'Energetic Particle Acceleration in the Sun and the Heliosphere (EPASunHelio)' Abstracts

Talks

Effects of solar wind convectional electric field on SEP propagation in the turbulent heliosphere

Authors

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Abstract

Solar Energetic Particles (SEPs) are accelerated during solar eruptions, and propagate in the heliosphere to be observed at different locations by in situ instruments. SEP observations are used to try to uncover their acceleration mechanisms, however as the SEPs propagate through the turbulent heliosphere, the imprint of the acceleration is convolved by complex transport processes. In this work, we investigate the effect of the convectional solar wind electric field on SEP propagation through space. We use 3D full-orbit simulations of 60 MeV protons in the large-scale interplanetary magnetic field with superposed turbulence. The latter is prescribed via a model that takes the geometry of the Parker spiral into account fully when specifying mode properties. The electric field includes a steady-state large-scale component from solar wind convection and a turbulent component. We show that the large-scale electric field causes protons to co-rotate with the Sun. The SEPs also decelerate due to the combined effect of drifting opposite to the large-scale electric field direction, due to gradient and curvature drifts, and scattering in the turbulent electric and magnetic fields. We discuss the implications of SEP deceleration and corotation on the interpretation of SEP event observations and analysis of their solar sources.

Multi-Diagnostic Studies of Particle Acceleration and Energy Release in Solar Flares

Authors

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Abstract

We are currently in an era of an unprecedented range of both in-situ and remote observables from multiple viewpoints. This comes from a combination of the Solar Dynamics Observatory (SDO) and Solar Orbiter (SolO). By performing data-driven simulations of specific solar flares, we can produce synthetic diagnostics and compare these to those observed. These simulations are initialised with non-force-free magnetic field extrapolations from photospheric magnetograms. They evolve according to magnetohydrodynamics (MHD) and then particle trajectories are modelled according to the outputs of the MHD simulations.

These diagnostics include direct impacts of energetic particles excited by the flare, both from the particles travelling towards and away from the Sun. For those accelerated downwards, time-evolution and location of the X-ray footpoint sources can be synthesised and compared to Spectrometer Telescope for Imaging X-rays (STIX) data; and for those accelerated upwards, time-evolution of particles escaping into the heliosphere which can be compared to the in-situ observations from SolO. Further, synthetic thermal emission can be created for multiple viewpoints, allowing for comparison with EUV images from SDO/ Atmospheric Imaging Assembly (AIA) and SolO/ Extreme Ultraviolet Imager (EUI).

There is currently no consensus on the heights and sizes of the regions where fast plasma heating and particle acceleration occur, with estimations using different individual diagnostics giving a wide range of heights. A combination of these synthetic and observed diagnostics allows for examination of these two regions within the simulation, and whether these occur in the same place as each other. It will also allow a more constrained estimate of their heights.

With this information, more accurate future models of solar flares which do not have the luxury of all these diagnostics can then be produced, increasing understanding of the processes behind particle acceleration and transport in solar flares.

Simulating Solar Quasi-Periodic Pulsations via Kinetic Modelling

Authors

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Abstract

Solar flares are explosive releases of magnetic energy stored in the solar corona, driven by magnetic reconnection. These events accelerate electrons, generating hard X-ray emissions, and often display quasi-periodic pulsations (QPPs) across the energy spectrum. The origin of QPPs remains unexplained within the standard flare model, and the energy transfer process is poorly constrained, with competing theories proposing different acceleration mechanisms. Here, we investigate two QPP events through spectroscopic analyses using RHESSI and GOES. We study electron acceleration and transport in a flaring coronal loop by solving a time-dependent Fokker–Planck equation with a transient source. Our model incorporates transient turbulent acceleration, simulating the effects of periodic energy input to emulate the dynamics of time-dependent reconnection processes at the top of the flaring loop. We compute the synthetic photon flux and compare it with observed X-ray emissions across different energy bands, finding an excellent correlation between the synthetic light curves and observations (6–100 keV). We also analyse the photon flux energy spectra and compare observations with simulations. We show that QPPs leave a fingerprint on the spectral indices in both observations and simulations. This work presents a novel methodology for analysing electron acceleration and transport in flares driven by time-dependent sources.

