Energetic particles in the heliosphere and GCR modulation: Reviewing of SH-posters

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Abstract. This rapporteur paper addresses the SH poster session titled "Energetic particles in the heliosphere (solar and anomalous CRs, GCR modulation)" of the 23rd European Cosmic Ray Symposium (ECRS) and the 32nd Russian Cosmic Ray Conference (RCRC). The 65 posters presented are tentatively divided into five sections: Instruments and Methods; Solar Energetic Particles; Short Term Variations; Long Term Variations; Heliosphere.

1. Introduction

Seventy papers were submitted for the pre-conference publication, but only fifty eight of them were presented as posters during the conference. Additionally seven posters were presented at the conference, which were not accompanied by the pre-conference publication. In this paper I review the SH poster session, therefore should consider totally 65 posters. In order to help the reader to navigate within the paper ocean Table 1 presents sections and subsections of the SH session and my tentative division of the presented posters to them. Below citing a particular work I refer to the name of first author and the initial abstract number (SH***). This is my personal view on the current situation in the SH cosmic ray physics, therefore I apologize in advance to all, whose results would be not mentioned properly. Since the 32nd ICRC Proceedings are not yet available (October 2012) as a reference point I suggest two rapporteur papers of the 31st ICRC [1-2].

The solar activity modulates cosmic ray (CR) intensity, which has a direct impact on activity of cosmic ray physicists. The current 24th solar cycle now is close to the maximum phase (fig. 1). It is similar to the 14th cycle, which is the lowest ever recorded. Ishkov (SH446) considered main characteristics of the 24th cycle after three and half years of its development. Mavromichalaki et al. (SH677) presented a review of current solar energetic particle (SEP) and geoeffective events, which numbers are low abnormally. Therefore, few posters dealt with observations and interpretation of the current events, most of them were devoted to retrospective data analysis, improvements of available methods. The first and sole up to now event of the 24th cycle accompanied by ground level enhancement (GLE) of solar CR intensity occurred on May 17, 2012 (Bazilevskaya, SH572). The first significant Forbush decrease of the 24th solar cycle was recorded on February 11, 2011 (Papaioannou et al., SH666).

The deep 2008–2009 solar minimum continues to be important to CR studies providing an opportunity to measure the highest galactic cosmic ray intensities of the space age [3]. Study of the solar cycle 23 minimum provides an opportunity to understand conditions that led to higher intensities in the past, and it may help us determine if the Sun is now evolving into a state similar to those during grand minima of the recent past [4].

The space weather is considered as the main practical reason to study the SH cosmic ray physics. Using the words "space weather" mean conditions on the Sun and in the solar wind, magnetosphere that can influence the performance and rehabilitation of space borne and ground based technological systems and can endanger human life in space. The SH cosmic ray physics is the physics beyond the slogan (see [5]). An indirect method based on measurements of CR intensities can give much earlier warnings (the exact forecast time is mainly defined by their free path) enabling effective protection measures. The invited talk on Space Weather studies was presented by Karel Kudela.

Table 1.

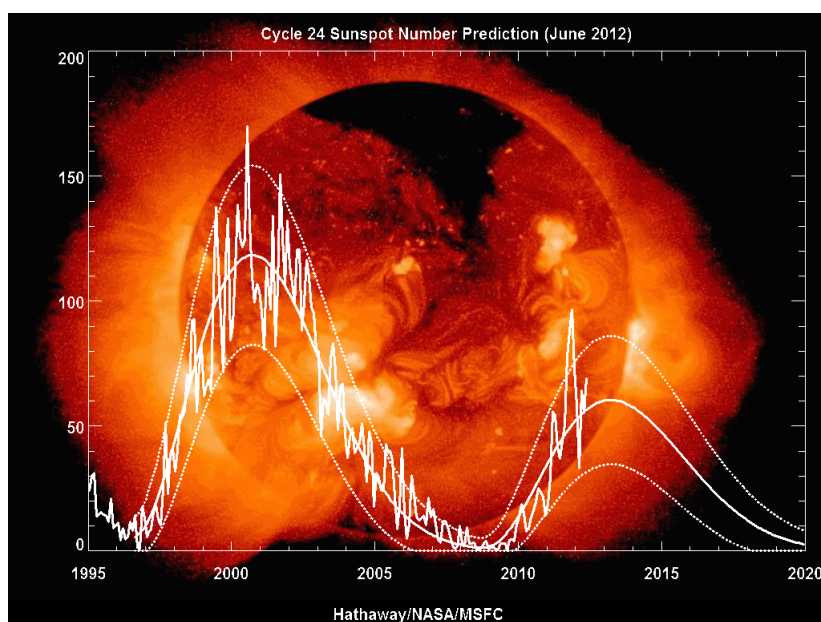|	Presented posters
Instruments and methods	SH285, SH293, SH332, SH481, SH519, SH562, SH584, SH636, SH647, SH730, GEO442 **11 posters**
SEP	SH194, SH326, SH356, SH446, SH557, SH563, SH572, SH667, SH731 **9 posters**
GLE	SH179, SH292, SH444, SH445, SH494 **5 posters**
Forbush decreases	SH186, SH187, SH288, SH290, SH371, SH414, SH475, SH526, SH529, SH559, SH567, SH574, SH605, SH652, SH666 **15 posters**
Short term variations	SH386, SH387, SH493, SH495, SH496, SH503, SH525, SH622 **8 posters**
Long term variations	SH189, SH289, SH346, SH347, SH400, SH451, SH454, SH460, SH489, SH498, SH579, SH587, SH637, SH670 **14 posters**
Heliosphere	SH341, SH398, SH633 **3 posters**

Figure 1. Cycle 24 sunspot number observations and predictions (June 2012).

Gaidash et al. (SH475) described the system, which was created on request of the Russian Federal Space Agency to specify the "space models" and to forecast the "space weather". This system

operates well and is upgraded permanently. Elements of this monitoring system are local ground stations, which provide forecast of geophysical conditions, including radiation level and geomagnetic activity. The system produces an alert signal, when intensities of energetic proton and electron fluxes increase. Centers for the continuous monitoring of the geomagnetic conditions, which resulted into short and long term geomagnetic forecast are in operational mode in Russia (IZMIRAN), Greece (Athens), Kazakhstan (Almaty) and Bulgaria (Sofia). The current work of these centers was described by Abunina et al. (SH622). Researchers look through all available data from the Sun and near-Earth space and the Earth that may demonstrate signs of intense solar and heliospheric activity. The most prominent and characteristic events on the Sun that are being constantly monitored by the community of SH physicists are solar flares, coronal mass ejections (CMEs) and coronal holes. The methods used for the forecasting of A_p index are demonstrated and the results of its forecast are compared with actual A_p indexes (Abunina et al., SH622).

