ALMA-T Summer Student Project

Indirect Detection of Dark Matter Particle:

Synchrotron Radiation Results from Electron-Positron Pair Production of Kaluza-Klein Particle Annihilation

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Abstract

In this paper, we gave two different dark matter candidates proposed by supersymmetry (neutralino) and extra dimensions (LKP). From the annihilation of these dark matter particles, we obtain high energy electron and positron pairs from one of their channels. These high energy electrons will experience magnetic field inside a galaxy and release energy through process of synchrotron radiation. Our goal is to compute the flux we expect from this synchrotron radiation. The model we construct is based on NFW profile that describes dark matter distribution with our Milky Way Galaxy. Moreover, the targets we will apply to with our model will be nearby (20 Mpc) elliptical galaxies. In our results, in section 5.1, we show a figure flux vs. frequencies and compute couple frequencies within ALMA observed frequency range, 90 GHz and 200GHz. The corresponding fluxes as observing from distance 20Mpc are 4.7 and 3.2 micro Jansky.

I. Introduction

The idea of dark matter had been proposed for centuries. Scientists also developed models and searched for them in order to explore the deepest question of physics in nature. Among these models, the dark matter candidate, neutralino, proposed by supersymmetry and the Kaluza-Klein particles, proposed by extra dimensions, are the most popular models that might resolve current problem. There are many approaches (directly and indirectly) for searching the existence of dark matter particles. In this paper, we will briefly introduce the idea of supersymmetry with the particle, neutralino, it proposed; also, the Kaluza-Klein particles from the idea of extra dimensions. Furthermore, we will focus on the indirect detection calculation of Kaluza-Klein particles. From its annihilation, high energy electron-positron pair and are generated. These relativistic electron-positron pairs generate synchrotron radiation such that we can detect this signal, within observed frequency range, by ALMA ground based telescope.

II. Supersymmetric Model and Neutralino

2.1 Supersymmetric Model

Supersymmetry is a non-observed symmetry in nature proposes the symmetry between fermions and bosons. Namely,

$$Q \mid B > = \mid F > \quad \text{or} \quad Q \mid F >= \mid B >, \tag{1}$$

where Q is the operator that interchanges between bosonic state, $\mid B >$, and fermionic state, $\mid F >$. This interchange gives rise of new particles pair up with their ordinary partners with more or less the same mass yet different characteristic in nature. In order to construct a space that is analogue to Lorentz invariance under Minkowski space-time, supersymmetry is manifest under the so-called "*Superspace*". The field in superspace is no longer dependent of space-time variables, but also in addition to the Grassmann variable which represent the Weyl spinors. Therefore, the "*Superfield*" can now be expressed as a function,$\Phi(x, \theta, \bar{\theta})$, where the x coordinates is the regular Minkowski space time coordinates $(\mathrm{x}=\mathrm{x}^{\mu}, \mu=0,1,2,3)$ and θ with $\bar{\theta}$ represent the Weyl spinors.

In the Minimal Supersymmetric Standard Model (MSSM), we consider the case of minimal extension of Standard Model that is sufficiently enough to compensate the correction of renormalization of Standard Model in a smaller scale. In this model, we enter the superpartner of bosons and named those particles by their ordinary partner with "ino" at the end, also, the superpartner of fermion named "*sfermion*". Another requirement for this model is we need an additional Higgs boson in order to explain the both spin up and down higgsinos which give mass to superparticles. These particles enter the superpotential defines as [1]

$$\Phi=\epsilon_{ij}\left(-\hat{e}_R^* Y_E \hat{l}_L^i \widehat{H}_1^j-\tilde{d}_R^* Y_D \hat{q}_L^i \widehat{H}_1^j+\hat{u}_R^* Y_U \hat{q}_L^i \widehat{H}_2^j-\mu \widehat{H}_1^i \widehat{H}_2^j\right), \qquad (2)$$

in addition, to explain the interaction of these particle by the following Lagrangian[2],

$$\mathcal{L}=-\frac{1}{2}\left(\Phi^{ij} \psi_i \psi_j+\Phi_{ij}^* \psi^{i^{\dagger}} \psi^{j^{\dagger}}\right)-\Phi^i \Phi_i^*, \qquad (3)$$

where ψ_i is fermion field, and scalar field is embedded inside Φ (for further detail, please see G. Bertone, D. Hooper and J. Silk 2008). Moreover, in order to explain the mass of superparticles, neutralino for example, we demand a soft-supersymmetric breaking potential, [1]

$$\begin{aligned}\mathrm{V}=\epsilon_{ij}\left(\hat{e}_R^* A_E Y_E \hat{l}_L^i \widehat{H}_1^j+\tilde{d}_R^* A_D Y_D \hat{q}_L^i \widehat{H}_1^j-\hat{u}_R^* A_U Y_U \hat{q}_L^i \widehat{H}_2^j-B \mu \widehat{H}_1^i \widehat{H}_2^j+h.c.\right)+\\ H_1^{i*} m_1^2 H_1^i+H_2^{i*} m_2^2 H_2^i+\tilde{q}_L^{i*} M_Q^2 \tilde{q}_L^i+\tilde{l}_L^{i*} M_L^2 \tilde{l}_L^i+\tilde{u}_R^* M_U^2 \tilde{u}_R+\tilde{d}_R^* M_D^2 \tilde{d}_R+\tilde{e}_R^* M_E^2 \tilde{e}_R+\\ \frac{1}{2} M_1 \tilde{B} \tilde{B}+\frac{1}{2} M_2\left(\widetilde{W}^3 \widetilde{W}^3+2 \widetilde{W}^{+} \widetilde{W}^{-}\right)+\frac{1}{2} M_3 \tilde{g} \tilde{g},\end{aligned} \qquad (4)$$

and the corresponds soft-supersymmetric breaking Lagrangian, [2]

$$\mathcal{L}_{soft}=-\frac{1}{2} \mathrm{M}_\lambda^a \lambda^a \lambda^a-\frac{1}{2}\left(m^2\right)_j^i \phi_i \phi^{j^*}-\frac{1}{2}(BM)^{ij} \phi_i \phi_j-\frac{1}{6}(Ay)^{ijk} \phi_i \phi_j \phi_k+h.c., \qquad (5)$$

where M_λ^a are gaugino masses (a=1,2,3), m^2 are soft scalar masses, B is a bilinear mass term, and A is a trilinear mass term.

2.2 Neutralino

Neutralino is a linear combination of Bino, Wino and two higgsino, where Bino and Wino are the superpartners of B-field and W boson while the two higgsinos are superpartners of 2 Higgs Boson in supersymmetry. This linear combination gives rise of four different states of neutralino (from higgsino like to gaugino like). In addition, Neutralino acquire its mass because of Anomaly mediated Supersymmetric Breaking (AMSB), the analysis of AMSB is pretty technical (please go to Ref [3] for further detail); therefore, we will skip the discussion of AMSB here. The mass of neutralino can be expressed as the following neatralino mass matric [2],

$$\mathcal{M}_{\tilde{\chi}^0_{1,2,3,4}} = \begin{pmatrix} M_1 & 0 & -\frac{g' v_1}{\sqrt{2}} & +\frac{g' v_2}{\sqrt{2}} \\ 0 & M_2 & +\frac{g v_1}{\sqrt{2}} & -\frac{g v_2}{\sqrt{2}} \\ -\frac{g' v_1}{\sqrt{2}} & +\frac{g v_1}{\sqrt{2}} & \delta_{33} & -\mu \\ +\frac{g' v_2}{\sqrt{2}} & -\frac{g v_2}{\sqrt{2}} & -\mu & \delta_{44} \end{pmatrix}, \tag{6}$$

where M_1 and M_2 are the mass parameters for bino and wino, g and g' are the usual gauge coupling constants, μ is the higgsino mass term, and δ_{33} and δ_{44} are the one-loop corrections.

Among these four states of neutralino, the lightest state is what we are interested the most and with mass, under prediction, at order about 100GeV ~ 1TeV. This is because the lightest state of neutralino, with parity conservation preserves in supersymmetry, is a stable particle inside the universe and will not decay arbitrarily. In addition, neutralino is known as cold dark matter, which indicates its velocity is relative slow; therefore, they will not cause too much collision throughout the age of Universe. These properties of neutralino give scientist a satisfactory reason to make it as a good candidate of dark matter.

III. Extra Dimensions and LKP

3.1 Extra Dimensions

The idea of extra dimensions comes from Kaluza in 1921 when he tried to resolve the problem to unify electromagnetism and gravity by adding an extra component to the metric tensor with the usual gauge field[1]. In the usual 3+1 Minkowski space-time we live in, matters and dynamics are well behave under this framework. However, in the higher spatial dimensions (3+ σ+1), according to Mathematical prediction and calculation, the frame will tend to wrap and curled together and which is hard to observe these higher dimensions from our usual 3+1 dimensions point of view.

However, in higher dimensions just as 3+1 dimensions, there are fields and dynamics in space-time. Thus, we are be able to write down the Lagrangian to represent the dynamics of these fields in a way such that these extra dimensions can be represented in our 3+1 dimensions, and the reduced 4D Lagrangian is[4]

$$\mathcal{L}_{4D} = \int d^{\sigma}y \, \{-\sum_{i=1}^{3} \frac{1}{2\hat{g}^2} Tr\left[F_i^{\alpha\beta} F_{i\alpha\beta}\right] + \mathcal{L}_{Higgs} + (\bar{Q}, \bar{U}, \bar{D})\left(\Gamma^{\mu} D_{\mu}\right)(Q, U, D)^T + [Q\left(\hat{\lambda}_u U i\sigma_2 H^* + \hat{\lambda}_D D H\right) + h.c.]\}, \tag{7}$$

where $F_i^{\alpha\beta}$ refers to the three gauge fields, Q, U, D are the fermion fields, H is the Higgs doublet, D_{μ} and Γ^{μ} are covariant derivative and gamma matrices, $\hat{g}$ is the gauge coupling constant, $\hat{\lambda}$ is the Yukawa coupling, and $\mathcal{L}_{Higgs}$ is the Higgs Lagrangian. These quantities are defined on the 3+ σ+1 dimensions and the Lagrangian is integrated over the extra dimensions. Furthermore, if fields have some energy and start to oscillate, those quanta in the higher dimensions are known as the Kaluza-Klein (KK) particles. However, since these particles exist in higher dimensions and the dimensions are curled, we do not normally see these particles. Moreover, the curvatures of these high dimensions space-time have a significant association with KK particles. The mass of KK particles is strictly determined by the curvatures of the curled dimensions with the mode of the field (excitation level) and can be expressed as[1] $m_n = n/R$, where m_n is the mass of KK particle, n represent the mode of the field, and R is the curvature radius of the dimension.

3.1 The Lightest Kaluza-Klein Particle

The Lightest Kaluza-Klein Particle (LKP) is another dark matter candidate we interest in. The real face of LKP is the first excitation state of KK photon and we will refer this state to be B^1[4]. To consider the mass of B^1, from the electroweak symmetry breaking induces mixing heavy partner with W_3^1, the mass matrix on these two basis yields[4]

$$\begin{pmatrix} \frac{1}{R^2}+\frac{1}{4}g_1^2v^2+\delta M_1^2 & \frac{1}{4}g_1g_2v^2 \\ \frac{1}{4}g_1g_2v^2 & \frac{1}{R^2}+\frac{1}{4}g_2^2v^2+\delta M_2^2 \end{pmatrix}, \tag{8}$$

where g_1 *and* g_2 are electroweak couplings, v is the Higgs expectation value, and δM_1^2 and δM_2^2 are corrections to masses of B^1 and W_3^1. In addition, the mass order of the LKP is predicted at range from 620 GeV~1 TeV. Another important ingredient for us to detect KK particle indirectly is to trace the production particles from this KK particles. Hence, the branching ratio of B^1 annihilation[4] are $B^1B^1 \to e^-e^+(20\%)$, $B^1B^1 \to \mu^-\mu^+(20\%)$, $B^1B^1 \to \tau^-\tau^+(20\%)$, $B^1B^1 \to q\bar{q}$(up type quarks)(33%), $B^1B^1 \to \nu\bar{\nu}(3.6\%)$, $B^1B^1 \to q\bar{q}(down\ type\ quarks) and\ Higgs(the\ rest\ \%)$. Also, the expectation value of the product of this annihilation cross section and velocity of B^1 is[1]

$$<\sigma v>=\frac{95g_1^4}{324\pi m_{B^1}^2} \cong \frac{0.6pb}{m_{B^1}^2[1TeV]}, \tag{9}$$

where g_1 is the coupling constant and m_{B^1} is the mass of B^1.

IV. Computation

4.1 Model Construction

The spatial distribution of dark matter halo in our calculation is based on Navarro, Frenk & White (NFW) profile[1],

$$\rho(r) = \frac{\rho_o}{(r/R)^\gamma-(1+(r/R)^\alpha)^{(\beta-\gamma)/\alpha}}, \tag{10}$$

with $\alpha = 1$, $\beta = 3$, $\gamma = 1$ and R=20kpc, where ρ_o is the dark halo parameter and varies from galaxy to galaxy. NFW profile is built based on N-body simulation, and N-body simulation take into account all the detail gravitation between particles and hierarchical problem. Therefore, it is useful for describing cold dark matter distribution. In addition, NFW gives the minimum requirement of dark matter particle's number density in order to explain the celestial phenomena. Hence, the annihilation rate based on calculation with NFW profile will be lower compare to other model but guaranteed amount (we will give improvement in section 6). With NFW profile, we firstly used Milky Way Galaxy to be the primary model for computation, and then we can generalize to other galaxies. To be more precise, the targets we will be testing on are chosen from nearby (about 20 Mpc away) elliptical galaxies.

4.2 Energy Distribution

Before calculating how much synchrotron radiation we can receive form the source, we will have to understand how the electrons are distributed in space. Both neutralino and LKP have channels that produce electron and positron pairs. Here, for simplicity, we will only consider the radiation from electrons. In this section, we will develop mechanism to tell annihilation rate from which the LKP will generate electron and positron pairs and the next section we will go over the calculation for synchrotron radiation. The analysis of production rate for both neutralino and LKP are mostly the same, but the differences between them are the yields of e^+e^- and $<\sigma v>$ which we will elaborate more lately in this section.

4.2.1 Source Function

Source function is a way to describe how electrons and positrons are produced. As a result, there are some ingredients that build in the source function to give us the information. First of all, to describe how electron and positrons are generated from the LKP, we will have a annihilation rate from the LKP to e^+e^- and is described as[5]

$$\Gamma = \frac{<\sigma v>}{m^2} \int dr\, \rho^2 4\pi r^2, \tag{11}$$

where Γ is the annihilation rate, $<\sigma v>$ is the expectation value of the product of the velocity and cross section of the LKP, m is the mass of the LKP, and integrated over all space to take into account the contribution of annihilation from all the LKP.

Second, besides annihilation, we will also demand to know how much electrons are generated per annihilation. Hence, the yields,

$$Y(>E), \tag{12}$$

tells how many electrons will be produced per annihilation by the LKP from certain energy of electrons, E, up until the highest energy that the LKP might produce and sum over this energy range. For LKP, the yields can be calculated by[1]

$$< \sigma v > Y_e(m_{DM}) = \sum_i (\sigma v)_i Y_e^i(m_{DM}), \tag{13}$$

summing over all the possible channels. For instance, the lepton channel[1],

$$Y_e^{e\pm}(m_{DM}) = Y_e^{\mu\pm}(m_{DM}) \approx 2, \tag{14}$$

the quark channel[1],

$$< \sigma v > Y_e(1TeV) \approx 6 \times 10^{-3} TeV^{-2}$$

and

$$Y_e(1TeV) \approx 4.5, \tag{15}$$

and from hadronic channel is roughly 20.

The yields for neutralino are harder to obtain, we will have to take into account some restrictions proposed by mSUGRA (phenomelogical MSSM), and this number can be obtained from the Dark SUSY package; therefore, we will skip the detail discussion for the yields from neutrlaino.

Lastly, the final ingredient is to tell how the electrons are distributed in space. Therefore, we need a spatial distribution of dark matter particles that will generate electrons at different points. The spatial function are described by

$$fe = \frac{\rho^2}{\int dr \rho^2 4\pi r^2}. \tag{16}$$

Consequently, we have our source function,

$$Q(r) = \Gamma \Upsilon(> \mathrm{E}) f e, \tag{17}$$

with all the ingredients we described above.

4.2.2 Cooling Mechanism

The electrons produced by dark matter particles with high energy inside a galaxy will release their energy through different process. In this subsection, we will discuss two main cooling mechanisms for electrons to release their energy, the synchrotron cooling and the inverse Compton cooling.

First of all, synchrotron cooling is the process that the relativistic electrons inside a magnetic field will follow Lorentz force rule and cycling around magnetic field, During this orbiting motion, electrons simultaneously release their energy in the form of photon known as synchrotron radiation. The power it release can be expressed as[6]

$$P = \frac{4}{3}\sigma_T c\beta\gamma^2 U_B, \tag{18}$$

where P is the power lost due to synchrotron cooling, σ_T is Thomson's scattering cross section, β is the ratio between the speed of electrons and light (for Lorentz factor greater than 1, β can be treated as 1), γ is the Lorentz factor, and U_B is the energy stored inside magnetic field that electrons interact with.

Second, inverse Compton cooling is considered when the electron is relativistic. In the frame of the moving electron, the radiation field is not isotropic and it tends to experience more radiation along the boosting direction. As a result the power radiates by electrons under this condition can described by[7]

$$P = \frac{4}{3}\sigma_T c\beta\gamma^2 U_E, \tag{18}$$

where U_E is the energy stored inside the electric field that electrons interact with. In our calculation, we only consider the main source from CMB for simplicity.

4.2.3 Energy distribution

From the previous subsections, we have discussed the energy flows for electrons through different process. Electrons obtain energy from the annihilation of dark matter particles and release through processes of different cooling mechanism. From a long term point of view (since the galaxies are formed), we assume dark matter exists since then and therefore the producing rate of electrons and cooling rate have reach an equilibrium. As a result, combing the power losing and the production rate from the previous subsections, we derive energy distribution as

$$\frac{dn(E,r)}{dE} = \frac{Q}{p}, \qquad (19)$$

where n(E,r) is the number energy density of electron.

4.3 Synchrotron Luminosity

Synchrotron radiation is produced by high energy electron experiencing magnetic field and radiates photon while it orbiting around the field. Therefore, one of the ingredients for synchrotron radiation to occur is the magnetic field. For galaxies inside a universe, the value of magnetic field inside a galaxy typically is about 5~10 micro gauss and we have used 6 micro gauss for doing calculation.

In order to calculate the total synchrotron luminosity, we need to know the power of electron radiates photon in frequency interval $(\nu, \nu + d\nu)$. Therefore, the power is given by[1]

$$P(\nu, E) = \frac{\sqrt{3}e^3}{m_e c^2} B \frac{\nu}{\nu_c(E)} \int K_{5/3}(y)dy = \frac{\sqrt{3}e^3}{m_e c^2} BF(\frac{\nu}{\nu_c(E)}), \qquad (20)$$

where

$$\nu_c(E) = \frac{3}{4\pi} \frac{eB}{m_e c} \left(\frac{E}{m_e c^2}\right)^2$$

and

$$\frac{\nu}{\nu_c(E)} \int K_{5/3}(y)dy = F(\frac{\nu}{\nu_c(E)}).$$

In (20), $v_c(E)$ is the critical synchrotron frequency and $K_n(y)$ is the second type modified Bessel function. In the approximation[8],

$$F(\frac{\nu}{v_c(E)}) \approx \delta(\nu/v_c(E) - 0.29). \tag{21}$$

To get the total synchrotron luminosity density, we integrate over all space volume and energy distribution

$$L_\nu = \int_0^\infty 4\pi r^2\, dr \int_{E_e}^{E_{DM}} \frac{dn(r,E)}{dE} P(\nu, E) dE, \tag{22}$$

and obtain

$$L_\nu = \frac{9}{8}\left(\frac{m_e^3 c^5}{0.29\,\pi\, e}\right)^{-1/2} \frac{\Gamma Y(>E)\phi}{U_E + U_B}\sqrt{\nu} \tag{23}$$

with

$$\phi = \int dr\ 4\pi r^2\, fe\, B^{-1/2}.$$

V. Result and Conclusion

5.1 Result

In this section we will briefly present our intermediate calculation and show the result with our model. First of all, the dark matter distribution (Figure 1.) based on NFW profile (equation (10)) with $\rho_o = 0.285 GeV/cm^3$ for Milky Way galaxy. We obtained ρ_o by finding the local dark matter density in our solar system $\rho_{local} = 0.34 GeV/cm^3$, and invert it according to NFW profile.

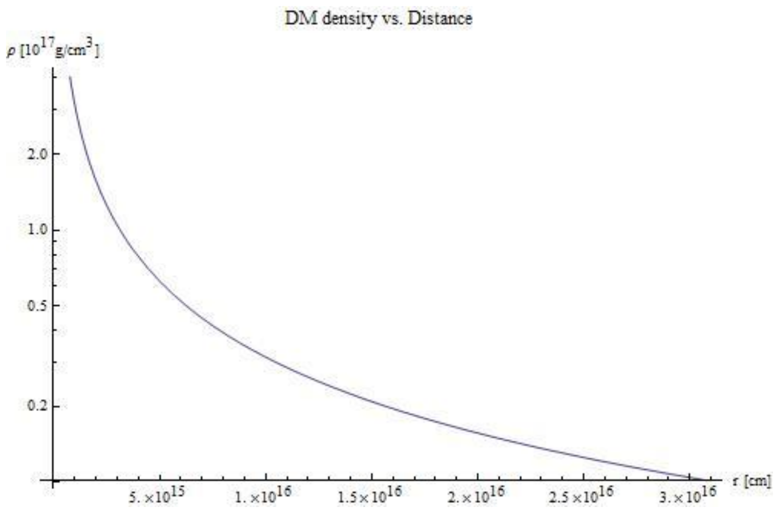

Figure 1. NFW profile

From the distribution of dark matter, we next construct the source function (Figure 2.) by calculating out the annihilation rate $\Gamma = 7.00 \times 10^{24} s^{-1}$, Y(>E)=26.5 and spatial distribution from equation (11), (12), (16) and (17) , and obtain

$$Q(r) = \frac{819.78}{r^2\,(1 + 1.6 \times 10^{-23} r)^4}\,\mathrm{cm}^{-3} s^{-1}$$

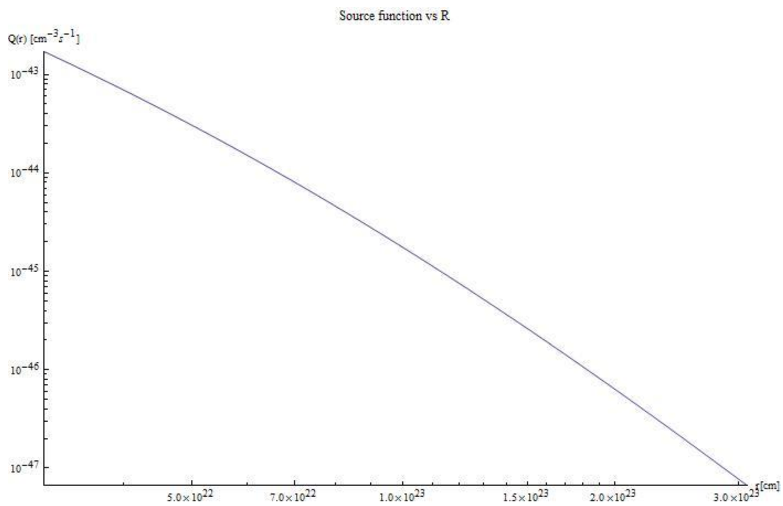

Figure 2. Source function Q(r)

After knowing the source function, next step is to plot the energy distribution according to (19) (Figure 3). Here we integrated over the energy range from electron mass to mass of dark matter and plot four different coloured line, from red to orange are distance at 4 kpc, 8 kpc, 16 kpc and 20 kpc respectively.

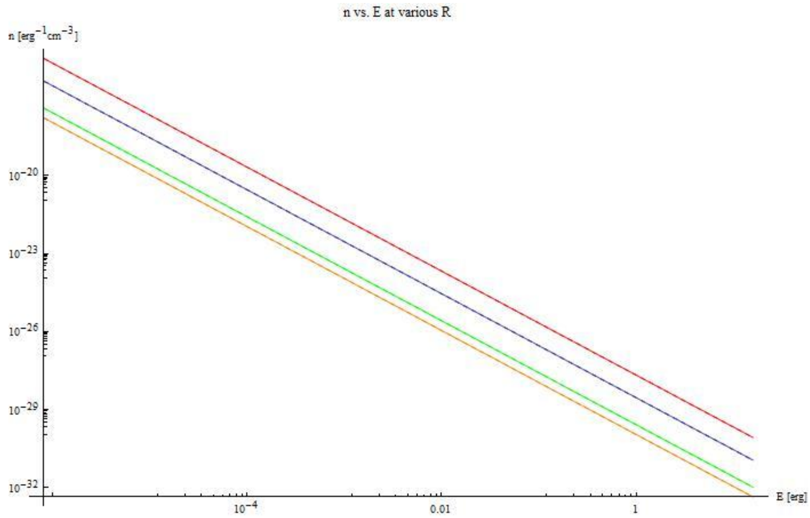

Figure 3. Energy Distribution n(E,r)

Last, the synchrotron luminosity from equation (23) with conversion between luminosity and flux,

$$F_\nu = \frac{L_\nu}{4\pi r^2},$$

we have

L_ν(10GHz)=$2.13 \times 10^{25} erg\ s^{-1} Hz^{-1}$
F_ν(10GHz, 20Mpc)= $44.6\mu Jy$
L_ν(90GHz)=$2.25 \times 10^{24} erg\ s^{-1} Hz^{-1}$
F_ν(90GHz, 20Mpc)= $4.7\mu Jy$
L_ν(200GHz)=$1.51 \times 10^{24} erg\ s^{-1} Hz^{-1}$
F_ν(200GHz, 20Mpc)= $3.2\mu Jy$

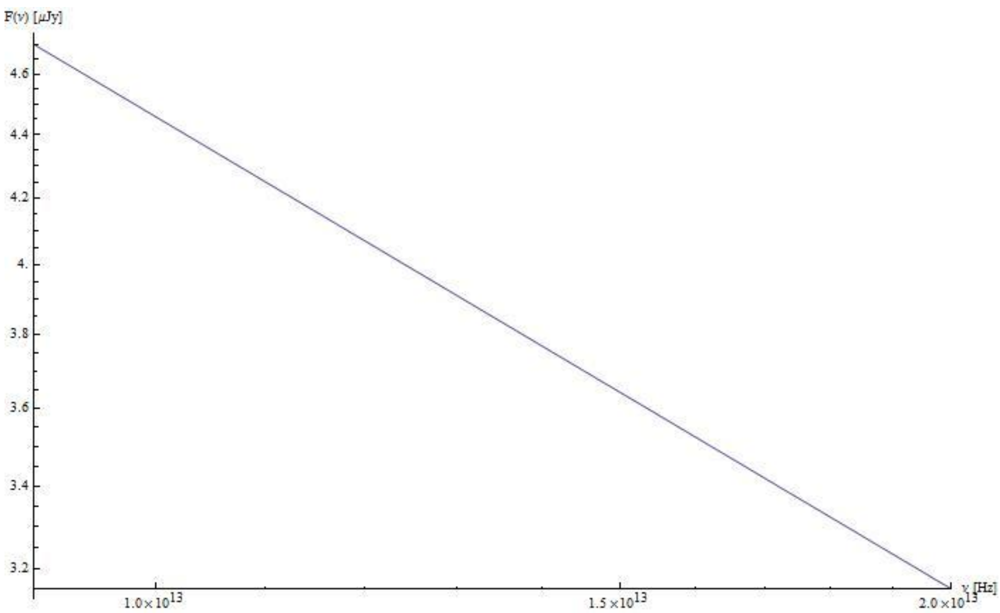

Figure 4. Flux vs. frequency

5.2 Conclusion

In this paper, we have shown the method of computing flux from synchrotron radiation based on our dark matter model. In the observed frequency range of ALMA ground based telescope, we have calculated flux with two typical frequencies in section 5.1, 90 GHz and 200 GHz, and the corresponding flux are 4.7 and 3.2 micro Jansky. The fluxes we have estimated are still too small to observe with ALMA and we will give some improvement to our model that will elaborate more in the next section. In our model, we have used the typical NFW profile which gives us the result of minimum flux we might see from the sky with dark matter model. In addition, the flux at various frequencies we have estimated are only valid until the frequency hits the critical synchrotron frequency since beyond this critical frequency the source of dark matter particle will have limited energy to preserve the shape of synchrotron power spectrum. In other words, for electrons to produce synchrotron radiation at higher frequencies, we demand the electrons to have high enough energy to produce this radiation. However, these electrons are produced by the dark matter particles which have a definite mass that can only produce certain amount of high energy electrons. As a result, when the frequency of synchrotron radiation goes beyond the critical frequency, the stability of the producing this high energy photon will decrease. To sum up, in this paper, we go over the idea of dark matter particles and developed a way to indirectly detect these particles if they do exist. In the future, we will be more precise and taking more factors to improve our model.

VI. Comment

In the conclusion we have summed up the general idea of indirect detection of dark matter particle and there are some ideas for our future work that we will illustrate more in this section. First of all, as mentioned before, NFW profile is a typical way to map out the distribution of dark matter particle; therefore, it only gives us the minimum amount of dark matter. To resolve the problem we have from too little flux that we can observe based on the calculation, we can consider the boost effect. Dark matter will clump together from location to location inside the dark halo is the result of gravitation. This boost effect could increase flux at certain location inside the dark halo by factor of 50 to 100. Another factor we might consider is the black hole and coannihilation effect at galactic center. This will also increase the number density of dark matter by factor of 100.

Second, in this model, we have chosen the LKP to be our dark matter candidate. However, neutralino is also a good candidate for dark matter. The analysis for neutralino is more technical, it is required to use Dark SUSY package in order to figure out the ingredients of $< \sigma v >$ and Y(>E). In the future, neutralino is another avenue for doing research since neutralino is proposed by supersymmetry. The idea of supersymmetry in modern science gives many good explanations in nature and scientists in present are more likely to test it compare to the idea of extra dimensions.

Last, in order to distinguish the high energy electrons from other mechanism that might also create high energy electrons, we can compare the spectrum of these synchrotron spectra. If the electron obtained energy from certain accelerating mechanism, we will see the source of contributing to these high energy electrons at a certain location, near galactic center for instance. Therefore, as we make several observations from inner region of a galaxy to outer region, we might observe the change of synchrotron spectrum because the source of that particular accelerating mechanism only valid nears the galactic center. On the other hand, if the high energy electrons are produced by these dark matter particles, the synchrotron spectrum will depends on the energy distribution of these dark matter particles. Therefore, if we look out the sky and observe some signal that is diffuse on the margin of a galaxy with similar synchrotron spectrum, this could be a smoking gun to the existence of dark matter.

VII. References

[1] arXiv:hep-ph/0404175v2

[2] arXiv:hep-ph/9704361v2

[3]Phys. Rev. D 77, 105020 (2008)

[4] arXiv:hep-ph/0206071v2

[5] arXiv:hep-ph/0002226v1

[6] http://www.cv.nrao.edu/course/astr534/SynchrotronPower.html

[7] http://www.cv.nrao.edu/course/astr534/InverseCompton.html

[8] G.B. Rybicki., A.P. Lightman , Radiative Processes in Astrophysics, 1979, John Wiley & Sons.