RESEARCH ARTICLE

Quasi-Dark Matter Candidate – Heavy, Charged Spin 1 Particle

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Abstract

A heavy, charged spin 1 particle is postulated as a quasi-dark matter candidate. Quasi-dark matter is a postulated form of matter that interacts with the fundamental forces, including gravity, and is not baryonic. However, quasi-dark matter is assumed to have different interaction characteristics than dark matter. Currently, dark matter is credited with comprising 23% of the mass of the universe. Quasi-dark matter is an additional postulated form of matter that comprises a portion of this 23% mass fraction.

The quasi-dark matter particle and its antiparticle are postulated to form a system that would produce a set of energy levels and a spectrum analogous to the charmonium system. The associated spectrum and postulated analogue electromagnetic quasi-dark matter interaction present a unique signature that could be observed experimentally. Although the proposed particle and associated analogue electromagnetic interaction are speculative, they provide an additional avenue for the detection of matter that is not baryonic.

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1. Introduction

Current evidence suggests that most of the mass–energy in the universe is unobserved except by its gravitational effects[1][2][3]. Baryons account for about 4% of the total, with dark matter comprising about 23%, and the remainder is assigned to dark energy. This paper postulates that a portion of the 23% mass fraction is composed of quasi-dark matter. The postulated quasi-dark matter is assumed to have unit spin, charge, and mass. This matter is represented by an X^+

particle and its X^- antiparticle. These assumptions preclude rigorous theoretical efforts to investigate quasi-dark matter unless they are speculative or limited to bounding characteristics.

Numerous dark matter candidates have been proposed[1][2][3]. Specific examples of dark matter candidates include, but are not limited to, dark photons, axions, inert Higgs doublets, sterile neutrinos, supersymmetric particles, weakly interacting massive particles (WIMPs), Kaluza-Klein particles including fuzzy cold dark matter, Chaplygin gas, dark photons, neutrinos, $e+e^-$ pairs, spin 3/2 gravitinos, neutralinos, sneutrinos, axinos, Q-balls, branons, mirror matter, WIMPzillas, and primordial black holes[1][2][3]. Additional publications have recently addressed the types and characteristics of selected dark matter candidates[4][5][6][7][8][9][10][11].

Although numerous candidates have been proposed for the 23% matter component, the proposed quasi-dark matter model has not yet been evaluated. In this paper, the characteristics of the spectrum of the X^+X^- system and its associated transitions are investigated. This investigation presumes that the quasi-dark matter interaction has an analogue electromagnetic component that facilitates transitions between states of the X^+X^- system. The X^+X^- system is an analogue of the charmonium system composed of c c-bar quarks[12].

In view of the postulated analogue electromagnetic interaction, selection rules applicable to gamma-ray transitions in nuclear systems[13] are assumed to be applicable. This is a key assumption in investigating the characteristics of the postulated quasi-dark matter candidate.

2. Quasi-Dark Matter Model

For a heavy, charged particle (X^+), a nonrelativistic model is a reasonable model to investigate the characteristics of the spectrum of the X^+X^- system, and its associated analogue electromagnetic transitions. This investigation presumes that the quasi-dark matter interaction includes an analogue electromagnetic component that facilitates transitions between states of the X^+X^- system. This approach is analogous to the nonrelativistic model for addressing heavy quarks utilizing standard model interactions (e.g., the charmonium system[12]). For quasi-dark matter, the appropriate interaction is unknown, as well as the mass and charge of the candidate X^+ particle. Given uncertainties in the postulated X^+ particle mass and charge, as well as the quasi-dark matter interaction, the determination of the specific value of associated X^+X^- system energy levels cannot be determined. However, the J^π values of the candidate states and the associated postulated analogue electromagnetic transitions can be determined. These levels and associated transitions provide a unique signature that could be observed experimentally. These transitions would be unique to the postulated quasi-dark matter and have not been proposed as a means to detect a portion of the 23% mass fraction.

The energy levels E_{NLSJ} of the X^+X^- system could be obtained by solving the radial Schrödinger Equation. This equation and its solution have been described in conventional nuclear physics calculations and are not repeated herein[14][15][16][17][18][19][20][21][22][23][24][25][26][27][28][29]. However, without knowledge of the quasi-dark matter properties and interaction characteristics, specific energy level values cannot be determined.

For the X^+X^- system with the postulated quasi-dark matter particles having spin 1, the total spin $S = s_1 + s_2$ values assume the values 0, 1, and 2. The total angular momentum (J) of the X^+X^- system is L + S, where L is the orbital angular momentum between the X^+X^- particles. Since X^+ and X^- have the same parity, the parity π of the X^+X^- system is given by $\pi(X^+X^-) = \pi(X^+)\ \pi(X^-)\ (-1)^L = (-1)^L$.

3. X^+X^- System

The model of Section 2 is used to formulate a set of X^+X^- system states characterized by the quantum numbers N, L, S, and J using the spectroscopic notation $N^{2S+1}L_J$, where N is the principal quantum number. The resulting set of energy levels of the X^+X^- system is provided in Table 1. For simplicity, only L = 0 and 1 values are illustrated.

