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Moons, Maths, and Middle-earth: Misconceptions about Tolkien's Scientific and Mathematical Prowess

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In scholarly studies of fictional world-building, J.R.R. Tolkien's classic sub-creation, Middle-earth, is often held up as the example par excellence. Mark Wolf (43) argues that the key to successful world-building is consistency, defined to be "the degree to which world details are plausible, feasible, and without contradiction." In the creation of a Secondary World a wide variety of physical changes can be made from our primary reality, including invented species, genetics, and ecosystems; geological, meteorological, and astronomical liberties; new technologies; and changes to the fundamental laws of nature. Of course, the author is also free to keep connections to our earth as it exists, especially if, as is the case of Middle-earth, the setting is considered to be our world in a mythical age (*Letters* 220; 239; 244; 283).

I have admittedly made quite a cottage industry over the years of pointing out Tolkien's use of real-world astronomy in crafting Middle-earth. Examples include his appropriation of real-world constellations such as the Big Dipper and Orion, mythological explanations for the phases of the moon and eclipses, and the apparent motions of Venus (Eärendil). What Tolkien gets right includes seasonal changes in the circumpolar motion of the Valacirca aka Big Dipper (Larsen "Diadem"), sideways rising of Menelmacar aka Orion (Larsen "A Definitive"), and the strange setting of Morwinyon aka Arcturus (Larsen "Myth"). He was undoubtedly an observer of the night sky. However, all of these observations are clearly visible to the unaided and untrained eye, and have been previously noted by numerous other literary figures, from Aratus and Boethius to Robert Frost.

There is additionally Tolkien's use of meteorites, for example in the swords made by the Dark Elf Eöl and possibly the mysterious Black Stone of Erech upon which the King of the Dead swore alliance to Isildur and later Aragorn (Larsen "The Stone"). The December 21, 1927 edition of Tolkien's charming "Father Christmas Letters" explains that the North Pole was so uncharacteristically dark that year due to an absence of the Northern Lights that Father Christmas had "hired a comet to do my packing by" (*LFC* 21). The lack of aurora was due to the mischief of the North Polar Bear, who had the previous year set off two years' worth of aurora in one display, leading to no aurora until 1928 (*FC* 16). Christina Scull and Wayne Hammond note in their *Chronology* (148) that Tolkien's reference to unusually high auroral activity in 1926 derives from the Primary World's enhanced

solar activity that year creating spectacular auroral displays. Comet Skjellerup-Maristany was also prominent in 1927, having been discovered with the unaided eye and so bright that it could be seen in broad daylight on December 18 (Yeomans n.p.).

A lunar eclipse also appears in the same 1927 Father Christmas letter, as the moon goes "out" when the Man in the Moon falls asleep during a visit to Father Christmas (*FC* 22). The Christmas holidays of 1927 also marked the first complete manuscript of the adventures of the mischievous dog Roverandom. During his adventures on the moon, Roverandom and the moon-dog awaken the Great White Dragon responsible for occasionally turning "the whole moon red," and the Man-in-the-Moon saves the canines by throwing a "dark, black spell that looked like jellified tar and honey" at the dragon, causing him to neglect his duties and making the next eclipse "a failure" (*Rov* 35-6). Scull and Hammond (*Rov.* xiii) argue that both of these incidences are references to the December 8, 1927, lunar eclipse, which they note was reported by the *Times* of London to have been obscured by clouds.

