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Reply to "Comment on Correlation between Compact Radio Quasars and Ultra-High Energy Cosmic Rays"

Glennys R. Farrar[a] and Peter L. Biermann[b]
[a] *Department of Physics, New York University, NY, NY 10003, USA*
[b] *Max Planck Institut für Radioastronomie Auf dem Hügel 69, D-53121 Bonn, Germany*
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In ref. [2] we investigated the hypothesis that the highest energy cosmic rays are created in and travel undeflected from an extraordinary class of QSO's, capable on physical grounds of producing the highest energy particles found anywhere in nature. This *a priori* hypothesis was motivated by theories of cosmic ray acceleration and the ansatz of a new, neutral, GZK-evading messenger particle. It is well known that many features of powerful AGN's are not characteristics of every one of them and thus would not be suitable markers (e.g., blazars only look like blazars when viewed from a special direction). The class of compact radio quasars (CQSOs) is the only kind of quasar which holds any hope of at once accelerating particles to very high energy, and at the same time converting them into another, possibly long-lived new particle by interacting with material surrounding the AGN. The distinctive radio spectrum which provides an objective definition of the source class, is in fact produced by interaction with the surrounding material and is thus indicative of the conditions required.

As pointed out by Elbert and Sommers [6], 3C147 is a remarkable, uniquely suitable candidate source for the highest energy cosmic ray event FE320, once one sets aside the GZK distance limitation. No matter what further restriction on characteristics of the source class is made, 3C147 must be the source of FE320, given our hypothesis that the source is an AGN. Precisely for this reason, it is correct to include it in the analysis independently of any additional constraint ultimately imposed to remove background such as the radio spectrum of a CQSO.

Our energy cut was not arbitrary and was decided before examining the events. Clearly, one must provide some buffer against contamination by mismeasured protons piled up just at the GZK limit. Convoluting a rapidly falling distribution with a gaussian measurement error means the sample is preferentially drawn from the low-side of the distribution. With an E^{-p} spectrum and $p = \{2, 3, 4\}$, an event with nominal energy 1(2)-sigma above $E^{\rm cut}_{1(2)}$ has a true energy lower than $E^{\rm cut}_{1(2)}$ $\{37\%,\ 40\%,\ 42\%\}$ ($\{5.0\%,\ 5.2\%,\ 5.5\%\}$) of the time. In the analysis reported in [2] we required that the event should have an energy of at least 8 10^{19} eV plus 1-sigma. This was motivated by the result of ref. [3] that protons from nearby AGN's (100 Mpc) have energies degraded to the $5 - 8$ 10^{19} eV range by interaction with CMBR, independently of their initial energy. In analyses of future data, we plan to impose an additional cut, that the nominal energy of the event be at least 5 10^{19} eV plus 2-sigma. For distant sources this would produce a $\sim$ 95% clean sample. The existing set of events passes this cut as well. These cuts are soft in the sense that the 8 10^{19} eV starting point for defining $E^{\rm cut}_1$ is not precise – 7 or 9 10^{19} eV could also have been chosen and would have provided weaker or stronger background rejection.

Ag110 has a central energy value of 1.1 ± 0.3 10^{20} eV and thus satisfies both cuts. Hoffmann adds a third significant figure to the energy and claims the event should be excluded from the analysis since 1.10 - 0.33 = 0.77. We disagree since the cut energy was defined at 1 significant figure. However our result is robust: excluding Ag110, the CQSO χ^2 probability is unchanged (0.53), the testQSO probability remains small (4 10^{-7}), and the probability that randomly distributed QSO's would produce as low or lower χ^2 is still small (0.016). The possible contention over whether or not to include the event underlines the point emphasized in our paper: a definitive resolution of the issue requires more and more precise data.

Table I contains three typos: the RA error for HP120 should be 2.7 deg; $\Delta\Omega$ for FE320 and HP120 should be 1.9 and 6.7 deg^2 respectively. Correct values of all parameters were used in the analysis. Note that $\Delta\Omega$ is only a figure of merit and does not enter the analysis. The conventional difference between how conical errors and rectilinear errors are quoted is correctly incorporated in the formulae (see Eq. 2 and text below) but not explicitly discussed due to space limitations.

Hoffman's Comment prompted us to analyze the three events which come closest to passing our cuts [4], keeping in mind that with the energies and errors of these three CR events and the falling cosmic ray spectrum, it is likely that at least one of them should be a proton because the probability that one of the three has a true energy below 5 10^{19} eV is $\{40\%,60\%\}$, for $\{p = 2,\ 4\}$, and at the source protons far outnumber the messengers for a given energy. Rather than diminishing the evidence in favor of the ansatz, the characteristics of these three events fit the CQSO hypothesis very well. Ya110 (RA = 75.2 ± 10 deg, Dec = 45.5 ± 4 deg [5]) would have the same source that produced the highest energy event FE320 (3C147), with a χ^2 residual of 2.0 for 2 degrees of freedom; the CQSO (0.53) and

random background probability (0.0058) are essentially unchanged by including Ya110. There is an excellent CQSO candidate for HP105 (B3 1325+436); it is an archtypal CQSO and has a χ^2 residual of 0.46. Adding this event in the analysis *decreases* the random background probability to 0.003 (0.0029 with Ya110 and 0.0028 without). There is no good candidate for HP102 within a cone of radius 5 deg so it is interpreted as a deflected proton.

We reiterate that whether the random background probability is 3% or 0.3% is not the essential point – either value is low enough that in coin-tossing experiments one would be surprised by it, but not low enough for a statistical fluctuation to be excluded. Our main message is that future detectors should aim for the best possible position resolution in order to settle this important question.

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