We can't solve problems by using the same kind of thinking we used when we created them.

Albert Einstein

WORLD – UNIVERSE MODEL

SUPER-WEAK INTERACTION

STERILE NEUTRINO DARK MATTER

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ABSTRACT

World – Universe Model (WUM) is based on two fundamental parameters in various rational exponents: Fine-structure constant α, and dimensionless quantity Q. While α is constant, Q increases with time, and is in fact a measure of the size and the age of the World.

WUM predicts that there exist two additional fundamental interactions – Super-Weak and Extremely-Weak – in addition to four commonly described. The cross-section of Super-Weak interaction is about 10 orders of magnitude smaller than the Weak; Extremely-Weak interaction is 10 orders of magnitude smaller still. These ratios are in good agreement with the published theoretical models concerning the origin of Strangeness and CP violation.

In this paper, we examine the role of super-weakly interacting sterile neutrinos in the structure of galaxies and galaxy clusters.

1. INTRODUCTION

World – Universe Model (WUM) predicts the existence of Super-Weak and Extremely-Weak interactions [1]. It is not, however, immediately obvious how observations of these interactions can be conducted in the presence of the much stronger Weak interaction. Lincoln Wolfenstein offers the following method in his "Superweak interactions" paper, drawing an analogy with observation of Weak interaction in the face of the Strong:

One must look at processes that violate some strong interaction selection rule. Thus weak interactions are observed in flavor-violating processes such as strange particle decay or in parity violation in nuclear physics. So we hope to observe Superweak interactions in amplitudes that vanish or are very small to order G_F *because of selection rules. CP violation is a very good place to look for a new Superweak interaction due to physics beyond the standard model* [2].

Signs of super-weakly interacting particles can also be found in the cosmic rays emitted from various macroobjects in the World.

The paper is organized as follows:

- In Section 2, we consider different interactions, including the predicted Super-Weak and Extremely-Weak, and the relationship between them.
- Section 3 discusses Strangeness and CP violation and their explanation by Super-Weak interaction.
- Section 4 describes the different super-weakly interacting particles.
- Section 5 considers the super-weakly interacting sterile neutrinos, and their role in the structure of macroobjects.

2. GRAND UNIFIED THEORY

Wikipedia states that *the Grand Unified Theory is a model in particle physics in which at high energy, the three gauge interactions of the Standard Model which define Weak, Electromagnetic, and Strong interactions, are merged into one Single interaction characterized by one Larger gauge symmetry and thus one Unified Coupling constant* [Wikipedia, Grand Unified Theory].

By definition of a Coupling constant, it is *a number that determines the strength of an interaction* [Wikipedia, Coupling constant].

For example, one of the ways to define the gravitational coupling constant α_G looks as follows:

$$\alpha_G = \frac{2\pi G m_e^2}{hc} = (\frac{m_e}{M_P})^2 \qquad 2.1$$

where G is the gravitational constant, h is Planck constant, c is the electrodynamic constant, m_e is the electron mass , and M_P is Planck mass.

The electromagnetic coupling constant α_{EM} can be defined as:

$$\alpha_{EM} = \frac{e^2}{2\varepsilon_0 hc} = \alpha \qquad 2.2$$

Fine-structure constant α determines the strength of the electromagnetic force of electrons (e is the electron charge and ε_0 is the electric parameter).

At an atomic scale, the strong interaction is about 100 times stronger than electromagnetic interaction, which in turn is about 10^{10} times stronger than the weak force, and about 10^{40} times stronger than the gravitational force, when forces are compared between particles interacting in more than one way.

The above comparisons are based on strength of the force between a particular pair of particles, and are therefore dependent on the choice of such particles. Clearly, the gravity between a pair of electrons will differ from that between a pair of protons.

A different way of comparing interactions is looking at their cross-sections – *the likelihood of an interaction between particles* [Wikipedia, Cross section (physics)]. Cross-sections are independent of the particle choice, and are thus a convenient way to compare interactions.

For example, an electromagnetically decaying neutral pion has a lifetime of about 10^{-16} seconds; a weakly decaying charged pion lives for about 10^{-8} seconds, and a free neutron lives for about 15 minutes, making it the unstable subatomic particle with the longest known mean life.

Coupling parameter of an interaction is a dimensionless quantity that is obtained by dividing the interaction's cross-section by σ_{max} , the maximum cross-section of any interaction (see the World – Universe Model [1] for details):

$$\sigma_{max} = (\frac{a}{2})^2 = \pi^2 a_0^2 \qquad 2.3$$

where $a = 2\pi a_0$ is the radius of the World's Nucleus at the Beginning, and a_0 is the classical electron radius.

