The Gaia narrative and its link with symbiosis and symbiogenesis

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1 Introduction

As a matter of historical fact, since the mid-1970s some scientists – Lynn Margulis in particular – have jointly advocated the pre-eminence of symbiosis as an explanatory mechanism in biology and the Gaia view of Earth as a living planet (Lovelock & Margulis 1974, Margulis & Hinkle 1992, Margulis 1995, 1998). Margulis's affiliation with Gaia was highlighted in biographies and, after November 2011, obituaries (Mann 1991, Lake 2012, Schaechter 2012). No earlier than two years ago, Gaia appeared extensively as shared background knowledge in a many-authored collection of essays edited by Margulis et al. (2011), evidence of the continued association between symbiogenesis and Gaia (Debernardi & Serrelli 2013). At the same time, many students of symbiosis and symbiogenesis – henceforth, 'symbio-studies'[1] – seem able to work without any reference to Gaia, and most importantly they do not seem to believe that their work has any implication towards a Gaia view (Sapp 1994, Surindar & Vernon 2000). Despite the historical factual association, Gaia and symbio-studies are thus distinct, and there seems to be no logically necessary link between them. Their association was (and still is) a choice, and indeed criticized by or actively contrasted by many symbio-students (Doolittle 1981, Martin pers. comm., Carrapiço pers. comm.). These researchers share the attitudes which are common among scientists in general, dominated by the conviction that Gaia has been simply demonstrated

[1] By symbio-studies we mean an interdisciplinary field dealing with symbiosis and symbiogenesis. Symbiosis is studied from different points of view, e.g. molecular, ecological, biological. Symbiogenesis is the field of symbioses that have been evolutionarily important, and researches on it try to assess or demonstrate the relative importance of symbiosis in evolution (Gontier 2007). Other phenomena of "horizontal evolution" can be associated with symbio-studies.

false (Müller 1993). There are some sympathetic critical supporters (Volk, Kirchner) and a few pugnacious advocates (Lovelock, Lenton) we shall encounter in this paper. Gaia is variably referred to as a theory or a hypothesis (late Lovelock, Ogle 2006, see Enting 2012), a metaphor (Müller 1993), or a worldview (Kineman 1992) [cf. metatheoretical terms]. However, the landscape of attitudes in the scientific community at large goes from indifference to ridiculization, to the idea that Gaia was a-scientific from the beginning, to the consideration of Gaia as a harm and an obstacle to serious scientific research and effective communication (but see Moody 2010).

In the meantime, Gaia remains very popular among the general public, and in the interaction between science and society. One recent telling example involves a press release by the University of Maryland (May 15, 2013) entitled "UMD finding may hold key to Gaia Theory of Earth as living organism".[2] The press release referred to a PNAS paper (Oduro et al. 2012) arguing that the latter would provide "a tool for tracing and measuring the movement of sulfur through ocean organisms, the atmosphere and the land in ways that may help prove or disprove the controversial Gaia theory". Interestingly, however, we find no mention of Gaia in the PNAS published paper. As Michael Ruse recently summarized: "Gaia theory: hated by the scientists, loved by the public" (Ruse 2013).

Under these premises, we are going to make two conceptual points.

First, we will address the unnecessary link between symbio-studies and Gaia, asking for the historical and epistemological reasons why they become associated. In particular, we contend that the association is mediated by the common interest in large-scale physico-chemical and biochemical patterns, rather than by an emphasis on harmony, equilibrium, and cooperation (Visvader 1992).

Second, we will ask what Gaia is in a metatheoretical sense: is it a scientific hypothesis, a theory, a metaphor, an inspired invention, or a resurgence of antiscientific attitude? After examining some alternatives that show the importance of metatheorizing, we will define Gaia a 'scientific narrative', this

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[2] http://newsdesk.umd.edu/uniini/release.cfm?ArticleID=2698, accessed on February 22nd, 2012, repeated on ScienceDaily with the title "Sulfur finding may hold key to Gaia Theory of Earth as living organism", http://www.sciencedaily.com/releases/2012/05/120515203100.htm, accessed on February 22nd, 2013. ScienceDaily is one of the most popular science news web sites. News are often taken up directly from press releases of research institutions, and are in turn used as a source for many other science information media.

being a technical term in a sketchy metatheory. Let us just say, for now, that by narrative we don't mean fairytale or artistic fiction, but rather a way of telling the history of our planet.

We are not going to answer the question whether or not we should ban Gaia from any scientific discourse, nor the question how symbio-students should deal with the traditional association of their field with Gaia. But we hope to frame the dilemma in which symbio-students and the scientific community at large are held in a better way than simply insisting on classic demarcations between science and non-science.

