Introduction

One of the most fertile minds ever, Johannes Kepler (1571–1630) made valuable contributions to every field he addressed. He changed the face of astronomy by abandoning principles that had been in place for some 2,000 years, made important discoveries in optics and mathematics, and even constructed astrological charts renowned for their uncanny accuracy. In addition, he was an uncommonly good philosopher.

One tends not to hear much about Kepler's philosophical prowess, probably because he did not actually write a treatise specifically on philosophy; his philosophical views were usually advanced as solutions to problems in other disciplines (the *Apologia pro Tychone contra Ursum* is an exception, but its content was constrained by Tycho Brahe). Consequently, in order to encounter Kepler's philosophical views, one has to study his treatment of other subjects. Kepler's astronomical works provide a particularly fruitful source for his epistemology and methodology of natural philosophy, what we now call "science."

For one thing, Kepler became a Copernican at a time when there was no empirical evidence that would support the Copernican over the well-entrenched Ptolemaic system (and, later, over the Tychonic system). His initial reasons for preferring Copernicanism, therefore, were extraempirical and were drawn in particular from metaphysics and methodology. Consequently, in his early astronomical works one finds interesting arguments on the logic of drawing predictions from theory, the virtue of the explanatory power of a theory, what makes a theory testable, and so on. Later, he added arguments from physics to his arsenal, which raised other philosophical issues.

For another thing, astronomers were well aware of certain philosophical problems having to do with the making and interpretation of observations. It was standard practice to *process* observations in the computation of planetary positions. One had to calculate the effects of refraction and to consider whether the body was observed at the horizon or directly overhead (consider the familiar phenomenon of the change in size of the moon as it approaches the horizon). One could not always make the desired observation at precisely the right time—for example, if it was clouded over. One had to take into account that, because the object stood at such a distance from the observer, a small error in observation could significantly influence the calculated position of the planet; and, if one was a Copernican, then the position of the Earth had to be taken into account. These and other considerations made it clear to astronomers that the relationship between observation and theory was quite complex and that a certain level of error was acceptable; even if an observation of a planet's position was five minutes off from the predicted position, this prediction could still be considered successful. In the *Astronomia nova* Kepler used discrepancies between prediction and observation that would have previously been within the acceptable margin of error to revolutionize astronomy. In order to do this, he needed to address the issue of how to make observations yield more precise information.

For the Copernican astronomer, moreover, the issue of the interpretation of observations was particularly keen. After all, it *looks* like the sun goes around the Earth. Yet being a Copernican does not mean that one ignores observations; rather, the question is how to determine a reliable and veridical method of interpreting observations, a concern that occupied Kepler throughout his career. Kepler's revolutionary approach to astronomy raised questions not only about the relationship between observation and theory but also about the very nature of astronomy and physics. Kepler argued that astronomy would progress only if it was grounded in physics. This position was unpopular at the time, prompting Kepler to address the philosophical problem of the relationships between disciplines.

In addition, the celestial physics Kepler developed was a mixture of Aristotelian qualitative physics and Archimedean mathematical mechanics. Because the relationship between mathematics and physics was an open question at the time (in contrast to today when it is taken for granted that one uses mathematics in physics), Kepler was subverting the standard methodology of physics, a situation that encouraged philosophical thought on the nature of physics. Aristotle had warned against the use of mathematics in physics. For Aristotle, the proper way to explain the behavior of physical objects was to deduce what they will do from a consideration of their essences. The mathematical features of objects are, for Aristotle, accidental rather than essential properties. Kepler's solution was to develop a metaphysics under which the mathematical properties of an object *are* its essential properties. One sees this position echoed in Descartes, who argued that the essential property of objects is their extension, which paved the way for a mechanical physics. His effort was sufficiently persuasive that Spinoza took it for granted that physics was the study of extension. This position became widespread enough that Leibniz felt the need to argue that physics required nonmathematical as well as mathematical principles.

Kepler's mathematical metaphysics is the central theme of this book, because it is this metaphysics that provided the inspiration and justification for the methodological innovations required by the new astronomy. Kepler believed that the world was created by God to express divine aesthetics, what Kepler called "Archetypes." This aesthetics was essentially geometrical in nature. If one knows the details of God's aesthetics, then one can infer a priori certain structural features of the world—for example, whether the world is Copernican or Ptolemaic. (The commitment to a priori knowledge about the world is a key feature of the early modern rationalist movement.) Conversely, if one knows the structural features of the world, then one can gain access to God's aesthetic plan.

In order to carry out this study, we need to look at Kepler's astronomy in some detail, which is interesting in its own right. Although no background in astronomy is presupposed, an assessment of some technical material is necessary if we are to get a sense of how Kepler applied the methodological principles developed from his mathematical metaphysics, and also of the problems that motivated the development of these principles. I have struggled to make Kepler's work as accessible as possible, a task most difficult with the material in chapter 6. Here I isolate commentary on technical details, which the reader can skip if desired.

