SCIENCE INDIA FORUM BAHRAIN

“promoting a new generation of creative scientists”

(UNDER THE PATRONAGE OF THE EMBASSY OF INDIA, BAHRAIN AND ISRO)

SASTRA PRATIBHA CONTEST – 2022

This study material is only indicative of the range of topics that will be covered in the test. This material covers 60% of the SPC syllabus, while 30% syllabus is from school curriculum and the general knowledge will cover the balance 10% syllabus. Therefore, the organizers appeal to all the students to explore further reading materials to prepare well for the test.

MEASUREMENT OF TIME

CATEGORY	SYLLABUS
GRADE 5-7	CHAPTERS 1 to 7
GRADE 8-10	CHAPTERS 1 to 7, 15, 16, 20
GRADE 11-12	ALL CHAPTERS

Wishing you all the best of luck for SPC-2022

SASTRA PRATHIBHA CONTEST

(NATIONAL TALENT SEARCH CONTEST)

Sastra Prathibha Contest (SPC) is a national science talent search contest for students studying in UAE organized by **Science India Forum, UAE** guided by VIBHA (Vijnana Bharti) in collaboration with NCERT – Ministry of Human Resources and Development and Vigyan Prasar, an autonomous organization under the Department of Science and Technology, Government of India.

SPC is a national contest for popularizing Science among school students of V to XII grade students following CBSE and ICSE curriculum.

SPC aims to identify and nurture the bright minds among the student community who are willing to pursue science related subjects at higher studies.

Objective of SASTRA PRATHIBHA Contest (SPC):-

To acquaint school children about India's contributions to the world of Science and Technology in traditional & modern format.

To conduct an annual talent search exam at the national level to identify students who have a scientific flavor of mind.

To enhance science learning experience by imparting hands on training through workshops and seminars.

To organize excursion visit for the winners to the various R & D institutions in the country.

To identify successful students at the national levels and felicitate them with prizes and certificates.

To mentor students in their progress of higher education in Science.

Acknowledgements

SCIENCE INDIA FORUM-UAE gratefully acknowledges the contribution of the individuals and organizations involved in the development of this book -Measurement of Time.

This in fact solely is the initiative of Vijnana Bharati to introduce literature prepared with material from ancient to modern period specially highlighting the contribution of India in the field of Science & Technology as a reading material for SASTRA PRATHIBHA CONTEST.

SIF UAE is grateful to CBSE- Ex Advisors- Shri Vineet Joshi (Ex-Chairman), Dr. Sadhana Parashar, Ex Director (Academics & Training), Convener Prof. Jagbir Singh, all the members of Material Production Team of K.T.P.I., supporting members (CBSE) and editors Prof. Kapil Kapoor and Prof. Michel Damino.

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The efforts of the publication Department- VIBHA in bringing out this publication are also appreciable.

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विद्यार्थी विज्ञान मंथन
SCIENCE TALENT SEARCH

MEASUREMENT OF TIME

Deepak Joshi

Sastrapratibha Contest 2021

MEASUREMENT

OF

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From Editor's Desk

Astronomy is the oldest science known to humans. Birth of stars, planets, galaxies or even life on the Earth can be traced back through such astronomical studies. Ancient Indian sages and *'Jyotirvids'* have done pioneering work in astronomy with precision and accuracy which is well documented in so many Sanskrit texts available today. It is a well-known fact that the human brain is an amazing organ that could think, react, and process information. These abilities enabled humans to develop the techniques of measurement, comparison, referencing, data processing and time keeping. The practice of measuring time based on the Earth's rotation and celestial events has a long tradition in India. This tradition is kept alive with continuous research in the field of astronomy, making and refining almanacs, and present day calendars.

This book takes an extensive account of evolution of science of measurement of time or Chronometry, not only in India but also in other civilisations of the world. We are sure that every Indian would feel proud to know the expertise of ancient Indians in chronometry.

We are happy to present this book to our readers, especially the students, as part of study material of Sastra Prathibha Contest 2021 - a national science talent search exam organised by Vigyan Bharati, Vigyan Prasar and NCERT. This book is a sequel of a book on life and work of an Indian *Jyotirvid,* born in 1854, titled as "Eminent Indian Scientist - Shri Venkatesh Bapuji Ketkar". He devoted his life for almanac research and purification continuing the tradition of Ganesh Daivajna (Born in 1507).

We are fortunate to have Shri. Deepak Joshi, a passionate astronomer and life member of 'Jyotirvidya Parisanstha' (founded in 1944) to author the original book in Marathi titled 'Kalamaapana'. Coincidently, he is also the member of the core team of VVM which triggered him to prepare study material for students. He readily accepted the task that demanded compiling the work on Measurement of Time and presenting it in a manner that appeals to the young generation. We are grateful to him and take joy in announcing that he has done it successfully.

The original Marathi book authored by Deepak Joshi is translated in English by Ms. Siddhi Mahajan, an active karyakarta from Goa Vidnyan Parishad. She was the obvious choice, as she was the author of the book 'Eminent Indian Scientist - Shri Venkatesh Bapuji Ketkar' which has direct relevance to the topic under consideration. We appreciate her talent and the hard work which reflects in this book.

We both, as editors, enjoyed the process of writing original Marathi book by Deepak ji and consequent English translation by Siddhi. Our suggestions and modifications were accepted by both wherever it was worth to be considered. The brainstorming sessions were mutually enriching!

We also put on record our sincere thanks and gratitude to Shri Jayant Sahasrabudhe, national organizing secretary of Vijnana Bharati for his idea and continuous support for bringing this topic and subject to the forefront.

The contents of this book make it worth adding to the home library of every Indian!

Ms. Sangeeta Abhyankar
Content Coordinator, VVM

Dr. Arvind C. Ranade
National Convenor, VVM

Preface

Chronometry or measurement of time is an incessant process. When and where this process originated is an unsolved mystery. This book reviews the Indian chronometry. While doing so, special attention has been paid to introduce concepts of the Indian chronometry to the school students. In Vidyarthi Vigyan Manthan 2020, Vijnana Bharati has decided to introduce the concepts of Indian Chronometry to school children along with the contribution of Venkatesh Bapuji Ketkar, a world class astronomer, to Astronomy. Bearing this in mind, this book has been penned.

I am especially grateful to Hon'ble Jayant Sahasrabuddhe, National Organizing Secretary of Vijnana Bharati and National Convenor of Vidyarthi Vigyan Manthan, Dr. Arvind C. Ranade for giving me this opportunity. The bibliotheca of the Jyotirvidya Parisanstha in Pune was extremely useful for compiling and editing the information from various sources. I am truly indebted to the organization for this. The concepts of Chronometry are in complex language and consist of intricate details. The book could not have been completed or made easy for students to understand, without the help of Ms. Sangeeta Abhyankar from Goa. I am extremely obliged to her for this.

Astronomy is the basis of Chronometry. The purpose behind this book is to make the students curious about this subject by reading this book.

Deepak Joshi
Pune

September 17, 2020
Śālivāhana Saka 1942, Bhādrapada Amavasya
Vikram Samvat 2077, 26 Īsh
According to the Indian National Calendar, *Saka 1942, 26 Bhādrapada* Julian Day Number 2459109.5

1 Measurement of Time

Measurement is an integral part of science. Historical evidence, such as archeological excavations, stone and copper inscriptions, suggest that length, area, and volume have been measured using various methods since time immemorial. Eventually a need was established to standardise the units of measurements; especially for communication of comparison of quantities. In modern times, we use the MKS (meters, kilograms, seconds) or FPS (feet, pounds, seconds) systems of standards. Surprisingly, the units of time measurement are the same i.e. seconds/minutes/hours in both these systems.

Have the same units been used to measure time, since ancient times? Today, we use seconds-minutes-hours-days-months-years very casually for measurement of time. We use units of measurement of time to describe any event. The units that are in use today have evolved over a long period of time. This book is an effort to introduce different methods of measurement of time. The contribution of the ancient Indians is very significant and indisputable in this field.

We still come across some people using various traditional standards based on human body parts. E.g. one *angul* (digit), one *hasta* (elbow length), one *purush* (Height of a person) as units of distance. In the olden times, it was customary to measure the distance between two villages by 'a day'. One village is seven days away from the other; which means that, if we travel for seven days, we will reach the other village. Even today, we say that a place is ten minutes away from home. This attempt to tell distance and time together is not scientifically

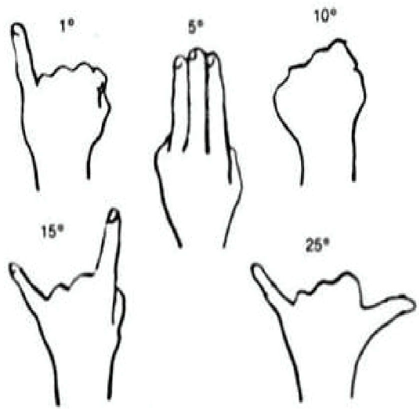

Figure No. 1: Use of fingers to measure celestial angular distance

accurate; however, we use it constantly in practice. Accuracy in measurement is required in scientific studies. Man has been working in that direction since ancient times.

Natural phenomena proved to be an important factor in these efforts. The rotation of the earth is the supportive pillar of the measurement of the day. The concept of a month is based on the time period required for the Moon to revolve around the earth. The concept of a year is based on the time taken by the earth to complete one rotation around the Sun. These natural events are periodic in nature. The process of observing the frequency of these events and expressing it in the form of equations is called the measurement of time. The science of accurate time measurement is called chronometry.

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2 *Divasa* (Solar Day)

The earth is constantly rotating around its own axis. This rotation occurs from west to east. Due to this, the Sun appears to rise in the east and set in the west. Numerous stars begin to shine in the sky after the sunset. These twinkling stars appear to be traveling westwards. The time period in which the Sun is seen in the sky is called the *Divasa* or a day; whereas the time period in which it is not visible in the sky is called the *Rātri* or the night. In Indian chronometry, day and night together are called *Ahorātrā*, and it is considered as a full day. The day begins at Sunrise.

In ancient India, a very simple and easy method was used for the measurement of time. *Ghaṭikā Pātra* and *Chāyā Shankū* were the main instruments used.

Ghaṭikā Pātra

Ghaṭikā Pātra is an instrument which was derived from a tool in daily use. It consists of a large container filled with water. A copper vessel of specific weight and size is suspended within it.

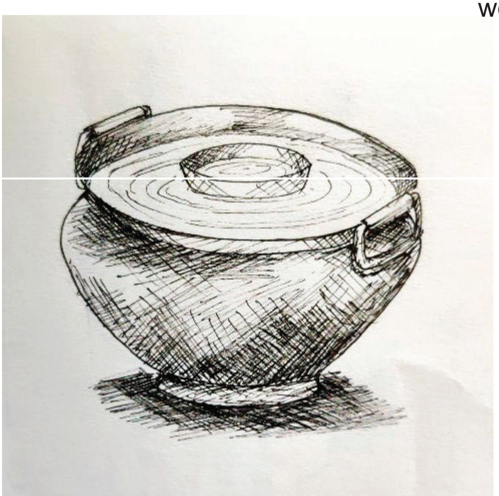

Figure No. 2: *Ghaṭikā Pātra*

This copper vessel has a small hole at its bottom. Water slowly starts accumulating from the bigger container, in the copper vessel. As the water level increases, the copper vessel starts sinking gradually. After some time, it sinks to the bottom of the larger container. The time taken by the copper vessel to sink fully is called a ghaṭikā. The structure of the *Ghaṭikā pātra* has been described by the ancient Indian scholar *Vārahamihir* as follows. Take a semicircular copper vessel

(*Tāmrapātra*) with a radius of six *angulas* and containing sixty *Paḷe* (240 *Toḷās* / ounces) of water. Pierce a hole at its bottom such that a golden needle of length of 4 *angulas*, weighing 31/3 *Māse*, (12 *Māse = 1 Toḷā*) can effortlessly pass through it. Thus a *Ghaṭikā Pātra* is designed.

The time measured by the *Ghaṭikā Pātra* as per the measurement of modern clock is as follows:

1 *Vipaḷa* = 4/45 seconds
1 *Prāṇa* = 4 seconds
1 *Vināḍī* / *Paḷa* = 24 seconds
1 *Nāḍī* or *Ghaṭikā* = 24 minutes
1 *Muhūrta* = 48 minutes

It takes a *Nāḍī* i.e. 24 minutes, to empty a pot full of water.

Chāyā Shankū (Solar Gnomon)

Chāyā means a shadow and *shankū* means a cone. It is a stick (Gnomon) casting a shadow against the Sun. The use of *Chāyā shankū* is mentioned in the book *Atharva jyōtiṣa* to measure the time when the Sun is in the sky. The standards they have set are as follows:

12 *Nimesha* = 1 *Lava*,
30 *Lava* = 1 *Kalā*
30 *Kalā* = 1 *Truṭī*
30 *Truṭī* = 1 *Muhūrta*
30 *Muhūrta* = 1 *Ahorātra* (full day)

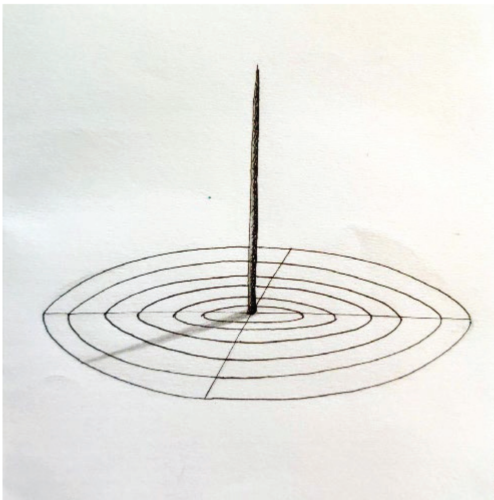

Figure No. 3: Chāyā Shankū

Thirty *Muhūrtas* occur in a full day, of which fifteen *Muhūrtas* occur when the Sun is seen in the sky, and fifteen *Muhūrtas* occur when it is not seen. While measuring the *Muhūrta*, a twelve '*angulas'* long stick is used which is tapering upward. The *Chāyā shankū* is an instrument used to measure the Sun's shadow casted by the gnomon. The length of the shadow is measured by the unit *'angula'.*

What is an *'Angula'*?

From ancient times, human body parts have been used as units in various measurements. The smallest unit is the finger/digit. An '*Angula'* is the distance equal to the breadth or thickness of a finger.

Muhūrtas in a day

The shadow of a gnomon falls to its west after Sunrise and the length of the shadow is the longest at Sunrise. As the Sun moves upwards in the sky, the length of the shadow begins to decrease. The unit *'angula'* is used to measure the length of shadow. The eight *Muhūrtas* from sunrise to the noon are calculated as depicted in Table No 1.