2. Instruments and Methods

The counting rate N of any CR detector operating on the ground in a point with at cutoff rigidity R_c is

$$N(R > R_c) = \int_{R_c}^{\infty} (-dN/dR)dR = \int_{R_c}^{\infty} S(R,x)j(R,t)dR,$$

where dN/dR is the differential response function, $j(R,t)$ is the differential spectrum of primary cosmic rays, and $S(R,x)$ is the yield function of the secondary cosmic rays at atmospheric depth x.

Ground-based neutron monitors (NMs) remain the state-of-the-art instruments for CR observations at GeV energies, which cannot be measured in the same simple, inexpensive, and statistically accurate way by space experiments. The worldwide network perfectly complements cosmic ray observations in space. Recent years considerable efforts were applied by several groups from Europe, Israel and Former Soviet Union for unification of NM data into one database (Neutron Monitor Data Base - NMDB) performing in real time in Internet (see www.NMDB.eu). The current status of the NMDB was presented by Steigies et al. (SH285).

The primary processing algorithms aim to correct or reject data from channels that are distorted by instrument variations [6]. The correction should be performed in a real time basis, since the data have to be sent to NMDB, whose data are used by online applications. Two new algorithms developing by the Athens NM group were presented by Pascahalis et al. (SH636). The first one is based on an Artificial Neural Network model, while the second one is based on a pure statistical model. Lukovnikova et al. (SH332) described operation in real time of several Siberian NM (Irkutsk, Irkutsk 2, Irkutsk 3, Norilsk) participating in the NMDB project.

One of the most important data corrections related to the primary data processing of the NM's is the pressure correction due to the barometric effect (varying atmospheric depth x). This effect induces considerable variation in the counting rate of a cosmic ray detector, which is not related to the real variation of the cosmic rays flux, but only to the local atmospheric pressure. In order to account pressure variations NM data are corrected by multiplying on the barometric coefficient. A new method that effectively calculates the barometric coefficient for a station using data of a reference station in order to subtract the primary variations of cosmic rays was presented by Paschalis et al. (SH519). This method is the prototype of an online tool that uses data of the NMDB stations and calculates the barometric coefficient for any available station.

NM's are not calibrated instruments, i.e. each instrument has its own differential response function and yield function. The calibration campaign started in 2002 and had not been finished yet. Two more calibrators (small neutron monitors) with new electronics heads were built in 2011 (Kruger&Moraal, SH481). One small NM is presently aboard the research vessel "Polarstern" of the German polar program to conduct latitudinal surveys between cutoff rigidities from 1 to 15 GV for at least the next solar cycle. In future it would be possible to calculate the new variant of differential response function. The second new calibrator was installed at the Neumayer station in Antarctica for continuous

monitoring of the cosmic-ray intensity. These two new detectors have broadened the concept of a calibration NM to that of a mini NM, i.e. a permanent detector in its own right. Another possibility is to cross-calibrate the CR measurements by the world-wide NM network with a single *in situ* high-energy spectrometer, for example, space detectors like PAMELA, Fermi, and AMS.

The most advanced code for modeling CR interactions in the atmosphere is PLANETOCOSMICS based on GEANT4 simulation framework. Using this program Murchev et al. (SH647) calculated energy spectra of secondary CR particles at various altitudes in the atmosphere. Mishev and Usoskin (SH293) went further and calculated the yield function by the PLANETOCOSMIC code. Figure 2 compares results of calculations by Mishev&Usoskin with previous findings [7-9]. The yield function of Mishiv&Usoskin is lower at a low rigidity range and above 100 GV.
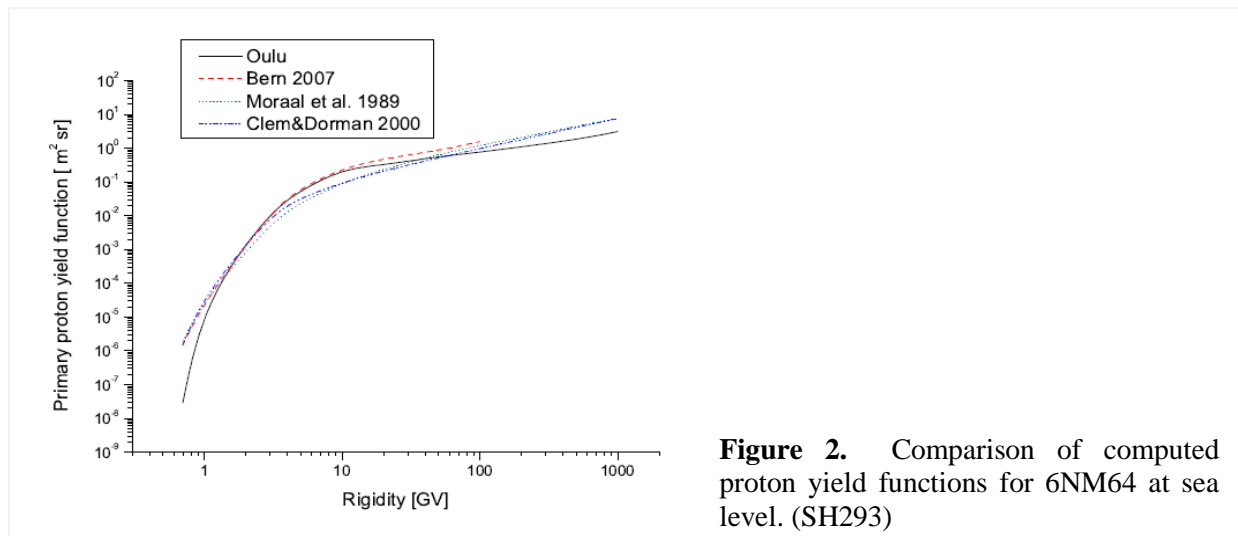

Figure 2. Comparison of computed proton yield functions for 6NM64 at sea level. (SH293)

Cosmic ray cutoff rigidity R_c controls the access of CR particles to a particular point in the Magnetosphere. Investigations of variations in cosmic rays give valuable information on the magnetospheric magnetic field, which can be used as independent information for testing of magnetospheric models [10]. Tyasto et al. (GEO442) compared the theoretical geomagnetic cut-off rigidities calculated in the magnetic fields of the Tsyganenko models (Ts04 and Ts01) and the geomagnetic cut-off rigidities obtained by the spectrographic global survey method based on the CR neutron monitor data of the world-wide network [11]. The Ts01 model that describes the middle disturbed magnetosphere is in better agreement with the experimental cut-off rigidities than the Ts04 model that describes the time evolution of the large-scale current systems of the magnetosphere. According to results of Tyasto et al. (GEO442) the geomagnetic cutoff rigidities ΔR_{eff}(Ts01) better correlate with D_{st}, B_z, and N_{sw} and, in general, are more "sensitive" to changes in the interplanetary parameters than ΔR_{eff}(Ts04). Cutoff rigidities deduced from CR data have their own errors due to unknown precisely yield functions, so it is not clear how to choose the better magnetospheric model.

