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ON ENERGETIC PARTICLES IN SPACE

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Particles energized above the Earth's atmosphere provide unique informations about specific physical processes in the outer space. This is an attempt to present a short review of the knowledge of the characteristics of the cosmic energetic particles in wide energy range as observed on the ground, in the atmosphere, on Earth's satellites and on space probes. However, the review is related only to selected problems of cosmic ray physics and space physics. The bias is especially towards lower energies. After the historical introduction the features of primary cosmic rays is described. The heliosphere, in which the direct measurements of cosmic energetic particles takes place, is modulating the primary flux by magnetic fields controlled by the processes on solar surface and, is contributing to the low energy population by acceleration via transient processes as well as by solar flares. Important processes occur near the heliospheric outer boundary from where recently the space probes provided new information. Heliospheric influence is summarized in the third chapter. Another important object, the magnetosphere, is changing trajectories of incoming charged particles by "magnetospheric optics". Magnetosphere iself by the acceleration, transport, trapping as well as losses of lower energy particles alternates significantly the radiation environment near the Earth. The knowledge of particle population for which the condition of trapping are suitable in magnetospheres of giant planets of solar system, have increased thanks to space probes and planetary orbiters. Chapter four summarizes few important points of the magnetospheric influence on energetic particles. The measurements of temporal variability of the flux, energy spectra and angular distribution of cosmic ray particles influenced by solar-terrestrial effects, provides a unique tool for monitoring and eventual prediction of space weather effects, in addition to the investigations of the photon flux of various wavelength from the Sun, solar wind plasma and the magnetic field in interplanetary space. This is the main part of the chapter five.

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Contents

1 Introduction: From the history

The energetic particles produced and accelerated to high energies outside the atmosphere of Earth provide informations about the physical processes in various regions of outer space in the conditions which are difficult to simulate in the laboratory. Their observations started almost a century ago. First it was based only on measurements of the secondary products in the atmosphere and thus limited to high energy portion of its energy spectra. After the launch of the first satellites it was possible to measure the fluxes of particles with lower energies not providing any response in the lower atmosphere.

1.1 Cosmic ray discovery

The discovery of radioactivity by Henri Becquerel in 1896 was connected with the assumption that ionisation of air is mainly caused by the radioactive sources from the Earth's ground and from gases of the lower atmosphere. Already at the beginning of the last century there started discussions about possible additional sources of ionisation of the air along with the radiactive emanations from surrounding materials [Elster & Geitel, 1900; Wilson, 1901].

The cosmic ray discovery was done by Victor F. Hess in his observations with Wulf radiation detectors in the balloon flights [Hess, 1912]. The detectors surrounded by 3 mm wall thickness were suitable for observation of penetrating radiation. There were several balloon flights equipped with that type of instruments. The seventh flight reached the altitude of 5350 m above sea level. While at 1500-2500 m the mean altitude the radiation was of similar value than that on the ground, above 2500 m a clear rise in the radiation level with the increasing altitude was observed. Two instruments showed the increase by the factor of $\sim$ 2.1-2.3 in the observed ionisation in comparison of measurements at 4000-5200 m with that at the ground. The result indicated that a radiation with high penetrating power is entering the atmosphere from above and it produces the ionization observed in closed vessels in the lowest layers of the atmosphere. There was no observation of difference in local time (night - day) and not at solar eclipse. Since the Sun was hardly to consider as the source of this radiation, it was supposed that gamma rays produced outside the atmosphere are the cause of that ionisation.

In 1913 and 1914 the ascents to 6 and 9 km respectively by the balloon lead to confirmation and to the extending of the finding [Kolhörster, 1915].

1.2 On the character of cosmic rays

R. Millikan introduced the term “cosmic rays” in 1925. He contributed significantly to measurements of cosmic rays in 1920s with the sounding balloons reaching 15 km altitude. The origin of cosmic rays is probably for the first time discussed in detail in the paper [Millikan & Cameron, 1928].

Skobeltzyn in 1929 prepared relatively a small cloud chamber between the poles of a magnet with purpose to measure the energies of electrons from beta radioactive decay based on the curvature of the tracks. He observed during these experiments sometimes the extraneous tracks hardly deflected by the magnet. Their energies were larger than 15 MeV. These were most probably the first pictures of tracks of secondary cosmic rays [Skobeltzyn, 1929]. The counter controlled cloud chamber was one of the most important devices for cosmic ray experimental physics in 1930s. Its original technical description with the references to original papers is in [Leone & Robotti, 2008].

One of the most important papers on the character of "high altitude" or cosmic radiation was that by [Bothe & Kolhörster, 1929]. They observed the coincidences of counts in the two Geiger Müller counters placed close together. From the records of the deflections of the two counters they indicated that the large number of coincidences observed could only be explained by corpuscular rays, not gamma rays.

For question whether the primary cosmic rays are corpuscular charged particles or not, the geomagnetic field must be a useful test. The observations of the variations of cosmic rays with the position on the Earth's surface were done by Clay and Berlage [Clay, 1932; Clay & Berlage, 1932]. The two instruments were firstly compared in Amstredam and then one of them was mounted on the board of the motorship and the observations were recorded during the journey from Genoa to Batavia. The instrument consisted of the ionisation chamber with the needle connected with an electrometer. The precision was high and at the end of each hour the position of the needle was photographed. They observed falling off of the intensity with the decrease of geomagnetic latitude and confirmed the tendency reported in the previous voyages. While the intensity at Amstredam was ~ 1.86, its minimum ~ 1.57 was observed near geomagnetic equator. Their conclusion was that the "ultra-high radiation" (cosmic rays) incident on the Earth is a charged corpuscular radiation, the distribution of which the hardest end is approximately exponentional with a mean energy of about 3×10^{10} eV, which is cut-off at lower limit of 4×10^9 eV by the atmosphere, whereas between 50° magnetic latitude and the magnetic equator an additional 16% is cut-off at the lowest side in consequence of Störmer's forbidden spaces. The primary radiation produces in the atmosphere the secondary one of positive rays of great energy and negative rays. Some of them produce the tertiary radiation. The geomagnetic effect on cosmic rays was studied later also in another measurements. E.g. twelve cosmic ray surveys through the Pacific Ocean reported by [Compton & Turner, 1937] lead to the conclusion that about 2/3 of the latitude effect is caused by influence of the geomagnetic effect while 1/3 is due to meteorological effects.

The sign of the charge of primary cosmic rays (CR) was investigated especially in the period of 1930-1950ies. The measurements near the equator reported by [Johnson, 1933] indicated that a cosmic ray flux from the west was bigger than that from the east by about 7% at the sea level and by about 16% at 4200 m in Peru. The asymmetry in the flux was also deduced from the experiment by Alvarez and Compton [Alvarez & Compton, 1933]. This indicated positive charge of primary particles. [Johnson, 1935] analyzed in detail the surveys of CR intensities during several measurements. [Lemaitre & Vallarta, 1936] extensively studied asymptotics of CR trajectories and concluded that the north-south asymmetry discovered by Johnson in the course of his experiments in Mexico are fully accounted by the action of the magnetic field of Earth. The question on the mass of primary particles was definitely solved by experiments on high altitude balloons reaching 20 km [Schein et al., 1941]. It showed that primary particles are mostly protons.

Systematical studies of CR time variations started since 1930s. One of the impulse was the construction of a special precision ionisation chamber with the shield of 10.7 cm Pb [Compton et al., 1934]. Spherical volume 19.3 liters filled with argon of 50 atm pressure was used. The chambers were used for measurements at several sites in North and South America, Greenland and New Zealand. In the beginning of 1950s the larger volume chambers constructed in former USSR started to measure at several sites. The hourly data of the intensity are collected in the book [Shafer & Shafer, 1985]. The network of ionization chambers worked continuously for more than 30 years. More recent observations of temporal variability of CRs are discussed in part 3.

In CR studies, especially before 1950, there were discovered a couple of elementary particles. The positron was the first one. In the paper [Anderson, 1933] the photographs of cosmic ray tracks from the Wilson chamber indicated those of positively charged particles with much smaller mass than protons. They occurred in groups so it was concluded they must be secondary particles ejected from atomic nuclei. Positive and negative muons in 1937, charged pions in 1947, charged kaons in 1948 and neutral kaons in 1953 were discovered in the secondary CRs (from the tables by [Powell et al, 1959; Hillas, 1972]). With the development of accelerator technique elementary particle studies were later oriented more to those methods. Nevertheless cosmic rays remain the object of high energy studies at extremal energies until now.

For discovery of cosmic radiation and positron, the Nobel Prize for Physics was awarded to V.F. Hess and C.D. Anderson, respectively, in 1936.

The early results of fundamental importance for understanding the cosmic rays are reviewed e.g. in the books [Hillas, 1972; Rossi, 1990; Dorman, 1981; 2004] and in the paper [Ginzburg, 1996].

1.3 Energetic particles observed on first satellites

In 1930s Störmer systematically described the trajectories of charged particles in dipolar magnetic field [Störmer 1931a,b; 1932]. These works contributed significantly to the understanding of geomagnetic effects on charged particles. He also found that the particles with certain momenta can be trapped by dipolar magnetic field and they can move from one magnetic pole to another one with magnetic mirroring.

In 1957 the International Geophysical Year was organized (IGY) intended to allow scientists from all countries to participate in coordinated observations of various geophysical phenomena. It lasted from July 1957 to December 1958. More than 70 countries contributed to IGY. The most important new technologies which contributed significantly to the success of IGY was the rocket technique.

The satellite era started by the launch of the first artificial satellite Sputnik 1 in the former USSR in October 1957 (the orbit 215-939 km, inclination 65.1°, actively working on the orbit from 4^{th} October until January 8, 1958) opened new possibilities for observations of particles with lower energy than the atmospheric threshold. The US followed in January, 31, 1958 with launching of the Explorer I satellite (354-2515 km, inclination 33.2°, working on the orbit until May 31, 1970 when entered the atmosphere). It was the first succesfully launched US satellite. The main instrument of scientific character was using Geiger-Müller counters with the purpose to make a detailed and comprehensive study of cosmic rays above the Earth atmosphere. The improved version of the instrument was attempted on Explorer II on March 5, but the measurement was not done due to rocket failure. Similar type of instrument was used on the Explorer III launched on March 26, 1958. For the first time the magnetic type recorder was used succesfully in space for writing up scientific data. The radiation detectors on the Explorer I and III found that above the atmosphere there exist regions with a huge number of electrically charged energetic particles which are trapped in the geomagnetic field of Earth [Van Allen et al., 1958; Van Allen & Frank, 1959]. The discovery was promptly confirmed by other missions, firstly by USSR investigators on Sputnik III launched on April 27, 1958 with the orbit 230 – 1880 km and inclination 65.5°. The outer radiation belt was discovered with measurements onboard the third Sputnik in USSR under the scientific leadership of S.N. Vernov and A.E. Chudakov [Vernov et al., 1969]. The history of the first observations of Sputniks is described e.g. in the book [Launius et al., 2000].

Soon it became clear that the variety of charged particle populations is present above the Earth's atmosphere. While the solar wind was theoretically studied long time ago, in January 1959, the first direct observations of the strength of the solar wind were made by the former USSR satellite Luna 1. Launched on January 2, 1959, this first spacecraft to approach the Moon, measured first the the radiation belts of Earth by scintillator, and then in interplanetary space the plasma particles of solar wind by hemispherical ion traps. The discovery, made by K. Gringauz and his coworkers was verified by next Luna 2, 3, by more distant measurements of Venera 1 and Mariner 2 spacecrafts [Harvey, 2007]. Special session of AGU Fall Meeting in 1993 was devoted to the history of the solar wind discovery. The discussion is summarized by [Cliver & Siscoe, 1994]. Other important findings of K. Gringauz and his team, including that of the plasmapause - the boundary region of the plasma envelope of Earth, at which in the altitudes $\sim$ 20.000 km the plasma particle density drops to much lower values, are summarized in paper [Verigin et al., 1998]. More details about history of plasmapause discovery can be found in the book [Lemaire et al., 1998].

2 Primary cosmic rays

Usually by the term primary cosmic rays or galactic cosmic rays there are assumed charged particles accelerated to very high energies outside the heliosphere, the region where the CR trajectories are determined primary by the solar wind plasma or by magnetosphere of the bodies in the solar system. The region of energies most usually discussed as primaries is from $\sim$ 1 GeV up to $\sim 10^{20}$ eV or even higher which are measured by different techniques at the ground or on the satellites and space probes. The lower portion of energy range will be discussed in part 3. Here we review some of the characteristics of primary CR at higher energies not influenced by heliospheric processes.

There are many potential sources of primary CR discussed as e.g. black holes, neutron stars, active galactic nuclei, quasars and the big bang. Along with theoretical works the experimental ones, namely those to describe the energy spectra, chemical and isotopic composition as well as anisotropy are in the center of interest.

2.1 The energy spectrum of primary CR

The primary CR energy spectrum represents very important information for astrophysical studies. Its range in energies is enormous (up to 21 orders of magnitude). The same is valid for its flux with 32 orders of magnitude. Figure 2.1 compiled in 1997 from several measurements by balloons, satellites (low energy part), ground and underground technique displays the energy spectrum of primary CRs.

The differential flux of primary CRs can be approximated by the power-law decrease with energy. The three spectral features are exhibited in the spectra, namely the first knee at energy of $\sim 3 \times 10^{15}$ eV (3 PeV), the second one at about 5×10^{17} eV (0.5 EeV) and the ankle beyond 10 EeV [Picozza et al., 2009]. All questions, like (a) how and where the primary CR are accelerated, (b) how they are propagating through interstellar medium, (c) at which portions of spectra are they of galactic or extragalactic origin must be answered assuming spectral features of CR.

Although the CR flux is relatively low and decreases sharply with the energy, the energy density of main components of CRs is not negligible in the galaxy. The area under the proton LIS (local interstellar spectrum) curve (fig. 1.6 in [Gaisser, 1990]) is 0.83 eV/cm^3. Heavier nuclei contribute another $\sim$ 0.27 eV/cm^3. This is comparable with the galactic magnetic field density of $\sim$ 0.25 eV/cm^3 in the typical magnetic field in the galaxy of B $\sim$ 3 μGauss. It should be mentioned that a half of the energy carried by CRs is not directly measured at Earth because of solar modulation. However, the two energy densities are comparable and the interaction between CR and magnetic field in the galaxy is mutual. Thus field configurations are influenced by CR and vice versa.

CR at least up to 10^{15} eV are considered of galactic origin. The index of power law spectrum of the CR flux vs energy is $\sim$ -2.7 in the approximation $\mathrm{d}N/\mathrm{d}E \sim E^{-\gamma}$. Observations of gamma rays of very high energies provide "second channel" of the information about processes leading to the galactic CR acceleration. The extensive review of results in gamma ray astronomy can be found e.g. in the book [Aharonian, 2004]. Observational evidence gathered especially in X-rays and gamma-rays during last years support the indication that Supernova remnants are galactic CR accelerators up to energies close to the first knee in the energy spectrum of CR [Funk, 2008].

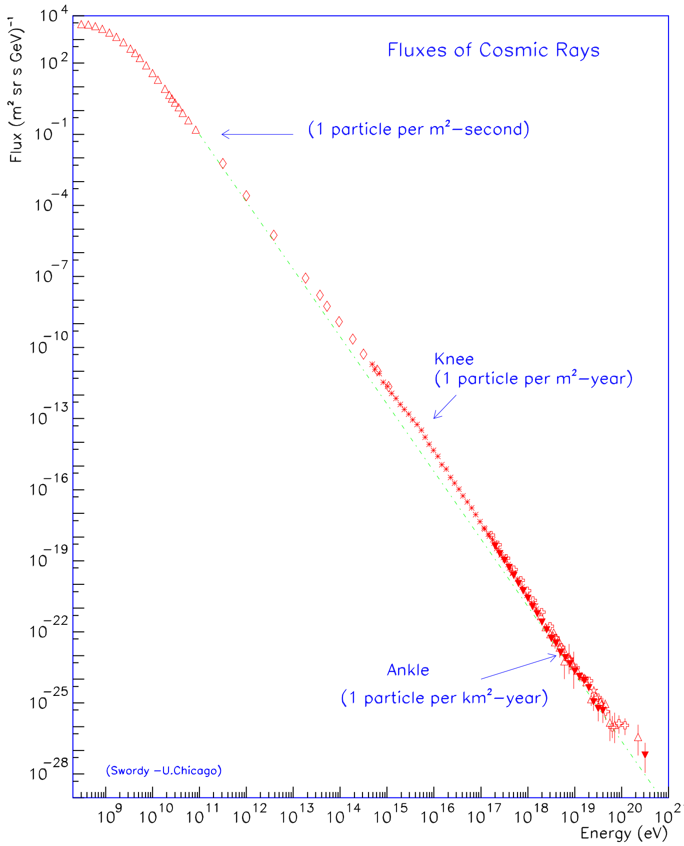

Fig. 2.1. Energy spectrum of cosmic rays (adapted from [Cronin et al., 1997]; downloaded from http://astroparticle.uchicago.edu/cosmic_ray_spectrum_picture.htm]). Courtesy of S. Swordy. For comparison with accelerators: the final Tevatron is 2 TeV and CERN LHC is 14 TeV (from more detailed figure of CR spectra at http://www.physics.utah.edu/∼whanlon/spectrum.html).

The update of the status of the knee in the spectrum at 3-4 GeV was considered recently and the evidence of presence of a single source was stressed [Erlykin and Wolfendale, 2009].

The range of energies between the two knees is very important subject of the studies. Above the knee (first one) a variety of supernovae and hypernovae, pulsars, a Giantic Galactic Halo is considered e.g. by [Erlykin & Wolfendale, 2005a,b]. Above the first knee, the energy spectra of CR is more steepen with $\Delta\gamma \sim 0.5$. The spectra at very high energy multiplied by $E^{2.7}$ is shown in Figure 2.2.

The subject of the very high energy CR is reviewed and discussed recently e.g. in the papers [Unger, 2009; Stanev, 2009; Berezinsky, 2009 and in several papers presented at recent 31st ICRC in Lodz, Poland, 2009]. The thickness of the atmosphere is about 20 radiation and interaction lengths or above that. Thus atmosphere is a proper calorimeter for invetsigation of primary CR particles. The data for Figure 2.2 were obtained from studies of the secondary CR.

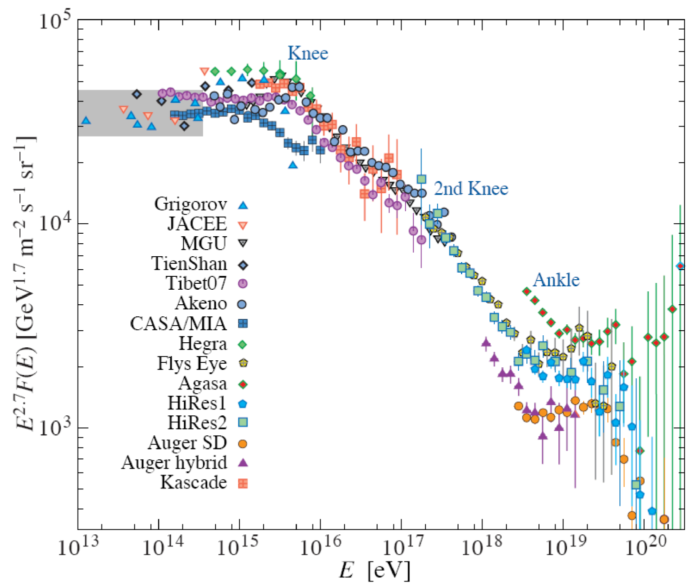

Fig. 2.2. CR flux according to [Amsler et al., 2008 and references therein compiled from several measurements]. Courtesy of C. Amsler.

These are mainly based on the air showers, the cascades of secondaries produced after entering the atmosphere the nuclei of primary CR. Their interpretation depends on the model used.

More than fourty years ago the two papers [Greisen, K., 1966; Zatsepin & Kuzmin, 1966] predicted the decrease of energy spectra of CR at extreme energies due to interactions with cosmic microwave background radiation. This effect is called Greisen-Zatsepin-Kuzmin suppression (GZK). Its existence was recently established by a large area ground based experiments [Abraham et al., 2004; Abbasi et al., 2008]. The paper by [Abbasi et al, 2008] indicates according to HiRes experiment a sharp suppression of the GZK cutoff with statistical significance of five standard deviations. The sharp suppression at the energy of 6×10^{19} eV, consistent with the expected cutoff energy, is reported. The ankle is observed at 4×10^{18} eV. The paper [Unger, 2009] stresses that the thresholds for photo-pion production of protons with photons of cosmic microwave background is at similar energy as the giant dipole resonance for iron nuclei. Figure 2.3 (adapted from that paper) shows the current statistical precision of the flux measurement at utra high energies is not yet sufficient for the spectral shape of CR with a pure proton and iron composition in the source. One of new space science missions under praparation is JEM-EUSO [Takahashi et al., 2009; Bertaina et al., 2009]. The instrument will watch the darkside of the Earth and will detect photons emitted from air-showers due to extremely high energy CR interactions in the atmosphere (above 10^{20} eV). This can be an important impulse to new astronomy with charged particles. In its 5 years of operation including the tilted mode, Extreme Universe Space Observatory an Japanese Experiment Module (JEM-EUSO) will detect at least 1000 events with $E > 7 \times 10^{19}$ eV with the GZK suppression spectrum.

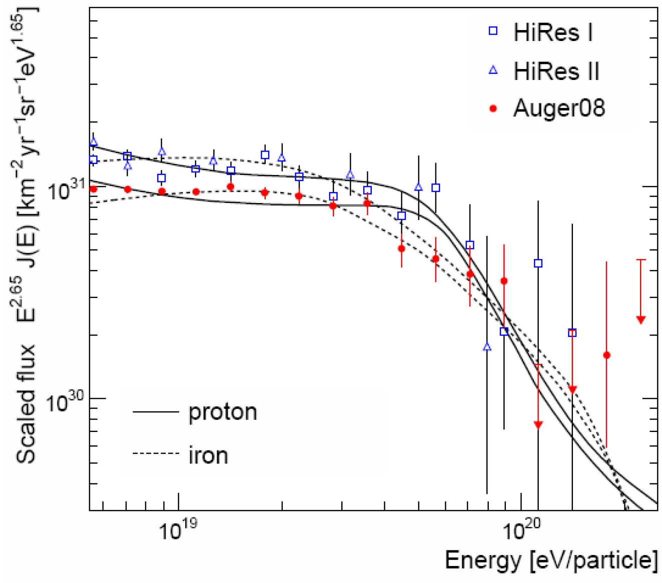

Fig. 2.3. (from [Unger, 2009 with references to Aloisio et al., 2008; Allard et al, 2008]). The cosmic ray spectrum multiplied by $E^{2.65}$ at ultra high energies compared to the predictions for propagated proton and iron primaries. Courtesy of M. Unger.

2.2 Composition of primary CRs

The dominant CR species are protons. However, with improving detection technique it became clear that also heavier nuclei and other particles are present in the primary CRs. The chemical and isotopic composition of primary CR ions measured near the Earth contain the unique information about the origin and the transport of the accelerated particles through interstellar medium. In [Simpson, 1983] there are compiled data on CR elemental abundances from He to Ni for CR at low energies (70-280 MeV/nucl) and high energies (1-2 GeV/A) and compared with solar system abundances. There are several differences in the comparison of solar system matter with CR composition. For both abundances indicate an odd-even effect with overabundance of even Z. Heavier nuclei relative to protons are more abundant in CR than in the solar system [Gaisser, 1990]. Two other differences are related to the propagation and confinement of CR in the galaxy. The group Li, Be and B is by more than 4 orders more abundant in CR than in the solar system. Another group, namely Sc, Ti, V, Cr, Mn, are also orders more abundant in CR in comparison with solar material, by 1-3 orders of magnitude. These elements, absent as the end products in the nucleosynthesis of the stellar material, are present in CR flux as spallation products due to fragmentation of heavier nuclei (group C,N,O and Fe) by collisions of primary CR with matter in interstellar medium. Assuming the knowledge of the cross-section of the fragmentation of heavier nuclei and the estimates of density of interstellar medium, it is possible to obtain approximations of the thickness of material which primaries traversed from the source to the detector near the Earth. The abundances of groups of CR nuclei is in Table 2.1.

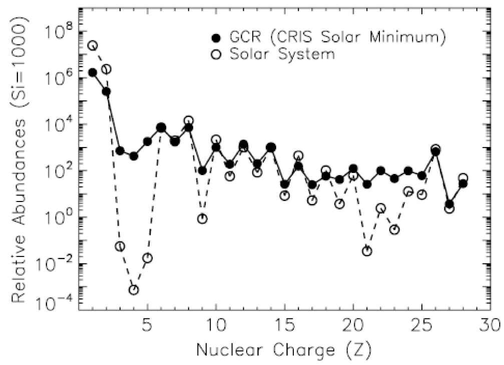

Fig. 2.4. (from http://www.srl.caltech.edu/ACE/ACENews/ACENews83.html). Composition of galactic CR abundances with solar system abundances normalized to Si (10^3). Published as figure 7 in [George et al., 2009]. Reproduced by permission of the AAS. CR abundances of the elements heavier than helium are obtained from ACE/CRIS instrument. The Solar System abundances in this figure are from the compilation [Lodders, K. 2003. *Astrophys. J.*, 591, 1220].

The abundance of hydrogen (and helium) relative to the heavier elements is the results of two effects in the acceleration of CR. First, refractory elements (those found in interstellar dust grains) are over abundant in CR relative to volatile elements (those found in interstellar gas). Second, there is a mass-dependent efficiency of acceleration, at least for the volatile experiments. These two features were noted and explained by [Meyer et al., 1997; Ellison et al., 1997]. That work was further advanced in a recent paper by [Rauch et al., 2009].

The instrument CRIS (Cosmic Ray Isotope Spectrometer) on ACE (Advanced Composition Explorer) measures deep in interplanetary space at distance $\sim 1.5 \times 10^6$ km from the Earth the CRs in the energy interval from ~ 50 to ~ 500 MeV/nucleon, with isotopic resolution for elements from Z $= 2$ to Z $= 30$ [Stone et al., 1998]. The comparison of the composition of galactic CRs with the solar system is shown in the Figure 2.4 which exhibits all features mentioned above.

The isotopic composition of CR as determined by the CRIS instrument is discussed with implications for CR origin in more details in other papers. E.g. [Wiedenbeck et al., 1999] report the abundances of CR isotopes ^{59}Ni and ^{59}Co. [Yanasak et al., 2001] discuss the implications of measured ^{10}Be, ^{26}Al, ^{36}Cl, ^{54}Mn, and ^{14}C for galactic CR age. [Binns et al., 2005] derived the ^{22}Ne/^{20}Ne ratio for the CR source which is significantly enhanced in comparison with solar wind.

Tab. 2.1. adopteded from [Amsler, 2008 and references therein] shows the relative abundances of different groups of CR nuclei normalized to oxygen at energy 10.6 GeV/nucl.

