Book Review Essay

Can a Biosphere be Selfish?: The Gaian Challenge to Darwinism[1]

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Scientists Debate Gaia: The Next Century, edt. S.H. Schneider, J.R. Miller, E. Crist and P.J. Boston. MIT Press, Cambridge, Massachusetts, 2004, 377 pp., ISBN: 0262194988.

In the mid-60's NASA was developing instruments for the Viking spacecraft to detect life on Mars. To assist in this effort, NASA consulted James Lovelock, an iconoclastic British atmospheric chemist. Lovelock wondered: Can the existence of life be recognized from knowledge of the chemical composition of a planet's atmosphere? What would the Earth be like now, if life had never evolved on it? Would there be oxygen in the air? Would the surface temperature be hot like Venus, or cold like Mars? He came to the conclusion that a spacecraft didn't need to be sent to Mars. All one needed was a determination of the composition of the Martian atmosphere to see if it were in chemical equilibrium. This was done, and to the accuracy of the measurements, unlike the Earth's atmosphere, the martian atmosphere was in chemical equilibrium. He concluded that Mars was dead (see Krasnopolsky et. al. 2004 and Formisano et. al. 2004 for a possibly low-level methane exception to this conclusion).

However, it seemed to Lovelock that terrestrial life didn't just passively produce chemical disequilibrium. There seemed to be some element of control or regulation. In 1974, Lovelock and his eukaryotic exosymbiont Lynn Margulis, published "Atmospheric homeostasis by and for the biosphere" The words "by" and "for" in the title are the revolutionary teleological prepositions that launched Gaia into a sea of controversy that continues to this day. The uncontroversial half of the new book being reviewed here is about the "by the biosphere" while the controversial other half is a debate over the meaning of "for the biosphere".

In 1978 Lovelock published a book called *Gaia* describing how the entire biosphere in many ways behaves like a living creature. For throngs of new age agnostics yearning to breathe free, *Gaia* resonated with their intuitive animism. The book became a best-seller. Since then Lovelock has written copiously and articulately on Gaia both in books of popular science (Lovelock 1990, 2000a,b, 2001) and in professional literature.

To separate Gaian science from pseudo-science, the American Geophysical Union, sponsored the 1988 Chapman Conference on Gaia in San Diego. This meeting resulted in an eclectic and authoritative conference proceedings: *Scientists on Gaia* (Schneider & Boston 1991). A second Chapman Conference on Gaia held in Valencia in 2000 has now

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resulted in a new book *Scientists Debate Gaia* (Schneider et. al. 2004), with almost the same title, and almost the same editors and many of the same contributors as its predecessor. Like its older twin, *Scientists Debate Gaia* is a wonderful book – informative, frustrating and inspirational. It is a well-bound (bravo MIT press) well-referreed (bravo editors) collection of a few dozen well-referenced chapters (bravo 54 contributing authors). In it you will find a potpourri of theoretical biologists wrestling with that nasty teleological preposition “for”, some ecological case studies and numerical simulations focusing on the “by”, along with a smattering of history and philosophy.

Why should astrobiologists read this book? Because Gaian science and Astrobiology have very similar programs. Astrobiologists look at the stars and ask “What has life done to the planets out there and how can we recognize it?” while Gaian scientists have been looking at the Earth for decades asking “What has terrestrial life done to our planet and how can we recognize it?” Astrobiology and Gaian Science share a common working hypothesis: Things are connected – so let’s find the connections and try to put the big picture together. When astronomers and biologists do this, it’s called astrobiology. When atmospheric chemists, geologists and concerned ecologists do it, it’s called Gaian science – a holistic version of biogeochemistry that has now worked its way into the mainstream as “Earth Systems Science”. Since Gaian scientists are a particularly Earth-centered group with little or no input from astronomers, their questions are more down to earth. They study the physiology of the Earth’s biosphere and atmosphere and pay little attention to the origin of life or to other terrestrial planets (with the exception of Chap 27, “Extraterrestrial Gaias” by Franck et. al.)

Over the past four and a half billion years, the Sun’s luminosity has increased by about 30%, but the temperature of the Earth’s surface doesn’t seem to have followed in step (Sagan and Chyba 1997). Maybe, as Lovelock and Margulis have hypothesized, the biosphere regulates the Earth’s surface temperature. There are two obvious ways to regulate the surface temperature of a planet. Regulate the albedo of the planet and/or regulate the composition of greenhouse gases in the atmosphere. Lovelock invented the parable of Daisyworld to demonstrate that the biosphere could regulate the albedo (Watson and Lovelock 1983). An interesting and perhaps devastating critique of this regulatory ability is given in Weber and Robinson’s chapter “Daisyworld Homeostasis and the Earth System” (Chap. 20). They suggest that Daisyworld’s thermoregulatory properties are a function of assumptions of the model — not some necessarily evolved or emergent phenomena.

