The extended MS is MIA

Douglas Futuyma from Stony Brook University made the case for the Modern Synthesis in a presentation entitled *Do we really need to extend the MS?* It was a argument largely recycled from Nature (October 2014). The Comment, *Does evolutionary science need a rethink?* that featured a point by Kevin Laland and colleagues and a counterpoint by Gregory Wray, Hopi Hoekstra and colleagues, including Douglas Futuyma.

Lynn Margulis would have celebrated her 79th birthday March 5, 2017

“You think individuals make discoveries? Discoveries are processes, but what individuals can do is promote different ways of seeing and different ways of doing. That’s phenomenal. Once in a while, you get these extraordinary individuals and Lynn was one of those.”—Jan Sapp from the documentary, *Symbiotic Earth*

(Right) Lynn on a late Autumn 2010 hike with her faithful companion, Menina, the Scottish wolfhound.

1984 "Where's the beef?" advertising campaign for the Wendy's fast food restaurant chain.

*environmental evolution*  
effects of the origin and evolution of life on Earth  

March 2017
What was missing in both the counterpoint and Futuyma’s presentation at the Royal Society was any trace of the theory that “accommodates evidence through relentless synthesis.”


Having succumbed to the temptation of certainty, Modern Synthetic scientism fought to keep the Creationists, Intelligent Design, and group selectionists out of all evolutionary classrooms along with any whiff of teleology, autonomy, altruism or interdependence [more on that later]. Ultimately, the problem for the Wray, Hoekstra and Futuyma axis is that gene-determinism is a weak link, a delusion.

One thing we can be certain of is that Wray, Hoekstra and Futuyma are NOT talking about the reductio ad absurdum Modern Synthesis.

Futuyma had said that all the “new trends” [sic] which the old MS knew about, but ignored “will be seen as a kind of gloss on what we already know.” Futuyma is NOT talking bout yo daddy’s or granddaddy’s Modern Synthesis cause “you can’t shine shit.”

But where is the statement of this shiny new theory that has relentlessly synthesised all of these long known or recently discovered evolutionary processes? I don’t know about you but I want to see it. Where’s the beef?

Why did Wray, Hoekstra and colleagues not include a statement of this theory in their counterpoint? When Futuyma had repeated opportunities to unveil the relentless synthesis beef at the Royal Society, why did he chicken out? This dissembling on a definition seems to be little more
than a crafty stratagem. As Wray and Hoekstra themselves pointed out in their counterpoint, “Lack of evidence also makes it difficult to evaluate” and, in this case, the absence of evidence appears to be evidence of absence.

There are three prongs to the argument made by Wray, Hoekstra and Futuyma. The first is to invent an alternate Modern Synthesis, but never state this alternate theory. The second is to claim that being aware of these additional evolutionary processes is the same as serious investigation. It’s a false equivalency. The third is to conflate the Modern Synthesis as a theory with the entire field of evolutionary biology or all evolutionary biologists. A theory is not a field or its scientists.

So it is that Wray and Hoekstra state, “What Laland and colleagues term the standard evolutionary theory is a caricature that views the field as static and monolithic. They see today’s evolutionary biologists as unwilling to consider ideas that challenge convention.”

The caricature is the idea of the MS as relentlessly synthesising. It is instead an admission that the real MS is insufficient. It is the field of biology writ large that has explored these new evolutionary processes. What the exchange between David Skuker and Denis Noble reveals is that if you approach the same experiment from a reductionist MS point of view or a systems point of view, you will end up with very different explanations of the same result. This is largely the difference in seeing static things versus dynamic processes as John Dupré illuminated in his Ontology of the evolutionary process talk at the Royal Society meeting. More on this later.

“This is not the first time that people have proclaimed the need for an extension or revision of the evolutionary synthesis,” Futuyma concedes
that there is a long history of pushback against the limits of the neo-Darwinist explanation, “Back in the 1980s, there was a book by Ho and Saunders [Beyond Neo-Darwinism: An introduction to the new evolutionary paradigm] which was basically a call for this from a great many people who felt as if they were disaffected members of biological disciplines that they thought were unjustly neglected. I think that the ideas in that book are pretty much sunk without...like a stone.”

The witch trial from Monty Python and the Holy Grail. Witches were made of wood, so the knight Bedeveer asks the angry mob, “What also floats in water?”

One of the mob takes a guess, “Very small stones?”

