JEMS II (2013), 1: 147–162

Method and the *a priori* in Keplerian metaphysics

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Abstract: I will analyze how a natural philosopher, according to Johannes Kepler (1571-1630), can move from phenomena to knowledge of *a priori* causes, those causes included in the divine "idea" of the world. By doing so, I hope to enlarge upon recent studies that discuss the influence of *regressus*-style logic on Kepler's natural philosophy. The first part of this article will focus on Kepler's influences at Tübingen and on the preface to the first edition of the *Mysterium Cosmographicum* (1596). The preface is an important document. In it, Kepler presents his own narrative of discovery. In the second half of the article, I will jump to his last *a priori* works, those published around 1620. I will argue that these add a level of detail and precision to the *a priori* method first presented in the *Mysterium.* I will end by considering the 1621 edition of the *Mysterium*, showing how Kepler strongly clarifies the limits of geometry in his natural philosophy.
Key words: Johannes Kepler, Michael Maestlin, *Mysterium Cosmographicum*, history of science, astronomy, scientific method, early modern period, *a posteriori*, *a priori*, *regressus*, measurement, demonstration, empiricism, philosophy of mathematics

1. The Mysterium cosmographicum*: a method of astronomical certainty*

In attempting to shed light on experimental practice in the 17th century, I propose looking at method: how can a natural philosopher analyze phenomena and reach truth? My subject is Johannes Kepler (1571-1630), universally celebrated as an astronomer, although he falls under the heading of natural philosopher almost as well as figures like Descartes and Leibniz do.

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In any case, he wished to be regarded as a philosopher, as one able to explore both physical and metaphysical causes, where "metaphysical" is understood to occupy itself with the *a priori*, with those formal causes stemming from God's nature.[1] In Kepler's first book, the *Mysterium Cosmographicum* (1596), he claims to give the true, *a priori* causes behind the Copernican structure of the world. How is he able to do so, by his own account?

There is no unanimous position in the sixteenth century on what can or cannot be known about the heavens. Neither is there a consensus on who is privy to such knowledge, astronomers or philosophers.[2] Barker and Goldstein have remarked that sixteenth century astronomers are best depicted as frustrated realists who "agree that it is impossible, in this life, to discover which pattern of orbs actually exists in the heavens."[3] Looking within the protestant universities, we see a wide consensus that *some* things can be known, even if much or most is beyond human grasp. Nicholas Jardine has called this kind of skepticism "moderate." In order to understand the usefulness of the qualifier "moderate," it suffices to consider Michael Maestlin (1550-1631), Kepler's professor of mathematics at the University of Tübingen. Maestlin was an early supporter and expert of Copernican astronomy, which he introduced to Kepler. He was also one of the finest observational astronomers in protestant Germany, if we are to take the word of Tycho Brahe.[4] Maestlin's position on

[1] "I had reached the point of ascribing to this same Earth the motion of the Sun, but where Copernicus did so through mathematical arguments, mine were physical, or rather metaphysical." Johannes Kepler, *The Secret of the Universe = Mysterium cosmographicum*, trans. ~~E. J. Aiton~~ A.M. Duncan, in *Janus series*, New York: Abaris Books, 1981, p. 63. See also *Gesammelte werke*, edited by Walther von Dyck, Max Caspar, and Franz Hammer, München: C.H. Beck, 1937-, vol. 1, p. 9. I will refer hereafter to this edition as KGW followed by the number of the volume (in Roman numerals) and the page number. Kepler also claims that metaphysical reasons are those stemming from first principles, where those first principles are determined by God. See, for example, Jean Kepler, *Le secret du monde*, trans. Alain Segonds, Paris: Gallimard, 1993, p. 261. n.1. For more on the metaphysical-physical relationship, see Gérard Simon, *Kepler, astronome astrologue*, [Paris]: Gallimard, 1979. Throughout his career, Kepler was adamant that "… the astronomer ought not to be excluded from the community of philosophers who inquire into the nature of things." Nicholas Jardine and Johannes Kepler, *The birth of history and philosophy of science : Kepler's A defence of Tycho against Ursus with essays on its provenance and significance*, Cambridge: Cambridge University Press, 1984, p. 144.

[2] Starting with Pierre Duhem's *Sauver les apparences*, there is an extensive literature analyzing sixteenth century astronomy in terms of realism, non-realism(s), certainty and uncertainty. Robert Westman's most recent book is one of the most comprehensive studies on the certainty issue. See Pierre Duhem, *Sauver les apparences*, Paris: Vrin, 2004; Robert Westman, *The Copernican Question: Prognostication, Skepticism, and Celestial Order*, Berkeley: University of California Press, 2011.

[3] Peter Barker and B.R. Goldstein, "Realism and Instrumentalism in Sixteenth-Century Astronomy: A Reappraisal," *Perspectives on Science* 6 (1998), pp. 235-258, p. 253.

