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Light signals from spin one tensor dark matter

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Abstract

In this work we report on some observables associated with the annihilation of dark matter, modeled as a spin one real field in the antisymmetric tensor representation. This formulation has the interesting feature that stability is achieved without the introduction of *ad hoc* symmetries, as reported by Cata and Ibarra in 2014. In this model, the coupling to photons occurs through a Higgs portal term. The expression for the cross section in the photon scattering is calculated as well as their energy and the gamma ray flux.

Palabras Clave: particle physics, dark matter, phenomenology

1. Introduction

There is overwhelming astrophysical evidence for the existence of non-luminous, non-baryonic matter in the universe, with gravitational interactions leaving an observable imprint at many different scales, from galaxy rotational curves to gravitational lensing and the power spectrum of the CMB(Trimble, 1987), (Freese et al., 2000), (Canetti et al., 2012).

The prevailing paradigm for explaining this wealth of evidence is Cold Dark Matter, where the gravitational signal is produced by matter particles that were non-relativistic at the time where galaxy formation started –although a plethora of alternatives is considered(Bertone et al., 2005). It is, of course, possible that there is more than a single component of dark matter.

Particle dark matter models have to consider the coupling of the new particles to the Standard Model. In order for particle dark matter to explain the astrophysical observation, we require that it be stable on cosmological scales, since it has survived to the present. It could be absolutely stable or simple be long-lived. When model-building, this stability is very often insured by fiat, imposing an *ad hoc* symmetry.

On the other hand, all the particles in the Standard Model transform in just three low-dimensional representations of the Lorentz group, as scalars, Dirac spinors and vectors. These, however, are not the only possibilities consistent with our principles. At present, we don't have fundamental principles to fix the matter content of quantum field theories; therefore, all possibilities should be explored.

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It has been pointed out that in a dark matter model making use of an unusual spin one chiral Lorentz group representation, stability can be achieved through the symmetries already present in the Standard Model(Cata and Ibarra, 2014). For this reason, this is a very economical model for dark matter.

In this work, we study the indirect detection signal coming from annihilation of a spin one particle in the chiral representation into SM particles.

The main observable to discuss is the gamma ray flux, but because of the dark matter particle properties, a direct photon interaction is absent(Gaskins, 2016), so it is necessary to study second order contributions.

In Sec. II, the model is discussed as well as the corresponding processes that are going to be analyzed. In Sec. III the main results are presented, the cross section, the resulting photon energy and the gamma ray flux. In Sec. IV, the conclusions are presented.

2. Chiral spin one dark matter

Spin one matter fields in the chiral representation $(1,0)\otimes(0,1)$ of the Lorentz group can be studied in an antisymmetric tensor(Cata and Ibarra, 2014) or a sixtor(Napsuciale et al., 2016) representation. If the field is complex, i.e., if there is a dark sector with new gauge interactions, the coupling with the Standard Model can occur via a multipole interaction(Hernández-Arellano et al., 2018). In this work we consider a singlet dark matter field.

The dark matter particle introduced with quantum numbers $J^{PC} = 1^{+-}$, transforms as a singlet under the SM symmetries which induces a Z_2 symmetry to ensure its stability.

The Lagrangian for the model(Cata and Ibarra, 2014) can be expressed as the sum of the Standard Model Lagrangian, the dark matter Lagrangian, and a DM-SM Lagrangian. The first one is of course known, while the second and third (after symmetry breaking) ones are given respectively by

$$\mathcal{L}_B = \frac{1}{4}\partial_\lambda B^{\mu\nu}\partial^\lambda B_{\mu\nu} - \frac{1}{2}\partial^\mu B_{\mu\nu}\partial_\rho B^{\rho\nu} - \frac{m_B^2}{4}B_{\mu\nu}B^{\mu\nu} - \lambda_B B_{\mu\nu}B^{\nu\lambda}B_{\lambda\rho}B^{\rho\mu} \quad (1)$$

$$\mathcal{L}_{int} = c_B B_{\mu\nu}B^{\mu\nu}H^2 + c_B v B_{\mu\nu}B^{\mu\nu}H \quad (2)$$

where $B_{\mu\nu}$ represents the dark matter antisymmetric tensor field, λ_B and c_B are the coupling constants and, as m_B, are free parameters and v is the Higgs field expectation value ($v \simeq 246.22$ GeV).

