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Gamma rays from dark matter annihilation in the Draco and observability at ARGO

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Abstract. The CACTUS experiment recently observed a gamma ray excess above 50 GeV from the direction of the Draco dwarf spheroidal galaxy. Considering that Draco is dark matter dominated, the gamma rays may be generated through dark matter annihilation in the Draco halo. In the framework of the minimal supersymmetric extension of the standard model we explore the parameter space to account for the gamma ray signals at CACTUS. We find that the neutralino mass is constrained to be approximately in the range between 100 GeV $\sim$ 400 GeV and a sharp central cuspy of the dark halo profile in Draco is necessary to explain the CACTUS results. We then discuss further constraints on the supersymmetric parameter space by observations at the ground-based ARGO detector. It is found that the parameter space can be strongly constrained by ARGO if no excess from Draco is observed above 100 GeV.

1 Introduction

The existence of cosmological dark matter has been established by various astronomical observations. However, the evidence comes mainly from the gravitational effects of the dark matter component. The nature of dark matter remains elusive and remains one of the most outstanding puzzles in particle physics and cosmology [1, 2]. The primordial nucleosynthesis and cosmic microwave background measurements constrain the baryon component and most of the dark matter component should be nonbaryonic. The development in understanding the large scale structure formation requires the dark matter to be cold. From the theoretical considerations the favored candidate for cold dark matter (CDM) seems to be weakly interacting massive particles (WIMPs) [1, 2].

The WIMPs can be detected indirectly by observing the annihilation products, such as gamma rays, neutrinos, anti-protons and positrons. Exploring the anomalous results from the cosmic ray experiments is one viable way to identify the dark matter. Since the annihilation rate is proportional to the square of the dark matter density, the ideal sites for dark matter detection should have high dark matter density. The galactic center is believed to be a promising source of dark matter annihilation [3]. However, the existence of the central supermassive black hole and the supernova remnant Sgr A* contaminates the dark matter signals heavily. Alternative sites, such as the substructures of the Milky Way or the dark matter dominated dwarf spheroidal galaxies (dSph), have been studied in [4–8].

Recently, the CACTUS gamma ray experiment reported an excess of gamma rays from the direction of Draco, a nearby dSph [9–12]. Since Draco is dark matter dominated and no other gamma ray sources are expected to be hosted [13, 14], the excess has been attributed to the annihilation of dark matter in the Draco halo [15, 16]. The results are still preliminary and, if confirmed, will have important implications on the nature of dark matter and the density profile of Draco. Additional observations of the signal by other experiments are therefore very important. GLAST [17], a satellite-based experiment, and MAGIC [18], a ground-based Atmospheric Čerenkov Telescope (ACT), have been considered to check the CACTUS results [15, 16]. In the present work, we will discuss the possibility of detecting or constraining the gamma rays observed by CACTUS at ARGO [19, 20], a ground-based extensive air shower (EAS) detector.

In the next section we will first give the general formula for dark matter annihilation. Then we will discuss the implications of CACTUS results on the gamma ray spectrum and fluxes in Sect. 3. The sensitivity of ARGO is given in Sect. 4 and the numerical results are presented in Sect. 5. We conclude in Sect. 6.

2 Gamma rays from dark matter annihilation

The annihilation of two WIMPs can produce the continuous spectrum of gamma rays arising mainly in the decays of the neutral pions produced in the fragmentation processes

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initiated by tree level final states. The fragmentation and decay processes can be simulated with the Pythia package [21].

The annihilation rate in unit time and unit volume is given by

$$R = \langle\sigma v\rangle n^2/2 = \frac{\langle\sigma v\rangle\rho^2}{2m^2}\,, \tag{1}$$

where σ and v are the annihilation cross section and the relative velocity of the two dark matter particles respectively, n and ρ are the number and mass densities of the dark matter, and m is its mass, while the factor 2 in the denominator arises due to the identical initial particles. We note that the annihilation rate is proportional to the square of the dark matter density, and, therefore, a high density region can greatly enhance the annihilation fluxes.

