

## THE SIXTEENTH-CENTURY EMPIRICAL DISPROOF OF PTOLEMAIC GEOCENTRISM

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**Abstract:** In 1573, Thomas Digges published a book entitled *Alae seu Scalae Mathematicae* and in 2023 we celebrate the 450th anniversary of its publication. The book was prompted by the apparition of the New Star of 1572, which Digges shows does not change position in the sky. He supplies its distances from some nearby stars in Cassiopeia, but the remainder of the book has long been under-valued. It presents a “new and unheard-of method” of ascertaining diurnal parallaxes of planets, yet Digges applies the theoretical developments only in illustrative examples. However, three years later in 1576 in an essay “A Perfit Description of the Caelestiall Orbes,” Digges makes the astounding claim that he has measured parallaxes of planets with sufficient accuracy to show that they do not circle the Earth at a constant distance but have some other center or centers. This paper examines Digges’ claim of an empirical disproof of geocentrism in the sixteenth century and its support for heliocentrism.

**Keywords:** astronomy, sixteenth-century, Thomas Digges, parallax, heliocentrism

### 1 INTRODUCTION

In 1934, historians Francis R. Johnson and Stanford V. Larkey noticed something odd about the publications of Thomas Digges (ca. 1546–1595; [Figure 1](#)). The historians wrote that strangely enough, his work has been mentioned less often than any other English supporter of Copernican heliocentrism, and that “... writers upon the history of science ... have almost entirely overlooked ...” his work ([Johnson and Larkey, 1934: 70](#)). The goal of this paper is to point out other anomalies associated with Thomas Digges’ publications and to examine his claim of 1576 to have disproved geocentrism. A preliminary version of this paper was presented at the 241<sup>st</sup> Meeting of the American Astronomical Society ([Usher, 2023](#)).<sup>1</sup>

### 2 THE NEW STAR OF 1572

The story begins in the early morning of 6 November 1572 with the first reported sighting of an exceptionally bright New Star in the constellation Cassiopeia. The New Star of 1572 is now known to be a supernova named SN1572. In an age rife with superstition, most people were anxious to know the significance of this apparently unique phenomenon. Less than four months later near the end of February 1573, with SN1572 still shining brightly in the night sky with an astronomical magnitude of  $m \approx 1$ ,<sup>2</sup> Digges published a book titled *Alae seu Scalae Mathematicae* (*Mathematical Wings or Ladders*). In *Alae*, he asserted that SN1572 did not change its position in the sky, which he

determined using a straightedge aligned with SN1572 and two stars. He presented several theorems and problems on methods to determine parallax accurately. He found that the alignment did not change as the Earth rotated, so that it had no detectable diurnal (daily) parallax.<sup>3</sup> Thus, he concluded that the phenomenon was not a comet since it lacked hair or a tail and remained motionless in the realm of stars, and he speculated that its steady decline in brightness was not intrinsic but due to its motion away from the Earth.

In March 1573, Digges’ erstwhile mentor John Dee (1527–1608) published *Parallatiae*



Figure 1: The Digges family coat of arms.

*Commentationis (Parallactic Commentary)* containing trigonometric theorems for determining stellar parallax. Digges and Dee knew that the celestial sciences needed to advance through parallax determination, but Dee was concerned also with philosophy and metaphysics, whereas Digges stressed mathematics and its applications (Johnston, 2006: 72–80).

Tycho Brahe first saw SN1572 on 11 November, and studied the phenomenon assiduously (Baade, 1945: 313–16). He wrote *De Stella Nova (On the New Star)* which was printed in 1573 after the Digges and Dee treatises. Later, in the voluminous tome *Astronomiae In-*

