☑ **Fact-Checked Science**

PAPER CHECK · SOLAR STORMS

A 7,300-year-old solar storm, now found in the ice

Tree rings recorded a sharp jump in radiocarbon in 5259 BCE [1 Results]. A 2026 study finds the matching spike in Greenland and Antarctic ice, supporting an extreme solar particle storm [2 Abstract]. The event is solid. Its place in the solar cycle is much less certain than the paper suggests, and its spectrum is unresolved, as the authors acknowledge.

By Fact-Checked Science · Published October 13, 2026

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

The storm holds up; two of its details are less certain

OUR ASSESSMENT

~10σ

Our calculation: how far the new Greenland beryllium-10 peak stands above its baseline. Three coarser records show peaks of about 3–4σ [3].

0.68

Our calculation: the chlorine-36 rise divided by the beryllium-10 rise. A soft event would give at least 2, and no modern event gives less than 1 [2 p. 5][2 p. 6].

~20–40%

Our re-test: how often chance alone gives a solar-cycle match as good as the paper's, once its window search and the similarity of neighbouring years are allowed for.

THE PAPER'S CLAIMS

TRUE

"The radionuclide records from the NGRIP, GRIP and EDML ice cores support the occurrence of a SEP event at 5259 BCE"

Paleari and colleagues, 2026 [2 p. 9]

A sharp beryllium-10 peak in the new Greenland record, and smaller peaks in three other records from both hemispheres and two isotopes, line up with the tree-ring spike once each ice timescale is shifted to match it; for Greenland, the shift needed agrees with an earlier, independent estimate. Volcanoes can't explain the peaks [2 p. 5]. See section 1.

UNCONFIRMED

The event "was very probably caused by an extreme SEP event characterized by a hard spectrum"

The same paper [2 p. 8]

A hard spectrum means a relatively high share of high-energy particles. The paper's case rests on analogy with earlier extreme events and on one chlorine-36 value from one core, which rules out a soft spectrum but matches no known event; the authors say the spectrum "cannot be robustly reconstructed" from the chlorine-36 to beryllium-10 relationship alone [2 p. 6]. See section 3.

OVERSTATED

"The SEP event probably occurred close to the solar maximum"

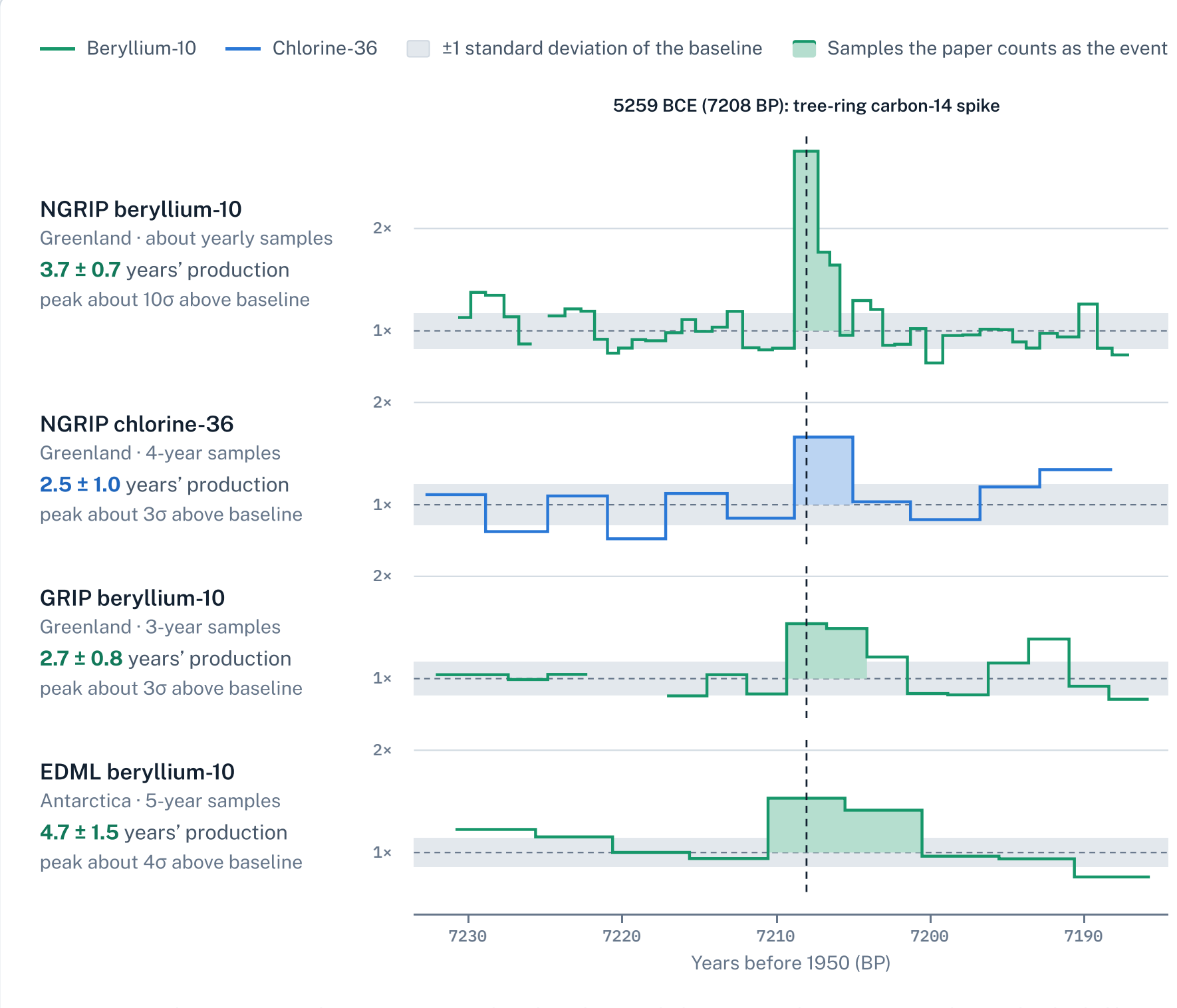
The same paper [2 p. 9]

The match behind it was the best of many possible windows, tested as if neighbouring years were independent [2 p. 8]. Allowing for both, in our re-test a match this good turns up by chance roughly 20–40% of the time. See section 5.

1 · ONE SPIKE, FOUR ICE RECORDS

The new Greenland record shows the spike most clearly

In 5259 BCE, radiocarbon in the air rose by nearly 2% within two years, a jump found in four tree-ring chronologies from the Alps, Ireland, Russia and the USA [1 Results]. Showers of solar particles also make beryllium-10 and chlorine-36, which settle into polar ice. The study measured both in Greenland's NGRIP core and compared them with beryllium-10 records from a second Greenland core, GRIP, and from EDML in Antarctica [2 p. 3].



Ages are years before 1950 on the ice-core timescales, shifted to match the tree-ring date [2 p. 3]. Each record is divided by its own baseline (dashed), the average of the samples outside the peak over 7185–7230 BP [2 p. 3]. Shading marks the samples the paper counts as the event; for NGRIP beryllium-10 that includes a fourth sample, just below the baseline [2 p. 3]. Enhancement factors are the paper's [2 p. 5]; the σ values are our calculation. Redrawn by us from the supplementary data [3].

ADDED BY THE EVENT

3.7 ± 0.6

years of normal beryllium-10 production, averaged over the three cores [2 p. 5]

PROTONS PER CM^2 ABOVE 200 MEV

~10^{10}

comparable to the other extreme events in the isotope record [2 p. 8]

