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INHALT

ENTROPY

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INTRODUCTION

'Entropy' is without a doubt one of the most profound and far-reaching concepts put forward by modern science and thus it should come as no surprise that it is also among the most confusing. Perhaps it is no exaggeration when Edwin T. Jaynes calls it the most "abused word in science."[1] Formally categorized in physics as the second law of thermodynamics as the probabilistic tendency of heat to dissipate, disperse, or (more generally) of every organized entity to return to disorder over time, its subsequent meaning is fractured throughout history and contexts of application.[2] Ranging from pessimistic claims about the fate of the universe, to anxieties of social degeneration and generally the decline of civilization, to answering key-questions regarding the continued existence of life, this concept has been applied to explain and justify a plethora of modern worldviews and perspectives.[3] Stark contrasts between these interpretations resulted in one of the many fronts on which the Science Wars, associated mostly with Alan Sokal and C.P. Snow's 'two cultures,' were fought out in the last decade of the twentieth century. Attempting to regain a grip on its meaning, natural-scientific agitators have (unsuccessfully, one might add) resisted free-floating uses of 'entropy' across disciplines for the sake of the concept's scientific integrity.[4]

Despite such openly displayed disputes, few efforts have been made to trace what the introduction of 'entropy' does to the epistemologies it attaches itself to. A brief look at the historical trajectory of this concept shows that 'entropy' started to flow outside and beyond its thermodynamic origin immediately after its conception in the nineteenth century and has since been permanently established in a number of other sciences, among which information theory, cybernetics and chaos theory are most notable.[5] From this impressive track record of the transversals of 'entropy,' it seems, then, that 'entropy' evades disciplinary capture. In order to do justice to "that most peculiar and *fugitive* of physical laws, the entropy principle," I will refrain from giving a 'true' definition of 'entropy,' as to do so would undermine the goal of the current investigation.[6] In an attempt to subvert the haughty attitude of scientific purists and its root in Snow's strict separation of the humanities from the natural sciences, the present paper will instead introduce and expand upon the so-called 'Boltzmann Bomb'-argument.[7] This argument presents the mature history of

1 Edwin T. Jaynes: "The minimum entropy production principle," in: *Annual Review of Physical Chemistry* 31/1 (1980): p. 593; see also: Dan Styer: "Entropy as Disorder: History of a Misconception," in: *The Physics Teacher* 58/5 (2020).

2 "The second law of thermodynamics is only a probabilistic tendency, not a necessity." Terrence W. Deacon: *Incomplete Nature: How Mind Emerged from Matter*, New York 2011, p. 122.

3 Gordon W.F. Drake, *Encyclopaedia Britannica Online,* "Entropy Physics," last edited June 7th, 2018, https://www.britannica.com/science/entropy-physics (accessed October 1st, 2019); Matteo Pasquinelli: "Introducing Four Regimes of Entropy: Notes on Environmental Fatalism and Energo-Determinism," paper presented at the Beyond Entropy Symposium, Fondazione Cini, Venice, (2010); Aristeidis Mousoutzanis: *Fin-de-Siècle Fictions, 1890s–1990s: Apocalypse, technoscience, empire*, Hampshire 2014.

4 A prime expression of this conservative attitude in regards to 'entropy' in an early phase of the 'Science Wars' is the Marxist-oriented Steven Best: "Chaos and entropy: Metaphors in postmodern science and social theory," in: *Science as culture* 2/2 (1991), pp. 188–226; for a more recent text explicitly discussing 'entropy's spread in terms of the science wars: Libb Thims: "Thermodynamics ≠ Information Theory: Science's Greatest Sokal Affair," in: *Journal of Human Thermodynamics* 8/1 (2012), pp. 1–120.

5 Pasquinelli: "Introducing Four Regimes of Entropy" (note 3); also Matteo Pasquinelli: "Matteo Pasquinelli," in: Stephano Raboli Pansera (ed.): *Beyond Entropy: When Energy Becomes Form*, London 2011, pp. 20–22.

6 Jeremy Campbell: *Grammatical Man: Information, Entropy, Language, and Life*, New York 1982, p. 18 (my emphasis).

7 Upon completing this article, it was pointed out to me that

'entropy,' especially during the twentieth century, as already contained in the writings of statistical-thermodynamic pioneer Ludwig Boltzmann (1844–1906) and as an intellectual time-bomb waiting to be detonated.

If 'entropy' had been less evasive, turning to French epistemologist Georges Canguilhem might have been a methodological consideration due to his conceptual history of science. A criticism of Canguilhem that holds particularly well with regards to 'entropy,' is levelled by German conceptual historians Falko Schmieder and Ernst Müller: "Many of the concepts that are currently interesting cannot be understood as defined in Canguilhem's sense. These concepts are inherently blurred and their development is incomplete, but it is precisely their tending towards uncontrollability that brings about unforeseen coherences."[8]

Instead, the current research receives critical impetus from one of Canguilhem's doctoral students (although he and Canguilhem would have a personal fall out on the day of the defense): namely, the recently deceased French historian of science Michel Serres (1930–2019). Few historians have been able to grasp and portray the gigantic rupture thermodynamics brought about for Western scientific paradigms as succinctly and intricately as Serres did throughout his life's work. Always eager to cross the division between natural sciences and social sciences or humanities, a path that he named "the Northwest Passage," Serres recognized that thermodynamics did not only challenge the paradigm of Newtonian physics but also the mode of knowledge production that emerged from it. Using the proto-thermodynamic image of early French engineer Sadi Carnot's (1796–1832) motor, Serres attacked the remnants of Newtonian physics (and, particularly, its perpetuum motion machines as models of knowledge) in contemporary ways of thinking. In Carnot's motor (or, more historically concrete, the steam engine), Serres saw a different model of knowledge, one that affected all domains of culture and directly threatened the base of the Newtonian model.[9] Thermodynamics' famous second law is different in this respect because, in contrast to the other thermodynamic laws which still work within the context of Newtonian mechanics, the tendency of entropy to increase probabilistically as time passes introduces a sense of irreversibility that is incompatible with this previous universal model of knowledge.

Moreover, the metaphor of the arrow of time associated with entropy's irreversibility not only gives direction to phenomena that were considered reversible by the Newtonian model (and thus a major preoccupation was to measure these processes equally both backwards and forwards). The direction implied by irreversibility is probabilistic and therefore always multidirectional (which is the reason why Serres will tell us, "Time doesn't flow, it percolates.").[10] In other words, the introduction of irreversibility also multiplies temporality: it is never just one arrow that is shot, so to speak. Rather than a temporally unified linearity, the arrow(s) of time imply a mosaic-like temporal multiplicity, a "knot of several times" as Serres put it, which directly alters the way we practice history.[11] In his typically poetic style Serres explains:

"We recognize several [times]: the irreversible, that of entropy, the fall towards disorder; that, on the other hand, which goes against the current, that of negentropy; the reversible, that of clocks, of the solar system, of our dating, that we have so long taken for that of history … Now what we are seeking in

renowned physicist Huw Price has a version of the Boltzmann Bomb argument as well, Huw Price: "Boltzmann's Time Bomb," in: *The British Journal for the Philosophy of Science* 53/1 (2002), pp. 83–119. Although Price adopts the exact same framework of Boltzmann planting an intellectual time bomb, his adaptation is preoccupied with attacking the asymmetry of the arrow of time and he appears to do so without being aware of the preceding tradition as presented here.

8 "Gerade viele aktuell interessierende Begriffe lassen sich im Sinne Canguilhems nicht als definierte begreifen. Sie sind konstitutiv unscharf, ihre Entwicklung ist nicht abgeschlossen, gerade die tendenzielle Unbeherrschbarkeit der Begriffe ist es aber auch, die unvorhergesehene Zusammenhänge stiftet." Ernst Müller/Falko Schmieder: "Einleitung," in: *Begriffsgeschichte in den Naturwissenschaften*, Berlin 2008, p. xviii.

9 "It was thermodynamics that shook the traditional world and shaped the one in which we now work." Michel Serres: "Language & Space: From Oedipus to Zola," in: *Hermes: Literature, Science, Philosophy*, ed. Josué V. Harari/David F. Bell, Baltimore 1982, p. 39; for focus on thermodynamics see especially Michel Serres: *Hermès IV: La Distribution*, Paris 1977; for secondary literature see e.g. Josué V. Harari/David F. Bell (eds.): "Introduction," in: Serres *Hermes*, pp. ix–xl, here pp. xix–xx; John Lechte: "Structuralism," in: *Fifty Key Contemporary Thinkers: From Structuralism to Post-Humanism*, London 1994, pp. 40–101, here pp. 95–100.

10 Michel Serres/Bruno Latour: *Conversations on Science, Culture, and Time: Michel Serres with Bruno Latour,* transl. Roxanne Lapidus, Michigan 1995, p. 58. In contemporary cosmology, theoretical physicist Lee Smolin is currently advancing a version of this radical idea of percolation.

11 Michel Serres: *Hermès V: Le Passage du Nord-Ouest*, Paris 1980, p. 163, as quoted in B. Herzogenrath (ed.): *Time and History in Deleuze & Serres*, London 2012, p. 213.

order to understand history, and not only that of the sciences, is a model that associates, combines and integrates these times."[12]

In order to comparatively evaluate Serres' model, the current paper puts forward a second candidate capable of operating on the premise of multiple times, thereby exploring the reach of both models. In the following pages, it will be shown that a recent reinterpretation of German historian Reinhart Koselleck's method of *Begriffsgeschichte* (as developed by Koselleck's team for the *Geschichtliche Grundbegriffe* lexicon, 1972–1997) provides such a complementary historical method.[13] This is done by further cultivating a crucial but as-of-yet undeveloped insight by the historian John Zammito. His paper "Drilling Down: Can Historians Operationalize Koselleck's Stratigraphical Times" elaborates on his original articulation of this reinterpretation, and briefly addresses the compatibility of Koselleck's theory of historical time(s) and the temporality of (non-linear) thermodynamics.[14] Therefore, the model provided by this reinterpretation of Koselleck's stratigraphical time(s) is of immediate interest to the aims of the present research.[15]

Whereas the vast majority of Koselleck's reception has reduced his notion of historical time(s) to a (linear) theory of periodization, Zammito and the Norwegian historian Helge Jordheim instead unequivocally discard all remnants of linearity in favor of a heterogeneous, multi-layered temporality. While Zammito initially opposed *Begriffsgeschichte* (for its alleged relapse into linearity), his attitude was revoked after the publication of Jordheim's "Against Periodization."[16] Following this, both authors directly contrast Koselleckian *Begriffsgeschichte* to Kuhnian *paradigms* and Foucaultian *épistèmes* – two highly influential figures in the field of history of science, whose theories, as will be addressed in part one and part three respectively, fail to escape linearity.[17] Koselleck, on the other hand, *is* able to avoid this linearity by recognizing how concepts fundamentally contain their "own internal temporal structure," characterized by being "multi-layered" and "complex."[18] By appreciating the layered, "intralinguistic"[19] temporal structure of concepts, *Begriffsgeschichte* displays how a *Begriff* evolves through the unfolding of stratification processes rather than following a uniform chronological succession of meanings.

Zammito's impulse to apply Koselleck to thermodynamics is, however, not the only – if perhaps the most recent – pressing call for a *Begriffsgeschichte* of 'entropy.' Internal developments within *Begriffsgeschichte* itself also affirm the necessity of such an undertaking: a shift toward scientific concepts has recently been registered meriting the diagnosis of a "scientification" within *Begriffsgeschichte*.[20] Moreover, since this scientification of *Begriffsgeschichte*, which encourages active but cautious experimentation with the historical method outside of the socio-political comfort zone in which Koselleck and the *Geschichtliche Grundbegriffe* lexicon operated, there have been numerous explicit demands for a *Begriffsgeschichte* of 'entropy' already. Most notably this call has been voiced by the editor of this journal and co-editor of the *Begriffsgeschichte in den Naturwissenschaften* vol-

12 Michel Serres: *The Birth of Physics*, ed. David Webb and transl. Jack Hawkes, Manchester 2000, p. 163, as quoted in B. Herzogenrath (ed.): *Time and History in Deleuze & Serres*, London 2012, p. 64.
13 For Serres' own historical model, cf. David Webb: "Michel Serres: From the History of Mathematics to Critical History," in Herzogenrath: *Time and History* (note 12), pp. 51–68.
14 John Zammito: "Drilling Down: Can Historians Operationalize Koselleck's Stratigraphical Times?," in: *Configurations* 23/2 (2015): pp. 199–215, here pp. 204–205; for original articulation see John Zammito: "Koselleck's Philosophy of Historical Time(s) and the Practice of History; Zeitschichten Studien zur Historik (Mit einem Beitrag von Hans-Georg Gadamer) by Reinhart Koselleck," in: *History and Theory* (2004) 43/1, pp. 124–135.
15 Koselleck's indebtedness to Ferdinand Braudel and Ernst Bloch for this geological metaphor of stratification and time-layers was often acknowledged by Koselleck himself as well as by contemporary historians operating in the field. See e.g. Helge Jordheim: "In the Layer Cake of Time: Thoughts on a Stratigraphic Model of Intellectual History," in: D. Timothy Goering (ed.): *Ideengeschichte heute. Traditionen und Perspektiven* (2017), pp. 195–214.
16 Helge Jordheim: "Against Periodization: Koselleck's Theory of Multiple Temporalities," in: *History and Theory* 51 (May 2012), pp. 151–171.
17 Zammito: "Koselleck's Philosophy of Historical Time(s)," "Drilling Down" (note 14); Helge Jordheim: "Does Conceptual History Really Need a Theory of Historical Times?," in: *Contributions to the History of Concepts* (2011) 6/2, pp. 21–41; Jordheim: "Against Periodization" (note 16).
18 Reinhart Koselleck: *Begriffsgeschichten: Studien zur Semantuk und Pragmatik der politischen und sozialen Sprache* (2002), Frankfurt a. M. 2006, p. 92, 95 as quoted in Jordheim: "Against Periodization" (note 16), p. 165.
19 Reinhart Koselleck: *Begriffsgeschichten* (note 18), p. 92, 95 as quoted in Jordheim: "Against Periodization" (note 16), p. 165.
20 See e.g. the second installment of Falko Schmieder's recent elaborative interview on the matter: Jonas Knatz/Falko Schmieder: "Begriffsgeschichte's Methodological neighbors and the Scientification of Concepts," in: *The Journal of the History of Ideas Blog,* posted October 2nd, 2019: https://jhiblog.org/2019/10/02/begriffsgeschichtes-methodological-neighbors-and-the-scientification-of-concepts/ (accessed on December 4th, 2019).

ume, Ernst Müller.[21] The current paper can not only be viewed as an attempt to satisfy this demand, but also as an experimental contribution to forward the current state of the field by applying *Begriffsgeschichte* to a scientific context while comparing Koselleck's model with Serres'.