However, as mammals we are proud of the way our bodies regulate our body temperature to within half a degree of 37 degrees Celsius. We accept that it is done “by and for” our bodies. Like any ability of a living organism, it evolved. There was a population that started out with little or no ability to regulate temperature. Members of the population that could regulate out-reproduced the non-regulators. And today we describe this behavior as “self-regulation” — the temperature is maintained “by and for” the benefit of our bodies. A nice Gaian extension of this idea is J. Scott Turner’s analysis (Chap. 5: “Gaia, Extended Organisms and Emergent Homeostasis”) of the thermoregulation of termite colonies, presumably by and for the colony (if a miniature ecosystem can do it, why can't a big one?).

Forget the uneducated debates with creationists and the theological debates with monotheistic intelligent designers; the scientific debate about the unit of selection, group selection and Gaia is one of the most important challenges that Darwinism has ever had to face. The Gaian Science in the chapters of this book poses that challenge by asking again and again: Did the biosphere evolve to regulate the Earth? – and if it did, how did it do it? How does the evolution of such a global mechanism relate to Darwinism?

On the surface, natural selection and Darwinian evolution are simple ideas, but a fundamental debate has been percolating for years in biology: what is the unit of selection? A gene?, a chromosome?, an individual?, a group of individuals of the same species? (the survival of whose members are highly correlated), an ecosystem? Do ecosystems compete with each other? If so, when one ecosystem out-competes the others and comes to dominate the biosphere, can we say that the characteristics and the environmental regulation that led to its success are the products of evolution? Maybe ecosystems compete and the most successful characteristics percolate to domination. Maybe regulatory mechanisms which are now global and seem to have no competitors, were once sub-global with competitors.

Dawkins (1982) and Williams (1966) have argued against this group selectionist idea and for the idea that genes or (since genes come in highly correlated packets called individuals) individuals are the units of selection. They argue: How can the behavior of the biosphere be interpreted as the result of Darwinian selection if there were no other biospheres to compete or cooperate with? For them, a large group of competing individuals, differentially reproducing, is a requirement of evolution.

Gaia is a wonderful idea because it does what good scientific ideas are supposed to do. It extends and extrapolates an accepted idea, in this case Darwinism, into challenging unfamiliar territory. It then tests Darwinism to see to what extent it can scale itself up to larger and larger units of selection — to groups, ecosystems, and the entire biosphere.

Tyler Volk's book *Gaia's Body* (Volk 1998) was cited in many chapters (I should read it). Volk's chapter here, "Gaia is Life in a Wasteworld of By-products" proposed that the atmosphere is one giant waste dump. Life produces wastes. These wastes build up and affect the environment. They become intolerable for some forms of life. But then along come new forms of life who take advantage of these waste products. Volk's point is that the effects of waste are certainly "by" but not necessarily "for" the biosphere. Volk got me wondering whether some waste products are fitter than others (Henderson 1913) and whether sewage treatment plants are as important as grocery stores.

Volk's wasteworld idea is an interesting counter to "by and for the biosphere" (and it solves the cheater objection raised by Dawkins(1982) — you can't cheat if no one cares). But the more I think about wasteworld the more unsettling it becomes, because if "for" doesn't make sense for the biosphere, how can it make sense for an ecosystem or a species? Isn't our body's ability to control our body temperature also a "by product" of evolution – the result of a series of random variations that happened to be compatible enough to survive and then the internal metabolism adapted to this new regime, just as aerobes adapted and flourished in the newly oxygenated atmosphere. The combinatorial (i.e. endosymbiosis) and mutational raw material that natural selection acts on are by-products — so every feature of life from thermoregulation in mammals to bat wings could be considered by-products that became beneficial (and costly and "for" something) only in hindsight.

How can we best express our understanding of how our biosphere came to be the way it is? Much of the book grapples with this question. The authors seem to be trying to answer the following multiple choice question:

The composition of the Earth's atmosphere

A) is a by-product of the biosphere produced at no cost to life but has a benefit to life forms that have learned to adapt to and consume these by-products.
B) is a product of the biosphere
C) is remediated by the biosphere
D) is managed by the biosphere
E) is controlled by the biosphere.
F) is set and regulated by and for the biosphere through mutual interactions and feedback between the producers and the consumers of the gases.

The semantic differences between "B", "C", "D" and "E" are too subtle for me. But there may be an important difference between "A" (Volk's wasteworld model) and "F" (Lovelock and Margulis' 1974 model). If "F" is correct we can then ask: Is this regulation an emergent property like the way a convection cell abiotically emerges to"regulate" heat flow, or is this regulation a result of variation and natural selection at the ecosystem level, requiring genetic inheritance? Lenton's Chapter "Clarifying Gaia: Regulation with or without Natural Selection" explores this issue and so does David Wilkinson's chapter "Homeostatic Gaia: An Ecologist's Perspective on the Possibility of Regulation" and so does Föllmi et. al.'s "Phosphorus, a Servant Faithful to Gaia? Biosphere Remediation Rather than Regulation".

