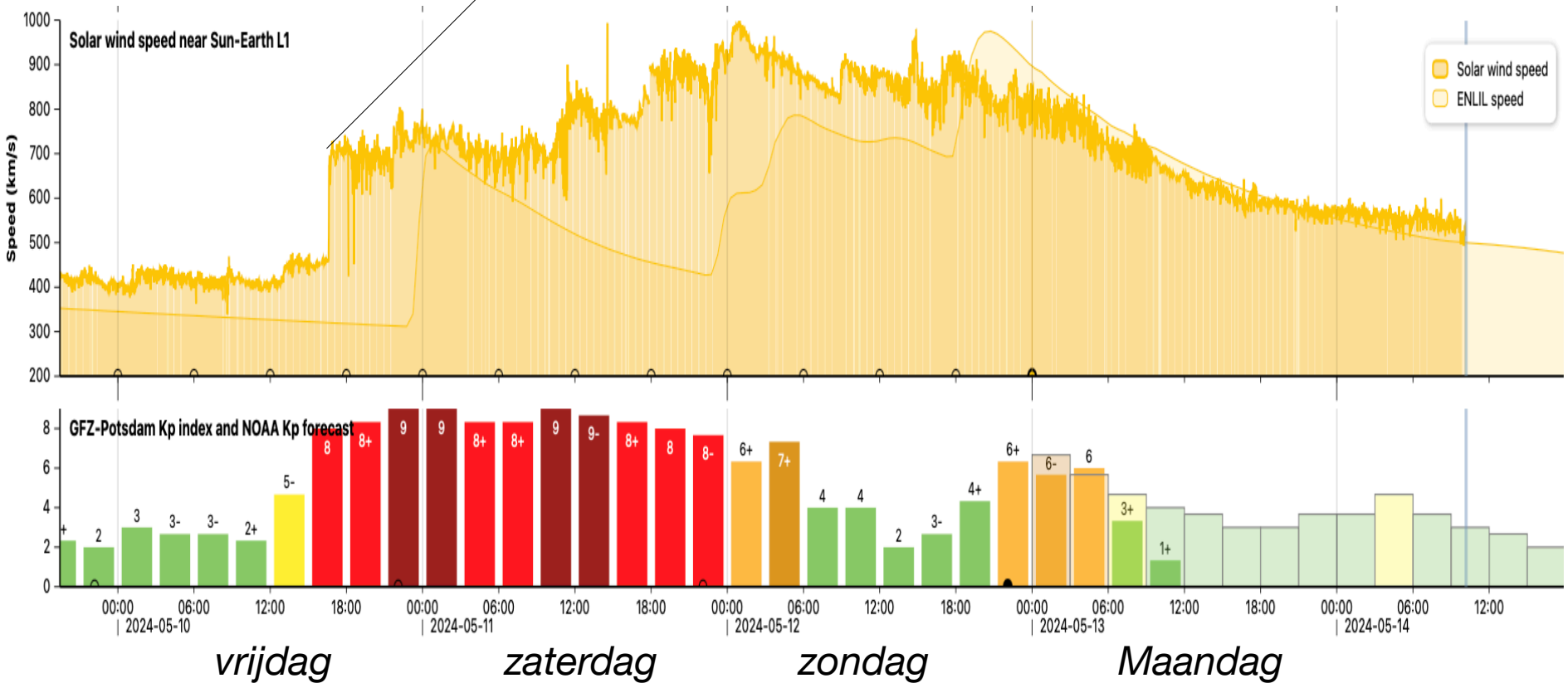
700 km/s to cross 150 million km => 60 h