To begin the historical 'drilling' (as Zammito put it in an attempt to operationalize Koselleck's theory of stratigraphical times) into the semantic layers of the entropy *Begriff*, awareness of the semantic particularity within different intellectual context is in order. As Ernst Müller says: "Indeed many key concepts of modern scientific disciplines [among which entropy is listed as an example, L.C.H.] are not restricted to their functions within a single discipline, nor can their semantics be defined by means of internal disciplinary categories."[22] Instead, their semantic composition is spread throughout "transdisciplinary discursive orders,"[23] which are to be carefully dissected here by taking four samples of the different semantic strata. These correspond to the four parts of the present paper.

In order to explore how the concept of entropy was shaped by and, in turn, shaped modernity, four samples from the multifarious intellectual history of 'entropy' were selected: Firstly, the nineteenth-century field of thermodynamics and the debates that gave rise to the concept in the first place will be examined, which requires a thorough contextualization of this discipline and its relation to the British and German industrial revolutions at the dawn of the Anthropocene. Secondly, in an attempt to counteract the disproportional reflection on Victorian British extra-scientific reception of 'entropy' in the secondary literature,[24] the present research stresses the Germanic context. This will be done through an analysis of the impact of thermodynamics and 'entropy' on the thought of three fundamental thinkers who have been grouped as the 'masters of suspicion' by Paul Ricœur,[25] 'the great unmaskers of the nineteenth century,[26] or comparable alternatives: Marx, Nietzsche, and Freud. Through their work, 'entropy' gained lasting importance in modern self-reflection. The third sample involves appropriations of entropy by information theory and cybernetics. Due to the formalization of language implied by these influential disciplines, connections with the rise of structuralism are emphasized. Finally, the contemporary meaning of entropy that arises from the 1970s onwards is examined by introducing four calls for a "fourth" law of thermodynamics, which involves a re-orientation towards the biosphere and life, a corresponding shift in visualizations of 'entropy' and a peculiar insistence on the relevance of scale.

The strategic excavation of these four samples of the semantic strata aims at subverting the reductionist conception of 'entropy,' by showing how the concept is epistemologically productive even beyond its strict allocated discipline. Furthermore, having shown how 'entropy' and the stochastic conception of the world it implies is becoming embedded deeper in our cultural-scientific practices reveals how this entanglement is not only changing the meaning of entropy, but the boundaries, concepts and methods of the disciplines it is assimilated into.

I. THE EMERGENCE OF 'ENTROPY' IN COSMOLOGICAL THERMODYNAMICS

Battles over the origin of the concept of entropy have been waged since its formal linguistic conception, and in some cases are still being fought out today. Although it is undeniable that Clausius coined the term in 1865,[27] others point to William Thomson's

21 See FIB's unfinished catalogue for the entropy entry: "Entropie," *Historisches Wörterbuch interdisziplinärer Begriffe,* last edited November 16th, 2017, https://begriffsgeschichte.de/doku.php/begriffe/entropie accessed November 1st, 2019; Schmieder/Müller: *Begriffsgeschichte in den Naturwissenschaften* (note 8); Ernst Müller: "Introduction: Interdisciplinary Concepts and their Political Significance," in: *Contributions to the History of Concepts* (2011) 6/2, pp. 42–52, here p. 44, 51.

22 Ernst Müller: "Introduction" (note 21), pp. 42–52, here p. 44.

23 Ibid.

24 One exception is Leonieke Vermeer, who addresses the literary reception of thermodynamic in two Dutch authors, while at the same time criticizing C.P. Snow's 'two cultures,' Leonieke Vermeer: *Geestelijke Lenigheid. De relatie tussen literatuur en natuurwetenschap in het werk van Frederik van Eeden en Felix Ortt, 1880–1930*, Groningen 2010.

25 Paul Ricœur: *Freud and Philosophy: An Essay on Interpretation,* transl. Denis Savage, New Haven 2008.

26 See Robert Brandom: "Reason, Genealogy, and the Hermeneutics of Magnamity," *UC Berkeley Graduate Council Lectures* 6, posted June 13th, 2013, https://www.youtube.com/watch?v=RiM7lwZWW5g (accessed July 1st, 2020).

27 Clausius did so with reference to the ambiguous Greek *τροπη* (*tropos*) - modifying tropein (*τρέπειν* or in-turning) from which it derives, so as to be able to juxtapose it to energy - though he translated it as *Verwandlung*. Thus, in light of the focus on the allegorical and metaphorical in the present study, it could be pointed out that entropy is etymologically related to 'trope,' with which it shares this Greek root. Rudolf Clausius: "Ueber verschiedene für die Anwendung bequeme Formen der Hauptgleichungen der mechanischen Wärmetheorie," lecture given at the Philoso-

(the later Lord Kelvin) formulation from 1852,[28] while some historians have preferred Boltzmann's 1895 probabilistic version as the 'true' starting point, or the proto-thermodynamicists such as French engineer Sadi Carnot or even the energy-thinkers in Antiquity.[29] Rather than getting stuck in the vortex of finding the 'true' discoverer, it is more productive to approach the arrival of 'entropy' by looking at the work done by historians of science analyzing the epistemological conditions in which the science of heat could attain its modern form.

The classic account on the emergence of linear thermodynamics remains Thomas S. Kuhn's essay on 'simultaneous discovery,' which preceded his paradigmatic *The Structure of Scientific Revolutions*.[30] Realizing that the emergence of thermodynamics is the most "striking instance" of this notion of 'simultaneous discovery,' this article was to become a major point of departure for what would grow into Kuhn's famous book on paradigms and their shifts.[31] Besides listing a number of European scientists who advance a more general theory of energy conservation (among others Sadi Carnot, Marc Séguin, and Justus Liebig), Kuhn uproots the standard narrative, which solely credited Helmholtz for articulating the first law (i.e. the law of energy conservation). Instead Kuhn finds three other scientists who made similar efforts between 1842–1847, publicly announced the law and added quantitative proof to it.[32] All, except indeed Helmholtz, were operating in ignorance of the work of the others. This co-occurrence was, according to Kuhn, possible for three reasons. Firstly, the "availability of conversion processes" meant scientists were, for the first time, confronted with energetic conversion in their daily lives, for example with batteries. Such experiences, secondly, became salient in the context of especially the French and English engineering traditions. And thirdly, the spirit of German *Naturphilosophie* had introduced a focus on transcendental energy with the power to unify all science and life to the European continent during the initial stages of the Industrial Revolution.[33] As Müller's *Begriffsgeschichte* of 'energy' emphasizes, this development not only meant energy became a physical concept for the first time, but – that "[a]s the law of the conservation of energy was so pervasive throughout nature, physics now became the leading science."[34] Physics became the discipline on which all others were henceforth modelled (physiology, for instance) and against which their claim to truth had to be measured.

While Kuhn's theory concerns the formation of the first law and thermodynamics generally, the first and second law appear to have essentially co-evolved. If energy remains constant at all times, the irreversible and inevitable dissipation of energy in (metallic or meaty) heat engines demands a supplementary principle. After all, energy, though remaining constant in the world, does get expended and released. While the second law demolished the metaphysical comfort provided by the law of conservation, Daggett tells us, "as scientists studied energy, it became almost immediately obvious that the energetic world was not constant."[35] Some even go so far as to claim that the conception of the second law actually precedes the formulation of the law of conversion, usually with reference to Sadi Carnot's 1824 work on the motor and the perpetual degradation of energy.[36] In any case, the marriage of energy and entropy was a strong, self-reinforcing one that led to new levels of sophistication as well as to a new cosmology.

The quick spread of the law of conservation is usually attributed to a cultural attitude in which scientific findings were directly meaningful to other socio-cultural contexts, embodied by, for instance, science popularizers such as John Tyndall and Balfour Stewart. Yet, the same does not hold for the second law, initially

phical Society of Zürich on April 24, 1865; for example crediting Clausius see Pasquinelli: "Introducing Four Regimes of Entropy" (note 3).

28 E.g. Ilya Prigogine/Isabelle Stengers: *Order Out of Chaos: Man's New Dialogue with Nature*, New York 1984.

29 E.g. Serres: *Hermes* (note 9); Samuel Sambursky: *The Physical World of the Greeks,* vol. 826, Princeton 2014.

30 Thomas S. Kuhn: "Energy Conservation as an Example of Simultaneous Discovery" (1959), in: *The Essential Tension: Selected Studies in Scientific Tradition and Change*, Chicago 1977; T. Kuhn: *The Structure of Scientific Revolutions* (1962), Chicago[4] 2012.

31 Kuhn: "Energy Conservation" (note 30), p. 69.

32 Namely, J.R. Mayer, James P. Joule, and L.A. Colding. Kuhn: "Energy Conservation" (note 30), pp. 66–67.

33 Kuhn: "Energy Conservation" (note 30), pp. 99–102.

34 "However, it was not the concept of energy itself that triggered an epistemic revolution in the middle of the nineteenth century. It was the law of the conservation of energy." Ernst Müller: "Energy," p. 29, see the following entry in this volume, transl. Anna Simon-Stickley.

35 Cara New Daggett: *The Birth of Energy: Fossil Fuels, Thermodynamics, and the Politics of Work*, Durham 2019, p. 42.

36 R. Duit: "Is the second law of thermodynamics easier to understand than the first law," in: *Tijdschrift Didactiek Natuurwetenschappen* 2/2 (1984), pp.102–112, here p. 103. Kuhn, however, argued against this reading in an earlier, lesser known paper, see Thomas Kuhn: "Carnot's Version of 'Carnot's Cycle,'" in: *American Journal of Physics* 23/91 (1955), pp. 91–95, here p. 93.

known as the dissipation (*Zerstreuung*) principle until Clausius coined the term entropy in 1865, where, according to some conservative estimates it would even take until the turn of the century before the *Begriff* would find a broader audience. The second law, according to Daggett, "kept the thoroughly mechanistic universe of the first law of thermodynamics from having the final word."[37] With the introduction of entropy a sense of irreversibility was added to the notion of cosmic energy, shattering older cosmologies that perceived nature as static and reversible. Anson Rabinbach, who is prominent in Müller's *Begriffsgeschichte* of 'energy' as well, captures this impact succinctly when he writes that "the paradoxical relationship between energy and entropy is at the core of the nineteenth-century revolution in modernity." [38] It shapes the modern conception of balance and change and constitutes a revolutionary shift, because it alters the way we perceive order: from order being the rule to order being the exception to the rule, the rule or tendency of order to perish. In other words, order becomes (thermodynamic) disequilibrium. A first dramatic instance of this shock follows from some of the "first fathers" of thermodynamics (including Helmholtz, Clausius, Thomson) extrapolating from this tendency of dissipation towards thermal equilibrium a "Final State Hypothesis" (signaling the imminent triumph of entropy in *Wärmetod*), after which it didn't take long before it signified inevitable deterioration, disorder and doom in the social realm.[39]

The manner in which this tremendous cosmological reversal was discussed differed substantially among the different centers of industrial production and scientific thinking. Most important were the differences between the competing nations of Victorian England and the drastically transforming German-speaking world. In Great Britain, the second law was met with more enthusiasm and, due to an already-existing mental infrastructure of thermodynamic ideas in these cultural realms, was quickly soaked up into literary and philosophical works from the 1860s on (perhaps most notably by Charles Dickens and Herbert Spencer), though its cosmological implications led to several frictions as well. As Kragh exposes with masterful detail, one of the first areas in which the second law was appropriated outside science is the 'entropic creation argument' – that is, the interpretation of the principle that energy always tends toward a maximum of disorder to imply a (created) beginning.[40] After all, if disorder is the state of the universe, who had created order? Just as captivating were the complementary apocalyptic visions of the heat-death of the universe and the associated image of the dying sun. The latter especially caused great anxieties in 'the Empire where the sun never set,' so that, "for many late Victorians, what the entropic end of the universe really meant was the end of the British Empire."[41] Thermodynamics' relationship with empire, however, runs deeper still: The direct interchangeability of insights derived from steam-engines and the industrial aspirations of Imperial Britain have led literary critic Katherine Hayles to remark that classical thermodynamics emerged as "the science of imperialism."[42]

Meanwhile, German imperialism diverged significantly from its British counterpart and was of another order of magnitude entirely. Furthermore, during the German 1860s and 1870s, the creationist connotations of 'entropy' ran into fierce resistance from the tradition of scientific materialists, which encompassed most German physicists. The scientific materialists, who followed the tradition of *Naturphilosophie* in direct opposition by actively refusing to practice any (theo-) philosophy whatsoever, were decisively shaped by the politically suffocating climate after the failure of the 1848 revolution. Described by Ernst Bloch as the classical country of 'non-synchronicity' (of both accelerating techno-economic progress and rigorous

37 Daggett: *Birth of Energy* (note 35), p. 73.

38 Anson Rabinbach: *The Human Motor: Energy, Fatigue, and the Origins of Modernity,* New York 1990, p. 63. Additionally, Serres describes: "Entropic irreversibility also changes direction and sign: negentropy goes back upstream." Serres: *Hermes* (note 9), p. 81.

