

SAṆKRAMAVĀKYAS OF THE VĀKYAKARAṆA

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Abstract

Computation of the time of transit of the Sun from one zodiacal sign to the next is one of the requisites for performing Hindu rituals. *saṅkramavākyas* have been instrumental in this task since the latter half of 13th century AD. Our effort in this article is to throw light on *saṅkramavākyas* of the *Vākyakaraṇa* (c. 1300 AD) as they have a very specific structure. We will explore whether the *saṅkramavākyas* can be called numerical tables and how they are obtained. The translation of the *saṅkramavākyas* of *Vākyakaraṇa* have also been provided in this content and that of the commentary of Sundararāja (c. 1500 AD).

Key words : *Aharaṇa, Dhruva, Kaṭapayādi, Rāśi, Saṅkrama, Vākya*

1. INTRODUCTION

In Indian tradition the transmission of knowledge from generation to generation was primarily oral. Writing was not the preferred system and it would not have been, given the fact that the writing tools (palm leaf and a metal stylus) weren't quite convenient. Even when something had to be written, the principle of parsimony was upheld unanimously by almost all the authors irrespective of the discipline or field in which they wrote their texts. The following adage may be quoted in support of what has been stated:

*ardhamātrālāghavena putrotsavaṃ manyante
vaiyyākaraṇāḥ*

Grammarians consider [the joy produced] by
reducing half a syllable [to be equal to]
the celebration of the birth of a son.

In the field of astronomy and mathematics also, several tools were invented to make the contents precise and memorable. We find many numerical data which were presented in the form of verses or sentences. The *Grahacāranibandhana* (c. 683 AD) [Sarma KV 1954], the *Vākyakaraṇa*

(c. 1300 AD) [Sastri and Sarma 1962] etc. present various numerical tables which can be memorised easily. These texts provide numerical data in the form of *vākyas*. The case of *saṅkrama* is an example in this regard, which we are going to discuss in detail.

Here in this paper, we provide the translation of Sanskrit text of *saṅkramavākyas* of the *Vākyakaraṇa* and also that of Sundararāja's explanation. The structure of the *vākya* is highlighted in the context of numerical tables. Under the light of the commentary of Sundararāja we explore the method by which the values of the *saṅkramavākyas* would have been obtained.

2. THE VĀKYA TRADITION

The word *vākya* literally means a sentence. It may simply consists of either a single word that can run to several lines or a group of words. When used in the context of astronomy, the word *vākya* does not refer to any ordinary sentence. It has a very special connotation. They are short

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meaningful sentences which when decoded present certain numerical data that either correspond to the longitudes of planets or something related to that. Usually they are constructed using the *kaṭapayādi* system [Plofker 2009, pp.76-77], one of the three major systems employed for denoting numerals in Indian astronomical texts. The words and phrases for composing were chosen with great care so that they become meaningful and convey ethical values and worldly wisdom. In other words, they had dual purpose of encoded numerical coding as well served a poetic and asthetic appeal.

2.1 Types of *vākyas*

Different types of *vākyas* emerged over a period of time, to code different types of numerical values in connection with various astronomical computations. Among them we find a large number of them representing longitudes. For example a group of 248 specifying the true longitudes of the Moon (known as *Candravākyas*) [Kunhan Raja 1984] pertaining to 9 anomalistic months and a set of 2075 called *Samudravākyas*, *Maṇḍala-vākyas* or *Kujādi-pañcagraha-vākyas* for the five planets (570 for Mars, 528 for Mercury, 231 for Jupiter, 195 for Venus and 551 for Saturn) can be cited. These *vākyas* present longitudes in terms of sign (*rāśi*)¹ and its subdivisions i.e., degrees and arc-minutes. We find a set of 37 *vākyas* for computing the motion of the Sun [Sastri and Sarma 1962, p. 15] which provide the longitude in degrees of arc corresponding to 10 day intervals. Besides these, there are *vākyas* that provide correctional values (such as equation of center) in arc-minutes [Sarma KV 1954, pp. 7-13].

Some of the *vākyas* represent a certain duration of time. The units of time used in such *vākyas* are days, *nāḍīs* or *vināḍīs*.² For example: *māsavākyas* [Sastri and Sarma 1962, p. 251] provide the duration of each of the twelve solar months in days. The rising time of zodiacal signs

is specified using *vināḍīs* [Sastri and Sarma 1962, p. 77]. In some instances we find both the day and its subdivisions being represented by *vākyas*. The *saṅkramavākyas* which are used in the computation of the moment of transits of the Sun into twelve zodiacal signs (which is going to be discussed in section 3 belonging to this category.

Some of the *vākyas* such as *śodhyavākyas*, *maṇḍala-vākyas* and *parivṛttivākyas* merely stand for a particular number which are used in the computations of the true longitudes of planets [Sastri and Sarma 1962, pp. 51-55].

2.2 Decoding *vākyas*

All *vākyas* are decoded using the *kaṭapayādi* notation of numerals [Sastri and Sarma 1962, p. 36].³

The decoded numbers may represent the units of arc length such as minutes, degrees and zodiacal signs (*rāśis*) or the units of time like days, *nāḍīs* and *vināḍīs*. Context quickly determines the absolute value of the grouping of the digits. As indicated in the previous section, though there are different types of *vākyas* a majority of them represent the longitudes of the planets. The *vākyas* specifying the longitudes more or less have a specific pattern in the sense that they represent three separate sets of numbers namely the signs (*rāśis*), degrees and minutes. Each of them can at most a two digit number and hence these *vākyas* have three to six syllables. By convention, while decoding the *vākyas* the numbers should be noted down from right to left. A conventional/popular adage *aṅkānāṃ vāmato gatiḥ* means that “the digits go towards left”. Thus the first two syllables represent minutes, the next two represent degrees, and whatever is left with represents zodiacal sign. Here, it may also be added that it is the completed zodiacal signs that are specified in *vākya*. So when a planet is in the first sign no number will be mentioned. When it is in the 12th sign, then *vākya* will specify the number ‘eleven’. For example: the first of the *candravākyas* namely *girnaḥ śreyah*

(1203) corresponds to the Moon's position being 03 minutes and 12 degrees. Here, since the Moon is in the first zodiacal sign, the number of the sign is not mentioned. Further computations are needed for calculating the exact position of the planet.

