Comets, Water, and Big Bang Nucleosynthesis

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Abstract

We argue that the cosmological origin-of-life problem is tightly connected to the origin-of-water problem, because life is not possible without abundant water. Since comets are astronomically dark and composed of water, as well as possessing microfossils, they are an underestimated candidate for the origin of life. If in addition dark matter is composed of comets, then water outweighs the visible stars, possibly solving several cosmological mysteries simultaneously. This motivates us to consider how it is possible to build a cosmological model in which water is formed in the Big Bang and then hidden from modern astronomy. In the process, we discover that magnetic fields play an important role in making water, as well as addressing several well-known deficiencies of the standard ΛCDM cosmological model of the Big Bang. We do not see this paper as a demonstration but as an outline of how to address the origin of life problem with dark comets.

1 Introduction

This paper attempts an outline of how to solve several hard problems simultaneously. This approach will satisfy no one, but without the coupling, the individual pieces remain unmotivated, and perhaps, unconvincing. We think that by addressing them all-at-once, not only will they make the whole more significant, but they will lend credibility to the model. At any rate, there did not seem to be a way to break the problem down into smaller, publishable parts.

The Origin-of-Life (OOL) is a "hard problem" of biology, since evolution manifestly cannot influence non-replicating, non-living objects, making OOL a bottleneck for the entire Darwinian theory. Since the Earth was molten and dry throughout the Hadean until the Late Heavy Bombardment delivered water, OOL could not commence until perhaps 3.85 Gya. But since the oldest stromatolite fossils date to perhaps 3.75 Gya, OOL must take less than 100My, a geologically brief time (Nutman et al., 2016). However if OOL takes so little time, then given the 3700My since, at least thirty-seven different types of life should now exist, yet no "shadow biosphere" has ever been found (Davies et al., 2009). Instead all life utilizes the same DNA code and appears to be descended from the same complex lifeform—the last universal common ancestor (Weiss et al., 2016). Indeed, with many of life's basic building blocks now available in the oceans from decaying organics, this calculation suggests OOL should be ridiculously easy today, as Hoyle was fond of remarking (Hoyle, 1999). Instead, Pasteur's flasks show that in 150 years since he sealed them up, life has not spontaneously generated.[1] Rather take an already unlikely spontaneous OOL theory and add *ad hoc* assumptions to explain the present absence of other spontaneous life, we postulate that life did not originate on Earth, but was transported here.

The recent discovery of microfossils on carbonaceous chondrite type I (CI) meteorites, widely thought to be extinct comets, suggests that life could be transported by comets (R. Hoover, 2011). In this case, we bypass the unlikely OOL on Earth and rely on the much more likely transport to Earth. Since comets outnumber and outweigh Earth-like planets in the universe, the cometary biosphere may be many orders of magnitude larger than the Earth biosphere. Then life is not just optimized for comets but is endemic throughout the galaxy, because comets can stably exist not just in the "Goldilocks zone" but anywhere (R. B. Sheldon and R B Hoover, 2007). This expanded locale can improve the OOL likelihood by some six to ten orders of magnitude. And if comets also make up the dark matter of the universe, as we argue later, we gain another ten to twelve orders of magnitude in probability.

Even this improvement in probability for OOL, however, pales in comparison to the 40,000 or so orders of magnitude improbability for spontaneous life estimated by Hoyle, calculated by assuming a random ordering of the amino acids making up the essential proteins of a cell (Hoyle and Wickramasinghe, 1982). On the other hand, if phase space is somehow structured, if the die are loaded, then there may be a way to beat the house odds (Davies, 1999). So in addition to dark matter comets, we also argue for a low-entropy, high-information, initial state

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[1] Swan-necked flasks prepared by Louis Pasteur (1862) in the Pasteur Museum, 25, rue du Docteur Roux – 75015 Paris.

for the universe, in essence, front loading information into the Big Bang. This paper traces the outline of a possible scenario for OOL where the initial state of the universe has high information, and comets are ubiquitous. Such a scenario makes predictions for the distribution of matter and life that can be tested by observation. It also changes the standard model of the Big Bang.

2 Benefits of a Magnetized Big Bang and Dark Matter Comets

2.1 Dark matter comets

The observed excess speed of stars orbiting the center of the Andromeda galaxy enabled astronomers to calculate the "extra" gravitational attraction necessary to keep the stars from flying out of the galaxy, which became the original definition of "dark matter" (DM) (Zwicky, 1933; Rubin and Ford Jr, 1970). Integrating this force gives the gravitational potential, which in galactic cross-section is a flat-bottomed well, unlike the cuspy potential of, say, a black hole at the center. Since galaxies are ~12Gy old, the evenly distributed DM must not be susceptible to viscous drag, the force which collapsed the nebular matter of our solar system to make the Sun and planets 5Gya. But the same gravitational attraction that binds the galaxy also inevitably produces viscosity, which over time should condense the majority of the DM to the center of the galaxy. Added to this mystery, is the "universal" shape of the galactic DM density curve when plotted against the gradient of the gravitational potential, a shape that is not "cuspy" but "cored" and tracks the visible matter outside of the galactic center (McGaugh, Lelli, and Schombert, 2016).

There are several solutions to this problem, with the majority of cosmologists adopting a cold dark matter (CDM) / weakly interacting massive particle (WIMP) solution. Unfortunately WIMP searches (LUX, IceCube, SuperKamiokande, etc.) have all come up negative, as have particle physics experiments that attempt to make WIMPs (Supersymmetry, axions, sterile neutrinos, etc.). The alternative option of massive compact halo objects (MACHOs) or black holes, has been observed in the galaxy, but not in sufficient quantities. Even the unorthodox modified newtonian dynamics/gravity (MOND) has not worked for all galaxy types, leaving theorists without a viable DM candidate (Joyce et al., 2015). In desperation, theorists propose new physics that only applies to exotic dark matter, called "dark interactions" or "dark sector", which, when evaluated by the rule that every theory is allowed one tooth fairy, is several tooth fairies too many.

In contrast to all these failed theories, we propose that ordinary comets possess exactly the right dynamical properties for DM that satisfy the galactic distribution as well as McGaugh's third law of galaxy rotation (R. Sheldon, 2015). There are three objections against the comet hypothesis that are often raised: DM lacks viscosity, visibility, and baryons (protons, neutrons, atoms).