39 In his own history of the reception of 'entropy,' Dan Styer: "Entropy as Disorder" (note 1) points to the widely-read autobiography of historian Henry Adams (1918) as the prime text responsible for the spread of the reading of 'entropy' as disorder in popular consciousness. Although Adams's apocalyptic and entropic historicism might be symptomatic for the technocultural shock of the Second Industrial Revolution (Mousoutzanis: *Fin-de-Siècle Fictions* (note 3)), Koselleck stands somewhat sympathetic to Adam's historicist-nomological model of acceleration as a heuristic: see Reinhart Koselleck: "Historia Magistra Vitae" in: *Futures Past: On the Semantics of Historical Times*, transl. Keith Tribe, New York 2004, pp. 26–43, here p. 42; Reinhart Koselleck: *Sediments of Time: On Possible Histories*, transl. and ed. Sean Franzel/Stefan-Ludwig Hoffman, Stanford 2018, p. 90, 265.

40 Helge S. Kragh: *Entropic creation: Religious contexts of Thermodynamics and Cosmology*, Burlington 2016.

41 Thomas Richards: *The Imperial Archive: Knowledge and the Fantasy of Empire*, London 1993, p. 87.

42 N. Katherine Hayles: *How We Became Posthuman: Virtual bodies in Cybernetics, Literature, and Informatics*, Chicago 2008, p. 40. See also Alf Hornborg: "Machine Fetishism, Value, and the Image of Unlimited Good: Towards a Thermodynamics of Imperialism," in: *Man* 27/1 (1992), pp. 1–18.

resistance against modernity), Germany's uprooting of all efforts at constructing liberal institutions left only science as a refuge for anti-religious, anti-autocratic and democratic ideals. Hence, the German scientists were especially eager to defend their intellectual space from being reinvaded by any unwanted biblical eschatology associated with the second law.[43]

One noteworthy example of what was perceived as a theological threat to the sober realm of scientific materialists is the controversy around Clausius' 1867-lecture at the German Association of Natural Scientists and Physicians. By contradicting the widely held materialist notion of an eternal and cyclical universe with his second law of thermodynamics, Clausius divided the German scientific community. William Thomson, whose earlier 1852-formulation of the second law has been described as "a dizzy leap from engine technology to cosmology," found agreement with Clausius on the final state hypothesis.[44] Influenced by geologists and evolutionary biologists (among which Charles Darwin was the most prominent), Thomson would challenge existing conceptions of the Earth's age and corresponding time-scales on the basis of his calculations of energy dissipation and, hence, render increasing scientific status to the idea of a dying sun.[45] While Thomson's contributions were to be superseded not long after,[46] retrospectively, his terrestrial focus can be read as symptomatic of the co-emergence of evolutionary theory and classical thermodynamics. As Daggett has convincingly argued, such co-evolution was the effect of "fossil fuel regimes connect[ing] the dizzying pace of industrial time to the deep time of planetary change."[47] However, these rapid cosmological advancements troubled the reception of 'entropy,' giving rise instead to the sentiment that (equilibrium) "thermodynamics turned its back on the real world" – not in the least because life itself seems to stand far from the constant increase of disorder that thermodynamic equilibrium implies.[48] As we shall see, it wasn't until the second half of the twentieth century that (far-from-equilibrium) thermodynamics would come to face the Earth (and its ecosystems) again.

In the same year as Clausius' lecture, a thought experiment was conducted by J.C. Maxwell, coined by Thompson as 'Maxwell's Demon' a few years later. Although initially Maxwell's attempt to 'pick a hole' in the second law (through the invention of an imagined intelligent being with the capacity of calculating, directing and ultimately reversing molecular flows) increased the sentiment that the first law was more fundamental than the second,[49] eventually his model would come to prove the probabilistic nature of irreversibility introduced by 'entropy.'[50]

As Müller stresses, however, it is through Ludwig Boltzmann's statistical reinterpretation of the second law that the scientific community would be exposed to this problematic notion of 'irreversibility' even more directly.[51] In response to Boltzmann's version of the law, two objections can be discerned: (a) the so-called 'Loschmidt-' or 'reversibility paradox' (*Umkehreinwand*), and (b) 'the recurrence paradox' (*Wiederkehreinwand*).[52] The subsequent clashes amounted to the next phase of debates on thermodynamics and cosmology. Boltzmann's paradoxical effort to argue for irreversibility through (reversible) mechanics of molecular gases in 1872 is at the center of this phase. After his Vienna colleague and former mentor Joseph Loschmidt addressed this supposedly contradictory nature of Boltzmann's effort (echoing a similar but less-heard argument by William Thompson), Boltzmann refined his theory and put probability at the heart of the matter. The objection made by Loschmidt juxtaposed the absolute validity of the law with the reversible terms in which the law was supposed to hold: Loschmidt contended that if the motion of all the increasingly disordered particles in Boltzmann's molecular gases were reversed (in accordance with classical dynamical time symmetry or time reversibility), order should return and entropy should decrease.

43 Cf. Frederick Gregory: *Scientific materialism in nineteenth century Germany*, Dordrecht 1977.

44 Prigogine/Stengers: *Order out of Chaos* (note 28), p. 116. Although we might concede with Kragh that this or the heat-death articulation by Clausius were preceded by *Naturphilosophische* final state of equilibrium hypotheses (such as Jean-Sylbvain Bailly's from 1777). Kragh: *Entropic creation* (note 40), p. 20. At the same time, we might have to point out that the 'final state hypothesis' is not reserved to the past: astrophysicist and 'social media phenom' Katie Mack has recently revitalised the profession of science popularisers in the line of heat-death prognoses, see Katie Mack: *The End of Everything (Astrophysically Speaking)*, New York forthcoming.

45 Mousoutzanis: *Fin-de-Siècle Fictions* (note 3), pp. 60–63

46 Ibid., p. 63.

47 See first epigraph in part four; Daggett: *Birth of Energy* (note 35), p. 56.

48 L. Truesdell as quoted in Duit: "Is the second law …" (note 36), p. 103.

49 See e.g. Kragh: *Entropic creation* (note 40), p. 64.

50 Mousoutzanis: *Fin-de-Siècle Fictions* (note 3), p. 85.

51 Müller: "Energie" (note 34), p. 127.

52 Stephen G Brush: *The Temperature of History: Phases of Science and Culture in the Nineteenth Century*, New York 1978, pp. 66–71.

Boltzmann answered this reversibility paradox by showing that while reversing a disordered state back into an ordered state is statistically possible, such reversal will only end up in another disordered state if the system was not before in an ordered state (which holds for the overwhelming majority of systems).[53] Henceforth, not only was the second law no longer an absolute but a statistical one, but by replacing causal explanation of natural events with matters of probability (i.e. stochastics), the meaning of mechanics would transform radically and would eventually become the model for other scientific domains too.

The second objection to Boltzmann's irreversible second law arose from the incompatibility of the reversible Newtonian framework. Building on Henri Poincaré's mechanical recurrence theorem, which calculated the amount of time necessary for mechanical systems to recur to their initial state, mathematician Ernst Zermelo challenged Boltzmann's hypothesis in 1896. He did so on the grounds that the recurrence theorem entails that given enough time the system in question (the universe) would mechanically return to its initial position, thus undermining the constant, unilinear increase of entropy. It was Zermelo's conviction that it was the (Newtonian) mechanical worldview suffering the defeat, as he held the entropy law to be absolute. The sheer magnitude of the temporal scales involved in such recurrences forced Boltzmann into further cosmological considerations. The (admittedly speculative) cosmological picture that he conceived considered the universe as a dead, closed whole in equilibrium, wherein fluctuations create local islands or pockets of negative entropy: "There must be then in the universe, which is in thermal equilibrium as a whole *and therefore dead*, here and there relatively small regions of the size of our galaxy (which we call worlds), which during the relatively short time of aeons deviate significantly from thermal equilibrium."[54] Besides this renovated image of the universe, Boltzmann also ventured a thought that anticipated the later information theoretical appropriation of the concept of entropy. In reference of Maxwell's Demon and its imagined capacity of processing information at the molecular level, Boltzmann wondered in 1904 whether entropy could be understood simply as missing information. This idea would turn out to be, as we shall see, an intellectual time bomb.

53 Ibid., p. 66.

54 Quoted in Kragh: *Entropic creation* (note 40), p. 185 (my emphasis).

However, by 1904 the scientific climate had changed once more: with scientific materialism facing decline, renewed idealism became popular. This epistemic attitude was paralleled by economic crises, the development of a secularized work ethic and the moral denunciation of decadence, in which apocalyptic futures and notion of degeneration reigned supreme. The co-development the entropy discourse and the debate on social or racial decay has been widely noted by historians. Besides the most vocal thinkers to stress the analogy between entropic and social decay, Mousoutzanis has revealed the influence of 'entropy' in many other contemporary scientific figures (such as T.H. Huxley) as well as in literary movements.[55] In this, he contributes to a growing interest in the impact of thermodynamics on Victorian literature and philosophy.[56] An equivalent scholarly attention for the impact of 'entropy' on the German literary and philosophical movements is, however, lacking. This can be ascribed partly to the aforementioned divergences in intellectual history. To counter this tendency, and while Boltzmann's time bomb is ticking, I will proceed to introduce three German-speaking pillars of modern thought, tracing the concept of entropy in the thought of Marx, Nietzsche, and Freud.

II. MARX, NIETZSCHE, FREUD, AND 'ENTROPY'

As discussed in the previous part, the historical circumstances in the second half of the nineteenth century and until the beginning of the First World War differed substantially between the British and German context regarding empire and attitudes towards science and secularism. The present part of this paper will take a closer look at the outer edges of the semantic layer of the *Begriff*, by analyzing how in the German(ic) context during this time the second law is absorbed in and transformed the thought of Karl Marx, Friedrich Nietzsche, and Sigmund Freud. Contrary to what one might expect in light of the post-1970s, "postmodern" renewed attention for their respective bodies of work, surprisingly few historians of ideas or historians of science have taken note of

55 Mousoutzanis: *Fin-de-Siècle Fictions* (note 3), p. 63.

56 See e.g. Allen MacDuffie: "Victorian Thermodynamics and the Novel: Problems and Prospects," in: *Literature Compass* 8/4 (2011): p. 206–213; Jessica Kuskey: "Our Mutual Engine: The Economics of Victorian Thermodynamics," in: *Victorian Literature and Culture* 41/1 (2013): pp. 75–89; Ted Underwood: *The Work of the Sun: Literature, Science, and Political Economy, 1760–1860*, New York 2005.

the interest all of these three critics of modern thought took in thermodynamics while the science of heat was still in its infancy. Such intellectual accord is not only indicative of how enormously influential the concept of entropy was during this formative stage, but also allows for a unique angle into the relation of the concept and the intellectual history of modernity, in other words, into its status as a *Grundbegriff*. As will become clear by critically using Michel Serres as interlocutor to zoom in on these three, even Serres himself underestimated the epistemological impact of 'entropy.' The intimate relationship between 'entropy' and the industrial steam engine, or the co-arrival of evolutionary theory, thermodynamics and what Daggett has called the beginning of the fossil fuel regime is most vividly embodied in the work of the distinguished analyst of industrial capitalism, Karl Marx.[57]

Marx's relationship with thermodynamics, if mentioned at all, is not usually included in historical and philosophical scholarship. The influence of thermodynamics has been all but silenced. Michel Serres himself, I would contend, is guilty of this silent treatment. Despite mentioning Marx as a thermodynamically influenced thinker, Serres withheld from explicating exactly how deep Marx's engagement with the science of heat was. Moreover, this influence of thermodynamics has been veiled and hidden by the ever persistent charge of pseudoscience levelled against Marx (and Engels) – quite in contrast to their self-proclaimed scientific socialism. This charge was made in no small measure from the principles of thermodynamics, a fact that was overlooked for a long time. The widespread idea that Engels (and Marx by implication) rejected the second law of thermodynamics[58] took root particularly within the discipline of ecological economics. John Foster and Paul Burkett have, however, shown that this position can be traced back to accusations made by Martinez-Alier in the early 1980s on the basis of a misreading of a few paragraphs of Engels' *Dialectics of Nature* and a 1869-letter to Marx.[59]

This letter, though not the only trace of both thinkers' preoccupation with thermodynamics, does not, on closer inspection, reject the second law.[60] What is contained therein is, in fact, a rejection of its interpretation as the heat death hypothesis: in line with the scientific materialists discussed in the previous part of this paper, Engels discards all religious connotations of the heat death eschatology or the (divine or external) "first heating" that it presupposes, warning of "clerics seiz[ing] […] this theory."[61] Foster & Burkett convincingly argue that the same subtle differences in meaning can be seen in mentions of the *Begriff* in *Dialectics of Nature*, where Engels includes Clausius and Thomson for their heat-death eschatology in his polemic.[62] Thus, what Engels was objecting to was not the general applicability of thermodynamics to the realm of socio-politics or the economy, but rather the religious abduction of the concept.

