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Kepler's "War on Mars"
and the Usurpation of
Seventeenth-Century Astronomy

Thesis submitted by

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ABSTRACT

This paper presents an interpretation of how Johannes Kepler changed the history and development of astronomy. It is proposed that in his metaphorical “War with Mars”, the *Astronomia nova*, Kepler used a revolutionary rhetoric to wage a “War on Mars” to bring about the usurpation of seventeenth-century astronomy. Kepler rhetorically redefined the axiomatic structure of the traditional astronomical framework and summarily replaced it with his own new discoveries, thereby affecting how we study astronomy. Kepler proposed a new conceptual framework based upon a new approach and methodology that was an obvious deviation and involved an intensive and extraordinary interplay between quantitative observation and theoretical construction, and between tradition and innovation. Here we examine how Kepler treated traditional astronomy with the use of rhetoric to usurp the entire well-established conceptual framework within which the hypotheses of Claudius Ptolemy, Nicolas Copernicus and Tycho Brahe functioned. We examine the principles, methods and subject matters that make up the elemental structure and character of Kepler’s new conceptual framework. We reveal that Kepler sought comprehensive physical principles that could determine the true form of the entire known Universe. This thesis suggests that although Kepler may have believed in and defended some Copernican ideas for a heliocentric system, the innovations in his ‘new astronomy’ opened up a whole new vista.

Key terms: Medieval science, rhetoric, rhetor, usurpatory rhetoric, philosophical rhetoric, philosophic rhetor, dialectics, rhetoric of science, metaphor, allegory, analogy, argument by analogy, deduction, ethos, logos and pathos.

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> "… I confess that when Tycho died, I quickly took advantage of the absence, or lack of circumspection, of the heirs, by taking the observations under my care, or perhaps *usurping* them..."
>
> Kepler (1992)

> "…we come to our fundamental human understanding not by proofs but by persuasion."
>
> Gingerich (2004)

1 INTRODUCTION

1.1 Prelude

When Copernicus, Kepler and Galileo suggested that the Earth revolved around the Sun, they weren't asking scientists to observe new data, they were proposing a new framework for understanding century's old observations. Their new framework constituted a radical assault upon millenniums of accepted belief. But, because they lacked the demonstrable proof to substantiate their claims and expected criticisms of their ideas, each one employed rhetoric as a means of persuasion. Each constructed and supported his argument in a different rhetorical style and directed it at a particular audience.

Copernicus' *De revolutionibus* (1543), Kepler's *Astronomia nova* (1609) and Galileo's *Siderius Nuncius* (1610) were published during the Late Renaissance, a time when strong lines of demarcation were drawn between science and the use of rhetoric or the art of persuasion when making scientific claims. Eons before, Aristotle had forbidden the use of rhetoric in scientific demonstration (see Aristotle, 1924: 1-20).

Presented in what follows is a new interpretation of how rhetoric, or the art of persuasion, affected the development and history of astronomy as a science. This study focuses on Johannes Kepler (1571–1630; Figure 1) and his use of rhetoric in his monumental *Astronomia nova* (1609) to help bring about the persuasion that his new astronomy was the only true astronomy. Kepler's new astronomy was a new scientific hypothesis or model of astronomical reality and he was aware that he had to convince the scientific community that his radical ideas were not only reasonable but were realistic.

This study proposes to show that Kepler ingeniously wrote the *Astronomia nova* (1609) as a purposeful philosophical rhetorical document – a mathematical one – and by doing so brought about the usurpation of seventeenth-century astronomy. It is proposed that the key to understanding how Kepler usurped seventeenth-century astronomy lies in the examination of Kepler's new principles, method and subject matters – which were the elements of an elaborate and purposefully-constructed rhetorical argument.

1.2 The Rhetoric of Science

If we are to appreciate the nature and character of Kepler's innovative us of rhetoric to communicate his science, a brief discussion of the rhetoric of science is necessary.

The history and development of astronomy has ostensibly been defined and concerned with investigating and elucidating the nature of observable phenomena, such as the position, the motion, and more recently, the life cycle of celestial bodies. Yet, among some historians of astronomy, it is less appreciated that rhetoric or the art of persuasion has played an important role in the process of communicating just what these phenomena are.

Indeed, until recently, the persuasive concerns of rhetoric were viewed as extrinsic to the factual concerns of science. Thomas Kuhn's *Structure of Scientific Revolutions* (1962) challenged and eventually helped to change this time-honored view, and, today some contemporary historians of astronomy, inquiring into their basic problems of trying to abstract the 'real science' from early modern scientific writing, are discovering strands or echoes of rhetoric in the work of some earlier astronomers (ibid.).

Today, in the study of the history and development of astronomy as a science, the general problem of accounting for the presence and role of rhetoric used in the support of scientific claims, whether ancient or modern, is becoming of paramount interest (see Gingerich, 1989; Gross, 1990; Kepler, 1992; Moss, 1993; Stephenson, 1987; Voelkel, 2001).

All scientists argue and their arguments are key to their success, yet today we live in an intellectual climate in which scientific certainty seems to be decaying and the reality of black holes, inflation, quarks, dark matter or string theory are all arguably matters of persuasion. Much of current science, indeed most of it, reaches conclusions that are only probable and are revisable. Importantly then, all discourse scientific treatises, whether spoken or written, must convince us of the truth of their claims. According to Gross:

> Rhetorically, the creation of knowledge is a task beginning with self-persuasion and ending with the persuasion of others. This attitude toward knowledge stems from the first Sophistic, an early philosophical relativism made notorious by Socrates. In spirit, the *Rhetoric*, my master theoretical text, is also Sophistic, its goal "to find out in each case the existing means of persuasion." It is a spirit, however, that Aristotle holds firmly in check by limiting the scope of rhetoric to those forums in which knowledge is unquestionably a matter of persuasion: the political and the judicial. If scientific texts are to be analyzed rhetorically, this Aristotelian limitation must be removed. (see Gross, 1990: 21).

For over 1500 years, the limitations that Aristotle placed on the use of rhetoric, restricting it to the political, ceremonial and legal arenas of argument, barred its use for the justification of scientific claims. Aristotle's rhetoric concerned itself more with correct grammatical structure and presentation of an individual's ethos, logos and pathos (see Section 1.3 below). Nevertheless, as William Wallace contends, during the Late Renaissance and early part of the seventeenth-century traditional Aristotelian rhetoric was powerless to foster change or scientific revolution. New and radical ideas in science, in order to be persuasive, had to be buttressed with rhetorical argument (see Wallace, 1989: 20; see also Kuhn, 1962).

Certainly, that there are rhetorical dimensions to doing science has been convincingly argued during the past five decades, yet, the definitive role of rhetoric in science and the interplay between science and rhetoric goes widely unappreciated today. Given that few studies focus on the use of rhetoric in science and even fewer on the role played by individuals who were the proponents of such rhetoric, Halloran's complaint that little attention has been paid to individual cases of scientific rhetoric remains true (see Halloran, 1984: 70-83).

An initial survey of the literature revealed a recent resurgence in the amount of activity concerning the role of rhetoric in the development and history of contemporary science and how science in general and rhetoric interact today (see Bazerman, 1988; Campbell, 2008; Fahnstock, 1999; Gross, 1990; Kuhn, 1962; Latour, 1987; Pera and Shea, 1999; Prelli, 1985; Rorty, 1984). Pera and Shea for example ask: “If there are no universal and precise methodological rules, how do scientists, during a theory-change, come to convince or convert their community to a new theory or way of seeing the world?” Pera and Shea answer in the affirmative that they “… take rhetoric as the art of persuasive argumentation; we thus aim at debating its role, nature, limits as well as efficacy.” (see Pera and Shea, 1999: 173).

The history of the rhetoric of science effectively begins with Thomas Kuhn's seminal work, *The Structure of Scientific Revolutions* (1962), where he is concerned with the paradigms or models of reality. Such models can constitute the first signs of new vistas. The choice of one over another by the scientific community, or the grounds of its acceptance, he argues, is a rhetorical problem where the opposition is between an old paradigm, which has been followed up exhaustively and a new one of remarkable promise. The feature relevant for purposes here is that the paradigm is an exemplary, particular scientific inquiry rather than the full theoretical structure or underpinning of a new movement. Kepler supplied the astronomical world with a new paradigm that offered the promise of being able to do new research to argue for or against new ideas.

Somewhat related to this, the astronomical historian Owen Gingerich has remarked:

> Today science marches on, not so much by proofs as by the persuasive coherency of its picture. No doubt this is old stuff to epistemologists, whose business it is to probe how we understand things. But, today it seems to be forgotten by two widely divergent camps. In one camp, there is—especially in America—a hard minority core of anti-evolutionists, who feel that biologists should furnish apodictic “proofs” of macroevolution and until that demonstration is in hand, evolution is a “mere hypothesis” that should not have a place in true science. They fail to understand that evolution offers biologists and paleontologists a coherent framework of understanding that links many wide-ranging elements, that it is persuasive, and that any critique of evolution will fall on stony ground unless it provides a more satisfactory explanation than evolution already does. (Gingerich, 2003).

Marlana Portolano's study of "John Quincy Adams's rhetorical crusade for astronomy" is illustrative of an attempt to demonstrate how rhetoric has played a role in the history and development of astronomy. During the early part of the nineteenth-century, Adams as the 6th U.S. President, in order to legitimize the study of astronomy in America, argued for the construction of a national observatory. Portolano's Abstract is both informative and invigorating:

> Astronomy thrived in Europe during the early nineteenth century, but in the United States a utilitarian mind-set opposed it. John Quincy Adams's oratory in support of American astronomical discovery reached its peak during congressional debate over the Smithsonian Institution (1838-1846). During this debate Adams countered proposals to found a university with plans for an observatory. His addresses to congressional and public audiences about observatories and astronomy were intended to foster interest in the science and encourage the growing astronomical community in America. Although the U.S. Naval Observatory in Washington, D.C., was established before the Smithsonian debate ended, many considered Adams its political father. Adams composed his speeches on astronomy in a systematic manner, following neoclassical principles of rhetoric that he had taught at Harvard University. His speeches both in and outside of Congress show evidence of the rhetorical principles he conscientiously used in the service of astronomy. (Portolano, 2000: 480).

Though he failed, Adams' oratory brought astronomy into the consciousness of the everyday average American citizen.

There is now increasing evidence that suggests that the involvement of rhetoric in scientific argument and its ensuing effect, particularly upon the history and development of astronomy during the late sixteenth and early seventeenth-century, may have been far greater than previously realized. (e.g., see Jardine, 1984; Shapin, 1996). A similar notion is further supported by the work of Jean Dietz Moss, who in *Novelties in the Heavens …* (1993: 66) stresses the influence of Galileo's prolific use of traditional Aristotelian rhetoric. While describing Copernicus and Kepler's use of rhetoric as merely 'cosmetic', Moss attributes to Galileo a revolution in how rhetoric was used during the Late Medieval period. Moss views Kepler's rhetoric as 'natural' and remarks that "… it seems to emanate spontaneously from his character …" (Moss, 1993: 66), but does not elaborate further. This is an important observation and will be related to the thesis being developed here.

Further work by James Voelkel in his study *The Composition of Kepler's Astronomia nova* (2001: 215) emphasizes Kepler's contextual and scientific circumstance as prime motivators for his use of rhetoric. Citing much of Kepler's numerous letters in support of his belief that the nature and character of the *Astronomia nova* can be attributed to Kepler's social and intellectual context, Voelkel's study is perhaps the single most penetrating attempt to date at examining Kepler's prime motivation for composing the *Astronomia nova* as he did. Voelkel insists that the narrative skeleton of the *Astronomia nova* must be viewed as rhetoric. As he states: "... many features of the *Astronomia nova* become comprehensible only when they are viewed in the context of Kepler's experience in writing the book as elements of an elaborate and purposefully-constructed rhetorical argument." (see Voelkel, 2001). Although, Voelkel refers to the *Astronomia nova* as being a 'rhetorically-philosophical' work, he nonetheless does not expand on how or why he views the work to be so. Voelkel's work is commendable, but, as he himself testifies, his "… examination of the rhetoric of the *Astronomia nova* (is) neither comprehensive nor grounded in a thorough study of the art." (see Voelkel, 2001: 214). Because this study owes much to the insights of Moss and Voelkel, their relevance will be discussed later.

In the second paragraph of his Introduction to the *Astronomia nova,* Kepler tells us that:

> The scope of this work is not chiefly to explain the celestial motions, for this is done in the books on Spherics and on the theories of the planets. Nor yet is it to teach the reader, to lead him from self-evident beginnings to conclusions, as Ptolemy did as much as he could. There is a third way, which I hold in common with the orators, which, since I present many new things, I am constrained to make plain in order to deserve and obtain the reader's assent, and to dispel any suspicion of cultivating novelty.
>
> No wonder, therefore, if along with the former methods I mingle the third, familiar to the orators; that is, an historical presentation of my discoveries. Here it is a question not only of leading the reader to an understanding of the subject matter in the easiest way, but also, chiefly, of the arguments, meanderings, or even chance occurrences by which I the author first came upon that understanding. (Kepler, 1992: 214).

For decades scholarly interpretation overlooked his clearly-stated intention: that he plans to give his readers an "… historical presentation …" (i.e., a rhetorical presentation) of his discoveries.

Fortunately, scholarly attitudes and the level of interest in Kepler's works began to change when Owen Gingerich (1964) noted certain problems in Kepler's manuscript that involved the calculation of the orbit of Mars and Kepler's account of his work. Gingerich first identified the convoluted path that Kepler took in performing some of the calculations that are merely summarized in the *Astronomia nova.* Gingerich's (1964) study revealed that Kepler's *Astronomia nova* was far from a linear autobiographical presentation of his researches, but rather a complex and "… carefully crafted account." Wilson (1968) first identified many of the complexities of Kepler's arguments that were imposed by the mathematical and physical problems themselves. He also pointed out flaws in various assumptions made in many other accounts of Kepler in this regard. In addition, Wilson examined the role that the theories of the inner planets had on Kepler's thought in the period between the *Mysterium Cosmographicum* and the *Astronomia nova.* Donahue (1988) continued in the direction of Gingerich's examinations and emphasized the internal evidence that Kepler rewrote many parts of the *Astronomia nova* for rhetorical reasons before it went to print.

Yet, it would be left to Bruce Stephenson (1987: 203) to characterize Kepler's rhetoric in the *Astronomia nova* as "… decidedly personal …" and address its complexity by proclaiming that the work was actually a 'physicalization' of astronomy. In *Kepler's Physical Astronomy*, Stephenson (1987) suggested that much more than data manipulation was present in the *Astronomia nova*, and he pointed out both the argumentative and rhetorical nature of the text. Stephenson observes:

> This profoundly original work has been portrayed as a straightforward account of converging approximations, and it has been portrayed as an account of gropings in the dark. Because of the book's almost confessional style, recounting failures and false trails along with successes, it has in most cases been accepted as a straightforward record of Kepler's work. It is none of these things. The book was written and (I shall argue) rewritten carefully, to persuade a very select audience of trained astronomers that all planetary theory they knew was wrong, and that Kepler's new theory was right. The whole of the *Astronomia nova* is one sustained argument. (Stephenson, 1987: 2-3).

As we shall come to see, in the *Astronomia nova,* Kepler did indeed take an argumentative approach to doing astronomy and, as an astronomical work, it differs in many respects from either the Copernican or the Galilean treatises, and it is more radical in its innovations. Yet, the phrase 'Copernican revolution' or 'Galilean revolution' is frequently used; seldom do we speak of a 'Keplerian revolution'. Here, it will be shown that Kepler's use of rhetoric is not merely ornamental or cosmetic, but serves a definite revolutionary purpose as well.

Rhetoric, like revolution, can be a way to redefine reality, and much like revolution, Kepler's philosophical rhetoric would comprehensively redefine astronomical reality and bring about the complete reformulation of what are determined here, for argumentative purposes, as the principles, methods and subject matters of traditional astronomy. This study proposes that Kepler used philosophical rhetoric to successfully change the conceptual framework of traditional astronomy in three fundamental ways when he summarily overturned its principle, method and subject matters with his own new elements.

It is proposed here that Kepler's philosophical rhetoric was revolutionary, and unlike the traditional Aristotelian rhetoric of Copernicus and Galileo, Kepler's rhetoric was 'usurpatory' in its effort to make physics basic to all of the subject matters of astronomy under question.

Rhetoric can be termed as being philosophical when it is primarily concerned with the exploratory construction of knowledge, where the speaker, or author or one who is better known as a 'rhetor' is less concerned with the grammatical composition of a particular text than with exploring ways of knowing and defining a subject. As a philosophic art, rhetoric guides rhetors to think and observe deeply – intuitively, systematically and empirically.

Kepler believed that in order for astronomy to progress, astronomical theory had to become subordinate to physics, and in order for this to occur he discovered that the principles of traditional astronomy had to be replaced with a new approach or perspective. Astronomy had to begin anew and Kepler at first had to redefine astronomy as being based upon physical causes.

Although, Kepler made it explicitly clear that the *Astronomia nova* was to be a rhetorical work, Kepler's use of rhetoric in the treatise has garnered little study and deserves much more attention because it has not been systematically or comprehensively explored as a rhetorical work that contributed much to the history and development of astronomy as a science. With a recent translation into English by William H Donahue (see Kepler, 1992), and despite its tremendous impact and popularity, the *Astronomia nova* remains a much-discussed but seldom-read book.

It is argued here that the *Astronomia nova* is based upon new principles, methods and subject matters directed at the reformation of traditional astronomical theory. The intention here is not to review in detail the astronomical aspects of Kepler's work, but only to explain what Kepler hoped to establish and to comment on the means he employed to do so. The goal here is not to reduce astronomy or its history to mere rhetoric or philosophy, only to acknowledge that argumentative theory can form a legitimate intellectual basis for viewing the practice of science. With this as its perspective, this study examines the force of Keplerian rhetoric in shaping the history and development of early astronomy.

1.3 Definitions

Although the general area of this study focuses on the history and development of astronomy, the primary concern is with Kepler's practical application of a practical art to the science of astronomy. The work here involves the complex of several fields of study and intellectual concerns that characterized the period. As such, working definitions need to be established for the several key terms and phrases that may be unfamiliar to some readers, among them: *Medieval science, rhetoric, rhetor, usurpatory rhetoric, philosophical rhetoric, philosophical rhetor, dialectics, rhetoric of science, metaphor, allegory, analogy, argument by analogy, deduction, ethos, logos and pathos:*

Medieval Science – The science of this early period in the history and development of astronomy was different from the science of our day, where the emphasis is on experiment and measurement. Medieval science sought knowledge that was certain and unchanging, it argued for universal truths that were necessary and represented the summit of intellectual achievement.

Rhetoric – Rhetoric, on the other hand, was much the same as we understand it today, an art of persuasion and debate. Rhetoric is concerned with language and words, and aims at the right use of words with a view to persuasion. An appeal is therefore made to the 'whole man', to his emotions and humors as well as to his reason. In his *Rhetorica,* Aristotle (1924) defined rhetoric as "… the art of making use of all of the available means of persuasion …" whereby a speaker or writer uses language and grammar to evoke the emotions of his/her audience. For Aristotle, an audience can be affected persuasively through the use of examples, logic, history, poetry and the representation of the speaker's or writer's character as being of a good ethical nature. Rhetoric is also a practical art of invention and disposition, as an art of communication between a speaker or a writer and an audience, and represents what they do to a subject matter.

Rhetor – A rhetor is the title given to anyone who uses rhetoric in a speech or written text to effect persuasion about something.

Usurpatory Rhetoric – Perhaps the most important word in the title of this study is 'usurpation'. The meaning here refers to its use as the power or force used to accomplish a particular goal, and when used with rhetoric to persuade someone of something it is termed as being revolutionary or usurpatory when it attempts to make rhetoric basic to all subjects, whereby it philosophically or comprehensively redefines a particular subject matter.

Philosophical rhetoric – This is the art of knowledge-making. Focusing more on exploring ways of knowing and defining a subject than with the composition of a particular text, philosophical rhetoric is primarily concerned with the systematic exploration and construction of new knowledge, whereby an entire system or field of belief can be redefined (Corvino and Jolliffe, 1995: 7). Unlike traditional Aristotelian rhetoric, which is modestly restricted to political, forensic and ceremonial concerns, philosophical rhetoric focuses on the ability to address any subject whatsoever and when used to do so it is termed as being usurpatory (Zyskind, 1970: 394). Much like revolution, it can serve to redefine reality when based upon certain first principles, philosophic methods and fundamental subject matters.

Philosophical rhetor – A philosophical rhetor is a rhetorician who makes use of philosophical rhetoric to invent or discover what could be said or written in specific situations when they plan a potentially active presentation or text, even if they do not actually produce it. A philosophical rhetor, unlike the traditional rhetor, makes or creates 'the' (an) issue, topic, or subject matter. By the ready redefinition of things, issues, etc., the philosophical rhetor defines reality.

Dialectics – During the Middle Ages dialectics was a form of argumentation used because it was believed to be capable of addressing the probable truths about the world, where only so-called demonstration via syllogistic reasoning could reveal true causes of things.

Rhetoric of science – This is the study of how scientists persuade or dissuade each other, as in the study of how scientists argue about the making of knowledge.

Metaphor – A metaphor compares two different things by speaking of one in terms of the other. Unlike a simile or analogy, metaphor asserts that one thing is another thing not just that one is like another. Frequently a metaphor is invoked by the verb 'to be'. Like simile and analogy, metaphor is a profoundly important and useful device. Aristotle says in his

Rhetorica, “It is metaphor above all else that gives clearness, charm, and distinction to the style.” (see Aristotle, 1924: 20).

Allegory – This is a form of extended metaphor, in which objects, persons, and actions in a narrative are equated with the meanings that lie outside the narrative itself.

Analogy – This compares two things, which are alike in several respects, for the purpose of explaining or clarifying some unfamiliar or difficult idea or object by showing how the idea or object is similar to some familiar one. It uses comparison to develop an idea. Unlike metaphor and simile, it looks for ‘like’ things to compare. It is used to illustrate or develop something difficult to describe. An analogy can be a spoken or textual comparison between two words (or sets of words) to highlight some form of semantic similarity between them. Such analogies can be used to strengthen political and philosophical arguments, even when the semantic similarity is weak or non-existent (if crafted carefully for the audience). Sometimes analogies are used to persuade those who cannot detect a flawed or non-existent argument.

Argument by analogy – This is an argument of the form:

s and **t** share the properties $\mathbf{P_1},\ldots,\mathbf{P_m}$.
s has the property $\mathbf{P_n}$.
Therefore, **t** has the property $\mathbf{P_n}$.

Deduction – Deduction can be used in persuasion as a ‘logical’ reasoning process that starts with general claims and then moves to specific instances to prove those claims.

Finally, Aristotle defined three essential elements of rhetoric. ‘***Ethos***’ used in persuasion, is an ‘ethical' appeal whereby a writer aims to make the reader trust him/her by creating an acceptable personal image; ‘***Logos***’ is the argument as presented by the rhetor; and ‘***Pathos***’ are the emotions of the audience as brought forth by the rhetor.

1.4 Review of the Literature

A comprehensive literature review revealed that the majority of Keplerian scholarship tends to focus more on Kepler’s laws of planetary motion, or on Kepler’s autobiographical accounts. Some writers place particular emphasis on one or more areas of interest, Kepler’s scientific or unscientific interests, or an admixture of both. First, much earlier studies by Dreyer (1953) and Small (1963) tend to focus on Kepler’s scientific interests, particularly his physical astronomy, where Kepler is represented as the technical or consummate scientist, and more recent works by such well-known historians as Caspar (1993), Gingerich (1992), Gingerich and Voelkel (1998), Jardine (1984), Mittelstrass (1972), Stephenson (1987), Voelkel (2001) and Westman (1972) stress Kepler’s image as the mathematical astronomer. Second, there are studies that concern themselves with Kepler’s so-called ‘unscientific interests', and which tend to focus on his preoccupation with archetypes and astrology and their relation to his astronomy (e.g. see Holton, 1956, Koyré, 1992, Martens, 1997, and Pauli, 1955). Thirdly, commentators like Kozhamthadam (1994) and Lindberg (1986) examine the relationship between Kepler's scientific and unscientific interests and his metaphysics, often in combination with Kepler's Neoplatonic mysticism and his astrology (Rosen, 1984). Kepler's biographers are numerous, with outstanding texts by Caspar (1993) and Koyré (1992), and he is depicted most popularly as the demented dream architect in *The Sleepwalkers* by Koestler (1968). Some scholars, however, have identified problems with Koestler's interpretation of Kepler's work.

As his own biographer, Kepler wrote voluminous manuscripts about his life and work in the form of letters, books, and pamphlets. For the most part these works have been collected in the *Johannes Kepler Gesammelte Werke* (Kepler, 1937-) and the *Johannes Kepleri astronomi opera omnia*.

Kepler wrote and published mainly in Latin, but central parts of his collected works have since been translated into German and English. Possibly his only philosophical treatise, the *Apologia pro Tychone contra Ursum* (1858), and some principle astronomical works, the *Mysterium Cosmographicum* (1596), the *Astronomia nova* (1609), and the *Harmonice mundi* (1619), along with selections of the *Epitome Astronomiae Copernicanae* (1618-1621) and some of his letters, have been translated into German, and/or partially or fully into English. The *Epitome astronomiae Copernicanae,* discussed later in this work, is an seven-book collection on Kepler's heliocentric astronomy and is worth a special mention because it includes his three Laws of Planetary Motion. Consisting of 119 pages of tables showing planetary positions, the *Tabulae Rudolphinae* was a project that Brahe had wanted Kepler to work on. When finally published in 1627, it was at the time, a table far more accurate than any other. James Voelkel has stated (2001) that he intends to do a study of the work. Caspar's original German translation of the *Mysterium Cosmographicum* in 1923 was followed by Duncan's (1981) translation with a commentary by Eric Aiton, while Edward Rosen produced English texts of Kepler's *The Dream* (Kepler, 1967) and *Conversations with Galileo's Sidereal Messenger* (Galileo, 1965). General introductions to Kepler's work are given in Alexandre Koyré's *Astronomical Revolution* (1992) and in Owen Gingerich's (1973) account of Kepler in the *Dictionary of Scientific Biography* (cf. Gingerich, 1972; 2002). Arthur and Peter Beer's edited Volume 18 of *Vistas in Astronomy* (1975), is a compendium based on a large number of Kepler symposia and offers the texts or abstracts of hundreds of major articles on every aspect of Kepler's life and work. Meanwhile, *Kepler's Heritage in the Space Age* … (Hadravová, Mahoney and Hadrava, 2010), published to celebrate the 400th anniversary of the *Astronomia nova*, contains a variety of Kepler-related studies.

Although the *Astronomia nova* is undoubtedly Kepler’s greatest work, and helped to shape the history and development of science in general and in particular that of astronomy, studies that investigate Kepler’s use of rhetoric in the text are almost non-existent. While much has been written about Kepler’s laws of planetary motion and his monumental ideas for a new astronomy contained therein, as mentioned earlier, relatively little has been written about his individual rhetorical strategies for communicating those ideas.

Some recent scholarship has acknowledged that there is a relationship between Kepler’s scientific interests and his use of rhetoric in the *Astronomia nova*; of particular note are the works of Donahue (see Kepler, 1992); Gingerich (1973; 1992); Gingerich and Voelkel (1998); Moss (1993); Martens (2000); Stephenson (1987) and Voelkel (2001). Though primarily writing about Kepler’s physical astronomy, both Stephenson (1987), and Donahue (1988), as mentioned earlier, make the effort to point out the didactic and argumentative nature of Kepler’s treatise. Stephenson (1987), in a brief statement, views Kepler’s work in the *Astronomia nova* as “… singular and highly personal …”, yet nowhere does he mention or describe Kepler’s work as ‘rhetorical’. Donahue (1988) in a short commentary asserted that Kepler ‘fudged’ his results. But, neither author supplies definitive evidence for their claims or offers an analysis of the role that rhetoric plays in Kepler’s physical astronomy. Similarly, as mentioned earlier, Moss (1993) points out that Kepler’s rhetoric seems to emanate from his “… character …”, but avoids any extended examination of Kepler’s science or his use of rhetoric. Moss’ rather cursory look at Kepler’s assertions finds her declaring that Kepler’s use of rhetoric in the *Astronomia nova* was purely ornamental.

James Voelkel’s attempt in *The Composition of the Astronomia nova* (2001) appears at first glance to be a traditional rhetorical analysis of Kepler’s use of Aristotelian rhetoric. A closer reading reveals that Voelkel is justified in dubbing his analysis as being neither comprehensive of rhetoric as a field of study or as being a definitive examination of Kepler’s rhetorical skills. However, Voelkel does refer to the *Astronomia nova* as a mathematically-based ‘rhetorical philosophical’ text. Unfortunately, Voelkel does not pursue his insight further, as his exposition proceeds to a discussion that focuses more on those elements in Kepler’s rhetoric that reflect traditional Aristotelian guidelines for rhetorical composition. Although, Voelkel’s analysis is similar to that of Moss (1993), in that it examines Kepler’s use of the linguistic and grammatical elements of classical Aristotelian persuasion, his work more so than others recognizes the fact that Kepler was proposing a complete revolution of traditional astronomical thought. In summary, although these researchers point out that Kepler made use of rhetoric, they do not supply evidence for their insights and they fail to give a definitive and comprehensive analysis of Kepler’s use of revolutionary rhetoric.

All of the foregoing authors maintain the parochial limits of rhetorics’ founders, principally those of Aristotle, focusing almost exclusively on the linguistic arrangement and grammar, in addition to overlooking an Aristotelian limitation which forbade the use of rhetoric in making scientific claims.

Summarily the literature review revealed that although there is somewhat of a limited interest in Kepler’s use of rhetoric, unfortunately this interest has not always been matched by a firm grasp and understanding of the ‘new rhetoric’ which Kepler employed. Kepler’s rhetoric was revolutionary in both its nature and character. Furthermore, the theoretical insights made by Stephenson, Donahue, Moss and Voelkel are diminished because not one of them has attempted to expand upon their insights or synthesize them into a single formulation. This study attempts to do so.

1.5 Relevance and Importance of this Study

With some notable exceptions, remarkably few astronomers, physicists or philosophers of science have concerned themselves with the technical details of Kepler's rhetorical arguments. Few have studied the astronomer’s work carefully. Generally they have focused on his laws of planetary motion, or sought out some of the many interesting passages as evidence for their own previously-derived convictions, or looked at Kepler’s correspondence. At times, they have simply ignored Kepler’s intentions altogether through selection and misinterpretation.

Whereas some prior studies of Kepler lay claim to his work as being ‘revolutionary’, none demonstrates or explains the nature and character of Kepler’s usurpatory rhetoric in the *Astronomia nova.* This study purports to show that Kepler changed all of astronomy by redefining the nature and character of traditional astronomy. Kepler used a revolutionary rhetoric to replace the principles, methods and subject matters of traditional astronomy. These elements had been understood for centuries as being correct.

This study and interpretation of Kepler is new to Keplerian analysis for it approaches Kepler from a different point of view; here Kepler is viewed as an astronomer who out of necessity had to defend himself as a philosophical rhetor. Here we examine for the first time Kepler’s use of new rhetoric as an argumentative means in the furtherance of his most fundamental assumptions and scientific claims for a new science. We discuss how Kepler used rhetoric to redefine reality and revolutionize astronomy. This treatment of Kepler’s *Astronomia nova* may very well challenge some time-honored beliefs about Kepler and Kepler’s work in the history and development of astronomy. By providing a discussion of a topic not frequently considered, namely, Kepler’s use of rhetoric in his monumental *Astronomia nova,* this study should contribute to the Keplerian corpus.

In the context of national and international studies of astronomy, this study is important because it attempts to explain how an extrinsic factor such as the art of rhetoric can universally affect the history and development of a science and contribute to our understanding of the use of persuasion as an instrument of scientific debate. Importantly, by examining rhetoric as a force in the work and achievements of those who came before, this study should contribute to our knowledge and further understanding of contemporary astronomy by throwing light on the nature and use of revolutionary concepts in science.

1.6 Research Method

In order to identify scholarly works that relate to this study, an extensive literature review of texts, journal articles, and archival research was performed. The work here is based on the initial findings of the literature review and justifiably represents a continuation of the initial proposal to approach Kepler's work from somewhat of a different perspective than previous researchers.

With an emphasis on Kepler's peculiar style of rhetoric, a rhetorical analysis of William H. Donahue's recent translation of the primary source text, the *Astronomia nova* (see Kelper, 1992), constitutes the bulk of this thesis, whereby Kepler's skills as a first-rate mathematical astronomer and rhetorician are examined. Kepler's summary of his discoveries is discussed in Chapter 8 of this work, Book IV of *The Epitome of Copernican Astronomy.* This study makes clear that Kepler has much to offer historians of astronomy, philosophers of science and anyone with an interest in the history and development of early scientific thought. This study seeks to understand these and other topics in terms consistent with Kepler's world view, and thus the evaluation of Kepler's contributions differs from those of the scientific textbook. On the one hand, this study searches for the integrity and unity of archetypal and physical causes employed by Kepler in the analysis of such apparently diverse fields as astronomy, astrology, and music. On the other hand, this study is concerned with the detailed knowledge of a single work and with the insights provided by the scrutiny of the mathematical details, which were so important to Kepler.

1.7 Structure of the Thesis

In order to carry out this study, Kepler's astronomy and his use of rhetoric need to be examined in some detail, although from a rhetorical point of view they do not need to be separated, as I argue here that Kepler's science is his rhetoric and his rhetoric is his science. Gross (1990: 6) supports this approach when he suggests that: "The notion is not that science is oratory; but that like oratory, science is a rhetorical enterprise, centered on persuasion."

The aim here is not to provide a comprehensive study of the entire *Astronomia nova*, a task that is beyond the scope of this study. The focus here is on how Kepler applies the foundational elements of his kind of rhetoric (i.e., the principles, the methods, and the subject matters), and therefore certain intimate aspects of Kepler’s astronomy will not be dealt with and others will only be touched upon.

Although no background in astronomy or rhetoric is presupposed, an assessment of some technical material is necessary if we are to get a sense of how Kepler applied his new approach and method to the several technical problems of his predecessors and in the creation of his new physical astronomy. His new principle, method and subject matters functionally contribute to Kepler’s concept of a harmonious whole. Following Chapter 1, the Introduction, and a brief biography of Kepler in Chapter 2, the remainder of this study is divided into chapters corresponding with these three major areas of concern, along with Kepler’s summarization of his work in the *Epitome*. The final chapters take a critical look at the historical importance of Kepler’s work after Kepler.

Chapter 2 is a brief selected biography of Kepler, including some of the more formative events in Kepler’s early life and times that probably served to influence the development of his ‘character’. Kepler informs us that certain events influenced his attitude toward his personal and intellectual pursuits. Introduced here is the notion that rhetorical effectiveness relies importantly on the character or *ethos* of the individual rhetor. As the most important element in Kepler’s rhetorical arsenal, character serves as the source of his ability to defend himself and control his own perspective on reality. Kepler’s ethos was his attitude or his way of attacking problems and propagating claims. Kepler adopts an argumentative position of ‘self-defense’ in his metaphorical ‘war with Mars’ and in argumentation, results or conclusions cannot be totally separated from the person who arrives at them. Kepler for example, establishes that he is the sole agent responsible for his point of view or perspective on astronomy, and by so doing, this act also serves functionally as a first step towards establishing his place in the competitive environment of traditional astronomy.

As one of the first committed Copernicans (see Gingerich, 1971), Kepler was confronted with objections from the time of his youthful conception of a geometrical relationship between the planets, which he presented in the *Mysterium Cosmographicum*, to his later accomplishments in the *Astronomia nova*. Traditional astronomy including Copernicus’ ideas presented conceptual and technical hurdles that Kepler had to overcome with as much courage as he could muster and it is in the *Mysterium Cosmographicum* that we encounter one of Kepler’s early attempts at employing pattern analysis, albeit *geometrical*, to order data and his experience of manipulating those data in a meaningful way. In the *Astronomia nova,* Kepler’s data-driven skills are decidedly more mature. Objections about his radical ideas came from the general astronomical community and his colleagues, and, it was against these objections and the problems of the dominant cosmological models of the time that he would have to test and defend his new approach and methods. The chapter concludes with a summary discussion of how Kepler’s character and the philosophical trends of the time most likely served to influence Kepler’s approach to doing astronomy.

Chapter 3 (Tradition vs. Innovation) is an in-depth look at the traditional conceptual framework of ancient astronomy. The nature and character of the principles, methods and subject matters of the traditional framework are examined, and the foundational assumptions of the principle of uniform circular motion are discussed and how these served to support the general content of the traditional framework. Also looked at are the differences between reflexive and comprehensive principles as basic approaches to the interpretation of reality.

The pre-Keplerian opinions of Ptolemy, Copernicus and Tycho are presented summarily as worlds in conflict, where each model was at odds in one respect or another, but was broadly similar in other respects. Kepler interpreted and confronted the traditional framework as a confused and challenging situation, and he therefore sought to establish his own approach and methodology. Kepler produced his *Mysterium Cosmographicum* as his first immediate response to the traditional framework, but he found differences that had to be accounted for. Eventually, Kepler went beyond mere geometrical explanation and built his theory round a new system based upon physical cause. Kepler’s response was an innovation that would take the very purposeful rhetorical structure of the *Astronomia nova.* Kepler wrote the *Astronomia nova* as an argument or a means of ‘self-defense’ for his most fundamental notion of the physical reality of the Universe. Several scholarly interpretations represent Kepler’s earliest work on heliocentrism, the *Mysterium Cosmographicum*, as a cosmological treatise in support of Copernicus’ heliocentrism, but here it is proposed that the *Astronomia nova* is more so a defense of heliocentrism, *qua heliocentrism*, and not of the Copernican variety. Kepler’s version is explicitly meant to be a mathematical exposition and defense designed to overturn a well-established theoretical framework that comprised the traditional approaches and methodologies of early seventeenth-century astronomy, including that of Copernicus. Cohen (1985: 126) for example, believes that Kepler was only allegedly a Copernican. In the final analysis Kepler “… abandoned all but the two most general Copernican axioms: that the Sun stands still and that the Earth rotates and revolves.”

Here I argue that Kepler’s use of rhetoric is new and different from traditional rhetorical presentations. Kepler intentionally adopts a personal-narrative approach throughout the *Astronomia nova* for recording his trials and tribulations while seeking the physical causes that will explain astronomical phenomena. Kepler’s rhetoric is a composite of traditional rhetorical techniques and his own innovative style. Kepler employs a new forceful style of rhetoric, one that is unique, as he uses a personal autobiographical narrative method for communicating his ideas, coupled with certain elements that function as new principles, new methods and new subject matters that serve to usurp traditional astronomy. This chapter concludes with the observation that it is in the *Astronomia nova* that Kepler not only establishes his approach and method, but he also defends them. Also discussed is the possibility that contemporary critics have not investigated Kepler’s personal commitment at the rhetorical level and how Kepler’s commitment serves to interact with these certain functional elements. It is suggested that this may be a factor contributing to the lack of understanding about the true nature and character of Kepler’s work.

Chapter 4 (Principle: From Physics) examines what comes first in the order of Kepler’s rhetorical operations directed at what were for him the problematic issues of traditional astronomy. Here I argue that Kepler’s concept of physical cause serves as the principle upon which he establishes his approach to doing astronomy, and that rhetorically, the use of this principle renders the text as a functioning whole. Kepler adopted the rhetorical stance of beginning with his own perspective by simply asking what he should cause the issue to be so that he could adopt an advantageous position. Kepler employed this principle throughout the text, whereby he initially asked physical questions of reality, questions that could only be satisfied with physical answers or reasons. This section concludes with a discussion of how Kepler’s principle functions as a ‘start-up’ beginning for the development of his new astronomy.

Chapter 5 (Method: Through Physics), focuses on Kepler’s eventual ‘conquest’ of Mars and the use of mathematical analysis as a way to explain physical cause, as well as a way to manage or order his empirical experience of doing physical astronomy. A method orders things and rhetorically the relation of the method to the author depends on the perspective of the text. With the publication of the *Astronomia nova*, Kepler inaugurated a new age of mathematical astronomy. The conceptual importance of Kepler’s method of using mathematics cannot be overstated for his methodology differed greatly from the traditional approach of using mathematics as a tool for simply plotting and predicting planetary positions. For Kepler mathematics was more than an efficient instrument for plotting. Kepler wanted to know how the Solar System *works*, not just to describe it with mathematical formulae. By Kepler’s capitalizing on formal patterns of inference and generalizing his data into recognizable scientific claims, we have today Kepler’s so-called ‘Laws of Planetary Motion’. The textual evidence for this is presented predominantly from the *Astronomia nova* where many of the more didactic and rhetorical passages are interspersed through with analogical reasoning and his mathematical arguments. Here we discuss Kepler’s use of analogy as a way to gain insight into reality. Kepler also made use of his mathematical discoveries in a rhetorical way by defining and re-defining from his perspective the astronomical lexicon and time-honored concepts of traditional astronomy. This chapter concludes with a discussion of Kepler’s initial progress towards his goal of determining the true structure of the Solar System and of the pervasive role played by Kepler’s rhetorical use of mathematics as it serves to quantify reality and usurp traditional Aristotelian astronomy.