CONFIRMED IN TREES AND ICE

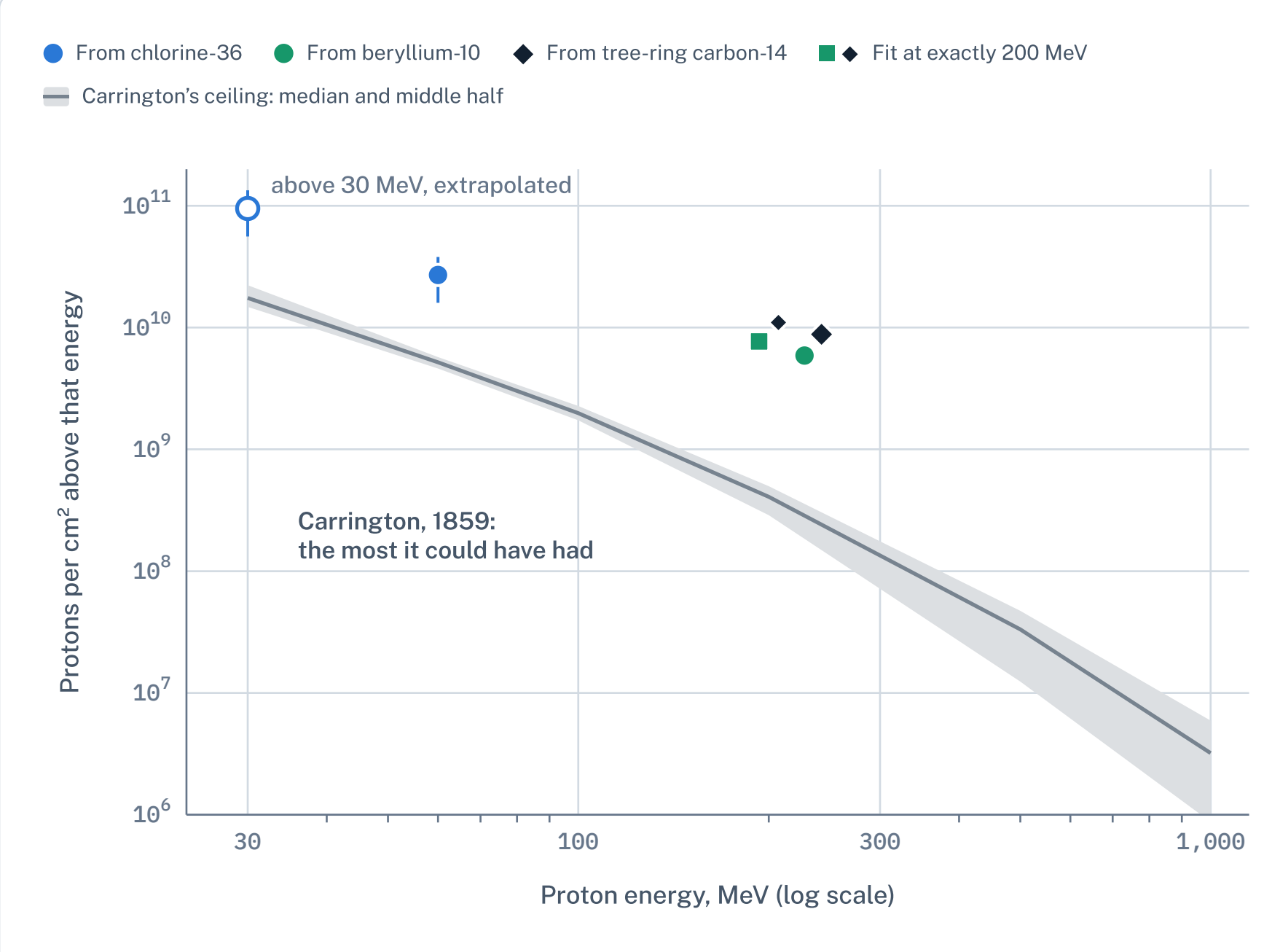
5 events

in the current warm period, the Holocene, by the paper's count [2 p. 8]

2 · HOW BIG WAS IT?

As big as the other extreme events, far above Carrington's ceiling

Each isotope's rise tracks the number of protons above its own "effective energy": 60 MeV for chlorine-36, 234 MeV for carbon-14 and 236 MeV for beryllium-10. The paper uses that to turn each rise into a particle count, assuming today's average solar activity and magnetic field [2 p. 6].



Estimates and uncertainties from the paper's Table 1 [2 p. 8]. The ceiling is the largest particle shower the Carrington event could have had, from Table 1 of Mekhaldi and colleagues: its median, with the middle half of their range shaded, joined by straight lines [4 Table 1]. Markers at 200 MeV and at 234–236 MeV are drawn slightly apart sideways so they don't overlap. Redrawn by us.

The firm part

Above about 200 MeV the estimates agree with the other extreme events, around 10^{10} protons per cm^2 [2 p. 8]. That part is well constrained: every scaled modern hard-spectrum event that fits the beryllium-10 rise converges between 200 and 300 MeV, and the fits behind the estimates have R^2 of 0.97 to 0.99 [2 p. 6][2 p. 8]. Below that, beryllium-10 alone constrains little [2 p. 6].

OUR ANALYSIS

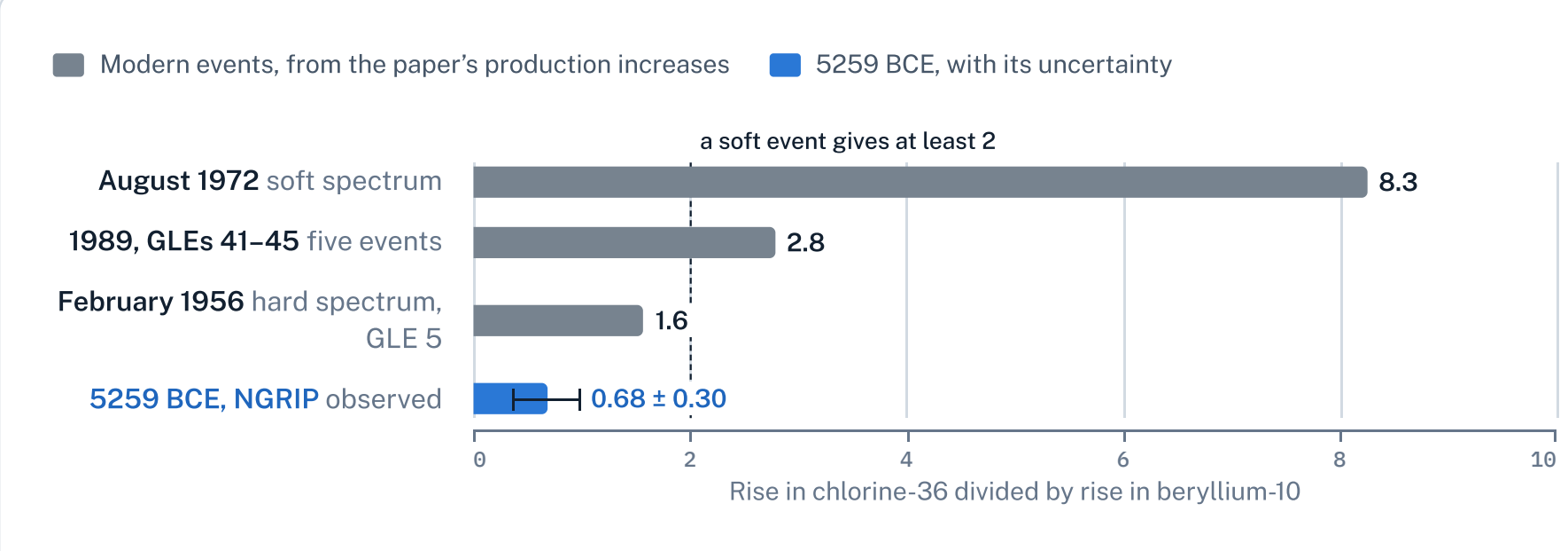
Against the ceiling the chlorine-36 study set for any Carrington particle shower, 5259 BCE was roughly 19–27 times larger above 200 MeV and about 5 times larger at 60 MeV [2 p. 8][4 Table 1]. Against the middle half of that ceiling's range, the multiples are about 15–38 and 5–6.

