Chapter 5

DEPARTMENT OF SPACE PHYSICS

5.1 STAFF

5.1.1 Scientific staff

Anna Antalová, Ján Baláž, Ladislav Just, Karel Kudela (Head of Department), Marián Slivka

5.1.2 PhD students

Pavol Bobik (PF UPJŠ), Radoslav Bučík (TU Zvolen)

5.1.3 Technical staff

Vladimír Kollár, Igor Strhársky, Ronald Langer, Jana Štetiarová, Samuel Štefánik, Anna Tomičová

5.2 SCIENTIFIC ACTIVITIES

5.2.1 Introduction

The department of Space Physics is one of the oldest departments of the Institute: its first participation in the research of energetic particles on satellite was 30 years ago (on August 7, 1970 a low altitude satellite, Intercosmos-3). The current research of the department is oriented to the experimental study of energetic particles in space. Along with the cosmic ray (CR) studies related mainly to the ground based measurements, the experimental studies of medium energy particles on the satelli tes are continuing. The two types of studies are devoted mainly to obtain the relevant information on the physical processes within the Earth's magnetosphere and in the heliosphere: those in which the energetic particles are either directly involved or those on which the particles provide a remote characteristics. In addition, the passive dosimetric studies on the orbital station and the heavy nuclei interactions are in progress.

5.2.2 Projects

in the frame of project Štefánik:

SK1 *Principal investigator*: L. Just

Projects of Slovak Scientific Grant Agency VEGA:

2/5137 Energetic particles in space: dynamics of magnetospheric and heliospheric fluxes.
Principal investigator: K. Kudela

NATO Collaborative Research Grant:

972312 Interball/ISTP Cooperation: A Comprehensive Project
Co-directors: D.G. Sibeck, K. Kudela

The staff is participating also in other projects (including VEGA) lead by other institutions.

5.3 RESULTS

5.3.1 Cosmic ray dynamics at neutron monitor energies and above

Neutron monitor 8-NM-64 with relatively high statistical accuracy of measurements (1.7×10^6 counts per hour) is in operation since December 1981 at Lomnický Štít (2634 m altitude, cutoff rigidity approx. 4 GV). The data collection, barometric pressure correction, archiving, continuous ',in situ'' checking of the measurements and upgrading of electronics is now routinely done by the group of technicians in High Tatras (V. Kollár, R. Langer, S. Štefánik and partially also by I. Strhársky). The plot of daily averages of count rate for the period 1982-1999 is shown in Fig. 5.1.

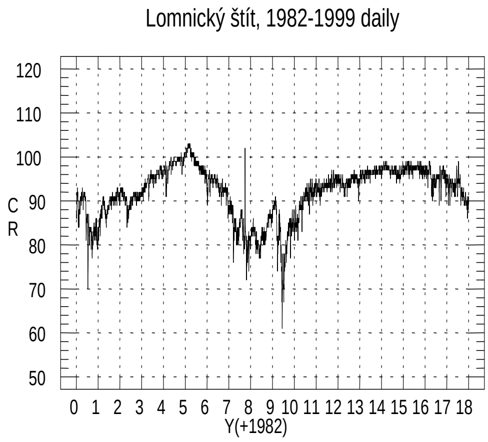

Figure 5.1: *The plot of daily averages of Lomnický Štít neutron monitor count rate (in per cents, 100% is adjusted to the monthly average of September 1986). The profiles of CR maxima in the subsequent solar cycles around solar activity minima with different solar magnetic field polarity is apparent. While in 1986-1987 relatively sharp peak is seen, in 1998 more flat one is observed. The difference is supporting the importance of drift motions of CRs at the rigidities > 4 GV. The largest inc rease observed at Lomnický Štít due to solar CRs is seen in 1989 (September 29). Very strong interplanetary and geomagnetic activity lead to complicated structure of decreases in 1991.*

