Comets, Water and Big Bang Nucleosynthesis

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Summary

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 microscopic fossils, they are an underappreciated 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 the consideration of cosmological models 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 cosmology model of the Big Bang. We conclude that nothing prohibits the construction of a Wet Big Bang model tracing life from the Big Bang to the present.

1 Introduction/Motivation

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 (found by Nutman et al. (2016)) date to perhaps 3.75 Gya, OOL must take less than 100My, a geologically brief time. 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" proposed by Davies et al. (2009) has ever been found. 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 (1999) was fond of remarking. Instead, Louis Pasteur's flasks show no sign of spontaneous generation in the 150 years since he sealed them up (Pasteur (1862)).

The recent discovery by Hoover (2011) of microscopic fossils on carbonaceous chondrite type I (CI) meteorites, widely thought to be extinct comets, suggests that life could be transported to the Earth by comets. In this case, OOL need not have occurred on the Earth, but may have been transported here, and indeed is much more likely than spontaneously generated. If comets outnumber and outweigh Earth-like planets, the cometary biosphere may be many orders of magnitude larger than the Earth biosphere, so that life is not just optimized for comets but is endemic throughout the galaxy; living not just in the "Goldilocks zone" but anywhere that comets can stably exist (Sheldon and 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 next, we gain another ten to twelve orders of magnitude in probability.

Even this improvement in OOL odds, however, pales in comparison to the 40,000 or so orders of magnitude improbability estimated by Hoyle (1982), calculated by assuming a random ordering of the amino acids making up the essential proteins of a cell. On the other hand, if the space of all possible arrangements is somehow structured, if the die are loaded, then as Davies (1998) concludes, there may be a way to beat the house odds. So in addition to dark matter comets, we must also argue for a low-entropy, high-information, initial state for the universe. This paper traces the outline of a possible scenario for OOL where the initial state of the universe has high information, and watery comets are ubiquitous information concentrators. Such a scenario makes predictions for the distribution of matter and life that can be tested by observation.

2 The Dark Matter Problem

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 (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 ~ 12 Gya, the evenly distributed DM must not be susceptible to viscous drag, the way nebular matter in our own solar system collapsed into the Sun and planets 5 Gya. But the same gravitational attraction that binds the galaxy also produces viscosity, which over time should condense the majority of the DM to the center of the galaxy! Added to this mystery, is the proposal of McGaugh et al. (2016) that the "universal" shape of the galactic DM density curve when plotted against the gradient of the gravitational potential, a shape that is not "cuspy" or "cored" but tracks the visible matter.

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 (BH), 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 (e.g., 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.

2.1 Dark matter comets

In contrast to all these failed theories, Sheldon (2015) 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. Against the comet hypothesis three objections are often raised: DM lacks viscosity, visibility, and baryons (protons, neutrons, atoms).

2.1.1 Inviscid DM

The first objection is that DM is apparently without viscosity (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 viscous, small-angle collisions are unlikely, then 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 "being a neutrino" and simply not colliding with anything. 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," which is a new field of study (e.g., 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 the cored distribution of the DM observations, and McGaugh's flat distribution correlated to stellar densities.

That is, McGaugh's observation that the DM follows the baryonic matter distribution very closely, but becomes more dominant as the acceleration decreases is understood if we consider that comets couple gravitationally to stars, so 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 fluid model, Bernoulli's principle says the faster the comets are moving, the lower their density. Hence McGaugh's third law: high acceleration lowers DM density, no exotic MOND required.

2.1.2 Invisible DM

The second objection is that astronomers cannot see this dark gravitating matter, whereas comets were thought to be "dirty snowballs" with high reflectivity (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 (Sheldon and Hoover (2006)). 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 (1990) "cometesimal" claims revealed just how difficult it was to observe these objects. Therefore invisibility is a property shared by both neutrinos and comets.

