Search for a dark matter particle in high energy cosmic rays

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(Dated: April 17, 2008)

Existing data hints that high energy cosmic ray experiments may offer the most promising shot at finding a dark matter particle. A search in the PeV mass range is suggested, where the discovery of such a particle might help explain the GZK cutoff violation data.

PACS numbers: 04.70.-s, 95.85.Pw, 95.85.Ry, 98.54.Cm

I. INTRODUCTION

An extensive search for a dark matter particle (DMP) is underway throughout the world[1] by underground detectors using cryogenic or electronic methods. However, there is no observational hint whatsoever as to the mass and interactions etc. of the particle searched for. A slight hope is that the forthcoming LHC experiment might give some hint as to the nature of the particle. Such a possibility might be wishful thinking, in view of the absence of any hint from Tevatron experiments in the few TeV energy range. The author will try to construct a scenario for a DMP search, as much as possible based on the observational data.

II. THE AGASA DATA ON THE GZK CUTOFF VIOLATION

High energy cosmic rays traversing intergalactic space suffer the GZK cutoff[2] above 100 EeV due to interactions with cosmic background radiation, if the primary cosmic ray particles are protons or nuclei. The Pierre Auger Project[3], HiRes[4] and Yakutsk[5] found the GZK cutoff, while Akeno-AGASA[6] observed the events above the cutoff (11 events in the past 10 years)[7]. Since the number of events that violate the GZK cutoff has been steadily increasing in the past 10 years, the discrepancies among the results for different detectors must be explained by experimentalists. Since the result of the Akeno-AGASA experiment is smooth near the cutoff energy, we have to accept their result and wait for a future explanation of the differences among the detectors. The author will assume that the Akeno-AGASA result is correct and consider its implication, until otherwise claimed.

A possible explanation for the AGASA data on GZK cutoff violation would be a shower caused by a DMP. A DMP is not constrained by the GZK cutoff, since it interacts weakly with cosmic background radiation. Then the question is how such a particle can be accelerated to an energy as high as 100 EeV. This is intimately related to the question of what is the source of high energy cosmic rays. Recent measurements by the Pierre Auger Project on the correlation between the direction of high energy cosmic rays and the location of AGN (Active Galactic Nuclei)[8] will shed some light on this question. The crucial question is then how any particle can be accelerated to as high as 100 EeV in connection with AGN. This is precisely the question that the author confronted since 1985. A model that the author presented in 1985 predicted the data from the Pierre Auger Project and at the same time solved the problem of accelerating a dark matter particle, which is a neutral particle. We start with a review of that model.

III. HIGH ENERGY COSMIC RAYS FROM AGN AND EXISTENCE OF A NEW PARTICLE AROUND THE PEV MASS RANGE

In a series of articles[8]-[16], 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[8],[10].

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[11]. 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[8]-[10].)

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[17] 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, in order to have the knee energy phenomenon in cosmic ray spectrum[18]. 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 in-
teracting with ordinary particles, then it becomes a candidate for a DMP. 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 DMP\textsuperscript{19}. 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 sion (xion\textsuperscript{18}), using the Chinese/Japanese word for knee, si (xi).

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, as was pointed out earlier. This is a possible resolution of the GZK puzzle.

In summary, this model predicts the Pierre Auger Project data. Moreover it suggests the existence of a new particle in the PeV mass range, in order to explain the knee energy phenomenon of cosmic ray spectrum.

IV. SEARCH FOR A NEW PARTICLE BY HIGH ENERGY COSMIC RAY DETECTORS.

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. In a model where the acceleration takes place by gravity such as that proposed by the author, there is no difficulty in accelerating a weakly interacting and neutral DMP. One has to explain a mechanism whereby the Akeno-AGASA detector is sensitive to such weakly interacting particles and all other detectors are not, as was pointed out earlier. This is quite conceivable, since the spacing of the detectors in the Akeno-AGASA apparatus is small (1 km between detectors) compared with that of the other detectors (1.5 km between detectors for the Pierre Auger Project). Besides, a direct measurement of showers may give higher sensitivity for weakly interacting particles: Since weakly interacting particles in high energy cosmic rays tend to make showers at lower altitude in the atmosphere due to the smaller cross sections, the Akeno-AGASA detector is expected to observe a higher percentage of weakly interacting particles. Leaving this task of quantitative estimate to the experimentalists, the author suggests the following method for detecting such a DMP.

