High Energy Solar Particle Events

foRecastIng and Analysis

HESPERIA

Workshop on Solar Energetic Particle Events

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Abstracts

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Testing the shock origin of protons responsible for solar long-duration gamma-ray events

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Observations with Fermi/LAT have revealed over twenty-five >100 MeV gamma-ray events on the Sun lasting from tens of minutes to several hours. All are associated with flares and all but one with fast CMEs. The gamma-ray emission is most probably from decay of pions produced by high-energy proton and alpha particle interactions deep in the chromosphere. Whether those particles are produced in the associated flare or in the CME-driven shock has been debated. In this work, we present modeling aimed at testing the shock hypothesis. The modeling was performed for two gamma-ray events: 17 May 2012 and 23 January 2012, and consists of two steps: 1) determination of the energy spectrum of protons at the shock and 2) simulation of the proton transport from the shock's downstream back to the Sun. To obtain the shock-accelerated proton spectrum, we applied two simulation models: the Coronal Shock Acceleration model with input from semi-empirical modeling of shock and plasma properties close to the Sun, and the Shock-and-Particle model utilizing SEP observations at 1 AU. The back-to-the-Sun transport simulations were performed in the diffusive approximation. We present modeled spectra of protons precipitated on the Sun and discuss the implications for the shock-acceleration hypothesis.

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Modelling The 2012 January 23 And 2012 May 17 SEP Event With The Shock-And-Particle Model

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In the frame of the HESPERIA project we have studied the hypothesis that Fermi/LAT long-duration gamma-ray events were produced by high-energy protons accelerated at coronal/interplanetary shock waves. From the HESPERIA Fermi/LAT event list, we selected two solar energetic particle events for detailed analysis and modelling: the 2012 January 23 and the 2012 May 17 events. We have used different models to analyse different aspects of these SEP events. Here we focus on the modelling of these events from the solar corona to the near-Earth space. We use the Shock-and-Particle model to describe the interplanetary shock propagation from about 3.5 solar radii to 1 au and to fit the observed proton intensity-time profiles by using data from several spacecraft covering the full range of energy channels where a particle enhancement was detected. We discuss the observed features of each SEP event and draw conclusions on the evolution of the derived particle source at the shock, in the interplanetary space.

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GLE Inversion Software – Assessment of Source and Transport Parameters Based on Neutron Monitor Data

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Within the Horizon 2020 project HESPERIA, we have developed a software package for the direct inversion of Ground Level Enhancements (GLEs) based on data of the worldwide network of Neutron Monitors (NMs). The new methodology to study the release processes of relativistic solar energetic particles (SEPs) makes use of several models, including: the propagation of relativistic SEPs from the Sun to the Earth, their transport in the Earth's magnetosphere and atmosphere, as well as the detection of the nucleon component of the secondary cosmic rays by the ground based NMs. The combination of these models allows to compute the expected ground-level NM counting rates caused by a series of instantaneous releases from the Sun. The proton release-time profile at the Sun and the interplanetary transport conditions are then inferred by fitting the NM observations with simulated NM counting rates. In the presentation, the used models for the different processes, the software as well as first results of the validation of the new software will be presented.

A Short-term Forecast Tool for ≥ S2 (≥ 100 pfu) Solar Proton Events: Preliminary Report

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We are evaluating the ESPERTA (Laurenza et al., 2009; Alberti et al., 2016) proton event forecast tool – which is based on flare location, 1-8 Å fluence, and 1 MHz radio fluence – for Space Weather Prediction Center (SWPC) ≥ S2 proton events, i.e, those with peak > 10 MeV intensity ≥ 100 proton flux units (pfu). Approximately 50 such events occurred from 1995 – 2015. Preliminary values for the probability of detection and false alarm rate for ESPERTA predictions of these events, made after the >10 pfu threshold is crossed, are ~85% and ~15%, respectively, with a median warning time of > ~1.5 hours. We compare CME speeds and decametric-hectometric type II starting frequencies for SWPC S1 (peak > 10 MeV intensity ≥ 10 pfu) and ≥ S2 events during this ~20-yr interval.

