Editing and Analysing Numerical Tables

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Editing and Analysing Numerical Tables

Towards a Digital Information System for the History of Astral Sciences

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Contents

List of Colour Plates

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Copying and Computing Tables in Late Medieval Monasteries*

Seb Falk

Richard of Wallingford, abbot of St Albans (1327–36), was perhaps the greatest astronomer of medieval England.[1] His legacy encapsulates a problem facing historians of medieval astronomy: how can we analyse technical and mathematical practices in their proper contexts? Whilst Richard's most notable works were composed at the University of Oxford, he continued to study astronomy after moving to St Albans, and devised a complex astronomical clock for his abbey church. His contemporaries and successors seem to have been as proud of his astronomic achievements as of his devotional writings or work restoring the abbey's lands; they worked hard to cement the reputation for learning he brought to the abbey.[2] Richard's most notable work was his treatise on the 'Albion' instrument he had invented, an astronomical compendium of great complexity and ingenuity. At least three of the surviving manuscripts of the *Tractatus Albionis* (1326–27) were produced at St Albans. In addition to the usual spiritual benefits arising from the monastic labour of reading, copying and correcting, the monks who produced these manuscripts were showing respect for their predecessor and demonstrating their own humility, qualities that were both central to the Rule of St Benedict.[3]

It is clear that the motivations for producing and studying astronomical works, the techniques required to compute and use them, and the networks of

* I am grateful to Matthieu Husson, Clemency Montelle, Glen Van Brummelen and Benno van Dalen for their advice on earlier drafts of this article. The research underlying it was funded by the Arts and Humanities Research Council, and supervised by Liba Taub. My arguments were refined at a workshop hosted by the TAMAS research project in January 2017, and I would like to thank the participants in that workshop for their constructive feedback.

[1] This was the judgement of Price, 'Review of J. D. North', p. 219.

[2] As narrated by Thomas Walsingham (*c.* 1390); see Riley, *Gesta abbatum monasterii Sancti Albani*, vol. II, pp. 182, 201, 207. See also Falk, 'I Found This Written', pp. 133–34.

[3] Oxford, Bodleian Library, MS Laud Misc. 657, fols 2r–45r; Oxford, Bodleian Library, MS Ashmole 1796, fols 118r–159v; Oxford, Corpus Christi College, MS 144 fols 44r–78v. Corpus Christi MS 144 is usually identified as a Tynemouth manuscript (see Thomson, *A Descriptive Catalogue*, pp. 72–73), but its tables for latitude 51;50°, the high quality of its parchment, and the fact that its chart of saints' days (fol. 59v) includes St Alban but not Tynemouth's patron St Oswine, all point to a southern production. *The Rule of St Benedict* is edited in Fry, *RB 1980*, chs 5, 7, pp. 29–38.

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scientific communication that made astronomy possible, varied between different contexts. Yet it is equally clear that such contexts are hard to define: texts circulated widely, and astronomers too could move between different settings. However, tables can help historians study these contexts. Where we can identify the algorithms and sources behind them, they can reveal not only astronomers' techniques, but also their wider practices and purposes.

Monks certainly had distinctive reasons to study the science: it was essential for the regulation of the ecclesiastical calendar; it supported monasteries' function as local centres of (astrological) medicine; and it was part of a long-established monastic culture of learning that monks worked hard to perpetuate.[4] Nevertheless, it is debatable how far these priorities resulted in distinctive ways of practising astronomy.[5] Put bluntly: how much did monks really *do* astronomy? In order to answer such questions, a case study approach, paying close attention to the individual contexts of production and transmission of its individual sources, may be helpful. Tables, whose astronomical content often allows them to be dated or geographically located with greater precision than other written sources, can be a valuable source for such case studies. Understanding whether – and how – a particular set of tables was copied or calculated can add some depth to analyses of monastic activity.

A manuscript well suited to this kind of case study is Oxford, Bodleian Library, MS Laud Misc. 657. Written almost entirely in a single hand around 1380, it collates two versions of the *Albion* treatise, critically copying and adding text and tables. It begins as follows:

> It should be known that Master Richard, abbot of the monastery of St Albans, first composed this book; and through it he devised and made that marvellous instrument which is called 'Albion'. But later a certain Simon Tunsted, professor of sacred theology, changed certain things not only in the book but also in the instrument, as will be clear to scholars in this book. Also, he added certain things.
>
> Master John of Westwyke gave this book to [the priory of] God and the blessed Mary and St Oswin, king and martyr, at Tynemouth; and to the monks serving the same God there. May the soul of the said John and the souls of all the faithful, through the mercy of God, rest in peace. Amen.[6]

[4] The links between astrology and medicine are well established. Evidence that this applied in a monastic context as much as elsewhere is provided by the existence of medico-astrological books in monastic libraries. See, for example, Cambridge, University Library, MS Gg.6.3; Oxford, Bodleian Library, MS Rawlinson D.238.

[5] The contexts of astronomy were particularly blurred because monks were encouraged to enhance their learning by studying at universities. See Pantin, 'The General and Provincial Chapters', pp. 209–10; Pope Benedict XII, 'Summi magistri' (1336), edited in Wilkins, *Concilia Magnae Britanniae*, vol. II, pp. 588–613, here p. 594.

[6] 'Sciendum est quod Dominus Ricardus Abbas monasterii sancti Albani primo composuit istum librum; Et per eum excogitavit & fecit instrumentum illud mirificum quod dicitur Albeon. Sed postea quidam Symon tounstede sacre theologie professor quedam mutavit tam in

This John was most likely from the manor of Westwick two miles west of St Albans, and probably moved to St Albans's dependent priory of Tynemouth around 1380.[7] The quality of parchment makes it likely that MS 657 was produced at the wealthy mother house, but the manuscript was always intended for its daughter, an outpost far to the north.[8] The clearest evidence of this is a table Westwyk added to the treatise, giving the oblique ascensions for 55°, the latitude of Tynemouth. Analysis of this and related tables can allow us to uncover the methods Westwyk used to produce MS 657; such analysis can supplement study of other features of the manuscript, in order to build a clearer picture of the ways – and perhaps the reasons – monks made astronomical books.

Westwyk evidently modelled his table for 55° on a table of oblique ascensions for 51;50° (the latitude of Oxford), which was already present in the treatise. This essay begins by evaluating Westwyk's copying of that earlier table and the *Tractatus Albionis* as a whole, as a way of exploring his scholarly competence and purposes. Following an explanation of the function of oblique ascensions, I then analyse the new table of oblique ascensions Westwyk added to Oxford, Bodleian Library, MS Laud Misc. 657, separating his processes of computation from copying. The *Albion* text which Westwyk copied hints at how this was done, alluding to Ptolemaic techniques, but this cannot be relied on as an account of his practices. However, we can – within certain limits – reconstruct his practices, and the rest of this essay attempts that reconstruction. The analysis is supported by some statistical tables, as well as by editions of Westwyk's tables of oblique ascensions for 51;50° and 55°. Neither has previously been edited. The *Albion* table for 51;50° has previously been published in a complete edition of the writings of Richard of Wallingford (which drew on Westwyk's manuscript among others).[9] However, its editor, John North, gave a corrected version of the table: an internally consistent table that reproduced what North judged as Richard's intention, with errors removed.[10] Since my focus is the contextualised practices of historical actors, my tables are correct

libro quam in instrumento, sicut patet studentibus in libro isto. Quedam eciam superaddidit. / Hunc librum dedit Dompnus Iohannes de Westwyke deo & beate marie & sancto Oswyno regi et martiri de tynemuth. Et monachis ibidem deo servientibus. Anima dicti Johannis & omnium fidelium anime per dei misericordiam requiescant in pace. Amen', MS Laud Misc. 657, fol. 1v.

[7] Rand, 'The Authorship of *The Equatorie*', p. 21.

[8] Falk, 'I Found This Written', pp. 134–36.

[9] North, *Richard of Wallingford*, vol. III, pp. 96–97.

[10] North, *Richard of Wallingford*, vol. II, pp. 238–39, 247–48. North changed thirteen values where the table was not internally symmetrical (that is, where $\rho(\lambda) \neq 360 - \rho(360 - \lambda)$). He substituted values from the table of oblique ascensions attributed to John Maudith in MS Laud Misc. 674, fols 72r–v.

in a philological sense: reproducing what appears in the manuscripts, including any errors and noting differences between six different manuscripts. It is hoped that the inclusion of blemishes and vestiges of production improves our understanding of such tables, and the contexts in which they were made.

