Functional principles of early time measurement at Stonehenge and Nebra

Friedel Herten & Georg Waldmann

Abstract – The world-famous Neolithic circle of Stonehenge might possibly have been used as a precise open-air lunisolar calendar over thousands of years. The Nebra Sky Disc, dating from the Bronze Age, and 1500 years later in age, offers surprisingly the same constructional features and characteristics. In this study, it is emphasised that Stonehenge and the Nebra Sky Disc served as lunisolar calendars based on an 18.6 yr cycle, made possible by the observation of the motion of the northern lunar standstills solely. With both calendar-systems, solar and lunar eclipses could be predicted precisely on the day — more than 5000 years ago. With this study, a solution of the enigma about the astronomical function principles of henge architectures in the British Isles is discussed. The functional principles of the lunisolar calendars are similar to a modern computer: the moon serves as an impulse generator (processor), the circular arrangement of posts memorises data and an algorithm in a form of a software or calendar is performed with simple equipment. The Nebra Sky Disc could possibly be referred to as a portable and progressed laptop version of this computer.

Key words – Stonehenge, lunisolar calendar, henge, Nebra Sky Disc, computer science, archaeoastronomy, lunar standstills, Neolithic, Bronze Age, Woodhenge, Avebury

Titel – Funktionsprinzipien früher Zeitmessung in Stonehenge und Nebra

Zusammenfassung – Die weltberühmte neolithische Kreisanlage von Stonehenge könnte möglicherweise über Jahrtausende als ein präziser Lunisolarkalender genutzt worden sein. Die aus der Bronzezeit stammende Himmelsscheibe von Nebra, die 1500 Jahre jünger datiert ist, verfügt in erstaunlicher Weise über die gleichen Konstruktionsmerkmale und Charakteristiken. In dieser Studie wird vermutet, dass die Lunisolarkalender von Stonehenge und der Himmelsscheibe von Nebra auf einem 18,6-Jahreszyklus basierten und ausschließlich auf der Beobachtung der Bewegung der nördlichen Mondwenden beruhten. Mit beiden Systemen hätten bereits vor mehr als 5000 Jahren Sonnen- und Mondfinsternisse auf den Tag genau vorhergesagt werden können. Mit den Ergebnissen dieses Beitrags könnte das große Rätsel gelöst worden sein, über welche astronomischen und funktionellen Möglichkeiten die Henge-Architekturen auf den britischen Inseln verfügten. Die Funktionsprinzipien der Lunisolarkalender erinnern an einen modernen Computer: Der Mond fungiert als Taktgeber (Prozessor), die kreisförmig angeordneten Pfosten speichern Informationen und es wird mit einfachen Mitteln ein Algorithmus in Form einer Kalendersoftware ausgeführt. Die Himmelsscheibe von Nebra könnte – bildlich gesprochen – als portable und weiterentwickelte Laptop-Version dieses Computers angesehen werden.

Schlüsselwörter – Stonehenge, Lunisolarkalender, Henge, Kreisgrabenanlage, Himmelsscheibe von Nebra, Informatik, Archäoastronomie, Mondwenden, Neolithikum, Bronzezeit, Woodhenge, Avebury

Introduction

The meaning and purpose of megalithic structures and Neolithic circles (henges) in Northwestern Europe are an unsolved enigma for archeology and astronomy. Some of these structures could have served as sky observatories.

The first reflections on the astronomical meaning of Stonehenge and its orientation towards the summer turn are from Stukeley (Stukeley, 1740) and Lockyer (Lockyer & Penrose, 1903, 137; Lockyer, 1906, 97). Devoir (1909) presumed a Neolithic calendar based on sun observation. Newham (1963) was the first to consider a moon observation. Hawkins (1963; 1964) assumed that the 56 Aubrey Holes were used as a digital computer to predict seasons, as well as lunar and solar eclipses. Hoyle (1966) extended this theory, while Sadler (1966) as well as Colton & Martin (1967) challenged this view. Brinkerhoff (1977) assumed that ritual ceremonies at times of lunar risings at the A-holes took place. Beach (1977) suspected that the 56 Aubrey Holes serve for the prediction of tides. The first concrete considerations that the megalithic structures could be lunar observatories, were given by Thom (Thom, 1973, 45–79). So Thom (1973) was also the first who experimented with lunar standstills.

Ruggles (1999) highlighted the end of a vacuum regarding archaeological and archaeoastronomical properties of the Neolithic and Early Bronze Age monuments. Nowadays, a religionist and ethnographic model to interprete the role of monumental alignments is widely accepted in archaeoastronomy (North, 1996; Ruggles, 2000; Sims, 2006, 3).

Some archaeoastronomers suggested *"that 'astronomer priests' were using the monuments as scientific observatories to construct calendars and predict eclipses (Hawkins & White, 1970; Mackie, 1977; Newham, 1972; Thom, 1971; Wood, 1980)"* (in: Sims,

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2006, 3). Sims rejects the current archaeoastronomical theories (summer sunrise, horizon extremes of the moon, forestalled horizon moonsets, eclipse prediction, full moon) to be inadequate against the archaeological details of sarsen Stonehenge (Sims, 2006, 10). He considers that the *"monuments are all designed to entrain winter sunset with 'dark moon'"* (Sims, 2006, 14). Sims discusses the 'dark moon' at winter solstice as the annual anchor to separate the twelve other monthly moon darknesses by this event to define the start of the longest and darkest night of the year (Sims, 2006, 12).

With regard to the Nebra Sky Disc, Hansen's Moon-Pleiades-Hypothesis (Hansen, 2007, 289-301) was introduced. Schlosser (2002; 2008) highlighted the recognition of important dates during the year. Schmidt-Kaler (2008) suspected a lunisolar calendar on a basis of 59 sidereal months.

Aims

In our following study, we want to show that lunisolar calendars based on lunar standstills could have been served since Neolithic times to synchronise a lunar calendar with a sun-related calendar. Focussing on Stonehenge (UK) and the Nebra Sky Disc (Germany) that derive from different time periods we examine whether they could have been designed to control and operate as a lunisolar calendar. The functional principles of the assumed lunisolar calendars of Stonehenge and of the Nebra Sky Disc are similar to a modern computer with a clocked processor using memory, and performing an algorithm. They offer an astonishing accuracy over thousands of years in use — they would probably still be usable today.

Our work initially deals with time measurement and calendars in prehistory. In particular, we will look at lunisolar calendars and the possibilities that arise in connection with lunar standstills. Using the example of the applications at Stonehenge and the Nebra Sky Disk, it will be demonstrated how lunisolar calendars based on lunar standstills could have worked. In the discussion we will examine further functions of the two construction types and will suggest explanations of other henge monuments.