Solar Electron Deceleration in Interplanetary Space

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The propagation of flare-generated electrons through interplanetary space is usually modelled by means of a 1D focussed transport equation. Within this framework ~100 keV electrons experience little deceleration over typical timescales of impulsive events. As a result their deceleration is usually thought to be negligible and in many cases no adiabatic deceleration term is included in electron propagation models.

Here we model the propagation of electrons using a 3D test particle code. We find that electrons experience only a very small spatial drift associated to the gradient and curvature of the Parker spiral, as would be expected due to their small mass-to-charge ratio. However we find that this small spatial drift is sufficient to produce a significant deceleration due to motion against the solar wind electric field. After 10 hours of propagation, a population of electrons injected at 100 keV has decelerated by 23% on average. A focussed transport model with standard adiabatic deceleration produces a deceleration of only 7% on average, for the same population. We discuss implications of this finding.

SEP Scoreboard: Real-time Forecasting Validation

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The Royal Belgian Institute for Space Aeronomy and the Met Office UK in collaboration with the Community Coordinated Modeling Center are developing a scoreboard for the predictions of solar energetic particle (SEP) events. Developers of forecast models are able to submit their predictions using a predefined xml schema allowing for an automated real-time validation. Since the submitted forecasts will be stored in a database, verification and validation measures during a longer time period may also be derived. The scoreboard will able to compare near real-time continuous (probabilistic) as well as event-triggered predictions. The SEP Scoreboard Planning Group intends to also coordinate the submission of predictions for historical events for an SEP challenge to compare the various models. This allows predictions which cannot be provided in near real-time such as elaborate physics-based simulations to be included in the comparisons as well. During this presentation, the differences in the various types of SEP forecasts and how they are dealt with in the SEP scoreboard will be explained. Furthermore, the participating models as well as the parameters they are providing will be presented, and the planned validation and verification techniques will be discussed in detail. Finally, a comparison between the predictions for a initial set of historical SEP events will be shown for forecast models from groups that are currently participating in the scoreboard.

Long-lasting solar energetic electron injection during the 26 Dec 2013 widespread SEP event

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The solar energetic particle (SEP) event on 26 Dec 2013 was observed all around the Sun by the two STEREO spacecraft and close-to-Earth observers and is part of the event catalog studied within the High Energy Solar Particle Events foRecastIng and Analysis (HESPERIA) project. While the two STEREOs were separated by 59 degrees and situated at the front side of the associated solar event, for Earth it was a backside-event. A remarkable feature of the in-situ observations is the long-lasting anisotropy observed at all three viewpoints lasting for many hours at Wind and up to more than a day at STEREO B. Also the near-relativistic electron intensities show long-lasting rises over many hours. To explain such observations a temporally extended injection scenario is required which could be realized by the associated CME-driven shock.
Because energetic electron events were previously attributed to the class of impulsive SEP events assuming the flare to be the main source, it is important to characterize the possible role of shocks for solar energetic electrons. Especially in the context of widespread SEP events the role of efficient perpendicular transport vs. an extended source region is discussed controversially and the question, if an extended injection region is necessary for widespread events, is not yet solved.
We analyze remote-sensing and in-situ observations and discuss the role of the shock or other possible scenarios to explain the energetic electron observations.

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Multi-spacecraft observations and transport modeling of solar energetic particles in the inner Heliosphere

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The appearances of solar energetic particle events in interplanetary space around the Earth's orbit, i.e., intensity-time profiles, anisotropies, energy spectra and elemental abundance ratios are determined by a combination of the underlying acceleration, injection and transport mechanisms at the Sun and in the inner Heliosphere. The analysis and theoretical modeling of these events offers not only the possibility to study the nature of eruptive events on the Sun and the interaction of charged energetic particles with solar and heliospheric magnetic fields, but might also provide insight into the nature of energetic processes in astrophysical plasmas in general. However, by the time the energetic particles have reached the Earth, the above effects generally cannot be uniquely unfolded with observations made only at one location. We therefore focus here on results from multi-spacecraft observations (ACE/Wind with STEREO) for a number of particle events which occurred in the current solar maximum, and present applications of recently developed numerical models to simulate the pitch-angle dependent three-dimensional propagation of energetic particles in the Heliosphere. Based on observations of the lateral gradients between the various spacecraft we discuss effects of the particle transport parallel and perpendicular to the interplanetary magnetic field. In particular, we address the questions how the particles' parallel and perpendicular diffusion mean free paths vary as a function of the distance from the Sun and the heliospheric longitude, whether there might be a functional relation between them, and how they can be related to current models of solar wind turbulence.

