# Solar flares and solar magnetic reconnection get new spotlight in two blazing studies

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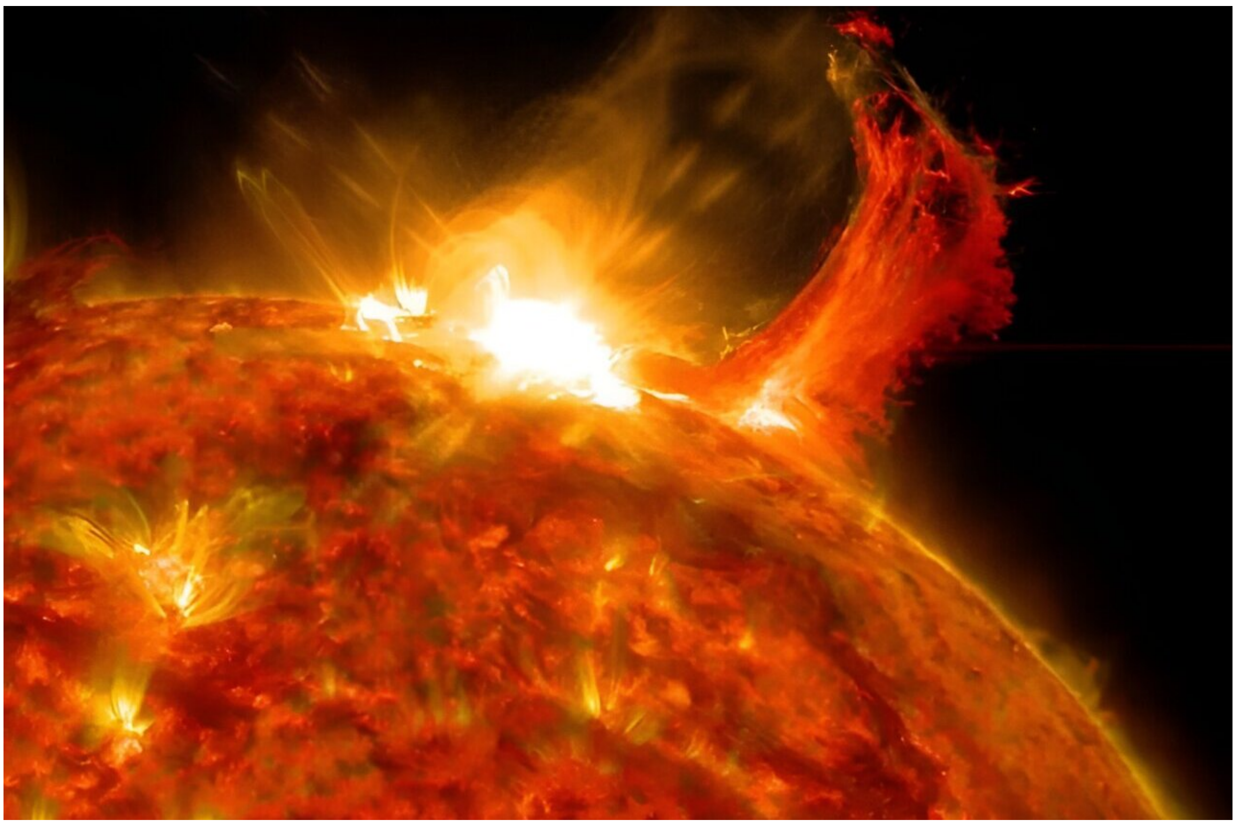

Image of a solar flare (bright flash) obtained by NASA's Solar Dynamics Observatory on Oct. 2, 2014, with a burst of solar material erupting being observed just to the right of the solar flare. Credit: NASA/SDO

Two recent studies published in *The Astrophysical Journal* discuss findings regarding solar flare properties and a new classification index and the sun's magnetic field, specifically what's called solar magnetic reconnection.