Addressing the first objection that DM is apparently inviscid, whereas normal matter should have a viscosity that transfers angular momentum within the swirling nebula or galaxy so as to minimize (or thermalize) the kinetic energy while conserving the total angular momentum. In the proto-solar nebula, this viscosity resulted in the majority of the matter collecting in the Sun at the center, while a small amount is spun off at high speed in the equatorial plane. But if the viscous small-angle collisions are unlikely, this transfer of angular momentum is slow, and the cloud does not collapse to a plane. Since DM has not collapsed to a disk, this lack of viscosity is usually taken to be an intrinsic property of some exotic particle, such as a neutrino or a WIMP that barely interacts with matter at all.

Low viscosity, however, can be achieved by other means than a low interaction cross section. If a directed energy source overcomes the viscous drag such as swimming bacteria, magnetic colloids, or buoyant particles in a boiling pot, they are called "active particles", a new field of study (Magistris and Marenduzzo, 2015). Likewise, comets that form steam jets as they approach a star have a "negative viscosity" that counters their stellar drag. These jets cause the comets to gain kinetic energy as the stellar density increases, so as to smooth out their distribution (or even decrease their density) in the crowded galactic center, naturally producing a "cored" distribution like the observed DM, or a flat distribution highly correlated to stellar densities. Notice that the surface temperature of the comets is low, making them invisible to astronomers, but the dynamic temperature is high, making them slightly more energetic than the visible stars, and expanding their density a bit beyond the radial extant of the galaxy, as observations show.

This also addresses McGaugh's observation that the DM follows the baryonic matter distribution very closely, but becomes more dominant as the acceleration decreases. If we consider that comets gravitationally couple strongly to stars, then the faster the star is moving, the faster the comet leaves the star, it is dynamically heated by rapidly moving outer disk stars. But from a simple Bernoulli fluid model, the faster the comets are moving, the lower their density. Hence McGaugh's third law: high acceleration lowers DM density, no MOND required.

The second objection is that astronomers cannot see this dark gravitating matter, whereas comets were thought to be "dirty snowballs" with high albedo and high molecular outgassing that should be observed with telescopes. But in the past 30 years, several satellite missions to comets (Giotto, Deep Impact, Deep Space 1, Rosetta) have revealed comet nuclei with extremely low albedo and a rigid crust that resists outgassing (R. B. Sheldon and R B Hoover, 2005). Even in our solar system, most comets are hard to detect and "stealthy" until they are within the orbit of Mars, and only pristine or long period comets retain their high-albedo, dusty, outgassing exteriors. The controversy over Frank's "cometesimal" claims revealed just how difficult it was to observe these objects (Frank, 1990). Therefore invisibility is a property shared by both neutrinos and comets.

If comets are black, shouldn't they be observable in absorption of starlight?

If the DM were a gas, it would be observable because there is so much of it. But the clumpy nature of comets reduces their optical cross section and makes them invisible. Now if DM clumps were the size of Jupiter, they could be seen by their gravitational lensing, but intermediate-sizes between peas and moons render baryonic matter invisible to both starlight and gravitational lensing. Not completely, however, for both McGaugh's third law, and the recent observation that the absorption lines in quasars—the Lyman alpha forest—are examples where baryonic matter and gravitating dark matter track each other very closely, suggesting they are the same thing (Doux et al., 2016).

The last objection is that Big Bang Nucleosynthesis (BBN) models predict the ratio of H, D, He and Li in the pristine gas clouds of the universe, which is highly constrained since increasing the baryonic density of the Big Bang shifts the equilibrium toward He and Li. Since the DM cannot be a hydrogen or helium gas (or we could see it by the extinction of starlight), then a baryonic DM solution would require a denser universe than is compatible with the observed He/H ratios and BBN models. By this negative argument, DM must consist of exotic matter such as WIMPs that do not take part in the usual BBN.

Implicit in any negative argument, however, is the assumption that everything is known to high level of certainty, a "precision cosmology" (Jones, 2017). Several auxiliary data sets are sometimes used to validate the BBN negative prediction of non-baryonic DM, such as baryon-acoustic oscillations seen in the cosmic microwave background radiation, however, we counter-claim that many of these corroborating datasets have enough adjustable parameters to fit our model as well as the standard model, and are therefore not useful for separating the two hypotheses. More exactly, all these claims of "precision" in the BBN are model-based claims, which are only as precise as the models are correct, so it is essential that we separate these 2nd-order claims from model-independent, observational 1st-order claims.

Therefore in order to address this devastating cosmology modeling objection, we need to consider how the BBN model can be modified to handle a higher baryonic density. As it turns out, BBN models are not "parameter-free" but explicitly depend on uncertain initial conditions, in particular, the proton to neutron density ratio (p/n), which it turn, depends on all four of the fundamental physical constants: the strong, the weak, the electromagnetic and the gravitational (e.g., Cyburt et al., 2016). In the 21st century, there has been a growing awareness that one more constant must be added to this mix, the entropy or informational content of the universe (Susskind, 2008). Following Calkin, we argue that organization of charged particles (information) in the GeV plasma preceding the BBN era, leads to a non-zero polarization vector field (Panofsky), which encodes currents and magnetic fields (Calkin, 1963; Panofsky and Phillips, 1956). And magnetic fields change the neutron to proton ratio. Therefore adding this fifth quantity, this information quintessence, to the basic physics of the Big Bang fundamentally changes the initial conditions, the models, the outcome, and life itself.

Summarizing the analysis section below, the result of non-zero magnetic fields is that magnetic Big Bang nucleosynthesis (MBBN) begins with far more neutrons, so that nucleosynthesis proceeds toward He, C, and O faster than is currently modeled. The extra C and O is then bound up in cometary ices to remove them from the observational astronomical inventory, leading to the mistaken impression that they are not a major constituent of the BBN. Thus is it not necessary to posit exotic DM particles that do not affect the BBN, but simply add back in the overlooked baryons.