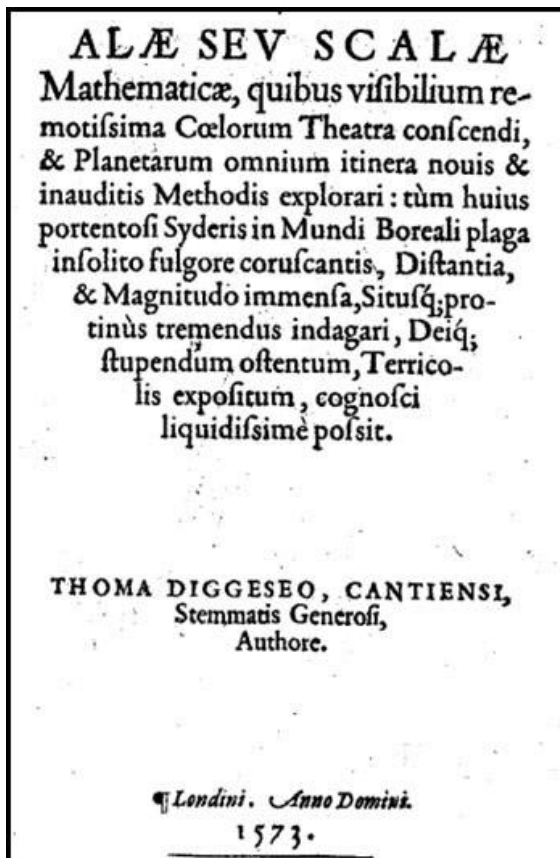


Figure 2: The title page of *Alae*.

*stauratae Progymnasmata (Introduction to the New Astronomy)* that was mostly printed by 1592, he collected and devoted nearly 300 pages to numerous other works on SN1572, especially praising the accuracy of Digges' astrometric measurements and his position for SN1572 which later was found to agree with the radio astronomical position (Dreyer, 1977: 57–60; Goulding, 2006: 47; Johnston, 1994: 79; Thoren, 1990: 61n48).

### 3 ALAE

Digges published *Alae* in 1573 on the one-hundredth anniversary of the birth of Nicholas

Copernicus, and this year (2023) we celebrate the 450<sup>th</sup> anniversary of *Alae's* publication. The full title is informative (see Figure 2). In translation from the Latin, it is:

Mathematical Wings or Ladders, with which it is possible to ascend to the very remote Theaters of the visible Heavens, and to explore the paths of all the Planets with new and unheard-of methods: in order to ascertain with extreme simplicity the immense Distance and Magnitude of this portentous Star shining with unusual brightness in the region of the Boreal World, and at the same time to investigate this amazing manifestation of God, revealed to terrestrial inhabitants.

The title purports to use a new method to explore the paths of the planets and only secondarily to investigate the New Star, which however was the ostensible reason to write the book in the first place. Another oddity is that mathematical theorems on the new method of determining diurnal parallax comprise the bulk of the book but are not applied to the New Star, nor to any planet. In the *Proemium* (Introduction), Digges states his desire to present a text "... devoid of all numbers." (B3v). He rationalizes his decision by not wanting to undermine his friendship with Dee by overshadowing Dee's booklet "... by a 'most' up-to-date' edition ..." of his own, and besides, the production of such a work "... is also very challenging." (B3r). Digges is content in *Alae* merely to announce the fixity of SN1572 relative to the stars, and he ends *Proemium* by intimating that he continues to gather data and that results from the data shall be forthcoming. Section 4 below discusses this promise.

In *Alae*, Digges writes that the method of data gathering developed by Johannes Regiomontanus (1436–1476) could be used effectively for measuring cometary parallaxes, but to determine small parallax angles, accurate measurement of time intervals were needed which contemporary clocks could not deliver. In a collection of 21 theorems and problems, Digges bypasses this difficulty. Perhaps SN1572 prompted this flurry of activity, but Goulding (2006: 45) argues that he must have been working on it for some time because it is unlikely that he could have completed the work in less than four months between the first sighting of the New Star and publication of *Alae*. Although this speculation is regarded with reserve (Pumfrey, 2011: 32–33), it is reasonable given Digges' conviction that he shared with Dee that the determination of parallax was the means to reform astronomy, for it seems unlikely that he

would suddenly decide to follow his conviction only when SN1572 had burst forth. Digges makes plain that problems numbered 15 to 21 in *Alae* precisely and straightforwardly reveal true parallaxes, and in *Praefatio* (Preface), he lauds their virtues (Goulding, 2006: 50):

Although the parallaxes of Saturn, Jupiter, and Mars, are so small as to be hardly discernable by our weak senses, if they can be truly detected by any method then I would dare to say that they can be found by the following problems of mine, or by no geometric method at all.

