Comets and entropy hydrodynamics: How does evolution violate the 2nd law?

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ABSTRACT

Information density can increase locally if one is careful to control the flow of entropy. Not diffusively but through clever use of "invariants of the flow". Replacing entropy with true invariants of the flow, we show how information can be concentrated or "added" consistent with the observation of increasing complexity on the Earth. Analogous to a digital computer made of fluid components, the "calculation" proceeds by clever manipulation of boundary conditions. Magnetized comets possess exactly the properties needed to produce the simplest entropy invariant, making them a prime candidate for driving evolution. They may also provide the origin of the chirality or "handedness" of life. Thus the Origin-of-life, evolutionary progress paradox can be solved, but at the cost of requiring the universe to be in a highly information-dense initial state.

1. INTRODUCTION

The study of comets has been a journey that brought most surprising results. We began in 2004 with a physics problem–can comets possess liquid water in the vacuum of space? The solution became clear once the question was asked as we wrote in 2004 and 2005 (Hetal04,SH05)[1,2] discovering how water explains all the peculiar properties of comets as they travel in from Jupiter's orbit. In 2006 we even published predictions for NASA's Deep Impact mission[3] but were disappointed–the spacecraft team targeted the hot, dry subsolar region, rather than the cooler liquid water pools. But even then, we predicted the "punching through" of the copper bolide to produce an anomalously small crater. JASA's Hyabusa mission was supposed to visit an asteroid, but Itikawa revealed itself as something other, an uninfected dehydrated comet–the exception that proves the rule. Finally NASA's Stardust returned material from a comet: clays, amino acids, cubanite, and something we did not expect–a sand grain. Yet this unexpected grain proved that comets do vacuum up the detritus of space and can be infected in the same way. Exhausting all of our comet encounters, in 2007 we looked at where comets go, and how they prepare for the journey (SH07).[4] In 2008 we argued (SH08)[5] that infected comets are more ancient than the Earth, filling the galaxy with information that bootstrapped life on Earth some 3.8 billion years ago. In 2011 we addressed[6–8] the Origin-of-life (OOL) that filled the galaxy with infected comets, arguing that the inter-connected network of comets holds more information than the mere multiplicity of comets, i.e., permutations rather than combinations can explain the information of OOL. In 2012 we looked inward, examining the nanometer-scale magnetites that fill infected comets, arguing that they are biological machines for harvesting energy and magnetic field (SH12).[9] Now in 2013 we bring the large and small together, showing how magnetic fields permit information addition, how biology "violates" the 2nd law of thermodynamics.

The twentieth century began the description of physics as a huge casino, calculating the statistics of heat or thermodynamics, and later, the probabilities of quantum mechanics. And while this description of the world has been enormously useful, providing the understanding of steel and concrete, of electricity and power, in the end it could not explain the exquisite design of bio-materials: the strength of tooth enamel, the water-repelling nature of lily pads, the low drag of shark skin. The study of these remarkable things revealed that the secret lies in their coherence, in their nanoscale structure, in their design. If the 20th century was the century of chance statistics, of bulk materials, of diffusive transport, then the 21st century has become the century of coherence, of smart materials, and of controlled transport. If the 20th century was about energy–hydroelectric dams, nuclear bombs, oil wells–then the 21st century is about energy use–wind turbines, nuclear rockets, hybrid cars. If the 20th century was about entropy, then the 21st century is about information.

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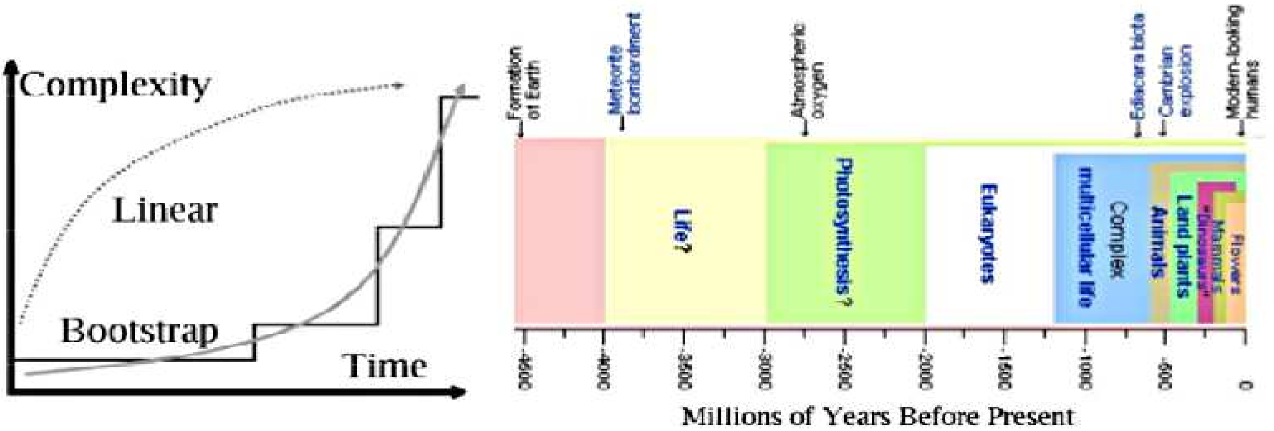

Figure 1. Left:Net information vs. time. Bootstrap is exponential. Right:Notable events in evolution timeline.

This paper is a discussion of the biggest problem in Evolution as viewed by a physicist–OOL, a violation of the 2nd Law of Thermodynamics. Indeed, much in biology violates the 2nd law, which says that over time everything should become degraded, disorganized, disordered, and dead. Biology gleefully, robustly, and manifestly violates the 2nd law so much so that physicists throw up their hands in despair. Yet even though biologists see and observe this anomaly, they are at a loss to explain it too. So this paper is an tentative attempt first to motivate biologists to consider the problem, then to have physicists define entropy and mathematicians fluids in order to find a mathematical object that intersects all three, and finally demonstrate that comets instantiate that mathematical object, reuniting these three branches of science.