But Tolkien invokes other sciences as well in crafting the natural history of Middle-earth. For example, numerous authors have studied the intersections between Tolkien and geology, including analyses of the geomorphology of his fictional landscape (e.g., Acks 2017; Pehrsson 2019; Reynolds 1974; Sarjeant 1996) and connections between Tolkien's experiences on a 1911 summer vacation in Switzerland and various geological features in Middle-earth (Lewis and Currie; Monsch). Larsen and Fimi (n.p.) aligned a close reading of the description of the Glittering Caves of Aglarond in *The Lord of the Rings* with the real-word geology of Cheddar Gorge, Somerset, known to be an important influence on this passage (*Letters* 407). Gerald Hynes (22) also pointed out that, although Tolkien's geology was largely catastrophic in nature, he did incorporate identifiable elements of what we would call the modern geological models of slow uniformitarianism over great lengths of time and continental drift. We also find clear references to paleontology (such as the pterodactylic steed of the Witch-King, the mammoth-like mûmakil, and similarities between the Púkel-men and the infamous Piltdown Man [Larsen "A Creature"]). Scull and Hammond (*Reader's Guide* 369) pointed out that Tolkien's cave paintings in his Father Christmas Letters were based on those in M.C. Burkitt's *Prehistory: A Study of Early Cultures in Europe and the Mediterranean Basin*.[1] As for botany, retired botany professor Walter Judd and his illustrator son Graham cataloged 141 plant species in Middle-earth (including many accurately described real-world varieties of flowers and trees). Elsewhere I have also pointed out his accurate descriptions of the life cycles of Emperor butterflies in *The Hobbit* (Larsen "Wilwarin"). Finally, in a 1954 draft letter Tolkien himself

[1] Thanks to Xu Zhan for bringing this updated reference to my attention.

famously noted of his own writings that "the chief difficulties I have involved myself in are scientific and biological – which worry me just as much as the theological and metaphysical…. Elves and Men are evidently in biological terms one race, or they could not breed and produce fertile offspring – even as a rare event" (*Letters* 189). While 'species' rather than 'race' is the scientifically correct terminology, the scientific intention is clear.

The level of scientific detail found in Middle-earth should not surprise us; after all, Tolkien explained in his classic essay "On Fairy-stories" that in his early years not only did he like fairy stories, but "many other things as well, or better: such as history, astronomy, botany, grammar, and etymology" (*OFS* 56). In drafts of the essay, Tolkien also mentioned geology (*OFS* 189) and natural history (*OFS* 235) by name. In contrast, Tolkien admitted that "If I preferred fairy-stories to arithmetic, it was merely because (alas!) I did not like arithmetic at all" (*OFS* 235) and, more damningly, "I was quite insensitive to poetry (I skipped it if it came in tales); and stupid at arithmetic" (*OFS* 287). While the time and effort Tolkien took in developing calendars and detailed chronologies as part of his world-building is evidence that he was not truly "stupid at arithmetic," at the same time we should take care not to overinflate his mathematical (or scientific) prowess. For example, in a 1965 interview with Denys Gueroult at a BBC studio in Oxford Tolkien openly admitted of moon phases and sunset times "I'm not a good enough mathematician or astronomer to work out where they might have been 7000, 8000 years ago," adding "Moons are much more tricky to deal with than the suns, of course" (Stump n.p.).

Tolkien was speaking from experience here, as it is well known that there are serious errors with the moon phases in *The Hobbit*, for example in the scene with Bilbo and the three trolls. Working backwards from the moon-letters scene in Rivendell, it was impossible for the phase of the moon to be waning (after full), as it was described in the first edition. This was later changed to "wandering," a term that makes little sense astronomically (Rateliff 829). More significantly the scene in Laketown in which Bard spied the gap in Smaug's jewel-encrusted armor by the light of a rising moon in the east late at night (similar to a moon after full) is also astronomically incorrect. Since the death of Smaug took place soon after Durin's Day (when the sun and moon appeared together in the sky), the moon must have been a waxing crescent, setting in the west within a few hours of sunset. Tolkien himself admitted of the moon in *The Hobbit* that it is "out of order – but this cannot be tolerated, since Durin's Day and the incidence of New Moon is integral to the plot" (Rateliff 825; emphasis original).

As explained in detail in *The History of The Hobbit*, Tolkien tried valiantly to correct all these problems in his post-*LOTR* updates to *The Hobbit*, but with very limited success, either because the changes would create a chain reaction of other difficulties in the text or because the changes would remove important dramatic

elements from the text. Not only was Tolkien unable to successfully disentangle his lunar chronology, I discovered that he had actually been working with wrong numbers (Larsen "The Lunacy"), as notes published in Rateliff's study refer to the moon's cycle as being 28 days long instead of (approximately) 29.5.[2] Indeed, Rateliff's own editorial explanations of Tolkien's notes *twice* repeat the same error, stating that the moon's cycle is 28 days long (832; 836). This is not the first case of Tolkien erroneously using 28 days as the length of the lunar cycle in his *legendarium*. In fact, in *The Book of Lost Tales Part One* (218) the mysterious Ranuin ('Month') sets the cycle of the moon's travels to be "twenty nights and eight."

