Fact-Checked Science

PAPER CHECK · SOLAR STORMS

The Carrington storm left no detectable radiation mark in the ice

Chlorine-36 is the isotope most sensitive to the soft particle showers that earlier searches could have missed. Three ice cores, from Greenland and Antarctica, show no significant rise around 1859 [1 Abstract]. Any shower was at most about three times the largest of the Space Age above 30 MeV, or none reached Earth.

By Fact-Checked Science · Published October 14, 2026

OUR ANALYSIS marks our own reasoning and calculations, and the verdicts are our assessment. Everything else comes from the numbered sources.

No extreme particle shower in 1859, though a smaller one can't be ruled out

OUR ASSESSMENT

1.75×10^{10}

Protons per cm^2 above 30 MeV: the most the ice allows, with a middle half of 1.48–2.23 × 10^{10} [1 p. 6].

≈ 3×

August 1972, the largest particle shower of the Space Age above 30 MeV [1 p. 7].

≈ 1/14

Of 774/5 CE above 30 MeV, by our calculation from the spectrum the paper compares with; it says "one order of magnitude" [2 Table 3][1 p. 6].

THE PAPER'S CLAIMS

TRUE

Three ice cores show no significant chlorine-36 rise around 1859

Mekhaldi et al. 2026 [1 Abstract][1 p. 4]

It holds in the authors' published data too: no chlorine-36 sample spanning 1859–60 is more than one standard deviation above its record's mean [3]. See section 3.

TRUE

"This allows us to rule out an extreme SEP event hitting Earth associated with the Carrington event in terms of fluence above 30 MeV."

Mekhaldi et al. 2026, abstract; SEP means solar energetic particles [1 Abstract]

"Extreme" here means far beyond the Space Age. An event like 774/5 CE, about 14 times the limit above 30 MeV, would have shown even in a single annual record at a strict 3σ test [2 Table 3][4 p. 15]. See section 1.

TRUE

Any particle shower was at most about three times August 1972's above 30 MeV, or none reached Earth

Mekhaldi et al. 2026 [1 Abstract][1 p. 7]

That is the paper's model-based limit. It counts a rise of about 20%, roughly one standard deviation, as detectable, and takes its shape from modern events; a stricter test would allow a bigger shower [1 p. 6]. See section 4.

PARTLY TRUE

"about 32% of the largest geomagnetic storms of the Space Age were accompanied by a severe SEP event"

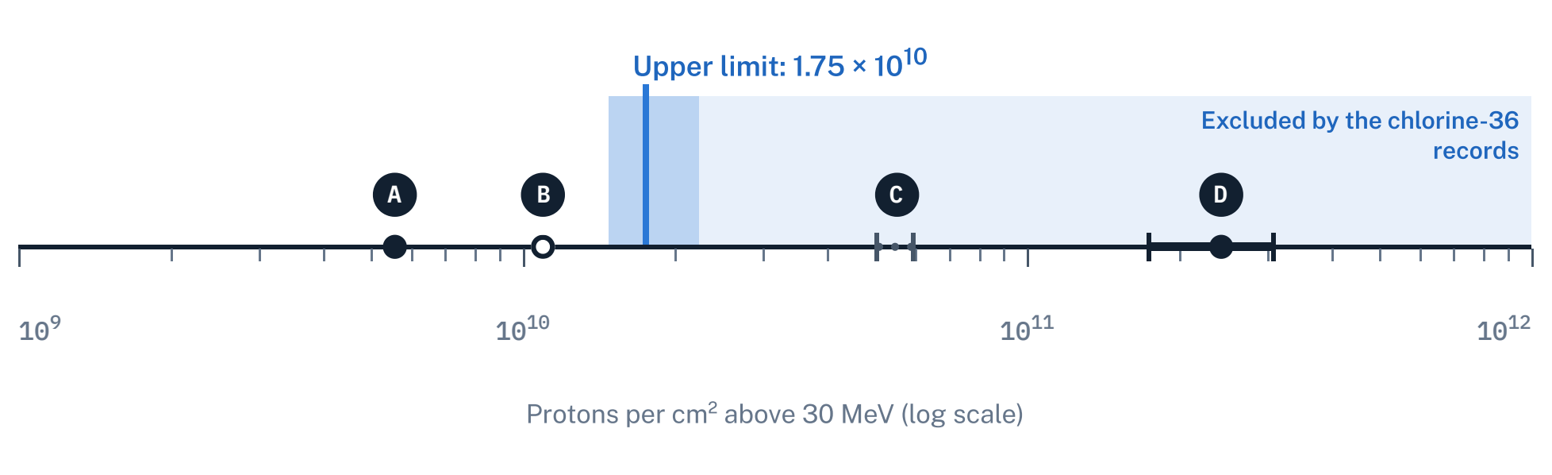
Mekhaldi et al. 2026 [1 p. 8]

