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Space physics in Košice:

History, present status, and benefit of EU funds for the future

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Abstract. Participation of Department of Space Physics (DSP) IEP SAS in Košice in the "Centre of Space Research: Space Weather Influences" established with the support of funds of EU in the frame of Operational program Research and Development, project ITM 26220120009, was motivated by the tendency to provide its dynamical development in the future. This effort is substantiated by the results obtained by the DSP during more than 40 years of study of cosmic energetic particles using ground-based and satellite measurements. We introduce shortly selected activities of the DSP related to the project.

Key words: space physics – energetic particles in space

1. Introduction

The IEP SAS in Košice through the DSP has participated over more than 40 years in the research of energetic particles in space via measurements on ground and in space. Cosmophysical research in the IEP SAS is oriented oneself on (i) ground-based measurements of secondary cosmic rays (CR, Lomnický Štít) and its analysis, and on (ii) studying the physical processes in outer space from where the information is "transmitted" by lower energy particles (space devices). More detailed information at http://space.saske.sk .

Financial support which the IEP SAS obtained from the funds of EU, is at present important incitement to participation in new space and ground-based experiments, and to the physical analysis in space physics.

2. CR measurement on the ground

Measurements take place in the high altitude mountain laboratory of the DSP Lomnický Štít (LS) via the neutron monitor (NM). First CR measurements in High Tatra mountains were done in 1958 during the International Geophysical Year. Since that time the NM has gone through many changes. Since the last time reconstruction in December 1981 there has been in operation a neutron monitor 8-NM-64 with high statistical accuracy (1.6 x 10^6 particles/hour). Presently there are available data with 1 min resolution in real time http://neutronmonitor.ta3.sk). The NM at LS is a "component" of the worldwide network. In the past years it became a constituent of the network of the European NMs in the frame of 7FP EU, project with the acronym NMDB (Neutron Monitor Data Base, http://www.nmdb.eu). More details about the measurements at LS can be found in Kudela and Langer (2009). The changes and extensions of the ground-based measurements due to the ITM project are discussed in Langer *et al.* (2011).

One of the most important measurement results at LS was the observation of solar neutrons during the solar flare on June 3, 1982, when along with the NM at Jungfraujoch the response of solar neutrons on the ground was detected for the first time. A couple of other results are shortly mentioned in references of the paper by Kudela and Langer (2009).

3. Satellite measurements of energetic particles

In the 1970s development of devices for satellite measurements of energetic particles also started in Košice. Prof. Juraj Dubinský, director and head of the CR department at that time, connected the IEP SAS into the program Intercosmos. The activities of the DSP can be divided into three directions, namely (i) research of high energy neutral emissions; (ii) exploration of nuclear-physics aspect of CR using passive detectors, and (iii) research of variability of fluxes of energetic particles with middle energies. A change of the orientation, mainly on cosmic particles of lower energies than the typical CR and higher than solar wind plasma, lead after 1980 in the transition of the name of the Department to the DSP. An important component of the DSP activities in space experiments was the development of its electronical parts. A review on electronics for cosmophysical research until 1997 in Slovakia is given in Rojko (1997). Table 1 includes the list of experiments for space physics research up to now, in which the electronic and later detector parts have been developed in the DSP. More at http://space.saske.sk .

3.1. Neutrons and gamma rays

The first experiment for measurements of neutrons at high altitudes in the IEP SAS was the one on the balloon BANAN. In collaboration with the Physico-technical Institute in Leningrad (the former USSR) there was designed in Košice an electronic part of the experiment SK-1 which measured on satellite Intercosmos-17 launched in the former USSR in 1977 constructed. It was the first space experiment with an automatic recording of data and subsequent transmission to the Earth, which was constructed in Slovakia. Solar neutrons were not observed, however the measurements of albedo neutrons were successful.

After 1990 the DSP backtracked to neutrons and gamma rays in the near-Earth environment. This was done by measurements of the device SONG on the CORONAS-I (1994) and the CORONAS-F (2001 - 2005) in collaboration with

Table 1. The list of experiments for space physics research up to now, in which the electronic and later detector parts have been developed in the DSP. (*Devices constructed at Charles University, Prague. IEP SAS participated in a data analysis obtained.)