Time measurement and calendars

Time measurement and calendars are characteristics of civilisations. The evidence of writing is debatable (Ruggles, 2015a, 28), but does not seem to be necessary, if knowledge is transmitted orally for generations. But what specific information is necessary to record and divide time by a calendar system? Practical time measurement includes determination, recording and registration of time units. A chronometer requires an impulse generator with an exactly constant frequency. In mechanical chronographs, balance wheels and pendulums are used to produce periodic impulses. The latter, processed into defined time units, such as second, minute and day via the clockwork, are displayed on a dial. Within nowadays quartz clocks the impulse is generated by a quartz oscillator, while an atomic clock is driven by the frequency of electron radiation of free atoms.

Flora and fauna offer phenological impulse generators, i.e. in the form of the arrival of migratory birds or the flowering and maturing periods of certain plants, which can vary.

Prehistoric people will have recognised that – besides the seasons – the phases of the moon, the course of the sun, and the position of fixed stars are repeated periodically and cyclically in the same time units. It could likewise be possible to determine the time unit of the day through the midday sun with its extreme elevation angle to the horizon — this corresponds to the time of day when an object on earth produces its smallest shadow. The duration of a solar year (tropical year) is measurable by showing a particular extreme azimuth of the sunrise or sunset on the horizon — as on summer solstice. The synodical lunar month or lunation observable from the earth indicating the duration of the return of an identical moon phase, was already measurable by early man as an important time unit. A synodical month represents 29.530589 days (Herrmann, 1973, 11).

Lunisolar calendar

The duration of an average month in the Gregorian calendar (in the following text *"month"*, *"tropical month"*, *"solar month"*) is defined with 30.436875 days. After a tropical year (solar year) of 365.2425 days, the day-deviation between lunar calendar and solar calendar differs by 11 days. In lunisolar calendars this deviation can be compensated by inserting an additional intercalary month if necessary (Ruggles, 2015a, 21). On a mathematical basis, an intercalary month needs to be inserted every 2.7 years to synchronise moon calendar and solar calendar to the same month.

A problem within Neolithic societies would have been the identification of an impulse generator with a countable multiple of its impulse frequency of the duration of 2.7 years, or a multiple of this time unit from sky observation. On Earth, there seems to be no such impulse generator observable other than the Moon with its phases and movements. The Sun would not allow any comparable viewing by human eye due to its sheer brightness.

On the basis of the depicted symbols for the moon and stars on the Nebra Sky Disc, it has been assumed that an intercalary month had to be inserted with the appearance of the Pleiades in constellation with a 3-day rising crescent moon (LDA, 2017). There is no astronomical and mathematical proof for this hypothesis, verifying this special Moon-Pleiades relationship to contribute to a functional lunisolar calendar.

Lunar standstills

A regular astronomical phenomenon in connection with the moon observation from earth could have been of interest for a lunisolar calendar: the lunar standstills. The lunar rising and setting within a month move on the horizon between extreme northern and southern positions. These azimuths are called the northern and southern lunar standstills of a month.

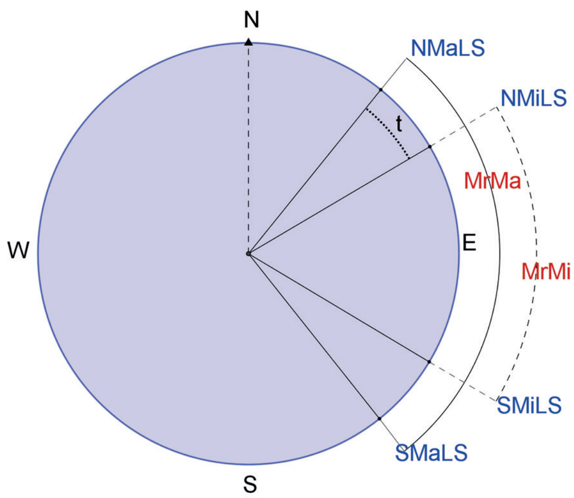

Fig. 1 Schematic presentation of the azimuths and angular dimensions of moonrises on the eastern horizon, as well as the azimuths of major and minor lunar standstills in an observatory at 51° latitude at 3000 BC. For an observer on earth, it is evident that these monthly standstills change with time. The most northerly of all northern lunar standstills is designated by the Northern Major Lunar Standstill (*NMaLS*), the most southerly with Southern Major Lunar Standstill (*SMaLS*). The least northerly of all northern moonrises is referred to as Northern Minor Lunar Standstill (*NMiLS*), the least southerly with Southern Minor Lunar Standstill (*SMiLS*). At the month of the Major Lunar Standstill, the moonrises can be observed on the horizon on the arc MrMa (Moonrises at Major Standstill) between *NMaLS* and *SMaLS*. At the month of the Minor Lunar Standstill the moonrises are visible on the eastern horizon on the arc *MrMi* (Moonrises at Minor Standstill). The circular arc t represents the time axis of the monthly northern standstills between the *NMaLS* to the *NMiLS* and back to *NMaLS*.

The Major Lunar Standstill repeats every 18.61 years (Steinrücken, 2011, 22) after the end of a lunar standstill cycle (LSC). During a LSC, the azimuth of the moonrise of the monthly northern lunar standstill turns on the circular arc t from *NMaLS* to *NMiLS* and back to the *NMaLS*. This time axis is a special impulse generator because every observable periodic time unit that is determined by the sun, the moon, and other heavenly objects, can be registered on this arc. This property would enable us to compare different time systems, such as those derived from the sun and moon movements, and to deduce rules for a harmonisation of moon calendars and solar calendars.

If we consider a circular arc t (**fig. 1**) as the time axis of the monthly northern standstills from some distance from the observation position, and then mark the observed lunations and tropical years on this axis, we can count the lunations covering this long period after the end of an *LSC* of 18.61 yrs. Using division of the solar years into twelve equal months by means of a geometric construction, the months can also be counted towards the end of the *LSC*.

The motion of the lunar standstills over the azimuths proceeds in a sinusoidal way. At the extreme positions (*NMaLS* and *NMiLS*) the lunar standstills seem to remain in the same location for some months, while in the middle between the extreme turning positions the exceeded angles are greatest per time unit. The observation of an *LSC* on the time axis t should therefore ideally begin in the middle between the extreme positions. In this case the applied time units are recognizable and measurable at the end of the cycle.

The time difference D-230 is approximately in the ratio 1: 6 to the duration of a lunar month *LM* (**fig. 2**). This means that such a lunisolar calendar will run approximately one lunation too slow after six *LSC*s have elapsed. This effect could be compensated by renunciation of inserting a seventh intercalary month after concluding the sixth cycle. As a result of this observation, we can note that a lunisolar calendar on the basis of lunar standstill cycles would have needed insertions of exactly 41 = (5 x 7) + (1 x 6) intercalary months within six *LSC*s. The sixth cycle includes only six instead of seven intercalary months to compensate almost exactly the previous running too fast of the calendar. The termination of six *LSC*s occurs after 111.66 years — after several human generations.

