Did the Universe Construct Itself?

Stuart Kauffman
Emeritus Professor of Biochemistry and Biophysics
University of Pennsylvania
1879 Camino de Cruz Blanca, Santa Fe, NM 87505
stukauffman@gmail.com

Stephen Guerin
Department of Earth and Planetary Sciences
Harvard University
24 Oxford Street, Cambridge, MA 02138
stephenguerin@fas.harvard.edu

Author Contributions:
Kauffman: conceptualization, formulation, analysis, writing initial and final draft.
Guerin: computational modeling, visualizations, analytics and deployment

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Abstract

Nonlocality is now established loophole free. Therefore, in a choice between locality – spacetime – as fundamental and nonlocality as fundamental, there is no *a priori* reason to choose locality. If we choose nonlocality, General Relativity, String Theory, Loop Quantum Gravity, the AdS/CFT duality, and the Holographic Principle are ruled out as fundamental, as all assume locality. AdS/CFT provides a mapping from entangled particles with no geometry (CFT) to a spacetime geometry (AdS). If we start with nonlocality, N coherent entangled particles from $SU(3) \times SU(2) \times U(1)$, then locality – spacetime – must somehow emerge from the behaviors of these particles. We report here that the particles of $SU(3) \times SU(2) \times U(1)$ are capable of collective autocatalysis. Via this autocatalysis, the universe can start with no matter and no spacetime and construct itself – Cosmogenesis. The autocatalytic process yields particles that break matter-antimatter symmetry – baryogenesis. Then, by entangling and actualizing, they yield a power law construction of classical spacetime. This is a candidate for the unknown physics of Inflation. It also proposes a mapping from entangled particles with no geometry to a spacetime geometry. It may become possible to explain our Laws and our values of the 25 constants: These Laws and values may maximize some measure of cosmogenesis.

Significance Statement

We report here that the particles of $SU(3) \times SU(2) \times U(1)$ are formally capable of collective autocatalysis that can drive Cosmogenesis. We propose that the universe started with no spacetime and no matter. The autocatalytic behavior of the particles yields more particles, breaks matter-antimatter symmetry – baryogenesis, and is also a new theory of cosmic inflation. This offers a possible explanation for our Laws and the 25 values of the Constants.

1 Introduction

Of the three great mysteries, the origin and evolution of the universe, of life, and of mind, we understand the origin and evolution of the universe best. The fundamental theory of particle physics, SU(3) x SU(2) x U(1), is very well tested [1]. General Relativity is very well tested [2]. Our account of cosmology is its standard Lambda CDM model plus Inflation [3, 4, 5, 6, 7, 8]. With the few relevant equations [6, 7], it is now possible to predict statistical features of the Cosmic Microwave Background, the formation and distribution of galaxies, and the abundance of the first elements [6, 7].

Despite these successes, much of the fundamental physics is unknown. We do not know how spacetime suddenly appeared [2, 6, 7]. We do not know why the universe has far more matter than antimatter, baryogenesis [6, 7]. We do not know how the universe started in such a low entropy state, perhaps as Boltzmann suppressed as $1/e^{10^{124}}$ [9]. We do not know the physics of Inflation [5, 6, 10], Dark Matter [7, 11], or Lambda – Dark Energy [6, 7, 12].

There are times in the evolution of science when a new conceptual framework may prove useful. The magnificent example is Copernicus, 1543 [13]. He proposes seven postulates, none of which has independent evidence. However, the seven together constitute an entirely new conceptual framework for The World. He writes the Pope to explain his audacity. The book is published as Copernicus lies on his deathbed.

The short-term success of Copernicus is to reduce the number of epicycles with some loss of predictive success compared to the Ptolemaic theory. The long-term success is transformative. Given the sun at the center of The World, might emanations from the Sun hold the planets in orbit? Then Kepler, Galileo, and Newton.

The difficulties we now have in our understanding of Cosmology might benefit from a new conceptual framework. That hope is the aim of this article.

We start with three claims. There is independent evidence for each. i. The quantum state corresponds to ontologically real potentia. This is Heisenberg's 1958 interpretation of quantum mechanics [14]. Thus, quantum mechanics can be interpreted in terms of potentia, neither true nor false. The variables of classical physics are True or False. ii. Nonlocality is firmly established and loophole free [15, 16, 17]. iii. The particles of SU(3) x SU(2) x U(1) are formally capable of collective autocatalysis [18]. We establish the truth of this claim in the present article.

Quantum Gravity If Nonlocality is Fundamental

The first two claims invite the following: If potentia are ontologically real, they may not exist in spacetime. Thus, we can conceive of something real that is not in spacetime. If nonlocality is real, then in a choice between locality versus nonlocality as fundamental, there is no *a priori* reason to choose locality. Cosmology has largely insisted on locality. If instead we choose nonlocality as fundamental, then locality – spacetime – cannot be fundamental. Should we choose nonlocality as fundamental, General Relativity cannot be fundamental, [2, 19], nor can String Theory [20], nor can Loop Quantum Gravity [21], be fundamental. These all start with locality.

The AdS/CFT duality [22], and Holographic Principle [23], map from entangled particles on a $D-1$ dimensional surface to a D dimensional spacetime. Nearby versus distant points on the $D-1$ dimensional surface map to points near and deeper into the D dimensional spacetime bulk [22, 23]. The AdS/CFT duality with the Holographic Principle is a famous way to map from a set of entangled particles with no geometry to a spacetime geometry. The AdS/CFT duality and the Holographic Principle depend upon locality. Both are ruled out if we start with nonlocality as fundamental.

There is an entirely independent way to map from entangled particles without a geometry to a spacetime geometry. If we choose nonlocality as fundamental, taken as $N = 2$ or more entangled coherent particles of SU(3) x SU(2) x U(1), then we must explain locality. Locality must somehow emerge from the behaviors of the N coherent entangled particles. But this flatly contradicts the foundation of General Relativity. General Relativity is local. There is no emergence of spacetime in General Relativity. General Relativity can be formulated in the absence of matter fields, so matter cannot be necessary for the very existence of spacetime. Yet if we start with nonlocality, spacetime cannot emerge without the matter comprised of the N coherent entangled particles.

The fundamental implication, if we start with nonlocality, is that matter somehow constructs spacetime. This implication is entirely new and surely not part of General Relativity.

One approach to taking nonlocality as fundamental is published [24]. This is a mapping from entangled coherent particles with no geometry to a classical spacetime geometry. The central steps are:

1. Start with N coherent particles entangled in some pattern. Between each pair of entangled particles, define the von Neumann entropy (VNE). Because VNE is sub-additive, it fits the Triangle Inequality and is a Norm, so can define a distance between each pair of entangled particles. From this there is a metric in Hilbert space.

2. Because Heisenberg demonstrates that quantum particles in Hilbert space can be interpreted as potentia, neither true nor false, and because all variables of classical physics are Boolean true or false, it becomes necessary to map from a metric in Hilbert space to true false variables. This is the "measurement problem", not solved by decoherence [25]. One choice is to use "actualization" to map from a metric among potentia in Hilbert space to actual events that will constitute classical spacetime. A means to construct a linear map of von Neumann distances in Hilbert space to real spacetime distances invokes "remember" where particles remember their former VNE distances to particles that have actualized. When the particles then actualize, they convert their former von Neumann distances to real distances on some length scale [24].

The resulting theory constructs an emergent and growing classical Minkowski [24], spacetime one element at a time by successive actualization events among four mutually entangled particles. At each actualization step a new tetrahedron arises adjacent to an old tetrahedron. That emergent classical spacetime has a metric so can have a Ricci Tensor. Because it arises from the quantum particles of SU(3) x S(2) x U(1) it can have a stress energy tensor [24].

In this view, quantum gravity does not somehow equate to the classical spacetime of General Relativity. Rather quantum gravity is to construct the classical spacetime in which General Relativity operates.

