Cosmic Rays from AGN, the Knee Energy Mass Scale and Dark Matter Particles

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Following the possibility of a new mass scale at the 3 PeV knee energy of the cosmic ray energy spectrum, the author suggests that the mass for a dark matter particle should be 8.1 TeV, using GLMR supersymmetry theory. The author discusses the possibility of detecting such a signature in various observational facilities, gamma ray, neutrino and other underground detectors. An analysis of recent data from HESS yields a gamma ray peak at 7.6 ± 0.1 TeV, providing observational evidence for a dark matter particle mass consistent with the theoretical prediction. The author also suggests that the observed discontinuity in the power law index in galaxy correlation functions is the knee energy counterpart in cosmology.

1. Introduction

An extensive search for a dark matter particle (DMP) is under way 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. There is a slight hope that a forthcoming LHC experiment might give some hint as to the nature of the particle. That 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.

2. High energy cosmic rays from AGN and existence of a new mass scale at the knee energy

In a series of articles[2]-[10] since 1985, 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[2],[4].
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[5]. Black holes are not black any more.
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[2]-[4].)
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[11] 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 the cosmic ray spectrum[12]. The following are additional features of the model.

7) The proposed new particle with mass in the knee energy range (at 3 PeV) may not be stable, as in the case of the standard model. If it is a member of a supersymmetric multiplet and weakly interacting with ordinary particles, then the stable particle of lowest mass becomes a candidate for a DMP. The only requirement is that such particles must be present in AGN or black holes so that the phenomenon of the knee energy is observed when cosmic rays are emitted from AGN.
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 electromagnetic at best. This is a possible resolution of the GZK puzzle[13],[14].

It will be discussed in a later section.
3. The knee energy of cosmic ray energy spectrum

In the traditional theory, cosmic rays below the knee energy are considered to be of galactic origin, such as those produced by supernova explosions.\[15\], \[16\]. They are confined inside the galaxy by the galactic magnetic field for a long time, as far as low energy components are concerned. The high energy components, however, cannot be confined inside the galaxy by the galactic magnetic field and therefore they are considered to fall down as a function of energy beyond the knee energy. This is inferred as the reason for the existence of the knee energy. Then, one has to introduce, say, extragalactic cosmic rays to supplement the missing components of the $E^{-3}$ spectrum above the knee energy. A perfect matching of the intensities of the galactic and extragalactic components of cosmic rays has to be assumed here. This is the intrinsic difficulty of the traditional model of cosmic rays, in particular for the explanation of the existence of the knee energy. This difficulty persists in any model which is constructed with two independent components for the total cosmic ray spectrum. How does one find a reason for the matching of intensities for two independent and unrelated components? The model proposed by the author since 1985 tried to eliminate such a difficulty. The details are described in the earlier references\[2\], \[3\], \[4\]. A simple discussion is recapitulated here.

As described in the previous section, the model started from the realization that quantum effects on gravity yield a repulsive force at short distances. As a result, the collapse of a black hole proceeds to an explosion and an expanding heat bath emits various kinds of particles. This is the reason for the emission of high energy cosmic rays, gamma rays, neutrinos and dark matter particles from black holes. The spectrum of an emitted particle $X$ with spin $s$ is calculated by

$$f_X(E) = \frac{2s+1}{2\pi^2} \int \frac{E^2 V_S dt}{e^{E/kT - \mu/kT} \pm 1}, \quad (1)$$

where $V_S$ is the effective volume around the surface of the heat bath with temperature $T$ that emits particles. The $\pm$ sign in the denominator is for fermions/bosons. With the assumption

$$V_S = \frac{4\pi a}{(kT)^3} \quad (2)$$

and the expansion rate

$$t = bR^\alpha \quad (3)$$

and

$$R = \frac{d}{kT}, \quad (4)$$

where a, b, and d are constants, one can compute the number of particles

$$f_X(E) = \frac{A_{X,\alpha}}{E^{\alpha+1}}, \quad (5)$$

where

$$A_{X,\alpha} = \frac{2(2s+1)ab^\alpha}{\pi} \int_0^\infty x^{\alpha+2}dx \quad (6)$$

and

$$\mu_0 = \mu/kT, \quad x = E/kT. \quad (7)$$

From the expansion rate in cosmology, the exponent $\alpha$ can be estimated as

$$\alpha = 2 \quad \text{for radiation-dominated regime} \quad (8)$$

and

$$\alpha = 3/2 \quad \text{for matter-dominated regime}. \quad (9)$$

This gives the energy spectrum at high energy

$$f_X(E) \approx 1/E^3 \quad (10)$$
and at low energy

\[ f_X(E) \approx \frac{1}{E^{2.5}}. \]  