How can you measure "by and for the biosphere"? How do you quantify "beneficial for life"? Volk (Chapter 2 and Volk 2002) suggests using cycling ratios. A cycling ratio is the amount of an element cycling through the biosphere and the Earth divided by the amount that would be cycling through the Earth in the absence of life. Volk estimates the cycling ratio of carbon to be about 200 — so 200 times more carbon is flowing through the veins of Gaia than would be cycling through an abiotic Earth due to plate tectonics and volcanism. Lenton (Chap 1) suggests that we measure resistance to change and resilience (or recovery) from change as properties that should be measured to quantify Gaia.

There are practical problems with these proposals, the largest being, in my opinion, unraveling the biotic and abiotic, e.g. differentiating biotic and abiotic chemical disequilibrium. This differentiation is complicated because the boundary between the general set of far-from-equilibrium-dissipative-structures and traditional life forms is blurry (Lineweaver 2006).

Two insightful chapters in the book address thermodynamics and the definitions of life and these got me the most excited. Eric Schneider's "Gaia: Toward a Thermodynamics of Life" (Chapter 4) discussed life as part of the universal set of far-from-equilibrium-dissipative-structures. Dorion Sagan and Jessica Hope Whiteside's "Gradient Reduction Theory: Thermodynamics and the Purpose of Life" (Chapter 15) discussed the second law of thermodynamics as the source of the purpose of life. Agnostics looking for purpose in their lives would do well to digest this chapter along with Lovelock's (2001) suggestion that agnostics consider Gaia worship to fill their religious vacuum. Unfortunately Sagan and Whiteside's profound insights and overviews sometimes revert to continental philosophizing. Oh well. There is still grandeur and universality in this thermodynamic view of life. It has the advantage of being so general that it can obviously be applied to life elsewhere in the universe — and at the same time it tells us what the purpose of life is. Not bad for $50.

In Darwinian evolution, there is a selector and a selectee. Traditionally, the environment is the selector and the individual is the selectee (= the unit of selection). Sexual selection was recognized as an exception to this default. The strutting peacock is the selectee while the peahen is the selector. But reality is more complicated than this selector/selectee dichotomy. Reality has feedbacks such that A controls B and B controls A. The environment controls the organisms which have to adapt to it or die. That these organisms can reach back and control the environment is obvious from the chemical disequilibrium of our atmosphere. The environment the life forms adapt to, is in large part controlled by the life forms. Hence the verb "adapt to" is inappropriately linear and misses the circularity and feedback. The reality of feedback undermines the traditional selector/selectee dichotomy and in included in the Gaian models discussed in this book. This circularity and the accompanying ambiguity about the unit of selection are the Gaian challenge to Darwinism.

I once heard Lynn Margulis give a lecture in Spanish to an enthralled Mexican audience. She said, "¿Cómo pueden los genes ser egoístas? Ellos no son uno mismo!" ("How can genes be selfish? They have no self!"). What in the world is a self I thought? Maybe the central debate of this book can be similarly synopsized: How can Gaia be selfish? How can it do anything "for" itself? It has no self! Margulis seems willing to accept a selfhood for Gaia but not for genes. Dawkins has the opposite view. Maybe both selfhood and purpose just fade away on the largest and smallest scales. Darwinism seems to involve a sharp boundary between life and non-life (Joyce 1994, Woese 2002, Eigen 2002). Yet at the smallest scales (viruses and prions) and at the largest scales (Gaia) the familiar properties of life seem to fade away, losing the discrete boundaries we assume when we use the words abiotic/biotic.

The debate about what life is, and how to recognize it, is at the heart of the question: What is our place in the universe? This is the Holy Grail of astrobiology. To make progress, we need to explore the martian subsurface and analyze the atmospheres of the nearest 100 or 1000 terrestrial planets. Lovelock's Gaian chemical equilibrium test for the presence of life is fundamental to these efforts. NASA is preparing to build the Terrestrial Planet Finder (http://planetquest.jpl.nasa.gov/TPF/tpf_index.cfm) and ESA is preparing Darwin (http://sci.esa.int/science-e/www/area/index.cfm?fareaid=28). Both are putting their money on Gaian tests — using interferometric infrared spectroscopy to look for the traces of chemical disequilibrium as the primary biomarker (Jones 2004, Selsis et. al. 2002).

I'm enthusiastic about the way the holistic Gaian program, presented so well in *Scientists Debate Gaia*, is opening scientific minds. But as an astronomer I'd like to see Gaian scientists recognize that Gaia is part of an even larger whole – that the Earth is not a closed system – that Gaia has a mother. However, when we begin to wonder whether our Galaxy is a life form called Galactea, are we so animistically open-minded that our brains have fallen out? Well, maybe this will be the subject of the next Gaian conference. Let a thousand flowers bloom, right in the middle of a cow paddy.

"Buy" this book "for" yourself. Scribble next to all the frustrating and inspirational ideas. My copy is thoroughly defaced. It is a must read for any life form that is even pretending to look for extraterrestrial life.

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