An Astronomical Analysis of an Inca Quipu

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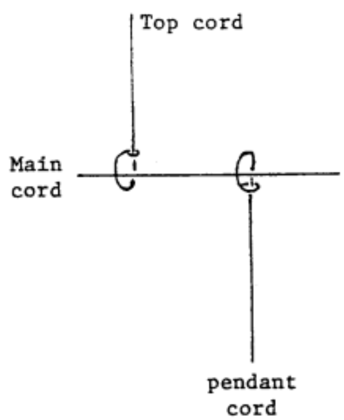
I. Introduction

The Incas were sophisticated astronomers who relied on astronomical observations to conduct daily activities such as agriculture, rituals, and construction. They mastered the art of solar and lunar observation, but information gathered from these observations needed to be recorded. The Incas did not have a written language, instead they used a system of knotted cords called quipus to record information. There is evidence that some quipus contain calendrical data.

Scholars have made much progress in understanding the information recorded in quipus, such scholars include Gary Urton, Carrie Brezine, Maria Ascher and Robert Ascher, but further research is necessary if we are ever to decipher fully the true content of an Inca quipu. In this paper we analyze a specific quipu and offer a provisional interpretation. In the first section we give a brief introduction to the quipu and state why scholars think quipus utilize a base 10 positional system to encode quantitative information. The second section contains a summary of Gary Urton's interpretation of quipu UR006 as a biennial calendric quipu. Lastly, we analyze quipu AS84 and argue that this quipu contains calendrical information. We hope that this study could be useful in advancing quipu research.

II. Structure of a Quipu

In the Inca's Quechuan language, quipu literally means *to knot* or *knot*, and these record keeping devices, quipus, are gracefully that- knotted cords tied together in which proximity, color, and numbers of knots are used to represent information. The structure of a quipu is simple and straightforward; its principal parts include a main (or primary) cord, top cords (not always present), pendant cords, subsidiary cords, and of course, a number of knots. The main cord is the horizontal cord. Both ends of the cord are usually free and one end may be knotted. Pendant cords are suspended from the main cord, and are usually held taut in place. They are distributed along the main cord with either short gaps between one another or placed very closely together. Top cords attached to the main cord fall in the opposite direction of pendant cords and can be held in place in the same way described above for pendant cords (see Fig. 2A). A top cord can also be attached through pendant cords where the free end of the top cord passes through the twisted ends of several pendant cords and then through its own twisted end before it's pulled taut. (See Fig. 2B) [Aschers]



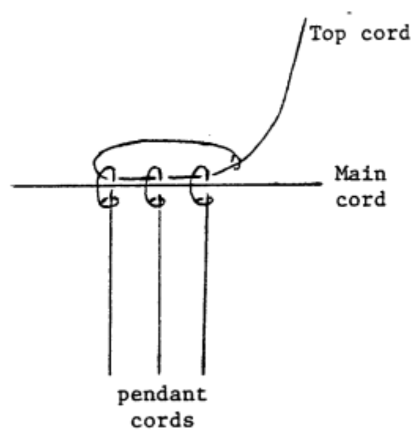


Figure 2A **Figure 2B** **[Aschers]**

A cord attached to either a pendant or a top cords is called a subsidiary cord. Subsidiary cords may be attached to other subsidiary cords and so on. These cords are attached in the same manner described above for pendant cord attachment. Not all quipus contain subsidiary cords. Figure 3 is a drawing of a quipu by American anthropologist Leland Locke, which he hypothesizes to be a record for six periods, possibly years, of four kinds of objects. The six periods (or years) are represented by the six top cords, each tying together four pendant loops that would represent the kind of object being recorded.

