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Use of high performance computer technology in cosmophysical research

P. Bobík and I. Strhárský

Institute of Experimental Physics of Slovak Academy of Sciences, Watsonova 47, 040 01 Košice, Slovak Republic
(E-mail: bobik@saske.sk, strharsk@saske.sk)

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Abstract. Department of Space Physics IEP SAS uses high-performance computing at cosmophysical simulations in several areas dealing with particles around the Earth, in the heliosphere and the Galaxy. Among the main issues may be mentioned calculations of particles trajectories in the Earth's geomagnetic field, distribution and modulation of the energy spectrum of particles in the heliosphere, particle acceleration at shock waves and the simulation of particle interactions of cosmic rays with the Earth's atmosphere, carried out under the JEM-EUSO experiment.

Key words: cosmic rays – cosmophysical simulations – supercomputing

1. Introduction

A long tradition of the Department of Space Physics IEP SAS in cosmophysical simulations in the result led to a series of publications in several areas dealing with particles around the Earth, in the heliosphere and the Galaxy. Among the main issues has the longest tradition in the area of particle trajectory calculations in the geomagnetic field of the Earth. Distribution and modulation of the energy spectrum of particles in the heliosphere and particle acceleration at shock waves is another area in which the department is active. Simulations of cosmic ray particle interactions with the Earth's atmosphere, carried out under the JEM-EUSO experiment are a new developing problem in recent years.

2. Trajectory calculations in the geomagnetic field

When calculating trajectories of particles in the Earth's geomagnetic field is concerned, the simulation is based on the so-called backtracing method (Shea et. al., 1968) calculating the trajectories in the Earth's geomagnetic field models.

In Kudela and Bobik (2004) it was intended to change the transmissivity of the geomagnetic field for charged particles in the last 2000 years. Transmissivity was investigated for a network of points uniformly covering the entire surface of the Earth. The article shows the increasing transmissivity of the geomagnetic field in the period studied for most of the Earth's surface.

In Bobik et. al. (2006) as well as in the chapter in the monography by Bobik et al. (2005) there is presented reconstruction of measurements of the AMS-01 experiment. The AMS-01 experiment has produced very accurate measurements of energy spectra of cosmic rays in June 1998 (STS-91 mission to the space station MIR) (Alcaraz et al., 2000). By particle trajectory calculations for all positions of the AMS-01 measurement and all directions of particle arrivals registered by the detector it is possible to split the measured cosmic ray spectrum into a primary and a secondary component. The calculations also indicate a high accuracy of geomagnetic field models (IGRF `http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html` and also Tsyganenko and Stern, 1996) for undisturbed magnetosphere.

Similar calculations are extremely compute-intensive. The results presented in Bobik et al. (2006) included the reconstruction of 10^9 trajectories, while one trajectory calculation takes about 1 second (on 1 core of a QuadCore Intel processor), that in summary means about 30 years of computing time.

3. Heliosphere

The modulation of the energy spectrum of particles and their distribution in the heliosphere is described by the Fokker-Planck equation (Parker, 1965). For its solution we use stochastic methods based on equivalence of systems of partial differential equations and stochastic differential equations (Zhang, 1999). In Bobik et al. (2008) and Bobik et al. (2008) we examine the possible occurrence of a new type of turbulence in the process of modulation of cosmic ray particles in the heliosphere within so-called reentrant particles. Reentrant particles are particles that were modulated in the heliosphere, escaped from there, returned again and are again modulated by irregularities of the heliospheric magnetic field and adiabatic energy losses in the heliosphere. The contribution of these particles to the energy spectrum depends on the properties of the diffusion tensor of Galactic magnetic field.

4. JEM-EUSO experiment

The JEM-EUSO experiment aims to investigate the origin of ultra high energy cosmic rays (>4.1019eV). At present, their origin is an open question, while, the current theory excludes their existence (Greisen, 1966; Zatsepin, 1966). The JEM-EUSO detector will be placed on the International Space Station (hereinafter the ISS), to its experimental module Kibo of the Japanese Space Agency JAXA since 2016. Detected is ultraviolet light produced by the ultra high energy particles interaction with the Earth's atmosphere. The detector on the ISS enables a larger area monitoring than the current ground experiments do (Pierre AUGER Collaboration, 2008) and thus obtaining sufficient statistics to determine their origin.

