

**Descartes and sunspots:
Matters of fact and systematizing strategies
in the *Principia Philosophiae***

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This is the Final pre-publication version

First published on line, *Annals of Science*, April 2012,
iFirst **DOI:** 10.1080/00033790.2012.669703

Hard copy publication is set for *Annals of Science* 70 no.1 Jan
2013.

Abstract: Descartes' two treatises of corpuscular-mechanical natural philosophy—*Le Monde* (1633) and the *Principia philosophiae* (1644/1647)—differ in many respects. Some historians of science have studied their significantly different theories of matter and elements. Others have routinely noted that the *Principia* cites much evidence regarding magnetism, sunspots, novae and variable stars which is absent from *Le Monde*. We argue that far from being unrelated or even opposed intellectual practices inside the *Principles*, Descartes' moves in matter and element theory and his adoption of wide swathes of novel matters of fact, were two sides of the same coin—that coin being his strategies for improving the systematic power, scope and consistency of the natural philosophy presented in the *Principia*. We find that Descartes' systematising strategy centered upon weaving ranges of novel matters of fact into explanatory and descriptive narratives with cosmic sweep and radical realist Copernican intent. Gambits of this type have recently been labelled as '*cosmographical*' (the natural philosophical relating of heavens and earth in contemporary usage). Realist Copernican natural philosophers, from Copernicus himself, through Bruno, Gilbert and Galileo did this to varying degrees; but, we suggest, Descartes presented in Books III and IV of the *Principia* the most elaborate and strategically planned version of it, underneath the ostensible textbook style of the work.

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1. Introduction

Descartes wrote two treatises in systematic corpuscular-mechanical natural philosophy, the unfinished *Le Monde*, composed between 1629 and 1633 and unpublished in his lifetime, and the *Principles of Philosophy*, which appeared in Latin in 1644 and French in 1647.¹ Both texts present Descartes' vortex celestial mechanics; his explanations of the orbital behaviour of planets, comets and satellites; and his mechanistic theory of light in its cosmic setting. But the differences are dramatic: the *Principles* is a textbook in the neo-Scholastic style; *Le Monde* an attempt at literary persuasion of *honnêtes hommes* in the vernacular. The *Principles* offers a theory of the Earth, absent from *Le Monde*, and is much more elaborate in its presentation of laws of motion and numerous other natural philosophical topics. Beyond these differences, historians of science have focussed on contrasts between the treatises in regard to the theory of matter, with Rosaleen Love and John Lynes having written well known analyses of the issue.² Commentators have also

¹ *Le Monde* was first published in Paris in 1664. In this paper standard works of Descartes, and their translations, are abbreviated as follows:

AT = *Oeuvres de Descartes* (revised edition, 12 vols.), edited by C. Adam and P. Tannery (Paris, 1964-76). References are by volume number (in roman) and page number (in Arabic).

SG = *The World and Other Writings*, edited and translated by Stephen Gaukroger (Cambridge, 1998).

MM = *René Descartes, The Principles of Philosophy*, translated by V. R. Miller and R. P. Miller, (Dordrecht, 1991)

MSM = *Rene Descartes, Le Monde, ou Traité de la lumière*, translated by Michael S. Mahoney (New York, 1979).

CSM(K) = *The Philosophical Writings Of Descartes*, 3 vols., translated by John Cottingham, Robert Stoothoff, and Dugald Murdoch, and (for vol. 3) Anthony Kenny, (Cambridge, 1988) References are by volume number (in roman) and page number (in arabic).

² Rosaleen Love, 'Revisions of Descartes' Matter Theory in *Le Monde*', *British Journal for the History of Science*, 8 (1975), 127-37; John W. Lynes, 'Descartes' Theory of Elements from *Le Monde* to the *Principles*', *Journal of the History of Ideas*, 43 (1982), 55-72. Love does not directly compare the matter theories of *Le Monde* and the *Principles*, but rather juxtaposes Descartes' implied matter theory in his *Essais* of 1637 to that of the *Principles*, as it were imputing the former to *Le Monde*, often in an erroneous sense it must be said. The particular problems raised by Love's manner of interpreting *Le Monde* are not the topic of the current paper, but further comment on Love, and Lynes, appears below at note 44. By 'matter theory' we shall mean Descartes' theories of the elements, or genres of micro-particles into which his matter-extension is taken to be divided in *Le Monde* and later in the *Principia Philosophiae*. Strictly, and most abstractly speaking, Descartes' theory of matter consists in his doctrine of matter-extension. However, that concept, taken in isolation, plays almost no role in the descriptions and explanations he offers in the working machinery of his natural philosophy, and it is these, rather than abstract doctrines on the metaphysical level with which we are concerned. (See note 32 below.) Accordingly, throughout this paper as we discuss Descartes' accounts of cosmology, cosmogony, magnetism, sunspots, variable stars, novae and the generation of planets, we indifferently label our object of study the 'matter theory' or 'element theory' of Descartes—or sometimes his 'matter and element theory'. It is worth recalling, in this regard, the sage words of T.S. Kuhn, discussing the inner workings of Cartesian natural philosophy: '...Descartes introduced a concept which since the seventeenth century has

noted the much richer invocation of well attested matters of fact in the *Principia*, most notably Descartes' detailed attention to the phenomena of magnetism (as reported by Gilbert), sunspots, novae and variable stars.³

In this paper we argue that Descartes was doing more in the *Principles* than, on the one hand, articulating problems in the narrow field of matter theory, and on the other hand, quite separately, displaying a new sensitivity to the value of novel empirical fact.⁴ We suggest that far from being opposed intellectual practices,⁵ Descartes' moves in matter 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 we take to have been strategies for improving the systematic power, scope and consistency of the overall natural philosophy presented in the *Principia* compared to *Le Monde*. Moreover, the center of gravity of these strategies does not reside in Descartes' metaphysical grounding of the natural philosophy; in its partly latent, partly overt theological framework; or, in the elaborate teaching concerning the laws of motion and collision. Rather, we argue that Descartes' systematising strategy consists largely in weaving ranges of novel matters of fact into explanatory and descriptive narratives with cosmic sweep and radical realist Copernican intent.

We shall focus on sunspots as our prime example of Descartes' adoption, reinterpretation and strategic, systematic deployment of new matters of fact, although we also examine his stance *via à vis* stellar novae and variable stars. Additionally, we shall need to glance at his creative co-optation of Gilbert's work on magnet-

greatly obscured the corpuscular basis of his science and cosmology. He made the universe full. But the matter that filled Cartesian space was everywhere particulate in structure.' T.S. Kuhn *The Copernican Revolution* (New York, 1959, 1st ed. 1957), 240.

³ For example, the expositions of such leading commentators as Stephen Gaukroger, *Descartes' System of Natural Philosophy* (Cambridge, 2002) and William Shea, *The Magic of Numbers and Motion: The Scientific Career of Rene Descartes* (Canton, Mass., 1991).

⁴ 'Novel' in this context does not necessarily mean newly adduced by the author in question. In the natural philosophical contest of the generation of Descartes, novel factual claims by others were routinely co-opted and reframed within one's own philosophy of nature. To be up to date in this style of work did not demand production of fresh claims about matters of fact. These rules of the game were to change considerably amongst the next generation of natural philosophers. Descartes does not mention magnetism or sunspots in *Le Monde*. However, he alludes to novae ever so briefly (see note 55 below).

⁵ Some historians of science seem to take natural philosophical systematizing and a thirst for novel matters of fact as opposed or mutually exclusive seventeenth-century practices. Just as it is currently fashionable to talk about the origin of 'experimental science' later in the century as some sort of revolutionary outbreak of truly modern protocols for getting, handling and communicating miraculously atheoretical matters of fact, whilst conveniently forgetting almost everything that post-Kuhnian history and sociology of scientific knowledge taught us about theory-loading of facts, and of experimental hardware, let alone the continued existence of a rapidly changing but still living field of natural philosophical contention. J. A. Schuster and A. B. H. Taylor, 'Blind Trust: The Gentlemanly Origins of Experimental Science', *Social Studies of Science* 27 (1997), 503-536; L. Boschiero, *Experiment and Natural Philosophy in Seventeenth Century Tuscany* (Dordrecht, 2007). (Cf. note 44 below.)

ism. Descartes' dealings about sunspots will serve as a telling exemplar of how in general important ranges of new and striking matters of fact were 'leveraged' for systemic benefits, by which we mean the following: First, putatively reliable and agreed reports of such striking facts were taken up as *explananda*, things to be explained in the system. Then, secondly, such initially explained facts, now integrated into the explanatory machinery of the natural philosophy, were themselves leveraged into *explanans*, used to explain further, more complex or arcane phenomena. Indeed, we shall contend that the system itself may be viewed as a network of such moves.

2. Cosmogony, cosmology and cosmography: key categories and insights

As we explore Descartes' co-optation of facts regarding sunspots and variable stars and his strategic exploitation of them in the system of the *Principles*, we shall be putting to work several explanatory insights which in turn depend upon understanding three pursuits woven into Descartes' natural philosophising: cosmogony, cosmology and cosmography.

First of all we must clarify and distinguish the first two categories, which are often conflated in reading the *Principles*. *Cosmogony* we take to consist solely in the short fabular narratives offered (in two different ways) in *Le Monde* and the *Principles*, dealing with how one gets from God's creation of matter 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 general fabric of innumerable, star centred vortices.⁶ That final and continuing state of the cosmos—in which we can additionally count the nature and orbital behaviour of planets, comets and planetary satellites—we shall label Descartes' *cosmology*. This accords with the way the term may generally be applied to denote that dimension of a natural philosophy dealing with matter, cause and structure in the universe.⁷ Descartes' cosmogonies are short. They do not contain details about the final (quite elaborate) vortex mechanics. Moreover, although the cosmogonies are closely linked to claims about matter theory—the emergence of the final and continuing formats (types of element) in which all matter will be found—they omit some very important constituents of the Cartesian cosmos. For example, in the *Principles* the particles of the

⁶ As we shall see in Section 3, this statement is not quite correct in the case of the *Principles*, where the third element does not appear during the cosmogony, but only during the actual cosmological steady state.

⁷ J. A. Schuster, 'L'Aristotelismo e le sue Alternative', in *La Rivoluzione Scientifica*, edited by Daniel Garber (Rome, 2002), 337-357 (337-338); J. A. Schuster, 'Descartes—Philosopher of the Scientific Revolution; Or Natural Philosopher in the Scientific Revolution', *Journal of Historical Biography* 5 (2009), 48-83 (57-59, 64-65).

third element (terrestrial matter) are neither present in the cosmogony, nor produced by the cosmogonical process. They come into being from (some types of) first matter—and may also be transformed back into it—only during the business as usual cosmological patterns of activity on the surfaces of stars. Similarly, in the *Principles*, Descartes' theory of magnetism, in what we shall term its 'cosmic', rather than merely terrestrial applications, is crucial to how the final and continuing universe of vortices functions, but little of this elaborate model is even hinted at in the cosmogony. We shall also learn that Descartes' history of the Earth in the *Principles*, which actually stands in for the developmental history of any and all planets in his cosmos, belongs to his cosmology, and is not continuous with, or part of, the cosmogonical story in the *Principles*.

Secondly, we need to refine further our understanding of Cartesian cosmology: In the *Principles*, as in *Le Monde*, cosmology denotes the final, subsisting state of the cosmos. But, compared to the static picture of the cosmos in *Le Monde*, the *Principles* teach what we shall term a 'dynamic steady state' cosmology. Although in the cosmology of the *Principles*, as well as that of *Le Monde*, the vortices and all the elements are present and accounted for, with planets and comets accomplishing their respective, appointed orbital duties, we are told in the *Principles* that some kinds of large cosmic changes routinely and rather randomly occur: Sunspots come and go—and they are the one and only place where the third (terrestrial) element is produced in the cosmos. Any star might become variable and even—completely encrusted with sunspots—die, leading to collapse of its vortex, the dead star becoming, depending upon circumstances, a planet or comet. Furthermore, such a planet, like the Earth, would then develop its final terraqueous structure, with its seas, continents, mountains, valleys, tidal phenomena, etc. as a result of a further sequence of natural events befalling the dead-star-turned-planet.⁸ The cosmos of the *Principles* is dynamic. But, since there is no overall, macro level, directional or historical process involved in these kinds of changes, it is also steady state.⁹

⁸ In Section 10 we shall see that the formation of planetary (Earth-like) structures is a necessary result of natural processes, given the contingent death of a star and its migration into/capture by a neighboring vortex. That the planet forming process is necessary has tended to lead commentators to conflate Descartes' Earth theory with his cosmogony. But his history of the Earth (or any planet) is not cosmogonical, rather a necessary process triggered by random events inside his dynamic, steady state cosmos. Indeed it may be said that Descartes' dynamic steady state cosmology resides entirely outside the purview, or implications, of his little cosmogonical story.

⁹ In an unusually prescient comment R. F. McRae ['Cartesian Matter and the Concept of a World', in *Descartes, Critical Assessments*, 4 vols, edited by Georges J. D. Moyal (New York, 1991), IV, 153-162 (159)], noted that in Descartes' natural philosophy, 'If it is the relation of the fixed stars to one another which constitutes the form of the world, then...the universe does, according to Descartes, have a history of change from one world to another world as a result of the growth of sunspots and the death of stars'. This remark foreshadows the entire thrust of our argument in this paper, although, as indicated in note 8, we do not quite at-

This brings us to our third key category, ‘*cosmography*’, and the interpretative insights about it used in this paper. Following the recent work of Jacqueline Biro, we take cosmography to mean that part of a natural philosophy addressed to the relations between its matter and cause account of the heavens (its cosmology) and its theory of the Earth. This was an actor’s category at the time and had emerged initially in the context of geo-centric natural philosophies, most notably Aristotelianism, in which the point of the ‘relation’ was certainly not identity or even similarity of matter and cause explanation.¹⁰ However, for Descartes and other realist Copernicans, for whom the Earth was a heavenly body and the traditional heavenly bodies were now arguably ‘like’ the Earth and closely ‘related’ to it, cosmography was a space of natural philosophical challenge and opportunity. The terms of argument shifted from the relation of ‘the Earth’ to everything else, that is, ‘the heavens’, to being about the relations, generally, of any and all planets, their structures and geneses, to any and all stars, their nature and developmental patterns.

tribute ‘world-making and world-breaking’ significance to the behaviour of variable stars or births of planets as treated by Descartes in the *Principles*.

¹⁰ Jacqueline Biro, *On Earth as in Heaven: Cosmography and the Shape of the Earth from Copernicus to Descartes* (Saarbrücken, 2009) pp. 8-9. Cosmography is defined by Biro, extrapolating from definitions by John Dee, Thomas Blundeville, Nathaniel Carpenter and William Barlow, as ‘that part of natural philosophy that provided within one explanatory framework the relationship between the heavens and earth’, or as John Dee said, ‘matcheth Heaven and the Earth in one frame’. Such early modern definitions usually say that cosmography requires the use of astronomy, geography and other disciplines. This demands some clarification. First of all, references to astronomy in this connection clearly are mistaken, if we are considering astronomy to be the mixed mathematical discipline devoted to construction of geometrical models of planetary motions. Cosmography was a domain within the field of natural philosophy, hence it is not astronomy that is being related to theorising about the Earth but rather that dimension of natural philosophy dealing with structure, matter and cause in the cosmos, to wit, cosmology as we have termed it above. As to the other term in the relation, loosely called geography above, one has to recognise that geography had many acceptations in the period, mirrored today by historians of the field (Biro, *ibid.*, 12, note 19, discussing the views of Lesley Cormack and David Livingstone). The portion of geography considered to be part of cosmography might be taken to be mathematical geography. But there are difficulties here, as part of what was meant by mathematical geography was just that, a mixed or practical mathematical field with at best highly debatable relevances for natural philosophy and cosmology. In addition, the other parts of mathematical geography—such as the study of terrestrial gravity and magnetism, the study of exact locations, and deep articulations to cartography—constituted a diffuse and only partially natural philosophically relevant suite of concerns. Given all this, Biro adopted a contemporary term ‘geognosy’ in order to construct an historian’s category of ‘geognosic opinion’ to serve as the ‘Earthly’ partner to cosmology in the cosmography pairing. Geognosic opinion would then be ‘ideas and knowledge about the Earth’s structure’; that is, geognosic knowledge claims concerned issues of *structure, matter and cause in regard to the Earth*. (Biro, *ibid.*, 16 and note 27 thereto) Within natural philosophical discourse, this is to be paired, cosmographically, with cosmology as claims about *structure, matter and cause in the cosmos*. (In this paper we simply denote the ‘Earth’ part of the heavens/Earth pairing as ‘theory of the structure and nature of the earth’. Hence, for us, cosmography is that dimension of natural philosophising in which cosmological and Earth theory claims were placed in relation to each other.)

Most importantly, as Biro has shown, claims about the structure of the Earth could now be exploited for cosmographical ends, specifically realist Copernican ends: Arguably true claims about the structure and nature of the Earth were now endowed with the property of being *ipso facto* claims about a heavenly body, arguably therefore closely related to other heavenly bodies and processes.¹¹ *Le Monde* to some extent reflects this shift and form of strategy,¹² but the *Principles*, in our

11 In other words, *What is the nature of the Earth as a planet? What can be gathered about the Earth, for example, about its structure, its magnetism (Gilbert), its tides (Galileo and Descartes), the nature of local fall, that would support its construal as a planet amongst planets and allow for the motions realist Copernicanism required of it?* For realist Copernicans the relation of 'the Earth' to everything else, that is, 'the heavens', changed, becoming the relation of any and all planets, their structures and geneses, to any and all stars, their nature and developmental patterns. Biro (note 10) has shown that claims about the structure of the Earth could now be exploited cosmographically, for realist Copernican ends: Early to mid sixteenth century technical developments in geography, consequent upon the re-discovery of Ptolemy's *Geography* and leavened by the findings of the voyages of discovery, were at first only grudgingly granted by the Scholastic Aristotelians, but were eagerly seized as a resource by natural philosophers advocating Copernican cosmology, with Galileo and Descartes offering late examples of such cosmographically focused tactics in a sequence of varied yet uniformly anti-Aristotelian natural philosophical gambits stretching from Copernicus himself, through Bruno, Gilbert and others. We further articulate Biro's initiative in our discussion below in Section 11 of the nature of Descartes' 'grand cosmographical gambit' in the *Principles*.

