Schnapps judgment

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Keep looking up

The awe-inspiring night skies we enjoyed last month when a powerful solar storm struck have a more sinister side. It's time we planned for the potentially deadly outcomes. **BY ERIC TRUMP**

"What is the Sun?" asks Wes Magee. From this British poet's perspective, it's an "orange dinghy/sailing across a calm sea ... a gold coin/dropped down a drain in Heaven ... a yellow beach ball/kicked high into the summer sky ... a red thumb-print/on a sheet of pale blue paper ... a milk bottle's gold top/floating in a puddle".

From a less metaphorical view, the sun is a G-type yellow dwarf main sequence star halfway through its 10-billion-year life. Compared with other stars, such as Orion's red supergiant Betelgeuse, the sun is middling in size, but for us, it ranks as a cyclopean presence, representing 99.8% of the total mass of the solar system. That includes all the planets, moons, asteroids, comets, Tesla Roadsters and whatever else is out there. We are just dust motes dancing in the sun's glow.

The heliosphere, the sun's magnetic atmosphere, cocoons the entire solar system, protecting it from interstellar radiation. Like a hula dancer, the sun spins faster at its equator than at its poles – and faster inside than outside. Its core is a thermonuclear furnace, where the pressure is more than one million tonnes per square centimetre, and every second, 609 million tonnes of hydrogen are converted through fusion into 605 million tonnes of helium, named for the Greek sun god, Helios.

The energy resulting from that elemental conversion takes 100,000 years to rise from the sun's core to its surface. After that, it blasts off and reaches our eyes in eight minutes and 20 seconds.

Although the sun is 150 million kilometres away, it bathes us in its solar wind. This "wind" is actually plasma, the fourth state of matter (after solid, liquid and gas). Plasma is hot, electrically charged gas made up of mostly protons and electrons. It's also what the sun is made of, not fire (fire is a chemical reaction between oxygen and carbon). If you imagine Earth as a rock in a stream, solar wind is the really fast, hot current flowing around it. This is the same current that makes a comet's tail point away from the sun, whether it's coming or going.

SUPPLIED

Otago physics professor Craig Rodger and, right, an illustration of a coronal mass ejection hitting Earth and destroying a satellite.

Since solar wind travels along the sun's magnetic field lines, it would whisk away our atmosphere and turn us into Mars if not for the magnetic envelope, or magnetosphere, that protects us, curving out into space and converging near the North and South poles. The sun's magnetic field is about twice as strong as ours, so solar wind squashes the magnetosphere on its sun-facing side and stretches it out on the night side into a long "magnetotail".

> **"Casually mention coronal mass ejections or solar energetic particles to this delightful instructor, and it's like plugging an electric guitar into an amp.**

For three days starting on May 10, we saw what happens when this stream of solar wind turns into a torrent. Our skies were lit up with the largest solar outburst in 20 years, as the sun lobbed extra plasma our way. The magnetosphere siphoned off the electrons and protons rushing past and deposited them like pennies into piggy banks at the North and South poles. Auroral inks stained the night sky green and red where solar particles collided with our atmosphere's oxygen, and blue and violet where they hit nitrogen.

Solar activity waxes and wanes every 11 years. We are currently in what is known as a solar maximum, when the sun is at its most restless. The present cycle began in about 2019 and is expected to peak between now and 2025 (so keep looking up). During a maximum phase, the sun ejects more of its plasma more frequently. This happens because the sun's unstable magnetic field lines twist and tangle, especially in dark areas on its surface called sunspots.

Magnetic energy builds up, reaches a breaking point and "snaps", causing the sun to geyser and belt out electromagnetic radiation in the form of solar flares and giant blobs of magnetised plasma called coronal mass ejections, or CMEs. A solar flare cannot be prepared for because it reaches us in eight minutes. CMEs take longer, usually about a day and a half.

