

John Holbroke, the Tables of Cambridge, and the “True Length of the Year”: A Forgotten Episode in Fifteenth-Century Astronomy

C. Philipp E. Nothaft

All Souls College, High Street, Oxford OX1 4AL, United Kingdom

email: philipp.nothaft@all-souls.ox.ac.uk

orcid.org/0000-0002-7454-8058

Abstract

This article examines an unstudied set of astronomical tables for the meridian of Cambridge, also known as the *Opus secundum*, which the English theologian and astronomer John Holbroke, Master of Peterhouse, composed in 1433. These tables stand out from other late medieval adaptations of the *Alfonsine Tables* in using a different set of parameters for planetary mean motions, which Holbroke can be shown to have derived from a tropical year of $365\frac{1}{4} - \frac{1}{132}$ or $365.\overline{24}$ days. Implicit in this year length was a 33-year cycle of repeating solar longitudes and equinox times, which has left traces in other astronomical tables from fifteenth-century England. An analysis of the manuscript evidence leads to the conclusion that Holbroke owed his value for the “true length of the year” to a certain Richard Monke, *capellanus de Anglia*, who employed this parameter and the corresponding 33-year cycle in an attempt to construct a perfect and perpetual solar calendar, leading to his *Kalendarium verum anni mundi* of 1434.

1. Introduction

Two trajectories seem to characterize the overall development of computational astronomy in Europe during the late Middle Ages. On the one hand, we can witness a diversification of the formats used in casting astronomical tables, as practitioners elaborated new layouts and computational techniques in order to render tables more time-efficient or user-friendly.¹ The flip side of this diversification, however, appears to have been a decrease of diversity in the underlying parameters, which remained the same in the vast majority of tables composed during this period.² In the case of the mean motions of the Sun, Moon, and five planets, the ultimate source for these parameters were the so-called *Alfonsine Tables*, which originated in the second half of the thirteenth century at the court of King Alfonso X of Castile and León (1252–1284) and were to enjoy a wide dissemination north of the Pyrenees from c.1320 until the second half of the sixteenth century.³ Although there are occasional signs that late medieval users of these tables were aware of their shortcomings,⁴ there is at present a remarkable dearth of documented attempts to alter, correct, or replace the parameters in question. One of the purposes of the present article is to demonstrate that a previously unnoticed instance of this kind can be discerned in a set of astronomical tables drawn up by John Holbroke (or Holbrook), an English Doctor of Theology who served as master of Peterhouse, Cambridge, between c.1421 and his death in c.1437.⁵ Holbroke's activities as an astronomer-astrologer have not been completely overlooked by twentieth-century historians of science, some of whom even granted him an important role in establishing a scientific

¹ See North 1977; Kremer 2007; 2008; 2011; Husson 2012; 2014; Chabás and Goldstein 2013, and the relevant chapters in Chabás and Goldstein 2015.

² This holds true, at any rate, for tables cast by Christian astronomers. A greater degree of diversity and independence in the area of parameters was exhibited by Jewish authors such as Levi ben Gerson. See Goldstein 1974; 1988; 1992; Mancha 1998a; 1998b. For other examples, see Goldstein 2001; 2003a; 2004.

³ The early history of these tables is fraught with uncertainty, but the most likely scenario remains that the *Alfonsine Tables* known in Paris after c.1320 originated on the Iberian peninsula. See the discussions in North 1996; Chabás and Goldstein 2003; Swerdlow 2004, and the opposing viewpoint taken by Poulle 1987; 2005.

⁴ See the examples mentioned in Nothaft 2014; 2017, pp. 227–235.

⁵ See Emden 1963, p. 309; Wordsworth 1904, p. 143; Lovatt 1993, pp. 130, 133–134; Clarke 2002, p. 700; Snedegar 2004.

tradition at East Anglia's oldest university.⁶ According to the *Oxford Dictionary of National Biography*,

Holbroke's reputation as a mathematician derived from his compilation of astronomical tables for the Cambridge meridian. His *Opus primum* is a set of tables which allow the calculation of the true and mean positions of the sun, moon, and planets. Striving for greater accuracy, Holbroke extended the calculation of planetary locations to ten sexagesimal places in his *Opus secundum*. The tremendous, if vain, effort of drafting the *Opus secundum* impressed users of the tables well into the next century. One sixteenth-century scholar remarked: "This man was the mathematical glory of Cambridge for ther was nower any one good in this knowledge before Holbrooke who was *satis profundus*".⁷

None of this is incorrect, yet the true significance of Holbroke's *Opus secundum* (1433), and the reason for its temporary success, is rooted in issues that run deeper than the number of sexagesimal places on display. Far from simply endowing his tables with an artificial degree of precision, Holbroke based himself on planetary mean motions that have no equivalent in the standard *Alfonsine Tables* or any of their countless late medieval derivatives. Most of the present article will be devoted to an analysis of these parameters and the computational method by which they were generated as well as to the reception of Holbroke's *Opus secundum* in fifteenth-century England. It will be shown that Holbroke's deviations from the computational mainstream were mostly due to his reliance on a different value for the length of the tropical year, which at $365\frac{1}{4} - \frac{1}{132}$ days = 365d 5; $\overline{49,5,27,16,21}$ h was approximately 10 seconds shorter than the Alfonsine counterpart.⁸ This surprising advocacy of a "true length of the year" (*vera anni quantitas*) different from the Alfonsine one can be linked to contemporary debates concerning a necessary reform of the ecclesiastical calendar, which inspired a number of different proposals for the creation of a "perfect" calendar. One such

⁶ See in particular Gunther 1937, pp. 138–141, and Price 1955, p. 8. Further remarks on Holbroke appear in North 1977, pp. 275–276; 1986, pp. 142–149, 156; Carey 1987, pp. 54–55; 1992, pp. 138, 145–148, 150–153, 155–157, 159, 215–218, 256.

⁷ Snedegar 2004. The sixteenth-century comment appears as a marginal note on fol. 164r of MS Gloucester, Cathedral Library, 21 (see n. 42 below).

⁸ In analogy to the standard convention for recurring decimals, the vinculum placed above the last five numbers in 365d 5; $\overline{49,5,27,16,21}$ h indicates an indefinitely repeating sequence of sexagesimals.

proposal is enshrined in the *Kalendarium verum anni mundi* that Holbroke's contemporary Richard Monke, *capellanus de Anglia*, composed in 1434. This enigmatic work employed a 33-year cycle of repeating solar longitudes as well as a modified intercalation cycle of 132 years, both of which were founded on the same non-Alfonsine year length as that recommended in Holbroke's *Opus secundum*. As will be seen below, there is substantial evidence to support the conclusion that Richard Monke had already discovered these cycles by 1432, one year prior to the *Opus secundum*, and that it was he who supplied Holbroke with the "true length of the year" that distinguishes his astronomical tables from other late medieval productions.

2. Planetary mean motions in Holbroke's *Opus secundum*

Use of the terms *Opus primum* and *Opus secundum* as a means of distinguishing between two different sets of astronomical tables attributed to John Holbroke can be traced back to a manuscript partly written by the Welsh physician and astronomer-astrologer Lewis Caerleon (d. in or after 1495), who made his personal copy of the two *Opera* in c.1482.⁹ It would appear likely that Caerleon copied Holbroke's tables and their respective prefaces from an astronomical compendium now in the British Library, which has been known as the *Codex Holbrookianus* ever since a full description was published by one of its previous owners, the antiquarian James Halliwell-Phillipps, in 1840.¹⁰ As this moniker would suggest, the manuscript features extended sections in Holbroke's own hand, as is easily seen from the initials *J.H.* added to the end of some items (fols. 18r, 68r) or the marker *quod H.* found at the end of others (fols. 110r, 120v, 133r). Holbroke's role as original owner of the manuscript in question receives full confirmation from a table of contents entered on fol. 6v, which adds a *memorandum* to the effect that John Holbroke, professor of theology, Master of Peterhouse, and erstwhile chancellor of the University of Cambridge, who was a man "most skilled in the

⁹ MS Cambridge, University Library, Ee.3.61, fols. 56r–68v. The approximate date of this copy seems to follow from Lewis Caerleon's calculations pertaining to the solar eclipses of 17 May 1482 and 28 May 1481 on fols. 1r and 12v–15r. On the owner of this manuscript, see Kibre 1952; North 1976, III, pp. 217–220; Carey 2012, pp. 694–696.

¹⁰ MS London, British Library, Egerton 889 (hereafter cited as *H*). See Halliwell 1840; Gunther 1923, pp. 65–66; North 1976, II, p. 37; Pedersen (Olaf) 1986, pp. 230–231; Clarke 2002, pp. 499, 557–558; Juste 2017.

liberal arts, especially in astronomy [...] bestowed this astronomical book” to Peterhouse on St Valentine’s Day 1426.¹¹

This date of donation (14 February 1426) would appear to have certain implications for the date of the various texts and tables assembled in the *Codex Holbrookianus*, but things are complicated by the fact that the latest date mentioned in the entire codex is the year 1430. According to a note on fol. 150v, this was the year in which Holbroke (here spelled *Holbrook*) made a table for the equation of time based on an assumed position of the apogee in the first degree of Cancer. The table appears at the end of the set of tables that Caerleon’s copy identifies as the *Opus M. Holbroke primum*,¹² but there are enough hints to conclude that it was not an original component of the work in question, but only a later addition. From Holbroke’s preface (fol. 133v), it emerges that the *Opus primum* was written to correct and replace the popular tables for the meridian of Oxford that were the work of William Rede, a fellow of Merton College and later Bishop of Chichester (d. 1385).¹³ Like many other sets of tables cast during the fourteenth century, Rede’s relied entirely on the mean motion parameters of the *Alfonsine Tables*, but presented them in a different and more easily intelligible format. In contrast to the Alfonsine principle of strictly sexagesimal mean motion tables that were applicable to different calendars and eras, Rede reduced all values to the Julian calendar and the Christian era by the traditional method of listing epoch values *ad annos Christi collectos*.¹⁴ Of the various complaints Holbroke levelled against this work in the preface to his *Opus primum*, one concerned the inclusion of an outdated table for the equation of time, which he felt the need to replace with a newer one. The copy of Rede’s tables included in the *Codex Holbrookianus* (fols. 113r–119r) supplements the mean motion tables with a combined table for the right ascension and equation of time (fol. 118v), which

¹¹ *H*, fol. 6v: “Memorandum quod magister Iohannes Holbrook quondam alme Universitatis Cantebrigiensis cancellarius, sacre pagine professor ac in artibus liberalibus, precipuus in astronomia tamen, peritissimus, et magister Collegii sancti Petri Cantebrigiensis, contulit eidem collegio antedicto in festo sancti Valentini anno domini 1426¹⁰ hunc librum astronomicum.”

¹² MS Cambridge, University Library, Ee.3.61, fol. 56r.

¹³ A separate copy of this preface appears in MS Oxford, Bodleian Library, Bodley 300, fol. 132vb, a codex from Clare College, Cambridge. Later parts of this codex once used to include Holbroke’s tables, but these have gone missing. See Clarke 2002, pp. 154–155. In passing, one should also note the existence of a stand-alone table of epoch values for the year 1460s that were derived from Holbroke’s *Opus primum*: MSS Oxford, Bodleian Library, Ashmole 340, fol. 78r; Oxford, Bodleian Library, Ashmole, 346, fol. 20v.