The paper's ten storms check out (its May 2024 values are the real-time ones). But its stated rule gives 34 storms, not 31, so about 29%, as our recount for another page also found; and, as the authors note, an event within five days needn't come from the same eruption: in three of the ten the only event came after the storm [1 p. 8][5][6]. See section 5.

1 · HOW BIG?

How big could a Carrington particle shower have been?

The ice sets an upper limit on the protons above 30 MeV that could have reached Earth: 1.75 × 10^{10} per cm^2, about three times August 1972 and about a fourteenth of 774/5 CE [1 p. 6][1 p. 7].



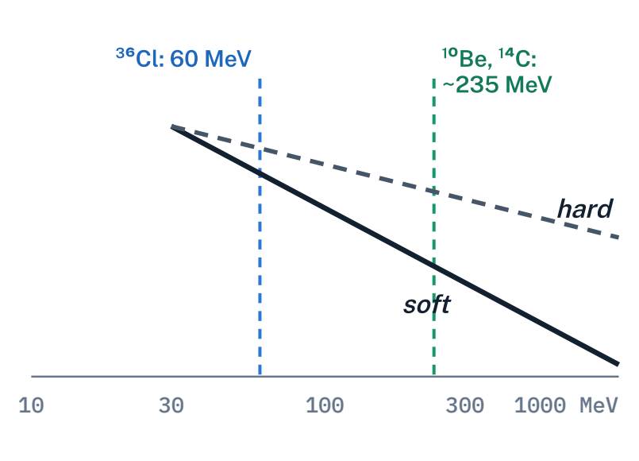
- **A** **August 1972: about 5.6 × 10^9**, the largest above 30 MeV on record [1 p. 5], in the spectra the paper scales (our evaluation) [7]
- **B** **About 1.1 × 10^{10}**: a 2013 estimate based on the flare's estimated X-ray class; the flare has since been rated bigger, so it needs revising [8][9][1 p. 6]
- **C** **5–6 × 10^{10}**: what one annual record could detect at a strict 3σ, by the same group's 2021 estimate [1 p. 6][4 p. 15]
- **D** **774/5 CE: about 2.4 × 10^{11}**, some 14 times the limit, with its uncertainty [2 Table 3]

The limit is the median of modern particle events that erupted within 30° of the Sun's central meridian, as Carrington's flare did, scaled up until the ice would have shown them; the darker band is their middle half. For a harder spectrum like the October–November 1989 events, the limit is lower, about 8 × 10^9, less than twice August 1972 [1 p. 6][1 p. 7].

2 · WHY CHLORINE-36

Why chlorine-36 narrows a loophole

Earlier searches with beryllium-10 in ice and carbon-14 in tree rings found no clear signal. One way out was a soft shower: many protons near 30 MeV but few at the energies those isotopes respond to [1 p. 2].



