A Standard Model Approach to Dark Energy and Inflation

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Abstract - By assuming the cosmological principle includes the Pauli Exclusion Principle (PEP) and that existence occurred post big bang within Planck time and length scales, a model for universal expansion is argued. All Fermionic matter is forced by the PEP to make a quantum transition to minimally orthogonal states. This results in an initial inflation effect due to nearest neighbor movements which is exacerbated by anti-matter annihilations and uncertainty energy caused by the initial location constraint. A coupling of low energy fermions (including neutrinos) having wavelengths comparable to or greater than the Hubble length (and so frozen into and coupled with the Hubble length) is postulated as a contributor to universal expansion due to PEP. The model provides a mechanistic explanation for universal expansion using only physics from the standard model specifically utilizing the PEP as a repulsion force between indistinguishable fermions. The present theory offers the benefit of not requiring any particles or fields outside of the standard model and does not offer a mathematical representation of the functional dependence but rather a mechanistic model for universal expansion.

Introduction

The inflationary model has enjoyed great success in describing modern cosmological observations of homogeneity and isotropy along with a flat space-time (Sato and Yokoyama 2015, Uzan 2015). Difficulties with any mechanistic origin of the ad-hoc inflaton (Turok 2002) have resulted in numerous alternative descriptions of the initial rapid expansion of the universe. These models include unique general relativity cases such as bouncing (Battefeld and Peter 2015, Lilley and Peter 2015, Qui and Wang 2015) and Klinkhamer (2012), varying speed of light requirements (Bessada et al. 2010, Kragh 2006, Moffat 2016), string theory (Alexander 2015, Lidsey et al, 2000) along with multiple other alternatives (Creminelli et al. 2010, Das, 2015, Hollands and Wald 2002, Poplawski 2010). Still, other models provide functional representations of both inflation and dark energy (Capozziello et al. 2006, Hossain et al. 2015, Nojiri and Odintsov 2008). This work diverts from the traditional functional representations of inflation or dark energy and proposes an almost strictly mechanistic model as a further alternative for later refinement and comparison to measurement.

The reversal in time based on general relativity requires that all matter began in a singularity without a sufficient time dependent cosmological constant to reverse the process early on (Ellis 1984). By assuming the singularity, this work is able to propose a mechanism to initiate universal expansion. It is reasonable to assume continuity of all the known physical laws even at the Planck scales (Ragazzoni et al 2003, Boyanovski et al 2006). In this work, particular attention is placed on requiring the Pauli Exclusion Principle (PEP) to also be in full effect at this level from which the proposed mechanism is derived.

The minimum state for baryonic matter which can be associated with adhering to the PEP requirement is postulated to scale with that of a neutron star (NS). This means that to a first approximation, all like Fermionic matter (i.e., quarks) which had been present in the big bang (BB) singularity are forced at a minimum to push their nearest neighbor Fermions away on the order of the maximum packing density for nucleonic matter. The principle being that by combining the fundamental assumption of existence at the Planck scale in the singularity, it can then be argued that PEP also applies at the Planck scale. Given that all leptons, quarks and baryons of the standard model are fermions, the anisotropy of their respective wavefunctions forces the PEP to uniformly distribute them into their minimally orthogonal and lowest energy states upon existence. This because overlap of identical antisymmetric wavefunctions would result in cancellation of some of the particle and so violate conservation of lepton and baryon numbers resulting in an effective separation force (Kaplan 2016).

One of the most fundamental observations arising from PEP in measurements is the repulsive force it provides when placing materials under pressure. It is the PEP which keeps crystalline materials at fixed interatomic distances despite the Coulombic attraction between the charged particles. When two objects are pushed together, it is the PEP which prevents the exterior surface valence electrons of the two objects from overlapping and so serves as the equal and opposite force to their being pushed together. The PEP only prohibits wavelength overlap but technically, wavefunctions do not ever go to zero except at infinity and nodes and so after PEP forces a minimally orthogonal Fermion configuration, some negligible (short range) residual effective force will be present to try to maximize orthogonality.

Analysis and Results

The standard FLRW metric given by Carroll et al (1992) is $H^2 = \frac{8\pi G}{3}\rho_M + \frac{\Lambda}{3} - \frac{k}{a^2}$ assuming k=0 describes the current model for universal expansion (where the standard symbol definitions apply i.e, $H^2 = (\dot{a}/a)^2$). When the Hubble length *a* approaches zero, the proper time from general relativity $d\tau^2 = dt^2 - dx^2 d\Omega^2$ becomes ill defined where both the spatial component *dx* and the temporal component *dt* approach zero as the FLRW model matter density ρ_M goes to infinity at τ=0=*a*.

