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Jetsu, Lauri

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Shifting Milestones of Natural Sciences: The Ancient Egyptian Discovery of Algol’s Period Confirmed

Lauri Jetsu1*, Sebastian Porceddu1
1 Department of Physics, P.O. Box 64, FI-00014 University of Helsinki, Finland
* lauri.jetsu@helsinki.fi

Abstract

The Ancient Egyptians wrote Calendars of Lucky and Unlucky Days that assigned astronomically influenced prognoses for each day of the year. The best preserved of these calendars is the Cairo Calendar (hereafter CC) dated to 1244–1163 B.C. We have presented evidence that the 2.85 days period in the lucky prognoses of CC is equal to that of the eclipsing binary Algol during this historical era. We wanted to find out the vocabulary that represents Algol in the mythological texts of CC. Here we show that Algol was represented as Horus and thus signified both divinity and kingship. The texts describing the actions of Horus are consistent with the course of events witnessed by any naked eye observer of Algol. These descriptions support our claim that CC is the oldest preserved historical document of the discovery of a variable star. The period of the Moon, 29.6 days, has also been discovered in CC. We show that the actions of Seth were connected to this period, which also strongly regulated the times described as lucky for Heaven and for Earth. Now, for the first time, periodicity is discovered in the descriptions of the days in CC. Unlike many previous attempts to uncover the reasoning behind the myths of individual days, we discover the actual rules in the appearance and behaviour of deities during the whole year.

Introduction

The Ancient Egyptians referred to celestial events indirectly [1–4] by relating them to mythological events. Many prognoses in the Calendars of Lucky and Unlucky Days have been connected to astronomical observations [1, 5–7]. Such connections between astronomical events and prognosis texts have been uncovered in most cases only for individual days [6, 8, 9]. The PM = 29.6 days period of the Moon has been discovered in CC [10]. We have claimed that this document also contains the PA = 2.85 days period of the eclipsing binary Algol [11]. However, it not a straightforward task to identify those indirect mythological references that are influenced by Algol in CC. Here we present a statistical analysis that reveals which CC prognosis texts describe Algol’s regular variability.
The Ancient Egyptian year contained 12 months (M) of 30 days (D) and five additional “epagomenal” days. CC gives three prognoses for each D of every M (G = “gut” = “good” and S = “schlecht” = “bad”) [11, 12]. CC also gives textual descriptions of the daily prognoses (S1 Fig). We study the dates of 28 selected words (hereafter SWs) in these mythological texts of CC. The dates are transformed into series of time points \( t_i \) with Eq (2). The \( P_A \) and \( P_M \) signals were originally discovered [11] from six large samples of lucky prognoses \((n = 6 \times 564 = 3384)\). We use these six samples to determine the zero epochs \( t_E \) of Eq (9) for the \( P_A \) and \( P_M \) signals. The time points leading to the discovery of these signals were close to phase, \( \phi = 0 \), of Eq (5) using the ephemerides of Eqs (11) and (12) based on these zero epochs \( t_E \). The lucky prognoses of each SW are a subsample of the above mentioned large samples of lucky prognoses. We compute an impact parameter \( z_x \) for the \( t_i \) of each SW with Eq (10). The time points \( t_i \) of the lucky prognoses of any particular SW may strengthen (if \( z_x > 0 \)) or weaken (if \( z_x < 0 \)) the \( P_A \) and \( P_M \) signals. The impact parameter \( z_x \) is used for identifying the SWs having lucky prognoses close to phase, \( \phi = 0 \), computed with the ephemerides of Eqs (11) and (12). We will show that Algol and the Moon were at their brightest close to phase \( \phi = 0 \) with these two ephemerides. Hence, Algol’s eclipse and the New Moon occurred close to \( \phi = 0.5 \).

Our statistical analysis also confirms two general things regarding the origin of the mythological texts of CC. First, the appearances and feasts of various deities are not independent of the prognoses, or randomly assigned, but regulated by the same periodic patterns. Second, the deities are used to represent the same astronomical phenomena that were also used to choose the prognoses for the days of the year.

Materials

In this section, we transform the dates of 28 SWs in the mythological texts of CC into series of time points \( t_i \). Our main aim is that all stages of the production of these data can be replicated. With these instructions, similar series of time points can be produced for any particular SW in CC or other similar calendars, where the SW dates are available. We create the data in two stages: Identification of SW dates and Transformation of SW dates into series of time points.

Identification of SW dates

CC is the best preserved Calendar of Lucky and unlucky Days. As in our two previous studies [10, 11], we use the best preserved continuous calendar found on pages recto III-XXX and verso I-IX of papyrus Cairo 86637. There are two CC translations, in English by Bakir [13] and in German by Leitz [12]. Our SWs have been identified according to the hieroglyphic transcription in Leitz [12] and the two aforementioned translations. In case of discrepancy we have consulted the photocopies of the original hieratic text given by Leitz [12]. For the sake of convenience, we quote sentences according to Bakir’s English translation despite its imperfections because there is neither space nor reason to discuss the linguistic details of the text in the present article. This approach should ascertain that our study of the CC sentences is objective. In other words, we do not ourselves translate any CC sentences into English, but we do check which individual Ancient Egyptian SWs were also identified by Bakir [13] and Leitz [12]. There is only one exception to our sentence quotation rule, i.e. the CC text connected to Horus where Bakir [13] did not identify Horus, but Leitz [12] and we did (Algol in lucky prognoses: the text at date \( g(g(1, 10)) \)).

Naturally, we can not analyse all words in CC. Our main selection criterion is to include deities, nouns or locations that could have been used to indirectly describe periodic phenomena, due to their significant mythological properties and multiple occurrences in the text. Our list of
SWs is not absolute and we give all the necessary information for other researchers to repeat our experiment on other SWs we may have ignored. Our 28 SWs in Ancient Egyptian language are given in Table 1.