12 An example of the presence of a definite cosmographical orientation in *Le Monde* occurs when Descartes offers his first account of the elements, in Chapter 5, a text we shall discuss in detail immediately below in Section 3. In these passages (AT XI 24-6; MSM 37-39; SG 17-18), Descartes identifies his three elements with Aristotelian traditional ones: first element with fire; second element with air and third element with earth. It is a commentators' commonplace that Descartes was attempting here to preserve some continuity with (at least part of) traditional element theory. In *Le Monde*, as some suggest, he may have viewed his 'naming' his elements as yet another rhetorical ploy to keep the intended francophone *honnête homme* reader on side. But, his gambit would have arguably been quite unconvincing to just about any natural philosophically literate reader. Moreover, if that was part of Descartes' aim, it certainly seems he did not stick with it, dropping the pretense in the *Principles*. Not previously noticed, however, is a deeper motive, one grounded in systematizing tactics: This naming of the elements seems to have *cosmographical* significance in the sense we have given to the term. In this new system, neither air nor fire are elements found on and about a unique Earth. In the light of his radical Copernican realism, envisioning effectively an infinite number of star and planetary vortical systems, Descartes was saying to the aware reader that 'air' had been misconstrued by Aristotelians as the essential constituent of the local terrestrial atmosphere only. No, 'air' is ubiquitous in the cosmos, constituted of the spherical *boules* of second element that make up each and every stellar vortex. What natural philosophers have termed air is just a mixture of various kinds of earthy particles of third element, with the usual unavoidable interstitial 'filler' material of fugitive second and first element particles. Similarly 'fire' is not the Aristotelian element at home in some peculiar sense just below the Earth's moon. Again, no, for fire is the first element, the very stuff of every star, including our sun. Renaming the elements was less an unconvincing bow to traditional teaching than it was—as we have foreshadowed—a hint and sign of a new cosmography; that is, a new relation between all planets, in any vortex whatsoever, including our Earth, and all the stars and stellar vortices of the universe. If we are correct about this, we have here a nice example of Descartes' well known proclivities toward both elusiveness and allusiveness, in his simulta-

view, amounts to one vast, interrelated set of such radical, realist-Copernican cosmographical arguments. Indeed the *Principles* of Descartes offers a dynamic, steady state cosmography, from the genesis of third matter as sunspots on the surfaces of stars to the explanation of planets as collapsed and modified debris of dead stars, still internally structured (as were the parent stars) to accept incoming, oppositely axially directed left- and right-handed magnetic screw particles of first element. Descartes' games with sunspots sit squarely in the middle of this radical Copernican realist cosmographical nexus. This is what we mean by saying that the center of gravity of the system of the *Principia* will be revealed to reside in a place few have previously sought to locate it, in a network of systematically co-opted matters of fact about magnetism, sunspots and variable stars, reframed in Cartesian mechanistic and cosmographical terms, so that they can leverage further explanations in the cosmographic vision.

Our argument will proceed as follows: First, in the following section we shall canvass in some detail the matter theories and cosmogonies in *Le Monde* and the *Principia*. Then, after a brief but necessary look at some technical points about Descartes' vortex celestial mechanics in Section 4, we shall turn in Section 5 to his co-optation of the cosmographical tactics William Gilbert had deployed in his radical and influential 'magnetic' natural philosophy. Sections 6 and 7 will deal respectively with claims about sunspots before Descartes and with his selection and theoretical reframing of those claims in the *Principia*. Then, after looking in Section 8 at the development of factual claims about variable stars in the period between Descartes' writing of *Le Monde* and the publication of the *Principia*, we shall examine how he leveraged his explanation of sunspots to account for both variable stars and novae. Section 9 will complete our tour of Descartes' cosmographical strategy in the *Principia* by looking at his account of planet formation anywhere in the cosmos, material usually treated merely as a 'theory of the Earth'. This will allow us in Section 10 to bring together the threads of our argument into a discussion of Descartes' 'grand cosmographical gambit' and in the *Principia*. Finally, Section 11 will explore, following Biro, Descartes' place at the culmination of a tradition of cosmographically sensitive, anti-Aristotelian and realist Copernican natural philosophers.

3. Matter and element theory in Descartes' two natural philosophical treatises

Both *Le Monde* and the *Principia* offer descriptions of the creation and initial cosmogonical development of matter, issuing in the emergence of three genres of

neous (and contradictory) appeal to the old element names and new cosmographical tactics. In any case, as this paper argues, the *Principles* will display a much greater attention to cosmographical strategies and content.

micro particle, or elements. These are initially described by Descartes in *Le Monde* as follows:

I conceive of the first [element]...as the most subtle and penetrating fluid there is in the world....I imagine its parts to be much smaller and to move much faster than any [other bodies]. ...in order not to be forced to imagine any void in nature, I do not attribute to this first element parts having any determinate size or shape; but I am persuaded that the impetuosity of their motion is sufficient to cause it to be divided, in every way and in every sense, by collision with other bodies, and that its parts change shape at every moment to accommodate themselves to the shape of the places they enter....

As for the second,...I conceive of it also as a very subtle fluid in comparison with the third; but in comparison with the first there is need to attribute some size and shape to each of its parts and to imagine them as just about all round and joined together like grains of sand or dust. Thus, they cannot arrange themselves so well, nor press against one another, that there do not always remain around them many small intervals, into which it is much easier for the first element to slide in order to fill them. And so I am persuaded that this second element cannot be so pure anywhere in the world that there is not always some little matter of the first with it.

[as to the third element]: Its parts I judge to be as much larger and to move as much less swiftly in comparison with those of the second as those of the second in comparison with those of the third. Indeed, I believe it is enough to conceive of it as one or more large masses, of which the parts have very little or no motion that might cause them to change position with respect to one another.¹³

There is at work here a set of constraints, arising jointly from the requirements in *Le Monde* of Descartes' theory of vortex mechanics and his cosmological theory of light. The three elements are designed to account for the three kinds of matter minimally needed for a theory of light as mechanical pressure: that which produces light by mechanical agitation, that which conveys light-pressure, and that which reflects light and is opaque to it. If Descartes started in the late 1620s with an unexplicated real theory of light as tendency to motion in a bearer medium,¹⁴ not very much imagination would have been needed to see that at the very least two other types of matter would be necessary, one in luminous bodies—the sun,

¹³ AT XI 24-6; MSM 37-39; SG 17-18. We should note Descartes' continual interjection of phrases such as 'I conceive', 'I accept' or 'I judge'. An epistemological constraint is involved, implicitly harking back to the doctrine of his *Regulae ad directionem ingenii* (left incomplete in 1628), in that nothing is conceived or imagined of these elements which is not clearly intuitable. [J. A. Schuster, 'Descartes' *mathesis universalis*: 1618-1628', in *Descartes: Philosophy, Mathematics and Physics*, edited by Stephen Gaukroger (Brighton, Sussex, 1980), 41-96] The description involves only considerations of motion, size, shape and arrangement. (Nevertheless, the behaviour of the first element is quite inexplicable. How can it continually change shape and adapt itself to the ever shifting interstices of the second element without experiencing a change in density?) Although it cannot be proved that elements exactly like these exist, the discussion moves within the discursive limits set out in the *Regulae* on the basis of a theory of perception, and further employed in Chapters 1 to 4 of *Le Monde*.

¹⁴ Cf. J. A. Schuster, 'Descartes *Opticien*: The Construction of the Law of Refraction and the Manufacture of its Physical and Methodological Rationales 1618-1629' in *Descartes' Natural Philosophy: Optics, Mechanics and Cosmology*, edited by S. Gaukroger, J. A. Schuster and J. Sutton (London, 2000), 258-312 (286-295).

stars and flame—providing the cause of that tendency to motion, and the other constituting opaque reflecting materials. These distinctions have obvious cosmological parallels which Descartes exploits. The sun and stars produce light and thus are identified with the first matter; the vortex heavens propagate light and so are identified with the bearer medium of second element; and, the Earth, moon, planets and comets reflect received light and thus consist of the gross opaque third matter.¹⁵ That is, we have here an elementary example of a systematic reason or motive behind how portions of the natural philosophy were constructed. We shall see much more of this in the *Principles*.

Notwithstanding the exposition of matter theoretical differences between the two works by Lynes and Love, mentioned earlier, the matter theory in *Le Monde* and the *Principia*, and the cosmogonical accounts related to them, are often seen as interchangeable. Such readings are defensible at a general level. After all, when most of the surrounding detail is stripped away, in both works we have in effect a divinely created infinite block of Cartesian matter-extension, precluding the existence anywhere and any time of even the smallest void space. Cartesian matter is the same incompressible, indestructible, homogenous substance in each and every particle, fragment, or corpuscle that might eventuate from the divine injection of motion into the block of matter-extension. Any and all differences that might exist amongst such pieces of matter arise solely from their size, shape, state of motion or rest. The three elements, once formed, are really three persistent formats, stipulating certain ranges of size, shape and distributions of degrees of motion, into which each and every corpuscle fits. No micro particle is not a member of one of those three classes or elements. In both works, sooner or later after a cosmogonical story, we have permanent differentiation amongst the three element formats: at any given moment in time thereafter matter appears only in one or another of the three guises.¹⁶

Nevertheless, the differences between the two theories of matter are greater than usually acknowledged, so that, in our view, it is not surprising that the development of Descartes' account of the elements between *Le Monde* and the *Principia* remains, as it was regarded twenty-five years ago by the pioneer of this topic, Lynes, a 'somewhat neglected task'.¹⁷ Most notably, in *Le Monde* there is no transmutation of elements, after their cosmogonical formation. Indeed, the third matter pre-exists the first and second produced by that cosmogony. In the *Principles*, again only the first and second elements emerge from the initial cosmogoni-

¹⁵ AT XI 29-30; SG 19-20; MSM 45-47

¹⁶ Here we ourselves offer at first a simple reading. In *Le Monde* the third element actually pre-dates the other two, being in a sense present from the moment God injects motion into the block of matter-extension. In the *Principia* the third matter is produced only in the dynamic steady state cosmos, out of portions of first element. So, 'sooner or later' applied to both texts means that in the end, somewhere in the steady state cosmos following the cosmogony, we have three and only three matter formats for micro-particles.

¹⁷ J. Lynes (note 2), 55.

cal process, but in this case the third element is nowhere to be seen until the steady state cosmos has emerged, because in the *Principles* the third element only arises, under special and portentous circumstances, from the first element (and can be transformed back into it).

We are next going to sketch these textual differences in a bit more detail. But we do this only as preparation for passing beyond such mere matter theoretical comparisons in search of bigger interpretive game. We shall find that in the *Principia* the third element, produced from certain types of first element, plays crucial roles in the dynamic steady state cosmographical processes which are central to the system-binding strategies of the *Principia*. Indeed, we shall argue that these processes constitute the heart of the *Principia* as a system of nature, and that their conceptualisation depended upon Descartes' lively and concerted attention to, and co-optation of, significant ranges of matters of fact circulating in the natural philosophical culture.¹⁸

There are three accounts of the elements in *Le Monde*, in Chapters 5, 6 and 8.¹⁹ The first passage, in the form of the bold stipulation of the nature of the elements we have just cited, occurs at the beginning of Chapter 5. It is similar to what can be extracted from a quick reading of the *Principia*, accounting for the understandable belief that the matter and element theories of the two works are effectively congruent. The second and third accounts in *Le Monde* occur respectively in Chapters 6 and 8, separated by the discussion of the laws of nature in Chapter 7. Both of these later accounts in *Le Monde* are framed in cosmogonical terms concerning God's initial creation of matter and injection of motion into it, and the resulting initial formation of a cosmos of multiple stellar vortices.

Descartes opens his cosmogonical fable by asking us to imagine that in the indefinitely large spaces beyond our real world God has created a uniform, space-filling continuous matter. This stuff is devoid of all secondary qualities and is conceived solely in terms of its solidity and continuous extension in three dimensions.²⁰ Local motion, which will be the principle of all natural change, must be

¹⁸ It has not always been the case that the matter theoretical contrasts between *Le Monde* and the *Principia* have been glossed over. Gabriel Daniel (1649-1728) for instance, who was a strong critic of Descartes, was not sure which of the two versions to accept: 'whether the third element be contemporary with the other two, as M. Descartes seems in some measure to suppose in his *Treatise of Light*: or, whether it be form'd by the Conjunction of several Parts of the first element hook'd to one another, as he seems to teach in the *Book of Principles*'. Gabriel Daniel, *A Voyage to the World of Cartesius* (London, 1692), 261.

¹⁹ These three accounts of the elements are foreshadowed at the end of Chapter 4 of *Le Monde*, which deals with the nature of the terrestrial atmosphere and arguments about the void, continuity of matter and phenomena of pumps. Descartes suggests it is reasonable to view the air to be a material plenum. This forces one to postulate the existence of other genres of unobservable particles completely filling the interstices which must exist amongst the grosser, but also unobservable, particles of air. Thus, Descartes hints at the later unveiling of his third matter, and other interstitial genres of matter.

²⁰ AT XI 33; MSM 53-55; SG 22-23. 'Let us rather conceive of it ['our matter'] as a true, perfectly solid body, which uniformly fills the entire length, breadth, and depth of the great

injected into this dead block-universe by a logically second but nonetheless simultaneous creative act of God. By imparting diverse motions to portions of the block, God constitutes particles of different sizes and shapes,²¹ and the particles thus created settle into a number of huge vortical motions.²²

As each vortex continues to rotate, the particles begin to sort themselves out into a definite distribution; those ‘naturally less agitated or smaller, or both, toward the places nearest to the centres than toward those farthest away’.²³ This distribution is based on an important condition for the stability of any vortex, to wit, that no ring of corpuscles has more centrifugal inclination than the next outer ring;²⁴

space at the centre of which we have halted our thought. Thus, each of its parts always occupies a part of that space and is so proportioned to its size that it could not fill a larger one nor squeeze itself into a smaller one, nor (while it remains there) suffer to find a place there.’

²¹ AT XI 34; SG 23; MSM 53-55 ‘Let us add further that this matter can be divided into any parts and according to any shapes that we can imagine, and that each of its parts is capable of receiving in itself any motions that we can also conceive. Let us suppose in addition that God truly divides it into many such parts, some larger and some smaller, some of one shape and some of another, as it pleases us to imagine them. It is not that He thereby separates them from one another, so that there is some void in between them; rather, let us think that the entire distinction that He makes there consists in the diversity of the motions He gives to them. From the first instant that they are created, He makes some begin to move in one direction and others in another, some faster and others slower (or indeed, if you wish, not at all): thereafter, He makes them continue their motion according to the ordinary laws of nature.’ [emphasis added]

²² AT XI 49; SG 32-33; MSM 79-81. ‘....to consider this matter in the state in which it could have been before God began to move it, one should imagine it as the hardest and most solid body in the world. And, since one could not push any part of such a body without pushing or pulling all the other parts by the same means, so one must imagine that the action or the force of moving or dividing, which had first been placed in some of the parts of matter, spread out and distributed itself in all the others in the same instant, as equally as it could.

‘It is true that this equality could not be totally perfect. First, because there is no void at all in the new world, it was impossible for all the parts of matter to move in a straight line; rather, all of them being just about equal and as easily divertible, they all had to come together in some circular motions. And yet, because we suppose that God first moved them diversely, we should not imagine that they all come together to turn about a single centre, but about many different ones, which we may imagine as diversely situated with respect to one another.’ [emphasis added]

Notice that this passage, contrasted to the one cited in the note 21, seems to presume that there is some time interval between God’s creation of matter extension and his injection into it of particle-producing motion. Alternatively, to preserve a unified and total creation by God, one might suggest that the gap between creation of matter-extension and insertion of motion to shatter it is merely logical, there being no temporality in God’s creative act. The consequences for the matter-theoretical cosmogonical narrative, as considered by us here, are irrelevant; but the consequences for articulating Descartes’ natural philosophy to one theological position or another might be considerable.

²³ AT XI 49; SG 33; MSM 81.

²⁴ Gaukroger (note 3), 152, note 19, where he cites Eric Aiton, *The Vortex theory of Planetary Motion* (London, 1972), 63 note 78.

For all of them having an inclination to continue their motion in a straight line, it is certain that the strongest (ie: the largest among those equally agitated and the most agitated among those equally large) had to describe the greatest circles, i.e. the circles most approaching a straight line.²⁵

The implication is that the 'inclination to continue in a straight line', identified with the instantaneously exerted force of motion, is measured by the agitation and size conjointly and that as one moves away from the centre of a vortex this inclination, which gives rise to centrifugal tendency to motion, will increase, or at least not decrease.²⁶

To this point Descartes has only set out a condition for the variation in force of motion of the particles with distance from the centre of a vortex. Next, he specifies in detail the relative sizes and speeds of the particles making up successive rings from the centre out. Again invoking the continual impact of the particles among themselves, he describes a kind of steady state in which size varies in some inverse ratio with speed, such that while the size of the particles decreases with radial distance from the centre, their increased speed more than compensates.²⁷ In this way the condition on force of motion can be maintained.²⁸

Apparently, the acquisition of speed is inhibited in proportion to the quantity of matter. The idea seems to be that, given the increasing difficulty of imparting velocity to large particles, it will be the relatively smaller particles which will first assume the higher levels of force of motion due to an overcompensating acquisition of speed. Thus the smaller particles will take their places in the outer regions of a vortex. It is important to note, however, that although we have called this a 'kind of steady state' for the sake of exposition, this distribution of particles is not the final steady state—as we defined it earlier—of any vortex, nor the end point of the cosmogonical story. Subsequent passages make clear that Descartes has been considering the system of particles before the definitive emergence of the three

²⁵ AT XI 49-50; SG 33; MSM 81.

²⁶ The dynamical concepts in play here in *Le Monde* and their origins are clarified in S. Gaukroger and J. A. Schuster, 'The Hydrostatic Paradox and the Origins of Cartesian Dynamics', *Studies in the History and Philosophy of Science*, 33 (2002), 535-572; Schuster (note 14); and J.A. Schuster, "'Waterworld': Descartes' Vortical Celestial Mechanics and Cosmological Optics—A Gambit in the Natural Philosophical Agon of the Early 17th Century", in *The Science of Nature in the 17th Century: Patterns of Change in Early Modern Natural Philosophy*, edited by Peter Anstey and J.A. Schuster (Dordrecht, 2005), 35-79.

²⁷ AT XI 50-1; SG 33; MSM 81-3: 'Thus, in a short time all the parts were arranged in order, so that each was more or less distant from the center about which it had taken its course, according as it was more or less large and agitated in comparison with the others. Indeed in as much as size always resists speed of motion, one must imagine that the parts more distant from each center were those which, being a bit smaller than the ones nearer the center were thereby much more agitated.'

²⁸ Force of motion is a function of size (quantity of matter) and speed (or instantaneous tendency to motion), so, as the size of particles in a vortex decreases, their speed must increase in order for the 'stability condition' to be maintained.

permanent forms of particle, the elements.²⁹ As the particles circulate they collide, breaking off each other's rough edges and protuberances, with the smallest of these cosmic scrapings forming the first matter. A portion of these first matter particles are forced to the center of their vortex, forming a sun or central star, while the rest of the first matter fills the interstices left between the particles of the vortex.³⁰ The particles smoothed by this process become the spherical *boules* of the second element, constituting the bulk of the rotating 'heavens'.

Note that these two elements have evolved out of the original 'ur-particles' established when the block of matter-extension was shattered by the injection of motion: particles of this type did not exist amongst the variety of originally created particles. But what of the particles of third matter? It turns out that they are assumed to have existed ever since that first creation of particles. Not every particle of the originally created matter changed into first or second element. There were some larger and more irregular parts in the beginning and these retain the form of the third element which makes up the bulk of planets (including the Earth), planetary satellites and comets. Some of the original particles of this third element were so large and cumbersome that whenever they met they easily joined up. There were others, even larger ones that were instrumental in reducing the size of the other particles when they collided, whilst they themselves remained intact.³¹ Nowhere in *Le Monde* does the third element change into either of the other forms. That is, although *Le Monde* takes a radical stance in cosmography, Descartes' Copernican unification of 'heavens and Earth' does not on this point go so far as element theory. Once the cosmos is constituted, and stars and vortices have formed, Earthy, that is planetary, matter can never change into the matter of the 'heavens' that is vortices or stars.³²

²⁹ Remembering that Descartes has introduced his element theory in Chapter 5 in a 'non-cosmogonical' context, shaped by his didactic strategy at that point.

³⁰ AT XI 53; SG 34; MSM 85.

³¹ AT XI 56-57; SG 37; MSM 93: 'In order for me to begin to tell you about the planets and comets, consider that, given the diversity in the parts of matter that I have supposed [at the creation] even though most of them have—through breaking up and dividing as a result of collision with one another—taken the form of the first and second element, there nevertheless remains to be found among them two kinds [as described in the text above] that had to retain the form of the third element.' And, two pages later (AT XI 60; SG 39; MSM 99), describing the formation of comets and planets out of third matter, he opens with '...no matter where the parts of matter that could not take the form of the second or the first element may have been initially...' [emphasis added] Thus Descartes reiterates the existence of third matter particles before the initial formation of the first and second element.