It is possible to construct a very rich self-interaction structure for the dark matter particle(Napsuciale et al., 2016). This could be important for the study of structure formation and other cosmological and astrophysical observables. In the present work, we focus only on the couplings with the SM.

The coupling with two photons is forbidden for spin-1 particles (Yang, 1950)(Landau, 1965) at tree level. In any case, because of the reality condition on the spin one field, the interaction terms with photons in the model vanish. So by using the second term in (2), the only way to get photons is by adding a quark loop.

The effective Lagrangian describing the final states is

$$\mathcal{L}_{SM}^{eff} = \kappa_\gamma \frac{\alpha}{2\pi v} A_{\mu\nu}A^{\mu\nu}H + \kappa_{Z\gamma}\frac{\alpha}{\pi v}A_{\mu\nu}Z^{\mu\nu}H, \quad (3)$$

where $\alpha = 1/137$, κ_γ and $\kappa_{z\gamma}$ are the effective coefficients which can be expressed in terms of the Standard Model coupling modifiers(Tanabashi and et al PDG, 2018)

$$\kappa_\gamma^2 = 1.59\kappa_V^2 - 0.66\kappa_V\kappa_F + 0.07\kappa_F^2$$
$$\kappa_{z\gamma}^2 = 1.12\kappa_V^2 - 0.15\kappa_V\kappa_F + 0.03\kappa_F^2 \quad (4)$$

In the SM, this modifiers can be approximated to 1, and consequently $\kappa_\gamma = \kappa_{z\gamma} = 1$.

3. γ signals

As shown in the last section, there are two possible processes with γs final state through the Higgs portal, $BB \to \gamma\gamma$ and $BB \to Z\gamma$.

The cross section for each one of the channels reads respectively

$$\sigma_{\gamma\gamma}(s) = \frac{\alpha^2 c_B^2 \kappa_\gamma^2}{18\pi^3 m_B^4}\frac{s\left(s^2 + 3m_B^4 - 2sm_B^2\right)}{\left(s - m_H^2\right)^2} \quad (5)$$

$$\sigma_{Z\gamma}(s) = \frac{\alpha^2 c_B^2 \kappa_{Z\gamma}^2}{9\pi^3 m_B^4}\frac{\left(s - m_Z^2\right)^2\left(s^2 + 3m_B^4 - 2sm_B^2\right)}{s\left(s - m_H^2\right)^2} \quad (6)$$

Comparing the values calculated with the ones obtained for the total cross section at tree level(Cata and Ibarra, 2014), the cross section calculated here is reduced by a factor of $(\alpha/\pi)^2 \simeq 5.4\times10^{-6}$. It is interesting to note that they have the same form.

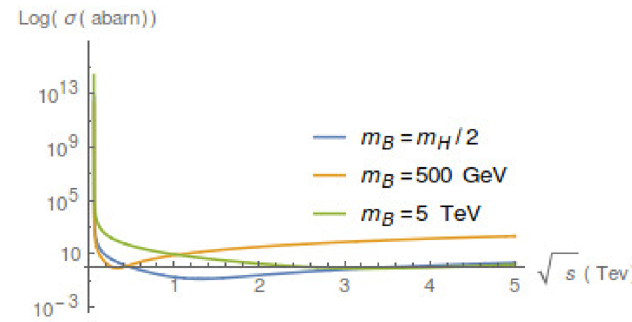

Figure 1: The cross section for the process $BB \to \gamma\gamma$ for different values of mass in logarithmic scale.

