BE condensates of weakly interacting bosons in gravity fields

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Abstract

The Bose-Einstein (BE) condensates of weakly interacting bosons in a strong gravity field, such as AGN (Active Galactic Nuclei), BHs (black holes) and neutron stars, are discussed. Being bound systems in gravity fields, these are stable reservoirs for the Higgs bosons, and vector bosons of $Z^0$ and $W^\pm$ as well as supersymmetric bosons. Upon gravitational disturbances, such as a gravitational collapse, these objects are relieved from the BE condensate bound states and decay or interact with each other freely. Using the repulsive nature of gravity at short distances which was obtained by the present author as quantum corrections to gravity, the particles produced by the decays or interactions of the bosons liberated from BE condensates can be emitted outside the horizon for our observation. It is suggested that the recently observed gamma ray peak at $129.8 \pm 2.4$ GeV from FERMI Large Area Telescope may be evidence for the existence of the Higgs boson condensates. The BE condensates of supersymmetric bosons are the most likely sources for the gamma rays from DMP (dark matter particle) and anti-DMP collisions. It is shown that the said process from the DMPs spread in the galaxy is too small for the incident DMP with the intensity of the cosmic ray energy spectrum.
I. INTRODUCTION

In a recent measurement, Fermi Large Area Telescope has reported a gamma ray peak at 129.8 ± 2.4 GeV as a possible evidence for a DMP[1]. This mass value is remarkably close to that of Higgs boson like particles discovered by LHC experiments[2], with the observed mass value of 126.0 ± 0.4 GeV or 125.3 ± 0.4 GeV. If such entirely different particles have a degenerate mass value, the reason for the degeneracy must be clarified. If both are identical objects (Higgs boson), then the process for producing such a gamma ray must be shown. Even if the gamma ray is due to DMP annihilation, the mechanism for such an encounter of DMP collision is not clear. Since the density of DMP in our galaxy is not large, even DMP of cosmic ray intensity cannot produce enough gamma rays due to a small cross section of weak interactions, as will be explained later. Clearly, a new mechanism or a new process is required for the explanation. This article provides such a scenario.

II. BE CONDENSATES OF HIGGS BOSONS IN GRAVITY

In a strong gravity field of AGN, BHs and neutron stars, BE condensates of weakly interacting bosons are conceivable. They satisfy Gross-Pitaevskii (PE) equation[3],[4]

\[\left[-\frac{\hbar^2}{2m} \nabla^2 + V(r) + U_0 \psi^2 \right] \psi = \mu \psi, \quad (1)\]

where \(m\) and \(\mu\) stand for the mass and chemical potential of condensate and

\[V(r) = -\frac{GmM}{r} \quad (2)\]

is the gravitational potential of a BH mass, \(M\). We consider three representative cases

\[M = 10^9 m_\odot; \ 3 \times 10^6 m_\odot; \ 3 m_\odot, \quad (3)\]

representing a typical AGN, the BH at the center of our Milky Way galaxy and a BH of the smallest mass in our galaxy, respectively. In the case of a neutron star, the result is close to the third case. In the following, the numerical estimate for these three cases are presented, whenever three numbers are listed.

Since a BE condensate is a bound state, all the BE states are stable unless an extra energy or chemical potential is provided. This is similar to neutrons in nuclei and neutron
stars which do not decay. This is a remarkable property of BE condensates in gravity. Most bosons are unstable in free state, but stable in a BE condensate state. In a gravitational collapse, they are released to a free state and decay or interact with each other. This is the essential point of this article. The emission of the observable events through the horizon of a BH will be discussed in the next section.

For the boson, we select the Higgs boson with the mass

\[ m_H = 126 GeV \]  

and its Compton wave length,

\[ \frac{\hbar}{m_H c} = 1.57 \times 10^{-16} cm \]  

as a representative particle. For the other particles, such as vector bosons, Z\(^0\) and W\(^\pm\), and supersymmetric bosons, one has to change the numerical values depending on their mass values.