John Westwyk, copying and compilation

In his prefatory remarks (quoted above), John Westwyk highlighted the work he had done to collate and compare two versions of the *Albion*: one apparently as written by Richard of Wallingford; the other adapted by Simon Tunsted. This was an explicit act of *compilatio*, not unusual in the later Middle Ages.[11] Throughout his copy of the treatise and accompanying tables Westwyk notes differences between the versions of 'the lord Abbot' and 'master Simon', and also compares them with an albion instrument ('instrumento nostro') which must have been available to him at the monastery.[12] The areas where he adds to the text reveal something of his interests. Chief among these were the practical aspects of instruments. He notes discrepancies between the differing instrument dimensions given in his source texts, and the dimensions of his own instrument; furthermore, in his most extended original contribution to the treatise, he adds commentary comparing the features of the albion with the saphea of al-Zarqālī (Arzachel) and the astrolabe (Wallingford had himself stated that his invention provided the functions of those and other instruments, but without giving details).[13] By contrast, Westwyk gave less attention to the diagrams that accompany part II of the treatise, illustrating the construction of the instrument. His diagrams are superficially acceptable, appearing in the same places as, and looking fairly similar to, those in other copies of the treatise; but closer inspection reveals that they do not accurately represent the instrument markings carefully described in the text.[14] Given the abilities Westwyk showed elsewhere in his compilation, the errors in his diagrams are unlikely to have been caused by imperfect understanding; rather, he may have realised that the diagrams were simply illustrations for processes that were sufficiently explained in Richard of Wallingford's text, and therefore chose to focus his efforts on making the compilation most useful to its readers.

[11] Hathaway, 'Compilatio', pp. 19–44.

[12] 'dominus abbas … magister Symon'; MS Laud Misc. 657, fols 45r, 22v. For detailed analysis of Westwyk's comparisons, see Falk, 'I Found This Written', pp. 133–40.

[13] MS Laud Misc. 657, fols 10v, 43r–44r; *Tractatus Albionis* III, in North, *Richard of Wallingford*, vol. I, p. 340.

[14] The best copy of the diagrams is in Corpus Christi MS 144. See the comparison in Falk, 'I Found This Written', pp. 137–39. It is just possible that the diagrams were drawn by another person, but they were certainly labelled by Westwyk so it seems more likely he drew them too.

32r	'True motus of the sphere of Saturn' (IV.1) [true centre: the arc at earth between a planet's *aux* and epicycle centre][15]
32v	'True motus of the sphere of Jupiter' (IV.2)
33r	'True motus of the sphere of Mars' (IV.3)
33v	'True motus of the sphere of the Sun and Venus' (IV.4)
34r	'True motus of the sphere of Mercury' (IV.5)
34v	'True motus of the sphere of the Moon' (IV.6)
35r–35v	'True motus of the Moon and of the equation of the argument for the hour of conjunction' (IV.7) [true argument: the arc at the epicycle centre between the Moon and the true epicyclic apogee]
36r	'Table of the equation of iomyn, that is, of the natural day' (IV.8) [normed equation of days + longitude]
36v	Latitude of the Moon (IV.9) [as a function of longitude measured from the node] Table of longitude with its twelfth part; table of twelve conjunctions (IV.10) [twelve equal steps of $1^s 2;30°$ and $11^s 19;17°$]
37r	Motion of the Moon in one hour at aux, mean distance, and opposite aux (IV.11)
37v	Table of fixed stars (IV.12)
38r–38v	Mean motus of Mercury (IV.13)
39r–39v	Mean motus of the Moon (IV.14)
40r–40v	Mean argument of the Moon (IV.15)
41r	Right ascensions (starting at Capricorn) (IV.16)
41v	Right ascensions (starting at vernal equinox) (IV.16)
42r	Oblique ascensions at latitude 51;50° (Oxford) (IV.17)
42v	Oblique ascensions at latitude 55° (Tynemouth)
44v–45r	Lunar elongations (to be inserted after table of mean motus of the Moon (39v))

Table 1: Tables in *Tractatus Albionis*, in Oxford, Bodleian Library, MS Laud Misc. 657.

This meant accurately copying, and where necessary updating, the tables in part IV of the treatise (see Table 1). Westwyk's copies of the standard sequence of tables of the *Tractatus Albionis* are exemplary.[16] This is demonstrated by examination of copies of four tables – IV.12, IV.16 (two versions) and IV.17

[15] These tables, explicitly drafted to aid in the construction of the Albion instrument, are standard in copies of the *Tractatus Albionis* (apart from the one for Tynemouth); their functions are fully explained in North, *Richard of Wallingford*, vol. II, pp. 237–48.

[16] The standard set is edited in North, *Richard of Wallingford*, vol. III, pp. 76–107. The chapter numbers given in brackets are used in some manuscripts (though not MS Laud Misc. 657) and in North's edition.

– in five manuscripts of the Albion, including the three St Albans copies.[17] The fact that tables in these five manuscripts were copied as part of the complete treatise can be established by some consistently occurring errors in the table of oblique ascensions for 51;50°, which can be observed by comparison with other contemporary tables of the same function.[18] Although it is hard to know whether unique errors in any one manuscript are the fault of the scribe of that manuscript, or arise from faithful copying of a faulty source, it is clear from the critical edition in Appendix 1a (see pp. 95–98) that the St Albans manuscripts exhibit greater consistency than the others, and have none of the obvious mistakes (such as in the degrees column) found elsewhere.[19] Two manuscripts are identical throughout table IV.17: Oxford, Corpus Christi College, MS 144 and Oxford, Bodleian Library, MS Laud Misc. 657. Thus John Westwyk may have copied MS Laud Misc. 657 in part from the earlier Corpus Christi MS 144 (while also using the copy ascribed to Simon Tunsted). The copy of the *Albion* in Corpus Christi MS 144 is 'by far the best', according to John North; like Laud Misc. 657 it was later to be taken to Tynemouth.[20] Westwyk's copy contains a diagram, in which the limb of the first face of the second disc is divided into 18 days, which is only found in MS 144, and Westwyk's error in naming a star 'Altayn' in table IV.12 might be traced to the slightly unclear way that the scribe of MS 144 formed the final letters of 'Altayir' (see Plates 4a and 4b).[21] All three St Albans manuscripts contain three identical discrepancies between the two versions of the table of right ascensions (IV.16), which do not appear in the other *Albion* manuscripts; that is, the values for right ascension for longitudes $11^s22°$, $8^s12°$ and $8^s25°$ in the table starting at Capricorn are the same across the three manuscripts, as are the values for those longitudes in the table starting at the vernal equinox, but within each manuscript the two tables disagree. It is clear, then, that although errors exist in the manuscripts, the overall standard of copying was high. Across the four tables examined, MS 657 differs from MS 144 in only two values, one in each table of right ascensions. One of Westwyk's values is unique in copies of this table, so the error was most likely introduced by Westwyk himself. However, the other difference appears at a place where the two tables within MS 144 do not match; Westwyk's change makes his two tables match at that point. This may be coincidental, but perhaps he had noticed the discrepancy and con-

[17] MS Laud Misc. 657, Corpus Christi MS 144 and MS Ashmole 1796, plus London, British Library, Harley MSS 80 and 625.

[18] Corpus Christi MS 144, fol. 122r, and MS Laud Misc. 674, fol. 72r, were used for this purpose.

[19] Such high standards are emphasised by the fact that North's edition of table IV.17 (North, *Richard of Wallingford*, vol. III, pp. 96–97) contains five errors.

[20] North, *Richard of Wallingford*, vol. II, p. 127; Thomson, *A Descriptive Catalogue*, p. 73.

[21] MS Laud Misc. 657, fol. 37v; Corpus Christi College, MS 144, fol. 76v.

sciously corrected it. Either way, it is safe to conclude that he was a particularly accurate copyist.[22]

Computation

If Westwyk's copying was impressively accurate, his computation was equally so. We see this in the table of oblique ascensions for latitude 55°, a table which is not found in contemporary manuscripts and which Westwyk surely computed for this manuscript. The heading of the table, which Westwyk adapted from Wallingford's heading for the table of oblique ascensions for latitude 51;50°, reads:

> Table of ascensions of signs on the oblique circle at latitude 55°. It was calculated and composed as explained in the canons in the second book of the Almagest; and with it the second circle on the second limb of the second face of the instrument should be divided, as is explained in chapter 18 of the second part of this [treatise]. // Tynemouth.[23]

The table gives oblique ascensions as a function of ecliptic longitude. Section II.18 of Richard of Wallingford's treatise explains that the limb (rim) of the albion is to be engraved with three scales: the ecliptic, right ascensions and, in the innermost circle, the oblique ascensions, calculated for the latitude of a place 'where we intend to stay for a long time and make many observations'.[24] This innermost scale was designed to allow the user to easily find the ascendant degree and divide the astrological houses. It was to be marked with degrees of ecliptic longitude ('gradus zodiaci', the argument of the table) corresponding to degrees of oblique ascension read on the 'ecliptic' scale. Thus on

[22] We should perhaps note a contrast with the other table Westwyk added to his copy of the *Tractatus Albionis*: a table of lunar elongations (MS Laud Misc. 657, fols 44v–45r) that does not appear in other copies of the treatise. The presence in the table of obvious copying errors indicates that Westwyk did not compute it himself, but transcribed it from another source. The large number of these errors (20 in a table with 366 values in signs, degrees and minutes) could be deemed a stain on Westwyk's otherwise impressive copying record, but it is quite possible that he made an accurate copy of a corrupt exemplar. The twenty errors do include some that are more likely to be computational, such as 20° instead of 19°; the nature of these, and the fact that the table does not follow a consistent arithmetical progression, suggest that it was computed by subtracting values for solar mean motion from an existing table of lunar mean motions. But that need not have been the table in the *Albion*; tables of mean motions and lunar elongations were sufficiently common to make it most likely that Westwyk copied the table, and did so from a source which itself probably had nothing to do with the *Albion*.