Schematic spectra, matched at 30 MeV; the vertical axis is the number of protons above each energy, on a log scale. Each isotope's effective energy is the threshold whose proton count best predicts its extra production during an event [1 p. 4][1 p. 5][10 Abstract].

Most chlorine-36 comes from galactic cosmic rays. But the extra production during a solar particle event is especially sensitive to protons of about 30–60 MeV, through a resonance with argon in the air, so a soft shower shows up in it far more strongly [1 p. 4][1 p. 5].

August 1972, soft spectrum
+10% ^{36}Cl
+1.2% ^{10}Be

February 1956, hard spectrum
+5.1% ^{10}Be
+8.0% ^{36}Cl

Estimated rise in global annual production, relative to the cosmic-ray baseline [1 p. 2][1 p. 3][1 p. 5][4 Table 1].

3 · THE ICE

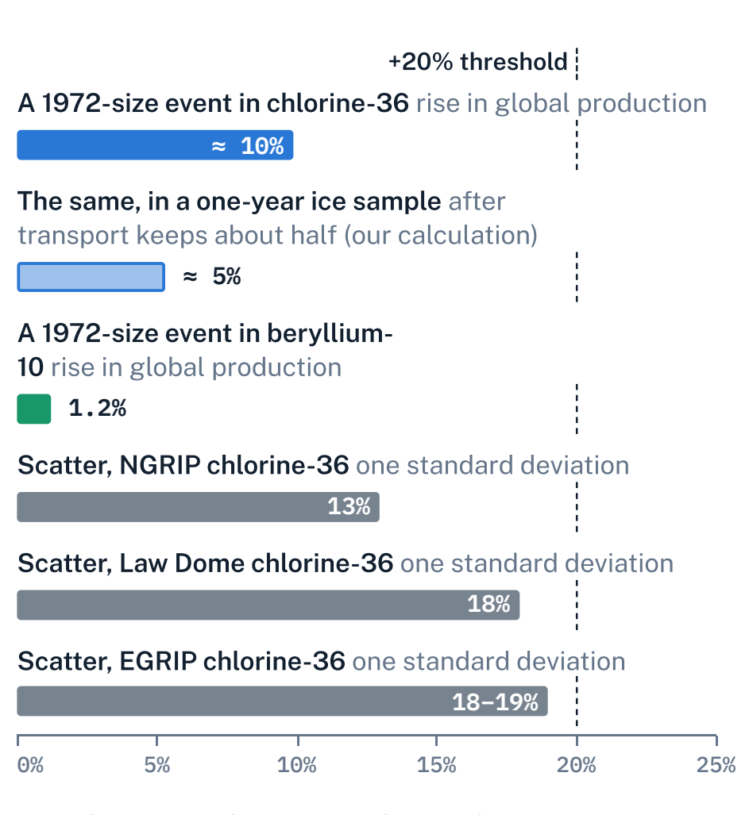
Three cores, two hemispheres, no signal

EGRIP S6
East Greenland, 75°38′N 36°00′W
^{36}Cl about every 1.6 years, scatter 18–19%
^{10}Be about every 0.4 years, scatter 25%

NGRIP 97-S2
North Greenland, 75°06′N 42°19′W
^{36}Cl every 4 years, scatter 13%
^{10}Be yearly, published in 2009, scatter 16%

DSS0506, Law Dome
East Antarctica, 66°46′S 112°48′E
^{36}Cl yearly, scatter 18%
^{10}Be yearly, scatter 18%

Sampling and one-standard-deviation scatter of each record [1 p. 2][1 p. 3][1 p. 4][1 p. 5].