[4] Tycho praises Maestlin's parallax analysis of the 1572 new star, this despite Maestlin's lack of access to good instruments. Tycho tells us that Maestlin, with only a string, took better measurements than many who availed themselves of instruments. Tycho Brahe, *Astronomiae Instauratae Progymnasmata*, Uraniborg, 1602, pp. 543-544.

astronomical knowledge is indeed "realist," although somewhere in the middle of the spectrum. Yet Maestlin has different ideas from Kepler. In particular, he feels that astronomy should rest with observation and geometrical analysis. He is against the introduction of physical reasoning into astronomical theory: astronomy should not venture too far into questions about cause, which is the domain of physics. Maestlin even criticizes the young Kepler for his speculation in the *Mysterium cosmographicum* about *how* the sun moves the planets:

> I do not reject this speculation of spirit and motive virtue. Nevertheless I fear that it is not very subtle if it is extended too much…I am really afraid that if too specific it would become the ruin of all astronomy. I deem that this speculation is to be used altogether sparingly and with great moderation.[5]

Which is not to say that astronomy is devoid of any certainty for Maestlin. Statements about movement, order and position, the bread and butter of astronomy, cannot be rejected if they follow correct mathematical demonstration. They can also give definite information about matters that usually fall outside of astronomy. In refuting Aristotle's theory of comets, a physical theory, Maestlin needed nothing more than an accurate measurement of parallax (easier said than done) and a correct calculation of distance: "And from this not probably but from necessity is it shown, [that] the comet has not only surmounted the whole elemental region, but has sought its place in the upper ether."[6] By rejecting physical speculation in astronomy, Maestlin was not only adhering to disciplinary categories.[7] He was also trying to protect astronomy, to keep out as much of the simply "probable" as possible.[8] If astronomical demonstrations must take the form of those in arithmetic and geometry, that is to their benefit. Such demonstrations are pure and irrefutable.[9] In this sense, Maestlin is close to Philip Melanchthon (1497-1560), who at least once

[5] Letter of 9 March 1597, in KGW, vol. xiii, 109-111, n. 63, quoted in James R. Voelkel, *The composition of Kepler's Astronomia nova*, Princeton: Princeton University Press, 2001, p. 67. For Kepler's use of physical speculation, see Bruce Stephenson, *Kepler's physical astronomy*, Princeton: Princeton University Press, 1994.

[6] "*Ex quo non probabiliter, sed ex necessitate euincitur, Cometam hunc non modo omnem elementorum regionem transcendisse, sed in summo aethere locum sibi quaesiuisse*." Michael MÆStlin, *Consideratio & observatio Cometæ aetherei astronomica, qui anno 1580 ... apparuit. Item descriptio terribilium ... chasmatum quæ his annis 1580 & 1581 conspecta sunt*: Heidelbergæ, 1581. Latin excerpt quoted in Charlotte Methuen, *Kepler's Tübingen : stimulus to a theological mathematics*, in *St Andrews studies in Reformation history*, Brookfield, VT: Ashgate, 1998, p. 179, n. 161.

[7] Still the most referenced article on astronomy and disciplinary roles in 16th century universities and courts is Robert Westman, "The Astronomer's Role in the 16th Century: A Preliminary Study," *History of Science* 18 (1980), pp. 105-147.

[8] On *probabilitas* and *veritas* in 16th century astronomy, see Willy Hartner, "Copernicus, the Man, the Work, and Its History," *Proceedings of the American Philosophical Society* 117 (1973), pp. 413-422 see particularly pp. 419-420.

[9] Methuen, *Kepler's Tübingen*, pp. 192-193.

claims mathematics as the surest type of knowledge and uses it as an example of divine inheritance remaining in the soul of fallen man.[10]

Maestlin's discussions on astronomical reasoning take place in the terminology later adopted by Kepler. Both admit two sorts of reasoning: *a priori* and *a posteriori*. Here is how Kepler presents the *a priori* and *a posteriori* in his *Mysterium*:

> For what could be said or imagined which would be more remarkable, or more convincing, than that what Copernicus established by observation, from the effects, *a posteriori*, by a lucky rather than a confident guess, like a blind man, leaning on a stick as he walks (as Rheticus himself used to say) and believed to be the case, all that, I say, is discovered to have been quite correctly established by reasoning derived *a priori*, from the causes, from the idea of the Creation.[11]

The use of these terms for Kepler and Maestlin follows, in a general sense, Melanchthon's. Melanchthon's *a priori* aligns with what was typically known in Aristotelian logic as a *propter quid* demonstration: a movement from the "prior in nature [causes] to consequences [effects]."[12] *A posteriori* reasoning aligns with *quia* demonstration and moves from facts to suppositions. Maestlin, in the *De astronomiae hypothesibus* (1582), states that astronomical reasoning must be *a posteriori*: "nobody can ascend to the aethereal region and see everything before his eyes."[13] As for the necessity of *a posteriori* demonstrations, Maestlin's opinion was changed in the 1590s. By his own account, it was Kepler who convinced him that *a priori* demonstrations were possible. In Maestlin's preface to the *Narratio prima*, published alongside the *Mysterium* in 1596, he suggests that Kepler's discovery should be enough to vault the young man to greatness.[14] As readers of Kepler know, the principal argument

[10] See Nicholas Jardine, "The Forging of Modern Realism: Clavius and Kepler Against the Sceptics," *Studies in History and Philosophy of Science* 10 (1979), pp. 141-173, p. 148. See also Peter Harrison, *The Fall of Man and the Foundations of Science*, Cambridge: Cambridge University Press, 2007, pp. 99-100.