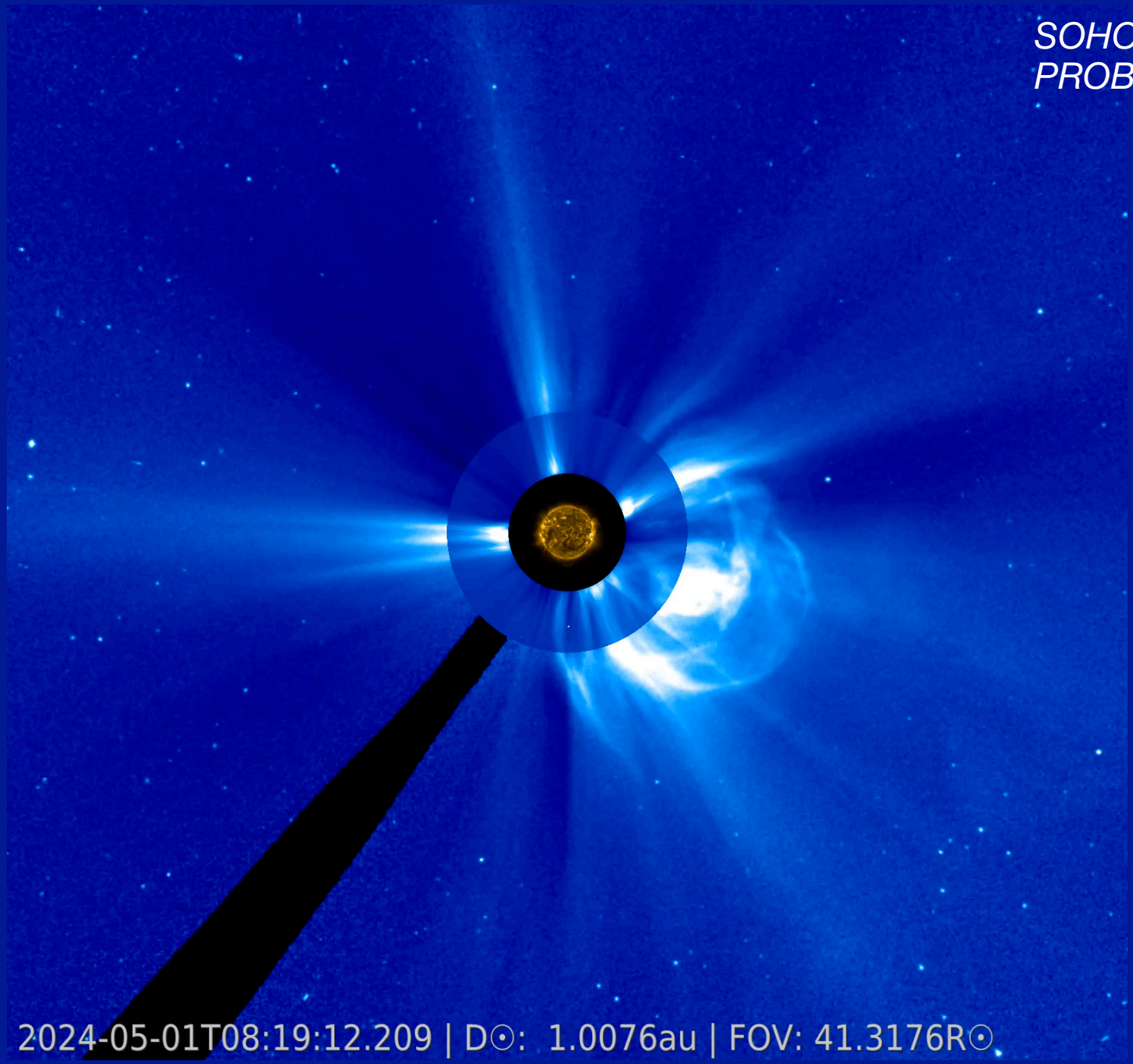
vrijdag *zaterdag* *zondag* *Maandag*

