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Galileo's *Assayer*: Sense and Reason in the Epistemic Balance

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by

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Abstract

Galileo's *The Assayer*, published in 1623, represents a turning point in Galileo's philosophical work. A highly polemical "scientific manifesto," *The Assayer* was written after his astronomical discoveries of the moons of Jupiter and sunspots on a rotating sun, but before his mature Copernican work on the chief world systems (Ptolemaic versus Copernican). *The Assayer* included major claims regarding the place of mathematics in natural philosophy and how the objects of the world and their properties can be known. It's in *The Assayer* that Galileo wades into the discussion about the ultimate constituents of matter and light, namely, unobservable particles and atoms. Galileo stressed the equal roles that the senses and reason served in the discovery of knowledge, in contradistinction to Aristotelian authoritarian dogma that he found to hinder the processes of discovery and knowledge acquisition. However, in his discussion about the physical and mathematical nature of atoms, Galileo can be found to reach the epistemic limits of his methodology in paradoxical fashion. After providing sufficient historical and historiographical context in an effort to situate *The Assayer*, I argue that this limit is less of a problem for Galileo than may be thought at first sight; for he was aware of this limit even if he didn't clearly or fully articulate it in *The Assayer*. Nevertheless, the epistemic balance in which the uses of Galileo's own sense and reason can be weighed are found to tip in favor of the latter.

Contents

Chapter 1

Introduction

I advance a thesis inspired by two crucial passages of Galileo's *Assayer*. The first is well known and has been quoted and analyzed many times; it reads as a *prima facie* programmatic statement of his mathematical philosophy:

> Philosophy is written in this grand book, the universe, which stands continually open to our gaze. But the book cannot be comprehended unless one first learns to comprehend the language and read the letters in which it is composed. It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures without which it is humanly impossible to understand a single word of it; without these, one wanders about in a dark labyrinth.[1]

Inasmuch as this statement entails both observation (requiring the senses) of the natural world and a mathematical understanding (requiring reason) of that observed world, they are related to other claims Galileo makes regarding the origins of his

[1] *The Assayer*, in *Discoveries and Opinions of Galileo*, pp. 237-238

capacity to observe with the senses and think mathematically. In arguing against the Aristotelian authority that constrained many scholastic philosophers as well as the Jesuit mathematical natural philosophers of the Collegio Romano, Galileo provided a dual justification for his method as well as his opposition to any such authority:

> I do not wish to be counted as an ignoramus and an ingrate toward Nature and God; for if they have given me my senses and reason, why should I defer such great gifts to the errors of some man?[2]

Galileo thus appealed to Nature and God in his attempt to justify the mathematical method that he outlined in his *Assayer*. The consequences of his method are not just epistemic, or concerning the justification of his knowledge or knowledge of the world in general; they are also cognitive, concerning states of belief and knowledge and doubt; and they are also metaphysical, or ontological, concerning the nature and order of things that go beyond, or are other than, those objects of the sensible world. Galileo's method was clearly intended to challenge the philosophical status quo of those natural philosophers who, in the scholastic and Aristotelian tradition, sought to discover the essences of physical things belonging to the natural world, but without the aid of any mathematical reasoning. Physical truths had indeed traditionally belonged to the cognitive domain of the natural philosopher, while truths of arithmetic and geometry belonged to the domain of the mathematician. The division was underscored, moreover, by Aristotle's philosophy of science and his metaphysics (or what Aristotle called "first philosophy"). Both subjects drew a strict disciplinary line between natural philosophy and mathematics.

Arguing against the general and specific views of the late-medieval scholastics and other Aristotelian natural philosophers, Galileo claimed that geometric demon-

[2]Ibid., p. 272.

strations could actually uncover or corroborate physical truth. From the scholastic, Aristotelian and theological point of view, this was a transgression of the prevailing cognitive division of knowledge. In particular, Galileo was proposing a method of mathematical reasoning that did not require syllogistic reasoning about essences. However, while Galileo aimed for certainty in natural knowledge via mathematical demonstration, he appears to have faltered where his geometric method of reasoning transgressed the limits of the senses; this apparent problem is most striking in his analysis of the cause of heat. But rather than stating the certainty of a geometric demonstration in various places of his account, he instead offered only his *beliefs* and *thoughts* about these supposedly physical yet mathematically construed causes. In doubting the commonsense realism grounded in the senses, he argued that the underlying causes of heat were to be found in an invisible micro-realm. He was nevertheless only able to "believe" or "think" that these causes may be subject to mathematization. Still, he would have his audience also believe that he had reached a sufficient degree of rational, mathematical certainty on par with what he claimed to have reached in other cases of his experiences or analyses found elsewhere in his mathematical discourse (e.g. his parabolic analysis of the telescopic lens).

This introduction serves to highlight what's at issue in my thesis — namely, the tension between sense and reason in Galileo's mathematical philosophy, which is quite apparent in *The Assayer*. In Chapter 2, I provide a historical overview of Galileo's works and analyze the title page of Galileo's *Assayer* for the purpose of illuminating the sociocultural conditions surrounding its motivation and publication; Galileo's aspiration to the title and standing of mathematical philosopher is clearly evident in the visual details of the title page. In Chapter 3, I provide a historiographical analysis of Galileo's *Assayer*, which has been called his "scientific manifesto"; it's in this work that a predominately mathematical philosophy surfaces. In contrast to some of his contemporaries, such as Kepler, I find that Galileo is far less indebted to the Platonic tradition by the time of his writing *The Assayer* than has otherwise been argued. The historiographical thread I follow instead reveals an alternative, more promising theme by which to comprehend his mathematical philosophy, namely, the metaphorical and mathematical image of the balance. Finally, in Chapter 4, I analyze the text of *The Assayer* for epistemological clues and argue that Galileo's mathematical philosophy, despite his striving for mathematical certainty, is tempered by other epistemological assumptions. This tempering crucially concerns what he takes to be the foundations of his reason and sense, namely, God and Nature. Nature is the basis of experience, and God is the exemplary mind to which reason aspires. I will argue that Galileo puts the greater epistemological emphasis on God, since it is ultimately He who has written the Book of Nature.

This is formally a research project in the history of science. However, inasmuch as Galileo's concerns in the *Assayer* are philosophical, the project borders on the philosophy of science. Thomas Kuhn warned would-be students of history of science and philosophy of science that the two need to be kept separate as disciplines, since the student "would risk depriving [himself] of any discipline at all".[3] As a student of both disciplines, I'm undertaking a history project that concerns philosophy, so the risk can be avoided. Stillman Drake noted that "*The Assayer* marked a crucial point in the history of Galileo's thought. Before, he had spoken as the experimental scientist; later he was to speak as a theoretical scientist. In this work he speaks as a philosopher of science".[4] This remark, which I find to be accurate, was Drake's justification for his view of Galileo's *Assayer* as a work to be taken up for study in the history *and* philosophy of science. However, the philosophy of science in question is that of

[3]Kuhn, "The Relations between the History and the Philosophy of Science" (1977).
[4]Drake, p. 227.

Galileo's, so I aim to historically contextualize his work. My thesis may therefore be more correctly categorized as one in the history *of* philosophy of science, but a history that incorporates other promising features of Galileo's story by which we can understand and appreciate the mathematical philosophy presented in *The Assayer*.

Chapter 2

The Context of Galileo's *Assayer*

In this chapter I provide an overview of Galileo's life and works. I then provide an analysis of the title page of *The Assayer* that reflects the historical circumstances of its publication. The Lyncean Academy is an important part of that story, so I give the Lynceans further consideration for their close relationship to Galileo. An interesting question arises about the relationship between Galileo's book and the intellectual context of Copernicanism. I next address that question. Finally, I briefly discuss Galileo's mathematical philosophy from the historical point of view of Renaissance mathematics. These parts are intended to provide an insightful context on which the historiography and analysis of *The Assayer* can be based in the following chapters.

2.1 Biographical and Bibliographical Remarks

Galileo Galilei (1564-1642) was born in Pisa, Italy, which was part of the Grand Duchy of Tuscany.[1] In 1581 he enrolled at the University of Pisa to study medicine before leaving in 1585 without a degree. He studied mathematics privately while at Pisa, and his heigtened aptitude for the subject was reflected in his original work on the uniformity of pendulum vibrations in 1583. He subsequently lectured on mathematics publicly and gave private lessons at Siena and Florence before assuming the position of professor of mathematics at the University of Pisa in 1589. He wrote in the same year, but did not publish, his first scientific work, *On Motion*. In 1592, he left Pisa for the Republic of Venice, where he became professor of mathematics at the University of Padua. During his years at Padua, he wrote his next three works for students but published none of them: *Treatise on Fortifications* (1593), *Mechanics* (1594), and *Treatise on the Sphere*, or *Cosmography* (1597). The latter work was undoubtedly consistent with Ptolemaic astronony, or the geocentric model of the universe, which he taught at the universities in Pisa and Padua. There are no clear signs of him inclining to Copernicanism in his work by this time; but one major bit of evidence that he had begun to entertain the physical truth of the Copernican hypothesis is found in a 1597 letter to Galileo written by Kepler, who implored him to come forward publically with his belief of the claim. We can appreciate any reluctance Galileo displayed in such dangerous matters, since the Roman Inquisition, under the auspices of a Counter-Reformation, was already vigorously pursuing heretics in response to the Protestant Reformation or similar heretical deviations from the Catholic faith. It was only three years after Kepler's letter to Galileo that Giordano Bruno had been burned at the stake in Rome for his heretical, Copernican-inspired cosmological views. Church

[1] I follow the timelines of Galileo's life provided by Drake, *Discoveries and Opinions of Galileo* (1957), and by Finocchiaro, *The Essential Galileo* (2008).

doctrine had formally adopted the Ptolemaic astronomical model of the universe as well as the geocentric cosmology of Aristotle. Nevertheless, Galileo's study of free fall by 1609, which led to his forumlation of the distance traversed as proportional to the square of time, was an early instance of his challenge to Aristotle's physics. For Aristotle had argued that the rate at which objects fell was proportional to their weight.

Galileo finally published in 1606 his *Operations of the Geometric and Military Compass*, the content and nature of which highlighted the traditionally proper place of mathematics, namely as an applied or practical field of study. The same point can be made about his earlier works. His writings took a dramatic turn by 1610, however, when he published his astronomical discoveries with the recently discovered telescope in his *Siderial Messenger*. In this work he detailed his observations of four new planets orbiting not the earth but Jupiter, as well as those of the irregular, mountainous surface of the moon and patches of the night sky that contained many more stars than had previously been observed. Subsequent to this first set of astronomical observations, he observed the phases of Venus, and the "ears of Saturn". His observations were exciting to many at the time due to their novelty; but they were alarming to others since they severely challenged the Aristotelian cosmology and Ptolemaic astronomical model — the very cosmology and astronomy sanctioned by the Church. Dedicating his publication of 1610 to Cosimo II de' Medici, the Grand Duke of Tuscany after whom Galileo named the newly discovered moons of Jupiter — namely, the Medician stars — he defined his status at the Medician court as mathematical philosopher, where he was politically and institutionally legitmated and recognized as such. Galileo was by now publicly partial to the Copernican theory of a heliocentric universe, and his observations strongly corroborated that view — especially the phases of Venus, which, if not absolute proof of the Copernican model, amounted to disproof of the Ptolemaic one.

Figure 2.1: Portrait of Galileo. Woodcut by Francesco Villamena, 1623. Leaf included in *The Assayer*. "Galileo Galilei, Lyncean, Philosopher and Mathematician of the Grand Duke of Tuscany." Note the representations of the mathematical practice of making and recording measurements with a protractor and of the new observational method of the telescope.

Galileo did not altogether drop his investigations into the terrestrial realm in the meantime, having published his *Discourse on Bodies in Water* in 1612. Publications of more astronomical observations resumed the following year with his *History and Demonstrations Concerning Sunspots*, which detailed his observations of sunspots and the attending motion of the sun on its own axis of rotation. The results of this work constituted yet additional evidence against the Aristotelian cosmology, which posited a perfect substance in the supralunar sphere in a geocentric universe; it's also in this work that Galileo can be seen to reason mathematically about the nature of sunspots, insofar as he demonstrated what sunspots are *not* (namely, other planets revoling about the sun, as the Jesuit astronomer Christoper Scheiner had argued).

By the time of his 1613 publication, Galileo was firmly in favor of the Copernican view, and his written letter to his student Castelli that year confirms this. He claimed there that Copernicanism is not necessarily wrong just because it contradicts Scripture. However, the letter was soon publicized, and Galileo's views on the relation of Copernicanism to Scripture and his purported authority were judged to be heretical by an Inquisition committee. In 1616, Cardinal Bellarmine warned Galileo that he was to abondon his Copernican views, and he gave the appearance of acquiescence.