Besides this surface-level controversy, another reading finds a more profound engagement with the entropic tendency in Marx's prognosis of capitalism's irreversible collapse in *Das Kapital* – more specifically in the infamous tendency of the falling rate of profit. According to this reading, Marx's thought was decisively altered through the rise of thermodynamics. At first this meant dropping the *naturphilosophische* notion of 'labor' in favor of Helmholtz's 'labor-*power*.' But increasingly thermodynamics came to influence not only Marx' attitude towards the working body, but also, paired with his conviction for the necessity to overcome capitalism, towards the system of capitalism as a whole.[63] Capitalism, thus, could be seen as a thermodynamic engine. As Amy Wendling has put it, Marx's image of capitalism is akin to "a poorly designed steam engine that must run at top speed, despite the fact that this speed contributes to a greater overall loss of heat. This increased overall heat

57 Daggett contrasts the modern fossil fuel regime associated with the Anthropocene to precapitalist *solar* regimes: cf. Daggett: *Birth of Energy* (note 35).

58 See e.g. Kragh: *Entropic creation* (note 40).

59 John Bellamy Foster/Paul Burkett: *Marx and the Earth: An Anti-Critique*, Leiden 2016, pp. 172–174; Friedrich Engels: *Dialectics of Nature* (1883), preface and notes by J.B.S. Haldane, New York 1940; Friedrich Engels: "Manchester, 21 March 1869" (1931), in: Karl Marx/Friedrich Engels: *Collective works* vol. 43, London 1988, p. 245: digitalized edition 2010, http://www.koorosh-modaresi.com/MarxEngels/V43.pdf (accessed 18th December 2019).

60 It is known, for example, that Marx and Engels read W. R. Grove's *The Correlation of Physical Forces* closely by 1865 successively – a 1850 publication that is deeply engaged with the second law. Foster/Burkett: *Marx and the Earth*, p. 173.

61 "Ich warte nur darauf, daß die Pfaffen sich dieser Theorie […] bemächtigen. […] Der erste Anstoß Newtons verwandelt sich in eine *erste Erhitzung*" (my emphasis). Friedrich Engels, in: Karl Marx/Friedrich Engels: *Collective works* (note 59), p. 245.

62 Foster/Buckett: *Marx and the Earth*, pp. 174–179.

63 Rabinbach: *Human Motor* (note 38), p. 46; Amy Wendling: *Karl Marx on Technology and Alienation,* London 2009, p. 84.

can be neither transformed into productive work nor released in adequate quantities. Instead it threatens to blow up the engine itself."[64]

Whereas Wendling builds on the work of the aforementioned Anson Rabinbach, Matteo Pasquinelli goes even further and recognizes Marx's ability to conceptually integrate 'entropy' not just in capitalism's finitude, but also in his problematization of capitalist accumulation: "In economics, the other side of the problem of entropy is indeed the problem of surplus and its accumulation. Marx perceived clearly the problem of scale, when the accumulation of surplus produces something different and breaks through another ontological scale – he saw when surplus becomes capital."[65] Precapitalist societies produce surplus, but only when profit becomes the goal in itself, when accumulation feeds back into itself, entropy is seized upon. Recall that while entropy must always increase at the highest scale of the closed system, at a lower scale, *locally*, deviations can be introduced from which disorder can be 'exported.' It is this continuous dynamic inherent to the machine of capitalism – a dynamic of overcoming and re-implementing (scalar) limits for the sake of production for profit – that allows it to process entropy as well as produce it faster than ever before. This grand rescaling enterprise, increasingly transforming the techno-economic landscape and enforcing itself onto the existing physical conditions of exchange, is called 'Capital.' In the discussion of its circulation and conversion, Marx notes in his draft for *Das Kapital*, "Capital by its nature drives beyond every spatial barrier."[66]

At this point, we are tempted to ask how Marx, as Rabinbach puts it, "discovered the principle of entropy at work in capitalism"?[67] What enabled him to draw the analogy between the entropy law and his study of social factory-work relations? Despite not having access to instruments to empirically observe batteries, Marx did research on the circulation and conversion of capital and was well-versed not only in German *Naturphilosophie* but also in its materialist successors – who, after all, formalized thermodynamics.[68] Moreover, his notebooks reveal that, in fact, Marx was engaged with the third and final of Kuhn's previously discussed requirements as well: namely, the French and English engineering tradition. Most directly he drew on Pelligrino Rossi's physiological political economy from the 1830s–40s, whose early application of 'labor-power' was evidently stimulated by Carnot's *Reflections*.[69]

Rabinbach's history of the metaphor of "the human motor" goes well beyond Marx to characterize the rise of the welfare state and its corresponding "social modern" or politico-sociological, physiological notion of work as a result of (societal) energy conservatism following the discovery of entropy.[70] Wendling counters, however, that this late-nineteenth- and early-twentieth-century model of work "does not wholly supplant the old moral discourse," but rather "springs up alongside it."[71] It is from this progressivist, physiological notion of labor that another interpretation of the *Begriff* as 'exhaustion' flourished. The historical importance of large-scale state-sponsored projects focused on maximizing efficiency and thereby combatting the "entropy, or fatigue"[72] of industrial labor (such as Fordism, Taylorism, Bolshevism) is evidence of the reformist interpretation of 'entropy' in terms of a progressive, secularized work ethic.[73] By the turn

64 Wendling: *Marx on Technology and Alienation* (note 63), p. 91.

65 Moreover, Pasquinelli: "Introducing Four Regimes of Entropy" (note 3), p. 4 will add: "This vision of scale is precisely what is missing in the current economic and political debate on energy and entropy."

66 Karl Marx: *Grundrisse: Foundations of the Critique of Political Economy (Rough Draft)* (1939–1941), transl. Martin Nicolaus, London 1973: https://www.marxists.org/archive/marx/works/1857/grundrisse/index.htm (accessed December 27th, 2019), p. 449.

67 Rabinbach: *Human Motor* (note 38), p. 80.

68 Cf. Gregory: *Scientific Materialism* (note 43).

69 The engineering term puissance du travail is also quoted directly in Marx. Rossi was Italian by birth, but succeeded J.-B. Say at the College de France as chair for political-economy. These notebooks have been available since Rainer Winkelmann's transcription and editing in Karl Marx: *Exzerpte über Arbeitsteilung, Maschinerie und Industrie. Historisch-kritische Ausgabe*, ed. Rainer Winkelmann, Frankfurt a. M.1982, p. CLIX, 95, 230. For Liebig and Büchner, cf. Marx's so-called 'Londoner Heften' from 1851 and *Grundrisse*: Karl Marx: *Marx-Engels Gesamtausgabe,* Zweite Abteilung, 1 "Ökonomische Manuskripte 1857/58 (*Grundrisse der Kritik der politischen Ökonomie*)," Amsterdam 2006; Karl Marx: *Marx-Engels Gesamtausgabe,* Vierte Abteilung, 9 "Exzerpte und Notizen. Juli bis September 1851 (*Londoner Hefte XI–XIV*)," Amsterdam 1991.

70 Rabinbach: *Human Motor* (note 38), p. 1, 8, 10.

71 These progressivist scientists aimed to answer what we now know as 'the social question,' or 'the worker question,' or 'maakbaarheid van de samenleving.' Wendling: *Marx on Technology and Alienation* (note 63), p. 79.

72 With regards to the latter, see also the recent Diana Kurkovsky West: "Cybernetics for the command economy: Foregrounding entropy in late Soviet planning," in: *History of the Human Sciences* 33/1 (2020), pp. 36–51.

73 For the Germanic world, Rabinbach identifies this shockwave of the social-reformist, physiological interpretation of entropy overtly as 'Social Helmholtzianism' in chapter five, and traces its implementation in Germany through the

of the century, as will be discussed shortly in more detail, the Austrian school of these thermodynamic physiologists would become especially relevant for intellectual history as the birthplace of psychoanalysis.

Not unlike the case of Marx, Nietzsche presents us another instance where the impact of thermodynamics has been obscured within the history of science and history of ideas. What has been described as Nietzsche's most fundamental thought – the eternal return, or eternal recurrence – puts the thinker squarely in the thermodynamic context, specifically the Boltzmann-Zermelo debate on the recurrence paradox, discussed in the last part of this paper.[74] Nietzsche's indirect participation has seldomly been acknowledged by historians of science, as his doctrine of the eternal recurrence is interpreted as invoking pagan cyclicality and thus bearing no explanatory power for scientific disputes of cosmology.[75] While both indeed comprise the idea that everything that has happened will repeat itself an infinite number of times, Nietzsche's doctrine of the eternal return of the same lets itself be distinguished from ancient cyclical theories of time by its positive instrumentalization of this idea (of 'time as a flat circle') towards affirmation (of life) rather than passive nihilism or than a mere cosmological precondition based on the cyclical movement of celestial bodies.[76] Moreover, Nietzsche did draw heavily on the ideas of thermodynamics, as becomes apparent when he says "[t]he law of conservation of energy demands *eternal recurrence*."[77] Among these historians of science, Brush is the exception that proves the rule when he acknowledges that Nietzsche's conception of the eternal recurrence is "not at all nonsense."[78]

Among the sceptics we find Michel Serres.[79] His attitude towards Nietzsche is one of complete antipathy. As noted by Duncan Large in his "Hermes contra Dionysus," Serres' problem with Nietzsche is primarily his interpretation of thermodynamics.[80] Serres observes Nietzsche's familiarity with Johannes Vogt, Clausius, Robert Mayer, and Thomson and, as with Marx, naturally gathers him with the thinkers influenced intellectually by Carnot's motor.[81] Yet, Nietzsche's eternal recurrence is sufficient reason for Serres to denounce him as suffering from old, early-thermodynamic metaphysics: "[I]ts circulation," Large notes, "is the perfect expression of the *first* law of thermodynamics," but eternal recurrence is completely at odds with the *second*.[82] Although he provides key insight in Serres' dismissal of Nietzsche, I argue that Large's account of the eternal recurrence as a theory that "purposely spurns scientific validation" short-circuits its potential.[83]

Tying into the previous part of this paper, I will argue that it is not necessary to subvert cosmology as a science (as Large proceeds to do) in order to make Nietzsche's eternal recurrence work, nor is it affected by passive assertions that "thermodynamics precludes" his doctrine.[84] In this vein, Nietzsche, once

succession of the ergonomic, physiological schools associated with the militarist Otto Fischer (and associates) on the one hand and 'psycho-physician' Emil Kraepelin (and Hugo Münsterberg) on the other in the 1890s, by Max Weber's efforts in the first decade of the next century with the project of the Verein für Sozialpolitik providing policy proposals for die Arbeiterfrage in chapter seven. After the 1910s, the ergonomic knowledge started to leak out of the European laboratories into society, and affect the way labour was organized. See, Rabinbach: *Human Motor* (note 38), p. 118.

74 See e.g. Peter de Graeve: *Friedrich Nietzsche: Chaos en [ver]wording*, Amsterdam 2004, p. 20.

75 See e.g. Kragh: *Entropic creation* (note 40), pp. 139–143; or Stanley L. Jaki: *Science and Creation, from Eternal Cycles to an Oscillating Universe*, Edinburgh 1974, p. 324.

76 "The eternal hourglass of existence is turned upside down again and again, and you with it, speck of dust!" Friedrich Nietzsche: "aphorism 341," in: *The Gay Science* (1882), transl. Walter Kaufmann, New York 1974, p. 273. Within the reception of the eternal recurrence, a "particularly 'French' orientation of the reading of Nietzsche during the second half of the twentieth century" has been identified, which advances an interpretation of eternal return with a focus on *difference* contrary to Nietzsche's own affirmation of the eternal return of the same, in the works of Deleuze, Derrida, Klossowski, Bataille, etc. Catherine Malabou: "The Eternal Return and the Phantom of Difference," in: *Parrhesia* 10 (2010), pp. 21–29, here p. 21. In the work of Paulo D'Iorio which will be introduced shortly in greater detail, this French reading is shown to be relying on an aphorism posthumously fabricated by the editors of *The Will to Power*, merging two posthumous fragments (that include discussion of thermodynamicist Johannes Vogt), and ultimately hinging on mistranslation. For difference between ancient and Nietzsche's eternal return, see Paulo D'Iorio: "The Eternal Return: Genesis and Interpretation," transl. Frank Chouraqui, in: *Lexicon Philosophicum: International Journal for the History of Texts and Ideas* 2 (2014), pp. 1–43, here p. 9n17.