The gamma ray flux from the Draco halo is therefore given by

$$\begin{aligned}\Phi_\gamma(E) &= \phi^\gamma(E)\frac{\langle\sigma v\rangle}{2m^2}\frac{\int \mathrm{d}V\rho^2}{4\pi D^2}\\ &= \frac{\phi^\gamma(E)}{4\pi}\frac{\langle\sigma v\rangle}{2m^2}\times\frac{1}{D^2}\int_{\Delta\Omega}\mathrm{d}\Omega\int 4\pi r^2\,\mathrm{d}r\rho^2(r),\end{aligned} \tag{2}$$

where the halo profile is assumed to be approximately spherically symmetric with the density profile $\rho(r)$, $D = 75.8\pm0.7\pm5.4\,\mathrm{kpc}$ is the distance to Draco [22], and $\phi^\gamma(E)$ is the differential flux at energy E in a single annihilation in units of 1 gamma GeV^{-1}. $\Delta\Omega$ represents the angular resolution of the detector.

The density profile $\rho(r)$ of Draco is constrained by observations. A recent analysis shows that both a cored and a cuspy profile, such as the NFW profile [23–25], are consistent with the observational data and the results of N-body simulation [26, 27]. The 'astrophysical factor' in (2) defined as

$$\Phi_{\mathrm{astro}} = \frac{1}{D^2}\int_{\Delta\Omega}\mathrm{d}\Omega\int 4\pi r^2\,\mathrm{d}r\rho^2(r)\,, \tag{3}$$

which is determined by the astrophysical quantities solely, is severely constrained by the observational data. It is found that Φ_{astro} varies by a factor of approximately only 200, i.e., $\Phi_{\mathrm{astro}} \cong (3.2\times10^{-4}\sim6.4\times10^{-2})\,\mathrm{GeV}^2\,\mathrm{cm}^{-6}\times\mathrm{kpc\,sr}$ following [26, 27].

The other part in (2) is determined by particle physics which defines the nature of dark matter. We will calculate the 'particle factor' in the framework of the minimal supersymmetric standard model (MSSM). The MSSM is the most attractive model beyond the standard model of particle physics. In the R-parity conserved MSSM, the lightest supersymmetric particle, the lightest neutralino, provides a natural candidate for WIMPs. The MSSM is well defined by a set of free parameters, which lead to the uncertainties in predicting the gamma ray flux from the particle physics. Once the particle factor is determined and combined with the astrophysical factor given above, we can give the predicted gamma ray flux from Draco.

3 The CACTUS experiment

CACTUS is a ground-based Air Čherenkov Telescope (ACT) located at Solar Two near Barstow, California. CACTUS utilizes a set of 144 heliostats, each $42\,\mathrm{m}^2$, to form a composite mirror with a total effective area of about $6000\,\mathrm{m}^2$. The threshold energy for gamma rays at CACTUS is about 50 GeV and the effective area for $\gtrsim 200$ GeV gamma rays reaches about $50\,000\,\mathrm{m}^2$.

Within the angular region of about 1° centered around the direction of Draco, CACTUS has recently observed an excess of approximately 30 000 photons for 7 h observation above the average background outside Draco [9–12]. The threshold energy of the photons is about 50 GeV. There is no significant excess observed if the cutoff energy is improved to about 150 GeV. Although the results are still preliminary, yet, if confirmed, the implications for dark matter are significant. It is interesting to consider the implications of the CACTUS experimental results seriously due to our completely ignorance of the nature of dark matter. In this section we will study the implications for the gamma ray spectrum and flux from the CACTUS results.

The gamma events are given by

$$N_\gamma^{\mathrm{observed}} = \epsilon_{\Delta\Omega}\int_{E_{\mathrm{th}},\Delta\Omega}^{m_\chi} A_{\mathrm{eff}}(E)\Phi(E)\,\mathrm{d}E\,\mathrm{d}\Omega\,\mathrm{d}xT\,, \tag{4}$$

where $\epsilon_{\Delta\Omega} = 0.68$ is the fraction of signal events within the angular resolution of the instrument and the integration is for the energies above the threshold energy E_{th} and below the mass of neutralino, m_χ, within the angular resolution of the instrument $\Delta\Omega$ and for the observational time. The effective area A_{eff} is a function of energy and $\Phi(E) = \phi_0\frac{\mathrm{d}N_\gamma}{\mathrm{d}E}$ is the flux of γ rays from DM annihilation with ϕ_0 the intensity normalization and $\frac{\mathrm{d}N_\gamma}{\mathrm{d}E}$ the shape of the spectrum. The effective area of CACTUS, which is energy dependent, can be parametrized as

$$A_{\mathrm{eff}} \approx 47\,000\,\mathrm{m}^2\left[1-\mathrm{e}^{-0.014(E_\gamma-39.6\,\mathrm{GeV})}\right]+11.9E_\gamma(\mathrm{GeV}), \tag{5}$$

due to the simulation results [9–12].