More astronomical events were soon to follow Galileo's first observations through the telescope, all interpretations of which would undermined both the Aristotelian and Ptolemaic learned worldviews. In particular, an incredible succession of three comets over the course of several months late in the year of 1618 inspired astronomical investigation into their nature and place in the cosmos. A subsequent succession of four tit-for-tat publications concerning the comets (and a lot more) then appeared from 1619-1626: first, *Discourse on Comets* (1619), written by Galileo's disciple Mario Guiducci, but likely strongly influenced, if not fully informed, by Galileo's thoughts on the matter; second, *Astronomical and Philosophical Balance* (1619), written by Orazio Grassi in critical response to Guiducci (and Galileo), but who published under the pseudonym Lothorio Sarsi; third, *The Assayer* (1623) by Galileo, who descended on the previous work and its author to a polemical degree unparalleled in the history of scientific publications; and fourth, *Comparison of the Weights of the Assayer and the Balance* (1626), again by Grassi, who again used a pseudonym in his response to Galileo's *Assayer*. The controversy between Galileo and Grassi goes no further, if for no other reason than the outcome of the debate was already determined by 1623 in Galileo's favor — even if Galileo was ultimately wrong about the nature of comets. It is an interesting aspect of the story that Grassi argued that comets were astronomical bodies in motion beyond the moon while Galileo argued that comets were optical atmospheric illusions. Galileo was wrong. What is also interesting is the philosophical theme that emerged from the comet controversy, namely, the balance: a balance between astronomy and philosophy, the balance of methods in *The Assayer*, and the balance between the two previous works.

Almost a decade after the comet controversy, Galileo published his next major work, *Dialogue on the Two Chief World Systems, Ptolemaic and Copernican* (1632). He and the strong Copernican, derisive content of this work were subsequently investigated by a special commission of the Inquisition, which then prohibited the sale of his book. He was tried by the Inquisition in 1633, at which time he was compelled to renounce his Copernican views and was sentenced to prison. His sentence was commuted to permanent house arrest, with a few changes in location. Galileo continued his work while confined to his home, but he now wrote on less suspicious topics in mechanics. His *Two New Sciences* was published in 1638, four years before his death at Arcetri, the final location of his house-arrest.

This brief overview of Galileo's life and works only begins to indicate how controversial a figure Galileo was for his time. The timing of his *Assayer* stands roughly in the middle of his published works, and a closer analysis of that work will reveal more about the circumstances in which Galileo was so compelled to challenge the reigning authorities of his time.

2.2 Title page of *The Assayer*

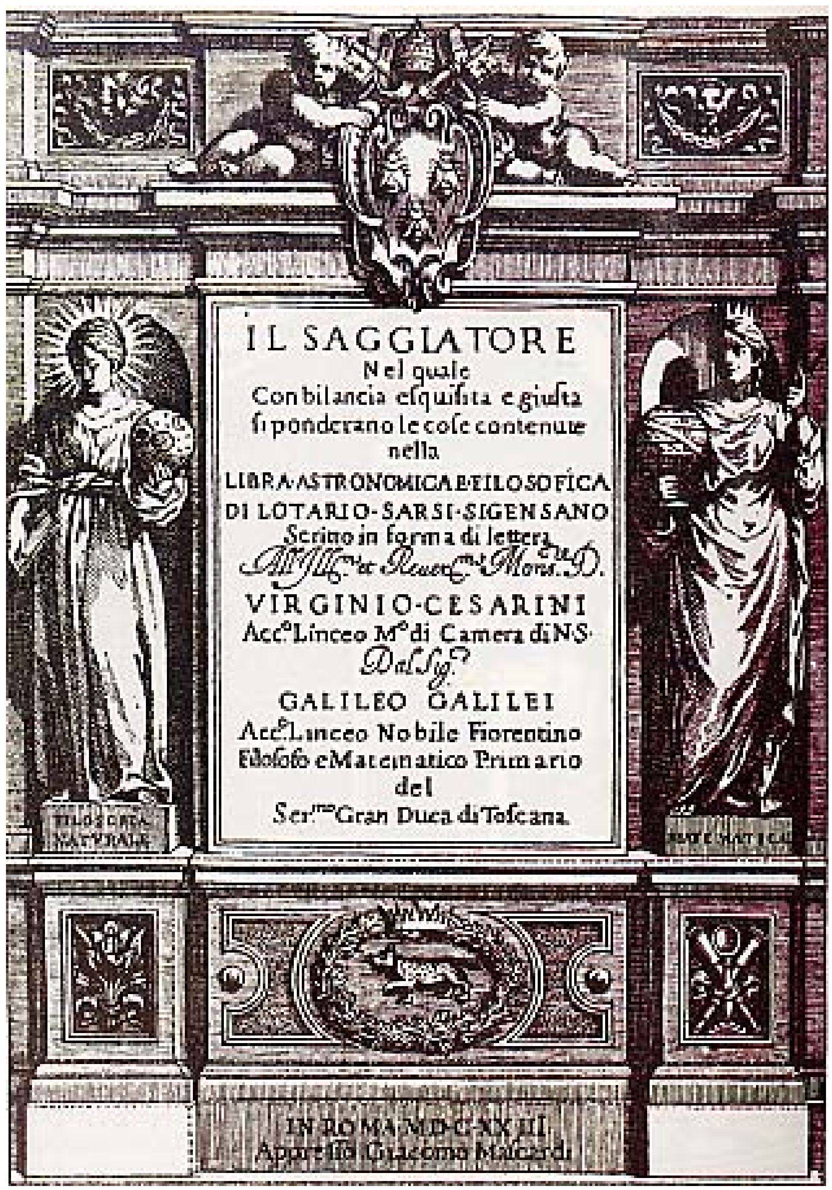

Figure 2.2: Title page Galileo's *Assayer*, 1623. Woodcut image by Francesco Villamena, 1623.

The title page of Galileo's *Assayer*[2] illuminates fascinating details regarding the socio-cultural context of the work and the nature of the philosophical and methodological problems that he set out to address in his rebuttal of Grassi's theory of comets and

[2]Translated by Drake, *Discoveries and Opinions of Galileo* (1957).

arguments concerning the nature of heat, among other things.

The title page is a woodcut image produced by the engraver and artist Francesco Villamena (1564-1624), who appears to have closely collaborated with the Lynceans on the publication of *The Assayer*. The image contains in its center the title of the work, its expressed philosophical purpose, the name of its addressee (Don Virginio Cesarini, a fellow Lyncean), and the name and identification of its author, Galileo. Additional parts of the image personify mathematics and natural philosophy, the two disciplines between which Galileo had already forged his identity at the Medici Court thirteen years earlier.

When we look to the border of the frontispiece, top center, we find a mantle on which are vertically positioned three bees; this is undoubtedly the trigon symbol for the Barberini Bees, which would have thus appealed to the papacy of Urban VIII, assumed by Maffeo Barberini in 1623 — the same year as the publication of the *Assayer*. Just prior to his election to the papacy, Barberini had interpreted his chance encounter with a swarm of bees while waiting in Vatican palace as "a fateful and prophetic event.... that Divine Providence had sent [as] a portent to announce the imminent accession to the papacy of a member of that Tuscan family whose coat of arms had long since been transformed from three wasps into an emblem of three bees".[3] Galileo's collaboraters, the Lynceans (see below), who published *The Assayer* had knowledge of this event in addition to the future Pope's interpretation of it, so they made good use of the bee trigon on the title page of *The Assayer* to the effect of soliciting his auspicious approval. According to David Freeberg, "When Galileo's *Assayer* was published just two and a half months after Urban's accession, the papal bees . . . appeared at the top of the title page, as if to encourage the support of the

[3]Freedberg, *The Eye of the Lynx: Galileo, His Friends, and the Beginnings of Natural History*, p. 154.

same Maffeo with whom Galileo had discoursed in friendship in Florence many years earlier".[4] That support would indeed be achieved to good effect.

As noted on the title page, Galileo's *Assayer* was addressed as a letter to Cesarini, "a Lyncean academician and Chamberlain to His Holiness." Cesarini was also a member of the personal staff to Pope Gregory XV and was socially close to Berberini and the Jesuits. In fact, it was one of those Jesuits who was the instigator (at least from Galileo's point of view) of the controversy over comets that Galileo sought to quell in his letter to Cesarini. Cesarini may have indeed been the "right addressee" for the letter for the reason that his friendly Jesuit audience "trusted him, and they would think twice before taking umbrage at the contents of the new work".[5]

In fact, Galileo attempted to tackle that and related issues in his *Assayer* by the dual role he assumed as natural philosopher and mathematician. We see his aspiration in this respect reflected in the two large figures on the title page, standing opposite each other. On the left side of the page stands a woman personifying *Filosophia Naturale*: she holds in her left hand a colored sphere adorned with stars and planets, the physical content of the universe, about which physical truths can be known; in her right hand, to which she appears to be gazing, is a book, presumably symbolizing the book of nature in which Galileo says natural philosophy is written. But there's more to the book of nature, "open to our gaze," even if its contents aren't all strictly sensory in nature. "This grand book, the universe, which stands continually open to our gaze," Galileo claimed, "is written in the language of mathematics." Hence the personification of *Mathematica* on the right-hand side of the page: this woman holds in her right hand an armillary sphere made only of latitudinal circles

[4]Ibid., p. 156.
[5]Ibid., p. 143.

and a band that is likely meant to represent the ecliptic, which would otherwise intersect the zodiacal band were it not for its absence from this particular model sphere. It is rather interesting that this abstract model of the universe appears on the title page, since it does indicate the mathematical approach Galileo would take in his investigations into physical phenomena. But this part of the image is also revealing for the relevance that his previous experience would play in his investigations: As Maria Portuondo notes, Galileo was among those interested in calculating longitudes at land and sea, as were many cosmographers of the Spanish Empire.[6] In fact, in 1597 (noted above) he had written for his students at the University of Padua the text *Treatise on the Sphere*, or *Cosmography*. The astronomical underpinnings for the work were certainly compatible with Ptolemaic astronomy.

Lady Mathematica holds in her left hand a protractor with which she (or the mathematician in general) goes about making measurements of the world. Measurements essentially depend on position, pertaining to a category (to use Aristotle's term) that is altogether different from such qualities as color. In *The Assayer*, Galileo distinguished between primary qualities, such as spatial position, and secondary qualities, such as color. Thus in contrast to the physical content of *Filosophia Naturale*, what matters for *Mathematica* is structure and measurement. We therefore find that Galileo's philosophical approach to the cosmos entailed the kind of mathematical reasoning that could get at the properties of things that were hidden from the senses: No armillary sphere was ever *seen* in the world accessible to the senses; it was rather abstracted from it.

The contrast between *Filosophia Naturale* and *Mathematica* in the title image is paralleled by another contrast: on the one hand, an illustration of a flower

[6]Portuondo, *Secret Science: Spanish Cosmography and the New World* (2009), p. 291.

or plant specimen, placed below Lady Filosophia in the bottom left corner; on the other hand, a symmetric display of crossing telescopes centered about a standing microscope, all of which are knotted together at their centers and placed below Lady Mathematica in the bottom right corner. The plant specimen belongs to the natural world accessible to senses, whereas the instruments of observation belong to the mathematical, inasmuch as their construction and principles are rooted in geometry. While there appears to be a rather sharp distinction now between the natural world and the mathematical realm, we shound't conclude that Galileo maintained any strict separation between the two. On the one hand, Galileo would go on to provide an account of his mathematical discovery of the telescope; on the other, he would use the mathematics-based technology of the telescope to report on his visual observations of the night sky. In some sense, mathematics for Galileo still maintains the role of a *practical* endeavor.

Finally, between the bottom images of the title page is the image of a lynx on the prowl under a crown that's large relative to the size of the lynx. The lynx symbolizes the methodological role and social presence of the Lynceans, a small but formal academic group of four Italian men led by Federico Cesi (1585 - 1630). The Lynceans intitially took a four-fold approach to knowledge in the primary directions of biology, philosophy, mathematics and astronomy. They strove to classify things belonging to all orders of phenomena, from the macroscopic to the microscopic realm and any middle nature or monstrous entity that nature produced in between. They disregarded the strictures of Aristotelian classification and Pliny's folklore, neither of which had anything to say about any such natures, let alone the numerous specimans from the New World that were pouring into collections, studies, and museums located in the Old World.[7] But if there was one observation that Pliny the Elder (A.D. 23-79)

[7] E.g. see Findlen, *Possessing Nature: Museums, Collecting, and Scientific Culture in Early*

had made in his *Natural History* that Cesi and his fellow Lynceans respected, it was that the lynx of all animals sees most clearly.[8] Galileo was not an original member of the Lynceans, but he was an early one to join the original group. The Lynceans, especially Cesi, had taken great interest in what Galileo saw with his telescopically empowered vision.

2.3 The Lynceans

The Lynceans played a major role in motivating Galileo to respond to Grassi's recently published work on comets. Grassi had challenged Galileo's reasons for not concluding that the comets could definitely be said to have a nature beyond the lunar sphere, but the Lynceans found this to be a general challenge to their own academic identity from the Collegio Romano with which they competed for space in approaches to knowledge. The Lynceans, therefore, deserve more discussion in their relation to Galileo's *Assayer*.