The PAMELA detector is relatively new instrument for SH studies. Here I would like to underline one very important PAMELA result for interpretation of NM data [12]. The PAMELA spectrometer is the first instrument, which directly measures the CR spectrum near the Earth within rather wide energy band. All previous measurements have been made by ground-based and stratospheric detectors. In this case the derived CR fluxes at top of the atmosphere depend on yield function of the detector. The SEP event on December 13, 2006 was the first studied by PAMELA. The PAMELA spectra appear to be always harder in the low-energy interval than obtained from NM data (fig. 3) indicating that NM yield functions are underestimated below ~700 MeV. Note that the yield function calculated by Mishev&Usoskin (SH293) using PLANETOCOSMIC code is even lower than the yield functions [7-

9]. New GLE events of the 24th solar cycle should justify this result. The PAMELA spectrometer observed eight SEP events with >100 MeV solar protons up to July 2012 (Bazilevskaya, SH572). A detailed analysis of the recorded events is in preparation and has not been presented yet.

With the launch of AMS-2 there is a remarkable opportunity to cross-correlate high-energy cosmic-ray spectra from three large spectrometers (including PAMELA and Fermi) [3]. Spectrometers ARINA and PAMELA on board of the Resurs-DK1 satellite perform precision measurements of galactic cosmic ray flux in the near-Earth space from 2006 till now. Combining these instruments gives the possibility to study solar modulation in the energy range from 30 MeV to dozens of GeV. Observations of galactic cosmic ray variations by the PAMELA spectrometer from 2006 till May 2012 were presented by Bzheumikhova et al. (SH587).
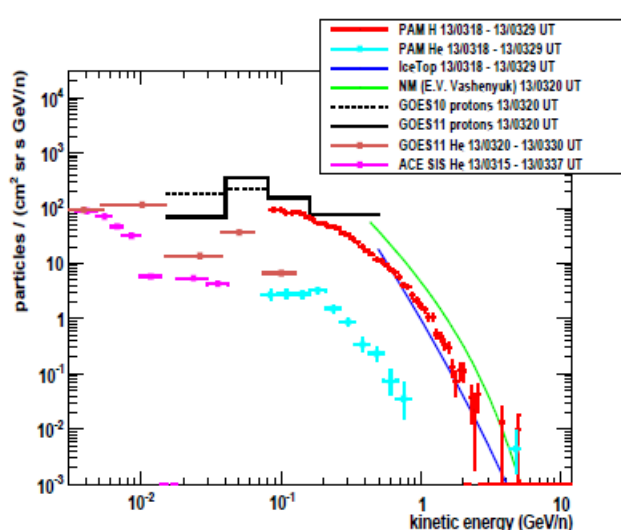

Figure 3. Energy spectra of solar particles measured by the PAMELA spectrometer and by other experiments. In red there are the PAMELA protons, in cyan the PAMELA He, horizontal bars are the GOES and ACE SIS data; green line is the spectrum derived from the neutron monitor network (Fig. 9a, [7]).

Recently the CARPET installation started measurements of secondary CR in El Leoncito (CASLEO, Argentina) with geographic coordinates (31.8S, 69.3W) at altitude of 2550 m. The estimated cut-off rigidity at this point is Rc=9.65 GV for quiet conditions and Rc=9.0 GV for disturbed conditions (Kp=4). The CARPET is a huge telescope consisted from 240 Geiger tubes. Some details of current observations were presented by Makhmutov et al. (SH-560). A statistically significant enhancement was detected by CARPET during the solar flare on March 7, 2011. The yield function of CARPET is not evaluated yet, therefore this is only an evidence of proton acceleration up to > 10 GeV during this particular event. Response of the ionosphere to solar energetic particles (SEP) studied by Correia et al. (SH563) supports conclusion (Makhmutov et al., SH560) that enhancements observed by CARPET have been caused by SEP.

The network of muon detectors situated in different points of the Earth allows studying of cosmic ray variations in secondary muons for higher energies of primary CR than do NM. A pilot variant of the muon detector data base is located at http://cr20.izmiran.ru/mddb/. Recently the Canadian Space Weather Forecast centre has launched a feasibility study to assess the signatures of approaching CMEs in cosmic-ray muons. Some details of the Canadian project were presented by Kalugin et al. (SH562). Two parts of the project are: 1) developing of the Canadian muon telescope at Carleton University (Ottawa, Ontario) to fill the gap existing over North America in current Global Muon Detector Network; 2) clarifying the signatures of the interplanetary CMEs in CR muon variations (precursors).

Muon hodoscopes, which measure intensities of secondary CR muon at different angles, allow to study CR anisotropy in the space using only one detector. The most impressive instrument of this kind is URAGAN installed in 2006 [13]. It provides continuous registration of muon flux from all directions of the celestial hemisphere allowing a new level of CR variation studies. Deployment of a

network of muon hodoscopes similar to the network of neutron monitors will allow creating a system for early detection of various phenomena in the heliosphere at any time of a day. The main problem of these studies is to separate correctly variations of different origin (solar, heliospheric, magnetospheric and atmospheric phenomena). Shutenko et al. (SH584) showed possibilities of the URAGAN detector to measure the vector of anisotropy. Annual, semi-annual, 27-day, diurnal and semi-diurnal variations are presented for zenith angle intervals $25º \leq \theta < 76º$ of the vector of local anisotropy. Variations of the vector of local anisotropy and muon counting rate have a different character expanding possibilities of muon detectors to study a response of the muon flux to various heliospheric, magnetospheric and atmospheric processes.

3. Solar Energetic Particles

The physical processes that accelerate solar energetic particles to high energies remain controversial. In particular, the accelerative properties and relative roles of reconnection inside solar flares and of coronal shocks around solar transients are still debated. More and more evidences appeared that the simplest "two class" picture of SEP events [14], with flares producing the particles in one (the impulsive) class and only shocks accelerating the particles in the other (the gradual class), doesn't correspond to reality [15].

Lytova&Ostryakov (SH356) simulated solar cosmic ray spectra (He3, He4, O and Fe) at the flare site and at the Earth using the Monte Carlo method. In their model ions were accelerated simultaneously by the Alfvenic turbulence and the impulsive electric field of the current sheet. Ishkov (SH326) showed that 16 out of 17 proton events considered by him were associated with solar flares, which are implemented in the complexes of active regions – the structure of the transition between the active region and a complex activity. Suggesting an important role of the magnetic structure for large proton fluxes have been released into the heliosphere. The geometrical factors should be considered to predict a proton event during preparation of the solar flare.

