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Feasibility Study for Giant Planet Origins of Life (GPOOLS)

Len Troncale

Biology Dept., and Institute for Advanced Systems Studies, California State Polytechnic University, 3801 W. Temple Ave., Pomona, CA 91768, U.S.A.

Abstract. We recognize the theoretical objections and strong assumptions in bioastronomy against the feasibility of non-carbon based life (NCBL). Yet, we make a long-term commitment to testing these assumptions by parameterization of a wide range of NCBL characteristics using General Morphology, direct lab tests of giant planet gasses and energy sources at extreme temperatures and pressures for spontaneous NCBL subunit formation, and development of a range of instruments for lab and remote sensing of putative NCBL complex macromolecules.

1. Basic Idea and Its History

In 1953, Miller & Urey simulated what was thought at that time to be the early earth atmosphere and demonstrated that many of the biochemical subunits necessary for life on earth could arise spontaneously under such conditions. Hundreds of useful articles followed. The Giant Planet Origins of Life Study (GPOOLs) will do the same with giant planet atmospheres, but will substitute other Group 14 elements for carbon, in unique combinations, exposed to and reacting at very high temperature and pressures to test if non-carbon based molecular complexity is possible. Non-carbon based, and especially silicon-based, life is not a new idea. In the late 1800's, Reynolds suggested at a meeting of the British Academy of Science that the characteristics of silicon might allow for life at very high temperatures. H.G. Wells and other science fiction writers, from the same period up until today, have produced some very interesting and creative versions of silicon life. J.B.S. Haldane noted that silicon in soils might allow for life deep in the interiors of planets with chemical transformation of iron as its "food source". The GPOOLs project organizes a wide range of specialists from science and engineering to conduct direct lab experimentation with silicon across a wide range of conditions, and in as yet unimagined combinations suggested by general morphology, to test NCBL feasibility.

2. Why Feasibility Studies

The human species has a long history of anthropomorphism. Considerable amounts of human resources go into the search for carbon-based life. What if NCBL is also possible? Such searches would completely miss their signal.

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Despite theoretical objections cited below, the history of humans assuming they know enough to eliminate alternative mechanisms suggests we should be cautious. Anthropomorphism, and extension of known facts to unknown domains, often inhibits adequate exploration of alternatives. Besides, exploring the feasibility of NCBL is particularly attractive now because of the following developments.

1. **Frequency of Binary Stars**: Binary stars appear to be more abundant in galaxies than single star systems, perhaps resulting in a bias toward solar systems with giant planets. Existence of these solar systems might yield much greater relative volumes for NCBL origins than carbon origins.

2. **Discovery of Giant Planets**: Most of the > 100 extra solar planets recently discovered are giant planets ($< 75\,MJ$). Again, if NCBL is possible on such planets, we now have proven target systems to examine.

3. **Abundance of Silicon**: Si is abundant on our planet; it is a main constituent of our soil. It is also modestly abundant to common in the universe and in stellar generation of elements. Although less common than carbon, it has characteristics that have not been adequately explored in extreme, non-human environments.

4. **Advances in High Pressure Chemistry**: The ability to study H at pressures of 100 GPa and temperatures of $\sim 105\,K$ have led to unexpected results, e.g. increase in conductivity by four orders of magnitude. What other surprises lurk at high temperatures and pressures (T/P) for other elements?

5. **Improved Knowledge of Giant Planet Atmospheres**: Data from the Galileo and Cassini probes have provided better knowledge of giant planet interiors, constituents, conditions, and dynamics.

6. **Use of General Morphology**: This approach methodically explores combinations of alternative hypotheses (much like modern combinatorial chemistry) and has proven itself in astronomical applications in the right hands in the past. It could generate significantly new predictions for testing by reductionist experiments.

7. **Developments in Systems Science**: The design of life is now studied as a system by systems biologists. The emerging knowledge can be utilized to perceive more generalizable characteristics of life allowing for broader biochemical and biophysical descriptions.

3. Reflections on Theoretical Obstacles

The literature raises several objections to the possibility of NCBL, especially silicon-based life. We would respond to each as follows.

1. **Insolubility in or Lack of Water**: There is no *a priori* reason for requiring that all life exist in water; only that the roles that water fulfills

for carbon life be present in an analogous way. Many other combinations potentially could have the "relations" of water without being water. Silicon is soluble in exotic solvents. At the temperatures and pressures of giant planets the behaviors of elements and compounds, and their phase transitions, may change making non-water based NCBL possible.

