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Did Descartes Teach a 'Philosophy of Science' or Implement 'Strategies of Natural Philosophical Explanation'?

In Stephen Gaukroger and Catherine Wilson [Eds.] *Descartes and Cartesianism: Essays in Honour of Desmond Clarke*, OUP, 2017, pp.3-25.

Abstract: Desmond Clarke's 1977 paper, 'Descartes' Use of Demonstration and Deduction', elucidated the conjoint roles of empirical evidence and metaphysical constraint in Descartes' construction of scientific explanations. This was a major step forward in understanding Cartesian science, but it focused on examples of single explanations in isolation, rather than exploring how such one-off instances of explanation relate to each other across ranges of differing explananda. I argue that Descartes' systematic natural philosophising aimed precisely at producing detailed explanations of ranges of new and old facts, and the 'systematisation' of the resulting suite of explanations into interrelated sets. Accordingly, this paper proposes a 'post–Clarkean' model of how explanation worked across Descartes' natural philosophical system. The model also brings to light certain inherent limitations and tensions involved in such system building; that is, it explains why Descartes' system of natural philosophy could never realize the rhetorical claims about systematic unity made its favor.

Descartes' standard works on natural philosophy and their translations cited in this paper are abbreviated as follows: AT =*Oeuvres de Descartes* (revised edition, 12 vols.), Eds. C. Adam and P. Tannery (Paris: Vrin, 1964-76). References are by volume number (in roman) and page number (in Arabic); SG = *The World and Other Writings*, Ed and Trans. Stephen Gaukroger (Cambridge: CUP, 1998); MM = *René Descartes, The Principles of Philosophy*, Trans. V. R. Miller and R. P. Miller, (Dordrecht: Reidel, 1991)

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Introduction: The 'Clarkean' consensus about Cartesian physical explanation

By the late 1970s, anyone examining the state of Descartes studies could have noticed surprising new findings about the structure of explanation in Descartes' scientific and natural philosophical works. Over the previous decade, Gerd Buchdahl, A.I Sabra, Laurens Laudan and Desmond Clarke had contributed to the fall of the scholars' myth that René Descartes both intended and sometimes practised a top-down deductivist physics—that he somehow drew out from metaphysical truths not only the principles of his physical explanations but also actual empirical details. These scholars collectively established what Descartes *actually* held concerning the status of the corpuscular-mechanical explanatory models deployed in his natural philosophy. In this paper, I shall term this the new 'consensus' about these matters. It has held at the highest levels of Cartesian scholarship for two generations. While not questioning this consensus as to fundamentals, this paper articulates the consensus in new directions in order to address hitherto unexamined questions about the work of the mature Descartes *qua* systematic, corpuscular-mechanical philosopher of nature in *Le Monde* and in the *Principia philosophiae*.[1]

Clarke *et al.* undermined Descartes' occasional, overblown claims to have been able to deduce—on some mathematical ideal of 'demonstration'—his system of natural [4] philosophy from absolutely certain metaphysical principles. This folklore had arisen from the strictly deductivist tone of Descartes' abortive method and from some of his more offhand, rhetorically motivated, statements about the issue—statements that belied his actual practices in 'doing' natural philosophy. In his mature work, Descartes increasingly came to see that neither the details of particular explanatory models, nor the facts to be explained, could be deduced from metaphysics. Rather, he held that we may know with certainty, from metaphysical deduction, that the essence of matter is extension, but we cannot deduce from this truth more detailed explanatory models (concerning corpuscular sizes, shapes, arrangements and motions) that can explain various phenomena. The best one can say is that such models *should not contradict metaphysically derived certainties*. Hence corpuscular-mechanical explanatory models have a necessarily hypothetical character—with the caveat that they must arguably not be inconsistent with metaphysical truths. Available evidence, and in particular the facts to be explained, also bear on the formulation of such detailed explanatory models and in the assessment of their 'goodness' in regard to explanatory power and scope of application. [2]

Makers of the consensus: Buchdahl, Laudan, Sabra and Clarke

The first contributor to these insights about Descartes was the brilliant Cambridge historian and philosopher of science, Gerd Buchdahl, who did this in several early papers, reprised within the hundred page chapter on

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[1] On *Le Monde* and the *Principia philosophiae* as systems of natural philosophy, see John Schuster, *Descartes–Agonistes: Physico–Mathematics, Method and Corpuscular–Mechanism, 1619-1633* (Dordrecht: Springer, 2013), chapters 10, 11, 12.

[2] As early as 1980, I tried to characterise this consensus, which I believed was crucial to any future work on Cartesian natural philosophy from a steadfastly historical and developmental perspective. John Schuster, 'Descartes' *mathesis universalis*: 1618-1628', in Stephen W. Gaukroger (ed.), *Descartes: Philosophy, Mathematics and Physics* (Brighton: Harvester, 1980), pp.41-96, at p.75. I argued that this new consensus view of Cartesian explanation applied to Descartes' career from the construction of *Le Monde*, his first system of corpuscular-mechanical natural philosophy, after the collapse in 1628-29 of his dream of method with the failure of the later portions of the *Regulae*.

Descartes in his monumental *Metaphysics and the Philosophy of Science*.[3] As early as 1963, Buchdahl realised that most of Descartes' explanations rely upon the formulation of corpuscular-mechanical hypotheses or models. For example, such significant explanatory entities as the three elements in *Le Monde* or the *Principles*—which will be examined in more detail later—are 'purely hypothetical elements in the formal sense of the term'. They are definitely not deducible from metaphysical principles. Rather, Cartesian science demands that such hypothetical corpuscular-mechanical models are constructed so as to be 'compatible' with metaphysics.[4] Hence, if anything within Cartesian physics were to be deducible from metaphysical principles, it would have to be 'some of the [5] most fundamental principles'.[5] This might sound promising for those holding out for some kind of deduction at the core of Cartesian metaphysical physics, but Buchdahl went on to argue that despite modern assertions, and occasional outbursts by Descartes himself, no such strict deducibility holds even between metaphysics and the highest of physical principles. For example, Buchdahl showed that the first law of nature in the *Principles* could not have been arrived at by derivation from metaphysics alone—it also depended on specific empirical elements being presupposed.[6] To all this, Buchdahl added an equally penetrating insight, based on the evidence of the *Principia*. He stated that Descartes' intended *explananda*, the realm of experiences, facts, and experimental outcomes, 'all the physical detail' dealt with in the *Principia*, 'is one vast set of contingent facts'.[7] Hence, Cartesian explanation by means of corpuscular-mechanical models clearly is no more strictly deductive than analogous proceedings are in modern science. Moreover, one can say that for Descartes empirical evidence of significant scope and consistency renders support to an explanatory hypothesis, whilst any specific negative instance serves to eliminate a particular hypothesis or model.[8]

In 1966 the young Laurens Laudan followed up Buchdahl's work, by presenting a crystal clear statement of much of what would emerge as the consensus view of Descartes' strategy of explanation in corpuscular-mechanical natural philosophy. Having carefully read both Buchdahl and Descartes, Laudan labelled the relation of metaphysics to middle level corpuscular-mechanical hypotheses as one of compatibility rather than derivation.[9] Moreover he stressed that empirical evidence bears a relation of arguable support to Cartesian corpuscular-models, reaching the striking conclusion that for Descartes,

> …a sound hypothesis is one which is both compatible with the data and with the first principles, matter and motion. On Descartes' view, the logical gap separating the first principles from the phenomena can be bridged only by hypotheses. Since compatibility rather than deductibility is the relation between the first principles and the hypotheses of physics, the first principles function the same way, vis-à-vis the hypotheses, as the facts do.[10]

[6] Emphasising that the new interpretation applied primarily to Descartes' detailed natural philosophising in later parts of *Principles,* Laudan offered an account of Cartesian explanation both more accessible and more clear than that of Buchdahl.[11]

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[3] Gerd Buchdahl, *Metaphysics and the Philosophy of Science. The Classical Origins: Descartes to Kant* (Cambridge, Mass.: MIT Press, 1969).

[4] Gerd Buchdahl, 'Descartes's anticipation of a "logic of scientific discovery"', in A. C. Crombie (ed.) *Scientific Change* (London: Heinemann, 1963), pp. 399-417, at pp.411, 412.

[5] Buchdahl, 'Descartes's anticipation', p.412, see also p. 400.

[6] Buchdahl, 'Descartes's anticipation', pp. 415-6. Buchdahl argues that the 'reflection' that leads Descartes to the first law of nature depends on more than clear intuition of the 'conceptual grammar' of the terms [body and motion] involved, together with 'the principle of causation'. Specific empirical elements are being presupposed.