He writes in the subjunctive mood (“if they can be truly detected”), and makes a prediction (“I would dare to say”) that planetary parallaxes will be found by use of his mathematical methods. We return to this assertion in Section 4 below.

In 1573, thirty years after publication of Copernicus’ major opus on heliocentrism, *De Revolutionibus* (*On the Revolutions*), Digges knew that heliocentrism predicted greater variation in the distances of planets from the Earth than the standard model of Ptolemaic geocentrism. Tycho Brahe knew this too (Pumfrey, 2011: 32), but no commonly used instrument was capable of measuring such small angles. Digges is known to have possessed, and is credited with using, a 10-foot cross-staff, his *radius astronomicus*, whereas the renowned naked-eye astronomer Tycho preferred to use a form of sextant (Goulding, 2006: 47; Thoren, 1990: 58, 191), but regardless of the choice and quality of such instruments, their limitation is set by the visual acuity of the observers. This may be expressed as a resolution angle, which for humans has a value of 60”, or at best 30”,<sup>4</sup> whereas we know today that the largest parallax angle of any Superior planet at any time is 27” for Mars. Tycho’s measurements were consistently accurate only to about 60” and his so-called ‘Copernican campaign’ to measure the parallax of Mars failed and he could not prove the correctness of his hybrid geoheliocentric model (Gingerich and Voelkel, 1998: 1–3). If Digges had used any such commonly available instrument, he too would have failed in the same endeavor, and this may be why he refers in the quotation immediately above to “our weak senses,” or more precisely,

... when we use these instruments, which although they are made and divided in a very fine and exact way, nevertheless, for small intervals of minutes or of other fractions, the weakness of sight does not allow us to appreciate very small differences.

Is there anything more to Digges’ reference to a “new and unheard-of method”? Certainly, this may include his newly devised mathematical methods of measurement and data reduction, but the phrase can hardly include reference to measuring instruments like cross-staffs or quadrants because these were not ‘new’ and ‘unheard-of’. However, ‘method’ is “... a way of doing anything ... a mode of procedure in any activity.” (OED 2a), and ‘mode’ means a “... way or manner in which something is done or takes place.” (OED 4a). Thus, we ask, could a ‘new and unheard-of method’ refer to a new and unheard-of instrument other than the standard ones in use at the time? Digges answers the question in the affirmative. In the context of celestial phenomena and parallax, he writes in *Alae* (emphasis added; Goulding, 2006: 50n38):

Concerning these matters and others hitherto unheard of and about an easy method of investigating them with a new kind of instrument [*per instrumentum novum*] I shall, God willing, perhaps expound more fully at a later date, if these first writings meet with approval.

Digges must have received some encouragement because three years later he published a remarkable essay with a remarkable title.

#### 4 DIGGES’ ESSAY

Digges published *Alae* in Latin in order to reach a wide audience of scholars and to ensure that the work will not perish in a short time,<sup>5</sup> but he vowed henceforth to write only in English. Thus, his next publication was an essay in the vernacular in an almanac founded in the 1550s by Thomas’s father Leonard Digges, the 1576 edition of which underwent a titular change to “A Prognostication everlasting ... Lately corrected and augmented by Thomas Digges.”<sup>6</sup>

Until 1934, Digges’ essay was completely overlooked by historians of sixteenth-century science (Johnson, 1936: 391; Johnson and Larkey, 1934: 69). Its title, reproduced in Figure 3, is: “A Perfit Description of the Caelestiall Orbes according to the most Aunciente Doctrine of the Pythagoreans, latelye revived by Copernicus and by Geometricall Demonstrations approved.”

