

KNO-007 · Calendars and Time Measurement

KNO · Ways of Knowing

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Article Abstract

Most time reckoning leans on three observable cycles that do not divide into one another. For epoch 2000 the mean tropical year is 365.24219 days and the mean synodic month 29.53059 days, both approximate means that change slowly, so a calendar seeking lunar or seasonal alignment must use rules, observation, intercalation or accepted drift. KNO-007 asks what follows from that. It compares lunar, solar and lunisolar strategies without ranking them as stages of refinement, performs its own arithmetic and marks it as its own, and shows that a calendrical cycle need not track an astronomical period at all. It then separates the SI second, defined by a caesium transition since 1967, from civil time scales still held by convention near a turning Earth. It closes on disputed prehistoric candidates, on what a calendar coordinates, and on the limits of the evidence.

In 60 Seconds

Twelve mean synodic months come to 354.36708 days, 10.87511 short of a tropical year, so a lunar calendar walks through the seasons and the Islamic calendar does that by design rather than by failure. Drop the lunar month and keep the year and the Egyptian civil year follows: twelve months of thirty days plus five epagomenal days, 365 in total, with no intercalated day and a slower drift of its own. Keep both and the price is intercalation, because nineteen tropical years and 235 synodic months differ by 0.08704 days, about 2.09 hours, which is close enough to build a nineteen year cycle on and not close enough to make it exact. The Julian year overshoots by 0.00781 days and the Gregorian by 0.00031, so 1582 reduced a residual rather than removing one, and it revised the lunar tables for Easter as well. Meanwhile the second stopped being astronomical in 1967 and civil time did not.

Why This Question Matters

Read as a ladder, this history becomes a march towards the Gregorian year with everything else a failed attempt at it, and the actual question disappears. A lunar calendar is not an inaccurate solar one, and a 260 day count is not an inaccurate year: thirteen and twenty day cycles have no direct astronomical basis to be inaccurate about. A calendar is also a coordination device, which is why reforming one is never only a calculation, and why the 2022 decision to let atomic and rotational time drift further apart was argued on the risk to critical digital infrastructure.

1. Three periods that do not fit

Many systems of time reckoning draw on three observable cycles: day and night, lunar phases and seasonal recurrence.

For epoch 2000, a standard astronomical reference gives a mean tropical year of 365.24219 days and a mean synodic month of 29.53059 days, where each day is 86,400 SI seconds (Richards 2013, in Urban and Seidelmann, eds.). The same source stresses that these are approximate mean periods and change slowly with time.

From those two figures three consequences follow by arithmetic alone. **The article performs this arithmetic itself; the products below are deductions from the cited values, not quotations.**

- Twelve synodic months come to 354.36708 days, which is **10.87511 days short of a tropical year**.
- The mean synodic month is not a whole number of 86,400-second days, so fixed-length calendar months cannot remain exactly aligned with every lunation.
- The mean tropical year is not a whole number of mean synodic months, so a fixed sequence of lunar months cannot remain exactly aligned with the seasons without adjustment.

This is not a defect of a particular calendar. It is a consequence of the approximate and changing relations among astronomical periods. Calendars that seek lunar or seasonal alignment must use rules, observations, intercalations or accepted drift. Calendars need not seek either alignment, as section 4 shows.

There is a useful but limited parallel with KNO-006. A projected map faces an exact geometric theorem; a calendar faces empirically measured periods that vary with time. Both make trade-offs visible, but the mathematical status of the two constraints is not the same.

Where That Leaves Us

Three observable cycles carry time reckoning, and the two measured periods are approximate mean periods that change slowly. From those two figures alone, months of fixed length cannot remain aligned with every lunation, and a fixed sequence of them cannot remain aligned with the seasons without adjustment. That arithmetic is performed here, not quoted, and what a calendar does about an empirical constraint is a choice.

2. Three widespread strategies

2.1 Keep the month, lose the season

A calendar of twelve mean synodic months runs about eleven days short of a tropical year, so its dates move through the seasons. By the figures above, the accumulated displacement is approximately one tropical year after 33.6 lunar years.