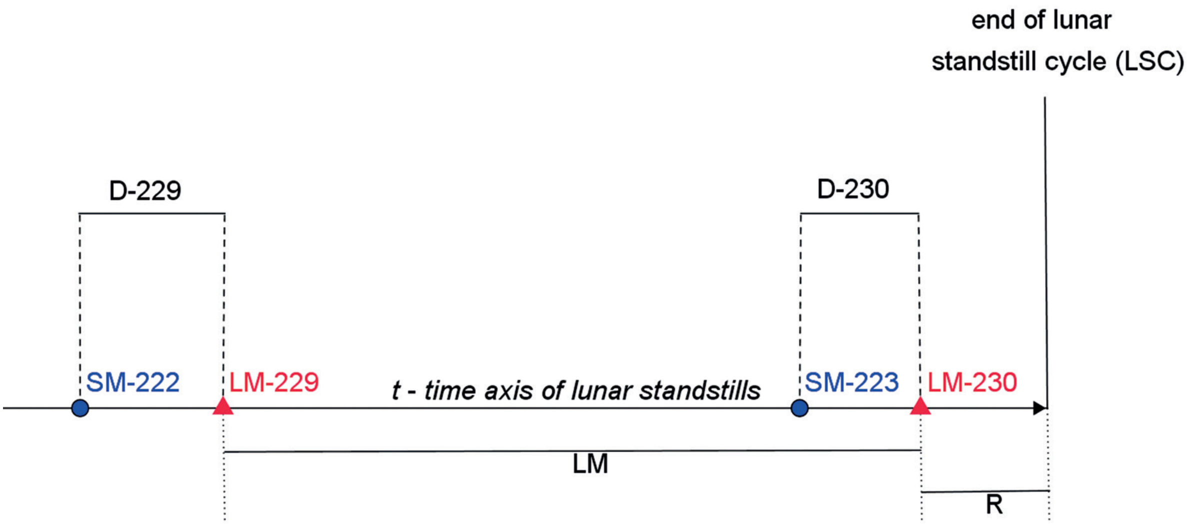

Fig. 2 Representation of the terminations of tropical "solar months" (*SM-222*, *SM-223*) and lunations (*LM-229*, *LM-230*) recorded on the time axis t (time axis of lunar standstills), as well as daily differences at the end of *LSC*. At the end of *LSC*, it is recognised that 223 tropical months (*SM-223*) have elapsed, and the 230th lunation *LM-230* terminates a few days later, before the *LSC* ends. From the geometric construction and the counting of the months, it becomes clear that with a lunisolar calendar, almost seven intercalary months have to be included within the *LSC*. Without knowledge of defined dimensions or special mathematical operations of division and multiplication, it becomes possible to estimate (by skillful geometry) the difference in the day count between the lunar calendar and the solar calendar after the end of LSC. A further task of our geometric construction with these measurements is to define the exact value for the day difference between the solar calendar and the lunar calendar to be corrected with intercalary months at the end of the *LSC*. With some geometrical calculations, this day difference and thus the inaccuracy of a lunisolar calendar on the basis of the *LSC* can be derived very precisely from the difference between *D-229* (day-difference between the terminations of lunar month *LM-229* and solar month *SM-222*) between and *D-230* (day-difference between the terminations of lunar month *LM-230* and solar month *SM-223*), as well as with the terms *LM* (duration of a lunar month) and *R* (remaining duration from *LM-230* to the end of *LSC*). The measures for the last two-month day-differences (*D-229* and *D-230*), the duration for a lunation *LM* and the remaining period *R* can be ascertained using simple devices such as a wooden rod, a thread, or a compass.

Sun and lunar eclipses

If we observe the astronomical events of the solar and lunar eclipses on the time axis t of the monthly standstills over several *LSC*s, we can analyze that similar eclipses occur periodically at the termination of 223 synodical months (Herrmann, 1973, 53). Solar eclipses then occur during a moon phase of the new moon and the lunar eclipses at full moon. Recording these events on the time axis t would offer a tool to predict the exact day of the occurrence of lunar and solar eclipses.

Application to the Neolithic circle of Stonehenge

The construction of the Neolithic circle of Stonehenge in Wiltshire, southern England probably began at the end of the 4th millennium BC. The first phase, Stonehenge I, is assumed to have taken place between 3100 BC and 2550 BC (Southern, 2014, 29–47). This original structure (**fig. 4**) has been considered to have included the outer ditches and walls, as well as the outer ring of posts and postholes, the *Aubrey Holes*, as well as the entrance to the northeast, before further structural elements were added or altered in later epochs (Cleal, 1995, 575–579; Ruggles, 1999, 37; Richards, 2013, 53). In later phases, the sarsens and bluestones of the interior have given an impressive and mystical appearance to Stonehenge visitors as well in prehistoric and modern times. The orientation of the monument is directed to the entrance in the northeast. It has been suggested that this orientation follows the sunrise, which can be observed at summer solstice on the northeastern horizon (Richards, 2013, 14). This however does not indicate that an accurate solar calendar existed basing upon the solstice itself (Ruggles, 2015b, 1230). In contrast, the Northeast entrance of the construction indicates that Stonehenge is straightened to the rising positions of the moon (Ruggles, 2015b, 1234).

