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Nonmonotonic change with energy of the mean logarithmic mass of cosmic rays in the knee region: the mechanism of formation of this feature and sources of particles

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Recently, the Large High Altitude Air Shower Observatory (LHAASO) published measurements of the all-particle CR energy spectrum and the mean logarithmic mass of CRs with unprecedented accuracy in 0.3 - 30 PeV. The mean logarithmic mass shows a nonmonotonic change with energy, a feature observed for the first time.

Phenomenological studies of the cosmic-ray flux and its mass composition in the knee region have been conducted in many papers utilizing the most up-to-date data available at different times. However, this technology is not a model in the usual sense since it does not try to explain the data.

In this work, we present a new approach to describe the mechanisms of formation of this feature. The key elements of this approach are the non-classical diffusion model of cosmic rays developed by the authors in which the knee in the observed spectrum occurs naturally without the use of additional assumptions, as well as power-law asymptotics before and after the knee, and a soft spectrum of particle generation in cosmic ray source.

To obtain a more complete picture of the spectrum formation in the region of the knee and the sources that form it, we carried out calculations of the spectra of the main groups of nuclei in the energy range of 1 TeV - 100 PeV. It is shown that the behavior of the all-particle spectrum and mass composition in the knee region is determined by local pevatrons located at a distance of 750-900 pc from the Earth. The position of the knee practically coincides with the break in the spectrum of helium nuclei. The contribution of the light components p + He is about 70%, the CNO group provides $\sim$ 13%. The energy spectrum index of the light components is -2.61 before the knee. The nonmonotonic change in the mean logarithmic mass is due mainly to a decrease in the contribution of the CNO group in the energy range of 0.3 - 3 PeV.

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