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RESEARCH ARTICLE

Do scientific objects have a life (which may end)?

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Argument
The aim of this article is to make a case for the pertinence of a biographical approach to the history of scientific objects. I first lay out the rationale of that approach by revisiting and extending my earlier work on the topic. I consider the characteristics of scientific objects that motivate the biographical metaphor, and I indicate its virtues and limitations by bringing out the positive and negative analogies between biographies of scientific objects and ordinary biographies. I then point out various ways in which scientific objects may pass away and argue that their demise should be conceptualized as a process. Finally, I sketch the history of the concept of "ether" in nineteenth and early twentieth century physics and suggest that it lends itself particularly well to a biographical treatment. To that effect, I discuss the identity, heuristic character, and recalcitrance of the ether and examine the reasons that may have led to its passing.

Keywords: biography; ether; history of physics; metaphor; scientific objects

1. Introduction

In *Killing Time*, Paul Feyerabend's autobiography, the final and moving chapter, where Feyerabend tries to come to terms with his impending death, is titled "Fading Away" (Feyerabend 1995). In this article, I will argue that the metaphor of "fading away" nicely captures the "death" of scientific objects. Talking about death inevitably invites talking about its complement, life. Therefore, to address their death, we first need to know in what sense scientific objects have a life of their own. Drawing upon my previous work, I will offer a synopsis of the biographical approach to scientific objects, explaining in what sense scientific objects have lives and how those lives can be lost. I will suggest that loss of life can happen in various ways, depending on the kind of objects that we are talking about. To unpack that multiplicity, I will then sketch a tentative taxonomy of scientific objects, and discuss how different kinds of objects in that taxonomy pass away or, rather, fade away. Finally, I will illustrate the biographical approach to scientific objects with vignettes from the history of the ether, one of the most important objects of nineteenth-century physics.

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2. Precis of the biographical approach to scientific objects

Scientific objects are the entities, processes, and phenomena individuated, represented, investigated and used as tools in scientific practice. They have beginnings in time, when boundaries are carved around them; they are endowed with properties, which enable them to perform their epistemic functions; they have blind spots, for which they become subject to theorizing and experimental investigation; they are often laden with values and emotional significance; and they sometimes pass away, for a multitude of reasons. Because of these characteristics, they lend themselves to biographical narratives.

Biographical approaches to scientific objects have been developed by Hans-Jörg Rheinberger (1997), Lorraine Daston (2000), and myself (Arabatzis 2006). In what follows I will focus on my own approach.[1] In *Representing Electrons*, I argued that the life of objects of a particular kind, namely theoretical entities, has to be unpacked along two dimensions: positive and negative agency and synchronic and diachronic identity. The first dimension, **agency**, refers to the fact that scientific objects have lives in the sense that they guide, constrain, and sometimes obstruct research. On the one hand, they enable and facilitate inquiry by raising questions that become the subject of theoretical and experimental investigation. In that respect, they have a **heuristic character**. On the other hand, they constrain, or even frustrate, research by resisting theoretical manipulation, becoming incoherent when scientists endow them with novel properties. In both of these senses, positive and negative, scientific objects are alive. They are agents (i.e., active participants) in scientific practice.

What about the second dimension, the objects' **identity**? The biography of any subject presupposes its stable (albeit evolving) identity. However, since the beliefs and practices associated with any scientific object vary across space and evolve across time, if we are to write its biography we need to know in what sense it remains the "same," that is, a "unified object of enquiry" to use MacIntyre's apt phrase (MacIntyre 1984, 38).

Thus, I found the biographical metaphor fruitful for two reasons: **First**, because it brings to center stage the issue of the identity of scientific objects. Scientific objects grow and mature, remaining at the focus of epistemic activity (theorizing, experimentation, manipulation, etc.), presumably without losing their identity.[2] **Second**, because it highlights the heuristic power of scientific objects (their positive life) and draws attention to their recalcitrance (their negative life).

To these first two motivations, I would now add two additional reasons in favor of a biographical approach to scientific objects. First, biographies are associated with beginnings (births) and often endings (deaths). Thus, a biographical approach reminds us that scientific objects are historical entities, which emerge and often pass away. Second, scientific objects have an emotional dimension. For one thing, their "discoverers" often think of them as their offspring. For instance, both J. J. Thomson and Robert Millikan "wanted to be remembered as the father of the electron" (Goodstein 2001, 59). For another, scientists often develop an emotional attachment to the objects that they study, an attachment that is associated with particular values and becomes evident when those objects are under threat of becoming extinct.

Let me elaborate on the biographical idiom. In *Representing Electrons* I suggested that the history of the electron's representation can be narrated using metaphors such as "birth" and "character formation" (Arabatzis 2006, 43-44). When the electron was postulated in response to empirical and conceptual problems in late nineteenth-century physics and chemistry, a new representation of a hidden object was born. Various phenomena, from cathode rays to magneto-optics, were thereby linked as experimental traces of that object. Those traces were

[1]I have discussed Daston's and Rheinberger's work on scientific objects in Arabatzis 2003, Arabatzis 2006, 47-49, and Arabatzis 2011.