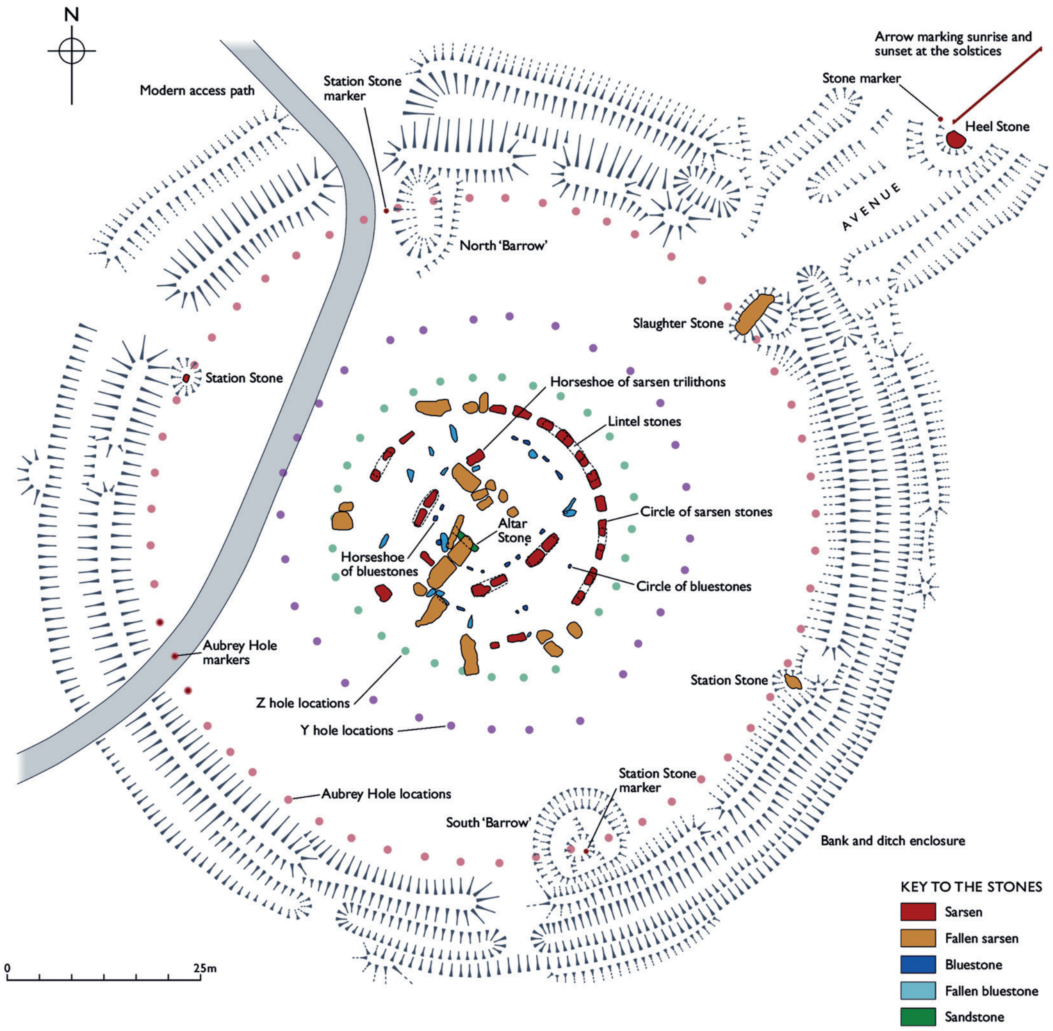

Fig. 3 Plan of Stonehenge with all phases of construction (© English Heritage Archive).

If, besides the azimuth of the summer sunrise, the azimuths of *NMaLS* and *NMiLS* are measured, it becomes evident that the entrance of the circle of Stonehenge lies almost precisely in the angular range of the extreme moon standstills (**fig. 5**). The *Aubrey Holes* with 56 post-holes, form the outer circle of the features within the ditch and wall. Three of these holes are located in the angular range between *NMaLS* and *NMiLS*, viewed from the circles-centre to the entrance (**fig. 6**).

Could it be that the constant monthly movement of the northern lunar standstills had been the decisive factor for the construction of the monument? If the lunar risings between *NMaLS* and *NMiLS* had been constantly observed from the centre of the site, the standstills would have had to reach these observation posts six times within one *LSC*. These posts could have served to determine when an intercalary month had to be inserted. It is known from the geometric construction (**fig. 2**) that almost seven intercalary months would have been required for the correction of an 18.6 yr cycle. A solution would be to add a further seventh intercalary month when *NMaLS* is reached, when this extreme position ends up again after one *LSC*.

Assuming that Stonehenge may have served as a lunisolar calendar cannot be proved *ad hoc*. In fact, it turned out that this construction would enable its builders to practise a proved lunisolar calendar, which would have shown an astonishing accuracy lasting for millennia.

The moment of the *NMaLS* could have been observed at Stonehenge in the southeast because the azimuth of the moonrise at *SMaLS* could have been targeted from the centre through a stone and a post within the site.

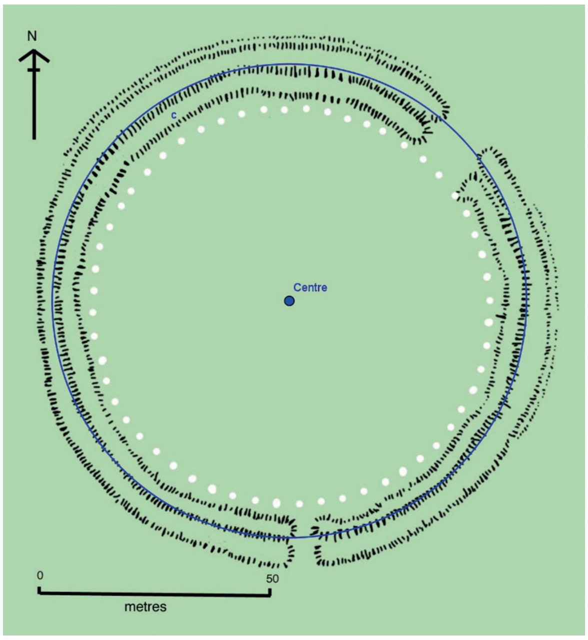

Fig. 4 Schematic representation of Stonehenge Phase I (Adamsan [CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0/)], via Wikimedia Commons).

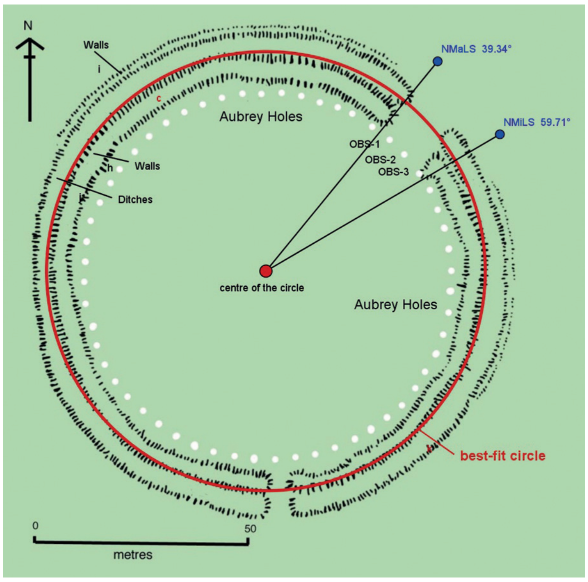

Fig. 5 Schematic drawing of the structures in Stonehenge and representation of the azimuths of northern extreme lunar standstills at the latitude 51.2° N around 3000 BC. The observation posts OBS-1, OBS-2 and OBS-3 are located at the Aubrey Holes in the angular range of the standstills NMaLS and NMiLS. The centre of the construction was determined by fitting a circle through the earthworks (henge). (Adamsan [CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0/)], via Wikimedia Commons).