[7] Buchdahl, 'Descartes's anticipation', p.405 citing *Principia* III 46; AT VIII1 100-1.

[8] Most corpuscular-mechanical explanations in Descartes fall into a category that Buchdahl termed 'analysis-H'—one of several competing and overlapping versions of 'analysis' that populate Cartesian philosophy. Buchdahl identifies analysis-H with the modern categories of retroductive (or inverse hypothetical) explanation. Buchdahl, 'Descartes's anticipation', p.402.

[9] Laurens Laudan, 'The clock metaphor and probabilism: The impact of Descartes on English Methodological Thought, 1650-65', *Annals of Science* 22 (1966), 73-104, at 77.

[10] Laudan, 'The clock metaphor', 80-81.

[11] The same could be said for A. I. Sabra, who a year later devoted the entire first chapter of his excellent *Theories of Light from Descartes to Newton* (London, Oldbourne: 1967) to similar insights about Cartesian explanation, although limited in the main to the realm of physical optics.

Next, Desmond Clarke emerged in the late 1970s with three important papers.[12] Arguably the most important was his 1977 paper on Descartes' use of the terms 'demonstration' and 'deduction'. He showed that when Descartes spoke, particularly in his later works, of 'deducing' or 'demonstrating' phenomena from his principles, he did not mean strictly mathematical deduction sometimes alluded to in other contexts dominated by formal 'method-talk'.[13] Rather, Descartes was employing a well known contemporary acceptation of deduce as 'plausibly explain'. Clarke showed that this clarified Descartes' otherwise confusing (to moderns) claim that whilst his physical hypotheses serve to 'explain' the relevant phenomena, the phenomena in turn 'prove' the hypothesis. Neither direction of argument is formally deductive and each, Clarke suggested, has the tonality of argument in modern science; that is, it is persuasive, complexly structured argumentation, not logical implication or mathematical deduction.[14]

Clarke's 1977 paper did not deal very much with the metaphysical conditioning of Descartes' explanatory hypotheses, although it was now clear that Descartes had not intended the rigorous deduction of explanation from metaphysical truths. Two years later Clarke documented this in a paper concerning the relation of Descartes' metaphysical findings to what Clarke felicitously termed the 'principles' of Cartesian science and natural philosophy—the highest level claims that both linked, somehow, to metaphysical groundings, and were woven into the details of particular explanatory explanations. Clarke gave five examples of such high 'P's, as he labelled them, showing that,

> The available evidence suggests that Cartesian physics is based on a metaphysical foundation in a number of overlapping ways—none of which is equivalent to strict implication—and that this complex relationship is typical of what Descartes would call a 'deduction' or 'demonstration' of the first principles of his physics.[15]

[7] The third paper in question was the first published. Dealing brilliantly with what Descartes meant by 'experience', this paper initiated Clarke's excellent work on Descartes' theory of mind, culminating later in an important book.[16] More importantly for us here, this paper, viewed retrospectively, complemented the next two papers by unpacking the function of 'experience' in Cartesian science and natural philosophy: 'experience' is explained by Descartes' metaphysically conditioned corpuscular-mechanical hypotheses, but 'experience' also provides some of the necessary, but not sufficient prompting for the construction of such hypotheses.

Each of these scholars was following his own agenda. Buchdahl's brilliant work on Descartes, and on early modern metaphysics, science, and philosophy of science generally, went well beyond what was cited here as central to the consensus. Buchdahl was mainly interested in throwing light on canonical modern philosophy issues. His work had important historical implications, but he was not concerned with constructing historical narratives or with historiographical issues. In contrast readers of Sabra and Laudan could find more straightforward statements of elements of the eventual consensus. However, Sabra had made his points about Cartesian explanation solely in the context of a seminal work devoted to the history of physical optics. And Laudan's central topic had been later seventeenth century English *savants*, notably Boyle, who, he claimed, had appropriated Descartes' hypothetical method in experimental corpuscular-mechanical natural philosophy. There ensued rather more attention to that particular headline claim, than to Laudan's clear and concise account of Cartesian explanation which was a necessary condition for it to have been made.

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[12] Desmond Clarke, 'The concept of experience in Descartes' theory of knowledge', *Studia Leibnitiana* 8 (1976), 18-39; 'Descartes' use of "Demonstration" and "Deduction",' *The Modern Schoolman* 44 (1977), 333-44; 'Physics and Metaphysics in Descartes' *Principles'*, *Studies in the History and Philosophy of Science* 10 (1979), 89-112.

[13] Clarke, 'Descartes' use'. On the term of art 'method-talk' used when deconstructing method claims, see John Schuster, 'Cartesian Method as Mythic Speech: A Diachronic and Structural Analysis', in John Schuster and Richard Yeo (eds.), *The Politics and Rhetoric of Scientific Method: Historical Studies* (Dordrecht: Reidel, 1986), pp.33-95.

[14] On modern views of scientific argument, see for example Jerome R. Ravetz, *Scientific Knowledge and its Social Problems* (Oxford: OUP, 1971).

[15] Clarke, 'Physics and metaphysics', 91.

[16] Clarke, 'The concept of experience'; Desmond Clarke, *Descartes's Theory of Mind* (Oxford: Clarendon Press, 2003).

All this helps explain the impact of Clarke's early papers. It is fair to give Clarke a great deal of credit for establishing the consensus in the wider worlds of Descartes and Scientific Revolution studies.[17] By 1980 the interested reader, such as myself, could make out for himself the lineaments of the new consensus, working out a reading, triggered and largely formed by Clarke, but which also took account of Buchdahl, Laudan, and Sabra.[18] [8]

Moving beyond the consensus: How did Cartesian systematic natural philosophy work?

The point about an impressive interpretive consensus in historiography is that, like a good scientific theory, it should be fruitful in terms of new research questions and answers, which over time alter the complexion of the consensus. For Buchdahl and Clarke the new view of Cartesian explanation was chiefly a portal to revised understandings in the philosophy of science.[19] Laudan and Sabra certainly wanted to elucidate Descartes' actual processes of formulating explanations whilst 'doing' science or natural philosophy. But none of these scholars focussed centrally on Descartes' two systematic works of natural philosophy, *Le Monde* and the *Principia*. That is why this paper considers what their 'myth-busting', anti-deductivist view of Cartesian explanation looks like if one takes seriously the scope of Descartes' explanatory aims in systematised natural philosophy. This may be explicated in the following way: Clarke and the others' analysis focuses on examples of one-off 'single explanations in isolation'. This is very much a philosopher's analysis: One philosophically reflects upon a set of individual cases, hoping that this will suggest the generic structure of Cartesian natural philosophical explanation. This nicely comports with relating Descartes' views about hypothetical explanation to those of later seventeenth century natural philosophers and even to much later philosophers of science. But, this approach does not encourage us to look at how such one-off instances of explanation related to each other across a range of differing *explananda*. Yet, this is the very nature of Descartes' systematic natural philosophising; that is, the *producing of detailed explanations of ranges of new and old facts, and the 'systematisation' of the resulting suite of explanations into interrelated sets.*

In the remainder of this chapter, I propose to articulate the consensus toward an understanding of Descartes, the practicing systematic natural philosopher. First, in the following Section, we shall look at an example of Cartesian natural philosophical explanation that conforms completely to the model contained in the consensus. That will serve as our baseline for the next three Sections, where the argument moves out from the consensus toward a more adequate understanding of Descartes' strategies of systematisation and explanation. The first of these will present an heuristic model of the structure of Descartes' system of natural philosophy and of how, in general terms, it was pursued. Then there will follow a three part Section, exploring in some detail [9] the contents of what that model terms 'the core' of Descartes' system—more or less the categories of physical 'principles' that Clarke and Buchdahl saw as sitting between metaphysics and individual physical explanations. This will begin to suggest some of the different degrees to which particular explanations in Cartesian natural philosophy depended upon aspects of 'the core'. On this basis we shall be able in the penultimate Section to disclose the further reaches of Descartes' systematising strategy in the

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[17] Clarke went on to trace how late Seventeenth century Cartesian experimental natural philosophers followed Descartes' schema of explanation: Desmond Clarke, *Occult Powers and Hypotheses: Cartesian Natural Philosophy under Louis XIV* (Oxford: Clarendon Press, 1989).

[18] Clarke's first two of the papers in question did not cite Buchahl, Laudan or Sabra although the final one from 1979 does acknowledge the first two scholars. In the latter paper, Clarke tries to differentiate himself from Buchdahl, Laudan and others by claiming that they belong to a group of scholars who, although they do not suffer from the traditional myth of strict deduction within the Cartesian system, have arrived at a position in which they detect 'tensions' between the deductive (metaphysics to high principles of physics) and hypothetical/empirical sides of Cartesian science. In fact, nothing could be more clear than that Clarke was adding to an already emerging new perspective on how Cartesian science and natural philosophy were structured.