(11)

This is exactly the observed spectrum of cosmic rays. That is the explanation for the observed cosmic ray energy spectrum and the existence of the knee energy, proposed in my model in 1985[2]...[10]. More recently, it was realized[12] that the model requires the existence of a mass scale at 3 PeV in order to produce the knee energy phenomenon, since without it all ordinary particles behave as mass-less radiations at temperature 3 PeV. The existence of a new mass scale is the starting point for the discussion of DMP in the sections that follow.

Coming back to the discussion of cosmic ray models, gravitational collapse yields the emission of high energy particles, cosmic rays, gamma rays, neutrinos and possibly DMP. The sources can be extragalactic AGN as well as galactic black holes. Their energy spectra have identical shapes, so simple addition should yield the final energy spectrum. In order to confront with the difficulty that galactic cosmic rays fall down above the knee energy, one may assume that cosmic rays from AGN and black holes dominate the energy spectrum. The magnitude of galactic cosmic rays produced by supernova explosion is assumed to be less than 10 % of the total cosmic ray intensity. Then, the decrease of the intensities of nuclear cosmic rays will not influence the total intensity. Of course, this assumption must be carefully examined by the analysis of future data. Certainly, heavy nuclear components of cosmic rays satisfy this assumption. The question whether the proton and helium components satisfy it must be scrutinized. A complicated structure around the knee energy observed by the KASCADE group[17] may be consistent with this picture: A small variation in nuclear cosmic rays at this energy can be the source for complicated structure in the spectrum around the knee energy.

The most important prediction for the author’s model is the existence the knee energy at 3 PeV in the spectra of gamma rays and neutrinos. Such an observation would clearly show that the knee energy phenomenon has nothing to do with the galactic magnetic field. One needs to wait a few more years to test this prediction by observation.

4. Probability of association between AGN and cosmic ray sources

In summary, the author’s cosmic ray model going back to 1985 has predicted the Pierre Auger Observatory data[18]. Moreover it suggests the existence of a new particle in the PeV mass range, in order to explain the knee energy phenomenon of the cosmic ray spectrum. There seem to exist some high energy cosmic ray events that are not associated with AGN among the Pierre Auger Project data. This is understandable since if AGN-like phenomena are produced exclusively by dark matter particles (one may call them pseudo-AGN) without a component of ordinary atomic particles, they won’t show up as AGN events. One needs atomic matter to have an AGN signature. In such cases, cosmic ray events should be associated with high energy gamma ray emitters. There are gamma ray emitters that are not associated with known astronomical objects. It is worth trying to match cosmic ray and gamma ray events with identical unknown sources. The probability of the association of AGN with high energy cosmic rays should be of the order of (baryonic matter)/(all matter) = 0.15. Namely, only 15 % should have a correlation in a first order approximation. In a second order approximation, this number might be increased by the emission of ordinary baryons from exploding black holes. In the long run, baryons emitted from black holes would increase the probability of converting from a pseudo-AGN to an ordinary AGN, but it might take a long time. If the probability of the association of AGN and high energy cosmic rays in the Pierre Auger Project data were much larger than 15 %, it would indicate a high probability of forming ordinary AGN from pseudo-AGN and would further indicate a probability of forming ordinary galaxies from pseudo-AGN and AGN.