The *vākyas* that provide information such as day and time would have five syllables. In that case the first two syllables stand for *vinādīs*, the next two for *nādīs* and the remaining one for day. This will be illustrated with example while explaining the *saṅkramavākyas* (in section 3.3).

2.3 History of *vākyas*

The earliest *vākyas* that are extant today are the *candravākyas* of Vararuci (4th century AD) [Pingree 1994, p. 558]. The *candravākyas* are also known as *Vararuci-vākyas* [Kunhan Raja 1984, p. 56]. These *vākyas* provide the longitudes of the Moon. There are 248 *candra-vākyas* corresponding to 9 anomalistic cycles of the Moon.

Another important text in which the *vākyas* appear is the *Grahacāranibandhana* of Haridatta (c. 683 AD). Haridatta clearly says that he is going to state *vākyas* (*atha vakṣyāmi vākyāni...*) [Sarma KV 1954, p. 6, verse no. 35] before listing the literal expressions of numbers.

The *Vākyakaraṇa*, (c. 13th century AD) presents an abundant number of elegant *vākyas* to specify the longitudes of the planets. This became much popular in south India especially among almanac-makers. The *Veṅvāroha* of Mādhava (c. 1350 AD) [Sarma KV 1956], *Sphuṭacandrāpti* of Mādhava (c. 1350 AD) [Sarma KV 1973] and *Dṛggaṇita* of Parameśvara (c. 1430 AD) [Sarma KV 1963] are prominent among the texts which present *vākyas*.

2.4 Earlier studies on *vākyas*

Scholars like Van der Waerden [Waerden 1955, pp. 230-233], G. J. Toomer [Toomer 1964, p. 13] and K. Chandrahari [Chandra 2001] have

already thrown light on the *vākyas* system of computation. Van der Waerden initiated an enquiry into the basis of calculation of the tables used by astronomers from Tamil speaking region of India. He claimed that the solar table was derived from Āryabhaṭa [Waerden 1955, pp. 230-233]. A mathematical analysis of Tamil solar table was presented by G. J. Toomer [Toomer 1964] with the computations of the equation of centre and mean longitudes corresponding to the days given in the table. The values given in the solar table (shown by G. J. Toomer [Toomer 1964, p. 13]) exactly match with the values of *saṅkramavākyas* of the *Vākyakaraṇa*. But neither the name of the *saṅkramavākyas* nor that of the *Vākyakaraṇa* does appear in his article. In another article, he points that the *vākyas* system comes originally from a work written in Sanskrit, *Parahita* [Toomer 2 1964, p. 255]. Clearly, Van der Waerden and Toomer were not aware of the text *Vākyakaraṇa*. Now, it is clear that 'Tamil' astronomical calculations were based on '*Vākyakaraṇa*', which is itself based on the works of the Āryabhaṭa school, and the *parahita* system of Haridatta prevalent in Kerala.

3. THE VĀKYAKARAṆA (C. 1300 AD)

The *Vākyakaraṇa* is an anonymous work generally believed to have been composed around 1300 AD. It has an erudite commentary called *Laghuprakāśikā* by Sundararāja (c. 1500 AD) [Sastri and Sarma 1962], an eminent astronomer of Tamilnadu who is supposed to have been a contemporary of Nīlakaṇṭha Somayāj (1444-1544 AD).⁴

From the citations appearing in the commentary it is clear that there exists another commentary of the *Vākyakaraṇa* called *Vāsanāprakāśikā*⁵ of Sundararāja.

There is no agreement among scholars regarding the authorship of the *Vākyakaraṇa*. While some consider it as an anonymous work [Sastri and Sarma 1962], there are other who have

opined that Vararuci could be the author [Helaine 1997, p. 955], [Sarma PD 2004, pp. 141-142]. Prof. Pingree [Pingree 1994, p. 559] states that “The *Vākyakarāṇa*....., is sometimes attributed to Vararuci”. Possibly the readings found in some of the manuscripts⁶ have led him to make this remark. Even if one were to accept Vararuci as the author of the *Vākyakarāṇa*, this Vararuci cannot be identified with the other Vararuci, the author of *candravākyas* who is supposed to have lived around the 4th century AD. This is because one of the *vākyas* describe the rise and decline of the Chola kingdom found in the *Vākyakarāṇa*. Since the period of Chola rule in Tamilnadu is fairly well known, this is considered as clear evidence that this text must have been composed during the 13th century AD [Sastri and Sarma 1962, pp. viii-ix]. In fact, K.V. Sarma states in an article that the *Vākyakarāṇa* is apocryphically (falsely) ascribed to Vararuci, and that the author hailed from Karisaila or Kanci in Tamilnadu, as he himself states in his work [Sarma, 1997, p.995].

4. SAṆKRAMAVĀKYAS OF THE VĀKYAKARĀṆA

The word *saṅkrama* or *saṅkramaṇa* is used in Indian astronomy to refer to the transit of the Sun into a *rāśi* (zodiacal sign) from another. A *rāśi* is one-twelfth part of the ecliptic. The division of the ecliptic into different *rāśi* starts from a fixed point along the ecliptic. That fixed point is taken to be the star *aśvini* (Aries) instead of the vernal equinox. The time of entry of the true Sun into the twelve zodiacal signs is given by the following verses.

*śrīrguṇamitrā| bhūrvidhipakṣā| stratiśūrā|
bhogavarāte||*

*bhāvacaroriḥ| tenavaśatvam| lokajabhitiḥ|
sthūlahayo'yam ||*

*aṅgadhigāraḥ| stambhitanābhiḥ| nityaśaśīśo|
yāgamayo'yam ||*

*tāvurupūrvaṃ| saṅkramavākyam|
tatkramayojyaṃ| pādavaśena ||*

VK 4-A

The first three verses provide twelve *vākyas*. They help to find the time of the transits (of the Sun); hence known as *saṅkramavākyas*. The fourth verse states how to use those *vākyas*. The literal meaning of the above verses is given below:

Wealth is a friend of virtues; A land supported by law; A very skillful women; A better [source of] enjoyment for you. The [actual] enemy resides in thought; Being controlled by that; Fear arising out of the world; This is quite a huge horse. One who has crooked parts; One whose centre is fixed; Eternal lord of the Moon; This is full of sacrifice – are the *saṅkramavākyas* beginning with [that of] Taurus which have to be added [to the *dhruva*] in their order according to the quarter [they belong to].