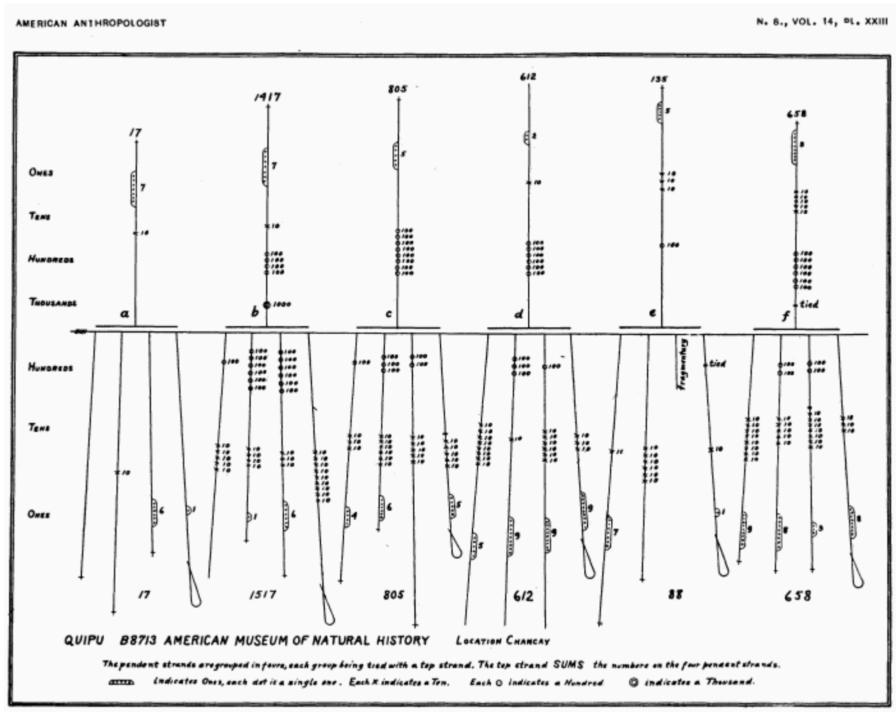


Figure 3 [Locke]

III. Base 10 Positional System of Quipus

One of the most fascinating theories about quipus was established by Leland Locke and is generally accepted by scholars who study this ancient device today. The theory states that when interpreting a quipu that contains quantitative information, the knots represent digits in a base 10 positional number system. There are three observations that Locke makes which he uses to support his theory. The first observation is that in quantitative quipus, knots are grouped together and align in row-like form throughout the pendants cords (see Figure 3). The second observation follows from the first in that when in groups, there are between 0 - 9 knots clustered together. Lastly, he gives an example of a quipu that if interpreted as a base 10 positional system, the top cord value is the sum of the suspended pendant cords.

Locke argues that the knots' distances from the main cord indicate the orders of a base 10 decimal system. To illustrate, we have included a picture from the Museo Nacional Arqueologia, Antropologia e Historia in Lima, Peru, of a quipu whose spacing on the pendant cords seem to be equally separated throughout and align in rows. In this image, we observe that the pendants that contain their first groupings of knots are aligned in rows, followed by spacing and the next set of groupings also aligned in rows; the same pattern continues until the pendant cord ends. This idea of spacing in order to show a decimal scale is one of the main attributes we have used to infer a missing value upon a quipu, under our own study, with missing or broken pendant cords.

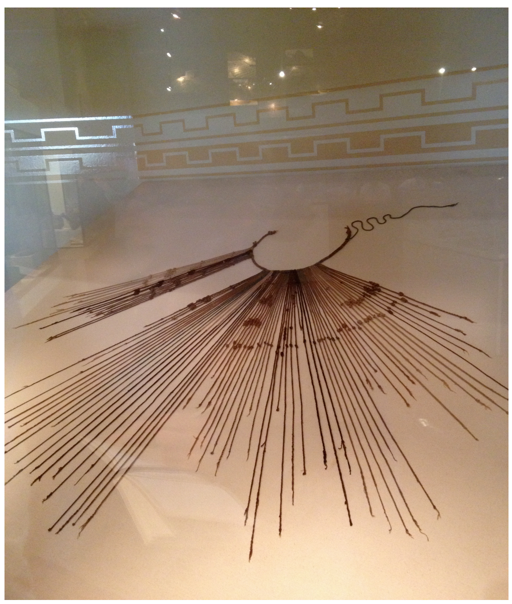


Figure 4 [Martins, 2013]

Therefore, knots aligned in rows and sums on the pendant and top cords are both highly suggestive observations that lead us to conclude that the knots on some quipus are in fact, represented in a base 10 decimal system.