77 Friedrich Nietzsche: *KSA 12, Nachgelassene Fragmente 1885–1887*, vol.12 in *Sämtliche Werke: Kritische Studienausgabe*, eds. Giorgio Colli und Mazzino Montinari, Berlin 1988, p. 205.

78 Brush: *Temperature of History*, p. 76.

79 Serres' engagement with Nietzsche remains largely untranslated as of yet.

80 Duncan Large: "Hermes contra Dionysus," in: Babette E. Babich/Robert S. Cohen (eds.): *Nietzsche, Epistemology, and Philosophy of Science* 204, Boston 1997, pp. 151–161.

81 Serres: *Hermès IV* (note 9), p. 69.

82 Large: "Hermes contra Dionysus" (note 80), p. 153.

83 Ibid., p. 154.

84 Ibid., p. 154; Kragh: *Entropic creation* (note 40), p. 143.

portrayed as prophet for postmodernism, has recently been credited by more outlandish scholars as foreseeing quantum mechanics.[85] Even more creatively, Daniel White has advocated for a parallel reading of Maxwell's Demon and of Nietzsche's *Beyond Good and Evil*, emphasizing Nietzsche's take on thermodynamics.[86] Instead, I would like to briefly stop at the neglected and unpublished notebook from spring to fall of 1881, kept by the Weimar's Goethe-Schiller archives as the 'M III 1' notebook and which Nietzsche wanted to use for his intended scientific exposition of eternal recurrence.

This octavo notebook (16x23) bound in a brown cover is the clearest surviving proof of Nietzsche's unrealized ambition to dedicate a full decade to a scientific exposition of the eternal recurrence. It remained unpublished in full until 1973 but has recently been made available online.[87] In a piece of brilliant scholarship, Paolo D'Iorio has commented on this notebook and its significance to eternal recurrence.[88] In its appendix, moreover, D'Iorio compares Nietzsche and Boltzmann. He finds many parallels, for example that "Boltzmann accepts the 'paradox' of recurrence – that is the eternal return of the same – as a legitimate consequence of the probabilistic conception of thermodynamics."[89] Both thinkers reject the final state hypothesis. Nietzsche's dismissal of the heat death is substantiated by the claim that if our universe would contain such a climactic endpoint, "this goal would have been reached" already.[90] Nietzsche and Boltzmann also found common ground in their shared conviction of the universe being dead. Nietzsche writes: "The most profound mistake possible is to affirm that the universe is itself an organism. … How? The inorganic would be the development and the decadence of the organic?! Horse-shit!!"[91]

Hence Serres' dismissal of Nietzsche from the perspective of thermodynamics appears to be premature. We might note, as Large does, that his attitude towards Nietzsche was influenced by his opposition to "Nietzsche's French Moment."[92] Taking into consideration that post-1945 France was a center of Western Marxism, we may, as Serres himself reveals, then, venture that it was a similar attitude that lead him to dismiss deeper engagement with Karl Marx's thermodynamic background.[93] One thinker exempt from such hostility on Serres' behalf, however, is Sigmund Freud. Serres boldly proclaims: "Freudian time is irreversible."[94]

85 See e.g. Marinus de Baar: "Review: Nietzsche, voorloper van de quantumfysica," in: *Trouw*, 03.04.04, https://www.trouw.nl/cs-b1d62063 (accessed December 12th, 2019); de Graeve: *Chaos* (note 74).

86 Daniel White: "Nietzsche's Demonology: Beyond Good & Evil in the Mode of Information," in: *Resetting Theory* 019 (Febr. 2010).

87 The 1973 version was edited by Giorgio Colli and Mazzino Montinari, who are responsible for the *Kritische Studienausgabe* (henceforth KSA), a 15 volume collection of his works including posthumous fragments. Montinari would explain that the preceding editions still lacked an consistant chronology because they weren't able to separate two layers of writing satisfyingly – a problem solved after having the ink tested; Friedrich Nietzsche: *KSA*: *Nachgelassene Fragmente 1880–1882*, vol. 9 of: Giorgio Colli/Mazzino Montinari (eds.) *Sämtliche Werke: Kritische Studienausgabe*, Berlin 1973/1988. The online facsimile version of the M III 1 notebook can be found at the Digital Facsimile Edition of the Nietzsche Estate (DFGA): http://www.nietzschesource.org/DFGA/M-III-1.

88 D'Iorio: "Eternal Return" (note 76).

89 Ibid., here p. 43. Additionally, this point is currently still being debated within contemporary cosmology. Among the strongest rebuttals of the standard narrative of so-called cosmic inflation comes from a cyclic conception of entropy, or popularly grasped as Big Bounce models, see e.g. Paul Howard Frampton: "Cyclic entropy: An Alternative to inflationary cosmology," in: *International Journal of Modern Physics* 30/21 (2015).

90 Both an early version of the famous dismissal (which can be found in posthumous fragment 11[245], p. 534) and additional argumentation against the universe being alive, or being an organism see Friedrich Nietzsche, M III 1, published in *KSA* 9 (as fragment 11[201]), p. 522 and translated by Paulo D'Iorio in D'Iorio: "Eternal Return" (note 76), p. 34: "In the modern scientific realm, what corresponds most to the belief in God is the belief in the whole as an organism: this disgusts me. Turning what is absolutely rare, unspeakably derivated, the organic, which we perceive only on the crust of the earth into the essential, the universal, the eternal! This is humanization of nature all over again! … If the universe could ever become an organism, it would already have become one.", and the original German: "Das modern-wissenschaftliche Seitenstück zum Glauben an Gott ist der Glaube an das All als Organismus: davor ekelt mir. Also das ganz Seltene, unsäglich Abgeleitete, das Organische, das wir nur auf der Kruste der Erde wahrnehmen, zum Wesentlichen Allgemeinen Ewigen machen! Dies ist immer noch Vermenschung der Natur! […] Wenn das all ein Organismus werden könnte, wäre es einer geworden."

91 "Der tiefste Irrthum ist, uns das All selber als etwas Organisches zu denken […] Wie! Das Unorganische wäre zuletzt gar die Entwicklung und der Verfall des Organischen! Eselei!!" Friedrich Nietzsche, M III 1, p. 74, published in the *KSA 14, Kommentar zu den Bänden 1–13*, vol. 14, in: Giorgio Colli/Mazzino Montinari (eds.): *Sämtliche Werke: Kritische Studienausgabe*, Berlin 1988, p. 254 (my translation). For the original page, see http://www.nietzschesource.org/DFGAapi/images/DFGA/M-III-1/secondary/medium/M-III-1,74.jpg (accessed January 10th, 2020).

92 Large: "Hermes contra Dionysius" (note 80), cf. Serres/Latour: *Conversations* (note 10), pp. 22-26.

93 Serres/Latour: Conversations (note 10), p. 5.

94 Serres: *Hermes* (note 9), p. 72.

Freud's connection to 'entropy' and its various interpretations is evident throughout his work – and that of historians studying it.[95] Not only did Freud read Nietzsche (the parallels between the eternal recurrence and Freud's notion of 'death drive' are particularly striking),[96] but his education as well as his theories bear a strong mark of Helmholtzian physiology. The key-figure for this heritage can be identified as the renowned Wilhelm von Brücke. As one of the best students and later friends of Helmholtz, Brücke would continue the 'Helmholtz school of Medicine' in Vienna, which rejected *Naturphilosophie* for the materialism of "physicalistic" physiology.[97] Freud entered the medical school in Vienna in 1873 and was shaped by Brücke and his laboratory works from 1877–1883, ultimately building a close relationship (Freud actually named his third son after Brücke).[98] Notwithstanding this biographical fact, the renowned Frank Sulloway has downplayed this Helmholtzian heritage in favor of Freud's vitalistic biologist sources (such as Fechner's constancy principle and Weissmann's work on plasm).[99] Contrary to Sulloway's intentions, however, this does not undermine the clear yet complex connection of the death drive to thermodynamics.

Death drive or Thanatos, that cornerstone of Freud's drive theory which he observed in 'shell-shocked' World War I victims, is complementary to the pleasure principle or Eros and was described in *Beyond the Pleasure Principle* as "an urge inherent in organic life to restore an earlier state of things." [100] Thus, the human being always tends toward the inorganic state of death – wherein we can clearly see invoked the popular reading of 'entropy' as the return to inertia. However, beyond this simple sense of a primordial desire for self-destruction lies another, more fundamental dynamic in the new layer of meaning of 'entropy' as *Todestrieb*: a dynamic of the intricate relationship between organic life and its alterity in inanimate death. In this dynamic an entropic principle can be discerned, for the organism is described as directing itself towards quiescence and (ultimately, fatal) rest by its attempt to keep the quantity of energy or excitation as low as possible; "not so low as to 'wind down,' to approach death, but low enough not to 'overstimulate' the organism."[101] And Elisabeth Grosz continues, "Life can be seen, on this Freudian scenario, as the limited deferment or delay of the death drive, a detour of death through the pleasure principle."[102] In other words, Freud's theory of the death drive blurs the distinction between the organic and the inorganic and views the intricate relationship of life and death as a function of one another. It should be noted that in his discussion, Freud does not engage with the work of Sabina Spielrein (to whom the death drive arguably should be attributed to, as is tentatively admitted in a footnote)[103] nor does he mention entropy explicitly (although he does so earlier in his career).[104]

However, this didn't stop his students (Alexander, Bernfeld, Feitelberg, Nunberg, and others) from consistently seeking to ground Freud's theory scientifically in terms of the second law of thermodynamics – albeit not to everyone's approval. Only one year after Freud expanded on his theory in *Civilization and its Discontents* (1930), a debate on the legitimacy of this physical scientific basis would unfold in several publications in the *International Journal of Psycho-Analysis*.[105] In the decades that followed, Freud himself would occasionally be criticized as misusing thermodynamics. After all, organisms are not closed systems where entropy (and thus *Todestrieb*)

95 For a Hayden White-inspired comparative study of the entropy 'trope' in Freud, see Martin E. Rosenberg: "Dynamic and Thermodynamic Tropes of the Subject in Freud and in Deleuze and Guattari," in: *Postmodern Culture* 4/1 (1993).

96 E. g. A. H. Chapman/M. Chapman-Santana: "The Influence of Nietzsche on Freud's ideas," in: *Br J Psychiatry* 166/2 (1995): pp. 251–253.

97 Siegfried Bernfeld: "Freud's Earliest Theories and the School of Helmholtz," in: *The Psychoanalytic Quarterly* 13/3 (1944): pp. 341–362.

98 Frank J. Sulloway: *Freud, Biologist of the Mind: Beyond the Psychoanalytic Legend*, Harvard 1992, p. 15.

99 Sulloway: *Freud* (note 98).

100 Sigmund Freud: "Beyond the Pleasure Principle" (1920), transl. James Strachey in: James Strachey (ed.): *The Standard Edition of the Complete Psychological Works of Sigmund Freud XVIII*, London 1955b, p. 36.

101 Elizabeth Grosz: *Space, Time, and Perversion: Essays on the Politics of Bodies*, New York 1995, p. 201.

102 Ibid.

103 Referring to this footnote of Freud's, Kirsch described Spielrein as follows: "She is no longer just a footnote in psychoanalytic history, and her papers linking sexuality, destruction, and creativity have become better known." Thomas B. Kirsch: *Jungian Analysis, Depth Psychology, and Soul: The Selected Works of Thomas B. Kirsch,* New York 2018, p. 48. For the footnote in question, see Freud: *Standard Edition XVIII*, p. 55n1.

104 For explicit references to entropy by Freud, see the well-known Wolfman essay, Sigmund Freud: "From the History of an Infantile Neurosis" (1918), transl. James Strachey in: James Strachey (ed.): *The Standard Edition of the Complete Psychological Works XVII*, London 1955a, pp. 3–179.

105 Siegfried Bernfeld/Sergei Feitelberg: "The Principle of Entropy and the Death Instinct," in: *International Journal of Psycho-Analysis* 12 (1931): pp. 61–81; Reginald O. Kapp: "Comments on Bernfeld and Feitelberg's "The Principle of Entropy and the Death Instinct," in: *IJoP* 12 (1931): pp. 82–86; L. S. Penrose: "Freud's Theory of Instinct and Other Psycho-Biological Theories," in: *IJoP* 12 (1931): pp. 87–97.

holds. Animate or living forms of (organic) matter are highly ordered open systems that absorb energy from sources so as to combat entropy. Thus, Freud's ideas on entropy in organisms from the perspective of the hydraulics of desire were subsequently denounced in the 1950s by Ernest Jones (with reference to Erwin Schrödinger's paradigmatic work on negentropy – a counter-*Begriff* to which we will return in the next part) and in the 1970s by Anthony Wilden (with reference to information theory and cybernetics).[106] These reoccurring charges against Freudian psychoanalysis, however, often suffer from the same ahistorical weakness: as Lydia Liu brutally laid bare in Wilden's case, his denouncements of Freud's entropy in favor of Claude Shannon's information-theoretical entropy are "anachronistic and flawed."[107] From his contemporary perspective in which Shannon's information theoretical approach to thermodynamics was gaining ground, he failed to see that both Freud's and Shannon's appropriations of entropy are of equal legitimacy.

