CHRISTOPHER M. GRANEY

MATHEMATICAL DISQUISITIONS

THE BOOKLET OF THESES IMMORTALIZED BY GALILEO

MATHEMATICAL DISQUISITIONS

MATHEMATICAL DISQUISITIONS

The Booklet of Theses Immortalized by Galileo

* * * * *

CHRISTOPHER M. GRANEY

University of Notre Dame Press

Notre Dame, Indiana

University of Notre Dame Press
Notre Dame, Indiana 46556
www.undpress.nd.edu

All images from the *Mathematical Disquisitions* are used
courtesy of ETH-Bibliothek Zürich, Alte und Seltene Drucke.

Published in the United States of America

Library of Congress Cataloging-in-Publication Data

Names: Graney, Christopher M., 1966–
Title: Mathematical disquisitions : the booklet of theses immortalized
by Galileo / Christopher M. Graney.
Description: Notre Dame, Indiana : University of Notre Dame Press, [2017] |
Includes bibliographical references and index. |
Identifiers: LCCN 2017030443 (print) | LCCN 2017038797 (ebook) |
ISBN 9780268102432 (pdf) | ISBN 9780268102449 (epub) |
ISBN 9780268102418 (hardcover : alk. paper) | ISBN 0268102414
(hardcover : alk. paper) | ISBN 9780268102425 (pbk. : alk. paper) |
ISBN 0268102422 (pbk. : alk. paper)
Subjects: LCSH: Locher, Johann Georg. Disquisitiones mathematicae. English |
Galilei, Galileo, 1564–1642. Dialogo dei massimi sistemi. English. |
Astronomy—Early works to 1800. | Sun—Early works to 1800. |
Sunspots—Early works to 1800.
Classification: LCC QB47 (ebook) | LCC QB47 . G73 2017 (print) |
DDC 520—dc23
LC record available at https://lccn.loc.gov/2017030443

∞ *This paper meets the requirements of ANSI/NISO Z39.48-1992
(Permanence of Paper).*

To my sister,

Laura Kathleen Graney (1971–2013).

She liked the moon, and my work.

She would have liked Disquisitions 25 through 27,

and how no one had read them for a long time.

CONTENTS

ACKNOWLEDGMENTS

Dennis Danielson first directed my attention to Johann Georg Locher and his *Disquisitiones mathematicae.* Matt Dowd of the University of Notre Dame Press expressed early interest in a translation of Locher's book, shepherded this project along, and introduced me to Darin Hayton of Haverford College. Darin served as a valuable consultant and referee on the translation. Absent Dennis, Matt, or Darin, this book would not exist in anything like its present form. I owe them all many thanks. I also owe many thanks to my wife, Christina Graney. She walked through the entire translation with me, insisting that I not drift too far from the original Latin in my effort to produce a student-friendly book. The idea for a student-friendly translation is entirely mine. The responsibility for the flaws that exist in it is likewise entirely mine.

I thank E-rara and Google Books for making high-resolution copies of Locher's original work freely available on the Internet. I thank the Louisville (Kentucky) Free Public Library, whose resources I used extensively in this project. I also thank my college, Jefferson Community & Technical College in Louisville—it is the academic soil in which I have grown.

Introduction

We know Johann Georg Locher because Galileo Galilei immortalized him as an exemplar of anti-Copernican silliness. Without Galileo, Locher might have vanished into obscurity.

But Galileo devoted many pages of his 1632 *Dialogue Concerning the Two Chief World Systems: Ptolemaic and Copernican* to Locher's short book of 1614 entitled *Mathematical Disquisitions Concerning Astronomical Controversies and Novelties*. This is the "booklet of theses, which is full of novelties"[1] that Galileo has his less-than-brilliant character Simplicio drag out in order to defend one or another wrongheaded idea. When Galileo (through his character of Salviati) describes the author of this booklet as producing arguments full of "falsehoods and fallacies and contradictions,"[2] as "thinking up, one by one, things that would be required to serve his purposes, instead of adjusting his purposes step by step to things as they are,"[3] and as being excessively bold and self-confident, "setting himself up to refute another's doctrine while remaining ignorant of the basic foundations upon which the greatest and most important parts of the whole structure are supported,"[4] he is speaking of Locher. He is also defining Locher (and anti-Copernicans in general), especially for modern readers who study the debate over the heliocentric world system of Nicolaus Copernicus by means of translations of the *Dialogue* or of Copernicus's 1543 *On the Revolutions*. And Galileo is not defining Locher alone.

Disquisitions has always been largely credited to Locher's mentor, the Jesuit astronomer Christoph Scheiner, under whose supervision it was published.[5] Galileo also devotes pages of the *Dialogue* to discussing Scheiner's work on sunspots.[6] Thus the *Dialogue* pertains all the more to the work of, and to defining, Locher and Scheiner. Indeed, one of the consultants asked by the Inquisition to study the *Dialogue* for Galileo's trial in 1633 described Galileo's principal aim within the book as attacking Scheiner.[7] Galileo immortalized Locher and Scheiner through criticism of them.

Modern readers may therefore be surprised to find that even leafing through Locher's *Disquisitions* raises questions regarding Galileo's portrayal of anti-Copernican thinking (Figure I-1). For example, in the *Dialogue* Simplicio argues, based on Aristotelian ideas about the heavens, for a moon that is smooth. He says that those things seen on the moon through a telescope, "mountains, rocks, ridges, valleys, etc." are "all illusions."[8] But *Disquisitions* contains a page-width illustration of the moon, showing these supposed illusions in detail. The *Dialogue* portrays the two chief world systems as being "Ptolemaic and Copernican," but leafing through *Disquisitions* reveals that the two systems most carefully illustrated within it (in detailed full-page diagrams) are the Copernican system on one hand and the hybrid geocentric system of Danish astronomer Tycho Brahe (in which the sun circles Earth while the planets circle the sun) on the other. *Disquisitions* also contains an illustration of the sun with spots, an illustration of Venus showing phases as it circles the sun, and two remarkable pages of illustrations of the Jovian system. One of these pages contains a diagram of the system complete with the orbits of moons, the Jovian shadow, indications of the points where eclipses of the moons occur, and more. The other contains careful drawings of the Jovian system as seen through a telescope. This certainly does not look like a work full of falsehoods, written by an ignorant person who thinks things up to serve his own purposes while ignoring things as they are.