These studies hold the potential to help researchers better understand the internal processes of the sun, specifically pertaining to solar flare activity and space weather. Here, Universe Today discusses these two studies with both lead authors regarding the motivation behind the studies, significant results, and implications on our understanding regarding solar flares and space weather.

The first study discusses new insights into solar flare properties and presents a new solar flare classification index that builds off previous classification indices along with scientific advancements in our understanding of solar flares. So, what was the motivation behind this study?

"The inception of our interest in this study was inspired by work that my advisor, Prof. Adam Kowalski, has done in the last decade in classifying stellar flares using a similar index," Cole Tamburri, who is a Ph.D. Candidate in the Department of Astrophysical & Planetary Sciences at the University of Colorado Boulder (CU Boulder) and lead author of the study, tells Universe Today.

"Traditionally, solar flares are classified according to the peak flux in GOES soft X-ray. However, as our understanding of flare physics has advanced, we've learned that there's much more diversity between flare events which is not captured by the GOES classification system—for example, two events with the same peak intensity might occur over much different time periods (a few minutes, to even a few hours!), which is indicative of significant differences in the physical mechanism."

The GOES soft X-ray currently classifies solar flares ranging from lowest intensity to highest using classes labeled as A, B, C, M, and X. This data is gathered from the Geostationary Operational Environmental Satellite (GOES) system of four active spacecraft currently in a geosynchronous orbit and operated by the National Oceanic and Atmospheric Administration (NOAA) in the United States.

This data is plotted in real-time on the GOES X-ray flux interface available on the NOAA website, where users can watch live solar activity while viewing which class the solar flares correspond to on the plot, with the data being updated every 10 minutes.

For the study, the researchers sought to expand upon and improve the GOES classification index by measuring what's known as impulsiveness, which Tamburri refers to as a "suddenness" of energy release.

During a four-year period between 2010 and 2014, the researchers obtained impulsiveness measurements using Solar Dynamics Observatory/Extreme Ultraviolet Experiment for 1,368 solar flares, categorizing their impulsiveness as low, mid, and high. So, what were the most significant results from this study?

"During this project, we developed and statistically analyzed the impulsiveness of a large number of flares in the extreme ultraviolet 304 Angstrom line," Tamburri tells Universe Today.

"Magnetic reconnection is the process that occurs when two oppositely oriented magnetic field structures interact to form new field lines, resulting in an intense outflow of energy from the region where reconnection is occurring, the effects of which we then observe in the lower solar atmosphere as a solar flare.

"We found that impulsiveness, interestingly, has a moderately strong correlation with the peak rate of magnetic reconnection. This suggests that the details of the magnetic field present during a solar flare may indeed be related to the energetics of the flare itself (magnitude and duration)."

As noted above, this study builds off initial research from Dr. Adam Kowalski, which Tamburri notes published a 2013 study discussing a connection between M-class solar flares and stellar properties. This work involving impulsiveness was further expanded upon by another advisor of Tamburri's, Dr. Maria Kazachenko, who published a 2017 study discussing a new catalog of flare ribbon properties.

Finally, two 2022 studies (Dahlin and others, 2022 and Qiu and others, 2022) discussed a potential connection between solar flare impulsiveness and the behavior of the sun's magnetic field when a solar flare occurs. According to Tamburri, the goal of this recent study was to expand upon the discussion of impulsiveness by sampling many solar flares.

Regarding future work, Tamburri tells Universe Today that there are three research directions they can go from here: 1) Expanding the impulsiveness index to include various wavelengths since that determines the accuracy of solar flare and impulsiveness measurements; 2) After identifying a satisfactory wavelength, a comparison of solar flares to stellar flares is planned to be made; 3) Using models to simulate and identify the origins and physics behind impulsiveness activity.

Observations and studies of solar flares date back to the mid-19th century, with the first recorded solar flare observation being conducted by two amateur astronomers, Richard Carrington and Richard Hodgson, using an optical telescope. Further studies occurred by accident using radio observations during World War II by British radio operators in February 1942, with their findings not being made public until after the war ended in 1945.