Strong particle acceleration in small flares

Authors

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Abstract

RHESSI observed 10,000s of microflares (GOES A,B class events) demonstrating particle acceleration and heating like larger events (Christe et al. 2008, Hannah et al. 2008). But one microflare showed unusual X-ray emission > 50 keV, evidence of strong electron acceleration, even though it was a low A-class microflare (Hannah et al. 2007). Recently dozens of these "hard microflares" have been found with Solar Orbiter on STIX (Battaglia et al. 2024, Saqri et al. 2024), showing similar behaviour of small flares accelerating electrons to high energies. Here we present a reanalysis of the original RHESSI hard microflare, not only in the context of the STIX work, but also using more advanced approaches than the 2007 paper – particularly in terms of the X-ray spectral fitting to determine the properties of this non-thermal energy release. This will then be used to investigate how the solar atmosphere responds to such an energy input through RADYN simulations, helping to understand the energy transport and deposition.

Particle energisation in an oscillatory collapsing magnetic trap model

Authors

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Abstract

One suggestion for a process leading to particle energisation during solar flares is the effect of the large-scale shrinkage of closed magnetic field lines on charged particles that are trapped on such field lines between stronger magnetic fields closer to the solar surface. These collapsing magnetic traps (CMTs) can energise particles via betatron acceleration as the collapsing field strengthens, and via Fermi acceleration as field lines shorten.

We present results from an oscillatory CMT model in which the field repeatedly collapses and rebounds before settling into an equilibrium state. In general, the rebounding phase cancels out energy gains particles make during the collapse, as the field weakens and mirror points move apart. However, ions and electrons with relatively low initial energies can gain much more energy than in a non-oscillatory CMT model. If these slower particles are located near the loop top at times of collapse and away from the loop tops at times when the field rebounds, they can experience a 'resonance' effect, due to undergoing loop top Fermi acceleration without this energy gain being reversed when the field line rebounds. The overall effect is that a significant subset of lower energy particles can reach much higher energies than in a simple CMT model.

Influence of Solar Energetic Particle Source Extent on Space Weather Forecasting with the Physics-Based Tool SPARX

Authors
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Abstract
The transport mechanisms governing the propagation of Solar Energetic Particles (SEPs) through the turbulent heliosphere remain a challenging aspect of space weather forecasting. Three-dimensional physics-based models provide a framework to incorporate the effects of solar wind turbulence and the interplanetary magnetic field on the intensity and arrival times of SEPs at Earth. In this study, the SEP forecasting tool SPARX (Marsh et al. 2015), is used to investigate how the injection region width affects the model's ability to reproduce SEP events. SPARX incorporates a relativistic full-orbit test particle approach to simulate SEP events. The real-time detection of a solar flare >M1.0 triggers SPARX to simulate SEP flux profiles from a precomputed database of test particle simulations. In the initial version of SPARX, the extended injection region was assigned a fixed width of 48° x 48° representing a CME-driven shock centered around the flare location. SPARX's performance was recently analysed using this configuration (Dalla et al 2018, Bhagwath et al 2025). We present a skill-based sensitivity analysis for assessing how the injection region width statistically affects SPARX's capability of reproducing intensity profiles and onset times. The model's performance is evaluated by applying SPARX to 160 flares occurring between 1997 and 2017. An SEP forecast is generated for each event and the synthetic flux profiles are compared with observations from GOES. Forecast performance is evaluated using categorical statistics, specifically the Probability of Detection and False Alarm Ratio. Preliminary results indicate the presence of an optimal parameter range for the injection width, reflecting a trade-off between enhanced event detection and elevated false alarm rates. Further analysis is performed to characterise how model performance varies with injection width. This assessment informs model improvements and supports bridging the gap between physics-based modeling and operational space weather forecasting.

Study of Particle Signatures and CME-CME interaction during the 11–12th Nov 2025 event

Authors

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Abstract

The intense solar activity of 11-12 November 2025, featuring an X5.1 flare from sunspot region 4274 and a G4-class Coronal Mass Ejection (CME), triggered significant interplanetary disturbances and the strongest Ground Level Enhancement (GLE #77) in two decades. This study investigates particle signatures and CME-CME interactions to understand how shocks and plasma compression drive relativistic particle production. The research aims to characterize the restructuring of plasma and the resulting complex ejecta that led to a minimum Dst index of -217 nT durin 11-12th Nov 2025. Multi-platform observations from Aditya-L1 (ASPEX-STEPS), ACE, WIND, and OMNI were used to analyze high-resolution IMF and plasma data at the L1 point. Interactions were identified through primary and secondary jumps in plasma beta ratio, velocity, density, and temperature during the passage of trailing CMEs. Results show the primary CME shock arrived at L1 at ~23:48 UT on 11 November, followed by secondary enhancements confirming the formation of complex ejecta, which are the optimal site for SEP acceleration. To quantify turbulence, magnetic field Power Spectral Density (PSD) was computed using Welch's method. Spectral analysis revealed a kinetic-scale slope of -2.602, which lies between KAW-like and Whistler-like slope, indicating energy transfer to dissipative scales. Neutron monitors confirmed GLE #77 with a rare double peak, highlighting multi-stage ejections. These results demonstrate that CME-driven shocks significantly enhance small-scale turbulence and plasma compression. The findings emphasize the non-linear nature of complex ejecta, necessitating multi-point observations and can be further improved by ML/DL analysis.