Regardless of his admitted difficulties, Tolkien clearly understood that the phases of the moon are a powerful way to keep track of the passage of time. This is most famously demonstrated in the well-known care he took with his lunar chronology of *The Lord of the Rings*, timing the parallel journeys of the main characters to the phases of the moon. Descriptions of the moon's phases within the text provide the astute reader with an internal timeline for the action without undue intrusion. Tolkien wisely relied on the moon phases associated with a real-world calendar while writing *The Lord of the Rings*, those of December 1941 through March 1942 plus six days, later plus five days (*Treason* 369). The dual needs of keeping the lunar chronology consistent and the geographical changes in character movements realistic in terms of how many miles one could travel in a day eventually led Tolkien to make additional changes in the movements of the Fellowship, as described in *The War of the Ring* (e.g., 140-3). John Rateliff described how the final novel-wide consistency was only achieved through the construction of "many-columned sheets listing where each character was on each day of the story," documents housed in the Tolkien archive at Marquette and recently published, with commentary, in *Tolkien Studies* (Rateliff 827-8; Hicklin 22).

However, upon closer examination, the chronology is no mere cheat-sheet but rather a monument to Tolkien's tinkering and tweaking – his 'niggling,' to use a term familiar to Tolkien fans – that never seemed to cease due to his evolving thoughts, always with an eye to enhance the internal consistency of his Secondary World. In addition, as Hicklin (135) explains, Tolkien's continuous adjustments to the chronology led to a number of small errors of a day or so that remained after publication, such as exactly how many days before or after full moon an event occurred, some of which were fixed in the 2005 printing. It is therefore somewhat ironic that in the aforementioned interview Tolkien offered of *The Lord of the Rings* "I don't think the moon is full or otherwise in the wrong place" (Stump n.p.), since Tolkien made a number of moon phase flubs in that work, as noted by Brandon

[2] This is also an average, and varies slightly from cycle to cycle.

Rhodes, among others. Perhaps the most well-known is the impossible situation of a waning gibbous moon illuminating the west-facing Gates of Moria in early evening, a situation Hicklin termed "perhaps the only instance in which Tolkien consciously allowed himself to violate his scrupulous adherence to the lunar cycle" (41).[3]

In addition, Tolkien scholars also make errors when describing the behavior of the moon in Middle-earth. For example, Hicklin (69) confidently yet erroneously asserts that during the oath-confirming scene at Erech (which occurred on March 8, near midnight, in the later timeline) the "moon, just past full, would have been almost directly overhead… adding to the eeriness of the scene, but there is no mention of it" due to the "Great Darkness." On the contrary, the full moon, which would have been close to the celestial equator so close to the Vernal Equinox, would have been nowhere near the zenith (the point directly overhead in the sky) thanks to the latitude of Erech. Given that Tolkien located Minas Tirith "at about the latitude of Florence" (*Letters* 376) – or 44°N – and that Erech is about 1° north[4] of Minas Tirith in latitude (according to Fonstad's map [173]), the moon should have reached a maximum height above the horizon around midnight at an altitude of only about 45° (halfway above the southern horizon). Hicklin's astronomical faux pas is understandable, as it reflects a rather common misconception that the sun and moon regularly pass directly overhead as seen from all locations (Chastenay and Riopel 3).

