

## THE SIXTEENTH-CENTURY EMPIRICAL DISPROOF OF PTOLEMAIC GEOCENTRISM: PAPER II

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**Abstract:** The standard model of the Universe in the 16<sup>th</sup> and 17<sup>th</sup> centuries was a geocentric planetary system imbedded in a homocentric shell that held the stars. In a previous paper, we discussed the book *Alae seu Scalae Mathematicae* of 1573 in which Thomas Digges laid out his methodology for the measurement of small diurnal parallaxes of celestial objects. Further, we discussed that book's sequel, the essay *A Perfit Description of the Caelestiall Orbes* of 1576, in which he claims to disprove the theory that the Earth is the center of the Universe. Here we examine the empirical grounds upon which Digges' claim rests in order to see whether the data that he might have collected support his claim. The methodology of the present argument is spelled out. We conclude that line-of-sight instruments like cross-staffs cannot account for Digges' claims, but that the higher resolution offered by telescopes can. The context of Digges' works is briefly discussed.

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

### 1 INTRODUCTION

In a previous paper (Usher and Massaro, 2023; herein Paper I), we discussed the belief of Thomas Digges (c.1546–1595) and his former mathematics tutor John Dee (1527–1608) that advances in astronomy would follow the determination of distances, and that diurnal planetary parallax was the way of the future. Diurnal parallax is the angle subtended at a relatively nearby celestial object by the radius of the Earth, measured by observing its apparent shift in direction with respect to more distant objects like stars as the sky appears to rotate. In this paper, we revisit Digges' works of 1573 and 1576 and put his conclusions to the test.

In apparent response to the New Star of November 1572 (SN 1572), a few months later Digges (1573) published a book *Alae seu Scalae Mathematicae* (herein *Alae*) whose full title in translation from Latin 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 the terrestrial inhabitants. (*Alae: sig. Ai*).<sup>1</sup>

Although *Alae* appeared ostensibly as a response to SN 1572, the title mentions the goal of exploring the paths of the planets first and only secondarily mentions SN 1572. This peculiarity suggests that planetary parallax may have been Digges' goal all along and that SN 1572 gave him an excuse to publish (Goulding, 2006: 45; Pumfrey, 2011: 33).

The core of the book are 22 + 5 = 27 'problems' or 'theorems' on data acquisition and reduction of diurnal parallax measurements suitable for application to objects at large distances with small parallaxes. In such cases, the method of data acquisition of Johannes Regiomontanus (1436–1476) for obtaining parallaxes of comets (*De cometae magnitudine, longitudineque ac de locus eius vero, problemata XVI*, printed 1531 and 1544) is unsuited owing to the difficulty of performing several measures accurately in a short amount of time, and to the large number of measurements needed.

Digges ascribes the novelty of his own work to a "... new and un-heard of method ..." (*novis & inauditis Methodis; Alae: sig. Ai*) that by implication refers to the data analysis schemes that he devised, and which bypasses the shortcomings of the standard approach. Despite this elaborate mathematical development, Digges determined an upper limit to the parallax of SN 1572 simply by aligning a straightedge through SN 1572 and two nearby stars, thereby discounting parallaxes of about a degree reported by some observers.



Figure 1: Portrait of William Cecil, Lord Burghley, dedicatee of Thomas Digges book *Alae seu Scalae Mathematicae* ..., and his coat-of-arms ([https://commons.wikimedia.org/wiki/File:William\\_Cecil,\\_1st\\_Baron\\_Burghley\\_from\\_NPG\\_\(2\)FXD.jpg](https://commons.wikimedia.org/wiki/File:William_Cecil,_1st_Baron_Burghley_from_NPG_(2)FXD.jpg)).

*Alae* is primarily theoretical with only exemplary applications of its theorems, but in the dedication to William Cecil, Baron Burghley, Digges promises to follow up by applying his theorems to the determination of planetary parallax. He promises to address the Earth-centered (geocentric) cosmology that was the standard model at the time and hints at the validity of the Sun-centered (heliocentric) system proposed 30 years earlier by Nicholas Copernicus (1473–1543). He writes:

I shall be committed from now on ... to accomplish further and more important works. I shall not stop at this my first effort but I shall progress perhaps to the point where anyone may clearly see whether the mechanism of Celestial Globes and of the Visible World of Sun, Moon, and planets that has been reformed by Copernicus was not fully correct or whether there are still some points to be carefully examined. (*Alae*: sig. Aiiij<sup>v</sup>).

Figure 1 shows a portrait of Burghley by an unknown artist, and his coat-of-arms that Digges includes in *Alae* (sig. Aij<sup>v</sup>).