The Islamic calendar is a lunar calendar: it keeps months in relation to lunations and does not keep its year in synchrony with the Sun (Richards 2013). Its seasonal drift is therefore a consequence of the chosen structure, not evidence that the calendar has failed to be solar.

2.2 Keep the season, lose the moon

The opposite choice abandons the lunar month as an astronomical unit and keeps only its name. The Egyptian civil year is the clearest early case: twelve months of thirty days plus five epagomenal days, three hundred and sixty five in total, described in the standard study as running without an intercalated day (Parker 1950).

A year of exactly 365 days is about a quarter day short, so it too drifts against the seasons, only far more slowly. The Egyptian system tolerated this and tracked the heliacal rising of Sirius separately; Parker records that rising as falling on 17 to 19 July in the Julian calendar throughout dynastic history.

2.3 Keep both, pay in intercalation

The third family keeps true lunar months and forces them back into agreement with the seasons by inserting an extra month at intervals. The arithmetic that makes this workable is a near coincidence:

- Nineteen tropical years come to 6939.60161 days.
- Two hundred and thirty five synodic months come to 6939.68865 days.
- **They differ by 0.08704 days, about 2.09 hours.**

Nineteen years therefore contain almost exactly 235 lunar months, which is twelve ordinary years of twelve months plus seven years with a thirteenth. The nineteen year cycle was in use in the Babylonian calendar from the early fifth century BCE, and the question of whether Greek knowledge of it came from Babylon or was found independently remains open, with an independent Chinese use of the same cycle cited as a reason not to rule out independent discovery (Steele 2020).

The residual is small but not zero. At about two hours per cycle, it accumulates to about 0.44 days, or 10.4 hours, after five cycles (ninety five years). Actual calendrical practice also has to accommodate the fact that the astronomical means themselves vary.

Where That Leaves Us

Keep the month and the year walks through the seasons, which the Islamic calendar does by design; keep the year and the Egyptian civil calendar drifts a quarter day at a time; keep both and the price is a thirteenth month, because nineteen years and 235 months differ by 0.08704 days. Whether Greek use came from Babylon is open, and the nineteen year fit is close without being exact.

3. The Julian error and what the Gregorian reform actually decided

Compared with the epoch-2000 mean used here, a year of exactly 365.25 days exceeds the tropical year by 0.00781 days. **As an illustrative calculation, that is one day every 128 years**, and 9.82 days across 1257 such years. It is not a reconstruction using a constant historical tropical year.

Richards reports that by the thirteenth century the displacement of the vernal equinox from 21 March was recognised, and that debate and attempted remedies preceded the 1582 reform by centuries (Richards 2013). The reform changed both leap-day rules and the method for calculating Easter.

The Gregorian year of 365.2425 days, obtained by dropping three leap days every four centuries, exceeds the tropical year by 0.00031 days, **which is one day in about 3226 years by the same arithmetic.**

The reform did not make the calendar exact; it reduced the long-term solar residual. It also revised the ecclesiastical lunar tables used to calculate Easter, so it should not be described simply as choosing the season and ignoring the Moon. The epoch-2000 comparison above is a transparent approximation, not a permanent error rate.

Where That Leaves Us

Against the epoch 2000 mean a Julian year exceeds the tropical year by 0.00781 days and a Gregorian one by 0.00031: a day every 128 years against one in about 3226. Both are illustrative: the periods change slowly. The 1582 reform reduced the residual without removing it and revised the ecclesiastical lunar tables, so it did not simply choose the Sun. Not every cycle aims at a period.

4. Calendrical cycles need not be astronomical periods

The assumption that a calendar exists only to track an agricultural or astronomical year is too narrow. Richards notes that Central American thirteen-day and twenty-day cycles have no direct astronomical basis (Richards 2013). Their combination yields a 260-day count, a calendrical period that is neither a synodic month nor a tropical year.

Šprajc, Inomata and Aveni infer from orientations of Formative ceremonial complexes that the 260-day calendar was in use between 1100 and 750 BCE, centuries before its previously known textual record (Šprajc, Inomata and Aveni 2023). That is peer-reviewed evidence for an early use, but it remains an archaeological inference from orientations rather than a surviving written calendar.

