ADVANCES IN THE HAMLET COSMIC ALLEGORY

Peter Usher

"Here's fine revolution and we had the trick to see't."

Hamlet: Act V Scene 1

THROUGHOUT most of written history the Earth was believed to lie at the center of creation, while the seven ancient planets (Sun, Moon, Mercury, Venus, Mars, Jupiter, and Saturn) revolved about it. The entire arrangement was encased in a shell of stars beyond which was the abode of the Prime Mover. This geocentric model reached an advanced state of refinement in the *Almagest* of Claudius Ptolemy of 140 AD (depicted in Figure 1, page 6). In 1543, the book *De revolutionibus* by the Polish mathematician Nicholas Copernicus (1473-1543) completely revised the cosmic world view, for it removed the Earth from the center of the planetary system and placed the Sun there instead. Figure 2 (page 7) shows the Copernican heliocentric model with the six planets that were known at the time orbiting the Sun, while the Moon orbits the Earth. Like the geocentric model, the heliocentric model was encased in a sphere of stars.

In 1576 the English mathematician, Thomas Digges (c.1546-1595) shattered the last and outermost sphere of the stars in a work entitled *A perfit description of the caelestiall orbes*. This was included in his book *Prognostication Everlasting*, written in partnership with his father, Leonard Digges. This book was first issued in 1553 and reprinted many times until 1605. Their model embraced Copernicanism, advancing beyond it to a new and even more revolutionary model of an infinite universe of stars like the Sun. Figure 3 (page 8) shows the model of a Copernican Solar System imbedded in a matrix of stars which are more-or-less uniformly distributed. The distribution of stars extends to the limit of the borders of the diagram and seems intended to fill all of space. The legend in the sphere below the stars reads:

This orbe of starres fixed infinitely up extendeth hit selfe in altitude spherically e, and therefore immovable the pallace of foelicitye garnished with perpetuall shininge glorious lightes innumerable farr excellinge our sonne both in quantitye and qualitye the very court of coelestiall angelles devoyd of greefe and replenished with perfit endless joye the habitacle for the elect.

Digges was the first Renaissance writer to propose a physically infinite universe.[1]

In 1577 another model emerged (Figure 4, page 29). The hybrid system of the Danish astronomer Tycho Brahe (1546-1601) had five planets revolving about the Sun as in the Copernican model, but the Sun and the Moon revolved about the Earth as in the Ptolemaic model. The Earth remained fixed and a sphere of the stars turned daily as in Ptolemy's model. The stars were spread about in a thin shell which enclosed the planetary system.

As early as 1556 the heliocentric model had begun to take root in England.[2] Both it and the Diggesian corollary of 1576 were already in place in 1601 when the writing of *Hamlet* is generally supposed to have been completed (Edwards 31). We know that astronomy is one of the Bard's many specialties (Michell 18) yet no unambiguous evidence exists that Shakespeare saw the universe in anything but geocentric terms (Hotson 123). Certain contemporary poets recognized the New Philosophy even if they did not fully appreciate its significance. In 1596 in *Have with You to Saffron Walden*, Thomas Nashe ridicules Gabriel Harvey for "hatching such another Paradoxe as that of Nicholaus Copernicus was, who held that the Sun remains immoveable in the center of the World & that the Earth is moov'd about the Sunne." By the early 1600s John Donne shows that he is aware of heliocentric doctrine, as he writes in "Verse-Letter to the Countesse of Bedford": "As new philosophy arrests the Sunne / And bids the passive earth about it runne . . ." Donne also shows that he, at any rate, grasps the significance of the new model, stating in 1611 in *The First Anniversary, An Anatomy of the World*, that the "new philosophy calls all in doubt."

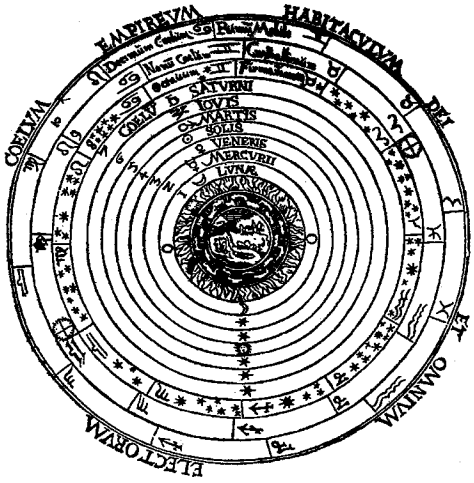

Figure 1: The Geocentric Model as depicted in Peter Apian's Cosmographie *of 1551.*

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That a poet of Shakespeare's stature could fail to notice the potential overthrow of the geocentric world view that had been the accepted model since ancient times must rank as a major mystery in the history of the Renaissance.

However, if we examine the text of the play *Hamlet* and its source in the Amleth legend of Saxo Grammaticus (fl. 1188-1201) in *Historia Danica*, we see that parallels exist between the events of the play and the development and competition between the four chief world models extant at the turn of the seventeenth century (Usher "*Transformation*" 48 et seq). On these grounds, I suggest that *Hamlet* contains a cosmic allegory. If I am correct in making these associations, Shakespeare was well aware of the astronomical revolutions of his time, and by dramatizing the triumph of heliocentricism and the infinite universe as a subtext of his great play, he celebrated what is in essence the basis for the modern world view.

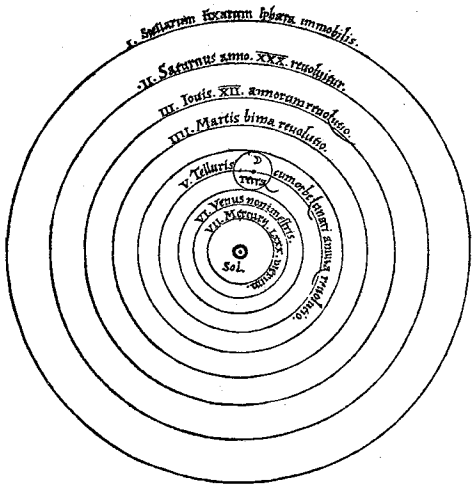


Figure 2: The Heliocentric Model of Nicholas Copernicus from De revolutionibus *of 1543.*

Appearance vs. Reality

The problem of Appearance and Reality is ubiquitous, but in astronomy it is preeminent because this is almost purely an observational science. Astronomy attempts to transform the appearance of the two-dimensional plane of the sky into the reality of three-dimensional space and must accomplish this almost entirely by observation, without benefit of direct physical experimentation. This situation reflects what today is regarded as the difference between empirically detected phenomena and their true physical nature (Pannekoek 102).

Then as now, observers have the misfortune always to be at the center of their own perception. In interpreting the phenomena of the sky from the vantage point of Earth it is common knowledge that the stars and the ancient planets appear to move westward, rising in the East and setting in the West. Early observers interpreted these phenomena naively by believing themselves to be at the cosmic center, with planets and sky revolving about them. However, from an observers' point of view, stars and planets do not progress westward from day to day at quite the same rate, for the planets change position relative to the stars. The planets appear to move eastward relative to the stars most of the time. However, at regular intervals, the ancient planets (except for the Sun and Moon) appear to reverse direction, moving westward briefly, then again reversing direction to resume their eastward drift. This

apparent reversal of direction is known as retrograde motion.

