# Draft Introduction to Thematic Section of *Synthese*, 185 no.2 (2012)

## Seeing the Causes: Optics and Epistemology in the Scientific Revolution

[In April 2012 *Synthese* published a 'Thematic Section' of three papers dealing with 'seeing the causes—optics and epistemology in the Scientific Revolution' a part of the Baroque Science Project conducted between 2006 and 2009 by Ofer Gal, Raz Chen-Morris and colleagues in the Unit for History and Philosophy of Science, University of Sydney

These papers are:

•Ofer Gal and Raz Chen-Morris, 'Nature's drawing: problems and resolutions in the mathematization of motion', *Synthese*, 185 no.3 (2012): 429-466.

•John A. Schuster, 'Physico-mathematics and the search for causes in Descartes' optics—1619–1637' *Synthese*, 185 no. 3 (2012): 467-499.

•Sven Dupré, 'Kepler's Optics without Hypotheses', *Synthese*, 185 no.3 (2012): 501-525.

The Thematic Section was supposed to be prefaced by an Introduction, linking the papers to each other and to the Baroque Science research program. In the event it was not possible to provide the Introduction in the published volume of *Synthese*. However, John Schuster, elaborating an earlier draft by Ofer Gal, here introduces the papers in the Thematic Section.]

'The Scientific Revolution', especially the dramatic changes in modes and contents of scientific knowledge that took place around the turn of the seventeenth century, originally was the chief proving ground where philosophy of science engaged best practice history of science in order to address problems about the origins, nature, dynamics and rationality of science. Although history and philosophy of science still share a keen interest in this period, the foci of their respective interests has diverged since the days they also shared the concept of 'scientific revolution'. The latter had originally been shaped by idealist and internalist historiographies of science, such as those of Koyré and Cassirer, and was reinforced later by the writings of Kuhn, Popper, Lakatos and their followers (despite all the disputes and debates amongst such scholars). Philosophers of science still stress the radical differences of 'before' and 'after' and use them in arguments about the progress of science, the epistemological claims of its theories and the ontological status of their entities. Historians of science, however, if they have not outgrown such issues, they have certainly moved away from them, and can claim considerable evidential (if not necessarily philosophical) grounds for so doing. Increasingly they appear to be satisfied with exploring the causes of change and the mechanisms of continuity they have identified for the transformations of the early modern period—indeed enough so to forsake the very debate about the propriety of the term 'revolution' in favor of filling up details and widening the scope of their accounts.

It is initially clear, then, that new engagements between the two disciplines are called for. Philosophy of science needs to come to grips with the newer foci and striking empirical widening of historians' concerns. It has much to gain from this, but also much to teach, because recent history of the Scientific Revolution has been rather philosophically bereft. After all, the newly emphasized causes of change and mechanisms of continuity merit as much philosophical attention as the over-stated 'incommensurability' they help put to rest. Categories such as mathematisation, instrumentation, artisanal knowledge, visualization and others that are in common use in current historiography are far from self evident and their exploration is an inquiry into the very foundations of scientific knowledge as we still recognize it.

The question becomes, where to start? The best place seems to be with the question of what exactly has more recent historical study of the scientific revolution opened up: when we think of 'causes of change' and 'mechanisms of continuity', we need to ask 'continuity of what'? and 'causes of change in what?' Here the answer is obvious. Recent historiography of early modern science has rightfully eschewed discussion of 'Science' as an hypostatized and emergent essence, and focused rather on the actual constellation of traditions, disciplines and institutions devoted to seeking knowledge of nature in early modern Europe. Chief amongst these fields or traditions is that of natural philosophy.

Historians of early modern thought today tend to employ the category 'natural philosophy' in preference to terms such as Science, Modern Science or new science. Early modern natural philosophy was a dynamic, elite sub-culture and field of contestation. When one 'natural philosophised' one tried systematically to explain the nature of matter, the cosmological structuring of that matter, the principles of causation and the methodology for acquiring or justifying such natural knowledge. The dominant genus of natural philosophy was, of course, Aristotelianism in various neo-Scholastic species, but the term applied to alternatives of similar scope and aim; that is, to any particular species of the various competing genera: neo-Platonic, Chemical, Magnetic, mechanistic or, later, Newtonian. Natural philosophers learnt the rules—or template for—natural philosophising at university whilst studying hegemonic Scholastic Aristotelianism. Even alternative systems followed the rules of this game. All natural philosophers and natural philosophies constituted one sub-culture in dynamic process over time. At its climax in the early and mid seventeenth century the 'Scientific Revolution' was a set of transformations, a virtual civil war, inside the seething, contested culture of natural philosophising. That culture then continued to evolve under internal contestation, and external drivers, and variously elided and fragmented into more modern looking, science-like, disciplines and domain**s**, plural, over a period of one hundred and fifty years from 1650.