The reference in the title to ‘The Pythagoreans’ is a reference to Philolaus (ca.470–385 BCE) who postulated that the Earth, Sun and other planets orbited a central Fire (Maniatis, 2009), and the reference to Copernicus is to his revival of the theory of Pythagorean pyrocentrism but with the Sun at center.<sup>7</sup> The word ‘demonstration’ in the title means: “The action,



process, or fact of establishing the truth of a proposition or theory by reasoning or deduction or (in later use) by providing practical evidence in support of it ..." and a "... sign or indication that something is true." (*OED* 1, 2). The *OED* exemplifies the first meaning by usage from 1553: "They affirm the earth to be round, which ... they prove with most certain and apparent demonstrations of Geometry ..." which exactly illustrates Digges' claim. In addition, and most importantly, in obsolete usage 'approved' means 'proved' which is the same usage as elsewhere in Digges' work (e.g., *OED* '1a' *Pantometria* F3v) and by using the word 'demonstration',

Digges clearly implies that he reaches a robust conclusion:

But those who wish to deny the truth of this work, let them do so freely: it will not invoke any patronage [receive support], for it is so firmly fortified by the strongest and firmest demonstrations that it does not fear any Academician's cunning. (*Alae*, A3).

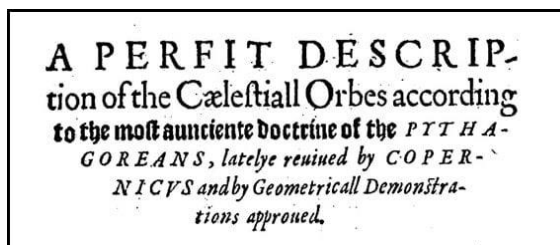


Figure 3: The title of Thomas Digges' essay in his father's almanac.

The title of "A Perfit Description ..." makes the astonishing claim that by 1576, geocentrism had been disproved observationally, and that the data were acquired were using 'geometric mensuration':

And seeing by proof of Geometrical mensuration we find that the Planets are sometimes nigher to us and sometimes more remote, and that therefore even the maintainers of the Earth's stability [immobility] are enforced to confess that the Earth is not their Orb's Centre, this motion *Circa medium* [around the middle] must in more general sort be taken and that it may be understood that every Orb hath his peculiar *Medium* [middle] and Centre in regard whereof this simple and uniform motion is to be considered. (*Alae*, O3r).

Digges reports that planets are 'sometimes nigher' and 'sometimes more remote' from Earth, yet the deferents, epicycles, and eccentrics of Ptolemy's planetary algorithms sim-

ulate that very property, so why does this phenomenon prove the *incorrectness* of geocentrism?<sup>8</sup>

In *Alae* in that early year 1573 of nascent scientific thinking, Digges argues for proceeding from observables toward theory, rather than the reverse, which is the case for the Ptolemaic algorithms (*Goulding*, 2006: 49–50, 50n33). In the preparatory remarks "To the Reader" in "A Perfit Description ...," he states a fundamental tenet of science, that:

There is no doubt but of a true ground truer effects may be produced then of principles that are false, and of true principles, falsehood or absurditie cannot be inferred. (*M1v*).

This is the gist of his criticism in *Alae* above. Digges states that 'Geometrical mensuration' is the key reason that the phenomenon of varying distances from Earth disproves geocentrism and he hints at the manner of discovery:

But in this our age one rare witte ... hath by long studies, painfull practise, and rare inuention deliuered a new Theorick or model of the world, shewing that the Earth resteth not in the Center of the whole world ... (*M1r*).<sup>9</sup>

This disproof of geocentrism is the grounded theory developed using a 'rare' invention, which is one not regarded as a member of a class or type (*OED* 3). The only geometrical measurements that give the distances of planets are diurnal parallaxes, and the only rare invention to gather such data is the telescope. Thomas Digges' father is arguably the developer of the modern telescopic theodolite (see *Digges and Digges*, *Pantometria*, title page; N2v) and is widely regarded as the developer (rather than 'inventor') of a device rare if not unique in the Elizabethan age (1508–1603), viz., the telescope. Thomas Digges worked closely with his father and it is not a stretch to presume that he availed himself of that connection.

