ELKO SPINOR AS DARK MATTER specific signatures and constraints for the interacting model

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General remarks

Dark matter has strong evidence due to gravitational effects such as

- Galaxy rotation curve
- gravitational lensing effects

However,

- Low interaction with standard matter particles

Therefore, some **NON-Luminous** matter must be throughout the universe.

According to cosmology 85% **of the total mass of the universe is associated to dark matter.**

General remarks

- Standard gravitational theory implies in decaying velocity outside the region with the major quantity of matter (Luminous) at R 15 (kpc) light years.
- TThe observed curve must be explained by some non-luminous matter in the region $> R$

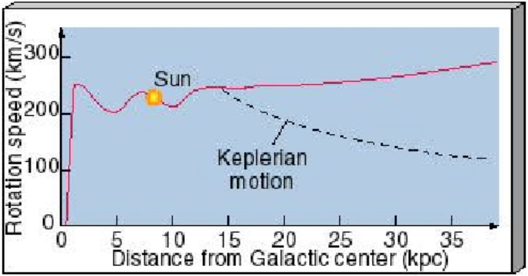

Figure: credit-astro.physics.uiowa.edu. (Milk way)

General remarks

ELKO spinor is defined as eigenspinors of charge conjugation operator. It transforms differently than Dirac ones under discrete symmetries $C; P; T$. They are candidates for a non-standard Wigner class.

It has some important characteristics:

- Are the expansion coefficients of Mass dimension one fermion fields
- Each species Just obey KG equation
- Then, **cannot** enter the standard model doublets in a **renormalizable** manner
- It is also important to highlight the fact that ELKO spinors enter as CLASS 5 spinors in LOUNESTO classification, DIFFERENTLY FROM MAJORANA fermions. Another characteristic feature is the fact that they DO NOT HAVE A DEFINITE HELICITY, each quiral component has a different one.

XENON-nT (noble gas)-Gran Sasso-Italy

- On the ground, low contamination, and $v = 232 Km=s$ with relation to DM approximately in rest in the center of the galaxy.
- Recognize scintillation due to nucleon recoil.
- Well known background. Searching for excess with statistical significance in terms of standard deviation.

Experimental searches

However, there are recent searches for Dark matter in nucleon recoil LAB experiments

- Xenon-nT, Lux, zeplin, CDMS, etc (scintillation)
- phonon mediated detections-2022
- Cross section $\quad 10 \; ^{39} cm^2$
- LAB **WIMP Mass expected to be of order** GeV event rate peak 2206.06772
- Tritium contamination in XENON (2020): fake $m \quad 2;3Kev$ WIMP
- Previous estimate from ELKO and Galaxy rotation curve $m \quad 0;1KeV$

To be detected in LAB (ordinary matter devices.) there must be coupling involving an **INTERMEDIATE boson** and the ELKO and also one involving this boson and the nucleons

Perspectives

- Considering an approximately flat universe.
- **A coupling with photon would be ne**(It is possible to find an exotic RENORMALIZABLE one.)
- But how to keep the darkness property with such coupling?
- We show that it leads to ZERO non-polarized Compton-like and pair annihilation squared amplitudes!

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Defining ELKO

Expressing the CHARGE CONJUGATION involutive operator as

$$\mathcal{C} = \begin{pmatrix} \mathbb{O} & i \\ i & \mathbb{O} \end{pmatrix} K; \qquad (1)$$