We do not use the occurrences of our SWs in compound words and composite deities (e.g. House of Horus or Ra-Horakhti), because it is uncertain to which word, if not both, the prognosis is connected to. Our identifications of 28 SWs in CC are given in Table 2. It shows that all our 460 SW date identifications are the same as those made by Leitz [12] (Column 5: 460× “Yes”). However, 21 of our identifications were not made by Bakir [13] (Column 6: 21× “No” : 1 × “Earth”, 2 × “Enemy”, 4 × “Fire”, 12 × “Heart”, 1 × “Horus” and 1 × “Osiris”). Fortunately, most days have combinations “GGG” or “SSS” and we know that the lucky or unlucky SW prognosis is certainly correct. We ignore the heterogeneous combinations “HET” (like “SSG” at D = 6 and M = 1), because the correct SW prognosis is uncertain. The dates with an unknown prognosis are shown in Table 3.

| Table 1. List of SWs in Ancient Egyptian language. |
|-----------------|-----------------|-----------------|
| ibdw            | Abydos          | bmr             |
| ddw             | Busiris         | rmt             |
| tš              | Earth (ground, land) | nwt             |
| ḫtyt            | Enemy           | nww             |
| psdt            | Ennead          | wnr-nfr         |
| ḫtrt            | Eye             | wsīr            |
| ḫtr             | Fire            | r             |
| nsrt            | Flame           | sbi             |
| ḫmyw-ḥt         | Followers (following) | sbmt            |
| ḫb              | Heart           | stḥ             |
| ḫt              | Heaven (sky)    | šw              |
| ḫmwnw           | Heliopolis      | sbk             |
| ḫr              | Horus           | ḫhwty           |
| mūt             | Lion            | wdt             |

Table 1. List of SWs in Ancient Egyptian language.

<table>
<thead>
<tr>
<th>SW</th>
<th>D</th>
<th>M</th>
<th>Prog</th>
<th>Ltz</th>
<th>Bkr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abydos</td>
<td>13</td>
<td>3</td>
<td>SSS</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Abydos</td>
<td>17</td>
<td>3</td>
<td>-</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Abydos</td>
<td>11</td>
<td>4</td>
<td>GGG</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Abydos</td>
<td>18</td>
<td>5</td>
<td>GGG</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Abydos</td>
<td>27</td>
<td>6</td>
<td>-</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Abydos</td>
<td>28</td>
<td>7</td>
<td>GGG</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Abydos</td>
<td>13</td>
<td>8</td>
<td>SSS</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Abydos</td>
<td>23</td>
<td>8</td>
<td>-</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Busiris</td>
<td>26</td>
<td>2</td>
<td>SSS</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Busiris</td>
<td>14</td>
<td>5</td>
<td>SSS</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Busiris</td>
<td>26</td>
<td>5</td>
<td>SSS</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The selected word (SW) identified on day (D) of month (M) in CC. The daily prognosis combinations (Prog) are “GGG” (All lucky), “SSS” (All unlucky), “-”-” (All unknown) or “HET” (Heterogeneous). The same SW was identified at the same date by Leitz [12] (Ltz = “Yes” or “No”) and by Bakir [13] (Bkr = “Yes” or “No”).

The twelve first lines of all 460 lines are shown here for guidance regarding the contents of this ASCII file which can be downloaded on Dryad (http://dx.doi.org/10.5061/dryad.tj4qg).

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doi:10.1371/journal.pone.0144140.0002
combination, “- - -”, are naturally also ignored. Our notations for the number of lucky and unlucky dates for each SW are \( n_G \) and \( n_S \). For example, "Abydos" has \( n_G = 3 \) and \( n_S = 2 \).

**Transformation of SW dates into series of time points**

The dating of CC does not influence the results of our current analysis, because we transform the time points to unit vectors with Eq (6). The mutual directions between these unit vectors do not depend on the chosen zero epoch \( t_0 \) in time. Adding any positive or negative constant value to these time points rotates all unit vectors with the same constant angle. Hence, our significance estimates of Eqs (8) and (13) do not depend on the connection between Gregorian and Egyptian days. The only assumption made in our Eq (2) below is that the separation between two subsequent days is exactly one day during the particular year that CC happens to describe.

The transformation relations in Eqs (2) and (3) of Jetsu et al.\[11\] were

\[
t_i = N_E / C_0 + a_i, \tag{1}
\]

where \( N_E = 30(M - 1) + D \) and \( a_i \) was a decimal part. This decimal part \( a_i \) was different for each of the three parts of the day. The \( a_i \) values depended on the chosen transformation between Egyptian and Gregorian year, and on the chosen day division. The \( P_A \) and \( P_M \) signals were discovered in samples of series of time points \( \text{SSTP} = 1, 3, 5, 7, 9 \) and \( 11 \) in Jetsu et al.\[11\]. The size of each sample was \( n = 564 \). The period analysis results were the same for all these six samples, although their \( a_i \) values were different for every \( N_E \). The time points \( t_i \) of these six samples are given in Table 3.

The mean of the decimal parts \( a_i \) of all these \( n = 6 \times 564 = 3384 \) values of \( t_i \) is \( m_t = 0.33 \). In this study, the time point for an SW at the day \( D \) of the month \( M \) in CC is therefore computed from

\[
t_i = t_i(D, M) = N_E / C_0 + m_t. \tag{2}
\]

This accuracy is sufficient, because we do not know to which part or parts of the day each SW refers to (\( a_i \approx \pm 0.45 \)) and some prognosis texts may refer to the previous or the next day (\( a_i \approx \pm 1.45 \)). The \( t_i \) of Table 3 (\( n = 6 \times 564 = 3384 \)) are also later used to determine the zero epochs \( t_E \) for the ephemerides connected to the \( P_A \) and \( P_M \) signals (Eqs (11) and (12)). Our “synchronization” of time points of Eqs (1) and (2) ensures that these ephemerides enable us to identify the SWs connected to the \( P_A \) and \( P_M \) signals. For a given \( t \) value, the inverse transformation is

\[
M = \text{INT}[(t + 1 - m_t)/30] + 1 \tag{3}
\]

\[
D = t - m_t + 1 - 30(M - 1), \tag{4}
\]