Local particle acceleration in the heliosphere and its effects on pitch-angle distributions of solar wind electrons

Authors

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Abstract

Suprathermal electrons with energies of ~70eV are observed at 1 AU as dispersionless halo and magnetic field-aligned beams of strahls. For a long time, it has been thought that both populations originate only from the solar corona. This view has consequently impacted interpretation of pitch-angle distributions (PADs) of suprathermal electrons observed in situ and stimulated creation of numerous models explaining features of halo and strahl electrons. Meanwhile, recent observational and theoretical studies allow suggesting the occurrence of an unaccounted population of suprathermal electrons accelerated locally at reconnecting current sheets and dynamical magnetic islands or flux ropes in the solar wind. We show multi-spacecraft observations of PAD spectrograms with signatures of local particle acceleration. The latter is modelled in frequently-observed magnetic field configurations, showing details of acceleration of core electrons up to suprathermal energies in reconnecting current sheets and merged or compressed magnetic islands. Corresponding PADs and electron trajectories are modelled and compared with observations. Our simulations show that the effect of locally-borne suprathermal electrons on PAD views is expected to be largest at crossings of strong current sheets of any origin, as well as in regions filled with magnetic islands. Taking into account the effects of local particle acceleration in reconnecting current sheets, one can explain dropouts and counterstreaming strahls observed in PADs at crossings of the heliospheric current sheet and recent observations of PADs with Parker's Probe.

Posters

Kinetic Simulations of Particle Acceleration in Collisionless Supercritical Shock-Shock Interaction

Authors
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Abstract
Understanding ion energization during the interaction between an Interplanetary (IP) shock and a Bow shock remains an important and intriguing problem in space plasma physics. In this context, we present hybrid particle-in-cell simulations using the 2D EPOCH code to investigate particle acceleration during supercritical collisionless shocks interactions. In order to estimate the level of particle energization in two shocks interaction, we consider two cases. First, we present an example of particle acceleration induced by an isolated bow shock resulting from the solar wind-Earth's magnetosphere interaction. Second, we present a case study of a Coronal Mass Ejection (CME)–driven IP shock interaction with the Earth's bow shock for both quasi-parallel and quasi-perpendicular geometries. During the interaction of two shocks, ions undergo multiple reflections between the converging magnetic fields, enabling efficient energy gain through Fermi acceleration. By modelling the system using hybrid simulations, we can further observe how this acceleration is modified and enhanced in the presence of ion-kinetic scale structures and non-stationary developed self-consistently at both shocks. As expected, the shock–shock configuration produces substantially stronger ion energization than a single isolated collisionless shock. Our simulations show that as the two shocks approach and overlap, their highly structured magnetic ramps, reflected-ion populations, and upstream waves interfere, producing time-dependent variations in shock thickness, amplitude, and position. By analyzing ion velocity distributions, bulk flow, temperature, and electromagnetic fields, we characterize key features of the interaction region, including shock evolution, reformation, ion reflection, and particle energization. These results provide new insight into how shock–shock interactions influence the turbulent shock transition and enhance ion acceleration compared with a single shock.

Effect of a collisional heliospheric environment on simulated in-situ electron spectra

Authors

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Abstract

High-energy particles responsible for solar weather events at the Earth are known to be non-thermally accelerated in the solar corona, established through both remote hard X-ray (HXR) observations and in-situ measurements of high-energy particles. However, the plasma conditions and turbulent properties within the acceleration region(s) remain poorly constrained. One approach is to use in-situ energy spectra to provide diagnostics, as these spectra include signatures of collisional processes in the acceleration region as well as non-collisional transport effects throughout the heliosphere.

Most solar energetic particle (SEP) transport models neglect collisional scattering in the extended corona and heliosphere, citing the comparatively low plasma densities and the computational cost of including such effects. As a result, the degree to which collisions within the heliospheric shape in-situ observations is not fully understood.

In this work, we implement a continuous plasma environment extending from the base of a coronal acceleration region to 1 AU to establish the role of collisional transport beyond the corona. We show how these collisional effects modify the resulting in-situ energy spectra and assess the implications for using such spectra to infer source-region plasma properties, turbulence characteristics, and acceleration region locations.