While the horizon scales are

\[ L = \frac{2GM}{c^2} = 3 \times 10^{14} cm; 9 \times 10^{11} cm; 9 \times 10^5 cm, \]  

the magnitudes of the coupling strengths of gravity are

\[ \frac{Gm_H M}{\hbar c} = \frac{1}{2} \frac{m_H c}{\hbar} \frac{2GM}{c^2} = 0.955 \times 10^{30}; 2.87 \times 10^{27}; 2.87 \times 10^{21}, \]  

and the Hawking temperatures are

\[ T_H = \frac{\hbar c^3}{8\pi GMk_B} = \frac{6.17 \times 10^{-8} K}{(M/M_\odot)} = 6.17 \times 10^{-17} K; 2.06 \times 10^{-14} K; 2.06 \times 10^{-8} K. \]

At low temperature, all condensates are in the ground states, which reside at the Bohr radius,

\[ \frac{\hbar}{m_H c} \frac{\hbar c}{Gm_H M} = 1.64 \times 10^{-46} cm; 5.47 \times 10^{-44} cm; 5.47 \times 10^{-38} cm. \]

This means that the condensates are in a relativistic regime. Also these distances are inside the Planck scale \(10^{-33} cm\). The physics in that region is not yet established. Nevertheless, one can estimate the number of BE condensates, \(N\), by

\[ \frac{Gm_H M}{r} > \frac{\lambda N}{L}, \]
where $\lambda$ is the coefficient of $\phi^4$ term in the Lagrangian, $\phi$ and $v$ being the Higgs field and its vacuum value, hence

$$
\lambda = \left( \frac{m_H}{v} \right)^2 = \left( \frac{126}{246} \right)^2 = 0.26
$$

(11)

Then, choosing $r$ to be the Bohr radius of the BE condensate one gets

$$
N < \frac{L \, G m_H M}{\lambda} = 6.72 \times 10^{90}; \ 1.82 \times 10^{83}; \ 1.82 \times 10^{65}.
$$

(12)

For the modification of physics, let us start with the quantum corrections on gravity, Eq. (2). The quantum corrections on gravity has been established recently by the present author[5]. In this work, the metric in a spherically symmetric and static metric is given by

$$
g_{00} = g_{rr}^{-1} = 1 + \frac{r^2}{\xi} - \sqrt{\frac{r^4}{\xi^2} + \frac{4GMr}{\xi}},
$$

(13)

where

$$
\xi = 16\pi G \kappa
$$

(14)

and

$$
\kappa = \frac{1}{2880\pi^2} \left( \frac{3}{4} N_S + \frac{19}{2} N_\nu + \frac{133}{2} N_V \right),
$$

(15)

$N_S$, $N_\nu$ and $N_V$ being the numbers of scalar fields, four component neutrino fields and vector fields respectively. For $N_S = 1$, $N_\nu = 3$ and $N_V = 12$, $\kappa = 0.0291$. Using

$$
\frac{\hbar G}{c^3} = 2.61 \times 10^{-66} cm^2,
$$

(16)

one gets

$$
\xi = 3.82 \times 10^{-66} cm^2.
$$

(17)

The minimum of Eq. (13) is reached at

$$
r_0 = \left( \frac{GM\xi}{2} \right)^{1/3} = 6.59 \times 10^{-18} cm; \ 0.951 \times 10^{-18} cm; \ 0.951 \times 10^{-20} cm
$$

(18)

with the minimum

$$
(g_{00}/2)_{\text{min}} = -\left( \frac{GM}{4\xi} \right)^{1/3} = -1.14 \times 10^{31}; \ -2.37 \times 10^{29}; \ -2.37 \times 10^{25}.
$$

(19)

This value of the minimum, $r_0$, indicates that this system is in the range of relativistic quantum physics. The Lorentz factor at $r_0$ is estimated as

$$
\gamma = \frac{\hbar}{m_h c r_0} = 2.39 \times 10^3; \ 1.65 \times 10^2; \ 1.65 \times 10^4.
$$

(20)
The lifetime of the Higgs boson in a free state is estimated to be
\[ \tau_H = \frac{1}{4MeV} = 1.65 \times 10^{-22} s \] (21)
in the standard model. Then the lifetime in BH is given as
\[ \tau_H \gamma = 3.94 \times 10^{-19} s; \ 2.72 \times 10^{-20} s; \ 2.72 \times 10^{-18} s, \] (22)
if it is in a free state.