The combination of *Disquisitions*' many large and intriguing illustrations, Galileo's attention to it, and its relatively short length invites a reading—or, as the case may be, a translation. Modern readers who proceed beyond a casual perusal of *Disquisitions* will find that indeed it is not at all as Galileo portrays it, and not what one might expect from an anti-Copernican work. If what one expects from an anti-Copernican work is (to borrow some phrases from Albert Einstein's foreword to Galileo's

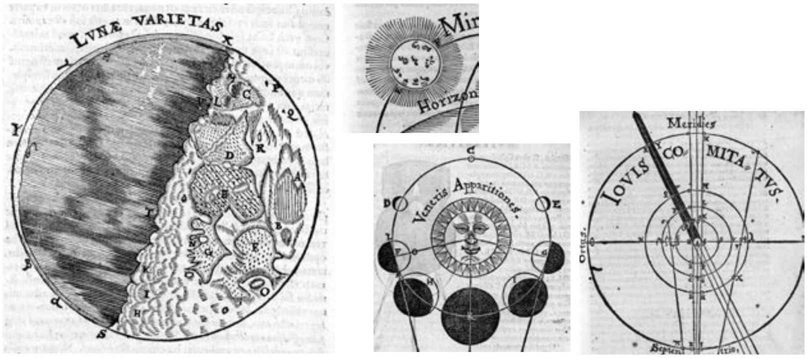

FIGURE I-1. Locher's illustrations of *(from left to right)* the moon, the sun (with spots), the phases of Venus showing that it circles the sun, and the Jovian system. All of Locher's illustrations used in this book are courtesy of ETH-Bibliothek Zürich, Alte und Seltene Drucke.

Dialogue) anthropocentric and mythical thinking, and opinions that have no basis but authority—against which Galileo stands as a representative of rational thinking[9]—then Locher's *Disquisitions* in fact invites a re-evaluation of that expectation.

Locher seems adept at rational thinking. He begins with an excursion into mathematics, emphasizing how it "is ageless, unchanging, and certain. Nothing stands in opposition to it. It yields to no difficulties of philosophy. It deals in no tricks." He separates astrology—which he says is "speculation that seeks to divine or judge the influence of heavenly bodies on earthly events, and to gain insight into future events based on the positions of the stars and planets"—from astronomy. Astronomy, he says,

> is more deliberate. It is that which studies absolute and inherent qualities of the heavens—number, shape, position, motion, time of occurrence, time of duration, qualities of light such as color or brilliance, and so forth. . . . It records and preserves celestial phenomena. It is the one friend with whom the heavens share their secrets. Elegant geometry and subtle arithmetic give it wings. Its paths become known to those who faithfully and carefully, through long and repeated experience, come to know its phenomena. Fine craftsmanship sustains their hands and strengthens their arms. Keen optics sharpen their eyes.

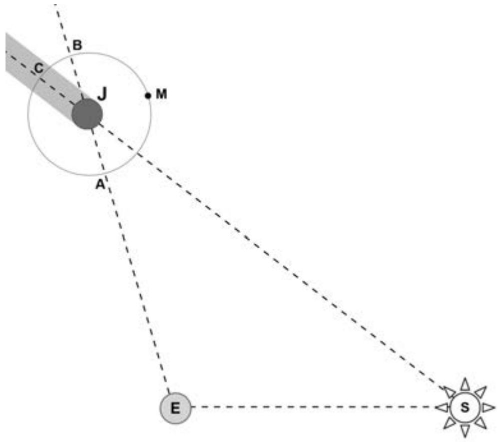

FIGURE I-2. Locher proposes using timings of the moons of Jupiter to measure distances between Jupiter, the sun, and Earth. Jupiter (J) casts a shadow that extends opposite the sun (S). A Jovian moon (M) circles Jupiter counterclockwise. An observer on Earth (E) notes by means of a telescope the time required for the moon to pass from the point at which it is in the center of Jupiter's shadow (C) to the point at which it is seen to stand directly in front of Jupiter (A). The ratio of that time to the period for one complete orbit of the moon is the same as the ratio of angle CJA to 360°. Thus angle CJA can be determined. Angles CJB and SJE can then be calculated using basic geometry. The angle SEJ between the sun and Jupiter can be directly measured from Earth. Since two angles, SJE and SEJ, are known in the sun-Earth-Jupiter triangle, and one side of that triangle (side ES) is one solar distance, the other two sides can be calculated in terms of solar distances, using basic trigonometry. Thus these distances can be directly determined, with no reliance on assumptions about the structure of the planetary system.

Thus Locher endorses what keen optics and skillfully constructed instruments reveal, and graphically and accurately represents that to his readers through the aforementioned illustrations.

Yet he goes further. Readers of *Disquisitions* will find that Locher proposes two research projects for the astronomical community. First he proposes that the newly discovered moons of Jupiter be used, together with geometry, to determine the distances between Jupiter, the sun, and Earth. Determining a certain angle in the Jovian system is key to this, he says (see Figure I-2), and "that in turn requires exact knowledge of the first emergences of the satellites from the shadow of Jupiter . . . after they have been eclipsed. This will require diligent and frequent observations." Then he proposes that the "attendants" of Saturn (not yet identified as rings) can be used to probe its orbital motion (Figure I-3). He says that "To find out what actually happens and settle these matters . . . Saturn must be diligently examined. . . . But we suspend judgment for now as regards all these matters of Saturn, and leave them to be decided by further experience with the phenomena."

Locher even advances a physical explanation for the phenomenon of Earth's motion around the sun in the Copernican system, namely that Earth is perpetually falling around the center of the universe, toward which it gravitates. In this way, he says, "we may be able now to imagine a manner by which Earth might be made to revolve" around the sun, even though he does not believe Copernicus to be correct. Indeed, students in introductory physics courses everywhere learn that Isaac Newton explained orbits as being a continual fall under the influence of a central gravitational force. The details are somewhat different, but Locher has the general idea.

Readers who delve into *Disquisitions* thus find Locher emphasizing the importance of mathematics, of long observation, and of recording data on position, motion, time of occurrence, time of duration, color, brilliance, and so forth. Readers find Locher creatively addressing interesting scientific questions, even about ideas with which he does not agree. Locher recognizes potentially productive research projects and encourages fellow astronomers to undertake prolonged efforts to gather the data needed to address these projects and answer certain questions, while holding off judgment until the results are in. In short, modern readers find Locher to be acting much like a modern astronomer, scientist, and rational thinker and not much like the exemplar of anti-Copernican silliness that Galileo portrays him to be.

Readers will also find that Locher displays a high regard for Galileo.[10] He is quite complimentary toward Galileo, a Copernican. At the same time Locher is extremely dismissive of Simon Marius, a fellow anti-Copernican. Locher's opinion seems to be that Galileo is outstanding, skilled, and learned, while Marius is, at best, a Galileo emulator.