³² Nowhere in *Le Monde* does Descartes state the element theoretical unity of heaven and Earth; that is stars and vortices and planets (plus comets and moons). The sun (and the other stars) differ from the Earth (and all other planets and comets). Descartes attributes to stars a nature 'totally contrary to that of the Earth because the action of their light is enough for me to recognise that their bodies are of a very subtle and very agitated matter.' (AT XI 29-30; SG 20; MSM 45-7) Here, again, we have an indication of the way the element theory in *Le Monde* is largely driven by the theory of light. Hence the needs of Descartes' theory of light tend to run

In the *Principles* we also (eventually) find the same three elements; but their relations are quite different and their cosmogonical genealogies altered. Descartes steps away from the conceit of the simple cosmogonical cracking of the infinite block of matter-extension by God's injection of motion, thus producing a variety of micro particles, with the vortices evolving out of the chaotic state manifested at that initial corpuscle producing instant. In the *Principles* the ur-particles are now 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. Descartes proclaims a type of principle of cosmic harmony or order, contrasting with the inchoate initial moments of the cosmos of *Le Monde*.³³ Additionally, we are informed that, 'All were moving with equal force in two different ways: each one separately around its own center but also several together around certain other centers'—a statement that strongly entails that the number and placement of (at least the initial set of vortices) is also inscribed in the cosmos at its moment of creation.

Leaving aside the new emphasis on pre-established harmony and pre-inscription of the vortex economy, the real puzzle here, not addressed by Descartes, but obvious to any contemporary or modern reader who understands his conception of completely full matter-extension is this: The original particles cannot have been all equal and all spinning around their own centers. John Heilbron has perspicaciously interpreted Descartes as speaking about equal, perfectly cubic particles, completely space filling on that account, which begin to spin, each

against the most radical implications of embracing an infinite universe realist Copernicanism, where such a strong 'bar' between 'planetary' and 'heavenly' types of matter would seem otiose and counterproductive. All this will change in the *Principia*.

It is, however, true that if by matter theory in Descartes, we mean solely the theory of matter-extension, then, of course, a unity of heavens and Earth was achieved from the start, and in principle Descartes *could* have gone on to assert the transmutability of the elements into which this matter-extension happened initially to be sorted. In fact, however, natural philosophising was about producing detailed explanations of ranges of new and old facts, and 'systematisation' of the resulting suite of explanations. To 'do' natural philosophy, Descartes could not simply devote himself *ad infinitum* to 'analysis' of the doctrine of matter-extension and its possible implications. (Cf. note 2.) We see this already in the simple fact that the purpose of the cosmogonical story is to produce the elements and the types of structures—stars, vortices, planets—they constitute. In Cartesian natural philosophy, matter-extension as such lasts an instant (the instant of creation). While it exists in its pure state, no 'nature' or cosmos yet exists, so there is not yet any subject matter for natural philosophy. Similarly, although Descartes 'could' have had transmuting elements in *Le Monde*, based on his matter-extension doctrine, in articulating his natural philosophy in *Le Monde*, he specifically denied that possibility. Therefore, historians need to look to Descartes' aims and tactics in natural philosophising for reasons for his insistence in 1633 on what became unnecessary to assert in 1644.

³³ 'Confusion seems less in accordance with the supreme perfection of God the creator of things than proportion or order' so he was 'supposing at this point that all the particles of matter were, initially equal in respect both of their size and their motion'. This point and the other textual references in this paragraph are located at: Principles III articles 46-47; AT VIII-1 102-3; CSM I 257; MM 106-107.

around its own centre, this immediately producing [1] spherical boules of second element, and [2] space filling debris of first element.³⁴ This is a nice and typically brilliant Heilbronian conceit. It convincingly decodes part of Descartes' text while obviously setting aside other parts of it. But it certainly has the benefit of capturing what turns out to be Descartes' clear intent in these *Principles* passages. The cosmogonical story issues only in second and first element. Third matter will come into being only later, for reasons we shall soon encounter, and only by virtue of the transformation of first matter. That is, in the *Principles*, regardless of the curious and tortured details of the opening of its cosmogony, it is clear that 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 agile, 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 described. How do they come into being?

When, in a given vortex, there are more first element particles created between the second element *boules* than necessary to fill in the space, then due to the revolution of the vortex the second element tends to recede toward the periphery and the first element flows into the centre thereby vacated, forming a star. From the manner first element particles are generated it follows that some move faster and some slower, some are larger and some are minute. Descartes tells us that the smaller and more agitated ones form the bodies of the stars.³⁵ (In essence, this is what happens in *Le Monde* as well.) But in the *Principles* Descartes' focus shifts to the exact shape and nature of some of the remaining particles of first element, and to implications about their total range of variation. Considering that the spaces between the heavenly globules are roughly triangular, the particles of the first element remaining amongst them often have a triangular cross-section, although they remain flexible enough to assume any shape. By constantly being forced in and out of the interstices of the second element, some of these particles become larger, more stable and acquire from the triangular interstices of the *boules* a more permanent channelled, grooved or rimmed surface with a distinctive right or left–

³⁴ John Heilbron, *Electricity in the 17th and 18th Centuries: A Study of Early Modern Physics* (Berkeley, 1979), 31-33.

³⁵ Two versions of star formation are offered in the *Principles*, III, articles 54 and 72; AT VIII-1 107-8, 125; MM 111, 122-3. The former version corresponds to our text above; the latter gives an explanation more dependent on diametrically opposite axial inflows of first element from the equatorial areas of neighboring vortices toward the center of the vortex the creation of whose central star is being discussed. Alternatively the second story might be interpreted as Descartes' detailed account of the movement of first element particles into and out of an already formed star. This latter account does map completely onto his explanation of the formation of oppositely handed rimmed particles of first element which cause magnetic phenomena, given later in Book III Articles 87 through 93.

handedness.³⁶ These particles are going to be used to explain magnetism, as we shall see later. For the moment we bracket those details, and, in the interest of our matter-theoretical inquiry, simply follow the cosmic pathways of some of these channelled, rimmed and handed particles of first element.

Firstly, there is a constant exchange of first element matter between neighbouring vortices. (Figure 1) According to some implied principles of inter-vortical stability and spatial relations, the vortices arrange themselves in such a manner that they do not hinder each other's motion and so their poles touch as near as possible to the equators of the others.³⁷

Due to the centrifugal tendency to motion generated by vortical rotation, some first element matter constantly leaves the equatorial part of one vortex and moves along the axis of the neighbouring one. Some of these inter-vortex travelling particles of first element are those larger, interstitial ones just discussed, some of which can be channelled, rimmed and handed. In general, these larger first element particles move more slowly and adhere to each other more readily than the smaller ones. These are the ones most commonly found moving in straight lines from the poles towards the centers of the vortices, because motion in straight lines requires less agitation. Thus, having entered the new vortex in diametrically opposite directions along the north and south directions of the axis of rotation of the vortex and its central star, the production of left and right handed channelled particles is completed or 'finished'.³⁸ These particles then penetrate into the polar re-

³⁶ The process of production of this sub-species of first element particles is related at *Principles* III articles 87-93; AT VIII-1 142-7; MM 132-6.

³⁷ Cf. Gaukroger (note 3), 150. *Principles*, III, articles 65-67; AT VIII-1, 116-119; MM 118-119.

³⁸ We put the matter this way because there is some ambiguity in Descartes' text on the issue of where and how the right and left handed rimmed particles are formed. There is no doubt he intended that the larger particles of first element, being pressed through the interstices of the spherical *boules*, can become rimmed and handed; but, on the other hand it is also clear that it is their passage along the axis of vortical rotation into the polar regions of a central star that gives the oppositely directed particles their opposite twists. We defer to the excellent hermeneutics of Gaukroger on this point, noting his reading at two places in his analysis of the *Principles*: [1] At Gaukroger (note 3), 152 the production of the rimming is elided with the twisting into handedness during the axial transit. 'The larger parts of the first element have to pass around the tightly packed globules of the second element, and they become twisted into grooved threads, those coming from opposite poles being twisted in opposite directions, that is, having left- and right-handed screws (article. 91)'. [2] But, at pp.175-6 discussing Descartes' treatment of terrestrial magnetism in Book IV of the *Principles*, Gaukroger seems to interpret the twisting into handedness to be a generic result of forcing through interstices of *boules*, and not necessarily (though perhaps sufficiently) a result of the cosmic transit along vortical axes of rotation: 'The generation of these grooved particles had been set out in Part III (articles. 87-93). Their grooves derive from the fact that they are squeezed through the interstices of contiguous spherical globules. As a result of this squeezing they end up as cylinders having three or four concave sides joined by rims....Moreover, because they rotate on being squeezed through these interstices, the channels or grooves are rotated, forming a

gions of the central star where their progress is impeded by the first matter already in the star, (and the flow of oppositely handed particles coming from the opposite axial direction). Since any backward flow is prevented by the particles continually flowing into the star behind them, these particles of first matter, including many of the newly finished, larger, left and right handed screw shaped particles, move sideways and radially toward the star's surface, mainly in the polar regions, where they constantly 'bubble' out onto the stellar surface, there to begin a slow drift toward the star's equator.³⁹ This process occurs in all central stars, including of course our sun.

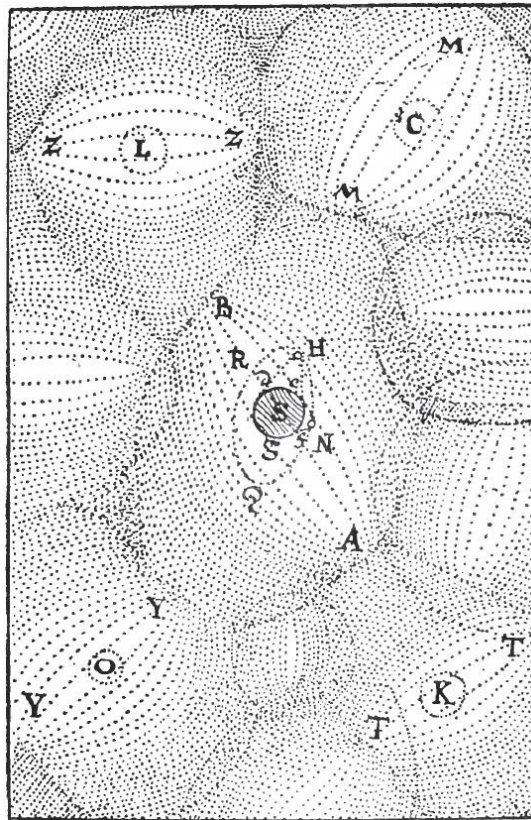


Figure 1. *Principles*, AT VIII-1 (1905) p.141. Contiguous vortices tend to orient with axes of rotation as close to orthogonal to one another as possible.

Descartes tells us that the particles of first element bubbling out onto a star's surface are sluggish, since they have had no time to become purified and clarified by the heat, that is the high agitation and imparting of motion by the smaller,

stream of diagonally grooved, cylindrical fragments, some of which have a left-hand screw, some a right-hand screw, according to the direction of the twist'.

³⁹ *Principles* III articles 94-95; AT VIII-1 147-8; MM 136.

highly agitated particles of first element making up the body of the star. The added first element material floats like scum on a boiling liquid and sometimes forms,

very large masses, which, being immediately contiguous to the surface of the heaven, are joined to the star from which they emerged. They resist that action in which ... the force of light consists; and are thus similar to those spots which are usually observed on the surface of the sun.⁴⁰

In the next paragraph Descartes refers to these accretions not as being similar to sunspots but simply as sunspots.⁴¹ This then is the origin of the third element. It comes into being by particles of the first element sticking together, and is manifested as the opaque, light-blocking material of sunspots—third matter in other words—which definitely lie on the surface of the sun. Sometimes such a body of third matter forms on the stellar surface only to be metaphorically 'boiled' away again by the roiling smaller first element particles which surround it. Hence, according to the *Principles*, third element originates from conglomerations of certain types of particles of first element on the surfaces of stars as sunspots, and it can also be changed back into first element again. Moreover, as we shall see in Descartes' further explanation of sunspots, variable stars and planet formation, stars can and actually do turn into planets, comets and satellites.⁴² For the moment, at the level of matter theory, we note this certainly is not the case according to *Le Monde*, where he wrote: 'each part of matter tends always to one of their forms and, once it has been so reduced tends never to leave that form'.⁴³

The foregoing comparison between *Le Monde* and the *Principles* operated mainly at the level of matter and element theory, although, in order to explicate the novelties emergent in the *Principles*, we perforce have had to touch lightly upon Descartes' theories of magnetism and sunspots. If we were to remain at this level of analysis, satisfied mainly with comparison of the respective matter theories treated in isolation from their systematic relations to other dimensions of the

⁴⁰ *Principles* III article 94; AT VIII-1 147-8; MM 136. Gaukroger (note 3), 153 comments: 'These grooved particles...move to the centre of the vortex. On account of their relatively small degree of agitation and their irregular surfaces, they easily lock together to form large masses at the surface of the star from which they emerge. Because of their size and small degree of agitation, they "resist that action in which we said earlier that the force of light consists" and as a result they appear as a spot on the surface of the Sun. Descartes compares the process by which they are formed to the boiling of water which contains some substance which resists motion more than the water: it rises to the surface on boiling to form a scum, which, by a process of agglutination, comes to acquire the character of the third element'.

⁴¹ *Principles* III article 96; AT VIII-1 148. MM 136.

⁴² *Principles* II article 23; AT VIII-1 52; CSM I 232. Descartes states explicitly 'celestial matter is no different from terrestrial matter'.

⁴³ AT XI 28; SG 19; MSM 43-5. But by January 1639 he must have begun to change his theory of matter, because in a letter to Mersenne Descartes says: 'some terrestrial particles continually take on the form of subtle matter when you crush them up; and some particles of this subtle matter attach themselves to terrestrial bodies, so there is no matter in the universe which could not take on all the forms'. (AT II 485; CSMK 133) See also above, note 32.

natural philosophy, we would miss exactly what is in view in this inquiry. On the one hand, we would ignore Descartes' very interesting co-optation in the *Principles* of wide swathes of available matters of fact, and, on the other hand, his much more elaborate strategies of systematisation in the *Principles* than in *Le Monde*. And, most importantly, we would not ask the key question, 'What is the strategic relation between Descartes' newly revealed thirst for hard, consensually agreed matters of fact and his breathtaking construction of improved systematicity in the *Principles*?'⁴⁴ To these ends, therefore, we next move beyond mere matter theo-

⁴⁴ As we have noted, leading interpreters, such as Lynes (note 2) and Love (note 2), approached the problem of the differences between *Le Monde* and the *Principles* as centrally concerning matter and element theory. Additionally they looked for external triggers or motives for Descartes making the changes. For example Lynes (note 2), 72 placed emphasis on religious motivations, with Descartes striving to overcome the possibly heretical implications of his early supposedly atomistic-looking matter theory in *Le Monde* by means of his putatively better ability later to demonstrate the absence of any void in nature in the *Principles*. (In fact Descartes has a robust plenist account in both treatises.) Similarly Love's explanation for the changes in matter theory boils down to Descartes' increasing commitment to a plenist physics in the *Principles*: She maintained that Descartes must have revised his theory of matter between 1637 and 1644, basing her claim on the fact that in the *Discourse*, published in 1637, there is only one subtle element, while in the *Principles* there are two. Love suggested that the change from one subtle element to two could have been triggered by Morin's criticism of Descartes' theory of light, in particular the need of some matter to fill in the void between globules that transmit light. This for Love meant in all probability that the unpublished 1633 version of *Le Monde* only had one subtle element and thus is not identical to the one eventually published in 1664. Hence, Love (note 2), 127, claimed that the differences between the two works 'follow from Descartes' well-known identification of substance with spatial extension, and his consequent rejection of the void'. We leave aside here the overwhelming evidence that a close analysis of the text of *Le Monde* and its course of construction undermine all this, since it is virtually certain that Descartes had the three elements in the original conception, and simply note that Love's explanation is based on a metaphysical driver, Lynes' on a theological one. In response to these and other guesses at circumstantial external drivers of Descartes' strategies and inscriptions, we suggest that the casting about for such putative causes is beside the point and actually rather ahistorical. When an actor is playing a competitive game in a field of contestation, the best initial explanation for the actor's moves resides in the best picture the historian can devise of the actor's assessment of the state of play, his resources and goals. (Cf. the seminal works on the socio-political dynamics of claim construction and negotiation in mature sciences by Pierre Bourdieu, 'The Specificity of the Scientific Field and the Social Conditions of the Progress of Reason', *Social Science Information*, 14 (1971), 19-47; and Steven Shapin, 'History of science and its sociological reconstructions', *History of Science*, 20 (1982), 157-210, especially his discussion of actors' vested interests in their own field and discipline's state of play and likely directions of development, pp.164-69.) That is why this paper stresses Descartes' systematizing goals inside the game of natural philosophising. It is also why we have related those goals to Descartes' healthy respect for facts. Like any good, competitive natural philosopher (or later modern scientist) he knew facts need to be assessed, interpreted, selected for use, reframed in terms of the theory and claims under discussion, and argumentatively deployed for persuasion. His appetite for facts, their theoretical reframing and leveraging for further explanatory uses were intimately linked to his goals and strategies for building a winning system of natural philosophy, proclivities that will be display below, especially in Sections 6 through 9.

retical comparison, to explore the texts more widely. We begin with what is more or less stable between *Le Monde* and the *Principia*, being almost identically articulated to the basic matter and element theory in each: the nature and celestial mechanical role of stars, the inner workings of the vortex celestial mechanics and the basic nature of planets and comets. Only then will we be able to engage the system binding, strongly cosmographical features and bodies of evidence introduced solely into the *Principles*; that is, the theory of cosmic magnetism, and our ultimate targets, the accounts of sunspots, novae and variable stars, and planet and comet formation.

4. Descartes' vortex celestial mechanics

As Eric Aiton correctly observed in his classic study of the vortex theory of planetary motion in Descartes and his followers, there is little essential difference in the model between *Le Monde* and the *Principles*.⁴⁵ It should be noted, however, that the exposition in the *Principles* is clearer, better ordered and argued than in *Le Monde*.⁴⁶ Scholars have sometimes discounted Descartes' celestial mechanics, depicting it as simply a question of a whirlpool of second element rotating around a star, sweeping along planets like boats in a current.⁴⁷ In fact the swishing along of planets in a vortex was the least of Descartes' concerns. What engaged his genius was the non-trivial and quite technical question of why planets maintain stable orbits at differing distances from their local vortical star.

We have already seen, in our discussion of the cosmogony in *Le Monde*, how Descartes deals with the early stages of vortex formation, invoking the condition he placed on the continuous increase in force of motion of the particles with distance from the center of a vortex: The vortical particles become arranged so that their centrifugal tendency increases continuously with distance from the center, with the size of the particles decreasing and their speeds increasing from the center out. Hence the speed of the particles increases proportionately faster, so that force of motion (size times speed) increases continuously. Figure 2 shows the dis-

⁴⁵ Aiton (note 24), 3.

⁴⁶ Hence, the exposition of the vortex theory in *Le Monde* can be heuristically aided by careful comparison with the later presentation in the *Principles*, a technique followed in Schuster (note 26).