Even 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 nearly 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. Not completely, however, for both McGaugh's third law and the recent Doux et al. (2016) observation that the absorption lines in quasars—called the Lyman-α forest as the distant light traverses dozens of red-shifted Hydrogen gas clouds before arriving—are examples where baryonic matter and gravitating dark matter track each other very closely, suggesting they are the same thing.

2.1.3 DM not baryonic

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 baryonic DM would require a denser universe than is compatible with the observed He/H ratios. By this negative argument, DM must consist of exotic (non-baryonic) 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" (e.g., 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. We counter-claim, however, 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" are model-based claims, which are only as precise as the models are correct, so it is essential that we separate these second-order (disagreeing with model) claims from model-independent, first-order (disagreeing with data) 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, and in particular, the neutron to proton, n/p, density ratio, which it turn, depends on all four of the fundamental physical constants: the strong, the weak, the electromagnetic and the gravitational constant (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 (e.g., Susskind (2008)). Following Calkin (1963) 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 and Phillips (1956)), which encodes currents and magnetic fields. Since magnetic fields change the n/p ratio, adding this fifth quantity, this information quintessence to the basic physics of the BB, 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 astronomical inventory, leading to the mistaken impression that they are not a major constituent of the BBN, but they reveal their presence gravitationally. 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 Galactic elemental composition

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 oldest Population III stars are often identified by their composition, so it has been difficult to assemble an unbiassed 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 nuclear 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 they exhibit comparable abundances (see Maeder et al. (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 comet hypothesis 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 NASA/COBE, NASA/WMAP and now ESA/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. How then can baryonic DM satisfy both the need for seeding density fluctuations and the observation of smooth radiation?

We point out that 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)). So neither baryonic nor non-baryonic dark matter appears to solve the riddle of early galactic origin.

Comets, on the other hand, do not form from gravitational instabilities, but from a physico-chemical process of condensation and freezing. 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 (blue-giant, hot white-dwarf). 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. Thus 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 $T > 1$eV, so that the galactic structure is not reflected in the CMBR, nor the smoothness of the CMBR limiting the galactic structure.

2.3 BBN formation of CNO

In the standard model of BBN, a network of particle mediated nuclear reactions couples the table of isotopes, such as the hydrogen (H) to deuterium (D) reaction $H + n \rightarrow D + \gamma$, compactly written $H(n,\gamma)D$. Some 40 to 120 reactions were solved simultaneously to determine the ratios of H, D, He, Li, C and O (Kawano (1992)). Most of the networks do not go beyond O, because at that point the O/H ratio has reached *ppt*, 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 H(n,γ)D→D(d,γ)4He or D(p,γ)3He. Likewise the lack of any stable A=5,8 elements (5He, 5Li, 8B, 8Be) require 4He(d,γ)6Li deuterium reactions to hop to A=6. But the fragile binding energy of D prevents its formation during the hot, dense phase of the BB, so by the time the universe has cooled for sufficient D-hopping reactions, the BB density is too low to continue nucleosynthesis. This bottleneck means that over large ranges of parameters, all BBN models produce nearly the same result for the same initial n/p ratio: 25% mass He/H (designated Y_P), 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 3σ from the BBN prediction, and no amount of fiddling over the past 20 years has brought the model into better agreement. The last theoretical cross-section in the network was experimentally measured this year, with no change in the discrepancy (Coc (2016)). 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 Alpher et al. (1948) (Alpher-Bethe-Gamow) paper on Big Bang Nucleosynthesis, the initial state of the universe was proposed as "a highly compessed neutron gas." Subsequent theory by Alpher et al. (1953) argued that the neutron decays into a proton and electron via the weak interaction mediated by the W-boson at T>2MeV, so abundant neutrinos, ν, right before BBN-era cause the exothermic transformation of neutrons into protons and the BBN-era began with a 1:7 n/p ratio. Then the observed 25% Y_P is simply due to the tightly bound helium soaking up all available neutrons. In Zel'dovich (1964), he argued that a quantum degeneracy of anti-neutrinos, ν^* filling the "Fermi sea" would exact an energy penalty from the exothermic conversion of neutrons to protons so an overabundance of ν^* would prevent the destruction of neutrons and keep protons from being created. These extra energy terms in the reaction are called chemical potentials (by analogy to physical chemistry), and in Wagoner et al. (1967) FORTRAN code was a free parameter, ξ, which was able to change the initial ratio of n/p, and thereby change the He/H ratios from the BBN. In this paper we add another chemical potential, μ, to Zel'dovich's degeneracy, arguing that a magnetic BBN (MBBN) had initial n/p> 1.