Three years after publication of *Alae*, Digges kept his promise by publishing an essay in English titled, *A Perfit Description of the Caelestiall Orbes according to the most auncient doctrine of the Pythagoreans* (herein *Perfit*). (Digges, T., 1576). This appeared in the 1576 edition of an almanac founded by his father Leonard (Digges, L., 1576). Henceforth we use the initial 'L.' to distinguish Leonard Digges from his son Thomas whom we refer to simply as

"Digges," and we note also that Leonard Digges had a grandson by the same name. Digges (1576) writes:

And seeing that by evident proof of Geometrical mensuration we find that planets are sometimes nearer to us and sometimes more remote, and that therefore even the maintainers of the Earth's stability are forced to confess that the Earth is not the Centre of their Orbs. (*Perfit*: sig. O3<sup>r</sup>; Johnson and Larkey, 1934: 94. In Paper I, this quote is incorrectly assigned to *Alae*.)

Here, "Orb" refers to the imaginary rigid transparent spherical shell believed to hold the planets in the standard geocentric model to prevent them from falling to Earth (*OED*: I.1.a). Thus, Digges concludes that it is unlikely that the Earth is immobile at the center of Creation and more probable that it is in motion around the Sun:

So it be Mathematically considered and with Geometrical Mensurations every part of every *Theoric* examined: the discreet Student shall find that Copernicus not without great reason did propose this ground of the Earth's mobility. (*Perfit*: sig. O3<sup>r</sup>).

A need for brevity obtained at the nascence of scientific publishing, as for Digges' *Mathematical Discourse* that he included in his father's *Pantometria* of 1571, for which publishing proofs of his theorems would have multiplied the text many times over (Johnston, 1994: 68). This could account for why *Alae* and *Perfit*

leave certain difficulties unanswered, chief among which are the absence of data to back up the two claims quoted immediately above and the absence of a named instrument by which to measure the data.

Whereas Digges himself asserts the conclusions quoted above with apparent certitude, the present approach is impartial. We characterize these difficulties broadly as follows:

- (1) *Alae* presents new methods of small diurnal parallax measurement, and *Perfit* claims that planetary parallax measurements disprove geocentrism and support heliocentrism, both without supporting data.
- (2) In neither work is the instrument used to measure planetary parallax angles named or described.
- (3) Digges' neglect of items (1) and (2) is odd.

In regard to such deficiencies, Thomas Kuhn (1996: 52) writes that discovery "... commences with the awareness of anomaly ...", and Leslie Hotson (1977: 182) advises: "Watch out especially for anything odd." This advice encourages inquiry into the categories listed above.

## 2 METHODOLOGY

The difficulties (1) and (2) above have been evident for decades, perhaps even for centuries. Carl Sagan (1979: 72–73) wrote in connection with research "... at the border of science ... [that] extraordinary claims require extraordinary evidence ..." and by the same token in the history of science, we suggest that extraordinary neglect requires extraordinary attention. This paper and its precursor, Paper I, are small steps in that direction.

Item (3) could be explained by the argument that in the sixteenth and seventeenth centuries the idea that geocentrism and heliocentrism could be distinguished was glossed over owing to the mistaken perception that geo- and heliocentrism were observationally equivalent (Gingerich and Voelkel, 1998: 2–3). And further, it appears that this perception somehow has persisted into the twenty-first century, but it is not true insofar as distances differ widely between the two theories. For heliocentrism in particular, Mars' greatest distance from Earth is about five times greater than its closest distance, whereas for geocentrism in its most primitive form the distances should be the same.

Items (1) and (2) are related, but inquiry into (1) can proceed independently of the type of instrument used. If Digges' claims in (1) are unsubstantiated in theory, the issue of (2) is moot and a host of new questions could arise. But if claims in (1) are substantiated, then we would be justified in asking how Digges' data

were obtained and so move on to item (2). There is no circular reasoning since we do not need discussion of item (2) to address item (1), and we do not assume at the start any conclusion that we might reach in the end.

## 3 DIGGES' DISPROOF OF GEOCENTRISM

Paper I addressed the question of the sixteenth-century disproof of geocentrism which during Digges' lifetime was the standard model of the Universe. That paper discussed evidence in support of Digges' claim to have disproved geocentrism, and this paper puts this evidence to the test.

In the second century CE, the Alexandrian astronomer Claudius Ptolemy (c.100–c.170 CE) refined the theory of geocentrism using epicycles revolving on deferents along with eccentrics and equants, all with values chosen