The data of NM Lomnický Štít with the resolution 1 min, 5 min and hourly one are now put on the server ultra.upjs.sk with one day delay. The plots jointly with those of Yakutsk neutron monitor can be found at http: //teor.ysn.ru/rswi/18nm64-yakutsk-lomnitsky.html. The data are used for computations of CR scintillation index applied for the experimental runs of the forecasts of space weather events. From October 2000 the testing of the real-time access to 1 min data of NM Lomnický Štít is in operation for purposes of checking the fast increases at the onsets of ground level events (GLE) at several stations simultaneously assuming possible strong anisotropy of GLE. The starting time of the increases could be used, if in the operative form, for the alert of high flux of solar particles (largest damage to exposed electronics, materials and human cells in space and at high altitudes (aircraft) are usually due to the enormous flux of particles of units to hundres of MeV energy which appear later after the onset of GLE by relativistic particles).

The new registration electronic unit unifying the records of different types of measurements at NM Lomnický Štít designed and constructed by I. Strhársky is now in the testing phase. Along with the recording of CR (each tube separately), housekeeping, pressure, temperature and other data defining the conditions of measurement, the device NEUMON allows to change the mode of the measurement also remotely.

Problems of studying relations of CRs to space weather continued. The indices of CR activity even from a single station, reflecting strong changes of CR anisotropy on the time scales of 1 day were examined. A review of the problematics including the crosscorrelations of CR variability and Dst variations was presented. A simple wavelet method was used to determine the temporal variability of 27 and 155 day CR variability over long time. The result confirmed the lack of the first periodicity during Gnevyshev gap intervals and similarity of presence of the second periodicity for intervals when it is observed in interplanetary magnetic field. The correlation dimension of underground muon time series was estimated with use removing the background noise by means of wavelet expansion. A periodicity of 2.53 hours in time series of muon records was described over two solar cycles. The decreasing phase of the solar cycles and its behaviour in even-odd cycles (A) as well as the dual peak behaviour of solar activity separated by the Gnevyshev gap (B) were studied. In (A) the differences in the long-term behaviour of the Sun reflects the variability of the distribution of magnetic fields during a complete heliomagnetic cycle (around 22 years). The remarkable difference was found during the descending activity phases of the last three cycles: the 20th and 22nd (even numbered cycle s) and the 21st cycle (odd-numbered). The even-odd activity cycle differences were found in the CR/XBG-L relation. During the descending phase of the 21-st cycle, the residual data subsets give statistically significant cross-correlation values. It implies that during the period July 1981–June 1986 (no. 21) the CR/XBG-L relation is partly determined by the short-term fluctuations, what is not true for the period July 1973–June 1978 (no. 20). The cross-correlation functions (ccf-s) were estimated on daily basis for each yearly sequence separately, in 1969 - 1987 or 1969 - 1997 interval. The main task of our papers is further clarification of the short–term relation of the low–rigidity CR to the large scale solar magnetic field distribution. The proxy data of the evolution of the large scale magnetic–structures of the Sun during the solar cycle, is taken the daily global soft X-ray flux of the non–flaring solar corona (i.e., the solar soft X-ray background) and its logarithmic transform (XBG–L). Using the 12-month basic, detrended, the running mean and the residual sequences, the crosscorrelation functions were computed with a time lag ranging from - 2 to + 60 days. The sequences helped to identify fluctuations on different time scales. The different decay phases of the 20–th, the 21–st, and the 22–nd cycles were revealed in the synodic recurrence of the CRs. Using the method of the autocorrelation analysis the successive yearly sequences of CRs from 1969 till 1996 were studied. The synodic recurrency of CRs was found in 1976, 1977 years (no. 20) and also in 1992, 1993, 1996 years (no. 22). As is well known, the synodic recurrence of the CRs is indicator of quasi–stable heliospheric conditions, which was not valid in decay phase of the 21–st cycle. It was shown that the 21–st solar cycle is unique in the density of the occurrence of 150-day periodicity in all solar parameters. The 154-day periodicity is located mainly during the decay phase of the 21–st cycle.