Replacing the gravitational potential by \( m \left( \frac{g_{00}}{2} \right)_{\text{min}} \), one gets the upper bound for the Higgs boson condensates
\[ N < \frac{L m_H \left| \frac{(g_{00})_{\text{min}}}{2} \right|}{2\lambda} = 0.838 \times 10^{62}; \ 5.23 \times 10^{57}; \ 5.23 \times 10^{47}. \] (23)

From the computation of the cross section for a Higgs pair production by gamma pair in the standard model and from the phase space consideration, one can estimate the cross section of the reverse reaction
\[ \sigma_{\gamma\gamma} = \sigma(Higgs + Higgs \rightarrow \gamma + \gamma) = 0.004 \text{ fb} = 4 \times 10^{-42} \text{cm}^2, \] (24)
for the Higgs bosons at rest. The cross section at higher energy increases linearly with energy \( E \). The gamma rays produced in the volume
\[ V = \frac{4\pi}{3} L^3 = 1.13 \times 10^{44} \text{cm}^3; \ 3.05 \times 10^{36} \text{cm}^3; \ 3.05 \times 10^{18} \text{cm}^3, \] (25)
are
\[ n_{\gamma} = 2 \times \frac{1}{2} \left( \frac{N}{V} \right)^2 \sigma_{\gamma\gamma} cV = 7.46 \times 10^{48} \text{s}^{-1}; \ 1.07 \times 10^{48} \text{s}^{-1}; \ 1.07 \times 10^{46} \text{s}^{-1}. \] (26)

Using the distance of
\[ R = 100 \text{Mpc} = 3.09 \times 10^{24} \text{m} \] (27)
for AGN and
\[ R = 10 \text{kpc} = 3.09 \times 10^{20} \text{m} \] (28)
for the galactic BHs (the galactic center and other galactic BH), one gets
\[ \frac{n_{\gamma}}{4\pi R^2} = 0.0602 \text{m}^{-2} \text{s}^{-1}; \ 8.92 \times 10^5 \text{m}^{-2} \text{s}^{-1}; \ 8.92 \times 10^{3} \text{m}^{-2} \text{s}^{-1}. \] (29)

Note that the Fermi Large Area Telescope has the area size of 0.7 \( m^2 \). The time integrated gamma rays that can be observed is then
\[ N_{\gamma} = \frac{n_{\gamma} L}{4\pi R^2 c} = 6.02 \times 10^2 \text{m}^{-2}; \ 2.68 \times 10^7 \text{m}^{-2}; \ 0.268 \text{m}^{-2}. \] (30)
assuming that all gamma rays produced are observed. If the estimate of the gamma ray cross section, Eq. (24), is changed, these values are changed accordingly, but the relative values of the three cases are unchanged. One should notice that these are the maximum number possible for one explosion. The accumulation of the BE condensates could be smaller than these numbers. Also one may not detect all photons due to possible dead time of the detecting instrument.