We argue that indeed there is a justification for ξ, 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 reactions:

$$\begin{aligned} n &\rightarrow p + e + \nu^* + (782\text{keV}), \qquad (.1)\\ n + \nu &\rightarrow p + e + (> 782\text{keV}),\\ n + e^* &\rightarrow p + e + (\sim 1.3\text{MeV}), \end{aligned}$$

result in 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, **b**. Since creating the magnetic field in a background field, **B**, takes extra energy, $E = \mu/2[(B+b)^2 - B^2] \sim \mu Bb$ then a strong background magnetic field will oppose the currents generated by the neutron decay, and favor the conservation of neutrons, adding magnetic energy to the neutrino degeneracy chemical potential.

In addition, 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 $\nu - \nu^*$ plasma that permits $n \leftrightarrow p$ 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, G_F, that enables a neutrino to moonlight as an electron depends on the square of 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 B-field is strong enough to overwhelm the thermal fluctuations, it is expected that only neutrons will be produced during this era. Once the BB expands and cools below $\sim$ 1MeV, however, there is insufficient energy to make electron-positron pairs, e-e*, so 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 principally electrons, 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 n/p.

In this scenario, essentially all the available protons are converted into He, which now floats in a bath of neutrons. But recalling that there are no A=5 stable elements, there are no fast, two-body reactions involving neutrons or protons to begin the stepwise nucleosynthesis beyond He. The only possible reactions are double hops using either minority projectiles such as 4He(d,γ)6Li, or barely unstable (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 channel becomes the triple-α jump, the 4He$(\alpha\alpha,\gamma)$12C reaction, which can begin the carbon cycle that produces CNO. 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 MBBN model, employing the Arbey (2012) code modified to include additional chemical potentials. Therefore the strength and topology of the magnetic field 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 magnetic field does more than simply change the ratio of n/p 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 that possesses energy, like boiling water or freezing ice, mapping the coherence of the field onto the coherence of the matter. The energy difference suppresses temperature fluctuations, which is why boiling water is uniformly at 100C, or melting ice 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 a voltage, 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 first 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 same coherence that was previously attributed to the global inflaton field (albeit indirectly).

The magnetic field 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 computed by 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, however, 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 first order phase transition stabilizes the temperature by coupling to a third energy source, the neutrinos set up a feedback that taps into the magnetic field 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 as discussed by Somov et al. (2008). 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 these waves where the temperature is a function of position.

If we then consider the neutrinos as the "radiative cooling" term for the dense BB plasma, we can see that increased density, temperature, or magnetic field also increases the opacity. So if the magnetic field energy is being dissipated into the neutrino plasma, the conditions for entropy waves are met. Since the entropy waves cannot grow forever, saturation occurs at maximum temperature for that density, maintaining a highly homogeneous system. 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, Missing Antimatter

When the temperature drops T$<$ 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 antimatter-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 antimatter go? It went into hiding.

The electroweak interaction permits the conversion e*$\rightarrow \nu^*$ while conserving lepton number, e.g. e*+n$\rightarrow \nu^*$+p. Then the apparent dominance of (leptonic) matter over antimatter is achieved by hiding the antimatter 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 E$\sim \mu_{\mathbf{B}} \cdot \mathbf{B}$, where $\mu_{\mathbf{B}}$ 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 magnetic energy can be either +/-, which we might naively imagine to cancel out in a spatial integral. If the magnetic field is twisted, or helical, however, 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." It is easier for a positive charge than for 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 antimatter.