VK 4-A

Sundararāja explains the structure of the *saṅkramavākyas* (see section C in the appendix) by pointing that the verses given above are constructed in the *pañkti* meter. Further, he informs us the following characteristics of the *pañkti*. The *pañkti* is a variety that comes under the *supraṭiṣṭhā* meter. It contains five syllables in each quarter. A *bhagaṇa*⁷ and two *guru* syllables constitute a *pañkti*. It is a uniform meter (*samavṛtta*) having the same pattern in all the quarters.⁸ In order to get the time of the transit of the Sun into twelve zodiacal signs, first we have to decode the *vākyas* given above using the *kaṭapayādi* system of numeration. The five syllables of each quarter give the week day, *nāḍis* and *vināḍis*⁹ sequentially but in the reverse order. The day, *nāḍis* and *vināḍis* correspond to the transit of the Sun into twelve signs beginning from Taurus. The numerical values provided by the *saṅkramavākyas* are the following:

2;55;32, 6;19;44, 2;56;22, 6;24;34, 2;26;44, 4;54;06, 6;48;13, 1;18;37, 2;39;30, 4;06;46, 5;55;10 and 1;15;31.

4.1. Importance of *saṅkramavākyas*

By definition, a solar month is the time interval between the transit of the Sun from one

rāśi (zodiac sign) to another. Though *rāśis* are equally spaced segments along the ecliptic, this time interval is not regular because of the variation in the rate of motion of the Sun. As the transit can happen at any moment during the day (0–24h) the actual moment of the beginning of a solar month can be any time during the day or night. However, certain rules exist for the purpose of observing rituals either on the previous day or the successive day depending upon whether the transit were to happen during the night or day at a given location. When there was a need to have an easy way to know the moment of the transits of the Sun, the *saṅkramavākyas* came as a great aid in this regard.

4.2. Can the *saṅkramavākyas* be considered as numerical tables?

A general feature that could define numerical tables is that they consist of a few rows and columns. Typically the first column would present a list of values of an independent variable against which one or more columns would list the values of dependent variable. Keeping this in mind and noting that in the case of the *saṅkramavākyas*, since it seems to be merely a list of numbers corresponding to the value of the dependent variable, a doubt has been encouraged as to,

whether these numbers are to be treated as a part of numerical tables or should they be merely categorized to be versified list of numbers.

In the case of *saṅkramavākyas* we do not have lines and columns. But it is important to note that here exists a functional relationship between the argument and result. Since the values of the independent variable are the multiples of degrees (true longitude of the Sun during the transit) they are not mentioned explicitly in the verses. The order/rank of the *vākyas* itself tells us the zodiacal sign to which the Sun enters. The fourth verse that starts with *tāvurupūrvam* states that the given set of entries (i.e., *saṅkramavākyas*) corresponds to the zodiacal signs starting from Taurus.

The second column in Table 1 displays the *saṅkramavākyas* which are given by the verses. The third column shows the literal meaning of the *vākyas*. Actually user is interested in the mathematical/astronomical information provided by the *vākyas* along with their sequence. The values represented by them as well as their order are also given in last two columns. The order of the gives the longitude covered by the Sun. The mathematical/astronomical information (provided by the sequence as well as by the *vākyas*) are given in the third and fourth column respectively.

Table 1: *Saṅkramavākyas*, their meanings as per the commonly employed classical Sanskrit and their decoded numerical values

No.	Vākya	Literal meaning	Longitude crossed	Transit on
01.	<i>śrīrguṇamitrā</i>	Wealth is a friend of virtues	30°	2 ^d 55 ⁿ 32 ^v
02.	<i>bhūrvīdhipakṣā</i>	A land supported by law	60°	6 ^d 19 ⁿ 44 ^v
03.	<i>strratiśūrā</i>	A very skillful woman	90°	2 ^d 56 ⁿ 22 ^v
04.	<i>bhogavarāte</i>	A better [source of] enjoyment for you.	120°	6 ^d 24 ⁿ 34 ^v
05.	<i>bhāvacarorih</i>	The [actual] enemy resides in thought	150°	2 ^d 26 ⁿ 44 ^v
06.	<i>tenavaśatvam</i>	Being controlled by that	180°	4 ^d 54 ⁿ 06 ^v
07.	<i>lokajabhṭih</i>	Fear arising out of the world	210°	6 ^d 48 ⁿ 13 ^v
08.	<i>sthūlahayo'yam</i>	This is quite a huge horse	240°	1 ^d 18 ⁿ 37 ^v
09.	<i>aṅgadhiḡāraḡ</i>	One who has crooked parts	270°	2 ^d 39 ⁿ 30 ^v
10.	<i>stambhitānābhiḡ</i>	One whose centre is fixed	300°	4 ^d 06 ⁿ 46 ^v
11.	<i>nītyaśāśīso</i>	Eternal lord of the Moon	330°	5 ^d 55 ⁿ 10 ^v
12.	<i>yāgamayo'yam</i>	This is full of sacrifice	360°	1 ^d 15 ⁿ 31 ^v

Looking at these points, we consider the *saṅkramavākyas* to be a versified numerical table.

4.3. Finding the time of transits using the *saṅkramavākyas*

The *saṅkramavākyas* are added to the time of the first transit of the year to provide the successive transits. That additive value (the time of first transit in weekday, *nāḍis* and *vināḍis*) which is fixed for a year is termed *dhruva* (a fixed [initial value]). The word *dhruva* literally means a constant. Here, the additive is the same for all twelve *vākyas*, and hence called so. In fact, this number remains fixed for a year. The number of days elapsed till the beginning of the present year (*ahargaṇa*) is used to compute the fixed [initial value]. The *Vākyakaraṇa* provides the following relation¹⁰ to get *ahargaṇa* using D , the number of passed years (of *Kaliyuga*) [Sastri and Sarma 1962, p. 3].

$$D_y = y \left(365 + \frac{1}{4} \right) + \frac{5y - 1237}{576}. \quad (1)$$

The above relation¹¹ (1) gives an integer of days and part of the day (in *nāḍis* and *vināḍis*). Normally, *ahargaṇa* is an integer of civil days. But here, fraction of the day is also taken into account. The integer represents the number of passed days and the fraction tells us when the new year begins on the coming day.¹² The remainder obtained by dividing the number of days (D_y) by seven indicates the weekday that precedes the day of the transit. This remainder and the fractional part together constitute the fixed [initial value] (*dhruva*). Thus the value of the fixed [initial value] indicates the day and moment of Sun's entry into the first zodiacal sign, *Meṣa*.