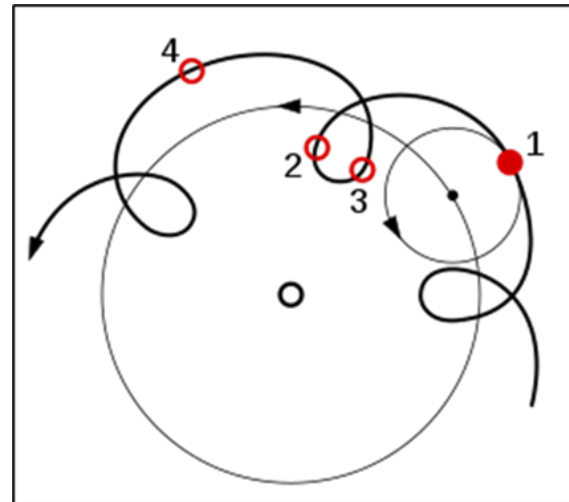


Figure 2: Schematic representation of the orbit of Mars according to the geocentric model (after [https://en.wikipedia.org/wiki/Deferent\\_and\\_epicycle](https://en.wikipedia.org/wiki/Deferent_and_epicycle); accessed 10 July 2023).

to suit each planet. The one shown schematically in Figure 2 has a red dot that we might consider represents the 'red planet' Mars. The spot moves along the epicycle, the center of which orbits the Earth along the deferent. At positions 1 and 4, Mars moves prograde relative to background stars, but between points 2 and 3, it moves retrograde, i.e., opposite to the direction of its motion at positions 1 and 4. Retrograde motion for the so-called Superior Planets Mars, Jupiter, and Saturn always occurs around the time of Opposition (when the planet is opposite the direction of the Sun), so a good test of geocentrism is to see empirically whether knowledge of the distances of these planets supports retrograde motion at those times. This can be accomplished knowing the parallax of a planet like Mars by tracing its orbit

between the apparent positions at points 1 to 4 in Figure 2.

Consider how Digges might have proceeded. In *Alae*, he states that problems (theorems) numbered 15 to 21 precisely and straightforwardly provide diurnal parallaxes, and in the Author's Preface (*Praefatio Authoris*) he lauds their virtues:

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. (*Alae*: sig. A4<sup>v</sup>; Goulding, 2006: 50).

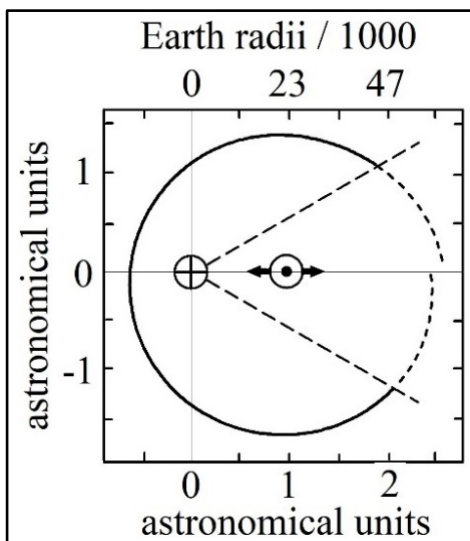


Figure 3: Locus of distances of Mars from Earth over one synodic period from 1571 to 1573. The dashed curves denote elongation angles within 30° of the Sun. The Earth lies at the origin and the Sun is located somewhere along the x-axis as denoted by the arrows. When the y-axis value is zero, Mars is at opposition on the negative x-axis or at conjunction on the positive x-axis (diagram: the authors).

Since Digges is trying to determine planetary parallaxes under the rubric of geocentrism, the best chance for securing data lies in observing Ancient Planets that come closest to the Earth. Plato supposed that the geocentric distances of the seven Ancient Planets were ordered as: Moon, Sun, Mercury, Venus, Mars, Jupiter, and Saturn (Dreyer, 1953: 62). A slightly different sequence obtains owing to the perpetual proximity of Sun, Mercury, and Venus in the sky, but the sequence of the last three planets remains unchanged.

Parallax must be measured relative to stars in the distant background. The Sun's parallax is difficult to observe because its bright scattered

light renders background stars invisible. The Inferior Planets Mercury and Venus are difficult to observe owing to the need to have two positional measurements separated in time as much as possible, and the proximity of the directions of these planets to the Sun shortens windows of accessibility. By far the best candidate is the nearest Superior Planet, Mars, which is readily visible at night during retrogradation around the time of Opposition when background stars are visible. It is the planet that Tycho Brahe (1546–1601) observed extensively in his attempt to measure its parallax (see below).

Diurnal parallax angles at time  $t$  are defined as

$$p(t) = R/d(t) \text{ radians,} \tag{1}$$

where  $R$  is the radius of the Earth and  $d(t)$  is the distance of the target. Digges would express distances in units of the Earth's radius (e.r.) whose value was fairly well known at the time and which we take to be  $R = 6,400$  km. Equivalently, we can let the unit of  $d$  be the astronomical unit (a.u.) equal to 150 million km, giving diurnal parallax in seconds of arc as  $p(") = 8.8/d(\text{a.u.})$ . The curve in Figure 3 typifies what Digges would observe with a suitable instrument. The curve gives the distance of Mars from Earth for Sun–Observer–Mars elongation angles over one synodic period from 3 March 1571 to 24 May 1573 (Old Style), or J.D. 2294954 to J.D. 2295740. Digges could calculate elongation angles from the known coordinates of the Sun and the measured position of Mars, and we calculated ephemerides using the IMCCE ephemeris calculation service through its Solar System portal (<https://ssp.imcce.fr>).