[23] 'Tabula ascencionum signorum in circulo obliquo in latitudine .55. gra. calculata est et composita sicut docent canones in secundo libro Almagesti; et debet per eam dividi circulus secundus in limbo secundo secunde faciei instrumenti sicut docetur capitulo 18° secunde partis huius'. 'tynemuth' is added as a gloss beneath the heading. MS Laud Misc. 657, fol. 42v.

[24] *Tractatus Albionis* II.18, in North, *Richard of Wallingford*, vol. I, p. 325.

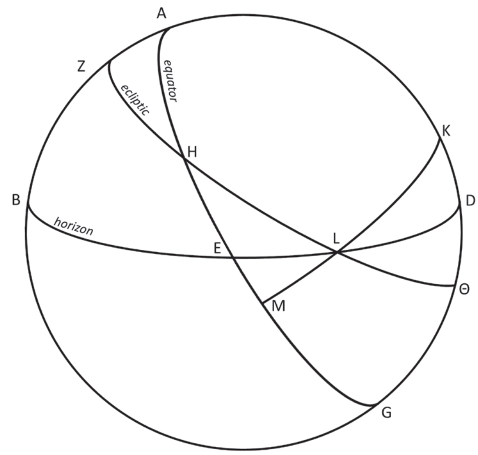

Figure 1: Diagram of ascensions on oblique circle, adapted from *Almagest* II.7. H is the vernal equinox and K the north pole of the equator. The table of oblique ascensions gives the arc of the equator (HE, ρ) rising at the same time as a given arc of the ecliptic (HL, λ). HE is computed by subtraction of the ascensional difference (EM, γ) from the right ascension (HM, α). $\angle$LEM is $90°-\phi$, where ϕ is the latitude of the observer.

the instrument longitude was 'tabulated' as a function of oblique ascension: the reverse of what we find in the tables.[25]

The table and scale of oblique ascension track the rising and setting of points on the celestial equator and ecliptic. Celestial longitude and latitude were defined as positions along and above or below the ecliptic, and these coordinates were the most common way of measuring the positions of stars, including the Sun, Moon and planets; the ecliptic is the path of the Sun (eclipses always take place at 0° latitude), and of course the best-known constellations were those of the zodiac, the band around the ecliptic. However, the rising and setting of signs on the ecliptic does not occur in equal times; rather, it is the equator, set at an angle to the ecliptic, on which points rise and set in equal times (see Figure 1). So the facility to read oblique ascensions – to convert between the rising of the ecliptic and equator – allowed the albion's user to find the ascendant degree at any given time, as Wallingford explains in Section III.18 of the *Albion* treatise.

The table heading cites *Almagest* Book II, where Ptolemy provides tables of rising times (equivalent to oblique ascensions) for a range of latitudes, as defined by the length of the longest day, from 12 hours (0°) to 17 hours (54;1°). Ptolemy explains how these may be computed from the right ascensions, by

[25] Owing to complications in the multiple uses of the ecliptic scale, Richard of Wallingford also instructed that the ascensions scales be graduated in the opposite direction to the ecliptic scale. See North, *Richard of Wallingford*, vol. II, pp. 177–78, 226–32.

calculating the ascensional difference (EM in the right spherical triangle ELM, in which the angle at E is $90°-\phi$, where ϕ is the latitude of the observer). In Figure 1, the oblique ascension (ρ) is the arc (HE) of the equator which rises in the same time as a given arc (HL) of the ecliptic; to find this, the ascensional difference (EM or γ) can be subtracted from the right ascension (HM or α). The right ascensions (rising times at *sphaera recta*) are explained in *Almagest* I.16, where Ptolemy notes that *sphaera recta* is a special case in which the horizon passes through the poles of the equator; an observer at the equator sees the stars ascending at right angles to the horizon. Ptolemy applied the spherical theorem he had proved in *Almagest* I.13 (known as Menelaus' Theorem, though Ptolemy only mentions Menelaus in the context of observations) to find the right ascension.[26] His method used the table of chords which he had provided in I.11, and is mathematically equivalent to the modern formula:

$$\sin \alpha = \tan \delta \cdot \cot \varepsilon, \tag{1}$$

where δ is the declination (arc LM in Figure 1) and ε is the obliquity of the ecliptic.[27] In *Almagest* I.12 he showed how the obliquity can be found by observation, and stated its extent as one half of approximately 11:83 of a complete circle. This matches the maximal value he gives in his table of declinations (I.15), which tabulates the length of the arc of a meridian between the equator and the ecliptic for longitudes (λ) from 0° to 90°. At $\lambda = 0°$ the declination is 0, since that is the vernal equinox, where the equator and ecliptic intersect; its maximal value at $\lambda = 90°$ is equal to the obliquity of the ecliptic, which Ptolemy specifies as 23;51,20°. The formula underlying the table of declinations is equivalent to:

$$\sin \delta = \sin \lambda \cdot \sin \varepsilon, \tag{2}$$

Thus obliquity is used twice in the process of computing right ascension, and so two different values of ε could, in principle, be used, though this would upset the clear symmetry of the right ascensions and prevent the right ascension at $\lambda = 90°$ being equal to 90°, which would be a starkly unacceptable result.

The size of the obliquity also underlies the ascensional difference (γ), for which Ptolemy outlines a method equivalent to the modern formula:

$$\sin \gamma = \tan \delta \cdot \tan \phi. \tag{3}$$

The oblique ascension HE can then be found by a simple subtraction.[28]

[26] Toomer, *Ptolemy's Almagest*, ch. VII.3, pp. 336, 338.

[27] Pedersen, *A Survey of the Almagest*, pp. 96–97.

[28] Pedersen, *A Survey of the Almagest*, pp. 110–13. It is possible to compute the oblique ascension directly, by a single formula in which λ, ϕ and ε are the only variables, but such

Analysis of tables of oblique ascensions for 51;50° and 55°

I analysed the oblique ascensions tables for 51;50° and 55° in MS Laud Misc. 657. It was established above that John Westwyk copied the former, perhaps from Corpus Christi MS 144, but that the latter involved at least some computation on his part. This analysis allows us to understand the extent of this computation, and some of the methods used. John Westwyk's heading for his table repeats Richard of Wallingford's statement that it has been computed with reference to *Almagest* Book II. This cannot be taken completely at face value, but we must start from the assumption that a method like Ptolemy's, which computes the oblique ascension by subtracting the ascensional difference from the right ascension, was used.

The first step in our analysis of the table is to check both its overall symmetry and that of its presumed underlying functions of right ascension (α) and ascensional difference (γ). These two functions have different symmetries: the former is symmetrical such that $\alpha(180 - \lambda) = 180 - \alpha(\lambda)$, while the latter is symmetrical such that $\gamma(180 - \lambda) = \gamma(\lambda)$. Both α and γ can therefore be extracted from oblique ascension ρ by the following formulae:

$$\alpha(\lambda) = 90 + \tfrac{1}{2}(\rho(\lambda) - \rho(180-\lambda)) \qquad (4)$$

$$\gamma(\lambda) = 90 - \tfrac{1}{2}(\rho(\lambda) + \rho(180-\lambda)) \qquad (5)$$

It follows from the above that the entire oblique ascension function is symmetrical such that $\rho(\lambda) = 360 - \rho(360 - \lambda)$.[29] Therefore we begin our analysis of Westwyk's tables by using this overall symmetry to check for large errors in the tables. Once any such errors have been isolated, we can then proceed to separate the functions of right ascension and ascensional difference in order to identify the underlying parameters.

This first check – whether pairs of values on either side of 180° add up to 360° – revealed 13 asymmetries (occasions where $\rho(\lambda) + \rho(360 - \lambda) \neq 360$) in Westwyk's 51;50° table, and 18 in his 55° table. All those in the table for 51;50° occurred in places where the *Albion* copies of this table are consistent but do not match the one in in the non-*Albion* MS Laud Misc. 674 (see Appendix 1a); the latter manuscript's values in those places are symmetrical (though it has mistakes of its own elsewhere).[30] This suggests that these asymmetries arose in an early copy of the *Albion* tables. Of the 18 asymmetries in Westwyk's 55° table, 14 were exactly 1′ in size, which suggests they may have arisen in

a formula does not exist in any medieval source. (It would also preclude the combination of more than one value for the obliquity, which does occur in medieval tables).

[29] van Dalen, *Ancient and Mediaeval Astronomical Tables*, pp. 67, 185.

