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## Search for a WIMP annihilation signature in the core of the globular cluster M15

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### Abstract

The Whipple 10m Very High Energy gamma-ray telescope has been used to search for indications of WIMP annihilation in the direction of the globular cluster M15. The upper limits derived constrain the amount of super-symmetric dark matter that may reside in globular clusters.

### 1. Introduction

Studies of the CMB have accurately determined the density of dark matter (non-baryonic clustering material) in the universe to be  $\sim 23\%$  of the total energy density, with most of the remainder being "dark energy" [14]. Weakly interacting massive particles (WIMPs) are an excellent dark matter candidate, especially those arising in super-symmetric extensions to the Standard Model. Such particles can annihilate, and the gamma rays produced should thus trace the dark matter density. The best targets for the search of annihilating dark matter are the most massive dense nearby structures. The Galactic Center is an interesting candidate [16] and is being observed above  $\sim 1$  TeV with the Whipple telescope [2]. Other galaxies may be of interest as well but their large distances is a strong penalty. Relatively nearby dwarf galaxies [15] have been considered as well as giant galaxies like M87 [1]. With mass to light ratios from 0.5 to 2.5 [12], globular clusters are

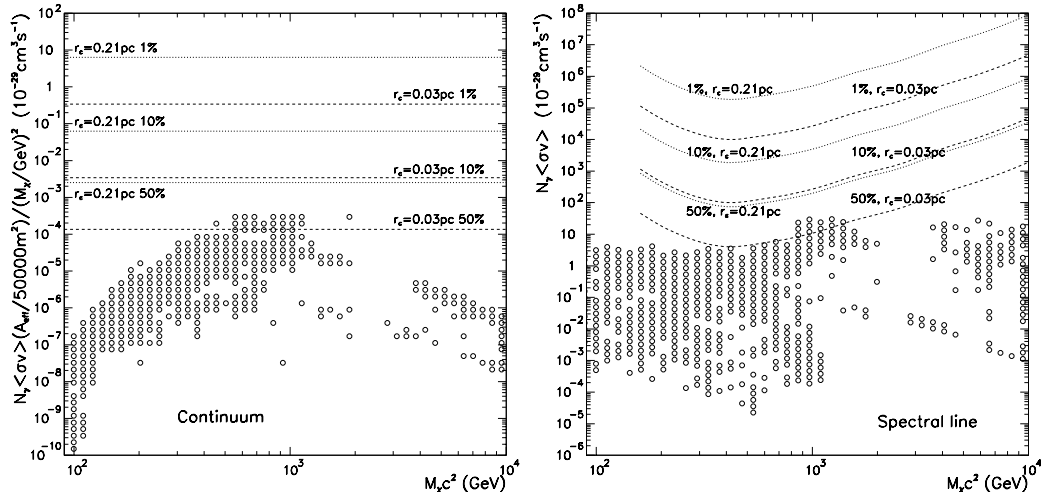
not a usual target in searches for dark matter. Their mass corresponding to the Jeans scales at the time of recombination suggests that they may have been the first structures to form and at least some of them [13] may be relics of the galaxy formation epoch. The cold dark matter driven structure formation scenario results in an extended dark matter halo. Dynamical studies have shown that if a dark matter halo is attached to globular clusters, it does not extend beyond the stellar distribution [11]. The halo is probably stripped by tidal effects when the cluster passes through the disk and close to the bulge [6]. Nevertheless some fraction of the original dark matter may remain inside the cluster. The density in the center of globular clusters typically reaches  $10^4 M_\odot \text{pc}^{-3}$  or even  $10^5 M_\odot \text{pc}^{-3}$  in core collapsed clusters such as M15, with a strong radial density gradient. If the dark matter traces the stellar distribution, it may yield interesting annihilation rates even for small amounts of dark matter in the form of WIMPs. A different situation could arise if a few thousand solar mass black hole occupied the center of the cluster as suggested by Gerssen et al. [5]. The gamma ray emission would then depend on the history of the black hole formation and on the central dark matter evolution rate (for references see [17]).

