

A Supergravity Scenario for Asymmetric Visible Matter and Symmetric Dark Sector

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Abstract

We explore a minimal set of elements required in a phenomenological supersymmetric scenario describing the early phases of the evolution of the universe to the present form. After the Big Bang, a condensed graviton phase is supposed to predominate the universe producing axion like particles and torsion. Thereafter inflation takes place within a Wess-Zumino no-scale supergravity model. All standard model and dark sector fermions are created as spectators during early inflation from the supersymmetric preons. The dark sector particles are spectators all the way beyond reheating while the visible sector particles couple to the inflaton. Before reheating is reached supersymmetry is broken to the minimal supersymmetric standard model by gravitational mediation from the preon sector. The asymmetric visible matter, symmetric dark matter and dark energy are formed, and much later nucleons and light nuclei are produced. The preon level structure is necessary for the main result of this note, namely the mechanism which creates from C symmetric preons the asymmetric standard model visible matter directly, without notable amount of antimatter and without the Sakharov conditions. The symmetric dark sector allows annihilations of dark objects.

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1 Introduction

People who worked in particle physics in the 1960's remember the plethora of particles and resonances observed in accelerator experiments. Sensible theorists were able read from the data that certain composite structure is implied, with two light and one heavier constituent, to predict for example the baryon decuplet mass values. With some more ingenuity even the structure of the weak interactions was understood leading finally to the celebrated, all-embracing standard model (SM) of particles.

Encouraged by the success of group theory in quantum field theory various generalizations were developed in the 1970's. These include grand unified theories (GUT), supersymmetry and string theory. Unfortunately, the experimental situation could not follow this evolution. Many predictions would need data at ever higher energies, even 10 TeV is not enough. But fortunately, data have become available from the sky, the cosmic microwave background radiation (CMB). Tiny, cold photons are sending a message from the hot early times of the universe when the energies were above 10^9 TeV. Gravitational wave signals are also today observed, more so in the future. For the present, the standard model concepts have survived quite well in the new cosmological arena. But there is not enough experimental evidence for the beautiful theories of the 1970's mentioned above. We attempt in this note to take a modest step beyond the SM with the attitude that only those theoretical concepts are to be taken into consideration that are required, and supported by the present data.

We explore and identify theoretical ingredients to build a simple unified phenomenological scenario that would be capable of describing the evolution of the

universe during the earliest moments, and which leads to the present visible matter-antimatter asymmetric universe. This asymmetry is the central point of this note. The mechanism we propose for the asymmetry necessitates quark and lepton constituents, preons, above some energy scale Λ_{cr} . This scale turns out to be close to the usual grand unified theory (GUT) scale, about 10^{16} GeV. Below Λ_{cr} our scenario becomes very close to the minimal supersymmetric standard model (MSSM) - except that quarks and leptons are to high accuracy point-like behaving composite states of three preons. Above Λ_{cr} a phase transition takes place, and we have for visible matter only two preons, and their antiparticles, obeying unbroken global supersymmetry. The preons have only gravitational and electromagnetic interactions. Their baryon and lepton numbers are zero. Therefore our approach is a contrary alternative to the GUT idea. The formation of the matter-antimatter asymmetry is not rigorously proven but it is made plausible. The dark sector is symmetric and may provide a new source for detecting gravitational waves.

In our proposal, the spectrum of fundamental fields gets smaller towards Planck scale. This has been typical of physics when going from larger to shorter distances: hundreds of nuclear states can be explained by two nucleons, and hundreds of hadronic states by six quarks.¹

The main time period considered below is the era of inflation, and we only briefly mention supersymmetry breaking, reheating and later phases ending to thermalization of matter, and quarks forming nucleons and nucleons making the nuclei of the three lightest elements. We conclude that global supersymmetry is supported by observations given that the standard model superpartners are found some day. Supergravity scalar potential has been found for inflation by other people. Fermion interactions need further study, a tentative preon gauge interaction is proposed. A number of bosons that can be associated with string theory are needed in this scenario.

The article is organized as follows. In subsections 2.1 and 2.2 we summarize briefly the elementary fields of our scenario: very minimum of strings and global supersymmetry. In later sections we connect these theoretical concepts with observations. In section 3 candidates for dark matter are discussed. The visible standard model matter is produced in reheating by coupling to the inflaton in a no-scale supergravity model, with hints from string theory, as described in section 4. In section 5 the scenario for the creation of matter-antimatter asymmetric universe by charge symmetric preons is proposed. The idea behind the asymmetry is that the *same* twelve C symmetric preons may form matter at one time and antimatter at another time, see (5.1). A prefatory mechanism is described why matter was chosen for our universe. The dark sector contains possibilities for large scale celestial annihilation processes. Conclusions are given in section 7. In the Appendix A we describe some computational

¹Gravity and electromagnetism with two fermions can make a perfect universe. With the SM non-Abelian sector chemistry and biology become available providing the universe with observers. Above Λ_{cr} the non-Abelian couplings are small anyhow.

methods from literature for cosmological simulations. – The original contributions of this author are the supersymmetric preon (superon from now on) scenario for the visible and dark sector particles, and the mechanism for producing the asymmetric universe. Material from the literature is added to make the presentation self-contained and entire.