¹⁴ See North 1977, pp. 274, 300, and the less than reliable account in Harper 1975. Rede’s tables and Holbroke’s commentary on them appear in *H* on fols. 111r–120v.

had originally been constructed by al-Battānī (d. 929) and later became a standard part of the Toledan Tables traditionally ascribed to Azarquiel (al-Zarqālī or al-Zarqālluh, d. 1100).¹⁵ Holbroke accepted the latter attribution and mistakenly believed that the table's values for the equation of time had been calculated for an assumed position of the solar apogee at 17° Gemini, which corresponds roughly to the longitude mentioned in the canons to the Toledan Tables (77;50°).¹⁶ In the context of the Toledan Tables, which used a sidereal frame of reference, this value was supposed to remain fixed. Holbroke, by contrast, assumed a tropical frame of reference and therefore insisted that the values in Azarquiel's table were in dire need of an update, as the *Alfonsine Tables* put the apogee in present times somewhere within the first degree of Cancer (90°–91°).¹⁷

As a quick and ready replacement for the unsatisfactory table used by Rede, Holbroke picked a table for the equation of time he had copied previously as part of Jean de Lignères's tables for the meridian of Paris (1322).¹⁸ In the preface to the *Opus primum* he explicitly attributes this table to “Jean de Lignères, the eminent astronomer”, but not without admitting that even this table was no longer fully reliable since it assumed the apogee of the Sun to be in the 28th degree of Gemini rather than the first degree of Cancer. “He who wishes to have a more precise [table] may take the method of composing it from the end of the third [book] of the *Almagest* and from the 29th chapter of al-Battānī.”¹⁹ Not long after completing the *Opus primum*, Holbroke proceeded to follow this advice himself and sat down to create an updated

¹⁵ See Pedersen (Fritz) 2002, III, pp. 968–976; Chabás and Goldstein 2012, pp. 27–28. Versions of this table appear to be present in most other copies of William Rede's tables. See e.g. MSS London, British Library, Egerton 847, fols. 142v–143v; Oxford, Bodleian Library, Digby 48, fols. 173v–174r; Oxford, Bodleian Library, Digby 97, fols. 18r–19r; Oxford, Bodleian Library, Wood D.8, fols. 83r–84r; Oxford, Jesus College, 46, fols. 31r–32v. The latter copy once belonged to William Rede.

¹⁶ See Pedersen (Fritz) 2002, I, p. 256; II, pp. 434–436; IV, p. 1223.

¹⁷ *H*, fol. 133v: “Adhuc inter antistitis tabulas ponuntur ascensiones signorum in circulo recto quibus permiscuit Arzachel tabulam equacionis dierum que supponit augem solis in 17 gradu Geminorum esse. Quoniam vero aux solis pervenit modo usque ad primum gradum Cancrī patet eam hiis nostris diebus nimis a vero remotam.”

¹⁸ See *H*, fols. 31r–52v. The table for the equation of time appears on fol. 38v. Other copies of this table can for instance be found in MSS Bernkastel-Kues, Cusanusstiftsbibliothek, 212, fol. 83r; Paris, Bibliothèque nationale de France, lat. 7286C, fol. 54r.

¹⁹ *H*, fol. 133v: “Quare relictā hac immisi tabulam magistri Iohannis de Lineriis astronomi eximii, que licet nunc precisa non sit, eo quod supponit augem solis in 28 gradu Geminorum existere, est tamen veritati propinquior quam tabula Arzachel. Qui vero precipiorem habere desiderat racionem compositionis ex fine tercii Almagesti et ex 29 capitulo Albategni capiat.”

table for the equation of time, which is the one he inserted on two unused pages at the end of the same quire (fols. 150v–151r), dating it to 1430. That the *Opus primum* and this table of 1430 came into being in two separate acts of creation is confirmed by the preface to the *Opus secundum*, where Holbroke notes that he composed at some point in the past (*ante hec tempora*) a set of mean motion tables for the meridian of Cambridge that included:

a table for the ascensions of the signs in the oblique circle for the true latitude of this town, which had never been made before. In addition to this, I made, not too long ago, a new table for the equation of [time] for which I assumed the apogee of the Sun to be at the end of the first degree of Cancer, so that it would be valid for a longer time. If anyone wishes to [use it] he will find it earlier in this same book.²⁰

As for the *Opus secundum* itself, the headings of several of its mean motion tables reveal that the year of writing was 1433 (fols. 154r–v, 155v–156r, 157r), which leads to the conclusion that the quire containing them was added to the *Codex Holbrookianus* only after its initial donation to Peterhouse in 1426. In stark contrast to the *Opus primum*, whose mean motion tables presupposed the Julian calendar and imitated Jean de Lignères in employing combined tables for “expanded” and “collected” years, the *Opus secundum* stuck very closely to the standard layout of the *Alfonsine Tables*, devoting to each planetary mean motion a table of sixty entries. One of the original purposes of this format was to make the tables independent of any particular era and calendar, as the strictly sexagesimal structure allowed the entries to represent the mean motion for any sexagesimal multiple or fraction of a day.²¹ Rather than supplementing the mean motion tables with a whole list of different epoch values, as was done in the *Alfonsine Tables*, Holbroke adhered to a principle he had already followed in the *Opus primum*, which was to place underneath each table a single *radix* for the beginning of the Christian era, as valid for the meridian of Cambridge. In addition, he expanded the number of sexagesimal places per entry to a standard of ten compared to nine in most

²⁰ *H*, fol. 153r: “Composui autem ante hec tempora alias tabulas mediorum motuum supponens quantitatem anni Alfonsii supponensque eis singulas radices ad eram domini Ihesu Christi pro meridie Cantebrigie fecique tabulam ascensionum signorum in circulo obliquo ad veram latitudinem eiusdem oppidi, que ante nusquam facta fuerat. Feci insuper non est diu tabulam novam equationis dierum cum noctibus suis supponens augem solis in fine primi gradus Cancrī, ut sic tabula diuturnior existeret. Hunc si quis desiderat eam ante in hoc eodem libro reperiet.” The table for oblique ascensions mentioned in this passage appears in *H* on fols. 149v–150r. See the discussion in North 1986, pp. 130–131.

²¹ See on this format Samsó 1987, pp. 31–32; Chabás and Goldstein 2012, pp. 55–57.

recensions of the *Alfonsine Tables* and only six in the *Opus primum*. For example, the Alfonsine table for the mean motion of the apogees and fixed stars tabulates a linear increase of 0.0.0.0.4.20.41.17.12 per line (Pouille 1984, p. 133), which can be read as representing a daily motion of 0 signs and 0;0,0,4,20,41,17,12°. In the *Opus primum*, this is rounded to 0;0,0,4,21° in the first line (fol. 145r), whereas the *Opus secundum* one-ups the Alfonsine template in displaying a linear increase of 0;0,0,4,20,41,17,31,13° per day (fol. 157r). By implication, the values in this table are precise to a sexagesimal of the eighth fractional place, or one 167,961,600,000,000th of a degree.²²

	Title	First entry	Alfonsine value
1.	<i>Tabula superflui 6 horarum super quantitatem anni</i>	0;10,54,32,43,38,11h	--
2.	<i>Tabula revolucionis annorum in suis fractionibus</i>	5;49,5,27,16,21,49h	5;49,15,43h
3.	<i>Tabula continens medium motum solis</i>	0;59,8,19,41,34,52,51,24°/d	0;59,8,19,37,19,13,56°/d
4.	<i>Tabula continens medium motum lune</i>	13;10,34,1,19,38,49,49,9°/d	13;10,35,1,15,11,4,35°/d
5.	<i>Tabula medii motus lune in elongacione sui a sole</i>	12;11,26,41,38,3,56,57,45°/d	12;11,26,41,37,51,50,39°/d
6.	<i>Tabula continens medium motum argumenti lune</i>	13;3,53,57,34,46,33,37,16°/d	13;3,53,57,30,21,4,13°/d
7.	<i>Tabula medii motus argumenti latitudinis lune</i>	13;13,45,39,26,54,43,32,59°/d	13;13,45,39,22,25,53,45°/d
8.	<i>Tabula medii cursus capitis Draconis</i>	0;3,10,38,7,15,53,43,50°/d	0;3,10,38,7,14,49,10°/d
9.	<i>Tabula augium et stellarum</i>	0;0,0,4,20,41,17,31,13°/d	0;0,0,4,20,41,17,12°/d
10.	<i>Tabula accessus et recessus octave spere secundum Alphonsum</i>	0;0,0,30,24,49°/d	0;0,0,30,24,49°/d
11.	<i>Tabula continens medium cursum argumenti Veneris</i>	0;36,59,27,26,39,25,23,58°/d	0;36,59,27,23,59,31°/d
12.	<i>Tabula continens medium cursum argumenti Mercurii</i>	3;6,24,7,56,6,39,25,4°/d	3;6,24,7,42,40,52°/d
13.	<i>Tabula continens medium cursum Saturni</i>	0;2,0,35,17,49,2,17,9°/d	0;2,0,35,17,40,21°/d
14.	<i>Tabula continens medium cursum Iovis</i>	0;4,59,15,27,28,57,28,53°/d	0;4,59,15,27,7,23,50°/d
15.	<i>Tabula continens medium cursum Martis</i>	0;31,26,38,42,20,55,1,38°/d	0;31,26,38,40,5°/d
16.	<i>Tabula revolucionis ascendentis annorum</i>	87;16,21,49,5,27,16,21,49,5,27°	87;18,55,55°
17.	<i>Tabula revolucionis annorum in suis fractionibus</i>	5;49,5,27,16,21,49,5,27,16h	5;49,15,43h

Tab. 1: List of tables in Holbrooke's *Opus secundum*

Tab. 1 offers a full list of the 17 tables that make up the *Opus secundum* in the *Codex Holbrookianus* together with the value of their starting entry as well as the corresponding

²² An even more extreme case of entries going up to sexagesimal ninths or tenths can be found among the tables drawn up in 1392 by John Westwyk to accompany his English-language treatise on the equatorium in MS Cambridge, Peterhouse, 75.I. See Falk 2016, pp. 12–15.