⁴⁷ In fact Descartes manages to invoke boats in a current as models for both planets and comets, quite different types of celestial objects which behave in vortices in contrasting ways, as we shall see. The 'boat in a current model' is far from trivial, because the detailed theory of celestial mechanics that it represents is quite sophisticated.

tribution of size and speed of the particles in any vortex before a central star and the three elements have formed.⁴⁸

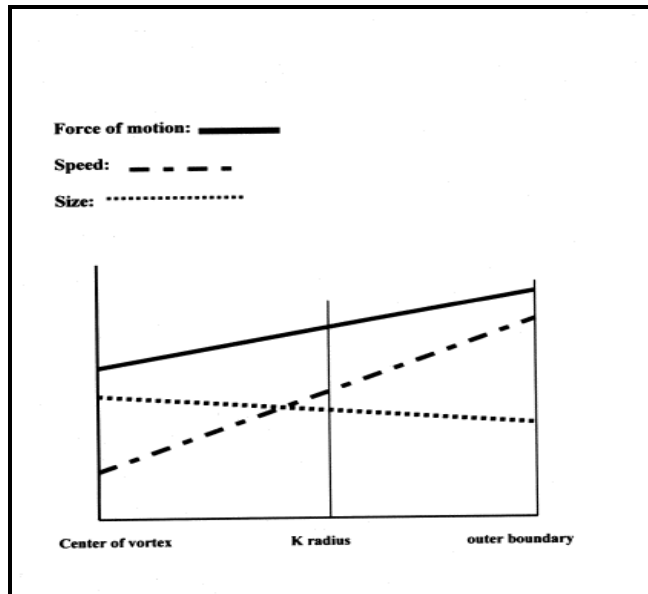


Figure 2. Size, Speed and Force of Motion Distribution of Vortex Particles, Prior to Existence of Central Star.

This, however, is the situation during cosmogony, without definitely formed elements, and consequently without stars of first element in the centers of vortices. It is crucial to Descartes' entire vortex mechanics, and indeed to his cosmographical strategy, that the presence and rotation of stars alters the mechanical situation just described, creating the dynamical steady state cosmos in which the known orbital behaviour of planets and comets becomes possible and explicable. This is because the presence of a star—dependent upon the emergence of the first element—alters the original size and speed distribution of particles in a vortex in a way that now allows planets to maintain stable orbits. 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 spheres of second element of the vortex near the star's

⁴⁸ Schuster (note 26), 46. Figures 2, 3 and 4 derive from Schuster's study, where their interpretative basis is also discussed. In these figures straight lines are used to represent the functional relations amongst *boules'* sizes, speeds and distances from the central star gathered from the verbal expressions in Descartes' texts. It is not intended that Descartes entertained such linear relations. What is important is the general representation of the force-stability principle and how that relates to Descartes' claims about the size and speed distributions with distance.

surface.⁴⁹ This increment of agitation decreases with distance from the star and vanishes at that key radial distance, called K.⁵⁰ (Figure 3)

⁴⁹ Descartes quite clearly says it is the rotation of a central star that adds this extra agitation to vortical *boules* up to a certain distance from the star. (AT XI 53; SG 34-5) It would seem reasonable, however, to attribute this effect in part to the simple fact of the high agitation of the particles of first element making up the star. After all, in other contexts in these treatises Descartes attributes important consequences to the activity of agitated first element particles on stellar surfaces. (See below notes 85 and 101 for other examples) It may be that Descartes wished to emphasize the rotation of the central star and not introduce a factor that, arguably, could have effect even if rotation did not occur. Since in *Le Monde* Descartes was not mobilizing sunspots as stellar surface phenomena demonstrating the rotation, he certainly seems to have believed in rotation quite apart from the issue of sunspots. This tends to support the idea that the genealogy of his celestial mechanical thinking back goes back to encountering Kepler, who initially asserted solar rotation in his celestial physics. On Descartes' engagement with Beeckman's work on Kepler in 1628-29, just prior to starting to write *Le Monde*, and its influence on the shape of his vortical mechanics, see Schuster (note 26), 70-72.

⁵⁰ *Le Monde*, AT XI 54-6; SG 35-7; *Principles*, III articles 84, 148; AT VIII-1 138-40; 196-7; Schuster (note 26), 48. In regard to our exposition here the following should be noted: Descartes' final cosmological model of the distribution of size, speed and force of motion of vortical spherical particles, and the dynamical role of the sun and other stars, are identical in the two treatises. The cosmogonical origins of the cosmological steady state, including the dynamics of pre-element vortices, are set out in more detail in *Le Monde*. In the *Principles* Descartes gives us his cosmogony of nearly identical Ur-particles which from the moment of creation rotate around their own centers and move at 'average' speed around numerous proto-vortical centers. He explains how second and first element particles evolve in this situation, but makes no explicit statement about vortex dynamics and distributions of size, speed and force of vortical particles in relation to the cosmogony. These details are supplied only for the cosmological dynamical steady state of the *Principles* after the formation of first element, spherical second element, and most importantly, stars. This difference is unimportant for our exposition here, which aims to bring out the nature of the vortex mechanics and the importance in it of the theory of rotating first element stars.

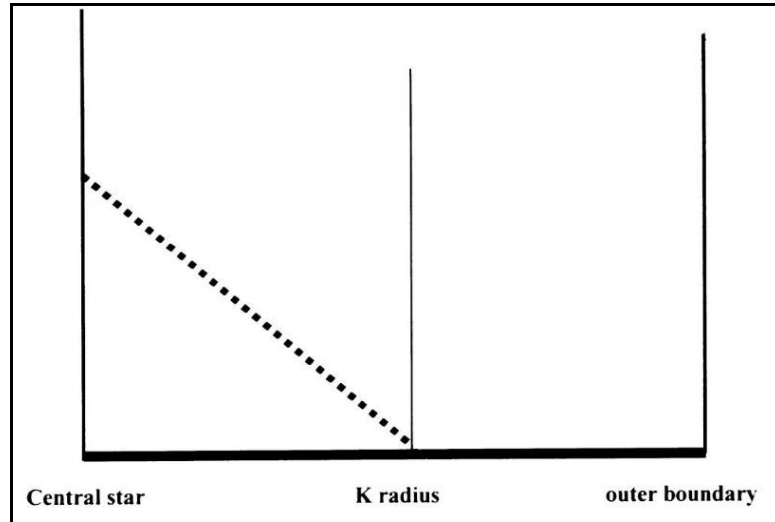


Figure 3 Agitation Due To Existence Of Central Star.

This stellar effect alters the original size and speed distribution of the spheres of second element in the vortex, below the K layer. We now have greater corpuscular speeds close to the star than in the pre-star situation. But the vortical stability principle still holds, so the overall size/speed distribution must change, below the K layer. Descartes ends with the situation in Figure 4, with the crucial inflection point at K: Beyond K we have the old (pre-star formation) stable pattern of size/speed distribution; 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, locks planets into appropriate orbits below K and extrudes them from inappropriate orbital distances.

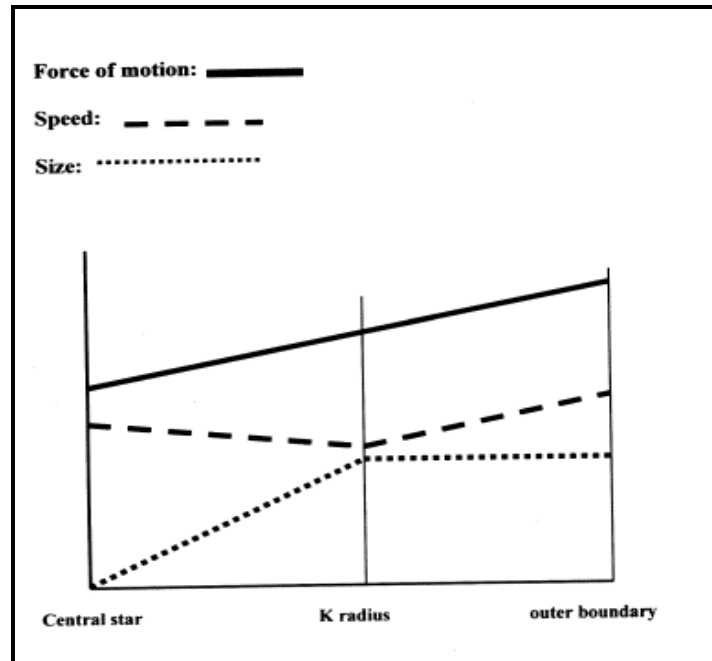


Figure 4. Size, Speed and Force of Motion Distribution Of Particles Of 2nd Element, In A Stellar Vortex.

The mechanics of this locking and extruding are the veritable key to Descartes' celestial mechanics. The central concept he employs is one of the 'massiveness' or 'solidity' of a planet, meaning its aggregate volume to surface ratio, which is indicative its ability to retain acquired motion or to resist the impact of other bodies.⁵¹ We already know that the *boules* of second element making up a vortex also vary in volume to surface ratio with distance from the central star, as may be gathered from Descartes' stipulations concerning the variation of the size (and speed) of the *boules* with distance from the central star, illustrated in Figure 4. (Volume of a sphere varies as the cube of its radius; surface area varies as the square of the radius.) Note also the important inflection point in the size and speed curves at radius K.⁵² A planet is locked into an orbit at a radial distance at which its centrifugal tendency, related to its aggregate solidity, is balanced by the counter force arising from the centrifugal tendency of the second element *boules* composing the vortex in the vicinity of the planet—that tendency similarly depending on the vol-

⁵¹ Descartes is characteristically more clear about the concept of massiveness or solidity in the *Principles* than in *Le Monde*. For discussion of this concept and of the interpretive principles involved in its extraction from the two texts, see Schuster (note 26), 41-43, 52-3.

⁵² Schuster (note 26), 49

ume to surface ratio of the those particular *boules*.⁵³ The most massive planet in a star system will orbit closest to, but not beyond the K layer—as Saturn is in our planetary system.⁵⁴

We conclude this section with comments on two paramount ways in which the vortex presentation in *Le Monde* and the *Principles* differ. First, although, as we discussed above, in *Le Monde* the central stars are quite clearly claimed to rotate with the sense of their vortices, these rotating stars carry no sunspots, of which there is no mention in *Le Monde*. Secondly, the relations amongst vortices are much simpler in *Le Monde* than in the *Principles*. In the former the main inter-vortical phenomena mentioned pertain to comets, their travel in the regions above the K-layers of vortices, and the fact that the light they reflect does not cross inter-vortical boundaries. These phenomena are also described in the *Principles*. But in that text, as we have seen, there is painted a vast picture of the circulation of particles of first matter out of the equatorial regions of vortices and into neighbouring vortices along the north and south directions of their axes of rotation. This is related to the implied conception of inter-vortical stability, mentioned above, which governs the arrangement of vortices so that their poles are as near as possible to the equators of their contiguous neighbours. Beyond this Descartes later in the *Principles* also inserts the idea that there is amongst neighbouring vortices a constant, dynamic jostling—pushing and shoving each other, thus causing slight deformations of vortical boundaries, hence vortical shape and size. Such movement of inter-vortical boundaries had been fleetingly mentioned in *Le Monde*, but in the *Principles*, as we shall explicate in detail below in Section 9, this becomes critically important in Descartes' treatment of variable stars and novae and is explicitly treated in relation to them. This is because the formation/destruction of crusts of sunspots on central stars is caused by these deformations (or vibrations) of vor-

⁵³ This is a very simplified, 'headline' version of Descartes' theory. The technicalities of Descartes' argument are more complicated than our short exposition here allows. For full details on the Cartesian locking and extruding mechanism see Schuster (note 26), 44-55, including especially note 32 to p.53. For our purposes, dealing with the strategic, cosmographical structure of the *Principles*, these further dynamical details need not concern us, notwithstanding their high significance for the understanding of Cartesian physics in the larger sense.

⁵⁴ As Descartes argues clearly in the *Principles* (Book III, article 140, cf. articles 121, 122, 147) and less clearly in *Le Monde* (AT XI 57-69; Schuster (note 26), 52-53), a planet too close to the central star for its given solidity will be translated to a higher orbit; a planet too far away from the central star for its given solidity will be translated (a form of fall, by the way) to a lower orbit. As for comets, they are planets of such high solidity that they overcome the resistance of *boules* at all distances up to and including K. Such an object will pass beyond the K level, where it will meet *boules* with decreasing volume to surface ratios, hence less resistance, and be extruded out of the vortex into a neighboring one. But, flung into the neighboring vortex, the comet meets increasing resistance from its *boules* above that vortex's K distance. Picking up increments of orbital speed, the comet starts to generate centrifugal tendency again, eventually being flung back out of the second vortex. [Schuster (note 26), 54] Descartes' vortex mechanics thus makes some interesting predictions about comets: they do not come closer to any star than the layer K of that star's vortex; they are 'more massive' than any and all planets, they move in spiral paths oscillating out of and into solar systems.

tical interfaces.⁵⁵ So, whilst these matters of inter-vortical behaviour are not often commented upon, they are crucial to our reading of the strategies of the *Principia*.

This closes our comparison of *Le Monde* and the *Principia* in terms of matter and element theory, cosmogony, vortex mechanics and inter-vortical behaviour. These set the interpretative baseline from which we can move to the full exposition of the cosmographical strategies of the *Principia*. The starting point for that must be Descartes' theory of magnetism as a cosmic phenomenon, which we have so far simply touched upon as needed in the course of making our comparisons. The *Principia*'s theory of cosmic magnetism underpins Descartes' entire account of the formation of sunspots on the surfaces of stars. The explanation of sunspots in turn becomes the veritable pivot of his vast cosmographical explanatory enterprise, ranging from novae and variable stars to the birth of planets and comets, and leading ultimately to the revelation of the generically 'earthly' structure of all planets—the closure of Descartes' cosmographical *tour de force*. Hence it is to Cartesian cosmic magnetism that we must first turn in our progressive dissection of the strategic core of the *Principia philosophiae*.

5. Co-opting and re-framing Gilbert's 'cosmic' magnetism

Emphasis is usually placed on Descartes' co-optation and reframing of Gilbert's 'lab' based experiments on magnetism, with Descartes re-writing Gilbert's manipulations in corpuscular-mechanical terms, using his left and right handed channelled magnetism corpuscles of first matter.⁵⁶ This focus ignores the kind of natu-

⁵⁵ In *Le Monde* (AT.XI. 104-9; SG 67-70; MSM 183-197.) Descartes briefly alludes to the novae of 1572 and 1604, explaining them as due to the shifting and bending of intervortical boundaries, which can produce multiple images of a single star, or, so he claims, a star's sudden appearance or disappearance. As we shall see, his explanation of novae in the *Principles* is quite different and is an integral part of his overall cosmographical strategy for dealing with magnetism, sunspots, novae, variable stars and planet formation and structure. His discussion of novae, variables and vortex jostling in the *Principia* focuses on Book III, articles 111-116 and includes the key figure to which the entire discussion is referred [which is introduced below as Figure 5 in Section 9]. At one point (article 114) Descartes interestingly likens the movement back and forth of a vortical boundary and the accompanying formation/destruction of stellar crusts of sunspots to the behaviour of a pendulum. Cf. note 108 below.

⁵⁶ As Richard Westfall, *The Construction of Modern Science: Mechanisms and Mechanics* (New York, 1971), 36-37, describes the encounter over lab based manipulations: '...the mechanical philosophy had to explain away magnetic attraction by inventing some mechanism that would account for it without recourse to the occult. Descartes' was particularly ingenious. In considerable detail, he described how the turning of the vortex generates screw-shaped particles which fit similarly shaped pores in iron. Magnetic attraction is caused by the motion of the particles, which in passing through the pores in magnets and iron, drive the air from between the two and cause them to move together. What about the fact of two magnetic poles? Very simple, Descartes replied; there are left handed screws and there are right handed screws'.

ral philosophical game and contest in which Descartes was involved, and misreads the nature of Gilbert's enterprise as well. Both Descartes and Gilbert had strategic cosmographical aims in mind for magnetism, which as a 'cosmic' cause was to play key roles in their respective systems of natural philosophy. Although writing a generation apart, they were both participants in a period of heightened natural philosophical contest, centrally, but not entirely focussed on the meaning and destiny of realist Copernicanism. The unit of contest was systematic natural philosophy. Competitors aimed at a scope of coverage of matter theory, cosmology and theory of causation (not to mention claims about method) similar to that offered by the neo-Scholastic Aristotelianism through which all players initially learned what a natural philosophical system was, and what the rules of formation of competing systems might be.⁵⁷ As we observed earlier (Note 4) it was not yet incumbent on a contestant to adduce new matters of fact off his own bat. It sufficed to co-opt and reframe key facts from others, according to one's own systematising strategies. Descartes did with Gilbert's lab facts precisely what he was to do with consensually accepted facts about sunspots and variable stars, as we shall see below.

Gilbert's *On the Magnet* (1600) was arguably the most influential and impressive new natural philosophical gambit of the turn of the seventeenth century. His program involved a new natural philosophical agenda and content, built on exploiting and metaphorically extending important experimental work he had done on the magnet and magnetic compass. Also indebted to a neo-Platonic view of ontology, Gilbert used a cosmographical strategy, basing his new system of nature on a new theory of the Earth, according to which the Earth's magnetism, which he established as a fact, is a form of immaterial, spiritual power. The Earth's magnetic 'soul' is responsible for its spinning on its axis, and since other celestial objects similarly have magnetic 'souls', a host of celestial motions could be explained. Gilbert worked in the first instance not on astronomical or cosmological questions, but on the structure and nature of the Earth. He co-opted and reinterpreted the craft knowledge and lore of miners and metallurgists, to argue that lodestone is the true elemental nature of the Earth; that the Earth is a gigantic spherical magnet; and that since magnetic force, even in a small magnet, is an immaterial, spiritual force, the magnetic nature of the entire Earth amounts to a cosmic soul or intelligence—capable of moving, or at least spinning the Earth. This natural philosophy, he claimed, showed the true nature of the Earth, as opposed to the superficial mutterings of Aristotelians about earth, air, fire and wa-

⁵⁷ On the points about the nature of the natural philosophical field in the critical phase of the scientific revolution c.1630-1660 in the this and previous two sentences: J. A. Schuster, 'The Scientific Revolution' in *The Companion to the History of Modern Science*, edited by R. Olby et al (London, 1990), 217-242 (224-7, 232-8); Schuster (2002, note 7), 339-41, 344-8; and Schuster, 'What was the Relation of Baroque Culture to the Trajectory of Early Modern Natural Philosophy', forthcoming in *Archives internationales d'histoire des idées*, 2012.

ter.⁵⁸ All of this was in turn meant to 'leverage', in our terms, a cosmographical extrapolation by which Gilbert could, in the final book of *de Magnete*, hold forth about celestial causation and motion, attributed to the magnetic souls of the Earth and other heavenly bodies.

Now, it was this same 'cosmic' side of magnetism that Descartes chiefly sought to explain and systematise. Descartes borrowed from Gilbert (and from Kepler it must be said) the idea that magnetism is a cosmic force. But, he changed its ontology, of course, and also its functions, relieving it of its celestial mechanical role. Tellingly, Gilbert's cosmographical gambit had started with his ultimate laboratory artefact, the sphere of lodestone, or *terrella*, on which he modelled the magnetic properties of the Earth, using it to argue analogically, but with realist intent, to the essentially magnetic character of the Earth, which displayed the highest manifestation of magnetism, a magnetic soul. In contrast, Descartes' explanatory cosmographical tale ends with planets (including the Earth) which, born of sunspot encrusted stars, continue to display the causal imprint of their stellar origins, most notably in their retaining through their structure an ability to accommodate axial inflows of left and right handed magnetic particles.

