Article

Why the Universe is Fractal

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ABSTRACT

Life exists in the universe because the laws of nature arising from cosmic symmetry-breaking are intrinsically fractal and embrace chaotic dynamics in a manner that permits new structure to emerge on increasing scales, as we move from the level of fundamental particles to organisms. In a fundamental sense this is a cosmological property of the universe, because complex living systems represent the most complete interactive consummation of the four fundamental forces of nature. If the laws of nature permitted only ordered periodic or stochastic solutions to molecular aggregation, as in crystals, or amorphous glasses, the complex structures of tissues and life would remain impossible.

Key Words: universe, law of nature, symmetry-breaking, fractal, chaotic dynamics.

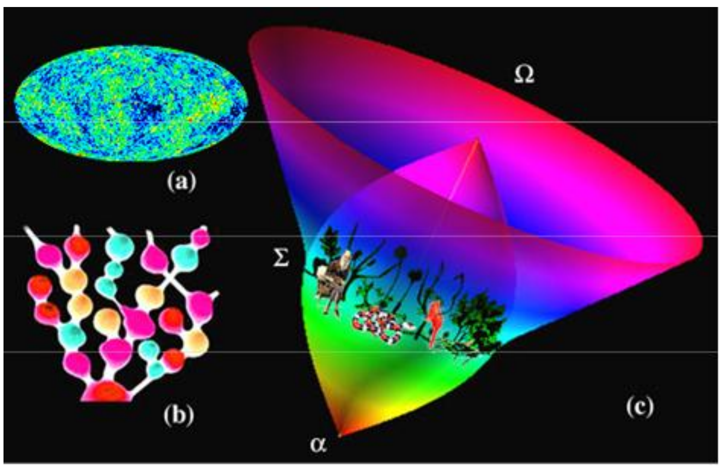

Fig 1: (a) WMAP survey. The cosmic background shows evidence consistent with cosmic inflation, (b) fractal inflation model[4] (c) Life on the cosmic equator - despite being dwarfed by annihilating forces such as black holes, life occurs as a Σ of complexity on the cosmic equator in space-time, an interactive peak as significant as the α of big bang or Ω of 'heat death' or 'big crunch'.

Symmetry-breaking and Cosmic Inflation

The source of this complexity also lies in cosmological processes right at the source of the 'big bang'. The basis of the cosmic inflation concept is symmetry-breaking, in which the fundamental forces of nature, which make up the matter and radiation we relate to in the everyday world gained the very different properties they have today. There are four quite different forces. The first two are well known - electromagnetism and gravity - both long-range forces we can witness as we look out at distant galaxies. The others are two short-range nuclear forces. The colour force holds together the three quarks in any

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neutron or proton and indirectly binds the nucleus together by the strong force, generating the energy of stars and atom bombs. The weak radioactive force is responsible for balancing the protons and neutrons in the nucleus by inter-converting the flavours of quarks and leptons.

Particles come in two types, fermions, of half-integral spin, which can only clump in complementary pairs in a single wave function and thus, being incompressible, make up matter, and bosons of integral spin which can become coherent and can all enter the same wave function in unlimited numbers, as in a laser, and hence form radiation. As well as virtual particles appearing and disappearing through quantum uncertainty, bosons mediate the forces which act between the particles. We thus have another fundamental complementarity manifesting as the relationship between matter and radiation. The half integral spin of electrons was first discovered in the splitting of the spectral lines of electrons in atomic orbitals into pairs whose spin angular momentum corresponded to ±1/2 rather than the 0, 1, 2 etc. of atomic *s, p* - orbitals. As spin states have to differ by a multiple of Planck 's constant *h*, a particle of spin *s* has $2s+1$ components. A glance at the known wave-particles, indicates that the bosons and fermions we know are very different from one another in their properties and patterns of arrangement. There is no obvious way to pair off the known bosons and fermions, however there are reasons why there may be a hidden underlying symmetry, which pairs each boson with a fermion of one-half less spin, called super-symmetry, because in super-symmetric theories the infinities that plague quantum field theories cancel and vanish, the negative contributions of the fermions exactly balancing the positive contributions of the bosons. This would mean that there must be undiscovered particles. For example corresponding to the spin-2 graviton would be a spin-3/2 gravitino, a spin-1 graviphoton a spin-1/2 gravifermion and a spin-0 graviscalar.