Cesi was the leading Lyncean who furnished the basic principles under which he and his fellow Lynceans would pursue their researches, investigations, observations or collections. As a matter of principle, he gave priority to detail. He maintained a constant interest in astronomy, but he made his special focus the microscopic realm that related to plants, fungi and insects. Now Galileo's earlier astronomical discoveries were of the sort that naturally peaked the Lynceans' interest, especially Cesi's; for Galileo's observations of a mountainous surface of the moon, an irregularly spotted sun, and an non-spherical Saturn were actually not unlike the kinds of middle natures or monsters (e.g. the deformed four-legged chick and the two-headed calf

Modern Italy (1996).

[8]Freedberg, p. 68.

that were carefully depicted) in which the Linceans took special interest. Galileo and the Lynceans were both seriously undermining the static worldview of Aristotelian essences, the philosophical edifice of which had become deeply entrenched with both the Scholastic philosophers of the thirteenth century on and the theology of the Church.

Galileo largely focused his telescopic gaze on the night sky and all that it might contain beyond what the unaided eyes could see. Cesi, who first received a microscope from Galileo in 1624, gazed on the newly discovered world of the microrealm, uncovering never before seen details of plants and bees, for instance. Both Cesi and Galileo therefore shared a similar analytic point of view in their investigations into the natural world. They both in fact supposed the existence of nonsensible particles in order to account for the causes of things: of heat, in Galileo's case, and of the reproduction of bees in Cesi's. So this is the place at which the two natural philosophers are seen to meet ontologically — that is, in a statement about *what there is* behind the appearances of things. And at this stage, both Cesi's and Galileo's methodological goals were to merge: "What is at stake, finally," as Freedberg succinctly explains, "is the ordered, mathematically determinable structure of all things.... [I]t was the microscope that provided further corroboration of this fundamental perception of the world.... Cesi had begun to realize that such geometrically structured forms could provide basic clues not just to the secrets of the heavens but to those of the earth as well".[9] Cesi was attempting to identify and provide an account of the "generative spirits" of an "effervescent liquid" behind reproduction; but in the end that was the real problem for Cesi since those spirits could not be directly observed.[10] Even with the use of a microscope, such elements of reproduction remained elusive or hidden,

[9]Ibid., p. 181.
[10]Ibid. pp. 176-177.

if they existed at all. A similar result is to be found in Galileo's attempt to mathematicize the microscopic realm of matter. The problem turns on what was available to Galileo's senses — not to mention Cesi's — on the one hand and what could be discovered by reason on the other.

2.4 Galileo's Copernicanism

Galileo's *Assayer* occupies a middle place of his published works and is unique in content in relation to his other works in at least two respects. First, *The Assayer* was concerned with the importance of method in natural philosophy; according to Galileo, that method is inherently mathematical. Second, the work contains scant reference to Copernicus or Copernicanism. The references that do surface in the work are carefully expressed and non-committal. By contrast, several of his earlier and later works addressed, to varying degrees, the Copernican question. Galileo was a third-generation Copernican who ultimately argued in favor the heliocentric model of the cosmos. Copernicanism was the central theme of Galileo's work in the *Dialogue*, and there are clear statements he had made in support of Copernicus in his earlier publications and letters. The virtual absence of Copernicanism and the predominant question of method in *The Assayer* are, in fact, complimentary features of the work, insofar as Copernicanism could in principle be defended or advanced with the method of a mathematical natural philosophy. In this section, I provide an account of these dual features *The Assayer* that are rooted in two earlier episodes of Galileo's story. First, from 1604 to 1607, Galileo was involved in the dispute about the nature of another new star that suddenly appeared in October of 1604. Second, from 1610 to 1616, he became increasingly public and vocal about his Copernican inclinations following his observations that supported the Coperincan hypothesis. I discuss each in turn and draw attention to their interrelatedness.

It is a striking historical parallel between recurring comets and recurring novas of the late sixteenth and early seventeenth centuries that informs the early context of Galileo's *Assayer*. Observations of the Great Comet of 1577, as ominous as its portent seemed to many, created a philosophical context for further discourse on the nature of comets that were later observed in 1618-19. And the nova of 1572 was equally important as a philosophical reference point for the comet that would be observed in 1604. Tycho Brahe's observations and account of the new star of 1572 challenged the Aristotelian premise of eternal immutability of the heavens. His observations and account of the Great Comet five years later further undermined Aristotelian cosmology, for neither the distant place of the comet beyond the moon nor its apparent motion through the planetary spheres were possible on that view. Tycho was nevertheless concerned to reconcile Copernicanism and that part of Aristotelian physics that entailed that elements of earth remain in natural motion toward the center of the universe. The model that he devised kept the earth at the center of the cosmos with the moon, sun and starry firmament in revolution around that center, while the remaining planets were put in revolution around the sun. Tycho's system was therefore something of a compromise between the Ptolemaic and Copernican systems. However, while he attempted to save the Aristotelian physical model, he seriously undermined Aristotelian cosmology.

The important philosophical debate about these earlier sudden and surprising celestial events that Tycho and other's had initiated included a precedent for the relevant place of geometric reasoning and measurement in cosmological or philosophical matters. Of course, the comets of 1618-19 were the events that framed the controversy that unfolded between Grassi and Galileo by the time of that latter's publication of Galileo's *Assayer*, and it's in that work that we find pronounced case for the relevance of mathematics in philosophical matters. This part of the history is further discussed in the next chapter, since it directly concerns *The Assayer*. The comet of 1604 is further discussed here, however, for the light it throws on Galileo as a budding mathematical philosopher.

The new star of 1604 was an occasion for Galileo to explore the Copernican hypothesis in connection with the mathematics of parallax. Parallax, as a mathematical measurement, is the distance between two positions of an object, with respect to a fixed point, that varies according to the location at which the object is observed. The measure of parallax of an object is inversely proportional to its distance from the positions of measurement. Thus the further the object is from two points of observation the smaller the measure of parallax, and conversely. This is an effect of observation that has a long history in astronomy, and it was a vital aspect of the debate into the nature of the earlier nova of 1572. It was the *absence* of any measurable parallax of the new star with respect to its position in the Cassiopeia constellation that led Tycho to place at the approximate distance of the other stars. Therefore, the mathematics of parallax made possible claims regarding the nature of the cosmos.

Lodovico delle Colombe, a notable Florentine with connections to the Tuscan court, advanced an argument in his *Discourse* of 1606 that concluded that the new star was not new *per se*, but only previously hidden due to the nature of the intervening sphere between Saturn and the firmament. He couldn't disagree with the parallax measurement that demonstrated the newly visible star's location relative to earth, so he instead supposed that the quintessential substance of intervening sphere was nonhomogenous in density. Upon the geocentric rotation of the sphere, the denser part could suddenly magnify a star so dim or distant as to make it appear brighter than any other in the sky. This theory was consistent with the Aristotelian requirement of an eternally unchanging heaven.

Galileo argued against delle Colombe's Aristotelian theory of the new star but in a rather curious way. Perhaps due in part to agitation caused by Tycho's cosmological requirement for an Aristotelian physics in the competing Tychonic system, Galileo rather supposed that the "new star" was indeed new but not a star. He instead surmised that it was caused by a kind of emission from the earth that sent earthly elements very far away from the planet on a straight line from the earth toward the firmament. Since the course of the nova's detectable light spanned eighteen months, Galileo believed that he might measure parallax at antipodal positions not on the surface of the earth, but rather on the orbit of the earth about the sun. The latter scenario would be far more likely to entail any notable degree of parallax than the former due to the vast difference in distances between the two sets of positions. Of course, Galileo was theorizing on the Copernican model, but he and others measured no parallax whatever. The star, or earthly emission, must have been very far from earth indeed. John Heilbron suggests that this failed outcome of Galileo's observations and Copernican reasoning may have undermined his confidence in the Copernican model as a matter of physical truth.[11]

While Galileo appears to have argued on the basis of principles or facts internal to the disputes over the new star and the subsequent comets, it is an intriguing feature of the time line that what chronologically separates the two controversies is the simultaneous condemnation of Copernicanism and the Church's warning issued to Galileo not to hold any such position. This is not to say that this intervening event of Church authority explains the difference. The chronological observation only calls

[11] J.R. Heilbron, *Galileo* (2010), pp. 120-121.

for a closer examination now of the heretical situation in which Galileo found himself in entertaining the Copernican theory prior to the *The Assayer's* publication.

The timing and religious context of the publication of the *The Assayer* in 1623 reveals the primary reason for the omission of Copernican discussion: by 1616, Galileo had been firmly and seriously warned by Church authority to entertain the Copernican thesis no further. As noted above, there is scant reference to the Copernican question, let alone any Copernican argument. In fact, where Galileo does refer to Copernicus and Copernicanism in *The Assayer*, he does so in a seemingly dismissive way in reference to Grassi's charge of Copernicanism made in the latter's *The Astronomical Balance*. Grassi had claimed there that Galileo, presumably gleaned from Mario Guiducci's earlier *Discourse on Comets*, would still prefer the Copernican over the Tychonic system, even after the condemnation of the former.[12] Galileo skirted the dilemma Grassi imposed upon him by arguing that the Ptolemaic, Copernican, and Tychonic systems were not even relevant to the matter of comets since those founders "never treat of hypotheses concerning comets".[13]

In any case, the greatest cosmological question of relevance for the Church was the relation of the earth to the cosmos. The Church declared the earth motionless on a geocentric model of the heavens. The scholastic scientific tradition reinforced the Church's cosmology on this point. This is an important intersection of religious and philosophical affairs that sheds further light on the competition for natural truth between the mathematician and the traditional natural philosopher.

Following the introduction of the Aristotelian corpus to the Latin West, Scholastic philosophy in the twelfth through sixteenth centuries maintained a strict separation

[12] Grassi, *The Astronomical Balance*, in *The Controversy on the Comets of 1618* (1960), p. 71.
[13] *The Assayer*, in *The Controversy on the Comets of 1618* (1960), p. 180.

between the subject matter of the mathematician, who was justifiably preoccupied with position and measurement, and that of the philosopher, who concerned himself with the nature and motion of things of the terrestrial and celestial worlds. However, as soon as the mathematician, using his instruments to measure such astronomical phenomena as parallax, started making inferences about the physical nature of the cosmos based on mathematical properties, the disciplinary distinction between mathematician and philosopher started to blur. The Great Comet of 1577 was indeed a source of considerable theoretical upset for the Aristotelian cosmology in at least two ways. First, Tycho Brahe's observations and astronomical account of the comet placed the cosmological novelty far beyond the moon. Second, the apparent motion of the comet through the heavens relative to the fixed stars was strong evidence that there could be no celestial spheres of any substance on which the planets could be positioned and revolved about. Galileo found himself in similar disciplinary circumstances by the time of his astronomical discoveries of 1610, at which time his Copernican leanings began to surface in his writings. As the nature of comets was the philosophical pretext of the *The Assayer*, the Copernican question for Galileo would have seemed unavoidable. However, he simply avoided the question.

Galileo nevertheless went against both the Church and the Scholastic tradition in the more insidious manner of his scientific methodological reasoning, which often resulted in a conclusion as to what something was *not*. It is a fascinating historical and philosophical aspect of his method, in connection with his astronomical observations, that he could reject the Aristotelian dogmas of essential natures and geocentrism in his simultaneous support for the Copernican hypothesis. Galileo discovered that Jupiter had moons revolved about Jupiter, not earth; he observed the phases of Venus and explained their appearance on the grounds of that planet's orbit about the sun, not earth; his description of Saturn's appearance was far from perfectly spherical; his analysis of the apparent bodies rotating along with the sun led him to conclude that they must be on the surface of the sun due to their proximity and physical properties; and his explanation the tides of the earth's oceans as a physical effect of the earth's planetary motion: all of this astronomical novelty and phenomena naturally constituted ample reason for Galileo to debate the relative epistemic merits of Scriptural authority and the new astronomical accounts of the heavens. Galileo's 1615 "Letter to Castelli," which explained the matter of Scripture in relation to Copernican natural philosophy, consequently perturbed Church authority, especially in the person of Cardinal Robert Bellarmine. Bellarmine's influential positions in both the Inquisition and the Index then motivated an investigation into Galileo's suspected heresy on the matter of the Copernican question. Galileo responded to the impending charge by expanding his version of his now-controversial letter to the *Letter to the Grand Duchess Christina*, also written in 1616 and soon after Bellarmine's consideration of the charge. But he fared no better in his attempt to reconcile the epistemic merits of Scripture and observation-based inquiry into the heavens. For Bellarmine next warned Galileo about holding Copernican views any longer and informed him that he would be spared condemnation in turn for his acquiescence in abandoning those views.

Meanwhile, the Roman Inquisition judged the physical premises of Copernicanism to be philosophically absurd. The Index went further by publishing a decree that declared any physical statement as to the earth's motion necessarily false, thus subjecting Copernicus' work, and others, to censure or correction. The responses by the Inquisition and Index against Galileo were swift and effective, as they were accomplished in less than a year after Galileo's "Letter to Castelli." It was only two years later, however, that the first of two comets appeared in the night sky forty years after the Great Comet that led to considerable philosophical debate. Five years later, Galileo's *Assayer* was in the making as the definitive statement in the controversy over the nature of comets that had been initiated between Orazio Grassi and Mario Guiducci by 1619.