Thus, with this rare instrument Thomas Digges could follow planets as they approached or left conjunction with the Sun, and since he had their distances he could follow their tracks and find that they did not retrogress. He did find that they increased in distance from the Earth as they moved away from opposition or inferior conjunction, but he could not claim that they all have the same orbital center. He argues that Copernican heliocentrism is thoroughly defensible, and he therefore incorporates it into his view of the planetary system (see *Figure 4*). This inductive leap is akin to the one that Johannes Kepler (1571–1630) made when in 1609 in *Astronomia Nova* (*The New Astron-*

omy) he announced what are known today as his Law of Ellipses and Law of Areas, viz., that which is true for Mars is true for all planets.

Digges' new mathematical methods notwithstanding, historians were inclined to neglect "A Perfit Description ..." because no-one could imagine that diurnal parallaxes could be measured. Even Johnson and Larkey who in 1934 urged attention to Digges' work, ignored the following excerpt which is the final sentence of the very essay they promoted and which may well be Digges' chief conclusion (Johnson and Larkey, 1934: 94–95):

So, if it be Mathematically considered and with Geometrical Mensurations every part of every Theory examined, the discreet Student shall find that Copernicus not without great reason did propose this ground of the Earth's mobility. (O3r).

Here, 'discreet' has its customary meaning of: "Possessing or exhibiting sound judgement in speech or action, esp. in such a way as to avoid one's own or another's disgrace or embarrassment." (OED 1a). The word implies that intelligent students would grasp the intent of the proposition and that they should treat that knowledge prudently. Historians too should have no difficulty being discreet since the essay also lacks data to back up the claim of the disproof, as well as a description of the instrument used. No wonder that historians have shelved both "A Perfit Description ..." and *Alae*.

## 5 STRATIOTICOS

But the year 1579 sees a new development. In the first edition of the book *Stratoticos* authored by Thomas and his father, Thomas asserts that henceforth like his father he shall follow the example of Pythagoras and communicate with only a few select friends. This means that the father/son duo would not publicize their discoveries, which is quite understandable given the tenor of the times. For example, religious intolerance was rife, proponents of Christianized geocentrism opposed the heresy of heliocentrism, and Elizabethan England was menaced militarily on all sides. Does this mean that the evidence for the claim of the falsity of geocentrism in *Alae* and "A Perfit Description ..." would be forever lost?

A partial answer lies in Thomas' account in *Stratoticos* of his life and work. He names six books that he started to write and promises to publish, one of which is titled:

Commentaries upon the revolutions of Copernicus, by evident demonstrations

grounded upon late observations, to ratify and confirm his theory and hypothesis, wherein also demonstratively shall be discussed whether it be possible upon the vulgar thesis of the Earth's stability [i.e., geostatic geocentrism], to deliver any true theory devoid of such irregular [i.e., retrograde] motions, and other absurdities repugnant [to] the whole principles of natural philosophy and apparent grounds of common reason.

Here, 'demonstration' has the meaning given in Section 4 above, meaning proof through empirical evidence. 'Late' means, "Belonging to the latter part of a particular historical, cultural, or developmental period." (OED adj.1, 9a), i.e., it means 'recent'. 'Observations' relates to "... watching, or noticing." (OED 5). 'Vulgar' means common or general (OED 2), here implying 'uncultured'. And 'irregular motions' refers to the appearance of planetary retrogradation in the old geocentric schemes.

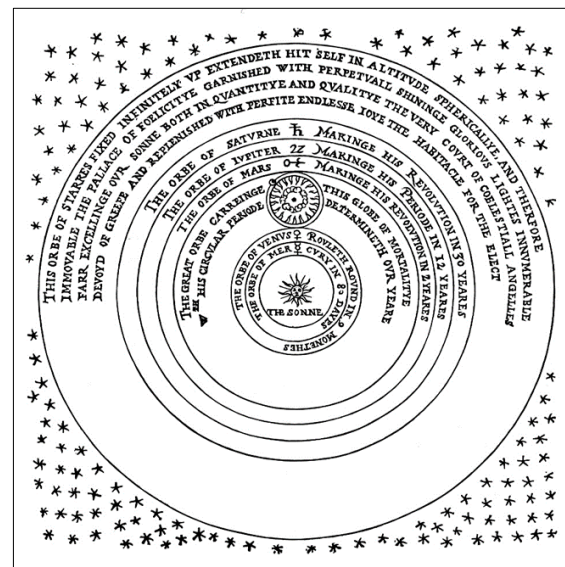


Figure 4: Thomas Digges' representation of a heliocentric planetary system imbedded in a boundless plenum of stars.

