Photon Signals from Axion-Cosmic Ray Scattering

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Abstract

Dark Matter is the most abundant form of matter in our Universe, yet the identity of the particles that comprise this form of matter remains unknown. Through our research, we propose that the theoretical Axion particle may be the elusive, fundamental particle that makes up Dark Matter. We will examine the effects of a cosmic ray electron collision with an Axion particle. This collision event can produce a specific signature that will be observed through a Gamma Ray telescope. For this project we will use data of the Local Interstellar Spectrum (LIS) and our own calculations to test whether the Axion could be a source of these signatures. With this information, this can become a new viable method of Dark Matter detection. This study could lead to answers not only regarding the ambiguities of Dark Matter, but regarding the Strong CP problem as well.

Objectives

Axion can interact with photons and Electrons. When these interactions occur, we know that they can produce novel gamma/x-ray signals. We can expect to be able to detect these interactions from naturally occurring axions interacting with cosmic rays in our galaxy. We will examine these interactions and estimate what type of signal we would expect to see from this interaction. Then compare to the Isotropic Gamma-Ray Background (IGRB)[4].

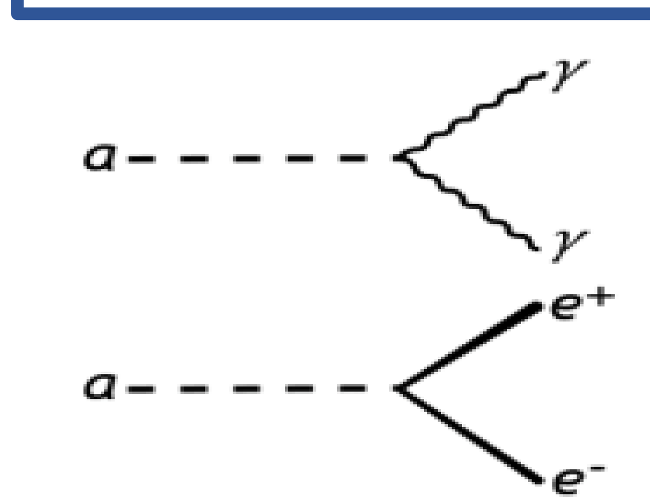

Figure 1: Fundamental Feynman diagram vertices for axion interactions.

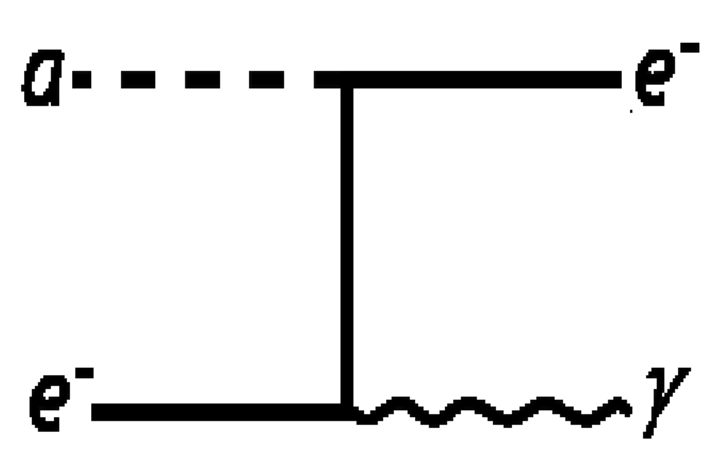

Figure 2: Cosmic ray electrons collide with axions to produce gamma-rays

Calculating Cross-Section

The first step in the process is to Calculate the type of Cross-Section we would expect to see in these interactions. There are two cases we look at, Axion-Electron coupling (gae) and Axion-Photon Coupling (gaγγ) with the axion being in the rest frame.

$$\frac{d\sigma}{dE_\gamma} = \frac{|\mathcal{M}|^2}{32\pi m_a |\vec{p}|^2}$$

Figure 3: Cross-Section equation

gae

The case Axion-Electron coupling we have the matrix element of:

$$\frac{1}{2}|\mathcal{M}_a + \mathcal{M}_b|^2 = g_{ea}^2 e^2 \Bigg[-\frac{2\left(m^4 - m^2(2m_a^2 + s + u) + su\right)}{(u-m^2)^2} - \frac{2\left(m^4 - m^2(2m_a^2 + s + u) + su\right)}{(s-m^2)^2} + \frac{4\left(m^4 + 3m_a^2 m^2 - m^2(2s+t) + (s-m_a^2)(s+t)\right)}{(s-m^2)(u-m^2)} \Bigg]$$