From (4), we can see that in order to obtain the gamma ray flux from the observed event number we have to assume the gamma ray spectrum first. The spectrum of the gamma rays through neutralino annihilation depends on the final states into which the neutralinos have annihilated. In Fig. 1 we show the spectrum of gamma rays for the final states of gauge bosons $\chi\chi\to W^+W^-$ and for the final states of $\chi\chi\to b\bar{b}$ and $\chi\chi\to\tau\bar{\tau}$, which represent the two extreme cases that the annihilated gamma rays have soft and hard spectra, respectively. In the figure we have plotted the spectrum for $m_\chi = 100, 500$ GeV respectively. We find that the spectrum, expressed as a function of the dimensionless quantity $x = E_\gamma/m_\chi$, is not sensitive to the mass of the neutralino, m_χ. The insensitivity of $\frac{\mathrm{d}N_\gamma}{\mathrm{d}x}$ to the neutralino mass was also found in [3].

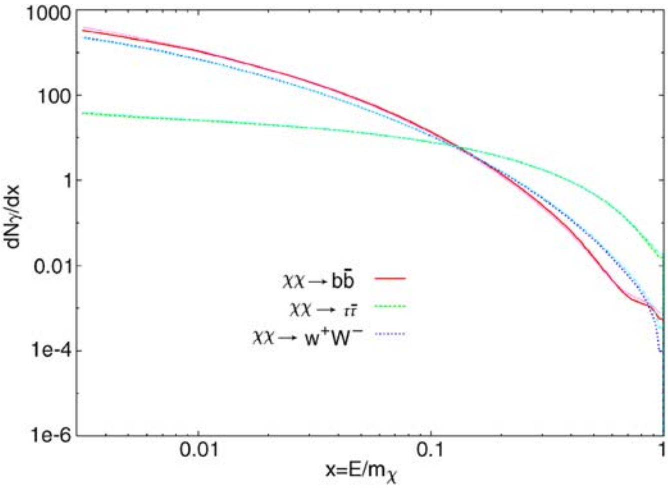

Fig. 1. The spectrum of gamma rays from neutralino annihilation, $\frac{\mathrm{d}N_\gamma}{\mathrm{d}x}$ with $x = E_\gamma/m_\chi$, for the final state of W^+W^-, $b\bar{b}$ and $\tau\bar{\tau}$. $m_\chi = 100, 500$ GeV has been taken, which gives an almost identical spectrum $\frac{\mathrm{d}N_\gamma}{\mathrm{d}x}$ for each final state

The integrated gamma ray flux above the threshold energy of 50 GeV is given by

$$I_\gamma(>50\,\mathrm{GeV}) = \int_{50\,\mathrm{GeV}}^{m_\chi} \Phi(E)\,\mathrm{d}E = \int_{50\,\mathrm{GeV}}^{m_\chi} \frac{\mathrm{d}N_\gamma}{\mathrm{d}E}\,\mathrm{d}E \times \frac{N_\gamma^{\mathrm{observed}}}{\epsilon_{\Delta\Omega}\int_{50\,\mathrm{GeV}}^{m_\chi} A_{\mathrm{eff}}(E)\frac{\mathrm{d}N_\gamma}{\mathrm{d}E}\,\mathrm{d}ET}\,, \quad (6)$$

where we have assumed that the effective area has no zenith angle dependence within the angular resolution. From this equation we know that the softer the spectrum the greater the gamma ray flux is, since A_{eff} is small at low energies. For a soft spectrum, taking $m_\chi = 100$ GeV and the $b\bar{b}$ final states, we get $I_\gamma(>50\,\mathrm{GeV}) = 1.7\times10^{-8}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, while for the hard spectrum, taking $m_\chi = 300$ GeV and the $\tau\bar{\tau}$ final states, we get $I_\gamma(>50\,\mathrm{GeV}) = 7.3\times10^{-9}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. This spectrum is taken in order not to give too much excess above 150 GeV. Concerning the uncertainties from the noise rejection procedures, the misidentification of the electronic and hadronic primary events and that the fact the angular region of CACTUS is larger than that of Draco, the observed excess may be much larger than the real *signal* of dark matter annihilation. Therefore in our theoretical calculation we make the assumption that the uncertainty of the gamma ray flux is larger than the current CACTUS data by relaxing the lower bound by an order of magnitude. We finally get the gamma ray flux from Draco which is approximately in the range of

$$7.3\times10^{-10} < I_\gamma(>50\,\mathrm{GeV}) < 1.7\times10^{-8}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,. \quad (7)$$