With no restrictions on mass and energy prior to the onset of time, all conservation laws would take force on whatever mass and energy came out of that singular genesis point when there were no assumed energy restrictions[1].

Expansion Initiation

The initial singularity scaling $a \approx 0$ is taken to be on the order of the Planck length l_p = 1.6e-35 m = $\hbar\, m_p^{-1} c^{-2}$ which is calculated using the Planck mass m_p=2.177e-8 kg = $(\hbar\, c/G)^{1/2}$ where c and G have their customary definitions of the speed of light and the gravitational constant respectively. These assumptions are also taken to occur in the initial time interval of the Planck time t_p = 5.4e-44 s = l_p/c which then provides a means to predict the effects from the PEP to all fermionic matter at its genesis.

The scale assumed here for quark density is taken to be similar to that associated with a NS or barionic nuclei. The minimally orthogonal baryon density of 0.16 fm^{-3} (Lattimer 2012) then provides some initial condition predictions. Adding the assumption that this separation has to take place within a single interval of the Planck time allows a calculation of the momentum transfer imparted to fermionic matter due to its genesis. Even with energies above quark coalescence levels, the PEP criteria requires a genesis transition of this form for any and all nearest neighbor Fermionic matter upon existence. Using the scaling from that of a neutron in a NS (Lattimer 2012), the resulting relative displacement between nearest neighbors for each quark would then be ≈2e-15 m in the initial time interval ~5e-44 s. This quantum transition then culminates in an apparent violation of special relativity as the initial relative speed of any two adjacent fermions becomes $v \sim$ 2e-15 m / 5e-44 s ≈ 1e20 c.

With the initial dimensions of fundamental particles assumed to be Planck length going to a nearest neighbor distance of 2e-15 m, this provides an expansion of 20 orders of magnitude during that initial Planck time interval alone. With minimally orthogonal states being required, this initiates a homogenous initial condition at this first instant in time.

Assuming further that first generation quarks are the lowest energy state available upon existence, this means each bare quark mass can be approximated as $m \approx 5$ MeV/c^2 (Griffiths 1987). The resulting kinetic energy KE from the initial quantum transition of nearest neighbors can then be calculated from $\sqrt{p^2c^2 + m^2c^4} - m^2c^4 \approx pc$. Using for momentum the value of p=mv=1e22 MeV/c, giving a contribution to the KE per quark of 1e22 MeV. This places the total energy of the transition more than 20 orders of magnitude greater than the initial rest mass.

From this, the energy per Fermion must also obey the uncertainty principle $\Delta E \sim \hbar\, /\, \Delta t \approx$ 7e-22 MeV s / 5e-44 s ~1e22 MeV placing this energy effectively equal to that caused by the PEP imposed on the existence criteria. This means the initial energy at the Planck time is equally divided between and

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[1] With no restrictions on energy prior to the big bang, it is just as reasonable for there to be an arbitrarily large amount of energy coming from that tolerance as there is to be an arbitrary small amount of energy as the resulting value is in effect a relative quantity.

expansion motion and random motion for all particles, a pleasant symmetry but more importantly a mechanism to insure effective thermal equilibrium at existence without the need for any empirical coupling between disjoint regions.

An assumed antimatter component is not quantified inasmuch as this would further contribute to the initial expansion effect at genesis due to PEP between like antiparticles. Subsequent annihilation and recreation upon evolution of the expansion motion then dilutes the energy density but would be expected to substantially exacerbate the PEP transition effect of inflation due to the massive overabundance of antimatter expected relative to total matter (Phillips 2016). Although it is generally accepted that all matter present today is an arbitrarily small fraction of overabundance of matter compared to antimatter present in the initial mix, other conditions are possible (Giovannini and Shapsoshnikov 1998) but these are all assumed here not to violate the PEP.

Although it is fair to say that at this energy level, all known particles would be swarming with the fantastic energy present, it should be born in mind that the primordial Fermions are initially modeled here as transitioning outside the horizon of each of their nearest neighbors due to the presumed quantum transition to independent states of all identical fermionic particles. Gluons as well as pseudoscalor and vector mesons would initially have very limited interaction potential.