The particles of SU(3)xSU(2)xU(1) are formally capable of collective autocatalysis

We establish this third claim, fundamental to our efforts, in this article. The claim is quite astonishing. Again, like Copernicus, one is invited to wonder if a capacity for collective autocatalysis among the particles of the standard model of particle physics might allow the universe to construct itself autocatalytically. In the remainder of this article, we hope to demonstrate that the universe, based on such collective autocatalysis, might indeed have constructed itself.

2 Testing the Autocatalytic Hypothesis: Baryogenesis and Cosmogenesis

We currently have no pathway to derive Cosmogenesis, Baryogenesis, and Inflation from the Standard Model of Particle Physics [1]. In this Part II, we propose a new and specific theory, now modelled computationally by the PAM model, as a possible pathway from SU(3) $\times$ SU(2) $\times$ U(1) to Cosmogenesis, Baryogenesis, and Inflation. The Particle Apothecary Model (PAM) is at best a "toy model." PAM treats the particles of SU(3) $\times$ SU(2) $\times$ U(1) as classical variables, not quantum variables. Doing so allows very complex stochastic dynamical systems to be studied. But use of classical variables may be badly misleading. With this caveat, this model, PAM, finds a kinetic phase transition breaking matter-antimatter symmetry, hence baryogenesis.

The PAM computational model constitutes our methods. The running version is online, access is at the end of this article.

In turn, baryogenesis with an increasing number of particles and their interactions, including entanglement and actualization, then drives a consequent quantum construction of spacetime. The resulting steep power law construction of spacetime becomes a candidate for Inflation itself.

The PAM model transiently breaks conservation of matter and energy in a controlled way. The total matter and energy of the universe increases in this model throughout Inflation, then stops increasing and is conserved thereafter. Is this possible or ruled out? General Relativity has no global conservation of energy [2, 19, 26]. Further, the proposal that Dark Energy is constant per unit volume of space implies that as Dark Energy drives an accelerating expansion of the universe, the total energy of the universe is, in fact, increasing. On these bases, we take a transient non-conservation of matter plus energy as a proposal.

2.1 Collectively Autocatalytic Motifs

Famously, the Standard Model of particle physics is formulated in three interwoven mathematical Groups, SU(3) $\times$ SU(2) $\times$ U(1). Because these are mathematical groups, all the particles transform directly or indirectly into one another and only into one another, see Figure 1 and Figure 2 below.

The set of particle transformations in SU(3) $\times$ SU(2) $\times$ U(1), taken as classical variables, can, in fact, function as a "collectively autocatalytic set," see below, as often considered with respect to the origin of life.

Nghe and colleagues have shown that there are only five collectively autocatalytic Motifs [18], Figure 3. Within a subset of transitions among only 13 particles of the Standard Model, Table 1: [Down quarks, Down antiquarks, Up quarks, Up antiquarks, electrons, positrons, neutrinos, antineutrinos, muons, antimuons, muon neutrinos, antimuon neutrinos, photons] one finds a very large number, four hundred and eighty-six, Nghe Collectively Autocatalytic Motifs. Of these 192 are Nghe type II motifs, 294 are Nghe Type III motifs, Figures 2 and 3 and Table 2.

Nghe motifs range from type I to type V [18], Figure 1. Higher numbered motifs have higher survival probability.

Collective autocatalysis need not include "catalysts" but can refer only to the structure of the set of transformations. Consider classical chemistry. Let substances A + B undergo a two-substrate one-product reaction to form C. A + B $\rightarrow$ 2C. Let C + D $\rightarrow$ 2E. Let E + F $\rightarrow$ 2A. The set of three reactions has a cycle A $\rightarrow$ C $\rightarrow$ E $\rightarrow$ A. If A, C, and E are present in the system, then given exogenous input of B, D, and F in an open thermodynamic system, A, C, and E will accumulate in concentration. There is no "catalyst." The cyclic structure of the reactions constitutes the "catalyst."

For the particles of SU(3) $\times$ SU(2) $\times$ U(1) to function autocatalytically, the universe may be closed, but the initial state of the universe is not at equilibrium and transient excesses of some particles can occur as a changing equilibrium is gradually approached while the temperature of the universe falls.

Ongoing collective autocatalysis requires exogenous input. In the PAM model, we propose a controlled way to do so below.

Figure 1 below includes the reversible transformations among the 9 particles: Down quarks, Down antiquarks, Up quarks, Up antiquarks, electrons, positrons, neutrinos, antineutrinos, and photons used in PAM. The other bosons are assumed. The PAM model does not yet include muons, antimuons, muon neutrinos, or antimuon neutrinos in the study of the branching stochastic processes among the particles. This work is in progress, see Figure 2. Their role in forming Nghe motifs is now included, Table 2.

3 Cosmogenesis

In the remainder of this article, we turn to initial considerations of the potential implications for Cosmogenesis of the fact that the woven group structure of particle physics can function as an autocatalytic system.

It is well known that there is no established pathway from the Standard Model of physics to Cosmogenesis, Baryogenesis, and Inflation [1, 2, 3, 4]. Our familiar theory of cosmogenesis starts with an existing universe near the Initial Singularity at extreme temperature and density, and a rapid power law or exponential Inflation driven by an unknown mechanism, the Inflaton field, from about 10^{-37} seconds to about 10^{-32} seconds for a 10^{27}-fold expansion of spacetime [4, 5, 6].

The fact that particle physics can possibly function as an autocatalytic system invites a radically different approach: The universe starts with nothing other than the quantum vacuum equipped with the standard model of particle physics. There is no matter, and no spacetime. The reversible time of quantum mechanics is present. Then, via collective autocatalysis, the universe is to construct itself.

There are two independent reasons to consider a theory in which the universe starts with nothing but the quantum vacuum:

3.1 The evidence for the Big Bang is twofold: The galaxies are receding according to the Hubble Law and the Cosmic Microwave Background.

Both strongly suggest the universe was very small long ago. However, we also typically start at or near an "Initial Singularity" which is naturally suggested by General Relativity. Yet we have no detailed evidence for such an Initial Singularity, and it is of some interest that we posit such a singularity exactly where General Relativity fails. Thus, it is of interest to consider possible theories that do not start with an initial singularity.

3.2 As noted, one reasonable approach to quantum gravity takes nonlocality as fundamental.

If we start with nonlocality, an absence of spacetime, as fundamental, we need not explain nonlocality, but must explain locality. Consider $N > 1$ entangled coherent quantum particles. These are nonlocal. Then for locality – spacetime – to emerge, something about these N-coherent quantum particles and their behaviors must be relevant. But this does flatly contradict the assumptions of General Relativity [2, 19, 24]:

1. General Relativity is the definition of local.
2. General Relativity can be formulated without matter, hence without N-entangled particles. Thus, matter can have nothing to do with the very existence of spacetime. But if we start with nonlocality, spacetime will not emerge without matter.
3. There is no "emergence" of spacetime in General Relativity.
4. There is no *a priori* reason not to take nonlocality as fundamental.
5. If we start with nonlocality, spacetime is not fundamental.
6. Then any initial state of the universe cannot yet have spacetime.

If starting with nonlocality as fundamental is starting without spacetime, this suggests considering starting the universe itself with no spacetime, no particles, merely the quantum vacuum. But then if entangled, coherent quantum particles are somehow to construct spacetime, from whence come the quantum particles? However, if the particles of SU(3) $\times$ SU(2) $\times$ U(1) can act autocatalytically, might this create the requisite quantum particles and, thus, a quantum creation of spacetime as a new candidate for Cosmogenesis? This Section answers, YES.

The hypothesis that the universe starts with no matter and no spacetime has important advantages:

1. The hypothesis provides a new account of the Arrow of Time. The Arrow of Time requires Past Hypothesis. The Past Hypothesis itself requires that the entropy of the initial state of the universe be the reciprocal of the current estimated complexity of the universe, $e^{10^{124}}$. [27]. Penrose points out how extremely improbable such a state with a very low but positive initial entropy is [27]. If the universe starts with no matter and no spacetime, its entropy is 0. The Arrow of Time emerges automatically.
2. There is no initial singularity. This obviates concern about why black holes were not formed [28].
3. The puzzle of the low gravitational entropy of the universe [29] is automatically explained.
4. If the universe starts with no matter and no spacetime, this is a unique initial state of the universe. The laws themselves do not specify any initial state at all.