[2]Under what conditions a scientific object can be said to retain its identity is a thorny issue, which I have addressed elsewhere (e.g., Arabatzis 2011). At any rate, the mere preservation of an object's name is no guarantee that its identity has remained stable.

crucial for the **individuation** of the electron. After that initial stage, the electron gradually acquired a **character**, that is, specific properties (e.g., charge, mass, spin) and modes of behavior (e.g., ways of radiating within the atom). Although the electron's character evolved, some of its properties proved robust and, thereby, it is possible to follow its lifeline across theoretical developments and different experimental situations. The electron's lifeline, however, has not been broken, and we therefore cannot use it as a case study for understanding the death of scientific objects.[3]

The biographical approach indicates several ways in which a scientific object may pass away. First, it may lose its identity, mutating into a different object altogether. This may happen, for instance, when the concept that denotes an object is "radically reconfigured, sometimes beyond recognition."[4] A symptom of that kind of death is the dissolution of the ties among an object's observable manifestations. For instance, when phlogiston was "killed," the connection between the combustibility of a substance and its metallic properties, both of which had been attributed to phlogiston, was broken.[5] Second, it may acquire multiple personalities, being endowed with different characteristics depending on the circumstances in which it is used. This also happened in the case of phlogiston, which by the end of the eighteenth century had turned into a protean entity, or so its opponents complained (Best 2015, 149). Third, an object may lose its heuristic power and its capacity to generate surprises, thus becoming sterile and of no use to further research. As I will indicate below, that may have been a reason for the death of the ether. Typically, when an object dies, it is replaced by another one, which takes over some of the epistemic functions of its predecessor (cf. Rheinberger 2016). The transition from phlogiston- to oxygen-based chemistry is one example of this replacement process.

3 The metaphorical character of "biography of objects"

According to Lakoff and Johnson's now-classic book *Metaphors We Live By*, metaphors are "pervasive in everyday life" (Lakoff and Johnson 2003, 3). "Personification" metaphors, in particular, enable us "to comprehend a wide variety of experiences with nonhuman entities in terms of human . . . characteristics" (ibid., 33). Those metaphors may also have added value for historiographical and philosophical purposes. For our purposes, the biographical metaphor is a "conceit" that brings into focus salient aspects of the history of scientific concepts, the objects to which they refer, and the practices associated with them.[6]

However, metaphors have limitations. They cannot be used without qualifications in the domain to which they are applied. The use of the term "biography" in connection with inanimate entities might create misunderstandings and give rise to extravagant claims. Thus, it is important to indicate the scope and limits of that metaphor. To that effect, I will draw upon the work of Mary Hesse on analogy and metaphor.

Hesse was concerned with analogies between different physical systems, but some of her insights are also relevant to our case. In *Models and Analogies in Science,* she drew a distinction between positive and negative analogies. Positive analogies comprise the properties that two systems have in common, whereas negative analogies concern the differences between those systems (Hesse 1966, 8, 58, 160).

The source and the target of the analogy in our case are, respectively, biographies of persons and biographies of scientific objects. The positive analogies between the former and the latter concern, among other things, the issues of identity and agency. Take identity first. In both cases

[3]The term "lifeline" comes from Kuhn 1993, 535. Kuhn, though, does not think that natural kind concepts have lifelines.

[4]Here I'm using the words of an anonymous referee, who urged me to reflect on this possibility.

[5]For this connection, see Chang 2012, 3.

[6]I owe the term "conceit" to the late Joan Bromberg. In a generous review of *Representing Electrons,* she classified the biographical approach "as a conceit, a literary/pedagogical device that does not alter our understanding in any way. What this biographical approach does do, however, is to clarify, vivify, and dramatize the narrative" (Bromberg 2006, 173). Whether the conceit in question enhances our understanding I leave for the reader to judge.

we are dealing with the lifeline of an entity, either animate (such as a human being) or inanimate (such as a concept or an object). In an ordinary biography there is an obvious sense in which the biographee remains the same throughout his or her life. There is sufficient continuity in a person's life to justify their selection as the subject of a biography. When it comes to the biography of a scientific object, however, one needs to show that the evolving representation of the object picks out the same "thing" and can, thus, become the subject of a coherent biography.[7] If this cannot be shown, because the object in question has been radically reconceptualized over time, then prosopography will have to replace biography as the pertinent metaphor for studying the history of that object.

Moving to agency, there is a clear sense in which scientific objects are active participants in scientific practice. They play a heuristic role by giving rise to questions that generate novel theoretical and experimental work; and they often exhibit a recalcitrant character by becoming incoherent when new properties are attributed to them. There are limits to their agency, however, and it is here that Hesse's negative analogies become relevant.

