

Heliospheric Energetic Particles and Galactic Cosmic Ray Modulation

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Abstract. The paper presents an overview of the SH ‘Solar and Heliospheric cosmic rays’ session of the 24th European Cosmic Ray Symposium (ECRS), Kiel, Germany, 2014. It covers the topics of Solar Energetic Particle (SEP) origin, acceleration and transport at the Sun and in the interplanetary medium, also from the aspect of multi-spacecraft observations, as well as the Galactic Cosmic Ray (GCR) short- and long-term variations and the Jovian electron variations in the heliosphere. Relevant instruments and methods presented are also covered by this review. The paper is written from a personal perspective, emphasizing those results that the author found most interesting.

1. Introduction

Solar Energetic Particles (SEPs) and Galactic Cosmic Rays (GCRs) are two high-energy particle populations in the heliosphere [1]. Both populations are important components of the space radiation environment [2], also posing risks to flight crews and instruments and constituting a major space weather concern in planning for long-duration manned missions [3]. Ground level enhancements (GLEs), the high-energy SEP component, provide the opportunity to detect energized coronal material from the Sun that reaches Earth’s atmosphere within a matter of ~10 minutes [4]. In this paper the results of the SH session ‘Solar and Heliospheric cosmic rays’ of the 24th European Cosmic Ray Symposium (ECRS) are reviewed. During this session 30 oral contributions and 34 poster contributions were presented and considered in this review. Throughout the paper a particular contribution is cited by reference to the name of the first author and the corresponding Abstract Number as in the ECRS Programme (SH***). It should be noted that the results considered as most interesting by the author are highlighted in the paper.

The paper is organized, based on my division of the presented papers, as follows: in section 2 the results on Solar Energetic Particles are presented, discussing the origin, acceleration and transport of SEPs, also based on multi-spacecraft observations as well as space weather and space climate results from the SEP perspective. In section 3, Forbush decreases and GCR short term variations are discussed, in section 4 the results presented on the long term variations of GCRs are highlighted, in section 5 Jovian electron variations in the heliosphere are discussed and in section 6 the instrumentation and methods are summarized. In section 7 the results are briefly summarized and future prospects are discussed.

2. Solar Energetic Particles



2.1. Origin of Solar Energetic Particles

The origin of SEPs has been an issue under debate for decades. Potential accelerators in different regions of the corona exist, namely magnetic reconnection in the flaring active region, as well as shock waves driven out from the Sun by fast Coronal Mass Ejections (CMEs) [5]. Many attempts were made in the past to identify a unique accelerator by establishing statistical relationships between SEP parameters, particularly their peak intensity measured near 1 AU and one of the quantities describing the importance of the associated eruptive activity – flare radiation on the one hand, and the speed of the CME on the other [6,7,8,9,10].

Klein et al. (SH423) carried out a comparative analysis of the correlation between SEP intensities – electrons between a few tens and a few hundreds of keV, protons at some tens of MeV- with quantities characterizing the eruptive solar activity: CME speed, and quantities describing the flare-related energy release: peak flux and fluence of the soft X-ray (SXR) emission and fluence of the microwave emission. Their sample comprises 38 SEP events associated with flares of SXR M and X-class at western longitudes during the period 1997-2006, as listed in [7], in which the flare-related particle acceleration is accompanied by radio bursts indicating electron escape into the interplanetary space [11]. The novel approach of this study compared to earlier work is that besides the classical Pearson correlation coefficient the partial correlation coefficients are calculated and the effects of correlations between the solar parameters themselves are disentangled. The partial correlation analysis shows that the only parameters that significantly affect the SEP intensity are the CME speed and SXR fluence, with no additional contribution by the SXR peak flux and the microwave fluence [12]. The authors concluded that their findings bring statistical evidence that both flare acceleration and CME shock acceleration contribute to the deka-MeV proton and near-relativistic electron population in large SEP events.

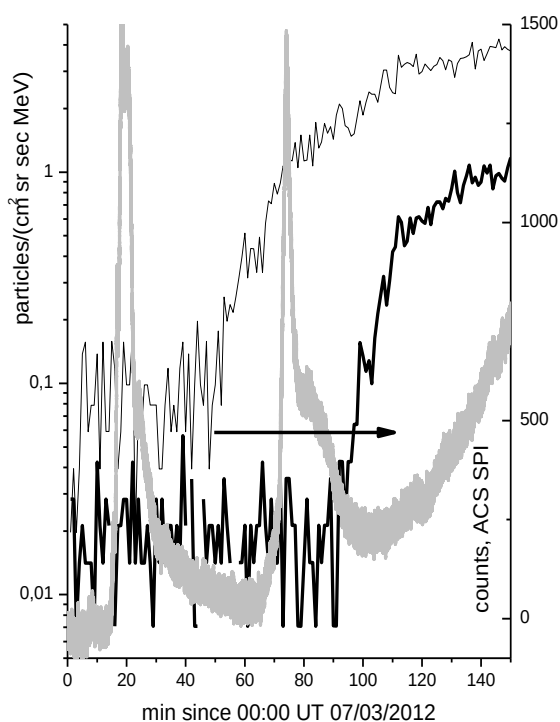


Figure 1. Onset of the SEP event observed on 7 March 2012 by HET/STEREO B (thin black line – 1.4-2.8 MeV electrons, thick black line – 29.5-33.4 MeV protons) in comparison with ACS SPI count rate (grey line). The arrow marks the first Fermi time window (Struminsky et al. SH316).

Investigating the origin of SEPs with new earlier unavailable instruments, Struminsky et al. (SH316) considered 18 solar flares in which high energy > 100 MeV γ -emission was registered by the Large Area Telescope (LAT) instrument onboard the Fermi Gamma-Ray Observatory (FermiGRO) [13, 14]. They checked for these events intensity time profiles observed in SXR (GOES)

(<http://www.ngdc.noaa.gov/stp/satellite/goes/>) and hard (INTEGRAL/ACS SPI) X-rays (HXR) [15, 16, 17] and fluxes of SEPs registered in the heliosphere. The STEREO mission consists of two nearly identical space-based observatories (STEREO-A and STEREO-B) launched on October 25, 2006 [18]. Figure 1 presents the onset of the SEP event observed by the HET/STEREO-B on March 7, 2012 in comparison with ACS SPI count rate. The arrow marks the first Fermi time window i.e. the time interval of first high energy gamma ray observations in the event of March 7, 2012 (see Table 1 of [14]). The ACS SPI data can show processes of energy releases and particle acceleration, which are not visible by instruments aboard the RHESSI [19] or FermiGRO spacecraft due to peculiarities of their low circular orbits. These authors found that bursts of solar HXR emission were observed in the impulsive phase of the 12 events detected by ACS SPI under study, whereas HXR-bursts were not detected during the prolonged decay phase of high energy γ -emission in these 12 solar flares (or in some cases were masked by SEP events). Four solar flares with >100 MeV γ -rays were found not to be associated with SEP events even considering data from three different point in the heliosphere, i.e. with STEREO A/B and SOHO [20]. Thus, these authors concluded that if particles interacting in the solar atmosphere and propagating in the heliosphere are the same populations, then processes of particle release are very important. Also, continuous high energy X-ray and gamma solar observations with better spatial, temporal and energy resolution for progress of the SEP origin issue are needed.

2.2. Solar Energetic Particle Acceleration and Transport

2.2.1. Acceleration and Transport Modelling. Petukhova and Petukhov (SH192) studied the efficiency of surfing acceleration [21] and concluded that it depends on the value of a potential jump, stream velocity, and particle distribution function injected into the acceleration process. The transport of Cosmic Rays (CRs) in the heliosphere is dominated by the interaction with magnetic irregularities (Spanier et al. (SH149)). Kocharov et al. (SH170) presented a semi-transparent shock model they developed for gradual SEP events. Based on plasma observations, the turbulence energy levels in neighbouring magnetic tubes of solar wind may differ from each other by more than one order of magnitude. These authors considered the effect of such intermittency on the acceleration and transport of protons in travelling shocks. [22] have modelled the diffusive shock acceleration of the sub-MeV seed particles available upstream of the shock and the transmission through the Interplanetary (IP) shock wave of high-energy ions from coronal sources situated behind the shock.

They performed new modelling, shown in figure 2, of the acceleration and transport of both the high-energy ions escaping into the IP medium and the ions precipitating into the solar chromosphere, where they produce via nuclear interactions the secondary emissions, γ -rays and neutrons [14, 23]. They modelled particle acceleration in the spherical IP shock wave expanding through the radial structure that comprises the highly turbulent central core (the acceleration core θ_A in figure 2) embedded into a wider cone of quiet plasma via which the accelerated particles can escape (the particle escape sector) and propagate towards or away from the Sun. The model presented also accounts for stochastic re-acceleration by shock-amplified turbulence behind the shock (shaded region in figure 2). Figure 3 shows the time-integrated energy spectra of accelerated protons for the two modelled cases: without (A) and with (B) stochastic re-acceleration of the shock accelerated particles. Interacting and interplanetary distributions are the time-averaged distributions of particles escaping at the bottom and the top of the simulation box, respectively. They found that including the shock downstream re-acceleration can increase the interacting-to-interplanetary proton ratio by an order of magnitude more than would be expected for original shock acceleration (closed red points in case B versus points of case A). They also concluded that the characteristics of the cross-field transport and seed particle distribution are crucial for such modelling. Dalla et al. (SH387) showed that drift motions of particles associated with gradient and curvature of the Parker spiral magnetic field lead to the particles experiencing a deceleration, which they quantified through full orbit test particle simulations of protons.