If the universe is to start with no matter, it cannot initially be a Hot Big Bang. Moreover, a universe cannot come to exist without matter, in contradiction to major models of Infinite Inflation [10, 30].

4 PAM: The Particle Apothecary Model

The Particle Apothecary Model (PAM) uses a subset of 9 of the total standard model: [up quarks, up antiquarks, down quarks, down antiquarks, electrons, positrons, neutrinos, antineutrinos, photons]. PAM is a "toy model" because it treats particles as classical objects. It uses a modified "Gillespie algorithm" [31] implemented in Netlogo [51] as a stochastic particle interaction model to study the branching processes in which these 9 classical variable particles undergo the 14 transformations from the first 7 bi-directional equations given in Figure 1 and Table 1. Transition rates are tunable in each direction. Access to the PAM code and running model online is available at https://particleapothecary.org.

4.1 Methods

Consider a set of particles $\mathcal{P}$ and a set of reversible transformations $\mathcal{R}$ between these particles:

$$\mathcal{P} = \{u, \bar{u}, d, \bar{d}, e^-, e^+, \nu_e, \bar{\nu}_e, \gamma\}$$

$$\mathcal{R} = \{u + \bar{u} \rightleftharpoons \gamma, \ldots\}$$

where u and $\bar{u}$ represent up quarks and anti-up quarks, d and $\bar{d}$ represent down quarks and anti-down quarks, e^- and e^+ represent electrons and positrons, ν_e and $\bar{\nu}_e$ represent electron neutrinos and antineutrinos, and γ represents photons.

For each transformation $j \in \mathcal{R}$, let c_j denote the associated probability for the transformation to occur, and let X_i denote the count of each particle $i \in \mathcal{P}$.

#	Transformation
1	$u + \bar{u} \rightleftharpoons \gamma$
2	$d + \bar{d} \rightleftharpoons \gamma$
3	$u + d \rightleftharpoons W^+$
4	$\bar{u} + \bar{d} \rightleftharpoons W^-$
5	$e^- + e^+ \rightleftharpoons \gamma$
6	$\nu_e + \bar{\nu}_e \rightleftharpoons \gamma$
7	$e^- \rightleftharpoons W^- + \nu_e$
8	$e^+ \rightleftharpoons W^+ + \bar{\nu}_e$
9	$\nu_e \rightleftharpoons W^+ + e^-$
10	$\bar{\nu}_e \rightleftharpoons W^- + e^+$
11	$\gamma + \gamma \rightleftharpoons Z^0$
12	$\nu_e + \bar{\nu}_e \rightleftharpoons Z^0$
13	$u + \bar{u} \rightleftharpoons Z^0$
14	$d + \bar{d} \rightleftharpoons Z^0$

Table 1: Particle Transformations in the PAM Model

- u = up quark
- $\bar{u}$ = up antiquark
- d = down quark
- $\bar{d}$ = down antiquark
- e^- = electron
- e^+ = positron
- ν_e = electron neutrino
- $\bar{\nu}_e$ = electron antineutrino
- γ = photon
- W^+ = W boson (positive)
- W^- = W boson (negative)
- Z^0 = Z boson

Tuning these rates indirectly tunes the relevant constants of the Standard Model. This allows study of the consequences of the specific values of the constants for the NGHE autocatalytic motifs among these 9 variables, Figures 1 and 2, for Baryogenesis and the construction of spacetime it drives. This means we may be able to answer, “Why our values of the constants?” Optimal values may optimize some measure of Cosmogenesis. This may be testable.

4.2 Simulations and results

A reasonable hypothesis for the vacuum to be an open source of energy can be based on the standard view that a single quark-antiquark pair borrows energy from the vacuum, transiently emerge from nothing out of the vacuum, then returns the borrowed energy and vanishes within $\Delta E \times \Delta T \geq \hbar/2$.

We therefore propose a working hypothesis: If two or more quark-antiquark pairs transiently emerge from nothing out of the vacuum, and if two or more quarks, or if two or more antiquarks "interact," for example entangle, this delays their return of the borrowed energy. Alternately stated, Delay extends the Lifetime of particles.

In [32] S. Patra and Kauffman propose a possible mechanism for Delay. We propose that the classical world emerges as a symmetry breaking among an initial set of 2^n bases to "choose one basis." An emerging basis shared among the N entangled particles can decay "slowly." As quark-antiquark pairs emerge and pairs of quarks or pairs of antiquarks entangle, an emergence of a basis shared among quarks or among the antiquarks, while still present, could delay return of the borrowed energy until the basis decays.

The delay assumption immediately implies the possibility of a phase transition. Consider a two-dimensional parameter space of: i. the delay, D. ii. the frequency, f, with which each variable interacts. Let "f" increase linearly with the number of variables that are available to interact. Then each particle undergoes interactions more frequently as the total number of particles increases. Generically as ever more quarks and antiquark pairs borrow energy from the vacuum, emerge and quarks "interact" or antiquarks "interact" with one another, interacting quarks or interacting antiquarks can mutually persistently delay return of the borrowed energy. Thus, there must be a second order phase transition in the two dimensional "delay" $\times$ "f" parameter space when the matter, or the antimatter, particles are so abundant and interact so rapidly that eventually they just persistently "steal" the borrowed energy. The further the system is beyond the phase transition in this two-dimensional parameter space, the more rapidly they just steal the energy. The phase transition forms what we will call a Kinetically Stable Nucleus of fermions and photons that persistently delays return of the borrowed energy. The particles in the Nucleus itself may change. The PAM model exhibits this in the baryogenesis it exhibits.

In short, the very collectively autocatalytic behavior of particle physics can supply the ever-increasing numbers of particles that entangle and persistently delay one another's return of the borrowed energy. The system of particles emerging from the vacuum steals the energy. The autocatalytic system of produced particles continues to interact, transform, and annihilate in a stochastic branching autocatalytic process as defined by the Standard Model.

The present theory requires free quarks and antiquarks, such as those in a quark gluon soup before hadronization.

Figures 4a and 4b demonstrate this second order phase transition. This numerical study using the Gillespie algorithm was carried out for a specific set of parameter values of the PAM model. One axis of the figure is labeled "lifetime extension". Increasing lifetime extension is identical to increasing delay in return of the energy borrowed from the vacuum. The second axis is labeled "probability of interaction". Each probability value is linearly proportional to the total number of particles with which a particle can interact, "f". For each pair of parameter values, PAM was run for 500-time steps and for 50 repetitions with different random seeds. The total number of quarks plus antiquarks that were created in 500-time steps were recorded for each run. The results reported for each pair of parameter values are the means of those 50 repetitions.

The results in 4a and 4b clearly demonstrate the second order phase transition. The dark purple region in figure 4a in the vicinity of both axes corresponds to a formation of less than 5 quarks in 500-time steps. Figure 4b shows that in most of this region near both axes, the average number of quarks formed is less than 1 but greater than 0.

Well beyond the second order phase transition the formation of quarks or of antiquarks is rapid. This is the basis for baryogenesis, discussed next. In addition, the rapid formation of quarks, or of antiquarks well beyond the phase transition will become the basis for the missing physics of Inflation, also discussed below. Slightly beyond the phase transition the rate of formation of quarks or antiquarks is slow.

4.3 Spontaneous baryogenesis

The Particle Apothecary Model is entirely symmetric with respect to matter and antimatter. Yet the dynamical stochastic processes investigated by PAM kinetically break matter-antimatter symmetry. The present theory includes consideration of Up quarks and Up antiquarks as well as Down quarks and Down antiquarks. Figures 5 a, b, c, d, show the resulting ratio of quarks/antiquarks for four conditions: i. Tuning the probability of Up quark or Up antiquark versus Down quark or Down antiquark emerging from the vacuum from .06 to 0.5. ii. Tuning whether the rate of emergence of quark-antiquark pairs is or is not proportional to the current number of particles. In all four conditions the initial symmetry between matter, quarks, and antimatter, antiquarks, is maintained.