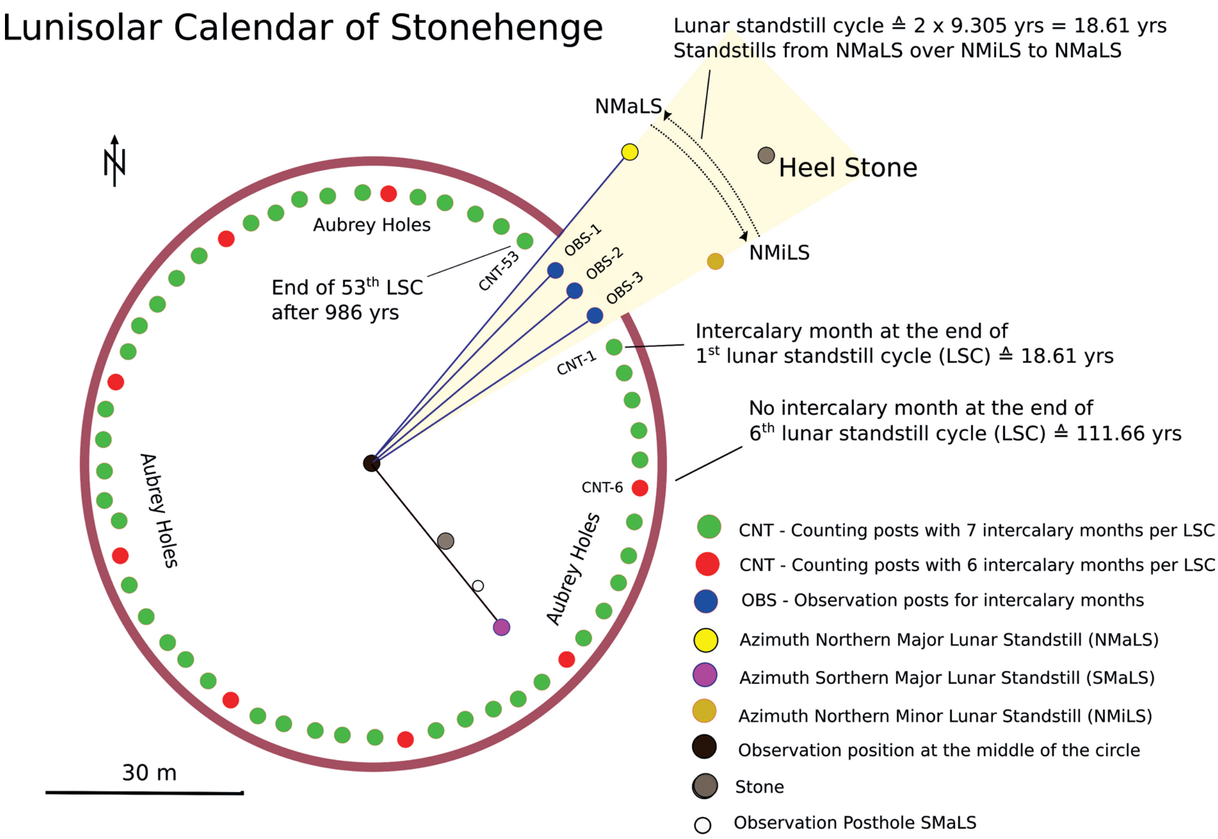

Fig. 6 Schematic representation of the Lunisolar Calendar of Stonehenge. The central element of the calendar would have been the movement of lunar standstills on the horizon acting as an impulse trigger at the three observation posts (*OBS-1*, *OBS-2*, *OBS-3*) and at Northern Major Lunar Standstill (*NMaLS*). *[legend is continued on page 7]*.

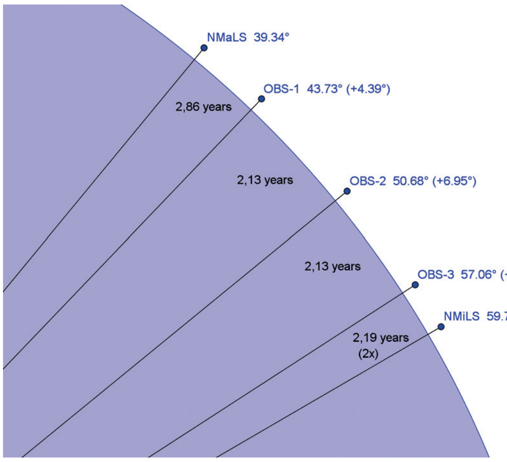

Fig. 7 Representation of the azimuth differences of Stonehenge around 3000 BC between the maximum northern lunar standstills (*NMALS*, *NMiLS*) and the observation posts (*OBS-1*, *OBS-2*, *OBS-3*) and the time differences between the azimuths of these positions, which are not linear to the angular differences, resulting from a sinusodial function (**fig. 8**).

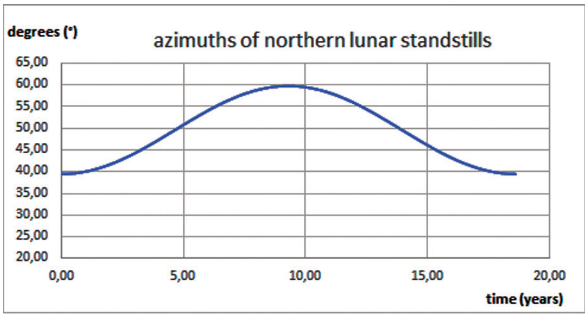

Fig. 8 Course of the exceeded azimuth values of the northern lunar standstills over the time as a sinusodial function.

The first eight periods of six *LSC* were presumably carried out identically. The ninth period would then consist of five 'normal' *LSC*s with seven intercalary months ending after 986 yrs. The next *LSC* would then start again at the beginning of the counting system.