In section 2, we describe how biology is going through a paradigm shift as it searches for a post-Darwinian evolutionary model. In section 3 we discuss an emerging consensus of physicists concerning entropy and a fluid approach to physics foundations. In section 4 we give a quick overview of some relevant math concepts, and in section 5 we bring all three disciplines together to consider the magnetic-entropy invariant (MEI). In section 6 we demonstrate how MEI is related to observations of comets, and draw conclusions in the final section 7.

2. WHAT IS ORIGIN-OF-LIFE (OOL)?

Darwin's theory of evolution argued that the biggest problem in the universe is going from non-life to life. Once this Origin-of-life (OOL) problem had been solved, then everything else flowed down from it.[10] When Darwin made this theory, most everyone viewed the world as he did–separated into non-living physical chemistry, and living organic chemistry.[11] Some even held that life was a fifth force, an *elan vital* that permeated organics and made them unobtainable from non-living ingredients. So it is not too surprising that Darwin simply postulated or assumed that OOL was the unexplained miracle that generated the biome of the Earth.

As the 20th century progressed, however, it became more apparent that there was a grayscale to life, a gradation from prions, to virons, to viruses, to bacteria, to eukaryotes, to plants, to animals, to mammals, to primates, to us, where the scale was information, or complexity. Furthermore, the scale kept getting larger and larger, as the intricacies of biochemistry and nanomachines were revealed. Plotted on the timeline of Figure 1 are the major changes of life on this planet, and it is apparent that when scaled by complexity, the history of evolution shows an exponential rise in information.

Therefore the step that Darwin envisioned from non-life to life barely registers on this complexity plot, it is too small to even be seen. But science (and metaphysics) would say that an effect must be proportional to its cause. How then can a step too small to be seen account for the present richness of life unless something else is involved?

If effects are not proportional to their cause, then we must give an explanation. The nursery rhyme, "For want of a nail, a shoe was lost. For want of a shoe a horse was lost. For want of a horse a battle was lost. For want of a battle ... a kingdom was lost, all for want of a horseshoe nail." But is this true? Can OOL leverage

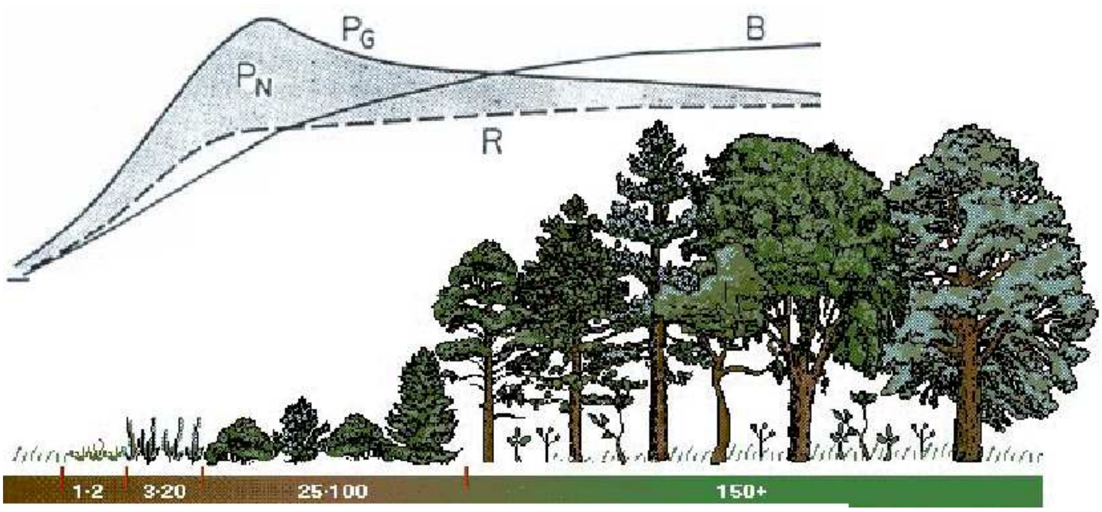

Figure 2. Evolution of a North American forest. Biomass: P_G=production rate, R=removal rate, P_N=net, B=total.

Random Mutation and Natural Selection (RM/NS), as Darwin suggested, so as to achieve exponential growth in information? Hidden in this nursery rhyme, however, is the hierarchy of a military machine and the special timing of a military engagement. Most of the time, a horse can lose a nail with no untoward results. It was not so much the nail, but the timing that was critical, which is to say, it was a Rube Goldberg machine. But where in RM/NS do we find a comparable hierarchical design?

For example, in 2013, seven species of ant had their genomes transcribed, and each specie was found to have ∼4000 "ORFAN" or unique genes with no precursor, no antecedent.[12] This is greater than the total information in Venter's minimal mycoplasmium, suggesting that every step of evolution is as large if not larger than the first OOL step.[13] Therefore Darwin's theory does not just need one OOL step, but an OOL step for every species, species which arrive in the fossil record at an increasing rate. But what in Darwin's theory has this property of exponential information production? Nothing, because in Darwin's theory, no one shares their progress with anyone else. It is survival of the fittest, and while we may have more and more organisms to search for information, they all search for it independently. The Darwinian search is linear, but the fossil history is exponential. The cause does not match the effect.

Forty years of searching for an exponential RM/NS have turned up nothing but counter-examples: Lenski's bacteria,[14] synthetic genomes,[15] Cambrian archaeology.[16] Is there another solution?