Alfonsine standard value. It is worth pointing out that items no. 2 and 17 on this list are two versions of the same table for the annual excess of revolution, which differ only in the number of sexagesimal-fractional places their respective entries take. In no. 2, the annual excess of revolution is given as 5;49,5,27,16,21,49h, with six fractional places. In item no. 17, the number of fractional places after the complete hour is blown up to nine, with the value of the first entry given as 5;49,5,27,16,21,49,5,27,16h. It is clear, however, that the value used to compute this table had at least one extra fractional place, as the number in the rightmost column does not grow steadily by 16 (*modulo* 60) per line. The same applies to items no. 3 (Sun), 4 (Moon), and 5 (elongation), each of which was evidently based on a value more precise than its first entry. That none of them were simply copied from the standard *Alfonsine Tables* is more than obvious not just from the greater number of sexagesimal places, but also from the values used. In the case of item no. 17, the first entry implies a tropical year of 365d 5;49,5,27,16,21,49,5,27,16h, which stays significantly below the 365d 5;49,15,43h in the first line of its common Alfonsine equivalent or the 365d 5;49,15,59,34,3h used in the last line of the Alfonsine *Tabula revolutionis mensium*.²³ It should be noted that the two Alfonsine values are not only mutually inconsistent, but also fail to agree with the year length that would follow from using the Alfonsine rate of mean solar motion. For the latter, a table in the *Codex Holbrookianus* shows a daily increase of 0;59,8,19,37,19,13,56,13°/d,²⁴ which implies a tropical year of $360^\circ \div 0;59,8,19,37,19,13,56,13^\circ/d = 365d\ 5;49,15,58,49,45,53,55,10\dots h$.²⁵ Eager to resolve the contradiction inherent in the *Alfonsine Tables*, Holbroke used this exact value to compute the tables for the excess of revolution included in his *Opus primum*, where the *Tabula revolucionis mensium anni* (fol. 134v) ends on 365d 5;49,15,58,49,45,53,55,10h and the

²³ Poulle 1984, p. 130. The purpose of this type of table is discussed in Chabás and Goldstein 2012, pp. 218–223; Goldstein and Chabás 2013.

²⁴ This value contains one sexagesimal place more than the corresponding table found in most manuscripts and the 1483 *editio princeps* of the *Alfonsine Tables*, where the first entry is 0;59,8,19,37,19,13,56°/d. See Poulle 1984, p. 134. The expanded version with ten rather than nine sexagesimal places also appears in MSS Cambridge, Peterhouse, 75.I, fol. 7v (s. XIV^{ex}); London, British Library, Royal 12.D.VI, fol. 7r (s. XVⁱⁿ); Oxford, Bodleian Library, Digby 97, fol. 8v (s. XV^{med}).

²⁵ An effort to spell out this value down to the 17th (!) sexagesimal-fractional place was made in MS London, British Library, Royal 12.D.VI, fol. 8r, where a table shows that it takes the Sun 1d 0;20,58,12,39,48,17,38,59,11,43,25,32,57,37,2,29,20h to traverse one degree of the zodiac, but 365d 5;49,15,58,49,45,53,55,10,20,33,17,45,42,14,56,0,0h to complete the whole 360°.

Tabula revolucionis annorum in suis fractionibus (fol. 134r) starts with a slightly rounded value of 365d 5;49,15,58,49,45,54h.²⁶

Why did Holbroke abandon these numbers and instead decide to employ a year length more than 10 seconds (365d 5;49,15,58,49,45,54h – 365d 5;49,5,27,16,21,49h = 0;0,10,31,33,24,5h) below the standard value when he cast the tables in his *Opus secundum*? An answer to this question is given in the work's preface, where Holbroke placed some emphasis on the notion that God had created the Sun and Moon to serve as markers of time (cf. Genesis 1:14). The text begins as follows:

From the beginning of all things, the glorious and exalted God placed luminaries in the firmament so that they would divide the day and the night and serve those who are mortal as [markers of] time, that is, as days and years, just as it is written that “He hath made the moon for seasons: the sun knoweth his going down” [Psalm 103:19]. For just as the Moon's course distinguishes the months—which is why the Greek word *mene*, from which derives “month” [*mensis*], indicates the Moon—, so the Sun gives rise to the year by its course, the length of which is described differently by different people.²⁷

As Holbroke went on to suggest in a somewhat oblique manner, the role of the Sun as a divinely ordained time-marker carried with it the implication that God had picked a length for the tropical year that was commensurate with the length of the day and, hence, with a particular calendrical cycle. This cycle, however, was not identical with the four-year intercalation cycle of the Julian calendar, which implied an average year of 365d 6h. Holbroke contrasted this crude estimate, which he attributed to Julius Caesar, with the

²⁶ Holbroke addresses his intervention in the preface, for which see *H*, fol. 133v: “Et quia inter Alfonsi tabulas due communiter reperiuntur revolutiones, scilicet annorum ac revolutiones mensium, que nec secum neque cum medio solis motu concordiam servant, prima nempe primo suo versu inventa est minus habens in tertiis, secunda autem superhabundat, sic neutra veram anni solaris continet quantitatem. Propterea has ipse ad concordiam duxi et in eis veram anni quantitatem ex motu unius diei secundum Ptholomei documentum inventam, in una quidem usque ad sexta, in alia vero usque ad octava inscripsi. Correxique et tabulam revolucionis ascendentium, quam super tabulam revolucionis annorum fundari certum est.”

²⁷ *H*, fol. 152v: “Gloriosus atque sublimis Deus a rerum exordio *luminaria in firmamento* posuit ut *diem noctemque dividerent* et in *tempora* mortalibus *dies* scilicet fierent atque *annos* [Genesis 1:14], sicut scriptum est ‘*Fecit lunam in tempora sol cognovit occasum suum*’ [Psalm 103:19]. Sicut enim lunaris cursus menses distinguit, unde et Greco vocabulo ‘mene’, a quo ‘mensis’, dicitur, lunam signat, ita et sol suo cursu annum efficit, cuius quantitas a variis varia describitur.”

tropical year in Ptolemy's *Almagest*, which lasted only 365;14,48d. King Alfonso had reduced the Julian value even further, subtracting another 0;0,14,50d to arrive at an approximate length of 365;14,33,10d. "Yet no one has yet reached the true and precise length of the year, although these two [i.e., Ptolemy and Alfonso] have come closer to the truth than others." According to Holbrooke, the year had to be "of such kind and length that the equinoxes and solstices may endure in the calendar unmoved", which fixity could be attained if the bissextile day in the Julian calendar was omitted in every 132nd year. Had this been done since Caesar's time, the equinoxes and solstices would have never drifted toward the beginning of the year, as they had visibly done over the past millennium and more.²⁸ In order to obtain what he kept referring to as the "*true* length of the year" (*vera anni quantitas*), Holbrooke recommended taking any existing estimate and subtracting it from 365d 6h, which left the surplus-difference between the Julian year and the tropical year.

If you multiply this by 132 and the result is exactly 24 hours, know that the surplus is the true one and that the estimated length is the true length of the year. [...] If, however, fewer than 24 hours result from the multiplication, you must subtract this from 24 hours and divide what is left by 132 and add what comes out [of this division] to the surplus and subtract the result from 6 hours and you will have the most reliable [*certissimam*] length of the year. If you divide the zodiac [i.e. 360°] by this [length], the result will be the mean motion of the Sun in one day and, conversely, if you divide the zodiac by the mean motion, the result will be the true length of the year.²⁹

²⁸ Ibid.: "Iulius namque, cuius decretum usque adhuc servat ecclesia, ex 365 diebus et 6 horis annum suum effecit. Ptholomeus autem, qui omnes antiquiores et sibi coetaneos astronomie vicit magisterio, annum ex 365 diebus, 14 minutis et 48 secundis constare dicit. Alfonsus vero huic tempori 14 secunda ac 50 tertia ademit. Nullus tamen ad veram atque precisam anni quantitatem pervenit, quamvis hii duo veritati propinquius ceteris accesserint. Talis namque ac tanta esse debet ut equinoctia et solsticia in kalendario immota permaneant. Abiecto tamen bisextili die anno 132°, quod si ab ipsius tempore Iulii factum esset, non hec solsticiorum aut equinoctiorum anticipacio, non error qui in pasche ceterorumque mobilium festorum celebritate frequenter nimis accidit, videretur."

²⁹ Ibid.: "Si ergo veram anni quantitatem scire cupis, accipe quantitatem aliquam estimatam quam precisiorem autumas, ut puta Ptholomei seu Alfonsi, eamque de 6 horis subtrahe et habes superfluum 6 horarum supra quantitatem estimatam. Quod per 132 multiplica et si hore 24 precise ex multiplicatione proveniant, scito quod superfluum est verum et quantitas estimata est vera anni quantitas. [...] Si autem ex multiplicatione minus 24 horis proveniat ipsum de 24 horis subtrahe et remanens per 132 divide et quod exierit superfluo adde et resultans a 6 horis deme et habebis anni certissimam quantitatem, per quam si zodiacum divideris exhibit medius motus

Two points deserve to be made here. The first of these is not strictly historical, but concerns the accuracy of the estimate advocated in this text, which happens to be nothing short of exquisite. At $365\frac{1}{4} - \frac{1}{132}$ days, Holbroke's "true length of the year" is equivalent to $365\text{d } 5; 49,5,27,16,21\text{h}$ or $365.\overline{24}\text{d}$, which is within less than 5 seconds of the currently measured interval between vernal equinoxes ($c.365.24237\text{d}$ in ephemeris days). This interval differs somewhat from the length of the mean tropical year (current value: 365.24219d), but makes for a more appropriate comparison with the parameter proposed in the *Opus secundum*.³⁰ After all, one of the purposes of finding the true length of the year, as declared by Holbroke, was to stabilize the date of the vernal equinox in the Julian calendar, which was deemed important due to the equinox's calendrical role as lower boundary for the date of Easter. In Holbroke's day it was widely known and understood that the Julian calendar used by the medieval Church allowed the true equinox to drift toward the beginning of the year due to a discrepancy of $c.0;11\text{h}$ between the tropical year and the average Julian year. One consequence of this error was that the vernal equinox moved farther and farther away from its canonical date on 21 March, which was the earliest permissible date for the Easter full moon, leading to situations when, astronomically speaking, Easter Sunday was celebrated in the wrong month. Holbroke had this problem in mind when he alluded to "the error that happens all too often in the celebration of Easter and the other mobile feasts", claiming that it could have been forestalled if the bissextile day had been suppressed once every 132 years.³¹ Attempts to cure this defect were already underway in his own lifetime, for instance at the Council of Basel in the years 1434–1437,³² but it was only in 1582, in the context of the Gregorian calendar reform, that the Julian leap-year rule was finally modified so as to halt the equinoctial drift. The Gregorian solution was to suppress three bissextile days over the course of 400 years, which lowered the average year length to $365\frac{97}{400}$ days = $365;14,33\text{d}$ = 365.2425d , creating a value that was identical to the Alfonsine year length up to the second

solis in uno die et, e contra, si per medium cursum diviseris zodiacum exhibit vera anni quantitas." I have omitted Holbroke's description of the converse case, where the surplus-difference found at first approximation is greater than $1/132$ th of a day.

³⁰ See on this point Meeus 2002, pp. 359–366; Steel 2000, pp. 380–383.

³¹ See n. 28 for the quoted passage.

³² See Nothaft 2015 and ch. 7 in Nothaft 2018.

sexagesimal-fractional place.³³ Holbroke's suggestion of omitting a day every 132 years would instead have generated an average calendar year of $365; 14, \overline{32,43,38,10,54}d$, which—with the benefit of hindsight—can be seen to provide a closer fit with the aforementioned interval between vernal equinoxes than was the case with the Gregorian leap-year rule.