---

**Table 3. The time points \( t_i \) of lucky prognoses in Jetsu et al.\[11\].**

<table>
<thead>
<tr>
<th>SSTP = 1</th>
<th>SSTP = 3</th>
<th>SSTP = 5</th>
<th>SSTP = 7</th>
<th>SSTP = 9</th>
<th>SSTP = 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.080</td>
<td>0.095</td>
<td>0.076</td>
<td>0.120</td>
<td>0.142</td>
<td>0.114</td>
</tr>
<tr>
<td>0.239</td>
<td>0.284</td>
<td>0.227</td>
<td>0.359</td>
<td>0.426</td>
<td>0.341</td>
</tr>
<tr>
<td>0.399</td>
<td>0.473</td>
<td>0.379</td>
<td>0.739</td>
<td>0.784</td>
<td>0.727</td>
</tr>
<tr>
<td>1.080</td>
<td>1.095</td>
<td>1.076</td>
<td>1.120</td>
<td>1.142</td>
<td>1.113</td>
</tr>
<tr>
<td>1.240</td>
<td>1.284</td>
<td>1.227</td>
<td>1.360</td>
<td>1.425</td>
<td>1.340</td>
</tr>
</tbody>
</table>

The \( t_i \) values of \( \text{SSTP} = 1, 3, 5, 7, 9 \) and \( 11 \) from Table 3 in Jetsu et al.\[11\]. The five first lines of all 534 lines are shown here for guidance regarding the contents of this ASCII file which can be downloaded on Dryad (http://dx.doi.org/10.5061/dryad.tj4qg).

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where \( \text{INT} \) removes the decimal part of \( (t + 1 - m_t)/30 \). In other words, if the analysis our data gives any particular \( t \) value, the \( D \) and \( M \) values of this \( t \) can be solved from Eqs (3) and (4).

The time points \( t_i \) for all dates with a “GGG” or “SSS” prognosis combination in CC are given in Table 4. These \( t_i \) are needed in computing the binomial distribution probabilities \( Q_B \) of Eq (13).

<table>
<thead>
<tr>
<th>( D )</th>
<th>( M )</th>
<th>( t_i )</th>
<th>Prog</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0.33</td>
<td>GGG</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1.33</td>
<td>GGG</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>4.33</td>
<td>GGG</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>6.33</td>
<td>GGG</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>8.33</td>
<td>GGG</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>9.33</td>
<td>GGG</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>10.33</td>
<td>SSS</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>11.33</td>
<td>SSS</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
<td>15.33</td>
<td>SSS</td>
</tr>
<tr>
<td>17</td>
<td>1</td>
<td>16.33</td>
<td>SSS</td>
</tr>
</tbody>
</table>

Table 4. The time points \( t_i \) of all GGG and SSS dates in CC.

The call \( \text{INT} \) removes the decimal part of \( (t + 1 - m_t)/30 \). In other words, if the analysis our data gives any particular \( t \) value, the \( D \) and \( M \) values of this \( t \) can be solved from Eqs (3) and (4).

The time points \( t_i \) for all dates with a “GGG” or “SSS” prognosis combination in CC are given in Table 4. These \( t_i \) are needed in computing the binomial distribution probabilities \( Q_B \) of Eq (13).

Methods

Let us assume that time is a straight line, where events are equidistant dots with a separation of \( 2\pi \). If this line is wound on a \( d = 1 \) diameter wheel, the dots line up at the same point on the wheel. Removing some dots produces gaps in the time line, but the remaining dots will still line up on the wheel. However, they will not line up on a \( d = 1/4 \) diameter wheel. This is an analogy for the Rayleigh test. It projects time points on a unit circle with the tested period \( P \). These points line up in the same direction, if their time distribution is regular with the tested \( P \).

Analysis

If the Rayleigh method discovers the period \( P \) in a series of time points points \( t = [t_1, t_2, \ldots, t_n] \), it is possible to identify those subsamples \( t' \) of \( n' \) time points that strengthen this signal. In other words, the signal can be separated from noise. The phases of the \( n \) time points \( t_i \) are

\[
\phi_i = \text{FRAC}\left[\left(t_i - t_0\right)/P\right],
\]

where \( t_0 \) is an arbitrary zero epoch and \( \text{FRAC} \) removes the integer part of \( (t_i - t_0)/P \). The unit vectors are

\[
r_i = [\cos \Theta_i, \sin \Theta_i],
\]

where \( \Theta_i = 360^\circ, \phi_i \) are the phase angles. The test statistic of the Rayleigh test is

\[
z = |R|^2/n,
\]

where vector \( R = \sum_{i=1}^{n} r_i \) points to \( \Theta_R = \text{atan}(R_y/R_x) \), \( R_x = \sum_{i=1}^{n} \cos \Theta_i \) and...
Table 5. Values of $t_6$ of the six samples.

<table>
<thead>
<tr>
<th>$P$</th>
<th>SSTP = 1</th>
<th>SSTP = 3</th>
<th>SSTP = 5</th>
<th>SSTP = 7</th>
<th>SSTP = 9</th>
<th>SSTP = 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.85</td>
<td>0.45</td>
<td>0.45</td>
<td>0.44</td>
<td>0.61</td>
<td>0.61</td>
<td>0.60</td>
</tr>
<tr>
<td>29.6</td>
<td>3.42</td>
<td>3.42</td>
<td>3.42</td>
<td>3.58</td>
<td>3.58</td>
<td>3.58</td>
</tr>
</tbody>
</table>

$R_y = \sum_{i=1}^n \sin \Theta_i$. The corresponding phase is $\phi_y = \Theta_y/(360^\circ)$. Coinciding directions $\Theta_i$ give $|R| = n$, while random $\Theta_i$ give $|R| \approx 0$. The critical level (i.e. significance) of the Rayleigh test is

$$Q_x = e^{-z}.$$  \hspace{1cm} (8)

We use the ephemeris zero epoch

$$t_E = t_0 + P\phi_R.$$  \hspace{1cm} (9)

The mutual directions of $r_i$ and the length $|R|$ are invariant for any constant shift of $m_i$, $t_b$, $t_0$ or $t_E$. Using the above $t_E$ of Eq (9), vector $R$ points to $\Theta = \Theta_R = 0^\circ$. All $r_i$ with $-90^\circ < \Theta_i < 90^\circ$ strengthen the $P$ signal, while the remaining $r_i$ weaken it. The test statistic can be divided into $z = R_y^2/n + R_z^2/n$. We fix $t_0 = t_E$ in Eq (5) and compute the “impact” of any subsample $t^*$ on the $P$ signal from

$$z_x = (R_y/|R|)(R_z^2/n),$$  \hspace{1cm} (10)

where $R_y$ is computed only for the $n = n^*$ time points of $t^*$. These $t^*$ may strengthen ($z_x > 0$) or weaken ($z_x < 0$) the $P$ signal, or represent noise ($z_x \approx 0$).