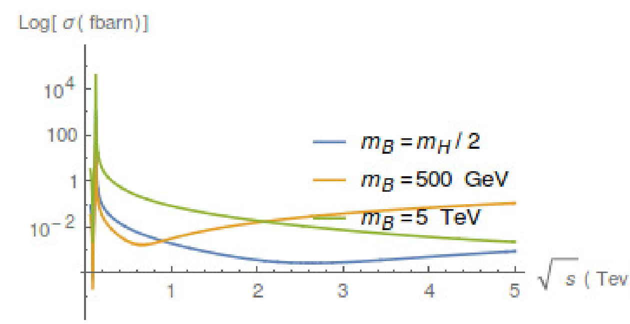

Figure 2: The cross section for the prows $BB \to Z\gamma$ for different values of mass in logarithmic scale.

The behavior of the cross section for each one of the available processes is shown in Fig.1 and in Fig.2 for different dark matter masses, including their resonances.

As for the photon energies, they depend on the variable s, and m_Z for the $BB \to Z\gamma$ case.

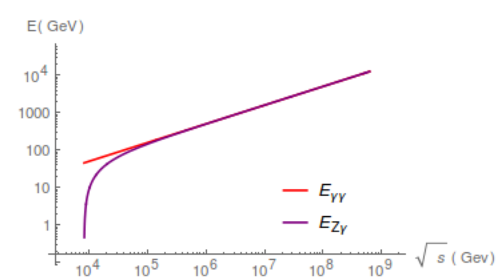

Figure 3: Photon energies for the processes $BB \to \gamma\gamma$ (left) and $BB \to Z\gamma$

The energies are similar, with a difference of the order of the Z mass. The only dependence from the dark matter mass comes from the range of s, with greater masses, greater will be the resulting photons energies as $m_H/2 \leq \sqrt{s} \leq 5m_B$, and so, the photon energies are between 0.01 TeV$\leq E_\gamma \leq$ 12.5 TeV, which can be considered as gamma rays.

To calculate the gamma ray flux, the treatment shown in Harding and B. (2015) is followed, by using the equation

$$\phi = \frac{\langle\sigma_A v\rangle}{8\pi M_B^2}\int dE_\gamma \frac{dN_\gamma}{dE_\gamma}\int_{\Delta\Omega} d\Omega \int dx \rho^2(r_g(\theta, x)) \quad (7)$$

where $\langle\sigma_A v\rangle$ is the annihilation cross section and it can be calculated from (Gondolo and Gelmini, 1990), dN_γ/dE is the spectrum of gamma rays coming from the WIMP annihilation(Bergstrom et al., 2005) and ρ is the density profile integrated over the line of sight, where r_g is the distance to the dark matter source.

Galaxy Name	Distance (kpc)
Bootes I	66
Carina	105
Coma Berenices	44
Draco	76
Fornax	147
Leo II	233
Segue 1	23

Table 1: Distance to dwarf spheroidal galaxies

Using the data from Table 1, integrating (7) over a circular region with a solid angle of $\Delta\Omega \simeq 2.4 \times 10^{-4}$sr, the photon flux coming from the dark matter annhilation in terms of the particle mass is as shown in figure 4 for several density profiles. The density profiles used are Einasto, Navarro-Frenk-White, Isothermal and Moore. The Moore density profile displays the highest gamma ray flux.

Comparing with the photon flux obtained from processes such as $BB \to b\bar{b}, \tau^+\tau^-, W^+W^-$, the one obtained here is smaller than the reported in (Abdo and et al., 2010)(Abramowski and et al., 2012)(Ackermann and et al., 2010). More sensitivity is needed in the detectors in order to distinguish this flux from the galaxies background.

4. Conclusions

In this work we explored some of the observable consequences of a very economical model for dark matter which uses an unusual spin one chiral representation of the Lorentz group. So far, this has proven to be a viable candidate.

The identity of dark matter is one of the most important open questions of contemporary particle physics. Many candidates have been considered in the literature, some of them well-motivated by other open problems, like the hierarchy problem in the case of neutralinos, or CP violation in the case of axions. An interesting feature of the model studied in this work is that *ad hoc* symmetries are not needed to obtain a stable dark matter particles.

Since ground-based and orbital observatories like HAWC and FermiLAT are sensitive to a very wide range of photon energies, gamma ray signals from the annihilation of dark matter are promising observables. The predictions obtained are in line with those of singlet scalar dark matter. A next logical step is studying the spin-dependent contributions to direct detection in underground experiments.

