High energy cosmic rays from AGN and the GZK cutoff

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Based on a model for the emission of high energy cosmic rays from AGN (Active Galactic Nuclei) that has been proposed by the author, he reviews the status of the GZK cutoff and the correlation of high energy cosmic ray sources with AGN locations in the existing data. The determination of mass for the incident particles seems to be a key factor, and a suggestion for doing that has been made in this article.

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I. INTRODUCTION

High energy gamma rays from AGN have been reported by the Compton Observatory [1] and by Cerenkov detectors [2], and high energy cosmic rays have been correlated with AGN [3]. However, the status of the GZK cutoff [4] has been a mystery for the past several decades [5]. The absence of the cutoff in the Akeno-AGASA detector [6] and its presence in the Fly’s Eye collaboration [7], the Yakutsk [8] and the Pierre Auger Project [3] present a puzzle. In this article, using the machinery of a model proposed by the author since 1985, a possible resolution for this puzzle is suggested. A further suggestion for the determination of the mass parameter for the incident particles is proposed as a crucial test.

II. SUMMARY OF THE MODEL

In a series of articles [3]-[17], the author has presented a model for the emission of high energy particles from AGN. The following is a summary of the model.

1) Quantum effects on gravity yield repulsive forces at short distances [9],[11].

2) The collapse of black holes results in explosive bounce back motion with the emission of high energy particles.

3) Consideration of the Penrose diagram eliminates the horizon problem for black holes [12]. Black holes are not black anymore.

4) The knee energy for high energy cosmic rays can be understood as a split between a radiation-dominated region and a matter dominated region, not unlike that in the expansion of the universe. (See page 10 of the lecture notes [9]-[11].)

5) Neutrinos and gamma rays as well as cosmic rays should have the same spectral index for each AGN. They should show a knee energy phenomenon, a break in the energy spectral index, similar to that for the cosmic ray energy spectrum.

6) The recent announcement by Hawking rescinding an earlier claim about the information paradox [18] is consistent with this model.

Further discussion of the knee energy in the model yields the existence of a new mass scale in the knee energy range [19]. The following are additional features of the model.

7) If the proposed new particle with mass in the knee energy range (0.1 PeV ~ 2 PeV) is stable and weakly interacting with ordinary particles, then it becomes a candidate for dark matter. It does not necessarily have to be a supersymmetric particle. That is an open question. However, if it is supersymmetric, then it is easy to make a model for a weakly interacting particle [20]. The only requirement is that such particles must be present in AGN or black holes so that the knee energy is observed when cosmic rays are emitted from AGN. A suggested name for the particle is kneeon, sion (xion) or hizon [19].

8) If the particle is weakly interacting, then it does not obey the GZK cutoff, since its interaction with photons in cosmic background radiation is weak. This is a possible resolution of the GZK puzzle.

III. RESOLUTION OF THE GZK PUZZLE

We assume that the incident particles above the GZK cutoff observed by the Akeno-AGASA detector are weakly interacting particles at the PeV mass scale, which are required to exist in order to explain the phenomenon of the cosmic ray knee energy in the model. One has to explain a mechanism whereby the Akeno-AGASA detector is sensitive to such weakly interacting particles and all other detectors are not. This is quite conceivable, since the spacing of the detectors in the Akeno-AGASA apparatus is small (1 km between two detectors) compared with that of the other detectors [21] (1.5 km between two detectors for the Pierre Auger Project). Since weakly interacting particles in high energy cosmic rays tend to make showers at a lower altitude of the atmosphere due to the smaller cross sections, the Akeno-AGASA detector is expected to observe higher percentage of weakly interacting particles. Leaving this task of quantitative estimate to the experimentalists, the author suggests that experimental groups to determine the mass value of the incident particles at least enough to discriminate whether they are ordinary particles (protons or nuclei) or have heavy mass...
in the PeV range. In the following, the author presents a simple program to determine the mass of the incident particles. 