Z	1	2	3-5	6-8	9-10	11-12	13-24	15-16	17-18	19-20	21-25	26-28
element	H	He	Li-B	C-O	F-Ne	Na-Mg	Al-Si	P-S	Cl-Ar	K-Ca	Sc-Mn	Fe-Ni
F	540	26	0.40	2.20	0.30	0.22	0.19	0.03	0.01	0.02	0.05	0.12

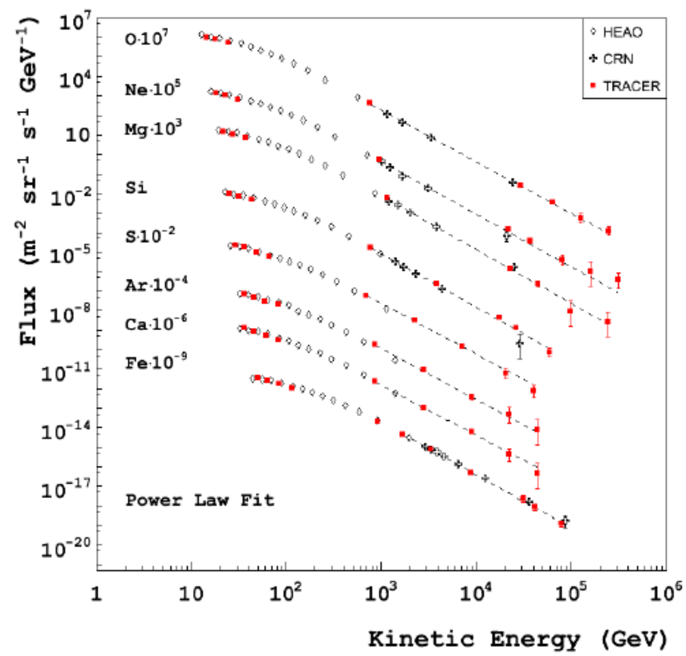

Fig. 2.5. (from [Obermeier et al., 2009]). Compilation of the energy spectra of several CR components at high energies. Courtesy of D. Muller.

The elemental composition of CR for elements with charge 4 to 18 and 14 energy windows from 0.6 to 35 GeV/nucl were earlier published by [Engelmann et al., 1990] from low orbital satellite measurements.

At higher energies the composition is deduced also from the balloon and air-shower ground based observations. Relatively recent measurements are reported e.g. in papers [Horandel, 2006; Obermeier et al., 2009]. Figure 2.5 shows the energy spectra of several species of CR at high energies. The highest energies are covered by observations on long duration balloon flights TRACER.

The mass composition of CR at ultra high energies is still under discussion. Results from Yakutsk extensive air showers array indicate that CR mean atomic number increases with the energy below 3×10^{17} eV, it has a maximum 2.6 ± 0.4 at $\sim 10^{17}$ eV, in the region 3×10^{17}-3×10^{18} eV there are seen some irregularities and it progressively decreases with the energy above 4×10^{18} eV [Knurenko et al., 2009 a,b]. Such behaviour is consistent with the scenario in which CR spectrum consists of three components, namely (i) CRs produced in supernova remnants; (ii) reaccelerated galactic CRs, and (iii) extragalactic CRs with hard spectrum. On the other hand composition from experiments HiRes and Auger gives different picture: at energies above 3×10^{17} eV it shows almost constant relatively light CR composition with $\langle \ln \mathrm{A} \rangle \sim 1.5$. That value depends on the hadronic interaction model. This situation is not sufficient for a reliable conclusion about transition from galactic to extragalactic CR components and more

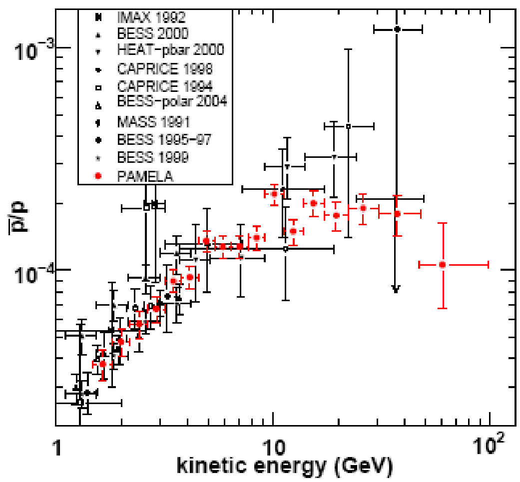

Fig. 2.6. (from [Bongi et al., 2009] and references therein). The ratio of antiprotons to protons obtained from PAMELA experiment along with other measurements performed before. Courtesy of F. Cafagna.

precise measurements of the CR composition is needed in the interval 10^{16} eV $< E < 10^{19}$ eV to determine the transition.

2.3 Other particles

Not only protons and heavier nuclei are present in primary CR. The asymmetry between matter and antimatter in the universe is one of the most important open questions also in particle physics. The interest to antiprotons and other antiparticles exists because of possibilities to test acceleration and propagation models of primary CR as well as to search for dark matter particle annihilations. The first experiments observing the antiprotons in CRs were done 1970s [Bogomolov et al, 1979; Golden et al, 1979]. The early discussions of the antiproton flux in CRs and its implications in CRs can be found e.g. in papers [Gaisser & Maurer, 1973; Szabelski et al., 1980; Király et al., 1981]. Recently the measurements from PAMELA experiment allowed to obtain the ratio of protons to antiprotons in wide energy range and with high statistics [Adriani et al, 2009a,c]. Figure 2.6 from ICRC Lodz is illustrating their results. This experiment is continuously taking data and the mission is planned until at least end of 2009, but probably longer.

These results are precise to put constraints on parameters relevant for secondary production calculations. At energies above 10 GeV it places limits on earlier discussed contributions from exotic sources such as dark matter particle annihilations.

There are other experiments under preparation with the aim to measure CR antiparticles. One of them is the AMS. Its scaled-down version has been flown on Space Shuttle Discovery for 10 days in June 1998. The spectrometer has a large geometrical factor and it is designated to operate on the ISS in near future for several years [Alcaraz et al., 2002; Casaus, 2009; Zuccon et al., 2009]. The AMS-02 with the large acceptance (5000 cm^2.sr) and the intense magnetic field

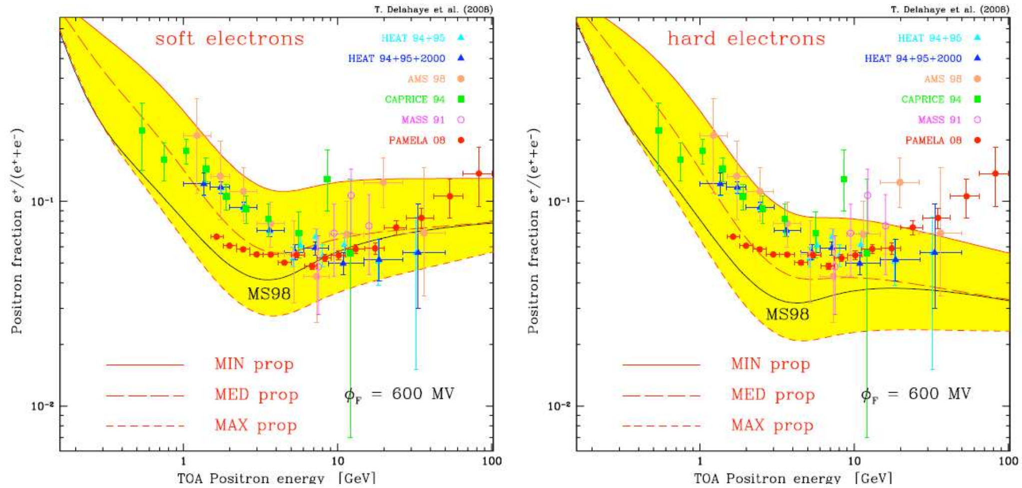

Fig. 2.7. (from [Delahaye, T. et al., 2009c]) Energy dependence of positron fraction for two different electron spectra, soft (left) and hard (right) in comparison with measurements. Dashed area denotes an uncertainty in the propagated flux caused by the uncertainty in the astrophysical parameters. Credit: A&A, 501,3, 821-833, Figure 12, 2009, reproduced with permission © ESO. Permission granted by Astronomy and Astrophysics. Courtesy of R. Lineros.

with a superconducting magnet of 0.7 T and with a precise particle identification will provide probably the highest accuracy of CR measurements up to TeV range of energies [Battiston, 2008]. Over 3-5 years on the orbit it is expected that instrument will collect $\sim 10^9$ nuclei and isotopes from deuterium to iron at high energies.

The electrons and positrons are another tool for a testing of various theories of CR origin and propagation as well as for a dark matter research. Secondary positrons are produced by CR fragmentation during its propagation via the interstellar gas. Measurements have been typically expressed in terms of positron fraction, which exhibits an increase above 10 GeV. To explain this feature several scenarios have been proposed. Paper [Adriani et al., 2009b] reports the measurement of positron fraction ($e^+/(e^- + e^+)$) in the energy range 1.5 to 100 GeV. The authors found that positron fraction increases sharply over much of that range and infer that this is completely inconsistent with secondary sources. They concluded that a primary source, be it an astrophysical object or dark matter annihiliation, is necessary. New predictions of the secondary positron flux and its theoretical uncertainties allowed to [Delahaye et al., 2009a,b] to discuss in greater depth the interpretation of the excess positron fraction. It was already noted [Moskalenko & Strong, 1998] that a change in the electron spectrum may affect the existence of an excess in the positron fraction. [Delahaye et al., 2009 a,b,c] assumed the dispersion observed in the data above a few GeV and below ~ 100 GeV, i.e., over the entire PAMELA energy range, is reproduced well by taking the spectral index of $\gamma = 3.44 \pm 0.1$, as mentioned above. To interpret the positron fraction measurements, they therefore considered two cases for the electron flux, a soft spectrum with index 3.54, and a hard spectrum with index 3.34 (see Fig.2.7).

There are other possibilities to explain the behaviour of positron flux at high energies. The

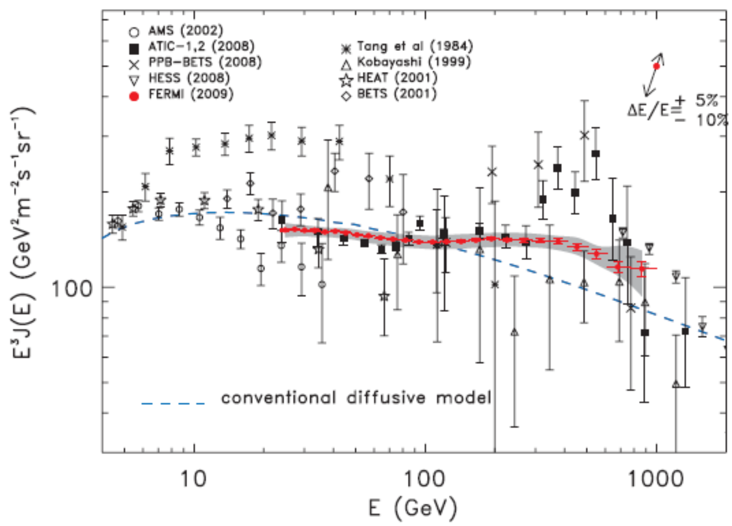

Fig. 2.8. (from [Abdo et al., 2009]). The energy spectrum of CR electrons from Fermi LAT instrument. The gray band indicates systematic errors. Comparison with other measurements with references therein is compiled. Conventional diffusive model prediction by [Strong et al., 2004] is marked as dashed line. Reprinted figure with permission from paper [Abdo, A.A. et al., Phys. Rev. Lett., 102, 181101-5, figure 3, 2009, http://link.aps.org/doi/10.1103/PhysRevLett.102.181101]. Copyright 2009 by the American Physical Society.

anomaly of the positron fraction observed by the PAMELA experiment can be attributed to recent supernova explosion(s) in a dense gas cloud near the Earth. This was shown in paper [Fujita et al., 2009] with the scenario that protons are accelerated around the supernova remnant. Hadronic interactions inside the dense gas cloud create positrons. Their spectrum is harder than that of the background because the supernova remnant spends much time in the radiative phase. That scenario predicts that the antiproton flux dominates that of the background for ≥ 100 GeV. Test for such scenario can be the ratio B/C (boron to carbon) measured with higher statistics than until now. The expected data statistics for AMS-02 on ISS is for 3 years of measurements on the orbit $\sim 3 \times 10^5$ above 10 GeV/c and 1600 for $E > 100$ GeV. At the same time it is expected to obtain 3200 antiprotons with energy above 100 GeV [Zuccon et al., 2009]. Such precision is very useful for resolving the question about the increase of positron fraction at high energies recently reported from the PAMELA experiment.

Recently, on Fermi space mission, there is the measurement of an electron-positron component at high energies. The electron detector with a huge geometrical factor 2 m^2.sr at 300 GeV is capable to obtain precisely e+e- energy spectra. Paper [Abdo et al., 2009] show that the electron spectrum falls with energy as approximately to $E^{-3.0}$ and does not exhibit spectral features. Figure 2.8 is illustrating that. The spectrum is much harder than the conventional one. This may be explained by assuming harder spectra of electrons in the source. The flattening of spectra at $E \geq 70$ GeV may also suggest the presence of a single or more local sources of high energy CR electrons.

3 Energetic particles in the heliosphere

CRs enter from outside in the heliosphere, the region which is a magnetic bubble containing our solar system. The trajectories of energetic particles are there controlled by interplanetary magnetic field and by magnetospheric fields in the vicinity of the planets. The interplanetary magnetic field (IMF) is governed by solar wind plasma which has higher energy density than IMF. The CR energy density in the inner heliosphere is lower than that of IMF and that of solar wind. Thus it represents a specific "autonomous" population of particles. In the outer heliosphere, however, the relations are changing.

Heliosphere with its IMF on one side modulates the CR flux especially at the low end of its energy spectra, on the other side it contributes to the energetic particle population by acceleration at the Sun and on plasma discontinuities in the interplanetary space. Additionally it is transparent to neutral atoms which may be ionized in the inner heliosphere and subsequently accelerated contributing thus to suprathermal particles.

The point where the solar wind slows down is named the termination shock. The surface at which the solar wind pressure is balanced by plasma flow in interstellar medium is called the heliopause.

3.1 Solar wind and interplanetary magnetic field

[Chapman & Ferraro, 1931] studied the geomagnetic storms and observed that some strorms commence with rather sharp increase of geomagnetic field observed by ground based magnetometers. They suggested the explanation that their cause is a corpuscular radiation from the Sun which reaches the Earth by about a day later. Charged corpuscular particles cannot penetrate the geomagnetic field and thus are deflected by that which leads to the changes of the field observed on the Earth. This was most probably start of the solar wind investigation. Later [Biermann, 1951] in cometary studies concluded that traditional explanation, i.e. the radiation pressure cannot account for observational facts. He suggested that there must also be a pressure by a stream of particles from the Sun which must exist all the time. His estimation of the velocity of the particle stream was about 500 km/s. This is a very good estimate which was revealed later by experiments mentioned in 1.3. S. Chapman and E.N. Parker proved that unlike the Earth's atmosphere, the solar corona is not in hydrostatic equilibrium and expands continuously, with matter leaving the Sun and streaming out into the space [Hargreaves, 1992]. The name solar wind was introduced by E.N. Parker. The existence of solar wind was proved experimentally soon after the starting of the satellite era (part 1.3).

Review of solar wind properties and basic physical concepts of its formation in the solar corona can be found e.g. in papers by [Hundhausen, 1995; Parker, 2007; Goldstein, 1998]. The solar wind is a flow of ionized solar plasma as a result of the large difference in the gas pressure between the solar corona and interstellar space. Due to that the plasma is driven outward from the solar surface despite the influence of solar gravity. In the simplest treatment the corona is assumed to contain only one type of particles. Using the equation of continuity and considering the forces acting on a unit volume of gas and the equation of state, the velocity of the outward flow can be expressed as a function of distance. From the theoretical assumptions, Parker in 1958 estimated solar wind velocities at the Earth distance from the Sun between 260 and 1160 km/s for coronal temperatures in the range 5×10^5 and 4×10^6 K [Parker, 1958]. Later works included

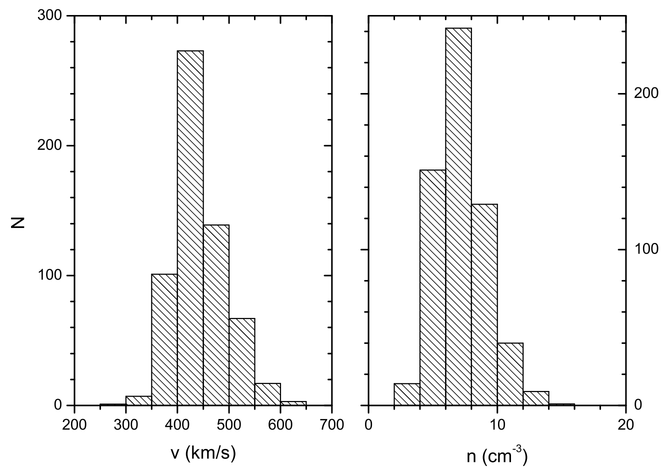

Fig. 3.1. Distribution of the 27-day averages of the solar wind speed and proton density from 1963 until middle of the year 2009. The data were downloaded from the NASA web site http://omniweb.gsfc.nasa.gov.

varying temperature, viscosity, the magnetic field as well as more types of particles.

The informations about solar wind being a hot, tenous and fast moving plasma, are obtained from spacecrafts measuring plasma characteristics outside the Earth's magnetosphere. It consists largely of ionized hydrogen with almost equal density of electrons and protons. A small component (about 5%) is of ionized helium and heavier elements. Typical characteristics [Hundhausen, 1995] are: proton density 6.6 cm^{-3}, electron density 7.1 cm^{-3}, flow speed is nearly radial ~ 450 km/s, proton temperature 1.2×10^5 K, electron temperature 1.4×10^5 K. The average magnetic field induction is about 7 nT. The flux density at 1 AU is for protons $\sim 3.0 \times 10^8$ cm^{-2}s^{-1}. The typical kinetic energy is 0.6 erg.cm^{-2}s^{-1}. This is different from the thermal energy of particles in the flow which is 0.02 erg.cm^{-2}s^{-1}. The energy density of the magnetic field is lower, it is about 0.01 erg.cm^{-2}s^{-1}. The magnetic field is embedded in the solar wind plasma and the concept of frozen in field lines in the plasma of extremely high conductivity is usually used. This concept is described e.g. by [Kivelson, 1995]. The gas pressure derived near the Earth's orbit is ~ 30 pPa. The sound speed assuming both protons and electrons is ~ 60 km/s. The time for wind to flow from the corona to the Earth is typically ~ 4 days during interplanetary quiet conditions. An important value is the speed of Alfven waves, the travelling oscillation of ions and magnetic field in the plasma with lower frequency than the cyclotron one. Its value for typical parameters of magnetic field and plasma density near Earth is ~ 40 km/s.

Solar wind characteristics are not stable in time. Their variations near the Earth occur especialy after strong disturbances on the solar surface. Figure 3.1 shows the distribution of solar wind density and velocity.

Solar wind characteristics depend on the heliolatitude. The Ulysses spacecraft reached during

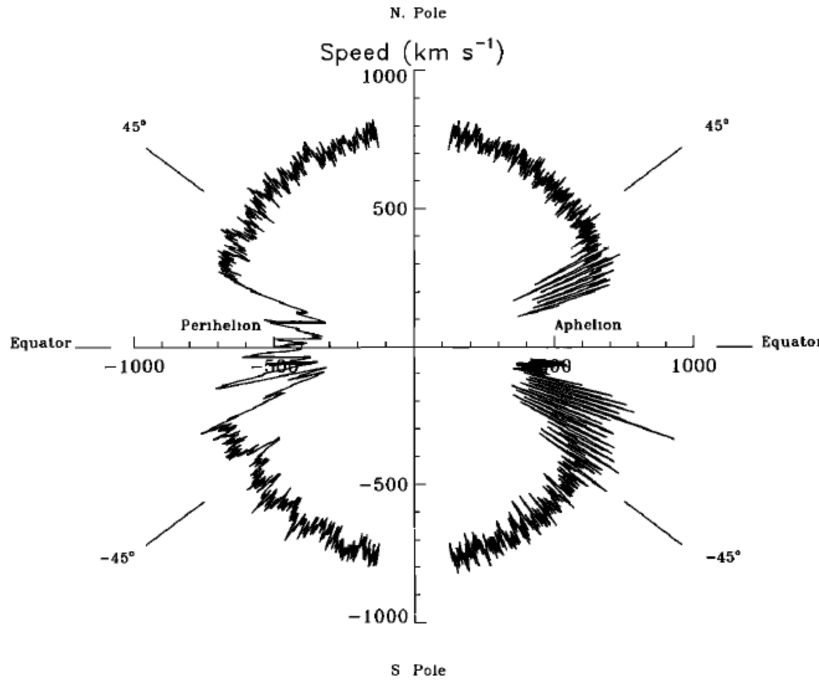

Fig. 3.2. (from [McComas et al., 1998]). The solar wind speed as a function of the heliolatitude obtained from Ulysses measurements from February 1992 until January 1997. Reproduced by permission of American Geophysical Union. Courtesy of D. McComas.

its mission high heliolatitudes. Declined from the ecliptic the velocity of plasma was found to have larger speed (Figure 3.2).

The solar wind plasma controls the configuration of field lines of IMF because its energy density is higher than that of magnetic field. One can think of a flow which drags the frozen-in field with it and it is forming a magnetic structure consistent with the plasma flow. Applying this concept to the spherically symmetric solar wind with its radial expansion, in the stable flow of solar wind the IMF is expected to have a simple structure. The IMF was discovered in 1963 by the IMP-1 (Interplanetary Monitoring Platform). Its orbit was eccentric with apogee of 32 Earth radii. The conservation of magnetic flux within the tube gives the intensity of exactly radial magnetic field would decrease with the distance r from solar surface as $\sim 1/r^2$. However, the solar atmosphere rotates about its axis which is nearly perpendicular to the plane of ecliptic. The rotation rate is depending on the heliolatitude and also on depth of the convective zone. The rotation period at the equator is ~ 25.67 days and at solar latitude $75°$ it is 33.40 days [Lang, 2007]. Thus near the solar equator solar corona and any fixed source are rotating at angular rate $\sim 2.67 \times 10^{-6}$ rad/s. The trace of the fluid parcels emitted from the fixed point on the solar surface takes the shape of a spiral. That is why also IMF field lines must have the same form of the spiral configuration. The field lines are carried through the interplanetary space. At the orbit of the Earth the azimuthal and radial components of IMF for a constant solar wind

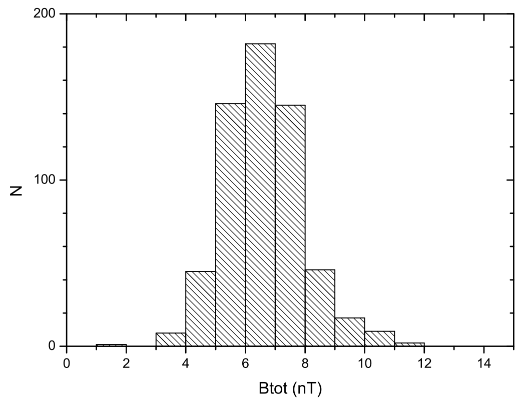

Fig. 3.3. Distribution of the 27-day averages of the IMF B from 1963 until middle of year 2009. The data were downloaded from the NASA web site http://omniweb.gsfc.nasa.gov.

velocity 400 km/s are equal and the angle between the field line and a radial line from Sun to the Earth at 1 AU should be approximately $45°$ which is conistent with the observations during quiet time periods. The magnetic field module measured near the Earth over a long time period is in Figure 3.3. The IMF as well as solar wind speed are changing dramatically at shorter time scales.

The measurements of IMF started by IMP-1 revealed the sector pattern of the field lines (toward the Sun, outward the Sun). The IMF polarity is uniform for some interval of time if measured near Earth (or stable over some extent of angular regions) and then changes its sign. During solar disc rotation period the Earth is inside few different sectors. The structure is more complicated during the solar activity maxima because of many transitional effects. The IMF in equatorial plane if viewed from solar polar regions would have the pattern divided into sectors of opposite polarity. However the structure is three dimensional with a wave like structure of the heliospheric current sheet which extends into the interplanetary medium. As the spiraling magnetic sheet changes polarity, it warps into a wavy spiral shape that has been likened to a ballerina's skirt [Rosenberg & Coleman, 1969]. The inclination of the current sheet, being a border "plane" between the regions of opposite polarities of the IMF, is changing (tilt angle) and the Earth is during some time intervals above or below that. The large scale strucure of the heliospheric current sheet is described e.g. by [Hoeksema, 1995].

3.2 Transport of galactic CR in the heliosphere

The energy spectra of CR measured near Earth (Fig. 2.1) has peculiarities at low energies. The bending of spectral form below few GeV is apparent. The spectral shape at low energies depends on the state of the heliosphere. The level of solar activity controls the outflow of the plasma from solar corona with embedded IMF. The sunspots observed for a long time in the photosphere

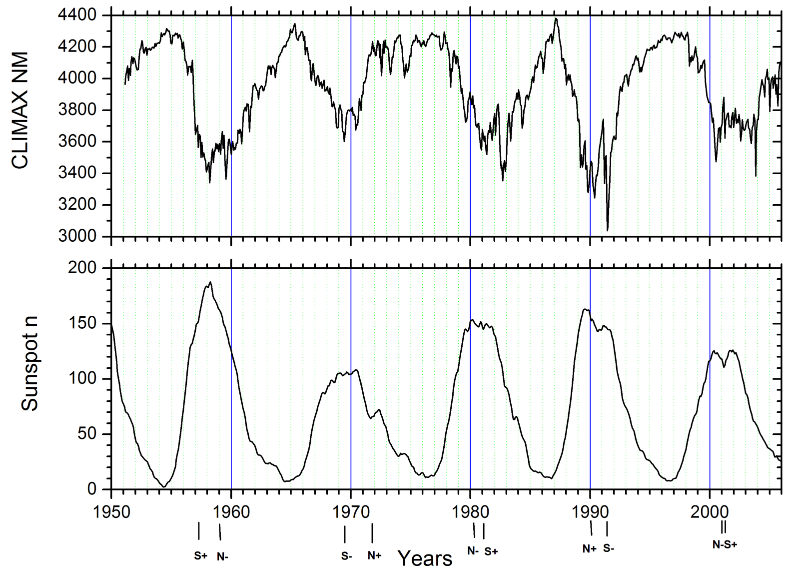

Fig. 3.4. CR - neutron monitor count rates Climax (downloaded from http://ulysses.sr.unh.edu/ NeutronMonitor/Misc/neutron2.html) and smoothed sunspot number monthly means (from http://www.ngdc.noaa.gov/stp/SOLAR/ftpsunspotnumber.html#american). Solar magnetic field polarity reversals indicated in bottom. The Climax data are acknowledged to the University of New Hampshire, "National Science Foundation Grant ATM-0339527".

are regions on the solar surface with much stronger magnetic field and lower temperature in comparison with the surrounding areas. Their extent is several thousands km and B inside is up to 4000 Gauss, the value larger by factor 10^3 in comparison with the Earth magnetic field near the equator. The magnetic field is measured with use of Zeeman effect. The solar activity measured by sunspot numbers or sunspot area are useful parameters for energetic particles measured in the interplanetary space.

