☑ Fact-Checked Science

PAPER CHECK · THE SUN

Superflares and the Sun’s extreme particle storms don’t appear to be one-to-one, and the link is still open

A 2026 review asks whether superflares on Sun-like stars and the extreme particle storms recorded in tree rings and ice are “two sides of the same coin” [1 p. 2]. It rules out a one-to-one link but can’t yet choose between the two other answers. We checked the infographic that sums it up and corrected its flare energies and charts.

By Fact-Checked Science · Published October 19, 2026

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

The review rules out a one-to-one link; which other answer is right is still open

OUR ASSESSMENT

7 + 2

extreme solar particle events confirmed in tree rings and ice cores over 15,000 years, plus two candidates [1 p. 3]

~100 ×

how much more particle fluence the biggest ancient events carried than strong events measured since the 1950s [1 p. 4]; against February 1956’s, less at the highest energies, by our reading of Fig. 2 [1 p. 5]

10^{34} erg

the flare energy above which the review counts superflare rates; elsewhere it puts the start of superflares at about 10^{33} erg [1 p. 6][1 p. 7]

THE REVIEW’S CLAIMS

PARTLY TRUE

“hypothesis (i) is rejected, with high confidence, by the observed data”

The review, on a one-to-one link between superflares and extreme particle events [1 p. 14]

It leans on the authors’ own estimate that superflares come about once a century on Sun-like stars [2], about 12 to 15 times as often as these events, or 15 to 20 times counting only the confirmed ones. At the other published rates, superflares would be between three times as frequent and four times rarer [1 p. 7]. See section 4.

TRUE

“we cannot distinguish between hypotheses (ii) and (iii)”

The review, on the two remaining answers [1 p. 14]

A scenario the review calls “speculative but physically plausible” fits (ii) [1 p. 15], and a probabilistic study by two of its authors favours (iii) [3]; the data exclude neither. See section 4.

CONTEXT

“hypothesis (ii) the current paradigm”

The review, on superflares that only rarely cause extreme particle events [1 p. 14]

This describes where the field stands, with two citations co-written by one or more of the authors; it isn’t a finding the review tests. The infographic reports it accurately. See section 4.

PARTLY TRUE

“roughly once per 1500 years”

The review, on how often extreme particle events happen [1 p. 3]

The review gets this by counting its two unconfirmed candidates with the seven confirmed events, as it says. The seven alone give about one per 2,000 years, in line with its own “one–two millennia” [1 p. 5]. See section 5.

UNCONFIRMED

“roughly one event per century for $E \gtrsim 10^{34}$ erg”

The review, on superflares on Sun-like stars [1 p. 8]

It comes from one team’s analysis of Kepler data, by the authors and colleagues, which they argue is the best matched to the Sun [2]. None of the other studies the review lists finds a rate that high, and it calls the results “rather inconsistent” [1 p. 7]. See section 5.

1 · TWO LINES OF EVIDENCE

Two kinds of extreme event, seen in different places

Extreme solar particle events are known only for our Sun, from isotopes in tree rings and ice; superflares are seen on other Sun-like stars. The two have been “discovered and are studied by different methods on different objects” [1 p. 14].

Extreme solar particle events

Sudden spikes of carbon-14 in tree rings, and of beryllium-10 and chlorine-36 in ice cores, archives that can be dated independently [1 p. 3]. Their isotope pattern “unambiguously confirmed” a solar origin: energy spectra like those of modern solar particle events, but about a hundred times stronger [1 p. 4]. Seven are confirmed and two are candidates, over 15 millennia [1 p. 3].