In short, *Commentaries* purports to remedy the lack of data in both *Alae* and "A Perfit Description ...", and such data can only be supplied by optical magnifying glasses and eye-pieces (herein 'telescopes'). As a rough guide to specifications, the Astronomer Royal of Great Britain, George Biddell Airy (1801–1892), applied the theory of diffraction of light and found that the angular resolution  $\theta$  in seconds of arc of a telescope with circular aperture of diameter  $d$  in inches is approximately  $5.5/d$  (Sidgwick, 1971: 45). Thus, in principle, a telescope of aperture  $d = 5.5$  inches (0.14 m) could provide resolution of  $\theta = 1''$ , a value that typifies

excellent atmospheric seeing. It is beyond the scope of this paper to debate the question of the existence of an Elizabethan telescope and to speculate on apparatus used and procedures followed other than to note that in theory a telescope of modest aperture would be sufficient to detect planetary parallax down to the limit imposed by the atmosphere, and that this is sufficient to observe planets on either side of Opposition. Of course, such usage would imply the existence of stable mounts and an ability to counter the rotation of the Earth.

The pledged book *Commentaries* did not materialize and neither did any of the other five books that Digges purported to have begun writing. *Stratoticos* tells why. In the first edition of 1579, Thomas complains in no uncertain terms about his home life and his isolation. He vows to discontinue his studies, and in the very book in which he promises to finish writing the tracts, he offers excuses for not doing so:

All these [books] and other[s] long since, the Author [would have] finished, had not the Infernal Furies, envying his Felicity, and happy Society with his Mathematical Muses, for many years so tormented him with Law-Brabbles, that he has been enforced to discontinue those his delectable Studies.

## 6 EXCUSES, EXCUSES

Are Digges' widely disseminated excuses credible? First, let us consider one of these law-brabbles. The Digges ancestral home was in county Kent, whose Chief Justice at the time was Roger Manwood (1524/5–1592). Manwood had "... great enemies ... [and was] exceptionally litigious in a litigious age ..." and so given to revenge that no one dared to meddle in his causes (Jack, 2016). He is known once to have tangled with Thomas Digges who in an amusing exchange got the better of him (*ibid.*), but more pertinent to the argument at hand is his claim documented in 1682 that he, Manwood, had invented the telescope (Birch, 1757 (4):156–157). Evidently, the telescopicist Thomas Digges was put in the position of having to defend himself and his father.

As early as 1571, the title of *Pantometria* refers to an optical device for land surveying called a 'Perspective Glass', which is an early term for 'telescope'. In Chapter 21 of the First Book, *Longimetra*, a magnifying device is described which Michael Gainer reproduced using materials and methods available in the sixteenth century, and through which he could readily resolve the disks of planets and discern the phases of Venus and craters on the Moon (Gainer, 2009: 18, 20). Digges' custom of com-

municating only with select friends could explain the lack of telescopic data available to the public.

These reports suggest that Leonard was involved with the development and use of telescopes, and that upon his death that Thomas Digges reported in *Pantometria*, Thomas inherited Manwood's ire. This would follow from the "... long-standing failure to distinguish between the work of Thomas Digges and that of his father, Leonard ..." and that Thomas' printed work is "... (quite literally) bound up with his father's." (Johnston, 1994: 51, 52n6). Manwood's antipathy toward the Diggeses argues for Thomas' continued use of telescopes and the veracity of his claim to have disproved geocentrism.