[19] We have seen this in Buchdahl's case. As for Clarke, he later represented his findings as the discovery of Descartes' actual philosophy of science—as though Descartes had been a working 'scientist' who also happened to be a philosopher working on explanation. See Desmond Clarke, 'Descartes' philosophy of science and the scientific revolution', in John Cottingham (ed.) *The Cambridge Companion to Descartes* (Cambridge: CUP, 1997), pp.258-285; and *Descartes, A Biography*. Cambridge: CUP, 2006. I criticised Clarke's tendency in the latter work to see Descartes as a 'scientist' with a 'philosophy of science' in John Schuster, 'Descartes—Philosopher of the Scientific Revolution; Or Natural Philosopher in the Scientific Revolution?,' *Journal of Historical Biography* 5, 48-83.

Principia—his strategy for binding together the system whose shape we initially glimpsed in the heuristic model. The Conclusion will briefly relate Clarke's discoveries to the picture emergent in the present study.

The basic explanatory stitch according to the consensus: the example of magnetism

William Gilbert's *De Magnete* (1600) offered an impressive natural philosophy, grounded in experiments, interpreting magnetism as an immaterial power, possessing in its higher manifestation the capabilities of soul or mind. In his *Principia* Descartes accepted Gilbert's experiments, but explained magnetism mechanistically, based on the movements of two species, right– and left–handed, of 'channelled' or cylindrical screw shaped particles of his 'first element'. Descartes claimed that magnetic bodies—naturally occurring lodestone, or magnetised iron or steel—have two sets of pores running axially between their magnetic poles: one set accepting only right handed channelled particles, with the other, directed in the opposite direction, receiving only the left handed particles. Descartes re–explained Gilbert's experiments with bar magnets, iron filings near magnets, and most importantly, Gilbert's use of a sphere of loadstone to demonstrate the properties of magnetised compass needles.[20]

What Descartes did in this case conformed exactly to the consensus model of Cartesian natural philosophical explanation. The explanation is mechanistic, depending on the shape, size and motion of certain corpuscles. Nothing is asserted about these corpuscles that is inconsistent with Descartes' underlying doctrine of matter-extension and the banishment of spiritual powers and causes from nature. But, quite obviously, there is nothing in the doctrine of matter-extension that dictates the making up a model about just these sorts of left– and right–handed channelled particles. On the side of the *explananda*, the set of empirical findings to be explained is accepted on the basis of Gilbert's reports. Arguably, Descartes' model adequately explains everything in the 'relevant' range of evidence, and similarly arguably, there is nothing in that empirical archive contradicting what can be 'deduced' (in Clarke's sense) from the model.

Perhaps the only thing to add to this fine illustration of the consensus view is that Descartes has exercised some kind of imaginative effort and reflection in 'making up' [10] this particular model. In this work, he needed to keep in mind the constraints of his metaphysics, as well as the content of the empirical reports to be explained. I observed elsewhere that this kind of creative model making on Descartes' part obviously eluded anything his putative method could have taught him about how to proceed.[21] It is equally obvious that a strategy of systematisation may have helped shape this particular model, since metaphysics and relevant facts certainly did not do that to any great degree. The next Section begins our search for that systematising strategy.

An introductory heuristic model of Cartesian systematising in natural philosophy

This model provides a way of thinking through what we mean by systematisation of any natural philosophy, Descartes' included. It makes use of the concepts of the explanatory 'core' of any natural philosophy; the 'horizontal' and 'vertical' articulations of the core toward particular domains of explanation; and the idea of 'system-binding strategies.[22] By the 'core', I mean a philosophy of nature's central doctrines of matter and cause, which are involved in all explanations formulated within that system. We shall address the core of Descartes' natural philosophy in the next Section, discovering that it included his theories of the elements and of vortices, as well as his laws or rules of nature. These constituents of the core correspond to Buchdahl and Clarke's conception of the highest level explanatory entities involved in physical explanations: they are

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[20] AT VIII1 275-311; MM 242-72.

[21] Schuster, 'Cartesian method', pp.63-4; Schuster, *Descartes-agonistes*, pp.273-8.

[22] Material in this Section is discussed in more detail in Schuster, *Descartes-agonistes*, pp.62-65, 527-37.

consistent with metaphysical foundations, but are also framed in the light of other considerations, both empirical ones, such as Clarke and Buchdahl pointed out, and systematising aims, as we shall observe.

By the horizontal articulation of the system (Figure 1), I denote the explication or modification of core entities in order to launch explanations of experimental results, 'matters of fact' or 'solid findings' in various domains of inquiry. In Descartes' case these targets of explanation included results in the mixed mathematical sciences (which he early on called 'physico-mathematical' fields); empirical findings claimed by himself and others (as in the case of the motion of the heart and circulation of the blood); experimental results (as in the case of Gilbert's experiments with magnets); celestial, meteorological, and optical *explananda*. Explanations of specific facts, or groups thereof, could not result from absolutely identical mobilisation of core elements. Some deformation or articulation was almost always required, as we shall see.

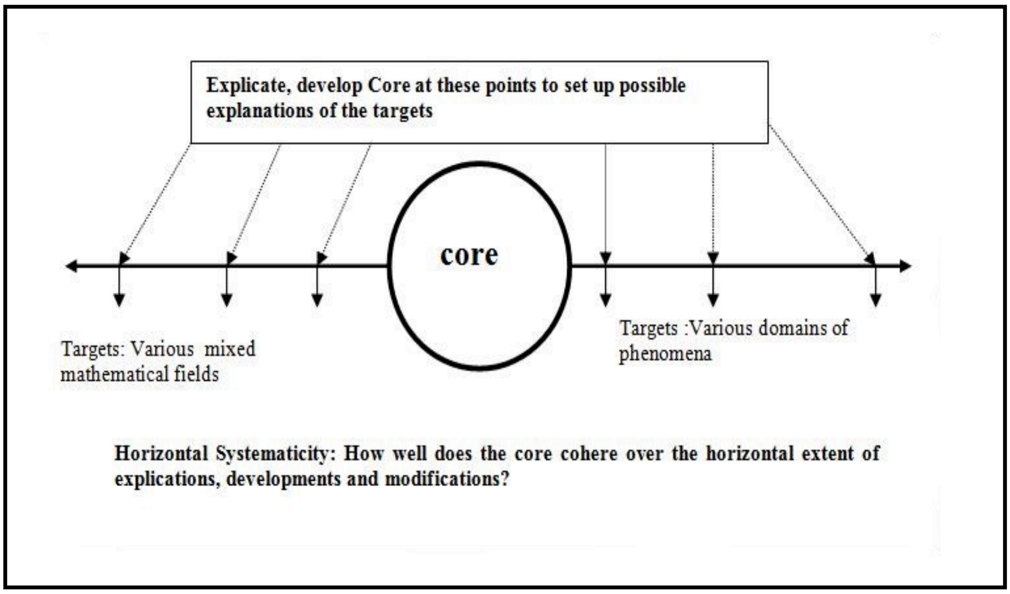

Figure 1 Horizontal Dimension of Articulation of System

By the vertical articulation of a system (Figure 2), I mean how fully and coherently a given sub-discipline (such as a field of mixed mathematics) or a domain of [11] inquiry (such as local motion and fall, or magnetism) is grasped and explained by (articulated) core constituents of the system. In this way, one can explore the arguable coherence of horizontal extension of the core to cover various sub-domains of *explananda*, and the arguable vertical depth and strength of the core's explanatory grasp of each one of those domains. System binding strategies occur across the horizontal dimension and involve elaborate attempts to tighten the relation of *explananda* to each other and to the core. It will become evident that by detecting system binding moves, one can unpack deep systematising goals and tactics, thereby demonstrating that the 'consensus' view, with its concentration of one-off generic cases of explanation, cannot be the last word on Cartesian natural philosophising.