There are many other solutions to this puzzle of exponential growth of information besides Darwin's. In the past decade the scientific literature has been buzzing with suggestions: self-organizing systems,[17] symbiosis,[18] a new physical law of complexity,[19] self-evolution evolution,[20] multiple miracles,[21] eusociality,[22] even panspermia.[23] They all share some common traits which we can discover by analyzing one model–symbiotic evolution, the Gaia hypothesis promoted by Lynn Margulis and James Lovelock.[24,25]

Using an ecological example to illustrate the Gaia hypothesis, Figure 2 follows an acre of bare ground–say, from a forest fire–and schematically shows the progression of plants that grow afterwards. Grasses dominate the first 5 years, to be replaced by pines in 25 years, oak in 100 years and hickory in 150. The grasses produce more biomass than they consume, and so for a while the soil is built up, which accounts for the 12 feet of prairie topsoil in Iowa. But if the biomass production peaks with grasses, the biomass total peaks when it reaches a climax forest. If we associate information with total biomass, then the system continually increases in complexity even as pioneering species come and go.

Globally, the system grows more complex, even if locally it decreases, as when the grasses die off. And this global information is shared among species since it is the environment that stores the complexity. In the Gaia hypothesis, the system is greater than the sum of its parts, for it is the system that provides the information

Table 1. Two kinds of OOL Theory

Mechanical	Theoretical
Matter-driven	Information-driven
Analog "hardware"	Digital "software"
Linear response to input	Non-linear response to input
Proportional to cause	Proportional to design
Self-limiting, Lenz' law	Self-multiplying
Negative feedback only	Positive feedback intended
Local search→NFL Theorem	Non-local, global search
Info grows @ linear rate	Info grows @ exponential rate
Internal RM/NS info	External supplied info
Charles Darwin	Alfred Russel Wallace

account from which every organism draws its share. Information lies not only within the organisms, but in between, in the connections among them.

Why is information banking not in Darwin? Because the information of an ecology is external to an organism and therefore purposeful, making use of the organism in a bigger whole. But "external" has no *a priori* limit; there is no reason to draw a boundary around our meadow alone and prohibit information from arriving from the next state or the next continent, or even the next world. It suggests that life is part of a much bigger design, which Darwin prohibited, only allowing for local internal information storage.

Since there is a lot of confusion concerning Darwin's theory and all these modern modifications, we have attempted to compare and contrast the original, stock version of Darwinism with these new theories. Actually, they are not new, but predate Darwin since his nemesis, Alfred Russel Wallace, who is grudgingly credited with inventing the theory that Darwin copied,[26] also argued for external information being essential to evolution, writing two books on the subject in 1903 and 1911.[27, 28] Particularly interesting, is that cosmologist and OOL theorist, Paul Davies, has thrown in his support for Wallace when he argues that OOL has to transition from a mechanical "analog hardware" to a information-driven "digital software" replicator.[29] As David Abel argues in several publications, that transition is as difficult a step as the more naïve theory of an accidental mechanical OOL.[30, 31]

Darwin's theory assumes that information is internal to the organism–there is no teleology. Darwin argues that evolutionary progress is linear, a direct result of a material (matter-based) cause.[11] Since progress is random, the speed of information gathering is actually sub-linear, or $d(\text{info})/dt \to \sqrt{\text{time}}$. Recent "No Free Lunch" math theorems (NFL) have proved that there is no "magic" search algorithm such as RM/NS that always works better than linear, so that genetic algorithms are no faster (or slower) than a random number generator.[32] Linear searches have self-limiting negative feedback, since any shortage of resources will linearly reduce the rate of information production–a restatement of Lenz' Law.

By contrast, most of the new theories assume information can grow exponentially because the external environment can affect evolution. This means that organisms "share" information either directly or through their changed environment. Informational progress is now exponential, proportional to the population size. Since population is proportional to information, we have positive feedback–the opposite of Lenz' Law. Now growth is not self-limiting, but exponentially growing as resource limitations are removed by other organisms. E.g., plants make oxygen that animals need for propagation, animals fertilize the plants and spread the seeds. The information then, is global, not local. And the results are not proportional to the cause, but to the $(\text{cause})^n$ power, where n is the number of connections. Then the cause is not material but informational or immaterial. Table 1 summarizes the two kinds of OOL / Evolutionary theory.

How does one go about scientifically constructing a non-local, global theory made up of non-material causes? Is not science only supposed to talk about material causes and leave the immaterial for religion and UFO kooks?

Surprisingly, science has always dealt with immaterial things–beginning with conservation laws for energy, and ending with information. It is from the science of thermodynamics that we develop the immaterial concept of entropy and its obverse–information. What makes science "scientific" is not the character of the causes, but the character of the results. Science should be quantitative and predictive; science requires causes that match effects; science looks for patterns; science is all about information.

Information, it turns out, is the opposite of random, the opposite of local, the opposite of internal. Information is a pattern, it is global, it requires an external context. That is, one may not be able to tell the difference between a file filled with random noise and one with a zipped program, but run on the right hardware, the zipped file will turn into glorious information. Thus information always requires a context, an external interpreter.

This paper then, explores the first baby steps of constructing a post-Darwinian evolutionary mechanism based on information. We must learn how to quantify information, how to transfer information, and finally, how to add information (for any fool can subtract it!) We follow in the footsteps of the masters when we assume that information is a fluid, whose transport must be conserved. Information addition, therefore, is akin to making a computer out of fluid, just as a carburetor calculated the right fuel-air mixture for the engine. As in our earlier papers, we think comets are the information carrier of the universe. In a nutshell then, we are engaged in an effort to describe OOL as the result of a cosmic carburetor powered by magnetic comets.

3. WHAT IS ENTROPY?

3.1. steam entropy

When the steam engine was invented in the 18th century, there were many improvements that enabled it to work with less coal. The improvements were so significant, that many people devoted their life to making better and better engines. Indeed, some thought it was possible to make an engine that consumed no coal, but provided infinite energy out of nothing.

To answer these questions and claims, physicists of the 19th century began to develop a terminology or science of heat engines, which is now called thermodynamics. By considering an ideal gas (instead of steam) Sadi Carnot showed that an engine cannot simply turn all the coal heat into work without wasting some, because there was a special quantity that stayed the same or increased, which Clausius called "Entropy". Entropy measured the "quality" of the heat energy, with higher temperatures having higher quality. It is easy to make a heat engine with a 600C fire, but a lot harder with 40C bath water. In symbols, this is was: $dS = dQ/T$. Building on Carnot's insight, other physicists such as Clausius and Kelvin developed the "3 Laws of Thermodynamics" expressed in many ways: No perpetual motion; No perfect refrigerators/engines; Heat must flow from hot to cold. The 2nd of the 3 Laws is often stated: "Entropy must either stay constant or increase".