The results are striking. Either quarks strongly win, or antiquarks strongly win. The stochastic dynamics of the nine particles breaks matter-antimatter symmetry. This is baryogenesis with respect to quarks and antiquarks.

Importantly, symmetry is not broken with respect to electrons versus positrons and neutrinos versus antineutrinos, Figures 6a and 6b.

Our current universe is dominated by quarks, not antiquarks and by electrons not positrons. The present theory seems unable to fully account for this asymmetry. However, the theory predicts that if Up quarks and Down quarks win over Up antiquarks and Down antiquarks, then when hadrons are formed, they will be neutrons and protons, not antineutrons and antiprotons. It is therefore of interest that "positron capture" by neutrons eliminates positrons and yields protons plus antineutrinos [33]. If this process is sufficiently abundant, it is a candidate to remove positrons from the early universe after hadrons form. In short, it seems worth considering that later processes as hadronization occurs, given a predominance of quarks not antiquarks, may further break matter antimatter symmetry.

Thus, a kinetic matter antimatter symmetry breaking, hence baryogenesis, naturally emerges in PAM. We have not been able to account for baryogenesis. The present theory offers a way.

Because the universe here starts with no matter and no spacetime, it is vastly out of equilibrium. Hence this process fulfills Sakharov's criteria for baryogenesis [34]. Such a symmetry breaking could not be seen were the universe to start with very many particles as in the standard Big Bang model. Only tiny fluctuations would be seen, as is normally assumed to account for the prevalence of matter over antimatter at one part in 5×10^7 [35].

Di Biagio and Rovelli have introduced the idea of mutually "stable facts" among a set of entangled particles not all of which are entangled, and they have noted that such stable facts imply breaking the symmetry of reversible time [36]. The autocatalytic behaviors in the PAM theory with its mutually induced "delay" among a set of quarks or a set of antiquarks constitutes just such mutually stable facts. The delayed quarks or delayed antiquarks are stable facts with respect to one another as they mutually entangle and interact and further delay one another, even as not all pairs are entangled at any moment. In yielding baryogenesis, the system presumably breaks CPT symmetry. A quantum arrow of time emerges [24].

4.4 The emergence of spacetime and inflation

Several models exist that attempt to relate multiparticle entanglement to spacetime. Carroll's Bulk Entanglement Gravity, BEG, is a well-known example [37]. BEG maps from a stable mutual information among a set of entangled quantum particles in Hilbert Space to classical spacetime via the Radon transform [37]. More recently, Singh and Doré [38] have proposed a model with a fixed number of quantum particles. An increasing entanglement among these drives Inflation. Inflation stops in this model because the total number of quantum particles is finite and fixed. This theory does not propose a mechanism for the existence of the initial fixed set of quantum particles [38]. Raamsdonk suggests that decreasing entanglement is associated with regions of spacetime pulling apart [39].

PAM yields baryogenesis with an increasing number of particles. Like the theory of Singh and Doré above with a fixed number of particles [38], in PAM the increasing number of entanglements among the increasingly numerous multiparticle system could be taken to drive Inflation. However, a mapping from Hilbert space to classical spacetime remains uncertain.

PAM proposes that the universe starts with pure potentia, here identified as the quantum vacuum. As noted, quantum superpositions do not obey the law of the excluded middle. With Heisenberg [14], we identify superpositions with ontologically real Possibles, *Res potentia* [14, 24]. Actualization then converts potentia to ontologically real Actuals, *Res extensa*, whose variables do obey the Law of the Excluded Middle, hence are true or false [24]. The variables of classical physics, including General Relativity, are all Actuals, either true or false. Decoherence alone is not sufficient to yield specific true false specific outcomes [25]. It becomes natural to propose that sequential actualization of the quantum potentia of the quantum vacuum "constructs" classical spacetime as the relations among the "true" actualized events. This is sketched above and discussed in detail in the companion to this paper, where the growing classical three-dimensional Minkowski spacetime has a metric, Ricci Tensor and Stress Energy tensor [24].

In PAM, each "interaction, entanglement, and actualization event" among the particles constructs a "unit volume of spacetime." PAM yields a steep power law construction of spacetime, Figures 6a, 6b and 7. This is an obvious candidate for Inflation itself [4, 5, 6, 7]. For example, PAM easily yields a power law creation of space with a slope equal to 4.0 or greater, Figure 8. If Inflation is to occur between 10^{-37} seconds and 10^{-32} seconds, 5 orders of magnitude, a power law creation of spacetime with slope 4.0 yields a 10^{20} expansion of the universe. A typical guess at the expansion during Inflation is 10^{27}. Were the duration of Inflation to occur from 10^{-38} seconds to 10^{-31} seconds, the universe would expand 10^{28}-fold.

5 Further Implications for Cosmogenesis

5.1 Inflation ends naturally

Further aspects of this broad new theory of cosmogenesis suggested by PAM are not yet numerically or formally studied; however, they seem plausible, interesting, and require further analysis. Propose that a metric exists, see [24], and propose merely that the probability of interaction among particles falls off monotonically with distance between particles. Then if the Universe expands very rapidly via Inflation, particle density should fall. This is seen in PAM. If so, the frequency, f, of interactions per particle must decline, moving the system in the two-dimensional parameter space of "delay" and "f" to ever smaller values of f. This is modeled in Figures 4a and 4b by a decreasing probability of interaction. This moves the system parallel to the probability of interaction axis. As this occurs, the system must pass from above to below the phase transition. In short, there must be a slowing then cessation of the capacity of particles to steal the borrowed energy. This cessation is a second-order transition from above where increasing distance between particles reduces the number of interactions per unit time for each particle so much that formation of kinetically stable nuclei is no longer possible. The universe no longer breaks matter-energy conservation.

A natural stopping of inflation needs careful study. If confirmed, this theory of Inflation is unlike most models of Inflation that yield infinite inflation and a multiverse of non-interacting pocket universes [10]. In these theories of Infinite Inflation, universes with no matter can exist. This is ruled out on the present theory which posits that nonlocality must be taken as fundamental. Thus, any universe must have matter to come to exist.

5.2 A possible union with General Relativity

This attempt based on PAM and taking nonlocality as fundamental as a theory of quantum gravity that constructs spacetime is not General Relativity. There is no construction of spacetime in General Relativity. General Relativity is local. Because General Relativity can be formulated without matter fields, General Relativity is incapable of addressing the formation of matter itself. Nor can General Relativity propose a role for matter in constructing spacetime.

Matter and energy are present from the first moment in this model of Cosmogenesis with its baryogenesis and construction of spacetime. Fermions form, transform, vanish, and exchange their bosons. Spacetime is the emergent relational metric among these events.

The ambition is to use a more mature version of the ideas discussed to modify General Relativity, perhaps a bit like the Chadwick *et al.* model where matter curves and also creates spacetime [40]. On such a view, the approach to quantum gravity constructing spacetime sketched above does not constitute General Relativity but unites with it in some new way.

The conceptual ingredients to do so may not be too far away. The forming spacetime with fermions and bosons emerging from the vacuum and transforming autocatalytically, has matter and energy within an emerging spacetime that has a metric. Thus, there is some stress energy tensor and a Ricci curvature tensor. It may not be too far-fetched to hope for union with General Relativity modified by a scalar field with amplitudes for a local construction of spacetime.

Here quantum gravity does not constitute General Relativity, but quantum actualization constructs the spacetime in which classical physics General Relativity operates [24]. In such a version of Quantum Gravity and General Relativity, matter constructs and curves spacetime. Curved spacetime tells matter how to move.