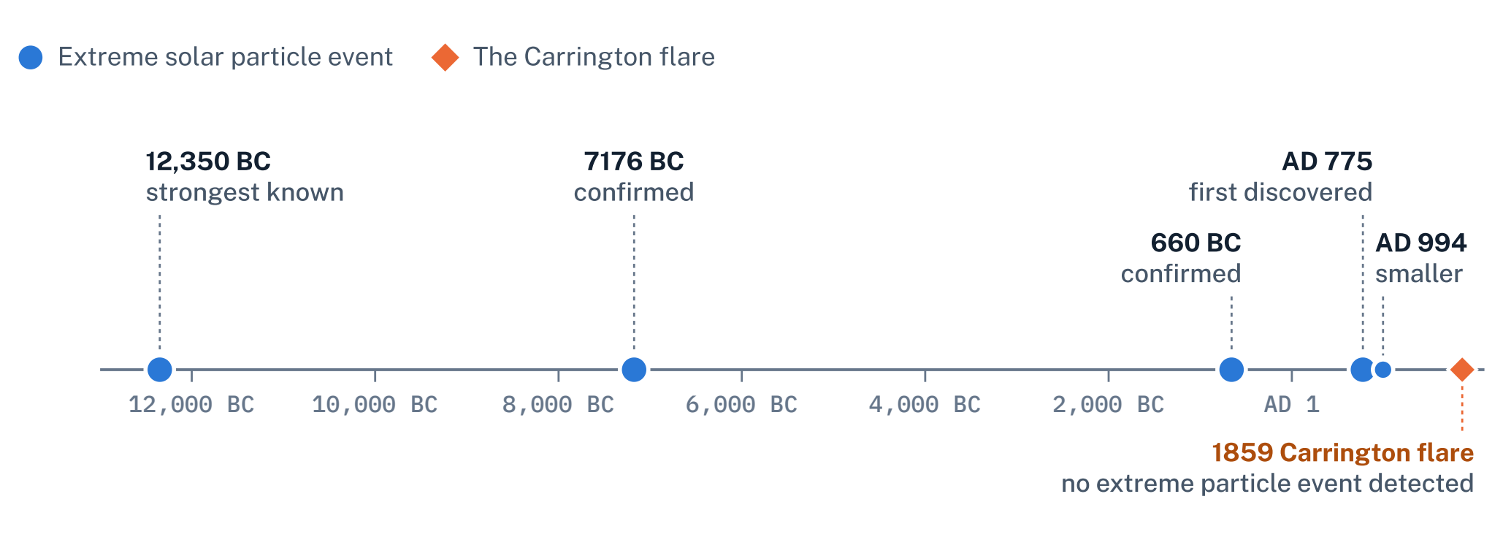
Superflares on Sun-like stars

Space telescopes such as Kepler and TESS see stars of the Sun’s type flare with about 10^{33} to 10^{36} erg, “several orders of magnitude more energy than the largest directly observed solar flares” [1 p. 6]. On the stars most like the Sun, they reach 10^{34}–10^{35} erg [1 p. 8].

2 · WHEN THE SUN WENT EXTREME

Five dated events, and a famous flare that left none

The review names five of the seven confirmed events. The strongest, in 12,350 BC, was 18% stronger than the first one found, in AD 774–775 [1 p. 3].



Dates from the review [1 p. 3][1 p. 4]. Not shown: two further confirmed events, plotted but not named in the review’s Fig. 1, and two candidates. Our page on a 7,300-year-old storm, now found in ice, covers another. Drawn to scale.

The Carrington flare left no matching event

Searches for a particle signal after the strongest flare on record, in 1859, “failed – there was no detectable ESPE” [1 p. 14]; one found no sign in Alaskan tree rings [4]. Another, in polar tree rings, did find a statistically significant, short-lived offset in carbon-14 that its model couldn’t reproduce [5]. Our page on the Carrington storm in the ice looks at the ice-core side.

3 · WHERE A FLARE’S ENERGY GOES

How a flare’s energy is split decides what reaches Earth

Free magnetic energy builds up as an active region’s field is “sheared and twisted”, and reconnection releases it [1 p. 10]. How it is shared between radiation, ejected mass and particles likely depends on the region’s magnetic flux and topology [1 p. 1].