The collision time of Eq. (24) is estimated as

$$\tau_{\gamma\gamma} = \left( \frac{1}{2} \left( \frac{N}{V} \right)^2 \sigma_{\gamma\gamma} c V \right)^{-1} = 4.90 \times 10^{-49} \text{ s}; \ 4.66 \times 10^{-49} \text{ s}; \ 4.66 \times 10^{-47} \text{ s}. \quad (31)$$

Now the estimate of Eq. (30) should be corrected by the area in which the Higgs condensates are most likely liberated to decay and interact with each other. By a gravitational collapse or a collision of binary black holes the Higgs condensates are sent to the edge of the horizon where the strength of gravity is weaker. So, most likely the condensates interact at the edge of the horizon. Let us assume that the region where the condensates are liberated to interact is between $L_1$ and $L$, then the time integrated gamma rays, Eq. (30), must be multiplied by a factor

$$a = \frac{L - L_1}{L} \frac{V - V_1}{V} = \frac{1 - L_1/L}{1 - (L_1/L)^3} = \frac{1}{1 + L_1/L + (L_1/L)^2}. \quad (32)$$

This factor $a$ approaches 1/3 in the limit of $L_1$ approaching to $L$. Thus the numbers in Eq. (30) should be multiplied by a factor of 1/3 for this correction

$$aN_\gamma = 2.01 \times 10^2 m^{-2}; \ 0.893 \times 10^7 m^{-2}; \ 0.0893 m^{-2}. \quad (33)$$

This shows that the BH in the galactic center is the most efficient emitter of the gamma rays from a Higgs boson collision, even only a fraction of Eq. (30) is emitted when a neighboring star is gravitationally collapsed to the central BH. These gamma rays reach at the observers on the Earth in a short time interval, depending on the size of $L - L_1$. The explosion after a gravitational collapse might repeat itself many times. Each time the BE condensates are created in the collapsed state. In other words, there could be an oscillation after a gravitational collapse, and each oscillation [8] can produce the BE condensates and the resulting gamma rays by the Higgs boson collisions.

Finally, a relativistic correction to the GP equation, Eq. (1), should be mentioned. One way to accomplish this is to use the Bethe Salpeter equation [10]. In this approach, the interaction terms can be used as pseudopotential form, so that the argument in this article
can be used in that formalism\cite{11}. For a general relativistic approach, see a reference \cite{12}. An alternative method is to use Dirac equation and to identify the spin average of the solution to the scalar boson field. In this approach the interaction terms can be carried to a relativistic formulation and the discussion of this section can be utilized.

III. PENOKE DIAGRAM AND THE ANSATZ OF MAXIMUM SYMMETRY

How can we observe gamma rays produced inside a horizon of a BH? First, the metric derived by quantum corrections, Eq. (13), behaves

$$g_{00} = 1 - 2 \sqrt{\frac{MG}{\xi}} r.$$  \hspace{1cm} (34)

near the origin. It is a repulsive force at the origin. In such a case, one has to use a Penrose diagram in order to describe a motion near the horizon, as in the case of the Reissner-Nordstrom metric for a charged BH. See Fig. 34.4 in the reference\cite{13}. The metric $g_{00}$ vanishes at the outer horizon,

$$r_+ = L,$$  \hspace{1cm} (35)

and at the inner horizon,

$$r_- = \frac{\xi}{2L} = 6.35 \times 10^{-81} cm; 2.12 \times 10^{-78} cm; 2.12 \times 10^{-72} cm.$$  \hspace{1cm} (36)

This value of the inner horizon, $r_-$, is much smaller than the Planck distance ($10^{-33} cm$) and then it may be changed by a theory in the future. However, one should notice that the repulsive force of the gravity starts at the minimum of $g_{00}$ at $r_0$, Eq. (18), which is a quantum mechanical distance. Besides, Boulware and Deser obtained the same metric, Eq. (13), independently from the present author for a solution of a string theory model\cite{9}. In other words, the discussion in this paper might survive in the realm of a new theory in the future. In fact, the solution of Eq. (13) is the outcome of the Gauss Bonnet term in general relativity, a quadratic form of the curvature, and appears in a quantum correction of field theory as well as in a string theory.