6 Discussion and Further Work

This article is one of a set of three articles:

The first article, "Quantum Gravity If Nonlocality Is Fundamental" [24], is based on two established facts:

1. Quantum Mechanics allows interpretation of the "quantum state" as "potentia," neither true nor false [14].

2. Nonlocality is now established [15, 16, 17].

Based on these, starting with nonlocality implies that matter somehow constructs spacetime [24]. The resulting quantum construction yields the sequential construction of a successive classical three-dimensional Minkowski space like slices that then constitutes a growing four-dimensional spacetime. The theory may be testable using the Casimir effect [24].

The present second article builds on the first and establishes a third claim: The particles of SU(3) × SU(2) × U(1) are formally capable of collective autocatalysis by which ever-new particles can be "stolen" from an "exogenous source" – the quantum vacuum. In short, by adding the "delay" hypothesis, the universe can start with no matter and no spacetime. Then, via the collectively autocatalysis and delay with its second-order phase transition, particles can be constructed and stochastically break matter-antimatter symmetry yielding baryogenesis. The creation, entanglement, and actualization of particles then drives a rapid power law construction of spacetime that is a candidate for the unknown physics of Inflation. The present theory offers a theory of Cosmogenesis, Baryogenesis, and Inflation.

One test of this theory of Cosmogenesis is to attempt to account for our values of the 25 Constants because this combination of values, better than other combinations, maximizes some measure of the efficiency of Cosmogenesis. Such a theory would require some form of Cosmic Natural Selection as first proposed by Smolin [41]. The current PAM computational model can be used to begin such efforts.

A second test of this theory of Cosmogenesis attempts to account for "Why our Laws?" SU(3) × SU(2) × U(1). C. Furey has located these among the Octonions [42]. If Cosmogenesis does indeed depend upon the capacity of our laws to support collective autocatalysis, then SU(3) × SU(2) × U(1) should be richer in Nghe Motifs than sub-adjacent groups among the Octonions. We can test this now. Confirmation could be quite startling.

A third test is experimental. The unexpected discovery that the particles of SU(3) × SU(2) × U(1) are capable of collective autocatalysis may well be open to direct experimental test, for example at CERN. The basic experiment is to partition the set of particles into at least two subsets, Set [A] and Set [B]. Use the set [A] injected as input and test if some or all members of Set [B] are produced. Reciprocally, use some or all of Set [B] injected as input and test if some or all of Set [A] is produced. If, in the most definitive outcome, the union of [A] and [B] is all or almost all of the particles, and injection of [A] produces all of [B], while injection of [B] produces all of [A], we would have strong evidence that the particles are collectively autocatalytic.

If we confirm that the particles of SU(3) × SU(2) × U(1) are indeed collectively autocatalytic, it would become difficult not to explore the potential role of such autocatalysis in cosmogenesis.

At present, our attempts to account for our values of the constants and our Laws rely on the Anthropic Principle [43], whose testability is widely doubted [44], and which most easily relies on the essentially untestable postulate of a multiverse [6, 7]. Our Laws and Constants may, instead, have been selected for ease of efficient Cosmogenesis.

The third article in this series is online [45]. This paper also proposes that spacetime is constructed by matter in each locale proportional to its 4th root, $M^{1/4}$. It is obvious that a construction of spacetime by matter is already a form of Dark Energy [6, 7, 45]. If the universe starts, as often assumed, with a high density of matter at high temperature, that dense matter, by constructing spacetime, becomes a candidate for the unknown physics of Inflation [45]. It is more surprising that the same proposed construction of spacetime by matter, a force that expands spacetime, can be a candidate for Dark Matter and can explain MOND, an alternative to Dark Matter [46, 47, 49]. This third article proposes a direct test of the hypothesis that matter constructs spacetime. It must predict that galaxies that have existed longer must have constructed more spacetime so must rotate faster than galaxies that have lived less long. This can now be tested using the scatter in the data for the Baryonic Tully Fisher Relation [46, 47, 49]. Preliminary data now support this prediction [45]. Were this prediction strongly confirmed, we would conclude that matter does construct or expand spacetime [49]. If so, General Relativity would have to be modified [2, 19, 24, 45].

Taken together, the first two articles may be an example of G. Ellis' proposed "The Evolving Block Universe" [50]. Taken together, the three articles propose new theories of Cosmogenesis, Baryogenesis, Inflation, Dark Matter, and Dark Energy. Some aspects of theory are now testable.

7 Conclusions

Copernicus in 1543 created a new heliocentric view of the world. He based his work on seven postulates, none of which had independent support. Yet, these seven provided a new conceptual framework for astronomy. More, with the hint of something radiating from the sun that held the planets in orbit, the new vision led to Newton.

The profound success of General Relativity has led almost all work on cosmogenesis to start with locality and spacetime as fundamental. The universe somehow suddenly appears, and somehow has very low entropy. Somehow "exponential" – whose physics is unknown – Inflation happens. Then with Cold Dark Matter, whose physics is unknown, and Dark Energy, whose physics is unknown, the Lambda CDM model is now the Standard Model of Cosmogenesis. Fortunately, a 1 in 50,000,000 excess of matter over antimatter leads to a matter-dominated universe. And ours is a Fortunate Universe [6], whose 25 constants are exquisitely tuned such that life can exist.

We have attempted a mini-Copernicus. We start with three claims:

1. Quantum particles in superposition can be interpreted as potentia. Potentia are ontologically real and could be outside of spacetime. Then we can at least conceive of something real that is not in spacetime.

2. Nonlocality is firmly established. There are no *a priori* grounds to choose locality over nonlocality as fundamental. Why not start with nonlocality and see what can be done? Somehow spacetime must emerge from and be constructed from entangled coherent particles chosen among those of SU(3) $\times$ SU(2) $\times$ U(1).

3. Upon examination, the particles of SU(3) $\times$ SU(2) $\times$ U(1) are formally capable of collective autocatalysis. We establish this third claim in the present article. Our analysis can be extended to all the particles and transformations among SU(3) $\times$ SU(2) $\times$ U(1). We can establish the total number of Nghe motifs and the number of Type 1, Type 2, Type 3, Type 4, and Type 5 Nghe motifs in our standard model and compare this objective measure of collective autocatalysis to other candidate laws among the octonions. Are our Laws better at collective autocatalysis than other candidate laws? We may even be able to experimentally test collective autocatalysis among the particles of SU(3) $\times$ SU(2) $\times$ U(1), stunning if confirmed.

Like the imagined rays from the sun holding the planets in orbit, might these three claims conspire to allow the universe to construct itself from no spacetime and no matter? We employ one further postulate: A "delay" in the return of borrowed energy back to the vacuum upon interaction of quarks or of antiquarks.

The postulates suffice. We can conceive of the universe starting from no matter and no spacetime and constructing itself. A construction of spacetime promises possible answers to: How did spacetime appear? If the universe starts from no spacetime and no matter, its entropy is 0, answering the struggle over the low entropy of the initial state needed for the Past Hypothesis. The universe starts from a unique initial state. Baryogenesis is natural, not an *ad hoc* 1 in 50 million-excess of matter over antimatter. A construction of spacetime by matter can be the unknown physics of Inflation.

The present article provides a testable new framework for cosmogenesis. The limitation of PAM to classical variables is severe. We hope our efforts prove useful.

Online access to the current Particle Apothecary Model is available at particleapothecary.org.

