Search for TeV annihilation radiation from supersymmetric dark matter in nearby galaxies

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Abstract

During the 2002-2003 observing season the Whipple 10m imaging atmospheric Čherenkov telescope was used to search for dark matter annihilation radiation in four nearby galaxies: M32, M33, Draco, and Ursa Minor. Scientific motivations for this choice of targets are discussed as well as accumulated exposure. The analysis results are to be reported in the conference presentation.

1. Introduction

The lightest supersymmetric particle, the neutralino, with a mass in the range 50 GeV - 5 TeV, is a plausible candidate for non-baryonic cold dark matter (CDM) [12, 16], which can be detected indirectly via its annihilation products [3, 32]. The annihilation rate is proportional to the square of the neutralino density integrated along the line of sight, suggesting strong enhancement in the direction of dark matter clumps. The increasing dark matter density profile toward the center of Milky Way (MW) galaxy and its proximity made the Galactic Center a natural choice for such searches [4, 5, 19]. The CDM annihilation flux from even nearby extragalactic objects, such as dwarf galaxies located only ten times father, would have to be suppressed by a factor of hundred. However, due to the squared neutralino density dependence, the distance penalty can be overcome by the equal increase of DM density in the cores of MW satellite and local group

galaxies. Although little is known about the distribution of DM in the central 1 - 10 pc of Galactic Nuclei (GN), which is the most relevant region for generating an annihilation signal, the current paradigm suggests that it is a strong function of the merger history of a galaxy [25] and its long-term evolution that could be affected by the presence and growth of central black holes (BHs), e.g. [13]. Because of this, D. Merritt argues that MW was perhaps unfortunate, and a DM spike in its center is unlikely [26]. On the other hand, if stellar, and stellar velocity distributions can be used as a guide to the distribution of dark matter at the very centers of galaxies, we suggest the following arguments to justify the choice of several extragalactic sources as plausible candidates for observation of DM annihilation.

2. M32

M32 is the closest compact elliptical galaxy believed to be formed in a rare cosmological event from a low luminosity spiral galaxy [2]. Stellar kinematic data as well as gas-dynamical studies strongly support the presence of a single supermassive compact object, $\sim 3.6 \times 10^6 M_o$ in the center of M32 [15]. The core of M32 has a relatively homogeneous stellar population that can be modeled as being coeval and of intermediate age (~ 4 Gyr) [7, 8]. Lauer et al. estimate M32 core relaxation time scale as $\sim 2-3$ Gyr [22]. These data suggest that the nucleus of M32 was unlikely to have undergone a recent merging event when a massive black hole binary could have depleted the central stellar density by evacuating stars and destroying potential dark matter cusps in the galaxy core [27]. The data also imply that enough time has passed for collisional two-body relaxation of stellar population around a black hole to form a cusp in the Stellar Density Profile (SDP), $\sim 1/r^\alpha$, with $\alpha = 3/2-7/4$ correspondent to Bahcall-Wolf solution [1]. Optical and infrared data indicate SDP compatible with α in the range 1.4 to 1.9 and still rising at the resolution limit of 0.07 pc. The exact spectral index and the possibility of its break at a distance ~ 1 pc from the GN center is being debated [7, 22]. The stellar density at the very center of M32's nucleus likely exceeds $10^7 M_o$ per pc^3, which is the highest known to us in nearby systems [22].

After initial violent relaxation during large scale structure formation non-interacting dark matter has no means of self-evolution on subgalactic scales because it cannot cool down without gravitational coupling to baryonic matter. This is true at least for spherically symmetrical systems. Thus it is likely that during formation of the galactic core the DM Density Profile (DMDP) should follow SDP with a characteristic relaxation time comparable to stellar relaxation that, in turn, is decreased by the heat transfer associated with the DM component in the nucleus. In addition, the slow growth of the central BH should cause adiabatic compression of DM with the adiabatic invariant rM_{BH} =const [20]. If almost all BH mass is acquired by slow growth, the amount of compression could be sub-

stantial, resulting in the appearance of a spike in the DMDP with $\alpha > 2.25$ [13]. If, however, galactic mergers have been dominantly responsible for BH growth this may not only destroy potentially created DM spikes, it will also drastically suppress the amount of adiabatic DM compression around the BH. Probably both the effect of adiabatic BH growth and the evolution of DMDP driven by baryonic stellar and gas components in the cores of the galaxies take place at the same time and cannot be completely disentangled [23]. For the case of M32 both scenarios of DM evolution seem to favor a cusp in DMDP with $\alpha \geq 1.5$.

