Prospects for constraining WIMP annihilation into $b\bar{b}$ using γ-ray observations with the MACE telescope

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Introduction

The existence of dark matter (DM) in Universe has been well established by the experimental evidences obtained from various astrophysical and cosmological observations [1]. However, exact particle nature and physical properties of DM remain an open question for modern science. Due to the elusive nature of its constituents, DM is treated as a set of particles beyond the standard model (SM) of particle physics. Among numerous candidates, hypothesis of weakly interacting massive particles (WIMPs) is the most favored and very promising [2]. According to the several extensions of SM, if WIMPs (χ) of mass above 10 GeV exist and interact via electro-weak force, they would have been produced and annihilate in thermal equilibrium during early phase of Universe. The cooling of Universe naturally led to a freeze-out with a relic density consistent with DM abundance at present epoch. Searches for DM are mainly based on the idea of looking for interplay of WIMPs with the SM particles via direct interaction or their production. WIMPs could annihilate/decay into the SM particles in open space which in turn hadronize to give secondary particles as the end products of the cascade [3]. They can be high energy γ-ray photons, neutrions, electrons-positrons, protons-antiprotons, antideuterons or synchrotron radiation, detectable using a variety of state-of-the art ground and space-based detectors. In this view, three types of experiments namely direct detection, production at colliders and indirect detection, are being performed world-wide to probe the nature of WIMPs. In particular, indirect detection experiments search for the SM particles produced as a result of WIMP annihilation or decay from the astrophysical objects. However, no conclusive evidence for the existence of WIMPs has been reported so far despite exquisite sensitivity of many detectors for direct and indirect detection in the world.

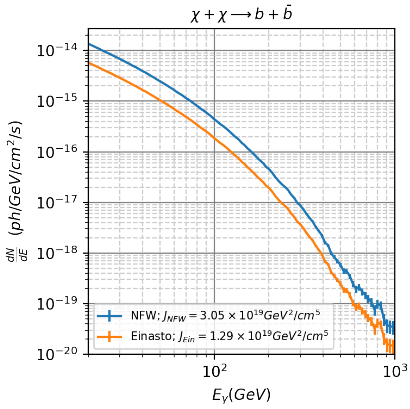

FIG. 1: Differential energy spectra of γ-ray photons from the annihilation of WIMPs of mass 1TeV into $b\bar{b}$ for NFW and Einasto profiles of DM in Segue1 galaxy.

The MACE Telescope

Major Atmospheric Cherenkov Experiment (MACE) is a ground-based γ–ray telescope, which has recently become operational at Hanle in the UT of Ladakh [5]. Equipped with a large quasi-parabolic optical reflector of 21m diameter and a state-of-the art fast imaging camera of $\sim 4^\circ$ field of view, the MACE telescope is capable of detecting high energy γ–ray photons of energy above 20 GeV emitted from the celestial sources in deep Universe.

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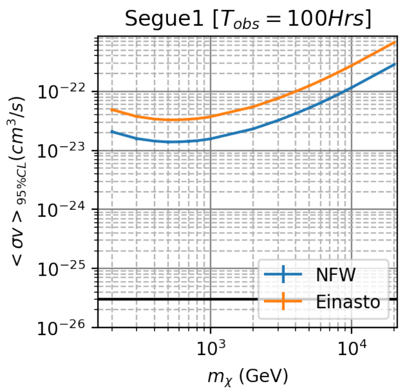

FIG. 2: Constraints on $< \sigma v >$ at 95% CL for annihilation of WIMPs into $b\bar{b}$ channel from 100 hours of observations of *Segue*1 galaxy using MACE.

γ-ray signal from WIMP

According to the WIMP miracle, if WIMPs exist with masses in the GeV-TeV range, they predict the right DM relic abundance as expected from the standard model of cosmology due to their electro-weak interaction [4]. Assuming that WIMPs are Majorana fermions, they can annihilate into variety of the SM particles ($\chi\chi \rightarrow b\bar{b}$, W^+W^-, $\tau^+\tau^-$, $\mu^+\mu^-$, $\nu\bar{\nu}$, ...) among which high energy γ-ray photons are dominantly expected as one of the final state products. The differential spectrum of γ-ray photons from a DM target due to the annihilation of WIMPs into a single channel is given by [6]

$$\frac{dN}{dE} = \frac{< \sigma v >}{8\pi m_\chi^2} \times \frac{dN_f}{dE} \times J \qquad (1)$$

where $< \sigma v >$ is the velocity averaged pair annihilation cross section, m_χ is the WIMP mass, $\frac{dN_f}{dE}$ describes differential γ-ray spectra per annihilation, and J is the so called astrophyical factor. If WIMPs were thermally produced in the early Universe, $< \sigma v >\sim 3\times10^{-26} cm^3/s$ is consistent with the relic density of DM estimated from the particle physics and cosmology knowledge. J is estimated as the line of sight integral of the squared DM density (ρ) toward the target object in the Universe and determines the overall strength of the γ-ray signal.

Results and Conclusion

We consider production of high energy γ-ray photons from the annihilation of WIMPs into $b\bar{b}$ quarks in the nearby galaxy *Segue*1 at a distance of 23 kpc from the Earth. We use *Pythia*8.307 software package to estimate the γ-ray spectra due to WIMP annihilation in the source for m_χ = 200GeV-20TeV. The source spectra corresponding to m_χ =1TeV for two most commonly used DM density profiles namely Navarro-Frenk-White (NFW) and Einasto are shown in Figure 1. The number of observable γ-ray events in an observation time of T_{obs} by the telescope from the direction of *Segue*1 galaxy is then estimated as

$$N_\gamma = T_{obs} \times \int_{E_{th}}^{E_{max}} \frac{dN}{dE} A_{eff}(E) dE \qquad (2)$$

where E_{th} and E_{max} are the minimum/threshold and maximum energy limits covered by a telescope respectively, and $A_{eff}(E)$ is the telescope effective area or response function as a function of photon energy. For T_{obs}= 100 hours, no significant detection of γ-ray signal is anticipated using MACE. Therefore, in case of null result, we estimate upper limits on the integral flux above E_{th} =20GeV at 95% confidence level (CL) for different values of m_χ and corresponding constraints on $< \sigma v >$ are shown in Figure 2. Our study suggests that more than 100 hours of dedicated observations of target galaxy *Segue*1 are required to effectively constrain the properties of WIMP dark matter using the MACE telescope.

References

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