Although Freud's thermodynamics of desire did not enjoy wide scientific recognition, his attention for the repetitiveness of compulsion (*Wiederholungszwang*), for word-association games and his aforementioned bridge between the inorganic and organic have been noted as important precursors of cybernetics in the second half of the twentieth century. Especially this latter aspect of a blurring of the inanimate and animate – which was particularly explicit in his analysis of our psychic relationship to automata – led to him being read by the cyberneticians directly.[108] Thus, proceeding to find the next semantic strata of 'entropy,' we will now drill into cybernetics and the controversy surrounding the transplantation of the entropy *Begriff* into Shannon's information theory.

106 See e.g. Ernest Jones: *The Life and Work of Sigmund Freud,* vol. 1, New York 1953; Anthony Wilden: *System and Structure: Essays in Communication and Exchange*, London 1972; for a more recent example see Frank Garcia-Castrillón Armengou: "The death drive: conceptual analysis and relevance in the Spanish psychoanalytic community," in: *The International Journal of Psychoanalysis* 90/2 (2009): pp. 263–289.

107 Lydia Liu: *The Freudian Robot: Digital Media and the Future of the Unconscious*, Chicago 2010, p. 203.

108 In addition to Freud's *Beyond the Pleasure Principle*, media theorists in the wake of cybernetician Marshall McLuhan have taken note of Freud's essay on "Das Unheimliche" as another instance of his so-called 'post-vitalist' impulse that is also characteristic of cybernetics. Sigmund Freud: "The 'Uncanny'" (1919), transl. James Strachey in: James Strachey (ed.): *The Standard Edition XVII*, London 1955a, pp. 217–253; see Lydia Liu: "Freudian Robot," in: Liu: *Freudian Robot* (note 107), pp. 201–248. Mark Fisher: *Flatline Constructs: Gothic Materialism and Cybernetic Theory-Fiction*, New York 2018.

III. INFORMATION ENTROPY: SHANNON, STRUCTURALISM, AND LANGUAGE

"A macro-molecule, or any given crystallized solid, or the system of the world, or ultimately what I call 'me' – we are all in the same boat. […] Nothing distinguishes me ontologically from a crystal, a plant, an animal, or the order of the world; we are drifting together toward the noise and the black depths of the universe, and our diverse systemic complexions are flowing up the entropic stream, toward the solar origin, itself adrift." (Serres, "The Origin of Language: Biology, Information Theory & Thermodynamics")[109]

With Europe tearing itself apart in both World Wars, the center of entropy research would move across the Atlantic. Intellectual capital flight to the US and war-motivated scientific innovation led to a readjustment of scope towards more earthly scales. "Nineteenth-century thermodynamics," Serres tells us, "had studied motors and, in general, systems, producers of movement."[110] However, at the beginning of the twentieth century, he continues, "communication theory introduced a series of concepts such as information, noise, and redundancy, for which a link to thermodynamics was rather quickly demonstrated."[111] This subsequently gave rise to the so-called 'daughter sciences' of thermodynamics – consisting of information theory, communication science and cybernetics. Instead of working with mechanical and bodily machines, they applied their inherited but reworked conceptual toolbox to ordinary practices such as reading, writing and the transmission and storing of signals. The common ground these 'daughters' shared with thermodynamics was their insistence on stochastics and statistics, following Boltzmann's probabilistic articulation of entropy. As we shall see, the importance of this readjustment is hard to overstate for the general trajectory of Western science. These cybernetic and information-theoretical innovations, coupled with Ferdinand de Saussure's ground-breaking work in linguistics, would be fundamental for the arrival of structuralism and post-structuralism.

In this regard, a central yet controversial role was played by Claude Shannon. Collaborating with MIT-colleague Warren Weaver who had worked on information transmission at the Bell Telephone

109 Serres: *Hermes* (note 9), pp. 82–83.
110 Ibid., here p. 73.
111 Ibid.

company, Shannon's work would inspire as much as it would provoke. Especially his appropriation of entropy, applying it to communication and the innate cost or decay of messages by means of analogy with the information-theoretical phenomenon 'noise' or 'nonsense,' was met with strong resistance for decades. Among the critics is Matteo Pasquinelli who, in a 2019 entry on the work and legacy of Serres, provides an exemplary expression of this sentiment.[112] While discussing a recently translated essay of Serres' published by the same editors, Pasquinelli articulates his disdain for Shannon, denouncing his appropriation of entropy as "audacious," leading to nothing but "misunderstanding" and "confusion."[113]

As is typical for this sentiment, Pasquinelli justifies this attitude by referring to what has come to be known as the Shannon-Neuman anecdote, which accuses Shannon of crediting von Neumann for suggesting the term entropy to describe what Shannon's theorems were quantifying, namely information loss. In an interview from 1971, Shannon would later deny having said this.[114] Nonetheless, critics throughout the decades would cite this instance (as well as Shannon's denial, only adding to the loss of his credibility as a scientist) seeking to weaken the credibility of Shannon entropy in lieu of the 'original,' thermodynamic definition of entropy.[115]

Pasquinelli objects, particularly, to the idea that information entropy and thermodynamic entropy are rooted in the same reality, "that they were sharing the same ontological *continuum,*" instead stating that the two notions "refer to two completely different scales."[116] Serres, in contrast, always affirmed the ontological continuum as professed in thermodynamics and its daughter sciences (as poetically expressed in the epigraph of this part), while respecting the respective reach of both.[117] Rather than to relapse into shallow ad-hoc attacks on Shannon's individual, contributions and word choices, as we shall see, it is argued here that information entropy would (indirectly) advance an ontological continuum without positing that information entropy is the same as thermodynamic entropy.

It is precisely Shannon's statistical way of understanding signals – entering on one end and coming out on the other while quantifying their likelihood of arriving, determining the probability with respect to all possibly sent signals – that the concept information enters its contemporary history.[118] Shannon's notion of information became logically coherent by systematically omitting semantics – the meaningful content of the message transmitted. This fundamental exclusion of meaning enabled Shannon to reliably transform speech into bits useful for management and (re-) production (which, as has recently been established, averages about 39 bits per second in a large number of languages across the world).[119] Republishing his 1948 article with Weaver, Shannon's co-authored *Mathematical Theory of Communication* not only demarcated the field of information theory and freed it from the communication science of which it had been a subdiscipline, but also ratified information's connection to energy and, subsequently, entropy.

Contemporary information theory mostly identifies this latter point with the contributions made by Rolf Landauer who set this fundamental insight in stone through the slogan 'information is physical' during the 1990s, but this connection was arguably already present in the years of formation in the 1940s.[120] Thus, it

112 Matteo Pasquinelli: "The exogenesis of light," in: Rick Dolphijn (ed.): *Michel Serres and the Crises of the Contemporary*, London 2019a, pp. 93–104.

113 Referring to Michel Serres: "Information and Thinking," in: Rosi Braidotti/Rick Dolphijn (eds.): *Philosophy after Nature*, London 2019b, pp. 13–20; Pasquinelli: "The exogenesis of light" (note 112), here p. 95, 99.

114 Thanks to Bernard Geoghegan for hinting to me the apocryphal nature of this anecdote; Pasquinelli: "The exogenesis of light" (note 112), here pp. 98–99.

115 The most extensive and hostile example of this is Thims: "Thermodynamics ≠ Information Theory" (note 4).

116 Pasquinelli: "The exogenesis of light" (note 112), here p. 97, 100.

117 "Now these [information-theoretical] energies, manipulated and calculated, were of a different order than energy of the first [thermodynamic], or macroscopic scale – they were very small in relation to this scale." Serres: *Hermes* (note 9), p. 73.

118 Ernst Müller: "Transferences in the Concept of Information," in: Jutta Weber (ed.): *Interdisziplinierung? Zum Wissenstransfer zwischen den Geistes-, Sozial- und Technowissenschaften*, Bielefeld 2010, pp. 143–166, here pp. 146–147.

119 Catherine Matacic: "Human speech may have a universal transmission rate: 39 bits per second," *Science Magazine,* posted September 4th, 2019, https://www.sciencemag.org/news/2019/09/human-speech-may-have-universal-transmission-rate-39-bits-second (accessed November 5th, 2019).

120 For contemporary information scientific history of the physical nature of entropy, see David Bawden/Lyn Robinson: "'Deep down things': in what way is information physical, and why does it matter for LIS?," in: *Information Research: an international electronic journal* 18/3 (2013); Rolf Landauer: "Information is physical," in: *Physics Today* 44/5 (1991), pp. 23–29; Rolf Landauer: "Information is Physical, But Slippery," in: M. Brooks (ed.): *Quantum Computing and Communications*, London 1999, pp. 59–62.

would be inadequate to transform this *Begriff*-stratum into a grand narrative of one great man, namely Shannon. There was, rather, a general conviction that information was energetic in nature and that there was a strong resemblance between the entropy of physical systems and that of communication systems. As information-historian Jeremy Campbell has said, "[the idea of] the relationship between information and entropy […] was in the air. At least half a dozen research centers in the United States and Britain had been working on the mathematics of communication and the separation of messages from noise since the early 1940s." [121]

At MIT, especially, a fertile environment for technologically informed and innovative communication sciences had been developing during this time. Most notably, it is in this post-war American institution that another daughter of thermodynamics would enter the stage, namely, cybernetics. Cybernetics was defined in 1948 as the science of communication and control in animals and machines, by Norbert Wiener. Similarly to Shannon's telegraph research that emerged from cryptographical interests during the war, Norbert Wiener was initially influenced by his military research on self-regulating shooting devices that integrated the pilot as part of the machine. It is through this epistemological integration of subject and object, of organic and the inorganic, that cybernetics systematically reinforces Freud's insights as well as the ontological continuum mentioned above.[122] Wiener's commitment to this principle was so deep that he, as a MIT information theorist recalled in 1947, had a habit of walking around offices, puffing his cigar saying nothing but 'Information is entropy,' before leaving again.[123]

Besides such autobiographical anecdotes, however, the co-development of these daughter sciences was already set up in what historian Bernard Geoghegan has termed "the cybernetic apparatus."[124] Cybernetics was an interdisciplinary, international research program (that included information theory and communication science), headed by structural linguist Roman Jakobson and anthropologist Claude Lévi-Strauss and intended to assimilate diverse scientific insights, many from exiled European scientists. Funded by the philanthropists of the Rockefeller Foundation who advocated an entrepreneurial liberal-positivist conception of science, this apparatus, institutionalized throughout the ranks of universities like MIT and Harvard, ensured mutual scientific entanglement between the United States and Europe (especially France).[125] Although information theory remained a subfield of communication engineering until the early 1960s and was out of fashion by the end of the decade, cybernetics contributed some of the most far-reaching ideas about information – ideas that were quickly taken up by other disciplines.[126]

The compatibility of information theory's codification of messages and cybernetics, with its attempt to formalize language as integral to the system, became apparent immediately after Weaver handed a copy of *The Mathematical Theory* to Jakobson in late 1949.[127] This "refashioning of linguistic acts as a technoeconomic matrix of production," Geoghegan suggests, would be taken up by the likes of Lévi-Strauss (with his cybernetic rereading of kinship structures and corresponding linguistic relations), Michel Foucault (with his historical discourse studies and structures of discipline), and Jacques Lacan (with his structuralist reworking of psychoanalysis).[128] Although Lacan's use of information entropy (for which he used the Americanized '*jam*' instead) as well as his affiliation with the cybernetic apparatus have been widely noted, neither Shannon nor his information entropy is mentioned by name.[129] Although Luciana Parisi asserts that Foucault's notion of *épistème* is insufficient to capture the emergence of thermodynamics which, as we have already seen, "exceeds paradigms, structures and systems,"[130] she shows that Foucault's microphysics of (bio-)power provide a sophisticated template to trace the flows of information energy in disciplinary society.[131] From these examples it can be seen that information entropy did not just travel substantially through the cybernetic apparatus, but could be said

121 Campbell: *Grammatical Man* (note 6), pp. 21–22.
122 Cf. Liu: *Freudian Robot* (note 107).
123 Robert Fano, as quoted in Campbell: *Grammatical Man* (note 6), p. 21.
124 Bernard Geoghegan: "From Information Theory to French Theory: Jakobson, Lévi-Strauss, and the Cybernetic Apparatus," in: *Critical Inquiry* 38 (2011), pp. 96–126.
125 Ibid.
126 Ibid., here p. 97; Campbell: *Grammatical Man* (note 6), p. 19.
127 Geoghegan: "From Information Theory to French Theory" (note 124), p. 109.
128 Ibid., p. 115.
129 Liu: *Freudian Robot* (note 107), p. 193.
130 Luciana Parisi: *Abstract Sex: Philosophy, Bio-Technology and the Mutations of Desire*, London 2004, p. 92.
131 See especially Luciana Parisi: "Disciplinary entropy," in Parisi: *Abstract Sex* (note 130), pp. 92–102; and Luciana Parisi/Tiziana Terranova: "Heat Death: Emergence and Control in Genetic Engineering and Artificial Life," in: *CTheory* (2000); for linearity in Foucault, cf. Jordheim: "In the Layer Cake of Time" (note 15).

to be an implicit cornerstone for the structuralist re-evaluation of language and of the human subject studied by the humanities.