The other point one should emphasize is that the accuracy of Holbroke's non-Alfonsine estimate for the length of the year was to a large degree fortuitous. From the rather concise remarks in Holbroke's preface, it may be gathered that his "true" solar year was the outgrowth of an idealizing and teleological way of thinking, which started with the assumption that God had created the Sun as a marker for telling time, from which it followed that the true length of the tropical year had to be compatible with a calendar of a moderate-to-low degree of complexity. The limiting criterion adopted by Holbroke, or by whoever first proposed the year length in question, was to restrict the necessary emendation of the Julian calendar to the bissextile day that was inserted in February of every fourth year. This was not easily possible if one followed the Alfonsine value, which at $c.365;14,33,10d$ implied a Julian error of close to day every 134 years. Since 134 was not a multiple of 4, it was tempting to either raise or decrease the correctional period by two years. The former was done in a proposal discussed, but not decreed at the Council of Basel in 1435, which called for the omission of the bissextile day once every 136 years.³⁴ The latter was the approach embodied by Holbroke's "true length of the year", which lasted no more and no less than $365\frac{1}{4} - \frac{1}{132}$ days. As expressly stated in the preface, it was possible to divide the 360° of the zodiac by this particular year length to yield a new value for the Sun's mean motion per day, which was $360^\circ / 365d\ 5; \overline{49,5,27,16,21}h = 0;59,8,19,41,34,52,51,23,34...^\circ/d$. This is evidently the value that underlies the table for the mean motion of the Sun in Holbroke's *Opus secundum* (fol. 154r), where the entry in the first line is rounded to $0;59,8,19,41,34,52,51,24^\circ/d$. As for his *modus operandi* in constructing the remaining tables, Holbroke summarized it as follows:

Once you have found the mean motion of the Sun per day, multiply by it the mean Alfonsine motion of any given planet and divide the product by the mean motion of the Sun you have in the *Alfonsine Tables*, and the result will be the true motion per day of any given planet. This way you will be able to calculate the first entries [*capita*] of all mean motions, both of the planets and of the apogees and fixed stars as

³³ See Swerdlow 1974; 1986.

³⁴ See Nothaft 2015, pp. 186–190.

well as the [mean motions in] anomaly of Venus and Mercury and the access and recess of the eighth sphere.³⁵

We have already seen that Holbroke took the Alfonsine value for the daily mean motion of the Sun to be 0;59,8,19,37,19,13,56,13°/d (S_a), while his newly adopted value for the “true length of the year” gave him 0;59,8,19,41,34,52,51,23,34...°/d (S_h). In order to convert any of the other Alfonsine mean motion parameters (P_a) into the corresponding “true” rate of mean motion (P_h), he had to do no more than apply the ratio between these two numbers, to wit $P_h = (S_h/S_a) \cdot P_a$. An attempt to re-compute the first entries in Holbroke’s tables on this very basis leads to a perfect match for Saturn, Jupiter, Venus, and Mercury, hence confirming that Holbroke practiced what he preached with great precision, down to the eighth sexagesimal-fractional place. Minor discrepancies are detectable in the cases of Mars and the mean motion of the apogees and fixed stars, which may be put down to slight computational errors. For Mars, an application of Holbroke’s algorithm should have led to a mean motion rate of 0;31,26,38,42,20,55,41,56°/d instead of the 0;31,26,38,42,20,55,1,38°/d Holbroke used in creating his table. For the apogees and fixed stars, the *Opus secundum* offers a daily rate of 0;0,0,4,20,41,17,31,13° instead of the arithmetically expected 0;0,0,4,20,41,17,30,46°/d. Another exception worth mentioning is the table for the argument of the access and recess of the eighth sphere (item no. 10 in Tab. 1), which retains the Alfonsine value 0;0,0,30,24,49°/d, explaining why the table’s heading reads *Tabula accessus et recessus octave spere secundum Alfonsum*.³⁶

Greater difficulties of interpretation are posed by Holbroke’s value for the daily mean motion of the Moon, where the standard conversion method would lead to an initial entry of

³⁵ *H*, fol. 152v: “Reperto igitur medio solis cursu in uno die per ipsum multiplica medium motum Alfonsi cuiusvis planete et productum divide per mediu⁵⁹m motum solis quem in tabulis Alfonsi habes, et exibat vere medius cursus cuiuslibet planete in uno die. Isto modo calculare poteris capita omnium mediorum motuum, tam planetarum, quam augium et stellarum fixarum, argumentorum quoque Veneris et Mercurii accessusque et recessus octave spere.”

³⁶ In his preface, Holbroke acknowledges that an extension of the entry-value beyond sexagesimals of the fifth place would have caused it to differ from the Alfonsine counterpart and announces his intention eventually to extend the table to the eighth place. See *H*, fol. 153r: “Motus autem augium non variat a tabula Alfonsi nisi in septimis et octavis et quoniam accessus et recessus octave spere non ponitur in tabulis ultra quinta, ideo in motu octave spere non accedit variacio. Si quis autem motum octave spere usque ad octava calculare vellet, inveniret diversitatem aliquam in radice motus illius, sicut in radicibus que ponuntur in capitibus aliarum tabularum, quamvis id non oporteat. Intendo tamen cum mihi vacaverit illam tabulam etiam usque ad octava deducere, ut plane pateat quid superaddendum sit motibus per Alfonsum repertis.”

13;10,35,2,12,8,39,31,8°/d. The *Tabula continens medium motum lune* on fol. 154v instead starts on 13;10,35,1,19,38,49,49,9°/d, which comes significantly closer to the Alfonsine value (13;10,35,1,15,11,4,35°/d). Holbroke's remarks in the preface would make one believe that his method in establishing the "true" daily mean motion of the Moon (M_h) was based on the relation $M_h = (S_h \cdot \eta + 360^\circ)/\eta$, where η is the independently determined length of the mean synodic month.³⁷ From Holbroke's tabulated values for M_h and S_h one would expect η to be 29;31,50,7,36,57,49,1,10d = 29d 12;44,3,2,47,7,36,28,8h, which is indeed the precise value implied by the initial entry in his table for the mean elongation $360^\circ/12;11,26,41,38,3,56,57,45^\circ/d = 29d 12;44,3,2,47,7,36,28,8h$. Apart from providing the just-mentioned Ptolemaic formula or "canon" to derive M_h from S_h and η , Holbroke's preface informs us that the length of the mean synodic month according to Ptolemy exceeds the Alfonsine value by 0;0,0,12,45h.³⁸ It would appear that the Ptolemaic value Holbroke had in mind here was 29;31,50,8,9,20d,³⁹ which is the same as 29d 12;44,3,15,44h. Adding 0;0,0,12,45h will yield 29d 12;44,3,2,59h, which is in good agreement with the mean elongation in the *Alfonsine Tables*. The latter is 12;11,26,41,37,51,50,39°/d (Pouille 1984, p. 138) and can be converted into a mean synodic month of 29d 12;44,3,2,58,51,22,8h \approx 29d 12;44,3,2,59h. Far from offering the key to M_h , however, an attempt to adjust this Alfonsine length using the ratio S_h/S_a would leave us with 29d 12;44,3,54,2,45,30...h compared to Holbroke's implied 29d 12;44,3,2,47,7,36,28,8h.

We are on much firmer ground when it comes to the remaining lunar parameters: the daily mean motion of the Moon in anomaly, the daily mean motion of the lunar nodes, and the argument of lunar latitude, which depended on Holbroke's mysterious M_h in the same way the mean motions of the five planets were derived from S_h . The tabulated mean motion in anomaly is 13;3,53,57,34,46,33,37,16°/d, which follows from the Alfonsine

³⁷ *H*, fol. 153r: "Pro medio cursu lune in die est hic Ptholomei canon specialis. Si multiplicaveris cursum medium solis diei unius per tempus inter duas coniunctiones medias et resultanti unam revolutionem addideris, scilicet 360 gradus, proveniet motus lune in mense, quem si per tempus inter duas coniunctiones divideris exhibit cursus medius lune diei unius, a quo si medium solis cursum subtraxeris proveniet media elongacio lune a sole, ut antedictum est. Mensis vero Ptholomei excedit mensem Alfonsi in 12 tertiis et 45 quartis hore unius."

³⁸ See n. 37 for the relevant quote. A note at the very end of the preface (*H*, fol. 153r), which was probably added at a later stage, gives the length of the mean lunation as 29;31,50,7,41,26d = 29d 12;44,3,0,4,34,24d. This would lead one to expect an elongation of 12;11,26,41,36,13,14,19,20°/d. Neither of these values seems to be attested in the previous astronomical literature.

³⁹ On the origin of this value, see Mancha 2002–2003; Goldstein 2003b, pp. 67–68.

13;3,53,57,30,21,4,13°/d if one increases it according to the ratio between M_h and the Alfonsine counterpart, to wit $13;3,53,57,30,21,4,13°/d \times 13;10,35,1,19,38,49,49,9°/d \div 13;10,35,1,15,11,4,35°/d = 13;3,53,57,34,46,33,37,16°/d$. The same is true for Holbroke's value for the ascending node (0;3,10,38,7,15,53,43,50°/d), which can be added to M_h to obtain the daily increase in the argument of latitude: $13;10,35,1,19,38,49,49,9°/d + 0;3,10,38,7,15,53,43,50°/d = 13;13,45,39,26,54,43,32,59°/d$.⁴⁰

3. The *Opus secundum* outside the *Codex Holbrookianus*

Besides the *Codex Holbrookianus* and the copy made by Lewis Caerleon in the 1480s, the tables that constitute the *Opus secundum* were transcribed into at least two other astronomical manuscripts produced during the fifteenth century, which provide us with evidence that Holbroke's revised parameter values enjoyed a certain degree of attention in his Cambridge environment. In one of these manuscripts, now Peterhouse MS 267, the original core of mean motion tables appears in a substantially augmented and rearranged form.⁴¹ The familiar format of the *Alfonsine Tables*, with sixty entries per table, has here been replaced with one akin to that used in the *Opus primum*. Each mean motion receives (a) a table of years, first expanded years from 1–20, then collected years in steps of 20 (20, 40 ... 100) and 100 (100, 200 ... 1000); (b) a table for the months of the Julian calendar (January to December); (c) a table for the motion per day (from 1 to 31); and (d) a table for the motion per hour, minute, second etc. (from 1 to 30). In addition to the respective epoch value (1 January AD 1) for the Cambridge meridian, which stays the same as in the *Codex Holbrookianus*, some of the tables for expanded and collected years also feature a second value for the Toledan meridian ordinarily used in conjunction with the *Alfonsine Tables*, which is here taken to lie 4;45° or 0;19h further west.

⁴⁰ See the corresponding remarks in *H*, fol. 153r: "Sed quoniam medius motus lune per proprium canonem inventus est, melius estimo sibi ceteros lune motus proportionare quam ad motum solis. Quapropter auxiliante Deo aptavi tabulas argumenti lune medii, per quas equationum tabulas ingrediens cito capere poteris verissimum lune motum. Motus autem medius argumenti latitudinis lune habetur per additionem medii motus capitis supra medium motum lune."

⁴¹ MS Cambridge, Peterhouse, 267, fols. 96r–100r. This is a large-size codex of approximately 395 × 275 mm made up exclusively of astronomical tables. A subscription at the very end reads "Expliciunt tabule magistri doctoris Holbrook perpetui magistri Collegii Sancti Petri in Cantabrigia" (fol. 100r). According to Kibre 1952, p. 103 (n. 32), and Snedegar 2004, this manuscript was presented to Peterhouse by Holbroke himself, but I am not aware of any evidence to support this.