A similarity of time profiles of flare plasma temperature allows to set a zero time for each flare [16] Solar protons of 100 MeV arrive at the same moment to the Earth relatively to this zero time of parent flares, i.e. the longitudinal dependence is not observed for solar longitudes of E10-W80 (fig. 4). Increasing rate and maximum values of proton intensity are determined by the source function (Struminsky, SH194). The proton event of March 7, 2012 associated with two parent flares is the largest one recorded so far in the 23rd solar cycle. Because its two parent solar flares were located at N17E27 and N22E12 the maximum of proton intensity was delayed and depressed.
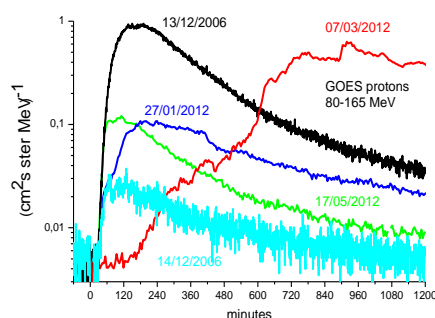

Figure 4. Proton intensity measured within 80-165 MeV energy band by the GOES detector during last five largest SEP events.
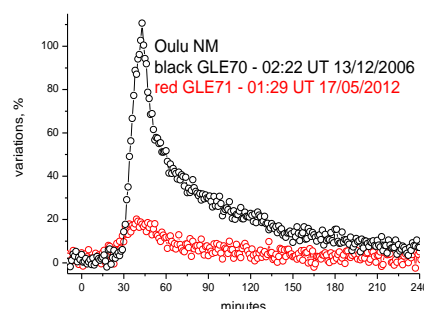

Figure 5. Comparison of last two GLE events observed by Oulu NM.

According to Ochelkov et al. (SH557) the heliolongitudinal decrease of peak intensity is practically absent for parent flares in the west half of solar disk. For heliolongitude interval within 00E-30 E (30E-90E) it is equal 30 (100-150). Solar proton fluencies of various energies for SEP

events of 1956 - 2012 years were calculated by Getselev et al. (SH667). The distribution of parent flares on the Sun is not homogeneous along the Carrington longitudes. An interval of "passive longitudes" extended over longitudes of ≈90–170° during the whole period of observations was discovered. From the 60 most powerful SEP events during the whole period of observations not more than one event has been originated from the interval of "passive longitudes". To check these conclusions multi-spacecraft observations of SEP events at different longitudes (STEREO A, B; ACE) are crucial. However such analysis was not presented at the conference. Intensity time profiles in some events observed from different points in the heliosphere were discussed by Klecker in his invited talk. The first referred paper devoted to STEREO observations of longitudinal dependence of SEP intensity appeared only few days before the conference [17].

Knowing of ion charge states is important to test different acceleration models. The charge state of $C(5.87 \pm 0.06)$, $O (6.81 \pm 0.07)$ and Fe (14.52 ± 0.25) ions in 51 gradual events of the 23rd solar cycle was determined by Nymnik (SH731) using his original method based on energy spectra approximation by broking power law spectra. The experimental data from the GOES satellites (protons) as well as from the ULEIS (all particles) and SIS instruments aboard the ACE satellite (ions He, C, O and Fe) were used in his calculations. Potentially very important results were obtained that the charge states of high-energy heavy ions of the Sun do not depend on the size (capacity) of SEP events, on the particle energy (in the interval 0.3-30 MeV / nucleon), or on the variation of the relative composition of heavy ion fluxes.

The 71st GLE event on May 17, 2012 is the first in the current solar cycle. Figure 6 shows variations observed by the Oulu NM during the 70th and 71st GLE events respectively on December 13, 2006 and May 17, 2012. These two events occurred nearly at the same UT time, so local conditions for their observation by the same NM should be similar. Their time profiles coincide first 30 min since zero time. Maximal enhancements are in agreement with maximal intensities observed by GOES (fig. 5). Kurt et al. (SH292) studied a delay of the earliest arrival time of high energy protons at 1 AU with respect to the observed peak time of the solar burst and found that the delay doesn't exceed 10 min in thirty events. This result (fig. 6) indicates that in majority of events the efficient acceleration of protons responsible for the GLE onset has to be close to the time of the main energy release in flares. However it is not clear what the authors mean saying main energy release.
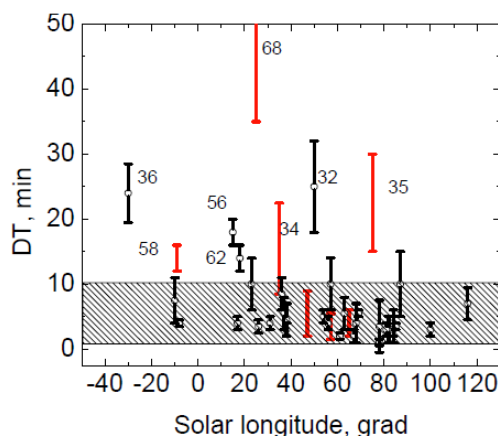

Figure 6. Time delay DT of the GLE onset versus the heliolongitude of associated flare. (SH292)

Particular cases of previous GLE's were studied in several papers. Kravtsova et al. (SH179) calculated the CR rigidity spectrum observed during the GLE event on 14 July 2000 over 1 -20 GV range and found that it is not described by power function of particle rigidity only. The distribution of CRs in the earthward direction varies with time and depends on their energy. The Bastille event is well studied by many authors, so it is very strange that results of Kravtsova et al. (SH179) are not compared with previous investigations. The absolute flow *J* and the energy spectral index γ of solar cosmic rays

during the isotropic phase for 14 GLE events observed during 1977-2006 years have been estimated by Grigoriev et al. (SH494) using the method of effective energy elaborated in [18]. This method was tested in [18] by one "maverick" event of December 13, 2006. Therefore its straightforward application to other 13 events is not justified. Authors did not provide arguments in favor of their methods and interpretations.

One of practical motivations for GLE studies is to estimate a radiation risk during GLE event [19]. Calculations of doze rate along flight roots for the GLE event on April 15, 2001 were presented by Buticofer and Fluckiger (SH445). Their results show how far we are from the desired goal. The characteristics of this GLE obtained by different groups differ considerably. As a consequence the computed radiation dose rates along flight routes do not have the desired agreement (fig. 7). Improvements and/or adjustments of the different GLE analysis methods or new procedures are needed.
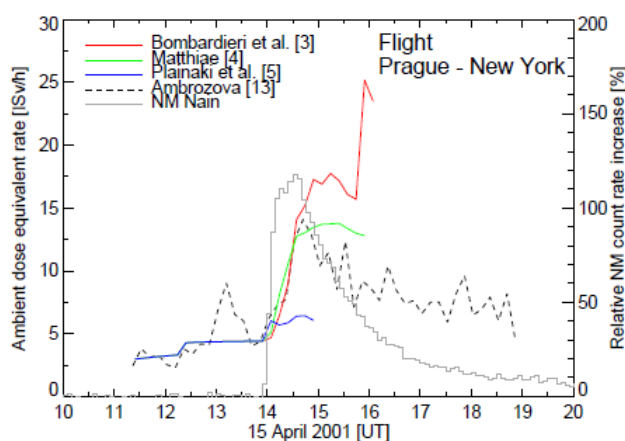

Figure 7. Ambient dose equivalent rates along the flight from Prague to New-York as computed in SH445 based on the SCR characteristics determined by [15-17]. Measured ambient dose equivalent rate (private communication). Relative count rate increase at the NM station Nain.