The negative analogies between ordinary biographies and biographies of scientific objects involve two issues: intentionality and reality. Scientific objects, unlike people, have no intentions. Furthermore, again unlike people, they may turn out not to be real, as happened with phlogiston, caloric, and the ether. In that sense, my approach is quite unlike that of Bruno Latour, who (in)famously wants to obliterate any distinction between human and non-human agents (cf. Schaffer 1991).

As regards the death of scientific objects, there are both positive and negative analogies with the death of people. On the positive side, the death of scientific objects can be painful for their adherents and is associated, as in ordinary death, with feelings of loss and denial. On the negative side, the death of objects, unlike the death of people, is not an event but a process. The biographical metaphor suggests that the demise of scientific objects has the character of a brief extinction episode. However, as Hasok Chang has shown for the case of phlogiston and Jaume Navarro for the case of the ether, scientific objects may persist well beyond their productive phase, the period when they generate novel questions and results (Chang 2012, Navarro 2018b). So, their death is often a protracted affair.[8] Furthermore, human death has a finality to it, whereas the death of objects does not preclude the possibility of their resurrection and revival. The history of the ether, as we will see below, exemplifies this possibility.[9]

Before expanding upon this discussion of the death of scientific objects, it would be pertinent to briefly sketch a tentative taxonomy of objects I have suggested elsewhere.[10] This taxonomy will indicate that the precise manner in which an object loses its life depends on the kind of object it is. Thus, an awareness of the plurality of scientific objects will further strengthen the biographical metaphor: in the life of objects, as in ordinary life, there are many ways to die.

4. The plurality of scientific objects and their modes of passing away

For analytic and historiographical purposes, it would be helpful to distinguish between several types of scientific objects:

- Natural entities (e.g., heavenly bodies) versus artificially created ones (e.g., certain particles in high energy physics).

[7]As Benjamin Straumann pithily put it, "conceptual change is change *of* something with sufficient continuity to qualify as the subject of a metaphorical biography" (Straumann 2019, 24).

[8]There are two caveats here: First, some scientific objects, especially in experimental contexts, may pass away very quickly (Rheinberger 2016). Second, human death is also not always sudden, but can be a slow and agonizing process, as illustrated by Feyerabend's portrayal of his death as a "fading away" (Feyerabend 1995).

[9]I am indebted to one of the anonymous referees for stressing this point.

[10]See (Arabatzis 2011), where I used that taxonomy to defend a pluralist account of the birth and historicity of scientific objects.

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- Regularities that occur in nature (e.g., planetary motions) versus phenomena that appear in the controlled environment of a laboratory (e.g., various effects in physics). The latter often do not occur in the wild.
- Manifest entities, the existence of which is undisputed, versus hidden entities (e.g., atoms), the existence of which is hypothetical, at least when they are introduced.
- Theoretical entities that resist experimental detection (e.g., dark matter) versus entities that are routinely manipulated in the laboratory (e.g., electrons).

These distinctions indicate that the demise of scientific objects may happen in different ways, depending on the type of object we are focusing on.[11] For instance, natural entities are transformed into scientific objects via a classificatory scheme (think of "planets" in Ptolemaic astronomy) and die out when the scheme in question is abandoned. Artificially created objects, on the other hand, exist in the context of man-made laboratory conditions and pass away when those conditions are not in place. Sometimes we may even discover that they were not real to begin with, but mere experimental artefacts.[12]

As regards the death of scientific objects, several questions need to be addressed:

- How and why does a scientific object pass away?
- When this happens, what is it that ceases to be? The representation of the object? The set of practices and skills associated with it? The values and aims embodied by it? Its explanatory function? Something else?
- Where does an object lose its life? Or, to put it another way, what is the geography of its death?[13]
- For whom is an object considered dead and who persists in treating it as alive?
- How is an object's demise received by its adherents? What emotional reactions are generated by its loss?
- What replaces an object after its death? How are its epistemic functions met by its successor(s)?

These questions are meant as an aid for exploring the demise of scientific objects and have to be "addressed at a local level, the level of particular kinds of objects" (Arabatzis 2011, 379). Hence the need for a taxonomy such as that outlined above.

Take, for instance, the distinction between manifest and hidden objects. The former are held together by conceptual ties, under a particular system of classification. Their demise goes hand in hand with the crumbling of that particular system, the realization that it does not "reflect a pre-existing order in the world," and the rise of a novel taxonomic system (Arabatzis 2011, 383). The latter, on the other hand, are "inferred entities," the existence of which is usually posited to account for certain phenomena.[14] Their identity is fixed by their epistemic aim, namely the phenomena that they are meant to explain, and their properties, which are figured out in the process of fulfilling that aim. They may pass away in various ways and for various reasons, such as:

1. Because of radical conceptual change: the concept associated with a hidden object changes so dramatically that the object is essentially wiped out (Chang 2011, 415).

[11]These categories are not distinguished by sharp boundaries and are not meant as absolutely distinct kinds. This, however, does not detract from their utility. See the discussion in Arabatzis 2011, 380-381.