Carrington, one of the largest magnetic storms on record, is often used as the benchmark worst case [4 Abstract]. For radiation, the worst cases on record are events like this one; 774/5 CE was slightly stronger and 12,350 BCE stronger still [1 Results][5 p. 3]. More on that in The Sun has two worst cases.

3 · THE CHLORINE-36 PUZZLE

Chlorine-36 rose less than beryllium-10, which no modern event does

Chlorine-36 is more sensitive to lower-energy protons, so the ratio of the two rises measures how "soft" an event was: the more low-energy particles, the higher the ratio [2 p. 6]. At NGRIP, chlorine-36 rose less than beryllium-10, and no modern event reproduces that [2 p. 6].



Modern ratios from the increases in production the paper quotes: chlorine-36 9.9% and beryllium-10 1.2% for August 1972, 12.8% and 4.6% for 1989, and 8.0% and 5.1% for February 1956 [2 p. 2][2 p. 6]. The 5259 BCE ratio, 2.5 ÷ 3.7, and its uncertainty are our calculation from the paper's enhancement factors [2 p. 5].

Two explanations, no choice

The chlorine-36 rise implies a particle count above 60 MeV about three times lower than estimates for other extreme events. The authors offer two explanations and don't choose: an event even harder than any on record, or a chlorine-36 value that is poorly constrained, coming from one core at four-year resolution and perhaps altered after it fell [2 p. 7]. They rule out one such effect, chlorine-36 escaping from the snow, and say more chlorine-36 measurements are needed [2 p. 8].

Why they still favour "hard"

For two reasons: every earlier extreme event that has been characterized had a hard spectrum, and a soft event would have raised chlorine-36 at least twice as much as beryllium-10 [2 p. 6].

OUR ANALYSIS

The measured ratio, 0.68 ± 0.30, is about 4σ below the soft-event value of 2, so it does argue against a soft spectrum. It is also about 3σ below the hard benchmark of February 1956, 1.6, so it fits no known event either. If that one value is unreliable, "hard" rests on the analogy with earlier events alone. That's why we rate the claim unconfirmed rather than wrong.

4 · WHAT HOLDS UP

The detection is sound

Both hemispheres, three isotopes

Greenland and Antarctic ice and tree-ring radiocarbon all register it, which points to solar particles rather than a local quirk [2 p. 5].

Volcanoes ruled out

Eruptions can raise beryllium-10 but not chlorine-36 or tree-ring carbon-14, and NGRIP's volcanic record shows no matching peak [2 p. 5].