Outward flowing solar wind with the IMF screens the access of primary CR into the heliosphere. The solar modulation of CR depends on primary particle energy. Below several hundreds MeV practically all galactic CR are expelled from the inner heliosphere [Jokipii, 1998]. Thus they are not measured near Earth at all. The modulation below about 10 GeV is present even during solar minimum. The main feature of a long term variation of low energy galactic CR near Earth is the anticorrelation of the flux with solar activity having about 11 year cyclicity. The anticorrelation between the solar activity and CR flux can be observed from the ground. It is shown in Figure 3.4.

The CR transport theory which is used until now with several small modifications was described first by E.N. Parker [Parker, 1965]. He supposed that energetic particles in the interplanetary space walk randomly in irregularities of the large-scale IMF when irregularities are moving with the solar wind velocity. The distribution function he described by a Fokker-Planck equation which characterizes the time evolution of the probability density function of the position and momentum of particle. Parker worked out general expression for particle diffusion coefficients including both scattering in magnetic irregularities and pressure drifts. The diffusion coefficient was reported $\sim 10^{21}$-10^{22} cm^2/s as estimated from earlier CR studies. Parallel diffusion coefficient is higher than perpendicular one. One of the most important effects is the convection – CR particles respond to the IMF convected by solar wind. The particles are rotating fast about the spiral magnetic field and at the same time they move parallel to IMF. The irregularities which are superimposed on the regular spiral structure of the IMF can scatter the particles and pitch angle diffusion occurs which leads to approximately nearly isotropic pitch angle distribution of particles in the frame of moving solar plasma. The mean free path for scattering along and perpendicular to the IMF spiral B similar to plasma description is characterizing the motion of CR particles. For the simplified picture in which just 1D radial diffusion against the outward convective motion is assumed and the resulting flux through the surafce unit are balanced, the diffusion coefficient is the function of energy, distance and time [Longair, 2004]. In addition to the convection and diffusion, the CR experience two additional effects. One of them is the acceleration or deceleration. The solar wind plasma is expanding in free space and compressing at the shocks near the planets or in the interplanetary medium. Thus the inhomogenities with different IMF are either drawing apart each other or approaching. This leads to the adiabatic cooling or heating due to multiple interactions of particles with inhomogenities. Another effect is the curvature and gradB drift. The rotation of particle around the field line is faster than scattering. Thus particles are subject of drift due to large scale spatial structure of the IMF. All four effects are combined in the theory by Parker.

In addition to the ~ 11 year CR variation in the “antiphase” with solar activity which indicates the importance of convective effects, there is also ~ 22 year variation. This is seen from Figure 3.4 where different shapes of CR profile during two subsequent solar minima are apparent. This effect is most probably related to the magnetic field cycle of the Sun. During two minima (~ 1987 and ~ 1975-1976) the CR profile are different. While for minima $\sim$1987 the polarity of solar magnetic field was negative (northward from the neutral current sheet the field points to the Sun, in the south out from the Sun), for the minima ~ 1975-1976 the polarity was opposite, positive. During the minima of solar cycles with different solar magnetic field polarity the drift motions bring positively charged particles into the inner heliosphere via different latitudes. For the minima as ~ 1987 and ~ 1964-1965 the access is via the equatorial heliosphere, and for the minima ~ 1975-1976 it is via polar regions. Particles arriving through the equatorial region are more sensitive to the latitudinal change of the tilt angle of the neutral current sheet. Thus around those minima the peaks in CR are sharper. On the other hand CR plateaus are seen around solar minima with the opposite solar magnetic field polarity since the acces of particles through polar regions is not strongly sensitive to the current sheet change (tilt angle).

Drift plays important role in modulation. [Kóta & Jokipii, 1982] presented 3D model simulations of the solar modulation of CR, including drift and obtained prediction for CR variation near the current sheet. The model produces negative gradient away from a wavy current sheet as seen by observer on the Earth.

Recently it was shown that even 50 GeV CR indicate spatial density gradient. [Okazaki et al., 2008] deduced the gradient from anisotropy derived from Global Muon Detector Network

(GMDN). The N-S gradient is oriented toward the current sheet. The theory of CR transport in the solar wind is summarized e.g. by [Jokipii, 1971] and application of the theory both to modulation of galactic CR by solar wind and propagation of solar CR is discussed in detail. The irregularities of the IMF can be important for understanding the transport of CR in the heliosphere. The turbulence and power spectra of fluctuations of plasma and magnetic field in the interplanetary medium is discussed in detail by [Jokipii, 1973]. The galactic CR intensity gradients were earlier obtained from Pioneer-10 spacecraft measurements in comparison with data from IMP-5 and 6 at 1 AU. Paper [McKibben et al, 1973] reports the preliminary integral intensity gradient for protons and helium, namely 4.5 ± 1.0%/AU over radial range 1-2.8 AU. [Axford, et al., 1976] obtained from measurements on Pioneer-10 and 11 en route from the Earth to Jupiter report radial gradient 0.15 ± 2.3%/AU basically consistent with zero. The discrepancy between theoretical value about 8%/AU is suggested to be explained either that accepted diffusion coefficients are too low, or spherically symmetric models are inadequate, or that temporal variations are important, or another transport mechanism is required. The unidirectional latitude gradients represents the asymmetry of CR density above and below the heliospheric current sheet. Particles approaching the Earth near ecliptic plane as they gyrate around the IMF on both sides of current sheet. If there is asymmetry of CR densities above and below current sheet, it can be detected as a CR streaming in the ecliptic plane and perpendicular to the IMF. Based on 18 years of measurements of Japanese network of muon multidirectional telescopes [Munakata et al., 1999] derived the latitude gradient which has no clear variation with 11 and 22 year solar cycles but remains positive after late 1980s implying higher density of CR in the southern hemisphere below current sheet.

There are several important papers dealing with the transport of CR in the heliosphere. We just mention two of them. Many other can be found in ICRC proceedings, 2007 and 2009, respectively. The present solar minimum is an unusual one with a relatively long duration of very low sunspot numbers. According to http://www.earthfiles.com/news.php?ID=1624&category=Science (R. Mewaldt) the CR intensity reaching the Earth will go up even more prehaps from 19% to even 30% more than was observed in the Space Age. This period with available measurements at different distances from the Sun is interesting for the study of CR transport. [Florinski & Pogorelov, 2009] investigated four dimensional transport of galactic CR protons in the 3D asymmetric heliosphere, including the inner heliosheath region, and tracking stochastic phase-space trajectories of Parker equation with steady state of plasma. The model is applied to quiet solar wind conditions appropriate for 2008-2009 solar minimum. Intensities of galactic p and He measured by Voyagers in 2008 were the highest ever recorded and most probably approching the interstellar values. The authors report CR gradients in the heliosheath are small in directions of Voyagers (1.5-1.8%/AU at 180 MeV) and that termination shock does not accelerate CR ions efficiently. The modulation of galactic CR of both charge signs, protons and electrons, was studied for the unusual solar minimum (2008) when during the latest Ulysses out-of-ecliptic orbit the solar wind density, pressure and the IMF have been observed the lowest ever in the history of space exploration [Heber et al., 2009]. It is expected that the weak IMF and plasma density cause the smallest modulation since the 1970s. In contrast to that, the galactic CR proton flux at 2.5 GV measured by Ulysses in 2008 does not exceed the one observed in the 1990s significantly, while the 2.5 GV GCR electron intensity exceeds the one measured during the 1990s by 30%-40%. At the solar minimum, however, the intensities of both electrons and protons are expected to be the same. In contrast to the 1987 solar minimum, the tilt angle of the solar magnetic field has remained $\sim 30^\circ$ in 2008. The comparison of the two epochs required the correction for the trajectory of Ulysses using latitudinal gradients for p and e and radial gradient. In 2008 and 1987, solar activity, as indicated by the sunspot number, was low. Thus the observations discussed in the paper confirm the prediction of modulation models that current sheet and gradient drifts prevent the CR flux to rise to typical solar minimum values. In addition, measurements of electrons and protons allowed the authors to predict that the 2.5 GV galactic CR proton intensity will increase by a factor of 1.3 if the tilt angle reaches values below 10°.

[Morales-Olivares & Caballero-Lopez, 2009] investigated the spatial distribution of CR in heliosphere at solar maxima for three solar cycles. They used 1D no shock model of CR transport equation. The radial intensity gradients from 1 AU to the outer heliosphere were deduced from data near the Earth and those from Voyager-1, 2, and Pioneer 10. Their analysis indicates that in the inner heliosphere adiabatic energy changes may play important role in radial distribution of CR. For the outer heliosphere the diffusion and convection are dominant.

The problem of the transverse diffusion in a strong magnetic field was analyzed by [Toptygin, 1985]. The statistical particle acceleration in a random anisotropic reflective non-invariant magnetic field by "alpha-effect" was analyzed in detail by [Fedorov et al., 1992]. Solutions of diffusion equations and/or Fokker-Planck equation are unapplicable in the case of large mean free path when it is comparable with the distance from a particle source. In that case one must use kinetic equations (modification of the Boltzmann equation, for example). Although this problem has been well known in the CR kinetics [Fisk & Axford, 1969; Earl, 1974], the solutions for particle distribution in the space has been obtained rather recently [Kóta, 1994; Fedorov et al., 1995; Webb et al., 2000; Shakhov & Stehlik, 2008]. Then the kinetic approach was applied to the study of particle distribution of a past solar event [Fedorov & Stehlik, 1997; Fedorov, et al., 2002] and in the strong inhomogeneous magnetic field [Fedorov & Stehlik, 2006].

For the experiment AMS [Bobik et al., 2009a,b] developed a stochastic 2D Monte Carlo model based on Fokker-Planck equation and including the diffusion, convection, adiabatic energy changes and drift. The modulated flux at several distances from the Sun was obtained, e.g. for the position of Pluto, Neptune, Uranus. Fig. 3.5 illustrates the result.

[Bobik, P. et al., 2008a,b] introduced a new concept into the transport model, namely that in which particle escape first the heliosphere and from interstellar medium re-enter it again. For parameters used in that paper, the effect of about 20% in CR intensity protons below few GeV was found (Figure 3.6).

The review of results related to the transport of CR particles in the heliosphere which were presented at ICRC in Merida, Mexico, 2007 can be found in papers [Cummings, 2009; Blasi, 2009]. An overview on the topic of the cosmic ray modulation in the heliosphere can be found e.g. in paper [Ferreira, 2009].

A comprehensive review on energetic particles in the heliosphere is e.g. in chapter 7 of the book [Kallenrode, 2004].

3.3 CR variability as observed from the Earth

3.3.1 Neutron monitor

Secondary particles produced by primaries in the atmosphere provide the possibility to measure temporal variations of low energy galactic CRs. The first CR data over longer time periods

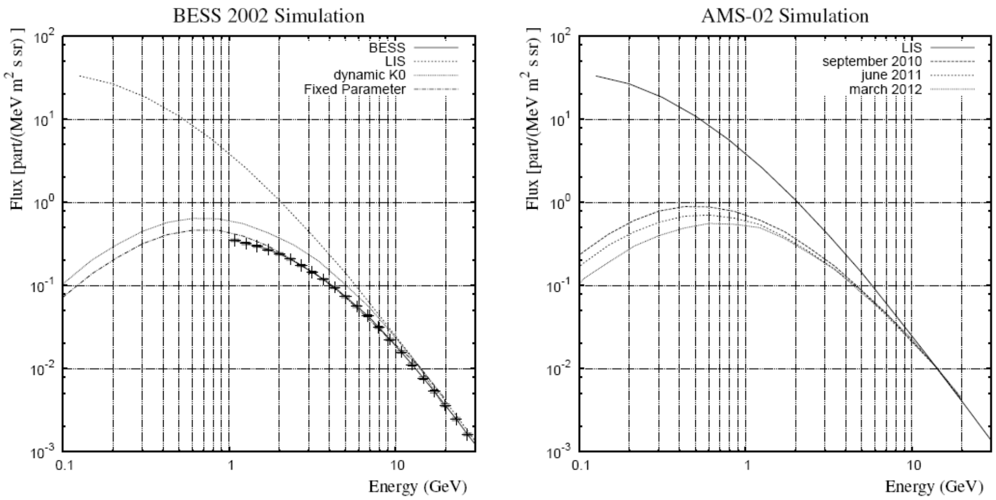

Fig. 3.5. (from [Bobik, P. et al., 2009b]). Left: CR modulation of 2D model in comparison with the BESS experiment. Values of K0, solar wind speed and tilt angle in the paper. LIS is the Local Insterstellar Spectra adopted from [Burger et al., 2000].

were obtained from ionization chambers. The routine monitoring of CR started in January 1932 with ionization chamber at Hefelekar, Austria and this instrument operated over next 20 years [Shea, 1972]. Ionization chambers respond to muons generated by primary protons. However, only nucleons with energy above ~ 4 GeV have a sufficient energy to generate a muon cascade capable of penetrating through the atmosphere and surviving to reach the Earth's surface. For lower energies it was desirable to develop a detector with response to lower energy portion of the primary CR spectra. One of the most widely used instruments for the study of CR variations is neutron monitor (NM). [Simpson, 1955] suggested and developed the neutron monitor with the purpose to detect deep in the atmosphere the variations of interplanetary CR flux. It is most sensitive to the energy range from 1 to 20 GeV of primaries. One of the secondary components of CR is the nucleonic. In neutron monitor the interaction rate of nucleonic component with the atmosphere or with lead target material surrounding the counters is measured. During early 1950s J. Simpson established a network of high altitude neutron monitor stations over wide range of geomagnetic latitudes [Simpson, 1957]. Neutron monitors replaced the ionization chambers and a world wide neutron monitor network started to provide the data. The neutron component (secondary) can be detected with the help of proportional counters. There are used two types of counters, namely those filled with the gas including a high concentration of the isotope ^{10}B (reaction with n gives ^{7}Li$_3$ and alpha particle with the double peak channels of neutron capture, namely 2.30 and 2.78 MeV) or with ^{3}He (reaction with n gives tritium and proton with single peaked spectrum at 764 keV). The experience with the second type of detection is recently described by [Storini et al., 2009]. The counters are usually about 2 m length and diameter 15 cm are surrounded by the moderator serving to slow down the neutrons before entering the counter and also to reflect low energy neutrons (the cross sections for n reactions with ^{10}B and ^{3}He are inversely proportional to neutron velocity – with thermal n the cross sections are 3840 barns and

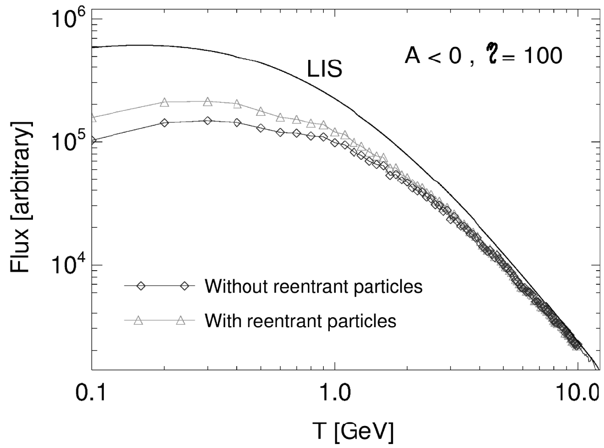

Fig. 3.6. (from [Bobik, P. et al, 2008b]. Modulated CR spectra at 1 AU for the ratio of the mean free path to gyroradius $\eta = 100$. The effect of particles which re-enter the heliosphere is seen at low energies.

5330 barns respectively). The moderator is surrounded by lead producer which serves as a thick heavy nucleus material for incoming particles (the production rate of neutrons is proportional to $\sim$A$^{0.7}$). The lead is surrounded by the outer moderator – reflector. This is rejecting unwanted low energy external evaporation neutrons produced in the local surrounding. During the years the neutron monitor construction was changed. First the IGY monitors were used and in some places they are used until now. For that one the moderator and reflector material is paraffin. The NM-64 monitor has a low density polyethylene moderator and reflector. The differences are also in geometry and tubes. Basic informations about the detection by NM can be found in the presentation [Clem, 2004]. To understand the ground based measurements by NMs the relationship between count rate and primary CR flux must be precisely known. Response functions of NMs at different atmospheric depths have been published e.g. in papers [Nagashima et al., 1989; Clem & Dorman, 2000]. Also the meteorological effects must be assumed, mainly the thickness of the atmosphere above the detector which can be approximately estimated by barometric pressure correction. [Shea & Smart, 2000a] summarized the CR measurements until 2000.

Important are high mountain NMs because the secondary component intensity increases with the altitude and thus high statistics allows to study the primary CR flux variation with a relatively high precision and with better temporal resolution. One of the NMs is working over long time period at Lomnický štít (2634 m above sea level). The real time data are available from http://neutronmonitor.ta3.sk. Figure 3.7 shows the construction of neutron monitor at that site.

3.3.2 Irregular CR variations. Forbush decreases

The CR time profile is quite complex and it is due to many effects of (a) interplanetary, (b) geomagnetic and (c) atmospheric origin. More extensive and detailed review of CR variations with references can be found in the books [Dorman 1963; 1974; 2004; 2006; 2009]. Here we

Fig. 3.7. Lomnický štít neutron monitor since 1981 measures with 8 proportional counters of the type SNM 15. The statistics is $\sim 1.6 \times 10^6$ counts/hour. The detail shows a reflector, moderator and partially one counter. More informations about the measurements of CR in High Tatra mountains can be found e.g in paper [Kudela & Langer, 2009].

mention just one of the a type.

In 1930s there were reported CR intensity decreases during some geomagnetic storms by $\sim$ 1% and the average decrease during 17 storms was 0.3% [Messerschmidt, 1933; Steinmauer and Graziadei, 1933]. Decreases of CR count rate which last typically several days were studied for the first time systematically by Forbush [Forbush, 1937; 1938] and also by [Hess & Demmelmair, 1937]. Since 1950s it came to be called the Forbush decrease (FD) or the Forbush effect. Two different types of FDs are observed, namely (i) the non-recurrent ones which are caused by interplanetary phenomena and related to coronal mass ejections from the Sun (CME) and (ii) the recurrent decreases with more gradual onset and associated with the corotating high speed solar wind streams [Lockwood, 1971; Iucci et al., 1979]. The CME typically carries about 10^{12} kg of coronal material from the Sun to the interplanetary space. The speed is ranging in wide interval; from 20 km/s up to 3000 km/s. The review of CMEs can be found e.g. in [Schwenn et al., 2006; Srivastava et al., 2006]. The close connection between CMEs and flares suggests that magnetic reconnection plays an important role in the CME eruption and evolution. There are however solar flares without major CMEs [Gopalswamy et al., 2009]. The paper [Cane, 2000] discusses in detail the first type of the FD and summarize the characteristics of CMEs, their effects on particles and presents the understanding the mechanisms behind. Relation between FDs and geomagnetic activity was analyzed statistically as a dependence of the FD magnitude on the maximum Kp-index measured during the associated magnetic storm by [Belov et al., 2001a]. The relation of geomagnetic activity strong increases to FDs is not one to one [Kudela & Brenkus, 2004]. FDs without strong geomagnetic storm and vice versa are observed in some cases. Fig. 3.8 shows one of the largest FDs observed during the last cycle of solar activity.

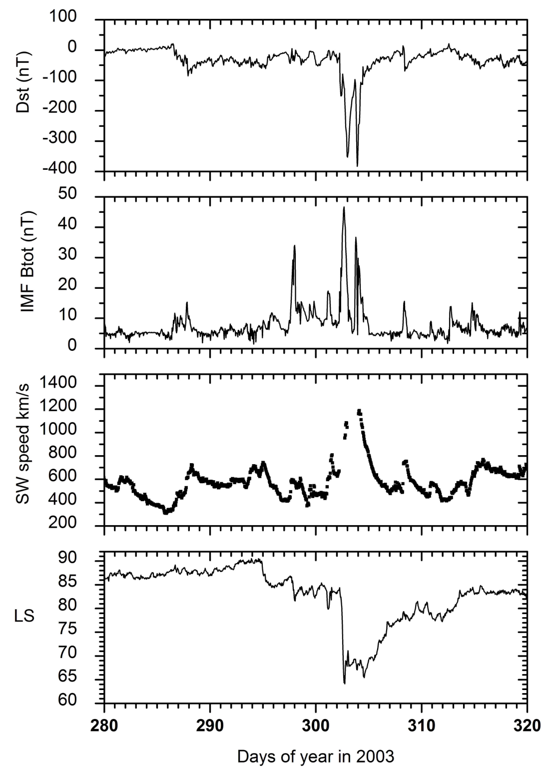

Fig. 3.8. Largest Forbush decrease in CR intensity observed at middle latitudes during the measurements with NM-64 at Lomnický štít (lowest panel, intensity in % normalized to 1.67×10^6 counts/hour = 100%). The uppermost panel is the Dst index of geomagnetic activity (definition at http://wdc.kugi.kyoto-u.ac.jp/dstdir/dst2/onDstindex.html). The value of IMF and solar wind speed are in the second and third panel (hourly data downloaded from http://omniweb.gsfc.nasa.gov/ web site).

Actually there were two FDs in that interval, one on days 295-300 and second larger one on daus 301-313. They had different energy spectra: the first one gradually hardening while the second one had very hard spectra (discussed e.g. by [Wawrzynczak & Alania, 2005]).

Although the FDs were reported first more than 70 years ago, the investigations of them, namely studies of mechanisms leading to the effects are still continuing along with a large amount of observations from ground based measurements. E.g. [Verma et al., 2009] found that all large FDs are associated with CMEs, majority of them are halo CMEs and that the vast majority of FDs are associated with interplanetary shocks. A model of piston shock produced due to sharp jump in the solar wind speed with a helical IMF is suggested to explain the origin of CR FD with hard energy spectrum at solar activity minimuma and in some cases at solar maximum [Krymsky et al., 2009]. FDs are observed also at higher energies by the detectors of secondary muons. Papers by [Barbashina et al., 2009a,b] analyze the FD by muon hodoscope URAGAN and found dependences of FD amplitudes on the median energy of primary CR protons at different zenith angles at higher energies than NMs provide. The non-recurrent FDs have been studied in conection to the interplanetary CMEs (ICME) [Kahler & Simnett, 2009]. They found good association of FDs with ICMEs observed by measurements of heliospheric imagers – Solar Mass Ejection Imager (SMEI) launched into the orbit in January 2003. Thus SMEI observations can be a useful forecast tool for FDs. The new installation ASEC (Aragats Space Environment Center) allows to measure the secondary CR of different types and in wide energy range. The analysis of FDs detected by this complex of devices during solar cycle 23 is analyzed by [Bostanyan & Chilingarian, 2009].

3.3.3 Periodical and quasi-periodical CR variations

There are many studies of diurnal variation of CR observed by NMs and by muon telescopes. Only few of the studies are mentioned here. [Parker, 1964] published the theory of streaming of cosmic rays and its relation to the diurnal variation. Also higher harmonics of diurnal CR variation were reported. [Ahluwalia & Singh, 1973] the tridiurnal variation of cosmic rays as observed by neutron monitors with different cutoff rigidities. [Ahluwalia & Riker, 1987] reviewed the long term changes of solar diurnal variation over period 1965-1976 and obtained the rigidity dependence of parallel diffusion coefficient. [Swinson et al., 1990] explored the diurnal anisotropies with IMF over 21 years. Results of other studies relevant to the diurnal variability of cosmic rays are e.g. in papers [Ananth et al., 1974; Duldig & Humble, 1990; Kudo & Mori, 1990; Vanstaden & Potgieter, 1991; El-Borie et al., 1996; Sabbah, 1999]. Assuming that at 1 AU the solar wind average speed is 400 km/s and the Earth orbital motion is about 30 km/s, cosmic rays will overtake the Earth from local time direction of ~ 18 h [Duldig, 2001]. Analysis by [El-Borie & Al-Thoyaib, 2002] have shown the difference in diurnal variations measured in toward and away polarity days of the IMF. In the study by [Kumar et al., 2002] the time/spatial variations in the amplitude and phase of the diurnal anisotropy become more pronounced for 60 geomagnetically quiet days for the period under investigation. [Mishra & Mishra, 2004] indicated the shift of the diurnal and semi-diurnal anisotropy vectors on quiet days to to early hours when the solar poloidal magnetic field was positive during the periods 1971-79 and 1992-95 as compared to that during the periods 1964-70 and 1981-90 when the the field was negative, showing a periodic nature of daily variation in the CR intensity with poloidal magnetic field of the Sun. [Tiwari & Tiwari, 2008] indicated that continuous decreasing trend in the diurnal phase with smaller change at high/middle latitude and significantly much larger change at low latitudes is deduced from several NM measurements in 1989-2000. [Moraal et al., 2005] have shown that during the solar minimum period of 1954 the cosmic-ray diurnal variation as observed by neutron monitors and muon telescopes underwent a dramatic swing in its direction of maximum intensity, from the normal value between 16 and 18 h local time to as early as 08 h. This can be explained as being due to a negative radial density gradient of cosmic rays in the inner heliosphere. [Singh & Badruddin, 2006] found that the amplitude of the diurnal anisotropy varies with a period of one solar cycle (similar to 11 years), while the phase varies with a period of two solar cycles (similar to 22 years). The authors also indicated the difference in time of maximum of diurnal anisotropy (shift to earlier hours) is observed during $A < 0$ (1970s, 1990s) polarity states as compared to anisotropy observed during $A > 0$ (1960s, 1980s). Enhanced and low amplitude

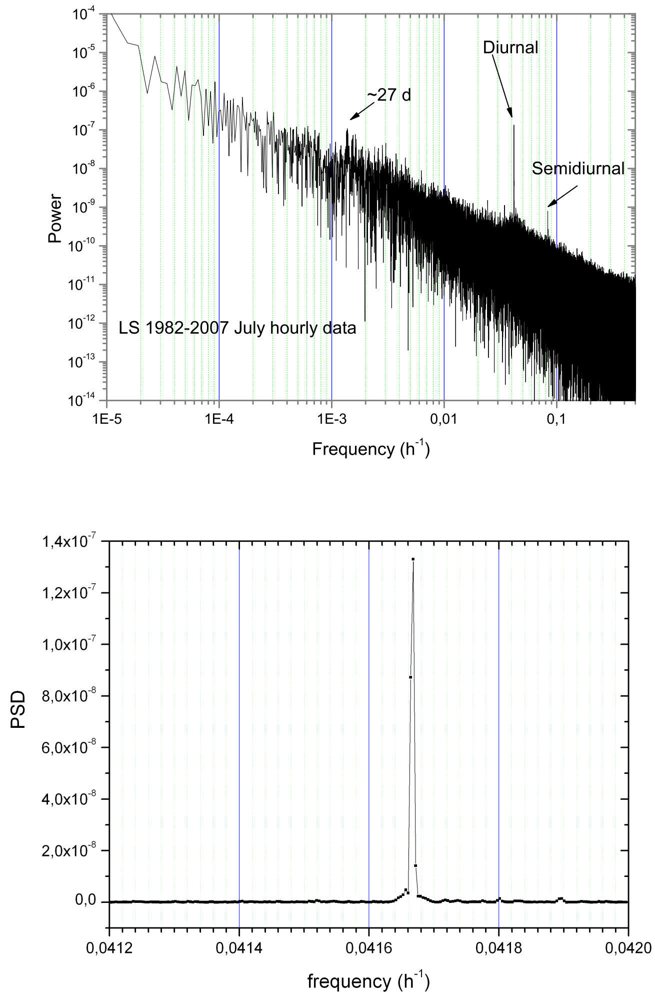

Fig. 3.9. Power spectrum density (in $\%^2$/Hz) of NM hourly count rate at Lomnický štít over 26 years of measurements. The diurnal CR variation peak is zoomed in the lower panel.

wave trains of diurnal variation were examined e.g. in paper [Mishra & Mishra, 2007]. [Sabbah & Duldig, 2007] pointed out that the amplitude of the diurnal variation observed by underground muon telescopes is lower for even cycles (20 and 22) than for the odd cycle.