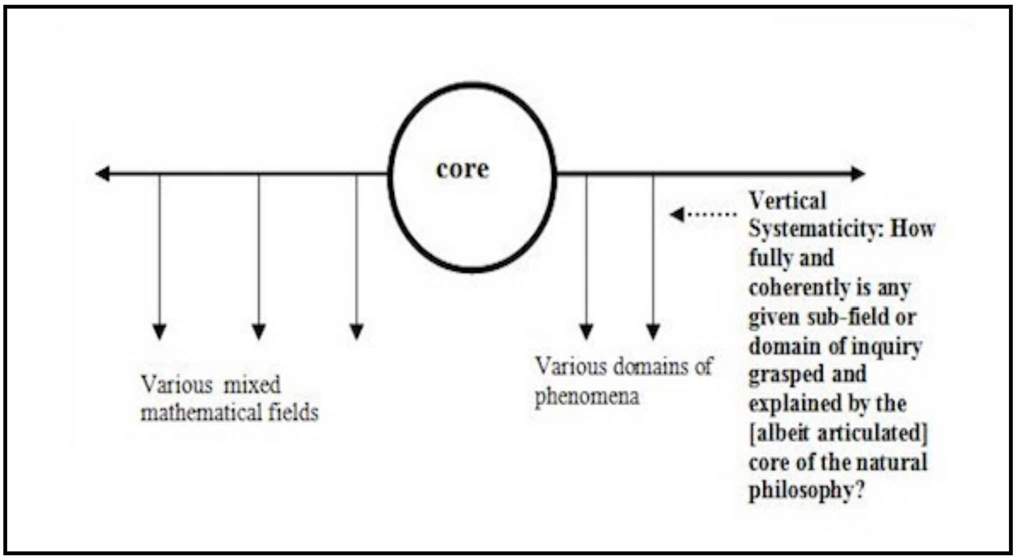

Figure 2 Vertical Dimension of Articulation of System

My heuristic model of natural philosophical systematicity is not meant to be the only way of sizing up a system. Nor do I imply that any actor, even Descartes, a skilled systematiser, embraced fully explicitly such a notion of system. Rather, this model— which reflects to some degree the goals and standards that actors like [12] Descartes arguably used— is an analytical tool for dissecting systems of the time, in the interest of building better accounts of the game of natural philosophising.

Three constituents of the core in Descartes' systems in *Le Monde* and the *Principia philosophiae*

Two Different Element Theories

Cartesian matter theory deals with a material plenum which has been broken up into three distinct types of particle or element. Descartes starts with an 'indefinitely' large chunk of divinely created matter/extension in which there are no void spaces whatsoever. When God injects motion into this matter/extension, it is shattered into micro-particles and myriads of 'circular' displacements ensue, forming large numbers of whirlpools or vortices. This process eventually produces three species of corpuscle, or elements, along with the birth of stars and planets. The third element forms all solid and liquid bodies on all planets throughout the cosmos, including the Earth. Interspersed in the pores of such planetary bodies are the spherical particles of the second element, which also makes up the bulk of every vortex. The spaces between these spherical particles are filled by the first element, which also constitutes the stars, including our sun. The parts of the first element 'are much smaller and to move much faster than any of those other bodies.' The second element is 'a very subtle fluid in comparison with the third', but has the highly active and shape-shifting first matter in its interstitial spaces. Third matter particles 'are as much larger and move as much less swiftly in comparison with those of the second as those of the second in comparison with those of the third.'[23]

That basic element theory has often been seen as identical in *Le Monde* and *Principles*, but that is not the case.[24] In each text the element theory emerges from a cosmogonical story, dealing with the movement from God's creation of matter/extension to the point where the final, and continuing state of the cosmos has emerged—in regard to the number and type of elements, and the fabric of innumerable, star centred vortices.

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[23] John Schuster and Judit Brody, 'Descartes and Sunspots: Matters of Fact and Systematizing Strategies in the *Principia Philosophiae*', *Annals of Science* 70 (2013), 1-45, at 7-18.

[24] The reformed view was pioneered by John W. Lynes, 'Descartes' Theory of Elements from *Le Monde* to the *Principles*,' *Journal of the History of Ideas* 43 (1982), 55-72 and Rosaleen Love, 'Revisions of Descartes' Matter Theory in *Le Monde'*, *British Journal for the History of Science* (1975) 8: 127-37.

Descartes' cosmogonies are short; they do not contain details about the final (quite elaborate) vortex mechanics. Instead, they are closely linked mainly to claims about element theory. Careful construal of the cosmogonical story in *Le Monde* shows that here the third element particles have existed since the divine shattering of the original matter/extension into fragments by the injection of motion. The second and first elements are produced as displacement circuits appear [13] in the plenum of particles and attrition of corpuscles occurs. In *Le Monde* transmutation of elements is specifically denied on several occasions.[25]

In contrast, in the *Principles* we also (eventually) find the same three elements; but their relations are quite different and their cosmogonical genealogies altered. Descartes drops the conceit of the cosmogonical cracking of the infinite block of matter-extension by God's injection of motion. Contrasting with the inchoate initial moments of the cosmos in *Le Monde*, the ur-particles in the *Principia* are claimed to be equal in size and motion—being 'average' in these respects compared to the (first matter) particles that will later constitute stars, and the (third matter) particles that will later constitute the bulk of planets, comets and satellites. Additionally, we are informed that, 'All were moving with equal force in two different ways: each one separately around its own centre but also several together around certain other centres'—thus implying that the number and placement of at least the initial set of vortices is also inscribed in the cosmos at its moment of creation.[26] Leaving aside difficulties of interpretation which attach to Descartes' story here,[27] the key point is that the cosmogony in the *Principles* issues only in second and first element. The original (supposedly equal) particles lose their initial shape[s] by constantly rubbing against each other, just as in *Le Monde*. Eventually they become spherical and are the building blocks of the second element. The debris, much smaller and therefore more easily moved, which fills the space between the globules (*boules*) of the second element is the first element. No third element particles were present at the creation, and none have been produced in the cosmogony. How and why third matter later emerges in the cosmos of the *Principles* turns out to be the key to Descartes' systematising strategy in that text, as we shall see.

As we would expect on the basis of the 'consensus', both of these element theories are consistent with, but not strictly deducible from the concept of matter/extension. Systematising needs, and differing ranges of facts to be grasped, drove the two formulations. Additionally, it should be noted that in Descartes' natural philosophical systems matter/extension, an indefinitely large, undifferentiated block of divinely created substance, only exists as such for an instant. The conceptual machinery of the systems depends upon and begins with the prime 'core' member, the theory of the elements.

The laws of nature, or rather, the principles of Cartesian corpuscular dynamics

The casual observer, or even an experienced Cartesian scholar, might expect that an essential ingredient in the core of Descartes' natural philosophical system would be the three laws or rules of nature that he provides in *Le Monde* and the *Principia*, [14] along with the detailed rules of collision of bodies that follow from these laws in the latter text.[28] This, however, is not quite true. What Descartes provided as the causal theory in his system were not so much laws and rules applicable to the translation of bodies in space and time; but rather, as I have shown elsewhere, a 'punctiform dynamics' applicable to corpuscles at particular instants in their motion, rest or impact.[29] Moreover, we can unearth the genealogy of this peculiarly Cartesian doctrine. I have also shown how Descartes constructed the principles of this corpuscular dynamics on the basis of his masterwork in physical optics, his discovery in 1626/7 of the law of refraction of light and his attempt to

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25 Schuster and Brody, 'Descartes and Sunspots', 9-13; Schuster, *Descartes-agonistes*, pp. 550-552.

26 *Principles* III articles 46-47; AT VIII-1 102-3; MM 106-107.

27 For discussion these difficulties see, Schuster and Brody, 'Descartes and sunspots', 13.

28 *Le Monde* AT XI, 38-47; SG, 25-30; *Principia* II arts 37-53; AT VIII1, 62-70; MM, 59-69.

29 John Schuster, 'Descartes *Opticien:* The Construction of the Law of Refraction and the Manufacture of its Physical and Methodological Rationales 1618-1629' in Stephen Gaukroger, John A. Schuster and John Sutton (eds.) *Descartes' Natural Philosophy: Optics, Mechanics and Cosmology* (London: Routledge, 2000), pp.258-312; '"Waterworld": Descartes' Vortical Celestial Mechanics—A Gambit in the Natural Philosophical Agon of the Early 17th Century', in Peter Anstey and John Schuster (eds.) *The Science of Nature in the 17th Century: Patterns of Change in Early Modern Natural Philosophy* (Dordrecht: Springer, 2005), pp. 35-79; and *Descartes-agonistes*, pp.127, 169-173, 204-209, 366-372.

read out of that work the principles of a mechanistic theory of light. The latter in turn then prompted, on the level of natural philosophical systematising, the content and form of his corpuscular dynamics.[30]

Descartes' corpuscular dynamics, which makes its first full appearance in *Le Monde*, may be characterised as follows: Descartes held that bodies in motion, or tending to motion, are characterised from moment to moment by the possession of two sorts of dynamical quantity: (1) the absolute quantity of the 'force of motion'—conserved in the universe according to *Le Monde's* first rule of nature and (2) the directional modes of that quantity of force, which Descartes termed 'determinations', introduced in *Le Monde's* third rule of nature. As corpuscles undergo instantaneous collisions with each other, their quantities of force of motion and determinations are adjusted according to certain universal laws of nature, rules of collision. Therefore Descartes' analysis focuses on instantaneous tendencies to motion, rather than finite translations in space and time.

