QCD's Low-Energy Footprint

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Abstract: QCD affects electrons and nucleons dynamics and gravity through the vacuum quark and gluon condensate dynamics. We propose a double well potential model for the electron and pion tetrahedron dynamics carried by quark flavor exchange waves that propagate in a pion tetrahedron lattice that represents the quantum vacuum. Quarks are exchanged between electron and pion tetrahedron creating effective motion of the electron. Dirac's electron Zitterbewegung frequency is related in the double well potential model to the ground state frequency. Magnetoresistance and spin torque of ferromagnetic layers may be explained by the proposed electron and pion tetrahedron model. We suggest adding the pion tetrahedrons condensate energy density to Einstein's equation energy-momentum tensor. QCD has a significant low-energy footprint where the vacuum quark flavor exchange wave that affects electron dynamics may be a significant example .

Keywords: Quantum Chromodynamics (QCD), Quantum Electrodynamics (QED), Electron-Ion Collider (EIC), Pion tetrahedrons, QCD vacuum, Zitterbewegung, Magnetic Materials, General Relativity (GR).

1. The Electron and Pion Tetrahedron Clouds

The Electron-Ion Collider (EIC) is aimed to explore the building blocks of matter and reveal the properties of the strong force that binds the protons and neutrons together to form the nuclei[1]. The EIC is aimed to explore the three-dimensional distributions in coordinate and momentum spaces of the quarks and gluons and the way in which the nucleons mass, spin, and mechanical properties emerge from the fundamental interactions of the quarks and gluons. The EIC program will include exotic meson spectroscopy aimed to observe the exotic meson states.

In this paper we argue that QCD has a low-energy footprint that affects electrons, atoms, and gravity through the quark and gluon condensate dynamics. In previous papers[2,3,4], the exotic meson, $u\tilde{d}d\widetilde{u}$, pion tetrahedron and the electron tetrahedron models were presented. We assumed that the exotic meson pion tetrahedron, $u\tilde{d}d\widetilde{u}$, fill space and form a non-uniform condensate with an atmospheric like density drop. The pion tetrahedron mass may be calculated by measuring the β decay rate time periodic variability[3]. We further assumed that the attraction between quarks and antiquarks may be the source of gravity[2]. The massive pion tetrahedrons density vary according to the gravitational field in space and the gravitational force is transferred by interaction of quarks with the anti-quarks of the non-uniform pion tetrahedron condensate.

We further assumed that the electron may be a comprised particle, a tetraquark tetrahedron, two quarks determine its electric charge, and two quarks determine the electron spin. High frequency quark exchange reactions may transform the electron tetrahedrons to pion tetrahedrons and vice versa and form together electron clouds with fixed spin state[2]. The $u\tilde{u}$ *and* $d\tilde{d}$ quark pairs assumed to be part of the electron tetrahedrons, allow forming chemical bonds between electron pairs and proton-neutron pairs in the nuclei forming the $u\tilde{d}d\tilde{u}$ pion tetrahedron that act as a QCD glue. We assumed that the valence quarks and antiquarks

$(u, d, \tilde{d}\ and\ \tilde{u})$ are conserved sub-particles and may only be exchanged between reactants forming products.

In this paper we propose that electron and pion tetrahedrons form together electron clouds in thermal equilibrium due to high frequency quark exchange reactions that occur between the electrons and the pion tetrahedrons forming a quark and antiquark flavor exchange waves. We further assume that two electron tetrahedrons scattering having opposite spins create a pion tetrahedron transition state complex that act like a QCD glue and dissipate heat to the pion tetrahedron condensate generating an electric resistance.

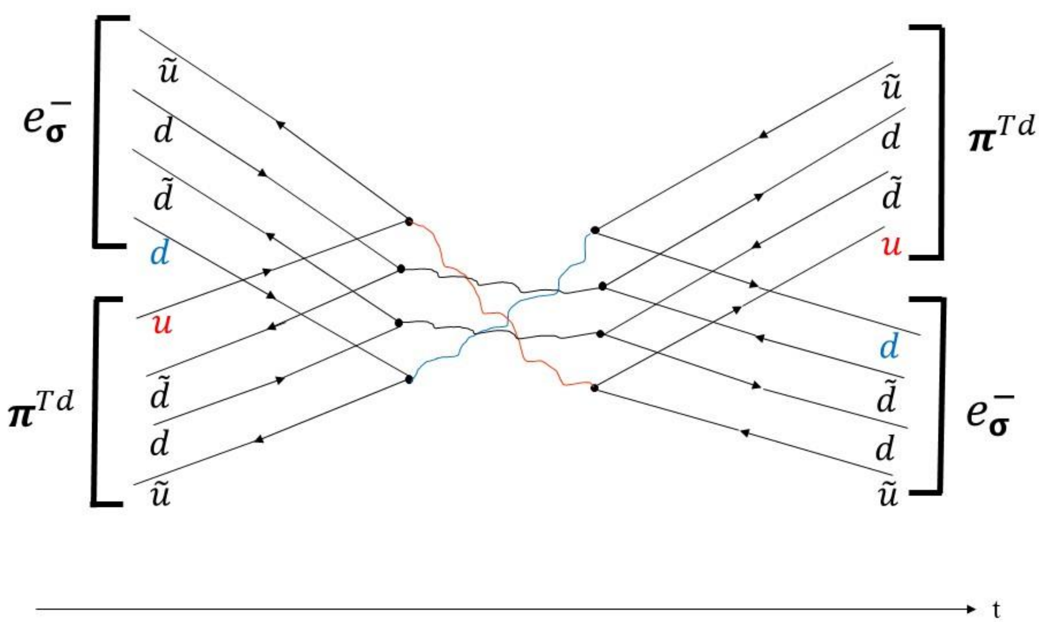

Figure 1 illustrates an electron tetrahedron and pion tetrahedron scattering exchanging d and u quarks, transforming the electron to a pion tetrahedron and vice versa. High frequency repetition of the quark exchange reactions generate an electron cloud that conserves charge and spin and may be seen as a quark flavor exchange wave.

We assume that when an electron is accelerated a plurality of pion tetrahedrons that surround it are accelerated with the electron in thermal equilibrium due to the rapid quark exchange reactions. The electron cannot be separated from its surrounding pion tetrahedrons cloud, and the electron becomes a many-body cloud composed of a plurality of pion tetrahedrons that perform rapid d and u quark exchange reactions with the electron tetrahedron. The thermal equilibrium with the pion tetrahedron condensate assumption applies not only to electrons. Protons and neutrons participate also in the rapid quark exchange reactions with the vacuum pion tetrahedrons. We assume that protons and neutrons of atom nuclei in a solid state are surrounded by the vacuum pion tetrahedrons since the pion tetrahedrons antiquarks are attracted to the quarks of the protons and neutrons. Since the density of matter inside the solid is much higher than in a gas, the non-uniform pion tetrahedron condensate density inside a solid may be higher and may also follow the lattice symmetry. In the next sections we describe the electron and pion tetrahedrons motion in a lattice in a hydrogen atom model generating quark flavor exchange waves.