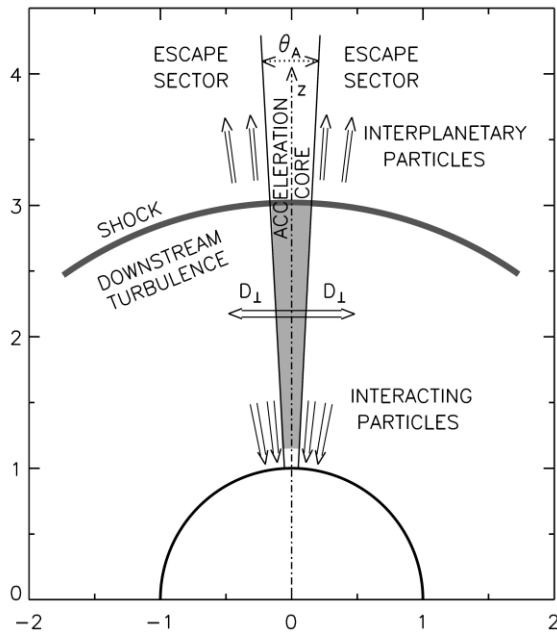


Figure 2. Particle acceleration and transport model. The model also accounts for stochastic re-acceleration by shock-amplified turbulence behind the shock (shaded region) (see text) (Kocharov et al. SH170).

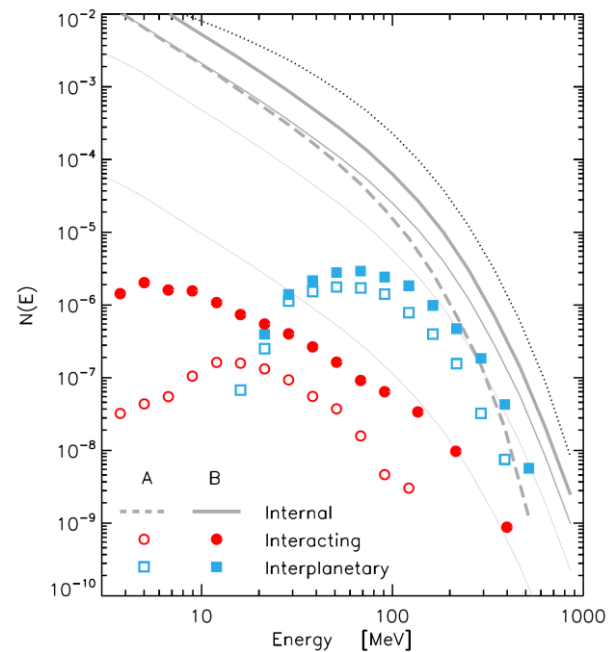


Figure 3. Energy spectra of accelerated protons for the two modelled cases: (A) without stochastic re-acceleration of the shock-accelerated particles and (B) with stochastic re-acceleration (Kocharov et al. SH170).

2.2.2. Multi-spacecraft Observations. The STEREO twin spacecraft have provided multi-spacecraft observations available to the SEP research community [19]. In February 2011 the two STEREO spacecraft reached a separation of 180 degrees in longitude, offering a complete view of the Sun for the first time ever. SOHO [20], ACE [24] and Wind [25] near-Earth observations can be used to offer a third vantage point (Zelina and Dalla, SH394, Klassen et al. SH447). Of particular importance for the extraction of conclusions on the particle acceleration and transport is the analysis of the particle anisotropy characteristics by Dresing et al. (SH287), who carried out a statistical survey of wide spread events in the heliosphere. Their main selection criterion for these events is that the longitudinal separation between active region and spacecraft magnetic footprint is at least 80 degrees for the widest separated spacecraft. They investigated the events in a statistical manner in terms of maximum intensities, onset delays, and rise times and determined their longitudinal extent. They also investigated energetic electron anisotropies (see [26] for anisotropy definition) to disentangle source and transport mechanisms leading to the observed wide particle events. These authors divided the events in three classes, presented in figure 4. In Class 1 significant anisotropy is observed at a well-connected spacecraft ($\phi < 60^\circ$) but almost no anisotropy at a far separated one ($A < 0.6$ at $\phi > 60^\circ$, with ϕ being the longitudinal separation). In the events of Class 2 the highest anisotropy is observed by the best connected spacecraft but significant anisotropy ($A > 0.6$) is still observed at far separated positions ($\phi > 60^\circ$). In the Class 3 events the highest anisotropy is not observed by the best-connected spacecraft but by a further-separated one. Figure 4 (top part) shows the three sketches presented by these authors, in agreement with the variable anisotropy distributions observed. While in the first sketch, corresponding in the Class 1 events, just a small source region at the Sun (flare) is present (yellow star), the scenarios for the other two Classes 2 & 3 comprise an extended source region at the Sun (red arc). In all three diagrams red areas mark regions of strong anisotropy, because here a good connection to the source is present. In the Class 1 sketch, just a well-connected observer detects an anisotropic increase but far-separated spacecraft observe an isotropic event. Thus, SEPs reach far-

separated positions just due to strong perpendicular diffusion, with vanishing anisotropies (represented by the gray areas). The presence of perpendicular transport in the IP medium is represented by the wavy magnetic field lines in the sketches. In the Class 2 scenario the SEPs are injected over a much wider angular range at the Sun and under normal conditions particles arrive at the spacecraft with a noticeable anisotropy. This results to a significant anisotropy detected over a larger longitudinal extent correlated with the extent of this source region. In the Class 2 events, the best-connected observer

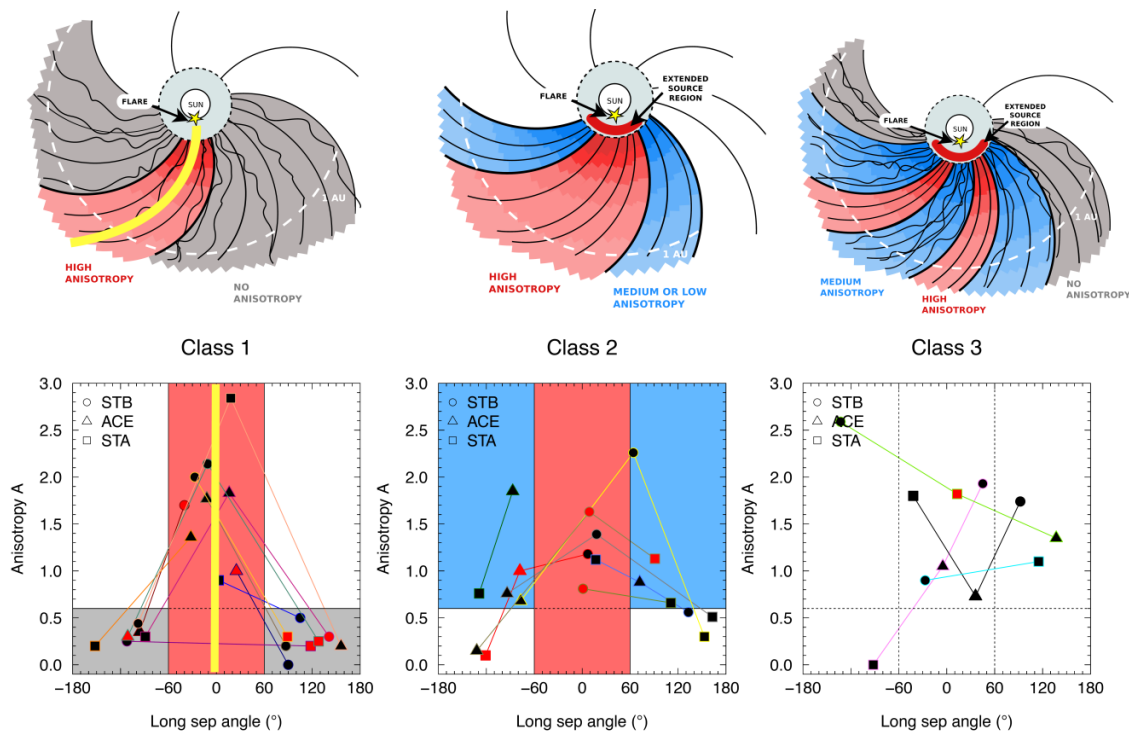


Figure 4. (Top) Sketches for each Class in agreement with the variable anisotropy distributions observed (Bottom) Maxima of absolute anisotropies observed during the early phases of the events for the three event classes. Black symbol fillings denote that the pitch angle coverage was sufficient whereas red symbol fillings denote that the anisotropy may be underestimated due to poor pitch angle coverage. The color fillings mark the borders defining the different anisotropy classes (see text) (Dresing et al. SH287).

detects the largest anisotropy but further-separated spacecraft still observe significant anisotropies during the rising phase of the event. The events in Class 3 are the more challenging to explain because the best-connected spacecraft does not observe the highest anisotropy but a further-separated one does. In the Class 3 sketch an extended source region is also present but the propagation conditions in the IP medium vary so that a nominally best-connected spacecraft may not observe the highest anisotropy because of a smaller parallel mean free path in this region. A neighbouring spacecraft, however, may detect the highest anisotropy because of a rather scatter-free transport to its position. However, also pre-event CMEs or large IP flux rope structures could produce Class 3 observations, when a better connection to a further-separated spacecraft is provided than the nominally best-connected one [27, 28]. Dresing et al. (SH287) concluded that they found evidence for both efficient perpendicular transport in the IP medium and a broad SEP spread close to the Sun. A mixture of processes is thus very likely.

