Primary and secondary cosmic rays in the NUCLEON space experiment after two years of data acquisition

A. Panov, on behalf of the NUCLEON collaboration

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Ionization Calorimeter - main detector for high-energy particles

1957

N.L. Grigorov  I.D. Rapoport  V.S. Murzin

carbon  Pb

detectors  Pb

detectors
"Proton" Experiments
1965 - 1968

Proton 4

S.N. Vernov

N.L. Grigorov
The composition of cosmic rays experiment SOKOL

N.L. Grigorov  I.P. Ivanenko  V.Ya. Shestoperov

“Kosmos -1543” SOKOL-1
“Kosmos -1713” SOKOL-2
The ATIC spectrometer

At the start position

Protons and nuclei — 30 GeV - 100 TeV
$e^- + e^+ — 30$ GeV - 2-3 TeV

In the flight
Physics: Approaching the knee area. Problems in cosmic-ray spectra at energies 10 TeV - 1PeV per particle. An example: proton spectra before NUCLEON.
The objectives of NUCLEON space experiment

Priority: experimental study of cosmic ray spectra in the energy range $10$ TeV - $1$ PeV per particle, with somewhat lower energy threshold, down to $100$ GeV, with elemental charge resolution.
Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow,

Joint Institute for Nuclear Research, Dubna, Russia

National Research Nuclear University “MEPhI”, Moscow

SDB Automatika, Ekaterinburg, Russia

ROSKOSMOS, Russia

JSC SRC "Progress"
NUCLEON mission

NUCLEON apparatus is placed on board of the RESURS-P regular satellite as an additional payload. The spacecraft orbit is a Sun-synchronous one with inclination 97.276° and an average altitude of 475 km. Launched December 28, 2014. From July 2015 up to now - regular measurements. The planned exposition time is not less than 5 years (more expected)

Vessel:
Weight ~360 kg
Power consumption ~160 W
Telemetry ~10 GB/day

The NUCLEON detector on board of the satellite RESURS-P N2.
IMPORTANT FEATURE OF THE EXPERIMENT:

Two different methods of measuring of the energy of particles are implemented in the NUCLEON experiment:

1. The kinematic method **KLEM**
   *(Kinematic Lightweight Energy Meter)*
   -for the first time *(main)*

2. The calorimetric method
   -usual and well studied
The kinematic method KLEM + calorimeter

The number of secondary particles with high pseudorapidity after the first interaction increases logarithmically along increasing of the primary energy of particle

The energies are reconstructed by S-parameter -

\[ S = \Sigma (I_i * \ln^2(2H/x_i)) \]

Primary particle

Target

Tungsten absorber

Tracker
The NUCLEON apparatus

- **system of charge measurements** – four planes of pad silicon detectors (1.5×1.5 cm²) (1);

- **tracker for KLEM energy measurement** – carbon target of 0.25 proton interaction lengths (2) and six planes of microstrip silicon detectors (0.4mm step) with tungsten between them (~2mm each, ~3 X-lengths summary) (3);

- **trigger system** – three double scintillator planes (4).

Active square 500*500 mm². Geometrical factor 0.24m²sr.

Ionization calorimeter (IC) (5) – six planes of tungsten absorber (~8mm each, ~12 X-lengths summary) with silicon strip detectors (1mm step).

Active square 250*250mm². Geometrical factor (together with charge and KLEM systems) ~0.06m²sr.

10604 independent electronic channels in total
Correlation of the calorimeter energy deposit (Ed) and KLEM parameter (S) ~90%

This correlation is a model-independent result
Charge resolution of four silicon planes detector
~0.2 charge units
An example of an event «portrait»

Selected-dat-160705-122731-V1A
Event = 44 (Index = 22665)
Chi2Max = 0.11705
Q = 10.0571
NPad = 7 DQ = 0
Qmax = 11.9144
MIK(X) = 12728; MIK(Y) = 12022
KLEM: The S-estimator is defined as:
\[ S = \Sigma I_k \ln^2 \left( \frac{2H}{x_k} \right); \quad E = aS^b \]
KLEM, CERN test for $\pi^-$, resolution ~60%
IC: E0 vs Ed scatter plots, simulation. $E_0 = \frac{E_d}{K(E_d)}$

Saturation bend

Protons

Carbon nuclei

Protons

Carbon nuclei
Calorimeter, CERN test for $\pi^-$, resolution $\sim 45\%$
Data acquisition

This presentation:
July 2015 - June 2017
AstroTime(days) = 334; LiveTime(days) = 218 (65%)

Last year autumn conferences:
July 2015 - June 2016
AstroTime(days) = 247 LiveTime(days) = 160

8 months delay in data acquisition in 2016-2017:

The solution of the main task of the Resource-P serial satellite was incompatible with the operation of the NUCLEON observatory as an additional payload :(

Currently, NUCLEON is working again continuously. No more than 1/3 expected data were collected.
Results and discussion
Abundant primary nuclei
Protons and Helium
p/He ratio

![Graphs showing the p/He ratio vs. energy (GeV and GeV/nucleon)]
Protons and Helium: break near $R \sim 10$ TV?
Statistical significance of the break is not high
Carbon and Oxygen: hard above ~3 TeV
Are the spectra of carbon and oxygen the same?
Ne-Mg-Si - a trend in the slopes of the spectra?

Significance of the trend: 2.3 $\sigma$
Iron spectrum - softer, than the spectra of other heavy nuclei? \((Z = 6-14)\)
S and Ca - hints of complicated behavior, more statistics are needed
Universal break near $R \sim 10$ TV
Zatsepin & Sokolskaya model predicts breaks near $R = 10$ TV both in spectra of protons and helium, and in spectra of heavy nuclei.
The possible feature in the proton spectrum ("bird")?

Data do not contradict the feature, but the statistics are too low yet.
Results and discussion
Secondary nuclei
Strange HEAO-3-C3 results, 1985-1988

W.R. Binns, et al.

Ar/Fe

Ca/Fe
Z=16-24/Fe

![Graph showing the ratio of Z=16-24/Fe against E/n, GeV]

- ATIC
- NUCLEON KLEM
- NUCLEON IC
Conclusions

• The 2 years preliminary analysis of the NUCLEON space experiment data gives multiple indications of the existence of a number of features in the energy spectra of cosmic ray nuclei at energies from few TeV to ~100 TeV (per particle).

• A number of question are posed which may be clarified with better statistics

• NUCLEON space experiment is continuing…
  No more than 1/3 expected data were collected.
Thank you for attention!
All particle spectrum and $\langle \ln A \rangle$