Data from the middle latitude high mountain neutron monitor at Lomnický štít over period of 1982-2007 were used for checking the characteristics of amplitude and phase of the diurnal variation on the day-to-day basis [Firoz, 2008; Kudela et al., 2009]. For comparison the hourly data from Oulu and Climax neutron monitors were used too. The distribution of the amplitude and phases for the complete data set was done. Fig. 3.9 shows the diurnal variation over the long time period.

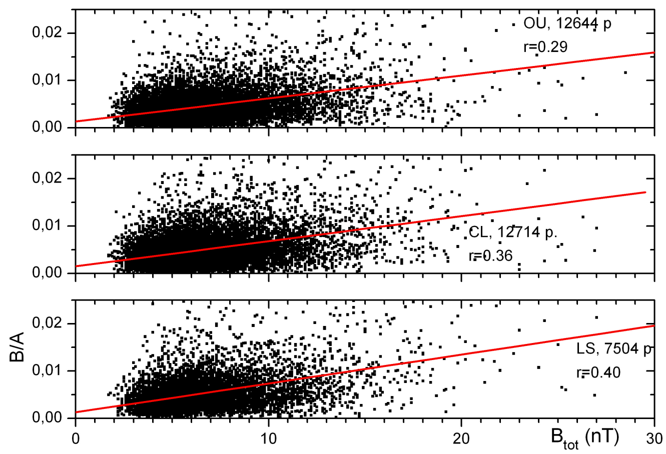

Fig. 3.10. Scatter plot of amplitude/average of the diurnal wave fit (amplitude to daily mean) vs the magnitude of IMF for three NMs (Oulu, Climax, Lomnický štít). The linear correlation coefficients and number of days is labeled for data of the three neutron monitors. (from [Kudela et al., 2009a]).

Selections with better quality of fits provide narrower phase distributions and better correlation with the total IMF which is the only one clear parameter for which the dependence of the diurnal wave amplitude out of "local" interplanetary plasma and magnetic field characteristics have been found (figure 3.10).

Although assuming the large data set, the correleation of amplitude with solar wind speed and geomagnetic activity indices is different from zero, their values are low. There is no clear dependence between diurnal wave characteristics and a north-south component of the IMF B. The dependences look similarly at Lomnický štít and Oulu neutron monitors. The data set constructed with extension to longer time interval and additions of more NMs and muon telescope data can be used in detailed studies of diurnal variation and its relation to the solar, interplanetary, and geomagnetic activity in future.

Another feature of quasi-periodicity in CR intensity measured by NMs is that of ~ 27 days (seen also from Fig. 3.9). One of the first papers reporting that quasiperiodicity in CR and relation to similar periodicities in terrestrial magnetic activity and sunspot areas was by [Broxon, 1942]. [Moussas et al., 2005] review various periodicities present in the variable physical characteristics driven from the Sun, among them 27 day peridicity. Period of 27 days related to solar rotation plays also a very important role in geophysical phenomena. It is noticeable that almost all periodicities are highly variable with time as wavelet analysis reveals. It is very important for humans to be in a position to forecast solar activity during the next hour, day, year, decade and century, because solar phenomena affect life on the Earth. For the investigation of that quasiperiodicity different methods are used. [Singh & Badruddin, 2006] describe two techniques to test the significance level of results obtained on the basis of superposed epoch (Chree) analysis. Study by

[Sabbah, 2007] revealed that the correlation of 27-day periodicity in CR is cross-correlated with the solar activity as measured by the sunspot number R, the interplanetary magnetic field (IMF) strength B, the z-component (north-south) of the IMF vector, and the tilt angle of the heliospheric current sheet (HCS). It is anticorrelated to the solar coronal hole area (CHA) index as well as to the solar wind speed V. The amplitude of the 27-day CR variation is better correlated to each of the these parameters during positive solar polarity ($A > 0$) than during negative solar polarity ($A < 0$) periods. [Mavromichalaki et al., 2003] analyzed by various methods CR at different NMs along with solar hard X-rays recorded by interplanetary stations for 3 years. In addition to 152, 27 and 14 days periodicities known earlier, they reported others too, namely 100, 70, 50 and 32 days. The $\sim$ 27 day periodicity in CR was observed also on space devices, e.g. by [Burlaga et al., 1991; Heber et al., 1997]. [Olemskoy & Mordvinov, 2009] established that the longitudinal inhomogenity of the solar magnetic field with the dipole distribution of polarities along the heliolongitude mainly contributes to $\sim$ 27 day modulation of galactic CRs. [Gupta & Badruddin, 2009] studied temporal evolution of the CR intensity during similar to 27-day Carrington rotation period by superposed epoch analysis. From the correlation analysis between the CR intensity and the solar wind speed during the course of Carrington rotation, they found that the correlation is stronger for positive polarity of solar magnetic field ($A > 0$) than for $A < 0$. [Modzelewska et al., 2006; Alania et al., 2008] demonstrated that the general features of radial and azimuthal components of galactic CR anisotropy can be studied by the harmonic analysis method using data of NMs at middle and low latitudes. [Gil et al., 2008] found that the larger amplitudes of the 27-day variations of the galactic CR anisotropy and intensity for the positive polarity period ($A > 0$) of solar magnetic cycle than for the negative polarity period ($A < 0$) in the minima epoch of solar activity are related with the heliolongitudinal asymmetry of the solar wind velocity.

Contrary to the diurnal period, the $\sim$27 day one is much more complicated and it has no character of "clocks". It is understandable because in the power spectrum of CR signal from NMs there are expected modulation effects from the IMF inhomogenities in 3 dimensions. Since the differential rotation of the solar disc is different at different heliolatitudes with different distributions of sunspots and inhomogenities connected, the resulting spectra are complex. This is seen from Figure 3.11.

The second harmonic, namely $\sim$ 13.5 day period of the CR intensity were compared with tilt angle of current sheet by [El-Borie, 2001]. The variations spectra of $\sim$ 27-day modulations revealed a clear dependence on the IMF polarity state, the spectra are harder during the period of 1981-1989, when $qA < 0$, than during the epoch with $qA > 0$. [Sabbah & Kudela, 2009] indicated the third and higher harmonics in the CR on the NMs but also at higher energies to which muon detectors are sensitive and compared it with solar wind characteristics, IMF and geomagnetic activity indices. The rigidity spectrum of the $\sim$ 27 day variability as well as of the second and third harmonics was recently analyzed over 1965-2002 with the NM data by [Gil, & Alania, 2009]. The rigidity spectra of all periodicities are similar, hard during solar maximum and softer during the solar minimum. The authors ascribe those features to the differences in the volume of effective CR modulation for the two phases of solar activity.

At NMs and to some extent at muon detectors, there are observed also other quasiperiodicities between $\sim$ 27 day and $\sim$ 11 year ones mentioned above. The low frequency evolution of CR variability based on NM measurements was examined e.g. by [Kudela et al., 1991]. The power spectrum density was shown to have abrupt change at $T \sim 20$ months. This indicated different

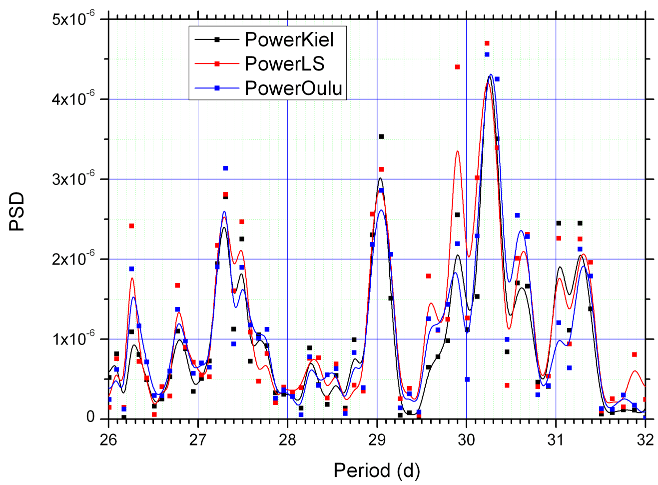

Fig. 3.11. (from [Kudela et al., 2009b]). The power spectrum density of the CR intensity at three european NMs during 1982-2008. The profile seems to be similar (coherent) at three stations at different geomagnetic latitudes and most probably shows the response to the transitional heliospheric effects driven from the Sun with rotation period depending on the heliolatitude.

processes responsible for the CR variability below and above that value. This is attributed to the large-scale IMF configuration determined by solar activity having maximum lifetime for modulation effects initiated at the Sun which propagate to the heliopause on time scales $\sim$ 20 months. From that it was speculating that it is due to heliospheric cavity oscillations with the boundary at distance 110-130 AU. Since the long term signal of CR observed by NMs is nonstationary time series, another techniques, namely wavelet transform has been used later. [Kudela et al., 2002] examined a long time series of daily means of CR intensity at few NMs by wavelet transform method checking the contribution of $\sim$ 150 days, $\sim$ 1.3 years and $\sim$ 1.7 years quasiperiodicity reported earlier in CR, solar and interplanetary phenomena (e.g. [Richardson & Cane, 2005; Mursula & Zieger, 2000; Valdés-Galicia et al., 1996] and/or various solar activity processes. Obtained results support the claimed difference in the solar activity evolution during odd and even solar activity cycles. In paper [Kane, 2005] the short-term periodicities of several solar indices are examined. The open fluxes, IMF and CR, all showed periodicities similar to those of solar indices. [Joshi, 1999] reported $\sim$ 170 day periodicity in CRs. [Mavromichalaki et al., 2003] reported that peaks in CR time series of 70, 56, 35, 27, 21 and 14- days were observed in all time series, while the periods of 140-154 and 105 days are reported only in the 21st solar maximum and are of particular importance. [Caballero & Valdés-Galicia, 2003] analyzed galactic CR fluctuations from six mountain altitude neutron monitors around the world during the period 1990-1999. A 38-day variation present in all neutron monitors, solar activity parameters, and IMF fluctuations, was found. Fig. 3.12 shows the power spectrum density of the intensity of CR from two european neutron monitors for long time periods.

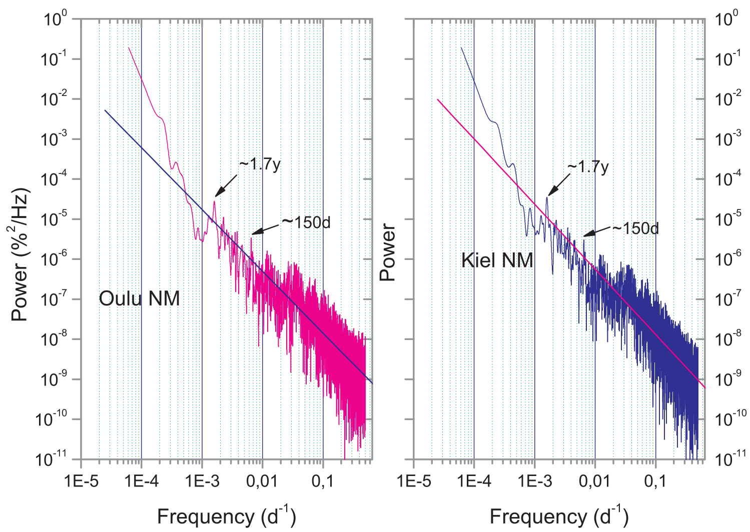

Fig. 3.12. Power spectra of Oulu and Kiel NMs for the period 1964-2008. The index of the slope of the spectra is approximately 1.7 (Power $\sim f^{-1.7}$). The two quasiperiodicities are marked (from [Kudela et al., 2009b]).

There are present also CR variations at longer time scales. [McCracken et al., 2002] using cosmogenic ^{10}Be data to study the period 1423-1980 AD, identified a previously unrecognized 5 year modulation process that occurs during epochs of a low solar activity. In this, the galactic CR exhibits a maximum intensity near the sunspot maximum.

Variability of CR at longer time scales than that from the first systematic measurements exist, is very important not only for understaning the mechanisms controlling their flux but also for applications. The galactic CR left records of its variability in different materials as ice cores, tree rings, and meteorits. Analyzing the isotopic composition of the materials very important information about CR variations can be deduced. The present status of the knowledge of changes of the CR flux over past 10,000 years is summarized, e.g by [McCracken, 2009]. [McCracken & Beer, 2007] analyzed the data by NM, ionization chambers and by production of ^{10}Be. An intercalibrated record (the "pseudo-Climax neutron monitor record") is developed for the interval 1428-2005. It is used to study several features of the long-term periodicities in CR. For correct interpretation of the records of cosmogenic isotopes the atmospheric, meteorological and other factors must to be known. The sources paleocosmic data which are analyzed are ^{10}Be in icecores, ^{14}C in tree rings and other biological materials, and ^{44}Ti in meteoritic material for the galactic CR checking. For the solar CR checking the useful materials are icecores with nitrates and ^{10}Be. While galactic CR produce ^{10}Be via spallation of atmospheric N and O and give this information which can be deduced from the materials, the solar energetic particles produce intense ionisation in polar caps where also a low energy charged particle have access. By collision with the nucleus of atom in the atmosphere the CR particle produces spallation reactions with various isotopes of different half-life and can be observed in various materials. The review can be found e.g. in paper [Beer, 2000]. The authors of the paper [Goel et al., 1953] report discovery of CR produced radioactive isotope ^{10}Be (half-life 2.7×10^6 y) in the upper and lower portions of a 15 m long core from the sediment of the Pacific Ocean and concluded that the decrease of concentration with depth indicates an intensity of cosmic rays in the past which has changed not at all or very slowly during the last ca. 2.5 million years. During the past decade the new mathematical models contribute significantly to clarifying the situation. Based on the knowledge of cross-section of reactions giving the yield of ^{10}Be, the nucleonic cascade have been simulated at different geomagnetic latitudes as a function of the value of geomagnetic dipole and solar modulation [Masarik & Beer, 1999]. Using those results [McCracken, 2004] constructed the response function. This function allowed to obtain the estimates of changes in cosmogenic nuclides due to modulation potential (depending on solar activity level), the interstellar local spectrum of primary CR and the geomagnetic field. In the past 10,000 years the galactic CR was affected by 22 major modulation events similar to that during Maunder minimum at the end of $17^{\rm th}$ century and that CR have been anomalously low during Space Era [McCracken, 2009]. The new computations are important for detailed analysis of the cosmogenic isotopes. [Masarik & Beer, 2009] extended their earlier model using new CR and nuclear data and calculated the production rate of ^{3}H, ^{7}Be, ^{10}Be, ^{14}C and ^{26}Cl. The production rates obtained agree well with most published experimental values. [Lal & Peters, 1962; Masarik & Reedy, 1995] computations predict that CR from large solar flares can generate a detectable signal in a cosmogenic record.

NMs especially those with a long period of measurements and good temporal resolution, as e.g. high mountain ones are, allow to investigate short time fluctuations of CR with a good statistics. The slope of power spectrum density at high frequencies was obtained by comparing the measurements from two high mountain stations, namely Lomnický štít and Jungfraujoch, and the fractal/multifractal characteristics of cosmic ray intensity scaling in time were described [Kudela et al., 1996]. The first evidence of fractal structure in solar wind speed fluctuations has been reported at different distancies [e.g. Burlaga & Klein, 1986; Burlaga, 1991a] as well as the multifractal structure of the IMF was observed [Burlaga, 1991b]. Thus it is of interest to describe also the scaling of CR time series. It was done by [Kudela & Venkatesan, 1993]. The scaling was shown to exist in the intervals 32-256 hours in data over several years. The fractal structure was deduced with statistically insignificant evidence of multifractal behaviour.

CR fluctuations will be discussed shortly in relation to space weather studies. Thus we include here only one result related to longer time evolution of interplanetary characteristics. [Starodubtsev et al., 2005] defined a proxy index of rapid CR fluctuations as the mean power of the CR power spectrum in the frequency range 10^{-4}-1.67×10^{-3} Hz (10 min to about 3 h). A dominant 11-year periodicity in the index is found in all neutron monitors. The authors also report on intermittent, short-term periodicities in the power of rapid CR fluctuations. A strong mid-term periodicity of about 1.6-1.8 years, possibly related to a recently found similar in the IMF, appears in CR fluctuation power since the 1980s. Another strong is found at ~ 1 year, which is likely related to the relative position of the Earth in the heliosphere.

3.4 Particles of middle energies in the heliosphere

The suprathermal ions in heliosphere comprises populations in a wide range of energies. At low energies dominates the solar wind with approximately maxwellian distribution and the peak of flux about few keV. At the high energy end $\sim$ 1 GeV the galactic CR is dominant (the lowest energy part of Figure 2.1). The difference in fluxes between that of solar wind maximum and 1 GeV CR is about 14 orders. In the schematic energy spectra (Fig. 1 from paper [Lin, 1980]) between these two extremes there are highly variable fluxes of populations as particles upstream from the shocks; magnetotail population in the magnetosphere of the Earth and other planets; the solar energetic particles (SEP) accelerated in flares and CIR (corotating interaction region) particles. Papers by [Klecker 2009a,b] summarize the recent progress in studies of energetic particles in relation ro the Sun, corona and transient phenomena in the heliosphere.

The characteristics of energetic particle populations in heliosphere as intensity, energy spectra, angular distribution and composition, namely in the energy range between CR and solar wind, is strongly variable in time. This is due to different transitional effects in the interplanetary medium affecting particle distribution. Thus it is quite important to understand the nature of the seed particles which are most probably present in heliosphere during quiet time periods. First we attempt to review shortly the "quiet time population" of particles, and in the second part we summarize some of the recent measurements related to the transitional effects, especially those related to corotational interaction regions.

Solar and heliospheric suprathermal and energetic ions are always present in the interplanetary space and dominate the energy spectrum up to several MeV, above which galactic cosmic rays and anomalous ions take over. Their intensity levels depend on the preceding solar activity, on the radial distance, and on the heliographic latitude. Although the fluxes are subject to huge variations of up to 6 orders of magnitudes or more, the energy spectra seem to remain surprisingly similar which displays a characteristic minimum in the range between about 5 to 30 MeV at low to the moderate solar activity [Logachev et al., 2002]. [Mewaldt et al., 2007] surveying 8 years of ACE data between 1997 and 2005 and found that, dominated by large SEP events, the fluence energy spectra for nuclei from He through Fe exhibit a similar E^{-2} shape. During extended periods of low solar activity the observed particle are usually referred to as the 'quiet-time' population, whose origin is still not fully understood. The available instruments often have poorly known background and their small geometry factor yield a low counting statistics. The careful analysis of available data in the energy range of $\sim$1 to 10 MeV, however, indicated, that the observed quiet-time background fluxes are genuine and never seem to vanish even under the quietest conditions [Valtonen et al., 2001; Reames, 1999b]. [Logachev et al., 2002] suggested that the spectrum is fairly well described in terms of a superposition of two power laws, where the spectral exponent of the low solar-heliospheric component is between -4 and -2 and decreases with the increasing energy.

Based on the pulse-height analysis of $\sim$1-8 MeV quiet-time proton data obtained by Helios, SOHO, Ulysses and Voyager, [Kecskeméty et al., 2005] found that all fluxes were very low, around and below 10^{-5} /(cm^2 s sr MeV). The Ulysses fluxes seem to be the lowest, whereas Helios and Voyager fluxes are nearly at the same level. The radial variation in 1-8 MeV suggests a negative gradient from 0.5 to about 2 AU and becomes nearly flat from 30 to about 60 AU. The candidates of sources of the quiet-time background ions include remainders of earlier corotating interaction (CIR), solar energetic particle (SEP) events, micro-, and nanoflares, etc. but their relative contribution is far from being understood.

By approximating the spectra with a 4-parameter form $J(E) = AE^{-\gamma} + CE^{\nu}$, describing solar/heliospheric and galactic components [Kecskeméty et al., 2008a] found that at 1 AU the exponent of the galactic branch was about 1.3 ± 0.15, significantly larger than predicted by the force-field approximation. They explained the inversion of the energy spectrum ($\nu > 1$) may occur if the radial diffusion coefficient is small, which means most of the low-energy particles reaching 1 AU have been cooled down in the inner heliosphere. Radial diffusion coefficients for < 500 MeV protons is calculated from the radial gradient based on measurements by Voyager and Ulysses and compared with the full drift model by [Kecskeméty et al., 2008b].

Recently [Zeldovich et al., 2009] studied the relation between low energy particle fluxes (0.3-10 MeV) in quiet solar activity periods and the index MgII which is the ratio of intensities at the center of MgII line and on its wings. From the observed correspondence between low proton fluxes and the MgII index the authors concluded that the index can serve as a solar activity index for studying variations of low energy particles in the interplanetary space. Probably the background (seed) particles are accelerated in very weak flares.

3.5 Solar energetic particles

Solar flares, the large eruptions in the solar atmosphere are releasing during relatively short time (order of 10^3 s) a huge amount of energy as much as 10^{25} J or even more. These effects are heating plasma in the surface layers of the Sun to tens of 10^6 K, accelerate charged particles to high energies and emit the electromagnetic waves in wide range of frequencies. Flares are differing from event to event. The typical distribution of energy is about $1/2$ for plasma, $1/4$ for electromagnetic radiation and $1/4$ for high energy particles. The classification of flares is done by the value of the peak flux in X-rays. Most extensive measurements of X-rays exist from GOES spacecraft. One of the aspects of solar flare research is analysis of high energy particles emitted during these events. The accelerated electrons emit photons in the range from shortest X- and gamma-rays to the long radio waves. These effects are usually connected with synchrotron non-thermal radiation. One class of processes suggested for proton acceleration in flares is a stochastic acceleration due to changes of particle energy in a random manner caused by their collision with moving scattering centers as with magnetic clouds, shock fronts or waves. Particles can be also accelerated at fast mode shocks. The shock accelerated ions have been observed directly in association with corotating interplanetary travelling shocks or planetary bow shock described e.g. by [Scholer, 1988]. Another one class of acceleration processes is that in the electric field. The electric field may occur in in solar flares due to magnetic reconnection or in double layers [Vlahos, 1989]. The book by [Miroshnichenko, 2001] contains comprehensive review of the theoretical as well as experimental results in the study of solar cosmic rays along with the list of references to that subject. The summary of acceleration models is e.g. in paper by [Miller et al., 1997]. The accelerated particles can interact with the ambient solar atmosphere (the next part). Conditions of their release from corona are important for the interpretation of the measurements near Earth. These effects are controlled by the configuration of magnetic field. The same is valid for particle transport to the site of their observations. Recently [Zhang et al., 2009] presented a model calculation of SEP propagation in a 3D IMF. The model includes all the particle transport mechanisms: streaming along magnetic field lines, convection with the solar wind, pitch-angle diffusion, focusing by the inhomogeneous IMF, perpendicular diffusion, and pitch-angle dependent adiabatic cooling by the expanding solar wind. SEP events have large variety regarding the energy spectra and composition. The ionic charge states of SEP events provide direct information about the environment of the source plasma. Thus mechanisms responsible for producing a solar flare and acceleration can be understood by measuring not only energy spectra but also the composition and charge state of these particles. The history of studies of SEP is summarized e.g. by [Cliver, 2008].

At the time of observations of first GLEs (ground level events, next part) there was practically no doubt that the high energy particles observed on the Earth during the strong solar activity are closely related to solar flares. After that it became clear that the acceleration at the shocks in corona and in interplanetary medium is also an efficient acceleration mechanism (e.g. [Bryant et al., 1962]). A new type of event was discovered in early 1970s with unusually a large content of 3He and with 3He/4He $>$ 1 in energetic particle composition (e.g. [Balasubrahmanyan & Serlemitsos, 1974]) which is by more than three orders higher than that in the solar wind. It was found that some events are enriched by heavy ions in comparison with solar wind abundances (e.g.[Mason et al., 1986]). According to the continuing observations of many events, differences of e/p ratio, temporal profile of particle fluxes, heliologitudinal distribution if observed from vicinity of the Earth and the ionic charge state of accelerated ions, the classification of SEP to gradual and imuplsive in connection with the duration of X-ray solar emission is used. While the impulsive SEP are related to solar flares, the gradual SEPs are connected to CMEs [Reames, 1999a]. The new results from several missions have shown this picture is a simplified one beacuse it was reported that enhancements of 3He is also present in particle populations accelerated at interplanetary shocks; that heavy ions are observed during large events at high energies and that high charge states of Fe are also observed in gradual events (references in paper [Klecker, 2009a]). The review on SEP is e.g. in paper [Ryan et al., 2000].

The interaction of high speed solar wind flow overtaking the slow speed solar wind is forming the pair of shocks at some distance from the Sun [Hundhausen & Gosling, 1976], namely forward shock propagating outward and reverse shock propagating inward. Since a long time it is known that these shocks accelerate efficiently particles to multi-MeV energies [Barnes, & Simpson, 1976]. Intensities of particles have the maximum at several AU. E.g. papers [Mason et al., 1999; Scholer, et al., 1999] include the review of the subject. Recent works [Chotoo et al., 2000] pointed out that measurements of CIR suprathermal ions at 1 AU are inconsistent with the standard picture associated with multi-MeV particles. The peak intensities at the low energies are observed within the CIR at places that are not magnetically connected to the shock [Richardson & Zwickl, 1984] and a turnover of the spectra below a few 10s of keV/n, as predicted by CIRs model, is not observed [Mason et al., 1997]. These observation features suggest that the ions are accelerated more locally, either by stochastic [Schwadron et al., 1996] or a compressional [Giacalone et al., 2002] mechanism.

It is expected that significant progress in understanding of SEP propagation and acceleration will be obtained from multispacecradft measurements. That can be done by observations from two STEREO spacecraft with enhancing separation in longitude in comparison with measurements “near Earth” at SOHO and ACE (e.g. [Kaiser et al., 2008].