Chapter 6 (Subject Matter: To Physics-Physical Astronomy), focuses on how Kepler literally uses physics to ‘physicalize’ and re-define astronomy and generate the new subject matters of physical astronomy, which forms the basis for a new Universe based upon physical principles. What is discussed here is the rhetorical inter-relationship among Kepler’s principle, method and subject matter and how they inter-relate functionally to influence the formation of Kepler’s new astronomy at various levels, e.g., formal patterns of inference constitute the method, while instances of them the subject matter. This section concludes with a commentary on the new world that Kepler’s rhetoric builds, an astrophysical world, one of unity and the sameness of disciplines.

In Chapter 7 (The Reception of Kepler’s New Astronomical Ideas) the response of the astronomical community to Kepler’s new radical ideas as represented in the *Astronomia nova* are discussed. To what extent was the contemporaneous community of astronomers affected by Kepler’s new ideas. The question whether Kepler’s use of a revolutionary rhetoric influences the immediate astronomical community is examined, and Kepler’s *Harmonice Mundi* is briefly looked at as it contains Kepler’s third law of planetary motion. A short discussion that reflects on Kepler’s rhetorical skills concludes this section.

Chapter 8 (The *Epitome of Copernican Astronomy*), examines Kepler’s summarization of Copernican astronomy with formal arguments. In *The Causes of the True Irregularities* in Book IV of the *Epitome* Kepler deliberately and systematically rejects the principles of traditional astronomy. In the *Epitome* we see Kepler’s metaphysics featured prominently along with his physics, and astronomy, which suggests that he considered all of them as part of his rhetorical arsenal. What are examined here are Kepler’s very explicit arguments, which he directs at the axiomatic foundation of traditional astronomy. Unlike the *Astronomia nova* written by Kepler for a professional audience of mathematicians, Kepler wrote the *Epitome* as a textbook for a general audience, and therefore it may well be another source for understanding the evolution of his thought.

Chapter 9. (Keplerian Astronomy after Kepler) examines Keplerian Astronomy after Kepler. Mathematical representations and examples of Kepler’s three laws are given. Addressed also is the question of whether or not Kepler’s new astronomy affected a revolution. Was Kepler’s work more of a personal revolution, a revolution on paper or did it change astronomy?

By Chapter 10 (Conclusion) it is hoped that Kepler’s use of philosophical rhetoric, as a conceptual apparatus to construct his new physical astronomy, will have been made clear. It is proposed that although Kepler’s new astronomy involved principles and methodologies that could be considered as being unsound during his time, Kepler nonetheless was able to construct, defend and present his new astronomy. Kepler’s rhetoric was usurpatory because he re-defined astronomy by applying his discoveries to all of the subject matters of traditional astronomy.

CHAPTER 2 Johannes Kepler

Chapter 2 Johannes Kepler: The Making of a Revolutionary

Figure 1: Anonymous portrait dated 1610 of Johannes Kepler, 1571-1630 (source: Wikimedia).

CHAPTER 2 JOHANNES KEPLER: The Making of a Revolutionary

2.1 Kepler’s Character and Self-defense

The purpose of this chapter is to build a convincing biographical connection between Kepler’s personal character, and his use of rhetoric as a way to defend his perspective on astronomical reality. Character may be defined by how an individual responds to the world, and in turn, how the world responds to the individual. The goal here is not to make a judgment of Kepler’s character as being morally just or ethically honest, etc. Rather, the belief here is that Kepler was a product of his environment and that much of Kepler’s aims and accomplishments in adult life could be due to the circumstances of his childhood. His broken home and less than presentable parents, his poverty and chronic ill health, his belief in God and the need to confront the several intellectual challenges of his time comprised the background of Kepler the man.

In the *Rhetorica* Aristotle tells us that ‘character’ or *ethos* may be the most effective means of persuasion that an orator or writer possesses (Aristotle, *Rhetorica* I, 2. 1356, 10). For Aristotle, the ethos of the author is paramount and should be *established* and *defended* by making use of “… all the available means of persuasion.”

Several commentators reflect on the crucial role that character can play in the arena of communication. Voelkel (1994: 215) observes that in the *Astronomia nova*, Kepler cultivated the image “… of an honest seeker of truth.” However, the concern here relates less immediately to Kepler’s moral (honest, just, etc.) qualities than to his possession of strong will power, drive, and vigor. The immediate concern here is with Kepler’s *ethos* as it involved his attitude and his way of attacking problems and propagating claims.

In his study of the *Rhetoric of Science*, Alan Gross remarks that rhetorical effectiveness relies importantly on the character of the speaker (see Gross, 1990: 206). As Bruce Stephenson in *Kepler’s Physical Astronomy* (1987) proposes, even Kepler’s manner of arriving at the elliptical orbit and the area law was “… decidedly personal”. Similarly, as mentioned earlier, Jean Dietz Moss (1993) concludes that in the *Astronomia nova*, Kepler’s rhetoric seems to emanate from his ‘character’.

Kepler’s way of responding to a world that was explosive with tensions that were private, social and intellectual was to defend his own view of things, and it is proposed here that Kepler’s character would serve as the source of his *‘self-defense’.* Self-defense begins defining or re-defining as much as it succeeds in preserving one’s identity. The interest here therefore, is in how Kepler’s individual character emanated a philosophy of self-defense that determined his approach to doing astronomy.

Kepler contributed to every field that his career touched upon, and without assigning an individual value to each of his accomplishments, any sound comprehension of the workings of his mind admittedly can only be attained through speculation. Because of this, Kepler has often been referred to as having been a natural philosopher, an astronomer, a mathematician and a mystic. Yet, Kepler could be characterized as having been all of these, for although he had a dedicated belief as regards scientific truth, he demonstrates a tendency to entertain astrological and mystical ideas frequently mixed with his science. In fairness to Kepler's intellectual makeup, it can also be observed that natural philosophy during the Late Middle ages and early part of the seventeenth-century included all of these fields of intellectual pursuit. As Holton (1973: 53) suggests, Kepler was "… more evidently rooted in a time when elements such as animism, alchemy, astrology, numerology, and witchcraft presented problems to be seriously argued." Holton attributes Kepler's mixing or commingling of these several 'incongruous' elements to the intellectual diversity and cultural milieu of his time. Additionally, some scholarly opaque assignments characterize Kepler as having been a genius or of possessing a certain charisma (e.g. see Armitage, 1966; Beer and Beer, 1975; Caspar, 1993; Gingerich, 1975a; and Koestler, 1968). These claims are ambiguous at most, and one is therefore forced to turn to Kepler's own account of his life and times.

2.2 A Selected Biography: Kepler's Life

Kepler was probably his own best biographer, and in a large quantity of his correspondence that still survives today Kepler has left us a wealth of knowledge about his life and his times. Because of this, we can surmise some things about his character and better interpret his work (see Baumgardt, 1952; see also Kepler, 1605a).

Kepler tells us that he was born on 27 December 1571 in Weil der Stadt; a city located in Swabia, a part of Southwest Germany, and was the first child born to Heinrich and Katherina Kepler. Born into what would be termed today as a dysfunctional family, Kepler describes his father as an immoral, rough and quarrelsome soldier, who left home for the last time when Johannes was still very young, and is believed to have died in a distant foreign war. Kepler's mother, Katherine, was raised by an aunt who was eventually burned as a witch. In later years, Katherine herself was accused of Devil worship, and barely escaped from being burned at the stake. Kepler had six brothers and sisters, three of whom died in infancy. As a child, Kepler lived with his mother in his grandfather's inn. Demonstrating early on that he was skilled in mathematics, he often helped customers, who frequently asked him to solve simple arithmetic problems. Kepler's life in Weil der Stadt was not remembered with fondness as he paints the picture of a youth whose early life and schooldays were beset with paranoia and constant illness. Kepler's personal account of his physical health leaves one with the impression that he was also something of a hypochondriac. In his own horoscope, he reports an endless chronicle of childhood misery and illness; he writes:

> My weakness at birth removes the suspicion that my mother was already pregnant at the marriage, which was the 15th of May ... Thus I was born premature, at thirty-two weeks, after 224 days, ten hours … [In] 1575 I almost died of smallpox, was in very ill health and my hands were badly crippled … During the age of 14-15, I suffered continually from skin ailments, severe sores, scabs, putrid wounds on my feet which wouldn't heal and kept breaking out again. On the middle finger of my right hand I had a worm, a huge sore on my left hand … When 16 I nearly died of a fever … when 19 I suffered terribly from headaches and disturbances of my limbs … I continually suffered from the mange and dry disease … At the age of 20 I suffered a disturbance of the body and mind …. (From a family horoscope, reprinted in Koestler, 1968: 233).

Kepler mentions that he suffered from terrible hemorrhoids, which required him to stand while working instead of sitting, and that he hated to bath, bragging that he had done so only once in his life. As a boy of seven, Kepler, already having demonstrated that he was talented, entered the Latin school at Leonberg, where the family was then living. The Latin schools that dominated the Württemberg community had been founded to take place of the former monastic schools and were designed to educate promising young men for the Church and the civil service.

In accounting for his youthful years, he relates that although his life was marked by family instability, personal misfortune and the ill health of smallpox, which would permanently damage his vision, he nonetheless as a student experienced intellectual achievements. Although, some of these experiences undoubtedly served as the foundation for his mature development as a professional astronomer, Kepler's eventual interest in astronomy and astronomy as a profession was not his first choice. Kepler originally intended on becoming a Protestant minister and following his early education, during which time he had distinguished himself in Latin studies, Kepler gained entrance and enrolled as a young seminarian to study theology at the University of Tübingen in 1589. Kepler says that he was very unpopular with his fellow students, and on occasion they would beat him because they were jealous of his intellectual abilities. He went so far as to develop a list of those schoolmates whom he considered to be enemies, but he did praise those who befriended him. Kepler also wrote a rather bitter portrait of himself:

> That man has in every way a doglike nature. His appearance is that of a little lapdog. His body is agile, wiry, and well proportioned. Even his appetites were alike: he liked gnawing bones and dry crusts of bread, and was so greedy that whatever his eyes chanced on he grabbed: yet, like a dog, he drinks little and is content with the simplest food. His habits were similar. He continually sought the good will of others, was dependent on others for everything, ministered to their wishes, never got angry when they reproved him, and was anxious to get back into their favor. He was constantly on the move, ferreting among the sciences, politics, and private affairs, including the lowest kind; always following someone else, and imitating his thoughts and actions. He is bored with conversation, but greets visitors just like a little dog; yet when the least thing is snatched away from him, he flares up and growls. (From a family horoscope, reprinted in Koestler, 1968: 237).

Koestler’s overall physical interpretation of Kepler is that Kepler was "... a sickly child, with thin limbs and a large, pasty face surrounded by dark curly hair. He was born with defective eyesight-myopia plus anocular polyopy (multiple visions). His stomach and gall bladder gave constant trouble; he suffered from boils, rashes, and possibly from piles, for he tells us that he could never sit still for any length of time ..." (see Koestler, 1968: 24).

Physical ailments aside, we must also consider that Kepler maintained an unquestionable belief in God, and that he seems to have always thought in theological terms (see Gingerich and Voelkel, 2005: 90). Kepler relates that he was always a deeply religious man, and at the most fundamental level, it could be said that all of his astronomical work was devoted to the glory of God. Kepler’s writing style gives one the impression that he is making a confessional to God, exposing repeatedly his failures, his misgivings, and doubts when pursuing the truth of his beliefs (see Stephenson, 1987: 3; Caspar (1993: 36). Armitage, (1966) speculate that despite or perhaps because of Kepler’s down-trodden image of himself and a questionable childhood, during which both his parents and grandparents seemed to be rather uncaring, Kepler sought solace in God. Indeed, Kepler was a profoundly religious man throughout his entire life. All his writings contain numerous references to God, and understanding the works of God was a goal that he wanted to achieve, as a fulfillment of what he believed was his Christian duty. For Kepler, Man was clearly capable of understanding the Universe that God had created. Moreover, Kepler was convinced that God had made the Universe according to a mathematical plan. In his astronomical works, Kepler repeatedly thanks God for granting him insights. As a devout Christian and Lutheran, he wrote in his first cosmological work, The *Mysterium Cosmographicum*:

> Dear Reader, it is my intention in this small treatise to show that the almighty and infinitely merciful God, when he created our moving world and determined the order of celestial bodies, took as the basis for his construction the five regular bodies which have enjoyed such great distinction from the time of Pythagoras and Plato down to our own days; and that he coordinated in accordance with their properties the number and proportion of celestial bodies as well as the relationships between the various celestial motions. (Preface to the reader, KGW I, see Koyré, 1992).

Yet, neither the *Mysterium Cosmographicum* nor the *Astronomia nova* was written as theological works. Kepler wrote the texts as astronomical treatises to communicate his ideas on the structure of the Solar System and as we shall come to understand, his prime motivation is in his desire to solve the problematic issues of astronomy that characterized the traditional astronomy of his time.

Kepler’s personal-narrative approach is clearly the one that came most naturally to him, and became standard in all of his later works; it allowed him to record his thinking in an accurate way rather than merely embellishing his results, as Moss claims that he does in her critique of Kepler’s rhetoric (see Moss, 1993). The personal-narrative approach gave him access to his brutal self-criticism; and helped to lead the reader through a process – a history of his discovery and what Kepler considered more important than the results, his constant toil and few small victories in his search for the truth (see Caspar, 1948; Koestler, 1960).

2.3 *The Mysterium Cosmographicum*

A transformation of religion and science began at Tübingen. Kepler's initial introduction to astronomy and Copernicus' ideas occurred while he was a young theology student. At Tübingen University Kepler studied the standard curriculum, which consisted of mathematics, astronomy, and physics, as well as dialectics, rhetoric, Greek and Hebrew. Astronomy was taught by one of the leading astronomers of the day, Michael Mästlin (1550–1631), who would become Kepler's Copernican mentor.

The astronomy of the curriculum was really mathematics and focused on a geocentric Ptolemaic astronomy, one in which all seven planets – the Moon, Mercury, Venus, Sun, Mars, Jupiter and Saturn -- moved round the Earth, their positions against the fixed stars being calculated by combining circular motions.

At the end of his first year, Kepler got an A grade for everything except mathematics. But, apparently Mästlin was trying to tell him he could do better, because Kepler was in fact one of the select pupils to whom Mästlin chose to teach more advanced astronomy by introducing them to the new, heliocentric cosmological system of Copernicus.

Mästlin exposed Kepler's mind to the mathematical advantages that the Copernican system had over the Ptolemaic (see Kepler, 1981) and Kepler seems to have accepted almost instantly that the Copernican system was physically true.

Writing a few years later Kepler said:

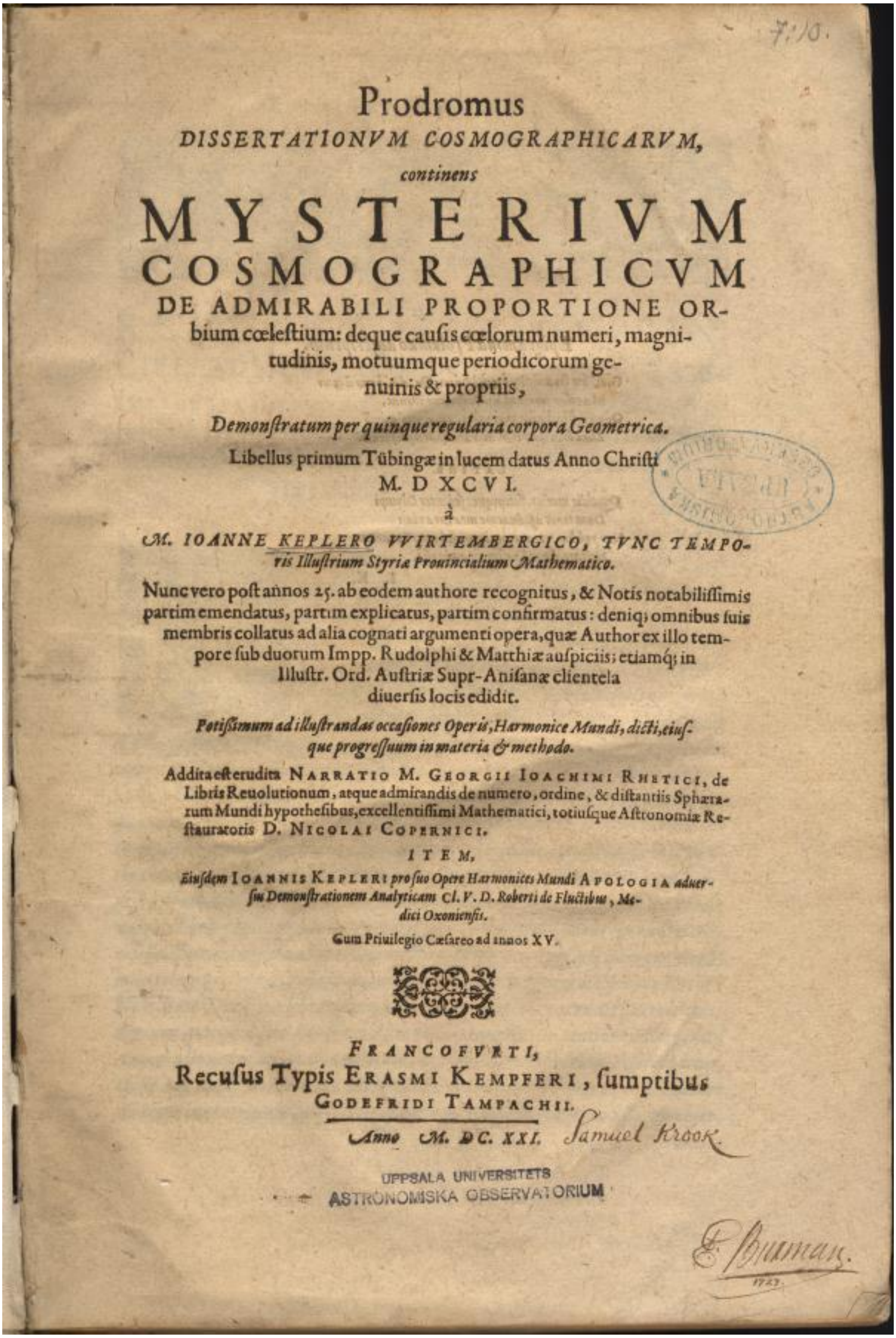
> When I was studying under the distinguished Michael Mästlin at Tübingen six years ago, I was disturbed by the many inconveniences of the commonly accepted theory of the universe, I became so delighted with Copernicus, whom Mästlin often mentioned in his lectures, that I often defended his opinions in the students' debates about physics. I even wrote a painstaking disputation about the first motion, maintaining that it happens because of the rotation of the Earth … I have by degrees – partly out of hearing Mästlin, partly by myself - collected all the advantages that Copernicus has over Ptolemy … At last in the year 1595 [in Graz] when I had an intermission in my lectures, I pondered on this subject with the whole energy of my mind. And there were three things above all for which I sought the causes as to why it was this way and not another - the number, the dimensions, and the motions of the orbs. (Preface to the reader, KGW I, see Gingerich, 1973).

In both his earlier and later writings, Kepler was given to laying his opinions on the line, but it was Kepler's religious beliefs that would prove to be more of a problem than his initial acceptance of Copernicanism. Kepler's problems with Protestant orthodoxy concerned the supposed relation between matter and 'spirit' (a non-material entity) in the doctrine of the Eucharist. Kepler's questioning was not entirely in accord with the orthodox Lutheranism current in Tübingen and appears as being problematic in Kepler's mature astronomy where he apparently found somewhat similar intellectual difficulties in explaining how a ‘force’ from the Sun could affect the planets. It seems likely that his tendency to openness led the authorities at Tübingen to entertain doubts about his religious orthodoxy. Their critique of his work served as an indication for Kepler that there is more than one side to every question. This in turn may explain why Mästlin along with the urging of the University authorities persuaded Kepler to abandon plans for ordination and instead take up a post teaching mathematics in Graz. Although accepting the post as an instructor interrupted his theological studies, it would prove to be somewhat opportunistic and prophetic for it was to be in Graz that Kepler had the opportunity to devote his full attention to proving his belief that the truth of heliocentrism could only be found in physical causes.

From his early youth Kepler had sought to identify the intimate relation between geometry and the physical world, and his ideas saw in geometry a connection with his religious beliefs as well. In Graz, Kepler began developing an original theory of cosmology based on the Copernican system. Kepler’s perspective on astronomical reality was to be dramatically influenced when, on 19 July 1595, while teaching in Graz, demonstrating the periodic conjunction of Saturn and Jupiter in the zodiac, Kepler claimed to have had an inspirational epiphany. Kepler noticed a connection between Plato’s five geometrical solids and the Copernican hypothesis. Kepler was so overwhelmed by the beauty of his insight that he wept, and this event more so than any other probably convinced him to become a mathematician rather than a theologian. With the help of his teacher, Michael Mästlin, Kepler produced his first book, the *Mysterium Cosmographicum* (*The Sacred Mystery of the Cosmos*) in 1596, his first cosmological model, where he defended the Copernican view and presented his own heliocentric proposal (see Figure 2).

In reality, Kepler’s Platonist polyhedral-spherist cosmology was representative of some of his medieval mystical beliefs. The *Mysterium Cosmographicum* was the earliest of his astronomical works where Kepler makes his first and well-known attempt to explain the distances of the planets from the Sun by means of the mathematical model of regular solids placed one inside another with a sphere in between each pair. He realized that regular polygons bound one inscribed and one circumscribed circle at definite ratios, which, he reasoned, might be the geometrical basis of the Universe.

Kepler began by experimenting with 3-dimensional polyhedrals and arguing that the distances of the planets from the Sun in the Copernican system were determined by the five regular Platonic solids (see Figure 3), if one supposed that a planet’s orbit was circumscribed about one solid and inscribed in another.



7:10.

Prodromus
DISSERTATIONVM COSMOGRAPHICARVM,
continens
MYSTERIVM
COSMOGRAPHICVM
DE ADMIRABILI PROPORTIONE ORbium
cœleſtium: deque cauſis cœlorum numeri, magnitudinis,
motuumque periodicorum genuinis
& propriis,

Demonſtratum per quinque regularia corpora Geometrica.
Libellus primum Tübingæ in lucem datus Anno Chriſti
M. D X C V I.
à
*M. IOANNE KEPLERO VVIRTEMBERGICO, TVNC TEMPOris
Illuſtrium Styriæ Prouincialium Mathematico.*

Nunc vero poſt annos 25. ab eodem authore recognitus, & Notis notabiliſſimis
partim emendatus, partim explicatus, partim confirmatus: deniq; omnibus ſuis
membris collatus ad alia cognati argumenti opera, quæ Author ex illo tempore
ſub duorum Impp. Rudolphi & Matthiæ auſpiciis; etiamq; in
Illuſtr. Ord. Auſtriæ Supr-Aniſanæ clientela
diuerſis locis edidit.

*Potiſſimum ad illuſtrandas occaſiones Operis, Harmonice Mundi, dicti, eiuſque
progreſſuum in materia & methodo.*

Addita eſt erudita NARRATIO M. GEORGII IOACHIMI RHETICI, de
Libris Reuolutionum, atque admirandis de numero, ordine, & diſtantiis Sphærarum
Mundi hypotheſibus, excellentiſſimi Mathematici, totiuſque Aſtronomiæ Reſtauratoris
D. NICOLAI COPERNICI.

ITEM,
Eiuſdem IOANNIS KEPLERI *pro ſuo Opere Harmonices Mundi* APOLOGIA *aduerſus
Demonſtrationem Analyticam* Cl. V. D. *Roberti de Fluctibus, Medici
Oxonienſis.*

Cum Priuilegio Cæſareo ad annos XV.

❧

FRANCOFVRTI,
Recuſus Typis ERASMI KEMPFERI, ſumptibus
GODEFRIDI TAMPACHII.
Anno M. DC. XXI. Samuel Krook

E. Bruman.
1727

Figure 2: Title page of the *Mysterium Cosmographicum* (source: Wikimedia).

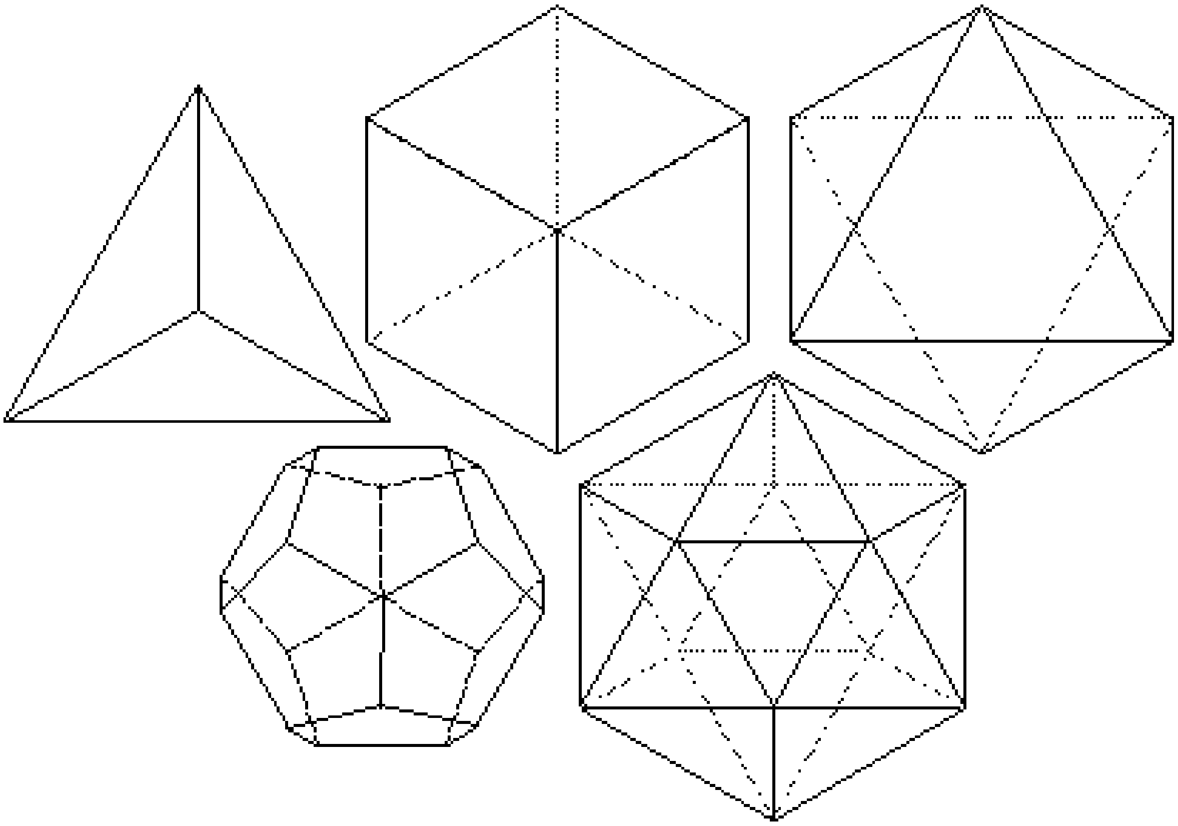


Figure 3: Regular Platonic solids; clockwise from top left: tetrahedron, cube, octahedron, icosahedron and dodecahedron (source: Wikimedia).

Assuming that the planets circled the Sun, Kepler found that each of the five Platonic solids could be uniquely inscribed and circumscribed by spherical orbs; nesting these solids, each encased in a sphere, within one another would produce six layers, corresponding to the six known planets – Mercury, Venus, Earth, Mars, Jupiter, and Saturn. Kepler then ordered the solids tetrahedron, cube, octahedron, icosahedron and dodecahedron (see Figures 4 and 5).

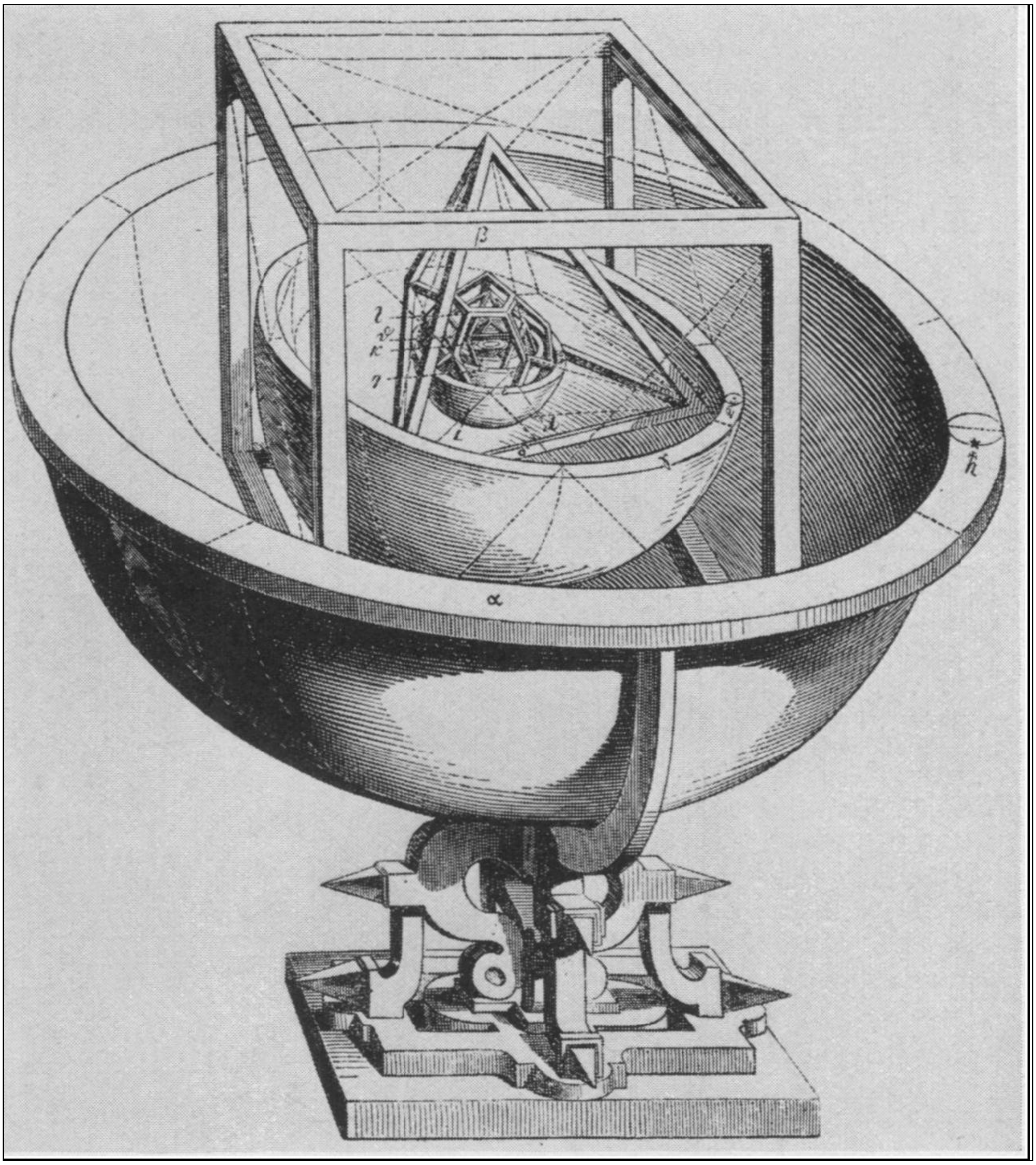


Figure 4: Kepler’s nested sphere models (source: Wikimedia).

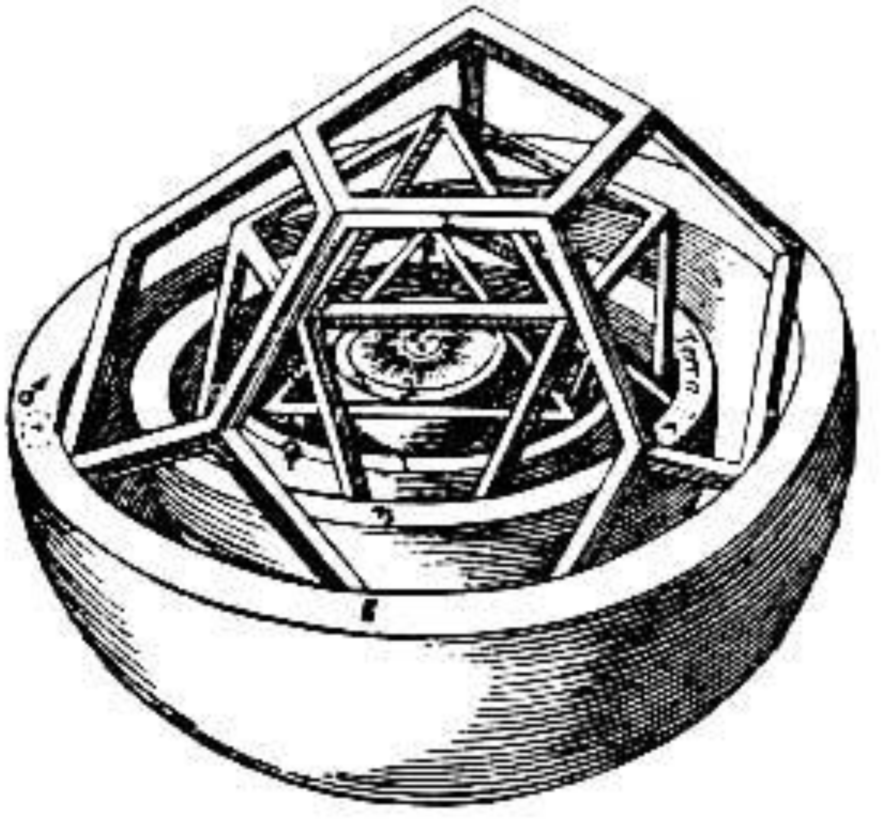


Figure 5: Close-up of the inner section of the model in Figure 4 showing the inner planets (source: Wikimedia).

Kepler also found a formula relating the size of each planet's orb to the length of its orbital period: from inner to outer planets, the ratio of increase in orbital period is twice the difference in orb radius. However, Kepler later rejected this formula, because it was not precise enough. Although this idea seems to involve a certain amount of Pythagorean mysticism, it ultimately stemmed from Kepler's belief that mathematical harmony was a reflection of God's perfection and, except for Mercury, Kepler's construction gave surprisingly accurate results.

While praised by some astronomers, the reaction of the general astronomical community toward the *Mysterium Cosmographicum* was mixed. In particular, as mentioned above, the theologians at the University of Tübingen had their objections and arranged to have a chapter of the text suppressed as Kepler had raised serious objections by his application of physical reasoning to mathematical planetary theory.

Kepler believed that with the *Mysterium Cosmographicum* he had revealed God's geometrical plan for the Universe. Much of Kepler's enthusiasm for the Copernican system stemmed from his theological convictions about the connection between the physical and the spiritual; the Universe itself was an image of God, with the Sun corresponding to the Father, the stellar sphere to the Son, and the intervening space between to the Holy Spirit. The *Mysterium Cosmographicum* contained an extensive chapter reconciling heliocentrism with biblical passages that seemed to support geocentrism. With the support of his mentor, Michael Mästlin, Kepler received permission from the Tübingen University Senate to publish his manuscript, pending removal of the Bible exegesis and the addition of a simpler, more understandable description of the Copernican system as well as Kepler's new ideas (see Caspar, 1993: 68).

Kepler received his copies of the *Mysterium Cosmographicum* and began sending them to prominent astronomers and patrons early in 1597; it was not widely read, but with some astronomers, it established Kepler's reputation as a highly-skilled astronomer. The effusive dedication, to powerful patrons as well as to the men who controlled his position in Graz, also provided a crucial doorway into the patronage system. Although the details would be modified in light of his later work, Kepler never relinquished the Platonist polyhedral-spherist cosmology of *Mysterium Cosmographicum*. His subsequent main astronomical works were in some sense only further developments of it. Kepler was concerned with finding the precise inner and outer dimensions for the spheres by calculating the eccentricities of the planetary orbits within it. In 1621, Kepler published an expanded second edition of *Mysterium Cosmographicum*, half as long again as the first, detailing in footnotes the corrections and improvements he had achieved in the 25 years since its first publication.

Although Kepler argued for a physical truth of heliocentrism, according to Stephenson, a large part of the *Mysterium Cosmographicum* had nothing to do with Kepler's notions of physical astronomy (see Stephenson, 1987: 8). As an argument, the *Mysterium Cosmographicum* was not primarily intended as a defense of Copernicus, it was for Kepler, a means by which he was able to see our Solar System, as created by God, in terms of a mathematically-beautiful model. Kepler argued here for a physical truth of heliocentrism, which was decidedly in opposition to the traditional belief that mathematics had no claim to physical truth. Thus it fulfilled not only certain physical requirements, but also his religious and aesthetic expectations. But, Kepler's Copernicanism was crucial to his reasoning and to his deductions in this new geometrical model of the Universe. Although, as just mentioned, the work was not strictly a defense of Copernicus, Kepler saw his cosmological theory as providing evidence for the heliocentric theory. In this, his earliest published work, Kepler considers the actual paths of the planets, not the circles used to construct them.

Kepler saw his cosmological theory as providing evidence for the Copernican theory. Before presenting his own theory, he gave arguments to establish the plausibility of the Copernican theory itself. Kepler asserts that its advantages over the geocentric theory are in its greater explanatory power. For instance, the Copernican theory can explain why Venus and Mercury are never seen very far from the Sun (they lie between Earth and the Sun) whereas in the geocentric theory there is no explanation of this fact. Kepler lists nine such questions in the first chapter of the *Mysterium Cosmographicum*.

Kepler's avowed and early enthusiasm for Copernicus would give one the impression that it would last forever, but as we shall come to see, Kepler would eventually become more of a Keplerian than a Copernican.

Kepler found that agreement with values deduced in the *Mysterium Cosmographicum* from observation was not exact, and even with extra planets added to the system, Kepler failed to find a unique arrangement of polygons that would fit known astronomical observations. Kepler hoped that better observations would improve his results, so he sent a copy of the work to Tycho Brahe (1546–1601) the Danish astronomer; creator and founder of the first European observatory. Kepler's main interest at the time of publication of *Mysterium Cosmographicum* and after was to get hold of Tycho's data, which he felt would confirm his picture of the Solar System. He twice mentions the possibility of 'usurping' Tycho's data. Before he had ever met Tycho, he wrote to his mentor Mästlin – "My opinion of Tycho is this: he is superlatively rich, but he knows not how to make proper use of it, as is the case with most rich people. Therefore, one must try to wrest his riches from him." (see Koestler, 1968: 280).

Brahe, then working in Prague, had written to Mästlin in search of a mathematical assistant. The *Mysterium Cosmographicum* served to introduce Kepler's new ideas to Tycho, who was the world's foremost observational astronomer of the time. Brahe having read and been impressed by Kepler's work in the *Mysterium Cosmographicum*, gave Kepler the job as his assistant. This initiated a short collaboration where Kepler was soon to find out that his priorities differed from Brahe's, and Kepler found himself working on Brahe's problems with the Martian planetary path. Brahe assigned the task of deriving the orbit of Mars and urged Kepler to temper his ideas with knowledge of the observations of planetary positions. Brahe was somewhat untrusting of Kepler and anyone else apparently, for he gave Kepler tidbits of data to work from, holding back the majority of his data. Tycho died in 1601 and Kepler succeeded him as Imperial Mathematician while continuing to work on the orbit of Mars. Upon Brahe's death Kepler entertained the idea of possibly 'usurping' the data. In a letter to Heydon he writes:

> I confess that when Tycho died, I quickly took advantage of the absence, or lack of circumspection, of the heirs, by taking the observations under my care, or perhaps *usurping* them ... (Kepler, 1605b: 231).

Following somewhat of a battle with Brahe's in-laws, Kepler according to some studies stole the Martian data from Tycho's room. James Voelkel's accounting in *The Composition of the Astronomia nova* of Kepler's confrontation with Brahe's family offers a good insight into one of Kepler's initial confrontations to secure his professional goals. When Kepler finally got around to it, the actual process of calculation for Mars was immensely laborious and although he completed what he metaphorically termed as his "War with Mars" in 1605, his great efforts were not finally published until 1609, as the *Astronomia nova*.

