Interplanetary Small Satellite Conference, Caltech 2014 "**Dyson Precursors**" Jonathan Vos Post, Computer Futures, Inc. 3225 N. Marengo Ave, Altadena, CA 91001 {16-page 1 & 1.5 spaced draft 5.0 of 26 April 2014; from 27-page partial draft 4.0 of 21 Feb 2014}

Abstract: Wessen, my coworker on Voyager at JPL, (Dr. Wessen received his Bachelors of Science in both Physics & Astronomy from Stony Brook U., Masters of Science in Astronautics from U. of Southern California; Doctorate in Operations Research from the University of Glamorgan, Wales, United Kingdom. He co-authored the books "Neptune: the Planet, Rings and Satellites" & "Planetary Ring Systems." Recipient of NASA's Exceptional Service Medal for contributions to the Voyager 2 Neptune Encounter")

"As the millennium closed, so did the era of once per decade, large-scale planetary spacecraft. Future robotic spacecraft will have a wide range of capabilities, diverse mission objectives, and be launched almost one per year. Among the many mission objectives, some of these future explorers will be the landers and sample return missions of tomorrow. To meet these bold endeavors, these ambassadors from Earth will require advanced mission concepts, new operational approaches...technologies yet to be developed."

To organize this effort, the United States robotic planetary exploration program has been divided into these areas:

* Earth Exploration	* Mars Exploration
* Outer Planet Exploration	* Universe"

In my paper for this conference in 2013 [NIUSAT P.1.2 " 'Starflight without Warp Drive' reappraised after 18 years" by: Jonathan Vos Post, Computer Futures, Inc., Altadena, California, 91001 AND

Geoffrey A. Landis NASA John Glenn Research Center

David Brin: scientist, inventor, and New York Times bestselling author

Dr. Robert L. Forward: Deceased

1st Interplanetary Small Satellite Conference California Institute of Technology, 20-21 June, 2013]
Last 2 on Wessen's list, coauthors and I summarized approaches for transneptunian, Kuiper belt, Oort cloud, and practical robotic interplanetary small spacecraft. In the accompanying poem, co-authored with Freeman Dyson,: Dyson's "Noah's Ark Egg" biospacecraft extrapolation.

This 2014 paper ("Dyson Precursors") examines possible predecessor technologies for Dyson's vision.

I. Introduction

[quote from Dyson Poem]   [context for this Conference]

Last year's co-authored paper emphasized astronautical enginering as such. References there, extensive.
This year's paper emphasizes the Biology, and how it may integrate with the astronautical engineering.

As Leroy Hood told me, as Chair of Biology at Caltech: “Adhere to the advice of my mentor, Dr. William J. Dreyer, 'If you want to practice biology, do it on the leading edge, and if you want to be on the leading edge, invent new tools for deciphering biological information.'” Dr. Hood: development of five instruments critical for contemporary biology: automated DNA sequencers, DNA synthesizers, protein sequencers, peptide synthesizers, and an ink jet printer for constructing DNA arrays. Instruments opened the door to high throughput biological data and the era of big data in biology and medicine. Helped pioneer the human genome program; possible with automated DNA sequencer. The Human Genome Center, under Dr. Hood, sequenced portions of human chromosomes 14 and 15.

Freeman Dyson added: CONSTRUCTING bio-informational constructs for Space Travel.

2^{nd} key scientist who advanced technology towards Dyson's vision; Ph.D. at Caltech in 1954, working with two-time Nobel Prize laureate Linus Pauling. Martin Karplus was one of three scientists awarded the 2013 Nobel Prize in Chemistry for pioneering work on computer programs that simulate complex chemical processes and have revolutionized research in areas from drug discovery to solar energy. The Royal Swedish Academy of Sciences awarded the prize of 8 million crowns ($1.25 million) to Karplus, Michael Levitt, and Arieh Warshel, noting that their work had transformed the modeling of chemical reactions, once done using plastic balls and sticks, and moved it into the computer age. Born Austria 1930, Karplus was a child when his family fled the country's Nazi occupation, emigrating to the United States. He received a BA from Harvard University in 1950, and a PhD from Caltech in 1954.

Karplus: significant contributions to many fields in physical chemistry, i.e. nuclear magnetic resonance spectroscopy, chemical dynamics, quantum chemistry, and molecular dynamics simulations of biological macromolecules. “The work of Karplus, Levitt, and Warshel is ground-breaking in that they managed to make Newton’s classical physics work side-by-side with the fundamentally different quantum physics,” the Royal Swedish Academy said in its announcement. “Previously, chemists had to choose to use either or.”