The genealogy of these conceptions reaches back into Descartes' optical researches and into his early commitment, with his mentor in corpuscular-mechanism, Isaac Beeckman, to a project of 'physico-mathematics'. Descartes and Beeckman meant by this term that reliable geometrical results in the mixed mathematical sciences were to be explained by invoking an embryonic corpuscular-mechanical matter theory and a causal discourse concerning forces and tendencies to motion. Descartes' early work, circa 1619-20 on hydrostatics, falling bodies and optics came under this framework of aspiration, and so did his more successful work in optics of the mid 1620s. Around 1627, Descartes found, by traditional mixed mathematical means, a simple (cosecant) version of the law of refraction. He immediately set to work attempting, in a 'physico-mathematical' [15] manner, to exploit his discovery by reading out of his results causal principles on the natural philosophical level. This proceeded in two steps. First, from his key geometrical diagram for the new law, he tried to read out the principles of a mechanical theory of light as an instantaneous impulse. As early as 1628, he was attempting to demonstrate his law of refraction to Beeckman, using these mechanical conceptions of light which he had obtained in this way. Then, in composing *Le Monde* between 1629 and 1633, he tried to extract further physico-mathematical causal 'insight' from the optical work. Using the principles of his mechanical theory of light elicited from the work on refraction, he reformulated and polished the central concepts of his dynamics of corpuscles—the 'causal register' of his emerging system of corpuscular-mechanism.[31] In *Le Monde*, this dynamics of corpuscles runs Descartes' vortex celestial mechanics and his corpuscular-mechanical theory of light in its cosmological setting.

These previously published findings license two new conclusions relevant to analysing the structure of Cartesian natural philosophy and the strategies involved in erecting it. Firstly, looking up from physical optics toward the core of the system, we can now see that Descartes' 'physico-mathematical' optics was the main source for a key ingredient of the core of his natural philosophy—the principles of his corpuscular dynamics, the very 'causal register' of the system.[32] There is nothing surprising in this. There is no reason why profound results in one domain of natural inquiry cannot provide the basis for concepts that might sit in the very core of an entire system of natural philosophy. This insight in turn supports the views of Buchdahl and Clarke that the physical 'principles' central to Descartes' 'science' had to have more than merely metaphysical content. In Descartes' physical optical results we have found exactly the key 'empirical' ingredients that were contained in his so-called laws of nature.

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30 For documentation of the findings sketched in the next two paragraphs, see Schuster, 'Descartes opticien', and *Descartes' agonistes*, chapter 4.

31 See Schuster, *Descartes-agonistes*, chapter 3 (the early physico-mathematical program); chapter 4 (the discovery of the law of refraction and its sequel in a mechanistic theory of light); chapter 8 pp.365-372 and chapter 9 pp.444-6 (the elaboration of the laws of nature/corpuscular dynamics in *Le Monde* and their grounding in Voluntarist theology and Descartes' dualist metaphysics). I say 'reformulated because strictly speaking the process of developing his corpuscular dynamics had begun with his hydrostatical work with Beeckman in 1619. Stephen Gaukroger and John Schuster, 'The Hydrostatic Paradox and the Origins of Cartesian Dynamics', *Studies in the History and Philosophy of Science* (2002) 33/3, 535-572.

32 On the term 'causal register', see Schuster, *Descartes-agonistes*, p.11 note 20 and the references therein.

Secondly, looking down from the core of the system and out (along the horizontal axis) to the various disciplinary domains and realms of matters of fact that were intended to be included in the Cartesian system of natural philosophy, we find, correspondingly, that physical optics had a most privileged relation to the core of the system. Its vertical 'articulation' to the core of the system was direct and powerful. The key concepts of Descartes' physical optics could now be seen to be directly explicable from the principles of corpuscular dynamics contained in the core. Both sides of the relation benefitted: His principles of dynamics were grounded in insight into the law-like behaviour of that especially revealing, instantaneously acting mechanical impulse which is light; and his pet discipline of physical optics was directly and [16] unambiguously 'deducible' (in the Clarkean sense) from the core of his natural philosophy. What could be a better outcome for an aspiring systematiser, such as Descartes; or for the historian, centuries later, seeking the long occluded strategies of his system–making?

Vortices

The theory of vortical celestial mechanics, as presented in the *Principles of Philosophy* and *Le Monde*, is the 'engine room' of Descartes' system of natural philosophy. Vortices—or at least proto-vortices productive of element formation—appear in Descartes' short cosmogonies in the two treatises. But what I mean by the vortical celestial mechanics only holds in the finished versions of the cosmos in the two treatises. That vortex mechanics is clearly a part of the 'core' of each system. Dependent upon element theory and corpuscular dynamics, the vortex mechanics in turn is the hinge upon which a vast proportion of the subsequent detail turns.

It has not generally been recognised that the key to Descartes' celestial mechanics is his concept of the 'massiveness' or 'solidity' of a planet, meaning its aggregate volume to surface ratio, which is indicative of its ability to retain acquired motion or to resist the impact of other bodies.[33] The particles of the second element making up a vortex also vary in volume to surface ratio with distance from the central star, as gathered from Descartes' stipulations concerning the variation of the size (and speed) of the second element particles with distance from the central star. (Figure 3)

[33] Material in this and the next five paragraphs is dealt with in more detail in John Schuster, 'Cartesian Physics' in Jed Z. Buchwald and Robert Fox (eds.) *The Oxford Handbook of the History of Physics* (Oxford, OUP, 2013), pp.56-95, at pp.73-78; and in Schuster, 'Waterworld', pp 41-55; *Descartes-agonistes*, 455-470.

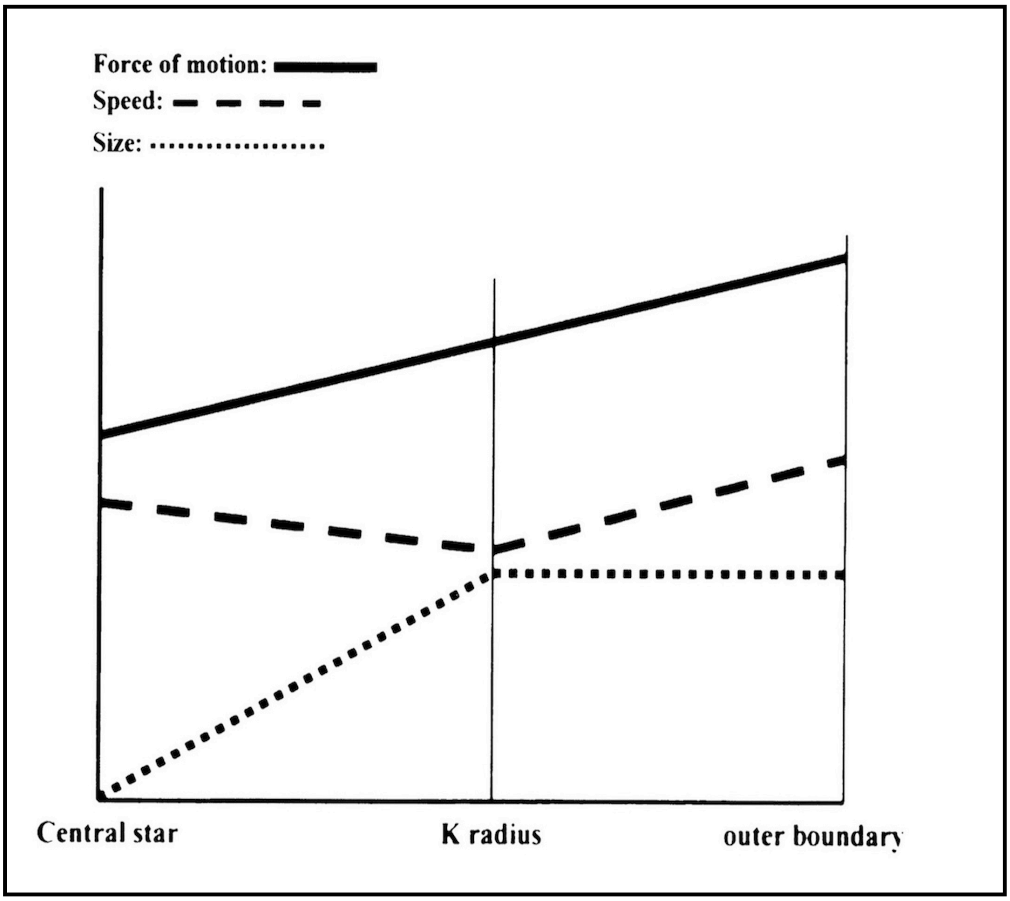

Figure 3. Size, Speed and Force of Motion Distribution Of Particles Of 2nd Element, In A Stellar Vortex