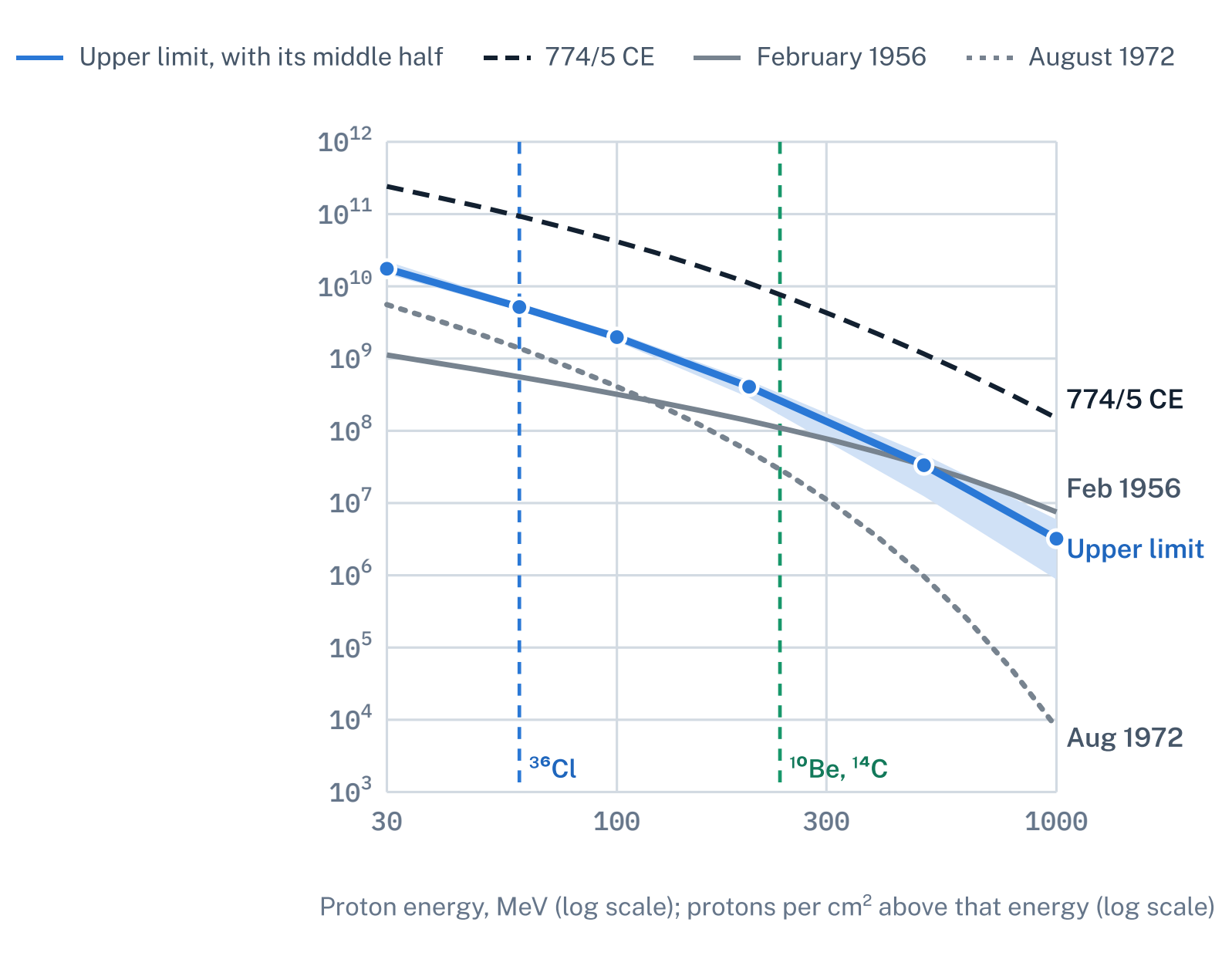
Rise above normal against each record's scatter [1 p. 5][4 Table 1]. The +20% threshold applies to the concentration in the ice, after transport; a one-year sample keeps about half (54%) of a one-year spike in production [1 p. 6].

None of the three records shows a significant rise around 1859. A beryllium-10 peak in EGRIP in 1862 is too far off the ±1-year dating and has no matching chlorine-36 rise [1 p. 3][1 p. 4].

