'Next Generation Observations and Theory of Solar Eruptive Events (NGEruptive)' Abstracts

Talks

Investigation of Quasi-periodic pulsations (QPPs) in solar flares

Authors

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Abstract

Solar flares are explosive, energetic events that produce radiative signatures at all layers of the solar atmosphere. Quasi-periodic pulsations (QPPs) are the most commonly observed phenomenon in solar flares, characterised by periodic fluctuations in the observed radiation. We present a systematic and comprehensive investigation of quasi-periodic pulsations in M7.3-class solar flare ribbons and of their height-wise distribution, using various low- and high-temperature UV spectral lines observed by the Interface Region Imaging Spectrograph (IRIS) during sit-and-stare observations. The non-linear and non-stationary properties of QPPs observed along flare ribbons across various time series were thoroughly studied using wavelet analysis. During the impulsive phase of the flare, time series analysis of GOES soft X-rays and RHESSI hard X-rays revealed multiple conspicuous oscillatory patterns. At the same time, the IRIS UV spectral images at various solar heights showed sawtooth-like fluctuations in space as the ribbon sweeps the slit with time. Small-scale substructures at various locations within the ribbon are tracked in Slit-Jaw images, and time-series analysis reveals similar sawtooth-like oscillatory patterns with characteristic periods. Combining data from various observatories facilitated us to study the role of QPPs in flare energy release at various heights in the solar atmosphere and study their relationship with the plasma properties, such as Doppler and Non-thermal velocities obtained for the stationary and moving components of spectral lines. The results confirmed the existence of multi-periodic regimes in space, intensity, and Doppler velocities at various solar heights, which may result from periodic magnetic reconnection episodes.

Revealing Coherent CME-Driven Waves in the Outer Corona Using Spectral Decomposition

Authors

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Abstract

Coronal mass ejections (CMEs) are well-established drivers of large-scale disturbances in the low corona. However, we still have very limited observational insight into how CME-driven waves behave once they propagate into the extended corona and inner heliosphere. Here, we present the first combined observational and numerical evidence of coherent, large-scale compressive oscillations in these outer regions. We identified those oscillations in white-light coronagraph data from SOHO/LASCO C3 and in global magnetohydrodynamic (MHD) simulations. Our analysis focuses on the extreme CME event of 23 July 2012. We use spectral proper orthogonal decomposition (SPOD) to break the data down into its most meaningful patterns. In practice, this means taking the time series of images and building a covariance matrix that tracks how the intensity patterns evolve from one frame to the next. Each matrix element measures how similar two frames are. Next, we use a filtering step based on the frequency to get rid of short-lived fluctuations (for example, noise or small misalignments), but keep more persistent and physically meaningful patterns. From there, solving the eigenvalue problem yields a set of spatial modes with the leading mode capturing the most dominant, recurring pattern in the data at a given frequency. The subsequent modes capture progressively weaker contributions to the main signal but still coherent structures. This approach allows separation of the broadband CME expansion from organised wave-like components and tracks their evolution across the full LASCO C3 field of view. The SPOD analysis reveals two distinct classes of compressive disturbances. First, we identify a fast, shock-like wave that propagates outward and decays within about three hours. In addition, we find a second, very different signal: a large-scale, nearly circular wave that spans the full coronagraph field of view and persists for around seven hours. This longer-lived pattern is much more uniform and coherent, consistent with a global fast-mode MHD wave travelling through the extended corona. To interpret these signatures from observations, we run a complementary global MHD simulation of the CME and compare it directly with the SPOD results. The simulation reproduces both the short-lived shock-like feature and the longer-lived global oscillation, giving us confidence that the latter is a real large-scale compressive disturbance propagating through the heliospheric plasma, rather than an artefact from line-of-sight effects or localised features. The agreement between data-driven modal decomposition and forward-modelled dynamics provides strong validation of the physical nature of the detected signals. These results reveal a previously unrecognised component of CME-driven wave activity in the extended corona and inner heliosphere.

First delay observation between two mid-infrared channels in solar flare footpoints.

Authors

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Abstract

Mid-infrared (mid-IR) observations of solar flares provide a powerful diagnostic of chromospheric energy deposition as the emission, which is mostly hydrogen continuum, closely tracks rapid flare-induced changes in electron density. However, such observations remain scarce, with only a limited number of events recorded over the past decade.
In this work, we investigate the temporal relationship between energy injection and mid-IR emission by analysing time lags between emissions at two channels (5.2 μm and 8.2 μm) for two spatially resolved flare footpoints. Using a local cross-correlation technique, we find for the first time that the 8.2 μm emission systematically peaks 0.3–0.45 s before the 5.2 μm channel.
To interpret these observations, we compute synthetic infrared emission using outputs from the F-CHROMA grid of RADYN radiation hydrodynamics simulations. The model reproduces lag values consistent with the observations, suggesting that opacity variations, primarily driven by the electron density variations, are responsible for the wavelength-dependent temporal offsets. In particular, longer wavelengths exhibit a shorter delay between the peak of energy injection and the peak of emission.
These findings provide new insight into the response of chromospheric layers during flare energy deposition and demonstrate the diagnostic potential of mid-IR timing measurements. With improved temporal resolution, such observations offer a promising way to characterise the dynamics of energy deposition during solar flares, opening a new avenue for studying heating and energy transport processes in the solar atmosphere.

