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Published in:
Journal of Astronomical History and Heritage

2022

Citation for published version (APA):
Gislén, L., & Orchiston, W. (2022). Analysis of the New Moon Times on the Disk of the Astronomical Clock in Gdansk, Poland. *Journal of Astronomical History and Heritage*, *25*(1), 75-82.

Total number of authors:
2

Journal of Astronomical History and Heritage, 25(1), 75–82 (2022).

ANALYSIS OF THE NEW MOON TIMES ON THE CALENDAR DISK OF THE ASTRONOMICAL CLOCK IN GDANSK, POLAND

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Abstract: The calendar disk of the fifteenth century astronomical clock in the church of Saint Mary in Gdansk (Poland) contains a wealth of astronomical and calendrical data. We make a statistical analysis of the mean conjunction times of all the mean New Moons as represented on the disk for four Metonic 19-year cycles. We find that the conjunction times were generated using the Alfonsine value for the length of the synodic month and with a mean longitude correction from the Alfonsine meridian (Toledo in Spain) by 1 hour and 16 minutes. This indicates a location with a longitude of a little more than 19° east of Toledo but due to the uncertainty of the actual locations in longitude at the time it is not possible to point out a specific location. The method of calculating the conjunction times differs from other contemporary calendars and has considerably less quality than other contemporary conjunction lists.

Keywords: conjunction, calendar, astronomical clock, synodic month, Julian year, Alfonsine Tables, Metonic cycle

1 INTRODUCTION

The astronomical clock in the cathedral of Saint Mary in Gdansk (now in Poland) was constructed by Hans Düringer (d. 1477) in 1464 and is a later type of the medieval astronomical clocks in the Baltic region (Schukowski, 2006). The calendar disk contains a complete set of mean times for all New Moons during the time interval 1463–1538 CE. It also contains other calendrical information, such as ferial letters (Sunday letters), golden numbers, and dates in the ancient Roman calendrical system. In an earlier paper Gislén (2020) studied the astronomical clocks in general in the Baltic region and their relation to the Hanseatic League and also more specifically showed that the conjunction times on the Gdansk calendar disk were based on the Alfonsine Tables (Alfonso, 1483) with a geographical longitude correction that could indicate Nuremberg as their origin.

In this paper we make a deeper statistical analysis of the conjunction times on the disk by considering all its 940 conjunction times and comparing them with computer-generated times using the mean synodic month length of the Alfonsine Tables. The concept of golden numbers is important in the analysis. The golden numbers are based on the Metonic cycle, which uses the fact that 235 synodic months (the mean time between two consecutive New Moons) are very nearly equal to 19 Julian solar years. The length of the synodic month in the Alfonsine Tables is about 29.53059 days and the average Julian year is 365.25 days:

29.53059 × 235 = 6939.6887 days
365.25 × 19 = 6939.7500 days

The cycle got its name from the Greek astronomer Meton who lived in the fifth century BCE, but the cycle was known earlier to Babylonian astronomers. The cycle implies that a New Moon on a specific date will on average occur almost on the same date nineteen years later. By assigning a golden number from 1 to 19 to each year, years with the same golden number will on average have New Moons on the same dates. There is a simple formula for calculating the golden number of a given year: divide the year by 19 and keep the reminder of the division. Add 1 to the remainder. For example, take the year 1465, dividing by 19 gives the quotient 77 and the reminder 2. Thus, the golden number of that year is 3.

The mean New Moon dates fluctuate from their positions given by the simple cycle reckoning. This is because a Julian 19-year cycle contains a whole number of days, and that number depends on the number of leap days in the cycle, which can be either 4 or 5. This means that a Julian 19-year period can have 19 × 365 + 4 = 6939 days or 19 × 365 + 5 = 6940 days. In the first case, there is a deficit of 0.6887 days or 16 hours 32 minutes (16;32) as compared with 235 synodic months. In the second case, there is an excess of 1 – 0.6887 = 0.3113 days or 7 hours 28 minutes (7;28). This fact can be

Figure 1: The Gdansk calendar disk (Wikipedia).

used to carry the conjunction times of a cycle to the following 19-year cycle once the times for the first cycle have been calculated. This will greatly facilitate computations. The numbers 16;32 and 7;28 hours are characteristic of the Alfonsine synodic month.

