Composition of cosmic rays with energy more than 0.1 EeV by long-term optical observations of Cherenkov emission at Yakutsk array

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Abstract: The paper presents results on longitudinal development of air showers with ultra-high energies (Xmax) and mass composition of cosmic rays (<lnA>). The data is obtained from observations of Cherenkov emission at the Yakutsk array in 1974-2014. Cascade curves of individual showers reconstructed by lateral distribution of Cherenkov light and depth of maximum Xmax analyzed in energy region 10^4-5.7⋅10^9 eV. It is shown that elongation rate dXmax/dE in the atmosphere has irregular nature and depends on energy. Such behavior indicates change of mass composition and is confirmed by fluctuations of Xmax in the energy region. Composition of cosmic ray is determined by interpolation of hadronic interaction QGSJetII-04 model.

Yakutsk Array

Location: 61°42' N, 129°24' E; Height: 110 m
Area of the array: ~8 km²;
Energy range: 10^4 ≤ E ≤ 10^9 eV
58 stations with 120 scintillation detectors tmax ≥ 10 MeV
Spacing: 500 m
Yakutsk array measures: charged component; muon component; Cherenkov light; radio emission

Small Cherenkov array

Area of array ~1 km². Spacing 50-250 m, 3 tracking Cherenkov detectors at 250, 300 & 500 m from center.

Air shower parameters reconstruction

To determine the depth of maximum Xmax we used cascade curve, which is reconstructed from the experimental function of Cherenkov light LDF.

Qmax = Q0 + \int \frac{\rho d\varepsilon}{\varepsilon} G(R, X/X0) \cdot \rho(E, X) \cdot K(A, X)

The energy E0 is estimated by formula:

E0 = (1.28 ± 0.44)⋅103 (Q(200) - 10^3) \cdot 10^{1.5 (3.84)}

Q(200) - density of the Cherenkov light flux at a distance of 200 m.

The cascade curve of the individual shower, E0 = 1.3⋅10^{10} eV, θ = 25°,

Xmax = 738 g/cm²

Average experimental cascade curves and simulations of QGSJetII-04 for proton and iron nucleus.

Dependence of Xmax on classification parameter Q(200).

Comparison of the experimental data obtained for the Yakutsk array

Earth shower parameters reconstruction

To determine the depth of maximum Xmax we used cascade curve, which is reconstructed from the experimental function of Cherenkov light LDF.

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Mass Composition of Cosmic Rays

Knowing the depth of maximum Xmax for the proton and iron nucleus from the simulation model QGSJetII-04, the value of <lnA> can be determined by interpolation method:

<lnA> = \frac{X_{max} - X_{Fe}}{X_{Fe} - X_{p}}

Where X_{max}^{Fe} – depth of maximum, from the experiment, lnA – logarithm of iron atomic weight.

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References: