Investigation of electron and positron spectrum expected by dark matter for the CALET experiment

T.Aiba[*]**, A.Kato**[*]**, S.Torii**[*] **and J.Chang**[§]

[*]*RISE,Waseda University, Tokyo, Japan*
[§]*Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing, China*

Abstract. **The PAMELA experiment has recently reported that the $e^+/(e^+ + e^-)$ increases apparently over 10 GeV. The electron (and positron) excess, furthermore, is observed at energies between 300 and 800 GeV in ATIC and PPB-BETS. Since these results are hardly understood in consistent only by an acceleration at SNR, many papers indicate new sources, such as WIMP and/or nearby pulsars, have been published. We have carried out a calculation of the cosmic-ray electrons and positrons by using the GALPROP code to understand these results. We try to determine an optimum candidate of the WIMP model by comparing to the observed spectra. We test KK particles which dilectly produced an electron and positron pair by annihilation or decay. A wino-like particle is also examined. It is shown the annihilation of KK particle is compatible with the present data.**

The CALET mission is planned for searching the nearby cosmic ray sources and the dark matter candidates at energies over 100 GeV. We will present an expected capability of CALET to distinguish the models by the excellent energy resolution over 100 GeV ($\sim$ 2%) for the 5-year observation.

Keywords: **electron+positron, dark matter, GAL-PROP**

I. INTRODUCTION

Electrons are mainly accelerated at the cosmic ray sources, propagate through the interstellar space, and arrive at the earth as they lose their energy by electromagnetic process. High energy electrons cause a synchrotron radiation and an inverse Compton scattering. Their energy loss rate is in proportion to E^2 as presented in Eq.1.

$$\frac{dE}{dt} = -bE^2 \tag{1}$$

As a result, electron life, T, becomes shorter in proportion to the inverse of energy. The life time of 1TeV electron is approximately 3×10^5 years. A mean propagation distance R is given by Eq.2

$$R = (2DT)^{1/2} \tag{2}$$

where D is a diffusion coefficient. The R is about 500pc at 1TeV. These might cause a steepening of the observed spectrum and the power index becomes, $\gamma + 1$, at highest energies. In the intermadiate energy region, the spectral index is affected by the propagation characteristics, the size of the galactic halo and disk, the distribution of sources, the reacceleration in interstellar space, etc. Positrons are mainly generated by the nuclear interactions with interstellar medium. Positron spectrum has a power index softer than that of electron. The $e^+/(e^+ + e^-)$ consequently decrease with energy.

However, according to the observation of PAMELA[1], the positron fraction increases between 10∼100GeV. Moreover, ATIC[2] observed an anomaly of the electron+positron flux between 300∼800GeV which is compatible with PPB-BETS[3]. It is proposed that this excess might be caused by nearby pulsars and/or WIMPs. We don't consider nearby pulsars in this paper.

We take a notice of the pair annihilation and the decay of WIMP, and verify these WIMP models. The difference of model affect the shape of electron+positron energy spectrum. We calculate electron+positron energy spectrum with the GALPROP code and determine an optimum candidate of the WIMP model by comparison with observed data. We will show, furthermore, an effect of injection spectrum to the observed flux which might change amount of the excess.

II. PROPAGATION IN GALAXY

In GALPROP, the transport equation presented as Eq.3 is used to calculate for high energy electron.[5]

$$\frac{\partial N(\vec{r}, E, t)}{\partial t} = q(\vec{r}, E) + \nabla \cdot (D_{xx} \nabla N(\vec{r}, E, t))$$
$$- \frac{\partial}{\partial E} \left(\frac{dE}{dt} N(\vec{r}, E, t) \right) \tag{3}$$

where D_{xx} is the spatial diffusion coefficent and $q(\vec{r}, E)$ is the source term of WIMP having continuous distribution. The initial condition is $N(\vec{r}, E, 0) = 0$. The boundary condition is $N(R, \pm Z_{max}, E, t) = N(R_{max}, Z, E, t) = 0$ where R is a radial distance, $\pm Z_{max}$ are the thickness of the galactic disc, and R_{max} is the radius. In this paper, we calculate as R_{max}=20kpc and Z_{max}=4kpc.