On our reading, in the *Principles* Descartes pursued a dual strategy of *co-option* of Gilbert's matters of fact and *displacement* of Gilbert's attempt to render magnetism 'the' key cosmic cause via a vast cosmographical gambit.⁵⁹ Descartes' response was also cosmographical, aimed at invoking magnetism in explaining how heavens and Earth are bound together. To this end the rewriting of Gilbert's experiments in corpuscular-mechanical terms was merely a necessary but hardly a sufficient move. Matter theory alone was not going to neutralise Gilbert's system and articulate a competing one. Descartes worked to insure that magnetism was not the principal cause guiding the planets in their orbits. That was the job of his vortex celestial mechanics which, considered in its narrow, technical senses, had no essential connection to his theory of magnetism (as the presentation in *Le Monde* proves). Nevertheless, in Descartes' natural philosophy magnetism retained, in three ways, something of the high cosmological status Gilbert had bestowed upon it: [1] There is a physical interweaving of each vortex and its central star with its neighbouring vortex/star complexes, by means of axial input and equatorial output of magnetic particles; [2] The particles in question become fully capable of causing magnetic phenomena by being given right and left handed twists during their incoming journeys along the axes of rotation of vortices—

⁵⁸ Similarly, Gilbert insisted that his knowledge was built on assiduous attention to experiments and to facts reported by craftsmen and artisans, and that it was productive of useful results, most notably improving the use of the magnetic compass in navigation.

⁵⁹ It might be asked whether we are maintaining that this strategy was deliberate on Descartes' part or whether it exists merely as an analyst's construct. We answer that it arguably was deliberate and part of his way of contesting for hegemony in natural philosophy. This is based on our reading the text of the *Principia* for its underlying goals and strategies, which we hold to be better than imputing motives based on circumstantial events or evidence. (Cf. above note 44 on Lynes and Love, and below Section 12, especially note 135.)

vortical rotation is the final, necessary forge of magnetic particles;⁶⁰ [3] The ultimate possibility of formation of planets and comets has to do with these cosmic flows of magnetic particles, which can form sunspots which in turn can lead to star-death and planet/comet formation.

6. Claims about sunspots from Galileo and Scheiner to Descartes

We now have in place all of the resources that Descartes adduced in the *Principles* to facilitate his explanation of sunspot formation, properties and behaviour. Before we turn to Descartes' explanation, we need to look at the evolution of agreed matters of fact about sunspots in the larger natural philosophical community, as well as at Descartes' move from ignoring them in *Le Monde*, to featuring them in the *Principles*.

Galileo's claim to discovery of sunspots and consequent brilliant mixed mathematics style argument that they are on the surface of the sun or vanishingly close to it, established, for those who accepted his claims, on the one hand that the sun rotates, and on the other hand that changes could take place on a celestial body. Galileo was quite clear about his claims that

...the solar spots are produced and dissolve upon the surface of the sun and are contiguous to it, while the sun, rotating upon its axis in about one lunar month, carries them along, perhaps bringing back some of those that are of longer duration than a month, but so changed in shape and pattern that it is not easy for us to recognize them.⁶¹

This showed that generation and corruption were taking place in the heavens, a notable argument on the cosmographical plane for the unity of heavens and Earth required by realist Copernican theory. But neither in 1613, nor over the next generation was there necessarily a consensus view, especially in the light of the masterful Jesuit astronomer Christoph Scheiner's competing claim (1612) that sunspots are small planets circling the sun.⁶²

⁶⁰ See our comments on this point above at note 38.

⁶¹ Galileo Galilei, *Letters on Sunspots*, in *Discoveries and Opinions of Galileo*, translated and edited by Stillman Drake (Garden City, 1957), 87-144 (102). Compare Galileo twenty years later in Galileo Galilei, *Dialogue Concerning the Two Chief World Systems*, translated by Stillman Drake (Berkeley, 1953), 54, '[many spots] dissolve and vanish far from the edge of the sun, a necessary argument that they must be generated and dissolved'.

⁶² There are four contenders for the discovery of sunspots: Within about 18 months in 1611/2 Johann Fabricius [*De Maculis in sole observatis, et apparente earum cum sole conversione, narratio*. (Witebergae, 1611)], Christopher Scheiner [*Tres epistolae de maculis solaribus* (Augustae Vindelicorum, 1612)] {under the pseudonym of Apelles and published by Marcus Welser}, and Galileo [*Istoria e dimostrazioni intorno alle macchie solari e loro accidenti*. (Roma, 1613)], appeared and claimed discovery. Fabricius probably saw them as early as March 1611, Scheiner in spring 1611 and Galileo, who in 1613 responded to Scheiner's published claims of 1612, claimed observations eighteen months earlier (this was in the pub-

Although Descartes undoubtedly knew about sunspots at the time he wrote *Le Monde*, he did not even mention them in that book, while they are one of the cornerstones of the *Principles*. In October 1629 he wrote to Mersenne, asking him for information about recently observed phenomena around the sun without mentioning the name of the observer.⁶³ These were parhelia seen in March of that year by Scheiner.⁶⁴ Wishing to explain parhelia induced Descartes to drop other projects. His new direction at first extended to work on meteorology in general and later into a description of the whole world that eventually became *Le Monde*.⁶⁵ However, in the very same letter to Mersenne in which he asks for information about parhelia, Descartes alludes, without explicitly referring to, Apelles, the Greek painter who reputedly hid behind his board and listened to what people were saying about his painting. Apelles was the pseudonym Scheiner used in 1612 to announce his claim to discovery of sunspots. As mentioned above, in this publication sunspots were conceived of as small planets circling the sun. The connection between Descartes saying that he will be hiding to hear what others are thinking of his work and Scheiner's publication on sunspots has been pointed out by the editors of Descartes' collected works and is extremely unlikely to be a coincidence.⁶⁶ In other words, it may tentatively be suggested that, triggered by Scheiner's name, not only parhelia but also sunspots were on Descartes' mind in October 1629.⁶⁷ In December of that year he asked Mersenne if sunspots have been more diligently observed 'de nouveau'.⁶⁸ He wrote to Mersenne for additional information about sunspots in January 1630 and again on March 4. He asked whether Gassendi had seen several at the same time and if so, how many; did they all move with equal

lished version of his first letter, to Welser, on sunspots, May 14, 1612, hence he was claiming observations as early as 1610). [In the *Dialogue Concerning the Two Chief World Systems*, Galileo (note 61), 345, he again claimed observations as early as 1610.] Harriot, whose observations exist only in manuscript form, has notes on sunspots dating from December 1610, but began regular observations only about year later, following Fabricius' publication [Judith Brody, *The Enigma of Sunspots: A Story of Discovery and Scientific Revolution* (Edinburgh, 2002), 68]. It should also be noted that the painter and poet Raffael Gualterotti [*Discorso sopra l'apparizione de la nuova stella* (Firenze, 1605)] claimed to have followed for several days movements of spots on the sun. He explained them as resulting from a conjunction of Mars and Saturn which attracted exhalations and vapors which were drawn to the sun, purified and rarified to become sunspots. Galileo knew Gualterotti and had corresponded with him. (Brody, op. cit, 25-6, 55)

⁶³ Descartes to Mersenne, 8 October 1629, AT I 23; CSMK 6.

⁶⁴ Parhelia or mock suns or sun dogs are 'two concentrations of light on the small halo at the same altitude as the sun' [Marcel Minnaert, *Light and Color in the Outdoors*, translated and revised by L Seymour (New York, 1993), 214].

⁶⁵ On the process of emergence of the project of *Le Monde*, see SG, x-xiii.

⁶⁶ AT I, 248 note referring back to p.23 l.25-29

⁶⁷ Eventually he dealt with parhelia in the *Météores* and with sunspots in the *Principia*.

⁶⁸ Descartes to Mersenne, 18 December 1630, AT I, 102-103.

speed and were they always round?⁶⁹ He also seems to express some scepticism about whether the spots can be small planets orbiting near the sun.⁷⁰

So why did Descartes not mention sunspots at all in *Le Monde*? That is a question which we can only answer after evaluating some additional facts: First of all, even if Descartes had known Galileo's *Letters on Sunspots* prior to, or during, the drafting of *Le Monde*, it is clear from the resulting text that he had no inclination to co-opt Galileo's claims into his *Le Monde* cosmology. His letters to Mersenne certainly show that at the time of writing *Le Monde* he knew about sunspots, was interested in their nature; yet, he did not even mention them. The text of *Le Monde*, as we have reviewed it, specifically excluded Galileo's explanation, as well as others suggested at the time involving the sun rather than nearby orbiting small planets.⁷¹ Changes on the sun would have violated his matter theoretical bar

⁶⁹ Descartes to Mersenne, January 1630, AT I 112-113; CSMK 18; Descartes to Mersenne, 4 March 1630, AT I 125. Gassendi observed spots between 1618 and 1638. Descartes was seeking information by correspondence regarding as yet unpublished material. Gassendi's detailed reports on the 1626 observations and others only appeared in his *Opera Omnia* (1658) in the following locations: Vol.1 *Syntagmatis philosophici* pt 2 of pt 2 *De rebus caelestibus* pp.553-554 on spots; Vol.4 *Observationes Coelestes ab anno 1618 in annum 1655* (repr.1658). *Maculae solares* [observations in 1626 p. 99-100, in 1638 pp.411-412]; *Mercurius in Sole visus et Venus invisus...* 1631 (1632) pp. 499-505 (letters to W. Schickard). Mercury was so small that at first Gassendi thought it was a sunspot.

⁷⁰ To Mersenne, 4 March 1630, AT I 125, Descartes writes, 'Vous ne me dites pas de quel costé font les pôles de cette bande, où se remarquent les taches du Soleil, encore que ie ne doute point qu'ils ne correspondent aucunement à ceux du monde, & leur ecliptique à la nostre'. This concerns the band to which sunspots seem confined, in particular, taking that band to be revolving around the sun, where the poles of its axis of rotation would be located. He doubts these poles correspond to the celestial poles and that the band's inclination to the celestial equator would equal that of our ecliptic. All of which seems to imply that at this time his view was that the sunspots are not planets, or at least are not like the known planets (and so might well be on the surface of the sun on this argument). Scheiner's original views had been supported by others, such as Jean Tarde [*Borbonia Sydera* (1620), French trans. (1623)] and C. Malapertuis [*Austriaca sidera* (Duaci, 1633)], whilst Fortunius Licetus [*De novis astris et cometis*. (1623), 124) held the interesting view, intermediate between theories of sunspots and orbiting planets, that spots cannot be solar exhalations because those would be more rarefied, not darker. He added that some falsely claim that there are craters on the sun. He thought they are parts of the aether condensing/rarefying in turn.

⁷¹ For example: Leaving aside Gualterotti, mentioned above, note 62; Galileo likened 'sunspots to clouds or smoke' [Galileo 1957 (note 61), 140]; Kepler in 1612 suggested to Simon Marius that spots might be like clouds originating from the fire of the sun and that perhaps cometary material also originates from the sun [*Johannes Keplers Gesammelte Werke*, edited by M. Caspar (München, 1938), vol. 17 p. 36]; J.R. Quietanus told Kepler, August 13, 1619 [*ibid.* vol 17 pp.371-374 at 372], that he thought comets 'ex maculis solis colligitur et coacervatur' and Kepler told him in reply, August 31, 1619 [*ibid.* vol 17, pp. 375-386 at 376], that Marius agreed with this; Marius himself in 1619 argued that comets might come from the sun because for the last year and half [covering the period of the comet of 1618] there had been few spots on the sun [*Astronomische und astrologische Beschreibung des Cometen...1618* (Nürnberg, 1619)]. He also stated that he had seen spots on the sun with tails; and generally held that the surface of the sun is like molten gold, the spots being like slag; Willebrord Snell, also

on the existence or generation/corruption of third matter in or on stars (or anywhere else). As he wrote in *Le Monde*, 'we have every reason to think that the Sun and the fixed stars have as their form nothing other than the first element'.⁷² It seems that of the available explanations, only that of small planets orbiting close to the sun would have fitted with the matter theoretical scenario in *Le Monde*. But, to have adopted this view would have required some modifications to the vortex celestial mechanics, in the service of a factual claim Descartes seems, in March 1630, to have held to be dubious.⁷³

However, in 1630 Scheiner published his *Rosa Ursina*, a huge volume containing his solar observations. Here Scheiner changed his mind and placed sunspots on the body of the sun.⁷⁴ Scheiner's careful observations are praised in the French

discussing the comet of 1618 explained comets as 'maculae istae exhalationes...solis flagrantis atque ista ex recessu & interiore corpore per sua crateras eructantis quemadmodum in terris Aetna'. [*Descriptione cometae anni... 1618*. (Lugduni Batavorum, 1619)]

⁷² *Le Monde*, AT XI 29; SG 20; MSM 45. Also: 'we shall take one of those round bodies composed of nothing but the matter of the first element to be the sun, and the others to be the fixed stars', *Le Monde*, AT XI 53; SG 35; MSM 87. Cf. above note 32 and text to which it refers.

⁷³ Moreover in that case Descartes probably would have had to have taken some account of the strong claims for their appearance and disappearance, as mentioned above (note 61), often on the middle of the sun, a difficult challenge if they are planets (compared to their appearance and disappearance near the edges of the solar disk, which could be explained as visibility effects concerning continuously existing small planets). It should also be noted that when Descartes in the *Principles* accepts that the spots exist and form on the surface of the sun, there are celestial mechanical consequences with which he must deal: Observations of the spots indicate that the sun does not spin as quickly on its axis (in terms of linear velocity, not radial velocity) as the vortex theory would imply—that is, faster than any planet in its orbit. [Gaukroger (note 3), 153 and *Principles*, III article 32, AT VIII-1 93; MM 97] where the rotational period for sunspots is given as twenty-six days.) For this and other reasons Descartes introduces the conception of stellar aether, an earthy atmosphere near a star, and extending out as far as its nearest planet, largely constituted by dissolved sunspots, which slows the rotational speed of the star. [*Principles* III article 148, AT VIII-1, 196-7; MM 172] On other functions of the aether see below, note 87 and text thereto. Finally, the detection and description of transits of Venus or Mercury across the sun, posed many difficulties at the time, not to mention the complications introduced if one took sunspots actually to be conjunctions of small planets orbiting near the sun. For example, Scheiner had failed to observe a transit of Venus which he could have used early on to argue for the visibility of the other smaller planets whose conjunctions he claimed produced the appearances of sunspots [Brody (note 62), 49] Gassendi in 1631 after hesitation, thinking he was observing a sunspot, claimed he had observed a transit of Mercury; while earlier, in 1607, Kepler had taken a sunspot for Mercury seen against the sun's disk [Brody (note 62), 27]. After Gassendi's observation there was more clarity about distinguishing a sunspot from a transiting planet. Hence by the time the transit of Venus was first observed in 1639 by Jeremiah Horrocks, as Brody (note 62), 78, writes, 'the argument had already turned around. Previously the emphasis was on proving that the spots were not planets, now it had to be shown that a planet was not a spot'.

⁷⁴ Scheiner, *Rosa Ursina* (Bracciano, 1630), 537, 'maculae & faculae in ipso sole sunt'. Scheiner also stated that the spots grow, change, diminish, darken, lighten, disappear in the middle of the sun. *Ibid.* p.490.

edition of the *Principles*.⁷⁵ Descartes referred to the book in a letter to Mersenne in February 1634.⁷⁶ But, by that time he had already abandoned the plan of completing and publishing *Le Monde*. It is highly questionable that he saw *Rosa Ursina* any earlier, since his remarks to Mersenne in 1634 show a clear and seemingly fresh and recent grasp of the cosmographical implications of Scheiner's new view. He told Mersenne that he had heard that Jesuits had had a hand in Galileo's condemnation and that from the book he could see that Scheiner and Galileo were not on friendly terms. But, tellingly, he also asserted that since *Rosa Ursina* had furnished ample proof for it, Descartes could not believe that Scheiner did not 'share the Copernican view in his heart of hearts'.⁷⁷ Consequently, taking all these points into consideration, we conjecture that when he wrote *Le Monde* Descartes may well have been undecided between the two main theories and unhappy with the way each sat with key positions taken in *Le Monde*.⁷⁸ However, by 1634, possibly stimulated by his recent reflections on Scheiner's change of view, he was perhaps beginning to glimpse the cosmographical potential of a co-option of the now Galileo-Scheiner consensus on sunspots as entities subject to generation and corruption located on the surface of the sun.⁷⁹

Whatever the dynamics of Descartes' views about sunspots over the next few years after 1634, we know for certain that in the *Principles* he was to take for granted the notable Galilean claims that the sunspots are generated and dissolved on the face of the sun and participate in its axial rotation. There is a sentence in the *Principles* to the effect that, 'spots which appear on the sun's surface also revolve around it in planes inclined to that of the Ecliptic', which could be interpreted as sunspots circling on the surface of a stationary sun.⁸⁰ However, there can be little ambiguity about his statement that, 'all the matter which forms the body of the

⁷⁵ *Principles*, III article 35; AT IX-2, 118; MM 98-99.

⁷⁶ Descartes to Mersenne, February 1634, AT I 281.

⁷⁷ *Ibid*, Mais d'ailleurs les obseruations qui font dans ce liure, fournissent tant de preuues, pour oster au Soleil les mouuemens qu'on luy attribuë, que ie ne scaurois croire que le P. Scheiner mesme en fon ame ne croye l'opinion de Copernic; ce qui m'étonne de telle forte que ie n'en ose écrire mon fentiment..[Also see MM 99, note 29]

⁷⁸ Arguably neither theory was fully acceptable to Descartes at the time of composing *Le Monde*: To decide that sunspots are generated and destroyed on the surface of the sun would violate the matter theory of *Le Monde*; but, to accept sunspots as small planets orbiting very near the sun would require first overcoming the scepticism he had expressed to Mersenne in 1630 about this claim (see note 70), and second, significant further articulation of his vortex celestial mechanics.

⁷⁹ Additionally, let us also recall that, thanks to Beeckman, Descartes first saw Galileo's *Dialogo* in 1634 and so was potentially exposed to Galileo's persuasive deployment of his claims about sunspots, which in turn served as powerful arguments for the (Copernican) unity of heaven and Earth. Of course, Descartes saw the book for a short time only, for thirty hours, but he made some reasonable use of it for his own purposes, as in his later reported critique of the natural philosophical relevance of Galileo's abstract and idealized account of fall and projectile motion. (To Mersenne, 11 October 1638, AT II 385).

⁸⁰ *Principles*, III article 35, AT VIII-1 95; MM 98.

Sun revolves' around a certain described axis.⁸¹ Moreover, the overall force of his argument makes it clear that Descartes now took the spots completely seriously as matters of fact and accepted Galileo's proof that sunspots were on the body of the sun or at least so close as to make no difference, a claim that by 1630 even Scheiner famously now accepted. Descartes also now took for granted as matters of fact that most sunspots appear in a belt near the equator of the sun; that they have irregular shapes; and that they sometimes have a dark nucleus surrounded by lighter areas occasionally even giving rainbow effects; and that sometimes there are bright structures, called faculae, close to the spots.⁸² As in the case of magnetism, the challenge was not to discover such new matters of fact, but rather first to co-opt them and then exploit them; that is, first to explain these properties and behaviours of sunspots within his natural philosophical system and then leverage the thus explained phenomena to aid in the explanation of additional facts and bind the system together.

