Fact-Checked Science

PAPER CHECK · SPACE WEATHER

# Earth's oxygen ions dominated May 2024's ring current, a record; the air lost almost none

Using Japan's Arase satellite, twenty researchers report that heavy ions from Earth's own upper atmosphere, mostly oxygen, carried over 85% of the ring current's energy near the peak of the May 2024 superstorm, a share no earlier measurement of the ring current had seen, while the dense solar wind supplied under 15% [1 Abstract][1 §3 ¶6]. S0 News of November 13 presented the paper as an "oxygen leak" that had begun because Earth's field is weak [2 00:02:22–00:02:44]. The paper measures oxygen ions lifted into near-Earth space and held there by the field, credits the storm to the Sun and says nothing about the field's decline. By our estimate the storm sent about 930 tonnes of oxygen to space, and 8,000 on generous assumptions: as much as the air's measured oxygen decline, which comes mainly from burning fossil fuels, removes in 1 to 8 seconds.

By Fact-Checked Science · Published November 13, 2026 · Updated November 14, 2026

OUR ANALYSIS marks our own reasoning and calculations, among them the oxygen budget, the checks of the paper's numbers against the public records, the scaling of escape with the field's strength and our compilation of earlier measurements, and the verdicts are our assessment. Everything else comes from the numbered sources. For the paper [1], read in full, § numbers its sections in order and ¶ a paragraph within a section; Fig. gives a figure and Fig. S a figure of its supplement. For the episode [2], times are those of its transcript.

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## A record share of Earth's oxygen in the ring current, and no leak to speak of

OUR ASSESSMENT

**≈90%**
of the ring current's energy carried by heavy ions from Earth's upper atmosphere as Arase passed through just after the storm's peak; in the only two earlier storms this deep that were measured, oxygen reached at most 59% and about 65–75% [1 §2.2 ¶5][1 §1 ¶5]

**30–170 t**
our rough estimate of the oxygen ions the ring current held at the storm's peak, from the storm's size and the paper's shares and energies (our analysis)

**8 seconds**
how long the air's measured oxygen decline, mainly from burning fossil fuels, takes to remove as much oxygen as a generous bound on what the storm sent to space, 8,000 tonnes (our analysis) [30]

THE CLAIMS

TRUE

*"In situ measurements of ring current ions by the Arase satellite demonstrate an unprecedented dominance of heavy ions originating from the Earth during the May 2024 super geomagnetic storm"*

The paper's abstract [1 Abstract]

Heavy ions from Earth, oxygen above all, carried about 90% of the ring current's energy on Arase's pass just after the storm's peak and about 70% eight hours later; hydrogen carried under 10% on the first of those passes [1 §2.2 ¶5][1 §2.2 ¶9]. In the only two earlier storms this deep with such measurements, oxygen reached at most 59% in 1986 and about 65–75% in 1991 [1 §1 ¶4–5][5 Abstract]. Oxygen-rich ring currents in great storms were known [9 Abstract], and the plasma sheet behind the ring current held over 90% oxygen in October 2003 [10 Abstract]; what is new is a share this high in the ring current, in a storm this size. It rests on two passes, on one side of Earth. See section 3.

TRUE

*"The solar wind, another expected source of ions, contributes little to the energy density of the ring current."*

The paper's abstract, which also says "despite the high solar wind density" [1 Abstract]

Hydrogen and helium, the ions the solar wind brings, carried under 14% of the energy on the pass after the peak and under 32% eight hours later, upper limits since some of the hydrogen is Earth's [1 §2.2 ¶9]; the paper sums it up as under 15% [1 §3 ¶6]. The wind was dense, up to 57 particles per cm$^3$ and about 20 on average during that pass (our check of NASA's OMNI data) [21], and a simulation of a storm in November 2003 had suggested that such a wind keeps its share of the ring current at about 30–60% [1 §1 ¶7][11]. Hydrogen above Arase's 184 keV per charge isn't counted. See section 2.

TRUE

*"This observational evidence highlights the critical role of ion supply processes from the Earth and transport in the magnetosphere in developing the ring current for the super geomagnetic storm."*

The paper's abstract [1 Abstract]

The ions' kinds give away their source: singly and doubly charged oxygen and molecular ions come from Earth's ionosphere [1 §2.2 ¶5][1 §2.2 ¶7]. The paper credits the storm's energy to "fast solar wind (>700 km s$^{-1}$)" with the interplanetary field mostly southward, and says the Sun's strong radiation, which "heats the ionosphere", made the oxygen's outflow easier [1 §2.1 ¶1–2]; the records of Kyoto [20], NASA [21] and GFZ [22] bear out its numbers (our check). The route the oxygen took, slow outflow from the dayside or injection from the nightside aurora, is the authors' inference, left to future missions [1 §3 ¶3–4]. See section 4.

MISREAD

*"Earth's oxygen has started leaking." … "And the data is in from the May 2024 solar supererstorm on this exact oxygen leak. It was unprecedented." … "The oxygen leak would begin to show itself, and now it has."*

The episode's opening [2 00:00:24–00:00:26], top story [2 00:02:22–00:02:27] and list of predictions [2 00:03:00–00:03:05], under the link label "EARTH OXYGEN LEAK Begins"; "supererstorm" is the transcript's error for "superstorm"

The paper measured oxygen ions lifted from the upper atmosphere and held 2 to 6 Earth radii out by Earth's field, not oxygen leaving Earth; it gives no escape rate, and its "unprecedented" is about their share of the ring current's energy [1 Abstract][1 §2.2 ¶5]. Nothing began in 2024: oxygen flows out of the upper atmosphere all the time and far faster in storms, as satellites have measured since the 1980s [23 Abstract][25 p. 721], and oxygen has carried great storms' ring currents before [5 Abstract][9 Abstract]. By our estimate the storm sent about 930 tonnes of oxygen to space, and 8,000 on generous assumptions; even a deliberately extreme ceiling, 160,000 tonnes, is 7,400 times too small to show in the air's oxygen record (our analysis). See sections 5 and 6.

FALSE

*"As viewers of this channel already know, the sun tossed a punch our way, but it wasn't massive. The problem is that our magnetic field is weak, shifting in the midst of an excursion reversal."*

The episode [2 00:02:33–00:02:44]

The paper credits the storm to "multiple coronal mass ejections from the Sun" and fast, dense solar wind, and says nothing about the strength or decline of Earth's own field [1 §2.1 ¶1]. The punch was among the space age's biggest: SYM-H fell to −518 nT, second only to March 1989 since 1981 [1 §1 ¶1][20], Kp reached 9 [22] and the wind's pressure 58 nPa [21] (our check). The one weakened field in the paper, about 40% below the standard model near Earth, was the ring current's own doing [1 §2.3 ¶2][1 §1 ¶9]. The rest repeats "An excursion is under way now", False on our guide to the field and our review of November 9: the dipole is about 9% weaker than in 1840 [41 p. 1]. See section 8.