Complex chemical reactions, such as how a drug couples to its target protein, generally understood at the molecular level. To learn what happens at the atomic scale, computers are needed to perform mathematically intense quantum theoretical simulations. Karplus, Levitt, Warshel helped to bridge those models, offering researchers tools to gain a complete view of such interactions at all levels.

“This year's recipients have done important computational and mechanistic work on protein and enzyme catalysis,” said Rudolph Marcus, the Arthur Amos Noyes Professor of Chemistry at Caltech and the 1992 recipient of the Nobel Prize in Chemistry. “That Karplus was a student of Pauling brings the prize this year close to home.” Karplus: Theodore William Richards Prof. of Chemistry, Emeritus, Harvard; Director Biophysical Chemistry Lab, French National Center for Scientific Research + University of Strasbourg, France. [Karpus via “Harvard professor wins Nobel in chemistry Martin Karplus is one of three to share in prize 'for the development of multiscale models for complex chemical systems'” By Corydon Ireland, http://news.harvard.edu/gazette/story/2013/10/harvard-professor-wins-nobel-in-chemistry/]

On the shoulders of such giants: my research goal 1973-1977: **computational theory of protein dynamics and evolution**; unifies mechanisms **from picosecond through organism lifetime through evolutionary time scales**. Ph.D. dissertation work at University of Massachusetts, Amherst, (world’s first dissertation on Nanotechnology and Artificial Life); chapters of dissertation as modified and published as refereed papers for international conferences [Post, 1976-2004]. The unification must describe the origin of complexity in several regimes, and requires bridging certain gaps in time scales, where previous theories were limited (as with the breakdown of the Born-Oppenheimer approximation in certain surface catalysis and solvated protein phenomena). The unification also requires bridging different length scales, from nanotechnological to microscopic through mesoscopic to macroscopic. The unification at several scales involves nonlinear, kinetic, and statistical analysis connecting the behavior of individual molecules with ensembles of those molecules, and using the mathematics of Wiener convolutions, Laplace transforms, and Krohn-Rhodes decomposition of semigroups. Recent laboratory results in several countries, including the ultrafast dynamics of femtochemistry and femtobiology, which probe the behavior of single molecules of enzyme proteins, shed new light on the overarching problem, and confirm the practicality of that goal. The unification in contemporary terms requires building bridges (compatible databases, interoperable software) between Genomics, Interactomics, Lipidomics, Metabolomics, Proteomics, Transcriptomics, and other fields. Challenges to 21st Century Computational Biology: perform measurements and integrated simulations over 28 orders of magnitude of time, as a means to study and to understand better the emergent, collective behaviors of metabolic, regulatory, neural, developmental, and ecological networks.

PhD research: Stanislau Ulam [13 April 1909 – 13 May 1984], Jewish-Polish-American mathematician, liked and said so (eyewitnesses). America's Manhattan Project; originated Teller–Ulam design of thermonuclear weapons; invented Monte Carlo method of computation; suggested nuclear pulse propulsion. In pure and applied mathematics, many results, proved many theorems, proposed key conjectures. He liked the key equations of my PhD research very much, teleconferenced between two Bell Labs sites circa 1979. We intended to co-author; he passed away before we had agreed on an abstract. What he liked best: I exploited **Krohn-Rhodes Theory** (algebraic automata theory): approach to the study of finite semigroups and automata (mathematical approach to decompose finite semigroups to finite aperiodic semigroups and finite groups), to continuous biomolecular open systems. Section II extrapolates Bioscience for the next century. Section III: Inverse Problem" of Phenome to Genome; designing Robo-systems back from desired behavior

II. Extrapolated Bioscience for the next century: Systems on borderline between life as we know it, and other: **definition of life**? Venn Diagram. Tree overlapping circles = 3 main definitions: The diagram as whole gives my tentative 'original' composite definition of life which combines the main 3 definitions given: "**A self-assembled, self-contained negentropic chemical system network of feedback mechanisms capable of undergoing Darwinian evolution**." see pp.56 ff 'What is Life' of 'Origin of Life', Alonso Ricardo & Jack W. Szostak, Sci. Am. Sep 2009.