The dual peaks separated with the Gnevyshev gap coincide with magnetic reversal of the Sun. The study of the distribution of the green corona line intensity and the soft X–ray solar activity parameters, confirmed the double–peaked character of the last three solar cycles. The similar structure was found in the heliomagnetic field. Wavelet transform has been used for the time–frequency decomposition of solar data series through the last three solar cycles (the 20-th, the 21-st and the 22-nd), on daily basis. In the maximum epoch of the last three solar cycles, there are multi-frequency dual peaks. Time location of wavelet power spectra impulses coincide with pre– and post– maximum years. It is very likely, that obtained impulsive episodes indicate those time intervals, in which the continuing eruption of the new solar magnetic flux existed.

The structure of the 11-year cycle depends on intermediate-term variations of the Sun. Our knowledge of intermediate–term periodicities is mainly based on the analysis of the solar soft X-ray data. The intermittent character of 27–day and 150–day periodicity during the maximum of the 21–st cycle was presented in CRs.

What concerns of the quasi–biennial period, which is generally but erroneously believed that is better expressed in the even than in the odd cycles, we obtained: (i) in solar magnetic data the occurrence of the quasi–biennial period is remarkable high during the 21–st cycle (2.4–year),(ii) The occurrence of soft X–ray flares is not related to the 21–st cycle, but to the 22-nd solar cycle maximum (LDE –2.3 year, IMP–2.2 year). This is very important difference between the 21–st and the 22–nd cycles. The expected the 1.7 year (647–days) period of the CRs is found in the 21–st cycle: the 1983.5 peak in CR. In the 22–nd cycle, the CR–peak is present in 1991; but its dominant periods are 400– and 800–days.

The detailed computations of CR trajectories in the geomagnetic field were done. The model includes both the internal and external sources of the field. The software for numerical integration of the equation of particle motion has been developed. Figure 5.2 shows the influence of the external field and the level of geomagnetic activity on the transparency of magnetosphere for CR accessing Lomnický Štít station.

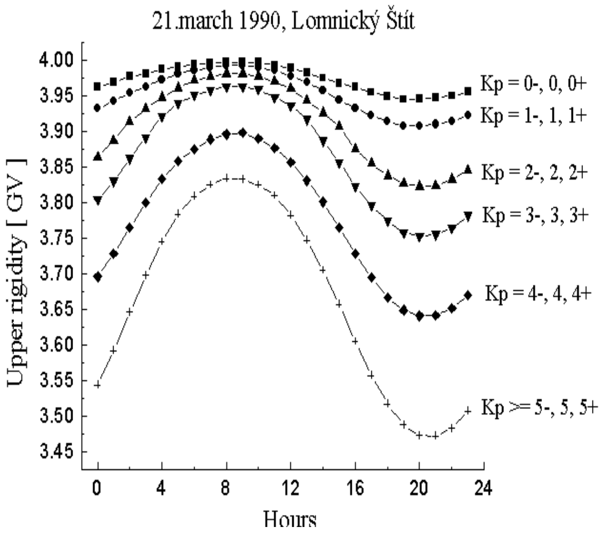

Figure 5.2: *The upper cutoff rigidity (the highest rigidity transition between the forbidden and allowed trajectories) dependence on the local time and on geomagnetic activity index Kp. Tsyganenko'89 model of the field is used. Using only the internal field (IGFR or DGRF) no local time variation is seen. The assymetry of the magnetosphere affects the access of CR particles near the cutoff. While at 8-9 LT the cutoff rigidities have highest values and are less variable with the level of geomagnetic activity, the most significant depression of cutoffs and highest variability with the activity level is expected at 20-21 LT. Here the vertically incident particles are assumed.*

The computations of trajectories revealed the value of the effects of local time, geomagnetic activity level, the epoch and obliquely incident particles. First results indicating the influence of residual atmosphere, especially at high latitudes, were obtained. The code can be used also for the transparency computations above the atmosphere. Figure 5.3 is presenting a map of cutoff rigidities for the ISS altitude.