## 7 CONCLUDING REMARKS

Lastly, we mention that multiple descriptions of celestial detail accessible only telescopically are contained in the plays of William Shakespeare (1564–1616) (Usher, 2022: *passim*). Relevant passages are incorporated into allegories and some character names are those of astronomers or those involved in the celestial arts, or else they closely resemble them (see Massaro and Usher, 2022). The passages are more than simply descriptive because they reveal that arcsecond optical resolution existed during or before Shakespeare's writing career of about 1590–1613. This further supports the claim of disproof of geocentrism argued above and suggests that empirical evidence for heliocentrism had been achieved by 1576, thirty-three years after the publication of Copernicus's *De Revolutionibus*.<sup>10</sup>

## 8 NOTES

1. Translations in this paper are from Massaro et al. (2023) and Goulding (2006).
2. The modern stellar magnitude scale follows a classification scheme the earliest known mention of which is in a poem *Astronomica* dating to 10–20 CE by the Roman poet Marcus Manilius (fl. 1st century CE), and thus the common attribution of the magnitude scale to Hipparchus (ca. 190–120 BCE) is conjectural (Cunningham, 2020: 242–244).
3. Parallax is the angle between two directions that results when an object is seen from two vantage points, such as might occur when the Earth rotates (a diurnal parallax) or revolves (an annual parallax).
4. *Encyclopædia Britannica*, "human eye" (<https://www.britannica.com/>, accessed 3 May 2023).

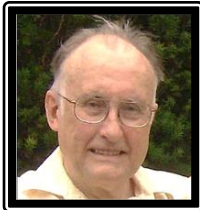


5. Nearly sixty years after Digges' decision the prominent Italian physicist Galileo Galilei (1564–1642) opted to publish in his native tongue. However, *Dialogo sopra i due massimi sistemi del mondo* ("Dialogue Concerning the Two Chief World Systems") which compared geocentrism to heliocentrism, was not well-received (see [Drake, 1995: 336–352](#)).
6. "A Perfit Description ..." appeared in all subsequent editions of the almanac (1578, 1583, 1585, 1592, 1596, and 1605) and was largely responsible for spreading the heliocentric doctrine among the English public. Fortuitously, the intervals between publication of *De Revolutionibus* in 1543 and Digges disproof of geocentrism in 1576, and between that date and the first documented evidence of telescropy in 1609 by Thomas Harriot (ca. 1560–1621), are both 33 years.
7. Early modern Copernicans were regarded as neo-Pythagoreans ([Reeves, 1999: 63](#)).
8. Robert Burton (1577–1640) wrote in *The Anatomy of Melancholy* (1620 and later): "For who is so mad to think that there should be so many circles, like subordinate wheels in a clock, all impenetrable and hard, as they feign, add & subtract at their pleasure." ([Burton, 1903: 58](#)).
9. A 'rare' individual is one who is rarely seen ([OED 3b](#)), and Leonard Digges was reported to have died eight times during the years 1558–1580 ([Usher, 2022: 132](#)). Note, too, that the penultimate paragraph of "A Perfit Description ..." contains a surprising amount of legalese, which is not surprising since Thomas' essay was printed in the almanac founded by his father Leonard who graduated from Lincoln Inn, one of four law schools in London ([Hall, 2014: 580](#); [The Records of the Honorable Society of Lincoln's Inn, 50, 1896](#)).
10. Shakespeare and the Digges family were acquainted, and one of two chief possibilities is that the bard was one of the privileged recipients of Thomas Digges' transferal of information prior to Thomas' death in 1595 ([Usher, 2022: 147](#)). His death preceded Shakespeare's first play *The Two Gentlemen of Verona* of about 1590–1591 or earlier ([Warren, 2008: 25–27](#)). Two passages, *TG* 2.6.9–10, 3.1.307–309, probably refer to the Copernican / Digges model (E. Feigelson, pers. comm., April 2023).

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His research included studies of quasars and faint blue objects using multiwavelength data. He is the author of the US survey of Ultraviolet Starlike sources, where 'U' = ultraviolet excess and 'S' = starlike morphology.

While at PSU Peter served as Assistant to the Director of the Interdisciplinary Program in the Humanities, and he sometimes inserted cultural references into his undergraduate and graduate astronomy courses. In 1996 he began researching Shakespeare's knowledge of astronomy, and this has lasted into retirement, with the publication of numerous research papers and four books.

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Enrico has always been interested in the history of science, especially astronomy, and its cultural and social impact. His first study, in 1972, was on Piazzi's original instrumentation at the Astronomical Observatory of Palermo. Since then, he has published on early gamma ray astronomy and cosmic radiation, and on the development of Renaissance Astronomy.