PandaX-4T Dark Matter WIMPs Are Probably Bound States of Dirac Magnetic Monopoles

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Abstract

The PandaX Collaboration reported on an excess of 4.3 events above the background in the PandaX-4T experiment. The best fit for this excess was obtained for a WIMP mass of 6 GeV. Here I show that both the mass and the interaction cross-section are compatible with bound states of Dirac magnetic monopoles.
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1 Introduction

Magnetic monopoles were suggested to describe electricity and magnetism equivalently. Dirac was able to show that electric charge can appear only in discrete units if magnetic charges exist [1]. I presented a very simple proof for this Dirac quantization condition for a special case [2]. A manifestly covariant quantum field theoretical description of Dirac magnetic monopoles requires the existence of the Salam magnetic photon [3], as I have shown some time ago [4]. By using this concept, I argued [5] that August Kundt has already observed an effect of the magnetic photon radiation [6]. I suggested a desktop experiment to verify the magnetic photon [7].

A consistent formulation of quantum field theory requires that the electric-magnetic duality is generalized to the other interactions.

This generalization requires the existence of new bosons which I named isomagnetic W and Z bosons and chromomagnetic gluons [8]. I have shown that the conservation of baryon and lepton number is a consequence of this generalization [8]. In the same publication I predicted the quantum numbers of both the fermionic and bosonic Dirac magnetic monopoles [8].

Moreover I have shown that Dirac magnetic monopoles usually do not appear as free particles, but in bound states. This is similar to quarks and leptons which usually appear in bound states such as mesons, baryons, atoms, and molecules [9].

Here I will calculate the mass and the interaction cross-section of the lightest of these bound states of Dirac magnetic monopoles (BSoDMM). I will show that both are compatible with the excessive events observed in the PandaX-4T experiment.

2 Mass of BSoDMM

I have shown that Dirac magnetic monopoles do not appear as free elementary particles, but in bound states. The lightest of these BSoDMM consists of one anti-gretelon (with spin 1/2, isospin $I_3 = +1/2$, baryon number $B = -1$, and lepton number $L = 0$)

and one anti-triplon which itself consists of three anti-hanselons (with spin 1/2, $I_3 = -1/2$, $B = 0$, and $L = -1$). As any orbital spin is an integer, the quantum numbers of the lightest BSoDMM are therefore $I_3 = -1$, $B = -1$, $L = -3$, and integer spin.

Baryon number is conserved. So the total baryon number of the universe should be zero. This can be satisfied if there exist as many baryons as anti-gretelons (and therefore BSoDMM) in the universe. If these BSoDMM are the major component of cold dark matter, then their rest mass is

$$m_\chi = m_N \Omega_c / \Omega_b \tag{1}$$

Here

$$m_N \simeq 0.938 \mathrm{GeV}/c^2 \tag{2}$$

is the mean mass of a baryon. Strictly, m_N is the ratio of the total mass of the atoms in the universe to the number of the nucleons in the universe. It is in essential a function of the mass of a hydrogen atom, the mass of a helium atom, and the helium fraction of the universe. Moreover

$$\Omega_c = 0.1200(12) h^{-2} \tag{3}$$

is the ratio of the cold dark matter mass density to the critical mass density of the universe and

$$\Omega_b = 0.02237(15) h^{-2} \tag{4}$$

is the ratio of the baryon mass density to the critical mass density of the universe, where h denotes the Hubble constant in units of 100 km $\mathrm{s}^{-1}\mathrm{Mpc}^{-1}$. Hence, the mass of a BSoDMM is

$$m_\chi = (5.03 \pm 0.10) \mathrm{GeV}/c^2 \tag{5}$$

3 Cross-Section of BSoDMM

BSoDMM have nonzero isospin. So they can interact with conventional matter by the neutral current of the weak interaction. BSoDMM are weakly interacting massive particles (WIMPs).

The low-energy limit of the Weinberg-Salam theory gives the ratio of the neutral current cross-section σ_Z to the charged current cross-section σ_W of the elastic scattering by the weak interaction,

$$\sigma_Z / \sigma_W \simeq \frac{1}{2} - \sin^2 \Theta_W \tag{6}$$

where the experimental value for the Weinberg angle Θ_W is

$$\sin^2 \Theta_W \simeq 0.23 \tag{7}$$

In the same low-energy limit the cross-section is

$$\sigma_W = \frac{4}{\pi} G_F^2 p^2 c^2 (\hbar c)^4 \tag{8}$$

Here

$$G_F^2 / \ (\hbar c)^3 \simeq 1.166 \times 10^{-5} \mathrm{GeV}^{-2} \tag{9}$$

denotes the Fermi constant, where

$$\hbar c \simeq 1.973 \times 10^{-14} \mathrm{GeV\ cm} \tag{10}$$

$$c \simeq 2.998 \times 10^{10} \mathrm{cm/s} \tag{11}$$

The square of the momentum of the BSoDMM of the Galactic halo relative to a terrestrial laboratory is given by

$$p^2 = m_\chi^2 v^2 \tag{12}$$

The velocity of the sun around the Galactic center is

$$v_\odot = (233 \pm 9) \mathrm{km/s} \tag{13}$$

As the BSoDMM of the Galactic halo have nonzero velocity relative to the Galactic center, the mean square v^2 of the BSoDMM velocity is probably larger than $v_\odot^2$, provided that the rotation velocity of the Galactic halo is not too large.