Despite this productive co-development of Shannon's and Wiener's respective sciences through the infrastructure provided by the cybernetic apparatus, their specific conceptualizations of information entropy also diverged. Both frameworks differed significantly in how they dealt with communication: Whereas the cybernetic framework, influenced by Wiener's (and other early cybernetician's) interest in teleology, assumed communication to be intentional and purposeful – or simply meaningful –, Shannon, as we have seen, fundamentally excluded meaning from the (literal) equation.[132] Mathematically or stochastically measuring communication thus implied setting information apart from the incoherent, meaningless disorder of noise. This culminated in Wiener's attempt to orient cybernetics toward the goal of fighting entropic disorder in information. This heroic yet futile battle was, however, not taken up by later generations of cyberneticians.[133] Instead, early-information theorists, cyberneticians and quantum physicists equated information with the *opposite* of entropy, negative entropy or (as Leon Brillouin coined it) negentropy.[134]

Shannon, on the other hand, would go in a totally different and counterintuitive direction. Following from his meaning-free concept of information, rather than oppose it to entropy, Shannon would *equate* the two: what is identified with Shannon entropy, then, is not the disorder against which the information-containing message is signaled. Instead, the inverted mathematical function quantifies information in such a way that its entropy signifies *potential* information: the more unexpected (or random) the message, or the higher its entropy, the more information it conveys. As Deacon adds, "Shannon entropy is thus a measure of how much information these media can possibly carry."[135] In Shannon's measurement of the redundancy of letters in Printed English (and with reference to James Joyce's textual experiments), the metaphor of 'noise' or 'nonsense' acquired a statistical rather than a mere phonemic dimension.[136] As Geoghegan recently remarks in his own comparison of the two, "[w]here Wiener's aim during the war was to subtract noise into communications, Shannon's was to introduce it."[137] Shannon entropy became enormously influential and was further developed by, for example, John von Neumann in his application of Shannon entropy to the physical realm of quantum mechanics, in the concept of Kolmogorov-Sinai entropy, and of Shannon-Fano coding. They further affirm Shannon's role in intellectual history, as Hayles has said: "Shannon's redefinition can be seen as a crucial crossing point, for this allowed entropy to be reconceptualized as the thermodynamic motor driving systems to self-organization rather than as the heat engine driving the world to universal heat death."[138]

With Shannon's mathematical expression of information entropy as *potential* higher forms of order, at last, Boltzmann's "intellectual time bomb," planted in 1904 by defining entropy as "missing information," was detonated.[139] Contrary to the dismissive attitude often brought against Shannon, thus, a different picture of information entropy is revealed, one that constitutes a distinguished branch in the evolution of the entropy *Begriff*, one that comprises a semantic layer in its own right. The interpretation of 'entropy' as missing information or noise and the probabilistic characteristic this entailed deeply altered not only the scientific research on language, but also influenced scientific method generally. Moreover, from this altered conception of language, the *Begriff* can be said to advance (epistemologically) an ontological continuum: the spread of information and cybernetic entropy through the discussed disciplines (including those that dealt with the realm of thought as studied by the *Geisteswissenschaften*), reveals language as ontologically occupying the same integrated realm as other physical forces.[140] Meanwhile, Boltzmann's

132 Thanks to Geoffrey Bowker, for pointing me in the direction of Norbert Wiener, Arturo Rosenblueth and Julian Bigelow: "Behavior, Purpose and Teleology," in: *Philosophy of Sciences* 10/1 (1943), pp. 18–24.
133 Mousoutzanis: *Fin-de-Siècle Fictions* (note 3), pp. 89–90.
134 This tendency to equate information to entropy's opposite happened often in dialogue with Maxwell's demon. Leo Szilard made this connection as early as 1929. Leon Brillouin: "Life, thermodynamics, and cybernetics," in: *American Scientist* 37/4 (1949), pp. 554–568; Leon Brillouin: "Maxwell's Demon Cannot Operate: Information and Entropy," in: *Journal of Applied Physics* 22/3 (1951), pp. 334–337.
135 Deacon: *Incomplete Nature* (note 2), p. 379.
136 Cf. Lydia Liu: "Sense and Nonsense in the Psychic Machine," in: Liu: *Freudian Robot* (note 107), pp. 99–152.
137 Thanks to Bernard Geoghegan for disclosing an earlier version to me of Bernard Geoghegan: "Architectures of information: A comparison of Wiener's and Shannon's theories of information," in: Theodora Vardouli and Olga Tououmi (eds.) *Computer Architectures: Constructing the Common Ground*, Abingdon 2019, pp. 135–159, here p. 146.
138 Hayles: *How We Became Posthuman* (note 42), p. 102.
139 Campbell: *Grammatical Man* (note 6), p. 44.
140 Geoghegan summarizes the Hayles' position by elaborating on precisely this point: "Information theorists rejected the notion that intelligence, speech, meaning, and life as something metaphysical essence that eluded materialist

statement goes further still, as Shannon's definition of 'entropy' as *potential* would, from the 1970s on, facilitate the view that self-organizing systems such as living beings do not just resist entropy but in fact prevail by turning its logic against itself.[141] It is this reconceptualization, this next semantic stratum, that will be explored in the following part.

IV. FOUR FOURTH LAWS OF THERMODYNAMICS: THE BIOSPHERE, SCALE, AND INTELLECTUAL HISTORY

"It was no accident that the two most influential bodies of scientific knowledge that emerged in the nineteenth century [i. e. thermodynamics and evolution theory, L. C. H.] both involved fossils, in the form of animal bones, Neanderthal skulls, and coal. … Meanwhile, the emerging fossil fuel regimes connected the dizzying pace of industrial time to the deep time of planetary change." (Cara Daggett, *The Birth of Energy*)[142]

"[G]iven that the Anthropocene consists in the collapse of scalar magnitudes, when the species as biological agent becomes species as geophysical force (through the historical mediation of the "species" as thaumaturgical engineer), *when political economy meets cosmic entropy*, it is the very idea of scale and dimension that seems out of scale." (Danowski and de Castro, *The Ends of World)*[143]

Entering into the next phase of entropy research and its semantic layer, the evasive nature of the concept of entropy becomes irrefutably clear. The research initiated from the 1970s onward – how to reconcile organic life on Earth with the omnipresent stream of entropy increase – was developed in various directions. In this part, four suggestions for extending the second law of thermodynamics (without denying its validity) by adding a 'fourth law of thermodynamics' are explored. As we have seen in the previous parts, there are intimate connections between thermodynamics and the industrial revolution, between 'entropy' and fossil-fuel extraction, and between entropy research with the trajectory of capitalism. From the 1970s on, however, this dynamic passed a threshold. In what follows, this coevolution of 'entropy' and industrial and computational capitalism will be analyzed historically. The Norwegian anthropological project "Overheating: An Anthropology of Accelerated Change" investigated these globalization trends through the concepts of heat and overheating.[144] Throughout the group's research projects, it became clear that the "the clashing of scales" can be singled out as the general ethnographic symptom of this development: The friction generated by perspectives and worldviews clashing as ever-larger masses of people are brought into contact with one another through globalization and technology.[145]

While 'the Anthropocene' and its conceptual mutations (Entropocene, Neganthropocene, Pyrocene, Capitalocene, Cthulucene, to name but a few) are often traced back to the beginning of the twenty-first century when it began to take hold in popular consciousness, the sensibility for scale associated with it emerged in the disciplines of anthropology and ecological studies from the late 1970s.[146] Ecological economists especially pioneered this all-encompassing view of human systems, a conceptual precursor of the Anthropocene. This, in fact, is hardly surprising. After all, ecology is essentially a bookkeeping of the energy flux of the biosphere, where economy is the practice

explanation, theorists of information sought to describe each of these phenomena in terms of patterned inscriptions travelling neurons, vocal cords, language, and cell tissue." Geoghegan: "From Information Theory to French Theory" (note 124), p. 156.

141 Hayles: *How We Became Posthuman* (note 42), p. 102.

142 Daggett: *Birth of Energy* (note 35), p. 56.

143 Déborah Danowski/Eduardo Viveiros de Castro: *The Ends of the World*, transl. Rodrigo Nunes, Cambridge 2017, p. 96 (my emphasis).

144 Thomas Hylland Eriksen: *Overheating: An Anthropology of Accelerated Change*, London 2016.

145 "Clashing Scales: Understanding Overheating," Eriksen: *Overheating* (note 144), pp. 131–156.

146 For the claim that scalar sensibilities associated with 'Anthropocene' were first institutionalized in anthropology and ecological studies, see Derek Woods: "Scale Critique for the Anthropocene," in: *Minnesota Review* 83 (2014): pp. 133–142. For the first two conceptual mutations, where the former refers to the constant production of *hubris* in the Anthropocene and the latter signifies a normative stance to it, see Bernard Stiegler: *The Neganthropocene*, ed. and transl. by Daniel Ross, London 2018; for Pyrocene, which refers to the constant production of fire in the Anthropocene, see Pyne's declaration of the Pyrocene, in Stephen J. Pyne: *Fire: A Brief History*, Washington[2] 2019; for Capitalocene, which is an attempt at merging Anthropocene with capitalism, see J. Moore: *Capitalism in the Web of Life: Ecology and the Accumulation of Capital,* London 2015; and for Capitolocene as well, Andreas Malm/Alf Hornborg: "The Geology of Mankind? A Critique of the Anthropocene Narrative," in: *Anthropocene Review* 1: pp. 62–69; for the Cthulucene, which refers to the Lovecraftian horror-entity Cthulu, see Donna Haraway: "Tentacular Thinking: Anthropocene, Capitalocene, Cthulucene," in: *e-flux* #75 (2016): https://www.e-flux.com/journal/75/67125/tentacular-thinking-anthropocene-capitalocene-chthulucene/ (accessed June 28th, 2020).

of bookkeeping of monetary flux in the economic sphere. Such perspectives, drawing on the discourse of political ecology of the 1970s, showed clearly the potentially disastrous consequences of ever-increasing scale and the obsession with economic growth.[147]

The nineteenth century fears of a dying sun, and the exhaustion of human labor associated with such celestial fatigue attains a new meaning in this last semantic layer: Here, the resource depletion of the Earth moves center stage. Besides the Marxist-oriented ecologists (briefly addressed in part two) or the environmentally oriented schools centered around the problem of sustainability and climate change, another paradigmatic discursive pillar of ecological economics was instigated by the Romanian statistician Nicholas Georgescu-Roegen with his magnum opus *The Entropy Law and the Economic Process* (1971). Narrowly missing the Nobel Prize, he therein declared a (first) fourth law of thermodynamics, which subsequently was rejected by physicists and early ecological economists alike. Despite such criticism, the notion of applying thermodynamic tools to measure the limits of economic growth was profoundly thought-provoking and, in due course, carefully taken up by scholars from these fields (joined by anthropologists and Earth system scientists).

Whereas the public intellectual Jeremy Rifkin would double-down on Georgescu-Roegen's farfetched conclusions during the 1980s, physicists were already busy supplanting the latter's work with more consistent and coherent alternatives to track the earthly economy of entropy-production.[148] Stuart Kaufmann, for example, building on his lab work on properties of self-organization in gene networks from the 1960s, would later propose his own (second) 'fourth law' specific to the biosphere. Kaufmann's *Origin of Order* attempts to unify the problem (or 'riddle') of life's thermodynamic exceptionality with Darwinian evolution. In fact, Kaufmann argued that this idea of life as 'exceptional' or improbable resistance to entropic disintegration is mistaken: although the self-amplifying chemical processes (i. e. [auto-]catalysis)[149] necessary for the emergence of living systems might be rare, Kauffman showed that spontaneous autocatalysis will almost inevitably happen as the potential catalytic possibilities already present themselves in relatively ordinary chemical conditions. In other words, the emergence of life becomes a matter of degree of complexity on an already existing network of relations. This attention for these spontaneous processes of biochemical self-organization, however, instead points to self-preserving, self-maintenance and self-promoting features of living systems as distinguishable among other runaway catalytic processes. In an environment where natural selection holds, organic bio-agents are thus forced to generate structures and processes that maximize access to favorable circumstances and minimize exposure to unfavorable environments and, emphatically, "in such a way that these capacities are preserved into the future."[150] It is in this way that biological activity does not only resist entropy, but also draws on the potential higher forms of order that are generated by the expenditure of work for future preservation. This basic characteristic of even the most simple living system to maintain the ability to "act on their own behalf" while operating at circumstances far from (thermodynamic) equilibrium is then traced through developmental biology as an expression of and a response to the need to adapt to fitness.[151]

This notion that life occurs far from equilibrium or more generally, this impulse to unify thermodynamics with Darwinism, however, can be traced back further to Erwin Schrödinger's thoughts on life and to the work of Belgian chemist Ilya Prigogine (who *did* win the Nobel Prize for his contributions in 1977). Throughout his career, Prigogine addressed irreversibility in nature through the notion of dissipative structures. Showing mathematically how complex systems operate at *local equilibrium* by producing or dissipating more entropy outside their local order, his Brussels-Austin school of thermodynamics revealed why self-organization is statistically possible.[152]
Thus, the initial reading of 'entropy' as disorder was transcended: higher entropy could also mean higher potential forms of order – the Boltzmann Bomb argument has detonated. Moreover, the non-linear dynamic perspective further defined chaos, specifying

147 The connection of increasing scale and economic growth was already addressed with reference to Marx' *Grundrisse* in part two. In the next entry of this volume, the conceptual history of the Anthropocene is developed in far greater detail by Anna Simon-Stickley.