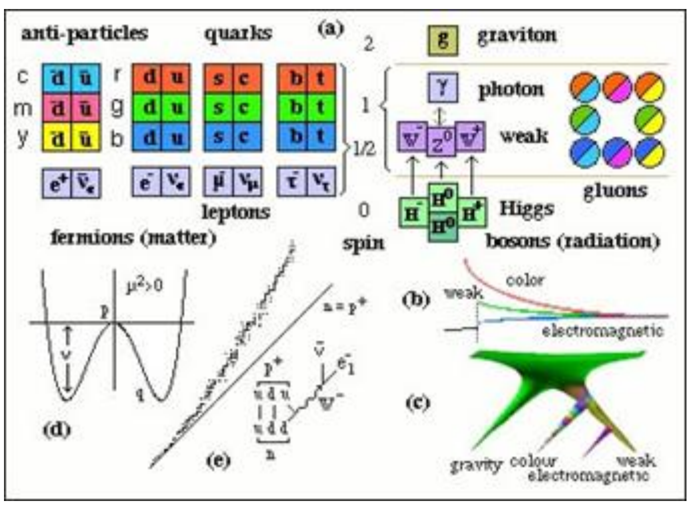

Fig 2: (a) The wave-particles are divided into two disparate groups of bosons and fermions. The fermions, which make matter are divided between quarks which experience all the forces including colour and leptons which experience only the electro-weak and gravity. The bosons, which mediate the forces have integer spin and freely superimpose, as in lasers and hence also make radiation. Half-integer spin fermions only superimpose in pairs of opposite spin and hence resist compression into one space, thus making solid matter. Each quark comes in three colours (RGB) and pairs of flavours (up, down etc.) Electromagnetism is first united with the weak force ostensibly through the spin-0 Higgs boson, then with the colour force gluons and finally with gravity. (b) The forces converge at high energies. (c) Force differentiation tree, in which the four forces differentiate from a single super-force, with gravity displaying a more fundamental divergence. (d) the scalar Higgs field has lowest energy in the polarized state, (e) the stable atomic nuclei with their increasing preponderance of neutrons are equilibrated by the weak force. This force is chiral, engaging left-handed interactions, for example in neutron decay, as shown. Weak interactions may explain the chirality of RNA and proteins.

The four fundamental forces appear to converge at very great energies and to have been in a state of symmetry at the cosmic origin as a common super-force. A key process mediating the differentiation of the fundamental forces is cosmic symmetry-breaking. The short-range weak force behaves in many ways as if it is the same as electromagnetism, except the charged W^+,W^- and neutral Z_0 carrier particles corresponding to the electromagnetic photon are very massive. One can consider this division of a common super-force into distinct complementary forces as a kind of sexual division, just as the symmetry-breaking division into male and female is a primary division. In this respect gravity stands apart from the other three forces, which share a common medium of spin-1 bosons and broke symmetry first. Originally the particles had zero rest mass like the photon, but some of the boson force carriers, like the W, changed to mediate a short-range force by becoming massive and gaining an extra degree of freedom in their wave function (the freedom to change speed) by picking up an additional spin-0 particle called a Higgs boson. The elusive Higgs may also explain why the universe flew apart.

The universe begins at a temperature a little below the unification temperature - slightly supercooled, possibly even a result of a quantum fluctuation. In the early symmetric universe, empty space is forced into a higher-energy arrangement than its temperature can support called the false vacuum. The result is a tremendous 'negative' energy of the Higgs field, which behaves as exponential anti-gravity, inflating the universe in 10^{-35} of a second to something already close to its present size. This inflationary phase becomes broken once the Higgs field collapses, breaking symmetry to a lower energy polarized state, rather like a ferro-magnet does, to create the asymmetric force arrangement we experience, to form the true vacuum. In this process, the Higgs particles, which are zero spin and have one wave function component, unite with some of the particles, such as $W^{+/-}$ and Z_0 to give them non-zero rest mass by adding their extra component, allowing the additional longitudinal component of the wave function associated with a varying velocity. Because the true vacuum is at a lower energy than the false one it grows to engulf it, releasing the latent heat of this energy difference as a shower of hot particles, the hot fireball we associate with the big bang. Gravity has now reversed to become the attractive force we are familiar with. Two energies, gravitational potential and kinetic, which previously cancelled, now add. An insignificant universe - almost nothing - becomes one of almost incalculable proportions. The end result is a universe flying apart at almost exactly its own escape velocity, whose kinetic energy almost balances the potential energy of gravitation.