It is this quantity that is computed first and added to all the *saṅkramavākyas* for getting the time of the Sun's successive transits. If a user wants to know the time of the transit into $(i + 1)^{th}$

sign then i^{th} *vākya* should be added to the value of the first transit or the fixed [initial value] (where $i=1$ to 12). The user has to keep in mind that the transit obtained using i^{th} *vākya* takes place in $(4i + 1)^{th}$ week of the given year. The first digit indicates the previous weekday and the other two couples of digits give the moment of transit in *nāḍis* and *vināḍis*.

An example

Let us calculate the transits of the Sun for the 5112th year of *Kali* era (2011 AD).

The number of elapsed years, $y = 5111$

Using (1), we get

the number of days elapsed, $D_y = 1866834;57^n;06^v$

The fixed [initial value], $Dhruva = D_y$ modulo 7

$$= 4^d; 57^n; 06^v.$$

Here, the number 4 indicates the weekday passed before the first transit. Monday happens to be the fourth day counting from Friday,¹³ thus we come to know that the first transit occurs on Tuesday. The moment of the transit is given by the numbers 57 and 06. It means that the transit occurs at 57 *nāḍis* and 06 *vināḍis* after sunrise. Table 2 displays the time of successive transits obtained by adding the fixed [initial value] to the *saṅkramavākyas*.

For example, to know the time of the transit into the 9th zodiacal sign, we have added 8th *vākya* ($i=8$) to the fixed [initial value]. Then we get the time of the transit as $6^d15^n42^v$. This indicates that the transit takes place when 6 days and 15 *nāḍis* and 42 *vināḍis* are passed. (Also, one should know that 32 weeks have passed since the beginning of the year.)

Sundararāja prescribes [Sastri and Sarma 1962, p. 11] two further corrections to the above

Table 2: The time of the Sun’s transits in 5112th year of *Kali* era (2011-2012 AD)

Transit to	Value from <i>vākya</i>	<i>Dhruva</i> + <i>vākya</i>
1. Meṣa		4 ^d 57 ⁿ 06 ^v
2. Vṛṣabha	2 ^d 55 ⁿ 32 ^v	0 ^d 52 ⁿ 38 ^v
3. Mithuna	6 ^d 19 ⁿ 44 ^v	4 ^d 16 ⁿ 50 ^v
04. Karka	2 ^d 56 ⁿ 22 ^v	0 ^d 53 ⁿ 28 ^v
05. Siṃha	6 ^d 24 ⁿ 34 ^v	4 ^d 23 ⁿ 40 ^v
06. Kanyā	2 ^d 26 ⁿ 44 ^v	0 ^d 23 ⁿ 50 ^v
07. Tulā	4 ^d 54 ⁿ 06 ^v	2 ^d 53 ⁿ 12 ^v
08. Vṛścika	6 ^d 48 ⁿ 13 ^v	4 ^d 45 ⁿ 19 ^v
09. Dhanus	1 ^d 18 ⁿ 37 ^v	6 ^d 15 ⁿ 42 ^v
10. Makara	2 ^d 39 ⁿ 30 ^v	0 ^d 36 ⁿ 36 ^v
11. Kumbha	4 ^d 06 ⁿ 46 ^v	2 ^d 03 ⁿ 52 ^v
12. Mīna	5 ^d 55 ⁿ 10 ^v	3 ^d 49 ⁿ 16 ^v
01. Meṣa	1 ^d 15 ⁿ 31 ^v	6 ^d 12 ⁿ 37 ^v

values in order to obtain the precise time of transit.¹⁴ One of them depends on the longitude and the other one on the latitude (of the place of the observer). For the passage explaining the need of these corrections see section B in the appendix.

4.4. How the numbers represented by the *saṅkramavākya*s are obtained?

The *saṅkramavākya*s provide the values which are ready to use. Now, let us see how the *saṅkramavākya*s (i.e., the numerical values presented by them) are obtained. Here, the main step behind the curtain is to compute the duration between the first and other transits. The number of days taken by the Sun to cross the zodiacal signs is computed by adopting the inverse process of computation (i.e., computing the number of days corresponding to a given longitude) which is explained below. It involves the computation of the equation of centre.

4.4.1. Computation of the duration between transits

In order to construct *saṅkramavākya*s the duration between the first transit and the transit to

the given zodiacal sign should be known. The procedure for the computation of that (the exact duration between the first transit and the transit in question) involves the following steps (the commentary based on which the following steps are explored is given in section D of the appendix):

Step 1:

Finding the mean time (t_i) taken by the Sun to cross multiples of 30 degrees along the ecliptic using:¹⁵

$$t_i = \frac{\text{No. of civil days in a Mahāyuga}}{\text{No. of solar months in a Mahāyuga}} \times i \quad (i = 1 \text{ to } 12)$$

$$= \frac{157,79,17,500}{43,20,000 \times 12} \times i$$

$$= 30.4382238i. \quad (2)$$

Step 2:

Find the equation of center (E_i) corresponding to the longitude (λ_i) of the Sun. Here, $\lambda_i = i \times 30$ ($i = 1$ to 12). E_i is given by

$$E_i = R \sin(\lambda_a - \lambda_i) \times \frac{r_0}{R}. \quad (3)$$

where λ_a is the longitude of the apogee of the Sun.

$\frac{r_0}{R}$ is the ratio of the circumference of Sun’s epicycle to that of the deferent circle. By inserting their values as given by Bhāskara I [Shukla 1960], the equation (3) can be rewritten as

$$E_i = 57.3 \sin(78 - \lambda_i) \times \frac{13.5}{360}. \quad (4)$$

Equation (4) gives the magnitude of the correction in degrees which is the difference between the mean and the true longitudes of the Sun.