[30] At λ = 0s19°, 2s8°, 2s29°, 4s18°, 6s2°, 6s18°, 7s3°, 7s6°, 7s29°, 8s0°, 9s12°, 10s29° and 11s28°.

the process of calculation, and may be analysed further.[31] The remaining four discrepancies (noted in Appendix 1b on pp. 99–101) were 1°, 30′, 1° and 10′. The large size and roundness of these suggests they came about through the misplacement of digits (whether in calculation or copying cannot be known), and so they may be corrected – made symmetrical – in order to produce an idealised (mathematically consistent) table for use in further analyses. Finally for this stage, a similar check for symmetry can be made in the table of right ascensions, where the values for $\alpha(\lambda)$ should be symmetrical with three other values: those for $180 - \lambda$, $180 + \lambda$ and $360 - \lambda$. Comparison of these sets of four values revealed seven asymmetries, of which five occurred in the same rows (same values of λ) as asymmetries in Westwyk's 55° table.[32] Since in all seven cases of asymmetry three of the four values remained in agreement, we may correct all seven to obtain a mathematically consistent right ascension table. The results of these checks are summarised in the table in Appendix 2 on pp. 102–05 (columns B to D); in most of the columns of this table results are only included where they are significant (i.e. where there are asymmetries).

Next we may derive values for right ascensions from the tables of oblique ascensions using formula 4, and compare these with both the manuscript tables of right ascensions and values computed using formula 1. First, the oblique ascensions table for 51;50° yields values that match the table of right ascensions exactly, except in places where asymmetries have already been noted in this oblique ascensions table, and at $\lambda = 15°$, where an asymmetry was noted in the right ascensions table but none in the oblique ascensions. In all of these cases the correction of the asymmetries as indicated above also removes the mismatch, thus further supporting the plausibility of the corrections.[33] The table for 55° yields values that also match the table of right ascensions, except in seven places where there are discrepancies of 30″.[34] Such discrepancies could, in principle, arise from the use of a table showing more sexagesimal places – a precision to seconds – to calculate the ascensional differences and/or the right ascensions; but the consistent use of such a table would have led to 30″ discrepancies in around half the extracted values – rather more than the seven found. In fact, as Appendix 2 shows, some of these 30″ discrepancies (namely those for arguments 15 and 85) arise from the asymmetries of 1′ in the oblique ascensions; others remain unaccounted for (they correspond to 30″ discrepan-

[31] At λ or $360 - \lambda$ = 15°, 20°, 34°, 35°, 50°, 56°, 85°, 87°, 92°, 136°, 137°, 165°, 168° and 169°. Some of these are apparent confusions of 1/2 and 2/3, which could arise from scribal misreading, but others, such as 3/4 and 7/8, are highly unlikely to arise from misreading.

[32] Asymmetries in the right ascensions table were found at λ (or equivalents) = 15°, 34°, 35°, 71°, 85°, 86° and 87°.

[33] Discrepancies at λ = 0s15°, 0s19°, 2s8°, 2s29° and 4s18° (the procedure only uses values from 0 to 180°).

[34] At λ = 0s11°, 0s15°, 1s13°, 1s14°, 1s20°, 2s25° and 2s28°.

cies in the derived right ascension values in column E). Comparing the corrected mathematically consistent values with values computed using formulas 1 and 2, using a least-squares fit (the sum of the squares of all differences, so that a smaller number indicates a closer match), the following results were obtained (Table 2; see also Appendix 2, columns D and E).[35] The numbers *n* in parentheses are the number of individual discrepancies.[36]

ε	Σ (51;50°)	Σ (55°)	Notes
23;33,30°	19 (*n*=19)	20 (*n*=20)	Value of ε used in Toledan Tables
23;34,45	8 (*n*=8)	9 (*n*=9)	Value of ε producing lowest Σ (but not attested in any medieval source)
23;35°	9 (*n*=9)	10 (*n*=10)	Value of ε attributed to al-Battānī.
23;51°	589 (*n*=80)	586 (*n*=80)	Value of ε used in Ptolemy's *Handy Tables*
23;51,20	611 (*n*=80)	608 (*n*=80)	Value of ε used in Ptolemy's *Almagest*

Table 2: Least squares fit for obliquities underlying right ascensions tables used to compute oblique ascensions.

These results suggest that the tables of oblique ascensions were based on a right ascensions table with obliquity 23;35° (the same conclusion applies irrespective of whether we use a least-squares fit or the simple number of discrepancies). It may be noted that an (insignificantly) closer match with the manuscript tables occurs with an obliquity of 24;34,45°, but this is not sufficient grounds to claim that that was the parameter used by medieval astronomers. We must maintain cautious of the spurious precision offered by the spreadsheet techniques used here. These techniques allow us to compare and choose from a limited range of discrete values attested in surviving manuscripts. The match will inevitably be imperfect, owing to the vagaries of calculation techniques and the imperfections of medieval reference tables. However, even a somewhat anachronistic technique, if used consistently, allows the degree of closeness to be measured so that different values for the obliquity can be compared. The use of squared residuals (Σ) is a fairly crude method of statistical analysis, but it is precise enough to allow us to compare a selection of historically attested parameters. Whatever the results obtained by such techniques of recomputation and statistical analysis, they can only ever be an adjunct to the examination of tangible manuscript evidence.[37]

[35] Values for Σ were rounded to integers. It is, as noted above, theoretically possible to use two different values of ε in formulas 1 and 2, but even small differences yield strikingly discrepant results.

[36] In principle this is to a maximum of 90 comparisons, but in practice four comparisons of the 51;50° table were excluded owing to flaws in the manuscripts.

[37] On the use of these and more complex statistical techniques in history of astronomy, see van Dalen, 'A Statistical Method'; Van Brummelen and Butler, 'Determining the Interdependence'.

Having analysed the right ascensions, we may proceed to derive values for the ascensional difference from the corrected oblique ascensions tables, using formula 5. These may be compared with values computed using formula 3, with the following results (Table 3). As above, the numbers in parentheses are the number of individual discrepancies.

ε	Σ (51;50°)	Σ (55°)	Notes
23;32,30	105 (n=51)	56291 (n=90)	Value of ε used in the Maghribian *zīj* of Ibn Isḥāq (*c.* 1300, value not attested in Latin sources)
23;33,0°	37 (*n*=37)	53507 (*n*=90)	Value of ε used in the *Mumtaḥan Zīj* (Baghdad, *c.* 830), which was also known in Muslim Spain (value not attested in Latin sources)
23;33,15°	23 (*n*=23)	52062 (*n*=90)	Value of ε producing lowest Σ for 51;50° table (but not attested in any medieval source)
23;33,30°	28 (*n*=28)	50594 (*n*=90)	Value of ε used in Toledan Tables
23;35°	367 (*n*=83)	42035 (*n*=89)	Value of ε attributed to al-Battānī.
23;50,44°	36850 (*n*=90)	17 (*n*=14)	Value of ε producing lowest Σ for 55° table (but not attested in any medieval source)
23;51°	38210 (*n*=90)	26 (*n*=23)	Value of ε used in Ptolemy's *Handy Tables*
23;51,20	39651 (*n*=90)	70 (*n*=64)	Value of ε used in Ptolemy's *Almagest*

Table 3: Least squares fit for obliquities underlying ascensional differences used to compute oblique ascensions.

In his 1976 edition of Richard of Wallingford's writings, John North noted that the table of oblique ascensions could incorporate two different obliquities; he remarked that 'there are too many possibilities for it to be profitable to investigate them all', but did test some values using $\lambda = 45°$ and suggested obliquities of 23;35° and 23;33,30° for the two stages of computing the table for latitude 51;50°.[38] The extraction of the underlying ascensional difference function, greater computing power available nowadays, and the development of statistical estimators for these purposes now allow us to state with some confidence that North's suggestion was correct. Although Richard of Wallingford had stated that his table was computed as explained in Book II of the *Almagest*, he clearly did not use Ptolemaic values for the obliquity of the ecliptic.

John Westwyk, on the other hand, updating Richard of Wallingford's treatise for use at a new latitude, did use a Ptolemaic value: the table above shows

[38] North, *Richard of Wallingford*, vol. II, pp. 247–48.

that his oblique ascensions match those computed with an obliquity of around 23;51°. It may not be possible to be certain that Westwyk used precisely 23;51° rather than 23;51,20°. The formula for the ascensional difference (formula 3) incorporates a value for the tangent of latitude (tan ϕ); this would surely have been rounded for the purposes of computation. Reverse-engineering the function will only yield this rounded value of tan 55°, which would produce a value of the latitude ϕ that is not precisely 55°, thus introducing an element of uncertainty into estimates at a precision of sexagesimal seconds. Nevertheless, we can certainly be confident that the new table was computed using a fresh set of ascensional differences with an obliquity different from that used by Richard of Wallingford.

There are two ways John Westwyk could have computed his full table of oblique ascensions: either (1) he could have subtracted ascensional differences from the existing table of right ascensions right across the table from 0–360°; or (2) exploiting the symmetry of the oblique ascensions function, he could have carried out the subtraction of ascensional difference only for $\lambda = 0$ to 180°, and then completed the second half of the table by subtracting the first-half values from 360°. The small asymmetries of Westwyk's table of oblique ascensions suggest that he used the first method; this is supported by the fact that the differences between the manuscript and a computed version are not symmetrically arranged (unlike the table for 51;50°). This hypothesis can be tested by comparing tables computed by both methods, using the manuscript right ascensions and an idealised ascensional difference; the two tables will be identical from 0 to 180° but slightly different from 180 to 360°.[39] Since the ascensional difference is itself derived from the table of oblique ascensions, this is simply a way of correlating errors in the oblique ascension tables with non-symmetric errors in the right ascensions.