But along with the study of the continuities and changes in the trajectory of early modern natural philosophy has come attention to those disciplines then thought to be superior to it, such as theology, cognate with it, such as mathematics, or subordinate to it, as in the traditional *scientiae mediae*, or mixed mathematical sciences of hydrostatics, statics, geometrical optics, positional astronomy and harmonics. The interrelations over time of all these enterprises, and their varying subjection to larger shaping forces, are the focus of attention in the 'post-revolution and rupture' historiography of early modern 'science'. It is this situation that motivated this "thematic section" of *Synthèse*; but, within that frame we can here only canvass one small sector of the enlarged empirical domain of study of early modern science, with its attendant new philosophical challenges.

Our preferred domain of study is the renaissance of the mixed mathematical sciences during the late sixteenth and early seventeenth century. Though the crucial import of their emergence for developments in natural philosophy and the eventual crystallization later in the seventeenth century of more modern looking scientific disciplines is hardly contested, it introduces more mysteries than it solves, and invites fundamental philosophically scrutiny, not only of the processes involved, but of historians' ways of studying and explaining them.

The vast majority of educated men encountered the mixed mathematical sciences within the framework of how they were understood in the hegemonic neo-Scholastic Aristotelianism taught in the universities. According to the Aristotelian view, the term 'mixed mathematics' referred to a group of disciplines intermediate between natural philosophy and mathematics. A natural philosophical account of something was an explanation in terms of matter and cause. For Aristotle, mathematics could not do that. This meant that the mixed mathematical sciences used mathematics not in an explanatory way, but merely to represent physical things and processes mathematically. So, for example, in geometrical optics, one used geometry, representing light as light rays—this might be useful but did not get at the underlying natural philosophical questions: “the physical nature of light” and “the causes of optical phenomena”—issues of matter and cause. Similarly, geometrical astronomy was an instrumental discipline used to predict positions, whilst cosmology was a part of natural philosophy, explaining reality in terms of matter and cause. In other words, even though the mixed sciences would be more intensively cultivated in the later sixteenth and early seventeenth century than ever before, the mixed sciences themselves would still be seen, at least under the dispensation of the Schools, as subordinate to natural philosophising, and not particularly relevant to discoveries and discussions about matter and natural causation.

However, the point about the later sixteenth and early seventeenth century in the wider history of natural philosophy is that Scholastic natural philosophy was increasingly challenged by a host of alternatives of neo-Platonic, Paracelsian, Stoic and, soon, mechanistic type, most often, but not always advanced by men who had originally learned the goals and grammar of natural philosophical discourse through Scholastic Aristotelian educations. Indeed, the period of the early to mid seventeenth century was marked by turmoil and crisis within and about the natural philosophy, and, it also entrained and included turbulence and debate about the nature and role of the mixed mathematical sciences, in relation to various types of natural philosophy competing for systematic coherence and cultural hegemony. Some alternative natural philosophers—particularly the ‘usual suspects’ amongst the makers of modern science, such as Kepler, Descartes, Galileo, Beeckman, Gilbert and Mersenne—desired to cultivate the mixed sciences, promote their relevances (in terms of concept, method and values) to the field of natural philosophy, and in so doing promote their own preferred versions of non-Aristotelian natural philosophy.

Some of the historical actors involved in these gambits had a name for their enterprise—‘physico-mathematics’. This denoted not a hardened, unified tradition or movement, but a term variously used, depending upon the natural philosophical agenda of any particular advocate, and his special concerns or talents within the set of mixed mathematical sciences. Thus ‘physico-mathematics’ broadly denoted a commitment to radically revising the Scholastic Aristotelian view of the mixed mathematical sciences as subordinate to natural philosophy, non explanatory and merely descriptive. Somehow, the mixed mathematical disciplines would become intimately related to natural philosophical issues of matter and cause, more closely intertwined with natural philosophising, regardless of which species of natural philosophy one pursued. Indeed in this sense we can apply the term as an historian’s category to those ambitious natural philosopher cum mathematicians who displayed such aims and tactics, even if they did not embrace the term itself. One can easily identify well over a half dozen variants of a physico-mathematical program from contemporary actors.