The uncertainty energy available in the second Plank interval can be approximated as being roughly equal partitions of massless and massive particles. The first generation creation particles will not have moved appreciably at the second Plank moment of 2x5e-44 s = 1e-43 s as the distance traveled is a very small fraction of their individual characteristic radii as they are only able to travel outward at c once in existence. This localization does generate uncertainty energy whose fraction in the form of bosons will not contribute in that moment to PEP generated expansion.

This uncertainty energy would contribute to the particle-photon sea which would include fermions allowing additional PEP transitions to further provide additional expansion energy until dissipated by the rapid expansion itself. Detailed calculations of this evolution are beyond the scope of the current work but initial scoping calculations are provided in the interim.

Initial Hints at Dark Energy

Neutrinos generated in these moments should still find their path opaque decreasing over time to an effective index of refraction (Prakash et al 2001) due to random interactions unrelated to expansion motion. After the temperature has decreased below around 1 MeV, the potential for very low mass neutrinos being generated having wavelengths $\lambda = h/mc$ scaling with or even greater than the Hubble radius could then be formed, these will be considered later. After this, the material then is only postulated to evolve using the standard model in a radiation dominated environment were $a \sim t^{1/2}$.

Inflation Analogy

It is worth reiterating that this genesis model is neither a classical motion nor a general relativity effect but rather a series of quantum steps from one state to another using only known conservation laws. Being that this is proposed as quantum transitions of adjacent fermions, it effectively is a tunneling action being that from the initial singularity to the lowest energy state availing the reality constraint of existence at the Planck scale. If there is no preferred origin, only transitions between nearest neighbors is reasonable for a minimum difference of energy and position consistent with existence.

After the quantum transition for all nearest neighbors, special relativity will limit standard particle velocities while henceforth conserving energy and momentum. The relative nearest neighbor recession rate can be used to estimate the initial value of the Hubble parameter in this model as $H = \dot{a}/a$= c/l_p= t_p.

With no preferred direction for the momentum variation caused by the uncertainty principle, the direction for each Fermion from this action can be assumed random. This energy component having no preferred direction, has no constraint on the subsequent particle evolution carrying out a 3D random walk through the melee of primordial material. With half the initial energy in expansion motion and the other half in random directional motion, and a potentially arbitrarily large amount of energy from antimatter, a vastly large amount of energy is available for creating large relative fractions of gluons and mesons to eventually attenuate the expansion during the density dilution and subsequent cool down of the system. Demonstration that this produces the expected power law for current observational density distributions (Vianna 2001) is left as a prediction of this model pending subsequent simulations sufficient to carry out this task.

As mentioned previously, one constraint in modeling the pulse of expansion motion is that it initially does not allow nearest neighbor interaction of any of the strong, gravitational and electric forces due to imposing the time constraint of the Planck scale. Each particle effectively begins with no other particles within its horizon so that all indistinguishable fermions initially scale with the Hubble length. Only subsequent random interactions superimposed on the expansion would then allow the various bonding force interactions between particles pulling back on the expansion as they would conserve momentum and energy post initial existence effects through complimentary attraction forces.

Those fermions which subsequently have sufficiently low energy to have wavelengths which are comparable or large compared to the Hubble length *a* will then be frozen into their horizon. This because the Hubble length by definition defines the recession rate from expansion at the velocity of light so the trailing edge of a wavefunction can never reach the prior location of the trailing edge of that same wavefunction.

Using then a wavelength cutoff of 2e-15 m, fermions with wavelengths greater than this value will push each other and force subsequent quantum transitions to nearest neighbor locations exacerbating the expansion expected from initial existence alone. Note that the expectation here is that for those wavelengths greater than *a*, they are coupled to that horizon and so any PEP force they experience will by nature also have to be coupled to that same Hubble length *a*.

PEP as the cause of homogeneity

The combination of maximum particle packing after the PEP transition and the greater than light initial separation creates an extremely uniform mass distribution within any horizon. Even if closed packed hexagonal or face centered cubic arrays are assumed at genesis, subsequent random walks will quickly dissipate the pattern. From this, standard BB evolution continues after the initiation event as described elsewhere (Olive 1990).

Details on predicted matter perturbations from the PEP transition model are not formulated in this work but the general driver for overall homogeneity should be clear. The quantum transition from nearest neighbors would go to the lowest distinct position and energy state being a minimally orthogonal configuration. This then is consistent with a homogeneous distribution, density and subsequent flat space within any horizon as required by current observation (Liddle 2001).