5. PeV supersymmetry of GLMR and the DMP mass

In order to have a mass scale of 3 PeV and DMP of relatively low mass, one has to have a supersymmetry model with a large mass ratio. Such a theory has been proposed by GLMR (Giudice, Luty, Murayama and Rattazzi). Assuming the absence of singlets, GLMR derived a large mass ratio[19], [20]

\[ M_2 = \frac{\alpha}{4\pi \sin^2 \theta_W} m_{3/2} \]

(12)

\[ = 2.7 \times 10^{-3} m_{3/2}, \]

(13)
among other parameter relations, where \( \alpha \) and \( \theta_W \) are the fine structure constant and the weak interaction angle respectively. Here \( M_2 \) and \( m_{3/2} \) stand for a gaugino and a gravitino mass for in the GLMR theory, respectively. Since this is the largest mass ratio obtained, one may choose the highest mass scale to be

\[
m_{3/2} = 3 \text{ PeV},
\]

then one gets

\[
M_2 = 8.1 \text{ TeV},
\]

which is the mass of the lowest mass particle (LMP), i.e., the DMP mass. The accuracy of the prediction is in the range of 10\(^{-20}\) % from the determination of the cosmic ray knee energy. Being weakly interacting, this particle must be produced by a pair in an accelerator experiment. This makes it impossible to discover such particles directly in LHC experiments at the presently planned energy scale. Since, however, this DMP mass will be close to the maximum energy of LHC experiments in the near future, it might be possible to see the existence of such a particle as a new physics signature in a LHC experiment. It is worth noting that if something like the GLMR supersymmetry is not used, then the DMP mass should be much higher than 8.1 TeV, insofar as it is related to the cosmic ray knee energy mass scale.

Although knee energy particles are produced at 3 PeV at AGN, they eventually decay into DMP of 8.1 TeV, and that is what will be observed on Earth. We consider the direct detection of DMP in cosmic rays, gamma rays and neutrinos in subsequent sections. Using the name cion (originally sion) for particles in generic sense\(^{[12]} \), one may call the particle at 3 PeV a prime-cion or urcion, since it is of primary importance. The DMP at 8.1 TeV may be called a dm-cion for obvious reasons. The name cion comes from the Chinese word for knee, Xi, pronounced shi. It is also an acronym for cosmic interphase particle. The cion is introduced to explain the cosmic ray knee energy by a mass scale that separates the radiation- and matter-dominated phases for black hole expansion.

The same phenomenon can apply to the expansion of the universe: The different expansion rates in radiation- and matter-dominated phases of the universe should be separated by a temperature of 3 PeV with the introduction of the prime-cion. This phenomenon may have contributed to the dominance of dark matter over baryons in the universe. It is worth searching for observational evidence for different expansion rates in the early universe. In a later section, the counterpart of the knee energy in cosmology will be sought in the galaxy correlation functions.

6. Production of DMP along with cosmic rays and its interaction

With center of mass energy \( m_{3/2} = 3 \text{ PeV} \), the interaction becomes maximum at the lab energy

\[
E_{\text{max}} = \frac{m_{3/2}^2}{2M} = 0.32 \times 10^{21} \text{eV} = 0.32 \text{ ZeV}
\]

\[\text{for } M = 14 \text{ GeV},\]

where the cross section is of the order of electromagnetic interactions. A mass scale of 14 GeV has been chosen from a dominant mass in the atmosphere, that of nitrogen. This energy is close to the GZK (Greisen, Zatsepin and Kumin\(^{[13]} \)) cutoff energy. The DMP cross section decreases linearly with energy, while the intensity increases with decreasing energy, \( (E^{-3} \text{ above the knee energy and } E^{-2.5} \text{ below the knee energy}) \). Therefore, the product of the cross section and the intensity function favors the low energy end for detection. In other words, DMP in cosmic rays accumulate on the earth and the lowest end of the spectrum can be observed most easily. This tells what is the best way to detect DMP in cosmic rays.