Table No. 1: The Eight *Muhūrtas*

***Muhūrta* number**	**Name of the *Muhūrta***	**Length of shadow in *Angulas***
First	*Raudra*	96 *Angulas*
Second	*Śveta*	60 *Angulas*
Third	*Maitra*	12 *Angulas*
Fourth	*Sārbhata*	6 *Angulas*
Fifth	*Sāvitra*	5 *Angulas*
Sixth	*Vairaj*	4 *Angulas*
Seventh	*Viśvāsū*	3 *Angulas*
Eighth	*Abhijāta*	Less than 3 *Angulas*

Abhijāta

'Yasmin chāyāpratiṣṭhitā' - (Meaning: The muhurta in which the shadow is fixed). The *Abhijāta* muhurta occurs at noon. The shadow is very small (less than 3 *angulas*) as the Sun is over the head at this time. In the region from the Tropic of Cancer to the Tropic of Capricorn, though the Sun appears overhead, it is not necessarily at zenith. There are only two days in a year; when the Sun is exactly at the zenith and the shadow is not cast at local noon. These days are called 'zero shadow days' (ZSD). This phenomenon can be experienced in India towards the south of the tropic of Cancer. The first 'Zero Shadow Day' falls between April 9 and June 21; The second falls between June 21 and August 30.

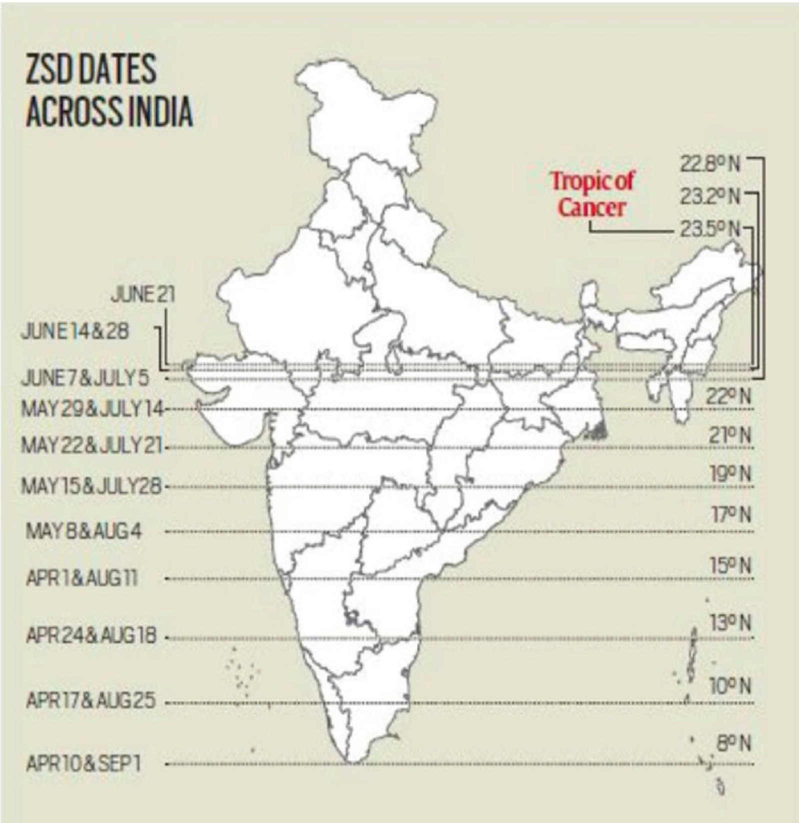

Figure No. 4: Image showing 'Zero Shadow Day' taking place in different locations and on different days in India.

As the Sun tilts westward, the shadow of *Chāyā Shankū* falls eastward and gradually grows larger. Thus, the 9th *Muhūrta* is again *Viśvāsū* muhurta. Similarly, in reverse order, the *Raudra Muhūrta* appears again at the time of Sunset.

Modern chronometry divides the time into seconds, minutes, hours, days, months, and years. Astronomy has been used in the construction of these chronometric components. Generally, we count 24 hours as a day in practical life.The Earth takes 23 hours, 56 minutes and 4.09053 seconds to complete a revolution around the Sun. We know that latitudes and longitudes are used to represent any place on the earth. The zero degree longitude passes through the city of Greenwitch in England. An observatory has been set up in the city of Greenwich. The telescope in this observatory is permanently pointed towards the zenith. The period of 23 hours, 56 minutes and 4.09053 seconds has been fixed for the rotation of the Earth upon observation of the star Beta cassiopeiae (Indian name *Śarmiṣṭhā).*

In modern chronometry, the time of rotation of the earth is calculated on the basis of the frequency of the vibrations of the atom of Cesium 133. The atomic clock is the most accurate tool used in modern chronometry. A second is officially defined as a duration of 9,192,631,770 oscillations of the atom of Cesium 133. Also, a year is officially defined as a duration of 290,09,200,500,000,000 oscillations of the atom of Cesium 133.

The nucleus of the element Cesium 133 consists of 55 protons and 78 neutrons. 55 electrons revolve around the nucleus in different stable orbits. The last orbit contains only one electron. The energy state of this electron can be changed by applying external energy; so that the electron changes its orbit for a very short interval of time and returns to its original state by emitting a wave of frequency 9,192,631,770. It is used in the atomic clock for measurement of time.

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3 *Vāra* (Weekday)

In Indian time keeping system, *Vāra* is one of the important attributes. It is difficult to tell exactly when and where the *Vāra* originated. *Vāras* are not mentioned in ancient Indian texts. However, since the time of *Vārahamihira*, mention of *Vāra* has appeared in Indian texts. According to *Vārahamihira*, the seven greatest celestial bodies, viz. Sun, Moon, Mars, Jupiter, Saturn, Venus and Mercury were invoked in the *yajna karma.* The ancient Indian texts *'Āryabhatiya'* and *'Sūrya Siddhānta'* give the rules to define the weekdays or *Vāras,* as follows:

'मंदातअधः मेणयुःचतुथाि◌दनाि◌धपाः'

'Mandāta adhaḥ Krameṇa syuḥ Caturthā dinādhipāḥ'

According to this verse, if planets are arranged from slower to faster; then the fourth planet is considered as *Dinādhipatī* (the one who rules the day). The Moon, the Sun, and the visible planets viz. Mars, Jupiter, Saturn, Venus, and Mercury appear to move in the sky against the background of the stars. Observations from the Earth show that Saturn is the slowest orbiting planet. Based on the time taken by the planets to move on the stellar background, an ascending order of their pace can be formed as Saturn, Jupiter, Mars, Sun, Venus, Mercury and Moon.

The word *'Hōrā'* is used in *Vārahamihira's* literature. *Vārahamihira* writes that the word *'Horā'* was formed by omitting the two letters *'A'* and *'Tra'* from the word *'Ahōrātra'*. There are 24 *Hōrās* in the *Ahōrātra*. One planet was considered the lord of each *Hōrā* and was called '*Hōrādhipatī*'. The *Hōrādhipatī* at Sunrise is called *'Dinādhipatī'* which decides the name of the *Vāra*. In the following table, the planets from Saturn to the Moon have been arranged according to their pace.

Table No. 2: Determining the names of the *Vāras*

***Śani* (Saturn)**	***Guru* (Jupiter)**	***Maṅgaḷa* (Mars)**	***Ravi* (Sun)**	***Śukra* (Venus)**	***Budha* (Mercury)**	***Candra* (Moon)**
***Hōrā* 1** *Śanivāra*	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	***Hōrā* 1** *Ravivāra*	2	3	4
5	6	7	8	9	10	11
19	20	21	22	23	24	***Hōrā* 1** *Somavāra*
2	3	4	5	6	7	8
23	24	***Hōrā* 1** *Maṅgaḷavāra*	2	3	4	5
20	21	22	23	24	***Hōrā* 1** *Budhavāra*	2
3	4	5	6	7	8	9
24	***Hōrā* 1** Guruvāra	2	3	4	5	6
21	22	23	24	***Hōrā* 1** *Śukravāra*	2	3

The first day in the Table No. 2 is Saturday as Saturn is the lord of the first *Hōrā* of the day. The lord of the twenty-fourth *Hōrā* is Mars. After this, the second day begins. *Ravī* (Sun) is the lord of the first *Hōrā*; So *Ravi* is the *'Dinādhipatī'*. Hence the day is Sunday. In the same way Monday (lunar day), Tuesday, Wednesday, Thursday, Friday come in an order.

How to find the weekday/*Vāra* from a specific date of the Gregorian calendar?

(The Gregorian calendar is a calendar started by Pope Gregory XIII in 1582 and used worldwide)

This is made possible by a very simple mathematical equation. The following formula can be used for this:

Day = Remainder (D+Y+integer(Y/4) - integer(Y/100) + integer(Y/400) + integer [(31 x M) / 12]) / 7

Day = Weekday/*Vāra*
D = date
Y = Year - A [A = 0 (if month> 2), and A = 1 (if month <3)] M =
Month - B [B = 2 (if month> 2), and B = 1 (if month <3)]

Day = 0 = Sunday Day = 1 = Monday Day = 2 = Tuesday	Day = 3 = Wednesday Day = 4 = Thursday	Day = 5 = Friday Day = 6 = Saturday

Example: To find out the weekday of August 5, 2020:
August 5, 2020 = 5/8/2020
D = 5
Y=2020-0=2020
M=8-2=6

Day = Remainder(5+2020+integer(2020/4)-integer(2020/100) + integer (2020/400) + integer ([31x 6)/12]) / 7
Day = Remainder ((5 + 2020+ 505 - 20 + 5 + 15) / 7)
Day = Remainder (2530/7)
Day = 3
August 5, 2020 was Wednesday.

****

4 *Pakṣa* (Fortnight)

The day/*Vāra* consists of 24 hours. Seven days make a week. We have seen the details about the names assigned for seven days of the week. The next unit consists of two weeks that make a fortnight. This group of fifteen days is called "*Pakṣa*". Two *Pakṣas* make a month. *Śukla Pakṣa* and *Krishna Pakṣa*, have been the terms used in the Indian chronometry. They are also called *Śuddha Pakṣa* and *Vadya Pakṣa* respectively. The day and night are caused by the rotational motion of the earth. During the day, the Sun appears to travel through the sky. The Sunlight is scattered by the dust particles from the earth's atmosphere. Thus the stars are not visible during the daytime. These stars are visible after the Sunset.

Through continuous observations, we can trace the apparent motion of the Moon in the stellar background. In the evening sky, a very feeble crescent moon can be seen near the horizon after the Sunset. Day by day, the crescent moon appears to move away from the western horizon, and becomes larger gradually (waxing moon). A half Moon can be observed within a week and appears at the zenith. The Moon gradually waxes and can be seen rising as a full Moon on the eastern horizon at the time of Sunset. This period of fortnight in which the western front of the Moon gets illuminated gradually is called *Śukla Pakṣa*.

Over the next fortnight, the Moon can be seen rising 52 minutes belated after the Sunset. Also, the Moon wanes gradually. Over a period of seven to eight days, the Moon rises in the east around midnight and sets in the west around noon next day. Over the next seven or eight days, the crescent moon wanes, becomes feeble and becomes invisible on the fifteenth day. On this day the Moon and the Sun have the same ecliptic longitude. This second fortnight in which the eastward front of the Moon is illuminated is called the *Krishna Pakṣa*.

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5 *Nakśatra* (Lunar Mansions)

When the lunar journey during *Śukla Pakṣa* and *Kriṣna Pakṣa* is observed, it is seen that the Moon travels against the background of specific stars. The lunar orbit was highlighted by ancient Indian astronomers. They gave specific names to the stars / lunar mansions, to identify them. The Moon takes 27.3 days to complete one orbit around the earth. Thus the lunar orbit was divided into twenty-seven parts, each called a *Nakśatra*. Every *nakśatra* is identified and named after one of its prominent stars, which is also called a *Yogatārā*. Every *nakśatra consists* of one, or more than one star. The Moon completes one orbit around the earth, after passing through the 27 *nakśatras* in twenty-seven days, moving in a new *nakśatra* every day.

Each *nakśatra* consists of 360/27 = 13.33 degrees. (1 degree = 60 minutes).

Thus One *nakśatra* spans (13.33 x 60) angular minutes = 800 angular minutes.
This sums the average daily speed of the Moon as 800 angular minutes.

Table No. 3: *Nakśatras* and their *Yogatārā*

Sl. No.	*Nakśatra*	*Yogatārā*
1	*Aśvinī* (अि वनी)	β Arietis
2	*Bharaṇī* (भरणी)	41 Arietis
3	*Krittikā* (कृ ि तक)	Pleiades Eta Tauri
4	*Rohiṇī* (रो हणी)	Aldebaran
5	*Mrigashīrṣa* (मृगशी)	λ Orionis
6	*Ārdrā* (आ ा)	Alhena Gemini
7	*Punarvasu* (पुनव)	Pollux
8	*Puṣya* (पु य)	δ Cancri

Sl. No.	*Nakśatra*	*Yogatārā*
9	*Āśleṣā* (आ लषा)	Zeta Hydrae (ζ Hya)
10	*Maghā* (मघा)	Regulus
11	*Pūrvā Phālgunī* (पूवा फा ग)	θ Leonis
12	*Uttarā Phālgunī* (उ तराफा गुन)	Denebola
13	*Hasta* (ह त)	δ Corvi
14	*Citrā* (च ◌ा)	Spica
15	*Svātī* वाती)	Arcturus
16	*Viśākhā* (वशाखा)	α Librae
17	*Anurādhā* (अनुराध)	δ Scorpionis
18	*Jyeṣṭhā* (ये ठ)	α Scorpionis
19	*Mūla* (मू)	λ Scorpionis
20	*Pūrvā Āṣādhā* (पूवषाढा)	λ Sagittarii
21	*Uttarā Āṣādhā* (उ तराषाढा)	π Sagittarii
22	*Śrāvaṇa* (वण)	α Aquilae
23	*Dhaniṣṭhā* (ध न ठा)	α Delphinus
24	*Śatatārakā* (शततारका)	γ Aquarii
25	*Pūrvā Bhādrapadā* (पूव भा पदा)	α Pegasi
26	*Uttarā Bhādrapadā* (उ तराभा पदा)	γ Pegasi
27	*Revatī* (रेवत)	ζ Piscium

The luminosity of the stars in every *nakśatra* is different. While marking the position of a *yogatārā* of a *nakśatra*, ancient Indians have considered it's distance from the vernal equinox. The distance of each *yogatārā* from the vernal equinox on the ecliptic is known as the *'Bhōga'* (celestial longitude) of that star. The celestial longitude of the Vernal equinox is considered as zero, after which, the first *nakśatra* is named as *aśvinī*. *Bhōga* (celestial longitude) of *aśvinī* *nakśatra* is 13 degrees 20 minutes. Celestial longitudes span from zero degrees to 360 degrees.