A weakly interacting DMP has interactions increasing with energy, similar to the ordinary weak interactions of the standard model. The strength reaches a maximum at an energy comparable to the mass scale, i.e., at PeV center of mass energy. This corresponds to a lab energy of 100 EeV. Thus, a weakly interacting DMP can make a shower, maybe at a lower level of the atmosphere. If it is a sion, it has to be produced abundantly in AGN, to the extent that it produces the knee energy phenomenon in cosmic ray energy spectrum. If it is a neutral component of a sion, a collision with an atmospheric nucleus has to produce the same particle carrying a significant fraction of the initial momentum along with a shower, but it does not contribute to the production of a shower. Such a particle can produce a secondary shower in the neighborhood of the center of the primary shower after passage through the atmosphere or it may completely disappear from the sight. It can produce an artificial shower from shielding material in front of, say the muon detectors. This consideration naturally yields a possible scenario for the detection of a DMP. See Fig. 1 for a schematic layout of experimental setup.

1) Choose a cosmic ray shower detector equipped with underground muon detectors. With muon detectors at an appropriate depth, the thickness of the earth may play the role of shield material. If not, one has to provide some thickness of shielding in front of the secondary muon detectors. An artificial shower in the shield-muon detector system coincident with the primary shower and near its center constitutes evidence for a DMP. Some of the existing cosmic ray shower detectors, Auger\textsuperscript{3}, hires\textsuperscript{4}, yakutsk\textsuperscript{5}, AGASA\textsuperscript{6}, tibet\textsuperscript{20}, dice\textsuperscript{21}, cacti\textsuperscript{22}, hegra\textsuperscript{23}, kascade\textsuperscript{24}, may be utilized for such a purpose with small modifications. If the incident particles are protons or nuclei, there is no secondary shower observed, unless much higher energy than 100 EeV are attained, where pair production of PeV DMP is expected.

2) Collect the shower energy data. The threshold value for the energy of the secondary shower provides the lowest mass value for a DMP. Find the energy dependence of the fraction of the DMP component in high energy cosmic rays. Extend the measurement above the GZK cutoff energy, 100 EeV.

3) Find whether measurements with the Akeno-AGASA equipment can relate the data above and below the GZK cutoff. This may establish the weakly interacting nature of the particle that causes the secondary shower and at the same time resolve the puzzle of the GZK cutoff violation\textsuperscript{7}.

4) Study the difference in nature between showers caused by nuclear particles and those caused by a DMP. That will be useful for confirmation of the detection of a DMP.

5) Large muon detectors in collider experiments may be combined with nearby cosmic ray shower detectors in the search for a DMP. Alternatively, they can be utilized as independent detectors for a DMP search, if the nature of a DMP shower is clarified.

The advantage of this method for a DMP search is that all the arguments are based on observational data, compared with existing DMP searches. Due to the nature of weakly interacting particles, the interaction cross sections increase with energy and therefore high energy cosmic rays are a natural place to look for DMP. Recent data of the Pierre Auger Project along with the prediction of the author’s model of the author suggests that new particles, sions, must be produced abundantly in the AGN.
Acknowledgments

The author would like to thank Lawrence W. Jones and Jean Krisch for useful discussion and David N. Williams for reading the manuscript.

[1] DM 2008, Dark Matter and Dark Energy in the Universe, Feb. 20-22 (2008), California, http://ppd.fnal.gov/experiments/cdms/.

[2] Greisen, K., Phys. Rev. Lett. 16, 748 (1966); Zatsepin, G. T. and Kuzmin, V. A., Pisma Z. Experim. Theor. Phys. 4, 114 (1966).