Kepler's manuscripts have been collected in the *Johannes Kepler Gesammelte Werke* and *Joannis Kepleri astronomi opera omnia*. The *Mysterium cosmographicum*, *Apologia pro Tychone contra Ursum*, *Astronomia nova*, *Harmonice mundi*, selections of *Epitome astronomiae Copernicanae*, and selections of Kepler's correspondences have been translated into English. I have included citations to both the English translations (where available) and to the Latin and German in *Johannes Kepler Gesammelte Werke*.

The audience I had in mind when writing this text includes both historians and philosophers of science, metaphysics, and epistemology, and anyone interested in understanding the scientific revolution. One thing that becomes clear in this study is that the process of constructing a new discipline (in this case physical astronomy) brings to the forefront epistemological, methodological, and metaphysical issues, and I offer a detailed examination of this process. In this case study, we see in detail the complex interplay between data and theory, and the role theory plays in "turning data into evidence"[1] for that theory. We also see the role that metaphysics played for Kepler in justifying his epistemology as truth tracking. In addition, in Kepler's work we see the first and perhaps the most rigorous attempt to test empirically a metaphysical worldview, as well as one of the most explicit uses of metaphysics to further an empirical discipline. Thus, although Kepler's metaphysics did not start a new metaphysical tradition, it was instrumental in starting the tradition of physical astronomy, and is of historical and philosophical significance for that reason alone. Kepler is clearly a key figure in the scientific revolution, and, given that he explicitly stated that his astronomy was related to his metaphysics, this study should aid in understanding the manner and extent to which this is so.

Until recently one was likely to encounter one of two Keplers: Kepler the consummate scientist as depicted by Small ([1804] 1963), Dreyer ([1906] 1953), and Strong (1966); or Kepler the demented dream architect, the sleepwalker depicted most notably and popularly by Koestler ([1959] 1968). The Kepler one encounters often depends on whether an author focuses on or away from Kepler's "unscientific" interests. There are notable exceptions. Cassirer ([1927] 1963, 164–65), for example, takes note of Kepler's interest in archetypes and astrology without concluding that his method was unscientific; indeed, he proposed that Kepler's aesthetic conception of the world was instrumental in overcoming the mystical approach to nature. Recently there has been a resurgence of Kepler scholarship, and a number of excellent works have been published on him. This text is heavily indebted to these works, most notably those of Stephenson 1987; 1994; Jardine 1979; 1984; Gingerich 1973; 1975a; 1992; Gingerich and Voelkel 1998; Voelkel 1994; Field 1988; Caspar [1959] 1993; Harper and Smith 1995; Westman 1972; 1975; 1980; 1984; and Mittelstrass 1972. Current Kepler scholarship tends to acknowledge that there is a relationship between Kepler's scientific and "unscientific" interests, and studies on his metaphysics (e.g., Lindberg 1986; Field 1988; Stephenson 1994; and Kozhamthadam 1994), and his astrology (e.g., Rosen 1984) have appeared. In addition, several texts have explored his astrology and archetypal cosmology in relation to his astronomy (e.g., Pauli 1955; Holton 1956; Koyré [1961] 1973; Simon (1975) and have indicated the importance of these interests in Kepler's conversion to Copernicanism. Holton, in particular, emphasizes the way that Kepler appealed to his archetypes when his physical arguments failed. In this text I approach Kepler from a somewhat different perspective; I am interested in those aspects of the relationship between Kepler's metaphysics, epistemology, and physical astronomy which promise the greatest philosophical yield. In particular, I examine Kepler's use of metaphysics to resolve the epistemological and methodological problems in astronomy generally acknowledged in his time.

In addition to complementing the recent Kepler scholarship, this text is intended to add detail and nuance to the recent broad discussions of the scientific revolution. On the whole I have found such narratives like John Henry's (1997) and Steven Shapin's (1996) to be quite responsive to recent detailed studies of key figures in their cultural contexts, some of which exhibit their so-called unscientific interests. The impression one often gets from these overviews featuring such unscientific aspects, however, is that the scientific revolution was a far less rationally motivated transition than had previously been supposed. My aim is to show that, in Kepler's case, such unscientific influences were used ingeniously to resolve the conceptual difficulties that faced his scientific program. While it is a welcome trend that recent narratives pay attention to the writings of Kepler erstwhile viewed as unscientific and therefore irrelevant, the Kepler one encounters in this book, which focuses on these "unscientific" ideas, is far more motivated by rational and scientific concerns than recent narratives would lead one to expect.

The book's first chapter is intended to provide just enough background information on Kepler's life and times to set the stage for the remaining discussion. After opening with a brief biography of Kepler (several detailed biographies of Kepler are available, most notably Caspar ([1959] 1993), I turn to the astronomy Kepler inherited. Here I review the technical apparatus available to Kepler, as well as prominent views at that time on the status and interpretation of astronomy, especially in light of the Copernican and Brahean challenges to traditional Ptolemaic astronomy. The chapter concludes with a discussion of the philosophical trends that most likely influenced Kepler's thought.