The kinetic energy spectra of several SEP events were investigated by Laurenza et al. (SH344) through the Shannon's differential entropy [29, 30] during different phases of the selected events and the implications for the shock acceleration mechanisms were discussed. As an example, figure 5

presents the energy integrated flux (upper panel) and Shannon's entropy $S(t)$ computed for the 21 March 2011 SEP event observed by STEREO A (lower panel). The change of the Shannon entropy indicates that the spectral shape continuously changes throughout all the considered SEP event. During the period indicated by the two vertical lines in figure 5 a relatively constant $S(t)$ is observed, where also the energy integrated flux is almost flat (plateau phase). In this plateau phase, the spectrum can be considered to be almost stable and should also contain the main source acceleration processes. At the shock arrival particles are accelerated locally (violet vertical lines). Figure 6 presents time averaged spectra over the plateau phase (green dots, left panel), at the shock passage (violet dots, left panel) and over the whole duration of the event (right panel in figure 6). As [31] previously also found for the 4 April 2000 SEP event the Weibull distribution is the best fit for the energy spectrum both at the shock passage at the Earth and for the plateau phase. These authors elaborated that this can be explained in terms of a stochastic multiplicative process, such as the first order Fermi acceleration, which is supposed to be effective at shock waves. In the theory of extreme deviations, the Weibull shape is associated with the Probability Density Function (PDF) of the multiplication of random variables, when assuming a threshold to mimic the system size limitation [32, 33]. The same functional form was also found to fit the spectra at reverse shocks of Corotating Interaction Region (CIR) events by these authors. As they stated more work is needed to provide a theoretical evidence for the link between this spectral shape and particle acceleration.

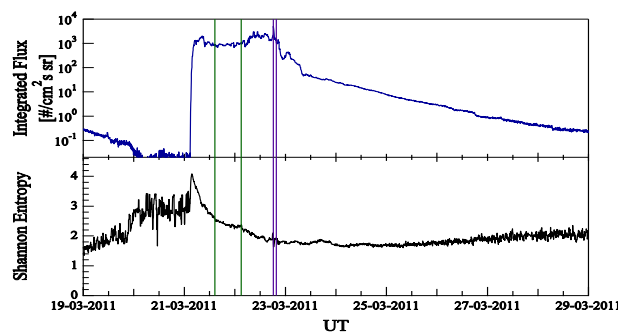


Figure 5. Energy integrated flux (upper panel) and Shannon's entropy computed for the 21 March 2011 SEP event (lower panel). Vertical lines indicate the time intervals during which the spectra in Figure 6 have been derived (Laurenza et al. SH344).

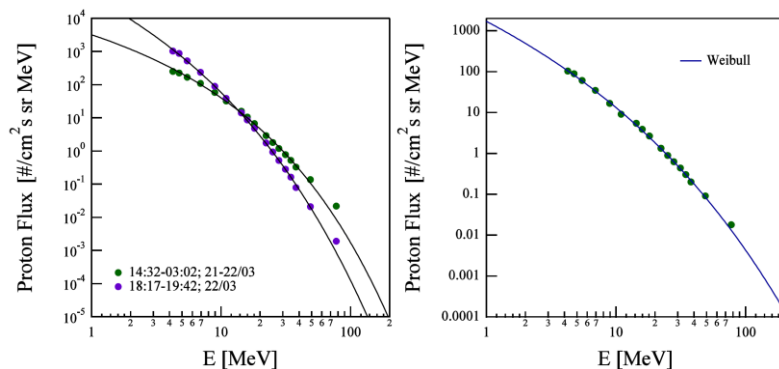


Figure 6. Time-averaged spectra over the plateau phase (green dots, left panel) at the shock passage (violet dots, left panel) and over the whole duration of the event (right panel) (Laurenza et al. SH344).

2.3 GLE Events: Observations and Modelling

GLE events are related to the most energetic class of SEP events, associated with both solar flares and CMEs, and requiring acceleration processes that produce particles with energies ≥ 500 MeV upon entry in the Earth's atmosphere. GLE data recorded by the worldwide Neutron Monitor (NM) network are a useful resource for space weather modelling during solar extreme events. Plainaki et al. (SH568) reviewed how their Neutron Monitor Based Anisotropic GLE Pure Power Law (NMBANGLE PPOLA) model [34] can lead to the derivation of the properties of the relativistic solar protons during a GLE. They presented results for two test cases, GLE60 and GLE71. 5-min GLE data for GLE60, on 15 April 2001, and 29 NM stations for GLE71, on 17 May 2012, widely distributed around the Earth were incorporated to fit the equations of the model giving the time variations $\Delta N/N_0$ of the total

neutron counting rate N_0 , observed at cut-off rigidity R_c , at level h in the atmosphere at some moment t , and the equation of A , the dimensionless normalized function that describes the spatially anisotropic arrival of the Solar Cosmic Rays (SCRs) at 1 AU, [34, 35]. The Levenberg-Marquadt non-linear optimization algorithm was applied for these events. The SEP spectrum obtained by these authors is presented in figures 7 and 8. Figure 7 shows the spectral index evolution (upper panel) and SEP fluxes (lower panel) on 15 April 2001 at an altitude of ~ 20 km, with a hard spectrum of accelerated protons during the initial phase of GLE60 and a rather soft spectrum in later phases i.e. after 14:00 UT ($\gamma \sim 5.5$). During the initial phase of GLE71 a spectral index $\gamma \sim 2.1$ is obtained (figure 8) whereas in later phases i.e. after 02:20 UT, the result is a rather soft spectrum of accelerated protons ($\gamma \sim 3.8$). These authors deduced that their results for both events are in good agreement with estimations based on other works, e.g. [36] and the results for GLE71 are consistent with the typical range found by [37] for shock wave acceleration in case of relativistic SEP events, although a direct flare contribution cannot

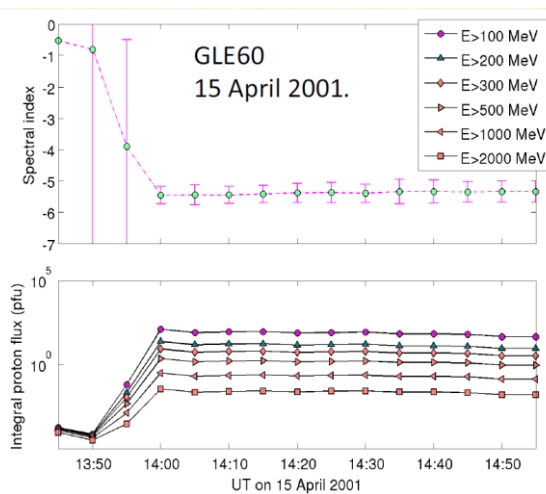


Figure 7. Spectral index evolution (upper panel) and SEP fluxes (lower panel) on 15 April 2001, at an altitude of ~ 20 km (Plainaki et al. SH568).

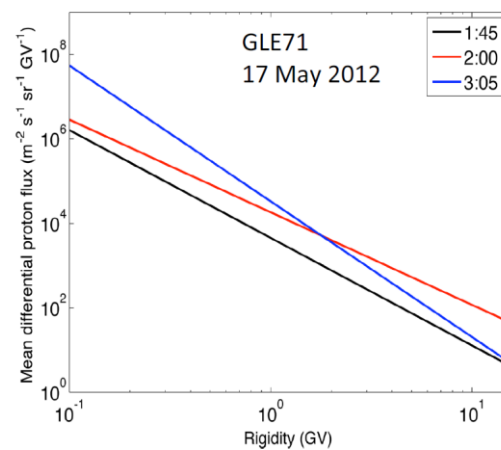


Figure 8. SEP spectrum on 17 May 2012, at an altitude of ~ 20 km (see text) (Plainaki et al. SH568).

be excluded. Comparison by these authors of the integral SEP fluxes calculated by the NMBANGLE PPOLA model with GOES observations showed that in the higher energy range the model results can provide realistic estimation of the SEP fluxes [35].