So if the neutrino plasma makes a helical magnetic field, then the e and 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.

Finally, a saturated B-field 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 may have fewer QM states available to them at finite temperature, reducing their entropy. In short, the large B-field "cools" the particles into a Bose-Einstein condensate that becomes the lowest entropy state possible for the universe. Since low entropy is often equated with high information, the magnetic field 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/antimatter asymmetry, flatness, horizon, BBN D/H and 7Li/H deviations, dark matter, dark energy, cold white dwarfs, CEMP stars, early galaxy formation, and ubiquitous comets with their payload of information.

3 Discussion

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 I 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 (2008) argues that QM requires information to be neither created nor destroyed, but Hawking's conception of black holes destroys information. After 10 years, Hawking (2014) conceded that his namesake radiation would destroy information, but unwilling to let go of his theory, he argues that black holes don't exist! 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 BB, represented by the enormous magnetic field is also responsible for OOL.

Penrose (1981) 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. The information is the number of permutations (bigger than a combination) of quantum states, calculated as $n!$ (or n-factorial where $4! = 4 \times 3 \times 2 \times 1$). 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! 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 (1982) 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), the only difficulty lies in concentrating it into a cell.

That is, if we treat entropy, S, as a fluid, $dS = dQ/T$ (where Q is thermal energy), then it would seem reasonable to treat its inverse, the information, also as a fluid, as an arrangement of the particles. So where there are no particles, there can be no information. And if the BB spread those particles out evenly, very likely the information is likewise diluted and scattered, which for OOL, must then be concentrated in a cell a few cubic microns in volume. Then the "hard" problem of OOL becomes merely the "difficult" problem of concentrating the initial BB information into a cell.

When we concentrate something, we are fighting entropy, we are battling diffusion and turbulence and mixing. So to concentrate information is 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. Then the difficulty lies in all the special machinery needed to manipulate fluids, or as they say about acquiring wealth, it takes money to make money, which still does not prevent a few select people from getting filthy rich. Or if we want 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 magnetic field 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 magnetic field 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 magnetic fields 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" anti-gravity 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 with the magnetic field 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 Sheldon (2012) argues that life would begin the transformation of a harsh universe into a hospitable home. Cyanobacteria, whose fossils have been found on every carbonaceous chondrite, are the only living thing that can make sugars and proteins from sterile sunlight, CO_n, H_2O and N_2. Some of those polysaccharides 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. Life-modified 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 icecream driven by density gradients, nor do they send out supernovae shock waves in successive arcs of stellar formation, but expand in streamers and trailers, like ants on a mission.

For the living strategy of an efficient search algorithm employed by bacteria, slime molds, ants and tigers, involves a fractal distribution, a lacy network, which is precisely the structure revealed by galactic surveys, with galaxies and supergalaxies stretched out on a three-dimensional lace of lanes, voids and walls. This structure is so information rich that modellers 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 communication network.

And as 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 (Hoover et al. (1986)), but they continuously filter down on the planets that plow through their meteor trails, as Brownlee et al. (1977) observed at Earth on stratospheric balloons. Earthlike 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. They 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, so that they lay down a layer of nutrient rich goo, ideal for fungi and multicellar plants to grow on, and perhaps later on, acorn worms and animals. They harbor viruses to horizontally transfer blueprints of cellular machinery among the fungi and algae and animas, they encourage ecological 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 $(\text{time})^{1/2}$, nor at a delivery pace $(\text{time})^{+1}$, but at infectious pace (e^{time}), a function whose derivative looks identical to the function. This suggests that the delivery of information is growing ever more efficient with time; the system is bootstrapping by adding more channels as it grows more sophisticated (Sheldon and Hoover (2008)). This is a characteristic of life, not of non-living diffusive chance.

And then a high-speed comet strikes this terraformed ocean and splashes its water into space, so that other passing comets can 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 Earthlike planet. In such a way, comets are the conduit, the nerves, the fiery 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 Earth environment was ready, life appeared. The moment the Earth had oceans, stromatolites appeared. As Meyer (2013) extensively records, the moment the atmosphere was oxygenated, the Cambrian Explosion occurred. The history of evolution is not history of instantaneous accidents, but a history of planned deployment, of staged development, of bootstrapping complexity.

