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Search for TeV Radiation from Selected Local Group Galaxies

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Some candidate dark matter particles, such as neutralinos in supersymmetry, would annihilate producing GeV/TeV gamma rays. We report on recent observations of two dwarf spheroid galaxies, Draco, Ursa Minor, the compact elliptical galaxy M32, and the spiral galaxy M33 with the Whipple 10m gamma-ray telescope. No significant signal was found, and we derived upper limits for the gamma-ray flux from each object. We discuss our astrophysical selection criteria for these galaxies in the context of an indirect search for dark matter and the implications of these flux upper limits on the density of neutralinos.

1. Introduction

One candidate for the dark matter (DM) motivated by particle physics is the lightest neutral supersymmetric particle, the neutralino. Supersymmetry is theoretically favored because it naturally leads to a unification of energy scales for all the fundamental forces and is a natural symmetry for grand unification theories such as string theory. The neutralino is a majorana particle, so it will annihilate and create particles with energies similar to the mass of the neutralino. Some of these particles would be photons, charged particles that would start emitting and scattering light, and neutral pions that would decay into photons illuminating a neutralino star at energies near the neutralino mass. This radiation could be detectable by ground and/or orbiting gamma ray observatories[1].

The Galactic Center (GC) was proposed early as a source of gamma-ray radiation from annihilation of DM[2], but recent TeV observations of the GC has shown a point source coincident with the GC [3, 4, 5] which appears to be a background for any observations of an annihilation signal. The next candidates for these observations are the local group galaxies [6]. We carried out an observational campaign on selected local group galaxies with the Whipple 10m gamma-ray telescope on Mt. Hopkins in Arizona, USA. No significant signal was found and we derive upper limits for the gamma-ray flux from these objects. The poster will include a spectrally dependent analysis and an extended source analysis.

2. Source Selection

The expected flux from neutralino annihiliation is

$$\frac{d\Phi}{dE\,d\Omega} = \frac{dN}{dE}\,\frac{\langle\sigma v\rangle}{8\pi m_\chi^2}\,\frac{dJ(\theta,\phi)}{d\Omega} \tag{1}$$

with the cross-section $\langle\sigma v\rangle$, the particle mass m, and the spectrum produced dN/dE. The source profile is related to the density profile through $dJ/d\Omega = \int dl\ \rho^2$ where integral is taken over the line of sight. This flux factorization shows the terms depending on the particle physics, separated from the astrophysical considerations which are contained in $dJ/d\Omega$. For a source small compared to the angular resolution of the detector at a distance D, the integrated J can be expressed as an integral over the volume of the source as

$$J \equiv \int\limits_{\text{source}} d\Omega\,\frac{dJ(\theta,\phi)}{d\Omega} = \frac{1}{D^2}\int\limits_{\text{source}} dV\rho^2. \tag{2}$$

This integrated J is a parameter that embodies the two astrophysical considerations for DM annihilation flux, the distance to the source and the density profile of the DM particles. Close, dense DM clumps are therefore the best targets for observation. We choose the local group galaxies in order to compete with the D^{-2} factor in J. Additionally we tried to choose a variety of galaxy morphologies, because the baryonic matter in the galaxy can disrupt any DM cusp through heating. Black holes are also expected to have a large effect on the inner regions of the DM profile. Adiabatic growth of a black hole can lead to a spike in the DM profile[7]. However any large merging event between two supermassive black holes should wash out any cusp in the profile.

We focused this search on local group galaxies. The Galactic Center gamma-ray flux is probably not due to DM annihilation and so represents a background for a search for an annihilation signal. Additionally annihilation in the halo of the Milky Way could be large compared to the field of view (∼3-5°) and ground based imaging instruments have less sensitivity for such sources.

2.1 Draco and Ursa Minor Dwarf Galaxies

Dark matter rich Milky Way satellite Dwarf Galaxies are favored due to their proximity, high mass to light ratio, and the possibility of self-interacting DM. If the DM is non-interacting the cores of these galaxies will not evolve within the Hubble time. The density of these smaller halos is found to be higher in simulations due to their earlier production epochs. The dwarf galaxies we chose were smaller than the field of view (2.4°). In the visible wavelengths they were each ∼0.5° in diameter.

The distance to Draco is measured to be 76 ± 6 kpc in [8] using variable stars. In [9] they measure the radial velocity dispersion of giant stars in Draco. They find the rotation curve is flat or slightly increasing away from the core. The best fit DM halo profile is a nearly isotropic sphere ($r \sim r^{-0.13}$) of DM with a total mass of $8^{+3}_{-2} \times 10^7$ $M_\odot$ in the inner 0.5°.

The distance to Ursa Minor is 69 ± 4 kpc [10]. Ursa Minor has clear substructure observed in the inner ∼ 10’ [11]. The existence of this structure and an associated second population of stars is a mystery as this structure should only exist for a few hundred million years based on observations of stellar proper motions[12]. This raises the possibility of self-interacting DM. A comparison of the observed astrophysical properties of Draco and Ursa Minor is given in [13].