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1 · THE PAPER

## Arase measured which ions carried the ring current as the May 2024 superstorm peaked

Twenty researchers from Japanese universities, JAXA, the University of New Hampshire and Kyung Hee University, among them the people who built and run Arase's ion, magnetic-field and electron instruments, report what the satellite saw in the ring current during the storm of 10–11 May 2024 [1]. The paper is peer reviewed and open access under CC BY 4.0; we read it in full, with its figures and supplement. S0 News linked it on November 13, 2026 [2].

### What the authors did

Arase carries two ion mass analysers, which sort ions by their energy per charge and their mass per charge. MEP-i, from 9.6 to 184.2 keV per charge, tells apart hydrogen, two kinds of helium, singly and doubly charged oxygen and a group of molecular ions ($N_2^+$, $NO^+$ and $O_2^+$); LEP-i covers lower energies [1 §4.1 ¶2][1 §4.1 ¶6]. The authors turned the measured ions into energy densities along three passes through the ring current on the dusk side, where ions injected from the night side drift past, and compared each kind's share [1 §2.2 ¶2][1 §4.2]. Arase also measured the magnetic field and high-energy electrons [1 §2.3 ¶2][1 §3 ¶2].

### The storm and the passes

Several coronal mass ejections drove the storm [1 §2.1 ¶1][18 Abstract]. SYM-H, a one-minute measure of the ring current's effect on the field at the ground, fell to −518 nT at 02:14 UT on 11 May, second only to March 1989 since the index began in 1981 [1 §1 ¶1][20]. Arase made its first pass as the storm began, its second 22 minutes after that minimum and its third eight hours later (table). The authors declare no competing interests [1 Competing interests] and list their public data and the code for their figures [1 Data availability][4].

Arase's three passes through the ring current

| PASS | TIME (UT) | SYM-H DURING THE PASS | EARTH'S HEAVY IONS | SOLAR WIND'S IONS, AT MOST |
|---|---|---|---|---|
| 1 | 16:48–18:54, 10 May; the shock arrived about 17:06 | −86 to +88 nT | A small share: hydrogen dominated, "as normally observed" | — |
| 2 | 02:36–04:09, 11 May | −439 to −353 nT | About 90% | Under 14% |
| 3 | 10:54–13:40, 11 May | −357 to −251 nT | About 70% | Under 32% |

Times and shares: [1 §2.2 ¶4–5][1 §2.2 ¶9]. SYM-H: Kyoto's provisional one-minute values, our check [20]. The solar wind's share counts all hydrogen and helium as its own.

**In the authors' words** $O^+$ is singly charged oxygen; Orbits 2 and 3 are the passes after the storm's peak.

> "Terrestrial-origin ions ($O^+$, $O^{++}$, and molecular ions) became overwhelmingly dominant during Orbits 2 (∼90%) and 3 (∼70%), far exceeding the increase in solar wind-origin ions, even though the high-density solar wind was expected to supply a large amount of $H^+$ into the ring current"
>
> Kitamura et al. (2026) [1 §2.2 ¶5]

> "As the first opportunity to our knowledge to provide observational evidence on this issue, here, we report in situ observations of the ring current ions during the May 2024 super geomagnetic storm"
>
> Kitamura et al. (2026) [1 §1 ¶9]

> "$O^+$ below these energies in the near-Earth plasma sheet and the transport pathway of $O^+$ to that region will be important observational subjects for future satellite missions."
>
> Kitamura et al. (2026) [1 §3 ¶3]

2 · EARTH'S IONS

## Oxygen from Earth's upper atmosphere carried the ring current; the solar wind's ions, at most 14%

An ion's kind gives away where it came from. The solar wind brings hydrogen and fully ionized helium; Earth's ionosphere supplies singly and doubly charged oxygen, nitrogen and molecular ions, and hydrogen too [1 §1 ¶3][1 §2.2 ¶9].

EARTH'S HEAVY IONS, PASS 2
**≈90%**
of the energy: oxygen, doubly charged oxygen and molecular ions [1 §2.2 ¶5]

HYDROGEN AND HELIUM, PASS 2
**<14%**
an upper limit on the solar wind's ions, since some of the hydrogen is Earth's [1 §2.2 ¶9]

SOLAR-WIND DENSITY
OUR ANALYSIS
**57 cm$^{-3}$**
at its highest, at 20:05 UT on 10 May; about 20 on average during pass 2 (NASA's OMNI data) [21]

### Where, and how much

Oxygen's energy peaked 2.5 to 3 Earth radii from Earth's centre [1 §3 ¶6], about 9,600–12,700 km above the equator by our conversion. Inside 2.5 Earth radii doubly charged oxygen outweighed hydrogen, and near 2 Earth radii hydrogen fell to about 1% [1 §2.2 ¶7][1 §3 ¶5]; molecular ions, which peaked on the third pass, matched hydrogen near 5.3 Earth radii [1 §2.2 ¶8]. Lower-energy ions were mostly oxygen too, but near oxygen's peak on pass 2 they carried under 1% of the energy [1 §2.2 ¶6]. The pattern held along the whole pass and was "neither a local nor a short-lived (<1 hour) phenomenon" [1 §2.2 ¶5].

### What the measurement leaves out

MEP-i counts ions from 9.6 to 184.2 keV per charge; the authors argue that each kind's energy sits around the middle of that range, "particularly in Orbits 2 and 3" [1 §2.2 ¶3]. Nitrogen is counted with oxygen, at about 30% of it or less [1 §4.1 ¶3]. Hydrogen above the range's top isn't counted, and the passes saw one side of Earth. Earlier missions used other ranges, 1–310 keV per charge in 1986 and 40–420 in 1991 [5 Abstract][1 §1 ¶5].

OUR ANALYSIS

### Could the caveats reverse it?

For the solar wind's ions to have carried even a third of the energy on pass 2, hydrogen above 184 keV per charge, which isn't counted, would need about twice the energy that all the hydrogen and helium carried inside the range (our arithmetic, from the paper's under 14%) [1 §2.2 ¶9]. The authors' argument that each kind's energy sits mid-range holds best for oxygen [1 §2.2 ¶3][1 Fig. 3]: a check made inside the range can't show what lies above it. But even if hydrogen's energy flux stayed level above 184 keV, the solar wind's ions would reach at most about 17% of the energy counting up to 300 keV, about 27% up to 1,000 keV, and a third only if the level ran on to about 2,000 keV (our arithmetic, with hydrogen under 10% inside the range) [1 §2.2 ¶9]. So the caveats could move the shares by some points, not turn them round. The night and dawn sides of the ring current were not measured; the paper chose the dusk side because MEP-i's Normal-mode data, which the analysis needs, were available near the magnetic equator there, and because ions arriving from the night side drift past it [1 §2.2 ¶2].