In Figure 3, let the direction of the Sun define the x-axis and let the Earth lie at the origin. Mars at Opposition is on the negative x-axis and at Conjunction with the Sun on the positive x-axis. Parallaxes for elongation angles within, say, 30° of the Sun would be more difficult to measure and such prospective distances are represented by dashed curves.

The trace in Figure 3 is a typical one for Mars as may be inferred from Figure 4 which shows  $d(t)$  from 1568 to 1575 as a function of Julian Day number. Shapes in Figure 4 are roughly the same through each cycle albeit slightly asymmetrical owing to the eccentric, asynchronous, non-coplanar orbits of Mars and Earth, but the general shape of the functions  $d(t)$  and  $p(t)$  in Figure 4 agrees with a representative heliocentric orbit for Mars devised by Diolatzis and Pavlogeorgatos (2019: 40–41). They approximate Mars' distance as

$$d(t) = [\rho_o^2 + \rho^2 - 2 \rho_o \rho \cos\{2\pi t (1 - 1/P)\}]^{1/2} \tag{2}$$

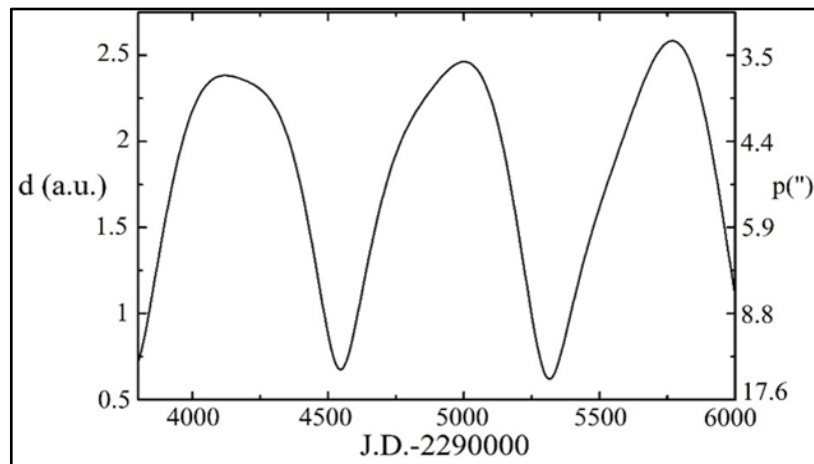


Figure 4: Changes in geocentric distance  $d$  for Mars as a function of time expressed in Julian Days from 1568 to 1575. Asymmetry is owing to differences in the orbits of Mars and Earth (diagram: the authors).

where  $\rho_0$  and  $\rho$  are the radii of Earth's and Mars' orbits which are assumed to be circular, and  $P = 1.8809$  is the sidereal period of Mars in units of the Earth's orbital period of 1 year. Their model curve  $d(t)$  resembles those in Figure 4, and we conclude that Digges' data through several synodic cycles should fall close to the locus shown in Figure 3.

If Digges had suitable instrumentation, he would observe what Figure 3 shows. On the assumption that temporal resolution is sufficiently fine, the data would resemble the solid-line curve, showing that Mars moves prograde relative to the Sun–Earth line.

#### 4 HELIOCENTRISM

In *Perfit*, Digges goes a step further to assert the correctness of Copernican heliocentrism. In Book I, Chapter 7 of *De Revolutionibus* (On the Revolutions) Copernicus states the three types of motion posited by Aristotle in *De Caelo* (On the Heavens) of which the first two are terrestrial and rectilinear but the third is celestial and “*circa medium*.” In *Perfit*, Digges uses the same term to refer to motion of the planets (Digges, 1576: sig. O2<sup>v</sup>–sig. O3<sup>r</sup>; Johnson and Larkey, 1934: 94). This Latin term can mean “... about the middle (of a space) ...” where the meaning of *medium* is as occurs for example in Julius Caesar's “*media regio totius Galliae*” (the central region of all Gaul; Smith and Lockwood, 1988: 427). Thus, *medium* can refer to a region of space, and not a particular point in space, and equally, Digges' uses “centre” to mean “... a place in the middle ...”, “... a central part ...”, and “... a position of being in the midst ...” (OED, c.1392).

Thereby, we understand Digges' conclusions in *Perfit* (Digges, 1576: sig. O3<sup>r</sup>; Johnson and Larkey, 1934: 94; italics original):

And seeing by evident 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 forced to confess that the Earth is not their Orbs Centre [i.e., the Earth is not the center of motion of the orbs supposed to hold the Ancient Planets]. This motion *Circa medium* must in more general sort be taken and that it may be understood that every Orb hath his peculiar *Medium* and Center in regard whereof this simple and uniform motion is to be considered.