[12]See, e.g., the N-rays episode (Nye 1980).

[13]I owe this question to Simon Schaffer.

[14]I borrow the term "inferred entities" from Russell (1959, 155). Their birth, especially in modern theoretical physics, may also be tied to mathematical or conceptual considerations. See, e.g., Pickering's reconstruction of the "Genesis of Quarks" (Pickering 1984, 85-89).

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2. Because the ties between the phenomena attributed to an object are dissolved (Chang 2011, 419; Arabatzis 2011, 385).
3. Because they give rise to intractable conceptual problems or resist persistently experimental detection.
4. Because their explanatory potential is exhausted, and they consequently lose their fertility and become sterile (cf. MacIntyre 1984, 42; Clain and Maršálek 2016, 263).
5. A related reason: they become irrelevant to scientific practice. A hidden object may pass away not because scientists become convinced that it does not exist, but rather because it ceases to be a target of scientific investigation and to play any active role in theoretical and experimental research (cf. Rheinberger 2016).
6. Because of **Ockham's razor**: they become superfluous and are eliminated in the interests of conceptual economy.
7. Because their epistemic aims cease to be considered important or legitimate. For instance, when non-accelerated motions ceased to be considered a legitimate explanandum, the medieval notion of impetus was discredited.
8. Because some of their epistemic functions are taken over by competing objects. The death of a hidden object is often accompanied by the birth of its successor. Phlogiston was substituted by oxygen, caloric by molecular motion, and the ether by the electromagnetic field.

The point of the above was to make plausible the thesis that scientific objects, and in particular hidden ones, may die in different ways and for different reasons. Nevertheless, there are some common elements that are worth pointing out.

First, the death of scientific objects is often a process, rather than an event. They **fade away** rather than disappear instantly.[15] This is easy to see in the case of manifest objects. Since their death goes hand in hand with the rejection of a particular system of classification and its replacement by another one, it is small wonder that it is an extended process. Moreover, in the case of hidden objects, the death-as-a-process-view is fully borne out by two salient instances: phlogiston and the ether. The persistence of the former well beyond the emergence of Lavoisier's oxygen theory of combustion has been amply documented (Chang 2012, chapter 1). As regards the latter, there is also abundant historical evidence that it did not abruptly disappear but gradually withered away over a period of three decades (Navarro 2018a).

Second, when a hidden object passes away, some of the practices associated with it become obsolete. Again, the phlogiston and ether cases are instructive. Experimental practices of phlogiston chemistry, such as the transfer of phlogiston between two different substances, and the theoretical practices of nineteenth-century ether physics, such as the construction of elaborate mechanical models of the ether, were abolished together with the objects that were constitutive of them. As Andrew Warwick has shown in a masterful study, "now discredited notions as the electromagnetic ether … were not only made familiar and legitimate entities to a generation of Cambridge mathematical physicists but routinely deployed by them in a number of highly technical and ongoing research projects" (Warwick 2003, 43).

Third, after the death of an object, history gets rewritten. What once was seen as a momentous discovery may turn into an unfortunate mistake. The examples of phlogiston and ether serve us well here too. Both objects were once considered very important discoveries. Joseph Priestley claimed that phlogiston "was at one time thought to have been the greatest discovery that had ever been made in the science. … [T]here had hardly been any thing that deserved to be called a *discovery* subsequent to it" (quoted in Conant 1957, 169). And Henry Williams asserted that the ether's "discovery may well be looked upon as the most important feat of our century" (Williams 1901, 231; cf. Swenson 1972, 137).

[15]Hence the pertinence of Feyerabend's phrase, with which I began the paper.

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5. The life and death of the ether

The ether was a preeminent object of nineteenth-century physics and its history has been meticulously studied (Whittaker 1951; Swenson 1972; Schaffner 1972; Cantor & Hodge 1981a; Navarro 2018a; Navarro 2020).[16] It was considered an all-pervading medium that was able to store and transmit energy. Its main function was to provide the resources for understanding light and electromagnetic phenomena as continuous wave processes.

The term "ether" goes back all the way to Aristotle, who regarded ether as the fifth element, the constituent of the heavens. The representation and epistemic function of Aristotelian ether were thus worlds apart from those of its nineteenth-century counterpart. In the early modern period, Newton conceived the ether as a medium that conveyed gravitational forces; its main function was to dispel the specter of action at a distance. In the eighteenth century, several ethers were put forward to account for other *prima facie* action-at-a-distance phenomena, such as electricity and magnetism (Swenson 1972, 37; Heimann 1981). Those ethers, however, fell short of their epistemic aims. As Maxwell pointed out in 1878, in his *Encyclopaedia Britannica* entry on the ether, "the nature of the motion of these media" remained obscure and their proponents could not show how they "would produce the effects they were meant to explain" (Maxwell 1890, 764).