The remaining chapters focus on Kepler's astronomical works as well as those on metaphysics and epistemology most relevant to his astronomy. Because my interest is also in the evolution of Kepler's metaphysical and epistemological thought, especially in how it changed in response to new astronomical discoveries, Kepler's works will be discussed in the order in which they were written.

Chapter 2 discusses Kepler's *Mysterium cosmographicum*, his first book, which was written before he developed proficiency as an astronomer. The primary thesis of the *Mysterium* is that the number and relative sizes of planetary orbits can be explained by the hypothesis that the five regular solids (the cube, tetrahedron, dodecahedron, icosahedron, octahedron), if nested inside each other in an order determined by their importance, roughly correspond to the relative sizes of the planetary orbits. This may seem a peculiar hypothesis, but as we shall see, Kepler's archetypal vision not only supported the Copernican hypothesis but underwrote his approach to natural philosophy. In the *Mysterium* Kepler explicitly argued that an astronomical hypothesis required converging support from an archetypal model, and that such a model was available to the Copernican but not the Ptolemaic hypothesis. He argued for the superiority of the Copernican account on other grounds as well (e.g., fruitfulness), and I show how Kepler justified these grounds by appeal to his archetypal cosmology.

Chapter 3 is a brief discussion of the *Apologia*, in which Kepler argued against the skeptics that astronomical hypotheses, when properly constructed, interpreted, and tested, could provide us with a true account of planetary motion. The main problem facing the realist in astronomy was the availability of competing empirically adequate models. I argue that Kepler's answer to the skeptic, while appearing quite modern, was motivated by, and grounded in, his cosmology.

The *Mysterium* and the *Apologia*, however, are early works of Kepler, written before he attained the prowess as an astronomer for which he is famous. Because there is little mention of the archetypes in his mature work, the *Astronomia*, it would not be surprising if his youthful commitment to an archetypal world order had been abandoned. There are, nonetheless, two strong sources of evidence to the contrary; Kepler's later works, the *Harmonice mundi* and the *Epitome astronomiae Copernicanae* make frequent reference to the archetypes. Given that Kepler did not abandon his youthful vision of the universe, what remains to be explored is whether this vision played a significant part in his "war on Mars."[2] In chapter 4 I argue that it does, and not only to the extent that Kepler applied the method developed in the *Mysterium* and the *Apologia*. Kepler also used his archetypal cosmology to rule out preempirically various hypotheses—to determine which kinds of hypotheses were plausible. This approach permitted him to focus attention on avenues of inquiry that, in the end, turned out to be quite fruitful.

Chapter 5 is a reflection on the conceptual apparatus Kepler made use of in constructing his new physical astronomy and, as such, breaks the flow of the narrative to some extent. This reflection shows in detail the relationship between his three diverse early books, the *Mysterium*, the *Apologia*, and the *Astronomia*. I argue that Kepler's new astronomy involved methodological principles that were considered unsound during his time. I also argue that Kepler's archetypal cosmology enabled him to blend Platonic and Aristotelian intuitions, providing him with rhetorical means to defend his account from expected criticisms.

By the end of chapter 5, I hope to have made clear that Kepler's archetypal interests should not be viewed as separate from his interests in natural philosophy. They had an influence on his new physical astronomy at various levels, from the methodological to the rhetorical. By the time Kepler finished the *Astronomia*, however, he was aware that his polyhedral hypothesis was incomplete: it failed to explain the nonuniform elliptical motion of the planets. Kepler tried to rectify this problem in the *Harmonice*. Kepler's new archetypal model, however, was not fully compatible with his original cosmological commitments, and it became an open question whether the material world corresponded to the archetypal *precisely*. Given the importance of making this match, as outlined in the foregoing chapters, one wonders whether the *Harmonice* really was Kepler's "mind's favorite child" (Caspar [1959] 1993, 288). While the *Harmonice* is a remarkable book, the universe that Kepler believed he discovered was not the perfect one he had expected. In chapter 6 I trace Kepler's failed attempt to provide an archetypal justification of his new astronomy and the methodological implications of this failure.

Chapter 7 is a discussion of Kepler's *Epitome*, which is 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. Finally, since books IV through VII were written after the *Harmonice*, they give evidence of the tension between Kepler's physics, metaphysics, and astronomy that, I argue, was brought about by Kepler's difficulty in developing a complete archetypal account in the *Harmonice*.

The final chapter is a short commentary on the implications that the shortcomings of Kepler's approach to natural philosophy had for his interpretation of his astronomy as true. I conclude by briefly addressing the question of Kepler's influence on subsequent philosophical thought. Granted, his approach as a whole suffered difficulties, but a number of aspects of his philosophical thought had proved very fruitful. In particular I was interested in the manner and extent to which Descartes and Leibniz—who both shared much in common with Kepler's metaphysical thought, and who both were well aware of Kepler's works—commented on Kepler's philosophical positions.

This study makes clear that Kepler has much to offer philosophers and historians of science, epistemology, and metaphysics. Although Kepler did not write a philosophical treatise, his thought on these matters is particularly valuable precisely because they were developed in the context of providing solutions to significant problems facing an emerging science. A peculiar philosophy thus served to establish a lasting astronomy.