Note also the important inflection point in the size and speed curves at radial distance K from the central star. A planet is locked into an orbit at a radial distance at which its instantaneously expressed centrifugal tendency to motion, related to its aggregate solidity, is balanced by the counter force arising from the centrifugal tendency of the second element particles composing the vortex in the vicinity of the planet—that tendency similarly depending on the volume to surface ratio of the those particular particles.[34]

The most 'massive' planet in a star system will be closest to, but not beyond the K layer—as Saturn is in our planetary system. Comets are planets of such high 'solidity' that they overcome the resistance of the second element particles at all distances up to and including K. Such an object will pass beyond the K level, where it will meet second element particles with decreasing volume to surface ratios, hence less resistance, and be extruded out of the vortex into a neighbouring one. Entering the neighbouring vortex, the comet falls, and spirals, downward toward its central star, all the time meeting increasing resistance from the second element particles [17] above that vortex's K distance.[35] Picking up increments of orbital speed, the comet generates increasing centrifugal tendency, begins to rise and spiral upward, and eventually is flung back out of the second vortex.

Also essential to Descartes' theory is a principle of vortex stability, which he introduces using his concepts of corpuscular dynamics. In the early stages of vortex formation, before stars and elements have evolved, the then existing vortical particles become arranged so that their centrifugal tendency increases continuously

[34] Descartes' actual model, properly decoded, is a bit more complicated than this. See the references in the previous note.

[35] The term 'falling' is chosen deliberately. Descartes makes it clear in discussing the placement of planetary orbits that a planet 'too high up' in the vortex for its particular solidity is extruded star-ward, falling (and spiralling) down in the vortex to find its proper orbital distance.

with distance from the centre.[36] As each vortex settles out of the original chaos, the larger corpuscles are harder to move, resulting in the smaller ones acquiring higher speeds. Hence, in these early stages, the size of particles decreases and their speed increases from the centre out. But the speed of the particles increases proportionately faster, so that force of motion (size times speed) increases continuously. Figure 4 shows the distribution of size and speed of the particles in any vortex before a central star and the three elements have formed.

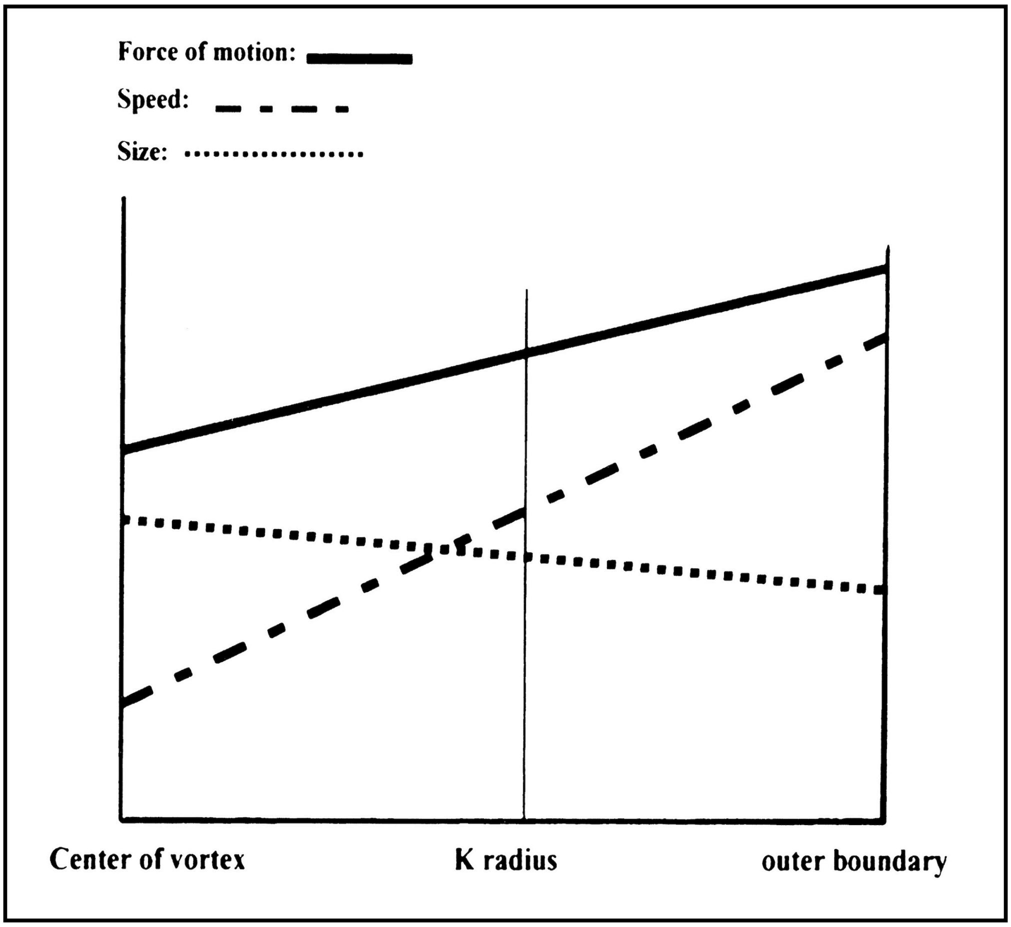

Figure 4. Size, Speed and Force of Motion Distribution of Particles of 2nd Element, Prior to Existence of Central Star

Hence stars do not exist in the early stages of vortex formation. They form in the centre of each vortex as part of the process leading to the emergence of the three [18] Cartesian elements. Every star alters the original size and speed distribution of the particles of its vortex, in a way that now allows planets to maintain stable orbits. Descartes explains that a star is made of up the most agitated particles of first element. Their agitation, and the rotation of the star, communicate extra motion to particles of the vortex near the star's surface. This increment of agitation decreases with distance from the star and vanishes at that key radial distance, called K.[37] (Figure 5) This stellar effect alters the original size and speed distribution of the spheres of second element in the vortex, below the K layer. There now are greater corpuscular speeds close to the star than in the pre-star situation. But, the all important vortical stability principle still holds, so the overall size/speed distribution must change, below the K layer. Descartes ends with the situation in Figure 3, with the crucial inflection point at K. Beyond K we have the old (pre-star formation) stable pattern of size/speed distribution;

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[36] AT XI 50-1; SG 33.

[37] AT XI, 54-6; SG 35-7; Schuster, 'Waterworld', p. 48.

below K we have a new, (post–star formation) stable pattern of size/speed distribution. This new distribution turns a vortex into a machine which, as described, locks planets into appropriate orbits below K and extrudes comets into neighbouring vortices.[38] [19]