The cross section for DMP interaction can be parametrized as

\[
\sigma = \sigma_{EM}(E/E_{\text{max}}),
\]

where

\[
\sigma_{EM} = 10^{-26} \text{cm}^2 = 10^{-30} \text{m}^2.
\]

Assuming that the energy distribution of DMP from AGN is the same as that of observed cosmic rays, one can parametrize it as

\[
F = \frac{\sqrt{2}m_{3/2}^3}{E^{5/2}(E + m_{3/2})^{1/2}}F_{KN},
\]
where

$$F_{KN} = 3.0 \times 10^{-14} \left( m^2 \text{sr s GeV} \right)^{-1}$$  \hspace{1cm} (21)$$

stands for the flux at the knee energy, $m_{3/2} = 3 \text{PeV}$. The resultant flux for target mass $M$ in one km w.e.
(water equivalent),

$$\rho = \left( \frac{1}{1.67 \times 10^{-30}} \right) 10^3 \frac{1 \text{GeV}}{M} m^{-2} = 0.59 \times 10^{33} \frac{1 \text{GeV}}{M} m^{-2}$$  \hspace{1cm} (22)$$
is given by

$$I = \int_{M^2}^{\infty} F \sigma \rho dE = \frac{F_{KN} \sqrt{2} m_{3/2}^2 \sigma_{\text{EM}} \rho}{E_{\text{max}}} \int_{M^2}^{\infty} \frac{dE}{E^{3/2} (E + m_{3/2})^{1/2}}$$  \hspace{1cm} (23)$$

$$= \frac{2 \sqrt{2} m_{3/2}^2 \sigma_{\text{EM}} \rho}{E_{\text{max}}} \sqrt{\frac{M^2 + m_{3/2}}{M^2}}$$  \hspace{1cm} (24)$$

$$= 3.0 \times 10^{-14} \times 4 \sqrt{2} \times 10^{-30} \times 0.59 \times 10^{33} \sqrt{m_{3/2}/M_2}$$  \hspace{1cm} (25)$$

$$= 1.92 \times 10^{-3} m^{-2} \text{sr}^{-1} \text{s}^{-1}. $$  \hspace{1cm} (26)$$
The final result is independent of the target mass, $M$, and is proportional to $\sqrt{m_{3/2}/M_2}$. The value of this quantity has been chosen to be

$$\sqrt{m_{3/2}/M_2} = 1/\sqrt{2.7 \times 10^{-3}} = 19.2$$  \hspace{1cm} (27)$$
in the above estimate. The choice of a smaller value for $M_2$ results in an increased value for Eq. (26).

### 7. Underground muons, a bump in the dip

The vertical muon intensity for underground muons as a function of depth (measured in the units of km.w.e.) is well investigated\[21\]. Cosmic ray muons impinging on the surface of the Earth ground level start to decrease by scattering and decay, and then become a flat distribution at a depth of 15 km.w.e. The vertical muon intensity is given as the saturated value of the vertical intensity with

$$F_\mu = 4.0 \times 10^{-9} \text{ m}^{-2} \text{sr}^{-1} \text{s}^{-1}$$  \hspace{1cm} (28)$$

$$= 2.0 \times 10^{-9} \text{ m}^{-2} \text{sr}^{-1} \text{s}^{-1}$$  \hspace{1cm} (29)$$
in the horizontal and vertically upward directions respectively. The interpretation of this data is that the flat distribution is due to muon production by atmospheric neutrinos, which are the product of cosmic rays hitting the atmosphere. The difference between horizontal and vertical in Eqs. (28) and (29) is considered to be due to neutrino oscillation. Depending on the direction and energy of the injected atmospheric neutrinos and the location of the interaction, the intensity of neutrinos and subsequently produced muons varies by neutrino oscillation.

The vertical muon intensity varies as

$$F_\mu = Ae^{-bX}$$  \hspace{1cm} (30)$$

for small depth $X$ measured in units of km.w.e. From Figure 20.5 of Ref. \[21\], one can read

$$\frac{F_\mu(X = 10)}{F_\mu(X = 1)} = e^{-9b} = 10^{-6},$$  \hspace{1cm} (31)$$

and then

$$b = \frac{6}{9} \ln 10 = 1.54 \ (\text{km.w.e.})^{-1}.$$

(32)
The dark matter contribution for muon production is computed by

\[ \frac{dF_\mu(DMP)}{dX} = a - bF_\mu(DMP), \]

where

\[ a = \epsilon_\mu I. \]

Here \( I \) is computed in Eq. (26) and \( \epsilon_\mu \) is the muon multiplicity. Since the process is dominated by the low energy end of the dark matter interaction, one can assume that

\[ \epsilon_\mu = 1. \]