7. Gaining strategic leverage: Sunspots as *explananda* and *explanans* in the *Principia Philosophiae*

We have seen how Descartes explains the circulation between vortices and through stars, and onto their surfaces, of particles of first matter, including that sub-set of them which are longer, channelled and left- or right-handed, having been, so to speak, finished and polished as magnetic particles on their trips from neighbouring vortices, toward the north and south poles of stars, along their axes of rotation. Now we can examine how he uses that framework to address those matters of fact about sunspots largely accepted by the early 1640s. Recall that the sun as it were 'bubbles' near its poles with magnetic first matter particles (channeled and handed) and that this material on its surface moves constantly towards its equator, possibly forming sunspots of third matter under the conditions we described earlier. Descartes now explains the observed properties of sunspots on the basis of his explanation of their generation within his system: We see most of them in a belt near the equator and not at the poles, because by the time they have managed to stick together into a mass big enough to be visible to our eyes they

⁸¹ *Principles*, III article 74, AT VIII-1 129; MM 124.

⁸² In addition, let us not forget that sunspots supplied observational evidence for the first time that the sun rotates. Although he does not say so, Descartes could not have wished for a better validation for his theory of vortices, notwithstanding the celestial mechanical issues requiring further adjustment, mentioned above at note 73. At the time of writing *Le Monde* he had passed up this advantage, which had been obvious to, and valued by Galileo and Kepler a generation earlier, when sunspots had first been observed.

have covered a considerable distance from the poles.⁸³ From the way they come into being, it naturally follows that they have irregular shapes. The spots, being on the sun's surface, are carried along by its rotation. The fact that the spots sometimes have a dark nucleus surrounded by a lighter area is explained by Descartes by claiming that at the lighter parts the accumulation of third element is thinner and lets some light pass through, occasionally even giving rainbow effects.⁸⁴ Finally, the nearby especially bright areas or *faculae* are explained in the *Principles* by first element matter surging faster than the rest of the sun's substance out through the tight spaces around the spots. Sunspots cause a restriction in the movement of the sun's material which then tends to surge away at the edges of the spots, which thus become more luminous, while the mass of the spot itself prevents the tendency to motion being communicated through it, i.e. stops the light.⁸⁵

Descartes writes that observations show some spots being destroyed 'in the same way as many liquids, by boiling longer, reabsorb and consume the same scum which they gave off in the beginning by bubbling up'.⁸⁶ His explanation of how they disappear is this: Sunspots, of third element material but originally generated from first element matter, get worn away by the rotating matter of the sun and disintegrate partially back into first element, partially into smaller but still relatively large and irregular (third element) stuff that then becomes the atmosphere around the sun slowing down its rotation (cf. note 73). This he terms aether. It surrounds the stars, consists mainly of third element and is inherited by planets resulting from the death of stars, becoming, as in the case of our own Earth, the ultimate source of their land masses, seas and atmospheres.⁸⁷

⁸³ Descartes' thoughts were later echoed by the Swiss astronomer Rudolf Wolf (1816-1893). 'I compared the whole appearance of the sunspots to currents which proceed periodically from the two poles of the sun towards its equator.' (Authors' translation.) Rudolf Wolf, *Die Sonne und ihre Flecken* (Zürich, 1861), 27.

⁸⁴ *Principles*, III article 97, AT VIII-1 149; MM 137. Descartes' explanation appeals to his explanation of prismatic colours in the *Météores* of 1637.

⁸⁵ *Principles*, III article 98, AT VIII-1, 149-50; MM 137-8; The explanation follows directly from Descartes' theory of light. The first matter surging around the edges of a spot not only contributes to a tendency to motion propagated out through the *boules* of the vortex, but also produces a more than normal intensity of that tendency, a set of stronger than normal rays. (It is crucial to understand that in Descartes' theory of light the propagation of the tendency to motion through the *boules* that constitutes light is always instantaneous, but the intensity or force of that tendency can vary. There can be weak or strong rays, albeit always instantaneously propagated. [This point is made clear in Schuster (note 14), 261, and applied to reconstructing the development of Descartes' physical optics.] Returning to Descartes' explanation of *faculae*, strictly speaking he claims that a *facula* can form following the existence of a spot, and, by extension of the process described, a spot can turn into a *facula*; and vice versa, meaning that he claims that dark spots can turn into bright regions and vice versa.

⁸⁶ *Principles*, III article 96, AT VIII-1 148 MM 137.

⁸⁷ *Principles*, III article 100, AT VIII-1 150; MM 138-39. The central thread of Descartes' narrative of the formation of the Earth in Part IV of the *Principles* involves the formation of all the third matter on Earth that exists above the inner, unreachable, crust that suffocated the

Coming back to our original matter theoretical concerns with the *Principles*, we see that according to the theory of stars, magnetism and sunspots in the *Principles*, third element originates on the surfaces of stars from conglomerations of first element particles, and it can also change back and become first element again. Moreover, we see that sunspots are theoretically constituted, their accepted properties re-derived from theory, and they can now be leveraged to be used (with rest of the machinery) as themselves *explicantes*—and this occurs in two dimensions [1] natural history of stars, as we might say—why there are novae and variable stars— and [2] the origin and nature of planets.

8. Claimed matters of fact about novae and variable stars before Descartes

We have already mentioned twice (in Sections 2 and 5) that in Descartes' explanation of sunspots a fully encrusted star leads to further phenomena in stellar life patterns. Now we take these up, looking first at the matters of fact concerning novae and variable stars that Descartes was going to try to co-opt and systematically exploit. New stars (novae) had already famously been observed in 1572 and in 1604.⁸⁸ Many problems surrounded their explanation and indeed their characterisation at the level of fact, even if a natural philosopher or astronomer intended to remain in the realm of natural causation, eschewing miraculous or supernatural causation.⁸⁹ Was it the case, for example, that all fixed stars were already in the catalogues? A faint star simply might not have been seen previously. Or, could it be suggested that only if a putatively new star was extremely bright, it was obviously new? Even with telescopes, parallax measurements were not easy and puta-

original star. This new planetary third matter is formed largely from material derived from the aether of the dead star (*Principles*, IV articles 1-7, AT VIII-1 203-6; MM 181-4).

⁸⁸ By modern definitions these of course were supernovae. The contemporary search for other novae included David Fabricius' claim regarding Mira Ceti in 1596 (which we discuss immediately below in the context of the later claims that it is in fact a variable); and Kepler and others' identification of a supposed nova in 1600 (Kepler acknowledged that it was first seen by W.J. Blaeu who put it on his celestial globe.) Cf. Michael A. Hoskin, 'Novae and Variables from Tycho to Bullialdus', *Sudhoffs Archiv für Geschichte der Medizin und der Naturwissenschaften*, 61 (1977), 195-204. The star of 1600 is now regarded as a LBV (luminous blue variable), hence it is neither a nova nor a supernova.

⁸⁹ Explanations invoking divine action could include the following: the star has been around since the creation but it was hidden and brought to the fore by God as a sign of his omnipotence; or, it had actually been newly created by God. A miracle could be carried out directly by God or through natural causes at the fiat of God. The latter might well violate the sense of 'natural' that previously held in a given natural philosophy. For example a Christian Aristotelian could take a new star as the result of God's decision to use (hitherto unknown but) natural causes in the heavens to generate a new star. Problems would be created for the natural philosophy as previously expounded.

tively new stars were difficult to tell apart from comets. Naturalistic explanations, such as causation by a conjunction of planets, might even be made consistent with an Aristotelian perspective, but not other seemingly naturalistic explanations, such as the star had always existed and moved towards the Earth in a straight line from infinity and back again.⁹⁰ It can also be said that in a general sense novae offered a prime opportunity to realist Copernicans to score points against the strict Aristotelian doctrine of incorruptibility and lack of change in the heavens. But everything depended upon the contents of one's natural philosophy and its cosmographical strategies. As we shall soon see, Descartes' dealings about novae fall into this category of manoeuvre.

Descartes would have been aware of novae as matters of fact his entire adult life, and, as we have seen (note 55), he briefly alluded to them in *Le Monde*. In contrast, the first well publicized claims bearing on the possible existence of variable stars fall into the interval between his writing *Le Monde* and the *Principles*. In 1596 David Fabricius (1564-1617) had made the first recorded observation of the star *Mira Ceti*, which was eventually subject of the first claim that a star could

⁹⁰ The latter possibility was discussed by Tycho Brahe, *Tychonis Brahe Dani Opera omnia*, edited by J.L.E. Dreyer (Hauniae, 1916), III, *Astronomiae instauratae progymnasmatum pars tertia*, 204. This reports the opinions of John Dee and Gemma Cornelius that the new star moves away in a straight line. However there is also evidence that both Gemma Cornelius [*De peregrina stella* (Antwerp, 1573)], and Michael Maestlin had thought the 1572 nova was newly created. Maestlin thought there were not enough exhalations and that the star was newly created by God. This was published in his *Demonstratio astronomica loci stellae novae, tum respectu centri mundi...* appearing pp.27-32 in N. Frischlin, *Consideratio nouae stellae...* (Tubingen, 1573). The key passage was recently cited by M. A. Granada, 'Michael Maestlin and the new star of 1572', *Journal for the History of Astronomy*, 38 (2007), 99-124 (104). Maestlin's 'edificatory poem' (Granada, *op. cit.*, p.101) states that the star announces the second coming. Maestlin deals mainly with the location of the star, except for the key passage in question, which was also quoted by Tycho, *op. cit.*, 60, as part of his reproduction of the entire document with commentary (*Progymnasmatum, Opera omnia*, III, 58-62, with commentary, 62-67.) Tycho himself said that the new star was formed of matter from the Milky Way, but not of such perfection or solid composition as other stars, in the *Conclusio* to *Tycho Brahe his Astronomicall coniectur of the new and much admired [star] which appeared in the year 1572* (Amsterdam, Theatrum Orbis Terrarum; reprinted New York, 1969); Fortunius Licetus, *De novis astris et cometis* (1623), held that the phenomena are created and then annihilated. He also writes that there are also some people who think a nova is an old star, neglected, not observed by the ancients. Reisacher and Valesius (or Vallesius) thought an old faint star got brighter through sudden transformation of the air between it and us, so it was not a new creation [J.L.E. Dreyer, *Tycho Brahe* (Edinburgh, 1890) p.64] [Vallesius is quoted in J. Tacke, (1653) *Coeli anomalon* (Gissae Hassorum, 1653) and by B. Reisacher, *De mirabili novae ac splendidissimae stellae* (Vienna, 1573)]. Kepler, *De stella nova in pede Serpentarii* (Pragae, 1606), in *Johannes Keplers Gesammelte Werke*, edited by M. Caspar (München, 1938), I, Chapter 20, 248-51 reports discussions with David Fabricius about where the material for the new star of 1596 (*Mira Ceti*) came from: whether the star had been around since the creation but hidden and then brought to the fore by God as a sign; or newly created either by God or by physical processes from existing material which must be all over the universe, since (*Ibid.*, Chapter 22, 259) the 'star in the whale', was not close to the Milky Way.

be variable, and later, periodically variable. It was considered, by Kepler and by others, a new star, similar to the one seen in 1572. When Fabricius saw it again in 1609, he still did not take note of any variability, nor, perforce, any periodicity.⁹¹

The story becomes much more interesting in the late 1630s. Putting the matter rather simply, *Mira Ceti* was recognised by J. P. Holwarda (1618-1651) as a 'new star' or 'phenomenon' that can appear, disappear and reappear. However, by 'new star' he meant that the phenomenon was not an actual star, but a solar emanation. Indeed, his claims gained notoriety, in part, because he couched them in natural philosophical terms, framed by a clearly stated anti-Aristotelian and pro-Copernican stance.⁹² The young professor in Franeker first saw this 'phenomenon' in December 1638 while watching a lunar eclipse. At first he did not trust his own eyes but a fellow professor, Bernard Fullenius (1602-1657) saw it too. Holwarda kept watching until the phenomenon disappeared from view, to be seen again the following year. These observations were published in 1640 in a cleverly designed small volume, aimed at wide and easy distribution.⁹³ Jeremiah Horrocks (1619-1641) observed the star in January 1640, and we generally know that news of it was widespread, although it was only in the 1660s that Boulliau (1605-1694) established the fact that the appearances of *Mira Ceti* are cyclical and provided an accurate calculation of its period.⁹⁴

⁹¹ In 1612 David Fabricius, (*Prognosticon astrologicum auff das Jahr 1615*, Nürnberg, J Lauer) wrote that novae, like comets, do not dissipate but can remain unseen, then reappear. Little note was taken of this claim, let alone any possible natural philosophical significances. Hence, in accord with modern understandings of the construction and attribution of discoveries in science, it would be quite wrong to credit Fabricius with the discovery of variable stars. See Arjen Dijkstra, 'A Wonderful Little Book. *The Dissertatio Astronomica* by Johannes Phocylides Holwarda (1618-1651)', in *Centres and Cycles of Accumulation in and Around the Netherlands during the Early Modern Period*, edited by Lissa Roberts (London, 2011), 73-100 (77).

⁹² Dijkstra (note 91) pp. 86-87.

⁹³ Johannes Phocylides Holwardus, *Panselenos, ...id est dissertatio astronomica* (Franekerae, 1640) *pars secunda de novis phaenomenis, sive stellis*, 185-288. The 'new star' disappeared after he first observed it, and Holwarda failed to observe it all through the summer of 1639 ('frustra omnia', p.285) But Holwarda saw it again about eleven months later, on Nov 7, 1639. By that time his book was being printed, so he added an appendix (pp.277-88) about the reappearance. Here he pointed out that he had already suggested the phenomenon might disappear and reappear, and now identified the observations with a star in Cetus. (Dijkstra, note 91, 86-87, see also 89ff on the design and aim of Holwarda's book). A slightly different account of the timing of Holwarda's observations, making use of the work of Michael Hoskin (note 88), is offered by William Donahue, 'Astronomy' in the *Cambridge History of Science, III, Early Modern Science*, edited by Katherine Park and Lorraine Daston (Cambridge, 2006), 590-91, according to which Holwarda re-observed *Mira Ceti* in 1640 while his book reporting the initial discovery was in press, the appendix being added to report that reappearance. Note that, given *Mira Ceti*'s eleven month cycle the 1640 observation by Holwarda must have been no earlier than October of that year.

⁹⁴ Ismael Bullialdus [Boulliau], *Ad Astronomos Monita Duo* (Paris, 1667) established *Mira Ceti*'s period as about 333 days, allowing him successfully to predict future appearances. He

All this fits in chronologically with Descartes dramatically rearticulating his natural philosophy when he came to write the *Principles*. We do not know whether Descartes, who was in the Netherlands at the time, knew personally Holwarda or Fullenius.⁹⁵ However, he deals extensively with variable stars in the *Principles*. Hence it may safely be concluded that between late 1639 and sometime during the composition of that text between 1640 and 1643,⁹⁶ he became acquainted with the possibility that variable stars might exist, without of course having any sense that they are strictly and characteristically periodic, since Boulliau's work appeared much later. As we are about to see, it is clear that for his *Principia*, Descartes decided to re-frame and articulate Holwarda's claims into something like the following form: '*the disappearing and reappearing 'phenomenon' [Holwarda's 'new star'] might indeed be a star in the normal, cosmological sense, and further natural philosophical significances (explanations and systematic relations) might be attributed to this type of object. In particular novae and variables might be intimately related.*' Descartes' bold working out of this strategy, indeed its deep cosmographical exploitation, is our next topic.

9. Extending the strategy: seizing upon novae and variable stars in the *Principia philosophiae*

Descartes explains the disappearance and appearance of certain stars and their change of apparent brightness using sunspots as explanatory devices; that is, using

proposed that the star rotates, periodically showing a more luminous region to earthly observers. So, as Dijkstra, note 91, pp.92-97, convincingly shows, and as we might expect based on modern studies of the negotiation and attribution of discovery, the historical process of recognizing that a periodically disappearing and reappearing star had been found was long and hotly contested.

⁹⁵ R. Vermij, *The Calvinist Copernicans* (Amsterdam, 2002) says Descartes was in contact with many Dutch scholars (as is well known in any case), but offers no evidence concerning Holwarda. H. Terpstra, *Friesche Sterrekunst* (Franeker 1981) says there is no proof that Descartes knew Holwarda, but also claims, p.67 that there is no doubt of Descartes' influence on natural philosophy in Franeker; that Descartes certainly influenced Holwarda; but, that there is no proof they met in person. This question is not definitively resolved. The authors are currently exploring it further. Mersenne was quickly made well aware of Holwarda's work and the ensuing debate (Dijkstra, note 91, 94-95), and so he may have been Descartes' main or initial informant on the matter.

⁹⁶ Desmond Clarke, *Descartes: A Biography* (Cambridge, 2006), Appendix 1 on 'Descartes' Principal Works'. Descartes was working on the *Principles* all during his controversy with Voetius and the University of Utrecht, the publication of the *Meditations* in 1641 and various entanglements with some Jesuits. It was only in January 1643 that he told Constantijn Huygens that he was currently working on the sections about magnetism. *Ibid.* 233. Clarke (p.233 note 30) assumes this applies to the explanation of Gilbert's lab manipulations in Book IV of the *Principles*, but it might just as well apply to the cosmic magnetism prominent in Book III.

sunspots as already explained and framed within his corpuscular-mechanical matter theory, vortex celestial mechanics, and theories of star formation and magnetism. Hence dramatic *explananda* dating from the debates about Galileo's and Scheiner's claims, became in turn—in the total context of the system—*explicantes*. According to Descartes in the *Principles*, when first formed spots are soft and rarefied and easily trap other particles but eventually their inner surface, the surface contiguous with the star, becomes hard and polished. Subsequently these spots are more stable and less easily reabsorbed. So, after a while it can happen that a spot gradually extends over the whole surface of the star and blocks its light.⁹⁷ This does not necessarily mean that there is absolutely no light coming from the direction of the star, since *boules* of second element constituting the vortex surrounding the star still exert tendency to motion away from the centre, but the light emitted may not be strong enough to cause sensation in our eyes.⁹⁸

Moreover, such a previously disappeared star can also reappear again.⁹⁹ This reappearance is intimately connected with his conceptions in the *Principles* about the stability of vortices, which we briefly discussed earlier at the end of Section 4. There is a constant interplay between vortices depending on their size, strength and situation.¹⁰⁰ Vortices are contained by neighbouring vortices, but they can weaken and they can even collapse. In general, a vortex whose central star is covered in spots is weakened, because the first element in the body of the star is prevented from pushing away on the globules of the surrounding heaven.¹⁰¹ At the same time Descartes points out that spots have a great number of pores through which first element material can pass, but in one direction only, because, forcing their passage through a pore, the particles bristle up the material which then prevents their return.¹⁰² It can happen that while the vortex of a star covered in spots is weakened, it is still stronger than some neighbouring vortices and extends into their space. By this Descartes means the globules of the second element getting further away from each other, with first element particles filling in the space between them.¹⁰³ A star completely covered in spots cannot expand; but, as a result of the constant alterations of the shape and radial extent of the boundaries of jostling vortices (Figure 5), the surrounding material—vortical *boules* of second element and interstitial first element particles—might move out further from its sur-

⁹⁷ *Principles*, III articles 102, 104; AT VIII-1 151-2; MM 139-40, 140-41.

⁹⁸ *Principles*, III article 111; AT VIII-1, 158-60; MM 144-5.

⁹⁹ Descartes refers explicitly only to novae, but here the reappearance at the same place is an important feature, as we shall see. *Principles*, III article 104; AT VIII-1 152; MM 140-1

¹⁰⁰ *Principles*, III article 111; AT VIII-1 158-60; MM 144-5.

¹⁰¹ This is yet another of many examples in the *Principles* of the outward thrust of stellar first element from the surface of a star. Compare our remarks above at notes 49 and 85.