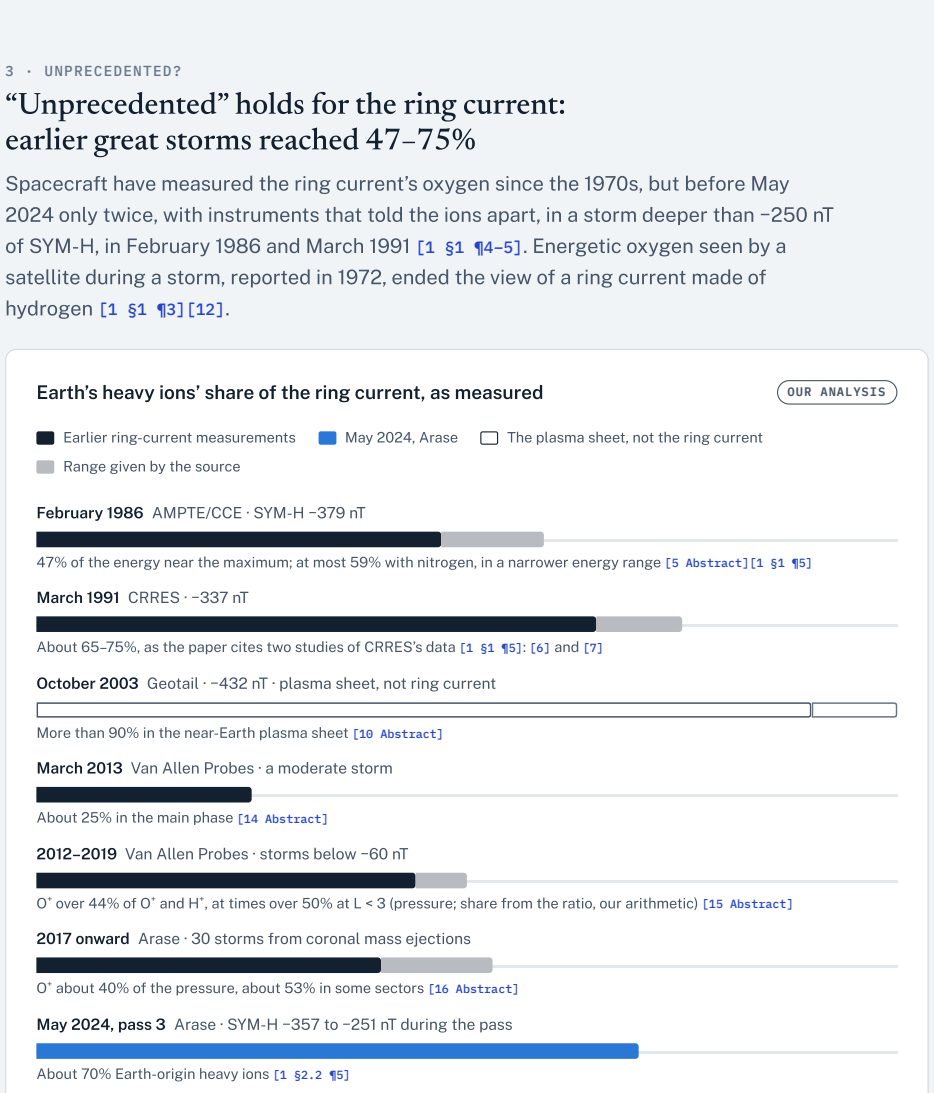
3 · UNPRECEDENTED?

## "Unprecedented" holds for the ring current: earlier great storms reached 47–75%

Spacecraft have measured the ring current's oxygen since the 1970s, but before May 2024 only twice, with instruments that told the ions apart, in a storm deeper than −250 nT of SYM-H, in February 1986 and March 1991 [1 §1 ¶4–5]. Energetic oxygen seen by a satellite during a storm, reported in 1972, ended the view of a ring current made of hydrogen [1 §1 ¶3][12].

Earth's heavy ions' share of the ring current, as measured

OUR ANALYSIS



Our compilation of published values; no figure is reproduced. The measures differ: energy density, energy content or pressure, over different energy ranges, and the 2024 shares count all of Earth's heavy ions where the earlier ones count mostly oxygen and nitrogen, so the rows compare only roughly. SYM-H values are Kyoto's provisional ones [20]. The table is hosted as a CSV file in section 9.

### What was known

A 1999 review: "During intense magnetic storms, the $O^+$ abundance increases dramatically, resulting in a rapid intensification of the ring current and an $O^+$ dominance around storm maximum." [9 Abstract] In 67 storms of the 1980s, oxygen's share near the peak grew with the Sun's ultraviolet output and with the storm's size, and oxygen outweighed hydrogen in four [8 Abstract]. In quieter years oxygen carried from a few per cent to about 10% on average [13 Abstract].

### Two expectations for a bigger storm

One extrapolated from 1986 and 1991, and from the plasma sheet of October 2003, where oxygen held over 90% of the energy and its observers estimated the ring current to be as oxygen-rich, to a still larger oxygen share [1 §1 ¶6][10 Abstract]. The other came from a simulation of November 2003: with a dense solar wind, its ions might keep about 30–60% of the ring current [1 §1 ¶7][11]. Arase's passes, with the solar wind measured at the same time, decide between them for one storm [1 §1 ¶8–9].

OUR ANALYSIS

### What is new, and what isn't

New: a heavy-ion share of about 90% in the ring current itself, beyond every earlier measurement we found, in the second-deepest storm on SYM-H since 1981, with the dense solar wind measured alongside [1 §2.2 ¶5][1 §1 ¶1]. Not new: oxygen in the ring current, reported in 1972 [12]; oxygen carrying great storms' ring currents near their peaks, as in 1986 and 1991 [5 Abstract][1 §1 ¶5]; and a plasma sheet over 90% oxygen, in October 2003 [10 Abstract]. So "unprecedented" is a fair word for what was measured, and it describes a share, not an amount.