The World – Universe Model interprets the cross-sections of known interactions as follows:

- The coupling parameter of strong interaction α_S equals to the coupling parameter of the electromagnetic interaction α_{EM}:

$$\alpha_S = \alpha_{EM} = 1 \qquad 2.4$$

- The weak interaction coupling parameter α_W:

$$\alpha_W = Q^{-1/4} \tag{2.5}$$

- The coupling parameter of gravity α_G:

$$\alpha_G = Q^{-1} \tag{2.6}$$

Recall that Q is a dimensionless quantity proportional to the size and age of the World, and equals to 0.75996×10^{40}.

The electromagnetic and strong interactions have identical coupling parameters, but vary in their strengths, since the strength of an interaction is dependent on the choice of particles.

At the very Beginning ($Q = 1$), when the World had the maximum energy density, all extrapolated fundamental interactions had the same cross-section σ_{max} and can be characterized by the Unified coupling parameter:

$$\alpha_U = \alpha_S = \alpha_{EM} = \alpha_W = \alpha_G = 1 \tag{2.7}$$

The gravitational coupling parameter α_G is decreasing in time t:

$$\alpha_G = Q^{-1} \propto t^{-1} \tag{2.8}$$

and the ratio of the coupling parameters now is

$$\alpha_G/\alpha_{EM} = Q^{-1} = 1.31586 \times 10^{-40} \tag{2.9}$$

The weak coupling parameter is decreasing as follows:

$$\alpha_W = Q^{-\frac{1}{4}} \propto t^{-\frac{1}{4}} \tag{2.10}$$

and the ratio of α_W to α_{EM} is

$$\alpha_W/\alpha_{EM} = Q^{-1/4} = 1.07103 \times 10^{-10} \tag{2.11}$$

The strong and electromagnetic coupling parameters remain constant in time:

$$\alpha_S = \alpha_{EM} = 1 \tag{2.12}$$

WUM predicts two more types of interactions with coupling parameters α_{SW} and α_{EW} for super-weak and extremely-weak interactions respectively:

$$\alpha_{SW} = Q^{-\frac{1}{2}} \propto t^{-\frac{1}{2}} \tag{2.13}$$

$$\alpha_{EW} = Q^{-\frac{3}{4}} \propto t^{-\frac{3}{4}} \tag{2.14}$$

The ratio of α_{SW} to α_W is

$$\alpha_{SW}/\alpha_W = Q^{-1/4} = 1.07103 \times 10^{-10} \qquad 2.15$$

and the ratio of α_{EW} to α_W is

$$\alpha_{EW}/\alpha_W = Q^{-1/2} = 1.14711 \times 10^{-20} \qquad 2.16$$

3. SUPER-WEAK INTERACTION

According to WUM, the Super-Weak interaction has coupling strength $\sim 10^{-10}$ times weaker than that of weak interaction. Let's consider the possibility of such ratio of interactions in the developed theoretical models explaining CP and Strangeness violation.

According to Wikipedia, *CP violation (CP standing for Charge Parity) is a violation of the postulated CP-symmetry (or Charge conjugation Parity symmetry): the combination of C-symmetry (charge conjugation symmetry) and P-symmetry (parity symmetry). CP-symmetry states that the laws of physics should be the same if a particle is interchanged with its antiparticle (C symmetry), and then its spatial coordinates are inverted ("mirror" or P symmetry).*

Until 1956, parity conservation was believed to be one of the fundamental geometric conservation laws (along with conservation of energy and conservation of momentum). However, in 1956 a careful critical review of the existing experimental data by theoretical physicists Tsung-Dao Lee and Chen Ning Yang revealed that while parity conservation had been verified in decays by the strong or electromagnetic interactions, it was untested in the weak interaction [3].

The first test based on beta decay of Cobalt-60 nuclei was carried out in 1956 by a group led by Chien-Shiung Wu, and demonstrated conclusively that weak interactions violate the P symmetry [4] [Wikipedia, CP violation].

Wikipedia defines strangeness S as *a property of particles, expressed as a quantum number, for describing decay of particles in strong and electromagnetic reactions, which occur in a short period of time. In our modern understanding, strangeness is conserved during the strong and the electromagnetic interactions, but not during the weak interactions. In most cases these decays change the value of the strangeness by one unit* [Wikipedia, Strangeness].