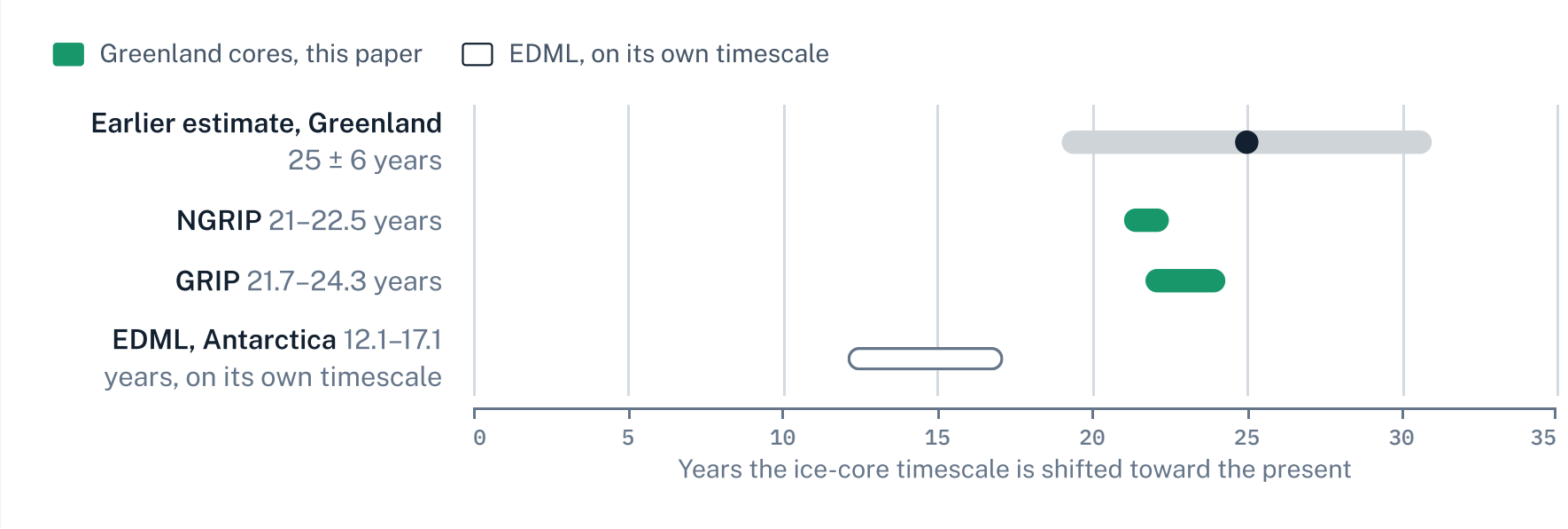
An independent dating check

To put the ice-core peak on the tree-ring date, the Greenland timescale has to shift by 21–24 years toward the present [3 Table S1]. That agrees with an earlier, independent estimate of the offset between the Greenland and tree-ring timescales, 25 ± 6 years [2 p. 5][6]. The shift was set from the sample where the beryllium-10 rise starts, so the check is that agreement, not the alignment itself [2 p. 5].

A candid paper

Its title says the ice cores "support" the event, and the authors flag their own chlorine-36 puzzle rather than hiding it [2 p. 6][2 p. 7].

Timescale shift needed to match the tree rings



Each core's shift as a range, from the supplement's Table S1 [3 Table S1]; the earlier estimate as cited by the paper [2 p. 5]. EDML's timescale was matched to Greenland's separately [2 p. 3], so its shift isn't directly comparable.

5 · WHERE WE PUSH BACK

The numbers reproduce; two conclusions go further than the data

Our own checks, using the paper and its supplementary data [3].

OUR ANALYSIS

The numbers reproduce. Recomputing from the supplementary data gives enhancement factors of 3.67, 2.51, 2.68 and 4.73, matching the paper's 3.7, 2.5, 2.7 and 4.7, and the uncertainties in its Table S2 [2 p. 5][3 Table S2].

Two size estimates are in tension. Near 235 MeV, beryllium-10 gives 5.9 ± 1.0 and carbon-14 8.8 ± 0.4 × 10^9 protons per cm^2, about 2.7σ apart. The paper calls the second "larger" [2 p. 6].

"Close to the solar maximum" is tentative. It rests on the best-matching 44-year stretch of about 70 years of modern data ($r = 0.47$, $p < 0.01$), tested as if neighbouring years were independent [2 p. 8]. A correlation of 0.47 explains about 22% of the variation. Our re-test, below, puts the chance of a match this good at roughly 20–40%.

Not all of the data may be new. The paper says it shows new data from all three cores, but it describes preparing and measuring only the NGRIP samples, cites the GRIP record to a 2004 study and gives no source for EDML's [2 p. 2][2 p. 3]. Either way, the Antarctic confirmation rests on two 5-year samples [3].

One strong signal, three moderate ones. NGRIP beryllium-10 stands about 10σ above its baseline; the other three peaks about 3–4σ. Convincing together, marginal alone: GRIP has a later bump of about 2.4σ that no one counts as an event.