Circular geocentric orbits with planets moving steadily in the same direction cannot account for the observed motions of the planets and are evidently incompatible with the appearance of retrograde motion (depicted in Figure 5, page 30). An arcane geometric complexity based on the primacy of the circle had to be introduced in order to "save the phenomenon"[3] namely, to save the classic view of the heavens with the Earth at the center. Despite their ingenuity, these *ad hoc* devices failed to provide an enduring solution to the need for accurate planetary positions for the ephemerides, tables of star positions upon which sailors relied for purposes of navigation, among other uses. Copernicus realized that at least part of the difficulty involved the issue of appearance and reality: "... why not admit that the appearance of daily revolution belongs to the heavens but the reality belongs to the Earth?" he wrote (I:8). Accordingly he took into account the special location of the observer and put forward arguments that suggested that it was the Sun and not the Earth that was the real center of the planetary system.

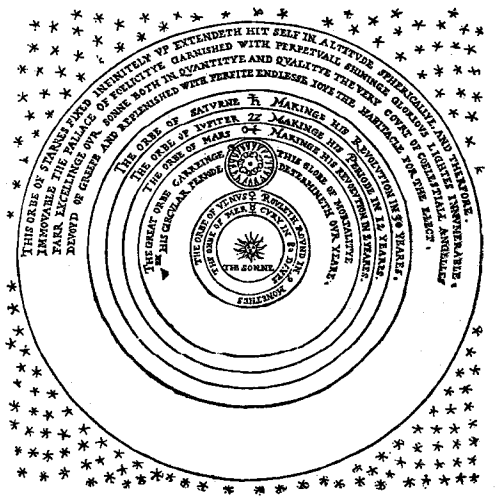


Figure 3: The Infinite Universe of Thomas Digges as depicted in A perfit description of the caelestiall orbes *of 1576*.

A virtue of the Copernican model over the Ptolemaic[4] was its ability to account for the gross properties of appearances with an economy of assumptions.[5] In particular, heliocentricism and the new planetary order was able to explain retrograde motion as an appearance arising from the various movements of Earth and planets as they orbit the Sun.[6]

In 1541, the mathematician Georg Joachim, better known as Rheticus, visited Copernicus in Frauenberg, Poland, in order to learn of his new heliocentric model. Rheticus returned to the University at Wittenberg, Germany, bringing the mathematical content of the new model with him. Thus Wittenberg became the first center of heliocentricism, the first place where a student might hear about the cosmic revolution which explained the appearance of retrograde motion.

Copernicus imbedded his new system in a shell of stars which he said must be very far away because they did not appear to change direction as the Earth orbited the Sun (see end notes 17 and 18 and Figure 6, page 43). This appearance of starry encapsulation was subsequently revised by Thomas Digges whose *A Perfit Description* of 1576 posited a reality in which infinite space was filled with stars like the Sun.

A craving for English epigrams

In 1590, the Danish astronomer, Tycho Brahe, wrote to one of England's most learned men, Thomas Savile (d. 1593). He enclosed two copies of his 1588 book along with four copies of a portrait of himself that had been engraved in copper in Amsterdam in 1586 (Halliwell 32-3). The portrait depicts Tycho framed by a stone portal comprised of an arch supported by columns on either side. Affixed to the structure are heraldic shields bearing the names of Tycho's ancestors, including Sophie Gyldenstierne and Erik Rosenkrantz (Thoren ii). In the letter, Tycho asked Savile to be remembered to the mathematician John Dee and to Dee's pupil, Thomas Digges. He also suggested that some excellent English poets might compose witty epigrams in praise of him and his work.

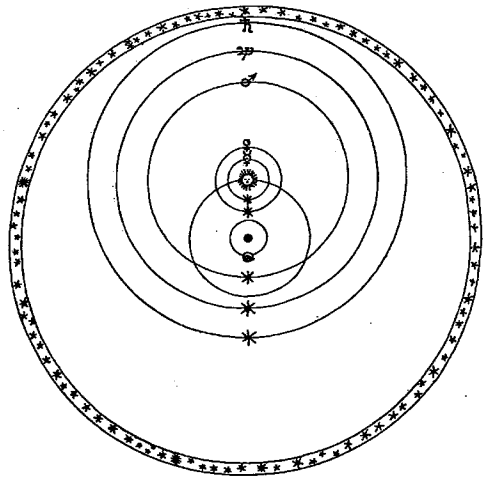


Figure 4: The Hybrid Cosmological Model of Tycho Brahe from his De Mundi aetherei recentoribus phaenomenis Liber secundus *of 1588.*

The renowned Shakespeare researcher, Leslie Hotson, has devoted much of his life's work to his idea that Shakespeare obtained his knowledge of science from Thomas Digges. In 1938 Hotson posited that the author of *Hamlet* learned of Tycho through Digges, and that access to Tycho's portrait prompted Shakespeare to select the names of Rosencrantz and Guildenstern (124). Hotson also holds that Shakespeare[7] gathered his military information from Digges's treatise *Stratioticos* of 1579 (118-121), and that Digges's other works have played a significant role in several Shakespearean plays (117-122, Chapter IX).[8] We see below that his other major works, *Pantometria* of 1571, *Aleu seu scalae mathematicae* of 1573, and *A Perfit Description* of 1576, also play roles in the *Hamlet* allegory.

Appearance vs. reality in Hamlet

The issue of appearances vs. reality lies at the heart of *Hamlet*, the plot as well as much of the confusing minor business. We posit that, among many other things, the play can be seen as a discussion of that most unsettling issue, the *appearance* of the heavens vs. the *reality* offered by Copernicus and Digges. Let us examine this thesis more closely.

We suggest that the development of the plot and the course of events in *Hamlet* are

closely related to two appearances on which pre-modern cosmology was based: that of *retrograde motion* (I:2: 114), which was explained by the so-called *Copernican Revolution*, and that of *a sphere of stars* (II:1:243-4), which would be replaced by the *Diggesian infinity*. Thus Hamlet's statement in the first scene of the last act: "Here's fine revolution and we had the trick to see't," refers to the two major transformations that occurred in the sixteenth century and that established the basis for the modern world view(Usher *BAAS, Mercury, RPS, ER*).

The tension between Appearance and Reality manifests itself right away in the first scene of the first act with talk of an "apparition" that has emerged without warning from the direction of a bright star "that's westward from the pole" (I:1:36), which Olson et al identify as the new star that appeared suddenly in 1572 in the constellation Cassiopeia. This phenomenon was researched both by Thomas Digges in *Alae seu* of 1573 and Tycho Brahe in *De Stella Nova* of the same year. They showed that the Nova lay beyond the sphere of the Moon and the most likely belonged to ance amounted to a flagrant violation of Aristotelian doctrine of the immutability of the heavens (Berry 149). The issue of appearances re-emerges in the next scene in the context of planetary motion when Hamlet tells his mother: "Seems, madam? Nay, it is. I know not 'seems.'" It turns out that Hamlet is in Elsinore but would rather be in Wittenberg.

