The most outstanding solar-flare eruptions are not always the most influential

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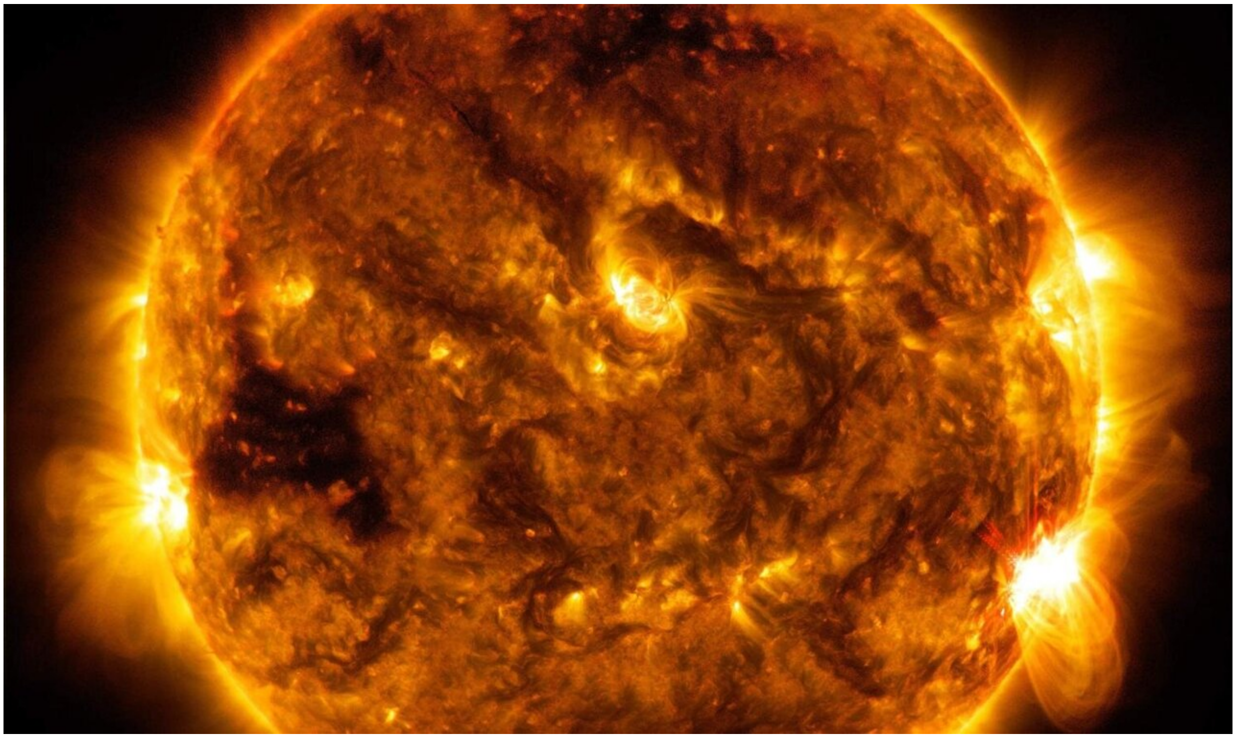

A solar flare captured by NASA's Solar Dynamics Observatory at 8:12 p.m. EDT Oct. 1, 2015. Credit: NASA/SDO

While many studies have compared the magnetic properties of confined and eruptive solar flares, few have considered the thermodynamic properties of confined flares and even fewer in comparison to eruptive ones.

Maria Kazachenko, an assistant professor in the University of Colorado Boulder Department of Astrophysical and Planetary Sciences, is one of the few to have explored this subject. In a paper published in *The Astrophysical Journal* and featured on AAS Nova, she conducted a study quantifying the thermodynamic and magnetic properties of hundreds of solar flares.

Solar flares are enormous explosions of electromagnetic radiation from the sun. They happen when energy stored in magnetic fields, usually above sunspots, is suddenly released. Some flares involve a coronal mass ejection (CME), in which a huge amount of charged particles, or plasma, is flung out.

Some of the study's results confirm the findings of earlier inquiries. However, the paper also includes new information suggesting that confined flares, or flares with no associated CME, may be more efficient at accelerating particles and therefore at producing ionizing radiation as well.

What is a solar flare?

Solar flares are caused by the sun's magnetic fields, which are strongest in the dark areas called sunspots. When inactive, these fields look like loops. However, when the subsurface flows of the sun begin to shear and twist the sunspots that they are tied to, the magnetic fields become twisted as well.