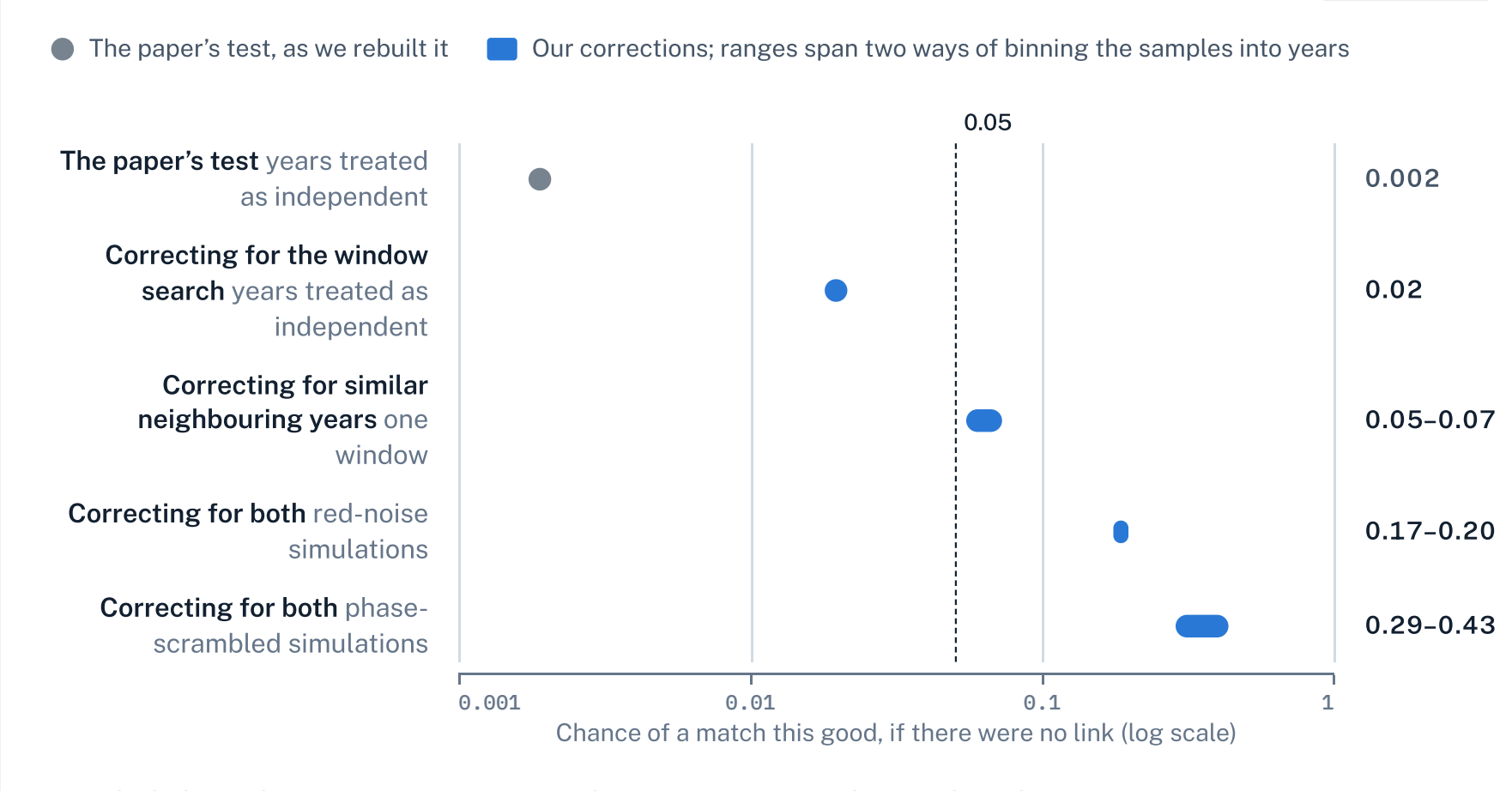
The spectrum isn't pinned down. The single chlorine-36 value rules out a soft spectrum but fits no known hard event either. If it's unreliable, "hard" rests on analogy with earlier events. The authors say as much and call for more chlorine-36 measurements [2 p. 6][2 p. 8].

A modern Sun and field are assumed. The fluences use today's average solar modulation, 650 MV, and magnetic dipole moment, 7.8 × 10^{22} A m^2 [2 p. 6]. The field was about 5–9% weaker in 5259 BCE, 7.1–7.4 × 10^{22} A m^2 [1 Table 1]. The carbon-14 estimate was already corrected to today's field, so this caveat applies to the ice-core estimates [2 p. 6]. We didn't check how the Sun's average activity then compares.

Small slips. Read as a continuous run, the paper's peak rule would also admit a third GRIP sample, raising GRIP's factor from 2.7 to about 3.4; read as only the values adjacent to the highest one, it wouldn't [2 p. 3]. EDML's factor is 4.7 in the text but 4.8 in Table S2, whose own integral gives 4.7 [2 p. 5][3 Table S2]. Figure 1 labels EDML in 10^3 atoms per gram where the data file says 10^4 [2 p. 4][3]. The text gives a Greenland shift of 23 to 21 years, while Table S1 lets GRIP run to 24.3 [2 p. 5][3 Table S1]. None of this changes the conclusion: with GRIP at 3.4, the average factor is 3.9 ± 0.6.

How often would chance match the solar cycle this well?