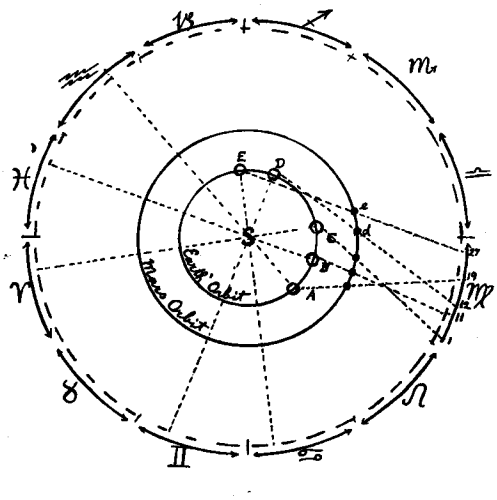


Figure 5: The apparent nature of retrograde motion: Earth approaches opposition with Mars at A; is in opposition at B; passes Mars at C, which then appears to slow down; at E, as Earth moves past the 90° angle, Mars appears to return to forward motion.

Claudius states his opposition to Hamlet's intent in going back to return there: ". . . your school in Wittenberg / It is most *retrograde* to our desire." In 1954, Cecilia Payne-Gaposchkin suggested that Shakespeare was aware of the Copernican theory (162), a suggestion all the more reasonable given that Wittenberg is mentioned in the context of the premier astronomical problem of the time. Retrograde motion is most readily observed at the time of *opposition* when a planet lies in a direction opposite to the Sun (Figure 5, above). The astronomical meaning of retrograde is further established when the word *opposition* precedes it by a mere fourteen lines. By opposing Hamlet's return to Wittenberg, Claudius opposes *heliocentricism* and identifies himself with the model of his namesake, *Claudius* Ptolemy. With the possible exception of the *Ur-Hamlet*, only in Shakespeare's version of *Hamlet* does the false king bear Ptolemy's first name (Usher, "*New Reading*" 1305).

Hamlet stays at Elsinore to please his mother, but his behavior prompts Claudius to seek the help of Rosencrantz and Guildenstern, an appeal from one geocentricist seeking the help of others of like mind. Soon after they arrive at Elsinore they enter into argument with their fellow student. Denmark is "too narrow for your mind" says Rosencrantz, to which Hamlet replies: "O God, I could be bounded in a nutshell and count myself a king of infinite space, were it not that I have bad dreams."

Infinite space is a direct reference to Digges's vision of a firmament filled with stars like the Sun. "Bad dreams" refers both to the oppressiveness of political and religious correctness and the fear of real persecution (Gatti 145) for within a few lines Hamlet says: "By my fay, I cannot reason" (II:2:251-2) meaning that free inquiry about the universe is proscribed at Elsinore. This explanation is textually supported, for in III:1:179-80 Polonius advocates prison for Hamlet if he does not divulge his mad schemes to his mother. Later Rosencrantz warns Hamlet directly: "You do surely bar the door upon your own liberty if you deny your griefs to your friend" (III:2:305-7). These exchanges suggest that Shakespeare may be using this hidden method to convey his own opinions on this momentous question for reasons of self-protection. Copernicus himself states plainly that he delayed publishing his work for nearly thirty-six years on account of his fear of reprisals.

After the players arrive in the second act, Hamlet refers to his "uncle-father" and "aunt-mother" (II:2:345-6). When about two years old, Tycho was kidnapped by his uncle and aunt who raised him as their own son (Thoren 4-5). Thus this couple doubled as uncle-father and aunt-mother respectively. In his student days Tycho suffered the loss of his nose in a sword-fight with a distant cousin. There are pointed references to noses in Hamlet. Such was the level of family violence at the time that in 1576 Denmark passed a law prohibiting a man from inheriting the estate of his dead brother.

In keeping with the Saxo tale, Hamlet disposes of Rosencrantz and Guildenstern before he slays the King. Tycho's model was never a serious contender, whereas the Ptolemaic model had been sufficiently refined over the centuries to endure to the bitter end. Thus Digges's *Perfit Description* first kills off the Tychonic model, represented by the courtiers, while Claudius and Hamlet, like Ptolemy and Digges, are "mighty opposites" (V:2:62) and so endure to the final act.

As Tycho was constructing his observatory Uraniborg on the island of Ven in the years 1579-1581, the King of Denmark was building Helsingor Castle a short distance away at the northern end of the Oresund Sound (Thoren 6). There is general agreement that Elsinore is named for Helsingor Castle. In addition, Hamlet's remark: "I am but mad north-north-west. When the wind is southerly, I know a hawk from a handsaw" (II:2:347-8), contains two directions: that from Ven to Helsingor is almost exactly north-north-west, whereas that from Ven to Wittenberg is almost exactly due south. When the wind is southerly, i.e. from the gen-

eral direction of Wittenberg, someone on Ven could correctly interpret what he sees ("knows a hawk from a handsaw"), but would be "mad" when the direction is north-north-west, i.e. from the direction of Elsinore. These words locate Tycho's Ven unambiguously and identify Hamlet's alleged "madness" with the oppressive regime at Elsinore.[9] The two prevailing winds may be seen also as a metaphor for the two influences on Tychonic cosmology, but only the southerly one makes sense to Hamlet.

In the third act, Guildenstern points out that geocentricism is associated with the royal establishment, and that with kingly centricity comes a duty to maintain those that depend upon it (III:3:8-10). Rosencrantz warns that "the cess of majesty / Dies not alone" (15-16) because the King is "a massy wheel" to which all "lesser things / Are mortised and joined" (17-20). The "ten thousand lesser things" are the approximately 10,000 stars visible to the limit of the naked eye (Jones 302). In the Ptolemaic model, these stars are part of the outermost sphere that is centered on the Earth, so if the King were to fall, so would these 10,000 lesser lights. Along with the planets, down would come the epicyclic machinery: "Each small annexment, petty consequence / Attends the boisterous ruin." (III:2:20-22). But such multiple dependencies have consequences, for: "Never alone / Did the king sigh, but with a general groan." (III:3:22-23). In the geocentric universe all stars and ancient planets revolve about the Earth just as all subjects are beholden to the false King who is struggling to maintain his sway in the face of the new cosmology.

Claudius makes it clear from the very moment that Rosencrantz and Guildenstern arrive that Hamlet's affectation—his "transformation"—is the reason for the summons: "Something have you heard / Of Hamlet's transformation, so call it, / Sith nor th'exterior nor the inward man / Resembles that it was" (II:2:4-7). The word *transformation* was used in the fifteenth century to mean "the changing in form, shape, or appearance" (OED). The first scientific use was in the sixteenth century by none other than Thomas Digges in *Pantometria*, which he co-authored with his father. In other words, cosmology must be transformed in its inner part by the Copernican Revolution, and in its outer part by the Diggesian. Claudius is concerned by Hamlet's transformation, because it would remove the cosmic justification for his position.

In *Aleu seu*, Thomas Digges stresses the need for empiricism in astronomy (Hotson 114) and Hamlet shows evidence that Shakespeare was cognizant of scientific methodology (Usher, "Astronomy" *BAAS* 856). Shakespeare may well have chosen the Amleth legend because it contained evidence of a primitive empiricism by which underlying realities were revealed. For Hamlet, as for Amleth, "madness" is both a means of survival and a tool for the acquisition of knowledge. In fact, Hamlet assures his mother that he is "not in madness, / But mad in craft" (III:4:188-9), i.e. crafty in eliciting truth by what may be called simply the "scientific method." He may also be referring to the apparent madness of scientists, whose methods often seemed bizarre, dangerous even, to those who did not understand the mechanics of

"the craft." By contrast, the pedant Polonius expresses a naive pre-scientific certainty: "Hath there been such a time . . . / That I have positively said, 'tis so, / When it proved otherwise"? (II:2:151-3) For Hamlet, on the other hand, doubt is a necessary ingredient of empirical inquiry, one which determines him to discover the truth by means of an experiment: "The play's the thing / Wherein I'll catch the conscience of the King"! (II:2:557-8) Hamlet's laboratory is the stage whereupon he performs experiments in social conscience and justice.

