Comment on “Violation of the Greisen-Zatsepin-Kuzmin Cutoff: A Tempest in a (Magnetic) Teapot? Why Cosmic Ray Energies above 10^{20} eV May Not Require New Physics”

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In a recent letter [1] with the same title, Farrar and Piran offered an explanation for the near isotropy of the arrival directions [2] of ultrahigh energy cosmic rays (UHECRs) and the apparent absence [3] of the so called ‘GZK cutoff’ in their spectrum around 10^{20} eV due to pion photoproduction on the cosmic background radiation (CMB) that was predicted independently by Greisen [4] and by Zatsepin and Kuz’min [5]. They suggested that the extragalactic magnetic fields near the Milky Way are strong enough to deflect and isotropise the arrival directions of the UHECRs from a few nearby sources for which their travel time to Earth is shorter than their attenuation time by pion photoproduction on the CMB. They also estimated that this allows active galactic nuclei (AGNs) or gamma ray bursts (GRBs) to be the source of the UHECRs. However, these suggestions are inconsistent with various observations:

a. If our Milky Way galaxy was embedded in a $\sim \mu$G magnetic halo/slab of the local supercluster (LSC) with dimensions larger than the Larmor radius (eq. 5 of ref. [1]) of UHECRs, then $\sim$ GeV cosmic rays would have been confined magnetically for times exceeding the Hubble time. This contradicts the much smaller ‘age’ of the bulk of cosmic rays in the Milky Way that was inferred [6] from the measured isotopic ratios Al^{26}/Al^{27} and Be^{10}/Be^{9}.

b. If our Milky Way galaxy was embedded in a $\sim \mu$G magnetic halo/slab of Mpc dimensions, diffusion in this halo/slab would have produced a quasi uniform distribution of the bulk of the cosmic rays inside it. This contradicts the much smaller upper bounds on the densities of cosmic rays at the small and large Magellanic clouds (SMC and LMC, respectively) that were inferred from the EGRET observational limits on the diffuse gamma-ray produced by cosmic rays interactions in the SMC and LMC [7].

c. Cosmic ray protons with energy smaller than the GZK cutoff are attenuated mainly by electron-positron pair production off the CMB. Their attenuation time is longer/comparable to the Hubble time. Thus, the density of cosmic rays in the magnetic halo/slab must drop at the GZK cutoff energy by a factor $\tau_{\rm h}(E < E_{\rm GZK})/\tau_{\rm GZK}$ where $\tau_{\rm h}(E < E_{\rm GZK})$ is the magnetic confinement time of UHECRs with energy below the GZK cutoff energy and $\tau_{\rm GZK}$ is their attenution time above it. Such a drop in the intensity of UHECRs has not been observed [5]. A cosmic 'fine tuning', $\tau_{\rm h}(E < E_{\rm GZK}) \approx \tau_{\rm GZK}$, is required to 'explain' why such a drop is not observed [3].

d. If the UHECRs are isotropised by large angle magnetic scatterings, then on the average only UHECRs that are produced within a distance smaller than their diffusion distance during $\tau_{\rm GZK}$ can reach Earth. The correct expression for their energy flux is given then by

$$\Phi = \frac{\Gamma(z=0)\, E_{\rm CR}\, D}{4\,\pi}\left(\frac{c\,\tau_{\rm h}}{D_{\rm LSC}}\right) \leq \frac{\Gamma(z=0)\, E_{\rm CR}\, D_{\rm GZK}}{4\,\pi} \tag{1}$$

where $\Gamma(z=0)$ is the local rate of GRBs, $E_{\rm CR}$ is the GRB energy output in UHECRs, and $\tau_{\rm h}$ is the mean residence time of UHECRs in the magnetic halo/slab and the near isotropy of arrival directions of UHECRs requires that $D \leq D_{\rm LSC}$ and $\tau_{\rm h} \leq \tau_{\rm GZK}$. Assuming a flat Universe with $\Omega_{\rm M} \approx 0.3$, $\Omega_\Lambda \approx 0.7$, and that the observed GRB rate is proportional to the star formation rate [8], $\Gamma(z=0) \approx 10^{-10}\,{\rm Mpc}^{-3}\,{\rm yr}^{-1}$. The energy output in UHECRs of GRBs which are powered by merger or collapse of compact stars is unlikely to exceed $E \approx 10^{52}\,{\rm erg}$, which is larger by approximately an order of magnitude than the total explosion energy of Type II supernova explosions. Consequently, eq. (1) yields $\Phi \leq 3\times 10^{-3}\,{\rm eV\,cm^{-2}\,s^{-1}\,sr^{-1}}$, which is smaller by 4 orders of magnitude than the observed flux of UHECRs.

The observed evolution function of AGNs plus similar arguments exclude the possibility that the isotropised UHECRs arrive from nearby AGNs. However, relativistic jets from GRBs in the Milky Way which are not pointing in our direction can accelerate/deposit

UHECRs in our Galactic halo and explain the absence of the GZK cutoff [10].

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