The energetic ions from CIRs are known to have very characteristic element abundances that distinguish them from other heliospheric energetic particle populations. The average heavy-ion composition of CIR elemental abundances is very close to the average fast solar wind composition with the exception of ^{4}He, ^{3}He and Ne [Mason et al., 2008]. The ^{3}He abundance several times higher than in the solar wind show that remnant impulsive flare suprathermal ions are accelerated in these events [Mason et al., 2008]. The recent surveys also reveal that suprathermal ions from the solar energetic particle (SEP) events may provide a seed population for the CIR acceleration (e.g. [Bučík et al., 2009a]). An overabundance of ^{4}He and Ne suggest an interstellar pick-up ion source with a possible role of the inner source material (e.g. interplanetary grains) [Mason et al., 2008].

The observations by the STEREO, which was launched in October 2006, offer new opportunities to address important questions related to the large-scale structures, and their propagation and interaction in the interplanetary space between the Sun and the Earth. The STEREO consist of two identical satellites, one preceding the Earth (STEREO-A) and the other trailing behind (STEREO-B) in its orbit around the Sun. The increasing angular separation between the STEREO-A and the STEREO-B allows to investigate the behavior of CIRs over time scales of days, rather than a solar rotation. [Mason et al., 2009] discussed that the large differences in energetic particle observations by the STEREO-A and -B were due to a relatively small and irregular coronal hole size, taken together with the changes in spacecraft connection to the Sun. [Leske et al., 2008] and [Gómez-Herrero et al., 2009] have discussed these effects for higher energy CIR particles observed on the STEREO. These new observations also show an importance of the shock acceleration of suprathermal particles in CIRs at heliocentric distances around 1 AU from the Sun [Bučík et al., 2009b].

3.6 Ground level events

In about 10 years of continuous measurements of CR by the ionisation chambers there were observed in 1942 two clear increases in CR which began almost simultaneously with solar flares on February 28 and March 7, 1942 and one more on July 25, 1946 [Forbush, 1946]. The first two events indicated increases in the ionisation which began within 0.3 hour after the commencement of radio fadeout (short waves). These were later marked as the ground level events (GLE) number 1 and 2. From that time, the GLEs - the events when the solar accelerated particles provided the response of secondaries on the ground, are studied. Until now there are 70 events of this type and their list can be found e.g at http://neutronm.bartol.udel.edu/∼pyle/GLE_List.txt.

The GLEs are different in the fluence of high energy particles, in their energy spectral shape and in the anisotropy as observed on the Earth. One of the recent GLEs (No 69) was that on January 20, 2005. It had a relatively hard spectrum and was observed at the stations with a higher geomagnetic cut-off rigidity. Fig. 3.13 shows the energy spectrum of that event and the increase at the middle latitude station Lomnický štít.

This event was strongly anisotropic and the computations of the radiation dose in the atmosphere indicate an asymmetry: in the southern high latitudes the ionization was much stronger than in the north ones [Desorgher et al., 2009]. That event consisted of two successive peaks in the NM data. The first relativistic protons detected at the Earth are accelerated together with relativistic electrons and with protons that produce the pion decay γ-rays during the second episode. The second peak in the relativistic proton profile at the Earth is accompanied by new signatures of particle acceleration in the corona within about 1 solar radii above the photosphere, revealed by hard X-ray and microwave emissions of low intensity, and by the renewed radio emission of electron beams and of a coronal shock wave [Masson et al., 2009]. [McCracken et al., 2008] pointed out that the GLE on 20 January 2005 may have been produced by more than one acceleration mechanism, with the first acceleration being directly associated with the solar flare and the second one with the CME associated with that event. That paper also noted several other GLEs with similar multiple pulse structures. [Moraal et al., 2009] analyzed the GLEs of the solar cycle 23 using NM data and found that three of these 16 events, namely those on April 15, 2001 and

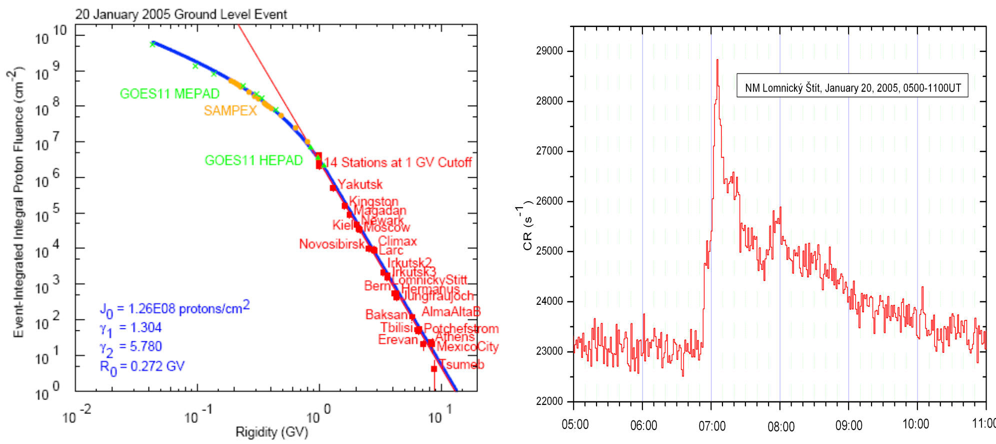

Fig. 3.13. (from [Usoskin, I.G. et al., 2009]). The GLE 69 integrated a proton fluence compiled from the satellite as well as the NM measurements at different geomagnetic cut-off positions. Courtesy of A. Tylka. The right panel shows the increase as observed on Lomnický štít (time in UT on January 20, 2005).

the latest two contain similar double pulse structure. Two of those three were discussed by [Ryan et al., 2009]. They found that in both events the leading-edge spike, besides being anisotropic, also exhibited the hardest spectrum. Each event then transitions into a lower intensity, softer, isotropic and prolonged feature.

At lower energies the satellite measurements provide important information on the GLE characteristics. [Mewaldt et al., 2009] report satellite and space probe measurements of 16 GLEs in solar cycle 23 over the wide energy range ~ 0.1 to ~ 700 MeV. They found all proton spectra have spectral breaks at energies from ~ 2.4 to ~ 33 MeV and all are well fitted by a double power law fit. Comparison of the GLEs with other solar energetic particle (SEP) events (lower energies, not providing response on the ground) shows that GLEs have harder spectra with a mean slope -3.17 above 40 MeV/nucl and on average they are enriched in species associated with impulsive ^{3}He rich SEP events.

[Vashenyuk et al., 2009] analyzed 32 large GLEs observed during the period 1956-2006 using the data from world wide network of NMs. In all studied cases two distinct relativistic solar proton populations were revealed: the early pulse-like intensity increase with exponential energy spectrum (prompt component, PC), and the late gradual increase with a softer energy spectrum of the power law form (delayed component, DC). The spectrum of DC has continuation into a range of lower energies and well agrees with the time of maximum spectrum obtained from direct solar proton measurements on spacecrafts and balloons. The exponential spectrum of PC has no continuation into lower energies. However, it gives the significant contribution into the responses of NMs resulting sometimes to huge increases e.g. for the large events as were the GLEs of 23.02.1956 and 20.01.2005.

The detailed analysis of the energy spectra, anisotropy and effects on the atmosphere from the two last GLEs recorded surprisingly close to the solar minimum epoch (January 20, 2005 and December 13, 2006) are summarized e.g. by [Flückiger, 2009]. Recently a new technique for analyzing data from the world-wide NM network has been developed [Tylka & Dietrich, 2009]. The fluences from the NM spectra were compared to measurements at $\sim$ 300-700 MeV from the IMP8, SAMPEX and GOES satellites. In addition the authors combined lower energy satellite and NM measurements and described the fluence by double power-law fit in rigidity. For the GLE on 13.12.2006 it is reported that the initial particle release time coincides with the flare emission and that the spectrum becomes softer and the anisotropy becomes weaker during the particle injection, indicating that the acceleration source changes from a confined coronal site to the widespread interplanetary CME-driven shock [Li et al., 2009].

While some authors find arguments for coronal mass ejections as a sole accelerator of SEPs, others indicate a flare to be the SEP origin. [Bazilevskaya, 2009] discusses the early phase of SEP events with acceleration to high energies. She considers the circumstances of SEP generation for several GLEs of the 23rd solar cycle. Timing of X-ray, CME, and radio emissions shows a great variety from event to event. However, the time of particle ejection from the Sun is closer to maximum of the X-ray emission than to any other phenomena considered. No correlation is found between the particle fluxes and the CME characteristics.

For practical purposes probabilistic models of SEP are important. Model constructed by [Nymmik, 1999] describes the probability for > 10 MeV/nucl SEP fluences and the peak fluxes near Earth outside the magnetosphere under varying solar activity levels. Paper by [Nymmik, 2007] discusses the probability of the extreme solar energetic particle events which are important also from the point of view of safety of space flights.

3.7 High energy gamma rays and neutrons from flares

3.7.1 Gamma rays

SEP measurements interpretations if based only on charged energetic particles have limitations. The assumptions about the injection from the acceleration site to the interplanetary space as well as on the particle propagation in the inner heliosphere must be used. On the other hand the high energy photon observations carry another important information about the acceleration process itself without corrections needed for the IMF and geomagnetic field transport. In the book [Chupp, 1976] there are summarized the mechanisms for the gamma ray line and continuum production, the estimates of the gamma emission from the Sun, on interactions of high energy particles with materials and a review of solar gamma ray observations until mid 1970s. Review of gamma rays from the nuclear deexcitation and from interactions of energetic particles with various targets is summarized by [Ramaty et al., 1975; Kozlovsky et al., 2002; Ramaty et al., 1979]. The deexcitation gamma ray lines from O and C as well as from the positron annihilation and neutron capture were first observed from the Sun on the NASA Seventh Orbiting Solar Observatory (OSO-7) by E.L. Chupp and his colleagues. The understanding of high energy processes producing gamma rays and neutrons were improved significantly in 1980s from data measured by the Gamma Ray Spectrometer aboard Solar Maximum Mission (SMM) satellite. Later, in 1990s the CGRO instrument provided important informations about gamma ray emissions from the Sun. Starting from 2002 a very detailed informations on that radiation are obtained from the RHESSI satellite. Recently new informations about the particle acceleration in solar flares were obtained (e.g. [Shih et al., 2009; Krucker et al., 2009]). The first images of the sites with the gamma ray emission from the Sun were obtained [Hurford et al., 2003]. The history of gamma

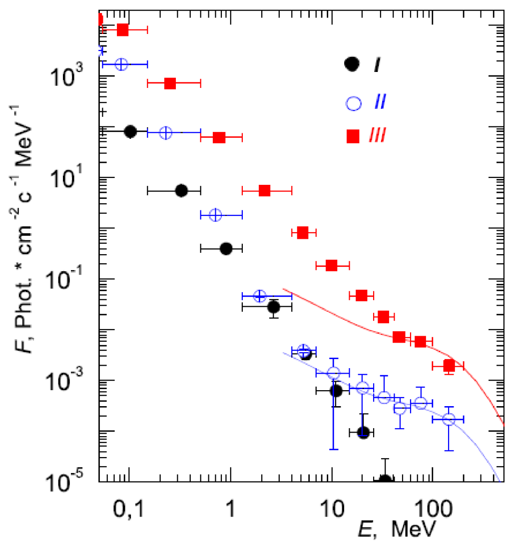

Fig. 3.14. (from [Kurt et al., 2009]). The energy spectra of very high energy gamma rays indicates neutral pion production which is possible only if p of high energy are available (SONG on CORONAS-F). While a pion-decay emission was absent during time interval I, intervals II and III indicate its presence. The spectra are from the observations of the flare August 25, 2001.

ray measurement devices for astronomy can be found e.g. in [Pinkau, 2009]. In a recent paper [Chupp & Ryan, 2009] review the knowledge of the highest energy solar emissions, and how the characteristics of the acceleration process are deduced from these observations. Results from the RHESSI, INTEGRAL and CORONAS-F missions are also discussed. The review also covers the solar flare capabilities of the new mission, the FERMI gamma ray space telescope, launched on 2008 June 11. Also the requirements for future missions to advance this vital area of the solar flare physics are stressed.

At high energies gamma rays were recently measured on the low altitude polar orbiting satelite CORONAS-F by the instrument SONG [Kuznetsov et al., 2004]. There were several solar gamma and neutron events observed with that device [Kuznetsov et al., 2003; 2005a,b; 2006; 2008; Myagkova et al., 2007]. The important new feature of the device is its capability to measure solar gamma rays up to very high energies. Another instrument on the same satellite, namely AVS, is analyzing count rates in a multichannel analyzer allowing thus to obtain the gamma ray line spectra [Arkhangelskaja et al, 2009a,b and references therein]. Figure 3.14 shows clear increase in the energy spectra of photons at energy 50-100 MeV, associated with π^0 decay. It indicates the exact time of the energetic proton appearance in the solar atmosphere. This allows to compare the proton acceleration time with the start time of the GLE recorded by the ground NMs, and to calculate the time interval when the GLE particle escaped from the corona. It is shown for the four large flares observed by the SONG instrument on CORONAS-F in the Table 3.1.

3.7.2 Neutrons

In addition to gamma rays, solar neutrons provide a direct information about high energy processes at the solar surface without assumptions on the IMF and on the geomagnetic field which are important for the deconvolution of the high energy charged particles of solar/interplanetary origin if observed near the Earth or at the ground. [Biermann et al., 1951] were the first ones who suggested possibility that the solar flare accelerated protons with energies above 100 MeV can interact with residual solar atmosphere and produce secondary neutrons. If high energy neutrons are produced, a portion of them can be observed undecayed at the Earth's orbit.

Basic considerations about the production of solar neutrons are e.g. in papers by [Lingenfelter et al., 1965; Lingenfelter & Ramaty, 1967]. The cross sections of neutron produced reactions can be found e.g. in paper by [Murphy et al., 1987]. [Ramaty and Murphy, 1987] reviewed the nuclear processes in solar flares by accelerated particles including the neutron production. For different products of αT ($\alpha = V^2/\lambda c$; V is velocity of scatterers, λ is the mean free path and T is the mean escape time) and for given parameters of spectra and the mechanisms of the acceleration of protons, they obtained neutron production spectra. Solar neutron production is related to gamma ray lines. While the capture on protons produces the 2.223 MeV one, the capture on ^{3}He gives no detectable radiation, but it affects the time profile of the 2.223 MeV line, and can set constraints on the ^{3}He/H ratio in the photosphere. The information about spectral properties of accelerated ions as well as ^{3}He/H in the photosphere can be determined from solar neutron observations (e.g. [Chupp, 1988]). [Hua et al., 2002] developed the new production kinematics of solar neutrons. By including the ion pitch-angle scattering and magnetic mirroring they calculated the production of neutrons in the solar flare loop models and obtained the energy spectrum of the surviving neutrons at the Earth orbit.

However there were at least two limits over long time for the direct measurements of solar neutrons near the Earth. One was related to the albedo neutrons which contribute to the neutron measurements on the satellites at low altitudes. The ground based observations provided for long time only measurements of secondary products of high energy nucleons and thus only very high energy neutrons could be observed.

[Lingenfelter et al., 1965] calculated the intensity and energy spectrum of solar neutrons at the Earth orbit relative to the flux of solar protons observed over one solar cycle. They found the time-averaged solar neutron flux > 10 MeV about 3×10^{-3} n/cm^{2}s with a peak intensity in 30-40 MeV. Such flux of solar neutrons is comparable to the neutron leakage (albedo) flux

Tab. 3.1. Major solar flares observed by the SONG/CORONAS-F. The time onset of pion-decay gamma rays and the flux observed during strong solar flares for the period July 2001 - January 2005.

Date	Location/Importance	Onset of pion-decay gamma emission, UT	Gamma ray flux at 100 MeV (MeV.cm^2.s)$^{-1}$	Particles observed
25.08.2001	S17E34, 3B/X5.3	16:30:16; $\pm$2 s	7.3.10^{-4}	N
28.10.2003	S16E08, 4B/17.2	11:03:51; $\pm$2 s	6.8.10^{-3}	GLE65, n
04.11.2003	S19W83, X28.9	19:42:38; $\pm$4 s	1.0.10^{-3}	N
20.01.2005	N14W61, 3B/X7.1	06:45:34; $\pm$4 s	3.6.10^{-3}	GLE69

produced in the atmosphere by the galactic CRs. The upper limit of a possible continuous flux of solar neutrons was searched in some experiments. At OSO-1 no effect in a day-night comparison was observed and an upper limit was reported on the solar neutron flux at the Earth of $J_n < 2 \times 10^{-3}$ cm^{-2}s^{-1} for $0.01 - 10$ MeV neutrons during the period without strong solar flares [Hess and Kaifer, 1967]. [Daniel et al., 1969] reported the upper limit of the neutron flux at 15-150 MeV for a flare with importance 2B about $\sim 1.2 \times 10^{-2}$ cm^{-2}s^{-1} from the baloon measurements at atmospheric depth 25 g.cm^{-2}. [Lockwood et al., 1973] obtained from the OGO-6 observations the upper limit on the quiet time solar neutron flux $< 2.10^{-3}$ n/cm^{2}s for the energy interval 1-20 MeV.

The first detection of a solar neutron signal at the Earth's orbit was reported from the solar flare on June 21, 1980 [Chupp et al. 1982] by using measurements of the Gamma Ray Spectrometer on the Solar Maximum Mission. Before that the presence of neutrons at the sites of solar flares was reported by the observation of 2.223 MeV neutron capture gamma-ray line [Chupp et al., 1973].

On June 3, 1982 the Gamma Ray Spectrometer on the SMM recorded an extremely intense γ ray line flare with the onset at ∼1140 UT with the counting rates at the high energy channels remained high, which is characteristic for a flux of high energy solar neutrons at the satellite (Chupp, personnal communication, 1982). The solar neutron response, observed for the first time at the surface of the Earth, was reported from the neutron monitor measurements at Jungfraujoch with 1-min time resolution [Debrunner et al, 1983; Chupp et al., 1987]. The air thickness along the line of sight to the Sun was $q = 745$ g.cm^{-2} for that event at Jungfraujoch. Also another high mountain neutron monitor in central Europe, namely Lomnický štít [883 g.cm^{-2}], observed in 5 min records an ∼3% increase in 1145-1150 UT on all independent channels. The estimate was ~ 4000 impulses from solar neutrons, corresponing to ∼200/cm^2 at the top of the atmosphere. This number was consistent with the ratio of the $n/2.23\gamma$-ray emission [Chupp et al., 1982], if characteristic rigidity of accelerated particles is P_o ∼200-250 MV [Efimov et al., 1983]. The increase from the same event was reported in the data of the Rome neutron monitor [Iucci et al. 1984].

Another possibility to detect solar neutrons in the space is to observe its decay products, protons and electrons. The energetic protons observed in the interplanetary space from the flare on June 3, 1982 which were interpreted as the decay products of neutrons were discussed by [Evenson et al., 1983a, b; 1985] and the spectrum of neutrons was obtained in the range 10-100 MeV. Another flare, namely April 24, 1984 produced protons from a neutron decay. The models of propagation of protons from a solar neutron decay providing the constraints on the interplanetry mean free path for two flares with neutron production were published by [Ruffolo, 1991]. Paper by [Dröge et al., 1996] reported an evidence for fluxes of energetic electrons in the interplanetary space on the board of the ISEE-3 spacecraft during the solar flare June 21, 1980 which was interpreted as decay product of neutrons produced in that flare. The indication was supported by the arrival of electrons earlier before the flux of electrons accelerated in the flare was observed. The analysis along with the direct measurement of high-energy neutrons places important constraints on the parent neutron spectrum.

Several other papers were dealing with an analysis of possible candidates of solar neutrons as observed by neutron monitors. The possibilities of a neutron monitor network for a detection of solar neutrons are discussed e.g. in paper by [Usoskin et al., 1997]. Superposed epoch analysis of 17 flares with gamma rays or hard X-ray production (1980-1985) gave a slight tendency of an occurring signal in cases of high heliocentric angles, indicating possible anisotropic production of neutrons at the Sun [Kudela, 1990].

After the first event on June 3, 1982, no clear direct solar neutron responses were observed on the ground during the solar cycle 21. The GLE on 19 October 1989 with an atypical particle anisotropy during the initial phase was discussed by [Shea et al., 1991a]. An increase with three neutron monitors in the Eastern Canadian region was reported ~ 25 min before comparable detectors in Europe observed that GLE. From the analysis of asymptotic cones of a proton acceptance, the early onset in the particle intensity increase may be the detection of relativistic protons that are the decay product of solar flare generated relativistic neutrons. During the event on 24 May 1990 an extremely impulsive onset in the particle intensity was observed at least on seven neutron monitors in North America (at Climax 23.5%) which was associated with response of a direct impact of solar neutrons on the top of the atmosphere [Shea et al., 1991b]. Responses were organized by the air thickness along the line of sight to the Sun. The first impulse was observed in the same minute with the soft X-ray and the H-alpha emission. After ~ 15 min the GLE onset was observed on many neutron monitors over the globe. This event with the high flux of solar neutrons was discussed e.g by [Debrunner et al., 1993; 1997] and in relation to the gamma ray lines and continuum as observed by the PHEBUS experiment aboard GRANAT [Vilmer et al., 2003]. By analysis of that event the attenuation length for solar neutrons was obtained [Valdés-Galicia et al., 2000]. The evidence for neutrons coming from the Sun associated with a large flare at 03:37 UT on 1991 June 4 was reported by [Muraki et al., 1992] with high statistical significancy of the signal based on measurements by a neutron telescope and by a muon telescope, located at Mount Norikura. [Flückiger et al., 2001] analyzed possible solar neutron events in flares 2000 and 2001. The solar neutrons from the flares on June 9 and 15, 1991 were reported from the COMPTEL measurements on the satellite GRO in the energy range 15-80 MeV [Schönfelder et al., 1993].

Since the detection of the first response from solar neutrons on the ground, the search for solar neutrons started more intensively both in the satellite as well as in the ground based measurements. Several new devices were constructed. The new solar neutron detector [Matsubara et al., 1999; Tsuchiya et al., 2001; Flückiger et al., 2005] has the ability to measure energy of incident neutrons and their arrival direction. The solar neutron monitor has a high detection efficiency for neutrons and signal to noise ratio for the background charged particles like muons and electrons. Comparison of pulses from the solar direction with other directions is used for the solar neutron response identification. The detector consists of four scintillation counters with the area 4 m^2. Plastic scintillators with the thickness 40 cm and the area 1m $\times$ 1m are installed in each scintillator box. Proportional counters are used as "anticounters" to distinguish neutrons from charged particles. The energy deposition of recoil protons produced in target scintillator is measured with several threshold energies. The solar neutron detectors were installed at several places at high mountains. Thus the global network of Solar Neutron Telescopes was set up during the 1990's, allowing the ground-based solar neutron observations in any time of the day. Important for the interpretation of the measurements is understanding of the neutron interactions and propagation in the atmosphere (described e.g. by [Shibata, 1994]) and response functions of the instruments. For one of the solar neutron telescopes, namely Aragats, the computation of reponse function was done recently by [Chilingarian et al., 2007].

During the 23^{rd} solar cycle 16 remarkable solar neutron events were observed by the worldwide network of solar neutron telescopes and neutron monitors. Out of them in 5 cases the information from the two solar neutron telescopes was important for the identification of the solar neutron response (table 1 in paper by [Flückiger et al., 2005]). Relatively strong signals from solar neutrons were observed with the help of solar neutrons telescopes on October 28, and November 4, 2003. The solar neutron events observed during solar cycle 23 were reviewed also by [Watanabe et al., 2005].

While solar neutrons on the ground have been limited to the solar flares with soft X-ray class greater than X8 in solar cycles before the 23^{rd} one, the detection of solar neutrons on the ground associated with a solar flare of X-ray class smaller than X8 was reported by [Watanabe et al., 2003] as a first one in that cycle. Solar neutrons have been detected by the neutron monitor at Mount Chacaltaya, Bolivia, in association with the solar flare on 2000 November 24 (X2.3 flare). The intense emission of hard X-rays and γ-rays has been observed by the Yohkoh Hard X-ray Telescope (HXT) and the Gamma Ray Spectrometer (GRS), respectively. The production time of solar neutrons is better correlated with those of hard X-rays and γ-rays than with the production time of soft X-rays.

[Muraki et al., 2008] reported recently that during the flare on April 15, 2001, the Chacaltaya neutron monitor observed a 3.6σ enhancement at 13:51-14:15 UT, about 11 min before the GLE. Thus solar neutrons must be involved in this enhancement. The integral energy spectra of neutrons and protons were obtained. It may be the first simultaneous observation of the energy spectra of both high-energy protons and neutrons.

There are also indications on solar neutrons from the satellite measurements in the past years. The instrument with the acronym SONG [Kuznetsov et al. 2004] mentioned in 3.7.1 measured along with the gamma rays also neutrons using the pulse shape discrimination technique onboard the satellite CORONAS-F from August 2001 until December 2005. Along with the detection of hard X-rays and gamma rays from several flares (e.g. [Myagkova et al., 2004]) in at least three solar flares, namely August 25, 2001; October 28, 2003 and November 4, 2003 the neutrons with energies above 20 MeV were observed [Kuznetsov et al., 2006b].

The identification of a solar neutron response on the ground can be done also by comparison of profiles at two neutron monitors situated at similar longitudes with a different atmospheric depth in the solar direction for flares occurring around local noon. For the event on October 28, 2003 the onset at Tsumeb NM (geomagnetic cut-off ~ 9.1 GV) was observed by ~ 10 min earlier than the first GLE increase at Lomnický štít (geomagnetic cut-off ~ 3.9 GV) having for that period larger atmospheric thickness and did not observe the neutron response [Watanabe et al., 2006]. SONG on CORONAS-F observed increase in neutron channel with energy deposited 15-100 MeV simultaneously with the Tsumeb NM profile starting from 1104-1105 UT which also corresponded to the high energy gamma rays arrival to the Earth. The acceleration of protons to unusually high energies in that solar flare was deduced from muon telescope measurements [Nonaka et al., 2006]. [Bieber et al., 2005] analyzed that event and found that the Tsumeb increase was consistent with the solar neutron event which occurred about 7 min before the onset of GLE at high latitudes. Relativistic neutrons were emitted over a duration of about 9 minutes with the onset 7 minutes before the main injection of relativistic protons. The analysis of the TRACE, SOHO, RHESSI, ACE, GOES, hard X-ray (INTEGRAL satellite), radio (Ondejov radio telescope), and neutron monitor data was done recently by [Li et al., 2007]. Since the neutrons were emitted a few minutes before the injection of protons and electrons, the authors propose a magnetic-field evolution configuration to explain this delay.