At this point readers may wonder why Locher is not a Copernican, if he is a rational scientist, is friendly toward Galileo, and can even put forth

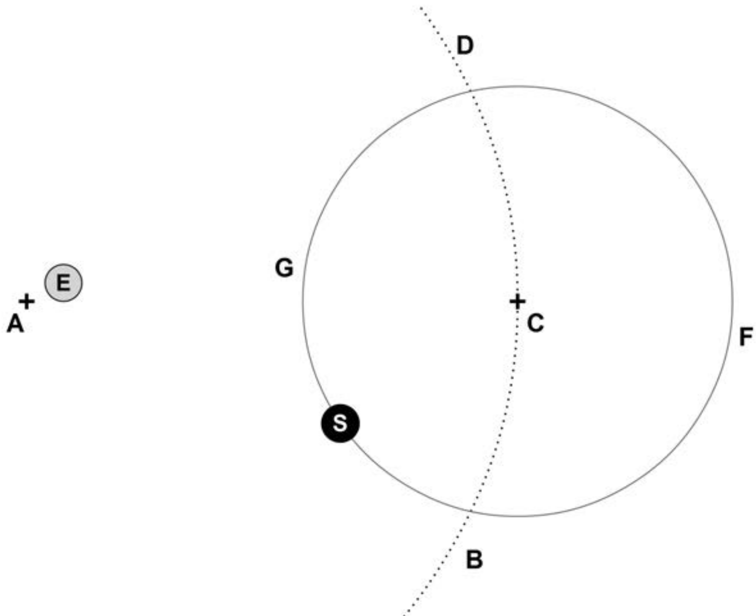

FIGURE I-3. Saturn is seen to slowly drift eastward through the constellations of the zodiac, but it periodically slows, stops, moves westward, and then stops again before resuming an eastward motion. While making the westward or *retrograde* motion, it grows brighter. The second-century Egyptian astronomer Claudius Ptolemy had explained retrograde motion *(above)* by supposing Saturn (S) to ride on a circle called an *epicycle*, which in turn rides on a larger circle called a *deferent*. The deferent is *eccentric* to Earth: its center (A) does not coincide exactly with Earth (E). Saturn is carried clockwise on the epicycle, going around once in roughly one year, while during that time the center of the epicycle moves on the deferent from B through C to D. The combination of motions means that Saturn generally moves clockwise relative to Earth, but when closest to Earth (at G), and therefore brightest, its motion relative to Earth is reversed.

a prescient explanation for how Earth could move around the sun. Why does he devote pages to arguments against the Copernican system, even when, as he puts it, so many astronomers of his time are burning incense at the altar of Copernicus?[11] Because, he says, "we follow reasoning and experience, and we are by no means easily swayed by assertions."

Modern readers of *Disquisitions* know that Copernicus was right and so may assume that reasoning and experience (observations, data collec-

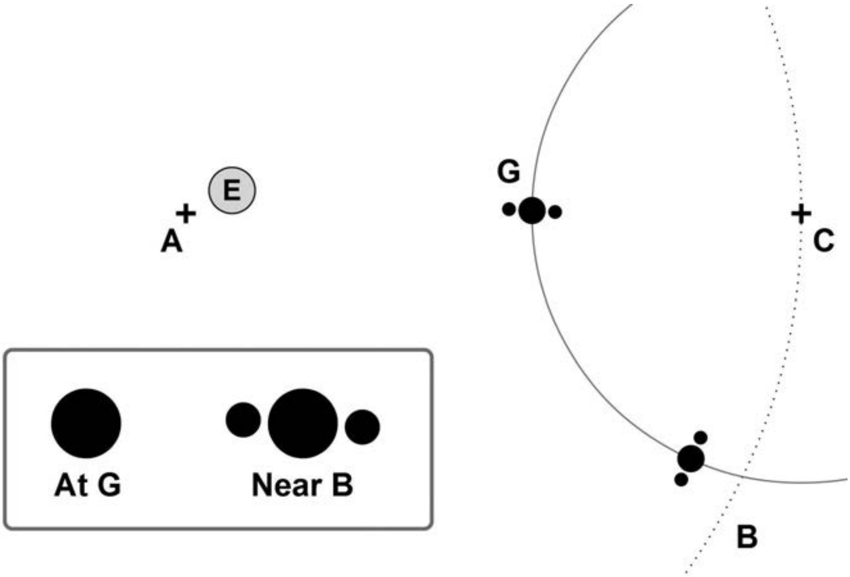

FIGURE I-3 (*cont.*). Galileo, using the telescope, had discovered Saturn to have two "companions" or "attendants," which had disappeared in 1612 and later reappeared. Locher argued that these attendants were probably not physically disappearing, but rather that this was an appearance caused by motion. He hypothesized that the companions might be locked to Saturn's epicycle *(below)*, so when Saturn is at G, the companions are in front of and behind the planet as seen from Earth and not apparent *(see insert, left)*, but when Saturn is near B they are visible *(insert, right)*. He proposed that astronomers engage in careful observation of Saturn and its companions over time to test this hypothesis, which at the same time would probe for the existence of a Saturnian epicycle. (Today we know that the "attendants" were Saturn's rings, poorly seen, and their temporary disappearance stemmed from them being edge-on to Earth in the summer of 1612.)

tion, calculations, etc.) would immediately lead to the right world system. The telescope proved the sun to have spots, Venus to circle the sun, and Jupiter to have moons that circle it. Clearly the telescope proved *wrong* the old Ptolemaic ideas about heavenly bodies being formed from a perfect celestial substance, about Earth being the center of all, and about epicycles and eccentrics explaining the motions of planets across the heavens (see Figure I-3). Readers' assumptions are encouraged by statements such as

Einstein's, or those found on the cover of a modern translation of Galileo's *Dialogue* describing Galileo "proving, for the first time, that the earth revolves around the sun."[12] According to this presumably reliable source, Galileo proved the matter. Considering that Locher illustrates in detail what the telescope reveals about the sun, Venus, and Jupiter, readers will certainly wonder how Locher does not see that proof.

Locher, readers will find, sees matters differently. To Locher, telescopic observations of the sun, Venus, and Jupiter have proved *right* the key Ptolemaic idea of epicycles: "the optic tube," he says, "has established that the center of Venus's own motion is the sun, that the center of the motions of the Jovian satellites is Jupiter, and that the center of motion of the solar spots is again the sun. Therefore epicycles do exist in the heavens." The second-century astronomer Ptolemy had *postulated* epicycles to exist because they explained the motions, as seen from Earth, of the planets (the "wandering stars"). Locher notes that the telescope now *proves* that epicycles exist, and that further telescopic study could reveal whether Saturn in particular is on an epicycle (see Figure I-3). Within the limits of the knowledge of his time,[13] Locher is correct. The motion of the Jovian moons is indeed epicyclic; the moons move on their orbital circles around Jupiter while Jupiter in turn moves on its own orbital circle.

Moreover, readers will find that Locher produces good reasons, following reasoning and experience and ignoring assertions, to reject Copernicus. He gives six arguments against Copernicus. The first is that the Copernican system inverts the words of astronomy (so that, for example, the sun doesn't rise, but rather Earth's horizon drops) and of Scripture (so that, for example, when Joshua told the sun to stand still, it was Earth that stood still). But Locher then retracts this first argument. The Copernicans can answer it, he says. Their answer might be convoluted, but it is satisfactory. Thus he gives five real arguments—ones to which the Copernicans have no satisfactory answer. All five are matters of science and reason. Not one relies on authority or mythical thinking.