Step 3:

Here, we find the time (Δ_i) taken by the Sun to cover the above difference of longitudes. That is obtained using the true rate of motion of the Sun at λ_i .

$$\Delta_i = \frac{E'}{d_i} \quad (5)$$

where d_i is the true daily motion of the Sun in degrees.¹⁶ The answer will be in terms of days. If the equation of center is positive then the obtained duration should be subtracted from t_i otherwise added.¹⁷

$$t'_i = t_i \pm \Delta_i \quad (6)$$

The obtained quantity, t'_i , is the time required for the Sun to reach λ_i .

Step 4:

Here, t'_i gives the time required for i^{th} transit from the beginning of the mean year. Actually we need the time elapsed since the beginning of true year. The true year begins before the mean year by $2^d;08^n;51^v;15$. Hence, this difference is added to t'_i to get the actual time difference between the first transit and the desired transit (D_i).

Now, we have

$$D_i = t'_i + 2^d;08^n;51^v;15 \quad (7)$$

Having found the durations between the transits, it has to be divided by seven to get remainder. The day of the transit is given by the remainder.¹⁸ If D_i ($i = 1$ to 12) represents the number of days (including the fractional part of it) taken by the Sun to cover the multiples of degree segments of the ecliptic, then the *vākya* is given by

$$V_i = D_i \text{ mod } 7. \quad (8)$$

It is quite unlikely that D_i will be an integer, and usually has a fractional part. The fractional part of a day obtained here is converted into *nāḍis* and *vināḍis*. And finally, by using the relation shown in (8) we get the values of the *saṅkramavākyas*.

The procedure given above is illustrated below using some examples.

Illustration

1. First, let us compute the time taken by the Sun to reach the second zodiacal sign.¹⁹ Hence we have $i = 1$ (the number of elapsed signs) and $\lambda_i = 30^\circ$. Now, using (2), we get

$$t_1 = \frac{157,79,17,500}{43,20,000 \times 12} \times 1$$

$$= 30.43822338.$$

Using equation (3), we get

$$E_1 = R \sin(48) \times \left(\frac{13.5}{360} \right)$$

$$= 1.596832444^\circ.$$

By dividing by the Sun's true daily motion (which is calculated for the 30th day of the year i.e., when the Sun is likely to cross the first sign), we get

$$\Delta_{t_1} = \frac{1.596832444}{0.960841027} = 1.661911179.$$

Now, from (6), we get

$$t'_1 = 30.43822338 - 1.661911179 \\ = 28.776312201 = 28;46;34;43.$$

Now, using (7), we get

$$D_1 = 30;55;25;58.$$

By using (8), we obtain

$$V_1 = 02;55;25;58.$$

2. The time taken by the Sun to transit two zodiacal signs is obtained as follows:

$$\lambda_2 = 60^\circ$$

$$t_2 = 60.87644676$$

Using equation (3), we get

$$E_2 = R \sin(18) \times \left(\frac{13.5}{360} \right)$$

$$= 0.664000267^\circ$$

By dividing by the Sun's true daily motion (which is calculated for the 60th day of the year i.e., when the Sun is likely to cross the second sign), we get

$$E'_2 = \frac{0.664000267}{0.950524254} = 0.698562151$$

Now, from (6), we get

$$t'_2 = 60.87644676 - 0.698562151$$

$$= 60.177884609 = 60;10;40;23.$$

Now, using (7), we get

$$D_2 = 62;19;31;38.$$

By using (8), we obtain

$$V_2 = 06;19;31;38.$$

Similarly, we get the time of other transits also. The values of we get are approximately equal to those given by the *saṅkramavākyas*.²⁰

5. CONCLUSION

Normally, the computations of the true longitudes of planets and the time of the transits involve the operations of huge numbers like the number of revolutions of the planet and the number

of civil days in an aeon and so on. Also, trigonometric functions should be employed as we have seen above. But the use of the *vākya* method of computation allows to circumvent the laborious procedures. The *vākya* 'tables' greatly simplify the computations by replacing trigonometric functions and reducing the multiplications and divisions of big numbers.

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Appendix

*Saṅkramavākyas of the Vākya karaṇa with the Laghuprakāśikā*²¹

A. Dhruva and saṅkramavākyas

अथ सौरवर्षसङ्क्रमभूतश्रीर्गुणादिध्रुवज्ञानायाह (?ज्ञानमाह) - श्रीर्गुणादिना (?श्रीर्गुणेत्यादिना) दृश्यत इत्यन्तेन।

.....सेनाभक्तावशेषितम्॥

VK 1.3b

श्रीर्गुणादिध्रुवं विद्याद् भान्तं वाक्यैस्तु दृश्यते।

VK 1.4a

पूर्वानीतशुक्रवासरादित्योदयकाले कलियुगसङ्क्रमात्, शुक्रवारोदयमारभ्य दिनगणे प्रवृत्ते सप्तहृतावशिष्टं शुक्रवारादि गणयित्वा वर्तमानवर्षसङ्क्रमणज्ञानावगतिः।

सेनाभक्तावशेषितदिनादिकं मेपरविसङ्क्रमणभूतम्।

वृषभादिरविसङ्क्रमणसाध्य(?साध्यन)भूतध्रुवं प्रतिसंवत्सरं वाक्यनिबन्धं कुर्यात्।

Now, this is stated for the knowledge of the fixed [initial value] (*dhruva*) of the transits of the solar year, by means of [the verse] which starts with *śrīrguṇa* and ends with *drśyate*.

The remainder of the division by seven (*senā*) has to be known as the fixed [initial value] for *śrīrguṇa* etc. Indeed, the ending of the signs (zodiac) is observed by means of .

(VK 1.3b- VK 1.4a)

Because the [first] transit of *Kaliyuga* [happened] at the time of sunrise on Friday, which is calculated earlier, when the group of the days (*dinagaṇa*) is commenced from the morning of Friday, the transit in the present year is known by counting the remaining [days], that obtained from the division [of days] by seven, from Friday. The remainder of the division by seven in days etc. is [the day] of the Sun's transit into Aries. The fixed [initial value] which is the means in [the knowledge of] the transits of the Sun into Taurus etc. should be constructed in *vākya* every year.