In 2005, close to the minimum phase of solar activity, there were at least two solar flares which are discussed in relation to a possible solar neutron production. From the flare on September 7, 2005, strong signals of neutral emissions were detected [Sako et al., 2006]. Relativistic neutrons were observed with the solar neutron telescopes at Mount Chacaltaya in Bolivia and Mount Sierra Negra in Mexico and with neutron monitors at the two sites. The satellite measurements (INTEGRAL and Geotail) observed hard X-rays and gamma rays due to the high energy electron radiation. While the model of impulsive neutron emission at the same time of X- and gamma-ray peak can explain the main observed peaks of neutron signals, this model is difficult for explanation of relatively long decaying phase of emissions. The case of simultaneous start of the acceleration of electrons and ions with longer time of acceleration of ions or their trapping is discussed. That event is analyzed also by [Gonzalez et al. 2008].

In recent years new instruments for solar neutron detection, especially for the satellites and solar probes have been designed and developed. The possibility to measure closer to the Sun than from the Earth orbit is promising for much more detailed studies of acceleration processes at solar surface. Combined observations of charged particles and neutrons in missions like planned Solar Orbiter are discussed e.g. by [Heber and Klecker, 2005; Posner et al., 2005; Bogomolov et al., 2005].

3.8 Anomalous component

In addition to galactic CR and solar accelerated particles the instruments on Pioneer 10, IMP 5 and IMP 7 discovered a third component of energetic particles in the heliosphere known as anomalous cosmic rays (ACR) [Mewaldt et al., 1998]. The "anomalous" is related to the energy spectra of several elements in CR at low energies. The excess of He, N, O and Ne is observed in the energy spectra below kinetic energy ~ 100 MeV/nucleon. While below 100 MeV/nucl the C flux is remaining less than ~ 0.01 / (m^2.s.sr.MeV/nucl), the flux of O which has similar flux to C above ~ 100 MeV/nucl, is increasing with the energy decrease and reaches the value ~ 2 / (m^2.s.sr.MeV/nucl) at ~ 5 MeV/nucl. [Garcia-Munoz et al, 1973; Hovestadt et al., 1973; McDonald et al., 1974] reported the anomalous flux increases of He, O, N in the energy range < 50 MeV/nucl. The ionic charge state of anomalous CR oxygen was determined by comparison of measurements obtained inside the magnetosphere on low orbit Cosmos sataellite flights and simultaneous measurements outside the magnetosphere on IMP 8 and ICE. The status of experimental and theoretical results on ACR until 1995 along with the constraints on acceleration process derived from available ionic charge measurements was reviewed by [Klecker, 1995].

The explanation of the origin of ACR was done soon after its discovery by [Fisk et al., 1974]: the anomalous composition of N and O observed at ~ 10 MeV/nucl can be understood if neutral particles that penetrate into the heliosphere are ionized and subsequently accelerated. In that model should enhance only N, O and to some extent Ne and He and particles of ACR should be mainly singly ionized. The ACR particles are supposed to be originally neutral and penetrating freely into the heliosphere. Their ionization can be via the charge exchange or via solar UV radiation. When ionized, these ions called pickup-ions can be convected to the outer heliosphere and accelerated. Acceleration was proposed to take place at the solar wind termination shock [Pesses et al., 1981]. The ex-interstellar neutral particles are suggested to be accelerated continuously in the polar regions of the termination shock and then drift into equatorial regions of the inner heliosphere. It is supposed that the ACR occurrence must be related to the first ionization potential of the elements. The atoms with a high first ionization potential are difficult to ionize.

The high first ionization potential elements have been found in the ACR [Cummings and Stone, 1987]. [Geiss et al., 1994] reported O, N and Ne pick-up ions of interstellar origin detected on the board Ulysses. The ions are singly charged. The pick-up ions were reported also from the AMPTE mission.

The composition of the trapped population of particles in the Earth's magnetosphere can also be related to the ACR. [Blake & Friesen, 1977] proposed that singly ionized ACR oxygen having the Larmor radius much larger than fully ionized oxygen can penetrate to the magnetosphere and can be trapped. The experimental evidence of the trapped ACR was reported by [Grigorov et al., 1991]. [Adams et al., 1991] found that the mean charge state of oxygen is close to unity at 10 MeV/nucl anomalous O. The magnetospheric screening (discussed in part 4) was used for that.

The investigation of ACR is continuing. In December 2004 the Voyager 1 crossed the termination shock at 94 AU. At the termination shock the observed intensity of ACR > 4 MeV/nucl is reported to be much lower than expected if it is the acceleration site [McDonald, 2009]. In that paper the temporal effects that contributed to the low ACR intensity at the time of termination shock crossing are discussed. [Strauss et al., 2009] studied the adiabatic heating and stochastic acceleration in the heliosheath and compared the results with recent Voyager 1 observations. The intensity gradients of ACR are discussed by [Stone et al., 2009]. ACR source is indicated beyond the location of the Voyager 1. In paper by [Reames et al., 2009] the observations of ACR near Earth are used for studies of magnetic clouds.

3.9 Particles in the outer heliosphere and near its boundary

The spacecrafts Pioneer 10 and the Voyager 1 and 2 have contributed to the understanding of physical processes in the outer heliosphere. Voyager 1 crossed the solar wind termination shock at the ecliptic latitude 35° and distance 94 AU [Stone et al., 2005] and Voyager 2 crossed the termination shock at the -31° latitude at distance ~ 84 AU [Stone et al., 2008; Burlaga et al., 2008]. [Frisch et al., 2009] review the characteristics of interstellar material inside and outside the heliosphere. The interaction and coupling of heliospheric boundary regions and the distributions responsible for the creation of neutral atoms is discussed by [Zank et al., 2009].

The energetic particle measurements on Voyager 1 and 2 are discussed e.g. in papers [Király, 2009a,b]. Here we mention only two peculiarities which are discussed in these papers. It is quite surprising how fast the variability of particles dropped following the transit of the Voyager 1 and how low it was during several years after the shock crossing (Figure 3.15). Surprising was also that particle streaming for the Voyager 1 and 2 behaved in a different way.

On October 19, 2008 the NASA's IBEX (Interstellar Boundary Explorer) was launched with the aim to image and map the dynamic interactions taking place in space where the hot solar wind slams into the cold expanse of the space (http://www.nasa.gov/mission_pages/ibex/launch/index.html). The satellite spins as it orbits Earth with the period of six months. [Lee et al., 2009] discuss the theory of physical processes in the outer heliosphere that are particularly important for the IBEX Mission. The sensors onboard IBEX collect particle from every part of the sky. Paper [McComas et al., 2009] sumarizes the scientific objectives of the mission. Among them there are the questions as (i) how are energetic protons accelerated at the termination shock; (ii) what are the global properties of the solar wind flow beyond the termination shock; (iii) how the interstellar plasma flow interacts with the heliosphere beyond the heliopause. The important

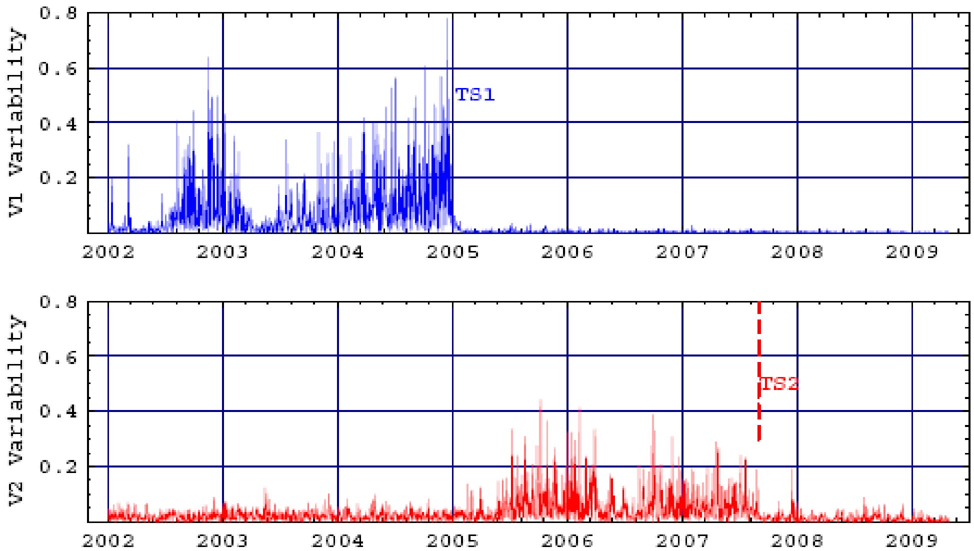

Fig. 3.15. (from [Király, 2009b]). Day-to-day variability of low energy ($>$ 0.5 MeV) count rates for Voyager 1 and Voyager 2. The differences in pre-shock and post-shock variability is clearly seen.

measurements are the images of ENA (energetic neutral atom) which are originating beyond the termination shock, in the inner heliosheath. The combination of full-sky imaging and energy spectral measurements of neutral atoms in the range from $\sim$ 10 eV to 6 keV provides important information. The ENAs are originally the plasma ions that are heated in the interaction region and by the charge exchange with the freely flowing cold neutral atoms of the local interstellar medium are neutralized. The IBEX-Hi and IBEX-Lo instruments described in [Funsten et al., 2009a; Fuselier et. al., 2009] belong to the most important devices on IBEX for solving the above mentioned questions. The first one covers the energy range of neutrals 0.01 to 2 keV and the second one measures neutrals from 0.38 to 6 keV, both with high angular resolution. Just on October 15, 2009 the IBEX first heliospheric results and sky maps are unveiled to the scientific community and public audience for the first time (http://www.ibex.swri.edu/) and first results summarized in papers by Science on that day. The flux maps of ENAs reveal distinct nonthermal (0.2 to 6 keV) heliosheath proton populations with spectral signatures ordered predominantly by ecliptic latitude [Funsten et al., 2009b].

4 Energetic particles and magnetosphere

Magnetosphere of Earth is formed due to the interaction of the solar wind (with frozen-in IMF) and the Earth's magnetic field generated inside the Earth's body. The resulting magnetic field controls the motion of charged particles within the magnetosphere. While the internal magnetic field is varying slowly, the field approximated by the external current systems is changing rapidly, especially during the geomagnetic storms. More about the basics of magnetospheric magnetic field configuration can be found e.g. in [Wolf, 1997; Cowley, 1998].

There is a variety of particle population within the magnetosphere. Their energy ranges from less than 1 eV (ionospheric plasma) up to the high energy CR for which the magnetic field is an obstacle for an access on the Earth's surface.

It is possible to separate particle populations in the magnetosphere into two "extremal" groups according to their characteristic extent of trajectories (gyroradius or curvature radius): (i) those with trajectory "extent" much less than the dimension of the magnetosphere; (ii) those having trajectories comparable to magnetospheric dimension. This is possible to make with use of Störmer length proportional to the square root of particle mass and velocity (e.g. [Fälthammar, 1973]). Particles of relatively low energy (rigidity) have the Störmer length comparable to the size of magnetosphere (a) while the high energy particle's Störmer length is much smaller than magnetospheric dimension (b).

In the first part of this chapter we provide the review of selected topics of magnetospheric energetic particles at energies lower than that of the CR (particles type a). In the second part the transmissivity of the CR through the magnetosphere will be touched, again in selected aspects for particles of the type b.

4.1 Magnetospheric particles

There are several particle populations within the magnetosphere. Cold and warm plasma (in the plasma sheet), the trapped radiation and CR of galactic and solar/interplanetary origin. In the first part we limit the discussion to the trapped population, its sources, transport and losses. Second part is devoted to particles in the vicinity of the Earth's bow shock and third part includes few references on energetic particles in the magnetospheres of other planets as observed from the space probes.

4.1.1 Particles trapped in the geomagnetic field

Soon after the discovery of the radiation belts (part 1.3) the origin as well as mechanisms of particle transport and losses within the magnetosphere have been investigated. Radiation belts are composed of mainly electrons and protons with energies above several tens of keV up to several hundreds of MeV. There are usually assumed two radiation belts, the inner and outer one. The energy density of trapped particles in the inner belt is $\sim 2 \times 10^{-3}$ cm^{-3} and in the outer belt it is ~ 0.2 cm^{-3}. Radiation belts are controlled by the mirror-like structure of the geomagnetic field and in the equatorial plane they are present up to the altitudes $\sim 70,000$ km.

The motion of the charged particles within the magnetosphere, taking the simplification of dipolar field, can be described by three separate cyclic motions. Theoretical description can be found e.g. in books [Roederer, 1970; Schulz and Lanzerotti, 1974; Lyons & Williams, 1984].

The guiding center approximation is used for trajectory description and three adiabatic invariants are sufficient for the trajectory characteristics if the phase of the cyclic motion is not of interest. First cyclicity is due to the gyrorotation of the particle around the field line and first adiabatic invariant is the magnetic moment of the gyrating charged particle. While the particles are gyrating around the field line at the minimum B equator and they have non-zero parallel velocity, their guiding center is moving along the field line to higher latitudes where the B is higher. The pitch angle having its minimum value at the equator, is increasing. Conservation of the first adiabatic invariant (proportional to the ratio of the square of perpendicular velocity to the magnetic field induction) leads to decreasing of the parallel velocity component and particle can find its mirror point at high latitude. If it is above the atmosphere, particle reflects there and moves towards the equator and subsequently finds its mirror point in the opposite hemisphere. The guiding center is oscillating between the mirror points. The second adiabatic invariant is integral of parallel momentum along one cyclic motion of that type. The third cyclicity is due to nonzero product of the grad B and B which is the cause of azimuthal drift of particles around the Earth on the given magnetic shell. This cyclic motion is the slowest one and its direction is opposite for different signs of particle charge (protons westward and electrons drifting eastward) and it is not depending on particle mass. Due to conservation of the first and second invariant, particles which are injected somewhere into the trap, are subsequently populating the toroidal drift shell. The shells are marked by the McIlwain's value L [McIlwain, 1966]. For the dipolar field L (in Earth radii) is just distance of the particular drift shell to the center of the Earth in equatorial plane The experimental distributions of trapped particles are described in two dimensions, L and B. In the stationary magnetic field the McIlwain L parameter is conserved. The third adiabatic invariant is the magnetic flux Φ – the total magnetic flux enclosed by the drift trajectory. It is the flux enclosed by the orbit of the bounce centre around the Earth.

When all three invariants are conserved, the particle is stably trapped. If the force acting on a particle is variable with the frequency around any of the cyclicities, the adiabatic invariant is not conserved and particle can leak from the trapping region. For dipolar field the drift shells are symmetric and all particles independently on their pitch angle follow the same drift shell. In real geomagnetic field where also L parameter is defined, and the shells especially at larger distances from Earth, are splitted (drift shell splitting). The day-night asymmetry of the magnetospheric field causes a pitch angle dependence in particle drift orbits, so that particles with different pitch angles disperse radially as they drift. The effect is known as the drift-shell splitting. It was studied e.g. by [Takahashi et al., 1997]. The authors showed that dispersive injections observed near noon outside geosynchronous orbit provide the greatest sensitivity to the drift-shell splitting effects and are therefore most suitable for remote sensing the radial boundaries of substorm injections.

Proton and electron distribution function in the trapping regions depends on various parameters. The elemental composition of ions in radiation belt is similar to that of solar wind up to energies of several tens of MeV during geomagnetically quiet periods. [Krimigis et al., 1970] reported the contribution of nuclei $Z \geq 3$ in the outer radiation belt and concluded that the present evidence is inadequate to distinguish between the solar wind and the earth's exospheric gas as basic ion sources. The ratio O/C si close to the values observed in the solar wind composition [Mogro-Campero, 1972; Hovestadt et al., 1978] and it is quite different to the ionospheric source.

There exist empirical models of radiation belts based on many satellite measurements (e.g. [Vette, 1991]). The NASA models are accessible e.g. at http://modelweb.gsfc.nasa.gov/models/-

trap.html for protons 0.1 to 400 MeV and electrons from 0.1 to 7 MeV with wide range of L and B/B_0 (B_0 is the equatorial value of B at the field line). The information about the new radiation belt model AE-9/AP-9 is at http://lws-set.gsfc.nasa.gov/Documents/NewRadiationBeltModelA-EP9.pdf.

Pitch angle distributions of radiation belt particles have a form with maximum at 90° and most usually are described by a form of product $(B/B_0)^{-a}\sin^a(\alpha)$ where α is the pitch angle and a is the parameter of anisotropy. The anisotropy parameter is increasing with L.

The electron radiation belts consists of two parts, the inner one and the outer one, separated by the deep slot at $L = 2.2$-3.5 during quiet periods. During disturbed periods the slot position is shifted to lower values (e.g. [Kuznetsov et al., 2005a]. Outer zone electron fluxes are related to the interplanetary characteristics: they have ~ 27 day variability; correlation with solar wind speed [Williams et al., 1966; Li et al., 2001]. During the geomagnetic storms the electron belt is reconstructed. In the main phase the flux of the outer belt of nonrelativistic electrons is increasing and the slot is filled. By the end of the storm the flux is recovered. Just after the maximum of "new belt" is built up and the lowest L value to which the belt is shifted, is well described by $\sim |\mathrm{Dst}|^{-1/4}$ [Tverskaya et al., 2003] dependence where Dst is the hourly value of geoamgnetic activity level (data with the description available at http://wdc.kugi.kyoto-u.ac.jp/dstdir/). The distribution of electron fluxes 30-500 keV under the radiation belts at low and middle latitudes ($L = 1.2$-1.9) have been investigated with using experimental data obtained onboard the low altitude ACTIVE satellite. The altitudinal distribution of electron fluxes and detailed analysis of these electron formations were obtained [Grigoryan et al., 2008a]. Three main regions of electron flux were found to be present constantly under the radiation belts., namely in the region (i) magneto-conjugated to the South Atlantic Anomaly (SAA) region (in the north hemisphere), (ii) in local zone of low intense electron flux accumulation to the west of SAA, and (iii) extensive region in the north hemisphere to the east. Strong redistribution of both electrons and protons in the radiation belt at low altitudes has been reported by [Kuznetsov et al., 2007] during the geomagnetic storms in period August 2001 through August 2003 by CORONAS-F measurements. The electron flux decreased abruptly in the outer belt during the main phase of the storms. During the recovery phase the outer radiation belt is found to recover much closer to the Earth, near the boundary of the penetration of solar electrons during the main phase of the storm. It is associated with the decrease in the electron flux with the abrupt decrease of the size of the magnetosphere during the main phase of the storm. In all cases studied, the Earth radiation belts exhibited rather long time (several days) variations. Results on electron and proton fluxes under the radiation belts obtained from several low orbital satellites during 1978-2005 are summarized and discussed by [Grigoryan et al., 2008b].

Altough majority of radiation belt particles has solar (solar wind) origin, another sources are not negligible. Interaction of primary CR with the residual atmosphere produces secondary neutrons and other particles. The CRAND (cosmic ray albedo neutron decay) source is important for the protons of the inner radiation belt [Singer, 1958; Farley et al., 1969]. There were numerous observations of albedo neutrons. One of them [Efimov et al., 1985] describes the latitudinal course of the neutron flux obtained from the low altitude polar orbiting satellite. The albedo electrons contribute also to the energetic electron population of inner belt. There are also indications that the solar protons with energy several MeV accelerated during the flares are trapped after their arrival to the Earth onto the outer L shells and contribute to the radiation belt sources. [Lazutin and Logachev, 2009] indicate that during periods of high level of solar activity for trapped protons with energy 1-5 MeV at $L = 2$-3 are important SEPs. The model presented by [Lazutin et al., 2009] explains the occurrence of the fast intensity decrease of the inner belt protons as a result of the magnetosphere reconfiguration and associated intrusion of the quasitrapping region boundary into the inner belt region. [Lazutin et al., 2007] present the experimental proofs of the existence of the formation and destruction mechanisms of solar proton belts in the inner magnetosphere at a rapid change in the penetration boundary of solar protons. Review on the physics of radiation belt ions can be found e.g. in [Panasyuk, 2004].

In the lower energy range close to hundred of keV which are related to the ring current, it is important to assume the contribution of accelerated oxygen ions. The central part in the mechanism of geomagnetic storms belongs to the ring current. During the storm the horizontal component of geomagnetic field at low and middle latitudes is depressed. The average depression on the ground is 0.1-1% with higher values in the huge storms. Such magnetic effect corresponds to the electric current circulating around the Earth. The strength of the current is usually measured by the Dst index – horizontal component of the disturbed magnetic field at low latitudes averaged over 1 hour. Soon after discovery of radiation belts there were attempts to identify it with the ring current. During the quiet time periods the contribution of particles with $E < 100$ keV to Dst is not larger than 20% [Kovtyukh et al, 1981]. However during the storms the magnetic field in the center of the trap is depressed which leads to adiabatic cooling of radiation belt particles and consequently to decrease of the current. That paradox was solved after discovery of the particle belt which is inreasing significantly during the geomagnetic storms [Frank, 1967]. There are many papers on the relation between ring current and the dynamics of radiation belts. One of the recent is e.g. by [Ebihara et al., 2008] using POLAR energetic particle data. The authors indicate that pitch angle distribution of protons and electrons can be used to distinguish nonadiabatic processes acting selectively on electrons from adiabatic ones.

Regarding the trapped particle losses there exist several mechanisms. One of them is ionisation (Coulomb) losses with the atoms of residual high altitude atmosphere. Another mechanism is the cyclotron instability. The relative contribution of the mechanisms of losses are different for ions and electrons. For electrons both mentioned effects are important while for protons and other ions the scattering can be neglected. The ions including those in the ring current, can be lost due to the charge exchange with residual low energy neutral atoms of the geocorona. The formerly trapped proton can capture the atomary electron and 'to convert' itself to the fast hydrogen atom and escape from trapping region. Due to the charge exchange the ions at large L values originated neutral atoms can move freely closer to the Earth (towards lower L) where they can be ionized and captured again by geomagnetic field. This effect may lead to formation of trapped ions of various elements at low L [Mazur et al., 1998].

According to measurements of fast neutral atoms which escape from radiation belts, it is possible to obtain the global picture of radiation belts and of ring current too [Williams et al., 1992]. Significant contribution to the imaging of the magnetosphere by the technique of remote measurements of distribution of energetic neutral atoms was done by IMAGE (Imager for Magnetopause-to-Aurora Global Exploration) [Burch, 2000]. The objectives of the mission as what are the dominant mechanisms for injecting plasma into the magnetosphere on substorm and magnetic storm time scales; what is directly driven response of the magnetosphere to solar wind changes; how and where are magnetospheric plasmas energized, transported, and subsequently lost during storms and substorms, are studied in addition to the ultraviolet and radio plasma imaging, by the neutral atom imaging in the energy range from 10 eV to 500 keV. The discoveries made by the IMAGE during its first 5 years of operation are reviewed in paper by [Burch, 2005]. New knowledge about ring current injection, the details of plasmasphere structure, remote sensing of the magnetopause were among the findings.

There are other measurements of the energetic neutral atoms targeting to the evolution of ring current and trapped particle dynamics. One of them is NUADU [McKenna-Lawlor et al., 2005a; Lu et al., 2008] measured on TC-2 satellite which is a complementary mission to CLUSTER. The redistribution of energetic charged particles in the magnetosphere during a geomagnetic storm was deduced on the basis of that experiment and compared with the predictions of a magnetospheric model with external current systems [McKenna-Lawlor et al., 2009].

Another important mechanism of the loss of radiation belt particles is the cyclotron instability. In the magnetosphere there exist large variety of waves. There can be generated waves which are propagating along the magnetic field lines and reflect from the ionosphere. The electron cyclotron waves have frequencies close to gyrofrequency of electrons and they are right hand polarized. They are usually named as whistlers. The ion cyclotron waves have opposite polarization and frequencies close to gyrofrequency of ions. The particle-wave interaction can lead to the pitch angle diffusion and consequantly to the precipitation of particles into the atmosphere. The critical energy of the precipitating particles (energy above which particles precipitate) decreases with the anisotropy and depends on B^2/n where n is plasma density in equatorial plane. There is also a limit of the cyclotron instability which evolves above the critical flux of trapped particles [Kennel & Petschek, 1966]. When fluxes are approaching to critical value, the pitch angle diffusion into the loss cone is close to the limit with the lifetime of particle (in the trapping regime) given just by the bounce time along the field line.

The waves are present also at low, ionospheric altitudes. The diagnostics of high frequency waves on a low orbiting satellite in the topside ionosphere detected increase of intensity of about 20 dB above the background, located over the specific areas of the Earth [Klos et al. 2000]. These emissions were correlated with the positions of the maximum fluxes of precipitating particles in the outer radiation belts, as determined by high-energy particle measurements in the 0.5-1.5 MeV energy range. The pumping of electromagnetic waves from the ground to the ionosphere and the precipitation of energetic particles from the radiation belts can, thus, disturb the top-side ionosphere and lead to an enhanced turbulence in the ionospheric plasma. The scattering of supra-thermal electrons of radiation belt origin on ion-acoustic or the Langmuir turbulence was proposed as a mechanism for the generation of broad-band HF emissions [Rothkaehl and Klos, 2003; Rothkaehl and Parrot 2005]. The processes due to wave particle interactions with radiation belt populations can influence the near Earth environment. Precipitation of particles can be related also to thunderstorms, lightning and sprites. Survey of these phenomena includes e.g. paper by [Siingh et al, 2008]. High energy electrons are connected also with the gamma rays observed at low altitudes. [Bučík, 2004] analyzed in detail the distribution of high energy gamma rays based on measurements by the low altitude polar orbiting satellite CORONAS-I.

During the geomagnetic disturbances the radial diffusion of particles is important for supplying fresh population to radiation belts. Sudden commencements (SC) or sudden storm commencements (SSC) – the impulses of the magnetic field with few minutes onset and several tens of minutes duration driven by interplanetary perturbations like CMEs cause the changes of the magnetopause position and shift trapped particles to different L shells. While the first and second adiabatic invariant are conserved, the third one is violated and the diffusion across L (radial) is observed. For particles of lower energies the fluctuactions of electric field are important

[Falthammar, 1972] while for higher energy particles the pulses of magnetic field contribute to radial diffusion. In periods of high geomagnetic activity the rate of radial diffusion increases. The distribution function of particles is described by Fokker-Planck equation. The diffusion coefficient is composed of the electric and magnetic part. Both have usually form of $\sim L^n$, where n is about 10 for magnetic fluctuations and about 6 for electric ones. More detailed description is e.g. in [Falthammar, 1972; Tverskoy, 1968].

The relativistic electrons are important subject of the study in relation to radiation belts. The energization of electrons to relativistic energies during the substorms puts also constraints on magnetospheric topology and on the geomagnetic field models [Antonova, 2009; Antonova et al., 2009]. In the past decade the electron dynamics was studied by many authors using data from numerous satellites. Recently e.g. review by [Shprits et al., 2008a,b] summarizes the understanding of acceleration, transport and loss processes of energetic electrons in radiation belt. There are several acceleration mechanisms proposed e.g. by [Li & Temerin, 2001; Horne, 2002]. Acceleration via wave-particle interactions are main candidate for local acceleration (e.g. [Horne & Thorne, 1998]. Review on energetic particle radiation environment including references to papers on dynamics of trapped electrons and protons is e.g. in [Vainio et al., 2009].