Since there is no significant excess observed above 150 GeV the gamma ray spectrum is further constrained. We assume that the events above 150 GeV do not exceed the Poisson fluctuation of the background, which includes the misidentification of hadronic cosmic rays as gamma signals, the electronic comic ray events and the galactic diffuse gamma rays. We have adopted the expressions

$$\phi_{\mathrm{h}}(E) = 1.49E^{-2.74}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1}\,\mathrm{GeV}^{-1} \quad (8)$$

for the hadronic contribution [28], and

$$\phi_{\mathrm{e}}(E) = 6.9\times10^{-2}\,\mathrm{E}^{-3.3}\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1}\,\mathrm{GeV}^{-1} \quad (9)$$

for the electronic contribution [29], and furthermore

$$\phi_{\mathrm{galac}-\gamma}(E) = 8.56\times10^{-6}\,\mathrm{E}^{-2.7}\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1}\,\mathrm{GeV}^{-1} \quad (10)$$

for the Galactic γ ray emission at the direction of Draco ($l = 86.4°$, $b = 34.7°$), extrapolated from the EGRET data at low energies [3].

In principle the gamma ray flux above 150 GeV also depends on the spectrum of the gamma ray. However, due to (5) the effective area above 150 GeV is not so sensitive to the energy different from that at energies below 100 GeV. Considering the large systematic uncertainties and the possible problems in the noise reduction procedure, we approximate the effective area above 150 GeV as $50\,000\,\mathrm{m}^2$, being a constant. Then we get a conservative upper limit of $I_\gamma(>150\,\mathrm{GeV})$. Assuming that about 90% of the hadronic comic ray background can be rejected within the angular region due to the different shape of the Čherenkov wavefront induced by electronic and hadronic showers, we get

$$I_\gamma(>150\,\mathrm{GeV}) \lesssim 3\times10^{-11}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,. \quad (11)$$

In the next sections we will explore the supersymmetric (SUSY) parameter space to account for the gamma excess observed at CACTUS taking into account the constraints given by (7) and (11).

4 Sensitivity of ARGO

The ARGO-YBJ experiment, located at YangBaJing (90.522° east, 30.102° north, 4300 m a.s.l.) in Tibet, China, is a ground-based telescope optimized for the detection of small size air showers. The energy threshold of the detector is designed to be about 100 GeV. The detector consists of a single layer of RPCs floored in a carpet structure covering an area of $\sim 10^4\,\mathrm{m}^2$. The detector is under construction, and the central carpet has been completed in June 2006 and put in stable data taking soon after.

The performances of the detector have been studied by means of Monte Carlo simulations [30, 31]. Defined as the product of the sampling area and the trigger efficiency, the effective area characterizes the power of the detector in recording the number of events for a given energy and time interval from a given direction. For both primary γ and hadrons with energy near the threshold, the effective area can be approximately parameterized as $A_{\mathrm{eff}} \approx$

$A_{100}\left(\frac{E}{100\,\mathrm{GeV}}\right)^{2.4}$, when the trigger condition is set to be larger than or equal to 20 fired pads, where $A_{100} \sim 100\,\mathrm{m}^2$ is the effective area for primary γ ray events at the threshold energy of about 100 GeV [30, 31]. Above the threshold energy the effective area increases rapidly and reaches about $10\,000\,\mathrm{m}^2$ for TeV gamma rays. At the same time, simulation also shows that at low energies the protons have lower trigger efficiency than the photons. The effective area for protons near the threshold energy is about one order of magnitude smaller than that of gamma, leading to a great suppression of the background.