2 Gaia claims

We mentioned above that Gaia's metatheoretical qualification is unstable - a theory, a hypothesis, a metaphor? The list of Gaia claims is also very changeable. James Lovelock himself, who conceived and popularized Gaia (1972), phrased it differently through the years (e.g., 1979). We shall not try here to sort out the different versions of Gaia, although a sorting is embedded in Kirchner's (1989, 2003) metatheoretical analyses we shall address below (Tables 1-2).[3] A good, concise start is Schneider's definition (2002): "The Gaia hypothesis [is] a controversial theory about the degree to which life on Earth controls the planetary environment". Ogle (2006) gives more of a spectrum of Gaia as a "compelling new way of understanding life on our planet": Gaia "asserts that living organisms and their inorganic surroundings have evolved together as a single living system that greatly affects the chemistry and conditions of Earth's surface". To some Gaia advocates, then, "Earth's living system appears to keep conditions on our planet just right for life to persist!". An oscillation between less and more demanding Gaia claims is found also in symbio-studies literature, e.g. in the book *Chimeras and Consciousness* (Margulis et al., cit.). Gaia is described as "an enormous set of nested communities" (p. 6) and "an interrelated dynamic life process" (p. 99) comprehending more than the biosphere; also, it "is a self-starting system with cybernetic tendencies" (p. 93), and "an open thermodynamic system" generating "organization and order" (p. 93); "reciprocity" would be "an emergent property of Gaia" (p. 100); furthermore, Gaia "produces and removes gases, ions,

[3] We don't address here other sortings that have been proposed, such as the distinction between "weak" and "strong" Gaia.

metals, and organic compounds" and in this way it modulates surface temperature, acidity and alkalinity, and "the chemically reactive gases of the atmosphere and the hydrosphere" (p. 124) as well as the persistence and quantity of liquid-state water (p. 11). The authors of *Chimeras and Consciousness* take upon themselves to specify that Gaia is "more an enormous set of nested communities that together form a single ecosystem than she is any single organism" (p. 6). In this way they evoke one of the most controversial and demanding Gaia claims, i.e. that Gaia is a single, giant organism, even deserving the personal pronoun "she". The organismal Gaia claim is, of course, also the most famous and catchy, as we see from the University of Maryland's press release about "Gaia Theory of Earth as a living organism" referred to above.

Some Gaia claims and counter-claims concern natural selection. The issue here can be split into two. One is the issue about the origin of Gaia: could Gaia be a product of natural selection, and even a necessary one? In early writings, Lovelock made this claim, and that was the main target of criticisms by evolutionary teorists (Dawkins 1982, Williams 1992, Wilson 2000). The other issue is about what would Gaia imply for the working and importance of natural selection within 'her'.

Ethical claims are also associated with Gaia, sometimes raised as a better worldview than neo-Darwinism, based on competition and exploitation of resources.[4] Discourses of such tone are sustained up to *Chimeras and Consciousness* (Margulis et al., cit.), where one essay (n. 7) matches Lovelock with Saint Francis of Assisi by virtue of their shared love for our planet considered as a living being, and another one denounces the fragmentation of knowledge, praising Gaia theorists together with Dadaists and Futurists (p. 263) as "holistic thinkers" (p. 261) in that they seek a message of hope for our future.

[4] Classic quotes by Lovelock sound like this: "The Gaia hypothesis is for those who like to walk or simply stand and stare, to wonder about the Earth and the life it bears, and to speculate about the consequences of our own presence here. It is an alternative to that pessimistic view which sees nature as a primitive force to be subdued and conquered. It is also an alternative to that equally depressing picture of our planet as a demented spaceship, forever travelling, driverless and purposeless, around an inner circle of the sun" (Lovelock 1979, chp. 1).

3 The unspecific affinity between symbio-studies and Gaia

"Gaia is a tough bitch" is a famous paper by Lynn Margulis, appeared in *The Third Culture*, collection edited by John Brockman (1995). Notwithstanding the title, the first 80% of the chapter is a story of Margulis's work in symbiogenesis: it tells the ideas she had, the stubborn rebuttal by the scientific establishment, the final acceptance, the ongoing work by other researchers, and her enthusiasm about symbiogenesis as a powerful explanation:

> I claim – she writes – that the most significant inherited variation comes from mergers […]. I contend that symbiogenesis is the result of long-term living together – staying together, especially involving microbes – and that it's the major evolutionary innovator in all lineages of larger nonbacterial organisms (pp. 134-135).

Gaia is eventually introduced in the very last part of the essay: "My primary work – Margulis writes – has always been in cell evolution, yet for a long time I've been associated with James Lovelock and his Gaia hypothesis" (p. 139).