Hamlet's remark: "Here's fine revolution and we had the trick to see't," contains the word *revolution*, the astronomical meaning of which (the orbital motion of ancient planets) was in use by 1390. By 1450, however, the word had come to refer also to "great change or alteration in affairs or in some particular thing" (OED). Therefore, when Copernicus made the word "revolution" essentially the entire title of *De revolutionibus*, the possibility of a double meaning was already in place in the English language. Shakespeare never could resist a good pun. In addition, a *trick* may mean a "clever . . . device or contrivance . . . or invention" (OED). This trick or device is none other than the forerunner of the telescope, the so-called *perspective glass* which was invented by Thomas's father, Leonard Digges (Ronan, vols 16 & 17). This early telescope is described in Book I of Digges's *Pantometria* of 1571 (Johnson 175-8). Thomas Digges's conviction of "an infinity of stars" suggests that, despite the absence of surviving evidence, some kind of optical penetration of space had been made possible by this new instrument, which in turn creates the likelihood that the "new philosophy" was based in part on observation. Hamlet may be saying, "Here's a revolution in thought based on the book *About Revolution*, to which we might subscribe if we had one of these new telescopes with which to see the phenomena for ourselves."

By training the new optical aid upon the heavens, Thomas Digges would have seen stars invisible to the naked eye. He would have seen an increasing incidence of stars with increasing faintness, suggesting the uniform space density of stars as depicted in his model (Firgure 3, page 28). This method, known as "star gauging," involves an estimate of the number of stars visible to the naked eye across the sky, the same number—"ten thousand"—stated in III:3:19.

The Death of Geocentricism

To Shakespeare, the Tychonic system was a bit player unworthy of a literary climax and the demise of Rosencrantz and Guildenstern are merely of passing interest: "They are not near my conscience . . ." says Hamlet (V:2:58). The real demise of geocentricism occurs during the homicidal frenzy of the fifth act. This is followed immediately by the allegorical climax where Shakespeare departs from Saxo Grammaticus and creates a unique ending. There is no significant Polish connection in *Historia Danica*, but Shakespeare needs one because the

English cosmological contribution is an outgrowth of the Polish contribution. Shakespeare achieves this goal by sending Fortinbras first to Poland, to pay homage to the grave of Copernicus, and then upon his return to salute the English ambassadors. Thus the two models favored by Shakespeare, the Polish and the English, are triumphant following the demise of geocentricism.

Stand ho! Who is there?

With these words we are introduced to Marcellus within the first minutes of the play and it is he who effectively begins the action, or has already begun it, for, having seen the "apparition," before the play begins, he has urged Horatio to see it for himself. Marcellus, though a minor character, is a harbinger of things to come. He is a harbinger in another respect as well if he is meant to represent the Marcellus who first presented an expanded vision of the heavens to the intelligent readers of Shakespeare's day. Pietro Angelo Manzoli (c.1500-1543), better known as Marcellus Palingenius Stellatus, the "Stellified Poet," wrote the poem *Zodiacus Vitae* (*The Zodiac of Life*) in twelve books, each one named for a Zodiacal constellation. *Zodiacus Vitae* was one of the first works to be placed on the Pope's Index of Forbidden Books when it was established in 1558, though the author escaped persecution, having died fifteen years earlier (Koyré 280n29). Soon thereafter, from 1560 to 1565, the poem was translated into English by Barnaby Googe, in installments, and became very popular in England, paving the way for further challenges to Aristotelian physics.

Palingenius had a considerable influence on Shakespeare's work (Baldwin 652; Hankins 11-7) and was also much admired by Thomas Digges who had the entire Book XI memorized and who quoted him at length in his *Perfit Description*. Though Palingenius subscribed to geocentric orthodoxy, he was clearly a free and original thinker (Tuve p. xxiv). In Book XI he lifts the reader from the mundane world to the celestial, suggesting that the heavens contain a plurality of worlds and stars:

> All stars are not of bigness like for many less there be,
> And in such sort, as comprehend no man may them we see.
> Some are again of larger size, in number few and fine,
> That in clear nights amid the skies with gorgeous light do shine . . .
> Some do in compass far exceed both seas, and earth, and all,
> And bigger are their shining globes, though they do seem so small
> Because so far from us they be. For everything beside,
> The farther it is from our eyes, the less in sight is spied,
> And do deceive the lookers on.

Palingenius states the common perception that the stars appear to vary in a property which he calls "bigness," or apparent size (technically: *apparent magnitude*), and goes on to note that some may be "too small" to be seen. He says that the stars are intrinsically large (i.e. luminous) and they only appear "small" (i.e. faint) because they are so far away. I read these lines to mean that Palingenius specifically allows for both luminosity and distance as factors in accounting for the appearances of the stars; that he is in effect stating the two dependences which occur in the Inverse Square Law of flux: $F = L/4\pi d^2$; so that the detected flux F may be small, not only because the intrinsic power or luminosity L is low but because distance d is large.

Though Palingenius subscribed to a geocentric universe, he believed it was created by an all-powerful God and so must be infinite. To achieve this he filled the space beyond the sphere of stars with light. In 1576 Digges took the next major step and accounted for the actual source of this light by dispensing with the closed firmament in favor of an infinity of shining stars like the Sun, essentially the same model we use today. Digges would have been able to verify Palingenius's hypothesis on the invisibility of some stars by training his father's perspective glass upon the heavens, thereby revealing some that had hitherto never before been seen. It is a matter of simple induction to believe that ever more powerful optical aids would reveal even fainter stars, and so on, *ad infinitum*. Thus given the empirical fact of "perpetuall shininge . . . lightes innumerable," the essential step to the concept of an infinite universe of stars is that an ever-diminishing perceived flux F may arise not just by decreasing power L but by increasing distance d.[10]

The poetry of Palingenius anticipated the concept of the infinite universe and thus had appeal for Thomas Digges. It would therefore also have had appeal for Shakespeare if he were intent upon writing an account of cosmology. Evidence indicates that this was indeed Shakespeare's intent, so it follows that the character Marcellus probably immortalizes the Stellified Poet who had predicted the existence of stars beyond the pale of human vision.[11]

But Marcellus is only the first of several characters that Shakespeare used to weave his allegory into the plot.

Reynaldo and Polonius

George R. Hibbard has suggested that Polonius was named for Robert Pullen (d. 1147) whose latinized name was *Polenius*, a medieval Schoolman and one of the founders of Oxford University; and that his servant Reynaldo is named for John Reynolds (1549-1607), a contemporary of Shakespeare and President of Corpus Christi College, Oxford. Reynolds was an inveterate enemy of the theater who in 1599 published a diatribe, *Th'overthrow of stage plays*, that opposed the staging of plays even by undergraduates. The juxtaposition of the names

Polonius and *Reynaldo* in II:1 could be a slight upon the Oxford schoolmen, a suggestion that is plausible given that when *Hamlet* was performed at Oxford the names of the two characters were changed in order to avoid trouble for the players (Clayton 77n2, 201).