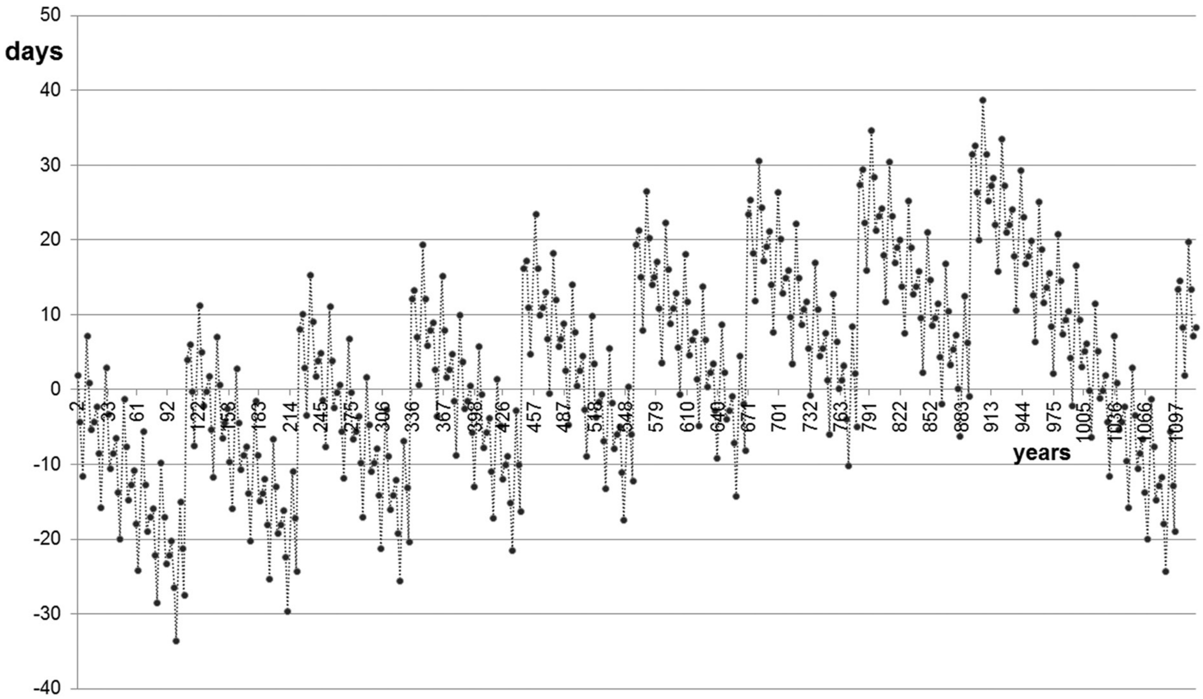

Fig. 9 Result of the computer simulation of the day-differences of the Stonehenge Lunisolar Calendar to the solar calendar after intercalary months and *LSC* for the duration of 1100 years since the beginning of the calendar. The trend shows that the Lunisolar Calendar is running slowly compared with the solar calendar, but the day-deviation is restored with the absence of an intercalary month at the end of the sixth *LSC* and then even runs fast compared to the solar calendar. The tendency shows that the Lunisolar Calendar will run fast about four days every period of six *LSC*, before this tendency is reset after the ninth period.

Fig 6 (continuation of legend): The movement from *NMaLS* to *NMiLS* and back to NMaLS takes place on the horizon in the northeast over 18.61 years. Whenever one of these observation posts was reached by the lunar standstills at moonrise, an intercalary month would probably have to be inserted. The remaining 53 *Aubrey Holes* may serve as counting posts (*CNT – counting post*) for an 18.61-year elapsed lunar standstill cycle. At the end of the *LSC*, a seventh intercalary month would have had to be inserted as far as the next unmarked post was designated as such (green post). After a 6-cyclic period of *LSC*s after 111.66 yrs at *NMaLS*, probably no seventh intercalary month was newly formed (red post). After expiration of the *LSC* at *CNT-53*, the calendar could have been forwarded again at *CNT-1*.

The instructions for the staff managing this open air calendar would have been simple and consisted of five rules only:

1. Observe the lunar risings at the northern and southern standstills beginning at *NMaLS*.
2. Add an intercalary month when one of these risings is observed exactly at an observation post *OBS-1*, *OBS-2* or *OBS-3*.
3. Mark the next counting post, which is not yet marked, starting with *CNT-1*. If the *LSC* is completed in the north at *NMaLS*, in the south-east the target position in direction to *SMaLS* is reached by one of these risings.
4. Insert an intercalary month when the counting post marked in step 3 indicates the corresponding status that it is one *LSC* with seven intercalary months (green status). Do not insert an intercalary month when this counter corresponds to the status of six intercalary months per *LSC* (status red).
5. When the *LSC* at *CNT-53* is terminated after 986 years, the process does not stop here but continues at *CNT-1*.

Computer simulation of the calendar with its day differences

Our proof of the suitability of this algorithm to run a lunisolar calendar is given by the angular distances of the observation posts to the lunar standstills (**fig. 7**). To this end, we have taken the angular distances by means of a true to scale drawing of Stonehenge and calculated the time of the movement of the standstills that are needed in order to exceed these angles. We assumed the azimuths of the extremes *NMaLS* and *NMiLS* for the latitude 51.2° N and for the year 3000 BC (Steinrücken, 2012, 13).

Fig. 9 shows the 1100-year trend of the day-differences of the lunisolar calendar from the solar calendar at the times of the intercalary months and at the end of lunar standstill cycles.

The Lunisolar Calendar of Stonehenge has the periodicity P=9 with a period duration of T=6 *LSC*. The number of counting posts of the calendar is:

#CNT = P×T - 1 = 53

The number of observation posts is:

#OBS = 3

The reason for the number of 56 Aubrey Holes could also be due to the astronomical phenomenon of solar and lunar eclipses repeating exactly at 223 lunations. If, i.e. the first counting post *CNT-1* was marked for every event of an eclipse and this marking was passed on to each next lunation — taking into account the observation posts of the open air calendar — this marker would again start at the first counting post after exactly four counting cycles with a total of 223 lunations. A solar eclipse would then be precisely predictable on the day of the new moon at this month. Lunar eclipses happen at the day of the full moon phase.

Application to the sky disc of Nebra

The Nebra Sky Disc was discovered in 1999 on the 51.3° N latitude on the Mittelberg in Saxony-Anhalt, Germany. The discus shaped, cold forged bronze disc with a diameter of 32 cm is deemed to be one of the most important archaeoastronomical finds of the 20th century (Meller, 2004, 11).

The golden inlays on the disc are supposed to symbolise sun, moon and stars. It is assumed that the disc was made in the Bronze Age, and hidden around 1600 BC on the Mittelberg in Saxony-Anhalt, Germany. Following Meller, Schlosser and Hansen, we also assume that the surviving golden right-hand margin (**fig. 10**) refers with the ends to the solstices (summer solstice, winter solstice) and the star depicted in the marginal position at the top of the disc (**fig. 10**) represents the celestial North Pole (Meller, 2004, 22–29; Schlosser, 2004, 44–47; Hansen, 2007, 289–303).

The constructive structure of the 38-hole disc resembles in an amazing way the architecture of Stonehenge (**fig. 13**). We have identified three possible observation holes in the angular range of the extreme lunar standstills. The other 35 holes could have served as counting holes for a lunisolar calendar. It might be assumed that metal pins or other suitable objects were attached to the holes, which on the one hand were suitable for observing the moonrise, and on the other hand could save counting information. Furthermore, it could have been possible to determine the status of a counting hole (intercalary month at the end of the *LSC*).

The lunisolar calendar of the Nebra Sky Disc has a periodicity P=6 with a period duration of *T=6 LSC*. The number of counting holes of the calendar is:

#CNT = P×T - 1 = 35

The number of observation holes is:

#OBS = 3

The lower tip of the crescent moon, symbolically represented on the right, almost exactly touches the azimuth of the *SMaLS*. With a moonrise in this direction, the time of insertion of an intercalary month at the end of the *LSC* could have been determined.

The consideration of the day-differences for the first 1100 calendar-years shows that the lunisolar calendar of Nebra is already reset after six periods with a total of 35 *LSC*s and then the initial situation is almost established again. The accuracy of this calendar with a periodicity P = 6 appears to be optimal. It can be assumed that other lesser explored circular monuments according to the design principle of Stonehenge and Nebra with periodicities between P = 5 and P = 10 (number of postholes: 32, 38, 44, 50, 56, 62, 68) would produce a sufficient accuracy of lunisolar calendars over thousands of years.

