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ABSTRACT

We have carried out a detailed calculation to determine the effectiveness of the universal radiation field in disintegrating ultrahigh energy cosmic-ray nuclei. We conclude that this process cannot explain the air-shower observations above 10^{17} eV unless there exists a large metagalactic flux of infrared photons as may have recently been detected. Other implications of our results are discussed.

PHOTODISINTEGRATION OF ULTRAHIGH ENERGY COSMIC-RAYS BY THE UNIVERSAL RADIATION FIELD

In a recent paper[1], we made a detailed study of the effect of photomeson production by the universal radiation field on ultrahigh energy cosmic-rays. Greisen[2] and Zatsepin and Kuz'min[3], who first proposed the significance of this effect, also pointed out that the universal radiation field can disintegrate cosmic-ray nuclei of 10^{19}eV energy and above. The purpose of this letter is to point out that by taking account of the details of the photodisintegration process, the recent air-shower data can be examined for implications on the origin and propagation time of the ultrahigh energy cosmic-rays.

In Reference 1, we showed in a detailed calculation that cosmic-ray protons of energies less than or equal to 6×10^{19} eV can exist for 10^{10} years (the age of the universe) against attenuation by photomeson production. It was also shown that the lifetime of a 10^{20} eV proton is of the order of 10^{9} years and that protons of all energies have lifetimes of at least 5×10^{7} years, long enough to reach us if produced within the local supercluster region.

A proton of 10^{20} eV energy was detected by Linsley[4] along with the detection of six other protons having energies greater than or equal to 2×10^{19} eV[5]. Recently, Andrews, et al.[6] have detected a proton of energy $\geq 5 \times 10^{19}$ eV. As we concluded in Reference 1, such observations are not incompatible with the existence of the universal blackbody radiation field, but only with the implicit assumption that ultrahigh energy cosmic-rays are primordal. These assumptions are compatible with the existence of these cosmic-rays with ages up to 10^9 years, and which may be reaching us from distances as great as 300 Mpc.

We now present a similar discussion of the implications of photodisintegration by the universal radiation field. Letting ϵ' denote the energy of a blackbody photon in the rest frame of an ultrahigh energy cosmic-ray nucleus, and letting $\sigma(\epsilon')$ denote the cross section of a nucleus of type i for photodisintegration, the lifetime of the nucleus is given by (cf. reference 1)

$$\tau_i(E_i) = 2\gamma_i^2 \hbar^3 \pi^2 c^2 \left[\int_{\epsilon'_{th}/2\gamma_i}^{\infty} \frac{d\epsilon}{e^{\epsilon/kT} - 1} \int_{\epsilon'_{th}}^{2\gamma\epsilon} d\epsilon' \, \epsilon' \, \sigma_i(\epsilon')\right]^{-1} \quad (1)$$

In previous discussions[2,3,7], photodisintegration has been stressed for iron nuclei where the cross section is large. However, recent observations[5,8] indicate that cosmic-rays of energies $\geq 10^{17}$ eV are purely protons. Such observations can be explained by photodisintegration only if all heavier nuclei can be broken down into individual nucleons. As one considers lighter and lighter nuclei, the photodisintegration cross section becomes smaller and smaller. Indeed[9], the photodisintegration cross section of a nucleus of atomic number A is proportional to $A^{4/3}$. Therefore, the question posed here is whether even the lightest nuclei can be broken down completely into their constituent nucleons. We thus consider here in detail, the photodisintegration of helium nuclei. We consider in particular, the well studied processes

$$\gamma + He^4 \rightarrow He^3 + n \tag{2}$$

and

$$\gamma + He^4 \rightarrow H^3 + p, \tag{3}$$

keeping in mind the fact that reactions (2) and (3) must be followed by the further breakup of He^3. Thus, lifetimes for the complete breakup of He nuclei are at least twice as long as those calculated here.

The data on reactions (2) and (3) have been compiled by Gorbunov[10], as shown in Figure 1. Equation (1) was solved numerically making use of these cross sections and the results are given in Figure 2 along with the lifetimes of protons against attenuation by photomeson production as given in Reference 1. We have also calculated the lifetimes for processes (2) and (3) as generated by dilute metagalactic starlight photons with a mean temperature of 5000°K and a dilution factor of 2.1×10^{-15} as given by Allen[11]. Recent calculations by Garmire[12] have yielded even lower estimates of the metagalactic starlight photon density. Such optical photon densities cannot produce complete photodisintegration even in 10^{10} years.

One can see from Figure 2 that complete photodisintegration by the universal radiation field is effective only above 10^{19} eV even for propagation times of the order of 10^{10} years. Considering more likely propagation times as discussed in Reference 1, we find complete photodisintegration effective only above energies of $2\text{-}3 \times 10^{19}$ eV. Thus, photodisintegration by microwave and dilute optical metagalactic photons cannot account for the absence of multinucleon nuclei between 10^{17} and 10^{19} eV.