The reasoning was rock-solid. If any of these laws were violated, infinite energy would be freely available and one could become infinitely powerful–a property usually reserved for God! All this was established by the middle 19th century when along came the atomic theory of matter.

3.2. atomic entropy

Around 1890 Boltzmann used the atomic theory of matter to argue that entropy was related to counting the number of ways to arrange the hard-sphere atoms of an ideal gas.[33] This converted an experimental fluid property into a statistical number, into a counting exercise. Suddenly the entire field of immaterial mathematical statistics took on a physical meaning. Not only so, but in 1948 Claude Shannon argued that these same statistics controlled the way AT&T could send messages along telegraph wires[34] reusing the word "entropy", and gross confusion reigned to the merriment of all. Brig Klyce has a nice blog page helping sort things out.[35]

To bring entropy back into the corral of well-behaved concepts, we need to understand what Boltzmann did. Before Boltzmann, the fields of thermodynamics and mathematical statistics were well-developed and unconnected. The thin, wobbly bridge connecting these two completely unrelated regimes was Boltzmann's famous equation, engraved on his gravestone:

$$S = k \ln(\Omega). \tag{1}$$

On the left hand side is S, a thermodynamic quantity, and on the right hand side is Ω, a mathematical quantity. Between the two lies k, or "Boltzmann's Constant", which converts one to the other, the way c^2 converts mass to

Table 2. Two Kinds of Entropy

Thermodynamic Entropy	←Bridge→	Logical Negentropy
Carnot, Clausius, Kelvin	Boltzmann	Shannon, Kolmogorov, Algorithmic
Heat → Work		Channel → Signal
$dS = dQ/T$	$S = k \ln(\Omega)$	$\Omega = p!\ \ I = p \ln p$
2nd Law: $dS \geq 0$		$dI \to 0$
"no perpetual motion"		"no free lunch theorem"

energy in Einstein's $E = mc^2$ equation. Boltzmann never calculated his eponymous constant, he merely asserted its existence because it is not theoretically derivable and unlike Einstein's constant, it is not based on ratios of h, c, π or α. It is empirically determined with some sophisticated apparatus measuring the speed of sound in a fluid. If we change the fluid, we need to change k. And if the fluid is really complex–say a protein solution, or the insides of a cell–then we really have no idea what to use for k^*.

We know it is there, because entropy drives many chemical reactions. The chemical cold packs that dissolve $NaNO_3$ in water and become very cold are an example of a reaction driven by the greater entropy of the dissolved salt that compensates for a negative dQ/T. Nevertheless, for truly complicated chemical reactions, we can not calculate dS because we do not know what k to use. For example, in 1991, a full 100 years after Boltzmann's assertion, P.-G. de Gennes received a Nobel Prize for calculating the entropy, the k for long, slippery molecules used in liquid crystal displays. Many more Nobel Prizes await those who can find the k^* for living cells.

The consequences of this ignorance are profound. We cannot convert the logical S of, say, amino acid sequences into a thermodynamic S. We cannot explain how life comes by its organization by examining the entropy of sunlight. We cannot even explain the entropy difference of a live versus dead cell. All we know is that biological information (negative logarithm of permutations Ω), is enormous for living things,[36] and that the laws of thermodynamic S should apply to biological information as well. This leads us to Claude Shannon's insight.

3.3. logical entropy

Claude Shannon, while working for Bell Labs, realized that the noise on telegraph lines that hindered transmission was random, whereas the transmission was ordered. This was precisely the way Boltzmann had described entropy of ideal gases. So Shannon proposed that the "bits" (he coined the word, as well as designed the first electronic computer), were like atoms, and their behavior was similar to adding heat to atoms.[34] By thinking of the noise as "all the arrangements that mean nothing", he could define information as

$$I = -S = -k \ln(\Omega) \tag{2}$$

where he set $k = \ln(2)$ for binary systems (experimentally slightly larger for a letter in English).[37] Then "all the arrangements" became $p!$ (p factorial), which in Stirling's approximation is written: $\ln(p!) \sim (p \ln p - p)$. This means for sufficiently large p, $I \sim -p \ln p$.

Many systems can be analyzed using this formula, including peptide sequences in proteins, or DNA codons themselves. But this is not the maximum amount of information in a system. Among other things, it assumes a binary encoding system, a fixed alphabet, and a n-dimensional "rearrangement space". If we change basis to base 20, or allow the system to redefine its alphabet, or add more spatial dimensions, we can get more information than this simple measure. For example, people talk of "kolmogorov information", or "algorithmic information", which is the shortest program that can produce the same output. That is, a million digits of pi have a huge amount of Shannon information, but a tiny program can generate them, so it has little algorithmic information.

Since there are so many formulations, Shannon information is not the maximum but the minimum amount of information in an arrangement. Nevertheless, we expect the 2nd law of thermodynamics to hold for whatever kind of information we are discussing: $\Delta S \geq 0$.

3.4. information summary

Summarizing in Table 2: The information of OOL cannot be collected from low entropy energy sources such as sunlight, radioactivity, or any simple thermodynamic system, because we can not inter-convert thermodynamic S to informational S for biological systems without a k (Or even if we could, the informational $k^* \gg k$, making sunlight useless.)

We cannot explain mathematical or "logical" information in terms of thermodynamic entropy, despite Boltzmann's bridge, because logical entropy always involves things more complex than billiard-ball ideal-gas atoms.

We cannot even put an upper limit on the information involved in OOL simply because the larger system that contains it, is unbounded, just as the information in a coacervate pales in comparison to the scientist manipulating it. Even without the external influence, a OOL system incorporating recursion can potentially have infinite information. At best, we can only find a lower limit to the amount of information in an OOL system.

