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Observation on Local Group using the Tibet Air Shower Array and the Possible Relation with Dark Matter Annihilation

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Using Tibet Air Shower Array, observations on some Local Group galaxies, such as M31, M33 and M87, are made, and 90% C.L. flux upper limit are set assuming a dark matter annihilation energy spectrum. The results are compared with the prediction from the dark matter annihilation.

1. Introduction

Both astronomical and cosmological observations have concluded that Dark Matter(DM) contributes a quarter of the energy partition in the universe and DM dominates the matter composition in galaxies. Among various theoretical DM particle candidates, neutralino predicted by SUSY models is the most attracting one. Though there is no electromagnetic radiation, as the antiparticle of itself, they can annihilate into a pair of photons or other particles which eventually decay to the final state photons. Theoretically, the corresponding gamma ray flux is proportional to the square of the dark matter density. Therefore, such a signal can most probably be observed from the center of the galaxies or substructure in the galaxies. Successful TeV gamma ray detection from M87 [1, 2] and from the center of our galaxy[3] therefore encourage us to further study the process in a wide area of the sky.

In this work, as a first step, we'll concentrate at three of the Local Group(LG) galaxies M31, M33 and M87. Using Tibet AS-γ experiment, we make observation on these LG galaxies, and set 90% C.L. flux upper limit by assuming DM annihilation energy spectrum. Furthermore, the experimental data are compared with theoretical prediction.

2. Observations and results

The Tibet air shower array has been conducted at Yangbajing (90.522°E, 30.102°N; 4,300 m a.s.l) in Tibet, China since 1990. The Tibet I array, which consisted of 49 scintillation counters forming a 7×7 matrix of 15 m span, was gradually expanded to the Tibet II array occupying an area of about 37000 m^2 by increasing the number of counters from 1994 to 1996. Both Tibet I and II have the same mode energy (the same probable energy) of 10 TeV. In order to observe TeV CRs, in 1996, part of the Tibet II array covering an area of 5175 m^2 was further upgraded to a high density (HD) array [4] with 7.5 m span. The area of Tibet III reaches 22050 m^2. And the energy resolution is about 100% for both Tibet HD and Tibet III arrays. The trigger rate is about 105 Hz for the HD and 680 Hz for the Tibet III. In this work, the sample includes data obtained by running the HD array for 555.9 live days from Feb. 1997 to Sept. 1999 and the Tibet III array for 456.8 days from Nov. 1999 to Oct. 2001. After applying data quality cut, about 40% of the shower events were selected, results in a total number of events to be about 7.0×10^9. Data analysis shows that there is no obvious γ-ray flux enhancement from those LG galaxies: M31, M33 and M87. After taking into account the γ ray spectrum from DM annihilation, the corresponding flux upper bounds are listed in TAB.1, slowly depending on DM Mass.

Table 1. Gamma ray integral flux upper limit $(E > 1TeV)$ at 90% C.L. are given by Tibet AS-γ data, while a DM annihilation energy spectrum is assumed.

LG name	RA. (deg)	DEC. (deg)	$\phi(m_\chi = 2TeV)$ $(cm^{-2}s^{-1})$	$\phi(m_\chi = 5TeV)$ $(cm^{-2}s^{-1})$	$\phi(m_\chi = 10TeV)$ $(cm^{-2}s^{-1})$	$\phi(m_\chi = 20TeV)$ $(cm^{-2}s^{-1})$
M31	10.7	41.3	$6.508407E-11$	$5.602135E-11$	$3.186636E-11$	$1.668202E-11$
M33	23.5	30.7	$2.632560E-11$	$3.874745E-11$	$2.223994E-11$	$1.170077E-11$
M87	187.7	12.4	$4.092594E-11$	$4.523610E-11$	$2.580358E-11$	$1.329792E-11$