One can define the ELKO, its **EIGENSPINORS** given in a $\left(\frac{1}{2};0\right) \quad \left(0;\frac{1}{2}\right)$ representation (INTRINSICALLY NEUTRAL)

$$\mathcal{C} \;\; ^{S}(p \;\;) = + \;\; ^{S}(p \;\;); \qquad \mathcal{C} \;\; ^{A}(p \;\;) = \quad ^{A}(p \;\;): \qquad (2)$$

$$^{S} = \lim_{\mathbf{p} \,!\, 0} \quad \frac{+i \quad [\quad (p \;\;)]}{(p \;\;)} \quad ; \qquad ^{A} = \lim_{\mathbf{p} \,!\, 0} \quad \frac{i \quad [\quad (p \;\;)]}{(p \;\;)} \quad : \qquad (3)$$

with the right/left handed structures transforming as $\left(\frac{1}{2};0\right) = \left(0;\frac{1}{2}\right)$

$$(\sigma \quad \mathbf{þ}) \quad (k \;\;) = \quad (k \;\;): \qquad (4)$$

$$\sigma \quad \mathbf{þ} \quad (p \;\;) \; = \quad (p \;\;) \; : \qquad (5)$$

Defining ELKO

- Defining parity as $\mathrm{P} = m^{\ \ 1} \quad p$ and the time-reversal operator $\mathrm{T} = \quad i \ _5\mathrm{C}$ yields [Phys. Reports 2205.04754v1 (2022)]

$$(\mathrm{CPT})^2 = \mathrm{I}; and \ f\mathrm{C}; \mathrm{P}g = 0 \tag{6}$$

- ELKO transform differently than Dirac: (Possible non-Standard Wigner Class)

$$\mathrm{P} \ ^{S=A}(p \ \ ) = \quad = \quad im \ ^{S=A}(p \ \ ) \tag{7}$$

$$\mathrm{T} \ ^{S=A}(p \ \ ) = \quad im \ ^{S=A}(p \ \ ) \tag{8}$$

- ELKO: general non-vanishing momenta by boost $^{S=A}(p \ \ ) = \mathrm{D}(L(p)) \ \lim_{\mathbf{p} \, ! \, 0} \ ^{S=A}(p \ \ ):$

Field expansion prescription:

$$\mathrm{f}(x) = \int \frac{d^3p}{(2 \ \ )^3} \frac{1}{(2mE(\mathbf{p}))^{1=2}} \sum \Big[a \ (\mathbf{p})'' \ (\mathbf{p})e^{\ ip^{\mu}x_{\mu}} + b^{y}(\mathbf{p}) \quad (\mathbf{p})e^{ip^{\mu}x_{\mu}} \Big] : \tag{9}$$

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Rotationally covariant basis, Dual, spin sums (Nuclear Physics B, Vol. 987 (2023) 116092)

This basis overcomes a recent criticism, successfully implementing FULL ROTATION COVARIANCE (in a Wigner anti-linear setting.)

$$''_1(p) = {}^{S}_{+}(p)\ ; \qquad ''_2(p) = {}^{S}(p) \tag{10}$$

$$''_3(p) = \ i\ {}^{A}_{+}(p)\ ; \qquad ''_4(p) = \ i\ {}^{A}(p); \tag{11}$$

and the anti-self-conjugate one has

$$_1(p) = {}^{A}_{+}(p)\ ; \qquad _2(p) = {}^{A}(p)$$

$$_3(p) = \ i\ {}^{S}_{+}(p)\ ; \qquad _4(p) = \ i\ {}^{S}(p): \tag{12}$$

with both bases being defined in terms of the ELKO spinors.

The dual is defined as

$$\overset{\text{¡}}{''}(p) = \mathrm{h}\ P\,''\ \mathrm{i}_y(p)\ _0; \qquad \overset{:}{}(p) = \mathrm{h}\ P\ \mathrm{i}_y(p)\ _0; \tag{13}$$

with $P = \frac{p\!\!\!/}{m}$.