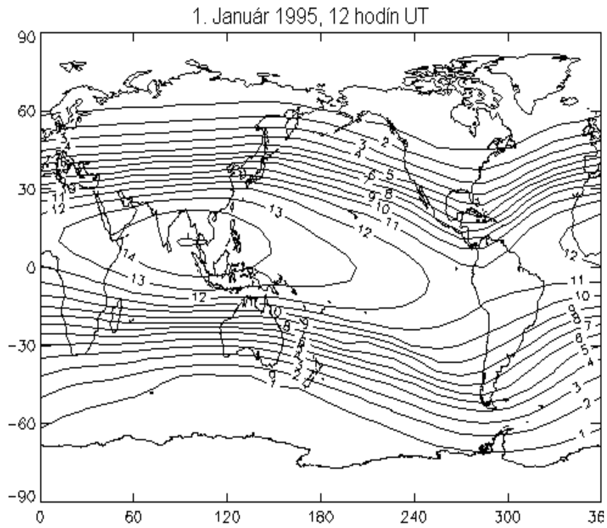

Figure 5.3: *The contours of cutoff rigidities at the altitude 450 km for undisturbed magnetosphere and a specific epoch. The lines, labelled by effective cutoff in GV are obtained from a grid* $15^\circ \times 5^\circ$ *(long x lat)*

[6-8, 11-16, 25, 26, 37, 39, 40, 52, 53,-58, 66, 67]

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5.3.2 Medium energy particles within the magnetosphere and near its boundaries

Large amount of data - measurements of ions and electrons in the energy range 20 - 600 keV on the satellites Interball-1 (August 1995 - October 2000) and 2 (August 1996 - January 1999) by DOK2 instruments and on subsatellites Magion 4 and 5 by DOKS instruments required the adequate effort in data processing and graphical works. Along with the basic data processing the review files with the detailed energy spectra on daily basis and the temporal profiles at selected energies have been prepared for comparative both for statistical and comparative types of studies (DOK2). Similar works are in progress for DOKS measurements (done by J. Štetiarová).

Two types of studies were done in the years 1999-2000: (A) statistical and (B) case ones. Large amount of data and good coverage (in local time, distance from the bow shock and from the magnetosheath, in periods of different interplanetary and geomagnetic activity conditions) provided extensive material for (A) type studies. In the region upstream from the bow shock both mechanisms theoretically predicted for the origin of medium energy ion population, namely the Fermi acceleration at the bow shock as well as leakage of magnetospheric particles are indicated in the data sets of DOK2. The dependence of the 2-min average fluxes of ions on the geometry to bow shock is becoming less pronounced with the increase of energy. While at 20-30 keV there is a clear difference in the distribution of fluxes for quasiparallel and quasiperpendicular model shocks (with the higher flux for the first cases which is consistent with the acceleration at the bow shock), this type of difference is negligible for energies above 200 keV with the exception of specific cases. On the other hand, especially within the magnetosheath, the fluxes are generally higher at higher level of geomagnetic activity measured by Kp index, which is consistent with the expectations of magnetospheric ions being the source population.

Two specific new features were observed with high resolution spectrometric measurements of DOK2: (i) they were observed, for the first time, almost monoenergetic fluxes of ions both in the magnetoaheath and in the region upstream from the bow shock. More than 200 cases with duration from few tens of seconds to few minutes with narrow peaks in the spectra (FWHM of 15-30%) , most probably corresponding to protons, helium and C,N,O group of ions were observed on Interball-1. Their origin is still not explained. As a working hypotheses it was proposed the acceleration of solar wind ions in a burst of a strong, perpendicular electrostatic field. The specific bow shock acceleration is also not yet excluded. (ii) The very detailed energy spectra in medium energies (56 quasilogarithmically distributed energy channels in the range approx. 20 - 600 keV) allow to study the dispersive events, as it shows example of Figure 5.4.