Using the zero epoch $t_0 = 0$ for the $n = 6 \times 564$ time points $t_i$ of the G prognoses in Table 3 gives the $t_6$ values of Table 5 for the $P_A$ and $P_M$ signals with Eq (9).

These six large samples have $t_E = 0.53 \pm 0.09$ for $P_A$ and $t_E = 3.50 \pm 0.09$ for $P_M$. Hence, we use the following two ephemerides

$$t_0 = t_E = 0.53, P = P_A = 2.85 \quad \text{(Algol)}$$  \hspace{1cm} (11)

$$t_0 = t_E = 3.50, P = P_M = 29.6 \quad \text{(Moon)}.$$  \hspace{1cm} (12)

for computing the phases $\phi_i$ of Eq (5). The lucky “GGG” prognoses of every SW are a subsample of the above six large samples of all “G” prognoses. We give the $z$ and $z_x$ values of Eqs (7) and (8) for any particular SW, if the analysed $t_i$ of this SW reach $Q_x \leq 0.2$ with the ephemerides of Eqs (11) or (12). These periodicities are called weak if $0.05 < Q_x \leq 0.2$.

In our Figs 1–13, we project the $t_i$ of each SW to $r_i = [\cos \Theta_i, \sin \Theta_i]$ on a unit circle, where time runs in the counter clock-wise direction. For the $P_A$ signal, we define four points $Aa, Ab, Ac$ and $Ad$. The first one, $Aa$, is at $\phi = 0 \equiv 0^\circ$ with the ephemeris of Eq (11). The next three points $Ab, Ac$ and $Ad$ are separated by $\Delta \phi = 0.25 \equiv 90^\circ$. Vectors $r_i$ pointing between $Ad \equiv -90^\circ$ and $Ab \equiv +90^\circ$ give $z_x > 0$ and strengthen $P_A$ signal, the other ones weaken it. Because $P_A$ equals $57^d/20$, the $\phi_i$ of $t_i$ separated by multiples of 57 days are equal. For clarity, we shift such overlapping $\phi_i$ values by $\Delta \phi = 0.005$ away from each other in our Figs 1–13. However, there are no such shifts in our computations. Our unambiguous terminology is:

“Connected to the $P_A$ signal” $\equiv t_i$ of an SW strengthen the $P_A$ signal $\equiv z_x \geq 1.0$ and $Q_x \leq 0.2$ with the ephemeris of Eq (11).

“Connected to Algol” $\equiv t_i$ of an SW show periodicity with $P_A$, but their contribution to
the $P_A$ signal is insignificant when $0 \leq z_x < 1.0$ or they weaken this signal when $z_x < 0 \equiv z_x < 1.0$ and $Q_z \leq 0.2$ with the ephemeris of Eq (11).

We use similar terminology for the Moon (Eq (12)), and Ma–Md points similar to Aa–Ad.

Our notations for the lucky and unlucky time points $t_i$ of each SW are $g_i$ and $s_i$. The notations for their unit vectors $r_i$ of Eq (6) are $g_i$ and $s_i$, respectively. The critical level $Q_z$ measures the probability for the concentration of all $n_G$ and $n_S$ directions of $g_i$ and $s_i$ of each SW. These directions are embedded within the directions of all $g_i$ (Table 4: $N_G = 177$) and $s_i$ (Table 4: $N_S = 105$). We first choose the direction $\Theta_R$ of $R$ for some SW. Then we identify the $n_1$ directions of $g_i$ or $s_i$ of this SW that are among the $n_2$ of all $N_G$ or $N_S$ directions closest to $\Theta_R$. For each SW, this gives the binomial distribution probability

$$Q_n = P(n_1, n_2, N) = \sum_{i=n_1}^{n_2} \binom{n_2}{i} q_\Theta(1 - q_\Theta)^{n_2-i},$$

(13)

where $N = N_G$ or $N_S$ and $q_\Theta = n_G/N_G$ or $n_S/N_S$. This $Q_n$ is the probability for that the directions of a particular SW occur $n_1$ times, or more, among all $n_2$ directions closest to $\Theta_R$. Many $Q_z$
estimates based on small samples (n_G or n_S) are unreliable, but the Q_b estimates based on large samples (Table 4: N_G = 177 or N_S = 105) are not.

All results of our analysis are given in S1 Table, where the results mentioned in text are marked with bold letters. The structure of S1 Table resembles the four panel structure of Figs 1–13. We give four separate tables for each SW. The results for the lucky and unlucky prognoses with P_A are those shown in figure panels “a” and “b”. The corresponding results for P_M are shown in figure panels “c” and “d”.

Results

Algol in lucky prognoses

Of all 28 SWs, only the lucky prognoses of Horus, Re, Wedjat, Followers, Sakhmet and Ennead unambiguously strengthen the P_A signal of Algol, because they have an impact of z_x ≥ 1.0 and a significance of Q_z ≤ 0.2 with the ephemeris of Eq (11). The lucky prognoses of Heliopolis and Enemy are connected to Algol (Q_z ≤ 0.2), but they are not connected to the P_A signal (z_x < 1.0). In this section, we discuss these eight SWs in the order of their impact on the P_A signal, i.e. in the order of decreasing z_x with the ephemeris of Eq (11).

Horus. This SW has the largest impact z_x = +3.5 on the P_A signal and the highest significance of the above eight SWs (Q_z = 0.03, n_G = 14). The unit vectors g_i and s_i of lucky and
unlucky prognoses with the ephemeris of Eq (11) are shown in Fig 1a. Point Aa is at $\phi = 0 \equiv 0^\circ$. Points Ab, Ac and Ad are separated by $\Delta \phi = 0.25 \equiv 90^\circ$. Only the $g_i$ pointing between Ad $\equiv -90^\circ$ and Ab $\equiv +90^\circ$ strengthen the $P_A$ signal. Twelve out of all fourteen $g_i$ are within this interval (Fig 1a). The four $\Theta_i$ closest to $\Theta_R = 11^\circ$ reach a high significance of $Q_B = 0.006$ ($n_1 = 4$, $n_2 = 10$, $N_G = 177$). The $g_i$ pointing closest to Aa and giving the strongest impact on the $P_A$ signal has the CC text [13]

$g_i(14, 2) \equiv +6^\circ$: "It is the day of receiving the white crown by the Majesty of Horus; his Ennead is in great festivity."