Since "Gaia is a tough bitch" is a shouting piece against neo-Darwinism,[5] many of Margulis's colleagues[6] reacted partly by contesting Margulis's description of neo-Darwinism as caricatural. More than such defense of neo-Darwinism, however, another accent is interesting here: the great majority of commentators explain Margulis's interest in Gaia as an extension of her preference for cooperation over competition, of harmony and unity over neo-Darwinian "nature red in tooth and claw", of altruism against selfishness, or even of "balance" and "homeostasis" vs. evolutionary change (Ruse 2013). So Daniel Dennett, Niles Eldredge, Richard Dawkins. For Dennett (in Brockman 1995, p. 141), Margulis tried to stress cooperation over competition also for political reasons: the "cooperative arrangement" of symbiogenesis, however "doesn't show that cooperation is the norm or that cooperation is always good or that it's always possible […] you can't read into it any message such as that nature is fundamentally cooperation; it isn't". According to Eldredge (Ivi, p. 143), Margulis's involvement with Gaia was

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[5] One of the most dramatic passages claims: "The neo-Darwinist population-genetics tradition is reminiscent of phrenology, I think, and is a kind of science that can expect exactly the same fate. It will look ridiculous in retrospect, because it is ridiculous" (pp. 132-133).

[6] An interesting aspect of *The Third Culture* was the possibility for authors to comment on each other's contributions.

"messy […]. Her comments on evolutionary biology sometimes miss the mark. She, like me and a lot of other people, thinks that the metaphor of competition for reproductive success is overdone in the ultra-Darwinian paradigm; but, on the other hand, there's no question that there's competition in nature, and *she's trying to stress cooperation*" (p. 144, our emph.).[7] And Dawkins claims: "I'm skeptical of the rhetoric of the Gaia hypothesis, when it comes down to particular applications of it, like explaining the amount of methane there is in the atmosphere, or saying there will be some gas produced by bacteria which is good for the world at large and so *the bacteria go to the trouble of producing it, for the good of the world*" (our emph.).

George C. Williams (Ivi, p. 141) establishes the most explicit link between Margulis's preference for cooperation and Gaia:

> Lynn Margulis is very much afflicted with a kind of 'God-is-good' syndrome […]. She likes to look there and see cooperation and things being nice to each other. This culminates in this Gaia idea.

Recently, Michael Ruse (2013) exposed a similar idea when he described Lynn Margulis as a "fervent believer in symbiosis, the idea of organisms coming together for mutual benefit", and he added that "For someone thinking this way, the idea of Earth as an integrated functioning entity was virtually a premise not a deduction", thus explaining Margulis's collaboration with Lovelock.

One of our premises exposed above in the introduction is that there is no logical necessity linking symbio-studies to Gaia. *Something* in Margulis's thought and work did establish that association. For the authors above, this "something" was Margulis her particular focus on cooperation boosted with explanatory over-enthusiasm.[8] Here we ague that the pathway could be a different one, as showed in an overlooked memory deposited in "Gaia is a tough bitch":

> In the early seventies, I was trying to align bacteria by their metabolic pathways. I noticed that all kinds of bacteria produced gases. Oxygen, hydrogen sulfide, carbon dioxide, nitrogen, ammonia – more than thirty different gases are given off by the bacteria whose evolutionary history I was keen to reconstruct […]. "Go talk to Lovelock", at least four scientists

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[7] Notice that Dawkins's target is the version of Gaia called 'optimizing Gaia' (Kirchner 1989, see below). Tyler Volk's view of Gaia as "built from byproducts" (2002, 2003) does not require any organism evolving "for the good of the world".

[8] [cf. Margulis's explanatory exuberance]

> suggested. Lovelock believed that the gases in the atmosphere were biological. He had, by this time, a very good idea of which live organisms were probably "breathing out" the gases in question. These gases were far too abundant in the atmosphere to be formed by chemical and physical processes alone. He argued that the atmosphere was a physiological and not just a chemical system (Margulis 1995, p. 139).

In accordance with this account, the interest in Gaia comes not much from the emphasis on cooperation, but rather from a large-scale chemical stance. The chemical path to Gaia is confirmed by Tyler Volk, one of the scientists who most embraced Gaia:[9]

> If anything, Gaia theory is going to be a theory about Earth's chemistry, because the chemical constituents of the air, water, and soil are what the organisms primarily affect […]. What we need are models that look at chemical flows with and without life in a generalized manner and that examine the consequences of life on the resistance and resilience of their environments (Volk 2002, pp. 425-426).

Margulis blames neo-Darwinism with ignorance of chemistry.[10] Such attitude is not typical of symbio-students as such. If it is typical at all, it is more of microbiologists: students of the micro-world have often been protagonists of this kind of zoom-in-zoom-out effect, with a wide opening to ecology, global ethical issues, and criticisms of the dangers of reductionism.[11]

The best essays in *Chimera and Consciousness* (Margulis et al. 2011) are those about the global biophysical and biochemical processes concerning light, time, water etc. (Debernardi & Serrelli 2013). If, as we argue, the affinity with Gaia doesn't derive from an exasperated attention to cooperation, but rather from a

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[9] Volk repeatedly pointed out (e.g., 1998, p. 3; 2002) the connection of Gaia with his technical papers (Volk 1987, 1989, 1996, Volk & Rummel 1989, Volk et al. 1995), and his enthusiastic participation in the major scientific Gaia conferences [cf. Gaia conferences].