Three of the five pertain to the physics of heavy falling bodies—to the question of how it can be that, on a rotating, spherical Earth, a heavy falling object is seen to drop vertically. The question is not a simple one. It almost overwhelms the pre-Newtonian, Aristotelian physics of Locher's time, but Locher is able to make his point: a rotating Earth transforms a simple fall into an incredibly complex phenomenon. Is not an immobile,

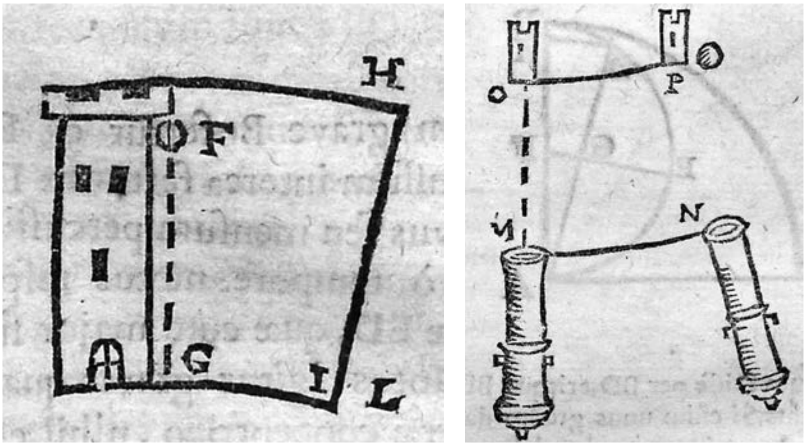

FIGURE I-4. The Coriolis effect. The top of a tower located near the Earth's equator is farther from Earth's center than the bottom of that tower. On a rotating Earth the top moves through a larger circle than, and thus faster than, the bottom.

Left: If Earth is stationary, then a ball dropped from the top F should fall straight down to the bottom G. If Earth is rotating, then as the ball falls the top moves to H while the bottom moves to I; but the ball, which is moving to the right at the speed of the top, should outrun the bottom and land at L. Thus, on a rotating Earth a falling ball should not drop straight down. Compare to Locher's disquisition 14. *Right:* Similarly, a projectile launched from the equator toward a target to the north should outrun the target and deflect to the right.

The Jesuit astronomer Giovanni Battista Riccioli developed this idea in the mid-seventeenth century as an argument against a rotating Earth (Graney 2015, 118–20; Graney 2011). These figures are from a later seventeenth-century Jesuit, Claude Francis Milliet Dechales; he used them likewise, as part of an argument against Earth's motion (Dechales 1690, 328). However, the effect does exist. It is the source of the rotation in hurricanes, among other things, and now bears the name of Gaspard-Gustave de Coriolis, who described it mathematically in 1835. Images courtesy of ETH-Bibliothek Zürich, Alte und Seltene Drucke.

central Earth, toward whose center heavy things naturally gravitate along straight lines, a far more simple and elegant solution to the question of falling bodies? Indeed, a description of a fall on a rotating world is not at all simple, even using modern Newtonian physics and the tools of differential equations; it involves terms such as *the Coriolis effect* (see Figure I-4).

Locher's remaining two arguments against Copernicus pertain to the stars, and in particular to the distances in the Copernican system of the

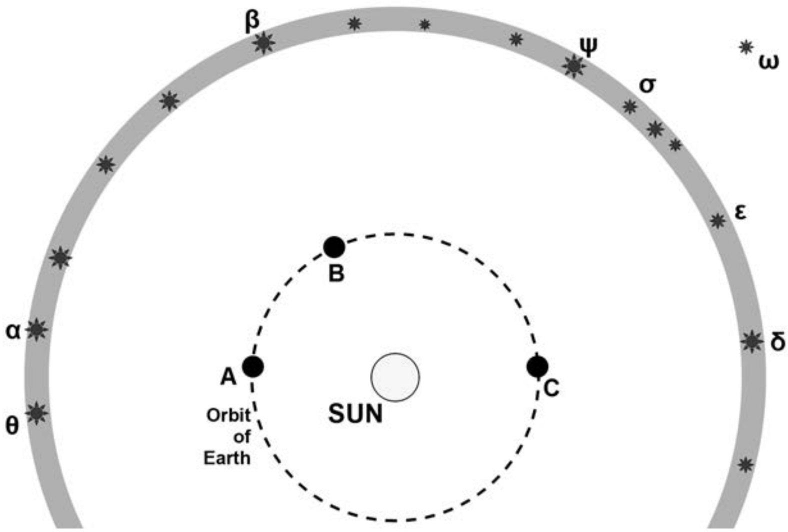

FIGURE I-5. Annual parallax. If Earth orbits the sun, moving from A to B to C within a six-month period, then a number of observable changes should be seen in the appearance of the stars. For example, when Earth is at A, star α will be closer and thus should appear larger than star β; two months later, when Earth is at B, the situation will be reversed. In short, the apparent size (magnitude) of a star should vary as the months pass. Or, if the stars extend into space, then stars σ and ω will appear close to one another in the sky when Earth is at B, but less so when Earth is at C. In fact, no such changes occur in the stars. The Copernican answer to why these sorts of changes are not seen is that the orbit of Earth is of negligible size compared to the distance to the stars: thus these annual parallax effects exist, but are negligibly small.

stars from Earth. These distances are vast compared to the distances of the sun, moon, and planets. If Earth circles the sun, then it moves relative to the stars and that movement should be reflected in the stars. But this effect, known as *annual parallax* (see Figure I-5), could not be detected in Locher's time. Indeed, it would not be detected until the nineteenth century. Copernicus attributed the lack of detectable annual parallax to the stars being so far away that the circle of Earth's orbit was vanishingly small by comparison, so any annual parallax would also be vanishingly small. By contrast, in a geocentric system the stars lie just beyond the planets, so the distances to all celestial bodies in such a system are comparable.

FIGURE I-6. An observer O on Earth sees a star as having a certain apparent size (indicated by arrows). The farther away the star is, the larger its true physical size must be in order to present that apparent size to the eye. If the star is located farther from Earth (at 2), then its physical size is much greater than if it is located closer to Earth (at 1). The heliocentric system required stars to be at vast distances from Earth and therefore to be enormous.

One of Locher's two star arguments is that the vast Copernican stellar distances serve no purpose. These distances are what we might call simply an ad hoc idea, introduced in order to make the heliocentric system conform to observations. Of course, we know today that Copernicus was right, but we can see Locher's point.