Although Leland Locke concluded that these knots were used purely for numerical purposes given that their positions were based on a decimal scale, not all quipus conform to this simplification. In fact, there have been many quipus found by researchers, such as Urton, that do not fit the base 10 positional system and have been referred to as narrative quipus. The picture below shows a quipu that does not have the same "row" property as the quipu shown above and can be argued to contain not quantitative information but rather narrative records.

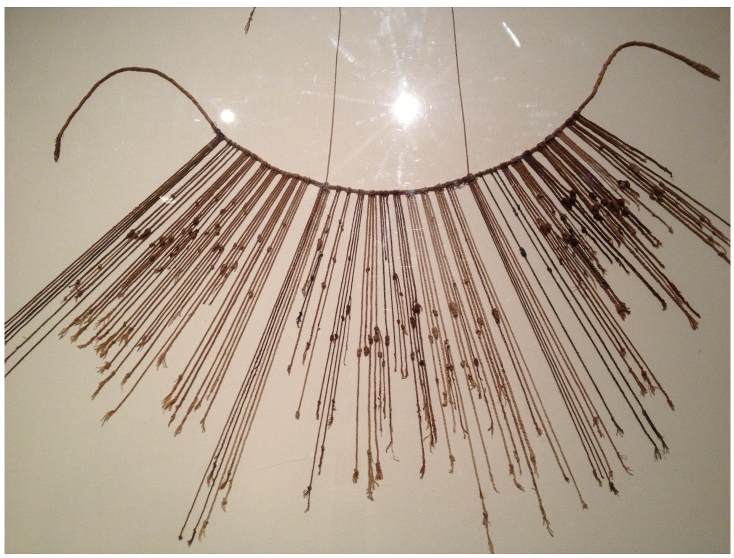
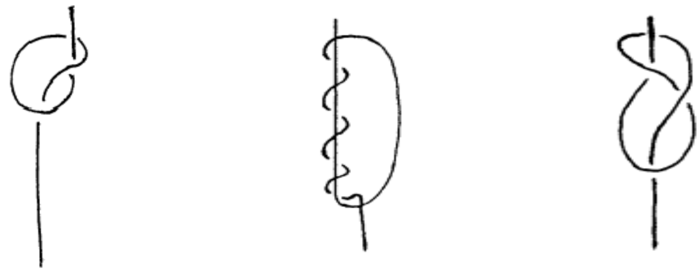


Figure 5 [Martins, 2013]

IV. Three Types of Knots

In general quipu scholars agree on the interpretation that the type of knot along with its position on the quipu serve as an indicator for numeric values. There are three types of knots found in quipus: single, long and figure-eight knot. Their illustration follows from the Ascher data book.



Single Knot **Long Knot (4 turns)** **Figure-Eight Knot**

Figure 6 [Ascher]

Single knots can occur alone or in clusters and each single knot can represent a digit in the 10's, 100's, 1000's or higher powers of 10. Larger powers are positioned closer to the main cord. When in groups, at most nine single knots appear tied closely together which is a great indicator for the assumption that the Incas knew and used a base 10 positional system. Long knots have been interpreted to denote unit values and are valued according to their number of turns: between 2 and 9. Below is an illustration of a single knot (the rightmost cord 1), a figure-eight knot (the second cord numbered 1 from the right) and long knots (2-9) with 2-9 turns respectively.