2. Electron and Pion Tetrahedron Cloud and the Hydrogen Atom

Werner Heisenberg introduced in 1925 matrix mechanics trying to explain the electron trajectories $(x(t), p(t))$ for the hydrogen atom in an electromagnetic field arguing that the electrons do not move in classical orbits as Niels Bohr suggested[5]. Quantum mechanics explained electron dynamics in terms of wave functions and discrete energy levels according to equations that were derived a year later by Erwin Schrodinger and in 1928 by Paul Dirac. The wave mechanics gave the correct spectra and the probability to find the electron but it did not provide a detailed description of the electron motion in classical trajectories or in another pattern.

The hydrogen atom hyperfine structure Hamiltonian may be written in terms of Dirac's exchange operator, $\hat{P}^{Ex}$, the exchange energy parameter A and the Pauli spin matrices for the electron σ^e and the proton σ^p are [6] -

$$\hat{H}^{hyperfine} = A\,\sigma^e\sigma^p = -A\,\sum(2\,\hat{P}^{Ex} - 1) \qquad (1)$$

Dirac's exchange operators, $\hat{P}^{Ex}$, exchanges the two particles' spins. If their spins are in the same state, the overall spin state remains unchanged but if their spin states are anti-parallel the two spins are switched.

$$\hat{P}^{Ex}\,|P^{\uparrow}, e^{\uparrow}\rangle = |P^{\uparrow}, e^{\uparrow}\rangle \qquad (2a)$$

$$\hat{P}^{Ex}\,|P^{\downarrow}, e^{\uparrow}\rangle = |P^{\uparrow}, e^{\downarrow}\rangle \qquad (2b)$$

$$\hat{P}^{Ex}\,|P^{\uparrow}, e^{\downarrow}\rangle = |P^{\downarrow}, e^{\uparrow}\rangle \qquad (2c)$$

$$\hat{P}^{Ex}\,|P^{\downarrow}, e^{\downarrow}\rangle = |P^{\downarrow}, e^{\downarrow}\rangle \qquad (2d)$$

The hyperfine Hamiltonian matrix in the basis set of the four possible spin states, $|P^{\uparrow}, e^{\uparrow}\rangle$, $|P^{\uparrow}, e^{\downarrow}\rangle$, $|P^{\downarrow}, e^{\uparrow}\rangle$, $|P^{\downarrow}, e^{\downarrow}\rangle$ is given by the following 4*4 matrix[6] -

$$\hat{H}_{i,j}^{hyperfine} = \begin{bmatrix} A & 0 & 0 & 0 \\ 0 & -A & 2A & 0 \\ 0 & 2A & -A & 0 \\ 0 & 0 & 0 & A \end{bmatrix} \qquad (3)$$

Solving the time dependent Schrodinger equation for the hyperfine Hamiltonian -

$$i\,\hbar\,\dot{C}_i = \sum_{j=1}^{4} \langle i|\hat{H}_{i,j}^{hyperfine}|j\rangle\; C_j \qquad (4)$$

gives the ground state solution as an antisymmetric combination of the two anti-parallel spin states, $1/\sqrt{2}\,\left(|P^{\uparrow}, e^{\downarrow}\rangle - |P^{\downarrow}, e^{\uparrow}\rangle\right)$, with the ground state energy -3A and the three other states have the same positive energy +A. The total energy difference is $\Delta\mathrm{E}^{\mathrm{hyperfine}} = 4A$. The hyperfine energy split is the source for the 21 cm line emission by hydrogen atom clouds in space of $5.87\;10^{-6}$ eV. The hyperfine energy split is six orders of magnitude smaller than the difference between the hydrogen electronic ground state $E_{n=1}^{hydrogen}$ and its first excited states $E_{n=2}^{hydrogen}$, which is 10.2 eV. Dirac's spin exchange operator $\hat{P}^{Ex}$ are used also in spin lattice models to exchange spins of two adjacent lattice sites generating spin waves[7] with energies $\hbar\omega_k = 2A(1-\cos(kb))$, where for small k values, kb << 1, equals to $\hbar\omega_k = Ak^2b^2$ and an effective mass may be calculated.

The two aspects, i.e. the hyperfine energy split and spin waves are adapted below for the description of the hydrogen atom surrounded by a pion tetrahedrons lattice. We propose that the electron dynamics may be explained by rapid quark exchange reactions that occur between the electrons and the pion tetrahedrons we describe as quark and antiquark flavor exchange waves in analogy to spin waves. Accordingly, QCD affects the electron motion in atoms via the vacuum pion tetrahedron condensate.

We assumed in a previous paper that the electron tetrahedrons have two quark compositions that determine their spin state[2]. One electron tetrahedron has the quark composition $d\tilde{u}\,\tilde{d}d$ (spin up configuration) and the second electron tetrahedron quark composition is $d\tilde{u}\,\tilde{u}u$ (spin down configuration). The two electron tetrahedrons are surrounded by the vacuum pion tetrahedrons $\tilde{u}d\tilde{d}u$ forming together electrons clouds in thermal equilibrium. The exchanged quarks for the spin up electrons are the d and u quarks, while the exchanged quarks for the spin down electrons are the $\tilde{u}$ and $\tilde{d}$ quarks.

We adapt the spin lattice model for the QCD vacuum and assume that each lattice site contains a pion tetrahedron or an electron tetrahedron. The transition between the two occurs by exchanging a d quark with a u quark or a $\tilde{d}$ and a $\tilde{u}$ quarks as shown in figure 2a below. Similar quark exchange reactions can be illustrated for spin up and spin down positrons exchanging d and u quarks or $\tilde{u}$ and $\tilde{d}$ anti-quarks as shown in figure 2b.

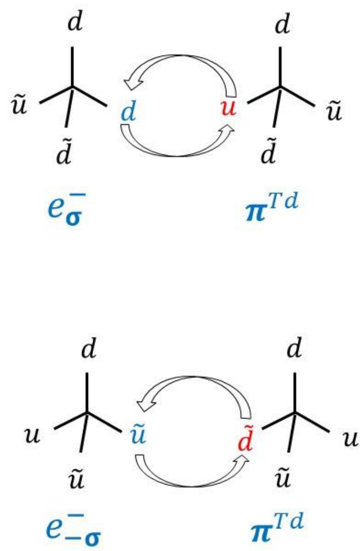

Figure 2a illustrates quark exchange reactions for the spin up and the spin down electrons with pion tetrahedrons. The exchanged quarks for the spin up electron are the d and u quarks, while the exchanged quarks for the spin down electron are the $\tilde{u}$ and the $\tilde{d}$ anti-quarks.