The catch: the natural scatter is larger than the signal of the biggest modern event. A repeat of August 1972 would be invisible here [1 p. 5]. The ice can exclude only showers well beyond anything seen since 1956.

4 · ENERGY BY ENERGY

The upper limit, energy by energy



Upper limit: the paper's Table 1, at 30, 60, 100, 200, 500 and 1,000 MeV [1 Table 1]. February 1956 and August 1972: our evaluation of the fitted spectra the paper scales [7]; 774/5 CE: the fitted spectrum it compares with [2]. Redrawn by factchecked.science.

The limit is a whole spectrum: modern spectral shapes scaled up until the ice would have shown them. The ice mainly constrains protons near 60 MeV; the rest of the curve follows from those shapes [1 p. 4][1 p. 6]. The line is the median of the scaled spectra; the band is their middle half.

At the low-energy end it allows more than any Space Age event. At 1 GeV and above it stays "similar to or lower than" the biggest modern events, including February 1956 [1 p. 6].

A shower at the limit would still mean "a severely high radiation dose rate for astronauts in interplanetary space" and would "probably cause widespread spacecraft disruptions", but it would not be an extreme ground-level event [1 p. 7].

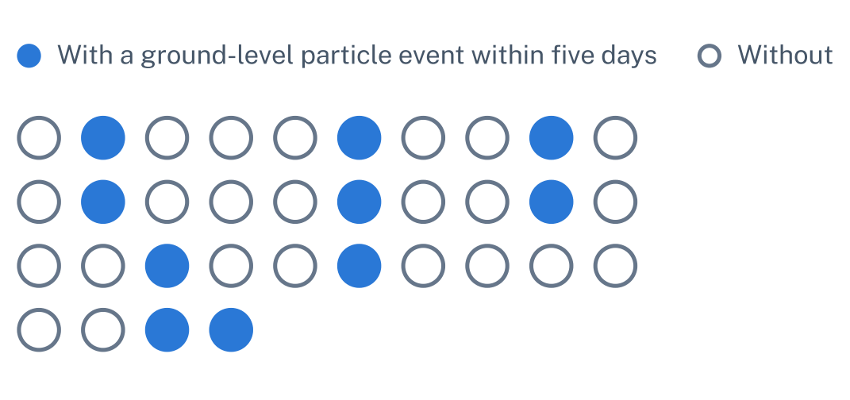
5 · STORMS AND SHOWERS

Big storms often come without a ground-level particle event

Storms and particle showers favour different parts of the Sun. The fiercest storms come from eruptions near the centre of the disc, aimed at Earth; particles reach Earth most easily from the western side, where the Sun's magnetic field lines connect to us [1 p. 8]. Carrington's flare was near the centre [1 p. 2].

The largest magnetic storms since 1957

OUR ANALYSIS



Our recount, largest storm first: the 50 days with the lowest hourly Dst in 1957–2024, consecutive days merged into one storm, give 34 storms; 10 had a ground-level enhancement within five days, the same 10 the paper lists [5][6][1 p. 8]. The paper counts 31 storms.

So a great storm without a ground-level particle event would not be unusual: about 7 in 10 of the biggest modern storms had none within five days. That isn't the same as no particles. March 1989, the most intense storm since 1957 (Dst −589 nT), had no ground-level event, but satellites recorded a strong proton storm; and August 1972's record shower came from an eruption near the disc centre [5][6][11][8].

The ten storms with a ground-level event

STORM	LOWEST DST, NT	GLE NO.
July 1959	−429	7 (after the storm)
April 1960	−325	8 (after the storm)
November 1960	−339	10, 11
April 1981	−311	34
October 1989	−268	43–45
July 2000	−300	59
April 2001	−271	60 (after the storm)
November 2001	−292	62
October 2003	−383	65–67
May 2024	−412 (−406 provisional)	74

Dst as the paper gives it [1 p. 8]; for May 2024 that is the real-time value [12 §1], and Kyoto's provisional index now gives −406 nT [5]. GLE numbers from the international database [6].