From Fig. 34.4 in ref.\cite{13}, the Penrose diagram has a multi-universe structure. Consider a test particle in one of the universes. It falls into the inside of the horizon. It takes an infinite time in the coordinate time to cross the horizon, but it requires a finite time in the
proper time of the test particle. After crossing the outer horizon at \( r_+ \), the particle goes inside the inner horizon, \( r_- \), and comes out at \( r_- \) and then crosses at \( r_+ \) of the next universe. Then, what is the implication of this phenomenon? One loses the symmetry between the starting universe and the next universe in this process. If one proposes that a test particle must be prepared at every universe as copies, then all universes are copies of the starting universe including the test particle. When a test particle of one universe comes out at the next universe, all the test particles behave the same motion and the symmetry of all the universes are restored. This is the ansatz of maximum symmetry. The advantage of this ansatz is the following: When a test particle comes out at the next universe, the center of BH in the next universe is moving according to the two body motion in this ansatz, since every universe has a test particle partner. When a test particle comes out at the horizon of the next universe, a copy of the test particle of the previous universe comes out in the original universe. This is a consistent picture for all multiple universes. Simply put, this implies that a test particle can cross the horizon. In the next section, the observed phenomenon of SN87A and the proposed emission of cosmic rays from AGN can be understood from the quantum mechanical metric and the ansatz of maximum symmetry for the Penrose diagram.

With this ansatz, one has to change the old concept of BH in which it was considered that nothing can come out of a BH. With the Penrose diagram for the quantum mechanical metric, Eq. (13), and the ansatz of maximum symmetry, all particles liberated from the BE condensates by decays and collisions should come out from the horizon. See more discussions in ref. [14]

IV. THE EXPLOSION OF SN87A AND HIGH ENERGY COSMIC RAYS FROM AGN

The discussion of the previous section yields an explanation for the observation of SN87A. A large progenitor, Sanduleak -69\(^\circ\) 202, in the Magellanic cloud became a supernova in February, 1987. Namely, the explosion of SN87A was observed at the location of this progenitor. When the core of the progenitor collapsed, the collapsed objects did not form a neutron star. Since a neutron star has not been found at the center of SN87A thus far, the formation of a neutron star is not the reason for the explosion. The formation of a neutron star after a supernova explosion is an end result of the whole process. The core collapse must go inside
a smaller region, smaller than the size of a neutron star which is 20 km or probably inside the horizon which is 3 km for 1 solar mass. It is conceivable that the subsequent explosion could be caused by the repulsive force of Eq. (34). High energy particles produced by the repulsive forces must come out from the inside of the horizon and cause the explosion of the outside materials as a result of a shock wave. This explains the nuclear components of cosmic rays from supernova. The fact that one observed the explosion of SN87A at the same location of the progenitor could be interpreted as a favorable evidence for the ansatz of maximum symmetry, which was discussed in the previous section. In summary, when the core collapsed, the most likely collapsed objects went into the inside the horizon and by explosion it comes out outside the horizon. The explosion can be explained by the presence of the repulsive force, Eq. (34), and the Penrose diagram for the repulsive component of gravity and the ansatz of maximum symmetry can explain the observation of an explosion in the same space of the progenitor.

The same idea has been used for the 1985 model of high energy cosmic ray generation by AGN by the present author [15], [16], [17]. Recent data of high energy cosmic rays of the Pierre Auger Observatory [18] confirmed this prediction. The ansatz of maximum symmetry was presented in ref. [14]. In this model, a gravitational collapse in a BH results in an explosion by the repulsive force, Eq. (34), and high energy particles such as cosmic rays, gamma rays, neutrinos and DMPs are emitted from the surface of an expanding heat bath. The emission of the particles outside the horizon can be provided by the nature of the Penrose diagram and the ansatz of maximum symmetry, as in the case of SN87A. The expansion rates in a radiation-dominated and a matter-dominated expansion provide the energy spectra, $E^{-3}$ and $E^{-2.5}$, above and below the knee energy at 3 PeV, respectively. The knee energy phenomena at 3 PeV strongly suggests that the existence of a new mass scale at 3 PeV [19]. A further prediction of the model is that all high energy particles produced by AGN have the knee energy at 3 PeV for the energy spectra. This prediction can be tested by the data of neutrinos, gamma rays and DMPs in the near future.