The same Toledan *radices* make an appearance in a manuscript written by the physician John Argentine (1442–1507/8), a fellow and later Provost of King’s College, Cambridge, who identified the tables of the *Opus secundum* as the “Tables of master John Holbroke, founded on the most true length of the year and made with profound diligence in Cambridge in the Year of the Lord 1433.”⁴² Unlike the Peterhouse manuscript, Argentine’s copy retains the sexagesimal format of the original recension, reproducing all the items in the *Codex Holbrookianus* except for the preface and the redundant table no. 2 (for the annual excess of revolution). Its approximate date can be inferred from a table placed before the beginning (fol. 163v), which updates Holbroke’s epoch values for Cambridge to the completed year AD 1476.⁴³ This inclusion of epoch values for a date close to the present suggests that Argentine intended to employ the *Opus secundum* for practical computational purposes, as is confirmed by the way his copy adds to Holbroke’s mean motion tables a large number of further tables that were needed to make the former fit for practical use. Most of these are drawn from the standard Alfonsine corpus, as is the case with the subjoined tables for chronological conversions, the equation of the eighth sphere, and the equations for the Sun, Moon, and five planets (fols. 171rb–182r). In addition, Argentine included two tables from the *Opus primum*: a table of oblique ascensions at the latitude of Cambridge (52;19°) as well as the table for the equation of time that Holbroke had originally created in 1430 (fols. 181v–182v).

Further evidence for the influence and utility of Holbroke’s “true length of the year” can be gleaned from a voluminous anthology of astronomical-astrological tables and texts assembled in mid-fifteenth century England, which is now MS Oxford, Bodleian Library, Digby 97. Fols. 14r–39v feature the Oxford tables of William Rede, which are here augmented by tables for planetary latitude (fols. 33v–39v) and by a set of a tables for the excess of revolution (fol. 33r). The latter are structurally similar to the tables normally found in the context of the *Alfonsine Tables*, but where the Alfonsine *Tabula revolutionis mensium* finishes on a tropical year length of 365d 5;49,15,59,34,3h, the last line in MS Digby 97 shows 365d 5;49,5,27,16,21,49h. The same number appears in the first line of the *Tabula revolucionis annorum in tempore*, which is accompanied by a *Tabula revolucionis*

⁴² MS Gloucester, Cathedral Library, 21, fol. 164r: “Tabule magistri Iohanne Holbroke fundate super verissimam anni quantitatem et facte erant gravi diligentia Cantebrigie anno domini 1433°.” The tables of the *Opus secundum* follow on fols. 164r–171ra. See Rhodes 1954–1958, p. 211.

⁴³ The same material was copied separately in MS Oxford, Bodleian Library, Lyell 37, fol. 123r.

ascendencium annorum in motu that shows the annual excess of revolution in degrees rather than hours (first entry: 87;16,21,49,5,27,16°). For the first 20 of their entries, these tables are practically identical to items no. 2 and 16 in the *Opus secundum*, where the 20 expanded years are followed by groups of collected years (20, 40 ... 100, 200 ... 1000). In MS Digby 97, by contrast, the two tables are arranged for a cycle of 33 consecutive years, such that the final line in each table can serve both the 33rd, 66th, and 99th year in a given sequence. By doing so, the tables reveal an intriguing arithmetical consequence of making the year last exactly $365\frac{1}{4} - \frac{1}{132}$ days = 365d and 5;49,5,27,16,21h, which is never addressed in the *Opus secundum*, although it could have been inferred from its item no. 2: the excess of 5;49,5,27,16,21h or 0;24d contained in this year length grows to a full number of hours after 11 iterations, as $5;49,5,27,16,21h \times 11 = 16h$. After 33 iterations this will have accumulated to 48h and hence to two complete days. It follows that the calculation of the excess of revolution will return to start after only 33 years, as $33 \times 365\frac{1}{4} - \frac{1}{132}$ days = 12,053 days.

A different attempt to convey the same principle in tabular form appears on fol. 41r of the same manuscript together with the heading “On the Sun’s entry into Aries in all perpetuity counted from the year in which you are” (*De introitu solis in Arietem imperpetuum connumerato anno illo in quo es*). Here, the idea was to arrange a table for the specific purpose of finding the time of the vernal equinox in future years if the time in some current or past year was already known. The table operates on the assumption that this time will increase by exactly 5;49,5,27,16,21,49h from one year to the next, such that by the start of the 33rd year the increment will have reached 18;10,54,32,43,38,8h. The table ends here, but the manifest implication of the whole scheme was that by the end of this year, the superfluous hours and minutes will have accumulated to almost exactly 8 days, falling short by only 0;0,0,0,0,3h ($18;10,54,32,43,38,8h + 5;49,5,27,16,21,49h = 23;59,59,59,59,59,57h$). The shortfall in question is explicable on the grounds that the author increased the value of each line by 5;49,5,27,16,21,49h while ignoring any of the additional fractions beyond the sixth fractional place, which are duly taken into account in the tables on fol. 33r as well as in the *Opus secundum*.

The precise year length of 365d 5;49,5,27,16,21,49h is encountered for a second time on fol. 71v at the start of a brief text with the incipit *Quantitas anni solaris sit*, which appears

in the same scribal hand as the aforementioned tables.⁴⁴ It includes a demonstration of how one might use knowledge of the length of the solar year to extract from it the Sun's daily mean motion and later moves on to discuss how the mean motion of the Sun can be used to generate "true" mean motion values for the remaining planets. The method was obviously inspired by the *Opus secundum*, which explains why the text ends up citing Venus's rate of mean motion in anomaly as 0;36,59,27,26,39,25,23,58°/d, expressly pointing out that this is the correct value "according to Master John Holbroke."⁴⁵ This testimony aside, *Quantitas anni solaris sit* gives us some idea of the computational method a fifteenth-century astronomer such as Holbroke would have used in converting an assumed length of the solar year into a parameter value for the daily mean motion. The basic move involved dividing 360° by the length of the year, but before this division was performed, it was expedient first to reduce both numbers to the same sexagesimal order of magnitude. If the assumed year length involved a precision up to sexagesimals of the sixth place, it made sense to write down the size of the zodiac as $360 \times 60^6 = 16,796,169,000,000$ sixths of a degree and then divide this number by the numbers of sixths of a day contained in a solar year.

Remnants of this type of calculation survive on a fly-leaf bound into MS Oxford, Bodleian Library, Ashmole 369, the verso-side of which contains the table of contents for this astronomical composite codex. On the recto-side (fol. 8r), we find a closely connected sequence of astronomical parameters and brief notes, some of which can be linked to the *Opus secundum*. Holbroke's mean motion parameter here appears concealed as 165,550,801,294,284, which is the number of sexagesimals of the eighth place contained in 0;59,8,19,41,34,52,51,24°. In addition, the scribe jotted down the number of sexagesimals of the thirteenth place contained in 360° of the zodiac: 47,018,498,457,600,000,000,000,000. Further below on the same page we find calculations for the date of the vernal equinox in the years 1432, 1434, and 1437, all of them made on the basis of the *Alfonsine Tables*, but for the meridian of Cambridge. The same location features prominently in the centrepiece of the fly-leaf in question, which is a table of epoch values for the Christian era. Most of these are identical to the values for Cambridge and Toledo noted in the modified *Opus secundum* of

⁴⁴ MS Oxford, Bodleian Library, Digby 97, fols. 71v–72r. An abbreviated version of the same text appears in MS Oxford, Hertford College, 4, fols. 53v–54r.

⁴⁵ MS Oxford, Bodleian Library, Digby 97, fol. 72r: "Deinde multiplica unum per alium et illud productum divide per medium motum solis in die secundum Alfonsum resolutum eciam in minutas fractiones et proveniet tibi veraciter motus medius argumenti Veneris, qui est 0.0.36.59.27.26.39.25.23.58 secundum magistrum Iohannem Holbrok."

MS Peterhouse 267 as well as in the copy made by John Argentine.⁴⁶ The heading of the table in MS Ashmole 369 informs us that the two meridians in question (Toledo and Cambridge) are 0;0,47,30d apart, which is equivalent to the 0;19h assumed in Holbroke's writings. On the preceding fol. 7v, we find values for the corresponding geographic longitudes (11° and 15;45°) as well as the latitude and co-latitude of Cambridge (52;19° and 37;41°), which are again identical to the numbers Holbroke had originally written below the autograph preface of his *Opus primum*.⁴⁷

4. Holbroke's "true length of the year" and the *Kalendarium verum anni mundi* of Richard Monke

A less straightforward, but still palpable connection between Holbroke's known works and the fly-leaf in MS Ashmole 369 (fol. 8r) lurks behind the parameters written above the aforementioned set of epoch values. The first three of these obviously depend on the length of the tropical year in the standard *Alfonsine Tables*, which is here given in days as

365;14,33,9,57,4,24,44,47,55,51,23,15,30,8h (14 fractional places)

and in days and hours as

365d 5;49,15,58,49,45,53,55,10,20,33h (10 places)

together with the corresponding excess in a Julian year of 365d 6h:

0;10,44,1,10,14,6,4,49,39,27h (10 places).

What follows is the "true length of the year" (*vera anni quantitas*), but "founded on [a period of] 136 years" (*fundata super 136 annos*). The rationale behind this year length appears to have been analogous to that of Holbroke's $365\frac{1}{4} - \frac{1}{132}$ days, as 136 years comprise a complete number of Julian leap-year cycles. Accordingly, a calendar that suppressed the bissextile day in every 136th could be claimed to be in perfect agreement with nature, provided the *vera anni quantitas* was as long as stated on the fly-leaf:

365d 5;49,24,42,21,10,35,17,38,49,24,42h (11 fractional places)

together with a corresponding Julian surplus (*superfluum a 6 horis subtrahendum*) of

0;10,35,17,38,49,24,42,21,10,35,17,38,49,24,42,21,10h (17 places).

There is an intriguing parallel between the way these two numbers were entered on the fly-leaf and a similar set of values found in the bottom margin of fol. 152v of the *Codex*

⁴⁶ MS Oxford, Bodleian Library, Ashmole 369, fol. 8r. The epoch values are for the mean Sun and the four lunar parameters. There are also *radices* for planetary apogees, but these are not Holbroke's.

⁴⁷ Compare MS Oxford, Bodleian Library, Ashmole 369, fol. 7v and *H*, fol. 133v.

Holbrookianus, which contains the beginning of the preface to the *Opus secundum*. In the latter case, a hand that appears to be Holbroke's stated the *vera anni quantitas* as

365d 5;49,5,27,16,21,49,5,27,16,21,49h (11 places)

and the corresponding Julian surplus (*superfluum 6 horarum*) as

0;10,54,32,43,38,10,54,32,43,38,11h (11 places).