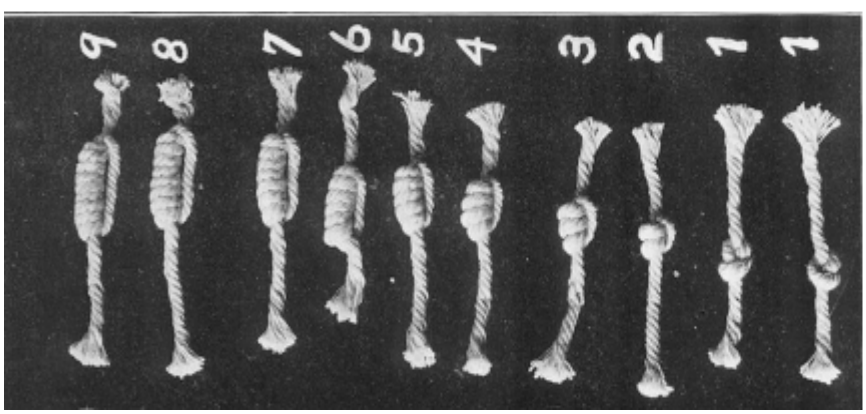


Figure 7 [Locke]

In practice, long knots were used for units only, but groups of single knots were used for higher orders. However, there have been a few cases where a long knot will contain up to 10 turns; quipu AS78 from the Ascher Databook is a good example to keep in mind as we run into these few irregularities.

The figure-eight knot has been designated its own special unit: one. Consider how the number 452 would be represented in a quipu; a pendant cord containing four single knots in a cluster would be placed at the highest point on the cord (4x100), followed by a space and five single knots also in another cluster (5X10), then finally, another spacing and a long knot with two turns (2x1).

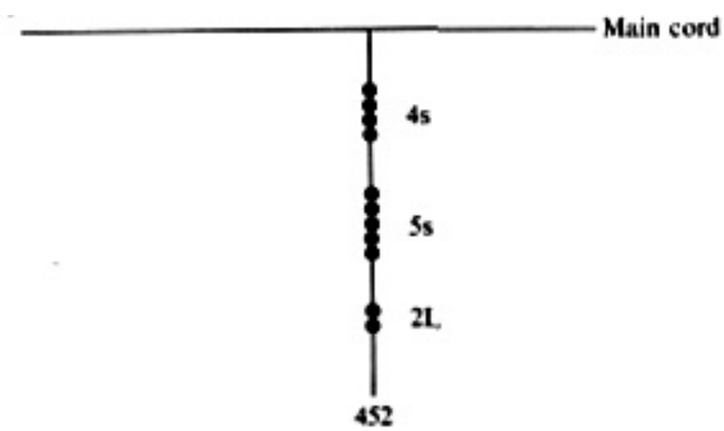


Figure 8 [Ascher]

V. A Top Cords Role in a Base 10 Positional System

Lastly, Locke provides an example of a quipu whose top cords depict the summation of the numbers of knots in the pendant cords associated with them. Although this is not universal and therefore not always true, it is most likely to occur in a quantitative quipu rather than a narrative quipu- in which a base 10 positional system would no longer apply. Nonetheless, if we commit to the interpretation of knots as representatives of a base 10 system, then we can physically count the knots on the pendant cords and see how they correlate to their corresponding sums in the top cord. In Locke’s figure shown above there are six top cords, each one groups four pendant cords together, and gives the total summation of the four groupings. The table that follows demonstrates the knot values for the first grouping of four pendant cords. The top cord, which is looped through the four pendant cords, contains the summation of all its suspending knots, in this case, a value of 17.

Pendant	Knot Type	Decimal value	Value
1	None	None	0
2	Single knot	Tens	10
3	Long knot	Ones	6
4	Figure-eight	Unit	1

This is highly suggestive and not completely conclusive, but when we discover a quipu whose top cord fits these criteria, Leland Locke argues that this is possibly the greatest indicator that the Inca used a base 10 positional system.

VI. Quipus as Numerical Record Keepers

The preceding argument shows strong evidence that some quipus clearly depict numerical purposes, but Leland Locke argues that they were not used for counting or calculating, but rather for record keeping. Evidence for numerical record keeping is supported by the fact that the mode of tying knots was not adapted to counting, and there was no need of its use for such a purpose because the Quechua language contained a complete and adequate system of numeration [Locke]. In addition to having their own system of numeration, one less intuitive reasoning the Incas would not have used quipus for calculations is in the way the knots are pulled so tightly, that modification in calculations would prove too difficult to undo. Even if we concede the theory that quipus were not used in calculations, there is still much dispute over the exact purpose and nature of quipus; some researches think they are simply record keeping devices while others think they are more sophisticated. Although it is widely believed that quipus are numerical record keepers, we are left with the question of what were these ancient, record-keeping devices exactly recording?