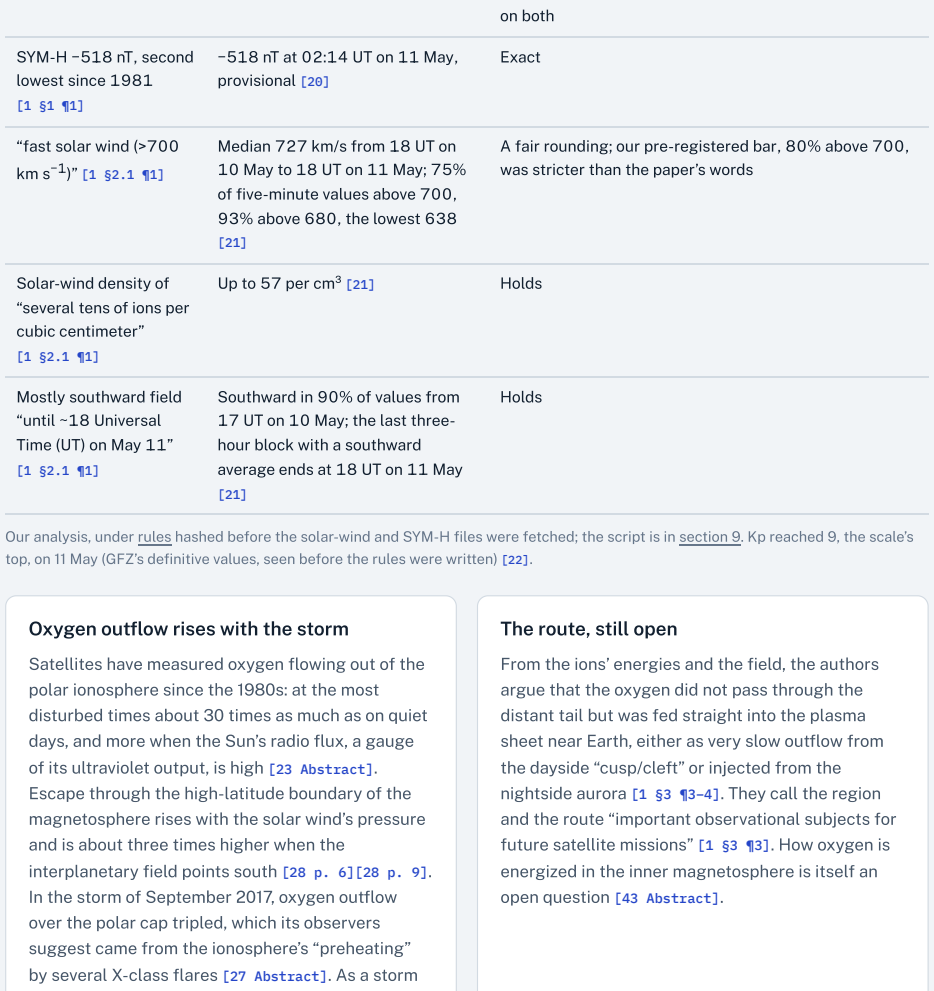
4 · WHAT DROVE IT

## The Sun's storm supplied the energy, and Earth's ionosphere the oxygen

The paper credits the storm's energy to the solar wind and the oxygen to outflow from the ionosphere, made easier by the Sun's strong radiation [1 §2.1 ¶1–2]. We checked its numbers against the public records, under rules written before we fetched the solar-wind and SYM-H data (our analysis).

The storm, and when Arase passed through the ring current

OUR ANALYSIS



Drawn by Fact-Checked Science from public data. SYM-H: provisional one-minute values of the World Data Center for Geomagnetism, Kyoto, drawn as six-minute lows and highs; we thank the WDC and the observatories that supply its data [20]. Interplanetary field (north–south part, GSM) and flow pressure: NASA's OMNI five-minute data, shifted to the bow shock [21]. The passes are the paper's; its Fig. 1 shows the same quantities [1 §2.2 ¶5][1 Fig. 1].

The paper's numbers about the storm, checked

| THE PAPER SAYS | THE RECORDS SHOW | RESULT |
|---|---|---|
| F10.7 above 200 on 7 May; 223.4, 213.7 and 221.8 on 10–12 May [1 §2.1 ¶2] | 203.6; 223.4, 213.7 and 221.8 [22] | Exact; the values for 10–12 May had been seen before the rules were written, 7 May's had not |
| Yearly F10.7 peaks of 181.1 (2001), 145.9 (2014) and 191.6 (2024) [1 §2.1 ¶2] | OMNI's series: 181.1, 145.9 and 191.6; the observatory's own, 184.4, 146.2 and 191.2 [21][22] | Exact on OMNI's series, though the paper names Canada's National Research Council as its source [1 Data availability]. Our pre-registered test used the observatory's file and missed for 2001; 2024 is highest on both |
| SYM-H −518 nT, second lowest since 1981 [1 §1 ¶1] | −518 nT at 02:14 UT on 11 May, provisional [20] | Exact |
| "fast solar wind (>700 km s$^{-1}$)" [1 §2.1 ¶1] | Median 727 km/s from 18 UT on 10 May to 18 UT on 11 May; 75% of five-minute values above 700, 93% above 680, the lowest 638 [21] | A fair rounding; our pre-registered bar, 80% above 700, was stricter than the paper's words |
| Solar-wind density of "several tens of ions per cubic centimeter" [1 §2.1 ¶1] | Up to 57 per cm$^3$ [21] | Holds |
| Mostly southward field "until ~18 Universal Time (UT) on May 11" [1 §2.1 ¶1] | Southward in 90% of values from 17 UT on 10 May; the last three-hour block with a southward average ends at 18 UT on 11 May [21] | Holds |

Our analysis, under rules hashed before the solar-wind and SYM-H files were fetched; the script is in section 9. Kp reached 9, the scale's top, on 11 May (GFZ's definitive values, seen before the rules were written) [22].

### Oxygen outflow rises with the storm

Satellites have measured oxygen flowing out of the polar ionosphere since the 1980s: at the most disturbed times about 30 times as much as on quiet days, and more when the Sun's radio flux, a gauge of its ultraviolet output, is high [23 Abstract]. Escape through the high-latitude boundary of the magnetosphere rises with the solar wind's pressure and is about three times higher when the interplanetary field points south [28 p. 6][28 p. 9]. In the storm of September 2017, oxygen outflow over the polar cap tripled, which its observers suggest came from the ionosphere's "preheating" by several X-class flares [27 Abstract]. As a storm develops, the plasma sheet that feeds the ring current shifts from solar-wind ions to ionospheric ones, oxygen among them [17 Abstract].

### The route, still open

From the ions' energies and the field, the authors argue that the oxygen did not pass through the distant tail but was fed straight into the plasma sheet near Earth, either as very slow outflow from the dayside "cusp/cleft" or injected from the nightside aurora [1 §3 ¶3–4]. They call the region and the route "important observational subjects for future satellite missions" [1 §3 ¶3]. How oxygen is energized in the inner magnetosphere is itself an open question [43 Abstract].