Shakespeare's aversion to pedants is evident in *Love's Labor's Lost* where in the first scene he takes to task those who accept Aristotle as their ultimate authority (I:1:82-7):

> Study is like the heaven's glorious sun
> That will not be deep searched with saucy looks.
> Small have continual plodders ever won
> Save base authority from others' books.

In the last act he has the pedant Holofernes utter Latin's longest word (V:1:41). Coincidentally, Thomas Digges attacks the infallibility of Aristotle in his *Perfit description* by again quoting the Stellified Poet (Johnson and Larkey 80, 101):

> Whatsoever Aristotle saith, or any of them all,
> I pass not for: since from the truth they many times doe fall.
> For famous men do oftentimes make great and famous lies.
> And often men do misse the truth though they be neuer so wise.

Osric and Laertes

After Osric tells Hamlet that the King has laid a wager on his head (V:2:98), there ensues an exchange (100-30) that is often considered ridiculous, confusing and beside the point (Jenkins 559). The Folger *Hamlet* comments: "Often we can only guess at what they might be saying" (Mowat 264n118-95). In 1623, about thirty lines altogether (100-25, 127-30) were omitted from the First Folio, ostensibly to shorten the long build-up to the scene, because they were considered non-essential to the plot (Edwards V:2:100-25). I suggest instead that the omitted portions may be understood in the context of the cosmic allegory.

Though the list of attributes seems to describe the qualities of Hamlet's adversary Laertes, every one of about two dozen identifiable items may, without a stretch, be read as a characteristic or accomplishment of the English scientist and mathematician, Thomas Harriot, up to the time that most believe *Hamlet* was written (c. 1601).[12] Laertes, of course, could represent other individuals as well, as may all the characters in the play, but when reading—or listening—for the allegory, he stands for Harriot. The excerpts below are quoted *seriatim* from lines V:2:100-30, of which only one (126) was included in the Folio edition:

1 "OSRIC: . . . here is newly come to court Laertes . . ."
Osric is announcing Laertes' return from France, but the line may also refer to

Harriot's return from the Virginia colony in 1586. Harriot emerged as a leading intellectual after publication in 1588 of his *A briefe and true report on the Virginia colony* (Hariot 317-87). He was recognized in 1590 also as a foremost mathematician, being mentioned along with John Dee (1527-1608) and Dee's student Thomas Digges, while citations to his work began mainly in the early 1590s (Shirley 200-2). Thus in c.1601 Shakespeare could legitimately write that Laertes (i.e. Harriot) was "newly come to court."[13]

2 ". . . believe me an absolute gentleman . . ."

Notes inscribed on the occasion of Thomas Harriot's matriculation to St. Mary Hall, Oxford, list his age as seventeen and the social status of his father as "plebian." Thus he "belonged to the social order of the common man." However his social class changed on graduating BA in 1580 at age twenty. It was further changed when in 1595 he received a gift from the Earl of Northumberland, Henry Percy, of a life interest in the income of Percy's holdings in Durham, by which means Harriot became a lifetime member of the landed gentry. On these grounds Harriot was entitled to attach the title "Gentleman" to his name (Shirley 40).

3 ". . . full of most excellent differences . . ."

"He excels in a variety of different accomplishments . . ." (Edwards nV:2:102). "Differences" are characteristics or distinctions that are out of the ordinary (Jenkins 400 nV:2:108). By 1601 Harriot was known for accomplishments in many fields, including navigation, cartography, ethnography, and linguistics. His studies in military science led to his work in atomism. He also made observations of the weather (Hariot 44-5).

4 ". . . of very soft society and great showing . . ."

The phrase "soft society" means "easy sociability," and "great showing" means "excellent appearance" (Edwards n102). Harriot had a "warm personal attractiveness," and his affability and learning were admired by Henry Percy (DNB).

5. "Indeed to speak freely of him, he is the card or calendar of gentry . . ."

He is the map or guide of gentility (Edwards n103-4). A "calendar" is a registry or directory essential to keeping track of events and time. A "card" can mean a map, or a stiff piece of paper containing the points of the compass (OED). Thus Harriot is both a model gentleman and an expert in cartography and navigation. He kept the maps of Sir Walter Raleigh up to date, especially those of the New World, and drew a map for the Guiana expedition and of Raleigh's Irish holdings (Shirley 162, 227-8).

6 ". . . for you shall find in him the continent of what part a gentleman would see."

On April 9, 1585, a fleet of seven ships led by Sir Richard Grenville and his flagship *Tiger* set sail from Plymouth bound for Roanoke Island. Evidence suggests that Harriot, a gentleman by virtue of his Oxford education, accompanied Grenville aboard the *Tiger* and reached the Carolina outer banks in late June (Shirley 125-9). In the present interpretation, "continent" refers to North America.

7 "HAMLET: Sir, his definement suffers no perdition in you, though I know to divide him inventorially would dozy th'arithmetic of memory . . ."

Hamlet agrees with Osric, adding that to list all qualities would make one dizzy (Edwards n107). Such an inventory would have to be made from memory for want of a significant number of published works (see "soul of great article" below). The words "divide" and "arithmetic" could refer to Harriot's mathematical prowess. (It should be clear from this line that Hamlet is playing around, both with words and with Osric.)

8 ". . . and yet but yaw neither in respect of his quick sail."

To "yaw" is to swing off course (Edwards n108). The fleet led by Grenville on the *Tiger*, having left Plymouth on April 9, soon encountered a storm that sank the *Tiger's* pinnace and scattered the fleet. The *Tiger* sailed on alone, reaching the Canaries on 14 April 1585. It continued west, reaching Dominica in the Lesser Antilles on 7 May, and Puerto Rico on 10 May 1585 (Quinn 158-60, 178-80). This was "a rapid passage" (Quinn 159) or "a rapid crossing" (Shirley 126). The phrase "quick sail" refers to this rapid passage, but is also a pun on Grenville's "fleet," for at least two meanings of "fleet" were in use at the end of the sixteenth century (OED): "a sea force," as in "flete of schyppys" (c. 1440) and "swift," as in "fleeter than arrowes" in *Love's Labour's Lost* (1588).

9 "But in the verity of extolment, I take him to be a soul of great article . . ."

In truth, "there would be many articles to list in his inventory" (Edwards n109), if only he had published them. Harriot's short tract *A briefe and true report* of 1588 is his only published work. He had raised expectations that he would publish a full account of his research on Virginia, "but this 'large discourse' . . . never appeared" (Sokol 2). His enduring reputation as a mathematician rests on the posthumous publication of *Artis Analyticae Praxis ad Aequationes Algebraicus resolvendas* (London, 1631) in which he "virtually gave to algebra its modern form," but no papers were published in his lifetime (DNB). His text-book on navigation, *Arcticon*, was never published either (Shirley 94-5).

10 ". . . and his infusion of such dearth and rareness . . ."

That which is "poured into him" by nature is dear and rare (Edwards nn109-10).

OED uses this line to illustrate these meanings of "infusion" and "dearth," but another meaning for "infusion" is stated to be the action of infusing some principle or idea into the mind. This meaning was in use as early as c. 1450, and would fit well with the antecedent comment on the rareness of Harriot's publications, since fewer publications imply less impact on people's thinking.