Symmetry-breaking can leave behind defects if the true vacuum emerges in a series of local bubbles which join. Depending on whether the symmetries, which are broken are discrete, circular, or spherical, corresponding anomalies in the form of domain walls, cosmic strings or magnetic monopoles may form. In addition other weakly-interacting particles may emerge, such as the axions which some researchers associate with cold dark matter. In some models, inflation is a fractal branched structure like a snowflake which is perpetually leaving behind mature universes like ours[4]. Recently it has become clearer that, even with additional dark matter, possibly comprising neutrinos and other exotic particles, there may not be enough mass to stop the expansion, which may even be accelerating. Various hyperbolic forms of inflation and an additional repulsion called quintessence involving a long-range repulsive dark energy have both been invoked to address this problem.

Life's Emergence as Symmetry-broken Interaction

Life is the ultimate cosmological consequence of the four forces of nature acting in hierarchical sequence, the colour and weak forces binding the quarks to form protons and neutrons, then atomic nuclei, then atoms, and finally the electromagnetic force becomes dominant in forming molecules. Complex molecular matter organized in the fractal form we find in tissues is the ultimate expression of the interaction of all the forces, which emerged in the symmetry-breaking at the cosmic origin[1].

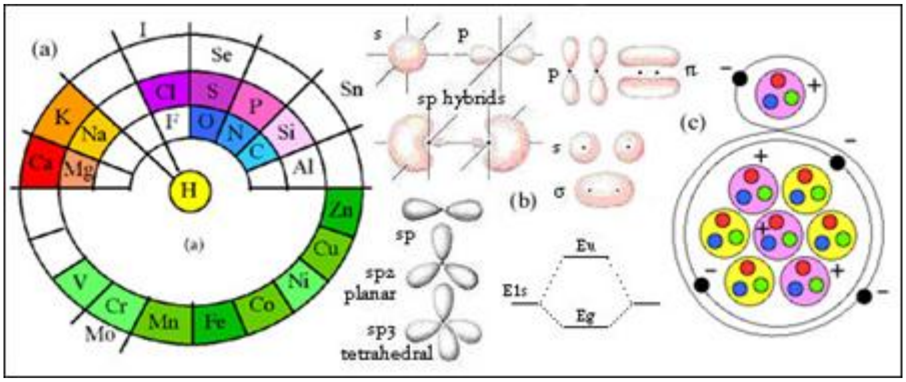

Fig 3: Interactive quantum bifurcation and wave nature in chemical emergence (a) Bifurcation diagram of the periodic table shows how the key bioelements arise from primal quantum interactions resulting from cosmic symmetry-breaking. (b) Atomic, hybrid and molecular orbitals are wave functions determining molecular geometry. Below energy diagram of the non-linear charge interactions causing molecular orbital formation. (c) The hierarchical interactive structure of a molecule (LiH) illustrating how the colour, weak and electromagnetic forces combine to form a complex polarized structure.

It is the twisted nature of cosmic symmetry-breaking, which makes the makes the combined action of the nuclear and electromagnetic forces capable of forming around a hundred different types of stable nuclei, through the mutual interaction of strong force attraction, electromagnetic repulsion of the protons, mediated by weak force conversion to neutrons. The fact that the stable nucleons are neutral and positively charged polarizes the entire electromagnetic make up of atoms. The positive charges of the protons clumped together in the nucleus give atoms their unique highly polarized structure of orbital negatively charged electrons. Without this uniquely polarized situation, which is itself a direct consequence of cosmic symmetry-breaking, complex molecular life would be impossible.

Moreover the non-linear interaction does not stop at the major bonding types, for molecules admit a whole cascade of non-linear bonding interactions from covalent and ionic through the hydrophobic and hydrogen bond interactions that shape nucleic acid and protein structure, to the long-range cooperative weak polar and van der Waal interactions that together make the global cooperativity of enzyme action and cellular organelles, including the excitable membrane, possible. It is the unresolved nature of the electromagnetic force in molecular bonding and the transition from strong bonds to global cooperative weak interactions that make the fractal dynamics and fractal supramolecular associations of complex molecules into organelles, cells and tissues possible. Symmetry-breaking has thus caused molecular matter to adopt a fractal structure, which ultimately becomes tissues and organisms on the planetary surface held together by the last force, gravity, energized by the negentropic surfeit of incoming solar radiation bathing our photosynthesis-based biosphere with its diversity of plant, animal fungal, protist and prokaryote forms.

