ENERGY SPECTRA OF COSMIC RAYS ABOVE 2 TeV AS MEASURED BY THE "SOKOL" APPARATUS


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ABSTRACT

Results on the energy spectra and charge composition of the primary cosmic rays at energies above 2 TeV measured onboard satellite by the "SOKOL" apparatus are presented. New data are included increasing the overall statistics by more than 50 percent. Analysis of the charge composition at different energies reveals the tendency to the decrease of the proton fraction in the cosmic radiation. We confirm our previous conclusion on the statistically significant difference in the ratio of the measured proton to helium fluxes over that measured at 10-100 GeV energies, which also implies non-identical energy spectra of those components.

In (Ivanenko 1988,1990) we presented the energy spectra of cosmic ray nuclei measured onboard the "COSMOS 1543" and "COSMOS 1713" satellites. The primary particle energy was measured by a calorimeter of depth 5.5 $\lambda_p$ and charge was measured by solid-state Cerenkov detectors. Details of the experimental setup may be found in (Vernov 1981).

The data in (Ivanenko 1988,1990) included particles with trajectories crossing the top and the bottom of the calorimeter. A continuation of the experimental data analysis enabled us to add particles with trajectories escaping the calorimeter from its side, (with the additional requirement that the cascades in the calorimeter develop over the depth not less than 3.5 $\lambda_p$). We also corrected the procedure of the energy determination, which resulted for previously published data in the average energy increase of about 5%.

Since the effective calorimeter depth for additional events diminishes the energy threshold grows. We use thus the new data at somewhat higher energies than the old ones, namely, at $E>5$TeV for protons, at $E$=4TeV for He nuclei and at $E$=3TeV for heavier nuclei. The overall increase of statistics at these energies amounts to more than 50%.
The differential energy spectra of protons and all particles are shown in Fig.1. Results of (Asakimori 1991, Linsley 1983, Ryan 1972, Zatsepin 1990) are also presented. A power approximation of our data at energies above 5 TeV looks for protons:
\[ \frac{dI}{dE} = (1.49 \pm 0.11) \times 10^{-1} \times E^{-2.85 \pm 0.14} \left( \text{m}^2 \cdot \text{sr} \cdot \text{s} \cdot \text{TeV}^{-1} \right) \]
and for all particles:
\[ \frac{dI}{dE} = (2.77 \pm 0.12) \times 10^{-1} \times E^{-2.68 \pm 0.07} \left( \text{m}^2 \cdot \text{sr} \cdot \text{s} \cdot \text{TeV}^{-1} \right) \]

Fig.2 shows our spectra of He, M, H and VH nuclei together with results of (Asakimori 1991, Engelmann 1990, Meyer 1991, Ryan 1972, Simon 1980). Our data can be described by the power law with the indexes: \( \gamma_{\text{He}} = 2.64 \pm 0.12 \), \( \gamma_{\text{M}} = 2.58 \pm 0.07 \), \( \gamma_{\text{H}} = 2.49 \pm 0.07 \) and \( \gamma_{\text{VH}} = 2.62 \pm 0.08 \).

Table 1 presents the charge composition of cosmic rays as derived from our data. Table 2 lists the ratios of the different cosmic ray components.

**TABLE 1** The charge composition of cosmic rays.

<table>
<thead>
<tr>
<th>E(TeV)</th>
<th>p</th>
<th>He</th>
<th>M</th>
<th>H</th>
<th>VH</th>
<th>M+H+VH</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;2.5</td>
<td>39±3</td>
<td>27±2</td>
<td>13±1</td>
<td>10±1</td>
<td>11±1</td>
<td>34±2</td>
</tr>
<tr>
<td>&gt;5</td>
<td>37±3</td>
<td>28±2</td>
<td>14±2</td>
<td>9±1</td>
<td>12±2</td>
<td>35±3</td>
</tr>
<tr>
<td>&gt;10</td>
<td>31±5</td>
<td>30±4</td>
<td>14±3</td>
<td>13±3</td>
<td>12±3</td>
<td>39±5</td>
</tr>
</tbody>
</table>

**TABLE 2** The ratios of integral fluxes of different cosmic ray components.

<table>
<thead>
<tr>
<th>E(TeV)</th>
<th>p/He</th>
<th>p/M+H+VH</th>
<th>He/(M+H+VH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;2.5</td>
<td>1.44±0.15</td>
<td>1.14±0.11</td>
<td>0.79±0.07</td>
</tr>
<tr>
<td>&gt;5</td>
<td>1.32±0.14</td>
<td>1.06±0.12</td>
<td>0.80±0.09</td>
</tr>
<tr>
<td>&gt;10</td>
<td>1.03±0.21</td>
<td>0.79±0.16</td>
<td>0.77±0.14</td>
</tr>
</tbody>
</table>

It follows from the presented results that the proton spectrum is steeper than the spectra of other nuclei. The helium spectrum does not exhibit statistically significant difference from the heavier nuclei spectra.

The ratio of the proton flux to that of helium
nuclei is given at energies near 60 GeV per nucleon in (Ryan 1972) as 26±3 and in the energy range 20-
100 GeV per nucleon in (Webber 1987) as 24±2. It follows from our data that at energies above 5 TeV
per particle the P/He ratio is 1.32±0.14. Provided
the He nuclei index equals to 2.64, this corresponds
to the value of the ratio at fixed energy per nucleon
12.8±2.1. The JACEE group gives a close value for
this ratio at energies above 10 TeV per nucleon:
12.6±2.1. Henceforth, the difference of the proton
to helium ratio in the two energy intervals separat-
ed by about two order of magnitude is far beyond the
statistical uncertainty.

A pronounced decrease in the P/He ratio agree
well with the model of the cosmic ray acceleration
presented in (Silberberg 1990). According to this
model cosmic ray composition at high energy derives
from the composition of the stellar wind of presu-
borna stars, including Wolf-Rayet stars featured
with poor hydrogen abundance.

We can state on the basis of the analyzed expe-
imental data that in order to come to definite con-
cclusions on the behavior of the proton and helium
spectra, in view of their important astrophysical
implications, it is desirable not only to increase
statistics at energies above several TeV per nucleon
but to measure with high precision the spectra in
above 100 GeV per nucleon.

REFERENCES
Linsley J.: 1983, Proc 10 ICRC, 12, 135

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Figure 1. Differential energy spectra of protons and all particles.

Figure 2. Differential energy spectra of He, H, D and V nuclei.