As the parameters used for this comparison are merely standardised values of those within the tables themselves, it is not surprising that there are few discrepancies (see Appendix 2, columns H and J). However, the values computed using the symmetry of the oblique ascension function contained more discrepancies with Westwyk's 55° table than the one computed by subtracting ascensional differences right across the table (10, as opposed to 6). On the other hand, when the same comparison was carried out on the table of oblique ascensions for 51;50°, it was found to be a better match with a table computed using the symmetry of the oblique ascension function (4 discrepancies, as opposed to 10). These numbers are small in every case, so it is hard to be sure, but the

[39] The idealised ascensional difference was the value that can be most consistently derived from the manuscript tables of oblique and right ascensions. Since the ascensional difference function is symmetrical such that $\gamma(180 - \lambda) = \gamma(\lambda)$, tables from 0 to 360° will contain 90 values of γ, each repeated four times. The manuscript values were always consistent in at least 3 of the 4 repetitions, so it was easy to identify the idealised ascensional difference.

evidence suggests that whilst Richard of Wallingford computed the second half of his table of oblique ascensions by subtracting the first 180 values from 360°, John Westwyk did so by subtracting ascensional differences from the entirety of Wallingford's table of right ascensions.

Conclusion

In 1326–27, in the heading to his table of oblique ascensions for the latitude of Oxford, where he was then a scholar, Richard of Wallingford wrote that it had been 'calculated and composed as explained in the canons in the second book of the *Almagest*'. This analysis has shown that statement to be only half-true, since Richard used parameters significantly different from those of Ptolemy. Yet half a century later, when the monk John Westwyk came to adapt Richard of Wallingford's tables for the latitude of Tynemouth, he seems to have taken Wallingford's table heading at face value. It is likely that, for the latitude of 55°, he worked through a process starting from his own accurate copy of the table of right ascensions (computed using an obliquity of 23;35°), adapting them by subtraction right across the table of an ascensional difference computed using an ecliptic obliquity of 23;51°.[40] This was done with only four clear errors. In other words, his claim to be following Ptolemy's method was truer than the source from which he copied that claim. It is hard to be certain to what extent either astronomer's choice of obliquity was a deliberate one, but in another (later) manuscript Westwyk used two different obliquities, so it is possible that he made a conscious choice to follow Ptolemy's method faithfully, in contrast to Wallingford's more flexible approach.[41]

Westwyk was not the only person to adapt the *Albion* tables to a new latitude. In three fifteenth-century copies of the version adapted by John of Gmunden in or around 1430, the Oxford table of oblique ascensions is followed by one for Nuremberg.[42] But we cannot know whether the monks of Tynemouth took advantage of Westwyk's efforts: his table was not annotated, and no instrument survives that draws on the table data in the way the *Albion* treatise instructs. On the other hand, it seems that the astrological subject of house divisions associated with Westwyk's table did excite the monks' interest, as blank pages Westwyk left in the manuscript were filled with tables of houses by a near-contemporary hand.[43] These tables are apparently unique in

[40] In the one place where John Westwyk's table of right ascensions starting at the vernal equinox does not match the table in Corpus Christi MS 144, Westwyk's value (which is correct) matches his table of oblique ascensions.

[41] Cambridge, University Library, Peterhouse MS 75.I, fols 63v (23;35°) and 64 (23;33,30°).

[42] Vienna, Österreichische Nationalbibliothek, MSS 5412, 5415; Munich, Bayerische Staatsbibliothek, Clm. 10662.

[43] Falk, *Improving Instruments*, pp. 34–36.

combining a layout starting at the tenth house (midheaven) with a time column enabling the user to adjust the noon values to other times of day.[44] But the copy is a poor one, and a user with moderate astronomical expertise would surely not have been satisfied with its obvious errors and omissions. The values in these tables accord best with an obliquity of 23;33,30° and latitude of 51;50°, but of course this does not preclude their having been copied at Tynemouth, since tables for the Oxford latitude were widespread.[45]

In a quest to understand the monastic context for astronomy, analysis of tables can only provide a small part of the picture, but it can make an important contribution. The mere existence of the collation of Richard of Wallingford's *Albion* treatise told us that John Westwyk, and the monks who followed him, were interested in instruments and astrology. Study of his tables has confirmed that this monk, about whose education little is known, was not only a painstaking copyist, but a careful and competent calculator, capable of using the existing tables available to him to extend his source materials and make them useful in new locations. In this way he played his part in venerating his predecessor Richard of Wallingford and perpetuating the legacy of monastic astronomy, and broader scholarship, which the abbot had left at St Albans and its network of daughter houses.

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[44] They bear some resemblance to the tables of John Walter, devised at Oxford in the late 1380s. See North, *Horoscopes and History*, pp. 126–30.

[45] Since the tables give only degrees, not minutes, we cannot be certain about this obliquity, and an obliquity of 23;35° may well have been used at some stage in their production.

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Appendix 1a: Edition of the table of oblique ascensions for 51;50°

Manuscripts

A = Oxford, Bodleian Library, MS Ashmole 1796, fol. 159r (s. xiv$^{\text{med}}$): *Tractatus Albionis* (St Albans)
C = Oxford, Corpus Christi College, MS 144, fol. 78v (s. xiv$^{\text{med}}$): *Tractatus Albionis* (St Albans)

H_1 = London, British Library, Harley MS 80, fol. 54r (s. xiv^2): *Tractatus Albionis*
H_2 = London, British Library, Harley MS 625, fol. 164r (s. xiv^{ex}): *Tractatus Albionis* (Merton College, Oxford)
L = Oxford, Bodleian Library, MS Laud Misc. 657, fol. 42r (*c.* 1380): *Tractatus Albionis* (St Albans, written by John Westwyk)
M = Oxford, Bodleian Library, MS Laud Misc. 674, fols 72r–v (s. xv): table attributed to John Maudith (d. *c.* 1343)

All but one of these copies of the table are taken from copies of the *Tractatus Albionis*. The last, **M**, is a near contemporary table of the same function. It was used by John North as a source of variant readings in his edition, and has been collated here for comparison purposes, especially to highlight the unity among the *Albion* manuscripts.

L has been used as the copy-text for this table. I have preserved the layout of the original table as far as possible, but had to split it into two parts (with the argument column repeated) due to space limitations.

The St Albans manuscripts (**A**, **C** and **L**) contain fewer errors, and no large errors (mistakes in the degree column or multiple adjacent cells), in contrast with the other copies (**H_1**, **H_2** and **M**). All the *Albion* manuscripts give degrees up to 30, noting the signs where they change (**M** gives degrees to 360, which should be borne in mind when examining the variant readings below the table). Most signs start with 0°, which allowed scribes to write the number of signs in the column usually used for degrees. These sign numbers are highlighted in various ways: **A**, **C** and **H_1** write the number larger and usually in a different colour; **L** (John Westwyk) draws a red box around the number. Where there is an additional 1° at the start of a new sign (4, 7 and 9 signs), **C** and **H_1** note this by writing the 1 alongside the sign number; **A**, **H_2** and **L** do not.

Gloss

[Hec tabula que intitulatur] tabula ascensionum signorum in circulo obliquo, ubi videlicet est elevatio poli 51 gra. et 50 mi. cuiusmodi est latitudo civitatis Oxonie, calculata est et composita sicut docent canones in 2° libro *Almagesti*; et debet per eam dividi circulus 3^{us} in limbo secundo secunde faciei huius instrumenti, sicut docetur capitulo 18° secunde partis huius. [Et hec est forma tabule.]

Gloss: Hec tabula que intitulatur] *om.* **L** signorum] *om.* **CH_1H_2** est latitudo] altitudo est **H_1** circulus 3^{us}] primus circulus **H_1** secundus circulus **H_2** circulus **C** secundo] primo **CH_1H_2** huius$_1$] *om.* **CH_1H_2** Et hec est forma tabule] *om.* **L**

The gloss is not present in **A** or **M**.