Computation of radiation dose rate at flight altitudes is of particular importance [38]. The dose rate can be strongly affected by the spread of GLE parameters deduced from NM data by different groups [35, 39, 40], the causes of which were investigated by Bütikofer and Flückiger (SH296). They performed detailed calculations of the GLE parameters for the GLE70 event, on 13 December 2006 using different NM response functions (figure 9) and found, that the ambient radiation dose rate caused by SCRs at high geomagnetic latitude and at typical cruise altitude (~ 11 km) is ~ 2 μ Sv/h, when they used the coupling function of [41] and ~ 5 μ Sv/h when they used the other two yield functions [42, 43], thus showing significant differences. Other possible reasons in the derived GLE parameters having significant consequences in the computed radiation dose rates were found to be the asymptotic directions and cut off rigidities computed with different geomagnetic field models, as well as the selection of NM stations. Based on their calculations, the assumed form of the particle pitch angle distribution wasn't found to play a significant role. These authors highlighted the need for more detailed exchange of information on the different GLE analysis procedures between specialists and suggested a forum for this to materialize (EURADOS WG11).

Kryakunova et al. (SH176) analysed the behaviour of the Cosmic Ray (CR) intensity at the worldwide NM network in the events of 2012 when there was a significant increase of the integral

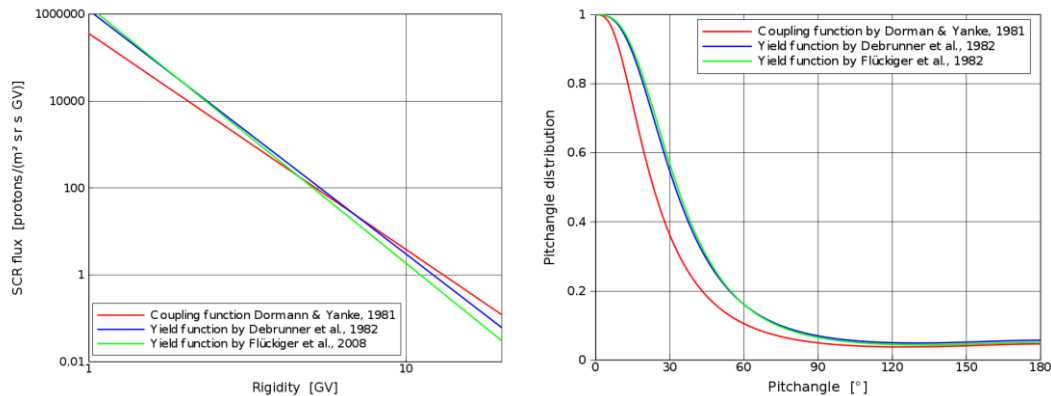


Figure 9. Deduced SCR spectra (left) and pitch angle distributions (right) by using different NM response functions (Bütikofer and Flückiger SH296).

proton flux with energies > 100 MeV, namely in the events of January 27, March 7, and March 13, 2012. According to them all these events can be considered as candidates for the GLEs of SCRs, increasing the number of GLEs observed in solar cycle 24 than widely recognised. Köhl et al. (SH271) presented the extended measurement capabilities of the EPHIN instrument onboard SOHO providing particle spectra up to 1 GeV. The solar source of GLEs, their propagation conditions as well as their impact on the Earth environment during the last two solar cycles was investigated by Catalán et al. (SH214) using NM and SOHO data.

2.4 Space Weather and Space Climate: The SEP Perspective

As Usoskin and Kovaltsov (SH510) pointed out a typical quantity for a Solar Particle Event (SPE) is the fluence of SEPs with energy above 30 MeV, F_{30} [44]. There is sufficient knowledge of SPEs over the space era since the mid-1950s [45] with only several events with $F_{30} = (1-10) \times 10^9 \text{ cm}^{-2}$ and hundreds of weaker SPEs observed. Figure 10, shows the probability of occurrence of the annual fluence (> 30 MeV) exceeding the given value F_{30} , with open triangles showing the measured annual fluences for the space era (1956-2008) and the black triangle reflecting the fact that no SPE with fluence $F_{30} > 10^{10} \text{ cm}^{-2}$ was observed [44]. However, it is important to know, both for purely theoretical aspects of solar/stellar physics and for technical applications, the statistics of extreme SPEs with $F_{30} > 10^{10} \text{ cm}^{-2}$, a study possible only by using indirect proxy data, as carried out by these authors. They used data on the cosmogenic isotopes ^{14}C and ^{10}Be in terrestrial archives spanning the timescale from centuries to 11 millenia. Figure 10 summarizes their obtained results. In the annually resolved ^{10}Be data, four events with $F_{30} = (1-1.5) \times 10^{10} \text{ cm}^{-2}$ (open red star in figure 10 corresponds to these 4 candidate SPE events) and no events with $F_{30} > 2 \times 10^{10} \text{ cm}^{-2}$ (filled red star corresponding to this) were identified since 1400 AD. From more roughly resolved data, they identified 20 SPE candidates with $F_{30} = (1-3) \times 10^{10} \text{ cm}^{-2}$, (represented in figure 10 by the open blue circles) and clearly no event with $F_{30} > 5 \times 10^{10} \text{ cm}^{-2}$ (represented by the filled blue circle) over the last 11,400 years. They found that practical limits can be set as $F_{30} \sim 1, 2-3$ and $5 \times 10^{10} \text{ cm}^{-2}$ for occurrence probabilities $\sim 10^{-2}, 10^{-3}$, and 10^{-4} yr^{-1} , respectively [44]. The authors also revisited these assessments on a timescale of up to 1 Myr, based on measurements of cosmogenic radionuclides in lunar rocks and concluded that the three timescales yield a consistent distribution, with the data suggesting a strong roll-over of the occurrence probability, so that SPE events with $F_{30} > 10^{11} \text{ cm}^{-2}$, are not expected on a Myr timescale [46]. Herbst et al. (SH323), besides the variation of cosmogenic radionuclides due to the modulation of GCRs, investigated the influence of 58 out of the 71 GLEs which occurred within the past 5 solar cycles and discussed the possibility to detect such events in present ice-core and tree-ring records. The investigations showed that none of the modern GLE events has had a detectable impact on the global ^{14}C , ^{10}Be and ^{36}Cl production. However, two major points were given: 1) surprisingly, most sensitive to the influence of GLEs is the radionuclide ^{36}Cl and 2) in order to increase the production about 15%,

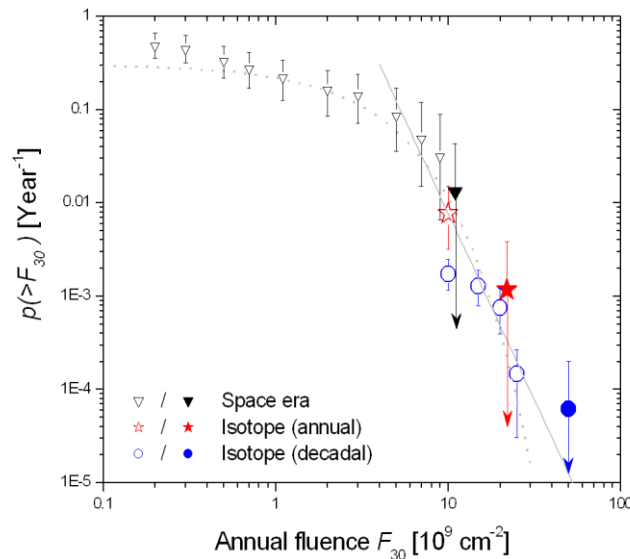


Figure 10. Summary of the obtained results based on cosmogenic isotope ^{14}C and ^{10}Be data (see text) (Usoskin and Kovaltsov SH510).

like e.g. during the 775AD event, a GLE flux up to 10 times higher than the strongest GLE ever measured (23rd February 1956) would have been necessary.

Following a different approach, Miroshnichenko (SH376) analysed all available data on the largest SPEs for the period from 1561 up to now, identifying a number of physical and methodological limitations that are important for the estimation and prediction of hazardous SCR radiation fluxes [47]. Very promising in this direction is the combination with the ‘Upper Limit Spectrum’ (ULS) [48, 49] they carried out to develop a new approach to the ‘worst-case’ concept with the Carrington event, providing a crucial normalization point for this goal.

As Bakaldin et al. (SH127) pointed out the direct ion charge measurement of CRs with energies more than several MeV/nucleon is impossible. They presented the main results of their experimental analysis and Monte-Carlo simulations of the geomagnetic separator technique possibility for the study of CR ion charge state composition in the energy range from several MeV/nucleon to hundreds of MeV/nucleon. Protopopov et al. (SH440) presented the exploitation results of the Roscosmos space radiation exposure on electronic components of engineering Monitoring System elements. Calculation of different particle contribution in dose rate increases were carried out and presented. These authors showed that solar particle exposure can be a cause of considerable dose rate increase and consequently electronic equipment failure. But the main cause of dose rate increasing events at the circular orbit ~ 20000 km is electron exposure.