I. Cybernetic Definition
"A network of inferior negative feedbacks (regulatory mechanisms) subordinated to a superior positive feedback (potential of expansion, reproduction)." [Korzeniewski, 2001]
"A network of feedback mechanisms" "Best fit to theory of 'Metabolism First' as opposed to 'RNA First' Biogenesis, network of catalysts which process energy."

II. Schrödinger's Physics Definition
"Self-assemble against nature's tendency towards entropy (disorder) (i.e. negentropy). [historically the first of these] "Schrödinger also predicted before DNA structure known : 1-dimensional aperiodic crystal." "Self-assemble" as opposed to assisted self-assembly on mineral substrate such as Clay (Jim Ferris et al.)"

III. Chemistry Definition

"Life is a self-sustained chemical system capable of undergoing Darwinian evolution." [Joyce]
"Gerald Joyce's 'working definition' adopted by NASA: 'self-sustained chemical system capable of undergoing Darwinian evolution.' [Panspermia allows the Darwinian evolution to have started on another planet or body."] "If we leave out Gerald Joyce's 'chemical system' can't simply exclude software 'artificial life' in silico -- or more exotic substrates. "In regions combining only 1 or 2 definitions, what counterexamples possible?"

Then: **overlapping areas of the Venn Diagram:**
I/II. Cybernetics + Physics
"self-assembled negentropic network of feedback mechanisms"

II/III. Physics + Chemistry
"self-assembled, self-sustained negentropic chemical system capable of undergoing Darwinian evolution."

I/III. Cybernetics + Chemistry

“self-contained network of feedback mechanisms capable of undergoing Darwinian evolution.”

Center, the triple overlap: **I/II/III. Cybernetics + Physics + Chemistry**
“A self-assembled, self-contained negentropic chemical system network of feedback mechanisms capable of undergoing Darwinian evolution.”
Clarify Schrödinger’s Physics definition, though many non-physicists persist in stating that life's dynamics somehow go against the tendency of second law (entropy of an isolated system tends to increase), the definition assuredly does not in any way conflict or invalidate this law. Because the principle that entropy can only increase or remain constant applies only to a closed system (i.e. one which is adiabatically isolated, so that no heat can enter or leave). Whenever a system can exchange either heat or matter with its environment, both of which apply to the planet Earth and its ecosystem, an entropy decrease of that system is entirely compatible with the second law.”
In more modern terminology, **life is a dissipative system**. Characterized by spontaneous appearance of symmetry breaking (anisotropy) and the formation of complex, sometimes chaotic, structures where interacting particles exhibit long range correlations. The term dissipative structure was coined by Russian-Belgian physical chemist **Ilya Prigogine**, who was awarded the Nobel Prize in Chemistry in 1977 for pioneering work on these structures, somerediscovered by me at the University of Massacusetts after my M.S. In Artificial Intelligence and Cybernetics, when I wrote the world's first PhD Dissertation of what was later known as Nanotechnology. Research on what he called “'**enzyme waves.**'”
“John Avery explains in his 2003 book Information Theory and Evolution, we find a presentation in which the phenomenon of life, including its origin and evolution, as well as human cultural evolution, has its basis in the background of thermodynamics, statistical mechanics, and information theory. The (apparent) paradox between the second law of thermodynamics and the high degree of order and complexity produced by living systems, according to Avery, has its resolution "in the information content of the Gibbs free energy that enters the biosphere from outside sources.” The process of **natural selection** responsible for such local increase in order may be mathematically derived directly from the expression of the second law equation for connected non-equilibrium open systems.
“'Ferris et al' and clay text: when free nucleotides combine in water solution, they do not react at all. Various teams of scientists searched for types of activating groups and inorganic catalysts involved in polymer bonding process. Dr. Ferris. Rensselaer Polytechnic Institute in Troy, NY, discovered inorganic material which facilitates this reaction, namely montmorillonite clay. The specific structure of this clay can provide a medium on which the individual activated RNA units combine to form larger chains.”

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Dr. James P. Ferris. "Montmorillonite Catalysis of RNA Oligomer Formation in Aqueous Solution. A Model for the Prebiotic Formation of RNA." Journal of the American Chemical Society. 1993, 155, 12270-12275. James P. Ferris is Director, New York Center

for Studies on the Origins of Life

Gerald Francis Joyce, "The RNA World: Life Before DNA and Protein". Professor Gerald Francis Joyce (born 1956) is a researcher at The Scripps Research Institute. His primary interests include the in vitro evolution of catalytic RNA molecules and the origins of life. He was elected to the National Academy of Sciences in 2001. Joyce received his Bachelor of Arts from the University of Chicago in 1978, completed his M.D. and Ph.D. at the University of California, San Diego in 1984, and joined Scripps in 1989. Joyce, quoted in commentary in Science (1992): “Obviously, Harry [Noller]'s finding doesn't speak to how life started, and it doesn't explain what came before RNA. But as part of the continually growing body of circumstantial evidence that there was a life form before us on this planet, from which we emerged - boy, it's very strong!”