Therefore, the laws of Thermodynamics apply to informational S separately from thermodynamic S. It is as if there are many different types of S, each one conserved and individually obeying the Three laws of Thermodynamics.

While this non-inter-convertibility is a major barrier for "metabolism-first", "RNA-world", "coacervate" or "clay-mineral" approaches to OOL,[38, 39] it still tells us more than the common physicist excuse, "No laws of thermodynamics apply to open systems." For the physicist deals with open systems all the time, and can apply standard conservation laws to them, namely "time rate of change = amount crossing the boundaries of the system + internal sources/sinks." This is Granville Sewell's conclusion, and the basis of all hydrodynamics.[40, 41] If we can describe this flow, then we can isolate sources/sinks from transport of information.

4. WHAT IS TOPOLOGICAL HYDRODYNAMICS?

4.1. physics as geometry

In the 18th and 19th century, Newton's laws were expressed in differential calculus, and the fields of celestial mechanics and analytical mechanics were developed. For example, the energy available for use, the Lagrangian $\equiv$ Kinetic $-$ Potential, was defined and spatial derivatives of this quantity resulted in Newton's Laws. By contrast, the total energy, the Hamiltonian $\equiv$ Kinetic+Potential, was defined and led to energy conservation and wave equations. In the early 20th century, Emmy Noether showed that these two bookkeeping methods were measuring the same thing, which turned out to be the symmetries of the system. Whenever something is conserved, say angular momentum, it means that there is a geometric symmetry, cylindrical symmetry, associated with this quantity.[42, 43] Noether's theorems, then, reduce physics to the set of geometrical symmetries of the system combined with some conserved quantity: energy, mass, etc. Thus Maxwell's equations turn out to be geometry+charge, Newton's laws are geometry+mass, and Thermodynamics are geometry+energy.[44]

Ernest Rutherford said "only physics is science, everything else is stamp collecting" but via Noether's theorems, (pace Rutherford) physics turns out to stamp collecting with geometry! But this is not your grade school plane geometry, it is geometry on steroids, it is differential geometry: the description of curved surfaces and flows. Our goal, then, is to apply these insights to information, so that the physics of information = geometry+entropy.

4.2. geometry as continuum

The first problem we face in this task, is to find a representation of entropy, S, that can be described by geometry. If our quantity is discrete, like atoms or $p!$ arrangements of atoms, then we cannot easily use geometry. Geometry, like space and time and flows, is generally taken to be continuous. Aristotle also viewed matter as continuous, and therefore capable of a geometric interpretation. This is why Clausius' entropy was a continuous fluid.

Atoms, however, are discrete, and follow counting statistics such as Boltzmann's S. The real power of quantum mechanics comes from converting atoms into waves so that they can then be treated as a continuous material. Possibly the resolution to our conundrum of representing atoms with entropy is quantum entropy,[45] but for our limited exploration, we use classical, continuous entropy.

Figure 3. Left:Vortex street observed over Canary Islands. Right: Airplane wingtip vortices imaged.

This is not such a bad approximation because biological information is so very large, that we do not expect to observe its discrete components, or for that matter, to observe a source of biological information. Therefore the important aspects of entropy / information are not its origin in the $p!$-permutations of biomolecules, $\sim p \ln p$, but rather its flow into and out of the control volume.

This brings up the second problem. How do we handle the flow of entropy? As Heraclitus said some 2500 years ago, "no man ever steps in the same river twice" for the river has changed and so has the man.[46] If entropy is a river, how can we ever control it or calculate with such liquid assets? Is it possible to concentrate the flow of entropy to get OOL?

4.3. continuum as constant

Some things in a river are conserved. If we watch the fish in the river (over a short period of time) they do not multiply or vanish from our imaginary box, but they swim in one side and out the other, their number is conserved. We could say the same for the mass, the same amount of mass flows in upstream side as leaves the downstream side. On the other hand, other things in the river are not conserved. Temperature fluctuations can enter and diffuse away, light can flicker and be absorbed. Speed or velocity can be high on the upstream side, flow over a waterfall and be slow on the downstream side.

Does entropy act like one of the conserved quantities or one of the non-conserved quantities? Since $dS = dQ/T$, it behaves more like heat or temperature, which obey the heat equation–they diffuse away from an initial sharp boundary. A pulse of entropy will diffuse away from an initially sharp distribution so that directing or concentrating entropy is like herding cats. (Since the units of S are J/K, but lack a SI name, we hereby propose to call this unit a Hobbes. Then $TdS = dQ$, or Kelvins $\times$ Hobbes = Joules.)

Then is it true, as is commonly believed, that all systems diffuse their information away, because increasing entropy is inevitable and there is no way to reverse the degradation of time and circumstance? While this may be true of inanimate objects, biology defies the ravaging of time and the diffusion of information. Then by observation it must be possible to control the flow of entropy and physics must be able to describe it.

The answer is found in topological invariants of the flow. If temperature or heat is not invariant, then we must find a structured flow that involves entropy.

We already know of structured fluid flows that do not decay away like heat or temperature. They represent a "knotted" topology of the flow, and are called vortices. Figure 3 shows several examples of vortices. The left panel shows vortices in the atmosphere as revealed by satellite photographs of the clouds downstream of the Canary Islands. The vortices alternate in polarity and form a "vortex sheet" or "vortex street". In the right panel, airplane wingtip vortices are made visible when the plane flies through the top of a cumulus cloud. Notice that the vortices are of opposite polarity.

Some observations:

Vortices are made out of a fluid. No special ingredients. No extra properties.

Vortices appear to come in + and − versions. They appear to be binary, where the sum remains zero. This can also be observed in the vortices leaving a canoe paddle in still water.