The models Corsika (Heck, 1998) and Conex (Bergmann, 2007) are used for a simulation of particle interactions of ultra high energy cosmic rays with the atmosphere. An example of a calculated result in the DSP IEP SAS is the distribution of the electron component of secondary cosmic rays at a depth of 200 g/cm2 for areas covered by the ISS flight trajectory. Similar calculations are used to estimate the UV light produced by secondary cosmic rays of medium and high energy and its contribution to the UV background measured by the experiment.

5. Technical implementation of cluster computing

When choosing a technical solution for the future of the computational cluster of the Department of Space Physics several concepts were considered when the price/performance ratio but also the ratio of performance/power consumption. It was assumed that the implementation of a cluster with 50 processors with RAM 4GB per processor and disk space 16TB. The cluster of this size can be accomplished in several ways:

– implementation using standard **desktop PC**:
  + good price/performance ratio
  + trouble free servicing
  — high consumption
  — area-intensive
  — complicated maintance

– **Blade systems**:
  + low power consumption
  + compact solution for saving space
  + simple maintance
  — price/performance ratio
  — expensive service

– **Rack mount systems**:
  + good price/performance ratio
  + compact solution for saving space
  + easy scalability and future upgrade
  — price/performance ratio worse than for the standard PCs

After evaluating the pros and cons of each solution a rack mount system was selected. The next step was the selection of a suitable processor for our applications. The current trend in supercomputing with high computing power using of graphics cards (eg. CUDA system from Nvidia) was not suitable for us because of the difficult adjustment of existing libraries and models, many of which have been written in Fortran language. Only platforms vendors like Intel and AMD remained to be chosen. At the time of the technical proposal (February 2010) in terms of price/performance and of course, with consideration of consumption, the processor AMD Opteron, series 61xx, came out best. The 8 and 12 core processors, while 4 can be connected in one system. This means the density 32 or 48 cores in a 1U rack cabinet.

The price but also prestige in particular have been taken into account when selecting. On this basis, an American company Supermicro was selected, which has in its agenda rack systems based on AMD processors Opteron 61xx. The advantage is the integration of IPMI and remote KVM via a separate Ethernet port already in the starting set. This enables complete remote management (operating parameters monitoring, particularly internal temperature and fan speed, switch on/off /reboot, remote terminal without an external KVM switch).

The finally selected and already delivered (November 2010) configuration of a small cluster for computational needs for cosmophysical simulation is as follows:

1. 12 computing nodes Supermicro® SuperServer AS-1042G-MTF: in configuration:
   - 4x Opteron 6134 (2,3GHz)
   - 16GB RAM
   - 600GB SATAII HDD (WD VelociRaptor)
2. 2x master/disk server Supermicro® SuperServer AS-1042G-MTF in configuration:
   - 1x Opteron 6134 (2,3GHz)
   - 16GB RAM
   - 4x 2TB SATAII HDD (WD RE4)
3. Network components:
   - 48 ports L2 manageable 1GB switch with fiber uplink
   - 2x switched PDU (Power Distribution Unit) with the consumption measurement of each output with the possibility of remote disconnection from the mains
4. Back-up power supply:
   - 1x 8000VA with remote management
   - 1x 5000VA with remote management

5. 2x 19" rack cabinet, height 42U, depth 100cm.

Summary of performance cluster computing:

- CPU number: 48 + 2 @ 2.3GHz
- Number of cores: 384 + 16
- RAM: 224 GB (4GB per procesor)
- Disk space: 12x600GB + 8x2TB = 23,2TB

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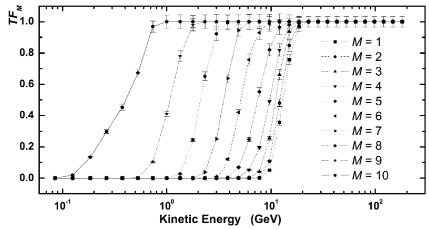

Figure 1. Magnetospheric transmission functions for 10 AMS geomagnetic regions (Bobík et al., 2006).