As I pointed out in the January EnvEvo newsletter, it is good to look critically at the Wray, Hoekstra and Futuyma argument. History has repeated calls for a new paradigm from “a great many
people” (presumably biologists) who felt their work was neglected. Futuyma implies that all these calls were based on ideas that sank like stones. Perhaps not all the ideas presented by Ho, Saunders and the other thirteen contributors to Beyond Neo-Darwinism have stood the test of time. However, it is equally arguable that many of the ideas in Richard Dawkins’s bibliography from the same period (and even decades later) have not remained afloat.

Here is one idea from a page chosen at random from Beyond Neo-Darwinism in the chapter by Jeffrey S. Wicken, “On the Increase in Complexity in Evolution.”

“There are indications that thermodynamic influences may operate beyond the random-generator, natural selective level in giving the environment itself a formative role in self-organization (Glansdorff and Prigogine, 1971, Ho and Saunders, 1979)—a notion quite incommensurable with even an expanded neo-Darwinism.” (Wicken, p. 92)

Wicken states an idea that underlies many of the presentations at the Royal Society meeting on “New Trends” and Denis Noble’s biological relativity. Wray, Hoekstra and Futuyma cannot have it both ways: an MS that has incorporated stones (because they were very small?) AND an MS that has sunk all such ideas.

Futuyma’s closed his remarks at the RS with this snarky salvo.

“The conclusions are that some of the emphases by the proponents of this extended synthesis are promising—if they are developed both theoretically and empirically, okay? I think above all we need evidence. I think there have been enough essays and position papers now. We need evidence. I want to finish with a quote from Peter Bowler. His book Evolution: The history of an idea in which he is talking about the popularity of Lamarckism in the early 20th-century and he wrote,

‘The key point seems to be Lamarckism allows life itself to be seen as purposeful and creative, living things are in charge of their own evolution and choose their response to environmental challenge and thus direct evolution by their own efforts. With or without any religious implications, this is certainly a more hopeful vision than life derived from
Darwinism. Life becomes an active force in nature. No longer merely responding in a passive manner to environmental pressures.

“He was, of course, trying to explain why people would have been...have clung to Lamarckism and I’m af [sic]...the tenor of much of ev [sic]...extended synthesis has much this flavor. And possibly this describes human cultural evolution, we might think so, but to think that it describes the evolutionary history of life I think would be to hold hypotheses on the basis of wishful thinking and I think what we may find emotionally or aesthetically more appealing is not the basis for science.”

By describing these extended synthesis processes as “promising” Futuyma implies that they lack evidence. He repeats this assertion two more times, “above all we need evidence. I think there have been enough essays and position papers now. We need evidence.” There is no lack of evidence as the majority of presentations demonstrate even without a literature search. The best defence against having to produce a statement of the relentlessly synthesising MS is a good defence: make an argument from authority.

Then Futuyma aims at what he imagines is the weakest link of the extended synthesis, Lamarckism, an idea rivaled only by astrology to deliver a knee jerk pseudoscience reaction. Lamarckism, the idea that acquired characteristics can be inherited, was named for Lamarck as a put down of French science. It could just as easily have been called Darwinism. Neither Darwin nor Lamarck originated the idea, but both believed in the basic concept. And as it turns out there are forms of Lamarckism that are supported by evidence if you have a systems viewpoint. As the Denis Noble dust-up with David Skuker will demonstrate.

Springtime for Trofim and Soviet Union. Lyseniko measuring the winter wheat.
Futuyma addresses an early 20th-century popularity of Lamarkism. Is his meaning Lysenkoism? If Lamarckism is a 10, then Lysenkoism is 11. Including Bowler’s “With or without any religious implications” is icing on the rhetorical cake, implying the Creationist menace. “…the tenor of much of ev …extended synthesis has much this flavor.” Yes, he’s going to La Ly Land, “to think that it [Lamarck-Lysenko-ism] describes the evolutionary history of life I think would be to hold hypotheses on the basis of wishful thinking and I think what we may find emotionally or aesthetically more appealing is not the basis for science.”

Aren’t parsimony and economy appeals to aesthetics? Isn’t blind chance more emotionally appealing to materialists, and selfish genes more appealing to those who want to feel good about being selfish? But let’s get back to relentlessly synthesising MS which easily qualifies as the poster child for holding hypotheses on the basis of wishful thinking. It should not be the basis for evolutionary biology.

