TOPIC OF THE WEEK

Bracing for a flare-up

Even as Rubin and Roman scour the skies, another doomsday clock continues ticking: solar superflares. Solar flares are commonplace and generally benign. They are outbursts of light and radiation launched from regions of the Sun with intense magnetic fields, whose endpoints are marked on the solar surface by the cooler dark patches known as sunspots.

Above sunspots, the Sun's magnetic field can stretch out for tens of thousands of miles, carrying tendrils of superheated, magnetically bound plasma. The magnetic field lines store energy like stretched and twisted rubber bands — and when they snap, they can release huge quantities of plasma, called coronal mass ejections (CMEs). If a CME happens to be aimed at Earth, a geomagnetic storm will hit us days later. Thanks to the protective magnetosphere generated by Earth's molten iron core, most CMEs are harmlessly deflected.

But once in a great while, a flare hundreds or thousands of times more powerful than normal — a superflare — belches a wallop that penetrates Earth's magnetosphere.

Analysis of radiocarbon spikes preserved in the rings of ancient trees shows that in the past 10,000 years, at least six such solar storms have showered Earth. These are named Miyake events after physicist Fusa Miyake, who in 2012 reported the first such event, detected in Japanese cedar tree rings from 774 c.e. Subsequent studies uncovered another spike in 993 c.e., and then four more in the years 663, 5259, 5410, and 7176 b.c.e.

There is still much debate surrounding the exact nature of Miyake events. A paper published in October 2022 suggests that some Miyake events may be series of consecutive solar storms within a given year. But the leading explanation for these occurrences are superflares from our Sun.

To our prehistoric ancestors, these events likely went unnoticed, aside from spectacular auroral light shows at unusually low latitudes. But in modern times, CMEs from superflares pose a serious threat. They could hobble satellites, crash GPS systems, and disrupt global communications. Electrical grids could overload and take months to be rebuilt. Cellphones, laptops, and other electronic devices would survive, but many would be limited by the lack of functioning telecommunications.

Modern civilization already experienced a small dose of these consequences in 1989, when a sizeable CME glanced across Québec, frying high-voltage lines and causing widespread blackouts. The last superflare before that was the Carrington Event of 1859; the ensuing geomagnetic storm sent currents coursing through telegraph wires, setting fires in telegraph offices across the U.S.

To learn how to predict superflares, astronomers are looking not just at the Sun but also to other stars. Young, hot, massive stars that burn blue and spin quickly can generate superflares at the blazing pace of one a day. Our Sun, a yellow dwarf, is much cooler and longer lived, so superflares are relatively rare.

But how rare? In 2019, a team led by Yuta Notsu of the University of Colorado Boulder used data from NASA's Kepler space telescope and the ESA's Gaia star-mapping satellite to determine that on Sun-like stars, Carrington-size flares occur every 500 to 600 years. High-end superflares — 100 times more powerful than Carrington — arise every 2,000 to 3,000 years.

By that measure, we aren't yet overdue for another Carrington Event. But the Federal Energy Regulatory Commission is hedging its bet. In 2013, it issued Order 779 directing the North American Electric Reliability Corporation, a nonprofit power grid overseer, to develop plans for "blocking geomagnetically induced currents from entering the Bulk-Power System."

Observing superflares in other star systems also gives a dramatic sense of the threats any other life-forms in the galaxy might face. In another sobering paper that Notsu co-authored in April 2023, he and colleagues described the largest superflare and prominence ever recorded in real time using ground- and space-based telescopes — albeit in a binary star system (V1355 Orionis) unlike our Sun.

“The observed velocity of that prominence far exceeded the escape velocity of its star,” says Notsu, “indicating that the eruption was capable of becoming a CME. Such eruptions are very important for evaluating the potential effects on planetary atmospheres.”

Notsu notes that the size and speed of the ejected material — trillions of tons traveling at 3 million mph (4.8 million km/h) — shows how large CMEs can get. The V1355 Orionis event was 10 times more powerful than anything the Sun is known to have ever produced, potentially enough to strip any nearby planets of their atmospheres.

Ancient trees — like the one at right, found in the eroded banks of the Drouzet River, near the town of Gap in the southern French Alps — hold the keys to dating the most powerful solar storms. These storms, known as Miyake events, cause radiocarbon spikes to appear in the trees’ rings. Credit: Cécile Miramont

Perhaps nothing symbolizes the cosmic cycle of life and death like a supernova. These events are either the explosive final act of a massive star or a white dwarf triggered by runaway nuclear fusion. Just like asteroids and superflares, there is ample evidence that supernovae have bombarded Earth and even shaped life throughout our planet’s history.