Veselovsky et al. (SH444) developed the method for early alert of 10-100 MeV proton arrival to the Earth after powerful eruptive events on the Sun using data the NM network. The retrospective analysis of the observations during 2001-2006 years indicates that the method doesn't work - more than 50% of solar proton events are omitted. For higher reliability, it is necessary to use additional data on the state of solar and heliospheric activity including measurements on-board different satellites and spacecrafts.

4. Forbush decreases and short term variations

It is a usual custom to divide the Forbush-decreases (FDs) to sporadic and recurrent ones [23]. The study of FDs is fundamental for understanding of the interplanetary medium and for the propagation of the cosmic ray particles through the medium itself. Sporadic FDs are a sudden decrease of the recorded galactic cosmic ray intensity caused by passing of the interplanetary coronal mass ejection. These decreases typically last for less than one day while the recovery phase may last for several days. The recurrent FDs are caused by a flow of high-speed solar wind from the low-latitude coronal holes. During the epoch of minimum solar activity the big and effective CMEs are rare, so the FDs are mainly recurrent.

Grigoriev et al. (SH493) checked the method developed previously in [24, 25] using the data of current events. The occurrence of radial component of the galactic CR diurnal anisotropy with the amplitude >0.2% in anti-solar direction with a probability of approximately 70%, is connected with the approach of the area of large-scale solar wind disturbance to the Earth. The criterion of predictor quality of the disturbance arrival is the simultaneity of occurrence of the significant radial anisotropy component in the data of both devices during the time of more than 3 hours. Figure 8 shows the results obtained for observations on April 21-23, 2012.
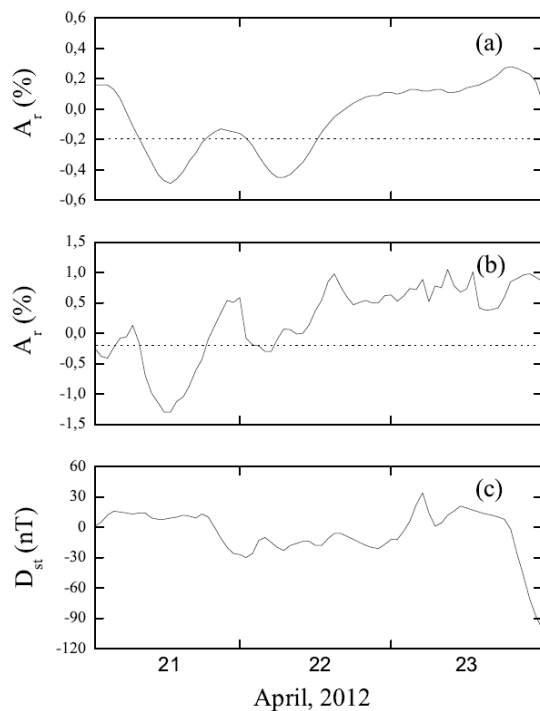
Figure 8. Changes of the value of radial CR anisotropy component by data of the harmonic analysis (a), global survey (b) before the onset of geomagnetic field disturbance (c) in April 2012. Critical levels of the value A_r for the forecast are shown by dashed lines. The CR anisotropy is presented in the GSE−coordinate system. (SH493)

Different Forbush decreases are studied by the muon hodoscope (Barbashina et al., SH574). Their declared goal is to accumulate statistics for future forecast of the space weather. For the analysis of two-dimensional dynamics of muon flux during the FD the projection of the relative anisotropy vector of the muon flux to the South and East (r_S and r_E respectively) were used. The anisotropy of the muon flux for 29 FD selected for the period from 2007 to 2011 only slightly depends on the amplitude of the event. The study of correlations between the projections of the relative local anisotropy vector r_E and r_S provides additional opportunities for study and identification of various heliospheric disturbances. The prognostic potential of the developed methods has been estimated. Disturbances of the horizontal projection of the vector of relative anisotropy for selected 14 FD are observed ahead of the perturbations in the characteristics of the SW and IMF by ~ 9 h, and in the magnetosphere by ~ 13 h. These results are preliminary and will be updated with the accumulation of the statistics.

Astapov et al. (SH605) analyzed a response of the muon hodoscope URAGAN for heliospheric disturbances caused by recent most powerful solar flares in March 2012. The Forbush decrease on March 7, 2012 became the greatest (up to June 2012) event of its kind in the current solar cycle (Mavromichalaki et al., SH652). During the period of the enhanced solar activity, there are significant changes in the anisotropy of the muon flux that began almost simultaneously with solar wind parameters. Horizontal projection of the relative anisotropy vector characterizes the "side influence" on the angular distribution of the muon flux. Maximum of r_h reached a record value 7.2% on March 8 at 13:00. However, the early appearance of the anisotropy of the muon flux in this event was not observed.

Since we do not have reliable numerical models statistical studies of previous observations are very important. Several works presented at the conference were devoted for retrospective analysis of FD's. Forbush decreases connected to western solar flares and accompanied by geomagnetic storms (25 events) gathered for the time period from 1967 to 2006 have a clear sign of precursor in 15 cases (60%) (Papailiou et al., SH529). Relations of Forbush decreases to different manifestations of the solar activity are very important in this regard and have been considered in several poster presentations.

Retrospective case studies of interplanetary shocks forecasting in advance of up to one day, using cosmic ray fluctuations and solar wind parameters measured onboard the ACE spacecraft were

presented by Starodubtsev et al. (SH525). Only those interplanetary shocks, for which a large flux of low-energy particles (10 keV-10 MeV) of solar or interplanetary origin exists in the upstream region, can be forecasted. Parameter of CR fluctuations observed by ground based detectors was introduced by Kozlov (SH387) as indicator of interplanetary "magnetic cork". Petukhov&Petukhov (SH503) further developed the kinetic method [26] determining the CR dynamics with account of realistic properties of the solar wind disturbances, which might be useful for future analysis.

A new approach to the early diagnostics of solar eruptions in which quantitative characteristics of such large-scale CME manifestations as dimmings and post-eruption arcades observed in the extreme ultraviolet (EUV) range are used as key parameters instead of the projected CME speed and shape [27-28]. Dimmings are CME-associated regions in which the EUV (and soft X-ray as well) brightness of coronal structures is temporarily reduced during an ejection and persists over many hours. Chertock et al. (SH290) sudied relations of FD's to magnetic flux changes in dimmings and arcades. The summarized unsigned magnetic flux of the line-of-sight magnetic field at the photospheric level within the dimming and arcade areas was used as a main parameter of eruptions. This parameter has a pronounced direct correlation with the FD magnitude (fig. 9) and a conspicuous reverse correlation with the interplanetary CME (ICME) transit time from the Sun to the Earth. These correlations indicate that main quantitative characteristics of major non-recurrent FDs are determined by parameters of solar eruptions.
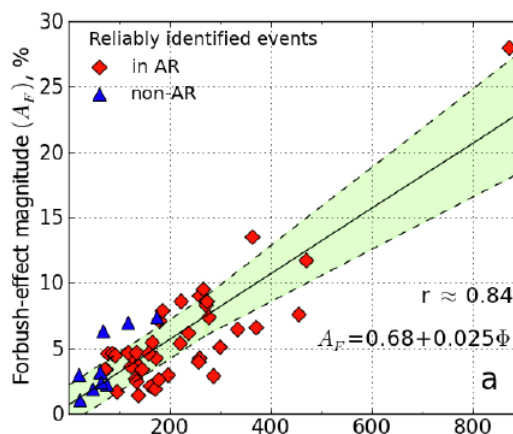

Figure 9. Dependence of the FD magnitude on the summarized unsigned magnetic flux in dimmings and arcades for FDs associated with solar events identified reliably. Here the diamonds denote eruptions in ARs, and triangles denote filament eruptions outside ARs. The dashed lines delimit the accepted deviation band. (SH290).

