Physics Letters B 744 (2015) 208–212

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Class of Higgs-portal dark matter models in the light of gamma-ray excess from galactic center

Tanmoy Mondal [a,b], Tanushree Basak [a,*]

[a] Theoretical Physics Division, Physical Research Laboratory, Ahmedabad 380009, India
[b] Department of Physics, Indian Institute of Technology, Gandhinagar, Ahmedabad, India

ARTICLE INFO

Article history:
Received 3 September 2014
Received in revised form 30 January 2015
Accepted 26 March 2015
Available online 30 March 2015
Editor: S. Dodelson

Keywords:
Dark matter phenomenology
Gamma-ray excess
Gauge extension of SM

ABSTRACT

Recently the study of anomalous gamma-ray emission in the regions surrounding the galactic center has drawn a lot of attention as it points out that the excess of ~ 1–3 GeV gamma-ray in the low latitude is consistent with the emission expected from annihilating dark matter. The best-fit to the gamma-ray spectrum corresponds to dark matter (DM) candidate having mass in the range ~ 31–40 GeV annihilating into $b\bar{b}$-pair with cross-section $\langle \sigma v \rangle = (1.4\text{–}2.0) \times 10^{-26}$ cm^3 s^{-1}. We have shown that the Higgs-portal dark matter models in presence of scalar resonance (in the annihilation channel) are well-suited for explaining these phenomena. In addition, the parameter space of these models also satisfies constraints from the LHC Higgs searches, relic abundance and direct detection experiments. We also comment on real singlet scalar Higgs-portal DM model which is found to be incompatible with the recent analysis.

1. Introduction

Gamma-ray emission from the galactic center (GC) and the inner galaxy regions as found in the Fermi-LAT data has gained a lot of attention from the perspective of dark matter (DM) searches. Past studies [1–8] have pointed out a spatially extended excess of ~ 1–3 GeV gamma rays from the regions surrounding the galactic center, the morphology and spectrum of which are best fitted with those predicted from the annihilations of a 31–40 GeV WIMP (weakly interacting massive particle) dark matter (DM) candidate annihilating mostly to b-quarks (or a ~ 7–10 GeV WIMP annihilating significantly to τ-leptons). Gamma rays from the galactic center are specially interesting because the region is predicted to contain very high densities of dark matter. Alternative explanations such as gamma-ray excess originating from thousands of unresolved millisecond pulsars have been disfavored since the signal extends well beyond the boundaries of the central stellar cluster. A more recent scrutiny of the morphology and spectrum of the anomalous gamma-ray emission in order to identify the origin has confirmed that the signal is very well fitted by a 31–40 GeV dark matter particle annihilating to $b\bar{b}$ with an annihilation cross section of $\sigma v = (1.4\text{–}2.0) \times 10^{-26}$ cm^3 s^{-1} (normalized to a local dark matter density of 0.3 GeV cm^{-3}) [9], which is accidentally close to the weak cross-section for producing correct relic abundance.

The excess seen in the gamma ray spectrum at the low latitude region can be well explained in a simple dark matter model, where the DM dominantly annihilates into quark pairs with cross-section in the desired range for obtaining correct relic abundance. Already a handful of particle physics models of dark matter [10–29] have been proposed to explain the reported gamma-ray excess. Among these some are focused on various Higgs-portal dark matter models [11,12,20]. These kinds of models are simply interesting because they enjoy a special feature of scalar resonances, provided dark matter mass is half of the scalar mass(es). This resonant feature is crucial as it enhances the annihilation cross-section.

In this letter, we have studied a class of Higgs-portal dark matter models to explain the reported excess. We showed that the simplest Higgs-portal model, i.e., the real singlet scalar extension of the Standard model (SM), is inconsistent with a 30–40 GeV dark matter, because of the absence of resonance. Another Higgs-portal model considered in this letter is the so-called Singlet fermionic dark matter (SFDM) model, which consists of SM along with a hidden sector with a gauge singlet scalar and a Dirac-fermion singlet, acting as a potential DM candidate. We analyze the parameter space of this model owing to constraints from LHC bound on SM-Higgs, relic density and direct detection of DM. We found this model to be consistent as well with the requirements to explain the galactic center γ-ray excess. The last model we consider is the minimal $U(1)_{B-L}$ extension of the SM with a SM singlet