When we estimate the number of particle observed at the earth, it is reflected by the solar modulation. In GALPROP the reflection of the solar modulation is estimated by using Force Field approximation[4]. Force Field approximation is presented in Eq.4.

$$\frac{N(r, E, t)}{E^2 - m^2} = \frac{N(\infty, E + \phi)}{(E + \phi)^2 - m} \tag{4}$$

where $N(r, E, t)$ is the flux at the earth, $N(\infty, E + \phi)$ is the flux without the solar modulation, $\phi = \phi(r, E, Z, t)$

is a parameter for the solar modulation. In this paper, we consider the energy region over 10GeV. The solar modualation affect little at this region. Therefore, we assume $\phi = 0$ in calculation.

Main mechanism of cosmic ray acceleration is the shock acceleration by super nova. After the acceleration by shock wave, the electron energy spectrum is assumed to be in the form:

$$q(E) \propto E^{-\gamma} \tag{5}$$

Calculating the spectrum, we have to determin the power index γ. Now we use $\gamma = 2.3$ which is commonly used.

III. DARK MATTER

A. Annihilation model

In annihilation model[2], the source term of the Eq.3 is given as below:

$$q(\vec{r}, E, t) = \frac{K}{2} < \sigma v > \frac{\rho(\vec{r})^2}{M_\chi^2} \frac{dN_e(E)}{dE} \tag{6}$$

where K is the normalization factor, M_χ is the mass of WIMP, $\rho(\vec{r})$ is the density of WIMP, and $\frac{dN_e(E)}{dE}$ is the fragmentation function. For the fragmentation function, we adopt the three paterns of the initial electron spectrum, monochromatic, flat, and double-peak ones[7]. The monochromatic spectrum means that the WIMPs annihilate dilectly into an electron-positron pair. This model corresponds to one of KK dark matter.

$$\frac{dN_e(E)}{dE} = \begin{cases} \delta(E - M_\chi) & \text{if } E = M_\chi \\ 0 & \text{if } E \neq M_\chi \end{cases}$$

The flat distribution is the case that the WIMP annihilates into a lighter particle, which further decays into an electron-positron pair.

$$\frac{dN_e(E)}{dE} = \begin{cases} 1/M_\chi & \text{if } E < M_\chi \\ 0 & \text{if } E > M_\chi \end{cases}$$

The double-peak distribution is the case that the WIMP annihilates into a specific particle except electron-positron and then this particle decays into an electron-positron pair.

$$\frac{dN_e(E)}{dE} = \begin{cases} \frac{3}{M_\chi^3} \left\{ \left(E - \frac{M_\chi}{2} \right)^2 + \frac{M_\chi^2}{4} \right\} & \text{if } E < M_\chi \\ 0 & \text{if } E > M_\chi \end{cases}$$

We calculate these three paterns. In the calculation, it is assumed that M_χ of monochromatic distribution is 610 GeV and M_χ of flat and double-peak distribution is 794GeV and also $< \sigma v >$ of monochromatic distribution is $0.7 \times 10^{-23} \text{cm}^3 \text{sec}^{-1}$, $< \sigma v >$ of flat and double-peak distribution is $2.4 \times 10^{-23} \text{cm}^3 \text{sec}^{-1}$[6]. The ectron+positron spectrum and positron spectrum are presented in Fig.1 and Fig.2, respectively.

We normalized the positron data as it is compatible with the positron fraction data of PAMELA. As a result, the electron+positron spectrum fits to the data of PPB-BETS. In the case of KK dark matter(KKDM), its peek
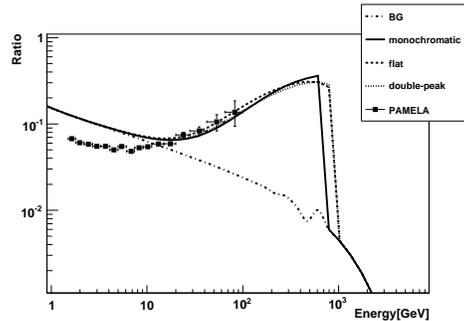

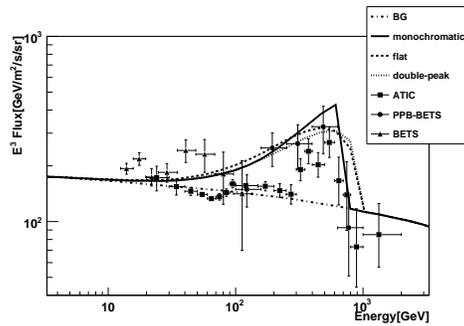Fig. 1.   Three paterns of annihilation model (positron fraction)

Fig. 2.   Three paterns of annihilation model (electron+positron spectrum)

has a steep shape and is compatible with cut-off around 600 to 700GeV observed by ATIC. Both the flat model and the double-peak model have a round peak. Thus it is difficult to distinguish these two models by the spectrum.