2. **Meta-Stability**: Silicon is a crystal; it tends toward forming solids. That is true at our temperatures and pressures. That is not reliably true under Giant Planet temperature and pressure (T/P) conditions.

3. **Absence of Chirality**: Biologically evolved enzymes on earth only work on biochemicals of one chiral form. But that is a result of earth's peculiar history. Probably any life chemical would have to recognize complex "form" to act; but there is no a priori reason that the form need be chiral in nature. Handedness in other evolutionary scenario's may not be needed.

4. **Smaller Proportion of Heavy Metals**: Heavier elements are found in smaller percentages in larger planets due to their ability to cast away planetessimals during formation. But their vast size still results in much greater absolute amounts of heavy elements.

5. **Oxidised Silicon is a Solid**: Again, at earthbound T/P. Have we adequately investigated a wide range of silanes in a wide range of solvents at high T/P?

6. **Silicon Biopolymers are not found in Meteorites**: Neither are large carbon biopolymers, although polymer subunits are found. It is possible, that like water, we are looking for the wrong items. ET matter is first treated by extreme means to remove all of the numerous Si-based constituents before the search for carbon-based molecules is possible. What are we throwing out?

7. **Silicon Does not form Chains**: It does not form carbon-like chains with hydrogen; but it does with oxygen. While some would eliminate this combination because of the role that oxygen plays in carbon biochemistry, at very high T/P in exotic solvents, the behaviors and dynamics could be unique. We will not know until such alternatives are tested.

4. Hypotheses and Research Objectives

This proposed feasibility study is based then on the following five observations leading to four specific research objectives. (1) The specific features of life biochemistry on our Planet are a restricted set of all possible features for life that were selected by our modest temperature and pressure regime. (2) The behavior of C- & non-carbon polymers in the very high temperature/pressure regimes of giant planets has not been investigated under controlled laboratory conditions in exotic combinations. (3) The systematic investigation of a range of alternative conditions for non-carbon polymer formation from a very wide range of possible initiation subunits has not been attempted. (4) Humans tend to conflate the "particulars" of manifest and emergent systems with their much more fundamental "relations". This results in difficulty in conceiving of non-carbon life and dangerously limits our species awareness of life possibilities. (5) The importance of a possible successful non-carbon "origins of life" scenario is so great that it is worth attempts to overcome the many theoretical and practical obstacles facing such a study.

The above leads to four specific research objectives. (1) Design, test, and evolve instrumentation capable of simulating a range of giant planet temperatures/pressures with adequate reaction/isolation chambers. (2) Do parameter-based "general morphological" studies to formulate multiple sets of alternative scenario's (i.e. energy, reactants, conditions) for non-carbon-based origins of life. (3) Test alternative scenario's and select for conditions leading to high T/P life chemistry. (4) Build computer-based simulations to inform and refine GPOOL attempts.

5. Non-Carbon Life Chemicals and General Morphological Methods

5.1. The General Morphology (GM) Method

Professor Fritz Zwicky of Caltech used GM in the 50's & 60's to discover new alternative jet propulsion systems and to predict the existence of unimagined, super-compact astronomical objects (like neutron stars) long before they were observed. He advocated use of GM in many diverse situations to help humans overcome their fixation on currently observed "particulars" to the exclusion of "possible observables". Nature actually proceeds much more like GM; it tries infinite variations of all possibilities, in vast numbers of events, across vast time spans. It essentially tries all possibilities. GM attempts to "map" or "juxtapose" all possibilities, at least as many as conceivable to human perception. Modern systems scientists add additional steps to the traditional method to make the deceptively simple GM into a more effective tool for hypothesis generation. Hypotheses, however, must still be followed by experiments.