Four Julian 19-year cycles forming a 76-year cycle contain a whole number of days, 365.25 × 76 = 27759, and the number of days in 4 × 235 synodic months is 4 × 235 × 29.53059 = 27758.7546 days. Thus, when we move from one 76-year cycle to the next we have to correct for the difference of 0.2454 days or 5 hours 53 minutes. Making these corrections, the list of conjunction times can be extended infinitely in the Julian calendar. The calendar disk in Gdansk only uses one 76-year cycle, the four 19-year cycles: 1463–1481, 1482–1500, 1501–1519, and 1520–1538. Each cycle starts with golden number 1.

2 DESCRIPTION OF THE CLOCK AND CALENDAR DISK

At its completion, the astronomical clock in Gdansk with a height of 14 meters was the largest clock in the world. The upper part of the clock contains the clock proper with its pointers for the hour of the day and for the positions of the Sun and the Moon in the zodiac, and shows the phase of the Moon in a circular opening in the dial. The lower part of the clock contains the circular calendar disk with a diameter of about 2.8 meters.

The calendar disk is divided into 365 radial slots one for each day of a normal Julian year. It rotates clockwise one slot per day and the current day is pointed out by the staff of a character placed on the left side of the disk (see Figure 1). Further, the disk is divided into several concentric bands. The outermost band contains the ferial or Sunday letters (see Figure 2, left part). They start with ‘a’ on 1 January, then run counter-clockwise around the disk with ‘b’, on 2 January, ‘c’, ‘d’ and so on until ‘g’ on 6 January. The series with the seven Sunday letters ‘a’ – ‘g’ then repeats around the whole year finally ending with ‘a’ on 31 December. This makes it easy to locate the start of the year on the disk where two ‘a’ letters collide. Knowing the Sunday letter of a specific year will tell the dates of the Sundays for the whole year. Leap years have two Sunday letters, one to use before 28 February, the other one after.