Modeling Of Energetic Particle Transport And Acceleration At Interplanetary Shock Waves In Mixed Solar Particle Events

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We use numerical solutions of the focused transport equation obtained by an implicit stochastic differential equation scheme to study the evolution of the pitch-angle dependent distribution function of protons in the vicinity of shock waves. We consider that a flare-accelerated population of ions is released close to the Sun simultaneously with a traveling interplanetary shock for which we assume a simplified geometry and investigate the consequences of adiabatic focusing in the diverging magnetic field on the particle transport at the shock, and of the competing effects of acceleration at the shock and adiabatic energy losses in the expanding solar wind for the case of both quasi-parallel and oblique propagating shocks. We analyze the resulting intensities, anisotropies, and energy spectra as a function of time and find that our simulations can naturally reproduce the morphologies of so-called mixed particle events in which sometimes the prompt and sometimes the shock component is more prominent, by assuming parameter values which are typically observed for scattering mean free paths of ions in the inner heliosphere and energy spectra of the flare particles which are injected simultaneously with the release of the shock.

Microwave observations for forecasting energetic particles from the Sun

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Solar energetic particles (SEPs), especially protons and heavy ions, are a major space weather hazard when they impact spacecraft and the terrestrial atmosphere. Forecasting schemes have been developed, which use earlier signatures of particle acceleration to predict the arrival of solar protons and ions in the space environment of the Earth. In this study, we investigate the advantages of microwave observations for forecasting the SEP occurrence and SEP energy spectrum. The UMASEP scheme forecasts the occurrence and the importance of a SEP event based on combined observations of soft X-rays, their time derivative, and protons above 10 MeV at geosynchronous orbit. We explore the possibility to replace the derivative of the soft X-ray time history by the microwave time history in the UMASEP scheme. For the forecast of the SEP energy spectrum, we investigate if the hardness or softness of the proton spectrum in interplanetary space can be predicted from the shape of the microwave spectrum. The technique developed by Chertok et al (2009) is to use the ratio of peak microwave flux densities near 9 and 15 GHz as a predictor. Here, we tested this scheme over solar cycle 23 and 24. A detailed analysis of the results including limitations the methods are presented. We conclude that microwave patrol observations improve SEP forecasting schemes that employ soft X-rays. High-quality microwave data available in real time appear as a significant addition to our ability to predict SEP occurrence and their energy spectrum.

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Solar Energetic Particle Events with Protons > 500 MeV between 1995 and 2015 Measured with SOHO/EPHIN

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The Sun is an effective particle accelerator that produces solar energetic particle (SEP) events, during which particles of up to several GeVs can be observed. These events, when they are observed at Earth with the neutron monitor network, are called ground-level enhancements (GLEs). Although these events with their high-energy component have been investigated for several decades, a clear relation between the spectral shape of the SEPs outside the Earth's magnetosphere and the increase in neutron monitor count rate has yet to be established. Hence, an analysis of these events is of interest for the space weather and for the solar event community. n this work, SEP events with protons accelerated to above 500 MeV have been identified using data from the Electron Proton Helium Instrument (EPHIN) aboard the Solar and Heliospheric Observatory (SOHO) between 1995 and 2015. For a statistical analysis, onset times have been determined for the events and the proton energy spectra were derived and fitted with a power law. As a result, a list of 42 SEP events with protons accelerated to above 500 MeV measured with the EPHIN instrument onboard SOHO is presented. The statistical analysis based on the fitted spectral slopes and absolute intensities is discussed with special emphasis on whether or not an event has been observed as GLE. Furthermore, a correlation between the derived intensity at 500 MeV and the observed increase in neutron monitor count rate has been found for a subset of events and is used in WP4 within the High Energy Solar Particle Events foRecastIng and Analysis (HESPERIA) project.