The texts [12, 13] for the next best $g_i$ closest to Aa are

$g_i(19, 12) \equiv +13^\circ$: "Horus has returned complete, nothing is missing in it."
$g_i(27, 1) \equiv +19^\circ$: "Peace on the part of Horus with Seth."
$g_i(24, 3) \equiv +19^\circ$: "He has given his throne to his son, Horus, in front of Re."
$g_i(1, 7) \equiv +32^\circ$: "Feast of entering into heaven and the two banks. Horus is jubilating."
$g_i(15, 11) \equiv +38^\circ$: "Horus hears your words in the presence of every god and goddess on this day."
$g_i(27, 3) \equiv +38^\circ$: "Judging Horus and Seth; stopping the fighting."
g_1(18, 1) \equiv -38^\circ: \text{"It is the day of magnifying the majesty of Horus more than his brother,} \\
\ldots\text{"
}
g_1(1, 9) \equiv +51^\circ: \text{"Feast of Horus son of Isis and ... his followers ... day"}
g_1(23, 7) \equiv -69^\circ: \text{"Feast of Horus ... on this day of his years in his very beautiful images."}
g_1(29, 3) \equiv -69^\circ: \text{"White crown to Horus, and the red one to Seth."}
g_1(7, 9) \equiv +88^\circ: \text{"The crew follow Horus in the foreign land, examining its list ... therein} \\
\text{when he smote him who rebelled against his master."}
g_1(1, 10) \equiv -120^\circ: \text{"Horus ... Osiris ... Chentechtai ... land"}
g_1(28, 3) \equiv +164^\circ: \text{"The gods are in jubilation and in joy when the will is written (lit.} \\
\text{made) for Horus, ..."}

These passages of lucky prognoses are suggestive of Algol at its brightest. The "white crown", Horus having "returned complete" and "entering into heaven" (i.e. into the sky) are not easy to explain as symbols for the eclipse. Among the g_i of all 28 SWs, the g_i of Horus are the "best hit" on Aa (z_x = +3.5). If these g_i represent Algol at its brightest, then Aa is in the middle of this brightest phase and the thick line centered at Ac in Fig 1a outlines Algol's eclipse. In this case, the g_i(7, 9) \equiv +88^\circ text may refer to an imminent eclipse and "the will is written" in g_i(28, 3) \equiv +164^\circ to the moment when the beginning of the eclipse is just becoming observable with naked eye. These passages could certainly describe naked eye observations of the regular changes of Algol.
Three \( s_i \) of Horus in Fig 1b concentrate close to Ad and reach \( Q_B = 0.07 \) \((n_1 = 3, n_2 = 25, N_S = 105)\). The fourth vector \( s_i \) points close to Aa. Their CC texts [13] are

\( s_i(26, 1) \equiv -107^\circ \): “... It is the day of Horus fighting with Seth. ...”

\( s_i(11, 11) \equiv -107^\circ \): “Introducing the great ones by Re to the booth to see what he had observed through the eye of Horus the elder. They were with heads bent down when they saw the eye of Horus being angry in front of Re.”

\( s_i(20, 9) \equiv -69^\circ \): “Mat judges in front of these gods who became angry in the island of the sanctuary of Letopolis. The Majesty of Horus revised it.”

\( s_i(5, 8) \equiv 6^\circ \): “The Majesty of Horus is well when the red one sees his form. As for anybody who approaches it, anger will start on it.”

If the \( g_i \) that described feasts were connected to the brightest phase of Algol, these \( s_i \) describing anger would have occurred after Algol’s eclipse. "Horus is well" for the last \( s_i(5, 8) \) would seem natural for a lucky prognosis of Horus (as it should be close to Aa) but it is deemed unlucky for some other reasons. This type of “conflict of interest” prognoses may explain, why there are significant concentrations of directions accompanied by a few irregular directions (e.g. Fig 7c).
The $g_i$ and $s_i$ of Horus have $Q_z > 0.2$ with the ephemeris of Eq (12), and are therefore not connected to the Moon, except for some $g_i$ texts mentioning both Horus and Seth. We argue that, as Leitz [12] also did, $M_C \equiv 180^\circ$ in Fig 1 coincides with the New Moon (see paragraph Seth). All the aforementioned lucky prognoses mentioning both Horus and Seth are close to $M_d \equiv -90^\circ$ in Fig 1c, i.e. $g_i(27, 1) \equiv -82^\circ$, $g_i(27, 3) \equiv -73^\circ$ and $g_i(29, 3) \equiv -48^\circ$ with the ephemeris of Eq (12). The texts of these three days may describe the “luminosity competitions” between Horus and Seth which come to an end when more than half of the lunar disk becomes illuminated immediately after $M_d$. The legend of the Contendings of Horus and Seth[14] (hereafter LE1) has inspired these descriptions. The text “White crown to Horus, and the red one to Seth” in $g_i(29, 3)$ would describe the brightening of Horus with Algol (Fig 1a: $\Theta = -69^\circ$) and the brightening of Seth (Fig 1c: $\Theta = -48^\circ$) with the approaching Full Moon at $M_a$. The most simple explanation for the context of these texts is that the lucky prognoses of Horus are connected to Algol at its brightest.

Re. The lucky prognoses reach $Q_z = 0.07$ ($n_G = 32$) with the ephemeris of Eq (11) and give the second largest impact $z_x = +2.5$ on the $P_A$ signal (Fig 2a). Absence of small $Q_B$ values, i.e. $g_i$ concentrations, may indicate that Re (the Sun) was casually following the undertakings of Horus. The $s_i$ of Re reach $Q_z = 0.2$ ($n_S = 26$) with the ephemeris of Eq (12), and explicitly avoid $M_a$, the proposed Full Moon phase (Fig 2d).
**Wedjat.** The lucky prognoses show weak periodicity ($Q_z = 0.1, n_G = 4$) with the ephemeris of Eq (11). They give the third largest impact $z_x = +2.0$ on the $P_A$ signal (Fig 3a). However, their impact on the $P_M$ signal is even larger, $z_x = +2.9$ (Fig 3c). **Wedjat** may represent **Algol** observed at its brightest close to the Full Moon. The $g_i$ and $s_i$ distributions of Horus and Wedjat are similar (Figs 1ab and 3ab) with the ephemeris of Eq (11). **Wedjat** is the Eye of Horus in Ancient Egyptian mythology.