2.5 Mathematical Philosophy in the Sixteenth Century

Galileo is rightly regarded as a central figure in the history of early modern science due to new methods in scientific reasoning he was forging. As indicated in the previous section, he used mathematics for the measurement of position or location of such heavenly phenomena as novas, but these results had implications for philosophy. Allen Debus highlights Galileo's publications in the Italian vernacular as classics in Renaissance science; his *Assayer* was indeed immediately recognized as a masterpiece. Galileo was not alone, however, in advancing mathematical philosophy in the early sixteenth century.[14]

There were significant cultural forces that were underway during Galileo's time that led to the development and proliferation of philosophies that were creating new and original spaces for mathematics to fill. In the case of Galileo, there were certainly unique circumstances that led to his self identification as mathematical philosopher, or a new variety of natural philosopher who would employ mathematical technique in an attempt to demonstrate natural matters of fact.

The flourishing of mathematical philosophies by Galileo's time was variously influenced by ancient sources, and they expressed many different aims. John Dee

[14]Debus (1978), pp. 7,9.

(1527 - c.1608), an earlier English Renaissance philosopher, is another early modern figure who took mathematics in yet another direction by appealing to the Hermetic tradition in emphasizing the central role of the Hieroglyphic Monad, or the fundamental geometric sign that generated all other astrological or cosmological signs. Debus elsewhere draws attention to the variety of "cosmic mathematics" that informed astrology, magic, medicine and alchemy[15]. In fact, much of the variety of Renaissance mathematical philosophies in its cosmic dimensions can be traced back to the influential work of Marsilio Ficino (1433 - 1499), who, incidentally, was commissioned by Cosimo d'Medici to translate the *Hermetic Corpus*. Ficino also translated works of Plato and established the Platonic Academy in Florence, so the Medici court atmosphere already included a strong philosophical presence of Platonic thought. Of course, Galileo would be employed by the Medici court as mathematical philosopher a century and half after Ficino's time at court, so we might naturally suppose his work to be indebted to at least one of the Hermetic or Platonic traditions. But neither of these ancient sources appears to have influenced Galileo's mathematical approach to nature. The historiographical account provided in the next chapter will bear on this point.

[15]Debus, *The Chemical Philosophy* (1977), pp.37-45.

Chapter 3

Galileo's *Assayer* in Historiographical Relief

In this chapter, I review some of the contemporary secondary literature that has critically assessed Galileo's *Assayer* with respect to the role of mathematics in his method and philosophy of science. As stated in the introduction, the history and philosophy of the *Assayer* is one of focused context: any philosophy of Galileo's *Assayer* (among his other works) is a part of its history; relevant discussion and analysis of the philosophy is therefore warranted from a historical point of view. However, personal, political and religious elements are factors that enter into that story as well. The historiographical thread I follow will include discussion of several of these factors.

3.1 The Question of Galileo's Philosophy

In 1597, Galileo wrote to Kepler thanking him for having sent to him for his consideration his first major work, *Mysterium Cosmographicum*, published in the previous year.[1] Kepler was an avowed public Copernican by this time while Galileo was still teaching Ptolemaic astronomy at the university. Kepler was nevertheless aware that Galileo had "been attached for many years to the Copernican heresy." Feeling encouraged by Galileo's response, Kepler replied in turn only to implore Galileo to finally appear in public with his Copernicanism after years of leading in a "cleverly veiled manner" against the "furious attacks of the scholarly crowd." Kepler nevertheless expressed his thanks for Galileo's protection of truth that followed in the example of Plato and Pythagoras, their "true masters."

Kepler's Copernican cosmology had strong Pythagorean and Neoplatonic elements, so we might suppose that Galileo's did too, especially in light of the above correspondence between the two. From the time Galileo started publicizing his Copernican beliefs, he was indeed attacked. Thomas Campanella defended Galileo in 1622 (one year before the publication of *The Assayer*) with the publication of his *Apologia* written on Galileo's behalf. Recall that six years earlier the Inquisition had issued a judgment against Galileo.[2] So Campanella admonished Galileo's accusers in the Church for foolishly basing their theology on Aristotle. He assured Galileo's accusers that he (Galileo) stood "firmly on the foundations of faith" and implied that Galileo's philosophy was "derived from God's book of the world and which serves as handmaid and witness for theology . . . not derived from the views of Aristotle or any one

[1] The correspondence between Galileo and Kepler here is published in Baumgardt's *Johannes Kepler: Life and Letters* (1951), pp. 38-43.

[2] Campanella, *Apologia pro Galileo, mathematico florentino*, (1994 [1622]), trans. Richard Blackwell.

else".[3]

Kepler may have supposed too much of Galileo's philosophical outlook, at least as far as Plato's influence is concerned. And Campanella may have supposed too little of Galileo, save his taken-for-granted faith in God's book. The answer to the question as to Galileo's philosophical roots seems to lie somewhere between Kepler and Campanella's views.

3.2 Galileo's purported Platonism

The question of Platonic influence on Galileo's philosophy and method was of considerable interest to Alexandre Koyre, an early proponent of the Platonist reading of Galileo's philosophico-mathematical works in general and the book-of-nature passage in particular. Including Koyre in the discussion may seem a dated source in Galilean scholarship, but when we recognize that a number of historians of Galileo (including Biagioli, for instance) uncritically accept Galileo as Platonist, it makes sense to root out and criticize what is perhaps the most prominent (if dated) position on the matter.

Koyre argued that there is a two-fold philosophical basis for the classification of seventeenth century natural philosophy rooted in the philosophy of Aristotle on the one hand, and that of Plato on the other. In his *Galileo Studies*, Koyre clearly located Galileo in the Platonic tradition of a mathematical realism; and after analyzing his Book of Nature claims, he was led to conclude that Galileo's methodological basis for the mathematical interpretation of nature amounted to modeling nature *a priori*

[3] Ibid., p. 85.

by using mathematical forms and geometrical laws.[4] Koyre's claim that mathematics precedes observation isn't necessarily problematic, since an interpretive framework naturally precedes that which is interpreted. However, Galileo's framework wasn't necessarily Platonist. So Koyre's rather lofty account of Galileo's emphasis on the role of mathematics in relation to the material world as one "born in the heavens," which he took to be evidence of his Platonism, is problematic.

Koyre also overgeneralized by claiming that "belief in mathematics was identified with Platonism".[5] This is certainly true in some cases (e.g. Kepler is a good candidate), but it may not apply to Galileo. Koyre's interpretation, moreover, anachronistically suffers from the very Platonist-inspired belief of his time that he consequently projected onto Galileo.[6] We will have good reason to doubt the pronounced Platonic character that Koyre imputes to Galileo's philosophy and any corresponding Platonic commitments.

Koyre, however, correctly noted Galileo's fundamental use of Archimedean static principles. He reminds us that one of Galileo's early works, *Bilancetta*, was on the hydrostatic balance, and he also noted that Galileo's Chair of Mathematics at the University of Pisa was awarded on the basis of his work on the center of gravity in solids, "a work entirely Archimedean in inspiration and technique".[7] Of course, Koyre used this aspect of Galileo's work to further support his claims for the "superiority of Platonist mathematicism over abstract empiricism." Discerning the Archimedean elements of Galileo's method is certainly significant, but they simply do not entail that Galileo was Platonist. Instead, Archimedes' results were clearly

[4]Koyre (1978 [1939]), p.204.

[5]Ibid.

[6]See Jeremy Gray's *Plato's Ghost: The Modernist Transformation of Mathematics* (2008), in which Gray identifies Plato as the dominant philosophy of mathematics that accompanied the origins and development of modern mathematics.

[7]Ibid., p. 36.

central to Galileo's mathematical thinking; Plato's philosophy was not.

The conclusion is supported by Peitro Redondi in his *Galileo Heretic*.[8] He observes an apparent disconnect between Galileo's and Plato's respective mathematical philosophies. He points to the crucial passages of *The Assayer* in which Galileo discusses the mathematical forms of atoms but stops short of assigning or defining actual geometric shapes belonging to the atoms. This is indeed in sharp contrast to Plato who, in his *Timaeus*, had the fictional Pythagorean Timaeus make a definite, *a priori* correspondence between the five regular solids (i.e. the "Platonic solids") and the four sublunary and single supralunar elements of the cosmos. If Galileo was as Platonic, as Koyre would have us believe, why would he have stopped short of the detailed Platonic geometric description of the elements? Presumably because Galileo never oberserved those shapes (see below, next chapter). Redondi finds this to be a rather perplexing aspect of Galileo's atomism, but one which nevertheless undermines the Platonic interpretation.

Additionally, in his *Galileo's Muse*, Mark Peterson finds no explicit evidence of Galileo's committement to Platonism in his biographical remarks. Although Galileo "praised" Plato's literary style and dialogues, "there is not a word for Plato's faith in mathematics.[9] The reason for Galileo's silence on Platonic philosophy may be due to the fact that he found a far more effective model of intelligibility to work with, as we will presently find to be the case.

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[8]Redondi (1987).

[9]Peterson, *Galileo's Muse* (2011), p. 31.

3.3 Attitude and Experience

If Koyre's two-fold source of ancient Greek philosophical roots is at all valid, Galileo might appear to have weaved a non-essentialist and non-occult methodological path between Aristotle's emphasis on experience, on the one hand, and Platonic or Pythagorean priority of mathematics on the other. The distinction here between these two possibilities is not new by Galileo's time. Sense and reason had clearly been distinguished by the ancients, who by and large fell on one side or the other: one group, represented by Pythagoras or Plato, would have pointed to the higher, non-sensible mathematical forms of the heavens; the other group, represented by Aristotle, pointed out into the world of sensory experience. Where Galileo stands, in contrast with these extremes, is apparently on the point of contact between sense and reason. Gary Hatfield suggests that this view of Galileo's method set him apart from other natural philosophers of his time who found inspiration in the revival of Plato or in the teachings of occult philosophy. In his "Metaphysics and the new science",[10] Hatfield argues that Galileo's work was certainly philosophical, but that it was without a metaphysics in either the Aristotelian or Platonic sense. This is evidently why, according to Hatfield, Galileo's non-metaphysical voice was heard above all others in the rise of modern science.[11] Hatfield is nonetheless aware that the famous Book-of-Nature passage of Galileo's *Assayer* would appear to suggest otherwise, especially on a Platonist reading. He instead offers an alternative interpretation of Galileo's mathematical Book of Nature that does away with any robust mathematical ontology and instead focuses on a certain *attitude*: his words about the Book of Nature revealed his attitude toward scientific knowledge as based on demonstrative or mathematical science. Hatfield also stresses the context of the *Assayer* in his drawing his conclusion; in particular,

[10] Lindberg and Westman (eds.), *Reappraisals of the Scientific Revolution* (1990), pp. 93-166.
[11] Ibid., p. 96.

Galileo may have needed considerable attitude to counter the prevailing scientific or even mathematical ontologies of his time, Platonist or Aristotelian. In discerning the true nature of comets, not to mention sunspots or the atomic constitution of matter, Galileo broke from Aristotelian essences and disembodied Platonic forms. "On this reading," according to Hatfield, "it is not the universe that is mathematical, but those of its properties that constitute the objects of scientific knowledge".[12] For example, sunspots were not essentially mathematical per se for Galileo, but their properties of *distance* from the sun were.

Hatfield suggests that Galileo's attitude toward mathematical demonstration in natural philosophy was strongly influenced by the Jesuits' writings on scientific method, by which the mixed sciences could be mathematically based. Peter Dear offers a more recent history of the relation between Galileo and the Jesuits at the Collegio Romano in his *Discipline and Experience: The Mathematical Way in the Scientific Revolution*.[13] Dear's interpretation of the controversy over comets between Galileo and Grassi, the leading mathematician at the college, gets at a difference in justificatory *experience*. On the one hand, Galileo, in his experiments with smooth motion of bowls, appealed to "universalized experience founded on many instances".[14] On the other hand, Grassi "appeals to the testimony of witnesses" in his own experiments the results of which were allegedly contrary to Galileo's.[15] For Dear, what was at stake for Grassi was his own personal authority as an expert on the matter. And for Galileo, what was at stake was the physical truth of the matter.

Dear highlights the fact that, despite the eventual animosity between Galileo and Grassi, there was considerable affinity between the two with respect to their

[12]Ibid., 131.
[13]Dear (1995).
[14]Ibid., p. 89.
[15]Ibid. 90.

common methodological use of mathematics. This early seventeenth century cross-disciplinary development led to the formation of what Dear identifies as "physico-mathematics," a certain bid for disciplinary authority over knowledge of nature".[16] The Jesuits, including Grassi, nevertheless forged this discipline under the auspices of Aristotelian philosophy, even if it did entail new method; for physico-mathematics "simultaneously exploited and overrode the standard scholastic disciplinary division between physics and mathematics . . . but did so by means of the Aristotelian characterizations of their subject matters".[17] In contrast to Grassi, who respected the Aristotelian methodological constraints on mathematics, Galileo appeared to be going it alone in his effort to undermine Aristotelian doctrine. He thus would have required another model of intelligibility.