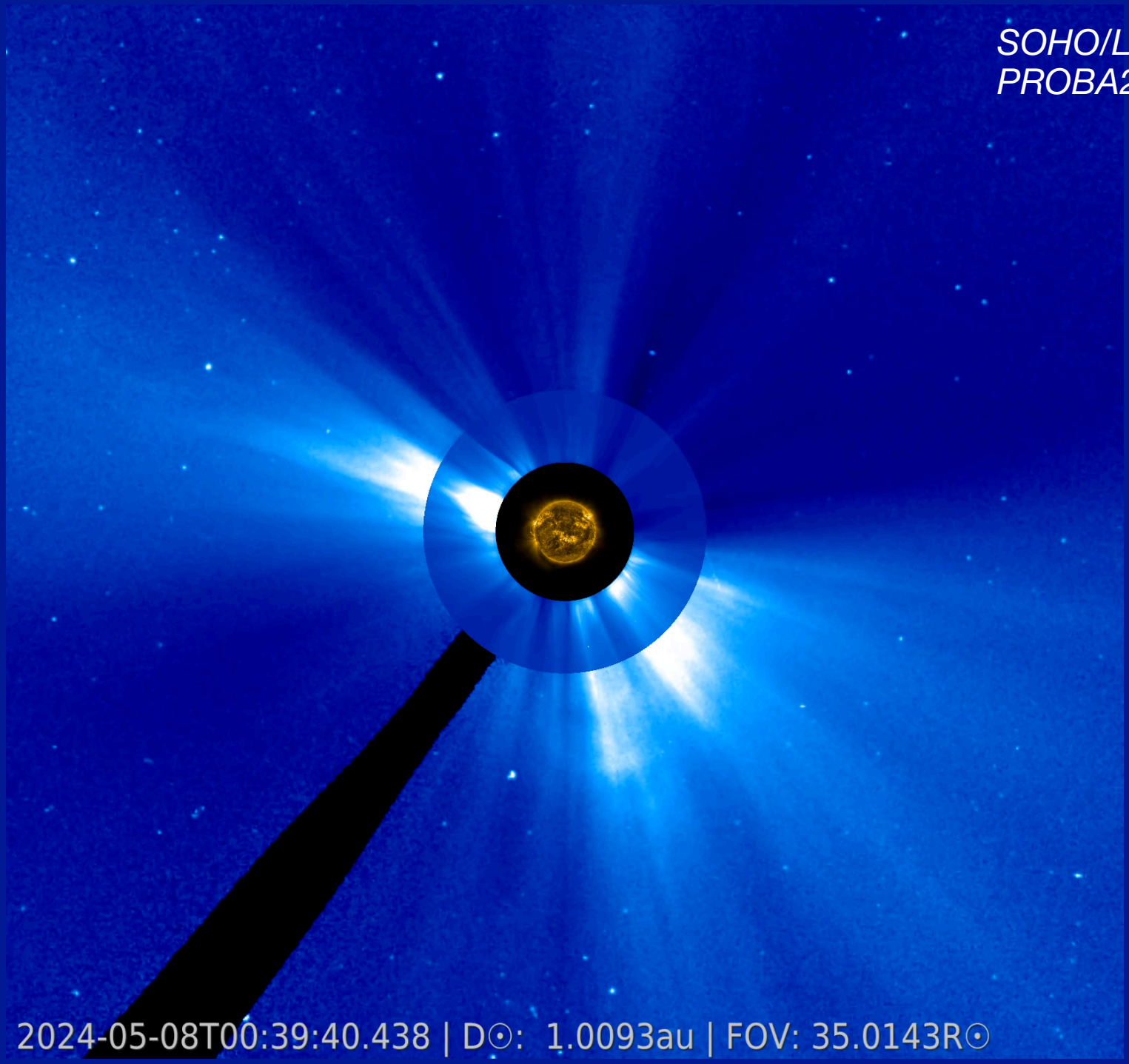
700 km/s to cross 150 million km => 60 h