After the Space Age began, it was discovered that space telescopes would be best suited for observing solar flares due to the Earth's atmosphere blocking large amounts of solar radiation, limiting ground-based telescope observations. This has allowed near unobscured observations of solar activity, resulting in better understanding of solar flares. Therefore, what implications could this new impulsiveness index have on our understanding of solar flares?

"At this point, we don't fully understand the fast, intense initial phase (the impulsive phase) of a flare," Tamburri tells Universe Today.

"Ultimately, an accurate, complete picture of the flaring process must tie together the flare process in all regimes—the magnetic field in the low-density corona, the high-energy processes in the dense chromosphere, and even what lies below, in the photosphere.

"While we're a far way from that, connecting what we see during a solar flare to what we can infer about the magnetic field in an active region before, during, and after an event can help to create this unified picture."

Solar flare activity falls under the category of space weather, which is the activity on the sun's surface that can influence activity both on Earth's surface and in orbit. While this often results in the beautiful auroral displays seen at high northern and southern latitudes, this harsh solar radiation can potentially damage satellites and electronic ground stations, causing widespread electrical and communication blackouts around the world.

The most revered incident of solar activity causing widespread damage to the earth's surface is known as the Carrington Event, which occurred between September 1–2, 1859, during the most intense solar storm on record.

The result was massive incidents of sparks and fires occurring at telegraph stations across the globe and auroral observations reported around the world, as well. Therefore, what implications could this new impulsiveness index have on our understanding of space weather and how to protect against it?

Tamburri tells Universe Today, "In a sense, one of the real dangers of solar flares/storms as they relate to space weather is the uncertainty regarding the specific characteristics of an event while it's happening—much like two snowflakes, no two solar flares are exactly the same! There are still many vagaries in flare prediction, despite decades of research; even once a flare begins, it's hard to tell exactly how energetic a flare will be, or how long it will last.

"If we are able to clearly tie the impulsiveness index to distinct signatures in the magnetic field topology (from which we can infer stored energy), this could possibly tell us a little more about how intense we expect a flare to be, using which knowledge we can mitigate the effects of a flare on technology on and around Earth."

Tamburri tells Universe Today that this work was supported by the National Science Foundation through the DKIST Ambassadors program, along with being administered by the National Solar Observatory and the Association of Universities for Research in Astronomy, Inc., with thanks also to the University of Colorado Boulder and the George Ellery Hale Graduate Fellowship.

The second study discusses new insights into the properties of solar magnetic reconnection, which is the primary process during solar storms that converts magnetic energy into thermal energy (heat), kinetic energy (motion), and particle acceleration.

While studying this phenomenon could help scientists better understand the mechanisms behind solar storms, a lack of high-resolution data has prevented in-depth observations from being made until now. Therefore, what is the specific motivation behind this study involving solar magnetic reconnection?

Marcel Corchado-Albelo, who is also a Ph.D. student in the Department of Astrophysical & Planetary Sciences at CU Boulder and lead author of the study, tells Universe Today, "Currently, our methods to measure the solar magnetic field are usually constrained to the solar surface or photosphere, or in the scarce cases in which the magnetic field has been measured from higher solar atmospheric layers the measurement lacks the temporal cadence to track the evolution of reconnection processes.

"Therefore, scientists have been using proxy measurements involving flare ribbons to calculate magnetic reconnection properties like magnetic reconnection flux."

Corchado-Albelo continues, "Extensive statistical work has shown that these flare ribbon derived measurements are well correlated with other flare variables like the strength of the solar flare. These results motivated us to examine how the solar magnetic reconnection flux changed in time during solar flares.

"When examining the rate of change of the magnetic reconnection flux we discovered that a large number of flares exhibited bursts that reminisce complex oscillatory features commonly found in multi-wavelength emission, called quasi-periodic pulsations (QPPs)."

For the study, the researchers analyzed high-resolution imaging data from a set of M-class and X-class solar flares and statistical analyses on 73 solar flares ranging from C-class to X-class using a known flare ribbon computer database to ascertain QPP properties.