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Table 2: Nghe Motifs Summary

#	Motif
486	core(s) found, including:
0	type I core(s)
192	type II core(s)
294	type III core(s)
0	type IV core(s)
0	type V core(s)

Table 3: Nghe Motifs: Type II and III

#Autocatalytic core number 53 of type 2
External set = { e^+, d, $\bar{d}$, $\bar{\nu}$, μ }
$2\gamma \rightleftharpoons u + \bar{u}$
$\bar{\mu} \rightleftharpoons \bar{u}$
$\bar{\mu} \rightleftharpoons u$
$e^- \rightleftharpoons u$
$2\gamma \rightleftharpoons e^-$
as part of the reactions:
$2\gamma \rightleftharpoons u + \bar{u}$
$\mu + \bar{\mu} + \bar{d} \rightleftharpoons \bar{u}$
$\mu + \bar{\mu} + d \rightleftharpoons u$
$e^- + \bar{\nu} + d \rightleftharpoons u$
$2\gamma \rightleftharpoons e^+ + e^-$

#Autocatalytic core number 80 of type 2
External set = { e^+, $\bar{d}$, $\bar{\nu}$, ν_μ, $\bar{\nu}_\mu$ }
$2\gamma \rightleftharpoons \mu + \bar{\mu}$
$\bar{\mu} \rightleftharpoons \nu$
$\nu \rightleftharpoons \bar{u}$
$\mu + \bar{\mu} \rightleftharpoons \bar{u}$
$\mu \rightleftharpoons e^-$
$2\gamma \rightleftharpoons e^-$
as part of the reactions:
$2\gamma \rightleftharpoons \mu + \bar{\mu}$
$\bar{\mu} \rightleftharpoons e^+ + \nu + \bar{\nu}_\mu$
$e^+ + \nu + \bar{d} \rightleftharpoons \bar{u}$
$\mu + \bar{\mu} + \bar{d} \rightleftharpoons \bar{u}$
$\mu \rightleftharpoons e^- + \bar{\nu} + \nu_\mu$
$2\gamma \rightleftharpoons e^+ + e^-$

#Autocatalytic core number 151 of type 2
External set = { d, $\bar{d}$, $\bar{\nu}$, ν, μ, $\bar{\nu}_\mu$ }
$2\gamma \rightleftharpoons u + \bar{u}$
$e^- \rightleftharpoons \bar{u}$
$e^- \rightleftharpoons u$
$e^+ \rightleftharpoons u$

$\bar{\mu} \rightleftharpoons e^+$
$2\gamma \rightleftharpoons \bar{\mu}$
as part of the reactions:
$2\gamma \rightleftharpoons u + \bar{u}$
$e^- + \bar{\nu} + \bar{d} \rightleftharpoons \bar{u}$
$e^- + \bar{\nu} + d \rightleftharpoons u$
$e^+ + \nu + d \rightleftharpoons u$
$\bar{\mu} \rightleftharpoons e^+ + \nu + \bar{\nu}_\mu$
$2\gamma \rightleftharpoons \mu + \bar{\mu}$

#Autocatalytic core number 233 of type 3
External set = { $\bar{d}$, $\bar{\nu}$, ν, $\bar{\mu}$, ν_μ }
$2\gamma \rightleftharpoons e^+ + e^-$
$e^+ \rightleftharpoons \bar{u}$
$2\gamma \rightleftharpoons \mu$
$\mu \rightleftharpoons \bar{u}$
$\mu \rightleftharpoons e^-$
as part of the reactions:
$2\gamma \rightleftharpoons e^+ + e^-$
$e^+ + \nu + \bar{d} \rightleftharpoons \bar{u}$
$2\gamma \rightleftharpoons \mu + \bar{\mu}$
$\mu + \bar{\mu} + \bar{d} \rightleftharpoons \bar{u}$
$\mu \rightleftharpoons e^- + \bar{\nu} + \nu_\mu$

#Autocatalytic core number 261 of type 3
External set = { e^-, d, $\bar{u}$, ν, ν_μ, $\bar{\nu}_\mu$ }
$2\gamma \rightleftharpoons e^+$
$2\gamma \rightleftharpoons u$
$\bar{\nu} \rightleftharpoons u$
$2\gamma \rightleftharpoons \mu + \bar{\mu}$
$\mu \rightleftharpoons \bar{\nu}$
$\bar{\mu} \rightleftharpoons e^+$
as part of the reactions:
$2\gamma \rightleftharpoons e^+ + e^-$
$2\gamma \rightleftharpoons u + \bar{u}$
$e^- + \bar{\nu} + d \rightleftharpoons u$
$2\gamma \rightleftharpoons \mu + \bar{\mu}$
$\mu \rightleftharpoons e^- + \bar{\nu} + \nu_\mu$
$\bar{\mu} \rightleftharpoons e^+ + \nu + \bar{\nu}_\mu$

#Autocatalytic core number 324 of type 3
External set = { e^+, d, $\bar{d}$, μ, $\bar{\nu}_\mu$ }
$2\gamma \rightleftharpoons e^-$
$2\gamma \rightleftharpoons u + \bar{u}$
$\nu \rightleftharpoons u$
$\bar{\mu} \rightleftharpoons e^-$

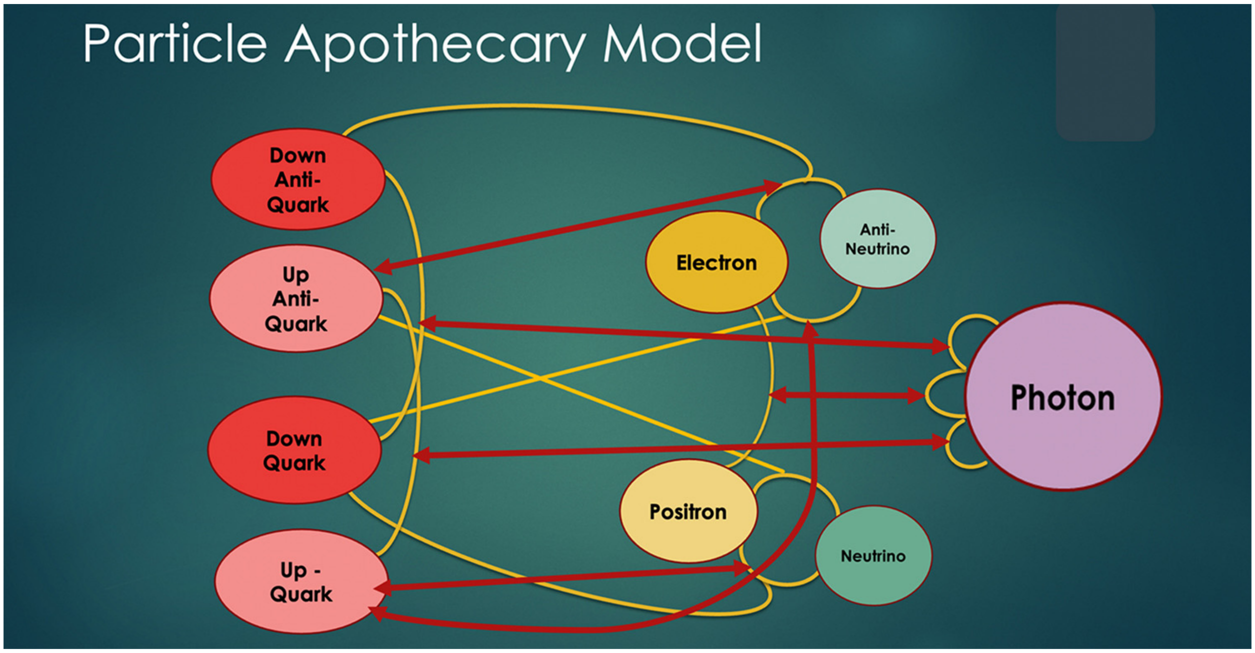

Figure 1: Transformations among the variables in the PAM Model. (See Transformations 1 – 14 in Table 1 below). Red lines with arrowheads at each end are transformations among the variables connected by yellow lines. Yellow lines connect variables that are inputs and outputs of transformations.