[11] KGW, i, 26. Kepler, *The Secret of the Universe*.

[12] See Philip Melanchthon, *Initia Doctrina Physicae*, Vitebergae, 1549, in *Corpus Reformatorum*, C. G. Bretschneider (ed.), Halis Saxonum: Schwetschke and Filius, 1846, vol. 13, quoted in Barker and Goldstein, "Realism and Instrumentalism in Sixteenth-Century Astronomy: A Reappraisal," p. 244. For more on Melanchthon's method see Sachiko Kusukawa, "Vinculum Concordiae: Lutheran Method by Philip Melanchthon," in Daniel A. Di Liscia, Eckchart Kessler, and Charlotte Methuen (eds.), *Method and Order in Renaissance Philosophy of Nature: The Aristotle Commentary Tradition*, Hampshire: Ashgate, 1997, pp. 319-336; *The transformation of natural philosophy : the case of Philip Melancthon*, Cambridge: Cambridge University Press, 1995. See also Jardine, "The Forging of Modern Realism: Clavius and Kepler Against the Sceptics."

[13] "*Non autem a priori, siquidem in aethercam regionem nemo ascendere potest, qui omnia coram spectet.*" Maestlin, *De astronomiae hypothesibus…*, Heidelberg: Mylius, 1582, quoted in Methuen, *Kepler's Tübingen*, p. 182 , n. 65.

[14] For Maestlin's preface, see KGW, i, pp. 82-85.

of the *Mysterium* is touted as *a priori*: Copernican planetary distances, and so the Copernican order, are determined by the five Platonic solids, which had intellectual currency in the Renaissance thanks to their predominance in the *Timaeus* and the *Elements*, whose book XIII is dedicated to their construction.[15] Kepler's *a priori* scheme of planetary distances is simple: each Platonic solid determines the gap size between two planetary orbs, where the superior orb circumscribes the solid, while the inferior orb is inscribed in the solid—for example, Saturn and Jupiter are separated by a cube, Jupiter and Mars by a pyramid.[16] Maestlin does not entertain Kepler's polyhedral hypothesis as probable; he accepts it with fanfare, lauding its potential for helping to restore astronomy. Astronomers now have an *a priori* door that stands open. Playing on the etymology of *calculus*, Maestlin sums up Kepler's contribution by calling it a touchstone with which to examine every observation and calculation.[17] We see, then, how *a priori* demonstrations should prove themselves useful in Maestlin's opinion. But missing in both Maestlin's preface and in the *Mysterium* itself is explicit information about how an astronomer can reach an understanding of *a priori* cause in the first place. After all, God did not simply transmit knowledge of the divine blueprint to Kepler's brain.

The Selection of a priori cause

In the sixteenth century, a well-known process did exist for moving from observations to possible causes, from possible causes to the true cause, and then, deductively, from true cause to phenomena. This process was often referred to as the *regressus*. It was widely discussed in Lutheran circles: the Wittenburg astronomer Erasmus Reinhold, author of the Prutenic Tables, describes it in his commentary on book V of the *Almagest* (1549). It also features in a book by Kepler's professor of logic at Tübingen, Andreas Planer.[18] In the *regressus*, an analysis is implied for sorting out true cause from false causes. *Regressus* literature sometimes describes this analysis as a third step between

[15] For more on the Platonic solids in the Renaissance see, Robert S. Westman, *The Copernican question : prognostication, skepticism, and celestial order*, Berkeley: University of California Press, 2011, p. 269.

[16] "Orb," in this case, is simply a planetary path. Kepler is against solid spheres.

[17] Touchstone as in "Lydian stone." KGW, i, 82: "*Ab hoc igitur tempore, qui coelorum motus pleniùs inquirere, et quae in Astronomia adhuc manca sunt, reficere et redintegrare volet, habet iam à priori patentem ianuam, qua ingrediatur, habet rectissimam normam, ad quam, ceu ad Lydium lapidem, omnes suas obseruationes, totumque calculum examinet.*" For a slightly different look at Maestlin's preface, namely at how Maestlin uses Kepler's *a priori* discovery to promote Copernicus, see, Pietro Daniel Omodeo, *Copernicus in the Cultural Debates of the Renaissance: Reception, Legacy, Transformation. Parts I and II,* Preprint 429, Berlin: Max Planck Institute for the History of Science, 2012, pp. 339-342.