Vortices are long lasting. They do not diffuse away at the same rate as other fluid properties. Notice how the clouds are distributed randomly, with short-term disorder, but the vortices remain coherent for hundreds of miles. The same is true for the jet contrails, where the steam diffuses, but the vortex remains.

Therefore vortices in a fluid can possess "digital" properties by nature of their topological invariance–they can perform the function of Shannon's bits.

5. WHAT IS A FLOW INVARIANT?

5.1. constants of geometry

This is a very brief introduction to some properties of differential geometry. Like the plane geometry taught high school, differential geometry has a subject matter that it manipulates, only it is not triangles, parallel lines and polygons, but rather scalars, vectors and dyadics and tensors. Or to simplify the jargon, scalars=0-forms, vectors=1-forms, dyadics=2-forms and tensors=3-forms (we do not distinguish them from vector spaces here.) There are no 4-forms because we live in 3-space.

Some operations move objects toward higher dimension. Perhaps you are familiar with a gradient operator that converts a scalar topo map into a vector map with little arrows pointing in the downhill direction. So ∇(0-form) $\rightarrow$ 1-form. It raises the dimension. Likewise there are operations that collapse dimensions. The scalar product, or contraction, takes two 1-forms and produces a scalar. So (1-form $\bullet$ 1-form) $\rightarrow$ 0-form. We can generalize the gradient to be an "outer derivative" that can operate on any size n-form, but when we operate on a 3-form, we always get zero. Or as John Wheeler once explained Einstein's equation: "the boundary of a boundary is zero".[47, 48]

Then the power of differential geometry, is that we can put in some 0-form, such as energy, and derive 1-forms (forces), or 2-forms (stress-tensors) simply by carrying out geometric transformation, so that all of Newton's Laws and much engineering can be obtained simply from the conservation of a scalar energy. Not only is it a powerful way to derive the physics, it is a powerful way to find topological invariants that greatly simplify the solution of a problem. For example, the freshman physics stumper–"an Eskimo slides off the top of his frictionless igloo, where does he go airborne?–was devilish to solve using Newton's vectors, but trivial using scalar energy conservation.

5.2. constants in physics

We are not the first to make this discovery, for 50 years ago Nobel laureate, Richard Feynman decided to teach his undergraduate physics course at CalTech using a scalar approach. Understand that for 100 years prior, every physics student has started the semester learning Newton's 3 Laws of motion, and has had to master the art of adding and subtracting and multiplying vectors. As the year progresses, he even has to master the 2-forms of rigid body mechanics. Only much later does he learn about energy conservation and perhaps in his 2nd or 3rd year, Hamilton's equations of motion. This steep learning curve has the unfortunate consequence of scaring off many potential physics majors.

Feynman decided that rather than starting with Newton's Laws in the first week of class, he could introduce the scalar energy and demonstrate its conservation. Since gradients of the energy are forces, then with a bit of differential geometry Newton's Laws fall out naturally (rather than being taught as gospel.) Lore has it that the class soon emptied of undergraduates who had all undoubtedly taken vector physics in high school and could not grasp this approach; but their seats were soon filled with graduate students and other instructors. The lectures were published in 3 volumes, and every graduate student has them on his shelf.[49]

Why did Feynman fail? We think it was because Newtonian mechanics is used to support a materialist, atomist, metaphysical world view, and the implications of an energy-dominated universe were too foreign for these freshmen.[50] Feynman just did not reach them young enough. But if we do not shrink from differential geometry and its non-Newtonian metaphysics, we can learn a lot as well.

5.3. constants with entropy

Since the entropy is a flow invariant that diffuses, we look for an entropy flow invariant that does not diffuse, but like a vortex, maintains its "digital" character. We are inspired by the well-studied Ertel invariant that plays a part in tornado formation, has gradient of the entropy with fluid vorticity,

$$I_E = \frac{\omega \bullet \nabla S}{\rho} \tag{3}$$

where $\omega = \nabla \times \mathbf{u}$ (the curl or vorticity of $\mathbf{u}$, the fluid velocity), S is the entropy, and ρ is the density. We can derive a very similar invariant by adding two other known invariants to the entropy invariant–Faraday's law and mass conservation–and carrying out a geometric integral. The new flow invariant still includes the entropy but has the vorticity replaced by the magnetic field, $\mathbf{B}$.

$$I_W = \frac{\mathbf{B} \bullet \nabla S}{\rho} \tag{4}$$

The substitution of the magnetic field for the vorticity is justified geometrically since $\mathbf{B} = \nabla \times \mathbf{A}$ where $\mathbf{A}$ is the magnetic vector potential, the same kind of vector field as $\mathbf{u}$. However this substitution requires that the fluid be a charged or a MHD fluid if the magnetic field is to have the desired vorticity effect. Details of how this invariant not only is time-independent–since $dI_W/dt = 0$–but also possesses "topological charge" giving a non-zero result when integrated over a closed path, are given in Webb et al. 2013.[51,52] For lack of a better label, we call I_W the magnetic entropy invariant (MEI).

Note also that this MEI is a scalar. That means it can be simply added or subtracted without having to take into account directions of flow or magnetic field. Like Feynman's lectures, this makes it a fundamental property of the fluid from which all other laws can be derived. Note that it involves the gradient of entropy, ∇S. Therefore adding and subtracting MEI involves adding and subtracting entropy as well. But rather than diffusing away like S, the MEI has topological charge, it acts like a fluid vortex that does not diffuse. So we are adding and subtracting entropy with digital precision.

Finally, note that the scalar is formed by a contraction of $\mathbf{B} \bullet \nabla S$. The invariant is proportional to the strength of the magnetic field. There are dissipative terms in a fluid that remove $\omega = \nabla \times \mathbf{u}$, but $\mathbf{B}$ can be non-dissipative: collisionless plasmas or permanent magnets. Both can be positioned exterior to the volume of MEI, so they do not necessarily participate in the entropy gradient, but they permit the near permanent existence of this topological quantity.