3. Comparing theoretical results with Tibet AS-γ experiment limit

Dark matter particle is usually considered as the lightest supersymmetric particle (LSP) which, in most supersymmetry breaking scenarios, is the neutralino χ. Theoretically, there are both monochromatic and continuum γ fluxes come from dark matter annihilation, but the latter dominates the process, which we consider mainly here. Suppose that the dark matter is concentrated in a spherical halo of the virial radius r_{vir} and density profile ρ_χ, then, the diffuse gamma ray from dark matter annihilation in galaxies can be written as[5]:

$$\frac{\mathrm{d}\phi_\gamma(E)}{\mathrm{d}E_\gamma} = \sum_F \frac{\mathrm{d}N_\gamma}{\mathrm{d}E_\gamma} b_F \frac{\langle\sigma \cdot v\rangle}{2m_\chi^2} \int_0^{r_{vir}} \frac{\rho_\chi^2(r)}{D^2} r^2 \mathrm{d}r, \tag{1}$$

where we take r as the distance to the galactic center.

Depending on the annihilation channel, the continuum differential energy spectrum can be parameterized[6] as $\mathrm{d}N/\mathrm{d}x = ax^{-1.5}e^{-bx}$ where $x = E_\gamma/m_\chi$, $a \sim O(1)$ and $b \sim O(10)$. Here we consider as a unique annihilation channel: $\chi\chi \to W^+W^-$, with parameters $a = 0.73$ and b=7.76 in the formula. The annihilation rate is determined by the dark matter number density at the freeze-out epoch[7]: $\Omega_\chi h^2 \sim \frac{3\times10^{-27}cm^3s^{-1}}{\langle\sigma\cdot v\rangle}$, where h is the Hubble constant and Ω_χ refers to the average density of dark matter in units of critical density. We take $\langle\sigma \cdot v\rangle = 2 \times 10^{-26}cm^3s^{-1}$ in the calculations.

Current observations give weak limits on the distribution of dark matter in galaxies. Two popular density profiles[8][9] are given by N-body simulations:

$$\rho_\chi^{nfw}(r) = \frac{\rho_s^{nfw}}{(r/r_s^{nfw})(1 + r/r_s^{nfw})^2} \tag{2}$$

$$\rho_\chi^{moore}(r) = \frac{\rho_s^{moore}}{(r/r_s^{moore})^{1.5}[1 + (r/r_s^{moore})^{1.5}]} \tag{3}$$

The scale radii r_s and the scale densities ρ_s can be decided by the virial mass of the halo and concentration parameter. The relevant parameters can get from Ref.[10]and[11].

Up to now, dark matter halo clustered in small length scales was wildly discussed. Since sub-halo will greatly enhance the γ emission, the effect including substructure should be considered. Following the approach of Ref.[12] and the references therein, Eq.(1)can be rewritten as

$$\frac{\mathrm{d}\phi_\gamma(E)}{\mathrm{d}E_\gamma} = \sum_F \frac{\mathrm{d}N_\gamma}{\mathrm{d}E_\gamma} b_F \frac{\langle\sigma \cdot v\rangle}{2m_\chi^2} \frac{f\delta\rho_0}{D^2} \int_{line\ of\ sight} \rho_\chi(r) r^2 \mathrm{d}r, \tag{4}$$

where f is defined as the fraction of the clumpy component in the total dark halo, and δ is a dimensionless