Under the assumption that $v^2 = v_\odot^2$ the calculation above gives

$$\sigma_W = (1.02 \pm 0.15) \times 10^{-42} \mathrm{cm}^2 \tag{14}$$

$$\sigma_Z = (2.7 \pm 0.4) \times 10^{-43} \mathrm{cm}^2 \tag{15}$$

σ_Z is the weak interaction cross-section of Galactic halo BSoDMM with conventional matter in the terrestrial laboratory.

4 Prediction for a Xenon Target

The de Broglie wavelength of a BSoDMM of rest mass m_χ and speed $v = v_\odot$ is

$$\lambda = \frac{2\pi\hbar}{m_\chi v} \simeq 3.171 \times 10^{-11}\text{cm} \tag{16}$$

Therefore, these BSoDMM interact rather with entire atomic nuclei than with their individual constituents (protons and neutrons). In atomic nuclei the isospins of protons and neutrons partially compensate one another. So the isospin of an atomic nucleus is proportional to $A - 2Z$.

The atomic weight of xenon is $A \simeq 131.29$ and the number of protons is $Z = 54$, so the isospin per mass is proportional to

$$(A - 2Z)/A \simeq 0.1774 \tag{17}$$

The number N of non-compensated neutrons in a xenon target of mass M is

$$N \simeq M \times 1.068 \times 10^{29}/\text{ton} \tag{18}$$

If t denotes the exposure time, then the number of weak interactions between Galactic halo BSoDMM and a xenon target of mass M is

$$n = \sigma_Z v \varrho N t / m_\chi \tag{19}$$

where

$$\varrho = (0.35 \pm 0.05)(\text{GeV}/c^2)\text{cm}^{-3} \tag{20}$$

is the canonical value of the local dark matter density. For an exposure

$$Mt = 1.54\text{ton} \times \text{year} \tag{21}$$

we get

$$n = 2.3 \pm 0.8 \tag{22}$$

expected events. (With regard to the uncertainties of its derivation, the numerical value of n should not be taken too seriously.)

5 Dark Matter WIMP Experiments

In 1977, Lee and Weinberg [10] suggested that the cosmological dark matter consists of weakly interacting massive particles (WIMPs). This idea found much interest after Peebles [11] recognized that WIMPs (and cold dark matter in general) are required by the gravitational instability theory for the formation of the large-scale structure of the universe.

A number of research groups have used xenon targets in order to search for WIMPs.

The LUX-ZEPLIN Collaboration [12] had an exposure of $Mt \simeq 0.9$ ton yr, but searched for masses $m_\chi \geq 9$ GeV/c^2 only.

The XENON Collaboration [13] had an exposure of $Mt \simeq 1.09$ ton yr, but searched for masses $m_\chi \geq 6$ GeV/c^2 only.

The PandaX-4T Collaboration [14] had an exposure of $Mt \simeq 0.63$ ton yr for its commissioning run.

It renamed as the PandaX Collaboration [15] and had an exposure of $Mt \simeq 1.54$ ton yr for its commissioning run and its first science run combined. They searched for masses $m_\chi \geq 5$ GeV/c^2. Indeed they reported on an excess of $n = 4.3$ events above the background with a best fit WIMP mass of $m_\chi \simeq 6$ GeV/c^2.

6 Outlook

My prediction of $n = 2.3 \pm 0.8$ dark matter BSoDMM events with mass $m_\chi = (5.03 \pm 0.10)\text{GeV}/c^2$ is compatible with the PandaX observation of $n = 4.3$ WIMP events with mass $m_\chi \simeq 6$ GeV/c^2.

The lightest BSoDMM have integer spin, isospin $I_3 = -1$, baryon number $B = -1$, and lepton number $L = -3$. So they can be distinguished from other hypothetical cold dark matter candidates.

(i) Heavy (sterile) neutrinos have spin $\pm 1/2$, $I_3 = 0$ or $I_3 = \pm 1/2$, $B = 0$, and $L = \pm 1$.

(ii) Neutralinos have spin $\pm 1/2$, $I_3 = 0$, $B = 0$, and $L = 0$.

(iii) Gravitinos have spin $\pm 3/2$, $I_3 = 0$, $B = 0$, and $L = 0$.

(iv) Z' bosons have spin ± 1, $I_3 = 0$, $B = 0$, and $L = 0$.

(v) Axions have spin 0, $I_3 = 0$, $B = 0$, and $L = 0$.

7 Summary

I have shown that Dirac magnetic monopoles appear in bound states and that these bound states have the quantum numbers isospin $I_3 = -1$, baryon number $B = -1$, lepton number $L = -3$, and integer spin. If they are the major components of cold dark matter, then the mass of these bound states is $m_\chi = (5.03 \pm 0.10)\mathrm{GeV}/c^2$. I have argued that they had already been observed by the PandaX Collaboration. By examining their spin and isospin, one can distinguish these bound states of Dirac magnetic monopoles from other WIMPs and dark matter candidates.

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