At first glance, a quipu appears to be solely a mechanism for recording numerical data such as, according to accounts by Spanish/Indian chronicler Felipe Guaman Poma, payment of tributes or census information [Ruggles]. In Felipe Guaman Poma's *New Chronicle and Good Government*, a 1,179-page consisting of 397 elaborate drawings of native life under the Incas, he included drawings of quipus that portray the quipumaker, the chief accountant or treasurer called Quipucamayocs in Quechuan.

Figure 9 [Guaman Poma]

VII. Calendric Information Found in Quipu UR006

Perhaps more intriguingly, there is reason to believe that some quipus contain information relating to the Inca calendar or astronomy. From the Khipu Database Project by Gary Urton and Carrie Brezine, there are three quipus that have been interpreted as calendrical devices: UR006, UR009 and UR021. We will focus our attention in describing how Gary Urton has provisionally deciphered quipu UR006 as a biennial calendric quipu and apply some of his ideas to similar aspects of the quipu we have taken under our own study, namely quipu AS84.

By focusing on the arrangements of the pendants of quipu UR006, Urton identified a highly systematic pattern in which pendant strings resulted in paired sets. Thus, a quipu containing 730 cords has been broken up into 24 paired sets, in which one member of these paired sets is composed of 20, 21, or 22 pendant strings and the other member is composed of 8, 9, or 10 pendant strings. To clarify, the pendants that were discarded did not fit the summation-[20,21,22]+[8,9,10] that all other paired sets fit into. Below is an illustration from Gary Urton of a 21+9 pendant pair.

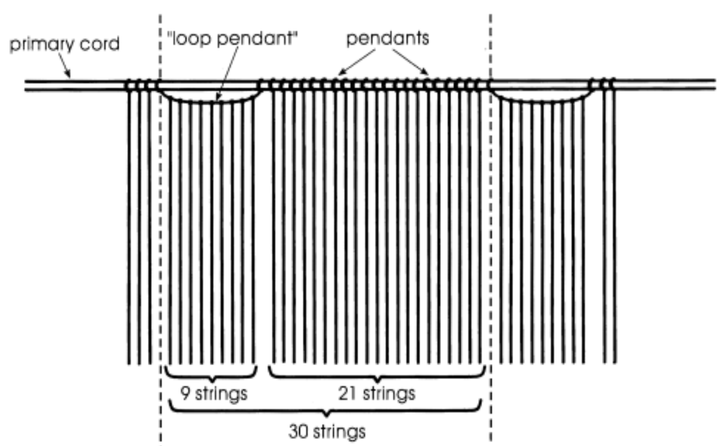


Figure 10 [Urton]

Similarly as striking is the number of paired sets- 24, which can be interpreted as 2 years consisting of exactly 12 months each. In fact, the pendant count in these paired sets closely coincides with the number of days in a month over a 24 month period. The actual count of pendants in the 24 paired sets is 730 and one half of this total is 365, which coincides with the number of days in a vague year (365.242 days), Urton further concludes that quipu UR006 represents a calendar integrating 24 synodic lunar months into two vague year periods.

VIII. Calendric Interpretation of Quipu AS84

Similar to Gary Urton, we have chosen to investigate quipu AS84, found in the Ascher Databook, by taking a closer look at its pendant cords and colors as well as its knot values. By means of manipulating and rearranging pendant cords, we have been able to provisionally provide an interpretation of quipu AS84 as a calendrical record-keeping device. One of the first drawbacks we encountered when studying this quipu was the missing information about the site of its discovery- although not essential to the study, the excavation of this quipu could have given us additional information.