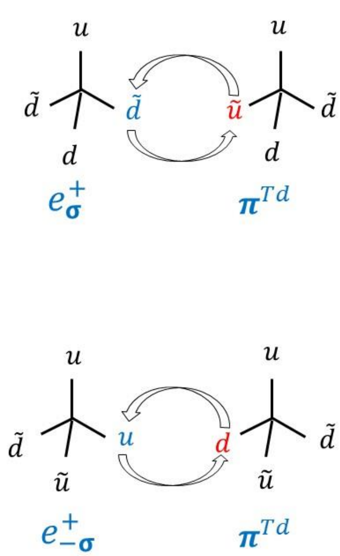

Figure 2b illustrates quark exchange reactions for the spin up and the spin down positrons with pion tetrahedrons.

The quark flavor exchange reactions may occur in two neighboring lattice sites and can also occur between two distant lattice sites, i and j, with a probability $P_{i,j}$.

For the hydrogen atom model, we propose a pion tetrahedron lattice with two co-centric spheres. In each lattice site there is a pion tetrahedron $|\, \pi_i^{Td} \,\rangle = |\tilde{u}d\tilde{d}u\,\rangle_i$ except for one site that contains an electron tetrahedron that we assume may have two possible configurations, a spin up electron configuration $|e_j^{\uparrow}\,\rangle = |\tilde{u}d\tilde{d}d\,\rangle_j$ or a spin down electron configuration $|e_j^{\downarrow}\,\rangle = |\tilde{u}d\tilde{u}u\,\rangle_j$. Four states characterized by the underlying quark flavor exchange waves in the two co-centric spheres may exist according to which quarks are exchanged, the quarks or the anti-quarks in each sphere domain.

The two quark flavor exchange reactions are -

$$\tilde{u}d\tilde{d}u\,(\pi^{Td})_i + \tilde{u}d\tilde{d}d\,(e^{\uparrow})_j \rightarrow \tilde{u}d\tilde{d}d\,(e^{\uparrow})_i + \tilde{u}d\tilde{d}u\,(\pi^{Td})_j \qquad (5)$$

$$\tilde{u}d\tilde{d}u\,(\pi^{Td})_i + \tilde{u}d\tilde{u}u\,(e^{\downarrow})_j \rightarrow \tilde{u}d\tilde{u}u\,(e^{\downarrow})_i + \tilde{u}d\tilde{u}u\,(\pi^{Td})_j \qquad (6)$$

Where in the first quark flavor exchange reaction the u and d quarks are exchanged (equation 5) and in the second the $\tilde{u}$ and $\tilde{d}$ were exchanged (equation 6). The four states possible are:

(u, d) flavor exchange in the inner sphere and (u, d) flavor exchange in the outer sphere,

(u, d) flavor exchange in the inner sphere and ($\tilde{u}$, $\tilde{d}$) flavor exchange in the outer sphere,

($\tilde{u}$, $\tilde{d}$) flavor exchange in the inner sphere and (u, d) flavor exchange in the outer sphere and

($\tilde{u}$, $\tilde{d}$) flavor exchange in the inner sphere and ($\tilde{u}$, $\tilde{d}$) flavor exchange in the outer sphere.

In each of the quark flavor exchange reaction, the electron spin is conserved as equation 5 and 6 show. Interaction with the proton spin may flip the electron spin according to equation 7 below that we assume may occur on the surface between the two spheres for the electron. For the proton, the spin flip requires the exchange of a $\tilde{u}u$ meson with a $\tilde{d}d$ meson or vice versa.

$$uud\tilde{u}u\,(P^{\downarrow})_i + \tilde{u}d\tilde{d}d\,(e^{\uparrow})_j \rightarrow uuddd\,(P^{\uparrow})_i + \tilde{u}d\tilde{u}u\,(e^{\uparrow})_j \qquad (7)$$

We note that the valence quarks and anti-quarks numbers are conserved by equation 7 and also that the proton's mass is higher than the mass of its three valence quarks, uud, where the extra mass is typically explained by additional gluons and possibly virtual mesons. The nucleons structure and spin are main research topics of the EIC[1]. We assume here that the proton contains additional $\tilde{u}u$ or $\tilde{d}d$ mesons that determine the proton spin states.

After the two spins are flipped, the quark flavor exchange wave can continue propagating according to equation 5 or 6 above in each domain. We assume that if the proton and electron spins are anti-parallel, the electron crosses the sphere surface smoothly with no need for a spin flip that cost in additional energy. The anti-parallel spin states are favorable and have lower energy. The four possible states of the two domains are shown below in figure 3. The first domain is the inner sphere with a radius a_s and the second domain is the outer sphere with Bohr radius a_0. If the proton and electron spins are antiparallel there is a single domain with the Bohr radius a_0 for the quark flavor exchange waves.

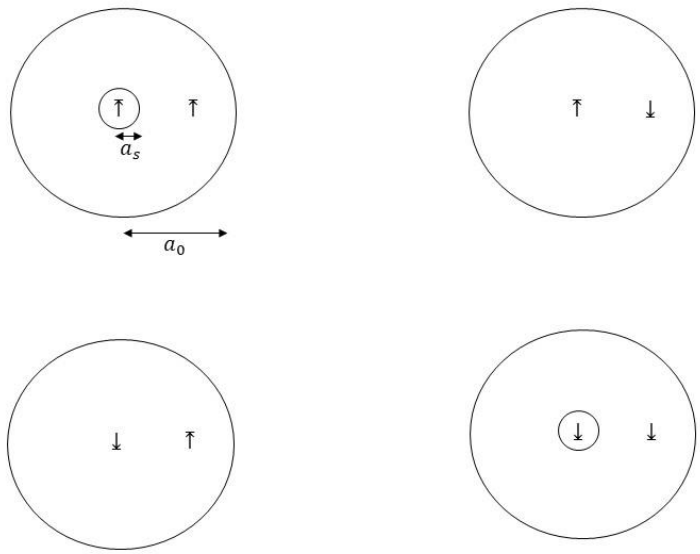

Figure 3 illustrates the hydrogen atom model with two co-centric pion tetrahedron spheres where the quark flavor exchange waves occur in separated domains or a single domain.

With the proposed model, the hyperfine energy split may be explained by the quark flavor exchange wave domains. With anti-parallel spins, there is only one domain with a larger volume for the quark or antiquark flavor exchange waves. If the two spins are parallel, two separated quark flavor exchange wave domains are created, and the configuration has higher energy.