In contrast to his messed-up moon phases, Tolkien's creation of original calendars has brought him real-world praise. A 1978 article in *Chemical and Engineering News* favorably discussed adopting Tolkien's logical and consistent Shire calendar (Reese 1978). Appendix D of *The Return of the King* describes how the Númenórean calendar handled leap years beyond the standard 'every four years' mantra,[5] leading to what he bragged in a 1955 letter to Naomi Mitchison was a calendar "just a bit better than the Gregorian: the latter being on average 26 secs [sic] fast p.a., and the N[úmenórean] 17.2 secs slow" (*Letters* 229). Appendix D makes the statement that the year of the Shire Calendar compared to ours "no doubt was of the same length, for long ago as those times are now reckoned in years and lives of men, they were not very remote according to the memory of the Earth" (*ROTK 385*). In a footnote the length is given as "365 days, 5 hours, 48 minutes, 46 seconds" (*ROTK* 385), which is indeed the length of the so-called tropical or

[3] Hammond and Scull (279) quote Christopher Tolkien as supporting keeping this error while others were fixed in the 2005 printing, because "I *suspect* that my father 'saw' the scene at the doors of Moria as moonlit" despite the obvious inconsistency.

[4] On Earth each degree of latitude corresponds to about 69 miles of geographical distance.

[5] The length of a year is not exactly 365.25 days, thus simply adding an extra leap day every four years is not sufficient to keep our calendar in sync with the seasons. There exist specific rules as to whether leap days are added at the end of centuries; see https://www.timeanddate.com/date/leapyear.html for more information.

solar year (365.242189 days). But this is only an average, as Tolkien may or may not have known. On his website *Redirected Insanity*, Aaron Chong examines the assumptions that went into Tolkien's calendars and connects them with modern astronomical knowledge. For example, the actual length of any one year is complicated, as the earth's orbit depends on the gravitational interactions between the sun, earth, and moon, and other major bodies in the solar system. As a result, the length of a tropical year can vary by up to 30 minutes (Hocken n.p.). Modern algorithms can calculate these changes and make predictions into both the past and future, but there is no evidence that Tolkien either delved into reading about this nor took part in such calculations himself. Indeed, his comment about the length of the year being the same as the modern value may have been a comparison of the average today to that in the past. In particular, in a 1958 letter to Rhona Beare, Tolkien offers that the "gap in time between the Fall of Barad-dûr and our Days" is "about 6000 years" (*Letters* 283), although in the 1965 interview he suggests – without explanation – that 7000 and 8000 years are reasonable time frames for discussing *The Lord of the Rings* (Stump n.p.). The difference between 6000 and 8000 is of no interest here, nor would be a gap of 6 million or 8 million years, as evidence demonstrates that there has been "negligible change in the length of the year" over geological time (Williams 55).

However, the length of a day (and hence the number of days in a year) *has* changed over geological time due to the slowing of the earth's rotation caused by tidal effects of the moon (and to a lesser extent, the sun). The existence of such 'secular acceleration' (of the moon receding from the earth to conserve angular momentum) may well have been known by Tolkien (especially given his late attempts published in *Morgoth's Ring* to create a more 'scientific' origin for the moon [Larsen "A Little"]). If the length of a day changes, so does the number of days in a year, even as the length of a year (in seconds) remains (on average) the same. Also the length of a lunar cycle increases as the moon retreats from the earth to conserve angular momentum. While the basic laws of physics dictate formulae that can be used to roughly estimate the size of this effect, detailed calculations are well beyond the type of back-of-the-envelope (sometimes quite literally) calculations Tolkien was prone to engage in (de Winter et al. 8-9). However this hasn't stopped some individuals from making claims to the contrary. For example, freelance writer Andreas Moehn (writing under the pen name Lalaith) invoked such physics to solve the problem of the inconsistent phases in *The Hobbit*, ignoring Tolkien's self-admitted inconsistency and instead using the problematic phase timing as evidence of a secular acceleration in Middle-earth.[6] Based on his personal evaluation of the timing of the phases of the moon in *The Hobbit* (which he argues

[6] The free, web-based version of this essay is no longer available. The author has not ordered the updated book version available through https://lalaithmesp.blogspot.com/p/collected-essays-from-lalaiths-middle.html.

are actually consistent and correct), Moehn posits that the lunar cycle of Middle-earth in the Third Age was twenty minutes shorter than its current real word value and suggested that this hypothetical difference might allow us to scientifically date just how long ago in the past the events in the novel took place in our real world's history. However, former NASA scientist and eclipse expert Fred Espenak (n.p.) warns that the size of the "secular acceleration of the Moon is very poorly known and may not be constant." In accordance with Occam's razor, the simplest explanation (and hence the most likely to be correct) is that Tolkien simply got his moons wrong.