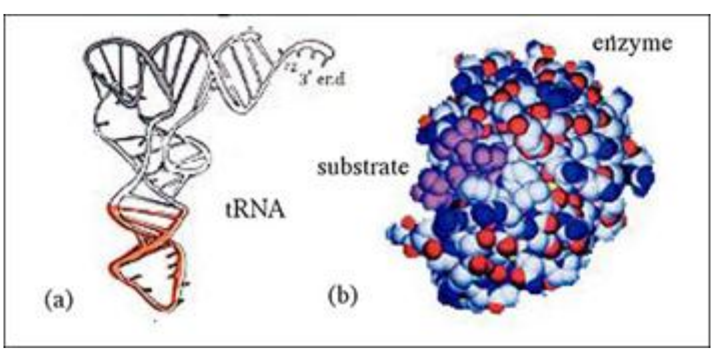

Fig 4: Global structures of t-RNA and protein enzymes are mediated by cooperative long-range weak bonding, in association with water structures. The hairpin loops of RNAs give them a similar tertiary structure to globular enzymes and permit catalytic activity, as well as the molecule being intrinsically capable of complementary replication through A-U and G-C H-bonding specificity in the same manner as DNA.

We owe to the unique twisted symmetry-breaking of the forces of nature the very capacity for molecular life and with it biological complexity and the tree of evolution to ramify. In effect biological complexity and with it the conscious brain becomes the ultimate cosmological interactive result of cosmic symmetry-breaking, the Σ at the cosmic equator, representing the fulfillment of both α and Ω.

Chemistry is often portrayed in terms of ball and stick models, as if only the particle properties of atoms are of significance in chemical bonding. Indeed the atomic nature of matter is one of the principle foundations for a reductionistic explanation of all living processes in terms of the simple actions of atoms as the "building blocks of the universe". However wave-particle complementarity is at the very core of all chemical interactions. The periodic table of the elements has periodicity only because the wave properties of the electronic orbitals give rise to a series of *s*, *p*, *d*, and *f* orbitals of increasing spins of 0, 1, 2 etc. Thus the second row of the periodic table, after H and He, as illustrated in fig 3, consists of the second layer of one 2*s* and three 2*p* orbitals. Because electrons are fermions, they can only enter a given wave orbital in pairs of opposite spin, these four orbitals allow eight electrons in to complete the shell, corresponding to the eight elements in the second row, running through C, N and O - carbon, nitrogen and oxygen. In fact the energies of these orbitals equilibrate to form hybrid *sp* orbitals by wave superposition, resulting in the planar sp_2 and tetradedral sp_3 arrangements we find in molecules, from water to diamonds.

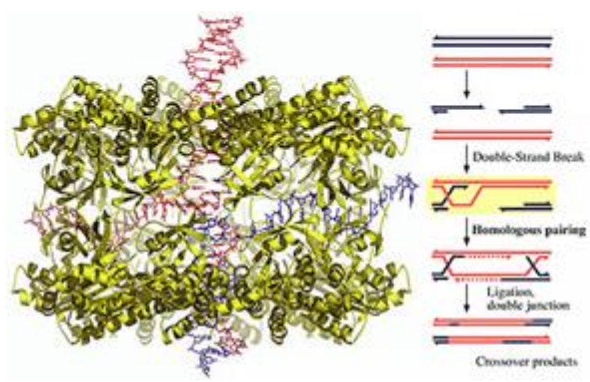

Fig 5: Recombinase involved in genetic crossing-over. Complex molecules and supra-molecular complexes are possible because the electromagnetic force involves a cascade of cooperative weak bonding effects, which result in a fractal structure of the active conformations and dynamics of large protein and nucleic acid molecules. Ion channels for example display fractal time-scale dynamics as well as fractal structure due to primary sequencing, secondary structures such as α-helices and tertiary conformations.

From here the process is highly non-linear. Electrons are capable of forming molecular wave orbitals, such as σ and π, which orbit around more than one atom - often two, but sometimes, in the case of conjugated single and double bonds, a whole molecular ring. Because of non-linear charge interactions between the electrons and with the nucleus, which, like gravitation, obey an inverse square law in 3-D space, the lowest energy molecular orbital is lower in energy than either atomic orbital and the electron enters it, binding the atoms together into a molecule such as H_2. This is the basis of the covalent bond. The ionic bond arises from a similar lowering of energy by electron transfer from one atom to another, resulting in net attraction between the resulting positively and negatively charged ions, such as Na^+ and Cl^-.