The case establishes the narrower point needed here: calendrical organisation can combine astronomical observations with conventional numerical cycles. The origin and full range of functions of the 260-day count remain matters for specialist evidence; this article does not assign it one exclusive cause.

Where That Leaves Us

Thirteen and twenty day cycles have no direct astronomical basis, and their combination gives a 260 day count that is neither a month nor a year. Orientations of Formative complexes are read as evidence of its use between 1100 and 750 BCE, an archaeological inference rather than a surviving written calendar. Calendrical order can be conventional as well as observed, and the unit underneath has its own history.

5. From the turning Earth to the caesium atom

Before 1960 the second was defined as $1/86,400$ of the mean solar day. In 1960 it was redefined through a fraction of the tropical year 1900, and in 1967 the CGPM adopted a caesium-based atomic definition. The 2018 wording, effective with the revised SI in 2019, defines the second by fixing the numerical value of the unperturbed caesium-133 ground-state hyperfine transition frequency at 9,192,631,770 Hz (BIPM, “Historical perspective: unit of time, second”; BIPM 2019).

The SI unit is therefore no longer defined by Earth's rotation. That does not mean all timekeeping is independent of Earth: UTC has the rate of atomic time but has been kept close to rotational time, UT1, through leap seconds.

In 2022 the General Conference on Weights and Measures adopted Resolution 4 of its twenty seventh meeting, on the use and future development of UTC. **The resolution's own operative language is that the maximum value for the difference UT1 minus UTC will be increased in, or before, 2035**, with the problem stated as the risk that leap second discontinuities cause serious malfunctions in critical digital infrastructure, and with a direction to propose a new tolerance ensuring continuity of UTC for at least a century.

The wording matters. The resolution decides that the permitted divergence will be increased; it does not itself specify the new maximum or literally say that leap seconds are abolished.

This is related to, but not identical with, section 1. Since 1967 the SI unit has been atomic, while civil time has retained a conventional relation to Earth's rotation. The 2022 decision changes the permitted tolerance between those time scales; it does not change the astronomical periods discussed in section 1.

Where That Leaves Us

The second was defined by the mean solar day, then by a fraction of the 1900 tropical year, and since 1967 by a caesium transition fixed at 9,192,631,770 Hz. The unit left Earth's rotation; UTC did not, kept close to UT1. In 2022 the CGPM decided that difference will be increased, without saying by how much. How far back deliberate reckoning goes is another question.

6. The earliest candidates are disputed

A pit alignment at Warren Field, Crathes, in Aberdeenshire, was interpreted by its investigators as a possible lunisolar time reckoner of the eighth millennium BCE and proposed as very early evidence of deliberate time reckoning (Gaffney et al. 2013). Their article repeatedly uses qualified language such as “appears” and “may”.

Earlier still, incised marks on Upper Palaeolithic bone and antler were argued to constitute deliberate sequential lunar notation (Marshack 1972), an interpretation challenged in a paper whose title puts the objection as a question about wishful thinking (d'Errico 1989).

The methodological warning from KNO-006 applies, but not without alteration. At Warren Field the case combines pit sequence, lunar interpretation and a midwinter alignment; for incised bones the inference depends more heavily on the organisation of marks. In both cases function is inferred rather than written on the artefact. A sequence of notches may be compatible with lunar counting, other tallying or non-notational patterning, so compatibility alone does not establish use.

A specific limitation of this round should be stated. No published scholarly critique specifically addressing the Warren Field interpretation was located during preparation. That is a statement about this search and not evidence that the interpretation is uncontested.

Where That Leaves Us

Warren Field was interpreted by its investigators as a possible lunisolar time reckoner, in language they kept qualified, and no published critique of that interpretation was located in this round, which is a statement about the search. Incised Palaeolithic marks were argued to be deliberate lunar notation, and the argument was challenged. Function is inferred in both cases, and what it was for is harder still.