11 ". . . as, to make true diction of him, . ."

Harriot was generations ahead of his time in creating a way to reduce speech to symbols. Unfortunately "he did not leave a treatise on phonetics nor a key to his symbols" (Shirley 109-11).

12 ". . . his semblable is his mirror, . ."

"The (only) person like him is his own image in the glass" (Jenkins 401 n118). Harriot brought several scientific instruments with him to Virginia, including "a perspective glasse whereby was shewed manie strange sightes" (Hariot 375). Harriot therefore possessed and demonstrated what is generally regarded as the forerunner of the telescope (Quinn 375) but it was not until after *Hamlet* was written that he studied celestial objects telescopically (see below).

13 ". . . and who else would trace him, . ."

The words "trace him" mean "follow him closely" (Edwards n111). Having sailed on alone after the storm had scattered the fleet, the *Tiger*, presumably with Harriot on board, arrived at the appointed rendezvous eight days ahead of the next fastest vessel (Shirley 126). Thus no ship of the fleet followed the flagship closely.[14]

14 ". . . his umbrage, . . ."

En mer Harriot observed a partial eclipse of the Sun and was thus partly in the "umbrage" or shadow (Edwards n111) of the Moon.

15 ". . . nothing more."

Harriot did not avail himself of the opportunity of the solar eclipse to determine his longitude[15] and thereby to help solve the difficult problem of determining longitude at sea.

16 "OSRIC: Your lordship speaks most infallibly of him."

Here, as in V:2:81 and elsewhere, Osric and Horatio address Hamlet as "lord," but Horatio and Osric are addressed as "Sir" (see discussion of 117-8 below).

17 "HORATIO "HAMLET: The concernancy, sir? Why do we wrap the gentleman

in our more rawer breath?"

"How does this concern us? Why do we clothe him in words of ours which can only fall short of his refinement?" (Jenkins 401 nn122-3).

18 "HORATIO: Is't not possible to understand in another tongue?"

The 1584 Amadas-Barlow expedition to Virginia brought back to England two American Indians. Harriot learned Algonquian from them and developed a special alphabet by which to record their language. The line may also refer to the fact that with the help of Richard Hakluyt, his *A briefe and true report* was published in three languages besides English (Shirley 105-9, 144-5).

19 "You will to't sir, really."

The words mean "You [are] Walter Sir, Raleigh." The remark is not addressed to Hamlet since Horatio always addresses Hamlet as "lord" (Jenkins 559). It must therefore be addressed to Osric. "You" then suggests that Horatio is identifying Osric as Raleigh. This possibility is credible given that Raleigh championed Harriot just as Osric is here championing Laertes. Support for this identification is found in the ensuing lines.

20 "HAMLET: What imports the nomination of this gentleman?"

i.e. "What is the purpose of naming this gentleman?" (viz. Raleigh). The question answers itself thanks to a pun on "imports." According to the OED, "import" meaning a commodity brought in from abroad, was in use only by 1690 but the associated verb was in use much earlier, in 1508 and 1548. Thus it is important to name Raleigh because of contemporary interest in importing natural resources. Raleigh had hoped to lead the 1585 expedition to England's first overseas colony and to become its first governor, but the Queen desired him by her side (Shirley 117, 126). Harriot wrote of the natural resources in Virginia and returned a collection of specimens from the West Indies to Raleigh to serve as examples of the wealth possible through colonization. Imports as a source of wealth are described in the contents of Harriot's *A brief and true report* where he makes "declaration of such commodities there alreadie found or to be raised, which . . . by way of trafficke and exchaunge with our owne nation of England, will enrich your selves the providers: those that shal deal with you; the enterprisers in general . . ." (Hariot 324; Shirley 146).

"OSRIC: Of Laertes?"

Understandably Osric continues to be confused, here thinking that Laertes is still the topic of conversation. Nevertheless his question shifts attention back to Laertes— i.e. (in the present reading) back to Harriot—and Horatio responds accordingly.

21 "HORATIO: His purse is empty already, all's golden words are spent."

"His purse" refers to Henry Percy and to his purse from which gifts of money were made to Harriot. In the early 1590s when Raleigh was in disfavor with the court, Harriot sought other patronage, and it was natural for him to turn to Raleigh's friend, Henry Percy. Percy's largesse commenced in 1593 with a sizable annual gift of £80 (Shirley 202, 210-1). Thus two persons who significantly influenced Harriot's life, the two close friends and noblemen Raleigh and Percy, are named in the text (117-8, 121) in the order in which they patronized Harriot (Shirley Chapters 3, 5). Though "His purse" refers to Henry Percy and his wealth, the second half of the sentence suggests that "His purse" might store "golden words" rather than gold coins, so that in this case "His" refers to Harriot. By 1601 Harriot had a paucity of published works to show for his labors, suggesting a depletion of his verbal treasure chest at the expense of Percy's purse. The line contrasts the cessation of Harriot's verbal output after 1588, with his receipt of a lavish pension from Henry from the early 1590s.

22 "HAMLET: Of him sir."

Osric asked in V:2:120: "Of Laertes?" and Horatio has replied, identifying Harriot with the words "Of him." These two words occur three times above, all seemingly to do with Laertes, i.e with H(im)arriot.

23 "OSRIC: I know you are not ignorant . . ."

Referring to his fellow Englishmen in the prologue to *A briefe and true report*, Harriot uses the word "ignorant" three times in the space of six paragraphs (Hariot 321-3). The presumption is that the Oxford graduate is himself not ignorant, which suggests the meaning of the line: when Osric addresses his fellow Dane, Hamlet (i.e. when Raleigh addresses his fellow Englishman, Harriot) Osric hastens to explain (emphasis added): "I know *you* are not ignorant . . ." (i.e. Raleigh knows that Harriot is not ignorant like some of his compatriots.)

"HAMLET: I would you did sir, yet in faith if you did, it would not much approve me." It is not to Hamlet's credit to have such testimony from Osric (Edwards n124-5) any more than Thomas Digges (i.e. Hamlet, in terms of the allegory) would benefit from a recommendation by Walter Raleigh (i.e. Osric).

"OSRIC: You are not ignorant of what excellence Laertes is."

[This line was not omitted in the Folio.]

24 "HAMLET: I dare not confess that, lest I should compare with him in excellence, but to know a man well were to know himself."

"For Hamlet to admit Laertes' excellence would be to claim that excellence for himself, since to know such excellence one would need to be able to perform such excellence"—but beyond that, this sentence "is not meant to have much meaning" (Edwards n127-8). However, the comparison between Laertes and Hamlet is like that between Harriot and Thomas Digges; Hamlet here acknowledges his being compared to Harriot, which therefore helps him to understand himself.

"OSRIC: I mean sir for his weapon; but in the imputation laid on him by them, in his meed he's unfellowed."

Undeterred, Osric continues to press the cause of Laertes. But Hamlet has had enough; there is a return to the full text with Hamlet's pointed question: "What's his weapon?"