Gradus zodiaci	**Tabula [ascensionum] signorum in circulo obliquo in latitudine 51 g et 50 m** (first half)											
	0		1		2		3		4		5	
	g	m	g	m	g	m	g	m	g	m	g	m
1	0	25	13	19	**1[,0]**	30	27	25	5	37	18	31
2	0	49	13	48	1	13	28	31	7	0	19	58
3	1	14	14	17	1	56	29	39	8	24	21	24
4	1	38	14	46	2	40	**2[,0]**	47	9	49	22	50
5	2	3	15	16	3	24	1	56	11	14	24	17
6	2	27	15	46	4	9	3	7	12	38	25	42
7	2	52	16	16	4	55	4	17	14	3	27	9
8	3	16	16	46	5	45	5	28	15	29	28	35
9	3	42	17	17	6	30	6	40	16	54	**5[,0]**	1
10	4	6	17	48	7	19	7	52	18	20	1	26
11	4	31	18	20	8	8	9	6	19	46	2	53
12	4	56	18	52	8	58	10	20	21	12	4	19
13	5	22	19	24	9	48	11	35	22	38	5	45
14	5	47	19	56	10	39	12	51	24	4	7	11
15	6	12	20	29	11	32	14	8	25	29	8	36
16	6	37	21	4	12	25	15	25	26	56	10	3
17	7	3	21	38	13	19	16	42	28	22	11	28
18	7	29	22	12	14	14	18	0	29	38	12	54
19	7	59	22	48	15	10	19	18	**4[,1]**	14	14	19
20	8	20	23	22	16	6	20	37	2	40	15	44
21	8	47	23	58	17	4	21	56	4	7	17	10
22	9	13	24	35	18	2	23	17	5	34	18	36
23	9	39	25	11	19	1	24	37	7	0	20	2
24	10	6	25	50	20	1	25	59	8	26	21	27
25	10	33	26	28	21	2	27	20	9	52	22	53
26	11	0	27	7	22	3	28	42	11	18	24	18
27	11	28	27	46	23	5	**3[,0]**	4	12	45	25	44
28	11	56	28	26	24	9	1	27	14	12	27	9
29	12	23	29	7	25	14	2	50	15	39	28	35
30	12	51	29	48	26	18	4	14	17	5	**6[,0]**	0

Title *adds* Maudith **M** ascensionum] ascensionis **L** in latitudine 15 g et 50 m] *om.* **CAH_1** oxonie cuius latitude est 51 g et 50 m verificata oxonia anno domini 1310 **M**

0,4 1;38] 1;28 **H_1** **0,19** 7;59] 7;55 **M** **0,25** 10;33] 10;31 **H_1** **0,27** 11;28] 11;18 **H_1** **2,8** 5;45] 35;43 **M** **2,27** 23;5] 23;11 **H_1** **2,29** 25;14] 55;13 **M** **4,1** 5;37] 5;27 **H_1** **4,17** 28;22] 119;22 **M** **4,18** 29;38] 119;48 **M** **4,25** 9;52] 7;52 **H_2** **4,27** 12;45] 12;25 **H_1** **4,29** 15;39] 15;30 **H_1** **5,20** 15;44] 15;24 **H_1** **5,28** 27;9] 27;0 **H_1**

Gradus zodiaci	**Tabula [ascensionum] signorum in circulo obliquo in latitudine 51 g et 50 m** (second half)											
	6		7		8		9		10		11	
	g	m	g	m	g	m	g	m	g	m	g	m
1	1	25	14	21	27	10	4	47	0	53	17	37
2	2	21	15	48	28	33	5	51	1	34	18	4
3	4	16	17	18	29	56	6	55	2	14	18	32
4	5	42	18	42	**9[,1]**	18	7	57	2	53	19	0
5	7	7	20	8	2	40	8	58	3	32	19	27
6	8	33	21	32	4	1	9	59	4	10	19	54
7	9	58	23	0	5	23	10	59	4	49	20	21
8	11	24	24	26	6	43	11	58	5	25	20	47
9	12	50	25	53	8	4	12	56	6	2	21	13
10	14	16	27	20	9	23	13	54	6	38	21	40
11	15	41	28	46	10	42	14	50	7	12	22	5
12	17	6	**8[,0]**	12	12	0	15	44	7	48	22	31
13	18	32	1	38	13	18	16	41	8	22	22	57
14	19	57	3	4	14	35	17	35	8	56	23	23
15	21	24	4	31	15	52	18	28	9	31	23	48
16	22	49	5	56	17	9	19	21	10	4	24	13
17	24	15	7	22	18	25	20	12	10	36	24	38
18	25	51	8	48	19	40	21	2	11	8	25	4
19	27	7	10	14	20	54	21	52	11	40	25	29
20	28	34	11	40	22	8	22	41	12	12	25	54
21	29	59	13	6	23	20	23	30	12	43	26	18
22	**7[,1]**	25	14	31	24	32	24	17	13	14	26	44
23	2	51	15	57	25	43	25	5	13	44	27	8
24	4	18	17	22	26	53	25	51	14	14	27	33
25	5	43	18	46	28	4	26	36	14	44	27	57
26	7	10	20	11	29	13	27	20	15	14	28	22
27	8	36	21	36	**10[,0]**	21	28	4	15	43	28	46
28	10	2	23	0	1	29	28	47	16	12	29	2
29	11	29	24	22	2	35	29	30	16	42	29	35
30	12	55	25	4	3	42	**11[,0]**	12	17	9	**12[,0]**	0

Title *adds* Maudith **M** ascensionum] ascensionis **L** in latitudine 15 g et 50 m] *om.* **CAH$_1$** oxonie cuius latitude est 51 g et 50 m verificata oxonia anno domini 1310 **M**

6,2 2;21] 2;31 **H$_1$** 182;51 **M** **6,6** 8;33] 8;23 **H$_1$** **6,18** 25;51] 205;41 **M** **6,22** 1;25] 1;27 **H$_1$** **6,29** 11;29] 11;19 **H$_1$** **6,30** 12;55] 22;55 (should be 222;55) **M** **7,3** 17;18] 227;15 **M** **7,6** 21;32] 231;34 **M** **7,18** 8;48] 8;58 **H$_2$** **7,21** 13;6] 13;8 **H$_1$** **7,29** 24;22] 264;23 **M** **7,30** 25;4] 25;46 **H$_1$** 265;46 **M** **8,4** 9,...18] 9,...58 **H$_2$** **8,28** 1;29] 1;39 **H$_1$** **9,12** 15,44] 315;46 **M** **9,14** 17;35] 318;35 **M** **9,15** 18;28] 319;28 **M** **9,16** 19;21] 320;21 **M** **9,17** 20;12] 321;12 **M** **10,5** 3;32] 3;22 **H$_1$** **10,7** 4;49] 4;40 **H$_1$** **10,12** 7;48] 7;44 **H$_1$** **10,13** 8;22] 8;28 **H$_1$** **10,18** 11;8] 11;12 **H$_1$** **10,29** 16;42] 16;43 **H$_1$** 346;41 **M** **10,30** 17;9] 17;0 **H$_1$** **11,1** 17;37] 13;37 **H$_1$** **11,6** 19;54] 20;54 **H$_1$** **11,13** 22;57] *om.* 57 **H$_1$** **11,12** 22;31] 22;21 **A** **11;15** 23;48] 23;28 **H$_1$** **11.19** 25;29] 25;20 **H$_1$** **11,22** 26;44] *om.* 44 **H$_1$** **11,28** 29;2] 359;11 **M** 29;4 **H$_2$**

Appendix 1b : Edition of the table of oblique ascensions for 55°

Manuscript

L = Oxford, Bodleian Library, MS Laud Misc. 657, fol. 42v (*c.* 1380): *Tractatus Albionis*, written by John Westwyk. See Plate 5.

This table is unique to **L**. I have preserved the layout of the original table as far as possible (see Plate 5), but had to split it into two parts (with the argument column repeated) due to space limitations.

As with the table for 51;50°, John Westwyk gives degrees up to 30, noting the signs where they change. Most signs start with 0°, so that Westwyk could write the new number of signs in the degrees column. He highlighted these sign numbers with a red box around the number. However, in some cases the new sign does not start with 0° (in other words, the oblique ascension jumps from 29;...° to 31;...°). Where this occurs (at the start of 3, 4, 7 and 10 signs), Westwyk did not note the additional 1°. So, for example, 2,0;6° and 3,1;24° are written as **2** 6 and **3** 24.

Gloss

Tabula ascencionum signorum in circulo obliquo in latitudine .55. gra. calculata est et composita sicut docent canones in secundo libro Almagesti; et debet per eam dividi circulus secundus in limbo secundo secunde faciei instrumenti sicut docetur capitulo 18° secunde partis huius.