In various ancient texts on astronomy from the *Vedānga* period, the vernal equinox is denoted lying in different *nakśatras*. Thus in some methods of measurement of time the first *nakśatra* is considered *as Krittikā*; while in some, *Dhanishthā* is considered as the first. Modern system considers the *aśvinī* as the first *nakśatra.*

The term *Śara'* (celestial or ecliptic latitude) measures the angular distance of an object from the ecliptic towards the north (positive) or south (negative) of the ecliptic pole. *Śara'* of *Pūṣya*, *Maghā*, *Śatatārakā* and *Revatī nakśatras* is zero degrees. It means that the stars mentioned above lie over the ecliptic. The stars in all the other *nakśatras* lie either to the north or to the south of the ecliptic.

The *Bhōga* and *Śara* are also used to represent the positions of the Moon, Sun and the other planets in the sky.

Every day, the Moon is moving eastwards in the sky away from the Sun. During the *Krișna Pakșa*, the Moon wanes and gets closer to the Sun, and one day the Moon and the Sun appear to be aligned together. During this day, the value of celestial longitude of moon and Sun becomes same/equal, i.e the east-west distance between the moon and Sun is equal to zero at a specific moment. Before that moment, the Moon is towards the west of the Sun. After that moment, the Moon shifts to the east of the Sun. Upon observing a total solar eclipse, we can experience this moment.

Amāvāsyā - (New Moon day)

The Sanskrit word *'Am'* means - with; *'vās'* means to live.

'सूया च मसोय:पर: सि नकष: सामावा या'

'***Sūryacandramasōryaḥ Paraḥ Sannikarṣaḥ Sāmāvāsyā***'

(The closest proximity of the Sun and the Moon is called the New Moon.)

According to an ancient scripture, the *tithī* at which the Moon is not visible in the sky is called the new Moon.

Paurnimā (Pūrnimā / Pūrnamāsī / Paurnamāsī):

This is the day on which the full Moon appears. It is the last *tithī* of the month ending with the full Moon. The word *'māsa'* also means the Moon, thus *Pūrnamās* is also called a full Moon. The full Moon is actually a moment in which the Earth is located between the Sun and the Moon and the angular distance of the Sun and the Moon as measured from the earth is 180 degrees. Thus they form an opposition. On this day, the lunar hemisphere facing Earth – the near side – is completely Sunlit and appears as a circular disk.

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6 *Tithī* (Lunar day)

A Tithī is an important unit used in the Indian chronometry. Just as the date is used to represent a day in the Gregorian calendar; similarly a *tithī* is used in the Indian calendar. A day in the Gregorian calendar consists of twenty-four hours. However, the *tithī* in the Indian calendar depends entirely upon the lunar location in the sky.

The Sun and Moon happen to be apparently moving from the west to the east on the celestial background. The Moon appears to move faster than the Sun. Thus the relative speed of the Moon with respect to the Sun can be calculated as follows, which is closely related with the concept of the *tithī*.

Relative speed of the moon w.r.t the Sun per day	=	**Relative speed of the moon w.r.t the Earth per day**	-	**Relative speed of the Sun w.r.t the Earth per day**

Relative speed of the moon w.r.t. the Earth per day: The Moon takes about twenty-seven days to complete a rotation around the Earth. This means that the Moon takes twenty-seven days to complete a span of 360 degrees.

Relative speed of the moon w.r.t the Earth per day = 360 degrees / 27 days
= 13.33 degrees per day
~13 degrees per day

Relative speed of the Sun w.r.t. the Earth per day - The earth takes 365 days to complete a rotation around the Sun. This means the earth takes 365 days to complete a span of 360 degrees. Thus when viewed from the Earth, the Sun appears to move against the background of the stars.

Relative speed of the Sun w.r.t the Earth per day = 360 degrees / 365 days
= 0.986 days
~1 degree per day

Relative speed of the moon w.r.t the Sun per day	**=**	**13 degrees per day**	**-**	**1 degree per day**

= 12 degrees per day

This means that the angular distance between the Sun and the Moon is approximately twelve degrees per day. The time it takes for the longitudinal angle between the Moon and the Sun to increase by 12° is called a *tithī.* The Sun and the Moon appear to align on the same ecliptic longitude on a New Moon day. The Moon then moves away from the Sun faster. On the *tithī* of *śukla pratipadā*, the angular distance between the Sun and the Moon is 12°. Similarly it is 24° on the *tithī* of dvitīyā, 36° on the *tithī* of tṛtīyā. Thus on the fifteenth *tithī* of the full Moon, the angular distance between the Moon and the Sun is 180°.

The Time Period of a *tithī*

The Moon revolves around the Earth in an elliptical orbit. Therefore, its angular speed changes constantly per day. When the Moon is closest to the earth, its apparent angular speed is 15.33 degrees per day, while when it is farthest, the apparent angular speed of the Moon is about 11.33 degrees per day. The *tithī* is defined as the time taken by the moon to span an angular distance of 12 degrees w.r.t. the Sun. But depending upon the speed of the Moon, this time period varies from 28 hours to 20 hours. A lunar month has 30 *tithīs*. Since the duration of the *tithī* is less than 24 hours, *tithī vṛddhi* and *tithī kṣaya* occur.

Tithī vṛddhi and *Tithī kṣaya* (Rise and Decay in a Tithī)

‘यांतर्थींसमनु ◌ा यउदयंया त भा कर:’

‘*Yāṁ tithīṁ samanuprāpya udayaṁ yāti bhāskaraḥ*’

The meaning of above verse is, "The *tithī* running during the Sunrise is the *tithī* of that day"

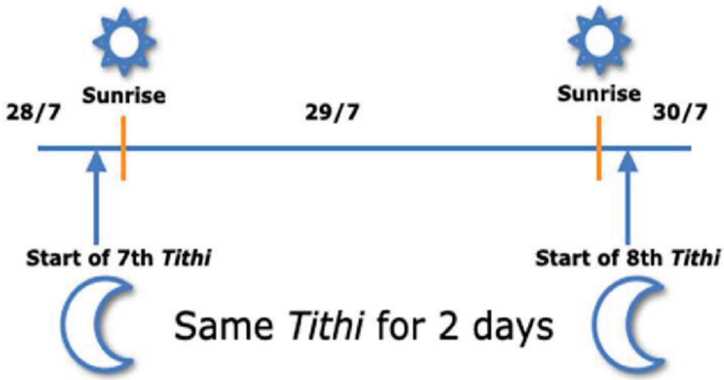

Figure No. 5: tithī vṛddhi

On days, when a *tithī* is completed under two solar days, *tithī vṛddhi* is said to have occurred. (one which comprises two sunrises).

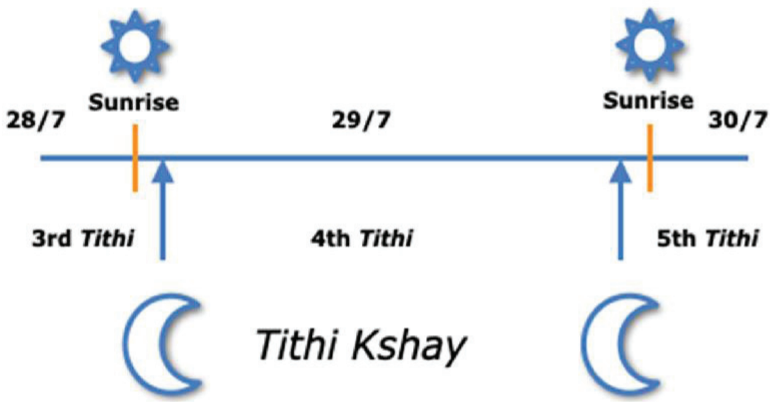

Figure No. 6: tithī kṣaya

If the Moon spans two *nakśatras* between two sunrises of two consecutive days, a *tithī* is dropped or *kṣaya* occurs. In Figure No. 6, *tṛtīyā tithī* is running at the time of Sunrise on 29th. Shortly thereafter, the Moon enters its fourth *tithī*, the *caturthī*. On 30th, the Moon moves 60 degrees away from the Sun before Sunrise on the 30th; i.e, the fifth *tithī* of *pañcamī* has started. So the *tṛtīyā* has started on 29th; and *pañcamī* has started on 30th. In the process, *caturthī* has vanished or *tithi ̄kṣaya* has occurred.

In a normal year, the *tithī vṛddhi* takes place seven times, while the *tithī kṣaya* occurs 13 times.

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7 *Māsa* (Month)

The chronometric unit that comes after the fortnight, is the *māsa* or a month. Months associated with the seasons or *ṛtu* have been mentioned in the *Vedic* literature. The position of the Sun gives an idea of the seasons. The *taittirīya saṃhitā* consists of a verse which mentions the six *ṛtu* and twelve *māsa*.

मधु चमाधव च वासं तकावृतूशु चशु च च ी मावृतू।
नाभ च नभ य च वा ष कावृतूईशधोज चशारदावृतू। सह
च सह य च हैमं तवृतूतपच तप य च शै शरावृतू॥

तै.सं.४:४:११

Madhuśca mādhavaśca vāsaṃtikāvṛtū śukraśca śuciśca grīṣmāvṛtū
Nābhaśca nabhasyaśca vārṣikāvṛtū īśadhorjaśca śāradāvṛtū
Sahaśca sahasyaśca haimantivṛtū tapaśca tapasyaśca śaiśirāvṛtū

Taittirīya Saṃhitā 4:4:11

Among these, *Madhu, Mādhava, śukra, śuci ,Nabhas, Nabhasya, īśa, ūrj, Sahas, Sahasya, Tapas, Tapasya* are the names of the twelve mās. All these names have *Vedic* origin and are directly related to the seasons. It was difficult to tell where exactly a season ends and the next one begins, making it impossible to distinguish these *mās*. Over time, the names of the *mās* based on the seasons were replaced by the names of the lunations adapted from the *nakśatras*. There are two types of *mās*, the *Cāndramās* and the *Sauramās*.

Cāndramāsa or Lunar month

According to the *'Sūrya Siddhānta'* and other ancient Indian texts, the lunar months based on motion of the Moon may have come into existence during the *Vedāṅga jyotiṣa* period, i.e around 1500 BC. The *nakśatras* were formed consisting of the brightest stars in the lunar pathway. The months have been named after the *nakśatra* in the lunar background on the corresponding full moon day. The Moon crosses the 27 *nakśatras* twelve times annually. These *nakśatras* after which the months have been named, are not equidistant from each other. Also, the orbiting speed of the Moon doesn't remain constant. In addition, the *nākṣatra* lunar month consists of 27.3 days and the coincidental lunar month consists of 29.53 days. The east-west distance between the Moon and the Sun becomes zero at one point on the day of the new Moon. Such two consecutive days occur after an average of 29.53 days. All this has an effect on the occurrence of any *nakśatra* on the day of the lunar full Moon.

Table No. 4: *Cāndramāsa* and *Nakśatras* on the Full Moon Day

Cāndramāsa	***Nakṣatra* on *Purṇimā***		***Cāndramāsa***	***Nakṣatra* on *Purṇimā***
Caitra	*Caitrā/ Svātī*		*Aśvin*	*Aśvinī/Bharaṇī*
Vaiśākha	*Viśākhā/ Anurādhā*		*Kārtika*	*Kṛttikā/Rohiṇī*
Jyeṣṭha	*Jyeṣṭhā/ Mūlā*		*Mārgaśīrṣa*	*Mṛgaśīrṣa / ārdrā*
Āsāṛh *āṣāḍha*	*Pūrvāshadha/ Uttarashadha*		*Pauṣa*	*Punarvasu/ Puṣya*
Śrāvaṇa *śrāvaṇa*	*Sravaṇa/ Dhaniṣṭhā*		*Māgha*	*śleṣā /Maghā*
Bhādrapadaa *Bhādrapadaa*	*Pūrvābhādrapada/ Uttarabhādrapada*		*Phālguna*	*PūrvāPhālguni/ Uttara Phālguni*

There are two types of lunar months, *Amānt* and *Pūrnimānt*. *Pūrnimānt* months are used extensively in Northern India while *Amānt* months are used extensively in South India.

Amānt -

This is the month which ends with the new Moon. The *Amānt* month is considered from a new Moon day to the next new moon day. The first fortnight of this month is *śuklapakṣa* and the second fortnight is *Krishnapakṣa*.

Pūrnimānt -

This is the month ending with *Pūrnimā* or the full Moon.The time period from one full Moon to another is known as the *Pūrnimānt* month. In this month the first fortnight is the *Krishnapakṣa* and the second fortnight is the *śuklapakṣa*.

Naming a lunar month: An important rule was set to determine the names of the lunar months in order to establish the relationship between the lunar month and the Sun, and to avoid any confusion created by the location of the Moon on the full Moon day. According to this, when the Sun enters *meṣa rāśi* in the lunar month ending with the new Moon, that *'amānta cāndramāsa'*, should be called *Caitra*. In the same way, the names of the lunar months or the *cāndramāsas* should be determined according to the solar transits through the next signs. This was one of the first attempts to interrelate the solar year and lunar year. When the Sun enters the *nakśatra aśvinī*, it is said to be a *'meṣa sankrānti.* (Aries transit). *Caitrā nakśatra* is situated at 180 degrees or exactly opposite from the starting point of *aśvinī nakśatra*. The time period during which the *Caitrā nakśatra* rises to the east at the Sunset, is called the month of *Caitra*. The *nakśatras* corresponding to each month given in the table above, rise at the time of the Sunset in that month and remain in the sky throughout the night.

Yutikālin Cāndramāsa **(Coincidental lunar month)**

On each new Moon, the Sun and Moon are in the same direction, thus the Moon is not visible on that day. On this day, at a specific moment the east-west distance between the Sun and the Moon becomes zero. The time period ranging from a new Moon to the next new moon is known as the coincidental lunar month, which is used for civil purpose. The coincidental lunar month consists of 29.530589 days.

Sāṃpātīya *Cāndramāsa* **(Tropical lunar month)**

The time taken by the Moon to return to the Vernal Equinox in the sky is called the tropical lunar month. This lunar month consists of 27.321582 days.

Nākṣatriya cāndramāsa **(*Nākṣatriya* Lunar Month):**

The time taken by the Moon to return again to a particular *nakśatra* or lunar mansion is called a *Nākṣatriya cāndramās*. The *Nākṣatriya* lunar month consists of 27.321662 days.