7. What a calendar is actually for

Section 1 framed calendars as solutions to an astronomical constraint, which is true and incomplete. A calendar is also a coordination device, which helps explain the need for predictable rules, shared procedures and communicable dates.

Calendars can coordinate hunting, agriculture, ritual, contracts and social life (Richards 2013). Different designs trade predictability against observation: arithmetic calendars can be computed by fixed rules, whereas observational calendars may wait for a crescent, solstice or other event and cannot always be constructed fully in advance. Coordination requires shared procedures and a way to communicate dates, not necessarily that every user personally perform the calculation.

This helps frame why reform is not only an astronomical calculation. Changing a calendar also changes a coordination standard, religious observances and administrative practice. The claim that these social costs explain a particular historical delay is an interpretation and requires case-specific evidence.

Where That Leaves Us

The framing in section 1 is true and incomplete. A calendar coordinates hunting, agriculture, ritual, contracts and social life, so its design has practical coordination consequences as well as astronomical ones. Arithmetic designs can be computed in advance while observational ones wait for a crescent or a solstice, and coordination needs shared procedure rather than universal calculation. Explaining a particular delay by its social cost would need case evidence.

8. What the evidence cannot settle

Whether an early artefact is a calendar. Without independent evidence of use, matching an artefact to a modern calendrical function is inference from resemblance.

Intention behind an observed period. That a structure aligns with a solstice does not establish that alignment was intended, and the number of possible alignments in any structure is large.

Whether early systems were understood as approximations. Later users of a nineteen year cycle knew it was inexact. Whether its earliest users did is not recoverable from the cycle's use alone.

Limits of the sources. Four descriptive claims in this article rely on sources whose relevant text was not available in full. Those claims are therefore stated conservatively rather than extended beyond what the accessible evidence supports.

Where That Leaves Us

The evidence stops in four places. Calling an early artefact a calendar is inference from resemblance, with no independent evidence of use. An alignment that exists was not necessarily intended, since the possible alignments in any structure are many. Whether the first users of an inexact cycle knew it was inexact is not recoverable from the cycle. And four descriptive claims rest on sources not read directly here.

9. Conclusion

Mean days, lunar months and tropical years do not occur in integral ratios, and calendars that seek to track them respond with drift, intercalation, observation or arithmetic rules. Other calendrical cycles need not represent an astronomical period at all.

Reading the history as simple progress towards the Gregorian calendar mistakes different purposes for stages on one ladder. A lunar calendar is not a failed solar one, and a 260-day count is not an inaccurate tropical year. The SI second has been atomic since 1967, while UTC still mediates between atomic rate and terrestrial rotation. In 2022 the CGPM decided that the allowed UT1-UTC difference would be enlarged by or before 2035; the new maximum was not fixed by that resolution.

Where That Leaves Us

The ladder is the mistake: it turns different purposes into stages and a lunar calendar into a failed solar one. Mean days, lunar months and tropical years are not in integral ratios, which leaves calendars a choice, and other cycles represent no astronomical period. Since 1967 the second has been atomic, and UTC goes on mediating between that rate and a rotating Earth. What is established, and how, follows.

What We Know, and How

For epoch 2000 a standard astronomical reference gives a mean tropical year of 365.24219 days and a mean synodic month of 29.53059 days, and stresses that both are approximate means that change slowly. Everything this article derives from them is its own arithmetic, marked as such: twelve synodic months fall 10.87511 days short of a year, and nineteen tropical years differ from 235 synodic months by 0.08704 days. The Egyptian civil year ran 365 days with no intercalated day, and the Islamic calendar keeps months in relation to lunations without keeping its year with the Sun. Central American thirteen and twenty day cycles have no direct astronomical basis. And the SI second has been atomic since 1967, its present wording fixing the unperturbed caesium 133 ground state hyperfine transition at 9,192,631,770 Hz.