2.4 Discussion

What has been presented so far concerning Kepler's biographical background tends to make a persuasive beginning for Kepler's establishment of an individual perspective or a point of view about the world around him. Kepler's early family and private struggles as well as his educational experiences at Tübingen contributed to the formation of his character and his perspective on reality. Kepler confronted resistance in the form of cultural pessimism, philosophical dogma, and at times, limited access to the technology necessary to make his observations. In total, it is justifiable to assume that these experiences presented both a personal and intellectually challenging environment in which he had to defend himself and his own ideas about astronomical reality.

Because of the priority of self-defense in such a (rhetorical) world, further specifications about Kepler's character can be derived. When Kepler writes his treatise he establishes a position of self-defense in his environment from qualities displayed by the fundamental act of communicating his perspective on astronomical reality. He is the authoritative voice, and thereby he establishes a place in his environment. On both counts, the act of communication can be interpreted as a peculiar first step needed for, but not determinative of, what follows. As Zyskind (1970: 380) remarks: "Indeed self-defense begins defining or re-defining as much as it succeeds in preserving one's identity or character." That is to say, that Kepler's perspective or principle of self-defense would not emerge if not laid down by him. If not laid down by Kepler, it would exert no force, and, in rhetoric, what exerts no force is not real, and this connects it more immediately with Kepler as the agent who performs it than with a philosophical universal of one kind or another. The *Mysterium Cosmographicum* represents Kepler's first attempt to explain how the planets moved geometrically as well as his first act at communicating his astronomical viewpoint. The book marks the beginning of his astronomical discoveries and Pólya (1954) remarks that it gives a lively and attractive picture of his personality. However, although the reception of his work raised his profile as a serious astronomer, as we shall see, it did not completely satisfy Kepler's personal appetite for accuracy. Kepler realized that his method like his approach would have to differ from that of the traditional framework - he would have to seek other reasons.

Chapter 3 Tradition vs. Innovation

Chapter 3 Tradition vs. Innovation

3.1 The Traditional Framework: Pre-Keplerian Astronomy
3.2 War of the Worlds
3.3 Innovation: Kepler's Perspective
3.4 The Martian Problem - "War with Mars"
3.5 The *Astronomia nova*
3.6 The Rhetorical Composition of the *Astronomia nova*
3.7 Discussion

CHAPTER 3 TRADITION VS. INNOVATION

3.1 The Traditional Framework: Pre-Keplerian Astronomy

The purpose of this chapter is to present the traditional conceptual framework of astronomy that Kepler had to confront; it also serves as a basis for understanding how Kepler came to approach traditional astronomy as he did.

The history and practice of the principles, methods, and subject matters upon which traditional astronomy was founded teaches us that the earliest astronomers, the Chinese and the Babylonians, did not attempt to translate observational data into three-dimensional paths as did their successors the Greeks. Instead, they concentrated on numerical analysis of the immediate data in order to discover *de facto* periodicities of the known planets. Yet, for more than fifteen hundred years, the study of Western Astronomy in Europe and eventually the Arab world consisted of attempts to ascertain the relationships between planets based on the manner in which they rotated in relationship to one another geometrically. In the Greek tradition, astronomy was based upon certain axiomatic beliefs, where, the axioms of circularity and constant angular velocity served as sufficient reasons to explain celestial phenomena. Although, observational data were used for the correct determination of planetary position and motion, there remained as one of astronomy's longest abiding problems – the making of a geometrically-acceptable and predictable model of the Universe that would 'save the appearances' of the heavens. For Plato and his followers, reality existed behind the 'appearances' or what was actually observed. For the Greeks the word phenomena meant 'appearances'. Moreover, 'saving the phenomena' meant reconciling what was believed to be true with what was actually observed.

Astronomers who were initially referred to as mathematicians, operated within a traditional conceptual framework that was geometrical, one that was functionally based upon what has come to be termed historically as the principle of *uniform circular motion*. Their primary goal was the construction of a suitable qualitative, kinematic model of the known Universe.

Generally, a conceptual framework is understood as being a collection of interrelated concepts or issues that represent a certain perspective on reality. All frameworks require a principle to function and the principle that caused the traditional geometrical framework to function was uniform circular motion. As Walter Watson has pointed out in *The Architectonics of Meaning*,

> Imagine, for example, a geometry that lacks definitions, axioms, and postulates. There may be an ordered set of statements about geometrical figures, but without principles there can be no proofs, and without proofs, geometry is not functioning as geometry. Principles then cause frameworks to function, and without a principle a framework cannot function. (see Watson, 1994: 101).

Relative to this, Hanson (1958: 88) suggests in his *Patterns of Discovery*, that a framework will become dysfunctional if the principle is removed.

Being the most important element in the makeup of any conceptual framework, principles can be understood as 'start-up' beginnings – or, as what is used to approach a problem or what is first directed at an issue.

We can historically trace the origin of the principle of uniform circular motion and much of the general content of the traditional framework to the contributions of early Greek thinkers. In their effort to explain the nature of the 'wanderers' of the celestial realm, these early investigators devised a model of the Universe that was for them, both realistic and practical. Yet, they were not concerned with finding physical explanations of planetary phenomena; they were trying to understand the celestial movements by showing that they exemplified ideal geometrical forms.

Socrates' pupil Plato and Plato's pupil Aristotle had espoused a geocentric system with Pythagorean 'celestial spheres' rotating one inside the other. All planetary motion was attributed to these celestial spheres or 'orbs'. Orbs were regarded as hollow spherical shells, where a planet was attached to its orb and its apparent observed motion was entirely due to the motions of the orb. Plato and Aristotle supplied the precept that uniform motions in circles should account for everything that happened in the heavens.

When applied to the Aristotelian-Ptolemaic system, as it has come to be called, the notion of uniform circularity helped describe an imaginary make-believe Universe in which planetary bodies moved in circles. For centuries, astronomers and mathematicians were not supposed to formulate ideas about the physical nature of the world, but only to 'save the appearances' by numerical techniques that adhered to the principle of uniform circular motion. Traditional astronomers sought to find mathematical regularities, not causal mechanisms. As Westfall (1977: 9) has commented, that regularity was found in the technical utility of the circle. Circles are consistently uniform as regards proportion and ratio, so there was no need to ask why they were as they were. The geometry of the circle allowed astronomers to confidently reason from circles to circles.

Definitively then, the principle of uniform circular motion had its origin in the assumptions of the Socratic philosophers. As a guide the traditional conceptual framework was based upon three indefatuigable assumptions that Ptolemy categorized in his *Syntaxis Mathematica (Mathematical Collection),* (circa 2nd century), later to become known as the *Almagest* (Ptolemy, 1998), an up-to-date compendium of the work of his predecessors and his own. By all accounts, these assumptions functioned as detail statements that served to support the principle of uniform circular motion, as they came first in the order of operations directed at the problems of accounting for planetary phenomena:

> (1) the assumption that the Earth was unmoving, located at the center of the Universe (geo-centrism);
>
> (2) the assumption that all motions of the planets can be described by circular motion; and
>
> (3) the assumption that objects in the heavens were made from a perfect, unchanging substance not found on the Earth.

Without hyperbole it can be argued, that all scientific arguments are only as good as the assumptions upon which they rely. Where the goal of traditional astronomy was to reconcile what was believed to be true with what was actually observed most observational anomalies such as retrograde motion could be explained by adapting the principle of uniform circularity. As a concept, the principle of uniform circular motion had its origin in assumptions (1) and (2), which were based upon the Platonic and Aristotelian assumption that circular motion was the most 'perfect motion'. It implied that no point in time and no position of a planet were special. Both assumptions (1) and (2) were found to be necessary to account for anticipated planetary phenomena, yet, neither could *prima facie* explain all of the observed irregularities of planetary movement. For example, one major flaw in the geocentric model was that it could not account for the changes in brightness of the planets caused by a change in distance.

Assumption (3) originated with Aristotle's separation of terrestrial and celestial subject matters. The conception of celestial bodies as eternal, i.e., not subject to any change except locomotion is derived from Aristotle's view of the Universe. In his work entitled *On the Heavens*, Aristotle argues that all terrestrial bodies are made up of four elements, namely, earth, water, fire, and air. These simple elements have simple motions that are natural to them: Earth and water naturally move downward; fire and air naturally move upward. Celestial bodies, however, are not made up out of these four elements, nor are upward or downward motion natural to them. Their natural motion is circular, and they are made up out of a new fifth element. Following Aristotle, Ptolemy and ancient astronomers generally, thought that terrestrial bodies were different from celestial ones and should be treated in a different manner.

Although, incorrect as they were, these assumptions served as the basis for understanding celestial phenomena or 'the way things ought to be'. As what was directed first at the problematic issue of planetary position and motion, these assumptions allowed for certain phenomena to occur, or not to occur – they made the things in heaven work. Much like T.S.Eliot's 'certain of certain certainties', these assumptions buttressed astronomers' beliefs about the nature of the Universe, and, tended to guide conclusions about what was observed and what was not observed.

Today we know that their assumptions served to hold back the development of modern astronomy from the time of Aristotle and Ptolemy until the early seventeenth-century. As mentioned earlier, Ptolemy (1998) embodied his astronomy in the *Almagest* with them and centuries later Copernicus and Tycho Brahe adjusted their astronomical hypotheses based upon them.

When confronted with the issue of retrograde motion, Ptolemy resisted the possibility that the planets' motions might not be circular. He was particularly apt at the construction of compensating components. With a slightly modified notion of the principle of uniform circularity, he elaborated the work of Apollonius of Perga and the geocentric system of Hipparchus producing his own system as shown in Figure 6:

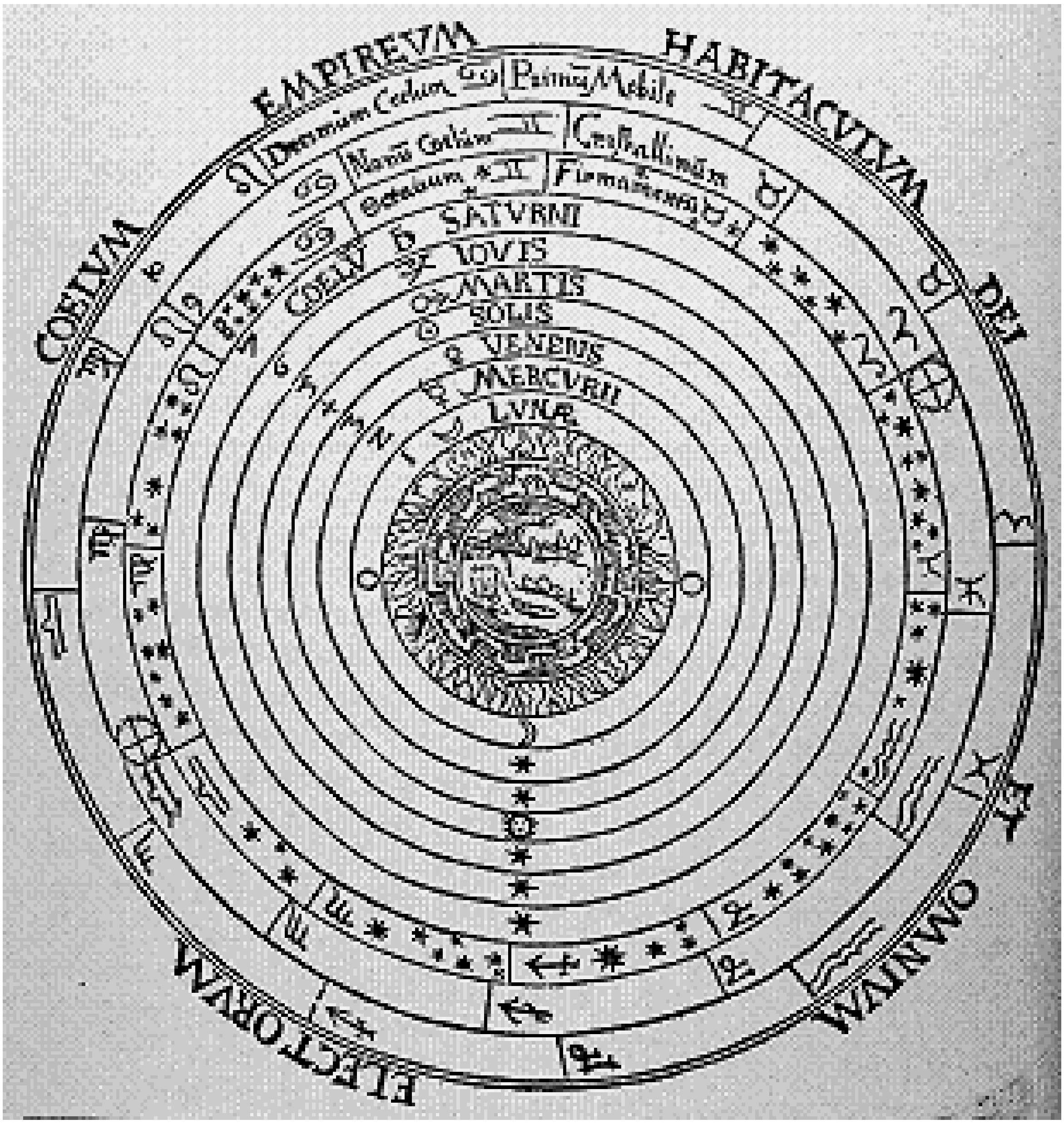


Figure 6: Ptolemy's Geocentric Universe (source: Wikimedia).

Accounting for various inequalities, he re-invented and applied epicycles to emulate the motion of the planets. In his models, Ptolemy used mathematical contrivances whereby his accounting was entirely geometrical and unrelated to physical principles. Ptolemy's model used a complex mechanism of eccentric circles to describe planetary motion. He imagined that planetary motion was due to a planet moving in a large circle or *deferent* around the Earth and the observed looping motion was due to the planet moving on a smaller circle, the *epicycle* (or circle-on-a-circle around which he claimed objects in space moved).

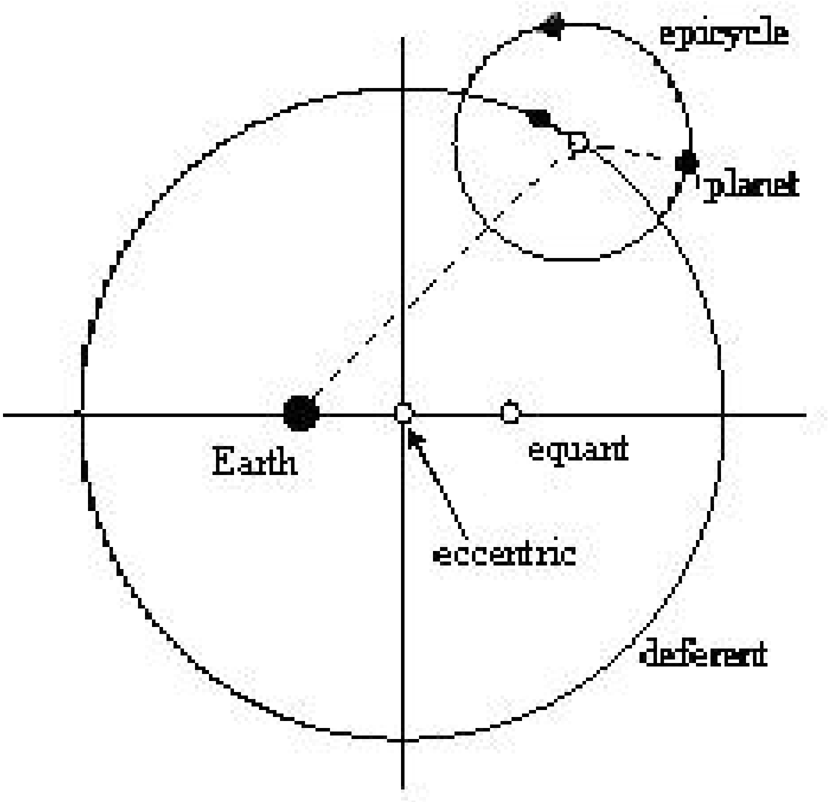


Figure 7: Ptolemy's epicycle and deferent (source Wikimedia).

As depicted in Figure 7, for Ptolemy, the eccentric is the true center of planet motion and not the Earth as Aristotle had proposed. The planet moves uniformly in relation to the equant. In Ptolemy's actual models, the center of the epicycle moved with uniform circular motion, not around the center of the deferent, but around a point that was displaced by some distance from the center of the deferent. This system was necessary to describe the actual elliptic orbits of the planets around the Sun in Ptolemy's Earth-center model using a combination of eccentric circular paths as shown in Figures 8 and 9:

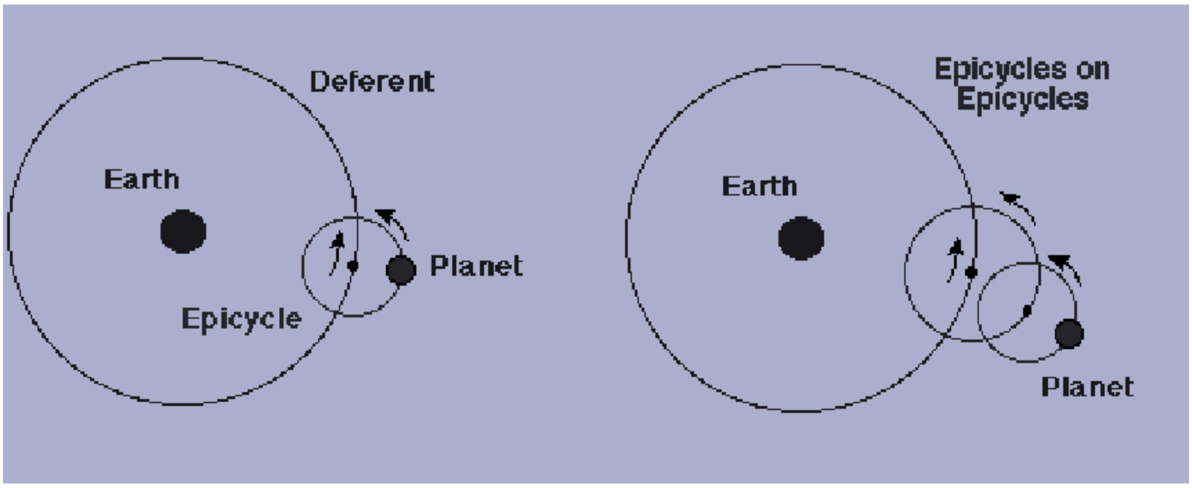


Figure 8: Representations of Ptolemy's planetary motion (source: Wikimedia).

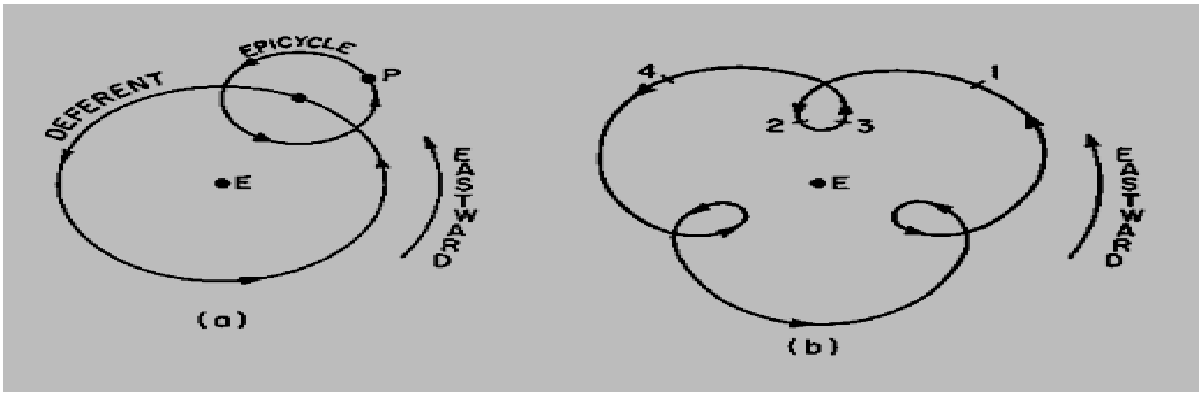


Figure 9: Further representations of Ptolemy's planetary motion (source: Wikimedia).

One of the first things Kepler did in the *Astronomia nova* was to illustrate the apparent motion of Mars based on Ptolemaic data. This move to test out Ptolemy's model by plotting his data was significant, as Donahue notes (see Kepler, 1992: 35): "It had apparently not occurred to anyone to consider the actual path traversed by a planet."

Kepler drew the geocentric (Earth-centered) planetary path as shown in Figure 8, where (a) depicts Ptolemy's epicycle, and (b) where the intricate spirals of Ptolemy's theory is revealed if plotted-out for the planet Mars for the period of 1580-1586. (As will be discussed later in Chapter 5 (Method), Kepler would note that the very complexity of this orbit can be an argument against its feasibility).

Ptolemy's geocentric picture of the World was entirely Aristotelian and he believed that it was close to the truth. Because the circle is the only geometric figure possessing perfect symmetry, Ptolemy, similar to Aristotle, insisted that the job of the astronomer was to explain the motions of the 'wanderers' using only uniform circular motion, a belief that even

Copernicus and Brahe fell victim to in their adherence to postulates of the Aristotelian-Ptolemaic system. Significantly, all of the pre-Keplerian models of the traditional framework started out with the incorrect assumption using a geocentric view of the Universe. Adopting assumption (1) obviously lead to problems requiring the addition of more epicycles to get a model that better matched observational reality.

In his *De Revolutionibus Orbium Coelestium* Copernicus (1995) challenged assumption (1), but not assumption (2). By moving the Earth from the center of the Universe, Copernicus transformed Ptolemaic astronomy and Aristotelian cosmology. Nevertheless, he retained both the traditional model of the celestial spheres and the medieval Aristotelian views of the causes of its motion. Copernicus follows Aristotle in maintaining that circular motion was natural to the form of a sphere. Copernicus somewhat resolved the issue of retrograde motion by arguing that any irregular motion was only perceived and apparent, rather than real.

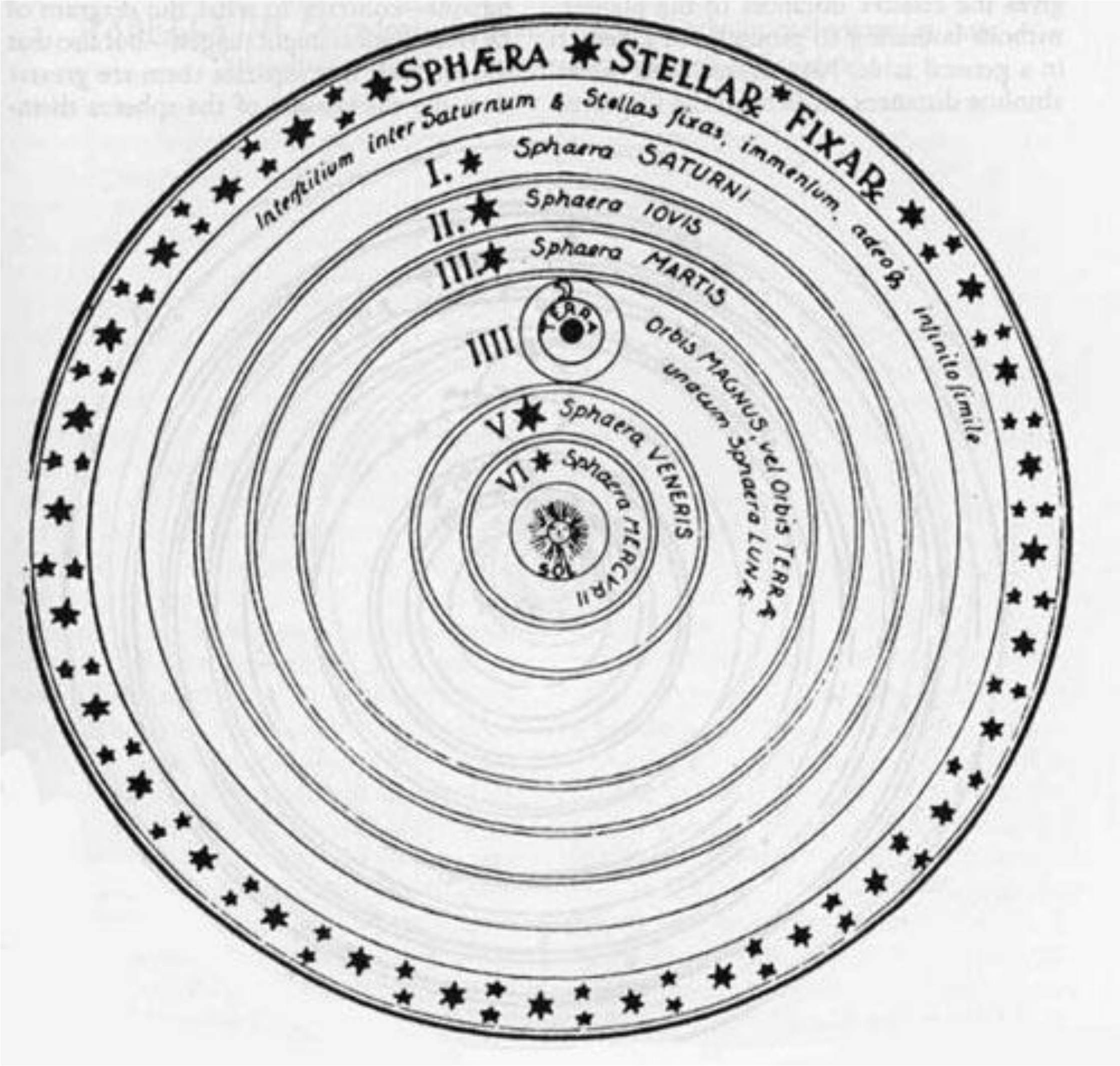


Figure 10: The Copernican heliocentric planetary paths (source: Wikimedia).

Unfortunately, Copernicus did not realize that what caused Ptolemy's model to differ from the observable Universe was not the relationship between the Earth and the rest of the Universe. It was the fact that he caused the planetary bodies to move in circular motions, a shortfall that Copernicus retained in his model.

Copernicus never denied the assumption of planetary motion as being circular nor the principle that all planetary motion was circular (see Figure 10). However, Copernicus' model implicitly questions the third tenet that the objects in the sky were made of special unchanging intrinsic stuff. Copernicus' efforts moved heliocentrism from philosophical speculation to a truly predictive geometrical astronomy and the shift from one to the other represents an important event in the history of astronomy.

As is well known, Tycho eventually dispelled the celestial spheres, and in his *De mundi aetherei recentioribus phaenomenis* (1588), he presents an embellished hybrid-geocentric model where his hypothesis retains as a physical reality the irregular back-and-forth motion of the planets. In Figure 11, the planetary paths orbit the Sun as it carries them along in its cycle around the Earth.

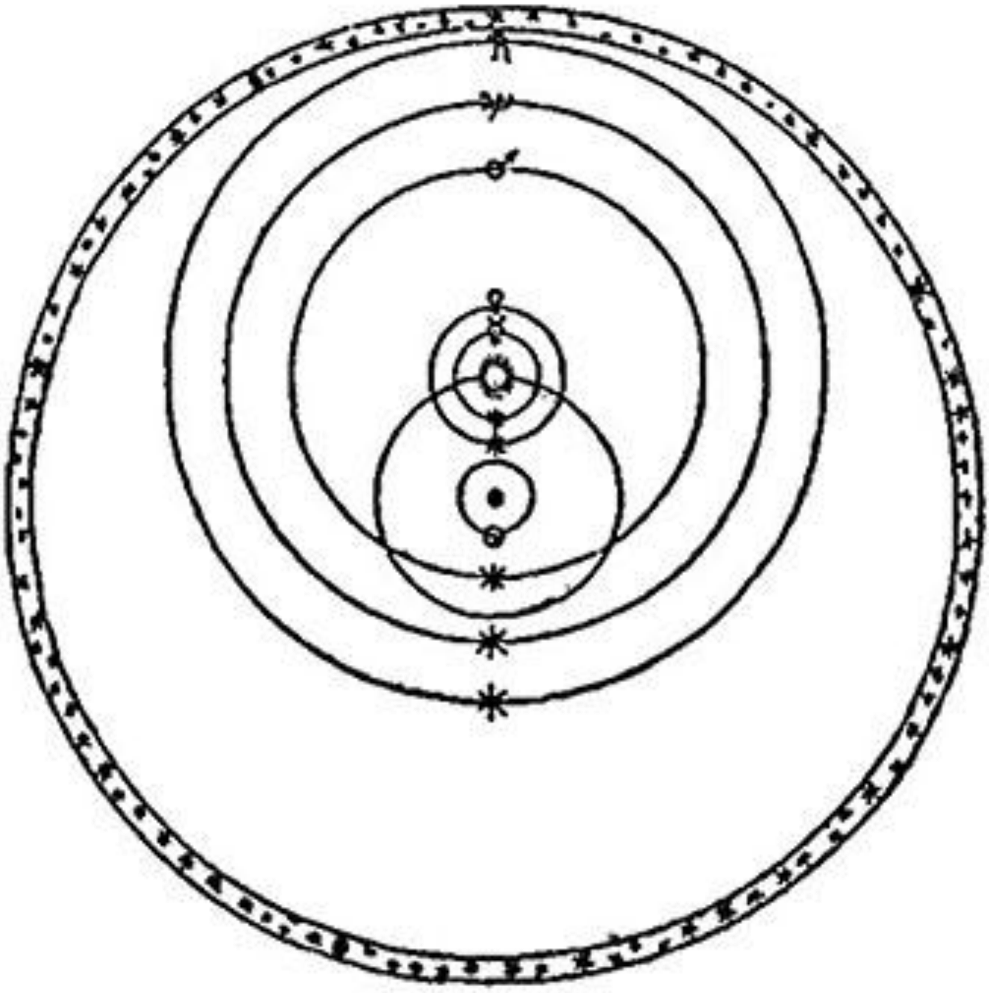


Figure 11: The Tychonic model (source: Wikimedia).

3.2 ‘War of the Worlds’

Over the centuries the assumptions and principles remained the same, yet, the worlds that astronomers had created seemingly differed and it could be said to have been a ‘war of the worlds’ as to which opinion would dominate astronomical interpretation. By the time of the late sixteenth-century and early seventeenth-century, the traditional theoretical framework of astronomy consisted predominantly of the three astronomical cosmological models of Claudius Ptolemy, Nicolas Copernicus and Tycho Brahe. These models were well known and available to European astronomers, and Kepler would inherit all three.

It could be said that to some extent, the leading predictive systems, the Ptolemaic and Copernican models, were in competition. Although, the major difference between the two systems was that one was geocentric and the other heliocentric, both systems were geometrical and almost identical mathematically and yielded nearly the same result. The Ptolemaic and Copernican hypotheses were incompatible only in the sense that one could not adopt both at once for the description of motion, or mix them up indiscriminately. Tycho Brahes’ model, also geometrical, was an interesting hybrid or geo-heliocentric hypothesis and shared some amount of popularity, but because of its intricacy, it is likely that it fell out of favor.

Conceptually, the three systems have traditionally been depicted as in Figure 12, where it can be seen that all three models are geometrically similar. They are circular and although by definition, the geometrical focal point of the concentric is the same, the number and locations of the planets and the Sun do vary, causing the models to differ radically:

(a) The Ptolemaic arrangement, with the Earth at the center and all the planets and the Sun moving around it in a circle.
(b) The Copernican arrangement, with the Sun at the center, and all the planets, including the Earth, moving around in circles.
(c) The Tychonic arrangement, with the Earth at the center, and all the planets move about the Sun in circles, while the Sun moves about the Earth in a circle.

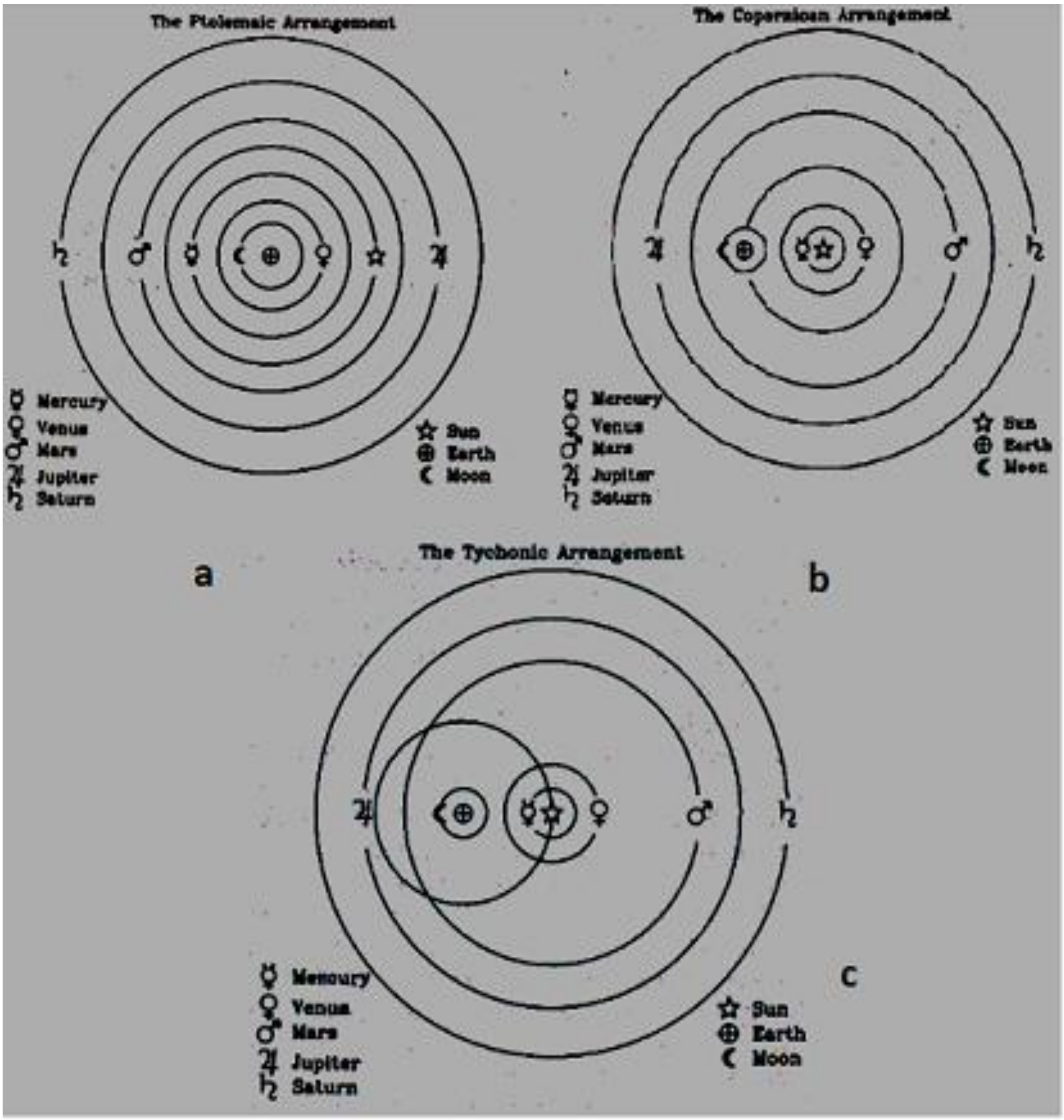


Figure 12: The three cosmological models.

Given the general use of the concept of geometrical circularity, it is crucial to understand how the concept of uniform circular motion functioned as a principle. The perfection of the heavens was for Aristotle, a *first principle*. Uniform circular motion could be considered as having been a first principle, as first principles are self-evident or self-sufficient and function independently of anything else. Aristotle based all of his sciences on reflexive principles. A science, according to Aristotle, can be set out as an axiomatic system in which necessary first principles lead by inexorable deductive inferences to all of the truths about the subject matter of a science (Aristotle, 1924: *Posterior Analytics* I.6). Some of these first principles are peculiar to the science in question, as the definition of a straight line is to geometry. Some – such as the principle of non-contradiction –are so general that they are common to all the sciences (Aristotle, 1924: *Metaphysics* IV.3). Scientific knowledge is therefore demonstrative; what we know scientifically is what we can derive, directly or indirectly, from first principles that do not themselves require proof. For Aristotle, the principles of physics, or natural science, were internal principles of motion or rest and were reflexive because they were not dependent upon anything else to function. (Reflexive principles are familiar to us in views that make activities ends in themselves – e.g., knowledge for its own sake, and art for art's sake.) By Aristotle's definition, principles that cause functioning are termed as reflexive. Uniform circular motion was a reflexive principle because it caused the traditional geometrical framework to function reflexively. Although, uniform circular motion relied on the assumption of perfect circularity, and as a concept incorporated some physical reasoning, it functioned as a reflexive principle because it caused its own functioning. At the same time it was a cause of itself, and as its own cause it produced its own effect and was therefore complete. As a reflexive principle, when the principle of uniform circular motion was employed in an argument it could be said to have been more of a fallacy than a basis for good reasons. Used primarily to make observed variations in planetary phenomena explainable, it was a logical 'dead-end' that is better known as a form of circular reasoning. When certain planets posed the problem of irregular motion, Ptolemy, Copernicus, and Brahe applied their assumptions in the form of a reflexive principle – it had to be invoked 'to save the appearances'. In reality, all three models acted in a retrogressive manner as they were based upon a history of past data patterns. Although, to some extent, this allowed astronomers to sometimes correctly predict future events. Their models required that the motion of each planet be described by a completely independent set of mathematical relationships whose only commonality was that each planet executes a complicated epicyclical orbit around the Earth, but an Earth that was set in a geometric position that differed for each planetary orbit! Each planet required its own independent set of rules in order to insure agreement between predicted and observed planetary positions. Based upon the time-honored assumptions of uniform circularity, these characteristics would prove to be the 'Achilles-heel' of the traditional astronomical framework. Traditional astronomy drew a picture of the world that we no longer accept today.

Summarily, it can be said that the traditional framework was based upon the principle of uniform circular motion; employed a method to reconstruct observations that was largely geometrical; and involved subject matters that separated terrestrial and celestial phenomena. In what follows, we shall see that it would take the innovations of Kepler to change astronomy and the world view.

3.3 Innovation: Kepler's Perspective

While studying at Tübingen University, Kepler got his exposure to the astronomical hypotheses of Ptolemy, Copernicus and Brahe. Although, as a mathematician, Kepler was formally taught Ptolemaic astronomy, with the help of his teacher Michael Mästlin, it would be Copernicus' ideas that eventually captured his interest and contributed to the mature development of his perspective on astronomical reality. Kepler got from Copernicus a conception of the Solar System in which the planets moved around the Sun in circles. Yet, in defense of his discoveries, in the *Astronomia nova* Kepler would ultimately challenge most of Copernicus' ideas from his own perspective.

In *The Architectonics of Meaning*, Walter Watson (1994: 15) suggests that:

> … "perspective" is an essential element in any text: Every text is the work of an author. The author can, however, be considered as separate from the text, and we are concerned with the internal determinants of the text, and therefore with the author as presented by the text itself. The text may of course present itself as the work of an author quite different from the actual author of the text. But in any case, this authorial voice will be present throughout the text as determining its approach or context or point of view or perspective.

Adopting Watson's interpretation, this study found evidence for Kepler's authorial voice throughout his metaphorical 'war with Mars', the *Astronomia nova*. Beginning with his introductory autobiography to the text, Kepler establishes that voice or perspective by strategically adopting a rhetorical 'personal-narrative' style as a mode of 'self-defense', or a way to defend his opinions. Kepler employs it throughout the entirety of the work i.e., as a way to defend his perspective on astronomical reality against the perspectives or hypotheses of Ptolemy, Copernicus and Brahe. Kepler's authorial voice is his perspective and for Aristotle the perspective of the author is paramount and should be *established* and *defended.*

Kepler does so, as Harold Zyskind (1970) states: "Because of the peculiar character of rhetorical principles, it is native to this art more than any other to know and treat as ultimate, the "fact" that there is more than one side to every question. In this context perhaps the model actional principle – certainly a fundamental one – is successful self-defense." Zyskind stresses the importance of the intimate role of character and 'self-defense' in rhetorical transactions, telling us that: "Rhetoric makes a prime virtue and philosophical necessity of self-defense – not as the mechanical working of an instinct but as the act of constituting the agent seen as such in his capacity to establish a place his environment, as an "actional principle." This act is literally prior to and a condition of any others, and it occurs without the necessity of a clear definition or even determination of what the *self* or *character* is." (see Zyskind, 1970: 380).

3.4 The Martian Problem - “War with Mars”

Today, we know that the planet Mars shows the largest retrograde motion due to its smaller distance from Earth, but, up and until the early seventeenth-century astronomers were confronted with the problem of determining from Mars’ apparent motions its true planetary motion in the Solar System. Mars was the planet whose movement was referred to by Pliny the Elder (c. AD 23–79), as very difficult to observe. As planetary paths or orbits had not yet been conceived of, the traditional astronomical framework could not account for Mars’ anomalous movement. Even Tycho’s data showed that Mars was the most perverse of the planets, and that he, the greatest observational astronomer of his time, probably required the help of the best mathematician of the time, Johannes Kepler.