The particles, if injected within a short time which is the usual case of substorm injection of accelerated particles in the night side magnetosphere, will undergo the curvature and gradient B drift during their motion which yields into temporal "sorting" according to their rigidity if observed in another local time sector. Many of the events observed have a temporal profile which can be well fitted by 1/E expected in simplified conditions for azimuthal drift period. Thus from the profiles, both injection time and position (in local time) can be derived. This may be useful for comparative studies of two or more satellites having different local time positions as well as with the auroral images covering large extent of local times and latitudes. Until now about 300 events of this type on both Interball-1 and 2 were found and first statistical review of their occurence has been prepared.

The data from DOKS on Magion 4 were used in the study of magnetopause motion driven by interplanetary magnetic field variations, along with the

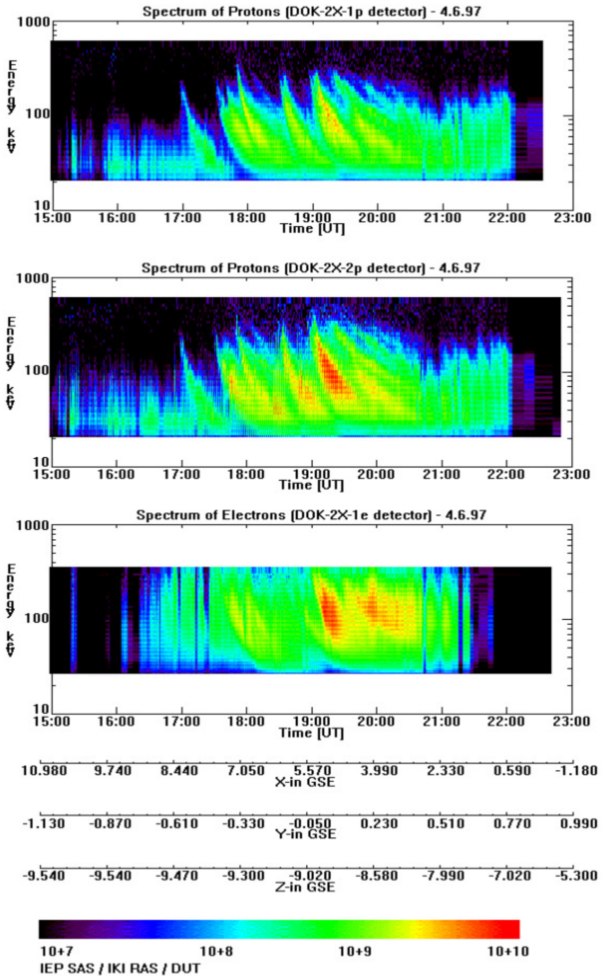

Figure 5.4: *The series of dispersive events of both ions and electrons observed in the outer magnetosphere. The values plotted are differential flux (in units* $(keV.s.ster)^{-1}$ *multplied by* E^4*, where E is kinetic energy of the species in keV)*

Interball-1, GOES-8 and 9. The analysis of the energetic particle event on May 4, 1998 when particles were probably locally accelerated at the bow shock to unusual energies of 600 keV on Interball-1 and Polar satellite are in progress. The comparative studies using also data from DOK2 on Interball-1 and 2 along with magnetic field on the same satellites, plasma distribution function on satellite Geotail and ground based observations indicated the place where that time dispersed ion structures are formed.

The simultaneous study of a radar measurement with the plasma and flux of precipitating energetic particleas measured by SPE1 device on Active satellite passing the region above the radar site was used to deduce fine structures of electron density and temperature.

Measurements of gamma rays by the device SONG on CORONAS-I during four months in 1994 when the satellite was in operation were used for obtaining the detailed geographic maps of distribution of the flux (Fig. 5.5). The temporal variability at $L > 3$ is seen in the data which can be used in updating the existing trapped population models and finding the correlations with electron flux being variable during geomagnetic disturbances during the time period of measurements. It was shown that the high energy protons observed by SONG instrument can be used in the Forbush effect studies using the advantage of single detector scanning the variability of primary CR flux at various latitudes during one orbit. The comparison with ground based neutron monitor data was done for two cases. The latitudinal anisotropy was deduced from these comparisons.