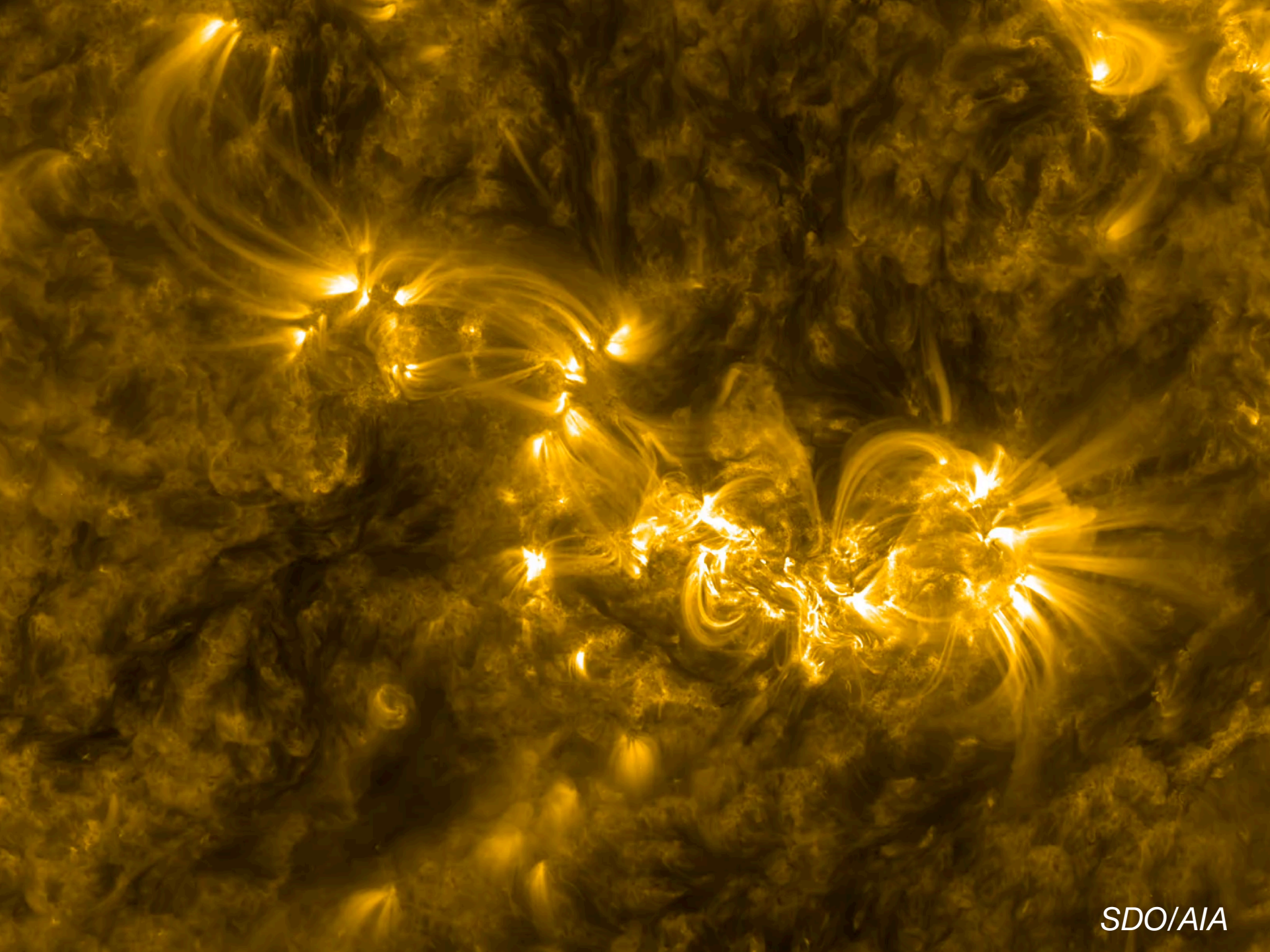
10 May 15:00 - 60h = 8 May 03:00

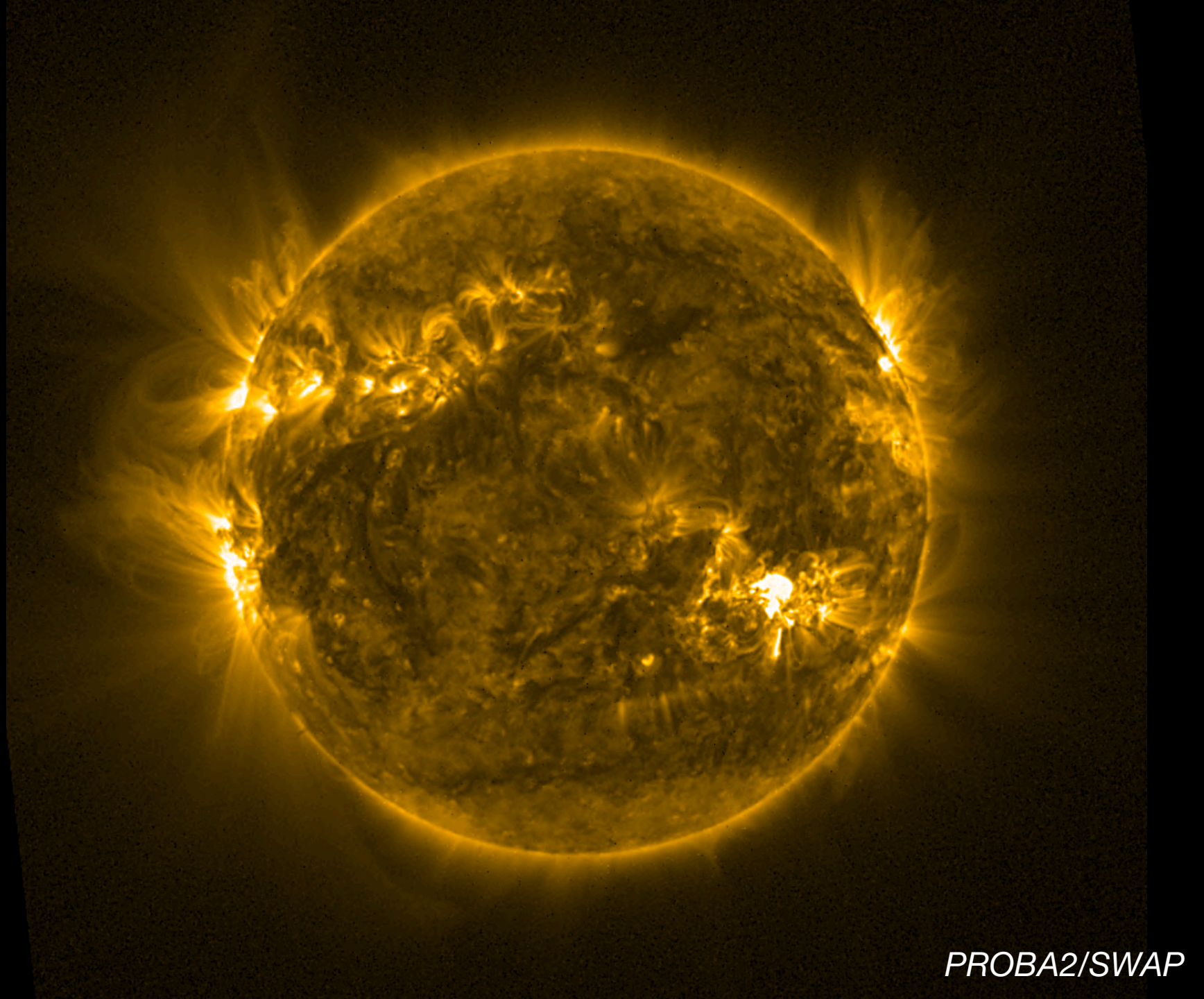