We can estimate the radius of the internal domain sphere, a_s , using the measured hydrogen atom hyperfine energy split of $5.87\ 10^{-6}$ eV and then calculate the quark flavor exchange wave energy density ρ_E for the hydrogen atom electron and pion tetrahedron cloud lattice model -

$$\Delta E^{\text{hyperfine}} = \frac{4}{3}\,\pi\, a_0{}^3 \rho_E - \left(\frac{4}{3}\,\pi\, a_0{}^3 - \frac{4}{3}\,\pi\, a_s{}^3\right)\rho_E = \frac{4}{3}\,\pi\, a_s{}^3\, \rho_E \qquad (8)$$

$$E_2^{hydrogen} - E_1^{hydrogen} = \frac{4}{3}\,\pi\,(a_{n=2})^3\,\rho_E - \frac{4}{3}\,\pi\,(a_{n=1})^3 \rho_E \qquad (9)$$

The ratio of the hyperfine energy and the difference between the hydrogen ground state (n=1) and the first excited states (n=2) is independent of the energy density ρ_E and allows calculating the internal sphere radius $a_s -$

$$\frac{\Delta E^{hyperfine}}{E_2^{hydrogen} - E_1^{hydrogen}} = \frac{5.87\ 10^{-6}}{10.2} = \frac{{a_s}^3}{{a_{n=2}}^3 - {a_{n=1}}^3}\ ; \quad a_{n=2} = 4\ a_{n=2},\ a_{n=1} = 0.529^{-10} \quad (10)$$

Accordingly, the radius of the inner domain, a_s, is $6.346^{-13}m$ and the ratio of a_s and Bohr radius is -

$$\frac{a_s}{a_0} = \frac{6.346 * 10^{-13}}{0.529 * 10^{-10}} = 0.01199 \quad (11)$$

Next, we can calculate the quark flavor exchange wave energy density ρ_E for the ground state of the hydrogen atom electron and pion tetrahedron cloud lattice using equation 8 -

$$\rho_E = \frac{\Delta \mathrm{E}^{\mathrm{hyperfine}}}{\frac{4}{3}\pi\, {\mathrm{a_s}}^3} = \frac{5.87 * 10^{-6}\ 1.60218 * 10^{-19}}{\frac{4}{3}\pi (6.346 * 10^{-13})^3} \frac{\mathrm{jouls}}{m^3} = 8.785 * 10^{11}\ \frac{\mathrm{jouls}}{m^3} \quad (12)$$

The quark flavor exchange wave energy density ρ_E in eV per atom is -

$$\rho_E = \frac{8.785 * 10^{11} * \frac{4}{3}\pi\, {\mathrm{a_0}}^3}{1.60218 * 10^{-19}} = 3.4\ \frac{\mathrm{eV}}{atom} \quad (13)$$

The quark flavor exchange wave energy density per atom, 3.4 eV, contributes about 25% of the hydrogen atom ground state energy of -13.6 eV. If we add the electron rest mass and the internal rotations and vibrations energy of the four pion tetrahedrons quarks in each lattice site as an effective rest mass energy, we may recover another 25% and over all get 50% of the ground state energy as a sum of kinetic and rest mass energies. The remaining 50% of the total ground state energy may be due to the electrostatic Coulomb potential of the proton.

In terms of the relativistic energy-momentum equation –

$$E^2 = (pc)^2 + (m_o c^2)^2 \quad (14)$$

We can relate the kinetic energy term pc to the quark flavor exchange wave describing the hoping of an electron from site to site on the lattice and the second rest mass term $m_o c^2$ with the electron rest mass and the internal rotation and vibration energies in each site of the lattice. It should be noted that the proposed vacuum pion tetrahedron lattice cell length may be observed as contracted to a moving electron with a velocity v according to the Lorentz transformation.

$$\Delta x' = \frac{\Delta x}{\Upsilon} \quad ; \quad \Upsilon = \frac{1}{\sqrt{1-(\frac{v}{c})^2}} \tag{15}$$

The motion of an electron in the vacuum pion tetrahedron lattice may be constrained to conserve the special relativity symmetry and we note that since the proposed pion tetrahedron lattice includes in each site a pion tetrahedron boson, $\tilde{u}d\tilde{d}u$, excitations of the lattice may be constrained to have a left or right rotation of the electric field based on the internal motion of the quark charges $\tilde{u}d_{(-\mathrm{q})}$ *and* $\tilde{d}u_{(+q)}$ in each lattice site. The motion of massless excitation that may model photons may be further constrained to conserve the special relativity symmetry on the lattice.

3. Electron and Pion Tetrahedron Tunneling Model and the Zitterbewegung

Using a double well potential Hamiltonian model[8],

$$H = \frac{p^2}{2m} + m\,\lambda\;(x^2 - a^2)^2 \tag{16}$$

The tunneling probability, T, from the first to the second potential well ground state through the barrier, $V_0 = m\,\lambda\,a^4$, is -

$$\mathrm{T} = e^{-\frac{8\,ma^3\sqrt{2\lambda}}{3\hbar}} = e^{-\frac{32V_0}{3\hbar\omega}} \tag{17}$$

ω is the ground state frequency of each well separately given by -

$$\omega = \frac{2\pi}{\tau} = \sqrt{8\,\lambda\,a^2} \tag{18}$$

Adapting the quartic Hamiltonian model of equation 16 to the quark flavor-exchange symmetric reaction between electron and a pion tetrahedron in lattice sites i and j (described by equation 5 or 6 above), the velocity of the electron tetrahedron from site i to j due to the flavor exchange wave is calculated by the distance between the sites, 2a, divided by the time period, τ, and multiplied by the tunneling probability T.

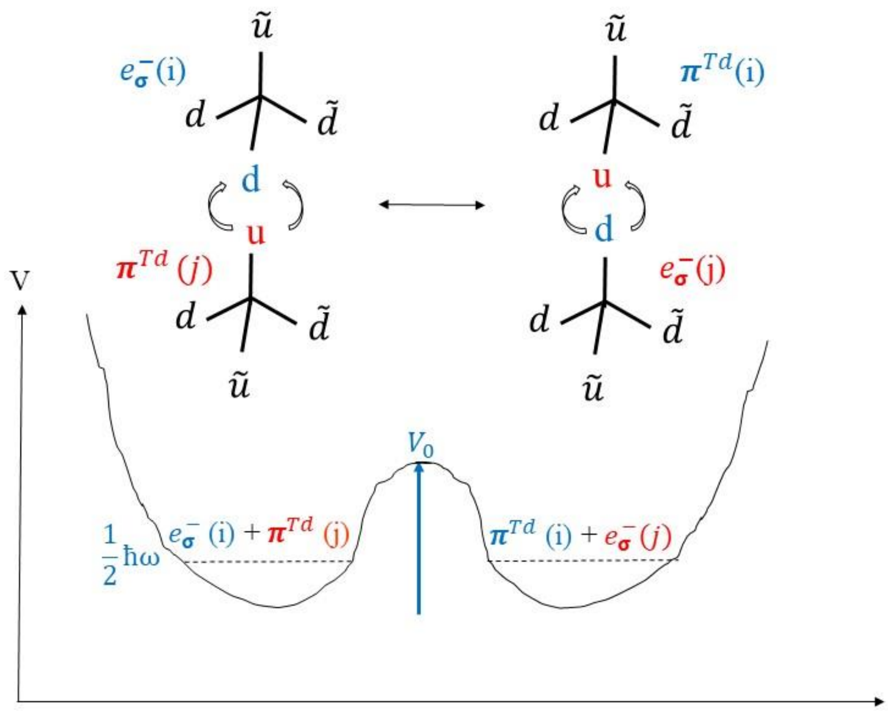

Figure 4 illustrates the double well model for the electron and pion tetrahedron quark flavor exchange reaction in lattice sites i and j.