In the "Possibility of Super-Weak Interactions and the Stability of Matter" paper (1959) Yoshio Yamaguchi discussed a "metastability" of matter and theorized the likelihood of the super-weak coupling with the strength between β-decay constant and the gravitation constant [5]. Yamaguchi found the ratio of super-weak coupling constant to gravitation constant to be $\sim 10^{20}$, which is close to the ratio predicted by WUM:

$$\alpha_{SW}/\alpha_G = Q^{1/2} = 0.87176 \times 10^{20} \qquad 3.1$$

When discussing CP violation, K. F. Kelly described *a new super-weak interaction which violates CP and has coupling strength* $\sim 10^{-9}$ *times weaker than that of weak interaction* [6].

B. A. Bian, *et al*. give the estimate of the super-weak interaction $\sim 10^{-8}$ of the weak interaction [7].

In the "Superweak interactions" paper, Lincoln Wolfenstein analyzed the different Selection Rule violations including $\Delta S = 2$ and $\Delta S = 2,\ CP$. The calculated ratios of the super-weak interaction to the weak one are $\sim 10^{-9}$ and $\sim 10^{-11}$ respectively [2].

All these estimations are in good agreement with the ratio of $\sim 10^{-10}$ predicted by WUM (see equation 2.15).

In conclusion of his paper, Lincoln Wolfenstein said that *superweak interactions provide an important clue to physics beyond the standard model but there are a quite limited number of places where it is practical to identify the effects of such interactions* [2]. In our opinion, astroparticle physics is one such place.

4. SUPER-WEAKLY INTERACTING PARTICLES

In the "Superweakly Interacting Massive Particles" paper (2003) J. L. Feng, A. Rajaraman, and F. Takayama postulated a new class of nonbaryonic cold DM: Superweakly-interacting massive particles (super-WIMPs or SWIMPs). They consider *two specific super-WIMPs: gravitinos in supersymmetric theories, and Kaluza-Klein (KK) gravitons in theories with extra dimensions. In contrast to conventional WIMPs, however, they interact superweakly and so evade all direct and indirect dark matter detection experiments proposed to date* [9].

In the "SuperWIMP Dark Matter Signals from the Early Universe" paper (2003) they propose a way to find signatures of SWIMPs: *Super-WIMP dark matter is produced in decays WIMP → SWIMP+S, where S denotes one or more standard model particles. The super-WIMP is essentially invisible, and so the observable consequences rely on finding signals of S production in the early universe. In principle, the strength of these signals depends on what S is and its initial energy distribution* [10].

A. Boyarsky, *et al.* have this to say about super-weakly interacting DM candidates: *There are many examples of super-WIMP DM models: sterile neutrinos, gravitinos in theories with broken R-parity, light volume moduli or Majorons* (see [11] and references therein). An axion appears to be a most popular SWIMP. It was introduced into particle physics many years ago to solve the problem of CP violation (see [12] and references therein).

S. Ando, *et al.* consider a different SWIMP – a charged massive particle, or CHAMP: *beyond high-energy collider experiments, the only direct experimental handle on a super-weakly interacting dark matter particle featuring a heavier, meta-stable charged partner is CHAMP pair production via neutrino–nucleon collisions, followed by direct observation at neutrino telescopes* [13, 14].

In the “Long-range interaction between spins” paper (1981) P. C. Naik and T. Pradhan analyze *a super-weak long-range spin-spin force between particles in vacuum. Recent experiments demonstrating repulsion and attraction between circular polarized laser beams are interpreted to be due to such a force enhanced by spin polarization of sodium vapor, through which these beams pass.*

This force is found to be weaker than the weak interaction; it is of the same order of magnitude as the super-weak interaction (Wolfenstein 1964, [16]*). The weak spin-spin coupling, like gravitation, may manifest itself in astrophysical phenomena through a photon-neutrino interaction* [15].

A large number of papers has been published in the field of Dark Matter in recent decades. Super-weakly interacting particles have been studied using different theoretical models. Numerous papers were dedicated to Dark Matter searches with astroparticle data (for example, see reviews [17-19] and references therein).

In the “Searching for Dark Matter” review (2010) A. Boyarsky, O. Ruchayskiy, and M. Shaposhnikov wrote: *A large class of extensions of the SM* (Standard Model) *predicts super-weakly interacting DM candidates. These models include: extensions of the SM by right-handed neutrinos, models with extra dimensions and string-motivated models, supersymmetric theories. The super-WIMP candidates are as possible as WIMPs and from many points of view are very compelling* [17].