Kepler was also in need, as he had found that his polyhedral approach and methodology in the *Mysterium Cosmographicum* was somehow incorrect and could not be used to interpret the simple planetary data available to him in constructing his Universe. Kepler believed that he required more accurate observational data and that possibly Tycho’s data would help.

Kepler sent a copy of the *Mysterium Cosmographicum* to Tycho who did not approve of what he believed were Kepler’s abstract speculations. Tycho advised Kepler to at first establish a firm foundation of observations, and from such a basis, come to know the causes of things. Nevertheless, Tycho hired Kepler as his assistant and assigned the Martian problem to Kepler and prophetically, it is from Brahe’s work assignment and Tycho’s excellent observational data on Mars that Kepler would come to successfully pursue the Martian problem.

Initially, Kepler boasted that he could get the job done in eight days. It would take him nearly eight years. However, when Kepler went to work as an assistant for Tycho, Kepler informs us that Tycho held back his much-cherished observations, exposing as little as necessary. Whether out of jealousy, or professional caution, Tycho apparently was not quick to relinquish his hard won data. Following Tycho’s sudden death, Tycho’s family was also reluctant to release them into the hands of Kepler. In their greed, Tycho’s heirs, as James Voelkel and others have observed, antagonized Kepler by publishing an unofficial version of the *Rudolphine Tables* and filed a lawsuit against Kepler. Kepler was forced to take Tycho’s data from his room before the estate was settled. (Kepler used the term ‘usurping’ to describe how he came by the observational data, and indeed, eventually used Tycho’s data to usurp the traditional astronomical framework of the seventeenth-century.)

Once Kepler had secured Tycho’s data, he set out to solve the problem of Mars’ irregularities and set himself the task of finally determining the exact orbit of Mars. Using a method he suggested in his *Apologia* (Kepler, 1937: XX.1, 24), to ground astronomy in physics, Kepler defined his target and focused on the planet Mars because more so than any other, Mars demonstrates that it is somehow unique amongst the planets. Stating somewhat later in his *Harmony of the World*, "By the study of the orbit of Mars, we must either arrive at the secrets of astronomy or forever remain in ignorance of them." (Kepler, 1939b).

In the *Astronomia nova*, he describes the techniques he devised to establish Mars' path. Kepler sought to find the curved planetary path around the Sun that would describe Mars' motion. This was a daunting task since his observations were of a moving body taken from a moving observatory (the Earth). However, before he could apply the data, he needed to understand the effect of the refraction of the Earth's atmosphere, since this could alter some of the data. As Donahue informs us, soon after declaring war on Mars, Kepler called a truce in order to address certain optical problems that he realized were essential to observational astronomy. He succeeded in doing so, and then went on to show how a lens focuses light. In particular he provided probably the first clear explanation of how the human eye focuses images on the retina, and what near-sightedness and far-sightedness are caused by; Kepler himself was very near-sighted. Two problems in particular struck him at the outset. First, when viewed through a camera obscura during a solar eclipse, the Moon appears smaller than it should. To resolve this anomaly meant making full sense of the projection of pinhole images. Second, Kepler was aware that the closer a celestial body gets to the horizon, the more its apparent location is shifted upward by atmospheric refraction. To correct for this displacement called for a precise determination of the law that governs the bending of light from such bodies when it impinges at various inclinations to the atmosphere's upper surface. In addressing these issues, Kepler became aware of various inconsistencies in the perspectivist account of light and sight as mediated by Alhazen (1030) and his close disciple Witelo (1275). He decided to submit that account to close scrutiny and, where necessary, to modify it according to both mathematical and empirical dictates. The results were published in 1604, under the misleadingly modest title *Ad Vitellionem Paralipomena Quibus Astronomiae Pars Optica Traditus* (A Supplement to Witelo's Perspectiva) (Kepler, 2000). Far from a mere supplement, the *Paralipomena* was a devastating critique of perspectivist optics. In Chapter 1, for instance, Kepler undertook a subtle, yet fundamental recasting of the perspectivist theory of light radiation. In Chapter 3 he addressed the shortcomings of the perspectivist analysis of reflection, demonstrating that, contrary to perspectivist doctrine, the cathetus (leg) rule of image location is not universally applicable. In Chapter 4 he attacked the perspectivist analysis of refraction, offering an alternative account based on conic sections, an account that is at least as noteworthy for its ingenuity as it is for its subtle inaccuracy. Finally, in Chapter 5 Kepler struck at the very heart of the perspectivist theory of vision with his account of retinal imaging. In all, then, Kepler's *Paralipomena* was not simply revisionary, as its title suggests, it was a revolutionary document in which Kepler redefines optical science. In the *Paralipomena*, Kepler suggested that the intensity of light from a point source varies inversely with the square of the distance from the source, that light can be propagated over an unlimited distance and that the speed of propagation is infinite. He explained vision as the formation of an image on the retina by the lens in the eye and correctly described the causes of long-sightedness and shortsightedness (see Kepler, 2000).

Kepler's presentation in the *Paralipomena* tends to be more narrative rather than expository. As he does in the *Astronomia nova*, Kepler delights in leading us down the paths of failed suppositions and hypotheses – each reduced to logical insufficiency – before taking us to the conclusion (see Armitage, 1967).

3.5 The Rhetorical Nature of the *Astronomia nova*

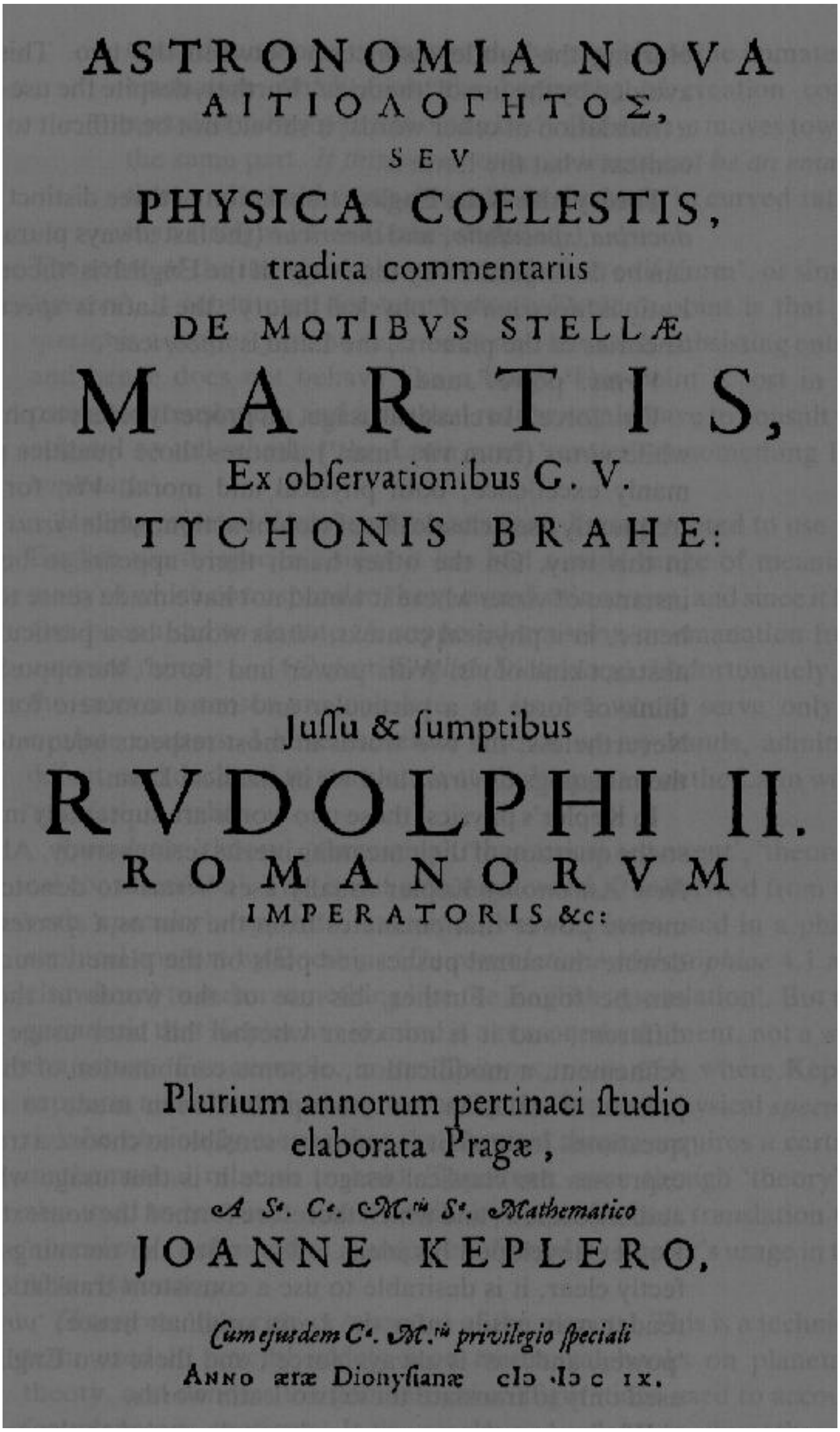
In 1609, Kepler published his metaphorical 'war with Mars', the *Astronomia nova*, wherein he introduced a new heliocentric hypothesis that would change the conceptual framework of traditional astronomy. Kepler took on the task of defining what he thought the issues were and wrote the *Astronomia nova* in the form of a personal rhetorical narrative, avoiding much of the pre-defined dictates of the predefined traditional framework.

The traditional theoretical framework was an argumentative field, a battleground of opinion characterized by the hypotheses of Ptolemy, Copernicus and Tycho Brahe. Kepler, as we shall see, questions all three models as well as the ancient assumptions embedded in the traditional framework, eventually replacing them with his own approach and method of doing astronomy.

As a philosophical rhetor, his first-step need was to defend himself (see Zyskind, 1970: 380). As Kepler had already encountered resistance to his theological ideas as well as his insistence on involving physics with astronomy, he begins by defending his perspective. However, Kepler first had to establish that perspective on reality from a *new* point of view, one that differed from his contemporaries. He does so rhetorically beginning with the title page of the *Astronomia nova,*

Although, the title page of the *Astronomia nova (*Figure 13) seems simply descriptive, Kepler is purposefully rhetorical as to how he constructed it.

Kepler announces the originality of its contents through an audacious association of terms. Bernard Goldstein (1997: 3) remarks: "The content ... as well as the rhetoric employed had many new features. The full title of the *Astronomia nova* includes the expression "physics of the Heavens": Kepler had invented a new genre of astronomical writing – a technical treatise unifying astronomy and physics."



ASTRONOMIA NOVA
ΑΙΤΙΟΛΟΓΗΤΟΣ,
SEU
PHYSICA COELESTIS,
tradita commentariis
DE MOTIBUS STELLÆ
MARTIS,
Ex obſervationibus G. V.
TYCHONIS BRAHE:

Juſſu & ſumptibus
RUDOLPHI II.
ROMANORUM
IMPERATORIS &c:

Plurium annorum pertinaci ſtudio
elaborata Pragæ,

A S^{æ}. C^{æ}. M.^{tis} S^{æ}. Mathematico
JOANNE KEPLERO,

Cum ejusdem C^{æ}. M.^{tis} privilegio ſpeciali
Anno æræ Dionyſianæ cIↃ ·IↃ c IX.

Figure 14: Title page of the *Astronomia nova* (source: Wikimedia). *Astronomia nova aitiologetos sev, Physica coelestis: tradita commentariis de motibvs stellae Martis, ex observationibus G.V. Tychonis Brahe: jussu & sumptibus Rvdolphi II. Romanorvm imperatoris &c.: plurium annorum pertinaci studio elaborata Pragae ... Joanne Keplero.*

3.6 The Rhetorical Composition of the *Astronomia nova*

In composing the *Astronomia nova*, Kepler was aware that it was his audience of contemporary astronomers that he had to persuade and that he had to use an historical approach to do so. In the second paragraph of his Introduction, he justifies his style of composition and tells us that:

> The scope of this work is not chiefly to explain the celestial motions, for this is done in the books on Spherics and on the theories of the planets. Nor yet is it to teach the reader, to lead him from self-evident beginnings to conclusions, as Ptolemy did as much as he could. There is a third way, which I hold in common with the orators, which, since I present many new things, I am constrained to make plain in order to deserve and obtain the reader's assent, and to dispel any suspicion of cultivating novelty.
>
> No wonder, therefore, if along with the former methods I mingle the third, familiar to the orators; that is, an historical presentation of my discoveries. Here it is a question not only of leading the reader to an understanding of the subject matter in the easiest way, but also, chiefly, of the arguments, meanderings, or even chance occurrences by which I the author first came upon that understanding. (Kepler, 1992: 214).

Kepler's use of rhetoric runs throughout most of his major works, but it is in the *Astronomia nova* that Kepler unites argument and rhetorical narrative into a single structure and creates a model for radical change in textual form. Kepler was certainly up to the task for he was a skilled rhetorician. As a student of the traditional Aristotelian rhetorical arts, he had been well versed in the art of persuasion, and during his time as an instructor, he taught rhetoric.

This study approaches the *Astronomia nova* as a rhetorical construct. Rhetorically, Kepler begins to redefine astronomy with the title page. The title page announces that Kepler's work is an investigation of the motion of Mars through the consideration of 'physical causes'. Kepler purposefully takes this first step and by doing so, steps outside of the feudal-like box of the traditional framework. With the title page Kepler lets it be known upfront that his subject matter is original and that it is *new* because it is based upon the study of *physical causes*; his type of astronomy in no way corresponds to traditional astronomical knowledge.

The *Astronomia nova* records the discovery of the first two of the three principles known today as Kepler's 'Laws of Planetary Motion'. Yet, the *Astronomia nova* was not undertaken by Kepler to establish laws about the Universe. Kepler was not studying planetary motion in general; he was engaged in the specific task of finding a mathematical model that could explain Mars' position and motion based upon physical reasons. The life-long question that concerned Kepler was the nature of the timing and motion of the celestial machinery, he was convinced that simple mathematical relations existed that could make sense of the planetary system.

Kepler saw the planetary system operating according to its own set of mathematical rules, which was quite a radical idea for those times. Yet, Kepler was not asking astronomers to observe new data; he was proposing a new framework for understanding centuries-old observations and a very new astronomical system based upon a new viewpoint.

As part of his rhetorical arsenal, in composing the *Astronomia nova,* Kepler adopted what Aristotle (1924) refers to in his *Rhetorica* as “The Rhetorical Perspective”. As defined by Aristotle, the rhetorical perspective comprises some five elements: perspective, audience, voice, purpose and organization. Beginning with the title page of the *Astronomia nova,* Kepler skillfully incorporates each element throughout the entire work.

Nevertheless, in considering Kepler’s work, both Moss and Voelkel attempt a traditional analysis of Kepler’s use of Aristotle’s precepts for rhetorical practice. However, our concern is not so much with Kepler’s use of traditional Aristotelian guidelines or how he employed them to persuade his fellow astronomers. The concern here is with Kepler as a *philosophical rhetor* whereby he pursues the possibility of new knowledge, focusing more on exploring ways of knowing and defining a subject and examining its construction, rather than with the composition of a particular text.

Philosophical rhetoric is primarily concerned with the systematic exploration and construction of new knowledge, whereby an entire system or field of belief is defined or redefined (see Covino and Jolliffe, 1995: 7). Unlike traditional Aristotelian rhetoric, which is modestly restricted to the persuasive concerns of political, forensic and ceremonial subject matters, and the proper construction of grammar and communication, philosophical rhetoric focuses on the ability of the rhetor to address any subject whatsoever and as Zyskind (1970: 394) relates, when used to do so it is termed as being *usurpatory*.

Much like revolution, rhetoric can serve to redefine reality when based upon certain first principles, philosophic methods and fundamental subject matters. As a philosophical rhetor, Kepler unlike the traditional rhetor, makes or creates ‘the’ (an) issue, topic, or subject matter. By the ready redefinition of things, issues, etc., Kepler was defining reality and fostering conceptual change, and as we shall see in Section 5.3, Kepler makes extensive use of rhetorical analogy, and mathematics to bring this about.

This study suggests that Kepler’s use of rhetoric, like his discoveries, was new. Indeed, Kepler used the old or traditional framework to the extent that much of what he examined was based upon the knowledge-base of Ptolemy, Copernicus, and Brahe. Yet, Kepler used their models as a basis for the invention of the new. It is because of his discoveries about the similarity of the three world models that Kepler soon came to realize that he had to redefine astronomical reality and that all of astronomy had to become part of physics.

Because of his background and training, Kepler had at first to operate within the traditional conceptual framework and therefore he examined the hypotheses of Ptolemy, Copernicus, and Brahe (Stephenson, 1987: 22). In the process, Kepler encountered certain elements or patterns that characterized all three models. Kepler found that each functioned because of certain patterns: a geometrical principle (uniform circularity) supported by mathematical representations of observations to describe planetary position, and a subject matter that was restricted to celestial phenomena. Bruce Stephenson in *Kepler's Physical Astronomy* is particularly clear that he believes that Kepler's task in the *Astronomia nova* was three-fold:

> First, Kepler had to attack and discredit the old hypotheses, in their own terms. Armed with Tycho's observations, which were of accuracy previously unattainable, he had to demonstrate that the models used by all astronomers were wrong, and that they could not be salvaged in any reasonable manner. Second, he had to develop his new astronomy, and show it to be accurate to the limits of the Tychonic observations. Finally, he had to argue that, compared with the alternatives; his theories were much more likely to represent what was actually taking place in the heavens. For the first and last of these reasons, Kepler reintroduced physical argument to astronomy, and thereby shifted the overall emphasis of his book from the mathematical representation of observations to the determination of how and why the planets, huge, physical bodies, moved through the heavens. (Stephenson, 1987: 22).

Kepler composed the original edition of the *Astronomia nova* in five parts, divided into some seventy brief chapters, consisting of some 337 pages. Kepler began, as we have seen, with rhetoric on the title page of the *Astronomia nova* and then elected to continue his rhetorical attack with a long Introduction. Kepler continued to present his discoveries in an oratorical or rhetorical manner that would relate his procedure historically, systematically, in a personal-narrative form. The *Astronomia nova* unfolds in five sections:

Part I – On the ancient hypotheses
Part II – On th first inequality of Mars
Part III – On the seconf inequality, and the causes of the motions
Part IV– On the discovery of the correct orbit
Part V – On latitude

In Part I, Kepler demonstrates that the three existing geometrical models of planetary motion, of the ancient Egyptian astronomer Ptolemy, his more recent predecessor, Copernicus and Danish astronomer Brahe are indistinguishable based on observations alone. The three models predict the same positions for the planets in the near term, although they diverge from historical observations, and fail in their ability to predict future planetary positions by a small if measurable amount. Kepler vigorously investigates Tycho Brahe's data for embedded errors. Kepler also questions the assumption that the Earth or Sun (depending on the model used) moves around the center of its orbit at a uniform rate. He finds that computing critical measurements based upon the Sun's actual position in the sky, instead of the Sun's mean position injects a significant degree of uncertainty into the models, opening the path for further investigations.

In order to attack and discredit the old hypotheses, in their own terms, one of the first things Kepler did was to directly address their opinions. In Part I, Kepler found that each model reasoned from pre-defined assumptions that included the reflexive principle of uniform circular motion. As we know, Kepler desired much more than a positional geometry based upon *a priori* philosophical assumptions to account for astronomical reality. In the Introduction to the *Astronomia nova* he remarks that:

> For each of these three opinions concerning the world there are several other peculiarities which themselves also serve to distinguish these schools, but these peculiarities can each be easily altered and amended in such a way that, so far as astronomy, or the celestial appearances, are concerned, the three opinions are for practical purposes equivalent to a hair's breadth, and produce the same results. (Kepler, 1992: 47-48).

and further,

> Now my first step in investigating the physical causes of the motions was to demonstrate that [the planes of] all the eccentrics intersect in no other place than the very centre of the solar body (not some nearby point), contrary to what Copernicus and Brahe thought. If this correction of mine is carried over into the Ptolemaic theory, Ptolemy will have to investigate not the motion of the centre of the epicycle, about which the epicycle proceeds uniformly, but the motion of some point whose distance from that centre bears the same ratio to the diameter [of the eccentric] as does the distance of the centre of the solar orb from the Earth for Ptolemy, which point is also on the same line, or one parallel to it. (Kepler, 1992: 48-49).

Kepler pointed out that the three radically different systems shared a common error. All three systems imposed, *a priori*, the geometry of the circle, and hence, assumed the reality of uniform motion throughout the physical Universe.

In order to develop his own new astronomy Kepler took a completely different and revolutionary approach. Rather than force the observations to conform to pre-existing mathematical assumptions, Kepler sought the physical causes or reasons for the observed non-uniform motion, and then rhetorically with analogical reasoning, conformed his mathematics to that physical hypothesis.

As we know, Kepler's formal differences with the traditional framework arose from his search for the true physical 'causes' of the Mar's motion, and in the Introduction to the *Astronomia nova* Kepler relates that his goal is to 'reform' astronomical theory and to discover or establish the physical relationship between constituents of the Universe. Kepler states upfront what his goals are and how he intends to accomplish them. At first glance, Kepler seems to describe his goals with his use of the term 'reform'; however, when understood from a rhetorical point of view, Kepler is establishing and defining much more:

> My aim in the present work is chiefly to reform astronomical theory (especially the motion of Mars) in all three forms of hypotheses, so that our computations from the tables correspond to the celestial phenomena. Hitherto, it has not been possible to do this with

> sufficient certainty. In fact, in August of 1608, Mars was a little less than four degrees beyond the position given by calculation from the Prutenic tables. In August and September of 1593 this error was a little less than five degrees, while in my new calculation the error is entirely suppressed.
>
> Meanwhile, although I place this goal first and pursue it cheerfully, I also make an excursion into Aristotle's Metaphysics, or rather, I inquire into celestial physics and the natural causes of the motions. The eventual result of this consideration is the formulation of very clear arguments showing that only Copernicus's opinion concerning the world (with a few small changes) is true, that the other two are false, and so on.
>
> Indeed, all things are so interconnected, involved, and intertwined with one another that after trying many different approaches to the reform of astronomical calculations, some well trodden by the ancients and others constructed in emulation of them and by their example, none other could succeed than the one founded upon the motions' physical causes themselves, which I establish in this work. (Kepler, 1992: 48).

There are two points of importance in this statement. These are Kepler's supposed desire to reform astronomy, and his inquiry into celestial physics as the natural causes of the motions. First, although, Kepler's innovative rhetoric begins with the rhetorically purposeful title page, this introductory passage can be understood as a rhetorical continuation of it. More importantly, the introductory passage is understood here as a definitive statement that is actually a 'declaration of war'. This interpretation has not (to my knowledge) been noted in the literature before. This interpretation of Kepler's introductory statement is new. From a rhetorical point of view, it represents Kepler's opening salvo or the 'laying down' or defining upfront what he views as the issue. His primary interest is in changing the status quo. It is proposed here that Kepler uses the term 'reform' modestly to disguise his real intention, which is to announce a 'revolution' directed against the traditional framework.

Kepler was not simply 'rebelling' or attempting to bring about a reformation. Normally, rebellions or reformations, whether they are social and or intellectual, are containable – they can be controlled. Kepler is calling for the complete over-throw of an established way of viewing astronomical reality. He also relates his belief that all three forms of hypotheses, that are representative of traditional astronomy, have failed. Secondly, Kepler repeats his declaration from the title page and definitively states that he will be pursuing 'celestial physics' and the 'physical causes' of motion, both of which were considered as topical areas or subject matters outside of the traditional framework. This indicates that Kepler is unlike astronomers who, operating under the traditional framework, began with the question – How do I prove this point on the issue? Kepler begins rhetorically with the question – What shall I cause the issue to be so that I may adopt an advantageous position? In usurpatory rhetoric, issues and problems are made, not born, and Kepler wanted to establish or define what he understands as astronomy's main problem – it is the subject matter of astronomy itself.

Traditional astronomers had busied themselves with the construction of models based on the predefined handed-down assumptions of the traditional framework. Kepler's viewpoint was new and an obvious deviation from the conceptual framework of traditional astronomy for it suggests that radical changes be made to the traditionally-accepted approach based upon the axioms, propositions and methodologies of the era.

It has been argued by some that Kepler's *Astronomia nova* is not an accurate account of his actual reasoning process, but is instead an elaborate argument constructed by Kepler after his discovery as a rhetorical strategy for convincing others to accept his hypothesis (e.g. see Kepler, 1992: 3, and Stephenson, 1987: 3). As evidence for this claim, Donahue (1988) suggests that several of Kepler's tables, purporting to represent observational data, were in fact generated by theoretical derivation after Kepler had invented the ellipse hypothesis. Nevertheless, given Kepler's rhetorical motivation to gain persuasion, it might be more productive to consider Kepler's so-called 'fudging' or 'flaws' of his procedure as a purposefully-constructed rhetorical strategy, whether or not it describes Kepler's actual discovery procedure (see Barker and Goldstein, 1992).

3.7 Discussion

The purpose of this chapter was two-fold: Firstly, to present the highly-qualitative nature and character of the traditional approach with an emphasis on its weakness as an astronomical framework. Secondly, to relate how Kepler's involvement with the planet Mars came about and his initial response to that challenge in the introduction and title page of the *Astronomia nova*.

By definition, the concept of uniform circularity restricted the functioning of the traditional framework to describing only circular motion. Combined with the assumption (3), that objects in the heavens were made from a perfect, unchanging substance not found on the Earth, severe limitations were placed on the three astronomical models. Planetary actions were imposed on observational data, rather than derived from them. By assuming that such motion was proper to planetary phenomena, each model relied on the principle to explain all anomalies. For the traditional framework, actual observation of any deviation from the ideal could be accounted for and explained away by the principle. The observations or actions of observers affected the very situations they were observing and also affected their interpretation of what was being observed. Obviously, it was an erroneous approach to describing how things went in the heavens, yet it 'saved the appearances'.

Again, as with their predecessors, Ptolemy, Copernicus and Tycho held in common the assumption that physical observations should be adjusted to conform to the pre-existing mathematical structure of the circle. The traditional framework served them well in their effort to describe an acceptable Universe based upon geometrical principles, a hypothesis that would support the presupposition that the Universe ought to look a certain way. Despite their individual differences, all three hypotheses functioned within a framework that was an argumentative arena. As such, no single idea could justifiably present itself as a description of the ‘true’ celestial situation. Copernicus argued for scientific reality, while both Ptolemy and Tycho Brahe believed that their systems were at least ‘real’. Copernicus, as we know, thought he had discovered the real, albeit heliocentric system of the World, and proposed that his Sun-centered model of the Universe explained physical reality. Advocating scientific realism for his system, he argued that his system was at least physically true. Believing that the practice of saving appearances was “… a confession of ignorance and confusion …” Tycho (Gingerich and Voelkel, 2005) nonetheless based his model on the uniform circular motion of circles. Both Ptolemy and Copernicus relied on the idea of transparent rotating spheres to carry the planets in their planetary treks, but Brahe having eliminated the crystalline spheres, believed that neither Ptolemy nor Copernicus was correct, and nevertheless, held that his compromise geo-heliocentric system represented the real Universe.

As a concept, uniform circular motion helped describe an imaginary make-believe Universe in which planetary bodies moved in circles. For centuries, astronomers and mathematicians were not supposed to formulate ideas about the physical nature of the world, but only to ‘save the appearances’ by numerical techniques that adhered to the principle of uniform circular motion.

Copernicus himself makes it clear that he, as much as Ptolemy, is an adherent of the view that all heavenly motions are essentially circular, and that any irregularity or non-uniformity is mere appearance. Where Copernicus encounters deviation in planetary motion, we find him employing epicycles in the Ptolemaic tradition in order to save appearances. Although, Copernicus correctly placed the Sun at the center of the Solar System, he erred in assuming the orbits of the planets to be circles. Thus, in the Copernican theory epicycles were still required to explain the details of planetary motion. All three hypotheses attempted to account for causes as determined by sense or by philosophy, rather than by experience.

Although, it is widely recognized today that Kepler eventually established a new philosophical interpretation that would better interpret planetary phenomena, when referencing the role that Kepler’s new astronomy played in the so-called Scientific Revolution many historians invoke the time-honored phrase ‘Copernican Revolution’. In suggesting that the Sun occupied a static position at the centre of the planetary system, Copernicus’ *De Revolutionibus Orbium Coelestium* (1995) did somewhat change the substantive content of orthodox astronomy, but because Copernicus’ hypothesis occurred within an already well-established conceptual framework that had guided Western astronomers for centuries, it hardly brought about any revolutionary changes to the traditional astronomical approach and methodologies of the time. As he asked the same questions and used the same method as

Ptolemy and Tycho, Copernicus' efforts did not change the traditional framework but rather helped to supplant many ideas that already existed. As it is well known, the concept of a Sun-centered Universe was certainly not new. In the third century B.C., the Greek astronomer Aristarchus of Samos had suggested such a system, a system that was summarily rejected by Aristotle and Ptolemy's geocentric cosmology. Beyond the Sun's physical location, which most astronomers of the time thought of as a ridiculous proposal, Copernicus ideas could be managed by the established framework and therefore, he would be more accurately described as being a rebel than a revolutionary. His heliocentric Universe lacked evidential support that later Kepler and Galileo would supply. Copernicus's scientific approach and methods were the same as those of Ptolemy with there being little difference in the data that each had used. With the use of Tycho's data he had some success but not enough to satisfy his appetite for accuracy.

In the *Astronomia nova,* Kepler explores the validity of the three hypotheses and found that they each employed a similar principle, and method directed at the subject matter of astronomy. Although, similarly-named elements are used to describe Kepler's new framework as well, there are crucial differences as regards content. Keplers approach and method are new as was his subject matter. These three elements operationally function in his *Astronomia nova* to perform the basic task of redefining traditional astronomical reality. The purpose here is not to categorize Kepler's thoughts but rather to establish to what extent Kepler's innovative conceptual ideas differed from those of his predecessors, and as well, those of his contemporaries.

Firstly, for Kepler, some of these conceptual elements do the work of basic *principles* in their ability to cause his new framework to function comprehensively, and are not merely terms with meanings or rules of a game; secondly, other elements constitute Kepler's basic *method* of using mathematical proofs to demonstrate formal patterns of inference that he used to define and or redefine astronomy's traditional lexicon, and serve to mathematically compress and order his experience of doing astronomy; and thirdy, some instances of these elements constitute patterns that serve to allow Kepler to connect the *subject matters* of astronomy with the physical Universe by redefining the traditional relationship between disciplines. These elements are explored in what follows.

Chapter 4 Principle: From Physics

Chapter 4 Principle: From Physics

CHAPTER 4 PRINCIPLE: FROM PHYSICS

4.1 Physical Cause

This chapter focuses on Kepler as a scientist who sought comprehensive physical principles to explain the cause of observed planetary phenomena. As Kepler's approach was to derive the principles of planetary motion from a physical perspective and not from the pre-defined mathematical models of his predecessors, it could be argued that Kepler's approach was like that of a physicist, who at first by definition sees every event in the world from a physical point of view. As we know, Ptolemy, Copernicus, and Brahe based their hypotheses upon the reflexive principle of uniform circular motion. Recalling that reflexive principles by definition are already ordered, they propagate or contribute only to the repetitive creation of themselves, i.e., they are cyclic, where the reasoning was from circles to circles. Needless to say, Kepler found this basis to be erroneous. Kepler's comprehensive principles differed from reflexive principles. As discussed earlier, a comprehensive principle by definition orders all things but is not itself ordered by anything else. Kepler's comprehensive principles by definition were philosophical and functioned by contributing to the design and completion of the harmony of his whole concept or to what he believed the Solar System was like. For example, the elliptical shape of the planetary path, with the Sun at one focus, was a comprehensive principle by which all points on the path were determined, and, with the law of areas, the relative speed of the planet at all points of its path were also determined. Both principles involved the physical entity of the Sun. As we shall see, Kepler would summarily replace the time-honored 'circle' with an ellipse – better known as his first law of planetary motion.

In order for Kepler to accomplish his ultimate goal he had to rhetorically redefine reality. It is proposed that Kepler deliberately and self-consciously started transitioning to his own interpretation of the physical nature of astronomical reality when he challenged Copernicus' first assumption concerning the Sun and its location. In Copernicus' system, as in Ptolemy's, the planets orbited an imaginary empty point in space. For mathematical reasons, Copernicus used the mean Sun$\bar{\odot}$, as the center of the Earth's path and placed the center of the Solar System at the center of the Earth's orbit, rather than at the true Sun$\odot$, itself. For both the Copernican and Tychonic systems the Sun was the central body in the Solar System.

Again, as Cohen (1985: 126) suggests, although Kepler began his query as a Copernican, he may not have been a completely convinced Copernican. Having had little success by applying Tycho's data to Copernicus' heliocentric model, Kepler decided to begin differently with his own unique assumption, which was possibly his most important advance.

Kepler’s assumption was that the ‘true’ Sun rather than Copernicus’ ‘mean Sun’ should be used as the basis for the construction of all astronomical models. This belief and action by Kepler has traditionally been interpreted as a technical refinement of Copernicus’ work. Yet, Kepler’s action accomplished much more than geometrical substitution.

4.2 Kepler’s Approach

Kepler’s approach to doing astronomy is both physical and mathematical. From the beginning of the *Astronomia nova* Kepler argues that ‘saving the phenomena’ is a necessary, but not a sufficient condition for the physical astronomy that he proposes. Although, had he included only the geometrical positional results of his researches in his published work, he would still have succeeded in revolutionizing astronomy. Indeed, history relates that almost all of Kepler's contemporary readers, while they rejected the physical reasoning so necessary for Kepler himself, had to concur with the geometrical advantages of the Keplerian astronomical hypotheses. The employment of the mean Sun in astronomy for example, would soon become an anachronism – but not, at least immediately, for all of the reasons for which Kepler had argued.

When Kepler began his pursuit of the Martian planet, the current astronomical theory was already insufficiently precise within even the restricted domain of positional astronomy. In particular, Brahe’s record of numerous and precisely measured observations showed that even the most recently-computed planetary tables contained serious errors. However. the very fact of these errors gave Kepler the means to argue that Copernicus was fundamentally correct in asserting the heliocentricity of the world-system – while simultaneously denying the mean Sun that Copernicus, Brahe, and others had adopted.

Kepler became acutely aware of the equivalence of the theories of the ancients and his contemporaries. As regards the limited domain of geometrical determinations, in the early chapters of the *Astronomia nova* Kepler made it abundantly clear that it did not matter whether the Sun orbited the Earth or the Earth orbited the Sun.

Kepler involved his physical reasons, with his rhetorical motivations. Kepler was arguing in an argumentative battlefield where there was more than one opinion as to what represented the true astronomical reality. Setting his own conditions, he adopts the most advantageous position; Kepler defends himself and at first defines what he sees as the issue in the competitive environment of traditional astronomy. One of the first things Kepler did in the *Astronomia nova* was to argue that both physical and astronomical models of the Solar System should be constructed around what he believed to be the source of planetary motion, the *true* Sun rather than the *mean* Copernican Sun, an empty point which, under the Copernican system, is the center of the Earth’s orbit. For physical reasons Kepler’s perspective was that one should measure the eccentricity from the Sun itself.

Kepler constructed the model based on the mean Sun shown in Figure 14 below, where the differences are represented in the placement of the apsidal line and the planetary path when the true Sun is used and when the mean Sun is used in the Copernican system. The equant point is fixed at E, and observations are taken as if from the mean Sun, then the apsidal line will be placed through points B and K. Kepler pointed out that this occurs because although the planet is actually moving slowest at D, it will appear to be slowest at K since K is further than D from B (the point furthest B is N. But, Kepler pointed out that while motion appears slower the further away it is, the planet is actually moving slowest at D, and these two effects counteract each other, making the motion appear slowest at K; *AN* 145 (see Martens, 2000: 71).

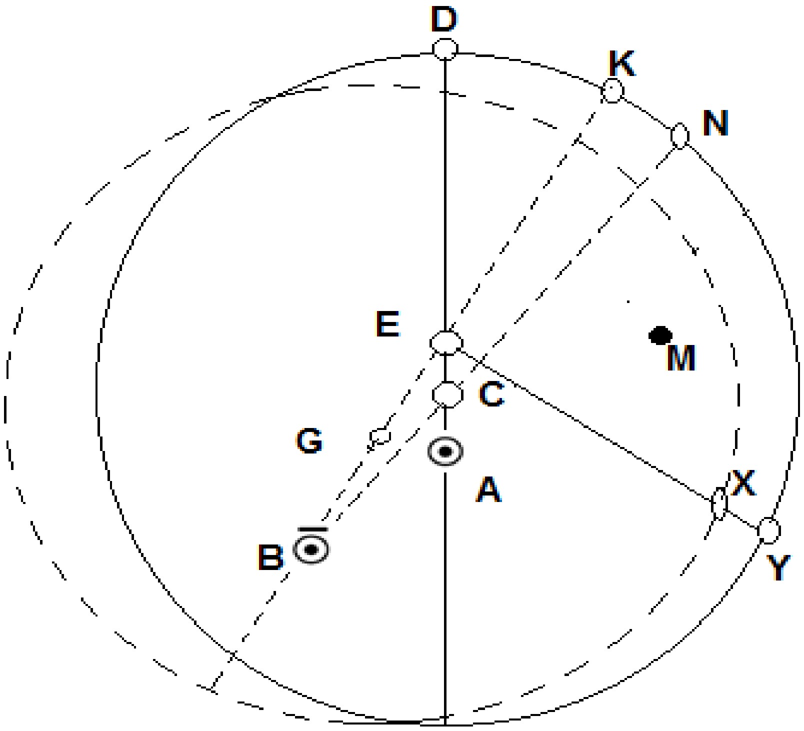


Figure 14: Diagram showing the mean Sun and the true Sun (adapted by the author from Martens, 2000: 72).

Again, it is proposed here that Kepler's first true break with the traditional framework and Copernicus' ideas occurs when Kepler applied his strategy of replacing the mean Sun with the true Sun to all three models. Taton (2003: 59) observes that:

> Kepler realized that Copernicus had used the center of the Earth's orbit, and not the Sun itself, as the fundamental reference center of his system. Copernicus's own arrangement was therefore heliostatic but not truly heliocentric.

As Owen Gingerich (1975a) notes, Copernicus gave the world a revolutionary heliostatic system, but Kepler made it into a heliocentric system. By locating the Sun centrally, Kepler reintroduced physical argument into astronomy, and established a genuine heliocentric system. Kepler redefines Copernican heliocentrism by first revealing that Copernicus' system was 'heliostatic' and then offers us a truly heliocentric system. Gingerich further remarks that:

> The idea is so important that we should perhaps call it Kepler's zeroth law. It is a sign of Kepler's genius that he so quickly recognized this as the crucial first move in the reform of astronomy. (Gingerich, 1975a: 264).

Gingerich's description of Kepler's proposal as being "… the crucial first move …" is important. From a rhetorical point of view it represents Kepler's laying down of his 'first-step need' which was to establish his physical perspective of causation. Kepler was the first to introduce the concept of physical causation into astronomy, and in accordance with his Copernican convictions, he naturally believed that the Sun was the generator of all causes.

For Kepler, the Sun was the most important physical object in the Universe, and for rhetorical purposes he uses an analogy to describe two reasons for relocating the Sun. He assumes that the Sun must be so located because of (1) its dignity and (2) its power and function in the Universe as the physical source of the force that causes planetary motion. In the Introduction to the *Astronomia nova* he writes:

> … the body of the Sun is the source of the power that drives the planets around ... the Sun, although it stays in one place, rotates as if on a lathe, and out of itself sends into the space of the world an immaterial species of its body, analogous to the immaterial species of its light. (Kepler, 1992).

As will be discussed in the next chapter, Kepler makes extensive rhetorical use of light in accounting for the 'power' of the Sun. Given that, the Sun was the most powerful and important object in the Universe, he argued, so it followed that the Sun should be physically responsible for the motion of the planets. In his search for causes, Kepler begins his efforts with a 'physical' assumption, i.e., the manipulation of the physical phenomena and not just a collection of observations as his predecessors were committed to doing. By subordinating all features of planetary motion to the physical assumption that the Sun, a physical body, was the real center of that motion led Kepler to find that his computing of measurements based upon the Sun's actual or true physical position in the sky, left a significant degree of uncertainty in the traditional models available to him. It gave him an intelligent basis whereby he could now question the principle of uniform circularity and all that it entailed. This physical assumption affected all of Kepler's work, and consequently all subsequent astronomy, for from it Kepler was able to determine various new methods of calculating the nodes and inclinations of the planetary paths. As Westman (1972: 238) notes: "… the solar force, attenuating inversely with distance in the planes of the orbits, was the major physical principle that guided Kepler's struggle to construct a better orbital theory for Mars."