We further assume that the potential barrier V_0 vary in space and determines the propagation velocity -

$$v_e = \frac{2a}{\tau}\mathrm{T} = \frac{a\omega}{\pi} e^{-\frac{32V_0}{3\hbar\omega}} \tag{19}$$

Rearranging equation 19 and assuming that v_e must be smaller than the speed of light c, we get the electron hoping velocity of equation 21

$$\frac{a\omega}{\pi} = c\, e^{\frac{32}{3}} \tag{20}$$

$$\frac{v_e}{c} = e^{-\frac{32}{3}\left(\frac{V_0}{\hbar\omega} - 1\right)} \tag{21}$$

The hoping frequency ω (equation 20) depends on the pion tetrahedron lattice cell length a -

$$\omega = \frac{\pi c e^{\left(\frac{32}{3}\right)}}{a} = \frac{4.0433*10^{13}}{a} \frac{1}{sec} \tag{22}$$

Using Dirac's electron zitterbewegung frequency[9,10], we can calculate the pion tetrahedron lattice cell length a in free space -

$$\frac{2m_e c^2}{\hbar} = \omega = \frac{4.0433*10^{13}}{a} \frac{1}{sec} \tag{23}$$

$$a = \frac{\hbar\ 4.0433*10^{13}}{2\, m_e c^2} = 2.6004 * 10^{-8} \text{ meter} \tag{24}$$

The ratio of the zitterbewegung frequency ω in the two extreme points of earth's elliptic trajectory around the sun will be proportional to the inverse ratio of the pion tetrahedron cell lengths due to the pion tetrahedron density atmospheric like drop[3].

$$\frac{\omega_{perhelion}}{\omega_{aphelion}} = \frac{m_e^{perhelion}}{m_e^{aphelion}} = \frac{a_{aphelion}}{a_{perihelion}} \tag{24}$$

A small variation of the zitterbewegung frequency may be measured due to the significant difference in elevation from the sun between the perihelion and the aphelion of about 5 million km. The zitterbewegung frequency is not directly measurable[9], however, the electron mass which may be measured with high accuracy using Penning-trap[11] may be sensitive enough to measure small variations expected in equation 24. Hence a deviation from 1 in the mass ratio will confirm that the vacuum is filled with pion tetrahedrons that interact with electrons as assumed here.

We assume that the propagation speed of the electron in the pion tetrahedron lattice is determined by the adaptive potential barrier height V_0. We assume that $V_0 > \hbar\boldsymbol{\omega}$ such that the electron speed does not exceed the speed of light c. The velocity of the electron due to the quark flavor exchange wave describes the electron dynamics as a quantum tunneling phenomenon. The electron is not moving in classical trajectories, quarks are exchanged between the pion tetrahedron sites by tunneling through a potential barrier and effectively create the motion of the electron as a delocalized cloud. The propagation speed of the flavor exchange wave is determined by the adaptive potential barrier height where for example acceleration by an external electric field will reduce the barrier height in the boost direction. The potential barrier height adaptation may occur with the speed of light and precedes the motion of the slower quark flavor exchange wave. For example, with $\frac{V_0}{\hbar\omega} = 2.29$ the electron velocity $\frac{v_e}{c}$ is 10^{-6}, with $\frac{V_0}{\hbar\omega} = 1.43$ the electron velocity $\frac{v_e}{c}$ is 0.1 and with $\frac{V_0}{\hbar\omega} = 1.0001$ the electron velocity $\frac{v_e}{c}$ is 0.999. The double well potential with $\frac{V_0}{\hbar\omega} = 1.0$ and with $\frac{V_0}{\hbar\omega} = 2.0$ are shown below. With larger potential barrier V_0 value the wells are steeper, the tunneling probability through the barriers is smaller, the quark flavor exchange wave propagation is slower and the electron ground state wavefunction is more localized inside the well.

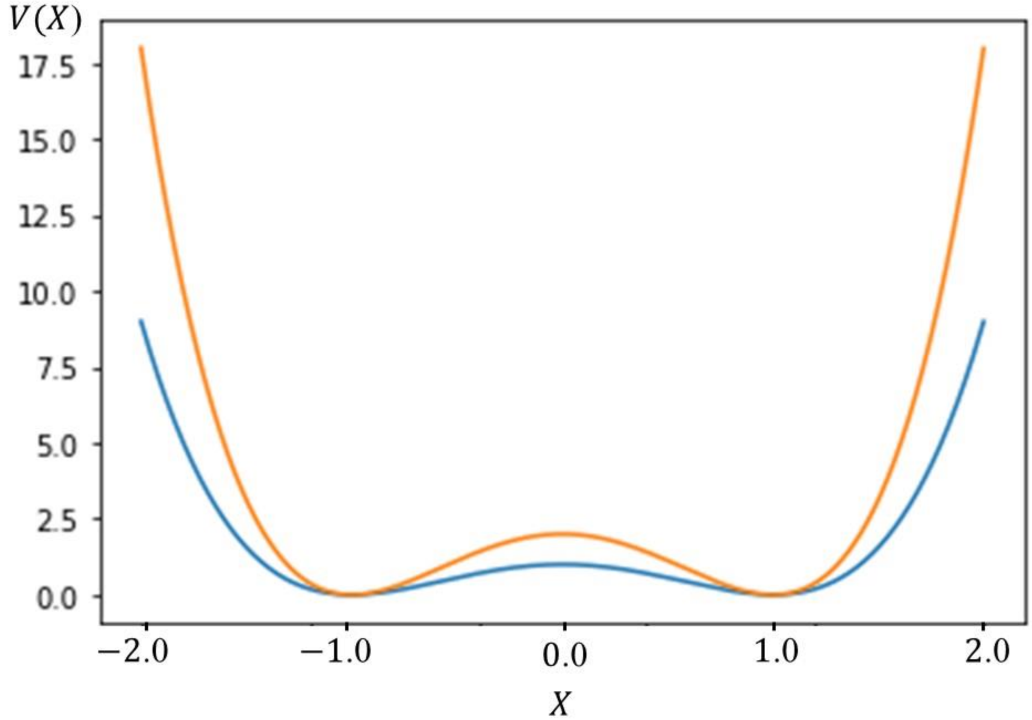

Figure 5 illustrates the double well potential with two values of the barrier height V_0 (in the figure m=ω=ħ=1 and $V_0 = \lambda$).