V. GAMMA RAYS FROM FERMI LARGE AREA TELESCOPE

Now let us come back to the gamma ray observed by Fermi Large Area Telescope [1] at 129.8 ± 2.4 GeV. The data is taken from the direction of the galactic center. From the
estimate of Eq. [30], the data is consistent with the gamma rays from BE condensates of Higgs bosons from the BH at the galactic center. It is desirable to get more accurate determination of the peak mass of the gamma rays and the determination of the sources. Of course, the data depends on the frequency of gravitational collapses in the BH at the galactic center. One may assume that at the end of a gravitational collapse in a BH, the accumulation of BE condensates of the weakly interacting bosons will be renewed by the condensates which moved inward and condensates created by the gravitational forces at the center. It is important to establish that the gamma rays observed are created by the BE condensates of the Higgs bosons. If confirmed, one can see that BHs are useful reservoirs for stable Higgs bosons. Nature provides a platform for studying the properties of the fundamental particles, the Higgs bosons and other weakly interacting bosons in the future.

VI. GAMMA RAYS FROM DMP COLLISION

In a supersymmetric theory, the lowest mass state is a candidate for a DMP. It may not be a boson. In fact, if a gluino or a gaugino is a DMP, it is a spinor. Then, all unstable excited particles decay to the DMP eventually. Bosons in a supersymmetric theory may be unstable, but become BE condensates in gravity as stable particles. When liberated in a gravitational collapse, they decay to DMP and the resulting DMPs interact with each other and produce gamma rays. In order to specify an explicit mass value, one has to fix a specific theory. I will choose the GLMR-RS theory[20] as an example.

I will choose the heaviest mass of the GLMR-RS theory to be the mass scale of the knee energy[21] of 3 PeV,

$$m_{3/2} = 3PeV.$$  \hspace{1cm} (37)

Then, the lower end of the mass spectrum which are gauginos becomes

$$M_1 = 8.9 \times 10^{-3} m_{3/2} = 26.7 TeV$$  \hspace{1cm} (38)

$$M_2 = 2.7 \times 10^{-3} m_{3/2} = 8.1 TeV$$  \hspace{1cm} (39)

$$M_3 = -2.6 \times 10^{-2} m_{3/2} = -78 TeV.$$  \hspace{1cm} (40)

The masses of the bosons in the theory are expected to be at the range of $m_{3/2}$, 3 PeV. They are unstable. The lowest mass which is a candidate of DMP is 8.1 TeV for $M_2$. In fact,
the analysis of the HESS data\cite{22} on the gamma ray spectrum from 8 unidentified sources yields a gamma ray peak\cite{23} of 3 $\sigma$ at 7.6 $\pm$ 0.1 TeV. For the rest of the section, one will assume that the masses of the DMP and the boson B to be

$$m_{DMP} = 8 TeV$$

and

$$m_B = 3 PeV,$$

respectively. Further one assumes that the simplest decay mode of B to be

$$B \rightarrow DMP + \nu + \nu^C,$$

$$B \rightarrow DMP + \gamma + \gamma$$

or

$$B \rightarrow DMP + \mu + \nu,$$

depending on the charge states involved. The decay of the B boson may be dominated by other processes. I have listed the simplest process of three body decay here from the point of view of detectability from a distance. The three body decays are typically distinguished by a bump in the energy spectrum of neutrinos and gamma rays at the half of the parent mass, due to a triangular phase space peaking at the maximum energy. This means that the energy spectrum of gamma rays and neutrinos emitted from a three body decay of a B boson should show a bump at 1.5 TeV.

The cross section of gamma ray pair production by a DMP pair is assumed to be

$$\sigma_{\gamma\gamma}(DMP) = \sigma(DMP + \text{anti}DMP \rightarrow \gamma + \gamma) = 10^{-42} cm^2,$$

with a similar value of the Higgs pair cross section, Eq. \cite{24}.