These non-linearities of charge interaction are also manifest in the ‘periodic’ table, which is not actually periodic, because charge interactions on the inner orbitals make the properties of corresponding elements in successive rows, such as those between O and S or between C and Si, qualitatively very different. Chemists love to describe chemical bonding as a simple ball and stick arrangement that, given appropriate energetic reagents in an artificial ‘closed’ system, can ‘stick’ almost any pair of atoms together in any arrangement we wish. This is central to the mechanistic atomic view of chemistry and biology. This mechanist picture begins to seriously unravel, however, when we consider what happens when we ask a very different kind of question - "What will happen if we simply let the chemical elements go in the kind of situation we find in the universe at large? - What structures will emerge in the free interaction of the elements under energetic stimulation?"

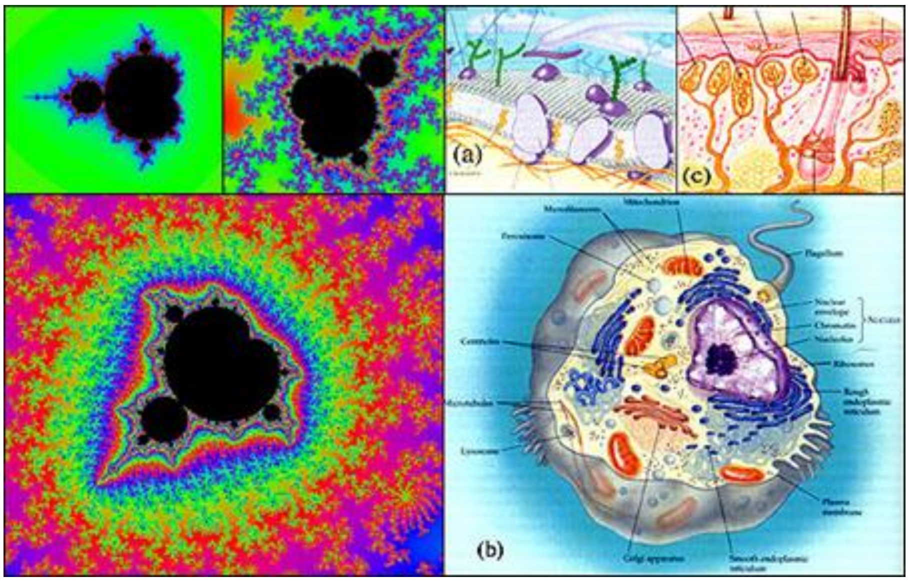

Fig 6: Tissues (right) have a fractal structure as a consequence of charge non-linearity in chemical bonding: (a) molecular level (b) cellular organelles (c) organs (skin). This fractal structure is similar to that arising from the non-linear quadratic dynamics of the Mandelbrot set (left). By contrast with the classical Mandelbrot set, which arises from a continuous global iterative map, the genetic process forming tissues is quantum-interactive and results from non-linearities of orbital charge interaction. In this respect it resembles the capacity of cellular automata, which also display fractal and chaotic dynamics, for universal computation[6].

We can see a first part of this answer lies in a series of quantum bifurcations that arise from cosmic symmetry-breaking. The backbone of life arises from the strongest covalent bonds of all among the elements, $-C \equiv N$ $-C \equiv C-$ and $>C=O$. Given the ubiquity of H this gives the interaction of the 1s orbital of H with the $2sp_3$ hybrid of carbon, nitrogen and oxygen primary status. Here we are using 'bifurcation' as a qualitative change in the interactive system caused ultimately by the underlying variables of cosmic symmetry-breaking. Despite suggested alternatives such as silicon-based life there is abundant evidence for this primary interaction being the central 'royal route' to living systems. Molecules containing chains of conjugated multiple C bonds have been detected in interstellar space. Clouds of cyanide HCN and formaldehyde HCHO have been discovered in the Orion nebula where new star and solar system formation is taking place and huge galactic gas clouds containing molecules such as the two-carbon sugar glycoaldehyde and the simplest amino acid, glycine. HCN and HCHO are also key energized intermediates in primal chemical simulations.