B. Correction due to longitude and ascensional difference

अत्र चरार्धदेशान्तरदोर्विवरकलासमानातिघटिकादिशोधनयोजनद्वारा स्फुटसङ्क्रमणावगतिः। तत्र देशान्तरज्ञानाय श्लोकौ -

लङ्कातः खरनगरं सितोरुगेहं
पाणाटं²² मिसितपुरी तथातपर्णी।
उत्तुङ्गं सितवरनामधेयदेशो
लक्ष्मीवत्पुरमपि वात्स्यगुल्मसंज्ञम्॥
विख्याता वरनगरी तथा ह्यवन्ती।
स्थानेशो मुदितमनास्तथा च मेरुः॥
अध्वाख्यः करणविधिस्तु मध्यमाना-
मेतेषु प्रतिवसतां न विद्यते तु॥

(महाभास्करीयम् II 1-2)

इति। एवं लङ्कातः खरनगर-सितोरुगेह-पाणाट-मिसितपुर्यातपर्णी- उत्तुङ्गसितवरनामधेय-
लक्ष्मीवत्पुर-वात्स्यगुल्म-वरनगर्यवन्ती-स्थानेश्वरमुदितमनो-
महामेर्ववगाहिरेखासमपूर्वापारेखासमवस्थायिनां द्रष्टृणां देशान्तरसम्भवः। न तु रेखास्थानाम्।
लङ्का-यवकोटि-सिद्धपुर-रोमकावगाहि- समपूर्वापररेखा-समतिरश्रीनरेखानिवासिनां द्रष्टृणामेव
चरसम्भवः, तत्र स्थितद्रष्टृदृष्टानुरूपं लङ्काक्षितिजमण्डलरूपोन्मण्डल-
स्वदेशक्षितिजमण्डलान्तरविवरसम्भवात्। न तु पूर्वापररेखास्थानाम्।
पूर्वापरदक्षिणोत्तररेखासम्पाताधिष्ठितद्रष्टृ- देशान्तरचरौ न स्तः। दोर्विवरन्तु
मध्यमस्फुटार्कभुक्तज्योतिश्चक्रप्रदेशविशेषत्वेन सर्वत्रनिवासिनामस्येव। एषां गणनप्रकारम्
उपरिष्टादाचार्यः स्वयमेव बक्ष्यति। तच्च तत्रोक्तधनर्णवैपरीत्येन अत्र सङ्क्रमे संस्कर्तव्यम्। तथा
सति स्फुटवर्षादिसङ्क्रमसिद्धिः। एतन्नावश्यं ज्ञातव्यं यत्र चरार्धदेशान्तरयोर्महत्ता, तत्र महतो
भेदस्य विद्यमानत्वात्। वर्षादिसङ्क्रमध्रुवेण श्रीर्गुणादिवाक्यैश्च भान्तं राशयन्तं द्रष्टव्यम्। भशब्दो
राशिवचनः।

राशिक्षेत्रग्रहर्षभानि भवनं चैकार्यसम्प्रत्ययाः। (बृहज्जातकम् १-४)

इत्याचार्यवचनात्।

Here, obtaining the true transit is by means of either addition or subtraction of the *ghaṭikās* etc. calculated from the minutes of half the ascensional difference, longitudinal difference and the equation of time (*deśāntara*, *carārdha* and *dorvivara*) Among these, to know the longitudinal difference, two verses are [given] as –

From²³ *Laṅkā* (towards the north, we have the following places on the prime meridian): *Kharanagara*, *Sitorugeha*, *Pāṇāṭa*, *Misitapurī*, *Taparṇī*, the lofty mountain called *Sitavara*, the wealthy town called *Vātsyagulma*, the well known *Varanagarī*, *Avantī*, *Sthaneśa*, and then *Meru*, which is inhabited by happy people. For those who reside in these places; the correction for the longitude does not exist.²⁴

(*Mahābhāskarīya*, Ch. II, 1-2)

Like this, there exists longitudinal difference for the observers who reside on the line which is towards the east or west of the line (standard meridian) that passes through *Laṅkā*, *Kharanagara*, *Sitorugeha*, *Pāṇāma*, *Misitapurī*, *taparṇī*, the lofty [mountain] named *Sitavara*, *Lakṣmvatpura*, *Vātsyagulma*, *Varanagara*, *Avantī*, *Sthaneśvara*, *Muditamanā* and the great *Meru*; and not for those residing on the line.

The ascensional difference does exist only for the observers those who reside on the line that is inclined to the east-west line passing through *Laṅkā*, *Yavakoṭi*, *Siddhapura* and *Romaka*; because of the existence of the difference between the horizon of one's place and the six o'clock circle (*unmaṇḍala*) that is the horizon of *Laṅkā* corresponding to the sight of the observer staying there. Indeed [it is] not for those who reside on the east-west line (equator). There are no longitudinal difference and ascensional difference for the observer located on the intersection of east-west [line] and south-north lines. Indeed, the Rsine difference *dorvivara* being the difference of the portions of the ecliptic that are covered by the mean and true Sun, certainly exists (or applicable) for all the residents (observers), there exists [the application of]. The master himself will say their computational method later on. And that should be applied herein the transit according to the contrariety of its additivity and negativity stated there. Being so, the true transit at the beginning of the year is obtained. Also, necessarily this has to be found where there is a large [amount of] ascensional difference and longitudinal difference because of the existence of a great difference. By means of the fixed [initial value] which is the first transit of the year and by means of the beginning with *śrīrguṇa* etc., [the Sun's transit at] the end-point of the *rāśis* (*bhāntam*) should be noted. The word *bha* stands for *rāśi*, since there is a statement of the master.²⁵

“The words *rāśi*, *kṣetra*, *grha*, *ṛkṣa*, *bha* and *bhavana* mean the same object.”