After going through half of the Ascher Databook, a digitized repository consisting of 215 quipus, and using the statistical program R64 to construct line graphs of the pendant cords and their corresponding knot values for nearly half of the quipus, we came upon a quipu that looked particularly interesting in its uniformity and periodicity, namely AS84 (see Figure 11). This quipu consists of 318 pendant cords - in which the Aschers found noticeable spacings between these cords that separates them into groups of 11,12,13,14 and 15 pendant cords for a total of 25 groups.

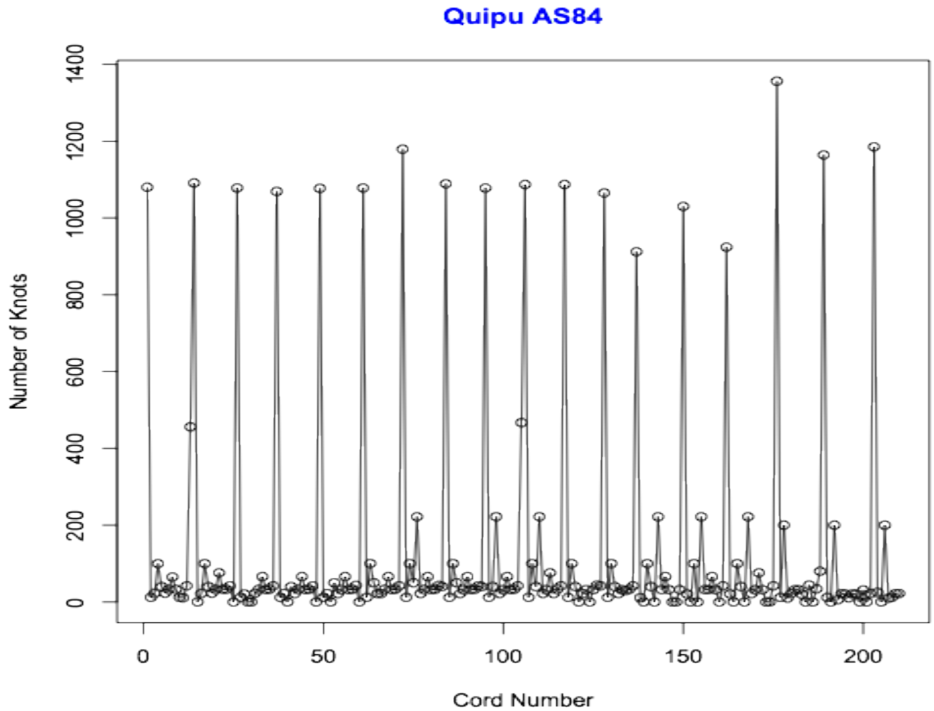


Figure 11 [My line graph of AS84]

The most obvious component of this graph is the knot value's close periodicity. Although these periodic intervals are not exact in their occurrences, they nevertheless fall within 3% of their corresponding total mean- the largest differences are from knot values of over 900 which fall close to the mean by up to 2.8%. One factor that could account for such differences could come from- and we are careful here- miscounting the number of single knots or the number of turns in long-knots due to its close proximity. Knot values, however, are not the only components of this quipu that show periodicity, although not illustrated in the graph above, the colors of the pendant cords also occur in a repeating pattern. To illustrate, we have included two nonconsecutive groups of 11 and 12 pendant cords, respectively below, where the first column contains cord colors and the second column contains knot values.

W	1078	W	1077
W	12	BY-W	12
W	21	W	22
MB	?	MB	?
BY:BL	?	BY:BL	50
BY-W	23	BY-W	22
BY-W	33	BY-W	32
BL:W	66	BL:W	66
BY:W	32	BY:W	32
MB:W	33	MB:W	33
W	42	W	43
		MB:W	?
First Group		**Second Group**	

Figure 12 [Ascher]

We notice similarities in color patterns between the two groups above in which the same color corresponds to a value that is either the same or only one digit off in the ones position from the value of the corresponding color in the other group. In the first group, the values 1078 and 21 are colored W (for white) which is the same color found in the second group for the values 1077 and 22 respectively. Furthermore, if we assume this pattern to be consistent, we can predict missing values where the cord was broken off, depicted '?', by looking at the color of the pendant. For example, MB is the color for 100 found in other groups on the quipu (not shown above), so we may infer that through this consistent display of 100 as the color MB, that the missing values in both groups for the corresponding color MB is also 100. Another observation is one that does not conform to our color matching pattern - where the value 12 has a color of W in the first group and a color of BY-W in the second group. It turns out, as we will investigate in a grid laid out by the Aschers, that this ambiguity in pendant color actually shows a division between groups that do not conform to the previous patterns.