3. Forbush Decreases and GCR Short Term Variations

During the passage of Interplanetary Coronal Mass Ejections (ICMEs) decreases in energetic particle fluxes are measured in a very wide energy range. These decreases were first observed by ground-based detectors and were termed Forbush decreases (FDs) [50]. They are characterised by a sharp decrease followed by a slow recovery phase. These decreases measured by spacecraft are often called FDs [51] in a similar way to the decreases observed by ground level detectors [50]. Blanco and Hidalgo (SH272) using unique measurements from the Helios mission (<https://www2.mps.mpg.de/de/projekte/helios/>) from 0.3 to 1 AU studied the effect of Magnetic Clouds (MCs) on the GCR background and the MC properties in the inner heliosphere. The E6 experiment onboard Helios is the energetic particle detector able to measure electrons, protons, and alphas in the range of 300 keV/n to > 50 MeV/n [52]. It has been shown previously that, in absence of strong SEP events the single detector rates of the E6 anti-coincidence (A) and sapphire Cherenkov detectors are sensitive to CRs with rigidities about GV.

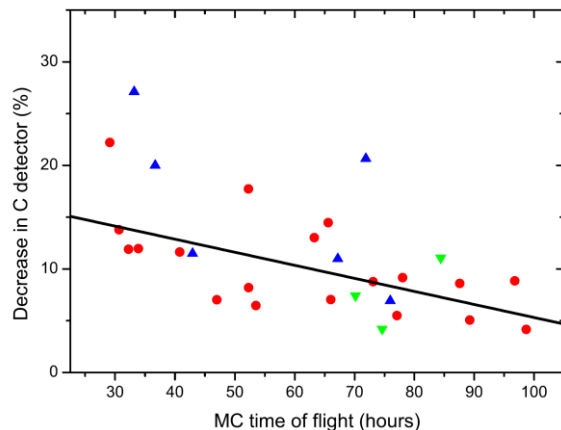


Figure 11. Decrease in the C detector versus MC time of flight. The solid line represents a linear fit to the type 1, 19 events (red circles). The other symbols represent events of other types as classified in [54] (Blanco and Hidalgo SH272).

Because their statistical precision is in the order of hundreds of counts per second, both detectors are very well-suited for studying the short-term decreases observed in their count rates during MC passages. These authors identified a total of 35 MCs at the Helios locations. They used the model of [53] as fit function to the measured magnetic field with the aim to confirm a flux rope structure, to establish the flux rope limits and thus the MC limits, as well as determine the MC orientation. 19 MCs were found to be free of SEP contamination and were used for the investigation of the effect of MCs on the GCR flux [54]. These authors found that the FD depth is linearly related to the magnetic field strength of the MC by a correlation factor of 0.66 and to the MC associated rigidity by a factor of 0.66 [54]. However, they found a poor linear relationship with the MC speed. Figure 11 presents the decrease in the detector C versus the MC time of flight. The solid line represents a linear fit to the 19 events (red circles) which the authors termed as type 1, in which the MCs were associated to count-rate decreases measured by the A and C detectors simultaneously. A negative linear relationship (Pearson coefficient=-0.64) was found with the time of flight of the MC, which implies a constant incoming rate of GCRs into MCs, and supports the idea of magnetically closed MCs i.e. with the two legs rooted back to the Sun. Their analysis of the MC properties showed that the MC diameter grows with the distance to the Sun, confirming the MC expansion during its travel in the IP medium. The CME speed did not show a clear dependence in the distance to the Sun. As these authors state, if these observations are confirmed, the deceleration process has to take place at close distances to the Sun < 0.3 AU [54]. These authors also presented results of an analysis of a pool of FDs detected at 1 AU by NMs, and produced by ICMEs with MCs and ICMEs with flux ropes and found that MCs are more effective than flux ropes in producing deeper FDs. Because the flux ropes were mostly aligned along the ICME legs, they concluded that the spacecraft path through ICME can affect the FD strength because the spacecraft is observing different regions of the ICME [55]. Hidalgo et al. (SH504) studied the effect of MC disturbances on the SEP spectra with the aim to evaluate the role of the arrival direction of the SEP into the MC.

Belov et al. (SH248) modelled the GCR density variations in MCs and estimated the contribution of different parameters into the model. They utilised the database of FDs in IZMIRAN (<http://www.izmiran.ru/>), based on the density and anisotropy variations of CR particles with 10 GV rigidity derived by the global survey method (GSM) [56], using data from the world network of NMs. These authors found that in most cases the behaviour of CR density within MCs at Earth can be described by a simple parabolic dependence on distance expressed in gyroradii. An important finding is that the majority of MCs modulate CRs, decreasing their density, although there is a group of events ($\sim 1/5$) in which the CR density increases within a MC. The extremum (minimum or maximum) of CR density more often settles down closer to the cloud center than its edges. They also derived a successful quantitative relation of the variation of CR density of a magnetospheric origin with the Dst-index. The obtained coefficient can be applied to variations of CR density during any periods.

Utilising the IZMIRAN database on FDs, Kryakunova et al. (SH409) studied the recurrent and sporadic FDs in deep solar minimum. They concluded that FDs caused by fast wind streams associated with Coronal Holes (CHs) are of a shorter duration compared to those caused by ICMEs. Regarding the distribution of times, a late minimum in CR intensity close to the solar wind speed maximum is observed, delayed with respect to the Interplanetary Magnetic Field (IMF) maximum. Furthermore, there are large differences between recurrent and sporadic FD in the CR anisotropy: in the recurrent case it is significantly smaller than for the sporadic case and exhibits a more smooth behaviour. Abunina et al. (SH253) carried out a statistical analysis of all FDs with a sudden onset during the period 1957-2012 and showed that the main features of the phase distribution of the first harmonic of the CR anisotropy persist throughout the main phase of the FDs, starting from the hour before the shock wave until the hour with the maximal amplitude of anisotropy.

Extending previous work [57], Wawrzynczak and Alania (SH329) analysed the temporal changes of the rigidity spectrum of FDs of the GCR intensity in different energy ranges, based on the hourly data from the worldwide network of NMs and muon telescopes. They confirmed that the rigidity spectrum of FDs of the GCR intensity is observed to depend on energy also for the FDs in November 2004 and October-November 2003. They analysed the time-evolution of the state of the turbulence of the IMF in various frequency ranges during FDs. The analysis showed that the decrease of the exponent ν of the Power Spectral Density ($PSD \sim Pf^{-\nu}$, where P is the power and f is frequency) with decreasing frequency resulted in the softer rigidity spectrum of FD for GCR particles with higher energies.

Stealth CMEs, that are CMEs with no apparent solar surface association and their IP counterpart have become a subject in recent studies of solar activity [58]. Whether all of such stealth CMEs can drive a FD is difficult to investigate on the basis of NM measurements, because these measurements not only reflect the GCR intensity variation in IP space but also the variation of the geomagnetic field as well as the conditions in the Earth's atmosphere. Heber et al. (SH393) studied FDs associated to 11 stealth CMEs using data by the Electron Proton Helium Instrument (EPHIN) onboard the spacecraft SOHO and Chandra, which is capable to measure CR variations of less than 0.1% when using 30 minute average single detector count rates of the anticoincidence A and the last semiconductor F [59]. None of the 11 events were accompanied by low energy particles, making single detector rates ideally suited to investigate the time profiles of the corresponding FDs. All stealth ICMEs were found to cause a FD with amplitudes between 0.6 and 3.5%. None of them can be found in the NM data unambiguously. The best case is displayed in figures 12. Figure 12 shows from top to bottom the measured count rates of the EPHIN detector F aboard SOHO and Chandra (blue, black color traces on top of this figure), together with the ones from the NM stations Tera Adelaide (black), Apatity (red), Norlisk (green), and Oulu (blue). While the FD is visible in the spacecraft data, there is no evidence at the NM stations used, apart from a small decrease observed in Tera Adelaide. This indicates either a strong rigidity dependence or effects caused by the Earth's magnetic field or by the atmosphere.

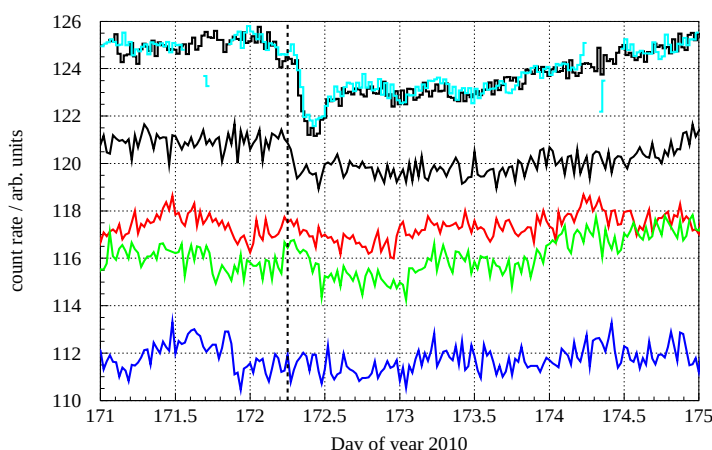


Figure 12. 30-min averaged count rates of the anticoincidence detector (EPHIN) in comparison with the neutron monitor count rates from different neutron monitors. The dotted line represents the start time of the count rate decrease (see text) (Heber et al. SH393).