6. COMETS

As described in our previous SPIE papers comets contain liquid water and ice (HETAL04,SH05), grow cyanobacteria,[53] (and now diatoms![54–57]), and form biomagnetites (SH12). Now with MEI, we are in a position to compare the properties of comets with the ingredients for a large invariant, that hopefully will allow us to add information and OOL.

6.1. thermodynamic constraints

First, we contrast comets with other suggestions for OOL. Almost all other models have followed Darwin's suggestion of a *warm* pond, hoping that the higher T will promote the "life" reactions.[58] However, looking at MEI invariant, T is our enemy and not our friend, since it diffuses S and destroys $\nabla\mathbf{S}$. John Sanford has also argued that even after OOL, entropy remains the enemy of life.[59] On the other hand, solid ice does not flow very fast. So ideally $\nabla\mathbf{S}$ will be a maximum on the interface between ice and liquid water.

Second, note that MEI is inversely proportional to density. Then larger gradients are possible when the density is also large. Water has one of the largest densities of comparable liquids, and reaches its peak density at 4C, very close to the water-ice interface. Once again, warm ponds dilute the entropy gradients away from the maximum.

6.2. geometric constraints

Darwin also thought that a warm *pond* had sufficient resources to begin life. For example, one can look at the elemental composition of a cell, and the elemental composition of fresh water (or sea water), and then extrapolate to how much water had to be collected to provide all the elements necessary for life. A slightly more sophisticated model might look at likely molecules that carry those elements. For example, most carbon molecules are insoluble, so CO_2 dissolved in water is the most likely source of carbon. From these sorts of considerations, and assuming some mechanism to concentrate phosphorus, one extrapolates to a pond-sized body of water. Undersea vents have some advantages over ponds for some elements, but not for others, leading to trade-offs and increasingly unlikely "concentration" events.

The key word is "unlikely" which is to say non-entropic, or informational. All these locations must possess information, and in large quantities. (Remember, we can not inter-convert information, so it is not possible to simply invoke a low entropy, or a far-from-equilibrium, energy source!) Furthermore, the information is not collected all-at-once, but like most organic compound syntheses, appears in multiple steps. In other words, our location must have enough information to collect, and there must be a way to progressively add information. Neither of these conditions apply to a warm pond, and while an undersea vent has a continuous flow, its high temperature precludes the adding of information via MEI.

What we need is a global system, that like the undersea vent, continuously brings in information to be added to the system. This is also the conclusion of Walker&Davies.[29] And between "adding events" information must be preserved against degradation–much as an organic chemist purifies his reaction products before starting the next reaction.

Comets fulfill these requirements, since between close encounters with a star, they freeze to 5K above absolute zero. While when melted, they supply maximum $\nabla \mathbf{S}$ at maximum ρ. But what about the B-field of MEI? Do comets possess $\mathbf{B}$?

6.3. magnetic constraints

But infected comets are magnetic! In SH12 we describe the many forms of biomagnetite and discuss how they can set up magneto-thermal convection and harvest interplanetary magnetic field. In Figure 4 we show photomicrographs of patterned magnetites in CI meteorites called "plaquettes" (platelets) and "framboids" (raspberries, or spheres of ball-bearings), which we argue are supremely sensitive paramagnetic bodies that engage in thermo-magnetic convection. We could not find a function for plaquettes but suggest they bore more than a passing resemblance to chloroplasts in panel (b). In SH12 we hypothesized that plaquettes may act as energy harvesters for growing cells.

While self-organizing paramagnetic Fe_3O_4 can spontaneously generate magnetic field, its strength is limited by the magnetic permittivity of magnetite. In addition, once all the Fe on the comet is used up, there is no further increase in field. However, comets travel through the magnetized plasma of stellar winds, and they can concentrate and collect these fields as well. In terms of total energy or volume, the interplanetary field can be much larger than the internally created field.

But in reality, they are synergistic. The interior field is randomly oriented, whereas the external field is global, so the exterior field will align and "magnetize" the random internal fields. In return, the interior fields will "trap" and harvest the exterior field, as described schematically in SH12. Therefore a comet will become more and more magnetized, particularly as it approaches a star and begins to melt. This is precisely the time when the liquid needs to conserve MEI, and so magnetized comets are ideally structured to maximize and add information.

6.4. MEI constraints

Now that we have MEI, we can apply the SH12 analysis to the consideration of $\mathbf{B} \bullet \nabla \mathbf{S}$. The magnetic field is clearly normal to the platelets. The spherical shape of all these structures enable them to align with the external B-field and so maximize their contribution to MEI. To further maximize MEI, the $\nabla \mathbf{S}$ must also be perpendicular to platelets. In these fossilized forms, we can only see an organic sheath around the entire ball (and holding it