Assuming that the mass of the pion tetrahedron is about 6 orders of magnitude smaller than the electron, the pion tetrahedron density in free space can be estimated –

$$\rho_{pion\ tetrahedron} = \frac{10^{-6}\, m_e}{(2.6004*10^{-8})^3} = 5.18 * 10^{-14} \frac{k_g}{m^3} \qquad (25)$$

The estimated density of the universe is $9.9 * 10^{-27} \frac{k_g}{m^3}$, which is equivalent to 5.9 protons in meter cube. Only 4.7% of the total density is due to visible matter and is about $4.33 * 10^{51} k_g$. The estimated volume of the visible universe is $9.322 * 10^{78} m^3$. If we assume that the pion tetrahedron density in the universe is uniform its mass will be about $4.8 * 10^{65}\ k_g$, 14 orders of magnitude larger than the universe visible mass. However, we assume that the pion tetrahedron density is much denser close to matter and extremely diluted in the cosmic web voids. The pion tetrahedron mass is probably much smaller than $4.8 * 10^{65}\ k_g$, however, due to the huge volume of the universe the pion tetrahedron mass is probably not negligible.

In the next section the magnetoresistance of electrons and pion tetrahedrons in a gas model are described.

4. The Electron and Pion Tetrahedron Gas Resistance

In contrast to most electronic devices and circuits where the electric charge is the main player, magnetic materials use the electron spin to store data and the spin-orbit coupling to switch between the spin states. For example, hard drive discs use magnetic domains formed by typically 10 nanometer size ferromagnetic Co-Pt-Cr grains to maintain stable spin states logical level 0s and 1s. Magnetic read heads include typically two ferromagnetic layers, one with a fixed magnetization and a second with a varying magnetization sensitive to the magnetic domains maintained by hard drive discs. The current that flows through the magnetic read head depends on the spin alignment of two ferromagnetic layers that produce the giant magnetic response (GMR) discovered by Fert and Grünberg[11].

Sinova et all described the spin hall effect and Mott's double scattering spin polarization proposed in 1929 inspired by Dirac's electron theory and magnetic tunnel junctions (MTJ)[12,13,14]. First scattering of an electron beam on heavy atom target creates a spin polarized beam that is scattered again by a second heavy atom target creating two currents that can be measured with different chirality.

We propose the following electron and pion tetrahedron gas resistance model that may be used to explains MTJs and Mott's double scattering. We assume that scattering of two electron tetrahedrons with the same spin that share their pion tetrahedron clouds are elastic collisions with no quark exchange and heat dissipation –

$$\tilde{u}d\tilde{d}d + \tilde{u}d\tilde{d}d \rightarrow \tilde{u}d\tilde{d}d + \tilde{u}d\tilde{d}d \qquad (26a)$$

$$\tilde{u}d\tilde{u}u + \tilde{u}d\tilde{u}u \rightarrow \tilde{u}d\tilde{u}u + \tilde{u}d\tilde{u}u \qquad (26b)$$

However, the scattering of two opposite spin electron tetrahedrons occurs via a pion tetrahedron transition state complex ($\tilde{u}d\tilde{d}d\tilde{u}u\tilde{u}d^{\dagger}, equation\ 27a$) and is an inelastic reaction between the two electron tetrahedrons where quarks are exchanged, heat is dissipated to the pion tetrahedron condensate causing a friction for the electric current flow and switching the electrons' spin as shown in equation 27b (the $\tilde{d}d$ and $\tilde{u}u$ are exchanged) -

$$\tilde{u}d\tilde{d}d + \tilde{u}d\tilde{u}u \rightarrow \tilde{u}d\tilde{d}d\tilde{u}u\tilde{u}d^{\dagger}\ (transition\ state\ complex) \quad (27a)$$

$$\tilde{u}d\tilde{d}d\tilde{u}u\tilde{u}d^{\dagger} \rightarrow \tilde{u}d\tilde{u}u + \tilde{u}d\tilde{d}d \qquad (27b)$$

Note that both $\tilde{d}$ and d quarks are exchanged with $\tilde{u}$ and u quarks of the second electron. The quark exchange reaction via the pion tetrahedron transition state complex cause heat dissipation and electrical resistance that is explained typically by scattering of electrons on solid impurities and the nuclei motion (solid-state phonons). The electron and pion tetrahedron gas model resistance may be an additional spin dependent mechanism. The proposed quark flavor exchange wave model includes a possible spin-spin interaction between electrons and protons (see equation 7 above) that may be equivalent to electrons interactions with the solid-state phonons.

The MTJ read process may be explained in terms of the electron and pion tetrahedron gas model as follows: the initial non-polarized electron current has equal number of spin up and spin down electron tetrahedrons, $\tilde{u}d\tilde{d}d$ and $\tilde{u}d\tilde{u}u$. The non-polarized current flows through a first ferromagnetic layer we assume is polarized and let's assume occupied mostly by $\tilde{u}d\tilde{d}d$ electron tetrahedrons. The scattering of two electron tetrahedrons of the same spin is elastic while the scattering of opposite spins creates the transition state complex of the two electrons with a pion tetrahedron "QCD glue" as illustrated in figure 4. The collision process dissipates heat and cause a selective delay for one electron tetrahedron configuration. The outcome is that the electron current has now higher percentage of $\tilde{u}d\tilde{d}d$ electron tetrahedrons that were elastically scatters with no delay, e.g. the electric beam is now polarized.

The polarized current enters the second ferromagnetic layer and the outcome will depend on the second ferromagnetic layer spin state. If it is dominated by $\tilde{u}d\tilde{d}d$ electron tetrahedrons, a favorable parallel ferromagnetic layer configuration (P), the quark exchange reactions will be elastic and a strong current will be measured. However, if the second layer magnetization is in anti-parallel configuration (AP), many more electron tetrahedron collisions with spin flips will occur, heat will be dissipated, and the measured current will be smaller.

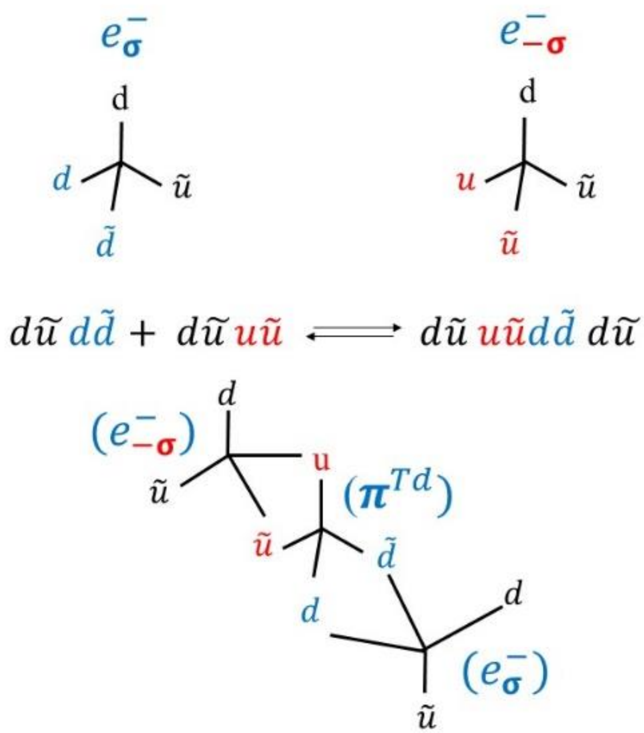

Figure 6 illustrates the pion tetrahedron transition state complex "QCD glue" formed in a collision between two electrons with opposite spins.