The solution of Eq. (33) is given by

\[ F_\mu(DMP) = \frac{a}{b} (1 - e^{-bX}), \]

where the asymptotic value of \( F_\mu(DMP) \) is

\[ F_\mu(DMP) = \frac{a}{b} = \frac{I}{b} = 1.25 \times 10^{-9} m^{-2} sr^{-1} s^{-1}. \]

Using Eq. (28), one gets a separation of neutrino and DMP contributions for the asymptotic value,

\[ \frac{F_\mu(\text{neutrino})}{F_\mu(DMP)} = 4.0 - 1.25 = 2.75. \]

In other words, we have concluded that the contribution of DMP for vertical muons is 45% of that for neutrinos.

Based on this estimate, one can propose a method of detecting the DMP contribution for vertical muons. First choose the direction for which the damping effect due to neutrino oscillation is maximal. This is the direction which creates maximum suppression of the peak in the muon momentum distribution. In other words, one should observe a deep dip in the muon momentum distribution. Since there is no oscillation phenomenon for DMP, the contribution of DMP to vertical muon production is determined as a bump in the dip. This is the key for the discovery of a DMP contribution in the muon distribution. In any other direction, there is a tilted excess over a dip.

Let me mention the status of the AMANDA observation. The data relevant for the DMP mass covers a range below 6 TeV at the present time, short of 8 TeV. The absence of significant DMP evidence in AMANDA is inevitable. Relevant data on a bump in the dip in AMANDA is given in Fig. 2, where the zenith angle distribution of the upward muon is shown. The number of events in one direction is of the order of 10. This is not enough events to see the phenomenon of a bump in the dip. One may need one order of magnitude more events. The same comments can be applied to other underground detectors, such as super-Kamiokande, Sudan etc. One may need a larger detector, such as DUSEL (Deep Underground Science and Engineering Laboratory), planned in Homestake, SD.

8. A sharp peak in gamma ray spectrum

The collision of a DMP and its antiparticle produces 2 gammas,

\[ DMP + AntiDMP \rightarrow \gamma + \gamma. \]

peaked at the DMP mass. In our model this sharp peak should occur at 8.1 TeV. This is in an accessible range for present gamma ray observatories such as HESS and VERITAS. Obviously, this is an event similar to the observation of 511 keV gamma rays as evidence for positrons. The author will present a discussion about where to look for such events.

8.1. PKS 2005-489

HESS observed gamma ray events above 100 GeV from BL Lac object PKS 2005-489 (\( z = 0.071 \)) in 2004-2007. A summary of their observation reads.

1) Below 2 TeV, they obtained the spectrum of a power law fit with a photon index of 3.2.
2) Above 2 TeV (upto 10 TeV), they observed a gamma ray excess relative to the above power law spectrum.

It would be interesting to see whether this excess would result in a sharp peak in the multi TeV range upon statistical improvement in the future.
8.2. Galactic center

There is a black hole of 2.6 million solar mass at the center of the Milky Way[24]. Using the model proposed by the author, one can expect the emission of cosmic rays, gamma rays and neutrinos as well as DMP from such black holes. This has an advantage for their detection by proximity. While high energy cosmic rays are diverted by galactic magnetic fields, all of the other particles mentioned above can be detected directly. In fact, the author has suggested that the DAMA data[25] implies that 30 % of any dark matter observed there should originate from the galactic center[26]. It would be worthwhile to see whether the remnant of gamma rays from the galactic center can be observed.

8.3. Sources of high energy cosmic rays observed by the Pierre Auger Project

The gamma rays observed from PKS 2005-489 (z = 0.071) by HESS suggest that TeV gamma rays can reach the Earth if the sources are relatively nearby. Therefore, the sources of high energy cosmic rays observed by the Pierre Auger Project can be attractive for TeV gamma rays and DMP, if the distances are nearby[18]. The Pierre Auger Project reported a high concentration of high energy cosmic ray sources near the location of Centaurus A (l = 309.5158, b = 19.4173). The distance to Centaurus A is 547 km/s or z = 0.001825. The abundance of high energy cosmic rays makes this direction an attractive target for gamma ray observation as well. Why does this direction have copious sources of high energy cosmic rays? The next subsection will provide a hint.