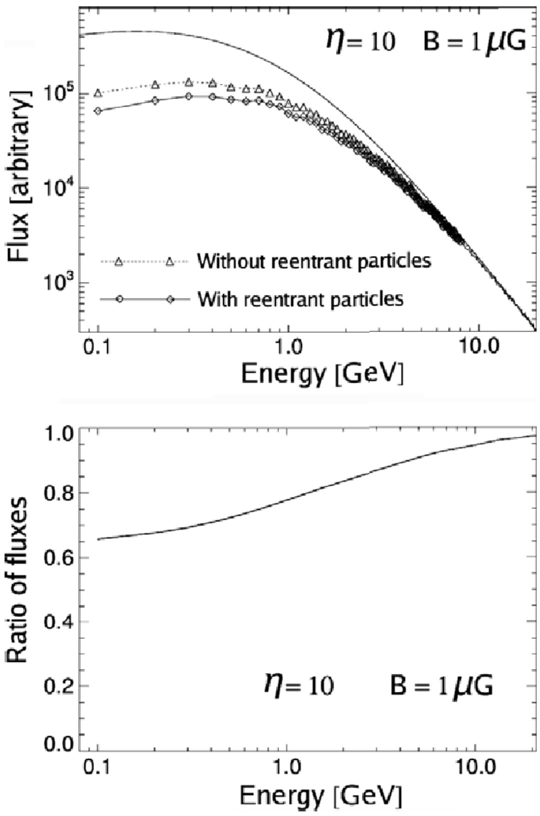

Figure 2. The effect of reentrant particles for selected parameters of the interstellar magnetic field and diffusion tensor (Bobík et al., 2008).

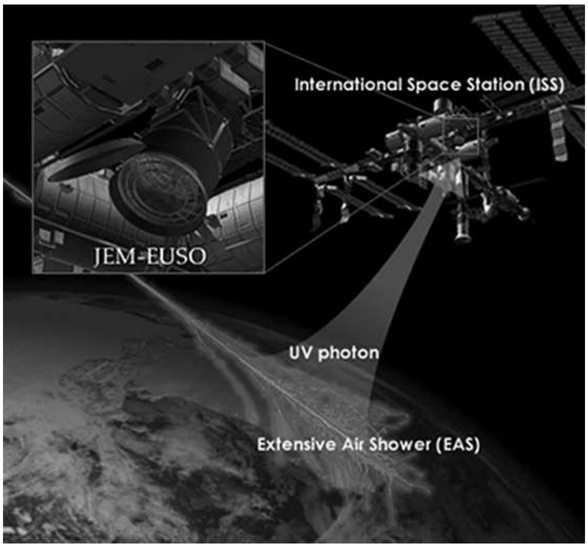

Figure 3. The planned location of the detector JEM-EUSO at the International Space Station (ISS - Kibo Exposed Facility).

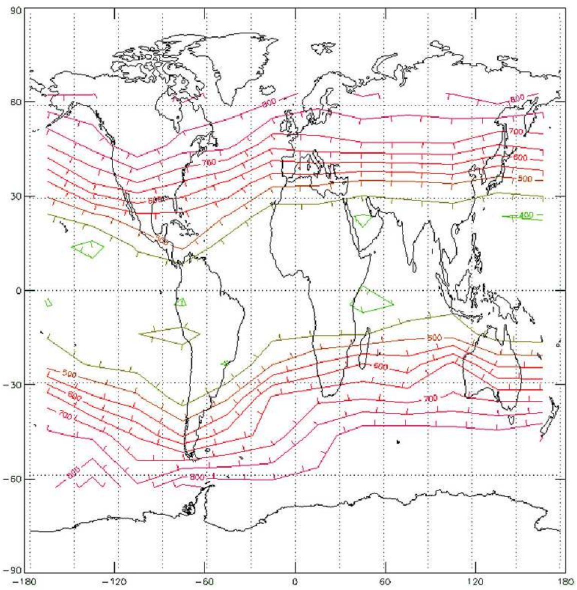

Figure 4. Distribution of the electron component of secondary cosmic rays in $(m^2 s)^{-1}$) v atmospherical depth 200 g/cm^2.

Figure 5. Constructing the cluster (november 2010).