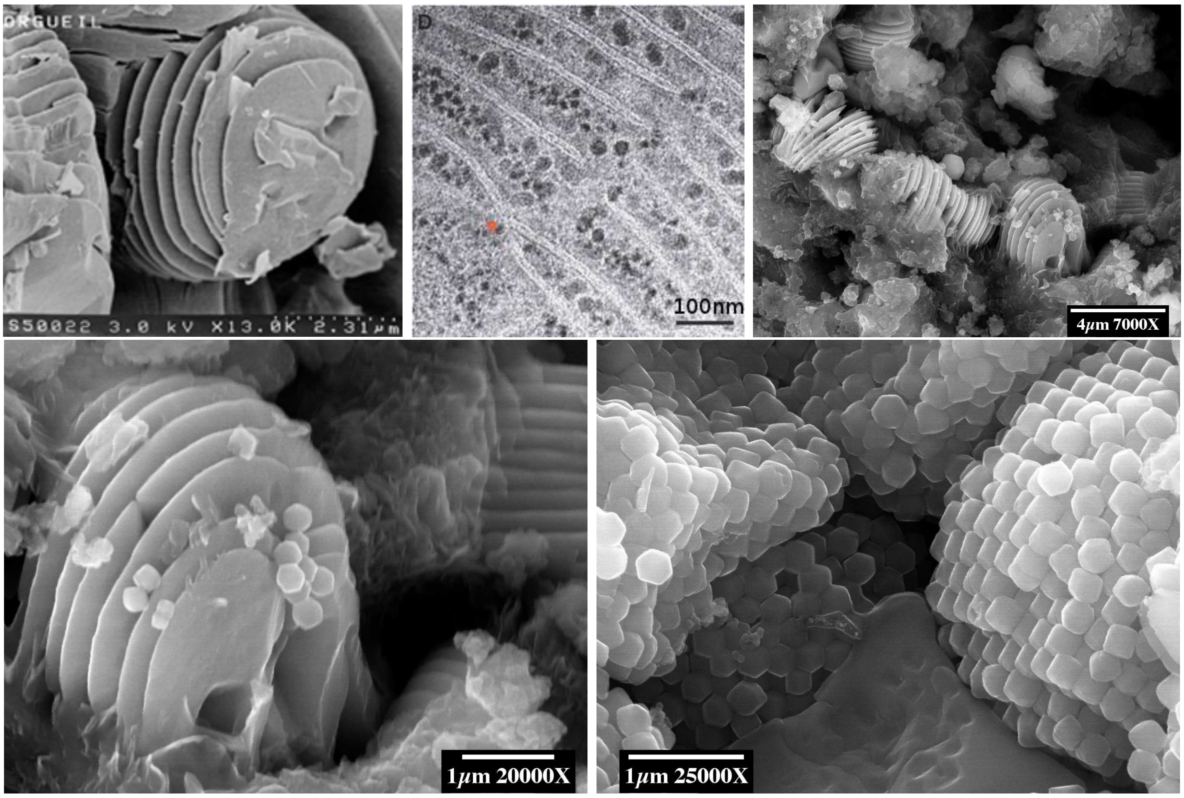

Figure 4. (a)Orgueil plaquette;[60] and (b) cyanobacterial thylakoid membrane in chloroplast.[61]; (c) Tagish Lake plaquettes; (d) plaquette with framboidal particles; (e) framboid made of framboidal particles.

together), but presumably each platelet also had an organic layer on which chemical reactions could proceed,[62] maximizing the surface area.

Since Fe_3O_4 has the ability to split H_2O at these temperatures,[63] it would appear that these devices may be functioning as chloroplasts, driving high entropy CO_2 to low entropy $[C(H_2O)]_n$, or concentrating information. Supporting this hypothesis, the oxygen triple isotope ratios for CI and the unclassified Polonnaruwa are also *below* the terrestrial (evaporational) fractionation line, appropriate for chemical reactions occurring near the freezing point of water.[56]

Thus it would seem possible that magnetic comets utilize MEI for carrying out the chemical reactions for life. If so, MEI switches sign for two polarities of the vector magnetic field, $\mathbf{B}$. Since ∇S always points in the same direction, from low S inside the magnetite to high S outside, it would seem that like airplane vortices, MEI would come in oppositely signed pairs: positive on one side of a plaquette, negative on the side opposite. This would require information addition to be very selective, lest it inadvertently subtract information. However, if the molecules in the chemical reaction were chiral ($\mathbf{X}$), with right- and left-handed versions, then there would potentially exist another $\mathbf{B} \bullet \mathbf{X}$ term in the chemical kinematics that switches the sign on ∇S. In such a case, not only is there no danger of inadvertently subtracting MEI information, but life would be forced to a single chirality.[64] This would explain one of the outstanding mysteries of how OOL came to favor L-amino acids and D-sugars.

7. CONCLUSIONS

Table 3 summarizes this application of MEI to magnetic comets:

Entropy gradients must be preserved to maximize MEI, which is achieved by barely melting a comet for each information addition, and then refreezing it for the next addition.

Table 3. MEI compared to Comets

MEI Requirements	Comet Observations
Low T	99% of time T<10K
Large $\nabla\mathbf{S}/\rho$	Frozen/liquid boundary
High B	Magnetites!
Large velocity w/global reach	Hyperbolic Orbits >30km/s
Fluid approximation	>1 trillion in Solar System alone

Entropy gradients are further maximized by operating at the ice-water interface where water has its largest density. In the case of plaquettes, operating at the Fe_3O_4–water interface also maximizes the gradient.

Magnetic field must be large to maximize MEI, and magnetic comets use both internal paramagnetism and external interplanetary B-harvesting to magnetize their interior.

Information must be collected globally if there is to be any hope for OOL. Comets not only move freely throughout our Solar System, but also throughout the galaxy (hyperbolic orbits), at speeds that approach 70km/s, relying on magnetic braking for transferring their payloads into trapped stellar orbits.

The fluid approximation for S that is used in MEI is a good approximation when there are a trillion comets per solar system, and 10+ billion solar systems per galaxy = 10^{22} particles in a galaxy, a reasonable fluid approximation corresponding to a gram of water molecules. (And if dark matter = comets, as SH08 suggest, then this number is closer to 10^{40} particles for a very good fluid approximation.)

Therefore we propose that magnetic comets can add information from the global reservoir of the galaxy (and perhaps the Universe!) providing the necessary location and machinery for OOL. Where does the information come from? From the boundary conditions of the universe perhaps, though we can only see back to the era when comets dominate the cosmos, some 100My–500My after the Big Bang. The sooner that cyanobacteria begin infecting comets, the sooner the comet era, since comets become far more "spaceworthy" when modified by life (SH07,SH08).

This potentially pushes OOL back to almost the initial conditions of universe, when the first stars burned their way through the mists of gas and ice to re-ionize space and render the heavens transparent to the cosmic background radiation. Those same stars would have melted comets and given them vapor jets for rapid diffusion through the vast gas clouds of the universe, where perhaps they provided the nuclei for new stars and galaxies. In this case, MEI would require the clumping of gas into high density to be accompanied by sharpening entropy gradients. If so, then their information gathering properties preceded even OOL, but were responsible for structuring the universe we see today.

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