2 Theory Concepts

In this section we present a brief list of the theoretical tools needed in later sections. The concepts are discussed in the order they are needed in the early universe. Our treatment is on the physics of the phenomena. The full mathematical treatment of these concepts is available in the literature and textbooks, see e.g. [1, 2, 3, 4].

2.1 Bosonic String

A point particle has one dimensional world line with a tangent vector $dx^\mu(\tau)/d\tau$, where τ is the world line parameter. The tangent vector and the Maxwell field can be multiplied to form a Lorentz scalar. The interaction of a point particle of charge e with the Maxwell gauge field is written as $e \int \frac{dx^\mu(\tau)}{d\tau} A_\mu(x(\tau)) d\tau$.

The endpoints of open strings may carry electric charge. But having two Lorentz indexes we hope to discover a new kind of charge that could be contracted with the string indexes. Such a field is the Kalb-Ramond antisymmetric tensor $B_{\mu\nu} = -B_{\nu\mu}$. It is a massless closed string. The obvious way to write a Lorentz scalar with two string tangent vectors of the form $\partial X^\lambda/d\rho$ is

$$- \int \frac{\partial X^\mu}{d\tau} \frac{\partial X^\nu}{d\sigma} B_{\mu\nu}(X(\tau, \sigma)) d\tau d\sigma \quad (2.1)$$

This describes how a string carrying electric Kalb-Ramond charge couples to the antisymmetric Kalb-Ramond field. The new field strength associated to $B_{\mu\nu}$ is $H_{\mu\nu\rho}$ is defined by

$$H_{\mu\nu\rho} = \partial_\mu B_{\nu\rho} + \partial_\nu B_{\rho\mu} + \partial_\rho B_{\mu\nu} \quad (2.2)$$

The $H_{\mu\nu\rho}$ plays the same role as torsion in general relativity providing an antisymmetric component to the affine connection.

The total action, analogous to the corresponding Maxwell action, is

$$S = S_{str} - \frac{1}{2} \int \frac{\partial X^{[\mu}}{d\tau} \frac{\partial X^{\nu]}}{d\sigma} B_{\mu\nu}(X(\tau, \sigma)) d\tau d\sigma + \int d^D x \left(-\frac{1}{6} H_{\mu\nu\rho} H^{\mu\nu\rho} \right) \quad (2.3)$$

where $x^{[\mu}y^{\nu]} \equiv x^\mu y^\nu - x^\nu y^\mu$. S_{str} includes general relativity. In summary, the bosonic string oscillation include these (26D) quantum fields: the symmetric metric tensor $G_{\mu\nu}(X)$, the antisymmetric $B_{\mu\nu}(X)$, and the scalar $\phi(X)$.

In 4D the equations of motion imply that the dual of H field strength, $\epsilon^{\mu\nu\rho\sigma} H_{\mu\nu\rho}$ can be represented as $\partial^\sigma b(x)$, where $b(x)$ is a pseudoscalar, the Kalb-Ramond axion. It is a generalization of Peccei-Quinn axion. We will discuss axions and torsion in later sections.

2.2 Supergravity

We briefly recap the superon scenario of [5, 6], which turned out to have close resemblance to the simplest N=1 globally supersymmetric 4D model, namely the free, massless Wess-Zumino model [7, 8] with the kinetic Lagrangian including three neutral fields m , s , and p with $J^P = \frac{1}{2}^+$, 0^+ , and 0^- , respectively

$$\mathcal{L}_{\text{WZ}} = -\frac{1}{2}\bar{m}\not{\partial}m - \frac{1}{2}(\partial s)^2 - \frac{1}{2}(\partial p)^2 \quad (2.4)$$

where m is a Majorana spinor, s and p are real fields (metric is mostly plus).

We assume that the pseudoscalar p is the axion [9], and denote it below as a . It has a fermionic superpartner, the axino n , and a bosonic superpartner, the saxion s^0 .

In order to have visible matter we assume the following charged chiral field Lagrangian

$$\mathcal{L}_- = -\frac{1}{2}m^-\not{\partial}m^- - \frac{1}{2}(\partial s_i^-)^2, \quad i = 1, 2 \quad (2.5)$$

The first generation standard model particles are formed combinatorially (mod 3) of three superons, the charged m^\pm , with charge $\pm\frac{1}{3}$, and the neutral m^0 , as composite states below an energy scale Λ_{cr} [6], see lower part of Table 1.