In his metaphorical 'war with Mars', Kepler 'declares war on Mars' and strategically launches and directs his first salvo not at the principle of uniform circular motion, a non-measurable belief, but at Copernicus' assigned (physical) location for a (physical) body – the Sun. This study proposes that Kepler's goal here was far from being a modest suggestion or with a few small changes to Copernicus' ideas as he stated. Based upon his findings, Kepler believed that the physical causes of Mar's planetary motion was knowable and therefore that the traditional belief in the principle of uniform circular motion could be questioned. Evidence for this exists in that at various points throughout the *Astronomia nova* Kepler would argue for his 'zeroth law' with each argument depending on previous results. In order to know the true path of the planet Mars, Kepler reasoned that it must be demonstrated that the apsidal line which divides the orbit into two equal halves of time and distance, passes directly through the center of the Sun.

Depending on the model used the question that the Earth or Sun moved around the center of its planetary path at a uniform rate became paramount and Kepler then questioned the traditional frameworks' assumption of pre-supposed 'uniformity' that had characterized all traditional explanations of planetary motion. Kepler's argument in the *Astronomia nova* for a truly heliocentric theory, as opposed to a theory of the mean Sun, is predicated on the introduction of physical reasoning into astronomy. By introducing physically meaningful coordinates, Kepler was able to describe the apparent motions of each of the planets in terms of physically meaningful components. In essence, the observed positions of the planets were shown to be describable as the rather simple effects of a physical emanation the strength of which is determined by nothing else than the distance of the planet from the Sun. For Kepler, the assumption of uniform circular motion was truly the 'Achilles heel' of the traditional framework, and as we shall see later, he uses mathematics as a weapon, as a method to attack it.

Kepler performed a preliminary analysis, which showed the orbit to be *very close to a circle*, but the Sun was *not* at the center of the circle – it was at a point almost one-tenth of a radius away (see Figure 15)! Furthermore, it was clear that Mars *varied in speed* as it went around this orbit, moving fastest when it was closest to the Sun (at perihelion) and slowest when it was furthest from the Sun (aphelion). Everybody (including Kepler) believed that the motion of planets must be a simple steady motion, or at least made up of simple steady motions.

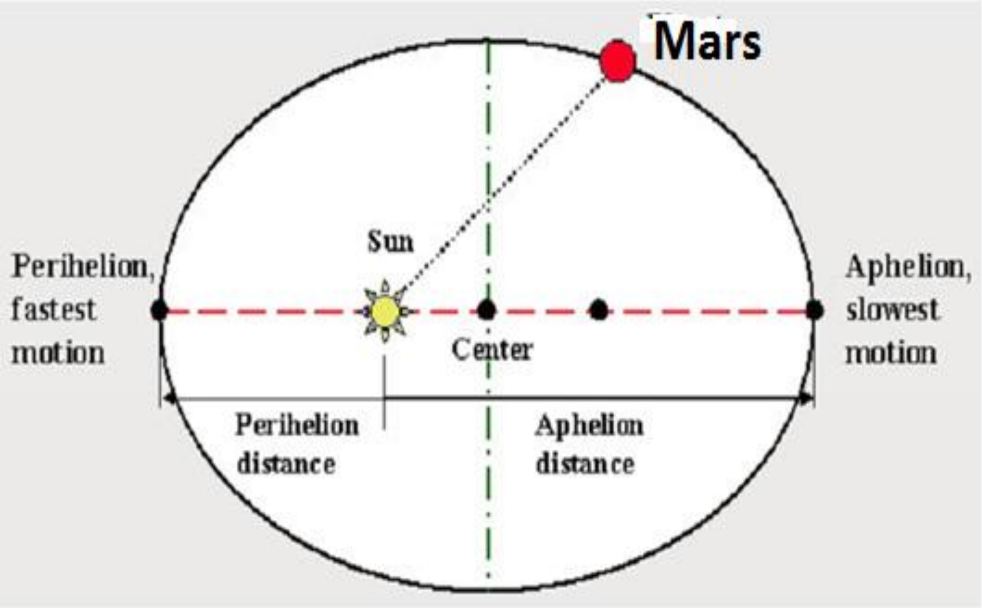


Figure 15: The orbit of Mars (adapted from Wikimedia).

Initially, Kepler was trying to establish the truth of the Copernican system over both the Ptolemaic, and Tychonic systems, and would try to use Tycho’s observations to prove Copernicus’ cosmology. Kepler was only able to demonstrate that the prevailing models of planetary motion could not be made to work by simply rebuilding them based on Tycho’s work.

In his first battle with Mars, Kepler developed his first surrogate model, the ‘Vicarious Hypothesis’. As depicted in Figure 16, it was Kepler’s attempt to cast the traditional model in the new heliocentric pattern.

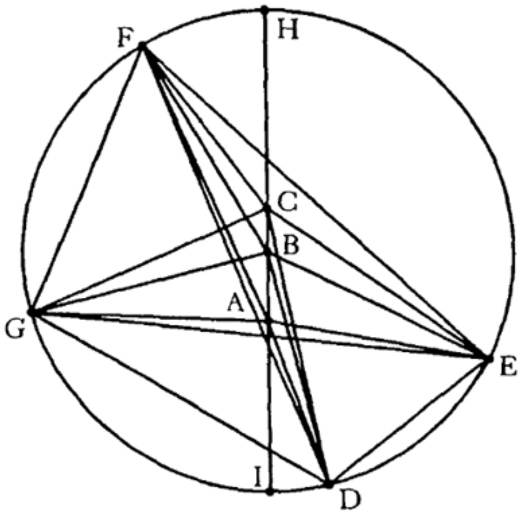


Figure 16: The Vicarious Hypothesis, taken from Kepler’s own diagram in Chapter 16 (after Kepler, 1992: 252).

Through Brahe's astronomical measurements and Kepler's own drawings of the geometrical relationship between the Sun and Mars in various parts of the planet's orbit, Kepler discovered that planets moved faster when they were closer to the Sun. However, as Kepler would discover, resting his model on the erroneous principle of uniform circular motion, the vicarious hypothesis led to discrepancies because it gave incorrect Sun-Mars distances. Kepler's vicarious hypothesis employed eccentric motion without employing Ptolemy's famous bi-section of the eccentricity. Such a construction resulted in errors of about 7.5′ at the octants of the planetary path. This as he informs us causes him to abandon the circular notion and reject the vicarious hypothesis and to seek other explanations:

> The testimony of the ages confirms that the motions of the planets are orbicular. It is an immediate resumption of reason, reflected in experience, that their gyrations are perfect circles. For among figures it is circles, and among bodies the heavens, that are considered the most perfect. However, when experience is seen to teach something different to those who pay careful attention, namely, that the planets deviate from a simple circular path, it gives rise to a powerful sense of wonder, which at length drives men to look into causes. (Kepler, 1992: 115).

Unlike his predecessors who had assigned epicycles to explain such an anomaly in Mars' planetary motion, Kepler would deliberately abandon the term "uniform" once he discovered that the velocity of Mars was not constant.

If the planet were moving in an orbit in which its distance from the Sun varied, it would physically speed up and slow down as it moved around the Sun. Kepler gave a physical explanation: that the planet moved more slowly when it was more distant from the Sun, in proportion to the distance. This means that equal portions of the planet's period do not correspond to equal distances along its orbital path. Kepler showed that these equal portions corresponded to equal areas swept out by a line connecting the planet to the Sun

This, the principle of non-uniform planetary motion is dependent on the magnitudes which are not susceptible of precise calculation. This gave rise to the famous 'Kepler problem'. If Kepler knew where the planet had been, he could calculate what portion of the orbit (time) had elapsed. But, owing to the transcendental relationship between the line and curve, he could not precisely calculate where the planet would be when an equal amount of time would have elapsed; Kepler needed some method by which to predict the locations of planets at given times.

4.3 Discussion

Kepler's approach to doing astronomy in the *Astronomia nova* is an interesting admixture of physical principles, mathematical analysis, and rhetorical devices. Throughout the work, Kepler attempts to render reality from appearances and in general, establish and develop a new science of astronomical hypotheses. Kepler replaced the ancient tradition of mathematical astronomy, and substituted a physical approach to astronomy – ‘celestial physics’ as he named it – in which theories of planetary motion were derived from the physical consideration of the cause of their motion. His starting point was the Sun, which became the anchor of his celestial system. All planetary motion could be ascribed to its influence and control.

Kepler’s initial discovery of the ‘equal areas, in equal times’ principle for example, was developed under his assumptions that a physical entity, the Sun, located at an eccentric point, and a planetary path that was circular. However, he will, summarily replace the circle with an ellipse – his first comprehensive principle.

In the development of his physical principles, Kepler based his mathematical analysis of observational data rhetorically on analogical reasoning. Analogical reasoning is a form of inductive reasoning that is important for the philosophical rhetor in generating new knowledge and involves the transfer of knowledge. The assertion that the Earth orbited the Sun, proof that the planets’ speeds varied, and use of elliptical orbits rather than circular orbits with epicycles are all based upon analogical reasoning. These notions challenged the long-accepted geocentric models of Aristotle and Ptolemy, and with the exception of elliptical orbits, generally supported the heliocentric theory of Copernicus.

Chapter 5 Method: Through Physics

Chapter 5 Method: Through Physics

5.1 Kepler's Method
5.2 Kepler's Methodological Differences
5.3 Mathematical/Rhetorical Analogies
5.4 The Magnetism Analogy
5.5 Kepler's Derivation of the Elliptical Path
5.6 Concept Formation-Definitions of Single Terms
5.7 Confrontation of Contraries-Two-term Relations
5.8 Patterns of Inference-Discovery
5.9 Discussion

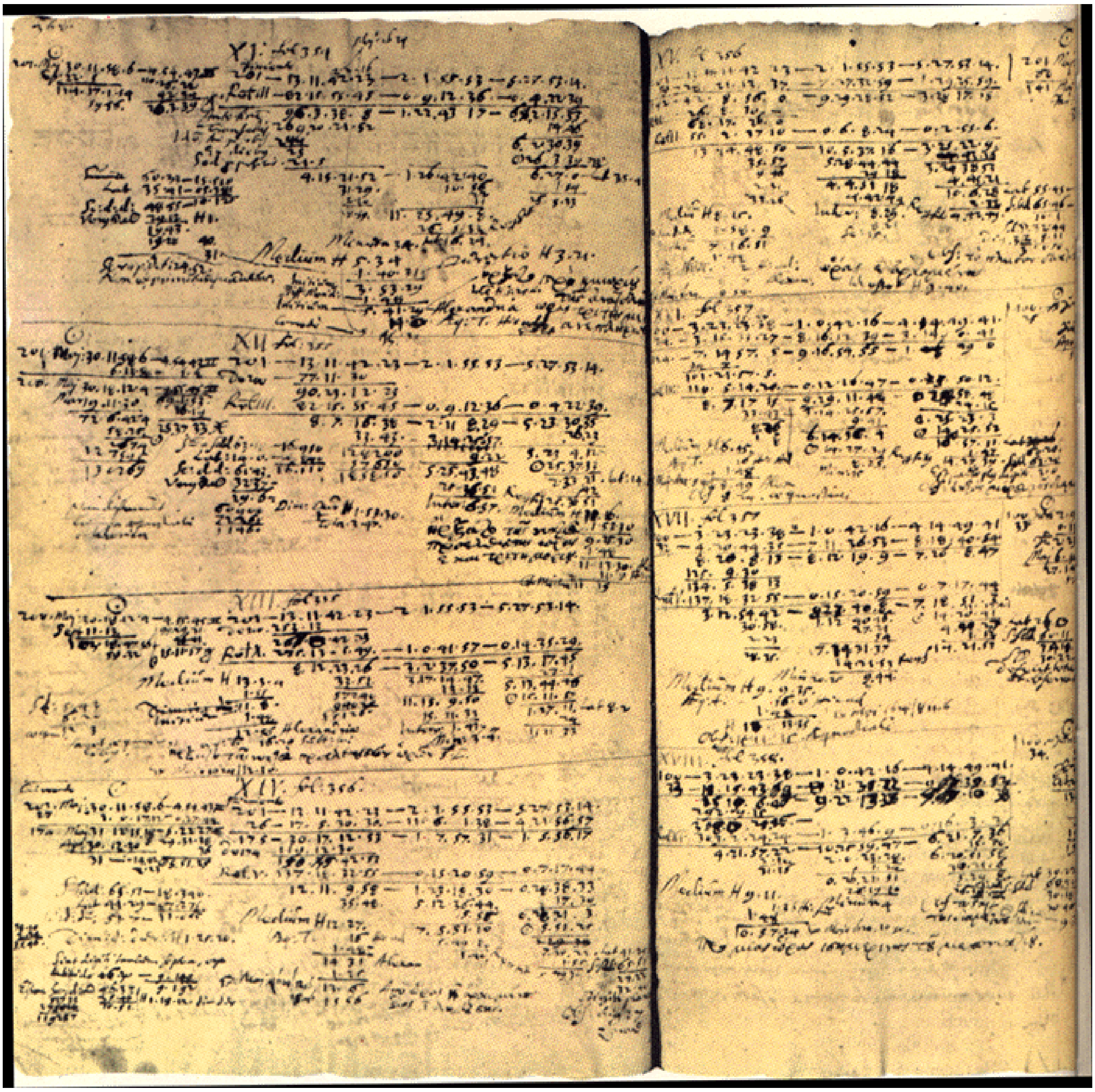


Figure 17: An example of Kepler’s astronomical calculations (source: Wikimedia).

Chapter 5 Method: Through Physics

5.1 Kepler’s Method

We turn now to Kepler’s method of doing astronomy. Every text expresses a perspective on reality, and says something about that reality from its perspective. What it says about the reality will have some kind of order or structure or form or connectedness or argument or *method.* The way in which the text orders this reality can be called its method, from the Greek *methodos*, derived from *meta,* following, plus *hodos*, way, a following-way, or pursuit (see Watson, 1994: 71). Here the concern is not with an order of ‘reality’ external to the text, but with the order of astronomical reality as presented in the *Astronomia nova*.

Kepler's methodological resources consisted of an impressive arsenal. He made extensive use of mathematics (e.g., see Figure 17), comparisons, analogies, rhetorical narrative, rhetorical argument, and inductive reasoning. At times, because Kepler's method concerns the entire conceptual structure of traditional astronomy, it can be difficult to separate out Kepler's method from his approach to doing astronomy. Yet, in a sense, Kepler's new astronomy is all method, if the term refers to what Kepler did to the subject matter, i.e., how he treated the traditional astronomy that he inherited and his own new astronomy. In the *Astronomia nova*, Kepler ends up exhausting the subject matter of astronomy within the process of constructing, presenting, and responding to what he believed were the physical causes of planetary motion.

It should also be noted that Johannes Kepler was not an astronomer; he was as a mathematician, whereby, in the second paragraph of his Introduction he laments that:

> I myself, a professional mathematician, on re-reading my own work find it strains my mental powers to recall to mind from the figures the meanings of the demonstrations, meanings which I myself originally put into the figures and the text from my mind. But when I attempt to remedy the obscurity of the material by putting in extra words, I see myself falling into the opposite fault of becoming chatty in something mathematical. (Kepler, 1992).

The *Astronomia nova* represented Kepler's ordering of his perspective on astronomical reality and Kepler used the text to relate his physical arguments about that reality. Once again, the concern here is not with an order of 'reality' external to the text, but with the order of astronomical reality as presented by Kepler in the text. Decidedly, as Kepler is creating his own world, that order is rhetorical.

It is significant that Kepler, unlike his predecessors and contemporaries, used mathematics as a method to order his experience of reality and used rhetoric as a tool to link his physical views and mathematical reasoning. Kepler integrated mathematics and rhetoric to derive the elliptical path of the planet Mars, and ultimately his derivation of the so-called first and second laws of planetary motion. The proofs of Kepler's first two laws are mathematical, but they deal with facts that belong to physics. However, this does not rule out Kepler's preferred method of proof, which is exactly that of Euclid: giving definitions and axioms and then proceeding by deduction.

As Kepler was determined to make the best possible use of the huge number of observations, he used a method that involved repeated trial and error. Historically, this is interesting precisely because we know he otherwise strongly preferred to model himself on Euclid. The method of "… try it and check …" in fact has a background in Medieval and Renaissance algebra. However, Kepler's methods were not known in astronomy which used geometry, generally regarded (at the time) as intellectually more respectable than algebra. Since Euclid was concerned with geometry, Kepler was inviting direct comparison. On the other hand, although at the time astronomers were known as ‘mathematicians’, their work did not actually involve proof in quite the same way as Euclid’s did. Kepler’s work is different in that it sets out to find a new geometrical description of the orbit of Mars, and of the structure of the Solar System, and thus gets into proving general laws that are somewhat like theorems.

In his wisdom, Aristotle had placed mathematics in the distant realm of reason and logic beyond the reach of rhetoric, yet, today it is well known that mathematics has always had rhetorical features that many scholars have almost entirely ignored. Indeed, for ancient and some modern scientists, seeing mathematics as rhetorical presents a challenge. From a rhetorical point of view, Kepler troubled that tradition, and viewed mathematics as something other than pure logic and used rhetorical elements in his mathematical discourse.

Toward that end, what we focus on now is Kepler’s attempt to derive mathematical predictions of celestial motions from assumed physical causes; Kepler was the first to do this.

Some of Kepler’s early thought, in the *Mysterium Cosmographicum*, which he published when only twenty-five years of age, is familiar to most Keplerian scholars. In that work Kepler provided his first suggestion as to the mathematical reason for the number and distances from the Sun of the planets; a solution he found in solid geometry. In his *Astronomia nova*, Kepler relied on nothing more complicated than the methods and results of Euclid that he had learned and taught as a young mathematician. As a collection of geometric axioms, definitions, propositions, and theorems, collected from other mathematicians and those developed by Euclid himself, the thirteen books of Euclid’s *Elements* (*circa* 300 BC) is often considered the greatest mathematical work in history. The Euclidean approach provided an entirely appropriate grounding for the astronomy of the day, whether one adopted the Ptolemaic geocentric system or the Copernican heliocentric system, since both depended solely on circles. It was the accepted custom during Kepler’s period to cite propositions from Euclid’s *Elements* to validate one’s reasoning, but Kepler additionally applied the Euclidean method in a very different way.

5.2 Kepler’s Methodological Differences

Such a radical and comprehensive undertaking required Kepler to have to account for his approach and method for doing physical astronomy. Aware that it was his contemporaries who he had to persuade, Kepler wrote the *Astronomia nova* as a rhetorical-philosophical argument, a mathematical one, primarily to be read by mathematicians.

Rhetoric like revolution can be a way to redefine reality. Kepler’s use of rhetoric as a philosophical tool to redefine astronomical reality and his application of mathematics as a way to reveal knowledge to determine the physical parameters of planetary phenomena required some justification.

Philosophic rhetoric by definition is exploratory. That is, systematic exploration leads prospective rhetors to find what they could say or write in specific situations when they plan a potentially active text. Kepler developed his own rhetorical method, whereby he analytically interpreted the mathematical properties of an object as being its essential properties; in Kepler's hands, mathematics became a philosophic method, prompting James Voelkel to label the *Astronomia nova* as "… a rhetorical philosophical book, a mathematical one." (see Voelkel, 2001: 215).

For the title of his biography of Kepler, the astronomical historian Angus Armitage (1966) who translated Kepler's first name, Johannes as John, commented of the *Astronomia nova*:

> This is not a treatise, a systematic presentation of results, but a testament, the record of an almost spiritual pilgrimage, conducting the reader along all the windings of the road (and up all its blind alleys) and recording the play of the great astronomer's passing moods. With its intricate calculations and speculative flights of fancy, the "New Astronomy" is the most difficult to read of all the half-dozen decisive cosmological books of the world, and the more so as its author was wrestling for much of the time with mathematical problems requiring for their rigorous and elegant solution concepts and notations not at that period available.

Armitage's observations make it evident that Kepler shares the process of his astronomical investigation by taking his readers with him every hesitant step of the way, discoursing all the while on his own fallibility but more importantly he points out Kepler's extensive use of mathematics.

As mentioned earlier, Kepler was a trained mathematician and not an astronomer. Above all he was a highly-skilled geometer who thought more like a physicist. During his graduate education at the University of Tübingen, Kepler inherited and became well educated in the approach, methods and problems of astronomy's traditional framework. As a devout Lutheran, Kepler was convinced that God had built the Universe on geometrical principles, and mathematics was itself a religious undertaking; a method by which nature's principles could be revealed. For Kepler then, everything in nature was arranged in a mathematical way, and could be discovered through calculation.

At first, similar to his predecessors, and under the rubric of the traditional framework, Kepler viewed the Universe geometrically. Kepler produced his now famous *Mysterium Cosmographicum*, yet, as we know, this early attempt did not completely satisfy his appetite to explain how the planets moved. Kepler realized that his method like his approach would now have to differ from that of the traditional framework. As he informs us, he adopts a mathematical-physical approach towards doing astronomy – as a way to do celestial physics.

Prior to the publication of the *Astronomia nova*, Kepler can be found to be arguing for his unconventional approach to doing astronomy, and as early as 1605, he wrote to Herwart von Hohenburg:

> I am much occupied with the investigation of the physical causes. My aim in this is to show that the celestial machine is to be likened not to a divine organism but rather to a clockwork … insofar as nearly all the manifold movements are carried out by means of a single, quite simple magnetic force, as in the case of a clockwork all motions [are caused] by a simple weight. Moreover I show how this physical conception is to be presented through calculation and geometry. (see Kepler, 1605a: 146).

Whereas, the traditional framework represented by the three competing hypotheses of Ptolemy, Copernicus, and Brahe focused on the celestial realm and the mathematical representation of data, Kepler in opposition to tradition announces that his method involves the mixing of the traditionally distinct realms. Kepler's approach will involve the terrestrial and celestial and will involve the mixing of mathematics, mechanics and celestial physics. Kepler's beliefs and aspirations ran counter to Aristotle's long-standing dictate that restricted astronomers to mathematical calculation and plotting. In order to solve his own immediate quest for the physical causes of Mars' planetary motion, he found that he at first had to address some of the significant problems that had long confronted and confined traditional astronomy. These problems ranged from the determination of real versus apparent motion, and terrestrial versus celestial phenomena, to questions concerning terminology.

Kepler found that as a means of solely calculating and plotting data, traditional mathematics was not up to the task. In order to address his goals, Kepler, thinking from a physical point of view, applied mathematics in several new ways. He ordered his experience of doing astronomy, and it is proposed here that Kepler's innovation was to use mathematics 'analytically' as a tool to proceed from problems to solutions. His predecessors had avoided any such application of mathematics. Kepler also found that based upon the traditional equivalences and ambiguities of the lexicon of the traditional hypotheses, he had to: (1) redefine old terminology and/or create new terminology that better described his new discoveries. These involved single terms such as an 'orbis' or 'path'. (2) He also had to adjudicate between contrary concepts (if interpreted in a physical sense), but empirically-equivalent concepts and planetary theories of his time, e.g., terrestrial versus celestial phenomena (motion, and finally, (3) Based upon his comprehensive principles he had to combine two subject matters or disciplines from the perspective of whichever one was being emphasized, e.g., astronomy and physics.

Kepler's initial aim was to understand the physical cause of the planetary path of Mars, and with the help of Tycho Brahe's planetary data he began working on the problem of Mars' planetary motion as early as 1600. Again, he followed tradition in basing his initial approach and method on arithmetic and the geometry of the circle. In Kepler's time, as we have seen, two millennia of scientific tradition, since before Ptolemy, dictated that all heavenly objects travel in uniform circular motion. Kepler therefore tried various combinations of circular orbits for both Earth and Mars. He worked first on circular orbits. Nothing worked. No combination of circles could match Tycho's data.

Kepler's use of mathematical models was consistent with his belief that the nature of physical objects was essentially geometrical. He soon found that his work based upon Copernicus' heliocentric model was not accurate enough and he needed to adjust both his approach and methodology. As Bruce Stephenson (1987) observes:

> Kepler's mathematical ingenuity was such that he could invent alternative theories, each good enough to "save" even the excellent observations of Tycho Brahe. These observations, therefore, did not provide enough guidance for him to reach his final solution to the problem of planetary motion…The necessary guidance he took from physics, rejecting theories for which he could find no plausible physical basis.

Where Ptolemy, Copernicus, and Brahe had used the pre-defined mathematical model of the circle, Kepler innovated and interweaved his speculations into physical causes with traditional mathematics. When Kepler explored, constructed and expressed his new knowledge mathematically, it was comparatively easy for him to distinguish between the equivalencies of his predecessors' hypotheses. Whereas they had operated under the assumption that physical observations should be adjusted to conform to the pre-existing mathematical structure of the circle, Kepler rhetorically flip-flopped, reversed their approach, and adjusted the mathematical structure or data to conform to the physical observation.

In retrospect, as early as 1596 Kepler was a freshly converted Copernican, and in the *Mysterium Cosmographicum* indicated that his mathematical method differed from tradition. He informs us: "But where Copernicus did so through mathematical arguments, mine were physical, or rather metaphysical." (see Caspar, 1993: 239). Yet, Kepler in keeping with his physical approach to interpreting reality derived the principles of planetary motion from comprehensive physical principles, not mathematical ones.

Kepler wanted to avoid being arbitrary, and to account for actual observations. Unlike his predecessors who imposed a pre-defined mathematical model on observational reality, Kepler applied mathematics to the physics and not the converse. Yet, Kepler's arguments were not mathematical arguments; they were physical arguments, whereby he appealled to the physical situation.

For our purposes here, it is sufficient to point out that Kepler's method was to form a physical hypothesis or model and test it mathematically and rationally. For example, when he wanted to express mathematically the problem of the relation between the distance of a planet from the Sun and the time it requires to traverse a given part of its trajectory, Kepler began with physics and questioned the relationship of one physical entity to another mathematically.

As William Boerst (2003) points out (in *Johannes Kepler: Discovering the Laws of Celestial Motion*), Kepler was looking for both the accurate distance of Mars from the Sun and the period it took to move from one degree to the next. To do so, he meticulously divided the orbit of Mars into 360 segments. When he looked at the measured distances with the Sun at the center for each of the 360 degrees, the variance from an ideal circle was enormous:

> Thus, since the time intervals a planet requires to cover equal parts of its eccentric circle stand in the same relation as the distances of those parts from the center, while individual points along a whole semicircle have different distances, was put too much effort to find out how to add up the individual distances. For unless we know all the partial sums--and there are infinitely many of them--we cannot establish the corresponding individual time intervals, and so we will not know the equations: every partial sum of the distances is related to the corresponding time span as the sum of all the distances is related to the total time of revolution.
>
> I therefore began by dividing the eccentric circle into 360 segments, which acted like (quasi) elementary particles (minimae particulae), and I supposed that the distances remained the same inside each of these separate particles. Then, using the method described in Chapter 20, I found the distance from the excenter to the beginning of each segment, or degree, and I added up those distances . . . .
>
> As the calculation was a mechanical and laborious one, and the equation for any individual degree could not be obtained without making use of equations for other degrees, I had to look for other methods. Since I realized that there are infinitely many points on the eccentric circle, and accordingly infinitely many distances, the idea came to me that all these distances are contained in the area of the eccentric circle. Here I remembered that it was in just such a fashion that Archimedes of old had subdivided the interior of the circle into an infinite number of triangles, seeking the ratio of the circumference to the diameter; that was the hidden meaning behind his indirect proof. So instead of dividing the circle into 360 parts, as I had done at first, I now divided the area of the eccentric circle into the same number of parts, drawing rays out from the point from which the eccentricity was reckoned. (Kepler, 1994).

To attempt a description of the orbit of Mars, Kepler raised the question, how much time does it take for the planet to sweep out certain areas described by a line from Sun to the planet moving through a segment of the orbit? Through his analysis of the data, he discovered that planets sweep out equal areas in equal times. Rigorously applying this physical comprehension to the orbits of the other planets led him to what we now refer to as Kepler’s First Law of Planetary Motion. Elliptical orbits were the only shape that fitted the data accurately. Finally, Kepler understood that the planets move in elliptical orbits, with the Sun at one focus. He abandoned the circular theory and wrote that he felt like he had been awakened from a sleep.

With these ideas, mathematical order was preserved. They accurately represented the data obtained by empirical observation. These comprehensive principles became known as Kepler’s First and Second Laws of Planetary Motion.

As we know, Kepler was not studying planetary motion in general; he was engaged on the specific task of finding an orbit of Mars – that is, a mathematical model for its motion. In the *Astronomia nova,* Kepler's method was to derive the principles of planetary motion from physical causes, not mathematical ones as his predecessors had done. Traditional astronomers employed mathematics as a tool for plotting astronomical data devoid of any reason to demonstrate cause. Astronomers were expected to predict positions of the Moon that were then found to agree, or not agree, with observation.

The proofs of Kepler's first two laws may be mathematical, but they are dealing with facts that belong to physics. However, this does not rule out Kepler's preferred method of proof, which is exactly that of Euclid: giving definitions and axioms and then proceeding by deduction. Kepler would spend almost five years, producing some 987-folio pages of arithmetic. All mathematicians of the time, and most philosophers, were agreed that this method was the most reliable one (ibid.).

5.3 Mathematical/Rhetorical Analogies

In this section, we want to look at another one of Kepler's methodological differences. Kepler also used rhetorical analogies in his method. Kepler's comparison of choice was analogy. Kepler was a prolific and intense analogizer and his writings are replete with analogies that were central to his discoveries; they range from his use of local comparisons to large extended analogies that evolved over the course of his numerous publications.

Analogy is a sophisticated process used in creative discovery. Using analogies, one may draw the listener or reader's attention to similarities between cases and re-organize existing information in a way that highlights certain regularities.

In the *Rhetorica* Aristotle explains that the use of analogies establishes a relation between the known and the unknown, the familiar and the unfamiliar, and in this way providing new knowledge (see Aristotle, 1924: 3.10.3; 3.11.61). These benefits account for the value of analogical reasoning for the philosophical rhetor who seeks new knowledge, and Kepler by definition seeks to uncover new things.

Kepler, as we know, inherited the traditional astronomy of spheres in which planets circumnavigated the Sun by the will of souls (later translated to angels or virtues or spirits). However, there were regularities and features in the data of the motions of the planets that required explanation. In seeking to understand why the planets that were further from the Sun moved more slowly, Kepler argued:

> … one of two conclusions must be reached: either the moving souls are weaker the further they are from the Sun; or, there is a single moving soul in the center of all the spheres, this is, in the Sun, and it impels each body more strongly in proportion to how near it is. (Kepler, 1992: 199).

That is, the Sun is responsible for the motion of the planets and the closer you are to the Sun the more it can make you move – the Sun is transmitting a motive power through space to the planets and this power is closer when one is closer to the Sun. To make sense of this argument, he appealed to analogy:

> I shall propose to the reader the clearly authentic example of light, since it also makes its nest in the sun … Who, I ask, will say that light is something material? Nevertheless, it carries out its operations with respect to place, suffers alteration, is reflected and refracted, and assumes quantities so as to be dense or rare, and to be capable of being taken as a surface wherever it falls upon something illuminable. Now just as it is said in optics, that light does not exist in the intermediate space between the source and the illuminable, this is equally true of the motive power (Kepler, 1992: 383).

In his optical treatise the *Paralipomena (Ad Vitellionem Paralipomena*, 1604) Kepler praised analogies as his "… most faithful masters, acquainted with all the secrets of nature...they bring the solution of an infinity of cases lying between the extreme and the mean, and where they clearly present to our eyes the whole essence of the question." (see Genter et al., 1997: 429).

Kepler's discoveries that the Earth orbited the Sun, proof that the planets' speeds varied, and use of elliptical orbits rather than circular orbits with epicycles are all based upon analogical reasoning. Kepler's thinking in analogies was part of the method he used to make the transference that give him insight, which then led him to further discovery and problem solving; it was a way of modeling a concept in familiar terms, as well as adding a new perspective.

Before examining Kepler's use of mathematical analogies, as examples of his work, there are two important points. First, that although we use Kepler's writings to infer his thought processes. it should be clear that in analyzing just a few of Kepler's analogies no claim is being made to capture anything like the whole of his thought processes. Second, can we assume that his extended analogies were actually rhetorical devices used in his thought processes, as opposed to being merely cosmetic dressing as Moss (1993) claims in *Novelties in the Heavens …*? There are some grounds for optimism on this point, for Kepler's writings are unusually rich in descriptions of his thought processes. Many of Kepler's commentators have noted the exceptional – at times even excessive – candor and detail of his scientific writing. Holton (1973), in noting that Kepler has been relatively neglected among the great early scientists, stated "Modern scientists are … taught to hide behind a rigorous structure the actual steps of discovery – those guesses, errors, and occasional strokes of good luck without which creative scientific work does not usually occur."

However, Kepler's embarrassing candor and intense emotional involvement force him to give us a detailed account of his tortuous process. "He gives us lengthy accounts of his failures, though sometimes they are tinged with ill-concealed pride in the difficulty of his task." (Holton, 1973). Pesic (2001: 114) comments that: "… where Kepler is expressive, Newton was impassive and avoided any image, analogy or figure or persuasion."

To illustrate one example: Kepler's used an analogy between light and the *virtus motrix or causal power* repeatedly in his publications, introducing it in *Mysterium Cosmographicum* and refining it throughout the *Astronomia nova* and *Epitome Astronomia Copernicanae*. The analogy between the influences that emanated from celestial bodies and the light that they emitted was well known among astronomers of the time, yet, "Perhaps no astronomer has insisted more on this analogy than Kepler did." (Duhem, et al., 1991: 245).

In the *Mysterium Cosmographicum* he points out that a few key early observations concerning light and *virtus motrix*: both emanate instantaneously from their source (essentially, in Kepler's mind, the Sun for both); both are geometrical surfaces that do not exist in the intervening medium; and neither loses any power in travelling from its source to its illuminable or movable object.

Kepler did not limit himself to similarities between light and the *virtus motrix*, however; he extended his analogy to the point that light and the *virtus motrix* nearly became one and the same. In Chapter 34 of *Astronomia nova* he describes light as "… an immaterial species of that fire which is in the body of the Sun, so this power which enfolds and bears the bodies of the planets, is an immaterial species residing in the Sun itself ... the primary agent of every motion in the universe." (see Donahue, 1988: 381). Kepler remarks:

> But least I appear to philosophize with excessive insolence, I shall propose to the reader the clearly authentic example of light, since it also makes its nest in the Sun, thence to break forth into the whole world as a companion to this motive power. Who, I ask, will say that light is something material? Nevertheless, it carries out its operations with respect to place, suffers alteration, is reflected and refracted, and assumes quantities so as to be dense or rare, and to be capable of being taken as a surface wherever it falls upon something illuminable. Now just as it said in optics, that light goes not exist in the intermediate space between the source and the illuminable, this is equally true of the motive power. (Kepler, 1992: 383).

The apparent similarities between both the quality and behavior of light and the *virtus motrix* were convincing, especially against the backdrop of Kepler's Copernican, mystical and theological convictions. The light-*virtus motrix* analogy provided Kepler with the crucial inference of action at a distance.

By assuming that the Sun rotated around its axis (a hypothesis he confirmed by noting that sunspots move) he could account for the planetary revolutions. The planets were pushed along by a kind of circular river of force whirling around the Sun, weakening with distance. However, this model still was not complete, for it did riot explain how a constant force from the Sun could account for the librations in the planetary orbits – that is, for the fact that the planets move inward and outward from the Sun in the course of a revolution. Kepler sought a mechanism whereby the planets could somehow interact with a constant push from the Sun and in such a way as to capture this variation. Kepler uses two analogies that show how the Sun, previously inferred to be the cause of planetary motion, could be the cause of noncircular orbital motion. The first analogy, introduced by Kepler in Chapter 57, used a river analogy he had originally raised in Chapter 39; it supposes that the Earth is like a boat steered by a ferryman (oarsman) in a circular river (see Figure 18 below).

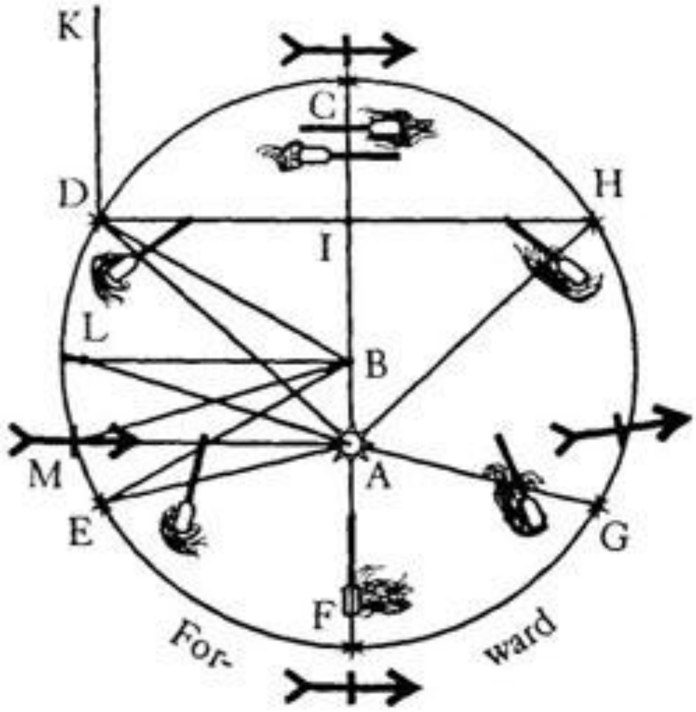


Figure 18: The ferryman analogy, taken from Kepler's own diagram in Chapter 57
(after Kepler, 1992: 549).

In Figure 18 the ship corresponds to the planet and the Sun provides the circular river pushing the ship around. Kepler asks us to consider the circle CDEFG, which contains a boat whose ferryman rotates his oar once in two revolutions around the circle. The ferryman could 'ride the river' by turning his oar in the appropriate way to catch the current as it flowed. The greater the inclination of the oar to the line of flow in the river, the greater surface area exposed to the flow and the greater the effect of the current's flow on the boat's motion. At C the oar is at right angles to the line of apsides (the line through the Sun [A] and the orbit's center [F]), and at F the oar is part of the line; at other positions it has intermediate inclinations. Then, at C and F the river's current will push the boat towards A only very slightly (but more at F than at C). At D and E the river's current will push down on the boat strongly, moving it towards A, because of the inclination of the oar in relation to the current. At G and H, the boat will be pushed away from A, because the river's current will be coming up beneath the oar. Thus the circle will be 'pushed out' into an oval shape, with the boats speed being highest near A and lowest farther from it (see Kepler, 1992: 549-550).

5.4 The Magnetism Analogy

In their study, Genter et al. point out that although Kepler returned to the ferryman analogy from time to time, the analogy was unsatisfying, in part perhaps because it seemed to require too much insight from the planets. How would they know when to shift the rudder? In keeping with a lifelong quest to explain seemingly intelligent planetary behavior in terms of a mechanical interaction, Kepler sought to explain the planet's behavior purely physically. He wanted the ship without the ferryman (see Genter et al., 1997: 434).

Kepler's longest and most determined effort in this direction was the use of an analogy between the *virtus motrix* and *magnetism*, an analogy Kepler developed over a long period. Kepler had first mentioned the magnetism analogy in the *Mysterium Cosmographicum* as one more instance of action at a distance that might make his Sun-planet force more plausible. By the time Kepler began his work on the *Astronomia nova* he had become familiar with the work of William Gilbert (*De Magnete*, 1600). In addition to setting forth the properties and behaviors of magnets, Gilbert had conjectured that the Earth might function as a giant magnet. Gilbert's work had a profound influence on Kepler. Kepler extended this analogy to the Sun and planets. He conceived that the Sun moved all the planets by the *virtus motrix* emanating from it, whose intensity diminished with distance. However, Kepler did not hit upon the why – he was getting close with his suggestion of some force able to act over a distance without having to be in physical contact with the planets. He thought this might be something like the force exerted by a magnet. He envisioned the Sun as the source of this force.

Not only was magnetism another example of action at a distance, it also had the potential to explain the variations in distance. "By modeling the planets and the Sun as magnets, Kepler thought he could explain the inward and outward movements of the planets in terms of attractions and repulsions resulting from which poles were proximate." (Genter et al., 1997: 435).

In the *Epitome of Copernican Astronomy* (1621), Kepler presented a long discussion of magnetism and its analogy to the planetary system. He began with a simple version of the magnetism analogy, likening the Earth to iron filings and the Sun to a lodestone (magnet). This analogy, mentioned only briefly, establishes a second example of action at a distance, in that a lodestone affects the behavior of iron filings without ever making contact with the filings. In addition, like the light-*virtus motrix* analogy, it suggests that action at a distance produces a qualitatively-negative relationship between the influences of one object over another and distance.