**Followers.** The lucky prognoses have an impact of $z_s = +1.4$ on the $P_A$ signal (Fig 4a). This periodicity is weak ($Q_z = 0.2, n_G = 15$). Six $s_i$ reach $Q_z = 0.01$ (Fig 4b). The five $s_i$ closest to $\Theta_R$ reach a high significance of $Q_B = 0.003 \ (n_1 = 5, n_2 = 18, N_S = 105)$ and may refer to an approaching eclipse of **Algol**. These $s_i$ also show a weak connection to the Moon (Fig 4d). It is tempting to suggest that **Followers** would be **Pleiades** following very close behind **Algol** in the revolving sky, e.g. in $g_i(7, 9) \equiv 88^\circ$ “The crew follow Horus in the foreign land” (Figs 1a and 4a).

**Sakhmet.** The $g_i$ and $s_i$ reach $Q_z = 0.06 \ (n_G = 4)$ and $0.05 \ (n_S = 3)$ with the ephemeris of Eq (11). The impact of $g_i$ on the $P_A$ signal is $z_x = +1.3$ (Fig 5a). The three $s_i$ at Ad, after the proposed eclipse at Ac, are strongly connected to **Algol**, because they reach the most extreme significance in this study, $Q_B = 0.0004 \ (n_1 = 3, n_2 = 6, N_S = 105)$. The texts [13] are $s_i(27, 8) \equiv -95^\circ$: “Re sets because the Majesty of the goddess Sakhmet is angry in the land of Temhu.”
It is the day of the proceeding of Sakhmet to Letopolis. Her great executioners passed by the offerings of Letopolis on this day.

It is the day of the executioners of Sakhmet.

These three unlucky prognoses (Fig 5b) are immediately followed by lucky ones (Fig 5a). The $g_i$ and $s_i$ distributions of Sakhmet (Fig 5ab) resemble those of Horus (Fig 1ab) with the ephemeris of Eq (11). The Eye of Horus (Wedjat) was transformed into the vengeful goddess Sakhmet in the legend [14] of the Destruction of Mankind (hereafter LE2). The $s_i$ vectors of Horus, Wedjat and Sakhmet point close to Ad which is after Algol’s proposed eclipse at Ac (Figs 1b, 3b and 5b), and may refer to the abrupt pacification of enraged Sakhmet in LE2.

Ennead. The lucky prognoses show weak periodicity (Fig 6a: $Q_z = 0.1, n_G = 18$) and an impact of $z_x = +1.1$ on the $P_A$ signal with the ephemeris of Eq (11), as well as some concentration ($Q_b = 0.02, n_1 = 12, n_2 = 63, N_G = 177$). Ennead was a group of nine deities in Ancient Egyptian mythology. We discussed earlier, why Followers may have represented Pleiades. Ennead may have been another name for Pleiades, having the modern name “Seven sisters”. However, the number of Pleiades members visible with naked eye depends on the observing conditions and the observer, the maximum number of such members being fourteen [15, 16]. The unlucky prognoses of Followers could be connected to Pleiades following the disappearing

$s_i(13, 6) \equiv -82^\circ$: “It is the day of the proceeding of Sakhmet to Letopolis. Her great executioners passed by the offerings of Letopolis on this day.”

$s_i(7, 10) \equiv -82^\circ$: “It is the day of the executioners of Sakhmet.”
Algol before eclipse (Fig 4b), while the unlucky prognoses of Ennead could be connected to Algol reappearing in front Pleiades after eclipse (Fig 6b). Furthermore, the lucky prognosis distributions of Followers and Ennead are very similar (Figs 4a and 6a).

Heliopolis. The lucky prognoses show weak periodicity with $P_A$, but their impact on this signal is insignificant, $z_x = +0.2$, with the ephemeris of Eq (11).

Enemy. These lucky prognoses weaken the $P_A$ signal, because their impact is $z_x = -1.0$ with the ephemeris of Eq (11).

The Moon in lucky prognoses

We discuss the remaining other 20 SWs in this section and in sections Algol in unlucky prognoses

The Moon in unlucky prognoses

No Algol or the Moon in lucky or unlucky prognoses

These SWs are discussed only briefly, because they are not connected to the $P_A$ signal.

The lucky prognoses of Earth, Heaven, Busiris, Rebel, Thoth and Onnophris are connected to the $P_M$ signal, because they have $z_x \geq 1.0$ and $Q_z \leq 0.2$ with the ephemeris of Eq (12). The lucky prognoses of Nut are weakly connected to the Moon.
Earth. These lucky prognoses reach the highest impact parameter value of this study, $z_x = +5.3$, on the $P_M$ signal. This periodicity also reaches the highest Rayleigh test significance of all, $Q_z = 0.001 \ (n_G = 19)$. The good moments on Earth occurred before and during Ma, the proposed Full Moon phase (Fig 7c). The unlucky prognoses also show a weak connection to Algol (Fig 7b: $Q_z = 0.06, n_S = 5$) and an even weaker connection to the Moon (Fig 7d: $Q_z = 0.2, n_S = 5$).

Heaven. The second largest impact $z_x = +3.4$ on the $P_M$ signal comes from these lucky prognoses. Again, the good moments coincide with Ma, the proposed Full Moon phase (Fig 8c). This is significant periodicity ($Q_z = 0.03, n_G = 19$) combined with a very significant concentration ($Q_B = 0.002, n_1 = 12, n_2 = 45, N_G = 177$). The unlucky prognoses also show a weak connection to the Moon (Fig 8d: $Q_z = 0.06, n_S = 4$).