Table 1. Selected States of the X^+X^- Quasi-Dark Matter System

$N^{2S+1}L_J$	J^π
N^1S_0	0^+
N^3S_1	1^+
N^5S_2	2^+
N^1P_1	1^-
N^3P_0	0^-
N^3P_1	1^-
N^3P_2	2^-
N^5P_1	1^-
N^5P_2	2^-
N^5P_3	3^-

The X^+X^- system has the J^π values noted in Table 1. Extension to higher orbital angular momentum and total angular momentum states follows basic nonrelativistic quantum mechanics rules.

The specific order of the aforementioned states depends on the characteristics of the quasi-dark matter interaction. The proposed model includes an analogue of the electromagnetic interaction. There could also be an analogue to the spin-orbit interaction. In addition to the usually assumed gravitational interaction, analogues of the strong and electroweak forces could also exist. Other fundamental forces, yet to be discovered, are also possible. This paper only assumes an analogue electromagnetic interaction and evaluates its consequences on the associated gamma-ray transition between postulated energy levels.

The associated X^+X^- system spectrum for the assumed charged spin 1 quasi-dark matter particle is more complex than the associated spectrum for a spin ½ particle-antiparticle system (e.g., the associated charmonium spectrum for charmed quark-antiquark pairs[12]). However, this spectrum depends on the existence of the assumed X^+ particle.

4. Selection Rules

Assuming an analogue electromagnetic quasi-dark matter interaction, the traditional electromagnetic selection rules are assumed to be applicable[13]. Given that gamma-rays emitted in electric transitions involve angular momentum L and parity $(-1)^L$, conservation of angular momentum and parity requires that the initial and final states be related by the relationship $| J_i - J_f | = \Delta J$ with $\Delta\pi = (-1)^L$. The corresponding magnetic selection rules are $| J_i - J_f | = \Delta J$ with $\Delta\pi = (-1)^{L-1}$.

These selection rules allow for more than a single transition between energy levels. Usually, the transition with the lowest L value dominates due to its larger transition rate. However, there are exceptions to the general rule[13]. The applicable selection rules are summarized in Table 2[13].

Table 2. Selection Rules for Gamma-Ray Transitions[a]

ΔJ	**0**	**1**	**2**	**3**
Parity Change	**(E1)**	**E1**	**M2**	**E3**
No Parity Change	**(M1), (E2)**	**M1, (E2)**	**E2**	**M3**

[a]*Transitions in parenthesis are not possible if either J_i or J_f is zero.*

5. Quasi-Dark Matter Analogue Electromagnetic Transitions

A set of transitions between the energy levels summarized in Table 1 can be determined. These transitions would provide additional insight as well as a unique signature of the quasi-dark matter spin 1 candidate and its associated X^+X^- system spectrum. Table 3 lists examples of the possible transitions for a quasi-dark matter interaction having an analogue electromagnetic component. Only a representative set of transitions is provided, but others follow by extension of the list of states and applicable selection rules. Higher order transitions (e.g., M2 and E3) are not included. Given uncertainties in the assumed quasi-dark matter interactions, only the analogue electromagnetic interaction is considered in determining the content of Table 3.

Table 3. Selected X^+X^- System Spectrum Transitions for a Quasi-Dark Matter Interaction with an Analogue Electromagnetic Interaction Component

Initial State	Final State	| ΔJ |	Δπ	Type
2^3S_1	1^3P_0	1	Y	E1
2^3S_1	1^3P_1	0	Y	E1
2^5S_2	2^3S_1	1	N	M1, E2
2^3S_1	2^1S_0	1	N	M1
1^5S_2	1^3S_1	1	N	M1, E2
1^3S_1	1^1S_0	1	N	M1
2^5S_2	1^3S_1	1	N	M1, E2
2^3S_2	1^1S_1	1	N	M1, E2
2^5S_2	1^5P_2	0	Y	E1
2^5S_2	1^5P_1	1	Y	E1
2^1S_0	1^1P_1	1	Y	E1
2^1S_0	1^3P_1	1	Y	E1
2^5S_2	1^1P_1	1	Y	E1
1^3P_2	1^3S_1	1	Y	E1
1^3P_1	1^3S_1	0	Y	E1
1^5P_2	1^3S_2	0	Y	E1
1^5P_1	1^3S_2	1	Y	E1
1^1P_1	1^3S_0	1	Y	E1
1^5P_1	1^1S_0	1	Y	E1
1^1P_1	1^5S_2	1	Y	E1

Detection of the associated X^+X^- transitions would establish a new component of the 23% mass fraction. Experimental observation of quasi-dark matter will be as challenging as current efforts to detect dark matter. However, the electromagnetic transitions summarized in Table 3 would present a unique signature for the postulated quasi-dark matter.

6. Conclusions

A heavy, charged spin 1 particle is postulated as a quasi-dark matter candidate. Quasi-dark matter is a postulated form of matter that interacts with the fundamental forces, including gravity, as well as other interactions. As such, quasi-dark matter is an additional possible form of matter that comprises a portion of the 23% of the mass in the universe currently assumed to be dark matter.

The postulated quasi-dark matter analogue electromagnetic transitions between the energy levels of the X^+X^- system are more complex than the quark-antiquark states such as the charmonium spectrum. The unique nature of the postulated X^+X^- system transitions and their characteristics provides an additional avenue to detect a part of the 23% matter fraction.

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