Confinement of superons within quarks and leptons can be caused by a gauge boson interaction, a Yukawa interaction, or an attractive gravity-like intense interaction (yet to be defined). The indexes (i, j, k) of the m and n in table 1 look, and are, SU(3) color indexes, but no $J \propto M^2$ QCD-like excitations are known.² The deconfinement temperature Λ_{cr} is in principle calculable but at present it has to be accepted as a free parameter. Numerically $\Lambda_{cr} \sim 10^{10-16}$ GeV, somewhat above the reheating temperature (at reheating there must be SM particles, i.e. visible matter). The R-parity of superons is simply $P_R = (-1)^{2 \times spin}$.

Introducing local supersymmetry for superons is an open question in our scenario at the moment. It is a task for the future. In section 4 we discuss a boson sector interaction potential for inflation within a mini supergravity model, and in section 5 we propose a tentative superon-superon gauge interaction.

²The superons may be in a Higgs phase of a gauge Higgs theory. The Higgs field would be in the fundamental representation of the gauge group SU(3). In this case it is claimed there are no fermion excitations [10, 11].

3 Dark Matter

For a general introduction to particle dark matter, see e.g. [14]. Literature on dark matter, dark energy, and axions is extensive, see e.g. [15, 16, 17, 18]. In this section we patch our shortage in [6] to consider the pseudoscalar of (2.4). So we start from the Lagrangian (2.4).

As stated in the previous section 2.2, the superpartners of the axion a are the fermionic axino n , and the scalar saxion s^0 , also indicated in Table 1.³ Particle dark matter consists of all these three particles. The axino n may appear physically as single particle dust or three n composite o dust, gas, or a large astronomical object. The fermionic DM behaves naturally very differently from bosonic DM, which may form in addition Bose-Einstein condensates.

Other candidate forms of DM include primordial black holes (PBH). They can be produced by gravitational instabilities induced from scalar fields such as axion-like particles or multi-field inflation. It is shown in [19] that PBH DM can be produced only in two limited ranges of 10^{-15} or 10^{-12} Solar masses (2×10^{30} kg). Dark photons open a rich phenomenology described [20]. We also mention another supergravity (the graviton-gravitino supermultiplet) based model [21], which may help to relieve the observed Hubble tension [22].

Table 1: Superon content of Dark Matter and the Standard Model particles.

Dark Matter	Superon state
boson(system)	axion, s^0
o -fermion(system)	$\epsilon_{ijk}n_i n_j n_k$
SM Matter	Superon state
e^-	$\epsilon_{ijk}m_i^- m_j^- m_k^-$
u_k	$\epsilon_{ijk}m_i^+ m_j^+ m_k^0$
d_k	$\epsilon_{ijk}m_i^- m_j^0 m_k^0$
ν	$\epsilon_{ijk}m_i^0 m_j^0 m_k^0$

The axion was originally introduced to solve the strong CP problem in quantum chromodynamics (QCD) [9], see also [23, 24]. The PQ axion has a mass in the range 10^{-5} eV to 10^{-3} eV. Axions, or axion-like particles (ALP), occur also in string theory in large numbers (in the hundreds), they form the axiverse.

The axion-like particle masses extend over many orders of magnitude making them distinct candidate components of dark matter. Ultra-light axions (ULA), with masses 10^{-33} eV $< M_a < 10^{-20}$ eV, roll slowly during inflation and behave like dark energy before beginning to oscillate (as we see below). The lightest ULAs with $M_a \lesssim 10^{-32}$ eV are indistinguishable from dark energy. Higher mass ALPs, $M_a \gtrsim 10^{-25}$ eV behave like cold dark matter [18]. Quantum mechanically, an axion of mass of, say 10^{-22} eV, has a Compton wavelength of 10^{16} m.

³In this note we mostly talk about all spin zero particles freely as scalars.

Ultra-light bosons with masses $\ll \text{eV}$ can form macroscopic systems like Bose-Einstein condensates, such as axion stars [12, 13]. Due to the small mass the occupation numbers of these objects are large, and consequently, they can be described classically.

The fermionic axino n is supposed to appear, like the m superons, as free particle if $T > \Lambda_{cr}$ and when $T \lesssim \Lambda_{cr}$ in composite states. If the mass of the axino composite state o is closer to the electron mass rather than the neutrino mass it may form 'lifeless' dark stars in a wide mass range. In general, dark matter forms haloes with galaxies residing within.

Let us go to the early universe. Axions are treated as spectator fields during inflation [15, 16, 17].⁴ In fact, all superons are spectators until reheating, which in turn heats the visible matter only. The axion is massless as long as non-perturbative effects are absent. When these effects are turned on the PQ symmetry is broken and the axion acquires a mass. A minimally coupled scalar field ϕ in General Relativity has an action

$$S = \int d^4x \sqrt{-g} \left[-\frac{1}{2}(\partial\phi)^2 - V(\phi) \right] \quad (3.1)$$

In the Friedmann-Lemaitre-Robertson-Walker metric with potential $V = \frac{1}{2}M_a^2\phi^2$ ⁵ the axion equation of motion is

$$\ddot{\phi}_0 + 2\mathcal{H}\dot{\phi}_0 + M_a^2 a^2 \phi_0 = 0 \quad (3.2)$$

where ϕ_0 is the homogeneous value of the scalar field as a function of the conformal time τ , a is here the cosmological scale factor, and dots denote derivatives with respect to conformal time.

