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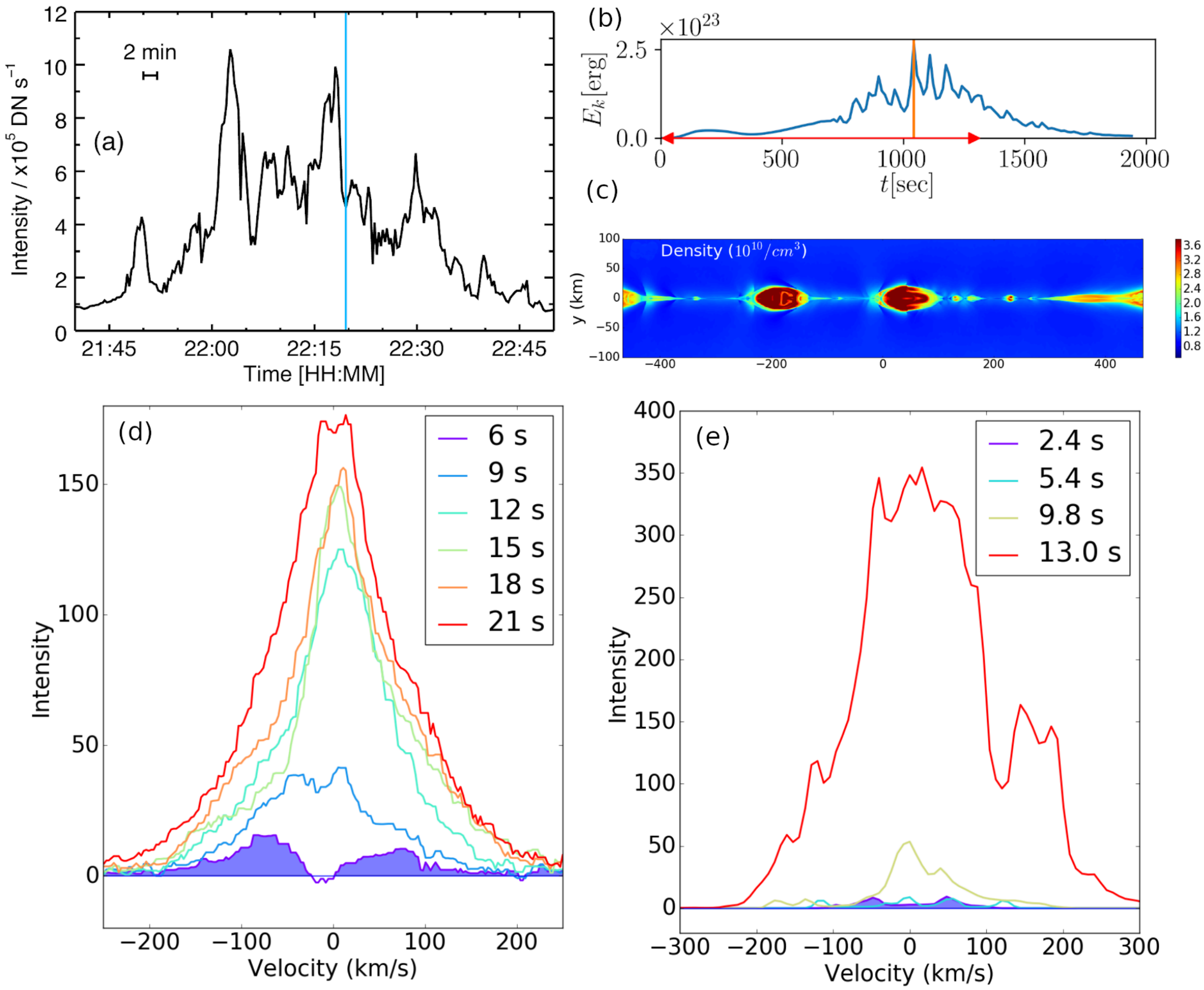
Unraveling the Physical Mechanism of Explosive Events in the Sun

High-resolution observations and supercomputer simulations reveal the mechanism that drives explosive events on the Sun



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(a) The light curve of emission intensity of an explosive event strong modulates on a time scale of minutes. (b) A proxy for the emission intensity shows similar modulations in simulation. (c) The plasma density profile shows multiple plasmoids of different sizes in simulation. (d) Emission line profiles observed by IRIS show a transition from a double-peaked profile to a triangle-shaped profile. The transition of the shape coincides with the brightening of the emission. (e) Synthetic emission line profiles shown a similar transition during the onset of fast reconnection.

The Science

Explosive events on the Sun occur over a wide range of sizes, from large-scale solar flares that drive coronal mass ejections to small-scale nanoflares that heat the solar corona to above one million Celsius degrees. Although these events are vastly different in size, they are driven by a universal physical mechanism called magnetic reconnection, the explosive snapping and rejoining of magnetic field lines that rapidly turns magnetic potential energy into kinetic energy. By using high-resolution, high-cadence solar observations and supercomputer simulations, we show that the fast magnetic reconnection that drives explosive events in the lower solar atmosphere is most likely triggered by a rapid "plasmoid" instability that creates plasma "bubbles". Understanding these small-scale explosions is crucial for understanding why the solar corona is so hot.

The Impact

Explosions on the Sun are the primary driver of the space weather, the ejection of charged particles and magnetic field – known as plasma – that leads to the polar auroras and which can present health risks to astronauts, and large coronal mass ejections directed towards the Earth can knock out satellites. Satellite communication is essential for our modern lifestyle – just think of what you would do without the internet and GPS navigation – and reliable prediction of the space weather is a critical strategic capability. Understanding the trigger of fast magnetic reconnection is crucial for predicting when and where explosive events will occur.

Summary

In highly-conducting plasma environments such as the solar atmosphere, magnetic reconnection is unstable to the plasmoid instability, which creates isolated "bubbles" of plasma that accelerate the reconnection process. Evidence of plasmoids has been observed in the large-scale coronal mass ejections. Our studies, in contrast, focus on the small-scale explosive events occurring in the lower solar atmosphere, where previously little was known. We use the small explosions to probe magnetic reconnection in a very different environment, where direct evidence of plasmoids is lacking.

Because of low resolution, solar imagers cannot observe the small plasmoids. To overcome this limit, we employ high-cadence observation of emission-line profiles obtained by NASA's Interface Region Imaging Spectrograph (IRIS) satellite mission to investigate the dynamics of the explosive events. The emission-line profile gives rich information about the distribution of plasma flow from the Doppler effect, where wave sources moving away seem lower in pitch. To interpret the observed line profile, numerical simulations were performed.

Our studies give evidence of plasmoids in the small reconnection events. The ultra-violet emission intensity is strongly modulated, indicating that the magnetic reconnection is unsteady, which is consistent with the presence of plasmoids. The high-cadence observation of emission spectral-line profiles reveals, for the first time, a transition from a double-peaked profile to a triangle profile and a brighter emission, which suggests a shift from slow to fast reconnection. Our simulations show the coincidence between the transition of the line profile and the onset of fast reconnection. This provides strong evidence that the plasmoid instability is the mechanism that triggers the onset of fast reconnection in the explosive events.

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Publications

H. Peter, Y.-M. Huang, L. P. Chitta, and P. R. Young, " Plasmoid-mediated reconnection in solar UV bursts." Astronomy & Astrophysics **628**, A8 (2019). [DOI: 10.1051/0004-6361/201935820]
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