In May, we were hit by solar flares and coronal mass ejections. As with everything solar, flares and ejections are

Brobdingnagian. Some sunspots are 10 times larger than Earth and send out flares with enough energy to power our planet for 20,000 years.

SMITTEN BY THE SUN

Craig Rodger, the Beverly professor of Physics at the University of Otago, was among those looking up at the bright night skies in May but he was doing it with a mix of awe and concern. When Rodger talks about our star, it becomes clear why, in 2011, he won the university's excellence in teaching award.

Casually mention coronal mass ejections or solar energetic particles to this delightful instructor and it's like plugging an electric guitar into an amp. His legs bounce. His eyes flash. His hands clap. "I'm smitten by the sun," he says. "It's just an amazing, fabulous, changing thing."

Rodger has been studying the sun for at least 25 years, a journey that has had him jet-setting from hemisphere to hemisphere and, on a Fulbright fellowship, to the wilds of Iowa to study the Van Allen radiation belt.

In 2020, the Ministry of Business, Innovation and Employment awarded him a $15 million Endeavour Fund grant to study space weather's effects on New Zealand's power grid and natural gas pipelines.

Space weather describes the effect of the sun's behaviour on Earth and in recent years has received a bit of high-level attention. When the sun throws plasma pies at us, the undulating tonsures of light at the poles are pretty, but the surges of energy plasma induces on and around our wired planet are not. Coronal mass ejections, what Rodger calls "solar tsunamis," compress our magnetosphere to such an extent that the ground becomes charged, endangering power networks and essential infrastructure such as hospitals, transport and agriculture.

Also, our atmosphere heats up and puffs out into space during severe solar events, which increases drag on satellites. Rodger says it's "not quite like ploughing through treacle, but it messes things up". The expanded atmosphere can cause satellites to slip or fall out of orbit back to Earth.

So, solar storms endanger everything from the International Space Station to power grids, planes and railway lines. They led to SpaceX losing 38 of its 49 Starlink satellites in 2022 after an average geomagnetic storm, a South Dakota farmer's

GETTY IMAGES

GPS-damaged tractor drove in circles and a transformer in Halfway Bush, Dunedin, was snuffed out in 2001.

We have known about the dangers of space weather for a while. The Space Weather Prediction Centre in Boulder, Colorado, was founded in 1961 to monitor the sun and act as a Neighbourhood Watch for Earth. In 2008, the National Academies of Sciences compared space weather events to earthquakes and tsunami and noted that a "loss of key infrastructure ... from a space weather event" could lead to restricted food and a loss of basic transport, fuel and refrigeration.

In 2009, the United Nations created the International Space Weather Initiative to advance our prediction and understanding of space weather events. A particularly dire warning came from a 2013 Lloyd's of London report. The authors wrote that a major storm could leave North Americans without power for up to two years and cost two trillion dollars to remedy.

PROTECTING THE GRID

Rodger's grant has allowed him, his former PhD student Daniel Mac Manus and other colleagues to concentrate on coming up with a plan to protect New Zealand's power grid and the natural gas pipelines that First Gas owns. "We've reconfigured the power network and redistributed currents so that customers aren't affected," he says. "We actually sat in Transpower's headquarters and simulated extreme solar events and huge surges in New Zealand's power currents. We learned how to plan and protect the grid."

There are "hot spots" around parts of Dunedin and Auckland, where the soil seemed to be highly conductive, so Transpower erected monitoring equipment there.

As the solar storm got going, Rodger was in constant contact with Transpower. "This is the first time I woke up to find a message from Transpower. Magnetic field instruments were going crazy. My phone just blew up!"

The plan he and Mac Manus developed was put into action. The company switched off some circuits and transmission lines as a precaution, and in the end, the storm did not disrupt our power supply. "It was really great to see our research applied to a real-world problem and work," says Rodger.

After the storm subsided, Transpower publicly thanked Rodger, and *Time* magazine reported that an exemplary "command and control system" to protect the Earth's infrastructure from a major solar storm does in fact exist – in New Zealand.