Digges concludes that each planet has its own central region about which it circulates, where in *Pantometria* (OED: 3<sup>†</sup>. Digges and Digges, 1571: sig. Pj) the Diggeses use “circulate” as a transitive verb to mean to “... go or run around; to encircle, encompass, surround ...” The word originates from the Latin *circulus* having the astronomical meaning of “... a circular path, orbit.” (Smith and Lockwood, 1988: 111), so we suggest deferentially that a term that might distinguish this motion appropriately from heliocentrism could be ‘heliocirculism’.

In the passage quoted above, Digges writes of “Planets” without naming them, but we cannot be sure that he would be capable of reaching the same conclusions for Jupiter and Saturn as for Mars. However, he could have generalized the conclusion of heliocirculism from four planets closest to the Sun to all planets. In 1609 in *Astronomia Nova* (New Astronomy), Johannes Kepler (1571–1630) argued the same way when he generalized the discovery of the ellipticity of Mars' orbit to include all planets.

Digges' claims deny the assumption championed by classical cosmologists that the Sun

has no fundamental role to play in the nature of planetary orbits, since in both ‘heliocirculism’ and heliocentrism the Sun is an inherent part of the formalism. The contrast of theory concocted without and with regard for observations is seen visually via the Ptolemaic Figure 2 versus the Diggesian Figures 3 and 5.

## 5 PARALLACTIC INSTRUMENTS

If Ptolemaic geocentrism is incorrect for Mars, then Digges could argue inductively that it is incorrect for all planets in the metaphysical belief that Nature is not fickle (Huff, 2000: 84). Therefore, we are justified in concluding that difficulty (1) at the end of Section 1 is resolved, and that difficulty (2) may now be fruitfully addressed.

With the disproof of geocentrism substantiated, the question arises as to what sorts of instruments could deliver the necessary data. In the title of *Alae*, Digges refers to his “... new unheard-of methods ...”, (*novis & inauditis Methodis*) and near the end of the Introduction (*Proemio*), after discussing the quest for the parallax of SN 1572, Digges mentions John Dee’s efforts in designing and making “... new and uncommon instruments ...” (*instrumenta nova et inusitata*) to measure “... the very small Parallax of this very rare Phenomenon [SN 1572] ...” (*Alae*: sig. B2<sup>v</sup> – B3<sup>r</sup>). He writes that measurements shall be made “... with a new kind of instrument ...” (*per instrumentum novum*) and he reiterates the possibility of reporting on this instrument if his initial publications are well-received:

Concerning these matters and others hitherto unheard of, and about an easy method of investigating them with a new kind of instrument, I shall, God willing, perhaps expound more extensively at a later date, if these first writings meet with approval. (*Alae*: sig. K4<sup>r</sup>. Goulding, 2006: 50n38).

The exposition he performs more fully at a later date is likely *Perfit* of 1576 wherein he claims that diurnal planetary parallaxes account for his disproof of geocentrism, but Digges does not explain what this new instrument is or whether it falls into the category of a “... new and unheard-of method ...” to which the title of *Alae* refers.

Digges reports in *Alae* (sig. I–K) that cross-staffs (*Radii Astronomici*) are the best instrument for measuring extremely small angles, and according to Goulding (2006: 47) he used only cross-staffs. But Goulding’s statement concerns *Alae* of 1573 and does not apply to *Perfit* whose parallactic instrument remains unknown to the present day. Cross-staffs were

well-known, having been described by Petrus Apianus (1533) in *Instrument Buch* and by L. Digges (1556) in his book on land surveying methods, *Tectonicon*. Cross-staffs were known and likely invented about a couple of centuries before by Levi ben Gerson (1288–1344; also known as Gersonides) (Goldstein 1977: 102–112) whose works were generally written in Hebrew (Rudavsky 2007: 415). Thus in 1573, cross-staffs do not qualify as new and unheard-of instruments and so are probably not included in Digges’ category of “... new and unheard-of methods”. Nevertheless, its candidacy as an instrument for planetary parallax should be fully considered since it would be an obvious choice.

In the sixteen pages of *Alae* that Digges devotes to a discussion of cross-staffs, he includes words of admiration for Richard Chancellor (Richardus Chanslerus, c.1520–1556), to whom he attributed the adoption of the transverse scale for increasing the precision of measurements. Transverse lines effectively lengthen the graduated interval in which a measurement falls, and are a refinement that dates to Levi ben Gerson; they may be seen for example in a depiction of Tycho Brahe’s great mural quadrant of 1582 that divides degrees into six parts of 10’ each (Thoren, 1990: 164).