4.1.2 Particles in the vicinity of the Earth's bow shock

The bow shock is formed in presence of the planetary magnetosphere at the position where the plasma (solar wind) velocity suddenly decreases. The Earth's bow shock is a natural laboratory for studying processes in non-collisionless plasma shocks. Its thickness is 10^2-10^3 km and at subsolar point its average location is about ~ 14 earth radii. In 1962 I. Axford and P. Kellogg independently predicted the existence of the planetary bow shock in front of the Earth [Chian & Kamide, 2007]. This prediction was confirmed by the IMP-1 a year later. In 1961 the Explorer-1 measurements indicated crossing of the magnetopause which separates the geomagnetic field and plasma of primarily terrestrial origin from the plasma of solar wind. More details on magnetopause and other boundary regions of the Earth's magnetosphere can be found e.g. in [Hughes, 1997].

Ions with energies ranging from ~ 10 keV to several hundreds of keV are common in the region upstream from the Earth's bow shock for long time (e.g. [Asbridge et al., 1968; Lin et al., 1974; Sarris et al., 1976; Krimigis et al., 1978; Gosling et al., 1978; Ipavich et al. 1981]). The ions are generally interpreted in terms of Fermi acceleration and reflection from the bow shock [Lee et al., 1981; Terasawa, 1979; Thomsen et al., 1993] or by leakage from the magnetosphere to the upstream region [Anagnostopoulos et al., 1998; 2005; Kudela et al., 1990]. One of the devices providing informations about energetic ions and electrons near the bow shock was the energetic ion spectrometer DOK-2 on Interball-1 during 5 years launched in 1996. Both case and statistical studies were done using the measurements (e.g. [Sibeck et al., 2004; Prech et al., 2005; Kudela et al., 2002b]). Statistical analysis of DOK-2 measurements near the bow shock revealed that most probably both mechanisms, namely leakage of ions from the magnetosphere and additional acceleration of the solar (and may be of magnetospheric particles) at the bow shock contributes to the population of ions upstream from the shock. This is illustrated in Figure 4.1.

Results of statistical analysis of upstream ion events based on AMPTE/IRM measurements is in [Trattner et al., 1994]. After normalizing the upstream particle densities to zero bow shock distance by using the exponential law, a good correlation (0.7) of the density of the diffuse ions

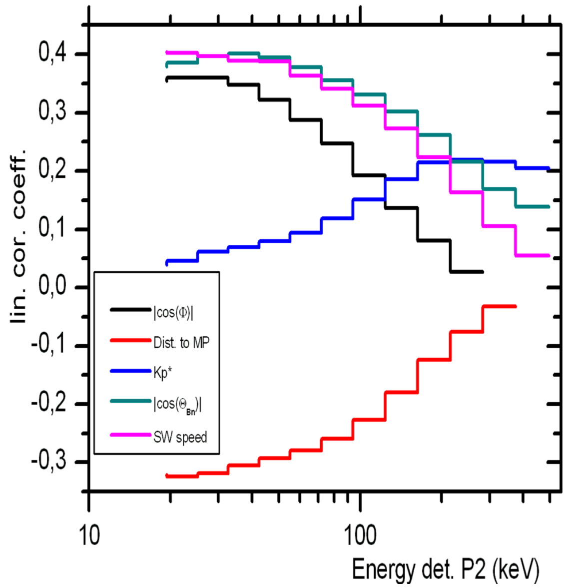

Fig. 4.1. Dependence of linear correlation coefficient between the diffusive ion upstream flux (insignificant difference in intensity of two detectors looking in different directions) from 2 min data ($\sim$ 6400 points) at different energies near the bow shock during 4 years of measurements on Interball-1. At low energies (20-30 keV) relatively high correlation coefficient is apparent with the angle Θ_{Bn} between normal to shock and B (probably indication of acceleration at quasi-parallel shocks). With increasing energy the dependence becomes less important. On the other hand the dependence on solar wind speed and on geomagnetic activity is increasing with energy. This indicates that ions of higher energies in the upstream region are better related to the geomagnetic activity and probably the leakage of magnetospheric particles becomes important. Φ is the cone angle of IMF; Kp is geomagnetic activity index and distance to magnetopause along the field line is one parameter too.

with the solar wind density was found. This supports the suggestion that the solar wind is the source of the diffuse ions. Further discussions and newer papers on upstream particles are based on the detailed measurements by Cluster, IMP, and other satellites as well as deep in interplanetary space allowing the multiple observations too (e.g. [Anagnostopoulos et al., 2009; Desai et al., 2008; Kronberg et al., 2009]). First of these papers stresses the importance of the efficient acceleration of the solar ambient energetic population via the shock drift acceleration mechanism for one event discussed in detail. [Kronberg et al., 2009] determine the spatial diffusion mean free path and the diffusion coefficient as a function of ion energy by assuming that upstream diffusion is balanced by downstream convection.

There are papers suggesting that the cusp (Earth's cusps are magnetic field features in the magnetosphere associated with regions through which plasma from the Sun can have direct access to the upper atmosphere [Smith and Lockwood, 1996]) may contribute to the particle population observed in the upstream region (e.g. [Chen and Fritz, 2005]). [Chen et al., 2005] analyze one high solar wind pressure event and indicate that the bow shock was not the main source of both the cusp and upstream energetic ions, and that the upstream energetic ions most likely came from the cusp for that case. [Lin et al, 2007] suggest that the bow shock accelerated ions, upon being transmitted into the cusp region, form the bulk of cusp energetic ions. [Wang et al., 2009] used the 3D hybrid simulation to check the energetic ions and electromagnetic waves in quasi-parallel bow shock and cusp. By tracing trajectories of cusp energetic ions in the simulation, the authors reveal the origin of these ions. The source is predominantly associated with the Fermi acceleration at the shock and foreshock.

4.1.3 Energetic particles in other magnetospheres

The Earth's magnetosphere has analogues in space in many situations and energetic particles are there either accelerated or transmitted from the outer space changing their arrival direction. Here we just briefly mention selected experimental results on energetic particles in the magnetospheres of the solar system planets. Review of understanding of magnetospheres in the solar system is e.g. in [Blanc et al., 2005]. All four giant planets (Jupiter, Saturn, Uranus, Neptune) have intrinsic magnetic fields which carve magnetospheric cavities of varying sizes into the solar wind. All of them have radiation belts, radio emissions and auroras, showing that they behave as giant charged particle accelerators [Bhardwaj and Gladstone, 2000].

The Jovian magnetosphere is one of the giant magnetospheres known well due to visits of interplanetary probes Pioneer 10, 11; Voyager 1, 2 and Ulysses and from measurements of one orbiter, namely Galileo. It can be divided into the inner one ($< 10R_J$), the middle (10-40 R_J) and outer one ($> 40R_J$). In the inner jovian magnetosphere they are radiation belt particles. One of major discoveries by the Voyager 1 and 2 was unusual character of the Jovian plasma characterized by the hot (20-40 keV) multicomponent plasma which co-rotates with the planet out to dayside magnetosheath and on the nightside to $\sim 150R_J$ at ~ 03 local time [Krimigis et al., 1980 and references therein]. Voyager-2 observed outside the nightside co-rotation/magnetospheric wind plasma boundary, an intense, nearly monoenergetic beam of probably heavy $\sim$ 100 keV ions flowing away from Jupiter. The beam of ions persisted for nearly 4 hours. Most regions of the Jovian magnetosphere covered by the Galileo spacecraft undergo quasi-periodic modulations of several earth days. These modulations appear also in energetic particles [Kronberg et al., 2007]. [Haggerty et al., 2009] report measurements of particles in Jovian magnetotail from New Horizons spacecraft. The authors examined the ion composition of energetic particles in the tail and suggest it is within these bursts that Jupiter releases the bulk of its energetic material. They also reported on the ion composition ratios as a function distance down the Jovian magnetotail. Paper [Horne et al., 2008] in analysis similar to the earth radiation belt electrons discuss the energetic electron population in the Jovian magnetosphere. A survey of data from the Galileo spacecraft at Jupiter, which shows that intense whistler-mode waves are observed outside the orbit of the moon Io and, using Fokker-Planck simulations, are strong enough to accelerate electrons to relativistic energies on timescales comparable to that for electron transport. Gyroresonant acceleration is most effective between 6 and 12 R_J and provides the missing step in the production of intense synchrotron radiation from Jupiter.

Cassini mission returned the new informations about the magnetosphere of Saturn. Electrons of higher energy (110-485 keV) were averaged into azimuthal bins and L shells. In the night local time the fluxes have maximum while at noon minimal flux is observed. This effect is suggested to be a result of nightside injection and subcorotational drift in nondipolar field. The inner belt is formed near Mimas L shell and outer belt between the Dione and Rhea Ls [Carbary et al., 2009a]. The periodic behavior of energetic particles in Saturn's magnetosphere observed with use of energergetic neutral atom imaging was revealed [Carbary et al., 2009b]. [Schippers et al., 2008] analyzed the radial distribution of electrons in the wide energy range from 0.6 eV up to 10 MeV inside 20 R_S in the Saturn's magnetosphere. A boundary at $\sim 9R_S$ for thermal and suprathermal populations is observed. While thermal electrons completely disappear beyond 15 R_S, the suprathermal ones are observed also in the outer magnetosphere.

The energetic particles in the Neptune's magnetosphere are reported by [Mauk et al., 1991]. The ions have $kT = 12$ to 100 keV, and kT is strongly correlated with position relative to Triton's L shell. Within the Neptunian magnetotail planetward, magnetic-field-aligned streaming of ions and electrons is observed within the distant $\sim 67R_N$ plasma sheet and within a closer region. The magnetic trapping of energetic particles on closed field lines is discussed by [Paranicas and Cheng, 1993].

The electrons 22-35 keV were observed in the Uranian magnetosphere during the time period when intense whistler waves were detected at the minimum L shell position of Ariel indicating that dynamical processes must be quite dissimilar to those in the magnetosphere of the Earth [Mauk et al., 1994].

4.2 Cosmic ray transmissivity in the magnetosphere

Particle trajectories at high energies are not describable by adiabatic invariants as it is the case for populations trapped in the geomagnetic field. The reason is that the three cyclicities (part 4.1) have comparable characteristic times. Figure 6 in [Roederer, 1970] displays the contours of constant adiabatic gyration, bounce and drift frequency in a dipole field. They depend on L, energy and type of particles. For protons at $L \sim 7$ (outer magnetosphere) the three periodicities for protons with energy > 100 MeV are of order of 1 Hz. Thus adiabatic invariant approach fails for CR particles with their typical energies entering the magnetosphere. For trajectory predictions and obtaining the CR transmissivity through the magnetosphere is the only possibility: numerical tracing of particle motion in the given geomagnetic field model. The equation describing the particle motion in the static magnetic field leads to the system of six linear differential equations with unknown values (position, velocity vector) which is usually solved numerically (e.g. [McCracken et al., 1962; 1965; Shea et al., 1965; 1968; Shea & Smart, 1966; 1970; 1975; Gall et al., 1982; Bobik, 2001]). Paper [Cooke at al., 1991] describes systematically the terminology of geomagnetic cut-offs, the allowed and forbidden cones and asymptotic directions. A useful formula for the Störmer cut-off rigidity (from [Cooke, 1983]) is $R_c = \frac{59.4\cos^4\lambda}{r^2\left[1+\sqrt{1-\cos^3\lambda\sin\theta\sin\psi}\right]^2}$ where R is in GV, λ is magnetic latitude, θ is zenith angle, ψ is azimuth measured clockwise from magnetic north, and r is the distance from dipole center in the earth radii. Relation between rigidity of particle (R) and its kinetic energy per nucleon (T_n) is $R = (A/Z)\sqrt{T_n(T_n + 2M)}$ where M is the rest mass of proton. This expression gives, for any location and direction in a dipole field, the cut-off value below which the CR access is unconditionally forbidden. It does not mean that particles with rigidity above that value have allowed access. A complex structure of allowed and forbidden trajectories is between the lowest cut-off (all trajectories are forbidden below that) and the highest one (all allowed above that).

The review of the progress of half a century of the CR trajectory calculation can be found in paper by [Smart and Shea, 2009]. For the trajectory computations with the step dR summarized

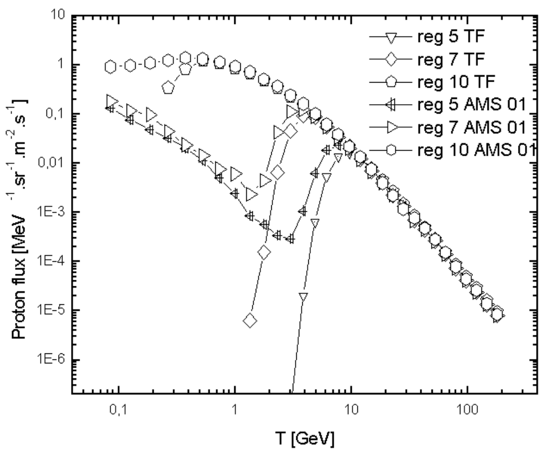

Fig. 4.2. (from [Bobik et al., 2003]). AMS-01 measured spectra (label AMS 01) compared with the evaluated primary spectra (label TF) for three geomagnetic regions, namely 5, 7 and 10 (corresponding geomagnetic latitude intervals are (0.5,0.6); (0.7;0.8) and > 1.0 in radians). The source energy spectrum CREME 96 was used [Tylka et al., 1997]. The correspondence of predicted and model spectra is reasonable. The static IGRF model of geomagnetic field was used.

over larger rigidity interval DR, the useful approach is transmissivity function $TF(R, DR)$ – the probability that particle of rigidity $(R, R+DR)$ can access the given point in the model field [Kudela and Usoskin, 2004]. This concept is isimilar to the earlier one introduced for satellite measurements at low altitudes [Heinrich and Spill, 1979]. In paper [Bobik et al., 2009] the nuclear abundances of He, C and Fe nuclei measured by AMS-01 in the magnetosphere were recalculated to the primary flux using TF at different latitudes. By using TF it was possible also to deconvolute the secondary albedo proton flux from the primary CR in the measurements at various geomagnetic latitude bands [Bobik et al., 2006]. The application of TF is illustrated in the Figure 4.2.

Most commonly the vertical cut-offs are used for estimates of geomagnetic field screening for the CRs. More detailed interpretation of the ground based measurements by NMs requires however also the knowledge of contribution of primary CR accessing the top of the atmosphere obliquely. Papers [Clem et al., 1997; Bieber et al., 1997] discuss the effect of off-vertical incidence of the CR particles for the NM response.

4.2.1 Changes during geomagnetic disturbances

The important element of trajectory computations is the geomagnetic field model used. Currently the 10^{th} generation of IGRF (International Geomagnetic Reference Field) model is available at (http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html). The geomagnetic field potential is represented as a truncated series expansion – function of geocentric coordinates and time – with use of the Schmidt semi-normalised associated Legendre functions of degree n and order m. The pairs of Gauss coefficients up to degree 10 and order 10 can be used with 5 year steps starting from 1900 until 2005.

However, this model does not assume asymmetry of magnetosphere (local time). Before the external field models were constructed using the large amount of data, the analysis of CR during geomagnetically disturbed periods showed the peculiarities and cut-off rigidities have been calculated for such periods (e.g. [Flückiger et al., 1986]). For the periods with a higher level of geomagnetic activity the additions of the field due to the various external systems as the magnetopause current, symmetric and partial ring current and field aligned current, in the magnetosphere have to be included. There exist now several geomagnetic models including the contribution of variable external currents. Paper [Desorgher et al., 2009] compares several different models in the context of the CR physics. For the GLE on January 20, 2005 the impact of differences in asymptotic directions obtained for different models is studied, especially from the point of view of dosimetric contribution to the aircraft altitudes.

[Kudela et al., 2008] illustrate that during large geomagnetic storms the system of asymptotic directions, of TF itself and of temporal variability of cut-off rigidity is strongly dependent on the model used and for the three models [Tsyganenko, 1989; Boberg et al., 1995; Tsyganenko & Sitnov, 2005] provides different systems even in the penumbra structure at low latitude stations. Comparison of cut-off rigidities during magnetic storms using different models is discussed also in papers [Tyasto et al., 2004; 2008]. However, for checking validity of geomagnetic models during strong disturbances by using middle and low latitude NMs, one has to assume that the ground based detector measures the response of the two superimposed effects: (i) the interplanetary anisotropy usually evolving itself during the geomagnetic storm and connected FD when the CME is passing in interplanetary space and (ii) reconfiguration of external magnetospheric currents which leads to the change of transmissivity and structure of asymptotic directions. For that the independent estimate of the interplanetary CR anisotropy is crucial. One possible way is to estimate it from the the low energies and from the high energies. The Spaceship Earth described by [Bieber & Evenson, 1995] consists of several high latitude NM measurements and provides the anisotropy. High latitude positions have their geomagnetic cut-off close or below the atmospheric threshold and thus geomagnetic activity is not strongly affecting the TF. Further, they have relatively narrow extent of asymptotic longitudes which is even shrinked during geomagnetic storm (computations by [Bobik, 2001]). On the other hand, the muon multidirectional detector system as e.g. described by [Munakata et al. 2001] is not strongly sensitive to geomagnetic disturbances since it is responding to the high energy CR. Thus, comparison of the interplanetary CR anisotropy at low and high energies, is suitable to check together with the responses of middle and low latitude NMs the validity of geomagnetic field models in future.

4.2.2 Long term variability of geomagnetic trasmissivity

CR long term variations are important for studies of solar terrestrial environment (e.g. [Usoskin, 2004; 2008; Storini et al., 2008]) as well as for trends in estimation of long-term CR variations in future [Dorman, 2005a]. Secular variations of cut-off rigidities were studied long time ago [Shea & Smart, 1970]. The estimates of geomagnetic cutoffs depend on the knowledge of geomagnetic field in the past. At some places on the Earth the geomagnetic cut-offs have been changed over the second half of the past century more dramatically than in another positions and the changes

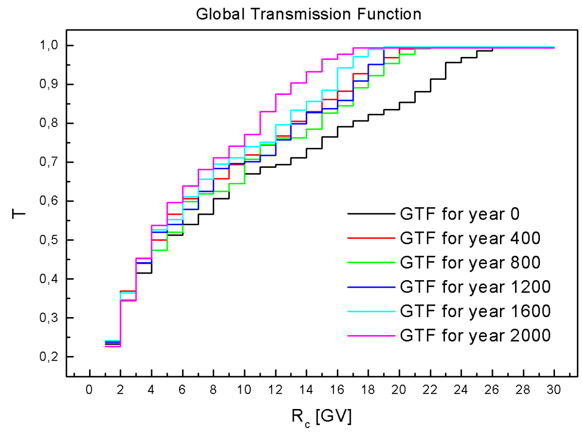

Fig. 4.3. The "Global Transmission Function" representing the fraction of the Earth's surface which was exposed to galactic CRs above the given rigidity was changing over long time scale. More details about the temporal evolution of vertical cutoff at different posistions at Earth can be found e.g. in paper [Kudela & Bobik, 2004].

are at different positions in opposite directions (decreasing or increasing the cut-off) (e.g. [Shea and Smart, 2001]). Before 1900 the approximation of the Earth's magnetic field is not as precise as its is in IGRF models. Thus long term changes of transmissivity are usually based on the changes of dipolar magnetic moment of the Earth or approximation of the field potential with low n and m values. Figure 4.3 shows the changes of cut-off over the globe for longer time period.

4.2.3 Penetration of solar particles into the magnetosphere

The magnetospheric measurements of energetic particles can also provide the informations about the solar and/or interplanetary acceleration of particles by using a geomagnetic field filter on charged particles.

If the detectors with large geometrical factor for energetic particles measure at low, nearly polar orbiting satellites, the arrival of SEP can be observed according to its boundary position and the flux at four segments of trajectory per one orbit. CORONAS-F was a low altitude satellite and one of the devices, namely the SONG, had such possibility. By checking the value of proton flux at different L shells (4 times per orbit at selected L from 1.75 to 3) and assuming the simple shape of energy spectra of the type $J(>E) = J_0 E^{-\gamma}$, the spectra in Figure 4.4 is obtained [Kuznetsov et al., 2007a].

Recently the PAMELA experiment provided important information on the energy spectra of SEP during GLE on December 13, 2006. Combining the low energy measurements by GOES (3 channels covering 30-500 MeV), three energy channels by PAMELA (from 0.1 to 1 GeV) and NM data, the authors obtained the evolution of the fit of spectra over a long time period [De Simone et al., 2009].

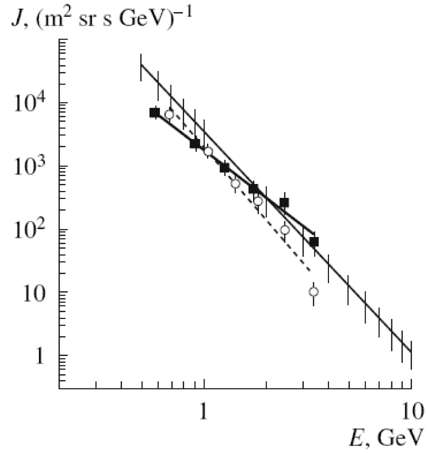

Fig. 4.4. From [Kuznetsov et al, 2007a]. Energy spectra of SEP on October 28, 2003 at 1142-1146 UT evening sector (black squares) and at 1204-1209 UT morning sector (circles). Comparison with NM data (line $>$ 400 MeV) according to [Vashenyuk et al., 2005; Miroshnichenko et al., 2005a].

The position of penetration boundary of SEP is fitted from a large amount of observations during different geomagnetic activity levels in the geographic coordinates with plots of constant lines of rigidity at different local times [Smart et al., 2006]. However, the position of the boundary of SEP penetration to low orbits is not known exactly for the given geomagnetic activity level. The large spread of magnetic latitude position of penetrating boundary at fixed Kp and Dst is reported by [Myagkova et al., 2009].

The boundary position during the penetration of SEP on low orbits has rather complicated character especially during strong geomagnetic events. One of specific features which is not understood quite well is the double structure of the boundary position (Lazutin, personnal communication). The value of L at given position during the storms depends on the geomagnetic field model used.

Two more questions obtained from the observations remain not understood well, namely (a) 1-100 MeV SEP penetrate into the magnetosphere to lower latitudes as deep as it is not allowed by any magnetic field model, and (b) during some strong magnetic storms penetration boundary positions coincide for a wide energy range contrary to normal (expected) penetration structure.

5 Energetic particles, space weather and environment

In a solar-terrestrial environment there occur many physical processes which are not only a subject of fundamental research but also have impact on the environment, technological systems and on people. The term Space Weather is defined as "Conditions on the Sun and in the solar wind, magnetosphere, ionosphere and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health." [US National Space Weather Programme, 1995]. In addition, these conditions may affect human life or health. The effects of the space weather and physics behind is described e.g. in the books [Bothmer and Daglis, 2007; Lilensten and Bornarel, 2006; Scherer et al., 2005].

Energetic particles have an important place in space weather (SW) studies. They have two types of relations to SW research and effects. Since particles in space and CRs interact with the materials of the satellite and airplane systems as well as with the atmosphere, monitoring of changes of its flux especially during the solar flares, space storms and geomagnetic disturbances, is important. This is a direct type of relations of energetic particles in space to SW. On the other hand high energy particles "transmit" fast the informations about the reconfigurations of magnetic fields in the interplanetary space which affects the magnetosphere and upper atmosphere later. This is a base for eventual possibilities in using the CR and energetic particles in space for SW forecasts. Earlier reviews on specific relations of CR to SW research are e.g. in papers [Kudela et al., 2000; 2009].

In the first subchapter we review selected results of a high temporal resolution of the CR ground measurements and show how the use experimental data in real time is important for space weather alert signals. The second part is devoted to the possibilities of CR data as an indication of geomagnetic disturbances. The part three deals with the impact of energetic particles on satelite technological systems and on biological objects and the final part shortly reviews some of recent results of the CR study to atmospheric processes.

5.1 CR before the onset of radiation storms

Populations of particles with energy several tens to hundreds of MeV are most important for the radiation effects during the radiation storms: for the electronic element failures on satellites, for communication, for biological objects especially in space and at high altitudes, for the atmosphere especially at high latitudes. CR detectors on the ground (at energies above the atmospheric threshold and at locations with various geomagnetic cutoff rigidity, if good temporal resolution and network by many stations is in a real time operation), can provide useful alerts ranging from several minutes to tens of minutes in advance of the massive arrival of tens to hundreds MeV particles to the vicinity of the Earth.

Measurements at a single specific point in the magnetosphere as the South Pole position is allows to obtain a real time energy spectrum (combination of usual NM and that lacking usual lead shielding) [Bieber et al., 2006]. It was shown for the January 20, 2005 event. Observations by more NMs at high latitudes for the same GLE provide the first alert of the space storm: for minute 1 of the event (Mc Murdo 11%, Terre Adelie 4%) GLE warning is issued at the end (by 2 stations); for minute 2 (McMurdo 93%, Terre Adelie 73%) the alert is issued by 3 stations. The GLE real-time alaram based on 8 high latitude NMs including those at a high mountain is described by [Kuwabara et al., 2006]. Three level alarm system (by number of NMs exceeding

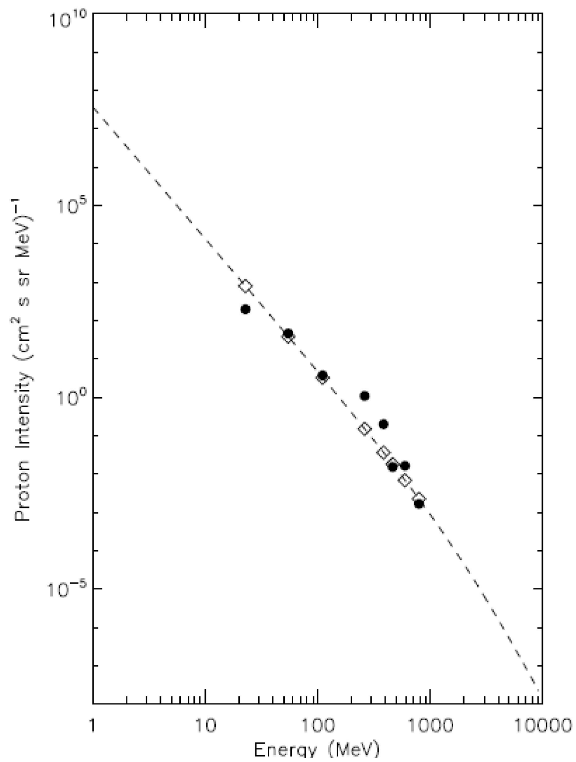

Fig. 5.1. (from [Su Yeon Oh et al., 2009]). Dashed line is the energy spectrum for July 14, 2000 GLE estimated from NM measurements for the time of NM peak. The filled lines are measurements by GOES (later) and open diamonds are predicted intensities at GOES channels from NM extrapolating to lower energies. Courtesy of Su Yeon Oh.

threshold value above that of baseline) is suggested. Out of 10 GLEs in 2001-2005 archived data the system produced 9 correct alarms. GLE systems give earlier warning than the satellite 2 (SEC/NOAA) alert ranging from $\sim$ 10 to $\sim$ 30 min. Recently [Su Yeon Oh et al., 2009] checked the potential of the South Pole neutron monitor data for prediction of the radiation storm intensity measured later by GOES. Using the two devices at the South Pole the energy spectrum was estimated. Two groups of GLE have been analyzed and additionally compared with high energy channels of GOES. It was shown that the South Pole GLE observations can be used to predict the radiation intensity of the higher energy proton channels from GOES. Figure 5.1 shows a comparison of predictions by ground based measurements with those obtained later by the satellite. For the group of GLE events there were found relatively high correlation coefficients between predicted and measured peak intensity and fluences in the energy channels covered by GOES below the atmospheric threshold.