But how were these issues of natural philosophical causation seen by emerging physico-mathematicians? Here we arrive at a central concern of the papers in this 'Thematic Section'. The physico-mathematisation of the mixed mathematical sciences in this period was motivated by, and expressed itself in, a very particular form of search for knowledge of causes; that is, in an epistemology which necessarily seems quaint, odd, or even 'Baroque' to modern tastes in science and philosophy of science. Physico-mathematical moves in the mixed mathematical sciences, linking them organically to the natural philosophy of one's choice, offered contemporary players the enchanting prospect of a new, secure, and useful type of knowledge of nature: the explanatory power of causes assured by mathematics, which, inheriting the virtues of the practical mathematical reaches of the disciplines in question, also could provide, and be sanctioned by, the practical advantages of applicable control. But the coherence of such an epistemology had to be demonstrated and the practices to realize it had to be developed, and they presented difficult challenges. This epistemology implied that all there is to know could be *viewed*; the mixed sciences' attraction lay in their ability to deal with the immediately observed without assuming anything hidden in the nature of things; now through physico-mathematisation, this promise would be fulfilled and natural philosophy enriched. But *viewing causes* may seem all but self contradictory. How can causes be given to experience without merging into the realm of phenomena? We shall see that this challenge—to show how in transformed mixed mathematics one could literally 'see the causes', and put them to practical and natural philosophical use— was pursued most assiduously, and with most success in the actors' terms, in the field of optics, rather than other mixed mathematical fields. We need to consider why this was so.

As physico-mathematical moves multiplied in the later sixteenth and early seventeenth century, certain sites of articulation between mixed sciences and natural philosophy became hotly contested possible growth points for new forms of natural knowing. Radical, mathematically literate natural philosophical players sought new links and articulations between the mixed mathematical fields (now increasingly seen and pushed by them as physico-mathematical) and their own natural philosophical agendas. Usually these moves were accompanied by significant borrowings from the increasingly important tradition of practical mathematics, involving appropriation of mathematical tools and techniques, as well as a rhetoric of utility and progress. Such hot spots included, for example, mechanics and astronomy, where attempts were made to transform and place them in more organic relation to natural philosophising.

In the case of mechanics, initiatives began to appear in the sixteenth century, in the form of attempts to bring mechanics, particularly a dynamical approach to the simple machines, into natural philosophy, including technical work and scattered discussions of the natural philosophical status and relevance of mechanics. This was a program—which we can call physico–mathematical—of long duration and complex internal structure. It consisted in a series of attempts, from the early sixteenth century onward, to move one or another of the constituent texts or sub-disciplines grouped under the label 'mechanics'—such as the statics and hydrostatics of Archimedes, the so-called Medieval science of weights, the more diffuse science of machines, or the pseudo-Aristotelian *Mechanical Problems*—into closer contact with natural philosophising. These gambits were expressed through classificatory arguments, rhetoric about values and aims, or downright technical moves. The aim was to modify natural philosophising by bringing in mechanics, and to shift the valencies of mechanics by making it relevant to, even central to, natural philosophising; that is, seeking explanations in terms of matter and cause.

Similarly, in the case of astronomy, its traditional mixed mathematical and merely instrumental status was fundamentally challenged and destabilised by the implications of Copernicanism, in particular the tendency of some Copernicans, starting with Copernicus himself, to advance a realist interpretation of the theory. For, if the Copernican system of astronomy is taken as real, not merely instrumental, then the gauntlet is set down, for proponents and opponents, about what sort of natural philosophy could accommodate it, because main line Aristotelianism certainly could not. Around the turn of the seventeenth century, as the debate heated up, it was not only realist Copernicans such as Kepler and Galileo who were de facto advancing physico-mathematical views of astronomy, but also innovative realist non-Copernicans, such as Tycho and Gilbert, both of whom closely linked natural philosophical truth claims to their particular castings of astronomical theory. (Any such tight articulations of one's natural philosophy to one favoured— realistically interpreted—astronomy was *ipso facto* a physico-mathematical gambit.) Hence opportunities for novel work and contention begin to loom in cosmology and in a new space of embryonic 'celestial mechanics', occupied famously and portentously by Gilbert, followed by Kepler's explicit creation of a celestial mechanics, and, on this view, Descartes' seriously intended and carefully worked out vortex celestial mechanics which resided at the core of his corpuscular-mechanical natural philosophy.

Generally speaking, these are the kinds of developments our approach would problematise. We have chosen, however, to concentrate on similar but much less studied developments in the mixed mathematical field of optics. Here, the Aristotelian take on geometrical optics as a subordinate, instrumental mixed mathematical science also began to be probed and contested by alternative natural philosophers on the make, such as the Descartes and Kepler. Let us consider, therefore, in actors' terms, some of the strengths and limitations of optics as a site for such physico-mathematical pursuit of 'seeing the causes'.