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Near realtime forecasting of MeV protons on the basis of sub relativistic electrons

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A major impact on human and robotic space exploration activities is the sudden and prompt occurrence of solar energetic ion events. In order to provide up to an hour warning before these particles arrive at Earth, relativistic electron and below 50 MeV proton data from the Electron Proton Helium Instrument (EPHIN) on SOHO were used to implement the 'Relativistic Electron Alert System for Exploration (REleASE)'. It has been demonstrated that the analysis of relativistic electron time profiles provides a low miss and false alarm rate.
Within the High Energy Solar Particle Events foRecastIng and Analysis (HESPERIA) project the REleASE forecasting scheme was rewritten in the open access programming language PYTHON. We have shown that the ACE/EPAM observations can be adapted to the REleASE forecasting scheme to provide reliable SEP forecasts. A comparison of measured and forecast proton intensities by SOHO/EPHIN and ACE/EPAM as well as the false alarm rates and detection probabilities for solar ion events will be presented.
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Secondary Electrons from Energetic Flare Ions

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Energetic ions in solar flares are traditionally studied via their gamma-radiation. However as they pass through a target they produce secondary electrons and positrons, via both elastic and inelastic (hadronic) interactions. We use the general purpose Monte Carlo code FLUKA to study the populations of secondary particles produced by ions of the energies revealed by gamma-rays, and to make estimates of their (gyro)synchrotron and bremsstrahlung radiation. In the case of energetic electrons produced in coulomb collisions ("knock-on" electrons) we also give some analytical results for the electron energy distribution. We show that the electron energy distribution developed in a thick target will have the same form as the primary distribution of energetic ions and relate the flux of X-rays to the number of accelerated ions.

Radiation from secondary electrons may offer the possibility of estimates of ion numbers and energy distribution independent of gamma-rays. We make some comments on observing strategies that would maximize the chances of discriminating primary and secondary electrons.

The HESPERIA project: An overview

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High-energy solar energetic particles (SEPs) emitted from the Sun are a major space weather hazard motivating the development of predictive capabilities. In this work, we will present the EU HORIZON2020 HESPERIA (High Energy Solar Particle Events foRecastIng and Analysis) project, its structure, its main scientific objectives and forecasting operational tools, as well as the added value to SEP research both from the observational as well as the SEP modelling perspective. The project addresses through multi-frequency observations and simulations the chain of processes from particle acceleration in the corona, particle transport in the magnetically complex corona and interplanetary space to the detection near 1 AU. Furthermore, publicly available software to invert neutron monitor observations of relativistic SEPs to physical parameters that can be compared with space-borne measurements at lower energies is provided for the first time by HESPERIA. In order to achieve these goals, HESPERIA is exploiting already available large datasets stored in databases such as the neutron monitor database (NMDB) and SEPServer that were developed under EU FP7 projects from 2008 to 2013. Forecasting results of the two novel SEP operational forecasting tools published via the consortium server of 'HESPERIA' as well as some scientific key results on the acceleration, transport and impact on Earth of high-energy particles will be extensively presented during this Workshop.

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Joint Ne/O and Fe/O Analysis to Diagnose Large Solar Energetic Particle Events during Solar Cycle 23

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We have examined 29 large solar energetic particle (SEP) events with the peak proton intensity J_{pp} (>60 MeV) > 1 pfu during solar cycle 23. The emphasis of our examination is put on a joint analysis of Ne/O and Fe/O data in the energy range (3-40 MeV/nucleon) covered by *Wind/*Low-Energy Matrix Telescope and *ACE/*Solar Isotope Spectrometer sensors in order to differentiate between the Fe-poor and Fe-rich events that emerged from the coronal mass ejection driven shock acceleration process. An improved ion ratio calculation is carried out by rebinning ion intensity data into the form of equal bin widths in the logarithmic energy scale. Through the analysis we find that the variability of Ne/O and Fe/O ratios can be used to investigate the accelerating shock properties. In particular, the high-energy Ne/O and Fe/O ratios can be used to investigate the accelerating shock properties. In particular, the high-energy Ne/O ratio is well-correlated with the source plasma temperature of SEPs.