2.2 CEMP stars and Galaxy formation

Another astronomical objection to the MBBN model, is that if C and O are produced in the Big Bang, then main sequence stars should show a much higher abundance of these elements, rather than the typical H and He composition observed. We argue that stars recycle matter that has been expelled by supernovae and stellar winds, so it is important to find the oldest stars in the galaxy and observe their composition to determine the original galactic ratios. Unfortunately, these Population III stars are often identified by their composition, so it has been difficult to assemble an unbiased data set. Recently, however, special purpose telescopes have identified an unexpected Population III category of "carbon enriched metal-poor" (CEMP) stars that have abnormally low levels of Fe, the unburnable ash of stellar furnaces (e.g., Caffau et al., 2016). The lack of Fe suggests that these are the oldest stars in the galaxy, made from pristine BB gas clouds. But if the BBN models are correct, they should have almost no carbon in their atmospheres, being some seven orders of magnitude less abundant than hydrogen, yet CEMP stars exhibit comparable abundances (Maeder and Maynet, 2015).

We argue that these CEMP stars are not the anomaly, but the trend, and that many more CEMP stars are now at the white dwarf stage where they are mistaken for terminal main sequence stars. Since white dwarfs are no longer burning nuclear fuel, their cooling rate is highly predictable, and as equally anomalous as CEMP stars are the cool white dwarf stars in the galaxy predicted by our model (Kaplan et al., 2014).

Another difficulty for the standard hypothesis solved by comets is the measured smoothness of the early universe. In order for gravitational accretion of primordial gas cloud to create comets or stars, the gas must be seeded with density fluctuations before instabilities can condense stars and galaxies. On the other hand, density fluctuations in the BB would manifest as brighter regions of the cosmological microwave background radiation (CMBR), which has been characterized by COBE, WMAP and now Planck satellites. The CMBR is too smooth to account for galactic structure, so density fluctuations are attributed to the DM, which they argue, must be decoupled from the CMBR to keep it smooth.

How then can baryonic DM satisfy both the need for seeding density fluctuations and the observation of smooth CMBR radiation?

Even in the case of exotic DM, the Hubble "deep survey" of distant galaxies observed mature galaxies so ancient that they must have formed within 400My of the BB, before the reionization era and far too quickly for the slowly developing gravitational instabilities of baryonic or exotic DM (Oesch et al., 2016). In addition, DM surveys show that the DM is too smooth for gravitational instabilities to start (Secco et al., 2021). So neither baryonic nor non-baryonic dark matter appears to solve the riddle of early galactic origins.

Comets, on the other hand, do not originate from gravitational instabilities, but from a physico-chemical process of condensation and freezing. Gravitational instabilities take millions of years to accrete stars, whereas comets accrete in thousands of years. This non-gravitational accretion driven by temperature alone produces the density fluctuations necessary to kick-start the formation of the first "ice stars", which due to their high C and O content, are particularly blue. Subsequently, the ultraviolet (UV) light from these first stars produce steam jets on the comets, giving them the velocity to actively sweep up further gas and dust, accreting and growing until they initiate a new star, far from the first. Comets streaming away from stellar nurseries will catalyze more star formation. All of this stellar activity occurs at $T<0.01$eV long after the CMBR has decoupled from the BBN at $T<13$eV, so that the galactic structure is not reflected in the CMBR, nor is the smoothness of the CMBR limiting the galactic structure.

2.3 BBN formation of C, O

In the standard model of BBN, a network of (particle mediated) nuclear reactions couples the table of isotopes, such as $H+n \rightarrow D+\gamma$, written $H(n,\gamma)D$ where H is hydrogen, D is deuterium, n is a neutron, and γ is a gamma-ray photon. Some 40 to 120 reactions are then solved simultaneously to determine the ratios of H, He, Li, C and O (e.g., Kawano, 1992). Most of the networks do not go beyond O, because at that point the O/H ratio has reached parts-per-trillion, and heavier nuclides are essentially non-existent. The low concentration of elements heavier than He is attributed to the "deuterium bottleneck", whereby the rarity of three-body reactions at low density require stepwise construction of heavier isotopes such as the reactions $H(n,\gamma)D$ and $D(d,\gamma)4He$ or $D(p,\gamma)3He$. Likewise the lack of any stable A=5,8 elements (5He, 5Li, 8B, 8Be) require $4He(d,\gamma)6Li$ deuterium reactions to hop to A=6 which takes a D. But the fragile binding energy of D prevents its formation during the hot, dense phase of the BB, so by the time sufficient D exists for reactions, the BB density is too low to continue nucleosynthesis. This bottleneck means that over large ranges of parameters and p/n ratios, all BBN models produce nearly the same result: 25% He but very little Li and beyond.

This robust result, which was touted as BBN model validation has instead turned out to be an Achilles heel, for observations of 7Li find it to be more than 3-sigma from the BBN prediction, and no amount of fiddling over the past 20 years has brought the model into better agreement. That is, a model with three parameters fits the first three elements well but misses the fourth. The last theoretical cross-section in the network was experimentally measured recently, with no change in the discrepancy (Coc and Vangioni, 2017). Therefore we argue that the initial success of the BBN model has masked an absolute discrepancy that justifies a completely reworked initial condition.

In the original 1948 paper on Big Bang Nucleosynthesis, the initial state of the universe was proposed as "a highly compressed neutron gas" (Alpher, Bethe, and Gamow, 1948). Subsequent theory in 1953 argued that the neutron decays into a proton and electron via the weak interaction mediated by the W-boson at $T>2$MeV, so abundant neutrinos right before BBN-era cause the exothermic transformation of neutrons into protons and the BBN-era began with a 7:1 p/n ratio (Alpher, Follin, and Herman, 1953). Then the observed 25% He/H mass ratio is simply due to the tightly bound helium soaking up all available neutrons. In 1964, Zel'dovich argued that a quantum degeneracy of anti-neutrinos filling the "Fermi sea" would exact an energy penalty from the exothermic conversion of neutrons to protons so an overabundance of anti-neutrinos would prevent the destruction of neutrons and keep protons from being created (Zel'dovich, 1964). These extra energy terms in the reaction are called chemical potentials, which Wagoner's 1967 FORTRAN code made a free parameter, showing how it was able to change the initial ratio of p/n, and thereby change the He/H ratios from the BBN (Wagoner, Fowler, and Hoyle, 1967). In this paper we add another magnetic chemical potential to Zel'dovich's degeneracy, arguing that the initial p/n of the MBBN was $p/n < 1$.