4 Magnetic Big Bang Nucleosynthesis model

In order to simulate the addition of a magnetic field, 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.

4.1 Theoretical considerations

1. The coupling of neutrinos The Fermi factor, G_F, characterizes the strength of the weak interaction. It is proportional to B^2, which we argue, exists as long as electron-positron, e-e*, pairs can be easily made (T> 1.1 MeV). When large currents can be maintained, the neutrino-matter interaction (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. Depending on temperature, the enhancement to the Fermi factor is either present or absent with a transition at T∼ 2MeV. In the Arbey (2012) code, unfortunately, only the $n \to p$ 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 yet.

2. 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, $\mu = \tanh((T - T_0)/\sigma)$, where T_0 is set to 2GK, 1.5GK and 1.2GK, and σ is fixed at 2GK.

3. 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, 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, μ, the helium ratio, Y_P, depends only on $\mu + \xi$.

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 proportional to the energy of the e/e* created (negative if destroyed), which depends on the external magnetic field parametrized by a tanh-function as above. 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 Arbey-code "effective number" of neutrinos from 3 down to 1, though in practice it has less effect than the chemical potential. 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 et al. (2014); Coc and Vangioni (2014)). So postponing a discussion of CNO production, we simply convert all the metals to equivalent helium atoms, deriving the formula for 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 so DM=$He_{12}H_9$. When combined with the visible matter, DM+(m)HeH_{16} where m= 12/20 to make the visible mass 20% of the total. Then Y_P=(48+2.4)/(9+9.6+48+2.4)=0.73 is our target MBBN 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 $1.2 < \mathrm{D/H} \times 10^5 < 5.3$. Just as the 4He/H ratio is enhanced, so is the 3He, which we scale with the calculated 4He/H ratio, 73/25, or $1.66 < \mathrm{3He/D} < 4.44$.

Are there reasonable solutions to the BBN model that achieve these three set points? The answer is yes. In Figure .1 we show on the left the results of the Arbey code for changing the neutrino degeneracy, ξ, and on the right the results of adding the magnetic chemical potential, μ, to the $n \rightarrow p$ weak reaction with a transition temperature of 1.5GK. Qualitatively they are very similar, though negative μ raises the initial neutron density more effectively than negative ξ. The important thing to note is that values of $Y_P = 0.73$ 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, but we find that increasing the baryon/photon ratio, η, by a factor of 4, suppresses D while enhancing 3He, as the left panel in Figure .2 shows. Therefore, around $\mu \sim -0.4$ has all the right numbers: a $Y_P \sim 0.7$, a D/H$\sim 2 \times 10^{-5}$, and a 3He/D> 1.5. All 3 set-points of our MBBN 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 6×10^{-10} value, but raise $\xi = -0.5$, 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 $\mu = -0.4$, which is what we expect if $\mu + \xi$ controls the n/p ratio of the initial conditions. But more significantly, this lowers the 7Li abundance without affecting the Y_P or 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 without invoking "exotic" or "new" physics.

5 Conclusions

We have shown how all steps in the origin-of-life from the Big Bang to the present can be sketched out. Our argument still has a major lacunae in the BB generation of water from extra helium, which we plan to address, but we are confident that a future MBBN model incorporating all carbon and oxygen cross-sections will justify our assumption. For 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 created in the Big Bang made the dark matter comets and condensed the first ice stars, which sealed comets in concrete shells, speeding them on lacy trails, seeding the galaxies and transforming the dark nebulae into starry skies. Water provided the extra gravitational attraction that held the spinning galaxies together and allowed the evolution of solar systems and rocky planets. Water cooled and transformed our molten rock into a blue-marble planet. Water tamed the climate by cloud- and snow-regulating albedo. Water formed the glaciers that recycled continental rock back 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 tolerable summer and winter. It is safe to say that without the information contained in and through water, our universe would be nothing but cooling gas, well on its way to heat death and oblivion. Therefore it is not coincidence that the second verse of Genesis says,

> The Earth was formless and void, and the Spirit brooded over the face of the waters.