[10] "The language of life is not ordinary arithmetic and algebra; the language of life is chemistry. The practicing neo-Darwinists lack relevant knowledge in, for example, microbiology, cell biology, biochemistry, molecular biology, and cytoplasmic genetics. They avoid biochemical cytology and microbial ecology. This is comparable to attempting a critical analysis of Shakespeare's Elizabethan phraseology and idiomatic expression in Chinese, while ignoring the relevance of the English language" (Margulis 1995, pp. 133-134).

[11] Cf. Anderson 2004.

sensitivity to global-scale chemistry, then this affinity is not specific to symbio-studies, nor of microbiology.[12] Many different fields can come to get it. And if this is a problem, it will not be specific either, but shared.

4 Gaia is not a hypothesis: on the importance of metatheory

Associations with and dissociations from Gaia are always accompanied by statements about whether and how much scientific Gaia is (Mann 1991).[13] The inclusion of Gaia in the 'corral' of science depends on a decision about whether Gaia is a theory, or many theories, or a hypothesis, or a model, or something else. Such attribution, in turn, requires definitions of a what theories, hypotheses, models are in science, to see whether Gaia matches any of these categories. Often, reflections of these kinds remain implicit. We want to name *metatheory* the field that deals with all these issues conceptually and explicitly, and *metatheorizing* the conscious and explicit effort of working out and enriching the field of metatheory. Metatheory can also be the name for *one* theory of what scientific theories are. Generally, a metatheory specifies the relationships between theories and other forms of knowledge, such as models, metaphors or narratives, as we are going to see below. Metatheory also embeds definitions of science that become demarcation principles, and this is particularly relevant in the story of Gaia, where metatheoretical statements are often functional to science "boundary work" (Gieryn 1983).

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[12] Palaeontologist Niles Eldredge, for example, repeatedly criticized the Modern Synthesis for its representation of evolution as a flow of inherited genetic information happening "in a vacuum". Eldredge and colleagues proposed the dual hierarchy view (the ecological and the genealogical hierarchy) and the sloshing bucket model as a way of integrating ecology with evolution, "flows of matter and energy" with lineage-forming entities (see Pievani & Serrelli 2013). The interest in "flows of matter and energy" as a missing domain in evolutionary biology is, however, not quite the same as an interest in global biochemistry, as Tyler Volk (2002) notices in a critical analysis on recent Daisyworld simulations (Lenton 2002).

[13] Reporting the opinion of several prominent scientists he had interviewed, Charles Mann wrote on *Science* that "many regard Gaia as an *unscientific* attempt to deify the biosphere" (Mann 1991, p. 380, our emph.). Gaia opponents are compared to "nonbelievers" (Ivi, p. 380).

James W. Kirchner, now emeritus professor of Earth and Planetary Science and Physical Sciences at the University of California, Berkeley, has been an interesting voice in the Gaia debate. More than the details of Gaia's predictions and refutations examined by Kirchner (Tables 1-2), we will be interested here in his explicit metatheorizing. Kirchner was present at the 1988 Gaia conference in San Diego, organized by the American Geophysical Union, where he first expressed what could be defined a Popperian evaluation of Gaia: "the first question to ask of a theory is not whether it is true or false, but what it means and whether it can be tested" (Kirchner 1989, p. 224). In Kirchner's view, a scientific theory is a hypothesis from which empirical predictions can be derived ("what it means") and tested, for the hypothesis to be refuted or corroborated. The idea of *prediction* is thus central here:

> In order to be testable, a hypothesis must be clear, and its terms must be unambiguous. It must be intelligible in terms of observable phenomena. And most importantly, it must generate predictions (phenomena that should be observed if the hypothesis is true and that would not be predicted by the existing body of accepted theory) and falsifying predictions (phenomena that should be observed if the hypothesis is false) (Ivi, p. 226).

Hypotheses can be either testable, untestable in practice, or untestable in principle. In the second case, the practical impossibility for testing a hypothesis can be overcome by surrogate tests. Instead, hypotheses that are untestable in principle (ill-defined, tautological, or void of empirical content) "can obstruct the progress of science", all the most because they usually show good agreement with experimental data, but "they fit because they are independent of the empirical facts". Kirchner also talked about the *usefulness* of a hypothesis, proportional to its distinction from other theories, to the amount of phenomena it predicts or explains, and to the reciprocal of the number of assumptions it needs. By these criteria, Kirchner split up Gaia in four different hypotheses that, for him, had been conflated by Lovelock and Margulis (see Table 1):