5.2. Steps in the GM Method

Zwicky (1969) described the following steps which he said were used by great discoverers from Newton to Mendeleev. (1) Formulate problem concisely. (2) Identify, analyze, and localize all relevant *parameters* of the problem important to the solution. (3) Construct a multidimensional "matrix" that captures all possible combinations of the parameters, and so contains many potential solutions. (4) Evaluate alternative solution combinations in the matrix according to criteria of problem formulation. (5) Use additional morphological matrices to select and test the most optimal solutions. The discerning use of the parameterization step is the most demanding and important step for success. To this technique modern systems science would add: (6) knowledge of > 100 "isomorphies" or systems mechanisms common to all "mature" systems, and (7) formalized "linkage propositions" between these systems mechanisms yielding a "system of systems processes". The graphics-based Linkage Proposition Template Model, is a product of our Institute for Advanced Systems Studies and is now being integrated with GM techniques.

5.3. General Parameterization for GPOOLS

Giant planets have more of all of the features that Miller & Urey used in their Nobel-prize winning research. For spontaneous origin of life polymers, whatever element initiates the bootstrapping, energy and reactants are key players. Giant planets have greater quantities of reactants, more diversity, and even more energy than smaller planets; and they are probably found more frequently in solar systems. General morphological and system process mappings will be made for each of the following parameter domains.

Parameterization of Energy Sources Giant planets have many possible *in situ* energy sources. Some examples include, the sheering forces of opposing massive gas flows, huge tidal forces, major intrinsic heat emissions that are fluid and convective (up to 1025 $erg\, s^{-1}$), and vast storms of chemical and heat inhomogeneity that dwarf the equivalent of electrical discharges on earth. New understanding of radiative zones that emit energy from the homogeneous levels supply a rationale for turbulent diffusion and mixing of materials needed for GPOOLs. We will do a GM for energy.

Parameterization of Substrate Conditions Constraint analyses suggest that GPOOLs phenomena would occur neither in the central dense ice & rock cores, nor in the fluid metallic hydrogen regions, but rather in the inhomogeneous atmosphere above the fluid metallic hydrogen at $< 100\, GPa$. We will do a GM for substrates.

Parameterization of Reactants Inhomogeneous regions of giant planets are the least understood parts of current models of giant planet interiors. This is a precisely where GPOOLs reactants occur. We need a GM for reactants.

Parameters of Life "Relations" Over "Particulars" This is the most critical of all the GM's needed. Just the right degree of abstraction of features such as bonding classes and strengths, complexity of chain, hierarchical levels of subunit to polymer and polymer variation, van der Waals forces, stereo form and fit, ionization, complementarities, and chain mobility will be investigated using GM.

5.4. New Instrumentation

There are a range of possible approaches to achieving GP T/P on earth. The GPOOLS team would have to engineer significant modifications of each to enable testing of the next four parameter explorations. Diamond Anvils are able to achieve pressures up to $500\, GPa$ and temperatures of $400\, K$. However, the reaction chambers are exceedingly small relative to those needed for optimal testing of proposed GPOOLs reactions. Laser Compression uses lasers to confine and increase pressure on samples. Lasers are being used both to compress and handle very small materials. However, current tools are not as functional for the volumes and diversity of reactants needed for GPOOLs. Gas Gun Experiments recently have achieved metallic liquid hydrogen and conditions at Jupiter's core, but with volumes of only a few drops of liquid so would require modifications for less T/P & more reaction volume. So GPOOLs will also produce four morphological matrix studies on instrumentation in addition to the four cited for life biochemistry.

Parameterization of T/P Tools Could GM help engineer and modify high T/P tools as it helped expand jet propulsion?

Parameterization of Reaction vs. Sampling Chambers Could GM suggest new methods for expanding the volume and accessibility of reactants and intermediate products?

Parameterization of Expected Products What would be expected besides well-known compounds of Si?

Parameterization of Product Analysis Technique and Tools Carbon-based life monomers, polymers and spectroscopic techniques for indicating their presence were well characterized as far back as the Miller-Urey experiments; how will we detect NCBL's?

6. Facilities and Interdisciplinary Research Team

CSU, Pomona has the capability for accomplishing the proposed feasibility study. The Cal Poly Pomona College of Engineering is nationally ranked in the top ten of Engineering Schools that grant the Masters Degrees in engineering. They recently completed a \$35M, $135,000\,ft^2$ lab building that will be used for this research.

7. Conclusion: A Space-Faring Species

The human species must become a space faring species in order to survive in the long term. We will undoubtedly encounter very strange environments. We need mind-expanding methods like General Morphology &Systems Science to be able to quickly understand and adapt the unique new systems we will encounter. GPOOLS is a step toward such methods and perspectives.

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