Development of the electronic part of SONG device for CORONAS F and preparing for the launch of the satellite (expected in 2001) required several technical changes. The works related to the tests and characteristics of particle devices, the development of testing device PPS-1 (Programmable PhotoStimulator) are in progress.

Along with these the works on two new projects have begun: (a) for ROSETTA the technical documentation and realization of the flight as well as the spare model of ESS Processor for the data connection between Lander and Orbiter, and (b) for Double Star the design of Neutral Atom Imager in the collaboration of Chinese Academy of Sciences, STIL Ireland and IRF Kiruna Sweden. These are important part of the joint works started with STIL Maynooth, Ireland in 2000.

[9, 10, 17-24, 33-38, 41-51, 59-64]

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5.3.3 Fragmentation of nuclei in nuclear emulsion. Passive detection of cosmic rays

Relativistic Heavy Ion Collisions offers the opportunity to study nuclear matter in extreme conditions of density and temperature. The Equation State of Nuclear matter is of fundamental importance, both for Nuclear Physics and Astrophysics. On the other hand, relativistic heavy ion collisions present a great interest in the field of Radiobiology, Medicine and Space, since Relativistic heavy ions undergo in matter both electromagnetic interactions, with the well known characteristics of high LET particles, and nuclear interactions which result principally in the fragmentation of the projectile and target nuclei. Fragmentation reactions correspond to the complete destruction of the projectile/target system, and results

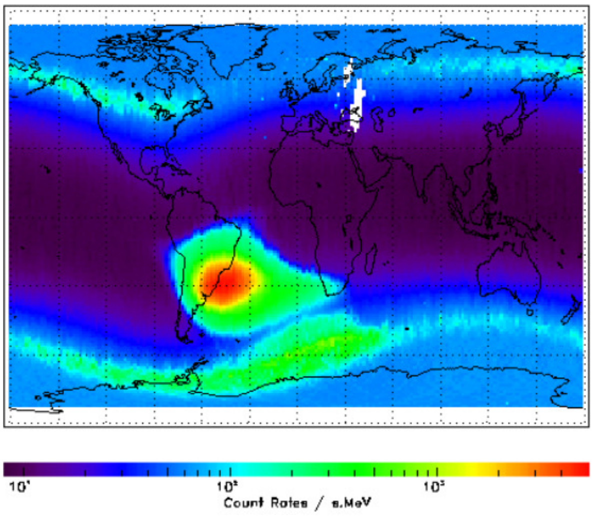

Figure 5.5: *The map of average flux of gamma rays in the energy range 3.0-8.3 MeV according to SONG measurements on CORONAS-I. Altogether* 1.8×10^6 *measurements with 2.5 sec resolution have been used and sorted into pixels of* 1° *in latitude* $\times 2^\circ$ *in longitude. Two components of gamma rays are indicated: (1) the Earth's albedo due to interactions of primary CRs with residual atmosphere and upward flowing of its part - showing the increase with the latitude copying the flux of primaries f iltered by Earth's magnetic field, and (2) bremsstrahlung origin due to locally trapped high energy electrons indicating different energy spectra in different regions of (L,B) space.*

in a modification of structure of the incident beam. Furthermore, it appears that most of the nuclear collisions are peripheral ones, and that the fragmentation of the projectile remnant is the most important component. Finally, fragmentation reactions of fast heavy ions occur during the long space manned missions, due to the interactions of CRs(C, N, O, Fe nuclei) with the matter of spacecrafts and with the body of astronauts. The very poor information about fragmentation cross sections for these light nuclei make difficult the precise evaluation of radiation risks for the crews. So it appears that measurements of fragmentation cross sections of nuclei on various targets are fundamental importance for space applications.