- *Coevolutionary* Gaia claims for the existence of reciprocal, processual influences between biota and abiotic environment; although the hypothesis is easily testable, for Kirchner it is unuseful for it restates a well-known and accepted observation;

- *Homeostatic* Gaia affirms that the biota's influence is stabilizing, by means of a dominance of negative feedback loops over positive ones in the interaction between biotic and abiotic components on out planet; although difficult to test, homeostatic Gaia might be testable fo Kirchner, but the scant available data tend to disprove it;
- *Geophysiological* Gaia compares the biosphere to an immense organism with both homeostatic and unstable behavior; for Kirchner, this hypothesis cannot be refuted by data, because what is to be intended as an organism is ill-defined and no predictions can be derived for testing;
- *Optimizing* Gaia states that the biota manipulates the physical environment in the direction of biologically favorable conditions. Like geophysiological Gaia, this hypothesis is ill-defined and, for Kirchner "given simple Darwinian elimination of the unfit, it is both unparsimonious and unfalsifiable" (Kirchner 1989, p. 233).

Table 1. The four hypotheses that, for Kirchner (1989), had been conflated in the idea of a single "Gaia hypothesis", classified by testability and usefulness.

	Testable	**Untestable in practice**	**Untestable in principle**
Useful		Homeostatic Gaia	
Unuseful	Coevolutionary Gaia		Geophysiological Gaia Optimizing Gaia

In Kirchner's view there isn't a Gaia hypothesis. There are four. Homeostatic Gaia is testable in principle, but not supported; coevolutionary Gaia restates the obvious, so it is not a useful hypothesis, although it can easily be tested and confirmed; the other two (geophysiological and optimizing Gaia) are untestable because ill-defined, and this makes them useless as scientific hypotheses.[14] Kirchner's consequent advice in 1989 was to stop doing empirical research under the label of a Gaia hypothesis: in the situation he describes, with the conflation of different hypotheses and the scarce value of many of them, any empirical support

[14] Kirchner's classification enjoyed a certain success (Kirchner 1990, 1992, 2002), and was assumed by several subsequent discussions of Gaia (e.g., Free & Barton 2007).

cannot but confuse and create unnecessary and misleaded arguments. 15 years later (2003), Kirchner spells out particular *conjectures* about specific domains of data that can be collected. The conjectures and the datasets that should exhibit their predictions are shown in Table 2. The conjectures are seemingly sub-specifications of homeostatic Gaia and, partly, of optimizing Gaia. Kirchner anyway argues that all these predictions have been refuted by available data, and blames "Gaia theorists" of neglecting the evidence we already have. He attacks in particular the insistence by Gaia theorists like Tim Lenton (2002, see also Lenton & Wilkinson 2003) on the prevalence of negative biological feedbacks (Table 2, row 3) pointing out the evidence for plenty of positive feedbacks both in present and past Earth.

Table 2. Six conjectures (left column) that, for Kirchner (2003), derive from Gaia hypotheses and have been refuted by the available evidence in relevant datasets (right column).

	Statements of the Gaia hypothesis	**Data domains for testing predictions**
1.	The composition of the atmosphere is tightly regulated by biological processes	The modulation of the rates of carbon uptake
2.	The regulation of atmospheric CO_2 by CO_2 uptake is more terrestrial than oceanic	The sensitivity of biological CO_2 uptake to CO_2 levels
3.	Feedbacks lower Earth's sensitivity to perturbation	The relative proportions of negative and positive biological feedbacks
4.	Biological by-products act as planetary climate regulators	The physico-chemical properties and effects of known biochemical compounds
5.	Biological feedback performs long-term regulation of Earth's climate	Paleo-CO_2 records
6.	Organisms alter their environment to their own benefit	Case studies in ecology and natural history

5 Gaia as a hypotheses-generator. And a metaphor?

If Kirchner dismisses Gaia as a scientific hypothesis, at the same time he finds another role for it as a *hypotheses-generating metaphor* in scientific research (Kirchner 1989). Again in 2003 Kirchner will write: "I believe that Gaia has been fruitful as a metaphor and a hypothesis generator, and I have consistently said so in print" (2003, p. 22). In Kirchner's metatheory, "metaphors and hypotheses are two different things, and it is important not to confuse them" (1989, p. 226). Metaphors are not scientific propositions (Ivi, p. 227), and they are untestable, but they can stimulate scientific hypotheses that consist in stipulations of how they do or do not apply (Tables 1-2).