3.4 The Balance as Model of Intelligibility

Hatfield's interpretation of Galileo as attitude-driven in advancing his mathematical philosophy against the Collegio Romano would have set him apart from the philosophical crowd, as it were. Galileo's attitude, in fact, corroborates Peter Machamer's finding of Galileo's "entrepreneurial-I", or an "individualism [that] is apparent in Galileo's texts by his ubiquitous and consistent use of the first person singular "I".[18] In *The Assayer* there are many explicit instances of this kind of first-person knowledge claim-making.

Machamer inclines to the anti-Aristotelian, Platonist interpretation of Galileo's mathematical philosophy but in a qualified sense. He instead concentrates on Galileo's

[16] Ibid., p. 168.
[17] Ibid.
[18] "Galileo's Machines, His Mathematics, and His Experiments", *Cambridge Companion to Galileo* (1998), ed. Peter Machamer

entrepreneurial-I as it is engaged in models of intelligibility, and thus we return to a rather prominent feature of Galileo's method: the balance. Machamer puts Galileo in a category of his own with his particular use of the balance as a model of intelligibility for a new philosophy of nature. This was a philosophy of nature which, according to Machamer, would lead Galileo to the mechanical way.

The new mechanical philosophy that Machamer identifies in Galileo's model of intelligibility immediately appears to be at odds with the view that Galileo was simply another proponent of Platonic mathematical realism who rejected or refuted Aristotle, not to mention the Jesuit Aristotelians and earlier scholastics. Archimedean static mathematics, after all, is a Hellenistic phenomenon, and not directly culturally associated with the Classical Greek culture of Plato or Aristotle. And it is precisely here that Machamer gets to the real crux of the issue in interpreting the roots and nature of Galileo's mathematical philosophy in terms of the Plato-or-Aristotle debate: "The categories of the historian's debate were not actor's categories. They were anachronistically imposed structural categories used by historians in an attempt to bring some order to the complexity".[19] Koyre had earlier recognized the importance of Archimedean statics in Galileo's mathematization of nature, even though he assimilated Galileo to the Platonist tradition. Machamer, who is looking for the native categories within which Galileo thought, identifies the balance as the predominant category that served as Galileo's model of intelligibility. He is then able to explain just how central the balance was for Galileo's thought, since he was able to put his questions in terms of an equilibrium problem while asking about the cause or force that leads to something becoming unbalanced.[20] "Galileo used this equilibrium model all of his life," Machamer emphasizes.[21] In particular, it is the model of intelligibility

[19]Ibid., p. 56.
[20]Ibid., p. 60.
[21]Ibid., p. 61.

that Galileo rhetorically wielded in *The Assayer* against the views of Lothario Sarsi in the former's rejection of the latter's account of comets. Machamer consequently finds that this instance of Galileo's use of the model is one which "takes on larger epistemological force" since he is able to contrast the many meanings of "balance".[22] Machamer's conclusion regarding Galileo's use of the balance is decidedly philosophical, a "conceptual and real" model of intelligibility; and he naturally implies that the model has cognitive content, inasmuch as the image of the balance "directs thought" and is a "concomitant of understanding.[23]

While Archimedes, Plato and Aristotle are relevant to understanding the complexity of Galileo's philosophy of nature, there are other philosophers and theologians included in the story of Galileo's mathematical philosophy. In "Galileo and the Philosophy of his Time," Mario Vigano examines a broader, more complex philosophical context of Galileo's thought that informed *The Assayer*.[24] For instance, in addition to Plato and Aristotle, Vigano identifies the significant roles that Averroes (the legendary Commentator of Aristotle), Aquinas (the great Dominican Doctor of the Church) and Pythagorean philosophy played, directly or indirectly, in the philosophical backdrop of Galileo's thought: Averroes' commentaries on Aristotle, on the one hand, supported Church justification for the separation of theology and philosophy, while Galileo explored their intersection; Aquinas's commentaries on Aristotle, on the other hand, further clarified and created a place for the mixed mathematical sciences, and this supported Galileo's self-defining identity as a mathematician and philosopher—an identity, of course, that was sociopolitically legitimated by the court of Cosimo Medici that followed soon after Galileo's observational discoveries of Jupiter's moons and other astronomical phenomena that falsified major parts of

[22] Ibid., pp. 61-63.
[23] Ibid., p. 71.
[24] *Galileo Galilei: Toward a Resolution of 350 Years of Debate — 1633-1983* (1983), pp. 63-102.

Aristotelian and Church cosmology. Galileo's subsequent astronomical observations and analyses of sunspots, both strongly underscored by mathematical reasoning, further undermined the Aristotelian cosmology held to so firmly by commentators, theologians and Aristotelian natural philosophers alike. In this respect, Vigano notes, Galileo was Pythagorean and Platonist, since "in his philosophy Pythagoras had placed mathematics in the first rank".[25] Vigano goes on to explain, however, that Galileo was not opposed to *Aristotle's* philosophy, which he notes Galileo held in high esteem. Rather, Galileo opposed the method of the *Aristotelians*, which was more doctrinal appeal to authority than knowledge based on experience. In fact, Vigano goes so far as to identify Galileo as an Aristotelian truer to Aristotle's cause than the others, "precisely because he puts experience at the base of physics".[26] Galileo's Aristotelianism may consequently explain why Galileo rejected the Pythagorean mystical component of Pythagoreanism, while nevertheless putting number or geometric proportion in "first rank." Vigano discerns the connection between this aspect of Galileo's thought and his writing of *The Assayer* along several lines (as considered further in the next chapter), particularly in his remarks concerning the place of the nominal Aristotelians in relation to himself and ultimately God in an epistemic hierarchy: the first group, or "the herd of senseless folk," Galileo places at the bottom with those "who know nothing"; while God sits at the top, where all is known; and Galileo finds himself somewhere inbetween, where a good part of philosophy is known.[27]

Koyre had found Galileo's use of the balance and Archimedean statics to be central to the mathematics that could be applied to the physical world in a new natural philosophy. Archimedean statics indeed has a long history of practitioners who employed its principles. Pierre Duhem emphasized this point as well.[28] Machamer's

[25]Ibid., p. 88.
[26]Ibid., p. 90.
[27]Ibid., p. 94.
[28]See Duhem, *Essays in the History and Philosophy of Science* (1996), p. 243. Duhem further

historical emphasis on Galileo's scientific and rhetorical use of the balance, however, is most illuminating for the purpose of my thesis, for it indicates how Galileo's thought itself might be weighed in a sort of epistemic balance.

3.5 Comets and Politics of Theory

Mario Biagioli, in *Galileo Courtier: The Practice of Science in the Culture of Absolutism*,[29] takes a special interest in *The Assayer* and the dispute between Galileo and Grassi. He analyzes the history from a cultural point of view by interpreting *The Assayer* as a product of court "duels," where what was at stake was one's reputation and legitimacy. He finds that the dueling nature of the dispute, through Grassi and Galileo, extended well beyond the two individuals involved: the dispute took on larger proportions between institutions — the Lyncean Academy, the Jesuits of the Collegio Romano, and now the Tuscan court — and between generations — the older, Aristotelian generation of philosophers, and the newer generation of philosophers completely willing to jettison the Aristotelian corpus due to its inability to account for new phenomena. However, as the Jesuits were aspiring mathematical philosophers, Galileo consequently experienced heightened competition. Biagioli argues Galileo had to deligitimate Grassi on mathematical grounds by challenging the results of his parallax argument, which were empirically supported by the observations of astronomers across Europe: "Through this move, Galileo had turned a situation in which he had to counter the resources of several Jesuit observational astronomers into one in which he faced Grassi alone, and not just as a mathematician but as a *natural philosopher*. Galileo thus conveniently shifted the discussion to less

notes, in his *Medieval Cosmology* (1985), the medieval, Islamic influence of Averroes and Avempace on Galileo's dynamics.

[29] Biagioli (1993).

empirical and more philosophical grounds on which he thought he could more easily outdo Grassi".[30]

Rowland suggests that Galileo had belittled Sarsi as one of many in a flock of sterlings bound by the walls of authority while he elevating himself to the status of a true philosopher that soars alone like an eagle, far above those sterlings that "befoul the ground below them." As a good philosopher, Galileo followed the path of the mathematical demonstration that could not contradict geometry. Contradiction to geometry is what he accused his adversaries of—most especially Grassi and Jesuits. However, Grassi and other Jesuits at the Collegio Romano were also mathematical philosophers, even if largely bound by the authority of Aristotle. But it was nevertheless Grassi who had argued that comets were celestial phenomena far removed from the atmosphere due to the fact that no parallax of the comets could be measured.

This is really the curious point in the history of the comet controversy between Grassi and Galileo. David Wootton finds the interpretative problem here to be one that defies the usual interpretive assumptions of historians, namely, to generally assume that a historical author means what he or she says. In his *Galileo: Watcher of the Skies.*[31], Wootton explains that Galileo responded to Grassi in the most unexpected way: by providing an Aristotelian account of comets as an atmospheric optical illusion, he argued against Grassi's theory of comets in orbit about the sun on a Tychonic model of the universe. Before the publication of the *The Assayer*, Grassi had actually believed that Galileo would have agreed with his account, given the latter's known objections to Aristotelian physics and cosmology. However, Galileo the Copernican strongly disagreed with the Tychonic model and sought to discredit

[30]Ibid., p. 279.
[31]Wootton (2010).

it by discrediting Grassi. Galileo's account of comets seemed so far from plausible to the astronomical community that Galileo "convinced no one." But "the interesting question," Wootton points out, "is whether it convinced Galileo himself".[32] A related reason for Galileo's attack on Grassi evidentally was rather personal, for Grassi had behaved "as if nothing had happened" following the recent condemnation of Copernican theory, while the condemnation "had left Galileo very angry".[33] It wasn't just a question of Galileo's commitment to Copernican's *heliocentric* model of the universe, for Copernicus, based on his humanist criticism of Ptolemy, also required perfect circular motion. William Shea[34] explains that Tycho's theory of a geocentric universe in which the planets (except the moon) revolve around the sun and the sun around the earth was further supported by the absence of any observed retrograde motion of comet trajectories; retrograde motion would have been accounted for if the earth did move about the sun. So Galileo attacked both Grassi and Tycho on account of their poor mathematical reasoning. Shea elegantly summarizes the situation for Galileo: "Fear of a dangerous rival turned Galileo into a biased critic, and one wonders whether, in the heat of the debate, he hoped to dislodge the comet from the sky by demolishing Tycho's reputation on Earth".[35] In light of Wootton's view, that's just what Galileo set out to do, even if it *meant* that he were to give an account of comets that he didn't even believe himself.

[32]Ibid., p. 161.
[33]Ibid., p. 163.
[34]Shea, *Galileo's Intellectual Revolution* (1977)
[35]Ibid., p. 87.

3.6 Imagination, Fable and Faith

Lorraine Daston has discerned the roles that imagination played in Galileo's philosophy in her "Galilean Analogies: Imagination at the Bounds of Sense".[36] First, there is Galileo's use of expository analogies, widely used in his literary efforts to describe nature to a popular, or vulgar, audience. Second, there are Galileo's mathematical analogies, most commonly made between physics and mathematics and seen in his later work on the continuum in which he interprets physical position and atoms as mathematical points. And third, there are explanatory analogies, which Galileo made no use of since he distrusted them. "Galileo's vision of a reformed natural philosophy and his distrust of the imagination," according to Daston, "conspired to all but exclude explanatory analogies from his scientific writings".[37] The problem with this type of analogy for Galileo, according to Daston, is due to an Aristotelian conception of the imagination that Galileo inhereted. She explains that Galileo's adherence to the Aristotelian theory of imagintion as a faculty that combined and rearranged ideas or perceptions wouldn't necessarily, if it ever would, reflect natural events to the end of explanation. Galileo believed, on Daston's account, that the imagination is simply too impovershed and inadequate to the task of identifying any true, singular causes of phenomena, for the power of nature far outstrips that of the imagination in the many possible causes of phenomena.

Daston is getting at a vital philosophical aspect of Galileo's method of reasoning to the causes of things which contemporary philosophers of science would identify as the problem of "multiple realizeability" of phenomena — that is, that a given phenomenon may be realized from multiple causes. The section of Galileo's *Assayer* in

[36] *ISIS* (1984) 75, pp. 302-310.
[37] Ibid., p. 302.

question, which Daston cites but provides no account of, concerns Galileo's fable of the cicada, which incidentally is an example of the first kind of analogy. As Galileo recounts the imaginative fable, this insect sings a sweet, beautiful song which a naturally curious man hears and sets out to discover the cause of. The problem with the curious man's insatiable appetite for knowledge is that no matter how far or wide one searches for *the* cause of this phenomenon — the beautiful tune of the cicada — one risks losing the beauty of the phenomenon by going too far in the search for causes; in the case of the cicada, the curious man goes too far by accidentally killing the insect in search of the cause, thereby losing all remaining chances of a future discovery as well as the song itself.