Geometrical optics embodied extensive resources for mathematically representing aspects of experience—of vision itself—although that mathematisation came at the expense of using the mathematically-idealized 'visual rays' as its subject matter, and hence submitting to the dominant Aristotelian interpretation of the representations as merely instrumental and not of serious natural philosophical import. Optics also offered a tradition of experimenting with light and some practical instrumental knowledge, hence it had some links to that vibrant world of sixteenth century practical mathematics and men of practice, containing resources that might be appropriated by mathematically literate, radical natural philosophers. However, the tradition of experimentation with light had hardly any relation to the mathematical theory of vision, whilst the realm of practical instrumentation was linked to the mathematical theory of vision, thus far, only by analogy.

The real key to the strategic place of optics in the program of ambitious physico-mathematical natural philosophers resided elsewhere, in the basic fact that optics dealt with a fundamental causal agency in nature, light, which therefore would be an obvious choice for such study. However, again the limitation was the traditional instrumental interpretation of the findings of geometrical optics. So, in order for light to become physico–mathematically relevant, even central, in radical natural philosophising, its discipline, geometrical optics, had to escape its marginal existence as a mainly instrumental mixed mathematical discipline. In a physico-mathematical optics, light would shed its ephemeral, Scholastic Aristotelian existence as a 'species' between matter and form, and take on two contradictory but fundamental functions: as a causal agent in the world and as a reliable carrier of visual knowledge. As we are going to see in the studies in this Thematic Section, both Descartes and Kepler focused on the nature and (law-like) behaviour of light as an exemplary—perhaps the exemplary—causal agency in nature, the study of which by means of a physico-mathematicised optics, might have gigantic natural philosophical consequences. Thus, it was in optical studies that both thinkers came to suspect that the best prospects were offered for 'seeing the causes' by means of sophisticated physicalisation of mixed mathematical material. Hence our focus in the present studies. Further to explicate this point, and to reinforce our choice of object of study, we might briefly consider why attempts 'to see the natural philosophical causes' were, if anything, rather occluded in the cases of our other physico-mathematical hot spots involving mechanics and realist Copernicanism.

Mechanics taught ways to represent some properties of motions and static forces geometrically, but to assume causal responsibility within a natural philosophy this mathematics had to be instilled *into* the motions, transgressing the boundaries between constant and changing on which the use of mathematics had always been predicated, both in official Aristotelianism and in wider understandings of the nature of mathematics. This no doubt hindered the early physico-mathematical forays of individuals like Tartaglia, Benedetti and the young Galileo. As subsequent experience revealed, the most promising avenue to making natural philosophical headway along these lines resided in pursuing a corpuscular-mechanical natural philosophy, where a mechanics of corpuscular impact and motion might be developed and its value exhibited. Descartes and Beeckman provide the best early examples of this; yet, in Descartes' case, as we shall see in this Thematic Section, it was precisely work in 'seeing the causes' in a physico-mathematical optics that provided him necessary hints for constructing a dynamics of corpuscles.

The astronomy/natural philosophy 'hot spot', owing to the realist Copernican challenge and debate, also had limitations as a growth point for a physico-mathematics of 'seeing the natural philosophical causes'. This was due to the very complexity of the debate, as shaped by a number of factors, such as: the continued relevance and employment of the huge archive of traditional geometrical astronomical tools and techniques; the sporadic yet dramatic injection of new and challenging empirical findings about the heavens and the additional debates they sparked; the highly polarized terms of the natural philosophical confrontations, since realist Copernicanism always and essentially demanded a strong assault upon Aristotelianism and hence elicited equally fixed defenses; and finally, the tactics first of Tycho and then more dramatically if unintentionally by Galileo, which recruited overt theological considerations into the debate. All this means that, with the exception of Kepler, it is difficult in the Copernican debate to find and isolate for study concerted attempts to physico–mathematically 'see the natural philosophical causes'. Descartes can at a stretch be added to this short list, but only on the telling condition that one carefully study the totality of his natural philosophical project, so that the physico–

mathematical 'chromosomes' of his vortex celestial mechanics may be brought into view for relevant study. Hence, in general, it can be argued that we might better understand the advent, with Kepler and Descartes, of physico-mathematical celestial mechanics if we stop first to re-evaluate their respective physico–mathematical projects for 'seeing the natural philosophical causes' in optics.

All of which returns us to the papers in our Thematic Section of *Synthese*, vol 185, no.2: 429-525. The three papers deal with different aspects and ways of approaching the challenge of achieving a 'seeing of mathematical causes' in the optical projects of Kepler and Descartes.