At an early time $t_i \gtrsim 10^{-36}\text{s}$, $M_a \ll H$ and the axion rolls slowly. If the initial velocity is zero it has equation of state $w_a \equiv P_a/\rho_a \simeq -1$. Consequently, the axion is a component of dark energy. With $t > t_i$ the temperature and H decrease and the axion field begins to oscillate coherently at the bottom of the potential. This happens when

$$M_a = 3H(a_{osc}) \quad (3.3)$$

which defines the scale factor a_{osc} . Now the number of axions is roughly constant and the axion energy density redshifts like matter with $\rho_a \propto a^{-3}$. The relic density parameter Ω_a is

$$\Omega_a = \left[\frac{1}{2a^2} \dot{\phi}_0^2 + \frac{M_a^2 a}{2} \phi_0^2 \right]_{M_a^2=3H} a_{osc}^3 / \rho_{crit} \quad (3.4)$$

⁴On the other hand, the axion can be modeled as causing the inflation [25].

⁵This is an adequate approximation over most of the parameter space observationally allowed provided $f_a < M_{\text{Pl}}$. The potential is anyway unknown away from the minimum without a model for nonperturbative effects.

where ρ_{crit} is the cosmological critical density today. Explicit estimates for the relic density are given in [18]. This applies to all axion-like particles, if there are many like in string theory.

When radiation and matter match in Λ CDM model the Hubble rate is $H(a_{eq}) \sim 10^{-28}$ eV. Axions with mass larger than 10^{-28} eV begin to oscillate in the radiation era and may provide for even all of dark matter. The upper limit of the ultralight axion mass fraction Ω_a/Ω_{DM} , where Ω_a is the axion relic density and Ω_{DM} is the total DM energy density parameter, varies from 0.6 in the low mass end 10^{-33} eV to 1.0 in the high mass limit 10^{-24} eV. In the middle region Ω_a/Ω_{DM} is constrained to be below about 0.05 [18].

The dark fermions may be at this stage be approximated as scalars or as fermion-antifermion pairs. Their behavior follows that of scalar particles until reheating at which time the composite states o may form (without heating up).

4 Inflation and Supergravity

This section is a brief review of work done by other authors. It is included because CMB measurements offer data of inflation in the relevant energy region for testing supergravity.

The era of the universe before inflation ($t < 10^{-36}$ s) is largely unknown. A possible assumption is that it is a phase of strings of gravitation, with quantum fluctuating energy. Within this scenario it would be a condensed state of gravitons. From section 2.1, we assume that some scalar ϕ will initiate inflation, which is discussed below in terms of supergravity, the low energy limit of string theory.⁶

At the beginning of inflation, $t = t_i \sim 10^{-36}$ s, the universe is modeled by gravity and a scalar inflaton ϕ with some potential $V(\phi)$. The Einstein-Hilbert action is

$$S = \int d^4x \sqrt{-g} \left(\frac{1}{2} R - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right) \quad (4.1)$$

Inflation ends at $t_R \approx 10^{-32}$ s when the inflaton, which is actually coherently oscillating homogeneous field, a Bose condensate, reaches the minimum of its potential. There it oscillates and decays by coupling to SM particles produced from m superons at the end of inflation. This causes the reheating phase, or the Bang, giving visible matter particles more kinetic energy than dark matter particles have.

The CMB measurements of inflation can be well described by a few simple slow-roll single scalar potentials in (4.1). One of the best fits to Planck data [27] is obtained by one of the very oldest models, the Starobinsky model [28]. The action is

$$S = \frac{1}{2} \int d^4x \sqrt{-g} \left(R + \frac{R^2}{6M^2} \right) \quad (4.2)$$

⁶The issues of the trans-Planckian zone for inflationary models are reviewed in [26] but they are beyond the scope of this note.

where $M \ll M_{\text{Pl}}$ is a mass scale. Current CMB measurements indicate scale invariant spectrum with a small tilt in scalar density $n_s = 0.965 \pm 0.004$ and an upper limit for tensor-to-scalar ratio $r < 0.06$. These values are fully consistent with the Starobinsky model (4.2) which predicts $r \simeq 0.003$.

The model (4.2) has the virtue of being based on gravity only physics. Furthermore, the Starobinsky model has been shown to correspond to no-scale supergravity coupled to two chiral supermultiplets. Some obstacles have to be sorted out before reaching supergravity. In this section we follow the review by Ellis, García, Nagata, Nanopoulos, Olive and Verner [29].