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Prof. Bernard Korzeniewski’s home page, http://awe.mol.uj.edu.pl/~benio/
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Alonso Ricardo and Jack W. Szostak, , “Origin of Life”, Scientific American, September 2009.

Schrödinger, Erwin (1944). What is Life - the Physical Aspect of the Living Cell. Cambridge U. Press. ISBN 0-521-42708-8. famous 1944 book What is Life?, Nobel-laureate physicist Erwin Schrödinger theorizes that life, contrary to the general tendency dictated by the Second law of thermodynamics, decreases or maintains its entropy by feeding on negative entropy. In a note to What is Life?, however, Schrödinger explains his usage of this term: “Let me say first, that if I had been catering for them [physicists] alone I should have let the discussion turn on free energy instead. It is the more familiar notion in this context. But this highly technical term seemed linguistically too near to energy for making the average reader alive to the contrast between the two things.”

III. Designing Robotic systems backwards from desired behavior

{Excerpt from a science fiction story of mine, “HALF A TRILLION MILES FROM EARTH” which extrapolates the development of Dyson Noah's Ark Egg technology.}
Then the next BioShip came to my neighborhood of the Oort Cloud. My ancestors in the 20^{th} century would have been baffled. “Is it a spaceship?” the would say. “Is it a genetically engineered organism?”

Well, of course, both. The 21^{st} century, after all, could be called the Biophysics Century.

Biophysics: an interdisciplinary science using methods of, and theories from, physics to study biological systems. Biophysics spanned all levels of biological organization, from molecular scale to whole organisms and ecosystems. Biophysical research shared significant overlap with biochemistry, nanotechnology, bioengineering, agrophysics, and systems biology. It was the bridge between biology and physics.

First, Molecular Biophysics addressed biological questions similar to those in biochemistry and molecular biology, but more quantitatively. Scientists in this field conducted research concerned with understanding the interactions between the various systems of a cell, including the interactions between DNA, RNA, and protein biosynthesis, as well as how these interactions are regulated. A great variety of techniques were used to answer these questions.

Fluorescent imaging techniques, as well as electron microscopy, x-ray crystallography, NMR spectroscopy, and AFM (atomic force microscopy) were often used to visualize structures of biological significance. Conformational change in structure were measured using techniques such as dual polarisation interferometry, and circular dichroism. Direct manipulation of molecules using optical tweezers and AFM were also used to monitor biological events where forces and distances were at the nanoscale.

Molecular biophysicists often considered complex biological events as systems of interacting units which could be understood through statistical mechanics, thermodynamics, and chemical kinetics. By drawing knowledge and experimental techniques from a wide variety of disciplines, biophysicists were often able to directly observe, model, and even (as the great Feynman had first imagined in 1959) manipulate the structures and interactions of individual molecules and complexes of molecules. In addition to traditional molecular and cellular biophysical topics, such as structural biology and Michaelis-Menten enzyme kinetics, biophysics by the middle of the 21^{st} century encompassed an extraordinarily broad range of research, from bioelectronics to quantum biology. This involved both experimental and theoretical tools. It became increasingly common for biophysicists to apply the models and experimental techniques derived from physics, as well as mathematics and statistics, to larger systems such as tissues, organs (as with cardiophysics), populations, and ecosystems. Biophysics was by then used extensively in the study of electrical conduction in single neurons, as well as neural circuit analysis in both tissue and whole brains.

Things kicked into even higher gear when two different forms of single-cell life were found within the rocky bodies of asteroids such as 21-Lutetia. As the BioShip cruised through the inner Oort Cloud, it deflected nanoparticles of protoplanetary and interstellar dust. It approached larger bodies, asteroidal and cometary. It sent Noah's Ark Eggs to velocity-match, rendezvous, and softly land. 20th century science fiction stories about starships usually depicted the universe in mechanical ways. But we got our grips on notions more diverse, as a collection of stars and planetary systems separated by vast stretches of empty space, for which there was a better way, in any case.