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Flare-accelerated particles' escape in 3D solar eruptive events

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During solar eruptions, particles can be accelerated to relativistic energies. Those energetic particles can escape from the Sun, propagate in the interplanetary medium and sometimes are detected in-situ at Earth. Solar Energetic Particles (SEPs) can be produced by the flare reconnection that is the primary driver of solar eruptive events (SEE). A key point is that in the standard SEE model, the particles should remain trapped in the coronal flare loops and in the ejected plasmoid, the CME. A fundamental question to understand the origin and the evolution of solar energetic particles the SEP is : How do solar energetic particles escape the Sun?

We developed a 3D model of a solar eruptive event that may lead to injection of energetic particles onto open interplanetary magnetic flux tubes. We performed high-resolution 3D MHD numerical simulations with the Adaptively Refined MHD Solver (ARMS). Our results demonstrate that the model does lead to the effective escape of energetic particles accelerated at the flare reconnection site. The release onto open field lines of energetic particles originating in the low corona is the bridge connecting the acceleration to the interplanetary propagation and is, therefore, the key to reconciling remote and in-situ observations of energetic particles.

We show how the complex interactions between the flare and breakout reconnection reproduces all the main observational features of SEEs and SEPs. We discuss the implications of our results for CME/flare models and for observations.

Predicting the occurrence of GLE events

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A tool for predicting the occurrence of Ground Level Enhancement (GLE) events using the UMASEP scheme [Núñez, 2011, 2015] is presented. This real-time tool, called HESPERIA UMASEP-500, is based on the detection of the magnetic connection along which protons arrive in the near-Earth environment, by estimating the lag-correlation between the time derivatives of 1-minute soft X-ray flux (SXR) and 1-minute proton fluxes observed by the GOES satellites. Unlike current GLE warning systems, this tool can predict GLE events before the detection by any neutron monitor (NM) station. For the 2000-2016 period, this prediction tool obtained a probability of detection (POD) of 53.8% (7 of 13 GLE events) and a false alarm ratio (FAR) of 30.0%. These performance metrics were calculated considering that a GLE prediction is successful when it is triggered before the first NM station's alert. For the aforementioned period, this tool also obtained average warning times (AWT) of 8 min with respect to the first NM station's alert and 15 min to the GLE Alert Plus's warning. This project has received funding from the European Union’s Horizon 2020 research and innovation program under grant agreement No 637324.

Interplanetary Transport Of Solar Electron Events Detected Over A Narrow Range Of Heliolongitudes

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The interplanetary transport conditions of solar energetic particles (SEPs) have a direct influence on the characteristics of the intensity-time profiles and the particle pitch-angle distributions observed in-situ at the spacecraft location. We analyze SEP events detected simultaneously by the two STEREOs, when the longitudinal separation between the two spacecraft was of only ~35º. The selected SEP events are magnetically well-connected to an unambiguous solar source location and they are not accompanied by type II radio bursts.

We use solar near-relativistic electron measurements provided by the STEREO/SEPT instrument. The four fields of view of this instrument allow us to include the evolution of the electron pitch-angle distributions in the study. The results of a Monte Carlo interplanetary transport model combined with an inversion procedure (SEPinversion) are then used to fit the observations. We present the results for the selected events and discuss the shapes of the intensity-time profiles in relation to the derived values of the electron mean free path and the observed solar wind conditions.

Data driven statistical approaches for Solar Energetic Particle (SEP) Events forecasting

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We report on new data driven statistical methods that have been developed for both the likelihood of Solar Energetic Particle (SEP) event occurrence and the expected SEP characteristics based on precursor information on solar flares (SFs) [forecasting mode] and actual data of solar flares, coronal mass ejections and radio bursts [nowcasting mode]. The former mode makes use of the expected full disk probability of SFs per active region, while the latter mode employs three independent sub-modules, each based on different input data. As concerns SFs (at either mode) a reductive statistical method for the SEP probability of occurrence has been implemented. It makes use of, either, the expected full disk probability or of the location of the flare (longitude) and the flare size (maximum soft X-ray [SXR] intensity). Moreover, employing CME parameters (velocity and width), proper functions per width (i.e. halo, partial halo, non-halo) and integral energy (E>30, 60, 100 MeV) have been identified. Finally, using as input the SXR and radio fluence, another (non-operational) module for the probability of SEP occurrence, based on the ESPERTA concept, has been implemented. We present the modules, their interconnection and the operational set up. Finally, we demonstrate the validation of each module using categorical scores (POD, FAR, HSS) constructed on archived data and we further discuss independent case studies.