Upabhūviya cāndramāsa (Subtropical Lunar Month):

The time it takes for the Moon to return to the apogee point (earth's closest proximity), is called the subtropical lunar month. The subtropical lunar month consists of 27.554550 days.

Sauramāsa (Solar month)

Just as the *Amānt* and *Pūrnimānt* lunar months are considered; similarly, the practice of considering the solar months based on the location of the Sun in the sky is prevalent in some parts of India. As the earth revolves around the Sun, the Sun appears to move in the sky along the ecliptic. The 360 degrees ecliptic has been further divided into twelve parts. Each part consists of thirty degrees and is called a zodiac sign or *rāśi*. Solar transit from one zodiac sign to the next is called as a *sankramaṇa*. This Solar transit in the sign of Capricorn is called The *Makara sankrānti*. Today, the *Makara sankrānti* falls on the 14th and 15th of January. Thus, every month a *sankrānti* occurs and those *sankrāntis* are named after the corresponding solar month. E.g. *'meṣa sankrānti'* in April, *Vṛṣabha sankrānti* in May.

Table No. 5: Solar Months and the Days of Solar Transits

Day of Solar transit	**Solar Transit and Solar Month**	***Transit (saṃkrāṃti)***	**Day of Solar transit**	**Solar Transit and Solar Month**	***Transit (saṃkrāṃti)***
13/14 April	Aries (*Meṣa*)	*Meṣa saṃkrāṃti*	14/15 May	Taurus (*Vṛṣabha*)	*Vṛṣabha saṃkrāṃti*
15/16 June	Gemini (*Mithuna)*	*Mithuna saṃkrāṃti*	16/17 July	Cancer (*Karka)*	*Karka saṃkrāṃti*
16/17 August	Leo (*Siṃha*)	*Siṃha saṃkrāṃti*	16/17 September	Virgo (*Kanyā)*	*Kanyā saṃkrāṃti*
17/18 October	Libra *(Tulā)*	*Tulā saṃkrāṃti*	16/17 November	Scorpio (*Vṛścika*)	*Vṛścika saṃkrāṃti*
15/16 December	Sagittarius (*Dhanu)*	*Dhanu saṃkrāṃti*	14/15 January	Capricorn (*Makara)*	*Makara saṃkrāṃti*
12/13 February	Aquarius (kumbha)	*Kumbha saṃkrāṃti*	13/14 March	Pisces *(mīna)*	*Mīna saṃkrāṃti*

These months are decided and named based upon the apparent motion of the Sun on the stellar background. Although the zodiac signs are expressed technically in terms of degrees, they consist of specific clusters of stars. The Sun is in Gemini from June 15 to July 16. During this period, the earth is in perihelion within its orbit. Thus the duration of solar months of July and August is the maximum. The Sun is in Sagittarius from December 16 to January 14, during which the Earth is in aphelion with the Sun. Therefore, the duration of the solar months of December and January is the minimum.

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8 *Adhik Māsa / Asankrāntimāsa* (Intercalary Month)

We have studied the concepts of *Tithī vṛddhi* and *Tithī kṣaya* along with the *tithī*. Just as the lunar motion from one sunrise to the next causes the *tithī vṛddhi* and *tithī kṣaya*, similarly when the lunar month ends before the Sun has moved to a new zodiac sign, a thirteenth month has to be added to the lunar year. This extra month can also be called *adhik māsa* or *asankrāntimāsa*.

Cāndravarṣa - Lunar year (354 days):

The coincidental lunar month consists of 29.53 days on average. Thus a lunar year consists of twelve lunar months, or 354 days.

Saurvarṣa - Solar year (365.2564 days):

The Earth takes 365.2564 days to complete an orbit around the Sun. We can derive the average days of a solar month by dividing the total number of the days in a year by twelve. The average duration of a solar month is thirty days, ten hours, twenty-nine minutes and four seconds (30d 10h 29m 4s).

Indian Luni - Solar Chronometry:

The lunar year is shorter than the solar year by eleven days. This excess of eleven days, causes unalignment between the pure lunar year and the seasons, and the occurrence of the lunar festivals eleven days earlier.

Assuming that in the year 2020, *dīpāvalī* commences on 14th November, thus it will happen eleven days earlier i.e. on the day of 3rd November in 2021. If we continue the same chronology, then in the year 2031, *dīpāvalī* will commence on 25th July and the alignment of festivals with the seasons will be disrupted. Thus ancient Indian astronomers came up with an innovative idea to keep the lunar festivals in alignment with the seasons. They added a month to a specific lunar year after a certain period of time. This month is called *adhik māsa.* This lunar year consists of thirteen months instead of twelve.

Method to identify *Adhik māsa* or the intercalary month:

The rule to identify the *adhik māsa* is as follows - the lunar month in which no *sankrānti* is observed or the solar month in which two new moons are observed, is called an *adhik māsa*.

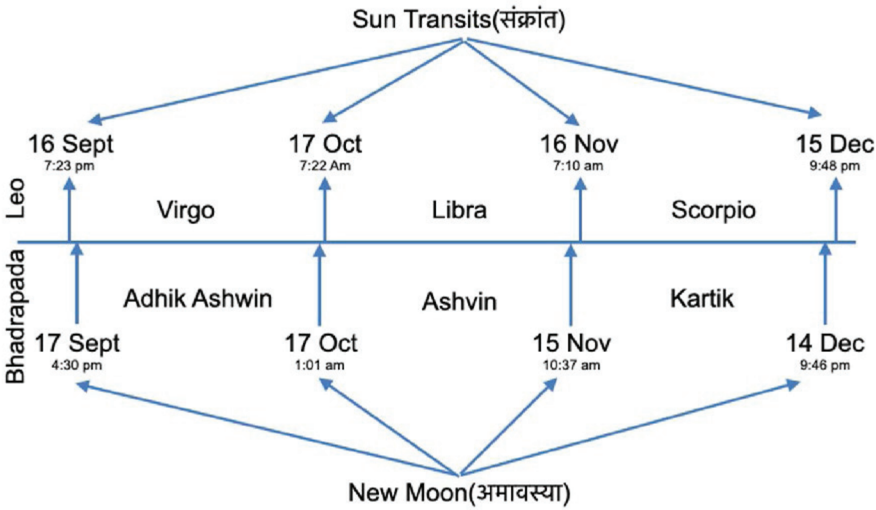

Figure No. 7: Identifying the *Adhik Māsa*

Figure No. 6 shows the solar transits and New Moons between September 2020 and December 2020.

Two New Moons occur during the Virgo transit. Therefore, the lunar month starting from the first new Moon is considered as an *Adhik aśvin* and the lunar month starting from the second new Moon is considered as *Nija aśvin*.

The earth revolves around the Sun in an elliptical orbit. Therefore, some solar months are shorter while some are longer. The shortest solar month consists of 29 days, ten hours and 48 minutes (29d 10h 48m); the largest solar month consists of 31 days, ten hours and 48 minutes (31d 10h 48m).

The Moon revolves around the earth in an elliptical orbit. Therefore, the duration of the lunar months is also not the same. The shortest lunar month consists of

29.26 days (29d 5h 54m 14.4s) and the longest lunar month consists of 29.80 days (29d 19h 36m 28.8s).

After how many solar months does the intercalary month or the *adhik māsa* occur?

A solar year consists of 365.2564 days.
The average duration of a solar month consists of 365.2564 / 12 = 30.4380 days.
Thus the lunar month is (30.4380-29.53) = 0.908 days shorter than the solar month.
Thus the number of solar months covered in 29.53 days = 29.53 / 0.908 = 32.522 solar months i.e. 2.71 solar years.

After how many lunar months does the intercalary month or the *adhik māsa* occur?

Since the lunar year is eleven days shorter than the solar year, number of lunar months required to be completed in order to add one intercalary lunar month is 29.53 / 11 = 2.68.
Thus a deficit of one lunar month is created after two years and eight months. Therefore, an intercalation to this lunar year is done in order to align it with the seasons.

A need for an intercalation is created after every 2.68 lunar years or 2.71 solar years because of the motion of the Sun and the Moon.

The table no. 6 shows that a total seven *adhik māsas* occur in the span of 19 years. The *Jyeṣṭha* month gets intercalated four times, the month of *Āsāṛh* gets intercalated three times, the month of *aśvin* and *Śrāvaṇa* get intercalated twice and the months of *Caitra*, *Vaiśākha* and *Phālguna* get intercalated once.

Table No. 6: *Adhik Māsa* occuring between 2010 to 2050

Year	***Saka***	***Adhik māsa***
2010	1932	*Vaiśākha*
2012	1934	*Bhādrapadaa*
2015	1937	*Āsāṛh*
2018	1940	*Jyeṣṭha*
2020	1942	*Aśvin*
2023	1945	*Śrāvaṇa*
2026	1948	*Jyeṣṭha*
2029	1951	*Caitra*
2031	1953	*Bhādrapadaa*
2034	1956	*Āsāṛh*
2037	1959	*Jyeṣṭha*
2039	1961	*Aśvin*
2042	1964	*Āsāṛh*
2045	1967	*Jyeṣṭha*
2047	1969	*Phālguna*
2050	1972	*Śrāvaṇa*

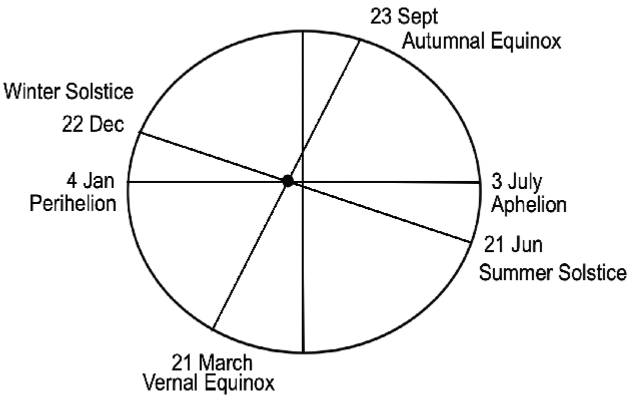

Figure No. 8: The position of the Earth at different days while rotating around the Sun.

The earth revolves around the Sun in an elliptical orbit having eccentricity 0.0167. An ellipse has two foci. The Sun is considered to be at one of these foci. Thus the distance between the earth and the Sun varies every day. On a specific day (January 4) The distance between the Sun and the Earth is minimal (147.5 million Km), i.e. the Earth is in the Perihelion with the Sun. Similarly, the distance between the Sun and the earth is maximum when it is in aphelion, i.e. (152.6 million km).

The solar month is shortest when the earth is in the perihelion. while the duration of the solar month is longest when the earth is in the aphelion. Therefore, the occurrence of *Jyeṣṭha* and *Āsāḍha* months is more frequent. When the earth is in perihelion with the Sun, the *Pauṣa māsa* never appears as an extra month. Also the extra months, *Mārgaśīrṣa* and *Maghā* appear least frequently.

(The Hijri chronology is based on the classical lunar year. Therefore, the Hijri calendar recedes by eleven days every year. For more information refer to the Islamic Chronology text.)

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9 *Kṣayamāsa* (Decay of a Month)

The smallest solar month consists of 29 days, 10 hours and 48 minutes (29d 10h 48m). If the largest lunar month incorporates the smallest solar month, then a new moon will not occur in this month. If there are two New Moons then *adhik māsa* is considered. If New Moon doesn't occur, *kṣayamāsa* is considered.

While the Sun is in sagittarius, the earth is in aphelion with the Sun and the lunar month is *Pauṣa*. Thus *Pauṣa māsa* is dropped or is a *kṣayamāsa*. *Mārgaśīrṣa* and *Maghā* are rarely dropped. The *adhik māsa* is added before and after the *kṣayamāsa*, in order to coordinate it with the seasonal cycle.

The year in which the *kṣayamāsa* occurs doesn't consist of 11 months. The occurrence of an *adhikmāsa* before and after the *kṣayamāsa* makes 13 total months in that year.In the recent history, examples of *kṣayamāsa* were observed in the month of Mārgaśīrṣa in 1963 AD and month of Magh in 1983 AD. The next *kṣayamāsa* will appear in 2123 AD.

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10 *Varṣa* (The Year)

In any chronometry, the year or a month has to be started from a specific point of reference of time. These reference points can be determined with the help of apparent orbits of the Sun and the Moon. The spring equinox or an autumnal equinox for the Sun and Full moon/new moon, or a distant star for the Moon, can be used as the reference points. Let's know the methods adopted in different chronometries around the world.

Tropical Year:

It is defined as the mean interval between two successive passages of the Sun through the Vernal equinox point. It consists of 365.2422 days. As the seasonal cycle commences from the Vernal Equinox point, the tropical year is considered extremely useful and important.

Julian Year:

The old Julian calendar consisted of 365.25 days. The leap year used to occur after every four years, thus 25 leap years used to occur in hundred years. The Julian calendar became out of practice after the Gregorian calendar was introduced.

Gregorian Year:

In 1582, Pope Gregory updated the calendar. It was accepted as a civil calendar worldwide. The normal year consists of 365 days while the leap year consists of 366 days. The Gregorian year consists of 365.2425 days. There is a difference of 0.0003 days in the Gregorian year and the Tropical year.

Solar year / Sidereal Year:

It is defined as the mean interval between two successive passages of the Sun through a specific Nakshatra. The Sidereal Year consists of 365.2564 days.

Lunar year:

The moon completes a rotation around the Earth in 29.530589 days. It takes 354.367068 days for the moon to complete twelve rotations around the Earth. Thus the classical lunar calendars (i.e. Islamic Calendar) consider a lunar year of 354 or 355 days.

The Anomalistic Year:

'The Perihelion' is the point of closest proximity of the Sun to the Earth. Every year, around January 4, the Sun is the closest to the Earth. It is defined as the mean interval between two successive passages of the Sun through the aphelion. This period is 365.2596 days.

Eclipse Year:

The Moon's apparent path intersects the ecliptic obliquely at two points called the nodes. These nodes are called the North/ascending node (*Rāhu)*, and the South/descending node *(Ketu)*. Thus the eclipse year is defined as the mean interval between two successive passages of the Sun through the ascending node. This period is 346.6201 days, which is comparatively smaller than other years. As *Rāhu* is in retrograde motion, the Sun requires comparatively less time to return to that point. The eclipse year is used to predict eclipses as well as in ecliptic mathematics.