What follows is a brief instruction on how to derive these numbers from an accepted year length of $365\frac{1}{4} - \frac{1}{132}$ days: "Divide 24 hours by 132 and out will come the surplus that must be subtracted from 6 hours and the remainder added to the days of the years—and you have the length of the year."⁴⁸ Rather than taking credit for this doctrine, however, Holbroke marked it with somebody else's initials, writing *secundum R.M.* both next to the sentence just cited and next to the two sets of numbers defining the *vera anni quantitas* and *superfluum 6 horarum*. This hint at the involvement of a second author matches the ambiguous manner in which Holbroke introduced the "true length of the year" in the main part of his preface, where he remarked that the "true length of the year, which has been hidden from the wise and the prudent, is now in our times revealed, with God's help, to the little ones."⁴⁹ Was it *R.M.* who had revealed the secret to Holbroke? And to whom were these letters supposed to refer?

One possibility would be to read *R.M.* as the signature of Roger Marchall (c.1417–d. 1477), who became a fellow of Peterhouse in 1437 and whose hand has been recognized as appearing in the *Codex Holbrookianus*, being responsible for the table of contents on fol. 6v and the titles added to several of the texts.⁵⁰ It has already been noted, however, that the passage at the bottom of fol. 152v was probably inserted by the same hand as the preface above it, in which case we must assume that it was written by Holbroke himself. A different interpretation of the initials *R.M.* is provided by the notes on the fly-leaf in MS Ashmole 369, the very first entry on which states that 4909 years flowed from the beginning of the world to the birth of Christ and that according to *R.M.* these 4909 years have to be counted from the

⁴⁸ *H*, fol. 152v: "Divide 24 horas per 132 et exhibit superfluum quod a 6 horis demens adde quod restat diebus anni et habes anni quantitatem. Secundum R.M." Below comes another entry comparing the true length of the year with the Alfonsine year length. The *superfluum* is here given as 0;0,10,31,33,24,4,49,43h, implying 365d 5;49,5,27,16,21,49,5,27h + 0;0,10,31,33,24,4,49,43h = 365d 5;49,15,58,49,45,53,55,10h for the Alfonsine year.

⁴⁹ *H*, fol. 152v: "Igitur, quia nostris temporibus vera anni quantitas, que *a sapientibus et prudentibus abscondita* est, auxiliante Deo *parvulis revelatur*, ad Dei honorem, a quo omnis sapientia est, eius inventionem adque posteritatis solatium demonstramus." The parts in italics derive from the Vulgate text of Matthew 11:25.

⁵⁰ See Voigts 1995, pp. 258, 278–279.

vernal equinox.⁵¹ As already noticed by John North, this unusual chronological figure of 4909 years can be linked to a table for the “true years of the world according to Richard Monke, chaplain from England” (*veri anni mundi secundum Ricardum Monke, capellandum de Anglia*), which appears together with several other tables by the same author in MS Oxford, Bodleian Library, Laud. Misc. 594, fols. 14v–21v (at fol. 14v).⁵² Oddly enough, this happens to be another codex for which the aforementioned Roger Marchall provided a contents list as well as text headings.⁵³

Monke’s table for the “true years of the world” serves an auxiliary function with respect to the following *Kalendarium verum anni mundi* in twelve parts (fols. 15r–20v), which is once again identified as the work of the English chaplain and dated to 1434. This *Kalendarium* was a complex and idiosyncratic production. It relates the astronomical situation in the year of creation, which is here assumed to have begun at the vernal equinox of 4909 BC, to the recent year AD 1428, in which the vernal equinox occurred at the beginning of 12 March. Next to two parallel sets of Golden Numbers (counted *secundum ecclesiam* and *ab origine mundi*), the *Kalendarium* lists the Sun’s daily increase in longitude according to both its mean and true motion. A further set of columns documents how the daily mean motion will accumulate to 360° in the course of a tropical year by juxtaposing a line-by-line increase of 1d 0;20,58h or 1d 0;20,59h with the 360° degrees of the zodiac. Whenever an additional day has accrued from this increment, the calendar inserts a line of zero-values (0;0h and 0°) to make sure it counts 365 rather than just 360 days per year. The final line of the calendar indicates that the total duration of the tropical year will be 365d 5;49,5h, while a note at the beginning notifies us that the same configuration of calendar days and degrees of longitude will reappear with the completion of every 33rd year since the creation of the world.⁵⁴

⁵¹ MS Oxford, Bodleian Library, Ashmole 369, fol. 8r: “Anni ab origine mundi usque ad Christum a [!] ad nativitatem Christi perfecti fluxerunt 4909 secundum R.M. inchoando annum ab equinoctio vernali.” A version of the same statement appears in John of Argentine’s codex containing the *Opus secundum*. MS Gloucester, Cathedral Library, 21, fol. 9r: “Sed secundum R.M. inchoando annum ab equinoctio vernali anni ab origine mundi usque ad annum nativitatis Christi perfecti fluxerunt 4909.”

⁵² North 1983, p. 91; 1992, p. 134; Carey 1992, p. 48.

⁵³ Voigts 1995, p. 284.

⁵⁴ MS Oxford, Bodleian Library, Laud. Misc. 594, fol. 15r: “Vera loca solis in nona spera anno mundi primo et deinde omni anno 33° completo usque ad finem istius seculi secundum Ricardum Monke capellandum de Anglia, videlicet super situm medium inter orientem et occidentem, meridiem et septemtrionem.” The only serious

That Richard Monke intended to operate with a 33-year cycle of the kind seen in the aforementioned tables in MS Digby 97—and hence with a tropical year of $365\frac{1}{4} - \frac{1}{132}$ days—becomes fully apparent from the subjoined “true and perpetual tables of the Sun” (*Tabule solis vere atque perpetue*) containing “true and perpetual epoch values” (*Radices solis vere atque perpetue*), from which users could derive the longitude increment they had to add to the solar longitudes listed in the *Kalendarium* in order to adapt them to any other year of the world.⁵⁵ The meridian of reference is here identified with the “middle of the world”, which in the context of Monke’s *Kalendarium* must be interpreted as whatever meridian showed the vernal equinox to be exactly at noon both in both 4909 BC and AD 1428 (the two years lie 192×33 years apart). While the left half of the “true and perpetual tables” serves this reference meridian, the values in the right half have a constant added to them in order to adjust the *Kalendarium* to the meridian of Oxford. From the size of this constant, which is $0;13,28^\circ$, it can be seen that the assumed middle of the world lies $c.82^\circ$ east of Oxford. The two halves for the *medium mundi* and Oxford each consist of 33 lines and four columns, which together cover a cyclical period of $4 \times 33 = 132$ years. Each of the four columns starts with a value of 0° corresponding to the longitude increment at the end of a 33-year period. With each subsequent line of the respective column, the value increases by 365 or 366 times the daily mean motion of the Sun (*modulo* 360°), depending on whether the year in question is identified as common or bissextile according to the Julian calendar. As seen from Tab. 2 below, the increment at the end of the first year of the first, second, and third 33-year cycle is each listed as $11^\circ 29;45,40^\circ$. In the fourth column, by contrast, the entry for the first year is $0s 0;44,48^\circ$ due to the fact that this particular year (e.g., AD 1432) is taken to contain a leap day. Both here and in the main *Kalendarium*, the entries relevant to the Sun’s daily longitude are given only to the nearest second of arc. As one would expect, however, nearly all of the values listed in the *Tabule solis vere atque perpetue* can be re-computed satisfactorily if one employs Holbrooke’s mean motion parameter of $0;59,8,19,41,34,52,51,23,34\dots^\circ/d$.

		1428	1461	1494	1527
	33	0s 0°	0s 0°	0s 0°	0s 0°

attempt in the previous literature to discuss the structure of Monke’s calendar is North 1983, pp. 91–94, who misunderstood and mischaracterized the material in a number of ways, for instance by claiming that Monke worked with a cycle of 33 “Egyptian years” of 365 days.

⁵⁵ MS Oxford, Bodleian Library, Laud. Misc. 594, fol. 21r.

	1	11s 29;45,40°	11s 29;45,40°	11s 29;45,40°	0s 0;44,48°
1430	2	11s 29;31,20°	11s 29;31,20°	0s 0;30,28°	0s 0;30,28°
	3	11s 29;16,59°	0s 0;16,8°	0s 0;16,8°	0s 0;16,8°
	4	0s 0;1,48°	0s 0;1,48°	0s 0;1,48°	0s 0;1,48°
	5	11;29,47,27°	11;29,47,27°	11;29,47,27°	0s 0;46,36°
...					
	28	0s 0;12,33°	0s 0;12,33°	0s 0;12,33°	0s 0;12,33°
	29	11s 29;58,12°	11s 29;58,12°	11s 29;58,12°	0s 0;57,21°
	30	11s 29;43,52°	11s 29;43,52°	0s 0;43,1°	0s 0;43,1°
	31	11s 29;29,32°	0s 0;28,40°	0s 0;28,40°	0s 0;28,40°
1460	32	0s 0;14,20°	0s 0;14,20°	0s 0;14,20°	0s 0;14,20°

Tab. 2: Excerpt from Richard Monke's *Radices solis vere atque perpetue super situm medium mundi* (MS Oxford, Bodleian Library, Laud. Misc. 594, fol. 21r). Bissexile years are indicated by grey shading.

In the ordinary Julian calendar, 33 years of the average length ($33 \times 365\text{d } 6\text{h}$) will amount to $12,053\frac{1}{4}$ days, leaving a surplus of a quarter-day, which will reach a full day after $4 \times 33 = 132$ years. One way fully to adjust the Julian calendar to the 33-year ‘solar cycle’ operative in Monke's *Kalendarium* would have been to postpone the eighth and final bissexile day contained in this period. If the fourth year of the first 33-year period is intercalary, as indicated in Tab. 2, so will the penultimate year. By extending the eighth intercalation interval from four to five years, the 33-year period can be made to comprise exactly 12,045 ordinary and 8 bissexile days, in line with the fact that $\frac{1}{4} - \frac{1}{132} = \frac{8}{33}$. It is interesting to note that Richard Monke's work shows absolutely no trace of this idea, as the internal structure of his “true and perpetual” tables (and hence of Tab. 2) was governed entirely by the traditional four-year rhythm of the Julian calendar. A modification to its intercalation pattern is indicated only in the final line of the fourth column, which corresponds to the 132nd year. Here, the longitude one must add to the *Kalendarium* is given as 0;14;20° (0;27,48° if the meridian is shifted to Oxford). The year in question is the fourth after a leap-year, in which case the next year should comprise 366 days and therefore raise this value by 0;44,48°. Instead, a return to the start of the table shows the familiar 0,0,0° in line 1, which suggests that instead of counting 366 days, the intervening year was common, with an increment of 11s 29;45,40°. Since the table in question was, by Richard Monke's own lights, meant to be perpetually

valid, its very structure presupposes that the bissextile day will be omitted at the end of every 132nd year.