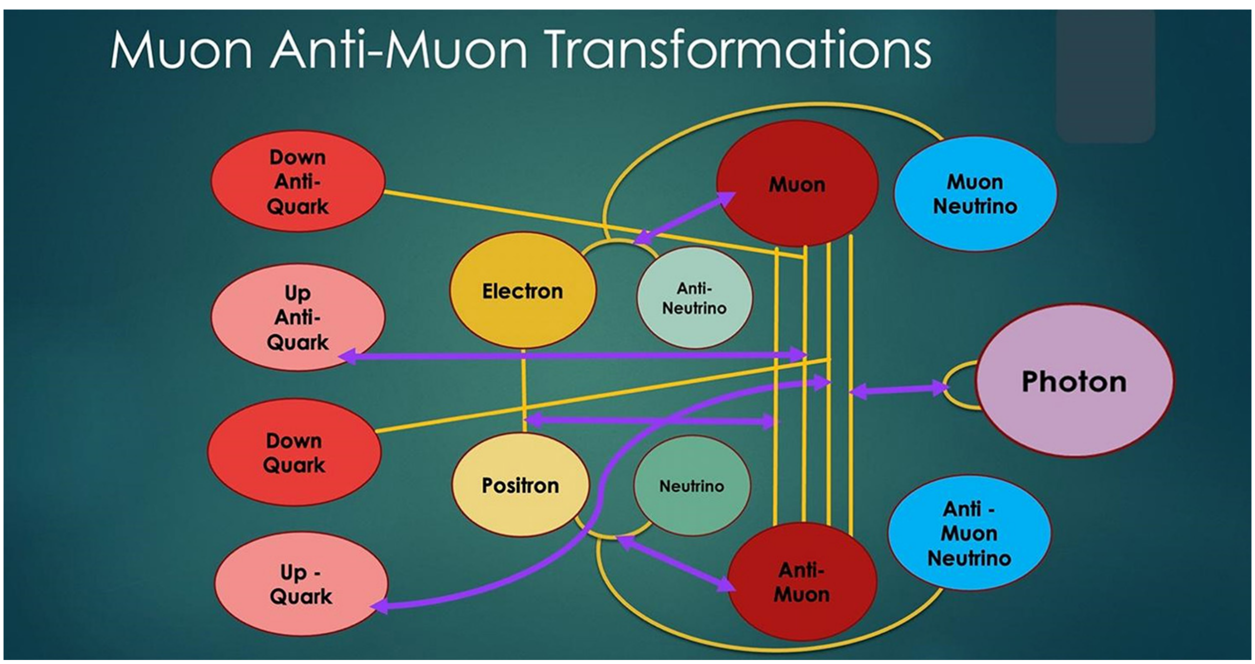

Figure 2: Transformations of muons, antimuons, muon neutrinos and antimuon neutrinos. Purple lines with arrow heads at each end are transformations among variables connected by yellow lines. Yellow lines connect variables that are inputs and outputs of transformations.

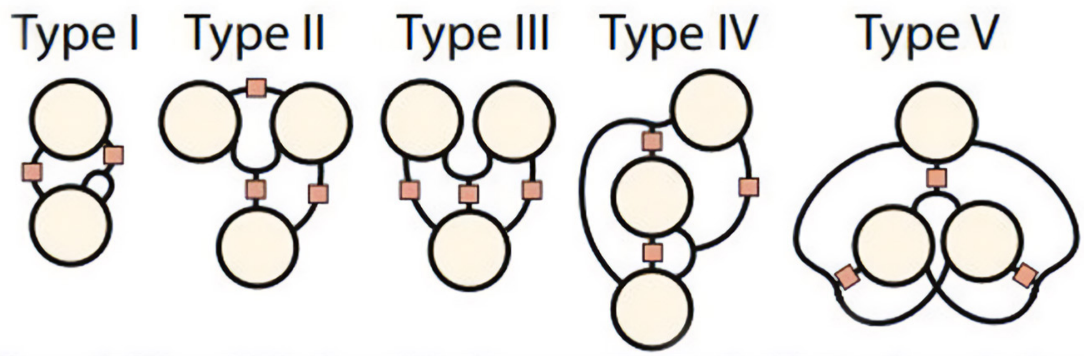

Figure 3: The five collectively autocatalytic motifs. The orange squares indicate locations where more reactions can be added as long as the motif type is preserved, (14).

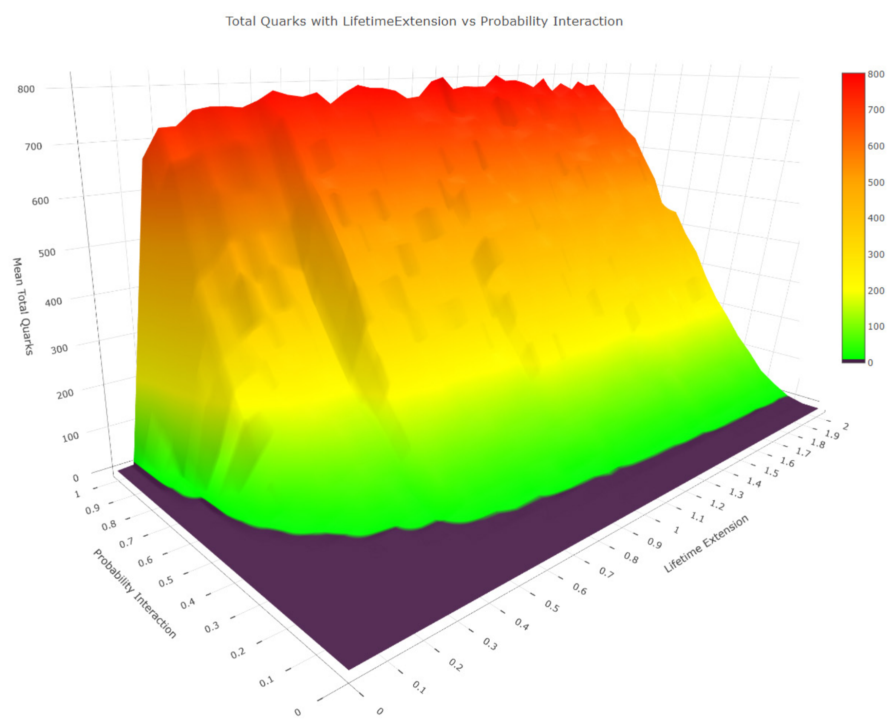

Figure 4a: One axis, labeled Lifetime Extension is identical to Delay. The other axis, Probability of Interaction ranges from 1 to 1.0. Each probability of interaction is linearly proportional to the number of variables in the system. The figure clearly shows the second order phase transition. The dark purple zone along both axes and extending into the two-parameter space corresponds to a formation of 5 or fewer quarks or antiquarks in 500-time steps. Further beyond the phase transition, the total number of quarks or of antiquarks created in 500-time steps increases.

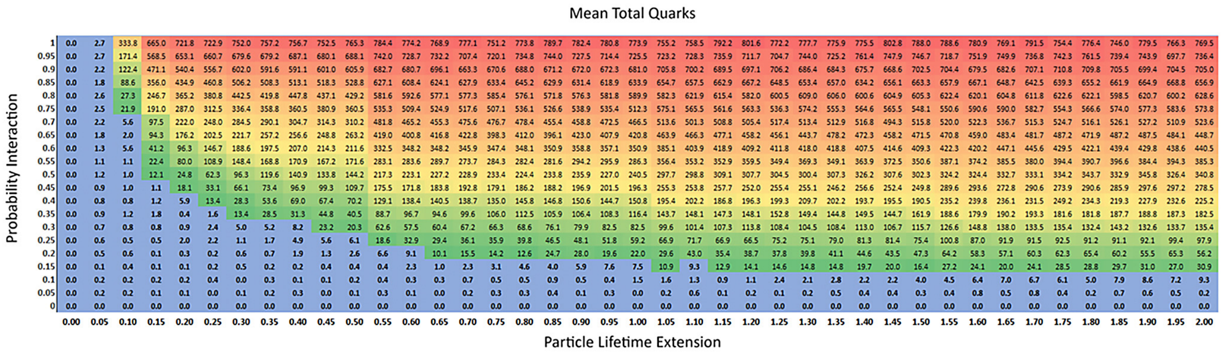

Figure 4b: The axes are identical to Figure 4a. Figure 4b shows the mean number of quarks plus antiquarks created in 500-time steps for all pairs of parameter values. Figure 4b shows the second order phase transition discussed. Decreasing probability of interaction can be used to model increasing spatial distance between variables during and after Inflation Note that even with a very small probability of interaction a slow rate of creation of quarks or of antiquarks continues.