Busiris. The third largest impact on the $P_M$ signal, $z_x = +3.0$, comes from the lucky prognoses of Busiris. This periodicity reaches $Q_z = 0.05 \ (n_G = 4)$ with the ephemeris of Eq (12). And again, the lucky prognoses are close to Ma, the proposed Full Moon phase (Fig 9c)

Rebel. The lucky prognoses show weak periodicity ($Q_z = 0.2, n_G = 3$) with the ephemeris of Eq (12) and have an impact of $z_x = 1.6$ on the $P_M$ signal.

Thoth and Onnophris. The lucky prognoses of these SW have a weaker impact on the $P_M$ signal, i.e. $1.0 \leq z_x \leq 1.3$ with the ephemeris Eq (12).

Nut. The lucky prognoses show a weak connection to the Moon. They have no impact on $P_M$, because $z_x \approx -0.1$ with the ephemeris of Eq (12).

Fig 10. Heart, otherwise as in Fig 1

\begin{align*}
\text{Heart:} & P = 2.85, n_G = 27 \\
\Theta_R & = -91 \\
\text{Heart:} & P = 29.60, n_G = 27 \\
\Theta_R & = 47 \\
\text{Heart:} & P = 2.85, n_S = 5 \\
\Theta_R & = -172 \\
\text{Heart:} & P = 29.60, n_S = 5 \\
\Theta_R & = 154 \\
\end{align*}
Algol in unlucky prognoses

The \( P_A \) and \( P_M \) signals were detected from the lucky prognoses \( g_i \)[10, 11]. It is therefore self-evident that the unlucky prognoses \( s_i \) had no impact on these two signals. However, this does not rule out the possibility that the \( s_i \) of some SW may be connected to \textit{Algol} or the \textit{Moon}. Most of these \( s_i \) vectors point away from Aa or Ma, i.e. \( z_x < 0 \) with the ephemerides of Eqs (11) or (12). \textit{Man} and \textit{Flame} are the only exceptions to this general rule (\( z_x \geq 0 \)).

\textbf{Heart.} The unlucky prognoses have \( z_x = -3.1 \) with the ephemeris of Eq (11). They point towards Ac, the proposed eclipse phase of \textit{Algol} (Fig 10b). This periodicity reaches a significance of \( Q_z = 0.04 \) \((n_s = 5)\) and \( Q_b = 0.04 \) \((n_1 = 5, n_2 = 39, N_S = 105)\).

\textbf{Nun.} The three unlucky prognoses of this SW reach \( Q_z = 0.06 \) and a high significance of \( Q_b = 0.003 \) \((n_1 = 3, n_2 = 11, N_S = 105)\) with the ephemeris of Eq (11). They also show a weaker connection to the \textit{Moon}.

The Moon in unlucky prognoses

We will first discuss the unlucky prognoses of SWs having negative \( z_x \) values with the ephemeris of Eq (12), and then the two exceptions of \textit{Man} and \textit{Flame}.
Seth. “See you on the dark side of the Moon” sums up the unlucky prognoses of Seth (Fig 11d). The significance is $Q_z = 0.05$ ($n_S = 9$) with the ephemeris of Eq (12). Leitz [12] has argued that the following texts [13] at two consecutive days

$s_i(16, 7) \equiv 173^\circ$: "Do not look, darkness being on this day (or, do not see darkness on this day)."

$s_i(17, 7) \equiv 185^\circ$: "Do not pronounce the name of Seth on this day."

take place during the New Moon. The $s_i$ vectors of these two particular texts point at the opposite sides of $M_c \equiv 180^\circ$, which supports both our “prediction” formula of Eq (12) and Leitz’ attribution [12] of the texts to the New Moon. We conclude that Seth is connected to the Moon and strongly suggest that $M_c$ computed with Eq (12) is close to the New Moon. Hence, the Full Moon is close to $M_a$.

Osiris. The four unlucky prognoses of this SW also point to the dark side of the Moon, assuming that $M_c$ is close to the New Moon (Fig 12d). The significance estimates are $Q_z = 0.05$ ($n_S = 4$) and $Q_B = 0.02$ ($n_1 = 3, n_2 = 15, N_S = 105$) with the ephemeris of Eq (12).

Abydos and Lion. These unlucky prognoses show a weak connection to the Moon.
Man. The significance estimates for the unlucky prognoses are \(Q_z = 0.02\) \((n_S = 6)\) and \(Q_B = 0.009\) \((n_1 = 5, n_2 = 23, N_S = 105)\) with the ephemeris Eq (12). These unlucky moments of Man concentrate on a few days after Ma, the proposed Full Moon phase (Fig 13d).

Flame. The significance estimates for these unlucky prognoses are \(Q_z = 0.03\) \((n_S = 4)\) and \(Q_B = 0.003\) \((n_1 = 4, n_2 = 17, N_S = 105)\) with the ephemeris of Eq (12).

No Algol or the Moon in lucky or unlucky prognoses

Eye, Fire, Majesty, Shu and Sobek. These SWs are not connected to Algol or the Moon, because their \(g_i\) and \(s_i\) have \(Q_z > 0.2\) with the ephemerides of Eqs (11) and (12).

Some general remarks

This concludes our analysis of 28 SWs. Numerous other [7] SWs in CC need to be analysed in the future. Combining the inverse relations of Eqs (3) and (4) to the ephemerides of Eqs (11) and (12) will have countless applications. For example, the first eclipse of Algol would have occurred on \(t(2.6, 1) = 1.96\) at \(D = 2.1\) in \(M = 1\) or the last New Moon on \(t(14.6, 12) = 343.9\) at \(D = 14.6\) in \(M = 12\). Any question about CC can now be studied within this precise framework, e.g. was some meaning given to the nights when an eclipse of Algol (Eq (11): \(\phi = 0.5\)) coincided with the New Moon (Eq (12): \(\phi = 0.5\))?
Previously, we [11] applied four tests to the astrophysical hypothesis $H_1$: “Period $P_A = 2.850$ days in CC was $P_{orb}$ of Algol.”

This is a summary of those tests:

**TEST I:** The mass transfer in this binary system should have increased the period in the past three millennia. The period value in CC is the first evidence for such an increase since Goodricke [17] discovered this periodicity over two centuries ago.

**TEST II:** The period change of 0.017 days from 2.850 to 2.867 days gives a reasonable estimate for the rate of this mass transfer.