Acronym of the device	Satellite /rocket	Date of launch	Perigeum [km]	Apogeum [km]	i [^{o}]
PG-1*	IK-3	7.8.1970	206	1315	48.4
PG-1A*	IK-5	2.12.1971	196	1202	48.6
PG-1B*	IK-13	27.1.1975	278	1681	83.5
SK-1	IK-17	24.9.1977	466	511	83
DOK-T	PROGNOZ-8	20.9.1981	980	197390	65
URE-1	VERTICAL-10	21.12.1989	0	1510	raketa
DOK-1	INTERSHOCK	26.4.1985	421	200520	65
SPE-1	ACTIVE	28.9.1989	511	2487	82.6
DOK-S/1	ACTIVE/MAG 2	28.9.1989	511	2487	82.6
DOK-S/2	APEX/MAG 3	18.12.1991	440	3050	82.5
SONG-E	CORONAS-I	2.3.1994	500	500	83
DOK-2X	INTERBALL-T	3.8.1995	371	193000	65
DOK-S/3	IB-T/MAG-4	3.8.1995	371	193000	65
DOK-2A	INTERBALL-A	29.8.1996	7144	25502	62.8
DOK-S/4	IB-A/MAG-5	29.8.1996	7144	25502	62.8
SPE-1M	MIR	1996	324	352	51.6
SLED-2	MARS-96	16.11.1996	-	-	-
SPRUT-6	MIR	10.1998	324	352	51.6
SONG-M	CORONAS-F	30.7.2001	500	500	83
EPD	CESAR	?	400	1000	70
MEP-1	COMPASS	?	350	400	79
NUADU	TC-2/Double Star	25.7.2004	700	39000	90
PEEL	HotPay2	31.1.2008	0	381	raketa

the Skobeltsyn Institute of Nuclear Physics, Moscow State University. Electronics for the SONG was developed in the IEP SAS.

The device SONG on-board the CORONAS-F observed outstanding fluxes of high energy solar gamma rays as well as neutrons during several solar flares. This is important information about proton acceleration in flares to high energies and it is helpful for identification of the time of acceleratin processes (Kuznetsov *et al.*, 2006; Kurt *et al.*, 2009).

3.2. Measurements of CR on recoverable satellites

The CR nuclei have been studied at the IEP SAS on recoverable satellites with use of passive detectors exposed in space since the satellite Intercosmos-6 in 1972 when nuclear emulsions were used. Later it was done on the satellites Kosmos as well as on the orbital station MIR. The aim was to study tracks of the primary

CR and its fragments in the detector. The last experiment of this series was as a single physical project during the mission of Slovak astronaut Ivan Bella on the MIR in February 1999. Basic data for satellites with passive detectors of the CR with the DSP participation is in Table 2. The work of Dr. Ladislav Just, PhD (14.9.1946 - 7.3.2005) was substantial for obtaining results in this type of studies.

Table 2. Basic data for satellites with passive detectors of the CR with the DSP participation

Satellite	Launch date	Duration [days]	per/apog	i[^{o}]	Exposed material (detectors)
IK-6	07.04.1972	4	210/250	51	emulsions
K-1129	25.09.1979	19	218/377	62,8	Kodak
K-1514	14.12.1983	5	226/288	82,4	K + CR 39
K-1667	10.07.1985	7	222/297	82,3	K + CR 39
K-1757	11.06.1986	15	189/252	82,3	4x Kodak
K-1781	17.09.1986	14	217/405	70,4	Kodak
K-2044	15.09.1989	14	216/294	82,3	Kodak
OS-MIR	24.06.1991	34	389/410	51,6	Kodak
MIR	20.2.1999	6	324/352	51,6	Kodak

3.3. Cosmic particles of middle energies

Charged cosmic energetic particles have been the main interest of the study in the DSP up to now. During the first years of the research there were mainly energetic electrons and protons with energy > 40 keV on low altitude satellites with help of devices with acronym PG developed at Charles University Prague (satellites Intercosmos-3, 5, 13) analyzed. At that time the dynamics of energetic particles trapped in the geomagnetic field pertained to the topical questions of space physics. The research was important also from the point of view of the radiation protection of astronauts.

After 1980 the Department's orientation changed into research of charged energetic cosmic particles of middle energies, namely from ~ 10 keV to few MeV. In that energy range from the very beginning of space era the remarkable spatial and temporal variability of particle fluxes was observed. It was of use for less financially ambitious techniques of particle detection. The energy interval (above solar wind plasma and below typical galactic CR) of particles studied was and still remains an interesting topic of the space plasma physics in the Earth's magnetosphere (as well as in the magnetospheres of other planets), near its boundary regions as well as in interplanetary space.