The electron and pion tetrahedron gas resistance model provides a mechanism that may explain why the magnetoresistance of two parallel ferromagnetic layers (P) is lower than the magnetoresistance of the antiparallel (AP) configuration. The pion tetrahedron condensate in the ferromagnetic layer is polarized favorably and allows coherent elastic scattering of electron tetrahedrons with the same spin with no heat dissipation.

The pion tetrahedron condensate lattice model in a ferromagnet material may be an expanded model of the hydrogen atom, where multiple electrons share and move on the same pion tetrahedron condensate lattice sites. Electrons with the same spin are scattered elastically if they collide on adjacent lattice sites, while electrons with opposite spins may create a transition state complex, may exchange their spin states and are inelastic collisions.

Magnetic Random Access Memory (MRAM) is an emerging non-volatile semiconductor memory technology[15] expected to replace traditional computer memory based on complementary metal-oxide semiconductors [16]. MRAM surpasses other types of memory devices in terms of nonvolatility, low energy dissipation and fast switching speed. Future developments in MRAM are based on spin-transfer torque. Spin transfer torque corresponds to the interaction of a spin polarized electronic current with the local magnetization. Magnetic moment is transferred from the conduction electrons to the magnetization resulting in a change of the magnetization orientation[17,18].

MRAM cells include a magnetic tunnel junction (MTJ) that provides the write, read and bit storing functionality, essentially using two magnetic layers, reference layer (RL) and the free layer (FL), separated by a magnesium oxide (MgO) tunnel barrier. The two-bit storage states are the parallel (P) and antiparallel (AP) magnetization orientations[19,20]. Topological insulators provide spin polarized current surface states due to the topology of the bulk band structure[19]. The interplay of electron transport and spin dynamics provide a method to electrical control the magnetization state in Weyl semimetals[21].

According to the electron and pion tetrahedron gas resistance model described here, we propose a mechanism for the spin torque, where the spin switching in the magnetic free layer (FL) occurs due to electron tetrahedron scattering quark exchanges via the pion tetrahedron transition state complex as shown in figure 4 above and figure 5 below.

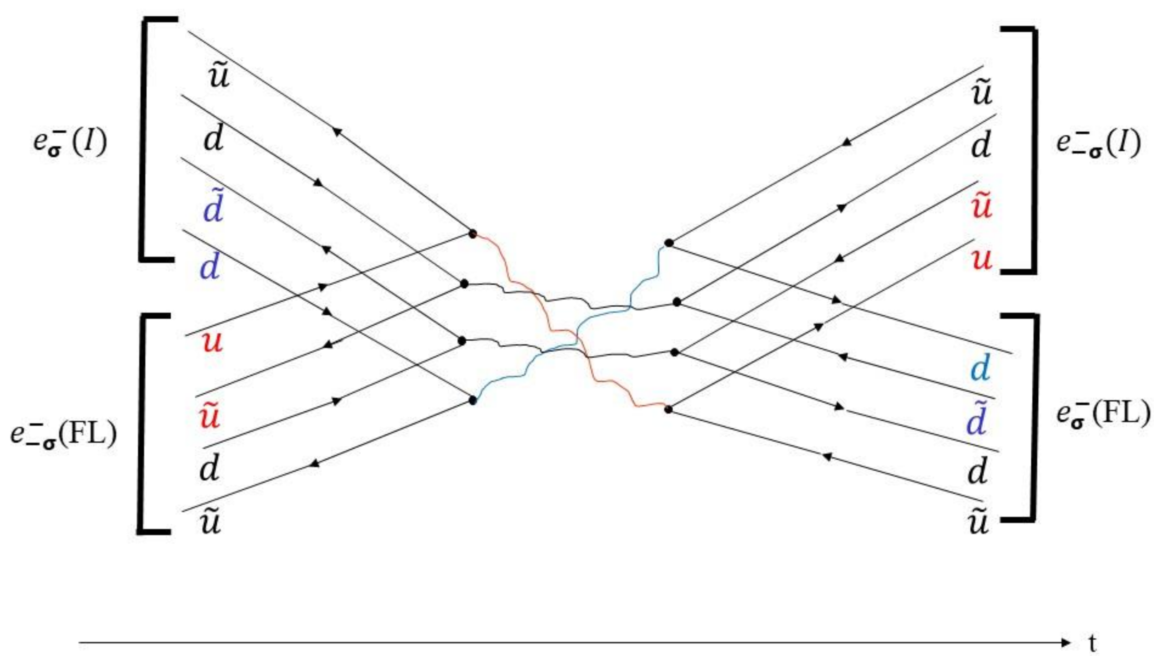

Figure 7 illustrates spin transfer torque by electron-electron scattering, where the upper electron represents a beam of spin polarized electrons $e^-_{\boldsymbol{\sigma}}(I)$ that flows through a free magnetic layer (FL) and are scattered by the FL electrons $e^-_{-\boldsymbol{\sigma}}$(FL) via a pion tetrahedron transition state complex that decays and flip the electrons' spins.

The upper electron represents a beam of spin polarized electrons $e^-_{\boldsymbol{\sigma}}(I)$ that flows through a free magnetic layer (FL) and are scattered by the FL electrons $e^-_{-\boldsymbol{\sigma}}$(FL) that we assume have an opposite magnetization state (AP). The two electron tetrahedrons exchange two quarks via the pion tetrahedron transition state complex and both plip their spin states. Assuming the initial spin state of the free layer was anti-parallel configuration (AP), $e^-_{-\boldsymbol{\sigma}}$(FL), after the scattering its spin is flipped up $e^-_{\boldsymbol{\sigma}}$(FL) while the spin of the incoming polarized electrons $e^-_{\boldsymbol{\sigma}}(I)$ that created the spin transfer torque is switched to the down state $e^-_{-\boldsymbol{\sigma}}(I)$. The FL magnetization state is switched from $e^-_{-\boldsymbol{\sigma}}$(FL) to $e^-_{\boldsymbol{\sigma}}$(FL). Both $\tilde{d}$ and d quarks need to be exchanged with the $\tilde{u}$ and u quarks for the spin exchanges.