A second key interaction arises from the increasing electronegativity, as we move from C to O. Electronegative oxygen binds its electrons very tightly because of the larger number of positive protons in its nucleus for the same electron shell. Oxygen is actually more electronegative than corrosive chlorine. The C-H bond is covalently neutral while the N-H and O-H bonds are successively more polarized. Water H_2O has the highest melting point of any hydride because of its very strong polar and ionic interactions. This is why oily hydrocarbons don't dissolve in highly polar water, effectively separating the entire biological milieu into two distinct polar and non-polar domains, typified by the division between the fatty lipid membrane and aqueous cytoplasm, the 'micelle' or oil-droplet structure of globular protein enzymes and the stacking of nucleic acids such and RNA and DNA in their double helices. Water also has one of the highest specific heats of any substance because of its many internal quantum modes and effectively forms the quantum substrate of all living molecules. Further complexifying bifurcations of the orbital interactions involve second row P and S, splitting between the ionic properties of Na^+/K^+ and Ca^{++}/Mg^{++} and involve orbital properties of transition elements, including Mn, Fe, Zn, Co and others.

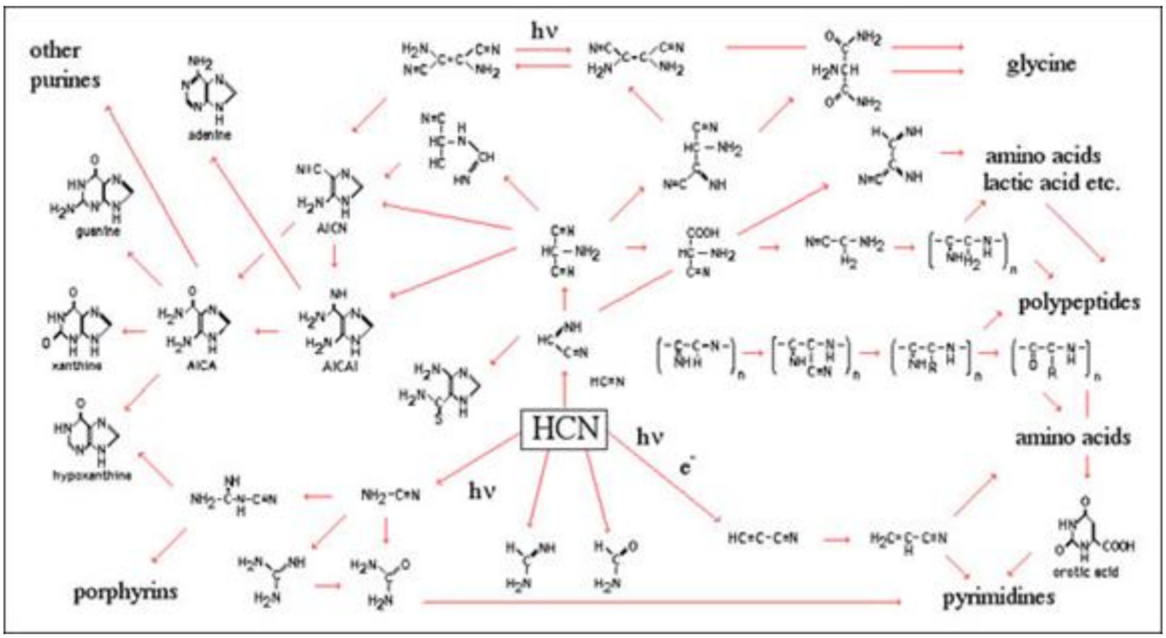

Fig 7: Polymerization of HCN can produce many molecular components of living systems including nucleic acid bases, amino acids, polypeptides, and porphyrins used in photosynthesis and respiration.

From here, the 'incompleteness' of the reductionistic description really begins to bite. A simple molecule like HCN, although it contains a mammoth triple bond is unstable to self-polymerization, because the triple bond's *p* orbitals are at a higher energy than the *s* orbitals and opening them up to form only single or alternate (conjugated) double bonds as in adenine and other molecules illustrated below reduces the energy. We thus find that HCHO and its sister molecules can polymerize to form a vast array of sugars and HCN can polymerize, particularly in association with ubiquitous simple molecules like urea $(NH_2)_2$ to form the purine and pyrimidine nucleic acid bases A, G, C and U, various amino acids and polypeptides and the porphyrins we associate with chlorophyll and hemoglobin. The nucleic acid base adenine for example is simply $(HCN)_5$ and ribose, the backbone of RNA is one of the forms of $(HCHO)_5$.