The orientation of the DSP mentioned above has been suitable for a relatively small group with limited financial sources. The use of devices of the type

DOK and SPE, designed and constructed at the IEP SAS, measuring the fluxes and energy spectra of electrons and protons in the range from 10 keV to 2 MeV by Si detectors, allowed the DSP to participate during 15 years in several space experiments with wide international collaboration (projects Intershock, Active, Apex, Interball). Data from the experiments have been used for the study of acceleration processes in various regions of the magnetosphere and in its surrounding; of the transport and losses of particles (e.g. in precipitation of the trapped particles, leakage through the boundary regions of magnetosphere) as well as for the studies of relations between particles and space weather.

The measurements in the project Interball ranked among the most successful experiments. There was a twin of satellites: one launched into the magnetospheric tail with apogee at 200000 km in 1995, the second one did it to the auroral region with a lower apogee. On both satellites the measurements by the DOK-2 devices running continuously for almost 5 years, with a temporal resolution of few seconds, in 52 energy channels, provided fluxes and energy spectra of protons and electrons from 10 keV to 2 MeV. The devices were developed in collaboration with the Space Research Institute Moscow and the Demokritos University, Xanthi (DU, Greece). A detailed data analysis allowed to obtain original results about the origin of particles in the vicinity of the Earth's bow shock and in various magnetospheric regions (e.g. Kudela *et al.*, 1992). Contribution of data from the two subsatellites (Magion-4 and 5) with simplified versions of the DOK-2 devices (DOK S) completed the analysis.

The project Interball helped in the enrichment of international collaboration after 1990. There was an interest to compare the Interball data with those measured simultaneously on US, European and Japanese satellites in other points of space near the Earth. In 1998 the DSP organized in Košice an international NATO Advanced Research Workshop with participation of scientists from various countries (Interball, 1999). The DSP was also the main organizing team of two European Cosmic Ray Symposia, namely in 1984 (9th ECRS) and in 2008 (21st ECRS) that substatntially contributed to the scientific cooperation of the DSP in the research of cosmic energetic particles.

After closure of the program Intercosmos the bilateral collaboration with its former participants in the laboratories of surrounding countries continued. The tendency went further towards participation in ESA projects. In cooperation with STIL Maynooth, Ireland (Prof. Susanne McKenna-Lawlor) the DSP takes part in the mission Double Star TC2 (ESA, China) via the experimental device NUADU (McKenna-Lawlor *et al.*, 2004). The device provides distribution of energetic neutral atoms created due to charge exchange in the geocorona and assists in displaying of the changes in plasma populations and related current systems during the geomagnetically disturbed periods. Some new results have been published e.g. in McKenna-Lawlor *et al.* (2010). On January 31, 2008 the rocket HotPay-2 was launched in northern Norway up to a height of 380 km. One of the devices working in the payload complex was PEEL measuring the precipitating electron fluxes (the device developed in DSP in collaboration with DU, Greece).

4. Future space experiments and their assuring

DSP has presently a preliminary agreement in several space experiments. During 2011 the launch of the satellite SPEKTR-R is expected including in the payload the monitor of energetic particles MEP-2 (for complex PLASMA-F see http://ilwsonline.org/china_russia.pdf) which extends the Interball measurements and contributes to the description of low fluxes of middle energy particles in interplanetary space. For the project RESONANCE the design of the particle experimental device DOR-R began. We assume possible participation of the devices in the project INTERHELIOS (measurements of solar neutrons and gamma rays). In the project BepiColombo (a probe to Mercury) DSP participates in the wide international collaboration in development of a mass ion spectrometer PICAM of the complex SERENA (http://www.ifsi-roma.inaf.it/serena/docs/SERENATEAM.pdf). We consider also participation in the projects SolarProbe and Cross-scale (details on the Cross-scale mission - http://www.cross-scale.org/Community.html).

Our experience in space physics research indicates fulfillment of several factors. A person (persons) with physical erudition involving the participation of the team in new space physics experiments as well as physical interpretation of data is needed. Further, the existence of a good technical basis eligible at the timely technological level to implement new scientific devices, assuming requirements of space projects. Last but not least, a factor is the state of the art data handling including the development of pre-experiment software, primary raw-data processing and its archiving in the form utilizable by a wider international scientific community. DSP has some activities in the frame of international programs ILWS (http://ilwsonline.org/ilws_organization.htm, http://ilwsonline.org/ilws_slovakia.pdf) and ISWI (http://stara.suh.sk/id/iswi/iswi_SK-en.htm).