Gilbert had established this relationship between distance and magnetic influence in *De Magnete*. However, it does not explain why the planets would move closer and farther away from the Sun, as iron filings would be uniformly attracted to a lodestone. Indeed, according to the iron filings analogy, the planets should be dragged into the Sun. In this second analogy, Kepler conceived of the planet as a magnet (or lodestone). This added some new inferential power to the magnetism analogy and Kepler could now use the attractive and repulsive forces between the different poles of a pair of magnets to explain the coming together and separating of the celestial bodies. Thus, the planet would move closer to the Sun when its attractive pole was turned toward the Sun and farther from the Sun when the repelling pole was turned toward the Sun. Given this varying distance from the Sun, the planet's varying speed could also be inferred (as Kepler had already established that the planets move faster when closer to the Sun-by the light-*virtus motrix* analogy, and his second law).

Kepler was unsure whether the lodestone-*virtus motrix* correspondences were merely analogical or actually represented an identity. He struggled with this issue throughout the *Astronomia nova*. Early in the treatise, he wrote:

> The example of the magnet I have hit upon is a very pretty one, and entirely suited to the subject; indeed, it is little short of being the very truth. So why should I speak of the magnet as if it were an example? For, by the demonstration of the Englishman William Gilbert, the Earth itself is a big magnet, and it is said by the same author, a defender of Copernicus, 17 to rotate once a day, just as I conjecture about the Sun. And because of that rotation, and because it has magnetic fibers intersecting the line of its motion at right angles, those fibers lie in various circles about the poles of the Earth parallel to its motion. I am therefore absolutely within my rights to state that the Moon is carried along by the rotation of the Earth, and the motion of its magnetic power, only thirty times slower. (Kepler, 1992: 390-391).

Later, he voiced the concern that there are significant differences between the *virtus motrix* and magnetism, and that they therefore cannot be equated:

> I will be satisfied if this magnetic example demonstrates the general possibility of the proposed mechanism. Concerning its details, however, I have my doubts. For when the Earth is in question, it is certain that its axis, whose constant and parallel direction brings about the year's seasons at the cardinal points, is not well suited to bringing about this reciprocation or this aphelion … And if this axis is unsuitable, it seems that there is none suitable in the Earth's entire body, since there is no part of it which rests in one position while the whole body of the globe revolves in a ceaseless daily whirl about that axis. (Kepler, 1992: 560).

Yet despite these concerns, Kepler continued to use the phrase 'magnetic force' or 'magnetic species' to describe the *virtus motrix* throughout the text. One reason that he did so may be that the only alternative he could think of to a magnetic force was a mind in the planet, one that would somehow perceive the planet's distance from the Sun (perhaps by registering the Sun's apparent diameter) and move accordingly. The desire to reduce or replace this intelligence with a mechanical force is a recurring theme in his analogies. By using familiar domains to inform his understanding of the *virtus motrix*, Kepler was able to pursue alignments and systems that would otherwise have been unapparent.

Despite the persuasion of the analogies, Kepler's own observations forced him to reject the tempting notion of a *virtus motrix* equating to light. Kepler's first and most basic observation was to note that light interacts with only the surfaces of the bodies it illuminates, while his *virtus motrix* interacts with the "… whole corporeality." (Lindberg, 1976: 39) of the planets it moves. Combined with the observation that light emanates spherically and the *virtus motrix* circularly from the Sun, this inevitably led to Kepler's analysis of light and the *virtus motrix* during a planetary eclipse: one planet may be eclipsed by another and therefore receive no visible light, yet the eclipsed planet does not stop moving and thus must still receive *virtus motrix* (see Genter, et al., 1997: 423). Here Kepler's theory of the *virtus motrix* starts to appear primarily empirically justified and independent from his theory of light, but this independence is less a rejection and more a development of the theory's originally theological and mystical motivation (see Lindberg, 1976: 41).

As mentioned earlier, traditional astronomy had been concerned with geometry or better, pure kinematics. The celestial spheres, Ptolemy's cycles and epicycles, were designed to describe the motions of the celestial bodies in order to calculate positions; they did not belong to Kepler's celestial physics or cosmology. Kepler's general aim in astronomy necessarily involved connecting astronomical theory with dynamics. This combination of kinematic and dynamic considerations resulted in Kepler's ability to determine the true planetary path for Mars. As Lothar Schäfer (2006: 86) has observed:

> ... it is for dynamical reasons that Kepler is giving up the idea of uniform circular motion, which had been accepted as valid from Plato to Copernicus and Brahe: when the planet is closer to the Sun it should move faster, when in greater distance it should slow down. The circual form of orbit Kepler does not question at the time. The *New Astronomy* preserves as a true document the tentative and erroneous attempts of Kepler to bring Tycho's data about the positions of Mars in accordance with an orbit that would meet the requirements of his dynamics. It is only through the analogy between the attraction and propagation of light that Kepler is led to adopt the elliptical orbit for Mars.

5.5 Kepler's Derivation of the Elliptical Path

The mathematical manner in which Kepler derived the elliptical path of the planet Mars and ultimately his derivation of the so-called First and Second Laws of Planetary Motion have often been described and will only be discussed briefly here. It is sufficient to point out that Kepler's method was to form a physical hypothesis or model and test it mathematically and rationally.

Wilson (1968: 2) observes that: "In Chapters 22 to 28 of the *Astronomia nova* Kepler is not engaged in a straight-forward empirical determination of the elements of the path, but is rather modifying Tycho's solar theory in a direction suggested by analogy and roughly supported by calculations from observation." The extended line of research that culminated in the *Astronomia nova* – including the first two laws of planetary motion – began with the analysis, under Tycho’s direction, of Mars’ orbit. It appeas that Kepler calculated and recalculated various approximations of Mars’ path using an equant (the mathematical tool that Copernicus had eliminated with his system), eventually creating a model that generally agreed with Tycho’s observations to within two arcminutes (the average measurement error). But he was not satisfied with the complex and still slightly inaccurate result; at certain points the model differed from the data by up to eight arcminutes. The wide array of traditional mathematical astronomy methods having failed him, Kepler set about trying to fit an ovoid orbit to the data. He then set about calculating the entire orbit of Mars, using the geometrical rate law and assuming an egg-shaped ovoid orbit. After approximately forty failed attempts, in early 1605 he at last hit upon the idea of an ellipse, which he had previously assumed to be too simple a solution for earlier astronomers to have overlooked. Finding that an elliptical path fitted the Martian data, he immediately concluded that all planets move in ellipses, with the Sun at one focus – Kepler’s First Law of Planetary Motion. Because he employed no calculating assistants, however, he did not extend the mathematical analysis beyond Mars.

Kepler’s method of finding areas is similar to that used by Archimedes (ca 287–212 BC) to find the area of a circle. But it is not exactly the same, and unlike Archimedes’ procedure, Kepler’s is not completely rigorous. However, Kepler’s method does, also, look a little like integration, and it did in fact, according to some, mark the beginning of a technique called ‘the calculus of indivisibles’ which is now seen as an ancestor of modern calculus.

As his calculations progressed, Kepler was able to use exact geometrical methods to find areas. At first finding the areas was a difficult task, and Kepler’s method was approximate, effectively adding up areas of triangles with their vertex at the Sun and very small vertical angles. Kepler found the area swept out by a line joining a planet to the Sun, and he used triangles whose vertical angle was one degree of arc (at the centre). His method is best near the apsides, that is the positions at which the planet is nearest to or furthest from the Sun, which (once he knows the shape of the path) will turn out to be the ends of the major axis of the ellipse. The calculations are made more difficult by having to allow for the motion of the Earth, which is, of course, not in the same plane as the motion of Mars. (The planes of the two orbits are inclined to one another at about 1 degree 50 minutes.)

Kepler boldly made his own assumption that possibly the planetary path of Mars was not circular and as further calculations showed, it could not be circular; rather it described some sort of oval shape. For Kepler, the Sun is the source of the power that moves the planets. He takes the position of the Sun as his point of reference for his calculations and not the center of the planetary orbit, a belief that eventually causes him to reject circular motion.

After more than five years of calculating and re-calculating the data, Kepler finally developed a crude physical model of the planetary system. The model showed that the Sun somehow caused the motion of the planet, exerting what he believed to be as a force that decreased with distance so that Mars for example moves slowest when furthest from the Sun. Kepler found that Mars did not exhibit constant speed nor perfect circular motion, From this realization, he concluded that the planetary path of Mars was elliptical, not circular. Kepler attributed these findings to the Sun's influence.

As Kepler remarks:

> I was almost driven to madness in considering and calculating the matter. I could not find out why the planet (Mars) would rather go on an elliptical orbit ... With reasoning derived from physical principles agreeing with experience, there is no figure left for the orbit of the planet except for a perfect ellipse ... Why should I mince words? The truth of Nature, which I had rejected and chased away, returned by stealth through the back door, disguising itself to be accepted ...I thought and searched, until I went nearly mad, for a reason why the planet preferred an elliptical orbit. (1992).

He also observes:

> My argument was as in Chapters 49, 50 and 56: The Circle of Chapter 43 is wrong because it is too large, and the ellipse of Chapter 45 is too small. And the amounts by which they respectively exceed and fall short are the same. Now between the circle and the ellipse there is no other intermediary except a different ellipse. Therefore the path of the planet is an Ellipse; and the lunula cut off from the semicircle has half the previous width, that is 429. (ibid.).

Kepler wanted to express mathematically the problem of the relation between the distance of a planet from the Sun and the time it requires to traverse a given part of its trajectory, Kepler began with physics and questioned the relationship of one physical entity to another. He proposed that the planets move more rapidly in their paths then closer to the Sun, and slower as they recede away. After comparing his results to Brahe's observations, Kepler found he was 8′ of arc off. It is a tribute to Kepler's genius, that he saw that this small discrepancy was a matter of principle, not simply a minor error.

Kepler (1992: 286) notes:

> To us, on whom Divine benevolence has bestowed the most diligent of observers, Tycho Brahe, from whose observations this eight-minute error of Ptolemy's in regard to Mars is deduced, it is fitting that we accept with grateful minds this gift from God, and both acknowledge and build upon it. So let us work upon it so as to at last track down the real form of celestial motions (these arguments giving support to our belief that the assumptions are incorrect). This is the path I shall, in my own way, strike out in what follows. For if I thought the eight minutes in [ecliptic] longitude were unimportant, I could make a sufficient correction (by bisecting the [linear] eccentricity) to the hypothesis found in Chapter 16. Now, because they could not be disregarded, these eight minutes alone will lead us along a path to the reform of the whole of Astronomy, and they are the matter for a great part of this work.

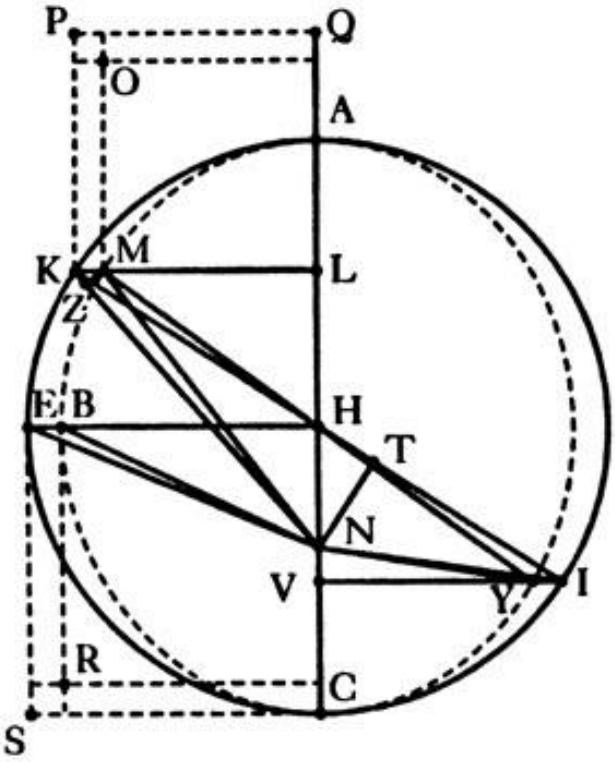


Figure 19: Kepler's diagram showing Mars' elliptical orbit, taken from Kepler's own diagrams in Chapters 59 and 60 (after Kepler, 1992).

He subsequently revised all his work, and discovered that the planetary orbits were ellipses, as depicted in Figure 19 above. In Kepler's diagram from the *Astronomia nova,* the dotted curve is an ellipse. As one can see, this ellipse is very close to a circle, but as Cusa had forecast in *On Learned Ignorance*, there is no perfectly circular motion in the created world (see Cusa, 1954).

Based upon distance Mar's speed was not uniform but varied at different stages of its path – planetary motion was a physical variable. Although, Kepler made these discoveries in reverse order, area first and the ellipse second, they yielded what we refer to today as his First and Second Laws of Planetary Motion, or the so-called law of elliptical orbits and the law of areas.

It is useful to recall two of his planetary laws: (1) Every planet travels round the Sun in an elliptical orbit, with the Sun at one focus. (2) The planet moves in such a way that a line joining the planet with the Sun sweeps out equal areas in equal times. Expressed in modern terms:

- Law I (the ellipse law): the path of the planet is an ellipse whose radius vector is measured from the Sun.

- Law II (the area law): The radius vector joining a planet and the Sun sweeps out equal areas during equal intervals of time.

Today, Kepler’s discoveries may be referred to as ‘laws’, however; Kepler did not consider them as laws. Given that Kepler sought reasons that could account for the entirety of astronomical phenomena, the interpretation here is that in the *Astronomia nova* these so-called ‘laws’ function as comprehensive physical principles that represent partial orderings along the way to the comprehensive harmony of Kepler’s new system.

As shown in Figure 20 below, the elliptical shape of the planetary path, with the Sun at one focus, is a comprehensive physical principle by which all points on the path are determined, and, with the principle of areas, his second comprehensive physical principle, the relative speeds of the planet at all points are also determined. In Figure 20, Kepler’s equal area law (second comprehensive physical principle), if the time interval taken by the planet to move from P to Q is equal to the time interval from R to S, then according to Kepler’s equal area law, the two shaded areas are equal.

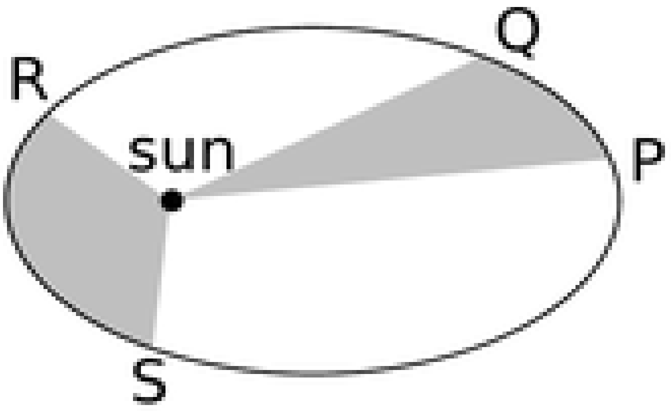


Figure 20: Kepler’s equal area law.

Kepler’s first and second comprehensive principles, either singularly or when combined, eliminated epicycles and deferent’s and destroyed any need to explain intricate planetary motion based upon uniform circularity.

Kepler found that not only did an elliptical orbit with the Sun at one focus explain the movement of Mars, but also of the other planets. In fact, as Gingerich (1975a) points out, Kepler realized the momentous nature of his discovery. In the *Astronomia nova,* the typeface suddenly becomes larger to account for the significance as Kepler explains the motion of Mars and puts forward his first two planetary laws.

As early as 1596 Kepler was a freshly converted Copernican, and in the *Mysterium Cosmographicum* indicated that his mathematical method differed from tradition. He informs us: “But where Copernicus did so through mathematical arguments, mine were physical, or rather metaphysical.” (Kepler, 1981). Yet, as discovered here, Kepler in keeping with his physical approach to interpreting reality derived the principles of planetary motion from comprehensive physical principles, not mathematical ones.

In his search for causal physical reasons to account for the planetary path of Mars, that is, a physical model of its motion, Kepler got more than he originally looked for. As to the methods used in the traditional framework, Kepler found that the geometrical models of Ptolemy, Copernicus and Tycho were essentially based upon a similar mathematical technique. Unlike his predecessors who had restricted the use of mathematics to mere plotting and calculation, Kepler would employ it as a rhetorical tool for exploration and discovery. Kepler clearly acknowledges his use of mathematics, but that his application is different. It should also be noted that by intentionally making his text mathematical, Kepler rhetorically narrowed his audience considerably.

Kepler wanted to avoid being arbitrary, and to account for actual observations. Unlike his predecessors who imposed a pre-defined mathematical model on observational reality, Kepler applied mathematics to the physics and not the converse. Yet, Kepler's arguments are not mathematical arguments; they are physical arguments, whereby he appeals to the physical situation, (*argumentum ad physica*).

For example, when he wanted to express mathematically the problem of the relation between the distance of a planet from the Sun and the time it requires to traverse a given part of its trajectory, again, Kepler began with physics and questioned the relationship of one physical entity to another.

He proposed that the planets move more rapidly in their paths then closer to the Sun, and slower as they recede away:

> Thus, since the time intervals a planet requires to cover equal parts of its eccentric circle stand in the same relation as the distances of those parts from the center, while individual points along a whole semicircle have different distances, was put too much effort to find out how to add up the individual distances. For unless we know all the partial sums--and there are infinitely many of them--we cannot establish the corresponding individual time intervals, and so we will not know the equations: every partial sum of the distances is related to the corresponding time span as the sum of all the distances is related to the total time of revolution.
>
> I therefore began by dividing the eccentric circle into 360 segments, which acted like (quasi) elementary particles (minimae particulae), and I supposed that the distances remained the same inside each of these separate particles. Then, using the method described in Chapter 20, I found the distance from the excenter to the beginning of each segment, or degree, and I added up those distances …
>
> As the calculation was a mechanical and laborious one, and the equation for any individual degree could not be obtained without making use of equations for other degrees, I had to look for other methods. Since I realized that there are infinitely many points on the eccentric circle, and accordingly infinitely many distances, the idea came to me that all these distances are contained in the area of the eccentric circle. Here I remembered that it was in just such a fashion that Archimedes of old had subdivided the interior of the circle into an infinite number of triangles, seeking the ratio of the circumference to the diameter; that was the hidden meaning behind his indirect proof. So instead of dividing the circle into 360 parts, as I had done at first, I now divided the area of the eccentric circle into the same number of parts, drawing rays out from the point from which the eccentricity was reckoned. (Kepler, 1992: 97).

5.6 Concept Formation-Definitions of Single Terms

To understand a particular problem clearly, such as planetary motion, Kepler at first had to deal with some of the equivocal single terms and amphibolies used in traditional astronomical practice. In some instances, Kepler invented and contributed several new terms to describe his own physical findings. Kepler introduced the terms ‘orbit’, ‘satellite’ and eventually ‘focus’, which were all new to the lexicon of traditional astronomy. The modern concept and term that describes a planetary path for example, the orbit, specifically owes its origin to Kepler. For Bernard R. Goldstein and Giora Hon, Kepler helped revolutionize traditional theoretical astronomy’s concept of planetary paths, which had been understood in terms of ‘orbs’ [Latin: orbes] or spherical shells to which the planets were attached. In their paper “Kepler’s move from orbs to orbits” (2005) they suggest that Kepler’s move from the notion of ‘a planetary path’ to ‘orbs’ to ‘orbits’ was revolutionary, and that planetary astronomy was no longer concerned with constructing models made up of orbs. The new goal was to seek physical causes for the orbit now that the supporting system of orbs had been eliminated (see Goldstein and Hon, 2005: 74).

One of the first things Kepler did in the *Astronomia nova* was to illustrate the apparent motion of Mars. Kepler drew the geocentric (Earth-centered) planetary path based on Ptolemaic data (see Figure 21 below).

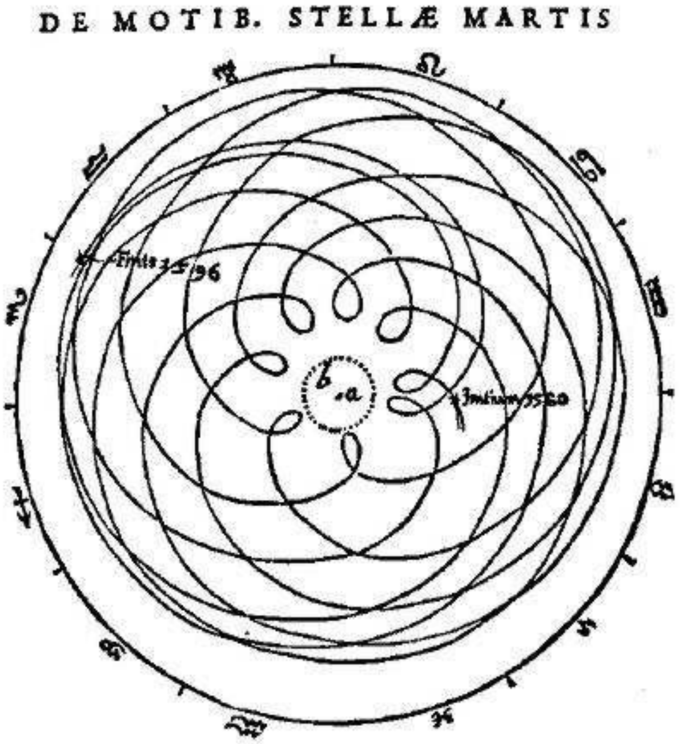


Figure 21: Kepler’s plotting of Ptolemy’s Martian data, taken from Kepler’s own diagram in Chapter 1 (after Kepler, 1992: 119).

Finding that Ptolemy's theory caused Mars to trace out what Kepler described as a rather convoluted path, forced Kepler to conclude that something was awry with the traditional astronomy as represented in the Ptolemaic model. Kepler's plotting of the actual planetary path was an astronomical first. As mentioned earlier, it had apparently not occurred to anyone to consider the actual path traversed by a planet.

As depicted in Figure 21, Kepler refers to the resulting path as a 'pretzel' or a 'coil' and remarks further that by attributing a single annual motion to the Earth, as Copernicus does, the planets rid themselves entirely of these intricate wreaths. But what appears prima facie to be a claim for simplicity – that is, an appeal to an aesthetic criterion – turns out to be a profound insight into the physics of planetary motion. Kepler had completely recast the problem of planetary motion in physical terms, and stated that:

> Copernicus, by attributing a single annual motion to the Earth, entirely rids the planets of these extremely intricate coils (spiris), leading the individual planets into their respective orbits (orbitas), quite bare and very nearly circular. (Kepler, 1992: 120).

By what might appear as a casual renaming of a long misunderstood concept, Kepler laid the basis for conceptual change. Again, as it was traditionally held that the path of the planets were composed of circles and moved at uniform velocity, the concept of neither a planetary path nor an orbit had been conceived of before Kepler. Indeed, as Hanson (1958: 4) remarks, "Before Kepler, circular motion was to the concept of a planet as 'tangibility' is to our concept of 'physical object'."

Indeed, the elliptical orbit involved much more than the feudal-like geometry of the circle or the simple substitution of one figure for another. Had that been Kepler's sole effort in describing a planetary path he would simply have replaced one geometrical figure with another. Early in his investigations Kepler realized that his models were not wrong, but saw that as physical models, they were incorrect because they were incomplete. Later in his work Kepler eventually discovered that the ellipse was not a physical cause, rather, it was the result of planetary motion, i.e., the ellipse does not cause the motion; the motion creates an ellipse. The ellipse was a physical model of motion and as such, it required dimensionality, and therefore could be measured. Kepler's measurements revealed that the elliptical planetary path was not a law; rather, it was the result of the quantifiable physical dimensions of distance, latitude and longitude. Henceforth, quantifiable physical dimensions could account for the path that planets followed in space, what he titled as an 'orbit'.

As we know, until Tycho's explanation of the comet of 1577 successfully shattered the Aristotelian physical theory of solid crystal spheres, it had been believed for centuries that the planets were attached to and moved with uniform circularity on orbs within crystalline celestial spheres. With the celestial spheres gone, Kepler needed to define and was free to redefine what had been understood traditionally as 'orbs' [orbis] into a new term, the 'orbit' [orbita], which by his determination was the path of a planet in space resulting from physical interaction.

By defining planetary motion as an instance of a physical event, Kepler took control of astronomical reality. To paraphrase Lewis Carroll's *Humpty Dumpty*, "He who has the power to define a word, defines reality." (Gardner, 1998: 180-181). Kepler recast the concept as a formal relationship between the planetary path, an orbit, and a physical entity, the Sun. For Kepler, an orbit was the result of the action of physical causes. His mathematical method allowed him to reject the time-honored notion that the 'real' motion of the celestial bodies must be uniform and circular, and eventually to accept the notion that an elliptical orbit represented the true motion of the Martian planet.

5.7 Confrontation of Contraries: 2-term Relations

We turn now to 2-term relations. Traditional astronomy held a marked distinction between terrestrial phenomena and celestial phenomena. As concepts of the traditional framework, these two subject matters were considered as opposites. The traditional framework also viewed terrestrial and celestial phenomena as fundamentally contrary, where explanations of events could not be interchanged. However, Kepler treated the notion that heavenly bodies were unchangeable, much differently than his predecessors. Zyskind informs us that:

> Philosophic rhetoric exploits the tendency of the mind to organize terms into pairs of contraries or to move in thought from a given term to its contrary ─ from an extreme to its opposite. Why this is so is not in question. Indeed, it would be inappropriate for the philosophic rhetorician to assume a fixed structure of the mind. (Zyskind, 1970: 384).

Accordingly, much of philosophic rhetoric is devoted to the discovery of how to acquire or retain the value of both of the contraries. Whereas much of traditional astronomical practice operated under Aristotle's precepts, or a 'fixed structure of the mind', Kepler as a philosophical rhetor innovated and essentially treated terrestrial and celestial phenomena as the same. Kepler precisely approaches astronomical reality based upon what terrestrial phenomena and celestial phenomena have in common – their physical nature and merges them. Kepler maintains this kind of flexibility of mind and physical approach throughout his research.

Apparently, in composing the *Astronomia nova*, Kepler assumed that his audience of mathematicians would follow and respond to any such movement of the mind. This is evident in Kepler's own approach and method to doing astronomy. He uses rhetorical analogy to adjudicate between the two subject matters, and to suggest the true nature of all astronomical phenomena as resting on physical principles. The analogies of light and magnetism are representative of his rhetorical skills, and served to bridge the assumed gap between things on Earth and things in the heavens.

5.8 Patterns of Inference-Discovery

As a philosophical rhetor, Kepler was a knowledge seeker, and much of his method was actually a process of discovery. Hanson (1958) in *Patterns of Discovery* illustrates this in the historical episode in which Kepler developed the theory that the orbit of Mars is elliptical. In formulating his theory Kepler had to reject the traditional belief held since Aristotle that the planetary paths of the planets were circular, because unlike sublunar motions the celestial motions are perfect.

Although, Kepler's mathematical findings indicated that there was no longer a need to substantiate the principle of uniform circular motion, still, scholarly opinions vary concerning the method and extent to which Kepler changed the fundamental axiomatic basis of the traditional framework.

In "The methodological elements of Keplerian astronomy", Jürgen Mittelstrass (1972) critiques Hanson's suggestion that Kepler's abandonment of the principle of uniform circularity was the sole basis for the demise of the traditional framework. Mittelstrass suggests that much more was involved. Indeed, Kepler believed that his major deviation and greatest contribution to Copernican heliocentrism was his notion of the elliptical orbit, because it got rid of any requirement for uniform circularity (see Kepler, 1939a: 852-853, 966-967). Hanson does offer some justification for his view that Kepler's work was key to the removal of uniform circularity. Hanson (1958: 88) also suggests that Kepler "… pulled the pattern …" of thinking that the planetary orbits were circular and more importantly, that "To deny a pattern statement is to attack the conceptual framework itself; and this denial cannot function in the same way." By the same way Hanson relates his belief that Kepler's new principle could not function under the rubric of the old traditional framework. On this point, recall Watson's (1994) contention that a framework cannot function without a principle.

5.9 Discussion

In his search for causal physical reasons to account for the planetary path of Mars, that is, a physical model of its motion, Kepler got more than he originally looked for. As to the methods used in the traditional framework, Kepler found that the geometrical models of Ptolemy, Copernicus and Brahe were essentially based upon a similar mathematical technique. Unlike his predecessors who had restricted the use of mathematics to mere plotting and calculation, Kepler would employ it as a rhetorical tool for exploration, discovery and definition. Kepler clearly acknowledges his use of mathematics, but also that his application is different. It should be noted that by intentionally making his text mathematical, Kepler rhetorically narrowed his audience considerably.

Kepler's methodological differences were in his use of logic and rhetoric to link his physical and mathematical reasoning where his use of a *mathematical analogy* is *de facto* the use of *physical analogy*. Kepler integrated mathematics and rhetorical analogy in his attempt to establish his new astronomy.

Gebhart (2009: 7) believes that "For Kepler, successfully matching calculation to observation was not enough; the pattern inherent in the observations had to lend itself to physical explanation and therefore to classification as a universal law (Han)." Kepler's light analogies from Chapter 34 of the *Astronomia nova* establish the physical basis for the mathematical example-based inferences that validate the distance-velocity law, or Kepler's Second Law of Planetary Motion, in Chapter 40. This same rhetorical pattern of a specific physical analogy to a broad mathematical example appears again in Chapter 57, which argues that reciprocation, or Kepler's First Law, represents a natural law and is therefore part of the plan, God's plan, for the world. Yet, Kepler found that he had to do more than redefine traditional astronomical principles and terminology, because first he had to adjudicate on the traditional frameworks separating contrary concepts, such as the division between the terrestrial and celestial realms. As discussed in Section 5.7 above, any such action required Kepler to have to compromise both realms based on what they held in common. This caused Kepler to have to use both his new approach and his new method comprehensively. This is discussed in the next chapter.

Chapter 6 Subject Matters: To Physics - Physical Astronomy

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6.1 Mixed Sciences: Physics and Astronomy

Of the three elements that comprise the basic structure of the traditional framework and Kepler's own new framework, *Subject Matters* represent the final topic that remains to be discussed. Subject Matters can be generally understood as those things that constituted issues or areas of substantive concern such as disciplines of study within the traditional conceptual framework and Kepler's new astronomy. Normally, empirical concepts, and entities, theories and practices and things that had a formal relationship represented such concerns for earlier astronomers.

Kepler lived in an era when there was a clear distinction between astronomy (a branch of mathematics) and physics, which was considered to be a branch of natural philosophy. Although Aristotle held that astronomy and physics were distinct as disciplines, they were considered by some astronomers and by Kepler to be in a formal relationship. As he stated, "I believe that both sciences are so closely interlinked that one cannot attain completion without the other." (Holton, 1956).

As we shall come to understand, Kepler's goal was to unite astronomy and physics, and the concept that he developed, whereby he attempted to explain the cosmic physics of the external Universe based on an extension of the known principles of terrestrial physics using the principle of magnetic attraction.

Up to this point, we have treated the question of the role of subject matters in Kepler's work only glancingly, while in our discussion of the traditional framework it has been more prevalent. This was possible because of the traditional frameworks' approach to interpreting reality based upon Aristotelian dictates. Aristotle's dictums placed severe boundaries on astronomical practice. Aristotle had warned against the mixing of disciplines and the use of mathematics in physics. Astronomy, for Aristotle, could not render knowledge about the real motions of celestial bodies, but physics, in contrast could. The traditional framework held to the Aristotelian distinctions between astronomy and physics, where the subject matter, the method of study, and the conclusions or results expected could differ considerably.

Holding that celestial phenomena were considered completely separate from Earthly physics Aristotle coupled these distinctions with his separation of mathematics (astronomy) and physics, and thereby stifled astronomical theory. Where mathematical disciplines could provide quantitative descriptions of the quantitative aspects of the world, physics (*physis* in Greek) was the qualitative study of 'natures' or 'essences' and was to be understood qualitatively. Aristotle believed that physics should provide qualitative causal explanations for why change (kinesis) takes place. In so far as terrestrial phenomena are capable of kinesis (change), physics studies these essences. Physics should therefore explain why motion takes place. For Aristotle, because the geometrical study of the planets did not rely on the essential characteristics of motion, but, relied on the geometrical or mathematical study of motion; it could not render knowledge about the actual motions of the celestial bodies. The separation of subject matters by Aristotle relaxed the need for any model to be more complex; especially one that proposed mixing the terrestrial and celestial realms.

Because much of the work of the traditional astronomer was already pre-defined, the traditional framework limited the goal of astronomers solely to the construction of an acceptable geometrical model, their method as we have seen involved no more than the adjustment of data to fit these predefined beliefs. Given that in the traditional framework, astronomical reality was already defined by time-honored assumptions, any astronomer operating within its arena had to begin with the question, How do I prove this point or issue? As mentioned earlier, for the traditional frame, principles so often preceded method. As we have seen, traditional astronomers had only to accept what had already been accepted as time-honored beliefs; they did not have to prove them. In this, the three competing equivalent hypotheses are classic representations of the belief that the motion of heavenly bodies was ‘real’, uniform and circular.

Kepler was a Pythagorean mystic. He considered mathematical relationships to be at the base of all nature, and all creation to be an integrated whole. This was in contrast to the Platonic and Aristotelian notion that the Earth was fundamentally different from the rest of the Universe, being composed of different substances and with different natural laws applying. In his attempt to discover universal laws, Kepler would apply terrestrial physics to celestial bodies. Kepler was convinced that celestial bodies influence terrestrial events and one result of this belief was his correct assessment of the Moon’s role in generating the tides, years before Galileo’s incorrect formulation.

In order to pursue his goal of unifying physics and astronomy, as a philosophical rhetor, Kepler once again began his search by asking a different and very crucial question: What shall I cause the issue to be so that I may adopt an advantageous position? Kepler’s predecessors attempted to created acceptable geometrical models based upon accepted issues and solutions. In philosophic rhetoric, issues are made, not born. Kepler was an explorer, and for him the issues and problems of the traditional framework, both known and unknown, had at first to be exposed and reconciled.

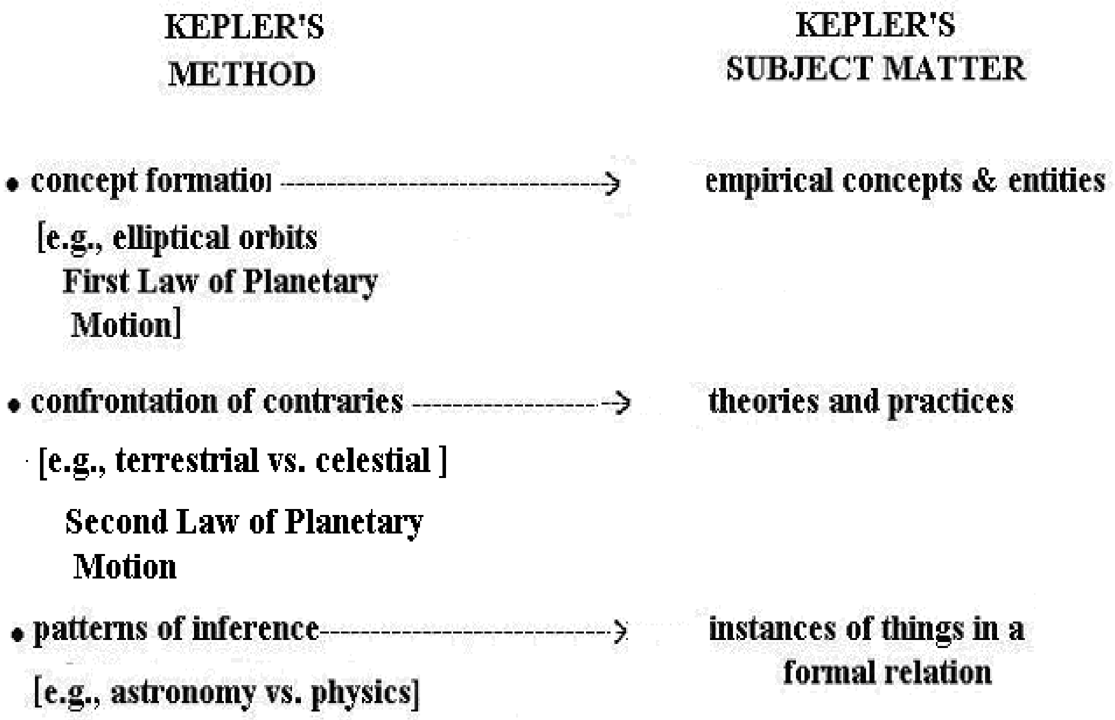

Figure 22: Kepler's method and subject matter.

Yet, there is less clarity or agreement on the question of how Kepler's method relates to his subject matter. Possibly this can be accounted for because at times the *Astronomia nova* seems to be all method. As stated earlier, Kepler ends up exhausting the subject matter of astronomy within the process of constructing, presenting and responding to what he believed were the physical causes of planetary motion. However, we can lead into it by reverting to its silent role in the preceding discussion of method. In that discussion, any effort to determine the relation between subject and method in Kepler's astronomy was avoided. The question was avoided by treating three phases of method in each of which the sense of what method means shifts as for example in the above diagram (Figure 22): (a) concept formation, (b) confrontation of contraries, and (c) patterns of inference, with parallel shifts in subject matter implied (empirical concepts and entities, perspectivally determined theories and practices, the instances of things in a formal relation).

Because there are graduated shifts in Kepler's work, it is possible that there is no final answer, but let us suppose the last term was for Kepler representative of the 'real' physical instance; i.e., that formal patterns of inference make up the method and instances of them the subject matter.

For Kepler, astronomy and physics also represented examples of such instances where he could successfully establish a formal relation between things. Kepler insists strongly upon the homogeneity of physics and astronomy and upon the identity of their methods; and he believes that these methods lead to conclusions, which, alike in physics and in astronomy, are demonstrably true.

What is true for the astronomer must be true also for the physicist. As Blake (1960: 38-43) contends: “If the empirical method can give the physician knowledge of the true causes of disease, then precisely similar methods of the astronomer can likewise give him knowledge of the true causes of celestial phenomena. If reasoning from effect to cause leads to valid conclusions in the one sphere, how can we deny that it may be similarly efficacious in the other? To cast doubt upon conclusions thus established is to indulge in a groundless skepticism.”

On this issue Kepler counters Aristotle, and makes no distinction between terrestrial and celestial phenomena, treating both as being essentially the same because they are subject to the same physical principles.

For Kepler then, terrestrial and celestial phenomena coexist as physical phenomena. Kepler freely extends terrestrial knowledge to astronomical phenomena and thereby applies (astronomical) mathematics to the physics and not physics to the mathematics. Kepler demanded that the same principles that apply to terrestrial physics must be applicable also to celestial physics.

Again, the *Astronomia nova* was not undertaken by Kepler to establish laws about the Universe, rather his stated goal was to discover or establish the cause of the ‘physical’ relationship between constituents of the Universe and consequently, the reformation of astronomical theory. Although, Aristotle was obviously concerned about astronomy and its status as a scientific discipline, Kepler was even more concerned.

As we have seen, in his search for the physical causes of the motion of the planet Mars Kepler had to deal with the competing hypotheses of others. Their traditional opinions or models embodied several long-abiding assumptions that Kepler questioned as being arbitrary, e.g., celestial phenomena were considered completely separate from earthly physics. Thinking as a physicist, Kepler deals with only the observed phenomena. He was not content with natural philosophy’s idea of celestial motion as being ‘natural’. As bodies they should be subject to the laws of motion. He conceives of an attraction acting between the Sun and the planets whereby, his comprehensible principle of areas, in accordance with which a line from the Sun to the planet sweeps out equal areas in equal times, was supposed by Kepler to be a consequence of the Sun’s moving the planets around their orbits with a *force* acting in the plane of the orbit at right angles to the radius from the Sun and varying inversely as the distance from the Sun.

It remained for Kepler to account for this imagined force and for that he adopted Gilbert’s notion of magnetism. As he tells us later in the Preface to Book IV of the *Epitome of Copernican Astronomy*, he erects the whole of astronomy on the Copernican hypothesis about the Universe, on Tycho's Brahe's observations, and on the Englishman William Gilbert's science of magnetism. In doing so, Kepler raised questions about the very nature of the relation of astronomy and physics and of astronomy as a discipline. He laid a basis for his belief that astronomy must be grounded in physics if it were to progress, and proposed a new disciplinary conception of the Universe that linked physics and astronomy to the extent that astronomy had to become subservient to the dictates of physics – better known today as astrophysics.