Another ether, however, proved to be more robust. It was the ether "invented by Huygens to explain the propagation of light" (ibid.; cf. Swenson 1972, 9). After receiving a boost in the early nineteenth century, when Thomas Young and Augustin-Jean Fresnel made it the foundation of the wave theory of light, the "luminiferous" ether enjoyed a thriving career. In the 1860s, Maxwell employed the ether in his construction of electromagnetic theory. His calculation of the speed of electromagnetic waves indicated that it was close to the velocity of light. Thereby, the luminiferous and the electromagnetic ether merged into a single object. That fusion led to tremendous theoretical and experimental achievements, such as the unification of electromagnetism and optics, and Heinrich Hertz's confirmation of Maxwell's prediction of electromagnetic waves (Swenson 1972, 100).

By the late nineteenth century, the ether had become well-entrenched in physics. Physicists in Britain and on the Continent thought of the ether as the best established entity of natural philosophy. Three examples would suffice to show this. First, Maxwell claimed that "there can be no doubt that the interplanetary and interstellar spaces are not empty, but are occupied by a material substance or body, which is certainly the largest, and probably the most uniform body of which we have any knowledge" (Maxwell 1890, 775). Second, in 1884 William Thomson asserted that the ether "is the only substance we are confident of in dynamics. One thing we are sure of, and that is the reality and substantiality of the luminiferous ether" (quoted in Swenson 1972, 77). And, third, Hermann von Helmholtz, in his preface to Hertz's *The Principles of Mechanics*, expressed his commitment to the ether in no uncertain terms: "There can no longer be any doubt that light waves consist of electric vibrations in the all-pervading ether" (quoted in ibid., 101). The ether's epistemic status was now perfectly secure.

Furthermore, by that time the ether had become the center of epistemic activity in theoretical and experimental physics: "the major problems in physics seemed to divide into two broad categories, namely, the physics of matter and the physics of the aether" (ibid., 28; cf. Cantor and Hodge 1981b, 50-53). Physicists theorized about it, used it to explain and predict optical and electromagnetic phenomena, and designed experiments to study its interactions with matter. The ether, thus, provided the foundation for a "theory of everything," including the structure of matter (Kragh 2002). As Joseph Larmor, one of the protagonists of British ether physics, put it, theoretical physics had become the "science of the aether" (Larmor 1911, 292; cf. Swenson 1972, 165; Navarro 2020, 285). By implication, the death of the luminiferous/electromagnetic ether in the early twentieth century must have left the older generation of physicists, who had invested so much in its existence, without their main object of study; but more on this below.

[16]My aim in what follows is neither to offer a coherent account of the history of the ether nor to add to those studies. Rather, I would like to draw upon them in order to illustrate key themes of the biographical approach.

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Several historians have used biographical language to narrate the vicissitudes of the ether. Loyd Swenson's study of the Michelson-Morley experiment is framed in biographical terms: the aim of *The Ethereal Aether* was to "narrate how Michelson's great failure, and its conceptual raison d'être, the aether, were born, suffered, and died" (Swenson 1972, xvi). Jed Buchwald, at the end of his article on "The quantitative ether in the first half of the nineteenth century," pointed out that "the hypothesis of the molecular ether gave birth to the science of the differential equations of wave optics" (Buchwald 1981, 233). Here the biographical metaphor was connected with the productive role of the ether hypothesis. The same theme is found in a later essay by Buchwald, this time on the role of the ether in the emergence of microphysics in the early twentieth century (Buchwald 2000).[17] Biographical language can also be found in several of the contributions to the recent collection *Ether and Modernity* (Navarro 2018a). Here the motivation for a biographical approach is to trace the "multiple lives of the ether in the first decades of the last century ... [from] pure mathematics to wireless technologies, from modernist art to spiritualism and from popular to alternative views of physics" (Badino and Navarro 2018, 2). Furthermore, in that collection we see three themes that could further justify a biographical approach to the ether: its identity, its heuristic character, and its recalcitrance.[18]

5.1. The ether's identity

Badino and Navarro begin their introduction to *Ether and Modernity* with the following questions: "When did **the** ether disappear? Did **it** actually ever exist? Is **it** not back among some contemporary physicists?" (Badino and Navarro 2018, 1, emphasis added) These questions presuppose that there was a single object, **the** ether, which remained the same across space (synchronically) and over time (diachronically), in some sense that we need to specify. The repeated occurrence of the same term, "ether," is not in itself enough to satisfy this presupposition.

Furthermore, some of the historians who have written on the ether have denied that the term "ether" referred to a single, same entity throughout its history. Cantor and Hodge, for instance, in their introduction to *Conceptions of Ether*, claim that the ether is not a "unifying theme". Rather, they approach their subject matter as an "unruly family of concepts" (Cantor and Hodge 1981b, ix). Simon Schaffer, in a review of that volume, put this difficulty in no uncertain terms: "it would be too easy and rather unhelpful to point out that there is *no* single ether, *nor* any single problem which links all these essays together" (Schaffer1982, 297).