**TEST III:** If eclipses were observed in Ancient Egypt, the orbital plane of the Algol A–B system must be nearly perpendicular to that of the Algol AB–C system [18, 19].

**TEST IV:** Algol and the Moon are the most probable objects, where naked eye observers could have discovered periodicity that we could then rediscover in CC.

**TESTS I and IV** supported $H_1$, while **TESTS II and III** indicated that it could be true. Algol’s observable night time mid eclipse epochs occur in groups of three separated with a period of 19 days and we also discovered this period in CC [11]. This phenomenon is displayed.
in Fig 14. First, a mid eclipse epoch occurs in the end of the night. After three days, the next one occurs close to midnight. After another three days, a mid eclipse epoch occurs in the beginning of the night. Then, the next observable night-time mid eclipse epoch occurs after 13 days. Naked eye observations could easily lead to the discovery of this $3 + 3 + 13$ days regularity. One could speculate that this is one of the reasons, why the prime number 13 is still considered unlucky. This would be consistent with our result that, if the brightest phases of Algol were considered lucky then the eclipses (i.e. the dimmer phases) were considered unlucky. The 2.85 days period is exactly equal to 57/20 days. This means that after $57 = 3 \times 19$ days the eclipses returned exactly to the same moment of the night (see Fig 14). All $D = 1$ days in CC have a prognosis combination “GGG”, while all $D = 20$ days have “SSS”. Perhaps this regular separation of 19 days was also inspired by Algol.

Only a skilled naked eye observer would have been able to discover the minor exceptions from the $3 + 3 + 13$ days regularity. Algol’s eclipses last $T_{A1} = 10$ hours. Naked eye can detect brightness differences of $0.1$ in ideal observing conditions. Hence, an eclipse detection is theoretically possible for $T_{A2} = 7$ hours when Algol is more than $0.1$ dimmer than its brightest suitable comparison star $\gamma$ And (Fig 14: tilted open triangle limits). This detection could become certain for $T_{A3} = 3$ hours when Algol is also at least $0.1$ dimmer than all its other suitable comparison stars $\zeta$ Per, $\epsilon$ Per, $\gamma$ Per, $\delta$ Per and $\beta$ Tri (Fig 14: tilted closed triangle limits). During the 57 days eclipse repetition cycle, only two mid eclipse epochs outside the 10 hour night time limits would qualify as certain observable eclipses (Fig 14: open circles at 19th and 48th days). However, a certain detection of these two events would have been very difficult so close to dawn and dusk. The same argument is true for three additional possible eclipse detections (Fig 14: open circles at 11th, 31st and 54th days).

Here, our statistical analysis of SWs giving the largest impact on the $P_A$ signal reveals that Algol was represented as Horus. The lucky prognoses were most likely connected to Algol’s brightest phase. Sakhmet may have represented Algol after eclipses, and Wedjat during periods close to the Full Moon. To the Ancient Egyptians, Algol’s cycle may have symbolised the familiar events of LE1 and LE2. At Aa, Re sends the Eye of Horus (Wedjat) to destroy the rebels, as in LE2. At Ab, Horus enters the “foreign land” in $g(7, 9)$, where he “smote him who rebelled”, as in LE1 or LE2. The “will is written” for him in $g(28, 3)$ at the beginning of an eclipse—the only vector of Horus overlapping the thick line centered at Ac in Fig 1a. After an eclipse, Wedjat returns as Sakhmet who is pacified immediately after Ad, as in LE2. And a new cycle begins.

Followers and Ennead may have represented Pleiades. Thus, these two, together with Horus, Re, Wedjat and Sakhmet, give the largest impact on the $P_A$ signal.

The two periods, $P_A$ and $P_M$, regulate the assignment of mythological texts to specific days of the year. The Moon strongly regulates the times described as lucky for Heaven and for Earth (Figs 7c and 8c). The unlucky prognoses of Seth are clearly associated with the phases of the Moon (Fig 11d). Other SWs follow $P_A$ or $P_M$, like Busiris, Heart, Osiris and Man (Figs 9, 10, 12 and 13). We show no figures for Heliopolis, Enemy, Rebel, Thoth, Onnophris, Nut, Nun, Abydos, Lion and Flame which also reach $Q_z \leq 0.2$ with $P_A$ or $P_M$. All these regularities can not simply be dismissed as a coincidence, let alone with the possible errors of $\sigma_t \approx \pm 0.5$ or $\pm 1.5$ days.

**Conclusions**

What was the origin of the phenomenon that occurred every third day, but always 3 hours and 36 minutes earlier than before, and caught the attention of Ancient Egyptians? Our statistical analysis leads us to argue that the mythological texts of CC contain astrophysical information about Algol. In 1596, Fabricius discovered the first variable star, Mira. Holwarda determined its eleven month period 44 years later. In 1669, Montanari discovered the second variable star,
Goodricke [17] determined the 2.867 days period of Algol in 1783. All these astronomical discoveries were made with naked eye. Since then, they have become milestones of natural sciences. Our statistical analysis of CC confirms that all these milestones should be shifted about three millennia backwards in time.

Supporting Information

S1 Fig. Text of Cairo Calendar page rto VIII. Inside our superimposed rectangle is the hieratic writing for the word Horus. Reprinted from Leitz [12] under a CC BY license, with permission from Harrassowitz Verlag, original copyright [1994].

S1 Table. Analysis results for all SWs. Day (D), month (M) of lucky (gi) and unlucky (si) time points, their phase (ϕi), phase angle (Θi), direction of their R vector (ΘR) and differences ΔΘi = Δi − ΘR with Eq (11) for PA = 2.85 days and Eq (12) for PM = 29.6 days. The binomial distribution parameters are n1, n2, qB for QB. Note that the parameters are given in the order of increasing ΔΘi, n1 and n2. All values mentioned in text are marked in bold. We also make available the code of a Python 3.0 program tables1.py which can be downloaded on Dryad (http://dx.doi.org/10.5061/dryad.tj4qg). This program can be used to reproduce and replicate all analysis results given in S1 Table.

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Author Contributions

Conceived and designed the experiments: LJ SP. Performed the experiments: LJ SP. Analyzed the data: LJ SP. Contributed reagents/materials/analysis tools: LJ SP. Wrote the paper: LJ SP.

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