The Draco dSph is within the field of view of the ARGO detector with the closest zenith angle to be $\sim 27°$. Follow-up observations on the gamma excess seen by CACTUS have been considered at GLAST and MAGIC [15, 16]. Ground-based extensive air shower (EAS) arrays with a low energy threshold, such as ARGO [19, 20] and the next generation all-sky high energy gamma ray telescope HAWC [32], have properties complementary to those of the satellite borne experiments and the ACTs. They have large effective areas and at the same time possess the advantages of a large field of view and near 100% duty cycle. However, the EAS arrays usually have a poorer hadron–photon identification power. In this work, we will discuss how to constrain the gamma ray signal from Draco by the ARGO experiment.

For this purpose, we focus on the events for the energy below ~ 400 GeV, since we will see in the next section that the CACTUS excess constrains the neutralino mass to be lower than ~ 400 GeV. The number of background events for one year's data taking at ARGO is therefore also estimated in this energy range. To constrain the signal at the 2σ level for one year's observation, the flux above 50 GeV from Draco is then constrained as

$$I_\gamma(>50\,\mathrm{GeV}) = \frac{2\sqrt{\mathrm{N_{bkg}}}}{A_{100}T} \cdot \frac{\int_{50}^{m_\chi} \frac{\mathrm{d}N_\gamma}{\mathrm{d}E}\,\mathrm{d}E}{\epsilon_{\Delta\Omega} \int_{100}^{m_\chi} \left(\frac{E}{100}\right)^{2.4} \frac{\mathrm{d}N_\gamma}{\mathrm{d}E}\,\mathrm{d}E}\,, \tag{12}$$

where again the zenith angle dependence of the effective area of the ARGO detector is ignored.

5 Numerical results

In this section we will explore the SUSY parameter space to account for the CACTUS excess, assuming that the excess (or a fraction of the excess) is generated by neutralino annihilation in the Draco halo. The constraint on the parameter space from ARGO is taken into account.

The R-parity conserved MSSM is described by more than one hundred parameters describing the soft supersymmetry breaking. However, for the processes related with dark matter production and annihilation, only several parameters are relevant under some simplifying assumptions, namely the higgsino mass parameter μ, the bino mass parameter M_1, the wino mass parameter M_2, the mass of the CP-odd Higgs boson m_A, the ratio of the Higgs vacuum expectation values $\tan\beta$, the scalar fermion mass parameter $m_{\tilde{f}}$, and the trilinear soft breaking parameter A_t and A_b. To determine the low energy spectrum of the SUSY particles and coupling constants, the following assumptions have been made: all the sfermions have common soft breaking mass parameters $m_{\tilde{f}}$; all trilinear parameters are zero except those of the third family; and the gluino and wino have the mass relation, $M_3 = (\alpha_\mathrm{s}(M_Z)/\alpha_\mathrm{em})\sin^2\theta_\mathrm{W} M_2$, coming from the unification of the gaugino mass at the grand unification scale. However, to explore a more general low energy phenomenological SUSY parameter space we relax the relationship between M_1 and M_2 derived from the grand unification scale.

We perform a numerical random scan in the 8-dimensional supersymmetric parameter space using the package DarkSUSY [34]. The ranges of the parameters are as follows:

$$\begin{aligned} &50\,\mathrm{GeV} < |\mu|, M_1, M_2, M_A, m_{\tilde{f}} < 5\,\mathrm{TeV}\,,\\ &1.1 < \tan\beta < 60,\ -3m_{\tilde{q}} < A_t,\ A_b < 3m_{\tilde{q}},\\ &\mathrm{sign}(\mu) = \pm 1\,. \end{aligned}$$

In DarkSUSY, the SUSY parameter space is constrained by taking the theoretical consistency requirements into account, such as the correct symmetry breaking pattern, the neutralino being the LSP, $\tan\beta$ being compatible with m_A, problems at loop-corrected Higgs potential and so on. The accelerator data constrain the parameters further from the spectrum requirement, the invisible Z-boson width, the branching ratio of $b \to s\gamma$ and so on. We adopt the default option in the DarkSUSY package which adopts the experimental data given by the Particle Data Group in the year of 2002 [35], except that we use the most updated branching ratio of $b \to s\gamma$ [36], $\mathcal{B}(b \to s\gamma) = (3.55 \pm 0.26) \times 10^{-4}$.