It may still be possible to obtain adequate photodisintegration for complete breakup if a large flux of infrared photons exists in metagalactic space. Recent preliminary observations between 0.4 and 1.3 mm wavelengths by Shivanandan, et al.[13] indicate the presence of a photon flux 2 orders of magnitude higher than to be expected from a 3°K blackbody background. If this flux is universal, it may help account for the absence of multinucleon nuclei above 10^{17} eV.

If the extragalactic ultrahigh energy cosmic-rays cannot undergo complete photodisintegration during propagation, then we must look for an alternative explanation. The most natural alternative which comes to mind, is the possibility that these cosmic-rays were exposed to a strong photon field at their source. This may have been a likely possibility during the length of time when they underwent acceleration. Indeed, powerful radiation fields may have been associated with, or even caused the acceleration process. The possibility of acceleration of cosmic-rays by radiation has been suggested by Tsytovich.[14]

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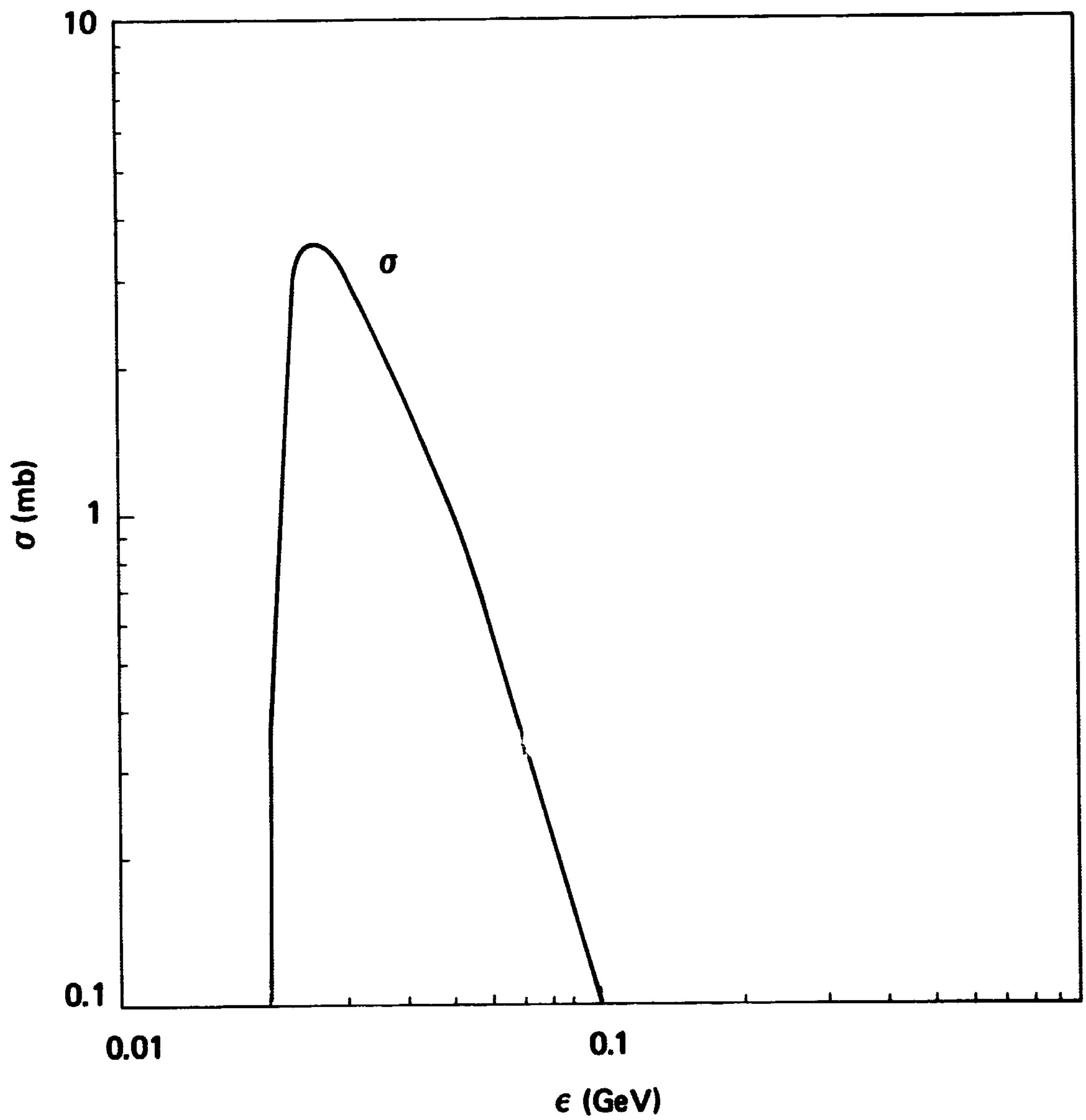

Figure 1. Total cross section for the processes $He^4(\gamma, p)H^3$ and $He^4(\gamma, n)He^3$ as a function of gamma-ray energy in the helium rest system.