The prescription of dropping the leap day once every 4×33 years is conveyed in a somewhat less oblique manner by an auxiliary *Tabula de veris litteris dominicalibus et primacionibus ab origine mundi*, which prefaces the main *Kalendarium* and once more carries an ascription to Richard Monke together with the year 1434. Its core part is taken up by a table of annual dominical letters covering a cyclical period of $7 \times 132 = 924$ years. As is common with calendrical tables of this type, Julian leap years are easily distinguished by having two dominical letters assigned to them: one in red, for the period prior to the insertion of the bissextile day (1 January–24 February) and another one in black, for the remainder of the year. In Monke's table, the first of these letters is absent from every 132nd year, thereby indicating the omission of the bissextile day against the standard Julian rule, as is also expressly noted in the corresponding heading.⁵⁶ An earlier version of this table appears near the end of MS Oxford, Bodleian Library, Ashmole 789 (fol. 373v), where it is paired with a second table founded on the same structural principle, but with dominical letters applied specifically to the 924 years from AD 1428 to 2351 (fol. 374r). The accompanying text informs us that this second table was “composed in the year of Christ 1432 by a simple priest with some degree of education in the art of astronomy”, who sought to teach others how to adjust, stabilize, and fix our calendar to the course of the Sun, so that no points of the year henceforth will ever deviate or recede from their current places or days, until the end of the world. [...] And, God willing, the changing nature and instability of our solar calendar, which was first put together by the ancients and has been kept until the present day, will cease in the future. May this grant Our Lord Jesus Christ, the true Sun of justice.⁵⁷

⁵⁶ MS Oxford, Bodleian Library, Laud. Misc. 594, fol. 14v: “Tabula de veris litteris dominicalibus et primacionibus ab origine mundi, in qua scribuntur littere rubie pro omnibus annis bissextilibus huius tabule. Et pro fixione perpetua equinoxii vernalis in kalendario veri anni mundi nulla habentur littera rubia in ultima linea transversali, secundum Ricardum Monke, capellandum de Anglia, anno Christi 1434.”

⁵⁷ MS Oxford, Bodleian Library, Ashmole 789, fol. 374r: “Ista tabula equacionis kalendarii anno Christi 1432 composita per simplicem sacerdotem aliqualem in arte astronomie informatum docet equare, stabilire et confirmare kalendarium nostrum ad cursum solarem, sic quod numquam de cetero aliqua anni tempora ab eisdem locis sive diebus in quibus iam sunt usque ad consummacionem seculi variabunt sive recedent. [...] Et sic Deo volente varietas et instabilitas nostri kalendarii solaris ex antiquis primo compositi et usque ad presens servati in posterum cessabunt, quod concedat dominus noster Ihesus Christi verus solis iusticie.”

That this “simple priest” was none other than Richard Monke, the English chaplain, is abundantly clear from the verso-side of the same page (fol. 374v), which offers a bundle of tables and calculations, all related to the 132-year period, the corresponding tropical year, and the computation of solar longitudes for the meridian of Oxford.⁵⁸ Noteworthy components include a table of expanded and collected years signed *R.M.*, which would look identical to items no. 1 and 2 in Holbroke’s *Opus secundum*, were it not for the fact that Monke multiplied the relevant entry values of 5;49,5,27,16,21,49h (for the annual excess of revolution) 0;10,54,32,43,38,11h (for the Julian surplus) in a linear fashion, leading to minor deviations from the precise result based on a year of $365\frac{1}{4} - \frac{1}{132}$ days.⁵⁹ Given Holbroke’s use of the initials *R.M.* in the bottom of margin of his autograph, it appears virtually certain that he had seen some version of the tables attested in MS Ashmole 789, drawing from them the inspiration for his “true length of the year”. Taking the 132-year cycle as his basis, he rendered Monke’s 5;49,5,27,16,21,49h more precise by increasing the sequence of sexagesimal fractions to the eleventh place (see p. 20 above) and proceeded to compute a table for the excess of revolution where the tally reached exactly 16 hours after 11 years and, by implication, 24 hours, after 33 years.⁶⁰ More than simply improving upon Monke’s original tables, Holbroke used their underlying parameter to recast completely the Alfonsine Tables, leading to the Tables of Cambridge that make up the core of his *Opus secundum*. Of course, what tied these tables to Cambridge was their meridian of reference, not their technical foundation in the guise of the doctrine of the “true length of the year”, the origins of which appear to lie in further west, in Oxford.

⁵⁸ MS Oxford, Bodleian Library, Ashmole 789, fol. 374v. On the bottom of the page we find another reference to Monke’s trademark world era: “Incarnacio Christi anno mundi 4909 imperfecto.” See n. 51 above.

⁵⁹ See also MS Oxford, Bodleian Library, Ashmole 789, fols. 372v–373r, for a set of tables that spell out the excess of revolution and accumulating Julian surplus for every year in a 132-year cycle, again using multiples of 5;49,5,27,16,21,49h and 0;10,54,32,43,38,11h. For year 132, these tables show complementary values of 23;59,59,59,59,59,48h and 24;0,0,0,0,0,12h as opposed to the 24 straight hours an application of the precise year length would have yielded. The 33-year table in MS Oxford, Bodleian Library, Digby 97, fol. 41r (see p. 18 above) generates the same imperfect results.

⁶⁰ The tables in MS Digby 97, fol. 33r (see p. 17 above), which reflect the same principle, are hence most likely based on the *Opus secundum*, whereas the imperfect table found on fol. 41r of the same manuscript, may go back directly to Richard Monke (see n. 59).

5. Conclusion

This article has presented previously overlooked manuscript evidence to show that during the early 1430s two English astronomers, Richard Monke and John Holbroke, endorsed a non-Alfonsine value for the length of the tropical year, which happened to be a superior approximation to the correct interval between vernal equinoxes. This value was the outgrowth of an anthropocentric and teleological conception of the cosmos, according to which the length of the year was by necessity such that it facilitated the construction of a perfect yet simple solar calendar. The assumed length of $365\frac{1}{4} - \frac{1}{132}$ days was one of two values in the vicinity of the commonly used Alfonsine tropical year that could be regarded as possessing precisely this virtue. Compared to its theoretical competitor, which would have lowered the Julian year by only $\frac{1}{136}$ of a day, the length adopted by Monke and Holbroke had the added advantage of giving rise to a “solar cycle” of 33 years involving a perfect repetition of all tabulated values for the longitude of the Sun and the annual excess of revolution.

In addition to this astronomical benefit, the 33-year cycle suggested a new way of improving the Julian calendar, which was to extend every eighth leap-year period from four to five years and hence to intercalate exactly eight days in 33 years. One attractive feature of this correctional cycle would have been its relatively short length of about one-third of a century. Since the discrepancy between the average Julian year and the “true length of the year” is no more than 0;11h, the postponement of the Julian *bissexus* once every 33 years would have made it possible to keep the time of the vernal equinox confined within the same 24-hour period. This point becomes especially relevant if the suggested 33-year cycle is compared to the solution implemented in the Gregorian calendar, where omissions of a bissextile day are only scheduled for every 100th or 200th year and the vernal equinox can oscillate between three different dates (19–21 March).⁶¹ In spite of the mentioned advantages of the 33-year cycle, however, there are no signs that either John Holbroke or Richard Monke pursued or were interested in such a calendrical solution. This is particularly striking in the case of Monke’s *Kalendarium verum anni mundi*, which seems to have been created with the

⁶¹ That the Church would have been better served with a 33-year intercalation cycle has been argued in more recent times by authors such as Duncan Steel, who unfortunately mars some valid points by interweaving them with a ludicrous historical conspiracy theory. See Steel 2000, pp. 187–194.

ambition of displaying a potential way of reforming the ecclesiastical calendar, as indicated by its inclusion of a modified set of *termini paschales* or Easter full moons.⁶²

Monke's failure to adopt or even mention a 33-year intercalation cycle renders moot any attempt to argue for a connection between his work and the Jalālī calendar introduced in Persia in AD 1079, which many have claimed relied on this very cycle to keep the vernal equinox fixed to the start of the year.⁶³ The first known trace of the Persian 33-year cycle in the Latin West can only be detected in 1579/80, when Ignatius Na'matallah, a recently exiled former Syriac Orthodox patriarch of Antioch, told Pope Gregory XIII and the commission in charge of his calendar reform that the equinoxes recede at a rate of one day every 132 years and that the best way to counteract this recession was to delay every eighth leap-day insertion by one year.⁶⁴ That the year length proposed by Ignatius already appears in English sources written in 1433 and 1434 is at the very least an interesting footnote in the annals of calendrical astronomy. More significant in historical terms, however, is John Holbroke's decision to use this year length to alter or "reform" the mean motion parameters that characterized the *Alfonsine Tables* and their many contemporary offshoots and adaptations. In doing so, he went against the grain of an astronomical culture that appears to have valued the uniformity of practice that stemmed from a shared use of identical parameters. How this uniformity first established itself in late medieval Europe and why it held sway for as long as it did are questions that would clearly deserve further research and reflection.

Acknowledgments: Warm thanks to José Chabás, Matthieu Husson, David Juste, and Noel Swerdlow for their helpful comments on earlier drafts.

Declaration of Conflicting Interests: The author states that there is no conflict of interest.

⁶² See MS Oxford, Bodleian Library, Laud. Misc. 594, fol. 15r, where these paschal *termini* are indicated to fall within a range of 13 March–10 April (traditionally: 21 March–18 April), in line with the updated location of the vernal equinox (12 March) and the new Golden Numbers inscribed into Monke's *Kalendarium*.

⁶³ The possibility of such a link was raised by North 1983, pp. 93–94. See on the Jalālī calendar Ginzel 1906, pp. 300–305.

⁶⁴ Ziggelaar 1983, pp. 215–217; Levi Della Vida 1984, pp. 19–22; Takahashi 2014, pp. 326–328.

Manuscripts Cited

Bernkastel-Kues, Cusanusstiftsbibliothek, 212
 Cambridge, Peterhouse, 75.I
 Cambridge, Peterhouse, 267
 Cambridge, University Library, Ee.3.61
 Gloucester, Cathedral Library, 21
 London, British Library, Egerton 847
 London, British Library, Egerton 889
 London, British Library, Royal 12.D.VI
 Oxford, Bodleian Library, Ashmole 340
 Oxford, Bodleian Library, Ashmole 346
 Oxford, Bodleian Library, Ashmole 369
 Oxford, Bodleian Library, Ashmole 789
 Oxford, Bodleian Library, Bodley 300
 Oxford, Bodleian Library, Digby 48
 Oxford, Bodleian Library, Digby 97
 Oxford, Bodleian Library, Laud. Misc. 594
 Oxford, Bodleian Library, Lyell 37
 Oxford, Bodleian Library, Wood D.8
 Oxford, Jesus College, 46
 Paris, Bibliothèque nationale de France, lat. 7286C

References

- Carey, Hilary M. 1987. Astrology at the English Court in the Later Middle Ages. In *Astrology, Science and Society: Historical Essays*, ed. Patrick Curry, 41–56. Woodbridge: Boydell Press.
- Carey, Hilary M. 1992. *Courting Disaster: Astrology at the English Court and University in the Later Middle Ages*. London: Macmillan.
- Carey, Hilary M. 2012. Henry VII's Book of Astrology and the Tudor Renaissance. *Renaissance Quarterly* 65: 661–710.
- Chabás, José, and Bernard R. Goldstein. 2003. *The Alfonsine Tables of Toledo*. Dordrecht: Kluwer.
- Chabás, José, and Bernard R. Goldstein. 2012. *A Survey of European Astronomical Tables in the Late Middle Ages*. Leiden: Brill.