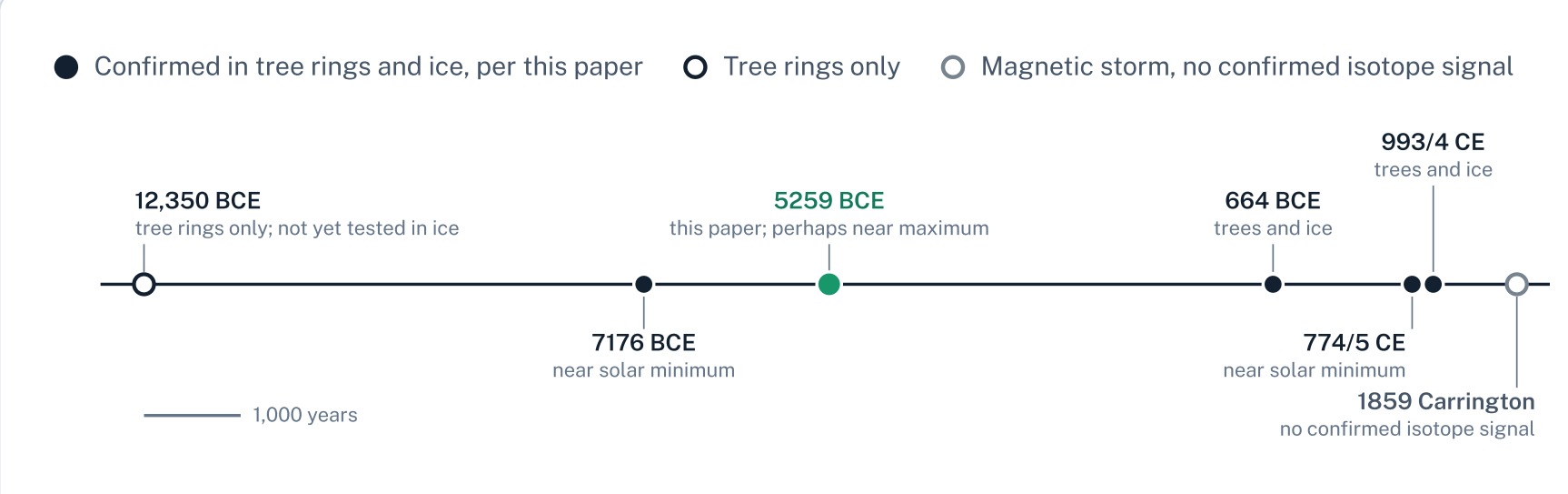
OUR ANALYSIS



We rebuilt the modern comparison series from the paper's Figure 3 and a record of solar activity from neutron monitors [2 p. 9][7], and, binning the samples into years centred on whole years, found the same best window, 1971–2014, with $r \approx 0.47$ (binning from whole years gives 1970–2013, $r \approx 0.46$). We then counted how often random stand-ins for the ice-core series do as well, with neighbouring years made alike either by a simple persistence model (red noise) or by keeping the series' own pattern of ups and downs (phase-scrambled). The single-window correction uses the effective number of independent years [8]; it ranges from about 0.05 to 0.10 depending on how the similarity of neighbouring years is estimated. The paper's modelled series isn't public, so these values are approximate.

6 · WHERE IT SITS

One of the Sun's rare extreme storms



Dates on a linear scale. Events and solar-cycle phases as the paper gives them; phase is shown only where it states one [2 p. 2][2 p. 8]. The 1859 Carrington storm brought no significant chlorine-36 rise in three ice cores, and a localized radiocarbon rise reported in polar trees hasn't been found elsewhere [4 Abstract][4 p. 6].

Counts differ by definition

This paper lists five events confirmed in both archives, with a sixth, older radiocarbon spike, 12,350 BCE, still to be tested in ice [2 p. 8][5 p. 3]. A review in the same issue counts seven confirmed events and two candidates over 15,000 years, requiring each to be confirmed independently by several groups using different archives [5 p. 3].

OUR ANALYSIS

With two events near solar minimum and perhaps one near maximum, there is no simple link to the 11-year cycle.

Limits of our check

An approximate re-test

The paper's modelled production series isn't public, so we rebuilt it from its Figure 3 and solar-activity records [7]. Our re-test reproduces the paper's best window and correlation with one of the two ways of binning the samples into years (the other puts the best window a year earlier), and its p-values are approximate.

Versions we read

We read the review's accepted version and took the 25 ± 6-year offset from the paper's citation [5][6].

σ depends on the spread used

Our σ values use the time-weighted spread of each baseline. With the ordinary sample spread, EDML's peak is 3.5σ rather than 3.7σ, and GRIP's and NGRIP chlorine-36's 3.1–3.2σ rather than 3.3σ; NGRIP beryllium-10 stays near 10σ.

What would change these verdicts

01 Chlorine-36 from other cores or at finer resolution. A ratio near February 1956's would back a hard spectrum; one confirmed below 1 would make this event unlike any on record [2 p. 8].

02 The paper's own modelled series, retested with the window search and neighbouring years allowed for. If the match survived, "close to the solar maximum" would stand.

03 Beryllium-10 at yearly resolution from a second core, especially in Antarctica, where the confirmation now rests on two 5-year samples.

Related checks

FALSE Superflares and Heinrich events The Disaster Cycle, Fact-Checked

Sources

Bracketed numbers refer to this list; p. gives a page (for the 2026 Royal Society papers, the page of the published PDF; for the Vasilyev review, the page of its accepted version), Table a table, and Abstract and Results the part of a work we used. Links checked October 13, 2026.

1 Brehm, N., Christl, M., Knowles, T. D. J., Casanova, E., Evershed, R. P., Adolphi, F., et al. (2022). Tree-rings reveal two strong solar proton events in 7176 and 5259 BCE. *Nature Communications* 13, 1196. CC BY 4.0.

2 Paleari, C. I., Mekhaldi, F., Christl, M., Gautschi, P., Vockenhuber, C., Anderberg, E., Beer, J., Raisbeck, G., Yiou, F., Brehm, N., Wacker, L., Wilhelms, F., and Muscheler, R. (2026). Ice-core cosmogenic radionuclides support the occurrence of an extreme solar particle storm 5259 BCE (7208 years BP). *Philosophical Transactions of the Royal Society A* 384(2329), 20250347. Published September 10, 2026. CC BY 4.0. We read the publisher's PDF, deposited in Eawag's institutional repository.