In the “Dark Matter Candidates from Particle Physics and Methods of Detection” review (2010) J. L. Feng gave a brief summary of the standard model of particle physics and its outstanding problems. He discussed several DM candidates motivated by these problems, including WIMPs, hidden DM, axions, and also super-weakly interacting super-WIMPs, light gravitinos, and sterile neutrinos. In conclusion he said: *Rather than attempt a summary of this review, we close with some optimistic, but plausible, scenarios for the future in which experiments from both particle physics and astrophysics are required to identify dark matter* [18].

In the “Dark Matter Candidates: A Ten-Point Test” review M. Taoso, G. Bertone, and A. Masiero said: *An extraordinarily rich zoo of non-baryonic Dark Matter candidates has been proposed over the last three decades* [19]. They gave detailed analysis of a small subset of 16 different DM candidates in accordance with the ten-point set of requirements that a particle has to fulfil in order to be considered a viable DM candidate. They did not conclude which of the DM candidates passed this test.

According to WUM, there are five DM candidates: neutralino, WIMP, DIRAC, ELOP, and sterile neutrino [1, 8].

5. SUPER-WEAKLY INTERACTING STERILE NEUTRINOS

According to Alexander Kusenko *the name "sterile" was coined by Bruno Pontecorvo in a paper [JETP, **53**, 1717 (1967)], which also discussed lepton number violation; neutrinoless double beta decay; rare processes (e.g. $\mu \to e\gamma$); vacuum neutrino oscillations; detection of neutrino oscillations; astrophysical neutrino oscillations* [20].

The Wikipedia gives the following description of a sterile neutrino:

It is possible to include both Dirac and Majorana terms: this is done in the seesaw mechanism. In addition to satisfying the Majorana equation, if the neutrino were also its own antiparticle, then it would be the first Majorana fermion [Wikipedia, Sterile neutrino].

The concept of a sterile neutrino has a long history. In the "Dynamical role of Light Neutral Leptons in Cosmology" paper (1979) S. Tremaine and J. E. Gunn calculated the minimum mass of any stable neutral lepton, including neutrino, that can compose massive galactic halos (so-called Tremaine-Gunn bound) [21].

S. Riemer-Sorensen gives the following explanation of that bound: *Liouville's theorem, stating that the phase space density is conserved along particle trajectories in a collisionless fluid, provides a fundamental constraint on the clustering of warm particles. Studies of the available phase space for dark matter domination in dwarf galaxies by Tremaine and Gunn leads to a very strong constraint on the mass of any dark matter particle. This limit of $m \gtrsim 0.5$ keV is called the Tremaine-Gunn bound* [22].

In the "Cosmological bounds on the masses of stable, right-handed neutrinos" paper (1982) K. A. Olive and M. S. Turner *generalize the previous results to stable ($\tau \gg \tau_{universe} \sim 10^{18}\ sec$), right-handed neutrinos which interact with effective strength $G \leq G_F \cong 1.15 \times 10^{-5}\ GeV^{-2}$. Such particles are predicted in many theories, particularly those with right-left symmetry. The arguments we present can be generalized to make them applicable to any stable, weakly interacting neutral particle*.

Light neutrinos ($\leq 1\ MeV$) are constrained to be less massive than $\sim 100\ eV - 2\ keV$, depending upon G and whether they are of the Dirac or Majorana type. Heavy neutrinos must be more massive than $\cong (G/G_F)\ GeV$, and less massive than about 10 TeV [23].

In their estimations they took the value of interaction strength G: $G/G_F < 0.1$ and $G/G_F < 0.01$, which means that they analyzed the super-weakly interacting neutrinos.

In the "Super-Weakly Interacting Particles and the Formation of Galaxies and Clusters of Galaxies" paper (1983) Tetsuya Hara discusses *the astrophysical effects of stable super-weakly interacting particles, with particular emphasis on their consequences for the formation of the first astronomical objects from the growth of adiabatic perturbations, derive some constraints on the number density and mass of these particles* [24].

He calculated the corresponding masses of massive neutrinos in the range $\sim (0.1 - 1)\ keV$, which are in good agreement with Tremaine-Gunn bound [22].

In the “Sterile Neutrinos as Dark Matter” paper (1993) S. Dodelson and L. M. Widrow *consider a single generation of neutrino fields* (ν_L,ν_R) *with a Dirac mass,* μ *, and a Majorana mass for the right-handed components only, M. For* $M \gg \mu$ *we show that the number density of sterile neutrinos is proportional to* μ^2/M *so that the energy density today is independent of M. However M is crucial in determining the large scale structure of the Universe. In particular,* $M \cong 0.1 - 1.0\ keV$ *leads to warm dark matter and a structure formation scenario that may have some advantages over both the standard hot and cold dark matter scenarios* [25].