Gaia's hypothesis-generating role is found in other accounts of scientific research. A very effective one is Tyler Volk's (2002):

> What initially made Lovelock's ideas so exciting, in the early books, was the potential of a common explanatory principle behind many aspects of biosphere chemistry. [His] initial conclusions, in my judgement, did not pan out. But many of us continued forth, at least inspired by Lovelock's emphasis on feedback loops and his knack for asking big questions. I was inspired […] to move into issues about the effects of life on a global scale that led to technical work I would not otherwise have accomplished. But for me at that point Gaia became more of a name for a scientific program. Gaia became a way of thinking, a mantra to be mindful of the biggest scale. But then what do we have if Gaia theory is a way of generating hypotheses and not a specific hypothesis about the way the biosphere works? (p. 428).[15]

For Volk and for Kirchner, Gaia is a way of generating hypotheses. But what kind of thing is it? We might be content of calling Gaia 'a hypothesis-generator'. After all, many things are called by their functional role – like 'washing machines'. However, a generic name does not help in recognizing that different devices can perform the same function: there are arguably very different tools for generating hypotheses in science. As for the terms used by Volk, "scientific program" is too a strong and specific technical name for philosophy of science, trademark of

[15] See also Volk (1998, pp. 22-29), where he conceptualizes "gaian inquiry" as a set of directives for thinking about the whole Earth. On p. 27 he expresses a specific preference of "hypothesis generation" over

Lakatosian philosophy (Lakatos 1978, Lakatos & Musgrave 1974). "Way of thinking" is perhaps too little specific, encompassing things with such different scope as 'scientific thinking', 'Darwinian thinking', 'population thinking' (Chung 2003), 'tree thinking' (Baum et al. 2005), 'homology thinking' (Ereshefsky 2012). Would "metaphor", proposed by Kirchner,[16] be a good term? Some metatheoretical work has been done on metaphors in biology (Paton 1992, Bradie 1999, Bailer-Jones 2000, 2008, Brown 2003, Ruse 2005). Kirchner (1989) uses the Shakespearean example "the world is a stage" to characterize a metaphor as opposed to a scientific hypothesis:

> One can agree with Shakespeare that all the world is a stage, in some sense (e.g., its inhabitants can be viewed as playing out their roles), but it is not a stage in all senses (e.g., it is not made of flooring and does not have a row of footlights at its edge) (p. 226).

Likewise, for Kirchner consideration of the biosphere as an organism would not be a scientific analogy: it would be a metaphor, costitutively ill-defined; then, scientific hypotheses would be proposals of *specific ways in which* the biosphere might *act like* a global organism, e.g., by being homeostatic. Kirchner's proposal of sending out Gaia as an extra-scientific metaphor, however, is not a safe pedestal in light of work in philosophy and cognitive science about modeling and metaphor. Philosophical arguments, for example, go by showing that *all* language is metaphorical (e.g., Mary Hesse 1988), therefore no model nor theory is an empirical claim by itself. Any model is fiction, and its application is an instance of metaphorical thought. It is our reasoning that relates the model to the world by epistemological assumptions and empirical claims, and there is no fixed relation between a model and any particular part of the world. A major case in point are the models of population genetics, a field we would certainly consider scientific given its mathematization and possibility of making predictions about the dynamics of alleles in populations. Too bad that Mendelian population is a *purely formal* construction (Lewontin 1963). No such object exists in nature, that is why the predictions of population genetics are routinely wrong: they have to be adapted and corrected every time in many ways. Why – the argument goes – should Gaia be regarded as a metaphor, while Mendelian models not? The tree of life could be another example of a scientific model-metaphor that have worked for

[16] See also Abram (1992), Müller (2003).

a long time and is still a reference picture without being an as-is empirical claim. Tree-like phylogenies are always around, although they stand to "real" natural history as Shakespeare's stage to the world (Doolittle 2010).

According to Fusco et al. (2013) a better criterion characterizing metaphors is lack of autonomy. Contrasting metaphors with models, they point out that a fortunate account of modeling called 'models as mediators' (Morgan and Morrison 1999) emphasized the autonomy of models with respect to, on the one hand, theory, and, on the other hand, observations and data. Autonomy consists in the possibility of performing intensive research on the model, itself a "stable target of explanation" (Keller 2002, p. 115). For Fusco et al. (cit.), the peculiarity of a metaphor is not that it conveys a very limited set of aspects of the metaphorized system (although, of course, it does). Rather, a metaphor is such because it cannot be deepened and modified independently: any amendment or addition is completely dependent on observations of other systems. The constitutional dependence of metaphors further implies that internal consistency is neither a requirement nor an assumption we can rely upon when we handle a metaphor: we cannot rely on the possibility of finding, in the world, analogs to footlights and flooring. As long as we find it useful, we will be able to amend the metaphor as knowledge progresses by other means (e.g., by testing scientific hypotheses).