Kryakunova et al. (SH526) analyzed events of 2007 and found that a relationship between FD magnitude and solar wind speed is much weaker than between FD magnitude and the interplanetary magnetic field. One of the typical signs of the impact of high-speed streams from coronal holes on cosmic ray intensity is a gradual onset of the Forbush decrease. As a rule, a direction of the equatorial vector component of anisotropy is changed before the Forbush decrease.

Retrospective analusis of Forbush decreases occured in the 19th cycle was presented by Abunin et al. (SH414). Comparison of the events in cosmic rays with solar and geomagnetic activity showed that the quantity and intensity of geomagnetic storms in the 19th cycle corresponded to abnormally high number of the sunspots. The authors underlined that a number of large FD is relatively low. Apparently, deficiency of the big Forbush-decreases during this period means that coronal mass ejections (CMEs/ICMEs) in the 19th cycle distinguished from later CMEs and differently affected of the cosmic ray modulation and geomagnetic activity. Kravtsova&Sdobnov (SH186 and SH187) calculated the rigidity spectrum of cosmic ray (CR) variations during certain Forbush decreases recorded at the worldwide network of neutron monitors over the period 1991–2005, but did not relate their findings with previous results of other researchers.
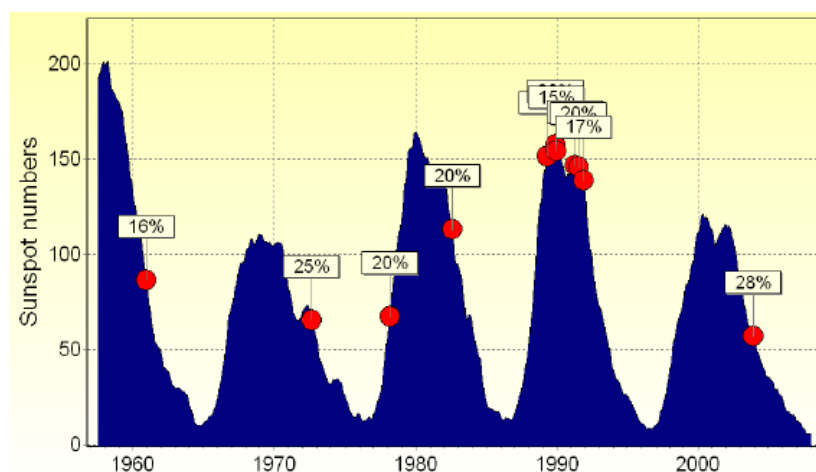
Figure 12. Sunspots and the largest effects for the last five cycles (19-23 cycles) (SH414).

Geomagnetic storm is accompanying by a significant disturbances of the magnetic cutoff rigidity, which results in additional magnetospheric variations. Magnetospheric variations are a subject of extensive researches the last seventy years. Mavromichalaki et al. (SH652) studied the relation between Dst-index, cosmic ray intensity variations and cut-off rigidity changes (dRc) during a number of geomagnetic storms. Alania et al. (SH559) showed that there exists some differences between the temporal changes of the exponents of the power law rigidity spectra of FD calculated by NM data corrected and uncorrected for the changes of the cut off rigidity. Blanko et al. (SH567) plotted Dst index against FD percentage and did an obvious conclusion that their physical causes are different.

Krymsky et al. (SH495) studied semi-diurnal variations on the basis of long-term registration of cosmic rays with the muon spectrograph at Yakutsk (62_010N, 129_430E) and multidirectional muon telescope at Nagoya (35_100N, 136_580E). They found the decrease of amplitude of cosmic ray semi-diurnal variations during the solar activity minimum and in the vicinity of sign-change period of the general magnetic field of the Sun and its seasonal variations. To clear up reasons of the revealed results the different models are discussed. The calculation of influence of the geomagnetic field on the galactic cosmic ray anisotropy was made by using the methods stated in [29]. In recent years the interest to the sidereal-diurnal variations of cosmic ray intensity in the range of TeV- energies registered with the major arrays grows all over the world. Gerasimova et al. (SH496) found a dependence of sidereal-diurnal variations on the polarity of the general magnetic field of the Sun that may indicate their heliospheric origin. The phase of sidereal- diurnal variations is approximately the 19 hour local time, which may indicate the existence of an anisotropic flow perpendicular to the axis of rotation of the Sun. Kozlov&Kozlov (SH386) suggested a parameter of CR fluctuations, which to their opinion might be considered as indicator of growing phase of the solar cycle.

Majority of the works presented in this section were performed by the IZMIRAN group or in strong cooperation with it. The excellent review of these works was presented by Anatoly Belov in his highlight talk. All posters dealing with short term CR variations were arrived from Yakutsk, the Shafer Institute of Cosmophysical Research and Aeronomy.

5. Long Term Variations

According to the current paradigm for GCR modulation [30-31] drift effects are dominant on the decline of the solar cycle and at solar minimum while diffusion is dominant at solar maximum. Climax Neutron Monitor count rate was reconstructed for the period from June 1936 to December 2011 in [3]. The late 2009 count rates appeared to be the highest of the space age, but this indirect comparison implied that the cosmic ray intensity was somewhat greater in late 1944 and possibly in the 1930s. The maximum of the 24th solar cycle is expected to be comparable to the lowest 14th maximum (Ishkov, SH446). Long term CR variations were studied theoretically and experimentally by authors of 14 poster presentations, the highlight talk on this topic was presented by Mikhail Krainev.