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11 *Saṃvatsara*

The ancient Indian chronometry considers a special time period called the *saṃvatsara* comparable to Year. The word *saṃvatsara* literally means the 'year'. But it carries a significant relation with the 60-year-long cycle of Jupiter. Each year of this cycle is assigned a specific name. Jupiter orbits the Sun five times in 60 years and returns to its initial position. Thus a *saṃvatsara* is 1/12th of the time taken by Jupiter to complete its orbit around the Sun.

Jupiter orbits the Sun in 11.8626 (about 12) years.

Thus one *saṃvatsara* consists of 11.86260/12= 0.98855 years.

Because of this difference, within 86 *Saṃvatsara*, 85 years are completed.
In order to establish one to one relationship between the *Saṃvatsara* and the year, one *Saṃvatsara* is dropped within 85 years.

According to the *"Sūrya Siddhānta"*, a *saṃvatsara* is defined as the time period taken by Jupiter to traverse a *rāśi* or angular distance of 30 degrees.

Bhaskaracharya has defined the *saṃvatsara* as,

'बृह पते:म यमराशीभोगंसंव सरसं ह तकावेदांती'

'bṛhaspate: madhyamarāśībhogaṃ saṃvatsara saṃhitikā vedānti'

Thus a *saṃvatsara* is 1/12th of the time taken by Jupiter to complete its orbit around the Sun.These ideas became outdated in course of time.

In South India, the beginning of the *saṃvatsara* is marked by *varṣa pratipadā* and it ends with that lunar year. In North India, the *saṃvatsara* commences with dīpāvalī *pāḍavā*. This method is more scientific. The South Indian *saṃvatsara* no longer relates with the Jupiter *saṃvatsara*.

‘स यक्वसि त मासादया: अि मन’्

'samyak vasanti māsādayāh asmin'

The *saṃvatsara* is the one which completely accomodates *māsa* and other the Indian chronological units.

The period of sixty years is very important in human life. In the past it was customary to tell the *saṃvatsara* of birth instead of age.

Śālivāhana and *Vikram saṃvat,* other *śakas* and *saṃvatsara*

- ***Śālivāhana saka saṃvat:*** *Śālivāhana saka* is associated with the Sātavāhana kings of Central India. This shaka was started in the year 78 AD. Thus Subtracting 78 or 77 from the AD number gives the Śālivāhana Saka number.
- ***Vikram saṃvat***: The new year of *Vikram saṃvatsar* begins on the *Dīpāvalī Padva* (*Kārtik śukla pratipadā-Bali pratipadā*). If we add 56 or 57 to the number of AD, then we get *Vikram saṃvat* number.
  Vikram saṃvat - 135 = *Śaka saṃvat.*
- ***Kalchuri saṃvat***: This is called *Chedi saṃvat* or *Trikutak saṃvat*. It is found in rock inscriptions in Gujarat, Konkan and Madhya Pradesh. If we add 249 in the *Kalchuri saṃvat*, then we get number of AD.
- ***Kaliyuga saṃvat:*** This is called the *Mahābhārata saṃvat* or *Yudhiṣṭhira saṃvat*. *Kaliyuga saṃvatsara* is mentioned in astrological texts and inscriptions. It started in the year 3102 BC (February 17). If we add 3102 in the year number of AD, 3043/44 in the number of *Vikram saṃvat* and 3179/80 in the number of *Saka saṃvat*, we obtain the year of *Kaliyuga saṃvat*. (According to other sources, *Yudhiṣṭhira Saka* started 3044 years after the beginning of *Kali Yuga*.)
- ***Gāṅgeya saṃvat:*** This is a *saṃvat* started by the king of *Kalinganagar* in Tamil Nadu. It is used in many places in southern India. If we add 579 in the figure of *Gāṅgeya saṃvat*, we get the number of AD.
- ***Gupta saṃvat***: This is called Guptakāla or *Guptavarṣa* or *Valbhi saṃvat*. It must have been started by a *Gupta* king. It was used from Nepal to Gujarat. If we add 320 in the year of *Gupta saṃvat*, we get the year in AD.

- ***Cālukya Vikram saṃvat***: This saṃvat was started by the 6th *Vikramāditya*, the *Chālukya Solanki* king of Kalyanpur in Andhra Pradesh. This *saṃvat* is also known as *Cālukya Vikramakāla*, *Cālukya Vikram Varṣa* or *Veer Vikram Kāl*. If we add 1076 in this *saṃvat* number, we get year in AD.
- ***Tamil Year***: It starts on or around April 14.
- ***Persian new year***: The Persian New Year begins on March 21 around the world, in India and Pakistan it usually begins on August 17.
- ***Barhaspatya saṃvat***: It depends upon the Rising and setting of Jupiter in the sky.
- ***Rajyabhishek saṃvat***: The *saṃvat* which started after the coronation of Chhatrapati Shivaji Maharaj. It started in the month of June, 1674 AD.
- ***Veeranirvana saṃvat***: Its Sana number = 69/70 + Vikram saṃvat.
- ***Shahur (Suhur / Suhur) saṃvat***: *Suhur saṃvat* is usually obtained after subtracting 599/ 600 years from *Vikram saṃvat*. In the letters during the Peshwa period, the dates were mentioned in the form of *Suhur saṃvat*.
- ***Saptarshi saṃvat:*** Began in the year 3076 BC.

The names of *Śālivāhana Saka saṃvatsara* - These names may have been derived from certain events that occured in a particular year. This is mentioned in *Jātaka Khaṃḍa* of *Bhṛgu Saṃhitā.* This period might be about 2000 to 2500 years. The names given below are of 'lunar years'. There are total 60 *saṃvatsaras.* At the end of these sixty *saṃvatsaras* (i.e. after the last 'dropped year') a new *saṃvatsara* called *Prabhav* begins again. The number of AD is given in brackets.

1. *Prabhava* (1927-28, 1987-88)
2. *Vibhava* (1928-29, 1988-89)
3. *Pramoda* (1929-30, 1989-90)
4. *śukla* (1930-31, 1990-91)
5. *Prajādhīśa* (1931-32, 1991-92)
6. *Aṅgirā* (1932-33, 1992-93)
7. *śrīmukha* (1933-34, 1993-94)
8. *Bhāva* (1934-35, 1994-95)
9. *Yuv* (1935-36, 1995-96)
10. *Dhātṛ* (1936-37, 1996-97)

11. *īśvara* (1937-38, 1997-98)
12. *Bahudhānya* (1938-39, 1998-99)
13. *Pramāthī* (1939-40, 1999-2000)
14. *Vikrama* (1940-41, 2000-2001)
15. *Vṛṣa* (1941-42, 2001-2002)
16. *Citrabhānu* (1942-43, 2002-2003)
17. *Subhānu* (1943-44, 2003-2004)
18. *Tāraṇa* (1944-45, 2004-2005)
19. *Pārthiva* (1945-46, 2005-2006)
20. *Vyaya* (1946-47, 2006-2007)
21. *śarat (sarvajita)* (1947-48, 2007-2008)
22. *Sarvadhārī* (1948-49, 2008-2009)
23. *Virodhī* (1949-50, 2009-2010)
24. *Vikṛta* (1950-51, 2010-2011)
25. *Khara* (1951-52, 2011-2012)
26. *Nandana* (1952-53, 2012-2013)
27. *Vijaya* (1953-54, 2013-2014)
28. *Jaya* (1954-55, 2014-2015)
29. *Manmatha* (1955-56, 2015-2016)
30. *Durmukha* (1956-57, 2016-2017)
31. *Vilaṃba* (1957-58, 2017-2018)
32. *Hemalaṃba* (1958-59, 2018-2019)
33. *Vikārī* (1959-60, 2019-2020)
34. *śārvarī* (1960-61, 2020-2021)
35. *Plava* (1961-62, 2021-2022)
36. *śubhakṛta* (1962-63, 2022-2023)
37. *śobhana(*1963-64, 2023-2024)
38. *Krodhī* (1964-65, 2024-2025)
39. *Viśvāvasu* (1965-66, 2025-2026)
40. *Parābhava* (1966-67, 2026-2027)
41. *Plavaṃga* (1967-68, 2027-2028)
42. *Kīlaka* (1968-69, 2028-2029)
43. *Saumya* (1969-70, 2029-2030)
44. *Sādhāraṇa* (1970-71, 2030-2031)
45. *Virodhakṛta* (1971-72, 2031-2032)
46. *Paridhāvī* (1972-73, 2032-2033)
47. *Pramādī* (1973-74, 2033-2034)
48. *ānaṃda* (1974-75, 2034-2035)

49. *Rākṣasa* (1975-76, 2035-2036)
50. *Nala* (1976-77, 2036-2037)
51. *Piṅgala* (1977-78, 2037-2038)
52. *Kala(Yukta)* (1978-79, 2038-2039)
53. *Siddhārtha* (1979-80, 2039-2040)
54. *Raudra* (1980-81, 2040-2041)
55. *Durmati* (1981-82, 2041-2042)
56. *Dudumbhi* (1982-83, 2042-2043)
57. *Rudhirodgārī* (1983-84, 2043-2044)
58. *Raktākṣi* (1984-85, 2044-2045)
59. *Krodhana* (1985-86, 2045-2046)
60. *Kṣaya* (1986-87, 2046-2047)

The *Śālivāhana saṃvatsara* is named after one of the below 60 names.

How to derive the name of a Śālivāhana saṃvatsara?

Add 12 in the number of *Śālivāhana saka*.Divide it by 60.Add the remainder in the number of the *Prabhav saṃvatsara*, the corresponding name will be the required *Śālivāhana saṃvatsara*.

For example,

On the day of Gudi padva in 2013, *Saka* 1935 had started.
1935+12 = 1947
1947÷60 = 32 (remainder of 27)

Vijaya is the 27th *saṃvatsara*.
Thus, On the day of *Gudi padva* in 2013, *Saka* 1935 was named
Vijaya. Similarly *Jaya* was the *saṃvatsara* in 2014
Manmatha was the *saṃvatsara* in 2015.

How to derive the name of a *Vikram saṃvatsara?*

Add 9 to the number of *Vikram saṃvatsara*. Divide this sum by 60. Add the remainder in the number of the *Prabhav saṃvatsara*, the corresponding name will be the *Vikram saṃvatsara*.

For example,

On the day of *dīpāvalī* (*Kārtika śukla pratipadā*) in 2013, *Vikram saṃvat* 2070 had started.
2070+9 = 2079
2079÷60 = 34 (remainder of 39)

Viśvāvasū is the 39th *saṃvatsara* commenced on the day of *dīpāvalī* in 2013.
Similarly *Parābhava* was the *Vikram saṃvatsara* in 2014
Plavaṃga was the *Vikram saṃvatsara* in 2015.

- *Sṛṣṭi saṃvat* : (according to Hindu chronology): 19555885121
- *Kalpābda*: 1972949121 (according to Hindu chronology)
- *Chinese saṃvat*: 96002318
- *Parsi saṃvat*: 1899123
- *Egyptian saṃvat*: 27674
- *Turkish saṃvat*: 7627
- *Adam saṃvat*: 7372
- *Iranian saṃvat*: 6022
- *Jewish saṃvat*: 5781
- *Śrīkṛṣṇa saṃvat*: 5246
- *Yudhisthira saṃvat*: 5121
- *Kaliyuga saṃvat*: 5121
- *Saptarshi saṃvat*: 5096
- *Ibrahim saṃvat*: 4460
- *Greek year*: 3593
- *Moses Year*: 3659
- *Roman year*: 2771
- *Mahavira saṃvat:* 2615
- *Buddhist saṃvat* 2595
- *Burmese Year*: 2561
- *Veer Nirvana saṃvat*: 2547
- *Malayaketū Saka*: 2332
- *Śaṃkarācārya saṃvat*: 2300
- *Parthian saṃvat*: 2267
- *Vikram saṃvat*: 2077
- 2020 A.D. (2020 A.D. according to Christian chronology)
- *Java Year*: 1946

- *Śālivāhana Saka*: 1942
- *Kalchuri saṃvat*: 1778
- *Vallabhi saṃvat*: 1700
- *Hijri year*: 1441 (according to Islamic chronology)
- *Bangla saṃvat*: 1431
- *Harshabda saṃvat*: 1413

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12 *Sāyana and Nirayana*

Astronomers follow two main systems of presenting the planets as they are in the sky, which are known as the *Sāyana* system and *Nirayana* system. The word '*ayana'* which is common between the two, literally means 'movement'. We use the words *Uttarāyaṇa* and *Dakṣiṇāyaṇa* frequently. *Uttarāyaṇa* means moving towards North while *Dakṣiṇāyaṇa* means moving towards South.

Sāyana: *(Saḥ+ayana)* This literally means 'movement along with' the vernal equinoxes. The Vernal Equinox is not fixed. It precesses 50.2 angular seconds every year. When the positions of heavenly bodies are measured by considering this movement, it is called the Sāyana system.

Nirayana: (Nir+ayana) This literally means 'no movement' or neglecting the precession of equinoxes. When positions of heavenly bodies are measured from a fixed point of reference, (without considering the precession of the vernal equinox), it is called Nirayana system. This point has been fixed on 21st March in the Gregorian calendar, thus it uses the Nirayana system.

Why does the Vernal Equinox shift?

Earth's axis of rotation is tilted 23.5 degrees from the plane of its orbit around the Sun. It completes a rotation around itself (like a vortex) in 25722 years. The star aligned with the axis of rotation towards the North is called the Pole star. At present, it is *Polaris*. The rotation of the earth's axis also causes the reference pole star to change over time. This motion of the Earth's axis is called 'Precession of the equinoxes'.

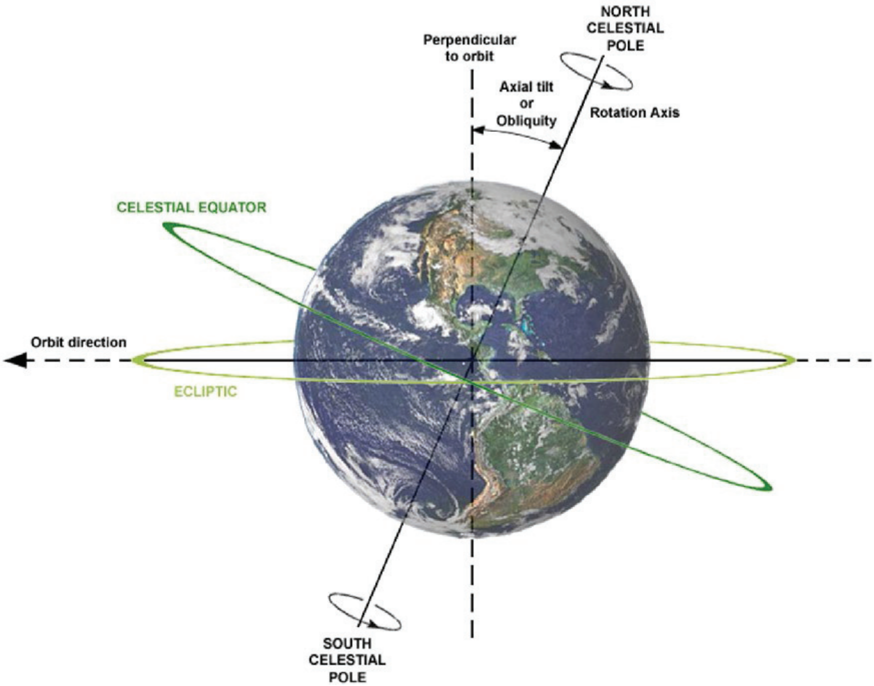

Figure No. 9: Image depicting tilted axis of rotation of the Earth and the tropics.