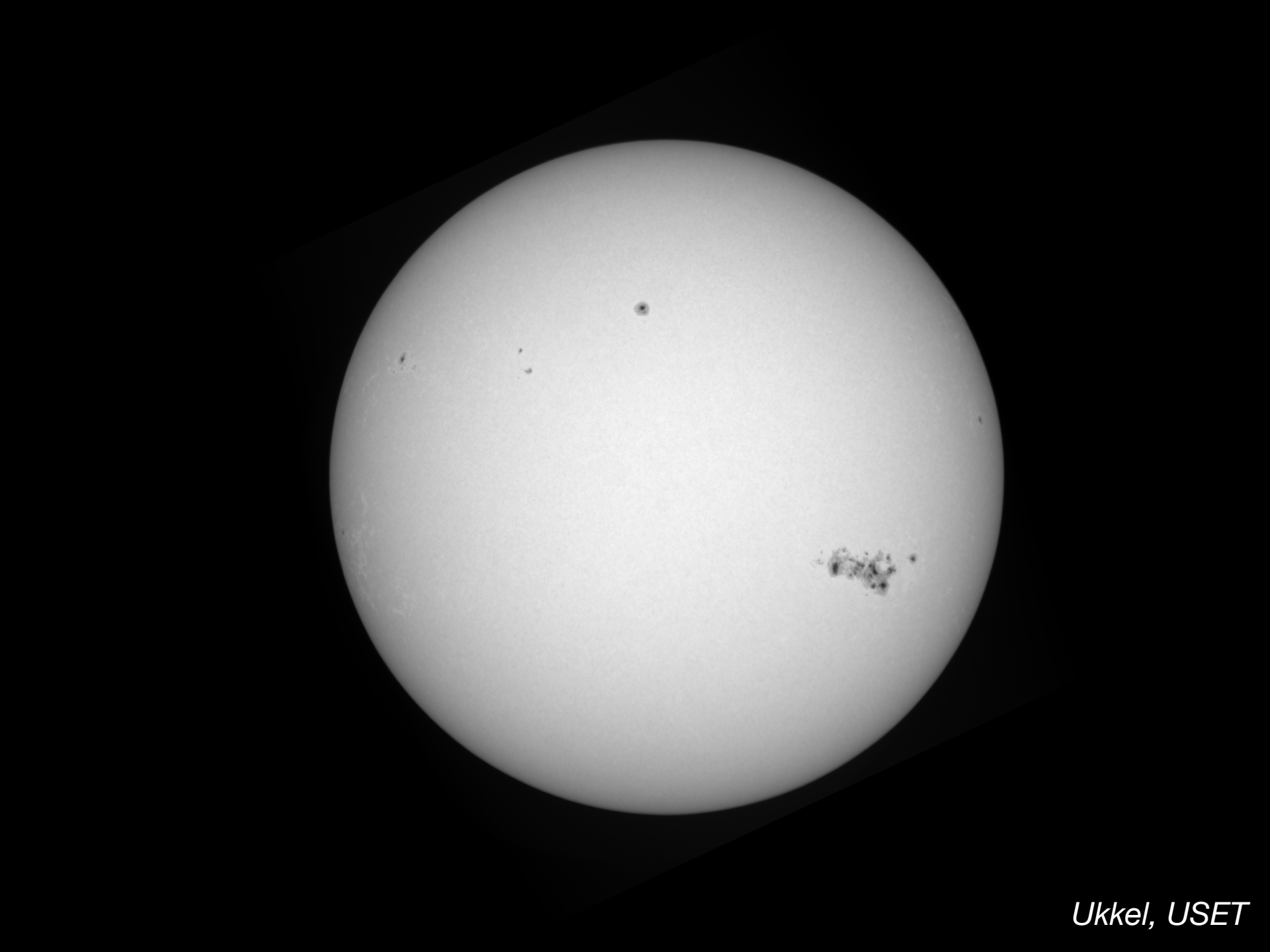
vrijdag *zaterdag* *zondag* *Maandag*

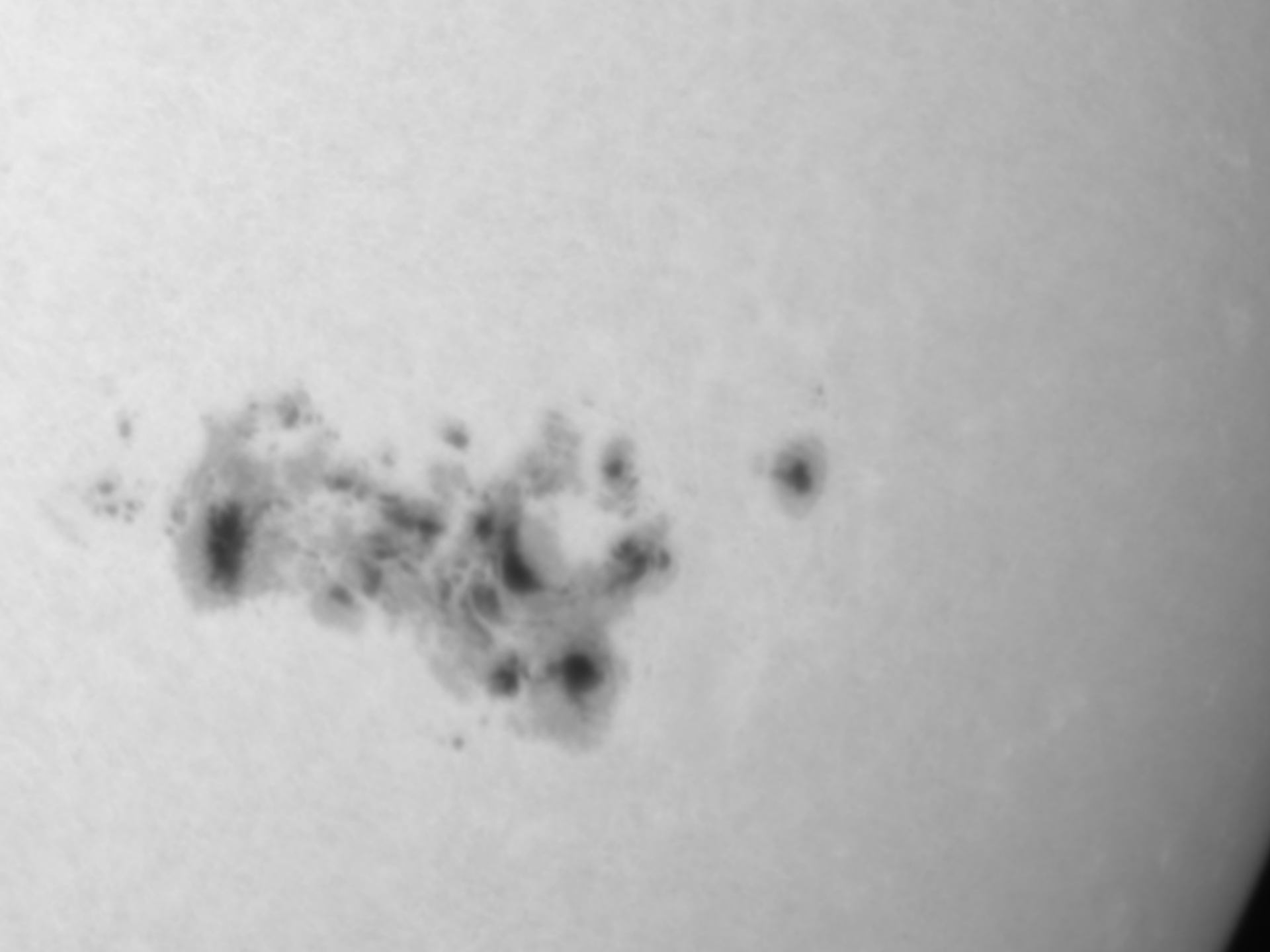

SOHO/LASCO
PROBA2/SWAP
2024-05-01T08:19:12.209 | D☉: 1.0076au | FOV: 41.3176R☉


SOHO/LASCO
PROBA2/SWAP
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SDO/AIA