Lawrence Lipking picks up on this thread in his *What Galileo Saw: Imagining the Scientific Revolution*.[38]He finds that the importance of the fable that Galileo had creatively employed to make his philosophical point is in fact "at the center" of *The Assayer*, where "Galileo clinches his argument." Lipking reminds the reader that the point Galileo was trying to make goes back to comet controversy: Galileo would not permit himself to conclude *exactly* what the comets were in their true nature. Lipking then explains why Galileo's fable had especially appealed to his most preeminent reader, Pope Urban VIII, who "didn't care about the nature of comets": he very much cherished the fable due to the religous lesson it offered: "All efforts to explain the ways nature could only be provisional, he [Urban] thought, because an omnipotent God might always have arranged things in some different way. The fable of sound exemplified that position".[39] Lipking goes on to note the corresponding irony of Galileo's position: for Urban also believed that Galileo's decision to include the fable in *The Assayer* highlighted his acquiesence to the earlier Inquisition's warnings.

[38]Lipking (2014)
[39]Ibid., p. 22.

Contrary to Urban's belief, Lipking suggests that Galileo took his approval of the fable as a sign that he might actually go further with his inquiries, including those into Coperinicanism. "Perhaps," Lipking remarks of Galileo, "he betrayed his own fable".[40]

The question of Galileo's acquiescence in relation to his religiosity is nevertheless an important one and will be further explored in the next chapter. Lipking's view of the fable is quite suggestive here, but what was it that was so agreeable to the pope about Galileo's acquiescence with respect to the religiousity that underscored the point of the allegory? Giorgio Spini's account of Galileo's religiousness sheds light on the question. In "The Rationale of Galileo's Religiousness",[41] Spini appears, like others, to uncritically assume that Galileo's epistemology was influenced by that of Plato's, and he makes this assumption *vis-a-vis* Aristotelian "bookish science," which stood in contrast to reading "directly in the great book of Nature".[42] Nevertheless, Spini's general question is still an important one: was Galileo's philosophy Christian? It's in *The Assayer* where Galileo first broaches the atomic theory of matter, which Grassi and other Church officials found heretical due to its implications for the Eucharist Theology.[43] This may have been an unintended consequence for Galileo, for, as Spini recounts, Galileo never thought that a heretical conflict with the Church would arise, let alone be any sort of theological issue.[44] As I'll argue in the following chapter, Galileo goes beyond any hidden meanings or implications of the cicada fable in his notable deference to God as *the* One who knows all. And Spini's argu-

[40]Ibid., p.23.

[41]*Galileo Reappraised* (1966), Ed. Carlo Golino, pp.44-66

[42]Ibid., p. 62.

[43]See also Sharrat, *Galileo: Decisive Innovator* (1994), pp. 148-149: "*The Assayer* had been examined on behalf of the Inquisition by a sympathetic expert, Giovanni di Guevara.... It was only Grassi's book that adverted them to possible difficulties over Eucharistic Theology, but they could reasonably tell themselves that a book which had not only delighted the Pope but also passed on Inquisitorial check after publication was pretty secure."

[44]Ibid.

ment will corroborate this part of my interpretation, inasmuch as he concludes that Galileo's strenuous, but ultimately futile (given the outcome of condemnation at his trial), efforts to uphold what he found to be the truth probably could not have been otherwise: "Galileo could not resign himself to admit that truth would not prevail, because in that case he would have to admit that God . . . was impotent".[45] Wade Rowland has also examined Galileo's problematic relationship with the Church in *Galileo's Mistake*.[46] He argues that the confrontation between the two symbolized the momentous transition from the Age of Faith to the Age of Reason.[47] He bases his conclusion on his defining the eventual dispute between Galileo and the Church as one between two conflicting views of truth and reality on the one hand, and the roles of science and religion in discovering truth and reality and the other.[48] Rowland finds that the issue boils down to what he takes to be Galileo's mathematical reductionism and the Church's denial of that explanatory method: "For the Church, a mathematical, mechanistic interpretation of nature could never be more than a model, an intellectual artifact. Between theory and reality, there would always be a gap that could not be bridged by human reason".[49] This was Galileo's mistake, according to Rowland—that is, his believing that that gap could be bridged.

Rowland and Lipking would both agree about Galileo's "mistake," inasmuch as they find Galileo ignoring the very lesson of the cicada fable. Rowland recounts that this was Maffeo Barberini's (later Pope Urban VIII) earlier objection to Galileo's as could be discerned in the latter's *History and Demonstration Concerning Sunspots* (1613) and his *Letter to the Grand Duchess Christina* (1615), both written before there was even a controversy about the true nature of comets leading to Galileo's

[45] Ibid., p. 66.
[46] Rowland (2001)
[47] Ibid., p. 4.
[48] Ibid., p. 6.
[49] Ibid.

writing of *The Assayer*. Barberini said then, eight years before being delighted by Galileo's fable of the cicada, that Galileo could never have knowledge of "a single and unique explanation to natural phenomena . . . which makes all other explanations wrong".[50]

Rowland also finds significance in the Pythagorean-inspired mathematical realism that has been attributed to Galileo, and this is why he refers to his "mathematical reductionism." There is no doubt mathematics was a crucial component of Galileo's methods, but the evidence that I bring to light based on my interpretation of *The Assayer* will rather suggest that Galileo, to a notable degree, was forced to respect the epistemic gap between theory and reality. I will argue that the epistemological tenets of his method rather constrained his mathematical demonstrations to a considerable degree.

3.7 The Book of Nature

Galileo's statements on the "Book of Nature," one of the two key passages of *The Assayer* with which I am primarily concerned, is what some have found to be clear evidence of Galileo's Platonist philosophy of, or perhaps attitude toward, nature. As this chapter has shown in the first few sections, there's far more reason to believe that Galileo didn't prescribe to a Platonist philosophy over an Aristotelian one, and the model of intelligibility with which Galileo worked, namely the balance, seems to give us a clearer picture of the mathematical view which Galileo in fact adopted. In the final section of this chapter, I further discuss Galileo's book of nature from some alternative perspectives.

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[50] Ibid., p. 145.

In *Galileo Heretic*, Redondi finds Galileo's proclamation "disappointing" for not telling his readers what *exactly* those shapes were as the "characters" of the language by which the universe could be understood geometrically. In particular, Redondi's disappointment with Galileo's apparent short-coming is connected to his (Galileo's) later remarks of *The Assayer* in which he tells the reader that the particles of heated matter have "such and such" shape.[51] I've already indicated that this may not be a critical problem for Galileo, a task I take up in the next chapter. Of course, it's here that Redondi has good reason to doubt Galileo's alleged Platonism:[52] Galileo never observed those shapes, nor could he have. Galileo nevertheless held firm to the geometric interpretation of nature. Redondi seems to take a last resort by interpreting the passage as Galileo's attempt to throw a "net" into the "infinite ocean" of experience "to capture, within the meshes of mathematical description, atoms invisible to the naked eye".[53] However, Redondi may be going too far to have Galileo *save the geometry* (as it were) of the universe when in fact he never intended to.

Wootton offers an interpretation of Galileo's Book-of-Nature claim by asking what Galileo meant by "book", "characters", and "written". His question is insightful, since it does seem reasonable to conclude that Galileo, a master rhetorician and polemicist, would have meant something by these words. Obviously, there is an analogy on the surface of the passage, as Daston would point out, with the use of "book". But what Galileo analogously means by "universe", according to Wootton, is a original copy, not unlike a manuscript, that can be subsequently reproduced like a printed book using the "characters" in which the original is written, that is, circles, triangles, and, as Wootton is inclined to include, parabolas. The meaning of "book" in

[51] Redondi (1987), p. 15.
[52] Ibid., p. 63.
[53] Ibid., p. 64.

particular therefore “flickers between these two meanings, between the unique object and the mass produced object”.[54] “Galileo’s text,” Wootton remarks, “generates a gestalt-shifting image, such as the duck/rabbit described by Wittgenstein”.[55] Wootton, like Redondi above and Biagioli below, finds that this aspect of *The Assayer* reflects a Platonist philosophy of nature, since there is the unique One of reason, which in its many instantiations, becomes Many in the world of experience; there is, in other words, the unique form of the world and its manifold copies. I find reason to doubt this in light of my analysis of *The Assayer* in the next chapter. But Wootton adds, however, that Galileo must have taken God to be the author of *the* Book of Nature, and this is the important point, as far as I’m concerned; for *Galileo’s* Christian conception of God — not Plato’s conception of a *demiurge* — is a central piece of the philosophical puzzle of *The Assayer* that I attempt to assemble in the next chapter.

Finally, Biagioli interprets Galileo’s book-of-nature trope in his *Galileo Courtier*, but he does so within the framework of his court-culture analysis: he argues that Galileo was writing to an audience of courtiers, and that the “image of the book of nature appealed to them because of the sense of *unmediated* knowledge it conveyed”.[56] Biagioli then considers the crucial passage in question as one that showed Galileo’s allegiance to Plato “in a quite roundabout way.” Biagioli doesn’t pursue the question of Platonic influence on Galileo, but only rather appears to accept earlier scholarship that concluded that there was such an influence.

More illuminating is Biagioli’s subsequent analysis of Galileo’s trope in *Galileo’s Instruments of Credit: Telescopes, Images and Secrecy*.[57] He still appears to uncriti-

[54] Wootton (2010), p. 166.
[55] Ibid., p. 167.
[56] Ibid., pp. 306-307; original emphasis.
[57] Biagioli (2006).

cally assume the Koyre-approved Platonist stamp on Galileo's mathematical philosophy, which he now refers to as mathematical realism.[58] Biagioli nevertheless provides a vital clue for an understanding of Galileo's attempt at making priority claims in the *The Assayer*. "The book of nature did not emerge as an abstract methodological reflection," Biagioli explains, "but as a remarkably context-specific response to critics who had invoked the absolute authority of another book: the Scripture".[59] We've seen how some of Galileo's claims of *The Assayer* implicated his relation to Church authority. The significance of the context to which Biagioli draws attention thus renders the comet dispute incidental to the larger issue at hand: namely, a dispute between books of authority. That Galileo's Book of Nature claims were supposed to yield *transparent* knowledge to all who would first learn the language necessary to understand nature — the language of geometry — would leave no question of interpretation, unlike the *Bible* and the mediated interpretation it often required.

Biagioli's analysis does come with an important proviso, however. He finds that the dispute between the two authoritative books does not imply that Galileo intended the Book of Nature to outweigh (as it were) the Book of God. This is consistent with Wootton's observations. Instead, "Galileo's book of nature deferred to the Scripture while differing from it", in Biagioli's words.[60] I find this part of Biagioli's interpretation of Galileo's Book of Nature quite compelling. I argue similar points with respect to other key passages of *The Assayer* in the following chapter, to which I now turn.

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[58]Ibid., p. 220.
[59]Ibid., p. 220.
[60]Ibid., 221.

Chapter 4

The Paradox of Galileo's Mathematical Philosophy

In the final chapter of my thesis, I aim to reveal the crux of the epistemological issue Galileo faced in his balancing act between the authorities of God on the one hand and Nature on the other. For Galileo, these two authorities are not just the sources of justification of knowledge; they are also the origins of the cognitive means by which Galileo — and anyone else so willing — is able to gain knowledge of the natural world.

In what follows, I provide an analysis of the key parts of *The Assayer* that are relevant to an understanding of the balance that Galileo tried to achieve. I argue that where Galileo seems to falter in his mathematics-based philosophical method is actually where there is a transition from one authority to another in a manner similar to what Biagioli suggests, as discussed in the closing lines of the previous chapter. At least one consequence of the argument will be further evidence that Galileo wasn't strictly Platonist, if he was Platonist at all.

I identify and interpret ten interrelated philosophical aspects of *The Assayer* in my effort to discover the limits of Galileo's knowledge. In later places of the his *Assayer*, he appears to transgress those limits in a paradoxical fashion.

Nevertheless, these aspects of the *Assayer* link together in such a way as to encapsulate a genuine "philosophy of science" (in Stillman Drake's words) of Galileo's own doing. I do not intend to systematize Galileo's thought as he articulated it in *The Assayer*, but rather to get at those features of the work for the purpose of reconstructing Galileo's mathematical philosophy as expressed in *The Assayer*. I discuss each item in turn and conclude with an assessment of the epistemological strength of Galileo's overall mathematical philosophy.

4.1 Galileo's definition of opinion

Galileo's *Assayer*, which was written in the form of a letter to his fellow Lyncean Cesarini, took an immediate defensive posture and, from the outset, appealed to the indubitable strength of the mathematical approach to nature. Grassi (writing as Sarsi) had previously taken issue with Galileo's method of mathematical analysis in his *Discourse on Floating Bodies*, in which he employed Archimedean principles to show that the objects would float or sink depending on their "specific gravity". His method here was essentially geometric. In his defense, Galileo sharply recounted that his

> opinions were contradicted without the least regard for the fact that what I set forth was supported and proved by geometrical demonstrations; and such is the strength of men's passion that they failed to notice how the

> contradiction of geometry is a bald denial of truth.[1]

This passage expresses Galileo's first appeal authority, namely geometry. However, prior to Galileo's "book of nature" statement in his *Assayer*, we find another clear statement concerning the connection between opinion, geometry and natural, or physical, truth. It is clear that Galileo defines "opinion" as an expression based on a geometrical demonstration that has the potential to yield a "truth" about the natural, or physical, world. The mathematical validity of an opinion may therefore be beyond doubt, which is to say that the opinion may correspond to a mathematical truth; but the validity of such an opinion in its purported correspondence to the natural world is not necessarily beyond doubt.