Flare radiation

Soft X-rays, the band behind a flare’s X-class, add “perhaps another roughly 1%” to the less than 1% in harder X-rays; most of the energy comes out in the ultraviolet, visible and near-infrared, where it remains “poorly constrained” [1 p. 11]. In a confined flare, most of the energy “remains trapped”, so it can look bright but usually releases fewer particles [1 p. 12].

The coronal mass ejection

In eruptive events, “often more than half” of the released energy goes into the ejection’s motion and potential energy, and above about X4–X5 “nearly all flares are eruptive” [1 p. 12]. On active stars, the overlying field may stop ejections from escaping in flares above 10^{34}–10^{35} erg [1 p. 12]; on the Sun, simulations suggest this may already happen above a few × 10^{32} erg [1 p. 15].

Particles, from two accelerators

Reconnection in the flare accelerates particles fast, with hard spectra, for tens of minutes to hours; shocks driven by the ejection work more slowly but over large volumes, for several hours to a day [1 p. 13]. The most extreme events “likely require both”, and an open magnetic field so the particles can escape [1 p. 13].

The strongest flares didn’t bring the strongest particle storms

“The strongest SEP events were not caused by the strongest flares and vice versa” [1 p. 13]: acceleration, magnetic topology and the particles’ path through space all matter [1 p. 14]. Flare size and particle output are related statistically for weak and moderate events, but for the strongest the relation “remains elusive” [1 p. 13].

4 · THREE HYPOTHESES

Not one-to-one, but where the events come from is still open

The review sets out three ways superflares and extreme particle events could be related [1 p. 14].

HYPOTHESIS (I) REJECTED

One-to-one

Superflares and these events would be nearly one-to-one, so their rates could be compared directly. The review rejects this because recent analyses, led by the authors, “demonstrated that superflares are significantly more frequent” on Sun-like stars than these events on the Sun, and because none followed the Carrington flare [1 p. 14].

HYPOTHESIS (II)

CURRENT PARADIGM

Superflares cause them, but rarely

Extreme particle events come from superflares, but only when conditions are favourable [1 p. 14]. In a scenario the review calls “speculative but physically plausible”, strong overlying fields hold back ejections and particles in the biggest flares, so that escape grows less likely as magnetic complexity and flare energy grow [1 p. 15].

HYPOTHESIS (III)

NOT EXCLUDED

Not directly related

Most of the events may come from “strong but not yet extreme flares in the X1–X10 range” when conditions happen to be favourable, with superflares causing one only rarely [1 p. 14]. That is what a probabilistic study by two of the review’s authors concluded [3].