148 Jeremy Rifkin/Ted Howard: *Entropy: A New World View*, New York 1980.

149 Cf. Benjamin Steininger: "Katalysator – Annäherung an einen Schlüsselbegriff des 20. Jahrhunderts," in: Müller/Schmieder: *Begriffsgeschichte in den Naturwissenschaften* (note 8), pp. 53–72.

150 Deacon: *Incomplete Nature* (note 2), p. 273.

151 Stuart A. Kauffman: *The Origins of Order: Self-Organization and Selection in Evolution*, New York 1993.

152 Nevertheless, the term dissipative system was already introduced by Belgian mathematical system theorist Jan Willems (MIT, RUG) in 1972.

it away from the binary of order and disorder, or, in Prigogine's own words: "A common misconception about chaos is that it is disorder. In modern science it's studied as a specific form of order with very specific and complex temporal sequences."[153]

The recognition of far-from-equilibrium states subsequently brought about a rupture as the non-linear phase in complexity theory and thermodynamics and the field of chaos theory took shape: While chaos theory currently operates more in the background, for a few decades tremendous scientific success was made in recognizing patterns (such as fractal self-similarity across scales) in inherently unpredictable phenomena such as the famous example of the butterfly effect or examples of weather and other turbulent open systems. Whereas Prigogine's contributions were (over-)enthusiastically hailed in 1972 as demanding a 'fourth law,' since the 1980s his influence was made felt by complex adaptive systems theories while dissipative system theory informed a broad array of research, including urban and spatial planning, ecology, cosmology. One particularly vivid way in which this phase shift towards non-linear dynamics has advanced is within visual semantics. Classic educational examples illustrating the second law and capturing irreversibility include the broken egg, whose yolk resists returning into the eggshell, the cup of coffee visualizing heat dissipation, and the battle of tidying up a room that will inevitably fall back into mess and disorder again.[154] From the 1970s onward, there was a general tendency to capture the non-linear reconsideration of the dynamic between order and disorder, of the role of entropy in the production of (self-)organization, through the emblematic Rayleigh-Bénard convection or simply the Bénard cell.[155] The experiment consists of heating a thin layer of fluid from below, to the point where highly regular hexagonal-shaped convection cells start to dissipate the heat faster than earlier in its more randomized state. Thus, through rather simple means the spontaneous emergence of a complex dissipative structure is shown and its tendency to maximize entropy production through efficient patterns is revealed.

The specifics of such complex systems regulating and maintaining the order of the organism, are still being debated today. By looking at structures approaching disintegration or near equilibrium systems, Prigogine and his Brussels school, for example, derived the Theorem of Minimum Entropy Production: this principle of MinEP holds that as a system depletes its resources, it will resist collapsing fully into (thermodynamic) equilibrium and remain near minimized levels of entropy production. One of the challenges made against Prigogine's strong legacy instead emphasizes the so-called Maximum Entropy Production principle. Whereas Kauffman's fourth law includes a variation of this MaxEP principle, Rod Swenson had been polemically vying for his Law of Maximum Entropy Production since 1988. Including not only near equilibrium but also far-from-equilibrium systems, MaxEP universalizes the tendency towards efficient entropy production embodied in the Bénard cell.

Although it should be noted that MinEP and MaxEP are technically not opposed, the MaxEP allows moving from the definition of 'entropy' as *potential* for higher order into new territory: From experiments with gas in a box, analogous to a heated cabin in the woods, Swenson showed that a system will always "choose" the fastest (potential) pathway available. Nevertheless, some gradients will be "allocated" to the slower path(s) so that the "system will put together an 'assembly of pathways' that minimizes potential […] and maximizes the entropy at the fastest rate given the constraints."[156] A closed system behaving according to MaxEP can thus be said to be 'ergodic,' 'stochastic' or simply statistical. The most recent and creative entropy research builds on these general advances made on far-from-equilibrium situations, developing its implications in rather different directions. Alex Wissner-Gross, for example, connects this dynamic of MaxEP to a physical conception of intelligence, while Jeremy England is cultivating the convergence of thermodynamics and Darwinism

153 Ilya Prigogine/John Cage/Huston Smith: "The Chaotic Universe," in: 'Art Meets Science & Spirituality,' in: a *Changing Economy,* Amsterdam: 1990, posted November 26th, 2013, https://www.youtube.com/watch?v=y4AnTsB-OsQ (accessed February 12th, 2020).

154 For an undermining of the 'broken egg' metaphor from the perspective of the new semantic layer, see Wynne Parry: "Unscrambled Eggs: Self-Organization Restores Cells' Order," in: *Quantamagazine*, posted January 2nd, 2020, https://www.quantamagazine.org/unscrambled-eggs-self-organization-restores-cells-order-20200102/ (accessed January 2nd, 2020).

155 As is captured in this 16-second demonstration: user ysumino55, "Benard Convection," *YouTube*, posted May 4th, 2009: https://www.youtube.com/watch?v=UhlmCA5DsQ0 (accessed December 4th, 2019).

156 Mayo Martínez-Kahn/León Martinéz-Castilla: "The Fourth Law of Thermodynamics: The Law of Maximum Entropy Production (LMEP): An Interview with Rod Swenson," in: *Ecological Psychology* 22/1 (2010), pp. 69–87, here p. 79.

in terms of dissipation-driven organization (notably through the dissipative function of self-replication or biological reproduction).[157]

Why, though, was thermodynamics projected onto the biosphere and onto the grand ecological questions of the existence of life during the 1970s? As hinted at the beginning of this part, it was in this decade, in the wake of the oil crisis, that energy became popularized as an object of politics.[158] The extent to which capitalism advanced onto a new (ontological) scale, is elaborated by Hornborg when he identifies 1971 as the year in which the nationally held gold standard of Bretton Woods was dropped in favor of paper or electronic money and an electronic stock market based on the American dollar.[159] From the perspective of the thermodynamically informed ecological economists, it was clear that such an immense and irreversible shift towards global integration would only aggravate the stress on the Earth's resources and the dizzying distortion of scale. Not only would this development be reflected popularly as increased concern and anxiety for planetary climate change, but this distortion of scale was registered in intellectual history as well: in the wake of what was diagnosed in the last part as an (epistemological) shift towards an ontological continuum, 'postmodernism' implied a deeply pluralistic relativism that would shatter established perspectives in the 1970s and beyond. While this confusing distortion spread, no fixed point of view was safe and no metanarrative was left unscathed. As global integration reached the verge of the planetary, the linguistic turn (discussed in the previous part in relation to information entropy) ultimately demolished the previous modern scientific custom to attempt to reach a universal scale and instead left 'truth' pluralized and localized, each truth corresponding to its respective reach.

157 Cf. Alex Wissner-Gross/C. E. Freer: "Causal Entropic Forces," in: *Physical Review Letters* 110/16 (2013); Jeremy England: "Statistical physics of self-replication," in: *The Journal of chemical physics* 139/12 (2013).

158 Daggett: *Birth of Energy* (note 35), p. 4.

159 Alf Hornborg: "Redesigning Money to Curb Globalization: Can We Domesticate the Root of All Evil?," in: Marc Brightman/Jerome Lewis (eds.): *The Anthropology of Sustainability: Beyond Development and Progress*, London 2017, pp. 291–307, here pp. 297–298. See also Paul Trawick/Alf Hornborg: "Revisiting the Image of Limited Good: On Sustainability, Thermodynamics, and the Illusion of Creating Wealth," in: *Cultural Anthropology* 56/1 (2015), pp. 1–27, here p. 4.

The confusion corresponding to this pluralization and localization of truth is grounded by Serres as a "regionalization of epistemology" and points to the changing character of the scientific enterprise.[160] As chance increasingly enforces itself upon practices of knowledge production, a tendency which has been studied here through a conceptual history of the inherently probabilistic concept entropy, the aim for objectivity (or truth) ultimately is bankrupted – but this does not leave us emptyhanded. As John Lechte says of Serres: "For Serres, 'the perception of stochastics replac[ing] the specification of form' is a breakthrough in linking the sciences." Rather than specialized sciences operating within set boundaries according to their conventional forms, Serres urges one to experiment with form so as to find new passages and pathways between scientific disciplines, literary or poetic faculties and philosophy; hence his choice for Hermes, god of communication. It is in this sense that Serres overcomes the distinction between nature and culture or the all too persistent 'two cultures' division. Furthermore, Serres attempts to move beyond the form/content dichotomy by consistently taking the form or means of communication and the message or content itself as the same thing. As Marshall McLuhan's popular phrase succinctly captures this ultimately cybernetic insight, "the medium is the message."

Beyond Serres, however, this part has attempted to show how the distinction between nature and culture, as Danowski and de Castro put it, "is precisely what is being *empirically* contested by the collapse of scales and strata of planetary reality, that is, by the metamorphosis of the human species into a major geophysical agent."[161] Once again the cosmological and the anthropological temporalities are synced, though this time not by way of the cyclicality of the celestial bodies and the seasonal rhythms but rather in the sense of disruption of cycles and the eruption of ecological disaster. The development of thermodynamics turning onto the biosphere, now applying 'entropy' to explain life itself as is evident from the four fourth laws, is driven historically by a species transforming itself and its environment as it grows into a geological force. The kinship between the concept of entropy and its twin-birth with evolutionary theory – conceived from

160 Michel Serres: *Hermès I: la Communication* Les Èditions de Minuit 1968, p. 66. Cf. Josué V. Harari and David F. Bell (eds.), "Introduction" to Serres: *Hermes* (note 9), pp. ix–xl, here p. xiv; Serres: *Hermès V* (note 11).

161 Danowski/de Castro: *Ends of the World* (note 143), p. 36.

reflection on fossils (ancestral in the latter, fossil fuels in the former) at the dawn of the Anthropocene – is thus reaffirmed once again during the (current) apex of the Anthropocene.

CONCLUSION

This demonstration of the Boltzmann Bomb argument has revealed how Boltzmann's statistical definition of 'entropy' as conceived in the late nineteenth century only fully detonates during the mid-twentieth century and afterwards. From the concept's appropriations by thermodynamics' daughter sciences and its nonlinear fission, the explosive impact of the inherently probabilistic 'entropy' upon the scientific enterprise has been delineated. As was concluded in the last part, the steady rise of 'entropy' as a universal model for knowledge, or, more specifically, the increase of stochastics in scientific practice has altered its character to such a degree that the dichotomy form/content is obsoleted. In the current article, form and content have been blended together through the suitable fit of stratigraphic *Begriffsgeschichte* as form with 'entropy' as its object.

This stylistic blend of stratification and 'entropy' follows the fact that thermodynamics emerges simultaneously with the theory of evolution upon reflection on the (stratified) interior of the Earth and the (ancestral) fossils that were extracted there and, at the same time, used for fuel for the steam engines. However, from the strategic excavation of the semantic layers of 'entropy' conducted here, the relation of the concept to modernity turns out to be far deeper. A variety of its meanings decisively alter the course of the modern, capitalist trajectory. Entropy's dissipation or dispersion initially engendered cultural anxieties of decay, death and degeneracy, and while, during the fin de siècle, the implication of exhaustion was countered by the political-economical fight against 'fatigue,' today, planetary fatigue in the form of resource depletion has again entered the cultural conversation. Moreover, the relation between the *Begriff* entropy and modern thought was further cultivated and solidified through the works of Marx, Nietzsche, Freud.

The arrival of a radical new, non-linear semantic layer of the *Begriff* entropy, the breakthrough of a new ontological scale in globalized modernity and the increase of perspectivism during the 1970s must be seen as interrelated. As such, 'entropy' registers and effected this new stage of modernity and thus qualifies as one of its fundamental concepts [*Grundbegriffe*]. Besides the numerous discussed metaphors associated with 'entropy,' and fundamental transitions in its meaning (such as from signifying disorder to signifying potentially higher levels of order) in between the different semantic layers, involvement of scale has been identified as an immediate effect of the application of this *Begriff*: After all, while *local* deviations of the law might exist, these are only viable by increasing entropy faster at the highest scale. Order is disequilibrium and knowledge and signs are perpetually forced to resist decay. No matter how strict and orderly the research conducted, in the end one will always have to face the sheer vastness of that which is outside of the knowledge produced. Given enough time, a *Begriffsgeschichte* of 'entropy' can signify nothing but its own extinguishment.