In addition, Aaron Chong points out that over the 6000–8000-year time gap suggested by Tolkien[7] the number of days per solar year would have been very close to the present value and the difference in the lunar phase (synodic) month is on the order of only a few seconds. Chong (n.p.) opines that "Tolkien, despite his boasts about consistency, is just as prone to making errors as any of us" and "can't calculate moons within a single year, let alone a range of two years, let alone 78, let alone thousands."

A more common astronomical assertion made by science-minded fans is that Tolkien took into account the 26,000 cycle of precession. Due to the slow wobbling of the earth's axis, the north celestial pole (NCP) – the projection of the earth's north pole onto the stars – traces out a circle relative to the northern stars. For example, in ancient Egyptian times, the NCP was closest to the star Thuban in Draco the Dragon. Naomi Getty (2) argues that at the time of the Elves Vega was the North Star, and using this logic argues that Lyra (the constellation in which Vega is found) combined with the nearby Cygnus the Swan (the Northern Cross) would be the unidentified Elvish constellation Telumendil. It is certainly true that Vega did serve as the North Star in the distant past (circa 11,000 BCE, rather than 4000-6000 BCE). However, as I pointed out in a recent thread on the Tolkien Society Facebook Group there is no evidence that Tolkien incorporated precession into his *legendarium*, and fairly convincing evidence that he did not. For if Tolkien had used precession, the Big Dipper would not have circled "round and round the pole" (*BOLT I* 133), and its seasonal appearance as described in the poem "Kortirion Among the Trees" would not have been accurate. The description of Orion's rising near midnight in late September found in *The Fellowship of the Ring* (91) would have also been negatively affected.

Clearly, Tolkien's attempts to flesh out his Secondary World involved mathematics as well as science, or, better put, mathematics in the service of science. For example, Hicklin (57) quotes a calculation by Tolkien of how much ground orcs can cover in five days, given their pace and rest requirements (math teachers,

[7] This does not take into account any late extensions to the timeline due to the expansion of the Valian year described in *The Nature of Middle-earth;* however, even in this extreme case the difference would not be of the scale suggested by Moehn.

make note: a trivial algebra problem). However, Hicklin also identifies apparent arithmetic errors in the chronology (61). But where do we draw the line in putting calculations and scientific assumptions, rather than words, into Tolkien's mouth? This line was certainly complicated by the 2021 publication of *The Nature of Middle-earth* (*NOME*).

When revisiting the *Silmarillion* texts during and especially after *LOTR* Tolkien sought to make his mythology more consistent, and his cosmology more scientific, seeking to avoid the "astronomically absurd business of the making of the Sun and Moon" (*MR* 370), the first inkling perhaps being the so-called Round Earth Cosmology or Ainulindalë C* (*MR* 39-43) which was extant by 1948 (*MR* 4). In his introduction to *NOME* (3), editor Carl Hostetter explains that "sometime between 1951 and 1957, Tolkien made two decisions that would have far-reaching effects on his *legendarium*," adopting the coeval birth of the Sun, Moon, and Earth mentioned above, and a change in the conversion rate between Valian Years (VY) and Sun Years (SY). The result of the latter was "complex ramifications" for the chronology of the First Age and the rates of growth and ageing for Elves" (*NOME* 4). Among the manuscripts Hostetter grappled with for his volume were "long tables and calculations regarding the maturation rate and population growth of the Eldar," justifying their publication by noting that "Despite this technical and undeniably dry accounting, they nonetheless contain many interesting details of historical and culture relevance" (*NOME* xiii). In addition, he opined that these "materials as a whole also exemplify … Tolkien's unsuspected (at least to me) mathematical skills and precision (in a time well before electronic calculators became affordable)" (*NOME* xiii). As Hostetter is a computer scientist, his enthusiastic pronouncements of Tolkien's mathematical accomplishments could carry considerable weight in the minds of those with more humanities-based backgrounds and, I argue, unwittingly feed two misconceptions concerning Tolkien's use of mathematics.