First let us consider the simple process $\pi^0 \rightarrow 2\gamma$. Assume that the $2\gamma$ decay is perpendicular to the direction of the $\pi^0$ in the rest frame of the pion and the energy and the angle of $2\gamma$ in the lab frame be $\omega$ and $2\theta$. Then, the total energy and momentum of the system are $2\omega$ and $2\omega \cos \theta$ respectively, and the mass of the incident pion is given by

$$\text{mass} = \sqrt{(2\omega)^2 - (2\omega \cos \theta)^2} = 2\omega \sin \theta. \quad (1)$$

In other words, the spread in the perpendicular momentum is a measure of the mass of the incident particle. Assuming that all the secondary particles are ordinary particles, i.e., massless particles compared with the PeV energy scale, the rest mass of the incident particle is estimated by

$$\text{mass} = \sqrt{\sum_j E_j^2 - \sum_j E_j \cos \theta_j^2}, \quad (2)$$

where $E_j$ and $\theta_j$ are the energy and angle relative to the direction of the incident particle for each component, respectively. We are assuming that each component is an ordinary particle and therefore massless relative to the PeV mass scale. If there is a subsystem that is like a jet so that it is difficult to separate into components, one has to treat this subsystem as a single object. In such a case, one has to determine the energy and direction of the subsystem.

The key issue is whether the Akeno-AGASA data for incident particles above the GZK cutoff have the PeV mass scale or not. That may be an opportunity to find a new particle. Intuitively, one could ask whether their data have large energy spreads. However, the determination of mass in the PeV range for the incident particle becomes more difficult for higher energy, almost impossible in the GZK cutoff range. The author suggests the following program as an alternative strategy.

1) Start with the analysis of air showers with the lowest possible energy around the knee energy. Determine the mass of the incident particles by the above method and determine the characteristics of such high mass events. A study of the correlation of energy and spread angle for the secondaries, characteristic of muon components etc., might be the important issues. This might suggest a signature for high mass events corresponding to new particles among the incident primaries.

2) Find the fraction of high mass events for higher energy. Combining that with a characteristic signature for high mass events might suggest how to determine the desired events. The most likely signature is the correlation of energy and angle for the secondaries.

3) Extension of the low energy data for this high mass event fraction to higher energy might suggest whether the proposed resolution is likely true or not. I.e., if this fraction is a constant or increasing function of energy, then it is very likely true. By continuity argument, one might be able to find whether the events that create the GZK cutoff violation are weakly interacting high mass particles.

This analysis is suggested for any experimental group doing high energy cosmic ray measurements. Such a program could lead to the discovery of a new particle, possibly a dark matter particle. That might go as follows.

I) The mass parameter for incident particles of cosmic ray showers near the knee energy is determined. A particle in the PeV mass range is expected. This would be the discovery of a sion (xion) or kneeon, which is responsible for the knee energy phenomenon in high energy cosmic rays emitted from AGN. Data from detectors for low energy showers above the knee energy, Akeno [22], Tibet [23], DICE [24], CACTI [25], HEGRA [26], HiRes/MIA [27], KASCADE [28] and Yakutsk [8] would be useful for the analysis.

II) A relationship between the observed high mass events and other signatures such as energy-angle correlation is established. Extention of this relationship to higher energy could establish that events violating the GZK cutoff are due to high mass particles established in I). This would be evidence that such particles are indeed dark matter particles.

IV. INVISIBLE AGN

Another problem among the data of the existing experimental groups is whether the correlation between high energy cosmic rays and AGN is positively established or not. In a recent article, the author has suggested the possibility of black holes made of dark matter, which results in invisible AGN [19]. Such an object is not noticed as an ordinary AGN, so that the correlation is not recognized. But, if one surveys gamma ray emitters, one should consider correlations with them as well. At the present time, the correlation has been recognized more in the data of the Pierre Auger Project than in that of other groups. It is unfortunate that the northern hemisphere component of the Pierre Auger Project has not been completed. One has to wait for a few more years to see whether the disparity between the correlations in the northern and southern hemisphere is real. More importantly, the correlation between the gamma ray emitters and high energy cosmic rays should be analyzed.

There is other observational data where a north-south asymmetry is observed [29]. This is the distribution of circular galaxies. An observed asymmetry is explained by the presence of a center for the expansion of the universe. A consistent result was obtained from the analysis of the cmb (cosmic microwave background) dipole [29]. It is conceivable to have a disparity in the distribution of dark matter due to the presence of the center of the universe and as a result, a disparity in the distribution of invisible AGN in both hemispheres.
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