2.2 M31-M33

The first rotation curve was made of M31 which was one of the earliest evidence of DM on galactic scales[14]. Andromeda is a galaxy larger than the Milky Way at a distance of 785 ± 25[15]. Unfortunately there is evidence that M31 is undergoing a merger with two distinct populations of stars and a double nucleus. This merging process should wash out any cusp in the DM density profile so M31 was not chosen for this survey.

M32 is the closest compact elliptical galaxy at a distance similar to M31. Stellar velocities as well as gas dynamics measure a single supermassive compact object, $\sim 3.6 \times 10^6$ $M_\odot$, in the core of M32 [16]. Hubble observations of the core of M32 suggest a density $>2 \times 10^6$ $M_\odot$ [17]. The core of M32 is relaxed and so it is a good candidate for structures such as DM spikes around the central black hole. M32 extends about 10’ across the sky so any emission should be point-like.

M33 is a spiral galaxy at a distance of 809 ± 24 kpc measured using red giant stars [15]. The mass and density profile of the DM halo of M33 derived from rotation curves is well studied due to its proximity and orientation[18]. M33 does not have a large black hole in the center [19] which could lead to larger densities of DM if supermassive black hole formation disrupts the halo. M33 has an angular size of 1° so it is contained

Source	RA	Dec	ON/TRK (hrs)	OFF (hrs)	ON used (hrs)	OFF used (hrs)
Draco	17 20 14	+57 55	14.5	7.5	10.3	5.6
Ursa Minor	15 09 10	+67 13	18.4	8.4	7.0	7.0
M32	00 42 00	+40 52	10.3	9.3	8.9	8.9
M33	01 33 51	+30 39	18.6	9.1	8.7	8.7

Table 1. The total exposure and the exposure used for this analysis on Draco, Ursa Minor, M32, and M33. The data were rejected most often for weather problems and high voltage failure. The data for Ursa Minor and Draco were taken in the 2002 observing season. The M33 dataset was taken in the 2004 observing season. The data for M32 was taken during both of these seasons.

in the field of view, but it may be an extended source. However most halos that would be visible with current sensitivities would be point-like.

3. Analysis

The data were taken on clear, moonless periods of the night during two observing seasons. The data on Ursa Minor and Draco were taken in 2002-2003 and the data on M32 were taken during 2004-2005. The M33 exposure was split evenly between these two periods. The Whipple 10m gamma-ray telescope records 40 ns exposures of extended air showers, and through the analysis electromagnetic showers are chosen and the anisotropy of these showers is studied for any significant excesses.

For this paper we use the traditional analysis method for the Whipple 10m telescope. The first step involves data selection for quality by studying the observing log of the telescope for any data problems such as clouds or high voltage failure. Once the data is accepted as high quality the pixels are padded to make up for any differences in field brightness. Then the images are cleaned to remove the signal from random fluctuations. Finally we use the standard cuts to select the electromagnetic showers from the hadronic background and the random triggers.

For the hypothesis of a point source in the center of the field of view we make a cut on the directions of the air showers to within $\sim 0.3^\circ$. Contemporaneous data on the Crab supernova remnant yields a signal with a significance of 5.5 $\sigma/\sqrt{\text{hour}}$ at a rate of 2.1 ± 0.1 photons/min with an energy threshold of $\sim$ 400 GeV. A more complete description of the Whipple standard operations are given by [20].

The results from the point source analysis are shown in table 2. These results will be used to place an upper limit on the density of neutralinos, specifically J defined in equation 2, given a particle model of $\langle\sigma v\rangle$, m, and dN/dE. Limits on J will be presented in the poster.

4. Conclusions

We have reported on a campaign to observe DM annihilation at TeV local group galaxies with the Whipple 10m telescope. Results from the standard point source analysis have been presented. No significant radiation was detected and upper limits were derived. A spectrally dependent analysis as well as an extended source analysis will be presented in the poster. A campaign to observe possible DM annihilation is ongoing within the VERITAS collaboration and observations are being expanded to cover systems such as clusters. Additionally VERITAS will have a better sensitivity and lower energy threshold than the Whipple 10m telescope which should allow stronger constraints on the density of neutralinos.

Object	Significance [σ]	Upper Limit [γ min^{-1}]	Upper Limit [Crab Flux]
Draco	-2.02	0.07	0.03
Ursa Minor	+0.79	0.24	0.12
M32	-0.42	0.20	0.10
M33	+1.23	0.25	0.12

Table 2. The 95% confidence level upper limits for the point source analysis of the data using the standard Whipple 10m analysis. The Crab flux normalization is determined by passing contemporaneous Crab data events through the same cuts. The energy range of these cuts will be described in the poster.

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