Although the final transition stages of the origins of life still remain to be elucidated, it is clear that ribonucleic acid, or RNA, which unlike DNA can form weak bonds between its backbone and its bases, can form complex 3-D tertiary structures based on hairpin loops of double helix and is thus capable of both participating in complementary replication and acting as a catalyst in a similar manner to the coded protein enzymes of living cells. RNA thus in a single molecule, whose components are relatively easily generated in free energy polymerizations, contains the combined capacity for autocatalysis and complementary genetic replication. Indeed the metabolism of higher eucaryote cells is dependent on extensive RNA processing in the nucleus, ribonucleotide coenzymes remain a evolutionary fossils in key metabolic pathways, and the ribosome which is responsible for translating DNA generated messenger RNAs into proteins consists of a functional core of RNA molecules.

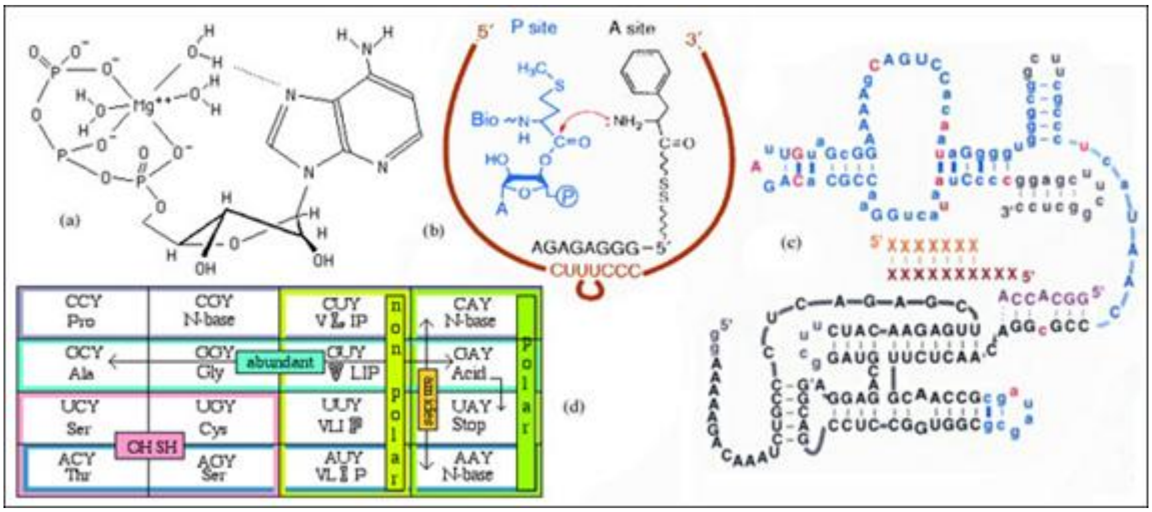

Fig 8: (a) ATP one of the four fundamental nucleotide units of RNAs, and the energy currency of the cell consists of pentamers of HCN and HCHO joined and energized by tri-phosphate. (b,c) Simple RNAs can produce autocatalytic reactions. (d) A symmetry-breaking model of the genetic code (King).

Ultimately this fractality and non-linear interaction leads to the evolutionary tree of life and to the paradigm of natural selection, mutation and a variety of forms of sexual recombination and the increasing algorithmic complexity of genetic life as a generator of fractal organismic form and function and to the ultimate peak of interactive complexity so far discovered in the universe, the sentient human brain, consisting of some 10^{11} neurons comprising some 10^{15} synaptic junctions and hence to the unsolved problems of subjective consciousness, free will and the possible role of conscious observer in collapsing the wave function of the universe into the unique trajectory of history we experience, rather than the overlapping quantum probabilities of the Schrodinger cat paradox experiment.