[18] Barker and Goldstein, "Realism and Instrumentalism in Sixteenth-Century Astronomy: A Reappraisal," p. 247; Methuen, *Kepler's Tübingen*, pp. 182-184.

a posteriori and *a priori*. Zabarella calls it the *mentale examen*, but it goes by other names too. All the magic of the *regressus* lies in this crucial stage of analysis.[19] And we must look indirectly for it in Kepler's *a priori* method.

When Kepler finally discovers his polyhedral thesis, he *knows* he has the right answer. Peter Barker and Peter Harrison have both pointed out the presence of natural light doctrine in Lutheran circles and in Kepler's work.[20] The natural light doctrine, insofar as it bears upon Kepler, is quite simple: that man is granted certain knowledge of logic and mathematics. While this innate knowledge is not explicitly discussed in the *Mysterium*, it is assumed. In other words, geometrical knowledge is assumed as an essential part of the religious experience, of how man relates to God. Kepler first published his famous God as sphere comparison in the *Mysterium*. God's *imago*, he tells us, is that of a sphere: the center of the sphere corresponds to the Father, the surface to the Son, and the space between to the Holy Spirit.[21] As we will see, this image implies a great deal: it implies that Kepler's God, unity and separateness, is a proportion from which every other knowable proportion unfolds.

In the second chapter of the *Mysterium*, creation is portrayed as an act of divine expression, wherein God communicated his being through geometry. Mainly, God wished to describe his status over his creatures' by the incommensurability of the curve and the line. In Kepler's account, the creation of matter was necessary to achieve a medium that might express quantity—and quantity (as in extension or dimension) was essential for the realization of geometric form.[22] Reading between the lines, *a priori* reasoning must incorporate

[19] As Alan Gabbey notes, it was also known as the *negotiatio intellectus* or *consideratio mentalis*. Gabbey describes it as follows: this step is "designed to protect the *regressus* from circularity through an appeal to the mind's intuition of universals … the effect is formally demonstrated as the effect of the cause thus inferred and certified, again syllogistically." Alan Gabbey, "Mechanical Philosophies and Their Explanations," in Christoph Luthy, John Emery Murdoch, and William Royall Newman (eds.), *Late Medieval and Early Modern Corpuscular Matter Theories*, Leiden: Brill, 2001, pp. 441-466, at pp. 442-443. For a list of texts dealing with *regressus*, several by Jardine and Wallace, see ibid., pp. 443 n. 6. Wallace makes a well-known case for the use of *regressus* by Galileo. See William A. Wallace, *Galileo's Logic of Discovery and of Proof: The Background, Content, and Use of his appropriated Treatises on Aristotle's Posterior analytics*, Dordrecht ; Boston: Kluwer Academic, 1992.

[20] See Peter Barker, "Kepler's Epistemology," in Daniel A. Di Liscia, Eckchart Kessler, and Charlotte Methuen (eds.), *Method and Order in Renaissance Philosophy of Nature: The Aristotle Commentary Tradition*, Hampshire: Ahsgate, 1997, pp. 355-368. "If God is a geometer, then his geometrical plan for the universe may also be understood with certainty by the same means. As we have seen, Kepler's early assurance about the certainty of geometry rested on the natural light doctrine. His lifelong adherence to a view that placed archetypes at the center of knowledge should be seen against this background. He could not abandon the archetypes without abandoning the claim to certainty at the foundations of his system." Ibid., pp. 366.

[21] This also appears slightly earlier, in a letter to Michael Mästlin, from October 1595. See KGW, xiii, 33-46.

[22] Kepler does not refer to "matter" in the *Mysterium* but to body (*corpus*). I take him to be referring to matter, however. See KGW, i, p. 23: "*Dico quantitatem Deo fuisse propositam: ad*

geometric forms that have a status determined by their nearness to the sphere, that is, by their simplicity and their equalities ("symmetry," as Goldstein and Hon have argued, is not the historically accurate term, however):[23]

> The nobility of the solids depends on their simplicity (*ex simplicitate*), and on the equality of the distances (*ex aequalitate distantiae*) of the faces from the center of the figure. For just as God is the model and rule for living creatures, so the sphere is for solids. Now the sphere has the following properties: 1. It is extremely simple, because it is enclosed by a single boundary, namely itself. 2. All its points are at a precisely equal distance from the center. Therefore among bodies the regular solids approach most closely to the perfection of the sphere.[24]

These issues aside, Kepler also furnishes, in his preface to the *Mysterium*, a very useful account of how he made his discovery. As he will in the *Astronomia nova*, he introduces his discovery as having taken shape from instructive failure. He uses a narrative, one meant not only to convince us of the task's difficulty and the author's skill, but also of the effort expended. Remarkably, there is no attempt to impose a method on his discovery process, not even in retrospect. Although Kepler is favoring certain proportions and checking them against the Copernican distances, he gives us the impression of someone throwing stuff at the wall and seeing what sticks.