For this preliminary analysis, we assumed the dark matter follows the observed stellar distribution to derive an expression for the expected gamma-ray flux from WIMP annihilation [9]. We describe the density profile as  $\rho(r) = \frac{\rho_0}{1+(r/R_c)^\alpha}$  with a truncation at the tidal radius and  $R_c$  being the core radius,  $\alpha = 2.2$  [18,19] and  $\rho_0$  is normalized to reproduce the cluster mass within the tidal radius truncation. This is quite a conservative description as it underestimates the central density. We have computed a gamma-ray flux for the 119 globular clusters tabulated by Gnedin et al. [6]. Restricting ourselves to declinations larger than  $+10^\circ$ , we find the most promising object to be NGC7078 (or M15)

## 2. Very High Energy observations

In 2002, the Whipple 10m telescope was used to search for gamma-ray emission from the globular cluster M15. The source was observed for 196 minutes. No significant excess was found and we derived the 99% confidence level upper limit on the rate to be  $0.19 \text{ min}^{-1}$ .

The flux upper limit depends on the energy distribution of the putative gamma-ray signal. WIMP annihilation should yield two different spectral components. Spectral lines should result from processes  $\chi\chi \rightarrow \gamma\gamma$  and  $\chi\chi \rightarrow Z_0\gamma$  while a continuum is produced by all the processes of type  $\chi\chi \rightarrow X_1X_2$  where  $X_1$  and  $X_2$  are both particles which may decay or hadronize producing secondary gamma rays. A set of super-symmetric models was explored with the DarkSUSY code [2,4,7], providing averaged gamma-ray emission rates from annihilation  $N_\gamma \langle \sigma v \rangle$  where  $N_\gamma$  is the number of gamma rays produced per annihilation and  $\langle \sigma v \rangle$  is the thermally averaged annihilation rate. In the case of the continuum, the energy of



**Fig. 1.** Estimated gamma-ray emission rate from WIMP annihilation and Whipple limits from observations of M15, as a function of the WIMP mass. A large number of super-symmetric models resulting from Monte-Carlo simulations as discussed in the text, are binned and then plotted for the continuum (left) and for the spectral line (right). For the continuum component, the annihilation rate is combined with the detector effective collection area ( $A_{eff}$ ). For both plots, the curves represent the 99%CL upper limit we derived from our observation of M15 under different assumptions of the relative amount of super-symmetric dark matter (1%, 10% & 50%) and for different values of the core radius (0.21pc & 0.03pc).

the gamma rays is different from the mass of the annihilating particles and the effective collection area  $A_{eff}$  of the detector estimated from Monte-Carlo simulations, has to be folded in as it depends on the energy. The gamma-ray emission rates are shown in figure 1 as a function of the WIMP mass  $m_\chi$  for the continuum (left) and the spectral line (right). We converted our upper limit into an upper limit of the gamma-ray production rate  $N_\gamma \langle \sigma v \rangle$  to be compared with the set of super-symmetric models. When we used the core radius value of 0.21pc provided by Gnedin and Ostriker [6] our upper limit does not constrain any of the models even when 50% of the cluster mass is in the form of WIMPs. Recent dynamical studies [10] of M15 and Hubble Space Telescope observations [8] indicate that the core radius is much smaller, possibly smaller than 0.03pc. We also calculated upper limits for such a small core radius and see that the 50% case starts to conflict with some super-symmetric models.

### 3. Conclusion

Our analysis did not take into account the gamma ray energy. Using a higher threshold should permit to obtain better constraints on heavy WIMPs

(mass  $> 1$  TeV) from the spectral line component. The rates are very sensitive to the details of the dark matter distribution in the center of the cluster, and our result should become more constraining when we will use more realistic radial profile as will be presented at the conference. Future ground-based gamma ray detectors with lower thresholds and improved discrimination should allow to probe annihilating super-symmetric dark matter in globular clusters such as M15 possibly to the level of few percents of the total cluster mass even for low mass WIMPS theories.

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