6 · READ WITH CARE

Two scenarios left standing

The paper leaves two possibilities [1 p. 9]. The boxes marked Our analysis are our assessment, checked against the paper, its data and the studies it cites.

A soft particle shower, capped

Up to about three times August 1972 above 30 MeV, and about a fourteenth of 774/5 CE. Large for astronauts and satellites; similar to or below modern extremes at the highest energies [1 p. 7][1 p. 9].

No particles reached Earth

An extreme magnetic storm with no particle shower at Earth. Given where the flare sat on the Sun, and how often modern great storms come without a ground-level event, this "cannot be ruled out" [1 p. 8].

OUR ANALYSIS

"Rules out an extreme event" is narrower than it sounds

A shower larger than any in the Space Age, up to about three times August 1972 above 30 MeV, is still allowed. What the ice excludes firmly is an event on the scale of 774/5 CE [1 Abstract][1 p. 7].

OUR ANALYSIS

The limit assumes a modest rise would be noticed

It counts a rise of about 20%, roughly one standard deviation of the records' scatter, as detectable, a criterion the authors state [1 p. 6]. A stricter test would allow a bigger shower: in 2021 the same group estimated that one annual record needs 5–6 × 10^{10} for a 3σ detection, about three times the limit [4 p. 15]. Three records in two hemispheres can do better than one, so that is a reference point, not a recomputed limit.

OUR ANALYSIS

A borrowed transport factor

The calculation assumes transport and deposition leave about half (54%) of a one-year production spike in the peak year for chlorine-36, as for beryllium-10 in 774/5 CE; the authors cite a model study finding similar deposition for the two isotopes [1 p. 6].

OUR ANALYSIS

32% is generous

It counts any ground-level event within five days, even one from another active region, as the authors note [1 p. 8]. With their stated rule we count 10 of 34, about 29%, and in three of the ten the only event came after the storm [5][6]. Showers big enough to register in ice are much rarer.

OUR ANALYSIS

One odd tree-ring offset

Uusitalo and colleagues report a carbon-14 offset of a few per mil in polar tree rings in 1861–63, compared with trees at mid-latitudes, highly significant but not reproduced by their own model [13 Abstract][13 p. 4][13 p. 5]. It hasn't been seen in trees from other regions, and Mekhaldi and colleagues don't count it as evidence of a particle event beyond their limit [1 p. 6].

OUR ANALYSIS

Not the radiation worst case

Either way, Carrington's claim to be the worst case rests on its magnetic storm. The radiation worst cases in the record are far larger: 774/5 CE, and the 12,350 BCE event, about 18% stronger still [14 p. 3]. Even a shower at the limit would be about a fourteenth of 774/5 CE above 30 MeV [2 Table 3].

OUR ANALYSIS

Bottom line: a careful null result that removes an extreme particle shower from the Carrington story.

It doesn't show there was no shower: one up to about three times the largest of the Space Age above 30 MeV still fits the ice, and so does none at all [1 Abstract].

Related checks

PARTLY TRUE A "small" flare? The Disaster Cycle, Fact-Checked

Sources

Bracketed numbers refer to this list; p. gives a page (for the Royal Society papers, the page of the published PDF; for the Vasilyev review, of its accepted version), Table a table, and Abstract the part of a work we used. Links checked October 14, 2026.