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List of acronyms and glossary

- η: The baryon/photon ratio at decoupling time ~ 3000 years, typically 6×10^{-10}.
- ΛCDM: The standard big bang model with dark energy (Λ) + Cold Dark Matter.
- μ_B: The magnetic (dipole) moment of a particle.
- μ: The (magnetic) chemical potential in binding energy/temperature units.
- ν: A neutrino (Fermi's little neutral particle), like a chargeless electron.
- ν*: An anti-neutrino identical to a neutrino, but annihilates it on contact.
- ξ: The neutrino degeneracy parameter in Fermi-energy/temperature units.
- A: the atomic number = #protons+#neutrons, e.g., A=5 could be 5He, 5Li, 5Be.
- BB: The Big Bang at the beginning of the universe.
- BBN: The BB Nucleosynthesis era 2MeV$< T <$ 100keV, or $10^{-21} < t < 1000$ seconds.
- bootstrapping: a process which updates itself–like starting Windows on an IBM PC.
- CDM: Cold Dark Matter needed to get cosmology models to form clumps and galaxies.
- CEMP: Carbon-enhanced metal-poor stars found among the oldest stars of the galaxy.

- CEMP-no: CEMP stars lacking the metals heavier than Sodium (r-process).
- CI: Carbonaceous chondrite type I are rare, black, water-soluble, grainy, wet meteorites.
- CMBR: Cosmic Microwave Background Radiation, relic BB photons now cooled to 2.73K.
- D/H: Deuterium (2H) to Hydrogen (1H) ratio, a direct fingerprint of the BBN.
- DM: Dark matter, the unseen matter that supplies extra gravity to the galaxy.
- DNA: Deoxyribo-Nucleic Acid that encodes the genes of all living things.
- e: The electron, a fundamental particle of negative charge.
- e*: The anti-electron, or positron with positive charge (and annihilates e on contact).
- ESA/Planck: The European Space Agency spacecraft “Planck” that measures the CMBR.
- G_F: The Fermi factor characterizing the strength of the weak interaction.
- keV: A kilo-electron-volt, a unit of energy=100 eV.
- LUX: The Large Underground Xenon detector for WIMP candidates. (No, none seen.)
- Lyman-α forest: Doppler-shifted Hydrogen Lyman-α absorption lines from many gas clouds.
- MACHO: Massive Compact Halo Objects (black holes, neutron stars).
- MBBN: Magnetic Big Bang Nucleosynthesis, a BBN model with large intrinsic B-field.
- MeV: Million electron Volts, a unit of energy=1,000,000 eV.
- MOND: Modified Newtonian Dynamics, altered gravity that fades at high speed and distance.
- n: The neutron, an uncharged composite baryon made of three quarks.
- NASA: National Aeronautics and Space Administration, the United States space program.
- NASA/COBE: NASA’s Cosmic Background Explorer spacecraft to measure the CMBR.
- NASA/WMAP: NASA’s Wilkenson Microwave Anisotropy Probe, successor to COBE.
- OOL: Origin-Of-Life, the hard problem of generating life from non-life.
- p: The proton, a positively-charged composite baryon made of three quarks.
- QM: Quantum Mechanics, at small length scales where particles act like waves.
- UV: Ultra-violet light, above purple in the spectrum, but below x-rays in energy.
- WIMP: Weakly Interacting Massive Particles, exotic particle physics candidate for DM.
- Y_P: The mass fraction of 4Helium/Hydrogen in the universe.