The first problem with generic supergravity models with matter fields is that their effective potentials do not provide slow-roll inflation as needed. Secondly, they may have anti-deSitter vacua instead of deSitter ones. Thirdly, looking into the future, any new model of particles and inflation should preferably be consistent with some string model properties. These problems can be overcome by no-scale supergravity models. No-scale property comes from their effective potentials having flat directions without specific dynamical scale at the tree level. This has been derived from string models, whose low energy effective theory supergravity is.

Other authors have studied other implications of superstring theory to inflationary model building focusing on scalar fields in curved spacetime [25] and the swampland criteria [30, 31, 32]. These studies point out the inadequacy of slow roll single field inflation. We find it important to establish first a connection between the Starobinsky model and (two field) supergravity.

The bosonic supergravity Lagrangian includes a Hermitian function of complex chiral scalar fields ϕ_i which is called the Kähler potential $K(\phi^i, \phi_j^*)$. It describes the geometry of the model. In minimal supergravity (mSUGRA) $K = \phi^i \phi_i^*$. Secondly the Lagrangian includes a holomorphic function called the superpotential $W(\phi^i)$. This gives the interactions among the fields ϕ^i and their fermionic partners. K and W can be combined into a function $G \equiv K + \ln |W|^2$. The bosonic Lagrangian is of the form

$$\mathcal{L} = -\frac{1}{2}R + K_i^j \partial_\mu \phi^i \partial^\mu \phi_j^* - V - \frac{1}{4} \text{Re}(f_{\alpha\beta}) F_{\mu\nu}^\alpha F^{\beta\mu\nu} - \frac{1}{4} \text{Im}(f_{\alpha\beta}) F_{\mu\nu}^\alpha \tilde{F}^{\beta\mu\nu} \quad (4.3)$$

where $K_i^j \equiv \partial^2 K / \partial \phi^i \partial \phi_j^*$ and $\text{Im}(f_{\alpha\beta})$ is the gauge kinetic function of the chiral fields ϕ^i . In mSUGRA the effective potential is

$$V(\phi^i, \phi_j^*) = e^K [|W_i + \phi_i^* W|^2 - 3|W|^2] \quad (4.4)$$

where $W_i \equiv \partial W / \partial \phi^i$. It is seen in (4.4) that the last term with negative sign may generate AdS holes with depth $-\mathcal{O}(m_{3/2}^2 M_{\text{Pl}}^2)$ and cosmological instability. Solution to this and the slow-roll problem is provided by no-scale supergravity models. The simplest such model is the single field case with

$$K = -3 \ln(T + T^*) \quad (4.5)$$

where T is a volume modulus in a string compactification.

The single field (4.5) model can be generalized to include matter fields ϕ^i with the following Kähler potential

$$K = -3 \ln(T + T^* - \frac{1}{3} |\phi_i|^2) \quad (4.6)$$

The no-scale Starobinsky model is now obtained with some extra work from the potential (4.4) and assuming $\langle T \rangle = \frac{1}{2}$. For the superpotential the Wess-Zumino form is introduced [33]

$$W = \frac{1}{2} M \phi^2 - \frac{1}{3} \lambda \phi^3 \quad (4.7)$$

which is a function of ϕ only. Then $W_T = 0$ and from $V' = |W_\phi|^2$ the potential becomes as

$$V(\phi) = M^2 \frac{|\phi|^2 |1 - \lambda \phi / M|^2}{(1 - |\phi|^2 / 3)^2} \quad (4.8)$$

The kinetic terms in the scalar field Lagrangian can be written now

$$\mathcal{L} = (\partial_\mu \phi^*, \partial_\mu T^*) \begin{pmatrix} 3 \\ (T + T^* - |\phi|^2 / 3)^2 \end{pmatrix} \begin{pmatrix} (T + T^*) / 3 & -\phi / 3 \\ -\phi^* / 3 & 1 \end{pmatrix} \begin{pmatrix} \partial^\mu \phi \\ \partial^\mu T \end{pmatrix} \quad (4.9)$$

Fixing T to some value one can define the canonically normalized field χ

$$\chi \equiv \sqrt{3} \tanh^{-1} \left(\frac{\phi}{\sqrt{3}} \right) \quad (4.10)$$

By analyzing the real and imaginary parts of χ one finds that the potential (4.8) reaches its minimum for $\text{Im} \chi = 0$. $\text{Re} \chi$ is of the same form as the Starobinsky potential in conformally transformed Einstein-Hilbert action [34] with a potential of the form $V = \frac{3}{4} M^2 (1 - e^{-\sqrt{2/3} \phi})^2$. when

$$\lambda = \frac{M}{\sqrt{3}} \quad (4.11)$$

Most interestingly, λ/M has to be very accurately $1/\sqrt{3}$, better than one part in 10^{-4} , for the potential to agree with measurements.