The average size of the field on the Sun and the size of the polar field can be regarded as characteristics of the solar activity leading to extraordinary high density of CR in 2009. Their joint influence resulted in the restored CR flux in 2009, which exceeded all previous observations (Guschina et al., SH454). The main unresolved problem of the CR modulation during the last solar minimum is the energy dependence observed within wide energy range (fig. 10). Bazilevskaya et al. (SH579) not found any features of interplanetary indices, which could explain the unusual rigidity dependence of the CR modulation in the minimum of the cycles.
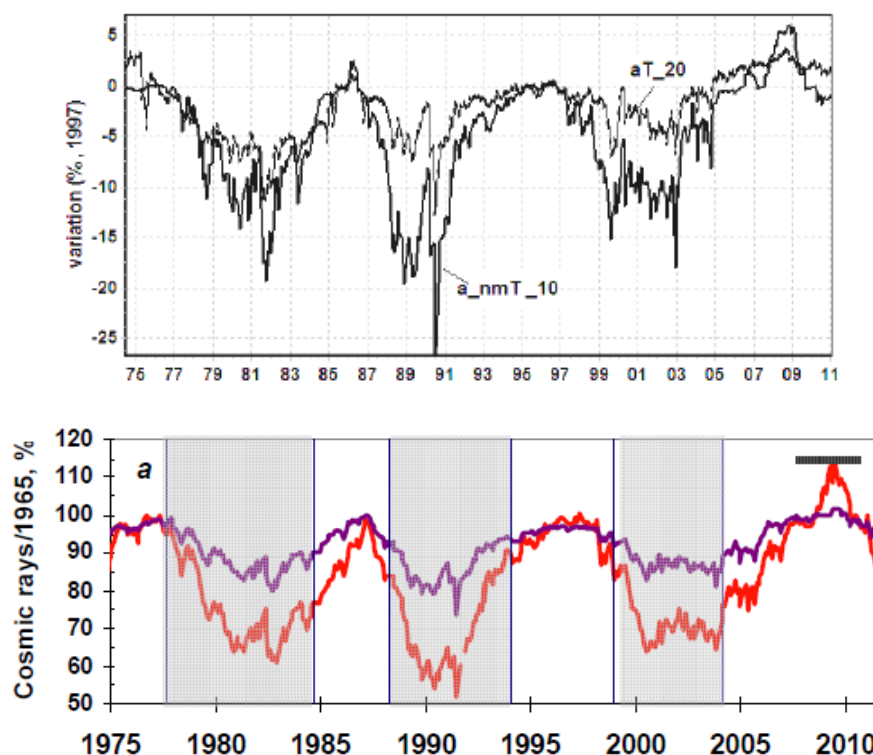

Figure 10. Long term CR variations observed by different detectors: the upper panel (SH454) - the NM network (R=10 GV , a_nm_T) and the Nagoya muon telescope (R=20 GV, aT_20); the lower panel (SH579) - monthly averaged fluxes of cosmic rays as measured by balloons (red curve) and by the Moscow neutron monitor (violet).

The first systematic study of long-term variations of amplitude-phase interdependence and phase distribution of the anisotropy was performed by Abunina et al. (SH400) on the basis of CR observations during the last five solar cycles (1957-2010 years). For each year of this period longitudinal distribution of the cosmic ray vector anisotropy and its amplitude-phase relation were calculated. The authors did an obvious conclusion that their results clearly demonstrate the dependence of cosmic ray anisotropy variations on the solar activity and solar magnetic cycles.

Krainev&Kalinin (SH346) tried to reproduce the main features of CR intensity profiles by solving the usual boundary task with the transport equation and rather simple models of its coefficients. They have calculated the partial "intensities" pertaining to the main physical processes $J = J_{diffp} + J_{convp} + J_{driftp} + J_{adiabp}$ and believe that their method can help in understanding the behavior of the GCR intensity in the heliosphere. Kalinin&Krainev (SH347) discussed how two types of the GCR intensity variations can be isolated using the observations and calculations. The authors tried to describe the observations

during two normal consecutive minima of solar activity and studied the space and energy distributions of the intensity.

Another work of the same authors (Krainev&Kalinin, SH498) compares the current characteristics of the sunspot activity and cosmic ray intensity with those expected in the future maximum of the current solar cycle. The values for maximum phase are estimated from the correlation between characteristics in the maximum and in the injection points (few years before maximum) for the previous solar cycles. The expected galactic cosmic ray phenomena typical for the maximum phase of solar cycle (Gnevyshev Gap effect, quasi-biannual oscillations and energetic hysteresis) were also discussed.

Rozza et al. (SH489) presented the HelMod code for the transport of Galactic Cosmic Rays through the inner heliosphere down to 1 AU using the Monte Carlo approach, which includes a general description of the diffusion tensor and the magnetic field. Particle drift effects are also treated. The HelMod results were compared with the measurements of differential intensities obtained in solar cycle 23 and latter observations. Okhlopkov (SH637) once tried to argue that there is a connection between   longitudes of the planets Venus, Earth and Jupiter and 22-year and 11-year cycles of solar activity.

The origin of low-energy particle population in the heliosphere during minima of the solar activity is not entirely understood yet. Previous investigations of the time variations of quiet-time low energy (0.3–1 MeV) proton fluxes, their energy spectra and radial gradients indicated that these protons should be predominantly of solar origin over the whole solar cycle at 1 AU [32]. The relative ion composition with energies of 0.1–1MeV/n in quiet periods in the 23rd solar cycle (SC) was studied in [33-35], where it was concluded that the C/O and Fe/O ratios of abundances in the suprathermal ion population depend on the solar activity. The results obtained by Zeldovich et al. (SH451) examining the ^{3}He/^{4}He ratio confirm their earlier suggestions [36-37] based on investigations of C, O, CNO, Ne-S and Fe ion populations that different seed particle populations were accelerated to suprathermal energies by different acceleration processes during different periods of solar activity.

Getselev et al. (SH670) calculated the average, minimal and maximal values of the fluences of protons with energies >1, 2, 4, 10, 30 and 60 MeV in the Earth's orbit beyond its magnetosphere using IMP-8 measurements for the time periods from 1 month to 10 years. In these calculations galactic and solar CR were not separated. It has appeared that the minimal and maximal values of total interplanetary proton fluences for periods of >5 years differ less than by one order of magnitude. This result is important for planning of spacecraft operations in space since that according to the formal requirements the life time of spacecraft's in space service must be > 5–10 years.

6. Heliosphere

Two posters considered variations of Jovian electron intensity observed in different locations in the heliosphere aboard SOHO (Daibog et al.,SH398) and Ulysses (Dunzlaff et al., SH633) spacecrafts. Early investigations of Jovian electrons supposed that they come to the vicinity of the Earth along magnetic field lines only during periods of optimal connection between the Earth and Jupiter [38, 39]. In the absence of direct magnetic connection between the Earth and Jupiter realized every 13 month (the synodical period of Earth-Jupiter) the presence of Jovian electrons in the Earth environment and their 27-day variations during the subsequent 5-6 months were explained by the hypothesis of perpendicular electron diffusion to the proper magnetic field line in the vicinity of Jupiter and corotating interaction regions (CIR) as barriers against their extra angular propagation [40, 41].