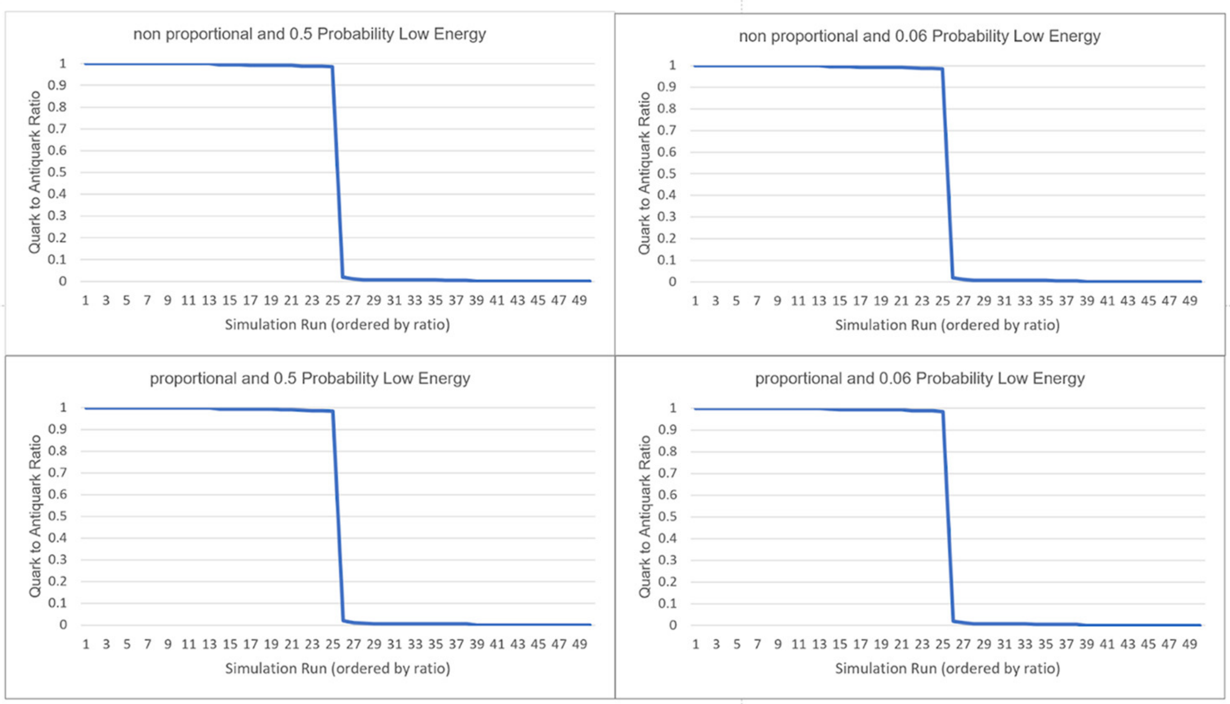

Figure 5: Panels a, b, c, and d, show 50 independent runs using different random “seeds” from the same PAM parameter settings. The data in each panel plot the “quark / antiquark ratio.” The results are striking. For half of the “runs,” the quark / antiquark ratio is 1.0 or slightly less, for the other half the ratio of quarks/antiquarks is 0.0 or slightly greater. The stochastic kinetic processes in PAM break matter antimatter symmetry and yields Baryogenesis with respect to quarks and antiquarks.

Figure 6a: PAM screen shot, power-law creation of spacetime and baryogenesis. PAM parameters make the rate of quark antiquark pair formation fully independent of the existing number of fermions and leptons. Power law creation of spacetime and baryogenesis with respect to quarks versus antiquarks. Above, upper right, quarks win. There is no baryogenesis with respect to electrons versus positrons or with respect to neutrinos versus antineutrinos, middle and lower right. Panel on the lower right shows the diversity of particles created in the system. The lower left panel shows the brief spike in matter density.

Figure 6b: PAM parameters make the rate of quark antiquark pair formation weakly dependent on the existing number of fermions and leptons. Power law creation of spacetime and baryogenesis with respect to quarks versus antiquarks. Above, upper right, antiquarks win. There is no baryogenesis with respect to electrons versus positrons or with respect to neutrinos versus antineutrinos, middle and lower right. Panel on the lower right shows the diversity of particles created in the system. The lower left panel shows the brief spike in matter density.

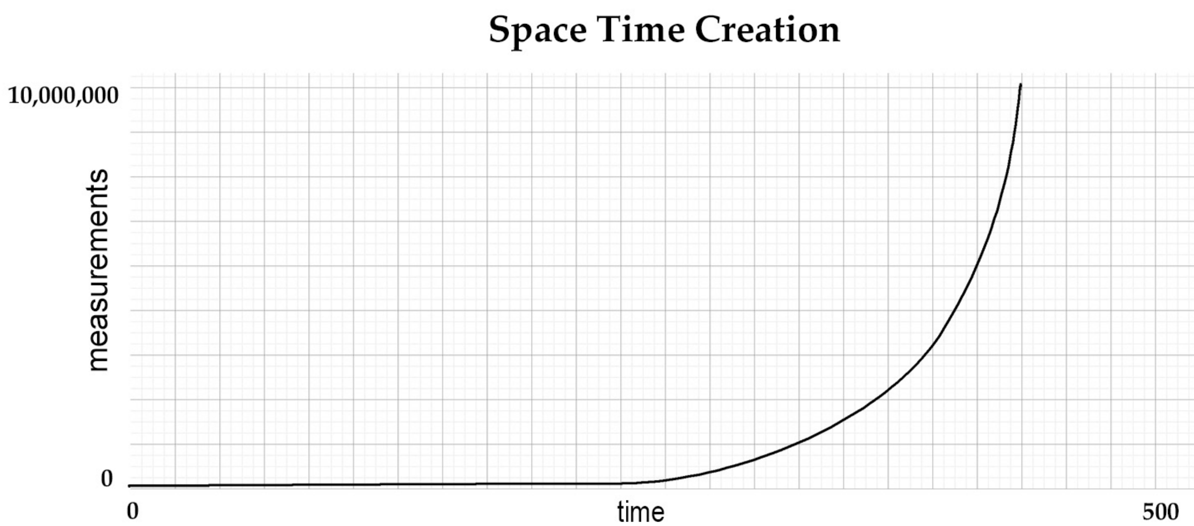

Figure 7: Spacetime Creation. Power law slope 4.643. PAM parameters set to make the rate of quark antiquark pair formation weakly proportional to the existing number of fermions and leptons. For each of the 100 runs from the same PAM parameter settings but from different random seeds, the kinetics of spacetime formation was analyzed both for the capacity to be fit by a power law and an exponential. In all PAM settings explored all curves are clearly best fit by a power law. The slopes vary, see Figure 8.

Prob Low Energy	mean slope of powerlaw	StdDev of slope	Max of slope	r^2 of powerlaw	r^2 of exponential
non proportional	**3.909**	**0.612**	**5.743**	**0.988**	**0.856**
0.06	3.844	0.494	4.940	0.989	0.853
0.5	3.975	0.710	5.743	0.987	0.858
proportional	**4.571**	**0.790**	**6.862**	**0.983**	**0.915**
0.06	4.843	0.885	6.862	0.984	0.922
0.5	4.300	0.572	5.794	0.983	0.908

Figure 8: Two conditions are varied independently: "i. The terms non-proportional" versus "proportional" refer to the independence or dependence of the process on the existing number of particles. ii. The terms 0.06 and 0.5 refer to the abundance of Up quarks or Up antiquarks relative to the abundance of Down quarks or Down antiquarks emerging from the vacuum. The ratio of Up to Down is higher for 0.06 than 0.5. The Figure shows the mean and standard deviation of the slope of the power laws for the creation of spacetime, the maximum slope seen, and the relative accuracy fitting of the observed curve of the creation of spacetime as a power law versus an exponential. In all cases the observed curves are better fit by a power law.