This is briefly the basic mechanism behind inflation in the Wess-Zumino mSUGRA model, which foreruns reheating for visible matter. Up to now, model dependence in our scenario has been rather mild. Essential during inflation is that none of the fields have interactions, apart from gravity. All particles in (2.4) and (2.5) fulfill this condition. At $T \sim \Lambda_{cr}$ the m and n superons form composite states. But only the particles containing m superons, i.e. the visible matter gets reheated. The dark sector is going through reheating unaffected and is distributed smoothly all over space. The quantum fluctuations of the dark fields are enhanced by gravitation and provide a clumpy underlay for visible matter to form objects of various sizes, from stars to large scale structures.

5 Matter-Antimatter Asymmetry

The crucial fact enabling the asymmetric creation of matter in the early universe is that the *same* twelve superons, namely four m^+ , four m^- and four m^0 , may form both hydrogen and anti-hydrogen atom by organizing the superons differently in sets of three using table 1:

$$\begin{aligned} p + e^- &:= u^{2/3} + u^{2/3} + d^{-1/3} + e^- \\ &:= \sum_{l=1}^4 [m_l^+ + m_l^- + m_l^0] =: \bar{p} + e^+ \end{aligned} \quad (5.1)$$

where the superscript is the charge of the particle and \pm indicates charge $\pm\frac{1}{3}$ (the $=:$ on the second line must be read from right to left). In this scenario neither baryon number B nor lepton number L is fundamental but the difference of baryon and lepton number is, which can be read from (5.1)

$$B - L \equiv 0 \quad (5.2)$$

If (5.2) is elevated as a rule of nature the proton decay $p \rightarrow e^+ \pi^0$ is forbidden. Here the present scenario differs from the MSSM, which deserves a study of its own.

One may consider B–L as a continuous gauge symmetry $U(1)_{B-L}$ [1, 35] above the energy scale Λ_{cr} . We call it $U(1)_{superon}$ because superons are available above Λ_{cr} , not baryons or leptons. The corresponding gauge boson couples only to superons and is not therefore detectable with current detectors.

The superon content of the early universe evolves as follows. The wave function of the universe at $t = t_i$ is an initial state $\Psi = c_0(t_i)\Psi_{superon}$ described by the gravitational superon sector of subsection 2.1.

Towards the end of inflation the phase transition takes place and Ψ develops into standard model universe

$$\Psi = c_1(t)\Psi_{matter} + c_2(t)\Psi_{antimatter} + c_3(t)\Psi_{radiation} \quad (5.3)$$

Nature has chosen the first line of (5.1), or $c_1 \approx 1$ and $c_2 \approx 0 \neq c_3$, but how?⁷

When a large number of superon-antisuperon pairs are created from vacuum the question is which way they will organize themselves: will they be mostly hydrogen, or anti-hydrogen, or mostly radiation? Observations favor the first alternative (the second means only charge redefinition). We try to develop a precursory mechanism for this case.

In this scenario fermionic superons m and n are created as spectator quantum fields when inflation starts and the metric still has significant quantum fluctuations. By the combinatorial (mod 3) rule, there is non-zero quantum

⁷The superon scenario offers a rudimentary candidate solution by assuming first that $c_1 \gtrsim c_2 > 0$. Later the antimatter section would annihilate its part of the matter section and the rest of matter remains.

probability for three m^- superons to gravitationally, or even spontaneously, form an electron at time $t \gtrsim t_i$. This probability is increased if there is a transient C asymmetry in spacetime like one caused by torsion which leads to a difference in fermion masses. The superon density is high enough in the early phase of inflation for torsion to be effective. The torsional correction to a fermion mass is $M_t = M + a/M_{\text{Pl}}^2$ where $a \propto 1$ [36]. For an antifermion the correction term is negative. In the environment at $t \gtrsim t_i$ this mass difference needs not be small. The newly formed e^- is expected to create subtle order by causing movement of the lighter superons in spacetime towards it. It generates a small correlation length λ_{cor} , and a corresponding 3D volume, within which different superon charge states are differentiated. Therefore the electron causes the formation of a correlated region, or bubble, contains antifermions m^+ and m^0 , which in turn form u and d quarks and much later hydrogen atoms with the electron.

Inflation is advanced by the potential (4.7). After the first electron-quark pair correlation has formed the correlation length scale λ_{cor} and the corresponding bubble volume expand exponentially due to inflation.⁸ Particles move away, in their co-moving frames, from each other due to inflationary expansion of space. Inside the first bubble, every new bubble, which contains twelve, or in fact a myriad more, superons at high density in the formation point, the torsion induced correlation occurs again between the three heavier m^- and the lighter two m^+ and an m^0 (or an m^+ and two m^0). Consequently, predominantly standard model matter production occurs during inflation.

The inflaton decay takes place after the inflaton has reached the minimum of its potential and it couples to the quarks and leptons while vibrating in its ground state causing reheating. The SM particles have now only a few antiparticles to annihilate with. Without further interactions we have $r_B \approx 0$. The expansion, reheating and all the later processes ultimately produce what we see as the observed universe.