CONVERSATIONS: A RANT

“Very little of life on Earth, perhaps 1%, is animal or plant. Bacteria which make up the vast majority of the biota don’t fit neatly into whatever species means.”—James MacAllister

So there I was, sitting at the corner cafeteria, trying to converse with the local cool bacteria. Their voices all were muzzy, or perhaps they all were cheering, or. . .quite possibly, I just had lost the last of all of my hearing.

I wanted to dispute about the latest Trump delusions or talk about the climate and the possible solutions, or maybe speak of television, movies, or a book I read. Bacteria were silent (or perhaps it was that they were dead?)

It’s really hard to converse with a species so disportionate. Cause they make the rest of us all look poor or more unfortunate. And even if Earth heats up, they’ll still be here re-creating. While the rest of us deplorables will just be carbon dating.

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THE NOBLE-SHUKER EXCHANGE

The Q&A and discussions at the Royal Society meeting, New Trends in Evolution are now part of the audio files posted online. I took the liberty of having Denis Noble’s presentation, Evolution viewed from medicine and physiology, transcribed. Noble’s discussion of Taylor, Mulley and Dills on restoration of flagella in 4 days is at [13:46] of the audio file. Here is the conclusion of Denis’s talk and his exchange with David Shuker of the University of St Andrews concerning that study.

Noble: “So, my final conclusion, I am going to finish on time, is that the approach that I would suggest we should be using in the 21st century is what I would call an integrative, rather than a reductive approach. I don’t apologize for that. I started in research 50 years ago at University College London as a card-carrying reductionist. I know the advantages of reductionism, particularly molecular reductionism. I’ve used it myself in my own work. Nobody needs to convince me of that. But it needs to be complemented by an integrative view if we’re going to work at the level of functionality. [emphasis added] And my main thesis here is that organisms harness stochasticity to generate functionality and therefore, evolution can be directional. And the subtext, it depends on physics as much as it depends on chemistry.”

“And my final slide highlights three articles in which I’ve laid out some of these ideas in more detail. The top one is an analysis of selfish gene theory to show that it has no predictable experimentally testable results to give in physiology. The second is the editorial article, it’s a whole issue of the Journal of Physiology devoted to evolutionary biology and its significance in physiology and medicine. There are about 25 articles in that issue by about 30 or 40 other authors. And finally, the article in which I’ve expressed the integrative view that I have described today in the Journal of Experimental Biology. And to quote from the editorial, nature is even more wondrous than the architects of the modern synthesis thought. I’ve no quarrel with the modern synthesis incidentally. I think it’s been the inspiration for some extremely important work, particularly in population genetics and in many other areas of biology. I simply think that we now know much more. We happen to know that there are processes previously believed impossible. Thank you very much.” [APPLAUSE]
SHUKER: “Hello there. David [Shuker] from the University of St Andrews [28:08]. Could you comment at all on the mechanism underlying that discovery of what you call genomic rewiring with respect to the loss of the machinery for making a flagellum in your bacteria, and then the flagellum coming back?”

Can we observe organisms reorganizing their genomes?

Example 2: Restoration of flagella after DNA deletion

Bacteria that have lost their flagella through deletion of the relevant DNA sequence can evolve the regulatory networks required to restore flagella and so restore motility in response to a stressful environment within just four days.


Noble: “Yes, the mechanism in general terms, I can, yes. The mechanism is that for the production of flagella, the networks at the, what I call the biochemical physiological networks of interactions between all the proteins and metabolites and the membranous systems involved have, in practice, got several processes by which flagella could be made. So, if you analyze the networking detail, which I’ve not done, you’d have to go back to the original paper; it’s Louise Johnson’s work in Reading, you’d be able to find, I think, the more detailed process by which that occurs in this particular case. Why it should take four or five days is very interesting. The answer to that is I don’t know. But it’s interesting, isn’t it, that in the process of responding to a stressful situation, it can sometimes take organisms a long
time to, as it were, find a solution. I think what they’re doing, a little bit like the immune system going through that hypermutation, I think they’re trying things out in all kinds of ways, in a kind of desperate search amongst the huge space involved to see whether a solution can be found. So, again, the harnessing stochasticity, how big can that space be, and why should it take days or even weeks to happen? It’s not too difficult to explain why in a general sense if you have 100 and even more so, if you have 1,000 components interacting in a biochemical network, you’ve got a combinatorial explosion. The number of pathways in a network like that is gigantic and somehow organisms have got to find ways in which they can search the right solution. So, I’ve no difficulty answering you in general, but for the specifics, I strongly recommend going to Louise Johnson’s paper.”