- Chabás, José, and Bernard R. Goldstein. 2013. Computing Planetary Positions: User-Friendliness and the Alfonsine Corpus. *Journal for the History of Astronomy* 44: 257–276, 479–480.
- Chabás, José, and Bernard R. Goldstein. 2015. *Essays on Medieval Computational Astronomy*. Leiden: Brill.
- Clarke, Peter D. 2002. *The University and College Libraries of Cambridge*. London: British Library.
- Emden, Alfred Brotherston. 1963. *A Biographical Register of the University of Cambridge to 1500*. Cambridge: University Press.
- Falk, Seb. 2016. Learning Medieval Astronomy through Tables: The Case of the *Equatorie of the Planetis*. *Centaurus* 58: 6–25.
- Ginzl, Friedrich Karl. 1906. *Handbuch der mathematischen und technischen Chronologie: Das Zeitrechnungswesen der Völker*. Vol. 1. Leipzig: Hinrichs.
- Goldstein, Bernard R. 1974. *The Astronomical Tables of Levi ben Gerson*. Hamden, CT: Archon Books.
- Goldstein, Bernard R. 1988. A New Set of Fourteenth Century Planetary Observations. *Proceedings of the American Philosophical Society* 132: 371–399.
- Goldstein, Bernard R. 1992. Levi ben Gerson's Contributions to Astronomy. In *Studies on Gersonides: A Fourteenth-Century Jewish Philosopher-Scientist*, ed. Gad Freudenthal, 3–19. Leiden: Brill.
- Goldstein, Bernard R. 2001. The Astronomical Tables of Judah ben Verga. *Suhayl* 2: 227–289.
- Goldstein, Bernard R. 2003a. An Anonymous Zij in Hebrew for 1400 A.D.: A Preliminary Report. *Archive for History of Exact Sciences* 57: 151–171.
- Goldstein, Bernard R. 2003b. Ancient and Medieval Values for the Mean Synodic Month. *Journal for the History of Astronomy* 34: 65–74.
- Goldstein, Bernard R. 2004. Preliminary Remarks on Judah ben Verga's Contributions to Astronomy. In *The Practice of Mathematics in Portugal*, ed. Luís Saraiva and Henrique Leitão, 63–90. Coimbra: Por ordem da Universidade.
- Goldstein, Bernard R., and José Chabás. 2013. Planetary Velocities and the Astrological Month. *Journal for the History of Astronomy* 44: 465–478.
- Gunther, Robert Theodore. 1923. *Early Science in Oxford*. Vol. 2, *Astronomy*. Oxford: Oxford Historical Society.
- Gunther, Robert Theodore. 1937. *Early Science in Cambridge*. Oxford: University Press.

- Halliwell, James Orchard. 1840. *A Catalogue of the Contents of the Codex Holbrookianus*. London: Richard and John E. Taylor.
- Harper, Richard 1975. The Astronomical Tables of William Rede. *Isis* 66: 369–378.
- Husson, Matthieu. 2012. Ways to Read a Table: Reading and Interpolation Techniques in Canons of Early Fourteenth-Century Double-Argument Tables. *Journal for the History of Astronomy* 43: 299–319.
- Husson, Matthieu. 2014. Remarks on Two Dimensional Array Tables in Latin Astronomy: A Case Study in Layout Transmission. *Suhayl* 13: 103–117.
- Juste, David. 2017. MS London, British Library, Egerton 889 (update: 18.05.2017). *Ptolemaeus Arabus et Latinus: Manuscripts*. <http://ptolemaeus.badw.de/ms/50>. Accessed 03 September 2017.
- Kibre, Pearl. 1952. Lewis of Caerleon, Doctor of Medicine, Astronomer, and Mathematician (d. 1494?). *Isis* 43: 100–108.
- Kremer, Richard L. 2007. “Abbreviating” the Alfonsine Tables in Cracow: The *Tabulae Aureae* of Petrus Gaszowiec (1448). *Journal for the History of Astronomy* 38: 283–304.
- Kremer, Richard L. 2008. John of Murs, Wenzel Faber and the Computation of True Syzygy in the Fourteenth and Fifteenth Centuries. In *Mathematics Celestial and Terrestrial*, ed. Joseph W. Dauben, Stefan Kirschner, Andreas Kühne, Paul Kunitzsch, and Richard P. Lorch, 147–160. Stuttgart: Wissenschaftliche Verlagsgesellschaft.
- Kremer, Richard L. 2011. Experimenting with Paper Instruments in Fifteenth- and Sixteenth-Century Astronomy: Computing Syzygies with Isotemporal Lines and Salt Dishes. *Journal for the History of Astronomy* 42: 223–258.
- Levi Della Vida, Giorgio. 1948. *Documenti intorno alle relazioni delle chiese orientali con la S. Sede durante il pontificato di Gregorio XIII*. Vatican City: Biblioteca Apostolica Vaticana.
- Lovatt, Roger. 1993. Two Collegiate Loan Chests in Late Medieval Cambridge. In *Medieval Cambridge: Essays on the Pre-Reformation University*, ed. Patrick Zutshi, 129–165. Woodbridge: Boydell Press.
- Mancha, José Luis. 1998a. Heuristic Reasoning: Approximation Procedures in Levi ben Gerson’s Astronomy. *Archive for History of Exact Sciences* 52: 13–50.
- Mancha, José Luis. 1998b. The Provençal Version of Levi ben Gerson’s Tables for Eclipses. *Archives internationales d’histoire des sciences* 48: 269–353.
- Mancha, José Luis. 2002–2003. A Note on Copernicus’ “Correction” of Ptolemy’s Mean Synodic Month. *Suhayl* 3: 221–229.

- Meeus, Jean. 2002. *More Mathematical Astronomy Morsels*. Richmond, VA: Willmann-Bell.
- North, John D. 1976. *Richard of Wallingford*. 3 vols. Oxford: Clarendon Press.
- North, John D. 1977. The Alfonsine Tables in England. In *ΠΙΣΜΑΤΑ: Naturwissenschaftsgeschichtliche Studien; Festschrift für Willy Hartner*, ed. Y. Maeyama and W. G. Saltzer, 269–301. Wiesbaden: Steiner.
- North, John D. 1983. The Western Calendar—“Intolerabilis, Horribilis, et Derisibilis”: Four Centuries of Discontent. In *Gregorian Reform of the Calendar*, ed. George V. Coyne, Michael A. Hoskin, and Olaf Pedersen, 75–113. Vatican City: Specola Vaticana.
- North, John D. 1986. *Horoscopes and History*. London: Warburg Institute.
- North, John D. 1992. Astronomy and Mathematics. In *The History of the University of Oxford*, vol. 2, *Late Medieval Oxford*, ed. J. I. Catto and Ralph Evans, 103–174. Oxford: Clarendon Press.
- North, John D. 1996. Just Whose Were the Alfonsine Tables? In *From Baghdad to Barcelona*, ed. Josep Casulleras and Julio Samsó, vol. 1, 453–475. Barcelona: Instituto “Millás Vallicrosa” de Historia de la Ciencia Árabe.
- Nothaft, C. P. E. 2014. Critical Analysis of the Alfonsine Tables in the Fourteenth Century: The Parisian *Expositio tabularum Alfonsii* of 1347. *Journal for the History of Astronomy* 46: 76–99.
- Nothaft, C. P. E. 2015. Thomas Strzemiński, Hermann Zoest, and the Initial Stages of the Calendar Reform Project Attempted at the Council of Basel (1434–1437). *Cahiers de l’Institut du Moyen-Âge Grec et Latin* 84: 164–303.
- Nothaft, C. P. E. 2017. Criticism of Trepidation Models and Advocacy of Linear Precession in Latin Medieval Astronomy. *Archive for History of Exact Sciences* 71: 211–244.
- Nothaft, C. P. E. 2018. *Scandalous Error: Calendar Reform and Calendrical Astronomy in Medieval Europe*. Oxford: Oxford University Press.
- Pedersen, Fritz S. 2002. *The Toledan Tables*. 4 vols. Copenhagen: Reitzel.
- Pedersen, Olaf. 1986. The Problem of Walter Brytte and Merton Astronomy. *Archives internationales d’histoire des sciences* 36: 227–248.
- Poulle, Emmanuel. 1984. *Les Tables Alphonsines avec les canons de Jean de Saxe: édition, traduction et commentaire*. Paris: CNRS Éditions.
- Poulle, Emmanuel. 1987. Les *Tables Alphonsines* sont-elles d’Alphonse X? In *De astronomia Alphonsi regis*, ed. Mercè Comes, Roser Puig, and Julio Samsó, 51–69. Barcelona: Instituto “Millás Vallicrosa” de Historia de la Ciencia Árabe.

- Pouille, Emmanuel. 2005. Les astronomes parisiens au XIV^e siècle et l'astronomie alphonsine. In *Histoire littéraire de la France*, vol. 43.1, 1–54. Paris: Boccard.
- Price, Derek J. 1955. *The Equatorie of the Planetis*. Cambridge: University Press.
- Rhodes, Dennis E. 1954–1958. Provost Argentine of King's and His Books. *Transactions of the Cambridge Bibliographical Society* 2: 205–212.
- Samsó, Julio. 1987. Alfonso X and Arabic Astronomy. In *De astronomia Alphonsi regis*, ed. Mercè Comes, Roser Puig, and Julio Samsó, 23–38. Barcelona: Instituto “Millás Vallicrosa” de Historia de la Ciencia Árabe.
- Snedegar, Keith. 2004. Holbrooke, John (d. 1437). *Oxford Dictionary of National Biography*. <http://www.oxforddnb.com/view/article/13482>. Accessed 02 September 2017.
- Steel, Duncan. 2000. *Marking Time: The Epic Quest to Invent the Perfect Calendar*. New York: Wiley & Sons.
- Sverdlow, Noel M. 1974. The Origin of the Gregorian Civil Calendar. *Journal for the History of Astronomy* 5: 48–49.
- Sverdlow, Noel M. 1986. The Length of the Year in the Original Proposal for the Gregorian Calendar. *Journal for the History of Astronomy* 17: 109–118.
- Sverdlow, Noel M. 2004. Alfonsine Tables of Toledo and Later Alfonsine Tables. *Journal for the History of Astronomy* 35: 479–484.
- Takahashi, Hidemi. 2014. L'astronomie syriaque à l'époque islamique. In *Les sciences en syriaque*, ed. Émilie Villey, 319–337. Paris: Geuthner.
- Voigts, Linda Ehram. 1995. A Doctor and His Books: The Manuscripts of Roger Marchall (d. 1477). In *New Science out of Old Books: Studies in Manuscripts and Early Printed Books in Honour of A. I. Doyle*, ed. Richard Beadle and A. J. Piper, 249–314. Aldershot: Scolar Press.
- Wordsworth, Christopher. 1904. *The Ancient Kalendar of the University of Oxford*. Oxford: Clarendon Press.
- Ziggelaar, August. 1983. The Papal Bull of 1582 Promulgating a Reform of the Calendar. In *Gregorian Reform of the Calendar*, ed. George V. Coyne, Michael A. Hoskin, and Olaf Pedersen, 201–239. Vatican City: Specola Vaticana.