- Successfully implementing Well-defined expressions for products, spin sums, etc

$$\ddot{\imath}\ (p\ )"\ {}_{\theta}(p\ ) = m \quad {}_{\theta} = \quad \dot{\imath}\ (p\ ) \quad {}_{\theta}(p\ ); \tag{14}$$

with spin sums

$$\sum \ "\ (p\ )\ \ddot{\imath}\ (p\ ) = 2m\mathbb{I} = \sum \quad (p\ )\ \dot{\imath}\ (p\ ); \tag{15}$$

with completeness relation

$$\sum^{h}\ "\ (p\ )\ \ddot{\imath}\ (p\ ) \qquad (p\ )\ \dot{\imath}\ (p\ )^{i} = 4m\mathbb{I}.$$

- ELKO do not obey Dirac, just Klein-Gordon equation

$$p \quad {}^{S}(p\ ) = \quad im \ {}^{S}(p\ ); \qquad\qquad p \quad {}^{A}(p\ ) = \quad im \ {}^{A}(p\ ); \tag{16}$$

- **The model has the following Lagrangian ensuring KG equation**

$$L_{free}(x) = @ \quad \dot{f}(x)@ \quad f(x) \quad m^2 \dot{f}(x)f(x) \tag{17}$$

It is invariant under z conjugation (generalized Hermitian conjugation) $L_{free} = L^{z}_{free}$ defined as

$$\Big[\quad_{S=A}(\mathbf{p}) \Big]^{z} = \quad i \quad \Big[\quad_{S=A}(\mathbf{p}) \Big]^{y} : \tag{18}$$

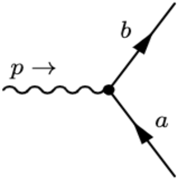
- The interaction lagrangian couples directly with physical fields being immediately gauge invariant (photon interaction with neutral fermions!)

$$L = \frac{g}{2} i \dot{f} \quad F \quad f \tag{19}$$

With $\quad \frac{1}{2}[\quad ; \quad]$ and $F \quad = @ \ A \quad @ \ A$

Interaction part

The interaction vertex



$$= igp \quad _{ba} \tag{20}$$

The BOSONIC sector is composed of the Podolsky Lagrangian (No mixing gauge)

$$L_{\text{pod}} = \quad \frac{1}{4}F \quad F \quad + \frac{1}{2M^2} @ \ F \quad @ \ F \quad + \frac{}{2} \quad a^2 \quad + 1 \quad @ \ A \quad ^2 \tag{21}$$

Electron-positron scattering with 12 **GeV** . $\sqrt{s}$. 46:8 **GeV yields the bound** M & 370 **GeV.**

- **The amplitude for the Compton scattering reads**
  $\Gamma \ (k) = \quad \not{k} \quad k$

$$M_{\ ;\ ^{0};\ ;\ ^{0}} = \frac{g^2}{2m\ s \quad m^2} i\ ^{\acute{}"} \ (p^{0})\Gamma\ (k^{0})\Gamma\ (k) \quad (k^{0}) \quad ^{0}(k)"\ _{0}(p) +$$

$$\frac{g^2}{2m\ u \quad m^2} i\ ^{\acute{}"} \ (p^{0})\Gamma\ (k)\Gamma\ (k^{0}) \quad (k^{0}) \quad ^{0}(k)"\ _{0}(p): \quad (22)$$

Replacing the s channel by t, $^{\acute{}"}\ (p^{0})$ by $^{:}\ (p^{0})$ and with all external photons being conjugated, we obtain the amplitude for the DARK MATTER pair annihilation

Compton and pair annihilation non-polarized process

- **In both y and z prescription, the probability is proportional to**

$$\sum_{;\,';\,;\,'} M_{;\,';\,;\,'} M^{z}_{;\,';\,;\,'} \tag{23}$$

is proportional to a linear combination of the following terms

$$Tr[\Gamma\ (k)\Gamma\ (k')\Gamma\ (k')\Gamma\ (k)]; \qquad Tr[\Gamma\ (k')\Gamma\ (k)\Gamma\ (k')\Gamma\ (k)] \tag{24}$$

with both being proportional to $(k\ \ k\ \ )(k' k'\ \ ) = 0$ In interacting case, the massive excitation becomes UNSTABLE just contributing to internal lines. The asymptotic spectrum is free of massive photons.