(*Bṛhajjātaka* Ch. 1, verse 4)

C. Structure of the *saṅkramavākya*s

अथ तानि वाक्यानि श्रीर्गुणमित्त्रेत्यादीनि सुप्रतिष्ठायां छन्दसि समवृत्तैः प्रदर्शितैः पङ्क्तिनामभिश्चतुर्भिः श्लोकैः श्रीर्गुणमित्त्रेत्यादिभिः पादवशेनेत्यन्तराह - श्रीर्गुणमित्त्र इति।

श्रीर्गुणमित्रा भूर्विधपक्षा खीरतियूरा भोगवराते।

भावचरोरिः तेनवशत्वं लोकजभीतिः स्थूलहयोयम्॥

अङ्गघिगारः स्तम्भितनाभिः नित्यशशीशो यागमयोयम्॥

तावुरुपूर्वं सङ्क्रमवाक्यं तत्क्रमयोज्यं पादवशेन॥ ४ - AII

एकैकः पादः पञ्चाक्षरः। तथा च वृत्तरत्नाकराचार्यवाक्यं - “सुप्रतिष्ठायां भगौदिति पङ्क्तिः” इति। तस्य श्रीनाथव्याख्यानवाक्यं - “भगणगुरुश्रान्त्यः प्रतिपादं चेत् पङ्क्तिर्नाम वृत्तं भवति इति। तानि वाक्यानि श्रीर्गुणमित्त्र इत्यादीनि पङ्क्तिवृत्तस्य पादरूपाणि पञ्चाक्षरमितानि विनाड्यादीनि दिनान्तानि सङ्क्रमद्वयावगाहीनि ज्योतिश्चक्रद्वादशांशरूपसौरभाग-
रविभोगप्रमाणदिकचक्रप्रमाणप्रमितिजनितभास्करभूमिभ्रमणभूतभगणविवरलक्षणसावनदिननि-
करसप्तावतक्षणावशिष्टानि द्वादशसङ्क्रमसम्बन्धीनि। तावुरुपूर्वं सङ्क्रमवाक्यं तत्क्रमयोज्यं
पादवशेन इति। तन्नामोक्तसङ्क्रमवाक्यं वृषभादितो वर्षादिसङ्क्रमे युक्त्वा चरार्धादि च
वैपरीत्येन संस्कृत्य स्फुटरविसङ्क्रमस्यावगतिः।

Now [the author] states those which start as *śrīrguṇamitrā* in ‘*supraṭiṣṭhā*’ metre; with four verses that appear with uniform metres called *pañkti* starting with *śrīrguṇamitrā* and ending with *pādavaśena* –

śrīrguṇamitrā | *bhūrvidhipakṣā* | *stratiśūrā* |
bhogavarāte ||

bhāvacaroriḥ | *tenavaśatvam* | *lokajabhitiḥ* |
sthūlahayo’yam ||

aṅgadhigārah | *stambhitanābhiḥ* | *nityaśaśīśo* |
yāgamayo’yam ||

tāvurupūrvam | *saṅkramavākyam* |
takramayojyam | *pādavaśena* ||

VK 4-A

are the *saṅkramavākyas* beginning with [that of] Taurus which have to be added in their order [to the *dhruva*] according to the quarter [they belong to].

(VK 4-A)

Each and every quarter has five syllables. Also, the saying of the master in *Vṛttaratnākara* is so “In *supraṭiṣṭhā* [category] it is the *pañkti* when there are one *bha* and two *gurus*.” The statement in its commentary by Srinātha is “In each quarter if there are a *bha* group, a *guru* and a *guru* at the end, then it is a metre called *pañkti*”. Those which begin as *śrīrguṇamitrā* form the quarter of the *pañkti* metre, limited to five syllables, start with *vināḍis* [and] end with days, immersed between two transits; the remainder of the division—by seven—of the group of the civil days which is characterised by the duration (*vivara*) of the revolutions which is the motion of the Sun around the Earth that is generated through [the rule of three with] the knowledge of the Sun’s longitude in the form of twelve segments of the ecliptic, the rate of motion of the Sun and the measure of the equator. The time corresponding to the longitude is measured on the equator are related to twelve transits. The *saṅkramavākyas* starting with Taurus should be added in their order depending on [their] quarter. Starting from Taurus (*Vṛṣabha*), by adding the corresponding *saṅkramavākyas* which are stated for each month to the first transit of the year and by applying the corrections like ascensional difference and etc. reversely, the knowledge of the true transit [is obtained].

D. Construction of the *saṅkramavākyas*

अत्र वासना

श्रीगुणादिवाक्येषु यावत्तिथं वाक्यं जिज्ञासितं तावत्तिथं वाक्यं ज्ञात्वा तत्पूर्वराश्यन्तमध्यमं च ज्ञात्वा तदन्तरालभूतमासिकसौरमध्यमभोगेन स्फुटमध्यमाहर्गणान्तरज्ञानेन उक्तत्रैराशिकसिद्धदिनादि। समावतश्रणावशिष्टदिनादिकं सङ्क्रमवाक्येन विज्ञेयम्। पुनरप्यत्र बहु वक्तव्यमस्ति। ग्रन्थविस्तरभयाद्भोच्यते। अतः परं गणितप्रक्रियाप्रकाशनमात्रमेव क्रियते। वासना त्वस्मदुक्तसुन्दरराजीयवाक्यकरणवासनाप्रकाशिकायां द्रष्टव्या ॥ ४-A॥

Here is the exposition (*vāsanā*)

Among the *vākyas* that begin with *śrīrguṇa*, having known [the rank of] that *vākyas* which is desired to be known, and having known the mean number [of days] corresponding to the end of the preceding *rāśi*, by means of the Sun’s average monthly longitude which is the difference between those two [*rāśis*]; and by finding the difference of true and mean number of days (*ahargaṇa*); (we get) the days etc. that are calculated through the rule of three which has been [already] stated. The remainder of the division [of the *ahargaṇa*] by seven in days etc. should be known as a *saṅkramavākyas*. Again much more has to be stated here. It is not said because of the fear of expatiation of the text. Hereafter, the exposure of the calculational procedure only will be done. The exposition should be seen in the *Vākyakaraṇa-vāsanā-prakāśikā* of Sundararāja which has been stated by us.

END NOTES

1. A *rāśi* (zodiacal sign) is one-twelfth part of the ecliptic. There are twelve *rāśis*; each comprising 30 degrees.
2. A day is divided into 60 *nāḍis*, and a *nāḍi* into 60 *vināḍis*.
3. **Kaṭapayādi notation:**
The following table shows the numerals corresponding to the letters of Sanskrit [Plofker 2009, pp. 75-76]:

Vowels

a ā i ī u ū ṛ e ai o au aṃ aḥ 0

Consonants

1	2	3	4	5	6	7	8	9	0
ka	kha	ga	gha	ṅa	ca	cha	ja	jha	ṅa
ṭa	ṭha	ḍa	ḍha	ṇa	ta	tha	da	dha	na
pa	pha	ba	bha	ma					
ya	ra	la	va	śa	ṣa	sa	ha	ḷa	

4. The following statement appears in the *Laghuprakāśikā* [Sastri and Sarma 1962, p. 119]:
nilakṣmḥāryeṇa... asmadanugrahārthe sundarārjapraśnottarākhye granthe pratipādītam
In order to bless us, it is explained in the text called “The answers to the questions of Sundararāja” by Nīlakaṇṭha...
5. ... *sundarārjīya-vāsanāprakāśikāyāṃ draṣṭavyā* (...should be seen in the *Vāsanā-prakāśikā* of Sundararāja) [Sastri and Sarma 1962, p. 13].