The Preface

Kepler, as he tells us in the preface, set himself to explaining the "number, the size, and motion" of the orbs during his leisure hours as a teacher in Graz. His first attempt was to find some simple numerical proportion between planetary sizes and distances. Although he does not say, we might speculate that since harmony was already on his mind he may have tried the Pythagorean proportions. In any case, nothing came of his first effort. He next attempted to find some relationship between the movements of the planets and their distances from the Sun, to no avail. He then tried to postulate planets, too

quam obtinendam omnibus opus fuit, quae ad corporis essentiam pertinent: vt ita quantitas corporis, quantenus corpus, quaedam forma, Definitionisque origo sit." A conception of matter will play an important role in Kepler's astronomical physics. He will equate the earth's attractive pull to the quantity of matter therein (*moles*), and he will also relate the amount of matter with the amount of resistance that a planet puts up against the solar force.

[23] Giora Hon and Bernard R. Goldstein, *From Summetria to Symmetry: The Making of a Revolutionary Scientific Concept*, Dordrecht: Springer, 2008, p. 34 and pp. 170-176. For a discussion of the *Mysterium* that touches on several points similar to my own, although from a different angle, see Rhonda Martens, *Kepler's Philosophy and the New Astronomy*, Princeton: Princeton University Press, 2000, pp. 39-56.

[24] KGW, i, pp. 27-28 and Kepler, *The Secret of the Universe*, p. 101.

small to be seen, *between* the visible planets, but he realized that this approach was also futile: it did not explain the number of planets being postulated. Even worse, he explains, space can be infinitely divided: extra planets can be added indefinitely. Plus, numbers acquire their significance only from the things they count, things that are posterior to creation. Numbers themselves cannot tell us why there are six planets rather than an infinity.[25]

The next attempt that Kepler describes gives us an early indication of how he was looking to use geometrical means to explain, not merely planetary movement, but the Sun's force upon the planets. In fact, it seems that he thought he would be able to explain the universal order based on how the solar force (*vis motus*) emanated.[26] Already in a student disputation from 1593, he had hypothesized that the Sun turns with "nearly infinite" speed.[27] In the following attempt, he holds to this physical hypothesis. Between the infinitely mobile sun and the perfectly immobile outer sphere, the planets are whirled around by a steadily decreasing force. Kepler attempts to explain not only how the force

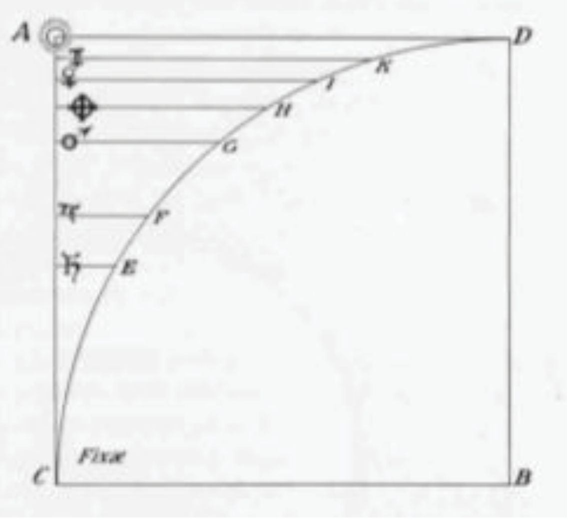

Figure 1: Kepler's 'Sine Scheme' (KGW, i, p. 11)

[25] KGW, i, p. 10: "*Neque enim ab vllius numeri nobilitate coniectari poteram, cur pro infinitis tam pauca mobilia extitissent…*"

[26] Early in his career, before his optical works, Kepler generally believed solar force to diffuse as light. In the *Mysterium*, he holds that both diminish as 1/r from the source. See David C. Lindberg, "The Genesis of Kepler's Theory of Light: Light Metaphysics from Plotinus to Kepler," *Osiris* 2, 2nd Series (1986), pp. 5–42. See also Ofer Gal and Raz Chen-Morris, "The Archeology of the Inverse Square Law: Metaphysical Images and Mathematical Practices," *History of Science* 43 (2005), pp. 391-414.