Space between stars was imagined to be filled with dilute interstellar gas, and nothing else. Yet there was something better, when we built in terms of gravitational mass out beyond the Kuiper belt's cold transneptunians of which we sing. The real universe was much more interesting.

The real universe contained a multitude of objects of various sizes, giving interstellar travelers
places to stop and visit friends and collect fresh supplies between the stars. We brought our personal effects beyond the reach of telephoto lens, a thousand times more far away than Mars. Ten thousand. A hundred thousand. Deep into the Oort Cloud. At first we know almost nothing about these objects, but that they existed. We knew that in the space around our own planetary system, there were two populations of comets known as the Kuiper Belt and the Oort Cloud. So we set forth, because it was allowed by laws of Physics and Biology, with precursor payloads well endowed with the appropriate technology.
We knew that they existed because the comets which we saw close wee visibly disintegrating,
and could not survive for a long time. We soon were in interstellar flight, participating in something which helped us climb out of the gravity well we called the Sun. Visionaries began anticipating. Investors began investing.

The tail which made a comet beautiful, was proof of its mortality. Meteor showers were debris marking the graves of dying comets. Extraterritoriality demanded that we set our feet beyond those graves, participated with practicality in adaptive radiation, waves after waves. There turned out to be other objects of intermediate kinds, from snowballs to black dwarf stars. A population of mythological monsters making their home in space. Our hearts were not black, but beat with blood hot and red, imagining the bud of equally hot blooded plants; gave our travels a much better chance.

Island hopping came first. Intercontinental voyages came later. The evolution of starships, like the evolution of Polynesian canoes and European galleons, proceeded by a process of trial and error.
People died on the Moon. People died on the red regolith of Mars. People died in Saturn space, their last sight of glorious rings. Otherwise we humans would not have been pioneers, but merely tourists.
So, around the campfires, the bard sings, of those who ventured far, far into the darkness.

Freeman Dyson wrote: two things needed to make a starship fly: **a place to go, and a way to get there**. The first was mainly a problem in **Biology**. The second was a problem of **Engineering**.

Not enough to have hotels for humans. Had to establish permanent ecological communities, including microbes and plants and animals, all adapted to survive, in the local environment. After life established itself with grass and trees, herbivores and carnivores, bacteria and viruses, humans began to arrive, and build homes in a friendly environment.

No future for humans tramping around in clumsy spacesuits on lifeless landscapes of dust and ice.

How did we expand the genomes of the Earth, and sea, and within rocks, using what we could know with **quantum computers** of awesome power? We mastered **Biophysics**. We learned how to use genetic information creatively. We were then in a position to design biosphere populations adapted to survive and prosper in various environments, on various planets, satellites, asteroids, and comets.

For each location we designed a biosphere genome, and for each biosphere genome we designed an egg, out of which an entire biosphere could grow. Each egg weighed a few kilograms, and look from the outside like an ostrich egg. Each was a miniature Noah's ark, containing thousand or millions of microscopic eggs programmed to grow into the various species of a biosphere. Each contained nutrients and life support to enable the growth of the biosphere to get started. What first came from each egg? What slithered, rolled, squirmed, or crawled into the starlight of the Sun, so distant that the ground was frozen gasses?

First species to emerge from each Noah's ark egg was warm blooded plants, designed to collect energy from sunlight, and keep themselves warm in a cold environment. Warm blooded plants then provided warmth and shelter for other creatures to enjoy. In this way, life was seeded in great abundance and variety in all kinds of places, traveling on small biospacecraft carrying payloads of a few kilograms.

Not huge generation ships with villages of people; the great-great grandchildren of those who left behind the cool green hills of Earth. Since life was inherently an unpredictable phenomenon, many of the biospheres failed and died. Those that survived had evolved in unpredictable ways. Their evolution would continue forever, with or without human intervention. We humans were the midwives, bringing life to birth all over the universe as far as our Noah's ark eggs could travel.

There was no law of physics that would prevent a warm blooded plant from growing a mirror to concentrate enough starlight to survive anywhere in our galaxy. So our ancestors traveled across the desert of outer space from wet and green oasis, to oasis. They island hopped, as did the Polynesians across the vaster Pacific of interstellar space. We went by way of Dyson's Noah's ark eggs, and followed the trail made for us by warm blooded plants, our emissaries, our ambassadors, and our trailblazers, on lightsails pushed by interstellar lasers. They were only one possible way to go. The real future was unpredictable. It was rich in surprises that we could not have imagined. All that we could say with some confidence,

was that biotechnology dominated our future. The awesome power of nature to evolve unlimited diversity, of ways of living, was in our hands. It was for us to choose how to use this power, for good or for evil.