First, let us estimate the rate of gamma ray production by the DMP distributed in the galaxy hit by a DMP which is emitted from AGN, similar to the emission of cosmic rays from AGN. Since it is a gravitational acceleration after gravitational collapse in a BH, the acceleration of the DMP is conceivable\cite{15},\cite{16},\cite{17}. One may assume that the energy spectrum of DMP is identical to that of cosmic rays, except that the spectrum terminated at its mass, 8 TeV. The flux of cosmic rays at energy of 8 TeV is

$$Flux = 10^{-10} (cm^2 st s GeV)^{-1}.$$
The number density of the nucleons in the Milky Way galaxy of $10^{12} M_\odot$, which has a volume of 10 kpc radius and 1 kpc depth, is

$$n_p = 10^{12} \frac{2 \times 10^{33} g}{1.67 \times 10^{-24} g/\pi (3.09 \times 10^{22})^2 (3.09 \times 10^{21}) cm^3} = 129 \text{ cm}^{-3}.$$ (48)

Assuming the same mass density for DMP which is distributed in a spherical symmetric sphere of a radius of 10 kpc, one gets the DMP number density in the galaxy

$$n_{DMP} = n_p/8000 = 1.61 \times 10^{-2} \text{ cm}^{-3}.$$ (49)

For simplicity, one assumes that the observer is at the center of the sphere of the DMP distribution. Then, integrated the incident flux of DMP over all direction ($4\pi$ steradian) and 1 GeV energy range, one gets the gamma rays at the observer

$$N_\gamma = 2 \times n_{DMP} \sigma_{\gamma\gamma}(DMP) \frac{4\pi \text{ Flux GeV}}{4\pi r^2} \int \frac{4\pi r^2 dr}{4\pi r^2}$$ (50)

$$= 2 \times (1.61 \times 10^{-2} \text{ cm}^{-3}) \left(10^{-42} \text{ cm}^2\right) 4\pi \left(10^{-10} \text{ s}^{-1} \text{ cm}^{-2}\right) (3.09 \times 10^{22} \text{ cm})$$ (51)

$$= 1.24 \times 10^{-30} \text{ s}^{-1} \text{ cm}^{-2}$$ (52)

This is an extremely small number. In other words, the gamma rays from the DMP pair collision cannot come from the DMP distributed in the Milky Way galaxy, or in any galaxies. It has to come from the BE condensates in a BH.

The value of the gravitational potential is increased by the ratio of the masses of the supersymmetric boson and the Higgs boson

$$\frac{m_B}{m_H} = \frac{3 PeV}{126 GeV} = 2.38 \times 10^4,$$ (53)

then the maximum number of the BE condensates of the supersymmetric bosons become, from Eq. (23)

$$N < 1.99 \times 10^{66}; \ 1.24 \times 10^{62}; \ 1.24 \times 10^{52}.$$ (54)

Here, one assumed the same value of $\lambda$ as that of the Higgs boson for simplicity. For the estimate of the observable gamma rays on the Earth, Eq. (33), one has to remembers that the choice of the combination of DMP and antiDMP gives a factor of 1/2, that the cross section is assumed be 1/4 of the Higgs cross section, and that the square of the mass ratio, Eq. (53), must be multilied. In other words, a factor of

$$\frac{1}{8} \left(\frac{m_B}{m_H}\right)^2 = 7.08 \times 10^7$$ (55)
must be multiplied for the value of Eq. (33). Hence one gets

\[ aN_\gamma = 1.42 \times 10^{10} m^{-2}; \ 6.32 \times 10^{14} m^{-2}; \ 6.32 \times 10^{6} m^{-2} \]  

(56)

for the observable gamma rays on the Earth. These numbers indicate that even if a small fraction of the gamma rays are emitted by a DMP pair collision, it is still in the range of observability.

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