SHUKER: “OK, great, so given we’ve had some quotes. From their abstract, they say, ‘under strong selection for motility, these bacteria consistently regained flagella within 96 hours via a two-step evolutionary pathway,’ which you’ll see is neo-Darwinian. ‘Step one mutations increase intracellular levels of phosphorylated NtrC, a distant homolog of FleQ, which begins to commander control of the FleQ regulon at the cost of disrupting nitrogen uptake and assimilation. Step two is a switch-of-function mutation that redirects NtrC away from nitrogen uptake and toward its novel function as a flagellar regulator. Our results demonstrate that natural selection can rapidly rewire regulatory networks in very few, repeatable mutational steps.' So, it’s a perfect, beautiful example of rapid neo-Darwinian evolution.”

[Here is Carl Zimmer’s description of this exchange from Quanta magazine.]

That didn’t sound right to Shuker, and he was determined to challenge Noble after the applause died down.

“Could you comment at all on the mechanism underlying that discovery?” Shuker asked.

Noble stammered in reply. [Really?] “The mechanism in general terms, I can, yes…” he said, and then started talking about networks and regulation and a desperate search for a solution to a crisis. “You’d have to go back to the original paper,” he then said.
While Noble was struggling to respond, Noble is clicking back through his slides to the one being discussed. Shuker went back to the paper on an iPad. And now he read the abstract in a booming voice.

“‘Our results demonstrate that natural selection can rapidly rewire regulatory networks,’” Shuker said. He put down the iPad. “So it’s a perfect, beautiful example of rapid neo-Darwinian evolution,” he declared.

Shuker distilled the feelings of a lot of skeptics I talked to at the conference. The high-flying rhetoric about a paradigm shift was, for the most part, unwarranted, they said.

That is where Zimmer leaves the story. It is presented as “gotcha”. It’s bad reporting because its not the end of the exchange. Zimmer has missed the crucial lesson of this exchange: that he and the reductionist neo-Darwinists in the audience display a trained incapacity to view phenomena from a systems perspective. Returning to the exchange.

NOBLE: [clicking back through his slides] “Thank you for that. If you read the part of the article that I referred to, which we can easily go back to, sorry, this is taking this bit of time to go. Yes. ‘Restoring motility and response to a stressful environment.’

NOBLE: “The important point is that the response is to an environmental change. It is an acquired characteristic and it is inherited. Now, it’s up to you if you want to call that neo-Darwinian. And we’ve heard, of course --”

SHUKER: [OVERLAPPING VOICES] [32:09] “It is mutation followed by natural selection...”

NOBLE: “No, no, I think you need to listen, if you don’t mind. Because I think this is a central issue to the arguments that have been going on at this meeting. The important point is the feedback. The important point is that it is a response to a challenge from the environment. Of course, there is stochasticity there. I’m going through the various ways in which you can arrive at a solution. I’m not denying that at all. The point I’m making in my paper is that it is by harnessing that kind of process that organisms can find stochasticity. Now, it’s partly a conceptual viewpoint. There is a difference between somebody like you and somebody like me. I choose to regard that as the way in which an organism is choosing to harness those processes to...
its own purposes and in a way that is inherited. And I repeat, it is a response to the environment that produces an acquired characteristic, which is inherited. That’s the original definition of one form of Lamarckism. I think we’re talking here at conceptual cross-purposes.”

Denis Noble ends with the fact that he is talking into an imbalance between skepticism and open-mindedness. Scientists should be capable of looking at a problem from a different vantage point with different rules and assumptions as long as those are supported by uninterpreted evidence. Is it a stretch to think that natural selection occurs within an organism, within the nucleus and ribosomes? There is sensing of the environment to be sure, but no competitive struggle affecting survival, no natural selection.

Evolution is not just about evolutionary biology anymore. Scientists and researchers from the many fields are now contributing to the science of evolution. Old-school biologists need to learn to look at problems from more that one limited vantage point. These multidisciplinary perspectives are complimentary and fruitful. These should be fertile partnerships as well as a necessary check.