As we briefly mentioned earlier, the cords in AS84 were divided in groups ranging between 11 and 15 pendants cords, however, the Aschers found a systematic pattern that followed from assuming each group contained 15 pendant cords with some nonexistent positions. The grid below shows the 25 groups (rows) of pendant cords where the 15 columns are laid out by corresponding pendant color - with the exception of where a value is circled or underlined, in which case it represents a change or ambiguity in pendant color.

	Position														
Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1080	12	22	100	40			23	33	65	33	12	11	42	456
2	1091	?	22	100	40			23	33	76	33	33		42	?
3	1078	12	21	?	?	M		23	33	66	32	33		42	
4	1069	12	22	?	40	M		22	33	66	32	33		42	?
5	1077	12	22	?	50	M	_	22	32	66	32	33		43	?
6	1078	12		100	50		222	22	33	66	32	33		42	?
7	1179	12		100	50		222	22	33	66	32	33		43	4??
8	1089	12		100	50		M	22	33	66	32	33		42	4??
9	1078	12		100	40		222	22	32	66	32	33		42	467
10	1087	12		100	40		222	22	32	76	22	33		42	
11	1087	12		100	40		M	22	32	?	32	44		42	
12	1065	12	_	100	40	_	?	22	32	M	3?	33		42	
13	912	11	0	100	4?	0	222	M	32	66	32	?		32	
14	1030	21	0	100	M	0	222	32	32	66	32	?	_	42	
15	924	21	0	100	40	0	222	32	32	66	32	?	M	42	_
16	1356	12		200	10	22	32	32	M	20	?	44	0	34	8??
17	1164	12	?	200	6	22	21	11	21	21	?	31	0	22	
18	1185	25	?	200	10	12	22	22	?	22	?	23	?	34	
19	1015	13	43	1??	15	12	22	23	23	23	M	32	?	34	
20	1575	14	?	200	7	32	64	64	54	54	M	32	?	22	
21	1162	13	45	100	6	12	23	23	23	23	?	32	?	31	
22	1385	12	?	100	10	22	43	34	3?	43		22	M	32	?
23	956	11	?	100	14	23	13	23	?	13	?	22	?	22	?
24	996	10	0	200	6	?	23	23	?	22	?	22			
25	997	11	0	200	10	12	24								

Figure 13 [Ascher]

In the second column of the fifth row, the value 12 is circled - this is the color ambiguity we described earlier where all preceding colors for the value 12 are 'W' and then there is a change in color to 'BY-W'. This color change after the first five groups, along with some other changes in colors such as the underlined values 22 and 50, the disappearance of number values for the third column and the new appearance of values for seventh column allows us to reasonably separate and further analyze the first five groups.

The first observation is that the grid above shows the first group (row) as containing 13 pendant cords; however, we draw our attention to columns (pendants) 12 and 13. In the quipu itself, these two pendant cords are tied together. We have interpreted this group to contain only 12 cords. Therefore, the table below illustrates the first five groupings of 12, 12, 12, 13, 13 pendant cords, respectively, for a total of 62 pendant cords.