A competing resilience against switching the magnetization state of the whole magnetic domain will occur where adjacent ferromagnetic electrons with opposite spins via the surrounding pion condensate will try to flip back the torqued spin.

$$\tilde{u}d\tilde{u}u(e^-_{-\boldsymbol{\sigma}}) + \tilde{u}d\tilde{d}d(e^-_{\boldsymbol{\sigma}}) \rightarrow \tilde{u}d\tilde{d}d\tilde{u}u\tilde{u}d^{\dagger} \quad (28a)$$

$$\tilde{u}d\tilde{d}d\tilde{u}u\tilde{u}d^{\dagger} \rightarrow \tilde{u}d\tilde{u}u(e^-_{\boldsymbol{\sigma}}) + \tilde{u}d\tilde{d}d(e^-_{-\boldsymbol{\sigma}}) \quad (28b)$$

However, if the torque of the incoming electric current is strong enough, an inversion of the magnetic domain will occur and the opposite spin electrons will be pushed out from the inverted magnetic domain. Kateel et al[23] showed that shaping the SOT channel to create a bend below the MTJ device causes an efficient and deterministic inversion of the spin of the FL magnetic domain.

Note that the double quark flavor exchange reaction creates a pion tetrahedron transition state complex “QCD glue” that dissipate heat to the pion tetrahedron condensate and may also create small vibrations of the pion tetrahedron lattice sites that are probably extremely small and negligible in low energies. However, in an extremely high-energy events, like black hole or neutron star binary mergers, the vibrations of the pion tetrahedron lattice may be the carry gravitation waves.

The pion tetrahedron condensate quark flavor exchange wave energy density in the vacuum with no matter particles is small, however, on cosmological scale it may still be significant. In the next section we propose a virtual box with a cosmological scale and propose that the vacuum pion tetrahedrons condensate non-matter should be included in Einstein's energy-momentum tensor $T^{\mu\nu}$.

5. The Pion Tetrahedrons and Friedmann Equation

Let's imagine a virtual box in intergalactic space that has a very low density of free electron and pion tetrahedron gas and equal density of protons and neutrons gas for neutrality. Next, let's increase the box such that it includes for example the Milky way galaxy with all its visible mass $M_{Milkyway}$ and in it its center the supermassive Sagittarius A black hole with its mass $M_{Sgr\ A}$.

The Einstein-Hilbert action with a cosmological constant ʌ is[24,25,26] -

$$I = \int d^4x \sqrt{-g}\ \left(\frac{R - 2\Lambda}{16\pi G} + L_M\right) \qquad (29)$$

Where L_M is the matter Lagrangian. Einstein's field equation is obtained by the requirement that the action will be an extremum with respect to variation of the metric tensor $\delta g^{\mu\nu}$-

$$R^{\mu\nu} - \frac{1}{2} R g^{\mu\nu} + \Lambda g^{\mu\nu} = 8\pi G\, T^{\mu\nu} \qquad (30)$$

The energy-momentum tensor $T^{\mu\nu}$ is given by -

$$T^{\mu\nu} = (\rho + \mathrm{p})\, u_\mu u_\nu + \mathrm{p}\, g^{\mu\nu} \qquad (31)$$

Where u_μ is the tangent velocity 4-vector, ρ is the matter-energy density and p is the pressure.

$$\rho = \frac{M_{matter}}{V} + \frac{M_{black\ holes}}{V} + \rho_{EM} + \frac{M_{\pi Td}}{V} \qquad (32)$$

The matter-energy density includes the matter and black hole mass densities and the electromagnetic energy density of the Milky-way galaxy. The vacuum pion tetrahedrons are not regular matter particles since they are composed of equal parts of matter and antimatter quarks and anti-quarks, however, since pion tetrahedrons are expected to be massive and to exchange quarks with matter particles[2] they contribute energy to Einstein's equation energy-momentum tensor $T^{\mu\nu}$. The pion tetrahedron density $\frac{M_{\pi Td}}{V} = < \Psi_u^\dagger \Psi_d^\dagger \Psi_{\tilde{u}} \Psi_{\tilde{d}} >_\pi$ represents the pion tetrahedron tetraquarks, $\tilde{u}d\tilde{d}u$, condensate. $\Psi_u^\dagger$ is the up quark creation operator, $\Psi_d^\dagger$ is the down quark creation operator, $\Psi_{\tilde{u}}$ and $\Psi_{\tilde{d}}$ are the anti-up and anti-down quark creation operators.

Using the state equation, $p = w\rho$, with $w = -1$, for the expanding universe and Friedmann equation with k=1[27], the following expression for the matter-energy is obtained -

$$H(t)^2 = \frac{\dot{a}^2}{a^2} = \frac{8\pi G}{3}\rho + \frac{\Lambda}{3} + \frac{1}{a^2} \tag{33}$$

The matter-energy density ρ is given in terms of the other variables as -

$$\rho = \frac{3\left(H(t)^2 - \frac{\Lambda}{3} + \frac{1}{a^2}\right)}{8\pi G} \tag{34}$$

The pion tetrahedron condensate density $\frac{M_{\pi Td}}{V}$ is given by equations 7 and 9 as -

$$\frac{M_{\pi Td}}{V} = \frac{3\left(H(t)^2 - \frac{\Lambda}{3} + \frac{1}{a^2}\right)}{8\pi G} - \left[\frac{M_{matter}}{V} + \frac{M_{black\ holes}}{V} + \rho_{EM}\right] \tag{35}$$

Equation 21 may give an estimate for the milky way galaxy pion tetrahedron condensate density $\frac{M_{\pi Td}}{V}$ assuming all other variables are known. A more direct method for calculating the pion tetrahedron mass is based on measurements of the time periodic variability of the $\boldsymbol{\beta}$ decay half-life times of radioactive nuclei's in the perihelion and aphelion of earth's trajectory around the sun[3]. On cosmological scale and due to the huge intergalactic voids, the pion tetrahedron condensate energy density contribution to Einstein's energy-momentum tensor and Friedmann equation may be significant. We suggest considering the possibility that the non-empty ground state pion tetrahedron condensate may replace the need to add dark matter and energy.

We note that the pion tetrahedron density is expected to be non-uniform and have an atmospheric like drop far from galaxy centers[2] and that it may grow with time since the pion tetrahedrons are bosons that may be duplicated exponentially by Corley and Jacobson's black hole laser effect[28]. The pion tetrahedron density growth and the separation of matter and antimatter particles next to black holes event horizons may increase the energy density and pressure expanding the universe without adding dark matter and energy, where the additional antimatter may be trapped under the event horizon of the supermassive black holes[29].

The pion tetrahedron condensate may be a non-empty non-matter ground state QCD ether that can mediate the QED and QCD forces and probably gravity too since the pion tetrahedrons are massive and their density is expected to vary in space. QCD has a significant low-energy footprint where the vacuum quark flavor exchange wave that affects the electron dynamics may be a significant example.

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