To account for the longer presence of Jupiter electrons near the Earth (fig. 11) Daibog et al. (SH398) considered a possible formation of magnetic CIR-like traps in the interplanetary medium, which are filled up with electrons under their passage by the Jupiter and subsequent electron registration under their passage by the Earth (fig. 12). In this model Jovian electrons may be observed permanently independently of the phase of Earth-Jupiter connection and their 27-day variations naturally arise. Passing by Jupiter the trap is filled up by electrons, which are continuously emitted by

the Jovian magnetosphere, and electrons are trapped for a sufficient time to be registered several times during their passage by the Earth.
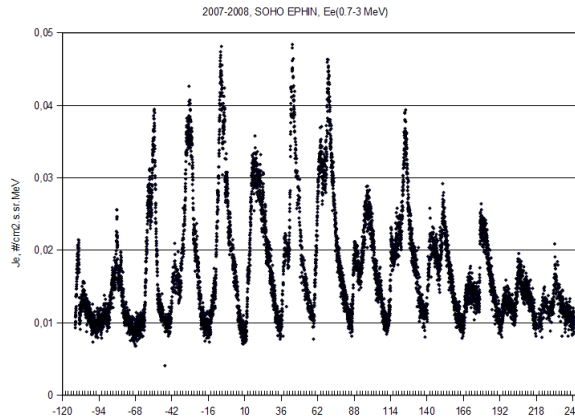

Figure 11. Intensity of electron flux within 0.7-3 MeV energy band measured by SOHO EPHIN in 2007-2008. Variations of ~27 days are clearly seen.
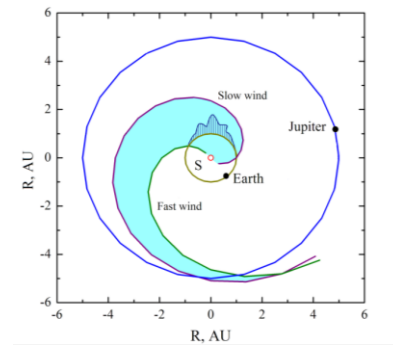
Figure 12. Schematic view of magnetic CIR-like trap in the interplanetary medium, filled up by electrons continuously emitted by the Jovian magnetosphere (SH398)

Jupiter's rotation period (~10h) can frequently be recovered in the energy spectrum of Jovian electrons in the vicinity of the planet [42, 43]. However, these modulation has never been reported to exist far beyond ~0.8AU upstream from the planet. Dunzlaff et al.(SH633) focused on the time interval from day 140 to 147 in 2004 (fig. 13) and show that the Jovian 10h periodicity can be detected in the Jovian electron flux at 1.2AU from the planet in the ecliptic plane. Beside the considerable length of the time interval, it is the most distant point from Jupiter, the 10h modulation had been reported up to now.

 Shakhov&Kolesnik (SH341) considered the heliosphere as a two-layer medium consisting of two spherical regions symmetrical about the Sun and adjacent to each other. In the internal region of the heliosphere, which is bounded by termination shock, solar wind has supersonic speed, and in the external region, which is bounded by heliopause, solar wind has subsonic speed. The authors settled a simplified boundary problem of CR propagation and obtained analytic expressions both for high energy particles (>2500 MeV) and for low energy particles (<1400 MeV) in the each region. Distribution of the low energy particles conform to results obtained on the «Voyager» spacecrafts. It was shown that density of the low energy particles should grow continuously from the Sun to the heliosphere boundaries**.**
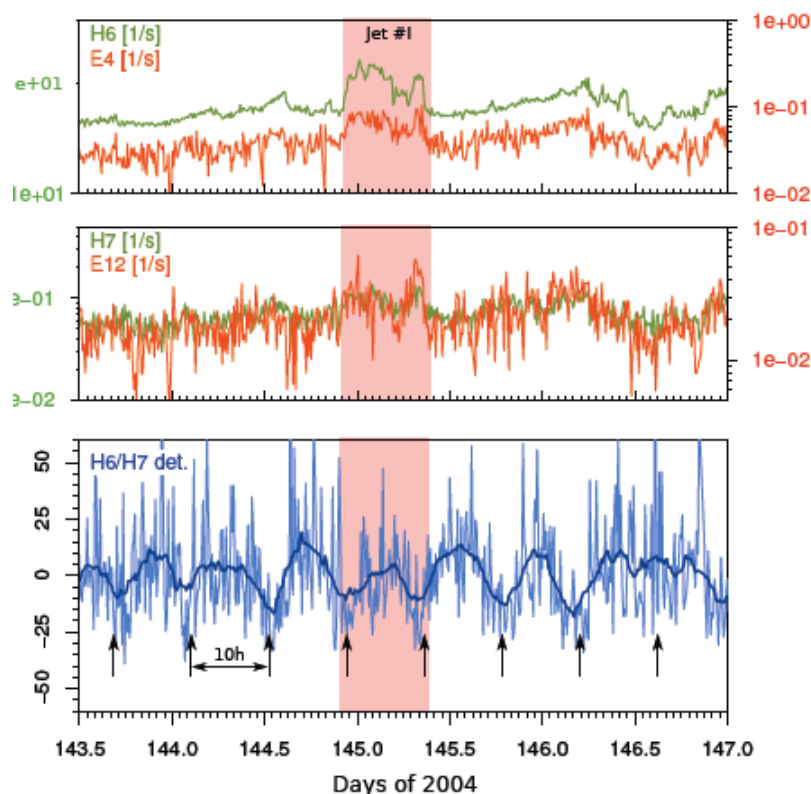
Figure 13. The time series of the KET/E4 (2.7-7 MeV), HET/H6 (1-3 MeV) and KET/E12 (7-170 MeV), HET/H7 (5-10 MeV) counting rates as well as the detrended H6/H7 ratio from day 143.5 to 147 in 2004. A 10h periodicity is visible in the ratio throughout the time interval. (SH633)

7. Conclusions and future prospects

Next two years the 24th solar cycle should pass its low maximum showing relatively high minimum of galactic CR intensity. We may expect new solar flares and CME's, SEP and geoeffective events observed by modern instruments in space and on the ground.

Sources of SEP would be investigated by methods of imaging hard X-ray and gamma spectroscopy aboard the RHESSI и Fermi space observatories. Solar magnetic field data will be available from SOHO and SDO spacecrafts supporting by ultraviolet images of loop systems observed aboard TRACE. Development of CME's in the 3D heliosphere will be continuously traced by two STEREO spacecrafts.

Our knowledge on longitudinal distribution of SEP should be improved by observations aboard STEREO A-B and spacecrafts near the Earth. The CR spectrum from hundreds of MeV up tens of GeV would be measured directly in space by PAMELA, Fermi, AMS detectors. The SH studies of CR would be continued by networks of ground based NM's and muon detectors. The calibration of ground based detectors may lead to improvements of magnetospheric and atmospheric models.

A new tool - the SEP Server, which greatly facilitates the investigation of solar energetic particles (SEPs) and their origin, developed by several research groups (EU FP7 project 262773) was presented by Malandraki et al. (SH730). The server would provide SEP and related EM data, methods of their analysis, including a comprehensive catalogue of the observed SEP events and educational/outreach material on solar eruptions.

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