We argue that indeed there is a justification for the neutrino chemical potential, and that in fact, the mechanism does more than simply modify the weak interaction, but also the electromagnetic energies as well. Schematically, if the three neutron destroying weak force reactions: (a) $n \rightarrow p+e+\nu*$, (b) $n+\nu \rightarrow p+e$, (c) $n+e* \rightarrow p+e$ (where * indicates anti-particle and ν a neutrino) represents the decay of a neutron into a proton and electron, then the conservation of momentum requires that the proton and electron be moving in opposite directions. Since they are also oppositely charged, they carry a current in the same direction, which produces a magnetic field, schematically written as $n \rightarrow p+e+\nu*+b$. Since creating the magnetic field, b, in a background field, B, takes extra energy, $E=\mu_B/2\ [(B+b)^2-B^2] \sim \mu_B Bb$ then a strong background magnetic field will oppose the currents generated by the neutron decay, and favor the conservation of neutrons, adding to the neutrino degeneracy chemical potential.

If the BB is hot enough for neutrinos to temporarily exist as electrons, then the neutrino can interact with matter. During this "electroweak" era of the BB, the neutrino-dominated universe becomes an electrically conductive ν-$\nu*$ plasma that permits n p reactions to reach an equilibrium favoring p because of its lighter mass (Beaudet and Goret, 1976). This same conductive plasma can carry a current that produces B, and the greater the B-field, the more the equilibrium is driven back toward neutrons. By itself, this thermal B-field provides a nearly negligible contribution to the chemical potential. But feedback makes it significant.

The electroweak interaction that enables a neutrino to moonlight as an electron depends on the magnetic field strength, so that the coupling that produces the neutrino current is itself enhanced by the current, which is a positive feedback situation. Fluctuations in the thermal B enhance the current which enhance the B which enhance the current, so that very quickly, the magnetic field grows until other non-linear effects cause its saturation (Dvornikov, 2016).

For this qualitative discussion, it is enough to simply assume a large and constant magnetic field strength develops, without discerning the saturation mechanisms. But if this magnetic field is strong enough to overwhelm the (now anisotropic) thermal fluctuations, it is expected that only neutrons will be produced during this era. Once the BB expands and cools below ∼1MeV, however, there is insufficient energy to make e-$e*$ pairs, the neutrinos no longer couple to the matter, the current dissipates, and the resistance of the plasma increases exponentially. Then the energy stored in the magnetic field is discharged into electrons principally, reheating them as the magnetic field decays away. In the equilibrium reaction with protons, the heated electrons drive the reaction toward neutrons, decreasing the density of current carriers and increasing the resistance further. In addition, the diminished neutrino interaction also means that neutrons are more stable against weak decay, and so, contrary to the standard model, we enter the BBN nucleosynthesis era with a large overabundance of neutrons compared to protons.

One objection to this scenario, is that there is no evidence a strong primordial magnetic field (*pmf*) (Gasso and Rubinstein, 2001; Subramanian, 2016). And should a *pmf* exist, it would be anisotropic and its magnetic pressure would cause the BB to expand and cool even faster (Kernan, Starkman, and Vachaspati, 1996; Matthews, Kusakabe, and Kajino, 2017). We reply that if the *pmf* is chaotic, as it most certainly was, it would be isotropic. And a chaotic magnetic field would compress rather than expand the BB due to the magnetic tension force and reconnection of tangled fields. Finally, there is evidence of these strong *pmf*s in the early formation of quasars (and absence after 3Gy), in which the magnetic field is converted into jets of high speed particles. Quasar formation is beyond the scope of this paper, but the mechanism is described in an earlier paper (M. Sheldon and R. Sheldon, 2015).

In this magnetic scenario, essentially all the available protons are converted into He, which now floats in a bath of hot neutrons. But recalling that there are no A=5 stable elements, there are no fast, two-body reactions to begin the nucleosynthesis ladder beyond He. The only possible reactions are either minority projectiles such as 4He(d,γ)6Li, or metastable states like 4He(α,γ)8Be*. But if the temperature is too high for D, and the He density is large enough, then the dominant reaction channel becomes the triple-α, 8Be*(α,γ)12C, which can begin the carbon cycle that produces N and O. Further expansion of the universe cools and releases a cloud of neutrons that subsequently decay into protons, which in the now cooler universe can produce some deuterium.

In the Analysis section, we present the results of our magnetized BBN (MBBN) model, employing the Arbey code modified to include additional chemical potentials (Arbey, 2012). Therefore the strength and topology of the *pmf* supplies "tuning" knobs giving us the flexibility needed to avoid the "robust" but wrong solution of the standard BBN models.

2.4 Coherent Magnetic fields

The *pmf* does more than simply change the ratio of p/n at the beginning of the nucleosynthesis era, it also supplies a reservoir of energy and a globally coherent field. The global coherence means that the universe looks the same even in disconnected, "space-like" spacetime regions, thereby addressing the "horizon problem" of the BB. The energy reservoir means that the transition from electroweak to nucleosynthesis era is a first order phase transition, like boiling water or freezing ice, mapping the coherence of the field onto the coherence of the matter. That is why boiling water is uniformly at 100C, or freezing water uniformly at 0C.

For example, suppose that a patch of plasma were slightly colder than the rest, then the neutrinos decouple, the current decreases, and immediately the magnetic field starts to decay. The energy of the decaying field produces an $Emf=-dB/dt$ that drives currents through the plasma, heating it up until the temperature is back to normal. A similar argument applies to density, whereby a low density patch decouples the neutrinos and drops the current, which lowers the magnetic pressure. This gradient accelerates nearby plasma into this patch until the pressure due to density (and adiabatic heating) is restored. The reservoir of energy in the phase transition maintains the system at the critical point.

As a consequence of this 1^{st} order phase transition, the universe achieves a uniform temperature and density that is reflected in the CMBR, without the need for a global inflaton field. Or more precisely, the global magnetic field provides the coherence that was previously attributed to the global inflaton field (albeit indirectly).