Firstly, Tolkien is not using calculus in the calculations included in *NOME*, nor trigonometry or any other advanced mathematical techniques, but arithmetic (addition, subtraction, multiplication, and division) and occasionally basic algebra (such as his conversion between Valian and Sun Years). Let us take as an example Tolkien's taking of the number of seconds in a day (86,400) and the number of days in a year (365.242199074) to calculate that the "Year is thus 674 secs (11m. 14 secs) short of 365 ¼ days" (*NOME* 11). In order to do this calculation one merely takes 365.25 - 365.242199074 = 00.007800926 and then multiply this by the number of seconds in a year (86400) to get 674 seconds. No advanced math is involved. Tolkien then develops divisions of a Valian Day in terms of new units of time and calculates the conversion factor between the smallest unit, the "minim," and our second, finding that the "Valian Minim is 0.88069589 of a second. Or very nearly. A true value [of] this would be 35,831,807.9581… minims in a year"

(*NOME* 11). Hostetter notes that Tolkien directly afterwards "calculated the fractional part of the relation of a minim to solar seconds to approximately 360 decimal places, noting where values started to repeat" *(NOME 11)*. Now while long division done out by hand to any number of decimal places, let alone several hundred, is not my idea of a roaring good time (and I was a math minor in college), it 'ain't rocket science,' to borrow a common catch phrase.[8] We are also not told within the text whether or not Tolkien's answer was correct, although given the obvious "wow" factor of such a lengthy calculation to the non-mathematician, I maintain that the editor should have checked the calculation for correctness rather than leaving the reader to assume that it was so. In fact, the calculation was later shown to be correct to less than 30 digits.[9] But then Tolkien does something distinctly Tolkienian: after all that work he creates a unit of time called a sext and moves the minim down to the next level ($1/12^{th}$ of a sext). In addition, Tolkien makes the flat statement in his commentary to the time scheme that the smallest three units (including the sext and minim) are "practically never" described in "the narrative" (*NOME* 12). Why, then, did Tolkien seemingly 'waste' so much time with that long division? As is often the case with the Professor, we will probably never know. Perhaps it simply amused him, or he was procrastinating, i.e., doing it in lieu of some other work he should have been doing. Regardless, he was not engaging in advanced mathematics.

It should be noted that this same section of the manuscripts contains an interesting assertion by Tolkien, that "the light of Valinor was quite independent of earth-rotation, and depended on the length of the light of the Trees" (*NOME* 10), which led to a definition of a Valian Hour that was "exactly 1/12 each of whatever was the length of the Sun-year. (*This is held to have varied and to have lengthened*)" (*NOME* 11; emphasis mine). This apparent statement about the variation – specifically lengthening – of the Primary World solar year is interesting, given our previous discussion of the known variations from the average value yet consistency of the average value itself over geological time (de Winter et al. 8). It is also at apparent odds with the statement in Appendix D of *ROTK* that the length of the

[8] The calculation also has no scientific meaning; since the value of the minim is only calculated to eight decimal places, calculating the number of minims in a year to 360-ish decimal places vastly violates the rules of 'significant figures,' a measure of reliability in a calculation. For example, if we can reliably *measure* the instantaneous distance to the moon to within a few millimeters, it makes no scientific sense to *calculate* the average distance to within a billionth of a millimeter, although your calculator will easily give you the number to that mathematical precision (a frustration I commonly face in grading my astronomy students' homework). For more information, see http://www.astro.yale.edu/astro120/SigFig.pdf.