OUR ANALYSIS

### The storm weakened the field near Earth, not the other way round

The only weaker field in the paper is the storm's own: near 3 Earth radii the field was about 40% below the standard model, IGRF-14, because the oxygen-rich ring current's pressure, above the magnetic pressure near Earth, deformed it [1 §2.3 ¶2][1 §3 ¶6]. Radiation-belt electrons nearly vanished beyond 3.5 Earth radii, which the paper calls consistent with their drifting out through the deformed field [1 §3 ¶1–2][1 Fig. S5], a loss our check of another Arase paper also cites. A study by the same team found the same storm-made weakening out to the magnetopause, which Arase crossed at 4.96 Earth radii [19 Abstract]. Today the magnetopause sits near 10 Earth radii [40 p. 3669], and even during a reversal of the field, under average solar conditions, it would come no closer than about 5 [40 p. 3670]: this storm brought it there.

5 · HELD, NOT LOST

## The paper measured oxygen held near Earth, not oxygen leaving it

The ring current is an electric current carried by ions "trapped by the geomagnetic field" 10,000–60,000 km above Earth [9 Abstract]. Arase measured those ions; it did not measure oxygen escaping to space [1 §2.2 ¶1].

### No escape measured

The paper gives energy densities and shares, not a mass, a flow or an escape rate, and its title, abstract and body never use the words "oxygen", "escape", "leak" or "atmosphere"; it writes $O^+$ and "terrestrial-origin" ions (our count) [1].

### Where the ions go

Near Earth, charge exchange with the hydrogen of the outer atmosphere removes 30–60 keV oxygen "within the timescale of the main phase (~10 hours)" [1 §3 ¶5]; the products are fast neutral atoms [9 Abstract]. Other ions drift out through the dayside magnetopause [1 §3 ¶1], a route that took at least 23% of the ring current's fast decay in one storm [44 Abstract]. The paper does not say how much of the oxygen left Earth.

### Nothing about the field's decline

The standard model of Earth's field, IGRF-14, appears only as the baseline for the storm's 40% dent [1 §2.3 ¶2]. The words excursion, reversal, pole, dipole, weakening and decline do not appear in the text (our count) [1].

### Nothing new in kind

Oxygen has flowed out of the ionosphere and into the magnetosphere for as long as it has been measured, more in storms [23 Abstract][9 Abstract]. What May 2024 showed is how much of a great storm's ring current that oxygen can carry [1 §3 ¶6].

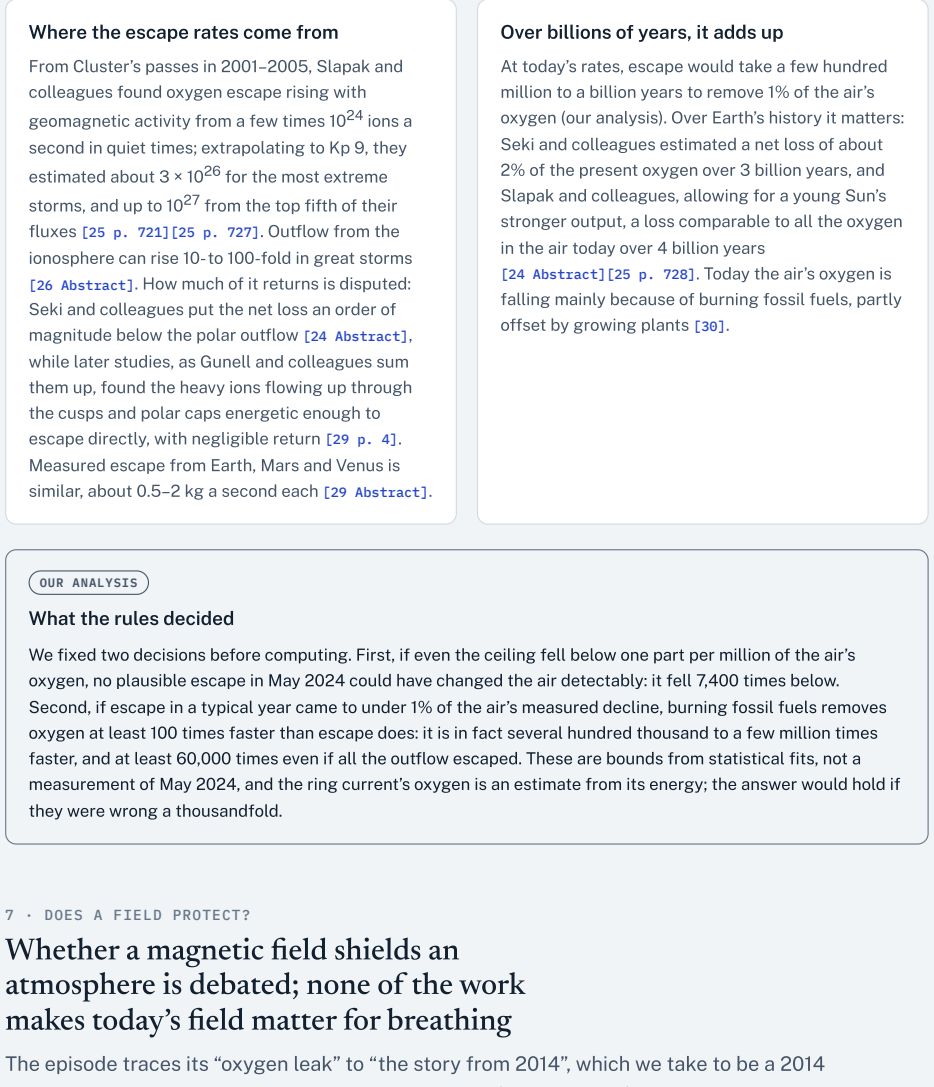
6 · HOW MUCH OXYGEN

## Even counted generously, the storm's oxygen loss was far too small to show in the air

To put the episode's "leak" on a scale, we bounded how much oxygen the storm could have sent to space, under rules written before any number was computed, and set it beside the air's oxygen and its measured decline [30]. Our review of the episode uses these numbers for its sentence "It doesn't make it impossible to breathe down at the ground, but it does have an effect" [2 00:02:02–00:02:06], which it rates Misleading.

How much oxygen, on a scale of a million billion

OUR ANALYSIS



Our analysis. Escape: Slapak and colleagues' fit of escape against Kp, from Cluster's measurements of 2001–2005, applied to GFZ's definitive Kp [25 p. 721][22]; the ring current: from its energy, by the standard relation between the storm's field at the ground and the ions' total energy, with the paper's shares and energies [1 §2.2 ¶5][1 §2.2 ¶10]; those energies split the ions' energy in half and are not an ion's average energy, so the upper end takes the average as 0.69 of them, as for a thermal (Maxwellian) spectrum. The air: the Scripps $O_2$ Program's inventory and its four stations' trend for 2016–2025 [30].