The *pmf* does more than simply redistribute the matter and heat evenly, it also balances them. Recall that the expansion velocity of the BB is finely adjusted to the matter density by $1{:}10^{60}$ (since it balances in an exponential) (Krauss, 1998). Since the visible matter of the universe corresponds to about 10^{80} protons, this fine tuning is equivalent to a clump of 10^{20} protons, or about a grain of sand. Then one sand grain more and the universe would have collapsed into a black hole before now, or one grain less, and an over-expansion would have prevented the formation of galaxies, stars and us. If we associate that expansion with the temperature, then this means that the temperature and density of the BB must be highly, very highly, correlated, an unexpected attribute of the standard BB that is often called "fine tuning".

If a mechanism can be found that correlates temperature and density to this degree, then the fine tuning is explicable in terms of physical laws. This neutrino cross section has all the properties needed to keep the correlation tight. It depends on density, magnetic field and temperature, so it can couple magnetic field to thermal energy. Much as a 1^{st} order phase transition stabilizes the temperature by coupling to a third energy source, the neutrinos set up a feedback that taps into the *pmf* to supply the constant temperature. As long as the neutrinos are coupled to the matter, they can correlate the density and temperature.

As an analogy, consider "entropy waves" in a plasma. If the plasma is supplied with a steady heat source, say, a globally decaying magnetic field that is driving current through the plasma, then equilibrium temperature is reached when the radiative cooling is exactly compensated by the inductive heating. But if the plasma temperature is such that a slight increase in temperature results in an increase of excited absorptive states, then the opacity of the plasma increases with temperature. A higher opacity lowers the cooling rate, so a new, higher temperature equilibrium is found. This positive feedback results in an exponential growth of "entropy waves" because the entropy is modulated as a function of position. Conversely, if the opacity decreases due to higher temperature, negative feedback creates a homogeneous plasma.

If we then consider the neutrinos as the "radiative cooling" term for the dense BB plasma, we can see that increased density or magnetic field increases the opacity which increases the temperature. Near the phase transition this holds the plasma at the phase transition temperature until it jumps to a lower value. So if the magnetic field energy is being dissipated into the neutrino plasma, the conditions for entropy waves are met making the transition very sharp. In this scenario, the cosmologically expanding magnetic field uniformly heats the neutrino plasma and stabilizes the temperature/density ratio, providing a solution to the Big Bang "flatness" problem.

2.5 Magnetic Helicity and Missing Antimatter

When the temperature drops below 1.1MeV e-e^* pairs can no longer form, so at these cold temperatures mutual annihilation converts a small excess of e/e^* into a matter-dominated (rather than anti-matter-dominated) mass density.

But why is there an excess at all? The conservation of lepton number means that e-e^* should balance with no excess at all, so where did all the anti-matter go?

Because of the electroweak interaction, we can convert $e^* \rightarrow \nu^*$ while conserving lepton number, e.g. $e^* + n \rightarrow p + \nu^*$. Then the apparent dominance of leptonic matter over anti-matter is achieved by hiding the anti-matter in an anti-neutrino. So the observed excess of e/e^* would naturally lead to an excess ν^*/ν, a fermionic chemical potential, as discussed earlier. This is not the only factor in the chemical potential, however, there is also an energy term $\sim \mu_B \bullet B$, where μ_B is the magnetic moment of the particle.

Now electrons and protons have intrinsic QM magnetic moments which give them a chemical potential, and in the standard model of Dirac (not Majorana) the same electroweak conversion via W-bosons that carries current also generates a magnetic moment though it is small. Depending on the direction the additional energy can be either +/-, which naïvely cancel out in a spatial integral and do not contribute to the chemical potential. However if the magnetic field is twisted, or helical (the Chern-Simons term), then the non-QM, spatial integral of the dot product does not cancel but has two choices: either right-handed or left handed. It is this same twist that in a self-starting or α-dynamo, sets up an amplification of both magnetic field intensity and helicity that in the Sun has a magnetic cycle of some 22 years. This helicity term in the chemical potential is even stronger for electrons and protons than for neutrinos because this "MHD" component to the magnetic moment, derives not from the small intrinsic QM spin, but from the extrinsic gyration in a magnetic field, the "first adiabatic invariant". Heuristically, it is easier for a positive charge than a negative charge to travel along a magnetic field of positive helicity, so the magnetic helicity introduces a potential difference or a chemical potential between matter and anti-matter.

So if the neutrino plasma makes a helical magnetic field, then the e-e^* chemical potentials are affected, changing the matter/anti-matter equilibrium ratio. Whether this effect can account for the observed asymmetric preference for matter or not requires far more theory and modeling than presented here, but our purpose was only to show the importance of including the neglected magnetic fields in BB modeling.

2.6 Magnetic tension and tests of Primordial Magnetic Field

If *pmf* solves so many problems, why have numerous papers found such stringent limits on the strength of the *pmf*?

Once again, making an argument for the absence of *pmf* is a negative argument, and depends strongly on having a complete model with all the physics included. Our argument is that two crucial properties of the magnetic field have been neglected heretofore, which when included permit most of these limits to be exceeded: magnetic reconnection and the magnetic tension force. That is, many theorists treat the magnetic field as a conserved scalar field, when it is a non-conserved vector field. This means that *pmf* field can be destroyed (as well as created in dynamo) and that in addition to pressure, the *pmf* possesses a tension force.[2] These two properties work together as follows.

The tension force of the B-field, which is a topological or global property, remains after reconnection has converted the tangled local B-field into structured loops. This tension force resists the expansion of the universe, leading to a deceleration term in the BB. In qualitative terms, the *pmf* first contributes to expansion of the cosmos as the tangled field reconnects and turns into energy, then it decelerates the cosmos as the remnant tension force becomes dominant. Finally, when recombination decouples the magnetic field from the plasma, its tension grip is released, and the B-field forms quasars. This complicated interaction delays the recombination era, which explains why the Hubble constant derived from the timing of recombination gives a smaller value than the Hubble constant derived from galactic expansion (Riess, 2020). That is, a delayed recombination era gives less time for the expansion phase and therefore a larger Hubble constant bringing the CMBR Planck 67 km/s/Mpc value into alignment with the distance-ladder 73 km/s/Mpc value.

In summary, all papers that assume the magnetic energy of the *pmf* is conserved are underestimates of the *pmf* strength. Likewise, all papers that assume that the magnetic field contributes only a pressure proportional to B^2 are likewise overestimates of the magnetic pressure. Thus, for example, the field could be large in the nucleosynthesis era and practically vanish in the CMBR reconnection era.