Now, a resolution of this difficulty is necessary for a biographical approach to the ether to get off the ground. It would probably require a book-length study of the history of the ether to come to grips with this tricky problem; here I can only indicate a few possible ways out. The problem can be attacked in three different but complementary ways: at the level of the individuation of the ether and its differentiation from, say, matter; at the level of the representation of its constitution, the properties that were attributed to it; and, finally, at the level of its epistemic functions, the phenomena that it was meant to explain and were considered its observable manifestations. The persistence of the ether as a scientific concept and object has to be understood in terms of the continuities at each of those levels. If there are sufficient continuities, then the ether may indeed "qualify as the subject of a metaphorical biography" (Straumann 2019, 24).

This is the case, I think, at least after the middle of the nineteenth century, when the "'ether' turn[ed] into a generally recognisable object of research" (Wise 1981, 269).[19] In the wake of

[17]Strictly speaking, Buchwald's metaphor is a reproductive, rather than a biographical, one. Note, though, that the former presupposes the latter: only living entities can give birth. Furthermore, both reproductive and biographical metaphors are species of the wider category of "personification" metaphors. See Lakoff and Johnson 2003, 33-34.

[18]This is my gloss on the volume. These themes are not explicitly discussed by either the editors or the contributors.

[19]Earlier "ethers" were entirely different animals. To take a particularly clear case, Aristotle's ether had nothing to do with Maxwell's. The function of Aristotle's ether was to account for celestial phenomena such as the perpetual circular motion of the stars.

Maxwell's unification of optical and electromagnetic phenomena, the ether was conceived as a medium pervading all space and functioning as an absolute frame of reference, capable of storing and transferring energy, and responsible for the transmission of light and other electromagnetic phenomena. At the same time, "General assent to the existence of a single ether ... did not imply agreement on its nature" (ibid., 270). So, its ultimate constitution remained a thorny problem. And this brings me to my next theme, the agency of the ether.[20]

5.2. The ether's heuristic character

The heuristic character of scientific objects is related to their elusiveness. Scientific objects "are the targets of research, those things about which we would like to know more. That is why they are particularly elusive" (Rheinberger 2016, 270). The ether raised questions about its constitution and its relations with matter. In Maxwell's words, "we have ... to inquire whether, when ... dense bodies are in motion through the great ocean of aether, they carry along with them the aether they contain, or whether the aether passes through them as the water of the sea passes through the meshes of a net when it is towed along by a boat" (Maxwell 1890, 768). As regards the constitution of the ether, the question raised was whether it was "molecular or continuous" (ibid., 773). The ether thus became the focus of an entire research industry. Lord Kelvin, for one, was throughout his career "centrally occupied with questions relating to ether" (Siegel 1981, 240). The same was true of George Francis Fitzgerald and Joseph Larmor, who "were concerned especially with the fine-scale structure (or lack of structure) of ether" (Stein 1981, 324). Physicists in continental Europe, such as Heinrich Hertz and Hendrik Antoon Lorentz, were also preoccupied with the ether and, especially, with its (non-)interaction with moving matter (ibid., 327). In all, the question "What is ether?" was considered "*the* question of the physical world at the present time" (Lodge 1892, x; cf. Swenson 1972, 104).

The ether also gave rise to first-rate experimental work, which aimed at elucidating its "state ... near the earth, and ... its connexion with gross matter" (Maxwell 1890, 770). The most famous of those experiments were initiated by Albert A. Michelson in 1881 and continued well into the twentieth century (Lalli 2018). Thus, the ether was productive in the sense that it led to experiments targeted at figuring out its properties and behavior. Some of those experiments, however, pulled in different directions. For instance, the results of the experiment performed by Michelson and Edward Williams Morley in 1887 were originally interpreted as indicating that the ether was dragged by the moving earth. Later experiments by Oliver Lodge, though, "seemed to contradict this, insofar as they suggested that the ether was not dragged by gross matter moving rapidly past it" (Noakes 2018, 95; cf. Lalli 2018, 161). From the point of view of the biographical approach, this tension was a manifestation of the ether's recalcitrance.

5.3. The ether's recalcitrance

Since the 1830s, the ether had been conceptualized as an elastic solid. Light was supposed to be a transverse wave in the ether, and only solids could sustain transverse vibrations (Swenson 1972, 20). Given that the ether was supposed to permeate all space, however, its solid-like qualities seemed to be at odds with its rarefied character, which was inferred from the unimpeded motion of the planets through it (Cantor and Hodge 1981b, 51). That was the first instance of incoherence in the representation of the ether, an incoherence that became a central theme in its subsequent career.

[20]A clarification is in order here. The agency of a concept derives from the agency of those who possess and use it. As Straumann points out, concepts are "causally inert." Their "effects in the world" are felt "through the intentionality and agency of the thinkers having the concepts" (Straumann 2019, 34).