4.2 The Grand Book of Nature according to Galileo

Galileo's full, programmatic-like statement regarding the connection between mathematics and natural philosophy is made in response to Grassi's method of reasoning that he finds to be so at odds with his own preferred mathematical method. According to Galileo, Grassi's method is full of ignorant appeal to authority, fancy, or fallacy, none of which can serve as the means to the discovery of natural truth. This was the pointed criticism of Grassi that informed the larger context of the famous, oft-quoted passage about the "book of nature."

> In Sarsi I seem to discern the firm belief that in philosophizing one must support oneself upon the opinion of some celebrated author, as if our minds ought to remain completely sterile and barren unless wedded to the reasoning of some other person. Possibly he thinks that philosophy

[1] Galileo, *Assayer*, pp.231-232

> is a book of fiction by some writer, like the *Iliad* or *Orlando Furioso*, productions in which the least important thing is whether what is written there is true. Well, Sarsi, that is not how matters stand. *Philosophy is written in this grand book, the universe, which stands continually open to our gaze. But the book cannot be understood unless one first learns to comprehend the language and read the letters in which it is composed. It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures without which it is humanly impossible to understand a single word of it....*[2]

Note here Galileo's underlying assumption concerning what is *humanly* possible, or impossible, to understand. Galileo furnished a role for the human senses, since it was the senses for him that made possible the human ability to "gaze" at the universe; and he provides a role for human reason, inasmuch as it is employed in the form of mathematical or geometric demonstration applied to the natural world — the very basis for Galileo's idea of opinion. According to Galileo, these two human capacities, sense and reason, are able to come together in a method of knowledge acquisition that leads to an understanding of the universe. He is clearly stressing the language of mathematics, a product of reason. The senses retain an equally important role, however. Without the senses it would be "humanly impossible" to understand the universe.

Galileo may have added without question that without the senses it would be humanly impossible to *experience* the universe. Thus the cognitive nexus for Galileo was to be found in the intersection of experience and mathematical reasoning.[3]

[2] Ibid. pp.237-238; emphasis mine.

[3] The relation between experience and mathematics is further analyzed by Peter Dear (1995), who takes a sociolinguistic approach to analyzing categories and terms of Galileo and the Jesuits; his approach, also touched upon in the previous chapter, is germane to Galileo's use of terms and

4.3 The knowledge of fools, God, and Galileo

The distinction Galileo makes between himself as one type of thinker and Sarsi as another is located in his remarks on increasing or decreasing degrees of knowledge in one of two directions: toward God, at the greatest extreme, or toward the fool, the lowest extreme. In admonishing Sarsi and calling him a fool, Galileo pictured a pyramid-like shape of human knowledge. He explained to Sarsi thus:

> The crowd of fools who know nothing ... is infinite. Those who know very little of philosophy are numerous. Few indeed are they who really know some part of it, and only One knows all.[4]

On the one hand, Galileo made Sarsi appear to be the fool, a philosopher at best. Galileo, on the other hand, took himself to be one of the few who really know, or perhaps a philosopher at worse. In light of the evidence that Galileo was against Aristotelians and not Aristotle *per se*, he might have even grouped himself with Aristotle as those few who really know. In any case, Galileo created an important space for the perfect knowledge of God, or the One who knows everything. What follows this passage in the text is a seemingly paradoxical connection between the nature of such perfect knowledge and the method of mathematical demonstration that he was undertaking:

> To put aside hints and speak plainly, and dealing with science as a method of demonstration and reasoning capable of human pursuit, I hold that the

linguistic framework.

[4] *The Assayer*, p. 239

> more this partakes of perfection the smaller number of propositions it will promise to teach, and fewer yet will it conclusively prove. Consequently the more perfect it is the less attractive it will be, and the fewer its followers.[5]

In other words, Galileo's method of demonstration inclined to perfection but with the result that fewer philosophers would be able to follow it due to both a diminishing aesthetic and role of the senses. What Galileo evidently had in mind is the increasing abstraction of mathematical thought, or perhaps, in anticipation of his subsequent analysis, the increasing non-sensory aspect of purported physical truth which only abstract mathematical thought can get at. That Galileo states that "fewer yet will it conclusively prove" seems to be an admission of the kind of problem that he may have faced with his atomic, primary-property based analysis of heated objects in particular and matter in general.

Galileo goes on to reject authority in general, especially any appeal to the masses: "Hence I consider it not very sound to judge a man's philosophical opinions by the number of his followers".[6] His message here reflects his opening remarks of *The Assayer*, and they help us understand his reasons for defending himself against the alleged likes of Sarsi, the fool. Moreover, these remarks would lend a degree of rational support to Galileo's more controversial claims, such as those made in defense of the Copernican hypothesis or an atomic account of matter.

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[5]Ibid. pp. 239-240.
[6]Ibid. p. 240.

4.4 Galileo's conditions for natural knowledge

What exactly is it about the method of demonstration, as Galileo claimed, that would compel few to follow it? He intitially explained the opposing appeals of the two directions in terms of the different accounts of the natural world that follow regularity on the one hand, or irregularity on the other. Galileo found regularity to be a property of the natural world in the way of its observable operations or events. For Galileo, mathematics is a method *par excellence* that can account for any discoverable regularity of the world. The question of regularity in *The Assayer* thus concerns description of the comet's motion, which Sarsi had earlier concluded had irregular motion. Galileo, however, supposed that the comet's motion could be described by some geometric form of regularity. The form of the account need not be irregular, according to Galileo, even if "there is no doubt whatever that by introducing irregular lines one may save not only the appearance in question but any other." However, he maintained that "this would only prejudice [the account] more seriously... because it would have been very flippant to do so".[7] Galileo's approach thus stressed mathematical regularity which, if no account could at first be found, should leave the mathematical philosopher in a state of epistemic *neutrality*, not doubt. In other words, the mathematical philosopher should not commit to any one account of regularity if it has not yet been observed; and neither should he assume or conclude that there must then be irregularity. Given the strong connection that Galileo makes between regularity and mathematics, in addition to the illustrative examples he provided, I quote in full the passage that concerns the issue at hand:

> Sarsi himself may understand this if he will consider what is meant by an irregular line. Lines are called regular when, having a fixed and definite

[7] Ibid. pp.240-241

> description, they are susceptible of definition and of having their properties demonstrated. Thus the spiral is regular, and its definition originates in two uniform motions, one straight and the other circular. So is the ellipse, which originates from the cutting of a cone or a cylinder. Irregular lines are those which have no determinacy whatever, but are indefinite and casual and hence indefinable; no property of such lines can be demonstrated, and in a word nothing can be known about them. Hence to say, "Such events take place thanks to an irregular path" is the same as to say, "I do not know why they occur." The introduction of such lines is in no way superior to the "sympathy," "antipathy," "occult properties," "influences," and other terms employed by some philosophers as a cloak for the correct reply, which would be: "I do not know." That reply is much more tolerable than the others as candid honesty is more beautiful than deceitful duplicity.[8]

This is a remarkable passage of *The Assayer* that connects observation, regularity, description, determinacy, honesty and demonstration of an object's properties in an account of that object. This is in sharp contrast to any occult, irregular, non-descriptive, indeterminant, non-demonstrative or dishonest account of an object or phenomenon. The former are clearly the positive criteria of Galileo's mathematico-philosophical account. That Galileo went beyond stressing just the correct mathematical form of the account by highlighting the kinds of incorrect forms that appear in astrological, magical or occultist views indicates what he finds himself up against. In contrast, to the latter views, his approach relied on explicit criteria for a mathematics-based knowledge of the world that ultimately depended on the demonstration of properties by mathematical reasoning. This result, however, was not sufficient for natural philo-

[8] Ibid. p. 241

sophical knowledge or natural truth; for they will still only amount to opinions, as defined by Galileo. This is only because opinion doesn't guarantee natural truth, even if the opinion is a mathematical demonstration. Galileo nevertheless proposed the primary requirement that what *is* necessary for natural philosophical knowledge is a mathematical demonstration of regularity belonging to the event or the appearance of a phenomenon; i.e., the absence of any such demonstration would have entailed the absence of any natural knowledge thereof, and the mathematical philosopher who, according to Galileo, was unable to provide such an account but could admit that he did not know could then be applauded for his honest ignorance.

Galileo's criticism of magical accounts that appealed to occult, or hidden, properties, is notable, given he thought in an atmosphere steeped in the revival of the Hermetic tradition and Platonic teachings. While not explicitly stated, his criticism of the occult way may lead us to conclude that another necessary requirement for natural philosophical knowledge is the *actual appearance* of the phenomenon in question; in other words, the phenomenon to be understood must be capable of observation, if it is to be capable of any mathematical analysis. This becomes a difficult issue for Galileo that required an additional distinction.

4.5 The question of essence: appearance vs. reality

The question of essence — of utmost important to the Aristotelian natural philosopher — is finally addressed by Galileo, but rahter in light of his skeptical reservations regarding the true nature of comets and other natural phenomena. The mere observation of an appearance simply cannot be, Galileo stressed, the sole criterion by which something can be said to be of some real nature. Moreover, there would be a problem in distinguishing "the real from the spurious," if the natural philosopher *only* appealed to the senses. The upshot of Galileo's criticism of the Aristotelian method of accounting for essence is that a geometric criterion, once again, is needed for mathematical reasoning. Otherwise:

> Who could distinguish between the moon seen in daylight and a cloud touched by the sun, were it not for difference of shape and size? If simple appearance can determine the essence of a thing, Sarsi must believe that the sun, the moon, and the stars seen in still water are true suns, real moons, and veritable stars.[9]

The distinction that Galileo made here between appearance and reality is related to yet another major distinction discussed below, namely, that between primary and secondary qualities. That he discussed the purpose of geometry before doing so is interesting, since it's a geometric question of reality that becomes very problematic for him.

4.6 The purpose of geometry

Galileo raises the likelihood that Sarsi would criticize him (Galileo) for contradicting his own lesson on the importance of regularity by actually assigning *irregular* shapes to the sky since, after all, he did just that following his observations of the rough, mountainous moon and the non-perfectly spherical shape of Saturn. Galileo responded by recounting his reasons why such heavenly bodies were necessarily rough and not smooth; it was precisely those properties by which they were able to reflect

[9] Ibid., p. 256.

the light of the sun and make themselves visible.[10] This is an account based on reason and one by which what is explained by reason is not essence, but *appearance*, something accessible to the senses.

There is another issue at stake here, however. Galileo strove to not presuppose the best or most perfect shape of anything in his premises or conclusions. Shape, as a property of bodies, must be discerned by observation and not imposed by any strict geometric instance of shape. In addition, any perfection that might be said of some shape in relation to the body in which it inheres may only be perfect due to the *purpose* it serves. "I believe," Galileo explained, "that in a way all shapes are ancient and noble; or, to put it better, that none of them are noble and perfect, or ignoble and imperfect, except in so far as for building walls a square shape is more perfect than the circular, and for wagon wheels the circle is more perfect than the triangle".[11] So construction of artifacts from shape with purpose is one thing; discovery of shape and corresponding function in natural phenomena is another. Until that shape is discerned by observation, the natural mathematical philosopher must admit that he "does not know." Thus what was central to Galileo's conclusions regarding the reflection of light from roughly shaped surfaces was observation of any such surface. The sensory observation, enhanced by instrumentation (in the case of the moon, the telescope), was the empirical basis for the reasoned conclusions that Galileo made. Aristotle and many others believed the contrary, since the shape of the moon, corresponding to its essense, was *necessarily* perfectly spherical.

[10]Ibid., p. 263.
[11]Ibid.

4.7 Causes and effects of heat

In addition to the shape of a thing and its possible purpose, the physical cause of a phenomenon was of interest to Galileo. Due to an investigation into the nature of comets, which appeared to some to be made up of fire or heat, Galileo turned to an analysis of the general causes and effects of heat. In contrast to the direct role that the senses may have played in discerning shape or other relevant properties of bodies that could form the basis of conclusions regarding true natures (i.e. essences), Galileo's analysis of heat turned on the *insensible* properties of matter, the existence of which he concluded could only be inferred indirectly. Suddenly Galileo argued for the existence of properties that were *not* open to our gaze but were rather assumed to be accessible *only* via mathematical reason. The question concerned the nature of comets: are they heated or rarified objects by their supposed *motion* through the atmosphere, if not in the supralunar realm? The arguments made for and against the cause of heat as motion (according to Sarsi) or friction (according to Galileo) occupy several pages in *The Assayer*.[12] Galileo argued that the production of heat, caused by friction, brought about the effect of an imperceptible, microscopic consumption, or loss, of matter belonging to the heated object; any corresponding loss of the object's weight was therefore negligible since no balance could ever measure or detect the loss. Galileo was therefore arguing against Sarsi's macroscopic, empirically constrained view of heated matter which could only be heated by motion. That the cause of heat and its methods of investigation became the central issue of *The Assayer* is now reflected by the title of the work; for Galileo found his subtle approach to the problem of heat similar to the "sensitivity of the assayer's balance in comparison with that of the philosopher's steelyard".[13]

[12]Ibid., pp. 266-270.
[13]Ibid., pp. 267-268.