Another important constraint comes from cosmology. Combining the recent observation data on the cosmic microwave background, large scale structure, supernova and data from the HST Key Project, the cosmological parameters are determined quite precisely. Especially, the abundance of the cold dark matter is given by [37, 38] $\Omega_\mathrm{CDM}h^2 = 0.113^{+0.008}_{-0.009}$. The relic density requirement will severely constrain the SUSY parameter space as given in [39]. We constrain the SUSY parameter space by requiring the relic abundance of neutralino $0 < \Omega_\chi h^2 < 0.137$, where the upper limit corresponds to the 3σ upper bound from the cosmological observations. When the relic abundance of the neutralino is smaller than a minimal value the thermally produced neutralino represents a subdominant dark matter component. We assume a non-thermal mechanism to give the correct dark matter relic density [40–45]. The effect of coannihilation between the fermions is taken into account when calculating the relic density numerically.

We find that a 'boost factor' at the order of $10 \sim 1000$ is necessary to account for the CACTUS results. The 'boost factor' means that the astrophysical factor calculated by a cored or a cuspy profile in Sect. 2 should be enhanced by this factor to give the observed flux. The 'boost factor' requires a much sharper density profile compared with the NFW profile, such as a Moore profile [46] or a spike profile due to the existence of an intermediate mass central black hole [47, 48] in Draco.

In Figs. 2–4, we plot the integrated γ ray fluxes above the threshold energy 50 GeV within the solid angle $\Delta\Omega = 10^{-3}$ as a function of the neutralino mass. The results in Figs. 2–4 have enhanced the astrophysical factor by a boost factor of 10, 100 and 1000 respectively. Each point in the figure corresponds to a model with a set of definite SUSY parameters in the 8-dimensional parameter space which can explain the CACTUS results constrained by (7) and (11) and allowed by all other collider and cosmology constraints. The scatter of the points represents the uncertainty coming from the unknown soft SUSY breaking parameters. The lines represent the 2σ constraints of ARGO by assuming the final states being W^+W^-, $b\bar{b}$ or $\tau\bar{\tau}$. For the upper set of lines we have assumed no hadron/photon discrimination at all, while for the lower set of lines we have assumed that part of the hadrons are rejected based on a neural network so that the significance of detection is improved by a quality factor of 1.6 [49]. From the figure we can see that if no excess is observed at ARGO above 100 GeV, a large part of the parameter space is constrained.

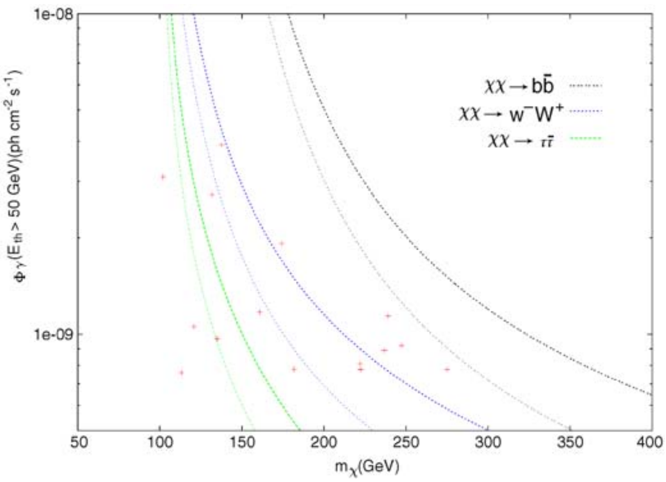

Fig. 2. The integrated γ-ray fluxes by neutralino annihilation from Draco above the threshold energy of 50 GeV as a function of the neutralino mass. The fluxes are given within the angular resolution of $\Delta\Omega = 10^{-3}$. Each point in the figure represents a set of low energy SUSY parameters which survive all the current limits. A boost factor 10 relative to the maximal astrophysical factor derived from [26, 27] has been assumed. The *lines* show the 2σ constraints from the ARGO experiment assuming a W^+W^-, $b\bar{b}$ or $\tau\bar{\tau}$ final state with or without gamma/hadron discrimination