ASTRONOMY and cosmology are chief characteristics of the *Hamlet* allegory, yet the items attributed to Harriot include little astronomy and no cosmology and might seem therefore to be selected here with insufficient reason. Harriot would not have merited a major role in a cosmic allegory because by 1601 at an age of about forty-one he had still not studied the heavenly bodies for any purpose other than navigation.[16] Nevertheless Harriot had by 1601 garnered support as a leading English mathematician and intellectual, though Shakespeare gives little credence to the Harriot candidacy when he characterizes his supporters as "rabble" (IV:5:102). Yet Shakespeare must include Harriot because by 1601 he and Digges were the two Englishmen who had contributed most to science and perhaps more importantly had opened up new vistas of the physical world. Digges beheld the starry firmament and in 1576 described his view of the New Heavens, while Harriot saw the Virginia colony and in 1588 described his view of the New World. In each case scholarship resulted in perceptual change, Harriot revealing a continent and Digges revealing the cosmos. The parallels between the terrestrial and celestial map-makers is striking since both frontiers of knowledge—geographic and cosmographic—were at the forefront of English consciousness at the time, as witnessed by the items depicted on the upper and lower shelves in Hans Holbein's painting *The Ambassadors* of 1533.

Shakespeare may have rendered these lines opaque because in 1601, while all leading protagonists of the cosmic allegory (Ptolemy, Copernicus, Tycho, Digges) were deceased, Harriot, Raleigh, and Percy, were not.

Infinity and "a nutshell"

After nearly half a millennium since publication of Copernicus's seminal work, we tend to think of the so-called Copernican Revolution as a sudden paradigm shift that seemingly

transformed our world view overnight. In reality Copernicus was a transition figure between the Old and the New Astronomy, retaining elements of the Old at the very time that he was instigating the New. In trying to solve one set of problems, the Copernican model raised several more: there was the inertial problem of how something as ponderous and sluggish as the Earth could be in motion, not just rotating on its axis but rapidly moving around the Sun; and there was the dynamical problem of the forces necessary to bring this about.

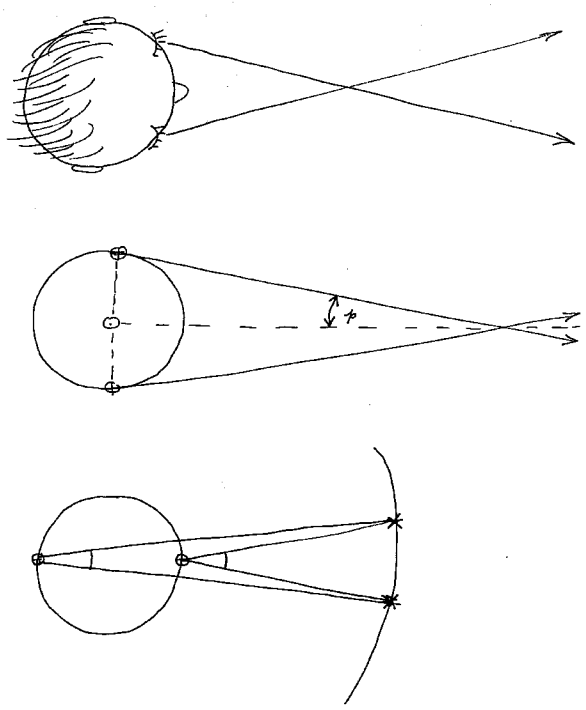


Figure 6: Parallax Angles in a Closed and Open Universe owing to the revolution of the Earth about the Sun. Drawing by Peter Usher.

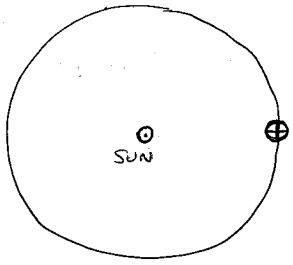
More relevant to the present article is the vexing question of *parallax*, for if the Earth revolved, why then were there no apparent shifts in the positions of stars on an annual timescale?[17] Figure 6 (right) shows how heliocentric parallax angles might be seen in a closed and an open universe. Since Copernicus's model was bounded by the sphere of stars, changes in their positions should occur, yet none was observed. For example, with dimensions in vogue at the time of Ptolemy, parallactic swings owing to the revolution of the Earth would have had an amplitude of about 6 degrees and thus should have been easily detected.[18] To avoid this difficulty, Copernicus was forced to argue that the stars are so far away compared to the Sun as to render stellar parallax undiscernible to the human eye. Thus for Copernicus the visible world contained within the vault of the stars was indeterminately large (an "immensum") so that by comparison the Earth was "as a point" (Koyré 32-4; Dreyer *History* 192).[19]

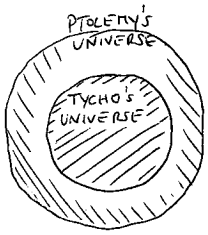
Tycho Brahe rejected the Ptolemaic model because he somehow believed that Mars was closer to the Earth than the Sun (Dreyer *Brahe* 179-80). He rejected the Copernican System as well, on several grounds. He theorized that the observed motion of comets around the Sun in a sense opposite to that of the planets argued against the Copernican solution.[20] Moreover, theological questions had been raised by Martin Luther (1483-1546) and Melanchthon (Philipp Schwarzerd, 1494-1560), both of whom declared that the Scriptures did not accord with the theory of a moving Earth (Dreyer *Brahe* 177-8).

Tycho subscribed also to a teleological belief common in the Middle Ages (Dreyer

History 257) that the heavens and the planets were created for a purpose. He argued that if the sphere of stars were to be indeterminately large as Copernicus required, then much empty space lay between the outermost reaches of the planetary system and the stars. Tycho believed that the immensum of Copernicus served no purpose and was wasted space (Pannekoek 204-6, 223). Consequently Tycho believed that the sphere of stars was closeby, and the lack of observed stellar parallax forced him to conclude that the Earth was stationary. These objections, and the inability of both the Ptolemaic and Copernican models to predict planetary positions accurately, convinced Tycho to devise a model of his own. True to his beliefs, he packed the planets into as small a space as permitted by his model. The result was a planetary system jammed into a sphere of radius about 14,000 Earth radii (E.r.) (Dreyer *Brahe* 191-2). The Ptolemaic universe was only slightly larger with a radius of about 20,000 E.r. (Koyré 34).[21] Since the size of the Earth was then fairly well-known, these distances can be accurately converted to terrestrial units of distance; Figure 7 (left) shows that both geocentric models would fit comfortably inside the present-day orbit of the Earth. By contrast the size of the Copernican sphere of stars was indeterminately—if not infinitely—large.[22]

Figure 7: The geocentric models of both Claudius Ptolemy and Tycho Brahe (lower) would fit inside the modern orbit of the Earth (upper). Drawing by Peter Usher.





In the present interpretation, when Hamlet speaks of "a nutshell" he probably has in mind Tycho's model, the smallest of the three bounded models, for, to the sixteenth century, a nut epitomized things of extremely small size. This metaphorical *cosmic nut* mimics the real thing, for in neither case is there much wasted space. At the same time (II:2:243-4) Hamlet is contrasting the tininess of the bounded geocentric models with an Infinite Universe,[23] compared to which even the size of the bounded heliocentric model shrinks into insignificance. So on the one hand it seems plausible that Hamlet has Tycho's model specifically in mind, but at the same time any of the bounded models would serve as well since any finite size is insignificant when compared to the Diggesian infinity.