Investigating Stellar Flare and CME detection using Solar and Sun-as-a-star observations

Authors
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Abstract
Understanding energetic and eruptive events such as flares and Coronal Mass Ejections (CMEs) on other stars requires careful interpretation of spatially unresolved signals. The Sun provides a unique opportunity to investigate them: high-resolution, spatially resolved observations that can be degraded to a Sun-as-a-star perspective to reveal how processes would manifest in stellar spectroscopic and photometric data.
In this talk we use the Numerical Empirical Sun-as-a-Star Integrator (NESSI) to construct synthetic full-disk flare spectra from small field-of-view high-resolution solar flare observations, exploring how chromospheric line enhancements and asymmetries appear when integrated over the disk and what spectral diagnostics of flare energy release are recoverable in unresolved observations.
We also combine solar data view from multiple vantage points with analytical modelling to assess how geometric projection and stellar rotation affect the observability of Doppler signatures associated with CME-like outflows. This framework helps explain apparent discrepancies between expectations from solar flare-CME relationships and the low incidence of clear stellar CME detections.
Our results provide new solar-based constraints on the interpretation of stellar flare and CME signatures, and inform strategies for future time-domain and spectroscopic surveys targeting activity on other stars.

Observational Analysis of Photospheric and Chromospheric Magnetic Fields During a Solar Flare

Authors

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Abstract

Solar flares can induce many changes in the Sun's atmosphere, with the majority of the energy deposited in the chromosphere from the magnetic reconnection site. The flare changes the configuration of the magnetic field, both in the chromosphere and in the lower photosphere. This can be particularly interesting in active regions, where the magnetic field is already strong. Here we show observational analysis of a solar flare in an active region observed with the Swedish Solar Telescope (SST). The region was observed with the CRisp Imaging SpectroPolarimeter (CRISP) and CHROMospheric Imaging Spectrometer (CHROMIS) instruments on the SST, capturing the M1.8 class flare and its associated ribbon appearing over the sunspot umbra and penumbra. We use Weak-Field Approximation (WFA) on the Ca II 8542 A and Fe I 6173 A lines to obtain values for the chromospheric and photospheric magnetic field strength and inclination angle. We then compare the magnetic fields before and after the flare at the two field heights and investigate how the field configuration evolves with time. These results can also be examined with respect to how they relate to flare signatures and timings.

Recent Advances in Understanding Solar Eruptive Events (Invited)

Authors

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Abstract

Eruptive solar flares and jets are arguably the most exciting and important phenomena on the Sun. One the one hand, they provide a excellent opportunities to probe fundamental plasma processes such as magnetic reconection and particle acceleration. At the same time, they are key drivers of space weather, through flare emission, coronal mass ejections and contributions to the solar wind. This review will highlight recent major developments that are transforming our understanding of the workings of Solar Eruptive Events – across observations, numerical modelling and theory. The talk will conclude with a look at upcoming opportunities, including forthcoming missions.

Posters

Magnetic origin and thermal properties of solar jets

Authors

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Abstract

Collimated plasma transients, such as solar jets, often exhibit multiwavelength radiative signatures originating from different heights in the solar atmosphere. Their frequent occurrence in various magnetic environments, along with their association with explosive events like solar flares, coronal mass ejections, sigmoids, non-thermal type III radio bursts, and both soft and hard X-ray emissions, makes them intriguing candidates for enhancing our understanding of heating and cooling processes, as well as the mass and energy transfer occurring within different layers of the solar atmosphere. We present our in-depth investigation of solar jets, utilizing various atomic and molecular lines (specifically H2) observed through the space-based Hinode/EIS and IRIS satellite. Our research primarily focuses on understanding the formation of radiation jets generated at multiple temperatures and their connection to the magnetic fields in the photosphere. This study highlights the formation of hydrogen molecules (H2) in the temperature minimum region and the cool UV emissions produced during jet activity associated with the dynamic magnetic flux emergence (MFE) process. We thoroughly investigated this using the Bifrost code in a 2.5D radiative MHD numerical experiment. Our findings contribute to a deeper understanding by providing key constraints for theoretical models of their thermodynamic characteristics.