Figure 4: Matrix Element for Axion-Electron coupling

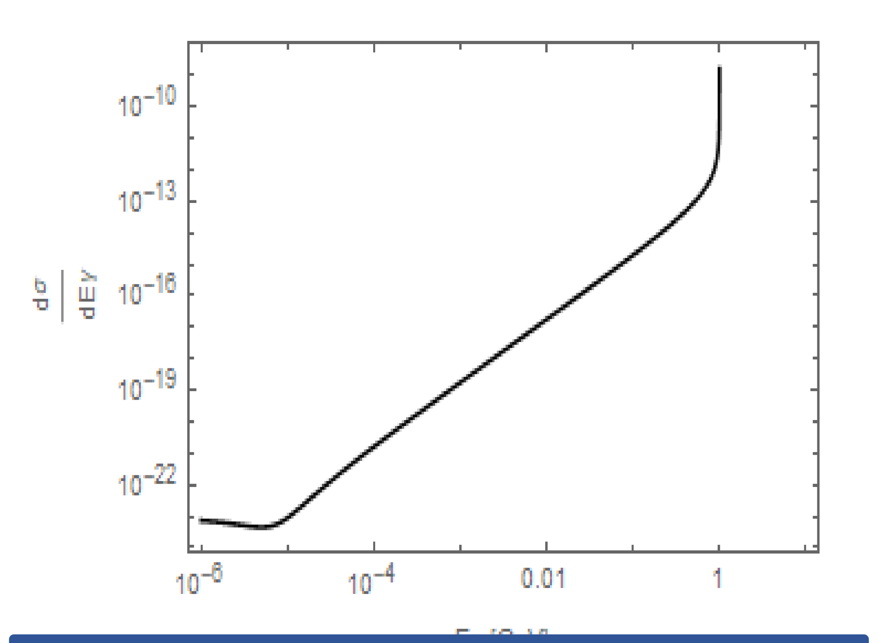

Figure 4: Cross section example via the axion-electron coupling. Here the axion mass = 10^{-3} eV

gaγγ

For the case of Axion-Photon coupling we have the matrix element of:

$$\frac{1}{2}|\mathcal{M}|^2 = \frac{e^2 g_{a\gamma\gamma}^2}{t^2}\left(m_a^2 t(m^2+s) - m_a^4 m^2 - t\left((s-m^2)^2 + st\right)\right)$$

Figure 5: Matrix Element for Axion-Photon coupling

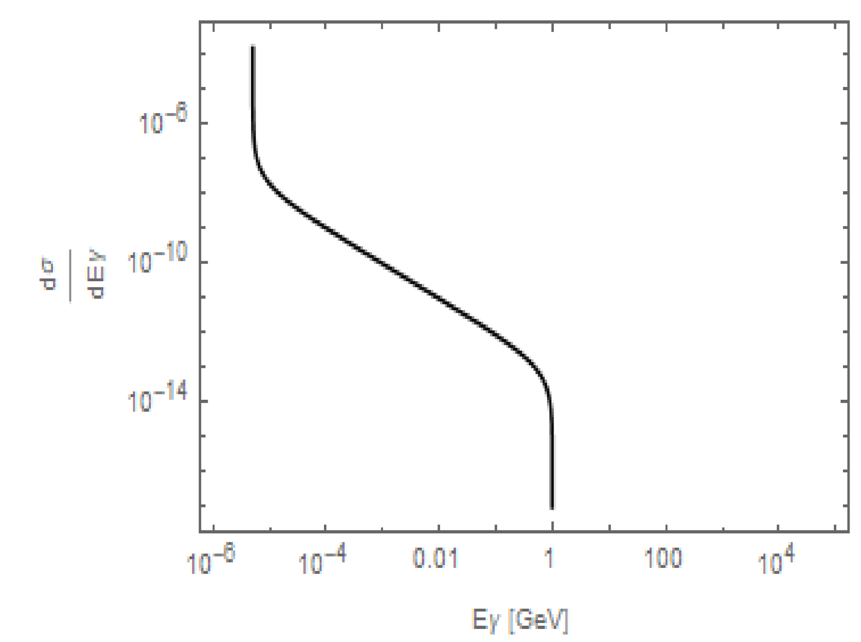

Figure 5: Cross section example via the axion-photon coupling. Here the axion mass is = 10^{-3} eV