Acknowledgements

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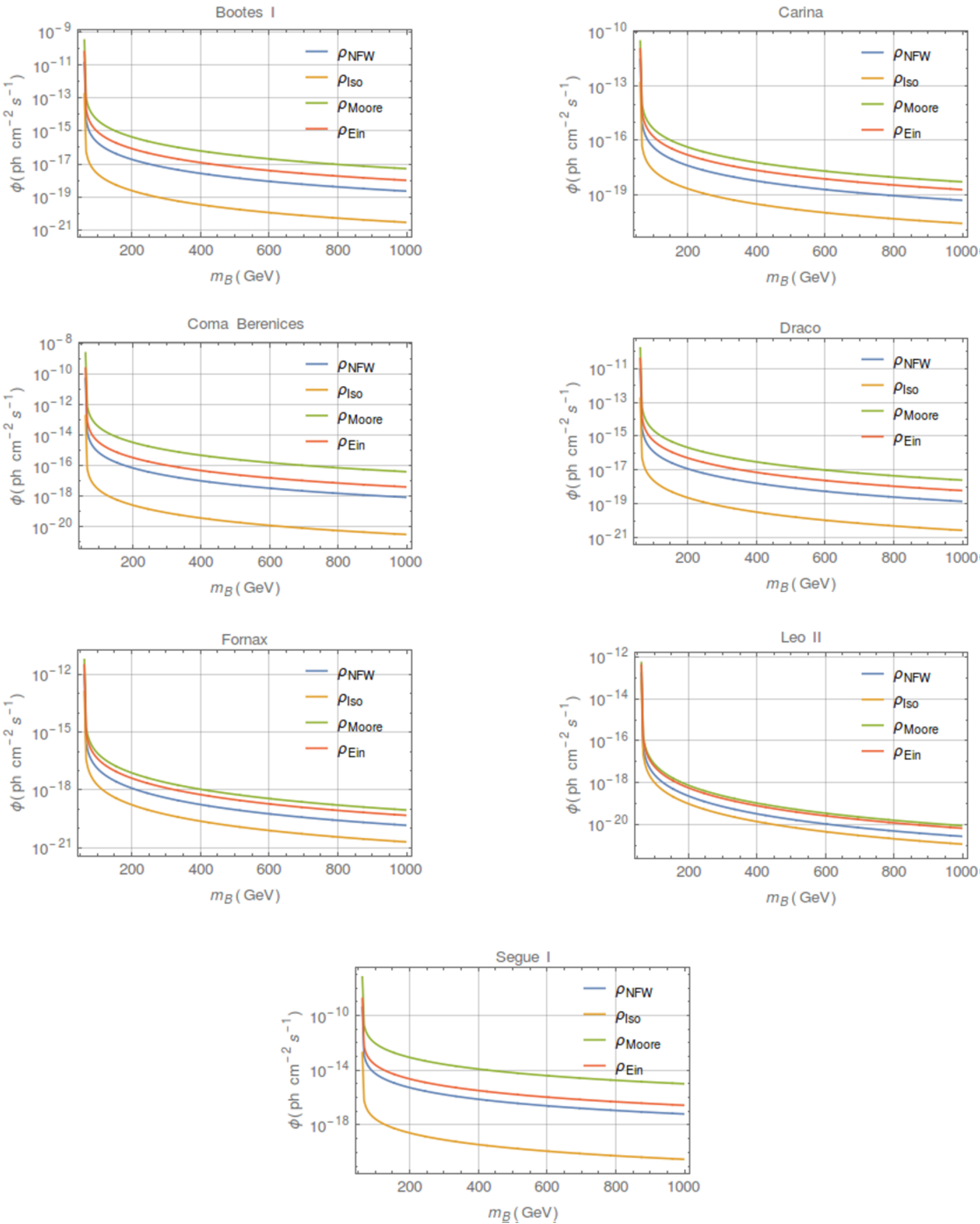

Figure 4: Photon flux from Galaxies Bootes I, Carina, Coma Berenices, Draco, Fornax, Leo II and Segues I.