Sterile neutrinos play a significant role in our Model. According to WUM, the heaviest macroobjects of the World include high-density preon plasma and sterile neutrino shells around their cores:

- Blazars are members of a large group of active galaxies that host active galactic nuclei (AGN) [Wikipedia, Blazar]. They are macroobjects with hot preon and sterile neutrinos shells.
- Quasars are the most energetic and distant members of AGN. They are macroobjects with very hot preon and sterile neutrinos shells.
- Seyfert galaxies are one of the two largest groups of AGN, along with quasars. They have quasar-like nuclei, but unlike quasars, their host galaxies are clearly detectable. Seyfert galaxies account for about 10% of all galaxies [Wikipedia, Seyfert galaxy].

The temperature of the preon and sterile neutrinos shells depends on the composition of the macroobject core. Macroobjects with cores made up of WIMPs and White Dwarf Shells (WDS) produce hot preon and sterile neutrino shells. Macroobjects whose cores consist of neutralinos and WDS have very hot preon and sterile neutrino shells [8].

Sterile neutrinos have both Dirac and Majorana terms. According to WUM, their mass is 3.7 keV and they can annihilate and decay. Masses in this range imply super-weak interaction strength between DM and the Standard Model sector with many orders of magnitude below weak-scale cross sections.

The annihilation is proportional to the square of the density and is especially efficient in places of highest concentration of dark matter, such as compact stars built up from fermionic dark matter particles. In shells of the heaviest macroobjects of the World the density of sterile neutrinos can be as high as $1.8 \times 10^{-4}\ kg/m^3$ that is equivalent to the concentration of $2.7 \times 10^{22}\ cm^{-3}$ [1, 8].

An important result, confirming the annihilation of sterile neutrinos with mass 3.7 keV, was obtained by S. Safi-Harb and H. Ogelman. In the “ROSAT and ASCA Observations of W50 Associated with the Peculiar Source SS 433” paper (1997) they reported that *the observations of the X-ray lobes of the large Galactic source W50 [are] associated with the two-sided jets source SS 433.*

They noted that *a continuum model (power law or thermal bremsstrahlung) plus a Gaussian improves the fit to region w2 slightly. However, a broken power-law model gives the best fit. The power-law indices are 1.9 and 3.6, with the break occurring at 3.7 keV. This result is also close to our findings for the spectral fitting of region e2 in the eastern lobe, except that the spectrum from the western lobe is softer* [26].

A. M. Bykov, *et al.* confirm the *3.7 keV* peak in their "Isolated X-ray–infrared sources in the region of interaction of the supernova remnant IC 443 with a molecular cloud" paper (2008): *The nature of the extended hard X-ray source XMMU J061804.3+222732 and its surroundings is investigated using XMM-Newton, Chandra, and Spitzer observations. The X-ray emission consists of a number of bright clumps embedded in an extended structured non-thermal X-ray nebula larger than 30" in size. Some clumps show evidence for line emission at ~ 1.9 keV and ~ 3.7 keV at the 99% confidence level. A feature at 3.7 keV was found in the X-ray spectrum of Src 3 at the 99% confidence level* [27].

The line emission $\sim$ *1.9 keV* is in good agreement with the decay of sterile neutrinos with half-mass *1.86 keV* and with the results of the observations of the central region of the Virgo cluster in the 1-10 keV range which show $\sim$ *2 keV* line in the spectrum viewed by *Chandra* [28].

A. Moretti, *et al*. measured the unresolved cosmic X-ray background in the 1.5-7.0 keV energy band at the deepest level and with the best accuracy available today. There are the emission lines around 3.7 *keV* and *2 keV*, clearly visible in the spectrum [29].

In conclusion, super-weak interactions provide an important clue to physics beyond the standard model. A new class of super-weakly interacting particles should be searched for in cosmic rays.

The Super-Weak interaction has been extensively discussed in literature for quite some time. The World-Universe Model also predicts the Extremely-Weak interaction, 10 orders of magnitude weaker, that is responsible for the decay of protons and other stable particles whose lifetimes considerably exceed the age of the World.

Acknowledgements

I am grateful to Felix Lev, my life-long friend, for our frequent discussions of history and philosophy of Physics. Special thanks to my son Ilya Netchitailo who questioned every aspect of the paper and helped shape it to its present form.

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