[27] KGW, xx.1, pp. 148-149; translation given in Voelkel, *The Composition of Kepler's Astronomia Nova*, p. 29.

decreases, but also how it can be infinite in the Sun and zero at the fixed stars. He thus devises a clever scheme based on the internal proportions of a circle. In the image above, we see a square, the length of which is equal to the radius r of the universe. Kepler then, from C to D, traces out the circle whose center is B, directly opposite the Sun at A. There are a few things to keep in mind here. Kepler's solar force always pushes planets in a circular orbit. His idea is to get the pushing force from the vertical distance by using the relationship between the length of a chord, perpendicular to the radius, and the length of the radius. In this scheme, the moving force (and so a planet's movement), is equivalent to $r - \sqrt{(r^2 - d^2)}$, where r is the radius and d the distance from point B. In Kepler's words, moving force is determined by the sine relation. The easiest way for us to see this is by once against converting his words into modern notation: moving power is equivalent to r - r sine (x), where x is the angle around point B.[28]

To summarize: this "sine" scheme begins with two physical presuppositions, the first that the motive power in the sun is infinite, the second that the motive power at the fixed stars is zero; Kepler then introduces a third postulate, that the power decreases as a circle's chord increases according to its distance from the center. Based on this scheme, if we only knew the radius of the universe, we could establish both periods and planetary distances. I would like to point out a very basic fact. While the universe is finite, and while Kepler is always adamant on this point, the infinity of the sun's motion poses no problem here in his thinking. Why? Probably because it is assured by a geometrical cause, *even if* there is no physical cause that could explain how a force, first infinite, suddenly turns finite. Moreover, this early geometrical diagram is very different from the ones that he will later employ. Kepler, in his optical and astronomical diagrams, generally pictures only possible motions of bodies and rays in space.[29] But the sine diagram is mixed. Both spatial elements and non-spatial elements are pictured on the same spatial plan: the sun's infinite power at the center of the universe is represented as an infinite line (extending beyond point D), even if this power is not infinitely extended in space. In fact,

[28] Kepler's exact words are, "…I investigated by another method whether the distance of any planet in the same quadrant may not be the remainder of the sine, and its motion the remainder of the complement of the sine." KGW, i, p. 10 and Kepler, *The Secret of the Universe*, p. 101.

[29] "Keplerian pictures are means of acquiring knowledge because of their geometrical regularities. They are transformed into diagrams. Yet these diagrams are not abstractions from static corporeal bodies, but are representations of possible motions and the relation of these motions to physical bodies." Raz Chen Morris, "From Emblems to Diagrams: Kepler's New Pictorial Language of Scientific Representation," *Renaissance Quarterly* 62 (2009), pp. 134-170, see p. 165. I also point to the reader to Robert Westman, "Nature, Art, and Psyche: Jung, Pauli, and the Kepler-Fludd Polemic," in Brian Vickers (ed.), *Occult and Scientific Mentalities in the Renaissance*, Cambridge: Cambridge University Press, 1984, pp. 177-229.

all the horizontal lines *represent* values that are not literally extended. The sine diagram almost makes one think of a bar graph in a newspaper.

As for the analysis part of Kepler's *regressus*, we can draw a conclusion from these considerations: the sine scheme, which Kepler would abandon before the composition of the *Mysterium*, is an attempt to unlock secrets from the internal proportions of the circle. True *a priori* causes are given *only* from geometric considerations—that is, only from proportions determined by internal elements of special geometrical forms. Those special forms are close to the sphere. The middle step in Kepler's *regressus*, as shown in the preface, is served by a basic constraint on the kinds of mathematical structures that can appear in the world. Natural philosophers are allowed to organize and explain phenomena by proportions given in these figures.

2. A priori *certainty in the late metaphysics: the* Mysterium cosmographicum *of 1621*

In 1619, Kepler published his *Harmonices Mundi*, which he viewed as the culmination of the *a priori* program begun in the *Mysterium*. Not only does it reaffirm the polyhedral thesis (and treat the construction of the polyhedra), it shows how harmony derives from privileged polygons and how planetary movements, at aphelion and perihelion, represent notes on a scale. Kepler highlights the essential consistency between the *Harmonices* and the *Mysterium*:

> That is, the former [the harmonies] provided the nose and eyes and other limbs of the statue, for which these latter [the Platonic solids] had prescribed the external quantity of bare mass.[30]

The *Harmonices* also goes into great depth on the human soul's constitution. Kepler takes natural light doctrine to a Pythagorean extreme: the soul is defined as an "irradiation shed from the divine face on the body."[31] It is the reflection of a sphere on a plane: a circle. That is, it is a mixture of the divine and the creaturely.[32] In the sense of being a circle, it is also a "storehouse" of all the geometrical and arithmetic knowledge it needs:

> Of course mathematical classes in fact are in the soul in a way no different from other universals, and various conceptions abstracted from sensible things; but among mathematical types that which is called the circle is in the

[30] KGW, vi, 361. See translated paragraph in Johannes Kepler, *The Harmony of the World*, edited by E. J. Aiton, A. M. Duncan, and J. V. Field, Philadelphia: American Philosophical Society, 1997, p. 490.

[31] Under section "*Animi quaedam definitio*," KGW, vi, 224; ibid., pp. 305.

[32] This is still all in accord with his comparison in the *Mysterium* of the creaturely with the straight, the divine with the curve, a common Renaissance motif.