Ecliptic:

It is the great circle on the celestial sphere representing the Sun's apparent path during the year. Along with the Sun, the Moon and other planets travel along the same trajectory in the sky. The ecliptic has been divided in twelve segments of 30-degrees and each segment is called *rāshī* (a zodiac sign).

Celestial equator:

The Celestial equator is the apparent celestial projection of the Earth's equator in the sky. (The equator is itself perpendicular to the axis of rotation of the earth.) The equator divides the earth into the Northern hemisphere and the Southern hemisphere. Similarly, the celestial equator divides this imaginary mega-circle into two equal halves, namely the northern and the southern sky.

The celestial equator is currently inclined by about 23.44° to the ecliptic plane. These two celestial circles intersect at two points. One of these points of intersection is called the Vernal equinox and another is called the Autumnal equinox. The precession of equinoxes does not change the plane of the ecliptic; but the location of the celestial equator keeps on changing frequently. That is why the position of the vernal equinox also changes.

How to measure the precession of equinoxes?

- It takes 25722 years for the axis of the earth to complete 360 degrees. Thus in 71.45 (~ 72) years, the vernal equinox recedes by a degree.

- A zodiac sign consists of 30 degrees over the ecliptic. There are 12 such zodiac signs. Therefore, it takes 2143.5 (25722/12) years for the vernal equinox to pass through one zodiac sign.

- A *nakśatra* spans 13.33 degrees on the ecliptic. There are 27 such *nakśatras*. It takes 952.66 (25722/27) years for the vernal equinox to pass through one *nakśatra*.

The vernal equinox was situated in front of the *Citrā* star in the *Vedāṅga Jyotiṣa* period of Indian astronomy . Therefore, this point was considered as the origin of Aries or *meśa rāśī*. Afterwards, the vernal equinox started receding backwards due to the precession of equinoxes. Today, the vernal equinox has receded backward by 24 degrees from its initial position. This has caused a gap of twenty four degrees between *Sāyana* Aries and *Nirayana* Aries.This difference is remarkably observed between the occurrence of *Makar Saṃkrāṃti* (January 14) and the beginning of the winter solstice (December 22). Once upon a time, *Makar Saṃkrāṃti* and *Uttarāyaṇa* or winter solstice used to begin on the same day.

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13 *Uttarāyaṇa* and *Dakṣiṇāyana*

Uttarāyaṇa and *Dakṣiṇāyana* are two important concepts in Indian chronometry. They carry religious significance. On the day of *Uttarāyaṇa*, ancient Indians used to perform religious deeds and holy sacrifices.The spring equinox, the autumnal equinox, the summer solstice day and the winter solstice day are the four major phases in the annular circummotion around the Sun.

The equator is considered as 0°(zero degrees). Throughout the year, the Sun travels from 23° 26′ 22″ N (Tropic of Cancer) to 23° 26′ 22″ S (Tropic of Capricorn).

Spring Equinox:

Presently, the Sun arrives at the vernal equinox on March 20th/21st. On this day, the Sun rises in the exact east. Day and night are of equal duration of twelve hours. On this day, the Sun is situated over the equator and is travelling towards the north.

The point of onset of the *Dakṣiṇāyana* or the winter solstice:

While travelling northwards, the Sun falls on the Tropic of Cancer on 21/22 June. On this day, Sunrise and Sunset occur far northward of the East and West. The longest day and shortest night of the year in the northern hemisphere, occurs on this day. Sunset does not happen on the North Pole during this period. Thus the Sun is in the sky for the whole 24 hours. On the South Pole Sunrise doesn't occur and the night is of 24 hours duration. The Tropic of Cancer is situated 23° 26′ 22″ (about twenty-five degrees) towards the North of the equator.

Figure No. 10 shows the change in the durations of day and night throughout the year. These are the local time figures for Nagpur, a city in India. The longest day in June and the longest night in December can be easily observed in this figure.

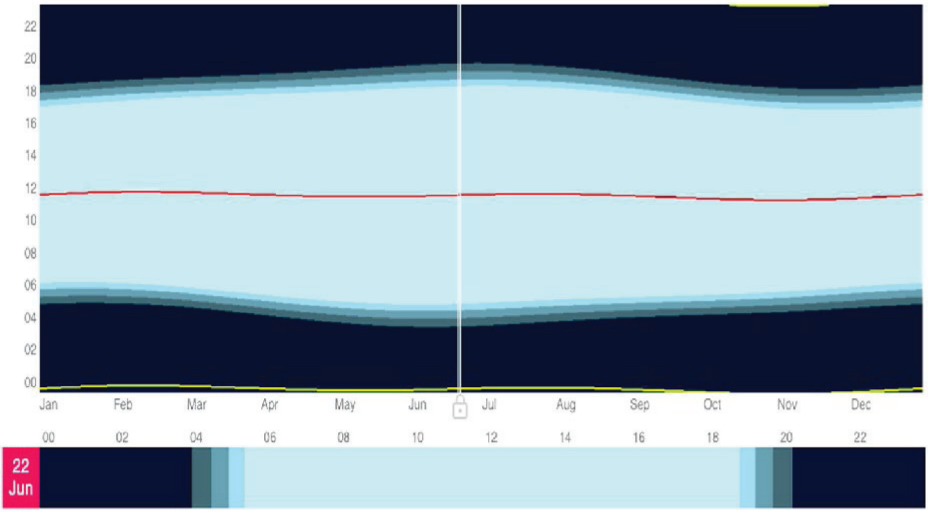

Figure No. 10: Graphical representation of durations of Sunrises and Sunsets over the year.

Autumnal equinox:

From June 21/22, the Sun starts moving southward from the Tropic of Cancer. On September 22, the Sun rises on the exact east. On this day, the day and night are of the same duration and the Sun falls on the equator. The southward journey of the Sun continues.

The point of onset of the *Uttarāyaṇa* or the Summer solstice

On December 21/22, the Sun falls on the Tropic of Capricorn. The Sunrise on this day occurs in the extreme south of the east. The duration of the day in the Northern Hemisphere is the shortest; thus the night is very long.The Sun begins to ascend towards the north after this day. Sunset does not happen at the south pole on this day, so the Sun is present in the sky for 24 hours. Simultaneously the Sun does not rise at the North Pole, and the night lasts for 24 hours during this period. The Tropic of Capricorn is 23° 26′ 22″ (about twenty three and a half) degrees away towards the south of the equator.

Throughout the year, the Sun travels from 23° 26′ 22″ S (about twenty-three and a half degrees) to 23° 26′ 22″ degrees N (about twenty-three and a half degrees). This has created a cycle of seasons on earth. At present, the Earth's axis is tilted by 23° 26′ 22″ degrees (about twenty-five degrees). This tilt varies from 22.1 degrees to 24.5 degrees in a span of about forty thousand years.

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14 History of Indian Astronomy

The history of Indian astronomy starts right from the Vedic period. The uninterrupted tradition that has been blooming since the Vedic period is still prevalent in India in the form of the *Pañcānga*. After the development of modern astronomy in the West, somewhere around 1790, the Almanac started to be published in order to locate the planets, Moon and the Sun in the sky easily.

The calendar was adapted in the Western world around 300 AD. The Indians started publication of *Dinadarśikā* (calendar) in the British period (nineteenth century) on the basis of western calendars.

India is a multilingual country, thus different methods of chronology have been adopted. Therefore, various *Pañcānga* and calendars in various regional languages are prevalent in different states of India.

The *Pañcānga* consists of five limbs or components, namely *Vāra, tithī, nakśatra, karaṇa* and *yoga*, which have astronomical significance. Similarly *karaṇa* and *yoga* have astrological significance. In addition to this, the almanac gives the 'accurate positions' of the Moon, Sun and the planets in the sky and is used for sky observations. In the same way, the *Pañcānga* gives information about eclipses of Moon-Sun-planets, planetary conjunctions, rising-setting of celestial bodies, retrograde and normal motion.

Vedic Period:

The use of *pañcānga* must have been started from the Vedic period. The solar year has been mentioned in *Vedas*; So are the lunar months. *Uttarāyaṇa* and *Dakṣiṇāyana*, the six seasons and the twenty-seven *nakśatras*, were observed at different times of the year. The full Moon months were being considered.

Vedāṅga jyotiṣa Period:

The time from 1500 BC to 400 AD is known as the *Vedāṅga Jyotiṣa* period. The sage Lagadha compiled a treatise called *RigJyotiṣa*, which consists of 36 verses, while *Yajus Jyotiṣa* consists of 43 verses. The concepts used in the *vedāṅga jyotiṣa* are as follows:

1. In *vedāṅga jyotiṣa* a *yug* was considered to be of duration of five years. These five years were known as *Saṃvatsara, Parivatsara, Idāvatsara, Anuvatsara and Idavatsara*. They believed that the Moon and the Sun reunite in a point in the sky after a period of five years.
2. A *yuga* consisted of 1830 days and 1860 tithīs.
3. In a *yuga* 62 lunar months and 60 solar months were considered.
4. In a *yuga*, 30 *kṣaya tithīs* were considered.
5. There were 67 months based on *nakśatras* in a *yuga.* Thus the Moon travelled through 67X 27 = 1809 *nakśatras.*
6. A *yuga* consisted of two *adhik māsa*.
7. *Uttarāyaṇa* used to start in *Dhaniṣtha nakśatra*.
8. The Indian new year would commence from the tithī of *Magh śukla pratipadā*
9. The zodiac signs were not mentioned in *Vedāṅga Jyotiṣa*

Siddhānta Jyotiṣa period:

In the year 499 AD, Aryabhatta wrote the first treatise over the *Siddhānta jyotiṣa* called the *Āryabhaṭīya*. After that, *Varāhmihira* compiled a book called *Pañcasiddhāntikā*, which included the five principles of *Paitāmaha,Vaśiṣṭha, Romaka, Poliśa, Surya*. Of these, only *"Sūrya Siddhānta"* survived over the time. It was constantly being improved until 1000 AD. All the topics related to measurement of time in modern astronomy have been covered in *'Sūrya Siddhānta'*. It consists of 14 chapters and 500 verses. It covers a wide range of topics such as the average speed, their actual positions, directions, location, time, eclipses, planetary conjunctions, Moon-Sun rise, various instruments and different methods of measuring time. The time period of orbital motion of the

Sun, Moon and planets mentioned in the *'Sūrya Siddhānta'* are as the Table No.7.

Table No.7: The time period of orbital motion of the Sun, Moon and planets

Object	**Period (As per *Sūrya Siddhānta'*)**	**Period (Modern)**	**Error**
Sun	365.25875 Days	365.2564 Days	0.00235 Days
Moon	27.32167 Days	27.32166 Days	0.00001 Days
Mercury	87.9697 Days	87.96928 Days	0.00042 Days
Venus	224.69856 Days	224.7007 Days	0.00214 Days
Mars	686.99725 Days	686.97945 Days	0.0178 Days
Jupiter	4332.32065 Days	4332.58480 Days	0.26415 Days
Saturn	10765.77307 Days	10759.21971 Days	6.55336 Days

The complex planetary mathematical calculations which consisted of the *Yuga, Mahayuga, Manvantara, Kalpa*, etc.,were introduced from the *Siddhānta jyotiṣa* texts. The ancient astronomers had understood that if we consider the farthest reference point in the past for Mathematical calculations, we get more accurate results. Considering the continuous recession of the vernal equinox, some adaptations had to be done in the Mathematical rules to determine the accurate positions of the Sun, Moon and the planets. After immense research, these mathematical adaptations were noted and formulated by the ancient Indian astronomers. *Gaṇesh Daivajna* wrote the treatise called the *'Grah Lāghav'* in 1520 AD. In this book, he avoided the use of trigonometry. While doing the planetary mathematics of the Moon, the Sun and other planets, a fixed reference position is considered on a specific date. Considering this reference point, the present position is obtained. While doing this, the difference between the actual date and the reference date and the planetary velocities are considered. This leads to larger mathematical figures, which make the calculations complicated. To avoid this, Ganesh Daivadnya considered an eleven year cycle. There are 4016 days in 11 years. Ganesh Daivadnya ensured through his formula, that the maximum difference of the number of days in the reference date and present date, while doing the planetary mathematics of the Moon, the Sun and other planets, will not exceed 4016. His work is still relevant and useful to the almanacists.

In modern period, great Astronomers like Kero Laxman Chhatre, Visaji Raghunath Lele, Vinayak Shastri Khanapurkar, Venkatesh Bapuji Ketkar, Shankar Balkrishna Dixit, Lokmanya Bal Gangadhar Tilak, Bapu dev Shastri, Sudhakar Dwivedi, Raghunaath Acharya have done tremendous work. The present version of pañcānga is the result of their extensive efforts.

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15 Indian National Calendar

After independence, in order to introduce a scientific method of chronometry and a calendar based on it, the Council of Scientific and Industrial Research (CSIR) of the Government of India started to make efforts. Under the chairmanship of Meghnath Saha, 'Calendar Reform Committee' was established in 1952.

The members of this committee were as follows: Dr. Meghnath Saha (President), N. C. Lahiri (Secretary), Prof. A. C. Banerjee, Dr. K. L. Daptary, J. S. Karandikar, Prof. R. V. Vaidya, Dr. Gorakh Prasad.

Purpose of the committee: To examine all the popular calendars in the country, to carry out an in depth scientific research on the *pancānga* and to provide a uniform and accurate *pancānga*.

The committee handed over its detailed report to the Government on 14 September 1954. The Government of India accepted the report and announced a new national calendar and the chronometry from March 22, 1957. The Reserve Bank gave orders to all the banks nationwide to accept all economic transactions according to this calendar.

The Indian National calendar didn't attain the required fame and pursuance as it was different from the popular regional calendars which had the connection to the religious rituals or practices followed by common man in day to day life.