1 Mekhaldi, F., Paleari, C. I., Smith, A. M., Aldahan, A., Beer, J., Christl, M., Vockenhuber, C., Hayakawa, H., Curran, M., Erhardt, T., Plummer, C., Simon, K., Wilcken, K., Zheng, M., and Muscheler, R. (2026). ^{36}Cl concentrations from polar ice cores set new constraints on the Carrington event. *Philosophical Transactions of the Royal Society A* 384(2329), 20250257. Published September 10, 2026. CC BY 4.0. We read the publisher's PDF, deposited in Eawag's repository; the April 2026 preprint, arXiv:2604.26608, has the same numbers with its two tables numbered the other way round.

2 Koldobskiy, S., Mekhaldi, F., Kovaltsov, G., and Usoskin, I. (2023). Multiproxy reconstructions of integral energy spectra for extreme solar particle events of 7176 BCE, 660 BCE, 775 CE, and 994 CE. *Journal of Geophysical Research: Space Physics* 128(3), e2022JA031186. CC BY 4.0. The 774/5 CE spectrum the paper compares with.

3 Mekhaldi, F., et al. (2026). Supplementary material from "^{36}Cl concentrations from polar ice cores set new constraints on the Carrington event". The Royal Society, figshare: the source data for Figure 1. CC BY 4.0.

4 Mekhaldi, F., Adolphi, F., Herbst, K., and Muscheler, R. (2021). The signal of solar storms embedded in cosmogenic radionuclides: detectability and uncertainties. *Journal of Geophysical Research: Space Physics* 126(8), e2021JA029351. CC BY 4.0.

5 Nose, M., Iyemori, T., Sugiura, M., Kamei, T., Matsuoka, A., Imajo, S., and Kotani, T. (2015). Geomagnetic Dst index. World Data Center for Geomagnetism, Kyoto. Hourly values, final for 1957–2020 and provisional after; read October 14, 2026.

6 International GLE Database. List of ground-level enhancements, GLE 5 to GLE 77. Sodankylä Geophysical Observatory and University of Oulu; read October 14, 2026.

7 Koldobskiy, S., Raukunen, O., Vainio, R., Kovaltsov, G. A., and Usoskin, I. (2021). New reconstruction of event-integrated spectra (spectral fluences) for major solar energetic particle events. *Astronomy & Astrophysics* 647, A132. The spectra the paper scales; we evaluated its fits for February 1956 and August 1972, reading the version on arXiv.

8 Cliver, E. W., and Dietrich, W. F. (2013). The 1859 space weather event revisited: limits of extreme activity. *Journal of Space Weather and Space Climate* 3, A31.

9 Hayakawa, H., Bechet, S., Clette, F., Hudson, H. S., Maehara, H., Namekata, K., and Notsu, Y. (2023). Magnitude estimates for the Carrington flare in 1859 September: as seen from the original records. *The Astrophysical Journal Letters* 954, L3. CC BY 4.0.

10 Koldobskiy, S., Usoskin, I., and Kovaltsov, G. A. (2022). Effective energy of cosmogenic isotope (^{10}Be, ^{14}C and ^{36}Cl) production by solar energetic particles and galactic cosmic rays. *Journal of Geophysical Research: Space Physics* 127(1), e2021JA029919. CC BY 4.0. We read the abstract.

11 NOAA Space Environment Services Center. Solar Proton Events Affecting the Earth Environment, 1976–present. Preliminary listing, hosted by NASA's Solar Data Analysis Center; its entries run to 2017. As read for our page on the Sun's two worst cases, October 13, 2026.

12 Hayakawa, H., Ebihara, Y., Mishev, A., Koldobskiy, S., Kusano, K., Bechet, S., et al. (2025). The Solar and Geomagnetic Storms in 2024 May: A Flash Data Report. *The Astrophysical Journal* 979(1), 49. We read the accepted version, arXiv:2407.07665; § gives its section.

13 Uusitalo, J., Golubenko, K., Arppe, L., Brehm, N., Hackman, T., Hayakawa, H., et al. (2024). Transient offset in ^{14}C after the Carrington event recorded by polar tree rings. *Geophysical Research Letters* 51(5), e2023GL106632. CC BY 4.0.