The storm's oxygen, three ways, against the air

| ESTIMATE | OXYGEN | BELOW THE RECORD'S SMALLEST CHANGE | THE AIR'S DECLINE REMOVES AS MUCH IN |
|---|---|---|---|
| **Central: the rise of escape with Kp measured in 2001–2005, extended to the storm's Kp of up to 9, over 3.5 days** | 930 t | 1.3 million times | 1 second |
| **Generous: $10^{27}$ ions a second for 3.5 days, Slapak and colleagues' upper estimate for Kp 9, extrapolated from the top fifth of their fluxes** | 8,000 t | 150,000 times | 8 seconds |
| **Ceiling: ten times that, for a week** | 160,000 t | 7,400 times | 2.7 minutes |
| **Held in the ring current at the peak, not lost** | 30–170 t | 7–45 million times | Under a fifth of a second |

Our analysis. The smallest change: one part per million of the air's oxygen, 1.2 billion tonnes [30], a deliberately generous threshold of our own. The decline: 26 parts per million a year in 2016–2025, 31 billion tonnes of oxygen [30]. Escape rates: [25 p. 721][25 p. 727].

### Where the escape rates come from

From Cluster's passes in 2001–2005, Slapak and colleagues found oxygen escape rising with geomagnetic activity from a few times $10^{24}$ ions a second in quiet times; extrapolating to Kp 9, they estimated about $3 \times 10^{26}$ for the most extreme storms, and up to $10^{27}$ from the top fifth of their fluxes [25 p. 721][25 p. 727]. Outflow from the ionosphere can rise 10- to 100-fold in great storms [26 Abstract]. How much of it returns is disputed: Seki and colleagues put the net loss an order of magnitude below the polar outflow [24 Abstract], while later studies, as Gunell and colleagues sum them up, found the heavy ions flowing up through the cusps and polar caps energetic enough to escape directly, with negligible return [29 p. 4]. Measured escape from Earth, Mars and Venus is similar, about 0.5–2 kg a second each [29 Abstract].

### Over billions of years, it adds up

At today's rates, escape would take a few hundred million to a billion years to remove 1% of the air's oxygen (our analysis). Over Earth's history it matters: Seki and colleagues estimated a net loss of about 2% of the present oxygen over 3 billion years, and Slapak and colleagues, allowing for a young Sun's stronger output, a loss comparable to all the oxygen in the air today over 4 billion years [24 Abstract][25 p. 728]. Today the air's oxygen is falling mainly because of burning fossil fuels, partly offset by growing plants [30].

OUR ANALYSIS

### What the rules decided

We fixed two decisions before computing. First, if even the ceiling fell below one part per million of the air's oxygen, no plausible escape in May 2024 could have changed the air detectably: it fell 7,400 times below. Second, if escape in a typical year came to under 1% of the air's measured decline, burning fossil fuels removes oxygen at least 100 times faster than escape does: it is in fact several hundred thousand to a few million times faster, and at least 60,000 times even if all the outflow escaped. These are bounds from statistical fits, not a measurement of May 2024, and the ring current's oxygen is an estimate from its energy; the answer would hold if they were wrong a thousandfold.

7 · DOES A FIELD PROTECT?

## Whether a magnetic field shields an atmosphere is debated; none of the work makes today's field matter for breathing

The episode traces its "oxygen leak" to "the story from 2014", which we take to be a 2014 paper on oxygen escape during reversals of the field (our inference) [2 00:01:50–00:02:20][32 p. 94]. Whether a magnetic field protects an atmosphere at all is an open question in the literature; here is what the papers say, without picking a winner.

### The 2014 hypothesis

Wei and colleagues proposed that during reversals a weak field lets oxygen escape as it does from Mars, and that repeated reversals could lower the air's oxygen enough to contribute to mass extinctions. Their model raised escape "by 3–4 orders only if the magnetic field was extremely weak", with the dipole set to zero; the Triassic–Jurassic drop would need about $6.5 \times 10^{29}$ ions a second, a thousand times the present outflow. They called it "a possible explanation", "if this causal relation indeed exists" [32 p. 94][32 p. 96], as our check of a Permian paper also notes.

### The field as shield

Lundin and colleagues described Earth's strong dipole as "a 'magnetic umbrella'" fending off the solar wind [33 Abstract]. Blackman and Tarduno found that a magnetosphere collects more of the solar wind's mass but lets in less of its energy, so that for most of Earth's history the field still protected on balance; its future role depends on recapturing the plasma it loses [35 p. 9].

### The field as no shield

Gunell and colleagues: Earth, Mars and Venus lose about the same, and "the escape rate can be higher for magnetised planets over a wide range of magnetisations" [29 Abstract]. Egan and colleagues: for a Mars-sized planet, strengthening a weak field first raises escape, then lowers it [36 Abstract]. Gronoff and colleagues: "the paradigm of the magnetic field as an atmospheric shield should be changed" [38 Abstract]. Ramstad and Barabash: a dipole "is not required to prevent stellar wind-driven escape" and "may instead increase the rate of ion escape" [39 Abstract].

### A reversal, modelled again

Tsareva and colleagues, modelling a reversal in which a four-pole field takes over, found that it would still shield the atmosphere "from sputtering and ion pickup but not from the polar and auroral winds", and that escape would rise about 2.5 times as the field weakens, then halve at the reversal itself [37 p. 1][37 p. 10]. Their introduction also expects a reversal "geologically soon, in about 1600 years" [37 p. 1], a kind of forecast our review of when the next excursion is due weighs. Reviewing reversals and life, Glassmeier and Vogt found "no clear picture of a geomagnetic link" [34 Abstract].

OUR ANALYSIS

### Today's field, on the models that let a weaker field raise escape

The dipole is about 9% weaker than in 1840 [41 p. 1]. Where escape scales with the area of the polar caps, as polar-cap escape does in Gunell and colleagues' model [29 p. 3], that raises it by 0–10%, by the standard scalings, and moves the magnetopause about 0.3 Earth radii closer [40 p. 3669][37 p. 9]. In their full model, an Earth-like planet loses about 1.4 kg a second at today's dipole and about 1.6 at a tenth of it; near today's dipole the curve is flat, with its lowest point at about half of it, so the 9% weakening since 1840 has changed escape in that model by under 1%, slightly downward (their Fig. 2, our reading) [29 p. 1][29 p. 2]. During a storm, the storm's effect is far larger: May 2024 raised escape about eightfold for 3.5 days, and the fit's range from quiet days to Kp 9 is about 57-fold (our analysis). Over a whole year, though, the field's 0–10% adds from nothing to about 6,200 tonnes of escape, depending on the scaling and the escape rate assumed: at most about as much as eight storms like May 2024 add above the usual rate. Both are millions of times smaller than a year of the air's measured decline (our analysis, added after a fresh review). Our pre-registered decision asked for every storm factor to exceed 10, so as worded it failed, on the 8. Wei and colleagues' hypothetical rate during a reversal would be 1.8% of the air's present measured decline. Our review of the episode rates "Oxygen loss surges in reversals" Overstated; our check of a simulation study covers why "magnetized means protected" is too simple.