B. Decay model

Thinking of the decay of WIMP, the source term of Eq.3 is in the form:

$$q(\vec{r}, E, t) = K \frac{1}{\tau_\chi} \frac{\rho(\vec{r})}{M_\chi} \frac{dN_e(E)}{dE} \tag{7}$$

where τ_χ is the decay time of DM. We malculate three paterns so as to the annihilation model. In the decay model, the relation between M_χ and E_{max} should be replaced with $E_{max} = \frac{M_\chi}{2}$[7]. In the calculation, it is assumed that M_χ is 1341GeV. τ_χ of the monochromatic distribution is 3.3×10^{26}sec, τ_χ of flat and double-peak distribution is 1.1×10^{26}sec.

As shown in Fig.3, the result of decay model is similar to annihilation model. However, in case of the electron+positron spectrum, the contribution of DM flux is larger than the annihilation model in general. The Decay model is not compatible with the observed data by ATIC and PPB-BETS.

C. Wino-like SUSY dark matter model

We explain the calculation of wino-like neutralino model[8]. Differently from KKDM, the wino-like neutralino needs some phase to generate electrons. First of all, wino-like neutralino annihilate to $W^\pm$ or Z^0. And then these bosons generate electrons and positrons by
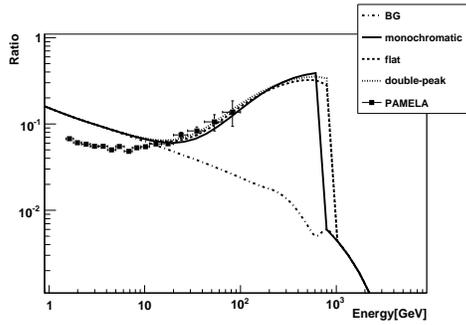
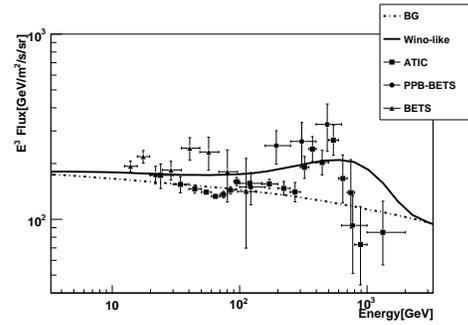Fig. 3.   Three paterns of decay model (positron fraction)

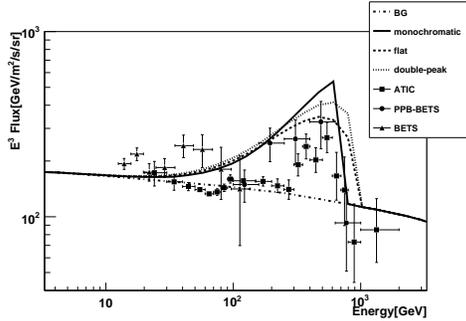Fig. 6.   Wino-like SUSY model (electron+positron spectrum)

IV. EFFECT OF INJECTION SPECTRUM TO BACKGROUND FLUX

We have to consider, furthermore, the background electrons derived from SNRs. In this paper, we calculate the power index of injection spectrum as $\gamma=2.3$, but we substitute another value of γ in the above calculation, the shape of the spectrum will change. We adopt another value of γ to check a possible change of the spectrum in the observed spectrum. Fig.7 shows the energy spectrum in case of the injection spectrum's power index $\gamma=2.2$ by KKDM. The amount of electron+psitron excess against background becomes smaller. The power index of the observed spectrum is approximately $\gamma=3.03$ in this case. For this reason, it is important to evaluate the background.

Fig. 4.   Three paterns of decay model (electron+positron spectrum)

lepton cascade and hadron cascade. When neutralino annihilates into some kinds of particle, we work out the sum of plural f,

$$q(\vec{r}, E, t) = \frac{K}{2} \frac{\rho(\vec{r})^2}{M_\chi^2} \sum_f < \sigma v >_f \left(\frac{dN_e(E)}{dE} \right)_f \quad (8)$$

We substitude the value for $< \sigma v >$ and fragmentation function. $< \sigma v >$ of f=ZZ, f=WW is $2.5 \times 10^{-26} \text{cm}^{-3} \text{sec}^{-1}$, $4 \times 10^{-25} \text{cm}^{-3} \text{sec}^{-1}$,respectively[8].