The Belgrade CR station at the Institute of Physics in Belgrade has been continuously measuring the CR muon intensity since 2002. Srećković et al. (SH438) presented comparative analyses of extreme solar events - GLEs and FDs using CR muon measurements and very-low frequency (VLF) radio wave measurements by the CR and VLF stations in Belgrade. They demonstrated how such measurements can be used as a new method for investigations of high-energy transient phenomena of astrophysical importance. Barbashina et al. (SH383) analysed FDs registered by the muon hodoscope URAGAN [60] during the period 2007-2012. During this period, 185 well-separated FDs, including 44 FDs with amplitude $> 0.5\%$, were found in the integral counting rate. One supermodule of the hodoscope registers and records in 2-dimensional angular matrix the arrival directions of about 80 thousand muons every minute. The analysis of such matrices allowed to study zenith-angular and azimuthal dependences and anisotropy of the muon flux using the single setup. These authors concluded that in the phase of the counting rate decrease, the relative local anisotropy of muon flux increases in the geographical directional from North to South, while in the phase of minimum as well as in the phases before the beginning of decrease and recovery it remains symmetric. Furthermore, the analysis of correlations between the projections of the relative local anisotropy vectors provide additional opportunities for the study and identification of various heliospheric disturbances.

The quasi-biennial oscillations (QBOs) appear to be the most prevalent quasi-periodicity shorter than the 11 yr cycle in solar activity phenomena. They are observed at all levels of the solar atmosphere and are transmitted to the heliosphere via open solar magnetic flux. However, the nature of the QBOs at the Sun and their influence on the heliosphere remain not well-understood and need further investigation. Towards this goal, Bazilevskaya et al. (SH200) studied the correlation of the QBOs in GCRs and the solar activity indices, in the context of contemporary ideas on the GCR modulation. Their main results are that the QBOs in CRs are due to the QBOs in solar activity, however, they are transmitted to the heliosphere via open magnetic flux. That is why the QBOs in CRs do not well correlate with the QBOs in solar indices, and are rather coherent with the QBOs in the Heliospheric Magnetic Field (HMF) strength B . Also, contrary to the solar QBOs, the QBOs in CRs are hardly modulated by the 11-year cycle. The CR QBO amplitudes and duration do not correlate with those of the 11-year cycle. Moreover, there is no apparent difference in the CR QBOs between the odd and even 11-year solar cycles, as well as between the $A>0$ and $A<0$ magnetic polarity periods. As these authors stated, they aim to perform future work on the search for the relation of QBO with Forbush decreases, and will attempt to understand the difference found in the 11-year and QBO CR modulation.

Analyzing data of the worldwide NM network, Balabin et al. (SH419) found a considerable annual variation of CR flux in 2011-2013. The variation was observed in all stations, circumpolar, mid-latitude and subequatorial. They found that it is present in the CR density changes obtained by the global survey. The phase variation was found to be the same for all NM with a maximum in December-January and a minimum in June-July. The amplitudes of the variation was more than 1%. These authors showed that, in the same period 2011-2013, quasi-annual variations of the IMF, other parameters of the IP medium (solar wind speed and dynamic pressure) and the parameters of the solar magnetic field are observed. They concluded that these variations are in good agreement with the identified CR variations. They suggested as possible agents of these variations the features of solar activity or the asymmetry of the heliosphere.

Paouris et al. (SH448) studied the GCR intensity modulation based on solar and heliospheric indices for solar cycle 23 (1996-2008). In previous works a number of different indices such as the sunspot number, the CME-index (as defined in [61]) the interplanetary magnetic field strength and the heliospheric current sheet tilt were selected to be the most appropriate ones in order to describe the CR intensity of 10 GV observed by the NM network. Their new approach was the extension to the influence of the solar magnetic field parameters, the mean magnetic field strength and the polar magnetic field strength. With use of the wavelet analysis method they confirmed a major periodicity of about 20-21 years, which indicated the existence of the 22-year cycle in CR variations. They derived the best empirical relation, as they state, of the CR modulation taking into account the sunspot number

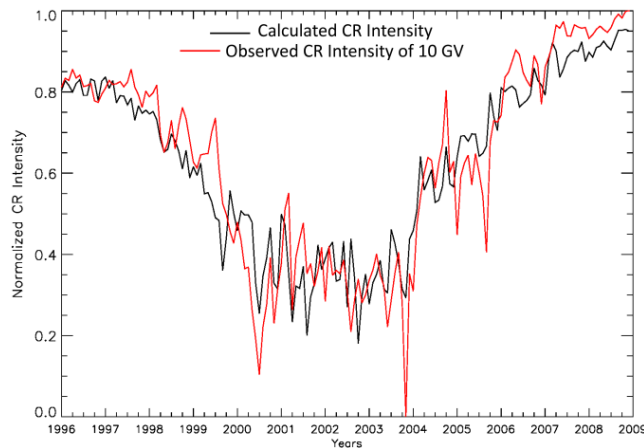


Figure 13. The observed values of CR intensity of 10 GV (red line) and those calculated by the derived new empirical relation (black line) (Paouris et al. SH448).

the CME-index, the mean magnetic field of the sun and the solar polar field, which was improved significantly to a relative Root Mean-Square Deviation (RMSD) of 8.7%, instead to the previous one of about 10% between the observed and the calculated CR intensity values (figure 14).

Various works studied the 27-day variation of the GCR intensity. Alania et al. (SH354) studied the period 2005-2008 of solar cycle 23 using NM data corrected and uncorrected for geomagnetic disturbances and the Dst index. They showed that the amplitudes of the 27-day variations of GCR intensity calculated for corrected and uncorrected data do not differ for NMs with cut-off rigidities less than 4-5 GV, while the difference is as notable as cut-off rigidity increases. Figure 15 presents their results on the rigidity spectrum of the 27-day variations of GCR intensity, calculated as described in [57], for corrected and uncorrected NM data, which they found to be generally soft, while it is hard for the corrected data case. For both cases they observed a clear tendency of a softening of the temporal changes of the rigidity spectrum from 2005-2008 (approaching solar activity minimum). These authors concluded that a study of peculiarities of the 27-day variations of the GCR intensity should be carried out by NMs with cut-off rigidities with less than 4-5 GV.

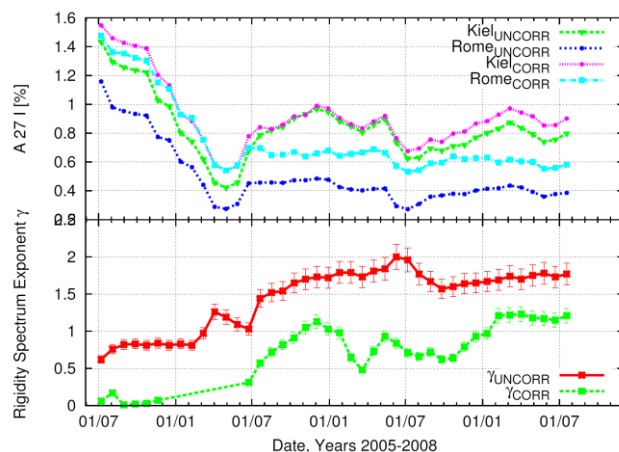


Figure 14. (Top part) Temporal changes of the amplitudes of the 27-day variation of the corrected and uncorrected GCR intensity for Kiel and Rome NMs. (Bottom part) The exponent γ of the rigidity spectrum of the 27-day variation of the corrected and uncorrected data GCR intensity in 2005-2008 (Alania et al. SH354).

[62, 63] had found a new class of quasi-periodicities. Alania and Gil (SH397) further investigated this effect and concluded that the 3-4 Carrington Rotation Periods (CRP) recurrence found is shaped by combined processes of the turbulent solar magnetic dynamo and differential rotation of the Sun leading to the conversion of the poloidal magnetic field into toroidal (α - ω effect). As the most appropriate candidate of the topological structure considered to be a cause of the 3-4 CRP effect they considered the diffusion of the current sheet in the Sun's atmosphere. Gil et al. (SH372) continuing the study of this phenomenon found quasi-periodicities with periods less than, and larger than 3-4

CRP. The 27-day variation of the 3-dimensional solar anisotropy of GCRs during the period 1965-2012 was studied by Modzelewska and Alania (SH399). They showed that the GG index, calculated by Nagoya telescope data (being a measure of the North-South asymmetry), is highly correlated with the Bx and By components of the IMF. Also they found that the 27-day variation of the GG index varies in accordance to the solar cycle with a period of 11-years, being in good agreement with the 27-day variation of the Az component of the GCR anisotropy calculated by the IZMIRAN group. They also demonstrated that the anisotropy component of the 3D GCR anisotropy is larger for positive polarity periods than for negative polarity periods.