OUR ANALYSIS

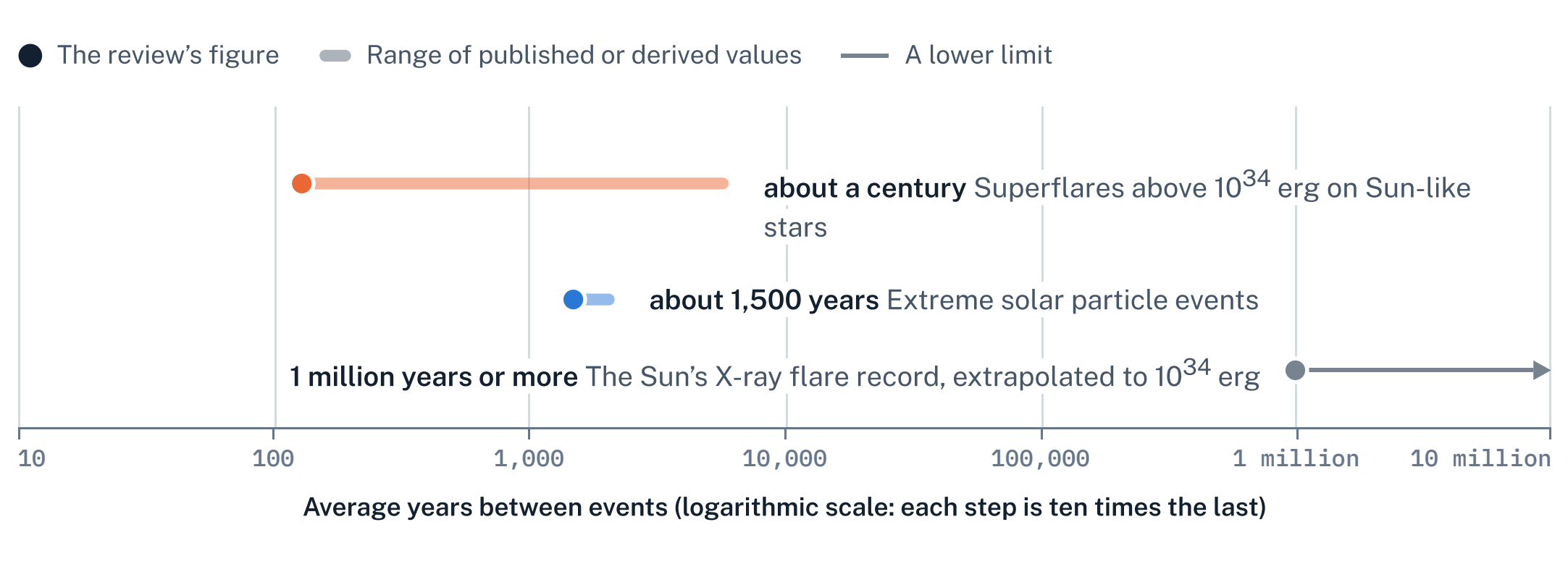
How firm is the rejection?

It rests mostly on rates. At the authors’ estimate of one superflare per century, superflares outnumber extreme particle events about 12 to 15 times, or 15 to 20 times counting only the confirmed events. At the other rates in the review’s Table 2, once per 500 to 6,000 years, they would be between three times as frequent and four times rarer [1 p. 7], a range that earlier work treated as close enough to allow a one-to-one link [1 p. 14]. The Carrington flare, at a few × 10^{33} erg, is below the 10^{34} erg used for the rates, though above where the review elsewhere says superflares begin [1 p. 11][1 p. 6]. Both arguments point the same way, but neither is decisive on its own.

5 · HOW OFTEN

Three rates, from measurements that can’t be compared directly

Superflare rates come from other stars, extreme particle events from isotopes, and a third estimate from the Sun’s own X-ray record. They span a factor of ten thousand.



Superflares: once per 130 years in the authors’ study, which they round to about once a century, and up to once per 6,000 years across the other studies in the review’s Table 2 [1 p. 7][1 p. 8]. Extreme particle events: once per 1,500 years counting the two candidates, about 2,000 for the seven confirmed [1 p. 3]. The X-ray record: “a lower limit return time of $\gtrsim 10^6$ yr” for flares of about 10^{34} erg [1 p. 9]. Drawn to scale.