We still have to answer the question how the lunisolar calendar would react if not 38 but 39 holes were present at the originally sky disc: The calendar would only run too slow for a further four days after six periods, if seven intercalary months were inserted during the additional 36th *LSC*.

The Moon-Pleiades intercalary hypothesis (LDA, 2017) should be reconsidered if the sky disc was used as a lunisolar calendar. In addition, one might assume that a different asterism as the Pleiades was depicted: The *Plough* within constellation *Ursa Major* or the *Little Dipper* within constellation *Ursa Minor*, consisting of seven circumpolar fixed stars each, observable all year round in the northern sky. Circumpolar stars, like the constellations *Cassiopeia* and *Ursa Major*, have great significance in astronomical time measurement. For an observer on earth, these stars seemingly turn around the celestial pole once per day. Because of the Earth's precession, the pole was not visible at 1600 BC. Today, the pole can be identified with *Polaris*. Because of the Earth's daily rotation around its own axis and the 365-day rotation of our planet around the sun, circumpolar stars seem to cross a circular angle of about 361° around the pole in one day.

The position of the *Plough*, observed at a certain night-time, i.e. at midnight, moves by 30° counterclockwise after one month. After one year, the *Plough* will return to the starting constellation at midnight. The circulation of the *Plough* around the pole could thus be interpreted as a face plate divided into twelve sections, on which it is recognizable at a fixed time, when months begin and end. The moment 'middle of the night' between sunset and sunrise could have been determined by simple means (such as burning a candle or by constant filling a container with water to determine the middle of the burning and filling process between sunset and sunrise).

Conversely, the current hour at night can be determined with the current month or date with a face plate divided into 24 sections. This knowledge was used during medieval times, when star-clocks were invented, which were oriented

Fig. 10 Nebra Sky Disc: On the outer edge of the disc, irregular perforations were applied. These holes have been assumed to have been added in a later processing phase of the disc and may have served to attach the sky disc to leather or wood. The count of holes is 38, although it can be assumed that there was a further hole at the top left of today's damaged area. A hole in the upper right hand side of the disc (4th hole in the clockwise direction) is obviously made with a less skilled technique. We assume that this hole was added after the disc had been damaged in prehistoric times. It seems likely that the original sky disc also showed 38 holes (© Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt, Juraj Lipták).

Fig. 11 Image of the backside of the Nebra Sky Disc (© Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt, Juraj Lipták).

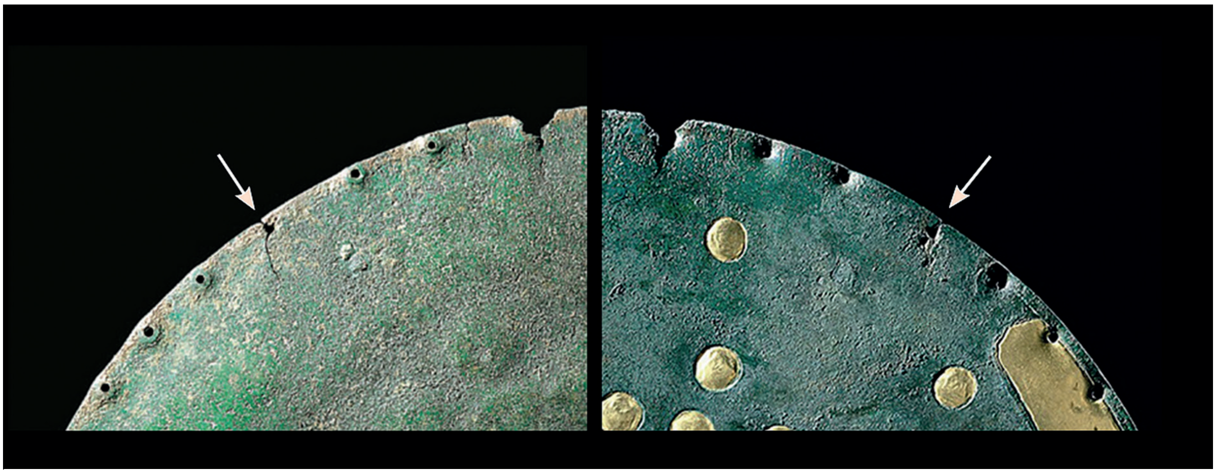

Fig. 12 Details at the back side (left) and front side (right) of the Nebra Sky Disc. The last counting hole (CNT-35), which is presumably subsequently made with other manufacturing techniques, is marked (© Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt, Juraj Lipták).

on the actual polar star and special circumpolar stars (*Dubhe* at *Ursa Major*, *Kochab* at *Ursa Minor*, *Schedir* at *Cassiopeia*). It seems to be possible that such knowledge could have existed in the Neolithic and in the Bronze Age already. This would probably explain seven stars being clustered symbolically on the sky disc.

Discussion and further work

At Stonehenge our interest then fell on the inner rings, designated as Y holes and Z holes (**fig. 3**), consisting of 30 exterior and 29 interior posts (Cleal, 1995, 256), with the posts being paired except in one case. These rings are of a different phase of the erection of the Aubrey Ring and the earthworks (Cleal, 1995, 578). They may have served to indicate the current day-difference between the lunisolar calendar and the solar calendar since the last intercalary month. If so, an initiating pair is marked at both rings and the markers are moved by a post every day. The distance between the posts marked in both rings will show how many days the lunisolar calendar runs too fast to the solar calendar. The ratio of 30 : 29 posts corresponds almost exactly to the ratio of the average days of a month (30.24 days) to the days of the lunar month (29.53 days). Thus, a 'solar day' could be determined at any time from the day of the month of the lunisolar calendar in the month of the solar calendar, calculated from the day difference since the last intercalary month.

The Y and Z holes could also have acted directly as a lunisolar calendar. If the markers in both rings are moved by a post every day, the intercalary month has to be included if the 33rd turn terminates. Then the Z holes are marked at post 4 and the Y holes are marked at post 30.

The calculated date ranges of the Z holes are assumed for 2030-1750 BC and of the Y holes 1640-1520 BC (Cleal, 1995, 534). They are the latest elements of the construction of Stonehenge, following the radiocarbon dates (Cleal, 1995, 579). Could there have been a connection to the theory of Bertemes and Sirocko that both the Nebra sky disk and Stonehenge were abandoned after the eruption of the volcano on Thera / Santorini about 3630 years ago (Bertemes, 2010)? Both authors assumed that volcanic ash had obscured the sky over Europe for 20 to 25 years and thus all sky observations became difficult. Was the lunisolar calendar of Stonehenge continued with the Y and Z holes, because the moonrises could not be observed any longer?