On the day of *Bharatiya Saur Caitra suddha 1, Saka 1878*; i.e. on March 21, 1956, the committee proposed that the Indian national calendar would be published and issued by the Government of India. The following points were considered.

1) *Ayanamsa* should be fixed as 23 degrees 15 minutes as on the day of March 21, 1956.

2) Annual rate of precession of equinoxes should be considered as 50.27 angular seconds.

3) As the *Śālivāhana Śaka* is used in most of the states of India, it should be used for measurement of years. The *Śālivāhana Śaka* chronology started in 78 AD.

4) The new year must start from the Spring Equinox day. Thus the time period between two consecutive spring equinox days, should be considered as a year. This year, known as the tropical year will consist of 365.2422 days.

5) Based on the leap year, the onset of the new year will be on 21/22 March.

6) Indian national calendar has been aligned with the Gregorian Calendar. Thus the leap year should be considered according to the Gregorian calendar.

7) The new year will commence from the month of Solar Caitra. The number of days in each month will be as follows: *Caitra 30/31, Vaiśākha, Jyeṣṭha*, *Āsāṛh, Śrāvaṇa, Bhādrapada* will consist of 31 days, while *aśvin, Kārtik, Mārgaśīrṣa, Pauṣa, Māgha, Phālguna* will consist of thirty days. When the Earth is close to the Sun (perihelion), it possesses a faster orbital speed, and when the Earth is far from the Sun (aphelion), it possesses a slower orbital speed, thus the time varies inversely proportional to the speed.

8) Indian Standard Time will be calculated on the basis of reference of 82.30' E longitude, and 23.11' N longitude (the coordinates of the city of Prayagraj).

9) New day will start at midnight.

Table No. 8: Month according to the Indian National Calendar

Solar Month	Celestial latitudes of Sun from Vernal Equinox	Period of the Solar Month	Month according to the Indian National Calendar
Vaiśākha	0 - 30 degrees	30h11m25.2s	*Caitra*
Jyeșțha	30 - 60 degrees	30h23m29.6s	*Vaiśākha*
Āsāṛh	60-90 degrees	31h08m10.1s	*Jyeșțha*
Śrāvaṇa	90-120 degrees	31h10m54.6s	*Āsāṛh*
Bhādrapada	120-150 degrees	31h06m53.1s	*Śrāvaṇa*
Aśvin	150-180 degrees	30h21m18.7s	*Bhādrapada*
Kārtika	180-210 degrees	30h08m58.2s	*Aśvin*
Mārgaśīrṣa	210-240 degrees	29h21m14.6s	*Kārtika*
Pauṣa	240-270 degrees	29h13m08.7s	*Mārgaśīrṣa*
Māgha	270- 300 degrees	29h10m38.3s	*Pauṣa*
Phālguna	300-330 degrees	29h14m18.5s	*Māgha*
Caitra	330-360 degrees	29h23m18.9s	*Phālguna*

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16 The Indian Standard Time

The globe of earth is divided into imaginary circles known as the latitudes and longitudes. They are used to determine exact locations of any object or place on earth's surface. The latitudes are circles parallel to the equator, while longitudes are lines running from the north pole to the south pole.

The imaginary line passing through the city of Greenwich has been considered as the line of reference. The longitudes are measured up to 180 degrees to the east and the west of this line. As the earth rotates from the west to the east, thus a new longitude faces the Sun once in the 24 hours.

The Prime Meridian: In astronomy, the meridian is the great circle passing through the celestial poles, as well as the zenith and nadir of an observer's location.

Consequently, it contains the north and south points on the horizon, and it is perpendicular to the celestial equator and horizon. When the Sun reaches the Zenith, it is said to be noontime on that meridian.

Noontime in New Delhi (77.1025°E), happens to be evening in Tokyo (139.6503° E), morning time in London (0.1278° W) and midnight in New York (74.0060 W).

While considering the time measurements globally, it becomes difficult to use local time at different locations. Therefore, a standard time has been decided to mark the timing in different locations. This standard time is called the Universal Time / UT. For common purposes, Greenwich Mean Time (GMT) is used. UT is used for scientific measurements.

For the measurement of time to be smooth and sustained; time zones have been decided over the globe. A zone consisting of 15 longitudes from the Greenwich longitude has been considered as the first time zone. Similarly twenty four time zones have been considered across the globe. Standard meridians are situated at every longitudinal displacement of 15° from the prime meridian (e.g., 15° W, 30° W, 45° W, etc.) The standard meridians also determine the local time in the specific time zone. The boundaries of each time zone are marked at longitudinal displacement of 7.5° about the west and east of the standard meridian. The time measurement in each time zone is done with the help of the middlemost meridian of that time zone.

For ex. In the time zone ranging from 7.5° E to 7.5° W, the time is measured in terms of the prime meridian in Greenwich or (0°) meridian.

In the time zone ranging from 7.5° W to 22.5° W, the time is measured in terms of the (-1) time zone. The time in this zone is shown shorter than the Greenwich standard time by one hour. Similarly the subsequent time zones towards the east of Greenwich are considered as +1 and +2. The time in those zones is more than the Greenwich mean time.

The International Date Line (IDL) is the longitude located halfway from the prime meridian at about 180° east (or west) of Greenwich. It is also known as the line of demarcation, and passes through the pacific ocean. When the IDL is crossed, a change in day occurs.

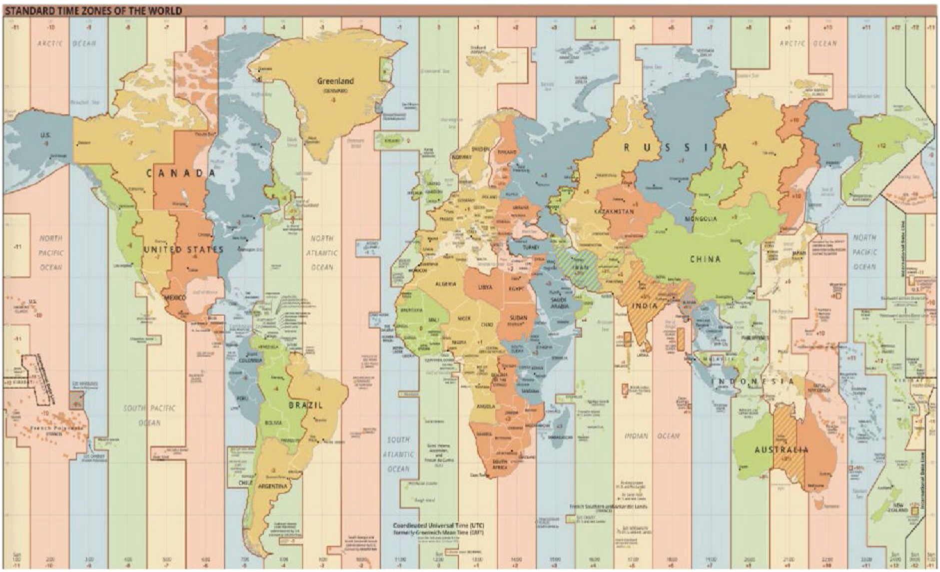

Figure No. 11: Time Zones across the World

Table No 9: The Time Zones

Zone	GMT +/-	Text Indicator	Zone	GMT +/-	Text Indicator
7.5W to 7.5E	0	Z	7.5W to 22.5W	-1	N
7.5E to 22.5E	+1	A	22.5W to 37.5W	-2	O
22.5E to 37.5E	+2	B	37.5W to 52.5W	-3	P
37.5E to 52.5E	+3	C	52.5W to 67.5W	-4	Q
52.5E to 67.5E	+4	D	67.5W to 82.5W	-5	R
67.5E to 82.5E	+5	E	82.5W to 97.5W	-6	S
82.5E to 97.5E	+6	F	97.5W to 112.5W	-7	T
97.5E to 112.5E	+7	G	112.5W to 127.5W	-8	U
112.5E to 127.5E	+8	H	127.5W to 142.5W	-9	V
127.5E to 142.5E	+9	I	142.5W to 157W	-10	W
142.5E to 157.E	+10	K	157.5W to 172.5W	-11	X
157.5E to 172.5E	+11	L	172.5W to 180	-12	Y
172.5E to 180	+12	M			

Each country selects a specific longitude for the reference of its time zone as per its convenience and determines the standard time of the country according to that longitude. India's wide terrain is situated within 67.7 degrees east to 97.25 degrees east longitudes. It is situated within the E and F (+5 and +6) time zones. Many countries in the world have fixed more than one time zones for their terrain. However, India has chosen 82.5 degrees east longitude as a reference line for its time zone. This longitude (82.5 degrees E) is situated to the east of Greenwich or 5.30 hours earlier.

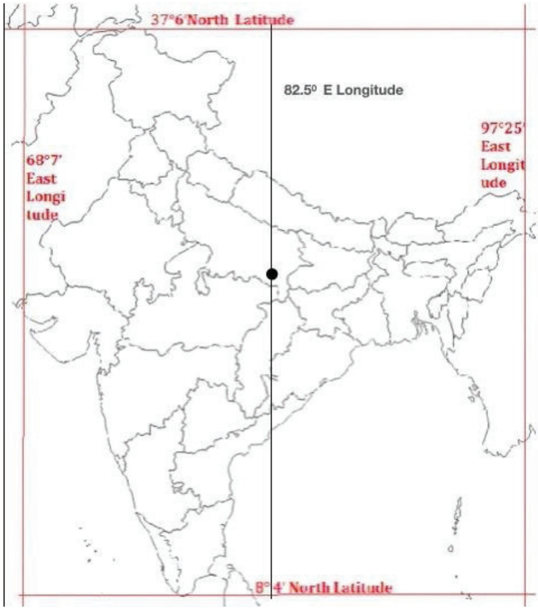

Figure No. 12: Shankargad Central Observatory in *Prayāgrāj* district located at 82.5° E longitude

Thus Indian standard time is fixed as +5.5 (+5 hours 30 minutes). The rotation of the earth around itself is completed in 24 hours. It means that the earth completes a rotation of 360° in 24 hours. Thus It takes an hour to travel over a 15° angle or four minutes to rotate over a 1° angle. The simple calculation of GMT + (longitude x 4) is used to decide the time over a specific longitude or meridian.

For ex. Indian reference longitude is 82.5°
82.5 x 4 = 330 = 5 hours 30 minutes.
Thus when It is 12:00 am in Greenwich, the time in India is 5:30 am.

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17 Gregorian Calendar

The Gregorian calendar was created by modifying the Julian calendar. Julius Caesar started the Julian calendar in 45 BC. The Sun used to be on the Vernal equinox on 25th march at that time. 370 years later, in the year 325 AD, the spring equinox began to happen on March 21. Every year the vernal equinox precesses backward by about 50.2 angular seconds. This means that after about seventy-two years the vernal equinox point deviates by one degree.

The year in the Julian calendar consists of 365.25 days. However, the tropical year consists of 365.2422 days. The difference between these two years is 0.0078 days. Thus an annual error of 11 minutes and 14 seconds in the Julian calendar, causes a difference of one day between the tropical and Julian years every 128 years.

At the Council of *Nicaea* held in 325 AD, an important Christian holiday of Easter, was decided to be celebrated on March 21, as the spring equinox of that year happened to be on March 21. In 700 AD, the spring solstice occurred on March 18, whereas, in 1100 AD, it occurred on March 15, and in 1550 AD on March 11. This way, the season of the easter or spring festival would have shifted in winter as the spring solstice was receding, which was not appropriate. Various scholars noticed these astronomical reasons and asked the Pope to interfere in the calendar.

Around 1275 AD, well-known philosopher Roger Bacon suggested amendments in the calendar, which were ignored. In 1344 AD, Pope Clement appointed a committee of astronomers to revise the calendar. However, due to various disagreements, the calendar could not be revised. In 1475 AD, Pope Sixtus tried again. Finally, in 1572, Pope Gregory XIII attempted to revise the calendar. Under the leadership of Christopher Clavius, a committee of eminent astronomers, mathematicians, and theologians was formed. The main difficulty in creating an accurate calendar was the incomplete day of 0.2422 in the tropical year. They realised that the calendar for the common use should consist of full days; at the same time, the incomplete day can't be ignored. The spring equinox happened to be on March 11 in 1572. Christopher Clavius accepted the challenge of accurate measurement of the tropical year. The tropical year in 1580-1581 was decided to consist of 365.242546296 days. On February 24, 1582, Pope Gregory XIII accepted the report of the Clavius Committee and announced that its implementation would begin on October 4, 1582. This announcement is called **'Papal bull'**.

The difference of 0.2425 days between the tropical year (365.2425 days) and the regular year (365 days) is difficult to account for every year. This difference tends to be 97 days in total 400 years. (0.2425 x 400 = 97). These missing 97 days of the calendar had to be compensated by considering 97 'leap years' in 400 years. In the prevailing Julian calendar of that time, the difference of 0.25 days per year was being compensated by considering 100 leap days in 400 years. Thus to reduce the number of leap days by 3 to to make it 97, a new rule was introduced in the prevailing rules for the leap year. It was proposed that centenary years which are not divisible by 400 should not be considered leap years. Therefore, even if the years 1700, 1800, 1900 are divisible by 4, they will not be considered leap years as they are not divisible by 400. Due to this amendment proposed by Clavious, at least for the next 3550 years, the Sun would enter the vernal equinox on March 21.

Important decisions in Papal Bull:

- The 10 days in the month of October in 1582 were removed. It was Thursday on October 4th. The next day was assumed to be October 15th, the friday. Therefore, the vernal equinox, which had occurred on March 11, in 1582, would come once again on March 21, in 1583. Also, the order of weekdays would be followed. As a result, the dates from 5 October to 14 October would not exist in 1582.
- Two rules must be followed to determine the leap year.
  A) To consider a year as the leap year, it should be divisible by 4, but not by 100.
  B) If the year is divisible by 400, it will be considered as a leap year.
- Julius Caesar had considered January as the beginning of the new year. But in the sixth century, the church had considered the beginning of the new year on 25 March. In the Gregorian calendar, the beginning of the year was once again introduced on 1st January. The distance

between the Sun and Earth is minimal in early January; thus suggestion of astronomers to begin the new year in January was accepted.

- The Sunday after the full Moon, which falls after the Sun enters the spring equinox is known as Easter Sunday. This traditional rule was continued to be accepted.

The Gregorian calendar was immediately accepted by all Catholic countries. But the protestant countries refused to accept the new calendar. In Germany, riots broke out over the calendar issue, as some organizations were Catholic and others Protestant. The global empire, England was a Protestant country and did not accept the Gregorian calendar until September 3, 1752. The country later adopted the Gregorian calendar, reducing the month of September in 1752 by 11 days. Following England, the British India accepted the Gregorian calendar in 1752. China accepted this calendar in 1912. After the Russian revolution, the Gregorian calendar was accepted in Soviet Russia in February 1918. Today, the Gregorian calendar is used worldwide.