Systematic Time Evolution of the Horizontal Magnetic Field Around the Polarity Inversion Line in Flares

Authors

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Abstract

The evolution of the horizontal magnetic field (B_h) at the photosphere during solar flares provides insights into how the photospheric field responds to coronal energy release. In this work, we investigate the spatial and temporal changes in the behaviour of B_h using unsupervised machine learning, namely k-shape clustering, to identify regions exhibiting step-like changes in B_h. We analysed 35 solar flares spanning X-, M-, and C-class events, using 135 s-cadence vector magnetograms obtained from the Solar Dynamics Observatory (SDO) Helioseismic and Magnetic Imager (HMI), and 1600 Å images from the SDO Atmospheric Imaging Assembly (AIA). Our results show that (i) in 14 out of 35 flares examined, stepwise increases in the horizontal magnetic field are concentrated near the region of polarity inversion and show spatial and temporal association with the onset of flare ribbon emission; (ii) the peak rate of increase of Bh generally lags the onset of UV ribbon brightening by several minutes and this time lag shows no statistically significant dependence on flare class; (iii) the lag increases with increasing distance from the region of polarity inversion; and (iv) decreases in Bh are more scattered across the active region and its penumbra. The increase of Bh progressing outwards from the region of polarity inversion provides strong observational evidence of the photospheric response to the sequential relaxation and downward contraction of coronal magnetic fields during energy release, sometimes identified as a coronal 'implosion'.

Flare ribbons substructures in simulations and observations

Authors

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Abstract

Observations from Solar Orbiter, the Swedish 1-m Solar Telescope (SST), and Interface Region Imaging Spectrograph (IRIS) continue to deepen our understanding of flare energy transport and evolution, and upcoming missions such as Multi-slit Solar Explorer (MUSE) and Solar Physics and Astrophysics Research Explorer (SPARK) promise further diagnostic capability.

In 2023–2024 we presented the first multidimensional models of chromospheric evaporation driven by electron beams. Here we present updates to these models that incorporate atmospheric asymmetry, an improved equation of state, refined lower-atmosphere modelling, and chromospheric substructures. These advances enable simulations of flare ribbon substructures, including recently reported riblets (SST) and UV riblets (Solar Orbiter/EUI 174), ribbon freckles (SST), leading-edge effects (IRIS), flare footpoint asymmetries in timing and emission (Solar Orbiter/SPICE, IRIS, and the McMath-Pierce Solar Telescope), and transition-region Doppler velocity spreads (IRIS). Together, these models help interpret the latest high-resolution observations of flare ribbon dynamics, and highlight the capacity of small-scale structuring for diagnosis of energy transport and flare dynamics.

Quasi-Periodic Pulsations from the Solar Atmosphere to the Earth's Ionosphere: A Multi-Wavelength Study of M- and X-Class Flares in AR3664 and Its Successors

Authors

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Abstract

Quasi-periodic pulsations (QPPs) observed across the electromagnetic spectrum during solar flares provide crucial insights into energy release and particle acceleration processes. The physical nature of these oscillations remains unclear, with their origins typically attributed to either magnetohydrodynamic (MHD) waves or episodic magnetic reconnection processes. To distinguish between these mechanisms, investigating the multi-wavelength temporal characteristics of QPPs is of critical importance.

This study focuses on NOAA Active Region (AR) 13664—one of the most remarkable active regions of Solar Cycle 25, which triggered severe geomagnetic storms in May 2024—along with its subsequent solar rotations (NOAA 13697 and 13723). The region's high magnetic complexity and the X-class flares it produced offer a unique laboratory for investigating QPP formation mechanisms. Our study addresses the following key questions: (i) Are QPP signals observed simultaneously across different wavelengths? (ii) How do the characteristic periods of these signals vary with the active region's evolution and flare class? (iii) Is there an observable relationship between QPP behaviors, coronal mass ejections (CMEs), and ionospheric responses on Earth?

The analysis incorporates multi-wavelength observations, including X-ray (GOES, Fermi/GBM, STIX) and radio (LOFAR, eCALLISTO) data. Furthermore, coronal processes are tracked using SOHO/LASCO, ionospheric Very Low Frequency (VLF) amplitude variations are monitored via Stanford SID monitors, and the morphological evolution of the active region is followed using observatory sunspot catalogs. To reliably detect QPP signals, Fourier analysis was performed by accounting for red-noise effects. Detrending methods, wavelet analysis, and cross-correlation techniques were used to investigate time delays and phase relationships across different atmospheric layers. This multi-layered approach aims to reveal the role of QPP signals within the interaction chain extending from the Sun to the Earth.

Evaluating Quasi-Periodic Pulsations with STIX Observations

Authors

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Abstract

Solar flares are among the most energetic events in the solar system, releasing vast amounts of energy and driving significant space weather effects at Earth. While magnetic reconnection is widely accepted as the primary driver, the detailed physical processes governing energy release, particle acceleration, and their temporal variability remain poorly understood.
Recent X-ray and extreme ultraviolet observations have revealed quasi periodic pulsations (QPPs) in flare emission on timescales of tens of seconds to minutes, offering a potential diagnostic of the underlying energy release and modulation processes. However, establishing the significance of these signals is challenging due to the inherently stochastic nature of flare light curves. In this work using STIX X-ray observations from Solar Orbiter, we perform a rigorous statistical analysis of X-ray light curves to assess the significance and physical plausibility of these QPP signatures. Our approach incorporates the stochastic nature of flare time series, including appropriate coloured noise models and underlying probability distributions. We present several compelling examples of statistically significant QPPs from our analysis, which can shed light on flare models and inform future observations.