PEP on Expansion Stretched Fermions

The surface of last scattering for neutrinos is estimated to occur around a temperature of 1 MeV which is just below the deuteron association energy of 2 MeV. During the ensuing radiation dominated epoch, these neutrinos could freely stream within their horizon. With a continuum of neutrino energies available through weak processes, wavelengths with low probability can become arbitrarily long. As with the 13.6 eV re-ionization photons which have been stretched into our cosmic microwave background (Malik and Wands 2009), these older neutrinos would likewise have been wavelength stretched. More specifically, the wavelength of the relic neutrinos are fixed to the scaling factor a.

It was only because the material prior to the surface of last photon scattering was fully ionized that the sharp antimatter annihilation peaks (such as the 511 peak from electron positron annihilation or the 2.2 MeV peak from deuteron creation) are not seen. Thompson scattering would have fully blurred all such gamma rays due to the opaque nature of the cosmos prior to cooling to these temperatures (3K).

Primordial Fermions - Dark Energy

Primordial neutrinos would also be undergoing wavelength stretching which can be taken to be on the order of one primordial antineutrino for each proton in the universe. Depending on the origin in time of the distribution of primordial neutrinos, their initial existence would have put them in a minimally orthogonal configuration but would later evolve to try and attain a maximally orthogonal state. As with the CMB wavelength of light being tied to the Hubble length, it can be asserted that the wavelength of these primordial antineutrinos are also tied to the Hubble length.

As free Fermions do not have purely zero amplitudes of their wavefunctions except at infinity, there will always be some overlap in free space. The conjecture offered being that the PEP will forever continue to push these primordial neutrinos apart and so to the extent that their wavelengths are coupled to the Hubble length and are not orthogonal (having distinct quantum numbers), they will continue to push the cosmos itself apart even if only at very small values. In this sense, they would behave as a positive cosmological constant. Note that a prediction on the density of states for these fermions is not offered here but left as a test for the theory as the source of dark energy.

Discussion

The model proposed utilizes the cosmological principle coupled with an existence requirement forcing a uniform distribution of fermions according to their initial minimum available energy states. Subsequent random behavior from uncertainty principle energy superimposed on the expansion motion allowed interaction and eventually bonding and attenuated expansion. As the model presented postulated a Planck scale for the time over which the cosmological principle could be evoked (which is assumed to include the PEP), there is no reason offered to assume the coefficient of this time scale is not unity.

Utilizing the PEP, the uncertainty principle and the conservation of energy and momentum subsequent to the Planck time scale provided some predictions on BB cosmology. These predictions include an overall homogenous distribution, a very large expansion energy per Fermion and a continual source of Fermions (including radioactive decay) in the form of neutrinos and fermions with wavelengths scaling with the Hubble parameter which would give a small overall expansion effect for the entire cosmos over all time.

This model effectively places inflation at the very initial moments of the BB eventually followed by random decceleration and cooling from subsequent particle interactions. Standard BB cosmological models then evolve using currently understood particle physics and general relativity models.

Conclusion

By making some basic assumptions regarding existence at the Planck scale along with an axiomatic adherence to the PEP, inflation is postulated effectively at genesis. Specifically, it is assumed that within the Planck time at the BB singularity, the PEP forces all adjacent like fermions apart sufficient to enable minimally distinct particle wavefunctions. This Pauli force effectively provides the initial starting energy of expansion by requiring all Fermions to have a set of distinct quantum states. All identical Fermions then start with all others outside their horizon with random motion driving subsequent evolution.

This model accounts for why the universe is so smooth on large scales, the requisite minimally orthogonal states at the initial Planck time forces this to be the initial condition everywhere. Likewise, the flatness is postulated to be due to a purely random walk in all directions of all particles preventing curvature on large scales while still allowing clumping due to the same mechanism on small scales. Finally, the initial cause of expansion is that of the standard model upon existence which includes PEP requiring a nearest neighbor quantum transition effectively triggering a massive expansion effect.

The Pauli principle may later account for small universal accelerated expansion through wavelength stretched fermions which in our matter dominated epoch do not have a zero projection upon each other. As the universe expands, relic neutrinos and fermions whose wavelength remains outside our horizon and have overlap will attempt to push each other away to attain a maximally orthogonal state. Their coupling to the Hubble parameter *a* then provides a mechanism to force this value to increase. As such, the PEP provides an apparent force to stretch the scale factor and so is no longer a negligible contribution compared to the attenuating effects of gravity. On limited scales, this can be reasonably modeled as a positive cosmological constant Λ.

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