HUMMINGBIRD IS PLANNING PREVIEWS OF SYMBIOTIC EARTH
John Feldman of Hummingbird Films is just putting the final touches on his film Symbiotic Earth: How Lynn Margulis rocked the boat and started a scientific revolution. I had the opportunity to look at the film in perhaps its penultimate cut. John did a splendid job of telling the story and including everything that is really meaningful about Lynn both scientifically and philosophically. He is planning preview screenings in the next several months and will be reaching out to Lynn’s colleagues around the world to host more preview screenings.
GAIA THEORY IS FIFTY

Gaia theory states: Over a trillion types of extant organisms, descendant from common ancestors and embedded in the biosphere, that directly and indirectly interact with one another and with the environment’s chemical constituents, form a biotic-planetary regulatory system within physical limits. They produce and remove gases, ions, metals, and organic compounds through their metabolism, growth and reproduction. These interactions in aqueous solution led to modulation of the Earth’s surface temperature, acidity-alkalinity, and the chemically reactive gases of the atmosphere and hydrosphere.

**Gaia and her microbiome** by John F. Stolz of Duquesne University celebrates the theory’s first 50 years. In the paper “Gaia theory is reexamined in light of recent discoveries about the extent and diversity of the global microbiome, extracellular electron transfer, microbial communication, biogeochemical cycling and climate change.” This paper is a splendid status report on Gaia studies and the increasing realization that we live on a bacterial world. Here is one excerpt from the abstract to whet you curiosity:

“Over a half of the elements in the periodic table are now known to have some biological role with many having complex biogeochemical cycles. The global microbiome inhabits a wide range of environments including deep into the Earth’s crust, with a population of ~10^{30} cells and more than a trillion species. Deep sequencing projects have revealed hitherto unknown phyla and ‘microbial dark matter’.”

1980 Baja field trip to examine the bacterial mats. Heinz Lowanstam (left), Lynn Margulis in red bandana and yellow shorts.

Lynn Margulis (lower right) and Bruce Scofield (top right) teaching Gaia theory in her Symbiosis and Earth History graduate seminar.
The paper is a engaging read. I won’t spoil anymore of the surprises, but here is a list of the headings: Gaia Theory, The Expanding View of the Biosphere, New Twists on Energy Production and Electron Transfer, [Microbial] Communication, Biogeochemical Cycles and ‘Odd Couples’, Climate Change and Outlook. Here is just one teaser for geoscientists. “The biota have dramatically altered the composition of the atmosphere, oceans and sediments over the millennia (Margulis and Stolz 1983). This is reflected in the number of minerals that can be identified. The mineral content of the early Earth’s crust, which was estimated to have been composed of about 1500 different types ... Today, the coexistence of a wide range of sedimentary environments with different redox chemistry due in large part to biological activity has
resulted in a planetary crust with more than 4300 minerals (Hazen et al. 2008)."

About the 1980 Baja California trip pictured above, John wrote, “I was on the 1980 trip that preceded the NASA PBME [Planetary Biology and Microbial Ecology] course. It was crazy as I was helping Lynn with the organization of the class as well as being a student. I remember very little about the trip other than carting gas tanks for a portable GC [gas chromatograph]. Jim Lovelock and Andy Watson were also there. I should also mention that Lynn was there in early spring of 1980 (neither Betsey [Dyer] or I were on that trip). They had to build a raft to get to the site because there was 3 meters of fresh water in the Lagoon. That’s when we knew something very different was going on with the mats (due to El Nino).”

DEEP TIME WALK FOR SMART PHONES

"Feeling the miracle of life evolve with each step"

"Everyone needs to do this walk, a trip through deep time exploring the history of the earth"

"A must experience for every human being"

"I've been amazed by it, and it's incredible pedagogical potentials"

"A perfect experiential journey into the mind-expanding story of our one, beautiful home - and ourselves. Awestruck."

REVIEWS FROM THE APPLE STORE

ASGARD ARCHAEA NEWEST “MISSING LINK” TO EUKARYOTES
John Stolz also sent along an article from Nature, Asgard archaea illuminate the origin of eukaryotic cellular complexity, by Zaremba-
Stolz’s email said, “I’ve attached the new publication in Nature on the eukaryote ancestor. It irks me no end to find that Lynn is not cited or even mentioned. Thankfully there will be a special issue of Theoretical Biology to commemorate the 50th anniversary of her landmark publication on the origin of the eukaryotic cell.”