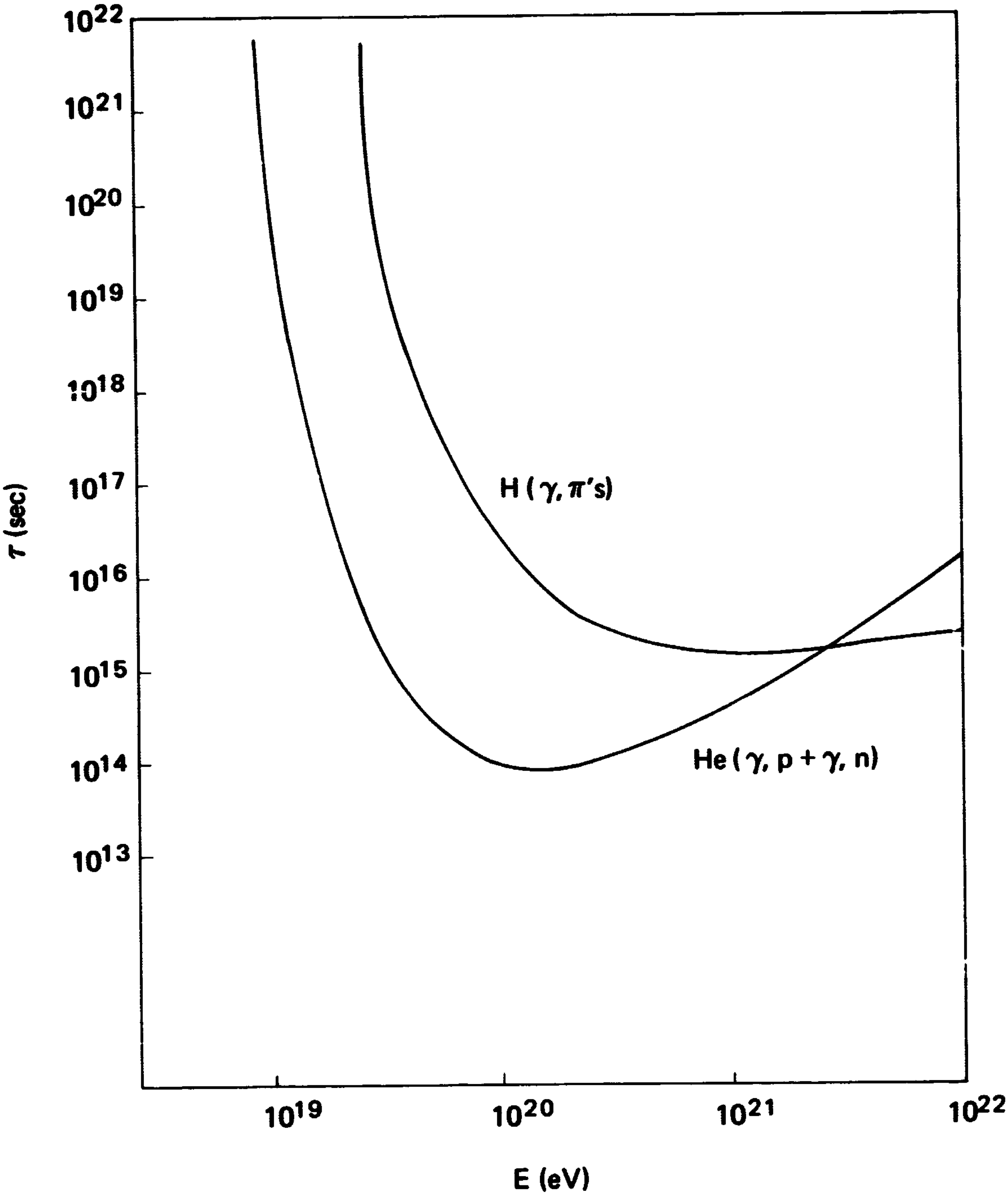

Figure 2. Characteristic lifetimes for helium nuclei against photodisintegration and for protons against photomeson production as a function of energy.

FIGURE CAPTIONS

Figure 1. Total cross section for the processes $He^4(\gamma, p)H^3$ and $He^4(\gamma, n)He^3$ as a function of gamma-ray energy in the helium rest system.

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