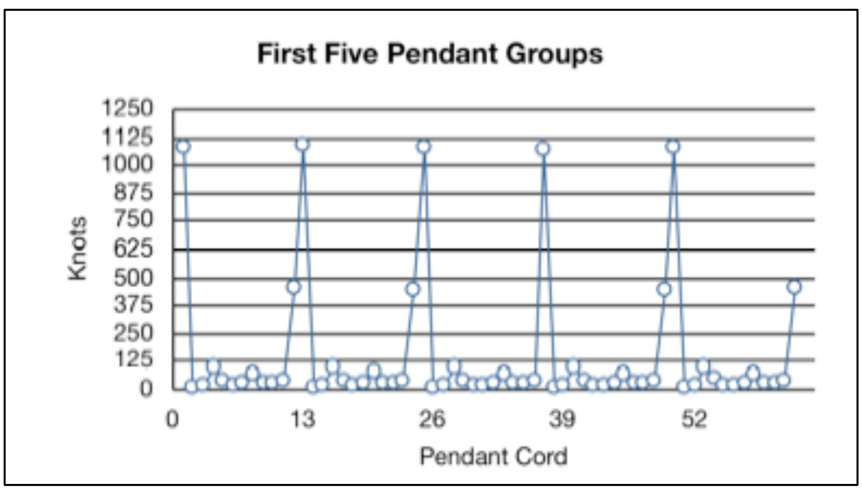


Figure 14 [My line graph]

We noticed that if we interpreted these 62 pendant cords as months containing 29.5 days based on the synodic lunar month, that the total mean was 1829 days. This is fairly close to the number of days in five solar years (365.25 x 5), or 1826.25 days. To help illustrate, see table below.

First 5 groups	**29.5 days**
12 cords	354
12 cords	354
12 cords	354
13 cords	383.5
13 cords	383.5
Total	**1829**

Thus by observing that the difference between five solar years and 62 lunar cycles is only 2.75 days, we proposed a question that perhaps the Inca would have asked: When do the solar and lunar calendars come closest to being in sync with one another? So we started by looking at the difference in days between one solar year and twelve lunar cycles in which the lunar year falls short of a solar year by 11.25 days. We noticed that in order to minimize the difference in number of days between the two calendars that we would have to add 13 lunar. Thus, 25 lunar cycles falls 7 days ahead of two solar years. We continued this pattern by adding 12 or 13 lunar cycles accordingly for a period of 10 solar years. The table below shows the difference in days between the two calendars where a positive number means the lunar year is ahead of the solar year and a negative number means the lunar year is behind the solar year.

Solar year	Lunar cycles	Difference in Days
1	12	-11.25
2	25	+7
3	37	-4.25
4	50	+14
5	62	+2.75
6	74	-8.5
7	87	+9.75
8	99	-2.5
9	112	+16.75
10	124	+5.5

As we can see in the table above, 99 lunar cycles fall behind 8 solar years by only 2.5 days which is the closest number of days that they come in syncing with each other over a 10 year period. But we also notice that after 62 lunar cycles, we are ahead 5 solar years by 2.75 days. But because the difference between 2.5 and 2.75 days is very minimal, we suggest that the Inca would have noticed that five solar years, or 62 lunar cycles, is nearly the shortest time in which the solar and lunar paths would be closest in sync with one another; 2.75 and 2.5 days are indistinguishable.

There is, however, further evidence found in AS84 that strengthens our calendrical interpretation; it's found in the pendant cords which we mentioned earlier that are tied together. In the first group, the 12th pendant cord is tied to the 13th pendant cord with values of 12, 11 respectively. If we look at the table above, we notice that after one solar year and 12 lunar cycles, the solar and lunar calendars are apart roughly 11 days (11.25). Therefore, it is interesting to note that the values on the pendant cords corresponds closely to the number of lunar cycles (12) and the number of days in which it falls short of a solar year, namely 11.25. Thus, by interpreting the

62 pendant cords as 62 lunar cycles and the five groups of pendant cords as five solar years, we can see how quipu AS84 perhaps would have served the Inca as a calendrical record-keeping device for tracking solar and lunar years.

X. Conclusion

The Incans have proven to be a hard civilization to study mainly due to the fact that they had no written language. By studying quipus we can gain insight into how they would have recorded information needed to conduct daily activities and tracked observations. We have thus been able to provide an interpretation for quipu AS84 as a record-keeping device containing astronomical information to the Inca Empire. However, there are many questions that can, and should rise from such interpretations, but conclusive answers will only come from further study and thorough investigation of these ancient, knotted devices.

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