> soul by a far different method, not only as an idea of external things, but also as a sort of form of the soul itself, and lastly as a single storehouse of all geometrical and arithmetic knowledge. The former of those is most obvious in the theory of sines, the latter in the wonderful business of logarithms, as in those, which arise from the circle, there is a sort of calculating machine of all the multiplications and divisions which can ever take place, as if they were already completed. But enough of the chief faculty of the soul … [33]

To complete the thought, I remind the reader that all knowable objects are, according to the *Harmonices*, constructible by ruler and compass.[34] This means simply that such objects arise naturally between the straight line and the curve, that is, between a radius and a circumference, the two chief elements of a circle. Such are the figures, or proportions, "stored in the soul." In the above quote we see Kepler justifying his entire *a priori* scheme of privileged figures by the circular nature of man and, at a higher level, the spherical nature of God.

But here we pose a question: in this "radical Platonism," as J.V. Field has called it, where the *Timaeus* is considered a commentary on *Genesis*, why should the astronomer have to make precision measurement?[35] Why should such measurement be necessary even after *a priori* schemes give every proportion? Here we can analyze what might be considered Kepler's last word on the application of geometry in natural philosophy: the second edition of the *Mysterium Cosmographicum*, published in 1621. This second edition is precious. In it, Kepler includes notes that serve as a sort of running commentary on his first book. It is late-career Kepler critiquing or praising his younger self. On the one hand, the reader notices just how consistent Kepler's metaphysics is over almost three decades. On the other hand, the reader sees how precise Kepler's understanding of the uses and abuses of geometry has become.

Kepler's philosophy of mathematics, from the beginning of his career, is played out in terms of infinity, finitude and relation. Geometrical form orders quantity; the former is finite and the latter infinite. Without the finite, there is no idea and no comprehension. In an earlier work, he writes:

> Reasonably speaking, we certainly cannot in thought comprehend an infinite body. For the mind's concepts of infinity, either they signify the meaning of the word 'infinity', or that it [an infinite body] exceeds all conceivable measure of number, of touch, of vision; because infinity is not immediate and actual; because never is a measure thought to be infinite.[36]

[33] KGW, vi, p. 277; Kepler, *The Harmony of the World*, pp. 373.

[34] For more on constructability and knowability, see ibid., pp. xxv.

[35] J. V. Field, *Kepler's Geometrical Cosmology*, London: Athlone, 1988, p. 188.

[36] The *De Stella Nova Serpentarii* (1606), KGW, i, p. 257: "*Sanè ne cogitatione quidem comprehendi potest infinitum corpus. Nam conceptus mentis de infinito, aut sunt de vocis Infiniti significatione; aut de eo, quod mensuram omnem cogitatam numeri, tactus, visusve excedit: quòd non statim et actu infinitum est; quia infinita mensura cogitatur nunquam*."

Matter, space and time, by themselves, have one essence: they are, in potential, infinitely divisible.[37] In and of themselves, they cannot give the causes or reasons for which a natural philosopher searches. In the 1621 edition of his *Mysterium Cosmographicum*, Kepler lists and invokes a series of senseless questions that seek reason in quantities without appeal to geometrical form.[38] Such questions include the following:

1) Why is the zodiac where it is, when it could have been placed in infinitely many other positions?[39]

2) Why did God establish the universe in one part of the void rather than another?

3) Why did God create the universe at such and such a moment rather than at some different moment?

4) Why do the planets turn from west to east, rather than from east to west?

It is not simply that these questions lack answers. They are absurd. They assume something, like space and time, to have existed before any reference. Before there were objects, and objects to move, there was neither "forward" nor "backward". One could imagine a world exactly as ours, but in mirror image. Why our world rather than that other world?[40]

Kepler's argument here is one of sufficient reason: "As for things that can arise indifferently in one way or another, nature has not found any way to choose between what is better and worse; this, in fact, implies a contradiction."[41] The argument is close to Leibniz's critique of absolute space as contradicting the principle of sufficient reason: no sufficient reason would exist why "everything was not placed the quite contrary way ... by changing East into West."[42] Kepler, however, does not for all this deny absolute space. Instead, he embraces

[37] KGW, viii, p. 63: "*Nam et spatium et tempus in genere quantitatum rationem habent materiae, respectu quidem figuratarum quantitatum. Materia vero de se rationes nullas suppeditat, ipsa in se vnam et solam proprietatem habet, infinitatem partium, actualem quidem, vel numeri, vel quantitatis, si ipsum totum actu infinitum: potentialem vero numeri, si totum actu finitum, quod solum est possibile, cum quantitas est in materia corporali physica vel coelesti*."

[38] I will be examining the notes to chapter XI. KGW, viii, pp. 62-65. The questions below are from note 13, ibid., 64-65.