Along with the human resources the space physics research requires a sufficient financial support. Without that it is impossible to buy the computing and instrumental technique, electronical components and detectors for space experiments, but also participation in various meetings, testings of the space devices, international conferences with the subject matters related to energetic particles in space. The sources, we are now drawing from, mainly from the Slovak grant agencies, are flexible and efficiently exploitable, but for building of the Centre of Space Research they are not sufficient. The possibility to draw the sources from the EU funds, is highly welcome by the DSP team, especially from the point of view of further evolution of the Department utilizing obtained experiences.

5. Centre of Space Research: Space Weather Influences

Energetic particles in space including the CR are important for understanding of space weather effects (e.g. Kudela *et al.*, 2000). The DSP participates in the Centre of Space Research: Space Weather Influences (CSR) as a partner place of work of the Astronomical Institute of SAS (leading Institute of CSR). Another partner place of work is P.J. Šafárik University, Košice. In the frame of the CSR and its specific aim 1: Build up of the basic infrastructure of the working places of the CSR, the DSP participates in the activity 1.2: Modernizing of the working places of DSP IEP SAS in Košice and at Lomnický štít (responsible K. Kudela). Three activities are included in that, namely 1.2.1 (Building of a Laboratory of Space Technique and Technology in Košice for development of satellite devices, resp. J. Baláž); 1.2.2 (Modernizing the ground based measurements of the CR at Lomnický štít and at a lower altitude, resp. R. Langer); and 1.2.3 (Building of a Space Physics Laboratory for the analysis of satellite and ground-based measurements of cosmic energetic particles and influences of space weather (resp. I. Strhárský). More scientists and other personnel of the DSP and other departments of the IEP SAS are involved in the above-mentioned activities.

Most of the financial sources gained by the IEP SAS in the frame of two phases of the project ITMS 26220120009 of the Operational Program Research and Development, are planned to be used for purchase of computing technique, for modernizing the the NM at LS as well as for improvement of the device accessories of the group in the DSP working in development of new scientific devices for experiments in space. The measurement devices, however, with the exception of the NM at LS, will work later in space and its scientific utilization is impossible presently unambigously define in time. It depends on the schedule of the space missions at which we plan to participate. The schedules of space missions are not fixed in many cases. That is why the temporal planning of scientific outputs from experiments is presenty difficult to estimate.

A peculiarity of our (DSP) participation in the project in comparison with the building of the laboratory of unique equipments, to which a lot of other centers of excellence utilizing support of EU funds are oriented, is especially in the activity 1.2.1 the fact that it is impossible to buy the ready devices for cosmophysical research which would operate directly in space missions. Specific demands put on space experiments require substantially better conditions for their technical design, development and testing than those which are at disposal now in the DSP. Only that affords the opportunity to participate directly in new space missions lead by space agencies in the world. More details about the design, development and qualification of the devices for space experiments in the DSP for future can be found in Baláž (2011).

In the scientific program of the DSP in the frame of the SCR along with the new space experiments there remains timely the analysis from the earlier space missions (e.g. Interball, CORONAS-F, Double Star etc.). The financial support of the project is utilized also for travel expenses, not only for a joint analysis of the obtained data from measurements, but also for preparing publications in the theoretical themes as the CR propagation computations, turbulence in relation to space plasma, simulations of particle motion in the heliosphere, the magnetosphere, etc.

Time consuming computations including the statistical procedures, preparing the data bases for a subsequent physical analysis, but mainly the simulation procedures for space physics, became recently an important tool for progress in understanding of the cosmophysical processes with "participation" of the energetic particles in space. This requires powerful computing technique. On the other hand that technique may assist in participation of the DSP in new space projects. This is the case of the large international project JEM-EUSO (http://jemeuso.riken.jp/en/members.html). The current status, requirements and the improvement of the lay-out at the DSP in computing technique and informatics domain with support of the project is discussed in Strhárský and Bobík (2011).

Further publications not listed here, however related to space physics research at the DSP IEP SAS, can be found in the concerned chapters of the biennal reports of the national committee of COSPAR in Slovakia which are available at http://nccospar.saske.sk.

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