6. *vararucinā gaṇanakarmoktam* [Sastri and Sarma 1962, p. 7].
7. One *guru* followed by two *laghu* syllables in order constitute a *bhagaṇa*. The syllable which is either long or preceded by a conjunct syllable is called *guru*. A *laghu* syllable is that which is short but not followed by a conjunct one.
8. There are three types of meters; (i) uniform: the one whose quarters follow uniform pattern (ii) non-uniform: that which has its quarters with different styles and (iii) half-uniform: that whose two quarters appear with same pattern.
9. A day is divided 60 *nāḍis* and a *nāḍi* into 60 *vināḍis*.
10. The following verse gives the procedure to compute *ahargaṇa*:
*kalyabdo mātulaguṇaḥ varcavāṃśena saṃyutaḥ |
punarabdānmānaguṇāt sālapiyavivarjitāt ||VK 2||
tatsamāptairdinairyuktaṃ śukravārādikaṃ dinam |*
11. Here, the term is introduced in (1) to deduct an amount equal to due to the equation of center. This deduction is done in order to provide the exact number of days (*sphuṭāhargaṇa*) passed at the junction of true solar year (see the commentary of Sundararāja [Sastri and Sarma 1962, p. 8])
12. By definition, a solar year begins when the Sun crosses a fixed point (*Aśvinī* star in Indian tradition) of the ecliptic. That moment need not be at the time of the beginning of a day (i.e. sunrise).
13. The weekdays are counted from Friday, because the *Kaliyuga* began on Friday. The *Laghubhāskarīya* of Sundararāja says that “*pūrvānitaśukravārādityodayakāle kaliyugasaṅkramāt śukravārodayamārabhya dinagaṇe pravṛtte...*” [Sastri and Sarma 1962, p. 10]. See section A in the appendix for translation.
14. *atra carārdhadeśāntaradorvivara...* [Sastri and Sarma 1962, p. 11].
15. A *Mahāyuga* 43,20,000 years. Here, we have used the parameters of *Laghubhāskarīya* as given by Sundararāja [Sastri and Sarma 1962, p. 6].
16. True daily motion of a planet is the difference in its true longitude in 24 hrs. It is calculated by taking the difference of its two (true) longitudes calculated for two successive days. Here in our computation the days are chosen such that when the Sun is likely to enter the zodiac signs (i.e., 30th & 31st days for second zodiac sign, 60th & 61st for the third etc.).

17. Since we are employing the inverse process of computing the number of days from the longitude, the correction has to be applied in the opposite way.
18. See section D in the appendix for the text in Sanskrit and its translation.
19. Here, we have used the parameters of *Laghubhāskarīya* as given by Sundararāja [Sastri and Sarma 1962, p. 6].
20. Here, the computations are done using computer.
21. This portion of the and its commentary is taken from [Sastri and Sarma 1962, p. 10-15].
22. The reading in Ms. B is taken instead of the edited version. The reading in *Mahābhāskarīya* [Shukla 1960, p. 47] is *pāṇāṭaḥ*.
23. The *Mahābhāskarīya* [Shukla 1960, p. 47] gives *Muditajanaḥ* instead of the name *Muditamanāḥ*.
24. Translation of these verses are taken as it is from [Shukla 1960, p. 47].
25. The word *bha* can refer to 27 constellations also. Hence this clarification is given by the commentator.
26. The time corresponding to the longitude is measured on the equator.

BIBLIOGRAPHY

- Chandrahari K., “*Vākyakaraṇa — A study*” in *Indian Journal of History of Science*, Vol.36, 2001, pp. 3-4.
- Helaine Selin, *Encyclopaedia of the history of science, technology, and medicine in non-western cultures*, Springer, 1997.
- Kunhan Raja C., *Candravākyas of Vararuci: A practical guide for calculating the position of the Sun and Moon, namely, tithi and nakcatra, or any day of the year*, Adyar Library, Chennai, 1984.
- Pingree David, *Census of the exact sciences in Sanskrit*, American Philosophical Society, Vol.5, series A, 1994.
- Plofker Kim, *Mathematics in India*, ch.4, Princeton University Press, 2009, pp. 75-76.
- Sarma K. V., *Dr̥ggaṇita of Parameśvara*, Vishveshvaranand Institute Publication, 1963.
- Sarma K. V., *Grahacāranibandhana or Parahita-gaṇita of Haridatta*, Kuppuswami Sastri Research Institute, 1954.

- Sarma K. V., *Sphutacandrāptih - Computation of true moon by Mādhava of Saṅgramagrama*, Vishveshvaranand Institute, Hoshiarpur, 1973.
- Sarma K. V., *The Vākyakaraṇa* in “Encyclopedia of the history of science, technology and medicine in non-western cultures” ed. By Helain Selin, Kluwer academic Publishers, 1997, p.995.
- Sarma K. V., *Veṅvāroha of Mādhava with Malayalam commentary of Acyuta Piśāraṭi*, The Sanskrit College Committee, Tripunithura, Kerala, 1956.
- Sarma P. D., *Hindu Astronomy*, Global Vision Publishing House, Delhi, 2004.
- Sastri Kuppanna T. S. & Sarma K. V., *Vākyakaraṇa with the commentary Laghuprakāśikā by Sundararāja*, Kuppuswami Sastri Research Institute, Madras, 1962.
- Shukla K. S., *Mahabhāskarīya*, University of Lucknow, 1960.
- Toomer G. J., “A Note on Tamil Astronomical Tables”, *CENTAURUS*, vol. 9, no. 1, 1964, pp. 11-15.
- Toomer G. J., “A Further Note on Tamil Astronomical Tables,” *CENTAURUS*, vol. 9, no.4, 1964, pp. 254-56.
- Waerden B. L., “Tamil Astronomy”, *CENTAURUS*, Vol. 4, 1955-56, pp. 221-34.