But if Digges had planned to report on planetary parallax using a line-of-sight instrument like a cross-staff, he may have been misled because like Tycho, he may have accepted low estimates of planetary distances that made planetary parallaxes larger and easier to detect (Gingerich and Voelkel, 1998: 3; Pumfrey, 2011: 32). Digges asserts that his theorems 15 to 21 will “... very precisely and simply reveal true parallaxes ...” (*Alae*: sig. L1<sup>v</sup>; Goulding, 2006: 47), yet at the same time he writes that “... the parallaxes of Saturn, Jupiter, and Mars, are so small as to be hardly discernable by our weak senses ...” (*Alae*: sig. A4<sup>v</sup>; Goulding, 2006: 50). Digges appears to have tried visual measurements but found a need for detection finer than the human eye can provide. For example, we know today that the maximum parallax of Mars lies in the range of only 23”–27” (Gingerich and Voelkel, 1998: 3; Thoren, 1990: 250; van Helden, 1985: 49), which is at or below the limit of human visual angular resolution which is no better than 28” (De Winkel et al., 2022: 3092; Deering, 1998: 1).

*Alae* supports this  $\approx 30''$  resolution limit. On page sig. A.ij<sup>v</sup> Digges lists coordinates for SN 1572 and nearby stars for which fractions of degrees are expressed both in minutes of arc and in scruples. The simultaneous usage suggests the equivalence of scruples (*OED*: 2a)

and arc minutes, and in addition the values of scruples never exceed 60, just as there are 60' in 1°. In one case, a coordinate is given accurate to ½ scruple which corresponds to 30" and happens to equal the minimum acuity of the human eye. However, this fraction could have resulted from accounting for observational uncertainty despite Digges never having reported any averaging procedure (Massaro et al., 2024). We note too that Digges used the trigonometric tables of Rheticus published in 1551 which were calculated for intervals of ten arcminutes (de Morgan, 1845: 228), and at the end of the First Canon (*Canon primus*) of Chapter eight (*Capitulum octavum*; *Alae*: sig. K.2') he writes that these tables are given in intervals of ten scruples, so that 1 scruple = 60" is consistent with the capabilities of line-of-sight instruments.

To test the capabilities of line-of-sight instruments further, let us examine the work of the world's premier naked-eye astronomer Tycho Brahe. He mounted a campaign to detect the parallax of Mars at its favorable 1582 opposition using visual sightings with an instrument akin to a sextant (Goulding, 2006: 47; Thoren, 1990: 58, 191). In the end, Tycho's instruments yielded an accuracy of only about 60" and eventually his herculean effort failed (Gingerich and Voelker, 2011: 3n2, 29). He might have had better luck if his eagle-eyed instrument-builder Hans Crol (d. 1591) (Christianson, 2000: 269; Thoren, 1990: 180, 303.) had been hired sooner than 1582. As noted, Digges may have tried what Tycho later tried, for he appears to have reached the same conclusion because he characterized parallaxes as being "... so small as to be hardly discernable by our weak senses." (*Alae*: sig. A4<sup>v</sup>).

Thus, it is doubtful if Digges' data were measured with line-of-sight instruments of sufficient quality to warrant the bold statements of *Alae* and *Perfit*. Although the range 30"–60" for minimum human acuity overlaps the range of 30"–50" for the angular size of Jupiter whose variations in principle could measure the relative distance of the planet and therefore would test geocentrism (as we discuss below), such observations would require sophisticated analysis because the signal would be buried in the noise. Ironically, like parallax for Mars, this approach is again just beyond the reach of human vision.

If a cross-staff or a similar instrument is inadequate, what might Digges' new instrument be? Prior to Paper 1, cross-staffs were the only possibility considered or implied, but when line-of-sight instruments prove inadequate perhaps we should consider telescopes since such in-

struments supply much higher resolution than that of the human eye, and at the same time atmospheric distortions ('seeing') can be small enough to allow parallaxes to be measured. From the standpoint of attempts to reconcile the claims of *Alae* and *Perfit*, any of the instruments listed in *Alae* (sig. H4<sup>r</sup>, "*Dioptra, Triquetra, Armillos, Astrolabia, Quadrantes*"), or any other instrument that a researcher might choose, are categorically on a par with cross-staffs as potential parallactic instruments, and this includes telescopes.