6 Gaia is a scientific narrative

Our idea is that Gaia should be best considered a *scientific narrative*. This proposal is a modification of Kirchner's Popperian metatheory, and, differently from Kirchner's, it does not cut Gaia away as an extra-scientific thing. The scientific narrative is deeply part of science, as Volk's quoted story seems to suggest. Gaia is a hypothesis-generator like in Kirchner and Volk, but it is best characterized as an open-ended, collaborative, and open-usage narrative, a way of telling the story of our planet from a particular point of view. In Ricoeur's (1984) words, Gaia poses a "semiotic constraint", and, from that, the narrative is *open to collaborative effort*: the story is not closed and unchanging, the constraint allows for various versions in the number and sequence of events in the story, for different pasts and different futures, and for different patterns in details (for instance, as seen above, prevalence of either negative or positive feedbacks, or relationships with natural selection). The narrative is something attractive and

calling for a common activity of story-building. Of course, such kind of attraction and appeal doesn't mean that scientists *must* accept to cooperate in the Gaia narrative: first of all, there are many other narratives on the table; second, often scientists claim to be worried about those narratives that are *too* attractive. An easy comparison here is Richard Dawkins's 'Selfish Gene' (1976). We propose to consider the Selfish Gene as a scientific narrative in exactly the same sense as Gaia (Barlow 1992).[17] The Selfish Gene has an inventor, Richard Dawkins (see Elsdon-Baker 2006), just as Gaia has James Lovelock. The Selfish Gene has its main developers such as Daniel Dennett and Susan Blackmore, just as Gaia has advocates like Lynn Margulis. Both narratives are open and call for cooperation: scientists can get involved in telling the story of life on Earth as a story of genes, uncovering their dynamics and strategies; and scientists can engage in telling the story of our planet as a bio-physico-chemical large-scale unity; and there is room for very different stories within each of the two 'semiotically contrained' spaces. The Selfish Gene is recalled by many scientists as an aid in hypothesis generation (Grafen & Ridley 2006), and as a reminder for explaining phenomena that are otherwise difficult to explain, just like Gaia is recalled by other scientists like Tyler Volk (2002, quot.). Finally, Gaia and the Selfish Gene are very attractive narratives [cf. Gaia-attraction explanations]. Both of them run into resistance among scientists who remark that 'falling in love' with a narrative or a metaphor is an obstacle to science. In particular, it would create tunnel visions and explanatory patterns that exclude different possibilities or entire fields: the Selfish Gene would rule out the importance ecology and any causal role of macroevolution (Eldredge 1995 for a critical view), and Gaia would be a radical alternative to neo-Darwinism (Margulis 1995, cit.). Looking closer, this is a problem of voracity for exhaustiveness that affects any scientific theory or model or approach or discipline. It is amusing to think that, standing this tendency to exhaustiveness, the difference between a field (say, mathematical population genetics) and a narrative could be that the former is very attractive for a few people, i.e. the practitioners of that field, while the narrative has a broader audience. Could a common narrative create a space for interdisciplinarity and be a

[17] The cited book is an antology of important writings in the life sciences, so the title *From Gaia to Selfish Genes* does not necessarily entail what we are arguing here, i.e. a metatheoretical similarity between the two (cf. Müller 1993).

reminder of the insufficiency of any approach taken in isolation?[18] Or could it be instead a source of illusion of common understanding, concealing any actual misunderstanding? We may consider a narrative such as Gaia or the Selfish Gene metaphorical (although with the caveats above, previous section), yet expressions such as "*a* metaphor" or "*a* mantra" (Kirchner, Volk) convey the feeling that Gaia is the somehow static idea "Earth is an organism", an idea getting transmitted and spread unchanged in a sort of epidemiological way. The semiotic constraint can be indeed analogous to Volk's mantra, but all the rest is changing and open to additions and modifications. Crucially, the narrative is available to scientists for their activity of generating hypotheses.

7 Science or not?

An implication of the above analysis is that a narrative like Gaia is open, available, and attractive not only to scientists but also to a wide audience of non-specialists and non-scientists [cf. Gaia-attraction explanations]. As Kirchner wrote, Gaia is "a colorful metaphor that many find intriguing; and its semantics allow it to be virtually all things to all people. For example, two groups with conflicting interests that immediately embraced Gaia "were environmentalists and, paradoxically, industrialists" (1989, p. 224): they saw the narrative as supporting their respective views.

A majority of scientists start to worry only when the public is involved. Before that, they see the positive effects of a narrative providing scientists with different specializations an important feeling of connection among their works, and allowing them to converge towards telling the same story under different aspects. The dominant view seems to be that the scientific community would 'knows how to handle' an attractive narrative, perhaps with some metatheoretical reflection and clarification like Kirchner's (1989). At the same time, if, as we argued, Gaia is not a scientific hypothesis but a scientific narrative, it is normal that the term doesn't appear in scientific papers. However, the banishment of the term and the active opposition are more than indifference. They are a face of the coin whose other face is the greedy curiosity of the public exemplified by press releases and

[18] Volk (1998, p. 14) vividly describes the interdisciplinary setting of Gaia conferences, fostering even a sharing of models between Earth scientists and biophysicists concerned with organismal physiology (p. 18).