6.2 Physicalization of Astronomy

Kepler was the first scientist of the modern era to attempt a unification of physics and astronomy, by unifying terrestrial and cosmic physics. Kepler needed a rational means of adjudicating between the contrary apects of the two realms, between the terrestrial and the celestial. As mentioned earlier, Kepler developed his own approach and sought physical principles. From a physical point of view, again, he makes no distinction between terrestrial and celestial phenomena, treating both as being essentially the same and, was first to apply terrestrial physics to the Universe.

What Kepler developed mathematically was an overarching concept that would embrace both realms, in effect, the so-called law of elliptical orbits. Both the so-called law of orbits and the law of areas represent Kepler's formal relating of traditional terrestrial and celestial phenomena.

Kepler uses rhetoric to collapse the traditional distinction between physics and astronomy. Unlike Aristotle, who held that the mathematical properties of an object were qualitative and accidental, Kepler rhetorically interpreted the mathematical properties of an object as being quantitative and essential, and therefore, capable of being revealed.

First, Kepler also makes no distinction between real and apparent celestial motion and believes that celestial bodies are changeable. Kepler dialectically juxtaposes the traditional way of viewing reality as two separate realms. For Kepler, objects that are at first physical characterize each realm, and therefore, from a physical point of view, he did not have to make any distinctions between the two. Second, Kepler reconciles the terrestrial with the celestial on the basis of what they have in common, the fact that each realm is concerned with physical entities. Kepler deals with what has been traditionally understood as being contrary by dialectically reconciling them with an overarching concept embracing both – their physicality. Kepler physicalized reality when he juxtaposed the concepts of terrestrial and celestial phenomena and bridged the gap between them and interpreted them as being essentially physical in nature, he could therefore demonstrate how the same physical causes could and should be used to explain both. He united them based on what they had in common. As noted earlier, this was a third way by which Kepler redefined astronomical reality: by merging the two subject matters of astronomy and physics.

6.3 Discussion

Although, prima facie, it may seem that the *Astronomia nova* is a loosely-organized treatise on several diverse and vaguely-related subjects, close examination reveals these subjects to be intimately conjoined to one another; they are, in Kepler's terms, "… interconnected. involved, and intertwined." (1992). Kepler had to convince astronomers that the merely probable truths of physics have a place in astronomical hypotheses, and he had to convince the physicists that a causal dynamics similar to that of terrestrial bodies should apply to the motions of the planets through space. This meant that Kepler had to write with a broad didactic purpose in mind. He had to present his case in both the axiomatic-deductive form of the traditional treatises of mathematical astronomy, and the more oratorical form of metaphysical studies. Individual chapters of the *Astronomia nova* that may seem tangential to one of the declared purposes of the work are nonetheless central to Kepler's wider objective. These unusual characteristics of the rhetorical style of Kepler's great work are not mere idiosyncrasies, but are an integral part of the project that engaged his efforts from his time at Graz onward. As he states in the Introduction*:*

> ... since I have mingled celestial physics with astronomy in this work, no one should be surprised at a certain amount of conjecture. This is the nature of physics, of medicine, and of all the sciences, which make use of other axioms besides the most certain evidence of the eyes. (Kepler, 1992: 47).

In the effort to make astronomy a part of physics, Kepler's rhetoric was usurpatory. In the *Astronomia nova,* Kepler placed both of the ancient scientific traditions of astronomy and physics together to found a new kind of theory of the motions of the planets – a theory that provided causal reasons for the facts of positional astronomy. In doing this, he was attempting to provide sound causal explanations for astronomical regularities that, before the *Astronomia nova*, were not even recognized as explicable in causal terms.

Chapter 7 The Reception of Kepler's New Astronomical Ideas

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7.1 A Revolution in Physical Science

Kepler's system was not immediately accepted and many of his contemporaries declared the mathematics of the *Astronomia nova* extremely difficult. During Johannes Kepler's lifetime (1571–1630) very few astronomers accepted his basic astronomical ideas, nor, for that matter, were a majority convinced of Copernicus's. Although the leading natural philosophers were aware of Kepler's elliptical planetary orbits, most hardly mentioned them – Galileo Galilei (1564–1642) not at all – or were noncommittal. According to Applebaum (2000: 540), mathematical astronomers, objected to his novelties for a number of reasons:

1. Celestial motions in circles had behind them the sanction and authority of the greatest philosopher, Aristotle (384–322 B.C.E.), and the greatest astronomer, Ptolemy (ca. 100–ca. 170), of antiquity and were perceived as part of the natural order of things.
2. Keplerian astronomy was a variant of the Copernican theory, which violated the known principles of celestial and terrestrial physics.
3. The calculation of planetary position in an elliptical orbit according to Kepler's rule governing the relation between speed in orbit and distance from the Sun (later called his second law) required difficult and tedious approximations and ill befit the nature of astronomy.
4. Kepler's insistence on physical explanations for the motions of the planets likewise went counter to the nature and purpose of astronomy as well as accepted principles of physics.
5. The use of Tycho Brahe's (1546–1601) observational data was unsupported by Tycho's independent publication of them, nor was there adequate contemporaneous empirical evidence in support of Kepler's novel theories.

As it is well known, Galileo and René Descartes seem to have completely ignored Kepler's work. Even those few who were willing to consider Kepler's and Copernicus's heliocentric views including Kepler's old mentor teacher, Mästlin, rejected his notion of a celestial physics governed by the same causal law as Earthly phenomena. Mästlin, objected to Kepler's introduction of physics into his astronomy. As late as 1616, he wrote to Kepler:

> I do not fully understand what you say concerning the Moon: that you have explained all the variations [of its orbit] by physical causes. I think that on this question one should not appeal to physical causes. Astronomical questions should be treated astronomically, by means of astronomical rather than physical causes and hypotheses. Astronomical calculation is based upon geometry and arithmetic, not on physical conjectures, which disturb the reader rather than informing him. (Mästlin, 1616).

Whereupon Kepler noted in the margin of the letter:

> I call my hypotheses physical for two reasons ... My aim is to assume only those things of which I do not doubt they are real and consequently physical, where one must refer to

> the nature of the heavens, not the elements. When I dismiss the perfect eccentric and the epicycle, I do so because they are purely geometric assumptions, for which a corresponding body in the heavens does not exist. The second reason for my calling my hypotheses physical is this ... I prove that the irregularity of the motion [of the planets] corresponds to the nature of the planetary sphere; i.e., is physical. (ibid.).

Some astronomers adopted compromise positions towards some of Kepler's new ideas. In particular, the French astronomer Ismael Boulliau (1605–1694) published the *Astronomia philolaica* (1645) in which he replaced Kepler's area law with uniform motion in respect to the empty focus of the ellipse. Boulliau accepted elliptical orbits but objected to Kepler's proposal that the strength of the force exerted on the planets by the Sun decreases in inverse proportion to their distance from it. He argued that if such a force existed it would instead have to follow an inverse square law. Boulliau claimed that if a planetary moving force existed then it should vary inversely as the square of the distance:

> As for the power by which the Sun seizes or holds the planets, and which, being corporeal, functions in the manner of hands, it is emitted in straight lines throughout the whole extent of the world, and like the species of the Sun, it turns with the body of the Sun; now, seeing that it is corporeal, it becomes weaker and attenuated at a greater distance or interval, and the ratio of its decrease in strength is the same as in the case of light, namely, the duplicate proportion, but inversely, of the distances that is, $1/d^2$ … (O'Connor and Robertson, 2006).

However, he then argued that the Sun does not produce a planetary moving force:

> .
> .. I say that the Sun is moved by its own form around its axis, by which form it was ignited and made light, indeed I say that no kind of motion presses upon the remaining planets ... indeed [I say] that the individual planets are driven round by individual forms with which they were provided ... (ibid.).

According to O'Connor and Robertson (2006), the *Astronomia philolaica* could represent the most significant treatise between Kepler and Newton; it was praised by Newton (1972) in his *Principia*, particularly for the inverse square hypothesis and its accurate tables. There is one aspect of Boulliau's philosophy which is well worth commenting on – namely the fact that he believed in simple explanations and he wanted many different observed properties to result from a single cause (O'Connor and Robertson, 2006).

In 1610, Kepler heard about Galileo's discoveries with the telescope and wrote a long letter of support, which he published as *Dissertatio cum nuncio sidereo* (Conversation with the sidereal messenger). Later that year, he presented his own observations of Jupiter's Moons. These writings gave tremendous support to Galileo, whose discoveries were being widely doubted and denounced by church authorities. Kepler went on to provide the theory of the telescope in his *Dioptrice* (1611). A couple of years later he wrote *De vero anno quo aeternus dei filius humanam naturam in utero benedictae Virginis Mariae Assumpsit* (Concerning the true year in which the son of God assumed a human nature in the uterus of the blessed Virgin Mary), arguing that the Christian calendar was out by five years, and that Jesus had been born in 4 BC (a conclusion that is now widely accepted).

Several astronomers tested Kepler's new astronomy. For example, using astronomical observations, two transits of Venus and Mercury across the face of the Sun provided sensitive tests of Kepler's theory, under circumstances when these planets could not normally be observed. In the case of the transit of Mercury in 1631, Kepler had been extremely uncertain of the parameters for Mercury, and advised observers to look for the transit the day before and after the predicted date. Pierre Gassendi observed the transit on the date predicted, a clear confirmation of Kepler's prediction. This was the first observation of a transit of Mercury. However, his attempt to observe the transit of Venus just one month later was unsuccessful due to inaccuracies in the *Rudolphine Tables*. Gassendi did not realize that it was not visible from most of Europe, including Paris. Jeremiah Horrocks, who observed the 1639 Venus transit, had used his own observations to adjust the parameters of the Keplerian model, predicted the transit, and then built apparatus to observe the transit. He remained a firm advocate of the Keplerian model (see Applebaum, 2010; Auton, 2004; Chapman, 1990).

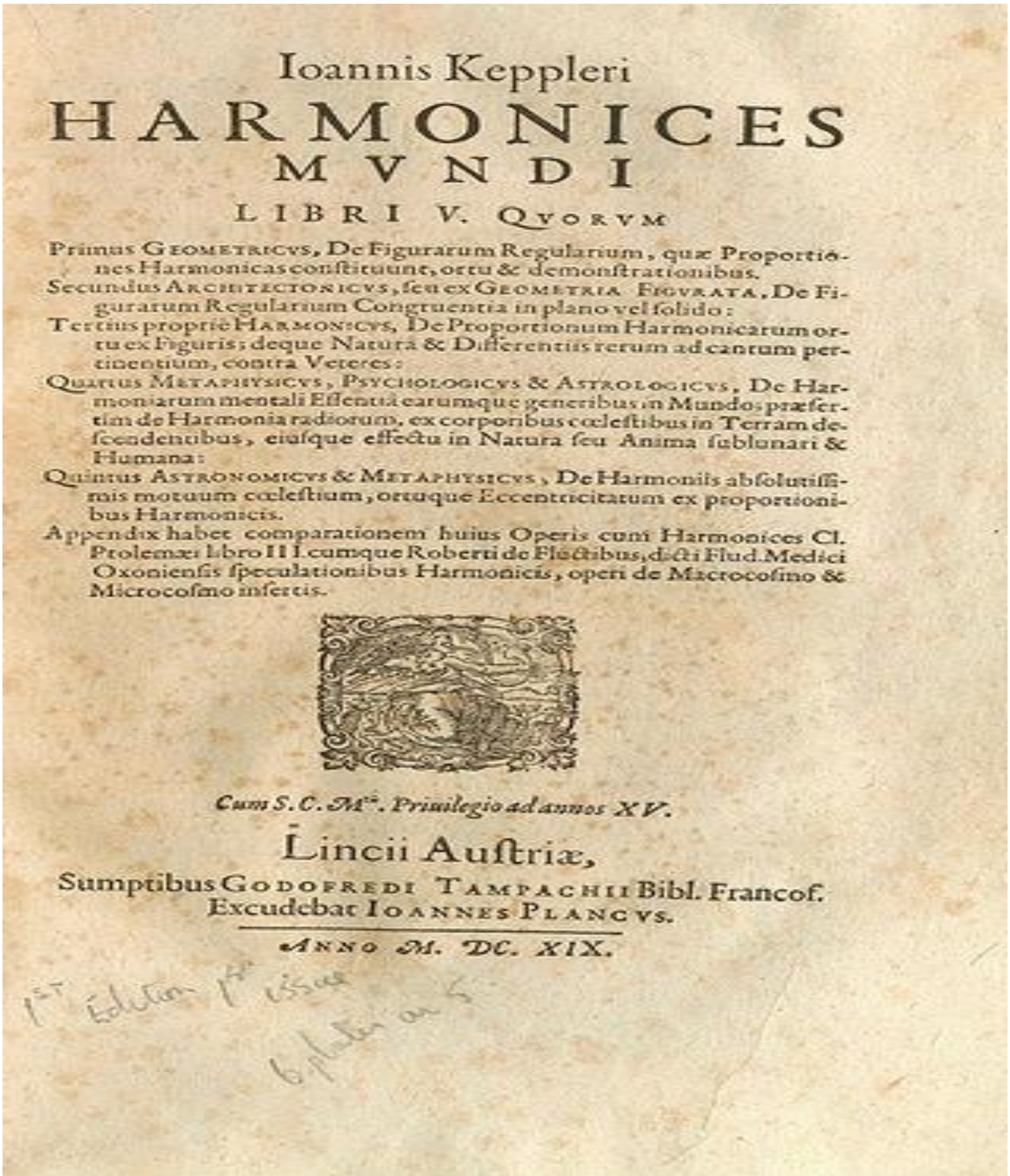
7.2 The *Harmonice Mundi*

Kepler considered the *Harmonice Mundi* (*The Harmony of the World*; see Figure 23) his greatest work. Although it was not completed and published until 1619 Kepler had planned the *Harmonice Mundi* in 1599 as a sequel to the *Mysterium Cosmographicum*. Caspar (1993: 264) relates that in the *Harmonice Mundi,* Kepler sought a unified model of cosmic harmony as could be revealed in geometry, astrology, music and astronomy, and in the course of his studies he discovered the so-called harmonic law, or third law of planetary motion (see Gingerich, 1975b).

The work consists of five books: the first is on regular polygons; the second is on the congruence of figures; the third is on the origin of harmonic proportions in music; the fourth is on harmonic configurations in astrology; and the fifth on the harmony of the motions of the planets.

In the *Harmonice Mundi*, Kepler argued that the human soul was endowed by God with the ability to know the harmony in the Universe. His favorite analogy was that the sphere of the Universe was created in the image of the Trinity. This book is the most eloquent example of Kepler's belief that astronomers were the priests of almighty God with respect to the 'Book of Nature' and that their business was to praise God's glory. Kepler proclaimed:

> ... I am stealing the golden vessels of the Egyptians to build a tabernacle to my God from them, far far away from the boundaries of Egypt. If you forgive me, I shall rejoice; if you are enraged with me, I shall bear it. See, I cast the die, and I write the book. Whether it is to be read by the people of the present or of the future makes no difference: let it await its reader for a hundred years, if God himself has stood ready for six thousand years for one to study him. (Aiton et al., 1997: 391).



Ioannis Keppleri
HARMONICES
MVNDI
LIBRI V. QVORVM

Primus GEOMETRICVS, De Figurarum Regularium, quæ Proportiones Harmonicas conſtituunt, ortu & demonſtrationibus.
Secundus ARCHITECTONICVS, ſeu ex GEOMETRIA FIGVRATA, De Figurarum Regularium Congruentia in plano vel ſolido:
Tertius propriè HARMONICVS, De Proportionum Harmonicarum ortu ex Figuris; deque Naturâ & Differentiis rerum ad cantum pertinentium, contra Veteres:
Quartus METAPHYSICVS, PSYCHOLOGICVS & ASTROLOGICVS, De Harmoniarum mentali Eſſentiâ earumque generibus in Mundo; præſertim de Harmonia radiorum, ex corporibus cœleſtibus in Terram deſcendentibus, eiuſque effectu in Natura ſeu Anima ſublunari & Humana:
Quintus ASTRONOMICVS & METAPHYSICVS, De Harmoniis abſolutiſſimis motuum cœleſtium, ortuque Eccentricitatum ex proportionibus Harmonicis.
Appendix habet comparationem huius Operis cum Harmonices Cl. Ptolemæi libro III. cumque Roberti de Fluctibus, dicti Flud. Medici Oxonienſis ſpeculationibus Harmonicis, operi de Macrocoſmo & Microcoſmo inſertis.

Cum S. C. M^tis. Priuilegio ad annos XV.

Lincii Auſtriæ,
Sumptibus GODOFREDI TAMPACHII Bibl. Francof.
Excudebat IOANNES PLANCVS.

ANNO M. DC. XIX.

1st Edition 1st issue
6 plates on 5

Figure 23: Title page of *Harmonice Mundi* (source: Wikimedia).

In the Introduction, Kepler states:

> Finite things, which are circumscribed and shaped can also be grasped by the mind: infinite and unbounded things, insofar as they are such, can be held in by no bonds of knowledge, which is obtained from definitions, by no bonds of constitutions. For shapes are in the archetype prior to their being in the product; in the divine mind prior to being in creatures, differently indeed in respect of their subject, but the same in the form of their essence. (Martens, 2000: 120).

As we know, Kepler’s greatest achievement was the formulation of the ‘Laws of Planetary Motion’, which made a fundamental break with astronomical tradition in describing the orbits of the planets as elliptical rather than circular and in recognizing that a planet’s speed is not uniform but varies at different stages of its orbit. Although, the first two Laws were contained in the l609 publication of the *Astronomia nova*, it took a further nine years to formulate the Third Law, which established a relationship between a planet’s distance from the Sun and the time it takes to complete an orbit. This was announced in the *Harmonice Mundi*. According to Job Kozhamthadam (1994: 8), Kepler “… announced this law without providing any clear clue as to how he arrived at it.” According to Koestler (1968), Kepler discovered it by ‘patient slogging’.

David Plant in *Kepler and the Music of the Spheres* (2004) is of the opinion that Kepler’s early enthusiasm for the Copernican system was inspired by the same sense of idealism that had motivated Copernicus. He could readily accept the Sun as the centre of the planetary system, but the necessity of rejecting circular orbits came as something of a shock. The circle is an archetypal symbol of harmony and perfection; Kepler recoiled with disgust when an unsightly bulge began to emerge from his analysis of the orbit of Mars. Yet the elliptical orbits eventually revealed a scheme of celestial harmony more subtle and profound than any that had gone before. Plant’s interpretation is that:

> Kepler’s, First Law states that the planets move in ellipses and that the Sun is not at the exact centre of their orbits. Each planet moves between a ‘perihelion’ point nearest the Sun and an ‘aphelion’ point furthest away. The Second Law states that the planets move faster at perihelion than at aphelion. Kepler measured their angular velocities at these extremes (i.e. how far they travel in 24 hours in minutes and seconds of arc as viewed from the Sun) and expressed this ratio as a musical interval. Saturn, for instance, moves at a rate of 106″ per day at aphelion and l35″ at perihelion. Cancelled down, the ratio 106:135 differs by only two seconds from 4:5 – equivalent to the interval of a major third. Kepler found that the angular velocities of all the planets closely correspond to musical intervals. When he compared the extremes for combined pairs of planets, the results were even more marvelous, yielding the intervals of a complete scale. Thus, the ratio between Jupiter’s maximum and Mars’ minimum speed corresponds, to a minor third; the interval between Earth and Venus to a minor sixth. Rather than the fixed-tone planetary scales of earlier schemes, Kepler’s measurements revealed ever-changing polyphonic chords and harmonies as the planets move between perihelion and aphelion. (Plant, 2004: 1).

Furthermore, Kepler shifted the focus of celestial harmony from the Earth to the Sun: “Henceforth it is no longer a harmony made for the benefit of our planet, but the song which the cosmos sings to its lord and centre, the Solar Logos.” (Godwin, 1979: 145).

Collectively, Kepler’s Laws superseded the ancient Ptolemaic concept of a spherical Universe with epicyclic motion. They provided the foundation upon which Isaac Newton (1972) was to build his epoch-making theory of universal gravitation towards the end of the seventeenth century.

To Kepler, however, the planetary ‘laws’ represented far more than the description of a physical mechanism. In the tradition of the legendary Greek philosopher Pythagoras (6th century BC), Kepler did not view science and spirituality as mutually exclusive. The deeper significance of Kepler’s Laws is that they reconcile the emerging vision of a Sun-centred planetary system with the ancient Pythagorean concept of harmonia, or universal harmony:

> Now because 18 months ago the first dawn, 3 months ago broad daylight but a very few days ago the full sun of the most highly remarkable spectacle has risen – nothing holds me back. I can give myself up to the sacred frenzy, I can have the insolence to make a full confession to mortal men that I have stolen the golden vessel of the Egyptians to make from them a tabernacle for my God far from the confines of the land of Egypt. If you forgive me I shall rejoice; if you are angry, I shall bear it; I am indeed casting the die and writing the book, either for my contemporaries or for posterity to read, it matters not which: let the book await its reader for a hundred years; God himself has waited six thousand years for his work to be seen. (Kepler, 1939b: Book V).

This exclamation is normally taken to represent Kepler’s rejoicing over discovering his Third Law, that the cube of a planet’s radius is proportional to the square of its orbital period. However, some scholars have pointed out that the cause (for his rejoicing) is in the success of the harmonical archetype, which now, thanks to the period-radius law, can give a full account of the observed structure of the planetary system. Kepler seems to be proclaiming his own success in the task at which Ptolemy failed, namely to give a true account of the harmony of the world, expressed in musical consonances, astrological aspects and the motions of the planets. Astrological harmony is an integral part of Kepler’s work, as it is of Ptolemy’s.

Kepler discovered Ptolemy’s *Harmonica* in 1617, saying that it afforded him an “… especial increase of his passionate desire for knowledge and encouragement of his purpose …”, so perhaps the “… golden vessels of the Egyptians …” referred to Ptolemy’s studies in Alexandria (1992). The apprehension that his endeavor might have to wait some time for readers who could understand it may have been justified. “But now, Urania, there is need for a louder sound while I climb along the harmonic scale of the celestial movements to higher things where the true archetype of the fabric of the world is kept hidden.” (Kepler and Hawking, 2005: 37).

Kollerstrom (2006) relates that Kepler articulated the polyphonic song of the Solar System in Book V of *Harmonice Mundi*. He expressed the hope that it would inspire musicians and one wonders whether it did so. For example, Venus and Earth in their periods expressed the ratio 5:8 which as a musical sixth he saw as quite a pleasant ratio. “The agreement is frighteningly good …” was the verdict of the astronomer, Fred Hoyle (cited in Beer, 1975: 408), concerning the tie up between musical ratios and planetary velocities as Kepler described it, and he added: “One wonders how many modern scientists faced by a similar situation in their work would fail to be impressed by such remarkable numerical coincidences”. (ibid.)

7.3 Celestial Harmony

Pythagoras discovered that the pitch of a musical note depends upon the length of the string that produces it. This allowed him to correlate the intervals of the musical scale with simple numerical ratios. When a musician plays a string stopped exactly half-way along its length an octave is produced. The octave has the same quality of sound as the note produced by the unstopped string but, as it vibrates at twice the frequency, it is heard at a higher pitch. The mathematical relationship between the keynote and its octave is expressed as a ‘frequency ratio’ of 1:2. In every type of musical scale, the notes progress in a series of intervals from a keynote to the octave above or below. Notes separated by intervals of a perfect fifth (ratio 2:3) and a perfect fourth (3:4) have always been the most important ‘consonances’ in Western music. In recognizing these ratios, Pythagoras had discovered the mathematical basis of musical harmony.

In one sense, Pythagoras had also invented much of Western science. By associating measurements of length with musical tones he made the first known reduction of a quality (sound) into a quantity (length and ratio). The understanding of nature through mathematics remains a primary objective of science today. However, as Plant (2001) relates, Pythagoras also recognized that the musical octave is the simplest and most profound expression of the relationship between spirit and matter. The ‘miracle of the octave’ is that it divides wholeness into two audibly distinguishable parts, yet remains recognizable as the same musical note – a tangible manifestation of the hermetic maxim ‘as above, so below’. The short-lived but profoundly influential Pythagorean Brotherhood sought to unite “… religion and science, mathematics and music, medicine and cosmology, body, mind and spirit in an inspired and luminous synthesis.” (Plant, 2001: 2).

The Pythagoreans used music to heal the body and to elevate the soul, yet they believed that Earthly music was no more than a faint echo of the universal ‘harmony of the spheres’. In ancient cosmology, the planetary spheres ascended from Earth to Heaven like the rungs of a ladder. Each sphere was said to correspond to a different note of a grand musical scale. The particular tones emitted by the planets depended upon the ratios of their respective orbits, just as the tone of a lyre-string depended upon its length. Another type of celestial scale related the planetary tones to their apparent rates of rotation around the Earth.

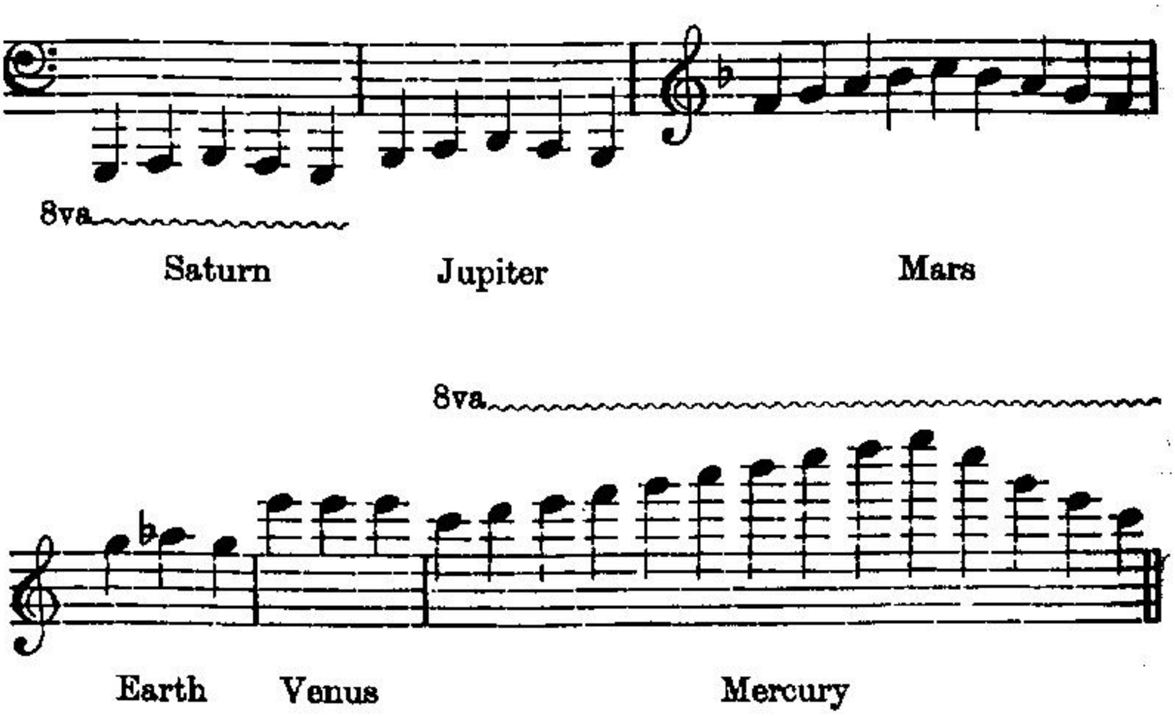


Figure 24: Kepler’s ‘Music of the Spheres’, adapted from Kepler’s own diagram in *Harmonice Mundi V*, Chapter 6 (after Kepler, 1939b).

The music of the spheres was never a fixed system of correspondences. Many variant schemes existed because each philosopher would necessarily approach it from a slightly different perspective (e.g., see Figure 24 for Kepler’s perspective). The musicologist Joscelyn Godwin comments: “... the celestial harmony of the solar system ... is of a scope and harmonic complexity that no single approach can exhaust. The nearest one can come to understanding it as a whole is to consider some great musical work and think of the variety of analytical approaches that could be made to it, none of them embracing anything like the whole.” (Godwin, 1979: 130).

Plato, Pliny, Cicero and Ptolemy are amongst the philosophers of the ancient world who contemplated the music of the spheres. The doctrine was transmitted to medieval Europe where it found its most glorious expression in the architecture of great abbeys and cathedrals consciously designed to conform to the proportions of musical and geometric harmony. The English hermeticist Robert Fludd (1574–1637) visualized grand celestial scales spanning three octaves and linking levels of existence from the sub-planetary elemental worlds to exultant choirs of angelic intelligences beyond the stars. Figure 25 illustrates one of the beautiful engravings of Fludd’s encyclopedic works that were amongst the most comprehensive descriptions of pre-Copernican cosmology ever devised (see Godwin, 1979).

Kepler and Fludd corresponded with one another, but Fludd regarded Kepler’s mathematical approach to cosmology as superficial, while Kepler regarded Fludd’s magical approach as superstitious (see Plant, 2001: Notes and References).

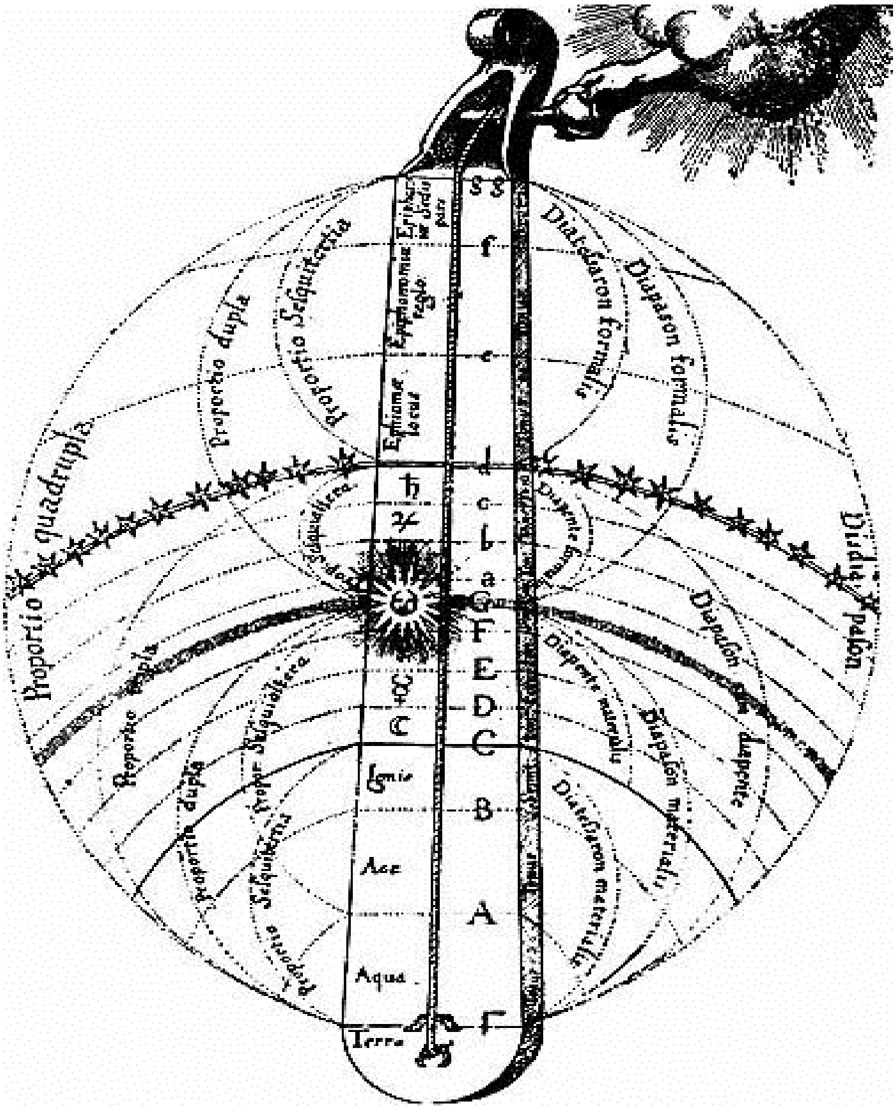


Figure 25: Fludd’s monochord (after Wikimedia).

David Plant (2001) suggests that the ideals of Pythagorean harmony inspired Copernicus himself. Copernicus spent most of his life in the fortified city of Frauenburg in Prussia fulfilling administrative duties as a canon of the cathedral chapter and devoting the rest of his time to contemplation of the cosmic harmonies. The cumbersome mathematics of the Ptolemaic system, with its maze of epicycles grafted on to reconcile various observational discrepancies, offended Kepler’s Pythagorean sense of proportion. He realized that a Sun-centred planetary system not only gave better predictions of celestial motion but could also he expressed through more elegant geometry – to the greater glory of God the Creator. Kepler’s early enthusiasm for the Copernican system was apparently inspired by the same sense of idealism. He could readily accept the Sun as the centre of the planetary system, but the necessity of rejecting circular orbits came as something of a shock. The circle is an archetypal symbol of harmony and perfection; possibly Kepler recoiled with disgust when an unsightly bulge began to emerge from his analysis of the orbit of Mars. Yet the elliptical orbits eventually revealed a scheme of celestial harmony more subtle and profound than any that had gone before:

> Kepler's measurements revealed ever-changing polyphonic chords and harmonies as the planets move between perihelion and aphelion. Furthermore, he had shifted the focus of celestial harmony from the Earth to the Sun: "Henceforth it is no longer a harmony made for the benefit of our planet, but the song which the cosmos sings to its lord and centre, the Solar Logos." (see Godwin, 1979: 145).

At the conclusion of the *Harmonice Mundi*, Kepler appended an *Epilogue Concerning the Sun by Way of Conjecture*, which provides a poetical summary of the development of his ideas from Pythagoras through to Cusa (in 1440):

> From the celestial music to the hearer; from the Muses to Apollo the leader of the Dance; from the six planets revolving and making consonances, to the Sun at the center of all the circuits, immovable in place, but rotating into itself ...
>
> Not only does light go out from the Sun into the whole world, as from the focus or eye of the world, as life and heat from the heart, as every movement from the King and mover, but conversely also by royal law these returns, so to speak, of every lovely harmony are collected in the Sun from every province in the world, nay, the forms of movements by twos flow together and are bound into one harmony by the work of some mind ...
>
> By that commencement, at the same time, he [Proclus] indicates what the Pythagoreans understood by the word of fire ... and at the same time he transfers his whole hymn from the body of the Sun and its quality and light, which are sensibles, to the intelligibles, and he has assigned to that intellectual fire of his—perhaps the artisan fire of the Stoics—to that created God of Plato, that chief or self-ruling mind, a royal throne in the solar body, confounding into one the creature and Him through Whom all things have been created. But we Christians, who have been taught to make better distinctions, know that this eternal and uncreated "Word," Which was "with God" and which is contained by no abode, although He is within all things, excluded by none ...
>
> As for the remainder concerning that abode, we believe it superfluous to inquire into it too curiously or to forbid the senses or natural reasons to investigate that which the eye has not seen nor the ear heard and into which the heart of man has not ascended; but we duly subordinate the created mind—of whatsoever excellence it may be—to its Creator, and we introduce neither God-intelligences with Aristotle and the pagan philosophers nor armies of innumerable planetary spirits with Magi, nor do we propose that they are either to be adored or summoned to intercourse with us by theurgic superstitions, for we have a careful fear of that …
>
> but if it is permissible, using the thread of analogy as a guide, to traverse the labyrinths of the mysteries of nature, not ineptly, I think, will someone have argued as follows: The relation of the six spheres to their common center; thereby the center of the whole world, is also the same as that of unfolded Mind (dianoia) to Mind (nous), according as these faculties are distinguished by Aristotle, Plato, Proclus, and the rest; and the relation of the single planets' revolutions in place around the Sun to the unvarying rotation of the Sun in the central space of the whole system ... is the same as the relation of unfolded Mind to Mind, that of the manifold discourses of ratiocination to the most simple intellection of the mind. For as the Sun rotating into itself moves all the planets by means of the form emitted from itself, so too—as the philosophers teach—Mind, by understanding itself and in itself all things, stirs up ratiocinations, and by dispersing and unrolling its simplicity into them, makes everything understood. And the movements of the planets around the Sun at their center and the discourses of ratiocinations are so

> interwoven and bound together that, unless the Earth, our domicile, measured out the annual circle, midway between the other spheres—changing from place to place, from station to station—never would human ratiocination have worked its way to the true intervals of the planets and to the other things dependent from them, never would it have constituted astronomy. (Wallis, 1939).

7.4 Discussion

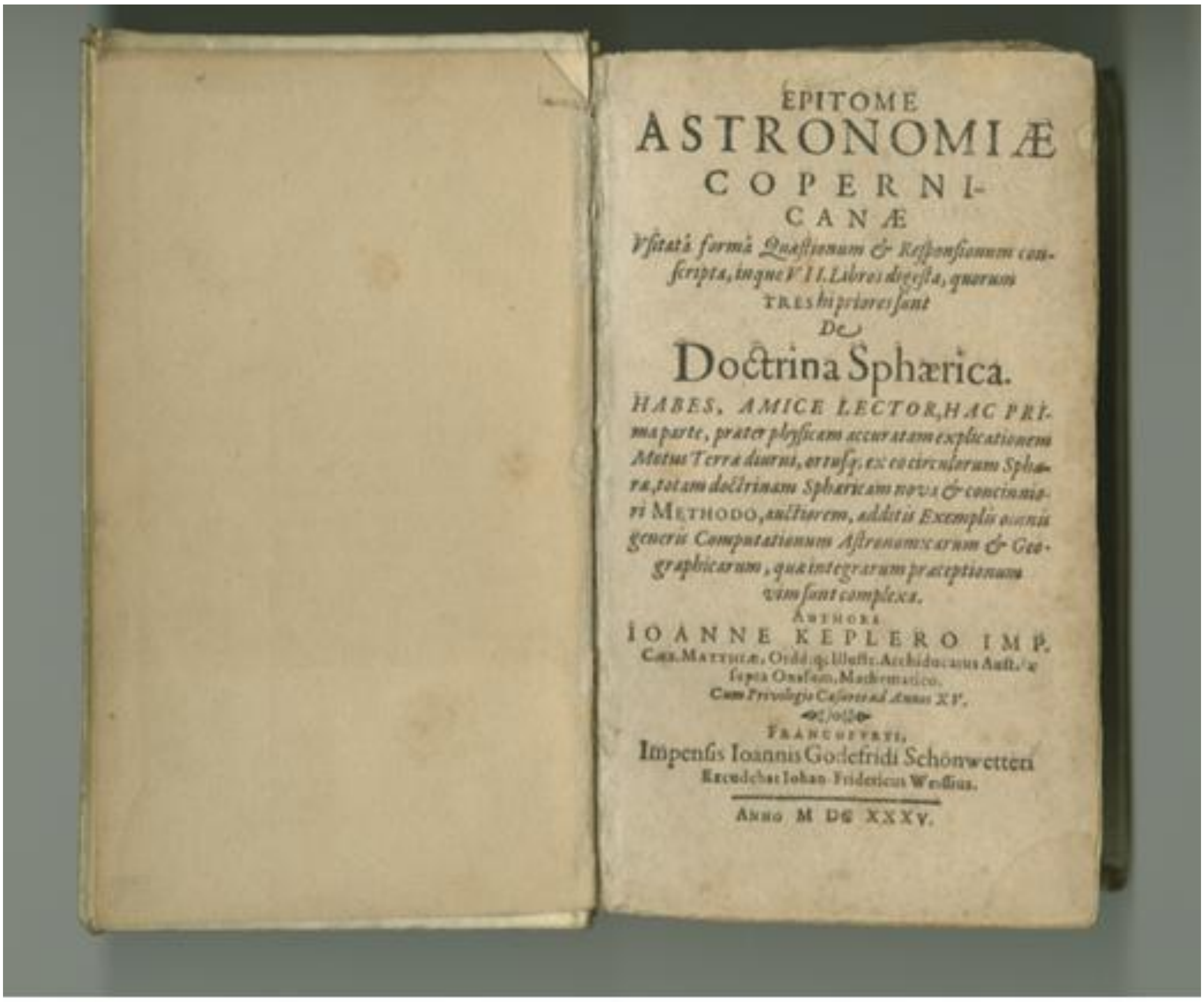
Kepler developed his completed hypothesis of planetary motion in the *Harmonies of the World.* The most historically-important result in the *Harmonice Mundi* is what is now known as Kepler's Third Law of Planetary Motion. Some scholars have tended to dismiss the spiritual dimension to Kepler's work as either the remnants of a deeply ingrained 'medievalism', which he was unable to shake off or, even less charitably, as the fantasies of an over-worked mind. His vision of the music of the spheres, however, is based upon the facts of astronomical measurement. As we have seen, Hoyle thinks that the correspondence between musical ratios and planetary velocities, as described by Kepler, is "… frighteningly good." (cited in Kollerstrom, 1989: 167). The Keplerian scholar Francis Warrain extended Kepler's researches and found that the angular velocities of Uranus, Neptune and Pluto, which were unknown during Kepler's lifetime, also correspond to harmonic ratios (see Warrain, 1942: 136). For some scholars the music of the spheres represents Kepler's poetic intuition, yet, even for them, the dynamics of the Solar System were first laid bare by Kepler's mathematical genius, and are directly analogous to the laws of musical harmony.