"You could imagine it like a rubber band that you start twisting," Kazachenko explains. "At some point, you cut it, then … energy will get released and you will get a snap on your hand."

Like the elastic energy of the rubber band is released when it is cut, a fraction of the magnetic energy of the sun is released during a process called magnetic reconnection. Magnetic reconnection can take different forms, but "one of the simplest configurations," Kazachenko says, "is when you have two oppositely directed field lines being pushed against each other … the magnetic fields could suddenly change their configuration and release a huge amount of energy, similar to rubber bands that get cut all of a sudden."

The free magnetic energy that is released during magnetic reconnection is stored in plasma currents. Electric currents produce magnetic fields, as seen in electromagnets, and charged particles moving within the sun's plasma function similarly.

Confined and eruptive flares

While some solar flares are associated with CMEs, where plasma is ejected from the solar atmosphere and into space, others are not. If a solar flare is associated with a CME, it is considered eruptive; if it doesn't have an associated CME, it is considered confined. The difference between the two goes deeper than that, however, because the mechanisms that determine whether a flare is confined or eruptive may also decide how quickly the magnetic fields will reconnect and how much hard X-ray and gamma ray radiation it will emit.

As their name suggests, confined flares are unable to escape the sun's atmosphere because of constraining influences. These influences, known as strapping fields, are also magnetic. For this reason, active regions with more magnetic flux also have stronger strapping fields and are therefore less likely to be eruptive.

According to Kazachenko, this explains why the confined flares that she studied had higher temperatures and underwent reconnection more quickly than eruptive flares of the same peak X-ray flux: "In confined flares, you have reconnection happening lower because you have a very strong strapping field of the active region that doesn't allow the structure to go up … the fields are stronger lower down, so reconnection proceeds much faster."

While the significance of faster reconnection may not be immediately obvious, the research paper explains, "As higher reconnection rates lead to more accelerated ions and electrons, large confined flares could be more efficient at producing ionizing electromagnetic radiation than eruptive flares."

This is not to say that more energy is released during the reconnection of a confined flare; in fact, eruptive flares have the same amount of reconnected flux as confined flares. Rather, because energy is released more quickly in confined flares, they may accelerate ions and electrons from the sun's plasma more efficiently.

Space weather in this solar system and beyond

When it comes to space weather, CMEs and the geomagnetic storms they can cause often get the most attention. This is for a good reason: While it is rare for CMEs to reach Earth, the consequences are dire when they do.

In the worst-case scenario, a geomagnetic storm would damage or destroy electrical transmission equipment, causing blackouts on a large scale. Additionally, such a storm would disrupt certain types of communication, damage satellite hardware, and expose astronauts and high-altitude aviators to potentially lethal radiation. While these are only predictions, evidence for them is based in part on the geomagnetic storm of 1859, which had pronounced effects, causing sparking and fires in telegraph stations.

Research like Kazachenko's contributes to a broader understanding of how solar flares work, which may one day allow scientists to predict when they will happen more accurately and therefore avoid the worst consequences of a geomagnetic storm by giving people time to take preventative measures. However, her studies have broader implications as well.

"What happens on other stars?" Kazachenko asks. "Are there flares there? Are there CMEs there? From recent studies, it seems that there are thousands of flares there, but the CMEs, the coronal mass ejections, are very hard to determine."

While it is possible that stars like the sun regularly undergo CMEs and that scientists and researchers have simply been unable to detect most of them, current evidence suggests that confined flares play a larger role in the space weather of other solar systems than they do in this one. For this reason, the seemingly less impactful type of solar flare may determine whether exoplanets are habitable—a major interest to astronomers looking for exoplanets that are suitable for colonization.

"So, it's a very fundamental question, both … for our equipment's safety, but also for understanding other planets," Kazachenko says.

Future inquiry

While Kazachenko has discovered a unique property of confined solar flares, there is still work to be done, she says. Her study suggests that confined flares reconnect magnetic fields faster and potentially accelerate charged particles more efficiently than eruptive ones, but the properties of these particles are outside its scope.

There should be a follow-up study, Kazachenko says. "Where you really look at the statistical population of particles' acceleration in both groups of flares … but that's where I think the future lies: looking not just at one singular event in high detail, but benefiting from these amazing observations that we now have from many different satellites flying there, like the new satellite launched by NASA and the European Space Agency called Solar Orbiter."

More information: Maria D. Kazachenko, A Database of Magnetic and Thermodynamic Properties of Confined and Eruptive Solar Flares, *The Astrophysical Journal* (2023). DOI: 10.3847/1538-4357/ad004e

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