At least the article didn’t credit Thomas Cavalier-Smith with the discovery of endosymbiosis or adopt his static thing definition of symbiogenesis, a dynamic process named 100 years ago by Mereschkovsky (see June 2016 EnvEvo newsletter).

Zaremba-Niedzwiedzka took samples of aquatic sediments from eight geographically separate sites. “Here we describe the metagenomic discovery of the Asgard superphylum...We show that these lineages comprise novel phylum-level groups that represent the closest archaeal relatives of eukaryotes. Detailed analyses of their reconstructed genomes provide new insights into the identity and genetic nature of the archaeal ancestor of eukaryotes and the primal stages of eukaryogenesis.”

Zaremba-Niedzwiedzka’s paper concludes, “Future exploration of novel branches in the tree of life, including novel members of the Asgard, as well as deep-branching eukaryotes, and the detailed characterization of their metabolic repertoires and cell-biological features, will undoubtedly provide new fundamental insights into the process of eukaryogenesis, and ultimately reveal how eukaryotic cells evolved their complex and compartmentalized nature.”

I was reminded of the Homage to Darwin debate when Stephen Bell, then an Oxford Professor of biochemistry whose lab had discovered ESCORT (endosomal sorting complex required for transport) in Archaeabacterial cell division. Bell advised Lynn Margulis that a Crenarchaeae Thermoacidophils would be a better archaeabacterial partner than Thermoplasma for the first merger of her serial endosym-
biosis theory (SET). You can see Margulis’s closed body language change as Bell describes that ESCRT used for DNA replication in Crenarchaea is more closely related to eukaryotes than *Thermoplasma*, a Euryarchaeaean. In the middle of the debate, Bell and Lynn become totally wrapped up in this reverie and must be called back by the moderator, Denis Noble.

Following the debate, Lynn Margulis repeatedly listened to Bell’s presentation on tape, learning all she could about each detail of the information he provided.

**ENVIRONMENTAL EVOLUTION COURSE IS LOOKING FOR ACADEMIC PARTNER**

Bruce Scofield (right) has designed online versions of the Lynn Margulis course, *Environmental Evolution: the effect of the origin and evolution of life on Earth*. Scofield taught the course with Margulis for a decade.

The undergraduate version of the course is being offered through Professional and Continuing Education at the University of Massachusetts Amherst. Sadly, this was the only option offered to us by the University and the Department of Biology, which will not accept the course credits toward an undergraduate biology degree. Originally, the course was presented only to undergraduate seniors and graduate
students. Bruce and I have been working on the online version of a 300-400 level course, which is the appropriate level given the sophistication of the materials presented and the student research required.

Bruce and I will be working on a demonstration video of the first class. This and the course syllabus should be available soon. We are hoping to interest colleges and universities who would be interested in offering the course for undergraduate senior or graduate credit toward degrees.

The course is multidisciplinary, including a comprehensive exploration of Gaia theory. Lynn Margulis’s course was groundbreaking in Earth systems science. It was also the first scientific Big Earth history course. It can be integrated easily into biology, geoscience, astrobiology, or history and philosophy of science curricula. If you are interested or have suggestions, please contact Bruce Scofield bcscofield at juno.com.

WOULD OXFORD FORGET DARWIN?
The University of Massachusetts system and the Commonwealth of Massachusetts seem unaware of the public relations potential that Lynn Margulis’s tenure as Distinguished University Professor of Geosciences represents. She was not mentioned in 2012 during the 150th anniversary celebration of the founding of the flagship campus in Amherst where she taught from 1983 to 2011. When Scott Gilbert, Professor of Biology at Swarthmore College and the University of Helsinki, delivered the Ninth Annual Sinauer Associates Distinguished Scientist Lecture, Expanding Lynn’s view: a new symbiotic biology, the University’s public relations people seemed to have no clue that the Lynn in the title was their own Distinguished University Professor! To quote Gilbert from that lecture, “I view her work like Einstein’s special relativity and general relativity. Special relativity is the endosymbiosis story, which has been one of the new pillars of modern biology. And then the general relativity, the general symbioses, the universal symbioses [Gaia].”

This year marks the 50th anniversary of Lynn Sagan’s publication of On the origin of mitosing cells. Next year, Lynn would have been 80-yrs old.
environmental evolution
effects of the origin and evolution of life on Earth

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