Finally, a strong *pmf* has extremely low entropy. Not only is it global and ordered, but it spreads the energy levels of charged particles (analogous to the Zeeman effect) to such an extent that they have fewer QM states available to them at finite temperature, reducing their entropy. In short, the large B-field "cools" the electrons into a lowest Landau level that becomes the lowest entropy state possible for the universe. Since low entropy is often equated with high information, the *pmf* may be responsible for the subsequent high information state of OOL.

In summary, a magnetized BB may solve multiple problems with the standard model: matter/anti-matter asymmetry, flatness, horizon, Hubble tension, BBN D/Li deviations, dark matter, cold white dwarfs, CEMP stars, early galaxy formation, and ubiquitous comets with their payload of information.

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[2] "the majority of studies analysing the magnetic effects on structure formation do not account for the tension contribution to the Lorentz force." (Kandus, Kunze, and Tsagos, 2011, pg. 20)

3 Consequences of Primordial Comets

We have traced backwards in time from the observation of comets to the conditions needed in the Big Bang to show the possibility of very early life, but, to show the inseparability of life from existence, we really must also go forwards in time, from the Big Bang to the present. Many physicalists/materialists who eschew teleology or purpose believe that life is a fortuitous accident, so that if the tape of the universe could be rewound, it would play a very different tune. We read statements such as “the appendix evolved independently 125 times” as if life is player in a Monte-Carlo casino with body parts for chips. What we would like to show is the exact opposite: that the glittering casino is itself the result of life paying a visit to a singularly rocky peninsula; that everything we see as we gaze at the starry night sky has been affected and created by life. Indeed, the marvellous, incomprehensibly beautiful world that we live on was constructed from a molten rock by life patiently carving the stubborn stone, the result of a cosmic computation whose closest gear is our solar system, whose farthest are the galaxies.

Susskind argues that QM requires information to be neither created nor destroyed, but Hawking’s conception of black holes destroys information. After 10 years, Hawking conceded that his namesake radiation would destroy information, but unwilling to let go of his theory, he argues that black holes don’t exist (Hawking, 2014)! If such notable physicists are having disagreements about the cosmological power of information, then perhaps it would not be too forward to suggest that the information in the Big Bang, represented by the enormous magnetic field is also responsible for OOL. We calculate this as follows:

Penrose argues that if the position of every atom in the universe holds significance, then the information in the universe is proportional to the likelihood of this particular state, particular arrangement of particles. The information is the number of permutations (bigger than a combination) of quantum states, calculated as n! (or “n factorial” where 4!=4x3x2x1). These are such big numbers, they are typically converted to logarithms, where $\log(n!) \sim n\log(n) - n$, known as Stirling’s approximation. Then if the visible universe has 10^{80} protons, and we add photons and the number of slots available to store them too, Penrose estimates $n \sim 10^{120}$ quantum states. Then $\log(n!) \sim 119*(10^{120})$. If we take anti-logs of both sides, we get $10^{10^{123}}$ for the amount of information in our universe today (Penrose, 1981, pg. 249). And if information is not created or destroyed, then this is also the information that had to be available at the very beginning in the BB. Comparing this number to Hoyle’s estimate for life, $10^{40,000}$, we see that the BB contains more than enough information to create life (which is trivial, since Penrose’s calculation includes present life). But perhaps we need to calculate instead the information density.

That is, if we treat entropy as a fluid, $dS = dQ/T$, then it would seem reasonable to treat information as a fluid too, as an arrangement of the particles. Where there are no particles, there can be no information. And if the BB spread those particles out evenly, then very likely the information is likewise diluted and scattered. But for OOL, that information must then be concentrated in a cell a few cubic microns in volume.

When we concentrate something, we are fighting entropy, we are battling diffusion and turbulence and mixing. So to concentrate information is also to add information, a seemingly impossible task. But like the heat pump on a house, we can concentrate the heat by supplying electricity to the pumps and raising the entropy of the coal in a distant power station. The gradient of heat energy gives us the Gibbs Free Energy, the ability to do work. We have no word for the gradients of information, but it turns out to be very important both mathematically and physically because it keeps the non-equilibrium system far from equilibrium. Assuming its importance without defining it, then the difficulty lies in all the special machinery needed to manipulate this fluid, a process we call computation.

To emphasize the non-material nature of information, we can analogize to a computer, where the information concentration is likened to a computation. Then the universe is a vast computer taking the information of the BB and carrying out an enormous calculation involving nebulae and comets and galaxies, and whose answer is us.

What evidence do we have that life is a cosmic computation?

We described how adding a global *pmf* to the BB model made the universe highly isotropic, which if absent (without other global fields), could only model massive superclusters with attendant black holes. That same *pmf* was a low-entropy event whose information created the chemical potential resulting in ice, but without it, water would have been unavailable until much later. And if water was unavailable, then H and He would not have condensed to form the first stars, and gravitational instabilities would have delayed the beginning of galaxies. And the delay in galaxy formation would delay the formation of stars that were necessary to burn sufficient hydrogen to make oxygen. And without oxygen, comets would not form, and further seeding would not start.

In fact, without *pmf* the universe is so inhospitable, that two arbitrary dials have been added to the standard model, a “dark matter” fluctuation to get the galaxies going, and a “dark energy” to prevent them from becoming monstrous black holes.

This balancing act is an attempt to give back to the standard model the information that was discarded in the hot early universe, despite there being no good reason why dark matter should have structure and why dark energy should exist (pax Perlmutter).

But if the information computation was successful and the first comets were able to achieve OOL, then life would begin the transformation of a harsh universe into a hospitable home (R. Sheldon, 2012). Cyanobacteria, whose fossils have been found on every carbonaceous chondrite or extinct comet, can make sugars and proteins from sterile sunlight, CO_2, H_2O and N_2. Some of those sugars polymerize to make polysaccharides that coat the outside of the comet, where they turn soot black in UV light, efficiently convert light to heat, melt ice, form a vapor barrier, permit liquid water to form, outgas in ruptures to form jets, and impart high velocity to these chunks of ice. High speed comets are then capable of escaping the star's gravity well, accreting more mass, and seeding new stars. Thus star and galaxy formation do not form diffusively like a melting scoop of ice cream driven by density gradients, nor do they send out supernovae shock waves in successive arcs of stellar formation, but expand fractally in streamers and trailers, like ants on a mission.