Recently, also the progress in using the NM at low and middle latitudes is reported before radiation storms. Several steps of GLE alert algorithm using the NM network have been described by [Mavromichalaki et al., 2009]. The NMDB project of 7FP EU is supporting that activity (http://www.nmdb.eu). Table 1 in the cited paper constructed from many NM measurements shows that with the exception of one event for all GLEs No 60-70 the NM station alert was obtained with at least 12 min in advance of GOES alert (>100 MeV). Another contruction of alerts before the GLE an solar neutron events was reported by [Anashin et al., 2009]. It is working in real time at http://cr0.izmiran.ru/SolarNeutronMonitoring, respectively.

The study by [Posner, 2007] demonstrates an important possibility of the short-term forecasting of the appearance and intensity of solar ion events by means of relativistic electrons measured on satellites. The onset of 31-50 MeV protons after the relativistic electrons is ranging from 10 to >100 min.

The system for the short-term radiation hazard forecasting is suggested e.g. by papers [Dorman et al., 2006a,b]. Probability of false alarms, missed alarms and model situation of the work of proposed system for historical events with an extremely high fluence of energetic protons is checked. The simultaneous measurements at several NMs providing real time data with 1 minute resolution or better and with a high statistics (high mountain, relatively high geomagnetic cutoff rigidity) combined with the reliable measurements of different multiplicities is important for this application. The trends in the forecast of radiation storms are discussed by [Posner et al., 2009].

5.2 CR before the geoeffective events

Time profiles of CR measurements at NM energies showed long time ago the existence of the precursors (pre-increases, pre-decreases) before the arrival of interplanetary shock to the Earth and before the onset of Forbush decrease (FD) [Dorman, 1963]. Some types of precursory anisotropies are interpreted as kinetic effects due to interaction of ambient CR with the approaching shock [Nagashima et al., 1992]. CR particles have a high velocity, a large gyroradius in IMF and a large value of the parallel mean free path ($\lambda_{\rm par}$). Thus, the information about redistribution of IMF large scale inhomogeneities and/or precursory anisotropies related to them, is transmitted fast to the remote locations. The intensity deficit of CR can be observed up to distance $\sim 0.1\lambda_{\rm par}\cos(\Phi)$, where Φ is the cone angle of the interplanetary magnetic field (IMF) [Ruffolo 1999]. The mathematical explanation of precursors to FD was proposed in the frame of pitch angle transport near oblique, plane-parallel shock. Assuming different values of power-law index of magnetic turbulence, mean free path and decay length for typical primary energies to which NMs and muon detectors (MD) are sensitive, the loss cone precursors should be observed by NM ~ 4 hr prior to shock arrival, and by MD ~ 15 hr prior to shock arrival [Leerungnavarat et al., 2003].

Fluctuations of CR (5 min data) indicated the changes in the power spectrum density (PSD, in the time scale range below the diurnal variation) before the onset of geomagnetic storms at a single NM, especially during the solar activity maximum [Kudela et al., 1995]. For lower level of solar activity the asymmetry is less pronounced but it still exists. Changes of NM fluctuation spectrum over long time period are discussed e.g. in paper [Starodubtsev et al., 2006]. Different slopes of PSD and different contribution of the diurnal peak of CR to the muon telescope signal for even and odd solar cycles are reported in paper [Sabbah & Duldig, 2007]. The study of the diurnal and semidiurnal peaks of CR variability started long time ago (e.g. in paper [Ahluwalia & Dessler, 1962]). The contribution of the diurnal variation to the CR variability at NM energies is variable (see e.g. [Mishra & Mishra, 2007] and references therein). A simplified index of

CR diurnal variability (D) constructed from three middle latitude NMs with different asymptotic directions is (i) better correlated with the solar wind velocity after that interval (day) than within it; (ii) multiple linear regression of Dst with the "prehistory" of CR variability for 3, 6, 9, 12, 15, 18 hours gives the estimate of linear cross-correlation coefficient ~ 0.46 (based on 183000 hourly data); (iii) $\sim 2/3$ of cases (83) with sudden Dst depression (> 50 nT/h) is accompanied by $D > 1$ while probability of $D > 1$ during geomagnetically quiet times is only 0.07 (based on data from years 1982-2002) [Kudela and Storini, 2005]. The studies of single events indicated that the CR anisotropy onset appears before geomagnetic disturbances. The strong enhancement of CR anisotropy was observed before and during January 1997 CME/magnetic cloud by seven high latitude stations [Bieber & Evenson, 1998]. The field-aligned anisotropy appeared ~ 9 hours prior to the shock arrival. In advance of strong geomagnetic storms the precursors on neutron monitors [Belov et al., 2001] and on muon detectors [Munakata et al., 2000] were observed with various lead time up to ~ 12 hours. Two types of anisotropy were identifed, namely (i) LC – loss cone, when the detector is magnetically (by asymptotics) connected to the CR depleted region downstream of the interplanetary shock; and EV – enhanced variance (not clearly aligned with the ambient magnetic field). One example of precursory effect in the CR is in Figure 1 of [Belov et al., 2001]. The strong geomagnetic storm accompanied by FD has a clear precursor 10-15 hours before the storm onset. Other examples and the discussion on precursors based on CR are e.g. in papers [Dorman, 1974; 2005; Dorman et al., 1995; 2003; Belov et al., 1995].

For some events the simplified measures of CR anisotropy is found to be changed few hours before the SSC onset. The comparison of middle/low latitude NM with strongly different asymptotic longitudes showed precursors 1-4 hr (change of the ratio of hourly counting rates at Lomnicky Stit and at Haleakala NM) before the decrease of Dst before selected disturbances [Kudela and Storini, 2006].

An important feature is that there exists a large variability of precursory timing from anisotropy onset to the onset of geomagnetic storm. The anisotropy seen in the CR during the motion of large scale inhomogenities and related shocks in the interplanetary space depend on the geometry, velocity and on direction of CME motion, as well as on the magnetic field structure. It is observed not only the variable timing of geomagnetic storm precursors based on CR measurements, but also different time shifts between the time when Dst reaches its minimum and the warning based on the IMF and solar wind data from ACE location as shown for the events in cycle 23 [Kane & Echer, 2007]. The warning time ranges from 4 up to 30 h. Geomagnetic storms are caused by the passage of an intense southward directed the IMF lasting for sufficiently long intervals of time [Gonzalez et al., 1994]. From "remote sensing" of interplanetary magnetic structures only by CR it is not easy to identify the North-South polarity of the IMF which is important for the geoeffectiveness. Different parts of energy spectra of CR, at least in some cases, behave differently before the FD. Pre-increase before the FD and particles accelerated at the shock front were indicated by combination of ground based NM and GOES-7 data during October 20, 1989 event [Struminsky, 2002]: different energy spectra < 1 GeV (shock accelerated, soft) and above (much harder, pre-increase) were oserved.

CR have different responses to various kinds of interplanetary structures. For example CIR events formed by an interaction of slow and fast solar wind streams originated in coronal holes affect the CR density decrease and pitch angle distribution (e.g. [Belov et al., 2001b; Da Silva et al., 2007]). [Badruddin, 2006] discusses the transient perturbations in heliosphere and in the vicinity of the Earth in connection to the SW perspective. The precursor to smaller ($<$

5%) amplitude FD due to weaker interplanetary shock is identified with the enhanced diurnal anisotropy. Larger amplitude ($> 5\%$) FD due to stronger interplanetary shock is related to the loss cone type of the precursor. [Petukhov et al., 2005] by using of trajectory tracing in quiet solar wind and in the presence of interplanetary disturbance, obtained the directions of CR arrival to magnetospheric border. The indications about CR anisotropy were deduced. Bidirectional streaming of CR within the interplanetary CMEs (ICME) was reported in several papers (e.g. in [Dvornikov et al., 1983; Richardson et al., 2000] among others). These signatures are sometimes observed before the onset of geoeffective events.

Both case and statistical type of studies on the precursors before the geomagnetic storms based on CR anisotropy or specific features of the counting rate variability have been reported recently. Muon detectors (MD) are used for multidirectional measurements. MD at S˜ao Martinho, Brazil have shown that subtracting contribution from the diurnal anisotropy determined by the Global Muon Detector Network (GMDN), the clear signatures of the precursor before the storm on December 14, 2006 were found [Fushishita et al., 2009]. The loss cone precursor (deficit of CR flux at small pitch angles) appeared only ~ 6.6 hrs after the CME eruption on the sun, when the interplanetary shock was expected to be located 0.2 AU from the sun. The September 2005 Forbush decrease is investigated and a clear modulation in the about 8-h periodicity is emerging from the pre-Forbush subsets. The analyzed case study suggests that CR datasets, containing seven days of data with 5-min time resolution, can give a signal for interplanetary storms approaching the Earth up to 9 hours before the onset of the FD-main phase at two NMs with different cutoff rigidities [Diego & Storini, 2009]. New muon measurements are reported. Data from large muon track detector – hodoscope URAGAN (surface 34 m^2 [Timashkov et al., 2009]) around the heliospheric disturbances in 2007-2008 were analyzed. Each track is reconstructed with accuracy $< 1^\circ$. Among 63 events, when URAGAN data exist, in 53 events (84%) disturbances of anisotropy vector have been observed. Although the distribution of time differences of perturbation between ACE and URAGAN is rather wide, the mean value of the onset time of perturbation by the two measurements is -13.6 ± 2.6 hour. The statistical study of CR precursors in 2001-2007 before different storms using the Global Muon Detector Network (GMDN) was done in paper by [Da Silva et al., 2009]. The storms were divided into three groups, namely the super storms ($\mathrm{Dst} < -250$ nT); intense storms (-250 nT $< \mathrm{Dst} < -100$ nT); and moderate storms (-100 nT $< \mathrm{Dst} < -50$ nT). The percentage of the events accompanied by the precursors prior to SSC increases with an increasing peak Dst is: 15% of moderate storms, 30% of intense storms and 86% of super storms are accompanied by CR precursors observed on average 7.2 hours in advance of the SSC.

Recently a method for the determining interplanetary coronal mass ejection (ICME) geometry from galactic CR data recorded by the ground-based muon detector network was developed and described in paper [Kuwabara et al., 2009]. The authors show that the CR-based method can be used as a complementary method for deducing the ICME geometry. The chain of high latitude NMs called "Spaceship Earth" mentioned in part 4 is the 11-station network of neutron monitors strategically located to provide precise, real-time, 3-D measurements of the CR angular distribution. It covers near equidistantly in the GSE equatorial plane all asymptotic longitudes. More informations and real time data both from muon network and Spaceship Earth can be found at the site http://neutronm.bartol.udel.edu/spaceweather/. Plots in real time with an hourly resolution at http://neutronm.bartol.udel.edu/spaceweather/lossconegraph.htmcontain the graphs of CR density (from 1^{st} order anisotropy fit); the averages of CR intensity relative to the density at each NM (different colors mean deficit and increase respectively, radius of circles mean the relative intensity); the deviations from the 1^{st} order anisotropy fit at each NM and IMF magnitude, IMF Bz and geomagnetic index Kp.

Along with the existing networks for anisotropy measurements of CR and investigation of other effects in CR as Spaceship Earth and GNDM metioned above, there is continuing effort to install new measurement devices and to establish their network. In addition to use of NM at different sites, there exist installations for space weather monitoring and eventual forecasts at a single site. The combination of high mountain neutron monitors, solar neutron telescope, and muon telescopes at two elevations with a high statistical accuracy built in Armenia is in operation for several years [Chilingarian et al., 2003; 2005].

5.3 Energetic particles and satellite anomalies

Numerous effects of energetic particles and CR on technological systems, especially on satellites and airplanes have been reported. Among satellite anomalies the effects of plasma induced charging (external and internal), sputtering effects, surface erosion due to the oxidation, phantom commands, induced mode switching, loss of attitude control/orientation, loss of signal phase and amplitude lock, solar cell degradation and common electronic malfunctions are listed and discussed e.g. by [McKenna-Lawlor, 2008]. A complete review on the particle interaction and displacement damage in silicon devices operated in the radiation environment including (not only) the effects in space is e.g. in [Leroy and Rancoita, 2007].

The satellite anomalies were studied e.g. by [Dorman et al, 2005]. The authors found a clear difference between satellite anomaly probability and various physical characteristics of the interplanetary space, geomagnetic field and energetic particles of different energy and type. The table in their study indicates the differences especially for quiet and dangerous days in the values of proton flux and in its daily maximum for > 10 MeV. The same is valid for the high energy electron fluence. Relations between the occurrence of high and low-orbit satellite anomalies and the solar, interplanetary and geomagnetic activity as well as energetic particle fluxes is statistically studied on large data set (~ 5700 satellite anomalies) in papers [Belov et al., 2004; Iucci et al., 2005; 2006]. It is clear that the anomaly probability increases (especially for a high altitude, high inclination orbits) with energetic proton fluence. Also the importance of relativistic electron fluxes for the anomalies at geostationary orbits and at low-altitude (< 1500 km) high inclination ($> 55°$) orbits was indicated. The satellite anomalies vs CR activity indices were also studied in recent years. Earlier, various indices of CR activity (empirical) were introduced (e.g. [Kozlov and Tugolukov, 1992; Kudela and Langer, 1995; Belov et al., 1999]) among others). For several NMs the variability index is routinely produced. For example the CR index of Moscow neutron monitor station is available in real time at http://helios.izmiran.troitsk.ru/cosray/indices.htm.

[Dorman et al., 2005] found clear relationship of high altitude satellite anomalies and the increase of CR anisotropy index. Even a CR variability index constructed from a single high mountain middle latitude station with a high statistical acurracy (Alma-Ata) has the relation to the frequency of the satellite anomalies [Belov et al., 2005]. There are much more works done on satellite anomalies which are not included in the reference list. One of reviews of radiation field including galactic and solar cosmic rays beyond the low Earth orbit can be found e.g. in [Miroshnichenko, 2005] and more complete review of radiation hazard in space e.g. in [Miroshnichenko, 2001]. The predictions of radiation situation near Mars are described in

[McKenna-Lawlor et al., 2005]. One of the summaries of geophysical aspects of solar energetic particles is presented in paper [Miroshnichenko, 2008]. Models of solar energetic particle fluxes are recently discussed e.g. in the study [Nymmik, 2008]. For the construction of models and predictions of the satellite and space probe anomalies, the monitoring of energetic particle flux, its variability as well as the energy spectra and angular distribution is important to be provided systematically along with utilizing data from earlier experiments.

5.4 Cosmic rays and energetic particle influence on the atmosphere

When high energy particles strike the atmosphere, they produce a secondary population (and tertiary one in NMs) and change the ionisation and contribute to the dose at airplane altitudes and above. The longest data set of ionizing component of secondaries at different altitudes has been collected in FIAN Moscow [Stozhkov et al., 2004]. While the ionization measured by Geiger counters has strong solar activity cycle variation at high altitudes, it is not the case for low latitudes [Bazilevskaya et al., 2009]. Figure 5.2 is showing the discrepancy.

There is an excess of charged particle fluxes in the lower atmosphere (below ~ 630 g.cm^{-2}) over the expected from the calculation based on the primary CR and their transport. Further work is needed to estimate natural radioactivity contribution and the role of atmospheric processes in the dynamics of charged particle fluxes.

There are now developed the methods for estimates of ionisation and dose in the atmosphere at different depths due to CR [Bütikofer & Flückiger, 2009] working in near-real time. Dosimetric measurements on the airplanes during the solar flare flight show the increase at middle-high latitudes (e.g. [Spurný & Dachev, 2001]). The FD indicates the decrease of the dose at middle latitudes [Spurný et al., 2004]. If the GLE occurs during the strong FD, the ionization exceeds the monthly mean value only at a very low cut-off position and at high altitudes [Usoskin et al., 2009].

The atmospheric electricity is linked to the CR from the very beginning. [Siingh et al., 2007; 2009] review the global electric circuit (GEC) research and critically examine and discuss the role of aerosols and CRs in controlling GEC and linkage between climate, solar-terrestrial relationship and GEC. There are several papers relating CR and lightning processes. [Khaerdinov & Lidvansky, 2005] observed enhancement of soft component of secondary CR by the air shower array Baksan. An interpretation of the event is given in the context of a possible scenario of the involvement of CR into the dynamics of the thunderstorm atmosphere. The feedback cycling acceleration of charged particles in the thundercloud electric field is a key process in this scenario.

Discussions on relation between CR and a low cloud coverage (LCC) started probably in late 1990s when [Svensmark and Friis-Christensen, 1997] have shown a very nice correlation between the two time series. [Wolfendale & Sloan, 2008] investigated the relation between CR and LCC and indicated that the correlation is most easily explained in terms of the CR being a proxy indicator of solar irradiance. The importance of that issue motivated the continuation of the discussion. E.g. papers [Erlykin et al., 2009a,b,c] provide a detailed analysis of that relations, searched the generation by different ionizing agents, and do not find support for the CR hypothesis for the cloud modulation. More tests of the causal connectivity is needed.

[Elsner & Kavlakov, 2001] found significant positive correlation between the averaged Kp index of geomagnetic activity and hurricane intensity as measured by maximum sustained wind speed. The results are consistent with a mechanism whereby ionization processes trigger glacia-

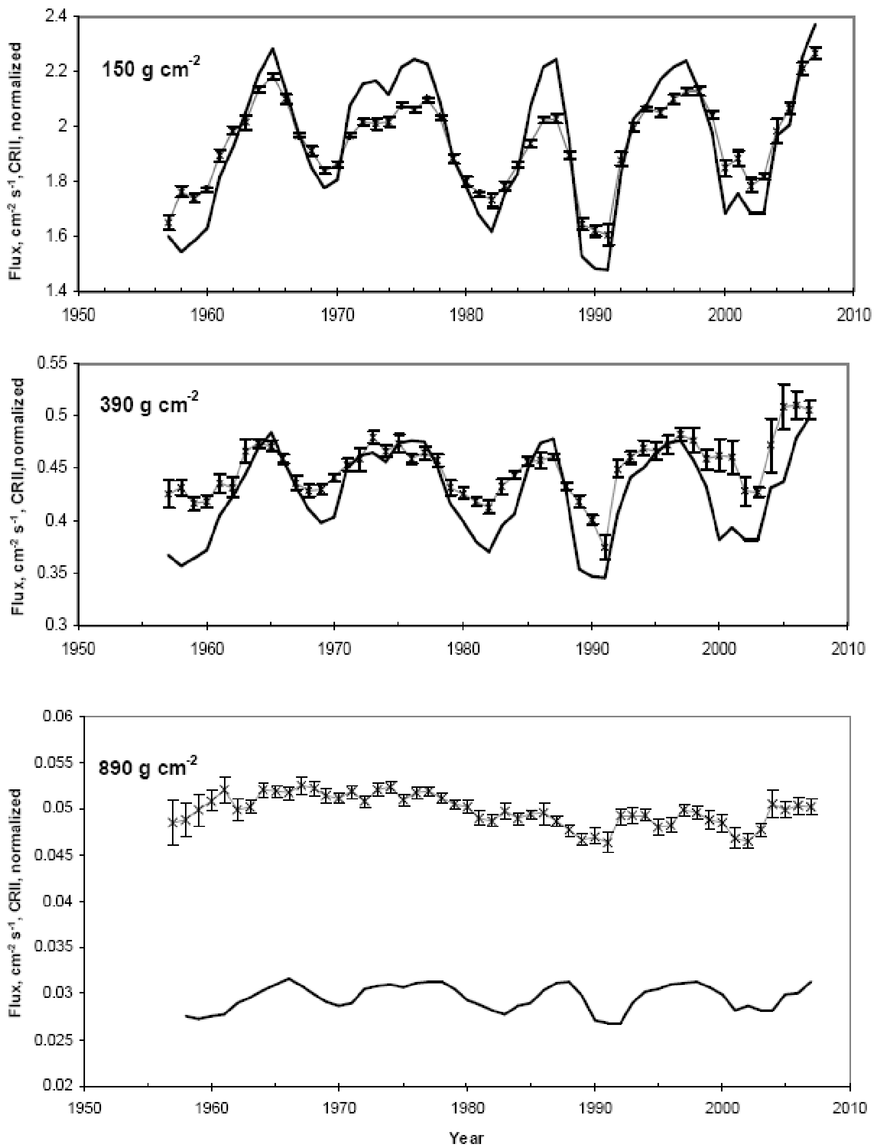

Fig. 5.2. (from [Bazilevskaya et al., 2009]). Variations of measured (crosses) and calculated (lines) of the ionization rates at different altitudes. Courtesy of G.A. Bazilevskaya.

tion at cloud top which leads to hurricane intensification through tropospheric upper latent heat release. More recent papers discuss the relation between the CR, geomagnetic activity and hurricanes [Kavlakov, 2005; Kavlakov et al., 2008; Perez-Peraza et al., 2008; Mendoza & Pazos, 2009]. This subject remains interesting and more studies of the mechanisms substantiated that relation are needed.

CR and solar energetic particles affect the chemistry at upper/middle atmosphere (e.g. [Ondrášková et al., 2008; Damiani et al., 2007]). [Damiani et al., 2006] found two weak and short (< 12 h) ozone depletions at outer boundary of polar cap in connection with January 2005 GLE. For mesospheric ozone decrease a N-S asymmetry was found (decrease weaker in southern regions).

5.5 Relations of CR to the biological objects (?)

There is at least one clear impact of CR and energetic particles in space on humans – radiation dose. At the Earth surface in middle latitudes the dose from CR is $< 10\%$ of the total value. With the altitude the dose increases by the factor of 10^3 (from sea level to ~ 25 km), with latitude on the ground the factor is ~ 2 with higher values near the pole, and with solar cycle the value is similar [Shea & Smart, 2000b]. The human exposure in space as it depends on flight trajectory, date, duration and the cyclogram of astronaut's activities is analyzed in various situation by [Petrov, 1994]. [Spurný & Dachev, 2009] are stressing the results of radiation exposure on humans in three directions, namely on the simultaneous research of galactic CR on aircraft and ISS; on neutron contribution to ISS dose; and on complex analysis of long term measurements on some airplanes. Planetary explorations with manned missions require good knowledge of the radiation to which humans will be exposed. [Hellweg & Baumstark-Khan, 2007] describe present-day estimates of equivalent doses from galactic CR and SEP radiation behind various shields and radiation risks for astronauts on a mission to Mars. [Benton & Benton, 2001] review sources and composition of the space radiation environment in LEO (low Earth orbit) as well as beyond the Earth's magnetosphere. [Wilson et al., 2004] studied mission scenarios of energetic particle exposures outside the magnetosphere screening.

There may be another link between the status of biological objects and variable CRs, namely chronobiology and CR variability. In CR time series there are many quasi-periodicities with their variable contribution to the signal over long time interval of CR observations. Quasi-periodicities $T > 27$ days up to ~ 115 days in CR are described e.g. in papers [Caballero & Valdés-Galicia 2001; Mavromichalaki et al., 2003]. Long-term evolution of low frequency in CR is described e.g. by [Kudela et al., 2002a]. The occcurrence in mid-term periodicities in the solar wind, geomagnetic activity and CR was studied e.g. in paper [Mursula, 1999]. Different periodicities in the range 4-47 months in several solar indices and CR were reported by [Kane, 2005]. Fluctuations of solar magnetic flux at ~ 1.3 y and ~ 1.7 y with the alternating importance during even and odd solar cycles were found in study [Valdés-Galicia et al., 2005]. The periodicity ~ 1.7 y was first reported in CR time series in the paper [Valdés-Galicia et al., 1996]. Such quasiperiodicity is also the dominant fluctuation in the solar magnetic flux [Mendoza et al., 2006]. A similar quasi-periodicity is recently reported also in the solar motion due to inner planets [Charvátová, 2007]. It is of some interest to check the similarities in quasiperiodicities of CR time series with those reported in chronobiology. The progress in chronobiology reviewed in [Halberg et al., 2006] mentions some relations to the studies of periodicities in CR. According to [Halberg, personnal communication] only at one frequency there is congruence of studied variables in a healthy man over 4 decades with solar, geomagnetic and CR frequency and it is the period of ~ 1.7 year.

An alignment of various data on health (epidemiological, physiological etc) with variations of

CR, geomagnetic activity and atmospheric pressure suggests the possibility of links among these environmental variations and health risks, such as myocardial infarctions and ischemic strokes, among others [Cornelissen et al., 2002]. In the study of relations between car accident events and CR, solar and geomagnetic activities the indications on such relation to outer conditions, especially around the epoch of the solar minimum was reported [Alania et al., 2004]. [Dzvoník et al., 2006] found significant differences in some parameters of mental performance and health of aviation personnel during the solar minimum and solar maximum epochs. Most of these type of studies are empirical (statistical) and require more deep analysis.

There are also some interesting results reported on CR relation to health problems. [Stoupel et al., 2005a] investigated the connection by time between suicide and homicide, between them and other fatalities, and their links with the level of cosmophysical activity. The temporal distribution of homicide and suicide is significantly interrelated. Both are linked to parameters of cosmophysical activity. The authors stress that the influence of cosmic rays deserves a special attention. [Stoupel et al., 2005b] report on basis of their statistical study that cosmophysical factors inversely related to solar activity play a role in the pathogenesis of chromosome aberrations should be considered. The authors report a strong trend towards an association between the cosmic ray activity level and the incidence of DS (Down syndrome). Most of these type of studies are empirical (statistical). The processes involved depend on many parameters, and both the clear causality as well as the mechanisms behind are not completely and satisfactorily clarified yet.

6 Concluding remarks

Beginning from the cosmic ray discovery by Victor Hess almost a century ago, the energetic particles in space have been subject of study from various aspects. Cosmic ray physics and space physics enriched the knowledge in elementary particle physics, nuclear physics and plasma physics. The influence has been mutual. Additionally to astronomy and related sciences which are most usually dealing with the photons from space, CR provide another channel of information on specific processes in the universe. Contrary to photons the energetic (charged) particles include the information about the magnetic and electric fields as well as about the material through which they propagated from the site(s) of origin to the detector. In recent years the relations of energetic particles to environmental processes and especially to space weather became important. This is an attempt to review the knowledge on the subject of energetic particles in space. However it is based only on *selected* papers and presentations and thus it is not completely covering the wide scope of physical interests to particles accelerated above the atmosphere.

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