3. M33

The neutralino annihilation flux from a "cuspy" DMDP ($\alpha > 1.5$) is formally divergent at small scales. The physically justified minimal radius is set by the equality between the annihilation rate and the rate of supply of neutralinos into annihilation region. The latter is related to the BH growth rate and/or relaxation rate of baryonic & DM components in GN. The general effect of the central BH is to increase the stellar velocity dispersion within the radius of its gravitational influence [30], and consequently increase GN relaxation time, limiting neutralino annihilation flux dynamically. From this point of view a galaxy with a small BH and very rapid GN evolution scale, such as M33, may be preferable for observations.

M33 is a normal low-luminosity dark matter dominated bulgeless spiral galaxy with dark halo $\sim 5.1 \times 10^{11} M_o$ [6]. The mass of the BH in its center is less than $\sim 1.5 \times 10^3 M_o$ [11, 24], and the stellar population in its nucleus can be modeled by two bursts of star formation ~ 2 and ~ 0.5 Gyr ago [29]. The nucleus of M33 hosts the most luminous steady X-ray source in the Local Group that is also associated with a radio source and reminiscent of the galactic microquasar GRS 1915+105 [9]. Small ($\sim\%10$) but significant X-ray spectrum and time variability have also been reported [21]. M33 is remarkable for its very small galaxy nucleus relaxation time ~ 3 Myr due to very dense, $> 2 \times 10^6 M_o$ per pc^3, stellar core (~ 1 pc) and extremely low velocity dispersion [22].

4. Draco and Ursa Minor dwarf galaxies

Dark matter rich MW satellite Dwarf Galaxies (DGs) are favored for observations due to their proximity, very low baryonic content, and/or possibility of self-interacting DM. Within non-interacting DM scenarios the cores of these galaxies are "frozen" due to particularly low stellar and gas densities and consequently slow evolution rates. Their typical core relaxation times, $\sim 5 \times 10^2$ Gyr, exceed Hubble time. Thus, the DGs could not have evolutionarily built any sub-parsec cusp or spike-like structure in their DMDP for efficient annihilation of neutralinos, and it is also difficult to imagine any DM evolutionary scenario on

Table 1. Accumulated exposure

Source	ON (hrs)	OFF (hrs)	Zenith angle range
M32	10	4.5	$10^o - 40^o$
M33	13	4.0	$1^o - 40^o$
Draco dwarf	4.5	3.0	$27^o - 35^o$
Ursa Minor dwarf	5.5	4.0	$35^o - 39^o$

the scale of ~ 1 pc, a typical separation between stars in the nuclei of DGs. Tyler argues that these perhaps might be the exact conditions which would preserve intact any sub-parsec DM structures from destruction by galaxy merger events or by particularly high abundance of stars in GN [31]. The initial perturbations in DMDP with the scales smaller than the Jeans instability scale could have formed during violent relaxation and survived without trapping a substantial amount of baryons [18, 28]. These invisible and very slowly evolving structures could have been gravitationally trapped in the MW halo or in the centers of dwarf galaxies. If so, the quantitative prediction of the annihilation flux from DM cusps will strongly depend on the cusp evolution mechanism because it will determine the maximal annihilation rate. This scenario becomes particularly interesting if DM is self-interacting indeed [14]. Among many other puzzling observations of dwarf galaxies there are indications of "clumpy" distribution of matter. For example, Ursa Minor dwarf has distinct stellar lumps within $\sim 10'$ circle [17]. The study of stellar proper motion suggests that the lump crossing time is ~ 5 Myr and six individual lumps shouldn't exist any longer than this [10]. Is it a coincidence to observe six of them at the same time?

5. Data

Table 1 shows the range of zenith angles at which all proposed targets were observed and the total exposure so far accumulated by the VERITAS collaboration for each source.

Acknowledgments

6. References

see astro-ph/0305584 for references