The first improvement that the telescopic hypothesis could deliver is that of the trace in Figure 3. However, such data alone might not decide whether Mars circles the Sun because toward conjunction, among other difficulties, Mars would be lost in the Sun's glare. However, the "Geometrical Mensurations" that Digges mentions in *Perfit* (Digges, 1576: sig. O3<sup>r</sup>; Johnson and Larkey, 1934: 94) and which we have

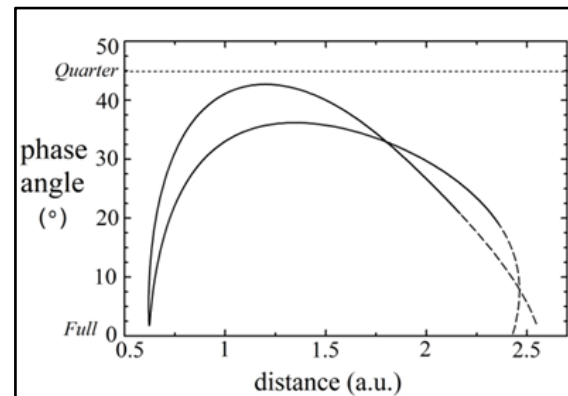


Figure 5: Phase angle of Mars for the interval of Figure 3. Dashed portions of the curve correspond to dashed portions in Figure 3.

assumed refer to parallax determinations, could as well cover angular diameters of planets. As mentioned above, these would yield curves like that in Figure 3, which also would show that planets do not undergo retrograde motion relative to the Sun.<sup>2</sup>

In the process of measuring angular sizes of planetary disks, phase angles could be measured as well. Phase angle is defined as the angle between the directions of the Sun and the observer seen from the center of the planet. Loosely speaking, phase angle is a measure of the unilluminated disk with zero corresponding to Full phase. Figure 5 shows the phase of Mars as a function of distance  $d$  through the circuit of Figure 3, with dashed curves retaining the same meaning as before. A telescope with resolution on the order of arcseconds would detect decreasing illuminated fraction of the disk of Mars on either side of Opposition, reaching an optimum, i.e., a minimum illuminated

fraction, followed by an increase in the illuminated fraction. Figure 5 indicates that the path of Mars curves toward the Sun's direction and so must go around it. The unilluminated disk fraction tends to zero which supports Copernican theory and Digges would conclude that Mars' trace in Figure 3 would enclose the Sun.

Thus, if Digges' "new instrument" were a telescope with arcsecond resolution, he could have disproved Ptolemaic geocentrism triply, via phase (Figure 5) and via parallax (Figure 3) with its analogue for angular size. There is no circular reasoning because these conclusions are not assumed to begin with, and the subjunctive mood ensures that there is no reverse logic.

## 6 COMMENTS ON TELESCOPY

Literature concerning the possible impact of telescopic observation on contemporary literature is too large to be revisited here,<sup>3</sup> but since Figures 3 and 5 depend on the hypothesis of the existence of a suitable parallactic instrument prior to 1576, it behooves us to note that telescopes may have existed in England by then. Although the existence of any telescope prior to 1608 or 1609 has been largely refuted (e.g., Dupré, 2010; Turner, 1993; Van Helden, 1977), absence of evidence is not evidence of absence. This is apt in the case of the Diggeses since by testimony of his son in the Preface to *Stratoticos* of 1579, L. Digges emulates Pythagoras (c.570–c.495 BCE) in discussing matters *per manus tradere*—with only a few close friends. Astronomy and mathematics were for Digges ennobling pursuits, and given the tenor of the times, prudence may have motivated his decision to publish *Perfit* in the vernacular, and in a vulgar non-academic almanac. It is tempting to believe that, like Pythagoras, L. Digges was reluctant to publish. This was so even after 1558 when Elizabeth I had ascended the throne and William Cecil, Baron Burghley was a chief protégé of the Queen.

In Paper I (Usher and Massaro, 2023: 664), we drew attention to documented evidence for the existence of sixteenth-century telescopic observation. The minutes of a 1652 meeting of the Royal Society (Birch, 1757(4): 156–157; Jack, 2004) record commentary by Robert Hooke (1635–1703) that L. Digges "... had a method of discovering all objects pretty far distant ... by the help of a book ... of Roger Bacon ...", and that the prominent jurist Roger Manwood (1524/5–1592) believed that he and not L. Digges had invented of the telescope. To this a member of the Society added that in *Pantometria*, Digges

describes the essence of his father's telescopic design, which the extended title calls a Perspective Glass. Digges writes:

But marvelous are the conclusions that may be performed by glasses concave and convex of circular and parabolical forms, using for multiplication of beams sometime the aide of glasses transparent, which by fraction [refraction] should unite or dissipate the images or figures presented by the reflection of other. (Digges, 1571: sig. G.i<sup>v</sup>–G.ij<sup>r</sup>; 1591, 28).

In 1578, William Bourne (c.1535–1582) wrote *Inventions or Devices* which he dedicated to Lord Burghley and which "... gives the best account of the Digges telescope that we know." (Moore, 1997: 9). Colin Ronan (Ronan, 1993: 177) and others have replicated the design apparently with mixed results, but more recently Michael Gainer (2009: 20) has replicated it as well using material and techniques deemed to be available in the sixteenth century (Figure 6). The quality of Gainer's replica may be judged from the resolution of the Moon shown in Figure 7 (Gainer, 2009: 21), which suggests that such a device or a similar one might have served as an early modern parallactic instrument.<sup>4</sup> Digges writes in definitive terms but we merely admit a possible interpretation, which of course does not constitute proof of Diggesian telescopic observation nor does it engage in reverse logic or circular argument.