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The ether's recalcitrance, its resistance to theoretical and experimental domestication, looms large in Navarro's *Ether and Modernity*. As Badino and Navarro note, its functions

> required the ether to be a material entity of a very peculiar nature. It had to be rigid enough to allow the extremely fast propagation of transversal waves, thin enough not to slow down the planets moving through it and capable somehow of keeping the dispersed energy until, at some point in time, it could be released. None of these formidable properties was ever made consistent with the others. (Badino and Navarro 2018, 8)

It is tempting to attribute the ether's eventual demise, at least partly, to its recalcitrant character. This intuitive judgment, however, is not borne out by the historical evidence. Maxwell, for one, did not think that "the difficulties we may have in forming a consistent idea of the constitution of the aether" undermined its existence (Maxwell 1890, 775). Some later physicists even portrayed the ether's recalcitrance as an asset. Lodge, for instance, acknowledged that "the Ether is recalcitrant. But its recalcitrance is not like mere surly obstruction, it is of a helpful and illuminating character" (Lodge 1917, 286; cf. Schirrmacher 2018, 113; Noakes 2018, 91). Eddington was even more adamant in making a virtue out of the ether's inscrutability (Navarro 2018b, 144).

5.4. The death of the ether

What, then, may account for the demise of the ether in the early twentieth century, if not its persisting recalcitrance? As I suggested above, several factors may be associated with the death of hidden objects. The **first** is the radical reconceptualization of an object, the dissolution of the ties among its manifestations, and a concomitant loss of its identity. Indeed, the ether was reconceptualized at several points of its late history. Maxwell had conceived it as a peculiar form of matter, a mechanical medium that was subject to Newton's laws. Subsequent theorists, such as Lorentz, distinguished it clearly from matter and suggested that it did not obey Newton's third law (Nersessian 1984). After the advent of relativity, various physicists in Britain and Germany "domesticated the aether within relativity physics" (Wright 2018, 229; cf. also Walter 2018). These conceptual shifts, however, did not undermine the identity and existence of the ether in the eyes of its proponents, perhaps because it continued to function as the epistemic "glue" tying together electromagnetic and optical phenomena.

In one case, though, the reconceptualization of the ether proved too much. When Einstein, well after his attempt to kill the ether in 1905, attempted to revive it in 1918, by interpreting it as the medium of gravitation, his opponents objected that "Einstein's concept of ether = not ether, but rather non-Euclidean space" (Staley 2018, 190). Einstein himself stressed that the content of his "conception of the ether ... differs widely from that of the ether of the mechanical undulatory theory of light (Einstein 1920, 177). For Einstein, the ether could be said to exist only in a minimal sense, namely as "space ... endowed with physical qualities" (ibid., 181).[21] Thus, a good case can be made for the view that Einstein's attenuated conception of the ether was so different from earlier versions that it did *not* constitute a continuation of the same concept, and that the older ether had therefore been abandoned altogether.

As I pointed out above, there should be sufficient continuity in the meaning and epistemic function of an evolving concept in order for it to qualify as a concept of the *same* object. However, it is difficult, if not ultimately arbitrary, to decide in a principled way what counts as sufficient continuity. To put it another way, it is hard to say whether a radically transformed concept continues to refer to the same object or not and, thus, whether an object remains alive or not.[22] At any rate, from a historical point of view, two issues are particularly important. The first is whether different scientists

[21]Einstein's changing attitudes towards the ether have been documented by Kostro 2000.

[22]This question is beyond the scope of this paper, but I have addressed it elsewhere (see, e.g., Arabatzis 2011, 2012).

conceptualize a tottering object in different ways. Einstein's emaciated version of the ether (c. 1920), for instance, differed substantially from, say, Lorentz's, who continued to conceive of it as a medium which carried electromagnetic waves and functioned as a privileged frame of reference. The second issue to be addressed is where and for whom an object is considered dead (or alive). Between 1905 and 1916, for example, the ether was dead for Einstein, but not for Lorentz or prominent British physicists such as Larmor or Lodge. Thus, the persistence of scientific objects is sometimes not an all-or-nothing affair. They may inhabit a "zombie zone," where different scientists conceptualize them differently and, moreover, some scientists consider them dead whereas others continue to believe in their existence.

A **second** possible reason for the death of a hidden object is the inability to detect it experimentally. That was, indeed, the case with the ether. As Maxwell indicated, the ether stimulated a hope of detecting absolute motion (Maxwell 1890, 768-770). That hope, though, never materialized. The persistent attempts to detect the earth's motion through the ether ended in failure: the earth's motion seemed to have no effect on terrestrial experiments with light (Swenson 1972, 41). The last episode in the history of those attempts took place in the 1920s, when Dayton Miller failed to convince his colleagues of the validity of his results: "the definitive disappearance of the ether concept from the physics literature … was probably related to the controversy on Miller's experiment" (Lalli 2018, 172).