End notes

1 Digges's model restored the earlier Epicurean-Lucretian cosmology, for his new cosmic reality replaced the appearance of starry encapsulation that was a feature of most earlier models. Nicolaus of Cusa (1401?-1464) had postulated the infinity of the Universe a century earlier. He denied the enclosure of the Earth and planets by the walls of the heavenly spheres, but did not assert the "positive infinity" of the Universe, reserving the term "infinite" for God alone (Kuhn 232-3, Koyré 6-8).

2 Early champions were Robert Recorde (1510-1558) and John Dee (1527-1608). Recorde's *Castle of Knowledge* (1556) hints at the superiority of the heliocentric model. Dee states in John Field's *Ephemeris anni 1557* that he persuaded Field to compile tables based on the Copernican system.

3 For a concise portrayal of the geometrical devices needed to account for the ephemerides of the ancient planets in general and their retrograde motion in particular, see Mitton 137-8.

4 Copernicus had recourse to epicycles but their role was secondary.

5 As per Occam's Principle: "It is futile to do with more elements what can be done with fewer."

6 The work of Johannes Kepler in the seventeenth century established the empirical fact that the periods of the heliocentric motions of the planets are greater, and their orbital speeds less, the farther from the Sun they are. Thus for example, a planet like Mars whose orbit lies outside the Earth's travels more slowly than the Earth and thus appears to move "backward" when the Earth overtakes it on the inside track (see Figure 5).

7 By "Shakespeare" I mean the author of the canon.

8 According to Honigmann (52n574), Hotson has proved a connection between Shakspere of Stratford and Thomas Digges, a view seconded by Rowse (197, 225-6), among others. This is based on the fact that William Shakspere lived near one of the Digges's homes when he was in London and that after the death of Thomas Digges in 1595, his widow Anne married Thomas Russell whom Shakspere later appointed as overseer of his will.

[Editor's note: In the Spring 2001 edition of the *Shakespeare Oxford Newsletter*, Oxfordian researcher Richard Whelan exposes the weaknesses in Hotson's attempts to establish the kind of vital connection between the Digges family and Shakspere of Stratford necessary to posit that Digges had the effect on Shakespeare's intellectual development claimed by Hotson. On the other hand, Whelan lists several possibilities that Digges could have this kind of influence on Edward de Vere (13), among them that the sons of Thomas Digges, Dudley and Leonard, author of a dedicatory poem in the First Folio, were members of Oxford's daughters set at James's Court (14). It should also be noted that Thomas Digges was a student at Queens' College, Cambridge at the same time (1546) that Oxford's tutor, Sir Thomas Smith, was a teaching Fellow there. Smith too was deeply versed in mathematics and astronomy. Among the books in his library during the period that Oxford was with him were both Ptolemy's *Tetrabiblos* and Copernicus's *de Revolutionibus*. S.H.H.]

9 In Usher *ER* I had interpreted this remark using the location of Wittenberge, Germany. On using the correct location (Wittenberg without an 'e' on the end) the interpretation becomes more precise since Wittenberg is almost due south of Ven. The corrected article is reprinted in "A Groat's Worth of Wit."

10 The Law of Flux describes the real dependence of physical quantities *L* and *F* with distance *d*, but since Palingenius is interpreting stellar appearances, perhaps the equivalent Distance Modulus equation $m-M = 5 \log d - 5$ relating apparent and absolute magnitudes *m* and *M* is more relevant.

11 [Editor's note: Barnabe Googe, who translated *Zodiacus Vitae* into English, was a member of the coterie of young intellectuals that clustered around William Cecil, Lord Burghley, and Matthew Parker, Archbishop of Canterbury, during the mid-1560s (Hughes). That Googe, whose father had worked for Cecil before his death, regarded Cecil as his kinsman and his patron, is made clear by his biographer, Judith Kennedy (4, 7-8), as is the fact that Cecil was involved in assisting Googe with his private affairs during 1563 and 1564, years that the thirteen- and fourteen-year-old de Vere was living at Cecil House under Cecil's care. It should be evident that de Vere must have been acquainted with Googe and also with his translation of Palingenius. Cosmology could have interested de Vere, due to his relationship with Sir Thomas Smith, whose near professional expertise in astronomy and astrology has been proven. S.H.H.]

12 Shakespeare's manuscript is thought to date to 1601; the second quarto (Q2) is dated 1604 (Edwards 9).

13 A discussion of the weather begins the conversation between Osric, Hamlet, and Horatio (V:2:92-6). This topic has begun many a conversation, and in this case Osric's and Hamlet's contrasting comments: "it is very hot"; "tis very cold"; "It is indifferent cold"; "it is very sultry and hot"; may refer to Harriot's *A briefe and true report on the Virginia colony* wherein Harriot compares the climates of Virginia and England: ". . . the excellent temperature of the ayre there at all seasons, much warmer than in England, and never so violently hot. . . ." (Harriot 383). If so, this would be the first of a series of references in Shakespeare's text to Harriot's monograph.

14 The present interpretation therefore supports the presumption that Harriot accompanied Grenville aboard the *Tiger* (cf. Shirley 125).

15 ". . . whether he attempted to use these observations to calculate longitude accurately is doubtful" (Shirley 125).

16 It was only after 1603 when James I had begun to alter the course of the lives of Harriot's benefactors Raleigh and Percy, that Harriot turned seriously to the application of his optical theories to the study of the heavens. In c. 1609 Harriot developed a refracting telescope at about the same time as Galileo (1564-1642) and like Galileo proceeded to make telescopic observations of the Sun, Moon, and planets. Harriot observed sunspots and deduced the Sun's period of rotation. In 1609 his drawing of the Moon was the first to be made with benefit of a telescope. He observed the *Comet of 1607* ("Halley's") and, three years before his death, the *Comet of 1618* (Shirley 380-97).

17 The phenomenon of parallax arises when for example a foreground object is seen from two different locations against a background of more distant objects. In rotating on its axis or orbiting the Sun according to the Copernican prescription, the Earth would carry observers first to one side and then the other on daily and annual timescales, and so produce apparent changes in the direction of nearby objects. The effect diminishes with increasing distance. See Figure 6.

18 In the Middle Ages the Earth's orbit was thought to have a semi-diameter of about 1,200 Earth radii (E.r) and the stars to be about 20,000 E.r. away, so an observed parallax should be about one-twentieth of a radian, or about 3 degrees, giving a total amplitude of twice that amount.

19 ". . . the Earth is to the heavens as a point [is] to a body . . . " (Copernicus I:6).

20 In the Copernican system all planets revolved in the same sense, but Tycho did not consider the possibility that comets were a class of object different than planets (Dreyer *Brahe* 180).

21 The equivalent value according to Arab astronomers of the 9th and 10th centuries lay between about 19,000 and 21,000 E.r. (cf. Dreyer *History* 257).

22 Though Tycho tried but failed to measure stellar distances, this consummate observer knew his measurement errors and so could place a lower limit on the desired value. Using his best data, he found on the Copernican hypothesis that the stars would have to be at least 700 times more distant than the value derived from his own model. This meant that the stars of the Copernican model defined a volume greater than the shell of stars of his own model by at least a factor of 700 cubed, or over 300 million times. To Tycho the possibility of such a vast amount of unused space was out of the question (Thoren 279).

23 In reality the ratio is indeterminate since a fraction with an infinite denominator cannot be computed. In the words of C.A. Whitney: "A little bit of infinity goes a long way."

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