The BioShip came to my neighborhood of the OC. And I gambled that I could find a way to ride it out to 8,484 AU. There, I would embrace my Beatrice. I was getting a crush on a young lady who lived farther out in the OC, 7.89 times a hundred billion miles from Earth. Three quarters of a trillion miles from Paris.

She and I both found Terrestrial History and Culture classes funny. Many of our peers cared not a fig for Earth. Their attention was on the human future, spreading out along the galactic spiral arm, to hundreds of billions of stars, most with more than one planet. Not that planets mattered. We in the OC knew better. Small was beautiful. When I felt that I'd waited too long for another message from that young lady who lived farther out in the OC, I felt short of oxygen.

Oxygen is a Group 16 element. While about one fifth of the atmosphere of old Earth was oxygen gas, and while the atmosphere of Mars contained only about 0.15% oxygen, we could make as much as we wanted from eletrolyzed melted ice from this comet nucleus. Oxygen, hird most abundant element found in the Sun, and it played a part in the carbon-nitrogen cycle, one process responsible for stellar energy production.

Oxygen in excited states was responsible for the bright red and yellow-green colors of Earth's auroras, which I have only seen in recordings. About two thirds of the human body, and nine tenths of water, is oxygen. The gas is colourless, odourless, and tasteless. Liquid and solid oxygen are pale blue and strongly paramagnetic, containing unpaired electrons.

In the earliest days of human spaceflight, took all the oxygen that they needed into orbit with them. Gradually, they developed CELSS (Controlled [or Closed] Ecological Life Support Systems). One of the most important spin-offs of the space program. Wolverton: In 1989, NASA completed a small facility called BioHome... integrated “biogenerative” components for recycling air, water and nutrients from human wastes: a single, integrated habitat. Maximum air closure achieved; experiments begun.

Little larger than a mobile home, the facility put living quarters in a compartment beside the crops and waste processing facilities, circulating air and water between them. Drinkable water from air condensate.

Facility initially focussed on wastewater treatment. Aquatic and semi-aquatic plants known for their ability to process sewage were studied. Not edible plants, but aquatic and semi-aquatic plants chosen for their history in making excellent compost material for food plants, after they grow based on the sewage. After growing to a certain size, they are harvested, cleaned and composted. This compost has been used as a complete growth media for tomatoes, sorghum, corn, potatoes, cucumbers and squash. The facility grew edible plants, though that information was not available on the web at the time of this writing.

PVC pipes slowly moved sewage downstream; pipes had holes cut in them; plants were emplaced. Experiments measured the effectiveness of several plants, each of which can utilize raw human sewage as a complete growth media. Samples of the water taken at different points in the flow; studied. In the end, the effluent water flowed through an ultraviolet unit to assure complete kill of all microorganisms, especially those pathogenic to humans. Water hen suitable for use in toilets and watering plants. Drinking water came from condensate from the air (e.g., dehumidifier and air conditioner condensate), which was also disinfected by ultraviolet equipment. Plant leaves emitted quite ample supplies of water vapors.

Plants purified the air of many manmade substances such as formaldehyde, benzene, toluene and other undesirable organics. Foliage plants were placed throughout the living quarters for absorbing the gases from the newly constructed and furnished facility. "When sewage is slowly filtered through an aquatic plant root filter system, complex biological processes take place during wastewater treatment and purification. The symbiotic relationship that is normally established betweeen the plant roots and microorganisms living on and around these roots is very complex and important in the wastewater treatment process... Not only removes organic chemicals, but contributes to reduction of other polluting substances: pathogenic bacteria and viruses. Roots of aquatic plants such as bulrush, reed, soft rush, water iris excrete substances to partially or completely kill pathogenic bacteria while not harming beneficial bacterial The aerobic zone around the aquatic root system can also support, in addition to bacteria, the growth of large numbers of protozoa which feed on bacteria, viruses and particular organic matter."

People did not leave the inner Solar System alone. People did not enter the Kuiper Belt alone. People did not enter the OC alone. We brought a carefully fine-tuned subset of terrestrial ecosystem with us.