The HESPERIA host server set-up

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The HESPERIA host server is a physical maschine distributed over six (5) Virtual Maschines (VMs), each of which serves a purpose. In this work, an overview of the HESPERIA Host Server is given, including the basic software and hardware architecture, its components, as well as, monitoring and backup procedures. We then go into details concerning the functionalities of each of the operating VMs of the system. In addition we describe how the functional and non-functional requirements were transformed into technical system design specifications from which the HESPERIA system was built. Finally, we show the high-level system design specifications and their decomposition into low-level detailed design specifications for each of the system's components, including hardware, internal communications, software and external interfaces.

Characteristics of 29 Sustained-Emission >100 MeV Gamma-Ray Events Associated with Impulsive Solar Flares

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We detail the characteristics of 29 sustained-emission >100 MeV solar gamma-ray events observed by Fermi that are distinct from the associated impulsive flares. The >100 MeV gamma-ray emission is well fit by pion-decay spectra produced by >300 MeV protons following a power-law spectrum, or one that rolls over at high energy, and is inconsistent with bremsstrahlung from primary electrons. Sustained gamma-ray emission results: 1) temporal characteristics -- onset times from CME launch to 80 min later, durations from 4 min to 20 hr that are correlated with >100 MeV SEP durations, neither due to tail of the impulsive flare nor post-flare episodic emission; 2) proton characteristics—spectra soften >100 MeV to a mean power-law index –4.5 > 300 MeV, evidence that spectra of long-duration events soften in time and that short-duration spectra harden in time, proton number >10 times that in the impulsive flare and 10^{-2} times that in accompanying SEP; 3) location: neither just from active region nor globally from Sun, but can extend tens of degrees from the AR; 4) associations: all with impulsive flare HXRs >100 keV and all but two with CMEs, bremsstrahlung from MeV electrons observed along with sustained gamma rays from a behind-the-limb flare. The sustained gamma-ray emission is likely produced by CME shock acceleration, common to that producing the associated SEPs, of a seed population that includes sub-MeV flare particles onto magnetic field lines returning to the Sun.

Simulating Solar Energetic Particle Transport

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The processes involved in solar energetic particle (SEP) transport are still poorly understood. This is especially true for perpendicular diffusion that may play an important role in producing so-called widespread SEP events. Here, we review our recent progress in simulating SEP transport, including perpendicular diffusion, using a theoretical basis for the relevant transport coefficients. Our results show that perpendicular diffusion is an important ingredient in SEP transport which cannot be neglected as was mostly done in the past, especially when comparing simulations with multi-spacecraft observations. Recently, a simplified version of the model was also used to simulate ground level enhancement (GLE) events, showing that, even for these high energies, particle diffusion must be taken into account when interpreting observations. Lastly, we discuss some of the future problems that we will address as part of this project.

Multi-spacecraft solar energetic particle analysis of FERMI gamma-ray flare events

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Multi-spacecraft observations of solar energetic particle (SEP) events, exploited within the HESPERIA Horizon 2020 project, are important for understanding the acceleration processes and the interplanetary propagation of particles released during eruptive events.

We analyse some gamma-ray flare events observed by FERMI and investigate possible associations with SEP-related events observed with STEREO and L1 spacecraft in the heliosphere. Data-driven analysis methods (e.g. velocity dispersion analysis) are used for deriving the release time of protons and electrons at the Sun and for comparing them with the respective times stemming from the gamma-ray event analysis and the respective electromagnetic emission signatures, aiming to interconnect them and better understand the physics involved.

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Extreme solar particle events: What is the worst case scenario?

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The era of direct or indirect (ground-based) observations of solar energetic particle (SEP) events covers 40 and 70-80 years, respectively. About 70 hard-spectrum events detectable at the ground-level (called GLE) have been recorded, the greatest being GLE #5 on 23-Feb-1956. Yet, for many practical purposes it is important to know whether the Sun can produce stronger events, how much stronger and what the expected rate of their occurrence can be. In order to answer these questions, we need to study much longer time scales, covering millennia, which can be done only using proxy data of cosmogenic radionuclides. Here we present an overview of the present day knowledge of the extreme SEP events and assessments of the worst case scenario for the SEP fluence in the vicinity of Earth.