The physicists' inability to detect the ether *qua* privileged inertial framework eventually led to the abandonment of the detection and measurement of absolute motion as an epistemic goal. The recognition of that goal as chimeric took center stage in Einstein's theory of relativity, which thereby rendered the ether "superfluous." Furthermore, in Einstein's theory, another epistemic function of the ether, the transmission of light and electromagnetic waves, was taken over by the electromagnetic field, which was now understood as a self-subsisting entity. The elimination of the ether dissolved the problems associated with it, such as its interaction with matter. Thus, the ether gradually ceased to be the center of epistemic activity and "became marginal to the work of most physicists and engineers" (Gooday and Mitchell 2013, 731). That may have been a **third** reason for its death. At any rate, it was a protracted death, a "slow erosion of confidence in all forms of the aether concept" (Swenson 1972, 156).[23]

The ether went through a long period of being "sick" before its ultimate demise.[24] This is not hard to understand. The ether's purported flaws were not universally recognized as such. Thus, the ether persisted more in some environments (e.g., in Britain and the US) than in others. Furthermore, the elimination of the ether brought about a severe epistemic loss: the inability to render electromagnetic waves visualizable and intelligible. That is why Einstein's 1905 exhortation to eliminate the ether was met with incomprehension, resistance, and denial. Those emotionally laden reactions reinforce the pertinence of the biographical metaphor for understanding the extinction of scientific objects. The loss of a life has a strong emotional impact and, therefore, it differs from a mere ending.[25]

Let me close with a sampling of some reactions to Einstein's original suggestion in 1905 that the ether should be "killed." Those reactions were due to the explanatory gap that the death of the ether would create and to the loss of qualities valued by the older generation of physicists, such as common sense, continuity, and intelligibility (cf. Clarke 2018; Henderson 2018; Lalli 2018; Schirrmacher 2018). According to the American physicist William F. Magie, "the abandonment of the hypothesis of an ether … [would be] a great and serious retrograde step in the development of speculative physics. The principle of relativity accounts for the negative result of the experiment of Michelson and Morley, but without an ether how do we account for the interference

[23]Several more factors that contributed to the ether's death are suggested in Navarro 2020.

[24]Einstein called ether "the sick man of theoretical physics" (Einstein 1918, 74; cf. Staley 2018, 189). Once again, we see the pertinence of conceptualizing the death of scientific objects as a process of "fading away."

[25]I am indebted for this point to Mat Paskins.

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phenomena which made that experiment possible?" (Magie 1912, 290; cf. Lalli 2018, 158). Thus, according to Magie, a heavy price would have to be paid for the elimination of the ether, namely the loss of an explanation of the wave properties of light.

The German physicists Max Abraham and Emil Wiechert had a similar reaction: "Abraham held that Einstein's light postulate was incomprehensible without an ether, arguing that electromagnetic waves and fields could not subsist without a substrate" (Walter 2018, 80). The same was true of Philipp Lenard, for whom the ether made possible the intelligibility of nature in mechanical terms (Schirrmacher 2018, 118-119, 124).

In Britain, Larmor and Lodge would not jettison the ether for similar reasons. Larmor "insisted that abandoning the ether, qua dynamical continuum, removed a proven source of progress in physics and of cosmic intelligibility" (Noakes 2018, 97). And Lodge argued that "Waves we cannot have, unless they be waves in something" (Lodge 1909, 2; cf. Swenson 1972, 169).

The explanatory indispensability of the ether and its centrality in the practice of nineteenth- and early twentieth-century physics had invested it with an emotional significance that seeped through the language employed by some physicists. Lord Kelvin, for instance, wrote in 1896 that for more than fifty years he had been "liable to fits of ether dipsomania" (quoted in Thompson 1910, 1065; cf. Siegel 1981, 242). Three decades later, Michelson looked back with nostalgia to "the beloved old ether (which is now abandoned, though I personally still cling a little to it)" (Michelson 1928, 342; cf. Swenson 1972, 218). It is small wonder, then, that the death of the ether was a cause of "heartbreak" for the older generation of physicists.[26]

The above is welcome grist to the biographer's mill. I hope to have shown that several features of the ether's history lend themselves particularly well to a biographical approach. First, by explicating the ether's synchronic and diachronic identity, at least from the mid-nineteenth century on, a biographical approach elucidates the physicists' intuition that they were grappling with the single same entity despite their inability to form a consistent picture of its constitution. Second, by highlighting the ether's heuristic character and its recalcitrance, a biographical approach enables us to understand the contribution of the ether to nineteenth century scientific practice. Finally, by stressing the value-laden character of the ether and its emotional significance for physicists, a biographical approach helps us come to grips with the strong feelings generated by the ether's demise. All in all, the case of the ether suggests that adopting a biographical perspective can be a fruitful way to understand the history of scientific objects.

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[26]The term is Gerald Holton's (1972, xx). The emotional hold of the ether on "classical physicists" is brilliantly captured in Russell McCormmach's captivating novel *Night Thoughts of a Classical Physicist* (1982, esp. 134, 204-207).

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