The complete charge distribution of products from Au nuclei fragmenting in nuclear emulsion at 10,7A GeV has been measured. The average multiplicities of the fast - moving projectile particle such as $< N_{He} >$, $< N_F >$, $< N_p >$ seem to depend upon the mass of the target. The majority of the multiply charged fragments are He nuclei, while the majority of those fragments with $Z \geq 3$ are light. The multifragment emission is a dominant reaction channel as observed when the distribution of $< N_H >$, $< N_{IMF} >$ are represented as function of Z_{bound}. These distributions are peaked at $Z_{bound} \approx 35 - 40$ and shows slight dependence on the target mass. We have observed the expected U-shaped charge distribution in the breakup of Au nuclei in collisions with emulsion nuclei at 10,7A GeV. The $N \sim Z^t$ power law is however not very selective and the value of t depends strongly on the Z interval for the fit. The investigation of ^{84}Kr induced interactions has been made using emulsion detector. The presence of general signatures of collective flow effects in ^{84}Kr + Ag(Br) collisions at 0,95A GeV were found. The bounce-off effect of projectile spectator fragments was observed, which allowed us to determine the reaction plane with accuracy $\sigma \sim 23.1^\circ$. Significant squeeze-out was observed for relativistic particles with $\eta \approx \eta_{CM}$. Side-splash was observed in azimuthal distributions of both relativistic particles at $\eta > \eta_{CM}$ and fast target fragments. Fe-, Kr- and Xe- induced heavy-ion reactions at ∼1A GeV show factorization in the production cross-sections only for light fragments. Both "strong" and "weak" factorization are found for light fragments. We confront our results on fragmentation cross-sections with the prescription of cold breakup of spectator residues. This model describes the fragmentation as a two-step process. In the first stage, participant nucleons form a "fireball", and spectator matter remains cold. In the second stage the fireball decays and some participant nucleons penetrate the cold spectator matter where they deposit energy momentum. This makes the spectator pieces unstable and they decay promptly into fragments following a statistical description. The angular distribution of projectile-associated He fragment from S induced reactions on nuclei in nuclear emulsion at 3,7 and 200 A GeV has been studied. Two emission components are appearing in the projected angular spectra of the He particles.

Project SK-1 of Štefánik expedition. *Monitoring of Cosmic Ray LET-spectra.*

Cosmic Rays (CR) have the influence on damage of material structure in the case when materials are exposed by CR either in the free space or below the shielding material. In last years considerable attention has attrated to the problem of description and understanding of complex radiation environment in low Earth orbits. Detailed knowledgies about influencies of this environment on various spacecraft shielding are necessary to minimise a risk due to radiation exposure. The aim of SK-1 project is the monitoring of energetic particles of CR by using of several different measurement methods. Scientific tasks of the SK-1 project are: measurement of CR LET-spectra of charged particles in the variable conditions in the space; study of fragmentation parameter nuclei of CR in shielding material; study of charge states and energy spectra of low energy CR nuclei ($E < 100$ MeV, $Z > 2$), which are mainly responsible for radiation damage of biological objects and electronic elements and components.

Preliminary results of the observations indicate about 84.5 particles/cm^2 in the first layer of our detectors. Their charge and energy are not determined yet. The mean value of $< LET >$ spectra measured by our detectors during Štefánik mission is <LET>=3,3 $\pm 10\% MeV/\mu m$, what is lower than a value measured in 1991 (<LET>=4,8 $\pm 10\% MeV/\mu m$).

This probably indicates increase of the number of nuclei with small charge into the MIR station. There are big difference between model's calculations and experimental values. Both types of studies the methodical works were performed by A. Tomičová.

Figure 5.6: *The stacks of passive detectors of CRs exposed on MIR station during the mission of the Slovak astronaut I. Bella in February 1999.*

[1-5, 27-32, 65]

L. Just

5.4 SELECTED PAPERS AND PRESENTATIONS

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The results shortly described here have been obtained in the wide international collaborations with laboratories in many countries.

Collected by K. Kudela and M. Slivka.