- **This is our de nition of darkness**

From the path integral U(1) invariance $A\ (x) = @\ \Lambda, \quad \mathrm{f}(x) = 0$ (Neutral.)

$$Z = N \int \prod_{=0}^{3} DA\ D\dot{\mathrm{f}}\ D\mathrm{f}$$

$$\exp\ i \int d^4x \quad \frac{1}{4} F\ \ F\ \ + \frac{1}{2M^2} @\ F\ \ @\ F$$

$$+\ @\ \ \dot{\mathrm{f}}\, @\ \ \mathrm{f} \quad m^2\, \dot{\mathrm{f}}\, \mathrm{f} + \frac{ig}{2}\, \dot{\mathrm{f}} \quad \mathrm{f}\,(F\ \ )$$

$$+\ (\frac{}{M^2} + 1)\ @\ A\ \ ^2 + J\ A\ + \bar{T}\,\mathrm{f} + \dot{\mathrm{f}}\ T \quad ; \tag{25}$$

one can obtain the Ward-like identity

$$K\ \ \frac{^3\Gamma}{\dot{\mathrm{f}}\,(p)\ \ \mathrm{f}(\tilde{p})\ \ A\ \ (k)} = 0 \tag{26}$$

Darkness survive full quantum corrections?

The existence of the basis $G_a = f I_4 \;\; _4; \;\;\; ; \;\;\;\; _5; \; _5; \;\;\;\; g$ allows us to conclude (until 2-loops)

$$g\Gamma^{2 \;\; LOOP}(p; \tilde{p}; k = p \quad \tilde{p}) = \; g F(p; \tilde{p}; k = p \quad \tilde{p}) \quad k \; : \qquad (27)$$

This, together with Schwinger-Dyson equations ensuring the ELKO propagator structure, may prove Darkness prevalence radiative corrections until g^6 order in cross-section.

- It is valid until g^6 even when considering 4-point 1PI contributions and complete vertexes to Compton. However, box-box products violate the property. That is why it is valid just until g^6 and not g^8.

Darkness survives full quantum corrections?

- One loop contributions to Compton scattering. (The associated amplitude respects darkness for order g^6!)
- This is enough for phenomenological darkness (i.e. Standard QED measures 70 BOX events in hundred billion tentatives in LHC!... our coupling is 10^5 times smaller!)

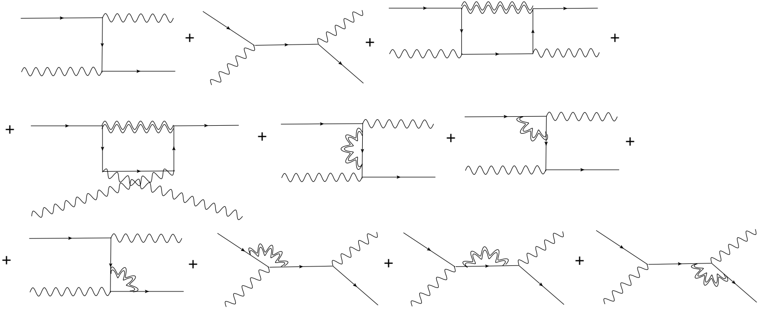


Figure: Compton radiative corrections.

Nucleon Recoil Bounds

CONSIDERING...

- **The e ective LOW ENERGY vertex for photon-proton interaction is**

$$V \qquad \frac{1}{m^{0}} \qquad p \;+ \tag{28}$$

  with $m^{0} \quad 1GeV$ denoting the proton mass.
- Using our machinery and the fact that the velocity $232Km{=}s$ of the DM approaching the target made of protons
- The cross-section bound from LUX (for spin-dependent WIMP-proton interaction) $\quad 10 \;\; ^{39}cm^{2}$
- considering the very stringent limits, a WIMP with mass $\quad GeV$ is our focus. Namely, (2206.06772) leads to an event rate peak at a possible WIMP with

$$M \qquad 5GeV \tag{29}$$

WE CAN CALCULATE THE CROSS-SECTION $\mathrm{f} + p \;\; ! \;\; \mathrm{f} + p$ (natural units.)

$$g \qquad 10 \;\; ^{5} \tag{30}$$