8.4. Center of the universe

The author has determined the location of the center of expansion of the universe from the observed values of thecmb (cosmic background radiation) dipole and peculiar velocity. The latter is the sum of that of the solar system towards the Virgo cluster and that of the Virgo cluster towards the Great Attractor. The observed cmb dipole and total peculiar velocity are very different both in magnitude and direction, as opposed to the assumption often made. Based on this observation, the author computed the location of the center of the universe to be[27]

\[
\begin{align*}
v &= 5325.8 \pm 198 \text{ km/s}, \quad l = 313.2 \pm 0.2^\circ, \quad b = 12.5 \pm 0.3^\circ \\
o &rder=40\end{align*}
\]

or

\[
\begin{align*}
v &= 5434.5 \pm 208 \text{ km/s}, \quad l = 313.0 \pm 0.2^\circ, \quad b = 16.4 \pm 0.3^\circ. \\
\end{align*}
\]

(These are corrected values from a numerical mistake in the values quoted in the reference[27]. See errata to appear.) The difference between these estimates originates from two different estimates of the peculiar velocity for the solar system towards the Virgo cluster by Sciama[28, 29, 30]. The directions of these solutions are close to that of Centaurus A The direction of Centaurus A is nothing but the direction of the center of the universe. It is a special direction, indeed. Since the model proposed by the author can be applied to the expansion of the universe, DMP can be emitted when the temperature of the universe is 3 PeV. This may have something to do with the dominance of dark matter in the universe over baryons, as was mentioned earlier. Then, remnants of the expansion accumulated in the neighborhood of the center of the universe. It would be worthwhile to see whether a sharp peak for gamma rays in the multi TeV range can be observed in this direction. The distance to the center of the universe is much closer than that to PKS 2005-489, which is 21285 km/s.

8.5. Statistical sum of all data in the multi-TeV range

An alternative general suggestion is that one could accumulate all gamma ray data in the multi-TeV region with an appropriate statistical weight. That could make it easier to see a sharp peak. After finishing the original version of this article, I have looked through all the data from HESS, VERITAS, MAGIC and CANGAROO, and I found one data set which gives a satisfactory answer to this question. See the following section for the data analysis.
9. Observed gamma ray peak as evidence for a dark matter particle

In a recent HESS report[31], high energy gamma rays from 8 unknown sources have been recorded. The data from each source cover the energy range of 1 to 40 TeV and have similar statistics, since they have been obtained in a recent systematic survey. That the sources are unknown may not be a drawback for a dark matter gamma ray search, since unknown sources may not be ordinary AGN or other known astronomical objects. If the source is an AGN type object consisting entirely of dark matter particles (called pseudo-AGN in Section IV), it may not have the signature of an ordinary AGN, since such a signature needs ordinary matter to emit atomic photons. The presence of abundant dark matter favors 2 gamma ray emission from DMP and anti-DMP annihilation. One does not need to exclude gamma ray emitters such as ordinary AGN etc, since one expects a DMP environment in such a case as well. The simple sum of gamma rays from the 8 sources is plotted in Fig. 1. The values at energy 2, 4, 6, 8, 10 and 12 TeV are estimated from the interpolation of those at the neighboring observed points. The error bars are estimated from the existing data. The sum clearly shows a peak at 7.6 ± 0.1 TeV. This is consistent with the predicted value of 8.1 ± 0.8 TeV (assuming 10 % accuracy for the knee energy determination). See a separate report for more discussion[32]. I did not include any analysis at energy higher than 12 TeV, since the data points there are in the range of a 10 TeV bin, while it is a 2 TeV bin below 10 TeV.

If this result were confirmed by further data from HESS and other high energy gamma ray detectors, that would suggest that LHC experiments will find neither a dark matter particle nor any supersymmetric new particle with the presently planned energy scale. One needs 16 TeV to produce a pair of dark matter particles, each having 8 TeV. A dark matter particle is the lowest mass member of any supersymmetric theory. The presently attained energy at LHC is 7 TeV, possibly reaching 14 TeV in the near future. It would be vitally important if a method could be found to increase the output energy of the particle accelerator.