[9] When I presented this paper at Oxonmoot 2022 an attendee afterwards shared with me that Hostetter has stated elsewhere that Tolkien ***did*** make errors in this long-division calculation but did not provide a reference. Xu Zhan recently pointed me to the following thread: https://www.tolkienguide.com/modules/newbb/viewtopic.php?topic_id=3727&start=200 .

year had not changed since the Third Age of Middle-earth. With the new expanded chronology of the early history of Middle-earth that was necessitated by the increase in the length of a Valian Year, Tolkien apparently assumed that he had better add a slow shift in the length of a year to make it more 'scientific' (perhaps confusing it with the lengthening of both days and the lunar cycle caused by the secular acceleration of the moon).[10]

We now turn to my second concern regarding Hostetter's comments about Tolkien's mathematical process, namely the "precision" of his calculations (*NOME* xiii). There have already been numerous examples presented in this paper where Tolkien got the math wrong, either through simple arithmetic errors or erroneous assumptions (such as assuming the moon's cycle to be 28 days long instead of about 29.5). While the terms are often (incorrectly) used interchangeably in the popular vernacular, having an 'accurate' mathematical answer (the right answer) is more important that having 'precise' calculations (done out to some number of decimal places). In his description of his editorial practices in *NOME*, Hostetter explains that he "made no attempt to either note or record where Tolkien has both made and subsequently corrected a mathematical error" (*NOME* xvii). While it is certainly laudable that Tolkien found and corrected some of this own errors in these manuscripts (and should be used to encourage students to always take the time to go back and check your own work!), given our past experiences with Tolkien and math we should expect that some errors persisted. Indeed, in the chronology-related calculations alone, Hostetter makes note of numerous mathematical errors in his editorial endnotes (e.g., *NOME* 41, 42, 55, 56, 57, 74). For instance, in the manuscript "The Awakening of the Quendi" Hostetter explains that "Tolkien actually wrote '57,334' here as the length of the existence of Men in Bel. 210, but that is a mathematical error. 395 VY X 155 = 56,880 + 310 = 57,190" (*NOME* 40-1). A second type of calculation included in *NOME* is population statistics for the initial generations of Elves. Again, in his editorial endnotes Hostetter points out a number of errors and inconsistencies with these calculations (e.g., *NOME* 112, 113, 114). For example, "Tolkien here miscalculated 13,100 X 5 as 75,500, and thus the total as 120,634" (*NOME* 113).

One might ask what the harm is of Tolkien making such simple errors – errors any of us could have made – especially as these calculations were never incorporated into the *Silmarillion* texts as published. The problem is that the fact that there *are* errors is not obvious to the reader unless they carefully read the editorial endnotes. Combined with Hostetter's glowing endorsement of Tolkien's mathematical skills, we should not be surprised that numerous reviewers of the book express awe (and sometimes horror) at what they consider to be Tolkien's apparent mathematical genius, spawning yet another urban legend within the

[10] This, of course, completely neglects the possibility that it is simply yet another example of Melkor's marring of the song of creation.

legendarium. Take, for instance, the observation in the *By-the-Bywater podcast* review of the book that it contained "frankly, more math than any of us would ever have guessed" (Raggett et al. n.p.). Co-host Jared Raggett admits to skipping about a third of the book, especially the population tables, noting that "I don't think any of us are really math people…. I'm happy he did all of this for his own, I don't need to see his work here. I'm not his math teacher…. There was so much math!" (Raggett et al. n.p.). Colleague Oriana Schwindt offers that "this math thing was Tolkien's Twitter," in other words, a way to kill time rather than working on what he was supposed to be working on, as we previously considered. Christian Kriticos (n.p.) of *Winteriscoming.net* similarly notes that "One of the most surprising revelations from the book is that Tolkien had an aptitude for mathematics. Getting the details right was important to Tolkien; at one point he goes so far as to calculate Elvish population growth across 29 generations. This table of numbers take up six pages." However, Kriticos is either unaware of, or ignores, the fact that the endnotes point out numerous mathematical errors in those six pages.

