Appendix D. Historical context of the Gaia concept and the teleology problem: what or who is Gaia?

There are precedents to Gaia, as the biosphere of Vernadsky, and the issue of the "identity" of Gaia has been extensively debated (e.g. Schneider, 2004, or, in the context of the OGT, see de Castro 2013, 2019, 2020).

The observation that our atmosphere is far away from the physical and chemical equilibrium that would be expected on an inert planet, or at least a planet devoid of an abundance of life, led James Lovelock (Lovelock, 1972) to formulate the idea that "… the presence of a *biological cybernetic system* able to homeostat the planet for an optimum physical and chemical state appropriate to *its* current biosphere becomes a possibility" (cursive added). This cybernetic system, which he called Gaia, would be under the control of the whole of life.

But in the same text and despite the mechanistic statements (i.e. "cybernetic system" with Gaia being referred to as 'it' in several phrases), the system is also ambivalently exposed as a creature and a living entity, comparing Gaia phenomenologically with other living beings, i.e. with organisms: "…it follows that *she* who controls the atmospheric composition must also be able to control the climate…", "… the air [is]… like the fur of a *mink* or the shell of a *snail*" (cursives added).

Already before (Lovelock 1965, pp. 568) he would assume the teleological character of living beings as a fundamental characteristic to distinguish them from inorganic processes: "an examination of the motion of a salmon swimming upstream suggests a degree of *purpose* inconsistent with a random inorganic process" (cursive added).

The ambivalence between a cybernetic/mechanical view and an organic/purposive view on Gaia is maintained in the publications with Lynn Margulis (Margulis and Lovelock 1974, Lovelock and Margulis 1974) and in his book (Lovelock 1979): The ensemble of life on the Planet is interpreted both as a cybernetic system and as a living entity that modulates, controls or manipulates the atmosphere and its immediate environment (the biosphere) for its/her benefit.

This expository ambivalence, together with the teleological character of Gaia and the incompatibility with Darwinism, generated various criticisms in the following decade (Doolittle 1981, Dawkins 1982, Gould 1988, Maynard-Smith 1988). These criticisms were first debated and then accepted by Lovelock and Margulis and other authors. This is shown in Lovelock's introduction of cybernetic models such as Daisyworld (Watson and Lovelock 1983) and all the literature based on this type of models that followed (e.g. Lenton and Lovelock (2001)). Daisyworld and other models tried to make the cybernetic system compatible with neo-Darwinism, which eliminated the teleological character and the organic resonances of Gaia (reviewed critically in de Castro and Rubin 2021). The idea of Gaia was deepened, no longer in the Gaia hypothesis, but in what Margulis and Lovelock called Gaia theory, where the idea of Gaia as an organic-like creature beyond the metaphorical sense was explicitly denied (e.g. Margulis 1996, Lovelock 2004).

The problem of the organic nature of Gaia was threefold: i) the mechanisms that would give rise to Gaia as a planet-sized living being were not found (Gould's criticism, see also Williams 1996), ii) the mechanisms sought were based on interpretations of Darwinian natural selection that seemed contradictory with Gaia (Dawkins and Maynard-Smith critiques) and iii) the scientific community, including Lovelock himself, confound the teleological phenomenon with the phenomenon of human self-awareness and our foresight and planning capacity during many decades (Doolittle's critique, see Appendix B).

Since those problems could not be resolved convincingly, since the 1980s until the present most authors have followed only the cybernetic vision. Nevertheless, neither Lovelock nor Margulis never completely resolved their ambiguous stance on the nature of Gaia.

Lovelock almost explicit in his contradiction or ambivalence. For example, he published a book on planetary medicine and physiology (Lovelock 1991, reedited in 2000 and 2004) and insists many times on the “Geophysiology” term (e.g. Lovelock 1986, 1989, 1997), although it is obvious that medicine and physiology apply only to living entities, to organisms, not cybernetic systems. On Vernadsky’s biosphere, Lovelock remarked that Vernadsky surely had the idea that the biosphere behaved like a living being and that he gave it up due to ideological pressure:: “I suspect that he [Vernadsky] would have liked to subscribe to the first traditional view, but the pressures of scientific rectitude in his days, and in particular the political pressures on him in Russia, probably forced him towards more the “liberal tendency” (Lovelock 1996, p. 16)”. In this text Lovelock points out that he does not renounce this idea of a living Gaia, and in fact, this organic vision is affirmed by Lovelock himself several times: "This then is the first tradition that sees the Earth as a living organism. It is the view to which I subscribe, and I believe it to have a firm scientific basis" (pp. 15-16). In this light, Lovelock's texts (Lovelock 2004) where he "killed" Gaia, could be also read as a concession to the academic pressure of his time (?).

For Lynn Margulis (Margulis 1993) and Sorin Sonea (Sonea 1991), bacteria formed a unique global community (no species definition could be defined) due to two of their interdependent characteristics: their acquired inability to live alone in the biosphere due to a lack of genes and organic metabolites that cannot synthesize in the field from inorganic compounds, and their ability to acquire genes and organic metabolites from other bacteria and viruses. Shapiro (1988) and Caldwell and Costerton (1996) argue that biofilms are possible units of natural selection and, therefore, organisms in the Darwinian sense. In biofilms, this process of “merging” of metabolites, genes and cells to form a macro-individuality is already evident at a local scale, even with strong physiological similarities of biofilms with lichens (Peneysan et al. 2021) and with the tissues of multicellular organisms (Chai et al. 2024).

Sonea (1991) (and Margulis (1993) seems to agree) maintains that it is the entire community of prokaryotes on a planetary scale that forms a single living entity, a single species and unique organism.. Although Margulis repeatedly denied that Gaia was an organism, she did so on the basis of a single argument: organisms do not live on their own waste products, as Gaia would. De Castro (2019) has already argued that this is not a valid objection if Gaia is defined at the level of the Biosphere rather than the entire Earth. In that sense, Lenton’s own studies on biogeochemical cycling (see Appendix F) indicate that Gaia does indeed have inputs and outputs, since living entirely on one’s own waste would imply an infinite cycling rate. Moreover, our argument is precisely the opposite: the higher the cycling ratio, the greater the degree of interiority and internal organization (see also the RAMO properties). Therefore, a “perfect” organism would live on its own residues and would be *more*—not less—‘organic’ than most existing organisms. Neither Gaia nor any other organism can exist without external material inputs and outputs. Thus, Margulis’s objection to an organic Gaia does not hold. In fact, Margulis contradicts herself: not only because she sees Gaia primarily as a product of prokaryotic metabolism and appears to agree with Sonea that prokaryotes constitute a single organism, but also because she maintains that Gaia is the symbiosis of symbiosis at the scale of the biosphere, a hierarchical chain of symbiosis (Margulis 2008, or in another form: the coulpled trinomials of fig. 2 of the main text). Furthermore, she holds that the main evolutionary novelties are the result of the acquisition of genes and genomes, that is, that symbiogenesis is the main force of biological evolution (Margulis 1993) and that Gaia is the natural selector of living beings (Margulis 2008). Last, she sees Gaia as the largest living

autopoiesis on our planet.t (Margulis 1990, Margulis and Sagan 2003). Autopoiesis is used in the sense of Maturana and Varela (1972), who were seeking with the concept the definition of the main characteristic of what defines a living being, an organism.

For us, bringing all of this together is what we have called *Margulis dynamics*, and it suggests that the body of Margulis's thought and work is, in fact, consistent with the organic hypothesis of Gaia.

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