8 · WHAT S0 NEWS SAID

## The episode read a storm's oxygen as a leak and blamed a weak field

S0 News of November 13 led with the paper under the label "EARTH OXYGEN LEAK Begins", after recalling a story from 2014 and a video of its own; we did not see the video [2][2 00:01:50–00:02:20].

**In the episode's words** "supererstorm" is the transcript's error for "superstorm".

> "And the data is in from the May 2024 solar supererstorm on this exact oxygen leak. It was unprecedented. They say it wasn't the solar wind delivering the huge amount of oxygen."
>
> S0 News, November 13 [2 00:02:22–00:02:33]

> "As viewers of this channel already know, the sun tossed a punch our way, but it wasn't massive. The problem is that our magnetic field is weak, shifting in the midst of an excursion reversal."
>
> S0 News, November 13 [2 00:02:33–00:02:44]

> "The oxygen leak would begin to show itself, and now it has."
>
> S0 News, November 13 [2 00:03:00–00:03:05]

TRUE

### Not the solar wind's oxygen

"They say it wasn't the solar wind delivering the huge amount of oxygen" [2 00:02:27–00:02:33] matches the paper: the ring current's ions came from Earth, and the solar wind's made up under 15% [1 Abstract][1 §3 ¶6]. "Huge" fits the ring current, where oxygen's energy density rose many times over [1 §2.2 ¶5]; as a mass it was about 30–170 tonnes (our analysis, section 6). The solar wind was never a candidate source of the oxygen: the question was its hydrogen and helium [1 §1 ¶7].

FALSE

### An excursion is under way now

"shifting in the midst of an excursion reversal" [2 00:02:41–00:02:44] repeats a claim our guide to the field and review of November 9 rate False: an excursion is a spell when the field's pole strays far from the geographic pole, with the dipole near half today's strength [42 §4.4], and the dipole is about 9% weaker than in 1840 [41 p. 1]. It is the second half of claim 5.

OUR ANALYSIS

### "The sun tossed a punch our way, but it wasn't massive"

The paper describes a storm built by several coronal mass ejections from the Sun, driven by fast, dense solar wind under a strongly southward field, and an outflow eased by the Sun's radiation [1 §2.1 ¶1–2]; the active region behind it "exhibited extraordinary activity" in a pileup of eruptions [18 Abstract]. The episode has a point in part: no superflare was involved, since the ejections behind the storm followed flares no larger than X5.8, as our check of the May 2024 aurora found; and the paper on the storm's "comparatively weak" effects, which S0 News linked on November 2, offers a reason for them, unconfirmed: a small jump in the solar wind's electric field at the fronts of its ejections (our check of that paper). But that paper still calls this the "2nd most intense geomagnetic storm in space age" [45 Abstract], which our check rated Partly true: second on SYM-H since 1981, sixth on hourly Dst since 1957. The same claim, that a weak field rather than the Sun explains the storm's effects, is "Less from the Sun does more" (False) on our review of November 11 and "Needs a superflare at full field" (False) on the aurora check. Our review of the episode covers its other claims, among them the 2014 story and "Leaking oxygen makes floodwater" (False).

9 · REPEAT OUR NUMBERS

## Three scripts, the rules we wrote before running them, and their outputs

Each script downloads its inputs from their makers under a plain client name and checks them against the SHA-256 of the copies we used on November 13, 2026; run on those copies, the hosted scripts reproduced every number of our registered runs. They need only Python's standard library.

PY **oxygen_budget.py**
The oxygen budget: the air's oxygen and its measured decline at four stations, the storm's escape three ways, the ring current's oxygen, a typical year's escape and the two pre-registered decisions; reads Scripps's and GFZ's files [30][22] · 16 KB

PY **storm_numbers.py**
The paper's numbers about the storm, against GFZ's Kp and F10.7 [22], Kyoto's provisional SYM-H [20] and NASA's OMNI data [21]; it reports no real-time SYM-H value, can write the series our storm chart draws and, since the fresh review, works out how much hydrogen above Arase's range could add · 15 KB

PY **field_scaling.py**
How much a 9% weaker dipole could change escape, by the standard scalings, against the storm factors and, since the fresh review, against the storm's amount over a year; reads the budget's output [40 p. 3670] · 5 KB

JSON **oxygen-budget.json**, **storm-numbers.json** and **field-scaling.json**
Every number from our analyses on this page, as the scripts write them · 10 KB in all

CSV **ring-current-composition.csv**
Our compilation of the measured heavy-ion shares in section 3, with each source and its energy range · 3 KB

TXT **RULES_oxygen_budget.txt**, **RULES_paper_numbers.txt** and **RULES_field_scaling.txt**
The rules, written and hashed before the numbers they govern were computed, with what we had already seen · 11 KB in all

TXT **analysis-log.txt**
The SHA-256 of the rules, the inputs, the scripts and the outputs, in the order they were made, and what was added after the registered runs · 8 KB

### Run it

`python3 oxygen_budget.py` and `python3 storm_numbers.py` download their inputs into `ring-current-oxygen-data` in the current folder (about 7 MB), say whether each matches our copy and write their JSON files there; `python3 field_scaling.py` then reads the budget's file. Scripps adds months and GFZ's Kp file grows daily, so later copies differ from ours; the values we used for 2016–2025 and May 2024 should not change.

10 · LIMITS

## What this check could and couldn't see

### One storm, one side

The paper's shares come from three passes on the dusk side of one storm [1 §2.2 ¶2]; the night and dawn sides were not measured.

### Comparisons across instruments

Earlier missions measured over other energy ranges and in other quantities, so the comparison in section 3 is rough [1 §1 ¶5][5 Abstract].

### No measured escape for May 2024

We found no measurement of how much oxygen left Earth during the storm. Our numbers are bounds from fits to Cluster's data of 2001–2005, extrapolated to Kp 9 as their authors did [25 p. 726].

### No Arase data on this page

The mission's rules ask users to contact its teams before any publication made from the data and forbid redistributing the files [3], so we used the paper's numbers and charted only public data and our own estimates.

### Abstracts and records

Of the earlier studies, many were read only as abstracts, and four as records, with their numbers as the paper cites them [6][7]; the paper itself we read in full, in Europe PMC's text and in its typeset version [1].

### What would change these verdicts

01
Measurements of the same storm's ring current on the night or dawn side with a much smaller share of Earth's ions, which would qualify claim 1.