Better understanding the mechanisms responsible for QPPs will provide greater insight into solar flare energy and activity within the sun's atmosphere and the relationship they have with solar magnetic reconnection.

Previous research into QPPs include observing QPPs using the European Space Agency's XMM-Newton space telescope, examining their relationship with recurrent jets, and conducting comprehensive analyses of QPPs. Therefore, what were the most significant results from this study?

"Our results showed that indeed the burst in the magnetic reconnection rate can be described as QPPs with similar characteristics as the ones found in X-ray emission of the same solar flares," Corchado-Albelo tells Universe Today.

"This result suggests that the process through which the magnetic reconnection flux described by flare ribbons is modulated is related, if not the same, to the process through which the X-ray QPPs are formed."

Corchado-Albelo continues, "Further evidence from the morphological evolution of the flare ribbon, when observations were available, suggest that the solar plasma in the magnetic reconnection region (called the current sheet) undergoes some plasma instability. Our results were inconclusive in what process leads to the co-observation of QPPs in the magnetic reconnection flux and X-ray emission."

Along with the above description, solar magnetic reconnection also involves the sun's massive magnetic field, also called the solar dynamo. Despite its much larger size than the Earth's magnetic field, its behavior can be just as erratic, as the Earth's magnetic field is known to experience variations due to its interaction with solar wind that the sun emits daily.

Unlike the Earth, the sun's surface is constantly changing since it's essentially a massive ball of plasma and causes even more erratic behavior within its magnetic field.

This behavior often results in the sun's magnetic field lines literally becoming tangled as the sun rotates, and specifically as its surface continuously rotates, resulting in periodic sunspots and solar activity, including solar flares. Therefore, what implications could this study have on our understanding of the sun's magnetic field?

"The results of this study suggest that the plasma contained within the region where magnetic reconnection occurs during solar flare are involved in highly complex dynamics," Corchado-Albelo tells Universe Today.

"Understanding the origin of these dynamics can help us diagnose properties of the solar magnetic fields involved in flare reconnection. Properties that could help us possibly constrain the flaring magnetic field geometry, as well as potentially the strength of the field in the reconnection region.

"These properties are of much value in our endeavors to better constrain our models of solar flares, and in cases where the underlying physics of the solar flares are comparable to those of the sun, stellar flares."

Like the first study discussed earlier, this research corresponds to better understanding solar flare activity and space weather, with the latter having direct influence regarding space-based and ground-based activities, ranging from communications to electricity.

Better understanding solar flare activity could help scientists better predict space weather, specifically since the sun goes through what's known as solar cycles every 11 years when the sun's magnetic field flips, which results in increased sunspots and other solar activity, including space weather. Therefore, what implications could this study have on our understanding of solar flares and space weather?

Corchado-Albelo tells Universe Today, "The QPPs in the X-ray emission are a well-known, and common feature of solar and stellar flares. Yet, there is no full consensus to the process through which the X-ray QPPs form.

"Our results provide direct evidence that these QPPs are at least related to processes that modulated the dynamic evolution of the flaring magnetic fields. It is a step forward towards understanding the details connecting how plasma particles within the reconnection region are accelerated and give rise to the QPPs observed in solar flares."

Corchado-Albelo continues, "All of these details need to be reproduced by flaring models in order to be a realistic representation of the process occurring in the sun, which can then be used to forecast solar flares and their properties. This is an invaluable first step to forecast space weather in a reliable manner."

**More information:** Cole A. Tamburri et al, The Relationships among Solar Flare Impulsiveness, Energy Release, and Ribbon Development, *The Astrophysical Journal* (2024). DOI: 10.3847/1538-4357/ad3047

Marcel F. Corchado Albelo et al, Inferring Fundamental Properties of the Flare Current Sheet Using Flare Ribbons: Oscillations in the Reconnection Flux Rates, *The Astrophysical Journal* (2024). DOI: 10.3847/1538-4357/ad25f4

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