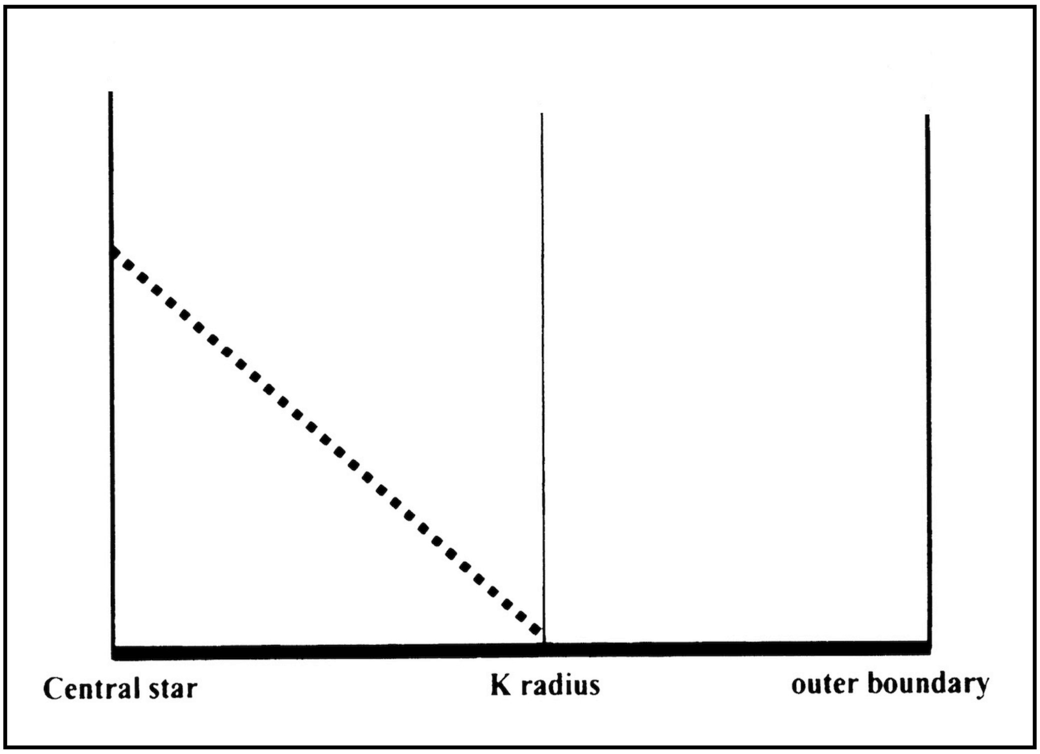

Figure 5 Agitation added to Vortex Due To Existence Of Central Star

In its intimate technical design, Descartes' vortex mechanics is a science of equilibrium, resembling his work on hydrostatics in his early program in physico-mathematics.[39] Hence celestial equilibrium and disequilibrium are analogous respectively to equilibrium and slippage in systems rigorously treated in the statics of Archimedes or Simon Stevin. However, Descartes' vortex celestial mechanics deals with equilibrium conditions described not in terms of volumes, densities and specific weights, but rather in terms of Cartesian centrifugal tendency to motion, as well as relative 'solidity', a property defined by volume to surface relations aggregated over the constituent third matter corpuscles of a planet or comet.

The forces at work upon a planet can only be fully specified when orbital equilibrium has been attained, although, of course no actual measurements are involved. This insight in turn allows us to specify a spectrum of *explananda* that the vortex mechanics was intended to tackle. As one moves through this spectrum, the full explanatory resources of the science of equilibrium kernel of the theory tend to fall away and the resulting explanations become more loose and theoretically impoverished.

[1] Planetary orbital equilibrium. This is the central target and successful exemplar of the theory.

[2] Radial movement of a planet or comet (its rise or fall in a vortex). For example, a comet extruded from one vortex enters a neighbouring one and 'falls' toward its K layer before picking up centrifugal force and 'rising' again out of the vortex [20] in question. Similarly, Descartes makes it clear that a planet 'too high up' in the vortex for its particular solidity is extruded sun-ward, falling (and spiralling) down in the

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38 In this way, Descartes follows Kepler's lead in attempting to theorise about the physical role played in celestial mechanics by the sun, or any central star in a planetary system. Copernicus had never raised the issue of the sun's causal role in planetary motion. This is the first set of significant, novel facts, consequent upon accepting realist Copernicanism, that is explained by deployment of the vortex theory.

39 Gaukroger and Schuster, 'The hydrostatic paradox'.

vortex to find its proper orbital distance.[40] In the vortex theory, these phenomena result from the breakdown of equilibrium and cannot be defined mathematically in the same way as orbital stability.

[3] The orbital movement of a planet, comet or planetary satellite. This is explained, with some difficulties and ambiguities, in terms of the rotation of the second element boules making up a vortex.[41]

[4] The fall of 'heavy' bodies (made up of third element) toward their local planet. Descartes' theory of local fall, taken in its very simplest acceptation, makes some sense in terms of the core, and indeed can be related to the theory of the orbital motion of the moon. Both make use of the notion of 'falling' in a vortex until a proper orbital level is found (assuming nothing prevents completion of the process, as happens in local fall of heavy terrestrial bodies near the surface of the Earth). However, Descartes' treatment of locally falling bodies and satellite motion both run into considerable difficulties when he attempts to explicate them in detail. For example, when treating the local fall of 'heavy' bodies, Descartes slips into the vocabulary of classical hydrostatics, which, however, simply does not mesh with his vortex mechanics, a science of volume to surface relations.[42]

These articulations of the core vortex theory to a range of problems and facts offer a microcosm of the challenges of 'making a system'. The core vortex theory is keyed precisely to *explanandum* [1]. But Descartes wished to articulate it to grasp the important phenomena in *explananda* [2] to [4]. There was horizontal extension of vortex theory out from the 'core'; and in each case a new vertical instance of explanation was required. Each case [2] through [4] raised questions about the goodness or plausibility of the systematic articulation. Descartes was not engaged with a set of unrelated, discrete 'consensus' style explanations. Rather, he was in the business of imagining and inscribing parts of a system of natural philosophy, and doing that with a recognisable, if debateable, strategy of construction.

We have examined the core of Descartes' system of corpuscular-mechanical natural philosophy, and we have seen a few different examples of articulation along the horizontal and vertical dimensions. The field of physico-mathematical optics was both the source of much that went into Descartes' principles of corpuscular dynamics, inside the core, whilst the domain of physical optics, taken as an *explanandum* inside the system, derived close and immediate explanatory 'cover' from those core principles it itself had prompted. The vortex celestial mechanics was articulated [21] toward a range of *explananda* with varying degrees of success. If space permitted, we could continue to multiply cases of horizontal and vertical systemic articulation, by examining, for example, Descartes' theory of the tides, or the details of his theory of the cause and properties of light in its cosmological setting.[43] The time has come, however, to explore Descartes' mature systematising strategy. This only appeared in the *Principles*, in portions of its Parts III and IV which have not often been studied, and certainly not studied to reveal Descartes' grand systematising strategy.

Descartes' systematising and explanatory strategy in the *Principia*

The *Principia*, unlike *Le Monde*, contains the theory of magnetism, part of which was examined above. Now we are going to see that there was much more to Descartes' theory of magnetism than we canvassed previously. By rather surprisingly linking his theory of magnetism to his account of sunspots (also absent in *Le Monde*), Descartes opened the way to a grand systematising strategy in his natural philosophical master work. This strategy runs from mundane magnetic phenomena to planetary and stellar magnetism, thence to sunspots, the formation of *novae*, variable stars, planets and comets, and ultimately to the formation of terraqueous planets, including the Earth. This highly conceptually and imaginatively engineered package amounted to one gigantic, systematic argument in favour of a realist interpretation of Copernicanism of quite

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[40] AT XI 65-66; SG 42; AT VIII1 193; MM 169.

[41] On this issue see Schuster, *Descartes-agonistes*, pp.459, 477 and Appendix 2.

[42] See Schuster, *Descartes-agonistes*, pp.478-483, 487-495 on local fall, and pp.495-498 on the theory of satellite motion.

[43] On the tides see Schuster, *Descartes-agonistes*, pp. 484-6; on the physical theory of light in cosmic setting, including the theory of cometary appearances, see Schuster, *Descartes-agonistes*, pp.499-514 (light), 515-521 (appearance of comets).

radical sort—a Copernicanism of an indefinite number of star and planets systems of which our solar system and our Earth are simply one tiny instance.[44]

In the *Principia*, Descartes did more than appropriate and reinterpret Gilbert's 'laboratory' work. As noted earlier, Gilbert's was an impressive and innovative natural philosophy. One of Descartes' targets in the *Principia* was Gilbert's competing system of natural philosophy. Gilbert called his sphere of lodestone, mentioned above, a *terrella*, a 'little earth', arguing that because compass needles behave identically on the *terrella* as on the earth itself, the earth is, essentially, a magnet. Hence, according to his natural philosophy, the earth possesses a magnetic soul, capable of causing it to spin. Magnetic souls similarly cause the motions of other heavenly bodies. Descartes, aiming to displace Gilbert's natural philosophy, focuses on the 'cosmic' genesis and function of his channelled and left- and right-handed magnetic particles. Descartes argues that the spaces between the spherical corpuscles of second element, making up the vortices, are roughly triangular, so that some particles of the first element, constantly being forced through the interstices of second element spheres, [22] are forged into relatively stable, longer, cylindrical forms, which are 'channelled' or 'grooved' with triangular cross–sections. All vortical interstitial first element corpuscles, including these bigger, longer channelled ones, tend to be flung by centrifugal tendency out of the equatorial regions of vortices and into neighbouring vortices along the north and south directions of their axes of rotation, where the large ones receive definitive opposite axial twists. The resulting left– and right–handed screw shaped first element particles penetrate into the polar regions of central stars and then bubble up toward their surfaces, and drift toward the equator, forming by accretion, Descartes claims, sunspots.[45]

This explanatory story about sunspots has two sets of consequences crucial to understanding Descartes' strategy in the *Principles*. Firstly, the sunspots formed on a star's surface out of accretions of the rimmed and handed first element particles are asserted to have become third matter. Sunspots consist of large third matter corpuscles, irregularly shaped and difficult to set in motion, which constitute the bulk of the matter in planets, comets and satellites in the cosmos, as we have already seen. In the *Principia*, third matter does not exist from the creation, and only comes into existence by means of the cosmic process of sunspot formation. All terrestrial matter is formed on stars out of the stuff of magnetism. Secondly, it also follows from Descartes' explanatory narrative that all stars are magnetic, as Gilbert maintained, but in a mechanistic sense, because they are all suited to reception of these oppositely handed, polar entrant first element particles. Moreover, for Descartes, planets are also magnetic, as Gilbert claimed, but again the explanation is mechanical. Descartes describes how a star may become totally encrusted by sunspots. This extinguishes the star, its vortex collapses and it is drawn into a neighbouring vortex to orbit its central star as a planet.[46] This is the only way planets are formed. Therefore, all planets, including our Earth, bear the magnetic imprint of their stellar origins, possessing axial channels between their magnetic poles accommodated to the right or left handed screw particles.