PROBA2/SWAP


Ukkel, USET



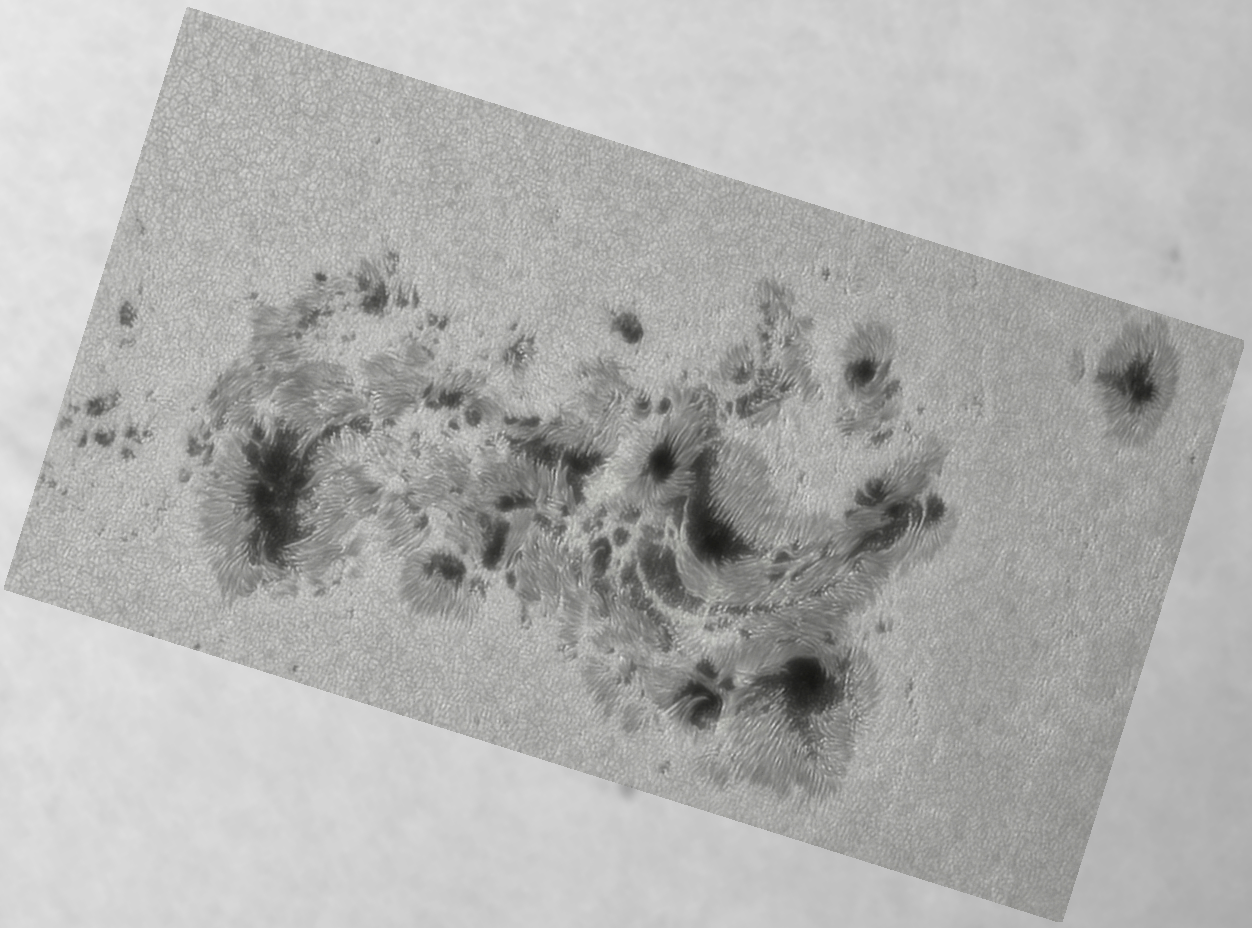


FOTO KSB Santiago Andres Triana

May 2024 - Agriculture

Join SPACE

May 2024 solar storm cost $500 million in damages to farmers, new study reveals

News By Tereza Pultarova | Published June 22, 2025

GPS receivers were off by up to 230 feet during the worst solar storm in 20 years.



Northern lights seen over a farmhouse in Iceland. (Image credit: redtea/Getty Images)

2 Newsletter

Location signals beamed to Earth by GPS satellites were off by hundreds of feet during the Gannon Solar Storm in May last year, and the disruption lasted for up to two days in some U.S. regions, a new study has revealed. The outage wreaked havoc across the farming sector, which suffered losses of more than $500 million as a result.

A succession of powerful solar eruptions in early May last year triggered the most powerful solar storm to hit Earth in 20 years. Later named after

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TRACTORS

Solar Storm Knocks Out Farmers' Tractor GPS Systems During Peak Planting Season

The accuracy of some critical GPS navigation systems used in modern farming have been "extremely compromised," a John Deere dealership told customers Saturday.

JASON KOEBLER · MAY 12, 2024 AT 9:39 AM



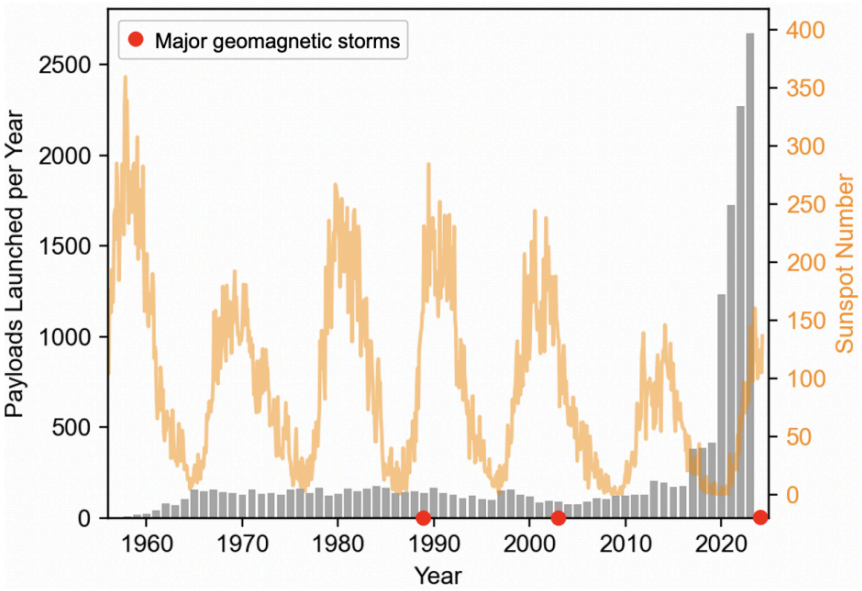
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May 2024 - Impacts on satellites