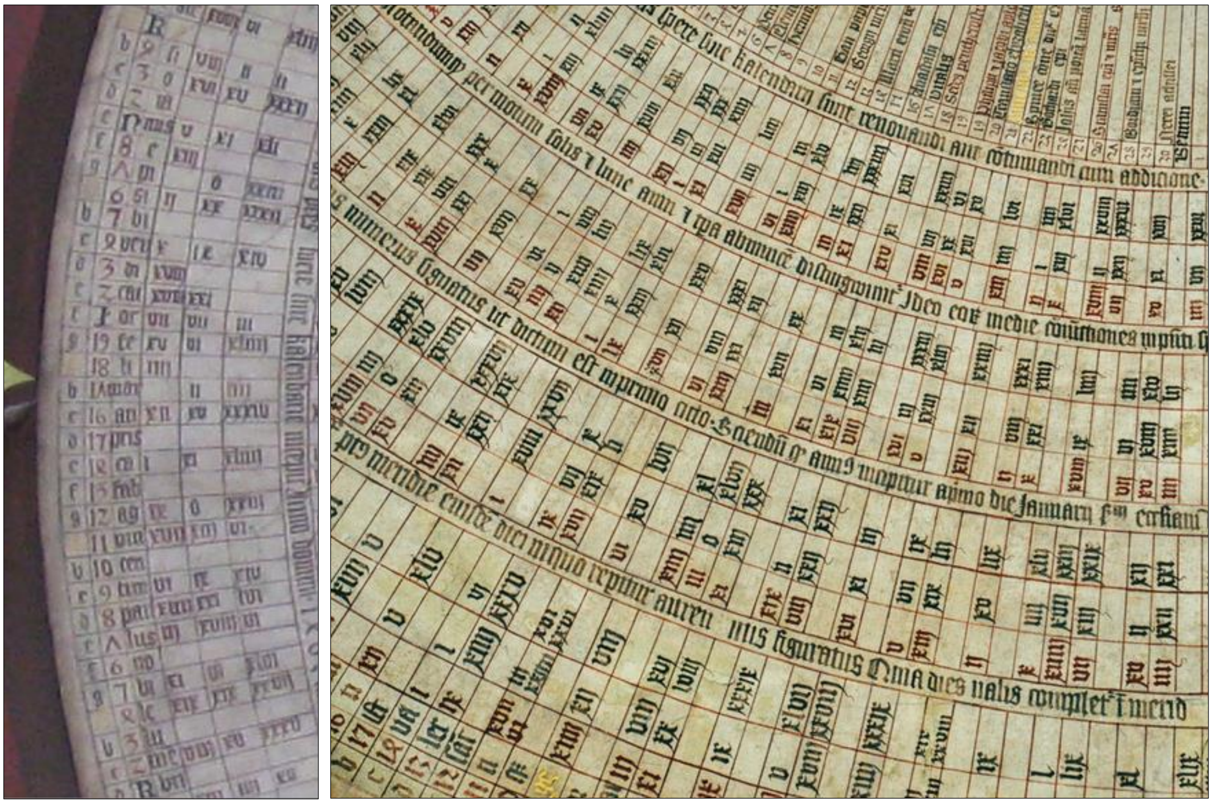

Figure 2: Details of the calendar disk (Wikipedia).

The next band inwards contains the dates in the rather complicated Roman calendar that starts each month with Kalende (denoted by the letter K). The 5th or 7th day is None (N) and the 13th or 15th day is Ides (I). Days are counted from the Kalendae of the following month to Ides, then again counted to None and finally again counted to the Kalende.

The next band contains the so called Cisiojanus, a sequence of syllables, one for each day of the year. The sequence is a mnemonic in the form of 24 lines, two for each month, of a hexameter poem for remembering the feria and days of the saints of the year. For January the lines go:

cí-si-o iá-nus e-pí ¦ si-bi vén-di-cat óc fe-li már an
prís-ca fab ág vin-cén ¦ tum páu lus nó-bi-le lú-men

The first five syllables stand for the circumcision of Christ in the beginning of January, epi stands for Epiphany, the day of the baptism of Christ and so on. It was frequently required by school children at that time to remember the Cisiojanus poem by heart (Schukowski, 2006: 52). Table 1 shows the arrangement for the month of January. The top row shows the day of the month (not shown on the disk), the second row the ferial letters, the third row the dates in the Roman calendar, and the last row the Cisiojanus.

The following four sets of bands are for the four 19-year cycles, each one with an outer band with a text that explains in Latin and medieval German that the following bands the times of the new moons for the cycle of 19 years, the time being given in equal hours and counted from noon with each hour divided into 60 minutes (Schukowski, 2006).[1] The numerical

Table1: The first three bands of January on the Gdansk disk (table: Lars Gislén).

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
a	b	c	d	e	f	g	a	b	c	d	e	f	g	a	b	c	d	e	f	g	a	b	c	d	e	f	g	a	b	c
K	4	3	2	N	8	7	6	5	4	3	2	I	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2
cí	si	o	iá	nus	e	pí	si	bi	vén	di	cat	óc	fe	li	már	an	prís	ca	fab	ág	vin	cén	tum	páu	lus	nó	bi	le	lú	men

conjunction information is given in three bands, the outermost containing the golden numbers, the following two bands the hour and minute of the conjunctions, all written with Roman numerals (Figure 2, right part).

The innermost bands show the ecliptic longitudes of the Sun, the religious feast days and days of the saints, the lunar letters, a set of 27 letters and digits that can be used to calculate the lunar phase (Grotefend, 1922: 6; Zimmermann, 1934: 83).

The central part has a separately movable smaller disk divided into 76 radial sectors and turns one sector each year. This disk is covered by a fixed circular copper plate with opening slots that show the current year, the number of the year in the 28-year solar cycle, the Sunday letter, the golden number, the number of the year in the Roman 15-year indiction cycle, and also some further calendrical information on the current year. A small statue of the Holy Virgin with the Child is attached to the middle of the cover disk.