May's solar tsunami has been classed as G-5, the highest level on the Space Weather Scale. "Unfortunately, the scale goes only to five," says Rodger. Then, clapping his hands to imitate plasma meeting planet, "We were struck by six CMEs, which is like being hit in the face six times by a huge pillow!"

GOLD STANDARD

Still, this was not the most spectacular tempest we've seen. "It was big and beautiful, and it was as bright as buggery, but it wasn't a Carrington," says Rodger.

When heliophiles think about starbursts, one name is the gold standard: Richard Carrington, an English brewer and astronomer who, while sketching sunspots on September 1, 1859, noticed "two patches of intensely bright and white light". These were solar flares launching CMEs from sunspots. Less than a day later, plasma dived into Earth's magnetosphere and sparked the largest solar storm in recorded history.

Things got weird. Northern Lights stretched down to Cuba and Panama. Southern Lights lit up Hawaii and southern Japan. Larks warbled at midnight. Rocky Mountain miners mistook the radiant darkness for sunrise. In New Zealand, the *Nelson Colonist* newspaper reported "distant but severe conflagrations". The *Taranaki Herald* noted "coruscations shooting up from the south". The Hippocrene blushed deep for American poet William Ross Wallace, who apostrophised: "O lights of the north! As in eons ago/Not in vain from your home do ye over us glow!" Telegraph systems shut down. An arc of fire jumped from a Mr Fred Royce's forehead to his transmitter. The sun sent phantom communications; the *Philadelphia Evening Bulletin* reported "fantastical" telegraph messages sent and received, sometimes through machines with the batteries removed.

Magnetic fields, and therefore solar storms, are measured in nanoteslas. Best estimates put the Carrington Event at around 5000 nanoteslas. The one we just experienced, says Rodger, was about 320 nanoteslas. Small potatoes by comparison.

> **I woke to a message from Transpower. Magnetic field instruments were going crazy. My phone just blew up!**

In 1859, haunted telegraph machines were as bad as it got. Things will be different in our electrified, connected world if we don't prepare.

"We've gone from almost nothing to something, but we have a way to go," says Rodger. "I worry about satellites getting fried in a major solar storm, and that affects things down here." New Zealand, he says, is a spacefaring nation now and needs to pay attention to the sun and what it can do.

He is also puzzled that while space weather is on the National Risk Register – a list of 42 dangers that have been deemed nationally significant – no co-ordinating agency has been assigned to work out who does what if space weather threatens.

"We need to bolster our capabilities and co-ordinate our action. Then, maybe we can come up with a coherent plan. As it is, we're not ready."

CARBON CLUES

Modern earthlings have lived through other storms, none as bad as the Carrington Event. In 1967, with the Cuban Missile Crisis a recent memory, a solar eruption scrambled American surveillance radars.

The Americans, suspecting the Soviets were gearing up for an attack, prepared for war. Until, that is, proto-space-weather forecasters intervened with news of solar mischief. Crisis averted. In 1989, a solar flare left six million people in Quebec without power for nine hours and melted power transformers in New Jersey.

Intriguing research into the radioactive isotope carbon-14 embedded in fossilised tree rings is giving us a glimpse into extreme solar activity from thousands of years ago. For example, a huge spike in carbon-14 has been found in pine trees buried in the French Alps. This spike is the trace of a solar explosion, a flare or CME, left 14,000 years ago – an explosion that was 10 times more severe than the Carrington Event. Imagine the wonder of our Ice Age ancestors as they looked up.

As we approach the peak of our current solar maximum, Rodger says, we can expect the sun to fling "more of everything" at us, including flares, CMEs, x-rays and radio waves. Skies will glow. Induced currents will flood electrical grids. The next Carrington hasn't hit yet, but, Rodger says, "it's not a question of if, but when".

So keep looking up. ▮