All dark matter is smoothly distributed, apart from quantum fluctuations of the corresponding fields, in the universe after inflation because they were unaffected by the reheating. Gravity strengthens, however, clumps in dark matter. Visible matter fields in turn lose their original quantum fluctuations and are remodulated by reheating towards uniform distribution in space. Quantum fluctuations in the dark fields during inflation may lead to formation of primordial black holes in the universe. These density variations of DM provide attractive gravitational potential regions for visible matter to accumulate in the various formations we observe [14].

Fermionic dark matter has in this scenario no mechanism to become 'baryon' asymmetric like visible matter. Therefore we expect that part of dark matter has annihilated into bosonic dark matter. Secondly, there should exist both dark matter and anti-dark matter clumps in the universe. Collisions of anti-dark matter and dark matter celestial bodies would give us a new source for

⁸This idea of λ_{cor} growing exponentially during inflation was suggested to us by R. Brandenberger.

wide spectrum gravitational wave production (the lunar mass alone is $\sim 10^{49}$ GeV). High dark matter density, see (A.4), is found only in the solitonic halo centers. Such collisions are obviously rare.

6 Supersymmetry Breaking

There are several ways supersymmetry may get broken, and they are described extensively in a number of articles, reviews and textbooks [1, 2, 3, 4]. The first and to us the relevant method is the gravitationally mediated scenario. Supersymmetry is unbroken in the superon sector and is mediated by gravitational interaction to the visible minimal supersymmetric standard model sector by soft term contributions, which means that the Lagrangian has two terms: symmetric and symmetry breaking

$$\mathcal{L} = \mathcal{L}_{susy} + \mathcal{L}_{soft} \quad (6.1)$$

where \mathcal{L}_{soft} violates supersymmetry but only by mass terms and coupling constants having positive mass dimension. It can be done consistently with the section 4.⁹

The brief description is that if supersymmetry is broken in the superon sector by a vev $\langle F \rangle$ then the soft terms in the visible sector are expected to be approximately $M_{soft} \sim \langle F \rangle / M_{\text{Pl}}$. For $M_{soft} \sim 200$ GeV one would estimate that the scale associated with supersymmetry breaking in the superon sector is about $\sqrt{\langle F \rangle} \sim 10^{10}$ or 10^{11} GeV, which must be below Λ_{cr} for consistency. This way the MSSM soft terms arise indirectly or radiatively, instead of tree-level renormalizable couplings to the supersymmetry breaking parameters. The gravitino mass is of the order of the masses of the MSSM sparticles. The gravitino in turn mediates the symmetry breaking with gravitational coupling to the MSSM. A gravitino mass of the order of TeV gives a lifetime 10^5 s, long enough not to disturb nucleosynthesis by decay products.

7 Conclusions

By defining the fundamental fields as superons in (2.4) and (2.5) in section 2 it has been possible to develop a scenario for asymmetric visible matter as well as for the symmetric dark sector. The latter includes both fermionic and bosonic fields. The bosonic sector of (2.4) contains axion-like particles, a string theory concept. They are obvious candidates for bosonic dark matter are axions when $M_a \gtrsim 10^{-25}$ eV and dark energy when $M_a \lesssim 10^{-32}$ eV.

The matter-antimatter asymmetry is, according to our proposal, created from C symmetric, baryon and lepton neutral superons without the Sakharov conditions. Below the transition energy Λ_{cr} fractional charge three superon composites form quarks while charge zero and one states are leptons. These

⁹If needed, the MSSM superpartners can be thought of in terms of superons by adding an m^0 to the three m composites.

composite states are to a good approximation point-like, radius between 10^{-18} cm and the electron Compton radius. Baryons and electrons are produced towards the end of inflation in equal amounts ($B-L=0$) by the matter production process described in section 5. Dark matter is insensitive to reheating and therefore occurs in the universe as a background gravitational potential for visible matter to form the astronomical objects we observe. Anti-dark matter celestial body annihilation phenomena would provide a new source for observing gravitational waves.

In nutshell, starting from the Wess-Zumino supergravity Lagrangians with three fermions (m^+, m^0, n), the mSUGRA potential (4.7) and some stringy hints for bosons we have constructed a unified picture of quarks, leptons and the dark sector. The main point, the creation of the matter-antimatter asymmetric universe has been made plausible. The dark sector, instead, is predicted to be C symmetric.

In this analysis the role of superstring theory remains tenuous. This is not surprising since we have discussed a non-GUT 4D low energy model. One would have to start from 10D or 11D.¹⁰ Torsion is a high energy density spacetime property in general relativity and string theory. We conjecture that the asymmetry caused by torsion to fermions is valid in general in higher dimensional theories. For decisive experimental tests one may have to wait for the next generation neutrino and gravitational wave detection experiments that are able to measure the energy range above EeV.