3 ANALYSIS

The conjunction times on the disk are computed using the Alfonsine length of the mean synodic month. This length is not given directly in the Alfonsine Tables but can be derived by dividing 360 by the difference between Alfonsine values of the mean lunar and solar daily motion: 13;10,35,1,15,11,4,35 – 0;59,8,19,37,19,13,56 = 12;11,26,41,37,51,50,39°.[2] The result is 29;31,50,7,37,27,8,25 days = 29 days 12;44,3,2,58,51,22,8 hours = 29.53059 ... days. An average using all the data on the Gdansk disk shows that the synodic month used was 29 days 12;44,3 hours, very close to the Alfonsine value.

Given an anchor with a precisely determined mean conjunction, any mean Alfonsine conjunction can be generated by adding or subtracting synodic months. We determined such an anchor, the first mean conjunction in January 1463 with golden number 1 which falls on 19 January 10;27.3615 hours after noon (Julian Day 2255438.4357) in Toledo. Starting from this anchor, a computer can easily generate a reference list of conjunction times by adding multiples of synodic months. This list will be denoted A. In order to have the conjunction time for some other location than Toledo the longitude time difference T with that location and Toledo must be added. The time T is related to the geographical longitude difference by 1 hour in time being equivalent to 15° in longitude. The list of such local mean conjunction times will be called L. We then have

$$L = A + T \qquad (1)$$

In order to compare the reference with an existing local set, C, of conjunction times, like that of the data on the Gdansk disk we compute for each conjunction the difference:

$$\Delta = C - L = C - (A + T) \qquad (2)$$

We tested a known set of conjunction data, that in a calendar by John of Gmunden/ Johannes von Gmunden (Simek and Chlench, 2006) set up for Vienna. John of Gmunden (ca. 1384–1442) was a famous German/Austrian mathematician and astronomer who worked as teacher and Vice-Chancellor at the University of Vienna and published of the order of 100 very accurate calendars and astronomical tables. He was succeeded at the University by the equally famous George von Peurbach (1423–1461) known for his presentation of the Ptolemaic astronomy in the *Theoricae Novae Planetarum*.

In the case of the Vienna calendar of Johannes von Gmunden (n.d.), see Figure 3, the value of T is known, 80 minutes (20°) (Kramer 1998). This calendar lists 940 conjunctions for the 76-year period 1438–1504. It is easy to verify that the conjunction times have the characteristic Alfonsine 16;32/7;28 time difference between its 19-year cycles. For this calendar the value of Δ is consistently equal to zero for 98% of the conjunctions and the standard deviation is 0.15. There are 7 instances where a digit is wrong or misplaced but which are obvious scribal errors. This indicates a very carefully done computation. Many contemporary conjunction tables were derived from John of Gmunden tables of conjunction times by adding a suitable longitude time difference to his times. An example is the Passauer calendar (Müller, 2009 see Figure 4) with 10 minutes subtracted from the Vienna calendar to express the fact that Passau is located about 2° 30′ west of Vienna (Nothaft, 2018).

We made a similar computation of Δ for the data on the Gdansk disk. By varying T to minimise the Δ:s it is found that the best value of T is a little bit more than 76 minutes corresponding to a geographical longitude difference with Toledo of 19° 6′, in between the longitudes of Vienna and Passau. In the Alfonsine Tables, as found in an earlier paper (Gislén, 2020), the town of Nuremberg is listed with a longitude of 19° 25′ from Toledo and would still be a possible origin for the data but due to the fact that the geography of Europe and the knowledge of the longitudes of key cities were very hazy at the time it is unfortunately impossible to specify the physical location of origin of