February 2022



May 2024 - Impacts on satellites

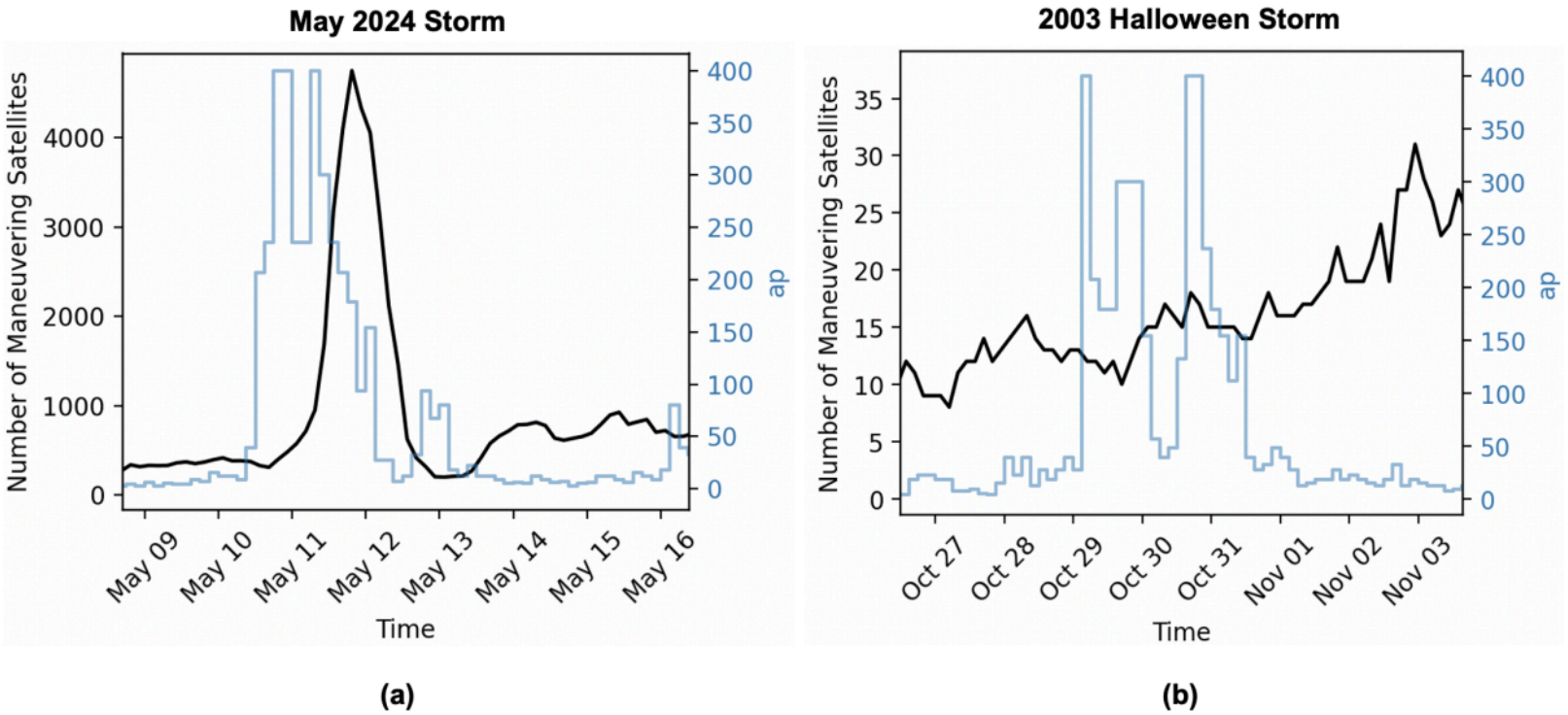


Fig. 6 (a) Satellites in LEO (mostly SpaceX) maneuver *en masse* in response to the sudden loss in altitude during the May 2024 Gannon storm. (b) During the 2003 Halloween storm, there was no comparable change in satellite maneuver activity (note the difference in scaling).