* Corresponding author.
E-mail addresses: tanmoym@prl.res.in (T. Mondal), tanu@prl.res.in (T. Basak).

http://dx.doi.org/10.1016/j.physletb.2015.03.055
0370-2693/

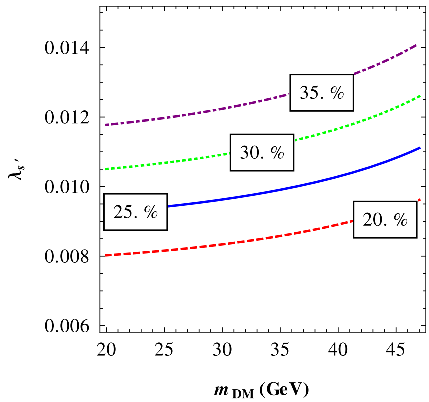

Fig. 1. Contours of invisible branching ratio for singlet scalar DM model, in the plane of $\lambda_{S'} - m_{DM}$. Region above red-dashed (blue-solid, green-dotted and purple-dot-dashed) line is excluded if the SM Higgs has invisible branching ratio up to 20% (25%, 30% and 35%).

scalar S and three right-handed (RH) neutrinos. The third generation RH-neutrino, which is a Majorana fermion, serves as a viable DM candidate as an artifact of $\mathbb{Z}_2$-symmetry. The parameters like DM coupling with the SM-Higgs boson and scalar mixing are subject to the constraints from the LHC Higgs searches apart from other observational constraints on dark matter. However, annihilation of Majorana fermionic dark matter through a scalar resonance is velocity suppressed. But, the presence of a very narrow scalar resonance in the DM annihilation channel lifts the cross sections considerably via Breit–Wigner enhancement at later times and makes the model compatible with the recent analysis.

2. Class of Higgs-portal dark matter models

The basic feature of Higgs-portal model is that all the interactions of DM are mediated through Higgs(es) and the presence of scalar resonance plays a crucial role in determining the correct relic abundance. Here, we will discuss a class of Higgs-portal DM model in the light of the recent analysis [9] of the excess gamma-ray emission in the Fermi-bubble.

2.1. Scalar singlet extension of SM

The scalar singlet extension of SM [30–36] is the most simplified Higgs-portal model to account for a WIMP candidate. The real singlet S', stabilized by odd $\mathbb{Z}_2$-parity, acts as a viable DM candidate. It interacts only with the SM Higgs boson through the renormalizable interaction term present in the lagrangian,

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{2}(\partial S')^2 - \frac{1}{2}\mu_{S'}^2 S'^2 + \mathcal{L}_{int} - \lambda S'^4, \quad (1)$$

where, $\mathcal{L}_{int} = -\lambda_{S'}|\Phi|^2 S'^2$.

The mass of the DM after EWSB becomes, $m_{DM}^2 = \mu_{S'}^2 + \frac{1}{2}\lambda_{S'} v^2$. The coupling between DM and SM-Higgs, i.e., $\lambda_{S'}$ is constrained from the invisible decay width of Higgs boson when $m_{S'} \lesssim m_h/2$, such that $BR(h \to SS) \lesssim 0.20$ [37]. Fig. 1 shows the contours of invisible branching ratio of the SM Higgs boson in $\lambda_{S'} - m_{DM}$ plane. Region above red-dashed line is excluded as in the region the invisible branching ratio of the SM Higgs is more than 20%. Blue-solid, green-dotted and purple-dot-dashed contours show the allowed region if the invisible branching ratio is 25%, 30% and 35% respectively. As expected, the more invisible decay, the higher values of $\lambda_{S'}$ are allowed. For example, $\lambda_{S'}$ must be $\lesssim 8 \times 10^{-3}$ if 20% of the SM Higgs decays invisibly.