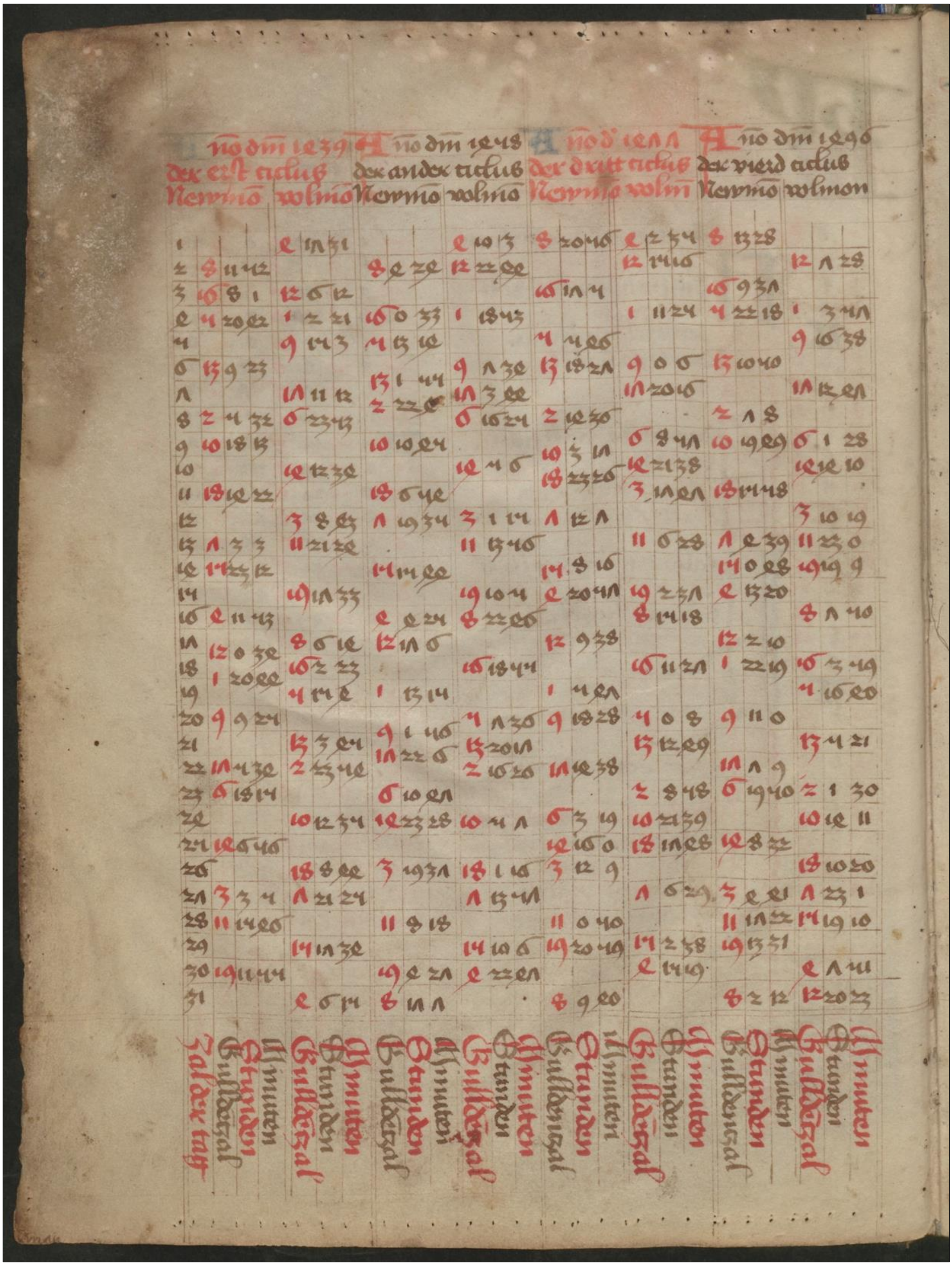

Figure 3: The month of March from the Vienna calendar (after von Gmunden, n.d.).

the conjunction data on the calendar disk in Gdansk.