ScienceDaily news (see Introduction). Kirchner's analysis of Gaia as a set of testable scientific hypotheses is addressed to colleagues, but also an instance of "boundary work" (Gieryn 1983) setting science apart from non-science, and scientists from non-scientists.

In the metatheoretical view we are proposing, instead, the question is not about whether Gaia is part of science or not. The point is that scientists on one side, and other actors on the other, have different ways of contributing and using. Scientists *contribute* to the narrative by their means: for example, as Kirchner and Volk say, by formulating and testing scientific hypotheses and by doing technical work. And scientists *use* the narrative and the semiotic constraint precisely as a generator of scientific hypotheses. There are many non-scientific, or even anti-scientific ways of interpreting the narrative and contributing to it: we have for example the extreme case of the interpretation of Gaia as a neo-Pagan New Age religion. Anthropocentrism and anthropomorphism, as well as a strong suggestion of teleology (Ruse 2013),[19] can occur in a lot of less extreme cases where Gaia enters all kinds of social, economic, and epistemological dynamics.

The multi-use attractiveness of a narrative creates a tension in science: on the one hand, struggling defense; on the other, expansive outreach. Lynn Margulis gives examples of both, again in "Gaia is a tough bitch":

> The Gaia hypothesis is a biological idea, but it's not human-centered. Those who want Gaia to be an Earth goddess for a cuddly, furry human environment find no solace in it. They tend to be critical or to misunderstand. They can buy into the theory only by misinterpreting it. Some critics are worried that the Gaia hypothesis says the environment will respond to any insults done to it and the natural systems will take care of the problems. This, they maintain, gives industries a license to pollute (1995, p. 140).

The problem scientists have with Gaia is not that it is not scientific. It is that the narrative exposes science to unwarranted contributions and uses. Successful narratives like Gaia bring science to the public, but the potential price is no less than the contamination of scientific knowledge and the exploitation of science. A

[19] For Ruse these ideas, overcome by Modern Science through centuries of study, are the true causes of scorn of scientists about Gaia. In this light, even the arguments about the non-scientific *form* of Gaia (see sect. 3) would be actually motivated by a battle against the *contents* of the Gaia story.

proposed solution is to simply forget about Gaia. But if, as Kirchner and Volk suggest, Gaia is a good hypothesis-generator for science, another solution would be to keep Gaia as a secret narrative, changing its name in more technical ones,[20] or preserving it in scientifically-trained minds by means of secret handshakes. On the other hand, Gaia might be important in the relationship between science and the public:

> Lovelock's position is to let the people believe that Earth is an organism, because if they think it is just a pile of rocks they kick it, ignore it, and mistreat it. If they think Earth is an organism they'll tend to treat it with respect. To me, this is a helpful cop-out, not science. Yet I do agree with Lovelock when he claims that most of the things scientists do are not science either. And I realize that by taking the stance he does he is more effective than I am in communicating Gaian ideas (Margulis 1995, p. 140).

At the elementary school, in Italy in the 1980s, we studied Earth science on a beautiful textbook: *Gaia: An Atlas of Planet Management* edited by Norman Myers and translated into Italian (Myers 1984). This is one of my few childhood memories about school. I don't remember me thinking to the Earth as a goddess or as a teleological system. I do remember that textbook conveying the idea of Earth as a living planet full of interconnections and delicate equilibria. A planet to care for. And I remember the sense of novelty that this textbook irradiated. Many commentators have defined Gaia as a metaphor potentially increasing people's responsiveness to environmental problems and respect for life and Earth (Bandi & Casiraghi 2011). Many others have pointed out the limits of conventional scientific training (Eldredge 1995), and recognized that Gaia emphasizes aspects of evolution that are left out by other, equally channeling, narratives. We may ask whether there is one best, all-inclusive narrative for talking about life on Earth. If the answer is no, scientists are in the middle of the eternal dilemma of science communication: do we prefer science falling besides people's ignorance and indifference, or science falling into people's active elaboration, distorsion, and, in the worst cases, abuse and perversion?

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[20] Many authors are arguing that there is no need of Gaia anymore, because the research trails it opened up are now taken care of by institutionalized fields such as 'geophysiology' (Lovelock & Kump 1994), 'earth systems science' (Schneider & Boston 1992, Schneider 2001) or 'biogeochemistry' (Martin, pers. comm.), or 'global ecology'.

8 Conclusion

Affinity with Gaia doesn't derive from an exasperated attention to cooperation, but from a sensitivity to global-scale chemistry, then this affinity is not a specific to symbio-studies, nor of microbiology. Many different fields can come to get it. If this is a problem, it will not be specific either, but shared. Gaia is a scientific narrative: open to collaborative effort, used as a hypotheses-generator. It is part of science. Its attractiveness and openness produces a dilemma between outreach and defense for the scientific community.

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