To prove or disprove the scenario presented above, extensive simulations are to be done, more detailed Lagrangians to be written and calculated. Phenomenological work is to be carried out with current data for supersymmetry breaking and particle masses while waiting for future precision experiments to be carried out in the years to come. A necessary step is to find the theory of gluing the fermionic superons back into standard model particles.

A Simulation

We consider briefly some simulation methods of the evolving universe for the next phase of this study. Galaxy formation starting from time zero to present time is a demanding task due to several energy scales and the many physical phenomena involved. Simulation methods form an extensive literature and they are beyond the scope of this note. A review of cosmological simulations of galaxy formation is [38], a recent paper on dark matter simulation is [39]. We limit below only to some general remarks that have to be taken into account.

Dark matter Boltzmann-Poisson simulation. The newly created dark matter particles are described by a phase-space density function $f = f(\mathbf{x}; \mathbf{v}; t)$ which obeys the collisionless Boltzmann equation. The particles are, however, influenced by a collective gravitational potential Φ obeying Poisson equation. These

¹⁰It is claimed in [37] that regions of 4-dimensional spacetime, in which extra compact dimensions are sufficiently rich to be observed, must be trapped behind black holes.

equations are [38]

$$\frac{df}{dt} = \frac{\partial f}{\partial t} + \mathbf{v} \frac{\partial f}{\partial \mathbf{x}} - \frac{\partial \Phi}{\partial \mathbf{x}} \frac{\partial f}{\partial \mathbf{v}} = 0 \quad (\text{A.1})$$

and

$$\nabla^2 \Phi = 4\pi G \int f d\mathbf{v} \quad (\text{A.2})$$

These two equations are to be solved in the expanding universe governed by the Friedmann equations obtained from general relativity. In (A.2) it is a good approximation to use Newtonian gravity rather than GR. It is customary to use periodic boundary conditions to mimic homogeneity and isotropy of the universe. The high dimensionality of (A.1) forbid any standard discretization method for solving partial differential equations. In the more efficient N-body method phase-space density is sampled by N initial points $\mathbf{x}_i, \dot{\mathbf{x}}_i, i = 1, \dots, N$ with masses M_i to get the initial distribution function $f(\mathbf{x}; \mathbf{v}; t)$. The resulting N-body system is evolved with a numerical method. Two body interactions are suppressed at small scales to prevent artificial formation of binaries. The discrete Boltzmann equation describes the evolution of gravitationally auto-interacting mass points. Dark fermionic matter proceeds like visible matter with the formation of three n composite states.

Dark matter Schrödinger-Poisson simulation. Assuming that the scalar dark matter particles are ultra light axions one can use the Schrödinger-Poisson equations, in dimensionless form [40]

$$\begin{aligned} i \frac{\partial \Psi}{\partial t} &= -\frac{1}{2} \nabla^2 \Psi + aV \Psi \\ \nabla^2 V &= |\Psi|^2 - 1 \end{aligned} \quad (\text{A.3})$$

where $a \equiv a(t)$ is the cosmic scale factor and Ψ is normalized in volume \mathcal{V} as $\frac{1}{\mathcal{V}} \int |\Psi|^2 d\mathcal{V} = 1$. The equations A.3 were solved using a classical spectral method using unitary operators, Fast Fourier transforms (FFTs), and inverse FFTs [41].

Experimental halo observations are well described by the calculations in [41]. The boson mass was taken to be $M = 2.5 \times 10^{-22}$. The simulation space consisted of 512^3 cells for a cubic box of a side of 1 Mpc. Run times were long enough for dynamic equilibrium to form. Typical mass values of halos were in the range of 10^7 to 10^9 solar masses.

The equations (A.3) have stable soliton solutions with a core approximated

$$\rho_s(r) \simeq \rho_0 \left[1 + 0.091 \left(\frac{r}{r_c} \right)^2 \right]^{-8} \quad (\text{A.4})$$

where r_c is the core radius and ρ_0 is the central density. The Heisenberg relations prevent the Bose system from collapse under self-gravity. This soliton profile has a flat center and r^{-16} behavior far away from the center. The core is characterized by a single parameter, the core radius, or core mass which are related like $M_c(r_c) \propto 1/r_c$. Fermionic dark particles are expected to follow

approximately (A.3) but instead of being inclined to condensation they build shell structure resembling inactive neutron stars.

Visible matter simulation. The modeling used for dark matter applies to visible matter in the very early phase of inflation but quarks and leptons begin to form soon, as described in section 4. The process $3m \rightarrow \text{quark/lepton}$ is assumed to be a smooth process like second order phase transition. Unlike dark matter, visible matter experiences the coupling to inflaton. This leads to smooth distribution of visible matter in the universe. Later visible matter is attracted gravitationally by the less smoothly distributed dark matter.

Quantum Simulation. A new era will start when quantum simulation methods become available some time in the future. The present situation is discussed in [40], [42].

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