## 7 CONCLUDING REMARKS

Of the items (1)–(3) of Section 1 above concerning Digges' authorship of *Alae* and *Perfit*, the final item (3) raises the issue of context in the neglect of the major results of items (1) and (2). Digges states in *Alae* that in the period of his life to which he refers, i.e., up to the time of writing 1573, he "... was forcibly removed, and almost torn, from these observations of celestial bodies by some recent human affairs ..." (*Alae*: sig. K4<sup>r</sup>). The proscription was lifted, but why and by whom we do not know. Other issues are how Digges' distress in 1573 affects the approval that he sought for *Alae*, and whether this has any bearing on the complaints that he reports in *Stratoticos* of 1579 concerning 'law brabbles' that beset him, and his vow nevermore to practice astronomy.

## 8 NOTES

1. Unless stated to the contrary, translations in this paper are by Massaro, Pizzo and Usher (2024) and are lightly edited.
2. Since the diameter of Mars is about equal to



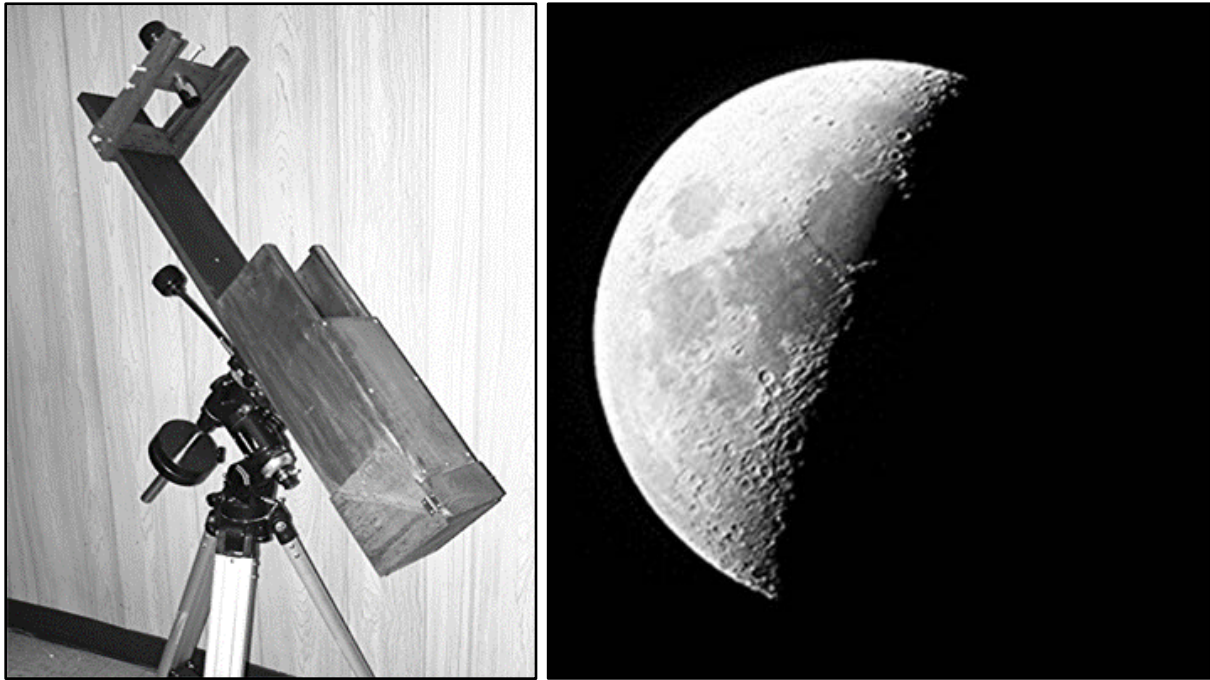


Figure 6 (left): Michael Gainer's replica of a Diggesian telescope (after [Gainer, 2009: 20](#)).  
 Figure 7 (right): The Moon seen through Michael Gainer's replica Diggesian telescope (after [Gainer, 2009: 21](#)).

- the radius of the Earth, its angular size is coincidentally roughly equal to its parallax  $p$ .
- See e.g. [Usher \(2022: 131–146\)](#) and references therein.
  - Gainer, now deceased, was a PhD physicist with a stellar career in research, teaching,

and designing and fabricating scientific instruments. He also replicated Galileo's telescope ([Gainer, 1981](#)).

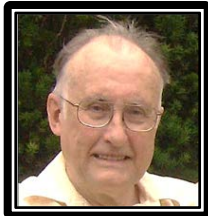
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