More precisely, the living strategy of an efficient search algorithm employed by bacteria, slime molds, ants and tigers, involves a fractal distribution, a lacy network of paths and voids. And this is precisely the structure revealed by galactic surveys, with galaxies and supergalaxies stretched out on a three-dimensional lace of lanes, voids and walls (Canavesi and Tapia, 2020). This structure is so information rich that modelers strain to reproduce it by balancing dark matter densities, fluctuation power laws and dark energy "anti-gravity" terms. It looks remarkably like the structure of neurons in the brain, because fractals are the natural organization of life, the most efficient search algorithm, and the way to maximize 3D connectivity with a minimum of matter.

And these comets labor tirelessly to make the universe fit for life; they evaporate, fragment and leave behind a trail of spores. Not only have these signatures been seen by infrared telescopes in quantities that make our Earth biosphere seem a mere speck (Hoyle and Wichramasinghe, 1977; Richard B Hoover et al., 1986; Rivilla et al., 2021), but they continuously filter down on the planets that plow through their meteor trails, as observed at Earth on stratospheric balloons (Brownlee, Tomandl, and Hodge, 1976). Earth-like planets are rare, but where they have sunlight and H_20 and N_2, spores of the same pioneering cyanobacterial life can begin the unheralded transformation of the world. Bacteria release oxygen to change the atmosphere; sequester carbon dioxide to prevent runaway greenhouse warming; release cloud seeding chemicals to regulate the temperature through cloud feedback; setting off ice ages whose glaciers grind down the mountains and fertilize the oceans. In the oceans they lay down a layer of nutrient rich goo, ideal for fungi and multicellular plants to grow on, and perhaps later on, acorn worms. They harbor viruses to transfer blueprints of cellular machinery among the fungi and algae, they encourage cooperation. All of these activities are processing information, concentrating more and more into the cellular DNA.

How can we tell that life is terraforming Earth?

Because the information on Earth, measured by metrics such as biomass, complexity, or species count, does not grow at a diffusion pace ($\mathrm{time}^{½}$), nor at a delivery pace (time^{+1}), but at infectious pace ($\exp^{\mathrm{time}}$), a function whose derivative looks identical to the function. This suggests that the delivery of information is growing more efficient with time, the system is bootstrapping, adding more information channels as it grows more sophisticated (R. B. Sheldon and R B Hoover, 2008). This is a characteristic of life, not of diffusive chance.

And when a high-speed comet strikes this terraformed ocean splashing its water into space, other passing comets can pick up and carry the virus load into the galactic cometary biosphere, where the viral information gets passed from comet to comet until it too finds itself floating down into the stratosphere of some Earth-like planet. In such a way, comets are the conduit, the nerves, the messengers of the cosmos. Planet by planet, comet by comet, the information is carried, concentrated and repackaged until 3.75 billion years ago, it came to Earth.

How do we know that life was delivered to Earth and not developed *in situ*?

Because the moment the environment was ready, life appeared. The moment the earth had oceans, stromatolites appeared. The moment the atmosphere was oxygenated, the Cambrian Explosion occurred (Meyer, 2013). The history of evolution is a history of planned deployment, of staged development, of bootstrapping complexity.

4 Analysis

4.1 Magnetic Big Bang Nucleosynthesis (MBBN)

In order to simulate the addition of the *pmf*, several quantities in the standard BBN model have to be altered. We list the changes made to the Arbey code, where we follow the weak-interaction modifications of the Parthenope version as noted below. Each of them was made a semi-empirical adjustment with no attempt at theoretical rigor. The purpose of this exercise is to demonstrate the effect of modifying the parameter, not rigorously deriving a theoretical fit. By optimizing on the output, we then can discover which parameters have the largest effect on the model.

The coupling of neutrinos

The strength of the weak interaction is proportional to B, which we argue, exists as long as *e-e** pairs can be easily made (T>1.1MeV). When large currents can be maintained, the neutrino coupling is strengthened, and lacking any theoretical constraints on the magnitude of the currents, we argue that the positive feedback rapidly approach a saturation field strength. Thus the enhancement to the interaction is either present or absent, with a transition near T=2MeV. In the Arbey code, unfortunately, only the $p \to n$ weak reaction permits a fiddling with the coupling, all the others are simply polynomial fits independent of temperature or neutrino density. So this modification to the code has not been implemented. Initial results with the PRIMAT code, however, look promising (Pitrou et al., 2020).

The chemical potential of the weak interactions

Since the weak interaction converts neutrons to protons and electrons, it generates current where none existed before. When immersed in a magnetic field, this produces a potential energy term, which adds to the chemical potential. Therefore we insert a chemical potential into all weak interactions proportional to the energy of the emitted *e/e** current-carrier. We simulate it in the Arbey code with a factor added to the binding energy of the neutron multiplied by a tanh function of specified width, μ=tanh((T-T$_0$)/σ), where T$_0$=2GK, 1.5GK and 1.2GK, σ=2GK.

The chemical potential of neutrinos

When the density of neutrinos is high, then the Fermi exclusion principle makes it difficult to create an identical fermion of the same quantum number, so the new particle must be created at higher energy. So if there is a superabundance of anti-neutrinos, a reaction that produces an antineutrino will have a slightly higher energy barrier, which from analogy to physical chemistry, is called a chemical potential and depends on density. The Arbey code permits this ξ potential to bias both the decay of the neutron, and weak interactions involving the anti-neutrino. Because it has the same units as the magnetic-field related chemical potential, we plot the helium fraction Yp versus $\mu+\xi$.

4.2 Charts

The Arbey code already permits adjusting the neutrino degeneracy and the lifetime of the neutron. To those free parameters, we add a chemical potential to the weak interaction proportional to the energy of the *e/e** created (negative if destroyed). Since both the neutron and weak interaction depend on the external magnetic field, we parameterize this chemical potential with a tanh function centered on a variable 2-1.2 GK temperature with a 2GK width. One thing we have not yet introduced is the reduction in the entropy caused by the magnetic field, which shows up as a reduced number of degrees of freedom. As a kluge for this effect, we can change the “effective number” of neutrinos from 3 down to 1. This introduces two new parameters (magnetic chemical potential and temperature transition) to the existing four parameters (neutrino number, neutrino degeneracy, neutron lifetime, and baryon/photon ratio).