What We Still Don't Know

Whether Warren Field worked as a lunisolar reckoner is an interpretation its own investigators hedged, and no published critique addressing it specifically was located in this round, which is a statement about the search and not about the literature. Whether Upper Palaeolithic incised marks record lunations is open, because compatibility with a lunar count does not establish one. Whether the earliest users of a nineteen year cycle understood it as inexact is not recoverable from the use of the cycle. The origin and full range of functions of the 260 day count need specialist evidence this article does not supply. And four descriptive claims rest on sources whose relevant text was not read directly in this round.

What Could Change Our Minds

Independent evidence of use, rather than resemblance to a modern calendrical function, would strengthen or break the Warren Field reading, and a published critique addressing it directly would change what this article can say about how contested it is. For the incised bones, a method that separated lunar counting from other tallying and from non notational patterning would settle what the marks alone cannot. Direct reading of the four delegated sources would move them off partial status. And the tolerance the CGPM was directed to propose will replace an open value with a decided one.

If You Remember Only One Thing

A lunar calendar is not a failed solar one: astronomical periods do not fit exactly, and calendars that track them must choose how to handle the mismatch.

Related Articles

- KNO-006 · *Maps and Spatial Representation*
- KNO-008 · *Instruments That Extend the Senses*

References

- BIPM. 2019. *SI Brochure, 9th Edition, Appendix 2: Mise en pratique for the Definition of the Second in the SI*. Bureau International des Poids et Mesures, 20 de mayo de 2019. URL estable: <https://www.bipm.org/documents/20126/41489667/SI-App2-second.pdf> **C-D**
- BIPM. «Historical Perspective: Unit of Time, Second». Bureau International des Poids et Mesures. URL estable: <https://www.bipm.org/en/history-si/second>
- CGPM. 2022. Resolución 4 de la 27.^a CGPM, «On the Use and Future Development of UTC». Conférence Générale des Poids et Mesures, 15 a 18 de noviembre de 2022. DOI 10.59161/CGPM2022RES4E. URL estable: <https://www.bipm.org/en/-/resolution-cgpm-27-4> **C-D**
- d'Errico. 1989. «Palaeolithic Lunar Calendars: A Case of Wishful Thinking?». *Current Anthropology* 30 (1). DOI 10.1086/203721.
- Gaffney, Vincent, Simon Fitch, Eleanor Ramsey, Ron Yorston, Eugene Ch'ng, Eamonn Baldwin, Richard Bates, Christopher Gaffney, Clive Ruggles, Tom Sparrow, Anneley McMillan, Dave Cowley, Shannon Fraser, Charles Murray, Hilary Murray, Emma Hopla, y Andy Howard. 2013. «Time and a Place: A Luni-Solar “Time-Reckoner” from 8th Millennium BC Scotland». *Internet Archaeology* 34. DOI 10.11141/ia.34.1. **C-D**
- Marshack, Alexander. 1972. *The Roots of Civilization: The Cognitive Beginnings of Man's First Art, Symbol and Notation*. New York: McGraw-Hill. ISBN 978-0-07-040535-6.
- Parker, Richard A. 1950. *The Calendars of Ancient Egypt*. Studies in Ancient Oriental Civilization 26. Chicago: Oriental Institute of the University of Chicago. URL estable: <https://isac.uchicago.edu/sites/default/files/uploads/shared/docs/saoc26.pdf>
- Richards, E. G. 2013. «Calendars». Capítulo 15 de *Explanatory Supplement to the Astronomical Almanac*, 3.^a ed., editado por S. E. Urban y P. K. Seidelmann. Mill Valley, CA: University Science Books. URL estable: https://aa.usno.navy.mil/downloads/c15_usb_online.pdf
- Šprajc, Ivan, Takeshi Inomata, y Anthony F. Aveni. 2023. «Origins of Mesoamerican Astronomy and Calendar: Evidence from the Olmec and Maya Regions». *Science Advances* 9 (1): eabq7675. DOI 10.1126/sciadv.abq7675.
- Steele, J. M. 2020. «Geminis and Babylonian Astronomy». En *Instruments, Observations, Theories: Studies in the History of Astronomy in Honor of James Evans*, editado por Alexander Jones y Cristián Carman, 205–212. DOI 10.5281/zenodo.3975741.