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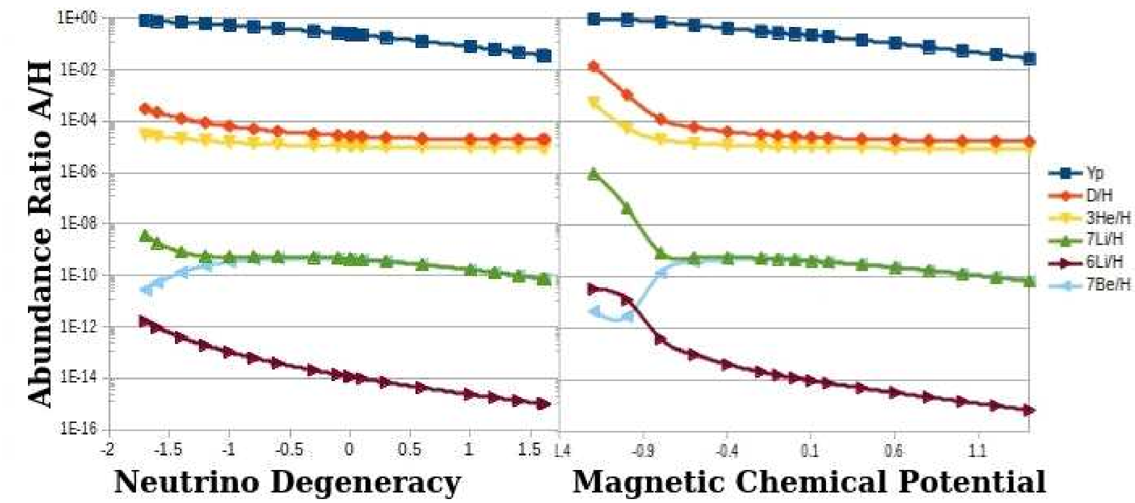

Figure .1: Primordial element abundances from Arbey MBBN code. L: Scan in neutrino degeneracy parameter. R: Scan in magnetic chemical potential.

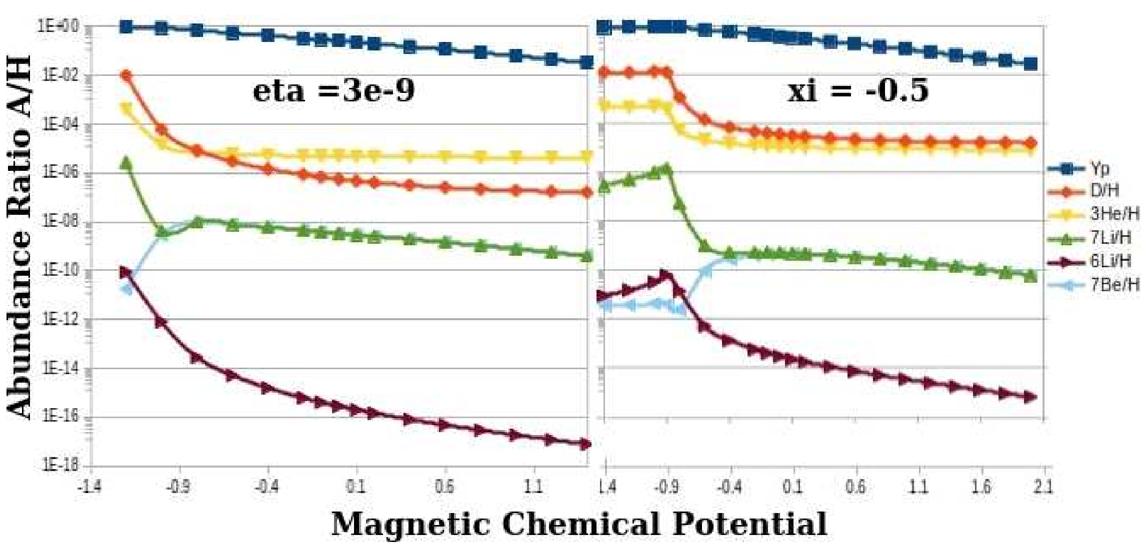

Figure .2: As above, L: Scan with 4X the baryon/photon ratio. R: Scan with fixed $\xi = -0.5$.