Why is Solar Cycle 24 Inefficient in Producing High-Energy Particle Events?

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The aim of the study is to investigate the reason for the low productivity of high-energy SEPs in the present solar cycle. We employ scaling laws derived from diffusive shock acceleration theory and simulation studies including proton-generated upstream Alfvén waves to find out how the changes observed in the average properties of the erupting and ambient coronal/solar wind plasma would affect the ability of shocks to accelerate particle to the highest energies. Provided that self-generated turbulence dominates particle transport around coronal shocks, it is found that the most crucial factors controlling the diffusive shock acceleration process are the number density of seed particles and the plasma density of the ambient medium. Assuming that suprathermal populations provide a fraction of the particles injected to shock acceleration in the corona, we show that the lack of most energetic particle events as well as the lack of low charge-to-mass ratio ion species in the present cycle can be understood as a result of the reduction of averate coronal plasma and suprathermal densities in the present cycle over the previous one.

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Energy Spectra and Abundance Ratios of Heavy Ions in HESPERIA Gamma-Ray Events

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We have investigated event-integrated energy spectra and abundance ratios of heavy ions (He, O, Ne, Fe+Ni) in some of the HESPERIA gamma-ray events by using data from SOHO/ERNE. For each element ten energy channels were nominally used ranging from 3.22 to 162 MeV/nucleon for oxygen. The studied events were selected from the HESPERIA list of FERMI/LAT gamma-ray events based on detection of heavy ions above the background and on the continuity of ERNE data over the entire event. These criteria limited the investigation to events n:o 1, 2, 3, 9, 15, 19, 23, and 24 of the HESPERIA list. Of these, event 2 was so weak that only helium and oxygen were observed above background, while event 9 was strong enough to partly saturate the instrument. For event 23, data from only five highest energy channels were available.

We fitted the measured intensities of all ion species as function of energy by using broken power-law functions. The break energies of oxygen and neon were similar in all events, while the break energy of the Fe+Ni group was typically by factor of two lower than that of O and Ne. From event to event, the O and Ne break energies varied from 5 to 20 MeV/nucleon. We also calculated to abundance ratios O/He, Ne/O, (Fe+Ni)/O, and (Fe+Ni)/Ne as function of energy. For most events, a regular behaviour of the abundance ratios as function of energy was found. The Ne/O ratio was remarkably constant in all events with values ranging from 0.1 to 0.3. In (Fe+Ni)/O and (Fe+Ni)/Ne ratios larger variations were found, partly explained by low statistics, and the energy dependence of the ratios was also different from event to event.

A search for radio and X-ray counterparts of long-lasting solar gamma-ray emission from relativistic protons

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The FERMI/LAT gamma-ray experiment observed a surprisingly large number of solar events with gamma-ray emission above photon energies of 100 MeV. The emission is likely due to pion-decay photons. This implies that the acceleration of protons in the solar corona to energies above 300 MeV is much more frequent than previously thought. In some cases, the emission persists over several hours. We conduct an extensive study on the relationship between these gamma-ray emissions and electromagnetic signatures of accelerated electrons in the corona. This contribution is to present the results on a sample of 25 gamma-ray events, some with a very long duration signature (> 6 hours) and some with a shorter duration (<1 hour) starting immediately after the impulsive phase. We compare the durations of the gamma-ray emission with hard X-ray, metric, decametric and microwave signatures, to see if long-duration gamma-ray events are accompanied by signatures of long-duration electron acceleration. In our sample, we found no evidence that microwave or X-ray signatures of electrons accompany the long-duration gamma-ray emission. However, type IV radio emission in the metric and decimetric range (lasting several hours) seems to be associated only with the gamma-ray events of very long duration. We review the origin of the type IV burst emission and its relationship with the flare and CME, and discuss whether there can be a physical link between the acceleration of the radio-emitting electrons and the gamma-ray emitting relativistic protons.

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