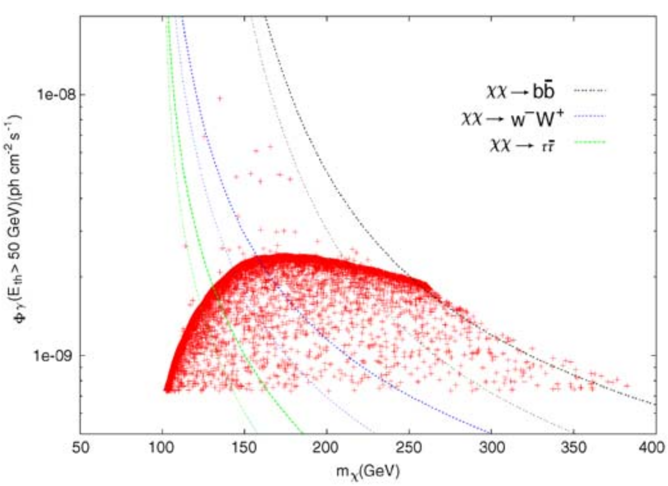

Fig. 3. Same as Fig. 2, except that a boost factor of 100 has been assumed

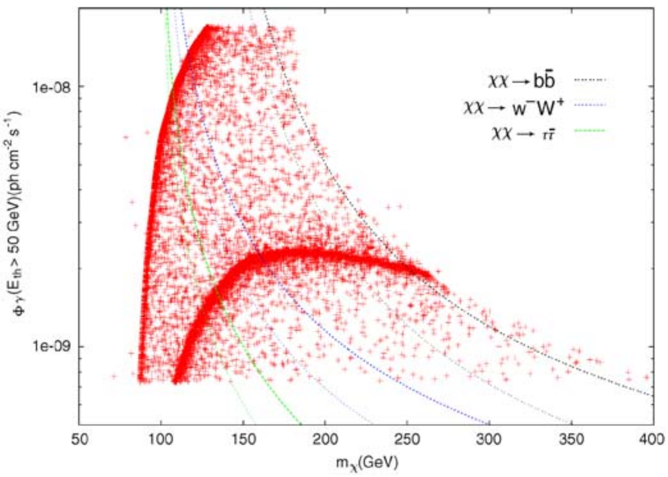

Fig. 4. Same as Fig. 2, except that a boost factor of 1000 has been assumed

It is worthwhile commenting on the results here. First, if extending the gamma spectrum to lower energies, we find that the CACTUS result is difficult to reconcile with the EGRET result which did not observe excess at the direction of Draco between $1 \sim 10$ GeV. Therefore a hard spectrum is expected to reconcile the EGRET and the CACTUS results, which requires the dominant annihilation product to be $\tau\bar{\tau}$ [15]. The hard spectrum leads to more opportunities to observe the signal in ARGO which can be seen from Figs. 2–4. Alternatively one would assume that only about 1 percent of the present excess is a real signal from the annihilation of the dark matter. In this case we find the parameter space to account for the signal and to be consistent with the EGRET result in the range of 250 GeV $< m_\chi <$ 800 GeV. The parameter space can be constrained by ARGO only for the $\tau\bar{\tau}$ final states. Second, the CACTUS result may also imply a monochromatic gamma spectrum at the energy of about 50 GeV. However, it is found that the branching ratio for two neutralino to annihilate into two photons should be more than a half to be consistent with the EGRET result, which is incompatible with the SUSY model [16]. Finally, if we assume that only about $\lesssim 1\%$ of the excess comes from DM annihilation, the signal can be explained without the introduction of any 'boost factor' if taking the non-thermal mechanism into account. This may be a natural assumption, while the confirmation of the gamma events from DM annihilation requires an instrument with better angular resolution, such as GLAST [16] to suppress the background.

6 Summary and conclusion

In this paper we discuss the possibility of constraining the signal observed by the CACTUS experiment at the ground-based EAS detector, ARGO. We assume that the excess of gamma rays observed at CACTUS is produced by supersymmetric dark matter annihilation. We then explore the SUSY parameter space to give a signal consistent with the CACTUS result and discuss the possibility to constrain the parameter space at ARGO. Our calculation shows that, depending on the gamma spectrum, ARGO will be able to constrain a large part of the parameter space if no signal is detected for one year's observation.

If the CACTUS signal is finally confirmed, the implication on dark matter is dramatic. The central cusp of the dark halo at Draco should be much sharper than that of a NFW profile. The neutralino mass should be at the range of $100 \sim 400$ GeV to explain the signal of CACTUS. Furthermore, the spectrum of the annihilation gamma rays should be very hard in order to be consistent with the EGRET null result at the direction of Draco at the energy range between 1 GeV and 10 GeV.

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