Further, in the case of Gdansk data there is a considerable spread of the values of the Δ:s around zero and the 16;32/7;28 rule has not been used. The frequency distribution of Δ is Gaussian with a standard deviation of 1 minute (see Figure 5), almost seven times larger than the standard deviation of the Vienna calendar. This shows that the Gdansk conjunction times

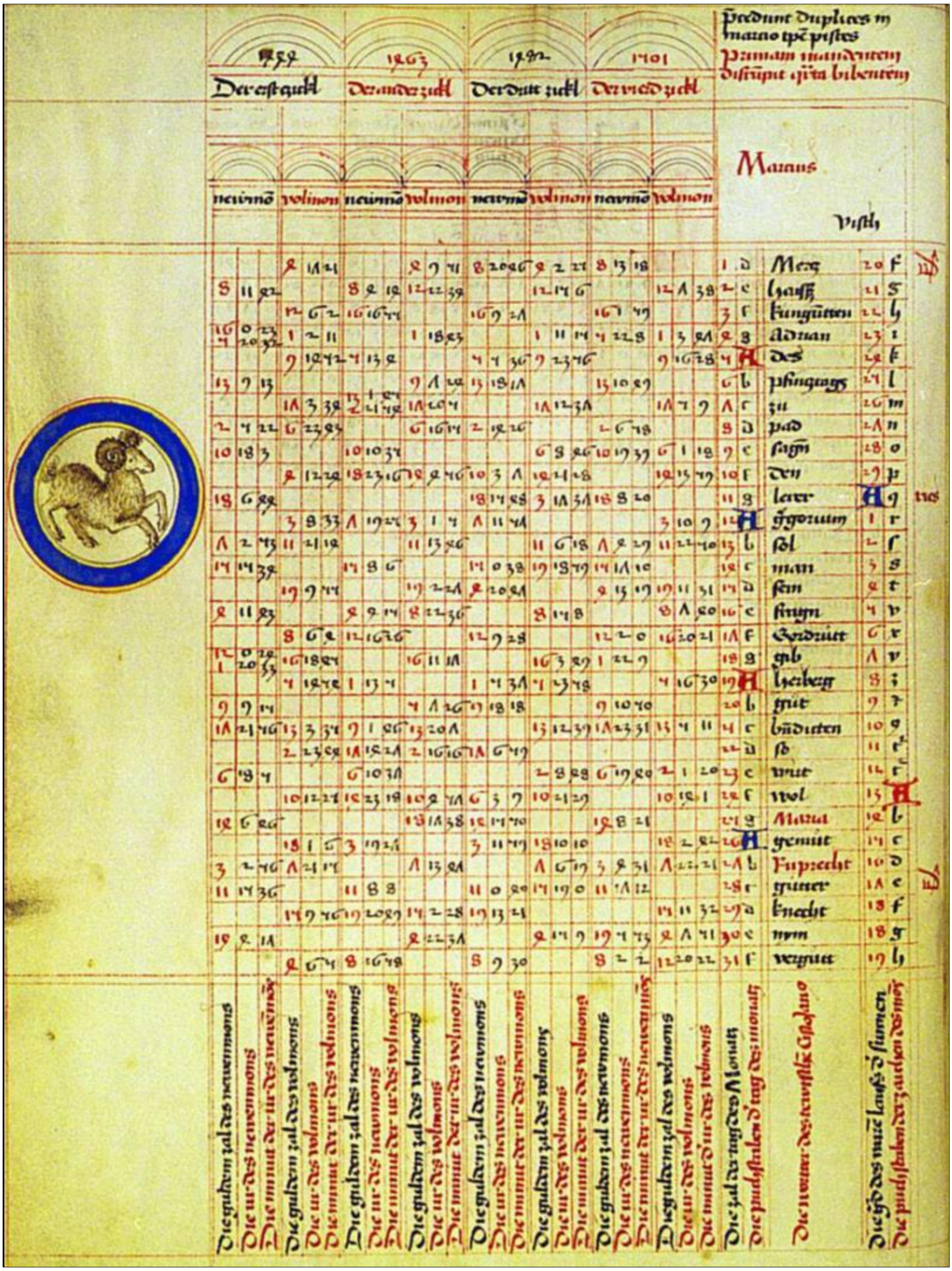

Figure 4: The month of March from the Passauer calendar (after Müller, 2009: 225).

were not just simply copied and adjusted with a time correction from some well-established standard source but were computed with less care or copied from less accurate computations.