It is in these passages of *The Assayer*, however, where Galileo seems to lose a grip on the empirical, sense-based requirement of observation. A shift in Galileo's choice of words conveys this slip in method, inasmuch as he now *believes* that the imperceptible diminishing of bodies is the cause of heat. He was no longer offering demonstrations or even opinions, and his deviation from sense and its epistemological consequences were further reflected in his anticipation of Sarsi's objection of how such an imperceptible loss of matter could even possibly be *empirically shown* to be the case. Galileo's response is an exercise in "physical logic": an enumeration of, and a process of elimination among, the three physically and logically possible effects of heated matter: first, the possibility of no consumption of the heated matter; second, the possibility of perceptibly consumed matter; and third, the imperceptible consumption of matter, which Galileo favors as the explanation of heated objects. He eliminates the alternatives as follows. First, if a body is heated but not perceptibly consumed, then any consumption of its matter is necessarily imperceptible. Second, while some objects, such as filed iron, may be heated in conjunction with an observable loss of matter, it doesn't necessarily follow that *all* heated objects perceptively lose matter. Hence the third possibility follows: heated objects that cannot be observed to have lost matter by the assayer's balance still nevertheless do; therefore the matter lost must be imperceptible. The problem here motivated Galileo to review the earlier results of his experiments with bodies in water; he had provided an account of such bodies by removing matter from a floating body that then caused it to sink due to a change in the specific gravity of the resulting mass.[14] Extrapolating that empirical result to the case of bodies that imperceptibly lose matter, Galileo argued that the loss of matter must be due to the existence of imperceptible particles, generally referred to at the time as "corpuscles." This is what the assayer's balance could register that

[14]Ibid., p. 268.

escaped the philosopher's steelyard. However, that register appears only to be filled by supposition, not demonstration, let alone observation; so there remain epistemic consequences for Galileo concerning what he can demonstrate geometrically or argue for empirically in the case of heat.

How did Galileo slip from observation-based mathematical demonstration (or "opinions") to mere belief in the existence of imperceptible particles? Any why? Pierto Redondi sheds some light on the matter, noting that Galileo was likely inspired by William Ockham's polemics against Scholastic metaphysics and theology. Redondi explains the problem with Galileo's introduction of atoms already discerned above:

> In addition, the medieval Ockhamist philosophers . . . were clearly in favor of theories in physics—owing to their identification of substance with quantity—that were close to the atomism of Democritus and of Plato's *Timaeus*. Democritus and the *Timaeus* had illustrated the forms of atoms. Galileo, in contrast, after his grand declaration on the geometric characters of the book of the universe, remained quite vague on this point. How could one insert microscopic matter into those circles, triangles, and so on?[15]

How indeed. "If Galileo had been a Platonist," Redondi further notes, "he would not have been so elusive and would have had to discuss critically the *Timaeus's* speculations on the solid geometry of atoms. It is this apparent "Platonism" of the book of the universe that perplexes us today".[16] This does appear to be the epistemic problem Galileo had created for himself. But he may yet have an answer to it (and

[15]Redondi, p. 63.
[16]Ibid.

to Redondi) in his remarks that concerned the roots of his reason and sense.

4.8 Galileo's appeal to God and Nature

Rejecting Sarsi's account of the cause of heat amounted to rejecting Aristotle's account, since Sarsi had appealed to Aristotle. The prima facie problem of *The Assayer* is the nature of comets. In one instance, however, Galileo happened to follow his analysis of heat to further disagreement with Sarsi over whether arrows shot in air can be caused to ignite due to their motion. Galileo argued to the contrary, despite Aristotle's alleged experience in the matter to which Sarsi appealed. Galileo's criticism was a persistent stress on the importance of experience, despite the empirical short-comings that have now been seen to crop up in other places of *The Assayer*:

> Sarsi goes on to say that since this experience of Aristotle's has failed to convince us [Galileo and Guiducci], many other great men also have written things of the same sort. To this I reply that if in order to refute Aristotle's statement we are obliged to represent that no other men have believed it, then nobody on earth can ever refute it, since nothing can make those who have believed it not believe it. But it is news to me that any man would actually put the testimony of writers ahead of what experience shows him.[17]

Galileo's appeal to *experience* over authority was reinforced by his view of "the facts of Nature, which remains deaf and inexorable to our wishes".[18] So his appeal to the authority was one to Nature, inasmuch as Nature presents the *facts* to the senses for

[17]Ibid., p. 270.
[18]Ibid.

the experience thereof. Moreover, Galileo did

> not wish to be counted as an ignoramus and an ingrate toward Nature and God; for if they have given me my senses and reason, why should I defer such great gifts to the errors of some man? Why should I believe blindly and stupidly what I wish to believe, and subject the freedom of my intellect to someone else who is just as liable to error as I am?

There are two highly noteworthy features of this passage that need to be considered. First, his appeal to Nature as an inexorable authority is complemented by his view that is is by Nature that he is able to experience nature. This is the more compelling reason he continually provided for the justification of his opinions and other claims. But Galileo also recognized God as the source of his reason. These dual aspects of his cognition, sense and reason, corresponded to their origins in Nature and God, respectively.

Second, despite his non-sensory belief in the existence of particles, Galileo nevertheless recognized and acknowledged his own fallibility, however free his intellect may have been. Then what is especially important between this passage (God and Nature as sources of knowledge) and the previous one (rejection of any other authority contrary to those sources) was his stress on the senses and experience, as well as his refusal to forgo either use of his own senses or experience for the sake of believing anyone who was just as fallible as he. Hence the grounds for Galileo's rejection of authority or anyone's possibly erroneous belief also applied to Galileo himself.

Biagioli, as noted in the closing lines of the previous chapter, argues that Galileo ultimately defers to the authority of Scripture over that of Nature, and so by extension he ultimately defers to the authority of God. God is the author of Nature, the Book of the Universe. So, if God is the source of Galileo's ability to reason, then some of Galileo's non-empirical claims may retain some measure of justification. However, if God alone is the One "that knows all," presumably by the highest reason possible, then it follows that there are some facts of nature about which Galileo may never have demonstrative knowledge. This latter possibility may account for the vagueness that Redondi identifies. The direction in which Galileo was moving was simply away from the senses and toward God, if we assume Galileo's picture of human knowledge. On the basis of his own methodological principles, Galileo may therefore have been perfectly justified for stopping short of confirming Plato's identification of the regular solid shapes with the elements: he could not observe those shapes, so he made no knowledge claims about them. He nevertheless *believed* that they must have *some* shape. While this ambiguous result might suggest that Galileo was Platonist after all, I suggest that it is rather Galileo's strained respect for experience or observation that was supposed to guide his method.

4.9 Galileo's uncertain results

Galileo nevertheless stressed the crucial role of experience and the senses while rejecting the appeal to authority that would compel him (or anyone else) to "believe their own words rather than our own eyes." However, he argued for the existence of particles, or atoms, which he did not, and could not, observe directly. So where does his non-sensory, more strictly rational-based atomic account of matter lead him? To a higher grade of knowledge, by his own epistemology. This is the paradoxical result of his picture of knowledge. It would rather appear that Galileo had *faith*, not experience, in the conclusions he is now drawing. In contrast to his empirically guided, mathematically reasoned opinions, Galileo issued several statements that do not amount to demonstration or opinion; otherwise, he need not have spoken of his "belief" in the pertinent matter. The philosophical problem he is engaged with further revolve around the distinction between primary and secondary qualities. This is a distinction related to that between the senses and reason, in that the former are ascertained by reason and the latter by the senses. For example, the shape of an object, is a primary quality of that object understoon by (geometric) reason; the color of the object, by contrast, is a secondary quality, ascertained simply by the senses. Now if Nature was the basis for Galileo's senses and God the basis for his ability to reason, then we may conclude that Nature, for Galileo, was the realm of secondary qualities, such as color and so on, and God more closely related to the primary qualities, such as the geometry of things. The three-fold, intersecting sets of distinctions that are now at play — Nature and God, sense and reason, secondary and primary qualities — are interacting in Galileo's methodology in a quite natural way, since they map onto each other quite directly.

Galileo went on to add a fourth distinction between what are, on the one hand, only words or names which correspond to the arbitrary features of sensible secondary qualities, and, on the other, the reality of primary qualities, such as shape, that exist independent of the senses or experience. The previous three distinctions now naturally map onto the fourth. Taking these fourfold distinctions together, Galileo has metaphysically elevated the domain of primary qualities over secondary qualities; he is emphasizing the *reality* of things, despite his insistence elsewhere on the importance of sensory experience. Again, it is quite natural to conclude that Galileo finds himself in a greater position in the epistemic hierarchy leading to God. As Biagioli claimed of Galileo's epistemology, God was an authority greater than Nature, and we now clearly see this born out in the text at this stage. The outcome for Galileo is paradoxical, for he would rather appear to move in the downward epistemic direction toward the fools.

He makes numerous less-than-certain remarks based on his "saying,", "believing," or "thinking" in many places of *The Assayer*.[19] Consider one of these remarks, which gets at the real issue for Galileo while simultaneously appearing to undermine his own knowledge of the matter:

> Now I *say* that whenever I conceive any material or corporeal substance, I immediately feel the need to think of it as bounded, and as having this or that shape; as being large or small in relation to other things, and in some specific place at any given time; as being in motion or at rest; as touching or not touching some other body; and as being one in number, or few, or many. From these conditions I cannot separate such a substance by any stretch of the imagination. But that it must be white or red, bitter or sweet, noisy or silent, and of sweet or foul odor, my mind does not feel compelled to bring in as necessary accompaniments. Without the senses as our guides, reason or imagination unaided would probably never arrive at qualities like these. Hence I *think* that tastes, odors, colors, and so on are no more than mere names so far as the object in which we place them is concerned, and that they reside only in consciousness.... But since we have imposed on them special names, distinct from those of the other and real qualities mentioned previously, we wish to believe that they really exist as actually different from those. [20]

Galileo really appears to do an about-face concerning the relevance of sense and experience in the discovery of primary qualities. In what way, that is, can the senses "as our guides" give us any real clue to the external world or nature if they all amount to

[19] E.g. see pp. 275, 276-278.
[20] Ibid., p. 274

internal experience constrained by consciousness? And are not “bounded,” “shape,” “motion,” “number,” etc. words in their own right which are subject to sensory cognition? Galileo was aware of this consequence and attempted to deny it by arguing that the senses are still a guide to reason before confinement to consciousness. Moreover, if reason is the only means of accessing mathematical primary qualities, where does it reside in the “human spirit”? It surely cannot be bound by consciousness, given the inherent constraints he imposed there.

No doubt Galileo gave his intellect free rein with reason, without its being tethered to — let alone guided by — the senses or experience which he by now has relegated to a consciousness ontologically inferior to the external, real world of nature. His reasoning was instead the guide for belief. As a result, his beliefs and thoughts do not appear to rank the same as the status of demonstration that Galileo had so strenuously argued for in the opening pages of his *Assayer*. Galileo’s assayer’s balance is no longer an appropriate means of measuring the differences in Galileo’s own approach based on reason and sense. Upon weighing the status of these non-sensory claims against his earlier demonstrations, we find that his having removed the direct role of either the senses or experience from the balance in inperceptible matters produced a corresponding loss of true *natural* philosophical knowledge, precisely what he set out to achieve as a mathematical philosopher in the first place. But the would-be truth of his claims, however non-sensory they may be, might rather be of an epistemic status that only God would know — that is, if we take Galileo’s epistemology at face-value as outlined above. As far as the precise shape of those particles are concerned, it would rather appear that Galileo heeded the central lesson of the cicdada after all.

In sum, it appears that Galileo’s playing the role of assayer — who weighed not only sense and reason, but Nature and God, secondary and primary qualities, and names and the things so named — found that there was no balance since it clearly tilted in the direction of things and their primary qualities known only by reason, and hence in the direction of the utmost perfect knowledge of God. Galileo seems to have put himself in the paradoxical state of knowledge that corresponded to his picture of knowledge. Joseph Pitt wrote of Galileo's *Dialogue on the Two Chief World Systems* that he relied so heavily on geometric reasoning that Galileo had severly constrained his realist account of the world.[21] The *Dialogue* was written ten years after *The Assayer*, but the seeds of any such constraint already appear fully present by the time of the latter's publication. My account suggests that the seemingly paradoxical result is nevertheless consistent with the mathematical philosophy that Galileo attempted to formulate. Nevertheless, we might ask of Galileo if he really could have had any knowledge of the kind he wanted but which are found to have relied only on his beliefs. Wittgenstein remarked of the would-be knower in his *On Certainy* that "if what he believes is of such a kind that the grounds that he can give are no surer than his assertion, then he cannot say that he knows what he believes".[22] At the expense of relinquishing knowledge based on mathematical demonstration, this epistemic scenario essentially seems to be the one in which Galileo had found himself.

[21] Joseph Pitt, "Galileo, Rationality, and Explanation," *Philosophy of Science* 55 (1988), pp. 87-103.

[22] Wittgenstein, *Major Works: Selected Philosophical Writings* (2009), p. 360.

Chapter 5

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