Alania et al. (SH400) studied the annual distribution of the visually observed cloudless days and cloudless nights at Abastumani Astrophysical Observatory in Georgia in 1957-1993, in relation with the GCR intensity variations. They showed that the inter-annual distribution of the geomagnetic Ap index for cloudless days and nights are different, a result which they used in the construction of a 2D non-stationary model of GCR propagation in the heliosphere. For the modelling they also took into account new data of primary GCR proton spectrum in the local interstellar medium (LISM). Uchaikin and Sibatov (SH557) following a new fractional approach presented a more realistic, as they stated, compound model of CR diffusion, and compared their results with those of other authors, discussing the reasons of discrepancy.

From a theoretical viewpoint, Wawrzynczak et al. (SH443) applied stochastic methodology to model the GCR transport in the heliosphere, based on the solution of the Parker's Transport Equation (PTE). They presented their model of the FD and the 27-day variation of the GCR intensity based on this stochastic approach. The modelling results are in good agreement with the NM data. They concluded that the models obtained based on the solution of the stochastic differential equations allow to reflect the stochastic character of the GCR particle distribution in the heliosphere. Gerasimova et al. (SH208) studied the tensor anisotropy of CRs, using long-term observations from the muon intensity of CRs at Nagoya and Yakutsk and also the observations of the NM worldwide network, which revealed amplitude-phase oscillations of the semidiurnal variation during a year and also oscillations of antisymmetric diurnal variation. These effects reflect the properties of a tensor anisotropy which these authors determined with simple geometric models. They concluded that the main mechanism of the formation of the CR anisotropy tensor is associated with loop structures in the IMF.

4. GCR Long Term Variations

Cosmic Rays entering in the heliospheric region propagate into the solar wind, i.e. an expanding medium out-flowing from the Sun. This causes particles to diffuse into the heliosphere losing energy causing the so-called solar modulation, exhibited in the decrease of CR differential intensity below 30 GeV. This variation is strongly related to solar activity, the greater the solar activity the less is the CR intensity. Boschini et al. (SH368) using the HelMod Monte-Carlo code (<http://www.helmod.org>), which is based on the Parker's transport equation, which contains diffusion, convection, particle drift and energy loss [64], explored the effect of high solar activity on CR intensity as function of time and at different energies during the present solar maximum. They implemented a short-term description of the diffusion coefficient based on NM measurements. The comparison they carried out between their model and the AMS-02 proton data from July 2011 up to May 2013, during the maximum of the present solar cycle 24, showed that their solutions well agree with the experimental data.

Gieseler et al. (SH308) investigated the radial and latitudinal gradients of GCR protons and alphas, using measurements by the Kiel Electron Telescope (KET) onboard the Ulysses spacecraft [65], the first ever to explore the 3D structure of the heliosphere, as well as 'baseline' measurements delivering the temporal variation for a stationary observer by the PAMELA space borne experiment launched in June 2006 [66]. For helium they found $G_r(\text{He}) \sim 2.2\%/AU$ and $G_\theta(\text{He}) \sim 0$ or slightly negative and the gradients for protons: $G_r(p) \sim 3\%/AU$ and $G_\theta(p) \sim -(0.05-0.12)\%/deg$. As Munini (SH285) showed the PAMELA experiment has measured the electron spectrum at Earth in great detail, extending up to ~ 100 GeV and now, with a special effort, down to ~ 70 MeV. The yearly GCR electron spectrum measured during the A<0 solar minimum of solar cycle 23 (2006-2009) was presented and the author

discussed future plans to extend the measure to positrons for the investigation of the drift effect and to data collected after 2009. Krainev et al. (SH364), using the Ulysses solar wind and HMF data for all three Ulysses orbits around the Sun, compared these characteristics in and outside of the HMF sector structure zone. Using a simple GCR model they considered how the differences found in the HMF distribution may influence the calculated GCR intensity in the heliosphere and compared the results of the calculations with the observations.

Stozhkov et al. (SH436) presented long-term observations of CRs in the Earth's atmosphere. The available data cover more than five 11-year cycles of solar activity from July 1957, i.e. the middle of the 19th solar cycle, till August 2014, i.e. the middle of the 24th solar cycle. These authors showed CRs play the main role in the Earth's atmospheric electricity processes. Sorokin et al. (SH445) performed an analysis of the relationship between CR fluxes observed in the atmosphere and solar activity. They carried out a comparison of the CR fluxes measured in positive and negative phases of the 22-year solar magnetic cycles for the period 1957 – 2014 and found that the CR drift fluxes do not exceed 10% from the total GCR flux. The long-term CR behaviour at a rigidity threshold of ~ 6 GV was studied by Storini et al. (SH345) using data for about 5 solar cycles. They derived results from a detailed analysis performed by using the descriptive statistics technique and discussed them in the context of variations in the heliospheric conditions. Krainev et al. (SH199) further discussed their method to decompose the calculated intensity into the partial 'intensities' related to the main physical processes: diffusion, convection, adiabatic cooling and magnetic drift as well as its limitations in more detail.

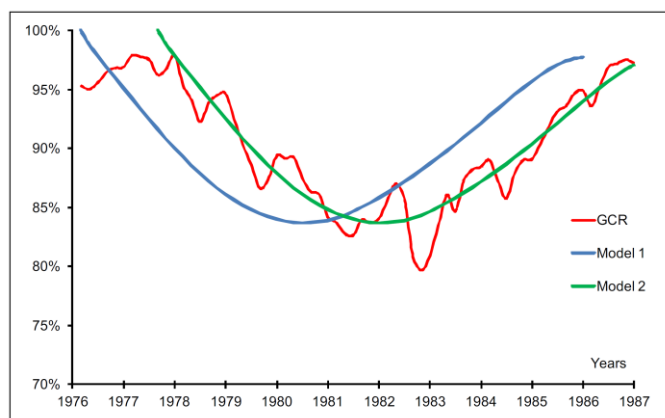


Figure 15. Changes of the amplitude of the 11-year variation of the GCR intensity in [%] registered by the Moscow NM (red line). Model 1: the solution of the Parker's non-stationary transport equation (blue line) Model 2: this solution shifted by 18 months (green line) (Siluszyk et al. SH458).

A new 2D time dependent model describing the long term variations of the GCR intensity has been developed by Siluszyk et al. (SH458). Their model implements in the Parker's transport equation the smoothed parameters characterizing temporal changes of the exponent γ of the Power Spectral Density (PSD) of the IMF turbulence, B magnitude of the IMF, tilt angle of the heliospheric current sheet for solar cycle 21 and changes of the drift effect of the GCR particles versus solar activity. Figure 16 shows how their model results compare with the observations for the period under study. As these authors concluded a delay time ~ 18 months can be accepted as an effective delay time caused by the combined influence of all parameters implemented in their 2D model. Iskra et al. (SH463) studied the relation of an exponent γ of the power law rigidity spectrum of the long period variations of the GCR intensity and the exponent ν_y and ν_z of the PSD of B_y and B_z components of the IMF turbulence. They showed that an inverse correlation between γ and ν_y and between γ and ν_z are universal, as expected from the Quasi-linear Transport theory for the rigidities of the GCR particles to which NMs respond.

5. Heliospheric Jovian Electron Variations

Early investigations of Jovian electrons assumed that they reach the Earth along IMF lines mainly during the period of direct connection between Earth and Jupiter (occurring every 13 months) [67, 68]. In the existing models, in the absence of direct Earth-Jupiter connection, the appearance of Jovian

electrons near Earth and their 27-day variation during the following 5-6 months were explained by perpendicular electron diffusion near Jupiter, and by CIRs limiting their angular spread [69, 70]. The interest to Jovian electrons resumed after the extremely quiet minimum of solar activity in 2007-2008, when electrons were observed near the Earth for 14 successive solar rotations. Kecskeméty et al. (SH306) suggested another propagation model to account for the recent observations. Their explanation of the long-term occurrence of electrons near the Earth is the possible formation of magnetic traps in the IP medium filled by electrons when they pass by Jupiter and then detected when passing near Earth.

According to the proposed model, Jovian electrons can be observed in any period irrespective of the phase of the Earth-Jupiter connection, whereas the 27-day variation of these electron fluxes is explained by the rotation of traps along with the Sun. These authors presented observational evidence during the quiet time of 2007-2008 which showed that, under the absence of stability of the solar wind structure the trap is unstable as well, with the periodicity of electron fluxes observed to be then broken. Furthermore, they showed an anti-correlation between the fluxes of trapped electrons and galactic protons. The Jovian electron flux maxima were found to coincide with galactic proton minima, indicating their entrance to the central part of the trap is inhibited by the enhanced magnetic

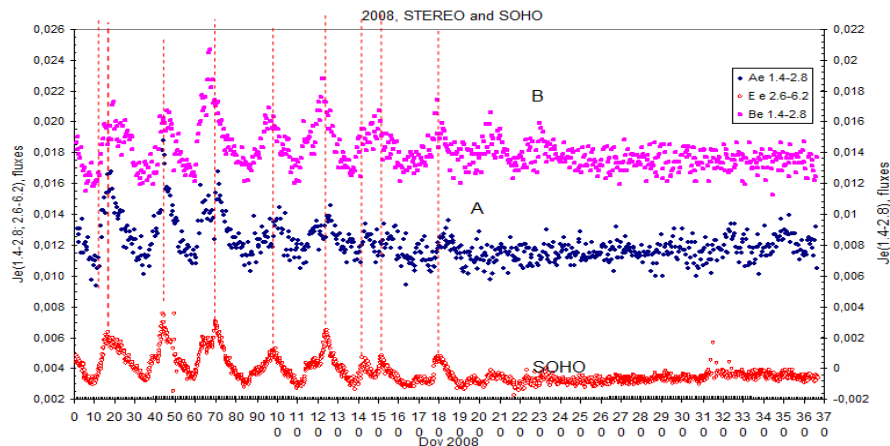


Figure 16. Due to rotation of the trap together with the Sun Jovian electrons are registered first at STEREO B, then at SOHO and then at STEREO A. The red dotted vertical lines indicate the times of maxima at the various spacecraft. The high background of HET makes the definition of exact times of maxima difficult, but the sequence is confirmed (Kecskeméty et al. SH306).