2.1.1. Relic abundance

The relic abundance of DM can be formulated as [38],

$$\Omega_{CDM}h^2 = 1.1 \times 10^9 \frac{x_f}{\sqrt{g^*} m_{Pl} \langle \sigma v \rangle_{ann}} \text{ GeV}^{-1}, \quad (2)$$

where $x_f = m_{DM}/T_D$ with T_D as decoupling temperature. m_{Pl} is Planck mass $= 1.22 \times 10^{19}$ GeV, and, g^* is effective number of relativistic degrees of freedom. $\langle \sigma v \rangle_{ann}$ is the thermal averaged value of DM annihilation cross-section times relative velocity. $\langle \sigma v \rangle_{ann}$ can be obtained using the well known formula [39],

$$\langle \sigma v \rangle_{ann} = \frac{1}{m_{DM}^2}\left\{ w(s) - \frac{3}{2}\left(2w(s) - 4m_{DM}^2 w'(s)\right)\frac{1}{x_f}\right\}, \quad (3)$$

where prime denotes differentiation with respect to s ($\sqrt{s}$ is the center of mass energy) and evaluated at $s = (2m_{DM})^2$. The function $w(s)$ is same as defined in [40].

In order to fit the spectrum of the gamma-ray emission near the galactic center, one requires a WIMP of mass $\sim$ 31–40 GeV, which dominantly annihilates into final state $b\bar{b}$ through the s-channel exchange of the SM-Higgs boson. Also we choose, $\lambda_{S'} \simeq 0.007$ as a benchmark value. We obtain that $\langle \sigma v \rangle_{b\bar{b}} = (0.92\text{–}2.17) \times 10^{-30}$ cm^3 s^{-1}, which cannot fit the observed gamma-ray signal. We also found that such a WIMP candidate cannot produce the required relic-abundance unless a scalar resonance is present i.e., when, $m_{S'} \simeq m_h/2 \sim 62$ GeV. Also Ref. [35] has mentioned that for $m_{S'} < m_h/2$, the parameter space is severely restricted from both LHC and direct detection constraints. We conclude that the singlet scalar DM with mass around 31–40 GeV is incompatible with the dark matter interpretation for the gamma ray excess from GC.

2.2. Singlet fermionic dark matter model

The singlet fermionic dark matter (SFDM) model is a renormalizable extension of SM with a hidden sector containing a scalar singlet Φ_s and a singlet Dirac fermion ψ [41,42]. Here, the singlet fermionic dark matter ψ, interacts with the SM sector via the singlet Φ_s which mixes with the SM-Higgs doublet Φ. Therefore, this is also an example of Higgs-portal model. The lagrangian of the SFDM model is given as,

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{hid} + \mathcal{L}_{int}, \quad (4)$$

where,

$$\mathcal{L}_{hid} = \mathcal{L}_{\Phi_s} + \bar{\psi}(i\partial_\mu \gamma^\mu - m_\psi)\psi - \lambda_{\psi S}\,\bar{\psi}\psi\Phi_s, \quad (5)$$

$$\mathcal{L}_{int} = \frac{\lambda_1'}{2}\Phi^\dagger\Phi\Phi_s + \frac{\lambda_2'}{2}\Phi^\dagger\Phi\Phi_s^2, \quad (6)$$

$$\mathcal{L}_{\Phi_s} = \frac{1}{2}(\partial\Phi_s)^2 - \frac{m_{\Phi_s}^2}{2}\Phi_s^2 - \frac{\lambda'}{3}\Phi_s^3 - \frac{\lambda''}{4}\Phi_s^4. \quad (7)$$

After EWSB, the singlet field Φ_s can be written as, $\Phi_s = x + s$, where x is the VEV of Φ_s and $\Phi = (0 \;\; v + \phi)^T$. The two scalar eigenstates are denoted as,

$$H_2 = (\sin\alpha)\, s + (\cos\alpha)\, \phi, \quad (8)$$

$$H_1 = (\sin\alpha)\, \phi - (\cos\alpha)\, s, \quad (9)$$

where, H_2 is identified as the SM-Higgs boson and we consider the case when, $m_{H_2} > m_{H_1}$. Now, the mass of the DM is given by, $m_{DM} = m_\psi + \lambda_{\psi S}\, x$, with m_ψ as a free parameter. In order to explain the observed gamma-ray excess in the low latitude, we consider the following set of parameters, $m_{DM} \sim 31$ GeV, $m_{H_1} \simeq 2m_{DM}$. The DM interaction strength depends on the parameter $\lambda_{DM} = \lambda_{\psi S}$.