Our target BBN abundances are a DM constituent of CNO that is four times more abundant than stellar (H, He) masses. From consideration of both pristine comets and CEMP-no stars, we target the DM as principally water, methane and ammonia ice—$CNOH_9$. We have not discussed the process that makes the 12C, which has two primary channels through the intermediate 8Be* and 7Be, both of which consume 4He, but are often overlooked in BBN models including Arbey’s (Coc, Uzan, and Vangioni, 2014). It also possible to make C through the triple-α which is possible given the higher density and temperature of the BBN era. Unfortunately this cross-section is also missing in the Arbey code. So postponing a discussion of CNO production, we simply convert all the metals to equivalent helium atoms deriving DM as $He_{10.5}H_9$. Comets also have CO and CO_2 ices which bind no hydrogen, so we round up the numbers to $He_{12}H_9$ for dark matter. When combined with the visible matter, DM+(num)HeH_{16} where num = 12/20 to make the visible mass 20% of the total. Then the BBN produced 4He (traditionally written as the mass fraction) Yp = (48+2.4)/(9+9.6+48+2.4) = 0.73 as our target Helium production.

In contrast to Helium, the Deuterium content will be not much greater in DM than in gaseous form, with a small amount of chemical fractionation due to the higher boiling point for D, but we expect that to be a few percent at most. Then our target D/H ratio remains unchanged from the observational constraints at 1.2<D/H*100k<5.3. Just as the 4He/H ratio is enhanced, so is the 3He, which we scale with the calculated 4He/H ratio, Yp=73/25, or 1.66<3He/D<4.44.

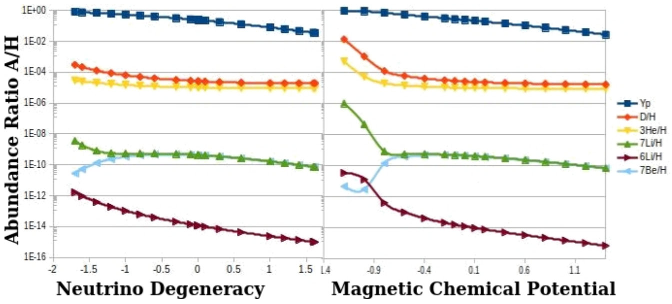

Figure 1: Abundance ratios of primordial elements from 4He/H to 6Li/H, as function of ξ=neutrino degeneracy parameter (left panel) and of μ=magnetic chemical potential (right panel).

Are there reasonable solutions to the BBN model that achieve these two/three set points?

The answer is yes. In Figure 1 we show on the left the results of the Arbey code for changing ξ, the neutrino degeneracy, and on the right the results of adding μ, the magnetic chemical potential to the $n \to p$ weak reaction with a transition temperature of 1.5GK. Qualitatively they are very similar, though negative μ raises the neutron density more effectively than ξ. The important thing to note is that values of Yp=0.73 are easily obtained for $\mu + \xi <$ -0.5 (since they appear additively in the equilibrium).

The increase in neutron density also raises the D/H ratio, as well as puts 3He/D<1.0. A magnetic field confines the electrons and increases the baryon/photon ratio, η, by a factor of 4X, which also suppressed D while enhancing 3He, as the left panel in Figure 2 shows. Therefore around μ ~-0.4 has all the right numbers: a Yp~0.7, a D/H~2e-5, and a 3He/D>1.5. All 3 set-points of our DM universe have been accomplished, with the next step requiring a demonstration of how the excess He can be burnt into CNO. Since this requires entering new cross-sections into the Arbey code, we postpone that work for another paper.

In the right panel of Figure 2, we set η back to its nominal η=6e-10 value, but raise ξ to -0.5, favoring anti-neutrinos. When we do a scan in μ, the curves appear displaced, so that the equilibrium between 7Be and 7Li now occurs at μ=-0.4, which is what we expect if $\mu + \xi$ controls the p/n ratio of the initial conditions. But more significantly, this shifts the 7Li down without affecting the Yp and the D/H, which is exactly the solution to the "Lithium problem" plaguing current BBN models. That is to say, the magnetic chemical potential gives us an additional "dial" that may solve many problems with the current BBN model.

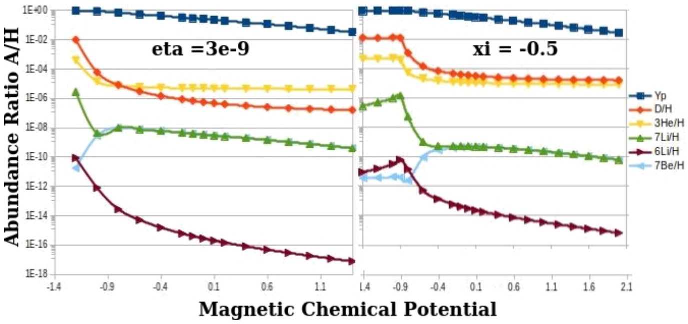

Figure 2: Abundance ratios of primordial elements as a function of μ, the magnetic chemical potential, where η=3e-9, the baryon/photon ratio (matter density), has been enhanced a factor of 4X (left panel), and where ξ=-0.5, the neutrino degeneracy, favors anti-neutrinos (right panel).

5 Conclusions

As we have argued in this paper, water is not just a necessary ingredient for life, it is the message of an information-rich Big Bang, and the medium that transfers it throughout the cosmos; it is the means to concentrate information, and the end of every message. Water in the Big Bang began the first ice stars, sealing comets in concrete shells, speeding them on lacy trails, seeding the galaxies and transforming the dark nebulae into starry skies. Water provided the gravitational attraction that held the spinning galaxies together and allowed the evolution of solar systems and rocky planets. Water transformed our molten rock into a blue-marble planet. Water tamed the climate by cloud-regulating albedo. Water formed the glaciers that recycled rock into the ocean, keeping the oceans fertilized. Water tidally locked the Moon to show a single face, which stabilized the Earth's axes and gave us summer and winter. It is safe to say that without water, our universe would be nothing but cooling gas, well on its way to heat death and oblivion.

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