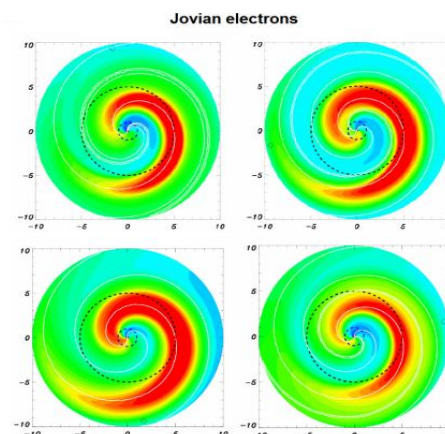


Figure 17. Contour plots of fluxes of Jovian electrons obtained for four different phases of the CIR model [69]. The position of Jupiter is at 3 hr (Kecskeméty et al. SH306).

field inside the trap. The temporal shifts of the profiles between STEREO A and B were found to be compatible with the rotation of the trap (figure 17). These authors carried out numerical simulations in which Jupiter is a moving source in the co-rotating frame and perfect co-rotation is assumed. The results of the simulations showed (figure 18) the appearance of traps under different time variations of solar wind speed in 2008, and confirm the hypothesis of stronger magnetic field behind Jupiter might trap electrons from escaping the region resulting to trap formation [71].

Using two different approaches, Vogt et al. (SH281) modelled the modulation of Jovian MeV-electrons by CIRs using the VLUGR3-Code [72, 73] to solve the Parker's transport equation. They modelled the diffusion coefficients as well as the solar wind speed from 0.1 to 50 AU and also compared their simulation results with the IMP-8 electron count rates.

6. Instrumentation and Methods

For many years, there have been astrophysical muon detector systems operated at the University of Adelaide, originally for teaching purposes. As Clay et al. (SH355) showed, the detectors have recently been rebuilt and upgraded with a new data acquisition system, to become H.E.A.M.S., the Adelaide High Energy Astrophysics Muon System (<http://www.physics.adelaide.edu.au/astrophysics/muon/>). These authors discussed the properties of the new system, including its various pressure coefficients, with illustrations of short term variations and solar wind sidereal anisotropies. Yashin (SH379), on behalf of the URAGAN Team, presented the real-time data recorded by the muon hodoscope URAGAN for each hour and also the results of their analyses which are available at the URAGAN website. They also discussed some peculiarities of the application of these data for the analysis of various events in the heliosphere, magnetosphere and atmosphere. Makhmutov et al. (SH337) presented the CARPET cosmic ray device at the astronomical complex CASLEO in Argentina [74, 75] and discussed the CR variation and solar flare activity observed in October-November 2003.

As Blanco et al. (SH124) presented, CaLMA, the Castilla-La Mancha NM [76], is a NM integrated by 15 boron trifluoride counters located in Guadalajara, Spain. With a vertical rigidity of 6.95 GV it is able to measure neutrons produced by primary CRs with energies > 6 GeV/nucleon. CaLMA has been monitoring the solar activity continuously since October 2011, and has reported more than 15 FDs. These authors presented preliminary results inferred from the CaLMA count rate variations and showed last improvements as well as future plans. García-Población et al. (SH125) presented mmPanel, a new software tool developed in CaLMA to control the station operation (<http://www.calmanm.es/start>). The application provides a tool to identify anomalies in data and allows the operator to trace its origin, and since the application is NMDB (Neutron Monitor Database)-aware, it also features automatic uploading of revisited data to the network. García-Tejedor et al. (SH126) presented the work in progress for the construction of a muon telescope in the same facilities as CaLMA, in order to use both instruments simultaneously to measure neutrons and muons produced by primary CRs at the same physical location and also analyse the possible correlation between both measurements. These authors presented the proposed muon telescope physical configuration, data acquisition system, local architecture (hardware and software), as well as the long term data storage and publication and the projected muon detection capabilities that this system should be able to perform.

Changes in the CR stations ISTP SB RAS of the Siberian Branch of the Russian Academy of Science for 2012-2014 were described by Lukovnikova (SH404). Proposed ways of solving problems that exist in each CR station were presented in order for data to be provided without failures and omissions every minute. Recent research applications at the Athens NM station were presented by Mavromichalaki et al. (SH457). These include the optimized automated GLE Alert Plus, currently a service under testing and evaluation by the European Space Agency, a simulation tool of the CR showers in the atmosphere, based on Geant4 and named DYNAMIC Atmospheric Shower Tracking Interactive Model Application (DYASTIMA) (<http://cosray.phys.uoa.gr/apps/DYASTIMA/DYASTIMAmannual.pdf>) as well as a Space Weather Forecasting Center which provides a 3-day geomagnetic activity report on a daily basis.

e-CALLISTO (Compound Astronomical Low-cost Low-frequency Instrument for Spectroscopy and Transportable Observatory) is a worldwide network with 24 hours a day solar radio burst monitoring (<http://www.e-callisto.org/>). As Russu et al. (SH437) presented, in 2013 the University of Alcalá joined the e-CALLISTO network with the installation of two Solar Radio Telescopes (SRTs), the Melibea and the EA4RKU SRTs. The Spanish e-CALLISTO SRTs routinely provide data to the network. These authors presented a list of type II radio bursts as observed by Melibea during its first year of operation and results of their study of their relation with SXR flares observed by GOES, and CMEs and SEP events observed by the SOHO spacecraft. In space, the Energetic Particle Detector (EPD) suite for the European Space Agency's Solar Orbiter mission will provide key measurements to address particle acceleration at and near the Sun. As Kulkarni et al. (SH416) highlighted, the EPD suite consists of four sensors (STEP, SIS, EPT and HET). The University of Kiel in Germany is responsible for the design, development and construction of EPT, HET, as well as STEP. The Electron-Proton Telescope (EPT) is designed to cleanly separate and measure electrons in the energy range from 20-400 keV and protons from 0.02 - ~15 MeV. EPT relies on the magnet/foil-technique. The High Energy Telescope (HET) will measure electrons from 300 keV up to 15 MeV, protons from 10-100 MeV, and heavy ions from ~20 to 200 MeV/nucleon. These measurement capabilities are accomplished by a combination of solid-state detectors and a scintillator calorimeter which allows use of the dE/dx vs. total E technique for particle identification and energy measurement. These authors also presented the current status of the development of the EPT and HET units focusing on test calibration results obtained with engineering model as well as future activities.

7. Summary and Future Prospects

An overview of the SH 'Solar and Heliospheric cosmic rays' session of the 24th European Cosmic Ray Symposium (ECRS), Kiel, Germany, 2014 was presented in this paper, with results highlighted in the various topics covered, based on a personal perspective of the author. The debate of the SEP origin in flares or CME-driven shocks is still undecided, with both mechanisms found to provide contributions in the observed SEPs. Methods of imaging HXRs and gamma spectroscopy aboard the RHESSI and Fermi observatories can lead to improvements of the investigation of the SEP sources.

Detailed analysis of multi-spacecraft observations by the twin STEREO spacecraft as well as near-Earth observatories have shed new light in the propagation processes of SEPs that lead to the observed longitudinal distributions in the heliosphere. This important research is expected to continue intensely in the next year and provide new insights on the acceleration and transport of SEPs. Evidently, these new observations comprise a challenge to the current models in order to account for them. More work is also needed to provide a theoretical evidence for the link between the SEP spectral shapes and particle acceleration.

The computation of radiation dose rate at flight altitudes is of particular importance but the dose rate can be strongly affected by the spread of GLE parameters as deduced currently from NM data by different groups. As highlighted, there is a need for more detailed exchange of information on the different GLE analysis procedures between specialists and this is expected to occur in the near future.

The study of CRs will continue to be carried out by networks of ground based NMs as well as muon detectors. The investigations of the CR spectrum from hundreds of MeV up to tens of GeV will continue to be implemented using direct measurements in space by PAMELA, Fermi, AMS and SOHO detectors.

Acknowledgments

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