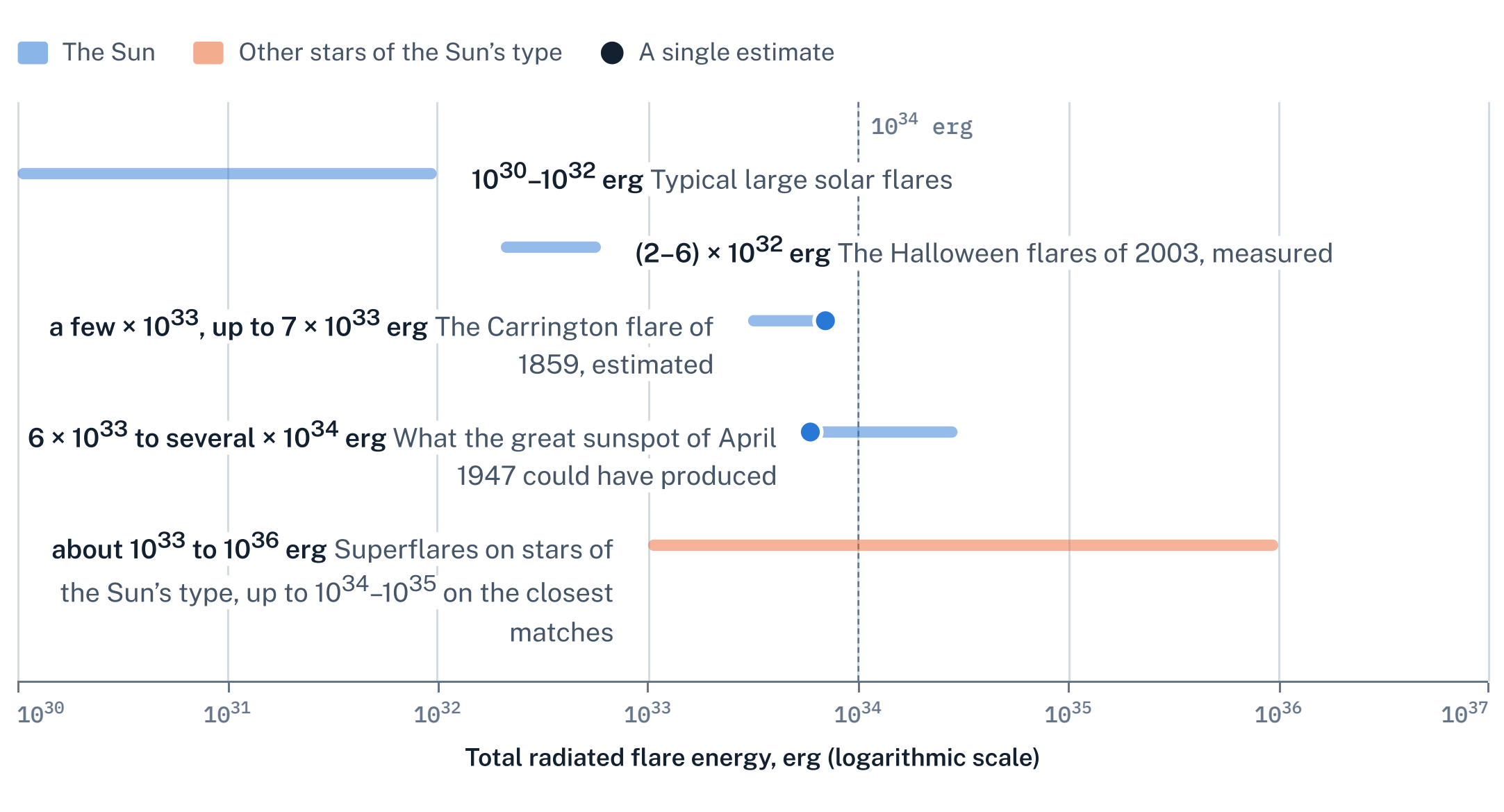
Not directly comparable

The review stresses that the X-ray and stellar estimates rely on different observables, baselines and degrees of extrapolation, so “the two estimates are not directly comparable” [1 p. 9]. A different extrapolation of the Sun’s flare record, by energy rather than X-ray brightness, does “align with these stellar results” [1 p. 8].

6 · HOW BIG

The largest solar flares may reach the superflare range

Typical large solar flares release 10^{30}–10^{32} erg. Estimates for the most extreme historical cases reach several times 10^{33} erg, and the largest sunspot group on record could have produced more [1 p. 11].



Values from the review [1 p. 6][1 p. 8][1 p. 11]. For 1947, a conservative 3-D model gives about 6 × 10^{33} erg, and other estimates put the Sun’s limit below 10^{34} erg; an empirical scaling gives several × 10^{34} erg, drawn as 3 × 10^{34} [1 p. 11][6]. The dashed line marks 10^{34} erg, above which the superflare rates in section 5 are counted. The review isn’t consistent about where superflares start: about 10^{33} erg on p. 6, while on p. 11 it calls several × 10^{34} erg “approaching the lower end”. By the first, the Carrington estimate already counts as a superflare. Drawn to scale.