Ray Palen (n.p.) of *Book Reporter* compares *NOME* to "reading an Advanced Placement work with many parts of it resembling the details you might find in a Calculus textbook," the comparison of arithmetic to calculus unfortunate hyperbole that furthers misconceptions concerning Tolkien's mathematical ability and does little to encourage the average reader to take up the volume. Similarly, user Ibid posted a warning on the *Science Fiction & Fantasy Stack Exchange* that "I wouldn't recommend the book to anyone who finds *Unfinished Tales* or *HoMe* too intimating. Or to someone who doesn't like reading lots and lots of math" (Ibid n.p.). Particularly telling is a review in the *Journal of Tolkien Research* by Douglas Kane, whose book *Arda Reconstructed* itself contains numerous tables tracing the evolution of the *Silmarillion* texts. Kane opines of *NOME* that while the "extensive mathematical calculations and tables" are "interesting in places, this material is confusing and fails to reach any satisfying resolution" (Kane 3). The unspoken message here is that if Kane find the first section "confusing," what hope does the average reader have in following along? This is indeed unfortunate, because again, as Hostetter explains of these mathematical exercise laden manuscripts they "contain many interesting details of historical and culture relevance" (*NOME* xiii).

It is undeniable that, despite the fact that he didn't always get the details correct, Tolkien took great care to utilize real world science and scientific observations of the real world in crafting Middle-earth. It was apparently his hope that this would aid the reader in immersing themselves into his Secondary World and avoid breaking the spell and allowing disbelief to arise (*OFS* 52). But he was making a rather important assumption, namely that his reader had a scientific understanding commensurate with his own; for example, that they understood the moon's cycle of phases and how it could be used to measure the passage of time,

or the way that Orion rises or the Big Dipper circles in the night sky. This, of course, begs the question of the average reader's understanding of science, especially in the early 21st century. The National Science Board has been publishing the results of national and international surveys of science literacy for decades, as part of their *Science and Engineering Indicators* volumes. For example, the average number of questions correctly answered by American adults on a standardized questionnaire has been stuck at just under six out of nine (between 5.6 and 5.8 or a score of 62 and 64%) since 2001 (7.35). Having the American public stuck at an average grade of 'D' is discouraging, especially given the important social and political issues that are deeply scientific in nature (such as climate change and energy policies). Statistics for other industrialized nations are not much more encouraging (National Science Board 7.43).

Since mathematics is the language of science, it is not merely science literacy that concerns us here, but mathematical literacy, or what is termed *numeracy*. A 2012 study of the average numeracy of American adults found that only 48% scored at a Level 3 (out of 5) or higher (Goodman et al. 20). Similarly, a 2014 British study reported that merely 22 percent of adults in the U.K. "reached the level of functionally numerate" (Murray n.p.). In addition, over 90% of American adults report having some math anxiety, with perhaps nearly a fifth of the entire US population suffering from high levels of math anxiety (Luttenberger et al. 312). Similarly, in a "sample of adolescent apprentices in the United Kingdom, approximately 30% of the study participants reported high math anxiety, and a further 18% were at least somewhat affected by it" (Luttenberger et al. 312). This comes as no surprise to this author, as unit conversion problems, such as Tolkien's calculations of the relation between Solar and Valian units of time, openly terrify college students in her general education astronomy class. Therefore in the case of Tolkien's calculations in *NOME,* perhaps we have an adaptation of Clarke's Third Law: Any sufficiently advanced technology is indistinguishable from magic. In this case, what would have been considered standard mathematics to Tolkien is considered 'calculus' – that is, nearly magical – to the average reader today. I suspect the Professor would be shaking his head in disbelief at our lack of what he would have considered to be basic mathematical understanding, especially as he considered himself to have been "stupid at arithmetic" (at least as a child).

David Bratman and Merlin DeTardo (250) rightfully rebuke Laura Miller's downplaying of the significance of what she sees as the "quantity, rather than quality, of invention" in his subcreation. Instead, they argue, it is precisely this quantity of his work in crafting a solid foundation for his imagined world that forms the "essential component of the quality of his kind of invention" (250). It is in this spirit that I have sought here to separate fact from wishful thinking, celebrating what Tolkien got right, accepting what he got wrong, and embracing the concept

that we need not ascribe Einstein-like prowess to an author to appreciate the undeniable brilliance of their work.

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