This strategic manoeuvring explains in large measure why Descartes designed his magnetic particles the way he did. What seemed idiosyncratic when we first looked at his explanation of magnetism, now seems nicely engineered, an imaginative exercise in a conceptually and strategically controlled sense. To do this Descartes had to articulate his element theory: there are now different genres of first element particle, and we are even further from the simple matter theory of *Le Monde* with its non-transmutable elements. Now transmutation from first to third element, on the surfaces of stars, is the key to every 'terrestrial' thing and process in the cosmos.

Returning then to sunspots, once Descartes has theoretically reconstituted them on the surfaces of stars in terms of his corpuscular-mechanism and theory of vortices and magnetism, he re-derives in terms of his

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[44] Material in this section is fully documented and further articulated in Schuster and Brody, 'Descartes and Sunspots', 29-45; and Schuster, *Descartes-agonistes*, pp.558-81; 'Cartesian Physics', pp. 79-82.

[45] AT VIII1 142-8; MM 132-6.

[46] AT VIII1 195-96; MM 171.

theory their consensually accepted [23] properties.[47] Then, in the pivotal move in this entire explanatory campaign, he uses this theory of sunspots further to explain *novae* and variable stars and, as just mentioned, the origin and nature of all planets, the Earth included. Variable stars had only been recognised in the late 1630s, after *Le Monde* and just before Descartes started writing the *Principles*. Alternate creation and destruction of complete sunspot crusts on a star explain its variability. *Novae*, accepted facts amongst European astronomers since the late sixteenth century, he explains as a sub-class of variables: A *nova* is a star which has been in an occluded phase and never before observed by humans which then comes into view for the first time, as far as humans are concerned. Subsequently, it might continue to shine or quickly or slowly become occluded again.[48] Thus Descartes unifies and rationalises the known empirical domains of *novae* and variables, subordinating to his natural philosophical strategy all the matters of fact he has chosen and framed as relevant.

Descartes' next move, expressing and completing the strategic intentions of his system, involves relating the Earth, and indeed every single planet in the universe, to a certain pattern of possible stellar development. As indicated above, occasionally, when a star becomes covered with sun spots, its vortex collapses and the defunct star is captured by another vortex, becoming a comet or a planet. This is usually termed Descartes' 'Theory of the Earth'.[49] He explains, how from a dead, encrusted star there results the formation of land masses, with mountains and declivities, the latter filled with water to form oceans subject to tides. But clearly all planets undergo the same processes: The dynamic of spots encrusting and eventually destroying stars is what accounts in matter theoretical and structural terms for each and every planet found in the universe. So, on this breathtaking vision, every planetary object in the cosmos traces its genealogy to a pattern of events that in principle might befall any 'star-in-a-vortex-afflicted-with-sunspots'.[50] Descartes unfolds his strategy by asserting a network of basic explanatory concepts involving element theory, magnetism, vortices and sunspot formation/dissipation that in principle can explain, via discursive causal/descriptive story telling, a spectrum of possible empirical outcomes. The causal/descriptive stories are filled out according to the varieties of observed outcomes by appealing, loosely, to a variety of possible interactions amongst sunspots, vortices, the surfaces of stars, and the 'aether' of old dissipated sun spot material that floats in each stellar vortex near each star.[51] [24]

This indeed is a grand strategic gambit, meant systematically to bind together his system and to establish his brand of realist Copernicanism of innumerable star and planetary systems, all worked by his corpuscular dynamics and vortex mechanics. At the time of writing *Le Monde*, Descartes had known the matters of fact claimed about sunspots, but he ignored the issue in his text. Later, having finally decided to go beyond *Le Monde*, and take seriously Galileo's and Scheiner's claims about sunspots, Descartes could still have played it more safely by adding a theory of sunspots to his natural philosophy as a marginal extra. This would have required changes to his element theory and cosmogony but probably little else. Instead, he selected relevant sunspot matters of fact as *explananda*, framed them in his own elaborate explanations—of element theory, magnetism, vortex and star structure—and then strategically leveraged them into *explicantes* for the creation of third matter and the existence and structure of planets and comets (by way of variable stars and *novae*). He appropriated accepted 'facts' about sunspots, but only on condition that he could frame them with an elaborate explanation linking back to his magnetic particles as sources for sunspots, and forward to variable stars, and planets as outputs of their now framed properties and modes of behaviour. Descartes was extending

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47 AT VIII1 148-50; MM 136-9 For technical details on the half dozen key matters of fact thus explained see Schuster, *Descartes-agonistes*, pp. 566-67; Schuster and Brody, 'Descartes and Sunspots', 30-31.

48 AT VIII1 158-62; M 144-7.

49 This material takes up the first forty-five articles in Bk IV of the *Principles of Philosophy*.

50 On the definitely realist Copernican intent of Descartes in the *Principles*, see Schuster and Brody, 'Descartes and Sunspots', 42-44; Schuster, *Descartes-agonistes*, pp.582-6. and 'Cartesian physics', pp.88-9.

51 Descartes introduces the section of Book III of the *Principles* dealing with sunspots, novae and variable stars at Article 101 by stating: (AT VIII1, 151; MM 139) 'That the production and disintegration of spots depend upon causes which are very uncertain.'

his natural philosophy, and systematically binding it together much better than he had in *Le Monde*, by scoring heavily in the game of realist Copernicanism.

Conclusions

Even if one decided to read Books III and IV of the *Principia* closely for their 'scientific content' one might easily conclude that what Descartes was doing there, on the one hand, was articulating problems in the narrow field of element theory, and on the other hand, quite separately, displaying a new sensitivity to the value of novel empirical facts. Then, to each separate case of explanation one might apply the findings of the Clarke *et al.* consensus. Instead, in this paper, I have suggested that Descartes was doing more than that in the *Principia*. His moves in element and vortex theory, and his adoption, and re-framing, of wide swathes of novel and interesting matters of fact, were two sides of the same coin, and that coin was an inventive and novel strategy of systematisation. The strategy consisted in weaving ranges of novel matters of fact into explanatory and descriptive narratives which have a definite textual and conceptual tonality, to wit, cosmic sweep and radical realist Copernican intent. Moreover, these narratives accomplish explanations by building hierarchical relations amongst the *explananda*, so that rather than all *explananda* being on the same plane and subordinate only to the core principles, some *explananda* are turned into *explicans* subsidiary to the core, interrelated to each other on the same level and grasping nets of *explananda* remaining below them. This refines the picture in our initial heuristic model.

Finally, let us contrast our findings here, on the one hand, with those of Rosaleen Love and John Lynes, cited earlier, who wrote about element theory; and, on the [25] other hand, with those of Clarke *et al.* who enlightened us about Cartesian explanation. Love and Lynes had been quite right to point out the element theory differences between *Le Monde* and the *Principia*. But, we can now see that they did not grasp that these differences are not simply about element theory. It is the vast new system-binding strategy of Descartes that makes the difference. The *Principia* did not have to be so much more systematically elaborated than *Le Monde*, but it is, and the strategy pivots on magnetism and sunspots of all things. Similarly, Clarke *et al* in their consensus view of Cartesian explanation had been quite right, but, as we can now see, they had been right about an ideal of one-off Cartesian explanations more interesting to philosophers than historians. They had not inquired about systematising strategies in Descartes' natural philosophy nor *a fortiori* about the vast step the *Principia* marks beyond *Le Monde* in that regard. As we have seen, insight into Descartes' systematising strategy puts the nature and complexity of Cartesian natural philosophical explanation into a richer and arguably more accurate historical light.