In the review’s words, solar flares “could reach energies of several 10^{34} erg, approaching the lower end of the stellar superflare regime” [1 p. 11].

7 · WHAT IT MEANS FOR EARTH

Harmless on the ground, dangerous in orbit

An extreme particle event today would be felt above the atmosphere, not on the ground.

On the ground

Past events “remained unnoticed by ancient societies”, because Earth’s magnetic field and thick atmosphere protect the surface [1 p. 6].

In orbit

The authors write that today “the spacecraft fleet could be instantly destroyed by corpuscular radiation”, probably sparing satellites in low-altitude, low-inclination orbits [1 p. 6].

Weak-field periods

During geomagnetic excursions and reversals, several per million years and each lasting a few millennia, shielding is greatly reduced for long enough “to accommodate several ESPEs” [1 p. 6]. OUR ANALYSIS At one event every 1,500–2,000 years, an excursion of a few thousand years would see one to three on average.

What would settle it

The PLATO mission will observe many more bright Sun-like stars, and spectroscopy can constrain stars’ ages and help reject unresolved binaries [1 p. 9]. More precise isotope measurements should find weaker events, “filling the observational gap” to the events measured today [1 p. 5].

The accepted version, not the published one

We read the accepted manuscript on arXiv, because the publisher’s site blocked automated access; the published abstract shows small copy edits, so the wording elsewhere may differ slightly [1].

Some figures rest on work we read only in summary

The highest estimates, about 7 × 10^{33} erg for the Carrington flare and several × 10^{34} erg for the 1947 sunspot, come from a study led by one of the authors and published in the same issue; we read only its abstract, which gives “a few ×10^{34} erg” for 1947 [6]. The lower estimates come from other teams the review cites [1 p. 11]. Of the other cited studies, too, we read only abstracts.

OUR ANALYSIS

Bottom line: a one-to-one link looks unlikely. Whether every extreme particle event comes from a rare superflare, or most come from smaller flares, is still open.

The review is careful: it rejects only the simplest link and says the data can’t separate the other two. Its rejection leans on the authors’ own superflare rate, which other published samples put lower, and the scenario it offers for (ii) is, in its own words, “speculative but physically plausible”. More Sun-like stars from PLATO and isotope records sensitive enough to catch weaker events are what would decide it.

Related checks

- PARTLY TRUE A “small” flare? The Disaster Cycle, Fact-Checked
- FALSE Superflares and Heinrich events The Disaster Cycle, Fact-Checked

Sources

Bracketed numbers refer to this list; p. gives a page of the review’s accepted version. Values without a reference are our calculations from the cited inputs. Links checked October 19, 2026.

1 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.

2 Vasilyev, V., Reinhold, T., Shapiro, A. I., Usoskin, I., Krivova, N. A., et al. (2024). Sun-like stars produce superflares roughly once per century. *Science* 386(6727), 1301–1305. We read the abstract.

3 Koldobskiy, S., Usoskin, I., Vasilyev, V., and Shapiro, A. I. (2025). Solar flares versus solar energetic particle events: Probabilistic projections to extreme events. *Astronomy & Astrophysics* 702, A195. CC BY 4.0. We read the abstract.

4 Miyake, F., Hakozaki, M., Hayakawa, H., Nakano, N., and Wacker, L. (2023). No signature of extreme solar energetic particle events in high-precision ^{14}C data from the Alaskan tree for 1844–1876 CE. *Journal of Space Weather and Space Climate* 13, 31. CC BY 4.0. We read the abstract.

5 Uusitalo, J., Golubenko, K., Arppe, L., 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. We read the abstract.

6 Krivova, N., Chatzistergos, T., Kazachenko, M., and Işık, E. (2026). Empirical flare energy limits for the largest historical sunspots. *Philosophical Transactions of the Royal Society A* 384(2329), 20250290. CC BY 4.0. We read the abstract.