Fig. 7.   Electron+positron spectrum($\gamma=2.2$)

V. SUMMARY AND DISCUSSIONS

We calculate the observed electron+positron spectrum and the positron fraction by GALPROP through modelizing the shape of DM fragmentation function for considering the cause of the positron fraction excess over 10GeV. We consider three paterns of fragmentation function; monochromatic distribution, flat distribution, and double-peak distribution. When fragmentation function has the shape of monochromatic, both of the annihilation and the decay have steep cut-off around $600 \sim 700\text{GeV}$. However, in the case of flat and double-peak, there is a cut-off at 1000GeV. The wino-like SUSY model doesn't have such a steep cut-off, and the enhancement becomes much smaller. The observed data of high energy electorns have large errors. Therefore it is still uncertain
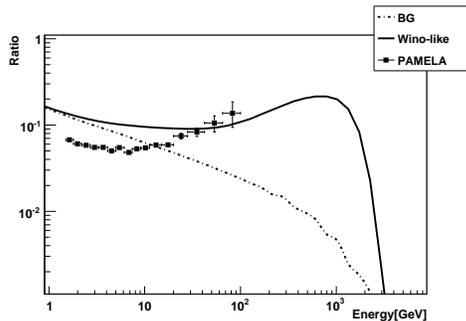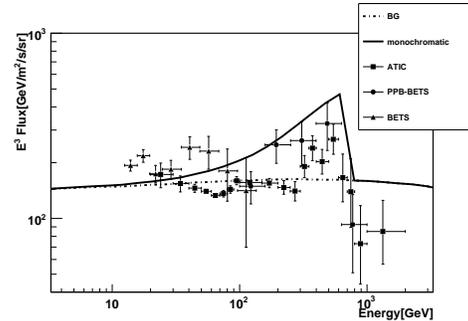

Fig. 5.   Wino-like SUSY model (positron fraction)

As Fig.5. indicates, positron faraction incleases around 100GeV and it has a gentle slope compered with another model. Thus it is not compatible with PAMELA's data. The electron+positron spectrum has no enhancement, and doesn't have a steep cut-off.

to get a conclusion. In case of the nearby pulsar being concerned we should find the anisotropy of the arrival direction. In the near future,we need precise observation of anisotropy of arrival direction and statistically enough amount of electron data at high energies.

The electron obsevation by the CALET mission is planed in 2013 expected to search for nearby sources and WIMPs. Fig.8 shows the CALET capability to KKDM with a mass of 300GeV[9]. The CALET
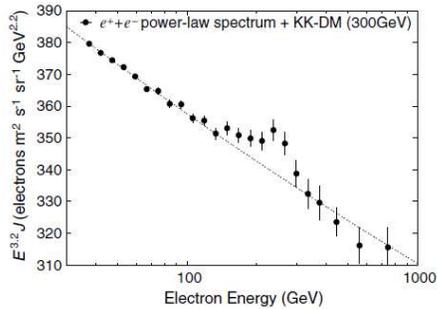
experiment might detect the anisotropy of the electron arrival direction in TeV energy region expected from nearby sources. Thus including to discriminating the contribution of pulsar, CALET is expected that it will derive most important result.

Fig. 8.   A result of electron+positron energy spectrum simulated in case of the CALET

REFERENCES

[1] O. Adriani, et al. 2008, arXiv:0810.4995v1[astro-ph]
[2] J. Chang, et al. 2008, Nature 456, 362-365
[3] S. Torii, et al. 2008, arXiv:08090760v1[astro-ph]
[4] L. Gleeson and W. Axford 1968, ApJ 154.1011G
[5] GALPROP HP,http://galprop.stanford.edu/web_galprop/galprop_home.html
[6] Hsin-Chia Cheng, et al. 2002, PhysRevLett.89.211301
[7] Chuan-Ren Chen, et al. 2008, arXiv:0812.4200v1[astro-ph]
[8] J. Hisano, et al. 2006, arXiv:hep-ph/0511118v2
[9] S. Torii, et al. Advances in Space Research, Volume 41, Issue 12, p.2032-2036