// tynemuth

Gradus zodiaci	**Tabula ascensionum signorum in circulo obliquo in latitudo .55. gra.** (first half)											
	0		1		2		3		4		5	
	g	m	g	m	g	m	g	m	g	m	g	m
1	0	20	11	8	26	10	21	58	**3[,1]**	24	16	29
2	0	41	11	33	26	49	23	5	2	52	17	59
3	1	1	11	57	27	28	24	13	4	21	19	30
4	1	22	12	23	28	8	25	21	5	49	21	1
5	1	42	12	48	28	49	26	32	7	18	22	32
6	2	2	13	13	29	30	27	42	8	47	24	1
7	2	23	13	39	**1[,0]**	13	28	54	10	17	25	33
8	2	43	14	4	1	57	**2[,0]**	6	11	46	27	3
9	3	4	14	31	1	41	1	20	13	16	28	33
10	3	25	14	58	2	26	2	34	14	46	**5[,0]**	3
11	3	45	15	25	3	12	3	50	16	15	1	33
12	4	6	15	53	3	59	5	6	17	46	3	4
13	4	27	16	20	4	46	6	23	19	16	4	34
14	4	48	16	48	5	35	7	42	20	48	6	4
15	5	8	17	17	6	25	9	1	22	17	7	33
16	5	30	17	48	7	16	10	21	23	47	9	4
17	5	52	18	16	8	7	11	40	25	17	10	33
18	6	14	18	46	9	0	13	1	26	49	12	4
19	6	35	19	17	9	54	14	22	28	19	13	34
20	6	57	19	47	10	48	15	44	29	50	15	3
21	7	19	20	20	11	44	17	7	**4[,1]**	21	16	32
22	7	41	20	52	12	40	18	31	2	52	18	3
23	8	3	21	25	13	38	19	55	4	23	19	33
24	8	25	21	59	14	36	21	20	5	53	21	2
25	8	48	22	32	15	37	22	45	7	24	22	32
26	9	11	23	7	16	37	24	10	8	55	24	2
27	9	34	23	43	17	39	25	36	10	25	25	31
28	9	57	24	18	18	42	27	3	11	57	27	1
29	10	21	24	54	19	46	28	30	13	28	28	30
30	10	45	25	31	20	51	29	57	14	59	**6[,0]**	0

Errors noted (with suggested correction based on the internal symmetry of the oblique ascension function)

2,8 1;57] 0;57

Gradus zodiaci	**Tabula ascensionum signorum in circulo obliquo in latitudo .55. gra.** (second half)											
	6		7		8		9		10		11	
	g	m	g	m	g	m	g	m	g	m	g	m
1	1	30	16	32	1	30	10	14	5	6	19	39
2	2	59	18	3	2	57	11	18	5	42	20	3
3	4	29	19	35	4	24	12	20	6	17	20	26
4	5	58	21	5	5	50	13	23	6	54	20	49
5	7	28	22	36	7	15	14	24	7	28	21	12
6	8	58	24	7	8	40	15	24	8	1	21	35
7	10	27	25	37	10	5	16	22	8	35	21	57
8	11	57	27	8	11	29	17	20	9	8	22	19
9	13	28	28	39	12	53	18	16	9	40	22	41
10	14	57	**8[,0]**	10	14	16	19	12	10	12	23	2
11	16	27	1	41	15	38	20	6	10	43	23	25
12	17	55	3	11	16	59	20	0	11	14	23	46
13	19	27	4	42	18	20	21	53	11	44	24	8
14	20	56	6	12	19	39	22	44	12	12	24	30
15	22	26	7	43	20	59	23	35	12	43	24	51
16	23	56	9	12	22	18	24	25	13	12	25	12
17	25	26	10	44	23	37	25	14	13	40	25	33
18	26	56	12	14	24	54	26	1	14	17	25	54
19	28	27	13	45	26	10	26	48	14	35	26	15
20	29	57	15	14	27	26	27	34	15	2	26	35
21	**7[,1]**	27	16	44	28	40	28	19	15	29	26	56
22	2	57	18	14	29	54	29	3	15	56	27	17
23	4	27	19	43	**10[,1]**	6	29	47	16	21	27	37
24	5	59	21	13	2	18	**11[,0]**	30	16	47	27	58
25	7	28	22	42	3	28	1	11	17	13	28	18
26	8	59	24	11	4	39	1	52	17	38	28	38
27	10	0	25	39	5	47	2	32	18	3	28	59
28	12	1	27	8	6	56	3	11	18	27	29	19
29	13	31	28	36	8	2	3	50	18	52	29	40
30	15	1	**9[,0]**	3	9	9	4	29	19	15	**12**	0

Errors noted (with suggested correction based on the internal symmetry of the oblique ascension function)

6,27 10;0] 10;30 **9,12** 20;0] 21;0 **10,18** 14;17] 14;07

Appendix 2

Comparison of values in John Westwyk's table of oblique ascensions for 55° (Oxford, Bodleian Library, MS Laud Misc. 657, fol. 42v) and related tables, showing significant results and deviations from symmetry

Columns

A: Longitude (λ), 0–360°.

B: Manuscript values of oblique ascension (ρ) as a function of λ, and as a function of 360°–λ.

C: Deviation from symmetry (in minutes): where columns B and C do not add up to 360°.

D: Manuscript values of right ascension (α) as a function of λ, of 180°–λ of, 180°+λ, and of 360°–λ. Values in columns D2 to D4 only supplied where these are not symmetrical with D1.

E: Right ascensions derived from symmetrically arranged values from John Westwyk's oblique ascensions table (see formula 4 above). Values supplied where these do not match D1.

F: Ascensional difference (γ) derived by subtracting the manuscript values of oblique ascension from manuscript values of right ascension (α – ρ; D1 – B1).

G: Ascensional difference derived from symmetrically arranged values from John Westwyk's oblique ascensions table (see formula 5 above). Values supplied where these do not match F.

H: Idealised manuscript oblique ascensions 360–180°, computed by subtracting most consistent value of derived ascensional difference from manuscript right ascension for λ = 180–360°. Values only supplied where these do not match column B2.

J: Idealised manuscript oblique ascensions 360–180°, computed by subtracting most consistent value of derived ascensional difference from manuscript right ascension for λ = 0–180° and subtracting the result from 360°. Values only supplied where these do not match column B2.

A	B1	B2	C	D1	D2	D3	D4	E	F	G	H	J
λ	ρ_{λ}	$\rho_{360-\lambda}$		α_{λ}	$\alpha_{180-\lambda}$	$\alpha_{180+\lambda}$	$\alpha_{360-\lambda}$	α_{derived}	γ_1	γ_2	ρ_1	ρ_2
1	0;20	359;40		0;55					0;35			
2	0;41	359;19		1;50					1; 9			
3	1; 1	358;59		2;45					1;44			
4	1;22	358;38		3;40					2;18			
5	1;42	358;18		4;35					2;53			
6	2;02	357;58		5;30					3;28			
7	2;23	357;37		6;25					4; 2			
8	2;43	357;17		7;20					4;37			
9	3; 4	356;56		8;16					5;12			
10	3;25	356;35		9;11					5;46			
11	3;45	356;15		10; 6				10;5½	6;21	6;20½		
12	4; 6	355;54		11; 1					6;55			
13	4;27	355;33		11;57					7;30			
14	4;48	355;12		12;52					8; 4			
15	5; 8	354;51	−1	13;47	166;12	193;48	346;12	13;47½	8;39	8;39½		354;52
16	5;30	354;30		14;43					9;13			
17	5;52	354;08		15;39					9;47			
18	6;14	353;46		16;35					10;21			
19	6;35	353;25		17;31					10;56			
20	6;57	353;02	−1	18;27					11;30		353; 3	353; 3
21	7;19	352;41		19;23					12; 4			
22	7;41	352;19		20;19					12;38			
23	8; 3	351;57		21;15					13;12			
24	8;25	351;35		22;12					13;47			
25	8;48	351;12		23; 8					14;20			
26	9;11	350;49		24; 5					14;54			
27	9;34	350;26		25; 2					15;28			
28	9;57	350;03		25;59					16; 2			
29	10;21	349;39		26;56					16;35			
30	10;45	349;15		27;53					17; 8			
31	11; 8	348;52		28;50					17;42			
32	11;33	348;27		29;48					18;15			
33	11;57	348;03		30;46					18;49			
34	12;23	347;38	1	31;44			328;17		19;21			347;37
35	12;48	347;13	1	32;42			327;19		19;54			347;12
36	13;13	346;47		33;40					20;27			
37	13;39	346;21		34;38					20;59			
38	14; 4	345;56		35;36					21;32			
39	14;31	345;29		36;35					22; 4			
40	14;58	345;02		37;34					22;36			

A	B1	B2	C	D1	D2	D3	D4	E	F	G	H	J
λ	ρ_{λ}	$\rho_{360-\lambda}$		α_{λ}	$\alpha_{180-\lambda}$	$\alpha_{180+\lambda}$	$\alpha_{360-\lambda}$	α_{derived}	γ_1	γ_2	ρ_1	ρ_2
41	15;25	344;35		38;33					23; 8			
42	15;53	344;17	10	39;32					23;39			
43	16;20	343;40		40;31				40;31½	24;11	24;11½		
44	16;48	343;12		41;30				41;30½	24;42	24;42½		
45	17;17	342;43		42;30					25;13			342;42
46	17;48	342;12		43;30					25;42			
47	18;16	341;44		44;30					26;14			
48	18;46	341;14		45;30					26;44			
49	19;17	340;43		46;31					27;14			
50	19;47	340;12	−1	47;31				47;30½	27;44	27;43½		
51	20;20	339;40		48;32					28;12			
52	20;52	339; 8		49;33					28;41			
53	21;25	338;35		50;34					29; 9			
54	21;59	338; 1		51;36					29;37			
55	22;32	337;28		52;37					30; 5			
56	23; 7	336;54	1	53;39					30;32		336;53	336;53
57	23;43	336;17		54;41					30;58			
58	24;18	335;42		55;43					31;25			
59	24;54	335; 6		56;45					31;51			
60	25;31	334;29		57;47					32;16			
61	26;10	333;50		58;50					32;40			
62	26;49	333;11		59;53					33; 4			
63	27;28	332;32		60;56					33;28			
64	28; 8	331;52		61;59					33;51			
65	28;49	331;11		63; 2					34;13			
66	29;30	330;30		64; 5					34;35			
67	30;13	329;47		65; 9					34;56			
68	31;57	329;03	60	66;13					35;16			
69	31;41	328;19		67;17					35;36			
70	32;26	327;34		68;21					35;55			
71	33;12	326;48		69;25		249;24			36;13			
72	33;59	326;01		70;29					36;30			
73	34;46	325;14		71;33					36;47			
74	35;35	324;25		72;37					37;02			
75	36;25	323;35		73;42					37;17			
76	37;16	322;44		74;47					37;31			
77	38; 7	321;53		75;52					37;45			
78	39; 0	320; 0	−60	76;57					37;57			
79	39;54	320; 6		78; 2					38; 8			
80	40;48	319;12		79; 7					38;19			