The Henge of Avebury shows 98 posts in the outer ring. Here, the number of posts corresponds to a periodicity of P=16. At Woodhenge, it is now assumed that the outer ring showed 60 postholes, two larger gaps being clearly visible in the plan. If Woodhenge actually consists of 62 posts, the principle of the lunisolar calendars of Stonehenge and Nebra would also be applicable here with a periodicity of P=10. The architecture of other henge monuments in western and central Europe allows an assumption that their construction would be analogous to a lunisolar calendar.

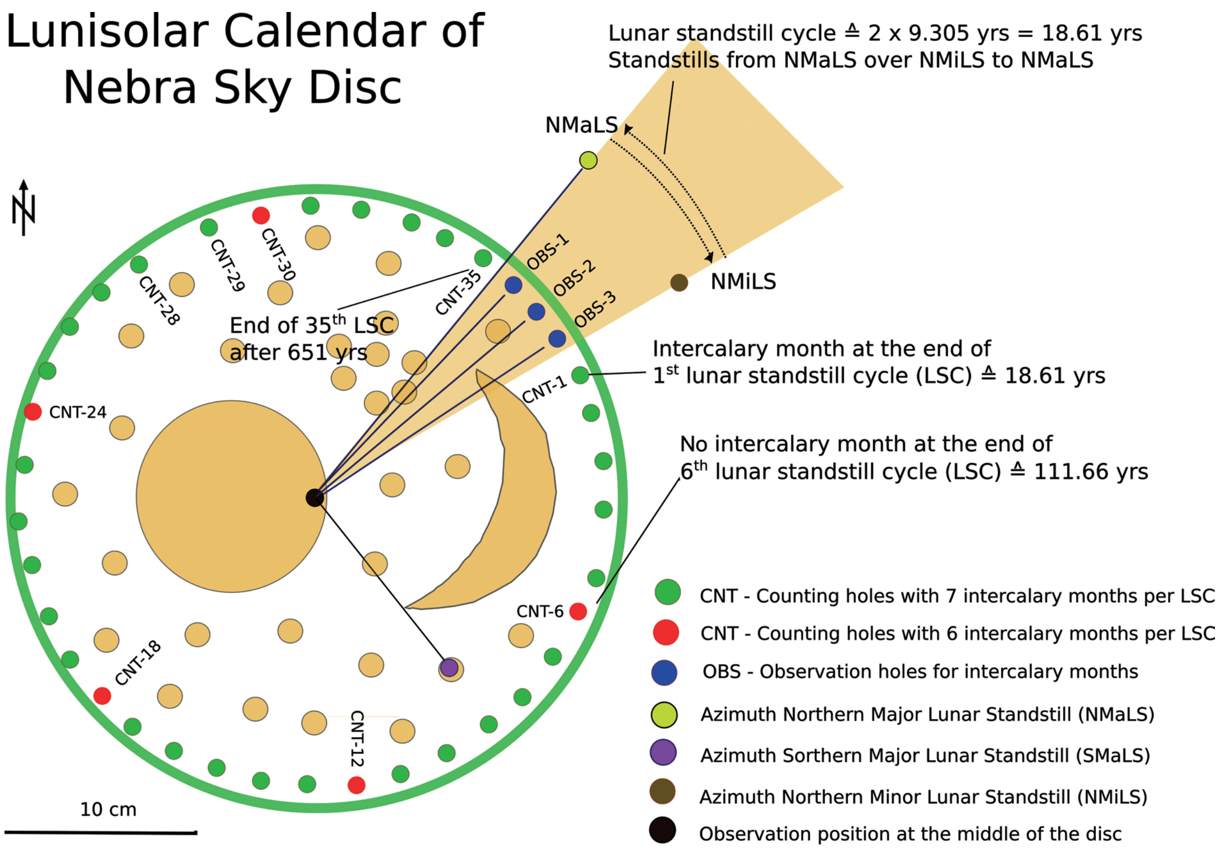

Fig. 13 Scheme of the lunisolar calendar of the Nebra Sky Disc, as well as azimuths of the *NMaLS* and *NMiLS*. The drawing shows three observation holes (*OBS-1*, *OBS-2*, *OBS-3*) lying within the observation range of the major and minor lunar standstills. The indicated extreme azimuths of the lunar standstills date of the year 1800 BC for the northern latitude 51.3 °. When observing a moonrise of a standstill at one of the observation holes OBS-x, an intercalary month needs to be inserted. The counting holes *CNT-1* to *CNT-35* are used to mark the expired *LSC*s of 18.6 yrs, with the colour of the counting hole determining whether a seventh intercalary month (green) has to be inserted or not (red) at the end of a *LSC*. After completion of the *LSC* at the counter hole *CNT-35*, the calendar is continued at the counter hole *CNT-1*.

Final considerations

The results applied to Stonehenge and the Nebra Sky Disc suggest that these constructions served to organize a Lunisolar Calendar. Avebury and possibly other henge monuments show very similar design features.

This study demonstrates that Neolithic astronomers, with an exact knowledge of the regular course of the moon and sun, were able to determine time units and important rules for lunisolar calendars by means of relatively simple geometrical constructions. The functional principles of a lunisolar calendar are similar to a modern computer: the moon serves as an impulse generator (processor), the circular arrangement of posts memorises data and an algorithm in a form of a software or calendar is performed with simple equipment. The Nebra Sky Disc could possibly be referred to as a portable 'laptop' version of this computer.

The engineers of the artefacts could have developed a procedure with their astronomical knowledge, which was designed for millennia, although their own life expectancy would only last a few lunar standstill cycles.

The prehistoric operators of the observatories would have to transmit their knowledge of the functionality and the rules, to be carried out for certain events (*software*), to further generations of 'knowing-persons'. A manual probably did not exist in a society without script.

The operators of the Stonehenge and Nebra observatories are likely to have determined that the information gained could be applied to the societies everyday life. Probably they impressed visitors with predictions of moon, earth and sun behaviour at certain times. They would have had highly respected social positions.

The western European man since the Neolithic would thus have lived in a civilisation with a uniform European-wide distributed calendar system together with an extraordinary knowledge of astronomy, probably underestimated so far.

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About the authors

Friedel Herten studied computer science at RWTH University Aachen with a degree Dipl.-Informatiker. He is the CEO of a software development company in the field of energy economics. His private interests are the interdisciplinary application of computer science in archeology, geography, astronomy and digital geographical information systems.

Dr. Georg Waldmann studied biology and geology at Heinrich-Heine-University Düsseldorf with a degree Dipl.-Biologe and was awarded a doctorate in geology. In addition to biology, his scientific work particularly covers glacial geology, ancient history and prehistory, as well as Paleolithic archeology.

Friedel Herten
Kleinenbroicher Straße 63
41352 Korschenbroich
Germany
friedel.herten@unitybox.de

http://orcid.org/0000-0002-9881-5317

Dr. Georg Waldmann
Am Trietenbroich 24
41352 Korschenbroich
Germany
georg.waldmann@gmx.net

http://orcid.org/0000-0003-1708-5779