¹⁰² *Principles*, III articles 105-108; AT VIII-1 153-56; MM 141-143.

¹⁰³ One should recall that first element particles are constantly flowing into the central star from the north and south along its axis of rotation.

face, allowing additional first element particles to pass through the pores from inside and cover the spots, with the result that a new star is born. This star now has a core (the old original star) then a crustal layer of spots and finally a new outer shell of roiling, agitated first element particles.¹⁰⁴ This shell building can continue and several layers can accumulate.¹⁰⁵ If the star in question has never been observed during its occluded phase, but then comes into view for the first time, as far as humans are concerned, it is a nova.¹⁰⁶ If the star in question had been observed, then disappeared and now reappears, it is a variable, as very recently attested in European astronomy.¹⁰⁷ It is also clear that all these processes can occur suddenly or gradually: a known star can quickly or slowly disappear; a previously known star which has disappeared may reappear (hence now recognised as a variable) suddenly or gradually; a previously unobserved star, presumably long occluded from human observation, may suddenly or gradually come into view (a nova according to the model Descartes is expounding).¹⁰⁸

¹⁰⁴ *Principles*, III article 111; AT VIII-1 158-60; MM 144-5.

¹⁰⁵ *Principles*, III articles 112, 114; AT VIII-1 160-2; MM 145, 146-7.

¹⁰⁶ *Principles*, III article 104; AT VIII-1 152; MM 140-1. Descartes cites the 1572 nova in Cassiopeia, 'a star not previously seen'. He also mentions, more controversially: [1] the possibility of the disappearance of one of the Pleiades in ancient times, seven stars being mentioned in myth but only six reported by later Greek writers (MM 140 note 105)—such a star, if it once was visible, has obviously been occluded for over two thousand years; and [2] the presumed fact that, 'We also notice other [more enduring] stars in the sky which formerly were unknown [to the ancients]', a claim which MM otherwise explain in their note 107 to p.141.

¹⁰⁷ *Principles*, III articles 112, 114, AT VIII-1 160-2; MM 145, 146-7. In contrast to the 1572 nova which he does report, Descartes does not name *Mira Ceti*, Fabricius, Fullenius or Holwarda. It is almost as though he is happier to offer the explanation in principle for a phenomenon of which he surely is aware in general, but without giving any firm citation of dates, discoverers or objects, thus revealing a still neo-Scholastic approach to the description and explanation of phenomena as 'generally well known'. Cf. Peter Dear, *Discipline and Experience: The Mathematical Way in the Scientific Revolution* (Chicago, 1995).

¹⁰⁸ See for example: *Principles*, III article 104, AT VIII-1 152; MM 140. Speaking of novae, in particular the 1572 nova, Descartes says that such a star 'may continue to show this brilliant light for a long time afterwards, or may lose it gradually'. Cf. *Principles*, III article 111, AT VIII-1 159; MM 145: the 'almost instantaneous' appearance of a star; *Principles*, III article 112, AT VIII-1 160-1; MM 145: a star 'slowly disappearing'; and, *Principles*, III article 114, AT VIII-1 162; MM 146-7, the same star can alternately appear and disappear, which phenomenon Descartes elucidates with the analogy of pendulum motion (see note 55 above). An excellent exposition of Descartes' theories of comets, variable stars and novae (as a subspecies thereof) may be found in Tofigh Heidarzadeh, *A History of Physical Theories of Comets from Aristotle to Whipple* (Dordrecht, 2008), 67-81. Very helpful and well conceived diagrams accompany the discussion of the key points.

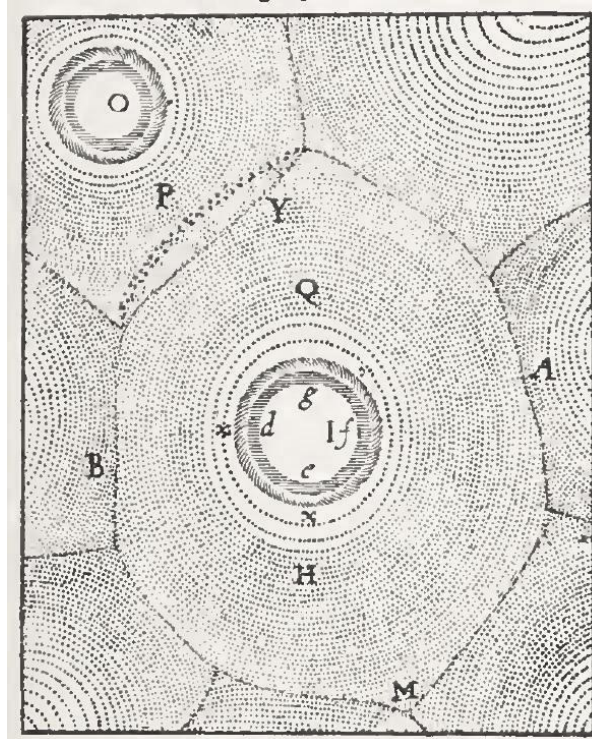


Figure 5 *Principles*, AT IX (1904) p.667, Planche IX, Figure 1, used for discussion of nova and variable formation, *Principles* Book III Articles 105-114, and showing changed position for inter-vortical boundary [P/Y] and possible shell formation around star. This plate in the French version of the *Principles* is clearer than the one used in the Latin edition; AT VIII-1, p.157 and several other times.

Thus, overall, Descartes seems concerned to assert a set of general causes involving sunspot formation and dissipation—along with varieties of contingent outcomes amongst interacting sunspots, vortices, the surfaces of stars and stellar ‘aethers’—that allow for a wide spectrum of in principle explanations of possible appearances.¹⁰⁹ Simultaneously, he is also implying it must be granted that human history and frailty have conditioned the appearances actually recorded, which perforce are the only ones we have that we can juxtapose to the explanatory resources he provides. Residing deeper in the tissue of his natural philosophical explanation are a number of key principles: all the processes are natural; no totally new balls of first element materialise inside vortices; there is no *ex nihilo* emergence or creation of a star where there has never before been one; any star may quickly or

¹⁰⁹ *Principles* III article 101, AT VIII-1 151; MM 139: ‘That the production and disintegration of spots depend upon causes which are very uncertain’, a remark to be taken in conjunction with his explanations offered in the next twenty or so articles of the *Principles*, dealing with novae, variables and sunspots.

slowly disappear, and quickly or slowly [re-]appear;¹¹⁰ but, the original sphere of first element is still there, possibly under additional alternating layers of third element crust and first element star stuff. This fully naturalises novae, and renders them in explanatory terms a sub-class of variables, whose categorisation is contingent upon the history of human observation of the star in question. Descartes thereby naturalises, 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. His next move, expressing and completing the cosmographical intentions of his system, involves relating the Earth, and indeed every single planet, comet and planetary satellite in the universe, to a certain pattern of possible stellar development.

10. Raising the cosmographical stakes: genealogy of the Earth and all other planets in all other systems

We have seen that ‘system-framed’, sunspots (or starspots) occupy a central role in Descartes’ system as presented in the *Principles*. They serve as explanations for the genesis of the third element and for variable stars and novae. But they have an additional, equally dramatic explanatory role. Occasionally a vortex collapses and the sunspot–encrusted defunct star in its centre is captured by another vortex, becoming a comet or a planet, entities that are composed mostly of the third element.¹¹¹ Here we encounter, on the systematic level, the material in the *Principles* most often treated as Descartes’ ‘theory of the Earth’. Indeed it is that, and it had significant impact on subsequent readers as a gambit in that domain, with huge theological and natural philosophical implications. However, properly understood in terms of systematising strategies and cosmographical plays, the intended scope of Descartes’ treatment is much wider.¹¹²

¹¹⁰ The ‘re’ is in brackets, because causally the star may be reappearing, but humans may only be noticing a star in that position for the first time; it is what European natural philosophers and astronomers had since 1572 called a new star.

¹¹¹ *Principia* III, arts, 118–119; AT VIII-1, 166–168; MM 149–50. On the orbital behaviours of planets, and comets, see above Section 4, especially note 54 and related text.

¹¹² The narration/explanation of Earth formation and structure occurs at *Principia*, IV, arts 1–44, AT VIII-1, 203–231; MM181–203. Most of the attention paid to this material has been devoted to seeing Descartes as a founder of the early modern and enlightenment tradition of speculative theorizing about the Earth. (Cf. Jacques Roger, ‘La Théorie de la Terre au XVII^e Siècle’, *Révue d’Histoire des Sciences*, 26 (1973), 23–48.) The unfolding of this tradition, particularly in its English Protestant context, has been most perspicaciously analysed by Peter Harrison, who correctly argues that the issue was not the substitution of a natural philosophical cosmogony for the account in Genesis, but rather the nuanced issue of which natural philosophical account best explicated or shed light on Genesis, a matter about which Descartes’ account arguably had already displayed some sensitivity. P. Harrison, ‘The Influence of Cartesian Cosmology in Eng-

The dynamic of star spots encrusting and eventually destroying stars is what accounts in matter theoretical and structural terms for each and every planet and comet to be found in the universe. When the sunspots have completely encrusted the surface of a star, it is unable to help to maintain the overall centrifugal tendency of its vortex, and rather than a variable star eventuating, as just described, the entire vortex might instead collapse, with the dead, encrusted star itself being sucked into a neighbouring vortex, there to become a planet or comet, according to its degree of 'solidity' or 'massiveness', and the usual workings of the vortex mechanics.¹¹³ So, on this breathtaking vision, every planetary and cometary object in the cosmos traces its genealogy to the pattern of events that in principle might befall any 'star-in-a-vortex'.¹¹⁴ Presumably, all planets, as opposed to comets, undergo the same further process of planetary shaping which is then described for the case of the Earth—the formation of land masses, with mountains and declivities, the latter filled with water to form oceans and seas subject to the phenomena of tides, which are a key cosmographical case for Descartes.¹¹⁵ The account of the process turns most importantly on the results of the collapse of a crust, eventually formed from aetherial material of third, second and first element particles inherited from its dead, parental star.¹¹⁶ Hence, all this material on 'Earth history' should not be treated in a piecemeal manner and as of marginal importance for the system of the *Principia*. Rather, the account of how planets and comets arise from stars, and the detailed theory of the process of formation of planet structure, ar-

land' in *Descartes' Natural Philosophy*, edited by S. Gaukroger, J. A. Schuster and J. Sutton (London, 2000), 168-192.

¹¹³ As analysed in Schuster (note 26) and above, Section 4.

¹¹⁴ Satellites are also planetary in nature, cf. Schuster (note 26), 75. Also see *Le Monde* AT X 69-70; SG 45; where the moon is termed a planet: '...if two planets meet that are unequal in size but disposed to take their course in the heavens at the same distance from the sun...'. In the *Principles*, of course, Descartes can rely on his genealogy of planets from encrusted stars—for example, at Book III article 146; AT VIII-1 195-96; MM 171: 'Concerning the creation of all the Planets' where it is clear that the planets of our solar system, along with the Earth's moon, the four satellites of Jupiter and the two Descartes attributes to Saturn all derive from encrusted stars in now defunct vortices, and are 'planetary' in nature.

¹¹⁵ For Galileo and Descartes the tides provide a prime example of a phenomenon on Earth which, if well theorised, provides strong evidence for the motion of the Earth. Biro (note 10, 73-110) devotes two chapters to their cosmographical use of theories of the tides. For Descartes in the *Principles*, tides are implied to be a feature of all planets, just as their magnetism is. Both sets of phenomena would be present on any and every planet, since their genealogies are identical to that of our Earth: Every planet carries with it the axial orientation of pores to accept the two species of screw shaped particles of first matter which it had as a star. Exactly how this is retained in the now third matter crustal layer[s] of the planet is detailed in Descartes' story of the Earth in Part IV of the *Principles*. Similarly the process of formation of oceans, mountains, valleys and atmosphere would be the same for all planets evolved from dead stars.

¹¹⁶ The crust in question is not the primordial crust formed of sunspots which initially strangled the star. That crust remains deep in the planet, untouched by this process of creation of oceans, seas, landforms and atmosphere. Cf. note 87.

guably should be looked at in detail in relation to one another, as part of Descartes' strategy for securing the *Principia* as a coherent, extensive and novel—because so essentially cosmographically focused—system of natural philosophy.

11. Radical realist Copernicanism and the grand cosmographical gambit

We have reached the climactic point in our analysis, where it is appropriate to reflect upon the totality of what we shall term Descartes' 'grand cosmographical gambit' in the *Principles*. The gambit may be defined as follows: It begins with Descartes' theories of vortices and star structure and his corpuscular-mechanical co-opting of Gilbert's gambit of making magnetism a phenomenon of 'cosmic' significance. That Cartesian 'cosmic magnetism' is then the starting point of the rest of Descartes' cosmographical narrative/explanation, whilst his account of the formation of third matter sunspots out of first element magnetic grooved particles on stellar surfaces is its pivot, as, on that basis, the *Principia* goes on to explain novae, variable stars, the origins of planets and comets, and—cosmographically taking the Earth as its exemplary case of a 'known planet'—not only the structure of the planets, but also the common process of formation of their common structure.

Figure 6 illustrates the content of the gambit and where its most bold strategic moves were placed. Consider two sequences of natural philosophical claims which we now know were offered in the *Principia*: On the left we move from cosmogony, through matter theory to star structure and Descartes' vortical celestial mechanics. On the right we move from claims about the nature of novae and variable stars through the genesis of planets (and comets) and via the 'theory of the Earth' to an account of the formation and structure of any planet, including the nature and cosmographical import of the tidal phenomena it will display. *Le Monde* had only offered an early version of the sequence on the left. The *Principia* offers both sequences, tied together by means of Descartes' theories of magnetism and of sunspots. His accounts of sunspots, novae and variable stars make use of judicious selection of available matters of fact and their framing for systematic natural philosophical use. The entire structure of cosmographical argument as presented in the *Principles* depends upon the way Descartes has elected to construct and place his theory of sunspots as generated by magnetic particles. The figure represents this point by linking the two sequences of claims through the claims about sunspots and by the dotted rather than full lines linking cosmic magnetism to sunspots, and then sunspots to variable stars and novae. The question marks and exclamation points attached to the dotted lines signal the strategic, novel and daring nature of the argumentative linkages flowing into and from the theory of sunspots.

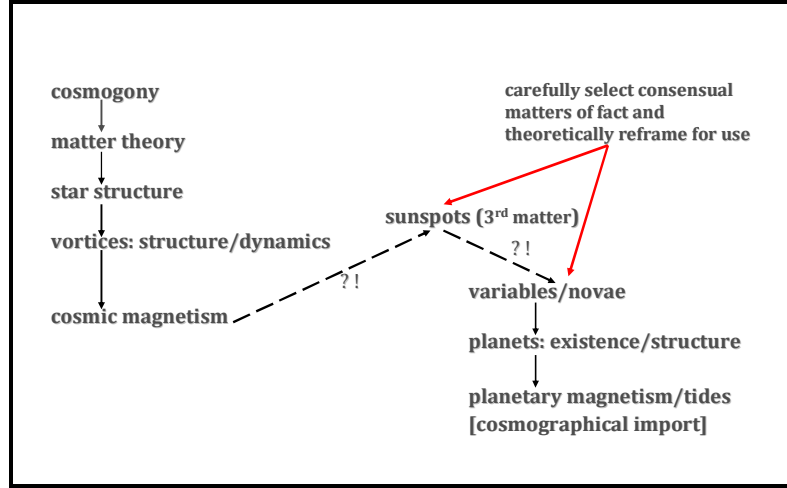


Figure 6: The Theory of Sunspots is Pivotal to Binding Together the Sequences of Cosmographical Claims in the *Principia*.

The point to be noted is that Descartes did not necessarily have to do anything as daring or elaborate as this, even if he wanted to extend and improve upon *Le Monde* and take account of recently consensually agreed facts about sunspots. Descartes could have played it simpler and safer by just adding a theory of sunspots to his natural philosophy as a marginal extra, probably requiring the changes to his matter theory and cosmogony we have noted in the *Principles*, but nothing else. In other words Descartes could have put into the *Principles* a theory of third matter formation and sunspots without the further articulations ‘back’ to a theory of cosmic magnetism or ‘forward’ to novae, variables and planet formation, etc. Or, he could have elaborated his theory of cosmic magnetism and still used it to ground his theory of sunspots, but without going on from sunspots to novae, variables, planets, their structure and tides. Either of these smaller gambits would have involved changes only in matter and element theory and cosmogony, rather than the ‘huge cosmographical gambit’ we are discussing.

In fact Descartes took just about the most daring and radical path one could imagine in the circumstances. He brought the entire right hand sequence of claims into his system, that is, novelties about novae and variables linked further to planet formation, structure and the emergence of tidal phenomena, and he did this on the basis of his theory of sunspots, which he had developed as an elaboration of the sequence of claims on the left, which are articulations of material in *Le Monde*, plus the theory of magnetism in cosmic setting. The resulting structure, the grand cosmographical gambit, is hardly some careless or unintended outcome; nor is it lacking systematic natural philosophical coherence, a coherence extending over a range of claims far beyond that contained in *Le Monde*; nor do the key new claims lack an empirical basis, constituted as they are by timely appeals to novel but consensually received matters of fact of the day.

In saying that Descartes had important recourse to matters of fact, and hence that his natural philosophy is more factually grounded than perhaps is usually granted, we are not thereby falling into the tired topos that he was ‘influenced’ by certain facts to design and execute his gambit. Descartes actively selected, interpreted and reframed for systematic natural philosophical use empirical claims from the available set of relevant matters of fact.¹¹⁷ As we have said, 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 *explanans* for the creation of third matter and the existence and structure of planets and comets (by way of variable stars and novae, about which he also selected recently announced matters of fact and treated them first as *explananda* and then as *explanans*). He *appropriated* the Galileo/Scheiner ‘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 trying to extend his natural philosophy, and systematically bind it together much better than he had in *Le Monde*, by scoring heavily in the realist Copernican cosmographical game of intimately relating the heavens and the Earth. And he did this, as we have found, by constituting the *Principles* as a set of radical, realist-Copernican cosmographical threads of narrative/explanation, tightly woven into a vast natural philosophical cloth.

To grasp fully the daring and scope of Descartes’ cosmographical gambit, we need to follow Jacqueline Biro—whose work was mentioned earlier—a bit further, so that we can appreciate that if Descartes was not the first ambitious realist Copernican natural philosopher to seize the cosmographical nettle, he may well have been the most daring and systematic to that point. Biro started out from a little noticed set of papers by Edward Grant, Thomas Goldstein and W.G.L.Randles (hereafter GGR).¹¹⁸ These dealt with Medieval Scholastic quandaries over Aris-

¹¹⁷ The historiographical view point behind this remark is the common, if often only tacit view that ideas have causal power; that earlier ideas (texts, books, core concepts) can ‘influence’ later thinkers. The *loci classici* for debunking this view in the history of ideas are John Dunn, ‘The Identity of the History of Ideas’, *Philosophy*, 43 (1968), 85-104 and Quentin Skinner, ‘Meaning and Understanding in the History of Ideas’, *History and Theory*, 8 (1969), 3-53. Later, post-Kuhnian sociologists of scientific knowledge, notably Barry Barnes and Stephen Shapin, widened this critique and applied it to the difficult terrain of scientific traditions. [Barry Barnes, *T.S.Kuhn and Social Science* (London, 1982) and Steven Shapin, ‘Discipline and Bounding: The History and Sociology of Science As Seen Through the Externalism-Internalism Debate’, *History of Science* 30 (1992), 333-369.] They insisted that articulation of concepts within a tradition cannot occur via influence, but rather through later actors’ access to, and appropriation, reinterpretation and redeployment of earlier intellectual or ‘cultural’ resources. This applies to ‘facts’ as well: it cannot be a question of how the past of the tradition—including claims about matters of fact previously accepted within it—forces or ‘influences’ present moves; but, of how later players mobilise and deploy resources for their present moves, subserving goals and tactics they have also chosen and framed.