A	B1	B2	C	D1	D2	D3	D4	E	F	G	H	J
λ	ρ_λ	$\rho_{360-\lambda}$		α_λ	$\alpha_{180-\lambda}$	$\alpha_{180+\lambda}$	$\alpha_{360-\lambda}$	α_{derived}	γ_1	γ_2	ρ_1	ρ_2
81	41;44	318;16		80;12					38;28			
82	42;40	317;20		81;17					38;37			
83	43;38	316;22		82;22					38;44			
84	44;36	315;24		83;27					38;51			
85	45;37	314;24	1	84;33	95;28	264;32	275;28	84;32½	38;56	38;55½		314;23
86	46;37	313;23		85;38			274;21		39; 1		313;22	
87	47;39	312;20	−1	86;43			273;16		39; 4			312;21
88	48;42	311;18		87;49				87;48½	39; 7	39; 6½		
89	49;46	310;14		88;54					39; 8			
90	50;51	309; 9		90;00					39; 9			
91	51;58	308; 2										
92	53; 5	306;56	1									
93	54;13	305;47										
94	55;21	304;39										
⋮												
108	73; 1	286;59										
109	74;22	285;38				249;24					285;37	
110	75;44	284;16										
⋮												
135	112;17	247;43										
136	113;47	246;12	−1									
137	115;17	244;42	−1									
138	116;49	243;11										
⋮												
152	137;59	222; 1										
153	139;30	220; 0	−30									
154	141; 1	218;59										
⋮												
164	156; 4	203;56										
165	157;33	202;26	−1	13;47	166;12	193;48	346;12				202;27	202;27
166	159; 4	200;56										
167	160;33	199;27										
168	162; 4	197;55	−1								197;56	197;56
169	163;34	196;27	1									
170	165; 3	194;57										
⋮												
179	178;30	181;30										
180	180; 0											

a) 

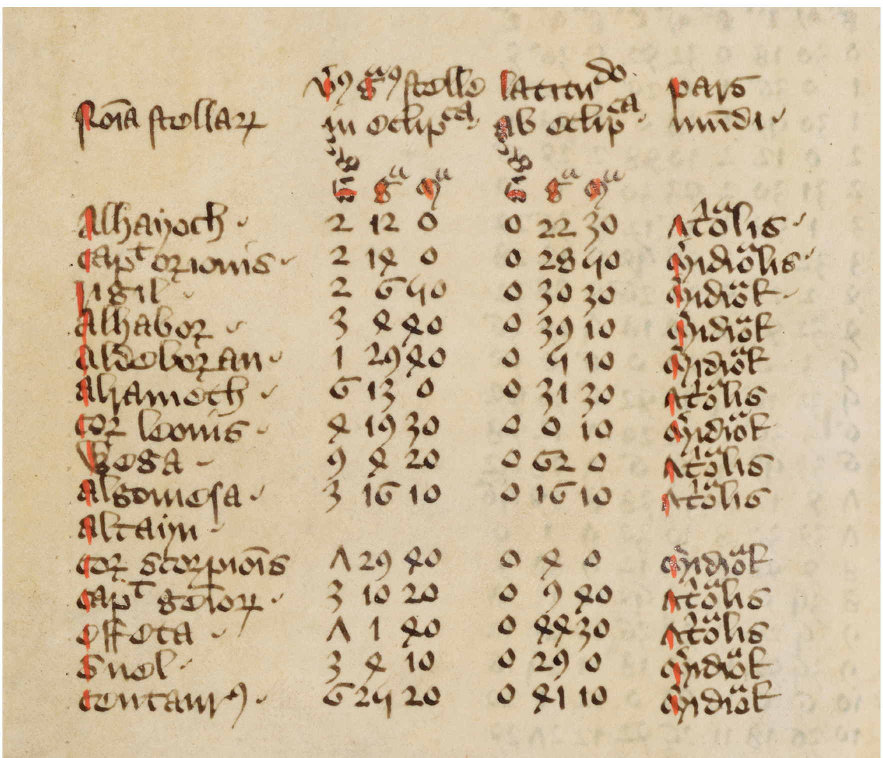
b) 

Plate 4a: Table of fixed stars, *Tractatus Albionis* IV.12, showing possible source of John Westwyk's misspelling 'Altayn'. Oxford, Corpus Christi College, MS 144, f. 76v.
Plate 4b: As above. Oxford, Bodleian Library, MS Laud Misc. 657, f. 37v.
By permission of the Bodleian Libraries, The University of Oxford.

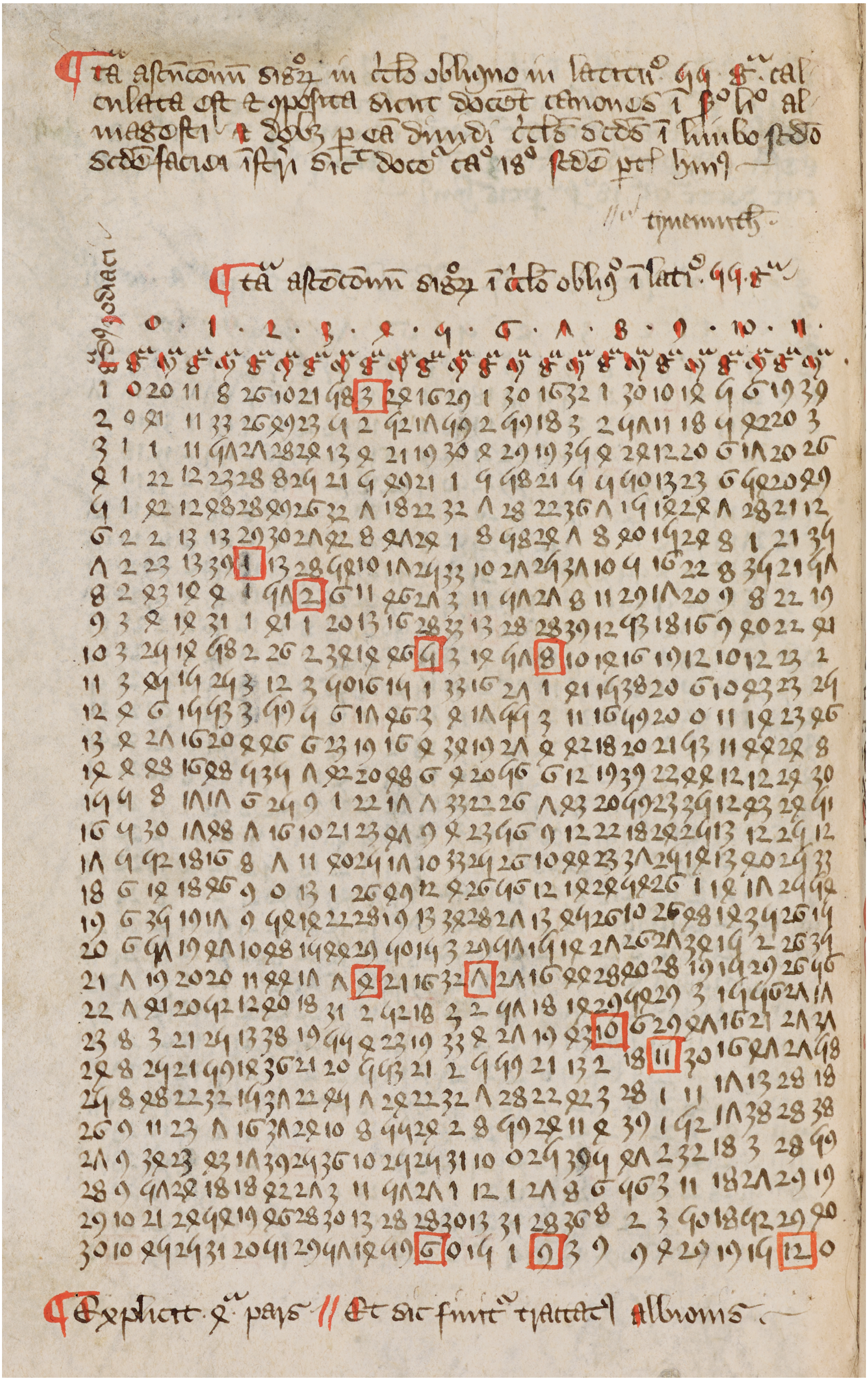


Plate 5: John Westwyk's table of oblique ascensions for 55°. Oxford, Bodleian Library, MS Laud Misc. 657, f. 42v.