10. Neutrinos from AGN: Energy spectrum and the knee energy

As the author has suggested since 1985, neutrinos and gamma rays should be emitted from AGN, for the same reason that high energy cosmic rays are emitted. The ratio of neutrinos and gamma rays is given by

$$\frac{A_{\nu, \lambda-1}}{A_{\gamma, \lambda-1}} = \frac{2 \times 3 \sum_{n=1}^{\infty} (-1)^n \frac{\Gamma(\lambda+2)}{n^{\lambda+2}}}{2 \sum_{n=1}^{\infty} \frac{\Gamma(\lambda+2)}{n^{\lambda+2}}} = 3(1 - \frac{1}{2^{\lambda+1}}),$$

(42)

where $\lambda$ is the gamma ray energy spectrum index. The same formula in ref. [12] is missing a factor of 2, which is the formula for a Majorana neutrino. This value is given as

$$3(7/8, 0.912, 15/16) \text{ for } \lambda = (2, 2.5, 3).$$

(43)

The energy spectra for neutrinos and gamma rays emitted from AGN should have the knee energy phenomenon at 3 PeV, the same energy as that for cosmic rays. This is because internal structure from the presence of the prime-cion is the cause of the knee energy. There should be a universal knee energy at 3 PeV for all particles emitted from AGN. For gamma rays, the energy spectrum may be modified by interaction with other photons or intergalactic materials, but a discontinuity in the spectral index should persist.

11. The AGASA data on GZK cutoff violation

High energy cosmic rays traversing intergalactic space suffer the GZK cutoff[13] above 100 EeV due to interactions with cosmic background radiation, if the primary cosmic ray particles are protons or nuclei. The Pierre Auger Project[16], HiRes[33] and Yakutsk[34] found a GZK cutoff, while Akeno-AGASA[35] observed the events above the cutoff (11 events in the past 10 years)[14]. 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 noted.

An important difference between the AGASA instrument and most of the other cosmic ray detectors is the capability of gamma ray shower observation[35]. Because of the small scale of the detector and direct
measurement of the shower, AGASA was able to detect a lot of gamma ray showers, and GZK-cutoff-violating showers are on the borderline between gamma ray showers and ordinary nuclear showers. Therefore, it is not surprising that only the AGASA detector has observed GZK-cutoff-violating events. One has to have the capability of observing gamma ray showers in order to catch GZK-cutoff-violating events. In this respect, a new project of the Utah group (TAP, Telescope Array Project[36]) that aims to detect gamma ray showers is the most promising approach.

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. The model described in this article and since 1985 answers precisely this question. As is described in the earlier sections, the production of DMP, as well as high energy cosmic rays, from AGN is a natural conclusion of the model.

12. The remnant of SN87A

Many remnants of supernovae II are neutron stars or pulsars. The remnant of the supernova SN87A is not a pulsar. Although there is no evidence reported yet, it is most likely a black hole, if not a neutron star with a slow rotation. If it is a black hole, it will never be a neutron star in the future according to the old theory of black holes, since the mass of a black hole can only increase, never decrease. However, with the model proposed by the author since 1985, the mass of a black hole can decrease by the emission of cosmic rays, gamma rays, neutrinos and DMP. Black holes are not black any more. Then, a black hole, a remnant of SN87A, can become a neutron star, if some matter such as a stray astronomical object collides with it, resulting in an explosion. It could lose enough mass to become a neutron star. At least that is a possible scenario.

13. Implication for cosmology: galaxy correlation functions

The scenario for black hole explosion by quantum-field-theory originated repulsive forces can be applied to the expansion of the universe. In particular, if the expansion of the universe is preceded by its collapse, then the both scenarios for black holes and the universe are identical. Therefore, the split between radiation-dominated and matter-dominated eras should occur at a temperature of 3 PeV for the universe, similar to that for AGN. The presence of prime-cion and dm-cion must be the cause of the predominant presence of dark matter in the universe. Then, can one find evidence for a discontinuity in the index of the expansion rate of the universe, just as the knee energy for cosmic rays is evidence for a difference in the expansion rates for AGN? Where is the history of the expansion of the universe imprinted? The most likely place would be in the galaxy correlation functions, since distance between galaxies or pre-galaxies should expand with the expansion of the universe. Can one find a discontinuity in the index of correlation functions?