A look at the conjunction times on the Gdansk disk shows that there are long series of subsequent conjunctions that differ by precisely 29 days 12;44 hours. This is slightly less than the Alfonsine approximation of the synodic month 29 days 12;44;3 hours. Adding this shorter synodic month will cause an error drift that must be corrected on average every 20 synodic months by adding an extra 'leap' minute. We investigated all such additions in the Gdansk material and found that this method indeed seems to have been used although these intercalations are not very systematic and sometimes being more than one minute. Figure 6 shows this error drift and the occasional corrections for the first 470 lunations. There are several scribal errors on the disk mostly one- or two-minute errors of the times that were detected by looking at the time differences between subsequent lunations. In several places on the disk the minutes were missing, in a few places the hours were wrong. The Roman Gothic script used is also prone to generate scribal errors: in one case “vij” was been written instead of “iii” and some cases an “x” for 10 had dropped out.

4 CONCLUDING REMARKS

The calendar disk of the astronomical clock in the cathedral of Saint Mary in Gdansk is unique, firstly because it is the original one from the middle of the fifteenth century, secondly because it contains more astronomical data than any comparable disk. The Gdansk clock has had a dramatic life during the centuries and was at times thought to have perished. However, in the beginning of the 1980s many parts of the clock, including the original calendar disk were found and work on the restoration of the clock began and is presently progressing.

The statistical analysis of the conjunction times on the Gdansk disk shows that they are mean conjunction times calculated according to the Alfonsine Tables with a geographical longitude time correction term of 1;16 hours or 76 minutes. There is a considerable spread of the conjunction times around the correct values with a standard deviation of 1 minute and there are quite a few scribal errors indicating that the times were calculated, probably afresh, but in a very different way of the contemporary calendars and with less care. The physical origin location of the data cannot be precisely determined.

5 NOTES

1. The Latin text band of the first 19-year cycle reads:

> Primus cyklus presentis spera sive kalendarie incipitur Anno domini 1463 currente et durabit per 19 annos immediate sequentes usque ad annum 1481 completum in quo /termin/abtur. Est nota quod hore et minuta que ponuntur post aureum numerum in ciclis hic descriptis computende sunt post meridiem eiusdem diei in quo reperitur aureus numerus figuratus. Quia dies naturalis completur in meridie et habet 24 horas equales secundum calculationem astronomicam continet 60 minuta.

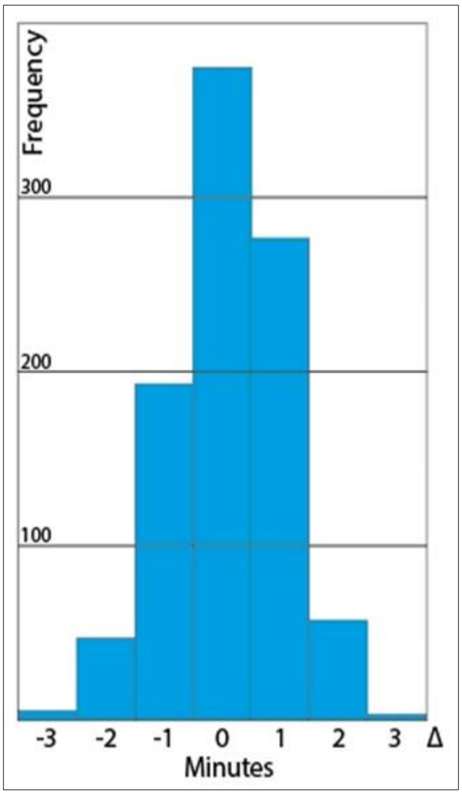

Figure 5. Δ-frequency of the Gdansk disk (diagram: Lars Gislén).

2. We use Neugebauer’s sexagesimal notation a;b,c, which means a + b/60 + c/3600 ...

6 ACKNOWLEDGEMENTS

We are grateful to Dr Richard Kremer for valuable discussions, and to the referees for their helpful suggestions.