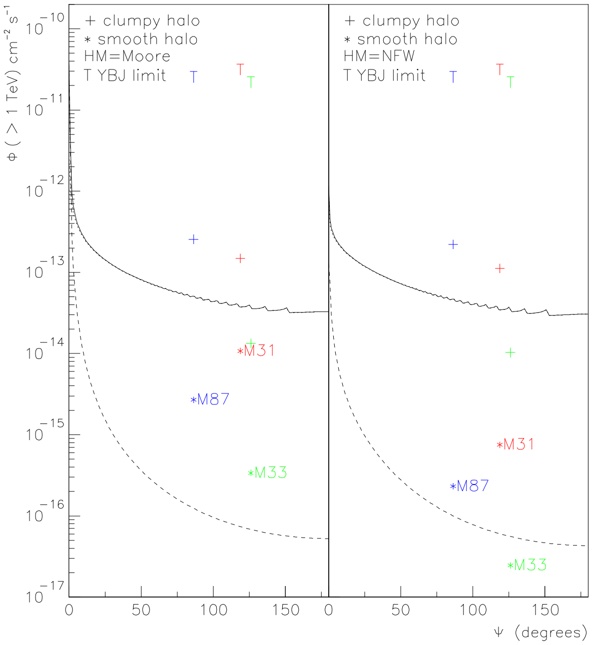

Figure 1. The γ fluxes from the Milk Way(real line) and local groups for Moore and NFW dark halo profile. The contribution from the smooth(dashed line) component is also given. For different local groups M31, M33 and M87, theoretical values and Tibet AS-γ experimental upper limits are marked, respectively.

parameter which gives the effective contrast between the sub-halo density and the local halo density ρ_0, $\delta = \rho_{cl}/\rho_0 \sim O(1000)$. From what we can get that the product of the parameter f and δ, determines the clumpy magnitude.

According to the theoretical framework given above, we compared the predicted γ ray fluxes due to different halo models(HM), the smooth and the clumpy ones, NFW and Moore profile. The expected γ fluxes from galaxies comparing with Tibet AS-γ observational data are showed in FIG. 1, where we take the mass of neutralino $M_\chi = 10TeV$ and consider 10% of dark halo is clumpy, typically $f\delta = 200$ in the calculations.

Actually, since different energy spectrum contributing different detection efficiency, it will be consistent to take the energy spectrum induced by DM annihilation. FIG.2 gives the integral flux upper limits$(E > 1TeV)$ from the three LG galaxies VS. different DM mass choices. The present limit is about two order of magnitude higher than the predict γ-ray flux by DM annihilation.

4. Discussion and conclusions

The gamma ray observation from galactic center made by HESS and HEGRA are in favour of multi-TeV M_χ in interpretation of neutralino annihilation. From FIG.2 we can conclude that in order to put a strict constrain to the theoretical model of supersymmetry dark matter, Tibet ASγ experiment need to further improve its sensitivity by orders of magnitude, which can not be reached by just including more data sample into analysis. Taking the advantage of large field of view, we hope to be able to combine the observations from more halos, especially from subhalos expected to be exist in our galaxy, this will be studied in our future work.

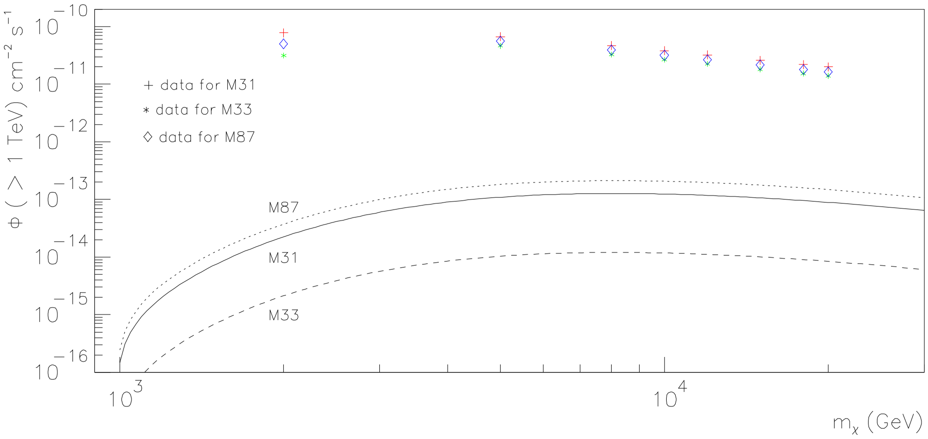

Figure 2. By assuming a energy spectrum induced by DM annihilation, γ-ray flux upper limit for M31, M33 and M87 are given by Tibet AS-γ experimental data. Theoretical fitting for different dark matter mass choices are plotted as well. The Moore halo profile and $f\delta = 200$ are adopted.

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