METHOD

How this was checked

On October 19, 2026, we checked every statement, number and chart on the original infographic, 69 items, against the review’s accepted manuscript, its Crossref record and the abstracts of the studies it relies on. We read the review’s Fig. 2 to compare its extreme events with the strongest event recorded on the ground, measured where the original placed each mark on its timeline and charts, and redrew all three to scale. The check corrected several statements; the change log lists them.

The verdicts and the items tagged “Our analysis” are our own assessment, built on the cited sources: the readings of Fig. 2, the rate arithmetic and our reading of the review’s claims. The review is open access under CC BY 4.0 [1]; the timeline and both charts are drawn by factchecked.science from its values.

After the page was built, a second reviewer who hadn’t seen the drafting re-read every quotation against the review, re-read Fig. 2 from the PDF’s vector paths, which agreed with our table within about 1%, converted every chart mark back to a value and checked every reference. The changes that followed: hypothesis (iii) is no longer described as no link at all, since in it superflares still cause an event now and then; the title now says the two don’t appear to be one-to-one, as the review’s abstract does; the review’s label for its scenario, “speculative but physically plausible”, is quoted in full; superflares outnumber the events about 12 to 15 times, or 15 to 20 times counting only confirmed events; the review’s two lower ends for superflares are both stated; the study behind the highest flare estimates, now published, is cited; and several locators and wordings were corrected.

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

UNCONFIRMED	Rests on a preliminary result that hasn’t been confirmed.
PARTLY TRUE	Part of the claim holds up and part doesn’t.
TRUE	The evidence supports the claim.
CONTEXT	A question or aside rather than a claim. We add the facts it leaves out.

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 19, 2026 Published on factchecked.science after a full check against the sources. Changes from the infographic: added our verdicts on five of the review’s claims, and the source line now gives the review’s real title, “Linking solar magnetism, extreme solar particle events and stellar superflares”, with its volume and DOI. “~100× the peak particle fluence of the 2003 Halloween event” misread the review: its hundredfold compares the biggest ancient events with strong events measured since the 1950s, and against February 1956 it is less at the highest energies. 10^{34} erg is the threshold for the superflare rates; the review elsewhere puts the start of superflares at about 10^{33} erg, and “10–1,000 times larger” isn’t in the review. The ice core is now credited with beryllium-10 and chlorine-36 rather than carbon-14, and the review’s confidence that the events are solar is restored. The timeline is redrawn to scale; the original put 1859 nearly 600 years too late. “No trace in the isotope record” became no detectable event, with the carbon-14 offset one study reports. The garbled exponents in section 3 are restored (a few × 10^{32} erg on the Sun, 10^{34}–10^{35} erg on active stars), the review’s own label, “speculative but physically plausible”, is kept, and the particle mismatch is put down to acceleration, topology and transport together; “a flare’s X-ray class alone does not predict its particle output” gave way to the review’s statistical wording. “Ordinary X1–X10 flares” became strong but not extreme ones, with superflares still causing an event only rarely, and the study behind hypothesis (iii) is identified as co-written by two of the authors. The rate chart is redrawn with the published range, 130 to 6,000 years, and the review’s caveat that the stellar and X-ray estimates aren’t directly comparable; “about 1 per 1,500 years” now notes that it counts two candidates; and the note that superflares are much more frequent was dropped, because it holds only for the authors’ rate. In the energy chart, typical large flares reach 10^{32} erg, not 10^{31}; the Carrington exponent, which reads as 10^{32} on the infographic, is 10^{33} in the review; a row for an event of about 10^{33} erg some 9,400 years ago, which has no basis in the review, is replaced by the great sunspot of 1947; the superflare row starts at 10^{33} erg; every bar is placed at its value; and the note that superflares sit far above any solar event became the review’s own two readings, by which the largest solar estimates reach or approach the superflare range. “Disable much of the satellite fleet” now quotes the authors’ “instantly destroyed”, and “Worst-field periods” became weak-field periods. The slogans and the image generator’s typos were dropped.

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