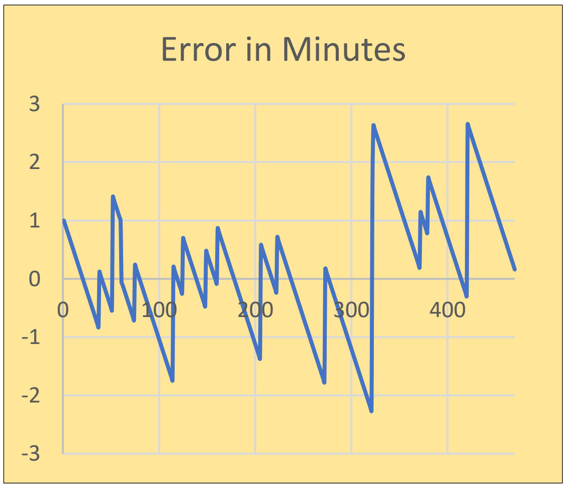

Figure 6: Variation of the error versus conjunction number (diagram: Lars Gislén).

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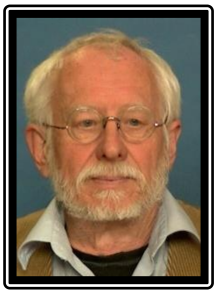

Dr Lars Gislén was born in Lund (Sweden) in 1938, and received a PhD in high energy particle physics from the University of Lund in 1972. He worked in 1970/1971 as a researcher at the Laboratoire de Physique Théorique in Orsay (France) with models of high energy particle scattering. He has also done research on atmospheric optics and with physical modelling of biological systems and evolution.

He has worked as an Assistant Professor (University Lector) at the Department of Theoretical Physics at the University of Lund, where he gave courses on classical mechanics, electrodynamics, statistical mechanics, relativity theory, particle physics, cosmology, solid state physics and system theory.

For more than twenty years he was a delegation leader and mentor for the Swedish team in the International Physics Olympiad and the International Young Physicists' Tournament.

Lars retired in 1983, and since then his interests have focused on medieval European astronomy and on the astronomy and calendars of India and Southeast Asia. He has published more than 20 research papers in this field. He has also made public several spreadsheet tools implementing a number of astronomical models from Ptolemy to Kepler as well as computer tools for the calendars of India and Southeast Asia. He is a member of the IAU.

Wayne Orchiston was born in Auckland (New Zealand) in 1943, has a PhD from the University of Sydney, and is an Adjunct Professor of Astronomy in the Centre for Astrophysics at the University of Southern Queensland in Toowoomba, Australia. He has wide-ranging research interests but has mainly published on historic transits of Venus; historic solar eclipses; historic telescopes and observatories; the emergence of astrophysics; the history of cometary, meteor and minor planet astronomy; the astronomy of James Cook's three voyages to the Pacific; amateur astronomy and the amateur-professional interface; the history of radio astronomy in Australia, France, India, Japan, New Zealand and the USA; and Indian, Southeast Asian and Māori ethnoastronomy.

Wayne's recent books include *Eclipses, Transits and Comets of the Nineteenth Century: How America's Perception of the Skies Changed* (2015, Springer, co-authored by Stella Cottam), *Exploring the History of New Zealand Astronomy: Trials, Tribulations, Telescopes and Transits* (2016, Springer); *John Tebbutt: Rebuilding and Strengthening the Foundations of Australian Astronomy* (2017, Springer), *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe* (2017, Springer, co-edited by Tsuko Nakamura), *Exploring the History of Southeast Asian Astronomy: A Review of Current Projects and Future Prospects and Possibilities* (2021, Springer, co-edited by Mayank Vahia) and *Golden Years of Australian Radio Astronomy: An Illustrated History* (2021, Springer, co-authored by Peter Robertson and Woody Sullivan). Wayne has also edited or co-edited a succession of conference proceedings.

Since 1985 Wayne has been a member of the IAU, and he is the current Immediate Past President of Commission C3 (History of Astronomy). He is the Founding Chair of the History & Heritage Working Group of the SE Asian Astronomy Network. In 1998 he co-founded the *Journal of Astronomical History and Heritage* and is the current Managing Editor. He and Dr Stella Cottam were co-recipients of the American Astronomical Society's 2019 Donald Osterbrock Book Prize, and in 2013 minor planet '48471 Orchiston' is named after him.