In the Gregorian calendar, the words BC and AD are used to number years. It was assumed that the year 1 AD began after the year 1 BC. Therefore, the year 0 does not exist. Since the terms BC and AD are not accepted by some religions, the method of numbering years is being used under the name Common Era (CE). In this method, the year 1 BC is considered to be 0 CE. Of course, this shows that 25 BC is the year -24 CE (minus twenty four CE). In astronomical mathematics, year numbers are represented by the Common Era (CE).

Errors in the Gregorian calendar:

- The year of the Gregorian calendar consists of 365.2425 days, while the tropical year consists of 365.2422 days. The difference between these two years is 0.0003 days or about 26 seconds. Thus after about three thousand years, the vernal equinox will shift by one day.
- The number of days in all the months are not equal, they vary from 28 to 31.
- Therefore, the number of days in a quarter year varies from 90 to 92 days.
- Number of days in the six months i.e. from January to June is 181, and the number of days in the period of July to December is 184.

- Due to the holiday on Sunday, the actual working days vary from 24 to 27 in each month.
- Although the word December means the tenth one, it is actually the twelfth month. This is true for every month from September.
- The important festival of Easter can happen anytime from March 22 and April 25.

India was ruled by English and Portuguese rulers during this period. The Portuguese began using the Gregorian calendar from 1582; The British, however, continued to use the Julian calendar till 1752. So let's take a look at an example of how Indian historians get confused when writing the dates of certain events.

According to Indian chronology, the birthday of Chhatrapati Shivaji Maharaj was on *Phālgun Vadya Tṛtīyā, Śālivāhana Saka 1551, (Śuklanām Saṃvatsar)*. The date is March 2, 1630, according to the Gregorian calendar, and February 19, 1630, according to the Julian calendar. This has caused a lot of confusion in history.

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18 Julian Day Number

Six different chronometric units are used in every chronometric system, to record the time and date of an event. These are 1) Year, 2) Month, 3) Day, 4) Hour, 5) Minute and 6) Second. The Gregorian calendar is widely accepted in modern world. But according to it, the number of days in each month varies. Also total number of days in a year vary from 365 to 366. It becomes very difficult to do the astronomical calculations, using all such variable chronometric units. The concept of the Julian dates was first proposed in 1583 by Joseph Scaliger, a chronometrist. According to it, Julian date is considered as 1, on 1 January 4712 BC, and each day is counted in subsequent order. Accordingly, the Julian date on November 30, 2020 is 2459183.5. This is also called the Julian day number.

While making astronomical calculations regarding the conjunctions or oppositions of planets and stars, the time difference between two specific events (the time gap within occurrence of one event and the other), is often derived in the form of Julian day number. In order to derive the positions of the planets, Moon and the Sun in the sky, as well as to record the pulsating brightness of the variable stars in astronomical events, various astronomical calculations are done. The time of various astronomical events is noted for this purpose, in the form of Julian day number. The date in the Gregorian calendar can be easily calculated using the Julian day number.

Julian day numbers are not related to any calendar. All the six chronometric units are denoted in the form of a number. This method is used to easily measure the time difference between two events.

Example 1

A total solar eclipse was observed from India on 16th February 1980.The next total solar eclipse was observed on 24 October 1995. Thus, for 5729 days in between these events, no total solar eclipse was observed in India. How to calculate the number of days?

- According to the regular calendar, the number of days after 16th February in the year 1980, and the number of days of the years from 1981 to 1994, will have to be added to the number of days till October 24 in the year 1995, to get the total of 5729. A leap will have to be compensated within.
- If the Julian day number method is used, then this figure can be determined in one step.
  16 February 1980= Julian Day number 2444285.5
  24 October 1995= Julian Day number 2450014.5
  Subtracting these two Julian Day numbers,
  (2444285.5- 2450014.5) = 5729

Thus, we find the time difference between the two total solar eclipses as 5729 days.

Example 2

How many days after India received independence, it was declared as a republic?

Indian Independence Day: 15th August 1947= Julian Day number 2432412.5

Republic day: 26 January 1950= Julian Day number 2433307.5

The difference between the two is 894.

Thus India was declared as a republic nation after 894 days from the day it was declared independent.

The Julian day number also accommodates a number of hours, minutes and seconds in a day. The day in a Gregorian calendar starts at midnight and ends after twenty-four hours. When the Julian day number was proposed, the day used to start at noon. Thus in every Julian day number, a fraction of 0.5 can be observed.

Example

India became independent on 15th August 1947 at midnight. When it was midnight, the International standard time on August 14 was 6:30 pm (18:30 pm) according to the world standard time. This can be represented by the Julian day number as 2432412.27083. The number 2432412 represents August 14, 1947; and the fraction 0.27083 represents six hours and thirty minutes after 12 noon.

The Julian day number can be derived from the date of the Gregorian calendar as follows:

$$J = \text{Int}(365.25 \times y) + \text{int}(30.6001 \times (m+1)) + D + 1720994.5 + B$$

J = Julian number of days
Y = Year Number in Gregorian Calendar
M = Month Number.
(1 = January, 2 = February ... ... 12 = December)

$m = M$. if $M > 2$

$m = M+12$ if $M \leq 2$

$y = Y$ if $M > 2$

$y = Y-1$, if $M \leq 2$

D= Number of day in a month.
INT= Integral part of the number or Z
B= 2-A + INT (A/4)
A= INT (y/100)

1720994.5 is a constant, which is the total number of days, since the day when the Julian day number system started (1 January 4712 BC) to 31 December 1.

Example 1

Obtain the Julian day number on 30 November 2020

Y = 2020
M=11
m = 11
y = 2020
D=30
A= INT (y / 100)= INT(2020/100) = INT(20.20) =20
B=2-A+INT(A/4)
= 2 - 20 + INT (20/4)
= 2-20+5
= - 13

J = INT(365.25x2020)+INT(30.6001x(11+1)+ 30 +1720994.5 -
13 J = INT(737805) + INT(367.20212) + 30 + 1720994.5 - 13
J= 737805 + 367+ 30 + 1720994.5 -
13 J = 2459183.5

The day of 30 November 2020 is denoted by the Julian day number 2459183.5.

Example 2

To Find the Julian day number for the day January 26, 1950

Y=1950,M=1,D=26

M ≤2 thus y = 1949 and m = 13

A=19,B=-13

J = INT(365.25 x y) +INT(30.6001 x (m+1)) + D + 1720994.5 + B

J = INT(365.25x1949) + INT(30.6001x(14) + 26 + 1720994.5 - 13

J= 711872 + 428 + 26 + 1720994.5 - 13 J = 2433307.5

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19 The Islamic Calendar

The Islamic Calendar started from the day of friday, 16th july 622. Actually it was a Thursday, but as per the Islamic traditional beliefs it was considered a friday because it started after the Sunset. Thus, the first day of Islamic calendar was considered as a Friday.

As per the Indian calendar, 16 july 622 was the day of *Śrāvaṇa Śukla Pratipadā, Śālivāhana Saka 544.* The Islamic calendar is called Hijri year. Hijri calendar was first published by Caliph Umar in 639 AD. Hijri year 17 was running at that time.

Islamic calendar is fully based on the Lunar cycle. The coincidental lunar month consists of (29.53 days) 29 days is 12 hours and 44 minutes. Therefore, days have been adjusted by considering the 30 and 29 days interspersed between the twelve months of the year.

Thus, 354 days of the year are adjusted and a fraction of 0.36 days is left. Thus practically one day is considered instead of this fraction, and an extra day is added in the leap year. In the Islamic calendar, odd months consist of 30 days, while even months consist of 29 days.

The chronometry shown in Table No. 10 was designed using the 29 days and 12 hours of the lunar month. But the lunar month consists of 29.53 days. The 44 minutes omitted per month become 11 days after 30 years. So one day is added after 11 years in every thirty-year cycle. In the 2nd, 5th, 7th, 10th, 13th, 16th, 18th, 21st, 24th, and 26th year, the twelfth month of the *Dhū al-Ḥijjah* is considered to be 30 days instead of 29.

Table No. 10: Months and Number of days according to the Islamic Calendar

Number of month	Name of month	No. of days in the month
1	*Muharram*	30
2	*Safar*	29
3	*Rabi' al-awwal*	30
4	*Rabīʿ ath-thānī*	29
5	*Jumada al-awwal*	30
6	*Jumādá al-ākhirah*	29
7	*Rajab*	30
8	*Sha'aban*	29
9	*Ramadan*	30
10	*Shawwal*	29
11	*Dhū al-Qaʿdah*	30
12	*Dhū al-Ḥijjah*	29/30

Every day in the Muslim calendar begins after sunset and ends at the next sunset. The beginning of the month is when the feeble crescent moon of *Pratipadā* appears in the sky. Although this rule applies to all months, it is strictly observed during the months of *Muharram* and *Ramadan*. Muslim clergyman or a moulana starts the month observing the crescent moon in the sky after the new moon. The moon of *Pratipadā* can be seen only if the moon rises past fifty minutes after sunset. Otherwise the month starts on the next day i.e. *Dvitīyā*.

Extra month is not considered in Islamic calendar. Therefore, the lunar calendar recedes by 11 days, compared to the seasonal cycle every year. So all the Muslim festivals happen in every season during the 33 years.

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20 The Calendar that Never Came into Existence!

The need to correct the numerous errors in the Gregorian calendar, had been noticed widely. But traditional beliefs and religious tendencies made it difficult to implement the reforms. A meeting of the United Nations Economic and Social Council was held in 1954. It discussed the Universal Calendar created by the World Calendar Association. On behalf of India, Dr. Meghnad Saha was present in this meeting. India had consented to this calendar. But the majority of other countries in the world voted and the topic was closed before it even came into existence.

The pros of the proposed calendar were:

1) There was no need to reprint the calendar every year as it would remain the same.

2) The year was divided into four equal parts. Each quarter year consisted of 91 days, 13 weeks, and three months.

3) 26 working days were mandatory each month. (Five Sundays in a 31-day month and four Sundays in a 30-day month)

4) The beginning of each year was to be on January 1, and that day was to be Sunday.

5) Every quarter of the year was to begin on a Sunday.

6) The 365th day (last day) would come after December 30 every year and it would be celebrated as a holiday without being assigned any weekday.

7) The leap year was to be extended one day after the last day of June and no weekday was to be assigned to it.

8) The proposed calendar was to remain constant and perpetual.

9) The months of January, April, July, and October would consist of 31 days, and the month would begin on Sunday.

10) The months of February, May, August, and November were supposed to have 30 days, supposed to start on Wednesday.

11) The months of March, June, September, and December were supposed to be 30 days long, supposed to start on Friday.

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Appendix-I

Modern Chronometry

1 Picosecond = 10^{-12} Second

1 Nanosecond = 10^{-9} Second

1 Microsecond = 10^{-6} second

1 Millisecond = 10^{-3} second

1 Centisecond = 10^{-2} second

1 Decisecond = 10^{-1} second

1 Second = 10 Deciseconds

1 Minute = 60 Seconds

1 Hour = 60 minutes

1 day = 24 hours

1 week = 7 days

1 year (Tropical) = 365.2422 days

Appendix-II

The Aphelion and Perihelion days with time in the upcoming years

1. The Aphelion is the point in the orbit of an object where it is farthest from the Sun.
2. The point in orbit where an object is nearest to the sun is called the perihelion.

Year	Perihelion	Time in UT	Aphelion	Time in UT
2020	January 5	07:48	July 4	11:35
2021	January 2	13:51	July 5	22:27
2022	January 4	06:55	July 4	07:11
2023	January 4	16:17	July 6	20:07
2024	January 3	00:39	July 5	05:06
2025	January 4	13:28	July 3	19:55
2026	January 3	17:16	July 6	17:31
2027	January 3	02:33	July 5	05:06
2028	January 5	12:28	July 3	22:18
2029	January 2	18:13	July 6	05:12

Appendix-III

The Equinoxes and Solstices in the upcoming years

1. Vernal Equinox :- The first point of intersection of the Ecliptic and the celestial equator.
2. Autumnal Equinox :- The second point of intersection of the Ecliptic and the celestial equator.
3. Summer Solstice :- The day when the Sun falls on the Tropic of Cancer.
4. Winter Solstice :- The day when the Sun falls on the Tropic of Capricorn.

Year	Vernal Equinox		Summer Solstice		Autumnal Equinox		Winter Solstice	
2020	20 Mar	09:19 IST	21 Jun	03:13 IST	22 Sep	19:00 IST	21 Dec	15:32 IST
2021	20 Mar	15:07 IST	21 Jun	09:02 IST	23 Sep	00:51 IST	21 Dec	21:29 IST
2022	20 Mar	21:03 IST	21 Jun	14:43 IST	23 Sep	06:33 IST	22 Dec	03:18 IST
2023	21 Mar	02:54 IST	21 Jun	20:27 IST	23 Sep	12:19 IST	22 Dec	08:57 IST
2024	20 Mar	08:36 IST	21 Jun	02:20 IST	22 Sep	18:13 IST	21 Dec	14:50 IST
2025	20 Mar	14:31 IST	21 Jun	08:12 IST	22 Sep	23:49 IST	21 Dec	20:33 IST

Appendix-IV

Sanskrit to English Transliteration

Vowels

Devanāgarī	Transcription	Devanāgarī	Transcription	Devanāgarī	Transcription
अ	a A	ऋ	ṛ Ṛ	ओ	o O
आ	ā Ā	ॠ	ṝ Ṝ	औ	au Au
इ	i I	ऌ	ḷ Ḷ	◌ं	ṃ Ṃ
ई	ī Ī	ॡ	ḹ Ḹ	◌ः	ḥ Ḥ
उ	u U	ए	e E	◌	~
ऊ	ū Ū	ऐ	ai Ai	ऽ	'

Consonants

क k K	च c C	ट ṭ Ṭ	त t T	प p P
ख kh Kh	छ ch Ch	ठ ṭh Ṭh	थ th Th	फ ph Ph
ग g G	ज j J	ड ḍ Ḍ	द d D	ब b B
घ gh Gh	झ jh Jh	ढ ḍh Ḍh	ध dh Dh	भ bh Bh
ङ ṅ Ṅ	ञ ñ Ñ	ण ṇ Ṇ	न n N	म m M
ह h H	य y Y	र r R	ल l L	व v V
	श ś Ś	ष ṣ Ṣ	स s S	

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vibha
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