Locher's other star argument is based on the fact that stars have an apparent size.[14] Tycho Brahe determined, for example, that the more prominent stars appear about one-fifteenth the apparent diameter of the moon. Thus, were a prominent star of the same physical size as the moon, it must be about fifteen times farther away than the moon; were it of the same physical size as the sun (which has the same apparent diameter as the moon), it must be about fifteen times farther away than the sun. The farther away the star is, the larger it must be (Figure I-6). As Locher points out through various calculations, at the distances the Copernican system requires, that prominent star would have to be huge—far larger than even the sun. By contrast, in a geocentric system, where the stars are not so far away, the physical size of a prominent star would be comparable to the other celestial bodies. This argument was not Locher's; it was Tycho Brahe's primary anti-Copernican argument (Figure I-7).

Locher then reduces Brahe's star-size argument to a simple, elegant point: even the smallest star has some apparent size. It occupies some measureable fraction of the dome of the sky. Thus even the smallest star, tiny though it may be, is not vanishingly small compared to the sphere of the stars. By contrast, the Copernican theory requires Earth's orbit to be

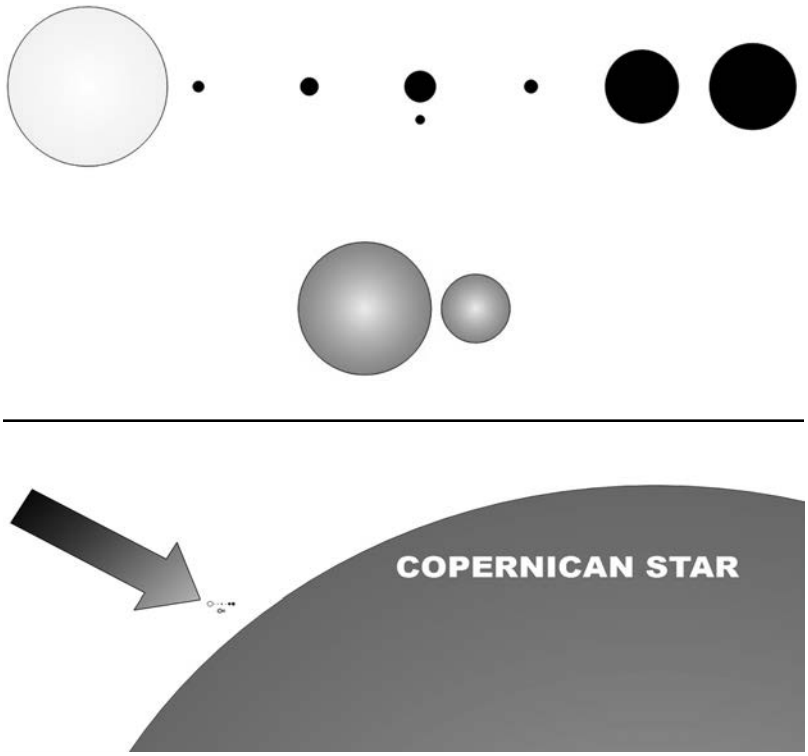

FIGURE I-7. Tycho Brahe calculated the physical sizes of stars required by both Copernicus's heliocentric system and Brahe's own geocentric system. A moderately prominent star appears to the unaided earthbound eye to be about the same size as Saturn. In a geocentric system, stars are just slightly beyond Saturn. Therefore, being about the same distance away as Saturn and about the same apparent size as Saturn, they turn out to have physical sizes comparable to Saturn. Shown in the upper figure are Brahe's calculated sizes for *(top row)* the sun, Mercury, Venus, Earth and the moon, Mars, Jupiter, and Saturn, and *(bottom row)* a prominent star and a modest star. Thus, in a geocentric system, all celestial bodies fall into a reasonable range of sizes, with the sun being the largest and the moon the smallest.

In the heliocentric system, by contrast, stars lie hundreds of times farther away than Saturn and therefore must be hundreds of times the diameter of Saturn. Shown in the lower figure is a modest star in the Copernican system, with the upper figure at its left for comparison. Diagrams from Graney 2013.

vanishingly small compared to the sphere of stars in order to explain the absence of parallax. *Small but measurable* is larger than *vanishingly small*, and therefore every last star must be larger in size than the orbit of Earth. Thus every last star must utterly dwarf the sun. Thus the Copernican theory does not just require the stars to be at vast distances, it requires them—every last one—to be spectacularly huge. The Copernicans, says Locher, do not deny this, but say all this testifies to the power of God. (And indeed, one prominent Copernican would eventually go so far as to declare the giant stars to be God's mighty warriors, the palace guard of heaven itself, and to support this notion with abundant quotations from Scripture.[15])

This is why Locher sees reasoning and experience as being contrary to Copernicus. This is his reasoning for not accepting the Copernican system, despite his detailed illustrations of what the telescope reveals, and despite even his explanation for how Earth could move in that system.

Modern readers of *Disquisitions* will find that Locher covers a number of other topics, also investigated in a thorough and rational manner wholly at odds with Galileo's portrayal of the "booklet of theses." These include the appearances of the moon and of small light sources seen at a distance, and the effect of the atmosphere on the appearance of heavenly bodies. Locher even discusses a topic that seems amazingly modern: the question of whether our universe is just one of an infinite number of universes randomly forming from and dissolving back into elementary particles within an infinite universe of universes (that is, within a multiverse, to use a modern term). He argues against the multiverse idea by means of a variety of mathematical arguments disputing the existence of any physical infinity. Today arguments against the existence of a multiverse, or of a physically or temporally infinite universe, have more than a little in common with those of Locher—usually arguing that infinities require all possible events, no matter how improbable, to occur within the infinity, and to occur infinitely often, and that postulating infinite numbers of improbable events (for example, infinitely many other universes in which this book is set with pink type, or purple type, or rainbow-colored type) to explain the existence of our universe represents an infinite violation of Ockham's razor. And, much like those who engage in such arguments today, Locher sees in the disproof of the multiverse evidence for the existence of God.

Thus readers of Locher's *Disquisitions* will find that it contains much that is interesting. It defies both Galileo's portrayal of it specifically and expectations of anti-Copernican works generally. It also defies modern portrayals. Even the best modern scholars have described *Disquisitions* in ways that are at variance with the contents of the book itself—describing it as violently attacking Copernicans, as opposing Galileo's descriptions of the moon as seen telescopically, or as putting forth trivial objections to heliocentrism.[16] No doubt this variance, which is always on the negative side with respect to Locher's work, is owed to the fact that Galileo himself conveyed a negative impression of this "booklet of theses."

Anti-Copernicans in general may be portrayed too negatively.[17] They backed a hypothesis that turned out to be wrong, and they faded into obscurity. Galileo backed a hypothesis that turned out to be right, and he became one of the most famous figures in the history of science. Galileo was not one to portray his opponents in a positive light, but of course in Galileo's time, his opponents had not yet faded into obscurity and could speak for themselves. In part because Galileo chose Locher as an example, immortalizing him in the *Dialogue*, modern readers can delve into *Disquisitions* and let Locher speak for himself. They can get a better sense of the scientific dialogue in Galileo's time—a dialogue that may seem, after reading *Disquisitions*, less like Einstein's rational thinking standing against authority and anthropocentric and mythical silliness, and more like a true scientific dialogue.