¹¹⁸ T. Goldstein, ‘The Renaissance Concept of the Earth in its Influence Upon Copernicus’, *Terrae Incognitae* 4 (1972), 19-51; E. Grant, ‘In Defense of the Earth’s Centrality and Im-

totetian doctrine concerning the shape of the Earth, the placement of 'land' (the element earth) and relative amounts of earth and water. Prominent in these debates was a conceit wherein the land mass of the known world protruded—like a bobbing apple—out of a much larger and encompassing spherical mass of water, thus spoiling the perfectly spherical shape of the Earth, and earning this model the epithet, 'bobbing apple' theory of the Earth.¹¹⁹ GGR variously show that these debates, including the rather widely known bobbing apple theory, were from the late fifteenth century overridden from outside the universities due to recovery of Ptolemy's *Geography* and the voyages of discovery, leading to the [re]emergence of Ptolemy's concept of the 'terraqueous' globe, consisting of a very nearly perfectly spherical mass of 'earth', marked by relatively small protuberances—mountains—and declivities, or relatively shallow hollows, containing water; that is, the seas and oceans. This reborn Ptolemaic terraqueous globe, enriched with the geographical findings of the voyages of discovery, was therefore very much a sixteenth century construction, taking place at first outside the universities, in the work of humanists, elite navigators, practical mathematicians and intellectually adventurous non-Aristotelian natural philosophers.¹²⁰ The sharp end of GGR's findings focussed on Nicolas Copernicus, with their contention that Copernicus was a relatively early convert to the newly re-minted terraqueous globe, and that his chapter on the shape of the Earth in Book I of *De Revolutionibus* reflects this, and is specifically used to advance the idea that only a truly spherical Earth (that is the terraqueous model as opposed, say, to the Scholastic bobbing apple model) was fit and able to rotate.¹²¹

mobility: Scholastic Reaction to Copernicanism in the seventeenth century', *Transactions of the American Philosophical Society*, 74 (1984), 20-32; W. G. L. Randles, 'Classical models of world geography and their transformation following the discovery of America' in *Geography. Cartography and Nautical Science in the Renaissance. The Impact of the Great Discoveries* (Aldershot 2000), 5-76. Grant cites an article in French by Randles dated 1980. This suggests that the concepts in the English version of the work by Randles appeared in the earlier French article and therefore Randles' work predates that of Grant.

¹¹⁹ In the thirteenth century, Aristotelians such as Sacrobosco and Michael Scot tried to reconcile the ideal picture of concentric spheres of the elements with the indubitable existence of dry land by proposing that the earth emerged slightly from the sphere of water. In the fourteenth century, Jean Buridan and Albert of Saxony articulated the 'floating apple' model of the Earth to square theory of the Earth with the additional belief, ascribed to Aristotle in some circles, that the sphere of water is ten times larger than that of earth. Biro (note 10), 17-21, 23-25, following GGR.

¹²⁰ In the late fifteenth and sixteenth century, controversy erupted with thinkers like Vadianus, Fernal, Nunes and Peucer rejecting the floating apple model of the Earth on the basis of knowledge gained from the voyages of discovery, and campaigning for the notion of a spherical, terraqueous globe derived from Ptolemy's *Geography*. It appears that the terraqueous globe entered university curricula only in the late sixteenth century through the efforts of Clavius. Biro (note 10), 17-21, 30-36.

¹²¹ Biro (note 10), 28-30, 36-39, synthesizing the important claims by GGR on this little appreciated point.

Biro's fruitful insight was to extend the intellectual trajectory started by GGR, emphasising cosmographical moves by a series of combative anti-Aristotelian natural philosophers—Bruno, Gilbert, Galileo and Descartes. These alternative natural philosophers of realist Copernican leanings found in the terraqueous globe a tool and a topic of natural philosophising, whereby increasingly articulated knowledge or speculation about the structure and make up of the Earth, could link to, support or ground realist Copernican cosmological arguments—the natural philosophical tactics and discourses evolving as one moved from Copernicus through the later cases. For pro-Copernican natural philosophers, the novel, terraqueous Earth, offered the possibility of articulating claims about that Earth that could lead to, support, and blend with their radical view of the heavens. Since the Earth is a planet, it must resemble the heavens, and the latter must resemble the Earth. In natural philosophical terms, this means that issues of resemblance, indeed identity of matter and cause were at stake, and that cosmography, as we defined it above in Section 2, following Biro, became for such players a preferred battlefield.

Opportunities might be available to argue from structure, matter and cause on Earth, near at hand and open to investigation, to the heavens. The terraqueous globe of the Earth had already played a small role for Copernicus himself in this regard, but more ambitious arguments could be built from further articulations of the nature of the terraqueous globe of the Earth, out to the heavens. Gilbert's natural philosophy and cosmology were built almost entirely on the basis of moving out to the heavens after having established the structure, and essentially magnetic character of the Earth. Where Copernicus had exploited in this regard simply the newly reaffirmed spherical shape of the terraqueous Earth, Gilbert was focusing on its structure and characteristics. In addition to all his straightforwardly astronomical and cosmological work, Galileo, too entered this cosmographical competition, amongst Copernicans. By this stage the terraqueous nature of the Earth was not in doubt. Rather, Galileo took pains to try to refute Gilbert's magnetic Earth, moving tactically to replace that form of earth theory-to-cosmology argument with one of his own, according to which only the phenomena of the tides, explicated according to his theory, could provide terrestrial based evidence for the Copernican system.¹²²

It was then left to Descartes to offer the most radical version of this sort of pro-Copernican cosmography, embedded in an anti-Aristotelian natural philosophy and articulated with extensive new claims about the structure, genesis and stellar heritage of the Earth, and indeed all planets in any vortex whatsoever. This is because in the *Principia*, his explanation *cum* narration of the heavenly origins of planets and their make up, drawing upon the vortex mechanics and theory of stars, cosmic magnetism and sunspots, and debouching in planet structure ripe for undergoing tidal phenomena, is not tangential to the system, but rather is the very core of its content, and its system-binding strategy.

¹²² Biro (note 10) on Gilbert, 57-64; on Galileo, 73-94.

12. Conclusion: cosmographical system and strategy in the *Principia*

The natural philosophical system in the *Principia*, unlike that in *Le Monde*, is cosmographical in essence:¹²³ [Some] stars are destined to be planets, products of processes involving cosmic magnetism and the now surprisingly cosmically significant sunspots; planets are transformed stars, and all planets necessarily are terraqueous, because dead, encrusted stars of less than 'cometary solidity' will undergo the further formative structural dynamics, ending in the production of a planetary crust, which collapses to produce uplifted mountains, and water filled declivities. Cosmography in this new dynamic steady state register becomes an essential component of the system of natural philosophy. In Descartes' *Principles*, the usually accepted keys to the system, shared with *Le Monde*—matter-extension, his laws of motion and vortex mechanics—are fused and entangled with his daring cosmography into the new style, theory-driven narrative of star/planet life. What was tactical or strategic for some Copernican natural philosophers had become, for Descartes, hyper-strategic and essential; that is, directly constitutive of the systematic natural philosophical utterance itself. His mature natural philosophy *is* (rather than rests upon) the dynamic steady state cosmography—there are not simply 'relations' or 'consistency' between Earth and heavens; rather, each Earth, each planet that is, was once a member of the highest class of macroscopic heavenly bodies—a star—and each star can in principle become a planet; and every planet must be terraqueous, magnetic and subject in principle to tides, and all this depends at its core upon how cosmic magnetism and cosmically indispensable sunspots are taken to work.¹²⁴

¹²³ We have of course seen important cosmographical elements in *Le Monde*: for example, the fundamental assertion that the Earth is just another planet, in a realist Copernican framework of infinitely many stellar systems; the overtones of the new element theory, discussed above in note 12, and the theory of the tides, as we have mentioned.

¹²⁴ We gratefully acknowledge that a number of the foregoing points in this paragraph emerged in the course of extensive discussions between Biro and Schuster, during the course of his supervision of her MA dissertation, which was later revised to produce Biro (note 10). There was an evolution from Copernicus' own concentration on the shape of planet Earth, through Gilbert's detailed natural philosophising about the inner structure and make up of the Earth, down to Descartes' invocation of a process of heavenly generation to cement his cosmography and provide a developmental story for what Biro (note 10) terms his 'geognosic' claims about Earth's structure and formation. For realist Copernicans the exploitation of strategic space in cosmography was a continuing theme in their corners of the natural philosophical field, and so Descartes' 'theory of the Earth' is not so much the stark novelty that some historians of geology sometimes make it out to be, but a radical turn embedded in a longer running strategic campaign by the supporters of realist Copernicanism. This approach allows Biro to compare and contrast the cosmographical strategies of various actors. For example, she points out the interesting differences in geognosic modelling of oceans in Galileo's and Descartes' theories of the tides: For Galileo it is the *containment* of particular seas and oceans in their basins that allows the combined orbital movement and diurnal spin of the Earth mechanically to cause the tides. For Descartes, as Biro shows, the theory of tides depends on stressing the

Before we conclude, two objections and one qualification to the foregoing claims need to be addressed, if only briefly. They concern: [1] the status of Descartes' belief in the motion of the Earth and hence the possibility of his having been the kind of radical realist Copernican bespoken by the cosmographical contents and structure of most of the latter portions of the *Principles*; [2] the problem of the lack of expert reception of his putative grand cosmographical gambit; and [3] the precise degree of Descartes' openness to novel facts within his new strategy of forming large explanatory/descriptive cosmographical narratives

[1] As is well known, Descartes was at great pains earlier in the *Principles* to establish a 'philosophical' (as opposed to vulgar) definition of motion. In such philosophically conceived motion, a body must translate from the vicinity of the layer of matter immediately contiguous to it at its initial position.¹²⁵ According to Descartes in the relevant early articles of Book III of the *Principles*, the Earth does not accomplish such motion.¹²⁶ But what is the status of this doctrine? Some quite excellent scholars take Descartes perfectly seriously on these points and accept that this was Descartes' default and fundamental position on motion, and hence motion of the Earth.¹²⁷ This can be argued by staying close to the relevant passages, but seems to raise problems when the totality of the *Principia* is read, particularly as we have now read it, stressing its deeply pro-Copernican and cosmographically oriented content and strategy. We therefore tend to agree with other, equally adept scholars, who would argue that what we have here is an elaborate smoke screen set down before the fact of possible theological objections (or worse) to the *Principia*, from either Catholic or Dutch Reformed forces.¹²⁸

fluid continuity of all the Earth's seas and oceans, a theme he over-stated in *Le Monde* and corrected for in the *Principles*. Biro (note 10), 106-107.

¹²⁵ Early in Book II of the *Principia*, at article 25, Descartes defines motion as 'the transfer of one piece of matter or of one body, from the neighbourhood of those bodies immediately contiguous to it and considered at rest, into the neighbourhood of [some] others' (AT VIII-1 53-54; MM 51). This is the philosophical definition of motion contrasted with vulgar or common understandings (Cf. Book II, article 24 'What movement is in the ordinary sense')

¹²⁶ *Principia*, III article 28, AT VIII-1 90; MM 94-95: '...no movement, in the strict sense, is found in the Earth or even in the other Planets; because they are not transported from the vicinity of the parts of the heaven immediately contiguous to them, inasmuch as we consider these parts of the heaven to be at rest. For, to be thus transported, they would have to be simultaneously separated from all the contiguous parts of the heaven, which does not happen'.

¹²⁷ Daniel Garber, *Descartes' Metaphysical Physics* (Chicago, 1992), 181-88, discusses the matter with his usual care and perspicacity. In the end, p.188, Garber rejects the view that Descartes' theory of motion and its laws is an 'elaborate mask', a 'contrived stratagem' to allow him to deny motion to the Earth.

¹²⁸ Peter Dear, *Revolutionizing the Sciences: European Knowledge and its Ambitions, 1500-1700* (Princeton, 2001), 96, 'Descartes was not worried about the potential heresy inherent in his ideas about the extent of the universe or the nature of the stars. His major concern... was the unorthodoxy (as defined by Galileo's trial) of holding that the earth is in motion. Descartes published the *Principles*, with its more elaborate version of the same world-picture as that of *Le Monde*, only once he had thought of a way to deny the movement of the earth without compromising any of his cosmology. The trick (and that is what is really was) involved emphasizing the relativity of motion'. And, p.98, 'The subtlety of Descartes' theology was

Hauled before any university debate, or worse an inquisition or other ecclesiastical inquiry, Descartes could have sworn up and down the anti-realist Copernican tenor in the text based on his reasoned, philosophical denial of the motion of the Earth.¹²⁹ Only a decade after the trial of Galileo, to thus prepare for the worst was the least any sensible, and very smart, Catholic natural philosopher and realist Copernican should have done, and he did it. We also know that very little in Descartes' writings or public behaviour that touched on his person, his persona or his career was presented in a straightforward way by him, ever.¹³⁰ Hence there is no reason to believe that his sublimely radical realist, infinite universe Copernicanism would come into the world without some clever masking upon which he could rely, if necessary. For excited seekers of natural philosophical novelty and forceful explication of realist Copernicanism, the message of the concluding two Books of the *Principia* would, however, be clear.

This brings us to [2] because it must be granted that no reader in his or the next two generations seems to have responded to the totality of what we have identified as Descartes' cosmographical gambit.¹³¹ He certainly was taken as a Copernican. However, as with his system as a whole, so with his cosmographical weave in the *Principia*: it was taken to pieces by critics and by proponents focussed on one or another facet of the complete edifice. For example, his theory of the earth was eagerly taken on board to be criticised, reformulated or surpassed, but by a new generation of Earth theorists, not cosmographical warriors, as the fight for Copernicanism was well and truly over.¹³² Similarly, there were both vulgar recountings, expert articulations, as Eric Aiton showed, and withering criticisms of his vortex theory. Arguably, only Descartes ever adhered on a full technical level to the Cartesian system of natural philosophy. However, none of this impugns a reading of the text of the *Principles* itself, in the context of Descartes' career and proclivities, as a grand Copernican cosmographical *tour de force*, the culmination of a series of

matched by the subtlety of his physics. As far as he could help it, no one would be able to accuse him of teaching that the earth moves'.

¹²⁹ Readers familiar with legal proceedings, then or now, would recognise the strength of Descartes' position, if threatened in a legal context. He could have quoted, verbatim, extensive and connected published passages about the true, 'philosophical' definition of motion and the non-motion of the Earth, and read those passages with pointed literalness.

¹³⁰ Innumerable instances of Descartes' habitually secretive, reclusive, publicly masked and overtly tricky persona are captured with great panache in Desmond Clarke (note 96).

¹³¹ Although we might make an exception for Christiaan Huygens, who mocks exactly the interweaving of cosmographical claims into what we termed the explanatory and descriptive narrative in the *Principles*. Huygens wondered how Descartes, 'an ingenious man, could spend all that pains in making such fancies hang together' [*Cosmotheoros* (The Hague, 1698), cited in Brody (note 62), 84] This mirrors a change in natural philosophical temper and rules in the next generation, leading to exactly the dissipation of the Cartesian system and piecemeal use and criticism of it that we discuss immediately below. However, Huygens (no modern historian!) misses the point about what the game of natural philosophising was about in the preceding Baroque age, and how well Descartes had played.

¹³² Cf. note 112.

such attempts by innovative realist Copernican natural philosophers, starting with Copernicus himself.

Finally, [3], an important qualification needs to be added to what has been said about Descartes' openness to and use of novel matters of fact in his mature system. Inside the toils of his radical realist Copernican cosmographical explanations *cum* narratives, Descartes did not and could not aim at linear, deductive explanations of each and every state of affairs he recognized as a reliably reported matter of fact. Descartes' laws of nature do not function as premises of deductive explanations. Rather, his laws of nature in these parts of the *Principia* function as human laws do in the making of legal arguments. The laws are woven, along with carefully selected matters of fact, into flows of argument, narrative lines of description-explanation, of the sort we have just canvassed.¹³³ Descartes proceeds by asserting a network of basic explanatory concepts involving matter and element theory, magnetism, vortices and sunspot formation/dissipation that in principle can explain, via *discursive causal story telling*, a spectrum of possible empirical outcomes. The causal 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.¹³⁴ So, although when compared to *Le Monde*, Descartes' mature natural philosophy in the *Principia* values novel matters of fact, the system remained relatively closed to registering novel, deep discoveries at the theoretical level, because unexpected observational outcomes were accounted for at the level of contingent narrative formation, rather than by considering modification to the structure of deep concepts.

We conclude by returning to our starting point: We have seen that commentators like Love and Lynes were on the right track in pointing out the consequential differences in matter theory between *Le Monde* and the *Principia*. But they did not grasp the sort of game of competitive natural philosophical systematising Descartes was playing, let alone realise that it was a game that necessitated the selection, reframing and deployment of available, more or less agreed novel matters of fact.¹³⁵ The differences between *Le Monde* and the *Principles* are not simply, or

¹³³ In the telling remark that ends Book III (AT VIII-1 202; MM 177), Descartes asserts that all inequalities of planetary motion can be sufficiently explained using the framework he has provided. Clearly, he in no way intends that explanations will proceed by deductions from laws of motion, plus boundary conditions, leading to the exposure and study of various levels and types of perturbations. So, for example, it is not elliptical orbits, and their deviations that he wishes to study, leading to refinement of the relevant laws. Rather, he offers a 'sufficient' (verbal and qualitative) explanation of orbital phenomena and the general facts that no orbit is perfectly circular, and that all orbits display variations over time.

¹³⁴ Cf. above notes 107, 108 and 109 and texts thereto.

¹³⁵ Cf. above notes 44, 59. By this point it is perhaps appropriate to point out that there was nothing defensive or reactive about Descartes' novel moves in the *Principles* which we have discussed in this paper. Love (note 2) and Lynes (note 2) might each be read as depicting Descartes as motivated, even forced, to make matter theoretical changes by defensive consideration of real or possible theological or metaphysical criticism. But merely defensive

mainly about matter and element theory and presence of metaphysical grounding. It is the vast system-binding cosmographical gambit of Descartes, entraining the use and reframing of key, available matters of fact—in turn leveraged into explanatory resources—that characterises the difference between *Le Monde* and the *Principles* and the novelty and daring of the latter text, thus expressing and grounding a case for a realist, infinite universe Copernicanism of the most radical type. Moreover, by looking at the *Principles* in this way and having appreciated the strategic aims and gambits Descartes employed, we see that these in themselves provide the 'reasons' behind not only his choice of changes in matter and element theory, but indeed the underlying design of the natural philosophical system as a whole.

Acknowledgments. Early versions of this paper were presented to the Annual Conference of the Australasian Association for the History, Philosophy and Social Studies of Science, University of Sydney, July 2010 and to the Descartes New Studies Workshop, Unit for History and Philosophy of Science, University of Sydney, April 2011. For substantive comments and criticisms on those occasions, we thank Stephen Gaukroger, Keith Hutchison, Ofer Gal, Gideon Manning and Alan Chalmers. David Oldroyd, Simon Schaffer, Paul Lodge and Peter Pesic each made pertinent strategic suggestions about this project.

gambits arguably would have taken quite different shapes, as we have hinted. Natural philosophical contestation may be decoded in part as like a game; its rules of utterance are in part determinable; and, as in other games, when master players make well considered, complex attacking moves, that is obvious to attentive spectators.