[39] Kepler had tried to answer it in the 1596 edition of the *Mysterium* by using the intersection of polyhedral edges and angles—in other words, he had early on tried a geometrical approach. In these 1621 notes, he chastises himself for not understanding that his attempt was in vain. The issue cannot be solved by the polyhedra.

[40] Likewise, there was no reason why human arms, hands and fingers should bend in the direction they do, rather than in the opposite direction. There was no reason why the heart was placed on one side of the chest and not the other.

[41] KGW, viii, p. 65: "*Nam inter ea, quae omnia ex aequo contingere possent, natura nullam inuenit Melioris et Deterioris electionem; hoc enim inuoluit contradictionem*."

[42] See Leibniz' third letter to Samuel Clark, point 5, in Gottfried Wilhelm Freiherr von Leibniz and Samuel Clarke, *A Collection of Papers, Which Passed between the Late Learned Mr. Leibnitz, and Dr. Clarke, in the years 1715 and 1716. Relating to the Principles of Natural*

it by anticipating a variation of Clarke's response to Leibniz. When there is no better choice, existence is nevertheless better than non-existence. Given an infinity of options, all of equal value, Kepler's God, unlike Leibniz's, will create *something*. What he creates will immediately have precedence over what is uncreated, because to exist is better than not to exist. Kepler's point, however, is that the question of "why" without recourse to geometrical form is senseless. Matter, space and time, can furnish no reason in and of themselves. In other words, quantities are not answers to natural philosophic questions. The specialness of the number six cannot explain why there are six planets, nor can the harmonies be explained by the status of numbers like three. Kepler criticizes Pythagorean philosophy on precisely this issue.[43] Any importance given to quantities originates from the nature of geometrical objects. It is geometry that gives reason by constraining the infinity of quantity. (Constraining infinity is after all a major goal of the *Mysterium Cosmographicum*, where not only do the polyhedra yield the proportional distances between planets, they also yield the number of planets;[44] likewise for the *Harmonices Mundi*, where geometry constitutes harmony and thus determines planetary speeds and eccentricities.)

Notice that geometry cannot give a reason, that is, proportion, when there is nothing to relate. Geometry can give reason only when basic physical references are already provided. For example, the Platonic solids of the *Mysterium Cosmographicum* give the planetary distances by way of relation: however, they cannot yield an original, measured distance. The astronomer *must* measure. For the actual distance between the earth and the sun—or whatever distance is taken as the "unit" distance—God had no reason why this distance wasn't a few kilometers closer or farther. We can assume that he had no reason for choosing the "scale" of the universe either. However, once unit distance and scale were established, everything else followed according to essential proportions. We should summarize here. Proportions drawn from key geometrical figures, all of them derivable from the sphere, are what give the universe order. Yet for these proportions to exist, certain basic quantities must be selected without sufficient reason. These values in Kepler's physics are those of mass, volume and distance.[45] It is primarily to establish and verify the key quantities

Philosophy and Religion, London: James Knapton, 1717, p. 59. See also Leibniz's fifth letter, point 53, ibid., pp. 212-215.

[43] Kepler, *The Harmony of the World*, pp. 179.

[44] Given that there are necessarily only five Platonic solids, a Platonic solid between each planet would allow for only six planets, the number of planets from ancient astronomy until William Herschel's discovery of Uranus in 1781.

[45] The Sun's power, for example, is related to its mass and volume; the way that the planets receive the power is related to their own masses and volumes. The harmonic law is something of a master proportion linking of all these qualities togheter. Kepler, *The Harmony of the World*, pp. 411-412, n. 46.

that the natural philosopher must measure. The *a priori* is therefore limited by a certain amount of contingency built into the mathematical structure of the world by way of quantity.

3. Conclusion

In a sense, this study has been devoted to metaphysical justification in early modern science. In order to justify astronomical certainty, Kepler provides a method of uncovering formal cause from observation. That method, while loose in his early metaphysics, gets about as tight as possible in his *Harmonices* and 1621 edition of the *Mysterium*. Throughout, the method rests on an allegiance to simple uniform figures, those closest to the sphere. In doing so, it proposes that natural philosophical analysis always start with those figures, or a combination of them. The elegance and consistency of Kepler's metaphysics comes as no shock from a self-professed disciple of Pythagoras and Plato. However, what surprises is just how deeply his *a priori* method and metaphysical writings embed an empirical content—a need to account for quantities. It is not just that astronomy, now a part of philosophy, can avail itself of all sorts of cause. It is also that natural philosophers must do as astronomers. In turning the world into geometric form and quantity, and in giving quantities a kind of essential contingency, Kepler demands from natural philosophy that it measure, that it track and weigh.

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JOURNAL OF EARLY MODERN STUDIES
Volume 2 • Issue 1 • Spring 2013

Special Issue:
THE CREATIVE ROLE OF EXPERIMENTATION IN EARLY MODERN SCIENCE
Editor: DANA JALOBEANU

CONTENTS

ISSN: 2285-6382
ISSN-L: 2285–6382