02
A published count of the solar wind's ions above 184 keV per charge large enough to give them a third or more of the energy, which would change claim 2.

03
A measurement of oxygen escape in May 2024 above our ceiling, which would change the numbers in section 6, though not what the paper says.

OUR ANALYSIS

**Bottom line: a careful paper on a record share, read as a leak that it doesn't describe.**

Arase found that oxygen and other heavy ions from Earth's upper atmosphere carried about 90% of the ring current's energy as the May 2024 superstorm peaked, a share no earlier measurement had seen, while the dense solar wind's ions carried under 15% [1 §2.2 ¶5][1 §3 ¶6]. The paper credits the storm to the Sun and the oxygen to outflow from the ionosphere, and says nothing about the strength or decline of Earth's field [1 §2.1 ¶1–2]. That oxygen was held near Earth, not lost. By our estimate the storm sent about 930 tonnes of oxygen to space, and 8,000 on generous assumptions: as much as the air's measured oxygen decline, which comes mainly from burning fossil fuels, removes in 1 to 8 seconds (our analysis) [30].

## Related checks

FALSE More auroras from less solar input? The Disaster Cycle, Fact-Checked

MISLEADING Venus and Mars The Disaster Cycle, Fact-Checked

## Sources

Bracketed numbers refer to this list. For the paper [1], read in full from its text in Europe PMC and its typeset version, § numbers its sections in order (§1 Introduction; §2.1–2.3 the three parts of Results: the storm, the ion measurements and the field; §3 Discussion; §4.1–4.3 Materials and Methods), ¶ a paragraph within a section (the same in both versions wherever this page cites one), Fig. a figure and Fig. S a figure of its supplement. For the episode [2], times run from the first transcript line quoted to the last, rounded down to the second. For the other sources, p. gives a page, § a section and Abstract the abstract; where only an abstract or a record was read, the entry says so. L is the McIlwain L shell, the distance in Earth radii at which a field line crosses the magnetic equator. Times are UT. Links checked November 13, 2026.

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METHOD

## How this was checked

On November 13, 2026, we read the paper in full, from its text in Europe PMC, with its five figures and its supplement, and later that day from its typeset version [1], and checked every statement this page makes about it against both; we checked the episode's words, from its transcript, against the paper [2]. We set the paper's "unprecedented" beside twelve earlier studies of the composition of the ring current and the plasma sheet, its account of where the ions came from beside the literature on oxygen outflow and escape, and its numbers about the storm beside the public records of Kyoto's World Data Center [20], NASA's OMNI [21] and GFZ [22]. Of the page's 45 sources, ten papers were read in full, 22 as abstracts and four as records only; five are cited as read for our guide to the field; six are data sets, their rules or a software record; and one is the episode itself.

The verdicts and the items tagged "Our analysis" are our own assessment, built on the cited sources. They include the oxygen budget, our estimate of the oxygen the ring current held, the checks of the paper's numbers against the data, the scaling of escape with the field's strength, our compilation of earlier measurements and our reading of what the paper and the episode do and do not say.

We ran three analyses under rules written before their results were computed: the oxygen budget, the check of the paper's numbers about the storm and the scaling of escape with the field (section 9). The field-scaling rules came after the paper's budget outputs, which they read, and the storm-number rules after GFZ's daily values for 8–14 May had been seen; analysis-log.txt says what was seen when. The hosted scripts fetch their inputs from their makers and reproduced every number of the registered runs on the same files. Two of the registered checks missed as worded, and one registered decision failed as worded; sections 4 and 7 say how. We did not analyse Arase's data, whose rules ask users to contact the instrument teams before publishing anything made from it [3], and did not run the authors' code [4]. No one we found measured how much oxygen escaped in May 2024, so our numbers bound it from statistical fits to earlier years.

After the page was built, a fresh reviewer fetched its own copy of the paper, checked every quotation, locator and source, re-ran our scripts on fresh downloads, which gave the same outputs byte for byte, and recomputed the three analyses in separate code. Its 2 must-fix, 10 should-fix and 23 minor findings led to these changes: the generous escape rate is described as the extrapolated upper estimate it is, not a measured rate; the summary gives all three of our estimates of the storm's escape; our estimate of the ring current's oxygen widens from 27–120 to about 30–170 tonnes, since the paper's energies are weighted by energy; the field's effect is set beside the storm's over a year as well as during it; the case that uncounted hydrogen could not turn the shares round rests on arithmetic; the pre-registration is described as it happened; the episode's point about the punch is conceded in part, as in our review of the episode; and about 25 smaller fixes of wording, figures and locators were made. The additions to our scripts are marked in them and in analysis-log.txt. No verdict changed.

After publication, the site's owner supplied two papers our tools had not fetched: the paper's typeset version and Gunell and colleagues' letter [1][29]. The typeset text matches Europe PMC's word for word apart from typography, so every quotation, number, figure reference and locator on this page holds; source 1 now gives the dates it prints. Gunell and colleagues' full text confirms what the page took from their abstract, except that section 6 had tied their 0.5–2 kg a second to ion outflow; it is all measured escape, and the sentence now says so. No number or verdict changed.

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**

| | |
|---|---|
| FALSE | The evidence contradicts the claim. |
| MISREAD | Cites a real source but gets wrong what it says. |
| 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**

Nov 14, 2026 Revised the day after publication: checked against two papers the site's owner supplied after publication. The paper's typeset version matches the Europe PMC text we had read, word for word apart from typography, so every quotation, number, figure reference and locator holds; source 1 now gives the dates it prints, and section 5 now says the words "oxygen", "escape", "leak" and "atmosphere" are absent from its title, abstract and body ("oxygen" appears in three titles in its reference list). Gunell and colleagues' letter, now read in full, confirms what the page took from their abstract, except that section 6 had tied the 0.5–2 kg a second to ion outflow; it is all measured escape, and the sentence now says so. Section 6 also adds its account that later studies found the oxygen ions leaving through the cusps and polar caps escape with negligible return, so the return Seki and colleagues estimated is now described as disputed; and section 7 adds its model's escape for an Earth-like planet, about 1.4 kg a second at today's dipole and 1.6 at a tenth of it, so that a weaker field changes the loss little. No verdict changed.

Nov 13, 2026 Published on Fact-Checked Science after a full check against the sources. The labels on the episode's words match our review of the same episode. A fresh review the same day changed no verdict: it led us to describe the generous escape rate as an extrapolation, give all three of our estimates of the storm's escape in the summary, widen our estimate of the ring current's oxygen to about 30–170 tonnes, compare the field's effect with the storm's over a year as well as during it, concede the episode's point about the punch in part, and make about 25 smaller fixes.

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Last updated Nov 14, 2026