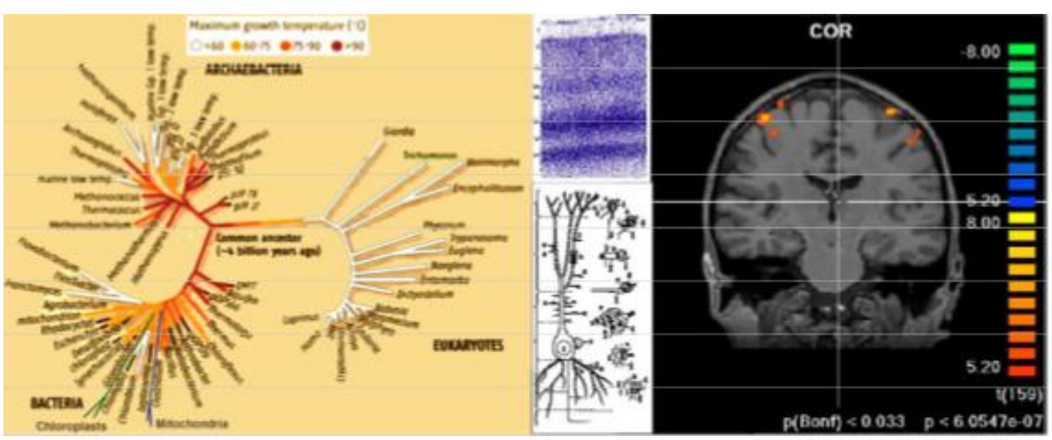

Fig 9: Left: Evolutionary tree has a hot origin Centre top: Five layers of neurons in the cerebral cortex. Centre bottom: Pyramidal cell. Neurons use their fractal dendritic structures to make many-to-many functional connections. Right: The author's brain performing a simple cognitive task under functional magnetic resonance imaging.

Fractality and Chaos in the Universe at Large

The inverse square law of gravitation in 3D space leads to chaotic dynamics as a natural feature of stellar and planetary interactions. The sheer diversity of both the planets in our solar system, and the moons of Jupiter, which do not have a basis in differential compositions of the major rocky and gaseous planets with increasing distance from the Sun, yet nevertheless have very different chemistries and dynamics, illustrate the sensitivity of planets to a variety of formative conditions in the early phases of solar system formation.

Fig 10: Both the major planets and the moons of Jupiter display a high degree of diversity, illustrating the sensitivity of solar system formation to the initial conditions leading to such systems.

It is clear from research into chaos in conservative orbits, the loss of strongly mode-locked asteroid orbits and the Henon-Heiles system, and recent prediction of possible major instabilities of the orbits of Mercury, Earth and Mars, leading to a possible planetary collision of Earth within 500 million years[5], that the periodicity of planetary orbits is only a temporary phase in a longer-term chaotic many-body process.

Fig 11: Hubble's image of Galaxy cluster Abell 1689, situated two thousand million light-years away, is one of the most massive objects in the Universe.

On a larger scale, solar systems, galaxies and galaxy clusters form a fractal distribution of matter in the universe at large, also molded by other forces such as dark matter and dark energy. Calculations of the fractal dimension of such clusters[3] suggest these are fractal with a fractal dimension approaching 2.

At the very largest scales there is controversy[2] as to whether the fractal structure gives way to the homogeneity cosmological theories predict should arise from the isotropic nature of the 'big bang' perturbed only by possible quantum fluctuations that have become inflated to the scale of galaxy clusters, as deduced from the maps of the cosmic background radiation (fig 1a).

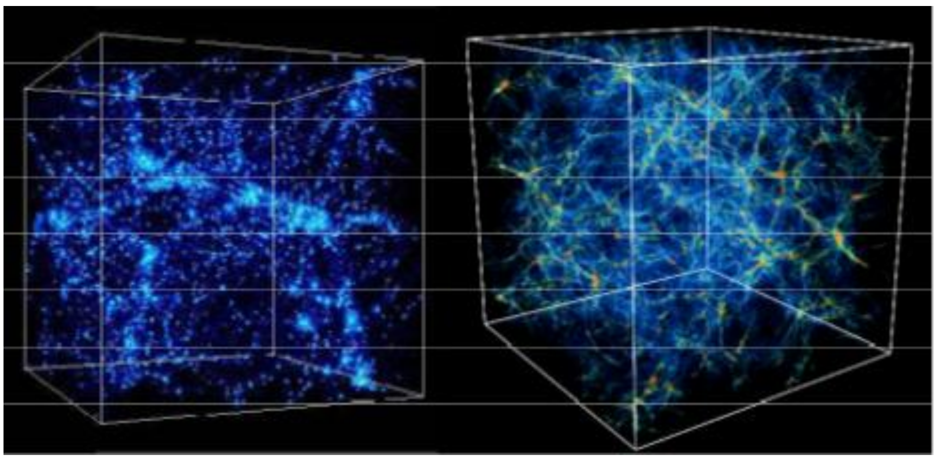

Fig 12: Left: Large scale structure of the universe showing clumping of galaxy clusters, possibly associated with streams of dark matter. Right: Super-computer simulation of the same fractal process.

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