Calculating Flux

With the Cross-Section calculated we have all we need to Calculate the flux of Axions over a distance of 1 kilaparsecs.

$$\frac{d\Phi_\gamma}{dE_\gamma} = \int_V dV \int_{E_e^{\min}} dE_e \frac{d^2\Gamma_{e\to\gamma}}{dE_e E_\gamma}$$

$$= D_{\text{eff}} \frac{\rho_{\text{DM}}}{m_a} \int_{E_e^{\min}} dE_e \frac{d\sigma_{e\gamma}}{dE_\gamma} \frac{d\Phi_e^{\text{LIS}}}{dE_e}$$

Figure 6: Equation for Flux

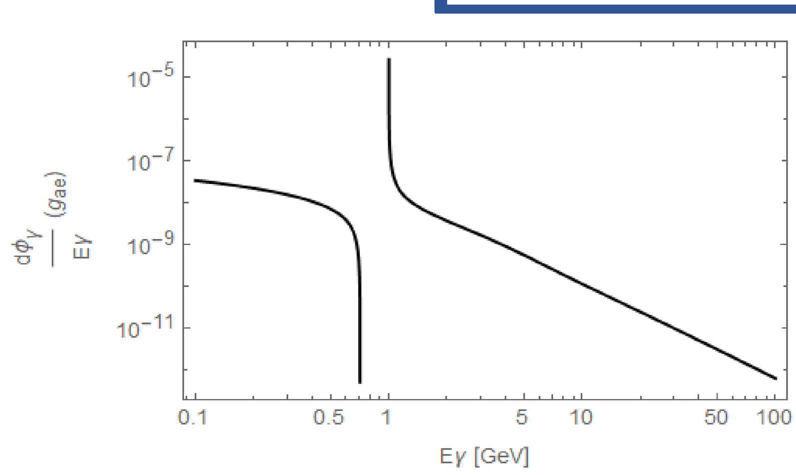

Figure 7: Calculated flux for Axion-Electron Coupling (gae)

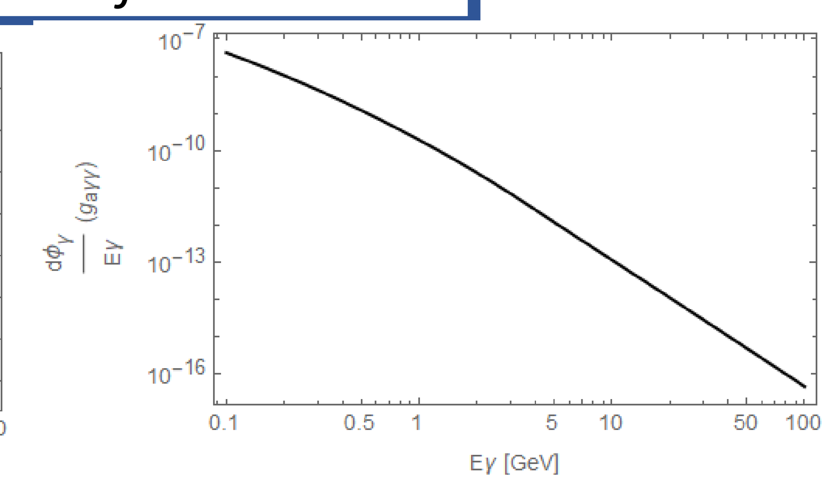

Figure 8: Calculated flux for Axion-Photon Coupling (gaγγ)

Conclusion

These results , need to be further investigated to be insure its validity. Once this is done the next step is to compare these results with the IGRB. Depending on the unknown strength of the axion interaction, this effect may lead to a detection of axions. Conversely, if data shows the absence of any anomalous photons, new constraints on axion-electron and axion-photon interactions can be placed for further investigation into the detection of Axions and Dark Matter.

References

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[4] Hooper, Dan; D. McDermott, Samuel. “Robust Constraints and Novel Gamma-Ray Signatures of Dark Matter That Interacts Strongly With Nucleons”. Physics Review D. 97, 115006 (2018)