13.1. Correlation functions in distance r and angular variable

The correlation function is represented by a single power law[37] in the distance variable,

\[ \xi(r) = \left( \frac{r_0}{r} \right)^{1.77 \pm 0.04}. \] (44)

However, the same book reported[38] a power law split in angular correlation functions. These two sets of data may indicate that the distance correlation functions may not reach to far distance, while the angular correlation functions may have a far reach. Thus one may look for more recent data from the galaxy redshift survey.

13.2. ESO Slice Project (ESP) Galaxy Redshift Survey

Recent data from the galaxy redshift survey[39] contains information on correlation functions at further distance than that of the distance correlation functions. They obtained a discontinuity in the power law index in the red shift variable hs. This discontinuity at hs = 3(Mpc) may be viewed as a split between radiation-dominated and matter-dominated expansion rates. Obviously, the smaller value of hs corresponds to radiation-dominated, and the larger value to matter-dominated expansion. In other words, this is the phenomenon in cosmology that corresponds to the knee energy in the cosmic ray energy spectrum.
14. Relation between AGN and galaxies

In the old picture of black holes, AGN is the outcome of collapsed or collided galaxies. Once the AGN stage is attained, that of a massive black hole, there is no way to go back to an ordinary galaxy, since going to a smaller black hole is prohibited. Then, why are most AGN observed at far distant locations? In the new picture of black holes, however, this is not required. By collision or collapse, a massive black hole can go to a smaller black hole or even to an ordinary galaxy, if enough objects are emitted and low energy components are accumulated at a nearby location. At least, that is an added scenario to play with. It is quite conceivable that an object can start as a massive black hole, i.e. an AGN object, then, by a collision or collapse of accumulated matter in the neighborhood yield an ordinary galaxy. This possibility provides flexibility in constructing added scenarios for galaxy formation in cosmology.

15. Implication of the proposed model

One of the most significant advancements in cosmic ray observations has been the discovery of correlations between very high energy cosmic rays and AGN by the Pierre Auger Observatory.[18] This may resolve the source of high energy cosmic rays and clarify the mechanism of cosmic ray acceleration. However, theoretical developments in that direction are yet to appear. The model described in this article is to respond to such a requirement. A summary is given in the following.

I). The author proposed a model in a series of papers in 1985, as quoted in [2]-[10]. In other words, these articles have predicted the data from the Pierre Auger Observatory.

II). It predicts a gravitational acceleration of cosmic rays from AGN, as well as that of neutral particles, such as gamma rays, neutrinos and dark matter particles.

III). The knee energy is caused by a difference in the rates of radiation-dominated and matter-dominated expansion. This requires the existence of a particle at the knee energy scale, 3 PeV. That can be tested by various kinds of cosmic ray detectors through the discovery of new particles in the near future, which would be reminiscent of the golden age of cosmic ray studies in 1950, when all new particles were discovered in cosmic ray events before the accelerator age.

IV). The energy spectra of all other neutral particles should show the knee energy phenomena at 3 PeV. This is an important prediction to be tested in the near future.

V). Using the GLMR theory, the mass of a dark matter particle has been calculated from the knee energy mass scale of 3 PeV to be 8.1 TeV. This matches the analysis of the HESS data which gives 7.6 ± 0.1 TeV.

VI). The explosion of supernovae can be explained by reasoning similar to that of AGN explosion after gravitational collapse. This gives a unified reasoning for the emission of cosmic rays from AGN and supernovae.

In summary, the proposed model explains the data from the Pierre Auger Observatory successfully and many other predictions for observations will be tested in the near future.

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Figure 1: Sum of gamma ray energy spectra of 8 unidentified sources [31]. The y axis is $E^{2.4}(dN/dE)$ in units of $10^{-12} (TeV)^{0.4} (erg cm^{-2} s^{-1})$.