3 Paleari, C. I., et al. (2026). Supplementary material from "Ice-core cosmogenic radionuclides support the occurrence of an extreme solar particle storm 5259 BCE (7208 years BP)". The Royal Society, figshare, version 1. CC BY 4.0. Tables S1 and S2 are in the Supporting Information; the measurements are in the workbook Dataset_240226.

4 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.

5 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.

6 Adolphi, F., and Muscheler, R. (2016). Synchronizing the Greenland ice core and radiocarbon timescales over the Holocene – Bayesian wiggle-matching of cosmogenic radionuclide records. *Climate of the Past* 12(1), 15–30. CC BY 3.0. The source of the 25 ± 6-year offset, as cited by Paleari and colleagues; we didn't re-derive that value from this paper.

7 Usoskin, I. G., Bazilevskaya, G. A., and Kovaltsov, G. A. (2011). Solar modulation parameter for cosmic rays since 1936 reconstructed from ground-based neutron monitors and ionization chambers. *Journal of Geophysical Research: Space Physics* 116(A2). We used the monthly values published by the Oulu Cosmic Ray Station, Phi_mon.txt, read on October 13, 2026.

8 Bretherton, C. S., Widmann, M., Dymnikov, V. P., Wallace, J. M., and Bladé, I. (1999). The effective number of spatial degrees of freedom of a time-varying field. *Journal of Climate* 12(7), 1990–2009.

METHOD

How this was checked

On October 13, 2026, we checked every statement, number and source on the original infographic, 94 items in all, against the published paper, its supplementary data, the Carrington study in the same journal issue that the infographic draws on, a review in that issue and the 2022 tree-ring study. We recomputed every number the supplementary data allow, the enhancement factors, their uncertainties and our σ values, and re-ran the paper's solar-cycle test as far as public data allow. 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-computed every number and chart mark from the supplementary data, re-ran the solar-cycle test with its own code and read the page for fairness. Everything reproduced, and its re-test gave about 19–43%. The changes that followed: the paper does call the data from all three cores new, though it cites the GRIP record to a 2004 study, and the page now says so; the verdict panel no longer counts the ice records' alignment with the tree-ring date as evidence, since each timescale was shifted to match it; a hard spectrum is now defined as a high share, not a majority, of high-energy particles; the re-test caption gives both ways of binning the samples into years; and a dozen smaller wording fixes.

The verdicts and the items tagged "Our analysis" are our own assessment: the σ values, the ratios and multiples, the GRIP re-count and the solar-cycle re-test. The charts are redrawn by factchecked.science from data in Paleari et al. 2026 and its supplement, and from Mekhaldi et al. 2026, Table 1 (all CC BY 4.0); values are normalized or recomputed [2][3][4 Table 1].

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

OVERSTATED	Has some basis but claims much more than the evidence supports.
UNCONFIRMED	Rests on a preliminary result that hasn't been confirmed.
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 13, 2026

Published on factchecked.science after a full check against the sources and a re-run of the paper's numbers from its supplementary data. Changes from the infographic: added our verdicts on three of the paper's claims. The title says 7,300 years rather than 7,200: 5259 BCE was 7,284 years before 2026, and 7,208 is the age counted from 1950. The dek now says the ice "supports" the storm, as the paper's title does, rather than "confirming" it; it calls the place in the solar cycle much less certain than the paper suggests and the spectrum unresolved, as the authors acknowledge, rather than both less certain. The dating check was described backwards: the timescale shift was set from the sample where the beryllium-10 rise starts, so only its agreement with the earlier 25 ± 6-year estimate is independent. The paper's second, data-based reason for a hard spectrum, that a soft event would give a chlorine-36 to beryllium-10 ratio of at least 2, is restored, and "an assumption … which the chlorine-36 value contradicts" became "isn't pinned down": the ratio rules out a soft spectrum but fits no known hard one. "Two size estimates disagree" became "are in tension"; "20–27 times" became 19–27; "the radiation worst case" now notes that 774/5 CE was slightly stronger and 12,350 BCE stronger still; "both differed" now says the magnetic field was 5–9% weaker, that the carbon-14 estimate was already corrected for it, and that we didn't check the Sun; and the third GRIP sample counts only under one reading of the paper's peak rule. "Only NGRIP is new data" and the cores' "new" and "existing" labels are gone: the paper calls the data from all three cores new, though it cites the GRIP record to a 2004 study and gives no source for EDML's. The fourth NGRIP sample the paper counts, just below the baseline, is now shaded. Carrington has "no confirmed isotope signal", and its marker now sits at its true date on the linear timeline, where it was about 220 years off. The fluence chart now says which markers are drawn slightly apart. The Carrington ceiling is in Table 1 of the published Mekhaldi paper, not Table 2. Added the results of our solar-cycle re-test, the full references, the 2022 tree-ring study and the source of the 25 ± 6 years.

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Last updated Oct 13, 2026