NOTES

1. Galilei 2001, 105.
2. Galilei 2001, 107.
3. Galilei 2001, 108.
4. Galilei 2001, 414.
5. For example, see Van Helden and Reeves 2010, a book specifically on Scheiner that speaks of Locher's work as though it were Scheiner's (307–8); see also Drake 1958, 157–58, and Heilbron 2010, 275–76, 436. From the beginning some have attributed *Disquisitions* to Scheiner. Galileo does not mention *Disquisitions* or its author by name, but Giovanni Battista Riccioli, in his *Almagestum Novum,* refers to the book and cites Scheiner as the author (Riccioli 1651, 54). An

interesting published reference to the *Disquisitions* that describes it as being Scheiner's is a 1793 work by Giovan Battista Clemente Nelli that mentions how "Jesuit Father Christopher Scheiner . . . composed a miserable brochure against the motion of the earth" (Nelli 1793, 417), namely *Disquisitions*. Nelli cites a letter of August 27, 1616, from Giovanni Francesco Sagredo to Galileo. Sagredo's letter was published by 1856 (see Galilei 1856), and after this time references to *Disquisitions* are more common and generally attribute the work to Scheiner. Sagredo writes, "Twenty-three months ago a book was sent to Sr. Magini, printed in Ingolstadt, entitled *Disquitiones mathematicae de controversiis et novitatibus astronomicis*," which he says he borrowed out of curiosity since he understood it to attack the Copernican system. He goes on to say that Galileo should look at it if he has not done so, it being "the work of Jesuit P. Cristofforo Scheiner, who is that friend of Sr. Velser, whose head you once washed without soap, because of the disrespectful manner in which he wrote of me. . . . I've only read the smallest part of it, having other business now, nor do I find satisfactory the teachings of this most pretendentious man" (Galilei 1856, 112). (I thank Lorenzo Smerillo and Roger Ceragioli for their assistance with translating Sagredo's letter from Italian via the HASTRO-L history of astronomy listserv on May 4, 2016. According to Smerillo, the "head wash" idiom is still in use in Italian.)

6. Galilei 2001, 60–63, 402–13, 548–49. Also see Van Helden and Reeves 2010, 321–27.

7. Finocchiaro 1989, 37, 265.

8. Galilei 2001, 80.

9. Galilei 2001, xxiii, xxviii.

10. Drake 1958, 158.

11. Locher notes that fewer people ascribe to a geocentric system in his time than in ancient times, "since the majority [in his time] burn incense to Copernicus" (cum plerique Copernico turiant). The Latin *tus* is "incense" and *turifico* is "burn or offer incense." See Locher 1614, 23.

12. Galilei 2001, back cover.

13. We all are constrained by the limits of the knowledge of our time, as students living in the twenty-fifth century will undoubtedly learn when they study early twenty-first-century astronomy.

14. Today we know that these apparent sizes are an illusion caused by the nature of light and that stars seen from Earth are actually point-like sources of light, entirely consistent with their being sun-like bodies at Copernican distances. How astronomers came to discover this fact, and therefore the solution to the star-size argument, is discussed at length in Graney and Grayson 2011 and in Graney 2015, 148–57.

15. Graney 2015, 63–85; Graney 2013.

16. Various writers have characterized *Disquisitions* in ways that are at odds with the contents of the book, and surely one reason for this is the influence of Galileo's characterization of it. See Finocchiaro 2010, 71; Finocchiaro 2013, 132; Reeves 1997, 205, 206, especially vs. Van Helden and Reeves 2010, 309; Heilbron 2010, 276; and Piccolino and Wade 2014, 132.

17. Giovanni Battista Riccioli has regularly received an inaccurate negative portrayal in secondary sources: see Graney 2015, 103–5.

Translator's Note

This translation of Locher's *Disquisitions* renders this Latin mathematical and astronomical work into English for students in even introductory classes in history, physics and astronomy, or history and philosophy of science. As such, I intend it to be an accurate reflection of his work that is readable by a broad audience, especially students (including advanced high school students) who might be assigned reading from Galileo's *Dialogue* as part of these classes. I thus err on the side of readability, often rendering technical astronomical or metaphysical terms in a manner that explains the terms. In the technical mathematical sections I at times significantly reorder or shorten Locher's original phrasing into a structure that is more familiar to modern readers, while taking care to ensure that Locher's mathematics itself is unaltered. Locher uses many marginal notes, usually to cite sources, but also for emphasis. Typesetting these as marginal notes is impractical, so I incorporate their content into the main text and indicate it with ‹pointed brackets›. Locher's figures are unlabeled and simply appear within the appropriate text. As a practical matter I have numbered the figures (e.g., the first figure in his fourth disquisition would be Figure 4-1, the third figure in his eighth disquisition would be Figure 8-3) and insert text into the translation directing readers to the figures by number. Inserted text I indicate with [square brackets].

This translation is not intended for expert scholars, although they should find it useful. Scholars interested in Locher's precise word use, marginal note structure, figure placement, and so on can easily consult the original *Disquisitiones mathematicae*, freely available online via, for example, E-rara and Google Books. (Indeed, thanks to the nature of technology, Locher's original is today more readily available to scholars than is this translation.) However, this translation should be an excellent resource for a scholar wishing to produce a scholarly rendition of Locher's original words.

There are two areas in which my approaches to the translation differ from what I have just described. One is the poems that come before and after Locher's work. These I have rendered extremely loosely—these renditions might better be described as words inspired by the original Latin. The other is those places where Locher directly quotes other authors. There I have used existing translations when available and attempted to produce close translations (with less concern for readability) when existing translations were unavailable. At times this means that such quotations contain awkward language, but the reason for doing this is to prevent all the material (Locher's words, and the words of the authors whom Locher quotes) from sounding the same. If I translated everything in the same manner, then both Locher's words and the material he quotes would have the same "voice"—that of their translator.

The Structure of the *Disquisitions*

This is an English rendition of the entirety of Johann Georg Locher's *Mathematical Disquisitions Concerning Astronomical Controversies and Novelties*; the only material not rendered into English is the list of typographical errors that occupies part of the last page. Therefore readers will encounter within this book more than just the forty-four disquisitions that comprise the heart of the book. There are three laudatory poems, one at the beginning and two at the end. There is a letter of dedication from Locher to his lord and another letter on the value of mathematics.

Then there are the disquisitions themselves. The early ones address the nature of mathematics and are generally brief. Astronomy begins to be discussed by disquisition 7. By disquisition 13 Locher is addressing the Copernican system and arguments against it, and the disquisitions grow much longer. He moves on to discussing other systems and the problems with them. By disquisition 25 he has begun discussing the specifics of different celestial bodies, starting with the moon. It, the sun, Venus, and Jupiter and its moons (with related excursions into subjects such as light and the effect of the atmosphere on observations) comprise the rest of the disquisitions, except for the last. That short disquisition, number 44, concerns Saturn and its rings (not yet recognized for what they are).