Yet, just as Kepler's writing style apparently made it difficult for astronomers to identify the two laws of planetary motion in the body of the *Astronomia nova*, it also barred an understanding of Kepler's overall system in the *Harmonice Mundi*. In order to right things, Kepler decided to produce a general astronomy textbook, and between 1617 and 1621 he published his *Epitome Astronomiae Copernicanae* (*Epitome of Copernican Astronomy*), which became the most influential introduction to heliocentric astronomy.

Chapter 8 The *Epitome of Copernican Astronomy*

Chapter 8 The *Epitome of Copernican Astronomy*

8.1 The Purpose of the *Epitome*
8.2 Traditional Arguments
8.3 Kepler’s Rejection of the Traditional Views
8.5 Discussion



EPITOME
ASTRONOMIÆ
COPERNI-
CANÆ
Vſitatâ formâ Quæſtionum & Reſponſionum conſcripta, inque VII. Libros digeſta, quorum
TRES hi priores ſunt
De
Doctrina Sphærica.
HABES, AMICE LECTOR, HAC PRIMA parte, præter phyſicam accuratam explicationem Motus Terræ diurni, ortuſq; ex eo circulorum Sphæra, totam doctrinam Sphæricam nova & concinniori METHODO, auctiorem, additis Exemplis omnis generis Computationum Aſtronomicarum & Geographicarum, quæ integrarum præceptionum vim ſunt complexa.
AUTHORE
IOANNE KEPLERO IMP.
Cæs. Matthiæ, Ordd. q. Illuſtr. Archiducatus Auſt. ſupra Onaſum, Mathematico.
Cum Privilegio Cæſareo ad Annos XV.
FRANCOFURTI,
Impenſis Ioannis Godefridi Schönwetteri
Excudebat Iohan. Fridericus Weiſſius.
ANNO M DC XXXV.

Figure 26: Title page of the *Epitome of Copernican Astronomy*, the posthumous edition of 1635, in which all seven books are published together.

Chapter 8 The *Epitome of Copernican Astronomy* (*Book IV*)

8.1 The Purpose of the *Epitome*

As we know, Kepler presented an account of his work in the *Astronomia nova* in the form of a rhetorical personal narrative, however, as noted, Kepler's writing style combined with his technical complexities made it difficult for some astronomers and others of his time to acquire a clear understanding of his overall system.

After 1609, while continuing his work on the problem of the motions of planets, and their causes, Kepler became aware of these difficulties and decided to write a didactic and systematic presentation of his astronomy. Over several years, while he was in Linz, Kepler produced a general astronomy textbook and published his *Epitome Astronomiae Copernicanae* or *Epitome of Copernican Astronomy* (hereafter *Epitome*). In the *Epitome*, for ease of communication Kepler adopts a question and answer (or Socratic) dialogue format.

He modeled his title page (see Figure 26) after the highly successful *Introduction to Astronomy* (1582) published in a number of editions by his former Tübingen Professor, Michael Mästlin. But, whereas Mästlin had deemed it prudent pedagogical practice to keep Copernicanism out of an elementary textbook, which he therefore entitled simply *Epitome of Astronomy*, Kepler emphasized his open espousal of the new cosmology by inserting the provocative label 'Copernican'. Despite the title however, and recalling that he wrote the *Astronomia nova* specifically for astronomers, it epitomizes Keplerian, rather than Copernican astronomy; purposefully written by Kepler for astronomers and a general audience.

Published between the years 1618 and 1621, Kepler's *Epitome* comprised three volumes and contained seven books: Volume I contains three books; Volume II contains book four, and Volume III contains books five through seven. Though consisting of seven books, only Book V, supported in places by Book IV, contains the really innovative work.

The *Epitome* introduced the heliocentric theory to a broad audience of astronomers throughout Europe, and to the general public, and following Kepler's death it was the main vehicle for spreading his ideas. Between 1630 and 1650 it was the most widely-used astronomy textbook, winning many converts to ellipse-based astronomy.

Although, the *Astronomia nova* contained the principles, the methods and subject matters of Kepler's new astronomy, Kepler did not explicitly point them out argumentatively or mathematically as he would do in the *Epitome.* Technically, the *Epitome* is less demanding than the *Astronomia nova.* In the *Epitome* Kepler combines much of his work in the *Astronomia nova* into what he believes to be a more accessible understanding of the planetary orbits. The *Epitome* also contained all three of his so-called 'Laws', the Third Law having been arrived at in the earlier *Harmonice Mundi.*

Kepler intended the *Epitome* as a basic beginning text in astronomy, and as noted above, organized it as a series of Socratic-like questions and answers that effectively constituted the natural pedagogical equivalent of Mästlin's *Epitome of Astronomy.* Here, as was his goal in the *Astronomia nova*, Kepler wanted to establish upfront what he understood the issue as being and to define his subject matter. In the Introduction he begins purposefully with a rhetorical question: "What is Astronomy?" His aim here is obviously to obtain a definition, which he already knows. For Kepler, astronomy was interdisciplinary. Astronomy for Kepler, should be the study of the heavens from a moving Earth and the causes of the appearances observed, and it must involve the study physics and metaphysics.

8.2 Traditional Arguments

Kepler is sufficiently trained in traditional astronomy and demonstrates by his clear exposition of what he understands as being the important issues. First, he states the traditional view:

> The ancients wished it to be the office of the astronomer to bring forward such causes of the apparent irregularity as would bear witness that the true movement of the planet or spheres is most regular, most equal, and most constant, and also of the most simple figure, that is, exactly circular. And they judged that you should not listen to him who had laid down that there was actually any irregularity at all in the real movements of these bodies. (Kepler, 1939a: 929a).

Kepler grants that there must be regularity in the planetary movements, and that the periodic times of the planets must have some relation to each other and to the planetary path. Clearly, Kepler does not reject the traditional view altogether. However, what he does reject is the traditional assumption that therefore the planets' movements must be circular and uniform. As we have seen, uniform circularity had been a cardinal point for his predecessors Ptolemy, Copernicus, and Brahe, but, in the *Astronomia nova,* Kepler discovered that the planetary path was neither uniform nor circular.

Arguing for his new system, it is in Book IV, Part III, Section I, "The Causes of the True Irregularities", where Kepler deliberately rejects the principles of traditional astronomy. Kepler first lists the traditional arguments:

- The first argument of the traditional framework was that the heavenly bodies are of a special nature. Whereas all terrestrial things are according to Aristotelian physics, are made up of the four elements (Earth, air, fire, and water), the celestial bodies are made up of the fifth element ('quintessence'). This fifth element is of such perfection that the heavenly bodies suffer no change or irregularity. That is why only uniformly circular motion is appropriate for them.

- The second argument is that the causes of planetary motion are minds or intelligences, which are attached to the planets. "And accordingly…the figures of the movements, on account of the very nature of the minds, are most perfect circles."

- The third argument is also derived from a principle of Aristotelian physics and is drawn from the first reason. The principle is that every (celestial) body has a motion proper to it. Heavy bodies have a natural downward motion, while light bodies move naturally upward. The natural movement of the Earth is down, while that of fire is up. The heavenly bodies are not made up of either Earth or fire, or water, or air, but of the fifth element. This fifth element must have a motion proper to it, and its natural motion is uniform circular motion.

- The fourth argument is that the circle is the most perfect geometrical figure and so necessarily is appropriate to the most perfect bodies.

8.3 Kepler's Rejection of the Traditional Views

As mentioned earlier, rhetoric like revolution can be a way to redefine reality. Kepler abilities as a philosophical rhetor are amply demonstrated in the *Epitome* whereby he systematically rejects each of the foregoing arguments by the use of new definitions. The arguments by which Kepler refutes the traditional assumptions are presented not as hypotheticals but as definitions, new definitions of familiar phenomena.

First, Kepler agrees that the heavenly bodies are of a special nature, but he insists nevertheless that they are *physical bodies* and as a result, some irregularity in their motion is accounted for simply by their being bodies. As bodies, they are subject to laws of motion. For example, Kepler maintains that there is a certain amount of attraction between two heavenly bodies and that this attraction is a function of the distance between them.

The notion of an attraction between bodies is something quite new. Kepler likens this attraction to magnetism and explains it in a highly complicated way. Nevertheless, there is here an anticipation of Newton and his law of universal gravitational attraction between bodies. The notion that magnetism, a terrestrial phenomenon, can be applied to heavenly bodies is an idea foreign to the ancient astronomers, for it implies that the heavenly bodies are constituted just like the terrestrial ones.

In refuting the second reason of the ancients, Kepler again uses modern notions. He denies that the heavenly bodies are moved by ‘intelligences’ or minds. A truer philosophy, he points out, referring to his own doctrine, places the cause of the motion in the natural power of the bodies. The combination of a body’s own natural power with the attraction of other bodies’ results in motion that is less perfect than circular motion.

Kepler dismisses the third argument simply because he grants that heavy bodies move down, light ones up. Furthermore, heavenly bodies traverse a closed path; i.e., they always return to where they started. But this, Kepler says, does not show that the path must be circular, but merely that it must be a closed curve, such as the ellipse also is.

With respect to the fourth argument, Kepler grants that the circle is the most perfect figure. He denies, however, that it is appropriate to planetary motion, since planets are bodies and are not, as the ancients thought, moved by ‘intelligences’.

8.4 Discussion

The *Epitome* became Kepler’s most influential work (Figure 27). It was the first astronomical treatise in which the doctrine of circles, real or hypothetical, carrying the various planets, was completely abandoned in favor of a physical explanation of planetary motions. It contained all three of Kepler’s comprehensive principles or ‘Laws’ and attempted to explain heavenly motions through physical causes.

In the *Epitome*, Kepler extended the first two laws of planetary motion to all the planets as well as the Moon and the Medicean satellites of Jupiter.

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ſeret, vt ex Homero patet, in vna die naturali quatuor ſolum, alij duodecim, poſteri 24. ſtatuerunt, quod retinent Aſtronomi, ut infra dicetur.

Quomodo numerant Aſtronomi horas & dies?

Vel à media nocte ab vno in 24. mediæ noctis ſequentis, vt Prutenicæ. Vel à Meridie numeratio iterum 24. vſq; ad Meridiem ſequentem, & dies interdum nominatur completo, interdum currens, cujus pars ſunt horæ expreſſæ.

Quot ſunt Horarum Genera?

Totidem quot dierum: quædam enim dierum Æquinoctiales [illegible], quædā Temporales [illegible], quod pro ratione temporum totius anni variam naciſcantur longitudinem.

Quid eſt Hora æquinoctialis?

Eſt pars viceſima quarta [illegible], ſeu diei noctiſque naturalis junctorum.

Quomodo dividuntur Hora Æquinoctialis Aſtronomica?

Dividitur vt Circuli alicujus pars 360. Gradus, vel Tempus, in minuta ſexaginta, ſic vt 15. Minuta faciant horæ quadrantem. Minutum vnum in 60. ſecunda abit, vnum ſecundum in 60. tertia; & ſic continuè, quo vſque opus eſt.

Compara ſectiones Æquinoctialis Horæ cum pulſu humano?

In homine valente robuſto & perfectæ [illegible] complexionis melancholicæ, aut conſeneſcēte, ſere ſingulis ſecundis exiſtunt ſinguli pulſus Arteriæ, nullo diſcrimine inter ſiſtolen, & diaſtolen, id eſſent in vno Minuto

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[illegible] pulſus ſexaginta: ſed rara eſt hæc tarditas; vulgariter numerantur 70. in Cholericis & fœminis & 80. [illegible] in terna ſecunda; Breviter in una hora quatuor millia plus minus.

Quomodo efficitur dies naturalis?

Revolutione apparente Solis, ab ortu per Meridiem in occaſum imumque cœli, ſed [illegible] in ortum; quæ revera eſt revolutio Telluris, & in eā Horizontis, per imaginationem in cœlum uſque continuat, circa axem Telluris velut immobilem, ut libris antecedentibus eſt demonſtratum.

Quæ ſunt hujus Revolutionis Metæ?

Per centrum Solis S immobile, perque Telluris axē PC, planum imaginatione concipitur traductum. Ergo

locus in ſuperficie terræ quiſcunque, cōſtitutus in hoc plano habet initium diei Naturalis, quod vel Meridies

S 4

Figure 27: In the *Epitome III*, *Part II*, Kepler illustrates the revolution of the Earth around the Sun. In the adjacent text the reader is told that the Sun does not move (source: Mathematical Sciences Digital Library).

Shortly after the publication of the third volume of the book, in 1619 the Catholic Church placed the *Epitome* in the index of prohibited books. Yet, astronomers throughout Europe read the *Epitome*, and following Kepler's death, it was the main vehicle for spreading his new ideas.

The *Epitome* was a significant work that is rhetorically justified. As Martens (2000) suggests, the *Epitome* was a significant work for three reasons. First, it was written as a textbook for a general audience and, as a result, is a good resource for determining what Kepler believed he needed to do to render his new astronomy plausible. Here we see Kepler's metaphysics featured prominently, which suggests that he considered it part of his rhetorical arsenal. Second, his mature physics, metaphysics, and astronomy are finally presented together in one work, which allows for further exploration not only of the evolution of his thought but also on how he conceived of the relationship between these diverse elements.

Chapter 9 Keplerian Astronomy after Kepler

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9.1 A Brief Summary of Kepler's Laws

According to J.L. Russell (1964), Kepler's new ideas were rather slow in establishing themselves. Russell reports that and until about 1630, there are few references to them in the literature of the time. However, from then onwards, interest in them increased rapidly. In particular, the principle of elliptical orbits or the First Law had been accepted by most of the leading astronomers in France before 1645 and in England by about 1655. The First Law also received quite strong support in Germany, Belgium and Holland.

Russell found that the Second Law had a more chequered history. It was enunciated in its exact form by a few writers and was used in practice by some others without being explicitly formulated, but the majority, especially after 1645, preferred one or another of several variant forms that were easier to use but only approximately correct.

J.R. Voelkel (2001) relates that when Kepler returned to his cosmological writing in his *Harmonice mundi* he took up the relationship of the planets' distances and periods. Almost accidentally, he discovered the Third Law of Planetary Motion – that the ratio of the square of a planet's period to the cube of its distance was constant for all of the planets. This finding fit only awkwardly within the book's broader argument that God had painstakingly arranged the planets' distances and periods so that their angular motions viewed from the Sun would embody all musical harmonies. The Third Law attracted less interest than the others did, chiefly perhaps because it had no satisfactory theoretical basis although at least six writers correctly stated it during this period.

Kepler is now famous for his three Laws of Planetary Motion. Although, not stated explicitly as 'laws' in the *Astronomia nova*, the First and Second Laws are expressed today in many different mathematical formats.

9.1.1 The First Law

The First Law states that the planets move in ellipses around the Sun, and one of the foci of the ellipse is occupied by the Sun. The other focus is in empty space. An ellipse is an oval figure (see Figure 28). There are various equivalent definitions of it; the following is one of them. An ellipse is a closed curve such that, for any point on it, the sum of the distances from this point to the foci is constant. If the curve in Figure 28 is an ellipse, then F_1 and F_2 are the two foci of the ellipse.

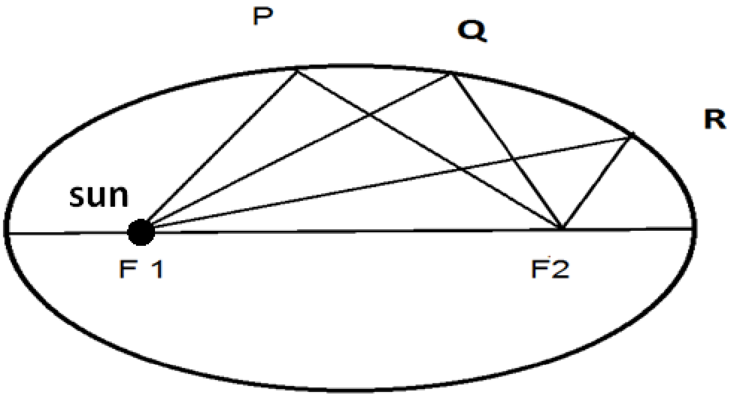

Figure 28: Kepler's 'First Law of Planetary Motion': a modern view.

9.1.2 The Second Law

The second law (Figure 29) tells us how long the planet takes to traverse any portion of its orbit. For Ptolemy and Copernicus this matter was simple. Since the orbit was composed of circles and since motion on the circles was uniform, the length of time a planet takes to transverse a given arc of a circle is simply proportional to the length of that arc. It takes one and a half times as long to traverse an arc of 45º as it takes to traverse an arc of 30º, and twice as much time to traverse an arc of 60º as it does an arc of 30º.

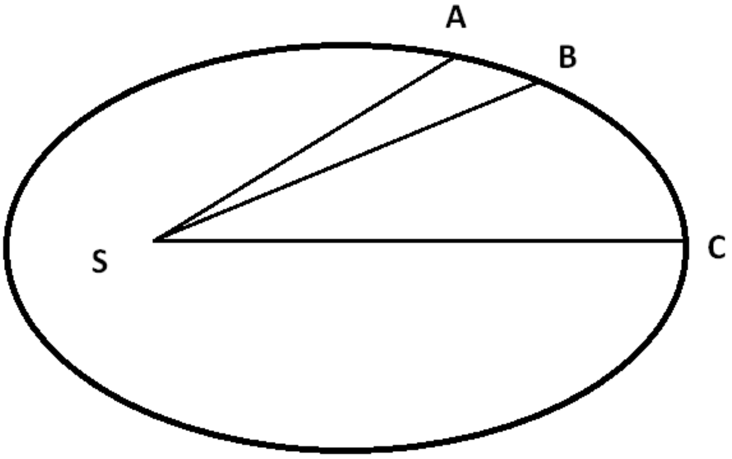

Figure 29: Kepler's 'Second Law of Planetary Motion', a modern view.

With an elliptical orbit, things are much more complicated then they are in the case of a circle. Different parts of the ellipse curve unequally, and it is not possible to measure the length of any part of the elliptical orbit simply in terms of the angle at the center, as can be done in a circle. Furthermore, the planet moves with varying speed in its orbit, so that equal portions of the ellipse are not traversed in equal times. Kepler discovered, largely through painstaking work on the planet Mars, the following remarkable fact: the time spent by this planet in traversing a part of its elliptical orbit is proportional to the area swept out by the line drawn from the Sun to the planet. If, for instance, in Figure 30, the area SAB, is one third the area SBC, then the planet will take one third as long to travel from A to B as it does to travel from B to C.

9.1.3 The Third Law

In the *Harmonice Mundi,* Kepler introduced the discovery of his Third Law, lamenting that:

> On the 8th of March of this year 1618, if exact information about the time is desired, it appeared in my head ... [but I] rejected it as false. Finally, on May 15, it came again and ... conquered the darkness of my mind, whereat there followed such an excellent agreement between my seventeen years of work at the Tychonic observations and my present deliberations ... it is entirely certain and exact that the proportion between the periodic times of any two planets is precisely one and a half times the proportion of the mean distances. (Caspar, 1993: 286).

Kepler's Third Law of Planetary Motion concerns two or more planets. Kepler's Third Law of was developed using algebraic equations, rather than geometrical shapes and patterns. This Law shows how the ratio of the squares of the revolutionary periods for two planets is equal to the ratio of the cubes of their semi-major axes. In Equation (1) below, T represents the period and R represents the length of its semi-major axes. The subscripts '1' and '2' distinguish quantities for planet 1 and 2 respectively.

Kepler's Third Law establishes that a definite relationship exists between the periodic times of the planets (the length of time for one revolution around the Sun) and their distances from the Sun. Since the First Law tells us that planets move in ellipses, the actual distance of a planet from the Sun varies in the course of a revolution. The 'distance' which the Third Law employs, therefore, is the average or mean, distance of the planet from the Sun. The greater the mean distance of a planet, the greater its periodic time, that is, the slower it moves. If the periodic times of two planets are T_1 and T_2 and if their mean distances from the Sun are R_1 and R_2, then this Law can be expressed as:

$$\frac{T_1^2}{T_2^2} = \frac{R_1^3}{R_2^3} \tag{1}$$

where T = time/period and R = distance.

The squares of the periodic times of two planets are to each other as the cubes of their mean distances from the Sun. Sometimes the Third Law is expressed in different but equivalent terms, such that the periodic times are to each other as the three-half powers of the distances:

$$\frac{T_1}{T_2} = \left[\frac{R_1}{R_2}\right]^{3/2} \tag{2}$$

where T = time/period and R = distance.

This Law can be illustrated using the Earth and Mars. The periodic time of Earth is one year, that of Mars, 1.881 years. $(1.881)^2 = 3.53$, while the square of 1 is, of course, 1. Hence, the square of the periodic time of Mars is to the square of the periodic time of the Earth as

$$\frac{3.53}{1} = 3.53 \tag{3}$$

If the distance of the Earth from the Sun (approx. 93,000,000 miles) is called 1, then the distance of Mars from the Sun (which actually is 141,700,000 miles) will be 1.524. The cube of 1.524 is 3.539 while the cube of 1 is, again, 1. Hence, the cube of the distance of Mars is to the cube of the distance of the Earth as

$$\frac{3.53}{1} \quad \textbf{or} \quad \mathbf{3.539} \tag{4}$$

The Third Law tells us more than this, however; it gives a numerical relation between distance and time. Figure 30 represents a plotting of the above calculations:

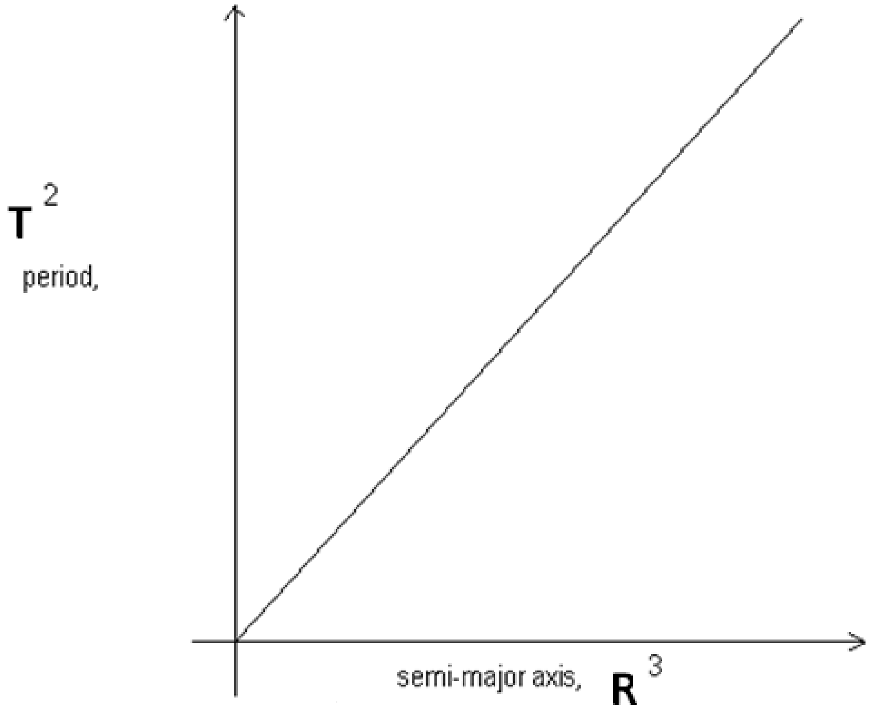

Figure 30: A graphical representation of Kepler’s ‘Third Law of Planetary Motion’, where T = time/period and R = distance.

9.2 The Reception of Kepler’s New Astronomy

As we saw in Chapter 7, Kepler’s contemporaries did not immediately accept his system. According to Russell, the *Astronomia nova* attracted little attention when first published in 1609. As Russell (1964) interprets it:

> Historians of seventeenth-century science have frequently asserted that Kepler's laws of planetary motion were largely ignored between the time of their first publication (1609, 1619) and the publication of Newton's Principia (1687). In fact, however, they were more widely known and accepted than has been generally recognized. Kepler's ideas were, indeed, rather slow in establishing themselves, and until about 1630, there are few references to them in the literature of the time. But from then onwards, interest in them increased fairly rapidly. In particular, the principle of elliptical orbits had been accepted by most of the leading astronomers in France before 1645 and in England by about 1655. It also received quite strong support in Germany, Belgium and Holland. The second law had a more chequered history. It was enunciated in its exact form by a few writers and was used in practice by some others without being explicitly formulated, but the majority, especially after 1645, preferred one or another of several variant forms which were easier to use but only approximately correct. The third law attracted less interest than the others, chiefly perhaps because it had no satisfactory theoretical basis, but it was correctly stated by at least six writers during the period under review. Between about 1630 and 1650 Kepler's *Epitome Astronomiae Copernicanae* (in which all three laws were clearly formulated) was probably the most widely read work on theoretical astronomy in northern and Western Europe, while the majority of astronomers as the most accurate planetary tables available regarded his Rudolphine Tables, which were based upon the first two laws.

As Russell observes, Kepler's three-pronged elemental attack on astronomical science eventually challenged the theoretical structure of traditional astronomy. Kepler's effort was an innovative attempt to render astronomical reality from celestial appearances. In the *Astronomia nova,* Kepler placed both of the ancient scientific traditions of astronomy and physics together to found a new kind of theory of the motions of the planets – a theory that provided causal reasons for the facts of positional astronomy.

Kepler's new principles, methods and subject matters replaced those of traditional astronomy. Indeed, each element was an innovation and revolutionary and they most certainly contributed to the acceptance of heliocentrism.

However, as Cohen (1985) suggests in *Revolution in Science*, we must ask whether it was a self-contained or personal revolution or a general one. In addition, did it produce in its time, and in and of itself, a revolution in science? Alternatively, did it remain as just a revolution on paper until someone else realized its potential? Numerous commentators have addressed these questions.

As Koestler (1960: 223) notes: "The three Laws are the pillars on which the edifice of modern cosmology rests; but to Kepler they meant no more than bricks among other bricks for the construction of his baroque temple." Thus, for Koestler at least, Kepler did not understand how influential his work would become to later scientists.

In the past four decades, the history of Kepler's three laws has been pursued in some depth, and our knowledge of how his astronomical innovations were received by his contemporaries has been expanded.

In "Keplerian astronomy after Kepler …" Applebaum (1996: 456) divides the reception of Kepler's astronomical ideas and heliocentrism in the seventeenth century into three periods: (1) from 1609 to 1630, (2) 1630 to 1660, and (3) until Newton's *Principia* in 1687. Although, seemingly arbitrary, these periods were divided by the following discoveries that eventually led to the complete acceptance of heliocentrism whereby:

- Kepler introduced the idea that the orbits of the planets were elliptical rather than circular.
- Using the newly-invented telescope, Galileo discovered the four large Moons of Jupiter (evidence that that the Solar System contained bodies that did not orbit Earth), the phases of Venus (the first observational evidence for Copernicus' theory) and the rotation of the Sun about a fixed axis as indicated by the apparent variation in the motion of sunspots.
- Newton proposed universal gravity and the inverse-square law of gravitational attraction to explain Kepler's elliptical planetary orbits.

Yet, the *Astronomia nova* was (and remains) a difficult book to read. It is diffuse, and much of it is simply a record of Kepler's early unsuccessful attempts to solve the problem of the orbit of Mars. "Out of a total of 337 pages, it is not until page 284 of the *Astronomia nova* that the first two laws are finally enunciated. Kepler and his contemporaries were quite unfamiliar with the properties of ellipses; his mathematical approach to them seems therefore clumsy and unsystematic, while his readers were even less qualified than he was to understand their properties and to apply them to astronomical calculations." (see Russell, 1964: 6).

Some scholars have accounted for a lack of enthusiasm and acceptance by Kepler's readers due to distaste for his mysticism, prolixity, stylistic clumsiness, his intricate and mistaken calculations, his emphasis on causality, and his peculiar insistence on discarding the traditional circles and uniform circular motion. Kepler's area rule for example violated traditional conceptions of the nature of astronomy, and was difficult to apply. Furthermore, even those few who were willing to consider Kepler's and Copernicus's heliocentric views (including Kepler's old mentor, Mästlin) rejected his notion of a celestial physics governed by the same causal law as Earthly phenomena.

During Johannes Kepler's lifetime (1571–1630) it is apparent that few astronomers accepted his new astronomical ideas, and although the leading natural philosophers were aware of Kepler's elliptical planetary orbits, most hardly mentioned them, or were noncommittal.

When examining Kepler's science, one must be mindful of the fact that any successful theory that followed Kepler has had to account for the regularities that he had demonstrated. Kepler's theory could be rejected based on the physical assumptions that underwrite it, some of which did not comply with widely-accepted Aristotelian ideas, but it could not be denied that the Keplerian hypotheses give a good mathematical account of ‘the appearances’. In effect, the theory of the *Astronomia nova* did to the theories of Ptolemy, Copernicus and Brahe what Einstein’s did to Newton’s in a much later time: it invoked a new conceptualization of the regularities accounted for by the older theory and delivered an account, on the same conceptual basis, of regularities previously unperceived. Most of practical astronomy from the period between Kepler and Newton (1972) was devoted to reformulating Kepler’s astronomy into traditional forms. Applebaum observes that:

> The very singling out of Kepler’s “laws” from among his multi-faceted encounter with astronomy betrays the presentist character of this perception of an interesting historical problem: the reception of Kepler’s astronomical ideas. Although the term “law” was already being used in the seventeenth century to characterize fundamental principles of natural philosophy, it seems to have been applied to certain of Kepler’s rules governing planetary motion only at a later date, beginning in the eighteenth century..., Epistemological and historiographical issues are here closely intertwined. The focus on the reception of his laws tends to obscure Kepler’s transformation of his discipline and of the new sorts of questions astronomers were being compelled to ask as a result of having received the fruit of his labors. (Applebaum, 1996: 452).

During the period following the publication of the *Astronomia nova* Galileo was the first person of note who was aware of Kepler’s new ideas. Kepler and Galileo corresponded, but a*s* Applebaum (1996: 455) and others have observed, “Galileo’s relationship to Kepler has caused even greater puzzlement and generated a literature far greater in volume than that devote to the rest of Kepler’s contemporaries combined.” While praising Kepler, Galileo seems to have over-looked Kepler’s discoveries concerning the shape and nature of the planetary paths. For the historian Koyré (1992), Galileo’s ignoring of the work of Kepler was a profoundly troubling fact.

CHAPTER 10 CONCLUSION

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It is impossible to give a brief description of Kepler’s contributions to the several fields of study upon which he left his mark; I should therefore like to make sure that the intended scope of this paper is not overstated. I have dealt not with astronomy or physics generally, but with Kepler’s efforts to address some of the key problems of traditional astronomy that prevailed during his time and as generally represented in the astronomical hypotheses of Ptolemy, Copernicus and Brahe. Their astronomical models represented a traditional framework and addressed an apparent reality, where attempts to account for the known Universe geometrically were based upon ‘the way things ought to be’. Traditionally, the role of the astronomer was to describe nature, but Kepler made the all-important leap from the descriptive mode to the explanatory mode. Kepler innovated and sought ‘the way things are’.

Historians dub the new astronomy the ‘Copernican revolution’, but in truth it should be the Keplerian revolution because the real innovations and discoveries come from Kepler. As Mittelstrass (1975: 1) suggests:

> If we accept that a scientific revolution consists not of changes in the individual meanings of terms, but of a change in the structure of the system of knowledge we can show that Kepler’s work is a turning point because of the methods he employed, and we may allow ourselves to refer to a Keplerian Revolution in the history of the natural sciences. Kepler’s laws altered the axiomatic structure of former (even Copernican) astronomy, which had been based on the qualitative (later also quantitative) construction of kinematic models, based on the principles that all planetary motions must be circular in form and uniform in angular velocity. Kepler is also the first to formulate clearly the idea that the traditional division of astronomy into a mathematical (kinematic) and a physical (dynamic) part can only be superseded by taking a new attitude to causality. In considering the force causing the motions he gives a precise formulation of the idea of a mutual attraction between two bodies, its size depending on their separation. This force acts towards a point such that the ratio of the distances of the two bodies from this point is the inverse of the ratio of their masses: dl: d2 = m2:ml.

Although Kepler presented his proposal for a new astronomy as Copernicus had, within an already well-established conceptual framework, Kepler’s ideas were more radical in both application and outlook. Kepler sought the complete redefinition of traditional astronomy as a new science and not a mere modification of it as Copernicus had.

Kepler conceived that the Copernican system needed a divine law or principle to unify it into a single divine entity, a Universe created by God. But, Kepler was more than a theologian; he was a natural philosopher who saw God’s work in the unity of heaven and Earth. Kepler imagined that it was a physical unity created by God. Kepler’s problem was to discover God’s plan and make it intelligible to the mind of man. For Kepler, this was accomplished by observation of God’s work in terms of God’s divine laws expressed mathematically.

The *Astronomia Nova* is the epitome of Kepler's work. The conceptual and rhetorical features of the *Astronomia nova* are intimately related and were purposely chosen by Kepler because of the response he knew to expect from the astronomical community to the revolutionary changes in astronomy he was proposing. Far from being a stream-of-consciousness or merely a traditional rhetorical narrative, as some scholars have argued, Kepler carefully formulated his expository method to convince his readers and to engage them in a critical discussion in the joint effort to know God's design. Westfall (1994: 245) asserts that Kepler's empirical data never operated independently of his religious and philosophic ideas.

Although Kepler worked simultaneously with the geocentric and the heliocentric schemas, conceptualizing much of his new Universe on the basis of the doctrines and contributions of his predecessors, he was nonetheless successful in innovating and creating something new out of the old traditional beliefs. Kepler discovered that he had to construct a 'new astronomy', one that was consistent with his physical explanations. In doing so, Kepler went against accepted dogma, and the *Astronomia nova* represents his defense of his approach and himself.

Because of his perspective, Kepler revolutionized the traditional astronomical framework by changing the principles, the methods and the subject matters that served as the foundation of seventeenth-century astronomical practice. Kepler was the first to understand astronomy as being a part of physics, and he was the first astronomer to attempt to derive mathematical predictions of celestial motions from assumed physical causes. As we have indicated, Kepler's physical principles demonstrate that he had the ability to integrate mathematical and physical explanations into a comprehensive technique for scientific investigation. Yet, Kepler's changes to traditional astronomy go beyond his new approach and new methodology; they also allowed him to usurp the substantive content of traditional astronomy as well. Kepler's astronomy placed new demands on the traditional astronomical framework, demands that required the complete overthrow of established beliefs and practices.

In order to understand the rhetorical dynamism of Kepler's *Astronomia nova*, this thesis has approached rhetoric without an emphasis on the substance/appearance dichotomy handed down by our Greek ancestors. Aristotle, for example, confined rhetoric to a frame that makes it more difficult to see rhetoric as constitutive of scientific and or mathematical discourse. This is so because it positions rhetoric as secondary to whatever substance it conveys. Such a perspective shackles language to the logic of representation in which language is the mediator between subject and object. This thesis attempts to explode any substance/appearance dichotomy by focusing on an important scientific concept and investigating its rhetorical features among a medley of elements; it shows that the rhetorical force of Kepler’s rhetoric operates beyond the threshold of representation, thus troubling any simple substance/appearance relation. The upshot of such critical maneuvers is the ability to analyze the constitutive rhetoric of scientific invention, for example, not as a language true to ‘reality’, but as a tool to help humans cope with the world. As Richard Rorty (1989: 6) has pointed out, because “… Newton’s vocabulary lets us predict the world more easily than Aristotle’s [this] does not mean that the world speaks “Newtonian”.” Rhetoric does not seek out the truth lying dormant in nature; it seeks out means for negotiating the world humans continuously encounter.

In his effort to extend his beliefs to the entire subject matter of astronomy, this study found that Kepler applied rhetoric in a new way. As we have seen, the traditional astronomical framework made a distinction between celestial and terrestrial phenomena. Kepler treated celestial and terrestrial phenomena as essentially the same. Thus Kepler makes no distinction for example between real and apparent celestial motion; he deals with the observed phenomena. What allows him to do this rests in his use of the true Sun as the physical source of motion and as the cause of non-uniform planetary motion in the Solar System. By establishing a physical cause, Kepler changed the traditional astronomical framework when he summarily used the true Sun instead of the mean Sun in calculating the intersection point of all orbital planes, conjunctions and oppositions. To explain all celestial motion based upon the true Sun also effectively eliminated Copernicus’s third motion, a conical rotation of the Earth’s axis.

The two comprehensive principles contained in the *Astronomia nova* gave a superior mathematical accounting of the appearances of things and presented a system of the world in which nothing was arbitrary – that a reason could, in principle, be given for everything.

Kepler understood the physical principles that served as the foundation for his research methodology, which, in effect was the expression of the principles that allowed him to move seamlessly from one context to another without a break in the process of discovery. In other words, his method was his principle, and his principle was his method, which today we refer to as the subject matter of astrophysics.

As we have seen, Kepler’s principles simplified the unjustified intricacies of the traditional framework by abolishing the need to resolve observed planetary motion into uniform circular motion. Kepler addressed the assumption of uniform circularity by abolishing ‘uniform’ with his second comprehensive principle (his Second Law of Planetary Motion) and ‘circular’ motion was abolished by his first comprehensive principle (his First Law of Planetary Motion). His method mathematically dismembered the principle of uniform circular motion, the concepts of real versus apparent planetary motion and the several arbitrary elements that characterized the traditional framework. Whereas astronomers for centuries had seen nothing but circles in the heavens, Kepler saw ellipses.

The ellipse represented a comprehensive physical principle that successfully explained the regularities and irregularities for which the assumptions of his predecessors could not account. It removed any need for circular motion and any arbitrary assignments.

Kepler's contribution to the history and development of astronomy was revolutionary. Thomas Kuhn (1957) has proposed that science evolves by going through periods of revolution, or crisis, in which the reigning paradigm or world-view goes through a dramatic shift. During Kepler's time for example, the reigning paradigm, or world-view, was that planetary orbits were circular – the three dominant systems of the Solar System included them. Tycho's data constituted what Kuhn has called an anomaly – a result that does not coincide with the current paradigm. According to Kuhn, anomalies cause the period of crisis that leads to a revolution. Kepler was the only one who saw this anomaly; and, it certainly precipitated a crisis in his thinking! His three 'laws' became part of a new paradigm.

This study places the history of astronomy in a new environment and opens the door to a discourse community previously thought to be outside the realm of rhetoric. In so doing, possibly more questions have been raised than have been answered. If indeed science is rhetorically constituted as Kuhn, Gross and others suggest, then what other rhetorical histories thrive among scientific concepts? What other rhetorical features does scientific discourse sustain, obfuscate, or ignore? How does seeing science as rhetorical affect the ways that science is thought of, communicated, and taught? All of these questions, and many others, require scholarly attention in the future. What this study does is open the way for scientific and rhetorical scholars to ask and seriously ponder these questions by exposing the constitutive role of rhetoric in science through the concepts of science (see Reyes, 2004).

Finally, as mentioned in the beginning of this study, Copernicus' *De revolutionibus* (1543), Kepler's *Astronomia nova* (1609) and Galileo's *Siderius Nuncius* (1610) were published during the Late Renaissance, a time when strong lines of demarcation were drawn between science and the use of rhetoric. Religious belief must also be included as well, as it was only after 1824 that the Catholic Church finally accepted the general opinion of modern astronomers and granted formal permission for the printing in Rome of books reflecting the theories of Copernicus, Galileo and Kepler.

To claim that Kepler was a rhetorician is not to dismiss his science, but to draw attention to his accommodation of his message to the professional audiences whose support was necessary for its acceptance. The notion here is not that Kepler's science was rhetoric; but that like rhetoric, Kepler's work was a rhetorical enterprise, centered on persuasion (see Gross, 1990).

The focus here has been on Kepler's use of rhetoric within the context of discovery and justification. Whether in his persuasive mathematical definitions of celestial phenomena, or in the circumstantial and shifting meanings of terms of his scientific semantics to substantiate his scientific claims for a new astronomy, his rhetoric was usurpatory because he applied his discoveries to all of astronomy. By uniting astronomy and physics Kepler physicalized astronomy and thereby created astrophysics as a new subject matter – a new astronomy. In the process of defining ‘things as they are’. Kepler did not redefine the traditional astronomical framework – it was no longer relevant. Kepler redefined astronomical reality. Kepler’s innovations offered a completely new conceptualization of the Universe that changed the axiomatic structure of traditional astronomy. As Westfall (1977: 12) remarks, “If it is true to say that Kepler perfected Copernican astronomy, it is equally true to say that he destroyed it.”

CHAPTER 11 REFERENCES

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