14 Vasilyev, V., Usoskin, I., and Krivova, N. (2026). Linking solar magnetism, extreme solar particle events and stellar superflares. *Philosophical Transactions of the Royal Society A* 384(2329), 20250261. CC BY 4.0. We read the accepted version, arXiv:2602.10243; p. gives its page.

METHOD

How this was checked

On October 14, 2026, we checked every statement, number and source on the original infographic, 63 items, against the published paper and its April 2026 preprint, the authors' source data, the 2021 and 2023 studies whose methods and spectra it uses, the tree-ring study, Kyoto's storm index and the international list of ground-level events. We recomputed the ratios, re-checked the ten storms and the core statistics, evaluated the published spectra and measured the original charts against their axes. The check corrected several statements; the change log lists them.

After the page was built, a second reviewer who hadn't seen the drafting re-downloaded Kyoto's Dst, the list of ground-level events and the authors' data, redid the storm count and the core statistics, evaluated the published spectra again, all of which matched, and checked every quotation and reference. The changes that followed: the summary on the library card and social image now says "around 1859" and "above 30 MeV"; no chlorine-36 sample spanning 1859–60 is more than one standard deviation above its record's mean (one late-1860 sample is lower than that); the paper's May 2024 values are credited as real-time values, with a source; the authors' own caveat about events from other eruptions is credited to them; and several references and locators were corrected.

The verdicts and the items tagged "Our analysis" are our own assessment, built on the cited sources: the spectra evaluations and ratios, the storm recount and our reading of the paper's threshold. The paper is open access under CC BY 4.0 [1]; the spectrum chart is redrawn from its Table 1 and the published spectra, and the other charts are our own.

This page was researched and written with Claude, an AI assistant made by Anthropic, and then re-checked against its sources in a separate verification pass.

The verdicts on this page

PARTLY TRUE	Part of the claim holds up and part doesn't.
TRUE	The evidence supports the claim.

All ten verdicts, and how we check

CORRECTIONS

Corrections and changes

If we get something wrong, we fix it and record the change below with the date. If a correction changes a verdict, the log says what the old verdict was.

Change log

Oct 14, 2026 Published on factchecked.science after a full check against the sources. Changes from the infographic: added our verdicts on four of the paper's claims. The title says "no detectable" mark, since the ice can't see a shower below about three times August 1972 above 30 MeV, and every "three times" now says "above 30 MeV". 774/5 CE is about 14 times the limit in the spectrum the paper compares with, rather than "about ten times", and August 1972 is about 5.6 × 10^9 in the spectra it scales rather than "about 6". The 2013 estimate was based on the flare's estimated X-ray class, not on X-ray measurements; the single-core detection level is 5–6 × 10^{10}, as the 2021 study gives 6; and the excluded range now starts at the limit. "Found nothing" became "found no clear signal" and "closes a loophole" became "narrows a loophole". February 1956 also raised chlorine-36 by 8%, and a 1972-size event would show only about 5% in a one-year ice sample after transport. The limit isn't measured "energy by energy": the ice constrains protons near 60 MeV and modern shapes supply the rest, now shown beside February 1956, August 1972 and 774/5 CE. "Probably" is restored before "widespread spacecraft disruptions". "10 of 31, about 32%" is given as the paper's count, beside our recount with its rule, 10 of 34; May 2024's −412 nT is the real-time value. "A great storm with no particle shower at all would be unremarkable" became one without a ground-level event, since March 1989 brought a proton storm and August 1972's shower came from near the disc centre. "A benchmark … not for radiation" and "the radiation worst case … is 774/5 CE" now note the shower allowed and the stronger 12,350 BCE event. The tree-ring offset is dated 1861–63, as its authors report it, and the threshold and transport factor are credited to the authors' own statements. The infographic quoted the paper as saying "about three times"; its words are "up to ca three times".

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Last updated Oct 14, 2026