DISQVISITIONES MATHEMATICÆ,

DE CONTROVERSIIS ET NOVITATIBVS ASTRONOMICIS.

Quas

SVB PRÆSIDIO CHRISTOPHORI SCHEINER, DE SOCIETATE IESV, SACRÆ LINGVÆ ET MATHESEOS, IN ALMA

Ingolstadiensi Vniuersitate, Professoris Ordinarij,

PVBLICE DISPVTANDAS POSVIT, PROPVGNAVIT,

Mense Septembri, Die

NOBILIS ET DOCTISSIMVS IVVENIS, IOANNES GEORGIVS LOCHER, BOIVS MONACENSIS, ARTIVM ET PHILOsophiæ Baccalaureus, Magisterij Candidatus, Iuris Studiosus.

INGOLSTADII,

Ex Typographeo Ederiano apud Elisabetham Angermariam.

ANNO M. DC. XIV.

⁎ ⁎ ⁎ ⁎ ⁎

MATHEMATICAL DISQUISITIONS, CONCERNING ASTRONOMICAL CONTROVERSIES AND NOVELTIES

The noble and learned young man,

JOHANN GEORG LOCHER

(Bavarian of Munich, bachelor of arts and of philosophy, master's candidate, student of law)

has publicly put forth for discussion and defended these,
under the supervision of Christoph Scheiner,
of the Society of Jesus,
ordinary professor of sacred language and mathematics,
at the University of Ingolstadt.

From the Ivy Press of Elizabeth Angermaria.

Ingolstadt, 1614.

To the most serene prince and lord, Lord Maximilian, imperial count of the Rhine, duke and most clement lord of Bavaria, etc.

The new, the rare, and the precious are owed to the prince, O mighty Duke. Custom has sanctioned this. Reason has advised this. The consensus of everyone has confirmed this. This is true not only in your Bavaria (where items that are of extraordinary value, or that are novelties, or rarities, or works of great craft have been gathered into and guarded within your own archive of special wonders in Munich), but indeed in all civilized nations.

Old coins dug out of the ruins at Rome soon reach the hands of the mighty. Monsters caught from the sea—the kind that once inspired poets to write of the Sirens—are promptly sent to the palace. Kingdoms in India fight among themselves for the white elephant, not because it is better than the dark elephant, but because it is rarer. Clovis II, the greatest king of the Gauls, even acquired a turnip of unusual size.

And now I entrust to you a rarity that is even lowlier than a turnip. I have published these mathematical theses concerning celestial novelties. Because these theses consider celestial things, perhaps they are not too lowly—after all, it is probably better to calculate about heavenly things based on philosophical opinion than to be learned about other things.

Because these theses consider things of fascinating rarity and abounding in novelty, perhaps they have worth.

I owe much to the professors of mathematics at your academy at Ingolstadt, some of whom I have acknowledged publicly, others of whom I have thanked privately. To both, I give this work as a sign of a grateful heart. And if you do not spurn it, then perhaps in the future this rarity may not seem so rare.

Live long, and prosper, God willing—to you, to our country, and to us. Ingolstadt 1614.

All the best,

your most dutiful servant in all things.

Johann Georg Locher

A Poem for the Most Learned Reader

Orpheus, put the Argonauts out of your mind. Put aside your lyre that once moved rocks and stilled waters. Hang the Golden Fleece back on the tree. Forget witches and the voices of Sirens. You may again rescue your beloved Euridice from Hades—for now you can pull the moon down from heaven and then watch Hades open wide in astonishment.[1] *The world of the ancient gods is no more, except for in poetry and Scripture. The old ground on which the heavens have shone now trembles.*

Now Cynthia the Moon shines only by the sun's fire, yet still she leads the stars through the night. The starry multitude celebrates God; the Milky Way is full of them. Jupiter drives a chain of four golden stars, while Saturn can but envy Jove. Shining Venus has no pristine form to her face. Instead, her brow bears two brazen horns. How fitting that she, whom the fool deems most pretty, in the end prefers the foolishness of these tasteless horns.

And the bright-shining phaethonic lamp—Phoebus the Sun—also bears a marred face. His face is branded with dark burns, an astral stigma that brings to mind the crime of Prometheus, who gave fire to man. But lest Phoebus be merely an orb darkened by spots, he is also whitened by numerous blazes.

When I consider all this, I leap up and cry, O heavens, what craft is this, when I find day and night, bright and dark, on the sun itself? What is this labor that drives the one who would seek dark spots to study solar fire?

Yet go on, look up at the stars, and summon them down. Argus,[2] why are you not indeed a lynx? I say you are above the lynxes. Others may be lynxes. To me you are an eagle.

Henricus Locher, brother to brother,
student of logic and mathematics.

The Author to the Reader

On the Preeminence, Necessity, and Utility of Mathematics

Dear Reader, lest I seem not credible, or too eager to press my case, I shall give to you not my words and opinions, but those of others. Thus I give you the words (abridged for length) of that great theologian Antonio Possevino,[3] from his Bibliothecae Selectae. *He is a better witness for such things in all ways. ‹In the "Argument" section of book 15›, he writes:*

> *I am persuaded, and I have proposed to others, that the mathematical disciplines have a place and a dignity ahead of the majority of the higher disciplines. This is because the mathematical disciplines are necessary not only to the rest of the sciences, and to medicine, but also very much to the conduct of war, to various operations of the Republic, and to studies of geography and human history. . . .*[4]

Then we find the following ‹in chapter 1 of book 15›, which I have abridged somewhat for length:[5]

> *Those demonstrate the necessity, dignity, and utility of the mathematical disciplines. Plato and Aristotle have adopted these disciplines for a method*

of contemplating and doing. And certainly the best evidence of this is the Timaeus *of Plato and the* Physics *of Aristotle. They bring forward the light of philosophy by means of mathematics itself, etc.*

Truly Aristotle's whole account about motion and rest, about time and the heavens, and also about the development of animals—and indeed his entire physical discussion—abounds not so much in examples as in geometrical foundations. Indeed, by the middle of the first book of Physics *Aristotle brings up Antiphon's "squaring of the circle," so that he may reject it.*[6] *In the second book he discusses the two right angles in a triangle,*[7] *which he also discusses in his* Posterior Analytics.[8] *In the third book he mentions some things about building gnomons, and then the remainder concerns infinity of size, motion, and time. Most people introduced to the ideas of Aristotle lack solid understanding of these books because they have never deeply perceived the mathematical disciplines.*

