High energy neutrons in cosmic rays

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Abstract. This work is about neutron astronomy. The registration of high energy neutrons can be used to investigate gas and dust components of the Kuiper belt. A new method for studying the diffuse matter in space based on observing high energy neutrons is analyzed. The high energy neutrons (with energies of hundreds of Gev) can travel distances comparable to the distance between the Earth and the Kuiper belt. A background of neutrons (at these energies) from beyond the Solar System is limited by decay. It is shown that the expected flux of high energy neutrons can be recorded by facilities using the data on the density of the gas and dust component obtained when analyzing the trajectories of space probes.

1. Introduction
The major advances in astronomical investigations have been associated with mastering new wavelength ranges and measuring methods. Therefore, we can anticipate an appreciable advance when using an additional type of radiation to serve as an information source. It is necessary to answer a number of essential questions to estimate the capabilities of the new approach. First, which regions of space can be studied using neutron fluxes (taking the neutron lifetime into account)? Second, how many neutrons can be recorded over an acceptable exposure time? Third, what are the background events and the necessary level of rejection? Fourth, what facilities can be used to make such measurements? The set of tools that are used in astronomical investigations has been considerably widened during the 20th century. Traditional studies of astronomical objects in the optical range have been supplemented with radio, X-ray, and gamma astronomy. The latter method is tightly linked to the physics of cosmic rays. However, charged components in cosmic rays travel under the influence of galactic magnetic fields and the direction of particle arrival is only weakly associated with the direction to the source. In the best case, one can search for some distribution anisotropy.

2. Properties of high energy neutrons
A new advance in astronomy may be linked with the possibility of observing high energy neutrons in space. These particles are known to be unstable but fairly long_lived (the mean lifetime is 896 s). Figure 1 shows the mean free path of a neutron versus its kinetic energy. The mean path is several tens of astronomical units for energies of tens of GeV; it achieves several parsecs if the energy is more than $10^{14} - 10^{15}$ eV. Correspondingly, we can indicate where objects could be located that can be studied using neutron astronomy. Relatively low_energy neutrons (tens and hundreds of GeV) carry information on the matter located at the periphery of the Solar System, while high_energy ones (more than $10^{14}$ eV) can overcome interstellar distances. Naturally, neutrons cannot be accelerated by shock
waves like the charged components of cosmic rays, but they can be produced in interactions between high energy cosmic rays and matter. Two basic channels for producing high energy neutrons are as follows: (1) inelastic hadron interactions; (2) the fragmentation of heavy nuclei. Both channels have specific features. The first process has a small cross section and produces neutrons with energies less than the energy of a bombarding particle (per one nucleon). However, the cross section grows with energy and all the active nucleus components of cosmic rays, including protons, contribute to this channel. In the second process, it is the heavy nuclei that make the greatest contribution, with the energy of a neutron corresponding to the energy of an original nucleus per nucleon. This process is similar to the production of secondary nuclei (Li, Be, B, and others.). However, the neutron propagation mechanism differs dramatically from the propagation of the component of a nucleus. Straight propagation takes less time than diffuse propagation. This defines the scope of tasks for which neutron astronomy may prove to be useful. The direction of the neutron trajectory must point to an agglomeration of diffuse matter where interaction with cosmic rays occurs. The distance to this agglomeration should not appreciably exceed the free path for the corresponding energy. Thus, as opposed to gamma astronomy, neutron astronomy allows us to study relatively nearby agglomerations of diffuse matter.

The anisotropy toward the Galactic center around $10^{18}$ eV (according to extensive air shower data) can be explained by neutrons created in the Galactic center region through charge exchange in proton-proton collisions [1].

![Figure 1. Mean path of a neutron before decaying as a function of energy.](image-url)
3. Expected high energy neutron fluxes
The question arises as to how possible fluxes of high-energy neutrons can be estimated. These fluxes must depend on both the cosmic ray spectra and the diffuse matter density. Since the distance is restricted, it is reasonable that the data on cosmic ray spectra obtained near the Earth (allowing for the absence of solar modulation at great distances from the Sun) are used in calculations. The density of diffuse matter can be derived from the data that are obtained when observing the “Pioneer 10” and “Pioneer 11” space probes [2]. The major problem is that the trajectory differs from the calculated ballistic path and an anomalous deceleration of the stations is observed [2]. Various hypotheses may explain this phenomenon. The simplest explanation is to assume the presence of a decelerating medium consisting of dust or gas [3, 4]. This corresponds to the observational data in the infrared [5], which indicates the presence of a gas and dust component in the Kuiper belt. The density estimated in [4] was used in further calculations.

It was assumed in the calculations that the gas and dust component is distributed homogeneously beyond Jupiter’s orbit (5.2 AU) and that neutrons are produced in interactions between cosmic rays and this component. The cosmic ray spectra were calculated according to [6] without allowing for solar modulation. The neutron yield in a single inelastic collision was calculated using the FLUKA package [7]. Integration was performed with allowance for neutron decay. The differential neutron spectrum thus obtained is presented in Figure 2 and the integral spectrum in Figure 3. These spectra differ appreciably from the original cosmic ray spectra because the cross section grows with energy. The slope of the differential spectrum is 1.3–1.5 (it increases with energy).

![Figure 2. Differential spectrum of neutrons from the Kuiper belt.](image)
4. Conclusions
The calculated neutron fluxes are small but can be estimated in upcoming space experiments provided that the geometric factors of the equipment are increased.
To calculate the ultra_high_energy neutron fluxes (>10^{15} eV) from possible cosmic ray sources at interstellar distances, the models of the sources must be specified.

5. References
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