[3] The Pierre Auger Collaboration, Science 318, 938 (2007); Correlation of the Highest-energy Cosmic Rays with the Positions of Nearby Active Galactic Nuclei, arXiv: 0712.2843 (2007).

[4] Abbasi, R. U. et al., Astropart. Phys. 27, 370 (2007); Observation of the GZK Cutoff by the HiRes Experiment, arXiv: astro-ph/0703099 (2007).

[5] Glushkov, A. V. and Pravdin, M. I., JETP 101, 88 (2005).

[6] Shinozaki, K. et al., Nucl. Phys. B (Proc. Suppl.) 136, 18 (2004); Nagano, M. and Watson, A. A., Rev. Mod. Phys. 72, 689 (2000).

[7] Berezinsky, V., Astroparticle Physics: Puzzles and Discoveries, arXiv:0801.3028 (2008).

[8] Tomozawa, Y., Magnetic Monopoles, Cosmic Rays and Quantum Gravity, in the Proc. of 1985 INS International Symposium on Composite Models of Quarks and Leptons (Tokyo, edit. Terazawa, H. and Yasue, M., 1985), pp. 386.

[9] Tomozawa, Y., The Origins of Cosmic Rays and Quantum Effects of Gravity, in Quantum Field Theory (ed. Mancini, F., Ersever Science Publishers B. V., 1986) pp. 241. This book is the Proceedings of the International Symposium in honor of Hiroomi Umezawa held in Positano, Salerno, Italy, June 5-7, 1985.

[10] Tomozawa, Y., Cosmic Rays, Quantum Effects on Gravity and Gravitational Collapse, Lectures given at the Second Workshop on Fundamental Physics, University of Puerto Rico, Humacao, March 24-28, 1986. This lecture note can be retrieved from KEK Kiss NO 200035789 at http://www-lib.kek.jp/KISS/kiss_preprint.html

[11] Tomozawa, Y., Gravitational Waves, Supernova and Quantum Gravity, in Symmetry in Nature, (Scuola Normale Superiore, Pisa, 1989) pp. 779, Section 2 and 3.

[12] Tomozawa, Y., Exact Solution of the Quantum Einstein Equation and the Nature of Singularity, in the Proc. 5th Marcel Grossman Meeting on General Relativity (ed. D. Blair et al., Perth, Australia, 1988) pp. 527.

[13] Tomozawa, Y., Black Hole Oscillation, in the Proc. 5th Marcel Grossman Meeting on General Relativity (ed. D. Blair et al., Perth, Australia, 1988) pp. 629.

[14] Majumdar, A. and Tomozawa, Y., Progr. Theoret. Phys. (Kyoto) 82, 555 (1989).

[15] Majumdar, A. and Tomozawa, Y., Nuovo Cimento 197B, 923 (1992).

[16] Tomozawa, Y., Astron. Astrophys. Suppl. Ser. 97, 117 (1993).

[17] Hawking, S., http://www.newscientist.com/article/dn6151.html

[18] Tomozawa, Y., High Energy Cosmic Rays, Gamma Rays and Neutrinos from AGN, arXiv: 0802.0301 (2008); High Energy Cosmic Rays from AGN and the GZK Cutoff, arXiv: 0802.2927 (2008).

[19] Wells, J. D., Phys. Rev D71, 015013 (2005).

[20] Amenomori, M. et al., Astrophys. J. 461, 408 (1996).

[21] Boothby, K. M. et al., Astrophys. J. Lett. 491, L35 (1997).

[22] Paling, S. et al., in the Proc. ICRC 1997 (ed. Potgieter, M. S. et al., World Scientific, Singapore, 1997), Vol. 5, p. 253.

[23] Cortina, J. et al., in the Proc. ICRC 1997 (ed. Potgieter, M. S. et al., World Scientific, Singapore, 1997), Vol. 4, p. 69.

[24] Antoni, T. et al., Astropart. Phys. 14, 245 (2001).

Figure caption

Fig. 1 Schematic figure for dark matter particle search in cosmic ray experiment.
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