Oxygen. Three stable isotopes of oxygen (16O, 17O, and 18O). Radioactive isotopes with mass numbers from 12O to 24O characterized, all short-lived, with the longest-lived being 15O with a half-life of 122.24 seconds. The shortest-lived is 12O with a half-life of 580 ×10^-24 second.
Oxygen: the most abundant element in Earth's crust: almost a third of the planet's mass. Of its three stable isotopes, oxygen 16 (whose nucleus contains eight neutrons) made up 99.762 percent of oxygen on Earth, while heavier oxygen 17 (with nine neutrons) accounted for just 0.038 percent, and the heaviest isotope, oxygen 18 (with 10 neutrons),

made up 0.2 percent. Yet minerals in some of the most primitive objects in the solar system, including carbonaceous chondrites, had quite different ratios of oxygen isotopes than on Earth. Presumably the rare heavy isotopes occurred in much greater abundances in the early solar system.

“For a chemist, the question of oxygen-isotope ratios is one that could help us understand the origins of the solar system,” said Musahid (Musa) Ahmed of Berkeley Lab’s Chemical Sciences Division, a beamline scientist at the Chemical Dynamics beamline, 9.0.2, at the Advanced Light Source (ALS). “Why meteoritic oxygen isotope ratios are significantly different from those on Earth has mystified scientists for years.” Various models had been proposed to explain these differences, including the notion that isotope ratios in our solar system resulted from their creation in an exotic star, or in several different stars, through nuclear processes -- models that Ahmed says “don’t work” -- or, more persuasively, that chemical processes within the solar nebula itself gave rise to the oxygen ratios. We know better now, in 2150 A.D. But it does not much affect our operations as we maintain and expand our watering holes between the stars. It pains me to say it, I'll never be rich enough to travel out to 8,484 AU and meet the young lady in the flesh.

Interstellar travel is not limited by oxygen. It is limited by the iron laws of Economics.

Termites Teach Robots a Thing or Two”, Robert Lee Hotz, Wall Street Journal, 13 Feb 2014
http://online.wsj.com/news/articles/SB10001424052702304703804579381321513900590
CHICAGO—Inspired by termites, Harvard University researchers have designed a construction crew of tiny robots able to build complicated structures without blueprints or outside intervention.
The robots, which took four years to design, are the latest innovation in what computer scientists and robotics researchers call swarm intelligence—a field in which scientists are exploring ways to enable large groups of simple robots or flying drones to collaborate.
"Every robot acts independently, but together they will end up building what you want," said team leader Justin Werfel, a staff scientist in bio-inspired robotics at the Wyss Institute for Biologically Inspired Engineering at Harvard University who helped demonstrate the robots Thursday at the annual meeting of the American Association for the Advancement of Science in Chicago. "One day, a system like this could build in settings where we could not easily build, like underwater or on Mars," Dr. Werfel said.

Scientists programmed the robots using rules based on the behavior of termite colonies. Acting without human-style intelligence or a central plan, termite swarms comprising millions of insects routinely build mounds up to 42 feet tall. Insects act individually, taking cues from their surroundings and from each other.
In a similar way, the robot swarm can build towers, castles and pyramids out of foam bricks. Acting autonomously, individual robots can even build themselves staircases to

reach the higher levels of the structures, adding bricks wherever they are needed, according to the researchers, who also published details of their project in Science. Researchers from the Wyss Institute and the Harvard School of Engineering and Applied Sciences collaborated on the work.

Robots are about 8 inches long and 4.5 inches wide. They have pinwheel-shaped tires to give them traction on the construction site and are powered by off-the-shelf motors. To sense its surroundings, each robot is equipped with an infrared sensor, an ultrasound sensor and an accelerometer. The robots were programmed with a few simple rubrics that allowed them to respond to changes in conditions around them and to each other. A computer program created these rules based on the design of the particular structure to be built.

Basically, the robots can sense the bricks they carry and the other robots nearby, said Harvard engineer Kirstin Petersen, who constructed them. They can move backward or forward, turn and move up or down a step. They can pick up, carry and deposit a simple brick. Despite their simplicity, the robots are smarter as a group than they are individually, able to complete relatively complicated projects, the scientists said. They usually can recognize mistakes they make and correct them. Each robot "walks around the structure until it sees something that needs to be done and then does it," said Dr. Werfel. "We are giving them enough feedback so that they can recognize errors and correct them."

IV. Conclusion {let us discuss this in the Poster Sessions}

V. References

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