“We are the children of supernovae,” says Brian Fields, an astronomer at the University of Illinois Urbana-Champaign. “Life would not be possible without them. The iron in your blood, the oxygen you’re breathing, the silicon in your computer, all are from supernovae that blew up long before the solar system was formed.”

While supernovae provide the building blocks of life, they can also destroy it. Being too close can mean instant incineration or lethal irradiation. Although the gamma rays supernovae produce cannot penetrate the upper reaches of our atmosphere, they can destroy our protective ozone layer through a chain of chemical reactions.

There are several types of supernovae, but it is the death throes of high-mass stars — weighing at least eight times our Sun — that spark the colossal core-collapse or type II supernovae. These supernovae produce nearly all atomic elements besides hydrogen and helium. Within our Milky Way Galaxy, two or three supernovae occur every century.

When shrouded in gas, type II supernovae become particularly potent. Months or years after the initial burst of gamma rays, superheated shock waves reverberate within the gas bubble and generate copious amounts of X-rays. Millennia later, as the blast barrels through space, it interacts with dust and radiation, producing high-energy particles called cosmic rays.

To understand the reach and frequency of these multistage killer events, scientists need more than Miyake dating. Tree-ring records go back only 15,000 years and carbon-14 dating isn't reliable after 60,000 years (too much of the sample has decayed away), so uncovering traces of nearby supernovae in the geological record requires different techniques.

In 2015, a team of scientists perfected the use of an isotope called iron-60, a byproduct of supernovae, as a powerful chronometer with a half-life of 2.6 million years, providing reliable dates up to 10 million years in the past.

"It's basically like tree rings," says Fields. "We know there were recent nearby supernovae explosions because there is a wealth of iron-60 in two specific layers on the ocean floor as well as on the Moon and in Antarctic snow. Something brought it here 3 million years ago, and another pulse 7 million years ago."

While iron-60 does an excellent job of detecting past supernovae, it can also help determine how far away they were. "The farther away you stand, the less iron-60 you intercept," says Fields. "By seeing how much is there, we can work out the distance."

Until a recent paper that Fields co-authored with principal investigator Ian Brunton, scientists deemed 10 parsecs — about 33 light-years — to be a safe enough distance for surviving supernovae. Their new research significantly expands the kill zone for gaseous type II supernovae to about 160 light-years, multiplying the affected volume of space about 125 times over.

The explosive death of a massive star 325 years ago created the Cassiopeia A supernova remnant. This composite image includes infrared data from the Spitzer Space Telescope (red), visible imagery from the Hubble Space Telescope (yellow), and X-ray data from the Chandra X-ray Observatory (green and blue). The X-rays — which pose a threat to the atmospheres of nearby planets — are emitted by gases that are caught in the expanding shock wave and heated to temperatures of up to 18 million F (10 million C). Credit: NASA/JPL-Caltech/O. Krause (Steward Observatory)

“That’s why we wrote the paper,” says Fields. “We realized that this kind of supernova can be dangerous to a much larger region than ordinary supernovae.”

Fields notes that the supernova 3 million years ago coincided with a notable megafauna die-off in the Pliocene.

According to one theory, muons may be the reason. These subatomic particles, about 200 times heavier than electrons, are produced by gamma rays. Large megafauna even half a mile (0.8 km) underwater would have been especially subject to their lethal effects. Based on iron-60 traces in seafloor sediments, astrobiologists have linked the die-off of whale-sized megalodon sharks with at least one supernova 2.6 million years ago in the Local Bubble, some 160 light-years away, at that very time.

The good news is that because supernova candidates are supermassive stars, they are also hard to miss, pumping out 100,000 times more light than the Sun. When they’re nearby, we know it, and even those shrouded in gas are brilliant in infrared wavelengths.

When this next occurs, it won’t likely be from any star we know by name today. Spica in Virgo is the nearest supermassive star likely to go supernova, and it lies some 250 light-years away — well outside the supernova danger zone.

But as our star system orbits the center of the Milky Way, it passes through our galaxy’s spiral arms every 100 million years or so. By some estimates, each passage is likely to bring Earth within 33 light-years of a supernova, leaving it potentially exposed to its devastating effects.

The inevitable collision between the Milky Way and Andromeda galaxies will create a spectacular skyscape 4 billion years in the future. Credit: NASA, ESA, Z. Levay and R. van der Marel (STScI), T. Hallas, and A. Mellinger