And in the book On the Heavens, *because a diameter is not comparable to a side, Aristotle discussed a sphere constructed around eight pyramids, and thus he discussed pyramids, and thus triangles.*[9] *His book* Meteorology *is full of mathematics.*[10] *The same must be said regarding* Metaphysics. *Indeed, book 12 of* Metaphysics *considers whether mathematics is a real thing, whether numbers are real things, and whether mathematical ideas are the most fundamental of all. Thus a certain knowledge of mathematics is a necessity.*

Mathematics also pertains to theology. For example, settling the date of the celebration of Easter—and of the rest of the "moveable feasts," as they are called—was a concern both at the ancient synod at Nicaea[11] *and at the most recent synod at Trent.*[12] *The order and management of the whole Christian Republic is arranged according to that date. I shall not digress to those things which occur everywhere in the Scriptures regarding the stars and the heavens, the measurements and architecture of the temple of Solomon,*[13] *and countless other things.*

If we consider medicine, we find Galen[14] *stating that a doctor who is ignorant of the timing and duration of proper treatments must not treat the sick. By such ignorance a doctor may bring a patient to ruin, rather than to the health and soundness the patient might expect. Likewise, a farmer who ignores the proper timing of grafting, transplanting, and sowing will usually experience want and require charity.*

Plutarch[15] *reports in his* Life of Marcellus *how Archytas and Eudoxus*[16] *added variety to geometry by removing it from the realm of pure mental exercise and bringing it into the realm of real and practical things,*[17] *which are now found in Aristotle's* Mechanics.

The fruits of such practical applications of mathematics are many. Archytas created a flying wooden pigeon.[18] *Archimedes and Posidonius*[19] *constructed working mechanical models, or planetaria, that replicated the movements of the sun, moon, and planets—this is reported by Cicero,*[20] *who notes that in making these planetaria they replicated the action of God in building the universe,*[21] *as Plato describes in the* Timaeus.[22] *In more recent times the Nürnberg artist, Albrecht Dürer, illustrated his fly and his eagle with geometrical wings. Claudius Gallus constructed for the gardens of Cardinal d'Este elaborate mechanical birds, driven by hydraulic action. Small copper birds would sing and move until a little mechanical owl appeared, and then when it departed they would resume their activities.*[23] *They were so realistic that a person who declared them fakes would seem more temerarious than a person who claimed them real birds would seem credulous.*

Other practical fruits of mathematics relate to measurement. A single measuring rod, used to measure distances, can also be used to determine the areas of surfaces and the volumes of bodies. Using a simple measuring rod, any geometer can describe buildings, lands, seas, the movements of the heavens, the risings of stars, and so forth.

But these things are not all that is encompassed by the discipline of mathematics. Plato wrote:

> *In dealing with encampments and the occupation of strong places and the bringing of troops into column and line and all the other formations of an army in actual battle and on the march, an officer who had studied geometry would be a very different person from what he would be if he had not.*[24]

Indeed, there are many military applications of geometry. In the Roman army, a centurion's flag served as a point around which a circular or rectangular formation of troops would be established, depending upon the circumstances of battle. Geometry guides the construction of bridges and ships, the channeling of water, and the movement of cavalry among foot soldiers. It can be used in both attack and defense—in the construction of both siege engines and defensive ramparts.

Geometry has influenced the outcome of a remarkable variety of battles. A small group of Caesar's soldiers broke through the ranks of a vast army by means of a wedge formation and escaped unharmed. Likewise, three hundred legionaries held back another vast army for hours through the use of a circular formation. At Syracuse, Archimedes constructed such defenses against Marcellus[25] that Marcellus called him "this Briarian[26] engineer and geometrician [who] hath with shame overthrown our navy, and exceeded all the fabulous hundred hands of the giants, discharging at one instant so many shot among us."[27] Zonaras[28] reports that Proclus,[29] by means of mirrors fashioned to collect and concentrate light from the sun, "burnt the fleet of Vitellius, at the siege of Constantinople, in imitation of Archimedes, who set fire to the Roman fleet at the siege of Syracuse."[30] And Archimedes and Proclus are but two of the people who have used geometry for military purposes.

Possevino was a noted theologian, but he was also a noted expert at law. Therefore, Reader, you will want to know that in a letter to a certain friend he writes,

It is right to acknowledge the importance to jurisprudence of the mathematical disciplines, especially arithmetic and geometry. Without arithmetic, who could apply Roman law in cases regarding inheritances and children born after the death of a father and not mentioned in his will? Such examples occur everywhere in law. And certainly no skill is more useful and more necessary to jurisprudence than knowledge of geometry. Who could settle matters of land ownership and titles without such knowledge? Who could make judgments in cases where sedimentation adds to land or causes new islands to arise, or where the changing courses of rivers alter the land? Likewise, how would a judge who lacks any skill in geometry ever determine whether a surveyor's measurements of a property are correct or incorrect?

Imagine a field of some sort being sold. There could be some contention that exists regarding the boundaries, or the buyer or seller may simply wish to know the boundaries. Perhaps the width of some right-of-way needs to be known. The labor required to work the land, the timber or other resources that can be extracted from the land, the grain or wine the land can produce, and the law as it pertains to these things—without cognition of geometry, *judgment cannot be made about any of this. Furthermore, without geometry, no one can determine the rightness or wrongness of any judgment that might be made. Indeed, geometry is no less necessary to the practice of the law than is that basic logic which says, for example, that two opposing statements cannot both be true simultaneously.*

For this reason it is well known that less prudent fathers push their sons to the study of law before they are imbued by liberal education to some extent. Such men, eager for profit, save a year or two in the short run, but in the long run they waste many years.

To these words of that most learned man I add this: Indeed, those who are erudite at law, but truly ignorant of astronomical things, will confuse astronomers with astrologers — the prudent with the temerarious. They will be unable to judge the testimony of a mathematician versus that of a crank. They will condemn the innocent with the guilty, contrary to human and divine law. May they all come into a knowledge of astronomical things.

I might add a third statement of testimony (one to the usefulness of astronomy specifically) from Christopher Clavius[31] *in the preface of his treatise on the astronomy of Johannes de Sacro Bosco.*[32] *However, he is so widely read that there is no purpose to repeating it here. And Proclus discusses in chapter 8, book 1 of his book on Euclid how the same mathematics may be conducive to political and moral philosophy, dialectics, rhetoric, poetry, and many other things which are matters of art or are done through the hands and work.*[33]

You have, Reader, the thoughts of my mind, through the words of others—through their thoughts in their words. Had I expressed my mind through my own words, they might have held less weight with you and perhaps have seemed less trustworthy to you. Tell me if you understand this study I have made. If your understanding is greater than mine, go before me, with Possevino—I shall eagerly follow you. If it equals mine, go with me—I shall not refuse you. If it is lesser, follow me—I shall not impede you should you overtake me. You have heard what I think. You see the point I wish to make. You understand what I would like you to do.

Farewell.

From my study at Ingolstadt. 15 August 1614.